# perClass Mira 3.1 User's Guide

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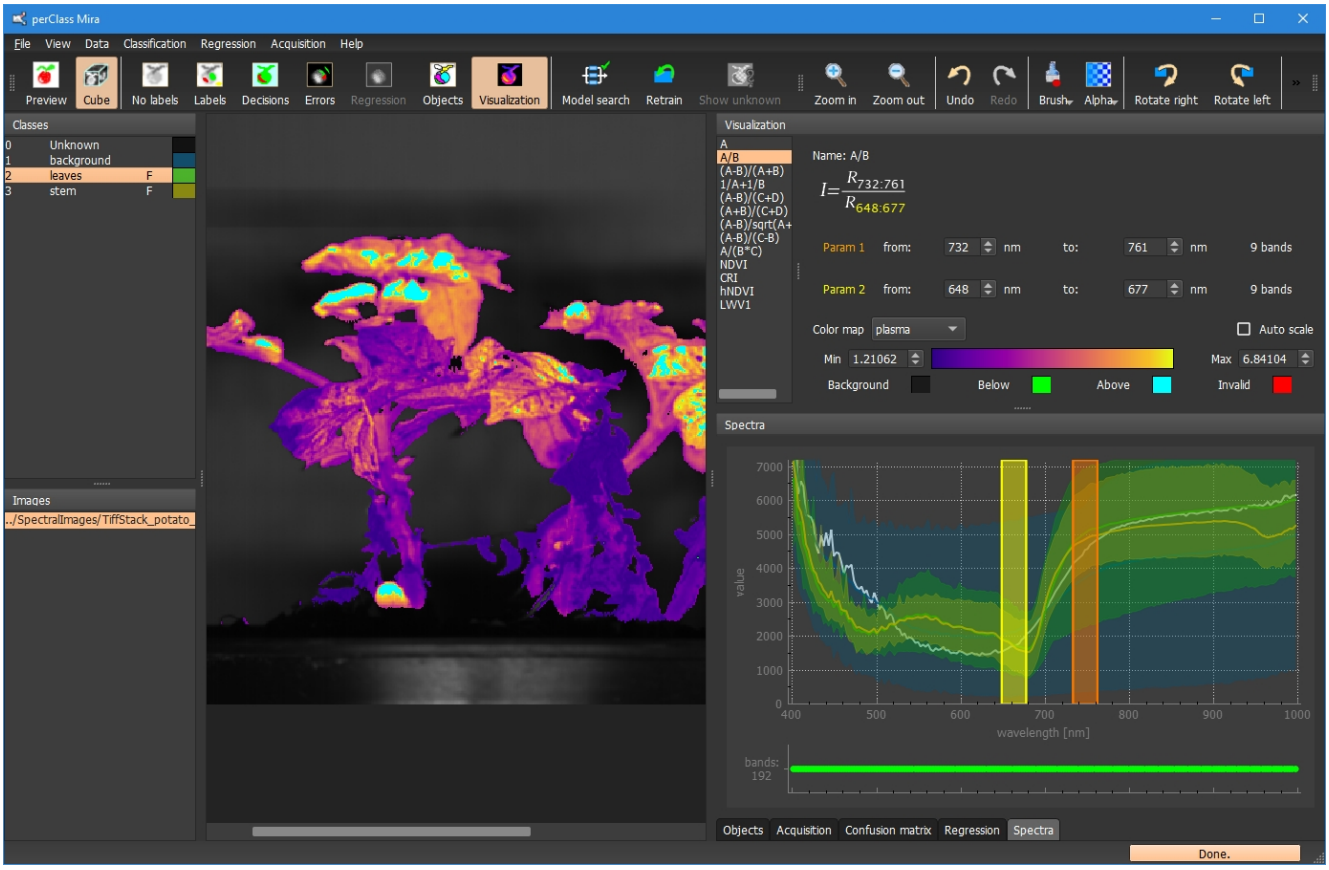
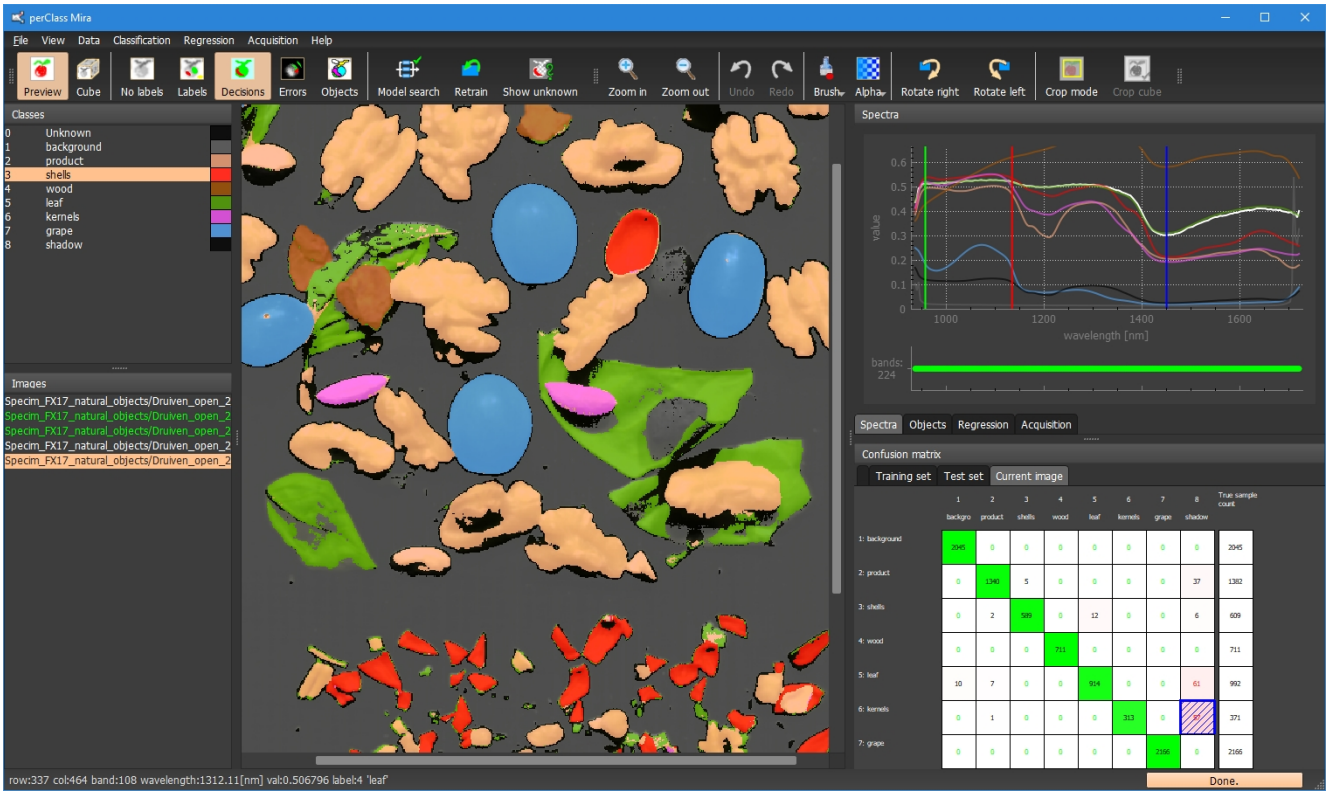
## Introduction

# perClass Mira

perClass Mira is a user interface for interpretation of spectral images. It allows users to define classification and regression solutions and deploy them in custom applications. It automatically selects machine learning models. It enables users to understand problems at hand and interactively improve the solutions.






# Release Notes

## 3.1 3-sep-21

- new project types
  - Inno-spec project including reflectance correction on scan load (correction can be specified per-image and per-directory)
  - Resonon project type supporting reflectance correction on scan load
- new installers
  - adding support for CUDA11.2
  - separate full installer including NVIDIA CUDA support
  - separate smaller installer for CPU + OpenCL backends convenient also for virtual machiens
- significant speedup of classification at runtime
  - holds for both CPU and GPU backends including also older projects
- new acquisition functionality
  - acquisition plugins allow use of different vendor SDKs
  - adding support for Resonon Pika cameras
  - SpecSensor plugins for 2019 and 2020 SDKs
  - Pleora eBUS support for eBUS 5.1 and 6.1 adds support for GenICam-compliant sensors such as Inno-Spec RedEye2
- improvements in regression
  - outlier score plot and error plots help to clean training/test set of outliers
  - performance measures panel with user-defined acceptance criteria
- GUI improvements
  - object-level confusion matrix with interactive visualization of ground-truth and detections allows full introspection of object-level decisions
  - added support for object shape features (Feret diameter, Hu moments, cirtularity)
  - added support for multiple directory selection for projects where each scan is a directory
  - images with labels show image names in italics
  - new auto-stretch of image brightness with slider-based adjustment in spectral plot menu

# 3.0 22-mar-21

- improvements in regression
  - support for multiple regression variables
  - significant speed-up when updating regression data sets
  - separate commands for model search, retraining model and applying model both to data and on a new scan
  - import regression meta-data from Excel also at region level (via named regions, see below)
  - easy inspection of outliers: jump to a scan containing specific object/annotation point
  - runtime API for per-object and per-pixel regression output for each variable
    - support for background pixel masking
- introducing user-defined regions
  - regions have unique names within each image and are assigned to a specific class
  - regions can define object ground-truth labels
  - by matching regions to object found it is possible to estimate of confusion matrix at object level and assess sorting performance
  - Excel export and import of region definitions
  - user-defined text annotation such as expert remarks can be added
- introducing feature extraction
  - extract and export user-defined features from objects or user-defined regions
    - mean spectra
    - spectral index mean or histogram per object
    - fraction of decisions per object
    - regression output per object
    - object count
  - information can be extracted from computed objects or from user-defined regions
    - for regions, presence/absence of data is reported (e.g. no plant in a germination well)
  - export to Excel and XML formats
- introducing batch feature extraction accessible from scripts without GUI via perClass_Mira_Batch.exe
  - export to XML format
  - define a template image specifying regions for extraction (e.g. grid of germination wells)
  - validating scans via a user-defined model rejecting data unseen in training
- improvements to image flagging
  - set selected images for testing or training
  - set a percentage of selected images as test (to perform user-defined cross-validation studies)
- batch crop applied to selected images
- spectral index definitions are saved in the .mira project file
- improves when processing large number of scans
  - ability to cancel long running operations (like result exports or regression meta-data imports)
- commands to switch between band subset used for a classifier and for a regressor
- possible to define band subset manually by band indices (e.g. 20:40 will enable bands 20 to 40)
  - adding and removing bands to/from existing band subset (useful to disabla certain ranges)
  - possible to set or toggle each Nth band
- new project type for Silios CMS cameras

# 2.4 28-sep-2020

- added reflectance correction for Headwall project type (correction by whiteReference and darkReference ENVI cubes in the same directory)
  - allows loading of externally corrected cubes in the same project
  - enables multiple scans per directory sharing the same correction
  - default cube extension is .bin, arbitrary extensions are supported
  - to apply correction at runtime, pass directory containing whiteReference and darkReference scans to mira_LoadCorrection (example: `mira_LoadCorrection(pmr,"path_to_dir_with_correction_files",NULL))`

- added general ENVI project type supporting arbitrary cube file extension
- added Corning project type
  - added perClass Mira Runtime support for native BIP data stream corrected with dark reference inside the camera
- improved selection of multiple images (click and drag supported, no image reload in multiple selection)
- improved drag&drop of directories (adding all files within each dropped dir)
- added support for NVIDIA CUDA11 (Ampere)
- when using floating licenses, specific licensing product can be requested based on `floatingLicenseProduct` setting in mira.ini (`mira` for perClass Mira Dev and `mira.gui` for perClass Mira)
- when importing regression annotation from Excel, existing points are removed to avoid duplicates
- fixed a problem when adding regression annotation to all objects in each scan
- fixed problem when label painting with large brushes
- fixed memory leak in loading large number of specim FX scans
- fix for dropped frames at the start of live acquisition session
- at runtime, all projects (including line-scans) must explicitly enable object segmentation with `mira_SetSegmentation(pmr,1)`

## 2.3 26-jun-2020

- support for foreign object detection with trully unknown objects
  - label materials you know. Enable *Show unknown* to highlight all materials unseen in training.
  - user-adjustable sensitivity on per-class basis provides extra control (slider via the right-click in the class-list)
  - objects unseen in training can be segmented out (flag *Unknown* decision as foreground)
  - the new foreign object optimizer is on by default, can be disabled in Classification menu.
- color wells display transparency (change alpha for a specific class in the color dialog or by via alpha toolbar button by holding Ctrl)
- crop improvements
  - crop rectangle line thickness auto-adjusted for very large cubes
  - adjust crop rectangle by dragging lines
- segmentation improvements
  - support for up to 20 foreground classes including access to their content information
  - per-object results can be batch-exported to Excel including per-class content in each object
  - fix for a crash due to changing object size in live acquisition mode
- confusion matrix improvements
  - added light mode (to allow copy/paste directly to documents)
  - added option to copy as text for direct copy/paste to Excel
- fixed live acquisition issue when Specim calibration file (.scp) was not found
- fix for min/max visualization setting in presence of NaNs and infinite values
- support for case insensitive fields ENVI in header files (for Python integration)
- runtime improvements
  - support for region of interest (ROI) for snapshots. Applying classifier only to specific ROI.
  - support for object segmentation for snapshot use-cases (Imec project type, float data type, BIP layout)

## 2.2 29-apr-2020

- new Visualization mode showing computed indices using different common equations
  - define using individual wavelengths or wavelength ranges
  - auto-scaling and manual scaling
  - indication of below, above and invalid values
  - define wavelength ranges interactively in spectral plot
  - render using different colormaps
- improved regression
  - visualize per-pixel regression output (e.g. distribution of moisture)

    - import point annotations from Excel (matching scan names exactly or with regular expressions)
    - move and edit point annotations
    - use only specific subset of spectral bands
    - show cross-validated regression error (RMSECV) which has the same units as the regressed value
    - when hovering over the results in the regression plot, display specific annotation points with their true and estimated values
    - visual indication that some point annotations are not linked to objects (e.g. point not on foreground class)
    - export regression results in Excel together with per-object size, bounding boxes, true and estimated regression outputs
- perClass Mira Runtime improvements
    - added model export for perClass Mira Runtime (new "Mira Pipeline" .mpl format using base64 encoding)
    - added API to query expected data type, data layout and geometry of data from spectral camera
    - added support for all object segmentation configurations created in the GUI including per-object content retrieval and object classification by rules
    - added snapshot processing mode (mira_ProcessCube). Currently only pixel decisions are provided, not yet the object segmentation or content.
- added support for OceanInsight Spectrocam and Pixelcam data formats
- added support for ENVI cubes with uint32 data type and little-endian float
- added classifier preprocessing (smoothing, 1st and 2md derivative)
- export and import labels as PNG images
- export per-image results to Excel allowing quick summary of fraction of decisions within foreground (e.g. disease within plant leaves)
- update of live acquisition using Specim SpecSensor SDK
    - Applying regression both per-object and per-pixel in live acquisition
    - Calibration pack information stored in settings, reused for further sessions
- fixes in object pannel: When retraining the classifier, object classification rules are preserved
- adding default class color map
- repeatable object label colors (can be change using random seed dialog)
- added per-class transparency (alpha setting in the color dialog and using the toolbar transparency slider - hold Ctrl to change only the current class alpha)

## 2.1 18-feb-2020

- Specim FX project type allows scan directories with different name than raw cube in capture sub-folder
- Unicode support in image file names for ENVI-based formats
- providing informative error messages when image cannot be loaded
- adding Cubert Tiff project type with native support for Cubert Ultris camera
- adding Headwall project type
- license file can be drag & dropped from Explorer to the license dialog
- RGB bands are set based on ENVI header file
- mira.log file is now written to AppData/Roaming, not to the installation directory (now by default in Program Files (x86))
- fix of calibration pack loading in SpecSensor
- labels can be exported into .png files
- ENVI import supports int16 data type
- when the number of sampes is too low, the output window shows a red message that can provide details on click
- when alpha is too low (high label transparency), the toolbar alpha button blinks to remind the user that labes may be badly visible

## 2.0 18-oct-2019

- new Cubert ENVI project enabling data from Cubert Ultris and upsampled UH185 images
- perClass Mira Runtime binaries adding dongle support

