MathGL

for version 2.3.4

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This manual is for MathGL (version 2.3.4), a collection of classes and routines for scientific plotting. Please report any errors in this manual to `mathgl.abalakin@gmail.org`.

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1 Overview

MathGL is ...

- a library for making high-quality scientific graphics under Linux and Windows;
- a library for the fast data plotting and handling of large data arrays;
- a library for working in window and console modes and for easy embedding into other programs;
- a library with large and growing set of graphics.

1.1 What is MathGL?

A code for making high-quality scientific graphics under Linux and Windows. A code for the fast handling and plotting of large data arrays. A code for working in window and console regimes and for easy including into another program. A code with large and renewal set of graphics. Exactly such a code I tried to put in MathGL library.

At this version (2.3.4) MathGL has more than 50 general types of graphics for 1d, 2d and 3d data arrays. It can export graphics to bitmap and vector (EPS or SVG) files. It has OpenGL interface and can be used from console programs. It has functions for data handling and script MGL language for simplification of data plotting. It also has several types of transparency and smoothed lighting, vector fonts and TeX-like symbol parsing, arbitrary curvilinear coordinate system and many other useful things (see pictures section at homepage (`http://mathgl.sf.net/`)). Finally it is platform-independent and free (under GPL v.2.0 or later license).

1.2 MathGL features

MathGL can plot a wide range of graphics. It includes:

- one-dimensional (Plot, Area, Bars, Step, Stem, Torus, Chart, Error, Tube, Mark, see Section 4.11 [1D plotting], page 195);
- two-dimensional plots (Mesh, Surf, Dens, Cont, ContF, Boxs, Axial, Fall, Belt, Tile, see Section 4.12 [2D plotting], page 207);
- three-dimensional plots (Surf3, Dens3, Cont3, ContF3, Cloud-like, see Section 4.13 [3D plotting], page 213);
- dual data plots: vector fields Vect, flow threads Flow, mapping chart Map, surfaces and isosurfaces, transparent or colored (i.e. with transparency or color varied) by other data SurfA, SurfC, Surf3A, Surf3C (see Section 4.14 [Dual plotting], page 217);
- and so on. For details see see Chapter 4 [MathGL core], page 158.

In fact, I created the functions for drawing of all the types of scientific plots that I know. The list of plots is growing; if you need some special type of a plot then please email me e-mail and it will appear in the new version.

I tried to make plots as nice looking as possible: e.g., a surface can be transparent and highlighted by several (up to 10) light sources. Most of the drawing functions have 2 variants: simple one for the fast plotting of data, complex one for specifying of the exact position of the plot (including parametric representation). Resulting image can be saved in

bitmap PNG, JPEG, GIF, TGA, BMP format, or in vector EPS, SVG or TeX format, or in 3D formats OBJ, OFF, STL, or in PRC format which can be converted into U3D.

All texts are drawn by vector fonts, which allows for high scalability and portability. Texts may contain commands for: some of the TeX-like symbols, changing index (upper or lower indexes) and the style of font inside the text string (see Section 3.5 [Font styles], page 152). Texts of ticks are rotated with axis rotation. It is possible to create a legend of plot and put text in an arbitrary position on the plot. Arbitrary text encoding (by the help of function `setlocale()`) and UTF-16 encoding are supported.

Special class mglData is used for data encapsulation (see Chapter 6 [Data processing], page 252). In addition to a safe creation and deletion of data arrays it includes functions for data processing (smoothing, differentiating, integrating, interpolating and so on) and reading of data files with automatic size determination. Class mglData can handle arrays with up to three dimensions (arrays which depend on up to 3 independent indexes a_{ijk}). Using an array with higher number of dimensions is not meaningful, because I do not know how it can be plotted. Data filling and modification may be done manually or by textual formulas.

There is fast evaluation of a textual mathematical expression (see Section 3.6 [Textual formulas], page 153). It is based on string precompilation to tree-like code at the creation of class instance. At evaluation stage code performs only fast tree-walk and returns the value of the expression. In addition to changing data values, textual formulas are also used for drawing in *arbitrary* curvilinear coordinates. A set of such curvilinear coordinates is limited only by user's imagination rather than a fixed list like: polar, parabolic, spherical, and so on.

1.3 Installation

MathGL can be installed in 4 different ways.

1. Compile from sources. The cmake build system is useded in the library. To run it, one should execute commands: `cmake .` twice, after it `make` and `make install` with root/sudo rights. Sometimes after installation you may need to update the library list – just execute `ldconfig` with root/sudo rights.

   There are several additional options which are switched off by default. They are: `enable-fltk, enable-glut, enable-qt4, enable-qt5` for ebabling FLTK, GLUT and/or Qt windows; `enable-jpeg, enable-gif, enable-hdf5` and so on for enabling corresponding file formats; `enable-all` for enabling all additional features. For using `double` as base internal data type use option `enable-double`. For enabling language interfaces use `enable-python, enable-octave` or `enable-all-swig` for all languages. You can use WYSIWYG tool (`cmake-gui`) to view all of them, or type `cmake -D enable-all=on -D enable-all-widgets=on -D enable-all-swig=on .` in command line for enabling all features.

   There is known bug for building in MinGW – you need to manually add linker option `-fopenmp` (i.e. `CMAKE_EXE_LINKER_FLAGS:STRING='-fopenmp'` and `CMAKE_SHARED_LINKER_FLAGS:STRING='-fopenmp'`) if you enable OpenMP support (i.e. if `enable-openmp=ON`).
2. Use a precompiled binary. There are binaries for MinGW (platform Win32). For a precompiled variant one needs only to unpack the archive to the location of the

compiler (i.e. mathgl/lib in mingw/lib, mathgl/include in mingw/include and so on) or in arbitrary other folder and setup paths in compiler. By default, precompiled versions include the support of GSL (www.gsl.org) and PNG. So, one needs to have these libraries installed on system (it can be found, for example, at `http://gnuwin32.sourceforge.net/packages.html`).

3. Install precompiled versions from standard packages (RPM, deb, DevPak and so on).

Note, you can download the latest sources (which can be not stable) from sourceforge.net SVN by command

```
svn checkout http://svn.code.sf.net/p/mathgl/code/mathgl-2x mathgl-code
```

IMPORTANT! MathGL use a set of defines, which were determined at configure stage and may differ if used with non-default compiler (like using MathGL binaries compiled by MinGW in VisualStudio). There are `MGL_SYS_NAN`, `MGL_HAVE_TYPEOF`, `MGL_HAVE_PTHREAD`, `MGL_HAVE_ATTRIBUTE`, `MGL_HAVE_C99_COMPLEX`, `MGL_HAVE_RVAL`. I specially set them to `0` for Borland and Microsoft compilers due to compatibility reasons. Also default setting are good for GNU (gcc, mingw) and clang compilers. However, for another compiler you may need to manually set this defines to `0` in file `include/mgl2/config.h` if you are using precompiled binaries.

1.4 Quick guide

There are 3 steps to prepare the plot in MathGL: (1) prepare data to be plotted, (2) setup plot, (3) plot data. Let me show this on the example of surface plotting.

First we need the data. MathGL use its own class `mglData` to handle data arrays (see Chapter 6 [Data processing], page 252). This class give ability to handle data arrays by more or less format independent way. So, create it

```
int main()
{
    mglData dat(30,40);     // data to for plotting
    for(long i=0;i<30;i++)   for(long j=0;j<40;j++)
        dat.a[i+30*j] = 1/(1+(i-15)*(i-15)/225.+(j-20)*(j-20)/400.);
```

Here I create matrix 30*40 and initialize it by formula. Note, that I use `long` type for indexes *i*, *j* because data arrays can be really large and `long` type will automatically provide proper indexing.

Next step is setup of the plot. The only setup I need is axis rotation and lighting.

```
    mglGraph gr;            // class for plot drawing
    gr.Rotate(50,60);       // rotate axis
    gr.Light(true);         // enable lighting
```

Everything is ready. And surface can be plotted.

```
    gr.Surf(dat);           // plot surface
```

Basically plot is done. But I decide to add yellow ('`y`' color, see Section 3.2 [Color styles], page 148) contour lines on the surface. To do it I can just add:

```
    gr.Cont(dat,"y");       // plot yellow contour lines
```

This demonstrate one of base MathGL concept (see, Chapter 3 [General concepts], page 147) – "new drawing never clears things drawn already". So, you can just consequently call different plotting functions to obtain "combined" plot. For example, if one need to draw axis then he can just call one more plotting function

```
	gr.Axis();                      // draw axis
```

Now picture is ready and we can save it in a file.

```
	gr.WriteFrame("sample.png");    // save it
}
```

To compile your program, you need to specify the linker option `-lmgl`.

This is enough for a compilation of console program or with external (non-MathGL) window library. If you want to use FLTK or Qt windows provided by MathGL then you need to add the option `-lmgl-wnd`.

Fortran users also should add C++ library by the option `-lstdc++`. If library was built with `enable-double=ON` (this default for v.2.1 and later) then all real numbers must be real*8. You can make it automatic if use option `-fdefault-real-8`.

1.5 Changes from v.1.*

There are a lot of changes for v.2. Here I denote only main of them.

- mglGraph class is single plotter class instead of mglGraphZB, mglGraphPS and so on.
- Text style and text color positions are swapped. I.e. text style '`r:C`' give red centered text, but not roman dark cyan text as for v.1.*.
- ColumnPlot() indexing is reverted.
- Move most of arguments of plotting functions into the string parameter and/or options.
- "Bright" colors (like {b8}) can be used in color schemes and line styles.
- Intensively use pthread internally for parallelization of drawing and data processing.
- Add tick labels rotation and skipping. Add ticks in time/date format.
- New kinds of plots (Tape(), Label(), Cones(), ContV()). Extend existing plots. New primitives (Circle(), Ellipse(), Rhomb(), ...). New plot positioning (MultiPlot(), GridPlot())
- Improve MGL scripts. Add 'ask' command and allow string concatenation from different lines.
- Export to LaTeX and to 3D formats (OBJ, OFF, STL).
- Add pipes support in utilities (`mglconv, mglview`).

1.6 Utilities for parsing MGL

MathGL library provides several tools for parsing MGL scripts. There is tools saving it to bitmap or vectorial images (`mglconv`). Tool `mglview` show MGL script and allow to rotate and setup the image. Another feature of `mglview` is loading *.mgld files (see `ExportMGLD()`) for quick viewing 3d pictures.

Both tools have similar set of arguments. They can be name of script file or options. You can use '`-`' as script name for using standard input (i.e. pipes). Options are:

- **-1** *str* set *str* as argument $1 for script;
- ... ...
- **-9** *str* set *str* as argument $9 for script;
- **-L** *loc* set locale to *loc*;
- **-s** *fname* set MGL script for setting up the plot;
- **-h** print help message.

Additionally `mglconv` have following options:

- **-A** *val* add *val* into the list of animation parameters;
- **-C** *v1*:*v2*[:*dv*] add values from *v1* ot *v2* with step *dv* (default is 1) into the list of animation parameters;
- **-o** *name* set output file name;
- **-n** disable default output (script should save results by itself);
- **-S** *val* set set scaling factor for [setsize], page 176;
- **-q** *val* set [quality], page 176 for output (val=0...9).

Also you can create animated GIF file or a set of JPEG files with names '`frameNNNN.jpg`' (here '`NNNN`' is frame index). Values of the parameter `$0` for making animation can be specified inside the script by comment `##a val` for each value `val` (one comment for one value) or by option(s) '`-A val`'. Also you can specify a cycle for animation by comment `##c v1 v2 dv` or by option `-C v1:v2:dv`. In the case of found/specified animation parameters, tool will execute script several times – once for each value of `$0`.

MathGL also provide another simple tool `mgl.cgi` which parse MGL script from CGI request and send back produced PNG file. Usually this program should be placed in `/usr/lib/cgi-bin/`. But you need to put this program by yourself due to possible security issues and difference of Apache server settings.

1.7 Thanks

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Javascript interface was developed with support of DATADVANCE (`www.datadvance.net`) company.

2 MathGL examples

This chapter contain information about basic and advanced MathGL, hints and samples for all types of graphics. I recommend you read first 2 sections one after another and at least look on Section 2.9 [Hints], page 111 section. Also I recommend you to look at Chapter 3 [General concepts], page 147 and Section 2.10 [FAQ], page 142.

Note, that MathGL v.2.* have only 2 end-user interfaces: one for C/Fortran and similar languages which don't support classes, another one for C++/Python/Octave and similar languages which support classes. So, most of samples placed in this chapter can be run as is (after minor changes due to different syntaxes for different languages). For example, the C++ code

```
#include <mgl2/mgl.h>
int main()
{
  mglGraph gr;
  gr.FPlot("sin(pi*x)");
  gr.WriteFrame("test.png");
}
```

in Python will be as

```
from mathgl import *
gr = mglGraph();
gr.FPlot("sin(pi*x)");
gr.WriteFrame("test.png");
```

in Octave will be as (you need first execute `mathgl;` in newer Octave versions)

```
gr = mglGraph();
gr.FPlot("sin(pi*x)");
gr.WriteFrame("test.png");
```

in C will be as

```
#include <mgl2/mgl_cf.h>
int main()
{
  HMGL gr = mgl_create_graph(600,400);
  mgl_fplot(gr,"sin(pi*x)","","");
  mgl_write_frame(gr,"test.png","");
  mgl_delete_graph(gr);
}
```

in Fortran will be as

```
integer gr, mgl_create_graph
gr = mgl_create_graph(600,400);
call mgl_fplot(gr,'sin(pi*x)','','');
call mgl_write_frame(gr,'test.png','');
call mgl_delete_graph(gr);
```

and so on.

2.1 Basic usage

MathGL library can be used by several manners. Each has positive and negative sides:

- *Using of MathGL library features for creating graphical window (requires FLTK, Qt or GLUT libraries).*

  Positive side is the possibility to view the plot at once and to modify it (rotate, zoom or switch on transparency or lighting) by hand or by mouse. Negative sides are: the need of X-terminal and limitation consisting in working with the only one set of data at a time.

- *Direct writing to file in bitmap or vector format without creation of graphical window.*

  Positive aspects are: batch processing of similar data set (for example, a set of resulting data files for different calculation parameters), running from the console program (including the cluster calculation), fast and automated drawing, saving pictures for further analysis (or demonstration). Negative sides are: the usage of the external program for picture viewing. Also, the data plotting is non-visual. So, you have to imagine the picture (view angles, lighting and so on) before the plotting. I recommend to use graphical window for determining the optimal parameters of plotting on the base of some typical data set. And later use these parameters for batch processing in console program.

- *Drawing in memory with the following displaying by other graphical program.*

  In this case the programmer has more freedom in selecting the window libraries (not only FLTK, Qt or GLUT), in positioning and surroundings control and so on. I recommend to use such way for "stand alone" programs.

- *Using FLTK or Qt widgets provided by MathGL*

  Here one can use a set of standard widgets which support export to many file formats, copying to clipboard, handle mouse and so on.

MathGL drawing can be created not only by object oriented languages (like, C++ or Python), but also by pure C or Fortran-like languages. The usage of last one is mostly identical to usage of classes (except the different function names). But there are some differences. C functions must have argument HMGL (for graphics) and/or HMDT (for data arrays) which specifies the object for drawing or manipulating (changing). Fortran users may regard these variables as integer. So, firstly the user has to create this object by function mgl_create_*() and has to delete it after the using by function mgl_delete_*().

Let me consider the aforesaid in more detail.

2.1.1 Using MathGL window

The "interactive" way of drawing in MathGL consists in window creation with help of class `mglQT`, `mglFLTK` or `mglGLUT` (see Chapter 5 [Widget classes], page 238) and the following drawing in this window. There is a corresponding code:

```
#include <mgl2/qt.h>
int sample(mglGraph *gr)
{
  gr->Rotate(60,40);
  gr->Box();
  return 0;
```

```
}
//-----------------------------------------------------
int main(int argc,char **argv)
{
  mglQT gr(sample,"MathGL examples");
  return gr.Run();
}
```

Here callback function `sample` is defined. This function does all drawing. Other function `main` is entry point function for console program. For compilation, just execute the command

```
gcc test.cpp -lmgl-qt -lmgl
```

Alternatively you can create yours own class inherited from Section 5.2 [mglDraw class], page 241 and re-implement the function `Draw()` in it:

```
#include <mgl2/qt.h>
class Foo : public mglDraw
{
public:
  int Draw(mglGraph *gr);
};
//-----------------------------------------------------
int Foo::Draw(mglGraph *gr)
{
  gr->Rotate(60,40);
  gr->Box();
  return 0;
}
//-----------------------------------------------------
int main(int argc,char **argv)
{
  Foo foo;
  mglQT gr(&foo,"MathGL examples");
  return gr.Run();
}
```

Or use pure C-functions:

```
#include <mgl2/mgl_cf.h>
int sample(HMGL gr, void *)
{
  mgl_rotate(gr,60,40,0);
  mgl_box(gr);
}
int main(int argc,char **argv)
{
  HMGL gr;
  gr = mgl_create_graph_qt(sample,"MathGL examples",0,0);
  return mgl_qt_run();
```

```
/* generally I should call mgl_delete_graph() here,
 * but I omit it in main() function. */
}
```

The similar code can be written for `mglGLUT` window (function `sample()` is the same):

```
#include <mgl2/glut.h>
int main(int argc,char **argv)
{
  mglGLUT gr(sample,"MathGL examples");
  return 0;
}
```

The rotation, shift, zooming, switching on/off transparency and lighting can be done with help of tool-buttons (for `mglQT, mglFLTK`) or by hot-keys: '`a`', '`d`', '`w`', '`s`' for plot rotation, '`r`' and '`f`' switching on/off transparency and lighting. Press '`x`' for exit (or closing the window).

In this example function `sample` rotates axes (`Rotate()`, see Section 4.4 [Subplots and rotation], page 172) and draws the bounding box (`Box()`). Drawing is placed in separate function since it will be used on demand when window canvas needs to be redrawn.

2.1.2 Drawing to file

Another way of using MathGL library is the direct writing of the picture to the file. It is most usable for plot creation during long calculation or for using of small programs (like Matlab or Scilab scripts) for visualizing repetitive sets of data. But the speed of drawing is much higher in comparison with a script language.

The following code produces a bitmap PNG picture:

```
#include <mgl2/mgl.h>
int main(int ,char **)
{
  mglGraph gr;
  gr.Alpha(true);   gr.Light(true);
  sample(&gr);              // The same drawing function.
  gr.WritePNG("test.png");  // Don't forget to save the result!
  return 0;
}
```

For compilation, you need only libmgl library not the one with widgets

```
gcc test.cpp -lmgl
```

This can be important if you create a console program in computer/cluster where X-server (and widgets) is inaccessible.

The only difference from the previous variant (using windows) is manual switching on the transparency `Alpha` and lightning `Light`, if you need it. The usage of frames (see Section 2.1.3 [Animation], page 11) is not advisable since the whole image is prepared each time. If function `sample` contains frames then only last one will be saved to the file. In principle, one does not need to separate drawing functions in case of direct file writing in consequence of the single calling of this function for each picture. However, one may use the same drawing procedure to create a plot with changeable parameters, to export in different

file types, to emphasize the drawing code and so on. So, in future I will put the drawing in the separate function.

The code for export into other formats (for example, into vector EPS file) looks the same:

```
#include <mgl2/mgl.h>
int main(int ,char **)
{
  mglGraph gr;
  gr.Light(true);
  sample(&gr);              // The same drawing function.
  gr.WriteEPS("test.eps");  // Don't forget to save the result!
  return 0;
}
```

The difference from the previous one is using other function `WriteEPS()` for EPS format instead of function `WritePNG()`. Also, there is no switching on of the plot transparency `Alpha` since EPS format does not support it.

2.1.3 Animation

Widget classes (`mglWindow`, `mglGLUT`) support a delayed drawing, when all plotting functions are called once at the beginning of writing to memory lists. Further program displays the saved lists faster. Resulting redrawing will be faster but it requires sufficient memory. Several lists (frames) can be displayed one after another (by pressing '`,`', '`.`') or run as cinema. To switch these feature on one needs to modify function `sample`:

```
int sample(mglGraph *gr)
{
  gr->NewFrame();             // the first frame
  gr->Rotate(60,40);
  gr->Box();
  gr->EndFrame();             // end of the first frame
  gr->NewFrame();             // the second frame
  gr->Box();
  gr->Axis("xy");
  gr->EndFrame();             // end of the second frame
  return gr->GetNumFrame();   // returns the frame number
}
```

First, the function creates a frame by calling `NewFrame()` for rotated axes and draws the bounding box. The function `EndFrame()` **must be** called after the frame drawing! The second frame contains the bounding box and axes `Axis("xy")` in the initial (unrotated) coordinates. Function `sample` returns the number of created frames `GetNumFrame()`.

Note, that animation can be also done as visualization of running calculations (see Section 2.1.5 [Draw and calculate], page 14).

Pictures with **animation can be saved in file(s)** as well. You can: export in animated GIF, or save each frame in separate file (usually JPEG) and convert these files into the movie (for example, by help of ImageMagic). Let me show both methods.

The simplest methods is making animated GIF. There are 3 steps: (1) open GIF file by `StartGIF()` function; (2) create the frames by calling `NewFrame()` before and `EndFrame()` after plotting; (3) close GIF by `CloseGIF()` function. So the simplest code for "running" sinusoid will look like this:

```
#include <mgl2/mgl.h>
int main(int ,char **)
{
  mglGraph gr;
  mglData dat(100);
  char str[32];
  gr.StartGIF("sample.gif");
  for(int i=0;i<40;i++)
  {
    gr.NewFrame();     // start frame
    gr.Box();          // some plotting
    for(int j=0;j<dat.nx;j++)
      dat.a[j]=sin(M_PI*j/dat.nx+M_PI*0.05*i);
    gr.Plot(dat,"b");
    gr.EndFrame();     // end frame
  }
  gr.CloseGIF();
  return 0;
}
```

The second way is saving each frame in separate file (usually JPEG) and later make the movie from them. MathGL have special function for saving frames – it is `WriteFrame()`. This function save each frame with automatic name '`frame0001.jpg, frame0002.jpg`' and so on. Here prefix '`frame`' is defined by *PlotId* variable of `mglGraph` class. So the similar code will look like this:

```
#include <mgl2/mgl.h>
int main(int ,char **)
{
  mglGraph gr;
  mglData dat(100);
  char str[32];
  for(int i=0;i<40;i++)
  {
    gr.NewFrame();     // start frame
    gr.Box();          // some plotting
    for(int j=0;j<dat.nx;j++)
      dat.a[j]=sin(M_PI*j/dat.nx+M_PI*0.05*i);
    gr.Plot(dat,"b");
    gr.EndFrame();     // end frame
    gr.WriteFrame();   // save frame
  }
  return 0;
}
```

Created files can be converted to movie by help of a lot of programs. For example, you can use ImageMagic (command '`convert frame*.jpg movie.mpg`'), MPEG library, GIMP and so on.

Finally, you can use `mglconv` tool for doing the same with MGL scripts (see Section 1.6 [Utilities], page 4).

2.1.4 Drawing in memory

The last way of MathGL using is the drawing in memory. Class `mglGraph` allows one to create a bitmap picture in memory. Further this picture can be displayed in window by some window libraries (like wxWidgets, FLTK, Windows GDI and so on). For example, the code for drawing in wxWidget library looks like:

```
void MyForm::OnPaint(wxPaintEvent& event)
{
  int w,h,x,y;
  GetClientSize(&w,&h);   // size of the picture
  mglGraph gr(w,h);

  gr.Alpha(true);         // draws something using MathGL
  gr.Light(true);
  sample(&gr,NULL);

  wxImage img(w,h,gr.GetRGB(),true);
  ToolBar->GetSize(&x,&y);    // gets a height of the toolbar if any
  wxPaintDC dc(this);         // and draws it
  dc.DrawBitmap(wxBitmap(img),0,y);
}
```

The drawing in other libraries is most the same.

For example, FLTK code will look like

```
void Fl_MyWidget::draw()
{
  mglGraph gr(w(),h());
  gr.Alpha(true);         // draws something using MathGL
  gr.Light(true);
  sample(&gr,NULL);
  fl_draw_image(gr.GetRGB(), x(), y(), gr.GetWidth(), gr.GetHeight(), 3);
}
```

Qt code will look like

```
void MyWidget::paintEvent(QPaintEvent *)
{
  mglGraph gr(w(),h());

  gr.Alpha(true);         // draws something using MathGL
  gr.Light(true);         gr.Light(0,mglPoint(1,0,-1));
  sample(&gr,NULL);
```

```
  // Qt don't support RGB format as is. So, let convert it to BGRN.
  long w=gr.GetWidth(), h=gr.GetHeight();
  unsigned char *buf = new uchar[4*w*h];
  gr.GetBGRN(buf, 4*w*h)
  QPixmap pic = QPixmap::fromImage(QImage(*buf, w, h, QImage::Format_RGB32));

  QPainter paint;
  paint.begin(this);  paint.drawPixmap(0,0,pic);  paint.end();
  delete []buf;
}
```

2.1.5 Draw and calculate

MathGL can be used to draw plots in parallel with some external calculations. The simplest way for this is the usage of Section 5.2 [mglDraw class], page 241. At this you should enable pthread for widgets by setting `enable-pthr-widget=ON` at configure stage (it is set by default). First, you need to inherit you class from `mglDraw` class, define virtual members `Draw()` and `Calc()` which will draw the plot and proceed calculations. You may want to add the pointer `mglWnd *wnd;` to window with plot for interacting with them. Finally, you may add any other data or member functions. The sample class is shown below

```
class myDraw : public mglDraw
{
        mglPoint pnt;   // some variable for changeable data
        long i;                 // another variable to be shown
        mglWnd *wnd;    // external window for plotting
public:
        myDraw(mglWnd *w=0) : mglDraw() {       wnd=w;  }
        void SetWnd(mglWnd *w)  {       wnd=w;  }
        int Draw(mglGraph *gr)
        {
                gr->Line(mglPoint(),pnt,"Ar2");
                char str[16];   snprintf(str,15,"i=%ld",i);
                gr->Puts(mglPoint(),str);
                return 0;
        }
        void Calc()
        {
                for(i=0;;i++)   // do calculation
                {
                        long_calculations();// which can be very long
                        Check();        // check if need pause
                        pnt.Set(2*mgl_rnd()-1,2*mgl_rnd()-1);
                        if(wnd) wnd->Update();
                }
        }
} dr;
```

There is only one issue here. Sometimes you may want to pause calculations to view result carefully, or save state, or change something. So, you need to provide a mechanism for pausing. Class `mglDraw` provide function `Check();` which check if toolbutton with pause is pressed and wait until it will be released. This function should be called in a "safety" places, where you can pause the calculation (for example, at the end of time step). Also you may add call `exit(0);` at the end of `Calc();` function for closing window and exit after finishing calculations. Finally, you need to create a window itself and run calculations.

```
int main(int argc,char **argv)
{
        mglFLTK gr(&dr,"Multi-threading test"); // create window
        dr.SetWnd(&gr); // pass window pointer to yours class
        dr.Run();       // run calculations
        gr.Run();       // run event loop for window
        return 0;
}
```

Note, that you can reach the similar functionality without using `mglDraw` class (i.e. even for pure C code).

```
mglFLTK *gr=NULL;       // pointer to window
void *calc(void *)      // function with calculations
{
        mglPoint pnt;   // some data for plot
        for(long i=0;;i++)              // do calculation
        {
                long_calculations();    // which can be very long
                pnt.Set(2*mgl_rnd()-1,2*mgl_rnd()-1);
                if(gr)
                {
                        gr->Clf();                      // make new drawing
                        // draw something
                        gr->Line(mglPoint(),pnt,"Ar2");
                        char str[16];   snprintf(str,15,"i=%ld",i);
                        gr->Puts(mglPoint(),str);
                        // don't forgot to update window
                        gr->Update();
                }
        }
}
int main(int argc,char **argv)
{
        static pthread_t thr;
        pthread_create(&thr,0,calc,0);  // create separate thread for calculations
        pthread_detach(thr);                    // and detach it
        gr = new mglFLTK;       // now create window
        gr->Run();                      // and run event loop
        return 0;
}
```

This sample is exactly the same as one with `mglDraw` class, but it don't have functionality for pausing calculations. If you need it then you have to create global mutex (like `pthread_mutex_t *mutex = pthread_mutex_init(&mutex,NULL);`), set it to window (like `gr->SetMutex(mutex);`) and periodically check it at calculations (like `pthread_mutex_lock(&mutex); pthread_mutex_unlock(&mutex);`).

Finally, you can put the event-handling loop in separate instead of yours code by using `RunThr()` function instead of `Run()` one. Unfortunately, such method work well only for FLTK windows and only if pthread support was enabled. Such limitation come from the Qt requirement to be run in the primary thread only. The sample code will be:

```
int main(int argc,char **argv)
{
        mglFLTK gr("test");
        gr.RunThr();    // <-- need MathGL version which use pthread for widgets
        mglPoint pnt;   // some data
        for(int i=0;i<10;i++)   // do calculation
        {
                long_calculations();// which can be very long
                pnt.Set(2*mgl_rnd()-1,2*mgl_rnd()-1);
                gr.Clf();                       // make new drawing
                gr.Line(mglPoint(),pnt,"Ar2");
                char str[10] = "i=0";   str[3] = '0'+i;
                gr->Puts(mglPoint(),str);
                gr.Update();            // update window
        }
        return 0;       // finish calculations and close the window
}
```

2.1.6 Using QMathGL

MathGL have several interface widgets for different widget libraries. There are QMathGL for Qt, Fl_MathGL for FLTK. These classes provide control which display MathGL graphics. Unfortunately there is no uniform interface for widget classes because all libraries have slightly different set of functions, features and so on. However the usage of MathGL widgets is rather simple. Let me show it on the example of QMathGL.

First of all you have to define the drawing function or inherit a class from `mglDraw` class. After it just create a window and setup QMathGL instance as any other Qt widget:

```
#include <QApplication>
#include <QMainWindow>
#include <QScrollArea>
#include <mgl2/qmathgl.h>
int main(int argc,char **argv)
{
  QApplication a(argc,argv);
  QMainWindow *Wnd = new QMainWindow;
  Wnd->resize(810,610);  // for fill up the QMGL, menu and toolbars
  Wnd->setWindowTitle("QMathGL sample");
  // here I allow to scroll QMathGL -- the case
```

```
  // then user want to prepare huge picture
  QScrollArea *scroll = new QScrollArea(Wnd);

  // Create and setup QMathGL
  QMathGL *QMGL = new QMathGL(Wnd);
//QMGL->setPopup(popup); // if you want to setup popup menu for QMGL
  QMGL->setDraw(sample);
  // or use QMGL->setDraw(foo); for instance of class Foo:public mglDraw
  QMGL->update();

  // continue other setup (menu, toolbar and so on)
  scroll->setWidget(QMGL);
  Wnd->setCentralWidget(scroll);
  Wnd->show();
  return a.exec();
}
```

2.1.7 MathGL and PyQt

Generally SWIG based classes (including the Python one) are the same as C++ classes. However, there are few tips for using MathGL with PyQt. Below I place a very simple python code which demonstrate how MathGL can be used with PyQt. This code is mostly written by Prof. Dr. Heino Falcke. You can just copy it to a file `mgl-pyqt-test.py` and execute it from python shell by command `execfile("mgl-pyqt-test.py")`

```
from PyQt4 import QtGui,QtCore
from mathgl import *
import sys
app = QtGui.QApplication(sys.argv)
qpointf=QtCore.QPointF()

class hfQtPlot(QtGui.QWidget):
    def __init__(self, parent=None):
        QtGui.QWidget.__init__(self, parent)
        self.img=(QtGui.QImage())
    def setgraph(self,gr):
        self.buffer='\t'
        self.buffer=self.buffer.expandtabs(4*gr.GetWidth()*gr.GetHeight())
        gr.GetBGRN(self.buffer,len(self.buffer))
        self.img=QtGui.QImage(self.buffer, gr.GetWidth(),gr.GetHeight(),QtGui.QImage.Format
        self.update()
    def paintEvent(self, event):
        paint = QtGui.QPainter()
        paint.begin(self)
        paint.drawImage(qpointf,self.img)
        paint.end()

BackgroundColor=[1.0,1.0,1.0]
```

```
size=100
gr=mglGraph()
y=mglData(size)
#y.Modify("((0.7*cos(2*pi*(x+.2)*500)+0.3)*(rnd*0.5+0.5)+362.135+10000.)")
y.Modify("(cos(2*pi*x*10)+1.1)*1000.*rnd-501")
x=mglData(size)
x.Modify("x^2");

def plotpanel(gr,x,y,n):
    gr.SubPlot(2,2,n)
    gr.SetXRange(x)
    gr.SetYRange(y)
    gr.AdjustTicks()
    gr.Axis()
    gr.Box()
    gr.Label("x","x-Axis",1)
    gr.Label("y","y-Axis",1)
    gr.ClearLegend()
    gr.AddLegend("Legend: "+str(n),"k")
    gr.Legend()
    gr.Plot(x,y)


gr.Clf(BackgroundColor[0],BackgroundColor[1],BackgroundColor[2])
gr.SetPlotFactor(1.5)
plotpanel(gr,x,y,0)
y.Modify("(cos(2*pi*x*10)+1.1)*1000.*rnd-501")
plotpanel(gr,x,y,1)
y.Modify("(cos(2*pi*x*10)+1.1)*1000.*rnd-501")
plotpanel(gr,x,y,2)
y.Modify("(cos(2*pi*x*10)+1.1)*1000.*rnd-501")
plotpanel(gr,x,y,3)

gr.WritePNG("test.png","Test Plot")

qw = hfQtPlot()
qw.show()
qw.setgraph(gr)
qw.raise_()
```

2.1.8 MathGL and MPI

For using MathGL in MPI program you just need to: (1) plot its own part of data for each running node; (2) collect resulting graphical information in a single program (for example, at node with rank=0); (3) save it. The sample code below demonstrate this for very simple sample of surface drawing.

First you need to initialize MPI

```
#include <stdio.h>
#include <mgl2/mpi.h>
#include <mpi.h>

int main(int argc, char *argv[])
{
  // initialize MPI
  int rank=0, numproc=1;
  MPI_Init(&argc, &argv);
  MPI_Comm_size(MPI_COMM_WORLD,&numproc);
  MPI_Comm_rank(MPI_COMM_WORLD,&rank);
  if(rank==0) printf("Use %d processes.\n", numproc);
```

Next step is data creation. For simplicity, I create data arrays with the same sizes for all nodes. At this, you have to create `mglGraph` object too.

```
  // initialize data similarly for all nodes
  mglData a(128,256);
  mglGraphMPI gr;
```

Now, data should be filled by numbers. In real case, it should be some kind of calculations. But I just fill it by formula.

```
  // do the same plot for its own range
  char buf[64];
  sprintf(buf,"xrange %g %g",2.*rank/numproc-1,2.*(rank+1)/numproc-1);
  gr.Fill(a,"sin(2*pi*x)",buf);
```

It is time to plot the data. Don't forget to set proper axis range(s) by using parametric form or by using options (as in the sample).

```
  // plot data in each node
  gr.Clf();   // clear image before making the image
  gr.Rotate(40,60);
  gr.Surf(a,"",buf);
```

Finally, let send graphical information to node with rank=0.

```
  // collect information
  if(rank!=0) gr.MPI_Send(0);
  else for(int i=1;i<numproc;i++)  gr.MPI_Recv(i);
```

Now, node with rank=0 have whole image. It is time to save the image to a file. Also, you can add a kind of annotations here – I draw axis and bounding box in the sample.

```
  if(rank==0)
  {
    gr.Box();   gr.Axis();   // some post processing
    gr.WritePNG("test.png"); // save result
  }
```

In my case the program is done, and I finalize MPI. In real program, you can repeat the loop of data calculation and data plotting as many times as you need.

```
  MPI_Finalize();
  return 0;
```

```
}
```

You can type '`mpic++ test.cpp -lmgl-mpi -lmgl && mpirun -np 8 ./a.out`' for compilation and running the sample program on 8 nodes. Note, that you have to set enable-mpi=ON at MathGL configure to use this feature.

2.2 Advanced usage

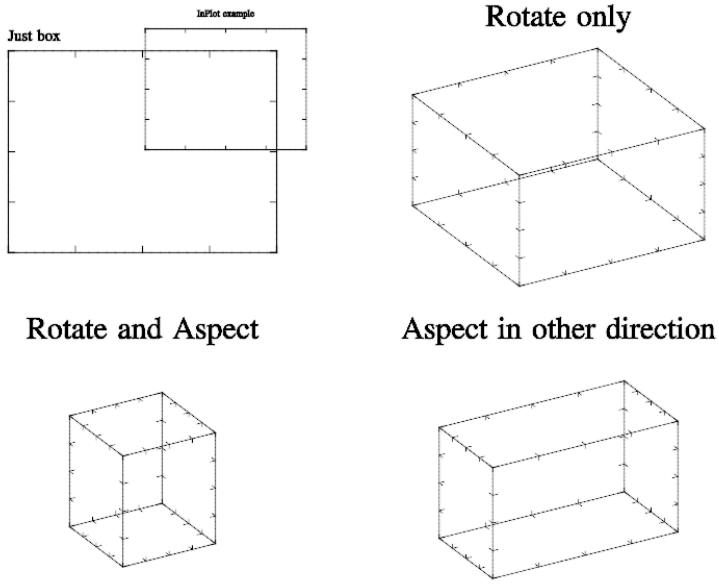
Now I show several non-obvious features of MathGL: several subplots in a single picture, curvilinear coordinates, text printing and so on. Generally you may miss this section at first reading.

2.2.1 Subplots

Let me demonstrate possibilities of plot positioning and rotation. MathGL has a set of functions: [subplot], page 173, [inplot], page 173, [title], page 174, [aspect], page 175 and [rotate], page 175 and so on (see Section 4.4 [Subplots and rotation], page 172). The order of their calling is strictly determined. First, one changes the position of plot in image area (functions [subplot], page 173, [inplot], page 173 and [multiplot], page 173). Secondly, you can add the title of plot by [title], page 174 function. After that one may rotate the plot (function [rotate], page 175). Finally, one may change aspects of axes (function [aspect], page 175). The following code illustrates the aforesaid it:

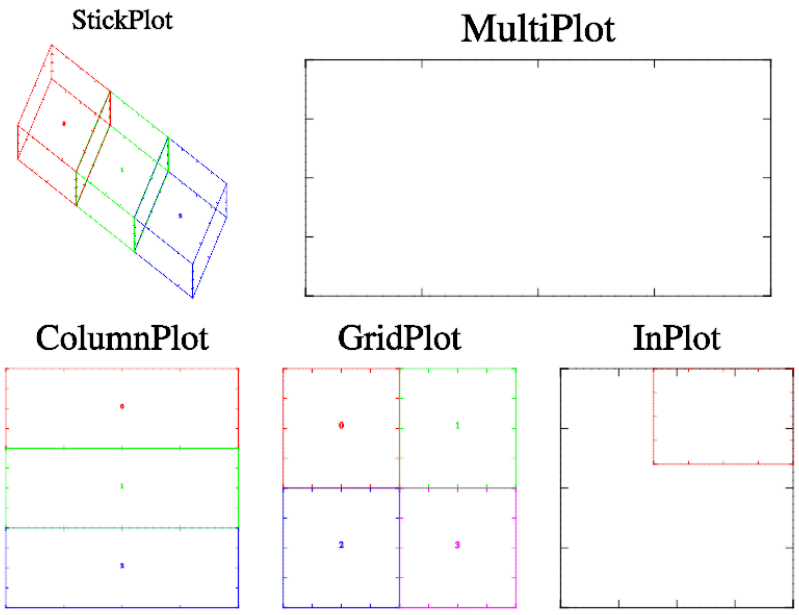
```
int sample(mglGraph *gr)
{
  gr->SubPlot(2,2,0); gr->Box();
  gr->Puts(mglPoint(-1,1.1),"Just box",":L");
  gr->InPlot(0.2,0.5,0.7,1,false);  gr->Box();
  gr->Puts(mglPoint(0,1.2),"InPlot example");
  gr->SubPlot(2,2,1); gr->Title("Rotate only");
  gr->Rotate(50,60);  gr->Box();
  gr->SubPlot(2,2,2); gr->Title("Rotate and Aspect");
  gr->Rotate(50,60);  gr->Aspect(1,1,2);  gr->Box();
  gr->SubPlot(2,2,3); gr->Title("Aspect in other direction");
  gr->Rotate(50,60);  gr->Aspect(1,2,2);  gr->Box();
  return 0;
}
```

Here I used function `Puts` for printing the text in arbitrary position of picture (see Section 4.8 [Text printing], page 189). Text coordinates and size are connected with axes. However, text coordinates may be everywhere, including the outside the bounding box. I'll show its features later in Section 2.2.7 [Text features], page 31.



More complicated sample show how to use most of positioning functions:

```
int sample(mglGraph *gr)
{
  gr->SubPlot(3,2,0); gr->Title("StickPlot");
  gr->StickPlot(3, 0, 20, 30);  gr->Box("r"); gr->Puts(mglPoint(0),"0","r");
  gr->StickPlot(3, 1, 20, 30);  gr->Box("g"); gr->Puts(mglPoint(0),"1","g");
  gr->StickPlot(3, 2, 20, 30);  gr->Box("b"); gr->Puts(mglPoint(0),"2","b");
  gr->SubPlot(3,2,3,"");  gr->Title("ColumnPlot");
  gr->ColumnPlot(3, 0); gr->Box("r"); gr->Puts(mglPoint(0),"0","r");
  gr->ColumnPlot(3, 1); gr->Box("g"); gr->Puts(mglPoint(0),"1","g");
  gr->ColumnPlot(3, 2); gr->Box("b"); gr->Puts(mglPoint(0),"2","b");
  gr->SubPlot(3,2,4,"");  gr->Title("GridPlot");
  gr->GridPlot(2, 2, 0);  gr->Box("r"); gr->Puts(mglPoint(0),"0","r");
  gr->GridPlot(2, 2, 1);  gr->Box("g"); gr->Puts(mglPoint(0),"1","g");
  gr->GridPlot(2, 2, 2);  gr->Box("b"); gr->Puts(mglPoint(0),"2","b");
  gr->GridPlot(2, 2, 3);  gr->Box("m"); gr->Puts(mglPoint(0),"3","m");
  gr->SubPlot(3,2,5,"");  gr->Title("InPlot");  gr->Box();
  gr->InPlot(0.4, 1, 0.6, 1, true); gr->Box("r");
  gr->MultiPlot(3,2,1, 2, 1,"");  gr->Title("MultiPlot"); gr->Box();
  return 0;
}
```



2.2.2 Axis and ticks

MathGL library can draw not only the bounding box but also the axes, grids, labels and so on. The ranges of axes and their origin (the point of intersection) are determined by functions `SetRange()`, `SetRanges()`, `SetOrigin()` (see Section 4.3.1 [Ranges (bounding box)], page 167). Ticks on axis are specified by function `SetTicks`, `SetTicksVal`, `SetTicksTime` (see Section 4.3.3 [Ticks], page 169). But usually

Function [axis], page 191 draws axes. Its textual string shows in which directions the axis or axes will be drawn (by default `"xyz"`, function draws axes in all directions). Function [grid], page 193 draws grid perpendicularly to specified directions. Example of axes and grid drawing is:

```
int sample(mglGraph *gr)
{
  gr->SubPlot(2,2,0); gr->Title("Axis origin, Grid"); gr->SetOrigin(0,0);
  gr->Axis(); gr->Grid(); gr->FPlot("x^3");

  gr->SubPlot(2,2,1); gr->Title("2 axis");
  gr->SetRanges(-1,1,-1,1); gr->SetOrigin(-1,-1,-1);  // first axis
  gr->Axis(); gr->Label('y',"axis 1",0);  gr->FPlot("sin(pi*x)");
  gr->SetRanges(0,1,0,1);   gr->SetOrigin(1,1,1);   // second axis
  gr->Axis(); gr->Label('y',"axis 2",0);  gr->FPlot("cos(pi*x)");

  gr->SubPlot(2,2,3); gr->Title("More axis");
  gr->SetOrigin(NAN,NAN); gr->SetRange('x',-1,1);
  gr->Axis(); gr->Label('x',"x",0); gr->Label('y',"y_1",0);
  gr->FPlot("x^2","k");
  gr->SetRanges(-1,1,-1,1); gr->SetOrigin(-1.3,-1); // second axis
  gr->Axis("y","r");  gr->Label('y',"#r{y_2}",0.2);
  gr->FPlot("x^3","r");
```

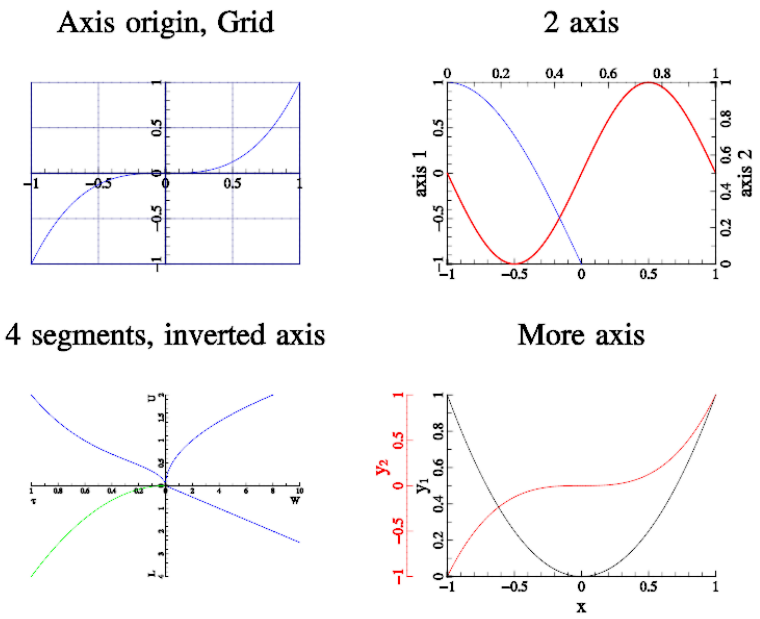
```
  gr->SubPlot(2,2,2); gr->Title("4 segments, inverted axis");
  gr->SetOrigin(0,0);
  gr->InPlot(0.5,1,0.5,1);  gr->SetRanges(0,10,0,2);  gr->Axis();
  gr->FPlot("sqrt(x/2)");   gr->Label('x',"W",1); gr->Label('y',"U",1);
  gr->InPlot(0,0.5,0.5,1);  gr->SetRanges(1,0,0,2); gr->Axis("x");
  gr->FPlot("sqrt(x)+x^3"); gr->Label('x',"\\tau",-1);
  gr->InPlot(0.5,1,0,0.5);  gr->SetRanges(0,10,4,0);  gr->Axis("y");
  gr->FPlot("x/4"); gr->Label('y',"L",-1);
  gr->InPlot(0,0.5,0,0.5);  gr->SetRanges(1,0,4,0); gr->FPlot("4*x^2");
  return 0;
}
```

Note, that MathGL can draw not only single axis (which is default). But also several axis on the plot (see right plots). The idea is that the change of settings does not influence on the already drawn graphics. So, for 2-axes I setup the first axis and draw everything concerning it. Then I setup the second axis and draw things for the second axis. Generally, the similar idea allows one to draw rather complicated plot of 4 axis with different ranges (see bottom left plot).

At this inverted axis can be created by 2 methods. First one is used in this sample – just specify minimal axis value to be large than maximal one. This method work well for 2D axis, but can wrongly place labels in 3D case. Second method is more general and work in 3D case too – just use [aspect], page 175 function with negative arguments. For example, following code will produce exactly the same result for 2D case, but 2nd variant will look better in 3D.

```
// variant 1
gr->SetRanges(0,10,4,0);  gr->Axis();

// variant 2
gr->SetRanges(0,10,0,4);  gr->Aspect(1,-1);   gr->Axis();
```



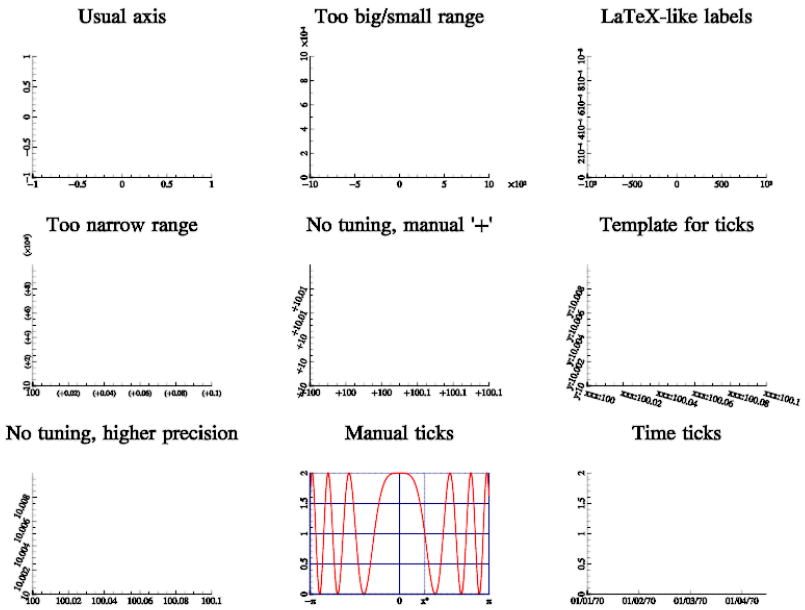
Another MathGL feature is fine ticks tunning. By default (if it is not changed by `SetTicks` function), MathGL try to adjust ticks positioning, so that they looks most human readable. At this, MathGL try to extract common factor for too large or too small axis ranges, as well as for too narrow ranges. Last one is non-common notation and can be disabled by `SetTuneTicks` function.

Also, one can specify its own ticks with arbitrary labels by help of `SetTicksVal` function. Or one can set ticks in time format. In last case MathGL will try to select optimal format for labels with automatic switching between years, months/days, hours/minutes/seconds or microseconds. However, you can specify its own time representation using formats described in `http://www.manpagez.com/man/3/strftime/`. Most common variants are '`%X`' for national representation of time, '`%x`' for national representation of date, '`%Y`' for year with century.

The sample code, demonstrated ticks feature is

```
int sample(mglGraph *gr)
{
  gr->SubPlot(3,3,0); gr->Title("Usual axis");  gr->Axis();
  gr->SubPlot(3,3,1); gr->Title("Too big/small range");
  gr->SetRanges(-1000,1000,0,0.001);  gr->Axis();
  gr->SubPlot(3,3,2); gr->Title("LaTeX-like labels");
  gr->Axis("F!");
  gr->SubPlot(3,3,3); gr->Title("Too narrow range");
  gr->SetRanges(100,100.1,10,10.01);  gr->Axis();
  gr->SubPlot(3,3,4); gr->Title("No tuning, manual '+'");
  // for version<2.3 you need first call gr->SetTuneTicks(0);
  gr->Axis("+!");
  gr->SubPlot(3,3,5); gr->Title("Template for ticks");
  gr->SetTickTempl('x',"xxx:%g"); gr->SetTickTempl('y',"y:%g");
  gr->Axis();
  // now switch it off for other plots
```

```
  gr->SetTickTempl('x',"");   gr->SetTickTempl('y',"");
  gr->SubPlot(3,3,6); gr->Title("No tuning, higher precision");
  gr->Axis("!4");
  gr->SubPlot(3,3,7); gr->Title("Manual ticks");  gr->SetRanges(-M_PI,M_PI, 0, 2);
  gr->SetTicks('x',M_PI,0,0,"\\pi");  gr->AddTick('x',0.886,"x^*");
  // alternatively you can use following lines
  //double val[]={-M_PI, -M_PI/2, 0, 0.886, M_PI/2, M_PI};
  //gr->SetTicksVal('x', mglData(6,val), "-\\pi\n-\\pi/2\n0\nx^*\n\\pi/2\n\\pi");
  gr->Axis();  gr->Grid();  gr->FPlot("2*cos(x^2)^2", "r2");
  gr->SubPlot(3,3,8); gr->Title("Time ticks");  gr->SetRange('x',0,3e5);
  gr->SetTicksTime('x',0);  gr->Axis();
}
```



The last sample I want to show in this subsection is Log-axis. From MathGL's point of view, the log-axis is particular case of general curvilinear coordinates. So, we need first define new coordinates (see also Section 2.2.3 [Curvilinear coordinates], page 26) by help of `SetFunc` or `SetCoor` functions. At this one should wary about proper axis range. So the code looks as following:

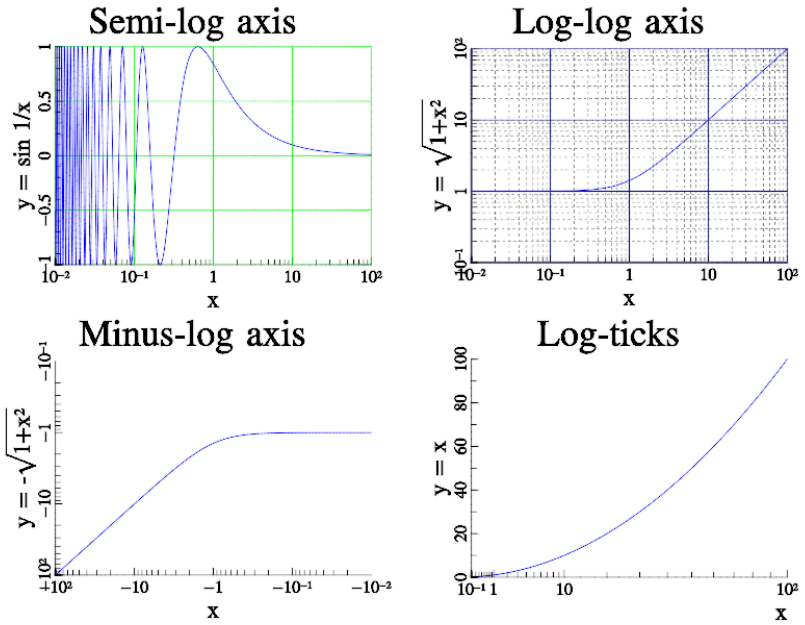
```
int sample(mglGraph *gr)
{
  gr->SubPlot(2,2,0,"<_");  gr->Title("Semi-log axis");
  gr->SetRanges(0.01,100,-1,1); gr->SetFunc("lg(x)","");
  gr->Axis(); gr->Grid("xy","g"); gr->FPlot("sin(1/x)");
  gr->Label('x',"x",0); gr->Label('y', "y = sin 1/x",0);

  gr->SubPlot(2,2,1,"<_");  gr->Title("Log-log axis");
  gr->SetRanges(0.01,100,0.1,100);  gr->SetFunc("lg(x)","lg(y)");
  gr->Axis(); gr->Grid("!","h=");   gr->Grid();
```

```
  gr->FPlot("sqrt(1+x^2)"); gr->Label('x',"x",0);
  gr->Label('y', "y = \\sqrt{1+x^2}",0);

  gr->SubPlot(2,2,2,"<_");  gr->Title("Minus-log axis");
  gr->SetRanges(-100,-0.01,-100,-0.1);  gr->SetFunc("-lg(-x)","-lg(-y)");
  gr->Axis(); gr->FPlot("-sqrt(1+x^2)");
  gr->Label('x',"x",0); gr->Label('y', "y = -\\sqrt{1+x^2}",0);

  gr->SubPlot(2,2,3,"<_");  gr->Title("Log-ticks");
  gr->SetRanges(0.1,100,0,100); gr->SetFunc("sqrt(x)","");
  gr->Axis(); gr->FPlot("x");
  gr->Label('x',"x",1); gr->Label('y', "y = x",0);
  return 0;
}
```



You can see that MathGL automatically switch to log-ticks as we define log-axis formula (in difference from v.1.*). Moreover, it switch to log-ticks for any formula if axis range will be large enough (see right bottom plot). Another interesting feature is that you not necessary define usual log-axis (i.e. when coordinates are positive), but you can define "minus-log" axis when coordinate is negative (see left bottom plot).

2.2.3 Curvilinear coordinates

As I noted in previous subsection, MathGL support curvilinear coordinates. In difference from other plotting programs and libraries, MathGL uses textual formulas for connection of the old (data) and new (output) coordinates. This allows one to plot in arbitrary coordinates. The following code plots the line y=0, z=0 in Cartesian, polar, parabolic and spiral coordinates:

```
int sample(mglGraph *gr)
```

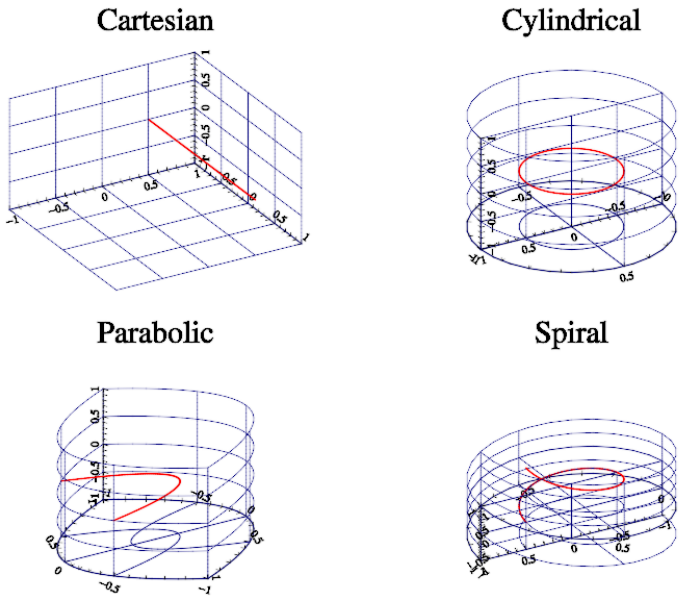
```
{
  gr->SetOrigin(-1,1,-1);

  gr->SubPlot(2,2,0); gr->Title("Cartesian"); gr->Rotate(50,60);
  gr->FPlot("2*t-1","0.5","0","r2");
  gr->Axis(); gr->Grid();

  gr->SetFunc("y*sin(pi*x)","y*cos(pi*x)",0);
  gr->SubPlot(2,2,1); gr->Title("Cylindrical"); gr->Rotate(50,60);
  gr->FPlot("2*t-1","0.5","0","r2");
  gr->Axis(); gr->Grid();

  gr->SetFunc("2*y*x","y*y - x*x",0);
  gr->SubPlot(2,2,2); gr->Title("Parabolic"); gr->Rotate(50,60);
  gr->FPlot("2*t-1","0.5","0","r2");
  gr->Axis(); gr->Grid();

  gr->SetFunc("y*sin(pi*x)","y*cos(pi*x)","x+z");
  gr->SubPlot(2,2,3); gr->Title("Spiral");  gr->Rotate(50,60);
  gr->FPlot("2*t-1","0.5","0","r2");
  gr->Axis(); gr->Grid();
  gr->SetFunc(0,0,0); // set to default Cartesian
  return 0;
}
```



2.2.4 Colorbars

MathGL handle [colorbar], page 192 as special kind of axis. So, most of functions for axis and ticks setup will work for colorbar too. Colorbars can be in log-scale, and generally as arbitrary function scale; common factor of colorbar labels can be separated; and so on.

But of course, there are differences – colorbars usually located out of bounding box. At this, colorbars can be at subplot boundaries (by default), or at bounding box (if symbol 'I' is specified). Colorbars can handle sharp colors. And they can be located at arbitrary position too. The sample code, which demonstrate colorbar features is:

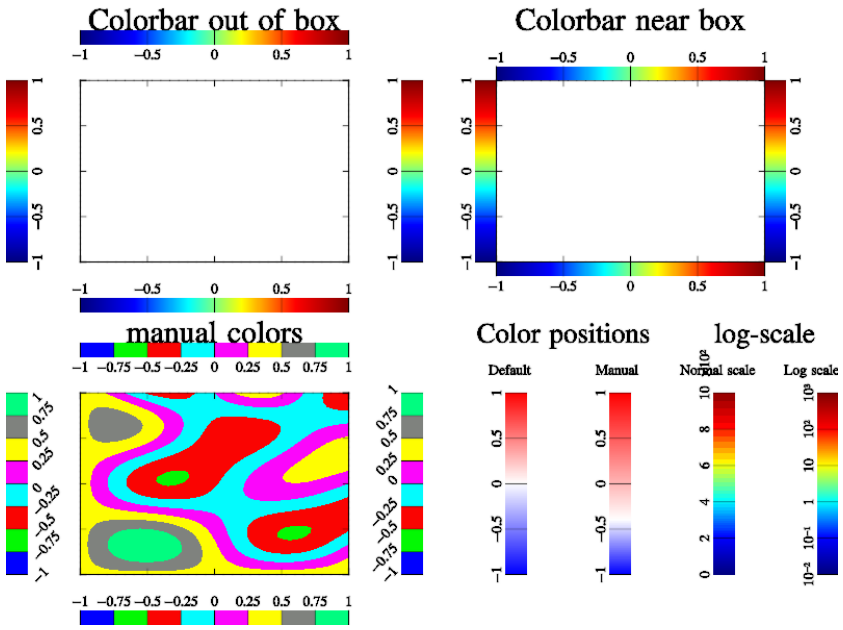
```
int sample(mglGraph *gr)
{
  gr->SubPlot(2,2,0); gr->Title("Colorbar out of box"); gr->Box();
  gr->Colorbar("<");  gr->Colorbar(">");
  gr->Colorbar("_");  gr->Colorbar("^");

  gr->SubPlot(2,2,1); gr->Title("Colorbar near box");   gr->Box();
  gr->Colorbar("<I"); gr->Colorbar(">I");
  gr->Colorbar("_I"); gr->Colorbar("^I");

  gr->SubPlot(2,2,2); gr->Title("manual colors");
  mglData a,v;  mgls_prepare2d(&a,0,&v);
  gr->Box();  gr->ContD(v,a);
  gr->Colorbar(v,"<");  gr->Colorbar(v,">");
  gr->Colorbar(v,"_");  gr->Colorbar(v,"^");

  gr->SubPlot(2,2,3);   gr->Title(" ");
  gr->Puts(mglPoint(-0.5,1.55),"Color positions",":C",-2);
  gr->Colorbar("bwr>",0.25,0);  gr->Puts(mglPoint(-0.9,1.2),"Default");
  gr->Colorbar("b{w,0.3}r>",0.5,0); gr->Puts(mglPoint(-0.1,1.2),"Manual");

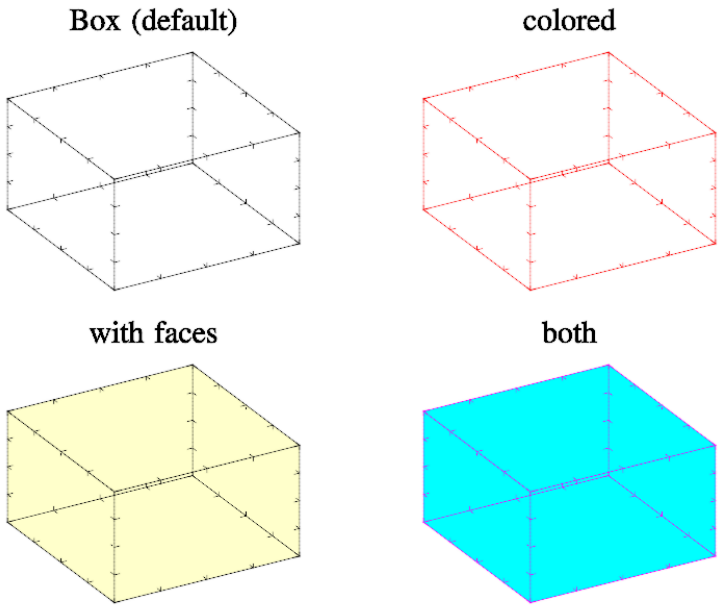
  gr->Puts(mglPoint(1,1.55),"log-scale",":C",-2);
  gr->SetRange('c',0.01,1e3);
  gr->Colorbar(">",0.75,0);  gr->Puts(mglPoint(0.65,1.2),"Normal scale");
  gr->SetFunc("","","","lg(c)");
  gr->Colorbar(">");    gr->Puts(mglPoint(1.35,1.2),"Log scale");
  return 0;
}
```



2.2.5 Bounding box

Box around the plot is rather useful thing because it allows one to: see the plot boundaries, and better estimate points position since box contain another set of ticks. MathGL provide special function for drawing such box – [box], page 193 function. By default, it draw black or white box with ticks (color depend on transparency type, see Section 2.9.3 [Types of transparency], page 114). However, you can change the color of box, or add drawing of rectangles at rear faces of box. Also you can disable ticks drawing, but I don't know why anybody will want it. The sample code, which demonstrate [box], page 193 features is:

```
int sample(mglGraph *gr)
{
  gr->SubPlot(2,2,0); gr->Title("Box (default)"); gr->Rotate(50,60);
  gr->Box();
  gr->SubPlot(2,2,1); gr->Title("colored");   gr->Rotate(50,60);
  gr->Box("r");
  gr->SubPlot(2,2,2); gr->Title("with faces");  gr->Rotate(50,60);
  gr->Box("@");
  gr->SubPlot(2,2,3); gr->Title("both");  gr->Rotate(50,60);
  gr->Box("@cm");
  return 0;
}
```



2.2.6 Ternary axis

There are another unusual axis types which are supported by MathGL. These are ternary and quaternary axis. Ternary axis is special axis of 3 coordinates a, b, c which satisfy relation $a+b+c=1$. Correspondingly, quaternary axis is special axis of 4 coordinates a, b, c, d which satisfy relation $a+b+c+d=1$.

Generally speaking, only 2 of coordinates (3 for quaternary) are independent. So, MathGL just introduce some special transformation formulas which treat a as '`x`', b as '`y`' (and c as '`z`' for quaternary). As result, all plotting functions (curves, surfaces, contours and so on) work as usual, but in new axis. You should use [ternary], page 169 function for switching to ternary/quaternary coordinates. The sample code is:

```
int sample(mglGraph *gr)
{
  gr->SetRanges(0,1,0,1,0,1);
  mglData x(50),y(50),z(50),rx(10),ry(10), a(20,30);
  a.Modify("30*x*y*(1-x-y)^2*(x+y<1)");
  x.Modify("0.25*(1+cos(2*pi*x))");
  y.Modify("0.25*(1+sin(2*pi*x))");
  rx.Modify("rnd"); ry.Modify("(1-v)*rnd",rx);
  z.Modify("x");

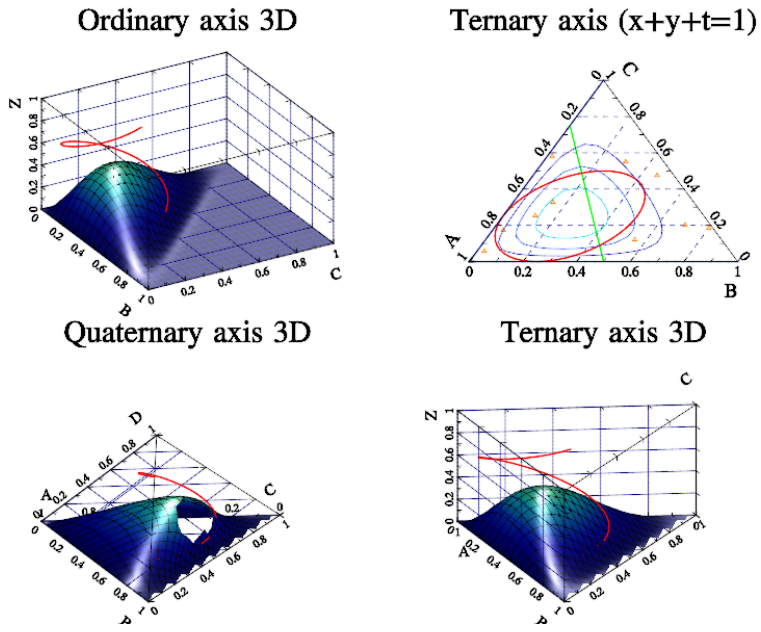
  gr->SubPlot(2,2,0); gr->Title("Ordinary axis 3D");
  gr->Rotate(50,60);    gr->Light(true);
  gr->Plot(x,y,z,"r2"); gr->Surf(a,"BbcyrR#");
  gr->Axis(); gr->Grid(); gr->Box();
  gr->Label('x',"B",1); gr->Label('y',"C",1); gr->Label('z',"Z",1);

  gr->SubPlot(2,2,1); gr->Title("Ternary axis (x+y+t=1)");
  gr->Ternary(1);
```

```
  gr->Plot(x,y,"r2"); gr->Plot(rx,ry,"q^ ");  gr->Cont(a,"BbcyrR");
  gr->Line(mglPoint(0.5,0), mglPoint(0,0.75), "g2");
  gr->Axis(); gr->Grid("xyz","B;");
  gr->Label('x',"B"); gr->Label('y',"C"); gr->Label('t',"A");

  gr->SubPlot(2,2,2); gr->Title("Quaternary axis 3D");
  gr->Rotate(50,60);    gr->Light(true);
  gr->Ternary(2);
  gr->Plot(x,y,z,"r2"); gr->Surf(a,"BbcyrR#");
  gr->Axis(); gr->Grid(); gr->Box();
  gr->Label('t',"A",1); gr->Label('x',"B",1);
  gr->Label('y',"C",1); gr->Label('z',"D",1);

  gr->SubPlot(2,2,3); gr->Title("Ternary axis 3D");
  gr->Rotate(50,60);    gr->Light(true);
  gr->Ternary(1);
  gr->Plot(x,y,z,"r2"); gr->Surf(a,"BbcyrR#");
  gr->Axis(); gr->Grid(); gr->Box();
  gr->Label('t',"A",1); gr->Label('x',"B",1);
  gr->Label('y',"C",1); gr->Label('z',"Z",1);
  return 0;
}
```



2.2.7 Text features

MathGL prints text by vector font. There are functions for manual specifying of text position (like `Puts`) and for its automatic selection (like `Label`, `Legend` and so on). MathGL prints text always in specified position even if it lies outside the bounding box. The default

size of font is specified by functions *SetFontSize** (see Section 4.2.6 [Font settings], page 162). However, the actual size of output string depends on subplot size (depends on functions `SubPlot`, `InPlot`). The switching of the font style (italic, bold, wire and so on) can be done for the whole string (by function parameter) or inside the string. By default MathGL parses TeX-like commands for symbols and indexes (see Section 3.5 [Font styles], page 152).

Text can be printed as usual one (from left to right), along some direction (rotated text), or along a curve. Text can be printed on several lines, divided by new line symbol '`\n`'.

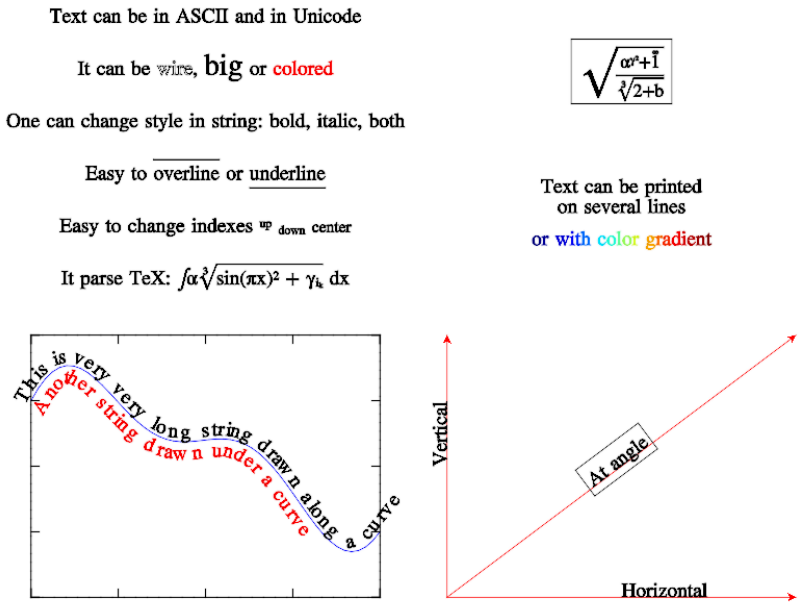
Example of MathGL font drawing is:

```
int sample(mglGraph *gr)
{
  gr->SubPlot(2,2,0,"");
  gr->Putsw(mglPoint(0,1),L"Text can be in ASCII and in Unicode");
  gr->Puts(mglPoint(0,0.6),"It can be \\wire{wire}, \\big{big} or #r{colored}");
  gr->Puts(mglPoint(0,0.2),"One can change style in string: "
  "\\b{bold}, \\i{italic, \\b{both}}");
  gr->Puts(mglPoint(0,-0.2),"Easy to \\a{overline} or "
  "\\u{underline}");
  gr->Puts(mglPoint(0,-0.6),"Easy to change indexes ^{up} _{down} @{center}");
  gr->Puts(mglPoint(0,-1),"It parse TeX: \\int \\alpha \\cdot "
  "\\sqrt3{sin(\\pi x)^2 + \\gamma_{i_k}} dx");

  gr->SubPlot(2,2,1,"");
  gr->Puts(mglPoint(0,0.5), "\\sqrt{\\frac{\\alpha^{\\gamma^2}+\\overset 1{\\big\\infty}}{\
  gr->Puts(mglPoint(0,-0.5),"Text can be printed\non several lines");

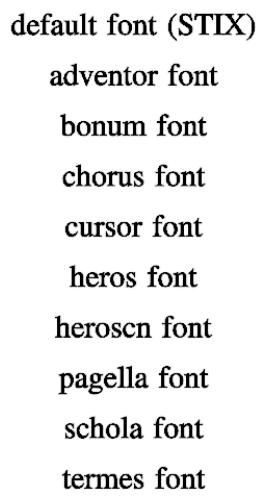
  gr->SubPlot(2,2,2,"");
  mglData y;  mgls_prepare1d(&y);
  gr->Box();  gr->Plot(y.SubData(-1,0));
  gr->Text(y,"This is very very long string drawn along a curve",":k");
  gr->Text(y,"Another string drawn under a curve","T:r");

  gr->SubPlot(2,2,3,"");
  gr->Line(mglPoint(-1,-1),mglPoint(1,-1),"rA");
  gr->Puts(mglPoint(0,-1),mglPoint(1,-1),"Horizontal");
  gr->Line(mglPoint(-1,-1),mglPoint(1,1),"rA");
  gr->Puts(mglPoint(0,0),mglPoint(1,1),"At angle","@");
  gr->Line(mglPoint(-1,-1),mglPoint(-1,1),"rA");
  gr->Puts(mglPoint(-1,0),mglPoint(-1,1),"Vertical");
  return 0;
}
```



You can change font faces by loading font files by function [loadfont], page 162. Note, that this is long-run procedure. Font faces can be downloaded from MathGL website (`http://mathgl.sourceforge.net/download.html`) or from here (`http://sourceforge.net/project/showfiles.php?group_id=152187&package_id=267177`). The sample code is:

```
int sample(mglGraph *gr)
{
  double h=1.1, d=0.25;
  gr->LoadFont("STIX");      gr->Puts(mglPoint(0,h), "default font (STIX)");
  gr->LoadFont("adventor"); gr->Puts(mglPoint(0,h-d), "adventor font");
  gr->LoadFont("bonum");     gr->Puts(mglPoint(0,h-2*d), "bonum font");
  gr->LoadFont("chorus");    gr->Puts(mglPoint(0,h-3*d), "chorus font");
  gr->LoadFont("cursor");    gr->Puts(mglPoint(0,h-4*d), "cursor font");
  gr->LoadFont("heros");     gr->Puts(mglPoint(0,h-5*d), "heros font");
  gr->LoadFont("heroscn");   gr->Puts(mglPoint(0,h-6*d), "heroscn font");
  gr->LoadFont("pagella");   gr->Puts(mglPoint(0,h-7*d), "pagella font");
  gr->LoadFont("schola");    gr->Puts(mglPoint(0,h-8*d), "schola font");
  gr->LoadFont("termes");    gr->Puts(mglPoint(0,h-9*d), "termes font");
  return 0;
}
```



2.2.8 Legend sample

Legend is one of standard ways to show plot annotations. Basically you need to connect the plot style (line style, marker and color) with some text. In MathGL, you can do it by 2 methods: manually using [addlegend], page 194 function; or use '`legend`' option (see Section 3.7 [Command options], page 154), which will use last plot style. In both cases, legend entries will be added into internal accumulator, which later used for legend drawing itself. [clearlegend], page 195 function allow you to remove all saved legend entries.

There are 2 features. If plot style is empty then text will be printed without indent. If you want to plot the text with indent but without plot sample then you need to use space ' ' as plot style. Such style ' ' will draw a plot sample (line with marker(s)) which is invisible line (i.e. nothing) and print the text with indent as usual one.

Function [legend], page 194 draw legend on the plot. The position of the legend can be selected automatic or manually. You can change the size and style of text labels, as well as setup the plot sample. The sample code demonstrating legend features is:

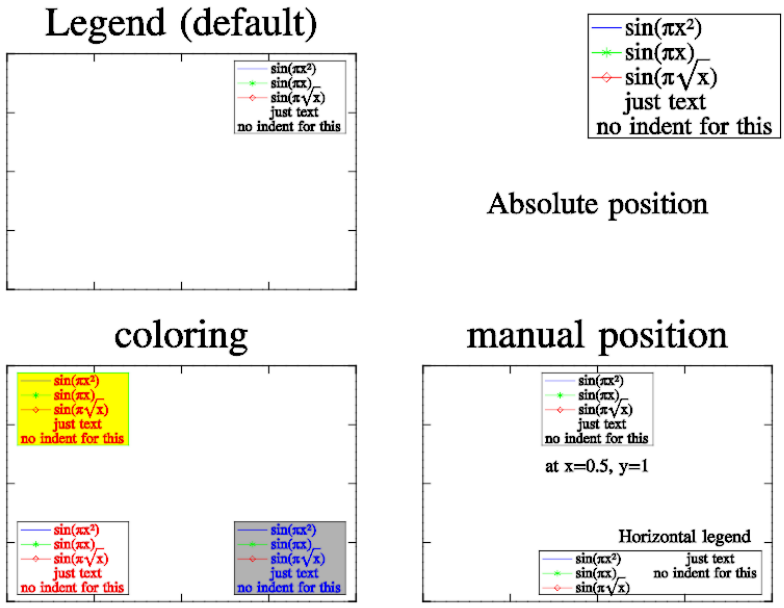
```
int sample(mglGraph *gr)
{
  gr->AddLegend("sin(\\pi {x^2})","b");
  gr->AddLegend("sin(\\pi x)","g*");
  gr->AddLegend("sin(\\pi \\sqrt{x})","rd");
  gr->AddLegend("just text"," ");
  gr->AddLegend("no indent for this","");

  gr->SubPlot(2,2,0,""); gr->Title("Legend (default)");
  gr->Box();  gr->Legend();

  gr->Legend(3,"A#");
  gr->Puts(mglPoint(0.75,0.65),"Absolute position","A");
```

```
  gr->SubPlot(2,2,2,"");  gr->Title("coloring");  gr->Box();
  gr->Legend(0,"r#"); gr->Legend(1,"Wb#");  gr->Legend(2,"ygr#");

  gr->SubPlot(2,2,3,"");  gr->Title("manual position"); gr->Box();
  gr->Legend(0.5,1);  gr->Puts(mglPoint(0.5,0.55),"at x=0.5, y=1","a");
  gr->Legend(1,"#-"); gr->Puts(mglPoint(0.75,0.25),"Horizontal legend","a");
  return 0;
}
```



2.2.9 Cutting sample

The last common thing which I want to show in this section is how one can cut off points from plot. There are 4 mechanism for that.

- You can set one of coordinate to NAN value. All points with NAN values will be omitted.
- You can enable cutting at edges by `SetCut` function. As result all points out of bounding box will be omitted.
- You can set cutting box by `SetCutBox` function. All points inside this box will be omitted.
- You can define cutting formula by `SetCutOff` function. All points for which the value of formula is nonzero will be omitted. Note, that this is the slowest variant.

Below I place the code which demonstrate last 3 possibilities:

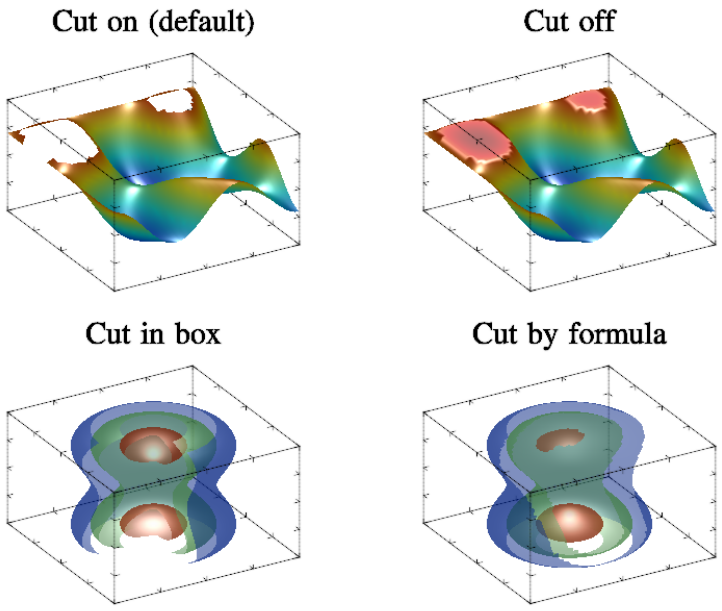
```
int sample(mglGraph *gr)
{
  mglData a,c,v(1); mgls_prepare2d(&a); mgls_prepare3d(&c); v.a[0]=0.5;
  gr->SubPlot(2,2,0); gr->Title("Cut on (default)");
  gr->Rotate(50,60);  gr->Light(true);
```

```
  gr->Box();  gr->Surf(a,"","zrange -1 0.5");

  gr->SubPlot(2,2,1); gr->Title("Cut off");   gr->Rotate(50,60);
  gr->Box();  gr->Surf(a,"","zrange -1 0.5; cut off");

  gr->SubPlot(2,2,2); gr->Title("Cut in box");  gr->Rotate(50,60);
  gr->SetCutBox(mglPoint(0,-1,-1), mglPoint(1,0,1.1));
  gr->Alpha(true);  gr->Box();  gr->Surf3(c);
  gr->SetCutBox(mglPoint(0), mglPoint(0));  // switch it off

  gr->SubPlot(2,2,3); gr->Title("Cut by formula");  gr->Rotate(50,60);
  gr->CutOff("(z>(x+0.5*y-1)^2-1) & (z>(x-0.5*y-1)^2-1)");
  gr->Box();  gr->Surf3(c); gr->CutOff(""); // switch it off
  return 0;
}
```



2.3 Data handling

Class `mglData` contains all functions for the data handling in MathGL (see Chapter 6 [Data processing], page 252). There are several matters why I use class `mglData` but not a single array: it does not depend on type of data (mreal or double), sizes of data arrays are kept with data, memory working is simpler and safer.

2.3.1 Array creation

There are many ways in MathGL how data arrays can be created and filled.

One can put the data in `mglData` instance by several ways. Let us do it for sinus function:

- one can create external array, fill it and put to `mglData` variable

```
double *a = new double[50];
for(int i=0;i<50;i++)   a[i] = sin(M_PI*i/49.);

mglData y;
y.Set(a,50);
```

- another way is to create `mglData` instance of the desired size and then to work directly with data in this variable

```
mglData y(50);
for(int i=0;i<50;i++)   y.a[i] = sin(M_PI*i/49.);
```

- next way is to fill the data in `mglData` instance by textual formula with the help of `Modify()` function

```
mglData y(50);
y.Modify("sin(pi*x)");
```

- or one may fill the array in some interval and modify it later

```
mglData y(50);
y.Fill(0,M_PI);
y.Modify("sin(u)");
```

- finally it can be loaded from file

```
FILE *fp=fopen("sin.dat","wt");   // create file first
for(int i=0;i<50;i++)   fprintf(fp,"%g\n",sin(M_PI*i/49.));
fclose(fp);

mglData y("sin.dat");             // load it
```

  At this you can use textual or HDF files, as well as import values from bitmap image (PNG is supported right now).

- at this one can read only part of data

```
FILE *fp-fopen("sin.dat","wt");   // create large file first
for(int i=0;i<70;i++)   fprintf(fp,"%g\n",sin(M_PI*i/49.));
fclose(fp);

mglData y;
y.Read("sin.dat",50);             // load it
```

Creation of 2d- and 3d-arrays is mostly the same. But one should keep in mind that class `mglData` uses flat data representation. For example, matrix 30*40 is presented as flat (1d-) array with length 30*40=1200 (nx=30, ny=40). The element with indexes {i,j} is a[i+nx*j]. So for 2d array we have:

```
mglData z(30,40);
for(int i=0;i<30;i++)   for(int j=0;j<40;j++)
  z.a[i+30*j] = sin(M_PI*i/29.)*sin(M_PI*j/39.);
```

or by using `Modify()` function

```
mglData z(30,40);
z.Modify("sin(pi*x)*cos(pi*y)");
```

The only non-obvious thing here is using multidimensional arrays in C/C++, i.e. arrays defined like `mreal dat[40][30];`. Since, formally these elements `dat[i]` can address the

memory in arbitrary place you should use the proper function to convert such arrays to `mglData` object. For C++ this is functions like `mglData::Set(mreal **dat, int N1, int N2);`. For C this is functions like `mgl_data_set_mreal2(HMDT d, const mreal **dat, int N1, int N2);`. At this, you should keep in mind that `nx=N2` and `ny=N1` after conversion.

2.3.2 Linking array

Sometimes the data arrays are so large, that one couldn't' copy its values to another array (i.e. into mglData). In this case, he can define its own class derived from `mglDataA` (see Section 9.2 [mglDataA class], page 310) or can use `Link` function.

In last case, MathGL just save the link to an external data array, but not copy it. You should provide the existence of this data array for whole time during which MathGL can use it. Another point is that MathGL will automatically create new array if you'll try to modify data values by any of `mglData` functions. So, you should use only function with `const` modifier if you want still using link to the original data array.

Creating the link is rather simple – just the same as using `Set` function

```
double *a = new double[50];
for(int i=0;i<50;i++)   a[i] = sin(M_PI*i/49.);

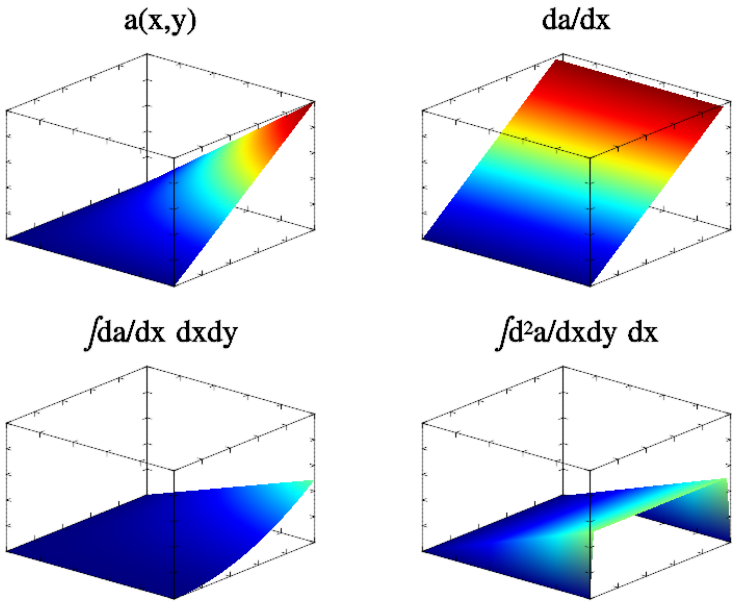
mglData y;
y.Link(a,50);
```

2.3.3 Change data

MathGL has functions for data processing: differentiating, integrating, smoothing and so on (for more detail, see Chapter 6 [Data processing], page 252). Let us consider some examples. The simplest ones are integration and differentiation. The direction in which operation will be performed is specified by textual string, which may contain symbols '`x`', '`y`' or '`z`'. For example, the call of `Diff("x")` will differentiate data along '`x`' direction; the call of `Integral("xy")` perform the double integration of data along '`x`' and '`y`' directions; the call of `Diff2("xyz")` will apply 3d Laplace operator to data and so on. Example of this operations on 2d array a=x*y is presented in code:

```
int sample(mglGraph *gr)
{
  gr->SetRanges(0,1,0,1,0,1);
  mglData a(30,40); a.Modify("x*y");
  gr->SubPlot(2,2,0); gr->Rotate(60,40);
  gr->Surf(a);    gr->Box();
  gr->Puts(mglPoint(0.7,1,1.2),"a(x,y)");
  gr->SubPlot(2,2,1); gr->Rotate(60,40);
  a.Diff("x");    gr->Surf(a);  gr->Box();
  gr->Puts(mglPoint(0.7,1,1.2),"da/dx");
  gr->SubPlot(2,2,2); gr->Rotate(60,40);
  a.Integral("xy"); gr->Surf(a);  gr->Box();
  gr->Puts(mglPoint(0.7,1,1.2),"\\int da/dx dxdy");
  gr->SubPlot(2,2,3); gr->Rotate(60,40);
  a.Diff2("y"); gr->Surf(a);  gr->Box();
  gr->Puts(mglPoint(0.7,1,1.2),"\\int {d^2}a/dxdy dx");
```

```
  return 0;
}
```



Data smoothing (function [smooth], page 271) is more interesting and important. This function has single argument which define type of smoothing and its direction. Now 3 methods are supported: '3' – linear averaging by 3 points, '5' – linear averaging by 5 points, and default one – quadratic averaging by 5 points.

MathGL also have some amazing functions which is not so important for data processing as useful for data plotting. There are functions for finding envelope (useful for plotting rapidly oscillating data), for data sewing (useful to removing jumps on the phase), for data resizing (interpolation). Let me demonstrate it:

```
int sample(mglGraph *gr)
{
  gr->SubPlot(2,2,0,"");  gr->Title("Envelop sample");
  mglData d1(1000); gr->Fill(d1,"exp(-8*x^2)*sin(10*pi*x)");
  gr->Axis();     gr->Plot(d1, "b");
  d1.Envelop('x');  gr->Plot(d1, "r");

  gr->SubPlot(2,2,1,"");  gr->Title("Smooth sample");
  mglData y0(30),y1,y2,y3;
  gr->SetRanges(0,1,0,1);
  gr->Fill(y0, "0.4*sin(pi*x) + 0.3*cos(1.5*pi*x) - 0.4*sin(2*pi*x)+0.5*rnd");

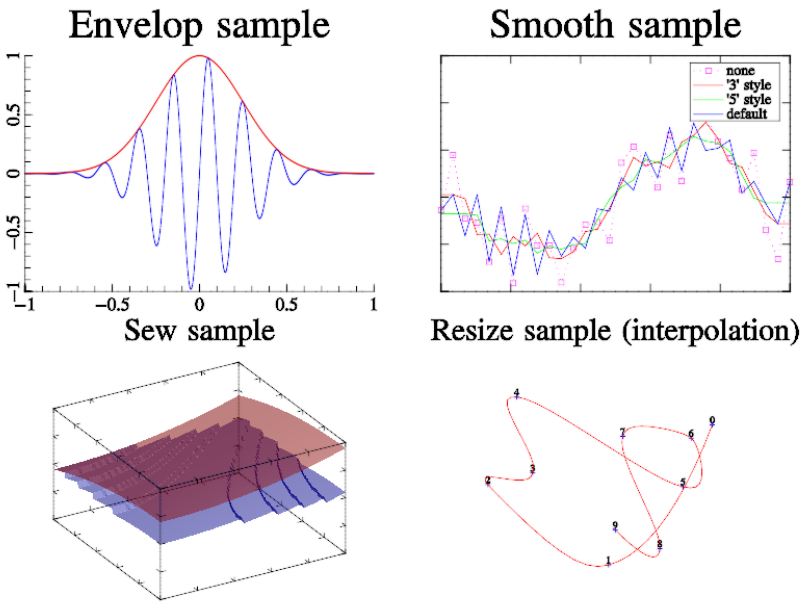
  y1=y0;  y1.Smooth("x3");
  y2=y0;  y2.Smooth("x5");
  y3=y0;  y3.Smooth("x");

  gr->Plot(y0,"{m7}:s", "legend 'none'"); //gr->AddLegend("none","k");
```

```
  gr->Plot(y1,"r", "legend ''3' style'");
  gr->Plot(y2,"g", "legend ''5' style'");
  gr->Plot(y3,"b", "legend 'default'");
  gr->Legend();   gr->Box();

  gr->SubPlot(2,2,2);   gr->Title("Sew sample");
  mglData d2(100, 100); gr->Fill(d2, "mod((y^2-(1-x)^2)/2,0.1)");
  gr->Rotate(50, 60);   gr->Light(true);  gr->Alpha(true);
  gr->Box();            gr->Surf(d2, "b");
  d2.Sew("xy", 0.1);  gr->Surf(d2, "r");

  gr->SubPlot(2,2,3);   gr->Title("Resize sample (interpolation)");
  mglData x0(10), v0(10), x1, v1;
  gr->Fill(x0,"rnd");     gr->Fill(v0,"rnd");
  x1 = x0.Resize(100);    v1 = v0.Resize(100);
  gr->Plot(x0,v0,"b+ ");  gr->Plot(x1,v1,"r-");
  gr->Label(x0,v0,"%n");
  return 0;
}
```



Also one can create new data arrays on base of the existing one: extract slice, row or column of data ([subdata], page 264), summarize along a direction(s) ([sum], page 267), find distribution of data elements ([hist], page 267) and so on.

Another interesting feature of MathGL is interpolation and root-finding. There are several functions for linear and cubic spline interpolation (see Section 6.8 [Interpolation], page 272). Also there is a function [evaluate], page 266 which do interpolation of data array for values of each data element of index data. It look as indirect access to the data elements.

This function have inverse function [solve], page 266 which find array of indexes at which data array is equal to given value (i.e. work as root finding). But [solve], page 266 function have the issue – usually multidimensional data (2d and 3d ones) have an infinite number of indexes which give some value. This is contour lines for 2d data, or isosurface(s) for 3d data. So, [solve], page 266 function will return index only in given direction, assuming that other index(es) are the same as equidistant index(es) of original data. If data have multiple roots then second (and later) branches can be found by consecutive call(s) of [solve], page 266 function. Let me demonstrate this on the following sample.

```
int sample(mglGraph *gr)
{
  gr->SetRange('z',0,1);
  mglData x(20,30), y(20,30), z(20,30), xx,yy,zz;
  gr->Fill(x,"(x+2)/3*cos(pi*y)");
  gr->Fill(y,"(x+2)/3*sin(pi*y)");
  gr->Fill(z,"exp(-6*x^2-2*sin(pi*y)^2)");

  gr->SubPlot(2,1,0); gr->Title("Cartesian space");   gr->Rotate(30,-40);
  gr->Axis("xyzU");   gr->Box();  gr->Label('x',"x"); gr->Label('y',"y");
  gr->SetOrigin(1,1); gr->Grid("xy");
  gr->Mesh(x,y,z);

  // section along 'x' direction
  mglData u = x.Solve(0.5,'x');
  mglData v(u.nx);  v.Fill(0,1);
  xx = x.Evaluate(u,v);   yy = y.Evaluate(u,v);   zz = z.Evaluate(u,v);
  gr->Plot(xx,yy,zz,"k2o");

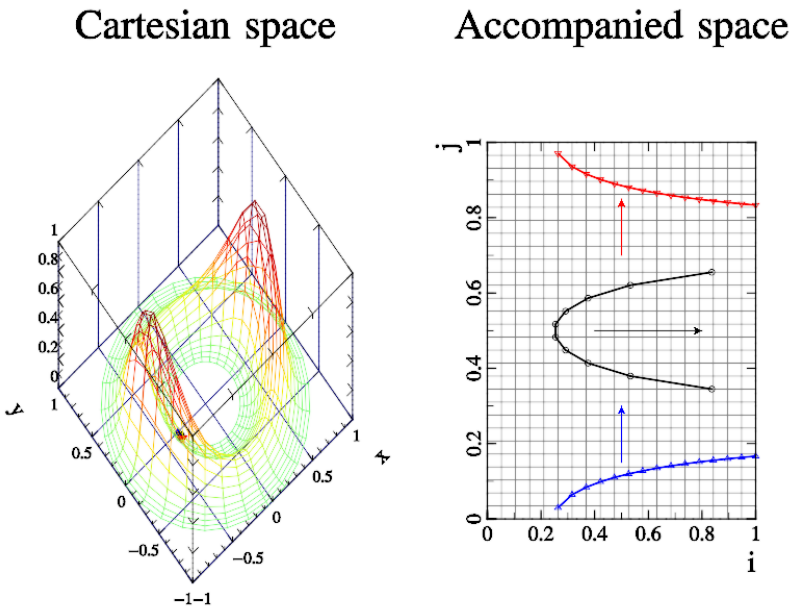
  // 1st section along 'y' direction
  mglData u1 = x.Solve(-0.5,'y');
  mglData v1(u1.nx);  v1.Fill(0,1);
  xx = x.Evaluate(v1,u1); yy = y.Evaluate(v1,u1); zz = z.Evaluate(v1,u1);
  gr->Plot(xx,yy,zz,"b2^");

  // 2nd section along 'y' direction
  mglData u2 = x.Solve(-0.5,'y',u1);
  xx = x.Evaluate(v1,u2); yy = y.Evaluate(v1,u2); zz = z.Evaluate(v1,u2);
  gr->Plot(xx,yy,zz,"r2v");

  gr->SubPlot(2,1,1); gr->Title("Accompanied space");
  gr->SetRanges(0,1,0,1); gr->SetOrigin(0,0);
  gr->Axis(); gr->Box();  gr->Label('x',"i"); gr->Label('y',"j");
  gr->Grid(z,"h");

  gr->Plot(u,v,"k2o");    gr->Line(mglPoint(0.4,0.5),mglPoint(0.8,0.5),"kA");
  gr->Plot(v1,u1,"b2^");  gr->Line(mglPoint(0.5,0.15),mglPoint(0.5,0.3),"bA");
  gr->Plot(v1,u2,"r2v");  gr->Line(mglPoint(0.5,0.7),mglPoint(0.5,0.85),"rA");
```

```
}
```



2.4 Data plotting

Let me now show how to plot the data. Next section will give much more examples for all plotting functions. Here I just show some basics. MathGL generally has 2 types of plotting functions. Simple variant requires a single data array for plotting, other data (coordinates) are considered uniformly distributed in axis range. Second variant requires data arrays for all coordinates. It allows one to plot rather complex multivalent curves and surfaces (in case of parametric dependencies). Usually each function have one textual argument for plot style and another textual argument for options (see Section 3.7 [Command options], page 154).

Note, that the call of drawing function adds something to picture but does not clear the previous plots (as it does in Matlab). Another difference from Matlab is that all setup (like transparency, lightning, axis borders and so on) must be specified **before** plotting functions.

Let start for plots for 1D data. Term "1D data" means that data depend on single index (parameter) like curve in parametric form {x(i),y(i),z(i)}, i=1...n. The textual argument allow you specify styles of line and marks (see Section 3.3 [Line styles], page 148). If this parameter is `NULL` or empty then solid line with color from palette is used (see Section 4.2.7 [Palette and colors], page 163).

Below I shall show the features of 1D plotting on base of [plot], page 195 function. Let us start from sinus plot:

```
int sample(mglGraph *gr)
{
  mglData y0(50);       y0.Modify("sin(pi*(2*x-1))");
  gr->SubPlot(2,2,0);
  gr->Plot(y0);         gr->Box();
```

Style of line is not specified in [plot], page 195 function. So MathGL uses the solid line with first color of palette (this is blue). Next subplot shows array *y1* with 2 rows:

```
  gr->SubPlot(2,2,1);
  mglData y1(50,2);
  y1.Modify("sin(pi*2*x-pi)");
  y1.Modify("cos(pi*2*x-pi)/2",1);
  gr->Plot(y1);          gr->Box();
```

As previously I did not specify the style of lines. As a result, MathGL again uses solid line with next colors in palette (there are green and red). Now let us plot a circle on the same subplot. The circle is parametric curve $x = cos(\pi t), y = sin(\pi t)$. I will set the color of the circle (dark yellow, '`Y`') and put marks '`+`' at point position:

```
  mglData x(50);         x.Modify("cos(pi*2*x-pi)");
  gr->Plot(x,y0,"Y+");
```

Note that solid line is used because I did not specify the type of line. The same picture can be achieved by [plot], page 195 and [subdata], page 264 functions. Let us draw ellipse by orange dash line:

```
  gr->Plot(y1.SubData(-1,0),y1.SubData(-1,1),"q|");
```

Drawing in 3D space is mostly the same. Let us draw spiral with default line style. Now its color is 4-th color from palette (this is cyan):

```
  gr->SubPlot(2,2,2);    gr->Rotate(60,40);
  mglData z(50);         z.Modify("2*x-1");
  gr->Plot(x,y0,z);      gr->Box();
```

Functions [plot], page 195 and [subdata], page 264 make 3D curve plot but for single array. Use it to put circle marks on the previous plot:

```
  mglData y2(10,3);      y2.Modify("cos(pi*(2*x-1+y))");
  y2.Modify("2*x-1",2);
  gr->Plot(y2.SubData(-1,0),y2.SubData(-1,1),y2.SubData(-1,2),"bo ");
```

Note that line style is empty ' ' here. Usage of other 1D plotting functions looks similar:

```
  gr->SubPlot(2,2,3);    gr->Rotate(60,40);
  gr->Bars(x,y0,z,"r"); gr->Box();
  return 0;
}
```

Surfaces [surf], page 208 and other 2D plots (see Section 4.12 [2D plotting], page 207) are drown the same simpler as 1D one. The difference is that the string parameter specifies not the line style but the color scheme of the plot (see Section 3.4 [Color scheme], page 150). Here I draw attention on 4 most interesting color schemes. There is gray scheme where color is changed from black to white (string '`kw`') or from white to black (string '`wk`'). Another scheme is useful for accentuation of negative (by blue color) and positive (by red color) regions on plot (string '`"BbwrR"`'). Last one is the popular "jet" scheme (string '`"BbcyrR"`').

Now I shall show the example of a surface drawing. At first let us switch lightning on

```
int sample(mglGraph *gr)
{
  gr->Light(true);       gr->Light(0,mglPoint(0,0,1));
```

and draw the surface, considering coordinates x,y to be uniformly distributed in axis range

```
mglData a0(50,40);
a0.Modify("0.6*sin(2*pi*x)*sin(3*pi*y)+0.4*cos(3*pi*(x*y))");
gr->SubPlot(2,2,0);   gr->Rotate(60,40);
gr->Surf(a0);         gr->Box();
```

Color scheme was not specified. So previous color scheme is used. In this case it is default color scheme ("jet") for the first plot. Next example is a sphere. The sphere is parametrically specified surface:

```
mglData x(50,40),y(50,40),z(50,40);
x.Modify("0.8*sin(2*pi*x)*sin(pi*y)");
y.Modify("0.8*cos(2*pi*x)*sin(pi*y)");
z.Modify("0.8*cos(pi*y)");
gr->SubPlot(2,2,1);   gr->Rotate(60,40);
gr->Surf(x,y,z,"BbwrR");gr->Box();
```

I set color scheme to `"BbwrR"` that corresponds to red top and blue bottom of the sphere.

