Intelligent Control Systems

Image Processing (1)
— Basic Concepts and Introduction of OpenCV —

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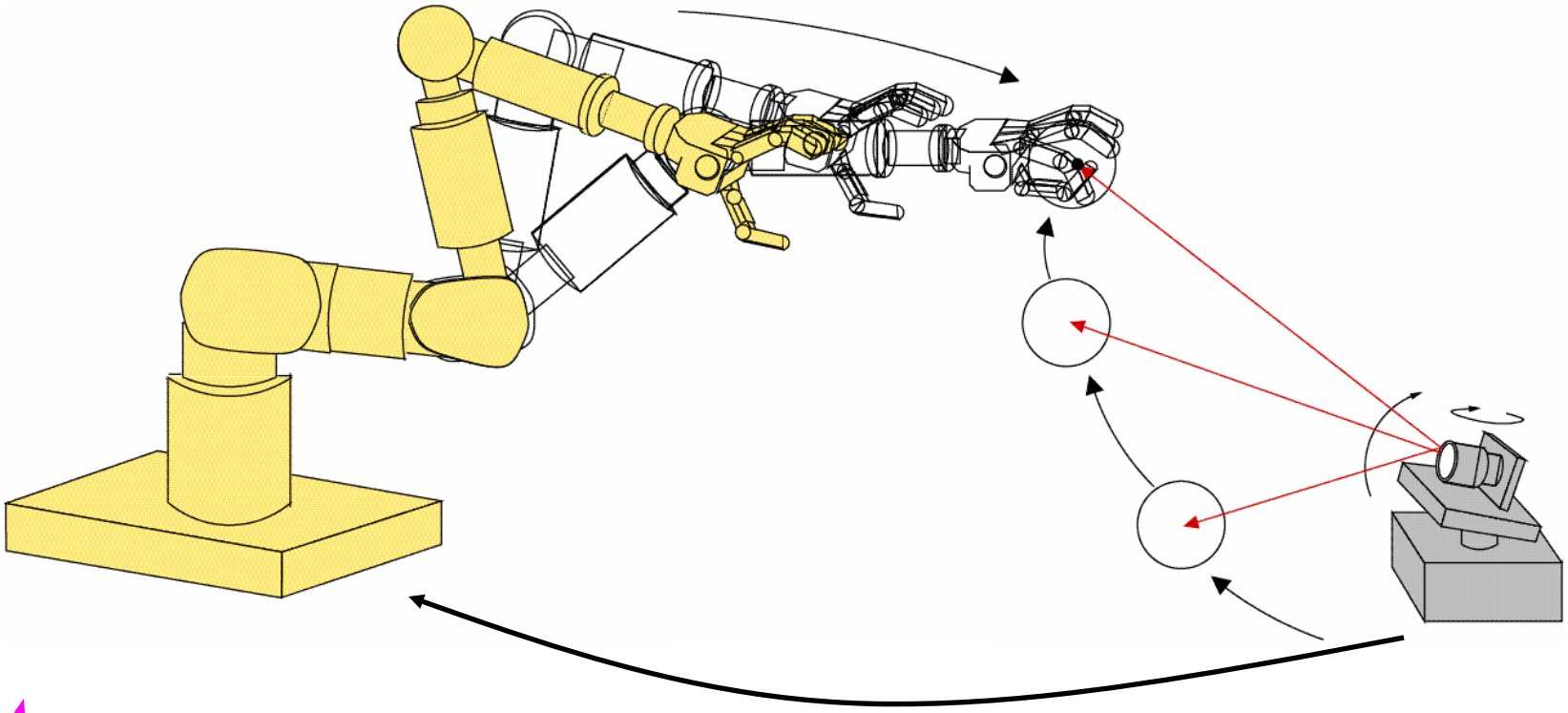
Basic Motivation

e.g. Vision-based Control of Robots

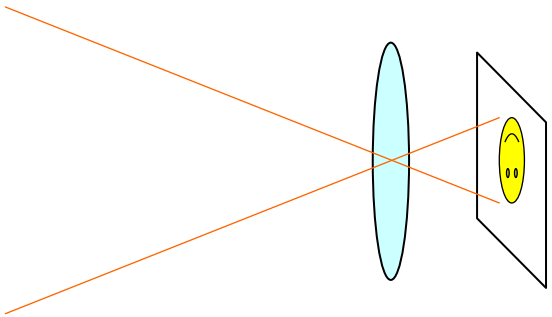


- image acquisition (May 13)
- image processing (from June 3 and on)
- robot control