# 2.0 10-oct-2019

- adding support for double-precision ENVI data cubes
- supporting model deployment for execution on live data from Cubert Ultris light-field hyperspectral camera
- enabling Cubert plugin export for ENVI-based projects.
- fixes in live acquisition using Specim FX cameras when device loading fails or opening FileReader gets cancelled
- fixing a crash due to very large training set
- fixing a bug in error visualization mode where switching to images without labels did not show proper image

# 2.0 20-sep-2019

- Fix: Installation directories with non-ASCI characters are now supported
- Live acquisition executables for Specim cameras included (perClass_Mira_live.exe and perClass_Mira_gpu_live.exe)
- Senop project: Images are automatically processed with per-band gain

# 2.0 6-sep-2019

- Estimate **object quality using regression** (examples: sugar content estimation per tomato)
  - annotate quality per object
  - automatic model selection reporting performance (R^2 and Q^2 statistics)
  - user-defined pre-processing (smoothing and derivatives)
  - apply regression to new images (show a bounding box + regression output per object)
  - allow localized information extraction by a radius around annotation points
- Images can be flagged for testing only (not used for building the model)
  - **Test confusion matrix** provides a detailed view of the performance on test images
- **Error visualization mode** brings insight in model performance.
  - visualize where the current model fails
  - this helps to identify incorrect labels or (together with test image flagging) whether the data is well represented in the training set
  - **Image confusion matrix** shows only labeled examples on the current image
  - interactive error visualization by moving mouse over the image confusion matrix
- **Object segmentation mode** with multiple options
  - one object / one class mode for object detection (e.g. detect plastic pieces in a food product stream for automatic removal)
  - one object / multiple classes for object classification (e.g. detect potato pieces, classify entire piece as defective if it contains more than 5% of greening or rot inside)
  - visualizing object labels or object decisions
  - object decisions by majority vote or rules (size of or fraction of a specific class)
- Usability improvements
  - **assign label stroke to the current class**. This allows one to exclude a specific label stroke from training and see the impact on model performance (define an additional class and exclude it, assign strokes to it and retrain)
  - the data validation mechanism excluding invalid spectra is now off by default. It can be enabled using context menu in the spectral plot.
  - all modes (labels, decisions, errors, objects) accessible by direct keystrokes
  - confusion matrix size can be decreases/increased (useful for large number of classes)
  - auto-check for software updates + direct link to download latest version from the GUI (Help / Check for updates)
- *experimental* **Live data acquisition** **from Specim FX cameras** using Specsensor SDK (needs to be installed separately)
  - apply a classifier and object segmentation to a live data stream
  - live visualization of processing speed and drop frame indication to assess production performance
  - user-control of exposure and camera frame-rate
  - supports practical situations where production light conditions are diffrerent from the training situation

        - the white and dark references used for live data processing can be specified without model retraining
    - automatic handling of spectral and spatial binning based on specific scan meta-data
    - support for **outdoor operation**: Define white reference by specifying an image region where a reference tile was placed
    - **recording data** from a live acquisition in the standard LUMO format

## 1.4 22-may-2019

- **perClass Mira Runtime** is now included in the distribution
    - high throughput (1.5ms/frame on NVIDIA GPU in an example foreign object detection project, Specim FX17, 640 spatial pixels, 224 bands, 6 materials)
    - the runtime directly reports object positions, sizes and classes
    - support for **NVIDIA Jetson** platform (both ARM CPU and NVIDIA GPU backend)
    - support for line-scan use-case on Specim projects (specific white/dark correction format)
- **Linux build** for both perClass Mira GUI and perClass Mira Runtime
    - accelerated CPU and GPU support on Linux
- new high-throughput segmentation engine
    - automatically discarding objects smaller than user-defined minimal size
    - supporting multiple foreground classes
    - high-speed line-scan segmentation with constant per-frame speed
- export visualization as PNG images (band or RGB, with labels, pixel decisions or segmented objects)\
- for Cubert projects, proper wavelength ranges are shown

## 1.3 8-feb-2019

- zoom using mouse wheel now follows cursor
- image rotation using toolbar buttons (and > < keyboard shortcuts)
- adding images using drag and drop from Windows explorer
- support for ENVI files with high-endian byte order uint16 (byte order=1)
- saved projects now preserve settings of the current band, R,G,B lines and allow direct execution of the trained model when project is loaded
- exported decision images (PNGs) contain meta-data such as class count and class names accessible by standard tools such as *tweakpng* or Matlab `imfinfo` command
- multiple directory selection for Specim FX and Tiff stack project types can be enabled in mira.ini file (using `useNativeDirSelection=false`). It is not enabled by default because it uses a non-native file dialog.
- new project type for Senop cameras (formerly Rikola)

## 1.2 5-dec-2018

- Added band-selection widget. It is now possible to manually select the wavelengths used for building models
    - Band brushing allows quick selection or clearing of wavelength ranges
    - Exported models start from the full set of wavelengths but use only the selected subset for the model. This allows quick deployment of different models to custom applications assuming full spectrum (single binding with perClass Runtime is needed)
- Added export of labeled data to perClass Toolbox sddata format
- Added export of entire data cube in Matlab format as 3D matrix
- Models results are now repeatable with a new random seed dialog controlling the internal data partitioning process.
- Separate CPU-only and CPU+GPU builds are available. The CPU-only build is always available by default to avoid issue related to GPU drivers or CUDA versions installed. The CPU+GPU executable is called perClass_Mira_gpu.exe
- Band index and the wavelength number are now updated on the status bar when dragging the band line in spectral plot
- Added support for logging of status messages when starting up the application. This is useful to understand some issues with GPU installations and CUDA versions. Logging is off by default, can be switched on in the

mira.ini file.

- Licensing improvements:
  - For activated licenses, there is now an auto-update mechanism that pulls updated license from the activation server when the application starts. The application may be used without on-line connection - it is needed only once in two weeks.
  - Adding support for floating licenses obtained over network from a license server. Floating licenses are now checked out one per session.
- Fixed wrong file name of previous project used for saving new project with File/Save command
- Fixed a crash when preview image could not be loaded

# 1.1 10-sep-2018

- **confusion matrix view** showing detailed error information
  - interactive performance optimization in a confusion matrix (slider in right-click context menu or a mouse wheel on confmat entries)
  - confusion matrix shows normalized errors and precisions, absolute sample counts available as well
  - quickly switch to confmat with 'c' key and to spectral plot with 's' key
  - define **performance constraints** via double click on a confusion matrix field (create/remove constrain)
  - constraints may be adjusted live by Ctrl+mouse wheel
  - constraints may be enabled/disabled to understand available performance options
  - move between available solutions fulfilling all constraints with [ and ] shortcuts
- **preview image from user-adjustable R,G and B bands** when spectral cube is loaded
  - this view improves labeling experience for many material types that look similar in a single band but their differences may be highlighted in R,G,B view
- **undo/redo** for label painting speeds up labeling
- **image crop** providing significant memory use reduction and processing speedups
  - when a project with a cropped image is loaded, the original cube is loaded and cropped
  - original cube may be loaded as a new image and multiple crops from the same cube are supported
- including perClass Runtime DLL and example of spectral cube processing in C
  - support for both **single precision** and double precision pipelines (with a new perClass 5.4 Runtime)
  - significant speedup of exported classifiers
  - legacy export option supporting older deployed runtimes <= 5.2
- a **preview rotation** command allows one to fix the rotation between preview and spectral cube (e.g. on Specim IQ projects)
- adding an option to **exclude a class from training** (right-click in class list or press 'x')
  - this allows one to quickly check the impact of specific classes on the overall solution
- option to purchase a license online and directly turn the demo into a commercial product
- dialog to request Skype/Teamviewer session on start up
- fix for a wrong class index after removing a class
- fix for clear labels of an image

# 1.0 13-jul-2018

- fix for a dock shift bug (when resizing a docked window and clicking on the image, the docked pannel resized back)
- adding band line dragging by mouse
- adding max valid line which is automatically set on image load
- when user is on preview and tries painting, a dialog is shown to load the entire cube (allows quick image changing without load)

# 1.0 29-may-2018

- first public release

# Installation

## System requirements

perClass Mira system requirements:

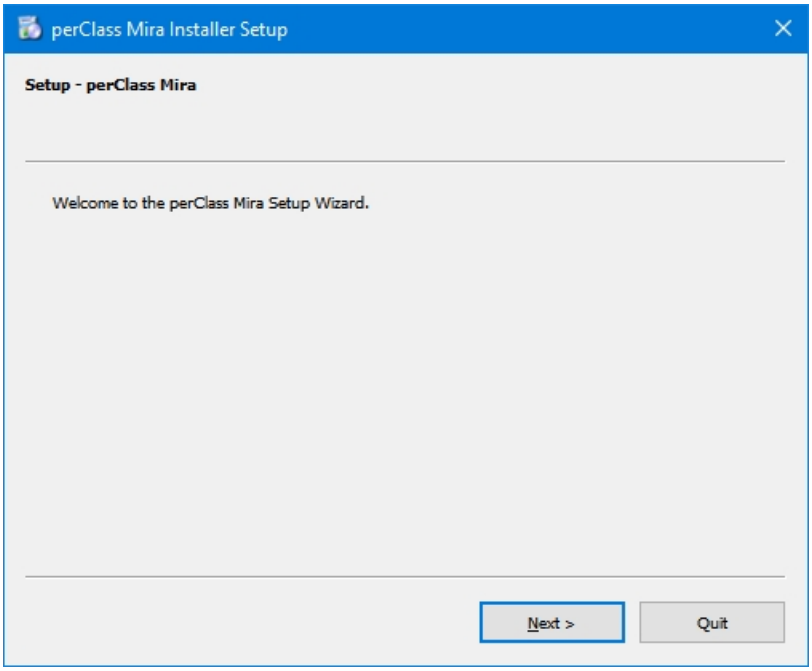
- PC with MS Windows (version 7 or higher) 64bit
  - memory of at least 8GB
- (optional) NVIDIA GPU supporting CUDA 9 or higher library (needs to be installed separately)
  - GPU memory at least 4GB
- (optional) mouse with a scroll-wheel is useful for many operations
- (optional) for live data acquisition using Specim FX cameras, Specsensor SDK needs to be installed

## Installer

perClass Mira installer will guide you through the installation process.

### *Welcome screen*

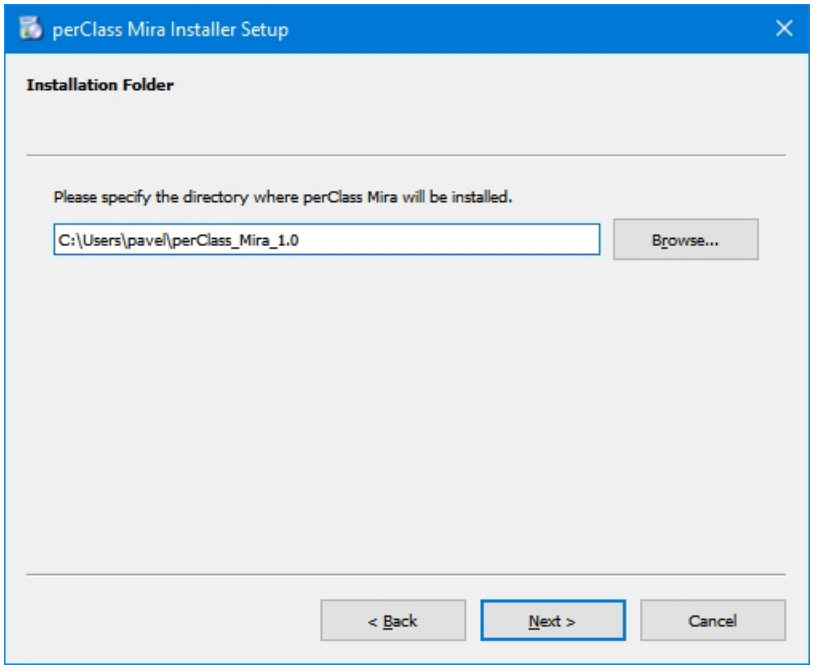
When the installer is launched, the following welcome streen appears:




**TIP:** In some situations, buttons at the bottom may not be directly visible. It is sufficient to resize the installer window to make buttons appear.

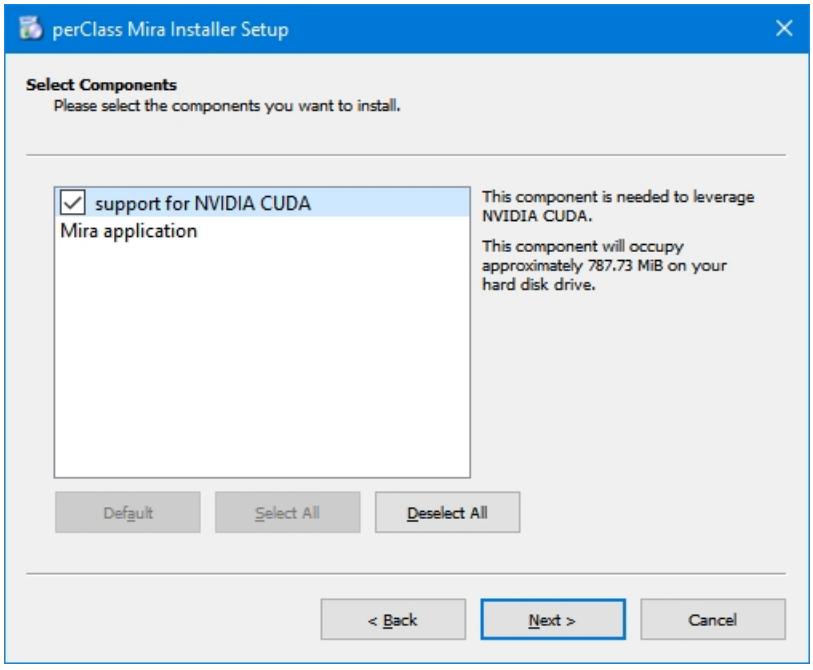
### *Installation directory*

Next, installation directory can be defined. By default, perClass Mira is installed in a user directory



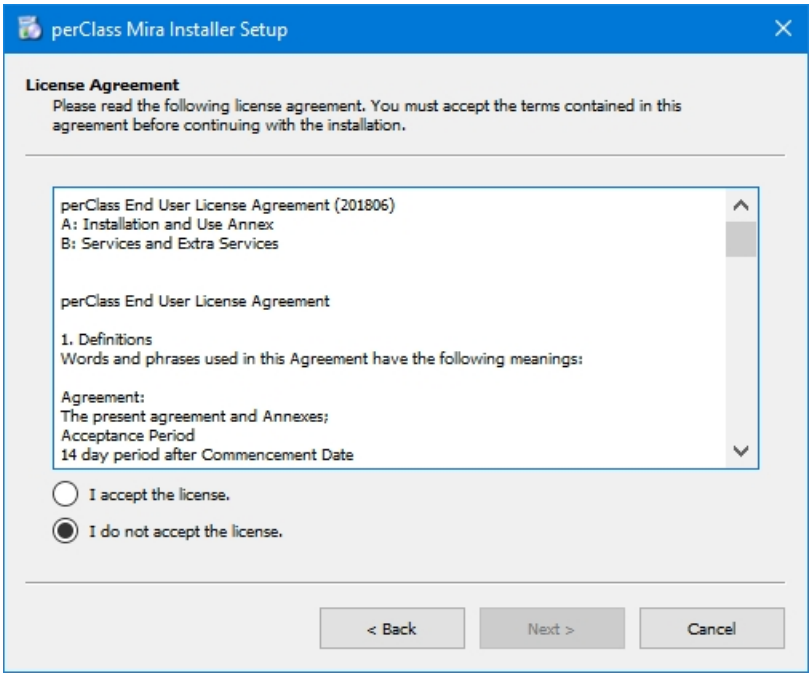

### *Component selection*

In the next window, software components may be selected. Although it is possible to deselect NVIDIA GPU support, we recommend keeping the default setup if possible.




### *License agreement*

In the next step, license agreement is provided and needs to be agreed in order to continue the installation.

