

# Face Detector

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Hello! This project is intended to be the final project for "2D Image Processing" course.

## Build

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Let's start from the basics. You need to build the project in order to try it out yourself.

A few prerequisites should be met beforehand:

- C++ 17 compiler installed, check out [this guide](#) to verify your compiler;
- OpenCV installed and configured to work with CMake: if not, please, [check out this guide](#);
- You have stable Internet connection as [CMake needs to download dlib library](#)

If everything is ready to go I am happy to proceed to the building stage. You need to navigate to the [Project](#) folder and run the following chain of commands:

```
mkdir build  
cd build  
  
cmake ..  
make -j7
```

Once is done, you should see `bin` directory inside your `build` folder. Please, do verify that the `bin` folder has an executable file and a few additional files: `dlib_face_recognition_resnet_model_v1.dat`, `haarcascade_frontalface_alt.xml`, `haarcascade_frontalface_alt2.xml`, `haarcascade_frontalface_default.xml`, `haarcascade_lefteye_2splits.xml`, `haarcascade_lefteye_2splits.xml`, and `shape_predictor_68_face_landmarks.dat`. If for some reason the files are not there you need to copy them into the `bin` directory from `misc`.

Hooray! You're ready to start using the app.

P.S.: to run the program you need to navigate to the `bin` folder.

```
cd bin
```

## Data

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I will briefly introduce the data before showing how to work with the app through your CLI.

I gathered photos of 10 actors for further classification:

- [Rowan Atkinson](#)
- [Emilia Clarke](#)
- [Sacha Baron Cohen](#)
- [Benedict Cumberbatch](#)
- [Martin Freeman](#)
- [Nick Frost](#)
- [Keira Knightley](#)
- [Hugh Laurie](#)

- [Andrew Lincoln](#)
- [Simon Pegg](#)

You can find data for training inside [Samples/Training](#) .

To test the quality I am using annotated video samples. Videos capture the same actors as actors above and contain some other people. Moreover, a few videos under the `unknown` folder predominantly contain people from the outside of the training set. You can find data for testing under [Samples/Test](#) .

Overall, the data follows principles from [Open Set Face Recognition](#).

P.S.: All the data is used for research purposes only. I believe that this case qualifies as [fair usage](#) and obey the UK copyright law. If you have any concerns, please, contact me using my email or opening an issue in the repository.

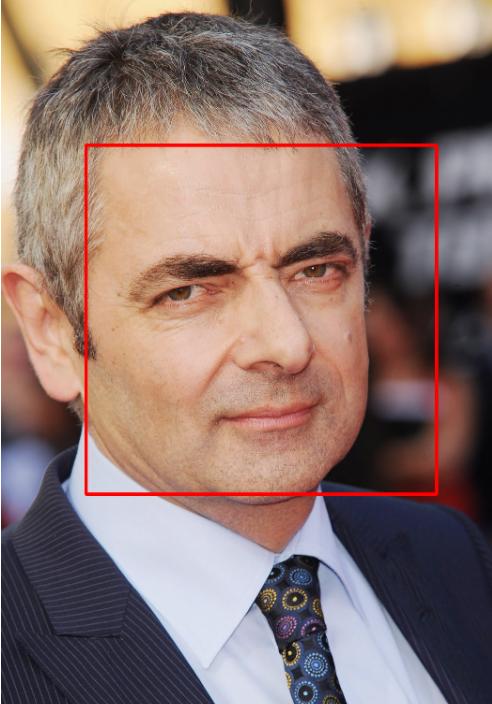
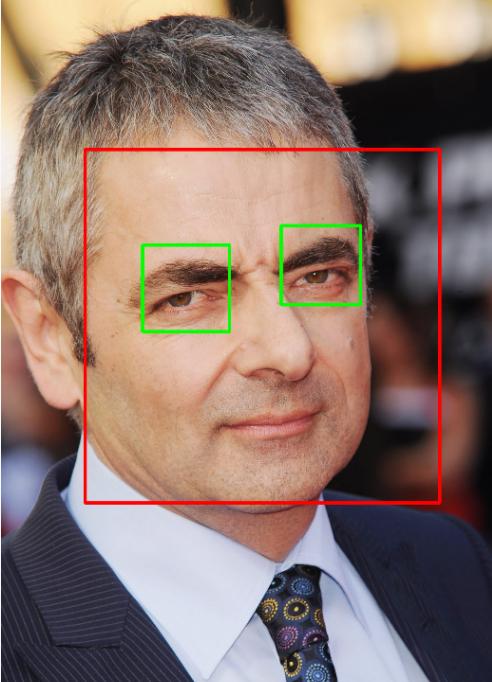
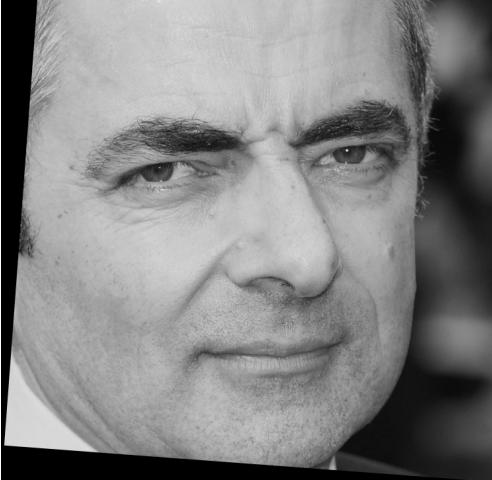
## Preparing dataset

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I made data pre-processing prior training the model.

Pre-processing can be represented in a few steps:

Step	Image	Description
0. Scan		Scan the image from the <a href="#">Samples</a> folder.
1. Greyscale		Convert the image to greyscale to reduce amount of information.

Step	Image	Description
2. Find faces		Extract faces from the image using any face detector.
3. Detect eyes		If applicable, detect eyes on within found faces and rotate them using a sample idea: left and right eyes' centers should be approximately on the same line.
4. Save		Save extracted faces to your disk.

Step	Image	Description
5. Validate		Discard invalid faces: bad image quality, extreme rotation angle, and so on.

You can find pre-processed data under the `TrainSet` folder.

