

# VisionLabs FaceEngine Handbook

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## Introduction

This short guide describes core concepts of the product, shows main FaceEngine features and suggests usage scenarios.

This document is not a full-featured API reference manual nor a step by step tutorial. For reference pages, please see Doxygen API documentation that is shipped with FaceEngine. For complete examples, please head to our developer portal.

What this book does, however, is this:

- It describes ideas behind resource management and gives a clue why one or another decision was made. With this in mind, you are ready to write efficient code with FaceEngine;
- It breaks down full face analysis and recognition pipeline in parts and shows how one part affects all the others. This information will help you to adapt FaceEngine to your needs, which is somewhat more productive than blindly following tutorials;
- It details things that are important and omits things that are obvious, so you get information that matters most.

This book is split up into several chapters. There are chapters dedicated to each FaceEngine facility; there are chapters with conceptual overviews; there are chapters with generic information. We tried to write the book starting from low-level concepts and moving on to face detection, description and recognition tasks solving one problem at a time. Although sometimes we just had to give references to chapters ahead, we tried to minimize such jumps.

The opening chapter of this book is called “Core concepts”. It will tell you about memory management techniques, object creation and destruction strategies that are widely used across the entire FaceEngine. The following chapters catch up telling how higher level FaceEngine components are created from those building blocks.

## Editions and Platforms

FaceEngine supports multiple platforms. Supported software and hardware platforms differ depending on editions.

This section includes information about features available for different platforms.

### MacOS differences

There are two MacOS distributions available depending on the utilized device:

- x86-64 CPU
- ARM

MacOS distributions have the following differences from the server distribution:

- Python bindings are not supported.
- GPU computing is not supported. All the information about GPU utilization given in this handbook should be skipped.
- Person reidentification is supported only on x86-64 systems. All the sections about **human** descriptor extraction and utilization should be skipped when distribution for ARM is used.

Some known problems with code signing are described in [“Appendix D. Known issues”](#) in the [“MacOS known issues”](#) section.

### 0.1 Indexing

Descriptor indexing is supported only for server platforms: Ubuntu, CentOS and Windows.

# 1 Core Concepts

## 1.1 Common Interfaces and Types

### 1.1.1 Reference Counted Interface

Everything in FaceEngine object system starts from here. The *IRefCounted* interface provides methods for reference counter access, increment, and decrement. All reference counted objects imply a custom memory management model. This way they support automated destruction when reference count drops to zero as well as more sophisticated strategies of partial destruction and weak referencing required for FaceEngine internal needs. The bare minimum of such functions is exposed to a user allowing:

- to notify the object that it is required by a client via *retaining* a reference to it;
- to notify the object that it is no longer required by *releasing* a reference to it;
- to get actual reference counter value.

Reference counted objects expect some special treatment as well. **Be sure never to call *delete* on any pointer to object derived from IRefCounted! Doing so leads to heap corruption.** Simply calling *release* notifies the system when the object should be destroyed and it does this properly for you.

However, it is not recommended to interact with the reference counting mechanism manually as doing so may be error-prone. Instead, you are strongly advised to use smart pointers that are specially designed to handle such objects and provided by FaceEngine. See section “[Automatic reference counting](#)” for details.

### 1.1.2 Automatic reference counting

For your convenience, a special smart pointer class *Ref* is provided. It is capable of automatic reference counter incrementing upon its creation and automatic decrementing upon its destruction. It also does an assertion of the inner raw pointer being non-null, thus preventing errors.

*Ref*<> always increments a reference counter by 1 during initialization. You may be not expecting such behavior from it in some first-time initialization scenarios. Consider a simple example:

```
ISomeObject* createSomeObject();
{
/* Here createSomeObject returns an object with initial reference count of 1
   (otherwise, it would be dead). Then Ref adds another one for itself
   making a total reference count of 2!
*/
Ref<ISomeObject> objref = createSomeObject();
/* Here we use the object in any way we want expecting it to be properly
   destroyed when control will leave this scope.
```



```

*/

}
/* Here we have left the scope and Ref was automatically destroyed like any
   other object created on the stack. At the same time, it decreased
   reference count of its internal object by 1 making it 1 again.
*/

```

However, the object is not destroyed automatically! For this to happen, it should have precisely 0 references. Moreover, in this example, the raw pointer to the object is lost, so it is impossible to fix it in any way; thus a memory leak is introduced.

So keeping that in mind we introduce a concept of ownership acquiring. By acquiring an object, you mean that its raw pointer is not going to be used and only a valid Ref to it is required. To acquire ownership, use a special `::acquire()` function. The fixed version of the above example would look like this:

```

ISomeObject* createSomeObject();
{
/* Here createSomeObject returns an object with initial reference count of 1
   (otherwise, it would be dead). Then we acquire it leaving a total
   reference count of 1.
*/
Ref<ISomeObject> objref = acquire(createSomeObject());
/* Here we use the object in any way we want.
*/
}

/* Here we have left the scope and Ref was automatically destroyed like any
   other object created on the stack. At the same time, it decreased
   reference count of its internal object by 1 making it 0. The object is
   destroyed properly by the object system.
*/

```

Do not store or use raw pointers to the object when using the `::acquire()` function, as ownership acquiring invalidates them.

To simply make a reference to existing raw pointer, you may use the `::make_ref()` function pretty much alike to the `::acquire()` function.

You can statically cast object type during acquiring or referencing. To achieve this, use special versions of the `::make_ref_as()` and `::acquire_as()` functions. It is your responsibility to ensure that such a cast is possible.

Please refer to FaceEngine Reference Manual for more details on available convenience methods and functions.

As a side note, be informed that *typedefs* for Ref's to all reference counted types are declared. All of them match the following naming convention: *InterfaceNamePtr*. So, for example, *Ref<IDetector>* is equivalent to *IDetectorPtr*.

### 1.1.3 Serializable object interface

This interface represents an object. Object's contents may be serialized to some data stream and then read back. Think of this as loading and saving.

To interact with the aforementioned data stream, the serializable object needs a user-provided adapter. Such adapter is called the *archive*. See a detailed explanation of it in section “[Archive interface](#)” in chapter “Core facility”.

Serializable interfaces: *IDescriptor*, *IDescriptorBatch*.

### 1.1.4 Auxiliary types

#### 1.1.4.1 Image type

Since FaceEngine is a computer vision library, it is natural for it to implement some image concept. Therefore, an *Image* class exists. It is designed as a reference counted container for raw pixel color data. Reference counting allows a single image to be shared by several objects. However, one should understand, that each *Image* object is holding a reference to some data, so if the data is modified in any way, this affects all other objects holding the same reference. To make a deep copy of an *Image*, one should use the *clone()* method, since assignment operators just make a reference. It is also possible to clip a part of an image into a new image by means of *extract()* method.

Pixel data may be characterized by color channel layout, i.e., a number of color channels and their order. The engine defines a *Format* structure for that. The *Format* determines:

- Number of color channels (e.g., RGB or grayscale);
- Order of color channel (e.g., RGB vs. BGR).

FaceEngine assumes 8 bits (i.e., 1 byte) per color channel and implements 8 BPP grayscale, 24 BPP RGB/BGR and padded 32 BPP formats. Format conversion functions are also provided for convenience; see the *convert()* function family.

The *Image* class supports data range mapping. It is possible to map a subset of bytes in a rectangular area for reading or writing. The mapped pixels are represented by the *SubImage* structure. In contrast to *Image*, *SubImage* is just a data view and is *not* reference counted. You are not supposed to store *SubImages* longer than it is necessary to complete data modification. See the documentation of the *map()* function family for details.

The supports IO routines to read/write OOM, JPEG, PNG and TIFF formats via FreeImage library.

The absence of image IO is dictated by the fact that FaceEngine focuses on being lightweight and with the minimum possible number of external dependencies. It is not designed solely with image processing purpose in mind. I.e., one may treat video frames as *Images* and process them one by one. In this case, an external (possibly proprietary) video codec is required.

## 1.2 Beta Mode

Some features in LUNA SDK are available just in Beta mode. This is experimental features which may be unstable. If you want use them, you have to activate betaMode param in config (faceengine.conf).

## 2 FaceEngine Structure Overview

FaceEngine is subdivided into several facilities. Each facility is dedicated to a single function. Below there is a list of all facilities with short descriptions of functionality they provide. Detailed information may be found in corresponding chapters of this handbook.

FaceEngine facility list:

- Core facility. This facility stores shared low-level FaceEngine types and factories. This facility is responsible for normal functioning of all other facilities by providing settings accessors and common interfaces. The core facility also contains the main FaceEngine root object that is used to create instances of all higher level objects;
- Face detection facility. This facility is dedicated to object detection. It contains various object detector implementations and factories;
- Parameter estimation facility. This facility is dedicated to various image parameter estimation, such as blurriness, transformation and so forth. It contains various estimator implementations and factories;
- Descriptor processing facility. This facility is dedicated to descriptor extraction and matching. The descriptor is a set of features, describing an object, invariant to object transformation, size or other parameters. Descriptor matching allows judging with certain probability whether two objects are the same. This facility contains various descriptor extractors and containers as well as factories, required to produce them.

So, each facility is a set of classes dedicated to some common for them problem domain. Facilities are independent of each other, with several exceptions, like that all higher level facilities depend on the core facility. Interfacility dependencies are thoroughly described in corresponding chapters of this handbook. The actual set of facilities may vary depending on particular FaceEngine distributions as facilities may be licensed and shipped separately.

This handbook describes the very complete FaceEngine distribution, assuming all facilities are available. The facilities are listed in order of increasing complexity. Applying functions from these facilities in this order allows creating a complete face detection, analysis, recognition and matching pipeline with a significant degree of flexibility. The following chapters break down such pipeline in details.

## 3 Core Facility

### 3.1 Common Interfaces

#### 3.1.1 Face Engine Object

The Face Engine object is a root object of the entire FaceEngine. Everything begins with it, so it is essential to create at least one instance of it. Although it is possible to have multiple instances of the Face Engine, it is impractical to do so (as explained in section “[Automatic reference counting](#)” in chapter “Core concepts”). To create a Face Engine instance call *createFaceEngine* function. Also, you may specify default *dataPath* and *configPath* in *createFaceEngine* parameters.

If you plan to use GPU acceleration, you should keep in mind CUDA runtime initialization and shutdown. Specifically, CUDA creates global runtime object with implicit lifetime; see [\[http://docs.nvidia.com/cuda/cuda-c-programming-guide/index.html#initialization\]](http://docs.nvidia.com/cuda/cuda-c-programming-guide/index.html#initialization).

To prevent FaceEngine runtime and lifetime mismatch, it is recommended to avoid creating static global instances of FaceEngine objects, as their destruction order is undetermined.

#### 3.1.2 Settings Provider

Settings provider is a special entity that loads settings from various locations. Since settings might be shared among several objects, it is useful to cache them to minimize disk reads and provide a dictionary-like interface for named value lookup.

This is what the provider does. The provider object stands somewhat aside FaceEngine facility structure and is created by a separate factory function *createSettingsProvider*. This function accepts configuration file path as a parameter (see section “[Configuration data](#)” for details). By default, the engine holds a single provider instance for all facilities. Think of it as a reference counted config file. This provider is passed by the Face Engine object to each factory it creates. The factory, in turn, can read its configuration data from the object and pass it further to its child objects. In typical scenarios, you should not bother with providers as the engine does everything for you. However, when relying on custom factory creation parameters (see the description in section “[Face engine object](#)”), you have to create and supply a provider wherever it is required manually.

### 3.2 Helper Interfaces

#### 3.2.1 Archive Interface

Archive interface is used to provide serialization functions with a data source. It contains methods primarily for data reading and writing. Note, that *IArchive* is not derived from *IRefCounted*, thus does not imply any special memory management strategies.

A few points to keep in mind when implementing your archive:

- FaceEngine objects that use *IArchive* for serialization purposes do call only *write()* (during saving) or only *read()* (during loading) but never both during the same process unless otherwise is explicitly stated;
- During saving or loading FaceEngine objects are free to write or read their data in chunks; e.g., there may be several sequential calls to *write()* in the scope of a single serialization request. The same is true for *read()*. Basically, *read()* and *write()* should behave pretty much like C *fread()* and *fwrite()* standard library functions.

Any *IArchive* implementation should be aware of these notes.

Since these interface methods are pretty obvious and mostly self-explanatory, we advise you to check out FaceEngine Reference Manual for the details.

### 3.3 Sensor type

SensorType determines which type of camera sensor is used to perform estimation. Currently two types of SensorType are available: *Visible*, *NIR*. The user can indicate the required type of sensor when creating an object by passing the appropriate parameter.

### 3.4 Data Paths

#### 3.4.1 Model Data

Various FaceEngine modules may require data files to operate. The files contain various algorithm models and constants used at runtime. All the files are gathered together into a single *data* directory. The data directory location is assumed to reside in:

- */opt/visionlabs/data* on Linux
- *./data* on Windows

One may override the data directory location by means of *setDataDirectory()* method which is available in *IFaceEngine*. Current data location may be retrieved via *getDataDirectory()* method.

#### 3.4.2 Configuration Data

The configuration file is called *faceengine.conf* and stored in */data* directory by default. ConfigurationGuide.pdf with parameter description and default values is located at */doc* package folder.

At runtime, the configuration file data is managed by a special object that implements *ISettingsProvider* interface (see section “[Settings provider](#)”). The provider is instantiated by means of *createSettingsProvider()* function that accepts configuration file location as a parameter or uses aforementioned defaults if not specified.

One may supply a different configuration to any factory object by means of *setSettingsProvider()* method, which is available in each factory object interface, including *IFaceEngine*. Currently, bound settings provider may be retrieved via *getSettingsProvider()* method.

## 4 Detection facility

### 4.1 Overview

Object detection facility is responsible for quick and coarse detection tasks, like finding a face in an image.

### 4.2 Detection structure

The detection structure represents an images-space bounding rectangle of the detected object as well as the detection score.

Detection score is a measure of confidence in the particular object classification result and may be used to pick the most “confident” face of many.

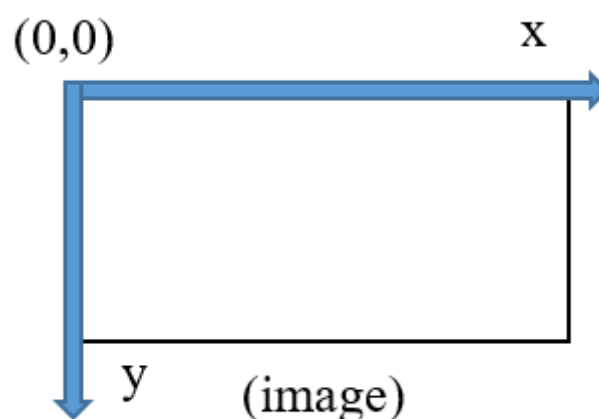
Detection score is the measure of classification confidence and not the source image quality. While the score is related to quality (low-quality data generally results in a lower score), it is not a valid metric to estimate the visual quality of an image.