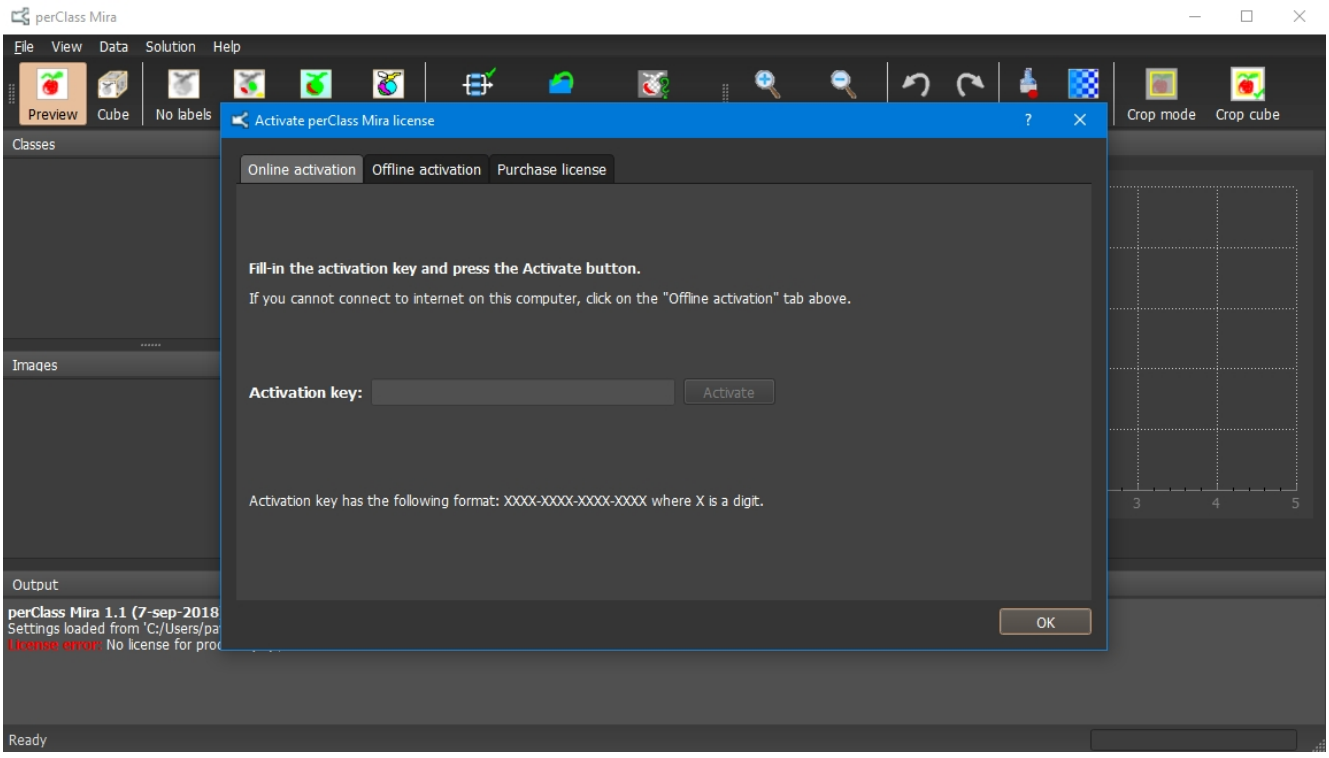



### *Start Menu Shortcut*

Finally, start menu shortcut may be dfined.

## First start

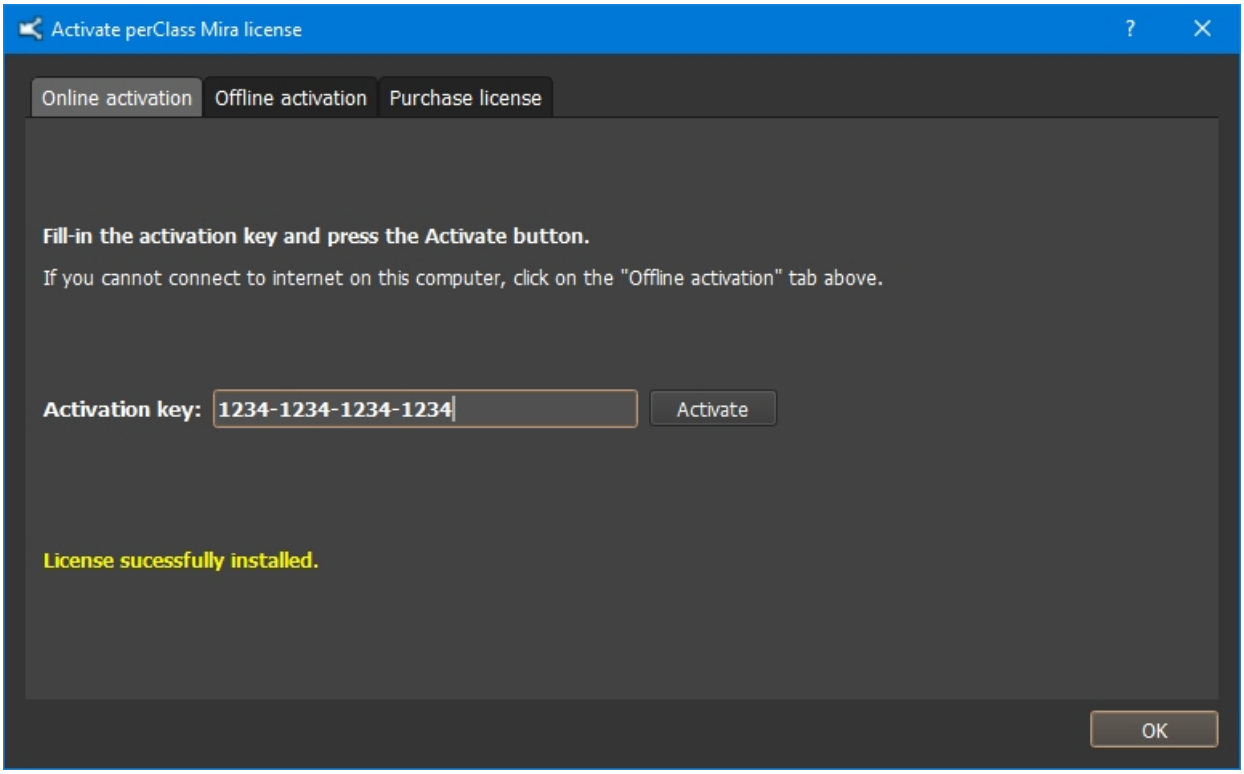
When starting perClass Mira for the first time, there is no license file present. Therefore, an activation dialog appears:




You need to provide an activation key that will pull a license, specific to your machine.

The key has twelve digits in a format such as: 1234-1234-1234-1234. Naturally, you need to use the key you obtained for a demo or for the full version, not this example.

By clicking *Activate* button, the license is installed:




**TIP:** The license file is stored in **`c:\users\USERNAME\AppData\Roaming\perClassBV`** directory together with perClass Mira configuration file.

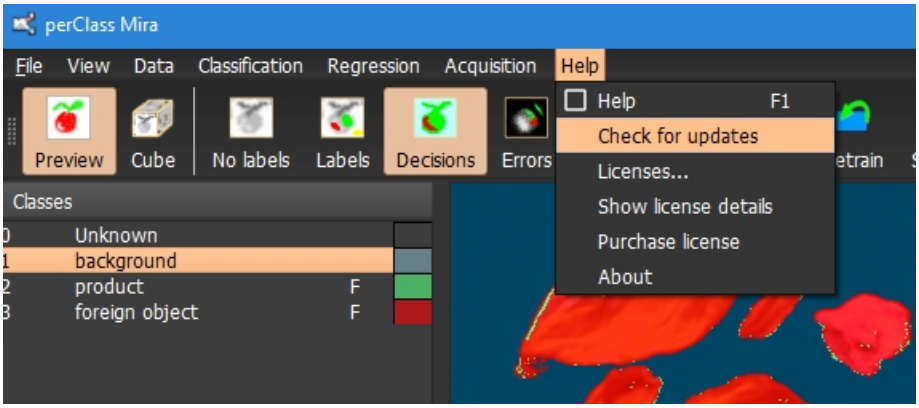
## Uninstall

In order to uninstall perClass Mira, run the **maintenancetool.exe** application in its installation directory (by default **`c:\users\USERNAME\perClass_Mira_3.1`**)

# Checking for updates

perClass Mira automatically checks for software updates. The default behaviour is that once in 10 days perClass BV server is contacted requesting the latest published software release. If a newer version exists a *Check for updates* dialog is shown with the details.

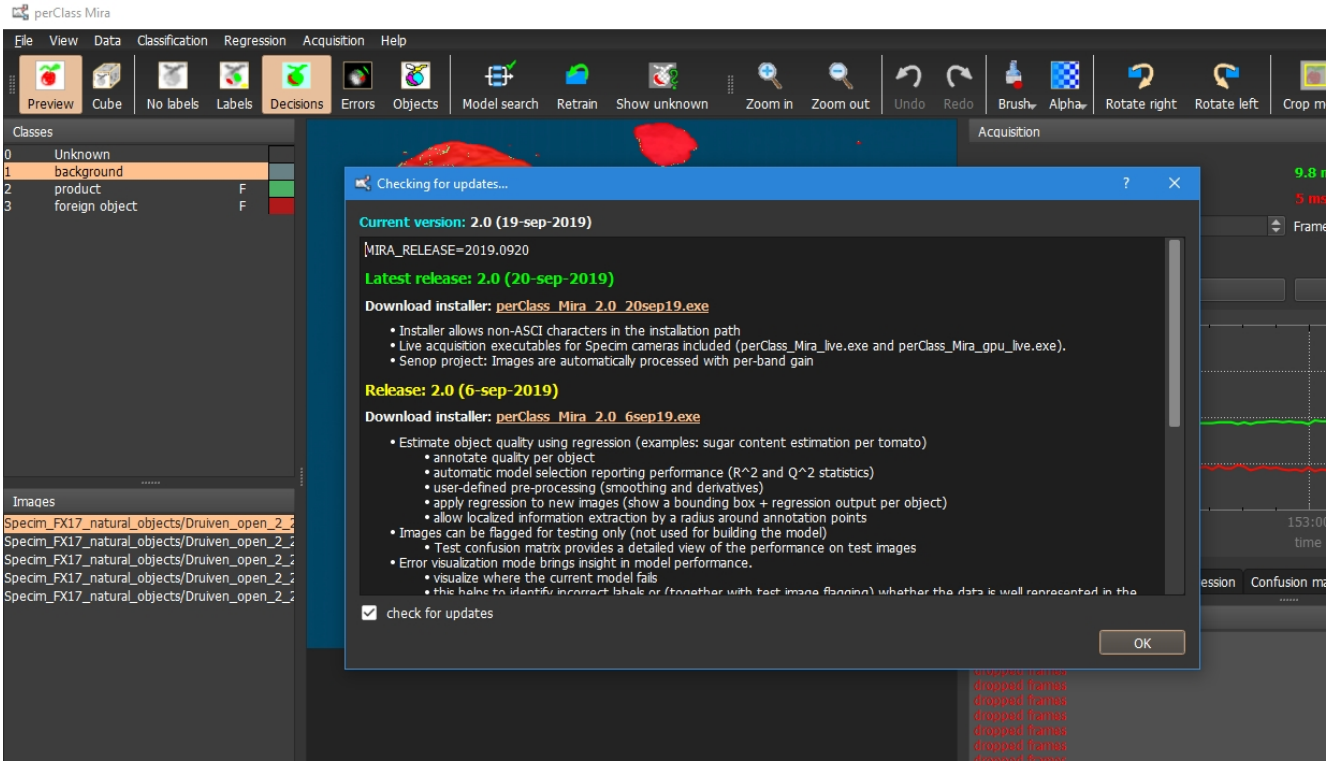
The check fot updates can be also initiated manually from the *Help* menu.




The Update dialog shows latest release notes and download links.

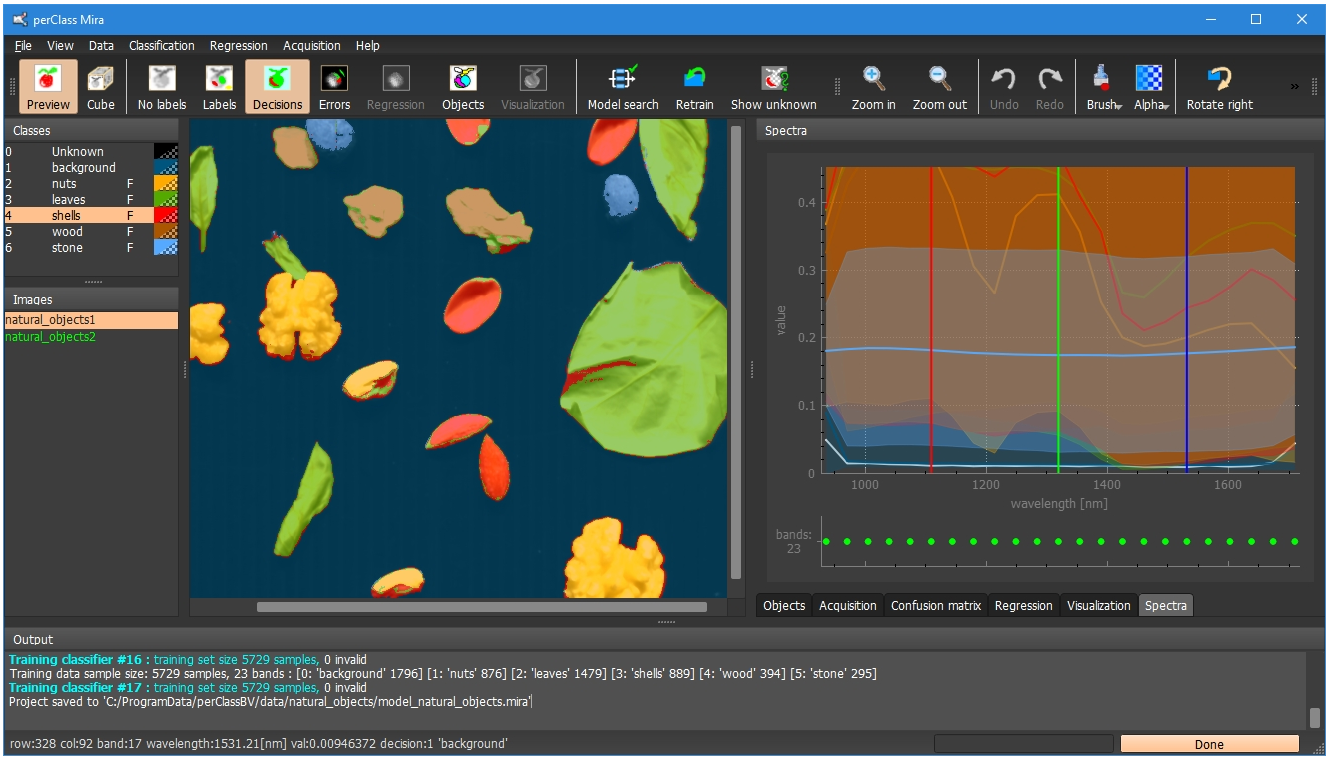
The user needs to manually click on the download link and install the software.

The default update checking behaviour can be switched off by the checkbox in the updates dialog or in the mira.ini file.



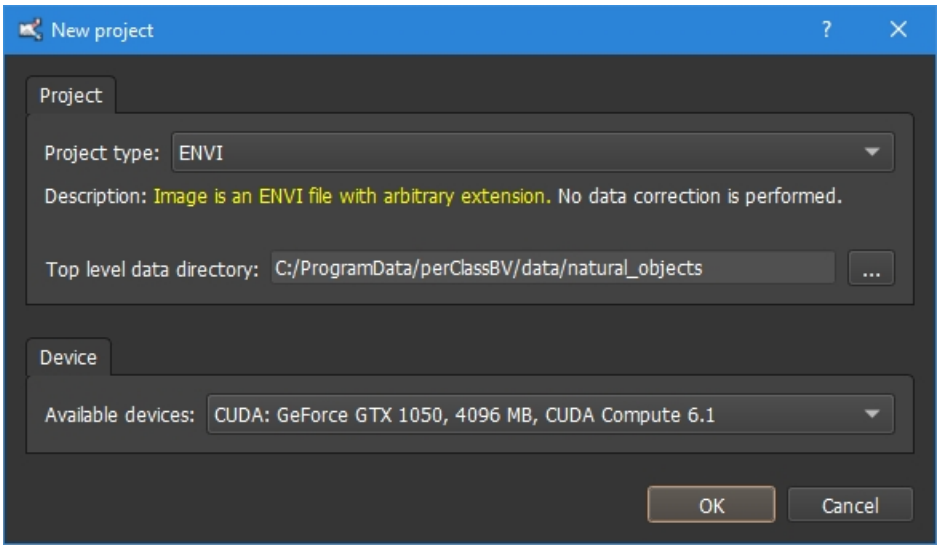

# Getting started

In this Getting started example, we walk through the process of creating a solution for detection of different types of natural objects.