This step can be performed automatically ✨ by using the command below:

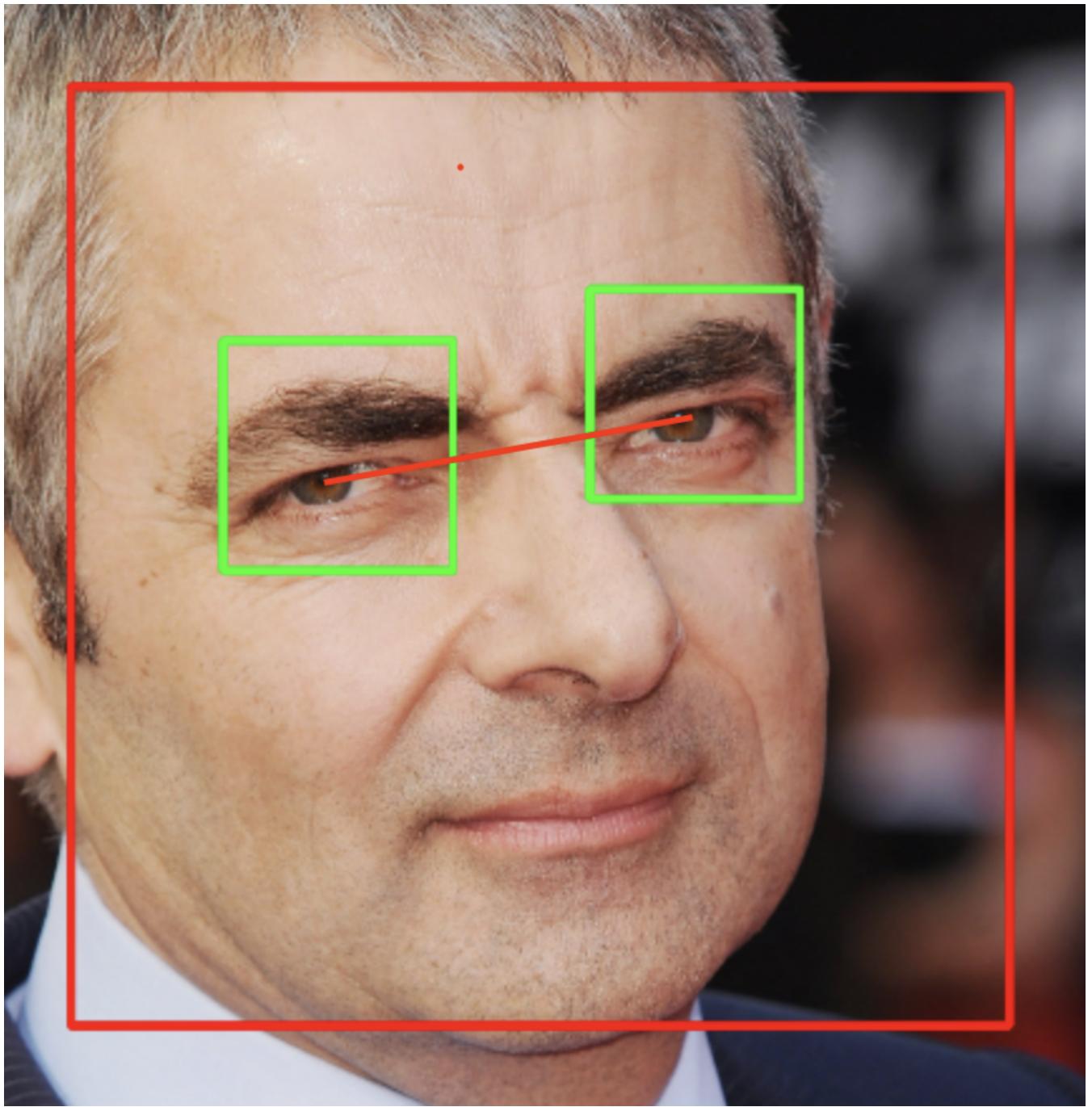
```
./FaceDetector ../../Samples/Training/atkinson --dataset -o ../preprocessing_results [-d]
```

The command accepts a list of image files and/or folder containing image files as the first parameter immediately followed by `--dataset` flag that specifies the mode. Although this arguments are making a complete command you can also find useful a few extra flags:

Argument	Optional	Description
<code>-o</code>	<input checked="" type="checkbox"/>	<i>Output folder</i> : specifies the final directory for output images. All images will be named in the following order `*original file name*face*id of a face*`.
<code>-d</code>	<input checked="" type="checkbox"/>	<i>Debug flag</i> : if specified then the app displays detected face on the image.

Note: I am using face detection at this step therefore I want to give you a heads-up about the face detection stage and face "normalisation" logic under the hood.

## Face rotation explained



To rotate the image back to the "normal" position we need to find an angle between the horizontal-axis and the line connecting two eyes' centers.

The angle can be calculated using school math ideas:

$$\text{angle} = \arctan\left(\frac{dy}{dx}\right)$$

where

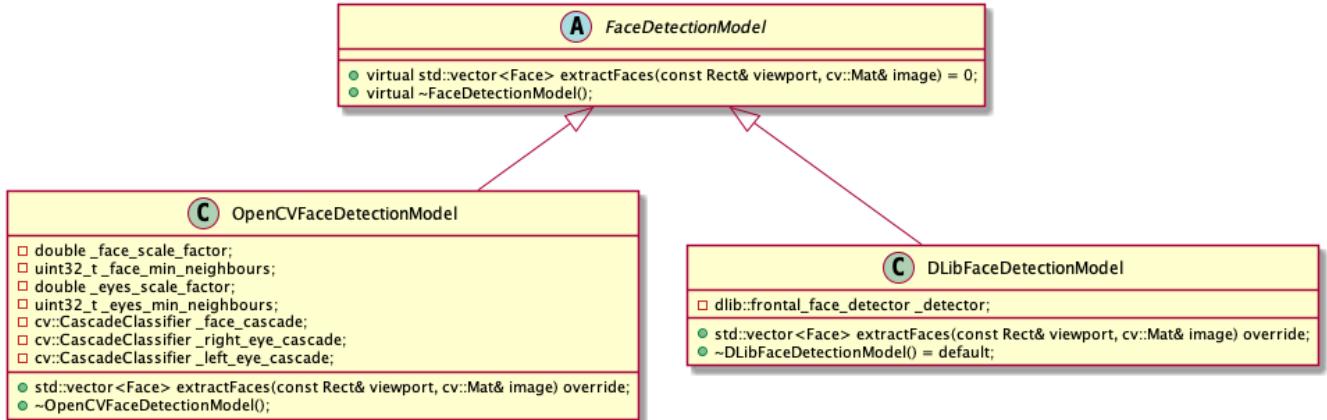
$$dx = |\text{left\_eye.x} - \text{right\_eye.x}|$$

and

$$dy = |\text{left\_eye.y} - \text{right\_eye.y}|$$

You can find the corresponding code in [OpenCVFaceDetectionModel](#).