### 4.3 Face Detection

Object detection is performed by the *IDetector* object. The function of interest is *detect()*. It requires an image to detect on and an area of interest (to virtually crop the image and look for faces only in the given location).

#### 4.3.1 Image coordinate system

The origin of the coordinate system for each processed image is located in the upper left corner.



**Figure 1:** Source image coordinate system



### 4.3.2 Face detection

When a face is detected, a rectangular area with the face is defined. The area is represented using coordinates in the image coordinate system.

### 4.3.3 Redetect method

Face detector implements *redetect()* method which is intended for face detection optimization on video frame sequences. Instead of doing full-blown detection on each frame, one may *detect()* new faces at a lower frequency (say, each 5th frame) and just confirm them in between with *redetect()*. This dramatically improves performance at the cost of detection recall. Note that *redetect()* updates face landmarks as well.

Detector works faster with larger value of `minFaceSize`.

### 4.3.4 Detector variants

Supported detector variants:

- FaceDetV1
- FaceDetV2
- FaceDetV3

There are two basic detector families. The first of them includes two detector variants: FaceDetV1 and FaceDetV2. The second family currently includes only one detector variant - FaceDetV3. FaceDetV3 is the latest and most precise detector. For this type of detector can be passed [sensor type](#). In terms of performance FaceDetV3 is similar to FaceDetV1 detector.

User code may specify necessary detector type while creating *IDetector* object using parameter.

FaceDetV1 and FaceDetV2 performance depends on number of faces on image and image complexity.  
FaceDetV3 performance depends only on the target image resolution.

FaceDetV3 works faster with batched redetect.

### 4.3.5 FaceDetV1 and FaceDetV2 Configuration

FaceDetV1 detector is more precise and FaceDetV2 works two times faster (See appendix A chapter [“Appendix A. Specifications”](#)).

FaceDetV1 and FaceDetV2 detector’s performance depend on number of faces in image. FaceDetV3 doesn’t depend on it, so it may be slower then FaceDetV1 on images with one face and much more faster on images with many faces.

### 4.3.6 FaceDetV3 Configuring

FaceDetV3 detects faces from `minFaceSize` to `minFaceSize * 32`. You can change the minimum size of the faces that will be searched in the photo from the `faceengine.conf` configuration.

For example:

```
config->setValue("FaceDetV3::Settings", "minFaceSize", 20);
```

The logic of the detector is very understandable. The smaller the face size we need to find the more time we need.

We recommend to use such meanings for `minFaceSize`: 20, 40 and 90. The size 90 pix is recommended for recognition. If you want to find faces with custom size value you will need to point with size with:  $95\% * \text{value}$ . For example we want to find faces with size of 50 pix, it means that in config we should set:  $50 * 0.95 \sim 47 \text{ pix}$ .

FaceDetV3 may provide accurate *5 landmarks* only for faces with size greater then 40x40, for smaller faces it provides less accurate landmarks.

If you have few faces on target images and target face sizes after resize will less then 40x40, it's recommended to require *68 landmarks*.

If you have many faces on target image (greater then 7) it will be faster increase `minFaceSize` to have big enough faces for accurate landmarks estimation.

All last changes in Face Detection logic are described in chapter "Migration guide".

### 4.3.7 Face Alignment

#### 4.3.7.1 Five landmarks

Face alignment is the process of special key points (called "landmarks") detection on a face. FaceEngine does landmark detection at the same time as the face detection since some of the landmarks are by-products of that detection.

At the very minimum, just **5** landmarks are required: two for eyes, one for a nose tip and two for mouth corners. Using these coordinates, one may warp the source photo image (see Chapter "Image warping") for use with all other FaceEngine algorithms.

All detector may provide *5 landmarks* for each detection without additional computations.

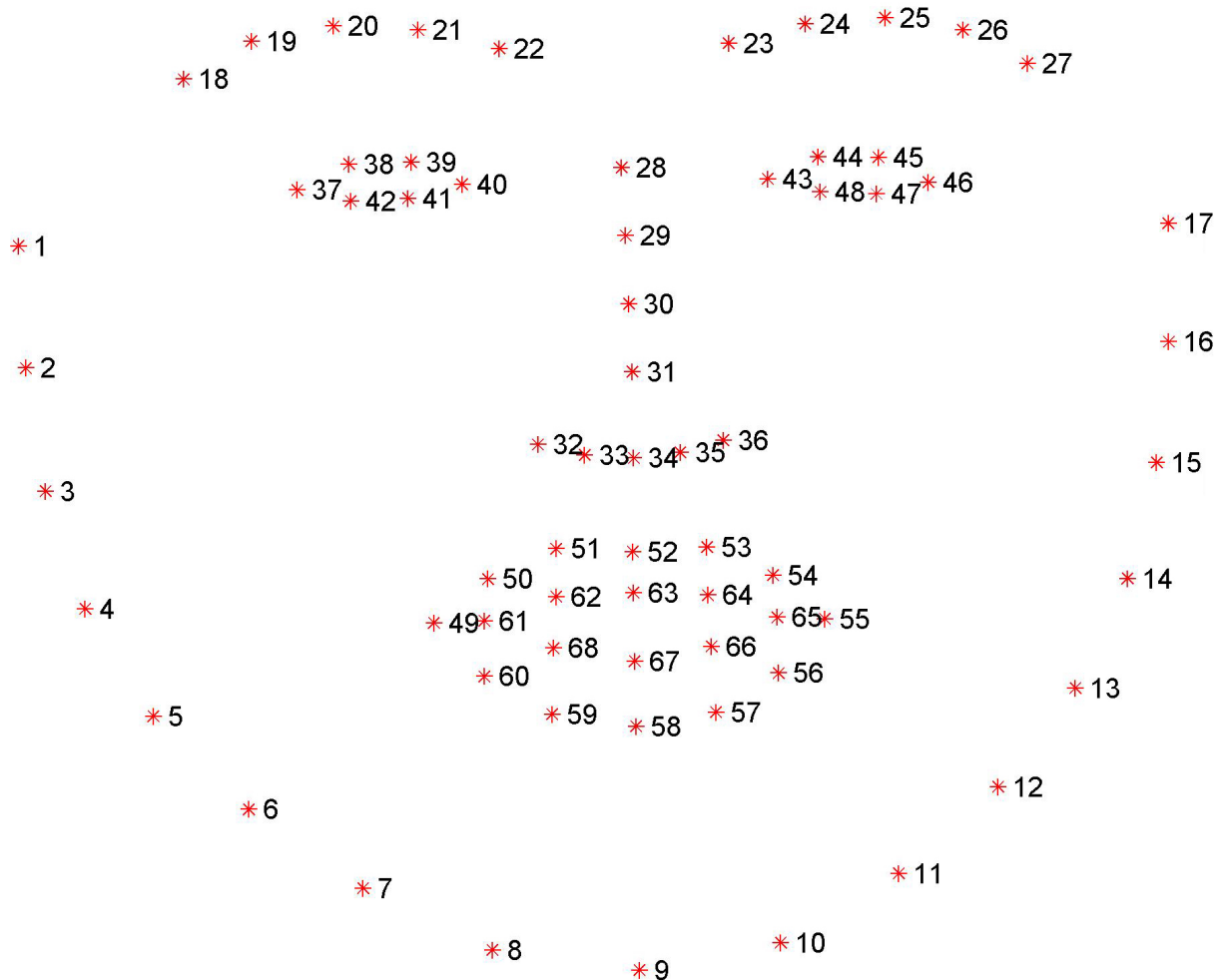
Typical use cases for 5 landmarks:

- Image warping for use with other algorithms:
  - Quality and attribute estimators;
  - Descriptor extraction.

#### 4.3.7.2 Sixty-eight landmarks

More advanced **68-points** face alignment is also implemented. Use this when you need precise information about face and its parts. The detected points look like in the image below.

The *68 landmarks* require additional computation time, so don't use it if you don't need precise information about a face. If you use *68 landmarks*, *5 landmarks* will be reassigned to more precise subset of *68 landmarks*.



**Figure 2:** 68-point face alignment

The typical error for landmark estimation on a warped image (see Chapter [“Image warping”](#)) is in the table below.

**Table 1:** “Average point estimation error per landmark”

Point	Error (pixels)	Point	Error (pixels)	Point	Error (pixels)	Point	Error (pixels)
1	±3,88	18	±3,77	35	±1,62	52	±1,65
2	±3,53	19	±2,83	36	±1,90	53	±2,01
3	±3,88	20	±2,70	37	±1,78	54	±2,00
4	±4,30	21	±3,06	38	±1,69	55	±1,93
5	±4,67	22	±3,92	39	±1,63	56	±2,18
6	±4,87	23	±3,46	40	±1,52	57	±2,17
7	±4,67	24	±2,59	41	±1,54	58	±1,99
8	±4,01	25	±2,53	42	±1,60	59	±2,32
9	±3,46	26	±2,95	43	±1,55	60	±2,33
10	±3,87	27	±3,84	44	±1,60	61	±2,06
11	±4,56	28	±1,88	45	±1,74	62	±1,97
12	±4,94	29	±1,75	46	±1,72	63	±1,56
13	±4,55	30	±1,92	47	±1,68	64	±1,86
14	±4,45	31	±2,20	48	±1,65	65	±1,94
15	±4,13	32	±1,97	49	±1,99	66	±2,00
16	±3,68	33	±1,70	50	±1,99	67	±1,70
17	±4,09	34	±1,73	51	±1,95	68	±2,12

Simple 5-point landmarks roughly correspond to:

- Average of positions 37, 40 for a left eye;
- Average of positions 43, 46 for a right eye;
- Number 31 for a nose tip;
- Numbers 49 and 55 for mouth corners.

The landmarks for both cases are output by the face detector via Landmarks5 and Landmarks68 structures. Note, that performance-wise 5-point alignment result comes free with a face detection, whereas 68-point result does not. So you should generally request the lowest number of points for your task.

Typical use cases for 68 landmarks:

- Segmentation;
- Head pose estimation.

## 4.4 Human Detection

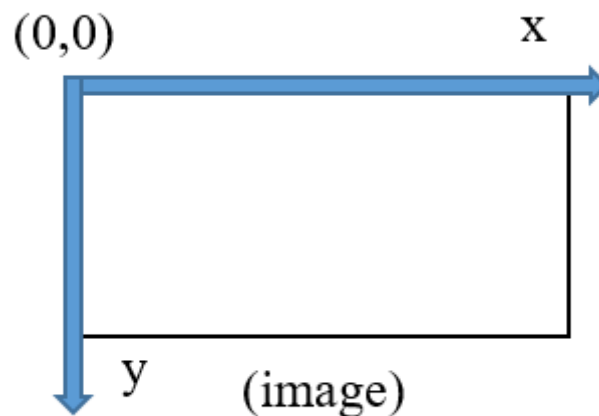
This functionality enables you to detect human bodies in the image.

During the detection process we receive special points (called “landmarks” or exactly “HumanLandmarks17”) for the body parts visible in the image. These landmarks represent the keypoints of a human body (see the [Human keypoints](#) section).

Human body detection is performed by the *IHumanDetector* object. The function of interest is *detect()*. It requires an image to detect on.

### 4.4.1 Image coordinate system

The origin of the coordinate system for each processed image is located in the upper left corner.



**Figure 3:** Source image coordinate system

### 4.4.2 Human body detection

When a human body is detected, a rectangular area with the body is defined. The area is represented using coordinates in the image coordinate system.

### 4.4.3 Constraints

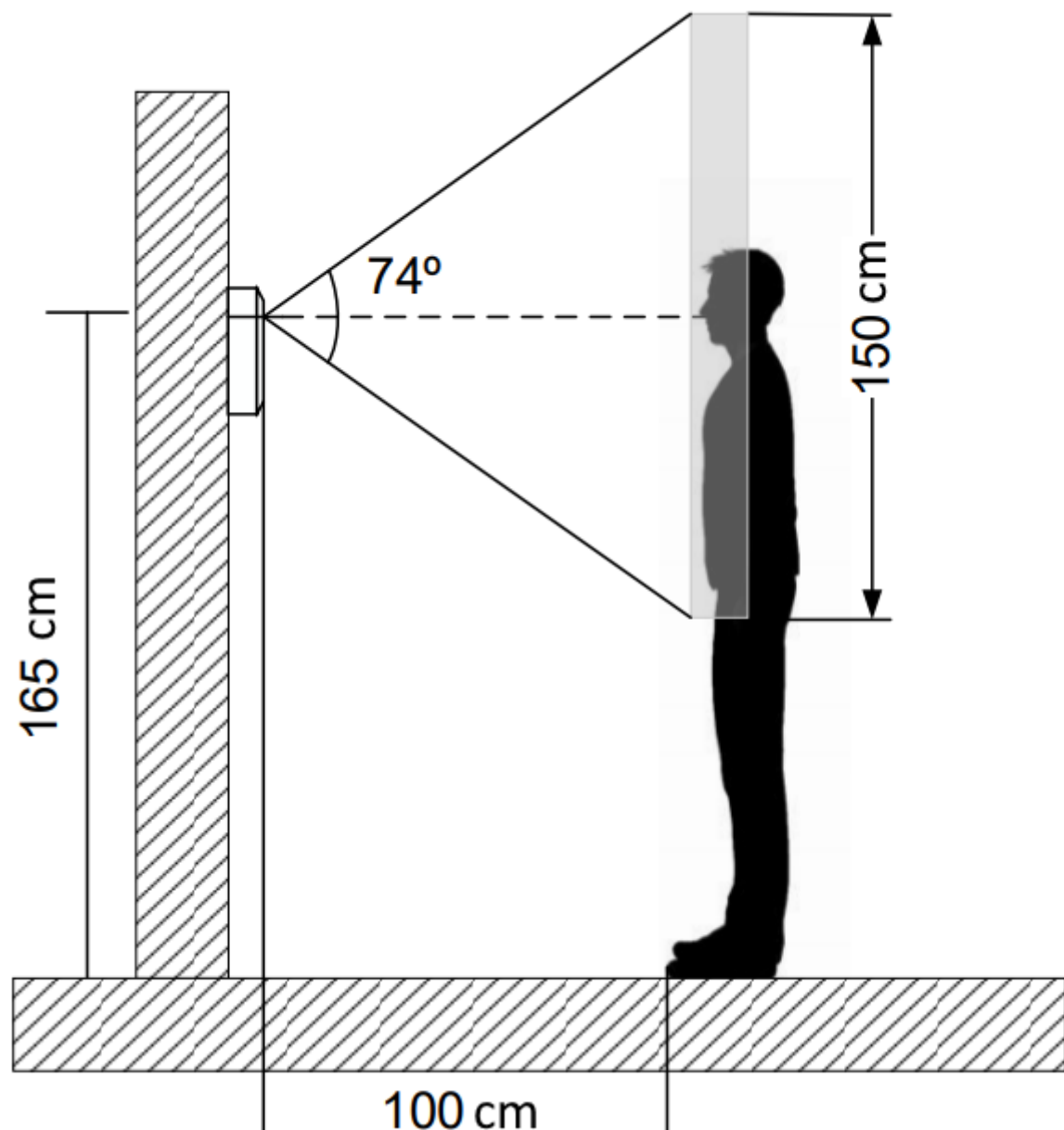
Human body detection has the following constraints:

- Human body detector works correctly only with adult humans in an image;

- The detector may detect a body of size from 100 px to 640 px (in an image with a long side of 640 px). You may change the input image size in the config (see [./doc/ConfigurationGuide.pdf](#)). The image will be resized to specified size by the larger side while maintaining the aspect ratio.