## Creating a project

Create a new project using *File / New project* menu command:




Select project type. In our case, we select ENVI because we are starting from generic ENVI cubes.

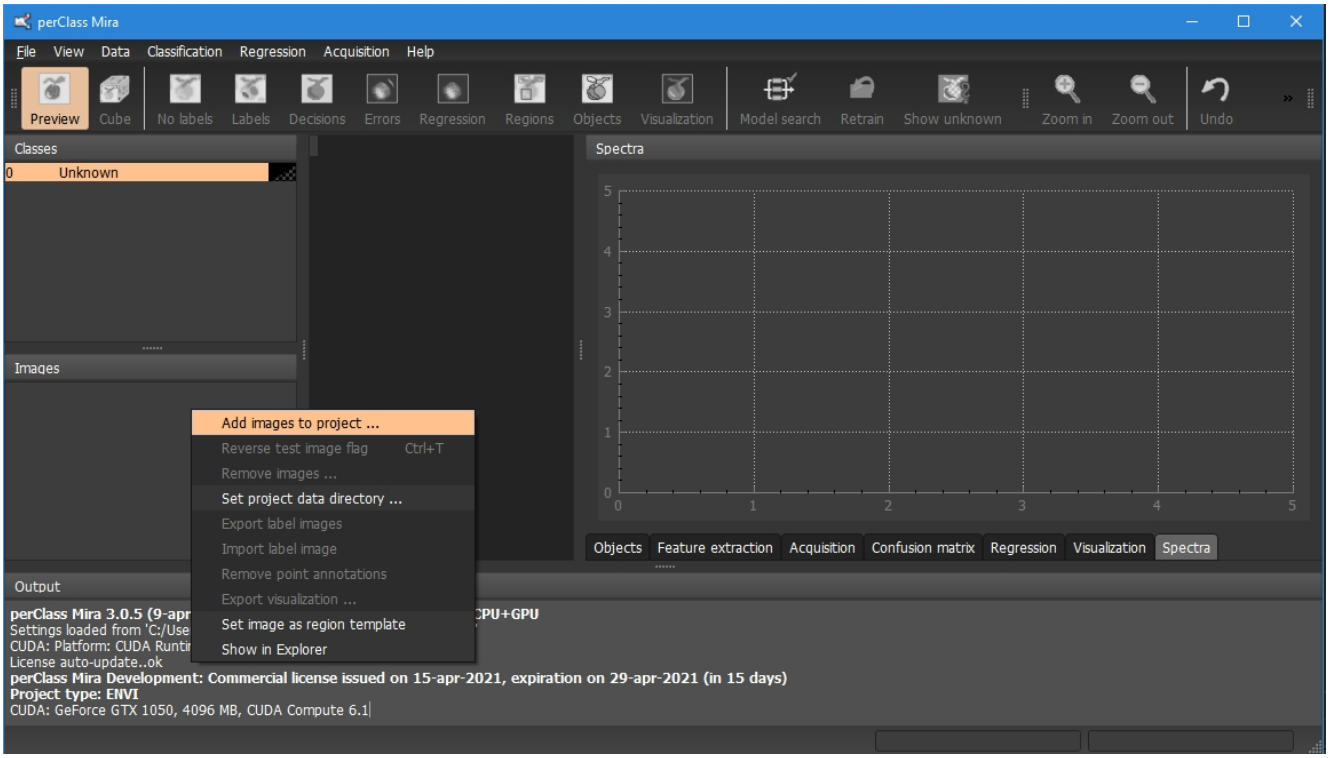
The *Top level data directory* is specifying where are spectral images reside on the file system.
perClass Mira does not write into your data directory unless explictly requested by the user (e.g. when exporting data).

The *Device* combo box allows us to select computation device used for processing.

In order to see GPU devices listed in the devices dialog, you need to use perClass_Mira_gpu.exe build.

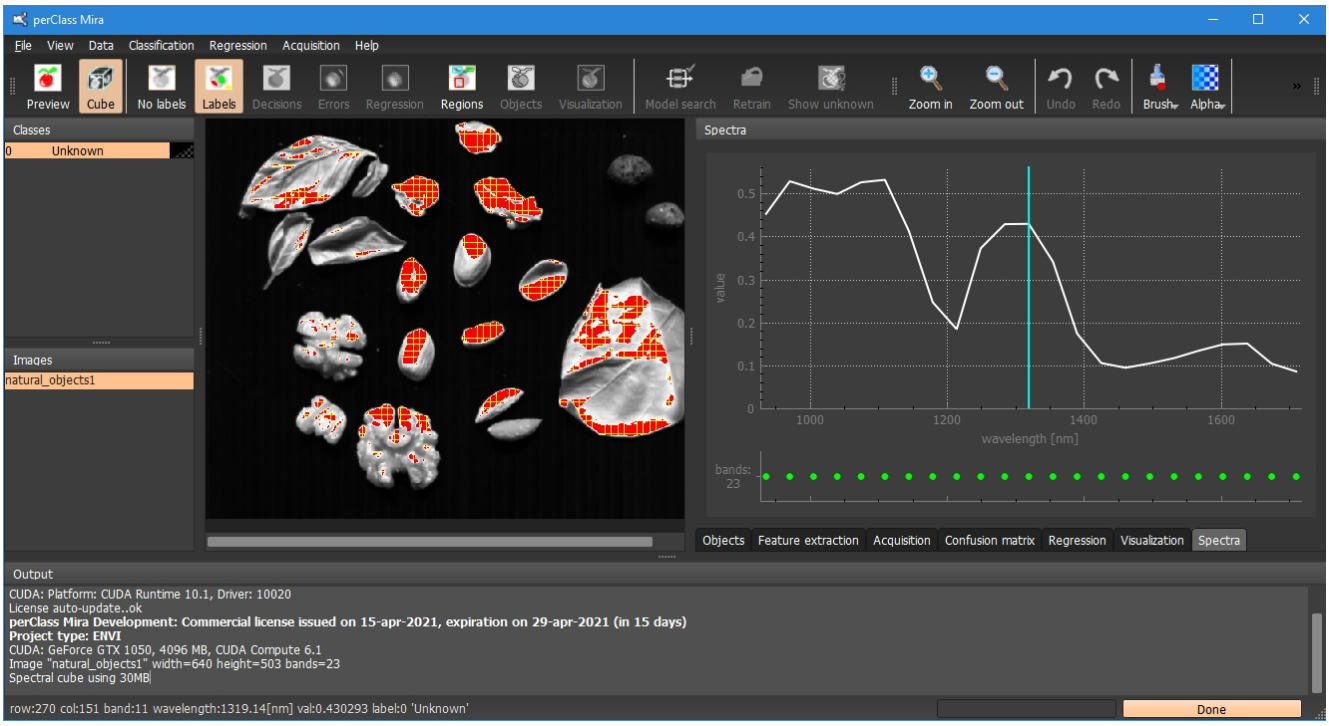
## Adding images

In order to add images to the project, right-click with your mouse in the images list and select *Add images to project...* command:




A dialog will open where you can select one or more images. For the ENVI project type, we select header files (.hdr) corresponding to the ENVI cubes.

**TIP:** In order to select more than one image, hold Ctrl and click on the desired file names. If you wish to select a set of images, you may click on the first one, then hold Shift key and click on the last one of the desired group.



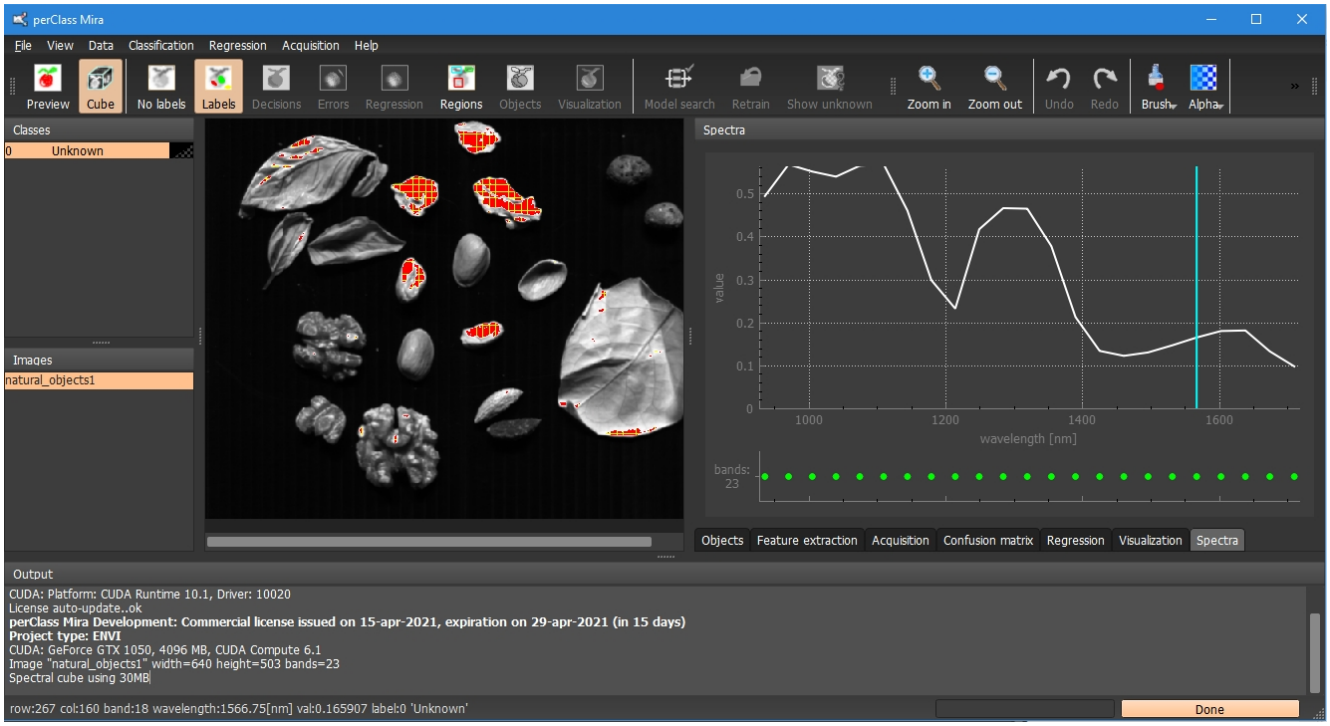

## Spectral cube visualization

By default, we view a single band of our spectral cube. The selected band is denoted by the light-blue vertical line (*the band line)* in the spectral plot.

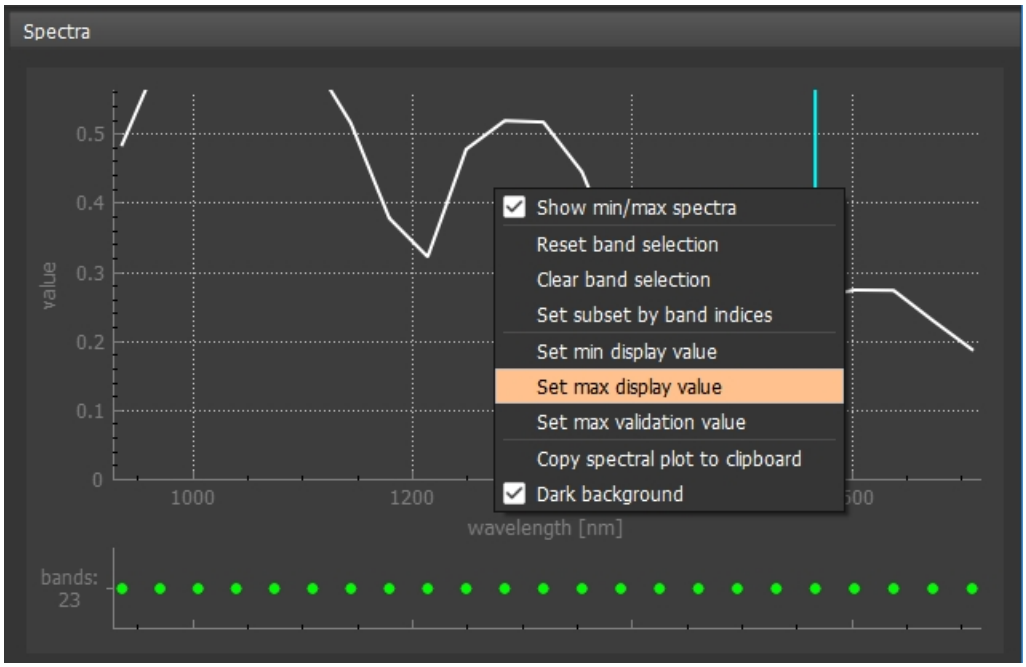
You may drag the band line using mouse to change the band.

Moving the mouse over the image, you will see the spectrum at each point as a white line in the spectral plot. Details on pixel coordinates, wavelength and a value can be found in the status bar area.

Note the red pattern on some of the pixels. This is a visualizaion feature that highlights pixels with values higher than the current maximum bound of the spectral plot.




You may adjust the spectral plot range by the mouse wheel or select a specific min/max values using right-click menu on the spectral plot:

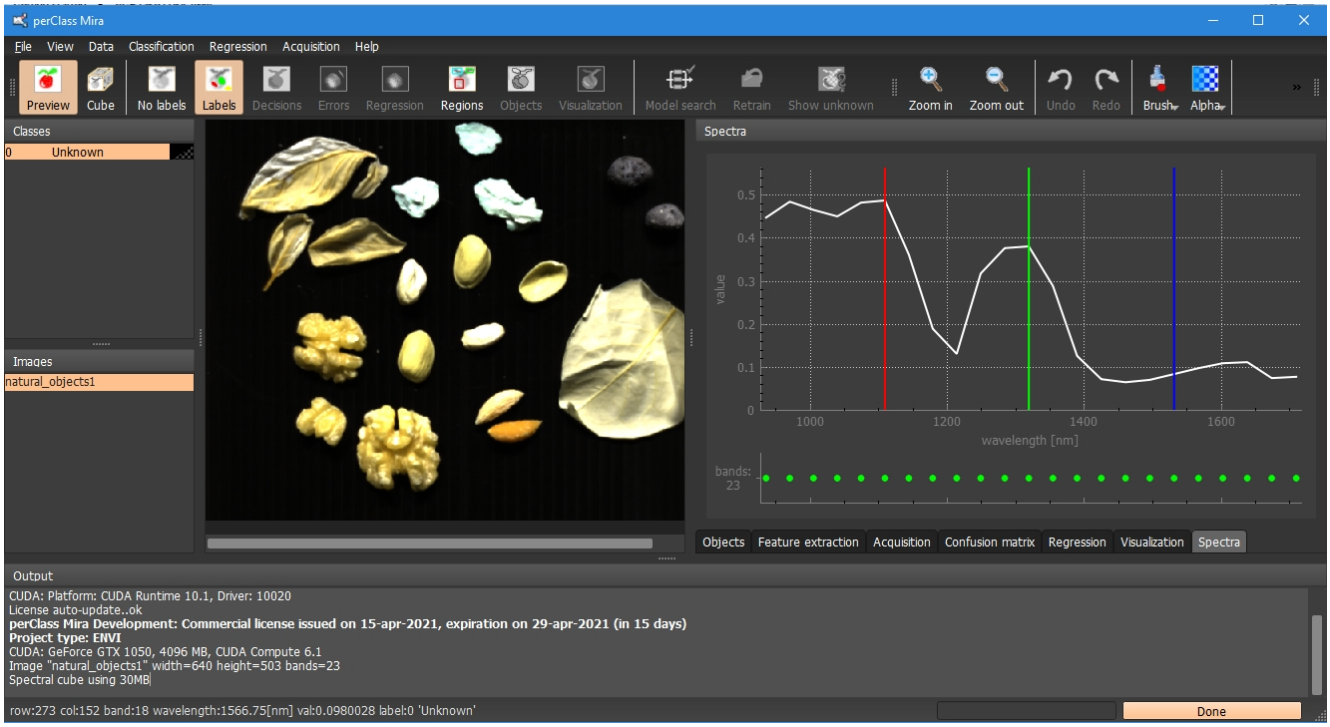



**TIPS:**

- The red pattern for out-of-bounds pixels can be changed into white in *View / Show saturated data as white* menu command.
- To select next or previous spectral band, you may use right/left cursor key or a mousewheel when holding Shift key