## A brief implementation overview



The base class `FaceDetectionModel` abstracts different approaches to face detection:

- `OpenCVFaceDetectionModel` uses Haar-like features cascade classifier. Moreover, the class accepts face cascades files in a constructor to provide more flexibility in trying different classifiers;
- `DLibFaceDetection` uses HOG-based classifier and allows to detect sides of the face in addition to frontal face detection. It seems like a more powerful technique but usually comes with additional performance overhead.

## Different approaches comparison

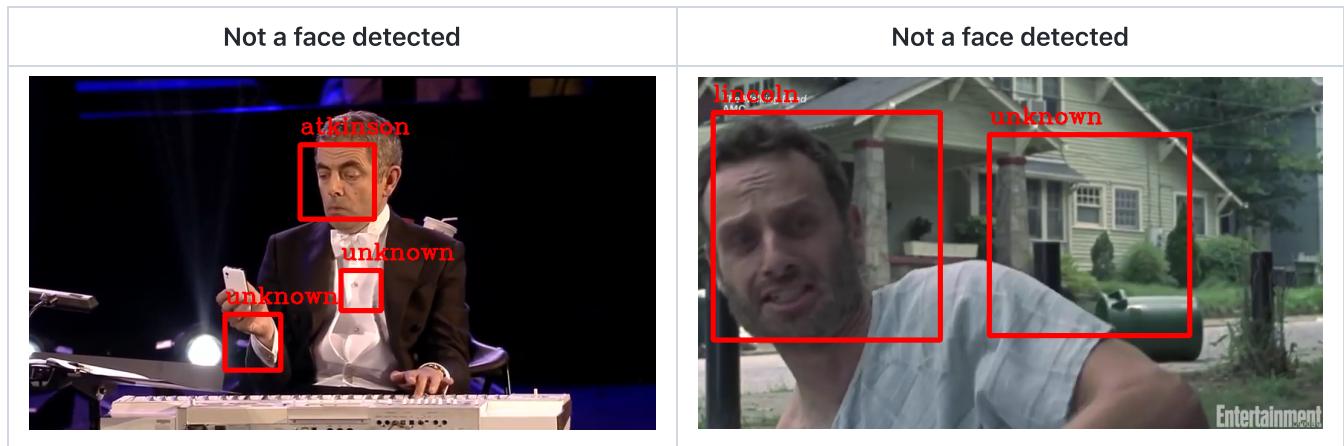
Classifier: `OpenCVFaceDetectionModel + haarcascade_frontalface_default.xml`

Pros:

- Fast: definitely can work in runtime

Cons:

- Classifier has a lot of false-positive detections, therefore not accurate



Metric	Score
Recall	~0.846

Classifier: `OpenCVFaceDetectionModel + haarcascade_frontalface_alt.xml`

Pros:

- Fast: can work in runtime
- Detects much less false-positive faces

Cons:

- Still has some false-positive detections
- Detects fewer faces: sometimes ignores the face that looks visible and just fine

Face was not detected	Not a face detected

Metric	Score
Recall	~0.828

Classifier: `OpenCVFaceDetectionModel` + `haarcascade_frontalface_alt2.xml`

Pros:

- Fast: can work in runtime
- Detects more faces than `frontalface_alt`
- Detects more false-positive faces than `frontalface_alt` but fewer than `default` classifier

Cons:

- Has some false-positive detections
- Sometimes does not detect faces as the `frontalface_alt` but amount of undetected faces is a bit smaller

Not a face detected	Face was not detected

Metric	Score
Recall	~0.884

Classifier: `DLibFaceDetectionModel`

Pros:

- Still can work in runtime but works slower than the other classifiers, so its usage is a bit arguable and depends on the task/project
- Can find faces even if they are partially outside of viewport bound

Cons:

- Has false-positive detections
- Finds fewer "small" faces: to solve this problem we can pyramid up the image more though it will affect performance

Face from the side	Face detected however the lighting conditions are not perfect
	

Metric	Score
Recall	~0.897

## Scores

Detection is performed for **every frame** to estimate the quality. Moreover, eyes detection does not commit to face recognition quality therefore these parameters are excluded from the table.

Metric	OpenCVFaceDetectionModel	OpenCVFaceDetectionModel
Hyperparameters: detector	haarcascade_frontalface_default.xml	haarcascade_frontalface_default.xml
Hyperparameters: face scale factor	1.1	1.05
Hyperparameters: face min neighbours	6	6
Detection: TPR	~0.846	~0.886
Detection: FNR	~0.154	~0.114
Detection: FPR	0	0

Metric	OpenCVFaceDetectionModel	OpenCVFaceDetectionModel
Hyperparameters: detector	haarcascade_frontalface_default.xml	haarcascade_frontalface_alt.xml
Hyperparameters: face scale factor	1.05	1.1
Hyperparameters: face min neighbours	8	6
Detection: TPR	~0.876	~0.828
Detection: FNR	~0.124	~0.172

Metric	<code>OpenCVFaceDetectionModel</code>	<code>OpenCVFaceDetectionModel</code>
Detection: FPR	0	0

Metric	<code>OpenCVFaceDetectionModel</code>	<code>OpenCVFaceDetectionModel</code>
Hyperparameters: detector	<code>haarcascade_frontalface_alt.xml</code>	<code>haarcascade_frontalface_alt.xml</code>
Hyperparameters: face scale factor	1.05	1.1
Hyperparameters: face min neighbours	6	8
Detection: TPR	~0.877	~0.798
Detection: FNR	~0.123	~0.202
Detection: FPR	0	0

Metric	<code>OpenCVFaceDetectionModel</code>	<code>OpenCVFaceDetectionModel</code>
Hyperparameters: detector	<code>haarcascade_frontalface_alt2.xml</code>	<code>haarcascade_frontalface_alt2.xml</code>
Hyperparameters: face scale factor	1.1	1.05
Hyperparameters: face min neighbours	6	6
Detection: TPR	~0.884	~0.893
Detection: FNR	~0.116	~0.107
Detection: FPR	0	0

Metric	<code>OpenCVFaceDetectionModel</code>
Hyperparameters: detector	<code>haarcascade_frontalface_alt2.xml</code>
Hyperparameters: face scale factor	1.2
Hyperparameters: face min neighbours	8
Detection: TPR	~0.732
Detection: FNR	~0.268
Detection: FPR	0

Metric	<code>DLibFaceDetectionModel</code>
Detection: TPR	~0.897
Detection: FNR	~0.103
Detection: FPR	0

## Conclusion

Perhaps in this work I will use the `frontalface_alt2` cascade classifier from OpenCV even if it works a bit worse than a dlib classifier as it feels a bit performance-wise better.