#### 4.4.4 Camera position requirements

In general, you should locate the camera for human detection according to the image below.

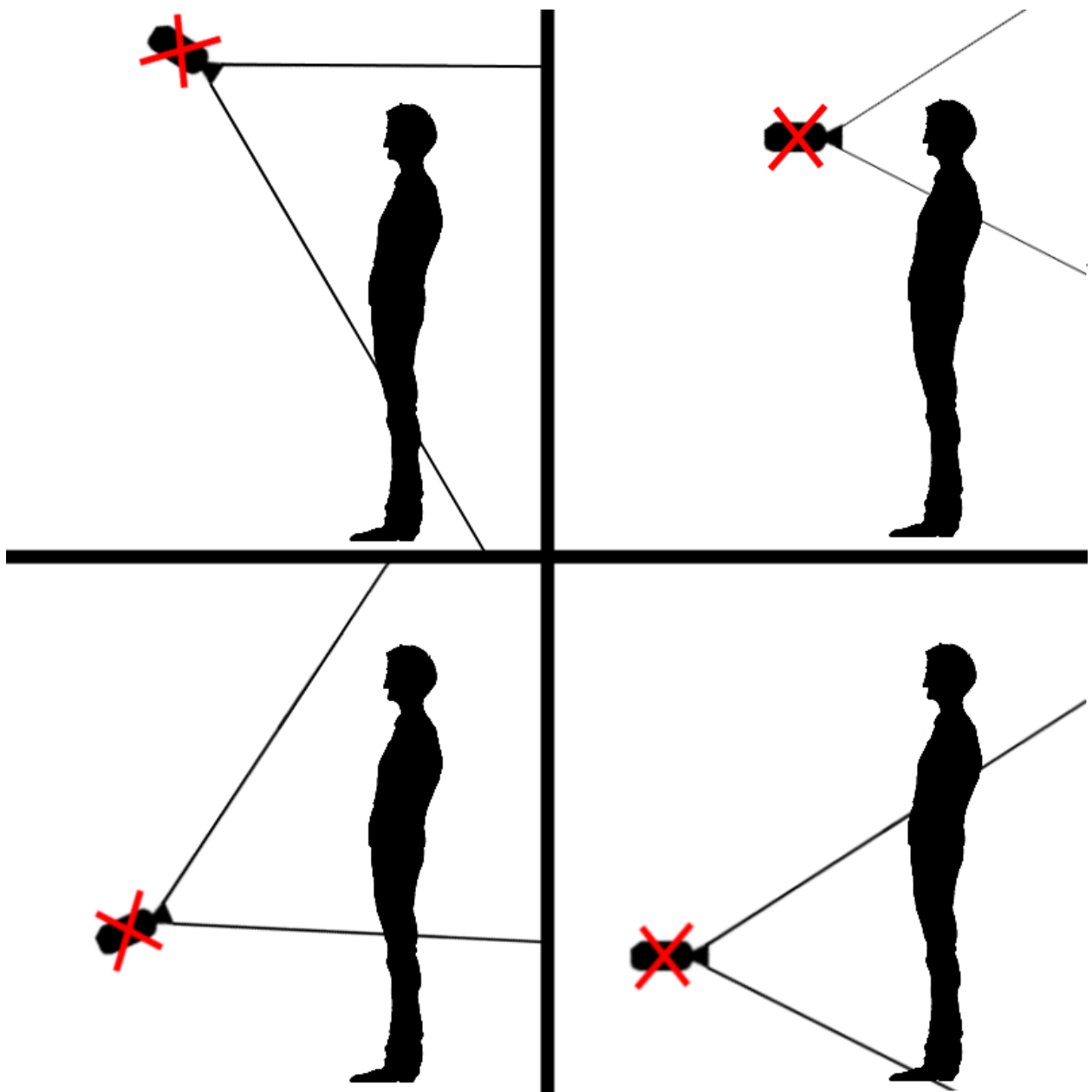


**Figure 4:** Camera position for human detection

Follow these recommendations to correctly detect human body and keypoints:

- A person's body should face the camera;
- Keep angle of view as close to horizontal as possible;
- There should be about 60% of the person's body in the frame (upper body);
- There must not be any objects that overlap the person's body in the frame;
- The camera should be located at about 165 cm from the floor, which corresponds to the average height of a human.

The examples of wrong camera positions are shown in the image below.



**Figure 5:** Wrong camera positions

#### 4.4.5 Human body redetection

Like any other detector in Face Engine SDK, human detector also implements redetection model. The user can make full detection only in a first frame and then redetect the same human in the next “n” frames thereby boosting performance of the whole image processing loop.

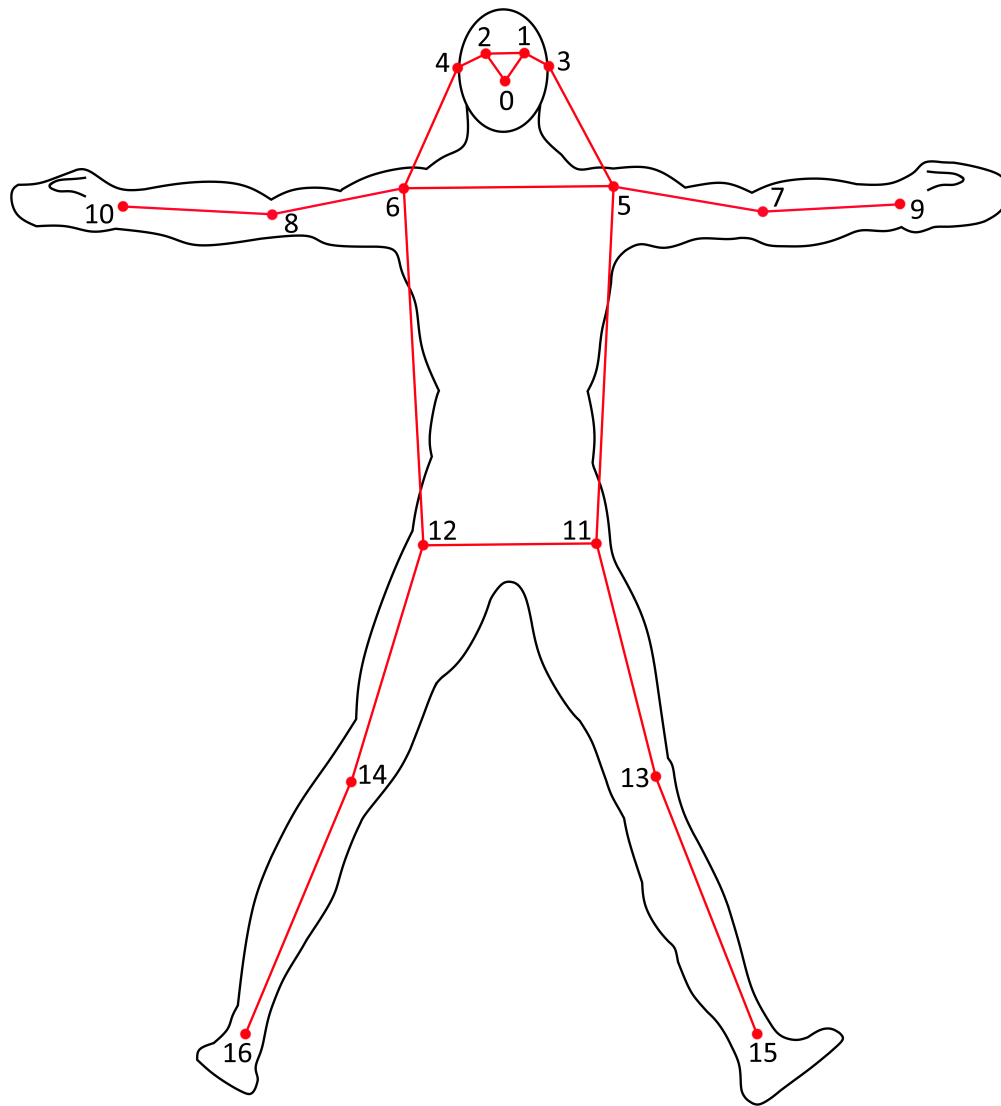
User can use *redetectOne()* method if only a single human detection is required, for more complex use cases one should use *redetect()* which can redetect humans from multiple images.



Detector give an opportunity to detect human body *keypoints* in an image.

#### 4.4.6 Human Keypoints

The image below shows the keypoints detected for a human body.



**Figure 6:** 17-points of human body

Point	Body Part	Point	Body Part
0	Nose	9	Left Wrist
1	Left Eye	10	Right Wrist

Point	Body Part	Point	Body Part
2	Right Eye	11	Left Hip
3	Left Ear	12	Right Hip
4	Right Ear	13	Left Knee
5	Left Shoulder	14	Right Knee
6	Right Shoulder	15	Left Ankle
7	Left Elbow	16	Right Ankle
8	Right Elbow		

Cases that increase the probability of error:

- Non-standard poses (head below the shoulders, vertical twine, lying head to the camera, etc.);
- Camera position from above at a large angle;
- Sometimes estimator predicts invisible points with high score, especially for points of elbows, wrists, ears.

#### 4.4.7 Detection

To detect *Human Keypoints* call *detect()* using `fsdk::HumanDetectionType::DCT_BOX` | `fsdk::HumanDetectionType::DCT_POINTS` argument.

Default is `fsdk::HumanDetectionType::DCT_BOX`.

#### 4.4.8 Main Results of Each Detection

The main result of each detection is an array. Each array element consists of a point (`fsdk::Point2f`) and a score. If the score value is less than the threshold, then the value of “x” and “y” coordinates will be equal to 0.

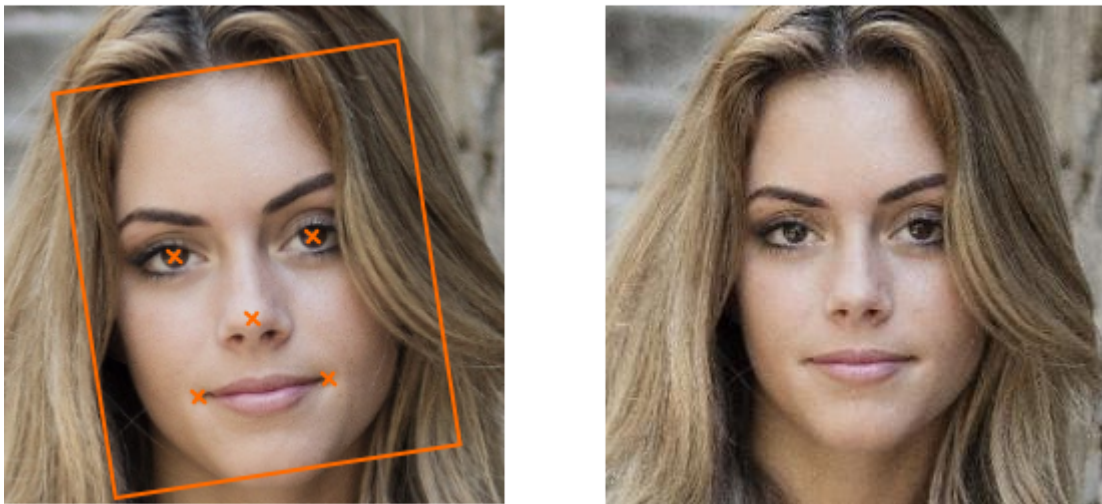
see [ConfigurationGuide.pdf](#) (“HumanDetector settings” section) for more information about thresholds and configuration parameters.

## 5 Image Warping

Warping is the process of face image normalization. It requires landmarks and face detection (see chapter “[Detection facility](#)”) to operate. The purpose of the process is to:

- compensate image plane rotation (roll angle);
- center the image using eye positions;
- properly crop the image.

This way all warped images look the same and one can tell that, e.g., left eye is always in a box, defined by the certain coordinates. This way certain transform invariance is achieved for input data so various algorithms can perform better.



**Figure 7:** Face warping

Be aware that image warping is not thread-safe, so you have to create a *warper* object per worker thread.

## 6 Parameter Estimation Facility

### 6.1 Overview

The estimation facility is the only multi-purpose facility in FaceEngine. It is designed as a collection of tools that help to estimate various images or depicted object properties. These properties may be used to increase the precision of algorithms implemented by other FaceEngine facilities or to accomplish custom user tasks.

### 6.2 Best shot selection functionality

#### 6.2.1 BestShotQuality Estimation

The BestShotQuality estimator was added to evaluate image quality to choose the best image before descriptor extraction.

The estimator (see `IBestShotQualityEstimator` in `IEstimator.h`):

- Implements the `estimate()` function that needs `fsdk::Image` in R8G8B8 format, `fsdk::Detection` structure of corresponding source image (see section “[Detection structure](#)” in chapter “Face detection facility”), `fsdk::IBestShotQualityEstimator::EstimationRequest` structure and `fsdk::IBestShotQualityEstimator::EstimationResult` to store estimation result;
- Implements the `estimate()` function that needs the span of `fsdk::Image` in R8G8B8 format, the span of `fsdk::Detection` structures of corresponding source images (see section “[Detection structure](#)” in chapter “Face detection facility”), `fsdk::IBestShotQualityEstimator::EstimationRequest` structure and span of `fsdk::IBestShotQualityEstimator::EstimationResult` to store estimation results.

Before using this estimator, user is free to decide whether to estimate or not some listed attributes. For this purpose, `estimate()` method takes one of the estimation requests:

- `fsdk::IBestShotQualityEstimator::EstimationRequest::estimateAGS` to make only AGS estimation;
- `fsdk::IBestShotQualityEstimator::EstimationRequest::estimateHeadPose` to make only Head Pose estimation;
- `fsdk::IBestShotQualityEstimator::EstimationRequest::estimateAll` to make both AGS and Head Pose estimations;

The description of attributes returned by the `estimate()` method is given below.

##### 6.2.1.1 AGS

AGS (garbage score) aims to determine the source image score for further descriptor extraction and matching.

