# libprofit Documentation

***Release 1.9.3***

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# Contents

*libprofit* is a C++ library that produces images based on different luminosity profiles.

# CHAPTER 1

# Getting *libprofit*

*libprofit* is currently hosted in GitHub. To get a copy you can clone the repository:

```
git clone https://github.com/ICRAR/libprofit
```

## 1.1 Compiling

*libprofit* depends on:

- GSL
- R

Both dependencies satisfy the same requirements, so they are mutually exclusive, but at least one of them is necessary. If both are present GSL takes precedence.

Optional requirements are:

- An OpenMP-enabled compiler
- An OpenCL installation
- FFTW

*libprofit*'s compilation system is based on cmake. `cmake` will check that you have a proper compiler (anything supporting some basic C++11 should do), and scan the system for all required dependencies.

To compile *libprofit* run (assuming you are inside the `libprofit` directory already):

```
$> mkdir build
$> cd build
$> cmake ..
$> make
$> # optionally for system-wide installation: sudo make install
```

With `cmake` you can also specify additional compilation flags. For example, if you want to generate the fastest possible code you can try this:

```
$> cmake .. -DCMAKE_CXX_FLAGS="-O3 -march=native"
```

You can also specify a different installation directory like this:

```
$> cmake .. -DCMAKE_INSTALL_PREFIX=~/my/installation/directory
```

Other `cmake` options that can be given in the command-line include:

- `LIBPROFIT_USE_R`: prefer R libraries over GSL libraries
- `LIBPROFIT_TEST`: enable compilation of unit tests
- `LIBPROFIT_DEBUG`: enable debugging-related code
- `LIBPROFIT_NO_OPENCL`: disable OpenCL support
- `LIBPROFIT_NO_OPENMP`: disable OpenMP support
- `LIBPROFIT_NO_FFTW`: disable FFTW support
- `LIBPROFIT_NO_SIMD`: disable SIMD extensions usage

Please refer to the `cmake` documentation for further options.

CHAPTER 2

# Using *libprofit*

## 2.1 From the command-line

*libprofit* ships with a command-line utility `profit-cli` that reads the model and profile parameters from the command-line and generates the corresponding image. It supports all the profiles supported by *libprofit*, and can output the resulting image as text values, a binary stream, or as a simple FITS file.

Run `profit-cli -h` for a full description on how to use it, how to specify profiles and model parameters, and how to control its output.

## 2.2 Programatically

As it name implies, *libprofit* also ships a shared library exposing an API that can be used by any third-party application. This section gives a brief overview on how to use this API. For a full reference please refer to *API*.

At the core of *libprofit* sits `Model`. This class holds all the information needed to generate an image. Different profiles (instances of `Profile`) are appended to the model, which is then evaluated.

The basic usage pattern then is as follows:

1. Add the profit include:

```
#include <profit/profit.h>
```

2. Initialize the library with the `init()` function. This needs to be called *only once* in your program:

```
profit::init();
```

3. First obtain a model instance that will generate profile images for a given width and height:

```
profit::Model model(width, height);
```

4. Create a profile. For a list of supported names see *Profiles*; if you want to support a new profile see *Adding a profile*. If an unknown name is given an `invalid_parameter` exception will be thrown:

```
profit::ProfilePtr sersic_profile = model.add_profile("sersic");
```

5. Customize your profile. To set the different parameters on your profile call *Profile::parameter()* with the parameter name and value:

```
sersic_profile.parameter("xcen", 34.67);
sersic_profile.parameter("ycen", 9.23);
sersic_profile.parameter("axrat", 0.345);
sersic_profile.parameter("nser=3.56");
// ...
```

   A complete list of parameters can be found on and *Profiles* and *API*.

6. Repeat the previous two steps for all profiles you want to include in your model.

7. Evaluate the model simply run:

```
profit::Image result = model.evaluate();
```

8. If the resulting image needs to be cropped (see *Image cropping* for full details) an additional argument needs to be passed to *Model::evaluate()* to receive the offset at which cropping needs to be, like this:

```
profit::Point offset;
profit::Image result = model.evaluate(offset);
profit::Image cropped_image = result.crop({width, height}, offset);
```

9. If there are have been errors while generating the image an *invalid_parameter* exception will be thrown by the code, so users might want to use a `try/catch` statement to identify these situations:

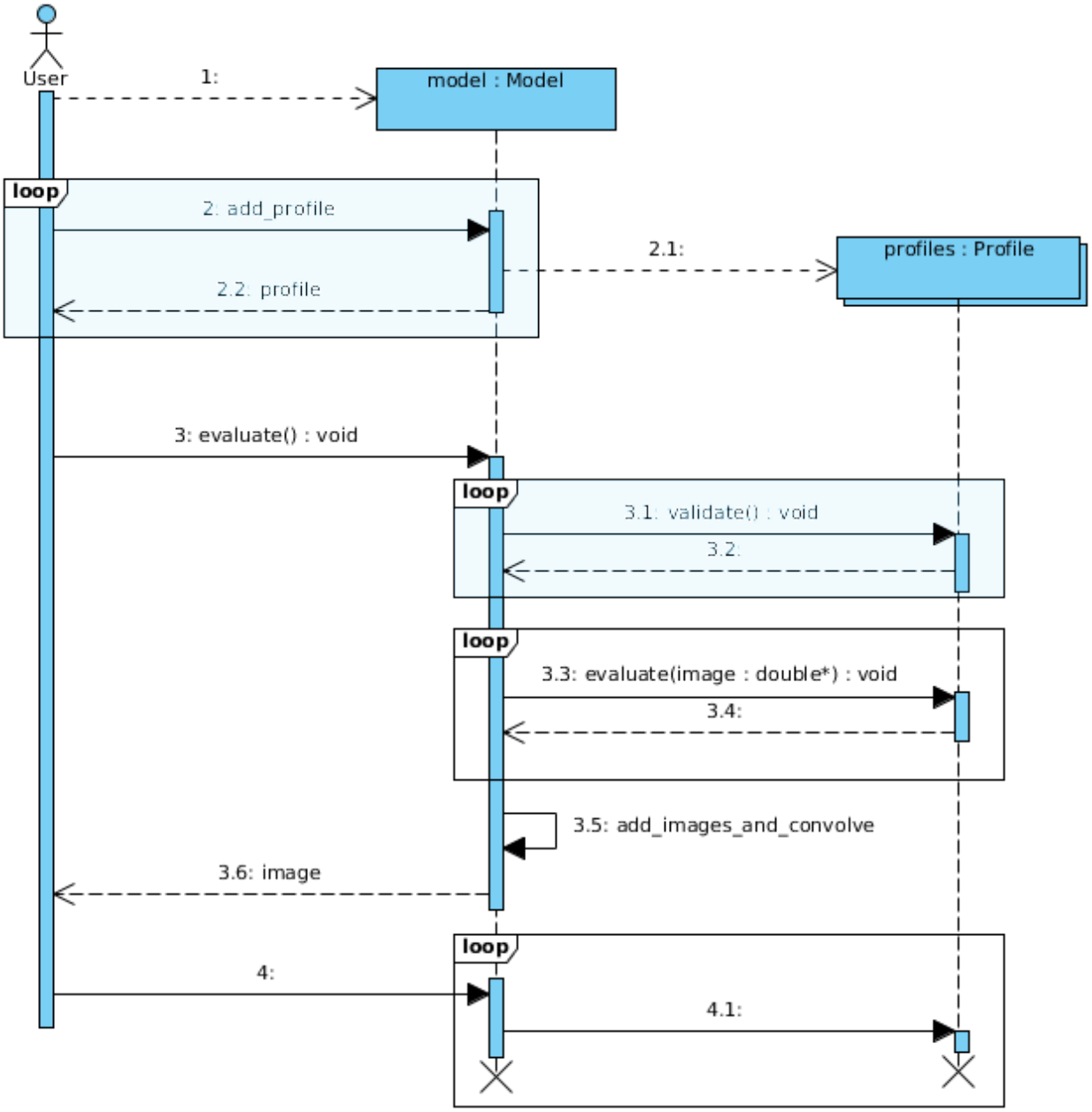
```
try {
    auto result = model.evaluate();
} catch (profit::invalid_parameter &e) {
    cerr << "Oops! There was an error evaluating the model: " << e.what() << endl;
}
```

10. When the model is destroyed the underlying profiles are destroyed as well.

11. When you are finished using the library, call the *finish()* function:

```
profit::finish();
```

To illustrate this process, refer to the following figure:


User
1:
model : Model
loop
2: add_profile
2.1:
profiles : Profile
2.2: profile
3: evaluate() : void
loop
3.1: validate() : void
3.2:
loop
3.3: evaluate(image : double*) : void
3.4:
3.5: add_images_and_convolve
3.6: image
loop
4:
4.1:

# CHAPTER 3

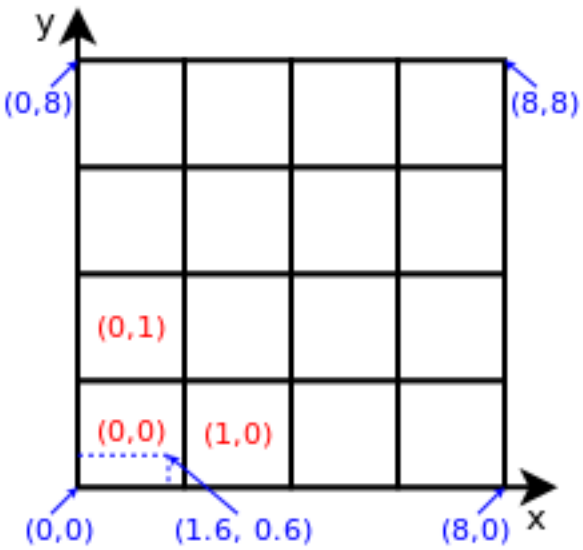
# Coordinates

*libprofit* differentiates pixels from actual image coordinates. Pixels are the individual dots that make up an image, but from the profiles' point of view the area where the image is drawn is a continuum coordinate space. Profiles use this coordinates to perform their calculations, as they are more fine grained than individual pixels.

