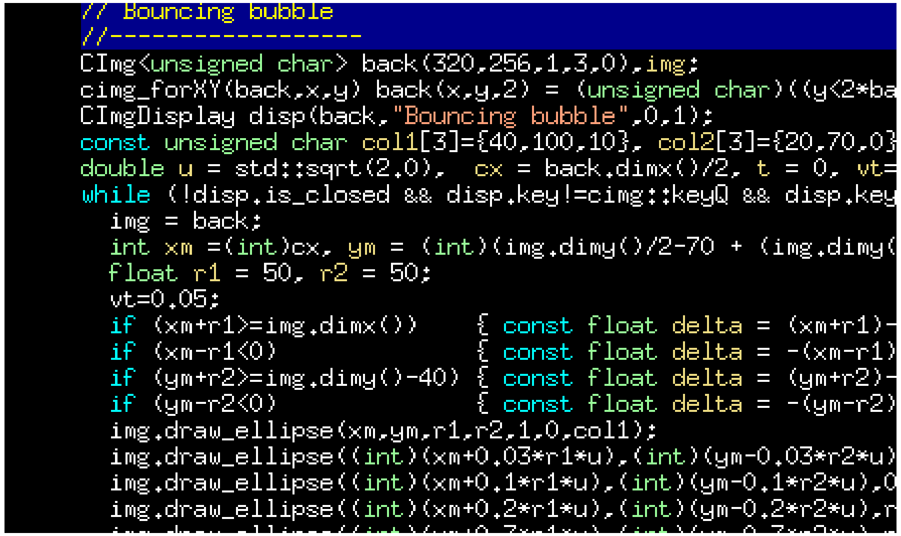
Introduction to The CImg Library

C++ Template Image Processing Toolbox (version 1.5)



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- Document available at : http://cimg.sourceforge.net/CImg_slides.pdf

Outline - PART I of II : CImg Library Overview

- **Context** : Image Processing with C++.
  - Aim and targeted audience.
  - Why considering The CImg Library ?
- **CImg<T>** : A class for image manipulation.
  - Image construction, data access, math operators.
  - Basic image transformations.
  - Drawing things on images.
- **CImgList<T>** : Image collection manipulation.
  - Basic manipulation functions.
- **CImgDisplay** : Image display and user interaction.
  - Displaying images in windows.

Outline - PART II of II : More insights

- **Image Filtering** : Goal and principle.
  - Convolution - Correlation.
  - Morphomaths - Median Filter.
  - Anisotropic smoothing.
  - Other related functions.
- **Image Loops** : Using predefined macros.
  - Simple loops.
  - Neighborhood loops.
- The plug-in mechanism.
- Dealing with 3D objects.
- Shared images.

PART I of II

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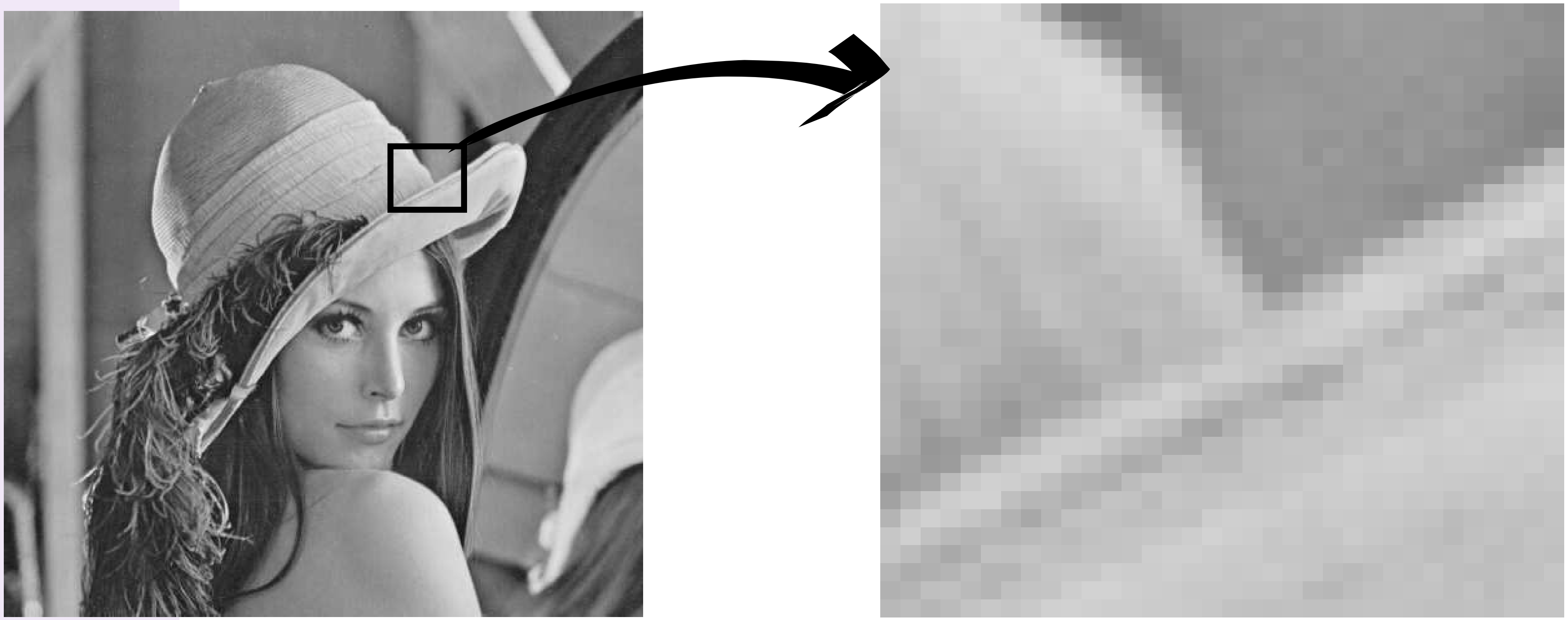
Context

- Digital Images.



- On a computer, image data stored as a discrete array of values (pixels or voxels).

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  - Domain dimensions : $2D$ (static image), $2D + t$ (image sequence), $3D$ (volumetric image), $3D + t$ (sequence of volumetric images), ...

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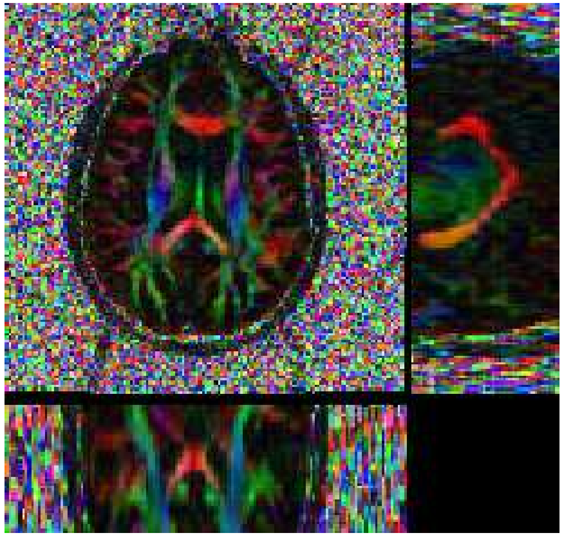
  - Pixel dimensions : Pixels can be scalars, colors, $N-D$ vectors, matrices, ...
  - Pixel data range : depends on the sensors used for acquisition, can be N-bits (usually 8,16,24,32...), sometimes float-valued.
  - Type of sensor grid : Rectangular, Octagonal, ...
- All these different image types are digitally stored using different file formats :
  - PNG, JPEG, BMP, TIFF, TGA, DICOM, ANALYZE, ...

Context

(a) $I_1 : W \times H \to [0, 255]^3$



(b) $I_2 : W \times H \times D \to [0, 65535]^{32}$

(c) $I_3 : W \times H \times T \to [0, 4095]$

- I_1 : classical RGB color image (digital photograph, scanner, ...) (8 bits)
- I_2 : DT-MRI volumetric image with 32 magnetic field directions (16 bits)
- I_3 : Sequence of echography images (12 or 16 bits).

Context

- Image Processing and Computer Vision aim at the elaboration of numerical algorithms able to automatically extract features from images, interpret them and then take decisions.

⇒ Conversion of a pixel array to a semantic description of the image.

- Is there any white pixel in this image ?
- Is there any contour in this image ?
- Is there any object ?
- Where's the car ?
- Is there anybody driving the car ?

Context

Some observations about Image Processing and Computer Vision :

- They are huge and active research fields.
- The final goal is almost impossible to achieve !
- There have been thousands (millions?) of algorithms proposed in this field, most of them relying on strong mathematical modeling.
- The community is varied and not only composed of very talented programmers.

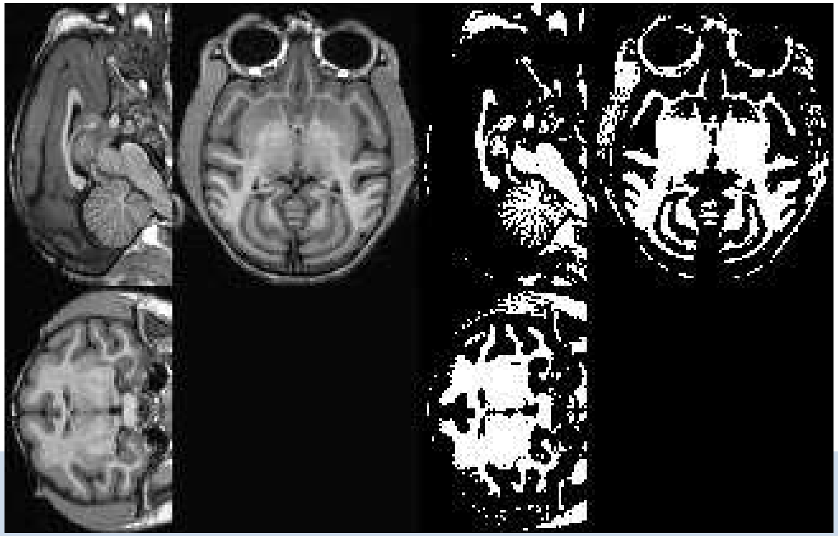
⇒ How to design a reasonable and useable programming library for such people ?

Observation

- Most of advanced image processing techniques are "type independent".
- Ex : Binarization of an image $I : \Omega \rightarrow \Gamma$ by a threshold $\epsilon \in \mathbb{R}$.

$$\tilde{I} : \Omega \rightarrow \{0,1\} \quad \text{such that} \quad \forall p \in \Omega, \quad \tilde{I}(p) = \begin{cases} 0 & \text{if } \|I(p)\| < \epsilon \\ 1 & \text{if } \|I(p)\| >= \epsilon \end{cases}$$

$I_1 : \Omega \in \mathbb{R}^2 \longrightarrow [0, 255]$



$I_2 : \Omega \in \mathbb{R}^3 \longrightarrow \mathbb{R}$

Context

- Implementing an image processing algorithm should be as independent as possible on the image format and coding.

⇒ Generic Image Processing Libraries :

(...), FreeImage, Devil, (...), OpenCV, Pandore, CImg, Vigra, GIL, Olena, (...)

- C++ is a “good” programming language for solving such a problem :
  - Genericity is possible, quite elegant and flexible (template mechanism).
  - Compiled code. Fast executables (good for time-consuming algorithms).
  - Portable , huge base of existing code.

- ***Danger*** *: Too much genericity may lead to unreadable code.*

Too much genericity... (Example 1).

[redacted]

- Main Page
- File List
- Class List
  - [redacted]::internal::_from_float< n, ncomps, qbits, color_system >
  - [redacted]::internal::_to_float< n, ncomps, qbits, color_system >
  - [redacted]::topo::combinatorial_map::internal::alpha< U >
  - [redacted]::any< E >
  - [redacted]::topo::combinatorial_map::internal::any< Inf >
  - [redacted]::any_ntg< E >
  - [redacted]::internal::any_ntg_< E >
  - [redacted]::topo::combinatorial_map::internal::anyfunc< U, V, Inf >
  - [redacted]::io::internal::anything
  - [redacted]::morpho::attr::attr_traits< ball_parent_change< I, Exact > >
  - [redacted]::morpho::attr::attr_traits< ball_type< I, Exact > >
  - [redacted]::morpho::attr::attr_traits< box_type< I, Exact > >
  - [redacted]::morpho::attr::attr_traits< card_full_type< I, T, Exact > >
  - [redacted]::morpho::attr::attr_traits< card_type< T, Exact > >
  - [redacted]::morpho::attr::attr_traits< cube_type< I, Exact > >
  - [redacted]::morpho::attr::attr_traits< dist_type< I, Exact > >
  - [redacted]::morpho::attr::attr_traits< height_type< T, Exact > >
  - [redacted]::morpho::attr::attr_traits< integral_type< T, Exact > >
  - [redacted]::morpho::attr::attr_traits< maxvalue_type< T, Exact > >
  - [redacted]::morpho::attr::attr_traits< minvalue_type< T, Exact > >

Too much genericity... (Example 2).

```
typedef cross_vector_image_view_types
    < mpl::vector<bits8, bits16>,
      mpl::vector<rgb_t, cmyk_t>,
      kInterleavedAndPlanar,
      kNonStepAndStep,
      false                            // false == mutable; true == read-only
    >::type my_views_t;
typedef any_image_view<my_views_t> my_any_image_view_t;
```

```
#include <boost/mpl/vector.hpp>
#include <gil/extension/dynamic_image/dynamic_image_all.hpp>
#include <gil/extension/io/jpeg_dynamic_io.hpp>

typedef mpl::vector<gray8_image_t, gray16_image_t, rgb8_image_t, rgb16_image_t> my_img_types;
any_image<my_img_types> runtime_image;
jpeg_read_image("input.jpg", runtime_image);

gray8s_image_t gradient(get_dimensions(runtime_image));
x_luminosity_gradient(const_view(runtime_image), view(gradient));
jpeg_write_view("x_gradient.jpg", color_converted_view<gray8_pixel_t>(const_view(gradient)));
```

- Strictly speaking, this is more C++ stuffs (problems?) than image processing.

⇒ **Definitely not suitable for non computer geeks !!**

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- It defines a set of C++ classes able to manipulate and process image objects.
- Started in late 1999, the project is now hosted on Sourceforge since December 2003 :

  http://cimg.sourceforge.net/

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#include ‘‘CImg.h’’                 // Just do that...
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- The library itself only takes 2.2Mb of sources (approximately 45000 lines).
- The library package contains the file **CImg.h** as well as documentation, examples of use, and additional plug-ins.

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- **Drawback** : Compilation time and needed memory important when optimization flags are set.

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- ... But, CImg is limited to images having a rectangular grid, and cannot handle images having more than 4 dimensions.

$\Rightarrow$ CImg covers actually 99% of the image types found in real world applications.

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- Advanced tools or libraries may be used by CImg (ImageMagick, XMedcon, libpng, libjpeg, libtiff, libfftw3...), these tools being freely available for any platform.

- Successfully tested platforms : Win32, Linux, Solaris, *BSD, Mac OS X.

- It is also “multi-compiler” : g++, Visual Studio .NET, Intel ICL, Clang++.

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- Enough genericity and library functions, allowing complex image processing tasks.

.... and **extensible** :

- Simple plug-in mechanism to easily add your own functions to the library core (without modifying the file `CImg.h` of course).