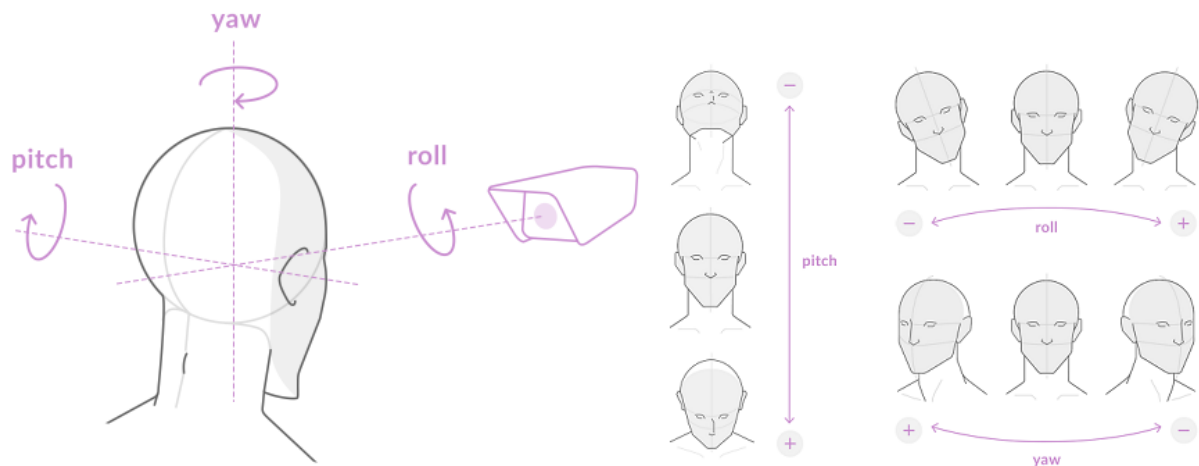
Estimation output is a float score which is normalized in range [0..1]. The closer score to 1, the better matching result is received for the image.

When you have several images of a person, it is better to save the image with the highest AGS score.

Recommended threshold for AGS score is equal to **0.2**. But it can be changed depending on the purpose of use. Consult VisionLabs about the recommended threshold value for this parameter.

#### 6.2.1.2 Head Pose

Head Pose determines person head rotation angles in 3D space, namely pitch, yaw and roll.



**Figure 8:** Head pose

Since 3D head translation is hard to determine reliably without camera-specific calibration, only 3D rotation component is estimated.

Head pose estimation characteristics:

- Units (degrees);
- Notation (Euler angles);
- Precision (see table below).

Prediction precision decreases as a rotation angle increases. We present typical average errors for different angle ranges in the table below.

**Table 3:** “Head pose prediction precision”

	Range	-45°...+45°	< -45° or > +45°
Average prediction error (per axis)	Yaw	±2.7°	±4.6°
Average prediction error (per axis)	Pitch	±3.0°	±4.8°
Average prediction error (per axis)	Roll	±3.0°	±4.6°

Zero position corresponds to a face placed orthogonally to camera direction, with the axis of symmetry parallel to the vertical camera axis.

## 6.2.2 Image quality estimation

The estimator is trained to work with warped images (see Chapter “Image warping”) for details).

The general rule of thumb for quality estimation:

1. Detect a face, see if detection confidence is high enough. If not, reject the detection;
2. Produce a warped face image (see chapter “Descriptor processing facility”) using a face detection and its landmarks;
3. Estimate visual quality using the estimator, finally reject low-quality images.

While the scheme above might seem a bit complicated, it is the most efficient performance-wise, since possible rejections on each step reduce workload for the next step.

At the moment estimator exposes two interface functions to predict image quality:

- **virtual Result estimate(const Image& warp, Quality& quality);**
- **virtual Result estimate(const Image& warp, SubjectiveQuality& quality);**

Each one of this functions use its own CNN internally and return slightly different quality criteria.

The first CNN is trained specifically on pre-warped human face images and will produce lower score factors if one of the following conditions are satisfied:

- Image is blurred;
- Image is under-exposed (i.e., too dark);
- Image is over-exposed (i.e., too light);
- Image color variation is low (i.e., image is monochrome or close to monochrome).

Each one of this score factors is defined in [0..1] range, where higher value corresponds to better image quality and vice versa.

Recommended thresholds for image quality of the first interface function are given below:

“saturationThreshold”: 0.0; “blurThreshold”: 0.93; “lightThreshold”: 0.9; “darkThreshold”: 0.9;

The second interface function output will produce lower factor if:

- The image is blurred;
- The image is underexposed (i.e., too dark);
- The image is overexposed (i.e., too light);
- The face in the image is illuminated unevenly (there is a great difference between light and dark regions);
- Image contains flares on face (too specular).

The estimator determines the quality of the image based on each of the aforementioned parameters. For each parameter, the estimator function returns two values: the quality factor and the resulting verdict.

As with the first estimator function the second one will also return the quality factors in the range [0..1], where 0 corresponds to low image quality and 1 to high image quality. E. g., the estimator returns low



quality factor for the Blur parameter, if the image is too blurry.

The resulting verdict is a quality output based on the estimated parameter. E. g., if the image is too blurry, the estimator returns “isBlurred = true”.

The threshold can be specified for each of the estimated parameters. The resulting verdict and the quality factor are linked through this threshold. If the received quality factor is lower than the threshold, the image quality is low and the estimator returns “true”. E. g., if the image blur quality factor is higher than the threshold, the resulting verdict is “false”.

If the estimated value for any of the parameters is lower than the corresponding threshold, the image is considered of bad quality. If resulting verdicts for all the parameters are set to “False” the quality of the image is considered good.

Examples are presented in the images below. Good quality images are shown on the right.



**Figure 9:** Blurred image (left), not blurred image (right)



**Figure 10:** Dark image (left), good quality image (right)



**Figure 11:** Light image (left), good quality image (right)





**Figure 12:** Image with uneven illumination (left), image with even illumination (right)



**Figure 13:** Image with specularities - image contains flares on face (left), good quality image (right)

The quality factor is a value in the range  $[0..1]$  where 0 corresponds to low quality and 1 to high quality.

Illumination uniformity corresponds to the face illumination in the image. The lower the difference between light and dark zones of the face, the higher the estimated value. When the illumination is evenly distributed throughout the face, the value is close to “1”.

Specularity is a face possibility to reflect light. The higher the estimated value, the lower the specularity and the better the image quality. If the estimated value is low, there are bright glares on the face.

**Table 4:** Image quality parameters and their thresholds

Threshold	Estimated property	Recomended range	Default value
blurThreshold	Blur	[0.57..0.65]	0.61
darknessThreshold	Darkness	[0.45..0.52]	0.50
lightThreshold	Light	[0.44..0.61]	0.57
illuminationThreshold	Illumination uniformity	[0..0.3]	0.1
specularityThreshold	Specularity	[0..0.3]	0.1

The most important parameters for face recognition are “blurThreshold”, “darknessThreshold” and “lightThreshold”, so you should select them carefully.

You can select images of better visual quality by setting higher values of the “illuminationThreshold” and “specularityThreshold”. Face recognition is not greatly affected by uneven illumination or glares.

## 6.3 Attributes estimation functionality

### 6.3.1 Face Attribute Estimation

The estimator is trained to work with warped images (see Chapter “Image warping”) for details).

The Attribute estimator determines face attributes. Currently, the following attributes are available:

- Age: determines person’s age;
- Gender: determines person’s gender;

Before using attribute estimator, user is free to decide whether to estimate or not some specific attributes listed above through *IAttributeEstimator::EstimationRequests* structure, which later get passed in main *estimate()* method. Estimator overrides *AttributeEstimationResults* output structure, which consists of optional fields describing results of user requested attributes.

- Age is reported in years:
  - For cooperative (see “Appendix B. Glossary”) conditions: average error depends on person age, see table below for additional details. Estimation precision is 2.3
- For gender estimation 1 means male, 0 means female.

- Estimation precision in cooperative mode is 99.81% with the threshold 0.5;
- Estimation precision in non-cooperative mode is 92.5%.

**Table 5:** “Average age estimation error per age group for cooperative conditions”

Age (years)	Average error (years)
0-3	±3.3
4-7	±2.97
8-12	±3.06
13-17	±4.05
17-20	±3.89
20-25	±1.89
25-30	±1.88
30-35	±2.42
35-40	±2.65
40-45	±2.78
45-50	±2.88
50-55	±2.85
55-60	±2.86
60-65	±3.24
65-70	±3.85
70-75	±4.38
75-80	±6.79

**Note** In earlier releases of Luna SDK Attribute estimator worked poorly in non-cooperative mode (only 56% gender estimation precision), and did not estimate child’s age. Having solved these problems average estimation error per age group got a bit higher due to extended network functionality.

### 6.3.2 Child Estimation

This estimator tells whether the person is child or not. Child is a person who younger than 18 years old. It returns a structure with 2 fields. One is the score in the range from 0.0 (is adult) to 1.0 (maximum, is child), the second is a boolean answer. Boolean answer depends on the threshold in config (faceengine.conf). If the value is more than the threshold, the answer is true (person is child), else - false (person is adult).

The estimator (see IChildEstimator in IEstimator.h):

- Implements the *estimate()* function accepts warped source image (see chapter “Image warping”). Warped image is received from the warper (see IWarper::warp());
- Estimates whether the person is child or not on input warped image;
- Outputs ChildEstimation structure. Structure consists of score of and boolean answer.

### 6.3.3 Credibility Check Estimation

This estimator estimates reliability of a person.

The estimator (see ICredibilityCheckEstimator in IEstimator.h):

- Implements the *estimate()* function that accepts warped image in R8B8G8 format and `fsdk::CredibilityCheckEstimation` structure.
- Implements the *estimate()* function that accepts span of warped images in R8B8G8 format and span of `fsdk::CredibilityCheckEstimation` structures.

**Note.** The estimator is trained to work with face images that meet the following requirements:

**Table 6:** “Requirements for `fsdk::HeadPoseEstimation`”

Attribute	Acceptable angle range(degrees)
pitch	[-20...20]
yaw	[-20...20]
roll	[-20...20]

**Table 7:** “Requirements for `fsdk::SubjectiveQuality`”

Attribute	Minimum value
blur	0.61
light	0.57

**Table 8:** “Requirements for `fsdk::AttributeEstimationResult`”

Attribute	Minimum value
age	18

**Table 9:** “Requirements for fsdk::OverlapEstimation”

Attribute	State
overlapped	false

**Table 10:** “Requirements for fsdk::Detection”

Attribute	Minimum value
detection size	100

**Note.** Detection size is detection width.

```
const fsdk::Detection detection = ... // somehow get fsdk::Detection object
const int detectionSize = detection.getRect().width;
```



## 6.4 Facial Hair Estimation

This estimator aims to detect a facial hair type on the face in the source image. It can return the next results:

- There is no hair on the face (see FacialHair::NoHair field in the FacialHair enum);
- There is stubble on the face (see FacialHair::Stubble field in the FacialHair enum);
- There is mustache on the face (see FacialHair::Mustache field in the FacialHair enum);
- There is beard on the face (see FacialHair::Beard field in the FacialHair enum);

The estimator (see IFacialHairEstimator in IFacialHairEstimator.h):

- Implements the *estimate()* function that accepts source warped image in R8G8B8 format and FacialHairEstimation structure to return results of estimation;
- Implements the *estimate()* function that accepts fsdk::Span of the source warped images in R8G8B8 format and fsdk::Span of the FacialHairEstimation structures to return results of estimation.

### 6.4.1 FacialHair enumeration

The FacialHair enumeration contains all possible results of the FacialHair estimation:

```
enum class FacialHair {  
    NoHair = 0,           //!< no hair on the face  
    Stubble,             //!< stubble on the face  
    Mustache,            //!< mustache on the face  
    Beard                //!< beard on the face  
};
```

### 6.4.2 FacialHairEstimation structure

The FacialHairEstimation structure contains results of the estimation:

```
struct FacialHairEstimation {  
    FacialHair result;      //!< estimation result (@see FacialHair  
                           enum)  
    // scores  
    float noHairScore;     //!< no hair on the face score  
    float stubbleScore;    //!< stubble on the face score  
    float mustacheScore;   //!< mustache on the face score  
    float beardScore;      //!< beard on the face score  
};
```

There are two groups of the fields:

1. The first group contains only the result enum:

```
FacialHair result;          //!< estimation result (@see FacialHair
enum)
```

Result enum field FacialHairEstimation contain the target results of the estimation.

2. The second group contains scores:

```
float noHairScore;          //!< no hair on the face score
float stubbleScore;         //!< stubble on the face score
float mustacheScore;        //!< mustache on the face score
float beardScore;           //!< beard on the face score
```

The scores group contains the estimation scores for each possible result of the estimation. All scores are defined in [0,1] range. Sum of scores always equals 1.

**Note.** The estimator is trained to work with face images that meet the following requirements:

**Table 11:** “Requirements for fsdk::HeadPoseEstimation”

Attribute	Acceptable angle range(degrees)
pitch	[-40...40]
yaw	[-40...40]
roll	[-40...40]

**Table 12:** “Requirements for fsdk::MedicalMaskEstimation”

Attribute	State
result	fsdk::MedicalMask::NoMask

**Table 13:** “Requirements for fsdk::Detection”

Attribute	Minimum value
detection size	40

**Note.** Detection size is detection width.

```
const fsdk::Detection detection = ... // somehow get fsdk::Detection object
const int detectionSize = detection.getRect().width;
```

### 6.4.3 Color/Monochrome Estimation

This estimator detects if an input image is grayscale or color. It implements *estimate()* function that accepts source *image* and outputs a Boolean, indicating if the image is grayscale (true) or not (false).

## 6.5 Face features extraction functionality

### 6.5.1 Eyes Estimation

The estimator is trained to work with warped images (see Chapter “[Image warping](#)” for details).

For this type of estimator can be defined [sensor type](#).

This estimator aims to determine:

- Eye state: Open, Closed, Occluded;
- Precise eye iris location as an array of landmarks;
- Precise eyelid location as an array of landmarks.

You can only pass warped image with detected face to the estimator interface. Better image quality leads to better results.

Eye state classifier supports three categories: “Open”, “Closed”, “Occluded”. Poor quality images or ones that depict obscured eyes (think eyewear, hair, gestures) fall into the “Occluded” category. It is always a good idea to check eye state before using the segmentation result.

The precise location allows iris and eyelid segmentation. The estimator is capable of outputting iris and eyelid shapes as an array of points together forming an ellipsis. You should only use segmentation results if the state of that eye is “Open”.

The estimator:

- Implements the *estimate()* function that accepts warped source image (see Chapter “[Image warping](#)”) and warped landmarks, either of type Landmarks5 or Landmarks68. The warped image and landmarks are received from the warper (see `IWarper::warp()`);
- Classifies eyes state and detects its iris and eyelid landmarks;
- Outputs EyesEstimation structures.

Orientation terms “left” and “right” refer to the way you see the *image* as it is shown on the screen. It means that left eye is not necessarily left from the person’s point of view, but is on the left side of the screen. Consequently, right eye is the one on the right side of the screen. More formally, the label “left” refers to subject’s left eye (and similarly for the right eye), such that  $x_{right} < x_{left}$ .

EyesEstimation::EyeAttributes presents eye state as enum EyeState with possible values: Open, Closed, Occluded.

Iris landmarks are presented with a template structure Landmarks that is specialized for 32 points.

Eyelid landmarks are presented with a template structure Landmarks that is specialized for 6 points.

### 6.5.2 Gaze Estimation

This estimator is designed to determine gaze direction relatively to head pose estimation. Since 3D head translation is hard to determine reliably without camera-specific calibration, only 3D rotation component is estimated.

For this type of estimator can be defined [sensor type](#).

