Face detection in Go and Webassembly

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About me

I am ...

- Software developer and open source enthusiast, tackling with image processing, computer vision, machine learning and procedural graphics as side projects
- I like the clean and readable code
- Performance and code optimization addict
- I consider the concurrency communication model (CSP) the most appealing parts of the Go language

Agenda

- About me
- What is Pigo?
- Key features
- Technical overview
- Pigo and GoCV (OpenCV) comparision
- Pupils/eyes localization
- Facial landmark points detection
- Use cases and integrations
- Pigo as a shared library
- Porting Pigo to Webassembly (WASM)
- Demo time
- What's next?

What is Pigo?

What is Pigo?

- Computer vision and machine learning library for face detection, pupils/eyes localization and facial landmark points detection
- The only face detection library in the Go ecosystem developed 100% in Go
- The implementation is based on *Pixel Intensity Comparison-based Object detection* paper

Why it has been developed?

- All of the existing face detection libraries developed in Go are actually bindings (wrappers) around some C/C++ libraries
- Bindings (using the cgo) most of the times are not cost effective
- Compiling a C library to Go results in slower build times
- Cross compilation is almost impossible
- The desire of a single binary file is just a desire
- Installing OpenCV sometimes can be daunting
- OpenCV is huge, impossible to deploy it on small platforms where space constraints are important

Key features

What are the benefits of using Pigo over other existing solutions? Just to name a few of them:

- Very lightweight, no requirements for 3rd party modules and external libraries
- Platform independent, one single executable
- Simple and elegant API
- High processing speed
- There is no need for image preprocessing prior detection
- The face detection is based on pixel intensity comparison encoded in the binary file tree structure
- Fast detection of in-plane rotated faces
- Pupils/eyes localization
- Facial landmark points detection

Technical overview

Technical overview

- **Pigo**, like the **Viola Jones** face detection algorithm is also constructed around cascade decision trees, but the cascade classifier is in binary format
- The role of a classifier is to tell if a face is present in the current region or not
- The classifier consists of a decision tree, where the results of pixel intensity comparison test are in binary format.
- Because the cascades are encoded into a binary tree structure they first need to be unpacked.

Upacking steps

- Read the depth of each tree and write it into the buffer array.
- Retrieve the number of stages and write it into the buffer array.
- Obtain the scale multiplier (applied after each stage) and write it into the buffer array.
- Obtain the number of trees per stage and write it into the buffer array.
- Obtain the depth of each tree and write it into the buffer array.
- Traverse all the stages of the binary tree
- Read prediction from tree's leaf nodes.

Unpacking the result

In the end we should get a cascade with the following structure:

```
return &PuplocCascade{
    stages:    stages,
    scales:    scales,
    trees:     trees,
    treeDepth: treeDepth,
    treeCodes: treeCodes,
    treePreds: treePreds,
}, nil
```

Classify regions

Next we classify the regions based on the parsed binary data.
For classification we are using a simple pixel intensity comparision test in binary format.

```
bintest := func(px1, px2 uint8) int {
    if px1 <= px2 {
        return 1
    }
    return 0
}
idx = 2*idx + bintest(pixels[x1], pixels[x2])
```

The `idx` will be the index in the prediction tree.
Note: for in plane rotated faces we are applying the same formula only that we are calculating the rotation angle.

Run cascade

- An image region is considered being face if it passes all the cascade members. Since this process is limited to a relatively small number of regions, this gains high computation speed.
- During the decision tree scanning each detection is flagged with a detection score.
- An image region is considered as face if the detection score is above a certain threshold ($\sim$**0.995**)
- The detector function will return a struct with the following structure

```
// Detection struct contains the detection results composed of
// the row, column, scale factor and the detection score.
type Detection struct {
    Row   int
    Col   int
    Scale int
    Q     float32
}
```

Cluster detection

- Due to the noisiness of the underlying pixel data, the detector might produce overlaps in detections.

- The cascade regions are clustered together by aplying an **IoU** (Intersection over Union) formula over the detection results.