At the model level there are two sets of parameters that control these two different aspects of the image:

- The `width` and `height` parameters indicate the width and height of the image in *numbers of pixels*.
- The `scale_x` and `scale_y` parameters indicate the horizontal and vertical scale to convert the `width` and `height` parameters into image coordinate sizes.

This is shown in the following example:




In the example an image is shown using both their pixels and their image coordinates. Each square on the grid represents a pixel on the image, which are indexed in red. This image's `width` is 4, and its `height` is also 4. Shown in blue on the other hand are the image coordinates. The image's `scale_x` is 2 and its `scale_y` is also 2. Finally a point is indicated in the image. Its image coordinates are `(1.6, 0.6)`, and is contained within the `(0,0)` pixel.

Profiles use image coordinate to perform their calculations but still need to store only one value per pixel. For this purpose the quantities `scale_x` and `scale_y` are stored by *libprofit* at the model level, making them available to all profiles to use. They indicate the width and height of each pixel in image coordinates. In most cases profiles evaluate a pixel's value using the pixel's center point in image coordinates; that is, evaluating at `x = i*scale_x + scale_x/2`, where `i` is the horizontal pixel index, and likewise for the vertical coordinate. In other cases, like in the `sersic` profile, sub-sampling needs to be performed to achieve an accurate result.

CHAPTER 4

# Profiles

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This section lists the profiles currently supported by *libprofit*.

## 4.1 sersic

An implementation of the Sersic luminosity profile. The sersic profile describes the intensity of a galaxy depending on its distance to the center.

The sersic profile accepts the following parameters:

- **xcen**: x centre of the Sersic profile (can be fractional pixel positions).
- **ycen**: y centre of the Sersic profile (can be fractional pixel positions).
- **mag**: Total magnitude of the Sersic profile. Converted to flux using `flux = 10^(-0.4*(mag - magzero))`, where `magzero` is that of the containing model.

- **re**: Effective radius
- **nser**: Sersic index of the Sersic profile.
- **ang**: The orientation of the major axis of the Sersic profile, in degrees. The starting point is the positive Y image axis and grows counter-clockwise.
- **axrat**: Axial ratio of the Sersic profile defined as minor-axis/major-axis, i.e. `axrat = 1` is a circle and `axrat = 0` is a line.
- **box**: The boxiness of the Sersic profile that traces contours of iso-flux, defined such that r = (x^(2+box)+y^(2+box))^(1/(2+box)). When `box = 0` the iso-flux contours will be normal ellipses, but modifications between `-1 < box < 1` will produce visually boxy distortions. Negative values have a pin-cushion effect, whereas positive values have a barrel effect (the major and minor axes staying fixed in all cases).

The sersic profile implements recursive sub-pixel sampling for better results in areas closer to the profile center. This sub-sampling can be controller by the following additional parameters:

- **rough**: Don't perform any sub-sampling, ignore the rest of the parameters.
- **rscale_switch**: Radius scale fraction within which sub-sampling is performed. Pixels outside this radius are not sub-sampled.
- **max_recursions**: The maximum levels of recursions allowed.
- **resolution**: Resolution (both horizontal and vertical) to be used on each new recursion level.
- **acc**: Accuracy after which recursion stops.

The sersic profile also implements far-pixel filtering, quickly zeroing pixels that are too far away from the profile center. This filtering can be controller by the following parameters:

- **rscale_max**: Maximum *re*-based distance to consider for filtering.
- **rescale_flux**: Whether the calculated profile flux should be scaled to take into account the filtering performed by **re_max**.

Finally, an **adjust** parameter allows the user whether adjustments of most of the parameters described above should be done automatically depending on the profile parameters. *libprofit* makes a reasonable compromise between speed and accuracy, and therefore this option is turned on by default.

## 4.2 `moffat`

The moffat profile works in exactly the same way as the sersic profile. It also supports sub-pixel sampling using the same parameters. Because of the nature of the profile the `re` and `nser` parameters from the `sersic` profiles are not present, and instead the following new parameters appear:

- **fwhm**: Full-width at half maximum of the profile across the major-axis of the intensity profile.
- **con**: Profile concentration.

## 4.3 `ferrer`

Again, the ferrer profile works in exactly the same way as the sersic profile. It replaces the `re` and `nser` parameters from the `sersic` profile with:

- **rout**: The outer truncation radius.
- **a**: The global power-law slope to the profile center

- **b**: The strength of truncation as the radius approaches **rout**.

## 4.4 coresersic

The coresersic profile works in exactly the same way as the sersic profile. In addition to the `re` and `nser` parameters from the `sersic` profile it also adds:

- **rb**: The transition radius of the sersic profile.
- **a**: The strength of the transition from inner core to outer sersic
- **b**: The inner power-law of the core sersic.

## 4.5 king

The king profile works in exactly the same way as the sersic profile. It replaces the `re` and `nser` parameters from the `sersic` profile with:

- **rc**: The effective radius of the sersic component.
- **rt**: The transition radius of the sersic profile
- **a**: The power-law of the King.

## 4.6 brokenexp

The broken exponential profile works in exactly the same way as the sersic profile. It replaces the `re` and `nser` parameters from the `sersic` profile with:

- **h1**: The inner exponential scale length.
- **h2**: The outer exponential scale length (must be equal to or less than `h1`).
- **rb**: The break radius.
- **a**: The strength of the truncation as the radius approaches `rb`.

## 4.7 sky

The sky profile provides a constant value for an entire image.

- **bg**: Value per pixel for the background. This should be the value as measured in the original image, i.e. there is no need to worry about the effect of the model's `magzero`.

## 4.8 psf

The psf profile adds the model's psf to the model's image at a specific location and for a given user-defined magnitude.

- **xcen**: The x position at which to generate the centred PSF (can be fractional pixels).
- **ycen**: The y position at which to generate the centred PSF (can be fractional pixels).
- **mag**: The total flux magnitude of the PSF.

## 4.9 null

The null profile leaves the image area untouched. It is only useful for testing purposes.

CHAPTER 5

# Convolution

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Image convolution in *libprofit* happens optionally as part of a `Model` evaluation. Internally, the `Model` uses a `Convolver` to perform convolution.

## 5.1 Supported convolution methods

Convolvers are objects that carry out convolution (via their `Convolver::convolve()` method). Depending on the size of the problem, and on the libraries available on the system, different convolver types will be available to be used:

- `BRUTE_OLD` is the simplest convolver. It implements a simple, brute-force 2D convolution algorithm.
- `BRUTE` is a brute-force convolver that performs better that `BRUTE_OLD`, but still implements simple, brute-force 2D convolution. It is the default convolver used by a `Model` that hasn't been assigned one, but requires one.
- `FFT` is a convolver that uses Fast Fourier transformations to perform convolution. Its complexity is lower than the `BRUTE`, but its creation can be more expensive.
- `OPENCL` is a brute-force convolver implemented in OpenCL. It offers both single and double floating-point precision and its performance is usually better that that of the `BRUTE`.

## 5.2 Creating a Convolver

Instead of manually selecting the class that should be used, users create *Convolver* instances via the *create_convolver()* function. *create_convolver()* lets the user specify which type of convolver should be created (either using an enumeration, or a standard string value), and a set of creation preferences that apply differently to different types of Convolvers.

If a *Model* needs to perform convolution and a *Convolver* has been set on its `Model::convolver` member then that convolver is used. If no convolver has been set, it creates a new *BRUTE* and uses that to perform the convolution.

## 5.3 Using a convolver

Once created, users can call the *Convolver::convolve()* method directly on the resulting convolver, (or assign it to a *Model* instance for it to use it). The *Convolver::convolve()* methods needs at least three parameters: an image, a kernel and a mask. Convolvers will convolve the image with the kernel only for the pixels in which the mask is set, or for all pixels if an empty mask is passed. This implies that the mask, if not empty, must have the same dimensions that the image.

## 5.4 Image cropping

Some convolvers internally work with images that are larger than the original source image (mostly due to efficiency reasons). After this internal image expansion occurs, and the convolution takes place, the resulting image is usually cropped at the corresponding point to match original source image size and positioning before being returned to the user.

However, users might want to pick into this internal, non-cropped result of the convolution process. To do this, an additional `crop` parameter in the *Convolver::convolve()* method determines whether the convolver should return the original, and potentially bigger, image. When a non-cropped image is returned, an additional `offset_out` parameter can be given to find out the offset at which cropping would have started. The cropping dimensions do not need to be queried, as they always are the same of the original source image given to the convolver.

## 5.5 Model convolution

During model evaluation (i.e., a call to *Model::evaluate()*) users might want to be able to retrieve the non-cropped result of the internal convolution that takes place during model evaluation (as explained in *Image cropping*).

To do this, users must first call *Model::set_crop()* with a `false` argument. When calling *Model::evaluate()*, users must then also give a *Point* argument to retrieve the offset at which cropping should be done to remove the image padding added by the convolution process.

