Computer Vision Systems Programming VO

Programming Languages and Libraries

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Topics

Characteristics of Computer Vision (CV) programming

- Implications on programming language choice

Which language is the best?

Overview of popular languages and libraries

- Matlab
- Python
- C++

Suggestions on language selection

Characteristics of CV Programming
Image Processing

We often start with Image Processing (IP)

- Resampling, normalization, color conversion
- Feature extraction

Involves operations on arrays / matrices

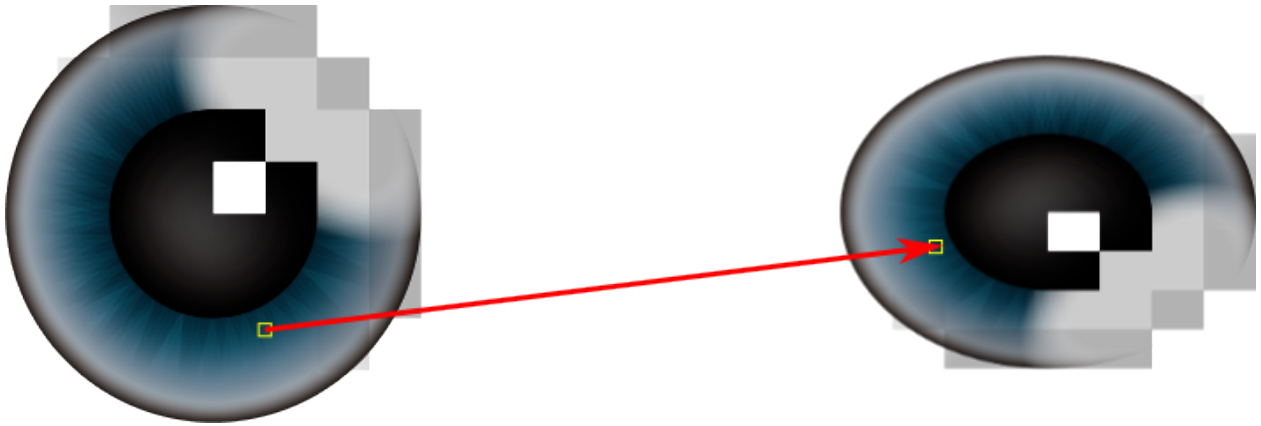
Many IP operations are local and sequential

- Favors languages with fast random access to pixels

Characteristics of CV Programming
Many IP Operations Are Local and Sequential

Image resampling is done independently for each pixel

Involves some form of local interpolation



Characteristics of CV Programming
Many IP Operations Are Local and Sequential

Local neighborhood operations such as linear filtering:

$$f'(x,y) = \sum_{i,j} f(x+i, y+j)\, h(i,j)$$

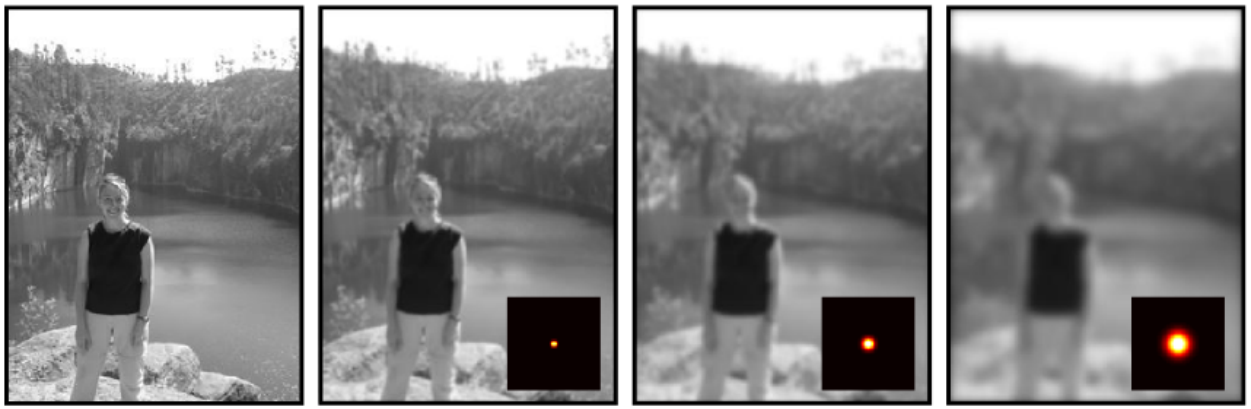


Image from Prince 2012

Characteristics of CV Programming
Numerical Computing

More generally, CV programming is all about numbers

Often, there are many of them

- BD stream: $\sim$ 50 million/sec
- Large optimization problems

Some languages are better at crunching numbers than others

- Faster, more memory-efficient

Characteristics of CV Programming
Does Speed and Efficiency Matter?

It depends!