## RGB false color view

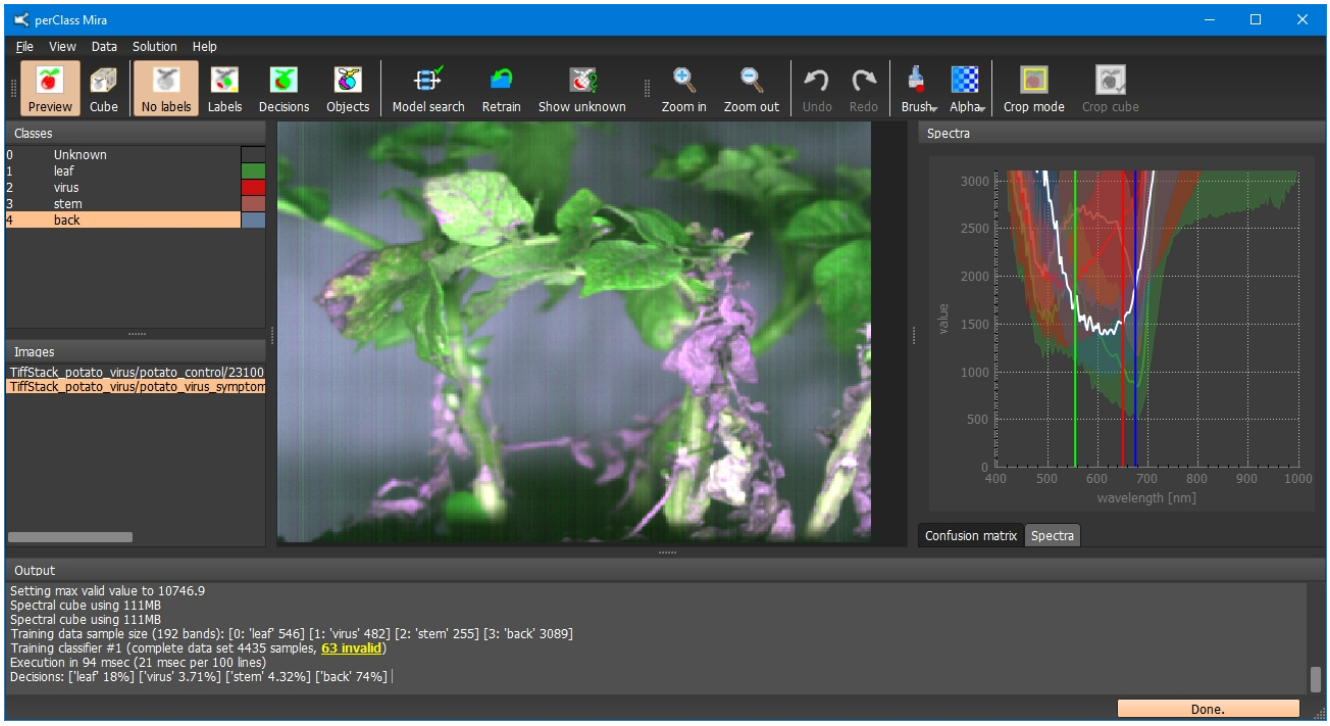
Select the *Preview* button on the toolbar to see the RGB false color view.




You can use the red, green and blua lines in the spectral plot to adjust the respective color channels.

Because our spectral cube represents NIR range from 900-1700nm, there is no true color information available. The RGB view only defines false color view of the data.

RGBi view may be useful in order to highlight specific material types. For example, in this screenshot, you may see potato plant with some leaves impacteb by a virus infection. Selecting good combination of bands in the RGB view, we can see clear difference from healthy leaves.



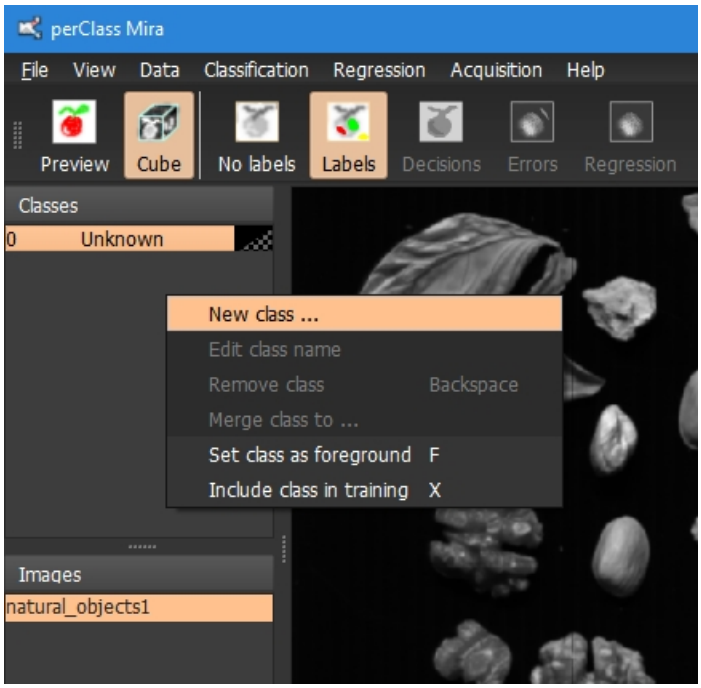

## Training a classifer

perClass Mira allows you easily define custom classification solutions. Classifier is an algorthm able to assign any pixel of your image to one of pre-defined classes.

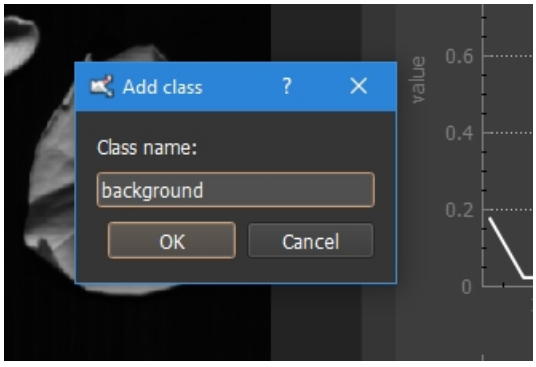
The process of building a classifier comprises three steps:

- Defining the classes of interest
- Labeling examples used for training
- Testing / validating that the classifier hevaes as expected on unseen examples or images

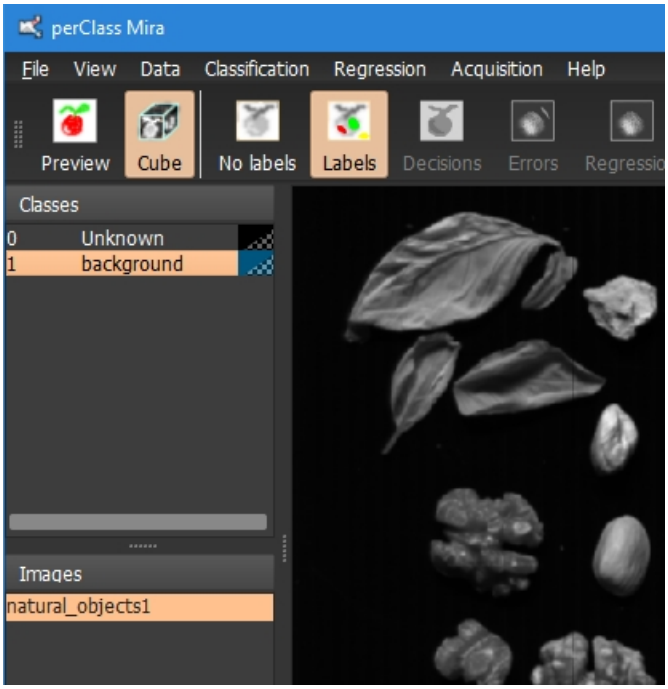
In order to define a class, right click in the Classes list and select *New class...* command:




A dialog will appear, where we can specify class name. We're interested to define the class called background:

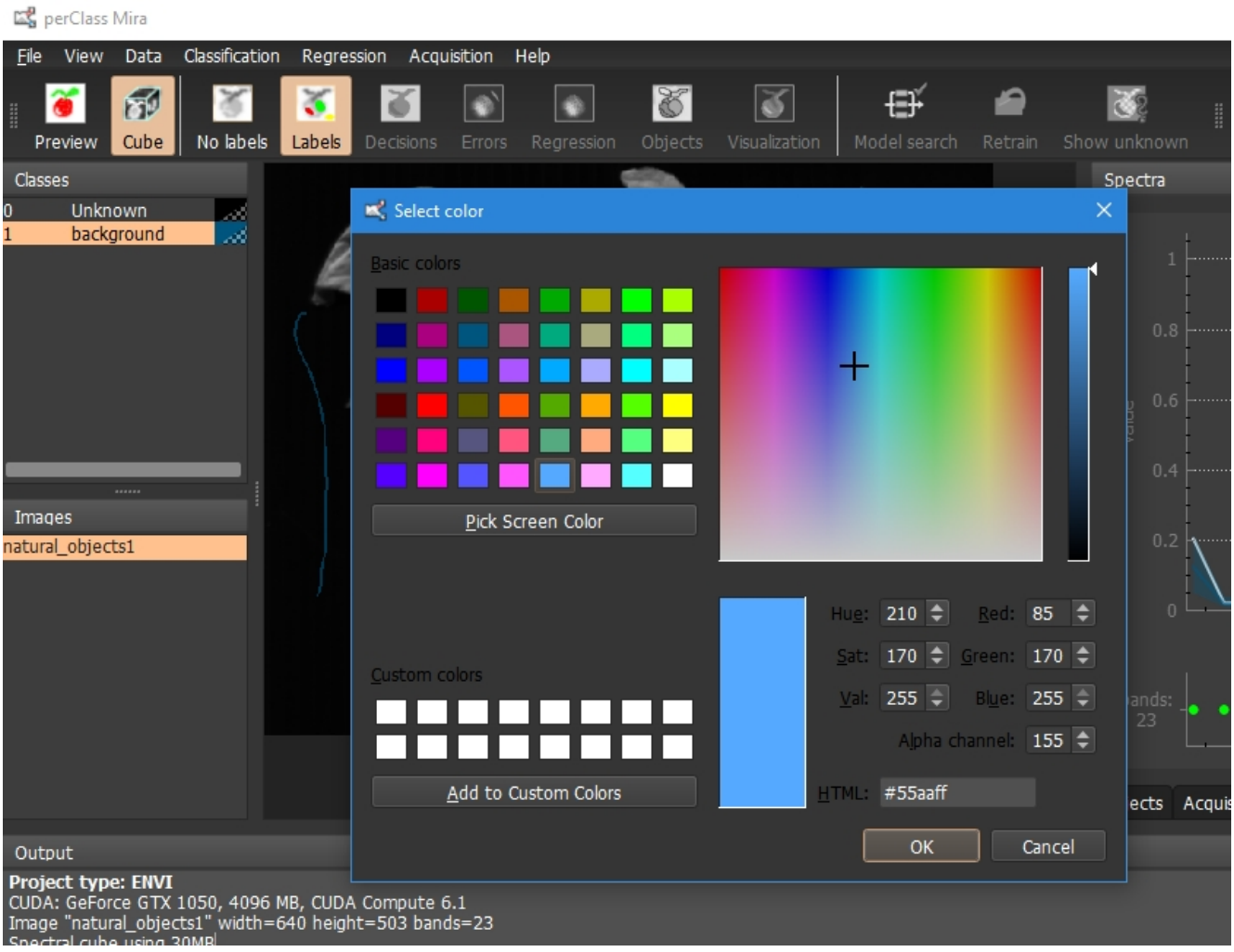



The new class will be added to the class list:

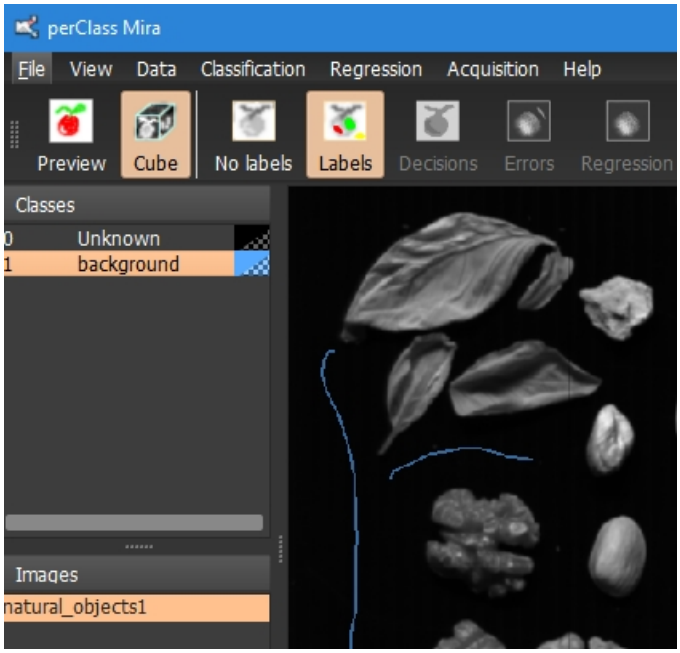


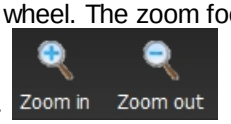

We may now label (paint) some pixels we consider background:

Let us change the color to lighter blue that is easier to see in our image by clicking on the color swatch next to the class name.

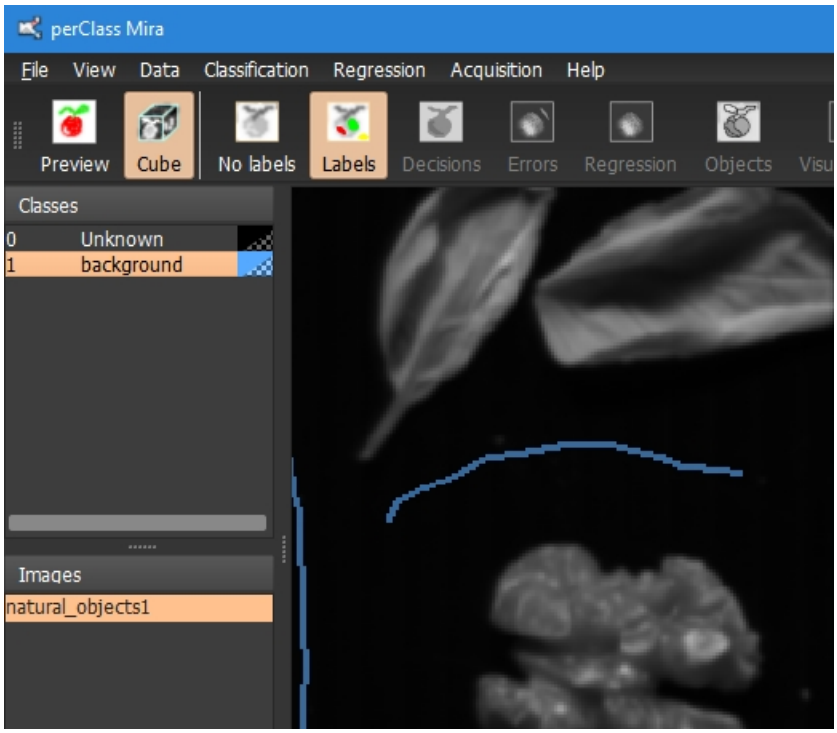



In order to label pixels using the selected class, hold left mouse button and move over the image.