Surfaces will be plotted for each of slice of the data if *nz*>1. Next example draws surfaces for data arrays with *nz*=3:

```
mglData a1(50,40,3);
a1.Modify("0.6*sin(2*pi*x)*sin(3*pi*y)+0.4*cos(3*pi*(x*y))");
a1.Modify("0.6*cos(2*pi*x)*cos(3*pi*y)+0.4*sin(3*pi*(x*y))",1);
a1.Modify("0.6*cos(2*pi*x)*cos(3*pi*y)+0.4*cos(3*pi*(x*y))",2);
gr->SubPlot(2,2,2);   gr->Rotate(60,40);
gr->Alpha(true);
gr->Surf(a1);         gr->Box();
```

Note, that it may entail a confusion. However, if one will use density plot then the picture will look better:

```
gr->SubPlot(2,2,3);   gr->Rotate(60,40);
gr->Dens(a1);         gr->Box();
return 0;
}
```

Drawing of other 2D plots is analogous. The only peculiarity is the usage of flag '`#`'. By default this flag switches on the drawing of a grid on plot ([grid], page 193 or [mesh], page 208 for plots in plain or in volume). However, for isosurfaces (including surfaces of rotation [axial], page 212) this flag switches the face drawing off and figure becomes wired. The following code gives example of flag '`#`' using (compare with normal function drawing as in its description):

```
int sample(mglGraph *gr)
{
  gr->Alpha(true);      gr->Light(true);        gr->Light(0,mglPoint(0,0,1));
  mglData a(30,20);
  a.Modify("0.6*sin(2*pi*x)*sin(3*pi*y) + 0.4*cos(3*pi*(x*y))");

  gr->SubPlot(2,2,0);   gr->Rotate(40,60);
  gr->Surf(a,"BbcyrR#");                gr->Box();
```

```
  gr->SubPlot(2,2,1);   gr->Rotate(40,60);
  gr->Dens(a,"BbcyrR#");                gr->Box();
  gr->SubPlot(2,2,2);   gr->Rotate(40,60);
  gr->Cont(a,"BbcyrR#");                gr->Box();
  gr->SubPlot(2,2,3);   gr->Rotate(40,60);
  gr->Axial(a,"BbcyrR#");               gr->Box();
  return 0;
}
```

2.5 1D samples

This section is devoted to visualization of 1D data arrays. 1D means the data which depend on single index (parameter) like curve in parametric form {x(i),y(i),z(i)}, i=1...n. Most of samples will use the same data for plotting. So, I put its initialization in separate function

```
void mgls_prepare1d(mglData *y, mglData *y1=0, mglData *y2=0, mglData *x1=0, mglData *x2=0)
{
  register long i,n=50;
  if(y) y->Create(n,3);
  if(x1)  x1->Create(n);    if(x2)  x2->Create(n);
  if(y1)  y1->Create(n);    if(y2)  y2->Create(n);
  mreal xx;
  for(i=0;i<n;i++)
  {
    xx = i/(n-1.);
    if(y)
    {
      y->a[i] = 0.7*sin(2*M_PI*xx) + 0.5*cos(3*M_PI*xx) + 0.2*sin(M_PI*xx);
      y->a[i+n] = sin(2*M_PI*xx);
      y->a[i+2*n] = cos(2*M_PI*xx);
    }
    if(y1)  y1->a[i] = 0.5+0.3*cos(2*M_PI*xx);
    if(y2)  y2->a[i] = 0.3*sin(2*M_PI*xx);
    if(x1)  x1->a[i] = xx*2-1;
    if(x2)  x2->a[i] = 0.05+0.03*cos(2*M_PI*xx);
  }
}
```

or using C functions

```
void mgls_prepare1d(HMDT y, HMDT y1=0, HMDT y2=0, HMDT x1=0, HMDT x2=0)
{
  register long i,n=50;
  if(y)   mgl_data_create(y,n,3,1);
  if(x1)  mgl_data_create(x1,n,1,1);
  if(x2)  mgl_data_create(x2,n,1,1);
  if(y1)  mgl_data_create(y1,n,1,1);
  if(y2)  mgl_data_create(y2,n,1,1);
  mreal xx;
  for(i=0;i<n;i++)
```

```
  {
    xx = i/(n-1.);
    if(y)
    {
      mgl_data_set_value(y, 0.7*sin(2*M_PI*xx) + 0.5*cos(3*M_PI*xx) + 0.2*sin(M_PI*xx), i,0
      mgl_data_set_value(y, sin(2*M_PI*xx), i,1,0);
      mgl_data_set_value(y, cos(2*M_PI*xx), i,2,0);
    }
    if(y1)  mgl_data_set_value(y1, 0.5+0.3*cos(2*M_PI*xx), i,0,0);
    if(y2)  mgl_data_set_value(y2, 0.3*sin(2*M_PI*xx), i,0,0);
    if(x1)  mgl_data_set_value(x1, xx*2-1, i,0,0);
    if(x2)  mgl_data_set_value(x2, 0.05+0.03*cos(2*M_PI*xx), i,0,0);
  }
}
```

2.5.1 Plot sample

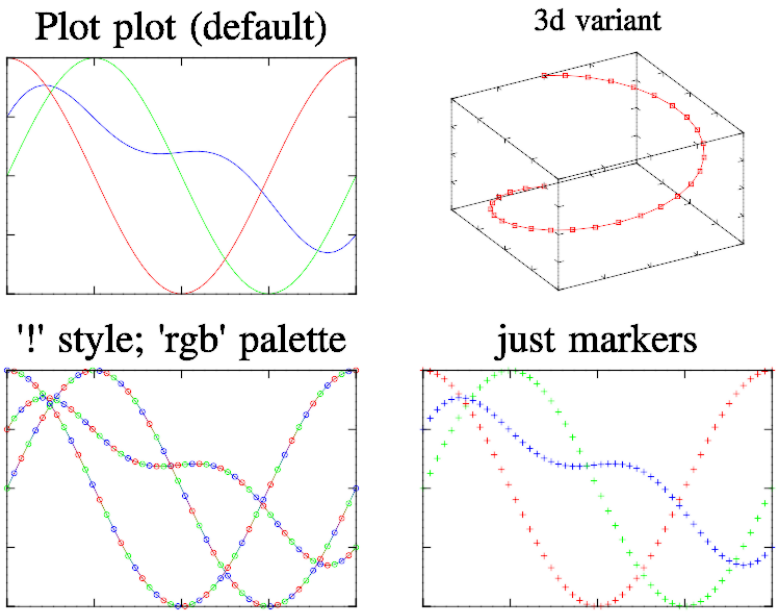
Function [plot], page 195 is most standard way to visualize 1D data array. By default, `Plot` use colors from palette. However, you can specify manual color/palette, and even set to use new color for each points by using '!' style. Another feature is ' ' style which draw only markers without line between points. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData y;  mgls_prepare1d(&y); gr->SetOrigin(0,0,0);
  gr->SubPlot(2,2,0,"");  gr->Title("Plot plot (default)");
  gr->Box();  gr->Plot(y);

  gr->SubPlot(2,2,2,"");  gr->Title("'!' style; 'rgb' palette");
  gr->Box();  gr->Plot(y,"o!rgb");

  gr->SubPlot(2,2,3,"");  gr->Title("just markers");
  gr->Box();  gr->Plot(y," +");

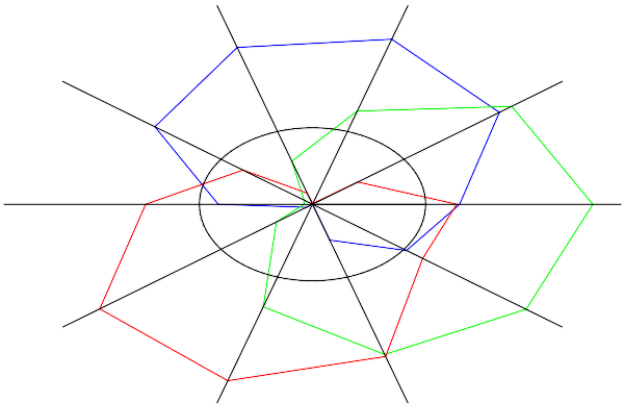
  gr->SubPlot(2,2,1); gr->Title("3d variant");
  gr->Rotate(50,60);  gr->Box();
  mglData yc(30), xc(30), z(30);  z.Modify("2*x-1");
  yc.Modify("sin(pi*(2*x-1))"); xc.Modify("cos(pi*2*x-pi)");
  gr->Plot(xc,yc,z,"rs");
  return 0;
}
```



2.5.2 Radar sample

Function [radar], page 195 plot is variant of `Plot` one, which make plot in polar coordinates and draw radial rays in point directions. If you just need a plot in polar coordinates then I recommend to use Section 2.2.3 [Curvilinear coordinates], page 26 or `Plot` in parabolic form with `x=r*cos(fi); y=r*sin(fi);`. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData yr(10,3); yr.Modify("0.4*sin(pi*(2*x+y))+0.1*rnd");
  gr->SubPlot(1,1,0,"");  gr->Title("Radar plot (with grid, '\\#')");
  gr->Radar(yr,"#");
  return 0;
}
```



2.5.3 Step sample

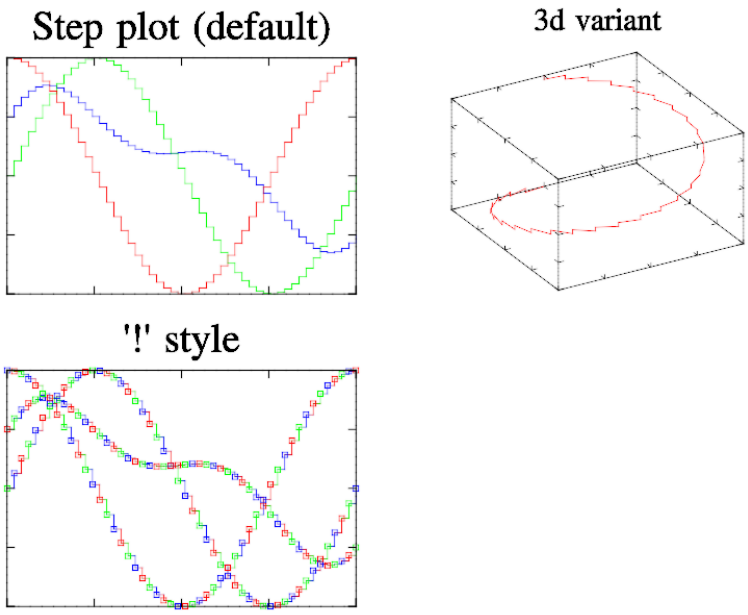
Function [step], page 196 plot data as stairs. It have the same options as `Plot`. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData y;  mgls_prepare1d(&y); gr->SetOrigin(0,0,0);
  mglData yc(30), xc(30), z(30);  z.Modify("2*x-1");
  yc.Modify("sin(pi*(2*x-1))"); xc.Modify("cos(pi*2*x-pi)");

  gr->SubPlot(2,2,0,"");  gr->Title("Step plot (default)");
  gr->Box();  gr->Step(y);

  gr->SubPlot(2,2,1); gr->Title("3d variant");  gr->Rotate(50,60);
  gr->Box();  gr->Step(xc,yc,z,"r");

  gr->SubPlot(2,2,2,"");  gr->Title("'!' style");
  gr->Box();  gr->Step(y,"s!rgb");
  return 0;
}
```



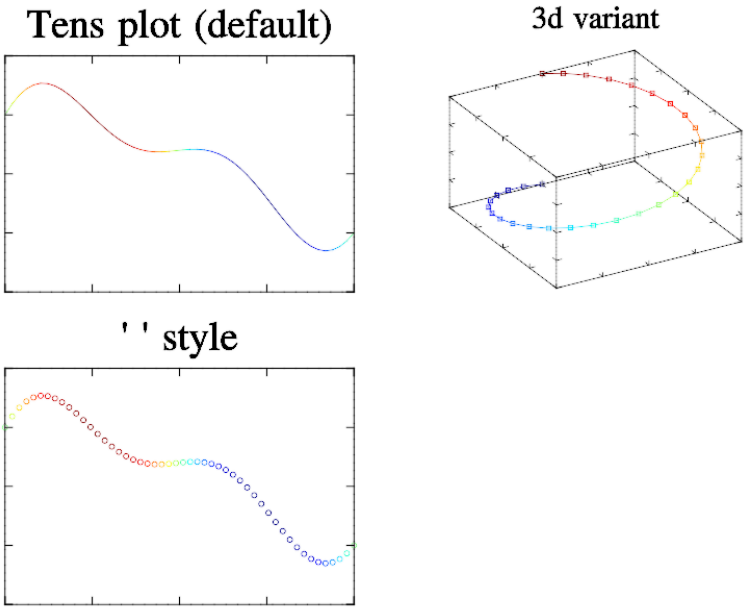
2.5.4 Tens sample

Function [tens], page 196 is variant of [plot], page 195 with smooth coloring along the curves. At this, color is determined as for surfaces (see Section 3.4 [Color scheme], page 150). The sample code is:

```
int sample(mglGraph *gr)
{
  mglData y;  mgls_prepare1d(&y); gr->SetOrigin(0,0,0);
  gr->SubPlot(2,2,0,"");  gr->Title("Tens plot (default)");
  gr->Box();  gr->Tens(y.SubData(-1,0), y.SubData(-1,1));

  gr->SubPlot(2,2,2,"");  gr->Title("' ' style");
  gr->Box();  gr->Tens(y.SubData(-1,0), y.SubData(-1,1),"o ");

  gr->SubPlot(2,2,1); gr->Title("3d variant");  gr->Rotate(50,60);  gr->Box();
  mglData yc(30), xc(30), z(30);  z.Modify("2*x-1");
  yc.Modify("sin(pi*(2*x-1))"); xc.Modify("cos(pi*2*x-pi)");
  gr->Tens(xc,yc,z,z,"s");
  return 0;
}
```



2.5.5 Area sample

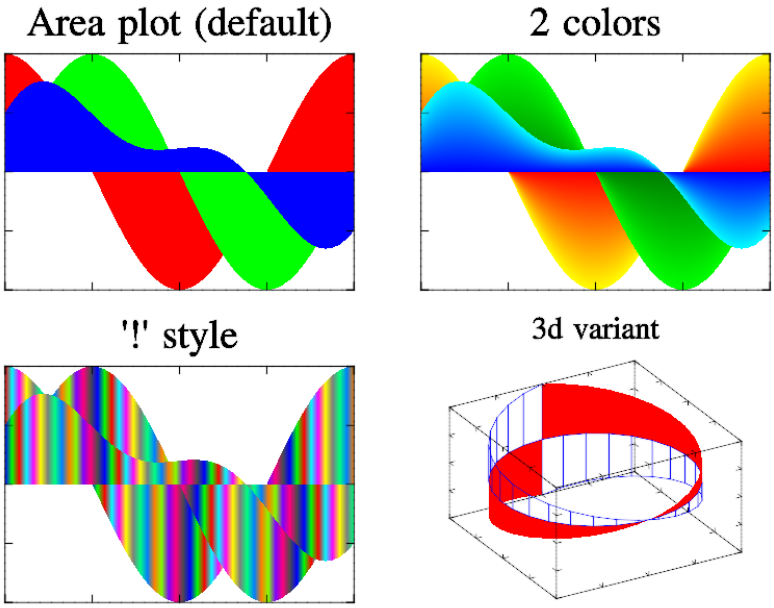
Function [area], page 197 fill the area between curve and axis plane. It support gradient filling if 2 colors per curve is specified. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData y;  mgls_prepare1d(&y); gr->SetOrigin(0,0,0);
  gr->SubPlot(2,2,0,"");  gr->Title("Area plot (default)");
  gr->Box();  gr->Area(y);

  gr->SubPlot(2,2,1,"");  gr->Title("2 colors");
  gr->Box();  gr->Area(y,"cbgGyr");

  gr->SubPlot(2,2,2,"");  gr->Title("'!' style");
  gr->Box();  gr->Area(y,"!");

  gr->SubPlot(2,2,3); gr->Title("3d variant");
  gr->Rotate(50,60);  gr->Box();
  mglData yc(30), xc(30), z(30);  z.Modify("2*x-1");
  yc.Modify("sin(pi*(2*x-1))"); xc.Modify("cos(pi*2*x-pi)");
  gr->Area(xc,yc,z,"r");
  yc.Modify("-sin(pi*(2*x-1))");  gr->Area(xc,yc,z,"b#");
  return 0;
}
```



2.5.6 Region sample

Function [region], page 197 fill the area between 2 curves. It support gradient filling if 2 colors per curve is specified. Also it can fill only the region y1<y<y2 if style 'i' is used. The sample code is:

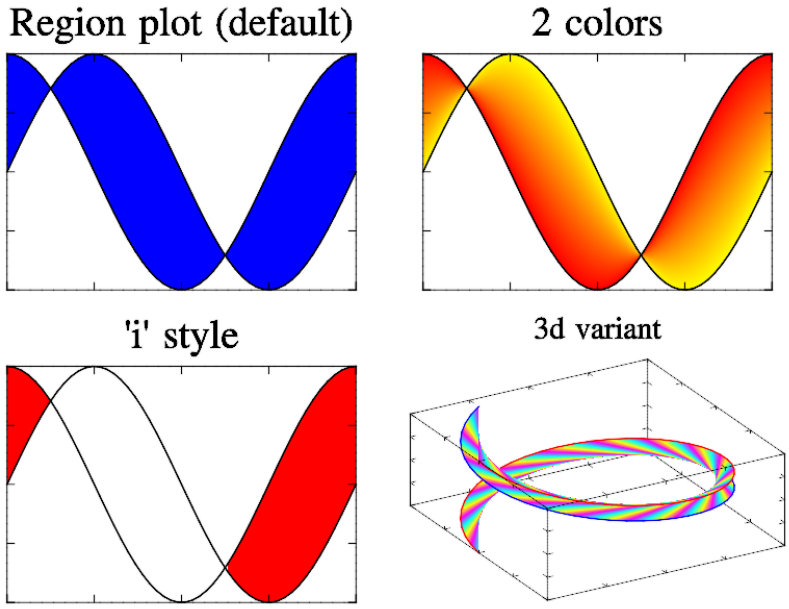
```
int sample(mglGraph *gr)
{
  mglData y;  mgls_prepare1d(&y);
  mglData y1 = y.SubData(-1,1), y2 = y.SubData(-1,2);  gr->SetOrigin(0,0,0);

  gr->SubPlot(2,2,0,"");  gr->Title("Region plot (default)"); gr->Box();
  gr->Region(y1,y2);  gr->Plot(y1,"k2");  gr->Plot(y2,"k2");

  gr->SubPlot(2,2,1,"");  gr->Title("2 colors");  gr->Box();
  gr->Region(y1,y2,"yr"); gr->Plot(y1,"k2");  gr->Plot(y2,"k2");

  gr->SubPlot(2,2,2,"");  gr->Title("'i' style");  gr->Box();
  gr->Region(y1,y2,"ir"); gr->Plot(y1,"k2");  gr->Plot(y2,"k2");

  gr->SubPlot(2,2,3,"^_");  gr->Title("3d variant");  gr->Rotate(40,60);  gr->Box();
  gr->Fill(y1,"cos(pi*x)"); gr->Fill(y2,"cos(pi*x+pi/3)");
  mglData x1(y1.nx), x2(y1.nx), z(y1.nx);
  gr->Fill(x1,"sin(pi*x)"); gr->Fill(x2,"sin(pi*x+pi/3)");  gr->Fill(z,"x");
  gr->Plot(x1,y1,z,"r2");   gr->Plot(x2,y2,z,"b2");
  gr->Region(x1,y1,z,x2,y2,z,"cmy!");
  return 0;
}
```



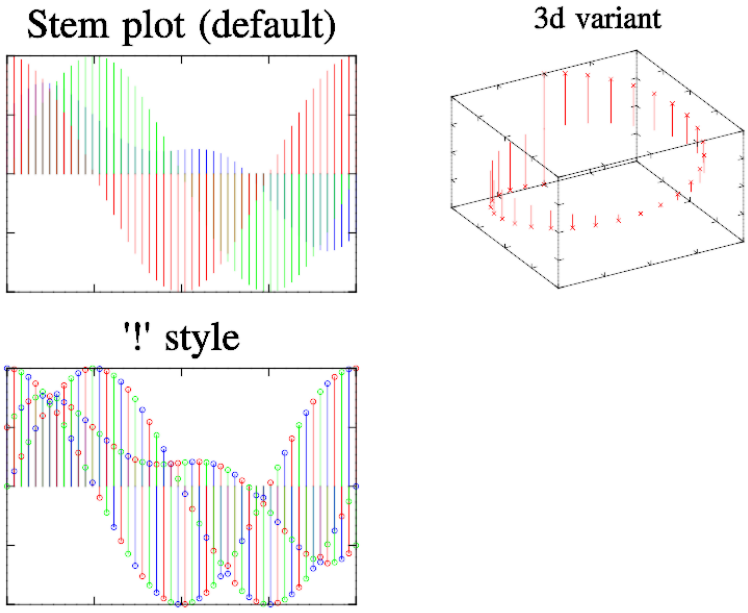
2.5.7 Stem sample

Function [stem], page 198 draw vertical bars. It is most attractive if markers are drawn too. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData y;  mgls_prepare1d(&y); gr->SetOrigin(0,0,0);
  mglData yc(30), xc(30), z(30);  z.Modify("2*x-1");
  yc.Modify("sin(pi*(2*x-1))"); xc.Modify("cos(pi*2*x-pi)");
  gr->SubPlot(2,2,0,"");  gr->Title("Stem plot (default)");
  gr->Box();  gr->Stem(y);

  gr->SubPlot(2,2,1); gr->Title("3d variant");  gr->Rotate(50,60);
  gr->Box();  gr->Stem(xc,yc,z,"rx");

  gr->SubPlot(2,2,2,"");  gr->Title("'!' style");
  gr->Box();  gr->Stem(y,"o!rgb");
  return 0;
}
```



2.5.8 Bars sample

Function [bars], page 198 draw vertical bars. It have a lot of options: bar-above-bar (‘`a`’ style), fall like (‘`f`’ style), 2 colors for positive and negative values, wired bars (‘`#`’ style), 3D variant. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData ys(10,3); ys.Modify("0.8*sin(pi*(2*x+y/2))+0.2*rnd");
  gr->SetOrigin(0,0,0);
  gr->SubPlot(3,2,0,"");  gr->Title("Bars plot (default)");
  gr->Box();  gr->Bars(ys);

  gr->SubPlot(3,2,1,"");  gr->Title("2 colors");
  gr->Box();  gr->Bars(ys,"cbgGyr");

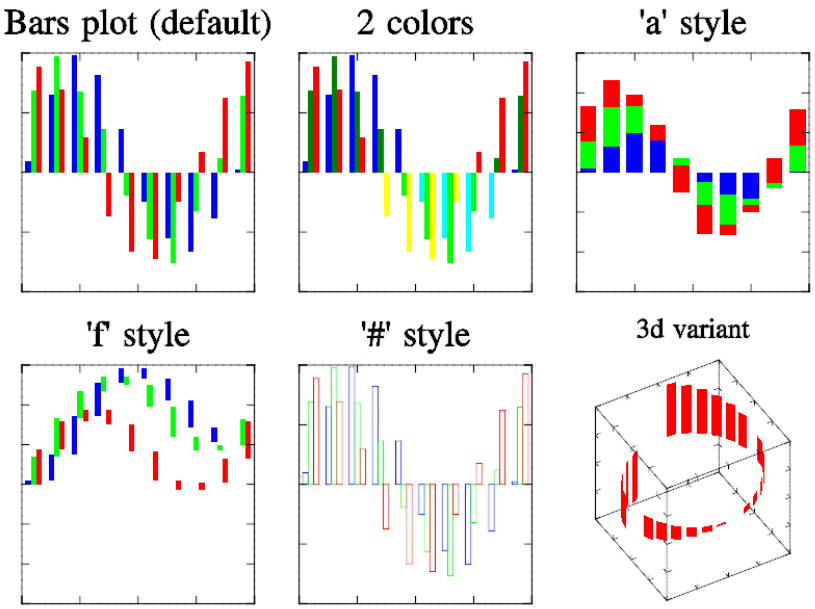
  gr->SubPlot(3,2,4,"");  gr->Title("'\\#' style");
  gr->Box();  gr->Bars(ys,"#");

  gr->SubPlot(3,2,5); gr->Title("3d variant");
  gr->Rotate(50,60);  gr->Box();
  mglData yc(30), xc(30), z(30);  z.Modify("2*x-1");
  yc.Modify("sin(pi*(2*x-1))"); xc.Modify("cos(pi*2*x-pi)");
  gr->Bars(xc,yc,z,"r");

  gr->SetRanges(-1,1,-3,3);
  gr->SubPlot(3,2,2,"");  gr->Title("'a' style");
  gr->Box();  gr->Bars(ys,"a");

  gr->SubPlot(3,2,3,"");  gr->Title("'f' style");
```

```
  gr->Box();  gr->Bars(ys,"f");
  return 0;
}
```



2.5.9 Barh sample

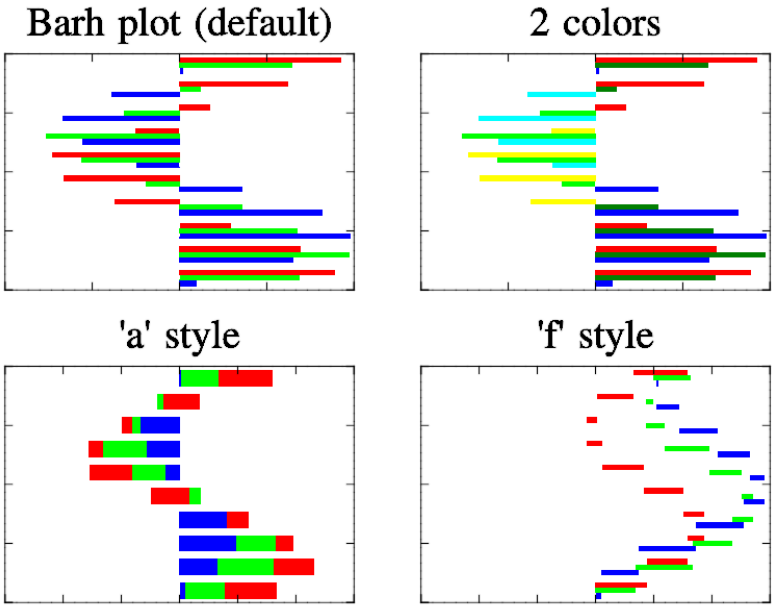
Function [barh], page 199 is the similar to `Bars` but draw horizontal bars. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData ys(10,3); ys.Modify("0.8*sin(pi*(2*x+y/2))+0.2*rnd");
  gr->SetOrigin(0,0,0);
  gr->SubPlot(2,2,0,"");  gr->Title("Barh plot (default)");
  gr->Box();  gr->Barh(ys);

  gr->SubPlot(2,2,1,"");  gr->Title("2 colors");
  gr->Box();  gr->Barh(ys,"cbgGyr");

  gr->SetRanges(-3,3,-1,1);
  gr->SubPlot(2,2,2,"");  gr->Title("'a' style");
  gr->Box();  gr->Barh(ys,"a");

  gr->SubPlot(2,2,3,"");  gr->Title("'f' style");
  gr->Box();  gr->Barh(ys,"f");
  return 0;
}
```



2.5.10 Cones sample

Function [cones], page 199 is similar to `Bars` but draw cones. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData ys(10,3);   ys.Modify("0.8*sin(pi*(2*x+y/2))+0.2*rnd");
  gr->Light(true);    gr->SetOrigin(0,0,0);
  gr->SubPlot(3,2,0); gr->Title("Cones plot");
  gr->Rotate(50,60);  gr->Box();  gr->Cones(ys);

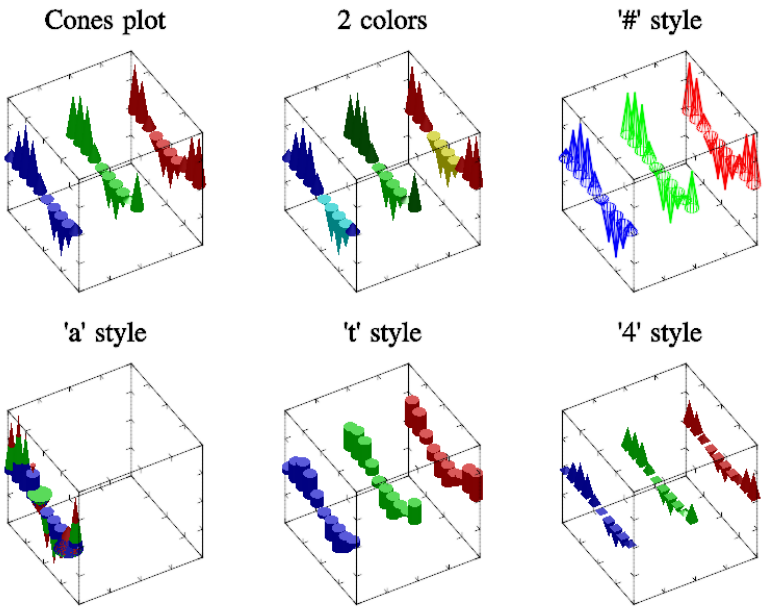
  gr->SubPlot(3,2,1); gr->Title("2 colors");
  gr->Rotate(50,60);  gr->Box();  gr->Cones(ys,"cbgGyr");

  gr->SubPlot(3,2,2); gr->Title("'#' style");
  gr->Rotate(50,60);  gr->Box();  gr->Cones(ys,"#");

  gr->SubPlot(3,2,3); gr->Title("'a' style");
  gr->SetRange('z',-2,2); // increase range since summation can exceed [-1,1]
  gr->Rotate(50,60);  gr->Box();  gr->Cones(ys,"a");

  gr->SubPlot(3,2,4); gr->Title("'t' style");
  gr->Rotate(50,60);  gr->Box();  gr->Cones(ys,"t");

  gr->SubPlot(3,2,5); gr->Title("'4' style");
  gr->Rotate(50,60);  gr->Box();  gr->Cones(ys,"4");
  return 0;
}
```



2.5.11 Chart sample

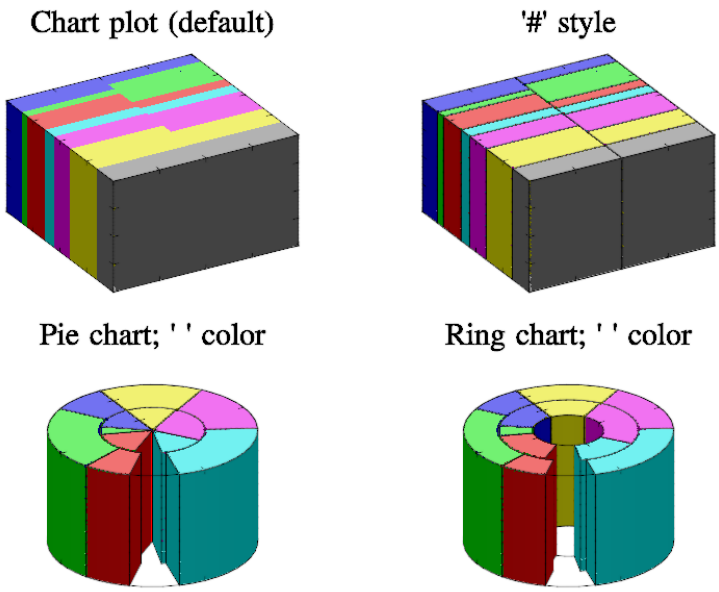
Function [chart], page 200 draw colored boxes with width proportional to data values. Use ‘ ’ for empty box. Plot looks most attractive in polar coordinates – well known pie chart. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData ch(7,2);  for(int i=0;i<7*2;i++)  ch.a[i]=mgl_rnd()+0.1;
  gr->SubPlot(2,2,0); gr->Title("Chart plot (default)");
  gr->Light(true);  gr->Rotate(50,60);  gr->Box();  gr->Chart(ch);

  gr->SubPlot(2,2,1); gr->Title("'\\#' style");
  gr->Rotate(50,60);  gr->Box();  gr->Chart(ch,"#");

  gr->SubPlot(2,2,2); gr->Title("Pie chart; ' ' color");
  gr->SetFunc("(y+1)/2*cos(pi*x)","(y+1)/2*sin(pi*x)","");
  gr->Rotate(50,60);  gr->Box();  gr->Chart(ch,"bgr cmy#");

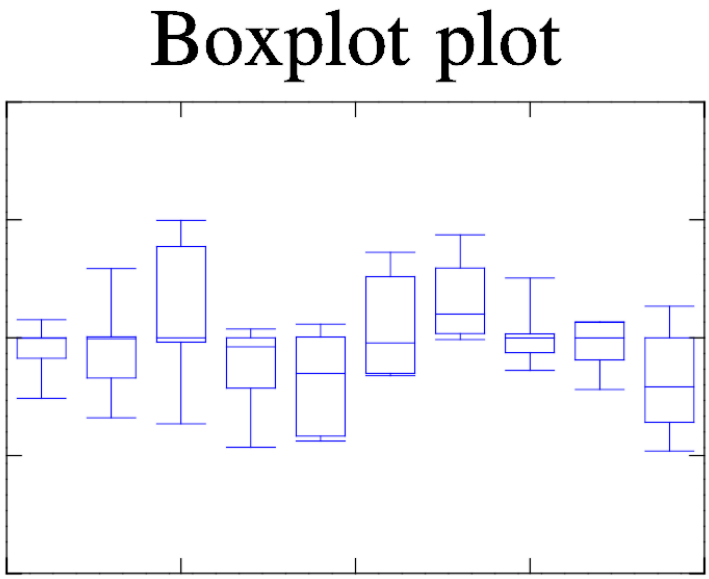
  gr->SubPlot(2,2,3); gr->Title("Ring chart; ' ' color");
  gr->SetFunc("(y+2)/3*cos(pi*x)","(y+2)/3*sin(pi*x)","");
  gr->Rotate(50,60);  gr->Box();  gr->Chart(ch,"bgr cmy#");
  return 0;
}
```



2.5.12 BoxPlot sample

Function [boxplot], page 200 draw box-and-whisker diagram. The sample code is:

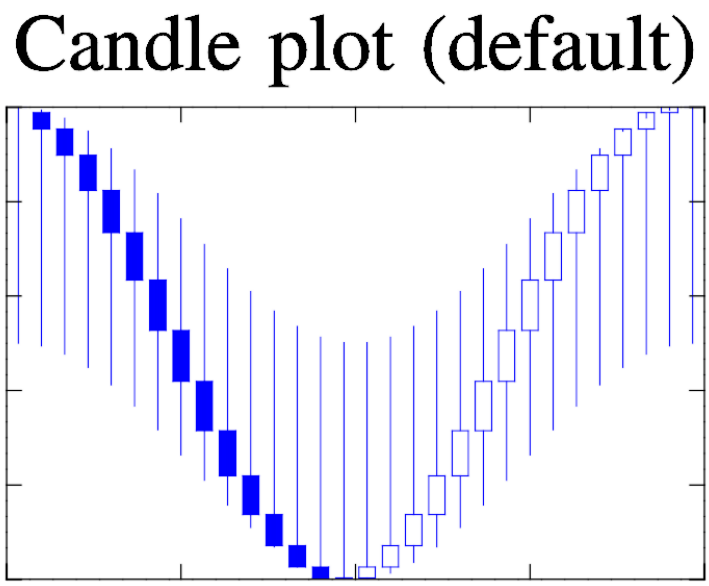
```
int sample(mglGraph *gr)
{
  mglData a(10,7);  a.Modify("(2*rnd-1)^3/2");
  gr->SubPlot(1,1,0,"");  gr->Title("Boxplot plot");
  gr->Box();  gr->BoxPlot(a);
  return 0;
}
```



2.5.13 Candle sample

Function [candle], page 201 draw candlestick chart. This is a combination of a line-chart and a bar-chart, in that each bar represents the range of price movement over a given time interval. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData y(30);  gr->Fill(y,"sin(pi*x/2)^2");
  mglData y1(30); gr->Fill(y1,"v/2",y);
  mglData y2(30); gr->Fill(y2,"(1+v)/2",y);
  gr->SubPlot(1,1,0,"");  gr->Title("Candle plot (default)");
  gr->SetRange('y',0,1);  gr->Box();  gr->Candle(y,y1,y2);
  return 0;
}
```

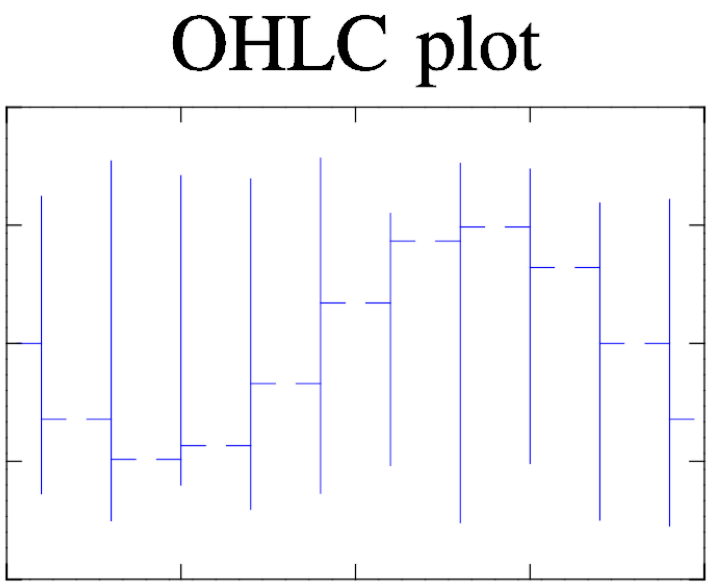


2.5.14 OHLC sample

Function [ohlc], page 201 draw Open-High-Low-Close diagram. This diagram show vertical line for between maximal(high) and minimal(low) values, as well as horizontal lines before/after vertical line for initial(open)/final(close) values of some process. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData o(10), h(10), l(10), c(10);
  gr->Fill(o,"0.5*sin(pi*x)");  gr->Fill(c,"0.5*sin(pi*(x+2/9))");
  gr->Fill(l,"0.3*rnd-0.8");    gr->Fill(h,"0.3*rnd+0.5");
  gr->SubPlot(1,1,0,"");  gr->Title("OHLC plot");
  gr->Box();  gr->OHLC(o,h,l,c);
  return 0;
```

```
}
```



2.5.15 Error sample

Function [error], page 202 draw error boxes around the points. You can draw default boxes or semi-transparent symbol (like marker, see Section 3.3 [Line styles], page 148). Also you can set individual color for each box. The sample code is:

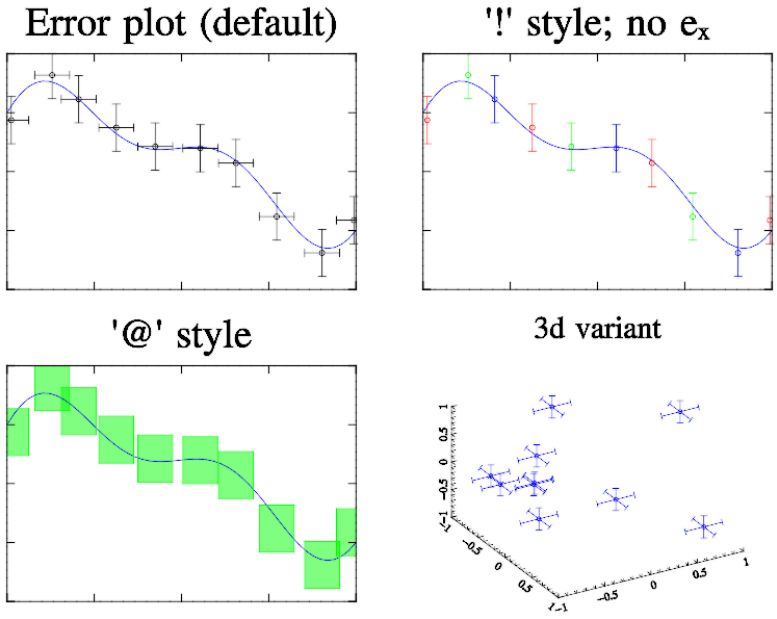
```
int sample(mglGraph *gr)
{
  mglData y;  mgls_prepare1d(&y);
  mglData x0(10), y0(10), ex0(10), ey0(10);
  mreal x;
  for(int i=0;i<10;i++)
  {
    x = i/9.;
    x0.a[i] = 2*x-1 + 0.1*mgl_rnd()-0.05;
    y0.a[i] = 0.7*sin(2*M_PI*x)+0.5*cos(3*M_PI*x)+0.2*sin(M_PI*x)+0.2*mgl_rnd()-0.1;
    ey0.a[i]=0.2; ex0.a[i]=0.1;
  }

  gr->SubPlot(2,2,0,"");  gr->Title("Error plot (default)");
  gr->Box();  gr->Plot(y.SubData(-1,0));  gr->Error(x0,y0,ex0,ey0,"ko");

  gr->SubPlot(2,2,1,"");  gr->Title("'!' style; no e_x");
  gr->Box();  gr->Plot(y.SubData(-1,0));  gr->Error(x0,y0,ey0,"o!rgb");

  gr->SubPlot(2,2,2,"");  gr->Title("'\\@' style");
  gr->Box();  gr->Plot(y.SubData(-1,0));  gr->Error(x0,y0,ex0,ey0,"@","alpha 0.5");
```

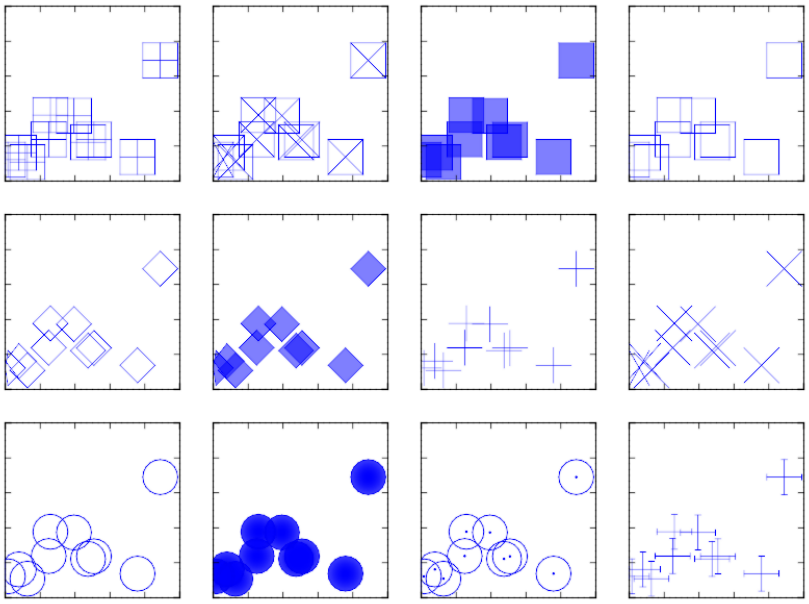
```
  gr->SubPlot(2,2,3); gr->Title("3d variant");  gr->Rotate(50,60);
  for(int i=0;i<10;i++)
    gr->Error(mglPoint(2*mgl_rnd()-1,2*mgl_rnd()-1,2*mgl_rnd()-1),
              mglPoint(0.2,0.2,0.2),"bo");
  gr->Axis();
  return 0;
}
```



Additionally, you can use solid large "marks" instead of error boxes by selecting proper style.

```
int sample(mglGraph *gr)
{
  mglData x0(10), y0(10), ex(10), ey(10);
  for(int i=0;i<10;i++)
  {  x0.a[i] = mgl_rnd(); y0.a[i] = mgl_rnd(); ey.a[i] = ex.a[i] = 0.1; }
  gr->SetRanges(0,1,0,1); gr->Alpha(true);
  gr->SubPlot(4,3,0,""); gr->Box(); gr->Error(x0,y0,ex,ey,"#+@");
  gr->SubPlot(4,3,1,""); gr->Box(); gr->Error(x0,y0,ex,ey,"#x@");
  gr->SubPlot(4,3,2,""); gr->Box(); gr->Error(x0,y0,ex,ey,"#s@","alpha 0.5");
  gr->SubPlot(4,3,3,""); gr->Box(); gr->Error(x0,y0,ex,ey,"s@");
  gr->SubPlot(4,3,4,""); gr->Box(); gr->Error(x0,y0,ex,ey,"d@");
  gr->SubPlot(4,3,5,""); gr->Box(); gr->Error(x0,y0,ex,ey,"#d@","alpha 0.5");
  gr->SubPlot(4,3,6,""); gr->Box(); gr->Error(x0,y0,ex,ey,"+@");
  gr->SubPlot(4,3,7,""); gr->Box(); gr->Error(x0,y0,ex,ey,"x@");
  gr->SubPlot(4,3,8,""); gr->Box(); gr->Error(x0,y0,ex,ey,"o@");
  gr->SubPlot(4,3,9,""); gr->Box(); gr->Error(x0,y0,ex,ey,"#o@","alpha 0.5");
  gr->SubPlot(4,3,10,""); gr->Box(); gr->Error(x0,y0,ex,ey,"#.@");
```

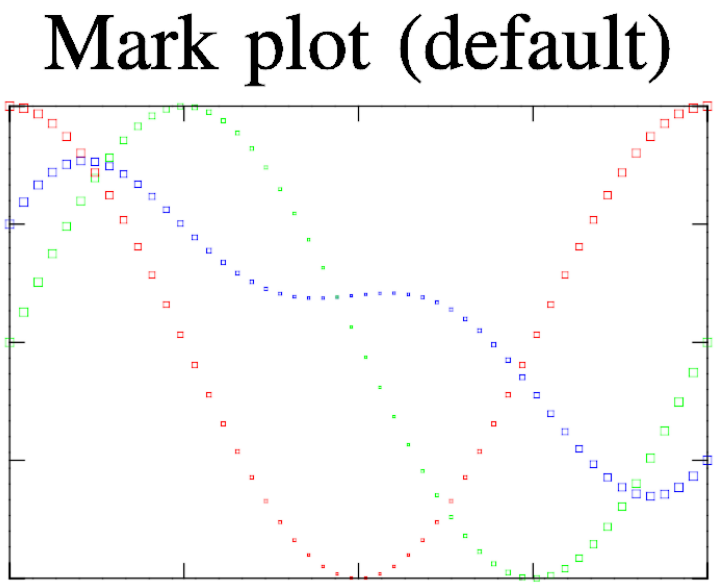
```
  gr->SubPlot(4,3,11,""); gr->Box(); gr->Error(x0,y0,ex,ey);
}
```



2.5.16 Mark sample

Function [mark], page 202 draw markers at points. It is mostly the same as `Plot` but marker size can be variable. The sample code is:

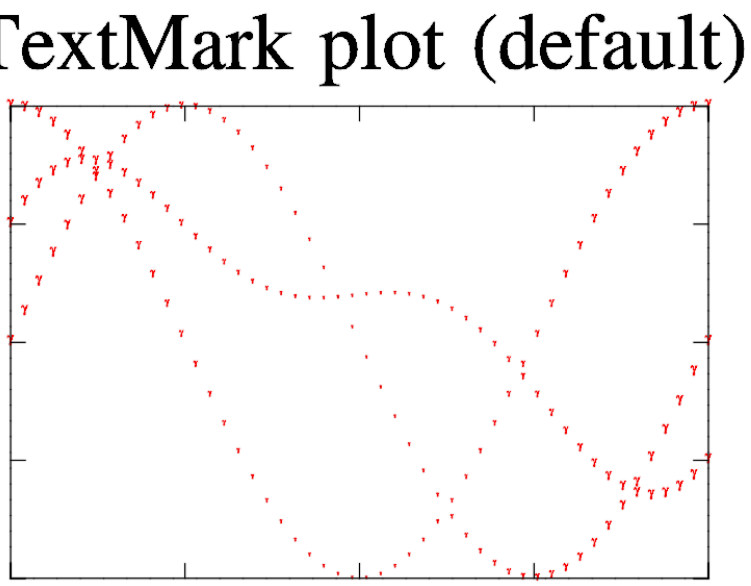
```
int sample(mglGraph *gr)
{
  mglData y,y1; mgls_prepare1d(&y,&y1);
  gr->SubPlot(1,1,0,"");  gr->Title("Mark plot (default)");
  gr->Box();  gr->Mark(y,y1,"s");
  return 0;
}
```



2.5.17 TextMark sample

Function [textmark], page 203 like `Mark` but draw text instead of markers. The sample code is:

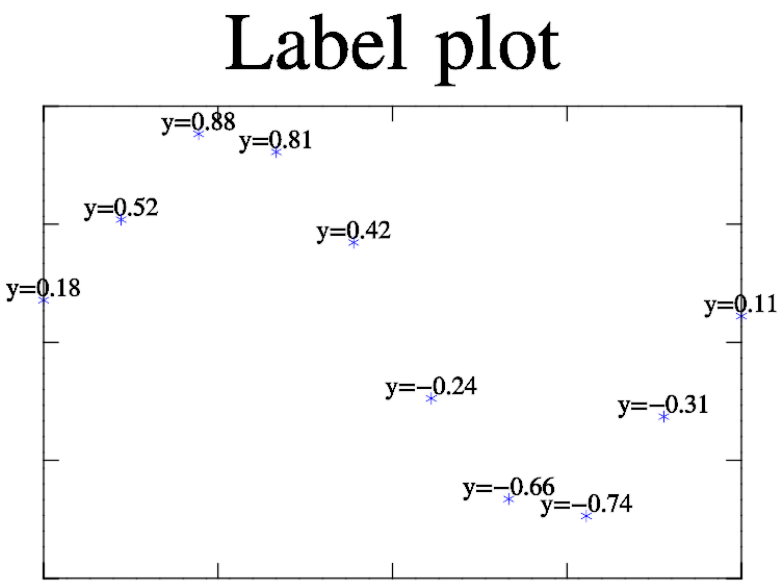
```
int sample(mglGraph *gr)
{
  mglData y,y1; mgls_prepare1d(&y,&y1);
  gr->SubPlot(1,1,0,"");  gr->Title("TextMark plot (default)");
  gr->Box();  gr->TextMark(y,y1,"\\gamma","r");
  return 0;
}
```



2.5.18 Label sample

Function [label], page 204 print text at data points. The string may contain '`%x`', '`%y`', '`%z`' for x-, y-, z-coordinates of points, '`%n`' for point index. The sample code is:

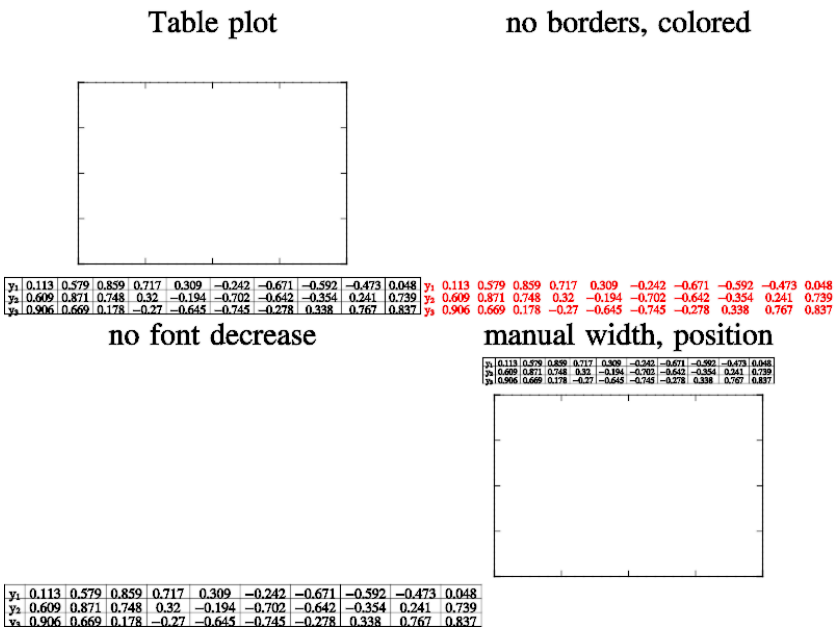
```
int sample(mglGraph *gr)
{
  mglData ys(10); ys.Modify("0.8*sin(pi*2*x)+0.2*rnd");
  gr->SubPlot(1,1,0,"");  gr->Title("Label plot");
  gr->Box();  gr->Plot(ys," *");  gr->Label(ys,"y=%y");
  return 0;
}
```



2.5.19 Table sample

Function [table], page 205 draw table with data values. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData ys(10,3); ys.Modify("0.8*sin(pi*(2*x+y/2))+0.2*rnd");
  gr->SubPlot(2,2,0);  gr->Title("Table plot");
  gr->Table(ys,"y_1\ny_2\ny_3");   gr->Box();
  gr->SubPlot(2,2,1);  gr->Title("no borders, colored");
  gr->Table(ys,"y_1\ny_2\ny_3","r|");
  gr->SubPlot(2,2,2);  gr->Title("no font decrease");
  gr->Table(ys,"y_1\ny_2\ny_3","#");
  gr->SubPlot(2,2,3);  gr->Title("manual width, position");
  gr->Table(0.5, 0.95, ys,"y_1\ny_2\ny_3","#", "value 0.7");  gr->Box();
  return 0;
}
```



2.5.20 Tube sample

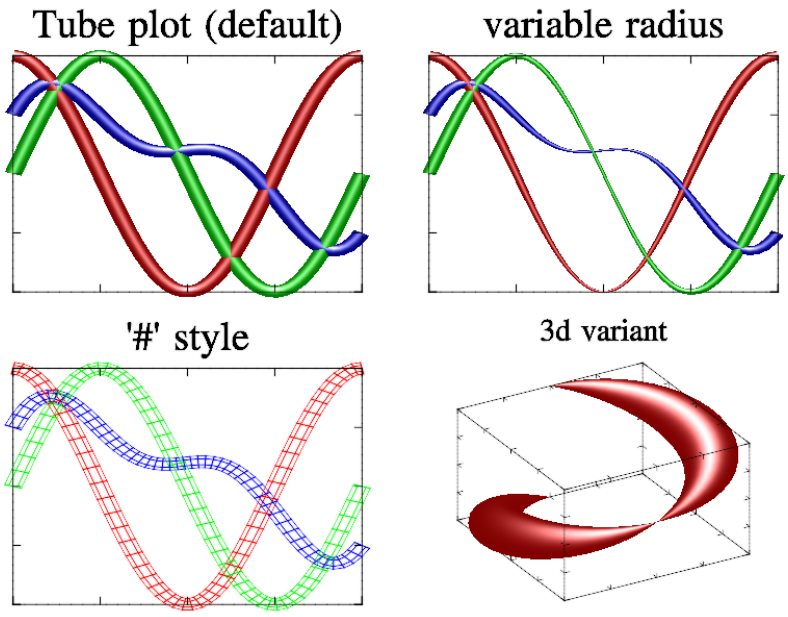
Function [tube], page 205 draw tube with variable radius. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData y,y1,y2;  mgls_prepare1d(&y,&y1,&y2); y1/=20;
  gr->SubPlot(2,2,0,"");  gr->Title("Tube plot (default)");
  gr->Light(true);  gr->Box();  gr->Tube(y,0.05);

  gr->SubPlot(2,2,1,"");  gr->Title("variable radius");
  gr->Box();  gr->Tube(y,y1);

  gr->SubPlot(2,2,2,"");  gr->Title("'\\#' style");
  gr->Box();  gr->Tube(y,0.05,"#");
  mglData yc(50), xc(50), z(50);  z.Modify("2*x-1");
  yc.Modify("sin(pi*(2*x-1))"); xc.Modify("cos(pi*2*x-pi)");

  gr->SubPlot(2,2,3); gr->Title("3d variant");  gr->Rotate(50,60);
  gr->Box();  gr->Tube(xc,yc,z,y2,"r");
  return 0;
}
```



2.5.21 Tape sample

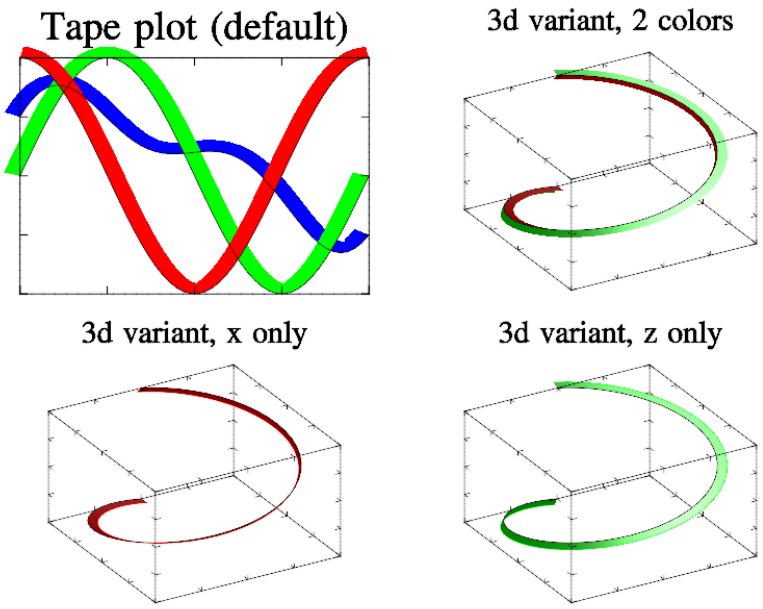
Function [tape], page 197 draw tapes which rotate around the curve as normal and binormal. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData y;  mgls_prepare1d(&y);
  mglData xc(50), yc(50), z(50);
  yc.Modify("sin(pi*(2*x-1))");
  xc.Modify("cos(pi*2*x-pi)");  z.Fill(-1,1);
  gr->SubPlot(2,2,0,"");  gr->Title("Tape plot (default)");
  gr->Box();  gr->Tape(y);  gr->Plot(y,"k");

  gr->SubPlot(2,2,1); gr->Title("3d variant, 2 colors");
  gr->Rotate(50,60);  gr->Light(true);
  gr->Box();  gr->Plot(xc,yc,z,"k");  gr->Tape(xc,yc,z,"rg");

  gr->SubPlot(2,2,2); gr->Title("3d variant, x only");  gr->Rotate(50,60);
  gr->Box();  gr->Plot(xc,yc,z,"k");
  gr->Tape(xc,yc,z,"xr"); gr->Tape(xc,yc,z,"xr#");

  gr->SubPlot(2,2,3); gr->Title("3d variant, z only");  gr->Rotate(50,60);
  gr->Box();  gr->Plot(xc,yc,z,"k");
  gr->Tape(xc,yc,z,"zg"); gr->Tape(xc,yc,z,"zg#");
  return 0;
}
```



2.5.22 Torus sample

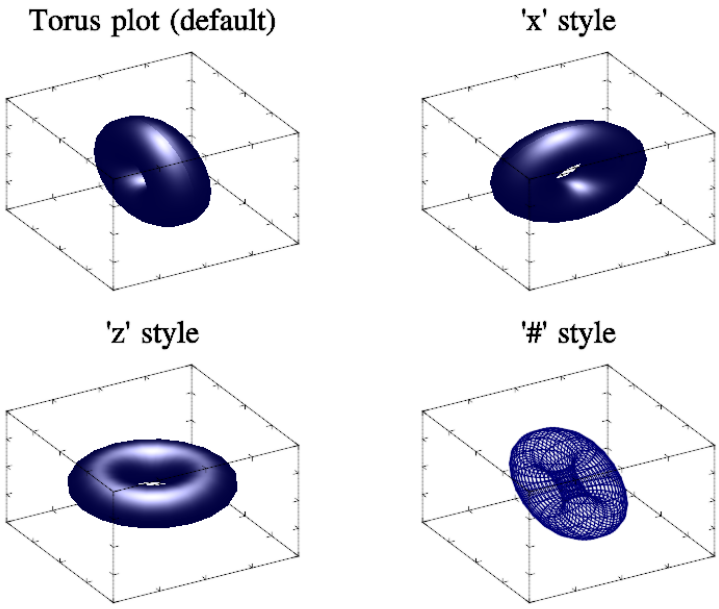
Function [torus], page 206 draw surface of the curve rotation. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData y1,y2;  mgls_prepare1d(0,&y1,&y2);
  gr->SubPlot(2,2,0); gr->Title("Torus plot (default)");
  gr->Light(true);  gr->Rotate(50,60);  gr->Box();  gr->Torus(y1,y2);
  if(mini)  return;

  gr->SubPlot(2,2,1); gr->Title("'x' style"); gr->Rotate(50,60);
  gr->Box();  gr->Torus(y1,y2,"x");

  gr->SubPlot(2,2,2); gr->Title("'z' style"); gr->Rotate(50,60);
  gr->Box();  gr->Torus(y1,y2,"z");

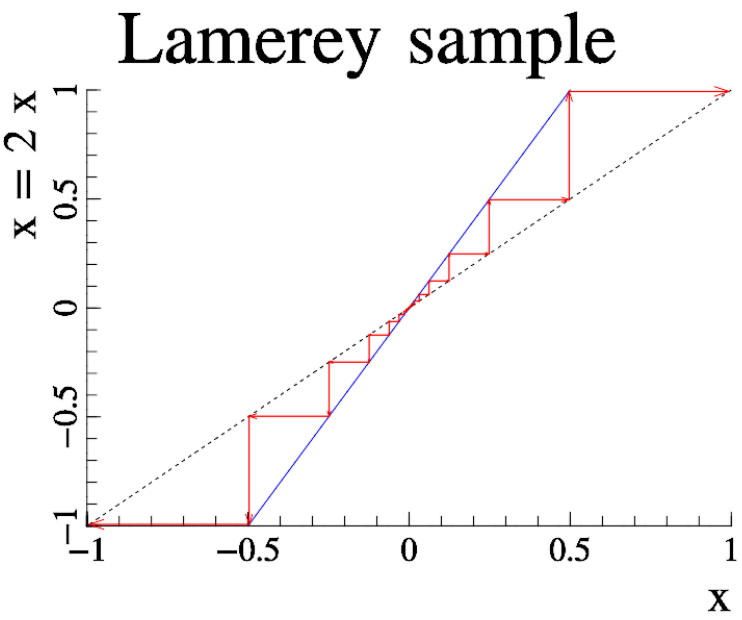
  gr->SubPlot(2,2,3); gr->Title("'\\#' style"); gr->Rotate(50,60);
  gr->Box();  gr->Torus(y1,y2,"#");
  return 0;
}
```



2.5.23 Lamerey sample

Function [lamerey], page 206 draw Lamerey diagram. The sample code is:

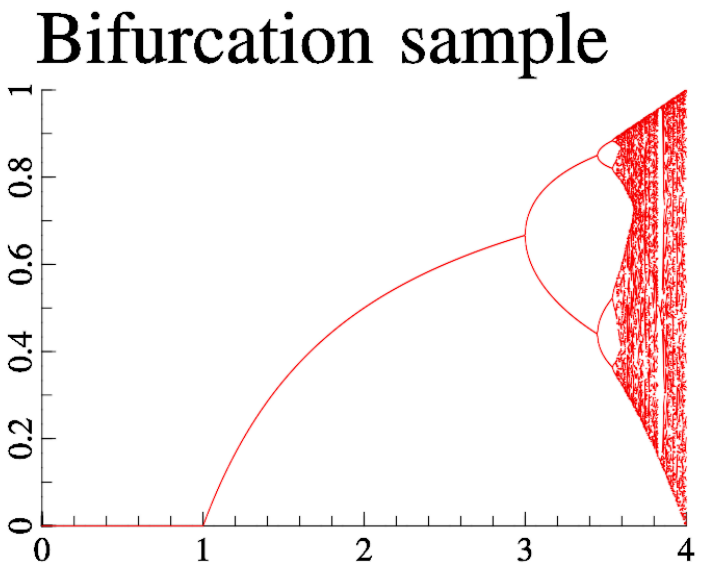
```
int sample(mglGraph *gr)
{
  gr->SubPlot(1,1,0,"<_");
  gr->Title("Lamerey sample");
  gr->Axis(); gr->Label('x',"\\i x");
  gr->Label('y',"\\bar{\\i x} = 2 \\i{x}");
  gr->FPlot("x","k=");  gr->FPlot("2*x","b");
  gr->Lamerey( 0.00097,"2*x","rv~");
  gr->Lamerey(-0.00097,"2*x","rv~");
}
```



2.5.24 Bifurcation sample

Function [bifurcation], page 207 draw Bifurcation diagram for logistic map. The sample code is:

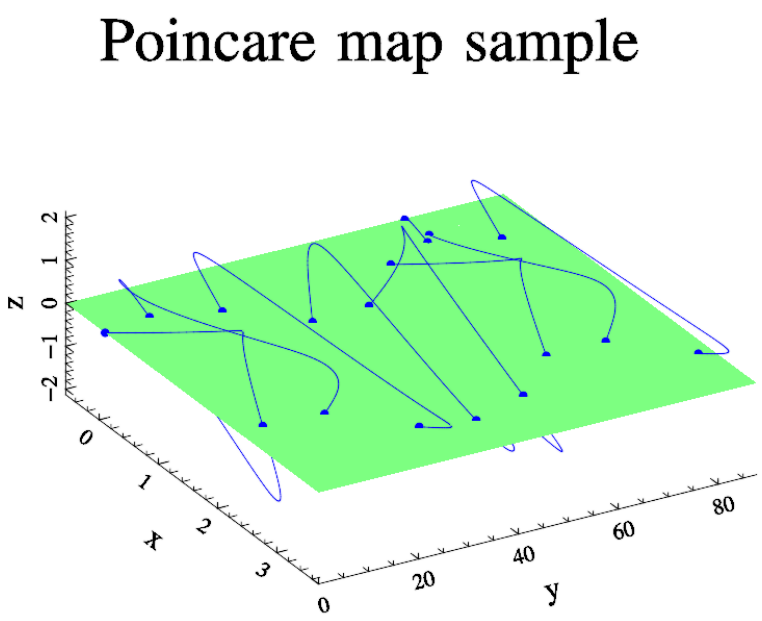
```
int sample(mglGraph *gr)
{
  gr->SubPlot(1,1,0,"<_");
  gr->Title("Bifurcation sample");
  gr->SetRanges(0,4,0,1);   gr->Axis();
  gr->Bifurcation(0.005,"x*y*(1-y)","r");
}
```



2.5.25 Pmap sample

Function [pmap], page 207 draw Poincare map – show intersections of the curve and the surface. The sample code is:

```
int sample(mglGraph *gr)
{
  gr->SubPlot(1,1,0,"<_^");
  gr->Title("Poincare map sample");
  mglData ini(3);       ini[0]=0.1;
  mglData r(mglODE("cos(y)+sin(z);cos(z)+sin(x);cos(x)+sin(y)","xyz",ini,0.1,100));
  mglData x(r.SubData(0)),y(r.SubData(1)), z(r.SubData(2));
  gr->Rotate(40,60);  gr->SetRanges(x,y,z);
  gr->Axis(); gr->FSurf("0"); gr->Plot(x,y,z,"b");
  gr->Label('x',"\\i x",0);   gr->Label('y',"\\i y",0);   gr->Label('z',"\\i z",0);
  gr->Pmap(x,y,z,z, "b#o");
}
```



2.6 2D samples

This section is devoted to visualization of 2D data arrays. 2D means the data which depend on 2 indexes (parameters) like matrix z(i,j)=z(x(i),y(j)), i=1...n, j=1...m or in parametric form {x(i,j),y(i,j),z(i,j)}. Most of samples will use the same data for plotting. So, I put its initialization in separate function

```
void mgls_prepare2d(mglData *a, mglData *b=0, mglData *v=0)
{
  register long i,j,n=50,m=40,i0;
  if(a) a->Create(n,m);   if(b) b->Create(n,m);
  if(v) { v->Create(9); v->Fill(-1,1);  }
  mreal x,y;
  for(i=0;i<n;i++)  for(j=0;j<m;j++)
  {
    x = i/(n-1.); y = j/(m-1.); i0 = i+n*j;
    if(a) a->a[i0] = 0.6*sin(2*M_PI*x)*sin(3*M_PI*y)+0.4*cos(3*M_PI*x*y);
    if(b) b->a[i0] = 0.6*cos(2*M_PI*x)*cos(3*M_PI*y)+0.4*cos(3*M_PI*x*y);
  }
}
```

or using C functions

```
void mgls_prepare2d(HMDT a, HMDT b=0, HMDT v=0)
{
  register long i,j,n=50,m=40,i0;
  if(a) mgl_data_create(a,n,m,1);
  if(b) mgl_data_create(b,n,m,1);
  if(v) { mgl_data_create(v,9,1,1); mgl_data_fill(v,-1,1,'x');  }
  mreal x,y;
  for(i=0;i<n;i++)  for(j=0;j<m;j++)
```

```
  {
    x = i/(n-1.); y = j/(m-1.); i0 = i+n*j;
    if(a) mgl_data_set_value(a, 0.6*sin(2*M_PI*x)*sin(3*M_PI*y)+0.4*cos(3*M_PI*x*y), i,j,0)
    if(b) mgl_data_set_value(b, 0.6*cos(2*M_PI*x)*cos(3*M_PI*y)+0.4*cos(3*M_PI*x*y), i,j,0)
  }
}
```

2.6.1 Surf sample

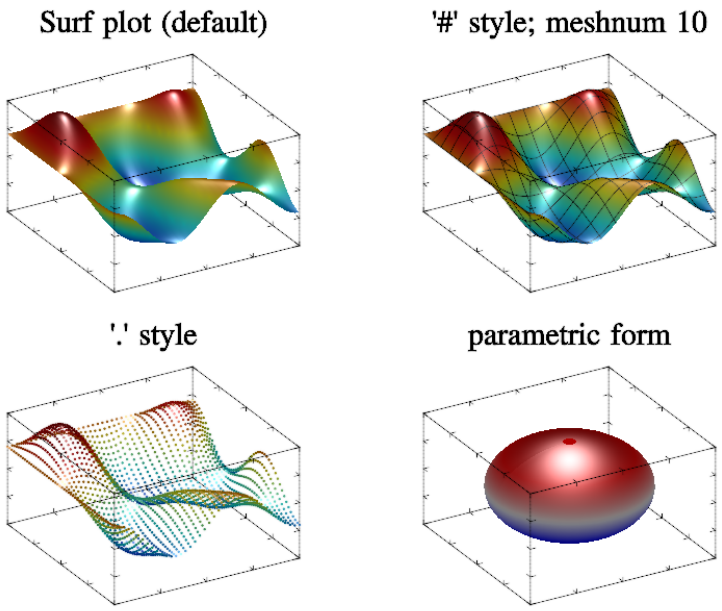
Function [surf], page 208 is most standard way to visualize 2D data array. `Surf` use color scheme for coloring (see Section 3.4 [Color scheme], page 150). You can use '`#`' style for drawing black meshes on the surface. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a;  mgls_prepare2d(&a);
  gr->SubPlot(2,2,0); gr->Title("Surf plot (default)");
  gr->Light(true);  gr->Rotate(50,60);  gr->Box();  gr->Surf(a);

  gr->SubPlot(2,2,1); gr->Title("'\\#' style; meshnum 10");
  gr->Rotate(50,60);  gr->Box();  gr->Surf(a,"#","meshnum 10");

  gr->SubPlot(2,2,2); gr->Title("'.' style");
  gr->Rotate(50,60);  gr->Box();  gr->Surf(a,".");

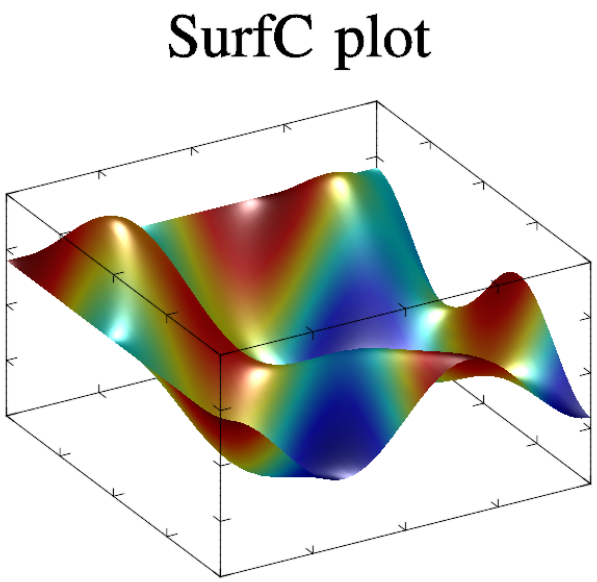
  gr->SubPlot(2,2,3); gr->Title("parametric form");
  mglData x(50,40),y(50,40),z(50,40);
  gr->Fill(x,"0.8*sin(pi*x)*sin(pi*(y+1)/2)");
  gr->Fill(y,"0.8*cos(pi*x)*sin(pi*(y+1)/2)");
  gr->Fill(z,"0.8*cos(pi*(y+1)/2)");
  gr->Rotate(50,60);  gr->Box();  gr->Surf(x,y,z,"BbwrR");
  return 0;
}
```



2.6.2 SurfC sample

Function [surfc], page 217 is similar to [surf], page 208 but its coloring is determined by another data. The sample code is:

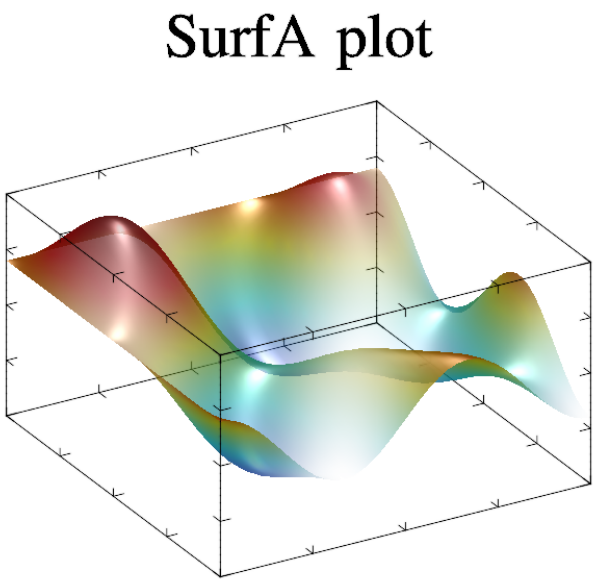
```
int sample(mglGraph *gr)
{
  mglData a,b;  mgls_prepare2d(&a,&b);
  gr->Title("SurfC plot");  gr->Rotate(50,60);
  gr->Light(true);  gr->Box();  gr->SurfC(a,b);
  return 0;
}
```



2.6.3 SurfA sample

Function [surfa], page 218 is similar to [surf], page 208 but its transparency is determined by another data. The sample code is:

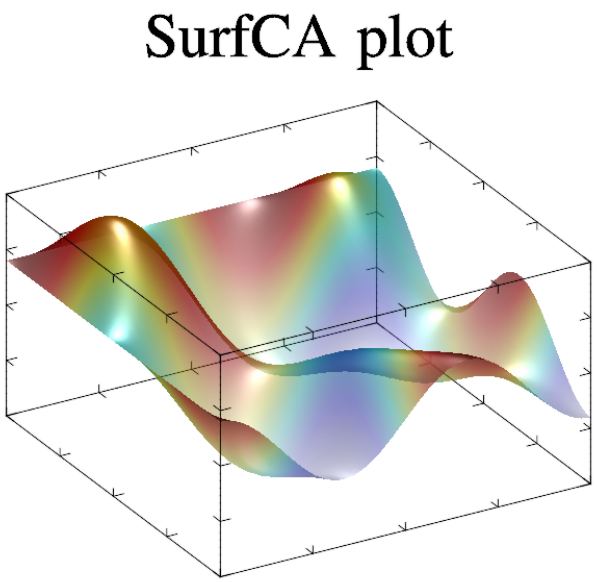
```
int sample(mglGraph *gr)
{
  mglData a,b;  mgls_prepare2d(&a,&b);
  gr->Title("SurfA plot");  gr->Rotate(50,60);
  gr->Alpha(true);  gr->Light(true);
  gr->Box();  gr->SurfA(a,b);
  return 0;
}
```



2.6.4 SurfCA sample

Function [surfca], page 220 is similar to [surf], page 208 but its color and transparency is determined by another data. The sample code is:

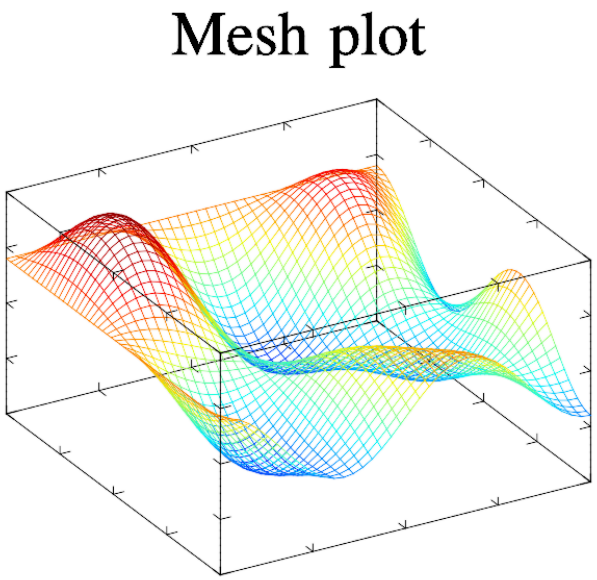
```
int sample(mglGraph *gr)
{
  mglData a,b;  mgls_prepare2d(&a,&b);
  gr->Title("SurfCA plot");  gr->Rotate(50,60);
  gr->Alpha(true);  gr->Light(true);
  gr->Box();  gr->SurfCA(a,b,a);
  return 0;
}
```



2.6.5 Mesh sample

Function [mesh], page 208 draw wired surface. You can use [meshnum], page 161 for changing number of lines to be drawn. The sample code is:

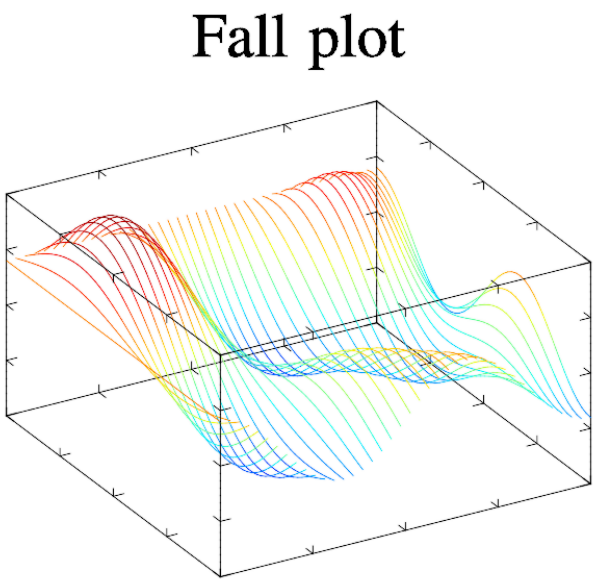
```
int sample(mglGraph *gr)
{
  mglData a;  mgls_prepare2d(&a);
  gr->Title("Mesh plot"); gr->Rotate(50,60);
  gr->Box();  gr->Mesh(a);
  return 0;
}
```



2.6.6 Fall sample

Function [fall], page 208 draw waterfall surface. You can use [meshnum], page 161 for changing number of lines to be drawn. Also you can use '`x`' style for drawing lines in other direction. The sample code is:

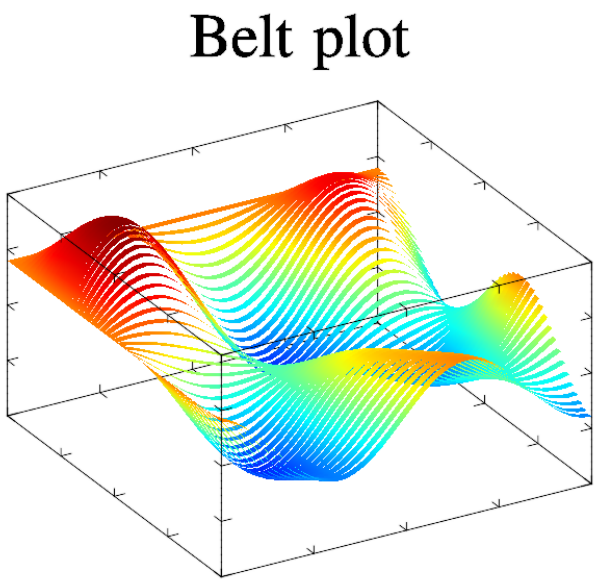
```
int sample(mglGraph *gr)
{
  mglData a;  mgls_prepare2d(&a);
  gr->Title("Fall plot"); gr->Rotate(50,60);
  gr->Box();  gr->Fall(a);
  return 0;
}
```



2.6.7 Belt sample

Function [belt], page 209 draw surface by belts. You can use '`x`' style for drawing lines in other direction. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a;  mgls_prepare2d(&a);
  gr->Title("Belt plot"); gr->Rotate(50,60);
  gr->Box();  gr->Belt(a);
  return 0;
}
```



2.6.8 Boxs sample

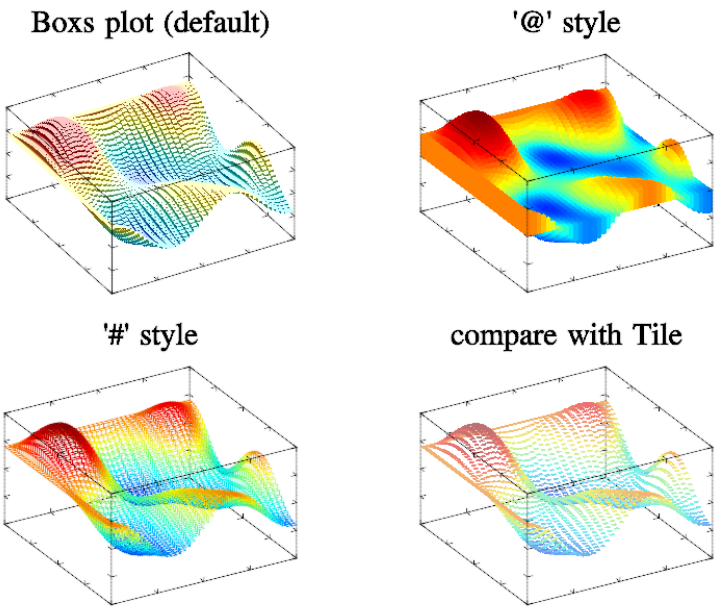
Function [boxs], page 209 draw surface by boxes. You can use '#' for drawing wire plot. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a;  mgls_prepare2d(&a);
  gr->SetOrigin(0,0,0); gr->Light(true);
  gr->SubPlot(2,2,0);  gr->Title("Boxs plot (default)");
  gr->Rotate(40,60);  gr->Box();  gr->Boxs(a);

  gr->SubPlot(2,2,1); gr->Title("'\\@' style");
  gr->Rotate(50,60);  gr->Box();  gr->Boxs(a,"@");

  gr->SubPlot(2,2,2); gr->Title("'\\#' style");
  gr->Rotate(50,60);  gr->Box();  gr->Boxs(a,"#");

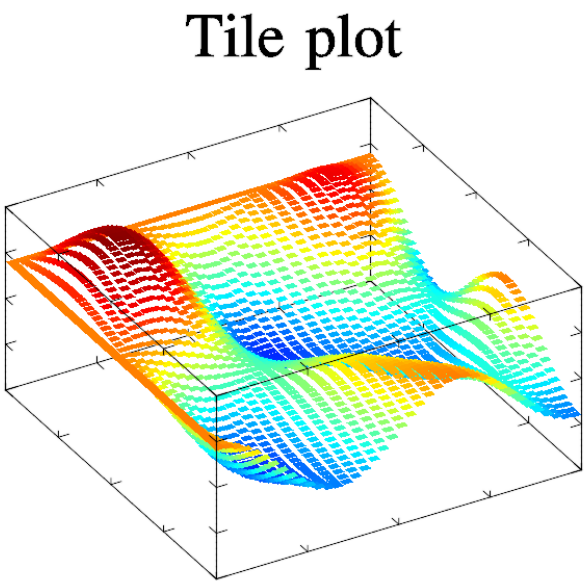
  gr->SubPlot(2,2,3); gr->Title("compare with Tile");
  gr->Rotate(50,60);  gr->Box();  gr->Tile(a);
  return 0;
}
```



2.6.9 Tile sample

Function [tile], page 209 draw surface by tiles. The sample code is:

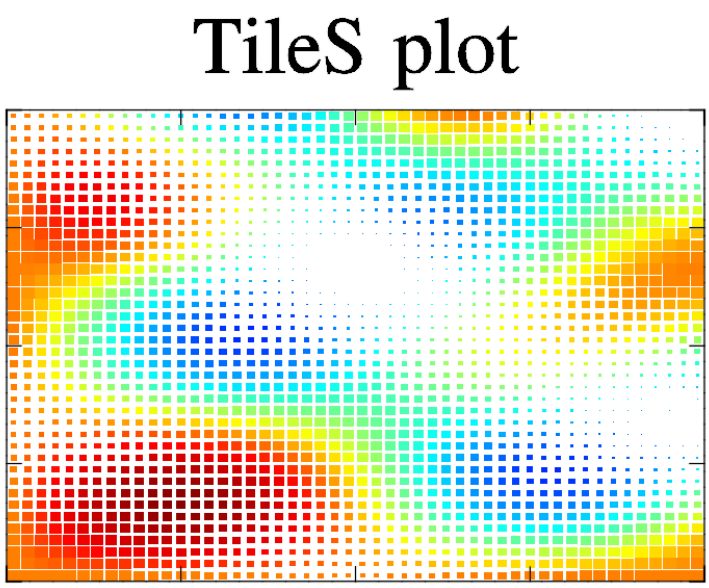
```
int sample(mglGraph *gr)
{
  mglData a;  mgls_prepare2d(&a);
  gr->Title("Tile plot");
  gr->Rotate(40,60);  gr->Box();  gr->Tile(a);
  return 0;
}
```



2.6.10 TileS sample

Function [tiles], page 221 is similar to [tile], page 209 but tile sizes is determined by another data. This allows one to simulate transparency of the plot. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a,b;  mgls_prepare2d(&a,&b);
  gr->SubPlot(1,1,0,""); gr->Title("TileS plot");
  gr->Box();  gr->TileS(a,b);
  return 0;
}
```



2.6.11 Dens sample

Function [dens], page 209 draw density plot for surface. The sample code is:

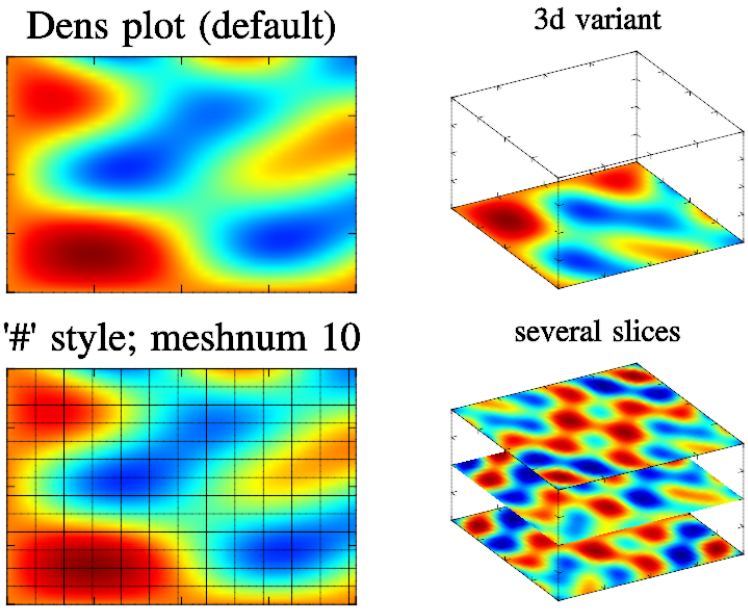
```
int sample(mglGraph *gr)
{
  mglData a,a1(30,40,3);  mgls_prepare2d(&a);
  gr->Fill(a1,"0.6*sin(2*pi*x+pi*(z+1)/2)*sin(3*pi*y+pi*z) + 0.4*cos(3*pi*(x*y)+pi*(z+1)^2/
  gr->SubPlot(2,2,0,""); gr->Title("Dens plot (default)");
  gr->Box();  gr->Dens(a);

  gr->SubPlot(2,2,1); gr->Title("3d variant");
  gr->Rotate(50,60);  gr->Box();  gr->Dens(a);

  gr->SubPlot(2,2,2,"");  gr->Title("'\\#' style; meshnum 10");
  gr->Box();  gr->Dens(a,"#","meshnum 10");

  gr->SubPlot(2,2,3); gr->Title("several slices");
```

```
  gr->Rotate(50,60);    gr->Box();  gr->Dens(a1);
  return 0;
}
```



2.6.12 Cont sample

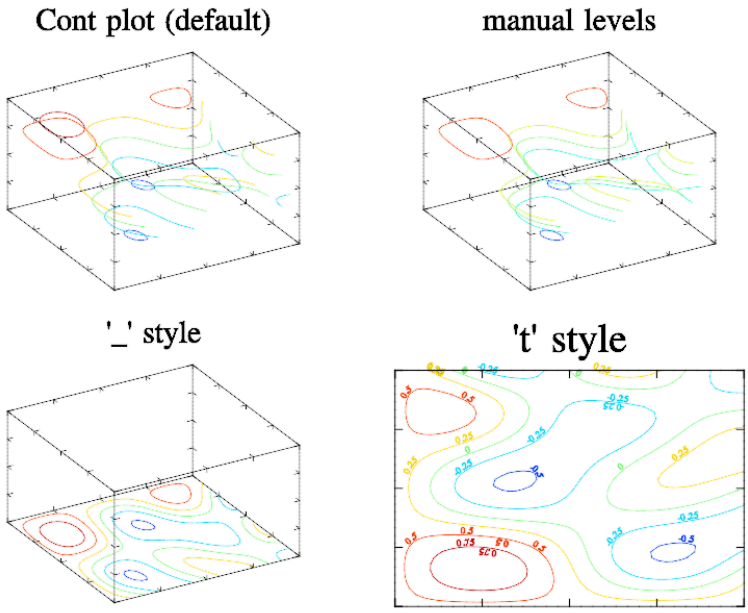
Function [cont], page 210 draw contour lines for surface. You can select automatic (default) or manual levels for contours, print contour labels, draw it on the surface (default) or at plane (as `Dens`). The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a,v(5); mgls_prepare2d(&a); v.a[0]=-0.5;  v.a[1]=-0.15; v.a[2]=0; v.a[3]=0.15;  v
  gr->SubPlot(2,2,0); gr->Title("Cont plot (default)");
  gr->Rotate(50,60);  gr->Box();  gr->Cont(a);

  gr->SubPlot(2,2,1); gr->Title("manual levels");
  gr->Rotate(50,60);  gr->Box();  gr->Cont(v,a);

  gr->SubPlot(2,2,2); gr->Title("'\\_' style");
  gr->Rotate(50,60);  gr->Box();  gr->Cont(a,"_");

  gr->SubPlot(2,2,3,"");  gr->Title("'t' style");
  gr->Box();  gr->Cont(a,"t");
  return 0;
}
```



2.6.13 ContF sample

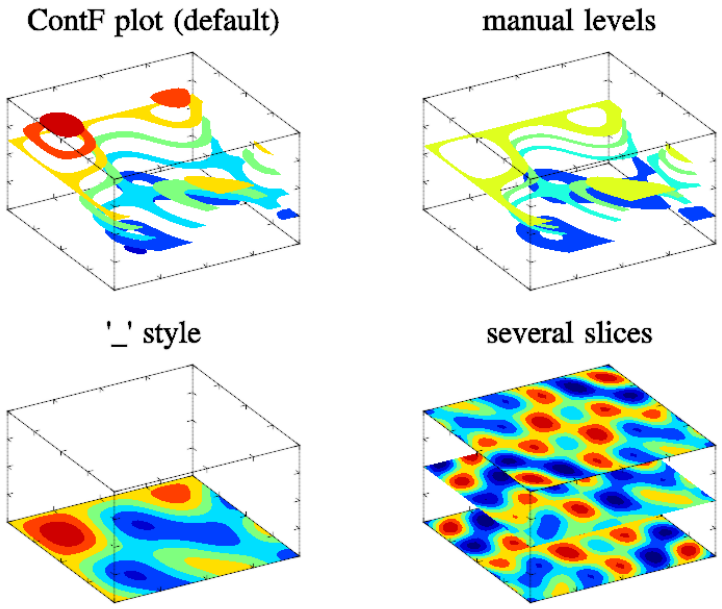
Function [contf], page 210 draw filled contours. You can select automatic (default) or manual levels for contours. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a,v(5),a1(30,40,3); mgls_prepare2d(&a); v.a[0]=-0.5;
  v.a[1]=-0.15; v.a[2]=0; v.a[3]=0.15;  v.a[4]=0.5;
  gr->SubPlot(2,2,0); gr->Title("ContF plot (default)");
  gr->Rotate(50,60);  gr->Box();  gr->ContF(a);

  gr->SubPlot(2,2,1); gr->Title("manual levels");
  gr->Rotate(50,60);  gr->Box();  gr->ContF(v,a);

  gr->SubPlot(2,2,2); gr->Title("'\\_' style");
  gr->Rotate(50,60);  gr->Box();  gr->ContF(a,"_");

  gr->Fill(a1,"0.6*sin(2*pi*x+pi*(z+1)/2)*sin(3*pi*y+pi*z) +
              0.4*cos(3*pi*(x*y)+pi*(z+1)^2/2)");
  gr->SubPlot(2,2,3); gr->Title("several slices");
  gr->Rotate(50,60);  gr->Box();  gr->ContF(a1);
  return 0;
}
```



2.6.14 ContD sample

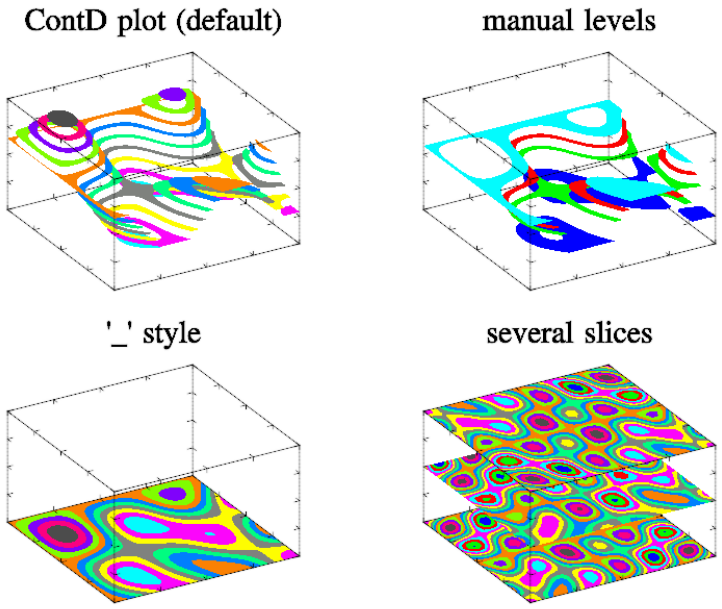
Function [contd], page 211 is similar to `ContF` but with manual contour colors. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a,v(5),a1(30,40,3); mgls_prepare2d(&a); v.a[0]=-0.5;
  v.a[1]=-0.15; v.a[2]=0; v.a[3]=0.15;  v.a[4]=0.5;
  gr->SubPlot(2,2,0); gr->Title("ContD plot (default)");
  gr->Rotate(50,60);  gr->Box();  gr->ContD(a);

  gr->SubPlot(2,2,1); gr->Title("manual levels");
  gr->Rotate(50,60);  gr->Box();  gr->ContD(v,a);

  gr->SubPlot(2,2,2); gr->Title("'\\_' style");
  gr->Rotate(50,60);  gr->Box();  gr->ContD(a,"_");

  gr->Fill(a1,"0.6*sin(2*pi*x+pi*(z+1)/2)*sin(3*pi*y+pi*z) + 0.4*cos(3*pi*(x*y)+pi*(z+1)^2/
  gr->SubPlot(2,2,3); gr->Title("several slices");
  gr->Rotate(50,60);  gr->Box();  gr->ContD(a1);
  return 0;
}
```



2.6.15 ContV sample

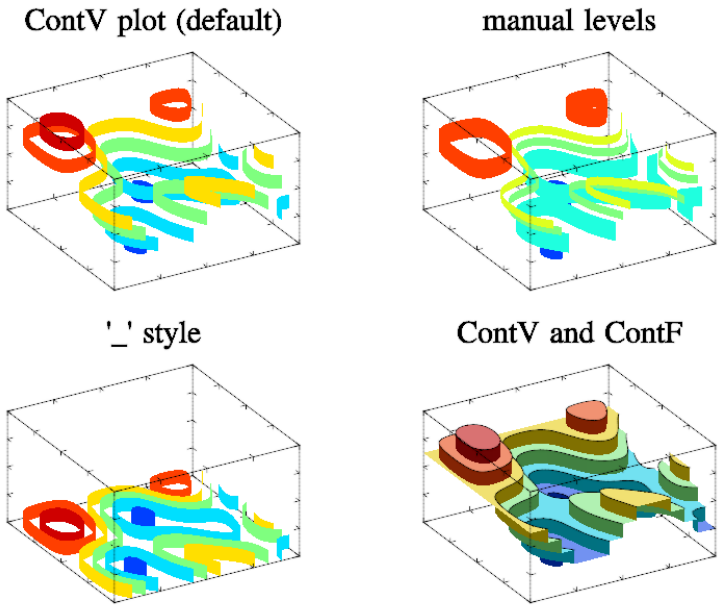
Function [contv], page 212 draw vertical cylinders (belts) at contour lines. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a,v(5); mgls_prepare2d(&a); v.a[0]=-0.5;
  v.a[1]=-0.15; v.a[2]=0; v.a[3]=0.15;  v.a[4]=0.5;
  gr->SubPlot(2,2,0); gr->Title("ContV plot (default)");
  gr->Rotate(50,60);  gr->Box();  gr->ContV(a);

  gr->SubPlot(2,2,1); gr->Title("manual levels");
  gr->Rotate(50,60);  gr->Box();  gr->ContV(v,a);

  gr->SubPlot(2,2,2); gr->Title("'\\_' style");
  gr->Rotate(50,60);  gr->Box();  gr->ContV(a,"_");

  gr->SubPlot(2,2,3); gr->Title("ContV and ContF");
  gr->Rotate(50,60);  gr->Box();  gr->Light(true);
  gr->ContV(a); gr->ContF(a); gr->Cont(a,"k");
  return 0;
}
```



2.6.16 Axial sample

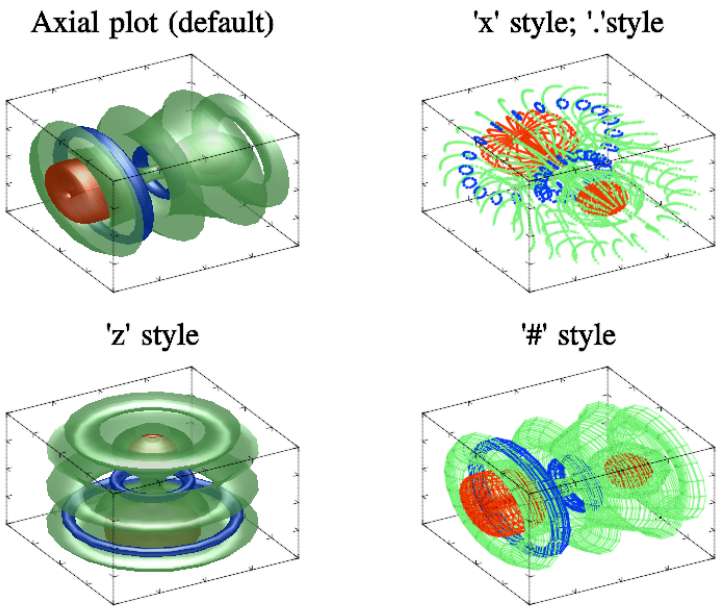
Function [axial], page 212 draw surfaces of rotation for contour lines. You can draw wire surfaces ('#' style) or ones rotated in other directions ('x', 'z' styles). The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a;  mgls_prepare2d(&a);
  gr->SubPlot(2,2,0); gr->Title("Axial plot (default)");
  gr->Light(true);  gr->Alpha(true);  gr->Rotate(50,60);
  gr->Box();  gr->Axial(a);

  gr->SubPlot(2,2,1); gr->Title("'x' style;'.' style"); gr->Rotate(50,60);
  gr->Box();  gr->Axial(a,"x.");

  gr->SubPlot(2,2,2); gr->Title("'z' style"); gr->Rotate(50,60);
  gr->Box();  gr->Axial(a,"z");

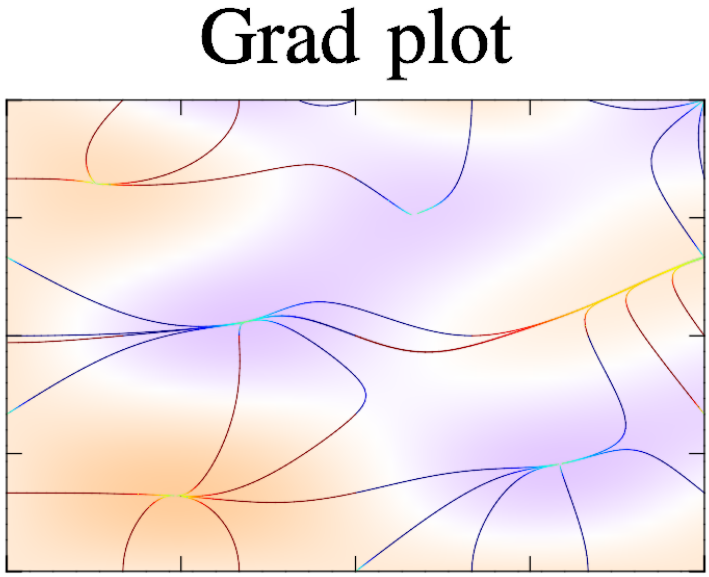
  gr->SubPlot(2,2,3); gr->Title("'\\#' style"); gr->Rotate(50,60);
  gr->Box();  gr->Axial(a,"#");
  return 0;
}
```



2.6.17 Grad sample

Function [grad], page 226 draw gradient lines for matrix. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a;  mgls_prepare2d(&a);
  gr->SubPlot(1,1,0,""); gr->Title("Grad plot");
  gr->Box();  gr->Grad(a);  gr->Dens(a,"{u8}w{q8}");
  return 0;
}
```



2.7 3D samples

This section is devoted to visualization of 3D data arrays. 3D means the data which depend on 3 indexes (parameters) like tensor a(i,j,k)=a(x(i),y(j),x(k)), i=1...n, j=1...m, k=1...l or in parametric form {x(i,j,k),y(i,j,k),z(i,j,k),a(i,j,k)}. Most of samples will use the same data for plotting. So, I put its initialization in separate function

```
void mgls_prepare3d(mglData *a, mglData *b=0)
{
  register long i,j,k,n=61,m=50,l=40,i0;
  if(a) a->Create(n,m,l);   if(b) b->Create(n,m,l);
  mreal x,y,z;
  for(i=0;i<n;i++)  for(j=0;j<m;j++)  for(k=0;k<l;k++)
  {
    x=2*i/(n-1.)-1; y=2*j/(m-1.)-1; z=2*k/(l-1.)-1; i0 = i+n*(j+m*k);
    if(a) a->a[i0] = -2*(x*x + y*y + z*z*z*z - z*z - 0.1);
    if(b) b->a[i0] = 1-2*tanh((x+y)*(x+y));
  }
}
```

or using C functions

```
void mgls_prepare3d(HMDT a, HMDT b=0)
{
  register long i,j,k,n=61,m=50,l=40,i0;
  if(a) mgl_data_create(a,n,m,l);
  if(b) mgl_data_create(b,n,m,l);
  mreal x,y,z;
  for(i=0;i<n;i++)  for(j=0;j<m;j++)  for(k=0;k<l;k++)
  {
    x=2*i/(n-1.)-1; y=2*j/(m-1.)-1; z=2*k/(l-1.)-1; i0 = i+n*(j+m*k);
    if(a) mgl_data_set_value(a, -2*(x*x + y*y + z*z*z*z - z*z - 0.1), i,j,k);
    if(b) mgl_data_set_value(b, 1-2*tanh((x+y)*(x+y)), i,j,k);
  }
}
```

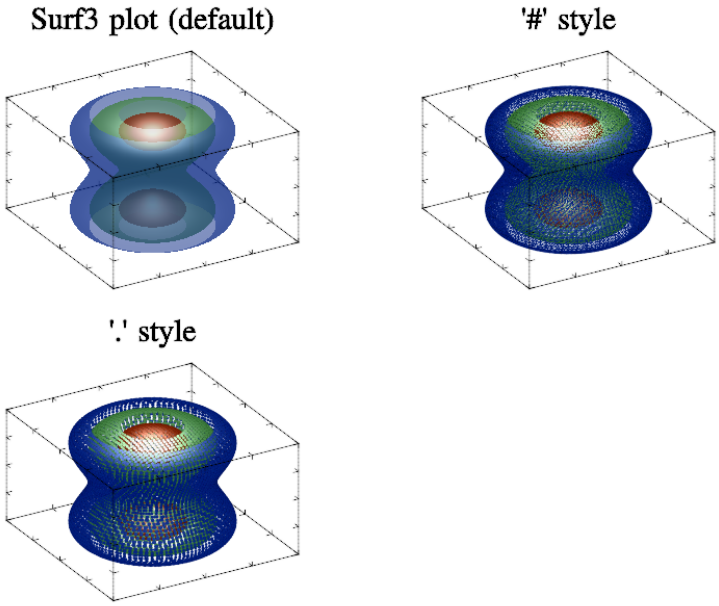
2.7.1 Surf3 sample

Function [surf3], page 214 is one of most suitable (for my opinion) functions to visualize 3D data. It draw the isosurface(s) – surface(s) of constant amplitude (3D analogue of contour lines). You can draw wired isosurfaces if specify '#' style. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData c;  mgls_prepare3d(&c);
  gr->Light(true);    gr->Alpha(true);
  gr->SubPlot(2,2,0); gr->Title("Surf3 plot (default)");
  gr->Rotate(50,60);  gr->Box();  gr->Surf3(c);

  gr->SubPlot(2,2,1); gr->Title("'\\#' style");
  gr->Rotate(50,60);  gr->Box();  gr->Surf3(c,"#");
```

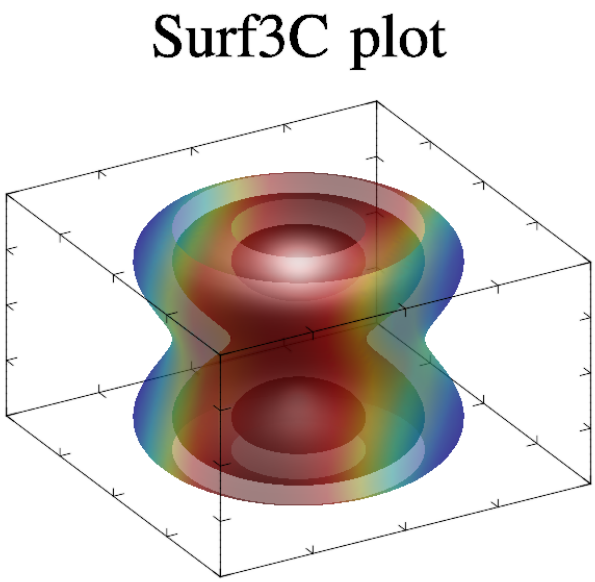
```
  gr->SubPlot(2,2,2); gr->Title("'.' style");
  gr->Rotate(50,60);  gr->Box();  gr->Surf3(c,".");
  return 0;
}
```



2.7.2 Surf3C sample

Function [surf3c], page 218 is similar to [surf3], page 214 but its coloring is determined by another data. The sample code is:

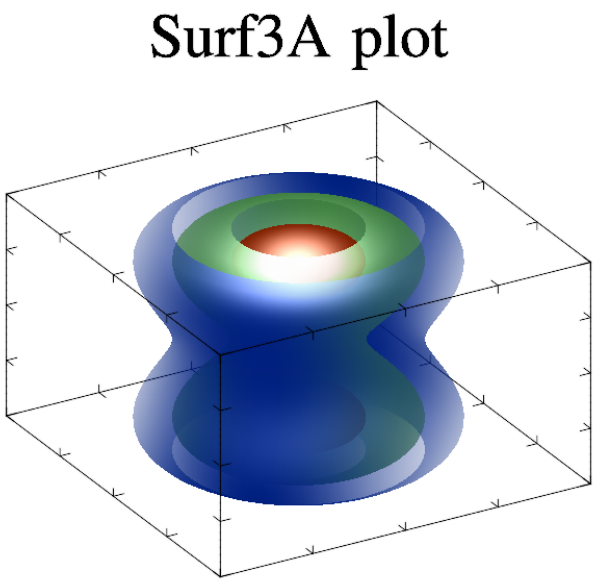
```
int sample(mglGraph *gr)
{
  mglData c,d;  mgls_prepare3d(&c,&d);
  gr->Title("Surf3C plot"); gr->Rotate(50,60);
  gr->Light(true);  gr->Alpha(true);
  gr->Box();  gr->Surf3C(c,d);
  return 0;
}
```



2.7.3 Surf3A sample

Function [surf3a], page 219 is similar to [surf3], page 214 but its transparency is determined by another data. The sample code is:

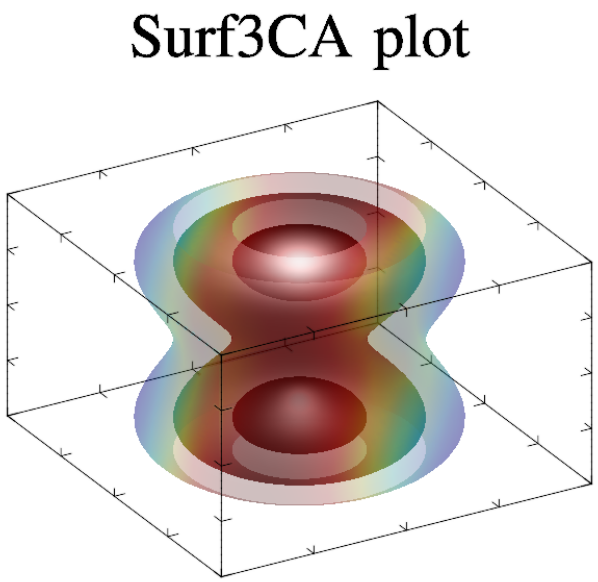
```
int sample(mglGraph *gr)
{
  mglData c,d;  mgls_prepare3d(&c,&d);
  gr->Title("Surf3A plot"); gr->Rotate(50,60);
  gr->Light(true);  gr->Alpha(true);
  gr->Box();  gr->Surf3A(c,d);
  return 0;
}
```