- Researchers often don't care
- Companies usually do
- Sometimes there are hard constraints (cars, space missions)

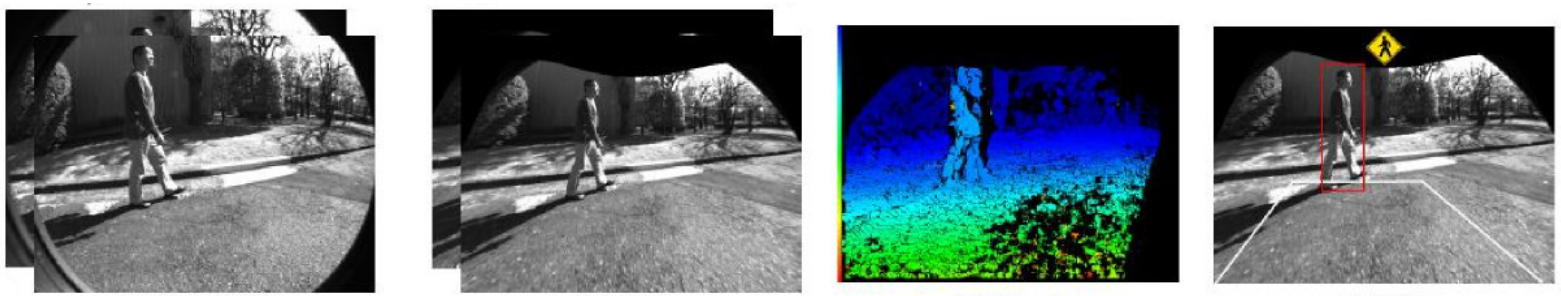


Image by Ryuzo Okada, Toshiba

Characteristics of CV Programming
Does Speed and Efficiency Matter?

Design choices can have a bigger impact than language

- Use appropriate data structures
- Utilize multiple CPU cores, GPUs

Language bottlenecks can be avoided by switching language

- Interpreted languages are slow “at the pixel level”
- Implement such parts in C, call from Matlab, Python
- Use higher-level functions (`mean`, `imfilter`)

Choosing a Programming Language

Other Factors

There are other important factors in language selection

- Ease of development (language features, libraries, IDEs)
- OS and platform support
- License fees

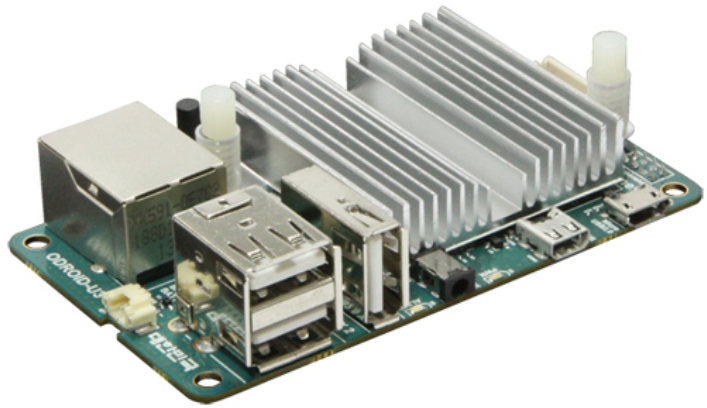


Image from pixhawk.org

Choosing a Programming Language

So there is no best language, it depends

- On the task at hand
- On the operating conditions

Let's take a look at some popular languages and libraries

Popular CV Programming Languages

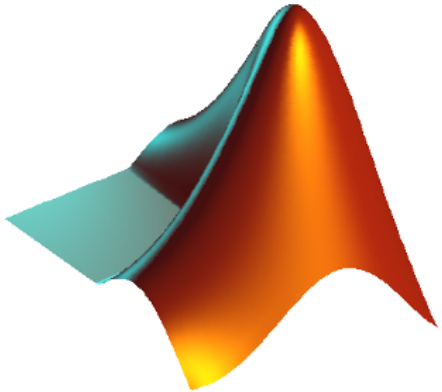


Image from matworks.de

Image from python.org

Image from cplusplus.se

Popular CV Programming Languages
Matlab

Numerical computing environment

Commercial software (student licenses)

Widely used in academics

Used in many courses at TU Wien

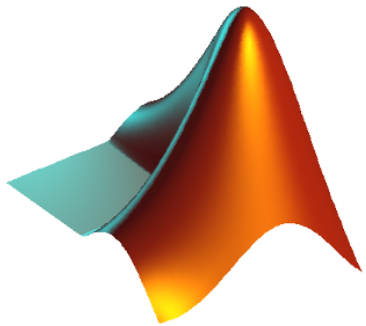


Image from matworks.de

Popular CV Programming Languages
Matlab

Pros

- Easy to learn and use
- Many high-quality toolboxes

Cons

- Not as fast/efficient from scratch as C++
- Commercial licenses are expensive
- Less suitable for general-purpose programming

