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OpenCV

a brief introduction (for C++)

- OpenCV
- Installation
- Modules
- C pointers
- `cv::Mat` class + companions
- Few examples and `simple.cpp` skeleton

- OpenCV (Open Source Computer Vision Library) is an Open Source library for computer vision and machine learning
- BSD License (also commercial use!)
- Thousands of algorithms
- Tenth of thousands of users
- Millions of downloads
- C++, Python, JAVA, MATLAB support

- Main functionalities
 - Read/write images, sequences of images, or videos
 - Process images
 - Many off the shelf libraries
 - Graphic output

- Linux/gcc
- Two possibilities
 - Package manager
 - Download and compile sources
- Remember to install both core and contribs

- Prerequisites:
 - Development environment (C++, cmake, git)
 - Specific packages (sudo apt install libgtk2.0-dev vtk7 libvtk7-dev)
- Use git for download
 - `git clone https://github.com/opencv/opencv.git opencv`
 - `git clone https://github.com/opencv/opencv_contrib.git opencv-contribs`

- Build instructions:
 - `mkdir opencv/build`
 - `cd opencv/build`
 - `cmake -DOPENCV_EXTRA_MODULES_PATH=../..../opencv-contribs ..`
 - Check errors and whether specific packages are installed (i.e. viz)
 - `make -j8` #if memory issues, reduce the 8
 - **`sudo make install`**

- OpenCV main modules are:
 - Core, basic data structures:
 - Mat, Scalar, Point, Range...
 - Image processing, we will use some just to match our results
 - Video, motion estimation, tracking, background subtraction...
 - Calib3d, camera calibration
 - Features2d, features extraction and matching
 - ...

- It is an OpenCV slide presentation, isn't it?
- Yes but we need some recap about how to access memory...
- What is a C pointer?
 - Kind of data to store memory addresses
 - 32 bits/64 bits

- Address is simply a number
- Anyway C pointers feature a data type:
 - `char *c` \rightarrow pointer to a char data
 - `float *f` \rightarrow pointer to a float data
 - ...
 - `void *v` \rightarrow pointer to something to be better specified

- Why we need a data type for pointers?
- Basically for pointer arithmetics
- $f=f+1 \rightarrow$ what is the result?
 - It depends on which kind of data is expected to be found at address f
 - If f is a `char*`, $f=f+1 \rightarrow$ address f is increased by 1 byte
 - If f is a `uint32_t`, $f=f+1 \rightarrow$ address f is increased by 4 bytes

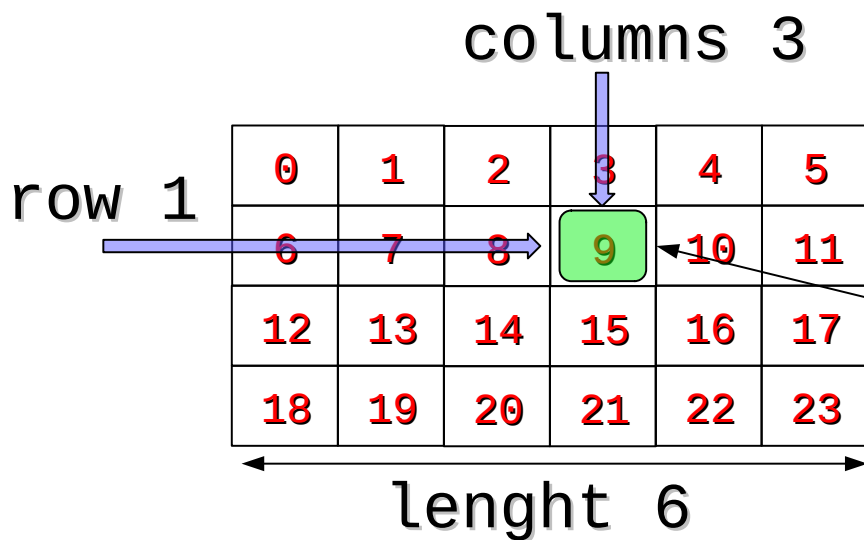
- How to access to the pointed data?
- When `f` is a pointer we can use `*f`
 - Both read/write
- Anyway usually we deal with large chunks of data → arrays
- To access the n^{th} element we can use:
 - `*(f+n)` → old fashion, please avoid...
 - `f[n]`

- `f[n]`
 - It makes sense only when `f` contains the address of a set of consecutive values
 - Monodimensional arrays \rightarrow only one index
 - It works when `*f` type exactly matches the type of data stored at the `f` address

- We already know that images are (at least) 2D structures
 - Two coordinates: column & row
- We can use pointers for that?
- Yes, we can use pointers to other pointers
 - `char **c;`
- If we consider other dimensions things get even creepier...
- Hint: do not do that!

- Use simple array to deal with multidimensional matrices
- If we need to store $n \times m$ values:
 - `data_type data[n*m];`
- Access element at coordinates (x,y)
 - Considering that
 - rows are one after the other
 - Each row contains m elements
 - `data[y*m + x]`
- Logical representation vs Physical one

Logical layout



Physical layout



Array index: $\text{Row index} \times \text{length} + \text{Column index}$

- Basic Image Container
- Two main elements:
 - Handler
 - Description of data
 - “Shared” pointer for data
 - Actual data pointer
 - Be careful! clone() and copyTo() methods
 - a=b (!)