The intersection over union method

```
sort.Sort(det(detections))

calcIoU := func(det1, det2 Detection) float64 {
    // Unpack the position and size of each detection.
    r1, c1, s1 := float64(det1.Row), float64(det1.Col), float64(det1.Sc
    r2, c2, s2 := float64(det2.Row), float64(det2.Col), float64(det2.Sc

    overRow := math.Max(0, math.Min(r1+s1/2, r2+s2/2)-math.Max(r1-s1/2,
    overCol := math.Max(0, math.Min(c1+s1/2, c2+s2/2)-math.Max(c1-s1/2,

    // Return intersection over union.
    return overRow * overCol / (s1*s1 + s2*s2 - overRow*overCol)
}
```

API usage

- Simple and elegant API
- Easy integration, cross platform interoperability
- Posibility to export the detection results to a JSON file
- Pipeline support

```
// Initialize the cascade parameters
cParams := pigo.CascadeParams{
    MinSize:     20,
    MaxSize:     1000,
    ShiftFactor: 0.1,
    ScaleFactor: 1.1,

    ImageParams: pigo.ImageParams{
        Pixels: pixels,
        Rows:   rows,
        Cols:   cols,
        Dim:    cols,
    },
}
```

API usage

```
pigo := pigo.NewPigo()
// Unpack the binary file. This will return the number of cascade trees
// the tree depth, the threshold and the prediction from tree's leaf no
classifier, err := pigo.Unpack(cascadeFile)
if err != nil {
    log.Fatalf("Error reading the cascade file: %s", err)
}

angle := 0.0 // cascade rotation angle. 0.0 is 0 radians and 1.0 is 2*p

// Run the classifier over the obtained leaf nodes and return the detec
// The result contains quadruplets representing the row, column, scale
dets := classifier.RunCascade(cParams, angle)

// Calculate the intersection over union (IoU) of two clusters.
dets = classifier.ClusterDetections(dets, 0.2)
```

- dets will return the coordinates of the detected faces, eyes and landmark points depending on the provided parameters

{"face":{"x":422,"y":336,"size":483},"eyes":[{"x":378,"y":267,"size":39

End result

Pigo and GoCV (OpenCV) comparision

Benchmark results

```
BenchmarkGoCV-4                3      414122553 ns/op          704 B/op
BenchmarkPIGO-4               10      173664832 ns/op            0 B/op
PASS
ok      github.com/esimov/gocv-test    4.530s
```

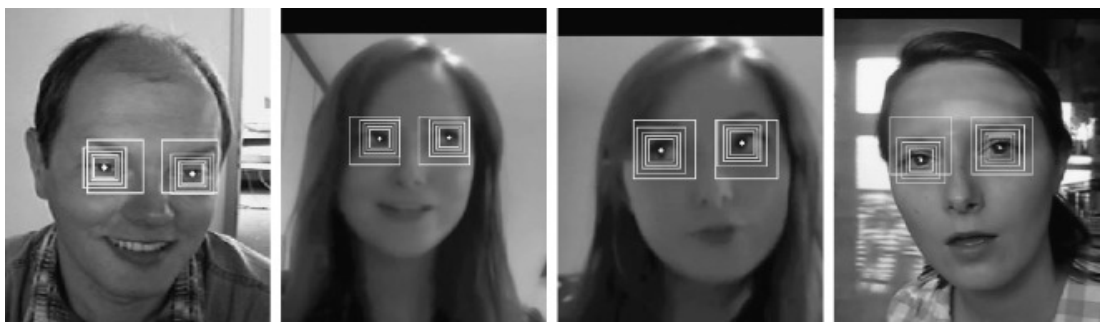
github.com/esimov/pigo-gocv-benchmark

Pupils/eyes localization

Pupils/eyes localization

Short overview

- The implementation pretty much resambles with the face detection method but with few remarkable differences.
- As on the face detection, the detection is based on the same pixel intensity binary test.
- The output of the regression trees might be noisy
- We introduce a random perturbation factor during runtime to outweigh the false positive rates on detection



- After the face region has been classified we sort the perturbations in ascendant order.