Popular CV Programming Languages
Python

General-purpose programming language

Free and open source

No IP/CV functionality by default

But great open-source libraries

Image from python.org

Popular CV Programming Languages
Python

Pros

- Easy to learn and use
- Extensive standard library
- Free and open source

Cons

- Not as integrated as Matlab
- Not as fast/efficient from scratch as C++

Popular CV Programming Languages
Python – NumPy

Fundamental numerical computing library

Arrays and matrices

Linear algebra

Matrix decompositions

Fourier analysis

Image from github.com/numpy

Popular CV Programming Languages
Python – SciPy

Family of scientific computing packages

Optimization

Image processing

Statistics & density estimation

Image from scipy.org

Popular CV Programming Languages

Python – scikit-image

Image processing library

Image transforms

Image filtering

Feature extraction

Segmentation

Image from scikit-image.org

Popular CV Programming Languages

Python – scikit-learn

Comprehensive machine learning library

Classification

Regression

Clustering

Dimensionality reduction

Image from goodfind.jp

Popular CV Programming Languages

Python – Keras

Deep learning library

Multilayer Perceptrons

Convolutional Neural Networks

Recurrent Neural Networks

CPU and GPU using CUDA

Image from keras.io

Popular CV Programming Languages
Python – matplotlib

Graph plotting library

Surface, wireframe, scatter, bar plots

Matlab-like syntax

Image from matplotlib.org

Popular CV Programming Languages

C++

General-purpose programming language

Focus on performance and efficiency

No IP/CV functionality by default

But great open-source libraries

Image from cplusplus.se

Popular CV Programming Languages
C++

Pros

- Fast and memory-efficient
- Free and open source

Cons

- Harder to learn and master
- Slower and less convenient to code

Popular CV Programming Languages

C++ – OpenCV

Comprehensive IP/CV library

Designed for real-time applications

Matrices and linear algebra

Image transforms and filtering

Feature extraction and matching

Stereo, structure from motion

Machine learning

Matlab and Python bindings available

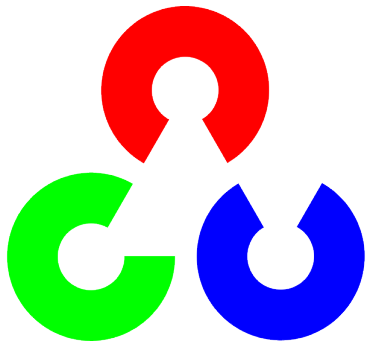


Image from opencv.org

Popular CV Programming Languages

C++ – Caffe

Deep learning library

Multilayer Perceptrons

Convolutional Neural Networks

CPU and GPU using CUDA

Trained models available (model zoo)

Used by e.g. Nvidia, Google

Matlab and Python bindings available

Popular CV Programming Languages

C++ – MathGL

Graph plotting library

Surface, wireframe, scatter, bar plots

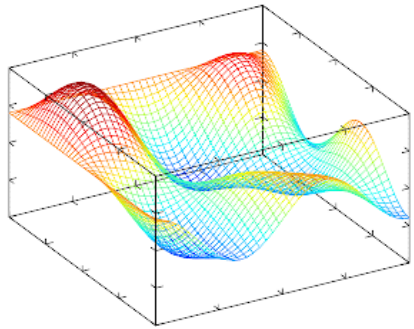


Image from

mathgl.sourceforge.net

Popular CV Programming Languages
Remarks

Comparable functionality

- Libraries for most CV tasks available
- This applies to other languages as well

Many libraries have language bindings

Code Comparison

Task is to load, blur, show, and save an image

Code Comparison

Matlab

```
img = imread('image.png'); % read
kernel = fspecial('gaussian', [5 5]); % blur
blur = imfilter(img, kernel); % blur
imshow(blur); % display
pause(5); % wait
imwrite(blur, 'blur.png'); % save
```

Code Comparison

Python with scikit-image

```
img = skimage.io.imread('image.png') # read
blur = skimage.filter.gaussian_filter(img, sigma=1.7) # blur
skimage.io.imshow(blur) # display
skimage.io.show() # wait
skimage.io.imsave('blur.png', blur) # save
```

Code Comparison
C++ with OpenCV

```cpp
cv::Mat img = cv::imread("image.png"); // read
cv::Mat blur; // blur
cv::GaussianBlur(img, blur, cv::Size(5, 5), 0); // blur
cv::imshow("blur", blur); // display
cv::waitKey(0); // wait
cv::imwrite("blur.png", blur); // save
```

Code Comparison

Similar programming effort in the example case

For many larger CV tasks

- Matlab requires least effort
- Closely followed by Python
- Not so closely followed by C++

Depends on the problem of course

- Libraries available?

Language Comparison

In summary, the discussed languages

- Differ in terms of execution speed and memory-efficiency
- Provide comparable CV programming functionality via libraries
- Differ in ease of development, licensing fees

So, to conclude

- There is no best CV language
- Different tasks favor different languages

Suggestions on Language Selection

Know the strengths and weaknesses of different languages

Be proficient in more than one language

- Allows you to select appropriate language for task at hand
- E.g. prototype in Matlab/Python, ship in C++

Learn C++

- Modern C++ is not a bad language if used correctly
- Some real-time applications require its speed and efficiency
- Many companies use it

Bibliography

Prince, S.J.D. (2012). *Computer Vision: Models Learning and Inference*. Cambridge University Press.