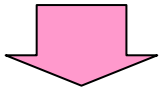
Outline

- General Concepts of Image Processing
- Image Processing Library: OpenCV
- Single Frame Image Processing
- Video Processing (i.e. Successive Multiple Frames)

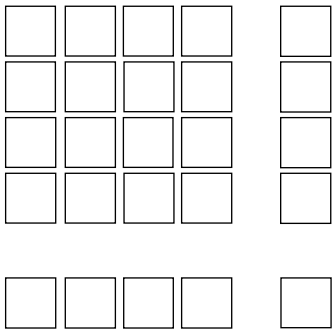
Digital Images



Analog distribution of light intensity



2-D discretization (into pixels)
quantization of intensity (ADC)

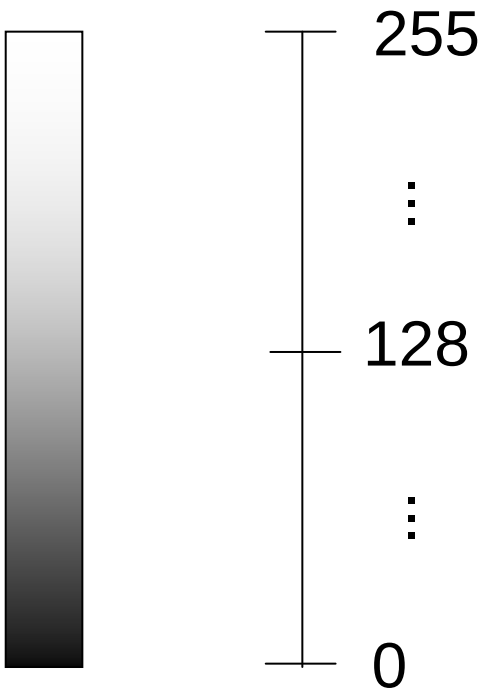


A digital image:

2-D array of pixel values

Pixel Value

(analog) light intensity; illuminance; voltage
(digital) pixel value; intensity value; gray level; grayscale value