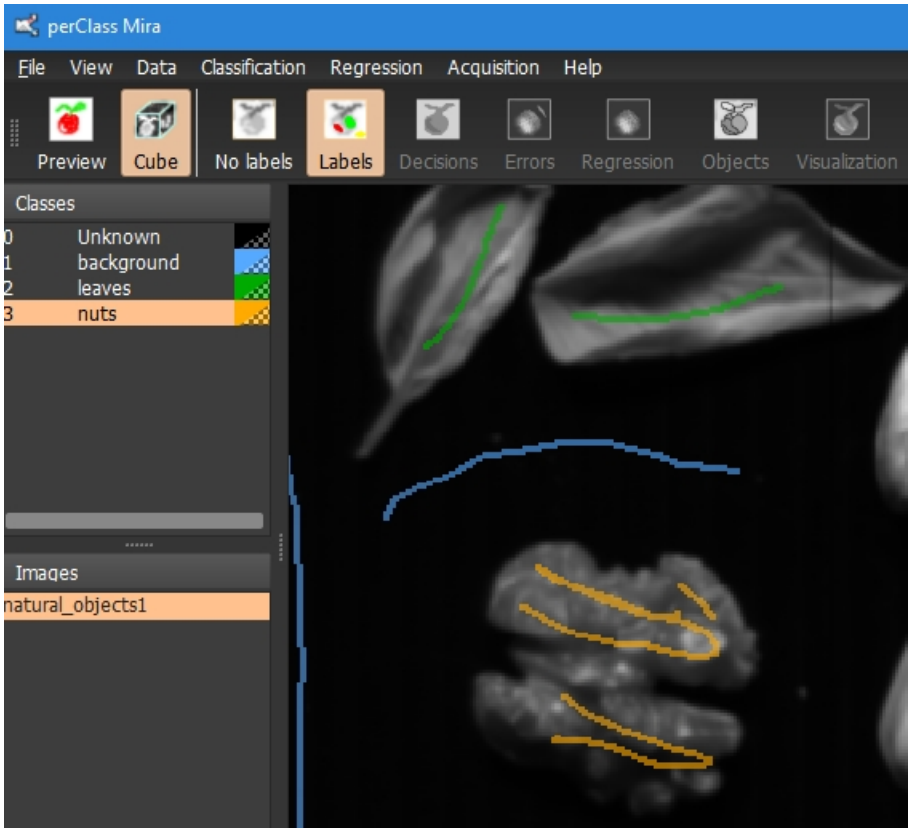


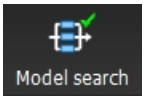

To zoom the view in or out, you may hold Ctrl key and use mouse wheel. The zoom focuses on the current mouse pointer position. Alternatively, use the Zoom buttons on the toolbar 


To delete the labels, hold Shift key and paint with a mouse. You may adjust the brush size using the Brush toolbar button 

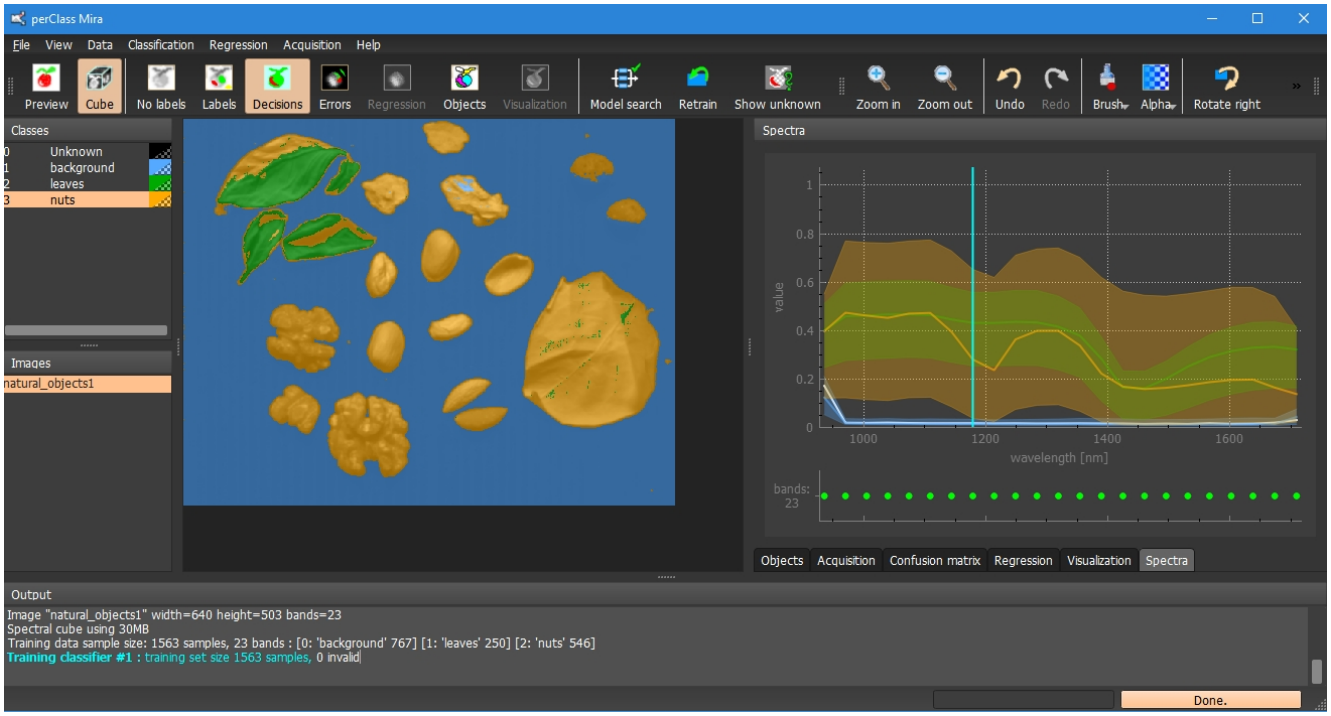




We define also the second class called leaves and the third one called nuts:




In order to train the classifier, click the *Model search* button on the toolbar 

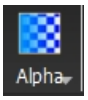

The software will use the labeled pixels to optimize classification model. It will then apply the trained model to the entire image switching to the Decisions view. To see the entire image, we zoomed out.




## Switching between labels and decisions

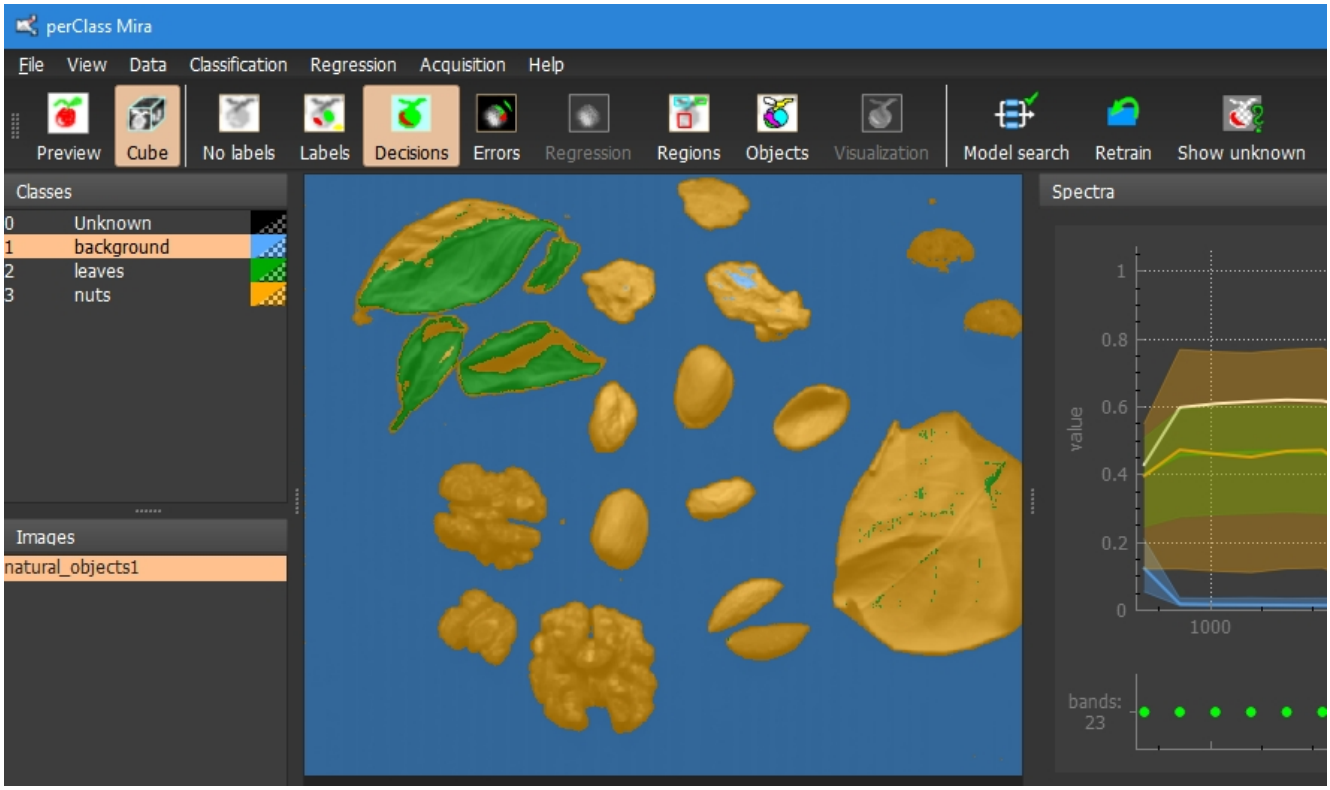
In the decision view, each image pixel is assigned to one of the user-defined classes.

Note, that we view a visualization comprised of the decision layer as a trasparent overlay over the data layer (RGB or single band).

You may change the transparency setting using the Alpha toolbar button 


No transparency: Each pixels shows pure class color:


High transparency: Each pixel shows also the underlaying image content




We may switch back to the Labels layer by pressing the Labels toolbar button 


**TIP** You may use Spacebar key to switch to the previous layer (here we would switch from Decisions to Labels)

## Improving the classifier

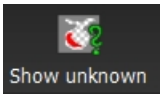
There are several ways we may improve the classification results:

- Improve the labeling and retrain
- Add / remove classes
- Remove noisy or uninformative bands

Subjectively, you may judge classifier performance visually by applying it to new images unseen in training.
In order to assess objective classification performance, you may estimate error using confusion matrix tool on test images, unseen in training.

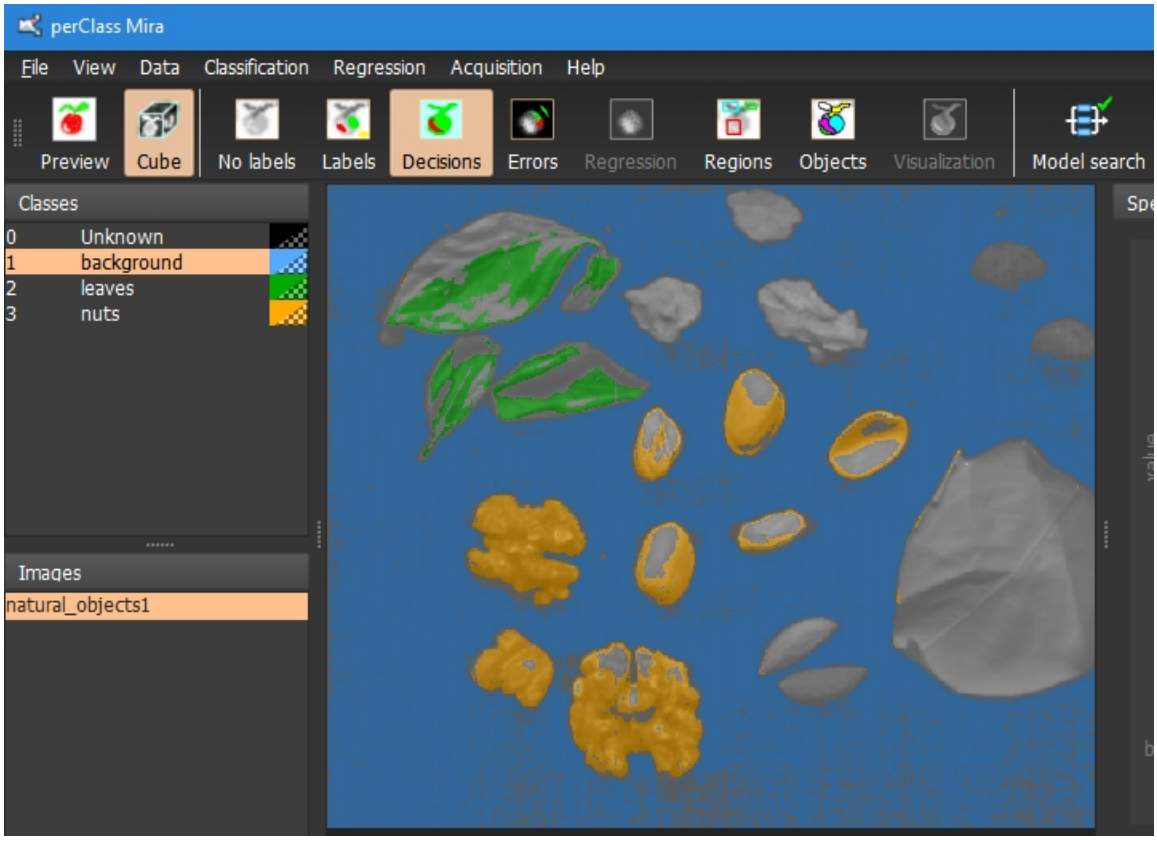
### Improving labeling

perClass Mira provides an active learning tool that helps us to understand what examples the model did not see in training.

You may enable it using the *Show unknown* toolbar button 

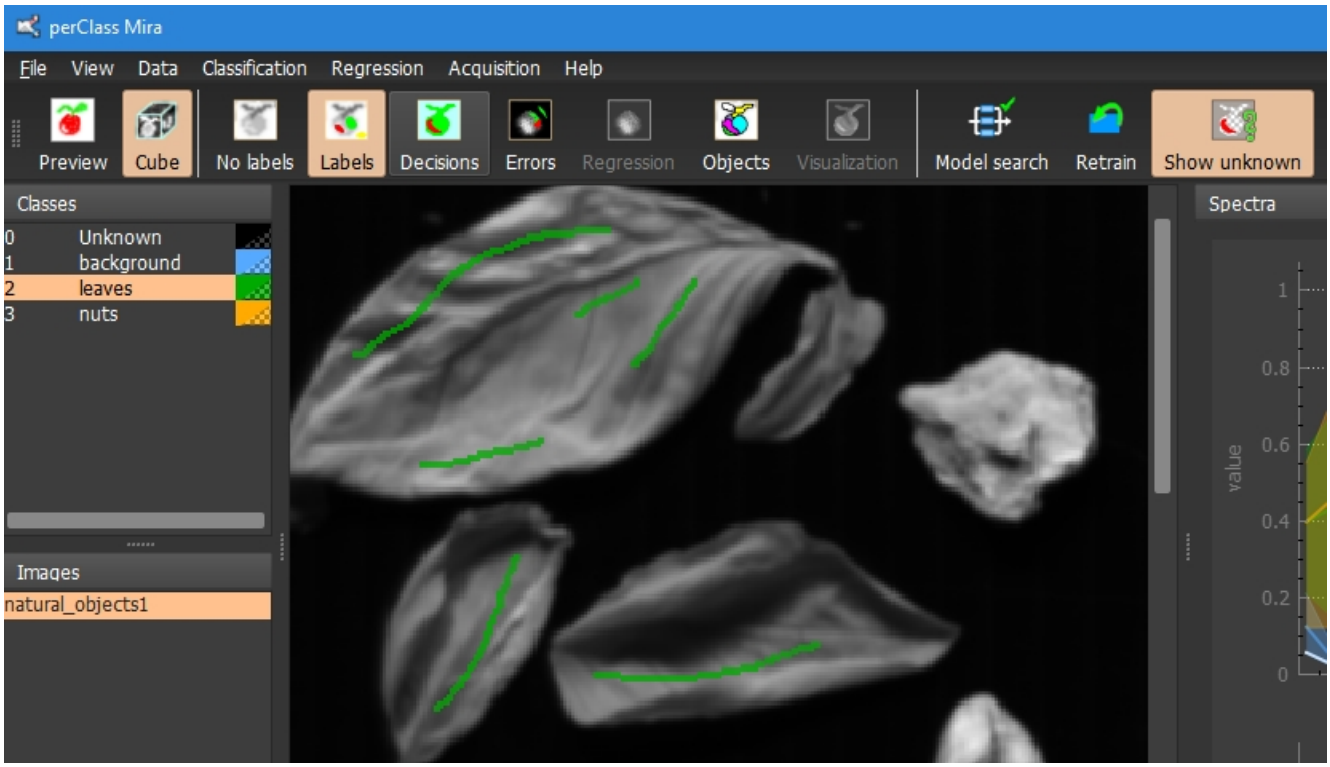
or by pressing u (unknown)