2.7.4 Surf3CA sample

Function [surf3ca], page 220 is similar to [surf3], page 214 but its color and transparency is determined by another data. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData c,d;  mgls_prepare3d(&c,&d);
  gr->Title("Surf3CA plot"); gr->Rotate(50,60);
  gr->Light(true);  gr->Alpha(true);
  gr->Box();  gr->Surf3CA(c,d,c);
  return 0;
}
```



2.7.5 Cloud sample

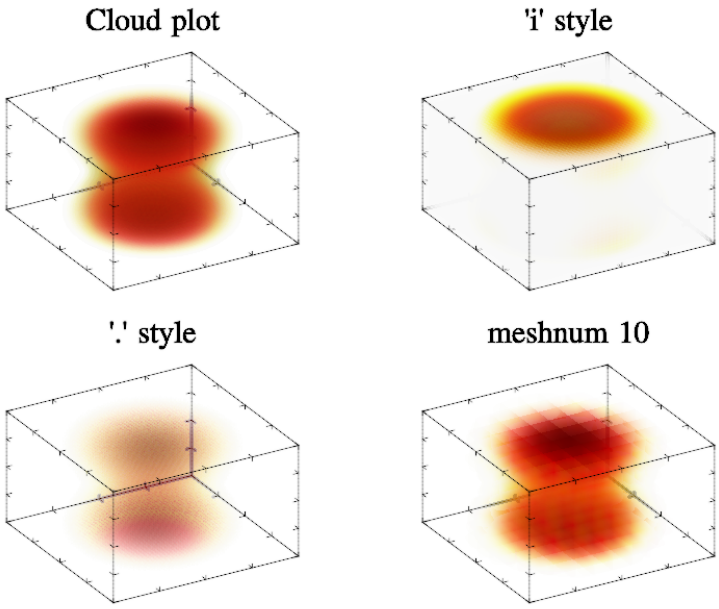
Function [cloud], page 214 draw cloud-like object which is less transparent for higher data values. Similar plot can be created using many (about 10-20) `Surf3A(a,a)` isosurfaces. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData c;  mgls_prepare3d(&c);
  gr->SubPlot(2,2,0); gr->Title("Cloud plot");
  gr->Rotate(50,60);  gr->Alpha(true);
  gr->Box();  gr->Cloud(c,"wyrRk");

  gr->SubPlot(2,2,1); gr->Title("'i' style");
  gr->Rotate(50,60);  gr->Box();  gr->Cloud(c,"iwyrRk");

  gr->SubPlot(2,2,2); gr->Title("'.' style");
  gr->Rotate(50,60);  gr->Box();  gr->Cloud(c,".wyrRk");

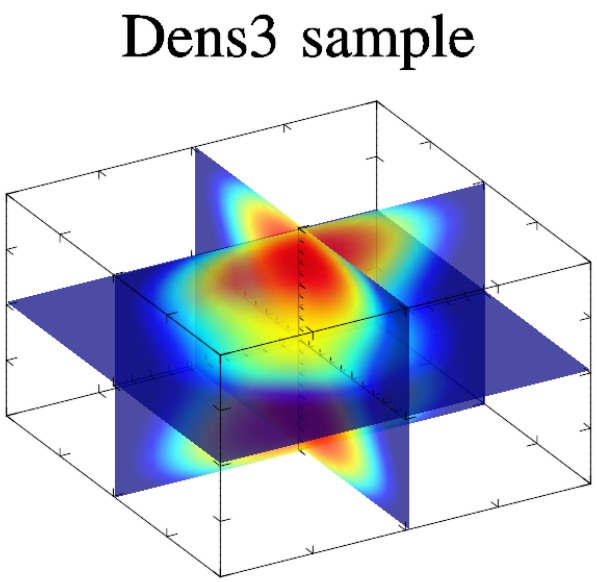
  gr->SubPlot(2,2,3); gr->Title("meshnum 10");
  gr->Rotate(50,60);  gr->Box();  gr->Cloud(c,"wyrRk","meshnum 10");
  return 0;
}
```



2.7.6 Dens3 sample

Function [dens3], page 215 draw just usual density plot but at slices of 3D data. The sample code is:

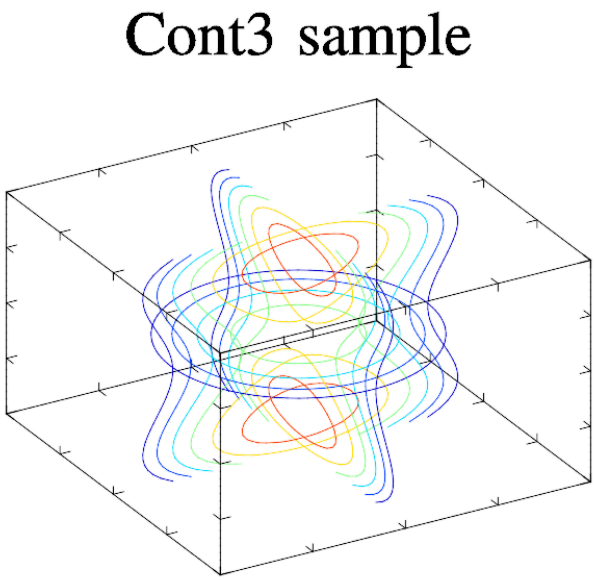
```
int sample(mglGraph *gr)
{
  mglData c;  mgls_prepare3d(&c);
  gr->Title("Dens3 sample");  gr->Rotate(50,60);
  gr->Alpha(true);  gr->SetAlphaDef(0.7);
  gr->SetOrigin(0,0,0); gr->Axis("_xyz"); gr->Box();
  gr->Dens3(c,"x"); gr->Dens3(c); gr->Dens3(c,"z");
  return 0;
}
```



2.7.7 Cont3 sample

Function [cont3], page 215 draw just usual contour lines but at slices of 3D data. The sample code is:

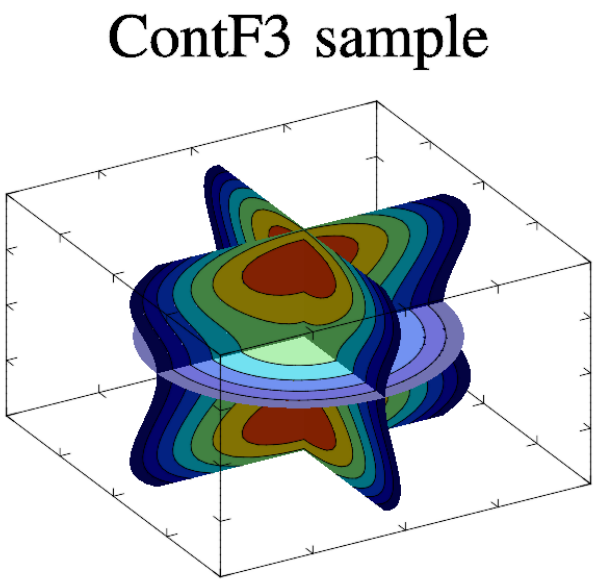
```
int sample(mglGraph *gr)
{
  mglData c;  mgls_prepare3d(&c);
  gr->Title("Cont3 sample");  gr->Rotate(50,60);
  gr->Alpha(true);  gr->SetAlphaDef(0.7);
  gr->SetOrigin(0,0,0); gr->Axis("_xyz"); gr->Box();
  gr->Cont3(c,"x"); gr->Cont3(c); gr->Cont3(c,"z");
  return 0;
}
```



2.7.8 ContF3 sample

Function [contf3], page 216 draw just usual filled contours but at slices of 3D data. The sample code is:

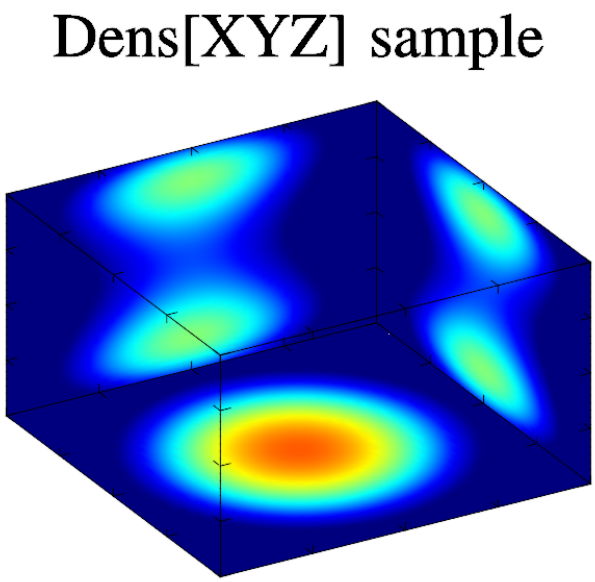
```
int sample(mglGraph *gr)
{
  mglData c;  mgls_prepare3d(&c);
  gr->Title("ContF3 sample");  gr->Rotate(50,60);
  gr->Alpha(true);  gr->SetAlphaDef(0.7);
  gr->SetOrigin(0,0,0); gr->Axis("_xyz"); gr->Box();
  gr->ContF3(c,"x");  gr->ContF3(c);    gr->ContF3(c,"z");
  gr->Cont3(c,"kx");  gr->Cont3(c,"k"); gr->Cont3(c,"kz");
  return 0;
}
```



2.7.9 Dens projection sample

Functions [densz], page 227, [densy], page 227, [densx], page 227 draw density plot on plane perpendicular to corresponding axis. One of possible application is drawing projections of 3D field. The sample code is:

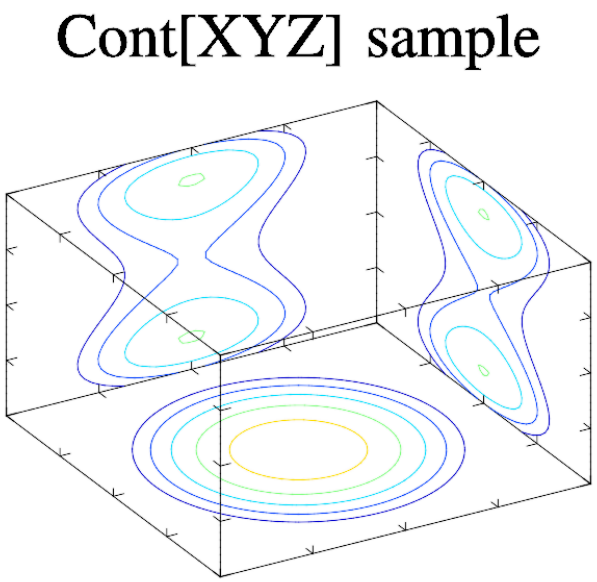
```
int sample(mglGraph *gr)
{
  mglData c;  mgls_prepare3d(&c);
  gr->Title("Dens[XYZ] sample");  gr->Rotate(50,60);
  gr->Box();  gr->DensX(c.Sum("x"),0,-1);
  gr->DensY(c.Sum("y"),0,1);  gr->DensZ(c.Sum("z"),0,-1);
  return 0;
}
```



2.7.10 Cont projection sample

Functions [contz], page 228, [conty], page 228, [contx], page 228 draw contour lines on plane perpendicular to corresponding axis. One of possible application is drawing projections of 3D field. The sample code is:

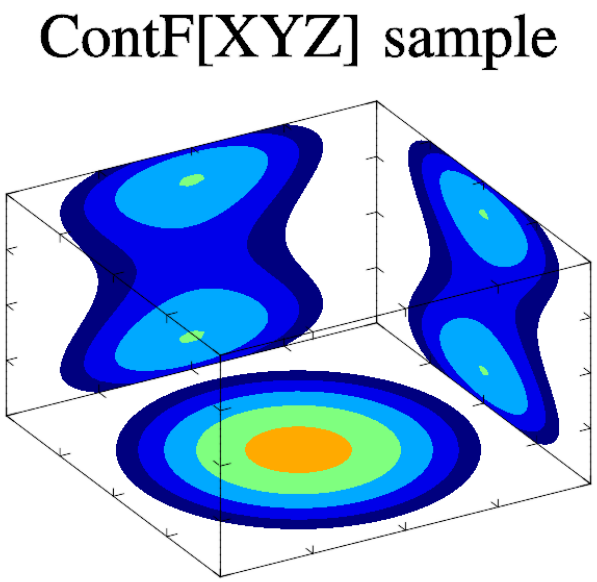
```
int sample(mglGraph *gr)
{
  mglData c;  mgls_prepare3d(&c);
  gr->Title("Cont[XYZ] sample");  gr->Rotate(50,60);
  gr->Box();  gr->ContX(c.Sum("x"),"",-1);
  gr->ContY(c.Sum("y"),"",1); gr->ContZ(c.Sum("z"),"",-1);
  return 0;
}
```



2.7.11 ContF projection sample

Functions [contfz], page 228, [contfy], page 228, [contfx], page 228, draw filled contours on plane perpendicular to corresponding axis. One of possible application is drawing projections of 3D field. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData c;  mgls_prepare3d(&c);
  gr->Title("Cont[XYZ] sample");  gr->Rotate(50,60);
  gr->Box();  gr->ContFX(c.Sum("x"),"",-1);
  gr->ContFY(c.Sum("y"),"",1);  gr->ContFZ(c.Sum("z"),"",-1);
  return 0;
}
```



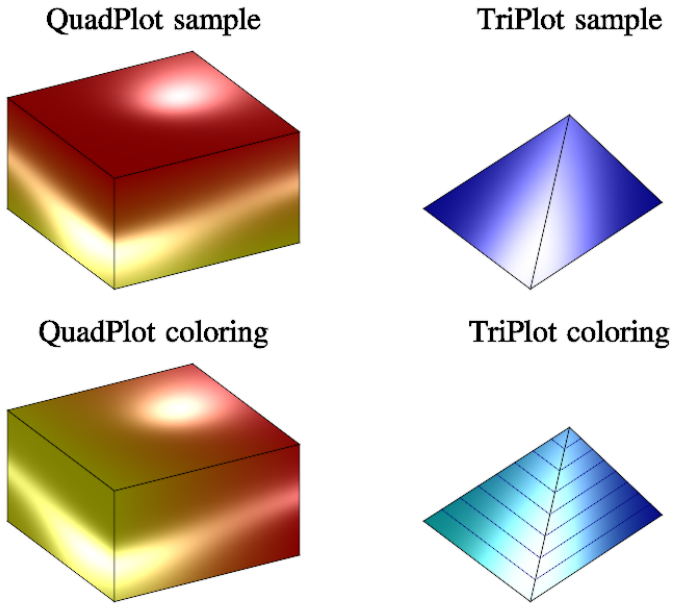
2.7.12 TriPlot and QuadPlot

Function [triplot], page 230 and [quadplot], page 231 draw set of triangles (or quadrangles for `QuadPlot`) for irregular data arrays. Note, that you have to provide not only vertexes, but also the indexes of triangles or quadrangles. I.e. perform triangulation by some other library. The sample code is:

```
int sample(mglGraph *gr)
{
  mreal q[] = {0,1,2,3, 4,5,6,7, 0,2,4,6, 1,3,5,7, 0,4,1,5, 2,6,3,7};
  mreal xc[] = {-1,1,-1,1,-1,1,-1,1}, yc[] = {-1,-1,1,1,-1,-1,1,1}, zc[] = {-1,-1,-1,-1,1,1
  mglData qq(6,4,q), xx(8,xc), yy(8,yc), zz(8,zc);
  gr->Light(true);  //gr->Alpha(true);
  gr->SubPlot(2,2,0); gr->Title("QuadPlot sample"); gr->Rotate(50,60);
  gr->QuadPlot(qq,xx,yy,zz,"yr");
  gr->QuadPlot(qq,xx,yy,zz,"k#");
  gr->SubPlot(2,2,2); gr->Title("QuadPlot coloring"); gr->Rotate(50,60);
  gr->QuadPlot(qq,xx,yy,zz,yy,"yr");
  gr->QuadPlot(qq,xx,yy,zz,"k#");

  mreal t[] = {0,1,2, 0,1,3, 0,2,3, 1,2,3};
  mreal xt[] = {-1,1,0,0}, yt[] = {-1,-1,1,0}, zt[] = {-1,-1,-1,1};
  mglData tt(4,3,t), uu(4,xt), vv(4,yt), ww(4,zt);
  gr->SubPlot(2,2,1); gr->Title("TriPlot sample");  gr->Rotate(50,60);
  gr->TriPlot(tt,uu,vv,ww,"b");
  gr->TriPlot(tt,uu,vv,ww,"k#");
  gr->SubPlot(2,2,3); gr->Title("TriPlot coloring");  gr->Rotate(50,60);
  gr->TriPlot(tt,uu,vv,ww,vv,"cb");
  gr->TriPlot(tt,uu,vv,ww,"k#");
  gr->TriCont(tt,uu,vv,ww,"B");
```

```
  return 0;
}
```

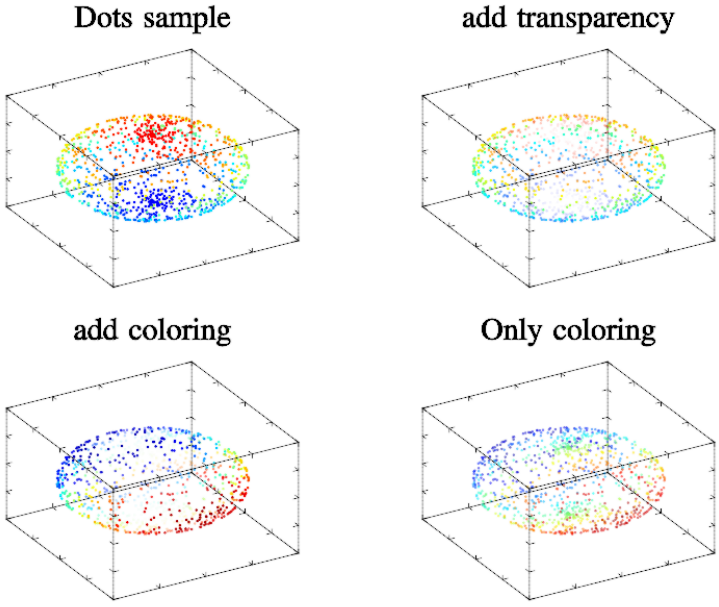


2.7.13 Dots sample

Function [dots], page 232 is another way to draw irregular points. `Dots` use color scheme for coloring (see Section 3.4 [Color scheme], page 150). The sample code is:

```
int sample(mglGraph *gr)
{
  int i, n=2000;
  mglData x(n),y(n),z(n),c(n);
  for(i=0;i<n;i++)
  {
    mreal t=M_PI*(mgl_rnd()-0.5), f=2*M_PI*mgl_rnd();
    x.a[i] = 0.9*cos(t)*cos(f);
    y.a[i] = 0.9*cos(t)*sin(f);
    z.a[i] = 0.6*sin(t);
    c.a[i] = cos(2*t);
  }
  gr->SubPlot(2,2,0); gr->Title("Dots sample");  gr->Rotate(50,60);
  gr->Box();  gr->Dots(x,y,z);
  gr->Alpha(true);
  gr->SubPlot(2,2,1); gr->Title("add transparency"); gr->Rotate(50,60);
  gr->Box();  gr->Dots(x,y,z,c);
  gr->SubPlot(2,2,2); gr->Title("add coloring"); gr->Rotate(50,60);
  gr->Box();  gr->Dots(x,y,z,x,c);
  gr->SubPlot(2,2,3); gr->Title("Only coloring");gr->Rotate(50,60);
  gr->Box();  gr->Tens(x,y,z,x," .");
```

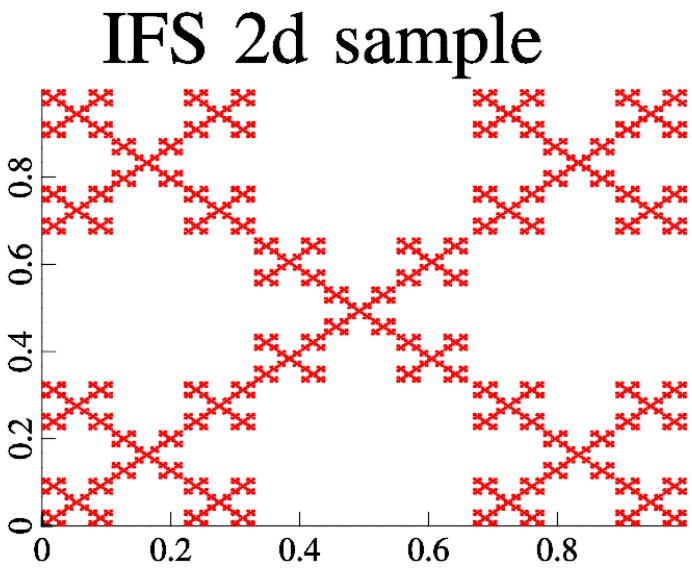
```
  return 0;
}
```



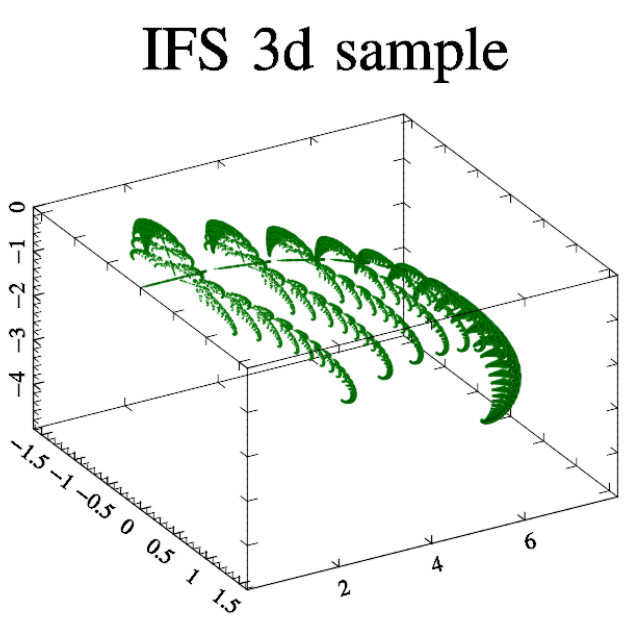
2.7.14 IFS sample

Commands [ifs2d], page 282 and [ifs3d], page 282 generate points for fractals using iterated function system in 2d and 3d cases correspondingly. The sample codes are:

```
int sample(mglGraph *gr)
{
  mglData A;
  A.SetList(35, 0.33,0.,0.,0.33,0.,0.,0.2, 0.33,0.,0.,0.33,0.67,0.,0.2, 0.33,0.,0.,0.33,0.3
                0.33,0.,0.,0.33,0.,0.67,0.2, 0.33,0.,0.,0.33,0.67,0.67,0.2);
  A.Rearrange(7);
  mglData f(mglIFS2d(A,100000));
  gr->SubPlot(1,1,0,"<_");
  gr->Title("IFS 2d sample");
  gr->SetRanges(f.SubData(0), f.SubData(1));
  gr->Axis(); gr->Plot(f.SubData(0), f.SubData(1),"r#o ","size 0.05");
}
```




```
int sample(mglGraph *gr)
{
  mglData A;
  A.SetList(52, 0.,0.,0.,0.,.18,0.,0.,0.,0.,0.,0.,0.,.01, .85,0.,0.,0.,.85,.1,0.,-0.1,0.85,
                .2,-.2,0.,.2,.2,0.,0.,0.,0.3,0.,0.8,0.,.07, -.2,.2,0.,.2,.2,0.,0.,0.,0.3,0.
  A.Rearrange(13);
  mglData f(mglIFS3d(A,100000));
  gr->Title("IFS 3d sample");
  gr->SetRanges(f.SubData(0), f.SubData(1), f.SubData(2));
  gr->Rotate(50,60);  gr->Axis(); gr->Box();
  gr->Dots(f.SubData(0), f.SubData(1), f.SubData(2),"G#o","size 0.05");
}
```



2.8 Vector field samples

Vector field visualization (especially in 3d case) is more or less complex task. MathGL provides 3 general types of plots: vector field itself (`Vect`), flow threads (`Flow`), and flow pipes with radius proportional to field amplitude (`Pipe`).

However, the plot may look tangly – there are too many overlapping lines. I may suggest 2 ways to solve this problem. The first one is to change `SetMeshNum` for decreasing the number of hachures. The second way is to use the flow thread chart `Flow`, or possible many flow thread from manual position (`FlowP`). Unfortunately, I don't know any other methods to visualize 3d vector field. If you know any, e-mail me and I shall add it to MathGL.

Most of samples will use the same data for plotting. So, I put its initialization in separate function

```
void mgls_prepare2v(mglData *a, mglData *b)
{
  register long i,j,n=20,m=30,i0;
  if(a) a->Create(n,m);   if(b) b->Create(n,m);
  mreal x,y;
  for(i=0;i<n;i++)  for(j=0;j<m;j++)
  {
    x=i/(n-1.); y=j/(m-1.); i0 = i+n*j;
    if(a) a->a[i0] = 0.6*sin(2*M_PI*x)*sin(3*M_PI*y)+0.4*cos(3*M_PI*x*y);
    if(b) b->a[i0] = 0.6*cos(2*M_PI*x)*cos(3*M_PI*y)+0.4*cos(3*M_PI*x*y);
  }
}
void mgls_prepare3v(mglData *ex, mglData *ey, mglData *ez)
{
  register long i,j,k,n=10,i0;
  if(!ex || !ey || !ez) return;
```

```
  ex->Create(n,n,n);  ey->Create(n,n,n);  ez->Create(n,n,n);
  mreal x,y,z, r1,r2;
  for(i=0;i<n;i++)  for(j=0;j<n;j++)  for(k=0;k<n;k++)
  {
    x=2*i/(n-1.)-1; y=2*j/(n-1.)-1; z=2*k/(n-1.)-1; i0 = i+n*(j+k*n);
    r1 = pow(x*x+y*y+(z-0.3)*(z-0.3)+0.03,1.5);
    r2 = pow(x*x+y*y+(z+0.3)*(z+0.3)+0.03,1.5);
    ex->a[i0]=0.2*x/r1 - 0.2*x/r2;
    ey->a[i0]=0.2*y/r1 - 0.2*y/r2;
    ez->a[i0]=0.2*(z-0.3)/r1 - 0.2*(z+0.3)/r2;
  }
}
```

or using C functions

```
void mgls_prepare2v(HMDT a, HMDT b)
{
  register long i,j,n=20,m=30,i0;
  if(a) mgl_data_create(a,n,m,1);
  if(b) mgl_data_create(b,n,m,1);
  mreal x,y;
  for(i=0;i<n;i++)  for(j=0;j<m;j++)
  {
    x=i/(n-1.); y=j/(m-1.); i0 = i+n*j;
    if(a) mgl_data_set_value(a, 0.6*sin(2*M_PI*x)*sin(3*M_PI*y)+0.4*cos(3*M_PI*x*y), i,j,0)
    if(b) mgl_data_set_value(b, 0.6*cos(2*M_PI*x)*cos(3*M_PI*y)+0.4*cos(3*M_PI*x*y), i,j,0)
  }
}
void mgls_prepare3v(HMDT ex, HMDT ey, HMDT ez)
{
  register long i,j,k,n=10,i0;
  if(!ex || !ey || !ez) return;
  mgl_data_create(ex,n,n,n);
  mgl_data_create(ey,n,n,n);
  mgl_data_create(ez,n,n,n);
  mreal x,y,z, r1,r2;
  for(i=0;i<n;i++)  for(j=0;j<n;j++)  for(k=0;k<n;k++)
  {
    x=2*i/(n-1.)-1; y=2*j/(n-1.)-1; z=2*k/(n-1.)-1; i0 = i+n*(j+k*n);
    r1 = pow(x*x+y*y+(z-0.3)*(z-0.3)+0.03,1.5);
    r2 = pow(x*x+y*y+(z+0.3)*(z+0.3)+0.03,1.5);
    mgl_data_set_value(ex, 0.2*x/r1 - 0.2*x/r2, i,j,k);
    mgl_data_set_value(ey, 0.2*y/r1 - 0.2*y/r2, i,j,k);
    mgl_data_set_value(ez, 0.2*(z-0.3)/r1 - 0.2*(z+0.3)/r2, i,j,k);
  }
}
```

2.8.1 Vect sample

Function [vect], page 223 is most standard way to visualize vector fields – it draw a lot of arrows or hachures for each data cell. It have a lot of options which can be seen on the figure (and in the sample code). `Vect` use color scheme for coloring (see Section 3.4 [Color scheme], page 150). The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a,b;  mgls_prepare2v(&a,&b);
  gr->SubPlot(3,2,0,""); gr->Title("Vect plot (default)");
  gr->Box();  gr->Vect(a,b);

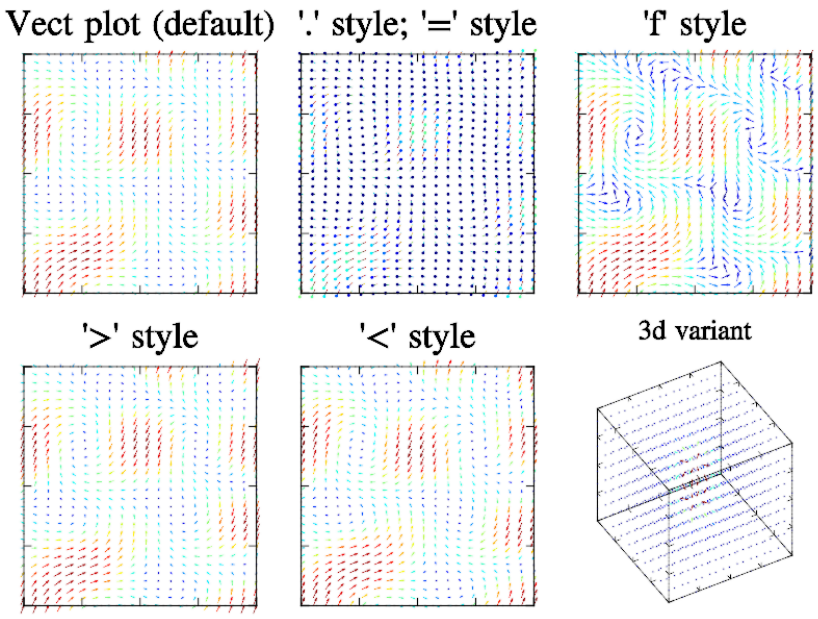
  gr->SubPlot(3,2,1,"");  gr->Title("'.' style; '=' style");
  gr->Box();  gr->Vect(a,b,"=.");

  gr->SubPlot(3,2,2,"");  gr->Title("'f' style");
  gr->Box();  gr->Vect(a,b,"f");

  gr->SubPlot(3,2,3,"");  gr->Title("'>' style");
  gr->Box();  gr->Vect(a,b,">");

  gr->SubPlot(3,2,4,"");  gr->Title("'<' style");
  gr->Box();  gr->Vect(a,b,"<");

  mglData ex,ey,ez; mgls_prepare3v(&ex,&ey,&ez);
  gr->SubPlot(3,2,5); gr->Title("3d variant");  gr->Rotate(50,60);
  gr->Box();  gr->Vect(ex,ey,ez);
  return 0;
}
```

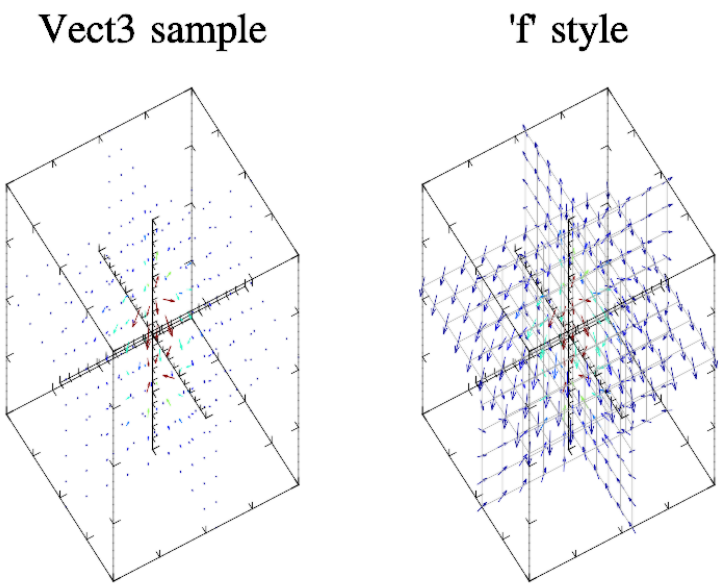


2.8.2 Vect3 sample

Function [vect3], page 223 draw just usual vector field plot but at slices of 3D data. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData ex,ey,ez; mgls_prepare3v(&ex,&ey,&ez);
  gr->SubPlot(2,1,0); gr->Title("Vect3 sample");    gr->SetOrigin(0,0,0);
  gr->Rotate(50,60);    gr->Axis("_xyz");   gr->Box();
  gr->Vect3(ex,ey,ez,"x");  gr->Vect3(ex,ey,ez);    gr->Vect3(ex,ey,ez,"z");

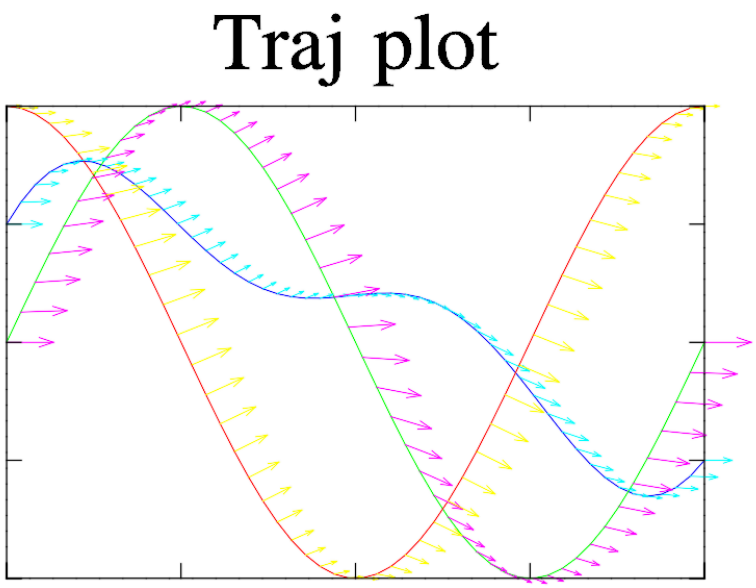
  gr->SubPlot(2,1,1);   gr->Title("'f' style");
  gr->Rotate(50,60);    gr->Axis("_xyz");   gr->Box();
  gr->Vect3(ex,ey,ez,"fx"); gr->Vect3(ex,ey,ez,"f");gr->Vect3(ex,ey,ez,"fz");
  gr->Grid3(ex,"Wx");   gr->Grid3(ex,"W");  gr->Grid3(ex,"Wz");
  return 0;
}
```



2.8.3 Traj sample

Function [traj], page 222 is 1D analogue of `Vect`. It draw vectors from specified points. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData x,y,y1,y2;  mgls_prepare1d(&y,&y1,&y2,&x);
  gr->SubPlot(1,1,0,""); gr->Title("Traj plot");
  gr->Box();  gr->Plot(x,y);  gr->Traj(x,y,y1,y2);
  return 0;
}
```



2.8.4 Flow sample

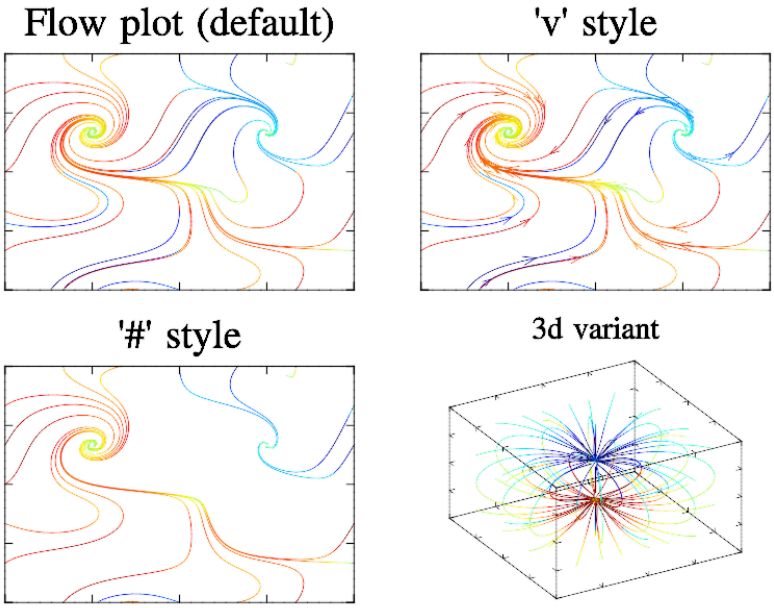
Function [flow], page 224 is another standard way to visualize vector fields – it draw lines (threads) which is tangent to local vector field direction. MathGL draw threads from edges of bounding box and from central slices. Sometimes it is not most appropriate variant – you may want to use `FlowP` to specify manual position of threads. `Flow` use color scheme for coloring (see Section 3.4 [Color scheme], page 150). At this warm color corresponds to normal flow (like attractor), cold one corresponds to inverse flow (like source). The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a,b;  mgls_prepare2v(&a,&b);
  gr->SubPlot(2,2,0,""); gr->Title("Flow plot (default)");
  gr->Box();  gr->Flow(a,b);

  gr->SubPlot(2,2,1,"");  gr->Title("'v' style");
  gr->Box();  gr->Flow(a,b,"v");

  gr->SubPlot(2,2,2,"");  gr->Title("'\\#' style");
  gr->Box();  gr->Flow(a,b,"#");

  mglData ex,ey,ez; mgls_prepare3v(&ex,&ey,&ez);
  gr->SubPlot(2,2,3); gr->Title("3d variant");  gr->Rotate(50,60);
  gr->Box();  gr->Flow(ex,ey,ez);
  return 0;
}
```



2.8.5 Pipe sample

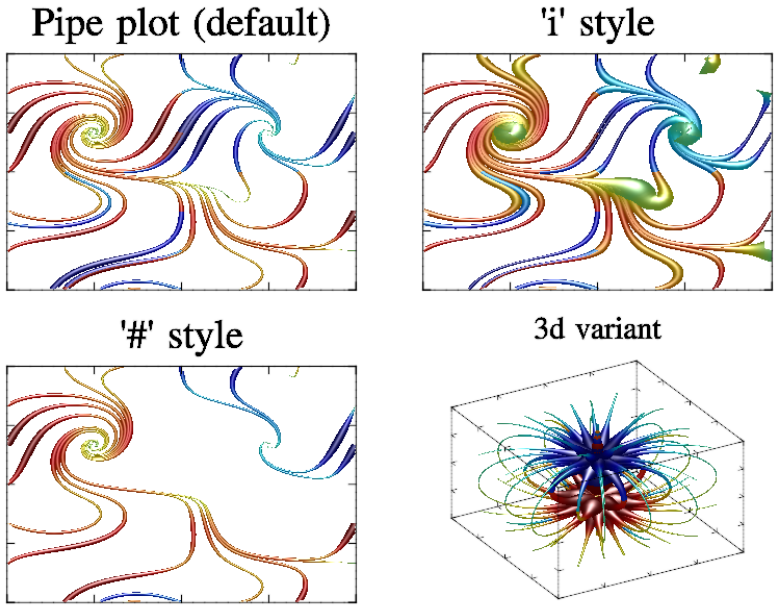
Function [pipe], page 226 is similar to [flow], page 224 but draw pipes (tubes) which radius is proportional to the amplitude of vector field. `Pipe` use color scheme for coloring (see Section 3.4 [Color scheme], page 150). At this warm color corresponds to normal flow (like attractor), cold one corresponds to inverse flow (like source). The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a,b;  mgls_prepare2v(&a,&b);
  gr->SubPlot(2,2,0,""); gr->Title("Pipe plot (default)");
  gr->Light(true);  gr->Box();  gr->Pipe(a,b);

  gr->SubPlot(2,2,1,"");  gr->Title("'i' style");
  gr->Box();  gr->Pipe(a,b,"i");

  gr->SubPlot(2,2,2,"");  gr->Title("'\\#' style");
  gr->Box();  gr->Pipe(a,b,"#");

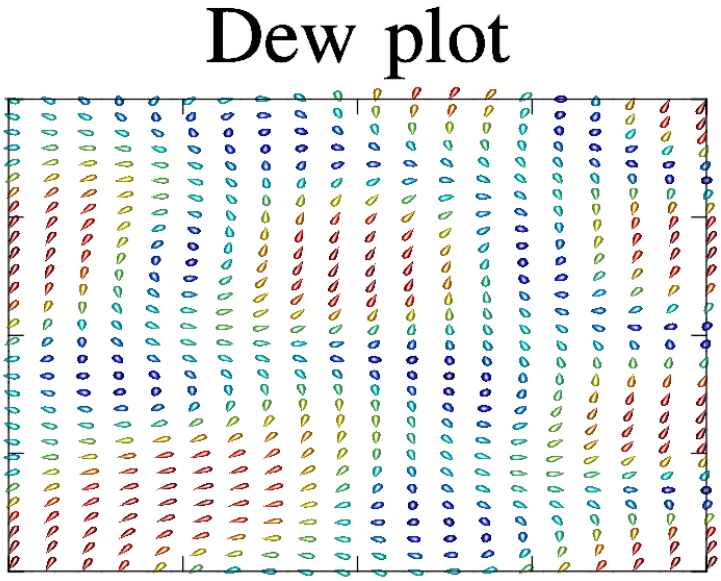
  mglData ex,ey,ez; mgls_prepare3v(&ex,&ey,&ez);
  gr->SubPlot(2,2,3); gr->Title("3d variant");  gr->Rotate(50,60);
  gr->Box();  gr->Pipe(ex,ey,ez,"",0.1);
  return 0;
}
```



2.8.6 Dew sample

Function [dew], page 224 is similar to `Vect` but use drops instead of arrows. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a,b;  mgls_prepare2v(&a,&b);
  gr->SubPlot(1,1,0,""); gr->Title("Dew plot");
  gr->Box();  gr->Light(true);  gr->Dew(a,b);
  return 0;
}
```



2.9 Hints

In this section I've included some small hints and advices for the improving of the quality of plots and for the demonstration of some non-trivial features of MathGL library. In contrast to previous examples I showed mostly the idea but not the whole drawing function.

2.9.1 "Compound" graphics

As I noted above, MathGL functions (except the special one, like Clf()) do not erase the previous plotting but just add the new one. It allows one to draw "compound" plots easily. For example, popular Matlab command `surfc` can be emulated in MathGL by 2 calls:

```
Surf(a);
Cont(a, "_");     // draw contours at bottom
```

Here *a* is 2-dimensional data for the plotting, `-1` is the value of z-coordinate at which the contour should be plotted (at the bottom in this example). Analogously, one can draw density plot instead of contour lines and so on.

Another nice plot is contour lines plotted directly on the surface:

```
Light(true);       // switch on light for the surface
Surf(a, "BbcyrR"); // select 'jet' colormap for the surface
Cont(a, "y");      // and yellow color for contours
```

The possible difficulties arise in black&white case, when the color of the surface can be close to the color of a contour line. In that case I may suggest the following code:

```
Light(true);   // switch on light for the surface
Surf(a, "kw"); // select 'gray' colormap for the surface
CAxis(-1,0);   // first draw for darker surface colors
Cont(a, "w");  // white contours
CAxis(0,1);    // now draw for brighter surface colors
Cont(a, "k");  // black contours
CAxis(-1,1);   // return color range to original state
```

The idea is to divide the color range on 2 parts (dark and bright) and to select the contrasting color for contour lines for each of part.

Similarly, one can plot flow thread over density plot of vector field amplitude (this is another amusing plot from Matlab) and so on. The list of compound graphics can be prolonged but I hope that the general idea is clear.

Just for illustration I put here following sample code:

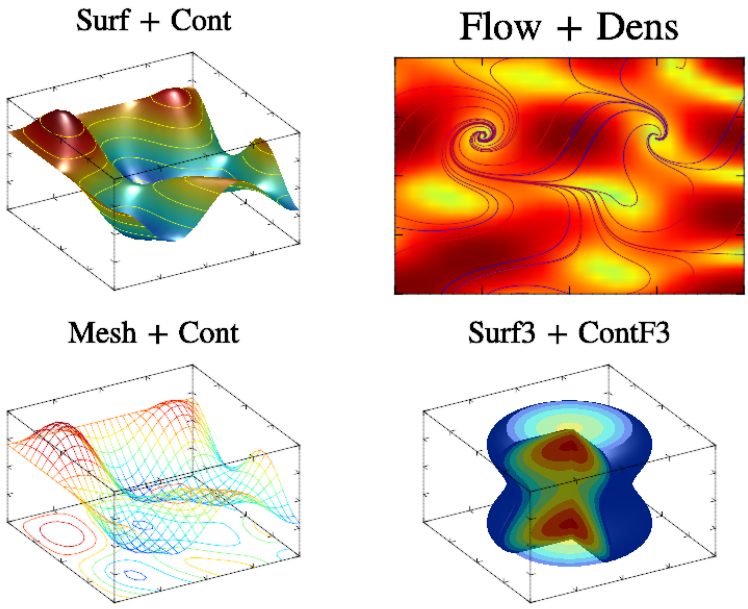
```
int sample(mglGraph *gr)
{
  mglData a,b,d;  mgls_prepare2v(&a,&b);  d = a;
  for(int i=0;i<a.nx*a.ny;i++)  d.a[i] = hypot(a.a[i],b.a[i]);
  mglData c;  mgls_prepare3d(&c);
  mglData v(10);  v.Fill(-0.5,1);

  gr->SubPlot(2,2,1,"");  gr->Title("Flow + Dens");
  gr->Flow(a,b,"br"); gr->Dens(d,"BbcyrR"); gr->Box();

  gr->SubPlot(2,2,0); gr->Title("Surf + Cont"); gr->Rotate(50,60);
  gr->Light(true);  gr->Surf(a);  gr->Cont(a,"y");  gr->Box();

  gr->SubPlot(2,2,2); gr->Title("Mesh + Cont"); gr->Rotate(50,60);
  gr->Box();  gr->Mesh(a);  gr->Cont(a,"_");

  gr->SubPlot(2,2,3); gr->Title("Surf3 + ContF3");gr->Rotate(50,60);
  gr->Box();  gr->ContF3(v,c,"z",0);  gr->ContF3(v,c,"x");  gr->ContF3(v,c);
  gr->SetCutBox(mglPoint(0,-1,-1), mglPoint(1,0,1.1));
  gr->ContF3(v,c,"z",c.nz-1); gr->Surf3(-0.5,c);
  return 0;
}
```



2.9.2 Transparency and lighting

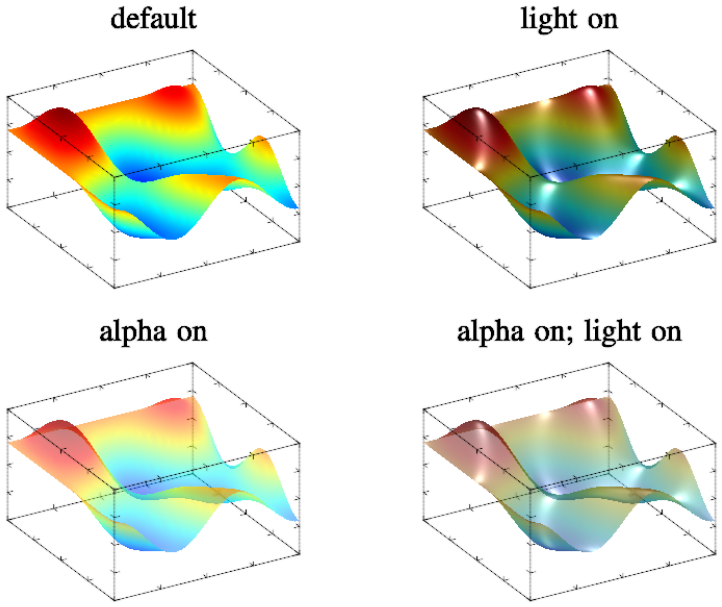
Here I want to show how transparency and lighting both and separately change the look of a surface. So, there is code and picture for that:

```
int sample(mglGraph *gr)
{
  mglData a;  mgls_prepare2d(&a);
  gr->SubPlot(2,2,0); gr->Title("default"); gr->Rotate(50,60);
  gr->Box();  gr->Surf(a);

  gr->SubPlot(2,2,1); gr->Title("light on");  gr->Rotate(50,60);
  gr->Box();  gr->Light(true);  gr->Surf(a);

  gr->SubPlot(2,2,3); gr->Title("alpha on; light on");  gr->Rotate(50,60);
  gr->Box();  gr->Alpha(true);  gr->Surf(a);

  gr->SubPlot(2,2,2); gr->Title("alpha on");  gr->Rotate(50,60);
  gr->Box();  gr->Light(false); gr->Surf(a);
  return 0;
}
```



2.9.3 Types of transparency

MathGL library has advanced features for setting and handling the surface transparency. The simplest way to add transparency is the using of function [alpha], page 159. As a result, all further surfaces (and isosurfaces, density plots and so on) become transparent. However, their look can be additionally improved.

The value of transparency can be different from surface to surface. To do it just use `SetAlphaDef` before the drawing of the surface, or use option `alpha` (see Section 3.7 [Command options], page 154). If its value is close to 0 then the surface becomes more and more transparent. Contrary, if its value is close to 1 then the surface becomes practically non-transparent.

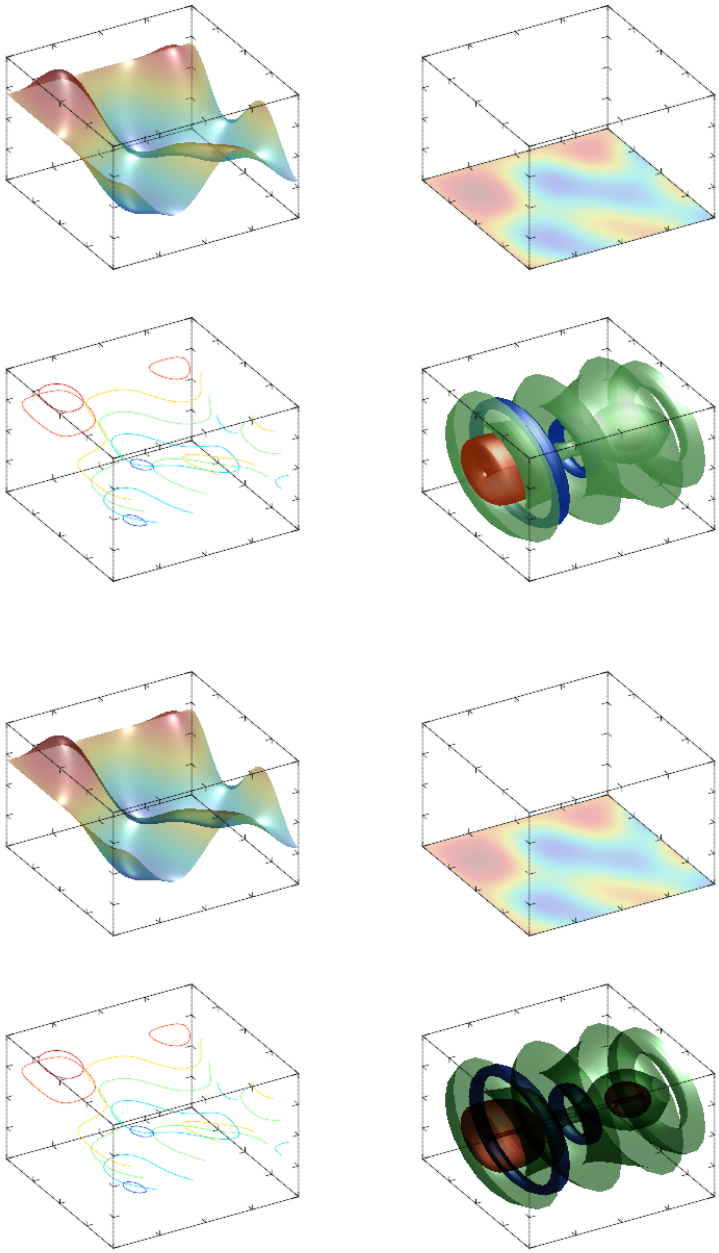
Also you can change the way how the light goes through overlapped surfaces. The function `SetTranspType` defines it. By default the usual transparency is used ('`0`') – surfaces below is less visible than the upper ones. A "glass-like" transparency ('`1`') has a different look – each surface just decreases the background light (the surfaces are commutable in this case).

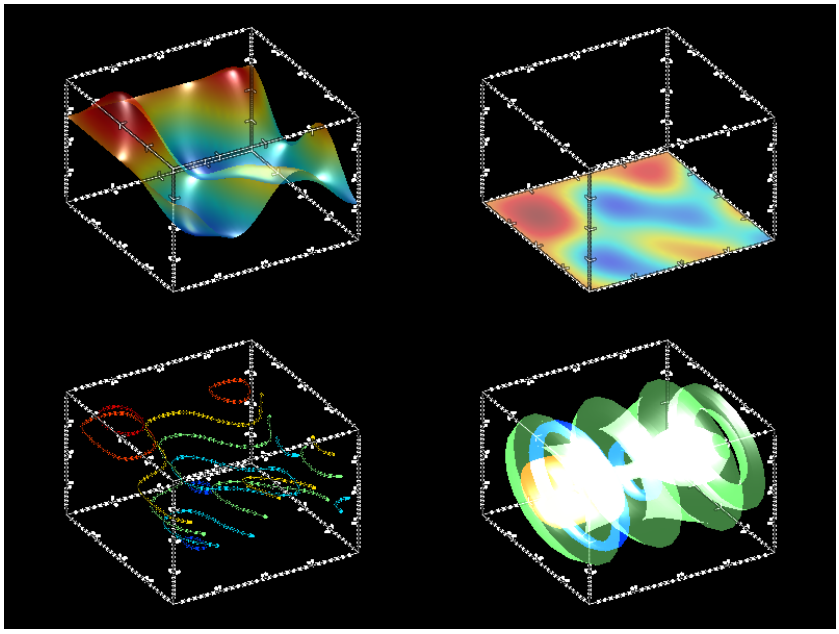
A "neon-like" transparency ('`2`') has more interesting look. In this case a surface is the light source (like a lamp on the dark background) and just adds some intensity to the color. At this, the library sets automatically the black color for the background and changes the default line color to white.

As example I shall show several plots for different types of transparency. The code is the same except the values of `SetTranspType` function:

```
int sample(mglGraph *gr)
{
  gr->Alpha(true);  gr->Light(true);
  mglData a;  mgls_prepare2d(&a);
  gr->SetTranspType(0); gr->Clf();
  gr->SubPlot(2,2,0); gr->Rotate(50,60);  gr->Surf(a);  gr->Box();
```

```
  gr->SubPlot(2,2,1); gr->Rotate(50,60);  gr->Dens(a);  gr->Box();
  gr->SubPlot(2,2,2); gr->Rotate(50,60);  gr->Cont(a);  gr->Box();
  gr->SubPlot(2,2,3); gr->Rotate(50,60);  gr->Axial(a); gr->Box();
  return 0;
}
```



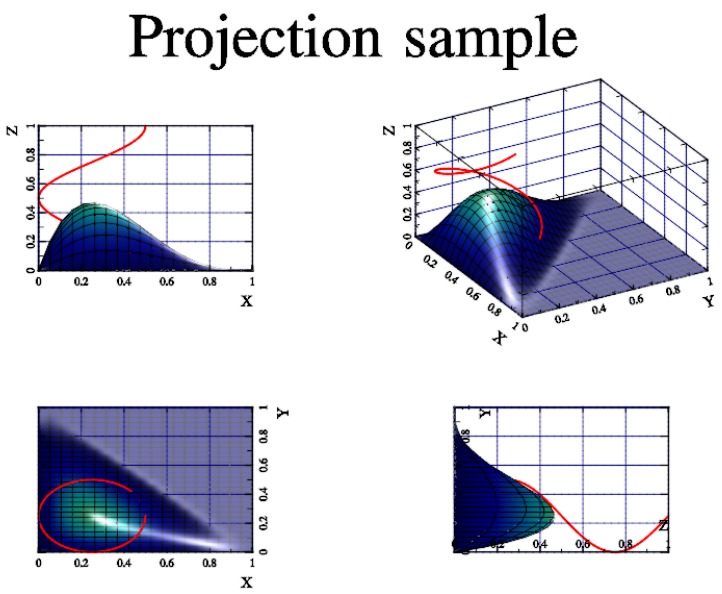


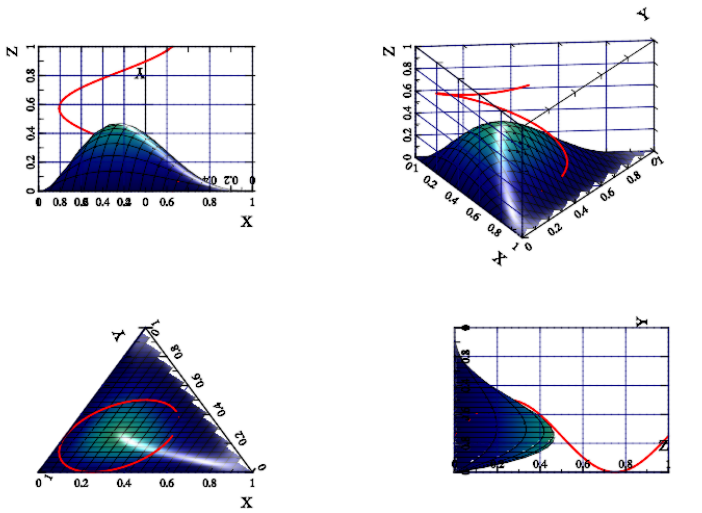
2.9.4 Axis projection

You can easily make 3D plot and draw its x-,y-,z-projections (like in CAD) by using [ternary], page 169 function with arguments: 4 for Cartesian, 5 for Ternary and 6 for Quaternary coordinates. The sample code is:

```
int sample(mglGraph *gr)
{
  gr->SetRanges(0,1,0,1,0,1);
  mglData x(50),y(50),z(50),rx(10),ry(10), a(20,30);
  a.Modify("30*x*y*(1-x-y)^2*(x+y<1)");
  x.Modify("0.25*(1+cos(2*pi*x))");
  y.Modify("0.25*(1+sin(2*pi*x))");
  rx.Modify("rnd"); ry.Modify("(1-v)*rnd",rx);
  z.Modify("x");

  gr->Title("Projection sample");
  gr->Ternary(4);
  gr->Rotate(50,60);      gr->Light(true);
  gr->Plot(x,y,z,"r2");   gr->Surf(a,"#");
  gr->Axis(); gr->Grid(); gr->Box();
  gr->Label('x',"X",1);   gr->Label('y',"Y",1);   gr->Label('z',"Z",1);
}
```



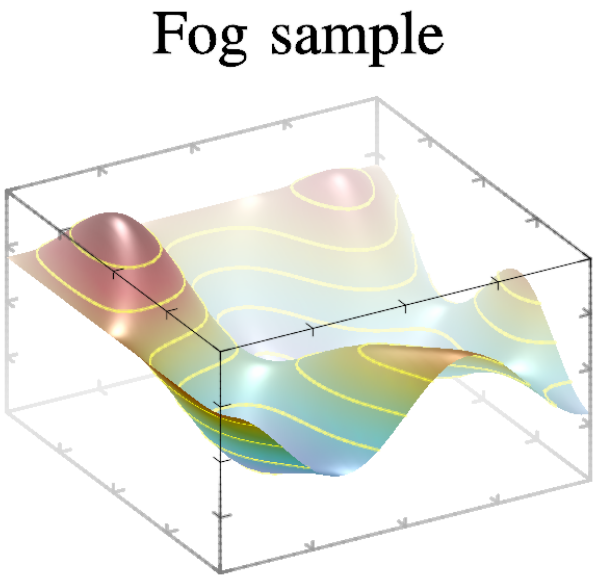


2.9.5 Adding fog

MathGL can add a fog to the image. Its switching on is rather simple – just use [fog], page 160 function. There is the only feature – fog is applied for whole image. Not to particular subplot. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a;  mgls_prepare2d(&a);
  gr->Title("Fog sample");
  gr->Light(true);  gr->Rotate(50,60);  gr->Fog(1); gr->Box();
```

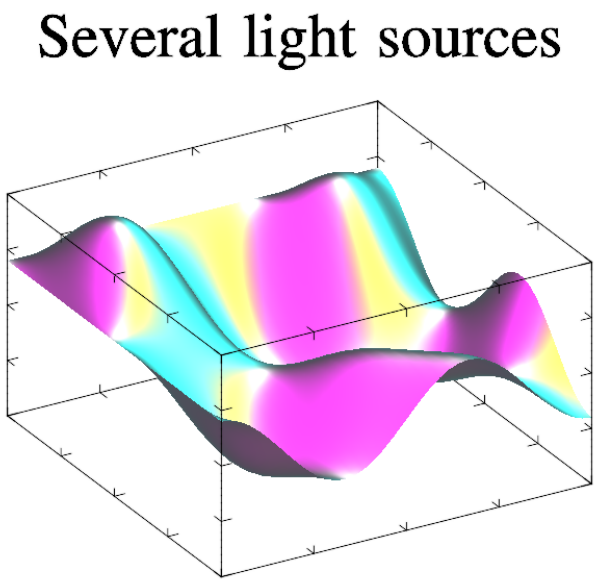
```
  gr->Surf(a);  gr->Cont(a,"y");
  return 0;
}
```



2.9.6 Lighting sample

In contrast to the most of other programs, MathGL supports several (up to 10) light sources. Moreover, the color each of them can be different: white (this is usual), yellow, red, cyan, green and so on. The use of several light sources may be interesting for the highlighting of some peculiarities of the plot or just to make an amusing picture. Note, each light source can be switched on/off individually. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a;  mgls_prepare2d(&a);
  gr->Title("Several light sources");
  gr->Rotate(50,60);  gr->Light(true);
  gr->AddLight(1,mglPoint(0,1,0),'c');
  gr->AddLight(2,mglPoint(1,0,0),'y');
  gr->AddLight(3,mglPoint(0,-1,0),'m');
  gr->Box();  gr->Surf(a,"h");
  return 0;
}
```



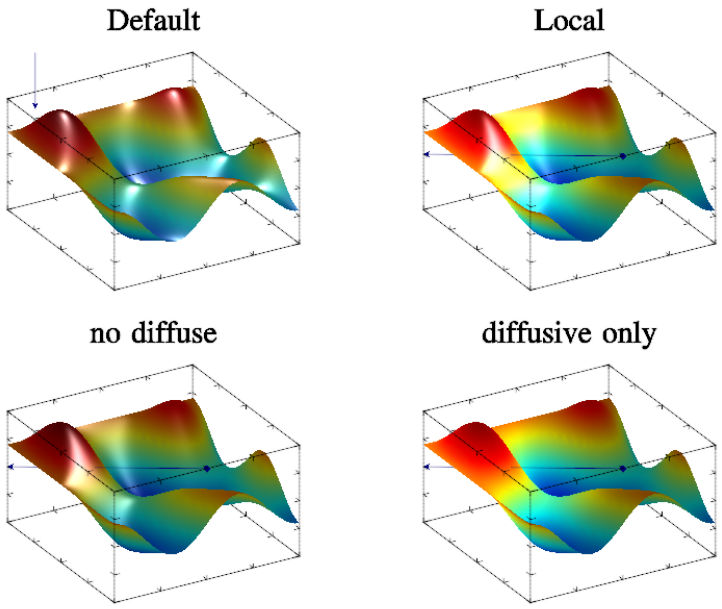
Additionally, you can use local light sources and set to use [diffuse], page 160 reflection instead of specular one (by default) or both kinds. Note, I use [attachlight], page 160 command to keep light settings relative to subplot.

```
int sample(mglGraph *gr)
{
  gr->Light(true);  gr->AttachLight(true);
  gr->SubPlot(2,2,0); gr->Title("Default"); gr->Rotate(50,60);
  gr->Line(mglPoint(-1,-0.7,1.7),mglPoint(-1,-0.7,0.7),"BA"); gr->Box();  gr->Surf(a);

  gr->SubPlot(2,2,1); gr->Title("Local");   gr->Rotate(50,60);
  gr->AddLight(0,mglPoint(1,0,1),mglPoint(-2,-1,-1));
  gr->Line(mglPoint(1,0,1),mglPoint(-1,-1,0),"BAO");  gr->Box();  gr->Surf(a);

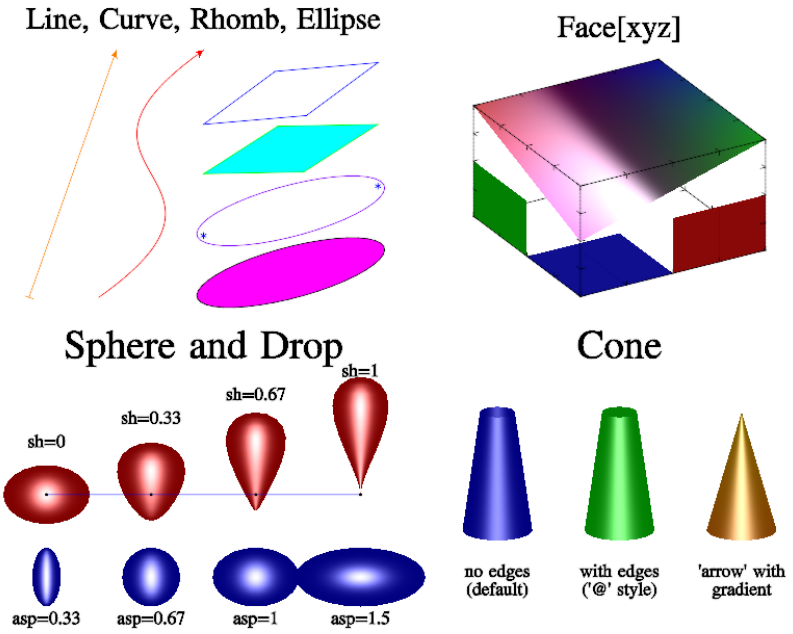
  gr->SubPlot(2,2,2); gr->Title("no diffuse"); gr->Rotate(50,60);
  gr->SetDiffuse(0);
  gr->Line(mglPoint(1,0,1),mglPoint(-1,-1,0),"BAO");  gr->Box();  gr->Surf(a);

  gr->SubPlot(2,2,3); gr->Title("diffusive only");  gr->Rotate(50,60);
  gr->SetDiffuse(0.5);
  gr->AddLight(0,mglPoint(1,0,1),mglPoint(-2,-1,-1),'w',0);
  gr->Line(mglPoint(1,0,1),mglPoint(-1,-1,0),"BAO");  gr->Box();  gr->Surf(a);
}
```



2.9.7 Using primitives

MathGL provide a set of functions for drawing primitives (see Section 4.7 [Primitives], page 185). Primitives are low level object, which used by most of plotting functions. Picture below demonstrate some of commonly used primitives.



Generally, you can create arbitrary new kind of plot using primitives. For example, MathGL don't provide any special functions for drawing molecules. However, you can do it using only one type of primitives [drop], page 187. The sample code is:

```
int sample(mglGraph *gr)
{
```

```
gr->Alpha(true);  gr->Light(true);

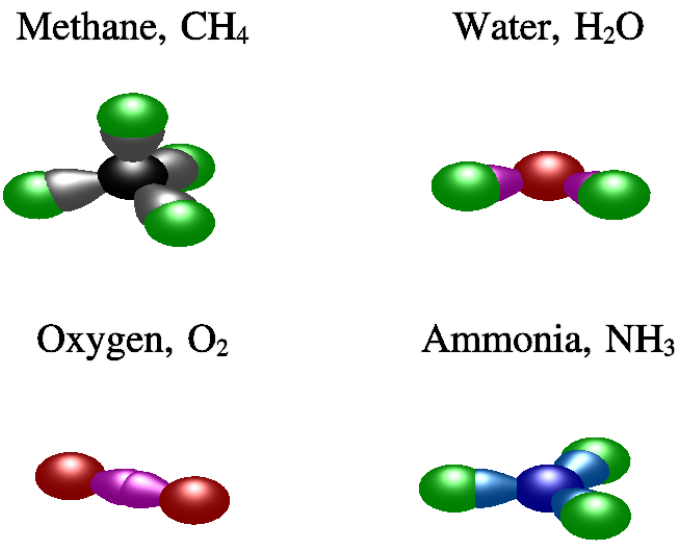
gr->SubPlot(2,2,0,"");  gr->Title("Methane, CH_4");
gr->StartGroup("Methane");
gr->Rotate(60,120);
gr->Sphere(mglPoint(0,0,0),0.25,"k");
gr->Drop(mglPoint(0,0,0),mglPoint(0,0,1),0.35,"h",1,2);
gr->Sphere(mglPoint(0,0,0.7),0.25,"g");
gr->Drop(mglPoint(0,0,0),mglPoint(-0.94,0,-0.33),0.35,"h",1,2);
gr->Sphere(mglPoint(-0.66,0,-0.23),0.25,"g");
gr->Drop(mglPoint(0,0,0),mglPoint(0.47,0.82,-0.33),0.35,"h",1,2);
gr->Sphere(mglPoint(0.33,0.57,-0.23),0.25,"g");
gr->Drop(mglPoint(0,0,0),mglPoint(0.47,-0.82,-0.33),0.35,"h",1,2);
gr->Sphere(mglPoint(0.33,-0.57,-0.23),0.25,"g");
gr->EndGroup();

gr->SubPlot(2,2,1,"");  gr->Title("Water, H_{2}O");
gr->StartGroup("Water");
gr->Rotate(60,100);
gr->StartGroup("Water_O");
gr->Sphere(mglPoint(0,0,0),0.25,"r");
gr->EndGroup();
gr->StartGroup("Water_Bond_1");
gr->Drop(mglPoint(0,0,0),mglPoint(0.3,0.5,0),0.3,"m",1,2);
gr->EndGroup();
gr->StartGroup("Water_H_1");
gr->Sphere(mglPoint(0.3,0.5,0),0.25,"g");
gr->EndGroup();
gr->StartGroup("Water_Bond_2");
gr->Drop(mglPoint(0,0,0),mglPoint(0.3,-0.5,0),0.3,"m",1,2);
gr->EndGroup();
gr->StartGroup("Water_H_2");
gr->Sphere(mglPoint(0.3,-0.5,0),0.25,"g");
gr->EndGroup();
gr->EndGroup();

gr->SubPlot(2,2,2,"");  gr->Title("Oxygen, O_2");
gr->StartGroup("Oxygen");
gr->Rotate(60,120);
gr->Drop(mglPoint(0,0.5,0),mglPoint(0,-0.3,0),0.3,"m",1,2);
gr->Sphere(mglPoint(0,0.5,0),0.25,"r");
gr->Drop(mglPoint(0,-0.5,0),mglPoint(0,0.3,0),0.3,"m",1,2);
gr->Sphere(mglPoint(0,-0.5,0),0.25,"r");
gr->EndGroup();

gr->SubPlot(2,2,3,"");  gr->Title("Ammonia, NH_3");
gr->StartGroup("Ammonia");
```

```
  gr->Rotate(60,120);
  gr->Sphere(mglPoint(0,0,0),0.25,"b");
  gr->Drop(mglPoint(0,0,0),mglPoint(0.33,0.57,0),0.32,"n",1,2);
  gr->Sphere(mglPoint(0.33,0.57,0),0.25,"g");
  gr->Drop(mglPoint(0,0,0),mglPoint(0.33,-0.57,0),0.32,"n",1,2);
  gr->Sphere(mglPoint(0.33,-0.57,0),0.25,"g");
  gr->Drop(mglPoint(0,0,0),mglPoint(-0.65,0,0),0.32,"n",1,2);
  gr->Sphere(mglPoint(-0.65,0,0),0.25,"g");
  gr->EndGroup();
  return 0;
}
```



Moreover, some of special plots can be more easily produced by primitives rather than by specialized function. For example, Venn diagram can be produced by `Error` plot:

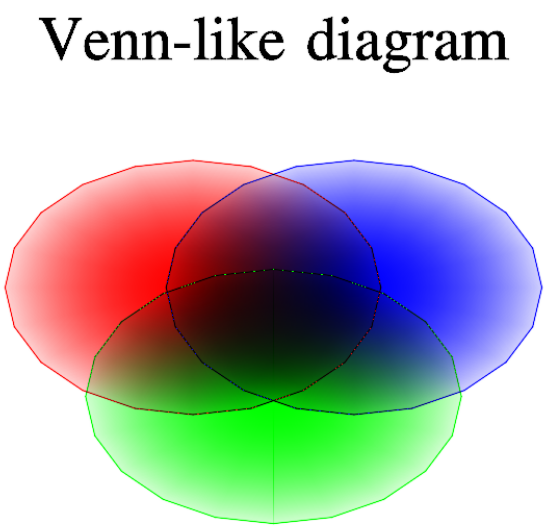
```
int sample(mglGraph *gr)
{
  double xx[3]={-0.3,0,0.3}, yy[3]={0.3,-0.3,0.3}, ee[3]={0.7,0.7,0.7};
  mglData x(3,xx), y(3,yy), e(3,ee);
  gr->Title("Venn-like diagram"); gr->Alpha(true);
  gr->Error(x,y,e,e,"!rgb@#o");
  return 0;
}
```

You see that you have to specify and fill 3 data arrays. The same picture can be produced by just 3 calls of [circle], page 187 function:

```
int sample(mglGraph *gr)
{
  gr->Title("Venn-like diagram"); gr->Alpha(true);
  gr->Circle(mglPoint(-0.3,0.3),0.7,"rr@");
```

```
  gr->Circle(mglPoint(0,-0.3),0.7,"gg@");
  gr->Circle(mglPoint( 0.3,0.3),0.7,"bb@");
  return 0;
}
```

Of course, the first variant is more suitable if you need to plot a lot of circles. But for few ones the usage of primitives looks easy.



2.9.8 STFA sample

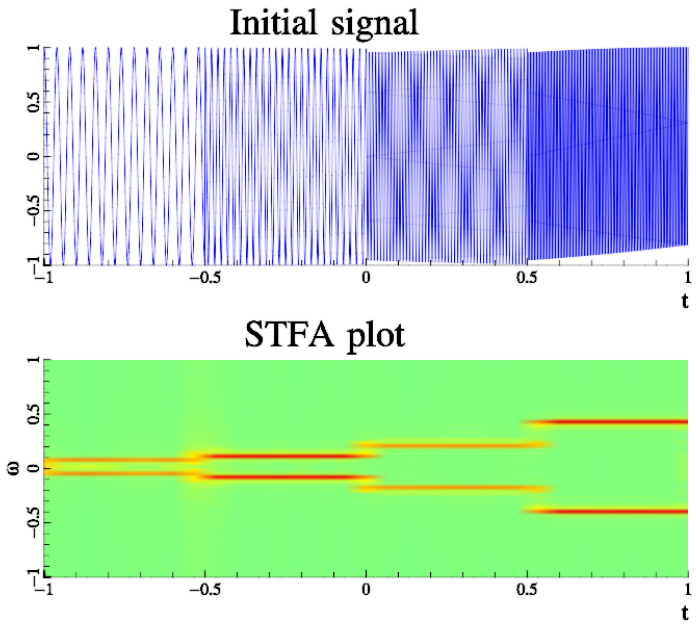
Short-time Fourier Analysis ([stfa], page 221) is one of informative method for analyzing long rapidly oscillating 1D data arrays. It is used to determine the sinusoidal frequency and phase content of local sections of a signal as it changes over time.

MathGL can find and draw STFA result. Just to show this feature I give following sample. Initial data arrays is 1D arrays with step-like frequency. Exactly this you can see at bottom on the STFA plot. The sample code is:

```
int sample(mglGraph *gr)
{
  mglData a(2000), b(2000);
  gr->Fill(a,"cos(50*pi*x)*(x<-.5)+cos(100*pi*x)*(x<0)*(x>-.5)+\
  cos(200*pi*x)*(x<.5)*(x>0)+cos(400*pi*x)*(x>.5)");
  gr->SubPlot(1, 2, 0,"<_");  gr->Title("Initial signal");
  gr->Plot(a);
  gr->Axis();
  gr->Label('x', "\\i t");

  gr->SubPlot(1, 2, 1,"<_");  gr->Title("STFA plot");
  gr->STFA(a, b, 64);
  gr->Axis();
```

```
  gr->Label('x', "\\i t");
  gr->Label('y', "\\omega", 0);
  return 0;
}
```



2.9.9 Mapping visualization

Sometime ago I worked with mapping and have a question about its visualization. Let me remember you that mapping is some transformation rule for one set of number to another one. The 1d mapping is just an ordinary function – it takes a number and transforms it to another one. The 2d mapping (which I used) is a pair of functions which take 2 numbers and transform them to another 2 ones. Except general plots (like [surfc], page 217, [surfa], page 218) there is a special plot – Arnold diagram. It shows the area which is the result of mapping of some initial area (usually square).

I tried to make such plot in [map], page 221. It shows the set of points or set of faces, which final position is the result of mapping. At this, the color gives information about their initial position and the height describes Jacobian value of the transformation. Unfortunately, it looks good only for the simplest mapping but for the real multivalent quasi-chaotic mapping it produces a confusion. So, use it if you like :).

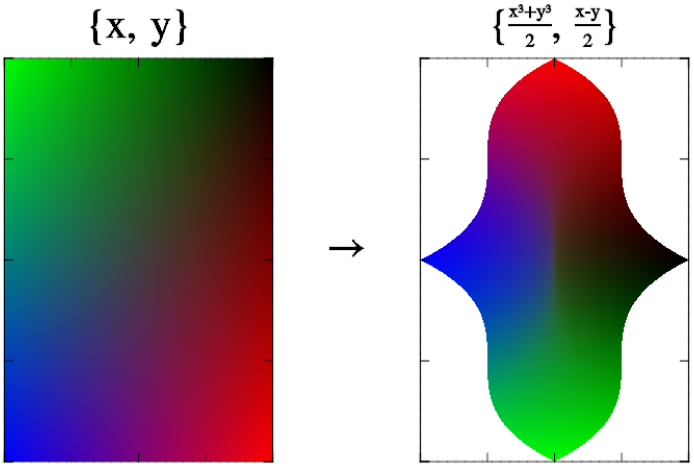
The sample code for mapping visualization is:

```
int sample(mglGraph *gr)
{
  mglData a(50, 40), b(50, 40);
  gr->Puts(mglPoint(0, 0), "\\to", ":C", -1.4);
  gr->SetRanges(-1,1,-1,1,-2,2);

  gr->SubPlot(2, 1, 0);
  gr->Fill(a,"x");  gr->Fill(b,"y");
```

```
  gr->Puts(mglPoint(0, 1.1), "\\{x, y\\}", ":C", -2);   gr->Box();
  gr->Map(a, b, "brgk");

  gr->SubPlot(2, 1, 1);
  gr->Fill(a,"(x^3+y^3)/2");  gr->Fill(b,"(x-y)/2");
  gr->Puts(mglPoint(0, 1.1), "\\{\\frac{x^3+y^3}{2}, \\frac{x-y}{2}\\}", ":C", -2);
  gr->Box();
  gr->Map(a, b, "brgk");
  return 0;
}
```



2.9.10 Data interpolation

There are many functions to get interpolated values of a data array. Basically all of them can be divided by 3 categories:

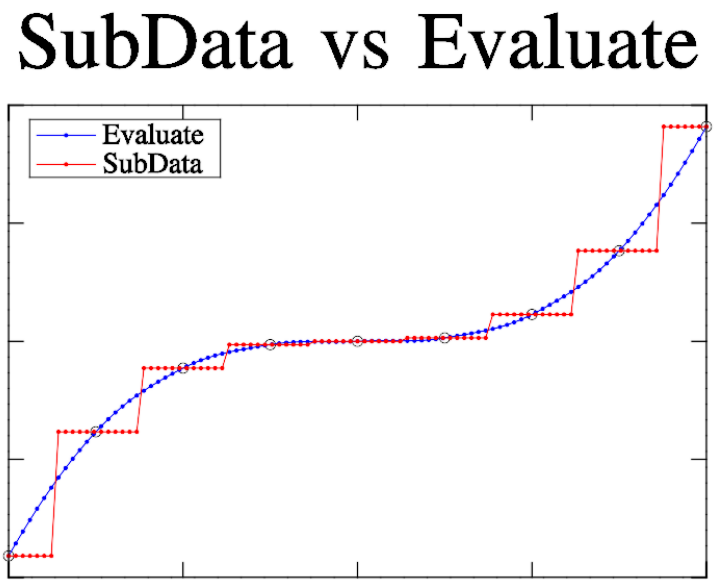
1. functions which return single value at given point (see Section 6.8 [Interpolation], page 272 and `mglGSpline()` in Section 6.11 [Global functions], page 277);
2. functions [subdata], page 264 and [evaluate], page 266 for indirect access to data elements;
3. functions [refill], page 261, [gspline], page 261 and [datagrid], page 260 which fill regular (rectangular) data array by interpolated values.

The usage of first category is rather straightforward and don't need any special comments.

There is difference in indirect access functions. Function [subdata], page 264 use use step-like interpolation to handle correctly single `nan` values in the data array. Contrary, function [evaluate], page 266 use local spline interpolation, which give smoother output but spread `nan` values. So, [subdata], page 264 should be used for specific data elements (for

example, for given column), and [evaluate], page 266 should be used for distributed elements (i.e. consider data array as some field). Following sample illustrates this difference:

```
int sample(mglGraph *gr)
{
  gr->SubPlot(1,1,0,"");  gr->Title("SubData vs Evaluate");
  mglData in(9), arg(99), e, s;
  gr->Fill(in,"x^3/1.1"); gr->Fill(arg,"4*x+4");
  gr->Plot(in,"ko ");     gr->Box();
  e = in.Evaluate(arg);   gr->Plot(e,"b.","legend 'Evaluate'");
  s = in.SubData(arg);    gr->Plot(s,"r.","legend 'SubData'");
  gr->Legend(2);
}
```



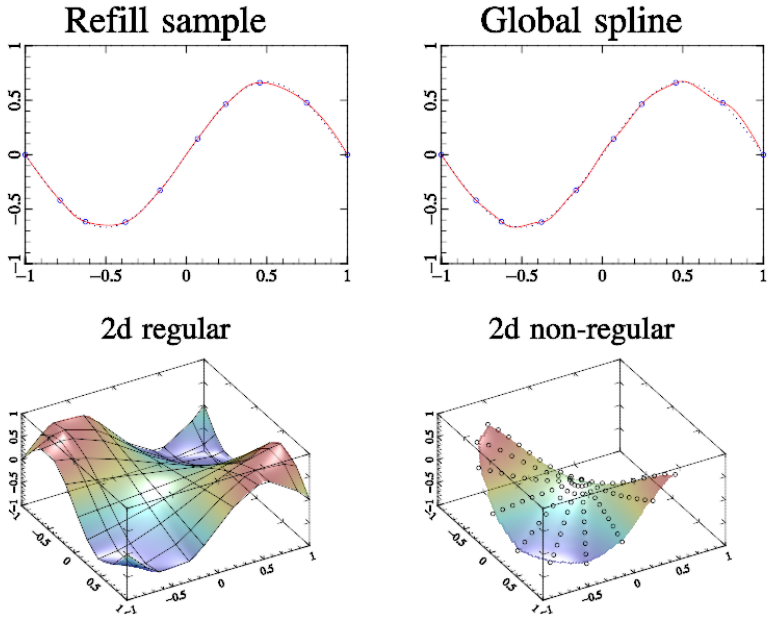
Example of [datagrid], page 260 usage is done in Section 2.9.11 [Making regular data], page 128. Here I want to show the peculiarities of [refill], page 261 and [gspline], page 261 functions. Both functions require argument(s) which provide coordinates of the data values, and return rectangular data array which equidistantly distributed in axis range. So, in opposite to [evaluate], page 266 function, [refill], page 261 and [gspline], page 261 can interpolate non-equidistantly distributed data. At this both functions [refill], page 261 and [gspline], page 261 provide continuity of 2nd derivatives along coordinate(s). However, [refill], page 261 is slower but give better (from human point of view) result than global spline [gspline], page 261 due to more advanced algorithm. Following sample illustrates this difference:

```
int sample(mglGraph *gr)
{
  mglData x(10), y(10), r(100);
  x.Modify("0.5+rnd");  x.CumSum("x");  x.Norm(-1,1);
  y.Modify("sin(pi*v)/1.5",x);
```

```
  gr->SubPlot(2,2,0,"<_");  gr->Title("Refill sample");
  gr->Axis();  gr->Box(); gr->Plot(x,y,"o ");
  gr->Refill(r,x,y);  // or you can use r.Refill(x,y,-1,1);
  gr->Plot(r,"r");  gr->FPlot("sin(pi*x)/1.5","B:");
  gr->SubPlot(2,2,1,"<_");gr->Title("Global spline");
  gr->Axis();  gr->Box(); gr->Plot(x,y,"o ");
  r.RefillGS(x,y,-1,1);   gr->Plot(r,"r");
  gr->FPlot("sin(pi*x)/1.5","B:");

  gr->Alpha(true);  gr->Light(true);
  mglData z(10,10), xx(10,10), yy(10,10), rr(100,100);
  y.Modify("0.5+rnd");  y.CumSum("x");  y.Norm(-1,1);
  for(int i=0;i<10;i++) for(int j=0;j<10;j++)
    z.a[i+10*j] = sin(M_PI*x.a[i]*y.a[j])/1.5;
  gr->SubPlot(2,2,2); gr->Title("2d regular");  gr->Rotate(40,60);
  gr->Axis();  gr->Box(); gr->Mesh(x,y,z,"k");
  gr->Refill(rr,x,y,z); gr->Surf(rr);

  gr->Fill(xx,"(x+1)/2*cos(y*pi/2-1)");
  gr->Fill(yy,"(x+1)/2*sin(y*pi/2-1)");
  for(int i=0;i<10*10;i++)
    z.a[i] = sin(M_PI*xx.a[i]*yy.a[i])/1.5;
  gr->SubPlot(2,2,3); gr->Title("2d non-regular");  gr->Rotate(40,60);
  gr->Axis();  gr->Box();  gr->Plot(xx,yy,z,"ko ");
  gr->Refill(rr,xx,yy,z);  gr->Surf(rr);
}
```

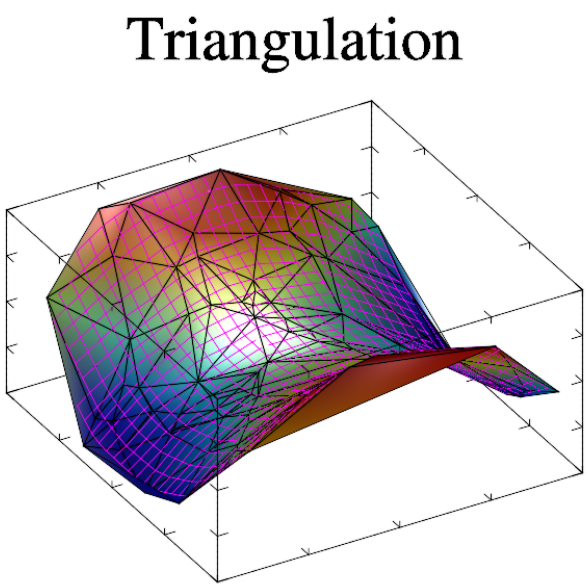


2.9.11 Making regular data

Sometimes, one have only unregular data, like as data on triangular grids, or experimental results and so on. Such kind of data cannot be used as simple as regular data (like matrices). Only few functions, like [dots], page 232, can handle unregular data as is.

However, one can use built in triangulation functions for interpolating unregular data points to a regular data grids. There are 2 ways. First way, one can use [triangulation], page 281 function to obtain list of vertexes for triangles. Later this list can be used in functions like [triplot], page 230 or [tricont], page 230. Second way consist in usage of [datagrid], page 260 function, which fill regular data grid by interpolated values, assuming that coordinates of the data grid is equidistantly distributed in axis range. Note, you can use options (see Section 3.7 [Command options], page 154) to change default axis range as well as in other plotting functions.

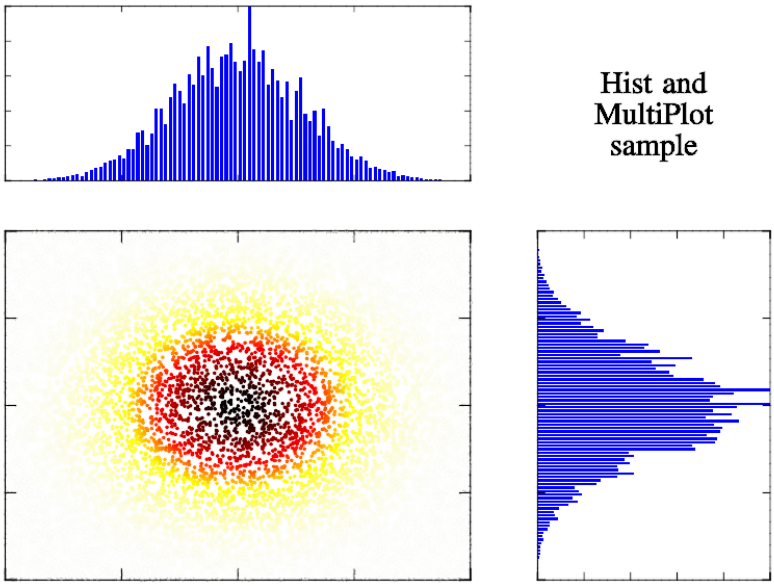
```
int sample(mglGraph *gr)
{
  mglData x(100), y(100), z(100);
  gr->Fill(x,"2*rnd-1"); gr->Fill(y,"2*rnd-1"); gr->Fill(z,"v^2-w^2",x,y);
  // first way - plot triangular surface for points
  mglData d = mglTriangulation(x,y);
  gr->Title("Triangulation");
  gr->Rotate(40,60);    gr->Box();      gr->Light(true);
  gr->TriPlot(d,x,y,z); gr->TriPlot(d,x,y,z,"#k");
  // second way - make regular data and plot it
  mglData g(30,30);
  gr->DataGrid(g,x,y,z);        gr->Mesh(g,"m");
}
```



2.9.12 Making histogram

Using the [hist], page 267 function(s) for making regular distributions is one of useful fast methods to process and plot irregular data. `Hist` can be used to find some momentum of set of points by specifying weight function. It is possible to create not only 1D distributions but also 2D and 3D ones. Below I place the simplest sample code which demonstrate [hist], page 267 usage:

```
int sample(mglGraph *gr)
{
  mglData x(10000), y(10000), z(10000);  gr->Fill(x,"2*rnd-1");
  gr->Fill(y,"2*rnd-1"); gr->Fill(z,"exp(-6*(v^2+w^2))",x,y);
  mglData xx=gr->Hist(x,z), yy=gr->Hist(y,z);   xx.Norm(0,1);
  yy.Norm(0,1);
  gr->MultiPlot(3,3,3,2,2,"");   gr->SetRanges(-1,1,-1,1,0,1);
  gr->Box();  gr->Dots(x,y,z,"wyrRk");
  gr->MultiPlot(3,3,0,2,1,"");   gr->SetRanges(-1,1,0,1);
  gr->Box();  gr->Bars(xx);
  gr->MultiPlot(3,3,5,1,2,"");   gr->SetRanges(0,1,-1,1);
  gr->Box();  gr->Barh(yy);
  gr->SubPlot(3,3,2);
  gr->Puts(mglPoint(0.5,0.5),"Hist and\nMultiPlot\nsample","a",-6);
  return 0;
}
```



2.9.13 Nonlinear fitting hints

Nonlinear fitting is rather simple. All that you need is the data to fit, the approximation formula and the list of coefficients to fit (better with its initial guess values). Let me

demonstrate it on the following simple example. First, let us use sin function with some random noise:

```
mglData dat(100), in(100); //data to be fitted and ideal data
gr->Fill(dat,"0.4*rnd+0.1+sin(2*pi*x)");
gr->Fill(in,"0.3+sin(2*pi*x)");
```

and plot it to see that data we will fit

```
gr->Title("Fitting sample");
gr->SetRange('y',-2,2); gr->Box();  gr->Plot(dat, "k. ");
gr->Axis(); gr->Plot(in, "b");
gr->Puts(mglPoint(0, 2.2), "initial: y = 0.3+sin(2\\pi x)", "b");
```

The next step is the fitting itself. For that let me specify an initial values *ini* for coefficients '`abc`' and do the fitting for approximation formula '`a+b*sin(c*x)`'

```
mreal ini[3] = {1,1,3};
mglData Ini(3,ini);
mglData res = gr->Fit(dat, "a+b*sin(c*x)", "abc", Ini);
```

Now display it

```
gr->Plot(res, "r");
gr->Puts(mglPoint(-0.9, -1.3), "fitted:", "r:L");
gr->PutsFit(mglPoint(0, -1.8), "y = ", "r");
```

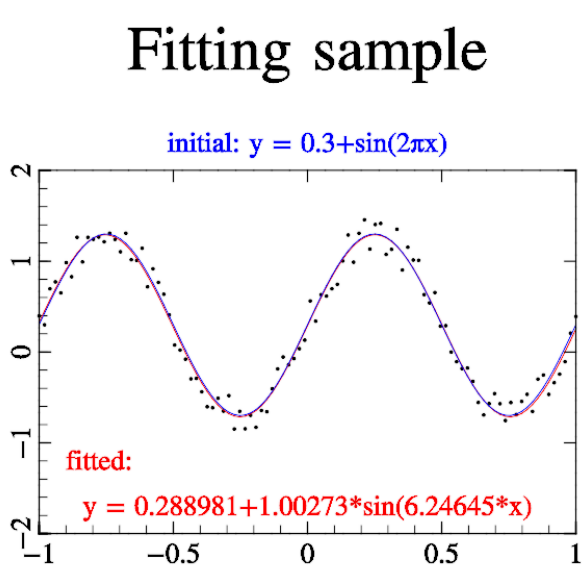
NOTE! the fitting results may have strong dependence on initial values for coefficients due to algorithm features. The problem is that in general case there are several local "optimums" for coefficients and the program returns only first found one! There are no guaranties that it will be the best. Try for example to set `ini[3] = {0, 0, 0}` in the code above.

The full sample code for nonlinear fitting is:

```
int sample(mglGraph *gr)
{
  mglData dat(100), in(100);
  gr->Fill(dat,"0.4*rnd+0.1+sin(2*pi*x)");
  gr->Fill(in,"0.3+sin(2*pi*x)");
  mreal ini[3] = {1,1,3};
  mglData Ini(3,ini);

  mglData res = gr->Fit(dat, "a+b*sin(c*x)", "abc", Ini);

  gr->Title("Fitting sample");
  gr->SetRange('y',-2,2); gr->Box();  gr->Plot(dat, "k. ");
  gr->Axis();   gr->Plot(res, "r"); gr->Plot(in, "b");
  gr->Puts(mglPoint(-0.9, -1.3), "fitted:", "r:L");
  gr->PutsFit(mglPoint(0, -1.8), "y = ", "r");
  gr->Puts(mglPoint(0, 2.2), "initial: y = 0.3+sin(2\\pi x)", "b");
  return 0;
}
```



2.9.14 PDE solving hints

Solving of Partial Differential Equations (PDE, including beam tracing) and ray tracing (or finding particle trajectory) are more or less common task. So, MathGL have several functions for that. There are [ray], page 279 for ray tracing, [pde], page 278 for PDE solving, [qo2d], page 279 for beam tracing in 2D case (see Section 6.11 [Global functions], page 277). Note, that these functions take "Hamiltonian" or equations as string values. And I don't plan now to allow one to use user-defined functions. There are 2 reasons: the complexity of corresponding interface; and the basic nature of used methods which are good for samples but may not good for serious scientific calculations.

The ray tracing can be done by [ray], page 279 function. Really ray tracing equation is Hamiltonian equation for 3D space. So, the function can be also used for finding a particle trajectory (i.e. solve Hamiltonian ODE) for 1D, 2D or 3D cases. The function have a set of arguments. First of all, it is Hamiltonian which defined the media (or the equation) you are planning to use. The Hamiltonian is defined by string which may depend on coordinates '`x`', '`y`', '`z`', time '`t`' (for particle dynamics) and momentums '`p`'=p_x, '`q`'=p_y, '`v`'=p_z. Next, you have to define the initial conditions for coordinates and momentums at '`t`'=0 and set the integrations step (default is 0.1) and its duration (default is 10). The Runge-Kutta method of 4-th order is used for integration.

```
const char *ham = "p^2+q^2-x-1+i*0.5*(y+x)*(y>-x)";
mglData r = mglRay(ham, mglPoint(-0.7, -1), mglPoint(0, 0.5), 0.02, 2);
```

This example calculate the reflection from linear layer (media with Hamiltonian '`p^2+q^2-x-1`'=$p_x^2 + p_y^2 - x - 1$). This is parabolic curve. The resulting array have 7 columns which contain data for {x,y,z,p,q,v,t}.

The solution of PDE is a bit more complicated. As previous you have to specify the equation as pseudo-differential operator $\hat{}H(x,\nabla)$ which is called sometime as "Hamiltonian" (for example, in beam tracing). As previously, it is defined by string which may depend on coordinates '`x`', '`y`', '`z`' (but not time!), momentums '`p`'=$(d/dx)/ik_0$, '`q`'=$(d/dy)/ik_0$ and field amplitude '`u`'=$|u|$. The evolutionary coordinate is '`z`' in all cases. So that, the equation

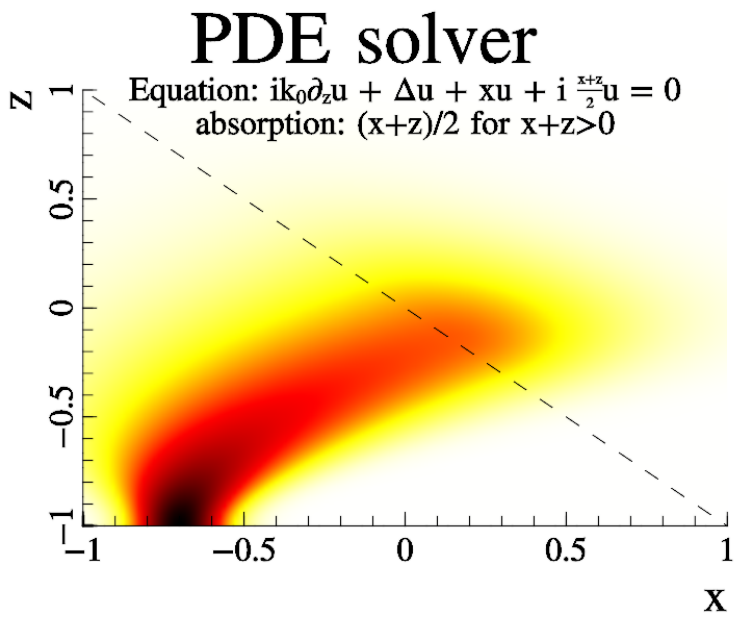
look like $du/dz = ik_0 H(x, y, \hat{}p, \hat{}q, |u|)[u]$. Dependence on field amplitude '`u`'=$|u|$ allows one to solve nonlinear problems too. For example, for nonlinear Shrodinger equation you may set `ham="p^2 + q^2 - u^2"`. Also you may specify imaginary part for wave absorption, like `ham = "p^2 + i*x*(x>0)"` or `ham = "p^2 + i1*x*(x>0)"`.

Next step is specifying the initial conditions at '`z`' equal to minimal z-axis value. The function need 2 arrays for real and for imaginary part. Note, that coordinates x,y,z are supposed to be in specified axis range. So, the data arrays should have corresponding scales. Finally, you may set the integration step and parameter k0=k_0. Also keep in mind, that internally the 2 times large box is used (for suppressing numerical reflection from boundaries) and the equation should well defined even in this extended range.

Final comment is concerning the possible form of pseudo-differential operator H. At this moment, simplified form of operator H is supported – all "mixed" terms (like '`x*p`'->x*d/dx) are excluded. For example, in 2D case this operator is effectively $H = f(p, z) + g(x, z, u)$. However commutable combinations (like '`x*q`'->x*d/dy) are allowed for 3D case.

So, for example let solve the equation for beam deflected from linear layer and absorbed later. The operator will have the form '`"p^2+q^2-x-1+i*0.5*(z+x)*(z>-x)"`' that correspond to equation $1/ik_0 * du/dz + d^2u/dx^2 + d^2u/dy^2 + x * u + i(x + z)/2 * u = 0$. This is typical equation for Electron Cyclotron (EC) absorption in magnetized plasmas. For initial conditions let me select the beam with plane phase front $exp(-48 * (x + 0.7)^2)$. The corresponding code looks like this:

```
int sample(mglGraph *gr)
{
  mglData a,re(128),im(128);
  gr->Fill(re,"exp(-48*(x+0.7)^2)");
  a = gr->PDE("p^2+q^2-x-1+i*0.5*(z+x)*(z>-x)", re, im, 0.01, 30);
  a.Transpose("yxz");
  gr->SubPlot(1,1,0,"<_"); gr->Title("PDE solver");
  gr->SetRange('c',0,1);  gr->Dens(a,"wyrRk");
  gr->Axis(); gr->Label('x', "\\i x");  gr->Label('y', "\\i z");
  gr->FPlot("-x", "k|");
  gr->Puts(mglPoint(0, 0.85), "absorption: (x+z)/2 for x+z>0");
  gr->Puts(mglPoint(0,1.1),"Equation: ik_0\\partial_zu + \\Delta u + x\\cdot u + i \\frac{x
  return 0;
}
```

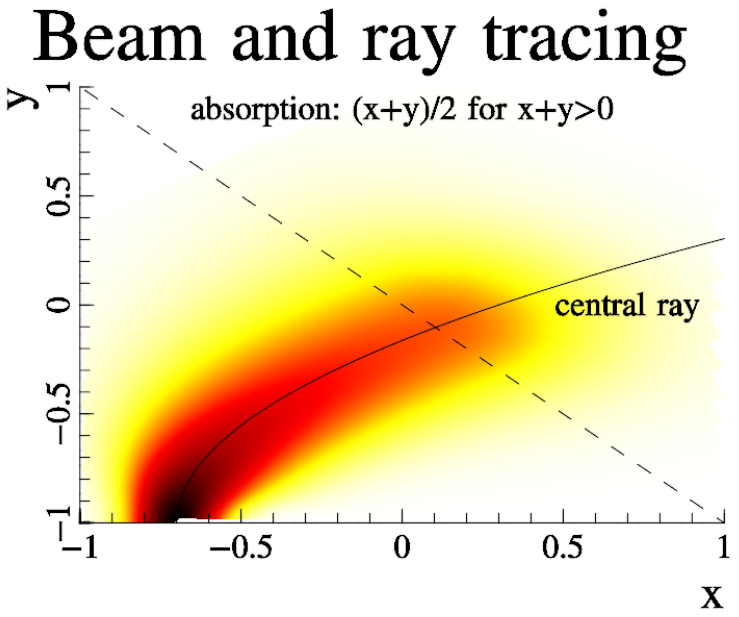


The last example is example of beam tracing. Beam tracing equation is special kind of PDE equation written in coordinates accompanied to a ray. Generally this is the same parameters and limitation as for PDE solving but the coordinates are defined by the ray and by parameter of grid width w in direction transverse the ray. So, you don't need to specify the range of coordinates. **BUT** there is limitation. The accompanied coordinates are well defined only for smooth enough rays, i.e. then the ray curvature K (which is defined as $1/K^2 = (|r''|^2|r'|^2 - (r'', r'')^2)/|r'|^6$) is much large then the grid width: $K >> w$. So, you may receive incorrect results if this condition will be broken.

You may use following code for obtaining the same solution as in previous example:

```
int sample(mglGraph *gr)
{
  mglData r, xx, yy, a, im(128), re(128);
  const char *ham = "p^2+q^2-x-1+i*0.5*(y+x)*(y>-x)";
  r = mglRay(ham, mglPoint(-0.7, -1), mglPoint(0, 0.5), 0.02, 2);
  gr->SubPlot(1,1,0,"<_"); gr->Title("Beam and ray tracing");
  gr->Plot(r.SubData(0), r.SubData(1), "k");
  gr->Axis(); gr->Label('x', "\\i x");  gr->Label('y', "\\i z");

  // now start beam tracing
  gr->Fill(re,"exp(-48*x^2)");
  a = mglQO2d(ham, re, im, r, xx, yy, 1, 30);
  gr->SetRange('c',0, 1);
  gr->Dens(xx, yy, a, "wyrRk");
  gr->FPlot("-x", "k|");
  gr->Puts(mglPoint(0, 0.85), "absorption: (x+y)/2 for x+y>0");
  gr->Puts(mglPoint(0.7, -0.05), "central ray");
  return 0;
}
```



2.9.15 Drawing phase plain

Here I want say a few words of plotting phase plains. Phase plain is name for system of coordinates x, x', i.e. a variable and its time derivative. Plot in phase plain is very useful for qualitative analysis of an ODE, because such plot is rude (it topologically the same for a range of ODE parameters). Most often the phase plain $\{x, x'\}$ is used (due to its simplicity), that allows to analyze up to the 2nd order ODE (i.e. $x'' + f(x, x') = 0$).

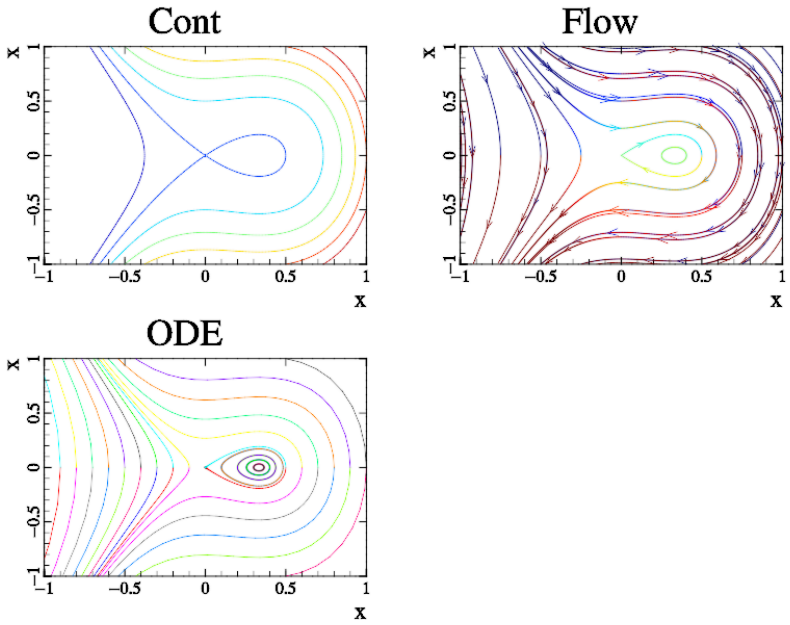
The simplest way to draw phase plain in MathGL is using [flow], page 224 function(s), which automatically select several points and draw flow threads. If the ODE have an integral of motion (like Hamiltonian $H(x, x') = const$ for dissipation-free case) then you can use [cont], page 210 function for plotting isolines (contours). In fact. isolines are the same as flow threads, but without arrows on it. Finally, you can directly solve ODE using [ode], page 279 function and plot its numerical solution.

Let demonstrate this for ODE equation $x'' - x + 3 * x^2 = 0$. This is nonlinear oscillator with square nonlinearity. It has integral $H = y^2 + 2 * x^3 - x^2 = Const$. Also it have 2 typical stationary points: saddle at {x=0, y=0} and center at {x=1/3, y=0}. Motion at vicinity of center is just simple oscillations, and is stable to small variation of parameters. In opposite, motion around saddle point is non-stable to small variation of parameters, and is very slow. So, calculation around saddle points are more difficult, but more important. Saddle points are responsible for solitons, stochasticity and so on.

So, let draw this phase plain by 3 different methods. First, draw isolines for $H = y^2 + 2 * x^3 - x^2 = Const$ – this is simplest for ODE without dissipation. Next, draw flow threads – this is straightforward way, but the automatic choice of starting points is not always optimal. Finally, use [ode], page 279 to check the above plots. At this we need to run [ode], page 279 in both direction of time (in future and in the past) to draw whole plain. Alternatively, one can put starting points far from (or at the bounding box as done in [flow], page 224) the plot, but this is a more complicated. The sample code is:

```
int sample(mglGraph *gr)
{
```

```
  gr->SubPlot(2,2,0,"<_");  gr->Title("Cont");  gr->Box();
  gr->Axis();  gr->Label('x',"x");  gr->Label('y',"\\dot{x}");
  mglData f(100,100);   gr->Fill(f,"y^2+2*x^3-x^2-0.5");
  gr->Cont(f);
  gr->SubPlot(2,2,1,"<_");  gr->Title("Flow");  gr->Box();
  gr->Axis();  gr->Label('x',"x");  gr->Label('y',"\\dot{x}");
  mglData fx(100,100), fy(100,100);
  gr->Fill(fx,"x-3*x^2");  gr->Fill(fy,"y");
  gr->Flow(fy,fx,"v","value 7");
  gr->SubPlot(2,2,2,"<_");  gr->Title("ODE");   gr->Box();
  gr->Axis();  gr->Label('x',"x");  gr->Label('y',"\\dot{x}");
  for(double x=-1;x<1;x+=0.1)
  {
    mglData in(2), r;   in.a[0]=x;
    r = mglODE("y;x-3*x^2","xy",in);
    gr->Plot(r.SubData(0), r.SubData(1));
    r = mglODE("-y;-x+3*x^2","xy",in);
    gr->Plot(r.SubData(0), r.SubData(1));
  }
}
```

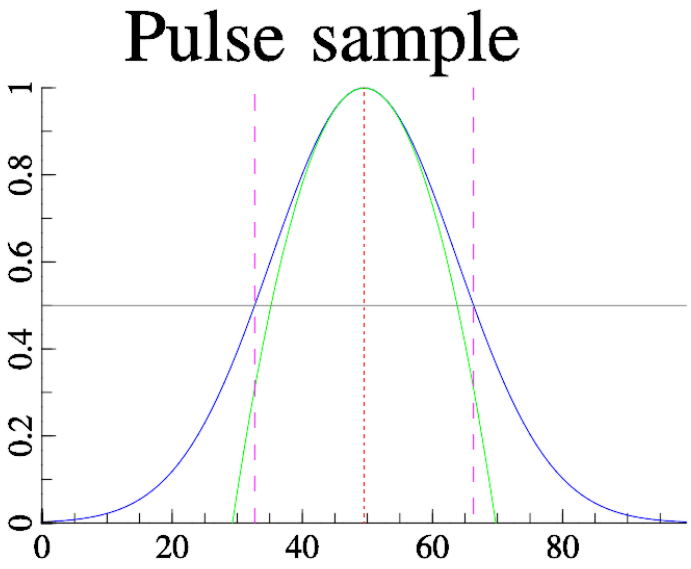


2.9.16 Pulse properties

There is common task in optics to determine properties of wave pulses or wave beams. MathGL provide special function [pulse], page 269 which return the pulse properties (maximal value, center of mass, width and so on). Its usage is rather simple. Here I just illustrate it on the example of Gaussian pulse, where all parameters are obvious.