quantized into [0, 255] integer:
8-bit grayscale image

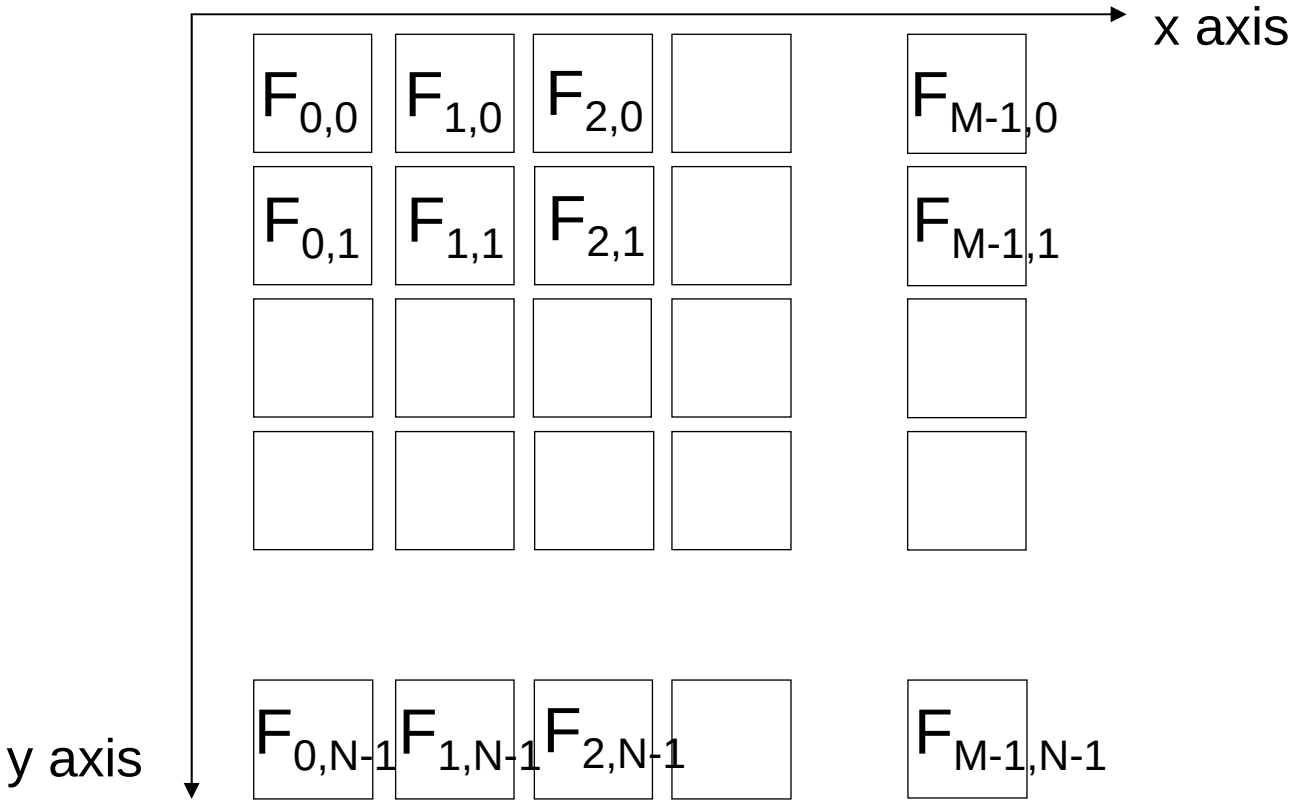
cf. binary image (= 1-bit grayscale)

Expression of a Digital Image

M $\times$ N pixels digital image:

$\{ F_{x,y} \}$, $x = 0, 1, \cdots, M-1$, $y = 0, 1, \cdots, N-1$

Pixel value at (x, y): $F_{x,y}$

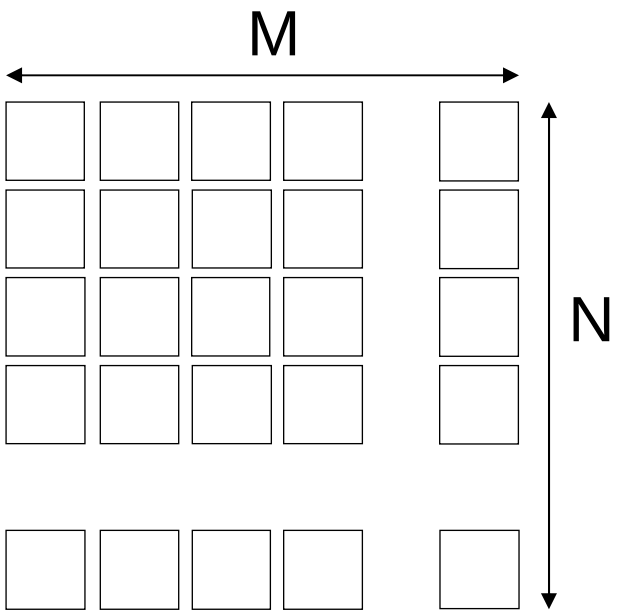


Example in C

```
#define M 640
#define N 480
unsigned char image[M * N];

image[M * y + x] = 30;
// F(x, y) := 30
```

8-bit



- 2-D array is not convenient in C (e.g. not flexible in sizes)
- 1-D array is often prefered