Estimation characteristics:

- Units (degrees);
- Notation (Euler angles);
- Precision (see table below).

Roll angle is not estimated, prediction precision decreases as a rotation angle increases. We present typical average errors for different angle ranges in the table below.

**Table 14:** “Gaze prediction precision”

	Range	-25°...+25°	-25° ... -45 ° or 25 ° ... +45°
Average prediction error (per axis)	Yaw	±2.7°	±4.6°
Average prediction error (per axis)	Pitch	±3.0°	±4.8°

Zero position corresponds to a gaze direction orthogonally to face plane, with the axis of symmetry parallel to the vertical camera axis.

### 6.5.3 Glasses Estimation

Glasses estimator is designed to determine whether a person is currently wearing any glasses or not. There are 3 types of states estimator is currently able to estimate:

- NoGlasses state determines whether a person is wearing any glasses at all;
- EyeGlasses state determines whether a person is wearing eyeglasses;
- SunGlasses state determines whether a person is wearing sunglasses.

**Note.** Source input image must be warped in order for estimator to work properly (see Chapter “[Image warping](#)”). Quality of estimation depends on threshold values located in faceengine configuration file (faceengine.conf ) in GlassesEstimator::Settings section. By default, these threshold values are set to optimal.

Table below contain true positive rates corresponding to selected false positive rates.

**Table 15:** “Glasses estimator TPR/FPR rates”

State	TPR	FPR
NoGlasses	0.997	0.00234
EyeGlasses	0.9768	0.000783
SunGlasses	0.9712	0.000383

### 6.5.4 Overlap Estimation

This estimator tells whether the face is overlapped by any object. It returns a structure with 2 fields. One is the value of overlapping in the range [0..1] where 0 is not overlapped and 1.0 is overlapped, the second is a Boolean answer. A Boolean answer depends on the threshold listed below. If the value is greater than the threshold, the answer returns true, else false.

The estimator (see `IOverlapEstimator` in `IEstimator.h`):

- Implements the *estimate()* function that accepts source image in R8G8B8 format and `fsdk::Detection` structure of corresponding source image (see section “[Detection structure](#)”);
- Estimates whether the face is overlapped by any object on input image;
- Outputs structure with value of overlapping and Boolean answer.

## 6.6 Emotion estimation functionality

### 6.6.1 Emotions Estimation

The estimator is trained to work with warped images (see Chapter “[Image warping](#)” for details).

This estimator aims to determine whether a face depicted on an image expresses the following emotions:

- Anger
- Disgust
- Fear
- Happiness
- Surprise
- Sadness
- Neutrality

You can pass only warped images with detected faces to the estimator interface. Better image quality leads to better results.

The estimator (see `IEmotionsEstimator` in `IEstimator.h`):

- Implements the *estimate()* function that accepts warped source image (see Chapter “[Image warping](#)”). Warped image is received from the warper (see `IWarper::warp()`);
- Estimates emotions expressed by the person on a given image;
- Outputs `EmotionsEstimation` structure with aforementioned data.

`EmotionsEstimation` presents emotions as normalized float values in the range of [0..1] where 0 is lack of a specific emotion and 1 is the maximum intensity of an emotion.

### 6.6.2 Mouth Estimation

This estimator is designed to predict person's mouth state. It returns the following bool flags:

- isOpened;
- isOccluded;
- isSmiling.

Each of this flags indicate specific mouth state that was predicted.

The combined mouth state is assumed if multiple flags are set to true. For example there are many cases where person is smiling and its mouth is wide open.

Mouth estimator provides score probabilities for mouth states in case user need more detailed information:

- Mouth opened score;
- Smile score;
- Occlusion score.

This estimator is trained to work with warped images (see Chapter [“Image warping”](#) for details).

## 6.7 Liveness check functionality

### 6.7.1 HeadAndShouldersLiveness Estimation

This estimator tells whether the person's face is real or fake (photo, printed image) and confirms presence of a person's body in the frame. Face should be in the center of the frame and the distance between the face and the frame borders should be three times greater than space that face takes up in the frame. Both person's face and chest have to be in the frame. Camera should be placed at the waist level and directed from bottom to top. The estimator check for borders of a mobile device to detect fraud. So there should not be any rectangular areas within the frame (windows, pictures, etc.).

The estimator (see `IHeadAndShouldersLiveness` in `IEstimator.h`):

- Implements the *estimateHeadLiveness()* function that accepts source image in R8G8B8 format and `fsdk::Detection` structure of corresponding source image (see section [“Detection structure”](#) in chapter [“Detection facility”](#)).
- Estimates whether it is a real person or not. Outputs float normalized score in range [0..1], 1 - is real person, 0 - is fake. Implements the *estimateShouldersLiveness()* function that accepts source image in R8G8B8 format and `fsdk::Detection` structure of corresponding source image (see section [“Detection structure”](#) in chapter [“Face detection facility”](#)). Estimates whether real person or not. Outputs float score normalized in range [0..1], 1 - is real person, 0 - is fake.



### 6.7.2 LivenessFlyingFaces Estimation

This estimator tells whether the person's face is real or fake (photo, printed image).

The estimator (see `ILivenessFlyingFacesEstimator` in `IEstimator.h`):

- Implements the *estimate()* function that needs `fsdk::Image` with valid image in R8G8B8 format and `fsdk::Detection` of corresponding source image (see section “[Detection structure](#)” in chapter “Face detection facility”).
- Implements the *estimate()* function that needs the span of `fsdk::Image` with valid source images in R8G8B8 formats and span of `fsdk::Detection` of corresponding source images (see section “[Detection structure](#)” in chapter “Face detection facility”).

Those methods estimate whether different persons are real or not. Corresponding estimation output with float scores which are normalized in range [0..1], where 1 - is real person, 0 - is fake.

**Note.** The estimator is trained to work in combination with `fsdk::ILivenessRGBMEstimator`.

**Note.** The estimator is trained to work with face images that meet the following requirements:

**Table 16:** “Requirements for `fsdk::BestShotQualityEstimator::EstimationResult`”

Attribute	Acceptable values
headPose.pitch	[-30...30]
headPose.yaw	[-30...30]
headPose.roll	[-40...40]
ags	[0.5...1.0]

**Table 17:** “Requirements for `fsdk::Detection`”

Attribute	Minimum value
detection size	80

**Note.** Detection size is detection width.

```
const fsdk::Detection detection = ... // somehow get fsdk::Detection object
const int detectionSize = detection.getRect().width;
```

### 6.7.3 LivenessRGBM Estimation

This estimator tells whether the person's face is real or fake (photo, printed image).

The estimator (see `ILivenessRGBMEstimator` in `IEstimator.h`):

- Implements the *estimate()* function that needs `fsdk::Face` with valid image in R8G8B8 format, detection structure of corresponding source image (see section “[Detection structure](#)” in chapter “Face detection facility”) and `fsdk::Image` with accumulated background. This method estimates whether a real person or not. Output estimation structure contains the float score and boolean result. The float score normalized in range [0..1], where 1 - is real person, 0 - is fake. The boolean result has value true for real person and false otherwise.
- Implements the *update()* function that needs the `fsdk::Image` with current frame , number of that image and previously accumulated background. The accumulated background will be overwritten by this call.

### 6.7.4 Depth Liveness Estimation

This estimator tells whether the person's face is real or fake (photo, printed image).

The estimator (see `ILivenessDepthEstimator` in `IEstimator.h`):

- Implements the *estimate()* function that accepts source warped image in R16 format and `fsdk::DepthEstimation` structure. This method estimates whether or not depth map corresponds to the real person. Corresponding estimation output with float score which is normalized in range  $[0..1]$ , where 1 - is real person, 0 - is fake.

The estimator is trained to work with face images that meet the following requirements:

**Table 18:** "Requirements for `fsdk::HeadPoseEstimation`"

Attribute	Acceptable angle range(degrees)
pitch	[-15...15]
yaw	[-15...15]
roll	[-10...10]

**Table 19:** "Requirements for `fsdk::Quality`"

Attribute	Minimum value
blur	0.94
light	0.90
dark	0.93

**Table 20:** "Requirements for `fsdk::EyesEstimation`"

Attribute	State
leftEye	Open
rightEye	Open

Also, the minimum distance between the face bounding box and the frame borders should be greater than 20 pixels.

## 6.8 Separately licensed features

### 6.8.1 LivenessOneShotRGBEstimator

This estimator shows whether the person's face is real or fake (photo, printed image).

#### 6.8.1.1 LivenessOneShotRGBEstimator requirements

The requirements for the processed image and the face in the image are listed above.

This estimator supports images taken on mobile devices or webcams (PC or laptop). Image resolution minimum requirements:

- Mobile devices -  $720 \times 960$  px
- Webcam (PC or laptop) -  $1280 \times 720$  px

There should be only one face in the image. An error occurs when there are two or more faces in the image.

The minimum face detection size must be 200 pixels.

Yaw, pitch, and roll angles should be no more than 25 degrees in either direction.

The minimum indent between the face and the image borders should be 10 pixels.

#### 6.8.1.2 LivenessOneShotRGBEstimation structure

The estimator (see `ILivenessOneShotRGBEstimator` in `IEstimator.h`):

- Implements the *estimate()* function that needs `fsdk::Image` and `fsdk::Face` with valid image in R8G8B8 format and detection structure of corresponding source image (see section "Detection structure" in chapter "Face detection facility"). This method estimates whether a real person or not. Output estimation is a structure `fsdk::LivenessOneShotRGBEstimation`.
- Implements the *estimate()* function that needs the span of `fsdk::Image` and span of `fsdk::Face` with valid image in R8G8B8 format and detection structure of corresponding source image (see section "Detection structure" in chapter "Face detection facility"). This method estimates whether a real person or not. Output estimation is a span of structure `fsdk::LivenessOneShotRGBEstimation`. The second output value (structure `fsdk::LivenessOneShotRGBEstimation`) is the result of aggregation based on span of estimations announced above. Pay attention the second output value (aggregation) is optional, i.e. default argument, which is `nullptr`.

The `LivenessOneShotRGBEstimation` structure contains results of the estimation:

```
struct LivenessOneShotRGBEstimation {  
    enum class State {
```

```

        Alive = 0,    //!< The person on image is real
        Fake,        //!< The person on image is fake (photo, printed image)
        Unknown      //!< The liveness status of person on image is Unknown
    };

    float score;      //!< Estimation score
    State state;      //!< Liveness status
    float qualityScore; //!< Liveness quality score
};

```

Estimation score is normalized in range [0..1], where 1 - is real person, 0 - is fake.

Liveness quality score is an image quality estimation for the liveness recognition.

This parameter is used for filtering if it is possible to make bestshot when checking for liveness.

The reference score is 0,5.

The value of State depends on score and qualityThreshold. The value qualityThreshold can be given as an argument of method `estimate` (see `ILivenessOneShotRGBEstimator`), and in configuration file `faceengine.conf` (see *ConfigurationGuide LivenessOneShotRGBEstimator*).

### 6.8.2 Usage example

The face in the image and the image itself should meet the estimator requirements.

You can find additional information in example (`examples/example_estimation/main.cpp`) or in the code below.

```

// Minimum detection size in pixels.
constexpr int minDetSize = 200;

// Step back from the borders.
constexpr int borderDistance = 10;

if (std::min(detectionRect.width, detectionRect.height) < minDetSize) {
    std::cerr << "Bounding Box width and/or height is less than `minDetSize`
        - " << minDetSize << std::endl;
    return false;
}

if ((detectionRect.x + detectionRect.width) > (image.getWidth() -
borderDistance) || detectionRect.x < borderDistance) {
    std::cerr << "Bounding Box width is out of border distance - " <<
        borderDistance << std::endl;
    return false;
}

```

```

}

if ((detectionRect.y + detectionRect.height) > (image.getHeight() -
borderDistance) || detectionRect.y < borderDistance) {
    std::cerr << "Bounding Box height is out of border distance - " <<
        borderDistance << std::endl;
    return false;
}

// Yaw, pitch and roll.
constexpr int principalAxes = 25;

if (std::abs(headPose.pitch) > principalAxes ||
    std::abs(headPose.yaw) > principalAxes ||
    std::abs(headPose.roll) > principalAxes ) {

    std::cerr << "Can't estimate LivenessOneShotRGBEstimation. " <<
        "Yaw, pith or roll absolute value is larger than expected value: "
        << principalAxes << "." <<
        "\nPitch angle estimation: " << headPose.pitch <<
        "\nYaw angle estimation: " << headPose.yaw <<
        "\nRoll angle estimation: " << headPose.roll << std::endl;
    return false;
}

```

We recommend using `Detector` type 3 (`fsdk::ObjectDetectorClassType::FACE_DET_V3`).

### 6.8.3 Personal Protection Equipment Estimation

The Personal Protection Equipment (a.k.a PPE) estimator predicts whether a person is wearing one or multiple types of protection equipment such as: - Helmet; - Hood; - Vest; - Gloves.

For each one of these attributes the estimator returns 3 prediction scores which indicate the possibility of a person wearing that attribute, not wearing it and an “unknown” score which will be the highest of them all if the estimator wasn’t able to tell whether a person on the image wears/doesn’t wear a particular attribute.

Output structure for each attribute looks as follows:

```
struct OnePPEEstimation {
    float positive = 0.0f;
    float negative = 0.0f;
    float unknown  = 0.0f;

    enum class PPEState : uint8_t {
        Positive, //!< person is wearing specific personal equipment;
        Negative, //!< person isn't wearing specific personal equipment;
        Unknown,  //!< it's hard to tell whether person wears specific
                  personal equipment.
        Count      //!< state count
    };

    /**
     * @brief returns predominant personal equipment state
     */
    inline PPEState getPredominantState();
};
```

All three prediction scores sum up to 1.

Estimator takes as input an image and a human bounding box of a person for which attributes shall be predicted. For more information about human detector see “Human Detection” section.

#### 6.8.4 Medical Mask Estimation

This estimator aims to detect a medical face mask on the face in the source image. It can return the next results:

- A medical mask is on the face (see `MedicalMask::Mask` field in the `MedicalMask` enum);
- There is no medical mask on the face (see `MedicalMask::NoMask` field in the `MedicalMask` enum);
- The face is occluded with something (see `MedicalMask::OccludedFace` field in the `MedicalMask` enum);

#### 6.8.5 Medical Mask Extended Estimation

This estimator aims to detect a medical face mask on the face in the source image. It can return the next results:

- A medical mask is on the face (see `MedicalMaskExtended::Mask` field in the `MedicalMask` enum);
- There is no medical mask on the face (see `MedicalMaskExtended::NoMask` field in the `MedicalMask` enum);
- A medical mask is not on the right place (see `MedicalMaskExtended::MaskNotInPlace` field in the `MedicalMask` enum);
- The face is occluded with something (see `MedicalMaskExtended::OccludedFace` field in the `MedicalMask` enum);

The estimator (see `IMedicalMaskEstimator` in `IEstimator.h`):

- Implements the `estimate()` function that accepts source warped image in R8G8B8 format and `MedicalMaskEstimation` structure to return results of estimation;
- Implements the `estimate()` function that accepts source image in R8G8B8 format, face detection to estimate and `MedicalMaskEstimation` structure to return results of estimation;
- Implements the `estimate()` function that accepts `fsdk::Span` of the source warped images in R8G8B8 format and `fsdk::Span` of the `MedicalMaskEstimation` structures to return results of estimation;
- Implements the `estimate()` function that accepts `fsdk::Span` of the source images in R8G8B8 format, `fsdk::Span` of face detections and `fsdk::Span` of the `MedicalMaskEstimation` structures to return results of the estimation.
- Implements the `estimate()` function that accepts source warped image in R8G8B8 format and `MedicalMaskEstimationExtended` structure to return results of estimation;
- Implements the `estimate()` function that accepts source image in R8G8B8 format, face detection to estimate and `MedicalMaskEstimationExtended` structure to return results of estimation;
- Implements the `estimate()` function that accepts `fsdk::Span` of the source warped images in R8G8B8 format and `fsdk::Span` of the `MedicalMaskEstimationExtended` structures to return results of estimation;
- Implements the `estimate()` function that accepts `fsdk::Span` of the source images in R8G8B8 format, `fsdk::Span` of face detections and `fsdk::Span` of the `MedicalMaskEstimationExtended` structures to



return results of the estimation.