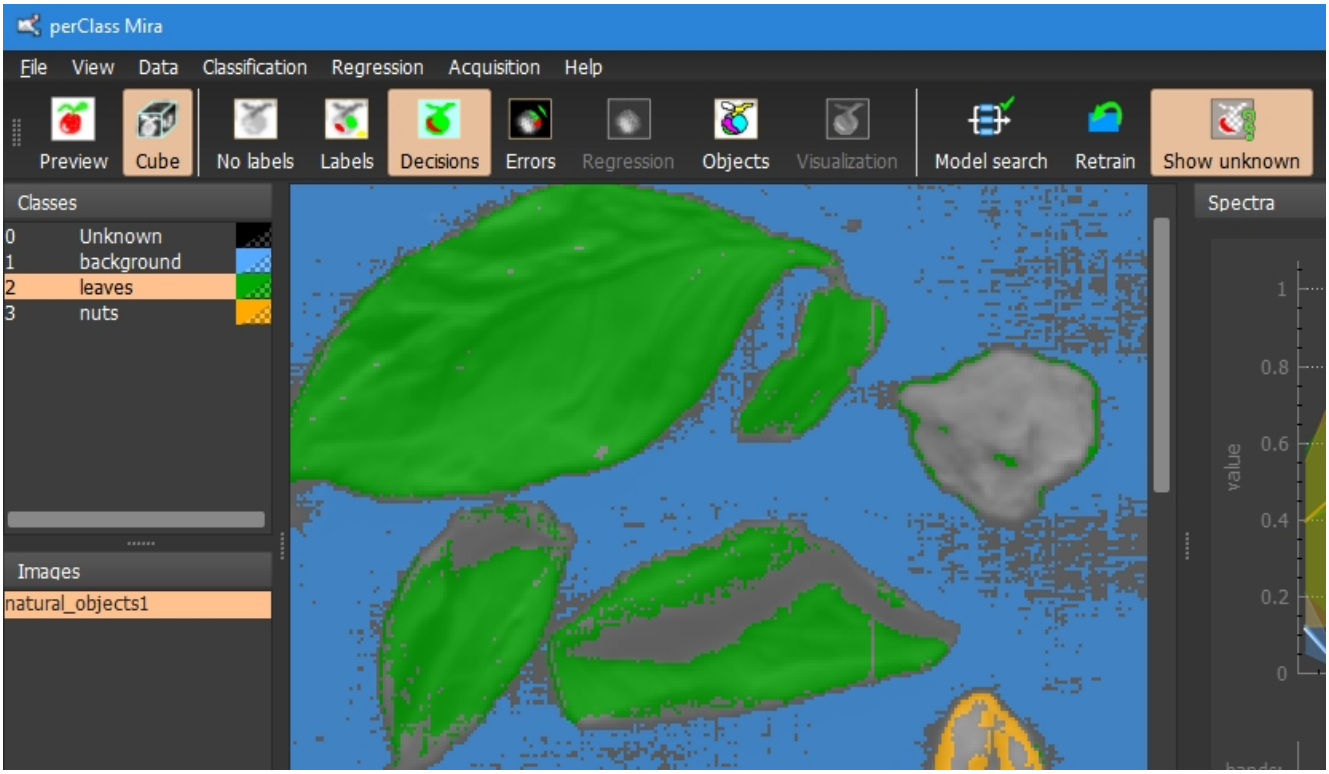
When on the Decision layer, you will see an additional transparent decision for 'Unseen in training' examples.




Note, the leaf in the upper left corner. Larger parts of this leaf are different from any labeled example. By inspecting the spectrum at these areas we may see it is probably due to lack of water content.

We will add leaf labeling and retrain by pressing the *Retrain* button 

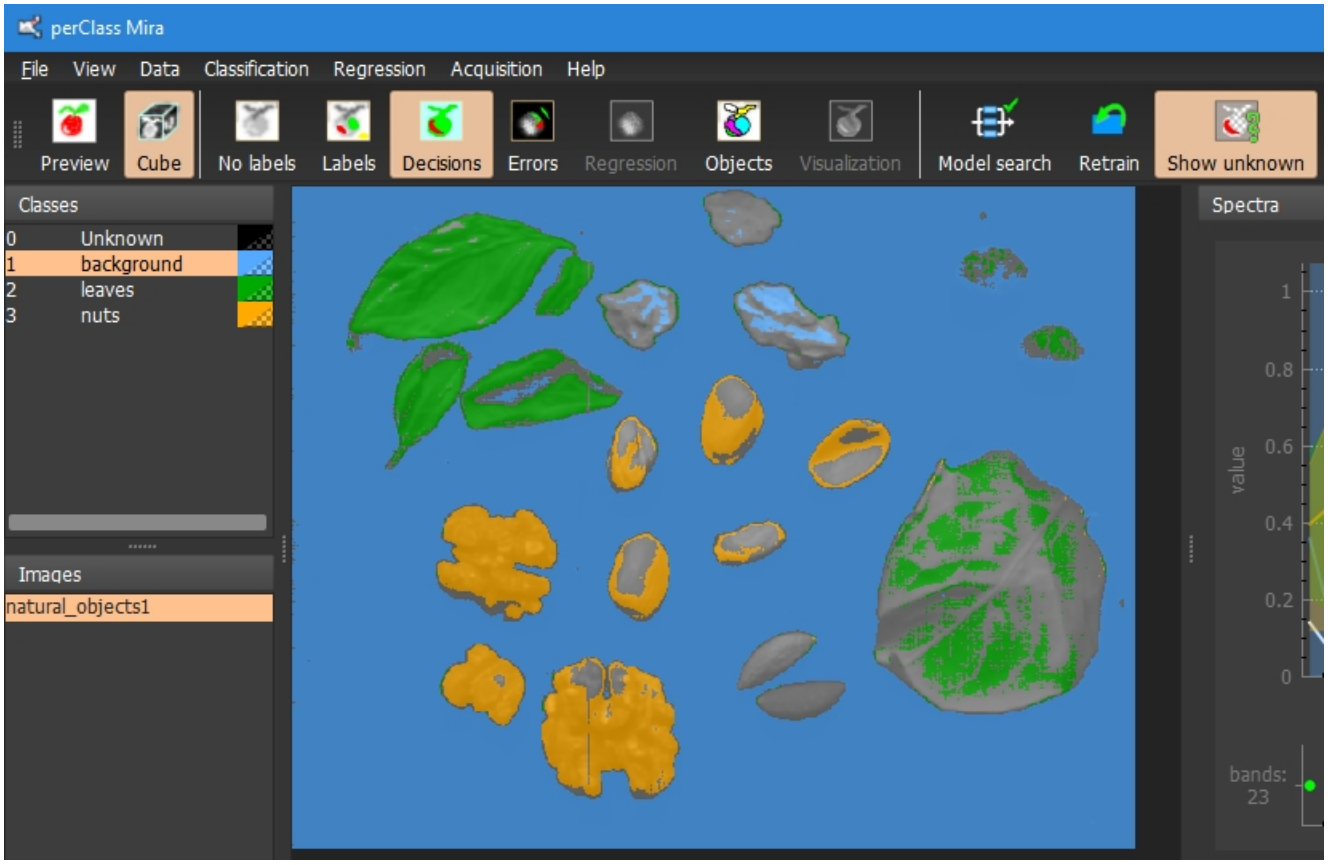



The Show unknown tool allows us to focus our labeling effort on relevant areas.

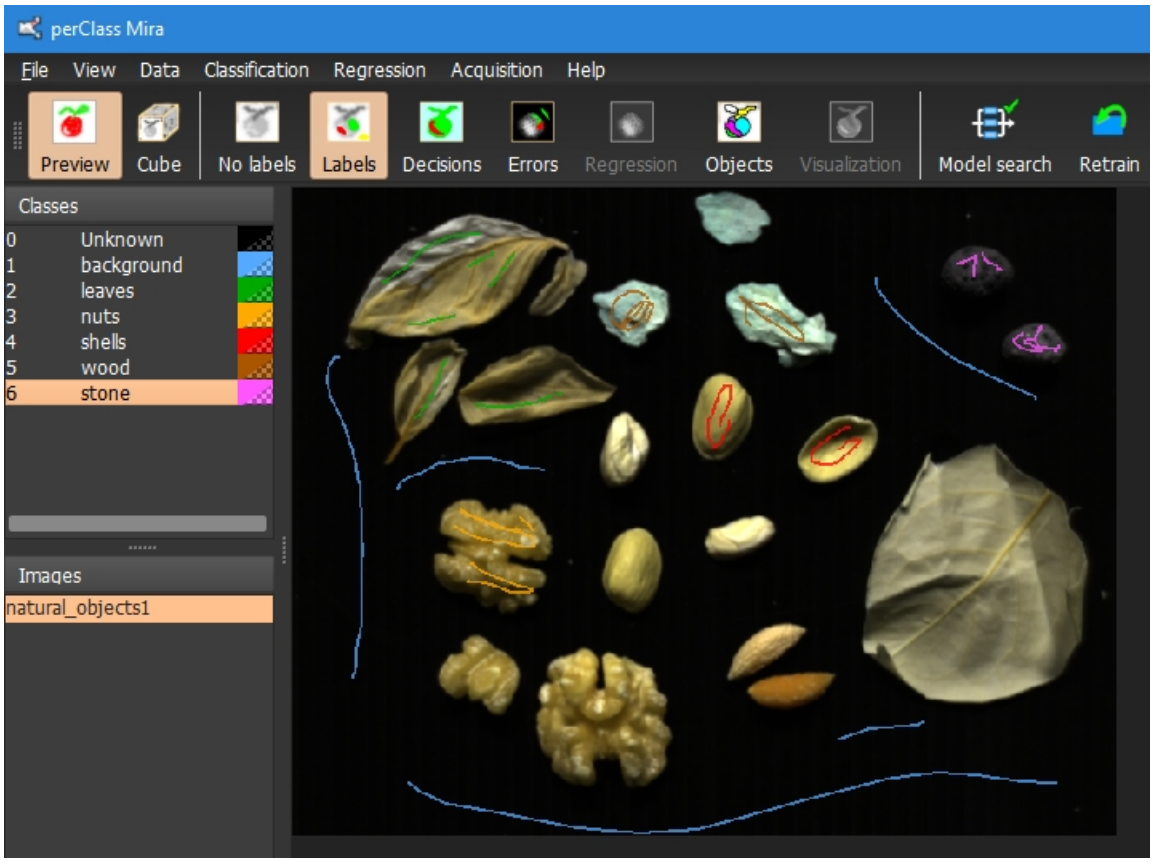
## Adding / removing classes

We may add or remove classes anytime.

In our example, we labeled only background, leaves and nuts, so far. However, there are other object types present:



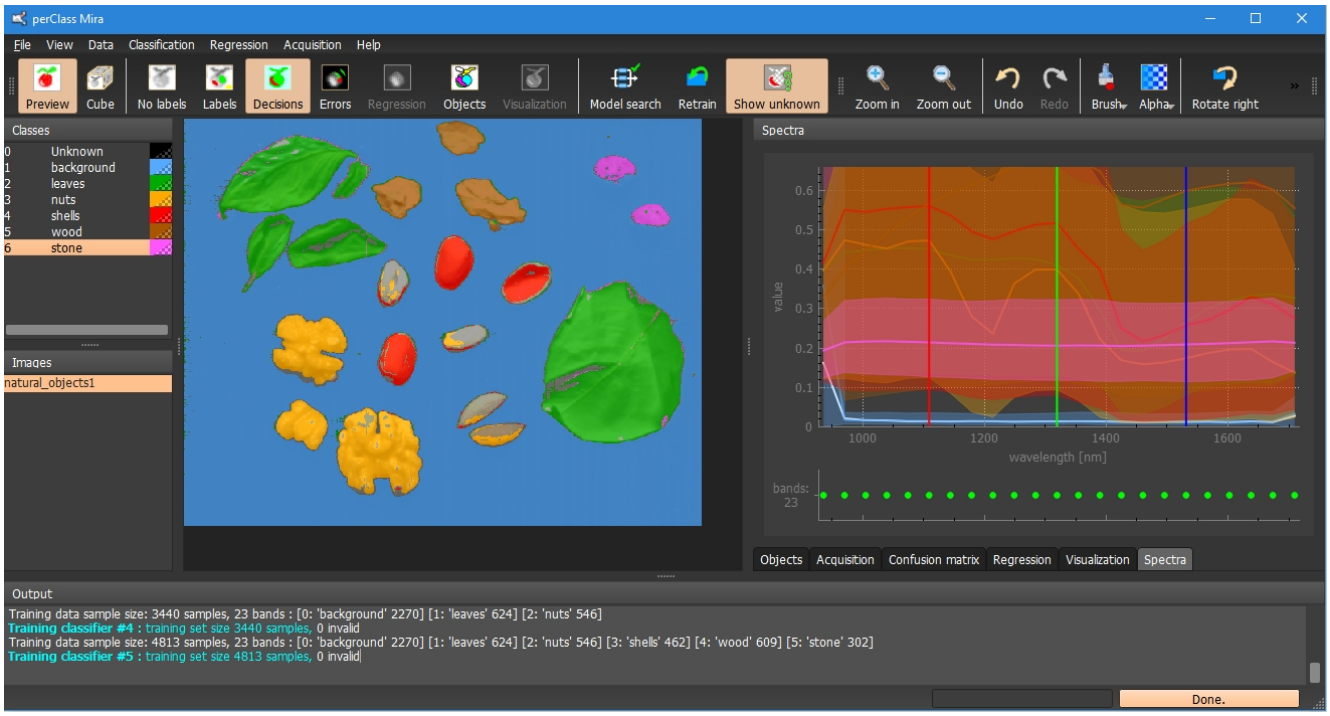

We will define aditional classes for shells, wood and stones:




We will then use *Model search* to find a new model. The difference between *Model search* and *Retrain* is as follows:

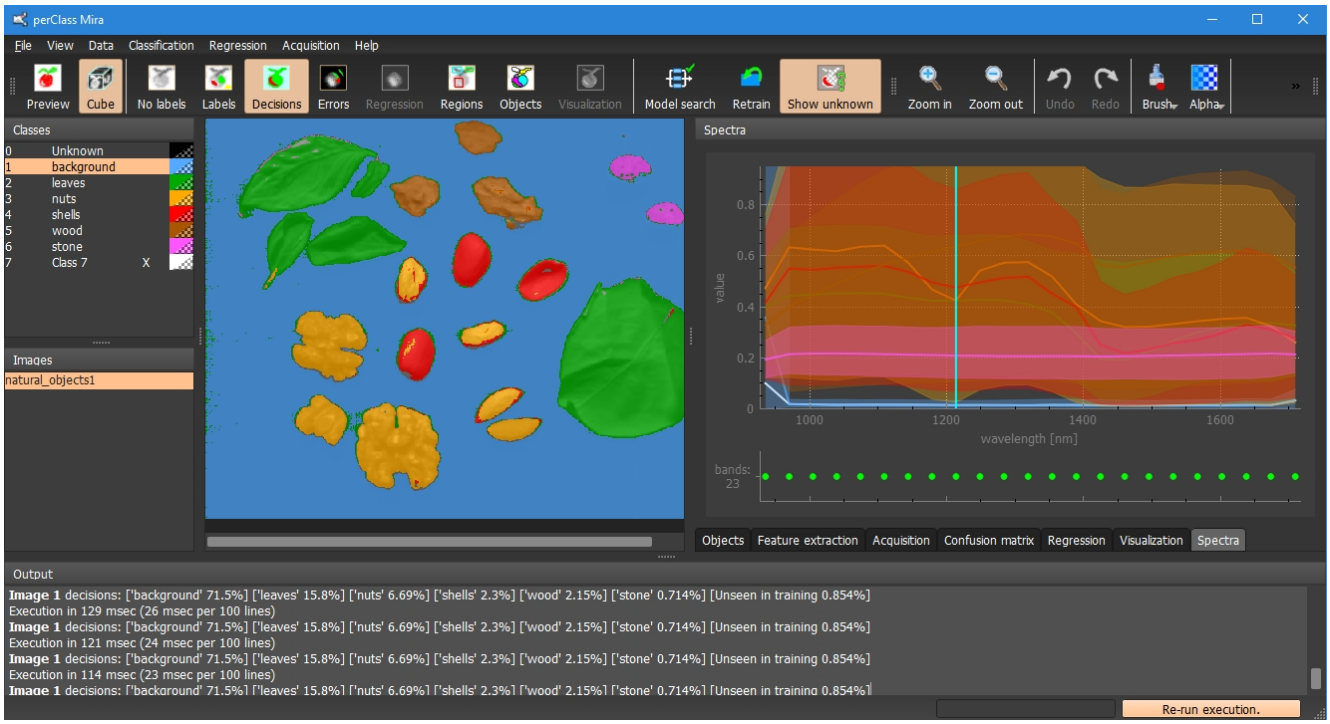
- *Model search* performs full search for the best model
- *Retrain* uses the existing model definition and retrains it using the current labels

If we only perform slight update of the labeling, for example, around the edges or adding more representative examples of existing materials, Retrain is sufficient. The model search is useful when we add entirely new classes or label quite defferent examples of the existing classes.