Hello World step by step

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#include "CImg.h"
using namespace cimg_library;

int main(int argc, char **argv) {


  return 0;
}
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int main(int argc, char **argv) {

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  CImg<unsigned char> img(300,200,1,3);
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  img.blur(2,0,0);
  const unsigned char white[] = { 255,255,255 };
  img.draw_text(80,80,"Hello World",white,0,32);

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Hello World step by step

Hello World step by step : animated

```
#include "CImg.h"
using namespace cimg_library;

int main(int argc, char **argv) {

   const CImg<unsigned char> img =
     CImg<unsigned char>(300,200,1,3).fill(32).noise(128).blur(2,0,0).
     draw_text(80,80,"Hello World",CImg<unsigned char>::vector(255,255,255).ptr(),0,32);

   CImgDisplay disp(img,"Moving Hello World",0);
   for (float t=0; !disp.is_closed(); t+=0.04) {
     CImg<unsigned char> res(img);
     cimg_forYC(res,y,v)
        res.get_shared_row(y,0,v).shift((int)(40*std::sin(t+y/50.0)),0,0,0,2);
     disp.display(res).wait(20);
     if (disp.is_resized()) disp.resize();
   }
   return 0;
}
```

Another example : Computing gradient norm of a 3D volumetric image

- Let $I : \Omega \in \mathbb{R}^3 \rightarrow \mathbb{R}$, compute

$$\forall p \in \Omega, \quad \|\nabla I\|_{(p)} = \sqrt{\left(\frac{\partial I}{\partial x}\right)^2 + \left(\frac{\partial I}{\partial y}\right)^2 + \left(\frac{\partial I}{\partial z}\right)^2}$$

- Code :

```
#include ``CImg.h''
using namespace cimg_library;

int main(int argc, char **argv) {
  const CImg<float> img(``brain_irm3d.hdr'');
  const CImgList<float> grad = img.get_gradient(``xyz'');
  CImg<float> norm = (grad[0].pow(2) + grad[1].pow(2) + grad[2].pow(2));
  norm.sqrt().get_normalize(0,255).save(``brain_gradient3d.hdr'');
  return 0;
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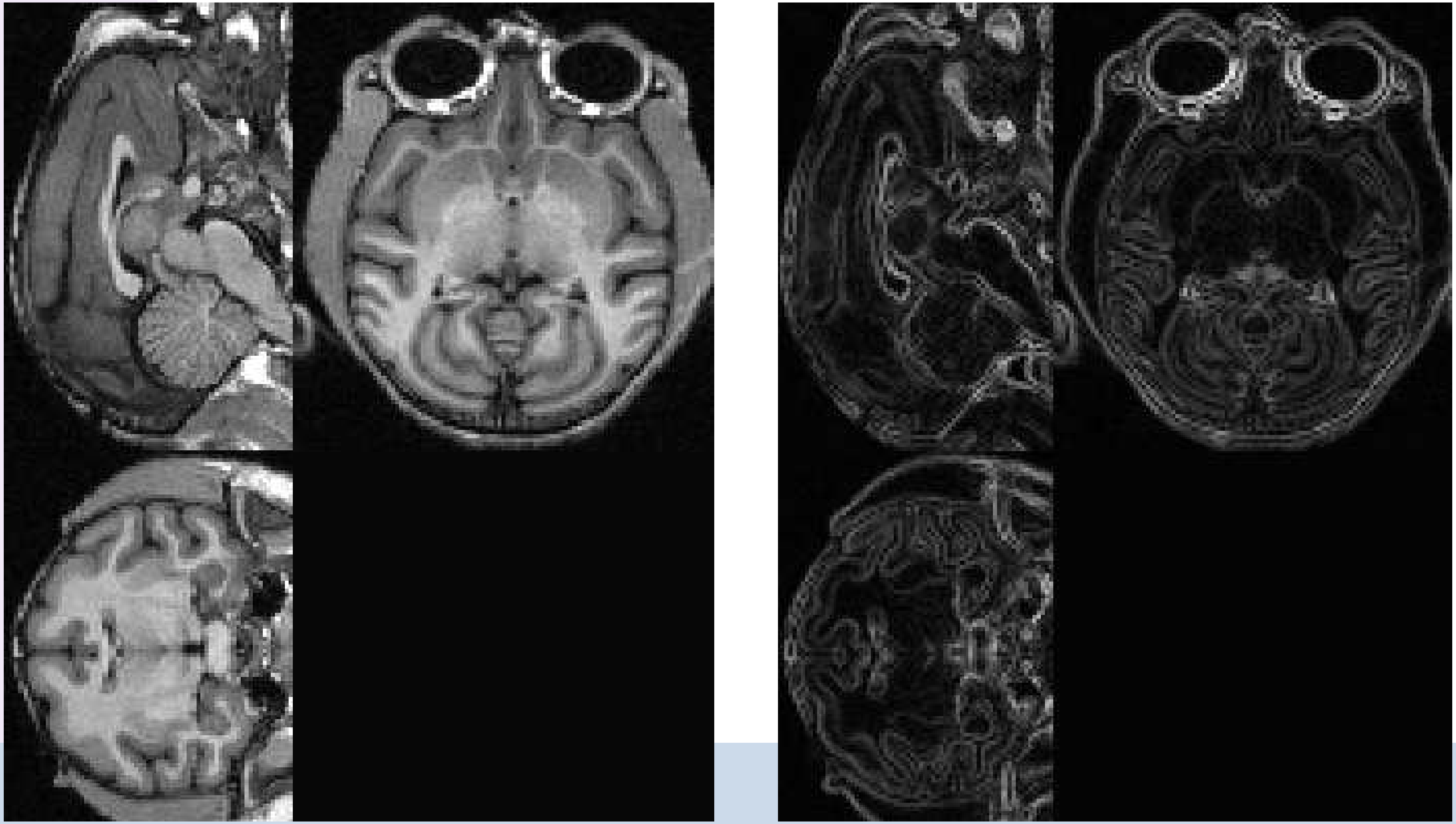
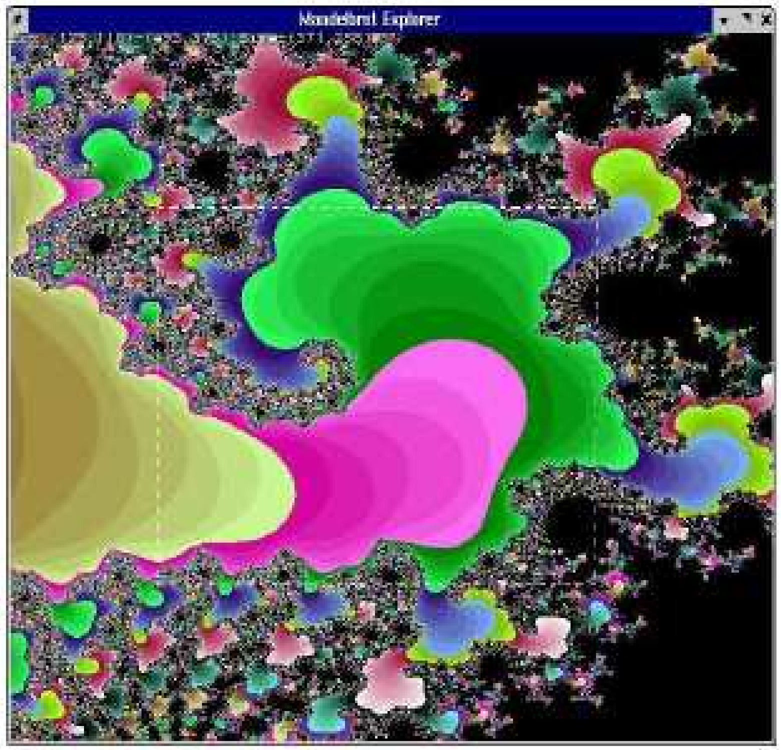
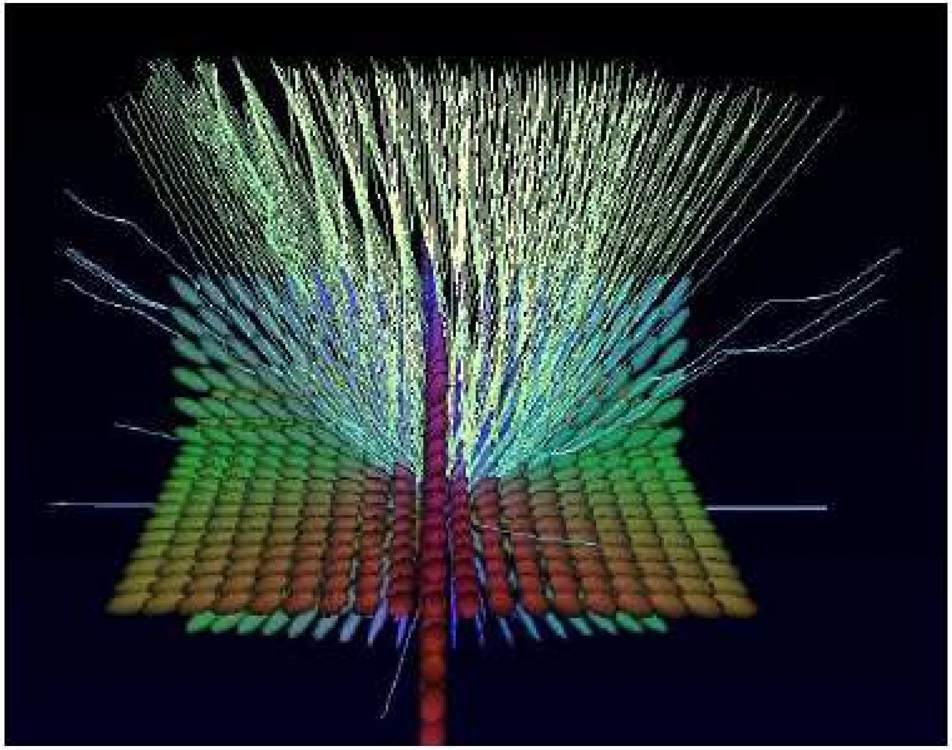


Live Demo !

- Let see what we can do with this library.





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- A sub-namespace `cimg_library::cimg::` defines some low-level library functions (including some useful ones as `rand()`, `grand()`, `min<T>()`, `max<T>()`, `abs<T>()`, `sleep()`, etc...).

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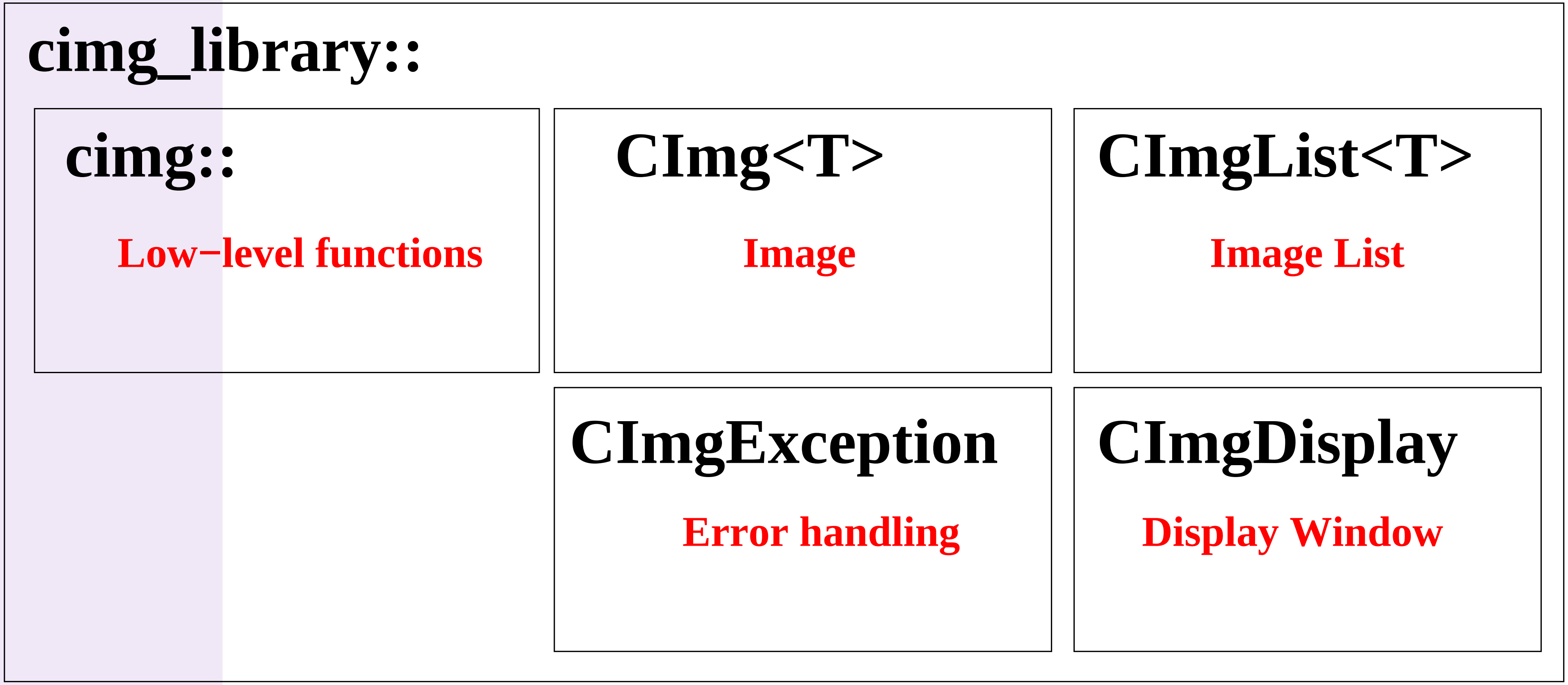

CImg methods

- All CImg classes incorporate two different kinds of methods :
  - Methods which act directly on the instance object and modify it. These methods returns a reference to the current instance, so that writting function pipelines is possible :

```
CImg<>(``toto.jpg'').blur(2).mirror('y').rotate(45).save(``tutu.jpg'');
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  - Methods which act directly on the instance object and modify it. These methods returns a reference to the current instance, so that writting function pipelines is possible :

```
CImg<>(``toto.jpg'').blur(2).mirror('y').rotate(45).save(``tutu.jpg'');
```

  - Other methods return a modified copy of the instance. These methods start with `get_*()` :

```
CImg<> img(``toto.jpg'');
CImg<> img2 = img.get_blur(2);                // 'img' is not modified
CImg<> img3 = img.get_rotate(20).blur(3); // 'img' is not modified
```

CImg methods

- All CImg classes incorporate two different kinds of methods :
  - Methods which act directly on the instance object and modify it. These methods returns a reference to the current instance, so that writting function pipelines is possible :

```
CImg<>(``toto.jpg'').blur(2).mirror('y').rotate(45).save(``tutu.jpg'');
```

  - Other methods return a modified copy of the instance. These methods start with `get_*()` :

```
CImg<> img(``toto.jpg'');
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```

⇒ **Almost all CImg methods are declined into these two versions.**

Outline - PART I of II : CImg Library Overview

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⇒ **CImg<T> : A class for image manipulation.**
  - Image construction, data access, math operators.
  - Basic image transformations.
  - Drawing things on images.

- **CImgList<T>** : Image collection manipulation.
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- **CImgDisplay** : Image display and user interaction.
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CImg<T> : Overview

- This is the main class of the CImg Library. It has a single template parameter `T`.

- A `CImg<T>` represents an image with pixels of type `T` (default template parameter is `T=float`). Supported types are the C/C++ basic types : `bool`, `unsigned char`, `char`, `unsigned short`, `short`, `unsigned int`, `int`, `float`, `double`, ...

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- An image has always 3 spatial dimensions (`width`, `height`,`depth`) + 1 hyperspectral dimension (`dim`) : It can represent any data from a scalar 1D signal to a 3D volume of vector-valued pixels.

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- An image has always 3 spatial dimensions (`width`, `height`,`depth`) + 1 hyperspectral dimension (`dim`) : It can represent any data from a scalar 1D signal to a 3D volume of vector-valued pixels.
- Image processing algorithms are methods of `CImg<T>` ($\neq$ STL) : `blur()`, `resize()`, `convolve()`, `erode()`, `load()`, `save()`....
- Method implementation aims to handle the most general case (3D volumetric hyperspectral images).

CImg<T> : Low-level Architecture (for hackers!)

- The structure `CImg<T>` is defined as :

```
template<typename T> struct CImg {
  unsigned int _width;
  unsigned int _height;
  unsigned int _depth;
  unsigned int _dim;
  bool _is_shared;
  T* _data;
};
```

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- A CImg<T> image is always entirely stored in memory.

- A CImg<T> is independent : it has its own pixel buffer.

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```

- A `CImg<T>` image is always entirely stored in memory.

- A `CImg<T>` is independent : it has its own pixel buffer most of the time.

- CImg member functions (destructor, constructors, operators,...) handle memory allocation/desallocation efficiently.

CImg<T> : Memory layout (for hackers!)

```
template<typename T> struct CImg {
  unsigned int _width;
  unsigned int _height;
  unsigned int _depth;
  unsigned int _dim;
  bool _is_shared;
  T* _data;
};
```

- Pixel values are not stored in a typical “RGBRGBRGBRGBRGB” order.
- Pixel values are stored first along the X-axis, then the Y-axis, then the Z-axis, then the C-axis :

R(0,0) R(1,0) ... R(W-1,0) ... R(0,1) R(1,1) ... R(W-1,1) .... R(0,H-1) R(1,H-1) ... R(W-1,H-1) ... G(0,0) ... G(W-1,H-1) ... B(0,0) ... B(W-1,H-1).

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CImg<T> : Constructors (1)

- Default constructor, constructs an empty image.

  `CImg<T>();`

- No memory allocated in this case, images dimensions are zero.

- Useful to declare an image without allocating its pixel values.

```
#include ‘‘CImg.h’’
using namespace cimg_library;

int main() {
  CImg<unsigned char> img_8bits;
  CImg<unsigned short> img_16bits;
  CImg<float> img_float;
  return 0;
}
```

CImg<T> : Constructors (2)

- Constructs a 4D image with specified dimensions. Omitted dimensions are set to 1 (default parameter).

```
CImg<T>(unsigned int, unsigned int, unsigned int, unsigned int);
```

```
#include ''CImg.h''
using namespace cimg_library;

int main() {
  CImg<float> img(100,100);  // 2D scalar image.
  CImg<unsigned char> img2(256,256,1,3);  // 2D color image.
  CImg<bool> img3(128,128,128);  // 3D scalar image.
  CImg<short> img4(64,64,32,16); // 3D hyperspectral image (16 bands).
  return 0;
}
```

- No initialization of pixel values is performed. Can be done with :

```
CImg<T>(unsigned int, unsigned int, unsigned int, unsigned int, const T&);
```

CImg<T> : Constructors (3)

- Create an image by reading an image from the disk (format deduced by the filename extension).