A Simple Example Code

binarization (or thresholding)

```
#define M 640
#define N 480
#define THRESHOLD 128
unsigned char image[M * N];
int i, j;

for (j = 0; j < N; j++) {
    for (i = 0; i < M; i++) {
        if (image[M * j + i] >= THRESHOLD) {
            image[M * j + i] = 255;
        } else {
            image[M * j + i] = 0;
        }
    }
}
```

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Image Processing Libraries

- Writing image processing programs by your own in this way is possible, but cumbersome
- How do you read image/video from a file or a camera?
- How do you display images?

There are many libraries or toolkits convenient for image processing, and using some of them is a good choice

In this lecture, we use OpenCV

note: our goal is not to show you detailed features of OpenCV, but to lecture basic concepts of image processing by using OpenCV as a tool

OpenCV (Open Computer Vision Library)

http://opencv.org/

- A de facto standard library in Computer Vision community
  - implements many state-of-the-art algorithms
  - offers simple but easy-to-use I/O and GUI

- Runs on Windows, Mac, Linux, Android, iOS etc.
- Main language: C++
  - also supports: python, Java

Are you OK with

C++?

Quotes

- C++ is Good for the Economy, It Creates Jobs! - Bjarne Stroustrup
- C makes it easy to shoot yourself in the foot; C++ makes it harder, but when you do, it blows away your whole leg. — Bjarne Stroustrup
- Being really good at C++ is like being really good at using rocks to sharpen sticks. — Thant Tessman
- If C++ has taught me one thing, it’s this: Just because the system is consistent doesn’t mean it’s not the work of Satan. — Andrew Plotkin
- It has been discovered that C++ provides a remarkable facility for concealing the trival details of a program — such as where its bugs are. — David Keppel
- C++ is an insult to the human brain — Niklaus Wirth
- C++: an octopus made by nailing extra legs onto a dog. — Steve Taylor

C to C++

Ah, yes, I admit C++ is such a complicated language that completely understanding it is almost impossible.

But what is really difficult is to design and implement your own classes, and just using classes and functions written by anyone else can be much easier (as long as they are appropriately designed…)

This lecture will also provide minimal guides for migration from C to C++ whenever needed

Setting Up OpenCV

Download and Install the binary package for your platform from
http://opencv.org/downloads.html

Additionally, you will need:

- to add Library Path
- to add Include Path
- to add Executable Path
- to add Depended Library Files

Go to
http://docs.opencv.org/doc/tutorials/tutorials.html
and see “Introduction to OpenCV” to find your platform guide

My Environment for Demonstration

- Microsoft Windows 7 Professional SP1, 64 bit
- Microsoft Visual Studio 2012 Express Edition (msvc11)
  - free!
- OpenCV 2.4.8
  - prebuilt binaries are extracted into C:¥OpenCV2.4.8 (so that we have C:¥OpenCV2.4.8¥build and C:¥OpenCV2.4.8¥sources folders)

Detailed Setup for msvc11 (1/2)

For each **project property**:

- In **Configuration Properties – Linker – General – Additional Library Directories**, add:
  - `$(OPENCV_DIR)¥lib`
- In **Configuration Properties - C/C++ - General – Additional Include Directories**, add:
  - `$(OPENCV_DIR)¥..¥..¥include`
- In **Configuration Properties – Linker – Input – Additional Dependencies**, add (at least):
  - `opencv_core248.lib opencv_imgproc248.lib opencv_highgui248.lib`

OpenCV version

With **Windows environments variables**:

OPENCV_DIR: set to `C:¥OpenCV2.4.8¥build¥x64¥vc11`

PATH: including `%OPENCV_DIR%¥bin`

x86 for Win32

`vc10` for Visual Studio 2010 for example

Detailed Setup for msvc11 (2/2)

- For Debug configuration (instead of Release), specify
  `opencv_core248d.lib opencv_imgproc248d.lib opencv_highgui248d.lib`

  •In general, the programs built in Release Configuration is much far faster than the ones in Debug Config.