CHAPTER 6

# Flux capturing

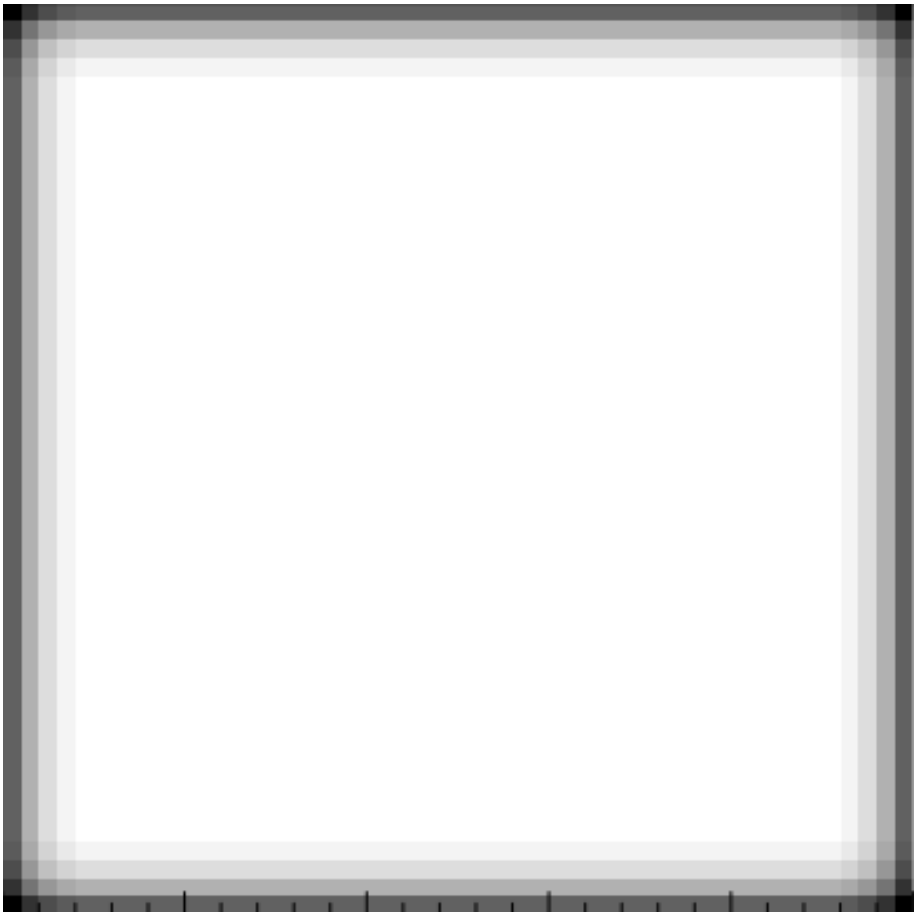
Flux capturing refers to the action of fully considering flux during the convolution process.

## 6.1 What is it

With no convolution taken into account, profiles already generate the correct luminosity for each pixel in their respective image. After that, if there is an extra convolution step the luminosity in these pixels gets spread out into their neighbours, and vice-versa.

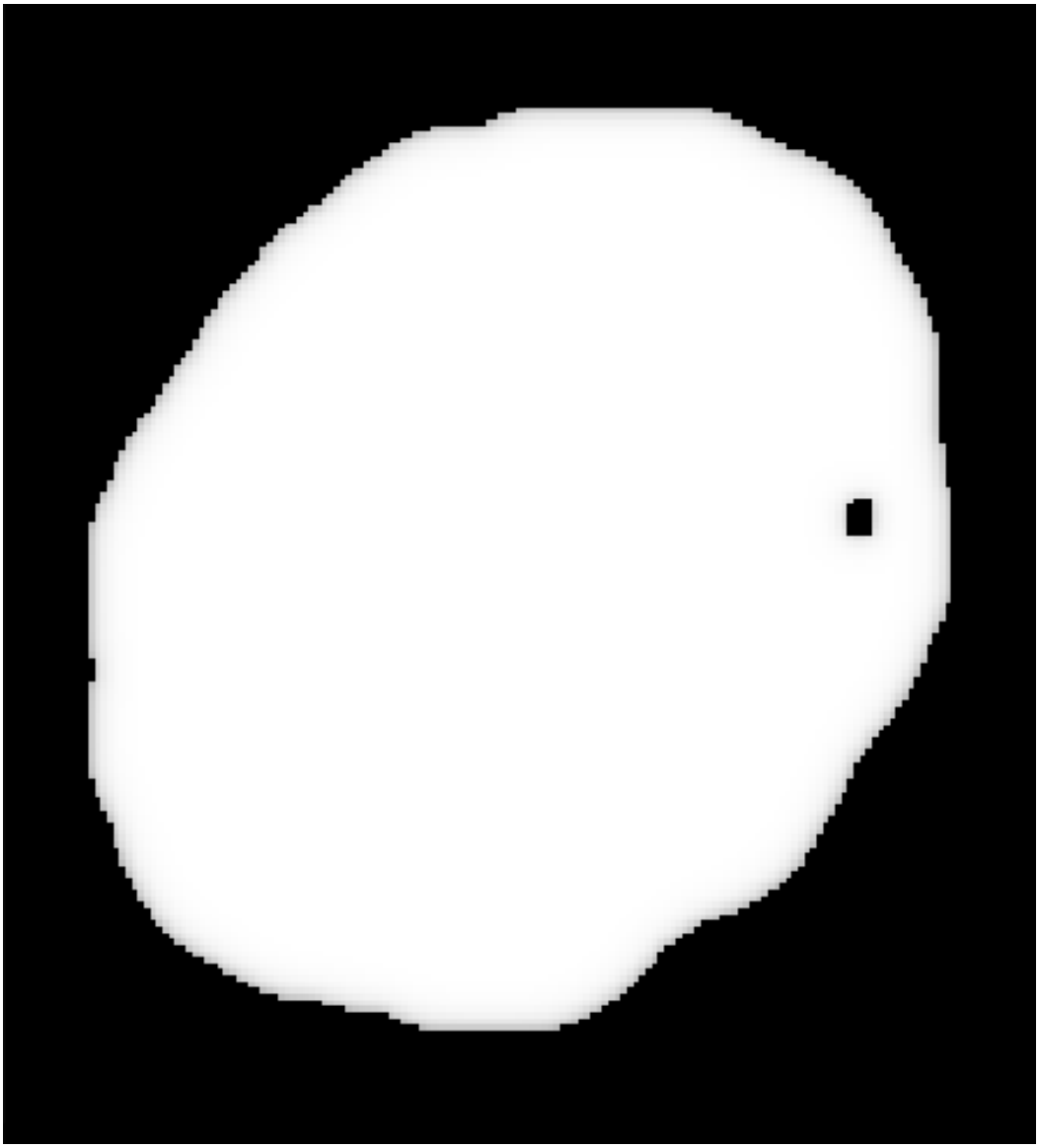
This is all and well, except when pixels are close to the edges of the image. When this happens, some of their neighbours are *outside* the image frame. Because they are outside, they had not been evaluated by the profiles, and their fluxes are considered to be 0. Therefore, when convolution happens for these pixels, their final luminosity will be less than what *would have been* if there was a value calculated for those pixels outside of the image.

This is better seen graphically. Here is an example of a plain image (using a *sky* profile) after convolution with a simple, gaussian-like PSF:



In this image, it is very clear how the pixels at the boundaries of the image frame are loosing flux during convolution. Again, this is because pixels *outside the image* have no flux, and therefore don't contribute to the flux of the pixels within the image after convolution.

A similar situation happens when there is a Mask involved:



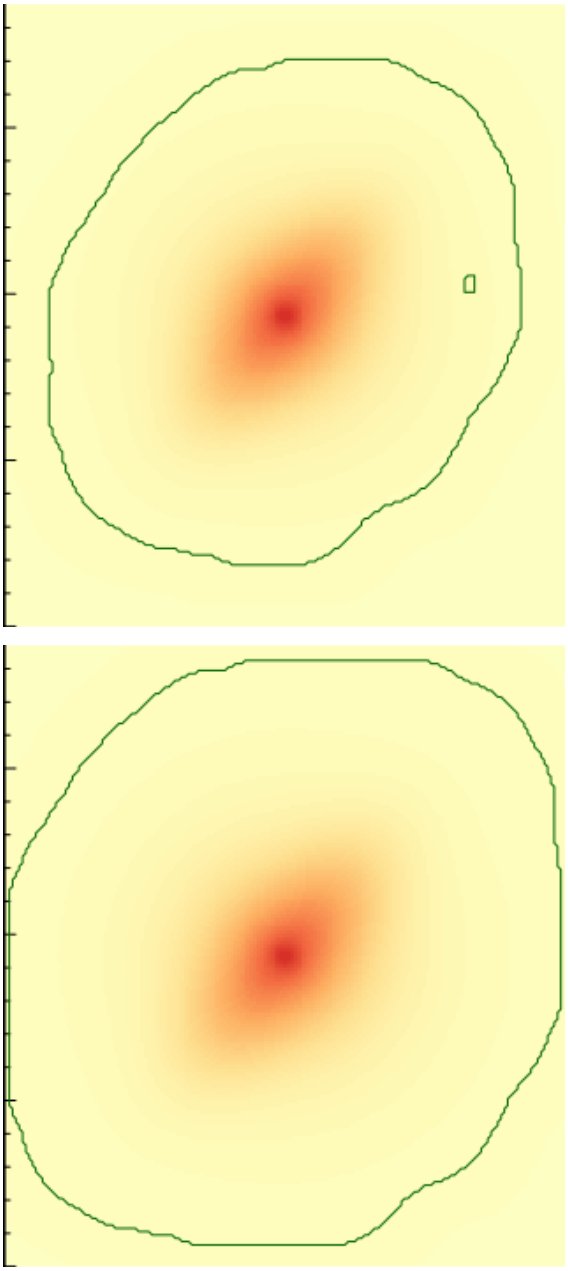
And a zoom into the top-right corner:

Correct flux capturing is important to correctly represent observed images, which *do include* flux coming from outside the field of view.