```
CImg<T>(const char *filename);
```

```
#include ``CImg.h''
using namespace cimg_library;

int main() {
  CImg<unsigned char> img(``nounours.jpg'');
  CImg<unsigned short> img2(``toto.png'');
  CImg<float> img3(``toto.png'');
  return 0;
}
```

- Pixel data of the file format are converted (static cast) to the specified template parameter.

CImg<T> : In-place constructors

- `CImg<T>& assign(...)`

  Each constructor has an in-place version with same parameters.

```
CImg<float> img;
img.assign(``toto.jpg'');
img.assign(256,256,1,3,0);
img.assign();
```

- This principle is extended to the other CImg classes.

```
CImgList<float> list;
list.assign(img1,img2,img3);
CImgDisplay disp;
disp.assign(list,''List display'');
```

CImg<T> : Access to image data informations

- Get the dimension along the X,Y,Z or C-axis (width, height, depth or channels).

```
int width() const;
```

```
int W = img.width(), H = img.height(), D = img.depth(), S = img.spectrum();
```

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```
int width() const;
```

```
int W = img.width(), H = img.height(), D = img.depth(), S = img.spectrum();
```

- Get the pixel value at specified coordinates. Omited coordinates are set to 0.

```
T& operator()(unsigned int, unsigned int, unsigned int, unsigned int);
```

```
unsigned char R = img(x,y), G = img(x,y,0,1), B = img(x,y,2);
float val = volume(x,y,z,v);
img(x,y,z) = x*y;
```

(Out-of-bounds coordinates are not checked !)

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float val = volume(x,y,z,v);
img(x,y,z) = x*y;
```

(Out-of-bounds coordinates are not checked !)

- Get the pixel value at specified sub-pixel position, using bicubic interpolation. Out-of-bounds coordinates are checked.

```
float cubic_pix2d(float, float, unsigned int, unsigned int);
```

```
float val = img.get_cubic_pix2d(x-0.5f,y-0.5f);
```

CImg<T> : Copies and assignments

- Construct an image by copy. Perform static pixel type cast if needed.

```
template<typename t> CImg<T>(const CImg<t>& img);
```

```
CImg<float> img_float(img_double);
```

CImg<T> : Copies and assignments

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```
template<typename t> CImg<T>(const CImg<t>& img);
```

```
  CImg<float> img_float(img_double);
```

- Assignement operator. Replace the instance image by a copy of `img`.

```
template<typename t> CImg<T>& operator=(const CImg<t>& img);
```

```
    CImg<float> img;
    CImg<unsigned char> img2(``toto.jpg''), img3(256,256);
    img = img2;
    img = img3;
```

- Modifying a copy does not modify the original image (own pixel buffer).

CImg<T> : Math operators and functions

- Most of the usual math operators are defined : +,-,*,/,+=,-=,...

```
CImg<float> img(``toto.jpg''), dest;
dest =(2*img+5);
dest+=img;
```

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```
CImg<float> img(''toto.jpg''), dest;
dest =(2*img+5);
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```

- Operators always try to return images with the best datatype.

```
CImg<unsigned char> img(''toto.jpg'');
CImg<float> dest;
dest = img*0.1f;
img*=0.1f;
```

CImg<T> : Math operators and functions

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```
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```

- Operators always try to return images with the best datatype.

```
CImg<unsigned char> img(``toto.jpg'');
CImg<float> dest;
dest = img*0.1f;
img*=0.1f;
```

- Usual math functions are also defined : sqrt(), cos(), pow()...

```
img.pow(2.5);
res = img.get_pow(2.5);
res = img.get_cos().pow(2.5);
```

CImg<T> : Matrices operations

- The $*$ and $/$ operators corresponds to a matrix product/division !

```
CImg<float> A(3,3), v(1,3);
CImg<float> res = A*v;
```

- Use `CImg<T>::mul()` and `CImg<T>::div()` for pointwise operators.

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```

- Use `CImg<T>::mul()` and `CImg<T>::div()` for pointwise operators.

- Usual matrix functions and transformations are available in CImg : determinant, SVD, eigenvalue decomposition, inverse, ...

```
CImg<float> A(10,10), v(1,10);
const float determinant = A.det();
CImg<float> pseudo_inv =
((A*A.get_transpose()).inverse())*A.get_transpose();
CImg<float> pseudo_inv2 = A.get_pseudoinverse();
```

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```
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```

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const float determinant = A.det();
CImg<float> pseudo_inv =
((A*A.get_transpose()).inverse())*A.get_transpose();
CImg<float> pseudo_inv2 = A.get_pseudoinverse();
```

- **Warning : Matrices are viewed as images, so first indice is the column number, second is the line number :** A_{ij} **=** `A(j,i)`

CImg<T> : Image destruction

- Image destruction is done in the `~CImg()` method.
- Used pixel buffer memory (if any) is automatically freed by the destructor.
- Destructor is automatically called at the end of a block.
- Memory deallocation can be forced by the `assign()` function.

```
CImg<float> img(10000,10000);  // Need 4*10000^2 bytes = 380 Mo
float det = img.det();

// We won't use img anymore...
img.assign();

// Equivalent to :
img = CImg<float>();
```

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CImg<T> : Image manipulation

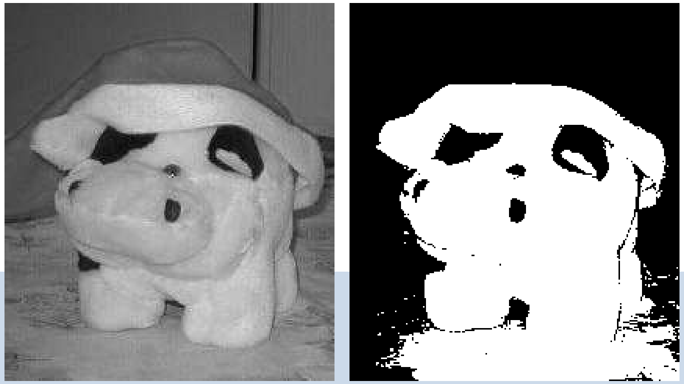
- `fill()` : Fill an image with one or several values.

```
CImg<> img(256,256), vector(1,6);
img.fill(0);
vector.fill(1,2,3,4,5,6);
```

- Apply basic global transformations on pixel values.

`normalize()`, `cut()`, `quantize()`, `threshold()`.

```
CImg<float>
img(“toto.jpg”);
img.quantize(16);
img.normalize(0,1);
img.cut(0.2f,0.8f);
img.threshold(0.5f);
img.normalize(0,255);
```



CImg<T> : Image manipulation

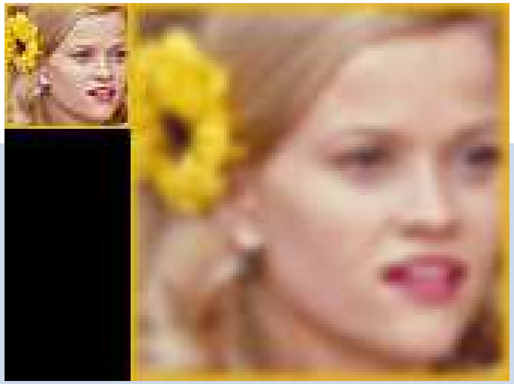
- `rotate()` : Rotate an image with a given angle.

```
CImg<> img(``milla.png'');
img.rotate(30);
```

- `resize()` : Resize an image with a given size.

```
CImg<> img(``mini.jpg'');
img.resize(-300,-300);  // -300 = 300%
```

⇒ Border conditions and interpolation types can be chosen by the user.



CImg<T> : Image manipulation

- `get_crop()` : Get a sub−image of the instance image.

```
CImg<> img(256,256);
img.get_crop(0,0,128,128);  // Get the upper-left half image
```

- Color space-conversions : `RGBtoYUV()`, `RGBtoLUT()`, `RGBtoHSV()`,... and inverse transformations.

- Filtering : `blur()`, `convolve()`, `erode()`, `dilate()`, `FFT()`, `deriche()`,....

- In the reference documentation, functions are grouped by themes....

http://cimg.sourceforge.net/reference/

CImg<T> : Image manipulation

```
#include ''CImg.h''
using namespace cimg_library;
int main() {
  CImg<unsigned char> img(''milla.jpg'');
  img.blur(1).crop(15,52,150,188).dilate(10).mirror('x');
  img.save(''result.png'');
  return 0;
}
```

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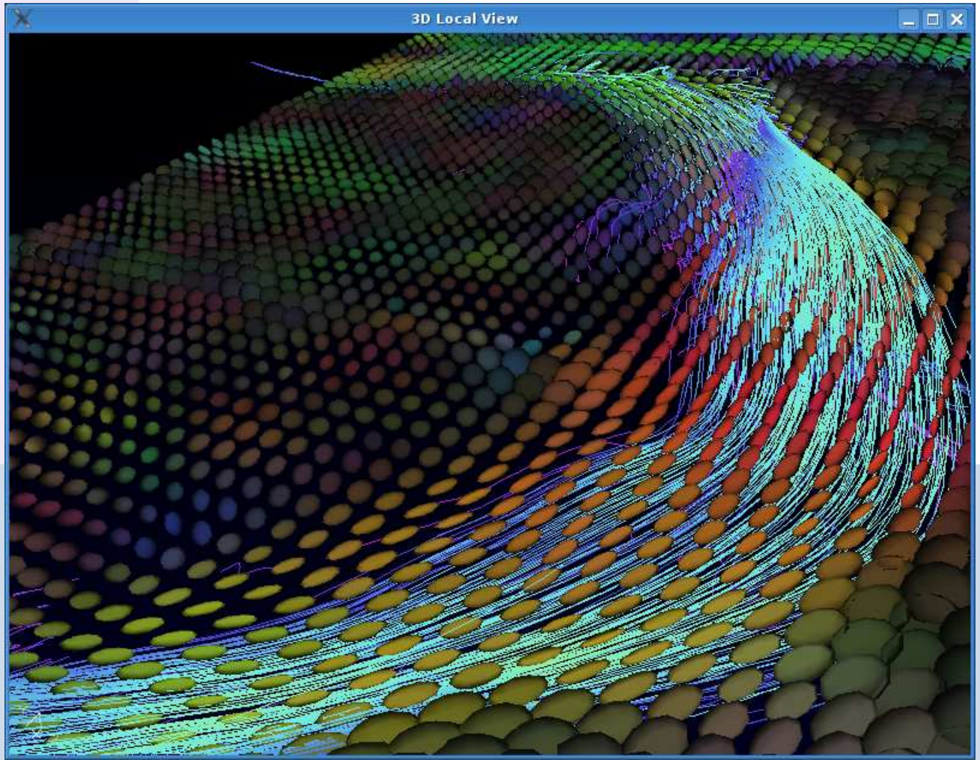
CImg<T> : Drawing functions

- CImg proposes a lot of functions to draw features in images.

⇒ Points, lines, circles, rectangles, triangles, text, vector fields, 3D objects, ...

- All drawing function names begin with `draw_*()`.

- Features are drawn directly on the instance image (so there are not `const`).



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- All drawing functions work the same way : They need the instance image, feature coordinates, and a color (eventual other optional parameters can be set).

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- They clip objects that are out of image bounds.

- Ex : `CImg& draw_line(int,int,int,int,T*);`

```
CImg<unsigned short> img(256,256,1,5);  // hyperspectral image of ushort
unsigned short color[5] = { 0,8,16,24,32 }; // color used for the drawing
img.draw_line(x-2,y-2,x+2,y+2,color).
    draw_line(x-2,y+2,x+2,y-2,color).
    draw_circle(x+10,y+10,5,color);
```

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    draw_circle(x+10,y+10,5,color);
```

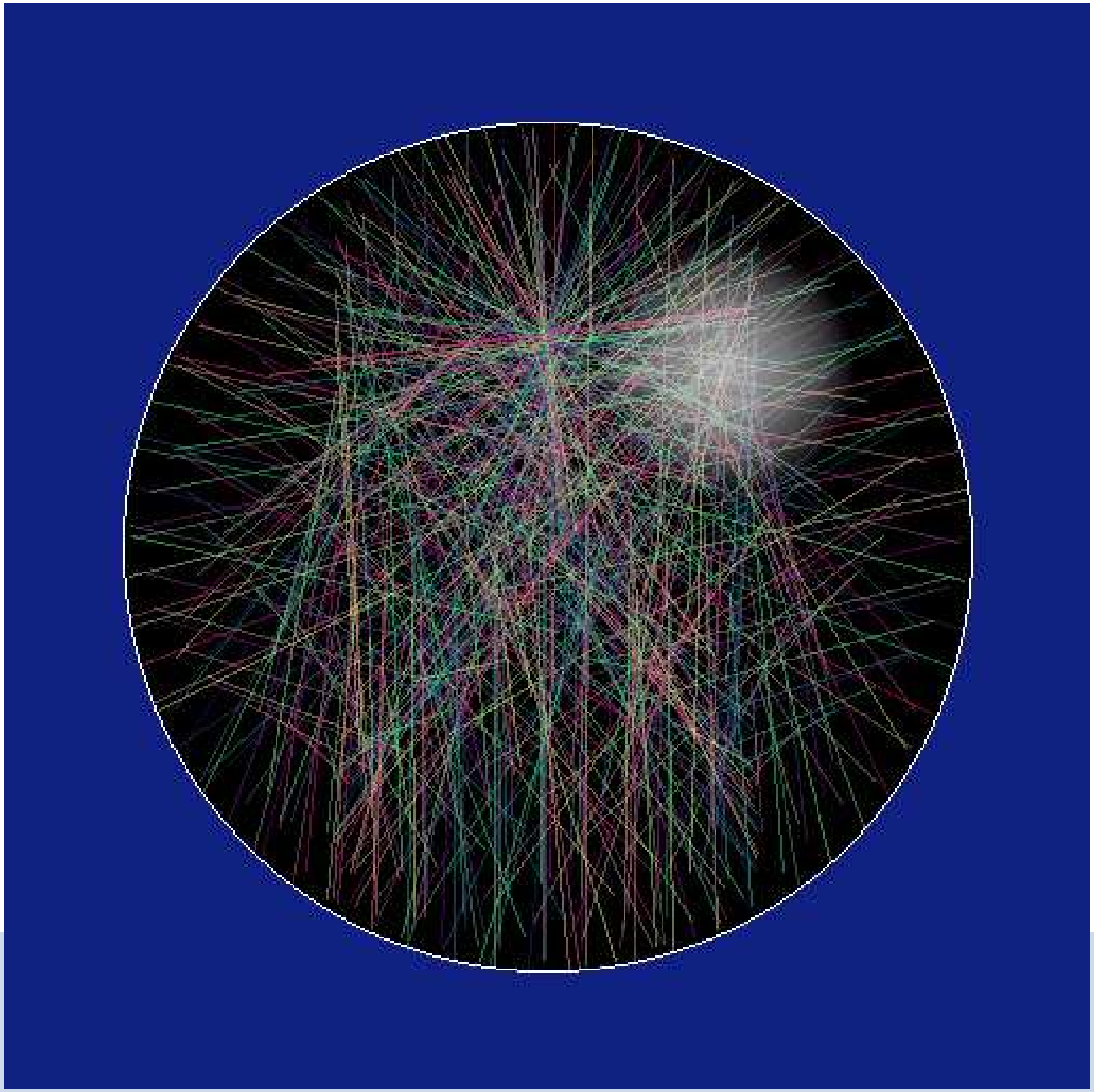
- `CImg<T>::draw_object3d()` can draw 3D objects (mini Open-GL!)