The estimator was implemented for two use-cases:

1. When the user already has warped images. For example, when the medical mask estimation is performed right before (or after) the face recognition;
2. When the user has face detections only.

Calling the *estimate()* method with warped image and the *estimate()* method with image and detection for the same image and the same face could lead to different results.

#### 6.8.5.1 MedicalMaskEstimator thresholds

The estimator returns several scores - one for each possible result. The final result calculated based on that scores and thresholds. If some score is above the corresponding threshold, that result is estimated as final. The default values for all thresholds are taken from the configuration file. See Configuration guide for details.

#### 6.8.5.2 MedicalMask enumeration

The MedicalMask enumeration contains all possible results of the MedicalMask estimation:

```
enum class MedicalMask {  
    Mask = 0,           //!< medical mask is on the face  
    NoMask,             //!< no medical mask on the face  
    OccludedFace        //!< face is occluded by something  
};
```

#### 6.8.5.3 MedicalMaskExtended enumeration

The MedicalMaskExtended enumeration contains all possible results of the MedicalMaskExtended estimation:

```
enum class MedicalMaskExtended {  
    Mask = 0,           //!< medical mask is on the face  
    NoMask,             //!< no medical mask on the face  
    MaskNotInPlace,     //!< mask is not on the right place  
    OccludedFace        //!< face is occluded by something  
};
```

#### 6.8.5.4 MedicalMaskEstimation structure

The MedicalMaskEstimation structure contains results of the estimation:

```

struct MedicalMaskEstimation {
    MedicalMask result;          //!< estimation result (@see MedicalMask
                                enum)
    // scores
    float maskScore;             //!< medical mask is on the face score
    float noMaskScore;           //!< no medical mask on the face score
    float occludedFaceScore;     //!< face is occluded by something score
};

```

There are two groups of the fields:

1. The first group contains only the result enum:

```
MedicalMask result;
```

Result enum field MedicalMaskEstimation contain the target results of the estimation.

2. The second group contains scores:

```

float maskScore;             //!< medical mask is on the face score
float noMaskScore;           //!< no medical mask on the face score
float occludedFaceScore;     //!< face is occluded by something score

```

The scores group contains the estimation scores for each possible result of the estimation. All scores are defined in [0,1] range. They can be useful for users who want to change the default thresholds for this estimator. If the default thresholds are used, the group with scores could be just ignored in the user code.

#### 6.8.5.5 MedicalMaskEstimationExtended structure

The MedicalMaskEstimationExtended structure contains results of the estimation:

```

struct MedicalMaskEstimationExtended {
    MedicalMaskExtended result;    //!< estimation result (@see
                                   MedicalMaskExtended enum)
    // scores
    float maskScore;               //!< medical mask is on the face score
    float noMaskScore;             //!< no medical mask on the face score
    float maskNotInPlace;          //!< mask is not on the right place
    float occludedFaceScore;       //!< face is occluded by something score
};

```

There are two groups of the fields:

1. The first group contains only the result enum:

```
MedicalMaskExtended result;
```

Result enum field MedicalMaskEstimationExtended contain the target results of the estimation.

2. The second group contains scores:

```
float maskScore;           //!< medical mask is on the face score
float noMaskScore;         //!< no medical mask on the face score
float maskNotInPlace;      //!< mask is not on the right place
float occludedFaceScore;   //!< face is occluded by something score
```

The scores group contains the estimation scores for each possible result of the estimation. All scores are defined in [0,1] range. They can be useful for users who want to change the default thresholds for this estimator. If the default thresholds are used, the group with scores could be just ignored in the user code.

**Note.** The estimator is trained to work with face images that meet the following requirements:

**Table 21:** “Requirements for fsdk::BestShotQualityEstimator::EstimationResult”

Attribute	Acceptable values
headPose.pitch	[-40...40]
headPose.yaw	[-40...40]
headPose.roll	[-40...40]
ags	[0.5...1.0]

## 7 Descriptor Processing Facility

### 7.1 Overview

The section describes descriptors and all the processes and objects corresponding to them.

Descriptor itself is a set of object parameters that are specially encoded. Descriptors are typically more or less invariant to various affine object transformations and slight color variations. This property allows efficient use of such sets to identify, lookup, and compare real-world objects images.

To receive a descriptor you should perform a special operation called descriptor *extraction*.

The general case of descriptors usage is when you compare two descriptors and find their similarity score. Thus you can identify persons by comparing their descriptors with your descriptors database.

All descriptor comparison operations are called *matching*. The result of the two descriptors matching is a distance between components of the corresponding sets that are mentioned above. Thus, from a magnitude of this distance, we can tell if two objects are presumably the same.

There are two different tasks solved using descriptors: person identification and person reidentification.

#### 7.1.1 Person Identification Task

Facial recognition is the task of making an identification of a face in a photo or video image against a pre-existing database of faces. It begins with detection - distinguishing human faces from other objects in the image - and then works on the identification of those detected faces. To solve this problem, we use a face descriptor, which extracted from an image face of a person. A person's face is invariable throughout his life.

In a case of the face descriptor, the extraction is performed from object image areas around some previously discovered facial landmarks, so the quality of the descriptor highly depends on them and the image it was obtained from.

The process of face recognition consists of 4 main stages:

- face detection in an image;
- warping of face detection – compensation of affine angles and centering of a face;
- descriptor extraction;
- comparing of extracted descriptors (matching).

Additionally you can extract face features (gender, age, emotions, etc) or image attributes (light, dark, blur, specularity, illumination, etc.).

#### 7.1.2 Person Reidentification Task

**Note!** This functionality is experimental.

The person reidentification enables you to detect a person who appears on different cameras. For example, it is used when you need to track a human, who appears on different supermarket cameras. Reidentification can be used for:

- building of human traffic warm maps;
- analysing of visitors movement across cameras network;
- tracking of visitors across cameras network;
- search for a person across the cameras network in case when face was not captured (e.g. across CCTV cameras in the city);
- etc.

For reidentification purposes, we use so-called human descriptors. The extraction of the human descriptor is performed using the detected area with a person's body on an image or video frame. The descriptor is a unique data set formed based on a person's appearance. Descriptors extracted for the same person in different clothes will be significantly different.

The face descriptor and the human descriptor are almost the same from the technical point of view, but they solve fundamentally different tasks.

The process of reidentifications consists of the following stages:

- human detection in an image;
- warping of human detection – centering and cropping of the human body;
- descriptor extraction;
- comparing of extracted descriptors (matching).

The human descriptor does not support the *descriptor score* at all. The returned value of the descriptor score is always equal to 1.0.

The human descriptor is based on to the following criteria:

- clothes (type and color);
- shoes;
- accessories;
- hairstyle;
- body type;
- anthropometric parameters of the body.

**Note.** The human reidentification algorithm is trained to work with input data that meets the following requirements:

- input images should be in R8G8B8 format (will work worse in night mode);
- the smaller side of input crop should be greater than 60 px;
- inside of same crop, one person should occupy more than 80% (sometimes several persons fit into the same frame).

## 7.2 Descriptor

Descriptor object stores a compact set of packed properties as well as some helper parameters that were used to extract these properties from the source image. Together these parameters determine descriptor compatibility. Not all descriptors are compatible with each other. It is impossible to batch and match incompatible descriptors, so you should pay attention to what settings do you use when extracting them. Refer to section “[Descriptor extraction](#)” for more information on descriptor extraction.

### 7.2.1 Descriptor Versions

Face descriptor algorithm evolves with time, so newer FaceEngine versions contain improved models of the algorithm.

Descriptors of different versions are **incompatible**! This means that you **cannot match descriptors with different versions**. This does not apply to base and mobilenet versions of the same model: they are compatible.

See chapter “[Appendix A. Specifications](#)” for details about performance and precision of different descriptor versions.

Descriptor version 59 is the best one by precision. And it works well Personal protective equipment on face like medical mask.

Descriptor version may be specified in the configuration file (see section “[Configuration data](#)” in chapter “Core facility”).

#### 7.2.1.1 Face descriptor

Currently next versions are available: 54, 56, 57, 58 and 59. Descriptors have **backend** and **mobilenet** implementations. Versions 57, 58 and 59 supports only **backend** implementation. Backend versions more precise, but mobilenet faster and have smaller model files (See Appendix A). Version 59 is the most precise.

See Appendix A.1 and A.2 for details about performance and precision of different descriptor versions.

#### 7.2.1.2 Human descriptor

Currently, only three versions of human descriptors are available: 102, 103, 104

To create a human descriptor, human batch, human descriptor extractor, human descriptor matcher you must pass the human descriptor version

- DV\_MIN\_HUMAN\_DESCRIPTOR\_VERSION = 102 or
- HDV\_TRACKER\_HUMAN\_DESCRIPTOR\_VERSION = 102, //!< human descriptor for tracking of people on one camera, light and fast version

- HDV\_PRECISE\_HUMAN\_DESCRIPTOR\_VERSION = 103, //!< precise human descriptor, heavy and slow
- HDV\_REGULAR\_HUMAN\_DESCRIPTOR\_VERSION = 104, //!< regular human descriptor, use it by default for multi-cameras tracking

### 7.3 Descriptor Batch

When matching significant amounts of descriptors, it is desired that they reside continuously in memory for performance reasons (think cache-friendly data locality and coherence). This is where descriptor batches come into play. While descriptors are optimized for faster creation and destruction, batches are optimized for long life and better descriptor data representation for the hardware.

A batch is created by the factory like any other object. Aside from type, a size of the batch should be specified. Size is a memory reservation this batch makes for its data. It is impossible to add more data than specified by this reservation.

Next, the batch must be populated with data. You have the following options:

- add an existing descriptor to the batch;
- load batch contents from an archive.

The following notes should be kept in mind:

- When adding an existing descriptor, its data is copied into the batch. This means that the descriptor object may be safely released.
- When adding the first descriptor to an empty batch, initial memory allocation occurs. Before that moment the batch does not allocate. At the same moment, internal descriptor helper parameters are copied into the batch (if there are any). This effectively determines compatibility possibilities of the batch. When the batch is initialized, it does not accept incompatible descriptors.

After initialization, a batch may be matched pretty much the same way as a simple descriptor.

Like any other data storage object, a descriptor batch implements the `::clear()` method. An effect of this method is the batch translation to a non-initialized state **except memory deallocation**. In other words, batch capacity stays the same, and no memory is reallocated. However, an actual number of descriptors in the batch and their parameters are reset. This allows re-populating the batch.

Memory deallocation takes place when a batch is released.

Care should be taken when serializing and deserializing batches. When a batch is created, it is assigned with a fixed-size memory buffer. The size of the buffer is embedded into the batch BLOB when it is saved. So, when allocating a batch object for reading the BLOB into, make sure its size is at least the same as it was for the batch saved to the BLOB (even if it was not full at the moment). Otherwise, loading fails. Naturally, it is okay to deserialize a smaller batch into a larger another batch this way.

## 7.4 Descriptor Extraction

Descriptor extractor is the entity responsible for descriptor extraction. Like any other object, it is created by the factory. To extract a descriptor, aside from the source image, you need:

- a face detection area inside the image (see chapter “[Detection facility](#)”)
- a pre-allocated descriptor (see section “[Descriptor](#)”)
- a pre-computed landmarks (see chapter “[Image warping](#)”)

A descriptor extractor object is responsible for this activity. It is represented by the straightforward *IDescriptorExtractor* interface with only one method *extract()*. Note, that the descriptor object must be created prior to calling *extract()* by calling an appropriate factory method.

Landmarks are used as a set of coordinates of object points of interest, that in turn determine source image areas, the descriptor is extracted from. This allows extracting only data that matters most for a particular type of object. For example, for a human face we would want to know at least definitive properties of eyes, nose, and mouth to be able to compare it to another face. Thus, we should first invoke a feature extractor to locate where eyes, nose, and mouth are and put these coordinates into landmarks. Then the descriptor extractor takes those coordinates and builds a descriptor around them.

Descriptor extraction is one of the most computation-heavy operations. For this reason, threading might be considered. Be aware that descriptor extraction is not thread-safe, so you have to create an extractor object per a worker thread.

It should be noted, that the face detection area and the landmarks are required only for image warping, the preparation stage for descriptor extraction (see section “[Image warping](#)”). If the source image is already warped, it is possible to skip these parameters. For that purpose, the *IDescriptorExtractor* interface provides a special *extractFromWarpedImage()* method.

Descriptor extraction implementation supports execution on GPUs.

