

# Computer Vision Systems Programming VO

## Programming Languages and Libraries

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# Topics

## Characteristics of Computer Vision (CV) programming

- ▶ Implications on 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

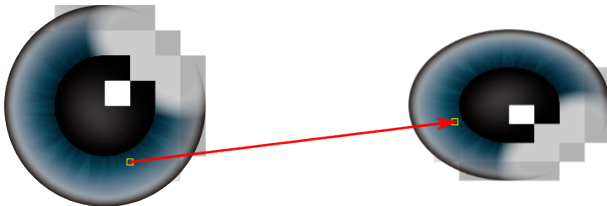
Many IP operations are local and sequential

- ▶ Favors languages with fast random access to pixels

# Characteristics of CV Programming

Many IP Operations are Local and Sequential

Resampling is independent for each pixel  
Usually involves some form of interpolation



# Characteristics of CV Programming

Many IP Operations are Local and Sequential

Local neighborhood operators such as linear filtering:

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

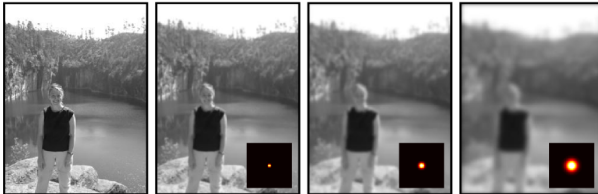


Image from [1]

# 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 (e.g. bundle adjustment)

<https://www.youtube.com/watch?v=HrgHFDPJHXo>

Some languages are better at crunching numbers than others

- ▶ Faster, more memory-efficient

# Characteristics of CV Programming

Does efficiency matter?

But does efficiency matter?

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

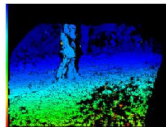


Image by Ryuzo Okada, Toshiba

# Characteristics of CV Programming

Does efficiency matter?

## It depends

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

- ▶ Implement parts in C, call from Matlab, Python



# Choosing a Programming Language

In summary, efficiency is often of little concern

There are other factors:

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

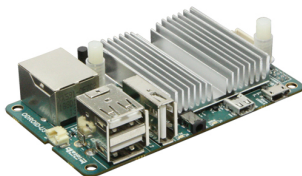


Image from [pixhawk.org](http://pixhawk.org)

# Choosing a Programming Language

**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

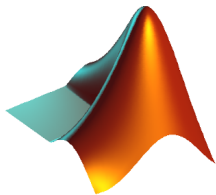


Image from [matworks.de](http://matworks.de)



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

- ▶ You probably already know it

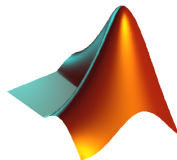


Image from [matworks.de](http://matworks.de)

# 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:

- ▶ NumPy
- ▶ SciPy, scikit-image
- ▶ scikit-learn
- ▶ matplotlib



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





# 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 – matplotlib

Graph plotting library

Surface, wireframe, scatter, bar plots

Matlab-like syntax



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

- ▶ OpenCV
- ▶ Shark, Caffe
- ▶ MathGL



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



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

# Popular CV Programming Languages

C++ – Shark, Caffe

Machine learning libraries

Optimization

Regression

Classification

Dimensionality reduction

Deep learning



Image from [image.diku.dk](http://image.diku.dk)



# Popular CV Programming Languages

C++ – MathGL

Graph plotting library

Surface, wireframe, scatter, bar plots

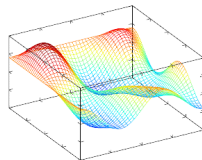


Image from  
[mathgl.sourceforge.net](http://mathgl.sourceforge.net)

# Popular CV Programming Languages

## Remarks

### Comparable functionality

- ▶ There are libraries for most CV tasks in all these languages
- ▶ This applies to other languages as well

### Many libraries have language bindings

- ▶ Python and Matlab bindings for OpenCV

# Language Comparison

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

# Language Comparison

## Matlab

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

# Language 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) # show
skimage.io.show() # show
skimage.io.imsave('blur.png', blur) # save
```

# Language 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); // show
cv::waitKey(0); // show
cv::imwrite("blur.png", blur); // save
```

# Language Comparison

Similar programming effort in the example case

For many larger CV tasks:

- ▶ Matlab requires least effort
- ▶ Closely followed by Python
- ▶ No so closely followed by C++

# 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

Learn C++

- ▶ Modern C++ is not a bad language if used correctly
- ▶ Many companies rely on it

- [1] S.J.D. Prince. **Computer Vision: Models Learning and Inference**. Cambridge University Press, 2012.