Left/right face detection

Same formula for left and rigth eye detection. The sign is flipped on the right eye.

```
// left eye
puploc = &pigo.Puploc{
    Row:      face.Row - int(0.075*float32(face.Scale)),
    Col:      face.Col - int(0.175*float32(face.Scale)),
    Scale:    float32(face.Scale) * 0.25,
    Perturbs: perturb,
}

// right eye
puploc = &pigo.Puploc{
    Row:      face.Row - int(0.075*float32(face.Scale)),
    Col:      face.Col + int(0.185*float32(face.Scale)),
    Scale:    float32(face.Scale) * 0.25,
    Perturbs: perturb,
}
```

Facial landmark points detection

Facial landmark points detection

Detection method

- The landmark points are detected based on the results returned by the pupil localization function

```
dist1 := (leftEye.Row - rightEye.Row) * (leftEye.Row - rightEye.Row)
dist2 := (leftEye.Col - rightEye.Col) * (leftEye.Col - rightEye.Col)
dist := math.Sqrt(float64(dist1 + dist2))

row := float64(leftEye.Row+rightEye.Row)/2.0 + 0.25*dist
col := float64(leftEye.Col+rightEye.Col)/2.0 + 0.15*dist
scale := 3.0 * dist

flploc = &Puploc{
    Row:      int(row),
    Col:      int(col),
    Scale:    float32(scale),
    Perturbs: perturb,
}
```

Compute the right landmark points

This can be achieved by:
1.) flipping the sign of the column coordinate in tree nodes

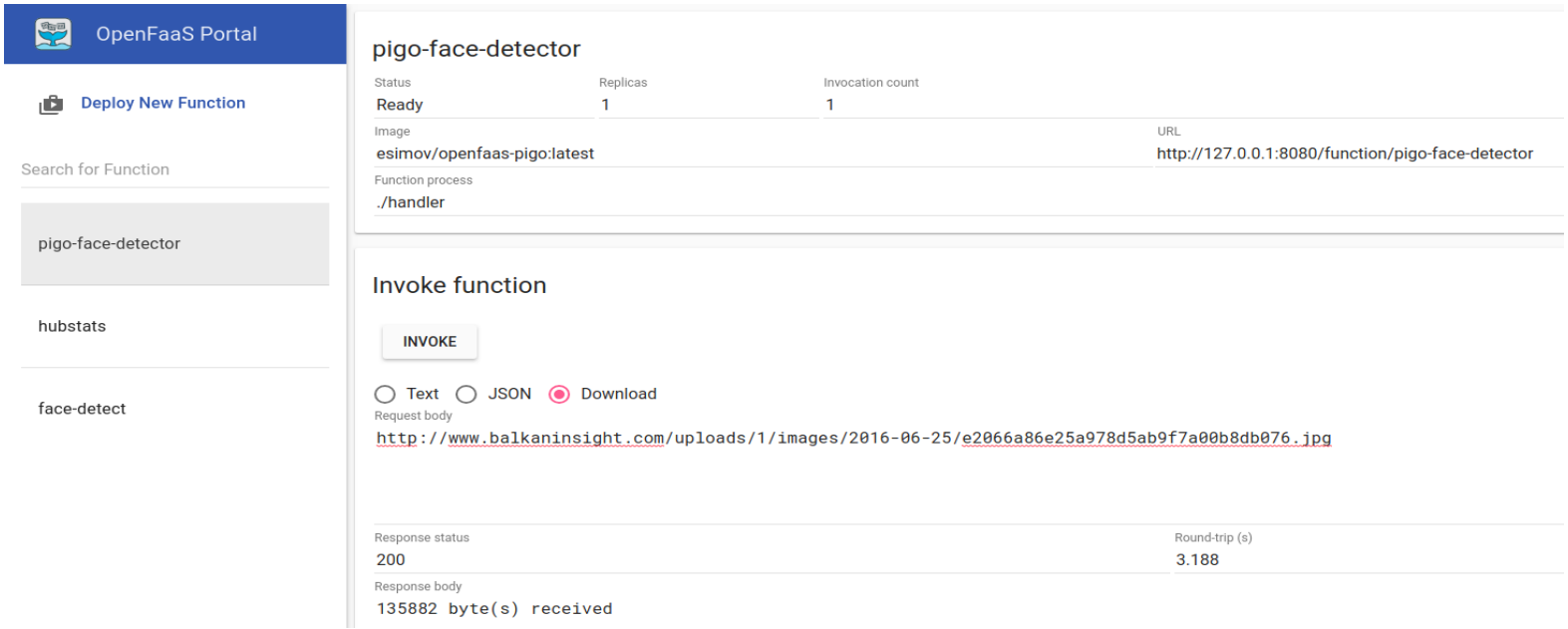
```
if flipV {
    c1 = min(ncols-1, max(0, (256*int(c)+int(-plc.treeCodes[root+4*idx+
    c2 = min(ncols-1, max(0, (256*int(c)+int(-plc.treeCodes[root+4*idx+
} else {
    c1 = min(ncols-1, max(0, (256*int(c)+int(plc.treeCodes[root+4*idx+1
    c2 = min(ncols-1, max(0, (256*int(c)+int(plc.treeCodes[root+4*idx+3
}
```