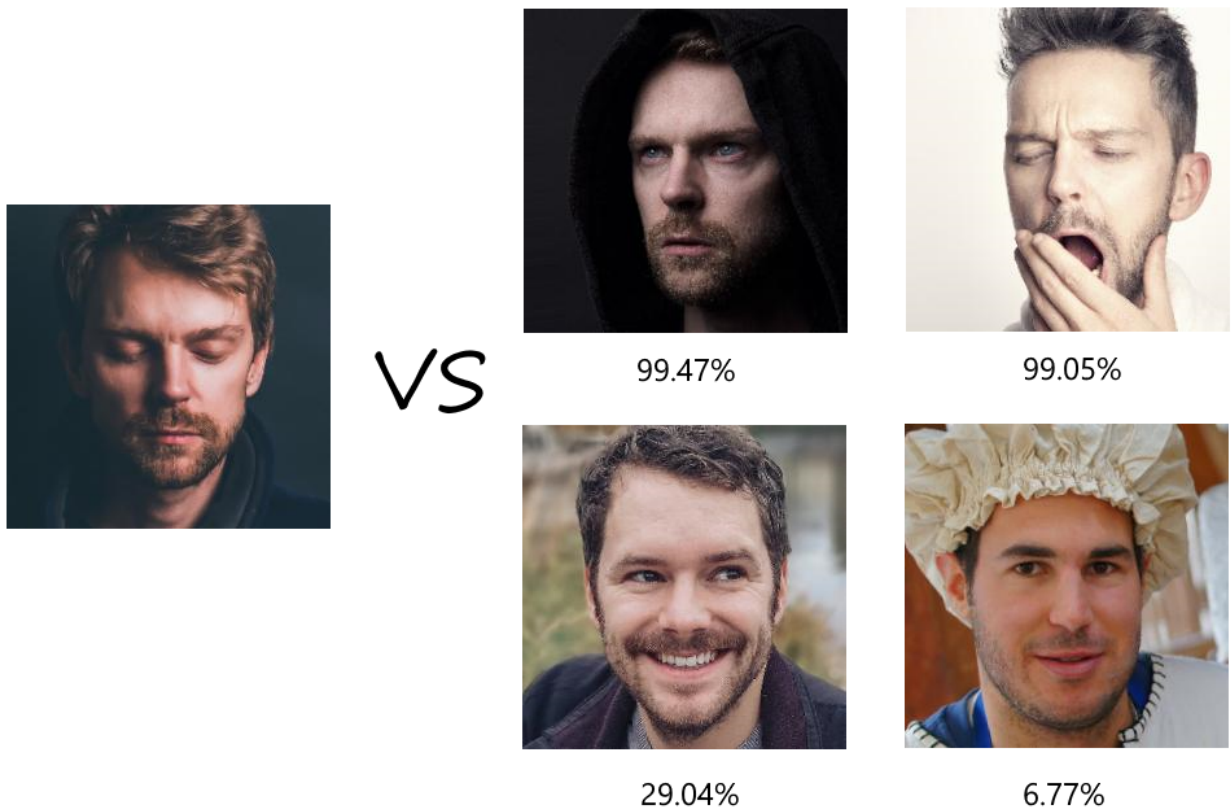
The *IDescriptorExtractor* interface provides *extractFromWarpedImageBatch()* method which allows you to extract batch of descriptors from the image array in one call. This method achieve higher utilization of GPU and better performance (see the “GPU mode performance” table in appendix A chapter “Specifications”).

Also *IDescriptorExtractor* returns *descriptor score* for each extracted descriptor. Descriptor score is normalized value in range [0,1], where 1 - face in the warp, 0 - no face in the warp. This value allows you filter descriptors extracted from false positive detections.

## 7.5 Descriptor Matching

It is possible to match a pair (or more) previously extracted descriptors to find out their similarity. With this information, it is possible to implement face search and other analysis applications.





**Figure 14:** Matching

By means of *match* function defined by the *IDescriptorMatcher* interface it is possible to match a pair of descriptors with each other or a single descriptor with a descriptor batch (see section “[Descriptor batch](#)” for details on batches).

A simple rule to help you decide which storage to opt for:

- when searching among less than a hundred descriptors use separate *IDescriptor* objects;
- when searching among bigger number of descriptors use a batch.

When working with big data, a common practice is to organize descriptors in several batches keeping a batch per worker thread for processing.

Be aware that descriptor matching is not thread-safe, so you have to create a matcher object per a worker thread.

## 7.6 Descriptor Indexing

### 7.6.1 Using HNSW

In order to accelerate the descriptor matching process, a **special index** may be created for a descriptor batch. With the index, matching becomes a two-stage process:

- First, you need to build indexed data structure - index - using *IIndexBuilder*. This is quite slow process so it is not supposed to be done frequently. You build it by appending *IDescriptor* objects or *IDescriptorBatch* objects and finally using build method - *IIndexBuilder::buildIndex*;
- Once you have index, you can use it to search nearest neighbors for passed descriptor very fast.

There are two types of indexes: *IDenseIndex* and *IDynamicIndex*. The interface difference is very simple: dense index is read only and dynamic index is editable: you can append or remove descriptors.

You can only build a dynamic index. So how can you get a dense index? The answer is through deserialization. Imagine you have several processes that might need to search in index. One option is for every one of them to build index separately, but as mentioned before building of index is very slow and you probably don't want to do it more than needed. So the second option is to build it once and serialize it to file. This is where the dense and dynamic difference arises: formats used to store these two types of index are different. From the user's point of view, the difference is that dense index loads faster, but it is read only. Once loaded, there are no performance difference in terms of searching on these two types of indexes.

To serialize index use *IDynamicIndex::saveToDenseIndex* or *IDynamicIndex::saveToDynamicIndex* methods. To deserialized use *IFaceEngine::loadDenseIndex* or *IFaceEngine::loadDynamicIndex*.

Index files are not cross-platform. If you serialize index on some platform, it's only usable on that exact platform. Not only the operating system breaks compatibility, but also different architecture of CPU might break it.

HNSW index isn't supported on embedded and 32-bit desktop platforms.

## 8 System Requirements

### 8.1 Android installations

FaceEngine requires:

- Android version 4.4.4 or newer.

For development:

- Android SDK 21;
- Android NDK 21 {Pkg.Revision = 21.0.6113669}.

Android development dependencies listed above can be downloaded directly from SDK manager in Android Studio IDE or via SDK manager command line tool. For more information, please visit <https://developer.android.com/studio/command-line/sdkmanager>.

## 9 Hardware requirements

### 9.1 Embedded installations

#### 9.1.1 CPU requirements

Supported CPU architectures:

- ARMv7-A;
- ARMv8-A (ARM64).

### 9.2 Android for embedded

One more step to online activation process, in addition to information about LUNA SDK licensing, described in **VisionLabs LUNA SDK Licensing**, paragraph **License activation**.

Besides the common steps for online-activation, described in document **VisionLabs LUNA SDK Licensing**, for **Android for embedded** systems, execute a native licensed binary for **Android for embedded** with **root permissions** at least once.

## 10 Migration guide

### 10.1 Overview

Here you can find information about important changes in the next releases of LUNA SDK.

### 10.2 v.5.5.0

From v.5.5.0 the default value of numThreads (runtime.conf) was replaced by -1. Which means that will be taken the maximum number of available threads. This number of threads is equal to according number of available processor cores.

Example of setting (before version 5.5.0):

```
<param name="numThreads" type="Value::Int1" x="4" />
```

Example of setting (from version 5.5.0):

```
<param name="numThreads" type="Value::Int1" x="-1" />
```

From v.5.5.0 the method loadFromFile(const char\* path) (See ILicense.h) is deprecated. The use is allowed, but can be useless. Please use the method loadFromFile(const char\* path, const fsdk::ISettingsProvider\* settings) instead.

#### 10.2.0.1 Examples of code

Example of code (before version 5.5.0):

```
const bool isLicenseFileLoadedSuccessfully = license->loadFromFile(path)
    .isOk();
```

Example of code (from version 5.5.0):

```
auto resSettings = fsdk::createSettingsProvider("License Config Path");
if (!resSettings.isOk()) {
    return -1;
}

fsdk::ISettingsProviderPtr settings = resSettings.getValue();

// Create new license from file
const bool isLicenseFileLoadedSuccessfully = license->loadFromFile(path,
    settings).isOk();
```

### 10.3 v.5.2.0

From v.5.2.0 the 101 version of human descriptor is not supported, it was changed by 104. Currently, three versions are available: 102 (tracker), 103 (precise), 104 (regular). It means that all instances (such as `IDescriptorExtractor`, `IDescriptorMatcher` and etc.) cannot be created with the version 101.

### 10.4 v.5.1.0

From version v.5.1.0 `IHeadPoseEstimatorPtr` and `IAGSEstimatorPtr` are deprecated. Use `IBestShotQualityEstimatorPtr` instead.

**Note.** AGS score thresholds are different for `IAGSEstimatorPtr` and `IBestShotQualityEstimatorPtr`. Read more on the [BestShotQuality](#) estimation page.

### 10.5 v.5.0.0

#### 10.5.1 Objects creation

The `fsdk::acquire(...)` method for the pointer acquiring for `IFaceEngine` objects is not allowed for usage starting from version 5.0.0. In addition, the types of values returned from the create methods of `IFaceEngine` were changed.

Most of the create methods now return the following structure - `fsdk::ResultValue<fsdk::FSDKError, ObjectClassPtr>`. Thus it is easy to check the correctness of the result (using one of the following methods `result.isOk()` or `result.isError()`) and get an error (using the `result.getError()` method). The `result.what()` method can be used to get the text description of the error.

##### 10.5.1.1 Examples of code

Example of code (before version 5.0.0):

```
fsdk::IAttributeEstimatorPtr estimator = fsdk::acquire(faceEngine->
    createAttributeEstimator());
if (estimator.isNull()) {
    std::cout << "Object pointer is nullptr" << std::endl;
    ... // process error
}
```

Example of code (from version 5.0.0):

```
fsdk::ResultValue<fsdk::FSDKError, fsdk::IAttributeEstimatorPtr>
    resEstimator = faceEngine->createAttributeEstimator();
```

```

if (resEstimator.isError()) {
    std::cout << "Error: " << resEstimator.what() << std::endl;
    ... // process error
}

fsdk::IAttributeEstimatorPtr estimator = resEstimator.getValue();

```

### 10.5.2 Interface of ILicense

From version v.5.0.0 we changed the interface of `ILicense`. Now all methods of this class return `fsdk::Result<fsdk::FSDKError>`, `fsdk::ResultValue<fsdk::FSDKError, bool>` or `fsdk::ResultValue<fsdk::FSDKError, uint32_t>` instead of `bool`.

#### 10.5.2.1 Examples of code

Example of code (before version 5.0.0):

```

const bool res = license->isActivated();
if (!res) {
    /* error case code */
}

```

Example of code (from version 5.0.0):

```

const fsdk::ResultValue<fsdk::FSDKError, bool> result = license->
    isActivated();
if (result.isError()) {
    /* error case code */
}

const bool value = result.getValue();
if (!value) {
    /* false case code */
}

```

From version v.5.0.0 we changed the arguments of methods `getExpirationDate` and `checkFeatureId` in class `ILicense`. Now the input arguments of `getExpirationDate` and `checkFeatureId` is `fsdk::LicenseFeature` instead of `uint32_t`. And the second argument of `getExpirationDate` was removed. The return value of `getExpirationDate` is `fsdk::ResultValue<fsdk::FSDKError, uint32_t>`.

Example of code (before version 5.0.0):

```

long long expDate = 0;
const bool result =
    license->getExpirationDate(static_cast<uint32_t>(fsdk::
        LicenseFeature::Detection), expDate);

if (result == false) {
    /* error case code */
}

```

Example of code (from version 5.0.0):

```

const fsdk::ResultValue<fsdk::FSDKError, uint32_t> result =
    license->getExpirationDate(fsdk::LicenseFeature::Detection);

if (result.isError()) {
    /* error case code */
}

const uint32_t expDate = result.getValue();

```

Example of code (before version 5.0.0):

```

const bool res = license->checkFeatureId(static_cast<uint32_t>(fsdk::
    LicenseFeature::Detection));
if (!res) {
    /* error case code */
}

```

Example of code (from version 5.0.0):

```

const fsdk::ResultValue<fsdk::FSDKError, bool> result = license->
    checkFeatureId(fsdk::LicenseFeature::Detection);
if (result.isError()) {
    /* error case code */
}

const bool value = result.getValue();
if (!value) {
    /* false case code */
}

```

### 10.5.3 Interface of HumanLandmark

From version v.5.0.0 we changed the interface of HumanLandmark. Now member point doesn't store zero coordinates in the case when it is not visible. For this purposes we added member visible which stores true if point is visible.

Example of code (before version 5.0.0):

```
if (humanLandmark.point.x == 0 && humanLandmark.point.y == 0) {  
    // point is not visible case code  
}  
else {  
    // point is visible case code  
}
```

Example of code (from version 5.0.0):

```
if (humanLandmark.visible == false) {  
    // point is not visible case code  
}  
else {  
    // point is visible case code  
}
```

### 10.5.4 Interface of IDescriptorBatch

From version v.5.0.0 we renamed method IDescriptorBatch::getDescriptorSize() to IDescriptorBatch::getDescriptorLength().

Example of code (before version 5.0.0):

```
uint32_t descriptorLength = descriptorBatch->getDescriptorSize();
```

Example of code (from version 5.0.0):

```
uint32_t descriptorLength = descriptorBatch->getDescriptorLength();
```

### 10.5.5 Interface of Detection

From version v.5.0.0 we changed the interface of the Detection structure. Now all members of this structure are private and could be available through the public methods.



Example of code (before version 5.0.0):

```
fsdk::Detection detection = ...; // Somehow initialized detection object
fsdk::Rect rect = detection.rect; // Get the detection rect
float score = detection.score; // Get the detection score
```

Example of code (from version 5.0.0):

```
fsdk::Detection detection = ...; // Somehow initialized detection object
fsdk::Rect rect = detection.getRect(); // Get the detection rect
float score = detection.getScore(); // Get the detection score
```

### 10.5.6 Interface of IDetector

From version v.5.0.0 we changed the interface of IDetector structure. Now method detect returns `ResultValue<FSDKError, Ref<IFaceDetectionBatch>>` instead of `ResultValue<FSDKError, Ref<IResultBatch<Face>>>`.

Example of code (before version 5.0.0):

```
fsdk::ResultValue<fsdk::FSDKError, fsdk::Ref<fsdk::IResultBatch<fsdk::Face>>>
    detectorResult = faceDetector->detect(
        fsdk::Span<const fsdk::Image>(&image, 1),
        fsdk::Span<const fsdk::Rect>(&imageRect, 1),
        detectionsCount,
        fsdk::DT_ALL);
```

Example of code (from version 5.0.0):

```
fsdk::ResultValue<fsdk::FSDKError, fsdk::Ref<fsdk::IFaceDetectionBatch>>
    detectorResult = faceDetector->detect(
        fsdk::Span<const fsdk::Image>(&image, 1),
        fsdk::Span<const fsdk::Rect>(&imageRect, 1),
        detectionsCount,
        fsdk::DT_ALL);
```

Also we changed input and output parameters of the method `redetectOne`. Now it takes `Image` and `Detection` instead of `Face`. And returns `ResultValue<FSDKError, Face>` instead of `ResultValue<FSDKError, bool>`.

Example of code (before version 5.0.0):

```
fsdk::ResultValue<fsdk::FSDKError, bool> redetectResult = faceDetector->
    redetectOne(face);
```

Example of code (from version 5.0.0):

```
fsdk::ResultValue<fsdk::FSDKError, fsdk::Face> redetectResult = faceDetector
    ->redetectOne(image, detection);
```

### 10.5.7 IFaceDetectionBatch

We added IFaceDetectionBatch structure to replace IResultBatch<Face>.