## Performance considerations

To save some computational resources and save some processing time the app performs face detection and recognition every 10 frames, in between the app tries to keep track of already detected frames.

There are a few image trackers implemented in the project. See the comparison table below. Please, do note, that to compute **detection + tracking score** I was using previously selected models: `OpenCVFaceDetectionModel` + `frontalface_alt2`. Moreover, values of hyperparameters are listed for the face detector.

### KCF

Pros:

- Fast: can work in runtime without any visible artifacts
- Mostly accurate: track faces in the vast majority of cases

Cons:

- Loose objects that have been previously detected
- Tracks objects that left the frame



Metric	Score
Hyperparameters: face scale factor	1.1
Hyperparameters: face min neighbours	6
TPR	~0.884
FNR	~0.116

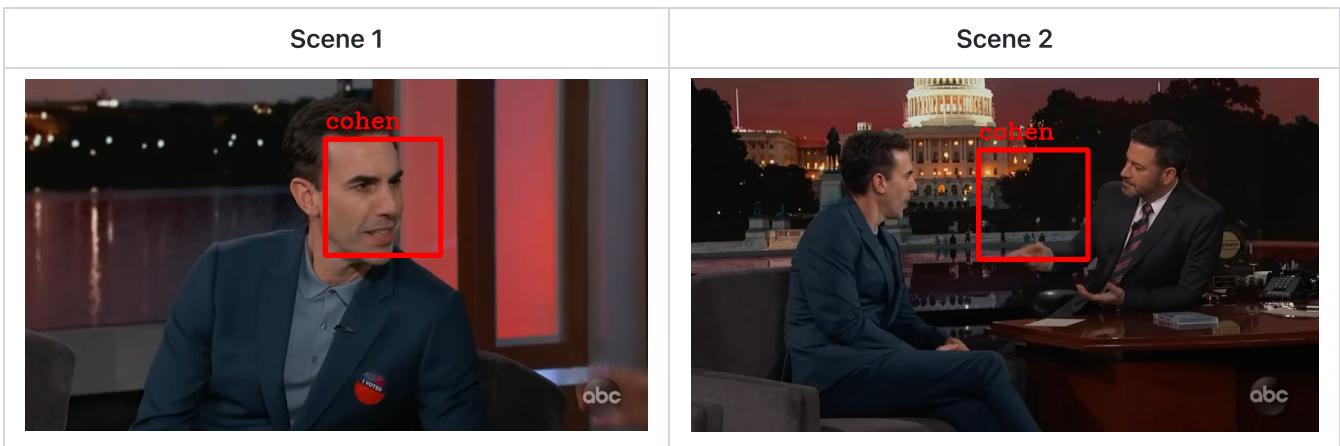
### MIL

Pros:

- Seems like detects faces more accurate than `KCF`

Cons:

- Slow: may be tolerated for runtime but works slower than `KCF`
- Tracks an object even if the object is not in the frame
- Still not perfect: sometimes as `KCF` just loose previously detected faces



Metric	Score
Hyperparameters: face scale factor	1.1
Hyperparameters: face min neighbours	6
TPR	$\sim 0.887$
FNR	$\sim 0.113$

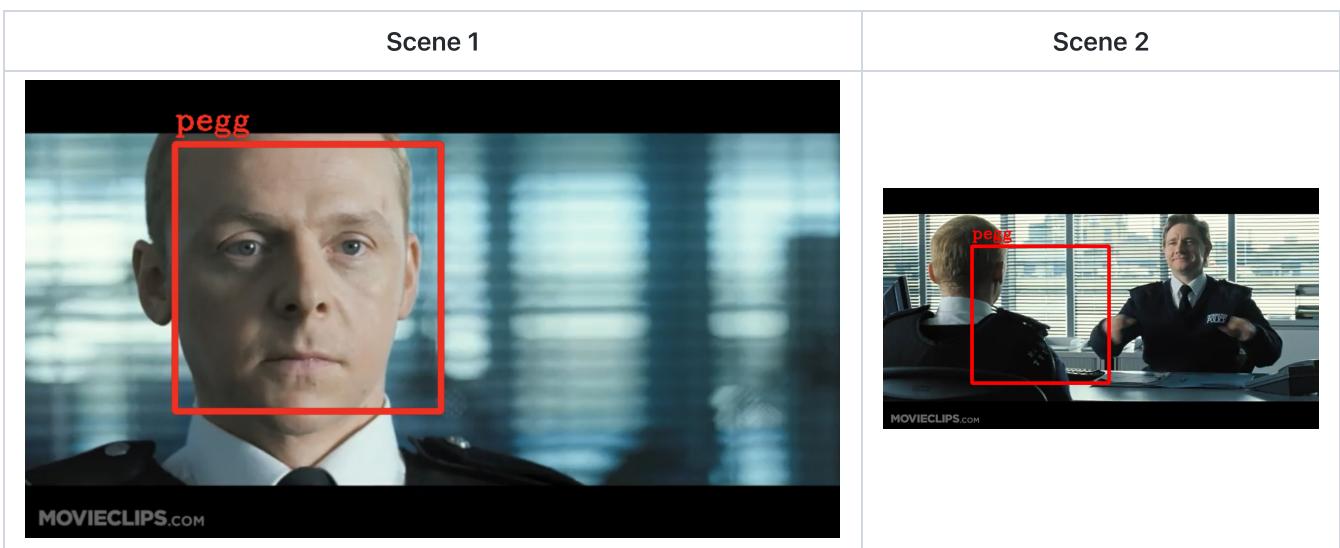
## CSRT

Pros:

- Seems like detects faces more accurate than KCF and even MIL
- Keeps tracking longer even when face is turned almost sideways

Cons:

- Slow: still may be tolerated for runtime usages but works slower than KCF and MIL
- May track an object even if the object left the frame



Metric	Score
Hyperparameters: face scale factor	1.1
Hyperparameters: face min neighbours	6
TPR	$\sim 0.893$
FNR	$\sim 0.107$

## GOTURN

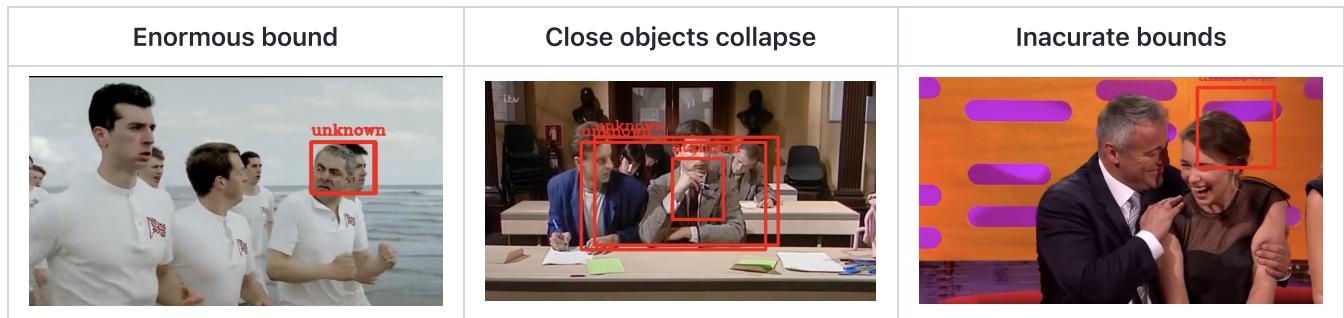
Please, note, you need to download from the Internet and put into the same folder where the executable file is located 2 special files: `goturn.caffemodel` and `goturn.prototxt`. The tracker won't work without these files.

Pros:

- Looks like tracking is mostly accurate

Cons:

- Slow: a total disaster, not feasible to use in runtime
- Has major tracking issues when there are a few objects close to each other resulting in visual artifacts or enormous detections bounds
- Sometimes the bounds are inaccurate



Metric	Score
Hyperparameters: face scale factor	1.1
Hyperparameters: face min neighbours	6
TPR	~0.484
FNR	~0.516

## Conclusion

I will use `KCF` in my final work as it seems as a good tradeoff between quality and performance.

## Training

After we pre-processed our faces and saved them to the disk we can train our recognition model. We can use the command below:

```
./FaceDetector ../../TrainSet --train -om ./output_model.yml -ol ./output_labels.txt
```

As you can see this command accepts a folder with images followed by mode `--train` and **2 mandatory flags**: output model file `-om` and output labels file `-ol`.

Please, do keep in mind that a **label** for the face will be extracted from the name of folder where the image lays.

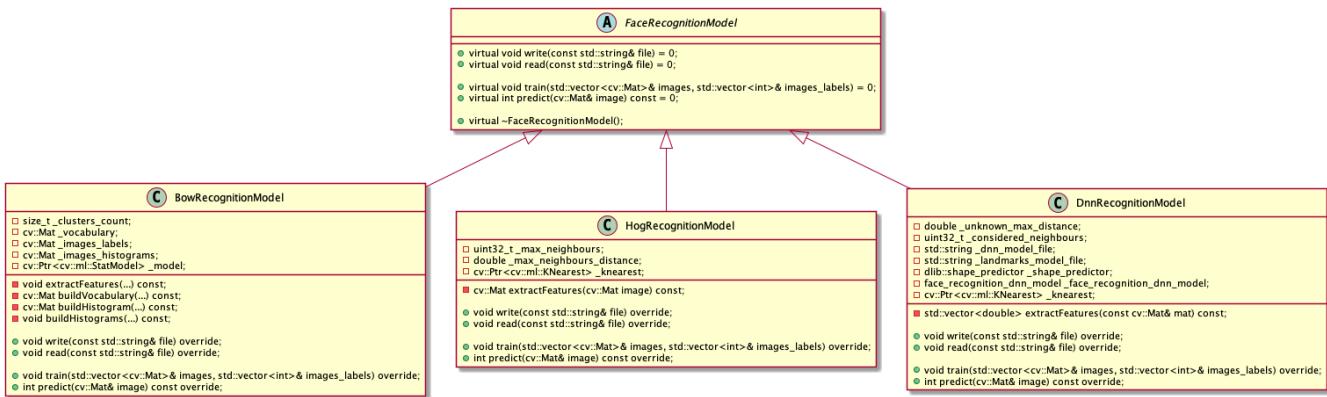
For example, if your image lays within `a/b/c/image.png` then the label for this image will be `c`.

After execution command creates 2 files: `model` and `labels`.

I am using preprocessed data from the previous step located in the `TrainSet` folder. The content of this folder looks like the images below:



## Implementation considerations



Base class [FaceRecognitionModel](#) represents an abstract recognition model. Every model supports 4 basic operations:

- **write:** to serialise the internal representation of the model into some file
- **read:** to deserialise model's representation from file
- **train:** teaches your model on some data; if your model has been trained, serialised, and then deserialised from a file it should be fine to skip the `train` step and do some predictions
- **predict:** predicts the class label for the given face image

An algorithm for face recognition can be represented in 2 steps:

1. Extract features from the image as a vector or vectors;
2. Use any machine learning technique to spot relationship between the extracted vector/vectors and the given classes.