## 6.2 How it works

As of *libprofit* 1.9.0, flux capturing is automatically taken into account without the user needing to worry about modifying the inputs to a `Model`. This process takes into account whether convolution is needed at all, the size of the PSF, the original `Mask`, the finesampling factor set into the `Model`, and any other factor affecting this computation.

There are two main transformations that take place when this automatic adjustment happens internally in the `Model`. First, if there is a `Mask` involved, its coverage is expanded. This coverage expansion is a convolution-like operation, which is required so the profiles evaluate pixels outside of the originally-intended area. Like this:



In the figure above, the left-hand image shows the original coverage of the *Mask*, while the right-hand side shows the *expanded* coverage after taking into account that the convolution process will require all the pixels in the expanded area to have values calculated on them.

The second transformation that needs to happen is the expansion of the *Model* dimensions. Like in the first case, if pixels outside of the *Model* original image frame need to be calculated, then the *Model* dimensions need to be adjusted so these pixels receive values during profile evaluation.

## 6.3 Using pre-calculated Masks

The process described above happens automatically without the user having to adjust any of the inputs of the *Model*.

However, in the case of image fitting, when we know that the original *Mask*, PSF, and other inputs will not change

across evaluations of a *Model*, some work can be pre-calculated. In particular, the final form of the *Mask* can be reused across *Model* evaluations. This is done in a two-step process:

- The user first calls *Model::adjust()* with the intended inputs. This results on a pre-calculated *Mask* that works for that set of inputs
- Then, the mask is passed down as usual to the *Model* via *Model::set_mask()*. Additionally, the *Model* is informed that no further adjustment should be done on that mask via *Model::set_adjust_mask()* with a `false` argument.

## 6.4 Current and previous status

Until libprofit 1.9.0, images produced by *libprofit* failed to correctly capture flux correctly in scenarios when there was a convolution involved. The ProFit R package implemented this as part of its fitting process though, but other users would have been lacking this feature.

CHAPTER 7

# Adding a profile

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This section explains the steps required to add a new profile to *libprofit*.

In a nutshell, to add a new profile one must:

- Create a new subclass of `Profile`
- Write the mandatory methods
- Associate the new profile with a standard name

In all steps below, a completely artificial `example` profile is being added, This new profile takes three parameters: `param1` and `param2` are double numbers, while `param3` is an unsigned integer. The profile fills the image by taking the X and Y coordinates and filling the pixel with the value `|(param1 - param2) * param3 * (x - y)|` and requires that all parameters are positive or 0.

The data types used in this example are described in detail in *API*.

## 7.1 New Class

The first step to add a new profile is to define the C++ class that will hold all its information. Any kind of information can be added to the class, but it is **required** that the class extends the base *Profile* class. The class should be defined in an `.h` file in the `profit` directory so it can be used by others, and should be part of the `profit` namespace.

So far, it should look like this:

```
class ExampleProfile : public Profile {
private:
    double param1;
    double param2;
    unsigned int param3;
};
```

## 7.2 Methods

Each profile requires a minimum of three methods that need to be written:

- The constructor,
- A method to validate the profile's values, and
- A method to evaluate it.

The two latter are imposed by the base class, and must be called `validate` and `evaluate`.

In addition, to be able to receive parameters given by the user, the *parameter* methods must be overwritten.

### 7.2.1 Parameters

To receive parameters given by the user the new class must overwrite the necessary *parameter* methods from the parent class. There are several flavours of this methods, depending on the parameter data type, so only the necessary ones are required.

In our example we only have parameters of type *double* and *unsigned int* so we only need to overwrite those two methods. This method must call its parent method to check if it already set a parameter with that name, in which case it should short-cut and return *true*; it then should check the parameter name against its own parameters, and return either *true* or *false* if the parameter was set or not.

In our example, *double* parameters are set like this:

```
void ExampleProfile::parameter(const std::string &name, double value) {

    if( Profile::parameter(name, value) ) {
        return true;
    }

    if( name == "param1" )       { param1 = value; }
    else if( name == "param2" ) { param2 = value; }
    else {
        return false;
    }

    return true;
```

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```
}
```

### 7.2.2 Validation

After parameters are all set, *libprofit* will call the validation function. The validation function's responsibility, as its name implies, is to validate the inputs of the profile, checking that they obey the required minimum to make the operation successful.

In the case of the `example` profile it was mentioned that all parameters must be positive, so the code must test for that. If a violation occurs, a *`invalid_parameter`* exception is thrown. This exception will prevent the profile (and in fact the whole model) from being evaluated.

An example implementation would thus look like this:

```
void ExampleProfile::validate() {

    if ( this->param1 < 0 ) {
       throw invalid_parameter("param1 is negative");
    }
    if ( this->param1 < 0 ) {
       throw invalid_parameter("param2 is negative");
    }
    if ( this->param3 < 0 ) {
       throw invalid_parameter("param3 is negative");
    }

}
```

Note also that the base *`Profile`* class has a reference to the model this profile is part of. Having access to the model means that one can validate profile-specific values against model-global values as well. For example, if a new restriction is added stating that the `example` profile can only be run on images that are bigger than 20 x 20 then the following code could be added:

```
if ( this->model->width < 20 || this->model->height < 20 ) {
    throw invalid_parameter("can't apply example profile to images less than 20x20");
}
```

Finally, if a profile needs no validation at all a validation function must still be provided with an empty body.

### 7.2.3 Evaluation

Next, we look to the `evaluate` method. Its `image` argument corresponds to the surface where the pixels must be drawn. All profiles in the model receive **the same** image surface, so care must be taken to *add* values into the image's pixel rather than *setting* them. The image is already initialized with zeros when created, so if your profile doesn't cover the entire image no action needs to occur.

It was mentioned earlier that the `example` profile fills the image by taking the X and Y coordinates and filling the pixel with the value `|(param1 - param2) * param3 * (x - y)|`. An implementation of this would then look like this:

```
1 void ExampleProfile::evaluate(std::vector<double> &image) {
2
```

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```
3       Model *model = this->model;
4       double x, y;
5       unsigned int i, j;
6       double half_xbin = this->model->scale_x/2.;
7       double half_ybin = this->model->scale_y/2.;
8
9       x = 0;
10      for (i=0; i < model->width; i++) {
11          x += half_xbin;
12
13          y = 0;
14          for (j=0; j < model->height; j++) {
15              y += half_ybin;
16
17              if ( !model->calcmask || model->calcmask[i + j*model->width] ) {
18                  double val = fabs( (this->param1 - this->param2) * this->param3 * (x -␣
    ↪y) );
19                  image[i + j*model->width] = val;
20              }
21
22              y += half_ybin;
23          }
24          x += half_xbin;
25      }
26  }
```

The code above performs the following steps:

1. On line 10 we loop around the X axis. `i` is the horizontal pixel index on the image and spans from 0 to `model->width`. At the same time we keep track of `x`, which is a floating point number representing the horizontal image coordinate used to evaluate the profile on that pixel. See *Coordinates* for more details on the coordinate system used by *libprofit*.
2. Similarly, on line 14 we loop around the Y axis.
3. The model might specify a calculation mask, indicating that some pixels should not be calculated, which is checked in line 17
4. Being now on a given X and Y coordinate, we evaluate our profile on line 18.
5. Finally on line 19 we store the evaluated profile on the corresponding pixel of the image.

### 7.2.4 Constructor

Last but not least we look at the constructor. Its signature looks like this:

```
ExampleProfile(const Model &model, const std::string &name);
```

The constructor arguments must be passed down to the parent class. The constructor is also in charge of populating the profile with its default values. For this example the code would look like this:

```
ExampleProfile::ExampleProfile(const Model &model, const std::string &name) :
    Profile(model, name),
    param1(1.),
    param2(2.),
    param3(3)
{
```

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```
  // no-op
}
```

## 7.3 Wiring up

To finally wire up your new profile with the rest of *libprofit* you need to give it a name. This is done at the `profit.cpp` file. Open it in an editor and look for the `Model::add_profile` method. This method creates different profile instances based on the given name. Add a new `else if` statement to create your new profile imitating what is done for the other ones.

To add the `example` profile the following lines should thus be added to the first `if/else if` block:

```
else if ( profile_name == "example" ) {
    profile = static_cast<Profile *>(new ExampleProfile());
}
```

In order to be able to "see" the constructor the `example.h` file must also be included, which is done earlier on in `profit.cpp`:

```
#include "profit/example.h"
```

Finally, you need to manually add the new `.cpp` file to the list of files to be compiled. This is done by adding it to the `PROFIT_SRC` list in the `CMakeLists.txt` file:

```
set(PROFIT_SRC
  [...]
  src/example.cpp
  [...]
)
```

## 7.4 Full example

Below are the full new files that have been described below. `example.h` contains the new data type definition, plus the signature of the creation function, while `example.cpp` contains the implementation of the creation, validation and evaluation of `example` profiles.

Listing 1: example.h

```
1  /* copyright notice, etc */
2  #ifndef _EXAMPLE_H_
3  #define _EXAMPLE_H_
4
5  #include <string>
6  #include <vector>
7
8  #include "profit/profile.h"
9
10 namespace profit
11 {
12
13 class ExampleProfile : public Profile {
```

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```
14
15  public:
16          ExampleProfile(const Model &model, const std::string &name);
17          void validate() override;
18          void evaluate(Image &image, const Mask &mask, const PixelScale &scale, const␣
    ↪Point &offset, double magzero) override;
19
20  protected:
21          bool parameter(const std::string &name, double value);
22          bool parameter(const std::string &name, unsigned int value);
23
24  private:
25          double param1;
26          double param2;
27          unsigned int param3;
28
29  };
30
31  } /* namespace profit */
32
33  #endif
```