CImg<T> : Plasma ball (source code)

- The following code draws a "plasma ball" from scratch :

```
CImg<unsigned char> img(512,512,1,3,0);
for (float alpha=0, beta=0; beta<100; alpha+=0.21f, beta+=0.18f) {
  const float
    ca = std::cos(alpha), cb = std::cos(beta),
    sa = std::sin(alpha), sb = std::sin(beta);
  img.draw_line(256+200*ca*sa,256+200*cb*sa,
                256+200*sa*sb,256+200*sb*ca,
                CImg<unsigned char>::vector(alpha*256,beta*256,128).
                ptr(),0.5f);
}
const unsigned char white[3] = { 255,255,255 }, blue[3] = { 16,32,128 };
img.draw_circle(256,256,200,white,1.0f,~0U).draw_fill(0,0,blue);
for (int radius = 60; radius>0; --radius)
  img.draw_circle(340,172,radius,white,0.02f);
```

CImg<T> : Plasma ball (result)



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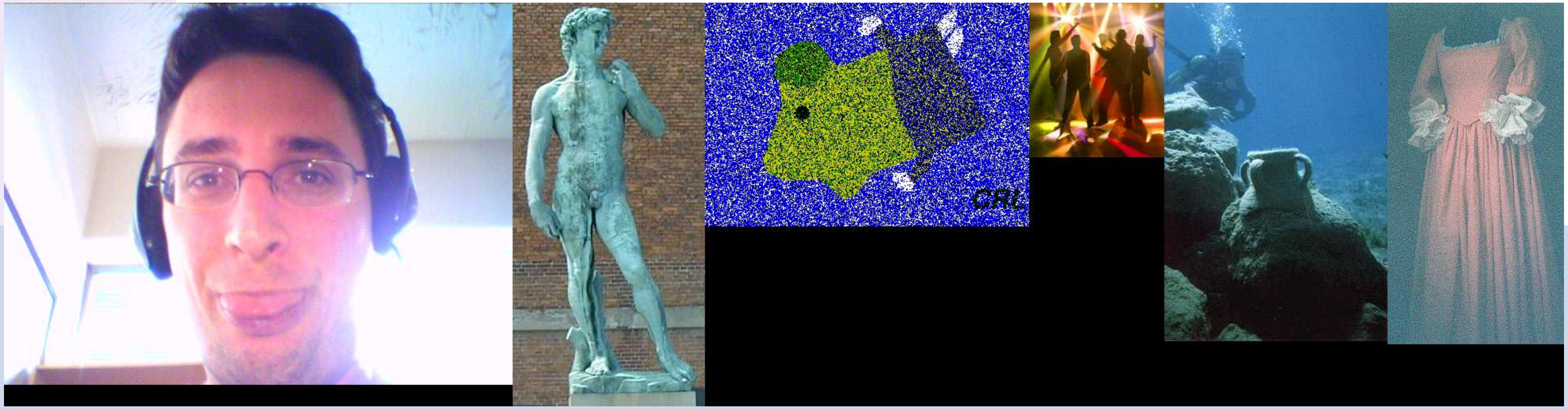
CImgList<T> : Overview

- A `CImgList<T>` represents an array of `CImg<T>`.
- Useful to handle a sequence or a collection of images.
- Here also, the memory is not shared by other `CImgList<T>` or `CImg<T>` objects.
- Looks like a `std::vector<CImg<T> >`, specialized for image processing.
- Can be used as a flexible and ordered set of images.



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CImgList<T> : Main functions

```
// Create a list of 20 color images 100x100.
CImgList<float> list(20,100,100,1,3);

// Insert two images at the end of the list.
list.insert(CImg<float>(50,50));
list.insert(CImg<unsigned char>(``milla.ppm''));

// Remove the second image from the list.
list.remove(1);

// Resize the 5th image of the list.
CImg<float> &ref = list[4];
ref.resize(50,50);
```

- Lists can be saved (and loaded) as .cimg files (simple binary format with ascii header).

CImgList<T> : `.cimg` files

- Functions `CImgList<T>::load_cimg()` and `CImgList<T>::save_cimg()` allow to load/save portions of `.cimg` image files.
- Single images (`CImg<T> class`) can be also loaded/saved into `.cimg` files.
- Useful to work with big image files, video sequences or image collections.

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CImgDisplay : Overview

- A `CImgDisplay` allows to display `CImg<T>` or `CImgl<T>` instances in a window, and can handle user events that may happen in this window (mouse, keyboard, ...)

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- A `CImgDisplay` allows to display `CImg<T>` or `CImgl<T>` instances in a window, and can handle user events that may happen in this window (mouse, keyboard, ...)
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- The destruction of a `CImgDisplay` closes the corresponding window.

CImgDisplay : Overview

- A `CImgDisplay` allows to display `CImg<T>` or `CImgl<T>` instances in a window, and can handle user events that may happen in this window (mouse, keyboard, ...)
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- The destruction of a `CImgDisplay` closes the corresponding window.

- The display of an image in a `CImgDisplay` is done by a call to the `CImgDisplay::display()` function.

- A `CImgDisplay` has its own pixel buffer. It does not store any references to the `CImg<T>` or `CImgList<T>` passed at the last call to `CImgDisplay::display()`.

CImgDisplay : Handling events

- When opening the window, an event-handling thread is created.
- This thread automatically updates `volatile` fields of the `CImgDisplay` instance, when events occur in the corresponding window :
  - Mouse events : `mouse_x()`, `mouse_y()` and `button()`.
  - Keyboard event : `key()`.
  - Window events : `is_resized()`, `is_closed()` and `is_moved()`.
- Only one thread is used to handle display events of all opened `CImgDisplay`.
- This thread is killed when the last display window is destroyed.
- The `CImgDisplay` class is fully coded both for GDI32 and X11 graphics libraries.
- Display automatically handles image normalization to display float-valued images correctly.

CImgDisplay : Useful functions

- Construction :

```
CImgDisplay disp1(img,``My first display'');
CImgDisplay disp2(640,400,''My second display'');
```

- Display/Refresh image:

```
img.display(disp);
disp.display(img);
```

- Handle events :

```
if (disp.key()==cimg::keyQ) { ... }
if (disp.is_resized()) disp.resize();
if (disp.mouse_x()>20 && disp.mouse_y()<40) { ... }
disp.wait();
```

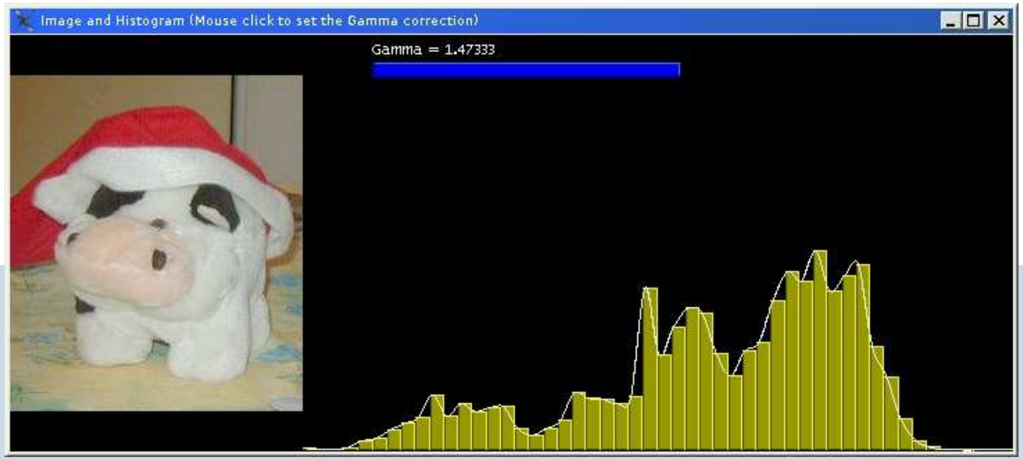
- Temporize (for animations) : `disp.wait(20);`

CImgDisplay : Example of using `CImgDisplay`

```
#include "CImg.h"
using namespace cimg_library;
int main() {
  CImgDisplay disp(256,256,"My Display");
  while (!disp.is_closed()) {
    if (disp.button&1) {
      const int x = disp.mouse_x(), y = disp.mouse_y();
      CImg<unsigned char> img(disp.width(),disp.height());
      unsigned char col[1] = {255};
      img.fill(0).draw_circle(x,y,40,col).display(disp);
    }
    if (disp.button()&2) disp.resize(-90,-90);
    if (disp.is_resized()) disp.resize();
    disp.wait();
  }
  return 0;
}
```

A more complete example of using `CImg<T>` (14 C++ lines)

```
CImg<> img = CImg<>("img/milla.ppm").normalize(0,1);
CImgl<unsigned char> visu(img*255, CImg<unsigned char>(512,300,1,3,0));
const unsigned char yellow[3] = {255,255,0}, blue[3]={0,155,255}, blue2[3]={0,0,255}, blue3[3]={0,0,155},
                    white[3]={255,255,255};
CImgDisplay disp(visu,"Image and Histogram (Mouse click to set the Gamma correction)",0);
for (double gamma=1;!disp.closed() && disp.key()!=cimg::keyQ && disp.key()!=cimg::keyESC; ) {
  cimg_forXYZC(visu[0],x,y,z,k) visu[0](x,y,z,k) = (unsigned char)(pow((double)img(x,y,z,k),1.0/gamma)*256);
  const CImg<> hist = visu[0].get_histogram(50,0,255);
  visu[1].fill(0).draw_text(50,5,"Gamma = %g",white,NULL,1,gamma).
  draw_graph(hist,yellow,1,20000,0).draw_graph(hist,white,2,20000,0);
  const int xb = (int)(50+gamma*150);
  visu[1].draw_rectangle(51,21,xb-1,29,blue2).draw_rectangle(50,20,xb,20,blue).draw_rectangle(xb,20,xb,30,blue);
  visu[1].draw_rectangle(xb,30,50,29,blue3).draw_rectangle(50,20,51,30,blue3);
  if (disp.button() && disp.mouse_x()>=img.width()+50 && disp.mouse_x()<=img.width()+450) gamma = (disp.mouse_x()-img.width()-50)/15
  disp.resize(disp).display(visu).wait();
}
```



Result :

Histogram manipulation and gamma correction (example from example file `CImg_demo.cpp`)

PART II of II

⇒ **Image Filtering : Goal and principle.**

- Convolution - Correlation.
- Morphomaths - Median Filter.
- Anisotropic smoothing.
- Other related functions.

- **Image Loops** : Using predefined macros.
  - Simple loops.
  - Neighborhood loops.
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Context : Image Filtering

- Image filtering is one of the most common operations done on images in order to retrieve informations.

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- Filtering is needed in the following cases :
  - Compute image derivatives (gradient) $\nabla I = \left(\frac{\partial I}{\partial x} \; \frac{\partial I}{\partial x}\right)^T$.
  - Noise removal : Gaussian or Median filtering.
  - Edge enhancement & Deconvolution : Sharpen masks, Fourier Transform.
  - Shape analysis : Morphomath filters (erosion, dilatation,..)
  - ...

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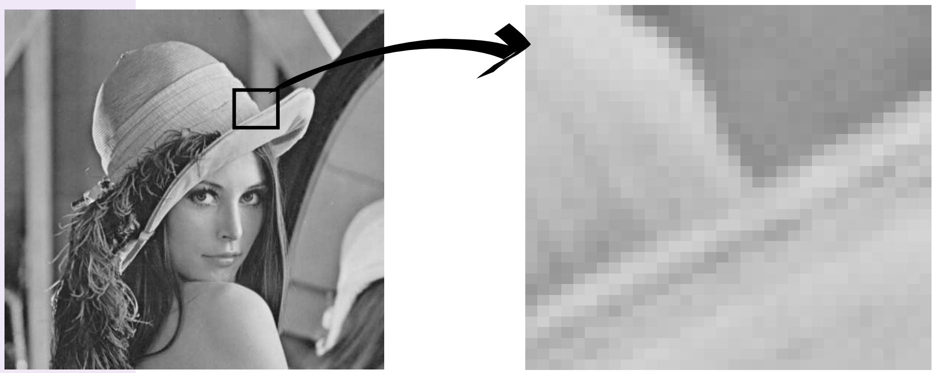
  - ...

- A filtering process generally needs the image and a mask (a.k.a kernel or structuring element).

How filtering works ?

- For each point $p \in \Omega$ of the image I, consider its neighborhood $\mathcal{N}_I(p)$ and combine it with a user-defined mask M.



$$\bullet \begin{bmatrix} -2 & 3 & \dots & 7 & 1 \\ 1 & \ddots & \vdots & \ddots & -3 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ -4 & \ddots & \vdots & \ddots & 6 \\ 1 & -2 & \dots & 8 & -5 \end{bmatrix}$$

- Neighborhood $\mathcal{N}_I(p)$ and mask M have the same size.

- The operator $\bullet$ may be linear, but not necessarily.

- The result of the filtering operation is the new value at p :

$$\forall p \in \Omega, \qquad J(p) = \mathcal{N}_I(p) \bullet M$$

Filtering examples

(a) Original image (b) Derivative along x (c) Erosion

- Derivative obtained with $\bullet = *$ and $M = [0.5 \quad 0 \quad -0.5]$
- Erosion obtained with $\bullet =$ min().

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- Convolution and Correlation implements linear filtering ($\bullet = *$)

$$\text{Convolution} \quad : \quad J(x,y) = \sum_i \sum_j I(x-i,y-j)\; M(i,j)$$

$$\text{Correlation} \quad : \quad J(x,y) = \sum_i \sum_j I(x+i,y+j)\; M(i,j)$$

- `CImg<T>::get_convolve()`, `CImg<T>::convolve()` and `CImg<T>::get_correlate()`, `CImg<T>::correlate()`.

- Compute image derivative along the X-axis :

```
CImg<> img(``toto.jpg'');
CImg<> mask = CImg<>(3,1).fill(0.5,0,-0.5);
img.convolve(mask);
```

Linear filtering (2)

- You can set the border condition in `convolve()` and `correlate()`
- Common linear filters are already implemented :
  - Gaussian kernel for image smoothing :
    `CImg<T>::get_blur()` and `CImg<T>::blur()`.
  - Image derivatives :
    `CImg<T>::get_gradient("xy")` and `CImg<T>::get_gradient("xyz")`.

⇒ Faster versions than using the `CImg<T>::convolve()` function !

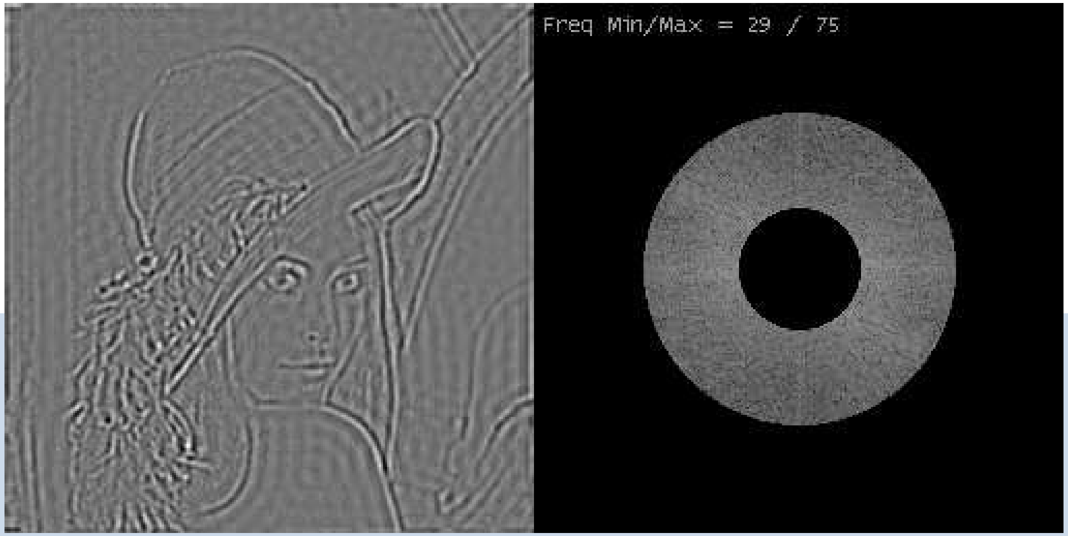

Blur an image with a Gaussian kernel with $\sigma = 10$.

Using `CImg<T>::convolve()` : 1129 ms.

Using `CImg<T>::blur()` : 7 ms.

Linear filtering (3)

- When mask size is big, you can efficiently convolve the image by a multiplication in the Fourier domain.
- `CImg<T>::get_FFT()` returns a `CImgList<T>` with the real and imaginary part of the FT.
- `CImg<T>::get_FFT(true)` returns a `CImgList<T>` with the real and imaginary part of the inverse FT.



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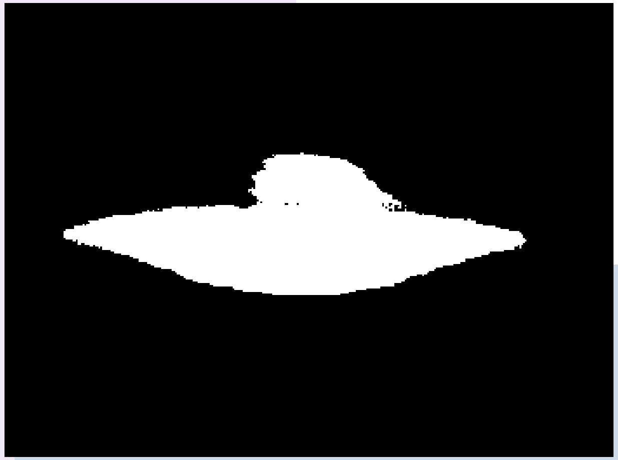
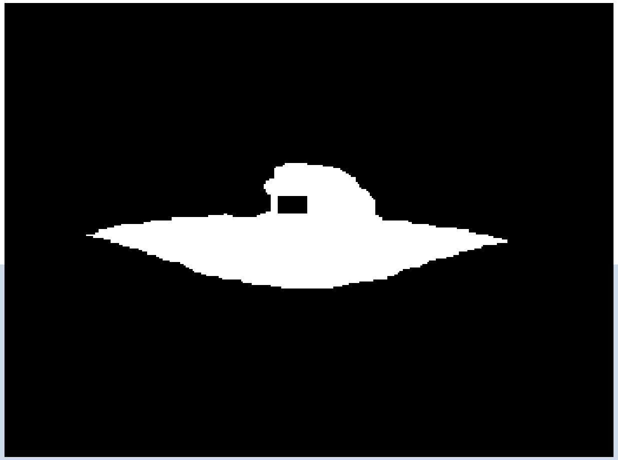
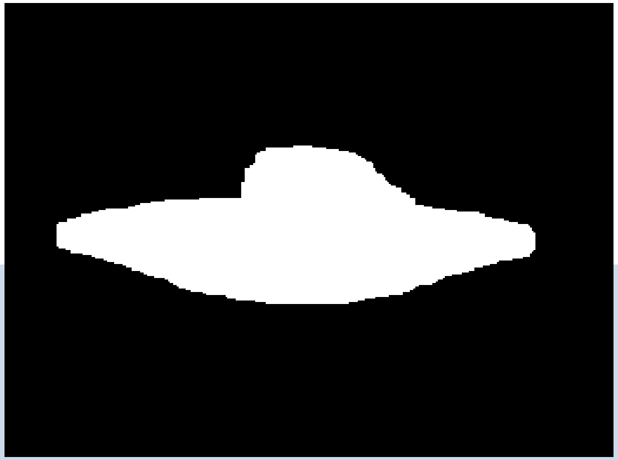
- Nonlinear filters.
- Erosion : Keep the mininum value in the image neighborhood having the same shape than the structuring element mask.
  `CImg<T>::erode()` and `CImg<T>::get_erode()`.
- Dilatation : Keep the maximum value in the image neighborhood having the same shape than the structuring element mask.
  `CImg<T>::dilate()` and `CImg<T>::get_dilate()`.