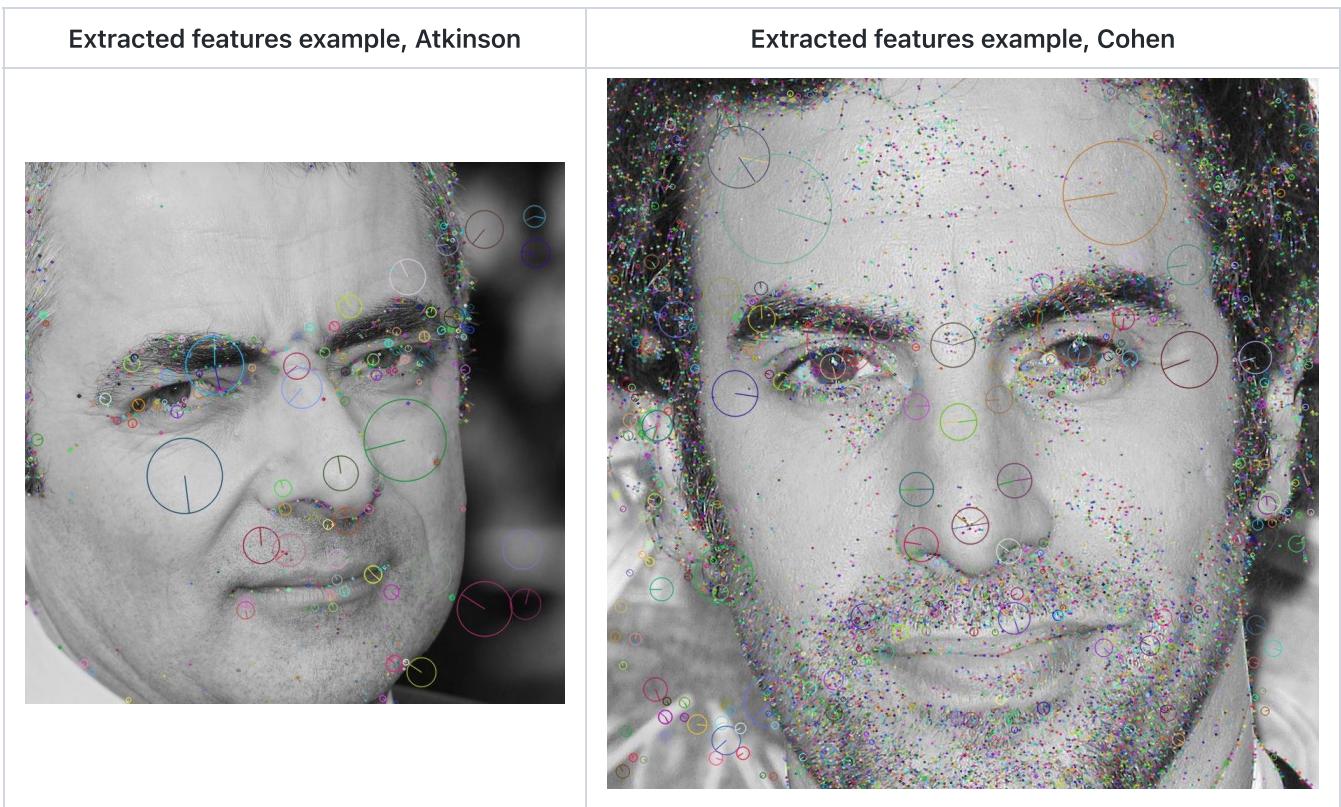
In there project were considered a few approaches with different scores.

### BowRecognitionModel

Bag of visual words: pretty classic approach to analyse different classes of objects.

I was using SIFT to extract features from the face and then tried to apply K Nearest Neighbours clustering algorithm to extract specific features from the given vectors.

At the end SVM or KNN used to match feature vectors.



Pros:

- Not observed

Cons:

- Prediction quality is quite low. My explanation for observed results:  
all faces have pretty close visual features and it is really hard to spot any distinct qualities unless the face under observation has some distinct features: scars, tattoo, hair patterns, and so on
- Bad performance: mapping extracted features to the specific visual words is an expensive operation and can be hardly applied in runtime, moreover, clustering during the training process on extracted features takes a significant amount of time (~10 mins).

For my case every object has been recognised as **Emilia Clarke**



I believe this is almost useless to calculate the metrics when you have the only classification result.

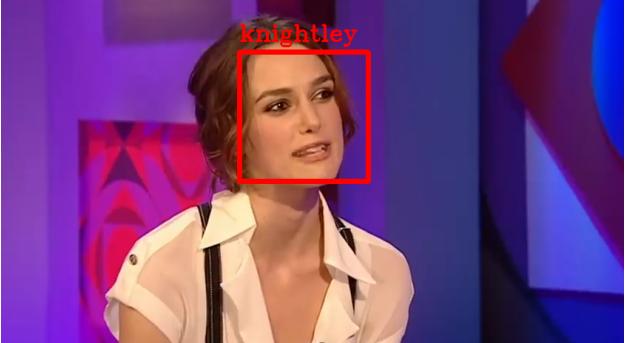
### HogRecognitionModel

Instead of extracting features and combining them into visual words we can try to consider extracted features as a face descriptor and then use KNN to match the vectors.

Frankly speaking, this approach works much better than Bag of Visual Words although far away from ideal.

To normalise the HOG vector I am scaling all images to the same size [128x128] without preserving aspect ratio. Such transformation should preserve possible image features while aspect ratio preserving rescaling followed by center cropping will leave some features behind.

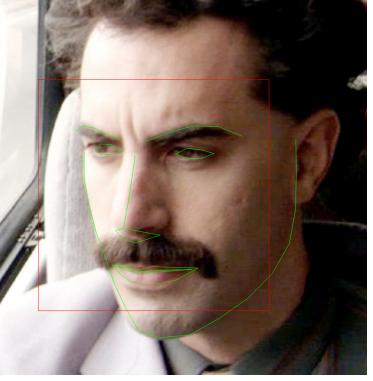
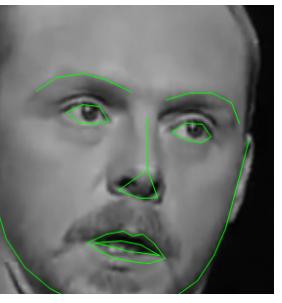
A few examples are given below:

<b>Correct: Atkinson</b> 	<b>Correct: Atkinson, however, has a few errors</b> 
<b>Correct: Knightley</b> 	<b>Incorrect: Knightley</b> 
<b>Incorrect. Was: Laurie, shoud be: Clarke</b> 	<b>Correct: Cohen</b> 