Listing 2: example.cpp

```
1   /* copyright statement, etc */
2
3   #include <cmath>
4   #include "example.h"
5
6   #include "profit/exceptions.h"
7   #include "profit/model.h"
8
9   namespace profit {
10
11  ExampleProfile::ExampleProfile(const Model &model, const std::string &name) :
12      Profile(model, name),
13           param1(1.),
14           param2(2.),
15           param3(3)
16  {
17          // no-op
18  }
19
20  bool ExampleProfile::parameter(const std::string &name, double value) {
21
22          if( Profile::parameter(name, value) ) {
23                  return true;
24          }
25
26          if( name == "param1" )       { param1 = value; }
27          else if( name == "param2" ) { param2 = value; }
28          else {
29                  return false;
30          }
31
32          return true;
```

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```
}

bool ExampleProfile::parameter(const std::string &name, unsigned int value) {
        if( Profile::parameter(name, value) ) {
                return true;
        }

        if( name == "param3" ) { param3 = value; }
        else {
                return false;
        }

        return true;
}

void ExampleProfile::validate() {

        if ( this->param1 < 0 ) {
                throw invalid_parameter("param1 is negative");
        }
        if ( this->param1 < 0 ) {
                throw invalid_parameter("param2 is negative");
        }
        if ( this->param3 < 0 ) {
                throw invalid_parameter("param3 is negative");
        }

        /*
        if ( this->model->width < 20 || this->model->height < 20 ) {
                throw invalid_parameter("can't apply example profile to images less than 20x20");
        }
        */
}

void ExampleProfile::evaluate(Image &image, const Mask &mask, const PixelScale &scale, double magzero) {

        double x, y;
        unsigned int i, j;
        auto width = image.getWidth();
        double half_xbin = scale.first/2.;
        double half_ybin = scale.second/2.;

        x = 0;
        for (i=0; i < width; i++) {
                x += half_xbin;

                y = 0;
                for (j=0; j < image.getHeight(); j++) {
                        y += half_ybin;

                        if ( not mask or mask[i + j * width] ) {
                                double val = std::abs( (this->param1 - this->param2) * this->param3 * (x - y) );
                                image[i + j * width] = val;
                        }
```

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```
87
88                          y += half_ybin;
89                  }
90                  x += half_xbin;
91          }
92  }
93
94  } /* namespace profit */
```

CHAPTER 8

# Language Bindings

Bindings exist to wrap *libprofit* into different languages.

At the moment of writing the following two are available:

- pyprofit: a Python wrapper for *libprofit*.
- ProFit: A package for R that wraps *libprofit* and performs high-level profile fitting against an input galaxy.

Additional language bindings can be easily added in the future if required.

# CHAPTER 9

# API

## 9.1 Library

**enum** profit::**simd_instruction_set**
SIMD instruction sets choosers can choose from

*Values:*

**AUTO** = 0
Automatically choose the best available SIMD instruction set.

**NONE**
No SIMD instruction set.

**SSE2**
The SSE2 instruction set.

**AVX**
The AVX instruction set.

bool profit::**init**()
Initializes the libprofit library. This function must be called once before using the library in any way. At the end, call *finish()*. If the user fails to call *init()* the library *might* work, but it's not guaranteed that it will do so correctly, or as intended.

A successful initialization does not mean that all went internally. Use init_diagnose() to get a report on what may have possibly gone wrong, specially if a call to *init()* does not succeed.

**Return** If the initialization was correct

void profit::**finish**()
Finalizes the libprofit library. All internal resources are freed. This method should be called after the library has been used. After a call to *finish()*, no other usage of the library should occur (except for finish_diagnose()) unless *init()* is called again.

std::string profit::**version**()
Returns the version of this libprofit library

**Return** The version of this libprofit library

unsigned short profit::**version_major**()
Returns the major version of this libprofit library

**Return** The major version of this libprofit library

unsigned short profit::**version_minor**()
Returns the minor version of this libprofit library

**Return** The minor version of this libprofit library

unsigned short profit::**version_patch**()
Returns the patch version of this libprofit library

**Return** The patch version of this libprofit library

bool profit::**has_openmp**()
Returns whether libprofit was compiled with OpenMP support

**Return** Whether libprofit was compiled with OpenMP support

bool profit::**has_fftw**()
Returns whether libprofit was compiled with FFTW support

**Return** Whether libprofit was compiled with FFTW support

bool profit::**has_fftw_with_openmp**()
Returns whether libprofit was compiled against an FFTW library with OpenMP support

**Return** Whether libprofit was compiled against an FFTW library with OpenMP support

bool profit::**has_opencl**()
Returns whether libprofit was compiled with OpenCL support

**Return** Whether libprofit was compiled with OpenCL support

unsigned short profit::**opencl_version_major**()
If OpenCL is supported, returns the major portion of the highest OpenCL platform version libprofit can work against. For example, if libprofit was compiled against a platform supporting OpenCL 2.1, this method returns 2. If OpenCL is not supported, the result is undefined.

**Return** The major highest OpenCL platform version that libprofit can work against.

unsigned short profit::**opencl_version_minor**()
If OpenCL is supported, returns the minor portion of the highest OpenCL platform version libprofit can work against. For example, if libprofit was compiled against a platform supporting OpenCL 1.2, this method returns 2. If OpenCL is not supported, the result is undefined.

bool profit::**has_simd_instruction_set**(*simd_instruction_set instruction_set*)
Returns whether libprofit was compiled with support for the specified SIMD instruction set

**Return** whether libprofit was compiled with support for the specified SIMD instruction set

**Parameters**

- instruction_set: The instruction set to check. *AUTO* and *NONE* will always be supported

## 9.2 Exceptions

**class invalid_parameter** : **public** profit::exception
Exception class thrown when an invalid parameter has been supplied to either a model or a specific profile.

Subclassed by *profit::unknown_parameter*

**class unknown_parameter** : **public** profit::*invalid_parameter*
Exception thrown by the *Profile* class when a user gives a parameter that the profile doesn't understand.

**class opencl_error** : **public** profit::exception
Exception class thrown when an error occurs while dealing with OpenCL.

**class fft_error** : **public** profit::exception
Exception class thrown when an error occurs while dealing with FFT.

## 9.3 Imaging classes

**class _2dcoordinate**
An (x, y) pair in a 2-dimensional discrete surface

Comparison between these objects can be done with the <, <=, ==, !=, > and >= operators, but users should not that there is no way to order values based on these operators (that is, objects of this type are by themselves non-sortable).

### Public Functions

bool **operator>=**(**const** *_2dcoordinate* &*other*) **const**
greater or equal comparison across both dimensions

bool **operator>**(**const** *_2dcoordinate* &*other*) **const**
greater than comparison across both dimensions

bool **operator<=**(**const** *_2dcoordinate* &*other*) **const**
less or equal comparison across both dimensions

bool **operator<**(**const** *_2dcoordinate* &*other*) **const**
less than comparison across both dimensions

**typedef** *_2dcoordinate* profit::**Dimensions**

**typedef** *_2dcoordinate* profit::**Point**

template<typename **T**, typename **D**>
**class surface** : **public** profit::surface_base
Base class for 2D-organized data

### Public Functions

void **zero**()
Assigns zero to all elements of this *Image*.

D **extend**(*Dimensions dimensions*, *Point start* = *Point*()) **const**

Creates a new surface that is an extension of this object. The new dimensions must be greater or equal to the current dimensions. The current contents of this surface are placed at `start`, relative to the new surface's dimension.

**Return** The new extended surface

**Parameters**

- `dimensions`: The dimensions of the new extended surface.
- `start`: The starting point of the original surface relative to the new one

void **extend**(D &*extended*, *Point start* = *Point*()) **const**

Extends this object into the given surface. The new surface's dimensions must be greater or equal to the current dimensions. The current contents of this surface are placed at `start`, relative to the new surface's dimension.

**Parameters**

- `extended`: The new surface to hold the extended version of this image. Its dimensions mandate how much the current image should extend.
- `start`: The starting point of the original surface relative to the new one

D **crop**(*Dimensions dimensions*, *Point start* = *Point*()) **const**

Creates a new image that is a crop of this image. The cropped image starts at `start` (relative to this image) and has new dimensions `dimensions`.

**Return** The new cropped image

**Parameters**

- `dimensions`: The dimensions of the cropped image. They should be less or equal than the dimensions of this image.
- `start`: The start of the new image relative to this image.

D **reverse**() **const**

Returns a copy of this surface with its underlying values in the reversed order, such that the top-right corner is now that bottom-left corner and vice-versa.

**Return** A new object with reversed values

Box **bounding_box**() **const**

Returns a "value-interesting" bounding box for this surface; that is, the subset of this surface inside which all values are different from zero.

**Return** The minimum bounding box within which all non-zero values of this surface are contained.

bool **operator==**(**const** surface &*other*) **const**

Comparison operator.

reference **operator[]**(**const** size_type *idx*)

subscript operator

const_reference **operator[]**(**const** size_type *idx*) **const**
subscript operator, const

reference **operator[]**(**const** *Point* &*p*)
[] operator that works with a Point

iterator **begin**()
iterator to beginning of data

iterator **end**()
iterator to end of data

**operator std::vector<T>**() **const**
type casting to std::vector<T>

**class Image** : **public** profit::surface<double, *Image*>
An image is a surface of doubles.

### Public Types

**enum UpsamplingMode**
Available image upsampling modes

*Values:*

**SCALE** = 0
Scales the value of the original pixel by `factor * factor` before copying it into each corresponding upsampled pixel. This has the effect of preserving the total flux of the original image

**COPY**
Copies the value of the original pixel unmodified into each corresponding upsampled pixel

**enum DownsamplingMode**
Available image downsampling modes

*Values:*

**AVERAGE** = 0
Pixel values on the resulting image are the average of the corresponding pixels on the original image.

**SUM**
Pixel values on the resulting image are the sum of the corresponding pixels on the original image.

**SAMPLE**
Pixel values on the resulting image are samples from the original image. Samples are taken from the lowest placed pixel, in both dimensions, of the corresponding pixels of the original image.