2.) flipping the sign in the column coordinate for each binary test

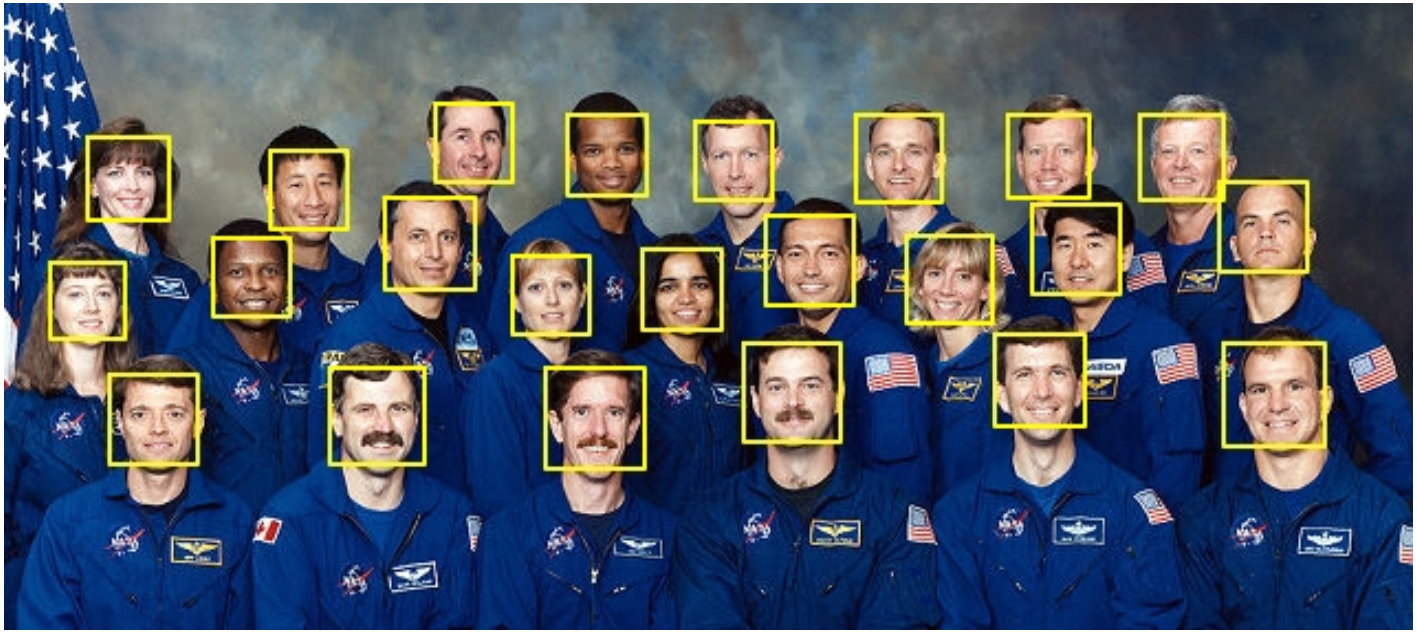
```
if flipV {
    dc += -plc.treePreds[lutIdx+1]
} else {
    dc += plc.treePreds[lutIdx+1]
}
```