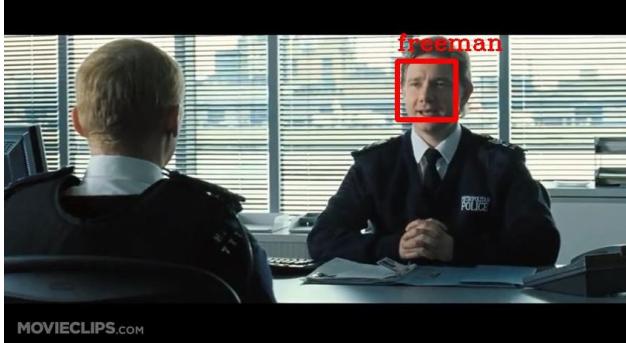
### DnnRecognitionModel

This is a Deep Neural Network model from DLib library. The recognition works in a few steps:

1. Using a random forest to find [68 facial landmarks](#)
2. Using a dnn model to convert these 68 points to 128D vector
3. Use KNN to find the class' label

Extracted features example, Lincoln	Extracted features example, Cohen	Extracted features example, Atkinson	Extracted features example, Pegg
			

This model works much better than the others.

Correct: Forst, Pegg, Unknown	Correct: Freeman
	

Correct: Pegg, Unknown	Correct: Cumberbatch
	

Correct: Freeman	Correct: Laurie
	

## Scores table

Note: to get new results you need to re-train your model with new parameters.

Metric	HogRecognitionModel	HogRecognitionModel
Hyperparameters: max neighbours distance	200	250
Hyperparameters: max neighbours	50	50
Recognition, Known: Accuracy	N/A (no matches)	~0.497
Recognition, Unknown: TPR	1	~0.073
Recognition, Unknown: FNR	0	~0.927
Recognition, Unknown: FPR	~0.303	~0.010

Metric	HogRecognitionModel	HogRecognitionModel
Hyperparameters: max neighbours distance	235	235
Hyperparameters: max neighbours	50	70
Recognition, Known: Accuracy	~0.494	~0.413
Recognition, Unknown: TPR	~0.116	~0.135
Recognition, Unknown: FNR	~0.884	~0.865
Recognition, Unknown: FPR	~0.015	~0.218

Metric	DnnRecognitionModel	DnnRecognitionModel
Hyperparameters: unknown distance	0.7	0.65
Hyperparameters: considered neighbours	100	50
Recognition, Known: Accuracy	~0.987	~0.938
Recognition, Unknown: TPR	~0.997	~0.947
Recognition, Unknown: FNR	~0.003	~0.053
Recognition, Unknown: FPR	~0.033	~0.004

Metric	DnnRecognitionModel	DnnRecognitionModel
Hyperparameters: unknown distance	0.55	0.7
Hyperparameters: considered neighbours	10	250
Recognition, Known: Accuracy	~0.926	~0.987
Recognition, Unknown: TPR	~0.360	~0.997
Recognition, Unknown: FNR	~0.640	~0.003
Recognition, Unknown: FPR	~0	~0.033

## Conclusion

I will bear with the DNN approach as the most accurate one and hyperparameters from the first column as it seems quite accurate and shows good performance results.

## Processing videos

It is time to see how the app works. To start the app one may use the command below:

```
./FaceDetector ../../Samples/Test --process  
-im ../../Samples/model_dnn_knn.yml  
-il ../../Samples/mapping_labels.dat [-t optional] [-d optional]
```

As you've seen earlier the command accepts a directory with images and/or images list separated by space and followed by `--process` mode. The command has **2 mandatory and 2 optional arguments**.

Argument	Optional	Description
<code>-im</code>		<i>Input model</i> : your trained model from the previous step.
<code>-il</code>		<i>Input labels</i> : your labels from the previous step.
<code>-t</code>		<i>Test against annotations</i> : test your videos against annotations and see the score.
<code>-d</code>		<i>Debug</i> : slows down the video when matching against some frame.

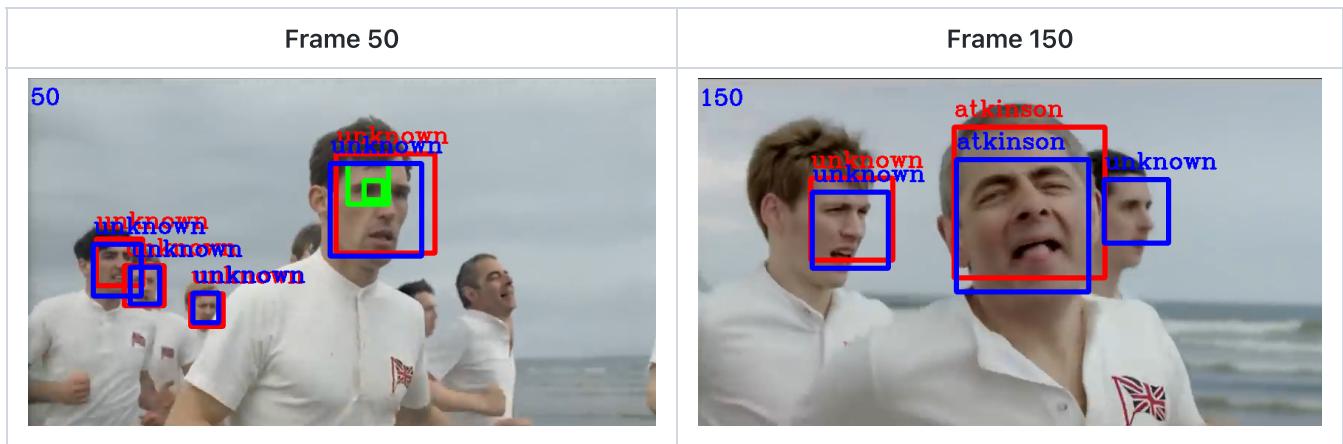
After running the command you will see the video output.



Below is a command example of running the app with a `debug` flag and testing against some config.

```
./FaceDetector ../../Samples/Test/atkinson/2.mp4 --process  
-im ../../Samples/model_dnn_knn.yml  
-il ../../Samples/mapping_labels.dat -t -d
```

When debugging you will see app detections in **red** and annotations in **blue**. See the example below:



## Annotations

### Make your own annotations

To make your own annotations file your file you need to follow the annotations structure given below:

```
frame_index_1
label1 rect1.x,rect1.y,rect1.width,rect1.height
label2 rect2.x,rect2.y,rect2.width,rect2.height

...
frame_index_n
labeln rectn.x,rectn.y,rectn.width,rectn.height
...
```

You can see an example under `Samples/Test`, like, `atkinson/1.txt`.