```
void sample(mglGraph *gr)
```

```
{
  gr->SubPlot(1,1,0,"<_");  gr->Title("Pulse sample");
  // first prepare pulse itself
  mglData a(100); gr->Fill(a,"exp(-6*x^2)");
  // get pulse parameters
  mglData b(a.Pulse('x'));
  // positions and widths are normalized on the number of points. So, set proper axis scale
  gr->SetRanges(0, a.nx-1, 0, 1);
  gr->Axis(); gr->Plot(a);  // draw pulse and axis
  // now visualize found pulse properties
  double m = b[0];  // maximal amplitude
  // approximate position of maximum
  gr->Line(mglPoint(b[1],0), mglPoint(b[1],m),"r=");
  // width at half-maximum (so called FWHM)
  gr->Line(mglPoint(b[1]-b[3]/2,0), mglPoint(b[1]-b[3]/2,m),"m|");
  gr->Line(mglPoint(b[1]+b[3]/2,0), mglPoint(b[1]+b[3]/2,m),"m|");
  gr->Line(mglPoint(0,m/2), mglPoint(a.nx-1,m/2),"h");
  // parabolic approximation near maximum
  char func[128];       sprintf(func,"%g*(1-((x-%g)/%g)^2)",b[0],b[1],b[2]);
  gr->FPlot(func,"g");
}
```



2.9.17 Using MGL parser

Sometimes you may prefer to use MGL scripts in yours code. It is simpler (especially in comparison with C/Fortran interfaces) and provide faster way to plot the data with annotations, labels and so on. Class `mglParse` (see Section 7.4 [mglParse class], page 292 parse MGL scripts in C++. It have also the corresponding interface for C/Fortran.

The key function here is `mglParse::Parse()` (or `mgl_parse()` for C/Fortran) which execute one command per string. At this the detailed information about the possible errors or warnings is passed as function value. Or you may execute the whole script as long string with lines separated by '`\n`'. Functions `mglParse::Execute()` and `mgl_parse_text()` perform it. Also you may set the values of parameters '`$0`'...'`$9`' for the script by functions `mglParse::AddParam()` or `mgl_add_param()`, allow/disable picture resizing, check "once" status and so on. The usage is rather straight-forward.

The only non-obvious thing is data transition between script and yours program. There are 2 stages: add or find variable; and set data to variable. In C++ you may use functions `mglParse::AddVar()` and `mglParse::FindVar()` which return pointer to `mglData`. In C/Fortran the corresponding functions are `mgl_add_var()`, `mgl_find_var()`. This data pointer is valid until next `Parse()` or `Execute()` call. Note, you **must not delete or free** the data obtained from these functions!

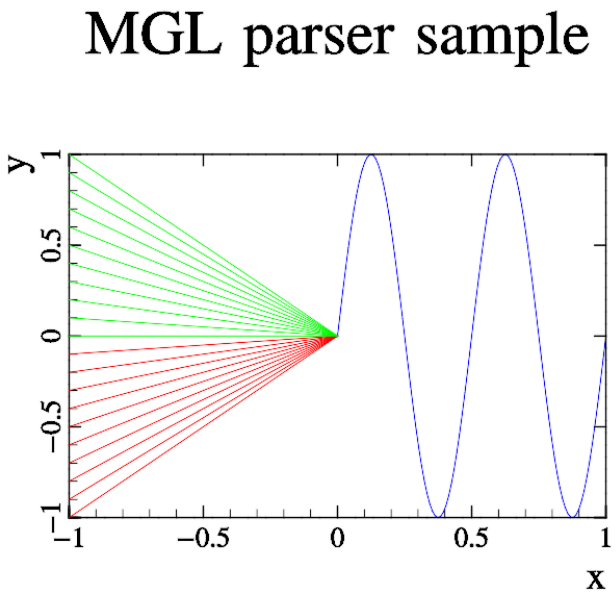
So, some simple example at the end. Here I define a data array, create variable, put data into it and plot it. The C++ code looks like this:

```
int sample(mglGraph *gr)
{
  gr->Title("MGL parser sample");
  mreal a[100];   // let a_i = sin(4*pi*x), x=0...1
  for(int i=0;i<100;i++)a[i]=sin(4*M_PI*i/99);
  mglParse *parser = new mglParse;
  mglData *d = parser->AddVar("dat");
  d->Set(a,100); // set data to variable
  parser->Execute(gr, "plot dat; xrange 0 1\nbox\naxis");
  // you may break script at any line do something
  // and continue after that
  parser->Execute(gr, "xlabel 'x'\nylabel 'y'\nbox");
  // also you may use cycles or conditions in script
  parser->Execute(gr, "for $0 -1 1 0.1\nif $0<0\n"
    "line 0 0 -1 $0 'r':else:line 0 0 -1 $0 'g'\n"
    "endif\nnext");
  delete parser;
  return 0;
}
```

The code in C/Fortran looks practically the same:

```
int sample(HMGL gr)
{
  mgl_title(gr, "MGL parser sample", "", -2);
  double a[100];   // let a_i = sin(4*pi*x), x=0...1
  int i;
  for(i=0;i<100;i++)  a[i]=sin(4*M_PI*i/99);
  HMPR parser = mgl_create_parser();
  HMDT d = mgl_parser_add_var(parser, "dat");
  mgl_data_set_double(d,a,100,1,1);    // set data to variable
  mgl_parse_text(gr, parser, "plot dat; xrange 0 1\nbox\naxis");
  // you may break script at any line do something
```

```
  // and continue after that
  mgl_parse_text(gr, parser, "xlabel 'x'\nylabel 'y'");
  // also you may use cycles or conditions in script
  mgl_parse_text(gr, parser, "for $0 -1 1 0.1\nif $0<0\n"
    "line 0 0 -1 $0 'r':else:line 0 0 -1 $0 'g'\n"
    "endif\nnext");
  mgl_write_png(gr, "test.png", "");  // don't forgot to save picture
  return 0;
}
```



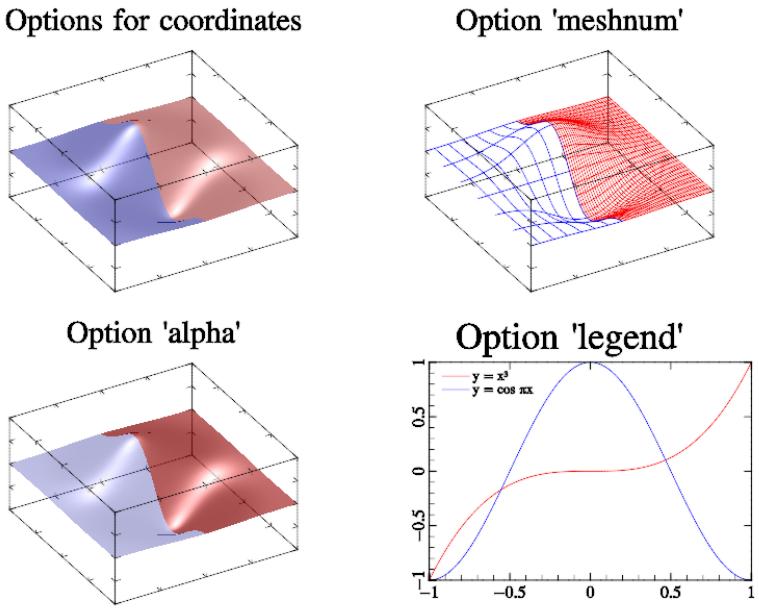
2.9.18 Using options

Section 3.7 [Command options], page 154 allow the easy setup of the selected plot by changing global settings only for this plot. Often, options are used for specifying the range of automatic variables (coordinates). However, options allows easily change plot transparency, numbers of line or faces to be drawn, or add legend entries. The sample function for options usage is:

```
void template(mglGraph *gr)
{
  mglData a(31,41);
  gr->Fill(a,"-pi*x*exp(-(y+1)^2-4*x^2)");

  gr->SubPlot(2,2,0);   gr->Title("Options for coordinates");
  gr->Alpha(true);      gr->Light(true);
  gr->Rotate(40,60);    gr->Box();
  gr->Surf(a,"r","yrange 0 1"); gr->Surf(a,"b","yrange 0 -1");
  if(mini)      return;
  gr->SubPlot(2,2,1);   gr->Title("Option 'meshnum'");
```

```
  gr->Rotate(40,60);    gr->Box();
  gr->Mesh(a,"r","yrange 0 1"); gr->Mesh(a,"b","yrange 0 -1; meshnum 5");
  gr->SubPlot(2,2,2);   gr->Title("Option 'alpha'");
  gr->Rotate(40,60);    gr->Box();
  gr->Surf(a,"r","yrange 0 1; alpha 0.7");
  gr->Surf(a,"b","yrange 0 -1; alpha 0.3");
  gr->SubPlot(2,2,3,"<_");  gr->Title("Option 'legend'");
  gr->FPlot("x^3","r","legend 'y = x^3'");
  gr->FPlot("cos(pi*x)","b","legend 'y = cos \\pi x'");
  gr->Box();    gr->Axis(); gr->Legend(2,"");
}
```



2.9.19 "Templates"

As I have noted before, the change of settings will influence only for the further plotting commands. This allows one to create "template" function which will contain settings and primitive drawing for often used plots. Correspondingly one may call this template-function for drawing simplification.

For example, let one has a set of points (experimental or numerical) and wants to compare it with theoretical law (for example, with exponent law $\exp(-x/2), x \in [0, 20]$). The template-function for this task is:

```
void template(mglGraph *gr)
{
  mglData  law(100);      // create the law
  law.Modify("exp(-10*x)");
  gr->SetRanges(0,20, 0.0001,1);
  gr->SetFunc(0,"lg(y)",0);
  gr->Plot(law,"r2");
```

```
  gr->Puts(mglPoint(10,0.2),"Theoretical law: e^x","r:L");
  gr->Label('x',"x val."); gr->Label('y',"y val.");
  gr->Axis(); gr->Grid("xy","g;"); gr->Box();
}
```

At this, one will only write a few lines for data drawing:

```
  template(gr);     // apply settings and default drawing from template
  mglData dat("fname.dat"); // load the data
  // and draw it (suppose that data file have 2 columns)
  gr->Plot(dat.SubData(0),dat.SubData(1),"bx ");
```

A template-function can also contain settings for font, transparency, lightning, color scheme and so on.

I understand that this is obvious thing for any professional programmer, but I several times receive suggestion about "templates" ... So, I decide to point out it here.

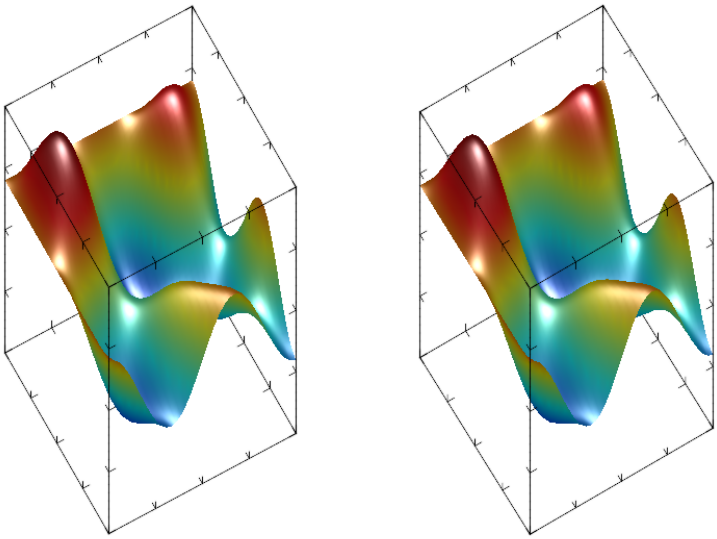
2.9.20 Stereo image

One can easily create stereo image in MathGL. Stereo image can be produced by making two subplots with slightly different rotation angles. The corresponding code looks like this:

```
int sample(mglGraph *gr)
{
  mglData a;  mgls_prepare2d(&a);
  gr->Light(true);

  gr->SubPlot(2,1,0); gr->Rotate(50,60+1);
  gr->Box();  gr->Surf(a);

  gr->SubPlot(2,1,1); gr->Rotate(50,60-1);
  gr->Box();  gr->Surf(a);
  return 0;
}
```



2.9.21 Reduce memory usage

By default MathGL save all primitives in memory, rearrange it and only later draw them on bitmaps. Usually, this speed up drawing, but may require a lot of memory for plots which contain a lot of faces (like [cloud], page 214, [dew], page 224). You can use [quality], page 176 function for setting to use direct drawing on bitmap and bypassing keeping any primitives in memory. This function also allow you to decrease the quality of the resulting image but increase the speed of the drawing.

The code for lowest memory usage looks like this:

```
int sample(mglGraph *gr)
{
  gr->SetQuality(6);   // firstly, set to draw directly on bitmap
  for(i=0;i<1000;i++)
    gr->Sphere(mglPoint(mgl_rnd()*2-1,mgl_rnd()*2-1),0.05);
  return 0;
}
```

2.9.22 Scanning file

MathGL have possibilities to write textual information into file with variable values. In MGL script you can use [save], page 263 command for that. However, the usual `printf();` is simple in C/C++ code. For example, lets create some textual file

```
FILE *fp=fopen("test.txt","w");
fprintf(fp,"This is test: 0 -> 1 q\n");
fprintf(fp,"This is test: 1 -> -1 q\n");
fprintf(fp,"This is test: 2 -> 0 q\n");
fclose(fp);
```

It contents look like

```
This is test: 0 -> 1 q
```

```
This is test: 1 -> -1 q
This is test: 2 -> 0 q
```

Let assume now that you want to read this values (i.e. [[0,1],[1,-1],[2,0]]) from the file. You can use [scanfile], page 263 for that. The desired values was written using template "This is test: %g -> %g q\n". So, just use

```
mglData a;
a.ScanFile("test.txt","This is test: %g -> %g");
```

and plot it to for assurance

```
gr->SetRanges(a.SubData(0), a.SubData(1));
gr->Axis();     gr->Plot(a.SubData(0),a.SubData(1),"o");
```

Note, I keep only the leading part of template (i.e. "This is test: %g -> %g" instead of "This is test: %g -> %g q\n"), because there is no important for us information after the second number in the line.

2.10 FAQ

The plot does not appear

Check that points of the plot are located inside the bounding box and resize the bounding box using [ranges], page 167 function. Check that the data have correct dimensions for selected type of plot. Be sure that `Finish()` is called after the plotting functions (or be sure that the plot is saved to a file). Sometimes the light reflection from flat surfaces (like, [dens], page 209) can look as if the plot were absent.

I can not find some special kind of plot.

Most "new" types of plots can be created by using the existing drawing functions. For example, the surface of curve rotation can be created by a special function [torus], page 206, or as a parametrically specified surface by [surf], page 208. See also, Section 2.9 [Hints], page 111. If you can not find a specific type of plot, please e-mail me and this plot will appear in the next version of MathGL library.

Should I know some graphical libraries (like OpenGL) before using the MathGL library?

No. The MathGL library is self-contained and does not require the knowledge of external libraries.

In which language is the library written? For which languages does it have an interface?

The core of the MathGL library is written in C++. But there are interfaces for: pure C, Fortran, Pascal, Forth, and its own command language MGL. Also there is a large set of interpreted languages, which are supported (Python, Java, ALLEGROCL, CHICKEN, Lisp, CFFI, C#, Guile, Lua, Modula 3, Mzscheme, Ocaml, Octave, Perl, PHP, Pike, R, Ruby, Tcl). These interfaces are written using SWIG (both pure C functions and classes) but only the interface for Python and Octave is included in the build system. The reason is that I don't know any other interpreted languages :(. Note that most other languages can use (link to) the pure C functions.

How can I use MathGL with Fortran?

You can use MathGL as is with `gfortran` because it uses by default the AT&T notation for external functions. For other compilers (like Visual Fortran) you have to switch on the AT&T notation manually. The AT&T notation requires that the symbol '`_`' is added at the end of each function name, function argument(s) is passed by pointers and the string length(s) is passed at the end of the argument list. For example:

C function – `void mgl_fplot(HMGL graph, const char *fy, const char *stl, int n);`

AT&T function – `void mgl_fplot_(uintptr_t *graph, const char *fy, const char *stl, int *n, int ly, int ls);`

Fortran users also should add C++ library by the option `-lstdc++`. If library was built with `enable-double=ON` (this default for v.2.1 and later) then all real numbers must be `real*8`. You can make it automatic if use option `-fdefault-real-8`.

How can I print in Russian/Spanish/Arabic/Japanese, and so on?

The standard way is to use Unicode encoding for the text output. But the MathGL library also has interface for 8-bit (char *) strings with internal conversion to Unicode. This conversion depends on the current locale OS. You may change it by `setlocale()` function. For example, for Russian text in CP1251 encoding you may use `setlocale(LC_CTYPE, "ru_RU.cp1251");` (under MS Windows the name of locale may differ – `setlocale(LC_CTYPE, "russian_russia.1251")`). I strongly recommend not to use the constant `LC_ALL` in the conversion. Since it also changes the number format, it may lead to mistakes in formula writing and reading of the text in data files. For example, the program will await a '`,`' as a decimal point but the user will enter '`.`'.

How can I exclude a point or a region of plot from the drawing?

There are 3 general ways. First, the point with `NAN` value as one of the coordinates (including color/alpha range) will never be plotted. Second, special functions `SetCutBox`() and `CutOff`() define the condition when the points should be omitted (see Section 4.2.5 [Cutting], page 162). Last, you may change the transparency of a part of the plot by the help of functions [surfa], page 218, [surf3a], page 219 (see Section 4.14 [Dual plotting], page 217). In last case the transparency is switched on smoothly.

I use VisualStudio, CBuilder or some other compiler (not MinGW/gcc). How can I link the MathGL library?

In version 2.0, main classes (`mglGraph` and `mglData`) contains only `inline` functions and are acceptable for any compiler with the same binary files. However, if you plan to use widget classes (QMathGL, Fl_MathGL, ...) or to access low-level features (mglBase, mglCanvas, ...) then you have to recompile MathGL by yours compiler.

Note, that you have to make import library(-ies) *.lib for provided binary *.dll. This procedure depend on used compiler – please read documentation for yours compiler. For VisualStudio, it can be done by command `lib.exe /DEF:libmgl.def /OUT:libmgl.lib`.

How make FLTK/GLUT/Qt window which will display result of my calculations?

You need to put yours calculations or main event-handling loop in the separate thread. For static image you can give `NULL` as drawing function and call `Update()` function when you need to redraw it. For more details see Section 2.1.3 [Animation], page 11.

How I can build MathGL under Windows?

Generally, it is the same procedure as for Linux or MacOS – see section Section 1.3 [Installation], page 2. The simplest way is using the combination CMake+MinGW. Also you may need some extra libraries like GSL, PNG, JPEG and so on. All of them can be found at `http://gnuwin32.sourceforge.net/packages.html`. After installing all components, just run cmake-gui (`http://www.cmake.org/cmake/help/runningcmake.html`) configurator and build the MathGL itself.

How many people write this library?

Most of the library was written by one person. This is a result of nearly a year of work (mostly in the evening and on holidays): I spent half a year to write the kernel and half a year to a year on extending, improving the library and writing documentation. This process continues now :). The build system (cmake files) was written mostly by D.Kulagin, and the export to PRC/PDF was written mostly by M.Vidassov.

How can I display a bitmap on the figure?

You can import data into a `mglData` instance by function [import], page 264 and display it by [dens], page 209 function. For example, for black-and-white bitmap you can use the code: `mglData bmp; bmp.Import("fname.png","wk"); gr->Dens(bmp,"wk");`.

How can I use MathGL in Qt, FLTK, wxWidgets etc.?

There are special classes (widgets) for these libraries: QMathGL for Qt, Fl_MathGL for FLTK and so on. If you don't find the appropriate class then you can create your own widget that displays a bitmap using mglCanvas::GetRGB().

How can I create 3D in PDF?

Just use `WritePRC`() method which also create PDF file if enable-pdf=ON at MathGL configure.

How can I create TeX figure?

Just use `WriteTEX`() method which create LaTeX files with figure itself '*fname*`.tex`', with MathGL colors '`mglcolors.tex`' and main file '`mglmain.tex`'. Last one can be used for viewing image by command like `pdflatex mglmain.tex`.

Can I use MathGL in JavaScript?

Yes, sample JavaScript file is located in texinfo/ folder of sources. You should provide JSON data with 3d image for it (can be created by `WriteJSON`() method). Script allows basic manipulation with plot: zoom, rotation, shift. Sample of JavaScript pictures can be found in `http://mathgl.sf.net/json.html`.

How I can change the font family?

First, you should download new font files from here (`http://mathgl.sourceforge.net/download.html`) or from here (`http://sourceforge.net/project/showfiles.php?group_id=152187&package_id=267177`). Next, you should load the font files into mglGraph class instance *gr* by the following command: `gr->LoadFont(fontname,path);`. Here *fontname* is the base font name like '`STIX`' and *path* sets the location of font files. Use `gr->RestoreFont();` to start using the default font.

How can I draw tick out of a bounding box?

Just set a negative value in [ticklen], page 172. For example, use `gr->SetTickLen(-0.1);`.

How can I prevent text rotation?

Just use `SetRotatedText(false)`. Also you can use axis style '`U`' for disable only tick labels rotation.

What is `*.so`? What is `gcc`? How I can use `make`?

They are standard GNU tools. There is special FAQ about its usage under Windows – `http://www.mingw.org/wiki/FAQ`.

How can I draw equal axis range even for rectangular image?

Just use `Aspect(NAN,NAN)` for each subplot, or at the beginning of the drawing.

How I can set transparent background?

Just use code like `Clf("r{A5}");` or prepare PNG file and set it as background image by call `LoadBackground("fname.png");`.

How I can reduce "white" edges around bounding box?

The simplest way is to use [subplot], page 173 style. However, you should be careful if you plan to add [colorbar], page 192 or rotate plot – part of plot can be invisible if you will use non-default [subplot], page 173 style.

Can I combine bitmap and vector output in EPS?

Yes. Sometimes you may have huge surface and a small set of curves and/or text on the plot. You can use function [rasterize], page 184 just after making surface plot. This will put all plot to bitmap background. At this later plotting will be in vector format. For example, you can do something like following:

```
gr->Surf(x, y, z);
gr->Rasterize(); // make surface as bitmap
gr->Axis();
gr->WriteFrame("fname.eps");
```

Why I couldn't use name '`I`' for variable?

MathGL support C99 standard, where '`I`' is reserved for imaginary unit. If you still need this name, then just use

```
#undef I
```

after including MathGL header files.

How I can create MPEG video from plots?

You can save each frame into JPEG with names like '`frame0001.jpg`', '`frame0002.jpg`', ... Later you can use ImageMagic to convert them into

MPEG video by command `convert frame*.jpg movie.mpg`. See also [MPEG], page 12.

3 General concepts

The set of MathGL features is rather rich – just the number of basic graphics types is larger than 50. Also there are functions for data handling, plot setup and so on. In spite of it I tried to keep a similar style in function names and in the order of arguments. Mostly it is used for different drawing functions.

There are six most general (base) concepts:

1. **Any picture is created in memory first.** The internal (memory) representation can be different: bitmap picture (for `SetQuality(MGL_DRAW_LMEM)`) or the list of vector primitives (default). After that the user may decide what he/she want: save to file, display on the screen, run animation, do additional editing and so on. This approach assures a high portability of the program – the source code will produce exactly the same picture in *any* OS. Another big positive consequence is the ability to create the picture in the console program (using command line, without creating a window)!
2. **Every plot settings (style of lines, font, color scheme) are specified by a string.** It provides convenience for user/programmer – short string with parameters is more comprehensible than a large set of parameters. Also it provides portability – the strings are the same in any OS so that it is not necessary to think about argument types.
3. **All functions have "simplified" and "advanced" forms.** It is done for user's convenience. One needs to specify only one data array in the "simplified" form in order to see the result. But one may set parametric dependence of coordinates and produce rather complex curves and surfaces in the "advanced" form. In both cases the order of function arguments is the same: first data arrays, second the string with style, and later string with options for additional plot tuning.
4. **All data arrays for plotting are encapsulated in mglData(A) class.** This reduces the number of errors while working with memory and provides a uniform interface for data of different types (mreal, double and so on) or for formula plotting.
5. **All plots are vector plots.** The MathGL library is intended for handling scientific data which have vector nature (lines, faces, matrices and so on). As a result, vector representation is used in all cases! In addition, the vector representation allows one to scale the plot easily – change the canvas size by a factor of 2, and the picture will be proportionally scaled.
6. **New drawing never clears things drawn already.** This, in some sense, unexpected, idea allows to create a lot of "combined" graphics. For example, to make a surface with contour lines one needs to call the function for surface plotting and the function for contour lines plotting (in any order). Thus the special functions for making this "combined" plots (as it is done in Matlab and some other plotting systems) are superfluous.

In addition to the general concepts I want to comment on some non-trivial or less commonly used general ideas – plot positioning, axis specification and curvilinear coordinates, styles for lines, text and color scheme.

3.1 Coordinate axes

Two axis representations are used in MathGL. The first one consists of normalizing coordinates of data points in axis range (see Section 4.3 [Axis settings], page 167). If `SetCut()` is

`true` then the outlier points are omitted, otherwise they are projected to the bounding box (see Section 4.2.5 [Cutting], page 162). Also, the point will be omitted if it lies inside the box defined by `SetCutBox()` or if the value of formula `CutOff()` is nonzero for its coordinates. After that, transformation formulas defined by `SetFunc()` or `SetCoor()` are applied to the data point (see Section 4.3.2 [Curved coordinates], page 168). Finally, the data point is plotted by one of the functions.

The range of *x, y, z*-axis can be specified by `SetRange()` or `SetRanges()` functions. Its origin is specified by `SetOrigin()` function. At this you can you can use `NAN` values for selecting axis origin automatically.

There is 4-th axis *c* (color axis or colorbar) in addition to the usual axes *x, y, z*. It sets the range of values for the surface coloring. Its borders are automatically set to values of z-range during the call of `SetRanges()` function. Also, one can directly set it by call `SetRange('c', ...)`. Use `Colorbar()` function for drawing the colorbar.

The form (appearence) of tick labels is controlled by `SetTicks()` function (see Section 4.3.3 [Ticks], page 169). Function *SetTuneTicks* switches on/off tick enhancing by factoring out acommon multiplier (for small coordinate values, like 0.001 to 0.002, or large, like from 1000 to 2000) or common component (for narrow range, like from 0.999 to 1.000). Finally, you may use functions `SetTickTempl()` for setting templates for tick labels (it supports TeX symbols). Also, there is a possibility to print arbitrary text as tick labels the by help of `SetTicksVal()` function.

3.2 Color styles

Base colors are defined by one of symbol '`wkrgbcymhRGBCYMHWlenupqLENUPQ`'. The color types are: '`k`' – black, '`r`' – red, '`R`' – dark red, '`g`' – green, '`G`' – dark green, '`b`' – blue, '`B`' – dark blue, '`c`' – cyan, '`C`' – dark cyan, '`m`' – magenta, '`M`' – dark magenta, '`y`' – yellow, '`Y`' – dark yellow (gold), '`h`' – gray, '`H`' – dark gray, '`w`' – white, '`W`' – bright gray, '`l`' – green-blue, '`L`' – dark green-blue, '`e`' – green-yellow, '`E`' – dark green-yellow, '`n`' – sky-blue, '`N`' – dark sky-blue, '`u`' – blue-violet, '`U`' – dark blue-violet, '`p`' – purple, '`P`' – dark purple, '`q`' – orange, '`Q`' – dark orange (brown).

You can also use "bright" colors. The "bright" color contain 2 symbols in brackets '`{cN}`': first one is the usual symbol for color id, the second one is a digit for its brightness. The digit can be in range '`1`'...'`9`'. Number '`5`' corresponds to a normal color, '`1`' is a very dark version of the color (practically black), and '`9`' is a very bright version of the color (practically white). For example, the colors can be '`{b2}`' '`{b7}`' '`{r7}`' and so on.

Finally, you can specify RGB or RGBA values of a color using format '`{xRRGGBB}`' or '`{xRRGGBBAA}`' correspondingly. For example, '`{xFF9966}`' give you melone color.

3.3 Line styles

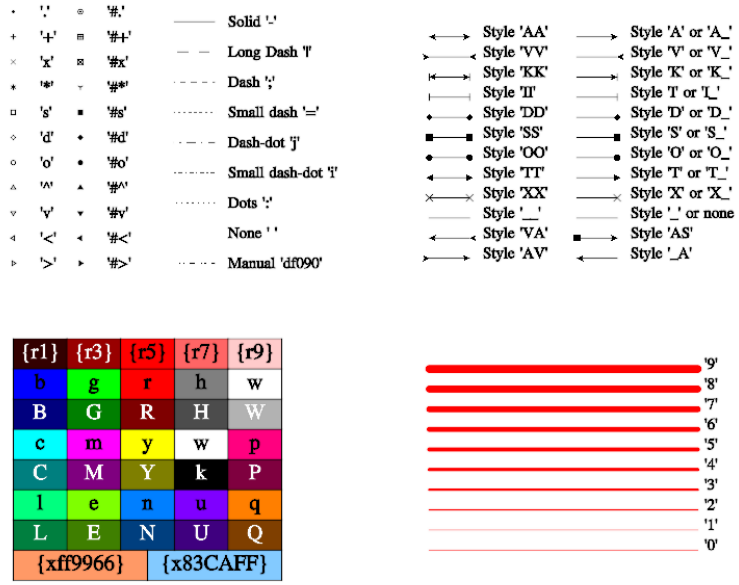
The line style is defined by the string which may contain specifications for color ('`wkrgbcymhRGBCYMHWlenupqLENUPQ`'), dashing style ('`-|;:ji=`' or space), width ('`123456789`') and marks ('`*o+xsd.^v<>`' and '`#`' modifier). If one of the type of information is omitted then default values used with next color from palette (see Section 4.2.7 [Palette and colors], page 163). Note, that internal color counter will be nullified by any change of palette. This includes even hidden change (for example, by

`Box()` or `Axis()` functions). By default palette contain following colors: dark gray '`H`', blue '`b`', green '`g`', red '`r`', cyan '`c`', magenta '`m`', yellow '`y`', gray '`h`', blue-green '`l`', sky-blue '`n`', orange '`q`', yellow-green '`e`', blue-violet '`u`', purple '`p`'.

Dashing style has the following meaning: space – no line (usable for plotting only marks), '`-`' – solid line (################), '`|`' – long dashed line (########--------), '`;`' – dashed line (####----####----), '`=`' – small dashed line (##--##--##--##--), '`:`' – dotted line (#---#---#---#---), '`j`' – dash-dotted line (#######----#----), '`i`' – small dash-dotted line (###--#--###--#--), '`{dNNNN}`' – manual mask style (for v.2.3 and later, like '`{df090}`' for (####----#--#----)).

Marker types are: '`o`' – circle, '`+`' – cross, '`x`' – skew cross, '`s`' - square, '`d`' - rhomb (or diamond), '`.`' – dot (point), '`^`' – triangle up, '`v`' – triangle down, '`<`' – triangle left, '`>`' – triangle right, '`#*`' – Y sign, '`#+`' – squared cross, '`#x`' – squared skew cross, '`#.`' – circled dot. If string contain symbol '`#`' then the solid versions of markers are used.

One may specify to draw a special symbol (an arrow) at the beginning and at the end of line. This is done if the specification string contains one of the following symbols: '`A`' – outer arrow, '`V`' – inner arrow, '`I`' – transverse hatches, '`K`' – arrow with hatches, '`T`' – triangle, '`S`' – square, '`D`' – rhombus, '`O`' – circle, '`X`' – skew cross, '`_`' – nothing (the default). The following rule applies: the first symbol specifies the arrow at the end of line, the second specifies the arrow at the beginning of the line. For example, '`r-A`' defines a red solid line with usual arrow at the end, '`b|AI`' defines a blue dash line with an arrow at the end and with hatches at the beginning, '`_O`' defines a line with the current style and with a circle at the beginning. These styles are applicable during the graphics plotting as well (for example, Section 4.11 [1D plotting], page 195).



3.4 Color scheme

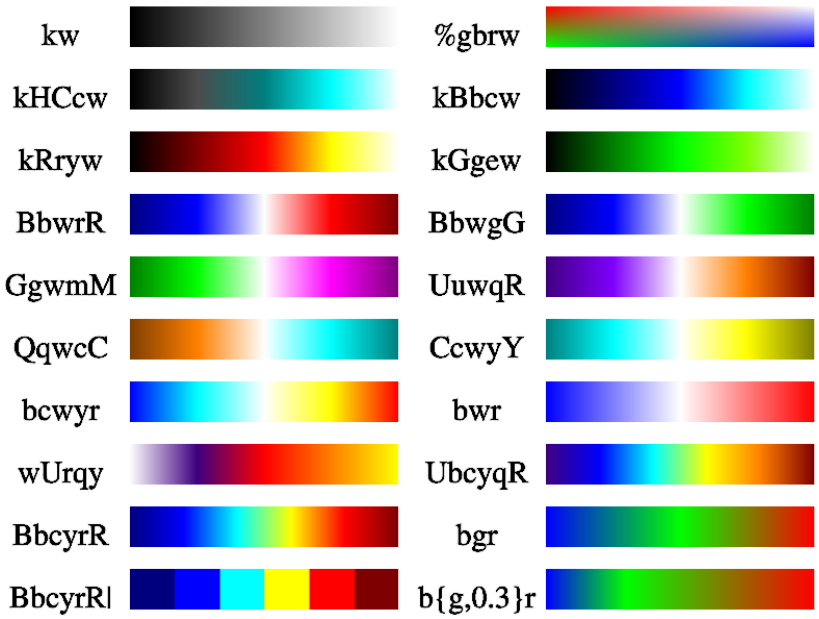
The color scheme is used for determining the color of surfaces, isolines, isosurfaces and so on. The color scheme is defined by the string, which may contain several characters that are color id (see Section 3.3 [Line styles], page 148) or characters '`#:|`'. Symbol '`#`' switches to mesh drawing or to a wire plot. Symbol '`|`' disables color interpolation in color scheme, which can be useful, for example, for sharp colors during matrix plotting. Symbol '`:`' terminate the color scheme parsing. Following it, the user may put styles for the text, rotation axis for curves/isocontours, and so on. Color scheme may contain up to 32 color values.

The final color is a linear interpolation of color array. The color array is constructed from the string ids (including "bright" colors, see Section 3.2 [Color styles], page 148). The argument is the amplitude normalized in color range (see Section 4.3 [Axis settings], page 167). For example, string containing 4 characters '`bcyr`' corresponds to a colorbar from blue (lowest value) through cyan (next value) through yellow (next value) to the red (highest value). String '`kw`' corresponds to a colorbar from black (lowest value) to white (highest value). String '`m`' corresponds to a simple magenta color.

The special 2-axis color scheme (like in [map], page 221 plot) can be used if it contain symbol '`%`'. In this case the second direction (alpha channel) is used as second coordinate for colors. At this, up to 4 colors can be specified for corners: {c1,a1}, {c2,a1}, {c1,a2}, {c2,a2}. Here color and alpha ranges are {c1,c2} and {a1,a2} correspondingly. If one specify less than 4 colors then black color is used for corner {c1,a1}. If only 2 colors are specified then the color of their sum is used for corner {c2,a2}.

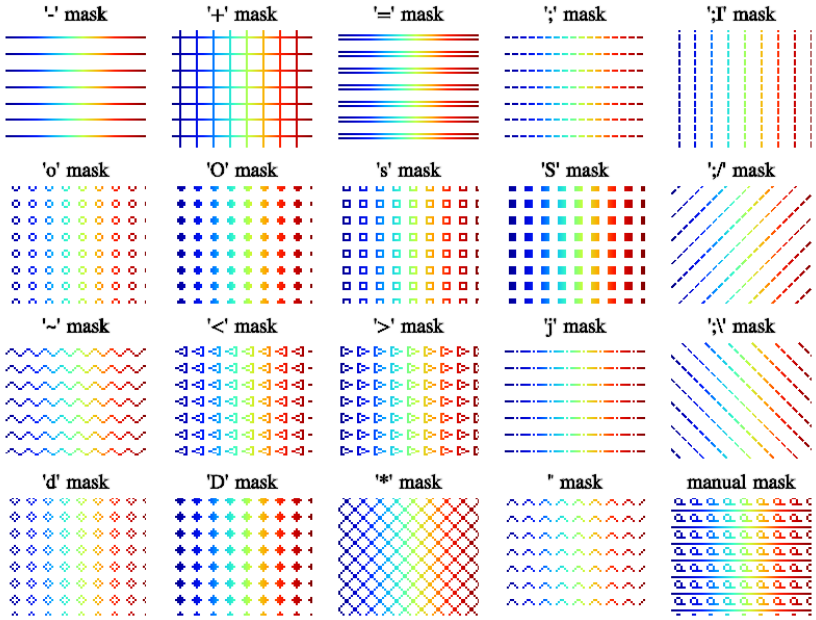
There are several useful combinations. String '`kw`' corresponds to the simplest gray color scheme where higher values are brighter. String '`wk`' presents the inverse gray color scheme where higher value is darker. Strings '`kRryw`', '`kGgw`', '`kBbcw`' present the well-known *hot*, *summer* and *winter* color schemes. Strings '`BbwrR`' and '`bBkRr`' allow to view bi-color figure on white or black background, where negative values are blue and positive values are red. String '`BbcyrR`' gives a color scheme similar to the well-known *jet* color scheme.

For more precise coloring, you can change default (equidistant) position of colors in color scheme. The format is '`{CN,pos}`', '`{CN,pos}`' or '`{xRRGGBB,pos}`'. The position value *pos* should be in range [0, 1]. Note, that alternative method for fine tuning of the color scheme is using the formula for coloring (see Section 4.3.2 [Curved coordinates], page 168).



When coloring by *coordinate* (used in [map], page 221), the final color is determined by the position of the point in 3d space and is calculated from formula c=x*c[1] + y*c[2]. Here, c[1], c[2] are the first two elements of color array; x, y are normalized to axis range coordinates of the point.

Additionally, MathGL can apply mask to face filling at bitmap rendering. The kind of mask is specified by one of symbols '`-+=;oOsS~<>jdD*^`' in color scheme. Mask can be rotated by arbitrary angle by command [mask], page 164 or by three predefined values +45, -45 and 90 degree by symbols '`\/I`' correspondingly. Examples of predefined masks are shown on the figure below.



However, you can redefine mask for one symbol by specifying new matrix of size 8*8 as second argument for [mask], page 164 command. For example, the right-down subplot on the figure above is produced by code
```
gr->SetMask('+', "ff00182424f800"); gr->Dens(a,"3+");
```
or just use manual mask style (for v.2.3 and later)
```
gr->Dens(a,"3{s00ff00182424f800}");
```

3.5 Font styles

Text style is specified by the string which may contain: color id characters '`wkrgbcymhRGBCYMHW`' (see Section 3.2 [Color styles], page 148), and font style ('`ribwou`') and/or alignment ('`LRC`') specifications. At this, font style and alignment begin after the separator '`:`'. For example, '`r:iCb`' sets the bold ('`b`') italic ('`i`') font text aligned at the center ('`C`') and with red color ('`r`'). Starting from MathGL v.2.3, you can set not single color for whole text, but use color gradient for printed text (see Section 3.4 [Color scheme], page 150).

The font styles are: '`r`' – roman (or regular) font, '`i`' – italic style, '`b`' – bold style. By default roman roman font is used. The align types are: '`L`' – align left (default), '`C`' – align center, '`R`' – align right, '`T`' – align under, '`V`' – align center vertical. Additional font effects are: '`w`' – wired, '`o`' – over-lined, '`u`' – underlined.

Also a parsing of the LaTeX-like syntax is provided. There are commands for the font style changing inside the string (for example, use \b for bold font): \a or \overline – over-lined, \b or \textbf – bold, \i or \textit – italic, \r or \textrm – roman (disable bold and italic attributes), \u or \underline – underlined, \w or \wire – wired, \big – bigger size, @ – smaller size. The lower and upper indexes are specified by '`_`' and '`^`' symbols. At this the changed font style is applied only on next symbol or symbols in braces {}. The text in braces {} are treated as single symbol that allow one to print the index of index. For example, compare the strings '`sin (x^{2^3})`' and '`sin (x^2^3)`'. You may also change text color inside string by command #? or by \color? where '`?`' is symbolic id of the color (see Section 3.2 [Color styles], page 148). For example, words '`blue`' and '`red`' will be colored in the string '`#b{blue} and \colorr{red} text`'. The most of functions understand the newline symbol '`\n`' and allows to print multi-line text. Finally, you can use arbitrary (if it was defined in font-face) UTF codes by command `\utf0x????`. For example, `\utf0x3b1` will produce α symbol.

The most of commands for special TeX or AMSTeX symbols, the commands for font style changing (\textrm, \textbf, \textit, \textsc, \overline, \underline), accents (\hat, \tilde, \dot, \ddot, \acute, \check, \grave, \bar, \breve) and roots (\sqrt, \sqrt3, \sqrt4) are recognized. The full list contain approximately 2000 commands. Note that first space symbol after the command is ignored, but second one is printed as normal symbol (space). For example, the following strings produce the same result $\tilde{a}$: '`\tilde{a}`'; '`\tilde a`'; '`\tilde{}a`'.

In particular, the Greek letters are recognizable special symbols: α – \alpha, β – \beta, γ – \gamma, δ – \delta, ϵ – \epsilon, η – \eta, ι – \iota, χ – \chi, κ – \kappa, λ – \lambda, μ – \mu, ν – \nu, o – \o, ω – \omega, ϕ – \phi, π – \pi, ψ – \psi, ρ – \rho, σ – \sigma, θ – \theta, τ – \tau, υ – \upsilon, ξ – \xi, ζ – \zeta, ς – \varsigma, ε – \varepsilon, ϑ – \vartheta, φ – \varphi, A – \Alpha, B – \Beta, Γ – \Gamma, Δ – \Delta, E – \Epsilon,

H – \Eta, I – \Iota, C – \Chi, K – \Kappa, Λ – \Lambda, M – \Mu, N – \Nu, O – \O, Ω – \Omega, Φ – \Phi, Π – \Pi, Ψ – \Psi, R – \Rho, Σ – \Sigma, Θ – \Theta, T – \Tau, ϒ – \Upsilon, Ξ – \Xi, Z – \Zeta.

The small part of most common special TeX symbols are: ∠ – \angle, ℵ – \aleph, · – \cdot, ♣ – \clubsuit, ∪ – \cup, ∩ – \cap, ♢ – \diamondsuit, ⋄ – \diamond, ÷ – \div, ↓ – \downarrow, † – \dag, ‡ – \ddag, ≡ – \equiv, ∃ – \exists, ⌢ – \frown, ♭ – \flat, ≥ – \ge, ≥ – \geq, ← – \gets, ♡ – \heartsuit, ∞ – \infty, ∈ – \in, ∫ – \int, ℑ – \Im, ⟨ – \langle, ≤ – \le, ≤ – \leq, ← – \leftarrow, ∓ – \mp, ∇ – \nabla, ≠ – \ne, ≠ – \neq, ♮ – \natural, ∮ – \oint, ⊙ – \odot, ⊕ – \oplus, ∂ – \partial, ∥ – \parallel, ⊥ – \perp, ± – \pm, ∝ – \propto, ∏ – \prod, ℜ – \Re, → – \rightarrow, ⟩ – \rangle, ♠ – \spadesuit, ∼ – \sim, ⌣ – \smile, ⊂ – \subset, ⊃ – \supset, √ – \sqrt or \surd, § – \S, ♯ – \sharp, ∑ – \sum, × – \times, → – \to, ↑ – \uparrow, ℘ – \wp and so on.

The font size can be defined explicitly (if *size*>0) or relatively to a base font size as |*size*|**FontSize* (if *size*<0). The value *size*=0 specifies that the string will not be printed. The base font size is measured in internal "MathGL" units. Special functions `SetFontSizePT(), SetFontSizeCM(), SetFontSizeIN()` (see Section 4.2.6 [Font settings], page 162) allow one to set it in more "common" variables for a given dpi value of the picture.

3.6 Textual formulas

MathGL have the fast variant of textual formula evaluation (see Section 6.12 [Evaluate expression], page 282) . There are a lot of functions and operators available. The operators are: '`+`' – addition, '`-`' – subtraction, '`*`' – multiplication, '`/`' – division, '`^`' – integer power. Also there are logical "operators": '`<`' – true if x<y, '`>`' – true if x>y, '`=`' – true if x=y, '`&`' – true if x and y both nonzero, '`|`' – true if x or y nonzero. These logical operators have lowest priority and return 1 if true or 0 if false.

The basic functions are: '`sqrt(x)`' – square root of x, '`pow(x,y)`' – power x in y, '`ln(x)`' – natural logarithm of x, '`lg(x)`' – decimal logarithm of x, '`log(a,x)`' – logarithm base a of x, '`abs(x)`' – absolute value of x, '`sign(x)`' – sign of x, '`mod(x,y)`' – x modulo y, '`step(x)`' – step function, '`int(x)`' – integer part of x, '`rnd`' – random number, '`random(x)`' – random data of size as in x, '`pi`' – number $\pi = 3.1415926..., inf = \infty$

Functions for complex numbers '`real(x)`', '`imag(x)`', '`abs(x)`', '`arg(x)`', '`conj(x)`'.

Trigonometric functions are: '`sin(x)`', '`cos(x)`', '`tan(x)`' (or '`tg(x)`'). Inverse trigonometric functions are: '`asin(x)`', '`acos(x)`', '`atan(x)`'. Hyperbolic functions are: '`sinh(x)`' (or '`sh(x)`'), '`cosh(x)`' (or '`ch(x)`'), '`tanh(x)`' (or '`th(x)`'). Inverse hyperbolic functions are: '`asinh(x)`', '`acosh(x)`', '`atanh(x)`'.

There are a set of special functions: '`gamma(x)`' – Gamma function $\Gamma(x) = \int_0^\infty dt t^{x-1} exp(-t)$, '`gamma_inc(x,y)`' – incomplete Gamma function $\Gamma(x,y) = \int_y^\infty dt t^{x-1} exp(-t)$, '`psi(x)`' – digamma function $\psi(x) = \Gamma'(x)/\Gamma(x)$ for x!=0, '`ai(x)`' – Airy function Ai(x), '`bi(x)`' – Airy function Bi(x), '`cl(x)`' – Clausen function, '`li2(x)`' (or '`dilog(x)`') – dilogarithm $Li_2(x) = -\Re \int_0^x ds \log(1-s)/s$, '`sinc(x)`' – compute $sinc(x) = \sin(\pi x)/(\pi x)$ for any value of x, '`zeta(x)`' – Riemann zeta function $\zeta(s) = \sum_{k=1}^\infty k^{-s}$ for arbitrary s!=1, '`eta(x)`' – eta function $\eta(s) = (1 - 2^{1-s})\zeta(s)$ for arbitrary s, '`lp(l,x)`' – Legendre polynomial $P_l(x)$, (|x|<=1, l>=0), '`w0(x)`', '`w1(x)`' – principal branch of the Lambert W functions. Function W(x) is defined to be solution of the equation $W \exp(W) = x$.

The exponent integrals are: '`ci(x)`' – Cosine integral $Ci(x) = \int_0^x dt \cos(t)/t$, '`si(x)`' – Sine integral $Si(x) = \int_0^x dt \sin(t)/t$, '`erf(x)`' – error function $erf(x) = (2/\sqrt(\pi)) \int_0^x dt \exp(-t^2)$, '`ei(x)`' – exponential integral $Ei(x) := -PV(\int_{\{} -x\}^{\infty} dt \exp(-t)/t)$ (where PV denotes the principal value of the integral), '`e1(x)`' – exponential integral $E_1(x) := Re \int_1^{\infty} dt \exp(-xt)/t$, '`e2(x)`' – exponential integral $E_2(x) := Re \int_1^{\infty} dt \exp(-xt)/t^2$, '`ei3(x)`' – exponential integral $Ei_3(x) = \int_0^x dt \exp(-t^3)$ for x>=0.

Bessel functions are: '`j(nu,x)`' – regular cylindrical Bessel function of fractional order *nu*, '`y(nu,x)`' – irregular cylindrical Bessel function of fractional order *nu*, '`i(nu,x)`' – regular modified Bessel function of fractional order *nu*, '`k(nu,x)`' – irregular modified Bessel function of fractional order *nu*.

Elliptic integrals are: '`ee(k)`' – complete elliptic integral is denoted by $E(k) = E(\pi/2, k)$, '`ek(k)`' – complete elliptic integral is denoted by $K(k) = F(\pi/2, k)$, '`e(phi,k)`' – elliptic integral $E(\phi, k) = \int_0^{\phi} dt \sqrt(1 - k^2 \sin^2(t)))$, '`f(phi,k)`' – elliptic integral $F(\phi, k) = \int_0^{\phi} dt 1/\sqrt(1 - k^2 \sin^2(t)))$.

Jacobi elliptic functions are: '`sn(u,m)`', '`cn(u,m)`', '`dn(u,m)`', '`sc(u,m)`', '`sd(u,m)`', '`ns(u,m)`', '`cs(u,m)`', '`cd(u,m)`', '`nc(u,m)`', '`ds(u,m)`', '`dc(u,m)`', '`nd(u,m)`'.

Note, some of these functions are unavailable if MathGL was compiled without GSL support.

There is no difference between lower or upper case in formulas. If argument value lie outside the range of function definition then function returns NaN.

3.7 Command options

Command options allow the easy setup of the selected plot by changing global settings only for this plot. Each option start from symbol '`;`'. Options work so that MathGL remember the current settings, change settings as it being set in the option, execute function and return the original settings back. So, the options are most usable for plotting functions.

The most useful options are `xrange, yrange, zrange`. They sets the boundaries for data change. This boundaries are used for automatically filled variables. So, these options allow one to change the position of some plots. For example, in command `Plot(y,"","xrange 0.1 0.9");` or `plot y; xrange 0.1 0.9` the x coordinate will be equidistantly distributed in range 0.1 ... 0.9. See Section 2.9.18 [Using options], page 138, for sample code and picture.

The full list of options are:

`alpha val` [MGL option]
: Sets alpha value (transparency) of the plot. The value should be in range [0, 1]. See also [alphadef], page 159.

`xrange val1 val2` [MGL option]
: Sets boundaries of x coordinate change for the plot. See also [xrange], page 167.

`yrange val1 val2` [MGL option]
: Sets boundaries of y coordinate change for the plot. See also [yrange], page 167.

`zrange val1 val2` [MGL option]
Sets boundaries of z coordinate change for the plot. See also [zrange], page 167.

`cut val` [MGL option]
Sets whether to cut or to project the plot points lying outside the bounding box. See also [cut], page 162.

`size val` [MGL option]
Sets the size of text, marks and arrows. See also [font], page 162, [marksize], page 161, [arrowsize], page 161.

`meshnum val` [MGL option]
Work like [meshnum], page 161 command.

`legend` *'txt'* [MGL option]
Adds string 'txt' to internal legend accumulator. The style of described line and mark is taken from arguments of the last Section 4.11 [1D plotting], page 195 command. See also [legend], page 194.

`value val` [MGL option]
Set the value to be used as additional numeric parameter in plotting command.

3.8 Interfaces

The MathGL library has interfaces for a set of languages. Most of them are based on the C interface via SWIG tool. There are Python, Java, Octave, Lisp, C#, Guile, Lua, Modula 3, Ocaml, Perl, PHP, Pike, R, Ruby, and Tcl interfaces. Also there is a Fortran interface which has a similar set of functions, but slightly different types of arguments (integers instead of pointers). These functions are marked as [C function].

Some of the languages listed above support classes (like C++ or Python). The name of functions for them is the same as in C++ (see Chapter 4 [MathGL core], page 158 and Chapter 6 [Data processing], page 252) and marked like [Method on mglGraph].

Finally, a special command language MGL (see Chapter 7 [MGL scripts], page 286) was written for a faster access to plotting functions. Corresponding scripts can be executed separately (by UDAV, mglconv, mglview and so on) or from the C/C++/Python/... code (see Section 7.4 [mglParse class], page 292).

3.8.1 C/Fortran interface

The C interface is a base for many other interfaces. It contains the pure C functions for most of the methods of MathGL classes. In distinction to C++ classes, C functions must have an argument HMGL (for graphics) and/or HMDT (for data arrays), which specifies the object for drawing or manipulating (changing). So, firstly, the user has to create this object by the function `mgl_create_*()` and has to delete it after the use by function `mgl_delete_*()`.

All C functions are described in the header file `#include <mgl2/mgl_cf.h>` and use variables of the following types:

- `HMGL` — Pointer to class `mglGraph` (see Chapter 4 [MathGL core], page 158).
- `HCDT` — Pointer to class `const mglDataA` (see Chapter 6 [Data processing], page 252) — constant data array.

- `HMDT` — Pointer to class `mglData` (see Chapter 6 [Data processing], page 252) — data array of real numbers.
- `HADT` — Pointer to class `mglDataC` (see Chapter 6 [Data processing], page 252) — data array of complex numbers.
- `HMPR` — Pointer to class `mglParse` (see Section 7.4 [mglParse class], page 292) — MGL script parsing.
- `HMEX` — Pointer to class `mglExpr` (see Section 6.12 [Evaluate expression], page 282) — textual formulas for real numbers.
- `HMAX` — Pointer to class `mglExprC` (see Section 6.12 [Evaluate expression], page 282) — textual formulas for complex numbers.

These variables contain identifiers for graphics drawing objects and for the data objects.

Fortran functions/subroutines have the same names as C functions. However, there is a difference. Variable of type `HMGL, HMDT` must be an integer with sufficient size (`integer*4` in the 32-bit operating system or `integer*8` in the 64-bit operating system). All C functions of type `void` are subroutines in Fortran, which are called by operator `call`. The exceptions are functions, which return variables of types `HMGL` or `HMDT`. These functions should be declared as integer in Fortran code. Also, one should keep in mind that strings in Fortran are denoted by ' symbol, not the " symbol.

3.8.2 C++/Python interface

MathGL provides the interface to a set of languages via SWIG library. Some of these languages support classes. The typical example is Python – which is named in this chapter's title. Exactly the same classes are used for high-level C++ API. Its feature is using only inline member-functions what make high-level API to be independent on compiler even for binary build.

There are 3 main classes in:

- `mglGraph` – provide most plotting functions (see Chapter 4 [MathGL core], page 158).
- `mglData` – provide base data processing (see Chapter 6 [Data processing], page 252). It have an additional feature to access data values. You can use a construct like this: `dat[i]=sth;` or `sth=dat[i]` where flat representation of data is used (i.e., i can be in range 0...nx*nx*nz-1). You can also import NumPy arrays as input arguments in Python: `mgl_dat = mglData(numpy_dat);`.
- `mglParse` – provide functions for parsing MGL scripts (see Chapter 7 [MGL scripts], page 286).

To use Python classes just execute '`import mathgl`'. The simplest example will be:

```
import mathgl
a=mathgl.mglGraph()
a.Box()
a.WritePNG("test.png")
```

Alternatively you can import all classes from `mathgl` module and easily access MathGL classes like this:

```
from mathgl import *
a=mglGraph()
```

```
a.Box()
a.WritePNG("test.png")
```

This becomes useful if you create many `mglData` objects, for example.

4 MathGL core

The core of MathGL is **mglGraph** class defined in `#include <mgl2/mgl.h>`. It contains a lot of plotting functions for 1D, 2D and 3D data. It also encapsulates parameters for axes drawing. Moreover an arbitrary coordinate transformation can be used for each axis. All plotting functions use data encapsulated in mglData class (see Chapter 6 [Data processing], page 252) that allows to check sizes of used arrays easily. Also it have many functions for data handling: modify it by formulas, find momentums and distribution (histogram), apply operator (differentiate, integrate, transpose, Fourier and so on), change data sizes (interpolate, squeeze, crop and so on). Additional information about colors, fonts, formula parsing can be found in Chapter 3 [General concepts], page 147 and Chapter 9 [Other classes], page 304.

Some of MathGL features will appear only in novel versions. To test used MathGL version you can use following function.

`version` *'ver'* [MGL command]
`bool CheckVersion (const char *`*ver*`) static` [Method on `mglGraph`]
`int mgl_check_version (const char *`*ver*`)` [C function]
Return zero if MathGL version is appropriate for required by *ver*, i.e. if major version is the same and minor version is greater or equal to one in *ver*.

4.1 Create and delete objects

`mglGraph (int` *kind*`=0, int` *width*`=600, int` *height*`=400)` [Constructor on `mglGraph`]
`mglGraph (const mglGraph &`*gr*`)` [Constructor on `mglGraph`]
`mglGraph (HMGL` *gr*`)` [Constructor on `mglGraph`]
`HMGL mgl_create_graph (int` *width*`, int` *height*`)` [C function]
`HMGL mgl_create_graph_gl ()` [C function]
Creates the instance of class mglGraph with specified sizes *width* and *height*. Parameter *kind* may have following values: '`0`' – use default plotter, '`1`' – use OpenGL plotter.

`~mglGraph ()` [Destructor on `mglGraph`]
`HMGL mgl_delete_graph (HMGL` *gr*`)` [C function]
Deletes the instance of class mglGraph.

`HMGL Self ()` [Method on `mglGraph`]
Returns the pointer to internal object of type `HMGL`.

4.2 Graphics setup

Functions and variables in this group influences on overall graphics appearance. So all of them should be placed *before* any actual plotting function calls.

`reset` [MGL command]
`void DefaultPlotParam ()` [Method on `mglGraph`]
`void mgl_set_def_param (HMGL` *gr*`)` [C function]
Restore initial values for all of parameters and clear the image.

4.2.1 Transparency

There are several functions and variables for setup transparency. The general function is [alpha], page 159 which switch on/off the transparency for overall plot. It influence only for graphics which created after [alpha], page 159 call (with one exception, OpenGL). Function [alphadef], page 159 specify the default value of alpha-channel. Finally, function [transptype], page 159 set the kind of transparency. See Section 2.9.2 [Transparency and lighting], page 113, for sample code and picture.

`alpha [val=on]` [MGL command]
`void Alpha (bool` *enable*`)` [Method on `mglGraph`]
`void mgl_set_alpha (HMGL` *gr*`, int` *enable*`)` [C function]

Sets the transparency on/off and returns previous value of transparency. It is recommended to call this function before any plotting command. Default value is transparency off.

`alphadef val` [MGL command]
`void SetAlphaDef (mreal` *val*`)` [Method on `mglGraph`]
`void mgl_set_alpha_default (HMGL` *gr*`, mreal` *alpha*`)` [C function]

Sets default value of alpha channel (transparency) for all plotting functions. Initial value is 0.5.

`transptype val` [MGL command]
`void SetTranspType (int` *type*`)` [Method on `mglGraph`]
`void mgl_set_transp_type (HMGL` *gr*`, int` *type*`)` [C function]

Set the type of transparency. Possible values are:

- Normal transparency ('`0`') – below things is less visible than upper ones. It does not look well in OpenGL mode (mglGraphGL) for several surfaces.
- Glass-like transparency ('`1`') – below and upper things are commutable and just decrease intensity of light by RGB channel.
- Lamp-like transparency ('`2`') – below and upper things are commutable and are the source of some additional light. I recommend to set `SetAlphaDef(0.3)` or less for lamp-like transparency.

See Section 2.9.3 [Types of transparency], page 114, for sample code and picture..

4.2.2 Lighting

There are several functions for setup lighting. The general function is [light], page 159 which switch on/off the lighting for overall plot. It influence only for graphics which created after [light], page 159 call (with one exception, OpenGL). Generally MathGL support up to 10 independent light sources. But in OpenGL mode only 8 of light sources is used due to OpenGL limitations. The position, color, brightness of each light source can be set separately. By default only one light source is active. It is source number `0` with white color, located at top of the plot. See Section 2.9.6 [Lighting sample], page 118, for sample code and picture.

`light [val=on]` [MGL command]
`bool Light (bool` *enable*`)` [Method on `mglGraph`]

`void mgl_set_light (HMGL` *gr*`, int` *enable*`)` [C function]
Sets the using of light on/off for overall plot. Function returns previous value of lighting. Default value is lightning off.

`light num val` [MGL command]
`void Light (int` *n*`, bool` *enable*`)` [Method on `mglGraph`]
`void mgl_set_light_n (HMGL` *gr*`, int` *n*`, int` *enable*`)` [C function]
Switch on/off *n*-th light source separately.

`light num xdir ydir zdir [`*'col'='w'*` br=0.5]` [MGL command]
`light num xdir ydir zdir xpos ypos zpos [`*'col'='w'*` br=0.5]` [MGL command]
`void AddLight (int` *n*`, mglPoint` *d*`, char` *c*`='w', mreal` *bright*`=0.5, mreal` *ap*`=0)` [Method on `mglGraph`]
`void AddLight (int` *n*`, mglPoint` *r*`, mglPoint` *d*`, char` *c*`='w', mreal` *bright*`=0.5, mreal` *ap*`=0)` [Method on `mglGraph`]
`void mgl_add_light (HMGL` *gr*`, int` *n*`, mreal` *dx*`, mreal` *dy*`, mreal` *dz*`)` [C function]
`void mgl_add_light_ext (HMGL` *gr*`, int` *n*`, mreal` *dx*`, mreal` *dy*`, mreal` *dz*`, char` *c*`, mreal` *bright*`, mreal` *ap*`)` [C function]
`void mgl_add_light_loc (HMGL` *gr*`, int` *n*`, mreal` *rx*`, mreal` *ry*`, mreal` *rz*`, mreal` *dx*`, mreal` *dy*`, mreal` *dz*`, char` *c*`, mreal` *bright*`, mreal` *ap*`)` [C function]
The function adds a light source with identification *n* in direction *d* with color *c* and with brightness *bright* (which must be in range [0,1]). If position *r* is specified and isn't NAN then light source is supposed to be local otherwise light source is supposed to be placed at infinity.

`diffuse val` [MGL command]
`void SetDiffuse (mreal` *bright*`)` [Method on `mglGraph`]
`void mgl_set_difbr (HMGL` *gr*`, mreal` *bright*`)` [C function]
Set brightness of diffusive light (only for local light sources).

`ambient val` [MGL command]
`void SetAmbient (mreal` *bright*`=0.5)` [Method on `mglGraph`]
`void mgl_set_ambbr (HMGL` *gr*`, mreal` *bright*`)` [C function]
Sets the brightness of ambient light. The value should be in range [0,1].

`attachlight val` [MGL command]
`void AttachLight (bool` *val*`)` [Method on `mglGraph`]
`void mgl_set_attach_light (HMGL` *gr*`, int` *val*`)` [C function]
Set to attach light settings to [inplot], page 173/[subplot], page 173. Note, OpenGL and some output formats don't support this feature.

4.2.3 Fog

`fog val [dz=0.25]` [MGL command]
`void Fog (mreal` *d*`, mreal` *dz*`=0.25)` [Method on `mglGraph`]
`void mgl_set_fog (HMGL` *gr*`, mreal` *d*`, mreal` *dz*`)` [C function]
Function imitate a fog in the plot. Fog start from relative distance *dz* from view point and its density growths exponentially in depth. So that the fog influence is determined by law ~ 1-exp(-*d***z*). Here *z* is normalized to 1 depth of the plot. If value *d*=0 then

the fog is absent. Note, that fog was applied at stage of image creation, not at stage of drawing. See Section 2.9.5 [Adding fog], page 117, for sample code and picture.

4.2.4 Default sizes

These variables control the default (initial) values for most graphics parameters including sizes of markers, arrows, line width and so on. As any other settings these ones will influence only on plots created after the settings change.

`barwidth val` [MGL command]
`void SetBarWidth ( mreal` *val*`)` [Method on `mglGraph`]
`void mgl_set_bar_width (HMGL` *gr*`, mreal` *val*`)` [C function]
Sets relative width of rectangles in [bars], page 198, [barh], page 199, [boxplot], page 200, [candle], page 201, [ohlc], page 201. Default value is `0.7`.

`marksize val` [MGL command]
`void SetMarkSize (mreal` *val*`)` [Method on `mglGraph`]
`void mgl_set_mark_size (HMGL` *gr*`, mreal` *val*`)` [C function]
Sets size of marks for Section 4.11 [1D plotting], page 195. Default value is `1`.

`arrowsize val` [MGL command]
`void SetArrowSize (mreal` *val*`)` [Method on `mglGraph`]
`void mgl_set_arrow_size (HMGL` *gr*`, mreal` *val*`)` [C function]
Sets size of arrows for Section 4.11 [1D plotting], page 195, lines and curves (see Section 4.7 [Primitives], page 185). Default value is `1`.

`meshnum val` [MGL command]
`void SetMeshNum (int` *val*`)` [Method on `mglGraph`]
`void mgl_set_meshnum (HMGL` *gr*`, int` *num*`)` [C function]
Sets approximate number of lines in [mesh], page 208, [fall], page 208, [grid2], page 213 and also the number of hachures in [vect], page 223, [dew], page 224 and the number of cells in [cloud], page 214. By default (=0) it draws all lines/hachures/cells.

`facenum val` [MGL command]
`void SetFaceNum (int` *val*`)` [Method on `mglGraph`]
`void mgl_set_facenum (HMGL` *gr*`, int` *num*`)` [C function]
Sets approximate number of visible faces. Can be used for speeding up drawing by cost of lower quality. By default (=0) it draws all of them.

`plotid` *'id'* [MGL command]
`void SetPlotId (const char *`*id*`)` [Method on `mglGraph`]
`void mgl_set_plotid (HMGL` *gr*`, const char *`*id*`)` [C function]
Sets default name *id* as filename for saving (in FLTK window for example).

`const char * GetPlotId ()` [Method on `mglGraph`]
`const char * mgl_get_plotid (HMGL` *gr*`)` [C function only]
`mgl_get_plotid (long` *gr*`, char *`*out*`, int` *len*`)` [Fortran subroutine]
Gets default name *id* as filename for saving (in FLTK window for example).

`pendelta val` [MGL command]
`void SetPenDelta (double val)` [Method on `mglGraph`]
`void mgl_pen_delta (HMGL gr, double val)` [C function]
Changes the blur around lines and text (default is 1). For *val*>1 the text and lines are more sharped. For *val*<1 the text and lines are more blurred.

4.2.5 Cutting

These variables and functions set the condition when the points are excluded (cutted) from the drawing. Note, that a point with NAN value(s) of coordinate or amplitude will be automatically excluded from the drawing. See Section 2.2.9 [Cutting sample], page 35, for sample code and picture.

`cut val` [MGL command]
`void SetCut (bool val)` [Method on `mglGraph`]
`void mgl_set_cut (HMGL gr, int val)` [C function]
Flag which determines how points outside bounding box are drawn. If it is `true` then points are excluded from plot (it is default) otherwise the points are projected to edges of bounding box.

`cut x1 y1 z1 x2 y2 z2` [MGL command]
`void SetCutBox (mglPoint p1, mglPoint p1)` [Method on `mglGraph`]
`void mgl_set_cut_box (HMGL gr, mreal x1, mreal y1, mreal z1, mreal x2, mreal y2, mreal z2)` [C function]
Lower and upper edge of the box in which never points are drawn. If both edges are the same (the variables are equal) then the cutting box is empty.

`cut 'cond'` [MGL command]
`void CutOff (const char *cond)` [Method on `mglGraph`]
`void mgl_set_cutoff (HMGL gr, const char *cond)` [C function]
Sets the cutting off condition by formula *cond*. This condition determine will point be plotted or not. If value of formula is nonzero then point is omitted, otherwise it plotted. Set argument as `""` to disable cutting off condition.

4.2.6 Font settings

`font 'fnt' [val=6]` [MGL command]
Font style for text and labels (see text). Initial style is 'fnt'=':rC' give Roman font with centering. Parameter `val` sets the size of font for tick and axis labels. Default font size of axis labels is 1.4 times large than for tick labels. For more detail, see Section 3.5 [Font styles], page 152.

`rotatetext val` [MGL command]
`void SetRotatedText (bool val)` [Method on `mglGraph`]
`void mgl_set_rotated_text (HMGL gr, int val)` [C function]
Sets to use or not text rotation.

`loadfont ['name'='']` [MGL command]
`void LoadFont (const char *name, const char *path="")` [Method on `mglGraph`]

`void mgl_load_font (HMGL` *gr*`, const char *`*name*`, const char *`*path*`)` [C function]
Load font typeface from *path*/*name*. Empty name will load default font.

`void SetFontDef (const char *`*fnt*`)` [Method on `mglGraph`]
`void mgl_set_font_def (HMGL` *gr*`, const char * `*val*`)` [C function]
Sets the font specification (see Section 4.8 [Text printing], page 189). Default is '`rC`' – Roman font centering.

`void SetFontSize (mreal` *val*`)` [Method on `mglGraph`]
`void mgl_set_font_size (HMGL` *gr*`, mreal` *val*`)` [C function]
Sets the size of font for tick and axis labels. Default font size of axis labels is 1.4 times large than for tick labels.

`void SetFontSizePT (mreal` *cm*`, int` *dpi*=72`)` [Method on `mglGraph`]
Set FontSize by size in pt and picture DPI (default is 16 pt for dpi=72).

`inline void SetFontSizeCM (mreal` *cm*`, int` *dpi*=72`)` [Method on `mglGraph`]
Set FontSize by size in centimeters and picture DPI (default is 0.56 cm = 16 pt).

`inline void SetFontSizeIN (mreal` *cm*`, int` *dpi*=72`)` [Method on `mglGraph`]
Set FontSize by size in inch and picture DPI (default is 0.22 in = 16 pt).

`void LoadFont (const char *`*name*`, const char *`*path*`="")` [Method on `mglGraph`]
`void mgl_load_font (HMGL` *gr*`, const char *`*name*`, const char *`*path*`)` [C function]
Load font typeface from *path*/*name*.

`void CopyFont (mglGraph * `*from*`)` [Method on `mglGraph`]
`void mgl_copy_font (HMGL` *gr*`, HMGL` *gr_from*`)` [C function]
Copy font data from another `mglGraph` object.

`void RestoreFont ()` [Method on `mglGraph`]
`void mgl_restore_font (HMGL` *gr*`)` [C function]
Restore font data to default typeface.

`void SetDefFont (const char *`*name*`, const char *`*path*`="")` *static* [Method on `mglGraph`]
`void mgl_def_font (const char *`*name*`, const char *`*path*`)` [C function]
Load default font typeface (for all newly created HMGL/mglGraph objects) from *path*/*name*.

4.2.7 Palette and colors

`palette` *'colors'* [MGL command]
`void SetPalette (const char *`*colors*`)` [Method on `mglGraph`]
`void mgl_set_palette (HMGL` *gr*`, const char *`*colors*`)` [C function]
Sets the palette as selected colors. Default value is `"Hbgrcmyhlnqeup"` that corresponds to colors: dark gray '`H`', blue '`b`', green '`g`', red '`r`', cyan '`c`', magenta '`m`', yellow

'y', gray 'h', blue-green 'l', sky-blue 'n', orange 'q', yellow-green 'e', blue-violet 'u', purple 'p'. The palette is used mostly in 1D plots (see Section 4.11 [1D plotting], page 195) for curves which styles are not specified. Internal color counter will be nullified by any change of palette. This includes even hidden change (for example, by [box], page 193 or [axis], page 191 functions).

`void SetDefScheme (const char *`*sch*`)` [Method on `mglGraph`]
`void mgl_set_def_sch (HMGL` *gr*`, const char *`*sch*`)` [C function]
Sets the *sch* as default color scheme. Default value is `"BbcyrR"`.

`void SetColor (char` *id*`, mreal` *r*`, mreal` *g*`, mreal` *b*`)` *static* [Method on `mglGraph`]
`void mgl_set_color (char` *id*`, mreal` *r*`, mreal` *g*`, mreal` *b*`)` [C function]
Sets RGB values for color with given *id*. This is global setting which influence on any later usage of symbol *id*.

4.2.8 Masks

`mask` *'id' 'hex'* [MGL command]
`void SetMask (char` *id*`, const char *`*hex*`)` [Method on `mglGraph`]
`void SetMask (char` *id*`, uint64_t` *hex*`)` [Method on `mglGraph`]
`void mgl_set_mask (HMGL` *gr*`, const char *`*hex*`)` [C function]
`void mgl_set_mask_val (HMGL` *gr*`, uint64_t` *hex*`)` [C function]
Sets new bit matrix *hex* of size 8*8 for mask with given *id*. This is global setting which influence on any later usage of symbol *id*. The predefined masks are (see Section 3.4 [Color scheme], page 150): '-' is 000000FF00000000, '+' is 080808FF08080808, '=' is 0000FF00FF000000, ';' is 0000007700000000, 'o' is 0000182424180000, 'O' is 0000183C3C180000, 's' is 00003C24243C0000, 'S' is 00003C3C3C3C0000, '~' is 0000060990600000, '<' is 0060584658600000, '>' is 00061A621A060000, 'j' is 0000005F00000000, 'd' is 0008142214080000, 'D' is 00081C3E1C080000, '*' is 8142241818244281, '^' is 0000001824420000.

`mask` *angle* [MGL command]
`void SetMaskAngle (int` *angle*`)` [Method on `mglGraph`]
`void mgl_set_mask_angle (HMGL` *gr*`, int` *angle*`)` [C function]
Sets the default rotation angle (in degrees) for masks. Note, you can use symbols '\', '/', 'I' in color scheme for setting rotation angles as 45, -45 and 90 degrees correspondingly.

4.2.9 Error handling

Normally user should set it to zero by `SetWarn(0);` before plotting and check if `GetWarn()` or `Message()` return non zero after plotting. Only last warning will be saved. All warnings/errors produced by MathGL is not critical – the plot just will not be drawn. By default, all warnings are printed in stderr. You can disable it by using `mgl_suppress_warn(true);`.

`void SetWarn (int` *code*`, const char *`*info*`="")` [Method on `mglGraph`]
`void mgl_set_warn (HMGL` *gr*`, int` *code*`, const char *`*info*`)` [C function]
Set warning code. Normally you should call this function only for clearing the warning state, i.e. call `SetWarn(0);`. Text *info* will be printed as is if *code*<0.

`const char *Message ()` [Method on `mglGraph`]
`const char *mgl_get_mess (HMGL` *gr*`)` [C function only]
`mgl_get_mess (long` *gr*`, char *`*out*`, int` *len*`)` [Fortran subroutine]

Return messages about matters why some plot are not drawn. If returned string is empty then there are no messages.

`int GetWarn ()` [Method on `mglGraph`]
`int mgl_get_warn (HMGL` *gr*`)` [C function]

Return the numerical ID of warning about the not drawn plot. Possible values are:

`mglWarnNone=0`
: Everything OK

`mglWarnDim`
: Data dimension(s) is incompatible

`mglWarnLow`
: Data dimension(s) is too small

`mglWarnNeg`
: Minimal data value is negative

`mglWarnFile`
: No file or wrong data dimensions

`mglWarnMem`
: Not enough memory

`mglWarnZero`
: Data values are zero

`mglWarnLeg`
: No legend entries

`mglWarnSlc`
: Slice value is out of range

`mglWarnCnt`
: Number of contours is zero or negative

`mglWarnOpen`
: Couldn't open file

`mglWarnLId`
: Light: ID is out of range

`mglWarnSize`
: Setsize: size(s) is zero or negative

`mglWarnFmt`
: Format is not supported for that build

`mglWarnTern`
: Axis ranges are incompatible

`mglWarnNull`
: Pointer is NULL

`mglWarnSpc`
: Not enough space for plot

`mglScrArg`
: Wrong argument(s) of a command in MGL script

`mglScrCmd`
: Wrong command in MGL script

`mglScrLong`
: Too long line in MGL script

`mglScrStr`
: Unbalanced ' in MGL script

`mglScrTemp`
: Change temporary data in MGL script

`void SuppressWarn (bool` *state*`) static` [Method on `mglGraph`]
`void mgl_suppress_warn (int` *state*`)` [C function]
Disable printing warnings to `stderr` if *state* is nonzero.

`void SetGlobalWarn (const char *`*info*`) static` [Method on `mglGraph`]
`void mgl_set_global_warn (const char *`*info*`)` [C function]
Set warning message *info* for global scope.

`const char * GlobalWarn () static` [Method on `mglGraph`]
`const char * mgl_get_global_warn ()` [C function]
Get warning message(s) for global scope.

4.2.10 Stop drawing

`void Stop (bool` *stop*`=true)` [Method on `mglGraph`]
`void mgl_ask_stop (HMGL` *gr*`, int` *stop*`)` [C function only]
Ask to stop drawing if *stop* is non-zero, otherwise reset stop flag.

`bool NeedStop ()` [Method on `mglGraph`]
`void mgl_need_stop (HMGL` *gr*`)` [C function only]
Return `true` if drawing should be terminated. Also it process all events in GUI. User should call this function from time to time inside a long calculation to allow processing events for GUI.

`bool SetEventFunc (void (*`*func*`)(void *), void *`*par*`=NULL)` [Method on `mglGraph`]
`void mgl_set_event_func (HMGL` *gr*`, void (*`*func*`)(void *), void *`*par*`)` [C function only]
Set callback function which will be called to process events of GUI library.

4.3 Axis settings

These large set of variables and functions control how the axis and ticks will be drawn. Note that there is 3-step transformation of data coordinates are performed. Firstly, coordinates are projected if `Cut=true` (see Section 4.2.5 [Cutting], page 162), after it transformation formulas are applied, and finally the data was normalized in bounding box. Note, that MathGL will produce warning if axis range and transformation formulas are not compatible.

4.3.1 Ranges (bounding box)

`xrange v1 v2 [add=off]` [MGL command]
`yrange v1 v2 [add=off]` [MGL command]
`zrange v1 v2 [add=off]` [MGL command]
`crange v1 v2 [add=off]` [MGL command]
`void SetRange (char` *dir*`, mreal` *v1*`, mreal` *v2*`)` [Method on `mglGraph`]
`void AddRange (char` *dir*`, mreal` *v1*`, mreal` *v2*`)` [Method on `mglGraph`]
`void mgl_set_range_val (HMGL` *gr*`, char` *dir*`, mreal` *v1*`, mreal` *v2*`)` [C function]
`void mgl_add_range_val (HMGL` *gr*`, char` *dir*`, mreal` *v1*`, mreal` *v2*`)` [C function]

Sets or adds the range for '`x`'-,'`y`'-,'`z`'- coordinate or coloring ('`c`'). If one of values is `NAN` then it is ignored. See also [ranges], page 167.

`xrange` *dat* `[add=off]` [MGL command]
`yrange` *dat* `[add=off]` [MGL command]
`zrange` *dat* `[add=off]` [MGL command]
`crange` *dat* `[add=off]` [MGL command]
`void SetRange (char` *dir*`, const mglDataA &`*dat*`, bool` *add*`=false)` [Method on `mglGraph`]
`void mgl_set_range_dat (HMGL` *gr*`, char` *dir*`, const HCDT` *a*`, int` *add*`)` [C function]

Sets the range for '`x`'-,'`y`'-,'`z`'- coordinate or coloring ('`c`') as minimal and maximal values of data *dat*. Parameter `add=on` shows that the new range will be joined to existed one (not replace it).

`ranges x1 x2 y1 y2 [z1=0 z2=0]` [MGL command]
`void SetRanges (mglPoint` *p1*`, mglPoint` *p2*`)` [Method on `mglGraph`]
`void SetRanges (double` *x1*`, double` *x2*`, double` *y1*`, double` *y2*`, double` *z1*`=0, double` *z2*`=0)` [Method on `mglGraph`]
`void mgl_set_ranges (HMGL` *gr*`, double` *x1*`, double` *x2*`, double` *y1*`, double` *y2*`, double` *z1*`, double` *z2*`)` [C function]

Sets the ranges of coordinates. If minimal and maximal values of the coordinate are the same then they are ignored. Also it sets the range for coloring (analogous to `crange z1 z2`). This is default color range for 2d plots. Initial ranges are [-1, 1].

`void SetRanges (const mglDataA &`*xx*`, const mglDataA &`*yy*`)` [Method on `mglGraph`]
`void SetRanges (const mglDataA &`*xx*`, const mglDataA &`*yy*`, const mglDataA &`*zz*`)` [Method on `mglGraph`]

`void SetRanges (const mglDataA &`*xx*`, const mglDataA &`*yy*`, const mglDataA &`*zz*`, const mglDataA &`*cc*`)` [Method on `mglGraph`]

Sets the ranges of '`x`'-,'`y`'-,'`z`'-coordinates and coloring as minimal and maximal values of data *xx*, *yy*, *zz*, *cc* correspondingly.

`void SetAutoRanges (mglPoint` *p1*`, mglPoint` *p2*`)` [Method on `mglGraph`]
`void SetAutoRanges (double` *x1*`, double` *x2*`, double` *y1*`, double` *y2*`, double` *z1*`=0, double` *z2*`=0, double` *c1*`=0, double` *c2*`=0)` [Method on `mglGraph`]
`void mgl_set_auto_ranges (HMGL` *gr*`, double` *x1*`, double` *x2*`, double` *y1*`, double` *y2*`, double` *z1*`, double` *z2*`, double` *z1*`, double` *z2*`)` [C function]

Sets the ranges for automatic coordinates. If minimal and maximal values of the coordinate are the same then they are ignored.

`origin x0 y0 [z0=nan]` [MGL command]
`void SetOrigin (mglPoint` *p0*`)` [Method on `mglGraph`]
`void SetOrigin (mreal` *x0*`, mreal` *y0*`, mreal` *z0*`=NAN)` [Method on `mglGraph`]
`void mgl_set_origin (HMGL` *gr*`, mreal` *x0*`, mreal` *y0*`, mreal` *z0*`)` [C function]

Sets center of axis cross section. If one of values is NAN then MathGL try to select optimal axis position.

`zoomaxis x1 x2` [MGL command]
`zoomaxis x1 y1 x2 y2` [MGL command]
`zoomaxis x1 y1 z1 x2 y2 z2` [MGL command]
`zoomaxis x1 y1 z1 c1 x2 y2 z2 c2` [MGL command]
`void ZoomAxis (mglPoint` *p1*`, mglPoint` *p2*`)` [Method on `mglGraph`]
`void mgl_zoom_axis (HMGL` *gr*`, mreal` *x1*`, mreal` *y1*`, mreal` *z1*`, mreal` *c1*`, mreal` *x2*`, mreal` *y2*`, mreal` *z2*`, mreal` *c2*`)` [C function]

Additionally extend axis range for any settings made by `SetRange` or `SetRanges` functions according the formula $min+ = (max - min) * p1$ and $max+ = (max - min) * p1$ (or $min* = (max/min)^{p}1$ and $max* = (max/min)^{p}1$ for log-axis range when $inf > max/min > 100$ or $0 < max/min < 0.01$). Initial ranges are [0, 1]. Attention! this settings can not be overwritten by any other functions, including `DefaultPlotParam()`.

4.3.2 Curved coordinates

`axis 'fx' 'fy' 'fz' ['fa'='']` [MGL command]
`void SetFunc (const char *`*EqX*`, const char *`*EqY*`, const char *`*EqZ*`="", const char *`*EqA*`="")` [Method on `mglGraph`]
`void mgl_set_func (HMGL` *gr*`, const char *`*EqX*`, const char *`*EqY*`, const char *`*EqZ*`, const char *`*EqA*`)` [C function]

Sets transformation formulas for curvilinear coordinate. Each string should contain mathematical expression for real coordinate depending on internal coordinates '`x`', '`y`', '`z`' and '`a`' or '`c`' for colorbar. For example, the cylindrical coordinates are introduced as `SetFunc("x*cos(y)", "x*sin(y)", "z");`. For removing of formulas the corresponding parameter should be empty or `NULL`. Using transformation formulas will slightly slowing the program. Parameter *EqA* set the similar transformation formula for color scheme. See Section 3.6 [Textual formulas], page 153.

`axis how` [MGL command]
`void SetCoor (int` *how*`)` [Method on `mglGraph`]
`void mgl_set_coor (HMGL` *gr*`, int` *how*`)` [C function]

Sets one of the predefined transformation formulas for curvilinear coordinate. Parameter *how* define the coordinates: `mglCartesian=0` – Cartesian coordinates (no transformation); `mglPolar=1` – Polar coordinates $x_n = x*cos(y), y_n = x*sin(y), z_n = z$; `mglSpherical=2` – Sperical coordinates $x_n = x*sin(y)*cos(z), y_n = x*sin(y)*sin(z), z_n = x*cos(y)$; `mglParabolic=3` – Parabolic coordinates $x_n = x*y, y_n = (x*x - y*y)/2, z_n = z$; `mglParaboloidal=4` – Paraboloidal coordinates $x_n = (x*x - y*y)*cos(z)/2, y_n = (x*x - y*y)*sin(z)/2, z_n = x*y$; `mglOblate=5` – Oblate coordinates $x_n = cosh(x)*cos(y)*cos(z), y_n = cosh(x)*cos(y)*sin(z), z_n = sinh(x)*sin(y)$; `mglProlate=6` – Prolate coordinates $x_n = sinh(x)*sin(y)*cos(z), y_n = sinh(x)*sin(y)*sin(z), z_n = cosh(x)*cos(y)$; `mglElliptic=7` – Elliptic coordinates $x_n = cosh(x)*cos(y), y_n = sinh(x)*sin(y), z_n = z$; `mglToroidal=8` – Toroidal coordinates $x_n = sinh(x)*cos(z)/(cosh(x)-cos(y)), y_n = sinh(x)*sin(z)/(cosh(x)-cos(y)), z_n = sin(y)/(cosh(x)-cos(y))$; `mglBispherical=9` – Bispherical coordinates $x_n = sin(y)*cos(z)/(cosh(x)-cos(y)), y_n = sin(y)*sin(z)/(cosh(x)-cos(y)), z_n = sinh(x)/(cosh(x)-cos(y))$; `mglBipolar=10` – Bipolar coordinates $x_n = sinh(x)/(cosh(x)-cos(y)), y_n = sin(y)/(cosh(x)-cos(y)), z_n = z$; `mglLogLog=11` – log-log coordinates $x_n = lg(x), y_n = lg(y), z_n = lg(z)$; `mglLogX=12` – log-x coordinates $x_n = lg(x), y_n = y, z_n = z$; `mglLogY=13` – log-y coordinates $x_n = x, y_n = lg(y), z_n = z$.

`ternary val` [MGL command]
`void Ternary (int` *tern*`)` [Method on `mglGraph`]
`void mgl_set_ternary (HMGL` *gr*`, int` *tern*`)` [C function]

The function sets to draws Ternary (*tern*=`1`), Quaternary (*tern*=`2`) plot or projections (*tern*=`4,5,6`).

Ternary plot is special plot for 3 dependent coordinates (components) *a*, *b*, *c* so that *a*+*b*+*c*=1. MathGL uses only 2 independent coordinates *a*=x and *b*=y since it is enough to plot everything. At this third coordinate z act as another parameter to produce contour lines, surfaces and so on.

Correspondingly, Quaternary plot is plot for 4 dependent coordinates *a*, *b*, *c* and *d* so that *a*+*b*+*c*+*d*=1. MathGL uses only 3 independent coordinates *a*=x, *b*=y and *d*=z since it is enough to plot everything.

Projections can be obtained by adding value `4` to *tern* argument. So, that *tern*=`4` will draw projections in Cartesian coordinates, *tern*=`5` will draw projections in Ternary coordinates, *tern*=`6` will draw projections in Quaternary coordinates. If you add `8` instead of `4` then all text labels will not be printed on projections.

Use `Ternary(0)` for returning to usual axis. See Section 2.2.6 [Ternary axis], page 30, for sample code and picture. See Section 2.9.4 [Axis projection], page 116, for sample code and picture.

4.3.3 Ticks

`adjust` ['*dir*'='*xyzc*'] [MGL command]

`void Adjust (const char *dir="xyzc")` [Method on `mglGraph`]
`void mgl_adjust_ticks (HMGL gr, const char *dir)` [C function]

Set the ticks step, number of sub-ticks and initial ticks position to be the most human readable for the axis along direction(s) *dir*. Also set `SetTuneTicks(true)`. Usually you don't need to call this function except the case of returning to default settings.

`xtick val [sub=0 org=nan]` [MGL command]
`ytick val [sub=0 org=nan]` [MGL command]
`ztick val [sub=0 org=nan]` [MGL command]
`ctick val [sub=0 org=nan]` [MGL command]
`void SetTicks (char dir, mreal d=0, int ns=0, mreal org=NAN, const char *fact="")` [Method on `mglGraph`]
`void SetTicks (char dir, mreal d, int ns, mreal org, const wchar_t *fact)` [Method on `mglGraph`]
`void mgl_set_ticks (HMGL gr, char dir, mreal d, int ns, mreal org)` [C function]
`void mgl_set_ticks_fact (HMGL gr, char dir, mreal d, int ns, mreal org, const char *fact)` [C function]
`void mgl_set_ticks_factw (HMGL gr, char dir, mreal d, int ns, mreal org, const wchar_t *fact)` [C function]

Set the ticks step *d*, number of sub-ticks *ns* (used for positive *d*) and initial ticks position *org* for the axis along direction *dir* (use 'c' for colorbar ticks). Variable *d* set step for axis ticks (if positive) or it's number on the axis range (if negative). Zero value set automatic ticks. If *org* value is NAN then axis origin is used. Parameter *fact* set text which will be printed after tick label (like `"\pi"` for *d*=M_PI).

`xtick val1 'lbl1' [val2 'lbl2' ...]` [MGL command]
`ytick val1 'lbl1' [val2 'lbl2' ...]` [MGL command]
`ztick val1 'lbl1' [val2 'lbl2' ...]` [MGL command]
`xtick vdat 'lbls' [add=off]` [MGL command]
`ytick vdat 'lbls' [add=off]` [MGL command]
`ztick vdat 'lbls' [add=off]` [MGL command]
`void SetTicksVal (char dir, const char *lbl, bool add=false)` [Method on `mglGraph`]
`void SetTicksVal (char dir, const wchar_t *lbl, bool add=false)` [Method on `mglGraph`]
`void SetTicksVal (char dir, const mglDataA &val, const char *lbl, bool add=false)` [Method on `mglGraph`]
`void SetTicksVal (char dir, const mglDataA &val, const wchar_t *lbl, bool add=false)` [Method on `mglGraph`]
`void mgl_set_ticks_str (HMGL gr, char dir, const char *lbl, bool add)` [C function]
`void mgl_set_ticks_wcs (HMGL gr, char dir, const wchar_t *lbl, bool add)` [C function]
`void mgl_set_ticks_val (HMGL gr, char dir, HCDT val, const char *lbl, bool add)` [C function]

`void mgl_set_ticks_valw (HMGL` *gr*`, char` *dir*`, HCDT` *val*`, const wchar_t *`*lbl*`, bool` *add*`)` [C function]

Set the manual positions *val* and its labels *lbl* for ticks along axis *dir*. If array *val* is absent then values equidistantly distributed in x-axis range are used. Labels are separated by '`\n`' symbol. Use `SetTicks()` to restore automatic ticks.

`void AddTick (char` *dir*`, double` *val*`, const char *`*lbl*`)` [Method on `mglGraph`]
`void AddTick (char` *dir*`, double` *val*`, const wchar_t *`*lbl*`)` [Method on `mglGraph`]
`void mgl_add_tick (HMGL` *gr*`, char` *dir*`, double` *val*`, const char *`*lbl*`)` [C function]
`void mgl_set_tickw (HMGL` *gr*`, char` *dir*`, double` *val*`, const wchar_t *`*lbl*`)` [C function]

The same as previous but add single tick label *lbl* at position *val* to the lest of existed ones.

`xtick` *'templ'* [MGL command]
`ytick` *'templ'* [MGL command]
`ztick` *'templ'* [MGL command]
`ctick` *'templ'* [MGL command]
`void SetTickTempl (char` *dir*`, const char *`*templ*`)` [Method on `mglGraph`]
`void SetTickTempl (char` *dir*`, const wchar_t *`*templ*`)` [Method on `mglGraph`]
`void mgl_set_tick_templ (HMGL` *gr*`, const char *`*templ*`)` [C function]
`void mgl_set_tick_templw (HMGL` *gr*`, const wchar_t *`*templ*`)` [C function]

Set template *templ* for x-,y-,z-axis ticks or colorbar ticks. It may contain TeX symbols also. If *templ*="" then default template is used (in simplest case it is '`%.2g`'). If template start with '`&`' symbol then `long` integer value will be passed instead of default type `double`. Setting on template switch off automatic ticks tuning.

`ticktime` *'dir'* [`dv` *'tmpl'*] [MGL command]
`void SetTicksTime (char` *dir*`, mreal` *val*`, const char *`*templ*`)` [Method on `mglGraph`]
`void mgl_set_ticks_time (HMGL` *gr*`, mreal` *val*`, const char *`*templ*`)` [C function]

Sets time labels with step *val* and template *templ* for x-,y-,z-axis ticks or colorbar ticks. It may contain TeX symbols also. The format of template *templ* is the same as described in `http://www.manpagez.com/man/3/strftime/`. Most common variants are '`%X`' for national representation of time, '`%x`' for national representation of date, '`%Y`' for year with century. If *val*=0 and/or *templ*="" then automatic tick step and/or template will be selected. You can use `mgl_get_time`() function for obtaining number of second for given date/time string. Note, that MS Visual Studio couldn't handle date before 1970.

`double mgl_get_time (const char*`*str*`, const char *`*templ*`)` [C function]

Gets number of seconds from 1970 year to specified date/time *str*. The format of string is specified by *templ*, which is the same as described in `http://www.manpagez.com/man/3/strftime/`. Most common variants are '`%X`' for national representation of time, '`%x`' for national representation of date, '`%Y`' for year with century. Note, that MS Visual Studio couldn't handle date before 1970.

`tuneticks val` [`pos=1.15`] [MGL command]
`void SetTuneTicks (int` *tune*`, mreal` *pos*`=1.15)` [Method on `mglGraph`]

`void mgl_tune_ticks (HMGL` *gr*`, int` *tune*`, mreal` *pos*`)` [C function]
Switch on/off ticks enhancing by factoring common multiplier (for small, like from 0.001 to 0.002, or large, like from 1000 to 2000, coordinate values – enabled if *tune*&1 is nonzero) or common component (for narrow range, like from 0.999 to 1.000 – enabled if *tune*&2 is nonzero). Also set the position *pos* of common multiplier/component on the axis: =0 at minimal axis value, =1 at maximal axis value. Default value is 1.15.

`tickshift dx [dy=0 dz=0 dc=0]` [MGL command]
`void SetTickShift (mglPoint` *d*`)` [Method on `mglGraph`]
`void mgl_set_tick_shift (HMGL` *gr*`, mreal` *dx*`, mreal` *dy*`, mreal` *dz*`, mreal` *dc*`)` [C function]
Set value of additional shift for ticks labels.

`void SetTickRotate (bool` *val*`)` [Method on `mglGraph`]
`void mgl_set_tick_rotate (HMGL` *gr*`, bool` *val*`)` [C function]
Enable/disable ticks rotation if there are too many ticks or ticks labels are too long.

`void SetTickSkip (bool` *val*`)` [Method on `mglGraph`]
`void mgl_set_tick_skip (HMGL` *gr*`, bool` *val*`)` [C function]
Enable/disable ticks skipping if there are too many ticks or ticks labels are too long.

`void SetTimeUTC (bool` *val*`)` [Method on `mglGraph`]
Enable/disable using UTC time for ticks labels. In C/Fortran you can use `mgl_set_flag(gr,val, MGL_USE_GMTIME);`.

`origintick val` [MGL command]
`void SetOriginTick (bool` *val*`=true)` [Method on `mglGraph`]
Enable/disable drawing of ticks labels at axis origin. In C/Fortran you can use `mgl_set_flag(gr,val, MGL_NO_ORIGIN);`.

`ticklen val [stt=1]` [MGL command]
`void SetTickLen (mreal` *val*`, mreal` *stt*`=1)` [Method on `mglGraph`]
`void mgl_set_tick_len (HMGL` *gr*`, mreal` *val*`, mreal` *stt*`)` [C function]
The relative length of axis ticks. Default value is `0.1`. Parameter *stt*>0 set relative length of subticks which is in `sqrt(1+stt)` times smaller.

`axisstl` *'stl'* `[`*'tck'*`=" '`*sub*`'="]` [MGL command]
`void SetAxisStl (const char *`*stl*`="k", const char *`*tck*`=0, const char *`*sub*`=0)` [Method on `mglGraph`]
`void mgl_set_axis_stl (HMGL` *gr*`, const char *`*stl*`, const char *`*tck*`, const char *`*sub*`)` [C function]
The line style of axis (*stl*), ticks (*tck*) and subticks (*sub*). If *stl* is empty then default style is used ('`k`' or '`w`' depending on transparency type). If *tck* or *sub* is empty then axis style is used (i.e. *stl*).

4.4 Subplots and rotation

These functions control how and where further plotting will be placed. There is a certain calling order of these functions for the better plot appearance. First one should be [subplot], page 173, [multiplot], page 173 or [inplot], page 173 for specifying the place. Second one can

be [title], page 174 for adding title for the subplot. After it a [rotate], page 175 and [aspect], page 175. And finally any other plotting functions may be called. Alternatively you can use [columnplot], page 174, [gridplot], page 174, [stickplot], page 174 or relative [inplot], page 173 for positioning plots in the column (or grid, or stick) one by another without gap between plot axis (bounding boxes). See Section 2.2.1 [Subplots], page 20, for sample code and picture.

`subplot nx ny m ['stl'='<>_^' dx=0 dy=0]` [MGL command]
`void SubPlot (int` *nx*, `int` *ny*, `int` *m*, `const char *`*stl*`="<>_^", mreal` *dx*`=0, mreal` *dy*`=0)` [Method on `mglGraph`]
`void mgl_subplot (HMGL` *gr*, `int` *nx*, `int` *ny*, `int` *m*, `const char *`*stl*`)` [C function]
`void mgl_subplot_d (HMGL` *gr*, `int` *nx*, `int` *ny*, `int` *m*, `const char *`*stl*, `mreal` *dx*, `mreal` *dy*`)` [C function]

Puts further plotting in a *m*-th cell of *nx***ny* grid of the whole frame area. This function set off any aspects or rotations. So it should be used first for creating the subplot. Extra space will be reserved for axis/colorbar if *stl* contain:

- '`L`' or '`<`' – at left side,
- '`R`' or '`>`' – at right side,
- '`A`' or '`^`' – at top side,
- '`U`' or '`_`' – at bottom side,
- '`#`' – reserve none space (use whole region for axis range) – axis and tick labels will be invisible by default.

From the aesthetical point of view it is not recommended to use this function with different matrices in the same frame. The position of the cell can be shifted from its default position by relative size *dx*, *dy*. Note, colorbar can be invisible (be out of image borders) if you set empty style ''.

`multiplot nx ny m dx dy ['style'='<>_^']` [MGL command]
`void MultiPlot (int` *nx*, `int` *ny*, `int` *m*, `int` *dx*, `int` *dy*, `const char *`*stl*`="<>_^")` [Method on `mglGraph`]
`void mgl_multiplot (HMGL` *gr*, `int` *nx*, `int` *ny*, `int` *m*, `int` *dx*, `int` *dy*, `const char *`*stl*`)` [C function]

Puts further plotting in a rectangle of *dx***dy* cells starting from *m*-th cell of *nx***ny* grid of the whole frame area. This function set off any aspects or rotations. So it should be used first for creating subplot. Extra space will be reserved for axis/colorbar if *stl* contain:

- '`L`' or '`<`' – at left side,
- '`R`' or '`>`' – at right side,
- '`A`' or '`^`' – at top side,
- '`U`' or '`_`' – at bottom side.

`inplot x1 x2 y1 y2 [rel=on]` [MGL command]
`void InPlot (mreal` *x1*, `mreal` *x2*, `mreal` *y1*, `mreal` *y2*, `bool` *rel*`=true)` [Method on `mglGraph`]
`void mgl_inplot (HMGL` *gr*, `mreal` *x1*, `mreal` *x2*, `mreal` *y1*, `mreal` *y2*`)` [C function]

`void mgl_relplot (HMGL` *gr*, `mreal` *x1*, `mreal` *x2*, `mreal` *y1*, `mreal` *y2*) [C function]

Puts further plotting in some region of the whole frame surface. This function allows one to create a plot in arbitrary place of the screen. The position is defined by rectangular coordinates [*x1*, *x2*]*[*y1*, *y2*]. The coordinates *x1*, *x2*, *y1*, *y2* are normalized to interval [0, 1]. If parameter *rel*=`true` then the relative position to current [subplot], page 173 (or [inplot], page 173 with *rel*=`false`) is used. This function set off any aspects or rotations. So it should be used first for creating subplot.

`columnplot num ind [d=0]` [MGL command]
`void ColumnPlot (int` *num*, `int` *ind*, `mreal` *d*=0) [Method on `mglGraph`]
`void mgl_columnplot (HMGL` *gr*, `int` *num*, `int` *ind*) [C function]
`void mgl_columnplot_d (HMGL` *gr*, `int` *num*, `int` *ind*, `mreal` *d*) [C function]

Puts further plotting in *ind*-th cell of column with *num* cells. The position is relative to previous [subplot], page 173 (or [inplot], page 173 with *rel*=`false`). Parameter *d* set extra gap between cells.

`gridplot nx ny ind [d=0]` [MGL command]
`void GridPlot (int` *nx*, `int` *ny*, `int` *ind*, `mreal` *d*=0) [Method on `mglGraph`]
`void mgl_gridplot (HMGL` *gr*, `int` *nx*, `int` *ny*, `int` *ind*) [C function]
`void mgl_gridplot_d (HMGL` *gr*, `int` *nx*, `int` *ny*, `int` *ind*, `mreal` *d*) [C function]

Puts further plotting in *ind*-th cell of *nx***ny* grid. The position is relative to previous [subplot], page 173 (or [inplot], page 173 with *rel*=`false`). Parameter *d* set extra gap between cells.

`stickplot num ind tet phi` [MGL command]
`void StickPlot (int` *num*, `int` *ind*, `mreal` *tet*, `mreal` *phi*) [Method on `mglGraph`]
`void mgl_stickplot (HMGL` *gr*, `int` *num*, `int` *ind*, `mreal` *tet*, `mreal` *phi*) [C function]

Puts further plotting in *ind*-th cell of stick with *num* cells. At this, stick is rotated on angles *tet*, *phi*. The position is relative to previous [subplot], page 173 (or [inplot], page 173 with *rel*=`false`).

`title` *'title'* [*'stl'*=''] `size=-2` [MGL command]
`void Title (const char *`*txt*, `const char *`*stl*=`""`, `mreal` *size*=`-2`) [Method on `mglGraph`]
`void Title (const wchar_t *`*txt*, `const char *`*stl*=`""`, `mreal` *size*=`-2`) [Method on `mglGraph`]
`void mgl_title (HMGL` *gr*, `const char *`*txt*, `const char *`*stl*, `mreal` *size*) [C function]
`void mgl_titlew (HMGL` *gr*, `const wchar_t *`*txt*, `const char *`*stl*, `mreal` *size*) [C function]

Add text *title* for current subplot/inplot. Parameter *stl* can contain:

- font style (see, Section 3.5 [Font styles], page 152);
- '`#`' for box around the title.

Parameter *size* set font size. This function set off any aspects or rotations. So it should be used just after creating subplot.

`rotate tetx tetz [tety=0]` [MGL command]
`void Rotate (mreal` *TetX*`, mreal` *TetZ*`, mreal` *TetY*`=0)` [Method on `mglGraph`]
`void mgl_rotate (HMGL` *gr*`, mreal` *TetX*`, mreal` *TetZ*`, mreal` *TetY*`)` [C function]
Rotates a further plotting relative to each axis {x, z, y} consecutively on angles *TetX*, *TetZ*, *TetY*.

`rotate tet x y z` [MGL command]
`void RotateN (mreal` *Tet*`, mreal` *x*`, mreal` *y*`, mreal` *z*`)` [Method on `mglGraph`]
`void mgl_rotate_vector (HMGL` *gr*`, mreal Tet, mreal x, mreal y, mreal z)` [C function]
Rotates a further plotting around vector {*x*, *y*, *z*} on angle *Tet*.

`aspect ax ay [az=1]` [MGL command]
`void Aspect (mreal` *Ax*`, mreal` *Ay*`, mreal` *Az*`=1)` [Method on `mglGraph`]
`void mgl_aspect (HMGL` *gr*`, mreal` *Ax*`, mreal` *Ay*`, mreal` *Az*`)` [C function]
Defines aspect ratio for the plot. The viewable axes will be related one to another as the ratio *Ax:Ay:Az*. For the best effect it should be used after [rotate], page 175 function. If *Ax* is `NAN` then function try to select optimal aspect ratio to keep equal ranges for x-y axis. At this, *Ay* will specify proportionality factor, or set to use automatic one if *Ay*=`NAN`.

`void Push ()` [Method on `mglGraph`]
`void mgl_mat_push (HMGL` *gr*`)` [C function]
Push transformation matrix into stack. Later you can restore its current state by Pop() function.

`void Pop ()` [Method on `mglGraph`]
`void mgl_mat_pop (HMGL` *gr*`)` [C function]
Pop (restore last 'pushed') transformation matrix into stack.

`void SetPlotFactor (mreal` *val*`)` [Method on `mglGraph`]
`void mgl_set_plotfactor (HMGL` *gr*`, mreal` *val*`)` [C function]
Sets the factor of plot size. It is not recommended to set it lower then 1.5. This is some analogue of function Zoom() but applied not to overall image but for each InPlot. Use negative value or zero to enable automatic selection.

There are 3 functions `View()`, `Zoom()` and `Perspective()` which transform whole image. I.e. they act as secondary transformation matrix. They were introduced for rotating/zooming the whole plot by mouse. It is not recommended to call them for picture drawing.

`perspective val` [MGL command]
`void Perspective (mreal` *a*`)` [Method on `mglGraph`]
`void mgl_perspective (HMGL` *gr*`, mreal` *a*`)` [C function]
Add (switch on) the perspective to plot. The parameter $a = Depth/(Depth + dz) \in [0, 1)$. By default (`a=0`) the perspective is off.

`view tetx tetz [tety=0]` [MGL command]
`void View (mreal` *TetX*`, mreal` *TetZ*`, mreal` *TetY*`=0)` [Method on `mglGraph`]

`void mgl_view (HMGL` *gr*, `mreal` *TetX*, `mreal` *TetZ*, `mreal` *TetY*) [C function]
Rotates a further plotting relative to each axis {x, z, y} consecutively on angles *TetX*, *TetZ*, *TetY*. Rotation is done independently on [rotate], page 175. Attention! this settings can not be overwritten by `DefaultPlotParam()`. Use `Zoom(0,0,1,1)` to return default view.

`zoom x1 y1 x2 y2` [MGL command]
`void Zoom (mreal` *x1*, `mreal` *y1*, `mreal` *x2*, `mreal` *y2*) [Method on `mglGraph` (C++, Python)]
`void mgl_set_zoom (HMGL` *gr*, `mreal` *x1*, `mreal` *y1*, `mreal` *x2*, `mreal` *y2*) [C function]
The function changes the scale of graphics that correspond to zoom in/out of the picture. After function call the current plot will be cleared and further the picture will contain plotting from its part [x1,x2]*[y1,y2]. Here picture coordinates *x1*, *x2*, *y1*, *y2* changes from 0 to 1. Attention! this settings can not be overwritten by any other functions, including `DefaultPlotParam()`. Use `Zoom(0,0,1,1)` to return default view.

4.5 Export picture

Functions in this group save or give access to produced picture. So, usually they should be called after plotting is done.

`setsize w h` [MGL command]
`void SetSize (int` *width*, `int` *height*, `bool` *clear*=`true`) [Method on `mglGraph`]
`void mgl_set_size (HMGL` *gr*, `int` *width*, `int` *height*) [C function]
`void mgl_scale_size (HMGL` *gr*, `int` *width*, `int` *height*) [C function]
Sets size of picture in pixels. This function **should be** called before any other plotting because it completely remove picture contents if *clear*=`true`. Function just clear pixels and scale all primitives if *clear*=`false`.

`void SetSizeScl (double` *factor*) [Method on `mglGraph`]
`void mgl_set_size_scl (HMGL` *gr*, `double` *factor*) [C function]
Set factor for width and height in all further calls of [setsize], page 176.

`quality [val=2]` [MGL command]
`void SetQuality (int` *val*=`MGL_DRAW_NORM`) [Method on `mglGraph`]
`void mgl_set_quality (HMGL` *gr*, `int` *val*) [C function]
Sets quality of the plot depending on value *val*: `MGL_DRAW_WIRE=0` – no face drawing (fastest), `MGL_DRAW_FAST=1` – no color interpolation (fast), `MGL_DRAW_NORM=2` – high quality (normal), `MGL_DRAW_HIGH=3` – high quality with 3d primitives (arrows and marks); `MGL_DRAW_LMEM=0x4` – direct bitmap drawing (low memory usage); `MGL_DRAW_DOTS=0x8` – for dots drawing instead of primitives (extremely fast).

`int GetQuality ()` [Method on `mglGraph`]
`int mgl_get_quality (HMGL` *gr*) [C function]
Gets quality of the plot: `MGL_DRAW_WIRE=0` – no face drawing (fastest), `MGL_DRAW_FAST=1` – no color interpolation (fast), `MGL_DRAW_NORM=2` – high quality (normal),

`MGL_DRAW_HIGH=3` – high quality with 3d primitives (arrows and marks); `MGL_DRAW_LMEM=0x4` – direct bitmap drawing (low memory usage); `MGL_DRAW_DOTS=0x8` – for dots drawing instead of primitives (extremely fast).

`void StartGroup (`*const char *name*`)` [Method on `mglGraph`]
`void mgl_start_group (HMGL` *gr*`, const char *`*name*`)` [C function]
Starts group definition. Groups contain objects and other groups, they are used to select a part of a model to zoom to or to make invisible or to make semitransparent and so on.

`void EndGroup ()` [Method on `mglGraph`]
`void mgl_end_group (HMGL` *gr*`)` [C function]
Ends group definition.

4.5.1 Export to file

These functions export current view to a graphic file. The filename *fname* should have appropriate extension. Parameter *descr* gives the short description of the picture. Just now the transparency is supported in PNG, SVG, OBJ and PRC files.

`write ['`*fname*`'="]` [MGL command]
`void WriteFrame (const char *`*fname*`="", const char *`*descr*`="")` [Method on `mglGraph`]
`void mgl_write_frame (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]
Exports current frame to a file *fname* which type is determined by the extension. Parameter *descr* adds description to file (can be `""`). If *fname*`=""` then the file '`frame####.jpg`' is used, where '`####`' is current frame id and name '`frame`' is defined by [plotid], page 161 class property.

`void WritePNG (const char *`*fname*`, const char *`*descr*`="", int` *compr*`="", bool` *alpha*`=true)` [Method on `mglGraph`]
`void mgl_write_png (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]
`void mgl_write_png_solid (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]
Exports current frame to PNG file. Parameter *fname* specifies the file name, *descr* adds description to file, *alpha* gives the transparency type. By default there are no description added and semitransparent image used. This function does nothing if HAVE_PNG isn't defined during compilation of MathGL library.

`void WriteJPEG (const char *`*fname*`, const char *`*descr*`="")` [Method on `mglGraph`]
`void mgl_write_jpg (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]
Exports current frame to JPEG file. Parameter *fname* specifies the file name, *descr* adds description to file. By default there is no description added. This function does nothing if HAVE_JPEG isn't defined during compilation of MathGL library.

`void WriteGIF (const char *`*fname*`, const char *`*descr*`="")` [Method on `mglGraph`]
`void mgl_write_gif (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]

Exports current frame to GIF file. Parameter *fname* specifies the file name, *descr* adds description to file. By default there is no description added. This function does nothing if HAVE_GIF isn't defined during compilation of MathGL library.

`void WriteBMP (const char *`*fname*`, const char *`*descr*`="")` [Method on `mglGraph`]
`void mgl_write_bmp (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]

Exports current frame to BMP file. Parameter *fname* specifies the file name, *descr* adds description to file. There is no compression used.

`void WriteTGA (const char *`*fname*`, const char *`*descr*`="")` [Method on `mglGraph`]
`void mgl_write_tga (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]

Exports current frame to TGA file. Parameter *fname* specifies the file name, *descr* adds description to file. There is no compression used.

`void WriteEPS (const char *`*fname*`, const char *`*descr*`="")` [Method on `mglGraph`]
`void mgl_write_eps (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]

Exports current frame to EPS file using vector representation. So it is not recommended for the export of large data plot. It is better to use bitmap format (for example PNG or JPEG). However, program has no internal limitations for size of output file. Parameter *fname* specifies the file name, *descr* adds description to file. By default there is no description added. If file name is terminated by '`z`' (for example, '`fname.eps.gz`') then file will be compressed in gzip format. Note, that EPS format don't support color interpolation, and the resulting plot will look as you use [quality], page 176=1 for plotting.

`void WriteBPS (const char *`*fname*`, const char *`*descr*`="")` [Method on `mglGraph`]
`void mgl_write_eps (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]

Exports current frame to EPS file using bitmap representation. Parameter *fname* specifies the file name, *descr* adds description to file. By default there is no description added. If file name is terminated by '`z`' (for example, '`fname.eps.gz`') then file will be compressed in gzip format.

`void WriteSVG (const char *`*fname*`, const char *`*descr*`="")` [Method on `mglGraph`]
`void mgl_write_svg (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]

Exports current frame to SVG (Scalable Vector Graphics) file using vector representation. In difference of EPS format, SVG format support transparency that allows to correctly draw semitransparent plot (like [surfa], page 218, [surf3a], page 219 or [cloud], page 214). Note, the output file may be too large for graphic of large data array (especially for surfaces). It is better to use bitmap format (for example PNG or JPEG). However, program has no internal limitations for size of output file. Parameter *fname* specifies the file name, *descr* adds description to file (default is file name). If file name is terminated by '`z`' (for example, '`fname.svgz`') then file will be compressed in gzip format. Note, that SVG format don't support color interpolation, and the resulting plot will look as you use [quality], page 176=1 for plotting.

`void WriteTEX (const char *`*fname*`, const char *`*descr*`="")` [Method on `mglGraph`]
`void mgl_write_tex (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]

Exports current frame to LaTeX (package Tikz/PGF) file using vector representation. Note, the output file may be too large for graphic of large data array (especially for surfaces). It is better to use bitmap format (for example PNG or JPEG). However, program has no internal limitations for size of output file. Parameter *fname* specifies the file name, *descr* adds description to file (default is file name). Note, there is no text scaling now (for example, in subplots), what may produce miss-aligned labels.

`void WritePRC (const char *`*fname*`, const char *`*descr*`="", bool` *make_pdf*`=true)` [Method on `mglGraph`]
`void mgl_write_prc (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`, int` *make_pdf*`)` [C function]

Exports current frame to PRC file using vector representation (see `http://en.wikipedia.org/wiki/PRC_%28file_format%29`). Note, the output file may be too large for graphic of large data array (especially for surfaces). It is better to use bitmap format (for example PNG or JPEG). However, program has no internal limitations for size of output file. Parameter *fname* specifies the file name, *descr* adds description to file (default is file name). If parameter *make_pdf*=`true` and PDF was enabled at MathGL configure then corresponding PDF file with 3D image will be created.

`void WriteOBJ (const char *`*fname*`, const char *`*descr*`="")` [Method on `mglGraph`]
`void mgl_write_obj (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]

Exports current frame to OBJ/MTL file using vector representation (see OBJ format (`http://en.wikipedia.org/wiki/Wavefront_.obj_file`) for details). Note, the output file may be too large for graphic of large data array (especially for surfaces). It is better to use bitmap format (for example PNG or JPEG). However, program has no internal limitations for size of output file. Parameter *fname* specifies the file name, *descr* adds description to file (default is file name).

`void WriteXYZ (const char *`*fname*`, const char *`*descr*`="")` [Method on `mglGraph`]

`void mgl_write_xyz (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]

Exports current frame to XYZ/XYZL/XYZF files using vector representation (see XYZ format (`http://people.sc.fsu.edu/~jburkardt/data/xyz/xyz.html`) for details). Note, the output file may be too large for graphic of large data array (especially for surfaces). It is better to use bitmap format (for example PNG or JPEG). However, program has no internal limitations for size of output file. Parameter *fname* specifies the file name, *descr* adds description to file (default is file name).

`void WriteSTL (const char *`*fname*`, const char *`*descr*`="")` [Method on `mglGraph`]

`void mgl_write_stl (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]

Exports current frame to STL file using vector representation (see STL format (`http://en.wikipedia.org/wiki/STL_(file_format)`) for details). Note, the output file may be too large for graphic of large data array (especially for surfaces). It is better to use bitmap format (for example PNG or JPEG). However, program has no internal limitations for size of output file. Parameter *fname* specifies the file name, *descr* adds description to file (default is file name.

`void WriteOFF (const char *`*fname*`, const char *`*descr*`="", bool` *colored*`=false)` [Method on `mglGraph`]

`void mgl_write_off (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`, bool` *colored*`)` [C function]

Exports current frame to OFF file using vector representation (see OFF format (`http://people.sc.fsu.edu/~jburkardt/data/off/off.html`) for details). Note, the output file may be too large for graphic of large data array (especially for surfaces). It is better to use bitmap format (for example PNG or JPEG). However, program has no internal limitations for size of output file. Parameter *fname* specifies the file name, *descr* adds description to file (default is file name).

`void ShowImage (const char *`*viewer*`, bool` *nowait*`=false)` [Method on `mglGraph`]

`void mgl_show_image (const char *`*viewer*`, int` *nowait*`)` [C function]

Displays the current picture using external program *viewer* for viewing. The function save the picture to temporary file and call *viewer* to display it. If *nowait*=`true` then the function return immediately (it will not wait while window will be closed).

`void WriteJSON (const char *`*fname*`, const char *`*descr*`="")` [Method on `mglGraph`]

`void mgl_write_json (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]

Exports current frame to textual file using Section B.3 [JSON format], page 328. Later this file can be used for faster loading and viewing by JavaScript script. Parameter *fname* specifies the file name, *descr* adds description to file.

`void ExportMGLD (const char *`*fname*`, const char *`*descr*`="")` [Method on `mglGraph`]
`void mgl_export_mgld (HMGL` *gr*`, const char *`*fname*`, const char *`*descr*`)` [C function]
Exports points and primitives in file using Section B.2 [MGLD format], page 327. Later this file can be used for faster loading and viewing by `mglview` utility. Parameter *fname* specifies the file name, *descr* adds description to file (default is file name).

`void ImportMGLD (const char *`*fname*`, bool` *add*`=false)` [Method on `mglGraph`]
`void mgl_import_mgld (HMGL` *gr*`, const char *`*fname*`, int` *add*`)` [C function]
Imports points and primitives in file using Section B.2 [MGLD format], page 327. Later this file can be used for faster loading and viewing by `mglview` utility. Parameter *fname* specifies the file name, *add* sets to append or replace primitives to existed ones.

4.5.2 Frames/Animation

These functions provide ability to create several pictures simultaneously. For most of cases it is useless but for widget classes (see Chapter 5 [Widget classes], page 238) they can provide a way to show animation. Also you can write several frames into animated GIF file.

`void NewFrame ()` [Method on `mglGraph`]
`void mgl_new_frame (HMGL` *gr*`)` [C function]
Creates new frame. Function returns current frame id. This is not thread safe function in OpenGL mode! Use direct list creation in multi-threading drawing. The function `EndFrame()` **must** be call after the finishing of the frame drawing for each call of this function.

`void EndFrame ()` [Method on `mglGraph`]
`void mgl_end_frame (HMGL` *gr*`)` [C function]
Finishes the frame drawing.

`int GetNumFrame ()` [Method on `mglGraph`]
`int mgl_get_num_frame (HMGL` *gr*`)` [C function]
Gets the number of created frames.

`void SetFrame (int` *i*`)` [Method on `mglGraph`]
`void mgl_set_frame (HMGL` *gr*`, int` *i*`)` [C function]
Finishes the frame drawing and sets drawing data to frame *i*, which should be in range [0, `GetNumFrame()`-1]. This function is similar to `EndFrame()` but don't add frame to the GIF image.

`void GetFrame (int` *i*`)` [Method on `mglGraph`]
`void mgl_get_frame (HMGL` *gr*`, int` *i*`)` [C function]
Replaces drawing data by one from frame *i*. Function work if `MGL_VECT_FRAME` is set on (by default).

`void ShowFrame (int` *i*`)` [Method on `mglGraph`]
`void mgl_show_frame (HMGL` *gr*`, int` *i*`)` [C function]
Appends drawing data from frame *i* to current one. Function work if `MGL_VECT_FRAME` is set on (by default).

`void DelFrame (int i)` [Method on `mglGraph`]
`void mgl_del_frame (HMGL gr, int i)` [C function]
Deletes drawing data for frame *i* and shift all later frame indexes. Function work if `MGL_VECT_FRAME` is set on (by default). Do nothing in OpenGL mode.

`void ResetFrames ()` [Method on `mglGraph`]
`void mgl_reset_frames (HMGL gr)` [C function]
Reset frames counter (start it from zero).

`void ClearFrame (int i)` [Method on `mglGraph`]
`void mgl_clear_frame (HMGL gr, int i)` [C function]
Clear list of primitives for current drawing.

`void StartGIF (const char *fname, int ms=100)` [Method on `mglGraph`]
`void mgl_start_gif (HMGL gr, const char *fname, int ms)` [C function]
Start writing frames into animated GIF file *fname*. Parameter *ms* set the delay between frames in milliseconds. You **should not** change the picture size during writing the cinema. Use `CloseGIF()` to finalize writing. Note, that this function is disabled in OpenGL mode.

`void CloseGIF ()` [Method on `mglGraph`]
`void mgl_close_gif (HMGL gr)` [C function]
Finish writing animated GIF and close connected pointers.

4.5.3 Bitmap in memory

These functions return the created picture (bitmap), its width and height. You may display it by yourself in any graphical library (see also, Chapter 5 [Widget classes], page 238) or save in file (see also, Section 4.5.1 [Export to file], page 177).

`const unsigned char * GetRGB ()` [Method on `mglGraph`]
`void GetRGB (char *buf, int size)` [Method on `mglGraph`]
`void GetBGRN (char *buf, int size)` [Method on `mglGraph`]
`const unsigned char * mgl_get_rgb (HMGL gr)` [C function]
Gets RGB bitmap of the current state of the image. Format of each element of bits is: {red, green, blue}. Number of elements is Width*Height. Position of element {i,j} is [3*i + 3*Width*j] (or is [4*i + 4*Width*j] for `GetBGRN()`). You have to provide the proper *size* of the buffer, *buf*, i.e. the code for Python should look like