(a) Original image



(b) Erosion by a 10×10 kernel



(b) Dilatation by a 10×10 kernel

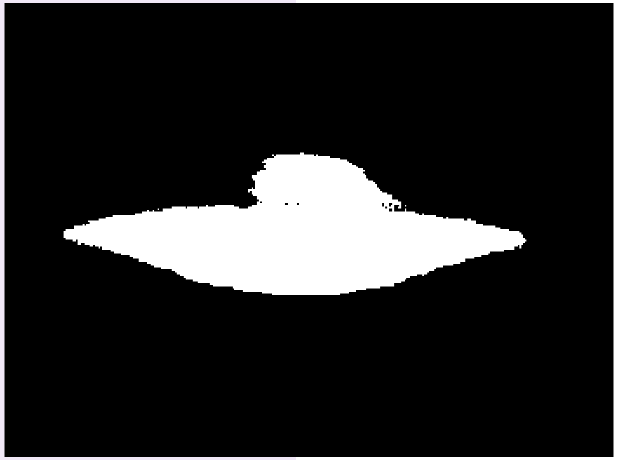
Morphomaths (2)

- Opening : Erode, then dilate :

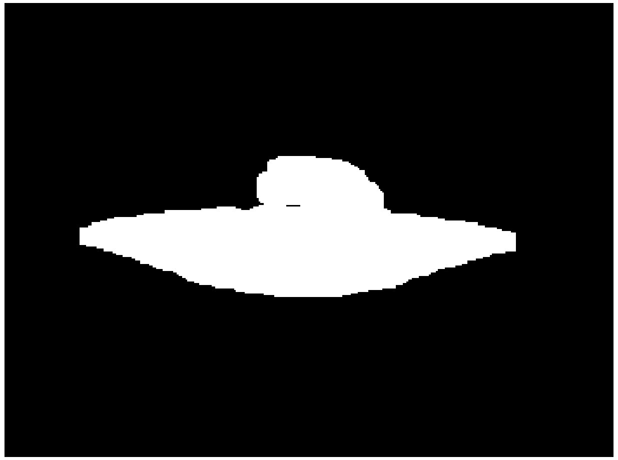
```
img.erode(10).dilate(10);
```

- Closing : Dilate, then erode :

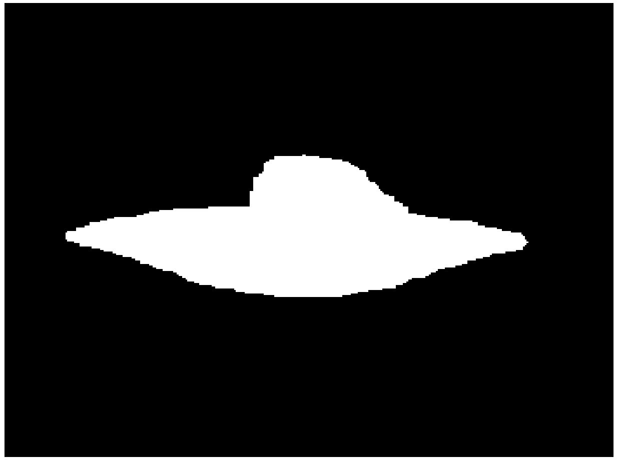
```
img.dilate(10).erode(10);.
```



(a) Original image



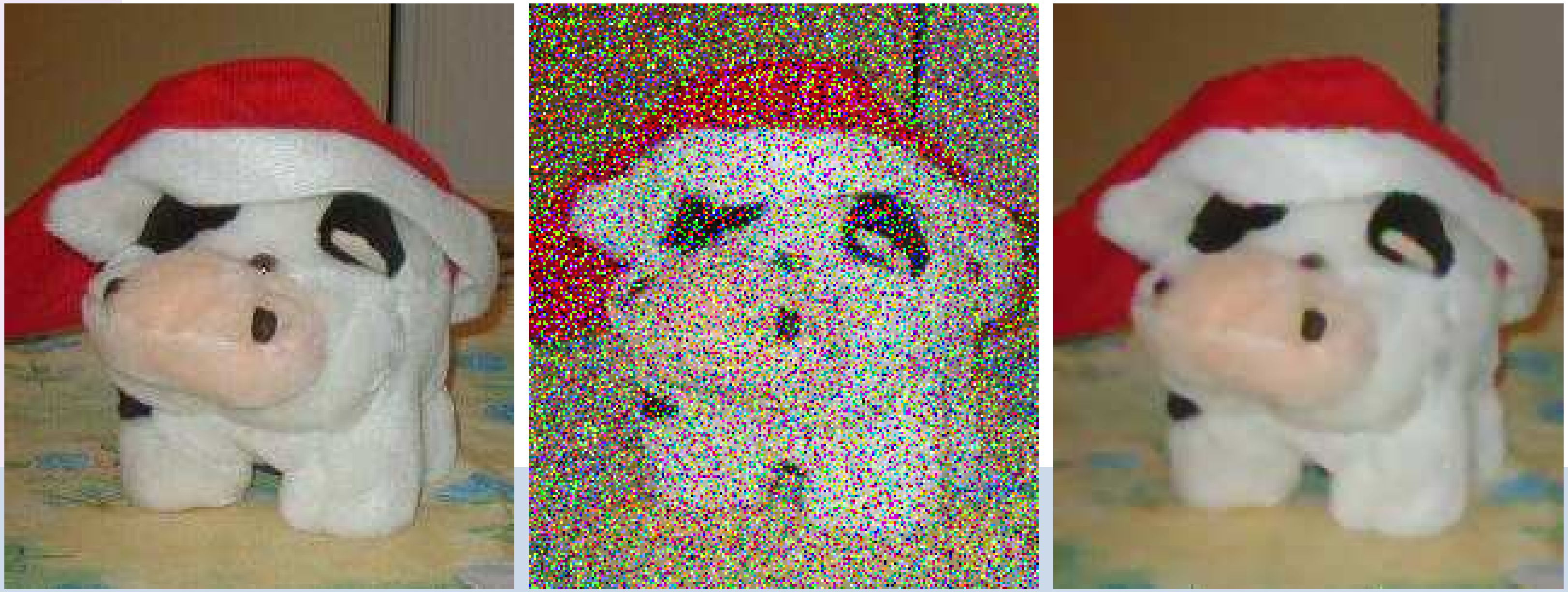
(b) Opening by a 10×10 kernel



(b) Closing by a 10×10 kernel

Median filtering

- Nonlinear filter : Keep the median value in the image neighborhood having the same shape than the mask.
- Functions `CImg<T>::get_blur_median()` and `CImg<T>::blur_median()`.
- Near optimal to remove Salt&Pepper noise.



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Anisotropic smoothing

- Non-linear edge-directed diffusion, very optimized PDE-based algorithm.
- Very efficient in removing Gaussian noise, or other additive noise.
- Able to work on $2D$ and $3D$ images.
- Function `CImg<T>::blur_anisotropic()`.
- A lot of applications : Image denoising, reconstruction, resizing.

Anisotropic smoothing

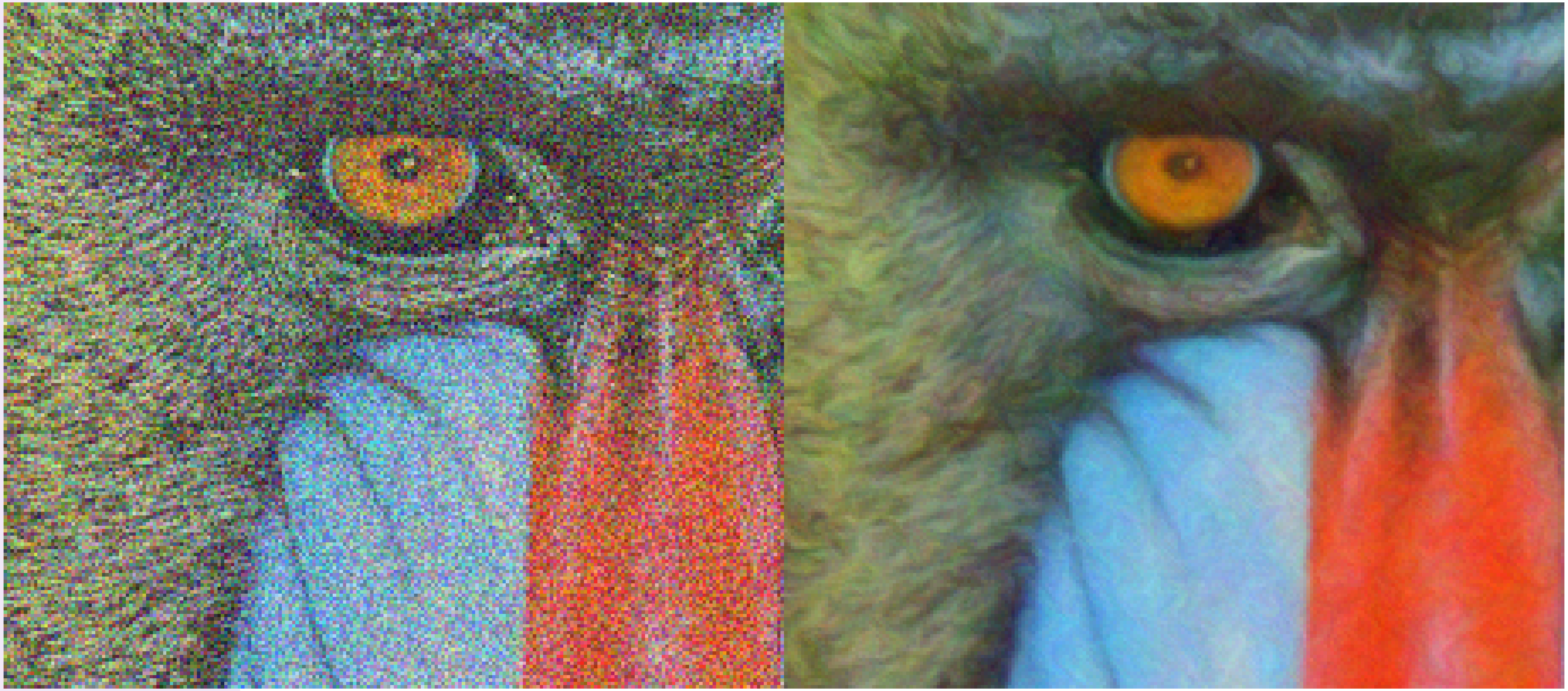
- `CImg<T>::blur_anisotropic()` implements the following diffusion PDE :

$$\forall i = 1, \dots, n, \qquad \frac{\partial I_i}{\partial t} = \text{trace}(\mathbf{T}\mathbf{H}_i) + \frac{2}{\pi} \nabla I_i^T \int_{\alpha=0}^{\pi} \mathbf{J}_{\sqrt{\mathbf{T}}a_\alpha} \sqrt{\mathbf{T}} a_\alpha \, d\alpha$$

where $\mathbf{J_w} = \begin{pmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} \end{pmatrix}$ and $\mathbf{H}_i = \begin{pmatrix} \frac{\partial^2 I_i}{\partial x^2} & \frac{\partial^2 I_i}{\partial x \partial y} \\ \frac{\partial^2 I_i}{\partial x \partial y} & \frac{\partial^2 I_i}{\partial y^2} \end{pmatrix}$.

- Image smoothing while preserving discontinuities (edges).
- One of the advanced filtering tool in the CImg Library.

Application of CImg<T>::blur_anisotropic()



“Babouin” (détail) - 512x512 - (1 iter., 19s)

Application of `CImg<T>::blur_anisotropic()`

“Tunisie” - 555x367

Application of `CImg<T>::blur_anisotropic()`

“Tunisie” - 555x367 - (1 iter., 11s)

Application of `CImg<T>::blur_anisotropic()`

"Tunisie" - 555x367 - (1 iter., 11s)

Application of `CImg<T>::blur_anisotropic()`

“Bébé” - 400x375

Application of `CImg<T>::blur_anisotropic()`

“Bébé” - 400x375 - (2 iter, 5.8s)

Application of `CImg<T>::blur_anisotropic()`

"Bébé" - 400x375 - (2 iter, 5.8s)

Application of `CImg<T>::blur_anisotropic()`

"Van Gogh"

Application of `CImg<T>::blur_anisotropic()`

“Van Gogh” - (1 iter, 5.122s).

Application of CImg<T>::blur_anisotropic()

“Fleurs” (JPEG, 10% quality).

Application of `CImg<T>::blur_anisotropic()`

“Corail” (1 iter.)

Application : Image Inpainting

“Bird”, original color image.

Application : Image Inpainting

“Bird”, inpainting mask definition.

Application : Image Inpainting

“Bird”, inpainted with our PDE.

Application : Image Inpainting

“Chloé au zoo”, original color image.

Application : Image Inpainting

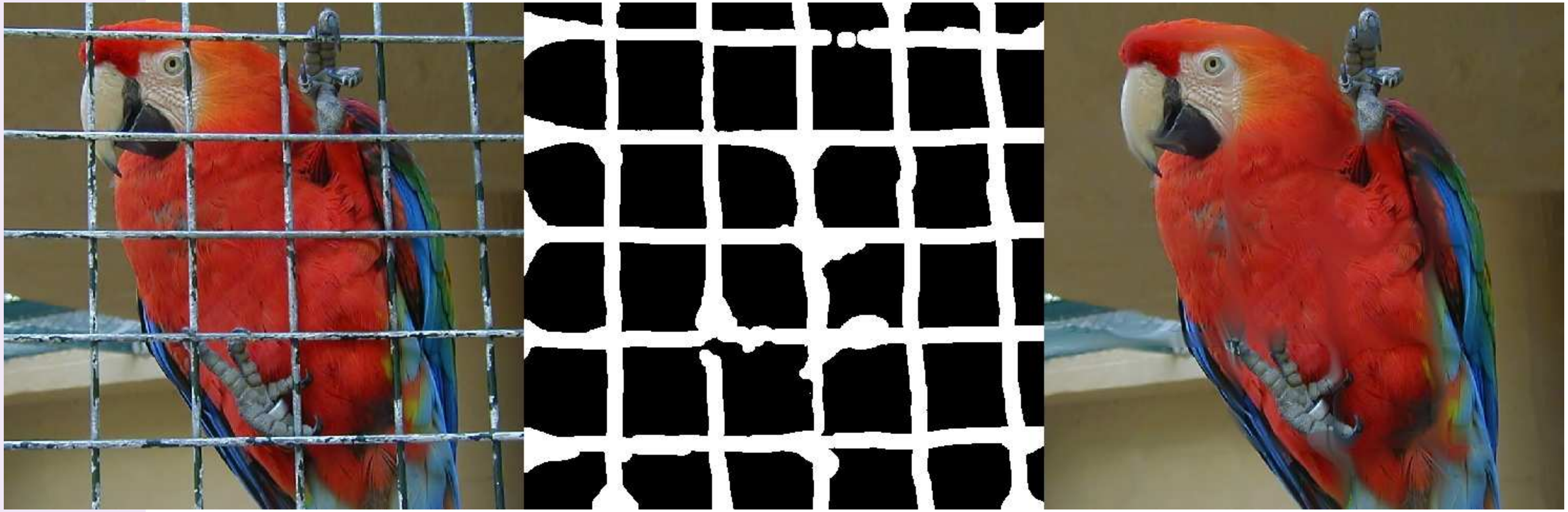
“Chloé au zoo”, inpainting mask definition.