- Sometimes we want to see console outputs after the program terminates. In order to keep the console window from vanishing, set **Configuration Properties – Linker – System – Subsystem** to /SUBSYSTEM:CONSOLE

- **File – Export Template** may be useful in avoiding tedious project-wise setups

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Typical Image Processing Code (for a single frame)

```
#include "opencv2/opencv.hpp"

int main()
{
    cv::Mat input = cv::imread("lena.jpg", cv::IMREAD_GRAYSCALE);
    cv::Mat output;

    cv::threshold(input, output, 128, 255, cv::THRESH_BINARY);

    cv::namedWindow("disp", cv::WINDOW_AUTOSIZE);
    cv::imshow("disp", output);
    cv::waitKey(0);

    return 0;
}
```

C++ namespace

```
#include "opencv2/opencv.hpp"

int main()
{
    cv::Mat input = cv::imread("lena.jpg", cv::IMREAD_GRAYSCALE);
    cv::Mat output;

    cv::threshold(input, output, 128, 255, cv::THRESH_BINARY);

    cv::namedWindow("disp", cv::WINDOW_AUTOSIZE);
    cv::imshow("disp", output);
    cv::waitKey(0);

    return 0;
}
```

cv:: is a namespace prefix to avoid the conflicts of names of functions, types, variables etc. Do you feel they are annoying?

C++ namespace

```
#include "opencv2/opencv.hpp"

int main()
{
    using namespace cv;
    Mat input = imread("lena.jpg", IMREAD_GRAYSCALE);
    Mat output;

    threshold(input, output, 128, 255, THRESH_BINARY);

    namedWindow("disp", WINDOW_AUTOSIZE);
    imshow("disp", output);
    waitKey(0);

    return 0;
}
```

`using namespace` directive can be used for compact codes (but with higher risk of conflicts).

cv::Mat type

```
#include "opencv2/opencv.hpp"

int main()
{
    int thresh = 128, max = 255;
    cv::Mat input = cv::imread("lena.jpg", cv::IMREAD_GRAYSCALE);
    cv::Mat output;

    cv::threshold(input, output, thresh, max, cv::THRESH_BINARY);

    cv::namedWindow("disp", cv::WINDOW_AUTOSIZE);
    cv::imshow("disp", output);
    cv::waitKey(0);

    return 0;
}
```

`cv::Mat` is a class for a matrix or an image defined in OpenCV. `input` and `output` are instances of class `cv::Mat`, just as `thresh` and `max` are instances of type `int`.

C++ class

An extension to C struct:

```
struct MyComplexInt {
    int re;
    int im;
};

int main()
{
    struct MyComplexInt x;
    x.re = 10;
    x.im = 20;
}
```

C struct can have member variables

C++ class

```
class MyComplexInt {
public:
    int re;
    int im;
    double magnitude() {
        return sqrt(re * re + im * im);
    }
};

int main()
{
    MyComplexInt x;
    x.re = 10; x.im = 20;
    double mag = x.magnituide();
}
```

C++ class can also have member functions (methods).

C++ reference type

```
cv::Mat input = cv::imread("lena.jpg", cv::IMREAD_GRAYSCALE);
cv::Mat output;

cv::threshold(input, output, thresh, max, cv::THRESH_BINARY);
```

how is it possible to write to `output`?

```
void conjugate(MyComplexInt& a) {
    a.im = -a.im;
}

int main()
{
    MyComplex x;
    conjugate(x);
}
```

a becomes a reference (alias) to the real argument `x`, so `x` in the `main` becomes modified.