Please, do keep in mind, to make the automagic  work you need to put your annotations file in the same folder where the video sample is located **and** give it exactly the same name with a different extension - `.txt`.

For example, your video sample is `a/b/c/amazing_video.mp4` the annotations file should be `a/b/c/amazing_video.txt`.

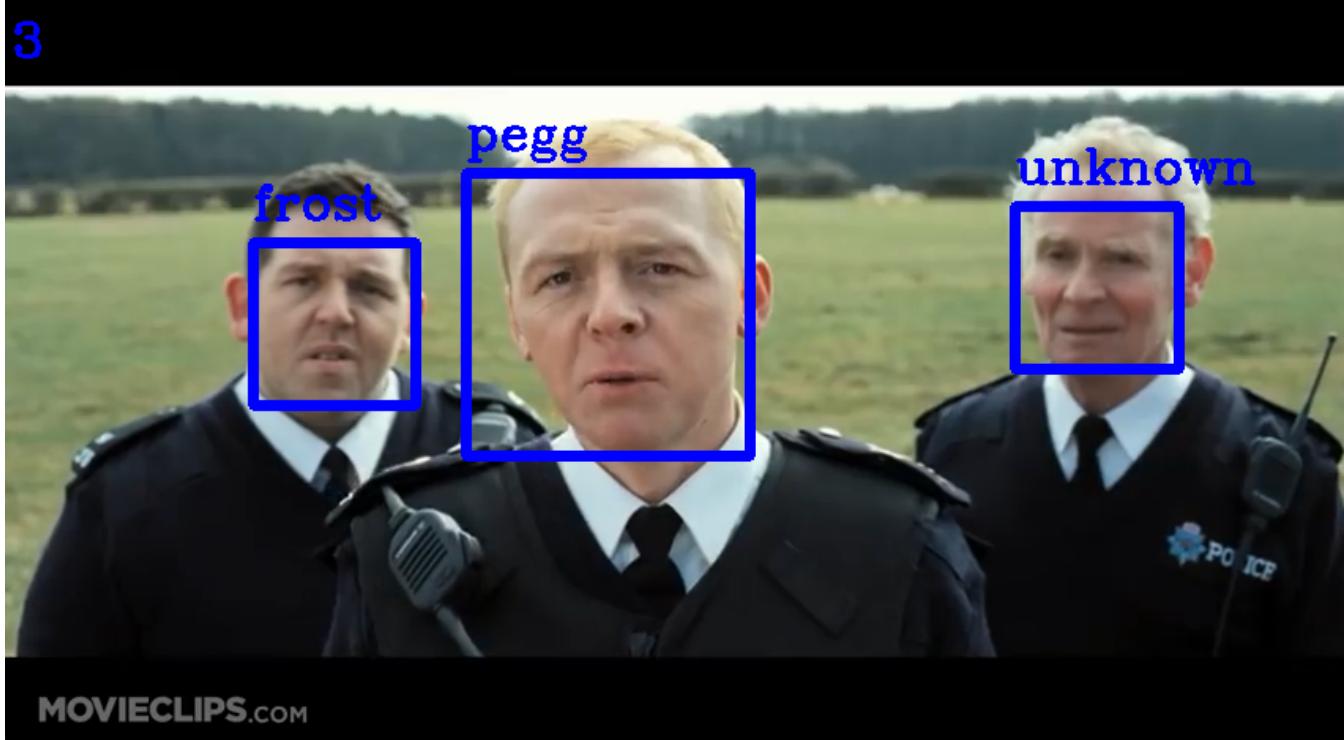
### Verify your annotations

To verify your annotations you may run the command in a specific `--config` mode:

```
./FaceDetector ../../Samples/Test/pegg/3.mp4 --config
```

You will see something similar to the image below. If you see similar result you created annotations config successfully. Congratulations!

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## Metrics calculation

### Detection quality

To analyse quality I am relying mostly on recall (aka true positive rate). True positive rate can be calculated using the following formulae:

$$TPR = \frac{TP}{FN + TP}$$

However, the task requires to show additional metrics, like FNR (false negative rate) and FPR (false positive rate). I have a few observations about these metrics that looks rather confusing.

#### FNR

$$FNR = \frac{FN}{FN + TP}$$

If we add FNR to TPR we will get

$$TPR + FNR = \frac{TP}{FN + TP} + \frac{FN}{FN + TP} = \frac{TP + FN}{FN + TP} = 1$$

therefore

$$FNR = 1 - TPR$$

However, I will calculate this metric using the original formulae.

#### FPR

We can get FPR using the formulae below:

$$FPR = \frac{FP}{TN + FP}$$

Calculating true negative cases does make any sense. True negative means that we do not detect the area as a face and this is a right call. So, there are a lot of rects (in theory infinitely many) that have not been recognized. Adding this metric to the final report will create unnecessary noise, therefore I am considering `TN` score as  $\infty$ .

Taking into considerations this logic we can modify `FPR` formulae

$$TN \rightarrow \infty$$

$$FPR = \frac{FP}{TN + FP} = \lim_{x \rightarrow +\infty} \frac{FP}{x + FP} = 0$$

It does not seem reasonable to keep track of the metric. So, `FPR` will be always `0` in my report.

## Recognition quality

For recognition there are 2 sets:

- **People we know.** I am using multiclass confusion matrix.
- **Unknown people.** I am using a confusion matrix for binary classification.

## Final hyperparameters + quality scores

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The given configuration is a good tradeoff between quality and performance

## Detection

### Hyperparameters

Parameter	Value
face scale factor	1.1
face min neighbours	6
eyes scale factor	1.1
eyes min neighbours	6

### Scores

Metric	Score
TPR	~0.884
FNR	~0.116
FPR	0

## Recognition

### Hyperparameters

Parameter	Value
unknown distance	0.7
considered neighbours	100

### Closed set of people (people we know)

Metric	Score
Accuracy	~0.987

### Unknown people

Metric	Score
TPR	~0.996
FNR	~0.003
FPR	~0.032

P.S.: Full program output can be found in [the report file](#)

Wow! You've really made this through the document. Thank you for reading!