Application : Image Inpainting

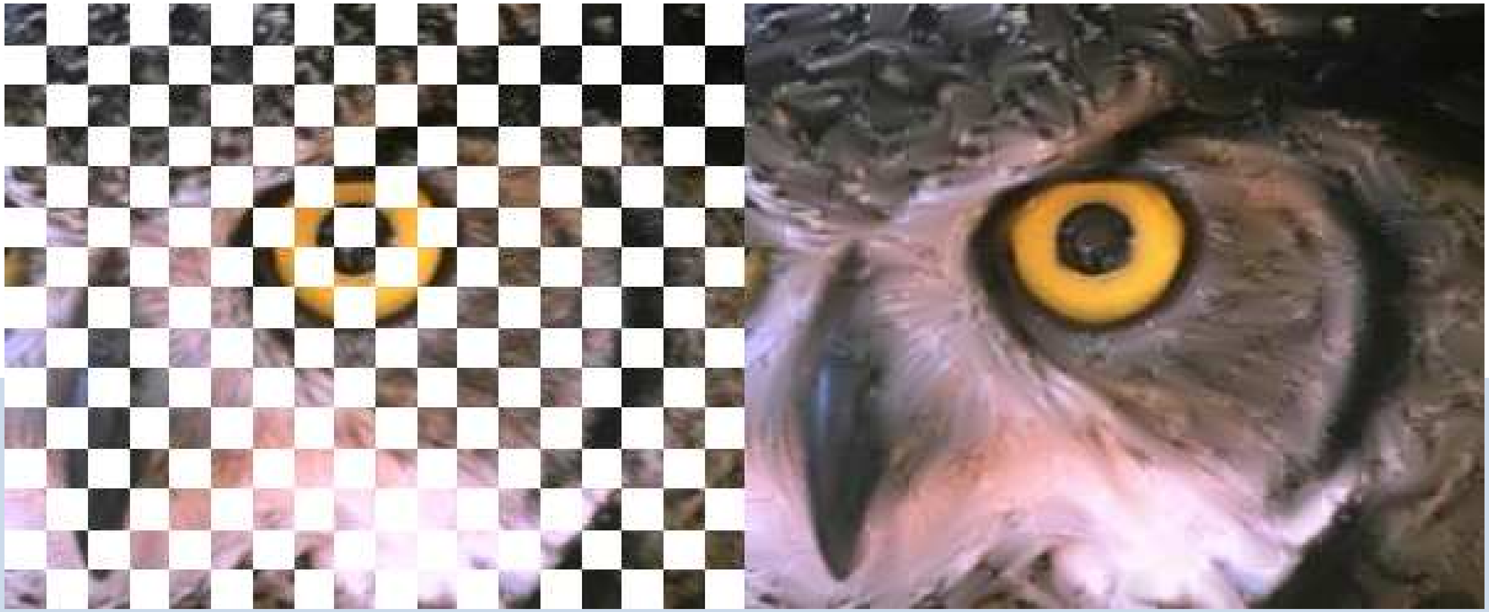
“Chloé au zoo”, inpainted with our PDE.

Application : Image Inpainting and Reconstruction

“Parrot”
500x500
(200 iter., 4m11s)



“Owl”
320x246
(10 iter., 1m01s)



Application : Image Resizing

(c) Details from the image resized by bicubic interpolation.

(d) Details from the image resized by a non-linear regularization PDE.

Application : Image Resizing

(a) Original color image

(b) Bloc Interpolation (c) Linear Interpolation (d) Bicubic Interpolation (e) PDE/LIC Interpolation

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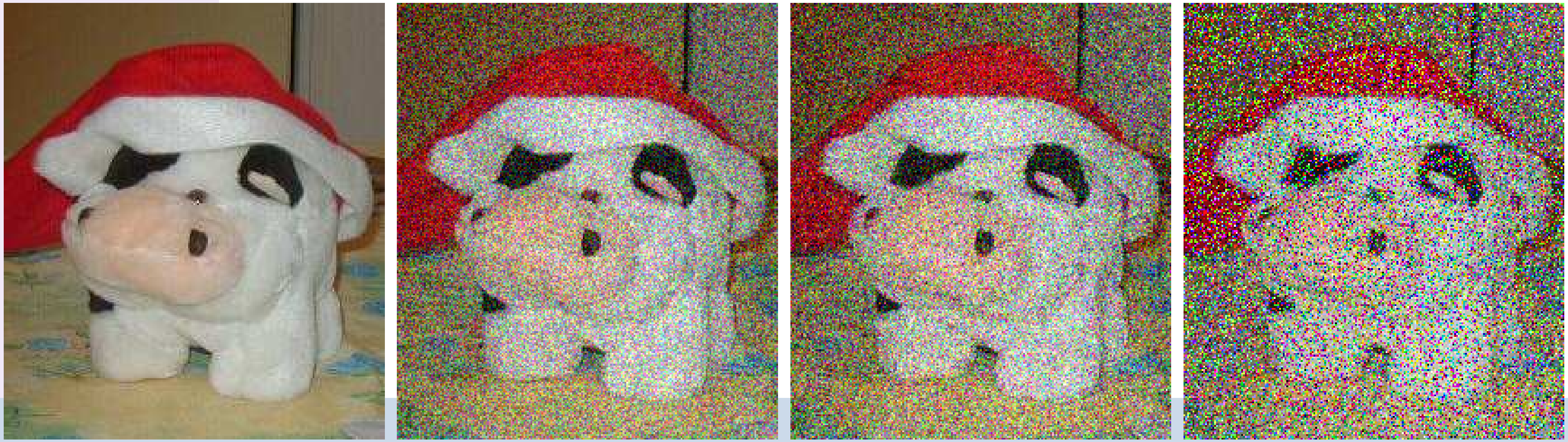
Adding noise to images

- `CImg<T>::noise()` and `CImg<T>::get_noise()`.
- Can add different kind of noise to the image with specified distribution : Uniform, Gaussian, Poisson, Salt&Pepper.
- One parameter that set the amount of noise added.



Retrieving image similarity

- Two indices defined to measure “distance” between two images $I1$ and $I2$: MSE and PSNR.

- MSE, Mean Squared Error : `CImg<T>::MSE(img1,img2)`.

$$\text{MSE}(I1,I2) = \frac{\sum_{p\in\Omega}(I1_{(p)} - I2_{(p)})^2}{\text{card}(\Omega)}$$

The lowest the MSE is, the closest the images $I1$ and $I2$ are.

- PSNR, Peak Signal to Noise Ratio : `CImg<T>::PSNR(img1,img2)`.

$$\text{PSNR}(I1,I2) = 20\log_{10}\left(\frac{M}{\sqrt{MSE(I1,I2)}}\right)$$

where M is the maximum value of $I1$ and $I2$.

- A lot of useful functions that does the common image filtering tasks.
- Linear and Nonlinear filters.
- But what if we want to define to following filter ???

$$\forall p \in \Omega, \qquad J(x,y) = \sum_{i,j} \text{mod}(I(x-i,y-j),M(i,j))$$

⇒ There are smart ways to define your own nonlinear filters, using neighborhood loops.

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Simple loops

- Image loops are very useful in image processing, to scan pixel values iteratively.

- CImg define macros that replace the corresponding `for(..;..;..)` instructions.

```
cimg_forX(img,x)  ⇔  for (int x=0; x<img.width(); x++)
cimg_forY(img,y)  ⇔  for (int y=0; y<img.height(); y++)
cimg_forZ(img,z)  ⇔  for (int z=0; z<img.depth(); z++)
cimg_forC(img,c)  ⇔  for (int c=0; c<img.spectrum(); c++)
```

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cimg_forC(img,c)  ⇔  for (int c=0; c<img.spectrum(); c++)
```

- CImg also defines :

```
cimg_forXY(img,x,y)  ⇔  cimg_forY(img,y) cimg_forX(img,x)
cimg_forXYZ(img,x,y,z)  ⇔  cimg_forZ(img,z) cimg_forXY(img,x,y)
cimg_forXYZC(img,x,y,z,c)  ⇔  cimg_forC(img,c) cimg_forXYZ(img,x,y,z)
```

Simple loops (2)

- These loops lead to natural code for filling an image with values :

```
CImg<unsigned char> img(256,256);
cimg_forXY(img,x,y) { img(x,y) = (x*y)%256; }
```

Simple loops (2)

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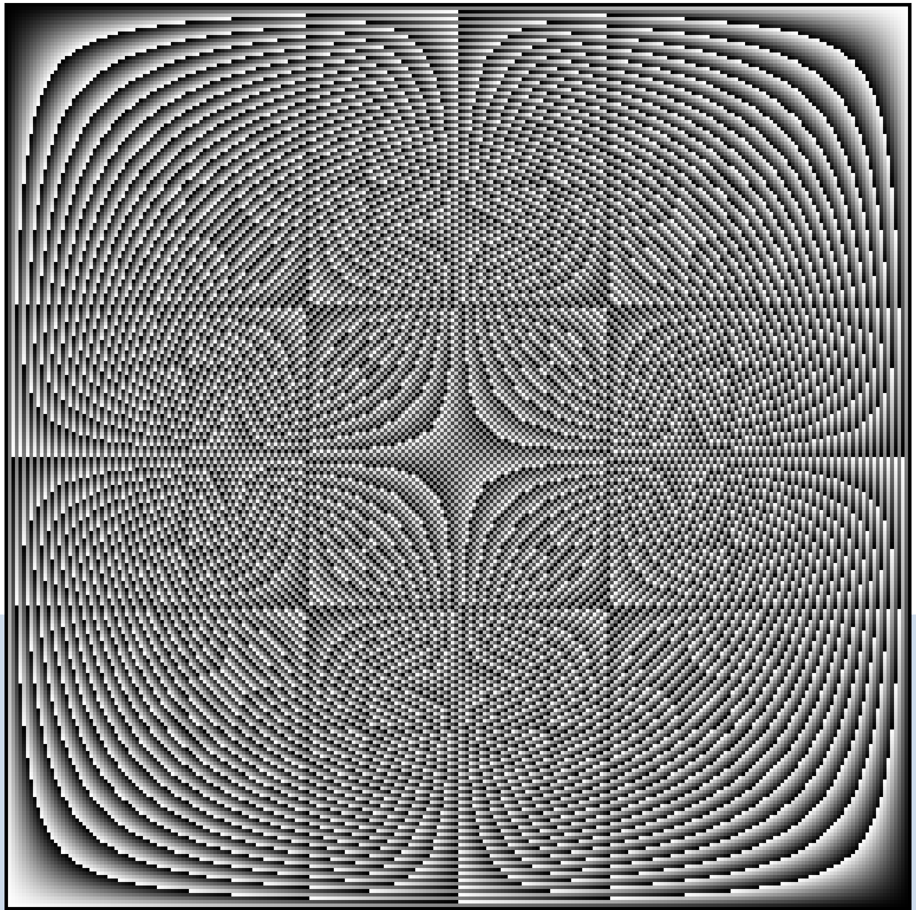
```
CImg<unsigned char> img(256,256);
cimg_forXY(img,x,y) { img(x,y) = (x*y)%256; }
```



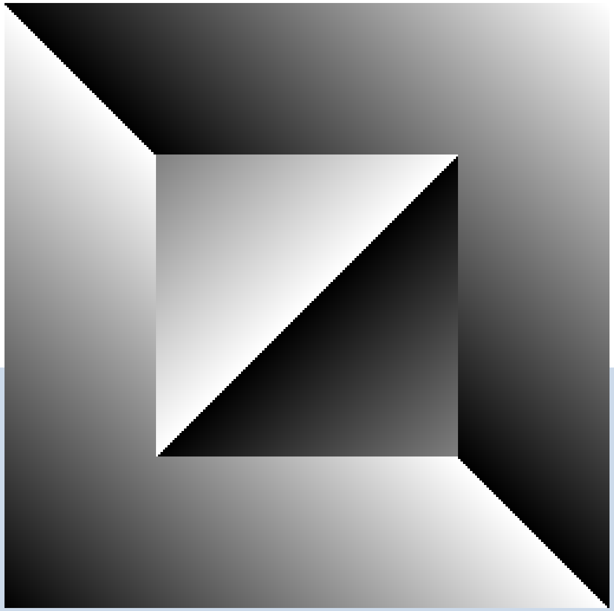
Interior and Border loops

- Slight variants of the previous loops, allowing to consider only interior or image borders.

- An extra parameter n telling about the size of the image border.

  `cimg_for_insideXY(img,x,y,n)` and `cimg_for_borderXY(img,x,y,n)` (same for 3D volumetric images).

```
CImg<unsigned char> img(256,256);
cimg_for_insideXY(img,x,y,64) img(x,y) = x+y;
cimg_for_borderXY(img,x,y,64) img(x,y) = x-y;
```



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Neighborhood-based loops

- Very powerful loops, allow to loop an entire neighborhood over an image.
- From 2×2 to 5×5 for $2D$ neighborhood.
- From $2 \times 2 \times 2$ to $3 \times 3 \times 3$ for $3D$ neighborhood.
- Border condition : Nearest-neighbor.
- Need an external neighborhood variable declaration.
- Allow to write very small, clear and optimized code.

Neighborhood-based loops : 3×3 example

- Neighborhood declaration :

```
CImg_3x3(I,float).
```

Neighborhood-based loops : 3×3 example

- Neighborhood declaration :

```
CImg_3x3(I,float).
```

- Actually, the line above defines 9 different variables, named :

`Ipp`	`Icp`	`Inp`
`Ipc`	`Icc`	`Inc`
`Ipn`	`Icn`	`Inn`

where *p = previous, c = current, n = next.*

Neighborhood-based loops : 3×3 example

- Neighborhood declaration :

```
CImg_3x3(I,float).
```

- Actually, the line above defines 9 different variables, named :

`Ipp`	`Icp`	`Inp`
`Ipc`	`Icc`	`Inc`
`Ipn`	`Icn`	`Inn`

where *p = previous, c = current, n = next.*

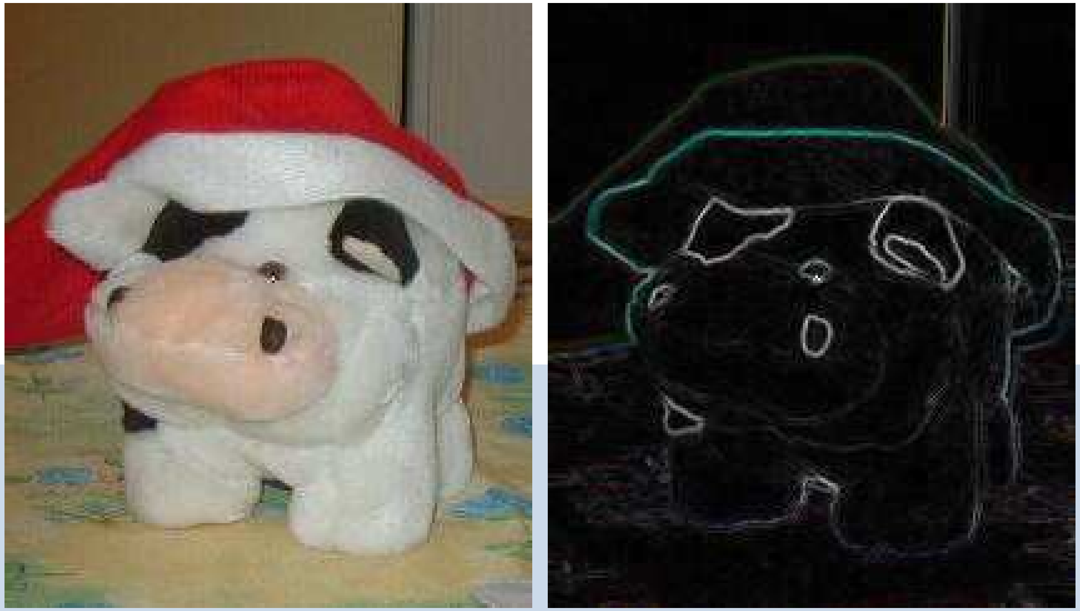
- Using a `cimg_for3x3()` automatically updates the neighborhood with the correct values.

```
cimg_for3x3(img,x,y,0,0,I,float) {
  .. Here, Ipp, Icp, ... Icn, Inn are updated ...
}
```

Neighborhood-based loops

- Example of use : Compute the gradient norm with one loop.