### Public Functions

double **total**() **const**
Returns the sum of the image pixel's values (or "total flux").

**Return** The sum of the image pixel's values

*Image* **upsample**(unsigned int *factor*, *UpsamplingMode* *mode* = *SCALE*) **const**
Upsamples this image by the given factor.

The resulting image's dimensions will be the original image's times the upsampling factor. The particular upsampling method is determined by `mode`

**Return** An upsampled image, without interpolation.

**Parameters**

- `factor`: The upsampling factor. Must be greater than 0. If equals to 1, the upsampled image is equals to the original image.
- `mode`: The upsampling mode to use

*Image* **downsample**(unsigned int *factor*, *DownsamplingMode* *mode* = *SUM*) **const**
Downsamples this image by the given factor.

The resulting image's dimensions will be the ceiling of this image's divided by the downsampling factor. The particular downsampling method is determined by `mode`

**Return** A downsampled image, without interpolation.

**Parameters**

- `factor`: The downsampling factor. Must be greater than 0. If equals to 1, the upsampled image is equals to the original image.
- `mode`: The downsampling mode to use

void **normalize**()
Normalized this image; i.e., rescales its values so the sum of all its pixels' values is 1. If all pixels are 0 the image is not changed.

*Image* **normalize**() **const**
Returns a normalized version of this image; i.e., one where the sum of all pixels' values is 1. If all pixels are 0 the returned image is identical to this image.

value_type ***data**()
Exposes the underlying data pointer in case it becomes necessary to access it directly.

**Return** The underlying data pointer

**const** value_type ***data**() **const**
Exposes the underlying data pointer in case it becomes necessary to access it directly

**Return** The underlying data pointer

*Image* &**operator+=**(**const** *Image* &*rhs*)
Addition assignment of another *Image*.

*Image* **operator+**(**const** *Image* &*rhs*) **const**
Addition of another image.

*Image* &**operator/=**(double *denominator*)
Division assignment against a double denominator.

*Image* &**operator*=**(double *denominator*)
Multiplication assignment against a double multiplier.

*Image* **operator/**(double *denominator*) **const**
Division against a double denominator.

*Image* &**operator&=**(**const** *Mask* &*mask*)
Bitwise AND assignment with a *Mask* (applies the mask to the image).

**const** *Image* **operator&**(**const** *Mask* &*mask*) **const**
Bitwise AND with a *Mask* (applies the mask to the image).

**class Mask** : **public** profit::surface<bool, *Mask*>
A mask is surface of bools

### Public Functions

*Mask* **expand_by**(*Dimensions pad*, int *threads* = 1) **const**
Returns a new *Mask* where the area covered by the new mask (i.e., where the new mask's value is `true`) is an "expanded" version of this mask. This is similar in nature to a convolution, but simpler as it is a simpler boolean operation that requires no additions or further scaling.

**Parameters**

- `pad`: the amount of cells to expand each input pixel on each dimension.
- `threads`: threads to use to perform computation. Only valid if compiled with OpenMP support

*Mask* **upsample**(unsigned int *factor*) **const**
Upsamples this mask by the given factor.

The resulting mask's dimensions will be the original mask's times the upsampling factor. The original mask's values are copied on the corresponding cells of the upsampled mask.

**Return** The upsampled mask

**Parameters**

- `factor`: The upsampling factor. Must be greater than 0. If equals to 1, the upsampled mask is equals to the original mask.

## 9.4 Model class

**class Model**
The overall model to be created

The model includes the width and height of the image to produce, as well as the resolution to use when performing calculations. Having resolution allows us to specify pixel position with decimal places; e.g., the center point for a given profile.

### Public Functions

**Model**(unsigned int *width* = 0, unsigned int *height* = 0)
Constructor

It creates a new model to which profiles can be added, and that can be used to calculate an image.

**Model** (*Dimensions dimensions*)
Like *Model(unsigned int, unsigned int)*, but accepting a Dimensions object.

ProfilePtr **add_profile** (**const** std::string &*profile_name*)
Creates a new profile for the given name and adds it to the given model. On success, the new profile is created, added to the model, and its reference is returned for further customization. If a profile with the given name is not supported an *invalid_parameter* exception is thrown.

**Return** A pointer to the new profile that corresponds to the given name

**Parameters**

- `profile_name`: The name of the profile that should be created

bool **has_profiles** () **const**
Whether this model contains any profiles or not.

**Return** `true` if this module contains at least one profile, `false` otherwise

*Image* **evaluate** (*Point* &*offset_out* = *NO_OFFSET*)
Calculates an image using the information contained in the model. The result of the computation is returned as an *Image*, which may be of a different size from the one originally requested if the user set this model's `crop` property to `false` (via *set_crop*). If users want to know the offset at which the image resulting of evaluating this *Model* with its configured parameters is with respect to the *Image* value returned by this method, hen they must provide a Point in `offset_out`, which will contain the information after the method returns.

In other words, the *Image* returned by this method can be bigger than the *Model*'s dimensions if the user requested this *Model* to return a non-cropped *Image*.

**Return** The image created by libprofit.

**Parameters**

- `offset_out`: The potential offset with respect to the image returned by this method at which the image of this *Model*'s dimensions can be found.

std::map<std::string, std::shared_ptr<ProfileStats>> **get_stats** () **const**
Return a map of all profile statistics.

**Return** A map indexed by profile name with runtime statistics

void **set_dimensions** (**const** *Dimensions* &*dimensions*)
Sets the dimensions of the model image to generate

**Parameters**

- `dimensions`: The dimensions of the model image to generate

void **set_finesampling** (unsigned int *finesampling*)
Sets the finesampling factor to use in this *Model*

void **set_psf** (**const** *Image* &*psf*)
Sets the PSF image that this *Model* should use

**Parameters**

- `psf`: The PSF image that this *Model* should use

void **set_psf**(*Image* &&*psf*)

**See** *set_psf(const Image &psf)*

void **set_image_pixel_scale**(**const** PixelScale &*scale*)
Sets the pixel scale of the generated model image.

The image scale is the width (and height) of a single pixel in image coordinates.

**Parameters**

- `scale`: The pixel scale of the model image

PixelScale **get_image_pixel_scale**() **const**
Returns the pixel scale of the generated model image.

**Return** the image scale of the generated model image

**See** set_image_pixel_scale(double, double)

void **set_psf_pixel_scale**(**const** PixelScale &*scale*)
Sets the PSF's pixel scale.

**See** set_image_pixel_scale(double, double)

**Parameters**

- `scale`: The pixel scale of the PSF

PixelScale **get_psf_pixel_scale**() **const**
Returns the pixel scale of the PSF.

**Return** the image scale of the generated model image

**See** set_psf_pixel_scale(double, double)

void **set_magzero**(double *magzero*)
Sets the base magnitude to be applied to all profiles.

**Parameters**

- `magzero`: The base magnitude to be applied to all profiles.

void **set_mask**(**const** *Mask* &*mask*)
Set the calculation mask. If given it must be the same size of the expected output image, and its values are used to limit the profile calculation only to a given area (i.e., those cells where the value is `true`).

**Parameters**

- `mask`: The mask to use to limit profile calculations

void **set_mask**(*Mask* &&*mask*)

**See** *set_mask(const Mask &mask)*

void **set_adjust_mask**(bool *adjust_mask*)

Sets whether the mask given by the user should be automatically adjusted in order to preserve flux during convolution or not. By default masks are adjusted as necessary, but if users have a pre-adjusted *Mask* (obtained via *adjust(Mask &, const Dimensions &, const Image &, unsigned int)*) and pass that to the *Model*, then they need to indicate that no further adjustment in necessary

**See** *adjust(Mask &, const Dimensions &, const Image &, unsigned int)*

**Parameters**

- `adjust_mask`: Whether this model should internally adjust the mask given by the user or not.

void **set_convolver**(ConvolverPtr *convolver*)

Set a convolver for this *Model*. A convolver is an object used to carry out the convolution, if necessary. If a convolver is present before calling `evaluate` then it is used. If missing and one is required, a new one is created internally.

void **set_crop**(bool *crop*)

Set the cropping flag.

Due to their internal workings, some convolvers produce actually bigger which are (by default) cropped to the size of the original images created by the profiles. If this option is set to true, then the result of the convolution will *not* be cropped, meaning that the result of the model evaluation will be bigger than what was originally requested.

**Parameters**

- `crop`: Whether this model returns a cropped image (default) or not to the user.

void **set_dry_run**(bool *dry_run*)

Sets the dry run flag. The dry run flag determines whether the actual evaluation of profiles should be skipped or not; if skipped profile validation still takes place.

**Parameters**

- `dry_run`: Whether evaluation of profiles should take place (default) or not

void **set_return_finesampled**(bool *return_finesampled*)

Set the return finesampled flag.

When users set a finesampling factor on the model (via *set_finesampling()*) the image calculated by this model will have bigger dimensions than those originally set in the *Model*. This flag controls whether this bigger image should be returned (default behavior), or whether a smaller version of the image with dimensions equals to the ones requested (plus any padding introduced by convolution) should be returned. If a smaller image is returned, the total flux of the image is still preserved.

**Parameters**

- `return_finesampled`: Whether this model should return finesampled images as-is (`true`) or if they should be downsampled to match the original model dimensions.

void **set_omp_threads**(unsigned int *omp_threads*)

Sets the maximum number of OpenMP threads to use to evaluate the profiles contained in this model. 0 threads means that no OpenMP support has been requested.