- `cv::Mat()`
- `cv::Mat(int rows, int cols, int type)`
- `cv::Mat(int rows, int cols, int type, cv::Scalar s)`
- `cv::Mat(cv::Size size, int type)`
- `cv::Mat(cv::Size size, int type, cv::Scalar s)`
- `cv::Mat(const cv::Mat &m)`
- `cv::Mat(const cv::Mat &m, cv::Range rowRange)`
- `cv::Mat(const cv::Mat &m, cv::Range rowRange, cv::Range colRange)`
- `cv::Mat(const cv::Mat &m, cv::Rect roi)`
- ...

| CV | • C1 | • C2 | • C3 | • C4 |
|-------|------|------|------|------|
| – | | | | |
| • 8U | 0 | 8 | 16 | 24 |
| • 8S | 1 | 9 | 17 | 25 |
| • 16U | 2 | 10 | 18 | 26 |
| • 16S | 3 | 11 | 19 | 27 |
| • 32S | 4 | 12 | 20 | 28 |
| • 32F | 5 | 13 | 21 | 29 |
| • 64F | 6 | 14 | 22 | 30 |

- Often used
 - CV_8UC1
 - greylevel images
 - CV_8UC3
 - RGB images
 - CV_32SCx or CV32FCx
 - result of different processings

- `cv::Scalar`
 - Basically a short vector (up to 4) template
- `cv::Rect`
 - Template class for 2D rectangles
- `cv::Range`
 - Template class for a continuous subsequence

cv::Mat construction examples

- `cv::Mat A, B;` // empty images
- `cv::Mat C(A);` // copy (!)
- `cv::Mat D(1024, 900, CV_8UC3)` // set size/type
- `cv::Mat E(A, Rect(10, 10, 100, 100));` // only part of A
- `cv::Mat M(2,2, CV_8UC3, Scalar(0,0,255));` // also set pixel initial value
- `cv::Mat F = A.clone();`
- `cv::Mat G;`
- `A.copyTo(G);`

- M.rows rows
- M.cols columns
- M.channels() channels
- M.type() image type (OpenCV type!)
- M.elemSize() pixel size (bytes)
- M.elemSize1() single channel size (bytes, \leq M.elemSize())

- i.e. RGB8
 - M.channels() == 3
 - M.elemSize() == 3
 - M.elemSize1() == 1
 - M.type() == CV_8UC3 3 channels, 1 byte/channel

- Where is my image?
- **uchar *cv::Mat::data** can be used
 - Sort of shared pointer
- M.data → address of image buffer
- M.data → points to first image byte
- It does not depend on pixel type
 - Cast can be needed

Example #1

- Bare image access

```
cv::Mat M;  
...  
for(size_t i =0;i<M.rows*M.cols*M.elemSize();++i)  
    M.data[i] = i;
```


- Single channel access

```
cv::Mat M;  
...  
for(size_t i =0;i<M.rows*M.cols;i+=M.elemSize())  
{  
    M.data[i] = i; //B  
    M.data[i+M.elemSize1()] = i + 1; //G  
    M.data[i+M.elemSize1()+M.elemSize1()] = i + 2; //R  
}
```

- Row/Column access

```
cv::Mat M;  
...  
for(size_t v = 0; v<M.rows; ++v)  
{  
    for(size_t u = 0; u<M.cols; ++u)  
    {  
        M.data[(u + v*M.cols)*M.elemSize()] = u;           //B  
        M.data[(u + v*M.cols)*M.elemSize() + M.elemSize1()] = u+1; //G  
        M.data[(u + v*M.cols)*M.elemSize() + M.elemSize1()] = u+2; //R  
    }  
}
```

Example #3

- Row/Column/Channel (1 byte) access

```
cv::Mat M;  
...  
for(size_t v = 0; v < M.rows; ++v)  
    {  
        for(size_t u = 0; u < M.cols; ++u)  
            {  
                for(size_t k = 0; k < M.channels(); ++k)  
                    {  
                        M.data[(u + v*M.cols)*M.elemSize() + k] = u + k;  
                    }  
            }  
    }
```

- To access specific row:
 - `uchar * cv::Mat::ptr(int i)`
 - Allows to access buffer at row `i`
- Actually a template
 - `T * cv::Mat::ptr<T>(int i)`
- Also single pixel can be referenced:
 - `T cv::Mat::at<T>(row=0,col=0)[channel]`
 - Allows to access to value/address
 - Do not use it before first homework

- Skeleton for... everything?
- Prerequisites:
 - OpenCV
 - g++
 - cmake + make
- Build:

```
mkdir build; cd build
cmake ..
make
```
- Enjoy!

- cmake .. fails
 - In OpenCV build folder you missed to run the “sudo make install”
- Everything compiles fine but execution fails when I try to show the image
 - Please install the gtk2.0-dev package and reconfigure, build and install OpenCV