```
from mathgl import *
gr = mglGraph();
bits='\t';
bits=bits.expandtabs(4*gr.GetWidth()*gr.GetHeight());
gr.GetBGRN(bits, len(bits));
```

`const unsigned char * GetRGBA ()` [Method on `mglGraph`]
`void GetRGBA (char *buf, int size)` [Method on `mglGraph`]
`const unsigned char * mgl_get_rgba (HMGL gr)` [C function]
Gets RGBA bitmap of the current state of the image. Format of each element of bits is: {red, green, blue, alpha}. Number of elements is Width*Height. Position of element {i,j} is [4*i + 4*Width*j].

`int GetWidth ()` [Method on `mglGraph`]
`int GetHeight ()` [Method on `mglGraph`]
`int mgl_get_width (HMGL` *gr*`)` [C function]
`int mgl_get_height (HMGL` *gr*`)` [C function]
Gets width and height of the image.

`mglPoint CalcXYZ (int` *xs*`, int` *ys*`)` [Method on `mglGraph`]
`void mgl_calc_xyz (HMGL` *gr*`, int` *xs*`, int` *ys*`, mreal *`*x*`, mreal *`*y*`,` [C function]
`mreal *`*z*`)`
Calculate 3D coordinate {x,y,z} for screen point {xs,ys}. At this moment it ignore perspective and transformation formulas (curvilinear coordinates). The calculation are done for the last used InPlot (see Section 4.4 [Subplots and rotation], page 172).

`mglPoint CalcScr (mglPoint` *p*`)` [Method on `mglGraph`]
`void mgl_calc_scr (HMGL` *gr*`, mreal` *x*`, mreal` *y*`, mreal` *z*`, int *`*xs*`,` [C function]
`int *`*ys*`)`
Calculate screen point {xs,ys} for 3D coordinate {x,y,z}. The calculation are done for the last used InPlot (see Section 4.4 [Subplots and rotation], page 172).

`void SetObjId (int` *id*`)` [Method on `mglGraph`]
`void mgl_set_obj_id (HMGL` *gr*`, int` *id*`)` [C function]
Set the numeric id for object or subplot/inplot.

`int GetObjId (int` *xs*`, int` *ys*`)` [Method on `mglGraph`]
`int mgl_get_obj_id (HMGL` *gr*`, int` *xs*`, int` *ys*`)` [C function]
Get the numeric id for most upper object at pixel {xs, ys} of the picture.

`int GetSplId (int` *xs*`, int` *ys*`)` [Method on `mglGraph`]
`int mgl_get_spl_id (HMGL` *gr*`, int` *xs*`, int` *ys*`)` [C function]
Get the numeric id for most subplot/inplot at pixel {xs, ys} of the picture.

`void Highlight (int` *id*`)` [Method on `mglGraph`]
`void mgl_highlight (HMGL` *gr*`, int` *id*`)` [C function]
Highlight the object with given *id*.

`long IsActive (int` *xs*`, int` *ys*`, int` *d*`=1)` [Method on `mglGraph`]
`long mgl_is_active (HMGL` *gr*`, int` *xs*`, int` *ys*`, int` *d*`)` [C function]
Checks if point {*xs*, *ys*} is close to one of active point (i.e. mglBase::Act) with accuracy *d* and return its index or `-1` if not found. Active points are special points which characterize primitives (like edges and so on). This function for advanced users only.

`long SetDrawReg (int` *nx*`=1, int` *ny*`=1, int` *m*`=0)` [Method on `mglGraph`]
`long mgl_set_draw_reg (HMGL` *gr*`, int` *nx*`, int` *ny*`, int` *m*`)` [C function]
Limits drawing region by rectangular area of *m*-th cell of matrix with sizes *nx***ny* (like in [subplot], page 173). This function can be used to update only small region of the image for purposes of higher speed. This function for advanced users only.

4.5.4 Parallelization

Many of things MathGL do in parallel by default (if MathGL was built with pthread). However, there is function which set the number of threads to be used.

`int mgl_set_num_thr (int n)` [C function]
Set the number of threads to be used by MathGL. If $n<1$ then the number of threads is set as maximal number of processors (cores). If $n=1$ then single thread will be used (this is default if pthread was disabled).

Another option is combining bitmap image (taking into account Z-ordering) from different instances of `mglGraph`. This method is most appropriate for computer clusters when the data size is so large that it exceed the memory of single computer node.

`int Combine (const mglGraph *g)` [Method on `mglGraph`]
`int mgl_combine_gr (HMGL gr, HMGL g)` [C function]
Combine drawing from instance *g* with *gr* (or with this) taking into account Z-ordering of pixels. The width and height of both instances must be the same.

`int MPI_Send (int id)` [Method on `mglGraph`]
`int mgl_mpi_send (HMGL gr, int id)` [C function]
Send graphical information from node *id* using MPI. The width and height in both nodes must be the same.

`int MPI_Recv (int id)` [Method on `mglGraph`]
`int mgl_mpi_send (HMGL gr, int id)` [C function]
Receive graphical information from node *id* using MPI. The width and height in both nodes must be the same.

4.6 Background

These functions change background image.

`clf ['col']` [MGL command]
`void Clf ()` [Method on `mglGraph`]
`void Clf (const char * col)` [Method on `mglGraph`]
`void Clf (char col)` [Method on `mglGraph`]
`void Clf (mreal r, mreal g, mreal b)` [Method on `mglGraph`]
`void mgl_clf (HMGL gr)` [C function]
`void mgl_clf_str (HMGL gr, const char * col)` [C function]
`void mgl_clf_chr (HMGL gr, char col)` [C function]
`void mgl_clf_rgb (HMGL gr, mreal r, mreal g, mreal b)` [C function]
Clear the picture and fill background by specified color.

`rasterize` [MGL command]
`void Rasterize ()` [Method on `mglGraph`]
`void mgl_rasterize (HMGL gr)` [C function]
Force drawing the plot and use it as background. After it, function clear the list of primitives, like [clf], page 184. This function is useful if you want save part of plot as bitmap one (for example, large surfaces, isosurfaces or vector fields) and keep some parts as vector one (like annotation, curves, axis and so on).

`background` *'fname'* [`alpha=1`] [MGL command]
`void LoadBackground (const char *` *fname*`, double` *alpha*`=1)` [Method on `mglGraph`]
`void mgl_load_background (HMGL` *gr*`, const char *` *fname*`, double` *alpha*`)` [C function]

Load PNG or JPEG file *fname* as background for the plot. Parameter *alpha* manually set transparency of the background.

4.7 Primitives

These functions draw some simple objects like line, point, sphere, drop, cone and so on. See Section 2.9.7 [Using primitives], page 120, for sample code and picture.

`ball x y` [*'col'='r.'*] [MGL command]
`ball x y z` [*'col'='r.'*] [MGL command]
`void Ball (mglPoint` *p*`, char` *col*`='r')` [Method on `mglGraph`]
`void Mark (mglPoint` *p*`, const char *`*mark*`)` [Method on `mglGraph`]
`void mgl_mark (HMGL` *gr*`, mreal` *x*`, mreal` *y*`, mreal` *z*`, const char *`*mark*`)` [C function]

Draws a mark (point '`.`' by default) at position $p=\{x, y, z\}$ with color *col*.

`errbox x y ex ey` [*'stl'=''*] [MGL command]
`errbox x y z ex ey ez` [*'stl'=''*] [MGL command]
`void Error (mglPoint` *p*`, mglPoint` *e*`, char *`*stl*`="")` [Method on `mglGraph`]
`void mgl_error_box (HMGL` *gr*`, mreal` *x*`, mreal` *y*`, mreal` *z*`, mreal` *ex*`, mreal` *ey*`, mreal` *ez*`, char *`*stl*`)` [C function]

Draws a 3d error box at position $p=\{x, y, z\}$ with sizes $e=\{ex, ey, ez\}$ and style *stl*. Use NAN for component of e to reduce number of drawn elements.

`line x1 y1 x2 y2` [*'stl'=''*] [MGL command]
`line x1 y1 z1 x2 y2 z2` [*'stl'=''*] [MGL command]
`void Line (mglPoint` *p1*`, mglPoint` *p2*`, char *`*stl*`="B", int` *num*`=2)` [Method on `mglGraph`]
`void mgl_line (HMGL` *gr*`, mreal` *x1*`, mreal` *y1*`, mreal` *z1*`, mreal` *x2*`, mreal` *y2*`, mreal` *z2*`, char *`*stl*`, int` *num*`)` [C function]

Draws a geodesic line (straight line in Cartesian coordinates) from point *p1* to *p2* using line style *stl*. Parameter *num* define the "quality" of the line. If *num*=`2` then the stright line will be drawn in all coordinate system (independently on transformation formulas (see Section 4.3.2 [Curved coordinates], page 168). Contrary, for large values (for example, =`100`) the geodesic line will be drawn in corresponding coordinate system (straight line in Cartesian coordinates, circle in polar coordinates and so on). Line will be drawn even if it lies out of bounding box.

`curve x1 y1 dx1 dy1 x2 y2 dx2 dy2` [*'stl'=''*] [MGL command]
`curve x1 y1 z1 dx1 dy1 dz1 x2 y2 z2 dx2 dy2 dz2` [*'stl'=''*] [MGL command]
`void Curve (mglPoint` *p1*`, mglPoint` *d1*`, mglPoint` *p2*`, mglPoint` *d2*`, const char *`*stl*`="B", int` *num*`=100)` [Method on `mglGraph`]

`void mgl_curve (HMGL` *gr*, `mreal` *x1*, `mreal` *y1*, `mreal` *z1*, `mreal` *dx1*, `mreal` *dy1*, `mreal` *dz1*, `mreal` *x2*, `mreal` *y2*, `mreal` *z2*, `mreal` *dx2*, `mreal` *dy2*, `mreal` *dz2*, `const char *`*stl*, `int` *num*) [C function]

Draws Bezier-like curve from point *p1* to *p2* using line style *stl*. At this tangent is codirected with *d1*, *d2* and proportional to its amplitude. Parameter *num* define the "quality" of the curve. If *num*=2 then the straight line will be drawn in all coordinate system (independently on transformation formulas, see Section 4.3.2 [Curved coordinates], page 168). Contrary, for large values (for example, =100) the spline like Bezier curve will be drawn in corresponding coordinate system. Curve will be drawn even if it lies out of bounding box.

`face x1 y1 x2 y2 x3 y3 x4 y4 ['stl'='']` [MGL command]
`face x1 y1 z1 x2 y2 z2 x3 y3 z3 x4 y4 z4 ['stl'='']` [MGL command]
`void Face (mglPoint` *p1*, `mglPoint` *p2*, `mglPoint` *p3*, `mglPoint` *p4*, `const char *`*stl*`="w")` [Method on `mglGraph`]
`void mgl_face (HMGL` *gr*, `mreal` *x1*, `mreal` *y1*, `mreal` *z1*, `mreal` *x2*, `mreal` *y2*, `mreal` *z2*, `mreal` *x3*, `mreal` *y3*, `mreal` *z3*, `mreal` *x4*, `mreal` *y4*, `mreal` *z4*, `const char *`*stl*`)` [C function]

Draws the solid quadrangle (face) with vertexes *p1*, *p2*, *p3*, *p4* and with color(s) *stl*. At this colors can be the same for all vertexes or different if all 4 colors are specified for each vertex. Face will be drawn even if it lies out of bounding box.

`rect x1 y1 x2 y2 ['stl'='']` [MGL command]
`rect x1 y1 z1 x2 y2 z2 ['stl'='']` [MGL command]

Draws the solid rectangle (face) with vertexes {*x1*, *y1*, *z1*} and {*x2*, *y2*, *z2*} with color *stl*. At this colors can be the same for all vertexes or separately if all 4 colors are specified for each vertex. Face will be drawn even if it lies out of bounding box.

`facex x0 y0 z0 wy wz ['stl'='' d1=0 d2=0]` [MGL command]
`facey x0 y0 z0 wx wz ['stl'='' d1=0 d2=0]` [MGL command]
`facez x0 y0 z0 wx wy ['stl'='' d1=0 d2=0]` [MGL command]
`void FaceX (mreal` *x0*, `mreal` *y0*, `mreal` *z0*, `mreal` *wy*, `mreal` *wz*, `const char *`*stl*`="w", mreal` *d1*`=0, mreal` *d2*`=0)` [Method on `mglGraph`]
`void FaceY (mreal` *x0*, `mreal` *y0*, `mreal` *z0*, `mreal` *wx*, `mreal` *wz*, `const char *`*stl*`="w", mreal` *d1*`=0, mreal` *d2*`=0)` [Method on `mglGraph`]
`void FaceZ (mreal` *x0*, `mreal` *y0*, `mreal` *z0*, `mreal` *wx*, `mreal` *wy*, `const char *`*stl*`="w", mreal` *d1*`=0, mreal` *d2*`=0)` [Method on `mglGraph`]
`void mgl_facex (HMGL` *gr*, `mreal` *x0*, `mreal` *y0*, `mreal` *z0*, `mreal` *wy*, `mreal` *wz*, `const char *`*stl*, `mreal` *d1*, `mreal` *d2*`)` [C function]
`void mgl_facey (HMGL` *gr*, `mreal` *x0*, `mreal` *y0*, `mreal` *z0*, `mreal` *wx*, `mreal` *wz*, `const char *`*stl*, `mreal` *d1*, `mreal` *d2*`)` [C function]
`void mgl_facez (HMGL` *gr*, `mreal` *x0*, `mreal` *y0*, `mreal` *z0*, `mreal` *wx*, `mreal` *wy*, `const char *`*stl*, `mreal` *d1*, `mreal` *d2*`)` [C function]

Draws the solid rectangle (face) perpendicular to [x,y,z]-axis correspondingly at position {*x0*, *y0*, *z0*} with color *stl* and with widths *wx*, *wy*, *wz* along corresponding directions. At this colors can be the same for all vertexes or separately if all 4 colors are specified for each vertex. Parameters *d1*!=0, *d2*!=0 set additional shift of the last

vertex (i.e. to draw quadrangle). Face will be drawn even if it lies out of bounding box.

`sphere x0 y0 r` ['*col*='*r*'] [MGL command]
`sphere x0 y0 z0 r` ['*col*='*r*'] [MGL command]
`void Sphere (mglPoint` *p*, `mreal` *r*, `const char *`*stl*`="r")` [Method on `mglGraph`]
`void mgl_sphere (HMGL` *gr*, `mreal` *x0*, `mreal` *y0*, `mreal` *z0*, `mreal` *r*, `const char *`*stl*) [C function]
Draw the sphere with radius *r* and center at point *p*={*x0*, *y0*, *z0*} and color *stl*.

`drop x0 y0 dx dy r` ['*col*='*r*' `sh=1 asp=1`] [MGL command]
`drop x0 y0 z0 dx dy dz r` ['*col*='*r*' `sh=1 asp=1`] [MGL command]
`void Drop (mglPoint` *p*, `mglPoint` *d*, `mreal` *r*, `const char *`*col*`="r"`, `mreal` *shift*`=1`, `mreal` *ap*`=1`) [Method on `mglGraph`]
`void mgl_drop (HMGL` *gr*, `mreal` *x0*, `mreal` *y0*, `mreal` *z0*, `mreal` *dx*, `mreal` *dy*, `mreal` *dz*, `mreal` *r*, `const char *`*col*, `mreal` *shift*, `mreal` *ap*) [C function]
Draw the drop with radius *r* at point *p* elongated in direction *d* and with color *col*. Parameter *shift* set the degree of drop oblongness: '`0`' is sphere, '`1`' is maximally oblongness drop. Parameter *ap* set relative width of the drop (this is analogue of "ellipticity" for the sphere).

`cone x1 y1 z1 x2 y2 z2 r1` [`r2=-1` '*stl*'=''] [MGL command]
`void Cone (mglPoint` *p1*, `mglPoint` *p2*, `mreal` *r1*, `mreal` *r2*`=-1`, `const char *`*stl*`="B")` [Method on `mglGraph`]
`void mgl_cone (HMGL` *gr*, `mreal` *x1*, `mreal` *y1*, `mreal` *z1*, `mreal` *x2*, `mreal` *y2*, `mreal` *z2*, `mreal` *r1*, `mreal` *r2*, `const char *`*stl*) [C function]
Draw tube (or truncated cone if *edge*=`false`) between points *p1*, *p2* with radius at the edges *r1*, *r2*. If *r2*<0 then it is supposed that *r2*=*r1*. The cone color is defined by string *stl*. Parameter *stl* can contain:

- '`@`' for drawing edges;
- '`#`' for wired cones;
- '`t`' for drawing tubes/cylinder instead of cones/prisms;
- '`4`', '`6`', '`8`' for drawing square, hex- or octo-prism instead of cones.

`circle x0 y0 r` ['*col*='*r*'] [MGL command]
`circle x0 y0 z0 r` ['*col*='*r*'] [MGL command]
`void Circle (mglPoint` *p*, `mreal` *r*, `const char *`*stl*`="r")` [Method on `mglGraph`]
Draw the circle with radius *r* and center at point *p*={*x0*, *y0*, *z0*}. Parameter *col* may contain

- colors for filling and boundary (second one if style '`@`' is used, black color is used by default);
- '`#`' for wire figure (boundary only);
- '`@`' for filling and boundary.

`ellipse x1 y1 x2 y2 r` ['*col*='*r*'] [MGL command]
`ellipse x1 y1 z1 x2 y2 z2 r` ['*col*='*r*'] [MGL command]

`void Ellipse (mglPoint` *p1*`, mglPoint` *p2*`, mreal` *r*`, const char *`*col*`="r")` [Method on `mglGraph`]

`void mgl_ellipse (HMGL` *gr*`, mreal` *x1*`, mreal` *y1*`, mreal` *z1*`, mreal` *x2*`, mreal` *y2*`, mreal` *z2*`, mreal` *r*`, const char *`*col*`)` [C function]

Draw the ellipse with radius *r* and focal points *p1*, *p2*. Parameter *col* may contain

- colors for filling and boundary (second one if style '`@`' is used, black color is used by default);
- '`#`' for wire figure (boundary only);
- '`@`' for filling and boundary.

`rhomb x1 y1 x2 y2 r ['col'='r']` [MGL command]

`rhomb x1 y1 z1 x2 y2 z2 r ['col'='r']` [MGL command]

`void Rhomb (mglPoint` *p1*`, mglPoint` *p2*`, mreal` *r*`, const char *`*col*`="r")` [Method on `mglGraph`]

`void mgl_rhomb (HMGL` *gr*`, mreal` *x1*`, mreal` *y1*`, mreal` *z1*`, mreal` *x2*`, mreal` *y2*`, mreal` *z2*`, mreal` *r*`, const char *`*col*`)` [C function]

Draw the rhombus with width *r* and edge points *p1*, *p2*. Parameter *col* may contain

- colors for filling and boundary (second one if style '`@`' is used, black color is used by default);
- '`#`' for wire figure (boundary only);
- '`@`' for filling and boundary.

`arc x0 y0 x1 y1 a ['col'='r']` [MGL command]

`arc x0 y0 z0 x1 y1 a ['col'='r']` [MGL command]

`arc x0 y0 z0 xa ya za x1 y1 z1 a ['col'='r']` [MGL command]

`void Arc (mglPoint` *p0*`, mglPoint` *p1*`, mreal` *a*`, const char *`*col*`="r")` [Method on `mglGraph`]

`void Arc (mglPoint` *p0*`, mglPoint` *pa*`, mglPoint` *p1*`, mreal` *a*`, const char *`*col*`="r")` [Method on `mglGraph`]

`void mgl_arc (HMGL` *gr*`, mreal` *x0*`, mreal` *y0*`, mreal` *x1*`, mreal` *y1*`, mreal` *a*`, const char *`*col*`)` [C function]

`void mgl_arc_ext (HMGL` *gr*`, mreal` *x0*`, mreal` *y0*`, mreal` *z0*`, mreal` *xa*`, mreal` *ya*`, mreal` *za*`, mreal` *x1*`, mreal` *y1*`, mreal` *z1*`, mreal` *a*`, const char *`*col*`)` [C function]

Draw the arc around axis *pa* (default is z-axis *pa*={0,0,1}) with center at *p0* and starting from point *p1*. Parameter *a* set the angle of arc in degree. Parameter *col* may contain color of the arc and arrow style for arc edges.

`polygon x0 y0 x1 y1 num ['col'='r']` [MGL command]

`polygon x0 y0 z0 x1 y1 z1 num ['col'='r']` [MGL command]

`void Polygon (mglPoint` *p0*`, mglPoint` *p1*`, int` *num*`, const char *`*col*`="r")` [Method on `mglGraph`]

`void mgl_polygon (HMGL` *gr*`, mreal` *x0*`, mreal` *y0*`, mreal` *z0*`, mreal` *x1*`, mreal` *y1*`, mreal` *z1*`, int` *num*`, const char *`*col*`)` [C function]

Draw the polygon with *num* edges starting from *p1*. The center of polygon is located in *p0*. Parameter *col* may contain

- colors for filling and boundary (second one if style '`@`' is used, black color is used by default);
- '`#`' for wire figure (boundary only);
- '`@`' for filling and boundary.

`logo` *'fname'* [*smooth=off*] [MGL command]
`void Logo (const char *`*fname*`, bool` *smooth*`=false,` [Method on `mglGraph`]
`const char *`*opt*`="")`
`void Logo (long` *w*`, long` *h*`, const unsigned char *`*rgba*`,` [Method on `mglGraph`]
`bool` *smooth*`=false, const char *`*opt*`="")`
`void mgl_logo (HMGL` *gr*`, long` *w*`, long` *h*`, const unsigned` [C function only]
`char *`*rgba*`, bool` *smooth*`, const char *`*opt*`)`
`void mgl_logo_file (HMGL` *gr*`, const char *`*fname*`, bool` *smooth*`,` [C function]
`const char *`*opt*`)`

Draw bitmap (logo) along whole axis range, which can be changed by Section 3.7 [Command options], page 154. Bitmap can be loaded from file or specified as RGBA values for pixels. Parameter *smooth* set to draw bitmap without or with color interpolation.

4.8 Text printing

These functions draw the text. There are functions for drawing text in arbitrary place, in arbitrary direction and along arbitrary curve. MathGL can use arbitrary font-faces and parse many TeX commands (for more details see Section 3.5 [Font styles], page 152). All these functions have 2 variant: for printing 8-bit text (`char *`) and for printing Unicode text (`wchar_t *`). In first case the conversion into the current locale is used. So sometimes you need to specify it by `setlocale()` function. The *size* argument control the size of text: if positive it give the value, if negative it give the value relative to `SetFontSize()`. The font type (STIX, arial, courier, times and so on) can be selected by function LoadFont(). See Section 4.2.6 [Font settings], page 162.

The font parameters are described by string. This string may set the text color '`wkrgbcymhRGBCYMHW`' (see Section 3.2 [Color styles], page 148). Starting from MathGL v.2.3, you can set color gradient for text (see Section 3.4 [Color scheme], page 150). Also, after delimiter symbol '`:`', it can contain characters of font type ('`rbiwou`') and/or align ('`LRCTV`') specification. The font types are: '`r`' – roman (or regular) font, '`i`' – italic style, '`b`' – bold style, '`w`' – wired style, '`o`' – over-lined text, '`u`' – underlined text. By default roman font is used. The align types are: '`L`' – align left (default), '`C`' – align center, '`R`' – align right, '`T`' – align under, '`V`' – align center vertical. For example, string '`b:iC`' correspond to italic font style for centered text which printed by blue color.

If string contains symbols '`aA`' then text is printed at absolute position {*x*, *y*} (supposed to be in range [0,1]) of picture (for '`A`') or subplot/inplot (for '`a`'). If string contains symbol '`@`' then box around text is drawn.

See Section 2.2.7 [Text features], page 31, for sample code and picture.

`text x y` *'text'* ['*fnt*'=" `size=-1`] [MGL command]
`text x y z` *'text'* ['*fnt*'=" `size=-1`] [MGL command]

`void Puts (mglPoint` *p*`, const char *`*text*`, const char *`*fnt*`=":C", mreal` *size*`=-1)` [Method on `mglGraph`]
`void Putsw (mglPoint` *p*`, const wchar_t *`*text*`, const char *`*fnt*`=":C", mreal` *size*`=-1)` [Method on `mglGraph`]
`void Puts (mreal` *x*`, mreal` *y*`, const char *`*text*`, const char *`*fnt*`=":AC", mreal` *size*`=-1)` [Method on `mglGraph`]
`void Putsw (mreal` *x*`, mreal` *y*`, const wchar_t *`*text*`, const char *`*fnt*`=":AC", mreal` *size*`=-1)` [Method on `mglGraph`]
`void mgl_puts (HMGL` *gr*`, mreal` *x*`, mreal` *y*`, mreal` *z*`, const char *`*text*`, const char *`*fnt*`, mreal` *size*`)` [C function]
`void mgl_putsw (HMGL` *gr*`, mreal` *x*`, mreal` *y*`, mreal` *z*`, const wchar_t *`*text*`, const char *`*fnt*`, mreal` *size*`)` [C function]

The function plots the string *text* at position *p* with fonts specifying by the criteria *fnt*. The size of font is set by *size* parameter (default is `-1`).

`text x y dx dy` *'text'* [*'fnt'=':L'* `size=-1`] [MGL command]
`text x y z dx dy dz` *'text'* [*'fnt'=':L'* `size=-1`] [MGL command]
`void Puts (mglPoint` *p*`, mglPoint` *d*`, const char *`*text*`, const char *`*fnt*`=":L", mreal` *size*`=-1)` [Method on `mglGraph`]
`void Putsw (mglPoint` *p*`, mglPoint` *d*`, const wchar_t *`*text*`, const char *`*fnt*`=":L", mreal` *size*`=-1)` [Method on `mglGraph`]
`void mgl_puts_dir (HMGL` *gr*`, mreal` *x*`, mreal` *y*`, mreal` *z*`, mreal` *dx*`, mreal` *dy*`, mreal` *dz*`, const char *`*text*`, const char *`*fnt*`, mreal` *size*`)` [C function]
`void mgl_putsw_dir (HMGL` *gr*`, mreal` *x*`, mreal` *y*`, mreal` *z*`, mreal` *dx*`, mreal` *dy*`, mreal` *dz*`, const wchar_t *`*text*`, const char *`*fnt*`, mreal` *size*`)` [C function]

The function plots the string *text* at position *p* along direction *d* with specified *size*. Parameter *fnt* set text style and text position: under ('`T`') or above ('`t`') the line.

`fgets x y` *'fname'* [`n=0` *'fnt'=''* `size=-1.4`] [MGL command]
`fgets x y z` *'fname'* [`n=0` *'fnt'=''* `size=-1.4`] [MGL command]

Draws unrotated *n*-th line of file *fname* at position {*x*,*y*,*z*} with specified *size*. By default parameters from [font], page 162 command are used.

`text` *ydat 'text'* [*'fnt'=''*] [MGL command]
`text` *xdat ydat 'text'* [*'fnt'=''*] [MGL command]
`text` *xdat ydat zdat 'text'* [*'fnt'=''*] [MGL command]
`void Text (const mglDataA &`*y*`, const char *`*text*`, const char *`*fnt*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Text (const mglDataA &`*y*`, const wchar_t *`*text*`, const char *`*fnt*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Text (const mglDataA &`*x*`, const mglDataA &`*y*`, const char *`*text*`, const char *`*fnt*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Text (const mglDataA &`*x*`, const mglDataA &`*y*`, const wchar_t *`*text*`, const char *`*fnt*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Text (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*text*`, const char *`*fnt*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void Text (const mglDataA &x, const mglDataA &y, const mglDataA &z, const wchar_t *text, const char *fnt="", const char *opt="")` [Method on `mglGraph`]

`void mgl_text_y (HMGL gr, HCDT y, const char *text, const char *fnt, const char *opt)` [C function]

`void mgl_textw_y (HMGL gr, HCDT y, const wchar_t *text, const char *fnt, const char *opt)` [C function]

`void mgl_text_xy (HCDT x, HCDT y, const char *text, const char *fnt, const char *opt)` [C function]

`void mgl_textw_xy (HCDT x, HCDT y, const wchar_t *text, const char *fnt, const char *opt)` [C function]

`void mgl_text_xyz (HCDT x, HCDT y, HCDT z, const char *text, const char *fnt, const char *opt)` [C function]

`void mgl_textw_xyz (HCDT x, HCDT y, HCDT z, const wchar_t *text, const char *fnt, const char *opt)` [C function]

The function draws *text* along the curve between points {*x*[i], *y*[i], *z*[i]} by font style *fnt*. The string *fnt* may contain symbols '`t`' for printing the text under the curve (default), or '`T`' for printing the text under the curve. The sizes of 1st dimension must be equal for all arrays `x.nx=y.nx=z.nx`. If array *x* is not specified then its an automatic array is used with values equidistantly distributed in x-axis range (see Section 4.3.1 [Ranges (bounding box)], page 167). If array *z* is not specified then *z*[i] equal to minimal z-axis value is used. String *opt* contain command options (see Section 3.7 [Command options], page 154).

4.9 Axis and Colorbar

These functions draw the "things for measuring", like axis with ticks, colorbar with ticks, grid along axis, bounding box and labels for axis. For more information see Section 4.3 [Axis settings], page 167.

`axis ['dir'='xyz' 'stl'='']` [MGL command]

`void Axis (const char *dir="xyz", const char *stl="", const char *opt="")` [Method on `mglGraph`]

`void mgl_axis (HMGL gr, const char *dir, const char *stl, const char *opt)` [C function]

Draws axes with ticks (see Section 4.3 [Axis settings], page 167). Parameter *dir* may contain:

- '`xyz`' for drawing axis in corresponding direction;
- '`XYZ`' for drawing axis in corresponding direction but with inverted positions of labels;
- '`~`' or '`_`' for disabling tick labels;
- '`U`' for disabling rotation of tick labels;
- '`^`' for inverting default axis origin;
- '`!`' for disabling ticks tuning (see [tuneticks], page 171);
- '`AKDTVISO`' for drawing arrow at the end of axis;
- '`a`' for forced adjusting of axis ticks;

- '`f`' for printing ticks labels in fixed format;
- '`E`' for using '`E`' instead of '`e`' in ticks labels;
- '`F`' for printing ticks labels in LaTeX format;
- '`+`' for printing '`+`' for positive ticks;
- '`-`' for printing usual '`-`' in ticks labels;
- '`0123456789`' for precision at printing ticks labels.

Styles of ticks and axis can be overrided by using *stl* string. Option `value` set the manual rotation angle for the ticks. See Section 2.2.2 [Axis and ticks], page 22, for sample code and picture.

`colorbar` ['*sch*'=''] [MGL command]
`void Colorbar (const char *`*sch*`="")` [Method on `mglGraph`]
`void mgl_colorbar (HMGL` *gr*`, const char *`*sch*`)` [C function]

Draws colorbar. Parameter *sch* may contain:

- color scheme (see Section 3.4 [Color scheme], page 150);
- '`<>^_`' for positioning at left, at right, at top or at bottom correspondingly;
- '`I`' for positioning near bounding (by default, is positioned at edges of subplot);
- '`A`' for using absolute coordinates;
- '`~`' for disabling tick labels.
- '`!`' for disabling ticks tuning (see [tuneticks], page 171);
- '`f`' for printing ticks labels in fixed format;
- '`E`' for using '`E`' instead of '`e`' in ticks labels;
- '`F`' for printing ticks labels in LaTeX format;
- '`+`' for printing '`+`' for positive ticks;
- '`-`' for printing usual '`-`' in ticks labels;
- '`0123456789`' for precision at printing ticks labels.

See Section 2.2.4 [Colorbars], page 28, for sample code and picture.

`colorbar` *vdat* ['*sch*'=''] [MGL command]
`void Colorbar (const mglDataA &`*v*`, const char *`*sch*`="")` [Method on `mglGraph`]
`void mgl_colorbar_val (HMGL` *gr*`, HCDT` *v*`, const char *`*sch*`)` [C function]

The same as previous but with sharp colors *sch* (current palette if `sch=""`) for values *v*. See Section 2.6.14 [ContD sample], page 84, for sample code and picture.

`colorbar` *'sch'* `x y` [`w=1 h=1`] [MGL command]
`void Colorbar (const char *`*sch*`, mreal` *x*`, mreal` *y*`, mreal` *w*`=1, mreal` *h*`=1)` [Method on `mglGraph`]
`void mgl_colorbar_ext (HMGL` *gr*`, const char *`*sch*`, mreal` *x*`, mreal` *y*`, mreal` *w*`, mreal` *h*`)` [C function]

The same as first one but at arbitrary position of subplot {*x*, *y*} (supposed to be in range [0,1]). Parameters *w*, *h* set the relative width and height of the colorbar.

`colorbar` *vdat 'sch'* `x y [w=1 h=1]` [MGL command]
`void Colorbar (const mglDataA &`*v*`, const char *`*sch*`,` [Method on `mglGraph`]
`mreal` *x*`, mreal` *y*`, mreal` *w*`=1, mreal` *h*`=1)`
`void mgl_colorbar_val_ext (HMGL` *gr*`, HCDT` *v*`, const char *`*sch*`,` [C function]
`mreal` *x*`, mreal` *y*`, mreal` *w*`, mreal` *h*`)`

The same as previous but with sharp colors *sch* (current palette if `sch=""`) for values *v*. See Section 2.6.14 [ContD sample], page 84, for sample code and picture.

`grid [`*'dir'='xyz' 'pen'='B'*`]` [MGL command]
`void Grid (const char *`*dir*`="xyz", const char` [Method on `mglGraph`]
`*`*pen*`="B", const char *`*opt*`="")`
`void mgl_axis_grid (HMGL` *gr*`, const char *`*dir*`, const char *`*pen*`,` [C function]
`const char *`*opt*`)`

Draws grid lines perpendicular to direction determined by string parameter *dir*. If *dir* contain '`!`' then grid lines will be drawn at coordinates of subticks also. The step of grid lines is the same as tick step for [axis], page 191. The style of lines is determined by *pen* parameter (default value is dark blue solid line '`B-`').

`box [`*'stl'='k'* `ticks=on]` [MGL command]
`void Box (const char *`*col*`="", bool` *ticks*`=true)` [Method on `mglGraph`]
`void mgl_box (HMGL` *gr*`, int` *ticks*`)` [C function]
`void mgl_box_str (HMGL` *gr*`, const char *`*col*`, int` *ticks*`)` [C function]

Draws bounding box outside the plotting volume with color *col*. If *col* contain '`@`' then filled faces are drawn. At this first color is used for faces (default is light yellow), last one for edges. See Section 2.2.5 [Bounding box], page 29, for sample code and picture.

`xlabel` *'text'* `[pos=1]` [MGL command]
`ylabel` *'text'* `[pos=1]` [MGL command]
`zlabel` *'text'* `[pos=1]` [MGL command]
`tlabel` *'text'* `[pos=1]` [MGL command]
`void Label (char` *dir*`, const char *`*text*`, mreal` *pos*`=1,` [Method on `mglGraph`]
`const char *`*opt*`="")`
`void Label (char` *dir*`, const wchar_t *`*text*`, mreal` *pos*`=1,` [Method on `mglGraph`]
`const char *`*opt*`="")`
`void mgl_label (HMGL` *gr*`, char` *dir*`, const char *`*text*`, mreal` *pos*`,` [C function]
`const char *`*opt*`)`
`void mgl_labelw (HMGL` *gr*`, char` *dir*`, const wchar_t *`*text*`, mreal` [C function]
pos`, const char *`*opt*`)`

Prints the label *text* for axis *dir*='`x`','`y`','`z`','`t`' (here '`t`' is "ternary" axis $t = 1-x-y$). The position of label is determined by *pos* parameter. If *pos*=0 then label is printed at the center of axis. If *pos*>0 then label is printed at the maximum of axis. If *pos*<0 then label is printed at the minimum of axis. Option `value` set additional shifting of the label. See Section 4.8 [Text printing], page 189.

4.10 Legend

These functions draw legend to the graph (useful for Section 4.11 [1D plotting], page 195). Legend entry is a pair of strings: one for style of the line, another one with description text

(with included TeX parsing). The arrays of strings may be used directly or by accumulating first to the internal arrays (by function [addlegend], page 194) and further plotting it. The position of the legend can be selected automatic or manually (even out of bounding box). Parameters *fnt* and *size* specify the font style and size (see Section 4.2.6 [Font settings], page 162). Parameter *llen* set the relative width of the line sample and the text indent. If line style string for entry is empty then the corresponding text is printed without indent. Parameter *fnt* may contain:

- font style for legend text;
- '`A`' for positioning in absolute coordinates;
- '`^`' for positioning outside of specified point;
- '`#`' for drawing box around legend;
- '`-`' for arranging legend entries horizontally;
- colors for face (1st one), for border (2nd one) and for text (last one). If less than 3 colors are specified then the color for border is black (for 2 and less colors), and the color for face is white (for 1 or none colors).

See Section 2.2.8 [Legend sample], page 34, for sample code and picture.

`legend [pos=3 'fnt'='#']` [MGL command]
`void Legend (int pos=0x3, const char *fnt="#", const char *opt="")` [Method on `mglGraph`]
`void mgl_legend (HMGL gr, int pos, const char *fnt, const char *opt)` [C function]

Draws legend of accumulated legend entries by font *fnt* with *size*. Parameter *pos* sets the position of the legend: '`0`' is bottom left corner, '`1`' is bottom right corner, '`2`' is top left corner, '`3`' is top right corner (is default). Option `value` set the space between line samples and text (default is 0.1).

`legend x y ['fnt'='#']` [MGL command]
`void Legend (mreal x, mreal y, const char *fnt="#", const char *opt="")` [Method on `mglGraph`]
`void mgl_legend_pos (HMGL gr, mreal x, mreal y, const char *fnt, const char *opt)` [C function]

Draws legend of accumulated legend entries by font *fnt* with *size*. Position of legend is determined by parameter *x*, *y* which supposed to be normalized to interval [0,1]. Option `value` set the space between line samples and text (default is 0.1).

`addlegend 'text' 'stl'` [MGL command]
`void AddLegend (const char *text, const char *style)` [Method on `mglGraph`]
`void AddLegend (const wchar_t *text, const char *style)` [Method on `mglGraph`]
`void mgl_add_legend (HMGL gr, const char *text, const char *style)` [C function]
`void mgl_add_legendw (HMGL gr, const wchar_t *text, const char *style)` [C function]

Adds string *text* to internal legend accumulator. The style of described line and mark is specified in string *style* (see Section 3.3 [Line styles], page 148).

`clearlegend` [MGL command]
`void ClearLegend ()` [Method on `mglGraph`]
`void mgl_clear_legend (HMGL` *gr*`)` [C function]
Clears saved legend strings.

`legendmarks val` [MGL command]
`void SetLegendMarks (int` *num*`)` [Method on `mglGraph`]
`void mgl_set_legend_marks (HMGL` *gr*`, int` *num*`)` [C function]
Set the number of marks in the legend. By default 1 mark is used.

4.11 1D plotting

These functions perform plotting of 1D data. 1D means that data depended from only 1 parameter like parametric curve {x[i],y[i],z[i]}, i=1...n. By default (if absent) values of x[i] are equidistantly distributed in axis range, and z[i] equal to minimal z-axis value. The plots are drawn for each row if one of the data is the matrix. By any case the sizes of 1st dimension **must be equal** for all arrays `x.nx=y.nx=z.nx`.

String *pen* specifies the color and style of line and marks (see Section 3.3 [Line styles], page 148). By default (`pen=""`) solid line with color from palette is used (see Section 4.2.7 [Palette and colors], page 163). Symbol '`!`' set to use new color from palette for each point (not for each curve, as default). String *opt* contain command options (see Section 3.7 [Command options], page 154). See Section 2.5 [1D samples], page 45, for sample code and picture.

`plot` *ydat* ['*stl*'=”] [MGL command]
`plot` *xdat ydat* ['*stl*'=”] [MGL command]
`plot` *xdat ydat zdat* ['*stl*'=”] [MGL command]
`void Plot (const mglDataA &`*y*`, const char *`*pen*`="",` [Method on `mglGraph`]
`const char *`*opt*`="")`
`void Plot (const mglDataA &`*x*`, const mglDataA &`*y*`,` [Method on `mglGraph`]
`const char *`*pen*`="", const char *`*opt*`="")`
`void Plot (const mglDataA &`*x*`, const mglDataA &`*y*`,` [Method on `mglGraph`]
`const mglDataA &`*z*`, const char *`*pen*`="", const char *`*opt*`="")`
`void mgl_plot (HMGL` *gr*`, HCDT` *y*`, const char *`*pen*`, const char` [C function]
`*`*opt*`)`
`void mgl_plot_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, const char *`*pen*`,` [C function]
`const char *`*opt*`)`
`void mgl_plot_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char` [C function]
`*`*pen*`, const char *`*opt*`)`
These functions draw continuous lines between points {x[i], y[i], z[i]}. See also [area], page 197, [step], page 196, [stem], page 198, [tube], page 205, [mark], page 202, [error], page 202, [belt], page 209, [tens], page 196, [tape], page 197. See Section 2.5.1 [Plot sample], page 46, for sample code and picture.

`radar` *adat* ['*stl*'=”] [MGL command]
`void Radar (const mglDataA &`*a*`, const char *`*pen*`="",` [Method on `mglGraph`]
`const char *`*opt*`="")`

`void mgl_radar (HMGL` *gr*`, HCDT` *a*`, const char *`*pen*`, const char *`*opt*`)` [C function]

This functions draws radar chart which is continuous lines between points located on an radial lines (like plot in Polar coordinates). Option `value` set the additional shift of data (i.e. the data *a*`+value` is used instead of *a*). If `value<0` then `r=max(0, -min(value)`. If *pen* containt '`#`' symbol then "grid" (radial lines and circle for *r*) is drawn. See also [plot], page 195. See Section 2.5.2 [Radar sample], page 47, for sample code and picture.

`step` *ydat* ['*stl*'=''] [MGL command]
`step` *xdat ydat* ['*stl*'=''] [MGL command]
`step` *xdat ydat zdat* ['*stl*'=''] [MGL command]
`void Step (const mglDataA &`*y*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Step (const mglDataA &`*x*`, const mglDataA &`*y*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Step (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_step (HMGL` *gr*`, HCDT` *y*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_step_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_step_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*pen*`, const char *`*opt*`)` [C function]

These functions draw continuous stairs for points to axis plane. See also [plot], page 195, [stem], page 198, [tile], page 209, [boxs], page 209. See Section 2.5.3 [Step sample], page 48, for sample code and picture.

`tens` *ydat cdat* ['*stl*'=''] [MGL command]
`tens` *xdat ydat cdat* ['*stl*'=''] [MGL command]
`tens` *xdat ydat zdat cdat* ['*stl*'=''] [MGL command]
`void Tens (const mglDataA &`*y*`, const mglDataA &`*c*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Tens (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*c*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Tens (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*c*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_tens (HMGL` *gr*`, HCDT` *y*`, HCDT` *c*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_tens_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *c*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_tens_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *c*`, const char *`*pen*`, const char *`*opt*`)` [C function]

These functions draw continuous lines between points {*x*[i], *y*[i], *z*[i]} with color defined by the special array *c*[i] (look like tension plot). String *pen* specifies the color scheme (see Section 3.4 [Color scheme], page 150) and style and/or width of line (see

Section 3.3 [Line styles], page 148). See also [plot], page 195, [mesh], page 208, [fall], page 208. See Section 2.5.4 [Tens sample], page 49, for sample code and picture.

`tape` *ydat* ['*stl*'=''] [MGL command]
`tape` *xdat ydat* ['*stl*'=''] [MGL command]
`tape` *xdat ydat zdat* ['*stl*'=''] [MGL command]
`void Tape (const mglDataA &`*y*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Tape (const mglDataA &`*x*`, const mglDataA &`*y*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Tape (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_tape (HMGL` *gr*`, HCDT` *y*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_tape_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_tape_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*pen*`, const char *`*opt*`)` [C function]

These functions draw tapes of normals for curve between points {*x*[i], *y*[i], *z*[i]}. Initial tape(s) was selected in x-y plane (for '`x`' in *pen*) and/or y-z plane (for '`x`' in *pen*). The width of tape is proportional to [barwidth], page 161 and can be changed by option `value`. See also [plot], page 195, [flow], page 224, [barwidth], page 161. See Section 2.5.21 [Tape sample], page 66, for sample code and picture.

`area` *ydat* ['*stl*'=''] [MGL command]
`area` *xdat ydat* ['*stl*'=''] [MGL command]
`area` *xdat ydat zdat* ['*stl*'=''] [MGL command]
`void Area (const mglDataA &`*y*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Area (const mglDataA &`*x*`, const mglDataA &`*y*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Area (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_area (HMGL` *gr*`, HCDT` *y*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_area_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_area_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*pen*`, const char *`*opt*`)` [C function]

These functions draw continuous lines between points and fills it to axis plane. Also you can use gradient filling if number of specified colors is equal to 2*number of curves. See also [plot], page 195, [bars], page 198, [stem], page 198, [region], page 197. See Section 2.5.5 [Area sample], page 50, for sample code and picture.

`region` *ydat1 ydat2* ['*stl*'=''] [MGL command]
`region` *xdat ydat1 ydat2* ['*stl*'=''] [MGL command]
`region` *xdat1 ydat1 xdat2 ydat2* ['*stl*'=''] [MGL command]
`region` *xdat1 ydat1 zdat1 xdat2 ydat2 zdat2* ['*stl*'=''] [MGL command]

`void Region (const mglDataA &`*y1*`, const mglDataA &`*y2*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Region (const mglDataA &`*x*`, const mglDataA &`*y1*`, const mglDataA &`*y2*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Region (const mglDataA &`*x1*`, const mglDataA &`*y1*`, const mglDataA &`*x2*`, const mglDataA &`*y2*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Region (const mglDataA &`*x1*`, const mglDataA &`*y1*`, const mglDataA &`*z1*`, const mglDataA &`*x2*`, const mglDataA &`*y2*`, const mglDataA &`*z2*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_region (HMGL` *gr*`, HCDT` *y1*`, HCDT` *y2*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_region_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y1*`, HCDT` *y2*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_region_3d (HMGL` *gr*`, HCDT` *x1*`, HCDT` *y1*`, HCDT` *z1*`, HCDT` *x2*`, HCDT` *y2*`, HCDT` *z2*`, const char *`*pen*`, const char *`*opt*`)` [C function]

These functions fill area between 2 curves. Dimensions of arrays *y1* and *y2* must be equal. Also you can use gradient filling if number of specified colors is equal to 2*number of curves. If for 2D version *pen* contain symbol '`i`' then only area with y1<y<y2 will be filled else the area with y2<y<y1 will be filled too. See also [area], page 197, [bars], page 198, [stem], page 198. See Section 2.5.6 [Region sample], page 51, for sample code and picture.

`stem` *ydat* ['*stl*'=''] [MGL command]
`stem` *xdat ydat* ['*stl*'=''] [MGL command]
`stem` *xdat ydat zdat* ['*stl*'=''] [MGL command]
`void Stem (const mglDataA &`*y*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Stem (const mglDataA &`*x*`, const mglDataA &`*y*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Stem (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_stem (HMGL` *gr*`, HCDT` *y*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_stem_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_stem_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*pen*`, const char *`*opt*`)` [C function]

These functions draw vertical lines from points to axis plane. See also [area], page 197, [bars], page 198, [plot], page 195, [mark], page 202. See Section 2.5.7 [Stem sample], page 52, for sample code and picture.

`bars` *ydat* ['*stl*'=''] [MGL command]
`bars` *xdat ydat* ['*stl*'=''] [MGL command]
`bars` *xdat ydat zdat* ['*stl*'=''] [MGL command]
`void Bars (const mglDataA &`*y*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void Bars (const mglDataA &x, const mglDataA &y, const char *pen="", const char *opt="")` [Method on `mglGraph`]

`void Bars (const mglDataA &x, const mglDataA &y, const mglDataA &z, const char *pen="", const char *opt="")` [Method on `mglGraph`]

`void mgl_bars (HMGL gr, HCDT y, const char *pen, const char *opt)` [C function]

`void mgl_bars_xy (HMGL gr, HCDT x, HCDT y, const char *pen, const char *opt)` [C function]

`void mgl_bars_xyz (HMGL gr, HCDT x, HCDT y, HCDT z, const char *pen, const char *opt)` [C function]

These functions draw vertical bars from points to axis plane. If string *pen* contain symbol '`a`' then lines are drawn one above another (like summation). If string contain symbol '`f`' then waterfall chart is drawn for determining the cumulative effect of sequentially introduced positive or negative values. You can give different colors for positive and negative values if number of specified colors is equal to 2*number of curves. If *pen* contain '`<`', '`^`' or '`>`' then boxes will be aligned left, right or centered at its x-coordinates. See also [barh], page 199, [cones], page 199, [area], page 197, [stem], page 198, [chart], page 200, [barwidth], page 161. See Section 2.5.8 [Bars sample], page 53, for sample code and picture.

`barh` *vdat* ['stl'=''] [MGL command]

`barh` *ydat vdat* ['stl'=''] [MGL command]

`void Barh (const mglDataA &v, const char *pen="", const char *opt="")` [Method on `mglGraph`]

`void Barh (const mglDataA &y, const mglDataA &v, const char *pen="", const char *opt="")` [Method on `mglGraph`]

`void mgl_barh (HMGL gr, HCDT v, const char *pen, const char *opt)` [C function]

`void mgl_barh_xy (HMGL gr, HCDT y, HCDT v, const char *pen, const char *opt)` [C function]

These functions draw horizontal bars from points to axis plane. If string contain symbol '`a`' then lines are drawn one above another (like summation). If string contain symbol '`f`' then waterfall chart is drawn for determining the cumulative effect of sequentially introduced positive or negative values. You can give different colors for positive and negative values if number of specified colors is equal to 2*number of curves. If *pen* contain '`<`', '`^`' or '`>`' then boxes will be aligned left, right or centered at its x-coordinates. See also [bars], page 198, [barwidth], page 161. See Section 2.5.9 [Barh sample], page 54, for sample code and picture.

`cones` *ydat* ['stl'=''] [MGL command]

`cones` *xdat ydat* ['stl'=''] [MGL command]

`cones` *xdat ydat zdat* ['stl'=''] [MGL command]

`void Cones (const mglDataA &y, const char *pen="", const char *opt="")` [Method on `mglGraph`]

`void Cones (const mglDataA &x, const mglDataA &y, const char *pen="", const char *opt="")` [Method on `mglGraph`]

`void Cones (const mglDataA &x, const mglDataA &y, const mglDataA &z, const char *pen="", const char *opt="")` [Method on `mglGraph`]

`void mgl_cones (HMGL` *gr*`, HCDT` *y*`, const char *`*pen*`, const char *`*opt*`)` [C function]

`void mgl_cones_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, const char *`*pen*`, const char *`*opt*`)` [C function]

`void mgl_cones_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*pen*`, const char *`*opt*`)` [C function]

These functions draw cones from points to axis plane. If string contain symbol '`a`' then cones are drawn one above another (like summation). You can give different colors for positive and negative values if number of specified colors is equal to 2*number of curves. Parameter *pen* can contain:

- '`@`' for drawing edges;
- '`#`' for wired cones;
- '`t`' for drawing tubes/cylinders instead of cones/prisms;
- '`4`', '`6`', '`8`' for drawing square, hex- or octo-prism instead of cones;
- '`<`', '`^`' or '`>`' for aligning boxes left, right or centering them at its x-coordinates.

See also [bars], page 198, [cone], page 187, [barwidth], page 161. See Section 2.5.10 [Cones sample], page 55, for sample code and picture.

`chart` *adat* ['*col*'=*"*] [MGL command]

`void Chart (const mglDataA &`*a*`, const char *`*col*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void mgl_chart (HMGL` *gr*`, HCDT` *a*`, const char *`*col*`, const char *`*opt*`)` [C function]

The function draws colored stripes (boxes) for data in array *a*. The number of stripes is equal to the number of rows in *a* (equal to *a.ny*). The color of each next stripe is cyclically changed from colors specified in string *col* or in palette Pal (see Section 4.2.7 [Palette and colors], page 163). Spaces in colors denote transparent "color" (i.e. corresponding stripe(s) are not drawn). The stripe width is proportional to value of element in *a*. Chart is plotted only for data with non-negative elements. If string *col* have symbol '`#`' then black border lines are drawn. The most nice form the chart have in 3d (after rotation of coordinates) or in cylindrical coordinates (becomes so called Pie chart). See Section 2.5.11 [Chart sample], page 56, for sample code and picture.

`boxplot` *adat* ['*stl*'=*"*] [MGL command]

`boxplot` *xdat adat* ['*stl*'=*"*] [MGL command]

`void BoxPlot (const mglDataA &`*a*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void BoxPlot (const mglDataA &`*x*`, const mglDataA &`*a*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void mgl_boxplot (HMGL` *gr*`, HCDT` *a*`, const char *`*pen*`, const char *`*opt*`)` [C function]

`void mgl_boxplot_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *a*`, const char *`*pen*`, const char *`*opt*`)` [C function]

These functions draw boxplot (also known as a box-and-whisker diagram) at points *x*[i]. This is five-number summaries of data *a*[i,j] (minimum, lower quartile (Q1), median (Q2), upper quartile (Q3) and maximum) along second (j-th) direction. If

pen contain '<', '^' or '>' then boxes will be aligned left, right or centered at its x-coordinates. See also [plot], page 195, [error], page 202, [bars], page 198, [barwidth], page 161. See Section 2.5.12 [BoxPlot sample], page 57, for sample code and picture.

`candle` *vdat1* ['stl'=''] [MGL command]
`candle` *vdat1 vdat2* ['stl'=''] [MGL command]
`candle` *vdat1 ydat1 ydat2* ['stl'=''] [MGL command]
`candle` *vdat1 vdat2 ydat1 ydat2* ['stl'=''] [MGL command]
`candle` *xdat vdat1 vdat2 ydat1 ydat2* ['stl'=''] [MGL command]
`void Candle (const mglDataA &`*v1*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Candle (const mglDataA &`*v1*`, const mglDataA &`*v2*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Candle (const mglDataA &`*v1*`, const mglDataA &`*y1*`, const mglDataA &`*y2*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Candle (const mglDataA &`*v1*`, const mglDataA &`*v2*`, const mglDataA &`*y1*`, const mglDataA &`*y2*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Candle (const mglDataA &`*x*`, const mglDataA &`*v1*`, const mglDataA &`*v2*`, const mglDataA &`*y1*`, const mglDataA &`*y2*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_candle (HMGL` *gr*`, HCDT` *v1*`, HCDT` *y1*`, HCDT` *y2*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_candle_yv (HMGL` *gr*`, HCDT` *v1*`, HCDT` *v2*`, HCDT` *y1*`, HCDT` *y2*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_candle_xyv (HMGL` *gr*`, HCDT` *x*`, HCDT` *v1*`, HCDT` *v2*`, HCDT` *y1*`, HCDT` *y2*`, const char *`*pen*`, const char *`*opt*`)` [C function]

These functions draw candlestick chart at points *x*[i]. This is a combination of a line-chart and a bar-chart, in that each bar represents the range of price movement over a given time interval. Wire (or white) candle correspond to price growth *v1*[i]<*v2*[i], opposite case – solid (or dark) candle. You can give different colors for growth and decrease values if number of specified colors is equal to 2. If *pen* contain '#' then the wire candle will be used even for 2-color scheme. "Shadows" show the minimal *y1* and maximal *y2* prices. If *v2* is absent then it is determined as *v2*[i]=*v1*[i+1]. See also [plot], page 195, [bars], page 198, [ohlc], page 201, [barwidth], page 161. See Section 2.5.13 [Candle sample], page 58, for sample code and picture.

`ohlc` *odat hdat ldat cdat* ['stl'=''] [MGL command]
`ohlc` *xdat odat hdat ldat cdat* ['stl'=''] [MGL command]
`void OHLC (const mglDataA &`*o*`, const mglDataA &`*h*`, const mglDataA &`*l*`, const mglDataA &`*c*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void OHLC (const mglDataA &`*x*`, const mglDataA &`*o*`, const mglDataA &`*h*`, const mglDataA &`*l*`, const mglDataA &`*c*`, const char *`*pen*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_ohlc (HMGL` *gr*`, HCDT` *o*`, HCDT` *h*`, HCDT` *l*`, HCDT` *c*`, const char *`*pen*`, const char *`*opt*`)` [C function]

`void mgl_ohlc_x (HMGL` *gr*`, HCDT` *x*`, HCDT` *o*`, HCDT` *h*`, HCDT` *l*`, HCDT` *c*`,` [C function]
`const char *`*pen*`, const char *`*opt*`)`

These functions draw Open-High-Low-Close diagram. This diagram show vertical line for between maximal(high *h*) and minimal(low *l*) values, as well as horizontal lines before/after vertical line for initial(open *o*)/final(close *c*) values of some process (usually price). You can give different colors for up and down values (when closing values higher or not as in previous point) if number of specified colors is equal to 2*number of curves. See also [candle], page 201, [plot], page 195, [barwidth], page 161. See Section 2.5.14 [OHLC sample], page 58, for sample code and picture.

`error` *ydat yerr* ['*stl*'=''] [MGL command]
`error` *xdat ydat yerr* ['*stl*'=''] [MGL command]
`error` *xdat ydat xerr yerr* ['*stl*'=''] [MGL command]
`void Error (const mglDataA &`*y*`, const mglDataA &`*ey*`,` [Method on `mglGraph`]
`const char *`*pen*`="", const char *`*opt*`="")`
`void Error (const mglDataA &`*x*`, const mglDataA &`*y*`,` [Method on `mglGraph`]
`const mglDataA &`*ey*`, const char *`*pen*`="", const char *`*opt*`="")`
`void Error (const mglDataA &`*x*`, const mglDataA &`*y*`,` [Method on `mglGraph`]
`const mglDataA &`*ex*`, const mglDataA &`*ey*`, const char *`*pen*`="", const char *`*opt*`="")`
`void mgl_error (HMGL` *gr*`, HCDT` *y*`, HCDT` *ey*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_error_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *ey*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_error_exy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *ex*`, HCDT` *ey*`,` [C function]
`const char *`*pen*`, const char *`*opt*`)`

These functions draw error boxes {*ex*[i], *ey*[i]} at points {*x*[i], *y*[i]}. This can be useful, for example, in experimental points, or to show numeric error or some estimations and so on. If string *pen* contain symbol '`@`' than large semitransparent mark is used instead of error box. See also [plot], page 195, [mark], page 202. See Section 2.5.15 [Error sample], page 59, for sample code and picture.

`mark` *ydat rdat* ['*stl*'=''] [MGL command]
`mark` *xdat ydat rdat* ['*stl*'=''] [MGL command]
`mark` *xdat ydat zdat rdat* ['*stl*'=''] [MGL command]
`void Mark (const mglDataA &`*y*`, const mglDataA &`*r*`,` [Method on `mglGraph`]
`const char *`*pen*`="", const char *`*opt*`="")`
`void Mark (const mglDataA &`*x*`, const mglDataA &`*y*`,` [Method on `mglGraph`]
`const mglDataA &`*r*`, const char *`*pen*`="", const char *`*opt*`="")`
`void Mark (const mglDataA &`*x*`, const mglDataA &`*y*`,` [Method on `mglGraph`]
`const mglDataA &`*z*`, const mglDataA &`*r*`, const char *`*pen*`="", const char *`*opt*`="")`
`void mgl_mark_y (HMGL` *gr*`, HCDT` *y*`, HCDT` *r*`, const char *`*pen*`, const char *`*opt*`)` [C function]
`void mgl_mark_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *r*`, const char *`*pen*`, const char *`*opt*`)` [C function]

`void mgl_mark_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *r*`, const char *`*pen*`, const char *`*opt*`)` [C function]

These functions draw marks with size *r*[i]*[marksize], page 161 at points {*x*[i], *y*[i], *z*[i]}. If you need to draw markers of the same size then you can use [plot], page 195 function with empty line style ' '. For markers with size in axis range use [error], page 202 with style '`@`'. See also [plot], page 195, [textmark], page 203, [error], page 202, [stem], page 198. See Section 2.5.16 [Mark sample], page 61, for sample code and picture.

`textmark` *ydat 'txt'* ['*stl*'=''] [MGL command]
`textmark` *ydat rdat 'txt'* ['*stl*'=''] [MGL command]
`textmark` *xdat ydat rdat 'txt'* ['*stl*'=''] [MGL command]
`textmark` *xdat ydat zdat rdat 'txt'* ['*stl*'=''] [MGL command]
`void TextMark (const mglDataA &`*y*`, const char *`*txt*`, const char *`*fnt*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void TextMark (const mglDataA &`*y*`, const wchar_t *`*txt*`, const char *`*fnt*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void TextMark (const mglDataA &`*y*`, const mglDataA &`*r*`, const char *`*txt*`, const char *`*fnt*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void TextMark (const mglDataA &`*y*`, const mglDataA &`*r*`, const wchar_t *`*txt*`, const char *`*fnt*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void TextMark (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*r*`, const char *`*txt*`, const char *`*fnt*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void TextMark (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*r*`, const wchar_t *`*txt*`, const char *`*fnt*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void TextMark (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*r*`, const char *`*txt*`, const char *`*fnt*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void TextMark (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*r*`, const wchar_t *`*txt*`, const char *`*fnt*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_textmark (HMGL` *gr*`, HCDT` *y*`, const char *`*txt*`, const char *`*fnt*`, const char *`*opt*`)` [C function]
`void mgl_textmarkw (HMGL` *gr*`, HCDT` *y*`, const wchar_t *`*txt*`, const char *`*fnt*`, const char *`*opt*`)` [C function]
`void mgl_textmark_yr (HMGL` *gr*`, HCDT` *y*`, HCDT` *r*`, const char *`*txt*`, const char *`*fnt*`, const char *`*opt*`)` [C function]
`void mgl_textmarkw_yr (HMGL` *gr*`, HCDT` *y*`, HCDT` *r*`, const wchar_t *`*txt*`, const char *`*fnt*`, const char *`*opt*`)` [C function]
`void mgl_textmark_xyr (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *r*`, const char *`*txt*`, const char *`*fnt*`, const char *`*opt*`)` [C function]
`void mgl_textmarkw_xyr (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *r*`, const wchar_t *`*txt*`, const char *`*fnt*`, const char *`*opt*`)` [C function]
`void mgl_textmark_xyzr (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *r*`, const char *`*txt*`, const char *`*fnt*`, const char *`*opt*`)` [C function]

`void mgl_textmarkw_xyzr (HMGL gr, HCDT x, HCDT y, HCDT z, HCDT r, const wchar_t *txt, const char *fnt, const char *opt)` [C function]

These functions draw string *txt* as marks with size proportional to *r*[i]**marksize* at points {*x*[i], *y*[i], *z*[i]}. By default (if omitted) *r*[i]=1. See also [plot], page 195, [mark], page 202, [stem], page 198. See Section 2.5.17 [TextMark sample], page 62, for sample code and picture.

`label` *ydat 'txt' ['stl'='']* [MGL command]
`label` *xdat ydat 'txt' ['stl'='']* [MGL command]
`label` *xdat ydat zdat 'txt' ['stl'='']* [MGL command]
`void Label (const mglDataA &y, const char *txt, const char *fnt="", const char *opt="")` [Method on `mglGraph`]
`void Label (const mglDataA &y, const wchar_t *txt, const char *fnt="", const char *opt="")` [Method on `mglGraph`]
`void Label (const mglDataA &x, const mglDataA &y, const char *txt, const char *fnt="", const char *opt="")` [Method on `mglGraph`]
`void Label (const mglDataA &x, const mglDataA &y, const wchar_t *txt, const char *fnt="", const char *opt="")` [Method on `mglGraph`]
`void Label (const mglDataA &x, const mglDataA &y, const mglDataA &z, const char *txt, const char *fnt="", const char *opt="")` [Method on `mglGraph`]
`void Label (const mglDataA &x, const mglDataA &y, const mglDataA &z, const wchar_t *txt, const char *fnt="", const char *opt="")` [Method on `mglGraph`]
`void mgl_label (HMGL gr, HCDT y, const char *txt, const char *fnt, const char *opt)` [C function]
`void mgl_labelw (HMGL gr, HCDT y, const wchar_t *txt, const char *fnt, const char *opt)` [C function]
`void mgl_label_xy (HMGL gr, HCDT x, HCDT y, const char *txt, const char *fnt, const char *opt)` [C function]
`void mgl_labelw_xy (HMGL gr, HCDT x, HCDT y, const wchar_t *txt, const char *fnt, const char *opt)` [C function]
`void mgl_label_xyz (HMGL gr, HCDT x, HCDT y, HCDT z, const char *txt, const char *fnt, const char *opt)` [C function]
`void mgl_labelw_xyz (HMGL gr, HCDT x, HCDT y, HCDT z, const wchar_t *txt, const char *fnt, const char *opt)` [C function]

These functions draw string *txt* at points {*x*[i], *y*[i], *z*[i]}. If string *txt* contain '`%x`', '`%y`', '`%z`' or '`%n`' then it will be replaced by the value of x-,y-,z-coordinate of the point or its index. String *fnt* may contain:

- Section 3.5 [Font styles], page 152;
- '`f`' for fixed format of printed numbers;
- '`E`' for using '`E`' instead of '`e`';
- '`F`' for printing in LaTeX format;
- '`+`' for printing '`+`' for positive numbers;
- '`-`' for printing usual '`-`';
- '`0123456789`' for precision at printing numbers.

See also [plot], page 195, [mark], page 202, [textmark], page 203, [table], page 205. See Section 2.5.18 [Label sample], page 63, for sample code and picture.

`table` *vdat 'txt'* [*'stl'='#'*] [MGL command]
`table` *x y vdat 'txt'* [*'stl'='#'*] [MGL command]
`void Table (const mglDataA &`*val*`, const char *`*txt*`,` [Method on `mglGraph`]
`const char *`*fnt*`="", const char *`*opt*`="")`
`void Table (const mglDataA &`*val*`, const wchar_t *`*txt*`,` [Method on `mglGraph`]
`const char *`*fnt*`="", const char *`*opt*`="")`
`void Table (mreal` *x*`, mreal` *y*`, const mglDataA &`*val*`,` [Method on `mglGraph`]
`const char *`*txt*`, const char *`*fnt*`="", const char *`*opt*`="")`
`void Table (mreal` *x*`, mreal` *y*`, const mglDataA &`*val*`,` [Method on `mglGraph`]
`const wchar_t *`*txt*`, const char *`*fnt*`="", const char *`*opt*`="")`
`void mgl_table (HMGL` *gr*`, mreal` *x*`, mreal` *y*`, HCDT` *val*`, const char` [C function]
`*`*txt*`, const char *`*fnt*`, const char *`*opt*`)`
`void mgl_tablew (HMGL` *gr*`, mreal` *x*`, mreal` *y*`, HCDT` *val*`, const` [C function]
`wchar_t *`*txt*`, const char *`*fnt*`, const char *`*opt*`)`

These functions draw table with values of *val* and captions from string *txt* (separated by newline symbol '`\n`') at points {*x*, *y*} (default at {0,0}) related to current subplot. String *fnt* may contain:

- Section 3.5 [Font styles], page 152;
- '`#`' for drawing cell borders;
- '`|`' for limiting table widh by subplot one (equal to option '`value 1`');
- '`=`' for equal width of all cells;
- '`f`' for fixed format of printed numbers;
- '`E`' for using '`E`' instead of '`e`';
- '`F`' for printing in LaTeX format;
- '`+`' for printing '`+`' for positive numbers;
- '`-`' for printing usual '`-`';
- '`0123456789`' for precision at printing numbers.

Option `value` set the width of the table (default is 1). See also [plot], page 195, [label], page 204. See Section 2.5.19 [Table sample], page 64, for sample code and picture.

`tube` *ydat rdat* [*'stl'='']* [MGL command]
`tube` *ydat* `rval` [*'stl'='']* [MGL command]
`tube` *xdat ydat rdat* [*'stl'='']* [MGL command]
`tube` *xdat ydat* `rval` [*'stl'='']* [MGL command]
`tube` *xdat ydat zdat rdat* [*'stl'='']* [MGL command]
`tube` *xdat ydat zdat* `rval` [*'stl'='']* [MGL command]
`void Tube (const mglDataA &`*y*`, const mglDataA &`*r*`,` [Method on `mglGraph`]
`const char *`*pen*`="", const char *`*opt*`="")`
`void Tube (const mglDataA &`*y*`, mreal` *r*`, const char` [Method on `mglGraph`]
`*`*pen*`="", const char *`*opt*`="")`

`void Tube (const mglDataA &x, const mglDataA &y,` [Method on `mglGraph`]
`const mglDataA &r, const char *pen="", const char *opt="")`
`void Tube (const mglDataA &x, const mglDataA &y,` [Method on `mglGraph`]
`mreal r, const char *pen="", const char *opt="")`
`void Tube (const mglDataA &x, const mglDataA &y,` [Method on `mglGraph`]
`const mglDataA &z, const mglDataA &r, const char *pen="", const char *opt="")`
`void Tube (const mglDataA &x, const mglDataA &y,` [Method on `mglGraph`]
`const mglDataA &z, mreal r, const char *pen="", const char *opt="")`
`void mgl_tube_r (HMGL gr, HCDT y, HCDT r, const char *pen, const char *opt)` [C function]
`void mgl_tube (HMGL gr, HCDT y, mreal r, const char *pen, const char *opt)` [C function]
`void mgl_tube_xyr (HMGL gr, HCDT x, HCDT y, HCDT r, const char *pen, const char *opt)` [C function]
`void mgl_tube_xy (HMGL gr, HCDT x, HCDT y, mreal r, const char *pen, const char *opt)` [C function]
`void mgl_tube_xyzr (HMGL gr, HCDT x, HCDT y, HCDT z, HCDT r, const char *pen, const char *opt)` [C function]
`void mgl_tube_xyz (HMGL gr, HCDT x, HCDT y, HCDT z, mreal r, const char *pen, const char *opt)` [C function]

These functions draw the tube with variable radius *r*[i] along the curve between points {*x*[i], *y*[i], *z*[i]}. See also [plot], page 195. See Section 2.5.20 [Tube sample], page 65, for sample code and picture.

`torus` *rdat zdat* ['*stl*'=''] [MGL command]
`void Torus (const mglDataA &r, const mglDataA &z,` [Method on `mglGraph`]
`const char *pen="", const char *opt="")`
`void mgl_torus (HMGL gr, HCDT r, HCDT z, const char *pen, const char *opt)` [C function]

These functions draw surface which is result of curve {*r*, *z*} rotation around axis. If string *pen* contain symbols '`x`' or '`z`' then rotation axis will be set to specified direction (default is '`y`'). If string *pen* have symbol '`#`' then wire plot is produced. If string *pen* have symbol '`.`' then plot by dots is produced. See also [plot], page 195, [axial], page 212. See Section 2.5.22 [Torus sample], page 67, for sample code and picture.

`lamerey x0` *ydat* ['*stl*'=''] [MGL command]
`lamerey x0` '*y*(x)' ['*stl*'=''] [MGL command]
`void Lamerey (double x0, const mglDataA &y, const char *stl="", const char *opt="")` [Method on `mglGraph`]
`void Lamerey (double x0, const char *y, const char *stl="", const char *opt="")` [Method on `mglGraph`]
`void mgl_lamerey_dat (HMGL gr, double x0, HCDT y, const char *stl, const char *opt)` [C function]
`void mgl_lamerey_str (HMGL gr, double x0, const char *y, const char *stl, const char *opt)` [C function]

These functions draw Lamerey diagram for mapping x_new = y(x_old) starting from point *x0*. String *stl* may contain line style, symbol '`v`' for drawing arrows, symbol '`~`'

for disabling first segment. Option `value` set the number of segments to be drawn (default is 20). See also [plot], page 195, [fplot], page 229, [bifurcation], page 207, [pmap], page 207. See Section 2.5.23 [Lamerey sample], page 68, for sample code and picture.

`bifurcation dx` *ydat* ['*stl*'=''] [MGL command]
`bifurcation dx` '*y*(*x*)' ['*stl*'=''] [MGL command]
`void Bifurcation (double` *dx*, `const mglDataA &`*y*, `const char *`*stl*="", `const char *`*opt*="") [Method on `mglGraph`]
`void Bifurcation (double` *dx*, `const char *`*y*, `const char *`*stl*="", `const char *`*opt*="") [Method on `mglGraph`]
`void mgl_bifurcation_dat (HMGL` *gr*, `double` *dx*, `HCDT` *y*, `const char *`*stl*, `const char *`*opt*) [C function]
`void mgl_bifurcation_str (HMGL` *gr*, `double` *dx*, `const char *`*y*, `const char *`*stl*, `const char *`*opt*) [C function]

These functions draw bifurcation diagram for mapping x_new = y(x_old). Parameter *dx* set the accuracy along x-direction. String *stl* set color. Option `value` set the number of stationary points (default is 1024). See also [plot], page 195, [fplot], page 229, [lamerey], page 206. See Section 2.5.24 [Bifurcation sample], page 69, for sample code and picture.

`pmap` *ydat sdat* ['*stl*'=''] [MGL command]
`pmap` *xdat ydat sdat* ['*stl*'=''] [MGL command]
`pmap` *xdat ydat zdat sdat* ['*stl*'=''] [MGL command]
`void Pmap (const mglDataA &`*y*, `const mglDataA &`*s*, `const char *`*stl*="", `const char *`*opt*="") [Method on `mglGraph`]
`void Pmap (const mglDataA &`*x*, `const mglDataA &`*y*, `const mglDataA &`*s*, `const char *`*stl*="", `const char *`*opt*="") [Method on `mglGraph`]
`void Pmap (const mglDataA &`*x*, `const mglDataA &`*y*, `const mglDataA &`*z*, `const mglDataA &`*s*, `const char *`*stl*="", `const char *`*opt*="") [Method on `mglGraph`]
`void mgl_pmap (HMGL` *gr*, `HMDT` *y*, `HCDT` *s*, `const char *`*stl*, `const char *`*opt*) [C function]
`void mgl_pmap_xy (HMGL` *gr*, `HCDT` *x*, `HMDT` *y*, `HCDT` *s*, `const char *`*stl*, `const char *`*opt*) [C function]
`void mgl_pmap_xyz (HMGL` *gr*, `HCDT` *x*, `HMDT` *y*, `HCDT` *z*, `HCDT` *s*, `const char *`*stl*, `const char *`*opt*) [C function]

These functions draw Poincare map for curve {*x*, *y*, *z*} at surface *s*=0. Basically, it show intersections of the curve and the surface. String *stl* set the style of marks. See also [plot], page 195, [mark], page 202, [lamerey], page 206. See Section 2.5.25 [Pmap sample], page 70, for sample code and picture.

4.12 2D plotting

These functions perform plotting of 2D data. 2D means that data depend from 2 independent parameters like matrix $f(x_i, y_j), i = 1...n, j = 1...m$. By default (if absent) values of *x*, *y* are equidistantly distributed in axis range. The plots are drawn for each z slice of the data. The minor dimensions of arrays *x*, *y*, *z* should be equal `x.nx=z.nx && y.nx=z.ny`

or `x.nx=y.nx=z.nx && x.ny=y.ny=z.ny`. Arrays x and y can be vectors (not matrices as z). String *sch* sets the color scheme (see Section 3.4 [Color scheme], page 150) for plot. String *opt* contain command options (see Section 3.7 [Command options], page 154). See Section 2.6 [2D samples], page 71, for sample code and picture.

`surf` *zdat* ['*sch*'="'] [MGL command]
`surf` *xdat ydat zdat* ['*sch*'="'] [MGL command]
`void Surf (const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Surf (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_surf (HMGL` *gr*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_surf_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]}. If string *sch* have symbol '`#`' then grid lines are drawn. If string *sch* have symbol '`.`' then plot by dots is produced. See also [mesh], page 208, [dens], page 209, [belt], page 209, [tile], page 209, [boxs], page 209, [surfc], page 217, [surfa], page 218. See Section 2.6.1 [Surf sample], page 72, for sample code and picture.

`mesh` *zdat* ['*sch*'="'] [MGL command]
`mesh` *xdat ydat zdat* ['*sch*'="'] [MGL command]
`void Mesh (const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Mesh (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_mesh (HMGL` *gr*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_mesh_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws mesh lines for surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]}. See also [surf], page 208, [fall], page 208, [meshnum], page 161, [cont], page 210, [tens], page 196. See Section 2.6.5 [Mesh sample], page 76, for sample code and picture.

`fall` *zdat* ['*sch*'="'] [MGL command]
`fall` *xdat ydat zdat* ['*sch*'="'] [MGL command]
`void Fall (const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Fall (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_fall (HMGL` *gr*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_fall_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws fall lines for surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]}. This plot can be used for plotting several curves shifted in depth one from another. If *sch* contain '`x`' then lines are drawn along x-direction else (by default) lines are drawn along y-direction. See also [belt], page 209, [mesh], page 208, [tens], page 196, [meshnum], page 161. See Section 2.6.6 [Fall sample], page 77, for sample code and picture.

`belt` *zdat* ['*sch*'=''] [MGL command]
`belt` *xdat ydat zdat* ['*sch*'=''] [MGL command]
`void Belt (const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Belt (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_belt (HMGL` *gr*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_belt_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws belts for surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]}. This plot can be used as 3d generalization of [plot], page 195). If *sch* contain '`x`' then belts are drawn along x-direction else (by default) belts are drawn along y-direction. See also [fall], page 208, [surf], page 208, [plot], page 195, [meshnum], page 161. See Section 2.6.7 [Belt sample], page 78, for sample code and picture.

`boxs` *zdat* ['*sch*'=''] [MGL command]
`boxs` *xdat ydat zdat* ['*sch*'=''] [MGL command]
`void Boxs (const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Boxs (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_boxs (HMGL` *gr*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_boxs_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws vertical boxes for surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]}. Symbol '`@`' in *sch* set to draw filled boxes. See also [surf], page 208, [dens], page 209, [tile], page 209, [step], page 196. See Section 2.6.8 [Boxs sample], page 79, for sample code and picture.

`tile` *zdat* ['*sch*'=''] [MGL command]
`tile` *xdat ydat zdat* ['*sch*'=''] [MGL command]
`void Tile (const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Tile (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_tile (HMGL` *gr*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_tile_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws horizontal tiles for surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]}. Such plot can be used as 3d generalization of [step], page 196. See also [surf], page 208, [boxs], page 209, [step], page 196, [tiles], page 221. See Section 2.6.9 [Tile sample], page 80, for sample code and picture.

`dens` *zdat* ['*sch*'=''] [MGL command]
`dens` *xdat ydat zdat* ['*sch*'=''] [MGL command]
`void Dens (const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="", mreal` *zVal*`=NAN)` [Method on `mglGraph`]

`void Dens (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="", mreal` *zVal*`=NAN)` [Method on `mglGraph`]
`void mgl_dens (HMGL` *gr*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_dens_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws density plot for surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]} at *z* equal to minimal z-axis value. If string *sch* have symbol '`#`' then grid lines are drawn. If string *sch* have symbol '`.`' then plot by dots is produced. See also [surf], page 208, [cont], page 210, [contf], page 210, [boxs], page 209, [tile], page 209, `dens[xyz]`. See Section 2.6.11 [Dens sample], page 81, for sample code and picture.

`cont` *vdat zdat* ['*sch*'=''] [MGL command]
`cont` *vdat xdat ydat zdat* ['*sch*'=''] [MGL command]
`void Cont (const mglDataA &`*v*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Cont (const mglDataA &`*v*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_cont__val (HMGL` *gr*`, HCDT` *v*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_cont_xy_val (HMGL` *gr*`, HCDT` *v*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws contour lines for surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]} at *z*=*v*[k], or at *z* equal to minimal z-axis value if *sch* contain symbol '`_`'. Contours are plotted for *z*[i,j]=*v*[k] where *v*[k] are values of data array *v*. If string *sch* have symbol '`t`' or '`T`' then contour labels *v*[k] will be drawn below (or above) the contours. See also [dens], page 209, [contf], page 210, [contd], page 211, [axial], page 212, `cont[xyz]`. See Section 2.6.12 [Cont sample], page 82, for sample code and picture.

`cont` *zdat* ['*sch*'=''] [MGL command]
`cont` *xdat ydat zdat* ['*sch*'=''] [MGL command]
`void Cont (const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Cont (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_cont (HMGL` *gr*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_cont_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The same as previous with vector *v* of *num*-th elements equidistantly distributed in color range. Here *num* is equal to parameter `value` in options *opt* (default is 7).

`contf` *vdat zdat* ['*sch*'=''] [MGL command]
`contf` *vdat xdat ydat zdat* ['*sch*'=''] [MGL command]
`void ContF (const mglDataA &`*v*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void ContF (const mglDataA &`*v*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void mgl_contf_val (HMGL` *gr*`, HCDT` *v*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

`void mgl_contf_xy_val (HMGL` *gr*`, HCDT` *v*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws solid (or filled) contour lines for surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]} at *z*=*v*[k], or at *z* equal to minimal z-axis value if *sch* contain symbol '_'. Contours are plotted for *z*[i,j]=*v*[k] where *v*[k] are values of data array *v* (must be `v.nx>2`). See also [dens], page 209, [cont], page 210, [contd], page 211, `contf[xyz]`. See Section 2.6.13 [ContF sample], page 83, for sample code and picture.

`contf` *zdat* ['*sch*'="] [MGL command]

`contf` *xdat ydat zdat* ['*sch*'="] [MGL command]

`void ContF (const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void ContF (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void mgl_contf (HMGL` *gr*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

`void mgl_contf_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The same as previous with vector *v* of *num*-th elements equidistantly distributed in color range. Here *num* is equal to parameter `value` in options *opt* (default is 7).

`contd` *vdat zdat* ['*sch*'="] [MGL command]

`contd` *vdat xdat ydat zdat* ['*sch*'="] [MGL command]

`void ContD (const mglDataA &`*v*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void ContD (const mglDataA &`*v*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void mgl_contd_val (HMGL` *gr*`, HCDT` *v*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

`void mgl_contd_xy_val (HMGL` *gr*`, HCDT` *v*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws solid (or filled) contour lines for surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]} at *z*=*v*[k] (or at *z* equal to minimal z-axis value if *sch* contain symbol '_') with manual colors. Contours are plotted for *z*[i,j]=*v*[k] where *v*[k] are values of data array *v* (must be `v.nx>2`). String *sch* sets the contour colors: the color of k-th contour is determined by character `sch[k%strlen(sch)]`. See also [dens], page 209, [cont], page 210, [contf], page 210. See Section 2.6.14 [ContD sample], page 84, for sample code and picture.

`contd` *zdat* ['*sch*'="] [MGL command]

`contd` *xdat ydat zdat* ['*sch*'="] [MGL command]

`void ContD (const mglDataA &z, const char *sch="", const char *opt="")` [Method on `mglGraph`]
`void ContD (const mglDataA &x, const mglDataA &y, const mglDataA &z, const char *sch="", const char *opt="")` [Method on `mglGraph`]
`void mgl_contd (HMGL gr, HCDT z, const char *sch, const char *opt)` [C function]
`void mgl_contd_xy (HMGL gr, HCDT x, HCDT y, HCDT z, const char *sch, const char *opt)` [C function]

The same as previous with vector *v* of *num*-th elements equidistantly distributed in color range. Here *num* is equal to parameter `value` in options *opt* (default is 7).

`contv` *vdat zdat* ['sch'=''] [MGL command]
`contv` *vdat xdat ydat zdat* ['sch'=''] [MGL command]
`void ContV (const mglDataA &v, const mglDataA &z, const char *sch="", const char *opt="")` [Method on `mglGraph`]
`void ContV (const mglDataA &v, const mglDataA &x, const mglDataA &y, const mglDataA &z, const char *sch="", const char *opt="")` [Method on `mglGraph`]
`void mgl_contv_val (HMGL gr, HCDT v, HCDT z, const char *sch, const char *opt)` [C function]
`void mgl_contv_xy_val (HMGL gr, HCDT v, HCDT x, HCDT y, HCDT z, const char *sch, const char *opt)` [C function]

The function draws vertical cylinder (tube) at contour lines for surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]} at *z*=*v*[k], or at *z* equal to minimal z-axis value if *sch* contain symbol '_'. Contours are plotted for *z*[i,j]=*v*[k] where *v*[k] are values of data array *v*. See also [cont], page 210, [contf], page 210. See Section 2.6.15 [ContV sample], page 85, for sample code and picture.

`contv` *zdat* ['sch'=''] [MGL command]
`contv` *xdat ydat zdat* ['sch'=''] [MGL command]
`void ContV (const mglDataA &z, const char *sch="", const char *opt="")` [Method on `mglGraph`]
`void ContV (const mglDataA &x, const mglDataA &y, const mglDataA &z, const char *sch="", const char *opt="")` [Method on `mglGraph`]
`void mgl_contv (HMGL gr, HCDT z, const char *sch, const char *opt)` [C function]
`void mgl_contv_xy (HMGL gr, HCDT x, HCDT y, HCDT z, const char *sch, const char *opt)` [C function]

The same as previous with vector *v* of *num*-th elements equidistantly distributed in color range. Here *num* is equal to parameter `value` in options *opt* (default is 7).

`axial` *vdat zdat* ['sch'=''] [MGL command]
`axial` *vdat xdat ydat zdat* ['sch'=''] [MGL command]
`void Axial (const mglDataA &v, const mglDataA &z, const char *sch="", const char *opt="")` [Method on `mglGraph`]
`void Axial (const mglDataA &v, const mglDataA &x, const mglDataA &y, const mglDataA &z, const char *sch="", const char *opt="")` [Method on `mglGraph`]

`void mgl_axial_val (HMGL` *gr*`, HCDT` *v*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_axial_xy_val (HMGL` *gr*`, HCDT` *v*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws surface which is result of contour plot rotation for surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]}. Contours are plotted for *z*[i,j]=*v*[k] where *v*[k] are values of data array *v*. If string *sch* have symbol '`#`' then wire plot is produced. If string *sch* have symbol '`.`' then plot by dots is produced. If string contain symbols '`x`' or '`z`' then rotation axis will be set to specified direction (default is '`y`'). See also [cont], page 210, [contf], page 210, [torus], page 206, [surf3], page 214. See Section 2.6.16 [Axial sample], page 86, for sample code and picture.

`axial` *zdat* ['*sch*'="] [MGL command]
`axial` *xdat ydat zdat* ['*sch*'="] [MGL command]
`void Axial (const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="", int` *num*`=3)` [Method on `mglGraph`]
`void Axial (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="", int` *num*`=3)` [Method on `mglGraph`]
`void mgl_axial (HMGL` *gr*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_axial_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The same as previous with vector *v* of *num*-th elements equidistantly distributed in color range. Here *num* is equal to parameter `value` in options *opt* (default is 3).

`grid2` *zdat* ['*sch*'="] [MGL command]
`grid2` *xdat ydat zdat* ['*sch*'="] [MGL command]
`void Grid (const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Grid (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_grid (HMGL` *gr*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_grid_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws grid lines for density plot of surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]} at *z* equal to minimal z-axis value. See also [dens], page 209, [cont], page 210, [contf], page 210, [grid3], page 216, [meshnum], page 161.

4.13 3D plotting

These functions perform plotting of 3D data. 3D means that data depend from 3 independent parameters like matrix $f(x_i, y_j, z_k), i = 1...n, j = 1...m, k = 1...l$. By default (if absent) values of *x*, *y*, *z* are equidistantly distributed in axis range. The minor dimensions of arrays *x*, *y*, *z*, *a* should be equal `x.nx=a.nx && y.nx=a.ny && z.nz=a.nz` or `x.nx=y.nx=z.nx=a.nx && x.ny=y.ny=z.ny=a.ny && x.nz=y.nz=z.nz=a.nz`. Arrays *x*, *y* and *z* can be vectors (not matrices as *a*). String *sch* sets the color scheme (see Section 3.4 [Color scheme], page 150) for plot. String *opt* contain command options (see Section 3.7

[Command options], page 154). See Section 2.7 [3D samples], page 88, for sample code and picture.

`surf3` *adat* `val` ['*sch*'=''] [MGL command]
`surf3` *xdat ydat zdat adat* `val` ['*sch*'=''] [MGL command]
`void Surf3 (mreal` *val*`, const mglDataA &`*a*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Surf3 (mreal` *val*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_surf3_val (HMGL` *gr*`, mreal` *val*`, HCDT` *a*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_surf3_xyz_val (HMGL` *gr*`, mreal` *val*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws isosurface plot for 3d array specified parametrically *a*[i,j,k](*x*[i,j,k], *y*[i,j,k], *z*[i,j,k]) at *a*(x,y,z)=*val*. If string contain '`#`' then wire plot is produced. If string *sch* have symbol '`.`' then plot by dots is produced. Note, that there is possibility of incorrect plotting due to uncertainty of cross-section defining if there are two or more isosurface intersections inside one cell. See also [cloud], page 214, [dens3], page 215, [surf3c], page 218, [surf3a], page 219, [axial], page 212. See Section 2.7.1 [Surf3 sample], page 88, for sample code and picture.

`surf3` *adat* ['*sch*'=''] [MGL command]
`surf3` *xdat ydat zdat adat* ['*sch*'=''] [MGL command]
`void Surf3 (const mglDataA &`*a*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Surf3 (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_surf3 (HMGL` *gr*`, HCDT` *a*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_surf3_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`, const char *`*sch*`, const char *`*opt*`)` [C function]

Draws *num*-th uniformly distributed in color range isosurfaces for 3d data. Here *num* is equal to parameter `value` in options *opt* (default is 3).

`cloud` *adat* ['*sch*'=''] [MGL command]
`cloud` *xdat ydat zdat adat* ['*sch*'=''] [MGL command]
`void Cloud (const mglDataA &`*a*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Cloud (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_cloud (HMGL` *gr*`, HCDT` *a*`, const char *`*sch*`, const char *`*opt*`)` [C function]

`void mgl_cloud_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws cloud plot for 3d data specified parametrically *a*[i,j,k](*x*[i,j,k], *y*[i,j,k], *z*[i,j,k]). This plot is a set of cubes with color and transparency proportional to value of *a*. The resulting plot is like cloud – low value is transparent but higher ones are not. The number of plotting cells depend on [meshnum], page 161. If string *sch* contain symbol '`.`' then lower quality plot will produced with much low memory usage. If string *sch* contain symbol '`i`' then transparency will be inversed, i.e. higher become transparent and lower become not transparent. See also [surf3], page 214, [meshnum], page 161. See Section 2.7.5 [Cloud sample], page 92, for sample code and picture.

`dens3` *adat* [*'sch'="* `sval=-1`] [MGL command]
`dens3` *xdat ydat zdat adat* [*'sch'="* `sval=-1`] [MGL command]
`void Dens3 (const mglDataA &`*a*`, const char *`*sch*`="", mreal` *sVal*`=-1, const char *`*opt*`="")` [Method on `mglGraph`]
`void Dens3 (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const char *`*sch*`="", mreal` *sVal*`=-1, const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_dens3 (HMGL` *gr*`, HCDT` *a*`, const char *`*sch*`, mreal` *sVal*`, const char *`*opt*`)` [C function]
`void mgl_dens3_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`, const char *`*sch*`, mreal` *sVal*`, const char *`*opt*`)` [C function]

The function draws density plot for 3d data specified parametrically *a*[i,j,k](*x*[i,j,k], *y*[i,j,k], *z*[i,j,k]). Density is plotted at slice *sVal* in direction {'`x`', '`y`', '`z`'} if *sch* contain corresponding symbol (by default, '`y`' direction is used). If string *stl* have symbol '`#`' then grid lines are drawn. See also [cont3], page 215, [contf3], page 216, [dens], page 209, [grid3], page 216. See Section 2.7.6 [Dens3 sample], page 93, for sample code and picture.

`cont3` *vdat adat* [*'sch'="* `sval=-1`] [MGL command]
`cont3` *vdat xdat ydat zdat adat* [*'sch'="* `sval=-1`] [MGL command]
`void Cont3 (const mglDataA &`*v*`, const mglDataA &`*a*`, const char *`*sch*`="", mreal` *sVal*`=-1, const char *`*opt*`="")` [Method on `mglGraph`]
`void Cont3 (const mglDataA &`*v*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const char *`*sch*`="", mreal` *sVal*`=-1, const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_cont3_val (HMGL` *gr*`, HCDT` *v*`, HCDT` *a*`, const char *`*sch*`, mreal` *sVal*`, const char *`*opt*`)` [C function]
`void mgl_cont3_xyz_val (HMGL` *gr*`, HCDT` *v*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`, const char *`*sch*`, mreal` *sVal*`, const char *`*opt*`)` [C function]

The function draws contour plot for 3d data specified parametrically *a*[i,j,k](*x*[i,j,k], *y*[i,j,k], *z*[i,j,k]). Contours are plotted for values specified in array *v* at slice *sVal* in direction {'`x`', '`y`', '`z`'} if *sch* contain corresponding symbol (by default, '`y`' direction is used). If string *sch* have symbol '`#`' then grid lines are drawn. If string *sch* have symbol '`t`' or '`T`' then contour labels will be drawn below (or above) the contours. See also [dens3], page 215, [contf3], page 216, [cont], page 210, [grid3], page 216. See Section 2.7.7 [Cont3 sample], page 94, for sample code and picture.

`cont3` *adat* [*'sch'="* `sval=-1`] [MGL command]
`cont3` *xdat ydat zdat adat* [*'sch'="* `sval=-1`] [MGL command]
`void Cont3 (const mglDataA &`*a*`, const char *`*sch*`="",` [Method on `mglGraph`]
`mreal` *sVal*`=-1, const char *`*opt*`="", const char *`*opt*`="")`
`void Cont3 (const mglDataA &`*x*`, const mglDataA &`*y*`,` [Method on `mglGraph`]
`const mglDataA &`*z*`, const mglDataA &`*a*`, const char *`*sch*`="", mreal` *sVal*`=-1, const char *`*opt*`="")`
`void mgl_cont3 (HMGL` *gr*`, HCDT` *a*`, const char *`*sch*`, mreal` *sVal*`,` [C function]
`const char *`*opt*`)`
`void mgl_cont3_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`,` [C function]
`const char *`*sch*`, mreal` *sVal*`, const char *`*opt*`)`

The same as previous with vector *v* of *num*-th elements equidistantly distributed in color range. Here *num* is equal to parameter `value` in options *opt* (default is 7).

`contf3` *vdat adat* [*'sch'="* `sval=-1`] [MGL command]
`contf3` *vdat xdat ydat zdat adat* [*'sch'="* `sval=-1`] [MGL command]
`void Contf3 (const mglDataA &`*v*`, const mglDataA &`*a*`,` [Method on `mglGraph`]
`const char *`*sch*`="", mreal` *sVal*`=-1, const char *`*opt*`="")`
`void Contf3 (const mglDataA &`*v*`, const mglDataA &`*x*`,` [Method on `mglGraph`]
`const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const char` *sch*`="", mreal` *sVal*`=-1, const char *`*opt*`="")`
`void mgl_contf3_val (HMGL` *gr*`, HCDT` *v*`, HCDT` *a*`, const char *`*sch*`,` [C function]
`mreal` *sVal*`, const char *`*opt*`)`
`void mgl_contf3_xyz_val (HMGL` *gr*`, HCDT` *v*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`,` [C function]
`HCDT` *a*`, const char *`*sch*`, mreal` *sVal*`, const char *`*opt*`)`

The function draws solid (or filled) contour plot for 3d data specified parametrically *a*[i,j,k](*x*[i,j,k], *y*[i,j,k], *z*[i,j,k]). Contours are plotted for values specified in array *v* at slice *sVal* in direction {'`x`', '`y`', '`z`'} if *sch* contain corresponding symbol (by default, '`y`' direction is used). If string *sch* have symbol '`#`' then grid lines are drawn. See also [dens3], page 215, [cont3], page 215, [contf], page 210, [grid3], page 216. See Section 2.7.8 [ContF3 sample], page 95, for sample code and picture.

`contf3` *adat* [*'sch'="* `sval=-1`] [MGL command]
`contf3` *xdat ydat zdat adat* [*'sch'="* `sval=-1`] [MGL command]
`void Contf3 (const mglDataA &`*a*`, const char *`*sch*`="",` [Method on `mglGraph`]
`mreal` *sVal*`=-1, const char *`*opt*`="", const char *`*opt*`="")`
`void Contf3 (const mglDataA &`*x*`, const mglDataA &`*y*`,` [Method on `mglGraph`]
`const mglDataA &`*z*`, const mglDataA &`*a*`, const char *`*sch*`="", mreal` *sVal*`=-1, const char *`*opt*`="")`
`void mgl_contf3 (HMGL` *gr*`, HCDT` *a*`, const char *`*sch*`, mreal` *sVal*`,` [C function]
`const char *`*opt*`)`
`void mgl_contf3_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`,` [C function]
`const char *`*sch*`, mreal` *sVal*`, const char *`*opt*`)`

The same as previous with vector *v* of *num*-th elements equidistantly distributed in color range. Here *num* is equal to parameter `value` in options *opt* (default is 7).

`grid3` *adat* [*'sch'="* `sval=-1`] [MGL command]
`grid3` *xdat ydat zdat adat* [*'sch'="* `sval=-1`] [MGL command]

`void Grid3 (const mglDataA &`*a*`, const char *`*sch*`="", mreal` *sVal*`=-1, const char *`*opt*`="")` [Method on `mglGraph`]
`void Grid3 (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const char *`*sch*`="", mreal` *sVal*`=-1, const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_grid3 (HMGL` *gr*`, HCDT` *a*`, const char *`*sch*`, mreal` *sVal*`, const char *`*opt*`)` [C function]
`void mgl_grid3_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`, const char *`*sch*`, mreal` *sVal*`, const char *`*opt*`)` [C function]

The function draws grid for 3d data specified parametrically *a*[i,j,k](*x*[i,j,k], *y*[i,j,k], *z*[i,j,k]). Grid is plotted at slice *sVal* in direction {'x', 'y', 'z'} if *sch* contain corresponding symbol (by default, 'y' direction is used). See also [cont3], page 215, [contf3], page 216, [dens3], page 215, [grid2], page 213, [meshnum], page 161.

`beam` *tr g1 g2 adat* `rval` ['*sch*'=" `flag=0 num=3`] [MGL command]
`void Beam (const mglDataA &`*tr*`, const mglDataA &`*g1*`, const mglDataA &`*g2*`, const mglDataA &`*a*`, mreal` *r*`, const char *`*stl*`="", int` *flag*`=0, int` *num*`=3)` [Method on `mglGraph`]
`void Beam (mreal` *val*`, const mglDataA &`*tr*`, const mglDataA &`*g1*`, const mglDataA &`*g2*`, const mglDataA &`*a*`, mreal` *r*`, const char *`*stl*`="", int` *flag*`=0)` [Method on `mglGraph`]
`void mgl_beam (HMGL` *gr*`, HCDT` *tr*`, HCDT` *g1*`, HCDT` *g2*`, HCDT` *a*`, mreal` *r*`, const char *`*stl*`, int` *flag*`, int` *num*`)` [C function]
`void mgl_beam_val (HMGL` *gr*`, mreal` *val*`, HCDT` *tr*`, HCDT` *g1*`, HCDT` *g2*`, HCDT` *a*`, mreal` *r*`, const char *`*stl*`, int` *flag*`)` [C function]

Draws the isosurface for 3d array *a* at constant values of *a*=*val*. This is special kind of plot for *a* specified in accompanied coordinates along curve *tr* with orts *g1*, *g2* and with transverse scale *r*. Variable *flag* is bitwise: '0x1' - draw in accompanied (not laboratory) coordinates; '0x2' - draw projection to $\rho - z$ plane; '0x4' - draw normalized in each slice field. The x-size of data arrays *tr*, *g1*, *g2* must be nx>2. The y-size of data arrays *tr*, *g1*, *g2* and z-size of the data array *a* must be equal. See also [surf3], page 214.

4.14 Dual plotting

These plotting functions draw *two matrix* simultaneously. There are 5 generally different types of data representations: surface or isosurface colored by other data (SurfC, Surf3C), surface or isosurface transpared by other data (SurfA, Surf3A), tiles with variable size (TileS), mapping diagram (Map), STFA diagram (STFA). By default (if absent) values of *x*, *y*, *z* are equidistantly distributed in axis range. The minor dimensions of arrays *x*, *y*, *z*, *c* should be equal. Arrays *x*, *y* (and *z* for `Surf3C, Surf3A`) can be vectors (not matrices as *c*). String *sch* sets the color scheme (see Section 3.4 [Color scheme], page 150) for plot. String *opt* contain command options (see Section 3.7 [Command options], page 154).

`surfc` *zdat cdat* ['*sch*'="] [MGL command]
`surfc` *xdat ydat zdat cdat* ['*sch*'="] [MGL command]
`void SurfC (const mglDataA &`*z*`, const mglDataA &`*c*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void SurfC (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*c*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void mgl_surfc (HMGL` *gr*`, HCDT` *z*`, HCDT` *c*`, const char *`*sch*`, const char *`*opt*`)` [C function]

`void mgl_surfc_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *c*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]} and color it by matrix *c*[i,j]. If string *sch* have symbol '`#`' then grid lines are drawn. If string *sch* have symbol '`.`' then plot by dots is produced. All dimensions of arrays *z* and *c* must be equal. Surface is plotted for each z slice of the data. See also [surf], page 208, [surfa], page 218, [surfca], page 220, [surf3c], page 218. See Section 2.6.2 [SurfC sample], page 73, for sample code and picture.

`surf3c` *adat cdat* `val` ['*sch*'="] [MGL command]

`surf3c` *xdat ydat zdat adat cdat* `val` ['*sch*'="] [MGL command]

`void Surf3C (mreal` *val*`, const mglDataA &`*a*`, const mglDataA &`*c*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void Surf3C (mreal` *val*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const mglDataA &`*c*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void mgl_surf3c_val (HMGL` *gr*`, mreal` *val*`, HCDT` *a*`, HCDT` *c*`, const char *`*sch*`, const char *`*opt*`)` [C function]

`void mgl_surf3c_xyz_val (HMGL` *gr*`, mreal` *val*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`, HCDT` *c*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws isosurface plot for 3d array specified parametrically *a*[i,j,k](*x*[i,j,k], *y*[i,j,k], *z*[i,j,k]) at *a*(x,y,z)=*val*. It is mostly the same as [surf3], page 214 function but the color of isosurface depends on values of array *c*. If string *sch* contain '`#`' then wire plot is produced. If string *sch* have symbol '`.`' then plot by dots is produced. See also [surf3], page 214, [surfc], page 217, [surf3a], page 219, [surf3ca], page 220. See Section 2.7.2 [Surf3C sample], page 89, for sample code and picture.

`surf3c` *adat cdat* ['*sch*'="] [MGL command]

`surf3c` *xdat ydat zdat adat cdat* ['*sch*'="] [MGL command]

`void Surf3C (const mglDataA &`*a*`, const mglDataA &`*c*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void Surf3C (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const mglDataA &`*c*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void mgl_surf3c (HMGL` *gr*`, HCDT` *a*`, HCDT` *c*`, const char *`*sch*`, const char *`*opt*`)` [C function]

`void mgl_surf3c_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`, HCDT` *c*`, const char *`*sch*`, const char *`*opt*`)` [C function]

Draws *num*-th uniformly distributed in color range isosurfaces for 3d data. Here *num* is equal to parameter `value` in options *opt* (default is 3).

`surfa` *zdat cdat* ['*sch*'="] [MGL command]

`surfa` *xdat ydat zdat cdat* ['*sch*'="] [MGL command]

`void SurfA (const mglDataA &z, const mglDataA &c, const char *sch="", const char *opt="")` [Method on `mglGraph`]

`void SurfA (const mglDataA &x, const mglDataA &y, const mglDataA &z, const mglDataA &c, const char *sch="", const char *opt="")` [Method on `mglGraph`]

`void mgl_surfa (HMGL gr, HCDT z, HCDT c, const char *sch, const char *opt)` [C function]

`void mgl_surfa_xy (HMGL gr, HCDT x, HCDT y, HCDT z, HCDT c, const char *sch, const char *opt)` [C function]

The function draws surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]} and transparent it by matrix *c*[i,j]. If string *sch* have symbol '`#`' then grid lines are drawn. If string *sch* have symbol '`.`' then plot by dots is produced. All dimensions of arrays *z* and *c* must be equal. Surface is plotted for each z slice of the data. See also [surf], page 208, [surfc], page 217, [surfca], page 220, [surf3a], page 219. See Section 2.6.3 [SurfA sample], page 74, for sample code and picture.

`surf3a` *adat cdat* `val` ['*sch*'=*"*] [MGL command]

`surf3a` *xdat ydat zdat adat cdat* `val` ['*sch*'=*"*] [MGL command]

`void Surf3A (mreal val, const mglDataA &a, const mglDataA &c, const char *sch="", const char *opt="")` [Method on `mglGraph`]

`void Surf3A (mreal val, const mglDataA &x, const mglDataA &y, const mglDataA &z, const mglDataA &a, const mglDataA &c, const char *sch="", const char *opt="")` [Method on `mglGraph`]

`void mgl_surf3a_val (HMGL gr, mreal val, HCDT a, HCDT c, const char *sch, const char *opt)` [C function]

`void mgl_surf3a_xyz_val (HMGL gr, mreal val, HCDT x, HCDT y, HCDT z, HCDT a, HCDT c, const char *sch, const char *opt)` [C function]

The function draws isosurface plot for 3d array specified parametrically *a*[i,j,k](*x*[i,j,k], *y*[i,j,k], *z*[i,j,k]) at *a*(x,y,z)=*val*. It is mostly the same as [surf3], page 214 function but the transparency of isosurface depends on values of array *c*. If string *sch* contain '`#`' then wire plot is produced. If string *sch* have symbol '`.`' then plot by dots is produced. See also [surf3], page 214, [surfc], page 217, [surf3a], page 219, [surf3ca], page 220. See Section 2.7.3 [Surf3A sample], page 90, for sample code and picture.

`surf3a` *adat cdat* ['*sch*'=*"*] [MGL command]

`surf3a` *xdat ydat zdat adat cdat* ['*sch*'=*"*] [MGL command]

`void Surf3A (const mglDataA &a, const mglDataA &c, const char *sch="", const char *opt="")` [Method on `mglGraph`]

`void Surf3A (const mglDataA &x, const mglDataA &y, const mglDataA &z, const mglDataA &a, const mglDataA &c, const char *sch="", const char *opt="")` [Method on `mglGraph`]

`void mgl_surf3a (HMGL gr, HCDT a, HCDT c, const char *sch, const char *opt)` [C function]

`void mgl_surf3a_xyz (HMGL gr, HCDT x, HCDT y, HCDT z, HCDT a, HCDT c, const char *sch, const char *opt)` [C function]

Draws *num*-th uniformly distributed in color range isosurfaces for 3d data. At this array *c* can be vector with values of transparency and *num*=*c*.nx. In opposite case *num* is equal to parameter `value` in options *opt* (default is 3).

`surfca` *zdat cdat adat* ['*sch*'="'] [MGL command]
`surfca` *xdat ydat zdat cdat adat* ['*sch*'="'] [MGL command]
`void SurfCA (const mglDataA &`*z*`, const mglDataA &`*c*`, const mglDataA &`*a*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void SurfCA (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*c*`, const mglDataA &`*a*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_surfca (HMGL` *gr*`, HCDT` *z*`, HCDT` *c*`, HCDT` *a*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_surfca_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *c*`, HCDT` *a*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]}, color it by matrix *c*[i,j] and transparent it by matrix *a*[i,j]. If string *sch* have symbol '`#`' then grid lines are drawn. If string *sch* have symbol '`.`' then plot by dots is produced. All dimensions of arrays *z* and *c* must be equal. Surface is plotted for each z slice of the data. Note, you can use [map], page 221-like coloring if use '`%`' in color scheme. See also [surf], page 208, [surfc], page 217, [surfa], page 218, [surf3ca], page 220. See Section 2.6.4 [SurfCA sample], page 75, for sample code and picture.

`surf3ca` *adat cdat bdat* `val` ['*sch*'="'] [MGL command]
`surf3ca` *xdat ydat zdat adat cdat bdat* `val` ['*sch*'="'] [MGL command]
`void Surf3CA (mreal` *val*`, const mglDataA &`*a*`, const mglDataA &`*c*`, const mglDataA &`*b*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Surf3CA (mreal` *val*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const mglDataA &`*c*`, const mglDataA &`*b*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_surf3ca_val (HMGL` *gr*`, mreal` *val*`, HCDT` *a*`, HCDT` *c*`, HCDT` *b*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_surf3ca_xyz_val (HMGL` *gr*`, mreal` *val*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`, HCDT` *c*`, HCDT` *b*`,const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws isosurface plot for 3d array specified parametrically *a*[i,j,k](*x*[i,j,k], *y*[i,j,k], *z*[i,j,k]) at a(x,y,z)=*val*. It is mostly the same as [surf3], page 214 function but the color and the transparency of isosurface depends on values of array *c* and *b* correspondingly. If string *sch* contain '`#`' then wire plot is produced. If string *sch* have symbol '`.`' then plot by dots is produced. Note, you can use [map], page 221-like coloring if use '`%`' in color scheme. See also [surf3], page 214, [surfca], page 220, [surf3c], page 218, [surf3a], page 219. See Section 2.7.4 [Surf3CA sample], page 91, for sample code and picture.

`surf3ca` *adat cdat bdat* ['*sch*'="'] [MGL command]
`surf3ca` *xdat ydat zdat adat cdat bdat* ['*sch*'="'] [MGL command]
`void Surf3CA (const mglDataA &`*a*`, const mglDataA &`*c*`, const mglDataA &`*b*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Surf3CA (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const mglDataA &`*c*`, const mglDataA &`*b*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void mgl_surf3ca (HMGL` *gr*`, HCDT` *a*`, HCDT` *c*`, HCDT` *b*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_surf3ca_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`, HCDT` *c*`, HCDT` *b*`, const char *`*sch*`, const char *`*opt*`)` [C function]

Draws *num*-th uniformly distributed in color range isosurfaces for 3d data. Here parameter *num* is equal to parameter `value` in options *opt* (default is 3).

`tiles` *zdat rdat* ['*sch*'="] [MGL command]
`tiles` *xdat ydat zdat rdat* ['*sch*'="] [MGL command]
`void TileS (const mglDataA &`*z*`, const mglDataA &`*c*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void TileS (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*r*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_tiles (HMGL` *gr*`, HCDT` *z*`, HCDT` *c*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_tiles_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *r*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws horizontal tiles for surface specified parametrically {*x*[i,j], *y*[i,j], *z*[i,j]}. It is mostly the same as [tile], page 209 but the size of tiles is determined by *r* array. This is some kind of "transparency" useful for exporting to EPS files. Tiles is plotted for each z slice of the data. See also [surfa], page 218, [tile], page 209. See Section 2.6.10 [TileS sample], page 81, for sample code and picture.

`map` *udat vdat* ['*sch*'="] [MGL command]
`map` *xdat ydat udat vdat* ['*sch*'="] [MGL command]
`void Map (const mglDataA &`*ax*`, const mglDataA &`*ay*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Map (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*ax*`, const mglDataA &`*ay*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_map (HMGL` *gr*`, HCDT` *ax*`, HCDT` *ay*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_map_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *ax*`, HCDT` *ay*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws mapping plot for matrices {*ax*, *ay* } which parametrically depend on coordinates *x*, *y*. The initial position of the cell (point) is marked by color. Height is proportional to Jacobian(ax,ay). This plot is like Arnold diagram ??? If string *sch* contain symbol '`.`' then the color ball at matrix knots are drawn otherwise face is drawn. See Section 2.9.9 [Mapping visualization], page 124, for sample code and picture.

`stfa` *re im* `dn` ['*sch*'="] [MGL command]
`stfa` *xdat ydat re im* `dn` ['*sch*'="] [MGL command]
`void STFA (const mglDataA &`*re*`, const mglDataA &`*im*`, int` *dn*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void STFA (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*re*`, const mglDataA &`*im*`, int` *dn*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void mgl_stfa (HMGL` *gr*`, HCDT` *re*`, HCDT` *im*`, int` *dn*`, const char *`*sch*`, const char *`*opt*`)` [C function]

`void mgl_stfa_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *re*`, HCDT` *im*`, int` *dn*`, const char *`*sch*`, const char *`*opt*`)` [C function]

Draws spectrogram of complex array *re*+i**im* for Fourier size of *dn* points at plane *z* equal to minimal z-axis value. For example in 1D case, result is density plot of data $res[i,j] = |\sum_d^d nexp(I*j*d)*(re[i*dn+d]+I*im[i*dn+d])|/dn$ with size {int(nx/dn), dn, ny}. At this array *re*, *im* parametrically depend on coordinates *x*, *y*. The size of *re* and *im* must be the same. The minor dimensions of arrays *x*, *y*, *re* should be equal. Arrays *x*, *y* can be vectors (not matrix as *re*). See Section 2.9.8 [STFA sample], page 123, for sample code and picture.

4.15 Vector fields

These functions perform plotting of 2D and 3D vector fields. There are 5 generally different types of vector fields representations: simple vector field (Vect), vectors along the curve (Traj), vector field by dew-drops (Dew), flow threads (Flow, FlowP), flow pipes (Pipe). By default (if absent) values of *x*, *y*, *z* are equidistantly distributed in axis range. The minor dimensions of arrays *x*, *y*, *z*, *ax* should be equal. The size of *ax*, *ay* and *az* must be equal. Arrays *x*, *y*, *z* can be vectors (not matrices as *ax*). String *sch* sets the color scheme (see Section 3.4 [Color scheme], page 150) for plot. String *opt* contain command options (see Section 3.7 [Command options], page 154).

`traj` *xdat ydat udat vdat* ['*sch*'=''] [MGL command]

`traj` *xdat ydat zdat udat vdat wdat* ['*sch*'=''] [MGL command]

`void Traj (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*ax*`, const mglDataA &`*ay*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void Traj (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*ax*`, const mglDataA &`*ay*`, const mglDataA &`*az*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void mgl_traj_xyz (HMGL` *gr*`, HCDT`*x*`, HCDT`*y*`, HCDT`*z*`, HCDT`*ax*`, HCDT`*ay*`, HCDT`*az*`, const char *`*sch*`, const char *`*opt*`)` [C function]

`void mgl_traj_xy (HMGL` *gr*`, HCDT`*x*`, HCDT`*y*`, HCDT`*ax*`, HCDT`*ay*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws vectors {*ax*, *ay*, *az*} along a curve {*x*, *y*, *z*}. The length of arrows are proportional to $\sqrt{\{ax^2+ay^2+az^2\}}$. String *pen* specifies the color (see Section 3.3 [Line styles], page 148). By default (`pen=""`) color from palette is used (see Section 4.2.7 [Palette and colors], page 163). Option `value` set the vector length factor (if non-zero) or vector length to be proportional the distance between curve points (if `value=0`). The minor sizes of all arrays must be equal and large 2. The plots are drawn for each row if one of the data is the matrix. See also [vect], page 223. See Section 2.8.3 [Traj sample], page 107, for sample code and picture.

`vect` *udat vdat* ['*sch*'=''] [MGL command]
`vect` *xdat ydat udat vdat* ['*sch*'=''] [MGL command]
`void Vect (const mglDataA &`*ax*`, const mglDataA &`*ay*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Vect (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*ax*`, const mglDataA &`*ay*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_vect_2d (HMGL` *gr*`, HCDT` *ax*`, HCDT` *ay*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_vect_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *ax*`, HCDT` *ay*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws plane vector field plot for the field $\{ax, ay\}$ depending parametrically on coordinates x, y at level z equal to minimal z-axis value. The length and color of arrows are proportional to $\sqrt{\{ax^2 + ay^2\}}$. The number of arrows depend on [meshnum], page 161. The appearance of the hachures (arrows) can be changed by symbols:

- '`f`' for drawing arrows with fixed lengths,
- '`>`', '`<`' for drawing arrows to or from the cell point (default is centering),
- '`.`' for drawing hachures with dots instead of arrows,
- '`=`' for enabling color gradient along arrows.

See also [flow], page 224, [dew], page 224. See Section 2.8.1 [Vect sample], page 105, for sample code and picture.

`vect` *udat vdat wdat* ['*sch*'=''] [MGL command]
`vect` *xdat ydat zdat udat vdat wdat* ['*sch*'=''] [MGL command]
`void Vect (const mglDataA &`*ax*`, const mglDataA &`*ay*`, const mglDataA &`*az*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Vect (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*ax*`, const mglDataA &`*ay*`, const mglDataA &`*az*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_vect_3d (HMGL` *gr*`, HCDT` *ax*`, HCDT` *ay*`, HCDT` *az*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_vect_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *ax*`, HCDT` *ay*`, HCDT` *az*`, const char *`*sch*`, const char *`*opt*`)` [C function]

This is 3D version of the first functions. Here arrays *ax*, *ay*, *az* must be 3-ranged tensors with equal sizes and the length and color of arrows is proportional to $\sqrt{\{ax^2 + ay^2 + az^2\}}$.

`vect3` *udat vdat wdat* ['*sch*'='' *sval*] [MGL command]
`vect3` *xdat ydat zdat udat vdat wdat* ['*sch*'='' *sval*] [MGL command]
`void Vect3 (const mglDataA &`*ax*`, const mglDataA &`*ay*`, const mglDataA &`*az*`, const char *`*sch*`="", mreal` *sVal*`=-1, const char *`*opt*`="")` [Method on `mglGraph`]
`void Vect3 (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*ax*`, const mglDataA &`*ay*`, const mglDataA &`*az*`, const char *`*sch*`="", mreal` *sVal*`=-1, const char *`*opt*`="")` [Method on `mglGraph`]

`void mgl_vect3 (HMGL` *gr*`, HCDT` *ax*`, HCDT` *ay*`, HCDT` *az*`, const char *`*sch*`, mreal` *sVal*`, const char *`*opt*`)` [C function]
`void mgl_vect3_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *ax*`, HCDT` *ay*`, HCDT` *az*`, const char *`*sch*`, mreal` *sVal*`, const char *`*opt*`)` [C function]

The function draws 3D vector field plot for the field {*ax*, *ay*, *az*} depending parametrically on coordinates *x*, *y*, *z*. Vector field is drawn at slice *sVal* in direction {'x', 'y', 'z'} if *sch* contain corresponding symbol (by default, 'y' direction is used). The length and color of arrows are proportional to $\sqrt{\{ax^2 + ay^2 + az^2\}}$. The number of arrows depend on [meshnum], page 161. The appearance of the hachures (arrows) can be changed by symbols:

- 'f' for drawing arrows with fixed lengths,
- '>', '<' for drawing arrows to or from the cell point (default is centering),
- '.' for drawing hachures with dots instead of arrows,
- '=' for enabling color gradient along arrows.

See also [vect], page 223, [flow], page 224, [dew], page 224. See Section 2.8.2 [Vect3 sample], page 106, for sample code and picture.

`dew` *udat vdat* ['*sch*'=''] [MGL command]
`dew` *xdat ydat udat vdat* ['*sch*'=''] [MGL command]
`void Dew (const mglDataA &`*ax*`, const mglDataA &`*ay*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Dew (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*ax*`, const mglDataA &`*ay*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_dew (HMGL` *gr*`, HCDT` *ax*`, HCDT` *ay*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_dew_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *ax*`, HCDT` *ay*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws dew-drops for plane vector field {*ax*, *ay*} depending parametrically on coordinates *x*, *y* at level *z* equal to minimal z-axis value. Note that this is very expensive plot in memory usage and creation time! The color of drops is proportional to $\sqrt{\{ax^2 + ay^2\}}$. The number of drops depend on [meshnum], page 161. See also [vect], page 223. See Section 2.8.6 [Dew sample], page 110, for sample code and picture.

`flow` *udat vdat* ['*sch*'=''] [MGL command]
`flow` *xdat ydat udat vdat* ['*sch*'=''] [MGL command]
`void Flow (const mglDataA &`*ax*`, const mglDataA &`*ay*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Flow (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*ax*`, const mglDataA &`*ay*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_flow_2d (HMGL` *gr*`, HCDT` *ax*`, HCDT` *ay*`, const char *`*sch*`, const char *`*opt*`)` [C function]

`void mgl_flow_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *ax*`, HCDT` *ay*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws flow threads for the plane vector field {*ax*, *ay*} parametrically depending on coordinates *x*, *y* at level *z* equal to minimal z-axis value. Number of threads is proportional to `value` option (default is 5). String *sch* may contain:

- color scheme – up-half (warm) corresponds to normal flow (like attractor), bottom-half (cold) corresponds to inverse flow (like source);
- '`#`' for starting threads from edges only;
- '`v`' for drawing arrows on the threads;
- '`x`', '`z`' for drawing tapes of normals in x-y and y-z planes correspondingly.

See also [pipe], page 226, [vect], page 223, [tape], page 197, [barwidth], page 161. See Section 2.8.4 [Flow sample], page 108, for sample code and picture.

`flow` *udat vdat wdat* ['*sch*'=''] [MGL command]
`flow` *xdat ydat zdat udat vdat wdat* ['*sch*'=''] [MGL command]
`void Flow (const mglDataA &`*ax*`, const mglDataA &`*ay*`, const mglDataA &`*az*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void Flow (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*ax*`, const mglDataA &`*ay*`, const mglDataA &`*az*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_flow_3d (HMGL` *gr*`, HCDT` *ax*`, HCDT` *ay*`, HCDT` *az*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_flow_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *ax*`, HCDT` *ay*`, HCDT` *az*`, const char *`*sch*`, const char *`*opt*`)` [C function]

This is 3D version of the first functions. Here arrays *ax*, *ay*, *az* must be 3-ranged tensors with equal sizes and the color of line is proportional to $\sqrt{\{ax^2 + ay^2 + az^2\}}$.

`flow x0 y0` *udat vdat* ['*sch*'=''] [MGL command]
`flow x0 y0` *xdat ydat udat vdat* ['*sch*'=''] [MGL command]
`void FlowP (mglPoint` *p0*`, const mglDataA &`*ax*`, const mglDataA &`*ay*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void FlowP (mglPoint` *p0*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*ax*`, const mglDataA &`*ay*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_flowp_2d (HMGL` *gr*`, mreal` *x0*`, mreal` *y0*`, mreal` *z0*`, HCDT` *ax*`, HCDT` *ay*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_flowp_xy (HMGL` *gr*`, mreal` *x0*`, mreal` *y0*`, mreal` *z0*`, HCDT` *x*`, HCDT` *y*`, HCDT` *ax*`, HCDT` *ay*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The same as first one ([flow], page 224) but draws single flow thread starting from point *p0*={*x0*,*y0*,*z0*}.

`flow x0 y0 z0` *udat vdat wdat* ['*sch*'=''] [MGL command]
`flow x0 y0 z0` *xdat ydat zdat udat vdat wdat* ['*sch*'=''] [MGL command]
`void FlowP (mglPoint` *p0*`, const mglDataA &`*ax*`, const mglDataA &`*ay*`, const mglDataA &`*az*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void FlowP (mglPoint` *p0*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*ax*`, const mglDataA &`*ay*`, const mglDataA &`*az*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void mgl_flowp_3d (HMGL` *gr*`, mreal` *x0*`, mreal` *y0*`, mreal` *z0*`, HCDT` *ax*`, HCDT` *ay*`, HCDT` *az*`, const char *`*sch*`, const char *`*opt*`)` [C function]

`void mgl_flowp_xyz (HMGL` *gr*`, mreal` *x0*`, mreal` *y0*`, mreal` *z0*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *ax*`, HCDT` *ay*`, HCDT` *az*`, const char *`*sch*`, const char *`*opt*`)` [C function]

This is 3D version of the previous functions.

`grad` *pdat* [*'sch'="*] [MGL command]

`grad` *xdat ydat pdat* [*'sch'="*] [MGL command]

`grad` *xdat ydat zdat pdat* [*'sch'="*] [MGL command]

`void Grad (const mglDataA &`*phi*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void Grad (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*phi*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void Grad (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*phi*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]

`void mgl_grad (HMGL` *gr*`, HCDT` *phi*`, const char *`*sch*`, const char *`*opt*`)` [C function]

`void mgl_grad_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *phi*`, const char *`*sch*`, const char *`*opt*`)` [C function]

`void mgl_grad_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *phi*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws gradient lines for scalar field *phi*[i,j] (or *phi*[i,j,k] in 3d case) specified parametrically {*x*[i,j,k], *y*[i,j,k], *z*[i,j,k]}. Number of lines is proportional to `value` option (default is 5). See also [dens], page 209, [cont], page 210, [flow], page 224.

`pipe` *udat vdat* [*'sch'="* `r0=0.05`] [MGL command]

`pipe` *xdat ydat udat vdat* [*'sch'="* `r0=0.05`] [MGL command]

`void Pipe (const mglDataA &`*ax*`, const mglDataA &`*ay*`, const char *`*sch*`="", mreal` *r0*`=0.05, const char *`*opt*`="")` [Method on `mglGraph`]

`void Pipe (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*ax*`, const mglDataA &`*ay*`, const char *`*sch*`="", mreal` *r0*`=0.05, const char *`*opt*`="")` [Method on `mglGraph`]

`void mgl_pipe_2d (HMGL` *gr*`, HCDT` *ax*`, HCDT` *ay*`, const char *`*sch*`, mreal` *r0*`, const char *`*opt*`)` [C function]

`void mgl_pipe_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *ax*`, HCDT` *ay*`, const char *`*sch*`, mreal` *r0*`, const char *`*opt*`)` [C function]

The function draws flow pipes for the plane vector field {*ax*, *ay*} parametrically depending on coordinates *x*, *y* at level *z* equal to minimal z-axis value. Number of pipes is proportional to `value` option (default is 5). If '`#`' symbol is specified then pipes start only from edges of axis range. The color of lines is proportional to $\sqrt{\{ax^2 + ay^2\}}$. Warm color corresponds to normal flow (like attractor). Cold one corresponds to inverse flow (like source). Parameter *r0* set the base pipe radius. If

r0<0 or symbol 'i' is specified then pipe radius is inverse proportional to amplitude. The vector field is plotted for each z slice of *ax*, *ay*. See also [flow], page 224, [vect], page 223. See Section 2.8.5 [Pipe sample], page 109, for sample code and picture.

`pipe` *udat vdat wdat* ['*sch*'=" `r0=0.05`] [MGL command]
`pipe` *xdat ydat zdat udat vdat wdat* ['*sch*'=" `r0=0.05`] [MGL command]
`void Pipe (const mglDataA &`*ax*`, const mglDataA &`*ay*`, const mglDataA &`*az*`, const char *`*sch*`="", mreal `*r0*`=0.05, const char *`*opt*`="")` [Method on `mglGraph`]
`void Pipe (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*ax*`, const mglDataA &`*ay*`, const mglDataA &`*az*`, const char *`*sch*`="", mreal `*r0*`=0.05, const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_pipe_3d (HMGL` *gr*`, HCDT` *ax*`, HCDT` *ay*`, HCDT` *az*`, const char *`*sch*`, mreal` *r0*`, const char *`*opt*`)` [C function]
`void mgl_pipe_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *ax*`, HCDT` *ay*`, HCDT` *az*`, const char *`*sch*`, mreal` *r0*`, const char *`*opt*`)` [C function]

This is 3D version of the first functions. Here arrays *ax*, *ay*, *az* must be 3-ranged tensors with equal sizes and the color of line is proportional to $\sqrt{\{ax^2 + ay^2 + az^2\}}$.

4.16 Other plotting

These functions perform miscellaneous plotting. There is unstructured data points plots (Dots), surface reconstruction (Crust), surfaces on the triangular or quadrangular mesh (TriPlot, TriCont, QuadPlot), textual formula plotting (Plots by formula), data plots at edges (Dens[XYZ], Cont[XYZ], ContF[XYZ]). Each type of plotting has similar interface. There are 2 kind of versions which handle the arrays of data and coordinates or only single data array. Parameters of color scheme are specified by the string argument. See Section 3.4 [Color scheme], page 150.

`densx` *dat* ['*sch*'=" `sval=nan`] [MGL command]
`densy` *dat* ['*sch*'=" `sval=nan`] [MGL command]
`densz` *dat* ['*sch*'=" `sval=nan`] [MGL command]
`void DensX (const mglDataA &`*a*`, const char *`*stl*`="", mreal` *sVal*`=NAN, const char *`*opt*`="")` [Method on `mglGraph`]
`void DensY (const mglDataA &`*a*`, const char *`*stl*`="", mreal` *sVal*`=NAN, const char *`*opt*`="")` [Method on `mglGraph`]
`void DensZ (const mglDataA &`*a*`, const char *`*stl*`="", mreal` *sVal*`=NAN, const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_dens_x (HMGL` *gr*`, HCDT` *a*`, const char *`*stl*`, mreal` *sVal*`, const char *`*opt*`)` [C function]
`void mgl_dens_y (HMGL` *gr*`, HCDT` *a*`, const char *`*stl*`, mreal` *sVal*`, const char *`*opt*`)` [C function]
`void mgl_dens_z (HMGL` *gr*`, HCDT` *a*`, const char *`*stl*`, mreal` *sVal*`, const char *`*opt*`)` [C function]

These plotting functions draw density plot in x, y, or z plain. If *a* is a tensor (3-dimensional data) then interpolation to a given *sVal* is performed. These functions are useful for creating projections of the 3D data array to the bounding box. See also

[ContXYZ], page 228, [ContFXYZ], page 228, [dens], page 209, Section 4.18 [Data manipulation], page 235. See Section 2.7.9 [Dens projection sample], page 96, for sample code and picture.