Thresholding Implementation Example

```
int main()
{
    int thresh = 128, max = 255;
    cv::Mat input = cv::imread("lena.jpg", cv::IMREAD_GRAYSCALE);
    int cols = input.cols, rows = input.rows;
    cv::Mat output(rows, cols, CV_8U);

    for (int j = 0; j < rows; j++) {
        for (int i = 0; i < cols; i++) {
            if (input.at<uchar>(j, i) >= thresh) {
                output.at<uchar>(j, i) = max;
            } else {
                output.at<uchar>(j, i) = 0;
            }
        }
    }

    ...
}
```

C++ constructor/destructor

```
class MyComplexInt {
public:
    MyComplexInt(int r, int i) { re = r; im = i; }
    MyComplexInt() { re = 0; im = 0; }
    ~MyComplexInt() { /* do nothing */ }
    int re;
    int im;
};

int main()
{
    MyComplexInt x(10, 20); // constructor called
} // destructor called
```

overloading is allowed

A constructor and destructor are called when an instance is generated and is expired, respectively, so that your library can do initialization and cleanup automatically (if needed).

C++ template

```
class MyComplexInt {
public:
    int re;
    int im;
};

class MyComplexDouble {
public:
    double re;
    double im;
};

class MyComplexUchar {
public:
    uchar re;
    uchar im;
};
...
```

Tedious!

C++ template

```
template<typename T>
class MyComplex {
public:
    T re;
    T im;
};

int main()
{
    MyComplex<int> x;
    MyComplex<uchar> y;
    MyComplex<double> z;
}
```

The compiler automatically does kind of copy&paste of codes.
Can be used not only for classes but for functions, methods, etc.

Now you make out …

```
cv::Mat output(rows, cols, CV_8U);
```

Constructor of cv::Mat is called with arguments rows, cols (rows × cols matrix), and CV_8U (8-bit unsigned).

```
for (int j = 0; j < rows; j++) {
    for (int i = 0; i < cols; i++) {
        if (input.at<uchar>(j, i) >= thresh) {
            output.at<uchar>(j, i) = max;
        } else {
            output.at<uchar>(j, i) = 0;
        }
    }
}
```

Template method `at` of class `cv::Mat` is called with template argument `uchar`. (to access the specified pixel value considering each pixel is 8-bit unsigned)

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Typical Image Processing Code (for video frames)

```
int main()
{
    cv::VideoCapture cap(0);
    cv::Mat input, output;
    cv::namedWindow("disp", cv::WINDOW_AUTOSIZE);

    while (1) {
        cap >> input;
        cv::cvtColor(input, input, CV_BGR2GRAY);
        cv::threshold(input, output, 128, 255, cv::THRESH_BINARY);
        cv::imshow("disp", output);
        if (cv::waitKey(30) > 0) {
            break;
        }
    }

    return 0;
}
```

0-th camera;
You can also specify a video filename here

wait for 30 ms at maximum.
If any key is hit within 30 ms, keycode is returned

C++ operator overload

```
class MyComplexInt {
public:
    int re;
    int im;
};

MyComplexInt operator+(MyComplexInt lhs, int rhs) {
    MyComplex ret;
    ret.x = lhs.x + rhs; ret.y = lhs.y;
    return ret;
}

int main()
{
    MyComplexInt x; x.re = 10; x.im = 20;
    MyComplexInt y = x + 5;
}
```

Summary

- Basic structure of image processing:
  - for a single frame
  - for a multiple (successive) frames
- Implementation examples in OpenCV

- Basic Concepts of C++:
  - namespace
  - class (constructor / destructor)
  - reference type
  - template
  - function overload, operator overload

References

- R. Szeliski: Computer Vision: Algorithms and Applications, Springer, 2010.
- A. Hornberg eds.: Handbook of Machine Vision, Wiley-VCH, 2006.
- G. Bradski and A. Kaebler: Learning OpenCV, O‘Reilly, 2008.
- OpenCV Documentation: http://docs.opencv.org/index.html

(in Japanese)
- ディジタル画像処理編集委員会, ディジタル画像処理, CG-ARTS協会, 2004.
- 田村: コンピュータ画像処理, オーム社, 2002.

Sample codes are in sample20140603.zip available at
http://www.ic.is.tohoku.ac.jp/~swk/lecture/