```
CImg<float> img(``milla.jpg''), dest(img);
CImg_3x3(I,float);
cimg_forC(img,v) cimg_for3x3(img,x,y,0,v,I,float) {
  const float ix = (Inc-Ipc)/2, iy = (Icn-Icp)/2;
  dest(x,y) = std::sqrt(ix*ix+iy*iy);
}
```



Example : Modulo Filtering

- What if we want to define to following filter ???

$$\forall p \in \Omega, \qquad J(x,y) = \sum_{i,j} \text{mod}(I(x-i, y-j), M(i,j))$$

Example : Modulo Filtering

- What if we want to define to following filter ???

$$\forall p \in \Omega, \qquad J(x,y) = \sum_{i,j} \text{mod}(I(x-i,y-j),M(i,j))$$

- Simple solution, using a 3x3 mask :

```
CImg<unsigned char> img(``milla.jpg''), mask(3,3);
CImg<> dest(img);
CImg_3x3(I,float);
cimg_forV(img,v) cimg_for3x3(img,x,y,0,v,I)
  dest(x,y) = mask(0,0)%Ipp + mask(1,0)%Icp + mask(2,0)%Inp
            + mask(0,1)%Ipc + mask(1,1)%Icc + mask(2,1)%Inc
            + mask(0,2)%Ipn + mask(1,2)%Icn + mask(2,2)%Inn;
}
```

- **Image Filtering** : Goal and principle.
  - Convolution - Correlation.
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  - Anisotropic smoothing.
  - Other related functions.
- **Image Loops** : Using predefined macros.
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⇒ **The plug-in mechanism.**

- Dealing with 3D objects.
- Shared images.

CImg plugins

- Sometimes an user needs or defines specific functions, either very specialized or not generic enough.
- Not suitable to be integrated in the CImg Library, but interesting to share anyway.

CImg plugins

- Sometimes an user needs or defines specific functions, either very specialized or not generic enough.
- Not suitable to be integrated in the CImg Library, but interesting to share anyway.

⇒ Integration possible in CImg via the plug-ins mechanism.

```
#define cimg_plugin ``my_plugin.h''
#include ``CImg.h''
using namespace cimg_library;

int main() {
  CImg<> img(``milla.jpg'');
  img.my_wonderful_function();
  return 0;
}
```

CImg plugins

- Plugin functions are directly added as member functions of the CImg class.

```
// File ``my_plugin.h''
//----------------------
CImg<T> my_wonderful_function() {
  (*this)=(T)3.14f;
  return *this;
}
```

CImg plugins

- Plugin functions are directly added as member functions of the CImg class.

```
// File ``my_plugin.h''
//----------------------
CImg<T> my_wonderful_function() {
  (*this)=(T)3.14f;
  return *this;
}
```

- Very flexible system, implemented as easily as :

```
class CImg<T> {
  ...
  #ifdef cimg_plugin
  #include cimg_plugin
  #endif
};
```

CImg plugins

- Advantages :
  - Allow creations or modifications of existing functions by the user, without modifying the library source code.

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⇒ A very good way to contribute to the library.

CImg plugins

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  - Allow creations or modifications of existing functions by the user, without modifying the library source code.
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  - Allow an easy redistribution of useful functions as open source components.

⇒ A very good way to contribute to the library.

- Existing plugins in the default CImg package :
  - Located in the directory `CImg/plugins/`
  - `cimg_matlab.h` : Provide code interface between CImg and Matlab images.
  - `nlmeans.h` : Implementation of Non-Local Mean Filter (*Buades etal*).
  - `noise_analysis.h` : Advanced statistics for noise estimation.
  - `toolbox3d.h` : Functions to construct classical 3D meshes (cubes, sphere,...)

CImg plugins

- Plug-ins variables :
  - `#define cimg_plugin` : Add functions to the `CImg<T>` class.
  - `#define cimglist_plugin` : Add functions to the `CImgList<T>` class.

- Using several plug-ins is possible : `#define cimg_plugin ``all_plugins.h''`.

```
// file ``all_plugins.h''
#include ``plugin1.h''
#include ``plugin2.h''
#include ``plugin3.h''
```

⇒ With the plugin mechanism, CImg is a very open framework for image processing.

Outline - PART II of II : More insights

- **Image Filtering** : Goal and principle.
  - Convolution - Correlation.
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  - Anisotropic smoothing.
  - Other related functions.
- **Image Loops** : Using predefined macros.
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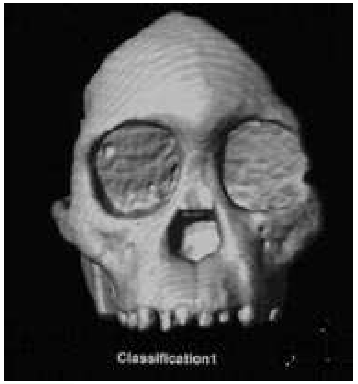
- The plug-in mechanism.

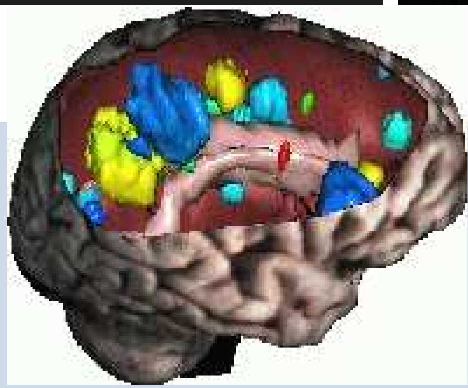
⇒ **Dealing with 3D objects.**

- Shared images.

3D Object Visualization : Context

- In a lot of image processing problems, one needs to reconstruct 3D models from raw image datasets.
  - 3D from stereo images/multiple cameras.
  - 3D surface reconstruction from volumetric MRI images.
  - 3D surface reconstruction from points clouds (3D scanner).





3D Object Visualization : Context

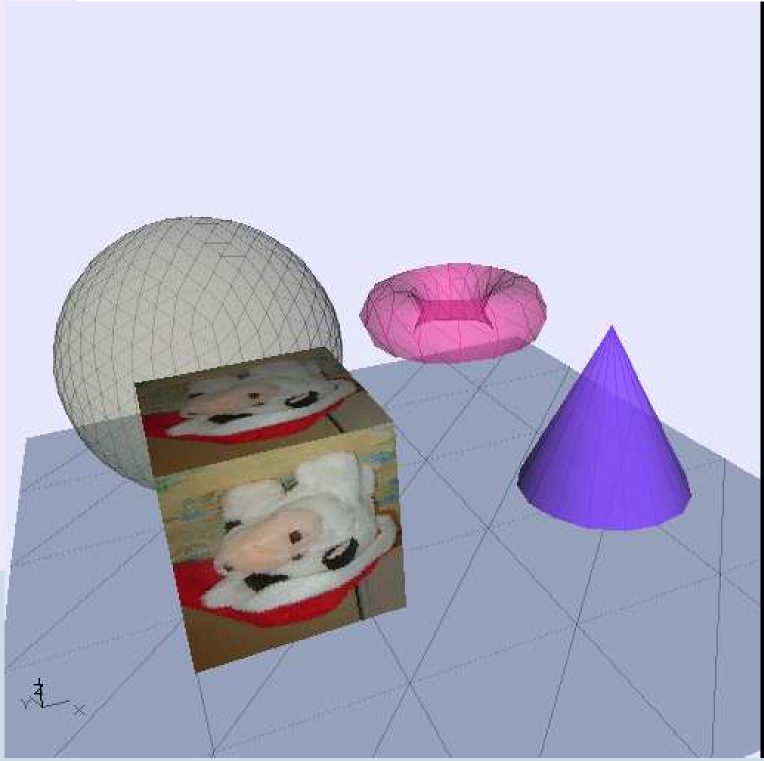
⇒ Basic and intergrated 3D meshes visualization capabilities may be useful in any image processing library.

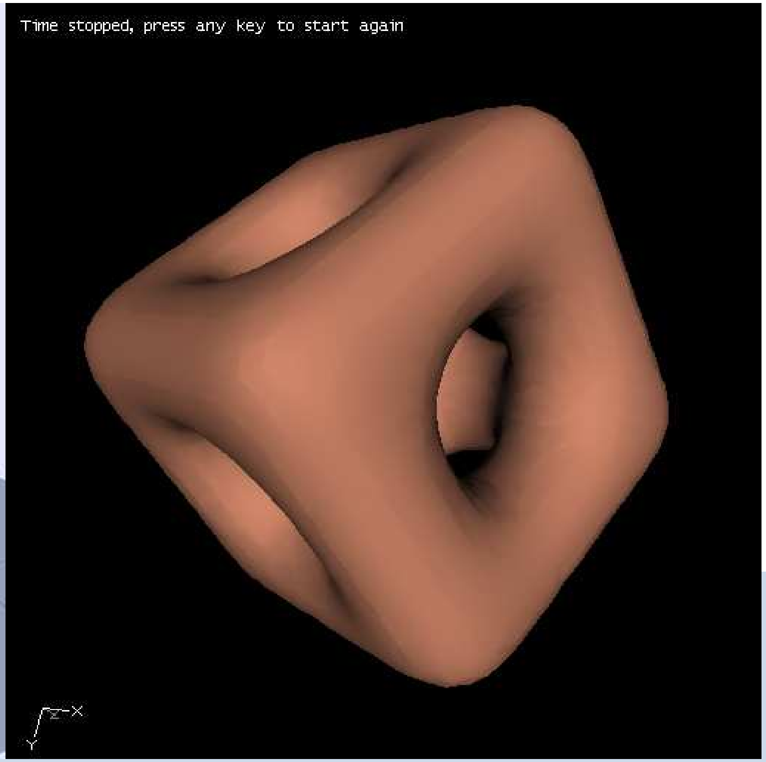
- ... but we don't want to replace complete 3D rendering libraries (openGL, Direct3D, VTK, ...).

- CImg allows to visualize 3D objects for punctuals needs.
  - Can displays a set of 3D primitives (points, lines, triangles) with given opacity.
  - Can render objects with flat, gouraud or phong-like light models.
  - Contains an interactive display function to view the 3D object.
  - Texture mapping supported.
  - No multiple lights allowed.
  - No GPU acceleration.

3D Object Visualization : Live Demo

- Mean Curvature Flow.
- Image as a surface.
- Toolbox3D.





3D Object Visualization : How does it works ?

- CImg has a `CImg<T>::draw_*()` function that can draw a projection of a 3D object into a 2D image :

  `CImg<T>::draw_object3d()`

3D Object Visualization : How does it works ?

- CImg has a `CImg<T>::draw_*()` function that can draw a projection of a 3D object into a 2D image :

```
CImg<T>::draw_object3d()
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- High-level interactive 3D object display :

```
CImg<T>::display_object3d()
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⇒ All 3D visualization capabilities of CImg are based on these two functions.

3D Object Visualization : How does it works ?

- CImg has a `CImg<T>::draw_*()` function that can draw a projection of a 3D object into a 2D image :

  `CImg<T>::draw_object3d()`

- High-level interactive 3D object display :

  `CImg<T>::display_object3d()`

⇒ All 3D visualization capabilities of CImg are based on these two functions.

- Needed parameters :
  - A `CImgList<tp>` of 3D points coordinates (size M).
  - A `CImgList<tf>` of primitives (size N).
  - A `CImgList<T>` of colors/textures (size N).
  - A `CImgList<to>` of opacities (size N) (optional parameter).

Display a house : building point list

```
CImgList<float> points(9,1,3,1,1,
                       -50,-50,-50,  // Point 0
                       50,-50,-50,   // Point 1
                       50,50,-50,    // Point 2
                       -50,50,-50,   // Point 3
                       -50,-50,50,   // Point 4
                       50,-50,50,    // Point 5
                       50,50,50,     // Point 6
                       -50,50,50,    // Point 7
                       0,-100,0);    // Point 8
```

⇒ List of 9 vectors (images 1x3) with specified coordinates.

Display a house : building primitives list

```
CImgList<unsigned int> primitives(6,1,4,1,1,
                                  0,1,5,4,  // Face 0
                                  3,7,6,2,  // Face 1
                                  1,2,6,5,  // Face 2
                                  0,4,7,3,  // Face 3
                                  0,3,2,1,  // Face 4
                                  4,5,6,7); // Face 5
primitives.insert(CImgList<unsigned int>(4,1,2,1,1,
                                          0,8,    // Segment 6
                                          1,8,    // Segment 7
                                          5,8,    // Segment 8
                                          4,8)); // Segment 9
```

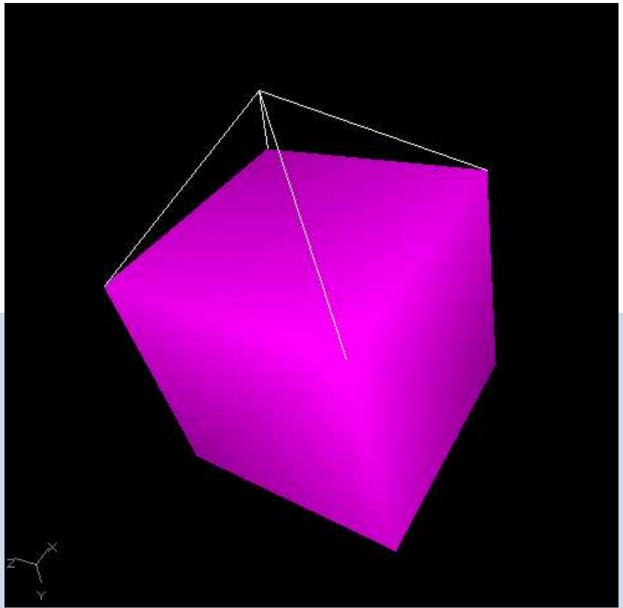
⇒ List of 10 vectors : 6 rectangle + 4 segments.

Display a house : building colors

```
CImgList<unsigned char> colors;
colors.insert(6,CImg<unsigned char>::vector(255,0,255));
colors.insert(4,CImg<unsigned char>::vector(255,255,255));
```

- Then,.... visualize.

```
CImg<unsigned char>(800,600,1,3).fill(0).
display_object3d(points,primitives,colors);
```



Display a transparent house : setting primitive opacities

```
CImgList<float> opacities;
opacities.insert(6,CImg<>::vector(0.5f));
opacities.insert(4,CImg<>::vector(1.0f));
```

- Then,.... visualize.