**Parameters**

- `omp_threads`: the number of OpenMP threads to use for profile evaluation

unsigned int **`get_omp_threads`**()
Returns the number of OpenMP threads this *Model* has been configured to work with

**Return** the number of OpenMP threads this *Model* has been configured to work with

### Public Static Functions

void **`adjust`**(*Mask* &*mask*, **`const`** *Dimensions* &*dims*, **`const`** *Image* &*psf*, unsigned int *finesampling* = 1)
Modifies `mask` in the same way that it would be modified internally by a *Model* object in order to preserve flux during the convolution step of the *Model* evaluation.

**See** *set_adjust_mask(bool)*

**Parameters**

- `mask`: The mask to be modified.
- `dims`: The dimensions of the *Model*
- `psf`: The PSF to be used during *Model* convolution
- `finesampling`: The finesampling factor to be used by the *Model*

### Public Static Attributes

*Point* **`NO_OFFSET`**
The Point object that indicates that users don't want to retrieve back the potential image offset when calling *evaluate(Point &)*

## 9.5 Profile classes

**`class Profile`**
The base profile class

Subclassed by *profit::NullProfile*, *profit::PsfProfile*, *profit::RadialProfile*, *profit::SkyProfile*

### Profile Parameters

bool **`convolve`**
Whether the resulting image of this profile should be convolved or not.

### Public Functions

void **`parameter`**(**`const`** std::string &*parameter_spec*)
Parses `parameter_spec`, which should look like `name = value`, and sets that parameter value on the profile.

**Parameters**

- `parameter_spec`: The parameter name

**Exceptions**

- *invalid_parameter*: if `parameter_spec` fails to parse, or the parameter's value cannot be parsed correctly
- *unknown_parameter*: if `parameter_spec` refers to a parameter not supported by this profile

void **parameter**(**const** std::string &*name*, bool *value*)

Sets the parameter `name` to `value`.

**Parameters**

- `name`: The parameter name
- `value`: The parameter value

**Exceptions**

- *invalid_parameter*: if `name` corresponds with no known parameter on this profile of type `bool`.

void **parameter**(**const** std::string &*name*, double *value*)

Sets the parameter `name` to `value`.

**Parameters**

- `name`: The parameter name
- `value`: The parameter value

**Exceptions**

- *invalid_parameter*: if `name` corresponds with no known parameter on this profile of type `double`.

void **parameter**(**const** std::string &*name*, unsigned int *value*)

Sets the parameter `name` to `value`.

**Parameters**

- `name`: The parameter name
- `value`: The parameter value

**Exceptions**

- *invalid_parameter*: if `name` corresponds with no known parameter on this profile of type `unsigned int`.

**class RadialProfile** : **public** profit::*Profile*

The base class for radial profiles.

This class implements the common aspects of all radial profiles, namely:

- High-level evaluation logic
- Region masking
- Translation, rotation, axis ratio and boxing handling
- Pixel subsampling

Subclasses are expected to implement a handful of methods that convey profile-specific information, such as the evaluation function for an given x/y profile coordinate and the calculation of the total luminosity of the profile, among others.

Subclassed by *profit::BrokenExponentialProfile*, *profit::CoreSersicProfile*, *profit::FerrerProfile*, *profit::KingProfile*, *profit::MoffatProfile*, *profit::SersicProfile*

### Profile Parameters

double **xcen**
The X center of this profile, in image coordinates

double **ycen**
The Y center of this profile, in image coordinates

double **mag**
The magnitude of this profile.

double **ang**
The angle by which this profile is rotated. 0 is north, positive is counterclockwise.

double **axrat**
The ratio between the two axes, expressed as minor/major.

double **box**
The *boxiness* of this profile.

bool **rough**
Whether perform sub-pixel integration or not.

double **acc**
Target accuracy to achieve during sub-pixel integration

double **rscale_switch**
Radius (relative to `rscale`) under which sub-pixel integration should take place

unsigned int **resolution**
Resolution of the sub-pixel integration: each area to be sub-integrated is divided in `resolution * resolution` cells.

unsigned int **max_recursions**
Maximum number of recursions that the sub-pixel integration algorithm should undertake.

bool **adjust**
Whether this profile should adjust the sub-pixel integration parameters automatically based on the profile parameters

double **rscale_max**
Radius (relative to `rscale`) after which the profile is not evaluated anymore

**class SersicProfile** : **public** profit::*RadialProfile*
A Sersic profile

The sersic profile has parameters `nser` and `re` and is calculated as follows at radius `r`:

$$\exp\left\{-b_n\left[\left(\frac{r}{r_e}\right)^{\frac{1}{n_{ser}}}-1\right]\right\}$$

### Profile Parameters

double **re**
The effective radius

double **nser**
The sersic index

bool **rescale_flux**
Rescale flux up to rscale_max or not

**class MoffatProfile** : **public** profit::*RadialProfile*
A Moffat profile

The moffat profile has parameters `fwhm` and `con`, and is calculated as follows at radius `r`:

$$\left[1 + \left(\frac{r}{r_d}\right)\right]^{-con}$$

with:

$$r_d = \frac{fwhm}{2\sqrt{2^{\frac{1}{con}} - 1}}$$

### Profile Parameters

double **fwhm**
Full-width at half maximum of the profiles across the major axis of the intensity profile.

double **con**
Profile concentration

**class FerrerProfile** : **public** profit::*RadialProfile*
A Ferrer profile

The ferrer profile has parameters `rout`, `a` and `b` and is calculated as follows at radius `r`:

$$\left[1 - \left(\frac{r}{r_{out}}\right)^{(2-b)}\right]^{a}$$

### Profile Parameters

double **rout**
The outer truncation radius

double **a**
The global power-law slope to the profile center

double **b**
The strength of the truncation as the radius approaches `rout`.

**class CoreSersicProfile** : **public** profit::*RadialProfile*
A CoreSersic profile

The CoreSersic profile has parameters `re`, `rb`, `nser`, `a` and `b` and is calculated as follows at radius `r`:

$$\left[1 + \left(\frac{r}{r_b}\right)^{-a}\right]^{\frac{b}{a}} \exp\left[-b_n \left(\frac{r^a + {r_b}^a}{{r_e}^a}\right)^{\frac{1}{a n_{ser}}}\right]$$

### Profile Parameters

double **re**
The effective radius of the Sersic component

double **rb**
The transition radius of the Sersic profile

double **nser**
The Sersic index of the Sersic profile

double **a**
The strength of transition from inner core to outer Sersic

double **b**
The inner power-law of the Core-Sersic.

**class BrokenExponentialProfile** : **public** profit::*RadialProfile*
A Broken Exponential profile

The Broken Exponential profile has parameters `h1`, `h2`, `rb` and `a` is calculated as follows at radius `r`:

$$e^{-r/h_1}\left[1+e^{a(r-r_b)}\right]^{\frac{1}{a}\left(\frac{1}{h_1}-\frac{1}{h_2}\right)}$$

### Profile Parameters

double **h1**
The inner exponential scale length.

double **h2**
The outer exponential scale length (must be equal to or less than `h1`).

double **rb**
The break radius.

double **a**
The strength of the truncation as the radius approaches `rb`.

**class KingProfile** : **public** profit::*RadialProfile*
A King profile

The King profile has parameters `rc`, `rt` and `a` is calculated as follows at radius `r`:

$$\left(\frac{1}{\left[1+\left(\frac{r}{r_c}\right)^2\right]^{\frac{1}{a}}}-\frac{1}{\left[1+\left(\frac{r_t}{r_c}\right)^2\right]^{\frac{1}{a}}}\right)^a$$

### Profile Parameters

double **rc**
The effective radius of the Sersic component

double **rt**
The transition radius of the Sersic profile

double **a**
The power-law of the King.

**class PsfProfile** : **public** profit::*Profile*
A PSF profile.

PSF profiles simply add the normalized PSF image (for a given magnitude) in a given position onto the model's image.

#### Profile Parameters

double **xcen**
The X center of this profile

double **ycen**
The Y center of this profile

double **mag**
The magnitude of this profile, based on the model's magnitude

**class SkyProfile** : **public** profit::*Profile*
A sky profile.

This profiles simply fills the image with a constant `bg` value, which is given as a parameter.

#### Profile Parameters

double **bg**
The value to fill the image with.

**class NullProfile** : **public** profit::*Profile*
A null profile.

The null profiles has no parameters, and leaves the incoming input image untouched. It is only useful for testing purposes.

## 9.6 Convolvers

**enum** profit::**ConvolverType**
The types of convolvers supported by libprofit

*Values:*

**BRUTE_OLD** = 0
A brute-force convolver. It optionally uses OpenMP to accelerate the convolution.

**BRUTE**
A faster brute-force convolver. It optionally uses OpenMP to accelerate the convolution.

The difference between this and the BruteForceConvolver is that this convolver explicitly states that the sums of the dot products that make up the result of a single pixel are associative, and can be computed separately, which enables better pipelining in most CPUs and thus faster compute times (we have seen up to ~3x speedups). The result is not guaranteed to be the exact same as the one coming from BruteForceConvolver. This is not because one of them is mathematically incorrect (neither is actually), but because IEEE floating-point math is not associative, and therefore different operation sequences *might* yield different results.

The internal loop structure of this class is also slightly different from BruteForceConvolver, but is still pure CPU-based code.

Additionally, and depending on the underlying CPU support, this convolver can use dot product implementations based on SIMD operations available in different CPU extended instruction sets. The default is to use the fastest one available, although users might want to use a different one.

**OPENCL**
A brute-force convolver that is implemented using OpenCL

Depending on the floating-point support found at runtime in the given OpenCL environment this convolver will use a float-based or a double-based kernel.