Use cases and integrations

OpenFaaS integration

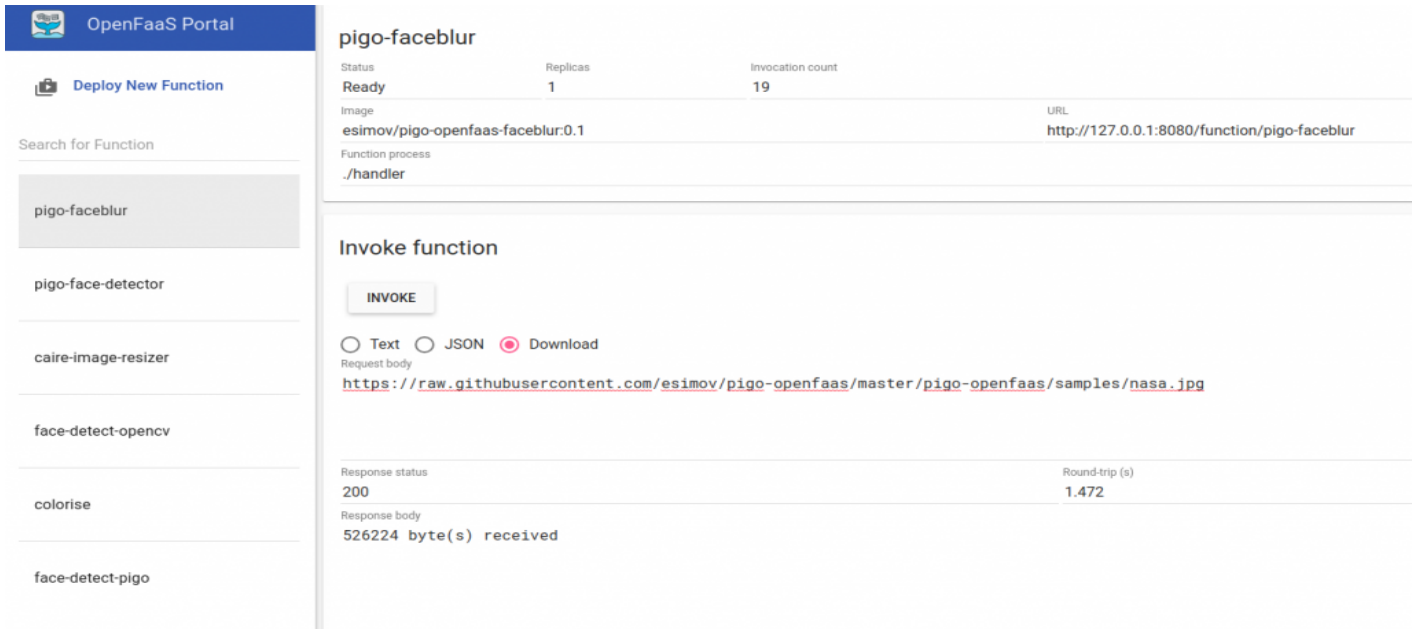


OpenFaaS integration



github.com/esimov/pigo-openfaas

OpenFaaS intergation



OpenFaaS integration

github.com/esimov/pigo-openfaas-faceblur
github.com/esimov/stackblur-go

Other integration

Original image	With face detection	Without face detection
		

Avoiding face deformation in Caire
github.com/esimov/caire

Pigo as a shared library

Running the face detector from Python as shared library

- Go is missing a well founded and generally available webcam library
- The idea is to transfer the Go face detection results to Python as a shared object (`.so`) library
- A few things we need to take care:

```
The exported function should be annotated with the //export statement.
The source must import the pseudo C package.
An empty main function should be declared.
The package must be a main package.
```

- In Python the **Ctype** library is used to interoperate with the Go code through **cgo**
- It provides C compatible data types, and allows calling functions in DLLs or shared libraries.

Limitations

- In Go is not possible transfer a 2D array as an array pointer.
- The trick is to convert the 2D array to a 1D array.

```
|-> delimit each detection group
|-> introduce as a first slice element the number of detected faces
```

- Using the **numpy** library we transform it to the desired shape.
- In the end we should obtain something like below:

```
[2 0 0 0 0 272 297 213 41 1 248 258 27 41 0 248 341 27 41 0 238 599 72
```

where the first value represents the number of detected faces and the rest are the **x**, **y** position and the **scale** factor

Transfer the detection result from Go to Python

```
go func() {
    // Since in Go we cannot transfer a 2d array trough an array pointe
    // we have to transform it into 1d array.
    for _, v := range result {
        det = append(det, v...)
    }
    // Include as a first slice element the number of detected faces.
    // We need to transfer this value in order to define the Python arr
    det = append([]int{len(result), 0, 0}, det...)

    // Convert the slice into an array pointer.
    s := *(*[]uint8)(unsafe.Pointer(&det))
    p := uintptr(unsafe.Pointer(&s[0]))

    // Ensure ‘det‘ is not freed up by GC prematurely.
    runtime.KeepAlive(det)

    // return the pointer address
    pointCh <- p
}()
return <-pointCh
```