```
CImg<unsigned char>(800,600,1,3).fill(0).
display_object3d(points,primitives,colors,opacities);
```

- Other parameters of the 3D functions allow to set :
  - Light position, and ambiant light intensity.
  - Camera position and focale.
  - Rendering type (Gouraud, Flat, ...)
  - Double/Single faces.

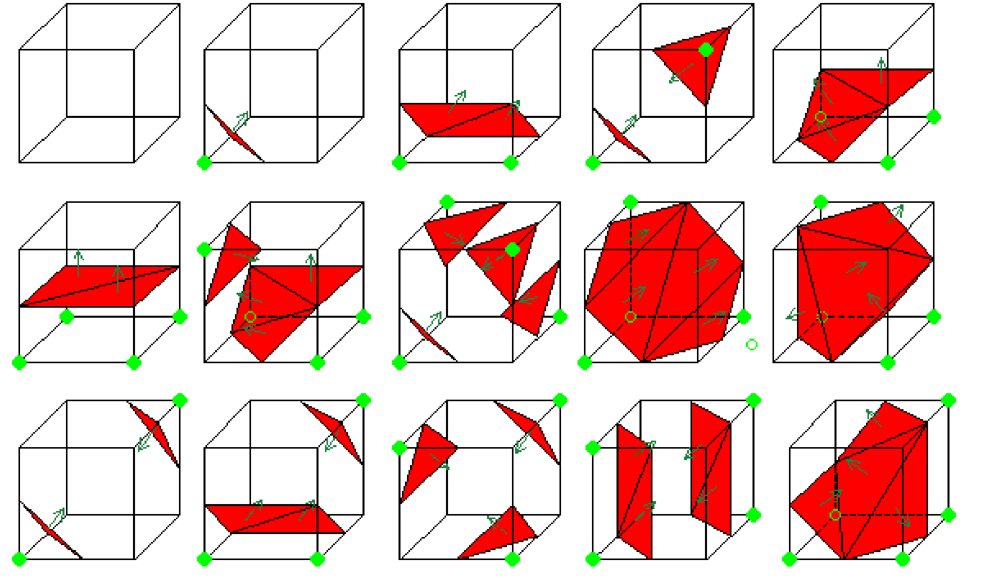
How to construct 3D meshes ?

- Plugin : `CImg/plugins/primitives.h` contains useful functions to retrieve classical meshes.

  `CImg<T>::cube()`, `CImg<T>::sphere()`, `CImg<T>::cylinder()`, ...

- Library functions : `CImg<T>::marching_cubes()` and `CImg<T>::marching_squares()`.

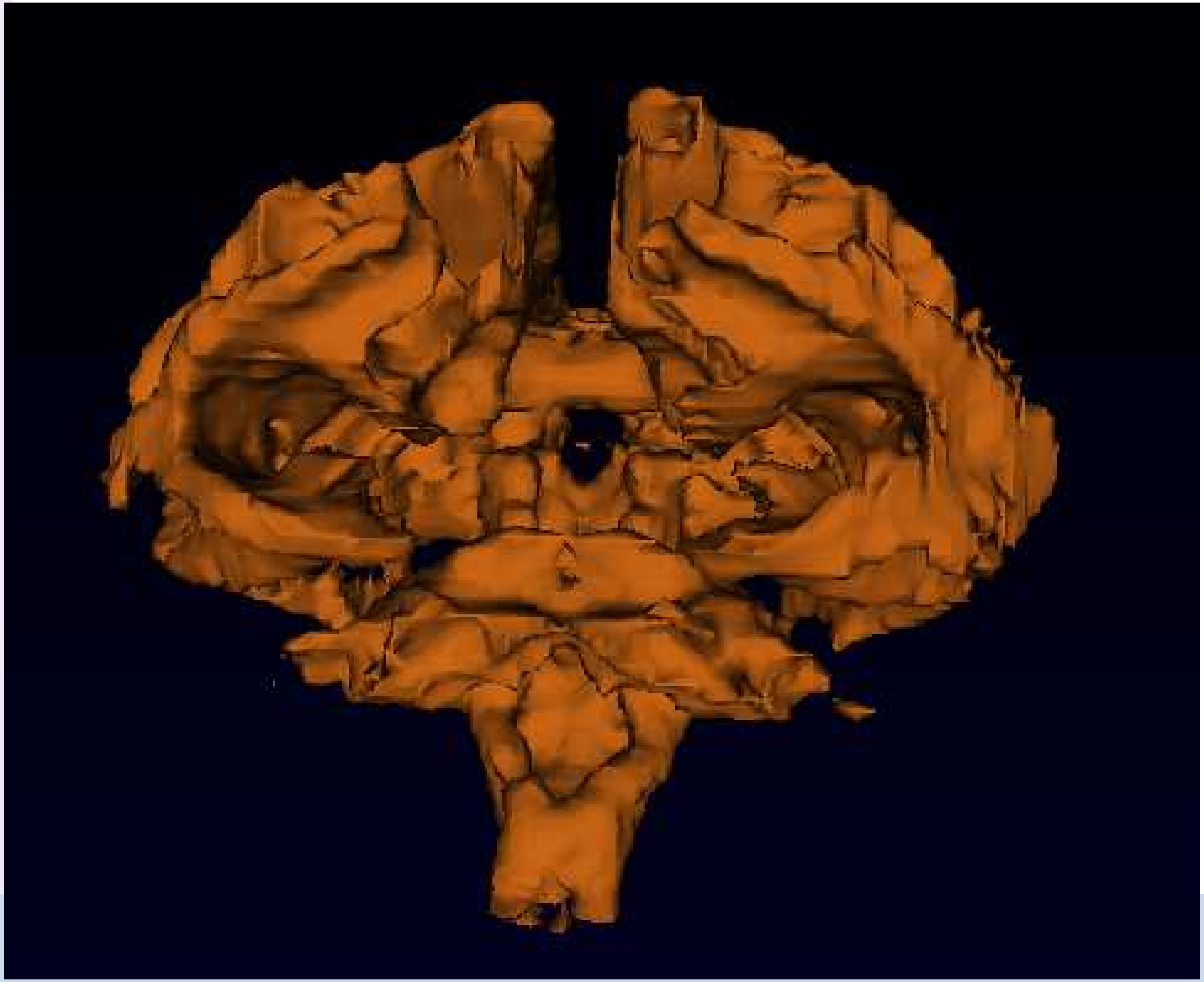
⇒ Create meshes from implicit functions.



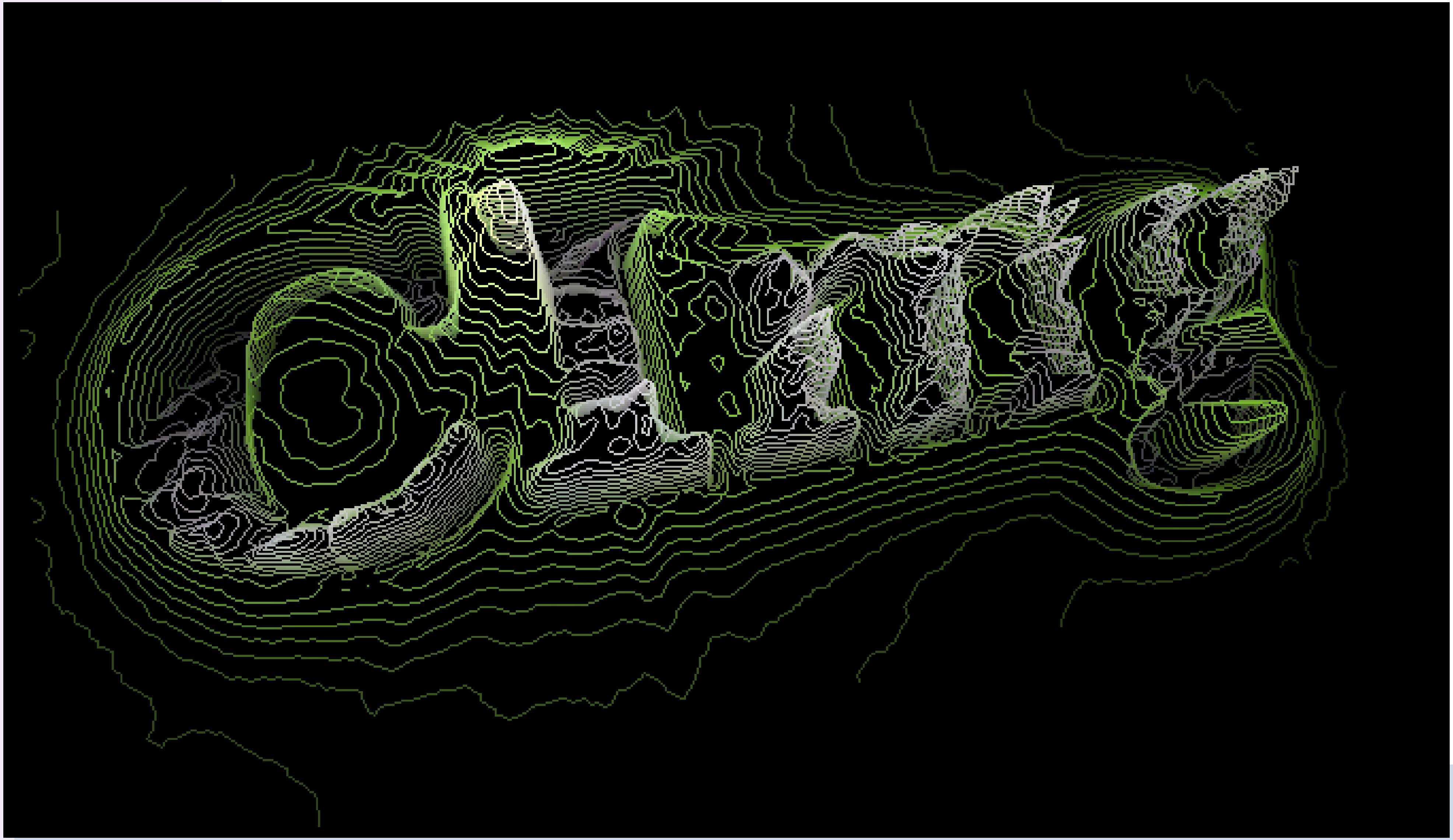
Example : Segmentation of the white matter from MRI images

```
CImg<> img(``volumeMRI.inr'');
CImg<> region;
float black[1]={0};
img.draw_fill(X0,Y0,Z0,black,region,10.0f);
(region*=-1).blur(1.0f).normalize(-1,1);

CImgList<> points, faces;
region.marching_cubes(0,points,faces);
CImgList<unsigned char> colors;
colors.insert(faces.size,CImg<unsigned char>::vector(200,100,20));

CImg<unsigned char>(800,600,1,3).fill(0).
display_object3d(points,faces,colors);
```

Example : Segmentation of the white matter from MRI images



Example : Isophotes with marching squares



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⇒ **Shared images.**

Shared images : Context

- Two frequent cases with undesired image copies :

1. Sometimes, we want to pass contiguous parts of an image (but not all the image) to a function :

```
const CImg<> img(``milla.jpg'');
CImgList<> RG = img.get_channels(0,1).get_split('v');
```

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1. Sometimes, we want to pass contiguous parts of an image (but not all the image) to a function :

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2. ..Or, we want to modify contiguous parts of an image (but not all the image) :

```
CImg<> img(``milla.jpg'');
img.draw_image(img.get_channel(1).blur(3),0,0,0,1);
```

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```
CImg<> img(``milla.jpg'');
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```

⇒ ... But we also want to avoid image copies for better performance...

Shared images

- Solution : Use shared images :

1. Replace :

```
const CImg<> img(``milla.jpg'');
CImgList<> RG = img.get_channels(0,1).get_split('v');
```

by

```
const CImg<> img(``milla.jpg'');
CImgList<> RG = img.get_shared_channels(0,1).get_split('v');
```

Shared images

- Solution : Using shared images :

2. Replace :

```
CImg<> img(``milla.jpg'');
img.draw_image(img.get_channel(1).blur(3),0,0,0,1);
```

by

```
CImg<> img(``milla.jpg'');
img.get_shared_channel(1).blur(3);
```

Shared images

- Regions composed of contiguous pixels in memory are candidates for being shared images :
  - `CImg<T>::get_shared_point[s]()`
  - `CImg<T>::get_shared_row[s]()`
  - `CImg<T>::get_shared_plane[s]()`
  - `CImg<T>::get_shared_channel[s]()`
  - `CImg<T>::get_shared()`
- Image attribute `CImg<T>::is_shared` tells about the shared state of an image.
- Shared image destructor does nothing (no memory freed).

⇒ Warning : Never destroy an image before its shared version !!

Shared images and CImgList<T>

- Inserting a shared image CImg<T> into a CImgList<T> makes a copy :

```
CImgList<> list;
CImg<> shared = img.get_shared_channel(0);
list.insert(shared);
shared.assign();            // OK, 'list' not modified.
```

- Function `CImgList<T>::insert()` can be used in a way that it forces the insertion of a shared image into a list.

```
CImgList<unsigned char> colors;
CImg<unsigned char> color = CImg<unsigned char>::vector(255,0,255);
list.insert(1000,colors,list.size,true);
color.fill(0);     // 'list' will be also modified.
```

Conclusion

Conclusion and Links

- The CImg Library eases the coding of image processing algorithms.
- For more details, please go to the official CImg site !

  `http://cimg.sourceforge.net/`

- A 'complete' inline reference documentation is available (generated with `doxygen`).
- A lot of simple examples are provided in the CImg package, covering a lot of common image processing tasks. It is the best information source to understand how CImg can be used at a first glance.
- Finally, questions about CImg can be posted in its active Sourceforge forum : (Available from the main page).

Conclusion and Links

- Now, you know almost everything to handle complex image processing tasks with the CImg Library.

⇒ **You can contribute to this open source project :**

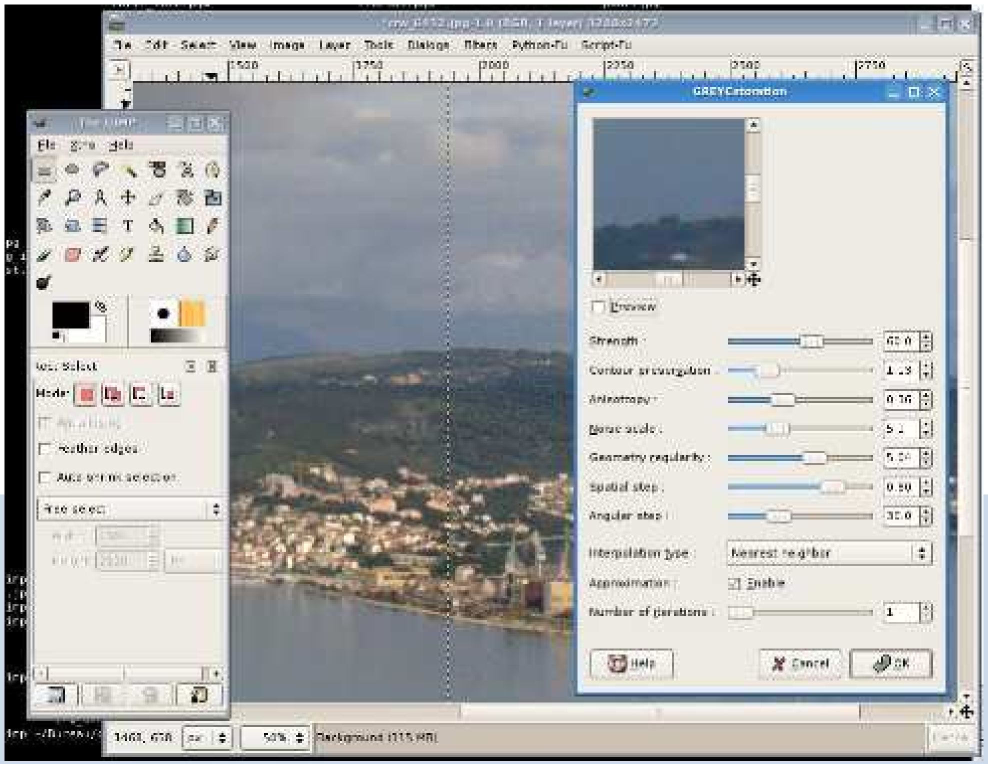
  - Submit bug reports and patches.
  - Propose new examples or **plug-ins**.

Used in real world : “GREYCstoration”

- This anisotropic smoothing function has been embedded in an open-source software : **GREYCstoration**.

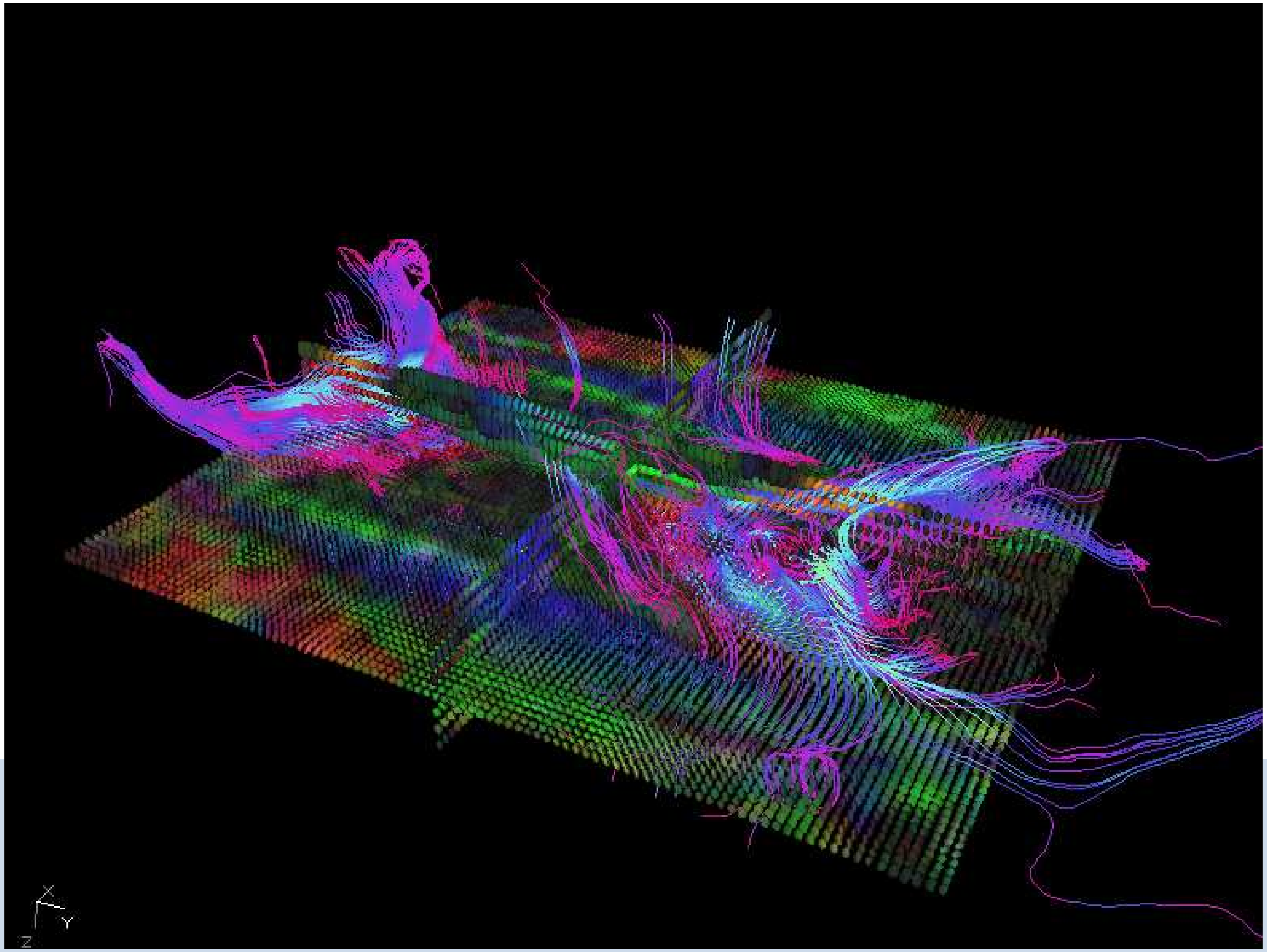
⇒ Distributed as a free command line program or a plug-in for GIMP.

⇒ `http://www.greyc.ensicaen.fr/~dtschump/greycstoration/`



Used in real world : DT-MRI Visualization and FiberTracking

- DTMRI dataset visualization and fibertracking code is distributed in the CImg package (File examples/dtmri_view.cpp, 823 lines).



Corpus Callosum Fiber Tracking

The end

Thank you for your attention.

Time for additional questions if any ..