**FFT**
A convolver that uses an FFTPlan to carry out FFT-based convolution.

The result of the convolution of images im1 and im2 is::

res = iFFT(FFT(im1) * FFT(im2))

To do this, this convolver creates extended versions of the input images. The size of the new images is 4 times that of the source image, which is assumed to be larger than the kernel. The extended version of the source image contains the original image at (0,0), while the extended version of the kernel image contains the original kernel centered at the original image's new mapping (i.e., `((src_width-krn_width)/2, (src_height-krn_height)/2)`). After convolution the result is cropped back (if required) to the original image's dimensions starting at the center of the original image's mapping on the extended image (i.e., `(src_width/2, src_height/2)` minus one if the original dimensions are odd).

This convolver has been implemented in such a way that no memory allocation happens during convolution (other than the final *Image*'s allocation) to improve performance.

**class Convolver**
A convolver object convolves two images.

This is the base class for all Convolvers. Deriving classes must implement the convolve method, which performs the actual operation.

Subclassed by profit::AssociativeBruteForceConvolver< SIMD >, profit::BruteForceConvolver, profit::FFTConvolver, profit::OpenCLConvolver, profit::OpenCLLocalConvolver

### Public Functions

*Image* **convolve**(**const** *Image* &*src*, **const** *Image* &*krn*, **const** *Mask* &*mask*, bool *crop* = true, *Point* &*offset_out* = NO_OFFSET)
Convolves image `src` with the kernel `krn`. A mask parameter also controls which pixels from the original image should be convolved. If empty, all pixels are convolved.

If the convolver extends the original image to perform the convolution, users might want to have the extended image returned, instead of getting a cropped image (that will be the same size as `src`). This behaviour is controlled with the `crop` parameter. If the image is not cropped, the offset of the otherwise cropped result with respect to the uncropped one is optionally stored in offset_out.

**Return** The convolved image, optionally without the cropping caused due to internal implementation details of the convolver. The potential offset is written into offset_out.

**Parameters**

- `src`: The source image
- `krn`: The convolution kernel

- `mask`: An mask indicating which pixels of the resulting image should be convolved
- `crop`: If `true` return an image with the same dimensions of `src`. If `false` the image returned might be potentially bigger, depending on the internal workings of the convolver.
- `offset_out`: If `crop` is `false` and `offset` is different from NO_OFFSET, stores the potential offset of the original image with respect to the uncropped image returned by this method.

**class ConvolverCreationPreferences**

A set of preferences used to create convolvers.

### Public Members

*Dimensions* **src_dims**

The dimensions of the image being convolved.

*Dimensions* **krn_dims**

The dimensions of the convolution kernel.

unsigned int **omp_threads**

The amount of OpenMP threads (if OpenMP is available) to use by the convolver. Used by the FFT convolver (to create and execute the plan using OpenMP, when available) and the brute-force convolvers.

OpenCLEnvPtr **opencl_env**

A pointer to an OpenCL environment. Used by the OPENCL convolvers.

effort_t **effort**

The amount of effort to put into the plan creation. Used by the *FFT* convolver.

bool **reuse_krn_fft**

Whether to reuse or not the FFT'd kernel or not. Used by the *FFT* convolver.

*simd_instruction_set* **instruction_set**

The extended instruction set to use. Used by the *BRUTE* convolver.

ConvolverPtr `profit::`**create_convolver**(**const** *ConvolverType type*, **const** *ConvolverCreationPreferences &prefs* = *ConvolverCreationPreferences*())

Creates a new convolver of type `type` with preferences `prefs`

**Return** A shared pointer to a new convolver

**Parameters**

- `type`: The type of convolver to create
- `prefs`: The creation preferences used to create the new convolver

ConvolverPtr `profit::`**create_convolver**(**const** std::string *&type*, **const** *ConvolverCreationPreferences &prefs* = *ConvolverCreationPreferences*())

Like *create_convolver(ConvolverType, const ConvolverCreationPreferences &)*, but indicating the convolver type as a string.

This is an overloaded member function, provided for convenience. It differs from the above function only in what argument(s) it accepts.

# CHAPTER 10

# Changelog

### 1.9.3

- A bug in the OpenCL implementation of the radial profiles prevented Models with multiple profiles from displaying correctly, as the output image would contain only the values of last profile. This was a problem introduced only in the last version of *libprofit*, and not an ongoing issue.
- When using OpenCL, any radial profile specifying `rough=true` caused the output image not to be scaled properly, with values not taking into account the profile's magnitude or pixel scale. This seems to have been an issue for a long time, but since `rough=true` is not a common option it had gone under the radar for some time.

### 1.9.2

- All profile evaluation has been changed from being absolute (profiles set the final value of a pixel) to be additive (their add their pixel values onto the image). This change in behavior has the effect that one less memory allocation is needed, which can be a big difference when generating big images, while also simplifying the logic of the *Model* evaluation.
- *Model* objects now internally store the normalized version of the PSF given by the user instead of the original, which was never really needed.
- **profit-cli** now makes it easier to specify multiple copies of the same profile, useful for scaling tests. Also, writing FITS files in little endian systems doesn't allocate extra memory anymore.
- Minor improvements to imaging classes.

### 1.9.1

- The implementation of the *Model* class has been improved. In particular it has been made more memory efficient, which is particularly important in scenarios where many profiles (in the order of thousands) are added into it. Previously each profile was allocated its own *Image*, which added both to the memory footprint, and to the total runtime. Now a single scratch space is used for all profiles, and individual results are immediately summed

up, respecting the convolution settings of each profile. Experiments with the *null profile* show a significant decrease in runtime when many Model evaluations take place.

### 1.9.0

- Implemented correct *flux capturing*. This feature was previously implemented in the ProFit R package as part of its fitting process, but it was otherwise unavailable.
- Added explicit support to allow convolution of images against kernels with bigger dimensions than the images themselves. This was previously supported implicitly, and only in certain cases, by the OpenCL convolver, while the FFT convolver threw an proper exception, and the brute-force convolvers usually crashed. This first implementation is not ideal, but the use case is rare.
- Several performance and code improvements, like removing unnecessary code, avoiding unnecessary conversions and avoiding a few dynamic allocations.

### 1.8.2

- Users can now select the underlying SIMD-capable instruction set to use for brute-force convolution.
- New library method `has_simd_instruction_set()` for users to check whether libprofit was compiled with support for different instruction sets.
- Improved FFTW-based convolver performance by avoiding dynamic memory allocation at convolution time. This brings a noticeable performance improvement of around 20%.

### 1.8.1

- Adding support for FFTW versions lower than 3.3.

### 1.8.0

- **`profit-cli`** compiling in Windows.
- New `Profile::parameter()` method to specify parameters and values with a single `name=value` string.
- New utility methods: `trim()`, `split()` and `setenv()`.
- Using SSE2/AVX SIMD extensions to implement brute-force convolution if the CPU supports it, with pure C++ implementation as a fallback. Can be disabled with `-DLIBPROFIT_NO_SIMD=ON`.
- Potentially fixed the importing of FFTW wisdom files in systems with more than one FFTW installation.
- Fixed compilation of `brokenexponential` OpenCL kernel in platforms where it was failing to compile.
- Compiling in release mode (i.e., `-O3 -DNDEBUG` in gcc/clang) by default.
- Lowering OpenMP requirement to 2.0 (was 3.0).
- OpenCL kernel cache working for some platforms/devices that was not previously working.
- Many internal code cleanups and design changes to make code easier to read and maintain.

### 1.7.4

- FFT convolution using hermitian redundancy. This increases performance of FFT-based convolution by at least 10% in release builds, and addresses some warnings pointed out by `valgrind`.

### 1.7.3

- Added `init_diagnose()` and `finish_diagnose()` functions to avoid printing to stdout/stderr from within libprofit.

### 1.7.2

- Fixed `double` detection support for OpenCL devices regardless of the supported OpenCL version.
- Fixed a few compiling issues under Visual Studio compiler.
- Continuous integration in Windows via AppVeyor

### 1.7.1

- Added *`Image::upsample()`* and *`Image::downsample()`* to scale an image up or down (using different modes).
- Added *`Model::set_return_finesampled()`* to return internally upsampled images.

### 1.7.0

- Internal implementation dependencies clearly hidden from users. This means that users compiling against libprofit don't need to search for header files other than libprofit's, making it much easier to write code against libprofit.
- *`Model`* redesigned. No member variables are exposed anymore; instead different setter/getter methods must be used.
- *`Image`* redesigned. In summary, it looks much more like a standard container now.
- New *`Model::set_crop()`* specifies whether cropping should be carried out after convolution, if the convolution needs to pad the image.
- *`Model::evaluate()`* has an extra optional parameter to receive the offset at which cropping needs to happen (if it hasn't, see *`Model::set_crop()`*) to remove padding from the resulting image.
- FFTW convolution uses real-to-complex and complex-to-real forward and backwards transforms respectively (instead of complex-to-complex transforms both ways), which is more efficient and should use less memory.
- New on-disk OpenCL kernel cache. This speeds up the creation of OpenCL environments by a big factor as compilation of kernels doesn't happen every time an environment is created.
- New on-disk FFTW plan cache. This speeds up the creation of FFT-based convolvers by a big factor as the plans are not calculated every time for a given set of parameters.
- New `null` profile, useful for testing.
- New *`init()`* and *`finish()`* calls to initialize and finalize libprofit. These are mandatory, and should be called before and after using anything else from libprofit.

### 1.6.1

- Brute-force convolver about 3x faster than old version.
- Fixing compilation failure on MacOS introduced in 1.6.0.
- Center pixel in sersic profile treated specially only if `adjust` parameter is on.

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