Some caveats

- The cost using cgo can be substantial
- C and Go exists in two different universe, they interoperate through cgo. This is not costs effective.
- The C compiler has to be invoked for every C file in the package.
- Slower build times
- Ctype introduce another latency factor

Porting Pigo to Webassembly (WASM)

Motivation

- Running Pigo in Python as shared object does not showed the library pure performance
- Webassembly is an emerging technology targeting the web browser and bringing almost native like performance
- Many low level languages are already offer support for WASM (C, C++, Rust, Go etc.)
- More and more projects are getting ported to WASM
- Go already offer good Webassembly support trough the **syscall/js** package
- Go **v1.11** was the first version targeting WASM
- The API has gone through some refactorings and improvements to be stable starting from **v1.13**

Considerations to keep in mind

- To access a Javascript global variable in Go you have to call the **js.Global()** function.
- Use the **Call()** function in Go in order to call a JS method.
- To get or set an attribute of a JS object or Html element we can call the **Get()** or **Set()** functions.
- *The JavaScript callback functions should always be invoked inside a goroutine , otherwise you will encounter deadlock*
- The JS methods need to be used for fetching a file. The standard **io** package is not usable here.
- In order to compile for Webassambly we need to explicitly specify and set the **GOOS=js** and **GOARCH=wasm** environment variables on the building process

```
$ GOOS=js GOARCH=wasm go build -o lib.wasm wasm.go
```

Building the wasm file

We need to use the following build constraint

```
// +build js,wasm*
```

The **Render()** method will call the underlying JS render method:

```
// +build js,wasm

package main

import (
    "github.com/esimov/pigo/wasm/canvas"
)

func main() {
    c := canvas.NewCanvas()
    webcam, err := c.StartWebcam()
    if err != nil {
        c.Alert("Webcam not detected!")
    } else {
        webcam.Render()
    }
}
```

The Render() method:

```
func (c *Canvas) Render() {
    var data = make([]byte, c.windowSize.width*c.windowSize.height*4)
    c.done = make(chan struct{})

    if err := det.UnpackCascades(); err == nil {
        c.renderer = js.FuncOf(func(this js.Value, args []js.Value) int
            go func() {
                width, height := c.windowSize.width, c.windowSize.heigh
                c.reqID = c.window.Call("requestAnimationFrame", c.rend
                c.ctx.Call("drawImage", c.video, 0, 0)
                rgba := c.ctx.Call("getImageData", 0, 0, width, height)

                uint8Arr := js.Global().Get("Uint8Array").New(rgba)
                js.CopyBytesToGo(data, uint8Arr)
                pixels := c.rgbaToGrayscale(data)
                res := det.DetectFaces(pixels, height, width)
                c.drawDetection(res)
            }()
            return nil
        })
        c.window.Call("requestAnimationFrame", c.renderer)
        <-c.done
    }
```

Calling the WASM file

The WASM file can be referenced in the main html file.

```
<script type="text/javascript">
    function fetchAndInstantiate(url, importObject) {
        return fetch(url).then(response =>
            response.arrayBuffer()
        ).then(bytes =>
            WebAssembly.instantiate(bytes, importObject)
        ).then(results =>
            results.instance
        );
    }
    var go = new Go();
    var mod = fetchAndInstantiate("lib.wasm", go.importObject);
    window.onload = function () {
        mod.then(function (instance) {
            go.run(instance);
        });
    };
</script>
```

wasm_exec.js

- Incompatibilities between Go versions
- Different Go versions have different **wasm_exec.js** file
- Copy the wasm_exec.js file from **$GOROOT** on the fly.

```
wasm:
    cp -f "$$(go env GOROOT)/misc/wasm/wasm_exec.js" ./js/
    GOOS=js GOARCH=wasm go build -o lib.wasm wasm.go
```

Demo time

- New repository exists to showcase WASM demos using the Pigo libray (this is continuously updated)

`github.com/esimov/pigo-wasm-demos`

Demo showcase

What's next?

- Image features detection and matching (to detect similarities inside images)
- This can be a starting point for facial recognition