Example of code (before version 5.0.0):

```
fsdk::Ref<IResultBatch<Face>> resultBatch = ...; // Somehow get the
IResultBatch<Face>
for (std::size_t i = 0; i < resultBatch->getSize(); ++i) {
    fsdk::Span<fsdk::Face> faces = resultBatch->getResults(i);
    for (auto& face : faces) {
        const fsdk::Rect& rect = face.detection.rect;
        const float score = face.detection.score;
        const fsdk::Landmarks5& lm5 = face.landmarks5.value();
        const fsdk::Landmarks68& lm68 = face.landmarks68.value();
        // Some code which uses received objects
    }
}
```

Example of code (from version 5.0.0):

```
fsdk::Ref<fsdk::IFaceDetectionBatch> faceDetectionBatch = ...; // Somehow
get the IFaceDetectionBatch
for (std::size_t i = 0; i < faceDetectionBatch->getSize(); ++i) {
    fsdk::Span<const fsdk::Detection> detections = faceDetectionBatch->
        getDetections(i);
    fsdk::Span<const fsdk::Landmarks5> landmarks5 = faceDetectionBatch->
        getLandmarks5(i);
    fsdk::Span<const fsdk::Landmarks68> landmarks68 = faceDetectionBatch->
        getLandmarks68(i);
    for (std::size_t j = 0; j < detections.size(); ++j) {
        const fsdk::Rect& rect = detections[j].getRect();
        const float score = detections[j].getScore();
        const fsdk::Landmarks5& lm5 = landmarks5[j];
```

```

        const fsdk::Landmarks68& lm68 = landmarks68[j];
        // Some code which uses received objects
    }
}

```

### 10.5.8 Interface of IHumanDetector

From version v.5.0.0 we changed the interface of IHumanDetector structure. Now method detect returns ResultValue<FSDKError, Ref<IHumanDetectionBatch>> instead of ResultValue<FSDKError, Ref<IResultBatch<Human>>>.

Example of code (before version 5.0.0):

```

fsdk::ResultValue<fsdk::FSDKError, fsdk::Ref<fsdk::IResultBatch<fsdk::Human>>>
    detectResult = humanDetector->detect(
        fsdk::Span<const fsdk::Image>(&image, 1),
        fsdk::Span<const fsdk::Rect>(&imageRect, 1),
        detectionsCount,
        fsdk::DCT_ALL);

```

Example of code (from version 5.0.0):

```

fsdk::ResultValue<fsdk::FSDKError, fsdk::Ref<fsdk::IHumanDetectionBatch>>
    detectResult = humanDetector->detect(
        fsdk::Span<const fsdk::Image>(&image, 1),
        fsdk::Span<const fsdk::Rect>(&imageRect, 1),
        detectionsCount,
        fsdk::HDT_ALL);

```

Also we changed input and output parameters of the method redetectOne. Now it takes Image and Detection instead of Human. And returns ResultValue<FSDKError, Human> instead of ResultValue<FSDKError, bool>.

Example of code (before version 5.0.0):

```

fsdk::ResultValue<fsdk::FSDKError, bool> redetectResult = humanDetector->
    redetectOne(human);

```

Example of code (from version 5.0.0):

```

fsdk::ResultValue<fsdk::FSDKError, fsdk::Human> redetectResult =
    humanDetector->redetectOne(image, detection);

```

### 10.5.9 IHumanDetectionBatch

We added IHumanDetectionBatch structure to replace IResultBatch<Human>.

Example of code (before version 5.0.0):

```
fsdk::Ref<IResultBatch<Human>> resultBatch = ...; // Somehow get the
IResultBatch<Human>
for (std::size_t i = 0; i < resultBatch->getSize(); ++i) {
    fsdk::Span<fsdk::Human> humans = resultBatch->getResults(i);
    for (auto& human : humans) {
        const fsdk::Rect& rect = human.detection.rect;
        const float score = human.detection.score;
        const fsdk::Landmarks17& lm17 = face.landmarks5.value();
        // Some code which uses received objects
    }
}
```

Example of code (from version 5.0.0):

```
const fsdk::Ref<fsdk::IHumanDetectionBatch> humanDetectionBatch = ...; //
Somehow get the IHumanDetectionBatch
for (std::size_t i = 0; i < humanDetectionBatch->getSize(); ++i) {
    fsdk::Span<const fsdk::Detection> detections = humanDetectionBatch->
        getDetections(i);
    fsdk::Span<const fsdk::HumanLandmarks17> landmarks = humanDetectionBatch
        ->getLandmarks17(i);
    for (std::size_t j = 0; j < detections.size(); ++j) {
        const fsdk::Rect rect = detections[j].getRect();
        const float score = detections[j].getScore();
        const fsdk::HumanLandmarks17 lm17 = landmarks[j];
        // Some code which uses received objects
    }
}
```

### 10.5.10 Interface of ILivenessFlyingFaces

From version v.5.0.0 we changed the interface of ILivenessFlyingFaces structure. Now both methods estimate take Image and Detection instead of Face.

Example of code (before version 5.0.0):

```
fsdk::LivenessFlyingFacesEstimation flyingFacesEstimation;
```

```
Result<fsdk::FSDKError> flyingFacesResult = livenessFlyingFacesEstimator->
    estimate(face, flyingFacesEstimation);
```

Example of code (from version 5.0.0):

```
fsdk::LivenessFlyingFacesEstimation flyingFacesEstimation;
Result<fsdk::FSDKError> flyingFacesResult = livenessFlyingFacesEstimator->
    estimate(
        image,
        detection,
        flyingFacesEstimation);
```

Example of code (before version 5.0.0):

```
Result<fsdk::FSDKError> flyingFacesResult = livenessFlyingFacesEstimator->
    estimate(
        fsdk::Span<const fsdk::Face>(&face, 1),
        fsdk::Span<fsdk::LivenessFlyingFacesEstimation>(&estimation, 1));
```

Example of code (from version 5.0.0):

```
fsdk::LivenessFlyingFacesEstimation flyingFacesEstimation;
Result<fsdk::FSDKError> flyingFacesResult = livenessFlyingFacesEstimator->
    estimate(
        fsdk::Span<const fsdk::Image>(&image, 1),
        fsdk::Span<const fsdk::Detection>(&detection, 1),
        fsdk::Span<fsdk::LivenessFlyingFacesEstimation>(&
            flyingFacesEstimation, 1));
```

## 10.6 v.3.10.1

### 10.6.1 Detector FaceDetV3 changes

From version 3.10.1 we changed the logic for image resizing in FaceDetV3 detector. Now you can change the minimum and maximum sizes of the faces that will be searched in the photo from the `faceengine.conf` configuration. To get new parameter which will be identical to old setting you need to set `minFaceSize`:

The old recommended `imageSize=640` will be identical to new meaning of setting `minFaceSize=20`

```
config->setValue("FaceDetV3::Settings", "minFaceSize", 20);
```

and `imageSize=320` will be identical to new meaning of setting `minFaceSize=40`

```
config->setValue("FaceDetV3::Settings", "minFaceSize", 40);
```

### 10.6.2 Detector FaceDetV1, FaceDetV2 changes

From version 3.10.1 we changed the name of parameter `minSize` to `minFaceSize` in `faceengine.conf` for FaceDetV1, FaceDetV2 detector types. The logic and default value for image resizing left unchanged.

## 11 Best practices

### 11.1 Overview

The following chapter provides a set of recommendations that user should follow in order to get optimal performance when running Luna SDK algorithms on their target device. Over time this list will be populated with more recommendations and performance tips.

#### 11.1.1 Multithread scenario

Creation and destroying Luna SDK algorithms from the different threads is prohibited due to internal implementation restrictions. All objects of the FaceEngine class and all objects of algorithms (for example, detectors, estimators, extractors and others) must be created and destroyed by the same thread. A typical scenario is as follows: Thread 1 (may be a main thread) creates the FaceEngine object and all needed algorithms (for example, IDetector). Threads 2..N (maybe several) uses that objects for any purpose. Thread 1 destroys the FaceEngine object and all algorithms after all work is complete.

#### 11.1.2 Thread pools

When running Luna SDK algorithms in a multithreaded environment it is highly recommended to use thread pools for user-created threads. For each thread Luna SDK caches some amount of thread local objects under the hood in order to make its algorithms run faster next time the same thread is used at the cost of higher memory footprint. For this reason, it is recommended to reuse threads from a pool in order to avoid caching new internal objects and to reduce penalty of creating/destroying new user threads.

#### 11.1.3 Estimators. Creation and Inference

Create face engine objects once and reuse them when you need to make a new estimate to reduce RAM usage and increase performance. The reason is that recreating of estimators leads to reopen the corresponding plan file every time. These plan files are cached separately for every load and will be removed only when they are flushed from the cache or after calling the destructor of FaceEngine root object.

#### 11.1.4 Forking process

UNIX-like operating systems implement a mechanism to duplicate a process. It creates a new child process and copies its parents' memory space into the child's. This is typically done programmatically by calling the fork() system function in the parent process. Care should be taken when forking a process running the SDK. Always fork before the first instance of IFaceEngine is created! This is because the SDK internally maintains a pool of worker threads, which is created lazily at the time the very first

IFaceEngine object is born and destroyed right after the last IFaceEngine object is released. When using GPU or NPU devices, their runtime is initialized and shut down in the same manner. The hazard comes from the fact that while `fork()` copies process memory, it only creates just one thread - the main thread (refer to man pages for details: <https://man7.org/linux/man-pages/man2/fork.2.html>). As a result, if at least one IFaceEngine object is alive at the time the process is being forked, the child processes will inherit the knowledge of the object, and therefore, the implicit thread pool (and device runtime, when appropriate). But there will be no worker threads actually running (in both, the inherited pool and the runtime, when appropriate) and attempting to call certain SDK functions will cause a deadlock.



## 12 Appendix A. Specifications

### 12.1 Classification performance

Classification performance was measured on a two datasets:

- Cooperative dataset ( containing 20K images from various sources obtained at several banks);
- Non cooperative dataset ( containing 20K ).

The two tables below contain true positive rates corresponding to select false positive rates.

**Table 22:** “Classification performance @ low FPR on cooperative dataset”

	TPR	TPR	TPR	TPR	TPR	TPR CNN	TPR CNN	TPR CNN
FPR	CNN 54	CNN 56	CNN 57	CNN 58	CNN 59	54m	56m	59m
$10^{-7}$	0.9765	0.9907	0.9906	0.9910	0.9911	0.9699	0.9652	0.9876
$10^{-6}$	0.9849	0.9914	0.9915	0.9916	0.9915	0.9829	0.9814	0.9904
$10^{-5}$	0.9892	0.9916	0.9917	0.9918	0.9919	0.9887	0.9886	0.9915
$10^{-4}$	0.9909	0.9917	0.9918	0.9919	0.9921	0.9910	0.9910	0.9919

**Table 23:** “Classification performance @ low FPR on non cooperative dataset”

	TPR	TPR	TPR	TPR	TPR	TPR CNN	TPR CNN	TPR CNN
FPR	CNN 54	CNN 56	CNN 57	CNN 58	CNN 59	54m	56m	59m
$10^{-7}$	0.9638	0.9698	0.9723	0.9767	0.9832	0.8813	0.8844	0.9377
$10^{-6}$	0.9773	0.9809	0.9817	0.9839	0.9880	0.9233	0.9229	0.9629
$10^{-5}$	0.9852	0.9871	0.9873	0.9880	0.9908	0.9538	0.9561	0.9794
$10^{-4}$	0.9896	0.9902	0.9905	0.9909	0.9924	0.9752	0.9757	0.9880

### 12.2 Descriptor size

The table below shows size of serialized descriptors to estimate memory requirements.

**Table 24:** “Descriptor size”

Descriptor version	Data size (bytes)	Metadata size (bytes)	Total size
CNN 54	512	8	520

Metadata includes signature and version information that may be omitted during serialization if the *NoSignature* flag is specified.

When estimating individual descriptor size in memory or serialization storage requirements with default options, consider using values from the “Total size” column.

When estimating memory requirements for descriptor batches, use values from the “Data size” column instead, since a descriptor batch does not duplicate metadata per descriptor and thus is more memory-efficient.

These numbers are for approximate computation only, since they do not include overhead like memory alignment for accelerated SIMD processing and the like.

## 13 Appendix B. Glossary

**Table 25:** Glossary

Term	Description
Host memory	Computer system RAM
Device memory	On-board RAM of GPU or NPU card
Memory transfer	Operation that copies memory from host to device or vice-versa

### 13.1 Descriptor

A set of features meant to describe a real-world object (e.g., a person's face). Computed by means of computer vision algorithms, such features are typically matched to each other to determine the similarity of represented objects.

### 13.2 Cooperative Photoshooting and Recognition

A procedure of taking person face photograph characterized by person awareness of the matter and his/her will to assist.

Typical highlights:

- Close to frontal head pose;
- Neutral facial expression;
- No occlusions (i.e., hair, hats, non-transparent eyewear, hands, other objects obscuring the face);
- No extreme lighting conditions (i.e., reasonable illuminance, no direct sunlight);
- Steady and well-tuned optics (i.e., no motion blur, depth of field, digital post-processing except noise cancellation).

Cooperative photoshooting is opposite to the so-called “in the wild” photoshooting, which is also called non-cooperative shooting (or recognition).

### 13.3 Matching

The process of descriptors comparison. Matching is usually implemented as a distance function applied to the feature sets and distances comparison later on. The smaller the distance, the closer are descriptors, hence, the more similar are the objects.

For convenience, helper functions exist to convert distance to a normalized similarity score, where 100% means completely identical, and 0% means completely different.

## 14 Appendix C. FAQ

**Q: This document contains high-level descriptions and no code examples nor reference. Where can one find them?**

**A:** The complete type and function reference are provided as an interactive web-based documentation; see the *doc/fsdk/index.html* inside the LUNA SDK package. The examples are located in the */examples* folder and “ExamplesGuide.pdf” is located in */doc* folder of LUNA SDK package.

**Q: Does FaceEngine support multicore / multiprocessor systems?**

**A:** Yes, all internal algorithm implementations are multithreaded by design and take advantage of multi-core systems. The number of threads may be controlled via the configuration file; see configuration manual “ConfigurationGuide.pdf” or comments in the configuration file for details.

**Q: What is the state of GPU support?**

**A:** As of version 2.7 the GPU support is implemented for face detection and descriptor extraction algorithms. Starting from version 2.9 GPU implementations are considered stable.

**Q: What speedup may be expected from GPUs?**

**A:** Typically GPUs allow accelerating algorithms by the factor of 2-4 times depending on microprocessor architecture and input data.

**Q: Are there any official bindings/wrappers for other languages (C#, Java)?**

**A:** No, such bindings are not provided. FaceEngine officially implements C++ API only, bindings to other languages should be created by users themselves. There are tools to automate this process, like, e.g., SWIG.

**Q: Does FaceEngine support DBMS systems?**

**A:** No, FaceEngine implements just computer vision algorithms. Users should implement DBMS communication themselves using serialization methods described in section “[Serializable object interface](#)” of chapter “Core concepts” and section “[Archive interface](#)” of chapter “Core facility”.

**Q: What image formats does FaceEngine support?**

**A:** FaceEngine does not implement image format encoding functions. If such functions are required, one should use a third-party library, e.g., FreeImage.

FaceEngine functions typically expect image data in the form of uncompressed unencoded pixel data (RGB color 24 bits per pixel or grayscale 8 bits per pixel).

FaceEngine implements convenience functions like RGB -> grayscale and RGB<-> BGR color conversions. The rationale of this design is explained in section “[Image type](#)” of chapter “Core concepts”.