

# 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

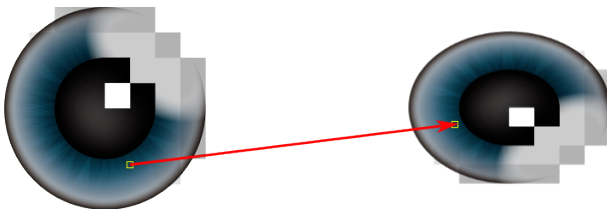
- ▶ Favors languages with fast random access to pixels

# 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:

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

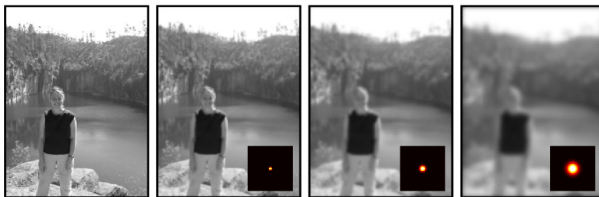


Image from Prince 2012

# 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)

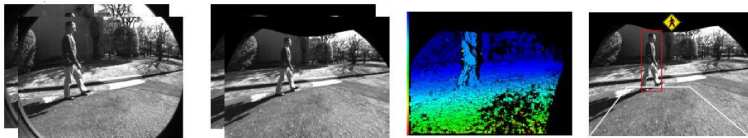


Image by Ryuzo Okada, Toshiba

# 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

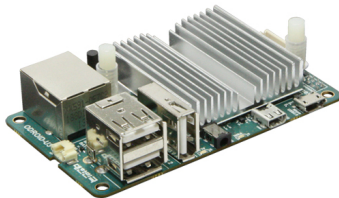


Image from [pixhawk.org](http://pixhawk.org)

# 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

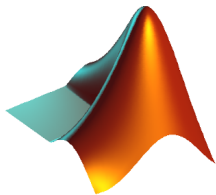


Image from [matworks.de](http://matworks.de)



Image from [python.org](http://python.org)



Image from [cplusplus.se](http://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

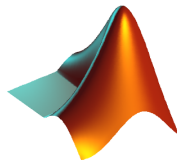


Image from [matworks.de](http://matworks.de)

# 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](https://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](https://github.com/numpy)



# Popular CV Programming Languages

Python – SciPy

Family of scientific computing packages

Optimization

Image processing

Statistics & density estimation



Image from [scipy.org](http://scipy.org)

# Popular CV Programming Languages

Python – scikit-image

Image processing library

Image transforms

Image filtering

Feature extraction

Segmentation



Image from [scikit-image.org](https://scikit-image.org)

# Popular CV Programming Languages

Python – scikit-learn

Comprehensive machine learning library

Classification

Regression

Clustering

Dimensionality reduction



# 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](https://keras.io)

# Popular CV Programming Languages

Python – matplotlib

Graph plotting library

Surface, wireframe, scatter, bar plots

Matlab-like syntax



Image from [matplotlib.org](http://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](http://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





# 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

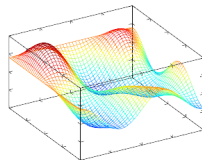


Image from

[mathgl.sourceforge.net](http://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

```
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

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