```
contx dat ['sch'='' sval=nan]                                          [MGL command]
conty dat ['sch'='' sval=nan]                                          [MGL command]
contz dat ['sch'='' sval=nan]                                          [MGL command]
void ContX (const mglDataA &a, const char *stl="",                     [Method on mglGraph]
        mreal sVal=NAN, const char *opt="")
void ContY (const mglDataA &a, const char *stl="",                     [Method on mglGraph]
        mreal sVal=NAN, const char *opt="")
void ContZ (const mglDataA &a, const char *stl="",                     [Method on mglGraph]
        mreal sVal=NAN, const char *opt="")
void mgl_cont_x (HMGL gr, HCDT a, const char *stl, mreal sVal,         [C function]
        const char *opt)
void mgl_cont_y (HMGL gr, HCDT a, const char *stl, mreal sVal,         [C function]
        const char *opt)
void mgl_cont_z (HMGL gr, HCDT a, const char *stl, mreal sVal,         [C function]
        const char *opt)
```

These plotting functions draw contour lines in x, y, or z plain. If *a* is a tensor (3-dimensional data) then interpolation to a given *sVal* is performed. These functions are useful for creating projections of the 3D data array to the bounding box. Option `value` set the number of contours. See also [ContFXYZ], page 228, [DensXYZ], page 227, [cont], page 210, Section 4.18 [Data manipulation], page 235. See Section 2.7.10 [Cont projection sample], page 97, for sample code and picture.

```
void ContX (const mglDataA &v, const mglDataA &a,                      [Method on mglGraph]
        const char *stl="", mreal sVal=NAN, const char *opt="")
void ContY (const mglDataA &v, const mglDataA &a,                      [Method on mglGraph]
        const char *stl="", mreal sVal=NAN, const char *opt="")
void ContZ (const mglDataA &v, const mglDataA &a,                      [Method on mglGraph]
        const char *stl="", mreal sVal=NAN, const char *opt="")
void mgl_cont_x_val (HMGL gr, HCDT v, HCDT a, const char *stl,         [C function]
        mreal sVal, const char *opt)
void mgl_cont_y_val (HMGL gr, HCDT v, HCDT a, const char *stl,         [C function]
        mreal sVal, const char *opt)
void mgl_cont_z_val (HMGL gr, HCDT v, HCDT a, const char *stl,         [C function]
        mreal sVal, const char *opt)
```

The same as previous with manual contour levels.

```
contfx dat ['sch'='' sval=nan]                                         [MGL command]
contfy dat ['sch'='' sval=nan]                                         [MGL command]
contfz dat ['sch'='' sval=nan]                                         [MGL command]
void ContFX (const mglDataA &a, const char *stl="",                    [Method on mglGraph]
        mreal sVal=NAN, const char *opt="")
void ContFY (const mglDataA &a, const char *stl="",                    [Method on mglGraph]
        mreal sVal=NAN, const char *opt="")
```

`void ContFZ (const mglDataA &a, const char *stl="", mreal sVal=NAN, const char *opt="")` [Method on `mglGraph`]
`void mgl_contf_x (HMGL gr, HCDT a, const char *stl, mreal sVal, const char *opt)` [C function]
`void mgl_contf_y (HMGL gr, HCDT a, const char *stl, mreal sVal, const char *opt)` [C function]
`void mgl_contf_z (HMGL gr, HCDT a, const char *stl, mreal sVal, const char *opt)` [C function]

These plotting functions draw solid contours in x, y, or z plain. If a is a tensor (3-dimensional data) then interpolation to a given *sVal* is performed. These functions are useful for creating projections of the 3D data array to the bounding box. Option `value` set the number of contours. See also [ContFXYZ], page 228, [DensXYZ], page 227, [cont], page 210, Section 4.18 [Data manipulation], page 235. See Section 2.7.11 [ContF projection sample], page 98, for sample code and picture.

`void ContFX (const mglDataA &v, const mglDataA &a, const char *stl="", mreal sVal=NAN, const char *opt="")` [Method on `mglGraph`]
`void ContFY (const mglDataA &v, const mglDataA &a, const char *stl="", mreal sVal=NAN, const char *opt="")` [Method on `mglGraph`]
`void ContFZ (const mglDataA &v, const mglDataA &a, const char *stl="", mreal sVal=NAN, const char *opt="")` [Method on `mglGraph`]
`void mgl_contf_x_val (HMGL gr, HCDT v, HCDT a, const char *stl, mreal sVal, const char *opt)` [C function]
`void mgl_contf_y_val (HMGL gr, HCDT v, HCDT a, const char *stl, mreal sVal, const char *opt)` [C function]
`void mgl_contf_z_val (HMGL gr, HCDT v, HCDT a, const char *stl, mreal sVal, const char *opt)` [C function]

The same as previous with manual contour levels.

`fplot 'y(x)' ['pen'=""]` [MGL command]
`void FPlot (const char *eqY, const char *pen="", const char *opt="")` [Method on `mglGraph`]
`void mgl_fplot (HMGL gr, const char *eqY, const char *pen, const char *opt)` [C function]

Draws command function '`y(x)`' at plane *z* equal to minimal z-axis value, where '`x`' variable is changed in `xrange`. You do not need to create the data arrays to plot it. Option `value` set initial number of points. See also [plot], page 195.

`fplot 'x(t)' 'y(t)' 'z(t)' ['pen'=""]` [MGL command]
`void FPlot (const char *eqX, const char *eqY, const char *eqZ, const char *pen, const char *opt="")` [Method on `mglGraph`]
`void mgl_fplot_xyz (HMGL gr, const char *eqX, const char *eqY, const char *eqZ, const char *pen, const char *opt)` [C function]

Draws command parametrical curve {'`x(t)`', '`y(t)`', '`z(t)`'} where '`t`' variable is changed in range [0, 1]. You do not need to create the data arrays to plot it. Option `value` set number of points. See also [plot], page 195.

`fsurf` *'z(x,y)'* ['*sch*'=''] [MGL command]
`void FSurf (const char *`*eqZ*`, const char *`*sch*`="", const char *`*opt*`="");` [Method on `mglGraph`]
`void mgl_fsurf (HMGL` *gr*`, const char *`*eqZ*`, const char *`*sch*`, const char *`*opt*`);` [C function]

Draws command surface for function '`z(x,y)`' where '`x`', '`y`' variable are changed in `xrange, yrange`. You do not need to create the data arrays to plot it. Option `value` set number of points. See also [surf], page 208.

`fsurf` *'x(u,v)' 'y(u,v)' 'z(u,v)'* ['*sch*'=''] [MGL command]
`void FSurf (const char *`*eqX*`, const char *`*eqY*`, const char *`*eqZ*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_fsurf_xyz (HMGL` *gr*`, const char *`*eqX*`, const char *`*eqY*`, const char *`*eqZ*`, const char *`*sch*`, const char *`*opt*`)` [C function]

Draws command parametrical surface {'`x(u,v)`', '`y(u,v)`', '`z(u,v)`'} where '`u`', '`v`' variable are changed in range [0, 1]. You do not need to create the data arrays to plot it. Option `value` set number of points. See also [surf], page 208.

`triplot` *idat xdat ydat* ['*sch*'=''] [MGL command]
`triplot` *idat xdat ydat zdat* ['*sch*'=''] [MGL command]
`triplot` *idat xdat ydat zdat cdat* ['*sch*'=''] [MGL command]
`void TriPlot (const mglDataA &`*id*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void TriPlot (const mglDataA &`*id*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*c*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void TriPlot (const mglDataA &`*id*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_triplot_xy (HMGL` *gr*`, HCDT` *id*`, HCDT` *x*`, HCDT` *y*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_triplot_xyz (HMGL` *gr*`, HCDT` *id*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`, const char *`*opt*`)` [C function]
`void mgl_triplot_xyzc (HMGL` *gr*`, HCDT` *id*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *c*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws the surface of triangles. Triangle vertexes are set by indexes *id* of data points {*x*[i], *y*[i], *z*[i]}. String *sch* sets the color scheme. If string contain '`#`' then wire plot is produced. First dimensions of *id* must be 3 or greater. Arrays *x*, *y*, *z* must have equal sizes. Parameter *c* set the colors of triangles (if *id*.ny=*c*.nx) or colors of vertexes (if *x*.nx=*c*.nx). See also [dots], page 232, [crust], page 232, [quadplot], page 231, [triangulation], page 281. See Section 2.7.12 [TriPlot and QuadPlot], page 99, for sample code and picture.

`tricont` *vdat idat xdat ydat zdat cdat* ['*sch*'=''] [MGL command]
`tricont` *vdat idat xdat ydat zdat* ['*sch*'=''] [MGL command]
`tricont` *idat xdat ydat zdat* ['*sch*'=''] [MGL command]

`void TriCont (const mglDataA &id, const mglDataA &x,` [Method on `mglGraph`]
`const mglDataA &y, const mglDataA &z, const mglDataA &c, const char *sch="", const char *opt="")`

`void TriCont (const mglDataA &id, const mglDataA &x,` [Method on `mglGraph`]
`const mglDataA &y, const mglDataA &z, const char *sch="", const char *opt="")`

`void TriContV (const mglDataA &v, const mglDataA &id,` [Method on `mglGraph`]
`const mglDataA &x, const mglDataA &y, const mglDataA &z, const mglDataA &c, const char *sch="", const char *opt="")`

`void TriContV (const mglDataA &v, const mglDataA &id,` [Method on `mglGraph`]
`const mglDataA &x, const mglDataA &y, const mglDataA &z, const char *sch="", const char *opt="")`

`void mgl_tricont_xyzc (HMGL gr, HCDT id, HCDT x, HCDT y, HCDT z,` [C function]
`HCDT c, const char *sch, const char *opt)`

`void mgl_tricont_xyz (HMGL gr, HCDT id, HCDT x, HCDT y, HCDT z,` [C function]
`const char *sch, const char *opt)`

`void mgl_tricont_xyzcv (HMGL gr, HCDT v, HCDT id, HCDT x, HCDT y,` [C function]
`HCDT z, HCDT c, const char *sch, const char *opt)`

`void mgl_tricont_xyzv (HMGL gr, HCDT v, HCDT id, HCDT x, HCDT y,` [C function]
`HCDT z, const char *sch, const char *opt)`

The function draws contour lines for surface of triangles at z=v[k] (or at z equal to minimal z-axis value if *sch* contain symbol '_'). Triangle vertexes are set by indexes *id* of data points {x[i], y[i], z[i]}. Contours are plotted for z[i,j]=v[k] where v[k] are values of data array v. If v is absent then arrays of option `value` elements equidistantly distributed in color range is used. String *sch* sets the color scheme. Array c (if specified) is used for contour coloring. First dimensions of *id* must be 3 or greater. Arrays x, y, z must have equal sizes. Parameter c set the colors of triangles (if *id*.ny=c.nx) or colors of vertexes (if x.nx=c.nx). See also [triplot], page 230, [cont], page 210, [triangulation], page 281.

`quadplot` *idat xdat ydat* ['*sch*'=''] [MGL command]

`quadplot` *idat xdat ydat zdat* ['*sch*'=''] [MGL command]

`quadplot` *idat xdat ydat zdat cdat* ['*sch*'=''] [MGL command]

`void QuadPlot (const mglDataA &id, const mglDataA &x,` [Method on `mglGraph`]
`const mglDataA &y, const char *sch="", const char *opt="")`

`void QuadPlot (const mglDataA &id, const mglDataA &x,` [Method on `mglGraph`]
`const mglDataA &y, const mglDataA &z, const mglDataA &c, const char *sch="", const char *opt="")`

`void QuadPlot (const mglDataA &id, const mglDataA &x,` [Method on `mglGraph`]
`const mglDataA &y, const mglDataA &z, const char *sch="", const char *opt="")`

`void mgl_quadplot_xy (HMGL gr, HCDT id, HCDT x, HCDT y, const` [C function]
`char *sch, const char *opt)`

`void mgl_quadplot_xyz (HMGL gr, HCDT id, HCDT x, HCDT y, HCDT z,` [C function]
`const char *sch, const char *opt)`

`void mgl_quadplot_xyzc (HMGL` *gr*`, HCDT` *id*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *c*`, const char *`*sch*`, const char *`*opt*`)` [C function]

The function draws the surface of quadrangles. Quadrangles vertexes are set by indexes *id* of data points {*x*[i], *y*[i], *z*[i]}. String *sch* sets the color scheme. If string contain '`#`' then wire plot is produced. First dimensions of *id* must be 4 or greater. Arrays *x*, *y*, *z* must have equal sizes. Parameter *c* set the colors of quadrangles (if *id*.ny=*c*.nx) or colors of vertexes (if *x*.nx=*c*.nx). See also [triplot], page 230. See Section 2.7.12 [TriPlot and QuadPlot], page 99, for sample code and picture.

`dots` *xdat ydat zdat* ['*sch*'="] [MGL command]
`dots` *xdat ydat zdat adat* ['*sch*'="] [MGL command]
`void Dots (const mglDataA &`*x*`, const mglDataA &`*y*`,` [Method on `mglGraph`]
`const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")`
`void Dots (const mglDataA &`*x*`, const mglDataA &`*y*`,` [Method on `mglGraph`]
`const mglDataA &`*z*`, const mglDataA &`*a*`, const char *`*sch*`="", const char *`*opt*`="")`
`void Dots (const mglDataA &`*x*`, const mglDataA &`*y*`,` [Method on `mglGraph`]
`const mglDataA &`*z*`, const mglDataA &`*c*`, const mglDataA &`*a*`, const char *`*sch*`="", const char *`*opt*`="")`
`void mgl_dots (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`,` [C function]
`const char *`*opt*`)`
`void mgl_dots_a (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`, const` [C function]
`char *`*sch*`, const char *`*opt*`)`
`void mgl_dots_ca (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *c*`, HCDT` *a*`,` [C function]
`const char *`*sch*`, const char *`*opt*`)`

The function draws the arbitrary placed points {*x*[i], *y*[i], *z*[i]}. String *sch* sets the color scheme and kind of marks. If arrays *c*, *a* are specified then they define colors and transparencies of dots. You can use [tens], page 196 plot with style '`.`' to draw non-transparent dots with specified colors. Arrays *x*, *y*, *z*, *a* must have equal sizes. See also [crust], page 232, [tens], page 196, [mark], page 202, [plot], page 195. See Section 2.7.13 [Dots sample], page 100, for sample code and picture.

`crust` *xdat ydat zdat* ['*sch*'="] [MGL command]
`void Crust (const mglDataA &`*x*`, const mglDataA &`*y*`,` [Method on `mglGraph`]
`const mglDataA &`*z*`, const char *`*sch*`="", const char *`*opt*`="")`
`void mgl_crust (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*sch*`,` [C function]
`const char *`*opt*`)`

The function reconstruct and draws the surface for arbitrary placed points {*x*[i], *y*[i], *z*[i]}. String *sch* sets the color scheme. If string contain '`#`' then wire plot is produced. Arrays *x*, *y*, *z* must have equal sizes. See also [dots], page 232, [triplot], page 230.

4.17 Nonlinear fitting

These functions fit data to formula. Fitting goal is to find formula parameters for the best fit the data points, i.e. to minimize the sum $\sum_i (f(x_i, y_i, z_i) - a_i)^2 / s_i^2$. At this, approximation function '`f`' can depend only on one argument '`x`' (1D case), on two arguments '`x,y`' (2D case) and on three arguments '`x,y,z`' (3D case). The function '`f`' also may depend on parameters. Normally the list of fitted parameters is specified by *var* string (like, '`abcd`').

Usually user should supply initial values for fitted parameters by *ini* variable. But if he/she don't supply it then the zeros are used. Parameter *print*=`true` switch on printing the found coefficients to *Message* (see Section 4.2.9 [Error handling], page 164).

Functions Fit() and FitS() do not draw the obtained data themselves. They fill the data *fit* by formula '`f`' with found coefficients and return it. At this, the '`x,y,z`' coordinates are equidistantly distributed in the axis range. Number of points in *fit* is defined by option `value` (default is *mglFitPnts*=100). Note, that this functions use GSL library and do something only if MathGL was compiled with GSL support. See Section 2.9.13 [Nonlinear fitting hints], page 129, for sample code and picture.

`fits` *res adat sdat 'func' 'var'* [*ini=0*] [MGL command]
`fits` *res xdat adat sdat 'func' 'var'* [*ini=0*] [MGL command]
`fits` *res xdat ydat adat sdat 'func' 'var'* [*ini=0*] [MGL command]
`fits` *res xdat ydat zdat adat sdat 'func' 'var'* [*ini=0*] [MGL command]
`mglData FitS (const mglDataA &`*a*`, const mglDataA &`*s*`, const char *`*func*`, const char *`*var*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData FitS (const mglDataA &`*a*`, const mglDataA &`*s*`, const char *`*func*`, const char *`*var*`, mglData &`*ini*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData FitS (const mglDataA &`*x*`, const mglDataA &`*a*`, const mglDataA &`*s*`, const char *`*func*`, const char *`*var*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData FitS (const mglDataA &`*x*`, const mglDataA &`*a*`, const mglDataA &`*s*`, const char *`*func*`, const char *`*var*`, mglData &`*ini*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData FitS (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*a*`, const mglDataA &`*s*`, const char *`*func*`, const char *`*var*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData FitS (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*a*`, const mglDataA &`*s*`, const char *`*func*`, const char *`*var*`, mglData &`*ini*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData FitS (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const mglDataA &`*s*`, const char *`*func*`, const char *`*var*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData FitS (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const mglDataA &`*s*`, const char *`*func*`, const char *`*var*`, mglData &`*ini*`, const char *`*opt*`="")` [Method on `mglGraph`]
`HMDT mgl_fit_ys (HMGL` *gr*`, HCDT` *a*`, HCDT` *s*`, const char *`*func*`, const char *`*var*`, HMDT` *ini*`, const char *`*opt*`)` [C function]
`HMDT mgl_fit_xys (HMGL` *gr*`, HCDT` *x*`, HCDT` *a*`, HCDT` *s*`, const char *`*func*`, const char *`*var*`, HMDT` *ini*`, const char *`*opt*`)` [C function]
`HMDT mgl_fit_xyzs (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *a*`, HCDT` *s*`, const char *`*func*`, const char *`*var*`, HMDT` *ini*`, const char *`*opt*`)` [C function]
`HMDT mgl_fit_xyzas (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`, HCDT` *s*`, const char *`*func*`, const char *`*var*`, HMDT` *ini*`, const char *`*opt*`)` [C function]

Fit data along x-, y- and z-directions for array specified parametrically *a*[i,j,k](*x*[i,j,k], *y*[i,j,k], *z*[i,j,k]) with weight factor *s*[i,j,k].

`fit` *res adat 'func' 'var'* [*ini=0*] [MGL command]
`fit` *res xdat adat 'func' 'var'* [*ini=0*] [MGL command]
`fit` *res xdat ydat adat 'func' 'var'* [*ini=0*] [MGL command]
`fit` *res xdat ydat zdat adat 'func' 'var'* [*ini=0*] [MGL command]
`mglData Fit (const mglDataA &`*a*`, const char *`*func*`, const char *`*var*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData Fit (const mglDataA &`*a*`, const char *`*func*`, const char *`*var*`, mglData &`*ini*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData Fit (const mglDataA &`*x*`, const mglDataA &`*a*`, const char *`*func*`, const char *`*var*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData Fit (const mglDataA &`*x*`, const mglDataA &`*a*`, const char *`*func*`, const char *`*var*`, mglData &`*ini*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData Fit (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*a*`, const char *`*func*`, const char *`*var*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData Fit (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*a*`, const char *`*func*`, const char *`*var*`, mglData &`*ini*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData Fit (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const char *`*func*`, const char *`*var*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData Fit (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const char *`*func*`, const char *`*var*`, mglData &`*ini*`, const char *`*opt*`="")` [Method on `mglGraph`]
`HMDT mgl_fit_y (HMGL` *gr*`, HCDT` *a*`, const char *`*func*`, const char *`*var*`, HMDT` *ini*`, const char *`*opt*`)` [C function]
`HMDT mgl_fit_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *a*`, const char *`*func*`, const char *`*var*`, HMDT` *ini*`, const char *`*opt*`)` [C function]
`HMDT mgl_fit_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *a*`, const char *`*func*`, const char *`*var*`, HMDT` *ini*`, const char *`*opt*`)` [C function]
`HMDT mgl_fit_xyza (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`, const char *`*func*`, const char *`*var*`, HMDT` *ini*`, const char *`*opt*`)` [C function]

Fit data along x-, y- and z-directions for array specified parametrically *a*[i,j,k](*x*[i,j,k], *y*[i,j,k], *z*[i,j,k]) with weight factor 1.

`mglData Fit2 (const mglDataA &`*a*`, const char *`*func*`, const char *`*var*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData Fit2 (mglData &`*fit*`, const mglDataA &`*a*`, const char *`*func*`, const char *`*var*`, mglData &`*ini*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData Fit3 (mglData &`*fit*`, const mglDataA &`*a*`, const char *`*func*`, const char *`*var*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData Fit3 (mglData &`*fit*`, const mglDataA &`*a*`, const char *`*func*`, const char *`*var*`, mglData &`*ini*`, const char *`*opt*`="")` [Method on `mglGraph`]
`HMDT mgl_fit_2 (HMGL` *gr*`, HCDT` *a*`, const char *`*func*`, const char *`*var*`, HMDT` *ini*`, const char *`*opt*`)` [C function]

`HMDT mgl_fit_3 (HMGL` *gr*`, HCDT` *a*`, const char *`*func*`, const char *`*var*`, HMDT` *ini*`, const char *`*opt*`)` [C function]

Fit data along all directions for 2d or 3d arrays *a* with *s*=1 and *x*, *y*, *z* equidistantly distributed in axis range.

`putsfit x y ['`*pre*`=" '`*fnt*`=" size=-1]` [MGL command]
`void PutsFit (mglPoint` *p*`, const char *`*prefix*`="", const char *`*font*`="", mreal` *size*`=-1)` [Method on `mglGraph`]
`void mgl_puts_fit (HMGL` *gr*`, mreal` *x*`, mreal` *y*`, mreal` *z*`, const char *`*prefix*`, const char *`*font*`, mreal` *size*`)` [C function]

Print last fitted formula with found coefficients (as numbers) at position *p0*. The string *prefix* will be printed before formula. All other parameters are the same as in Section 4.8 [Text printing], page 189.

`const char *GetFit ()` [Method on `mglGraph`]
`const char * mgl_get_fit (HMGL` *gr*`)` [C function only]
`mgl_get_fit (long` *gr*`, char *`*out*`, int` *len*`)` [Fortran subroutine]

Get last fitted formula with found coefficients (as numbers).

`mreal GetFitChi ()` [Method on `mglGraph`]
`mreal mgl_get_fit_chi ()` [C function]

Get \chi for last fitted formula.

`mreal GetFitCovar ()` [Method on `mglGraph`]
`mreal mgl_get_fit_covar ()` [C function]

Get covariance matrix for last fitted formula.

4.18 Data manipulation

`hist` RES *xdat adat* [MGL command]
`hist` RES *xdat ydat adat* [MGL command]
`hist` RES *xdat ydat zdat adat* [MGL command]
`mglData Hist (const mglDataA &`*x*`, const mglDataA &`*a*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData Hist (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*a*`, const char *`*opt*`="")` [Method on `mglGraph`]
`mglData Hist (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*a*`, const char *`*opt*`="")` [Method on `mglGraph`]
`HMDT mgl_hist_x (HMGL` *gr*`, HCDT` *x*`, HCDT` *a*`, const char *`*opt*`)` [C function]
`HMDT mgl_hist_xy (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *a*`, const char *`*opt*`)` [C function]
`HMDT mgl_hist_xyz (HMGL` *gr*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *a*`, const char *`*opt*`)` [C function]

These functions make distribution (histogram) of data. They do not draw the obtained data themselves. These functions can be useful if user have data defined for random points (for example, after PIC simulation) and he want to produce a plot which require regular data (defined on grid(s)). The range for grids is always selected as axis range. Arrays *x*, *y*, *z* define the positions (coordinates) of random points.

Array *a* define the data value. Number of points in output array *res* is defined by option `value` (default is *mglFitPnts*=100).

`fill` *dat 'eq'* [MGL command]
`fill` *dat 'eq' vdat* [MGL command]
`fill` *dat 'eq' vdat wdat* [MGL command]
`void Fill (mglData &`*u*`, const char *`*eq*`, const char *`*opt*`="")` [Method on `mglGraph`]
`void Fill (mglData &`*u*`, const char *`*eq*`, const mglDataA &`*v*`, const char *`*opt*`="")` [Method on `mglGraph`]
`void Fill (mglData &`*u*`, const char *`*eq*`, const mglDataA &`*v*`, const mglDataA &`*w*`, const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_data_fill_eq (HMGL` *gr*`, HMDT` *u*`, const char *`*eq*`, HCDT`*v*`, HCDT`*w*`, const char *`*opt*`)` [C function]

Fills the value of array '`u`' according to the formula in string *eq*. Formula is an arbitrary expression depending on variables '`x`', '`y`', '`z`', '`u`', '`v`', '`w`'. Coordinates '`x`', '`y`', '`z`' are supposed to be normalized in axis range. Variable '`u`' is the original value of the array. Variables '`v`' and '`w`' are values of arrays *v*, *w* which can be `NULL` (i.e. can be omitted).

`datagrid` *dat xdat ydat zdat* [MGL command]
`void DataGrid (mglData &`*u*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*opt*`="")` [Method on `mglGraph`]
`void mgl_data_grid (HMGL` *gr*`, HMDT` *u*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*opt*`)` [C function]

Fills the value of array '`u`' according to the linear interpolation of triangulated surface, found for arbitrary placed points '`x`', '`y`', '`z`'. Interpolation is done at points equidistantly distributed in axis range. NAN value is used for grid points placed outside of triangulated surface. See Section 2.9.11 [Making regular data], page 128, for sample code and picture.

`refill` *dat xdat vdat* [*sl=-1*] [MGL command]
`refill` *dat xdat ydat vdat* [*sl=-1*] [MGL command]
`refill` *dat xdat ydat zdat vdat* [MGL command]
`void Refill (mglDataA &`*dat*`, const mglDataA &`*x*`, const mglDataA &`*v*`, long `*sl*`=-1, const char *`*opt*`="")` [Method on `mglData`]
`void Refill (mglDataA &`*dat*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*v*`, long `*sl*`=-1, const char *`*opt*`="")` [Method on `mglData`]
`void Refill (mglDataA &`*dat*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*v*`, const char *`*opt*`="")` [Method on `mglData`]
`void mgl_data_refill_gr (HMGL` *gr*`, HMDT` *a*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *v*`, long` *sl*`, const char *`*opt*`)` [C function]

Fills by interpolated values of array *v* at the point {*x*, *y*, *z*}={`X[i], Y[j], Z[k]`} (or {*x*, *y*, *z*}={`X[i,j,k], Y[i,j,k], Z[i,j,k]`} if *x*, *y*, *z* are not 1d arrays), where `X,Y,Z` are equidistantly distributed in axis range and have the same sizes as array *dat*. If parameter *sl* is 0 or positive then changes will be applied only for slice *sl*.

`pde` RES *'ham' ini_re ini_im* [`dz=0.1 k0=100`] [MGL command]

`mglData PDE (const char *`*ham*`, const mglDataA &`*ini_re*`, const mglDataA &`*ini_im*`, mreal `*dz*`=0.1, mreal `*k0*`=100, const char *`*opt*`="")` [Method on `mglGraph`]

`HMDT mgl_pde_solve (HMGL` *gr*`, const char *`*ham*`, HCDT` *ini_re*`, HCDT` *ini_im*`, mreal` *dz*`, mreal` *k0*`, const char *`*opt*`)` [C function]

Solves equation du/dz = i*k0**ham*(p,q,x,y,z,|u|)[u], where p=-i/k0*d/dx, q=-i/k0*d/dy are pseudo-differential operators. Parameters *ini_re*, *ini_im* specify real and imaginary part of initial field distribution. Coordinates '`x`', '`y`', '`z`' are supposed to be normalized in axis range. Note, that really this ranges are increased by factor 3/2 for purpose of reducing reflection from boundaries. Parameter *dz* set the step along evolutionary coordinate z. At this moment, simplified form of function *ham* is supported – all "mixed" terms (like '`x*p`'->x*d/dx) are excluded. For example, in 2D case this function is effectively $ham = f(p,z) + g(x,z,u)$. However commutable combinations (like '`x*q`'->x*d/dy) are allowed. Here variable '`u`' is used for field amplitude `|u|`. This allow one solve nonlinear problems – for example, for nonlinear Shrodinger equation you may set `ham="p^2 + q^2 - u^2"`. You may specify imaginary part for wave absorption, like `ham = "p^2 + i*x*(x>0)"`, but only if dependence on variable '`i`' is linear (i.e. $ham = hre + i * him$). See Section 2.9.14 [PDE solving hints], page 131, for sample code and picture.

5 Widget classes

There are set of "window" classes for making a window with MathGL graphics: `mglWindow`, `mglFLTK`, `mglQT` and `mglGLUT` for whole window, `Fl_MathGL` and `QMathGL` as widgets. All these classes allow user to show, rotate, export, and change view of the plot using keyboard. Most of them (except `mglGLUT`) also have toolbar and menu for simplifying plot manipulation. All window classes have mostly the same set of functions derived from Section 5.1 [mglWnd class], page 239.

For drawing you can use: `NULL` pointer if you'll update plot manually, global callback function of type `int draw(HMGL gr, void *p)` or `int draw(mglGraph *gr)`, or instance of class derived from Section 5.2 [mglDraw class], page 241. Basically, this class have 2 main virtual methods:

```
class mglDraw
{
public:
    virtual int Draw(mglGraph *) { return 0; };
    virtual void Reload() {};
};
```

You should inherit yours class from `mglDraw` and re-implement one or both functions for drawing.

The window can be constructed using one of following classes (see Section 2.1.1 [Using MathGL window], page 8 for examples).

`mglFLTK (const char *`*title*`="MathGL")` [Constructor on `mglFLTK`]

`mglFLTK (int (*`*draw*`)(HMGL` *gr*`, void *`*p*`), const char *`*title*`="MathGL", void *`*par*`=NULL, void (*`*reload*`)(HMGL` *gr*`, void *`*p*`)=`*0*`)` [Constructor on `mglFLTK`]

`mglFLTK (int (*`*draw*`)(mglGraph *`*gr*`), const char *`*title*`="MathGL")` [Constructor on `mglFLTK`]

`mglFLTK (mglDraw *`*draw*`, const char *`*title*`="MathGL")` [Constructor on `mglFLTK`]

`HMGL mgl_create_graph_fltk (int (*`*draw*`)(HMGL` *gr*`, void *`*p*`), const char *`*title*`, void *`*par*`, void (*`*reload*`)(HMGL` *gr*`, void *`*p*`))` [C function]

Creates a FLTK-based window for plotting. Parameter *draw* sets a pointer to drawing function (this is the name of function) or instance of Section 5.2 [mglDraw class], page 241. There is support of a list of plots (frames). So as one can prepare a set of frames at first and redraw it fast later (but it requires more memory). Function should return positive number of frames for the list or zero if it will plot directly. Note, that *draw* can be `NULL` for displaying static bitmaps only (no animation or slides). Parameter *title* sets the title of the window. Parameter *par* contains pointer to data for the plotting function *draw*. FLTK-based windows is a bit faster than Qt ones, and provide better support of multi-threading.

`int RunThr ()` [Method on `mglFLTK`]

`int mgl_fltk_thr ()` [C function]

Run main loop for event handling in separate thread. Note, right now it work for FLTK windows only.

`mglQT (const char *title="MathGL")` [Constructor on `mglQT`]
`mglQT (int (*draw)(HMGL gr, void *p), const char *title="MathGL", void *par=NULL, void (*reload)(HMGL gr, void *p)=0)` [Constructor on `mglQT`]
`mglQT (int (*draw)(mglGraph *gr), const char *title="MathGL")` [Constructor on `mglQT`]
`mglQT (mglDraw *draw, const char *title="MathGL")` [Constructor on `mglQT`]
`HMGL mgl_create_graph_qt (int (*draw)(HMGL gr, void *p), const char *title, void *par, void (*reload)(HMGL gr, void *p))` [C function]

Creates a FLTK-based window for plotting. Parameter *draw* sets a pointer to drawing function (this is the name of function) or instance of Section 5.2 [mglDraw class], page 241. There is support of a list of plots (frames). So as one can prepare a set of frames at first and redraw it fast later (but it requires more memory). Function should return positive number of frames for the list or zero if it will plot directly. Note, that *draw* can be `NULL` for displaying static bitmaps only (no animation or slides). Parameter *title* sets the title of the window. Parameter *par* contains pointer to data for the plotting function *draw*.

`mglGLUT (const char *title="MathGL")` [Constructor on `mglGLUT`]
`mglGLUT (int (*draw)(HMGL gr, void *p), const char *title="MathGL", void *par=NULL, void (*reload)(HMGL gr, void *p)=0)` [Constructor on `mglGLUT`]
`mglGLUT (int (*draw)(mglGraph *gr), const char *title="MathGL")` [Constructor on `mglGLUT`]
`mglGLUT (mglDraw *draw, const char *title="MathGL")` [Constructor on `mglGLUT`]
`HMGL mgl_create_graph_glut (int (*draw)(HMGL gr, void *p), const char *title, void *par, void (*reload)(HMGL gr, void *p))` [C function]

Creates a GLUT-based window for plotting. Parameter *draw* sets a pointer to drawing function (this is the name of function) or instance of `mglDraw` class. There is support of a list of plots (frames). So as one can prepare a set of frames at first and redraw it fast later (but it requires more memory). Function should return positive number of frames for the list or zero if it will plot directly. Note, that *draw* can be `NULL` for displaying static bitmaps only (no animation or slides). Parameter *title* sets the title of the window. Parameter *par* contains pointer to data for the plotting function *draw*. GLUT-based windows are fastest one but there is no toolbar, and plot have some issues due to OpenGL limitations.

There are some keys handles for manipulating by the plot: 'a', 'd', 'w', 's' for the rotating; ',', '.' for viewing of the previous or next frames in the list; 'r' for the switching of transparency; 'f' for the switching of lightning; 'x' for hiding (closing) the window.

5.1 mglWnd class

This class is abstract class derived from mglGraph class (see Chapter 4 [MathGL core], page 158). It is defined in `#include <mgl2/wnd.h>` and provide base methods for handling window with MathGL graphics. Inherited classes are exist for QT and FLTK widget libraries: `mglQT` in `#include <mgl2/qt.h>`, `mglFLTK` in `#include <mgl2/fltk.h>`.

`int Run ()` [Method on `mglWnd`]
`int mgl_qt_run ()` [C function]

`int mgl_fltk_run ()` [C function]

Run main loop for event handling. Usually it should be called in a separate thread or as last function call in `main()`.

`void SetDrawFunc (int (*draw)(HMGL gr, void *p), void *par=NULL, void (*reload)(void *p)=NULL)` [Method on `mglWnd`]

`void SetDrawFunc (int (*draw)(mglGraph *gr))` [Method on `mglWnd`]

`void SetDrawFunc (mglDraw *obj)` [Method on `mglWnd`]

`void mgl_wnd_set_func (HMGL gr, int (*draw)(HMGL gr, void *p), void *par, void (*reload)(void *p))` [C function]

Set callback functions for drawing (*draw*) and data reloading (*reload*), or instance *obj* of a class derived from `mglDraw`.

`void SetClickFunc (void (*func)(HMGL gr, void *p))` [Method on `mglWnd`]

`void mgl_set_click_func (void (*func)(HMGL gr, void *p))` [C function]

Set callback function *func* which will be called on mouse click.

`void SetMutex(pthread_mutex_t *mutex)` [Method on `mglWnd`]

`void mgl_wnd_set_mutex(HMGL gr, pthread_mutex_t *mutex)` [C function]

Set external mutex for lock/unlock external calculations by widget. This functions is called automatically at using Section 5.2 [mglDraw class], page 241.

`void ToggleAlpha ()` [Method on `mglWnd`]

`void mgl_wnd_toggle_alpha (HMGL gr)` [C function]

Switch on/off transparency but do not overwrite switches in user drawing function.

`void ToggleLight ()` [Method on `mglWnd`]

`void mgl_wnd_toggle_light (HMGL gr)` [C function]

Switch on/off lighting but do not overwrite switches in user drawing function.

`void ToggleRotate ()` [Method on `mglWnd`]

`void mgl_wnd_toggle_rotate (HMGL gr)` [C function]

Switch on/off rotation by mouse. Usually, left button is used for rotation, middle button for shift, right button for zoom/perspective.

`void ToggleZoom ()` [Method on `mglWnd`]

`void mgl_wnd_toggle_zoom (HMGL gr)` [C function]

Switch on/off zooming by mouse. Just select rectangular region by mouse and it will be zoomed in.

`void ToggleNo ()` [Method on `mglWnd`]

`void mgl_wnd_toggle_no (HMGL gr)` [C function]

Switch off all zooming and rotation and restore initial state.

`void Update ()` [Method on `mglWnd`]

`void mgl_wnd_update (HMGL gr)` [C function]

Update window contents. This is very useful function for manual updating the plot while long calculation was running in parallel thread.

`void ReLoad ()` [Method on `mglWnd`]
`void mgl_wnd_reload (HMGL` *gr*`)` [C function]
Reload user data and update picture. This function also update number of frames which drawing function can create.

`void Adjust ()` [Method on `mglWnd`]
`void mgl_wnd_adjust (HMGL` *gr*`)` [C function]
Adjust size of bitmap to window size.

`void NextFrame ()` [Method on `mglWnd`]
`void mgl_wnd_next_frame (HMGL` *gr*`)` [C function]
Show next frame if one.

`void PrevFrame ()` [Method on `mglWnd`]
`void mgl_wnd_prev_frame (HMGL` *gr*`)` [C function]
Show previous frame if one.

`void Animation ()` [Method on `mglWnd`]
`void mgl_wnd_animation (HMGL` *gr*`)` [C function]
Run/stop slideshow (animation) of frames.

`void SetDelay (double` *dt*`)` [Method on `mglWnd`]
`void mgl_wnd_set_delay (HMGL` *gr*`, double` *dt*`)` [C function]
Sets delay for animation in seconds. Default value is 1 sec.

`double GetDelay ()` [Method on `mglWnd`]
`double mgl_wnd_get_delay (HMGL` *gr*`)` [C function]
Gets delay for animation in seconds.

`void Setup (bool` *clfupd*`=true, bool` *showpos*`=false)` [Method on `mglWnd`]
`void mgl_setup_window (HMGL` *gr*`, bool` *clfupd*`, bool` *showpos*`)` [C function]
Enable/disable flags for:

- clearing plot before Update();
- showing the last mouse click position in the widget.

`mglPoint LastMousePos ()` [Method on `mglWnd`]
`void mgl_get_last_mouse_pos (HMGL` *gr*`, mreal *`*x*`, mreal *`*y*`, mreal *`*z*`)` [C function]
Gets last position of mouse click.

5.2 mglDraw class

This class provide base functionality for callback drawing and running calculation in separate thread. It is defined in `#include <mgl2/wnd.h>`. You should make inherited class and implement virtual functions if you need it.

`int Draw (mglGraph *`*gr*`)` [Virtual method on `mglDraw`]
This is callback drawing function, which will be called when any redrawing is required for the window. There is support of a list of plots (frames). So as one can prepare a set of frames at first and redraw it fast later (but it requires more memory). Function should return positive number of frames for the list or zero if it will plot directly.

`void Reload ()` [Virtual method on `mglDraw`]
This is callback function, which will be called if user press menu or toolbutton to reload data.

`void Click ()` [Virtual method on `mglDraw`]
This is callback function, which will be called if user click mouse.

`void Calc ()` [Virtual method on `mglDraw`]
This is callback function, which will be called if user start calculations in separate thread by calling `mglDraw::Run()` function. It should periodically call `mglDraw::Check()` function to check if calculations should be paused.

`void Run ()` [Method on `mglDraw`]
Runs `mglDraw::Calc()` function in separate thread. It also initialize `mglDraw::thr` variable and unlock `mglDraw::mutex`. Function is present only if FLTK support for widgets was enabled.

`void Cancel ()` [Method on `mglDraw`]
Cancels thread with calculations. Function is present only if FLTK support for widgets was enabled.

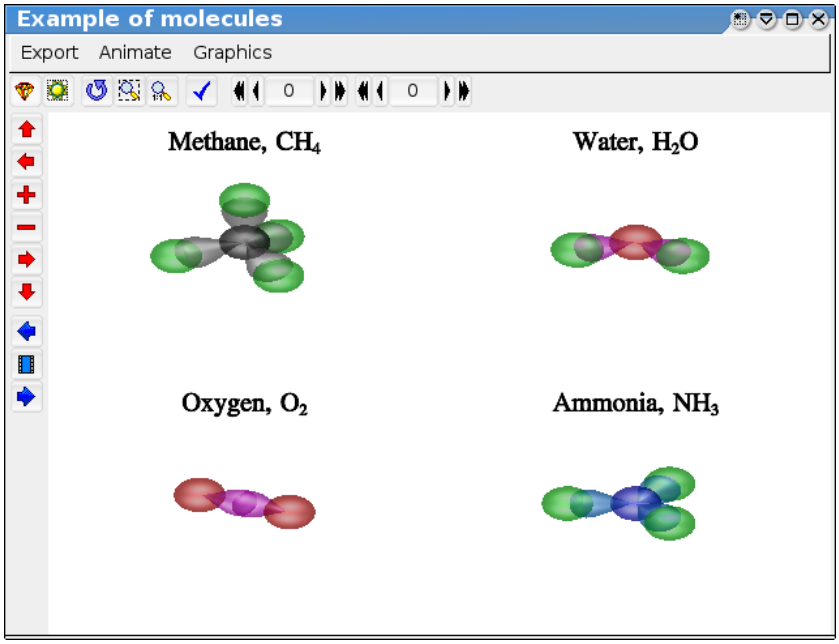
`void Pause ()` [Method on `mglDraw`]
Pauses thread with calculations by locking `mglDraw::mutex`. You should call `mglDraw::Continue()` to continue calculations. Function is present only if FLTK support for widgets was enabled.

`void Continue ()` [Method on `mglDraw`]
Continues calculations by unlocking `mglDraw::mutex`. Function is present only if FLTK support for widgets was enabled.

`void Continue ()` [Method on `mglDraw`]
Checks if calculations should be paused and pause it. Function is present only if FLTK support for widgets was enabled.

5.3 Fl_MathGL class

Class is FLTK widget which display MathGL graphics. It is defined in `#include <mgl2/fltk.h>`.



`void set_draw (int (*`*draw*`)(HMGL` *gr*`, void *`*p*`))` [Method on `Fl_MathGL`]
`void set_draw (int (*`*draw*`)(mglGraph *`*gr*`))` [Method on `Fl_MathGL`]
`void set_draw (mglDraw *`*draw*`)` [Method on `Fl_MathGL`]
Sets drawing function as global function or as one from a class `mglDraw`. There is support of a list of plots (frames). So as one can prepare a set of frames at first and redraw it fast later (but it requires more memory). Function should return positive number of frames for the list or zero if it will plot directly. Parameter *par* contains pointer to data for the plotting function *draw*.

`void update ()` [Method on `Fl_MathGL`]
Update (redraw) plot.

`void set_angle (mreal` *t*`, mreal` *p*`)` [Method on `Fl_MathGL`]
Set angles for additional plot rotation

`void set_flag (int` *f*`)` [Method on `Fl_MathGL`]
Set bitwise flags for general state (1-Alpha, 2-Light)

`void set_state (bool` *r*`, bool` *z*`)` [Method on `Fl_MathGL`]
Set flags for handling mouse: *z*=`true` allow zooming, *r*=`true` allow rotation/shifting/perspective and so on.

`void set_zoom (mreal` *X1*`, mreal` *Y1*`, mreal` *X2*`, mreal` *Y2*`)` [Method on `Fl_MathGL`]
Set zoom in/out region

`void get_zoom (mreal *`*X1*`, mreal *`*Y1*`, mreal *`*X2*`, mreal *`*Y2*`)` [Method on `Fl_MathGL`]
Get zoom in/out region

`void set_popup (const Fl_Menu_Item *`*pmenu*`, Fl_Widget *`*w*`, void *`*v*`)` [Method on `Fl_MathGL`]
Set popup menu pointer

`void set_graph (HMGL` *gr*`)` [Method on `Fl_MathGL`]
`void set_graph (mglGraph *`*gr*`)` [Method on `Fl_MathGL`]
Set new grapher instead of built-in one. Note that Fl_MathGL will automatically delete this object at destruction or at new `set_graph()` call.

`HMGL get_graph ()` [Method on `Fl_MathGL`]
Get pointer to grapher.

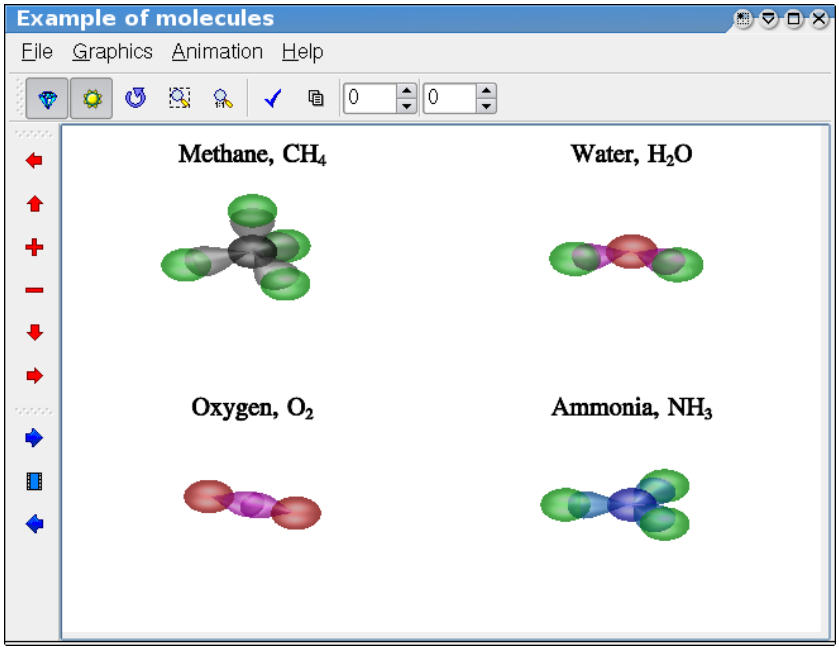
`void adjust ()` [Method on `Fl_MathGL`]
Adjust image size to fit whole widget.

`Fl_Valuator * tet_val` [Fl_MathGL option of `Fl_MathGL`]
Pointer to external tet-angle validator.

`Fl_Valuator * phi_val` [Fl_MathGL option of `Fl_MathGL`]
Pointer to external phi-angle validator.

5.4 QMathGL class

Class is Qt widget which display MathGL graphics. It is defined in `#include <mgl2/qt.h>`.



`void setDraw (mglDraw *`*dr*`)` [Method on `QMathGL`]
Sets drawing functions from a class inherited from `mglDraw`.

`void setDraw (int (*`*draw*`)(mglBase *`*gr*`, void *`*p*`), void *`*par*`=NULL)` [Method on `QMathGL`]
`void setDraw (int (*`*draw*`)(mglGraph *`*gr*`))` [Method on `QMathGL`]
Sets the drawing function *draw*. There is support of a list of plots (frames). So as one can prepare a set of frames at first and redraw it fast later (but it requires more memory). Function should return positive number of frames for the list or zero if it will plot directly. Parameter *par* contains pointer to data for the plotting function *draw*.

`void setGraph (HMGL` *gr*`)` [Method on `QMathGL`]
`void setGraph (mglGraph *`*gr*`)` [Method on `QMathGL`]
Set pointer to external grapher (instead of built-in one). Note that QMathGL will automatically delete this object at destruction or at new `setGraph()` call.

`HMGL getGraph ()` [Method on `QMathGL`]
Get pointer to grapher.

`void setPopup (QMenu *`*p*`)` [Method on `QMathGL`]
Set popup menu pointer.

`void setSize (int` *w*`, int` *h*`)` [Method on `QMathGL`]
Set widget/picture sizes

`double getRatio ()` [Method on `QMathGL`]
Return aspect ratio of the picture.

`int getPer ()` [Method on `QMathGL`]
Get perspective value in percents.

`int getPhi ()` [Method on `QMathGL`]
Get Phi-angle value in degrees.

`int getTet ()` [Method on `QMathGL`]
Get Theta-angle value in degrees.

`bool getAlpha ()` [Method on `QMathGL`]
Get transparency state.

`bool getLight ()` [Method on `QMathGL`]
Get lightning state.

`bool getZoom ()` [Method on `QMathGL`]
Get mouse zooming state.

`bool getRotate ()` [Method on `QMathGL`]
Get mouse rotation state.

`void refresh ()` [Slot on `QMathGL`]
Redraw saved bitmap without executing drawing function.

`void update ()` [Slot on `QMathGL`]
Update picture by executing drawing function.

`void copy ()` [Slot on `QMathGL`]
Copy graphics to clipboard.

`void copyClickCoor ()` [Slot on `QMathGL`]
Copy coordinates of click (as text).

`void print ()` [Slot on `QMathGL`]
Print current picture.

`void stop ()` [Slot on `QMathGL`]
Send signal to stop drawing.

`void adjust ()` [Slot on `QMathGL`]
Adjust image size to fit whole widget.

`void nextSlide ()` [Slot on `QMathGL`]
Show next slide.

`void prevSlide ()` [Slot on `QMathGL`]
Show previous slide.

`void animation (bool` *st*`=true)` [Slot on `QMathGL`]
Start/stop animation.

`void setPer (int` *val*`)` [Slot on `QMathGL`]
Set perspective value.

`void setPhi (int` *val*`)` [Slot on `QMathGL`]
Set Phi-angle value.

`void setTet (int` *val*`)` [Slot on `QMathGL`]
Set Theta-angle value.

`void setAlpha (bool` *val*`)` [Slot on `QMathGL`]
Switch on/off transparency.

`void setLight (bool` *val*`)` [Slot on `QMathGL`]
Switch on/off lightning.

`void setGrid (bool` *val*`)` [Slot on `QMathGL`]
Switch on/off drawing of grid for absolute coordinates.

`void setZoom (bool` *val*`)` [Slot on `QMathGL`]
Switch on/off mouse zooming.

`void setRotate (bool` *val*`)` [Slot on `QMathGL`]
Switch on/off mouse rotation.

`void zoomIn ()` [Slot on `QMathGL`]
Zoom in graphics.

`void zoomOut ()` [Slot on `QMathGL`]
Zoom out graphics.

`void shiftLeft ()` [Slot on `QMathGL`]
Shift graphics to left direction.

`void shiftRight ()` [Slot on `QMathGL`]
Shift graphics to right direction.

`void shiftUp ()` [Slot on `QMathGL`]
Shift graphics to up direction.

`void shiftDown ()` [Slot on `QMathGL`]
Shift graphics to down direction.

`void restore ()` [Slot on `QMathGL`]
Restore zoom and rotation to default values.

`void exportPNG (QString` *fname*`="")` [Slot on `QMathGL`]
Export current picture to PNG file.

`void exportPNGs (QString` *fname*`="")` [Slot on `QMathGL`]
Export current picture to PNG file (no transparency).

`void exportJPG (QString` *fname*`="")` [Slot on `QMathGL`]
Export current picture to JPEG file.

`void exportBPS (QString` *fname*`="")` [Slot on `QMathGL`]
Export current picture to bitmap EPS file.

`void exportEPS (QString` *fname*`="")` [Slot on `QMathGL`]
Export current picture to vector EPS file.

`void exportSVG (QString` *fname*`="")` [Slot on `QMathGL`]
Export current picture to SVG file.

`void exportGIF (QString` *fname*`="")` [Slot on `QMathGL`]
Export current picture to GIF file.

`void exportTEX (QString` *fname*`="")` [Slot on `QMathGL`]
Export current picture to LaTeX/Tikz file.

`void exportTGA (QString` *fname*`="")` [Slot on `QMathGL`]
Export current picture to TGA file.

`void exportXYZ (QString` *fname*`="")` [Slot on `QMathGL`]
Export current picture to XYZ/XYZL/XYZF file.

`void exportOBJ (QString` *fname*`="")` [Slot on `QMathGL`]
Export current picture to OBJ/MTL file.

`void exportSTL (QString` *fname*`="")` [Slot on `QMathGL`]
Export current picture to STL file.

`void exportOFF (QString` *fname*`="")` [Slot on `QMathGL`]
Export current picture to OFF file.

`voidsetUsePrimitives (bool` *use*`)` [Slot on `QMathGL`]
Enable using list of primitives for frames. This allows frames transformation/zoom but requires much more memory. Default value is `true`.

`void setMGLFont (QString` *path*`)` [Slot on `QMathGL`]
Restore (*path*="") or load font for graphics.

`void about ()` [Slot on `QMathGL`]
Show about information.

`void aboutQt ()` [Slot on `QMathGL`]
Show information about Qt version.

`void phiChanged (int` *val*`)` [Signal on `QMathGL`]
Phi angle changed (by mouse or by toolbar).

`void tetChanged (int` *val*`)` [Signal on `QMathGL`]
Tet angle changed (by mouse or by toolbar).

`void perChanged (int` *val*`)` [Signal on `QMathGL`]
Perspective changed (by mouse or by toolbar).

`void alphaChanged (bool` *val*`)` [Signal on `QMathGL`]
Transparency changed (by toolbar).

`void lightChanged (bool` *val*`)` [Signal on `QMathGL`]
Lighting changed (by toolbar).

`void gridChanged (bool` *val*`)` [Signal on `QMathGL`]
Grid drawing changed (by toolbar).

`void zoomChanged (bool` *val*`)` [Signal on `QMathGL`]
Zooming changed (by toolbar).

`void rotateChanged (bool` *val*`)` [Signal on `QMathGL`]
Rotation changed (by toolbar).

`void mouseClick (mreal` *x*, `mreal` *y*, `mreal` *z*`)` [Signal on `QMathGL`]
Mouse click take place at position {x,y,z}.

`void frameChanged (int` *val*`)` [Signal on `QMathGL`]
Need another frame to show.

`void showWarn (QString` *warn*`)` [Signal on `QMathGL`]
Need to show warning.

`void posChanged (QString` *pos*`)` [Signal on `QMathGL`]
Position of mouse click is changed.

`void objChanged (int` *id*`)` [Signal on `QMathGL`]
Object id is changed (due to mouse click).

`void refreshData ()` [Signal on `QMathGL`]
Data can be changed (drawing is finished).

`QString appName` [QMathGL option of `QMathGL`]
Application name for message boxes.

`bool autoResize` [QMathGL option of `QMathGL`]
Allow auto resizing (default is false).

5.5 wxMathGL class

Class is WX widget which display MathGL graphics. It is defined in `#include <mgl2/wx.h>`.

`void SetDraw (mglDraw *`*dr*`)` [Method on `wxMathGL`]
Sets drawing functions from a class inherited from `mglDraw`.

`void SetDraw (int (*`*draw*`)(mglBase *`*gr*`, void *`*p*`), void *`*par*`=NULL)` [Method on `wxMathGL`]
`void SetDraw (int (*`*draw*`)(mglGraph *`*gr*`))` [Method on `wxMathGL`]
Sets the drawing function *draw*. There is support of a list of plots (frames). So as one can prepare a set of frames at first and redraw it fast later (but it requires more memory). Function should return positive number of frames for the list or zero if it will plot directly. Parameter *par* contains pointer to data for the plotting function *draw*.

`void SetGraph (HMGL` *gr*`)` [Method on `wxMathGL`]
`void SetGraph (mglGraph *`*gr*`)` [Method on `wxMathGL`]
Set pointer to external grapher (instead of built-in one). Note that wxMathGL will automatically delete this object at destruction or at new `setGraph()` call.

`HMGL GetGraph ()` [Method on `wxMathGL`]
Get pointer to grapher.

`void SetPopup (wxMenu *`*p*`)` [Method on `wxMathGL`]
Set popup menu pointer.

`void SetSize (int` *w*`, int` *h*`)` [Method on `wxMathGL`]
Set widget/picture sizes

`double GetRatio ()` [Method on `wxMathGL`]
Return aspect ratio of the picture.

`int GetPer ()` [Method on `wxMathGL`]
Get perspective value in percents.

`int GetPhi ()` [Method on `wxMathGL`]
Get Phi-angle value in degrees.

`int GetTet ()` [Method on `wxMathGL`]
Get Theta-angle value in degrees.

`bool GetAlpha ()` [Method on `wxMathGL`]
Get transparency state.

`bool GetLight ()` [Method on `wxMathGL`]
Get lightning state.

`bool GetZoom ()` [Method on `wxMathGL`]
Get mouse zooming state.

`bool GetRotate ()` [Method on `wxMathGL`]
Get mouse rotation state.

`void Repaint ()` [Method on `wxMathGL`]
Redraw saved bitmap without executing drawing function.

`void Update ()` [Method on `wxMathGL`]
Update picture by executing drawing function.

`void Copy ()` [Method on `wxMathGL`]
Copy graphics to clipboard.

`void Print ()` [Method on `wxMathGL`]
Print current picture.

`void Adjust ()` [Method on `wxMathGL`]
Adjust image size to fit whole widget.

`void NextSlide ()` [Method on `wxMathGL`]
Show next slide.

`void PrevSlide ()` [Method on `wxMathGL`]
Show previous slide.

`void Animation (bool` *st*`=true)` [Method on `wxMathGL`]
Start/stop animation.

`void SetPer (int` *val*`)` [Method on `wxMathGL`]
Set perspective value.

`void SetPhi (int` *val*`)` [Method on `wxMathGL`]
Set Phi-angle value.

`void SetTet (int` *val*`)` [Method on `wxMathGL`]
Set Theta-angle value.

`void SetAlpha (bool` *val*`)` [Method on `wxMathGL`]
Switch on/off transparency.

`void SetLight (bool` *val*`)` [Method on `wxMathGL`]
Switch on/off lightning.

`void SetZoom (bool` *val*`)` [Method on `wxMathGL`]
Switch on/off mouse zooming.

`void SetRotate (bool val)` [Method on `wxMathGL`]
Switch on/off mouse rotation.

`void ZoomIn ()` [Method on `wxMathGL`]
Zoom in graphics.

`void ZoomOut ()` [Method on `wxMathGL`]
Zoom out graphics.

`void ShiftLeft ()` [Method on `wxMathGL`]
Shift graphics to left direction.

`void ShiftRight ()` [Method on `wxMathGL`]
Shift graphics to right direction.

`void ShiftUp ()` [Method on `wxMathGL`]
Shift graphics to up direction.

`void ShiftDown ()` [Method on `wxMathGL`]
Shift graphics to down direction.

`void Restore ()` [Method on `wxMathGL`]
Restore zoom and rotation to default values.

`void About ()` [Method on `wxMathGL`]
Show about information.

`void ExportPNG (QString` *fname*`="")` [Method on `wxMathGL`]
Export current picture to PNG file.

`void ExportPNGs (QString` *fname*`="")` [Method on `wxMathGL`]
Export current picture to PNG file (no transparency).

`void ExportJPG (QString` *fname*`="")` [Method on `wxMathGL`]
Export current picture to JPEG file.

`void ExportBPS (QString` *fname*`="")` [Method on `wxMathGL`]
Export current picture to bitmap EPS file.

`void ExportEPS (QString` *fname*`="")` [Method on `wxMathGL`]
Export current picture to vector EPS file.

`void ExportSVG (QString` *fname*`="")` [Method on `wxMathGL`]
Export current picture to SVG file.

6 Data processing

This chapter describe classes `mglData` and `mglDataC` for working with data arrays of real and complex numbers. Both classes are derived from abstract class `mglDataA`, and can be used as arguments of any plotting functions (see Chapter 4 [MathGL core], page 158). These classes are defined in `#include <mgl2/data.h>` and `#include <mgl2/datac.h>` correspondingly. The classes have mostly the same set of functions for easy and safe allocation, resizing, loading, saving, modifying of data arrays. Also it can numerically differentiate and integrate data, interpolate, fill data by formula and so on. Classes support data with dimensions up to 3 (like function of 3 variables – x,y,z). The internal representation of numbers is mreal (or dual=std::complex<mreal> for `mglDataC`), which can be configured as float or double by selecting option `--enable-double` at the MathGL configuring (see Section 1.3 [Installation], page 2). Float type have smaller size in memory and usually it has enough precision in plotting purposes. However, double type provide high accuracy what can be important for time-axis, for example. Data arrays are denoted by Small Caps (like DAT) if it can be (re-)created by MGL commands.

6.1 Public variables

`mreal * a` [Variable of `mglData`]
`dual * a` [Variable of `mglDataC`]
Data array itself. The flat data representation is used. For example, matrix [nx x ny] is presented as flat (1d-) array with length nx*ny. The element with indexes {i, j, k} is a[i+nx*j+nx*ny*k] (indexes are zero based).

`long nx` [Variable of `mglData`]
`long nx` [Variable of `mglDataC`]
Number of points in 1st dimensions ('x' dimension).

`long ny` [Variable of `mglData`]
`long ny` [Variable of `mglDataC`]
Number of points in 2nd dimensions ('y' dimension).

`long nz` [Variable of `mglData`]
`long nz` [Variable of `mglDataC`]
Number of points in 3d dimensions ('z' dimension).

`std::string id` [Variable of `mglData`]
`std::string id` [Variable of `mglDataC`]
Names of column (or slice if nz>1) – one character per column.

`bool link` [Variable of `mglData`]
`bool link` [Variable of `mglDataC`]
Flag to use external data, i.e. don't delete it.

`std::wstring s` [Variable of `mglDataA`]
Name of data. It is used in parsing of MGL scripts.

`bool temp` [Variable of `mglDataA`]
Flag of temporary variable, which should be deleted.

`void (*)(void *) func` [Variable of `mglDataA`]
Pointer to callback function which will be called at destroying.

`void * o` [Variable of `mglDataA`]
Pointer to object for callback function.

`mreal GetVal (long i)` [Method on `mglData`]
`mreal GetVal (long i)` [Method on `mglDataC`]
`void SetVal (mreal val, long i)` [Method on `mglData`]
`void SetVal (mreal val, long i)` [Method on `mglDataC`]
Gets or sets the value in by "flat" index *i* without border checking. Index *i* should be in range [0, nx*ny*nz-1].

`long GetNx ()` [Method on `mglDataA`]
`long GetNy ()` [Method on `mglDataA`]
`long GetNz ()` [Method on `mglDataA`]
`long mgl_data_get_nx (HCDT dat)` [C function]
`long mgl_data_get_ny (HCDT dat)` [C function]
`long mgl_data_get_nz (HCDT dat)` [C function]
Gets the x-, y-, z-size of the data.

`mreal mgl_data_get_value (HCDT dat, int i, int j, int k)` [C function]
`dual mgl_datac_get_value (HCDT dat, int i, int j, int k)` [C function]
`mreal * mgl_data_value (HMDT dat, int i, int j, int k)` [C function]
`dual * mgl_datac_value (HADT dat, int i, int j, int k)` [C function]
`void mgl_data_set_value (HMDT dat, mreal v, int i, int j, int k)` [C function]
`void mgl_datac_set_value (HADT dat, dual v, int i, int j, int k)` [C function]
Gets or sets the value in specified cell of the data with border checking.

`const mreal * mgl_data_data (HCDT dat)` [C function]
`const dual * mgl_datac_data (HCDT dat)` [C function]
Returns pointer to internal data array.

`void mgl_data_set_func (mglDataA *dat, void (*func)(void *), void *par)` [C function only]
Set pointer to callback function which will be called at destroying.

`void mgl_data_set_name (mglDataA *dat, const char *name)` [C function]
`void mgl_data_set_name_w (mglDataA *dat, const wchar_t *name)` [C function]
Set name of data, which used in parsing of MGL scripts.

6.2 Data constructor

`new` DAT [`nx=1` *'eq'*] [MGL command]
`new` DAT `nx ny` [*'eq'*] [MGL command]
`new` DAT `nx ny nz` [*'eq'*] [MGL command]
`mglData (int mx=1, int my=1, int mz=1)` [Constructor on `mglData`]
`mglDataC (int mx=1, int my=1, int mz=1)` [Constructor on `mglDataC`]

`HMDT mgl_create_data ()` [C function]
`HMDT mgl_create_data_size (int` *mx*`, int` *my*`, int` *mz*`)` [C function]
`HADT mgl_create_datac ()` [C function]
`HADT mgl_create_datac_size (int` *mx*`, int` *my*`, int` *mz*`)` [C function]
Default constructor. Allocates the memory for data array and initializes it by zero. If string *eq* is specified then data will be filled by corresponding formula as in [fill], page 259.

`copy` DAT *dat2* ['*eq*'=''] [MGL command]
`copy` DAT `val` [MGL command]
`mglData (const mglDataA &`*dat2*`)` [Constructor on `mglData`]
`mglData (const mglDataA *`*dat2*`)` [Constructor on `mglData`]
`mglData (int` *size*`, const float *`*dat2*`)` [Constructor on `mglData`]
`mglData (int` *size*`, int` *cols*`, const float *`*dat2*`)` [Constructor on `mglData`]
`mglData (int` *size*`, const double *`*dat2*`)` [Constructor on `mglData`]
`mglData (int` *size*`, int` *cols*`, const double *`*dat2*`)` [Constructor on `mglData`]
`mglData (const double *`*dat2*`, int` *size*`)` [Constructor on `mglData`]
`mglData (const double *`*dat2*`, int` *size*`, int` *cols*`)` [Constructor on `mglData`]
`mglDataC (const mglDataA &`*dat2*`)` [Constructor on `mglDataC`]
`mglDataC (const mglDataA *`*dat2*`)` [Constructor on `mglDataC`]
`mglDataC (int` *size*`, const float *`*dat2*`)` [Constructor on `mglDataC`]
`mglDataC (int` *size*`, int` *cols*`, const float *`*dat2*`)` [Constructor on `mglDataC`]
`mglDataC (int` *size*`, const double *`*dat2*`)` [Constructor on `mglDataC`]
`mglDataC (int` *size*`, int` *cols*`, const double *`*dat2*`)` [Constructor on `mglDataC`]
`mglDataC (int` *size*`, const dual *`*dat2*`)` [Constructor on `mglDataC`]
`mglDataC (int` *size*`, int` *cols*`, const dual *`*dat2*`)` [Constructor on `mglDataC`]
Copy constructor. Allocates the memory for data array and copy values from other array. At this, if parameter *eq* is specified then the data will be modified by corresponding formula similarly to [fill], page 259.

`read` DAT *'fname'* [MGL command]
`mglData (const char *`*fname*`)` [Constructor on `mglData`]
`mglDataC (const char *`*fname*`)` [Constructor on `mglDataC`]
`HMDT mgl_create_data_file (const char *`*fname*`)` [C function]
`HADT mgl_create_datac_file (const char *`*fname*`)` [C function]
Reads data from tab-separated text file with auto determining sizes of the data.

`delete` *dat* [MGL command]
`~mglData ()` [Destructor on `mglData`]
`void mgl_delete_data (HMDT` *dat*`)` [C function]
`~mglDataC ()` [Destructor on `mglDataC`]
`void mgl_delete_datac (HADT` *dat*`)` [C function]
Deletes the instance of class mglData.

6.3 Data resizing

`new` DAT [`nx=1 ny=1 nz=1`] [MGL command]
`void Create (int` *mx*`=1, int` *my*`=1, int` *mz*`=1)` [Method on `mglData`]

`void Create (int` *mx*`, int` *my*`=1, int` *mz*`=1)` [Method on `mglDataC`]
`void mgl_data_create (HMDT` *dat*`, int` *mx*`, int` *my*`, int` *mz*`)` [C function]
`void mgl_datac_create (HADT` *dat*`, int` *mx*`, int` *my*`, int` *mz*`)` [C function]
Creates or recreates the array with specified size and fills it by zero. This function does nothing if one of parameters *mx*, *my*, *mz* is zero or negative.

`rearrange` *dat* `mx [my=0 mz=0]` [MGL command]
`void Rearrange (int` *mx*`, int` *my*`=0, int` *mz*`=0)` [Method on `mglData`]
`void Rearrange (int` *mx*`, int` *my*`=0, int` *mz*`=0)` [Method on `mglDataC`]
`void mgl_data_rearrange (HMDT` *dat*`, int` *mx*`, int` *my*`, int` *mz*`)` [C function]
`void mgl_datac_rearrange (HADT` *dat*`, int` *mx*`, int` *my*`, int` *mz*`)` [C function]
Rearrange dimensions without changing data array so that resulting sizes should be *mx***my***mz* < nx*ny*nz. If some of parameter *my* or *mz* are zero then it will be selected to optimal fill of data array. For example, if *my*=0 then it will be change to *my*=nx*ny*nz/*mx* and *mz*=1.

`transpose` *dat* `['dim'='yxz']` [MGL command]
`void Transpose (const char *`*dim*`="yx")` [Method on `mglData`]
`void Transpose (const char *`*dim*`="yx")` [Method on `mglDataC`]
`void mgl_data_transpose (HMDT` *dat*`, const char *`*dim*`)` [C function]
`void mgl_datac_transpose (HADT` *dat*`, const char *`*dim*`)` [C function]
Transposes (shift order of) dimensions of the data. New order of dimensions is specified in string *dim*. This function can be useful also after reading of one-dimensional data.

`extend` *dat* `n1 [n2=0]` [MGL command]
`void Extend (int` *n1*`, int` *n2*`=0)` [Method on `mglData`]
`void Extend (int` *n1*`, int` *n2*`=0)` [Method on `mglDataC`]
`void mgl_data_extend (HMDT` *dat*`, int` *n1*`, int` *n2*`)` [C function]
`void mgl_datac_extend (HADT` *dat*`, int` *n1*`, int` *n2*`)` [C function]
Increase the dimensions of the data by inserting new (|*n1*|+1)-th slices after (for *n1*>0) or before (for *n1*<0) of existed one. It is possible to insert 2 dimensions simultaneously for 1d data by using parameter *n2*. Data to new slices is copy from existed one. For example, for *n1*>0 new array will be $a^{new}_{ij} = a^{old}_{i}$ where j=0...*n1*. Correspondingly, for *n1*<0 new array will be $a^{new}_{ij} = a^{old}_{j}$ where i=0...|*n1*|.

`squeeze` *dat* `rx [ry=1 rz=1 sm=off]` [MGL command]
`void Squeeze (int` *rx*`, int` *ry*`=1, int` *rz*`=1, bool` *smooth*`=false)` [Method on `mglData`]
`void Squeeze (int` *rx*`, int` *ry*`=1, int` *rz*`=1, bool` *smooth*`=false)` [Method on `mglDataC`]
`void mgl_data_squeeze (HMDT` *dat*`, int` *rx*`, int` *ry*`, int` *rz*`, int` *smooth*`)` [C function]
`void mgl_datac_squeeze (HADT` *dat*`, int` *rx*`, int` *ry*`, int` *rz*`, int` *smooth*`)` [C function]
Reduces the data size by excluding data elements which indexes are not divisible by *rx*, *ry*, *rz* correspondingly. Parameter *smooth* set to use smoothing (i.e. $a_{out}[i] = \sum_{j=i,i+r} a[j]/r$) or not (i.e. $a_{out}[i] = a[j*r]$).

`crop` *dat* `n1 n2` *'dir'* [MGL command]
`void Crop (int` *n1*`, int` *n2*`, char` *dir*`='x')` [Method on `mglData`]
`void Crop (int` *n1*`, int` *n2*`, char` *dir*`='x')` [Method on `mglDataC`]
`void mgl_data_crop (HMDT` *dat*`, int` *n1*`, int` *n2*`, char` *dir*`)` [C function]
`void mgl_datac_crop (HADT` *dat*`, int` *n1*`, int` *n2*`, char` *dir*`)` [C function]
Cuts off edges of the data *i*<*n1* and *i*>*n2* if *n2*>0 or *i*>`n[xyz]`-*n2* if *n2*<=0 along direction *dir*.

`insert` *dat 'dir'* [`pos=off num=0`] [MGL command]
`void Insert (char` *dir*`, int` *pos*`=0, int` *num*`=1)` [Method on `mglData`]
`void Insert (char` *dir*`, int` *pos*`=0, int` *num*`=1)` [Method on `mglDataC`]
`void mgl_data_insert (HMDT` *dat*`, char` *dir*`, int` *pos*`, char` *num*`)` [C function]
`void mgl_datac_insert (HADT` *dat*`, char` *dir*`, int` *pos*`, char` *num*`)` [C function]
Insert *num* slices along *dir*-direction at position *pos* and fill it by zeros.

`delete` *dat 'dir'* [`pos=off num=0`] [MGL command]
`void Delete (char` *dir*`, int` *pos*`=0, int` *num*`=1)` [Method on `mglData`]
`void Delete (char` *dir*`, int` *pos*`=0, int` *num*`=1)` [Method on `mglDataC`]
`void mgl_data_delete (HMDT` *dat*`, char` *dir*`, int` *pos*`, char` *num*`)` [C function]
`void mgl_datac_delete (HADT` *dat*`, char` *dir*`, int` *pos*`, char` *num*`)` [C function]
Delete *num* slices along *dir*-direction at position *pos*.

`sort` *dat* `idx` [`idy=-1`] [MGL command]
`void Sort (lond` *idx*`, long` *idy*`=-1)` [Method on `mglData`]
`void mgl_data_sort (HMDT` *dat*`, lond` *idx*`, long` *idy*`)` [C function]
Sort data rows (or slices in 3D case) by values of specified column *idx* (or cell {*idx*,*idy*} for 3D case). Note, this function is not thread safe!

`clean` *dat* `idx` [MGL command]
`void Clean (lond` *idx*`)` [Method on `mglData`]
`void mgl_data_clean (HMDT` *dat*`, lond` *idx*`)` [C function]
Delete rows which values are equal to next row for given column *idx*.

`join` *dat vdat* [*v2dat ...*] [MGL command]
`void Join (const mglDataA &`*vdat*`)` [Method on `mglData`]
`void Join (const mglDataA &`*vdat*`)` [Method on `mglDataC`]
`void mgl_data_join (HMDT` *dat*`, HCDT` *vdat*`)` [C function]
`void mgl_datac_join (HADT` *dat*`, HCDT` *vdat*`)` [C function]
Join data cells from *vdat* to *dat*. At this, function increase *dat* sizes according following: z-size for data arrays arrays with equal x-,y-sizes; or y-size for data arrays with equal x-sizes; or x-size otherwise.

6.4 Data filling

`list` DAT `v1 ...` [MGL command]
Creates new variable with name *dat* and fills it by numeric values of command arguments `v1 ...`. Command can create one-dimensional and two-dimensional arrays with arbitrary values. For creating 2d array the user should use delimiter '`|`' which

means that the following values lie in next row. Array sizes are [maximal of row sizes * number of rows]. For example, command `list 1 | 2 3` creates the array [1 0; 2 3]. Note, that the maximal number of arguments is 1000.

`list` DAT *d1 ...* [MGL command]
Creates new variable with name *dat* and fills it by data values of arrays of command arguments *d1 ....* Command can create two-dimensional or three-dimensional (if arrays in arguments are 2d arrays) arrays with arbitrary values. Minor dimensions of all arrays in arguments should be equal to dimensions of first array d1. In the opposite case the argument will be ignored. Note, that the maximal number of arguments is 1000.

`void Set (const float *`*A*, `int` *NX*, `int` *NY*=1, `int` *NZ*=1) [Method on `mglData`]
`void Set (const double *`*A*, `int` *NX*, `int` *NY*=1, `int` *NZ*=1) [Method on `mglData`]
`void mgl_data_set_float (HMDT` *dat*, `const mreal *`*A*, `int` *NX*, `int` *NY*, `int` *NZ*) [C function]
`void mgl_data_set_double (HMDT` *dat*, `const double *`*A*, `int` *NX*, `int` *NY*, `int` *NZ*) [C function]
`void Set (const float *`*A*, `int` *NX*, `int` *NY*=1, `int` *NZ*=1) [Method on `mglDataC`]
`void Set (const double *`*A*, `int` *NX*, `int` *NY*=1, `int` *NZ*=1) [Method on `mglDataC`]
`void Set (const dual *`*A*, `int` *NX*, `int` *NY*=1, `int` *NZ*=1) [Method on `mglDataC`]
`void mgl_datac_set_float (HADT` *dat*, `const mreal *`*A*, `int` *NX*, `int` *NY*, `int` *NZ*) [C function]
`void mgl_datac_set_double (HADT` *dat*, `const double *`*A*, `int` *NX*, `int` *NY*, `int` *NZ*) [C function]
`void mgl_datac_set_complex (HADT` *dat*, `const dual *`*A*, `int` *NX*, `int` *NY*, `int` *NZ*) [C function]
Allocates memory and copies the data from the **flat** `float*` or `double*` array.

`void Set (const float **`*A*, `int` *N1*, `int` *N2*) [Method on `mglData`]
`void Set (const double **`*A*, `int` *N1*, `int` *N2*) [Method on `mglData`]
`void mgl_data_set_mreal2 (HMDT` *dat*, `const mreal **`*A*, `int` *N1*, `int` *N2*) [C function]
`void mgl_data_set_double2 (HMDT` *dat*, `const double **`*A*, `int` *N1*, `int` *N2*) [C function]
Allocates memory and copies the data from the `float**` or `double**` array with dimensions *N1*, *N2*, i.e. from array defined as `mreal a[N1][N2];`.

`void Set (const float ***`*A*, `int` *N1*, `int` *N2*) [Method on `mglData`]
`void Set (const double ***`*A*, `int` *N1*, `int` *N2*) [Method on `mglData`]
`void mgl_data_set_mreal3 (HMDT` *dat*, `const mreal ***`*A*, `int` *N1*, `int` *N2*) [C function]
`void mgl_data_set_double3 (HMDT` *dat*, `const double ***`*A*, `int` *N1*, `int` *N2*) [C function]
Allocates memory and copies the data from the `float***` or `double***` array with dimensions *N1*, *N2*, *N3*, i.e. from array defined as `mreal a[N1][N2][N3];`.

`void Set (gsl_vector *v)` [Method on `mglData`]
`void Set (gsl_vector *v)` [Method on `mglDataC`]
`void mgl_data_set_vector (HMDT dat, gsl_vector *v)` [C function]
`void mgl_datac_set_vector (HADT dat, gsl_vector *v)` [C function]
Allocates memory and copies the data from the `gsl_vector *` structure.

`void Set (gsl_matrix *m)` [Method on `mglData`]
`void Set (gsl_matrix *m)` [Method on `mglDataC`]
`void mgl_data_set_matrix (HMDT dat, gsl_matrix *m)` [C function]
`void mgl_datac_set_matrix (HADT dat, gsl_matrix *m)` [C function]
Allocates memory and copies the data from the `gsl_matrix *` structure.

`void Set (const mglDataA &from)` [Method on `mglData`]
`void Set (HCDT from)` [Method on `mglData`]
`void mgl_data_set (HMDT dat, HCDT from)` [C function]
`void Set (const mglDataA &from)` [Method on `mglDataC`]
`void Set (HCDT from)` [Method on `mglDataC`]
`void mgl_datac_set (HADT dat, HCDT from)` [C function]
Copies the data from `mglData` (or `mglDataA`) instance *from*.

`void Set (const mglDataA &re, const mglDataA &im)` [Method on `mglDataC`]
`void Set (HCDT re, HCDT im)` [Method on `mglDataC`]
`void SetAmpl (HCDT ampl, const mglDataA &phase)` [Method on `mglDataC`]
`void mgl_datac_set_ri (HADT dat, HCDT re, HCDT im)` [C function]
`void mgl_datac_set_ap (HADT dat, HCDT ampl, HCDT phase)` [C function]
Copies the data from `mglData` instances for real and imaginary parts of complex data arrays.

`void Set (const std::vector<int> &d)` [Method on `mglData`]
`void Set (const std::vector<int> &d)` [Method on `mglDataC`]
`void Set (const std::vector<float> &d)` [Method on `mglData`]
`void Set (const std::vector<float> &d)` [Method on `mglDataC`]
`void Set (const std::vector<double> &d)` [Method on `mglData`]
`void Set (const std::vector<double> &d)` [Method on `mglDataC`]
`void Set (const std::vector<dual> &d)` [Method on `mglDataC`]
Allocates memory and copies the data from the `std::vector<T>` array.

`void Set (const char *str, int NX, int NY=1, int NZ=1)` [Method on `mglData`]
`void mgl_data_set_values (const char *str, int NX, int NY, int NZ)` [C function]
`void Set (const char *str, int NX, int NY=1, int NZ=1)` [Method on `mglDataC`]
`void mgl_datac_set_values (const char *str, int NX, int NY, int NZ)` [C function]
Allocates memory and scanf the data from the string.

`void SetList (long n, ...)` [Method on `mglData`]
Allocate memory and set data from variable argument list of *double* values. Note, you need to specify decimal point '`.`' for integer values! For example, the code `SetList(2,0.,1.);` is correct, but the code `SetList(2,0,1);` is incorrect.

`void Link (mglData &`*from*`)` [Method on `mglData`]
`void Link (mreal *`*A*`, int` *NX*`=1, int` *NZ*`=1)` [Method on `mglData`]
`void mgl_data_link (HMDT` *dat*`, mreal *`*A*`, int` *NX*`, int` *NY*`, int` *NZ*`)` [C function]
`void Link (mglDataC &`*from*`)` [Method on `mglDataC`]
`void Link (dual *`*A*`, int` *NX*`=1, int` *NZ*`=1)` [Method on `mglDataC`]
`void mgl_datac_link (HADT` *dat*`, dual *`*A*`, int` *NX*`, int` *NY*`, int` *NZ*`)` [C function]
Links external data array, i.e. don't delete this array at exit.

`var` DAT `num v1 [v2=nan]` [MGL command]
Creates new variable with name *dat* for one-dimensional array of size *num*. Array elements are equidistantly distributed in range [*v1*, *v2*]. If *v2*=`nan` then *v2*=*v1* is used.

`fill` *dat v1 v2* [*'dir'='x'*] [MGL command]
`void Fill (mreal` *v1*`, mreal` *v2*`, char` *dir*`='x')` [Method on `mglData`]
`void Fill (dual` *v1*`, dual` *v2*`, char` *dir*`='x')` [Method on `mglDataC`]
`void mgl_data_fill (HMDT` *dat*`, mreal` *v1*`, mreal` *v2*`, char` *dir*`)` [C function]
`void mgl_datac_fill (HADT` *dat*`, dual` *v1*`, dual` *v2*`, char` *dir*`)` [C function]
Equidistantly fills the data values to range [*v1*, *v2*] in direction *dir*={'`x`','`y`','`z`'}.

`fill` *dat 'eq'* [MGL command]
`fill` *dat 'eq' vdat* [MGL command]
`fill` *dat 'eq' vdat wdat* [MGL command]
`void Fill (HMGL` *gr*`, const char *`*eq*`, const char *`*opt*`="")` [Method on `mglData`]
`void Fill (HMGL` *gr*`, const char *`*eq*`, const mglDataA &`*vdat*`, const char *`*opt*`="")` [Method on `mglData`]
`void Fill (HMGL` *gr*`, const char *`*eq*`, const mglDataA &`*vdat*`, const mglDataA &`*wdat*`, const char *`*opt*`="")` [Method on `mglData`]
`void Fill (HMGL` *gr*`, const char *`*eq*`, const char *`*opt*`="")` [Method on `mglDataC`]
`void Fill (HMGL` *gr*`, const char *`*eq*`, const mglDataA &`*vdat*`, const char *`*opt*`="")` [Method on `mglDataC`]
`void Fill (HMGL` *gr*`, const char *`*eq*`, const mglDataA &`*vdat*`, const mglDataA &`*wdat*`, const char *`*opt*`="")` [Method on `mglDataC`]
`void mgl_data_fill_eq (HMGL` *gr*`, HMDT` *dat*`, const char *`*eq*`, HCDT` *vdat*`, HCDT` *wdat*`, const char *`*opt*`)` [C function]
`void mgl_datac_fill_eq (HMGL` *gr*`, HADT` *dat*`, const char *`*eq*`, HCDT` *vdat*`, HCDT` *wdat*`, const char *`*opt*`)` [C function]
Fills the value of array according to the formula in string *eq*. Formula is an arbitrary expression depending on variables '`x`', '`y`', '`z`', '`u`', '`v`', '`w`'. Coordinates '`x`', '`y`', '`z`' are supposed to be normalized in axis range of canvas *gr* (in difference from `Modify` functions). Variable '`u`' is the original value of the array. Variables '`v`' and '`w`' are values of *vdat*, *wdat* which can be `NULL` (i.e. can be omitted).

`modify` *dat 'eq'* [`dim=0`] [MGL command]
`modify` *dat 'eq' vdat* [MGL command]

`modify` *dat 'eq' vdat wdat* [MGL command]
`void Modify (const char *`*eq*`, int` *dim*`=0)` [Method on `mglData`]
`void Modify (const char *`*eq*`, const mglDataA &`*v*`)` [Method on `mglData`]
`void Modify (const char *`*eq*`, const mglDataA &`*v*`, const mglDataA &`*w*`)` [Method on `mglData`]
`void Modify (const char *`*eq*`, int` *dim*`=0)` [Method on `mglDataC`]
`void Modify (const char *`*eq*`, const mglDataA &`*v*`)` [Method on `mglDataC`]
`void Modify (const char *`*eq*`, const mglDataA &`*v*`, const mglDataA &`*w*`)` [Method on `mglDataC`]
`void mgl_data_modify (HMDT` *dat*`, const char *`*eq*`, int` *dim*`)` [C function]
`void mgl_data_modify_vw (HMDT` *dat*`, const char *`*eq*`, HCDT` *v*`, HCDT` *w*`)` [C function]
`void mgl_datac_modify (HADT` *dat*`, const char *`*eq*`, int` *dim*`)` [C function]
`void mgl_datac_modify_vw (HADT` *dat*`, const char *`*eq*`, HCDT` *v*`, HCDT` *w*`)` [C function]

The same as previous ones but coordinates '`x`', '`y`', '`z`' are supposed to be normalized in range [0,1]. If *dim*>0 is specified then modification will be fulfilled only for slices >=*dim*.

`fillsample` *dat 'how'* [MGL command]
`void FillSample (const char *`*how*`)` [Method on `mglData`]
`void mgl_data_fill_sample (HMDT` *a*`, const char *`*how*`)` [C function]

Fills data by 'x' or 'k' samples for Hankel ('h') or Fourier ('f') transform.

`datagrid` *dat xdat ydat zdat* [MGL command]
`mglData Grid (HMGL` *gr*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const char *`*opt*`="")` [Method on `mglData`]
`mglData Grid (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, mglPoint` *p1*`, mglPoint` *p2*`)` [Method on `mglData`]
`void mgl_data_grid (HMGL` *gr*`, HMDT` *u*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, const char *`*opt*`)` [C function]
`void mgl_data_grid_xy (HMDT` *u*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, mreal` *x1*`, mreal` *x2*`, mreal` *y1*`, mreal` *y2*`)` [C function]

Fills the value of array according to the linear interpolation of triangulated surface assuming x-,y-coordinates equidistantly distributed in axis range (or in range [x1,x2]*[y1,y2]). Triangulated surface is found for arbitrary placed points '`x`', '`y`', '`z`'. NAN value is used for grid points placed outside of triangulated surface. See Section 2.9.11 [Making regular data], page 128, for sample code and picture.

`put` *dat* `val [i=: j=: k=:]` [MGL command]
`void Put (mreal` *val*`, int` *i*`=-1, int` *j*`=-1, int` *k*`=-1)` [Method on `mglData`]
`void Put (dual` *val*`, int` *i*`=-1, int` *j*`=-1, int` *k*`=-1)` [Method on `mglDataC`]
`void mgl_data_put_val (HMDT` *a*`, mreal` *val*`, int` *i*`, int` *j*`, int` *k*`)` [C function]
`void mgl_datac_put_val (HADT` *a*`, dual` *val*`, int` *i*`, int` *j*`, int` *k*`)` [C function]

Sets value(s) of array a[*i*, *j*, *k*] = *val*. Negative indexes *i*, *j*, *k*=-1 set the value *val* to whole range in corresponding direction(s). For example, `Put(val,-1,0,-1);` sets a[i,0,j]=*val* for i=0...(nx-1), j=0...(nz-1).

`put` *dat vdat* [`i=: j=: k=:`] [MGL command]
`void Put (const mglDataA &`*v*`, int` *i*`=-1, int` *j*`=-1, int` *k*`=-1)` [Method on `mglData`]
`void Put (const mglDataA &`*v*`, int` *i*`=-1, int` *j*`=-1, int` *k*`=-1)` [Method on `mglDataC`]
`void mgl_data_put_dat (HMDT` *a*`, HCDT` *v*`, int` *i*`, int` *j*`, int` *k*`)` [C function]
`void mgl_datac_put_dat (HADT` *a*`, HCDT` *v*`, int` *i*`, int` *j*`, int` *k*`)` [C function]
Copies value(s) from array *v* to the range of original array. Negative indexes *i*, *j*, *k*=-1 set the range in corresponding direction(s). At this minor dimensions of array *v* should be large than corresponding dimensions of this array. For example, `Put(v,-1,0,-1);` sets a[i,0,j]=v.ny>nz ? v[i,j] : v[i], where i=0...(nx-1), j=0...(nz-1) and condition v.nx>=nx is true.

`refill` *dat xdat vdat* [*sl=-1*] [MGL command]
`refill` *dat xdat ydat vdat* [*sl=-1*] [MGL command]
`refill` *dat xdat ydat zdat vdat* [MGL command]
`void Refill (const mglDataA &`*x*`, const mglDataA &`*v*`, mreal` *x1*`, mreal` *x2*`, long` *sl*`=-1)` [Method on `mglData`]
`void Refill (const mglDataA &`*x*`, const mglDataA &`*v*`, mglPoint` *p1*`, mglPoint` *p2*`, long` *sl*`=-1)` [Method on `mglData`]
`void Refill (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*v*`, mglPoint` *p1*`, mglPoint` *p2*`, long` *sl*`=-1)` [Method on `mglData`]
`void Refill (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*v*`, mglPoint` *p1*`, mglPoint` *p2*`)` [Method on `mglData`]
`void Refill (HMGL` *gr*`, const mglDataA &`*x*`, const mglDataA &`*v*`, long` *sl*`=-1, const char *`*opt*`="")` [Method on `mglData`]
`void Refill (HMGL` *gr*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*v*`, long` *sl*`=-1, const char *`*opt*`="")` [Method on `mglData`]
`void Refill (HMGL` *gr*`, const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`, const mglDataA &`*v*`, const char *`*opt*`="")` [Method on `mglData`]
`void mgl_data_refill_x (HMDT` *a*`, HCDT` *x*`, HCDT` *v*`, mreal` *x1*`, mreal` *x2*`, long` *sl*`)` [C function]
`void mgl_data_refill_xy (HMDT` *a*`, HCDT` *x*`, HCDT` *y*`, HCDT` *v*`, mreal` *x1*`, mreal` *x2*`, mreal` *y1*`, mreal` *y2*`, long` *sl*`)` [C function]
`void mgl_data_refill_xyz (HMDT` *a*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *v*`, mreal` *x1*`, mreal` *x2*`, mreal` *y1*`, mreal` *y2*`, mreal` *z1*`, mreal` *z2*`)` [C function]
`void mgl_data_refill_gr (HMGL` *gr*`, HMDT` *a*`, HCDT` *x*`, HCDT` *y*`, HCDT` *z*`, HCDT` *v*`, long` *sl*`, const char *`*opt*`)` [C function]
Fills by interpolated values of array *v* at the point {*x*, *y*, *z*}={`X[i], Y[j], Z[k]`} (or {*x*, *y*, *z*}={`X[i,j,k], Y[i,j,k], Z[i,j,k]`} if *x*, *y*, *z* are not 1d arrays), where `X,Y,Z` are equidistantly distributed in range [*x1*,*x2*]*[*y1*,*y2*]*[*z1*,*z2*] and have the same sizes as this array. If parameter *sl* is 0 or positive then changes will be applied only for slice *sl*.

`gspline` *dat xdat vdat* [*sl=-1*] [MGL command]
`void RefillGS (const mglDataA &`*x*`, const mglDataA &`*v*`, mreal` *x1*`, mreal` *x2*`, long` *sl*`=-1)` [Method on `mglData`]

`void mgl_data_refill_gs (HMDT` *a*`, HCDT` *x*`, HCDT` *v*`, mreal` *x1*`, mreal` *x2*`, long` *sl*`)` [C function]

Fills by global cubic spline values of array *v* at the point *x*=`X[i]`, where `X` are equidistantly distributed in range [*x1*,*x2*] and have the same sizes as this array. If parameter *sl* is 0 or positive then changes will be applied only for slice *sl*.

`idset` *dat 'ids'* [MGL command]
`void SetColumnId (const char *`*ids*`)` [Method on `mglData`]
`void SetColumnId (const char *`*ids*`)` [Method on `mglDataC`]
`void mgl_data_set_id (HMDT` *a*`, const char *`*ids*`)` [C function]
`void mgl_datac_set_id (HADT` *a*`, const char *`*ids*`)` [C function]

Sets the symbol *ids* for data columns. The string should contain one symbol 'a'...'z' per column. These ids are used in [column], page 265.

6.5 File I/O

`read` DAT *'fname'* [MGL command]
`bool Read (const char *`*fname*`)` [Method on `mglData`]
`bool Read (const char *`*fname*`)` [Method on `mglDataC`]
`int mgl_data_read (HMDT` *dat*`, const char *`*fname*`)` [C function]
`int mgl_datac_read (HADT` *dat*`, const char *`*fname*`)` [C function]

Reads data from tab-separated text file with auto determining sizes of the data. Double newline means the beginning of new z-slice.

`read` DAT *'fname'* `mx [my=1 mz=1]` [MGL command]
`bool Read (const char *`*fname*`, int` *mx*`, int` *my*`=1, int` *mz*`=1)` [Method on `mglData`]
`bool Read (const char *`*fname*`, int` *mx*`, int` *my*`=1, int` *mz*`=1)` [Method on `mglDataC`]
`int mgl_data_read_dim (HMDT` *dat*`, const char *`*fname*`, int` *mx*`, int` *my*`, int` *mz*`)` [C function]
`int mgl_datac_read_dim (HADT` *dat*`, const char *`*fname*`, int` *mx*`, int` *my*`, int` *mz*`)` [C function]

Reads data from text file with specified data sizes. This function does nothing if one of parameters *mx*, *my* or *mz* is zero or negative.

`readmat` DAT *'fname'* `[dim=2]` [MGL command]
`bool ReadMat (const char *`*fname*`, int` *dim*`=2)` [Method on `mglData`]
`bool ReadMat (const char *`*fname*`, int` *dim*`=2)` [Method on `mglDataC`]
`int mgl_data_read_mat (HMDT` *dat*`, const char *`*fname*`, int` *dim*`)` [C function]
`int mgl_datac_read_mat (HADT` *dat*`, const char *`*fname*`, int` *dim*`)` [C function]

Read data from text file with size specified at beginning of the file by first *dim* numbers. At this, variable *dim* set data dimensions.

`readall` DAT *'templ'* `v1 v2 [dv=1 slice=off]` [MGL command]
`void ReadRange (const char *`*templ*`, mreal` *from*`, mreal` *to*`, mreal` *step*`=1, bool` *as_slice*`=false)` [Method on `mglData`]
`void ReadRange (const char *`*templ*`, mreal` *from*`, mreal` *to*`, mreal` *step*`=1, bool` *as_slice*`=false)` [Method on `mglDataC`]

`int mgl_data_read_range (HMDT` *dat*`, const char *`*templ*`, mreal` *from*`, mreal` *to*`, mreal` *step*`, int` *as_slice*`)` [C function]
`int mgl_datac_read_range (HADT` *dat*`, const char *`*templ*`, mreal` *from*`, mreal` *to*`, mreal` *step*`, int` *as_slice*`)` [C function]

Join data arrays from several text files. The file names are determined by function call `sprintf(fname,templ,val);`, where *val* changes from *from* to *to* with step *step*. The data load one-by-one in the same slice if *as_slice*=`false` or as slice-by-slice if *as_slice*=`true`.

`readall` DAT *'templ'* `[slice=off]` [MGL command]
`void ReadAll (const char *`*templ*`, bool` *as_slice*`=false)` [Method on `mglData`]
`void ReadAll (const char *`*templ*`, bool` *as_slice*`=false)` [Method on `mglDataC`]
`int mgl_data_read_all (HMDT` *dat*`, const char *`*templ*`, int` *as_slice*`)` [C function]
`int mgl_datac_read_all (HADT` *dat*`, const char *`*templ*`, int` *as_slice*`)` [C function]

Join data arrays from several text files which filenames satisfied the template *templ* (for example, *templ*=`"t_*.dat"`). The data load one-by-one in the same slice if *as_slice*=`false` or as slice-by-slice if *as_slice*=`true`.

`scanfile` DAT *'fname' 'templ'* [MGL command]
`bool ScanFile (const char *`*fname*`, const char *`*templ*`)` [Method on `mglData`]
`int mgl_data_scan_file (HMDT` *dat*`, const char *`*fname*`, const char *`*templ*`)` [C function]

Read file *fname* line-by-line and scan each line for numbers according the template *templ*. The numbers denoted as '`%g`' in the template. See Section 2.9.22 [Saving and scanning file], page 141, for sample code and picture.

`save` *dat 'fname'* [MGL command]
`void Save (const char *`*fname*`, int` *ns*`=-1) const` [Method on `mglDataA`]
`void mgl_data_save (HCDT` *dat*`, const char *`*fname*`, int` *ns*`)` [C function]
`void mgl_datac_save (HCDT` *dat*`, const char *`*fname*`, int` *ns*`)` [C function]

Saves the whole data array (for *ns*=`-1`) or only *ns*-th slice to the text file *fname*.

`save` *'str' 'fname'* `['mode'='a']` [MGL command]

Saves the string *str* to the text file *fname*. For parameter *mode*='`a`' will append string to the file (default); for *mode*='`w`' will overwrite the file. See Section 2.9.22 [Saving and scanning file], page 141, for sample code and picture.

`readhdf` DAT *'fname' 'dname'* [MGL command]
`void ReadHDF (const char *`*fname*`, const char *`*dname*`)` [Method on `mglData`]
`void ReadHDF (const char *`*fname*`, const char *`*dname*`)` [Method on `mglDataC`]
`void mgl_data_read_hdf (HMDT` *dat*`, const char *`*fname*`, const char *`*dname*`)` [C function]
`void mgl_datac_read_hdf (HADT` *dat*`, const char *`*fname*`, const char *`*dname*`)` [C function]

Reads data array named *dname* from HDF5 or HDF4 file. This function does nothing if HDF5|HDF4 was disabled during library compilation.

`savehdf` *dat 'fname' 'dname'* [`rewrite=off`] [MGL command]
`void SaveHDF (const char *`*fname*`, const char *`*dname*`,` [Method on `mglDataA`]
`bool` *rewrite*`=false) const`
`void mgl_data_save_hdf (HCDT` *dat*`, const char *`*fname*`, const` [C function]
`char *`*dname*`, int` *rewrite*`)`
`void mgl_datac_save_hdf (HCDT` *dat*`, const char *`*fname*`, const` [C function]
`char *`*dname*`, int` *rewrite*`)`
Saves data array named *dname* to HDF5 file. This function does nothing if HDF5 was disabled during library compilation.

`datas` *'fname'* [MGL command]
`int DatasHDF (const char *`*fname*`, char *`*buf*`, long` *size*`)` [Method on `mglDataA`]
`static`
`int mgl_datas_hdf (const char *`*fname*`, char *`*buf*`, long` *size*`)` [C function]
Put data names from HDF5 file *fname* into *buf* as '\t' separated fields. In MGL version the list of data names will be printed as message. This function does nothing if HDF5 was disabled during library compilation.

`import` DAT *'fname' 'sch'* [`v1=0 v2=1`] [MGL command]
`void Import (const char *`*fname*`, const char *`*scheme*`,` [Method on `mglData`]
`mreal` *v1*`=0,` *mreal v2*`=1)`
`void mgl_data_import (HMDT` *dat*`, const char *`*fname*`, const char` [C function]
`*`*scheme*`, mreal` *v1*`,` *mreal v2*`)`
Reads data from bitmap file (now support only PNG format). The RGB values of bitmap pixels are transformed to mreal values in range [*v1*, *v2*] using color scheme *scheme* (see Section 3.4 [Color scheme], page 150).

`export` *dat 'fname' 'sch'* [`v1=0 v2=0`] [MGL command]
`void Export (const char *`*fname*`, const char *`*scheme*`,` [Method on `mglDataA`]
`mreal` *v1*`=0,` *mreal v2*`=0, int` *ns*`=-1)` *const*
`void mgl_data_export (HMDT` *dat*`, const char *`*fname*`, const char` [C function]
`*`*scheme*`, mreal` *v1*`,` *mreal v2*`, int` *ns*`)` *const*
Saves data matrix (or `ns`-th slice for 3d data) to bitmap file (now support only PNG format). The data values are transformed from range [*v1*, *v2*] to RGB pixels of bitmap using color scheme *scheme* (see Section 3.4 [Color scheme], page 150). If *v1*>=*v2* then the values of *v1*, *v2* are automatically determined as minimal and maximal value of the data array.

6.6 Make another data

`subdata` RES *dat* `xx` [`yy=: zz=:`] [MGL command]
`mglData SubData (mreal` *xx*`, mreal` *yy*`=-1, mreal` *zz*`=-1)` [Method on `mglData`]
`const`
`mglData SubData (mreal` *xx*`, mreal` *yy*`=-1, mreal` *zz*`=-1)` [Method on `mglDataC`]
`const`
`HMDT mgl_data_subdata (HCDT` *dat*`, mreal` *xx*`, mreal` *yy*`, mreal` *zz*`)` [C function]
Extracts sub-array data from the original data array keeping fixed positive index. For example `SubData(-1,2)` extracts 3d row (indexes are zero based), `SubData(4,-1)`

extracts 5th column, `SubData(-1,-1,3)` extracts 4th slice and so on. If argument(s) are non-integer then linear interpolation between slices is used. In MGL version this command usually is used as inline one `dat(xx,yy,zz)`. Function return NULL or create empty data if data cannot be created for given arguments.

`subdata` RES *dat xdat* [*ydat=: zdat=:*] [MGL command]
`mglData SubData (const mglDataA &`*xx*`, const mglDataA &`*yy*`, const mglDataA &`*zz*`) const` [Method on `mglData`]
`mglData SubData (const mglDataA &`*xx*`, const mglDataA &`*yy*`, const mglDataA &`*zz*`) const` [Method on `mglDataC`]
`mglData SubData (const mglDataA &`*xx*`, const mglDataA &`*yy*`) const` [Method on `mglData`]
`mglData SubData (const mglDataA &`*xx*`, const mglDataA &`*yy*`) const` [Method on `mglDataC`]
`mglData SubData (const mglDataA &`*xx*`) const` [Method on `mglData`]
`mglData SubData (const mglDataA &`*xx*`) const` [Method on `mglDataC`]
`HMDT mgl_data_subdata_ext (HCDT` *dat*`, HCDT` *xx*`, HCDT` *yy*`, HCDT` *zz*`)` [C function]
`HADT mgl_datac_subdata_ext (HCDT` *dat*`, HCDT` *xx*`, HCDT` *yy*`, HCDT` *zz*`)` [C function]

Extracts sub-array data from the original data array for indexes specified by arrays *xx*, *yy*, *zz* (indirect access). This function work like previous one for 1D arguments or numbers, and resulting array dimensions are equal dimensions of 1D arrays for corresponding direction. For 2D and 3D arrays in arguments, the resulting array have the same dimensions as input arrays. The dimensions of all argument must be the same (or to be scalar 1*1*1) if they are 2D or 3D arrays. In MGL version this command usually is used as inline one `dat(xx,yy,zz)`. Function return NULL or create empty data if data cannot be created for given arguments. In C function some of *xx*, *yy*, *zz* can be NULL.

`column` RES *dat 'eq'* [MGL command]
`mglData Column (const char *`*eq*`) const` [Method on `mglData`]
`mglData Column (const char *`*eq*`) const` [Method on `mglDataC`]
`HMDT mgl_data_column (HCDT` *dat*`, const char *`*eq*`)` [C function]

Get column (or slice) of the data filled by formula *eq* on column ids. For example, `Column("n*w^2/exp(t)");`. The column ids must be defined first by [idset], page 262 function or read from files. In MGL version this command usually is used as inline one `dat('eq')`. Function return NULL or create empty data if data cannot be created for given arguments.

`resize` RES *dat* `mx` [`my=1 mz=1`] [MGL command]
`mglData Resize (int` *mx*`, int` *my*`=0, int` *mz*`=0, mreal` *x1*`=0, mreal` *x2*`=1, mreal` *y1*`=0, mreal` *y2*`=1, mreal` *z1*`=0, mreal` *z2*`=1) const` [Method on `mglData`]
`mglData Resize (int` *mx*`, int` *my*`=0, int` *mz*`=0, mreal` *x1*`=0, mreal` *x2*`=1, mreal` *y1*`=0, mreal` *y2*`=1, mreal` *z1*`=0, mreal` *z2*`=1) const` [Method on `mglDataC`]
`HMDT mgl_data_resize (HCDT` *dat*`, int` *mx*`, int` *my*`, int` *mz*`)` [C function]

`HMDT mgl_data_resize_box (HCDT` *dat*`, int` *mx*`, int` *my*`, int` *mz*`, mreal` *x1*`, mreal` *x2*`, mreal` *y1*`, mreal` *y2*`, mreal` *z1*`, mreal` *z2*`)` [C function]

Resizes the data to new size *mx*, *my*, *mz* from box (part) [*x1*,*x2*] x [*y1*,*y2*] x [*z1*,*z2*] of original array. Initially x,y,z coordinates are supposed to be in [0,1]. If one of sizes *mx*, *my* or *mz* is 0 then initial size is used. Function return NULL or create empty data if data cannot be created for given arguments.

`evaluate` RES *dat idat* [`norm=on`] [MGL command]
`evaluate` RES *dat idat jdat* [`norm=on`] [MGL command]
`evaluate` RES *dat idat jdat kdat* [`norm=on`] [MGL command]
`mglData Evaluate (const mglDataA &`*idat*`, bool` *norm*`=true) const` [Method on `mglData`]
`mglData Evaluate (const mglDataA &`*idat*`, const mglDataA &`*jdat*`, bool` *norm*`=true) const` [Method on `mglData`]
`mglData Evaluate (const mglDataA &`*idat*`, const mglDataA &`*jdat*`, const mglDataA &`*kdat*`, bool` *norm*`=true) const` [Method on `mglData`]
`mglData Evaluate (const mglDataA &`*idat*`, bool` *norm*`=true) const` [Method on `mglDataC`]
`mglData Evaluate (const mglDataA &`*idat*`, const mglDataA &`*jdat*`, bool` *norm*`=true) const` [Method on `mglDataC`]
`mglData Evaluate (const mglDataA &`*idat*`, const mglDataA &`*jdat*`, const mglDataA &`*kdat*`, bool` *norm*`=true) const` [Method on `mglDataC`]
`HMDT mgl_data_evaluate (HCDT` *dat*`, HCDT` *idat*`, HCDT` *jdat*`, HCDT` *kdat*`, int` *norm*`)` [C function]

Gets array which values is result of interpolation of original array for coordinates from other arrays. All dimensions must be the same for data *idat*, *jdat*, *kdat*. Coordinates from *idat*, *jdat*, *kdat* are supposed to be normalized in range [0,1] (if *norm*=`true`) or in ranges [0,nx], [0,ny], [0,nz] correspondingly. Function return NULL or create empty data if data cannot be created for given arguments.

`solve` RES *dat* `val` *'dir'* [`norm=on`] [MGL command]
`solve` RES *dat* `val` *'dir' idat* [`norm=on`] [MGL command]
`mglData Solve (mreal` *val*`, char` *dir*`, bool` *norm*`=true) const` [Method on `mglData`]
`mglData Solve (mreal` *val*`, char` *dir*`, const mglDataA &`*idat*`, bool` *norm*`=true) const` [Method on `mglData`]
`HMDT mgl_data_solve (HCDT` *dat*`, mreal` *val*`, char` *dir*`, HCDT` *idat*`, int` *norm*`)` [C function]

Gets array which values is indexes (roots) along given direction *dir*, where interpolated values of data *dat* are equal to *val*. Output data will have the sizes of *dat* in directions transverse to *dir*. If data *idat* is provided then its values are used as starting points. This allows to find several branches by consequentive calls. Indexes are supposed to be normalized in range [0,1] (if *norm*=`true`) or in ranges [0,nx], [0,ny], [0,nz] correspondingly. Function return NULL or create empty data if data cannot be created for given arguments. See [Solve sample], page 40, for sample code and picture.

`roots` RES *'func' ini* [*'var'='x'*] [MGL command]
`roots` RES *'func'* `ini` [*'var'='x'*] [MGL command]

`mglData Roots (const char *`*func*`, char `*var*`) const` [Method on `mglData`]
`HMDT mgl_data_roots (const char *`*func*`, HCDT `*ini*`, char `*var*`)` [C function]
`mreal mgl_find_root_txt (const char *`*func*`, mreal `*ini*`, char `*var*`)` [C function]
Find roots of equation 'func'=0 for variable *var* with initial guess *ini*. Secant method is used for root finding. Function return NULL or create empty data if data cannot be created for given arguments.

`hist` RES *dat* `num v1 v2 [nsub=0]` [MGL command]
`hist` RES *dat wdat* `num v1 v2 [nsub=0]` [MGL command]
`mglData Hist (int `*n*`, mreal `*v1*`=0, mreal `*v2*`=1, int `*nsub*`=0) const` [Method on `mglData`]
`mglData Hist (const mglDataA &`*w*`, int `*n*`, mreal `*v1*`=0, mreal `*v2*`=1, int `*nsub*`=0) const` [Method on `mglData`]
`mglData Hist (int `*n*`, mreal `*v1*`=0, mreal `*v2*`=1, int `*nsub*`=0) const` [Method on `mglDataC`]
`mglData Hist (const mglDataA &`*w*`, int `*n*`, mreal `*v1*`=0, mreal `*v2*`=1, int `*nsub*`=0) const` [Method on `mglDataC`]
`HMDT mgl_data_hist (HCDT `*dat*`, int `*n*`, mreal `*v1*`, mreal `*v2*`, int `*nsub*`)` [C function]
`HMDT mgl_data_hist_w (HCDT `*dat*`, HCDT `*w*`, int `*n*`, mreal `*v1*`, mreal `*v2*`, int `*nsub*`)` [C function]
Creates *n*-th points distribution of the data values in range [*v1*, *v2*]. Array *w* specifies weights of the data elements (by default is 1). Parameter *nsub* define the number of additional interpolated points (for smoothness of histogram). Function return NULL or create empty data if data cannot be created for given arguments. See also Section 4.18 [Data manipulation], page 235

`momentum` RES *dat 'how'* ['*dir*'='z'] [MGL command]
`mglData Momentum (char `*dir*`, const char *`*how*`) const` [Method on `mglData`]
`mglData Momentum (char `*dir*`, const char *`*how*`) const` [Method on `mglDataC`]
`HMDT mgl_data_momentum (HCDT `*dat*`, char `*dir*`, const char *`*how*`)` [C function]
Gets momentum (1d-array) of the data along direction *dir*. String *how* contain kind of momentum. The momentum is defined like as $res_k = \sum_{ij} how(x_i, y_j, z_k) a_{ij} / \sum_{ij} a_{ij}$ if *dir*='`x`' and so on. Coordinates '`x`', '`y`', '`z`' are data indexes normalized in range [0,1]. Function return NULL or create empty data if data cannot be created for given arguments.

`sum` RES *dat 'dir'* [MGL command]
`mglData Sum (const char *`*dir*`) const` [Method on `mglData`]
`mglData Sum (const char *`*dir*`) const` [Method on `mglDataC`]
`HMDT mgl_data_sum (HCDT `*dat*`, const char *`*dir*`)` [C function]
Gets array which is the result of summation in given direction or direction(s). Function return NULL or create empty data if data cannot be created for given arguments.

`max` RES *dat 'dir'* [MGL command]
`mglData Max (const char *`*dir*`) const` [Method on `mglData`]
`mglData Max (const char *`*dir*`) const` [Method on `mglDataC`]

`HMDT mgl_data_max_dir (HCDT dat, const char *dir)` [C function]
Gets array which is the maximal data values in given direction or direction(s). Function return NULL or create empty data if data cannot be created for given arguments.

`min` RES *dat 'dir'* [MGL command]
`mglData Min (const char *dir) const` [Method on `mglData`]
`mglData Min (const char *dir) const` [Method on `mglDataC`]
`HMDT mgl_data_min_dir (HCDT dat, const char *dir)` [C function]
Gets array which is the maximal data values in given direction or direction(s). Function return NULL or create empty data if data cannot be created for given arguments.

`combine` RES *adat bdat* [MGL command]
`mglData Combine (const mglDataA &a) const` [Method on `mglData`]
`mglData Combine (const mglDataA &a) const` [Method on `mglDataC`]
`HMDT mgl_data_combine (HCDT dat, HCDT a)` [C function]
Returns direct multiplication of arrays (like, res[i,j] = this[i]*a[j] and so on). Function return NULL or create empty data if data cannot be created for given arguments.

`trace` RES *dat* [MGL command]
`mglData Trace () const` [Method on `mglData`]
`mglData Trace () const` [Method on `mglDataC`]
`HMDT mgl_data_trace (HCDT dat)` [C function]
Gets array of diagonal elements a[i,i] (for 2D case) or a[i,i,i] (for 3D case) where i=0...nx-1. Function return copy of itself for 1D case. Data array must have dimensions ny,nz >= nx or ny,nz = 1. Function return NULL or create empty data if data cannot be created for given arguments.

`correl` RES *adat bdat 'dir'* [MGL command]
`mglData Correl (const mglDataA &b, const char *dir) const` [Method on `mglData`]
`mglData AutoCorrel (const char *dir) const` [Method on `mglData`]
`mglDataC Correl (const mglDataA &b, const char *dir) const` [Method on `mglDataC`]
`mglDataC AutoCorrel (const char *dir) const` [Method on `mglDataC`]
`HMDT mgl_data_correl (HCDT a, HCDT b, const char *dir)` [C function]
`HADT mgl_datac_correl (HCDT a, HCDT b, const char *dir)` [C function]
Find correlation between data *a* (or this in C++) and *b* along directions *dir*. Fourier transform is used to find the correlation. So, you may want to use functions [swap], page 271 or [norm], page 272 before plotting it. Function return NULL or create empty data if data cannot be created for given arguments.

`mglData Real () const` [Method on `mglDataC`]
`HMDT mgl_datac_real (HCDT dat)` [C function]
Gets array of real parts of the data.

`mglData Imag () const` [Method on `mglDataC`]
`HMDT mgl_datac_imag (HCDT dat)` [C function]
Gets array of imaginary parts of the data.

`mglData Abs () const` [Method on `mglDataC`]
`HMDT mgl_datac_abs (HCDT dat)` [C function]
Gets array of absolute values of the data.

`mglData Arg () const` [Method on `mglDataC`]
`HMDT mgl_datac_arg (HCDT dat)` [C function]
Gets array of arguments of the data.

`pulse` RES *dat 'dir'* [MGL command]
`mglData Pulse (const char *dir) const` [Method on `mglData`]
`HMDT mgl_data_pulse (HCDT dat, const char *dir)` [C function]
Find pulse properties along direction *dir*: pulse maximum (in column 0) and its position (in column 1), pulse width near maximum (in column 3) and by half height (in column 2), energy in first pulse (in column 4). NAN values are used for widths if maximum is located near the edges. Note, that there is uncertainty for complex data. Usually one should use square of absolute value (i.e. `|dat[i]|^2`) for them. So, MathGL don't provide this function for complex data arrays. However, C function will work even in this case but use absolute value (i.e. `|dat[i]|`). Function return NULL or create empty data if data cannot be created for given arguments. See also [max], page 267, [min], page 268, [momentum], page 267, [sum], page 267. See Section 2.9.16 [Pulse properties], page 135, for sample code and picture.

6.7 Data changing

These functions change the data in some direction like differentiations, integrations and so on. The direction in which the change will applied is specified by the string parameter, which may contain '`x`', '`y`' or '`z`' characters for 1-st, 2-nd and 3-d dimension correspondingly.

`cumsum` *dat 'dir'* [MGL command]
`void CumSum (const char *dir)` [Method on `mglData`]
`void CumSum (const char *dir)` [Method on `mglDataC`]
`void mgl_data_cumsum (HMDT dat, const char *dir)` [C function]
`void mgl_datac_cumsum (HADT dat, const char *dir)` [C function]
Cumulative summation of the data in given direction or directions.

`integrate` *dat 'dir'* [MGL command]
`void Integral (const char *dir)` [Method on `mglData`]
`void Integral (const char *dir)` [Method on `mglDataC`]
`void mgl_data_integral (HMDT dat, const char *dir)` [C function]
`void mgl_datac_integral (HADT dat, const char *dir)` [C function]
Integrates (like cumulative summation) the data in given direction or directions.

`diff` *dat 'dir'* [MGL command]
`void Diff (const char *dir)` [Method on `mglData`]
`void Diff (const char *dir)` [Method on `mglDataC`]
`void mgl_data_diff (HMDT dat, const char *dir)` [C function]
`void mgl_datac_diff (HADT dat, const char *dir)` [C function]
Differentiates the data in given direction or directions.

`diff` *dat xdat ydat* [*zdat=0*] [MGL command]
`void Diff (const mglDataA &`*x*`, const mglDataA &`*y*`)` [Method on `mglData`]
`void Diff (const mglDataA &`*x*`, const mglDataA &`*y*`, const mglDataA &`*z*`)` [Method on `mglData`]
`void mgl_data_diff_par (HMDT` *dat*`, HCDT` *x*`, HCDT`*y*`, HCDT`*z*`)` [C function]
Differentiates the data specified parametrically in direction x with y, z=constant. Parametrical differentiation uses the formula (for 2D case): $da/dx = (a_j * y_i - a_i * y_j)/(x_j * y_i - x_i * y_j)$ where $a_i = da/di, a_j = da/dj$ denotes usual differentiation along 1st and 2nd dimensions. The similar formula is used for 3D case. Note, that you may change the order of arguments – for example, if you have 2D data a(i,j) which depend on coordinates {x(i,j), y(i,j)} then usual derivative along '`x`' will be `Diff(x,y);` and usual derivative along '`y`' will be `Diff(y,x);`.

`diff2` *dat 'dir'* [MGL command]
`void Diff2 (const char *`*dir*`)` [Method on `mglData`]
`void Diff2 (const char *`*dir*`)` [Method on `mglDataC`]
`void mgl_data_diff2 (HMDT` *dat*`, const char *`*dir*`)` [C function]
`void mgl_datac_diff2 (HADT` *dat*`, const char *`*dir*`)` [C function]
Double-differentiates (like Laplace operator) the data in given direction.

`sinfft` *dat 'dir'* [MGL command]
`void SinFFT (const char *`*dir*`)` [Method on `mglData`]
`void mgl_data_sinfft (HMDT` *dat*`, const char *`*dir*`)` [C function]
Do Sine transform of the data in given direction or directions. The Sine transform is $\sum a_j \sin(kj)$ (see `http://en.wikipedia.org/wiki/Discrete_sine_transform#DST-I`).

`cosfft` *dat 'dir'* [MGL command]
`void CosFFT (const char *`*dir*`)` [Method on `mglData`]
`void mgl_data_cosfft (HMDT` *dat*`, const char *`*dir*`)` [C function]
Do Cosine transform of the data in given direction or directions. The Cosine transform is $\sum a_j \cos(kj)$ (see `http://en.wikipedia.org/wiki/Discrete_cosine_transform#DCT-I`).

`void FFT (const char *`*dir*`)` [Method on `mglDataC`]
`void mgl_datac_fft (HADT` *dat*`, const char *`*dir*`)` [C function]
Do Fourier transform of the data in given direction or directions. If *dir* contain '`i`' then inverse Fourier is used. The Fourier transform is $\sum a_j \exp(ikj)$ (see `http://en.wikipedia.org/wiki/Discrete_Fourier_transform`).

`hankel` *dat 'dir'* [MGL command]
`void Hankel (const char *`*dir*`)` [Method on `mglData`]
`void Hankel (const char *`*dir*`)` [Method on `mglDataC`]
`void mgl_data_hankel (HMDT` *dat*`, const char *`*dir*`)` [C function]
`void mgl_datac_hankel (HADT` *dat*`, const char *`*dir*`)` [C function]
Do Hankel transform of the data in given direction or directions. The Hankel transform is $\sum a_j J_0(kj)$ (see `http://en.wikipedia.org/wiki/Hankel_transform`).

`wavelet` *dat 'dir'* `k` [MGL command]
`void Wavelet (const char *`*dir*`, int` *k*`)` [Method on `mglData`]
`void mgl_data_wavelet (HMDT` *dat*`, const char *`*dir*`, int` *k*`)` [C function]
Apply wavelet transform of the data in given direction or directions. Parameter *dir* set the kind of wavelet transform: '`d`' for daubechies, '`D`' for centered daubechies, '`h`' for haar, '`H`' for centered haar, '`b`' for bspline, '`B`' for centered bspline. If string *dir* contain symbol '`i`' then inverse wavelet transform is applied. Parameter *k* set the size of wavelet transform.

`swap` *dat 'dir'* [MGL command]
`void Swap (const char *`*dir*`)` [Method on `mglData`]
`void Swap (const char *`*dir*`)` [Method on `mglDataC`]
`void mgl_data_swap (HMDT` *dat*`, const char *`*dir*`)` [C function]
`void mgl_datac_swap (HADT` *dat*`, const char *`*dir*`)` [C function]
Swaps the left and right part of the data in given direction (useful for Fourier spectrum).

`roll` *dat 'dir' num* [MGL command]
`void Roll (char` *dir*`, num)` [Method on `mglData`]
`void Roll (char` *dir*`, num)` [Method on `mglDataC`]
`void mgl_data_roll (HMDT` *dat*`, char` *dir*`, num)` [C function]
`void mgl_datac_roll (HADT` *dat*`, char` *dir*`, num)` [C function]
Rolls the data along direction *dir*. Resulting array will be out[i] = ini[(i+*num*)%nx] if `dir='x'`.

`mirror` *dat 'dir'* [MGL command]
`void Mirror (const char *`*dir*`)` [Method on `mglData`]
`void Mirror (const char *`*dir*`)` [Method on `mglDataC`]
`void mgl_data_mirror (HMDT` *dat*`, const char *`*dir*`)` [C function]
`void mgl_datac_mirror (HADT` *dat*`, const char *`*dir*`)` [C function]
Mirror the left-to-right part of the data in given direction. Looks like change the value index *i*->*n*-*i*. Note, that the similar effect in graphics you can reach by using options (see Section 3.7 [Command options], page 154), for example, `surf dat; xrange 1 -1`.

`sew` *dat* ['*dir*'='*xyz*' `da=2*pi`] [MGL command]
`void Sew (const char *`*dir*`, mreal` *da*`=2*M_PI)` [Method on `mglData`]
`void mgl_data_sew (HMDT` *dat*`, const char *`*dir*`, mreal` *da*`)` [C function]
Remove value steps (like phase jumps after inverse trigonometric functions) with period *da* in given direction.

`smooth` *data* `type` ['*dir*'='*xyz*'] [MGL command]
`void Smooth (const char *`*dir*`="xyz", mreal` *delta*`=0)` [Method on `mglData`]
`void Smooth (const char *`*dir*`="xyz", mreal` *delta*`=0)` [Method on `mglDataC`]
`void mgl_data_smooth (HMDT` *dat*`, const char *`*dir*`, mreal` *delta*`)` [C function]
`void mgl_datac_smooth (HADT` *dat*`, const char *`*dir*`, mreal` *delta*`)` [C function]
Smooths the data on specified direction or directions. String *dirs* specifies the dimensions which will be smoothed. It may contain characters: '`x`' for 1st dimension, '`y`' for 2nd dimension, '`z`' for 3d dimension. If string *dir* contain: '`0`' then does nothing, '`3`' – linear averaging over 3 points, '`5`' – linear averaging over 5 points. If string *dir*

contain 'dN' (where 'N' is digit 1,2,...,9) then linear averaging over (2*N+1)-th points is used. By default quadratic averaging over 5 points is used.

`envelop` *dat* [*'dir'='x'*] [MGL command]
`void Envelop (char` *dir*`='x')` [Method on `mglData`]
`void mgl_data_envelop (HMDT` *dat*`, char` *dir*`)` [C function]
Find envelop for data values along direction *dir*.

`norm` *dat* `v1 v2 [sym=off dim=0]` [MGL command]
`void Norm (mreal` *v1*`=0, mreal` *v2*`=1, bool` *sym*`=false,` [Method on `mglData`]
`int` *dim*`=0)`
Normalizes the data to range [*v1*,*v2*]. If flag *sym*=`true` then symmetrical interval [-max(|v1|,|v2|), max(|v1|,|v2|)] is used. Modification will be applied only for slices >=*dim*.

`normsl` *dat* `v1 v2 [`*'dir'='z'* `keep=on sym=off]` [MGL command]
`void NormSl (mreal` *v1*`=0, mreal` *v2*`=1, char` *dir*`='z',` [Method on `mglData`]
`bool` *keep_en*`=true, bool` *sym*`=false)`
`void mgl_data_norm_slice (HMDT` *dat*`, mreal` *v1*`, mreal` *v2*`, char` [C function]
dir`, int` *keep_en*`, int` *sym*`)`
Normalizes data slice-by-slice along direction *dir* the data in slices to range [*v1*,*v2*]. If flag *sym*=`true` then symmetrical interval [-max(|v1|,|v2|), max(|v1|,|v2|)] is used. If *keep_en* is set then maximal value of k-th slice will be limited by $\sqrt{\sum a_{ij}(k)/\sum a_{ij}(0)}$.

6.8 Interpolation

MGL scripts can use spline interpolation by [evaluate], page 266 or [refill], page 261 commands. Also you can use [resize], page 265 for obtaining a data array with new sizes.

However, there are much special faster functions in other modes (C/C++/Fortran/Python/...).

`mreal Spline (mreal` *x*`, mreal` *y*`=0, mreal` *z*`=0) const` [Method on `mglData`]
`dual Spline (mreal` *x*`, mreal` *y*`=0, mreal` *z*`=0) const` [Method on `mglDataC`]
`mreal mgl_data_spline (HCDT` *dat*`, mreal` *x*`, mreal` *y*`, mreal` *z*`)` [C function]
`dual mgl_datac_spline (HCDT` *dat*`, mreal` *x*`, mreal` *y*`, mreal` *z*`)` [C function]
Interpolates data by cubic spline to the given point *x* in [0...nx-1], *y* in [0...ny-1], *z* in [0...nz-1].

`mreal Spline1 (mreal` *x*`, mreal` *y*`=0, mreal` *z*`=0) const` [Method on `mglData`]
`dual Spline1 (mreal` *x*`, mreal` *y*`=0, mreal` *z*`=0) const` [Method on `mglDataC`]
Interpolates data by cubic spline to the given point *x*, *y*, *z* which assumed to be normalized in range [0, 1].

`mreal Spline (mglPoint &`*dif*`, mreal` *x*`, mreal` *y*`=0, mreal` [Method on `mglData`]
z`=0) const`
`mreal mgl_data_spline_ext (HCDT` *dat*`, mreal` *x*`, mreal` *y*`, mreal` *z*`,` [C function]
`mreal *`*dx*`, mreal *`*dy*`, mreal *`*dz*`)`

`dual mgl_datac_spline_ext (HCDT` *dat*`, mreal` *x*`, mreal` *y*`, mreal` *z*`, dual *`*dx*`, dual *`*dy*`, dual *`*dz*`)` [C function]

Interpolates data by cubic spline to the given point *x* in [0...nx-1], *y* in [0...ny-1], *z* in [0...nz-1]. The values of derivatives at the point are saved in *dif*.

`mreal Spline1 (mglPoint &`*dif*`, mreal` *x*`, mreal` *y*`=0, mreal` *z*`=0) const` [Method on `mglData`]

Interpolates data by cubic spline to the given point *x*, *y*, *z* which assumed to be normalized in range [0, 1]. The values of derivatives at the point are saved in *dif*.

`mreal Linear (mreal` *x*`, mreal` *y*`=0, mreal` *z*`=0) const` [Method on `mglData`]
`dual Linear (mreal` *x*`, mreal` *y*`=0, mreal` *z*`=0) const` [Method on `mglDataC`]
`mreal mgl_data_linear (HCDT` *dat*`, mreal` *x*`, mreal` *y*`, mreal` *z*`)` [C function]
`dual mgl_datac_linear (HCDT` *dat*`, mreal` *x*`, mreal` *y*`, mreal` *z*`)` [C function]

Interpolates data by linear function to the given point *x* in [0...nx-1], *y* in [0...ny-1], *z* in [0...nz-1].

`mreal Linear1 (mreal` *x*`, mreal` *y*`=0, mreal` *z*`=0) const` [Method on `mglData`]
`dual Linear1 (mreal` *x*`, mreal` *y*`=0, mreal` *z*`=0) const` [Method on `mglDataC`]

Interpolates data by linear function to the given point *x*, *y*, *z* which assumed to be normalized in range [0, 1].

`mreal Linear (mglPoint &`*dif*`, mreal` *x*`, mreal` *y*`=0, mreal` *z*`=0) const` [Method on `mglData`]
`dual Linear (mglPoint &`*dif*`, mreal` *x*`, mreal` *y*`=0, mreal` *z*`=0) const` [Method on `mglDataC`]
`mreal mgl_data_linear_ext (HCDT` *dat*`, mreal` *x*`, mreal` *y*`, mreal` *z*`, mreal *`*dx*`, mreal *`*dy*`, mreal *`*dz*`)` [C function]
`dual mgl_datac_linear_ext (HCDT` *dat*`, mreal` *x*`, mreal` *y*`, mreal` *z*`, dual *`*dx*`, dual *`*dy*`, dual *`*dz*`)` [C function]

Interpolates data by linear function to the given point *x* in [0...nx-1], *y* in [0...ny-1], *z* in [0...nz-1]. The values of derivatives at the point are saved in *dif*.

`mreal Linear1 (mglPoint &`*dif*`, mreal` *x*`, mreal` *y*`=0, mreal` *z*`=0) const` [Method on `mglData`]
`dual Linear1 (mglPoint &`*dif*`, mreal` *x*`, mreal` *y*`=0, mreal` *z*`=0) const` [Method on `mglDataC`]

Interpolates data by linear function to the given point *x*, *y*, *z* which assumed to be normalized in range [0, 1]. The values of derivatives at the point are saved in *dif*.

6.9 Data information

There are a set of functions for obtaining data properties in MGL language. However most of them can be found using "suffixes". Suffix can get some numerical value of the data array (like its size, maximal or minimal value, the sum of elements and so on) as number. Later it can be used as usual number in command arguments. The suffixes start from point '`.`' right after (without spaces) variable name or its sub-array. For example, `a.nx` give the x-size of data *a*, `b(1).max` give maximal value of second row of variable *b*, `(c(:,0)^2).sum` give the sum of squares of elements in the first column of *c* and so on.

`info` *dat* [MGL command]
`const char * PrintInfo () const` [Method on `mglDataA`]
`void PrintInfo (FILE *`*fp*`) const` [Method on `mglDataA`]
`const char * mgl_data_info (HCDT` *dat*`)` [C function only]
`mgl_data_info (long` *dat*`, char *`*out*`, int` *len*`)` [Fortran subroutine]
Gets or prints to file *fp* or as message (in MGL) information about the data (sizes, maximum/minimum, momentums and so on).

`info` *'txt'* [MGL command]
Prints string *txt* as message.

`info` *val* [MGL command]
Prints value of number *val* as message.

`print` *dat* [MGL command]
`print` *'txt'* [MGL command]
`print` *val* [MGL command]
The same as [info], page 273 but immediately print to stdout.

`echo` *dat* [MGL command]
Prints all values of the data array *dat* as message.

`(dat) .nx` [MGL suffix]
`(dat) .ny` [MGL suffix]
`(dat) .nz` [MGL suffix]
`long GetNx ()` [Method on `mglDataA`]
`long GetNy ()` [Method on `mglDataA`]
`long GetNz ()` [Method on `mglDataA`]
`long mgl_data_get_nx (HCDT` *dat*`)` [C function]
`long mgl_data_get_ny (HCDT` *dat*`)` [C function]
`long mgl_data_get_nz (HCDT` *dat*`)` [C function]
Gets the x-, y-, z-size of the data.

`(dat) .max` [MGL suffix]
`mreal Maximal () const` [Method on `mglDataA`]
`mreal mgl_data_max (HCDT` *dat*`)` [C function]
Gets maximal value of the data.

`(dat) .min` [MGL suffix]
`mreal Minimal () const` [Method on `mglDataA`]
`mreal mgl_data_min (HMDT` *dat*`) const` [C function]
Gets minimal value of the data.

`mreal Minimal (int &`*i*`, int &`*j*`, int &`*k*`) const` [Method on `mglDataA`]
`mreal mgl_data_min_int (HCDT` *dat*`, int *`*i*`, int *`*j*`, int *`*k*`)` [C function]
Gets position of minimum to variables *i*, *j*, *k* and returns the minimal value.

`mreal Maximal (int &`*i*`, int &`*j*`, int &`*k*`) const` [Method on `mglDataA`]
`mreal mgl_data_max_int (HCDT` *dat*`, int *`*i*`, int *`*j*`, int *`*k*`)` [C function]
Gets position of maximum to variables *i*, *j*, *k* and returns the maximal value.

`mreal Minimal (mreal &x, mreal &y, mreal &z) const` [Method on `mglDataA`]
`mreal mgl_data_min_real (HCDT dat, mreal *x, mreal *y, mreal *z)` [C function]

Gets approximated (interpolated) position of minimum to variables x, y, z and returns the minimal value.

`(dat) .mx` [MGL suffix]
`(dat) .my` [MGL suffix]
`(dat) .mz` [MGL suffix]
`mreal Maximal (mreal &x, mreal &y, mreal &z) const` [Method on `mglDataA`]
`mreal mgl_data_max_real (HCDT dat, mreal *x, mreal *y, mreal *z)` [C function]

Gets approximated (interpolated) position of maximum to variables x, y, z and returns the maximal value.

`(dat) .sum` [MGL suffix]
`(dat) .ax` [MGL suffix]
`(dat) .ay` [MGL suffix]
`(dat) .az` [MGL suffix]
`(dat) .aa` [MGL suffix]
`(dat) .wx` [MGL suffix]
`(dat) .wy` [MGL suffix]
`(dat) .wz` [MGL suffix]
`(dat) .wa` [MGL suffix]
`(dat) .sx` [MGL suffix]
`(dat) .sy` [MGL suffix]
`(dat) .sz` [MGL suffix]
`(dat) .sa` [MGL suffix]
`(dat) .kx` [MGL suffix]
`(dat) .ky` [MGL suffix]
`(dat) .kz` [MGL suffix]
`(dat) .ka` [MGL suffix]
`mreal Momentum (char dir, mreal &a, mreal &w) const` [Method on `mglDataA`]
`mreal Momentum (char dir, mreal &m, mreal &w, mreal &s, mreal &k) const` [Method on `mglDataA`]
`mreal mgl_data_momentum_val (HCDT dat, char dir, mreal *a, mreal *w, mreal *s, mreal *k)` [C function]

Gets zero-momentum (energy, $I = \sum dat_i$) and write first momentum (median, $a = \sum \xi_i dat_i/I$), second momentum (width, $w^2 = \sum(\xi_i - a)^2 dat_i/I$), third momentum (skewness, $s = \sum(\xi_i - a)^3 dat_i/Iw^3$) and fourth momentum (kurtosis, $k = \sum(\xi_i - a)^4 dat_i/3Iw^4$) to variables. Here ξ is corresponding coordinate if *dir* is ''`x`'', ''`y`'' or ''`z`''. Otherwise median is $a = \sum dat_i/N$, width is $w^2 = \sum(dat_i - a)^2/N$ and so on.

`(dat) .fst` [MGL suffix]
`mreal Find (const char *cond, int &i, int &j, int &k) const` [Method on `mglDataA`]
`mreal mgl_data_first (HCDT dat, const char *cond, int *i, int *j, int *k)` [C function]

Find position (after specified in i, j, k) of first nonzero value of formula *cond*. Function return the data value at found position.

`(dat) .lst` [MGL suffix]
`mreal Last (const char *`*cond*`, int &`*i*`, int &`*j*`, int &`*k*`) const` [Method on `mglDataA`]
`mreal mgl_data_last (HCDT` *dat*`, const char *`*cond*`, int *`*i*`, int *`*j*`, int *`*k*`)` [C function]
Find position (before specified in *i*, *j*, *k*) of last nonzero value of formula *cond*. Function return the data value at found position.

`int Find (const char *`*cond*`, char` *dir*`, int` *i*`=0, int` *j*`=0, int` *k*`=0) const` [Method on `mglDataA`]
`mreal mgl_data_find (HCDT` *dat*`, const char *`*cond*`, int` *i*`, int` *j*`, int` *k*`)` [C function]
Return position of first in direction *dir* nonzero value of formula *cond*. The search is started from point {i,j,k}.

`bool FindAny (const char *`*cond*`) const` [Method on `mglDataA`]
`mreal mgl_data_find_any (HCDT` *dat*`, const char *`*cond*`)` [C function]
Determines if any nonzero value of formula in the data array.

`(dat) .a` [MGL suffix]
Give first (for `.a`, i.e. `dat->a[0]`).

6.10 Operators

`copy` DAT *dat2* ['eq'="] [MGL command]
`void operator= (const mglDataA &`*d*`)` [Method on `mglData`]
Copies data from other variable.

`copy` *dat* `val` [MGL command]
`void operator= (mreal` *val*`)` [Method on `mreal`]
Set all data values equal to *val*.

`multo` *dat dat2* [MGL command]
`multo` *dat* `val` [MGL command]
`void operator*= (const mglDataA &`*d*`)` [Method on `mglData`]
`void operator*= (mreal` *d*`)` [Method on `mglData`]
`void mgl_data_mul_dat (HMDT` *dat*`, HCDT` *d*`)` [C function]
`void mgl_data_mul_num (HMDT` *dat*`, mreal` *d*`)` [C function]
Multiplies data element by the other one or by value.

`divto` *dat dat2* [MGL command]
`divto` *dat* `val` [MGL command]
`void operator/= (const mglDataA &`*d*`)` [Method on `mglData`]
`void operator/= (mreal` *d*`)` [Method on `mglData`]
`void mgl_data_div_dat (HMDT` *dat*`, HCDT` *d*`)` [C function]
`void mgl_data_div_num (HMDT` *dat*`, mreal` *d*`)` [C function]
Divides each data element by the other one or by value.

`addto` *dat dat2* [MGL command]
`addto` *dat* `val` [MGL command]
`void operator+= (const mglDataA &`*d*`)` [Method on `mglData`]
`void operator+= (mreal` *d*`)` [Method on `mglData`]
`void mgl_data_add_dat (HMDT` *dat*`, HCDT` *d*`)` [C function]
`void mgl_data_add_num (HMDT` *dat*`, mreal` *d*`)` [C function]
Adds to each data element the other one or the value.

`subto` *dat dat2* [MGL command]
`subto` *dat* `val` [MGL command]
`void operator-= (const mglDataA &`*d*`)` [Method on `mglData`]
`void operator-= (mreal` *d*`)` [Method on `mglData`]
`void mgl_data_sub_dat (HMDT` *dat*`, HCDT` *d*`)` [C function]
`void mgl_data_sub_num (HMDT` *dat*`, mreal` *d*`)` [C function]
Subtracts from each data element the other one or the value.

`mglData operator+ (const mglDataA &`*a*`, const mglDataA &`*b*`)` [Library Function]
`mglData operator+ (mreal` *a*`, const mglDataA &`*b*`)` [Library Function]
`mglData operator+ (const mglDataA &`*a*`, mreal` *b*`)` [Library Function]
Adds the other data or the number.

`mglData operator- (const mglDataA &`*a*`, const mglDataA &`*b*`)` [Library Function]
`mglData operator- (mreal` *a*`, const mglDataA &`*b*`)` [Library Function]
`mglData operator- (const mglDataA &`*a*`, mreal` *b*`)` [Library Function]
Subtracts the other data or the number.

`mglData operator* (const mglDataA &`*a*`, const mglDataA &`*b*`)` [Library Function]
`mglData operator* (mreal` *a*`, const mglDataA &`*b*`)` [Library Function]
`mglData operator* (const mglDataA &`*a*`, mreal` *b*`)` [Library Function]
Multiplies by the other data or the number.

`mglData operator/ (const mglDataA &`*a*`, const mglDataA &`*b*`)` [Library Function]
`mglData operator/ (const mglDataA &`*a*`, mreal` *b*`)` [Library Function]
Divides by the other data or the number.

6.11 Global functions

These functions are not methods of `mglData` class. However it provide additional functionality to handle data. So I put it in this chapter.

`transform` DAT *'type' real imag* [MGL command]
`mglData mglTransform (const mglDataA &`*real*`, const mglDataA &`*imag*`, const char *`*type*`)` [Global function]
`HMDT mgl_transform (HCDT` *real*`, HCDT` *imag*`, const char *`*type*`)` [C function]
Does integral transformation of complex data *real*, *imag* on specified direction. The order of transformations is specified in string *type*: first character for x-dimension,

second one for y-dimension, third one for z-dimension. The possible character are: '`f`' is forward Fourier transformation, '`i`' is inverse Fourier transformation, '`s`' is Sine transform, '`c`' is Cosine transform, '`h`' is Hankel transform, '`n`' or ' ' is no transformation.

`transforma` DAT *'type' ampl phase* [MGL command]
`mglData mglTransformA const mglDataA &`*ampl*`, const mglDataA &`*phase*`, const char *`*type*) [Global function]
`HMDT mgl_transform_a HCDT` *ampl*`, HCDT` *phase*`, const char *`*type*) [C function]
The same as previous but with specified amplitude *ampl* and phase *phase* of complex numbers.

`fourier` *reDat imDat 'dir'* [MGL command]
`fourier` *complexDat 'dir'* [MGL command]
`void mglFourier const mglDataA &`*re*`, const mglDataA &`*im*`, const char *`*dir*) [Global function]
`void mgl_data_fourier HCDT` *re*`, HCDT` *im*`, const char *`*dir*) [C function]
Does Fourier transform of complex data *re*+i**im* in directions *dir*. Result is placed back into *re* and *im* data arrays.

`stfad` RES *real imag* `dn` ['*dir*'='*x*'] [MGL command]
`mglData mglSTFA (const mglDataA &`*real*`, const mglDataA &`*imag*`, int` *dn*`, char` *dir*`='x')` [Global function]
`HMDT mgl_data_stfa (HCDT` *real*`, HCDT` *imag*`, int` *dn*`,char` *dir*`)` [C function]
Short time Fourier transformation for real and imaginary parts. Output is amplitude of partial Fourier of length *dn*. For example if *dir*='`x`', result will have size {int(nx/dn), dn, ny} and it will contain $res[i,j,k] = |\sum_d^d nexp(I*j*d)*(real[i*dn+d,k]+I*imag[i*dn+d,k])|/dn$.

`pde` RES *'ham' ini_re ini_im* [`dz=0.1 k0=100`] [MGL command]
`mglData mglPDE (HMGL` *gr*`, const char *`*ham*`, const mglDataA &`*ini_re*`, const mglDataA &`*ini_im*`, mreal` *dz*`=0.1, mreal` *k0*`=100, const char *`*opt*`="")` [Global function]
`mglDataC mglPDEc (HMGL` *gr*`, const char *`*ham*`, const mglDataA &`*ini_re*`, const mglDataA &`*ini_im*`, mreal` *dz*`=0.1, mreal` *k0*`=100, const char *`*opt*`="")` [Global function]
`HMDT mgl_pde_solve (HMGL` *gr*`, const char *`*ham*`, HCDT` *ini_re*`, HCDT` *ini_im*`, mreal` *dz*`, mreal` *k0*`, const char *`*opt*`)` [C function]
`HADT mgl_pde_solve_c (HMGL` *gr*`, const char *`*ham*`, HCDT` *ini_re*`, HCDT` *ini_im*`, mreal` *dz*`, mreal` *k0*`, const char *`*opt*`)` [C function]
Solves equation du/dz = i*k0**ham*(p,q,x,y,z,|u|)[u], where p=-i/k0*d/dx, q=-i/k0*d/dy are pseudo-differential operators. Parameters *ini_re*, *ini_im* specify real and imaginary part of initial field distribution. Parameters *Min*, *Max* set the bounding box for the solution. Note, that really this ranges are increased by factor 3/2 for purpose of reducing reflection from boundaries. Parameter *dz* set the step along evolutionary coordinate z. At this moment, simplified form of function *ham* is supported – all "mixed" terms (like '`x*p`'->x*d/dx) are excluded. For example, in 2D case this function is effectively $ham = f(p,z) + g(x,z,u)$. However

commutable combinations (like 'x*q'->x*d/dy) are allowed. Here variable 'u' is used for field amplitude |u|. This allow one solve nonlinear problems – for example, for nonlinear Shrodinger equation you may set ham="p^2 + q^2 - u^2". You may specify imaginary part for wave absorption, like ham = "p^2 + i*x*(x>0)", but only if dependence on variable 'i' is linear (i.e. $ham = hre + i * him$). See also [qo2d], page 279, [qo3d], page 280. See Section 2.9.14 [PDE solving hints], page 131, for sample code and picture.

ray RES *'ham'* x0 y0 z0 p0 q0 v0 [dt=0.1 tmax=10] [MGL command]

mglData mglRay (const char *ham, mglPoint *r0*, mglPoint *p0*, mreal *dt*=0.1, mreal *tmax*=10) [Global function]

HMDT mgl_ray_trace (const char *ham, mreal *x0*, mreal *y0*, mreal *z0*, mreal *px*, mreal *py*, mreal *pz*, mreal *dt*, mreal *tmax*) [C function]

Solves GO ray equation like dr/dt = d *ham*/dp, dp/dt = -d *ham*/dr. This is Hamiltonian equations for particle trajectory in 3D case. Here *ham* is Hamiltonian which may depend on coordinates 'x', 'y', 'z', momentums 'p'=px, 'q'=py, 'v'=pz and time 't': $ham = H(x, y, z, p, q, v, t)$. The starting point (at t=0) is defined by variables *r0*, *p0*. Parameters *dt* and *tmax* specify the integration step and maximal time for ray tracing. Result is array of {x,y,z,p,q,v,t} with dimensions {7 * int(*tmax*/*dt*+1) }.

ode RES *'df' 'var' ini* [dt=0.1 tmax=10] [MGL command]

mglData mglODE (const char *df, const char *var, const mglDataA &*ini*, mreal *dt*=0.1, mreal *tmax*=10) [Global function]

HMDT mgl_ode_solve_str (const char *df, const char *var, HCDT *ini*, mreal *dt*, mreal *tmax*) [C function]

HMDT mgl_ode_solve (void (**df*)(const mreal *x, mreal *dx, void *par), int *n*, const mreal **ini*, mreal *dt*, mreal *tmax*) [C function]

HMDT mgl_ode_solve_ex (void (**df*)(const mreal *x, mreal *dx, void *par), int *n*, const mreal **ini*, mreal *dt*, mreal *tmax*, void (**bord*)(mreal *x, const mreal *xprev, void *par)) [C function]

Solves ODE equations dx/dt = df(x). The functions *df* can be specified as string of ';'-separated textual formulas (argument *var* set the character ids of variables x[i]) or as callback function, which fill dx array for give x's. Parameters *ini*, *dt*, *tmax* set initial values, time step and maximal time of the calculation. Result is data array with dimensions {*n* * int(*tmax*/*dt*+1)}.

qo2d RES *'ham' ini_re ini_im ray* [r=1 k0=100 *xx yy*] [MGL command]

mglData mglQO2d (const char *ham, const mglDataA &*ini_re*, const mglDataA &*ini_im*, const mglDataA &*ray*, mreal *r*=1, mreal *k0*=100) [Global function]

mglData mglQO2d (const char *ham, const mglDataA &*ini_re*, const mglDataA &*ini_im*, const mglDataA &*ray*, mglData &*xx*, mglData &*yy*, mreal *r*=1, mreal *k0*=100) [Global function]

mglDataC mglQO2dc (const char *ham, const mglDataA &*ini_re*, const mglDataA &*ini_im*, const mglDataA &*ray*, mreal *r*=1, mreal *k0*=100) [Global function]

`mglDataC mglQO2dc (const char *ham, const mglDataA &ini_re, const mglDataA &ini_im, const mglDataA &ray, mglData &xx, mglData &yy, mreal r=1, mreal k0=100)` [Global function]

`HMDT mgl_qo2d_solve (const char *ham, HCDT ini_re, HCDT ini_im, HCDT ray, mreal r, mreal k0, HMDT xx, HMDT yy)` [C function]

`HADT mgl_qo2d_solve_c (const char *ham, HCDT ini_re, HCDT ini_im, HCDT ray, mreal r, mreal k0, HMDT xx, HMDT yy)` [C function]

`HMDT mgl_qo2d_func (dual (*ham)(mreal u, mreal x, mreal y, mreal px, mreal py, void *par), HCDT ini_re, HCDT ini_im, HCDT ray, mreal r, mreal k0, HMDT xx, HMDT yy)` [C function]

`HADT mgl_qo2d_func_c (dual (*ham)(mreal u, mreal x, mreal y, mreal px, mreal py, void *par), HCDT ini_re, HCDT ini_im, HCDT ray, mreal r, mreal k0, HMDT xx, HMDT yy)` [C function]

Solves equation du/dt = i*k0*ham(p,q,x,y,|u|)[u], where p=-i/k0*d/dx, q=-i/k0*d/dy are pseudo-differential operators (see `mglPDE()` for details). Parameters *ini_re*, *ini_im* specify real and imaginary part of initial field distribution. Parameters *ray* set the reference ray, i.e. the ray around which the accompanied coordinate system will be maked. You may use, for example, the array created by [ray], page 279 function. Note, that the reference ray **must be** smooth enough to make accompanied coodrinates unambiguity. Otherwise errors in the solution may appear. If *xx* and *yy* are non-zero then Cartesian coordinates for each point will be written into them. See also [pde], page 278, [qo3d], page 280. See Section 2.9.14 [PDE solving hints], page 131, for sample code and picture.

`qo3d` RES *'ham' ini_re ini_im ray* [`r=1 k0=100` *xx yy zz*] [MGL command]

`mglData mglQO3d (const char *ham, const mglDataA &ini_re, const mglDataA &ini_im, const mglDataA &ray, mreal r=1, mreal k0=100)` [Global function]

`mglData mglQO3d (const char *ham, const mglDataA &ini_re, const mglDataA &ini_im, const mglDataA &ray, mglData &xx, mglData &yy, mglData &zz, mreal r=1, mreal k0=100)` [Global function]

`mglDataC mglQO3dc (const char *ham, const mglDataA &ini_re, const mglDataA &ini_im, const mglDataA &ray, mreal r=1, mreal k0=100)` [Global function]

`mglDataC mglQO3dc (const char *ham, const mglDataA &ini_re, const mglDataA &ini_im, const mglDataA &ray, mglData &xx, mglData &yy, mglData &zz, mreal r=1, mreal k0=100)` [Global function]

`HMDT mgl_qo3d_solve (const char *ham, HCDT ini_re, HCDT ini_im, HCDT ray, mreal r, mreal k0, HMDT xx, HMDT yy, HMDT zz)` [C function]

`HADT mgl_qo3d_solve_c (const char *ham, HCDT ini_re, HCDT ini_im, HCDT ray, mreal r, mreal k0, HMDT xx, HMDT yy, HMDT zz)` [C function]

`HMDT mgl_qo3d_func (dual (*ham)(mreal u, mreal x, mreal y, mreal z, mreal px, mreal py, mreal pz, void *par), HCDT ini_re, HCDT ini_im, HCDT ray, mreal r, mreal k0, HMDT xx, HMDT yy, HMDT zz)` [C function]

`HADT mgl_qo3d_func_c (dual (*ham)(mreal u, mreal x, mreal y, mreal z, mreal px, mreal py, mreal pz, void *par), HCDT ini_re, HCDT ini_im, HCDT ray, mreal r, mreal k0, HMDT xx, HMDT yy, HMDT zz)` [C function]

Solves equation du/dt = i*k0*ham(p,q,v,x,y,z,|u|)[u], where p=-i/k0*d/dx, q=-i/k0*d/dy, v=-i/k0*d/dz are pseudo-differential operators (see `mglPDE()` for details). Parameters *ini_re*, *ini_im* specify real and imaginary part of initial field distribution. Parameters *ray* set the reference ray, i.e. the ray around which the accompanied coordinate system will be maked. You may use, for example, the array created by [ray], page 279 function. Note, that the reference ray **must be** smooth enough to make accompanied coodrinates unambiguity. Otherwise errors in the solution may appear. If *xx* and *yy* and *zz* are non-zero then Cartesian coordinates for each point will be written into them. See also [pde], page 278, [qo2d], page 279. See Section 2.9.14 [PDE solving hints], page 131, for sample code and picture.

`jacobian` RES *xdat ydat* [*zdat*] [MGL command]

`mglData mglJacobian (const mglDataA &x, const mglDataA &y)` [Global function]

`mglData mglJacobian (const mglDataA &x, const mglDataA &y, const mglDataA &z)` [Global function]

`HMDT mgl_jacobian_2d (HCDT x, HCDT y)` [C function]

`HMDT mgl_jacobian_3d (HCDT x, HCDT y, HCDT z)` [C function]

Computes the Jacobian for transformation {i,j,k} to {*x*,*y*,*z*} where initial coordinates {i,j,k} are data indexes normalized in range [0,1]. The Jacobian is determined by formula $\det||dr_\alpha/d\xi_\beta||$ where r={*x*,*y*,*z*} and ξ={i,j,k}. All dimensions must be the same for all data arrays. Data must be 3D if all 3 arrays {*x*,*y*,*z*} are specified or 2D if only 2 arrays {*x*,*y*} are specified.

`triangulation` RES *xdat ydat* [MGL command]

`mglData mglTriangulation (const mglDataA &x, const mglDataA &y)` [Global function]

`HMDT mgl_triangulation_2d (HCDT x, HCDT y)` [C function]

Computes triangulation for arbitrary placed points with coordinates {*x*,*y*} (i.e. finds triangles which connect points). MathGL use s-hull (`http://www.s-hull.org/`) code for triangulation. The sizes of 1st dimension **must be equal** for all arrays `x.nx=y.nx`. Resulting array can be used in [triplot], page 230 or [tricont], page 230 functions for visualization of reconstructed surface. See Section 2.9.11 [Making regular data], page 128, for sample code and picture.

`mglData mglGSplineInit (const mglDataA &x, const mglDataA &y)` [Global function]

`mglDataC mglGSplineCInit (const mglDataA &x, const mglDataA &y)` [Global function]

`HMDT mgl_gspline_init (HCDT x, HCDT y)` [C function]

`HADT mgl_gsplinec_init (HCDT x, HCDT y)` [C function]

Prepare coefficients for global cubic spline interpolation.

`mreal mglGSpline (const mglDataA &`*coef*`, mreal` *dx*`, mreal *`*d1*`=0, mreal *`*d2*`=0)` [Global function]
`dual mglGSplineC (const mglDataA &`*coef*`, mreal` *dx*`, dual *`*d1*`=0, dual *`*d2*`=0)` [Global function]
`mreal mgl_gspline (HCDT` *coef*`, mreal` *dx*`, mreal *`*d1*`, mreal *`*d2*`)` [C function]
`dual mgl_gsplinec (HCDT` *coef*`, mreal` *dx*`, dual *`*d1*`, dual *`*d2*`)` [C function]
Evaluate global cubic spline (and its 1st and 2nd derivatives *d1*, *d2* if they are not `NULL`) using prepared coefficients *coef* at point *dx*+*x0* (where *x0* is 1st element of data *x* provided to `mglGSpline*Init()` function).

`ifs2d` RES *dat* `num [skip=20]` [MGL command]
`mglData mglIFS2d (const mglDataA &`*dat*`, long` *num*`, long` *skip*`=20)` [Global function]
`HMDT mgl_data_ifs_2d (HCDT` *dat*`, long` *num*`, long` *skip*`)` [C function]
Computes *num* points {x[i]=res[0,i], y[i]=res[1,i]} for fractal using iterated function system. Matrix *dat* is used for generation according the formulas

```
x[i+1] = dat[0,i]*x[i] + dat[1,i]*y[i] + dat[4,i];
y[i+1] = dat[2,i]*x[i] + dat[3,i]*y[i] + dat[5,i];
```

Value `dat[6,i]` is used as weight factor for i-th row of matrix *dat*. At this first *skip* iterations will be omitted. Data array *dat* must have x-size greater or equal to 7. See Section 2.7.14 [IFS sample], page 101, for sample code and picture.

`ifs3d` RES *dat* `num [skip=20]` [MGL command]
`mglData mglIFS3d (const mglDataA &`*dat*`, long` *num*`, long` *skip*`=20)` [Global function]
`HMDT mgl_data_ifs_3d (HCDT` *dat*`, long` *num*`, long` *skip*`)` [C function]
Computes *num* points {x[i]=res[0,i], y[i]=res[1,i], z[i]=res[2,i]} for fractal using iterated function system. Matrix *dat* is used for generation according the formulas

```
x[i+1] = dat[0,i]*x[i] + dat[1,i]*y[i] + dat[2,i]*z[i] + dat[9,i];
y[i+1] = dat[3,i]*x[i] + dat[4,i]*y[i] + dat[5,i]*z[i] + dat[10,i];
z[i+1] = dat[6,i]*x[i] + dat[7,i]*y[i] + dat[8,i]*z[i] + dat[10,i];
```

Value `dat[12,i]` is used as weight factor for i-th row of matrix *dat*. At this first *skip* iterations will be omitted. Data array *dat* must have x-size greater or equal to 13. See Section 2.7.14 [IFS sample], page 101, for sample code and picture.

6.12 Evaluate expression

MathGL have a special classes `mglExpr` and `mglExprC` for evaluating of formula specified by the string for real and complex numbers correspondingly. These classes are defined in `#include <mgl2/data.h>` and `#include <mgl2/datac.h>` correspondingly. It is the fast variant of formula evaluation. At creation it will be recognized and compiled to tree-like internal code. At evaluation stage only fast calculations are performed. There is no difference between lower or upper case in formulas. If argument value lie outside the range of function definition then function returns NaN. See Section 3.6 [Textual formulas], page 153.

`mglExpr (const char *`*expr*`)` [Constructor on `mglExpr`]
`mglExprC (const char *`*expr*`)` [Constructor on `mglExprC`]

`HMEX mgl_create_expr (const char *expr)` [C function]
`HAEX mgl_create_cexpr (const char *expr)` [C function]
Parses the formula *expr* and creates formula-tree. Constructor recursively parses the formula and creates a tree-like structure containing functions and operators for fast further evaluating by `Calc()` or `CalcD()` functions.

`~mglExpr ()` [Destructor on `mglExpr`]
`~mglExprC ()` [Destructor on `mglExprC`]
`void mgl_delete_expr (HMEX ex)` [C function]
`void mgl_delete_cexpr (HAEX ex)` [C function]
Deletes the instance of class mglExpr.

`mreal Eval (mreal x, mreal y, mreal z)` [Method on `mglExpr`]
`dual Eval (dual x, dual y, dual z)` [Method on `mglExprC`]
`mreal mgl_expr_eval (HMEX ex, mreal x, mreal y, mreal z)` [C function]
`dual mgl_cexpr_eval (HAEX ex, dual x, dual y, dual z)` [C function]
Evaluates the formula for `'x','r'`=*x*, `'y','n'`=*y*, `'z','t'`=*z*, `'a','u'`=*u*.

`mreal Eval (mreal var[26])` [Method on `mglExpr`]
`dual Eval (dual var[26])` [Method on `mglExprC`]
`mreal mgl_expr_eval_v (HMEX ex, mreal *var)` [C function]
`dual mgl_expr_eval_v (HAEX ex, dual *var)` [C function]
Evaluates the formula for variables in array *var*[0,...,'z'-'a'].

`mreal Diff (char dir, mreal x, mreal y, mreal z)` [Method on `mglExpr`]
`mreal mgl_expr_diff (HMEX ex, char dir, mreal x, mreal y, mreal z)` [C function]
Evaluates the formula derivation respect to *dir* for `'x','r'`=*x*, `'y','n'`=*y*, `'z','t'`=*z*, `'a','u'`=*u*.

`mreal Diff (char dir, mreal var[26])` [Method on `mglExpr`]
`mreal mgl_expr_diff_v (HMEX ex, char dir, mreal *var)` [C function]
Evaluates the formula derivation respect to *dir* for variables in array *var*[0,...,'z'-'a'].

6.13 Special data classes

This section describe special data classes `mglDataV`, `mglDataF`, `mglDataT` and `mglDataR` which sometime can noticeable speed up drawing or data handling. These classes are defined in `#include <mgl2/data.h>`. Note, that all plotting and data handling routines can be done using usual `mglData` or `mglDataC` classes. Also these special classes are usable in C++ code only.

Class `mglDataV`

represent variable with values equidistantly distributed in given range.

`mglDataV (const mglDataV & d)` [Constructor on `mglDataV`]
Copy constructor.

`mglDataV (long nx=1, long ny=1, long nz=1, mreal v1=0, mreal v2=NaN, char dir='x')` [Constructor on `mglDataV`]
Create variable with "sizes" *nx*x*ny*x*nz* which changes from *v1* to *v2* (or is constant if *v2*=`NaN`) along *dir* direction.

`void Create (long nx=1, long ny=1, long nz=1)` [Method on `mglDataV`]
Set "sizes" *nx*x*ny*x*nz*.

`void Fill (mreal x1, mreal x2=NaN, char dir='x')` [Method on `mglDataV`]
Set ranges of the variable.

`void Freq (mreal dp, char dir='x')` [Method on `mglDataV`]
Set as frequency variable with increment *dp*.

Class `mglDataF`

represent function which values are evaluated (instead of access to data array as in `mglData`).

`mglDataF (const mglDataF & d)` [Constructor on `mglDataF`]
Copy constructor.

`mglDataF (long nx=1, long ny=1, long nz=1)` [Constructor on `mglDataF`]
Create variable with "sizes" *nx*x*ny*x*nz* with zero function.

`void Create (long nx=1, long ny=1, long nz=1)` [Method on `mglDataF`]
Set "sizes" *nx*x*ny*x*nz*.

`void SetRanges (mglPoint p1, mglPoint p2)` [Method on `mglDataF`]
Set ranges for internal x,y,z variables.

`void SetFormula (const char *func)` [Method on `mglDataF`]
Set string which will be evaluated at function calls. Note this variant is about 10 times slower than `SetFunc`() one.

`void SetFunc (mreal (*f)(mreal x,mreal y,mreal z,void *p), void *p=NULL)` [Method on `mglDataF`]
Set pointer to function which will be used for data.

Class `mglDataT`

represent named reference to column of another data array.

`mglDataT (const mglDataT & d)` [Constructor on `mglDataT`]
Copy constructor.

`mglDataT (const mglDataA & d, long col=0)` [Constructor on `mglDataT`]
Create variable which reference *col*-th column of data *d*.

`void SetInd (long col, wchar_t name)` [Method on `mglDataT`]
`void SetInd (long col, const wchar_t * name)` [Method on `mglDataT`]
Set reference to another column of the same data and its name.

Class mglDataR

represent named reference to row of another data array.

`mglDataR (const mglDataR & d)` [Constructor on `mglDataR`]
Copy constructor.

`mglDataR (const mglDataA & d, long row=0)` [Constructor on `mglDataR`]
Create variable which reference *row*-th row of data *d*.

`void SetInd (long row, wchar_t name)` [Method on `mglDataR`]
`void SetInd (long row, const wchar_t * name)` [Method on `mglDataR`]
Set reference to another row of the same data and its name.

7 MGL scripts

MathGL library supports the simplest scripts for data handling and plotting. These scripts can be used independently (with the help of UDAV, mglconv, mglview programs and others , see Section 1.6 [Utilities], page 4) or in the frame of the library using.

7.1 MGL definition

MGL script language is rather simple. Each string is a command. First word of string is the name of command. Other words are command arguments. Command may have up to 1000 arguments (at least for now). Words are separated from each other by space or tabulation symbol. The upper or lower case of words is important, i.e. variables *a* and *A* are different variables. Symbol '`#`' starts the comment (all characters after # will be ignored). The exception is situation when '`#`' is a part of some string. Also options can be specified after symbol '`;`' (see Section 3.7 [Command options], page 154). Symbol '`:`' starts new command (like new line character) if it is not placed inside a string or inside brackets.

If string contain references to external parameters (substrings '`$0`', '`$1`' ... '`$9`') or definitions (substrings '`$a`', '`$b`' ... '`$z`') then before execution the values of parameter/definition will be substituted instead of reference. It allows to use the same MGL script for different parameters (filenames, paths, condition and so on).

Argument can be a string, a variable (data arrays) or a number (scalars).

- The string is any symbols between ordinary marks '`''`'. Long strings can be concatenated from several lines by '`\`' symbol. I.e. the string '`'a +'\<br>' b'`' will give string '`'a + b'`' (here '`<br>`' is newline). Also you can concatenate strings and numbers using '`,`' with out spaces (for example, '`'max(u)=',u.max,' a.u.'`').
- Usually variable have a name which is arbitrary combination of symbols (except spaces and '`''`') started from a letter. Note, you can start an expression with '`!`' symbol if you want to use complex values. For example, the code `new x 100 'x':copy !b !exp(1i*x)` will create real valued data x and complex data b, which is equal to $exp(I*x)$, where $I^2=-1$. A temporary array can be used as variable too:
  - sub-arrays (like in [subdata], page 264 command) as command argument. For example, `a(1)` or `a(1,:)` or `a(1,:,:)` is second row, `a(:,2)` or `a(:,2,:)` is third column, `a(:,:,0)` is first slice and so on. Also you can extract a part of array from m-th to n-th element by code `a(m:n,:,:)` or just `a(m:n)`.
  - any column combinations defined by formulas, like `a('n*w^2/exp(t)')` if names for data columns was specified (by [idset], page 262 command or in the file at string started with `##`).
  - any expression (without spaces) of existed variables produce temporary variable. For example, '`sqrt(dat(:,5)+1)`' will produce temporary variable with data values equal to `tmp[i,j] = sqrt(dat[i,5,j]+1)`.
  - temporary variable of higher dimensions by help of []. For example, '`[1,2,3]`' will produce a temporary vector of 3 elements {1, 2, 3}; '`[[11,12],[21,22]]`' will produce matrix 2*2 and so on. Here you can join even an arrays of the same dimensions by construction like '`[v1,v2,...,vn]`'.

- result of code for making new data (see Section 6.6 [Make another data], page 264) inside {}. For example, '`{sum dat 'x'}`' produce temporary variable which contain result of summation of *dat* along direction 'x'. This is the same array *tmp* as produced by command '`sum tmp dat 'x'`'. You can use nested constructions, like '`{sum {max dat 'z'} 'x'}`'.

  Temporary variables can not be used as 1st argument for commands which create (return) the data (like '`new`', '`read`', '`hist`' and so on).

- Special names `nan=#QNAN, inf=INFINITY, rnd=random value, pi=3.1415926..., on=1, off=0, :=-1`, variables with suffixes (see Section 6.9 [Data information], page 273), names defined by [define], page 287 command are treated as number. Also results of formulas with sizes 1x1x1 are treated as number (for example, '`pi/dat.nx`').

Before the first using all variables must be defined with the help of commands, like, [new], page 253, [var], page 259, [list], page 256, [copy], page 254, [read], page 262, [hist], page 267, [sum], page 267 and so on (see sections Section 6.2 [Data constructor], page 253, Section 6.4 [Data filling], page 256 and Section 6.6 [Make another data], page 264).

Command may have several set of possible arguments (for example, `plot ydat` and `plot xdat ydat`). All command arguments for a selected set must be specified. However, some arguments can have default values. These argument are printed in [], like `text ydat ['stl'='']` or `text x y 'txt' ['fnt'='' size=-1]`. At this, the record `[arg1 arg2 arg3 ...]` means `[arg1 [arg2 [arg3 ...]]]`, i.e. you can omit only tailing arguments if you agree with its default values. For example, `text x y 'txt' '' 1` or `text x y 'txt' ''` is correct, but `text x y 'txt' 1` is incorrect (argument `'fnt'` is missed).

7.2 Program flow commands

Below I show commands to control program flow, like, conditions, loops, define script arguments and so on. Other commands can be found in chapters Chapter 4 [MathGL core], page 158 and Chapter 6 [Data processing], page 252. Note, that some of program flow commands (like [define], page 287, [ask], page 287, [call], page 288, [for], page 288, [func], page 288) should be placed alone in the string.

`chdir` *'path'* [MGL command]
: Changes the current directory to *path*.

`ask` *$N 'question'* [MGL command]
: Sets *N*-th script argument to answer which give the user on the *question*. Usually this show dialog with question where user can enter some text as answer. Here *N* is digit (0...9) or alpha (a...z).

`define` *$N smth* [MGL command]
: Sets *N*-th script argument to *smth*. Note, that *smth* is used as is (with '' symbols if present). Here *N* is digit (0...9) or alpha (a...z).

`define` *name smth* [MGL command]
: Create scalar variable `name` which have the numeric value of `smth`. Later you can use this variable as usual number.

`defchr` *$N smth* [MGL command]
Sets *N*-th script argument to character with value evaluated from *smth*. Here *N* is digit (0...9) or alpha (a...z).

`defnum` *$N smth* [MGL command]
Sets *N*-th script argument to number with value evaluated from *smth*. Here *N* is digit (0...9) or alpha (a...z).

`call` *'funcname'* [*ARG1 ARG2 ... ARG9*] [MGL command]
Executes function *fname* (or script if function is not found). Optional arguments will be passed to functions. See also [func], page 288.

`func` *'funcname'* [*narg=0*] [MGL command]
Define the function *fname* and number of required arguments. The arguments will be placed in script parameters $1, $2, ... $9. Note, script execution is stopped at `func` keyword, similarly to [stop], page 289 command. See also [return], page 288.

`return` [MGL command]
Return from the function. See also [func], page 288.

`load` *'filename'* [MGL command]
Load additional MGL command from external module (DLL or .so), located in file *filename*. This module have to contain array with name `mgl_cmd_extra` of type `mglCommand`, which describe provided commands.

`if` *dat 'cond'* [MGL command]
Starts block which will be executed if *dat* satisfy to *cond*.

`if val` [MGL command]
Starts block which will be executed if `val` is nonzero.

`elseif` *dat 'cond'* [MGL command]
Starts block which will be executed if previous `if` or `elseif` is false and *dat* satisfy to *cond*.

`elseif val` [MGL command]
Starts block which will be executed if previous `if` or `elseif` is false and `val` is nonzero.

`else` [MGL command]
Starts block which will be executed if previous `if` or `elseif` is false.

`endif` [MGL command]
Finishes `if/elseif/else` block.

`for` *$N* `v1 v2` [`dv=1`] [MGL command]
Starts cycle with $*N*-th argument changing from *v1* to *v2* with the step *dv*. Here *N* is digit (0...9) or alpha (a...z).

`for` *$N dat* [MGL command]
Starts cycle with $*N*-th argument changing for *dat* values. Here *N* is digit (0...9) or alpha (a...z).

`next` [MGL command]
Finishes `for` cycle.

`once val` [MGL command]
The code between `once on` and `once off` will be executed only once. Useful for large data manipulation in programs like UDAV.

`stop` [MGL command]
Terminate execution.

`rkstep` *eq1;... var1;...* [`dt=1`] [MGL command]
Make one step for ordinary differential equation(s) {var1' = eq1, ... } with time-step *dt*. Here variable(s) '`var1`', ... are the ones, defined in MGL script previously. The Runge-Kutta 4-th order method is used for solution.

7.3 LaTeX package

There is LaTeX package `mgltex` (was made by Diego Sejas Viscarra) which allow one to make figures directly from MGL script located in LaTeX file.

For using this package you need to specify `--shell-escape` option for *latex/pdflatex* or manually run *mglconv* tool with produced MGL scripts for generation of images. Don't forgot to run *latex/pdflatex* second time to insert generated images into the output document. Also you need to run *pdflatex* third time to update converted from EPS images if you are using vector EPS output (default).

The package may have following options: `draft`, `final` — the same as in the *graphicx* package; `on`, `off` — to activate/deactivate the creation of scripts and graphics; `comments`, `nocomments` — to make visible/invisible commentaries contained inside `mglcomment` environments; `jpg`, `jpeg`, `png` — to export graphics as JPEG/PNG images; `eps`, `epsz` — to export to uncompressed/compressed EPS format as primitives; `bps`, `bpsz` — to export to uncompressed/compressed EPS format as bitmap (doesn't work with *pdflatex*); `pdf` — to export to 3D PDF; `tex` — to export to *LaTeX/tikz* document.

The package defines the following environments:

'`mgl`' It writes its contents to a general script which has the same name as the LaTeX document, but its extension is *.mgl*. The code in this environment is compiled and the image produced is included. It takes exactly the same optional arguments as the `\includegraphics` command, plus an additional argument *imgext*, which specifies the extension to save the image.

An example of usage of '`mgl`' environment would be:

```
\begin{mglfunc}{prepare2d}
  new a 50 40 '0.6*sin(pi*(x+1))*sin(1.5*pi*(y+1))+0.4*cos(0.75*pi*(x+1)*(y+1))'
  new b 50 40 '0.6*cos(pi*(x+1))*cos(1.5*pi*(y+1))+0.4*cos(0.75*pi*(x+1)*(y+1))'
\end{mglfunc}

\begin{figure}[!ht]
  \centering
  \begin{mgl}[width=0.85\textwidth,height=7.5cm]
    fog 0.5
```

```
    call 'prepare2d'
    subplot 2 2 0 : title 'Surf plot (default)' : rotate 50 60 : light on : box :

    subplot 2 2 1 : title '"\#" style; meshnum 10' : rotate 50 60 : box
    surf a '#'; meshnum 10

    subplot 2 2 2 : title 'Mesh plot' : rotate 50 60 : box
    mesh a

    new x 50 40 '0.8*sin(pi*x)*sin(pi*(y+1)/2)'
    new y 50 40 '0.8*cos(pi*x)*sin(pi*(y+1)/2)'
    new z 50 40 '0.8*cos(pi*(y+1)/2)'
    subplot 2 2 3 : title 'parametric form' : rotate 50 60 : box
    surf x y z 'BbwrR'
  \end{mgl}
\end{figure}
```

'`mgladdon`'
: It adds its contents to the general script, without producing any image.

'`mglcode`' Is exactly the same as '`mgl`', but it writes its contents verbatim to its own file, whose name is specified as a mandatory argument.

'`mglscript`'
: Is exactly the same as '`mglcode`', but it doesn't produce any image, nor accepts optional arguments. It is useful, for example, to create a MGL script, which can later be post processed by another package like "listings".

'`mglblock`'
: It writes its contents verbatim to a file, specified as a mandatory argument, and to the LaTeX document, and numerates each line of code.

'`mglverbatim`'
: Exactly the same as '`mglblock`', but it doesn't write to a file. This environment doesn't have arguments.

'`mglfunc`' Is used to define MGL functions. It takes one mandatory argument, which is the name of the function, plus one additional argument, which specifies the number of arguments of the function. The environment needs to contain only the body of the function, since the first and last lines are appended automatically, and the resulting code is written at the end of the general script, after the [stop], page 289 command, which is also written automatically. The warning is produced if 2 or more function with the same name is defined.

'`mglcomment`'
: Is used to contain multiline commentaries. This commentaries will be visible/invisible in the output document, depending on the use of the package options `comments` and `nocomments` (see above), or the `\mglcomments` and `\mglnocomments` commands (see bellow).

‘`mglsetup`’
: If many scripts with the same code are to be written, the repetitive code can be written inside this environment only once, then this code will be used automatically every time the ‘`\mglplot`’ command is used (see below). It takes one optional argument, which is a name to be associated to the corresponding contents of the environment; this name can be passed to the ‘`\mglplot`’ command to use the corresponding block of code automatically (see below).

The package also defines the following commands:

‘`\mglplot`’
: It takes one mandatory argument, which is MGL instructions separated by the symbol ‘`:`’ this argument can be more than one line long. It takes the same optional arguments as the ‘`mgl`’ environment, plus an additional argument *setup*, which indicates the name associated to a block of code inside a ‘`mglsetup`’ environment. The code inside the mandatory argument will be appended to the block of code specified, and the resulting code will be written to the general script.

  An example of usage of ‘`\mglplot`’ command would be:

```
\begin{mglsetup}
    box '@{W9}' : axis
\end{mglsetup}
\begin{mglsetup}[2d]
  box : axis
  grid 'xy' ';k'
\end{mglsetup}
\begin{mglsetup}[3d]
  rotate 50 60
  box : axis : grid 'xyz' ';k'
\end{mglsetup}
\begin{figure}[!ht]
  \centering
  \mglplot[scale=0.5]{new a 200 'sin(pi*x)' : plot a '2B'}
\end{figure}
\begin{figure}[!ht]
  \centering
  \mglplot[scale=0.5,setup=2d]{
    fplot 'sin(pi*x)' '2B' :
    fplot 'cos(pi*x^2)' '2R'
  }
\end{figure}
\begin{figure}[!ht]
  \centering
  \mglplot[setup=3d]{fsurf 'sin(pi*x)+cos(pi*y)'}
\end{figure}
```

'`\mglgraphics`'
: This command takes the same optional arguments as the '`mgl`' environment, and one mandatory argument, which is the name of a MGL script. This command will compile the corresponding script and include the resulting image. It is useful when you have a script outside the LaTeX document, and you want to include the image, but you don't want to type the script again.

'`\mglinclude`'
: This is like '`\mglgraphics`' but, instead of creating/including the corresponding image, it writes the contents of the MGL script to the LaTeX document, and numerates the lines.

'`\mgldir`'
: This command can be used in the preamble of the document to specify a directory where LaTeX will save the MGL scripts and generate the corresponding images. This directory is also where '`\mglgraphics`' and '`\mglinclude`' will look for scripts.

'`\mglquality`'
: Adjust the quality of the MGL graphics produced similarly to [quality], page 176.

'`\mgltexon, \mgltexoff`'
: Activate/deactivate the creation of MGL scripts and images. Notice these commands have local behavior in the sense that their effect is from the point they are called on.

'`\mglcomment, \mglnocomment`'
: Make visible/invisible the contents of the `mglcomment` environments. These commands have local effect too.

'`\mglTeX`'
: It just pretty prints the name of the package.

As an additional feature, when an image is not found or cannot be included, instead of issuing an error, `mgltex` prints a box with the word '`MGL image not found`' in the LaTeX document.

7.4 mglParse class

Class for parsing and executing MGL script. This class is defined in `#include <mgl2/mgl.h>`.

The main function of mglParse class is `Execute()`. Exactly this function parses and executes the script string-by-string. Also there are subservient functions for the finding and creation of a variable (object derived from `mglDataA`). These functions can be useful for displaying values of variables (arrays) in some external object (like, window) or for providing access to internal data. Function `AllowSetSize()` allows one to prevent changing the size of the picture inside the script (forbids the MGL command `setsize`).

`mglParse (bool` *setsize*`=false)` [Constructor on `mglParse`]
`mglParse (HMPR` *pr*`)` [Constructor on `mglParse`]
`mglParse (mglParse &`*pr*`)` [Constructor on `mglParse`]
`HMPR mgl_create_parser ()` [C function]

Constructor initializes all values with zero and set *AllowSetSize* value.

`~mglParse ()` [Destructor on `mglParse`]
`void mgl_delete_parser (HMPR` *p*`)` [C function]
Destructor delete parser

`HMPR Self ()` [Method on `mglParse`]
Returns the pointer to internal object of type `HMPR`.

`void Execute (mglGraph *`*gr*`, const char *`*text*`)` [Method on `mglParse`]
`void Execute (mglGraph *`*gr*`, const wchar_t *`*text*`)` [Method on `mglParse`]
`void mgl_parse_text (HMGL` *gr*`, HMPR` *p*`, const char *`*text*`)` [C function]
`void mgl_parse_textw (HMGL` *gr*`, HMPR` *p*`, const wchar_t *`*text*`)` [C function]
Main function in the class. Function parse and execute line-by-line MGL script in array *text*. Lines are separated by newline symbol '`\n`' as usual.

`void Execute (mglGraph *`*gr*`, FILE *`*fp*`, bool` *print*`=false)` [Method on `mglParse`]
`void mgl_parse_file (HMGL` *gr*`, HMPR` *p*`, FILE *`*fp*`, int` *print*`)` [C function]
The same as previous but read script from the file *fp*. If *print*=`true` then all warnings and information will be printed in stdout.

`int Parse (mglGraph *`*gr*`, const char *`*str*`, long` *pos*`=0)` [Method on `mglParse`]
`int Parse (mglGraph *`*gr*`, const wchar_t *`*str*`, long` *pos*`=0)` [Method on `mglParse`]
`int mgl_parse_line (HMGL` *gr*`, HMPR` *p*`, const char *`*str*`, int` *pos*`)` [C function]
`int mgl_parse_linew (HMGL` *gr*`, HMPR` *p*`, const wchar_t *`*str*`, int` *pos*`)` [C function]
Function parses the string *str* and executes it by using *gr* as a graphics plotter. Returns the value depending on an error presence in the string *str*: 0 – no error, 1 – wrong command argument(s), 2 – unknown command, 3 – string is too long, 4 – strings is not closed. Optional argument *pos* allows to save the string position in the document (or file) for using `for|next` command.

`mglData Calc (const char *`*formula*`)` [Method on `mglParse`]
`mglData Calc (const wchar_t *`*formula*`)` [Method on `mglParse`]
`HMDT mgl_parser_calc (HMPR` *p*`, const char *`*formula*`)` [C function]
`HMDT mgl_parser_calcw (HMPR` *p*`, const wchar_t *`*formula*`)` [C function]
Function parses the string *formula* and return resulting data array. In difference to `AddVar()` or `FindVar()`, it is usual data array which should be deleted after usage.

`mglDataC CalcComplex (const char *`*formula*`)` [Method on `mglParse`]
`mglDataC CalcComplex (const wchar_t *`*formula*`)` [Method on `mglParse`]
`HADT mgl_parser_calc_complex (HMPR` *p*`, const char *`*formula*`)` [C function]
`HADT mgl_parser_calc_complexw (HMPR` *p*`, const wchar_t *`*formula*`)` [C function]
Function parses the string *formula* and return resulting data array with complex values. In difference to `AddVar()` or `FindVar()`, it is usual data array which should be deleted after usage.

`void AddParam (int` *n*`, const char *`*str*`)` [Method on `mglParse`]
`void AddParam (int` *n*`, const wchar_t *`*str*`)` [Method on `mglParse`]

`void mgl_parser_add_param (HMPR p, int id, const char *val)` [C function]
`void mgl_parser_add_paramw (HMPR p, int id, const wchar_t *val)` [C function]
Function set the value of n-th parameter as string *str* (n=0, 1 ... 'z'-'a'+10). String *str* shouldn't contain '$' symbol.

`mglVar * FindVar (const char *name)` [Method on `mglParse`]
`mglVar * FindVar (const wchar_t *name)` [Method on `mglParse`]
`HMDT mgl_parser_find_var (HMPR p, const char *name)` [C function]
`HMDT mgl_parser_find_varw (HMPR p, const wchar_t *name)` [C function]
Function returns the pointer to variable with name *name* or zero if variable is absent. Use this function to put external data array to the script or get the data from the script. You must **not delete** obtained data arrays!

`mglVar * AddVar (const char *name)` [Method on `mglParse`]
`mglVar * AddVar (const wchar_t *name)` [Method on `mglParse`]
`HMDT mgl_parser_add_var (HMPR p, const char *name)` [C function]
`HMDT mgl_parser_add_varw (HMPR p, const wchar_t *name)` [C function]
Function returns the pointer to variable with name *name*. If variable is absent then new variable is created with name *name*. Use this function to put external data array to the script or get the data from the script. You must **not delete** obtained data arrays!

`void DeleteVar (const char *name)` [Method on `mglParse` (C++)]
`void DeleteVar (const wchar_t *name)` [Method on `mglParse` (C++)]
`void mgl_parser_del_var (HMPR p, const char *name)` [C function]
`void mgl_parser_del_varw (HMPR p, const wchar_t *name)` [C function]
Function delete the variable with given *name*.

`void DeleteAll ()` [Method on `mglParse` (C++)]
`void mgl_parser_del_all (HMPR p)` [C function]
Function delete all variables and reset list of commands to default one in this parser.

`void RestoreOnce ()` [Method on `mglParse`]
`void mgl_parser_restore_once (HMPR p)` [C function]
Restore Once flag.

`void AllowSetSize (bool a)` [Method on `mglParse`]
`void mgl_parser_allow_setsize (HMPR p, int a)` [C function]
Allow to parse [setsize], page 176 command or not.

`void AllowFileIO (bool a)` [Method on `mglParse`]
`void mgl_parser_allow_file_io (HMPR p, int a)` [C function]
Allow reading/saving files or not.

`void AllowDllCall (bool a)` [Method on `mglParse`]
`void mgl_parser_allow_dll_call (HMPR p, int a)` [C function]
Allow to parse [load], page 288 command or not.

`void Stop ()` [Method on `mglParse`]
`void mgl_parser_stop (HMPR` *p*`)` [C function]
Sends stop signal which terminate execution at next command.

`long GetCmdNum ()` [Method on `mglParse`]
`long mgl_parser_cmd_num (HMPR` *p*`)` [C function]
Return the number of registered MGL commands.

`const char * GetCmdName (long` *id*`)` [Method on `mglParse`]
`const char * mgl_parser_cmd_name (HMPR` *p*`, long` *id*`)` [C function]
Return the name of command with given *id*.

`int CmdType (const char *`*name*`)` [Method on `mglParse`]
`int mgl_parser_cmd_type (HMPR` *p*`, const char *`*name*`)` [C function]
Return the type of MGL command *name*. Type of commands are: 0 – not the command, 1 - data plot, 2 - other plot, 3 - setup, 4 - data handle, 5 - data create, 6 - subplot, 7 - program, 8 - 1d plot, 9 - 2d plot, 10 - 3d plot, 11 - dd plot, 12 - vector plot, 13 - axis, 14 - primitives, 15 - axis setup, 16 - text/legend, 17 - data transform.

`const char * CmdFormat (const char *`*name*`)` [Method on `mglParse`]
`const char * mgl_parser_cmd_frmt (HMPR` *p*`, const char *`*name*`)` [C function]
Return the format of arguments for MGL command *name*.

`const char * CmdDesc (const char *`*name*`)` [Method on `mglParse`]
`const char * mgl_parser_cmd_desc (HMPR` *p*`, const char *`*name*`)` [C function]
Return the description of MGL command *name*.

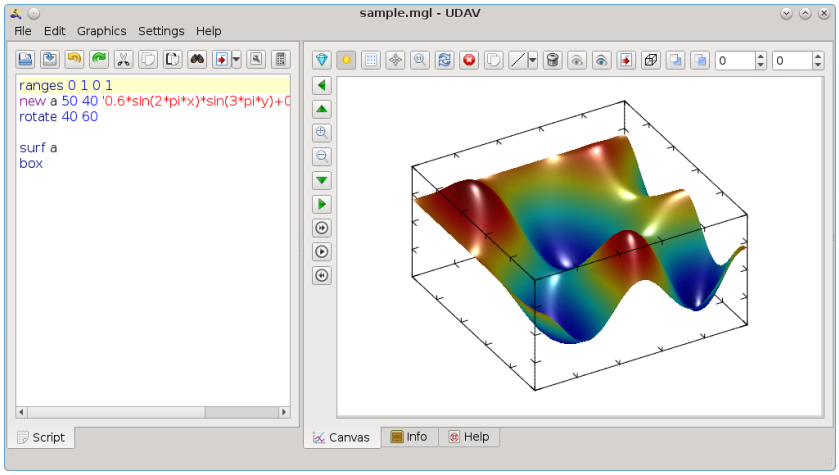
`void RK_Step (const char *`*eqs*`, const char *`*vars*`, mreal` *dt*`=1)` [Method on `mglParse`]
`void RK_Step (const wchar_t *`*eqs*`, const wchar_t *`*vars*`, mreal` *dt*`=1)` [Method on `mglParse`]
`void mgl_rk_step (HMPR` *p*`, const char *`*eqs*`, const char *`*vars*`, mreal` *dt*`)` [C function]
`void mgl_rk_step_w (HMPR` *p*`, const wchar_t *`*eqs*`, const wchar_t *`*vars*`, mreal` *dt*`)` [C function]
Make one step for ordinary differential equation(s) {var1' = eq1, ... } with time-step *dt*. Here strings *eqs* and *vars* contain the equations and variable names separated by symbol '`;`'. The variable(s) '`var1`', ... are the ones, defined in MGL script previously. The Runge-Kutta 4-th order method is used.

8 UDAV

UDAV (Universal Data Array Visualizator) is cross-platform program for data arrays visualization based on MathGL library. It support wide spectrum of graphics, simple script language and visual data handling and editing. It has window interface for data viewing, changing and plotting. Also it can execute MGL scripts, setup and rotate graphics and so on. UDAV hot-keys can be found in the appendix Section A.3 [Hot-keys for UDAV], page 323.

8.1 UDAV overview

UDAV have main window divided by 2 parts in general case and optional bottom panel(s). Left side contain tabs for MGL script and data arrays. Right side contain tabs with graphics itself, with list of variables and with help on MGL. Bottom side may contain the panel with MGL messages and warnings, and the panel with calculator.



Main window is shown on the figure above. You can see the script (at left) with current line highlighted by light-yellow, and result of its execution at right. Each panel have its own set of toolbuttons.

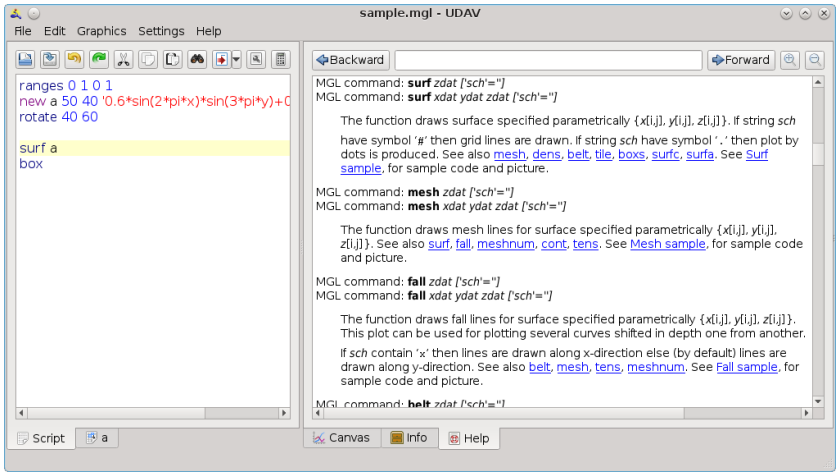
Editor toolbuttons allow: open and save script from/to file; undo and redo changes; cut, copy and paste selection; find/replace text; show dialogs for command arguments and for plot setup; show calculator at bottom.

Graphics toolbuttons allow: enable/disable additional transparency and lighting; show grid of absolute coordinates; enable mouse rotation; restore image view; refresh graphics (execute the script); stop calculation; copy graphics into clipboard; add primitives (line, curve, box, rhombus, ellipse, mark, text) to the image; change view angles manually. Vertical toolbuttons allow: shift and zoom in/out of image as whole; show next and previous frame of animation, or start animation (if one present).

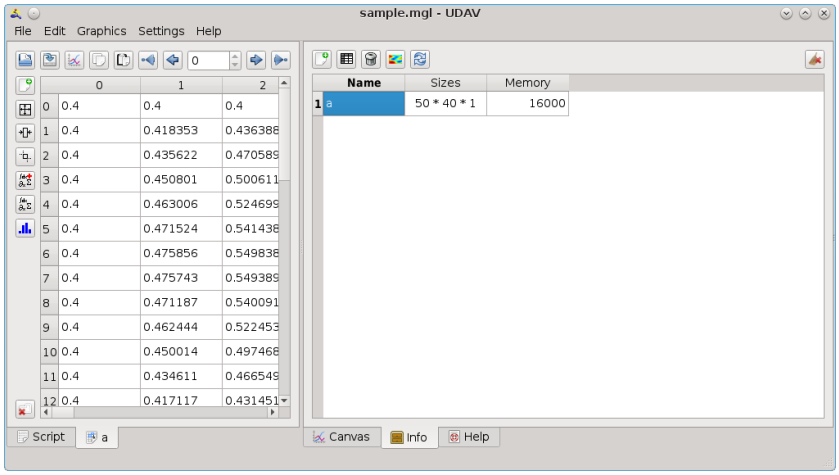
Graphics panel support plot editing by mouse.

- Axis range can be changed by mouse wheel or by dragging image by middle mouse button. Right button show popup menu. Left button show the coordinates of mouse click. At this double click will highlight plot under mouse and jump to the corresponded string of the MGL script.

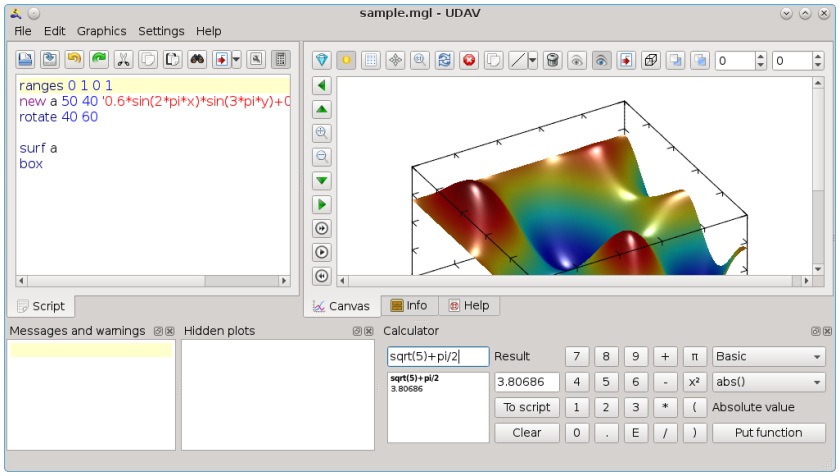
- Pressing "mouse rotation" toolbutton will change mouse actions: dragging by left button will rotate plot, middle button will shift the plot as whole, right button will zoom in/out plot as whole and add perspective, mouse wheel will zoom in/out plot as whole.
- Manual primitives can be added by pressing corresponding toolbutton. They can be shifted as whole at any time by mouse dragging. At this double click open dialog with its properties. If toolbutton "grid of absolute coordinates" is pressed then editing of active points for primitives is enabled.



Short command description and list of its arguments are shown at the status-bar, when you move cursor to the new line of code. You can press `F1` to see more detailed help on special panel.



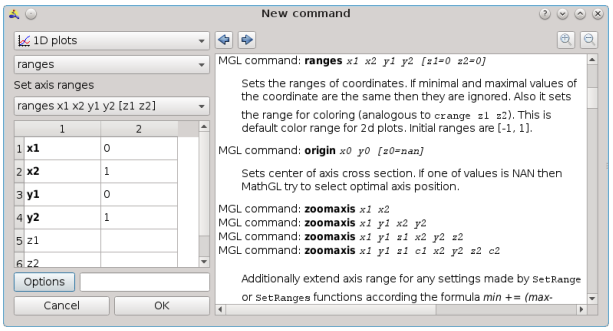
Also you can look the current list of variables, its dimensions and its size in the memory (right side of above figure). Toolbuttons allow: create new variable, edit variable, delete variable, preview variable plot and its properties, refresh list of variables. Pressing on any column will sort table according its contents. Double click on a variable will open panel with data cells of the variable, where you can view/edit each cell independently or apply a set of transformations.



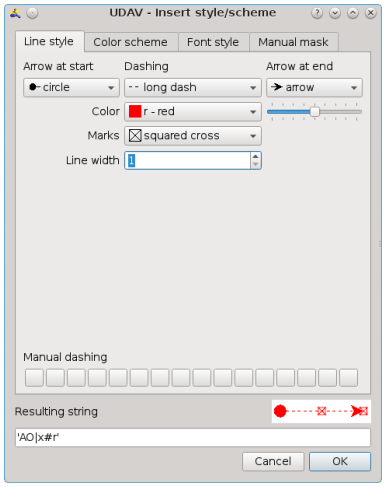
Finally, pressing `F2` or `F4` you can show/hide windows with messages/warnings and with calculator. Double click on a warning in message window will jump to corresponding line in editor. Calculator allow you type expression by keyboard as well as by toolbuttons. It know about all current variables, so you can use them in formulas.

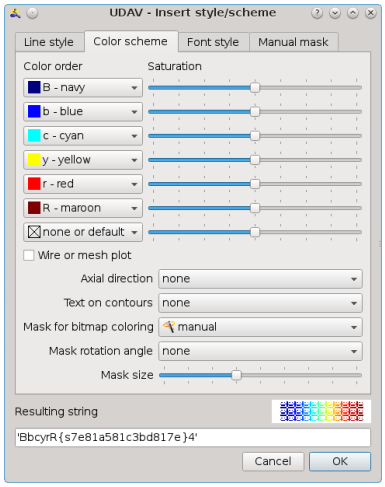
8.2 UDAV dialogs

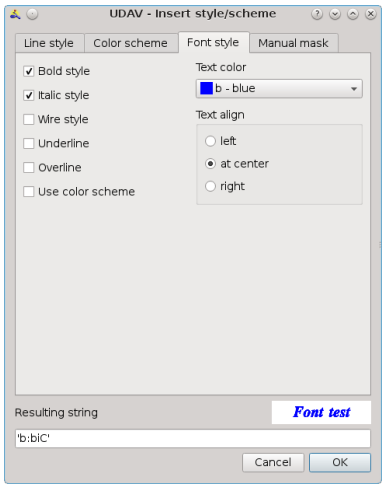
There are a set of dialogs, which allow change/add a command, setup global plot properties, or setup UDAV itself.

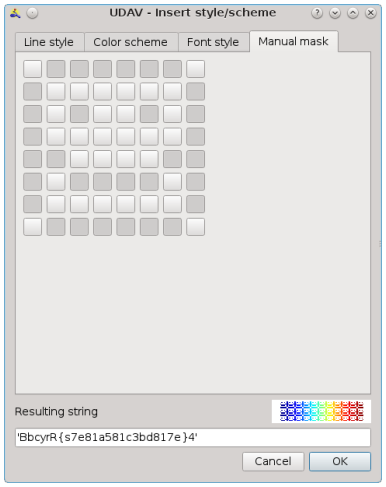


One of most interesting dialog (hotkey `Meta-C` or `Win-C`) is dialog which help to enter new command or change arguments of existed one. It allows consequently select the category of command, command name in category and appropriate set of command arguments. At this right side show detailed command description. Required argument(s) are denoted by bold text. Strings are placed in apostrophes, like `'txt'`. Buttons below table allow to call dialogs for changing style of command (if argument `'fmt'` is present in the list of command arguments); to set variable or expression for argument(s); to add options for command. Note, you can click on a cell to enter value, or double-click to call corresponding dialog.

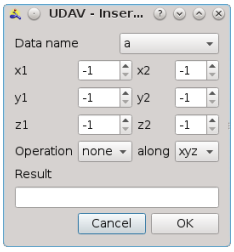

UDAV - Insert style/scheme
Line style
Color scheme
Font style
Manual mask
Arrow at start
Dashing
Arrow at end
circle
long dash
arrow
Color
r - red
Marks
squared cross
Line width
Manual dashing
Resulting string
'AO|x#r'
Cancel
OK


UDAV - Insert style/scheme
Line style
Color scheme
Font style
Manual mask
Color order
Saturation
B - navy
b - blue
c - cyan
y - yellow
r - red
R - maroon
none or default
Wire or mesh plot
Axial direction
none
Text on contours
none
Mask for bitmap coloring
manual
Mask rotation angle
none
Mask size
Resulting string
'BbcyrR{s7e81a581c3bd817e}4'
Cancel
OK

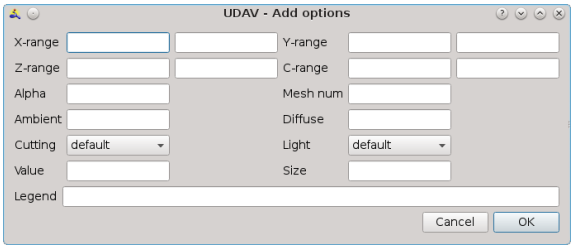

UDAV - Insert style/scheme
Line style
Color scheme
Font style
Manual mask
Bold style
Italic style
Wire style
Underline
Overline
Use color scheme
Text color
b - blue
Text align
left
at center
right
Resulting string
Font test
'b:biC'
Cancel
OK



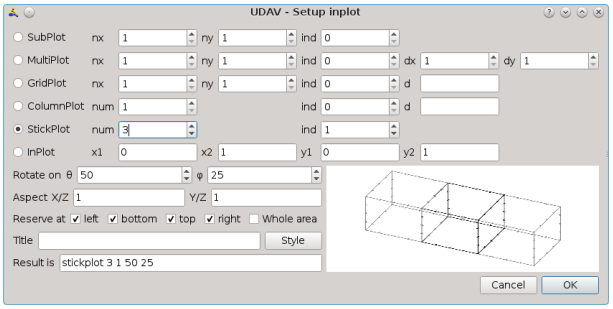
Dialog for changing style can be called independently, but usually is called from *New command* dialog or by double click on primitive. It contain 3 tabs: one for pen style, one for color scheme, one for text style. You should select appropriate one. Resulting string of style and sample picture are shown at bottom of dialog. Usually it can be called from New command dialog.



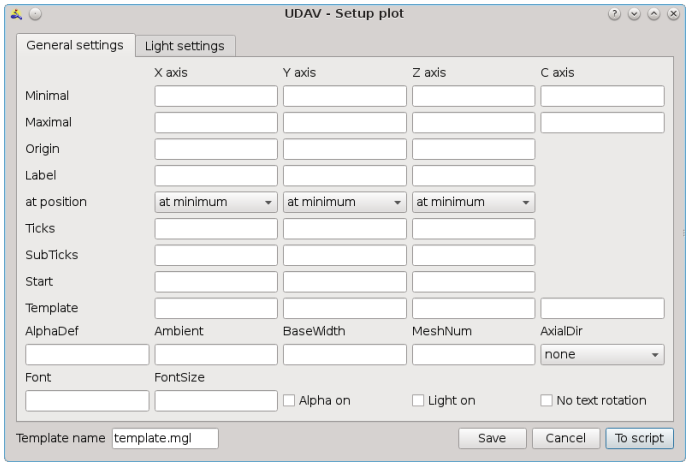
Dialog for entering variable allow to select variable or expression which can be used as argument of a command. Here you can select the variable name; range of indexes in each directions; operation which will be applied (like, summation, finding minimal/maximal values and so on). Usually it can be called from New command dialog.

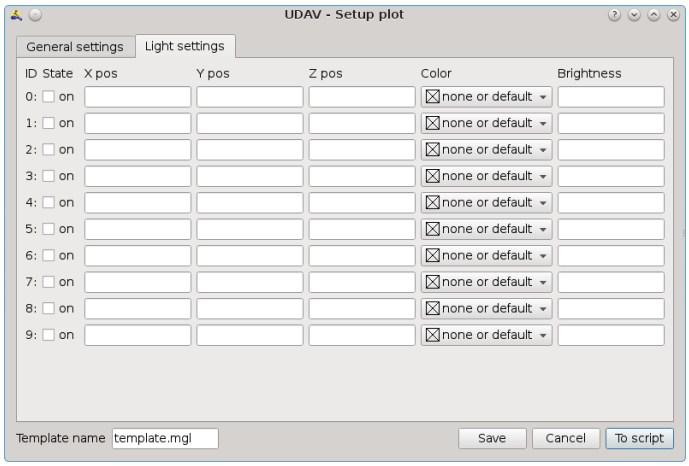


Dialog for command options allow to change Section 3.7 [Command options], page 154. Usually it can be called from New command dialog.

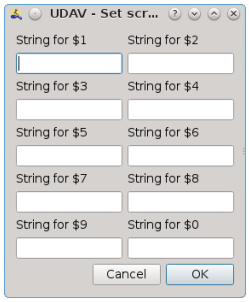


Another interesting dialog, which help to select and properly setup a [subplot], page 173, [inplot], page 173, [columnplot], page 174, [stickplot], page 174 and similar commands.

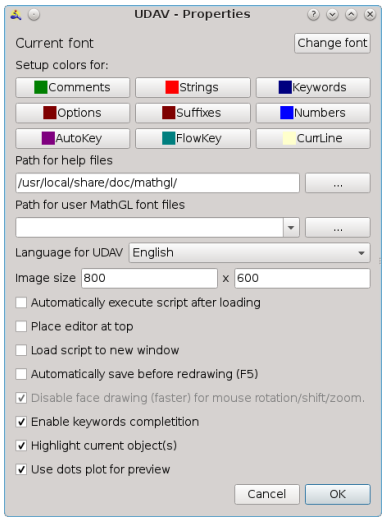




There is dialog for setting general plot properties, including tab for setting lighting properties. It can be called by called by hotkey `???` and put setup commands at the beginning of MGL script.



Also you can set or change script parameters (‘`$0`’ ... ‘`$9`’, see Section 7.1 [MGL definition], page 286).



Finally, there is dialog for UDAV settings. It allow to change most of things in UDAV appearance and working, including colors of keywords and numbers, default font and image size, and so on (see figure above).

There are also a set of dialogs for data handling, but they are too simple and clear. So, I will not put them here.

8.3 UDAV hints

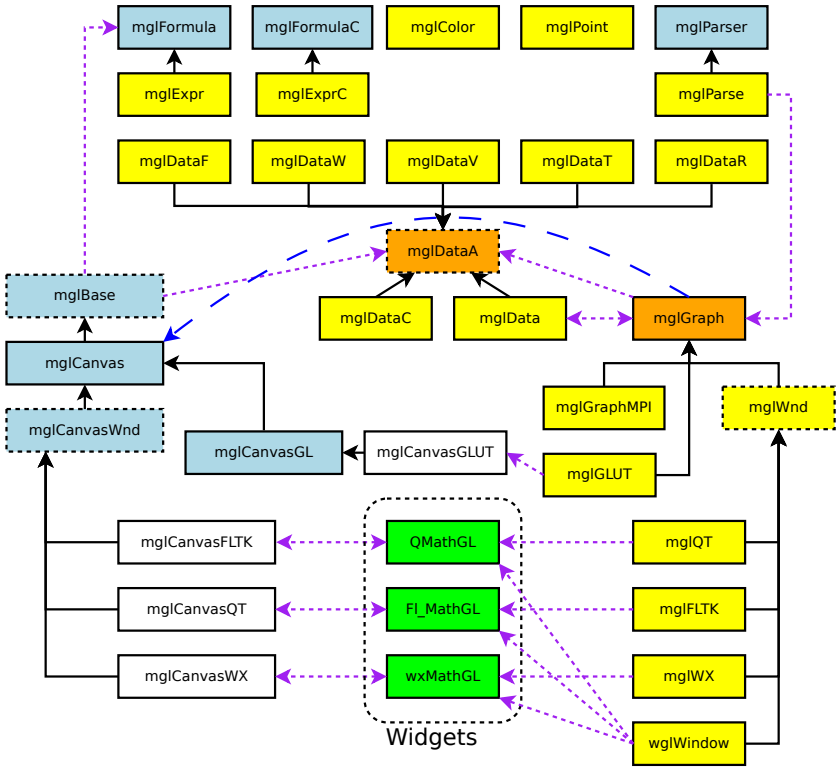
- You can shift axis range by pressing middle button and moving mouse. Also, you can zoom in/out axis range by using mouse wheel.
- You can rotate/shift/zoom whole plot by mouse. Just press ’Rotate’ toolbutton, click image and hold a mouse button: left button for rotation, right button for zoom/perspective, middle button for shift.
- You may quickly draw the data from file. Just use: udav ’filename.dat’ in command line.
- You can copy the current image to clipboard by pressing `Ctrl-Shift-C`. Later you can paste it directly into yours document or presentation.
- You can export image into a set of format (EPS, SVG, PNG, JPEG) by pressing right mouse button inside image and selecting ’Export as ...’.

- You can setup colors for script highlighting in Property dialog. Just select menu item 'Settings/Properties'.
- You can save the parameter of animation inside MGL script by using comment started from '##a ' or '##c ' for loops.
- New drawing never clears things drawn already. For example, you can make a surface with contour lines by calling commands 'surf' and 'cont' one after another (in any order).
- You can put several plots in the same image by help of commands 'subplot' or 'inplot'.
- All indexes (of data arrays, subplots and so on) are always start from 0.
- You can edit MGL file in any text editor. Also you can run it in console by help of commands: `mglconv`, `mglview`.
- You can use command 'once on|off' for marking the block which should be executed only once. For example, this can be the block of large data reading/creating/handling. Press `F9` (or menu item 'Graphics/Reload') to re-execute this block.
- You can use command 'stop' for terminating script parsing. It is useful if you don't want to execute a part of script.
- You can type arbitrary expression as input argument for data or number. In last case (for numbers), the first value of data array is used.
- There is powerful calculator with a lot of special functions. You can use buttons or keyboard to type the expression. Also you can use existed variables in the expression.
- The calculator can help you to put complex expression in the script. Just type the expression (which may depend on coordinates x,y,z and so on) and put it into the script.
- You can easily insert file or folder names, last fitted formula or numerical value of selection by using menu Edit|Insert.
- The special dialog (Edit|Insert|New Command) help you select the command, fill its arguments and put it into the script.
- You can put several plotting commands in the same line or in separate function, for highlighting all of them simultaneously.

9 Other classes

There are few end-user classes: `mglGraph` (see Chapter 4 [MathGL core], page 158), `mglWindow` and `mglGLUT` (see Chapter 5 [Widget classes], page 238), `mglData` (see Chapter 6 [Data processing], page 252), `mglParse` (see Chapter 7 [MGL scripts], page 286). Exactly these classes I recommend to use in most of user programs. All methods in all of these classes are inline and have exact C/Fortran analogue functions. This give compiler independent binary libraries for MathGL.

However, sometimes you may need to extend MathGL by writing yours own plotting functions or handling yours own data structures. In these cases you may need to use low-level API. This chapter describes it.



The internal structure of MathGL is rather complicated. There are C++ classes `mglBase`, `mglCanvas`, ... for drawing primitives and positioning the plot (blue ones in the figure). There is a layer of C functions, which include interface for most important methods of these classes. Also most of plotting functions are implemented as C functions. After it, there are "inline" front-end classes which are created for user convenience (yellow ones in the figure). Also there are widgets for FLTK and Qt libraries (green ones in the figure).

Below I show how this internal classes can be used.

9.1 Define new kind of plot (mglBase class)

Basically most of new kinds of plot can be created using just MathGL primitives (see Section 4.7 [Primitives], page 185). However the usage of `mglBase` methods can give you higher speed of drawing and better control of plot settings.

All plotting functions should use a pointer to `mglBase` class (or `HMGL` type in C functions) due to compatibility issues. Exactly such type of pointers are used in front-end classes (`mglGraph, mglWindow`) and in widgets (`QMathGL, Fl_MathGL`).

MathGL tries to remember all vertexes and all primitives and plot creation stage, and to use them for making final picture by demand. Basically for making plot, you need to add vertexes by `AddPnt()` function, which return index for new vertex, and call one of primitive drawing function (like `mark_plot(), arrow_plot(), line_plot(), trig_plot(), quad_plot(), text_plot()`), using vertex indexes as argument(s). `AddPnt()` function use 2 mreal numbers for color specification. First one is positioning in textures – integer part is texture index, fractional part is relative coordinate in the texture. Second number is like a transparency of plot (or second coordinate in the 2D texture).

I don't want to put here detailed description of `mglBase` class. It was rather well documented in `mgl2/base.h` file. I just show and example of its usage on the base of circle drawing.

First, we should prototype new function `circle()` as C function.

```
#ifdef __cplusplus
extern "C" {
#endif
void circle(HMGL gr, mreal x, mreal y, mreal z, mreal r, const char *stl, const char *opt);
#ifdef __cplusplus
}
#endif
```

This is done for generating compiler independent binary. Because only C-functions have standard naming mechanism, the same for any compilers.

Now, we create a C++ file and put the code of function. I'll write it line by line and try to comment all important points.

```
void circle(HMGL gr, mreal x, mreal y, mreal z, mreal r, const char *stl, const char *opt)
{
```

First, we need to check all input arguments and send warnings if something is wrong. In our case it is negative value of r argument. We just send warning, since it is not critical situation – other plot still can be drawn.

```
  if(r<=0)  { gr->SetWarn(mglWarnNeg,"Circle"); return; }
```

Next step is creating a group. Group keep some general setting for plot (like options) and useful for export in 3d files.

```
  static int cgid=1;  gr->StartGroup("Circle",cgid++);
```

Now let apply options. Options are rather useful things, generally, which allow one easily redefine axis range(s), transparency and other settings (see Section 3.7 [Command options], page 154).

```
  gr->SaveState(opt);
```

I use global setting for determining the number of points in circle approximation. Note, that user can change `MeshNum` by options easily.

```
  const int n = gr->MeshNum>1?gr->MeshNum : 41;
```

Let try to determine plot specific flags. MathGL functions expect that most of flags will be sent in string. In our case it is symbol '@' which set to draw filled circle instead of border only (last will be default). Note, you have to handle NULL as string pointer.

```
bool fill = mglchr(stl,'@');
```

Now, time for coloring. I use palette mechanism because circle have few colors: one for filling and another for border. SetPenPal() function parse input string and write resulting texture index in *pal*. Function return the character for marker, which can be specified in string *str*. Marker will be plotted at the center of circle. I'll show on next sample how you can use color schemes (smooth colors) too.

```
long pal=0;
char mk=gr->SetPenPal(stl,&pal);
```

Next step, is determining colors for filling and for border. First one for filling.

```
mreal c=gr->NextColor(pal), d;
```

Second one for border. I use black color (call gr->AddTexture('k')) if second color is not specified.

```
mreal k=(gr->GetNumPal(pal)>1)?gr->NextColor(pal):gr->AddTexture('k');
```

If user want draw only border (fill=false) then I use first color for border.

```
if(!fill) k=c;
```

Now we should reserve space for vertexes. This functions need n for border, n+1 for filling and 1 for marker. So, maximal number of vertexes is 2*n+2. Note, that such reservation is not required for normal work but can sufficiently speed up the plotting.

```
gr->Reserve(2*n+2);
```

We've done with setup and ready to start drawing. First, we need to add vertex(es). Let define NAN as normals, since I don't want handle lighting for this plot,

```
mglPoint q(NAN,NAN);
```

and start adding vertexes. First one for central point of filling. I use -1 if I don't need this point. The arguments of AddPnt() function is: mglPoint(x,y,z) – coordinate of vertex, c – vertex color, q – normal at vertex, -1 – vertex transparency (-1 for default), 3 bitwise flag which show that coordinates will be scaled (0x1) and will not be cutted (0x2).

```
long n0,n1,n2,m1,m2,i;
n0 = fill ? gr->AddPnt(mglPoint(x,y,z),c,q,-1,3):-1;
```

Similar for marker, but we use different color *k*.

```
n2 = mk ? gr->AddPnt(mglPoint(x,y,z),k,q,-1,3):-1;
```

Draw marker.

```
if(mk)  gr->mark_plot(n2,mk);
```

Time for drawing circle itself. I use -1 for *m1*, *n1* as sign that primitives shouldn't be drawn for first point i=0.

```
for(i=0,m1=n1=-1;i<n;i++)
{
```

Each function should check Stop variable and return if it is non-zero. It is done for interrupting drawing for system which don't support multi-threading.

```
    if(gr->Stop)  return;
```

Let find coordinates of vertex.

```
    mreal t = i*2*M_PI/(n-1.);
    mglPoint p(x+r*cos(t), y+r*sin(t), z);
```

Save previous vertex and add next one

```
    n2 = n1;  n1 = gr->AddPnt(p,c,q,-1,3);
```

and copy it for border but with different color. Such copying is much faster than adding new vertex using `AddPnt()`.

```
    m2 = m1;  m1 = gr->CopyNtoC(n1,k);
```

Now draw triangle for filling internal part

```
    if(fill)  gr->trig_plot(n0,n1,n2);
```

and draw line for border.

```
    gr->line_plot(m1,m2);
  }
```

Drawing is done. Let close group and return.

```
  gr->EndGroup();
}
```

Another sample I want to show is exactly the same function but with smooth coloring using color scheme. So, I'll add comments only in the place of difference.

```
void circle_cs(HMGL gr, mreal x, mreal y, mreal z, mreal r, const char *stl, const char *op
{
```

In this case let allow negative radius too. Formally it is not the problem for plotting (formulas the same) and this allow us to handle all color range.

```
//if(r<=0)  { gr->SetWarn(mglWarnNeg,"Circle"); return; }

  static int cgid=1;  gr->StartGroup("CircleCS",cgid++);
  gr->SaveState(opt);
  const int n = gr->MeshNum>1?gr->MeshNum : 41;
  bool fill = mglchr(stl,'@');
```

Here is main difference. We need to create texture for color scheme specified by user

```
  long ss = gr->AddTexture(stl);
```

But we need also get marker and color for it (if filling is enabled). Let suppose that marker and color is specified after ':'. This is standard delimiter which stop color scheme entering. So, just lets find it and use for setting pen.

```
  const char *pen=0;
  if(stl) pen = strchr(stl,':');
  if(pen) pen++;
```

The substring is placed in *pen* and it will be used as line style.

```
  long pal=0;
  char mk=gr->SetPenPal(pen,&pal);
```

Next step, is determining colors for filling and for border. First one for filling.

```
  mreal c=gr->GetC(ss,r);
```
Second one for border.
```
  mreal k=gr->NextColor(pal);
```
The rest part is the same as in previous function.
```
  if(!fill) k=c;

  gr->Reserve(2*n+2);
  mglPoint q(NAN,NAN);
  long n0,n1,n2,m1,m2,i;
  n0 = fill ? gr->AddPnt(mglPoint(x,y,z),c,q,-1,3):-1;
  n2 = mk ? gr->AddPnt(mglPoint(x,y,z),k,q,-1,3):-1;
  if(mk)  gr->mark_plot(n2,mk);
  for(i=0,m1=n1=-1;i<n;i++)
  {
    if(gr->Stop)  return;
    mreal t = i*2*M_PI/(n-1.);
    mglPoint p(x+r*cos(t), y+r*sin(t), z);
    n2 = n1;  n1 = gr->AddPnt(p,c,q,-1,3);
    m2 = m1;  m1 = gr->CopyNtoC(n1,k);
    if(fill)  gr->trig_plot(n0,n1,n2);
    gr->line_plot(m1,m2);
  }
  gr->EndGroup();
}
```

The last thing which we can do is derive our own class with new plotting functions. Good idea is to derive it from `mglGraph` (if you don't need extended window), or from `mglWindow` (if you need to extend window). So, in our case it will be

```
class MyGraph : public mglGraph
{
public:
  inline void Circle(mglPoint p, mreal r, const char *stl="", const char *opt="")
  { circle(p.x,p.y,p.z, r, stl, opt); }
  inline void CircleCS(mglPoint p, mreal r, const char *stl="", const char *opt="")
  { circle_cs(p.x,p.y,p.z, r, stl, opt); }
};
```

Note, that I use `inline` modifier for using the same binary code with different compilers.

So, the complete sample will be

```
#include <mgl2/mgl.h>
//-----------------------------------------------------------
#ifdef __cplusplus
extern "C" {
#endif
void circle(HMGL gr, mreal x, mreal y, mreal z, mreal r, const char *stl, const char *opt);
void circle_cs(HMGL gr, mreal x, mreal y, mreal z, mreal r, const char *stl, const char *op
#ifdef __cplusplus
```

```
}
#endif
//-----------------------------------------------------------
class MyGraph : public mglGraph
{
public:
  inline void CircleCF(mglPoint p, mreal r, const char *stl="", const char *opt="")
  { circle(p.x,p.y,p.z, r, stl, opt); }
  inline void CircleCS(mglPoint p, mreal r, const char *stl="", const char *opt="")
  { circle_cs(p.x,p.y,p.z, r, stl, opt); }
};
//-----------------------------------------------------------
void circle(HMGL gr, mreal x, mreal y, mreal z, mreal r, const char *stl, const char *opt)
{
  if(r<=0)  { gr->SetWarn(mglWarnNeg,"Circle"); return; }
  static int cgid=1;  gr->StartGroup("Circle",cgid++);
  gr->SaveState(opt);
  const int n = gr->MeshNum>1?gr->MeshNum : 41;
  bool fill = mglchr(stl,'@');
  long pal=0;
  char mk=gr->SetPenPal(stl,&pal);
  mreal c=gr->NextColor(pal), d;
  mreal k=(gr->GetNumPal(pal)>1)?gr->NextColor(pal):gr->AddTexture('k');
  if(!fill) k=c;
  gr->Reserve(2*n+2);
  mglPoint q(NAN,NAN);
  long n0,n1,n2,m1,m2,i;
  n0 = fill ? gr->AddPnt(mglPoint(x,y,z),c,q,-1,3):-1;
  n2 = mk ? gr->AddPnt(mglPoint(x,y,z),k,q,-1,3):-1;
  if(mk)  gr->mark_plot(n2,mk);
  for(i=0,m1=n1=-1;i<n;i++)
  {
    if(gr->Stop)  return;
    mreal t = i*2*M_PI/(n-1.);
    mglPoint p(x+r*cos(t), y+r*sin(t), z);
    n2 = n1;  n1 = gr->AddPnt(p,c,q,-1,3);
    m2 = m1;  m1 = gr->CopyNtoC(n1,k);
    if(fill)  gr->trig_plot(n0,n1,n2);
    gr->line_plot(m1,m2);
  }
  gr->EndGroup();
}
//-----------------------------------------------------------
void circle_cs(HMGL gr, mreal x, mreal y, mreal z, mreal r, const char *stl, const char *op
{
  static int cgid=1;  gr->StartGroup("CircleCS",cgid++);
  gr->SaveState(opt);
```

```
  const int n = gr->MeshNum>1?gr->MeshNum : 41;
  bool fill = mglchr(stl,'@');
  long ss = gr->AddTexture(stl);
  const char *pen=0;
  if(stl) pen = strchr(stl,':');
  if(pen) pen++;
  long pal=0;
  char mk=gr->SetPenPal(pen,&pal);
  mreal c=gr->GetC(ss,r);
  mreal k=gr->NextColor(pal);
  if(!fill) k=c;

  gr->Reserve(2*n+2);
  mglPoint q(NAN,NAN);
  long n0,n1,n2,m1,m2,i;
  n0 = fill ? gr->AddPnt(mglPoint(x,y,z),c,q,-1,3):-1;
  n2 = mk ? gr->AddPnt(mglPoint(x,y,z),k,q,-1,3):-1;
  if(mk)  gr->mark_plot(n2,mk);
  for(i=0,m1=n1=-1;i<n;i++)
  {
    if(gr->Stop)  return;
    mreal t = i*2*M_PI/(n-1.);
    mglPoint p(x+r*cos(t), y+r*sin(t), z);
    n2 = n1;  n1 = gr->AddPnt(p,c,q,-1,3);
    m2 = m1;  m1 = gr->CopyNtoC(n1,k);
    if(fill)  gr->trig_plot(n0,n1,n2);
    gr->line_plot(m1,m2);
  }
  gr->EndGroup();
}
//-----------------------------------------------------------
int main()
{
  MyGraph gr;
  gr.Box();
  // first let draw circles with fixed colors
  for(int i=0;i<10;i++)
    gr.CircleCF(mglPoint(2*mgl_rnd()-1, 2*mgl_rnd()-1), mgl_rnd());
  // now let draw circles with color scheme
  for(int i=0;i<10;i++)
    gr.CircleCS(mglPoint(2*mgl_rnd()-1, 2*mgl_rnd()-1), 2*mgl_rnd()-1);
}
```

9.2 User defined types (mglDataA class)

`mglData` class have abstract predecessor class `mglDataA`. Exactly the pointers to `mglDataA` instances are used in all plotting functions and some of data processing functions. This

was done for taking possibility to define yours own class, which will handle yours own data (for example, complex numbers, or differently organized data). And this new class will be almost the same as `mglData` for plotting purposes.

However, the most of data processing functions will be slower as if you used `mglData` instance. This is more or less understandable – I don't know how data in yours particular class will be organized, and couldn't optimize the these functions generally.

There are few virtual functions which must be provided in derived classes. This functions give:

- the sizes of the data (`GetNx`, `GetNy`, `GetNz`),
- give data value and numerical derivatives for selected cell (`v`, `dvx`, `dvy`, `dvz`),
- give maximal and minimal values (`Maximal`, `Minimal`) – you can use provided functions (like `mgl_data_max` and `mgl_data_min`), but yours own realization can be more efficient,
- give access to all element as in single array (`vthr`) – you need this only if you want using MathGL's data processing functions.

Let me, for example define class `mglComplex` which will handle complex number and draw its amplitude or phase, depending on flag *use_abs*:

```
#include <complex>
#include <mgl2/mgl.h>
#define dual std::complex<double>
class mglComplex : public mglDataA
{
public:
  long nx;      ///< number of points in 1st dimensions ('x' dimension)
  long ny;      ///< number of points in 2nd dimensions ('y' dimension)
  long nz;      ///< number of points in 3d dimensions ('z' dimension)
  dual *a;      ///< data array
  bool use_abs; ///< flag to use abs() or arg()

  inline mglComplex(long xx=1,long yy=1,long zz=1)
  { a=0;  use_abs=true; Create(xx,yy,zz); }
  virtual ~mglComplex()  { if(a)  delete []a; }

  /// Get sizes
  inline long GetNx() const { return nx;  }
  inline long GetNy() const { return ny;  }
  inline long GetNz() const { return nz;  }
  /// Create or recreate the array with specified size and fill it by zero
  inline void Create(long mx,long my=1,long mz=1)
  { nx=mx;  ny=my;  nz=mz;  if(a) delete []a;
  a = new dual[nx*ny*nz]; }
  /// Get maximal value of the data
  inline mreal Maximal() const  { return mgl_data_max(this);  }
  /// Get minimal value of the data
  inline mreal Minimal() const  { return mgl_data_min(this);  }
```

```
protected:
  inline mreal v(long i,long j=0,long k=0) const
  { return use_abs ? abs(a[i+nx*(j+ny*k)]) : arg(a[i+nx*(j+ny*k)]);  }
  inline mreal vthr(long i) const
  { return use_abs ? abs(a[i]) : arg(a[i]);  }
  inline mreal dvx(long i,long j=0,long k=0) const
  { register long i0=i+nx*(j+ny*k);
    std::complex<double> res=i>0? (i<nx-1? (a[i0+1]-a[i0-1])/2.:a[i0]-a[i0-1]) : a[i0+1]-a[
    return use_abs? abs(res) : arg(res);  }
  inline mreal dvy(long i,long j=0,long k=0) const
  { register long i0=i+nx*(j+ny*k);
    std::complex<double> res=j>0? (j<ny-1? (a[i0+nx]-a[i0-nx])/2.:a[i0]-a[i0-nx]) : a[i0+nx
    return use_abs? abs(res) : arg(res);  }
  inline mreal dvz(long i,long j=0,long k=0) const
  { register long i0=i+nx*(j+ny*k), n=nx*ny;
    std::complex<double> res=k>0? (k<nz-1? (a[i0+n]-a[i0-n])/2.:a[i0]-a[i0-n]) : a[i0+n]-a[
    return use_abs? abs(res) : arg(res);  }
};
int main()
{
  mglComplex dat(20);
  for(long i=0;i<20;i++)
    dat.a[i] = 3*exp(-0.05*(i-10)*(i-10))*dual(cos(M_PI*i*0.3), sin(M_PI*i*0.3));
  mglGraph gr;
  gr.SetRange('y', -M_PI, M_PI);  gr.Box();

  gr.Plot(dat,"r","legend 'abs'");
  dat.use_abs=false;
  gr.Plot(dat,"b","legend 'arg'");
  gr.Legend();
  gr.WritePNG("complex.png");
  return 0;
}
```

9.3 mglColor class

Structure for working with colors. This structure is defined in `#include <mgl2/type.h>`.

There are two ways to set the color in MathGL. First one is using of mreal values of red, green and blue channels for precise color definition. The second way is the using of character id. There are a set of characters specifying frequently used colors. Normally capital letter gives more dark color than lowercase one. See Section 3.3 [Line styles], page 148.

`mreal r, g, b, a` [Parameter of `mglColor`]

Reg, green and blue component of color.

`mglColor (mreal R, mreal G, mreal B, mreal A=1)` [Method on `mglColor`]
Constructor sets the color by mreal values of Red, Green, Blue and Alpha channels. These values should be in interval [0,1].

`mglColor (char c='k', mreal bright=1)` [Method on `mglColor`]
Constructor sets the color from character id. The black color is used by default. Parameter *br* set additional "lightness" of color.

`void Set (mreal R, mreal G, mreal B, mreal A=1)` [Method on `mglColor`]
Sets color from values of Red, Green, Blue and Alpha channels. These values should be in interval [0,1].

`void Set (mglColor c, mreal bright=1)` [Method on `mglColor`]
Sets color as "lighted" version of color *c*.

`void Set (char p, mreal bright=1)` [Method on `mglColor`]
Sets color from symbolic id.

`bool Valid ()` [Method on `mglColor`]
Checks correctness of the color.

`mreal Norm ()` [Method on `mglColor`]
Gets maximal of spectral component.

`bool operator== (const mglColor &c)` [Method on `mglColor`]
`bool operator!= (const mglColor &c)` [Method on `mglColor`]
Compare with another color

`bool operator*= (mreal v)` [Method on `mglColor`]
Multiplies color components by number *v*.

`bool operator+= (const mglColor &c)` [Method on `mglColor`]
Adds color *c* component by component.

`bool operator-= (const mglColor &c)` [Method on `mglColor`]
Subtracts color *c* component by component.

`mglColor operator+ (const mglColor &a, const mglColor &b)` [Library Function]
Adds colors by its RGB values.

`mglColor operator- (const mglColor &a, const mglColor &b)` [Library Function]
Subtracts colors by its RGB values.

`mglColor operator* (const mglColor &a, mreal b)` [Library Function]
`mglColor operator* (mreal a, const mglColor &b)` [Library Function]
Multiplies color by number.

`mglColor operator/ (const mglColor &a, mreal b)` [Library Function]
Divide color by number.

`mglColor operator! (const mglColor &a)` [Library Function]
Return inverted color.

9.4 mglPoint class

Structure describes point in space. This structure is defined in `#include <mgl2/type.h>`

`mreal x, y, z, c` [Parameter of `mglPoint`]
Point coordinates {x,y,z} and one extra value c used for amplitude, transparency and so on. By default all values are zero.

`mglPoint (mreal` X=0, `mreal` Y=0, `mreal` Z=0, `mreal` C=0) [Method on `mglPoint`]
Constructor sets the color by mreal values of Red, Green, Blue and Alpha channels. These values should be in interval [0,1].

`bool IsNAN ()` [Method on `mglPoint`]
Returns `true` if point contain NAN values.

`mreal norm ()` [Method on `mglPoint`]
Returns the norm $\sqrt{\{x^2+y^2+z^2\}}$ of vector.

`void Normalize ()` [Method on `mglPoint`]
Normalizes vector to be unit vector.

`mreal val (int` i) [Method on `mglPoint`]
Returns point component: x for i=0, y for i=1, z for i=2, c for i=3.

`mglPoint operator+ (const mglPoint &`a, `const mglPoint &`b) [Library Function]
Point of summation (summation of vectors).

`mglPoint operator- (const mglPoint &`a, `const mglPoint &`b) [Library Function]
Point of difference (difference of vectors).

`mglPoint operator* (mreal` a, `const mglPoint &`b) [Library Function]
`mglPoint operator* (const mglPoint &`a, `mreal` b) [Library Function]
Multiplies (scale) points by number.

`mglPoint operator/ (const mglPoint &`a, `mreal` b) [Library Function]
Multiplies (scale) points by number 1/b.

`mreal operator* (const mglPoint &`a, `const mglPoint &`b) [Library Function]
Scalar product of vectors.

`mglPoint operator/ (const mglPoint &`a, `const mglPoint &`b) [Library Function]
Return vector of element-by-element product.

`mglPoint operator^ (const mglPoint &`a, `const mglPoint &`b) [Library Function]
Cross-product of vectors.

`mglPoint operator& (const mglPoint &`*a*`, const mglPoint &`*b*`)` [Library Function]
The part of *a* which is perpendicular to vector *b*.

`mglPoint operator| (const mglPoint &`*a*`, const mglPoint &`*b*`)` [Library Function]
The part of *a* which is parallel to vector *b*.

`mglPoint operator! (const mglPoint &`*a*`)` [Library Function]
Return vector perpendicular to vector *a*.

`mreal mgl_norm (const mglPoint &`*a*`)` [Library Function]
Return the norm sqrt(`|`*a*`|^2`) of vector *a*.

`bool operator== (const mglPoint &`*a*`, const mglPoint &`*b*`)` [Library Function]
Return true if points are the same.

`bool operator!= (const mglPoint &`*a*`, const mglPoint &`*b*`)` [Library Function]
Return true if points are different.

Appendix A Symbols and hot-keys

This appendix contain the full list of symbols (characters) used by MathGL for setting up plot. Also it contain sections for full list of hot-keys supported by mglview tool and by UDAV program.

A.1 Symbols for styles

Below is full list of all characters (symbols) which MathGL use for setting up the plot.

'`space ' ''
: empty line style (see Section 3.3 [Line styles], page 148);

  empty color in [chart], page 200.

'`!`'
: set to use new color from palette for each point (not for each curve, as default) in Section 4.11 [1D plotting], page 195;

  set to disable ticks tuning in [axis], page 191 and [colorbar], page 192;

  set to draw [grid], page 193 lines at subticks coordinates too;

  define complex variable/expression in MGL script if placed at beginning.

'`#`'
: set to use solid marks (see Section 3.3 [Line styles], page 148) or solid [error], page 202 boxes;

  set to draw wired plot for [axial], page 212, [surf3], page 214, [surf3a], page 219, [surf3c], page 218, [triplot], page 230, [quadplot], page 231, [area], page 197, [bars], page 198, [barh], page 199, [tube], page 205, [tape], page 197, [cone], page 187, [boxs], page 209 and draw boundary only for [circle], page 187, [ellipse], page 187, [rhomb], page 188;

  set to draw also mesh lines for [surf], page 208, [surfc], page 217, [surfa], page 218, [dens], page 209, [densx], page 227, [densy], page 227, [densz], page 227, [dens3], page 215, or boundary for [chart], page 200, [facex], page 186, [facey], page 186, [facez], page 186, [rect], page 186;

  set to draw boundary and box for [legend], page 194, [title], page 174, or grid lines for [table], page 205;

  set to draw grid for [radar], page 195;

  set to start flow threads and pipes from edges only for [flow], page 224, [pipe], page 226;

  set to use whole are for axis range in [subplot], page 173, [inplot], page 173;

  change text color inside a string (see Section 3.5 [Font styles], page 152);

  start comment in Chapter 7 [MGL scripts], page 286 or in Section 3.7 [Command options], page 154.

'`$`'
: denote parameter of Chapter 7 [MGL scripts], page 286.

'`%`'
: set color scheme along 2 coordinates Section 3.4 [Color scheme], page 150.

'`&`'

  set to pass long integer number in tick template [xtick], page 170, [ytick], page 170, [ztick], page 170, [ctick], page 170.

  operation in Section 3.6 [Textual formulas], page 153.

‘’’ denote string in Chapter 7 [MGL scripts], page 286 or in Section 3.7 [Command options], page 154.

‘*’ one of marks (see Section 3.3 [Line styles], page 148);
one of mask for face filling (see Section 3.4 [Color scheme], page 150);
operation in Section 3.6 [Textual formulas], page 153.

‘+’ one of marks (see Section 3.3 [Line styles], page 148) or kind of [error], page 202 boxes;
one of mask for face filling (see Section 3.4 [Color scheme], page 150);
set to print ‘+’ for positive numbers in [axis], page 191, [label], page 204, [table], page 205;
operation in Section 3.6 [Textual formulas], page 153.

‘,’ separator for color positions (see Section 3.2 [Color styles], page 148) or items in a list.

‘-’ solid line style (see Section 3.3 [Line styles], page 148);
one of mask for face filling (see Section 3.4 [Color scheme], page 150);
place entries horizontally in [legend], page 194;
set to use usual ‘-’ for negative numbers in [axis], page 191, [label], page 204, [table], page 205;
operation in Section 3.6 [Textual formulas], page 153.

‘.’ one of marks (see Section 3.3 [Line styles], page 148) or kind of [error], page 202 boxes;
set to draw hachures instead of arrows for [vect], page 223, [vect3], page 223;
set to use dots instead of faces for [cloud], page 214, [torus], page 206, [axial], page 212, [surf3], page 214, [surf3a], page 219, [surf3c], page 218, [surf], page 208, [surfa], page 218, [surfc], page 217, [dens], page 209, [map], page 221;
delimiter of fractional parts for numbers.

‘/’ operation in Section 3.6 [Textual formulas], page 153.

‘:’ line dashing style (see Section 3.3 [Line styles], page 148);
stop color scheme parsing (see Section 3.4 [Color scheme], page 150);
range operation in Chapter 7 [MGL scripts], page 286.

‘;’ line dashing style (see Section 3.3 [Line styles], page 148);
one of mask for face filling (see Section 3.4 [Color scheme], page 150);
end of an option in Chapter 7 [MGL scripts], page 286 or in Section 3.7 [Command options], page 154.

‘<’ one of marks (see Section 3.3 [Line styles], page 148);
one of mask for face filling (see Section 3.4 [Color scheme], page 150);
style of [subplot], page 173 and [inplot], page 173;
set position of [colorbar], page 192;
style of [vect], page 223, [vect3], page 223;

align left in [bars], page 198, [barh], page 199, [boxplot], page 200, [cones], page 199, [candle], page 201, [ohlc], page 201;

operation in Section 3.6 [Textual formulas], page 153.

'>' one of marks (see Section 3.3 [Line styles], page 148);

one of mask for face filling (see Section 3.4 [Color scheme], page 150);

style of [subplot], page 173 and [inplot], page 173;

set position of [colorbar], page 192;

style of [vect], page 223, [vect3], page 223;

align right in [bars], page 198, [barh], page 199, [boxplot], page 200, [cones], page 199, [candle], page 201, [ohlc], page 201;

operation in Section 3.6 [Textual formulas], page 153.

'=' line dashing style (see Section 3.3 [Line styles], page 148);

one of mask for face filling (see Section 3.4 [Color scheme], page 150);

set to use equidistant columns for [table], page 205;

set to use color gradient for [vect], page 223, [vect3], page 223;

operation in Section 3.6 [Textual formulas], page 153.

'@' set to draw box around text for [text], page 189 and similar functions;

set to draw boundary and fill it for [circle], page 187, [ellipse], page 187, [rhomb], page 188;

set to fill faces for [box], page 193;

set to draw large semitransparent mark instead of error box for [error], page 202;

set to draw edges for [cone], page 187;

set to draw filled boxes for [boxs], page 209;

reduce text size inside a string (see Section 3.5 [Font styles], page 152).

'^' one of marks (see Section 3.3 [Line styles], page 148);

one of mask for face filling (see Section 3.4 [Color scheme], page 150);

style of [subplot], page 173 and [inplot], page 173;

set position of [colorbar], page 192;

set outer position for [legend], page 194;

inverse default position for [axis], page 191;

switch to upper index inside a string (see Section 3.5 [Font styles], page 152);

align center in [bars], page 198, [barh], page 199, [boxplot], page 200, [cones], page 199, [candle], page 201, [ohlc], page 201;

operation in Section 3.6 [Textual formulas], page 153.

'_' empty arrow style (see Section 3.3 [Line styles], page 148);

disable drawing of tick labels for [axis], page 191;

style of [subplot], page 173 and [inplot], page 173;

set position of [colorbar], page 192;

set to draw contours at bottom for [cont], page 210, [contf], page 210, [contd], page 211, [contv], page 212, [tricont], page 230;

switch to lower index inside a string (see Section 3.5 [Font styles], page 152).

'[]' contain symbols excluded from color scheme parsing (see Section 3.4 [Color scheme], page 150).

'{}' contain extended specification of color (see Section 3.2 [Color styles], page 148), dashing (see Section 3.3 [Line styles], page 148) or mask (see Section 3.4 [Color scheme], page 150);

denote special operation in Chapter 7 [MGL scripts], page 286;

denote 'meta-symbol' for LaTeX like string parsing (see Section 3.5 [Font styles], page 152).

'|' line dashing style (see Section 3.3 [Line styles], page 148);

set to use sharp color scheme (see Section 3.4 [Color scheme], page 150);

set to limit width by subplot width for [table], page 205;

delimiter in [list], page 256 command;

operation in Section 3.6 [Textual formulas], page 153.

'\' string continuation symbol on next line for Chapter 7 [MGL scripts], page 286.

'~' disable drawing of tick labels for [axis], page 191 and [colorbar], page 192;

disable first segment in [lamerey], page 206;

one of mask for face filling (see Section 3.4 [Color scheme], page 150).

'0,1,2,3,4,5,6,7,8,9'

line width (see Section 3.3 [Line styles], page 148);

brightness of a color (see Section 3.2 [Color styles], page 148);

precision of numbers in [axis], page 191, [label], page 204, [table], page 205;

kind of smoothing (for digits 1,3,5) in [smooth], page 271;

digits for a value.

'4,6,8' set to draw square, hex- or octo-pyramids instead of cones in [cone], page 187, [cones], page 199.

'A,B,C,D,E,F,a,b,c,d,e,f'

can be hex-digit for color specification if placed inside {} (see Section 3.2 [Color styles], page 148).

'A' arrow style (see Section 3.3 [Line styles], page 148);

set to use absolute position in whole picture for [text], page 189, [colorbar], page 192, [legend], page 194.

'a' set to use absolute position in subplot for [text], page 189;

style of [bars], page 198, [barh], page 199, [cones], page 199.

'B' dark blue color (see Section 3.2 [Color styles], page 148).

'b' blue color (see Section 3.2 [Color styles], page 148);

bold font face if placed after ':' (see Section 3.5 [Font styles], page 152).

'C' dark cyan color (see Section 3.2 [Color styles], page 148);
align text to center if placed after ':' (see Section 3.5 [Font styles], page 152).

'c' cyan color (see Section 3.2 [Color styles], page 148);
name of color axis;
cosine transform for [transform], page 277.

'D' arrow style (see Section 3.3 [Line styles], page 148);
one of mask for face filling (see Section 3.4 [Color scheme], page 150).

'd' one of marks (see Section 3.3 [Line styles], page 148) or kind of [error], page 202 boxes;
one of mask for face filling (see Section 3.4 [Color scheme], page 150);
start hex-dash description if placed inside {} (see Section 3.3 [Line styles], page 148).

'E' dark green-yellow color (see Section 3.2 [Color styles], page 148).

'e' green-yellow color (see Section 3.2 [Color styles], page 148).

'F'
set LaTeX-like format for numbers in [axis], page 191, [label], page 204, [table], page 205.

'f' style of [bars], page 198, [barh], page 199;
style of [vect], page 223, [vect3], page 223;
set fixed format for numbers in [axis], page 191, [label], page 204, [table], page 205;
Fourier transform for [transform], page 277.

'G' dark green color (see Section 3.2 [Color styles], page 148).

'g' green color (see Section 3.2 [Color styles], page 148).

'H' dark gray color (see Section 3.2 [Color styles], page 148).

'h' gray color (see Section 3.2 [Color styles], page 148);
Hankel transform for [transform], page 277.

'I' arrow style (see Section 3.3 [Line styles], page 148);
set [colorbar], page 192 position near boundary.

'i' line dashing style (see Section 3.3 [Line styles], page 148);
italic font face if placed after ':' (see Section 3.5 [Font styles], page 152).
set to use inverse values for [cloud], page 214, [pipe], page 226, [dew], page 224;
set to fill only area with y1<y<y2 for [region], page 197;
inverse Fourier transform for [transform], page 277.

'j' line dashing style (see Section 3.3 [Line styles], page 148);
one of mask for face filling (see Section 3.4 [Color scheme], page 150).

'K' arrow style (see Section 3.3 [Line styles], page 148).

‘k’ black color (see Section 3.2 [Color styles], page 148).

‘L’ dark green-blue color (see Section 3.2 [Color styles], page 148);
align text to left if placed after ‘:’ (see Section 3.5 [Font styles], page 152).

‘l’ green-blue color (see Section 3.2 [Color styles], page 148).

‘M’ dark magenta color (see Section 3.2 [Color styles], page 148).

‘m’ magenta color (see Section 3.2 [Color styles], page 148).

‘N’ dark sky-blue color (see Section 3.2 [Color styles], page 148).

‘n’ sky-blue color (see Section 3.2 [Color styles], page 148).

‘O’ arrow style (see Section 3.3 [Line styles], page 148);
one of mask for face filling (see Section 3.4 [Color scheme], page 150).

‘o’ one of marks (see Section 3.3 [Line styles], page 148) or kind of [error], page 202 boxes;
one of mask for face filling (see Section 3.4 [Color scheme], page 150);
over-line text if placed after ‘:’ (see Section 3.5 [Font styles], page 152).

‘P’ dark purple color (see Section 3.2 [Color styles], page 148).

‘p’ purple color (see Section 3.2 [Color styles], page 148).

‘Q’ dark orange or brown color (see Section 3.2 [Color styles], page 148).

‘q’ orange color (see Section 3.2 [Color styles], page 148).

‘R’ dark red color (see Section 3.2 [Color styles], page 148);
align text to right if placed after ‘:’ (see Section 3.5 [Font styles], page 152).

‘r’ red color (see Section 3.2 [Color styles], page 148).

‘S’ arrow style (see Section 3.3 [Line styles], page 148);
one of mask for face filling (see Section 3.4 [Color scheme], page 150).

‘s’ one of marks (see Section 3.3 [Line styles], page 148) or kind of [error], page 202 boxes;
one of mask for face filling (see Section 3.4 [Color scheme], page 150);
start hex-mask description if placed inside {} (see Section 3.4 [Color scheme], page 150);
sine transform for [transform], page 277.

‘t’ draw tubes instead of cones in [cone], page 187, [cones], page 199;

‘T’ arrow style (see Section 3.3 [Line styles], page 148);
place text under the curve for [text], page 189, [cont], page 210, [cont3], page 215.

‘t’ set to draw text labels for [cont], page 210, [cont3], page 215;
name of t-axis (one of ternary axis);
variable in Section 3.6 [Textual formulas], page 153, which usually is varied in range [0,1].

'U' dark blue-violet color (see Section 3.2 [Color styles], page 148);
disable rotation of tick labels for [axis], page 191.

'u' blue-violet color (see Section 3.2 [Color styles], page 148);
under-line text if placed after ':' (see Section 3.5 [Font styles], page 152);
name of u-axis (one of ternary axis);
variable in Section 3.6 [Textual formulas], page 153, which usually denote array itself.

'V' arrow style (see Section 3.3 [Line styles], page 148);
place text centering on vertical direction for [text], page 189.

'v' one of marks (see Section 3.3 [Line styles], page 148);
set to draw vectors on flow threads for [flow], page 224 and on segments for [lamerey], page 206.

'W' bright gray color (see Section 3.2 [Color styles], page 148).

'w' white color (see Section 3.2 [Color styles], page 148);
wired text if placed after ':' (see Section 3.5 [Font styles], page 152);
name of w-axis (one of ternary axis);

'X' arrow style (see Section 3.3 [Line styles], page 148).

'x' one of marks (see Section 3.3 [Line styles], page 148) or kind of [error], page 202 boxes;
name of x-axis or x-direction or 1st dimension of a data array;
start hex-color description if placed inside {} (see Section 3.2 [Color styles], page 148);
style of [tape], page 197.

'Y' dark yellow or gold color (see Section 3.2 [Color styles], page 148).

'y' yellow color (see Section 3.2 [Color styles], page 148);
name of y-axis or y-direction or 2nd dimension of a data array.

'z'
name of z-axis or z-direction or 3d dimension of a data array;
style of [tape], page 197.

A.2 Hot-keys for mglview

Key	Description
Ctrl-P	Open printer dialog and print graphics.
Ctrl-W	Close window.
Ctrl-T	Switch on/off transparency for the graphics.

`Ctrl-L`	Switch on/off additional lightning for the graphics.
`Ctrl-Space`	Restore default graphics rotation, zoom and perspective.
`F5`	Execute script and redraw graphics.
`F6`	Change canvas size to fill whole region.
`F7`	Stop drawing and script execution.
`Ctrl-F5`	Run slideshow. If no parameter specified then the dialog with slideshow options will appear.
`Ctrl-Comma`, `Ctrl-Period`	Show next/previous slide. If no parameter specified then the dialog with slideshow options will appear.
`Ctrl-Shift-G`	Copy graphics to clipboard.
`Alt-P`	Export as semitransparent PNG.
`Alt-F`	Export as solid PNG.
`Alt-J`	Export as JPEG.
`Alt-E`	Export as vector EPS.
`Alt-S`	Export as vector SVG.
`Alt-L`	Export as LaTeX/Tikz image.
`Alt-M`	Export as MGLD.
`Alt-D`	Export as PRC/PDF.
`Alt-O`	Export as OBJ.

A.3 Hot-keys for UDAV

Key	**Description**
`Ctrl-N`	Create new window with empty script. Note, all scripts share variables. So, second window can be used to see some additional information of existed variables.
`Ctrl-O`	Open and execute/show script or data from file. You may switch off automatic exection in UDAV properties

`Ctrl-S`	Save script to a file.
`Ctrl-P`	Open printer dialog and print graphics.
`Ctrl-Z`	Undo changes in script editor.
`Ctrl-Shift-Z`	Redo changes in script editor.
`Ctrl-X`	Cut selected text into clipboard.
`Ctrl-C`	Copy selected text into clipboard.
`Ctrl-V`	Paste selected text from clipboard.
`Ctrl-A`	Select all text in editor.
`Ctrl-F`	Show dialog for text finding.
`F3`	Find next occurrence of the text.
`Win-C` or `Meta-C`	Show dialog for new command and put it into the script.
`Win-F` or `Meta-F`	Insert last fitted formula with found coefficients.
`Win-S` or `Meta-S`	Show dialog for styles and put it into the script. Styles define the plot view (color scheme, marks, dashing and so on).
`Win-O` or `Meta-O`	Show dialog for options and put it into the script. Options are used for additional setup the plot.
`Win-N` or `Meta-N`	Replace selected expression by its numerical value.
`Win-P` or `Meta-P`	Select file and insert its file name into the script.
`Win-G` or `Meta-G`	Show dialog for plot setup and put resulting code into the script. This dialog setup axis, labels, lighting and other general things.
`Ctrl-Shift-O`	Load data from file. Data will be deleted only at exit but UDAV will not ask to save it.
`Ctrl-Shift-S`	Save data to a file.
`Ctrl-Shift-C`	Copy range of numbers to clipboard.
`Ctrl-Shift-V`	Paste range of numbers from clipboard.

`Ctrl-Shift-N`	Recreate the data with new sizes and fill it by zeros.
`Ctrl-Shift-R`	Resize (interpolate) the data to specified sizes.
`Ctrl-Shift-T`	Transform data along dimension(s).
`Ctrl-Shift-M`	Make another data.
`Ctrl-Shift-H`	Find histogram of data.
`Ctrl-T`	Switch on/off transparency for the graphics.
`Ctrl-L`	Switch on/off additional lightning for the graphics.
`Ctrl-G`	Switch on/off grid of absolute coordinates.
`Ctrl-Space`	Restore default graphics rotation, zoom and perspective.
`F5`	Execute script and redraw graphics.
`F6`	Change canvas size to fill whole region.
`F7`	Stop script execution and drawing.
`F8`	Show/hide tool window with list of hidden plots.
`F9`	Restore status for 'once' command and reload data.
`Ctrl-F5`	Run slideshow. If no parameter specified then the dialog with slideshow options will appear.
`Ctrl-Comma`, `Ctrl-Period`	Show next/previous slide. If no parameter specified then the dialog with slideshow options will appear.
`Ctrl-W`	Open dialog with slideshow options.
`Ctrl-Shift-G`	Copy graphics to clipboard.
`F1`	Show help on MGL commands
`F2`	Show/hide tool window with messages and information.
`F4`	Show/hide calculator which evaluate and help to type textual formulas. Textual formulas may contain data variables too.
`Meta-Shift-Up`, `Meta-Shift-Down`	Change view angle θ.

`Meta-Shift-Left`, `Meta-Shift-Right`	Change view angle ϕ.
`Alt-Minus`, `Alt-Equal`	Zoom in/out whole image.
`Alt-Up`, `Alt-Down`, `Alt-Right`, `Alt-Left`	Shift whole image.
`Alt-P`	Export as semitransparent PNG.
`Alt-F`	Export as solid PNG.
`Alt-J`	Export as JPEG.
`Alt-E`	Export as vector EPS.
`Alt-S`	Export as vector SVG.
`Alt-L`	Export as LaTeX/Tikz image.
`Alt-M`	Export as MGLD.
`Alt-D`	Export as PRC/PDF.
`Alt-O`	Export as OBJ.

Appendix B File formats

This appendix contain description of file formats used by MathGL.

B.1 Font files

Starting from v.1.6 the MathGL library uses new font files. The font is defined in 4 files with suffixes '`*.vfm`', '`*_b.vfm`', '`*_i.vfm`', '`*_bi.vfm`'. These files are text files containing the data for roman font, bold font, italic font and bold italic font. The files (or some symbols in the files) for bold, italic or bold italic fonts can be absent. In this case the roman glyph will be used for them. By analogy, if the bold italic font is absent but the bold font is present then bold glyph will be used for bold italic. You may create these font files by yourself from *.ttf, *.otf files with the help of program `font_tools`. This program can be found at MathGL home site.

The format of font files (*.vfm – vector font for MathGL) is the following.

1. First string contains human readable comment and is always ignored.
2. Second string contains 3 numbers, delimited by space or tabulation. The order of numbers is the following: *numg* – the number of glyphs in the file (integer), *fact* – the factor for glyph sizing (mreal), *size* – the size of buffer for glyph description (integer).
3. After it *numg*-th strings with glyphs description are placed. Each string contains 6 positive numbers, delimited by space of tabulation. The order of numbers is the following: Unicode glyph ID, glyph width, number of lines in glyph, position of lines coordinates in the buffer (length is 2*number of lines), number of triangles in glyph, position of triangles coordinates in the buffer (length is 6*number of triangles).
4. The end of file contains the buffer with point coordinates at lines or triangles vertexes. The size of buffer (the number of integer) is *size*.

Each font file can be compressed by gzip.

Note: the closing contour line is done automatically (so the last segment may be absent). For starting new contour use a point with coordinates `{0x3fff, 0x3fff}`.

B.2 MGLD format

MGLD is textual file, which contain all required information for drawing 3D image, i.e. it contain vertexes with colors and normales, primitives with all properties, textures, and glyph descriptions. MGLD file can be imported or viewed separately, without parsing data files itself.

MGLD file start from string

```
MGLD npnts nprim ntxtr nglfs # optional description
```

which contain signature '`MGLD`' and number of points *npnts*, number of primitives *nprim*, number of textures *ntxtr*, number of glyph descriptions *nglfs*, and optional description. Empty strings and string with '`#`' are ignored.

Next, file contain *npnts* strings with points coordinates and colors. The format of each string is

```
x y z c t ta u v w r g b a
```

Here *x*, *y*, *z* are coordinates, *c*, *t* are color indexes in texture, *ta* is normalized *t* according to current alpha setting, *u*, *v*, *w* are coordinates of normal vector (can be `NAN` if disabled), *r*, *g*, *b*, *a* are RGBA color values.

Next, file contain *nprim* strings with properties of primitives. The format of each string is

```
type n1 n2 n3 n4 id s w p
```

Here *type* is kind of primitive (0 - mark, 1 - line, 2 - triangle, 3 - quadrangle, 4 - glyph), *n1...n4* is index of point for vertexes, *id* is primitive identification number, *s* and *w* are size and width if applicable, *p* is scaling factor for glyphs.

Next, file contain *ntxtr* strings with descriptions of textures. The format of each string is

```
smooth alpha colors
```

Here *smooth* set to enable smoothing between colors, *alpha* set to use half-transparent texture, *colors* contain color scheme itself as it described in Section 3.4 [Color scheme], page 150.

Finally, file contain *nglfs* entries with description of each glyph used in the figure. The format of entries are

```
nT nL
xA yA xB yB xC yC ...
xP yP ...
```

Here nT is the number of triangles; nL is the number of line vertexes; xA, yA, xB, yB, xC, yC are coordinates of triangles; and xP, yP, xQ, yQ are coordinates of lines. Line coordinate xP=0x3fff, yP=0x3fff denote line breaking.

B.3 JSON format

MathGL can save points and primitives of 3D object. It contain a set of variables listed below.

‘`width`’ width of the image;

‘`height`’ height of the image

‘`depth`’ depth of the image, usually =sqrt(width*height);

‘`npnts`’ number of points (vertexes);

‘`pnts`’ array of coordinates of points (vertexes), each element is array in form [x, y, z];

‘`nprim`’ number of primitives;

‘`prim`’ array of primitives, each element is array in form [type, n1, n2, n3, n4, id, s, w, p, z, color].

Here *type* is kind of primitive (0 - mark, 1 - line, 2 - triangle, 3 - quadrangle, 4 - glyph), *n1...n4* is index of point for vertexes and *n2* can be index of glyph coordinate, *s* and *w* are size and width if applicable, *z* is average z-coordinate, *id* is primitive identification number, *p* is scaling factor for glyphs.

‘`ncoor`’ number of glyph positions

‘`coor`’ array of glyph positions, each element is array in form [dx,dy]

‘`nglfs`’ number of glyph descriptions

‘`glfs`’ array of glyph descriptions, each element is array in form `[nL, [xP0, yP0, xP1, yP1 ...]]`. Here `nL` is the number of line vertexes; and `xP, yP, xQ, yQ` are coordinates of lines. Line coordinate xP=0x3fff, yP=0x3fff denote line breaking.

Appendix C Plotting time

Table below show plotting time in seconds for all samples in file examples/samples.cpp (`http://sourceforge.net/p/mathgl/code/HEAD/tree/mathgl-2x/examples/samples.cpp`). The test was done in my laptop (i5-2430M) with 64-bit Debian.

Few words about the speed. Firstly, direct bitmap drawing (Quality=4,5,6) is faster than buffered one (Quality=0,1,2), but sometimes it give incorrect result (see [cloud], page 214) and don't allow to export in vector or 3d formats (like EPS, SVG, PDF ...). Secondly, lower quality is faster than high one generally, i.e. Quality=1 is faster than Quality=2, and Quality=0 is faster than Quality=1. However, if plot contain a lot of faces (like [cloud], page 214, [surf3], page 214, [pipe], page 226, [dew], page 224) then Quality=0 may become slow, especially for small images. Finally, smaller images are drawn faster than larger ones.

Results for image size 800*600 (default one).

Name	**q=0**	**q=1**	**q=2**	**q=4**	**q=5**	**q=6**	**q=8**
alpha	0.0994	0.106	0.137	0.034	0.0565	0.068	0.0332
area	0.0813	0.0666	0.11	0.0342	0.0426	0.0794	0.0435
aspect	0.0924	0.142	0.118	0.0281	0.0376	0.0693	0.0246
axial	0.706	0.606	0.911	0.243	0.264	0.475	0.0657
axis	0.136	0.163	0.155	0.0299	0.0293	0.0494	0.0506
barh	0.0811	0.105	0.121	0.0299	0.0326	0.0454	0.0273
bars	0.739	0.134	0.134	0.0477	0.0832	0.0662	0.0641
belt	0.0576	0.0984	0.0916	0.0429	0.0307	0.0465	0.0252
box	0.0938	0.105	0.127	0.0312	0.0352	0.0549	0.0501
boxplot	0.0469	0.127	0.0534	0.0587	0.0252	0.035	0.0152
boxs	0.242	0.223	0.331	0.0567	0.0683	0.189	0.095
candle	0.0842	0.132	0.0634	0.0541	0.0509	0.0532	0.016
chart	0.506	0.427	0.715	0.182	0.199	0.477	0.154
cloud	0.0927	4.72	5.16	0.0308	1.2	1.64	0.0265
colorbar	0.266	0.273	0.246	0.174	0.182	0.253	0.267
combined	0.603	0.401	0.458	0.306	0.276	0.362	0.256
cones	0.308	0.189	0.241	0.144	0.132	0.172	0.109
cont	0.079	0.0795	0.124	0.0374	0.0374	0.0606	0.0326
cont_xyz	0.14	0.106	0.249	0.33	0.159	0.115	0.152
conta	0.135	0.106	0.132	0.0822	0.101	0.0894	0.083
contd	0.209	0.181	0.2	0.0722	0.075	0.109	0.0666
contf	0.156	0.157	0.177	0.0645	0.0658	0.0881	0.0584
contf_xyz	0.214	0.211	0.175	0.0934	0.111	0.104	0.0851
contfa	0.293	0.224	0.259	0.142	0.165	0.176	0.14
contv	0.113	0.105	0.135	0.051	0.0482	0.071	0.0386
correl	0.0597	0.0798	0.0772	0.0617	0.0697	0.0569	0.0284
curvcoor	0.0906	0.0892	0.134	0.0434	0.0432	0.0688	0.0403
cut	1.21	0.776	0.795	0.843	0.632	0.683	0.62
dat_diff	0.144	0.104	0.13	0.105	0.0779	0.0954	0.0927
dat_extra	0.442	0.279	0.304	0.122	0.213	0.257	0.0869
data1	5.13	4.08	3.72	3.74	3.45	3.95	3.35

data2	3.31	2.72	2.81	3	2.98	2.82	2.61
dens	0.105	0.118	0.168	0.0456	0.0547	0.085	0.0426
dens_xyz	0.158	0.16	0.23	0.0827	0.168	0.106	0.148
densa	0.127	0.138	0.159	0.0915	0.0981	0.11	0.0805
dew	1.7	0.831	0.765	0.204	0.172	0.182	0.0895
dots	0.148	0.119	0.13	0.0535	0.0535	0.0674	0.0636
error	0.104	0.0724	0.0861	0.0999	0.121	0.111	0.0285
error2	0.0625	0.0672	0.0873	0.0463	0.0359	0.0558	0.0365
export	0.177	0.221	0.249	0.112	0.124	0.154	0.17
fall	0.135	0.0346	0.0641	0.0363	0.0485	0.0797	0.084
fit	3.11	0.169	0.13	0.0734	0.0727	2.99	0.123
flow	0.513	0.386	0.497	0.272	0.423	0.377	0.262
fog	0.1	0.113	0.117	0.0297	0.039	0.0712	0.0616
fonts	2.67	2.63	3.03	2.74	2.67	2.88	2.94
grad	0.124	0.119	0.192	0.127	0.0672	0.109	0.0476
hist	0.216	0.202	0.226	0.131	0.149	0.142	0.0786
indirect	0.0602	0.0582	0.0586	0.0844	0.0792	0.152	0.0262
inplot	0.148	0.139	0.0964	0.0399	0.0624	0.0449	0.0495
label	0.146	0.0577	0.169	0.0578	0.0959	0.079	0.0289
legend	0.168	0.227	0.23	0.0345	0.0364	0.073	0.0382
light	0.107	0.0814	0.0821	0.0804	0.073	0.0774	0.073
loglog	0.0776	0.0741	0.113	0.0451	0.0375	0.0559	0.0335
map	0.178	0.119	0.188	0.0767	0.0887	0.111	0.0304
mark	0.0785	0.141	0.0551	0.028	0.0311	0.0365	0.016
mask	0.0854	0.131	0.115	0.0296	0.0412	0.0547	0.0213
mesh	0.11	0.112	0.0894	0.0368	0.0518	0.0508	0.0724
mirror	0.197	0.104	0.146	0.0363	0.0433	0.0695	0.0384
molecule	0.153	0.107	0.199	0.0653	0.0657	0.086	0.037
ode	1.49	0.618	0.718	0.62	0.595	0.72	0.556
ohlc	0.0347	0.0487	0.0551	0.0406	0.0281	0.0389	0.0167
param1	0.316	0.247	0.321	0.119	0.155	0.158	0.0958
param2	0.505	0.428	0.496	0.152	0.138	0.187	0.104
param3	3.33	3.59	3.37	1.82	1.89	1.94	1.65
paramv	4.31	4.7	4.25	1.21	1.13	1.23	1.07
parser	0.074	0.102	0.128	0.0973	0.154	0.104	0.145
pde	0.943	0.934	0.987	1.01	0.816	0.79	0.809
pipe	4.13	2.98	2.46	0.597	0.848	0.815	0.588
plot	0.0702	0.0848	0.112	0.0409	0.0409	0.0568	0.029
primitives	0.0998	0.0958	0.175	0.0313	0.0363	0.0815	0.0265
projection	0.138	0.14	0.222	0.0463	0.046	0.157	0.104
projection5	0.124	0.132	0.197	0.0414	0.0423	0.1	0.0353
qo2d	0.375	0.331	0.364	0.244	0.279	0.287	0.244
radar	0.0348	0.0503	0.0598	0.0582	0.0297	0.083	0.0147
refill	0.391	0.28	0.233	0.161	0.133	0.155	0.0867
region	0.0748	0.0719	0.117	0.0291	0.0319	0.0566	0.0256
schemes	0.123	0.102	0.184	0.0371	0.0392	0.0717	0.0469
several_light	0.0862	0.102	0.128	0.0284	0.0327	0.0912	0.0246

solve	0.126	0.0944	0.148	0.06	0.078	0.0841	0.0579
stem	0.061	0.0558	0.124	0.0312	0.0315	0.0479	0.0265
step	0.132	0.0962	0.0708	0.0321	0.0322	0.191	0.0398
stereo	0.0706	0.0877	0.137	0.0304	0.0334	0.0672	0.0394
stfa	0.177	0.0918	0.146	0.0518	0.0657	0.0935	0.059
style	0.176	0.166	0.226	0.0408	0.0426	0.082	0.0252
surf	0.191	0.191	0.233	0.0669	0.0704	0.105	0.118
surf3	3.1	2.9	2.88	2.89	2.78	3.57	1.16
surf3a	0.754	0.471	0.526	0.399	0.394	0.511	0.349
surf3c	0.736	0.448	0.502	0.383	0.387	0.494	0.333
surfa	0.0647	0.112	0.0916	0.0298	0.0311	0.0626	0.025
surfc	0.0588	0.103	0.139	0.0313	0.0311	0.0602	0.0248
table	0.194	0.226	0.279	0.0358	0.0361	0.0809	0.0438
tape	0.1	0.108	0.125	0.0302	0.0326	0.0526	0.0405
tens	0.0959	0.109	0.0642	0.0727	0.0965	0.074	0.0254
ternary	0.142	0.137	0.205	0.041	0.0418	0.0942	0.0355
text	0.123	0.124	0.166	0.045	0.0567	0.0758	0.025
text2	0.132	0.132	0.167	0.0721	0.0872	0.095	0.0467
textmark	0.224	0.0722	0.0939	0.126	0.0474	0.0575	0.0242
ticks	0.186	0.145	0.207	0.0341	0.042	0.0689	0.0609
tile	0.0861	0.0811	0.11	0.0277	0.0299	0.0451	0.0618
tiles	0.0558	0.0581	0.0772	0.0272	0.0303	0.0454	0.0583
torus	0.121	0.116	0.193	0.038	0.0448	0.104	0.0314
traj	0.0354	0.0395	0.0789	0.0467	0.0253	0.0364	0.0173
triangulation	0.0603	0.214	0.139	0.0455	0.0734	0.0845	0.0265
triplot	0.0692	0.0519	0.131	0.0497	0.0325	0.0943	0.0124
tube	0.151	0.135	0.294	0.0491	0.0601	0.108	0.0609
type0	0.251	0.187	0.248	0.113	0.0785	0.157	0.0567
type1	0.249	0.179	0.274	0.0796	0.0786	0.145	0.0564
type2	0.246	0.212	0.25	0.0868	0.104	0.151	0.0625
vect	0.166	0.155	0.255	0.13	0.132	0.181	0.174
vecta	0.121	0.0841	0.108	0.0755	0.0672	0.155	0.0686
venn	0.0182	0.0527	0.0913	0.0368	0.0385	0.0706	0.013

Results for image size 1920*1440 (print quality)

Name	**q=0**	**q=1**	**q=2**	**q=4**	**q=5**	**q=6**	**q=8**
alpha	0.16	0.184	0.362	0.0868	0.105	0.246	0.0674
area	0.102	0.165	0.327	0.0795	0.124	0.255	0.0656
aspect	0.094	0.0939	0.15	0.0664	0.0674	0.11	0.0618
axial	0.909	0.985	2.03	0.371	0.464	1.28	0.105
axis	0.121	0.121	0.198	0.0705	0.0683	0.123	0.0951
barh	0.0886	0.105	0.181	0.068	0.0795	0.137	0.13
bars	0.11	0.126	0.207	0.0868	0.0973	0.162	0.0754
belt	0.0944	0.12	0.212	0.0674	0.089	0.192	0.0629
box	0.122	0.161	0.25	0.0735	0.0951	0.174	0.0641
boxplot	0.0696	0.0699	0.118	0.0633	0.0634	0.106	0.0514

boxs	0.296	0.354	0.786	0.111	0.213	0.58	0.0872
candle	0.0762	0.0787	0.143	0.0789	0.0859	0.135	0.0548
chart	0.572	0.778	2.39	0.244	0.429	1.64	0.2
cloud	0.0818	7.16	9.38	0.0691	2.43	4.96	0.063
colorbar	0.221	0.248	0.363	0.227	0.285	0.378	0.11
combined	0.583	0.464	0.697	0.339	0.375	0.586	0.293
cones	0.289	0.24	0.452	0.184	0.191	0.375	0.131
cont	0.124	0.123	0.208	0.0785	0.0778	0.14	0.0774
cont_xyz	0.134	0.13	0.184	0.113	0.113	0.163	0.108
conta	0.128	0.154	0.289	0.112	0.129	0.162	0.177
contd	0.239	0.255	0.354	0.12	0.142	0.236	0.103
contf	0.203	0.226	0.334	0.111	0.13	0.226	0.0992
contf_xyz	0.17	0.215	0.305	0.126	0.151	0.236	0.118
contfa	0.287	0.369	0.493	0.18	0.203	0.401	0.165
contv	0.162	0.176	0.306	0.089	0.103	0.212	0.076
correl	0.099	0.0894	0.169	0.0815	0.0855	0.129	0.0659
curvcoor	0.132	0.131	0.231	0.084	0.0843	0.151	0.124
cut	1.25	0.842	1.06	0.743	0.768	1.13	0.644
dat_diff	0.127	0.163	0.261	0.115	0.135	0.216	0.0846
dat_extra	0.328	0.26	0.351	0.17	0.267	0.3	0.114
data1	4.98	3.75	3.98	3.6	3.52	3.9	3.29
data2	3.28	2.74	2.82	2.81	2.78	3.2	2.61
dens	0.153	0.244	0.407	0.1	0.141	0.273	0.0771
dens_xyz	0.15	0.211	0.358	0.123	0.162	0.282	0.0961
densa	0.183	0.211	0.351	0.12	0.154	0.296	0.0912
dew	1.7	0.942	1.03	0.224	0.241	0.361	0.129
dots	0.161	0.167	0.217	0.104	0.11	0.148	0.0639
error	0.101	0.109	0.176	0.11	0.113	0.194	0.0688
error2	0.0931	0.112	0.209	0.0742	0.0808	0.156	0.0675
export	0.287	0.363	0.531	0.174	0.22	0.36	0.253
fall	0.079	0.0752	0.157	0.0652	0.064	0.122	0.0868
fit	0.109	0.824	0.173	0.0894	0.0918	0.136	0.0793
flow	0.39	0.395	0.566	0.313	0.423	0.435	0.3
fog	0.111	0.169	0.362	0.0716	0.127	0.3	0.063
fonts	3	3.02	3.14	2.75	2.57	2.88	2.66
grad	0.119	0.229	0.424	0.103	0.158	0.306	0.0859
hist	0.294	0.303	0.358	0.209	0.217	0.274	0.0886
indirect	0.108	0.0908	0.147	0.111	0.114	0.16	0.0556
inplot	0.102	0.0998	0.174	0.0747	0.0726	0.123	0.0664
label	0.0836	0.0803	0.129	0.0808	0.08	0.12	0.0529
legend	0.185	0.195	0.3	0.0758	0.0864	0.171	0.0622
light	0.273	0.271	0.299	0.277	0.274	0.299	0.274
loglog	0.12	0.123	0.198	0.076	0.0779	0.133	0.0692
map	0.107	0.159	0.255	0.12	0.149	0.316	0.0684
mark	0.083	0.0937	0.126	0.072	0.0723	0.11	0.0507
mask	0.12	0.24	0.257	0.0723	0.141	0.169	0.0597
mesh	0.0866	0.0906	0.189	0.0661	0.0932	0.156	0.0638

mirror	0.163	0.164	0.305	0.08	0.094	0.209	0.0679
molecule	0.155	0.166	0.354	0.0754	0.111	0.263	0.0628
ode	0.652	0.654	0.788	0.631	0.636	0.793	0.635
ohlc	0.0668	0.0668	0.117	0.0675	0.0734	0.104	0.053
param1	0.288	0.295	0.518	0.137	0.158	0.352	0.147
param2	0.555	0.54	0.767	0.591	0.232	0.51	0.151
param3	3.15	3.63	3.78	1.86	2.03	2.35	1.61
paramv	4.55	4.9	4.7	1.14	1.19	1.35	1.11
parser	0.118	0.116	0.195	0.115	0.122	0.225	0.0954
pde	0.883	0.961	1.13	0.834	0.843	0.953	0.781
pipe	4.27	3.23	3.04	0.664	0.831	0.993	0.52
plot	0.154	0.119	0.221	0.0921	0.0933	0.143	0.0835
primitives	0.143	0.188	0.43	0.0749	0.108	0.313	0.0879
projection	0.182	0.207	0.494	0.0878	0.103	0.349	0.0768
projection5	0.17	0.2	0.427	0.0835	0.0956	0.323	0.11
qo2d	0.325	0.423	0.596	0.286	0.341	0.5	0.26
radar	0.0724	0.0738	0.115	0.076	0.0804	0.135	0.0499
refill	0.329	0.263	0.38	0.197	0.167	0.286	0.114
region	0.0964	0.235	0.265	0.0729	0.0986	0.191	0.0663
schemes	0.158	0.205	0.358	0.0947	0.116	0.231	0.0633
several_light	0.121	0.136	0.494	0.0704	0.0966	0.427	0.0609
solve	0.138	0.134	0.247	0.108	0.104	0.204	0.0741
stem	0.103	0.101	0.171	0.079	0.0745	0.135	0.0653
step	0.114	0.11	0.157	0.0782	0.0755	0.119	0.0636
stereo	0.12	0.138	0.308	0.0715	0.0996	0.274	0.065
stfa	0.128	0.168	0.366	0.0982	0.122	0.273	0.0732
style	0.181	0.202	0.338	0.0814	0.0929	0.19	0.0614
surf	0.235	0.233	0.395	0.12	0.137	0.284	0.0811
surf3	3.33	3.34	4.02	3.66	3.31	5.02	1.18
surf3a	0.825	0.581	0.901	0.469	0.641	1.34	0.378
surf3c	0.797	0.577	0.91	0.471	0.637	1.34	0.375
surfa	0.0979	0.141	0.358	0.0698	0.0953	0.264	0.0639
surfc	0.0992	0.135	0.3	0.0682	0.0964	0.252	0.0619
table	0.213	0.205	0.33	0.0784	0.0796	0.159	0.0633
tape	0.1	0.117	0.211	0.07	0.0808	0.147	0.0662
tens	0.0891	0.0865	0.14	0.108	0.11	0.153	0.181
ternary	0.18	0.199	0.376	0.0867	0.0968	0.263	0.07
text	0.164	0.165	0.253	0.0863	0.088	0.155	0.0635
text2	0.145	0.145	0.211	0.109	0.109	0.168	0.0717
textmark	0.115	0.113	0.171	0.0847	0.0815	0.133	0.16
ticks	0.18	0.184	0.277	0.0756	0.074	0.161	0.063
tile	0.0826	0.116	0.209	0.0671	0.0839	0.16	0.0638
tiles	0.0856	0.134	0.217	0.0685	0.0901	0.157	0.0678
torus	0.168	0.202	0.521	0.0812	0.114	0.372	0.0758
traj	0.0641	0.065	0.13	0.066	0.0625	0.112	0.0529
triangulation	0.0895	0.127	0.304	0.0839	0.117	0.271	0.0707
triplot	0.0721	0.176	0.581	0.0639	0.118	0.439	0.0497

tube	0.151	0.219	0.48	0.0922	0.132	0.347	0.0719
type0	0.296	0.289	0.656	0.135	0.196	0.555	0.117
type1	0.294	0.286	0.661	0.138	0.196	0.566	0.116
type2	0.311	0.304	0.67	0.155	0.215	0.574	0.135
vect	0.19	0.192	0.31	0.175	0.164	0.273	0.12
vecta	0.0971	0.0982	0.186	0.108	0.118	0.31	0.0698
venn	0.064	0.24	0.397	0.0631	0.155	0.323	0.0474

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