We can see that several objects in the middle of the scan are still showing pixels unseen in training. The two close objects in the lowe part of the scan are olive kernels. Therefore, we label then into shell class. The two objects in the middle are pistacia nuts. We will therefore label then as nuts.

Our updates led to the following result. As we may note in the Output windows, although *Show unknown* is enabled, only 0.854% of image pixels are assigned this decision. This is a sign our classifier is well trained. In practical projects, we need to make sure that the there is a low fraction of 'unsee in training' pixels in a large number of training images with different objects following production situation.

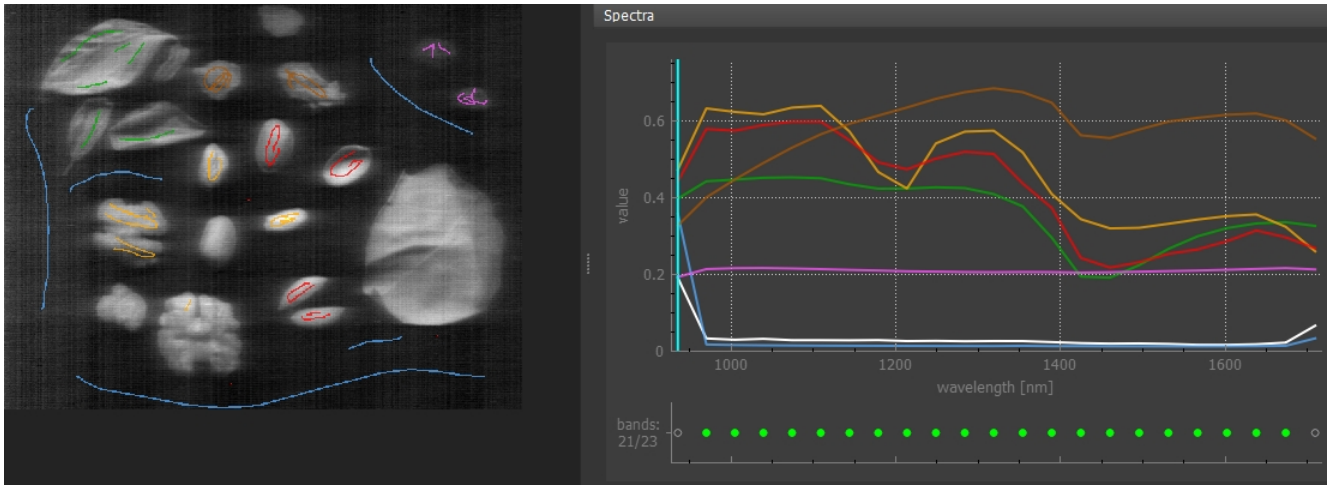



## Remove noisy or uninformative bands

Sometimes, it is useful to limit the spectral bands used when training a classifier. This is possible throught the

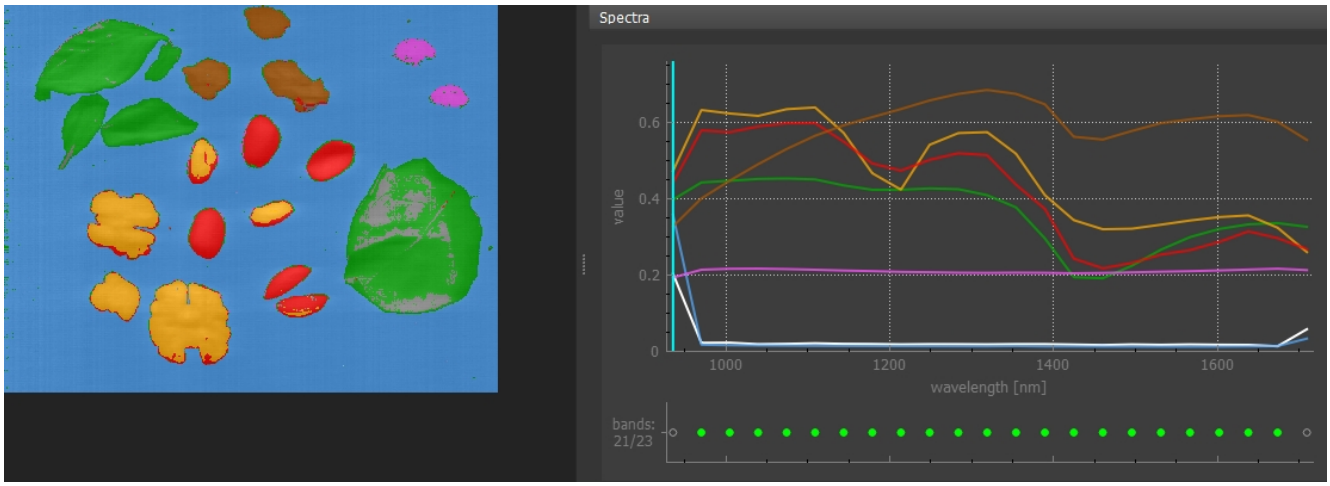
Spectral plot widget.

In our natural objects example, we may see that the first band at 935nm is




By default, all bands are enabled and used when training models.

You may disable any specific band by clicking on the corresponding green dot under the spectral plot. When you retrain the model (or search for a new model), the currently selected bands are used.
In our example, we removed the first and last band exhibiting higher noise. This may often improve classification peformance.

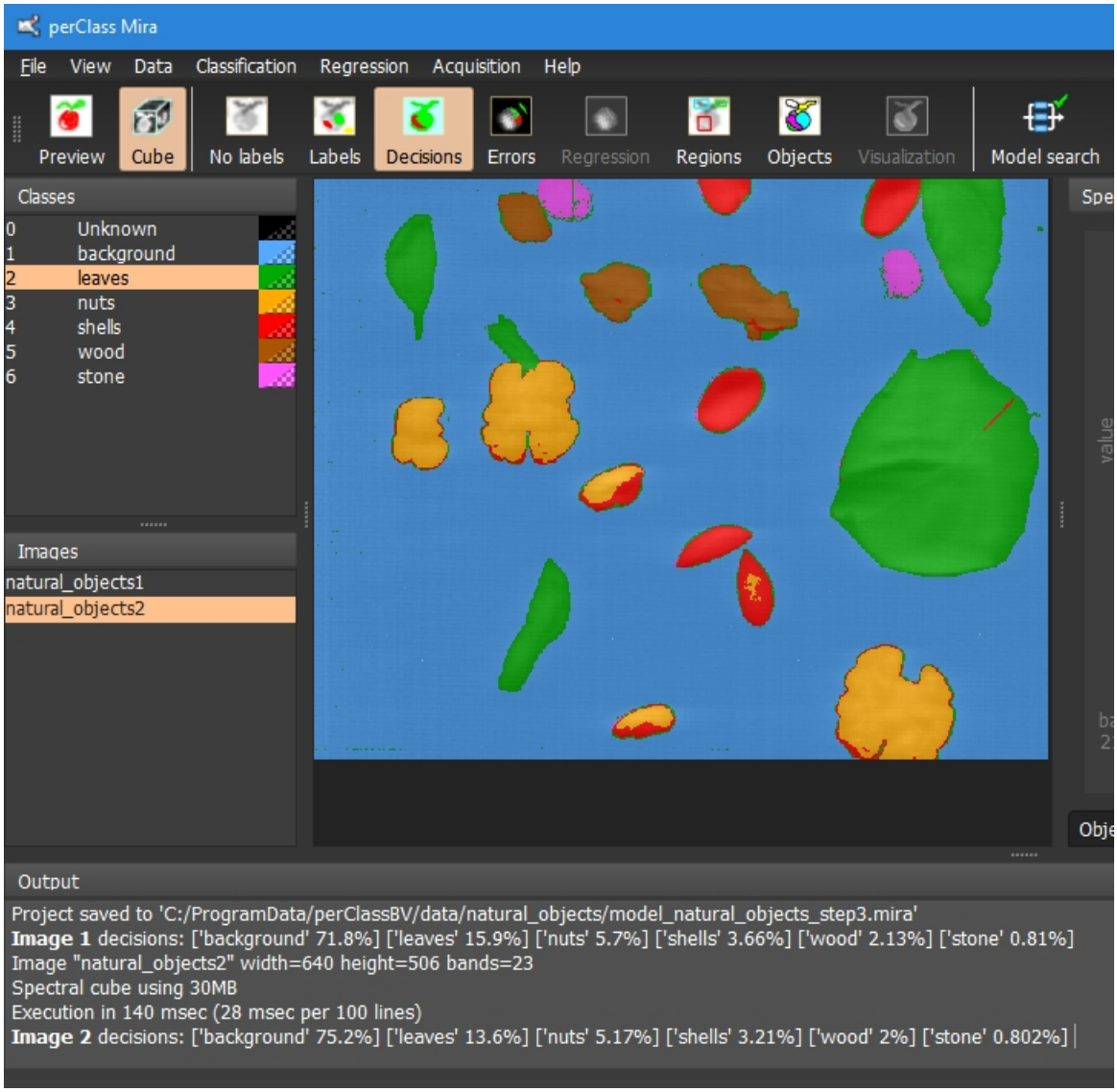



**TIP:** When you change band selection, you may return to the bands, currently used by the classifier, from the right-click context menu and *Set band subset from a classifier* command.

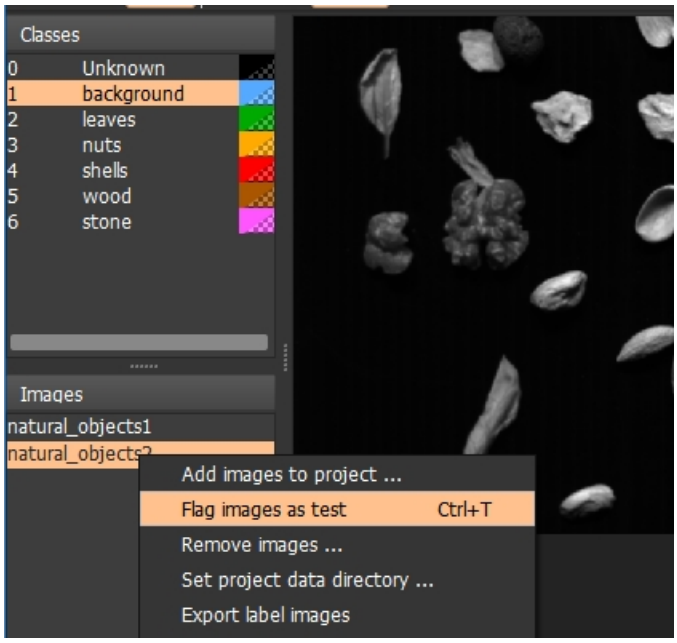
## Testing on unseen data

Before deployment for production, any machine learning algorithm needs to be propely validated. The best validation is using new images, unseen in algorithms training.

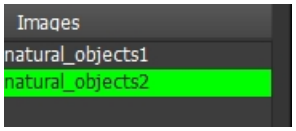
We may add a new image to the project. Apart of the right-click menu and *Add images to project...* command, you may also simply drag some image files from explorer. For the ENVI project type, you need to select .hdr header files and drop them anywhere on perClass Mira window.




We may flag any image or selected images as testing using the right-click menu *Flag images as test* command or Ctrl+T keystroke.




The image, flagged for testing, are not used in training process and are displayed in green color.



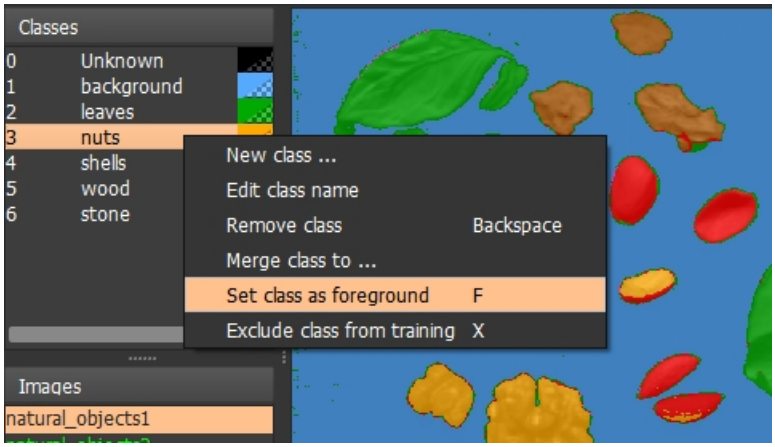

You may freely label on the test images. However, the labeled data will not be used for training. This is important to avoid over-optimistic prediction of performance (so called positive bias).

If you change the test flags, **you need to retrain the classifier to take this new situation into account**. Until a classifier is retrained (or new model searched), the current model is still active.

## Segmenting objects

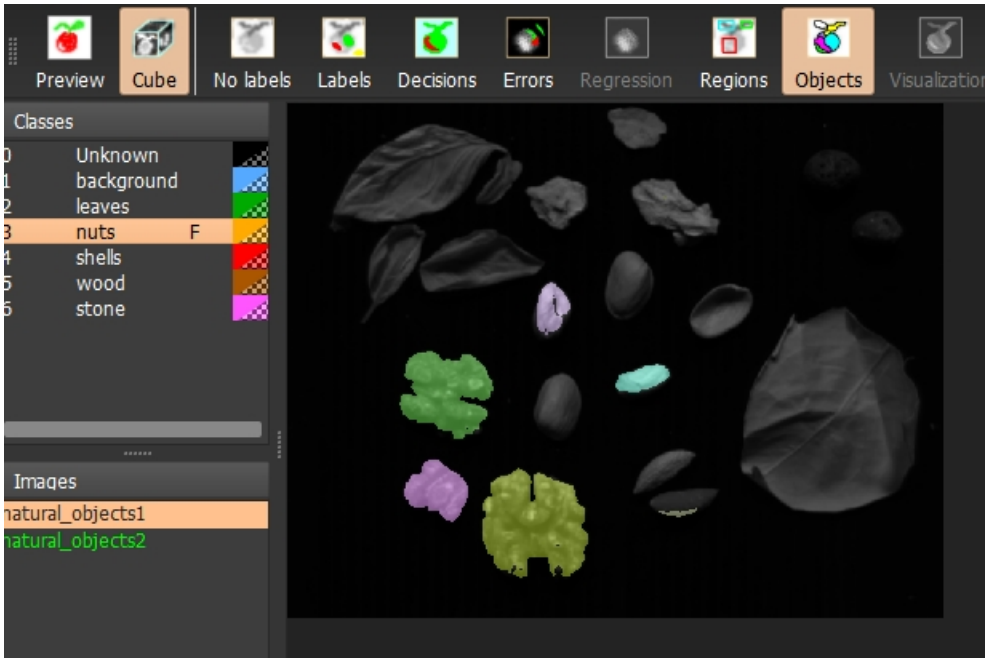
Per-pixel classification is useful to distinguish different materials locally. However, in many applications, we are more interested in objects than individual pixels. By an object, we mean a connected component i.e. a set of pixels assigned by a classifier to the same class and spatially separated from other objects.

In perClass Mira, we can segment and even classify objects easily. All we need to do is to define a class or classes of interest (called foreground). This can be done by the right-click cotext menu on the class list or by pressing f (foreground).




A letter F will appear next to the class name.

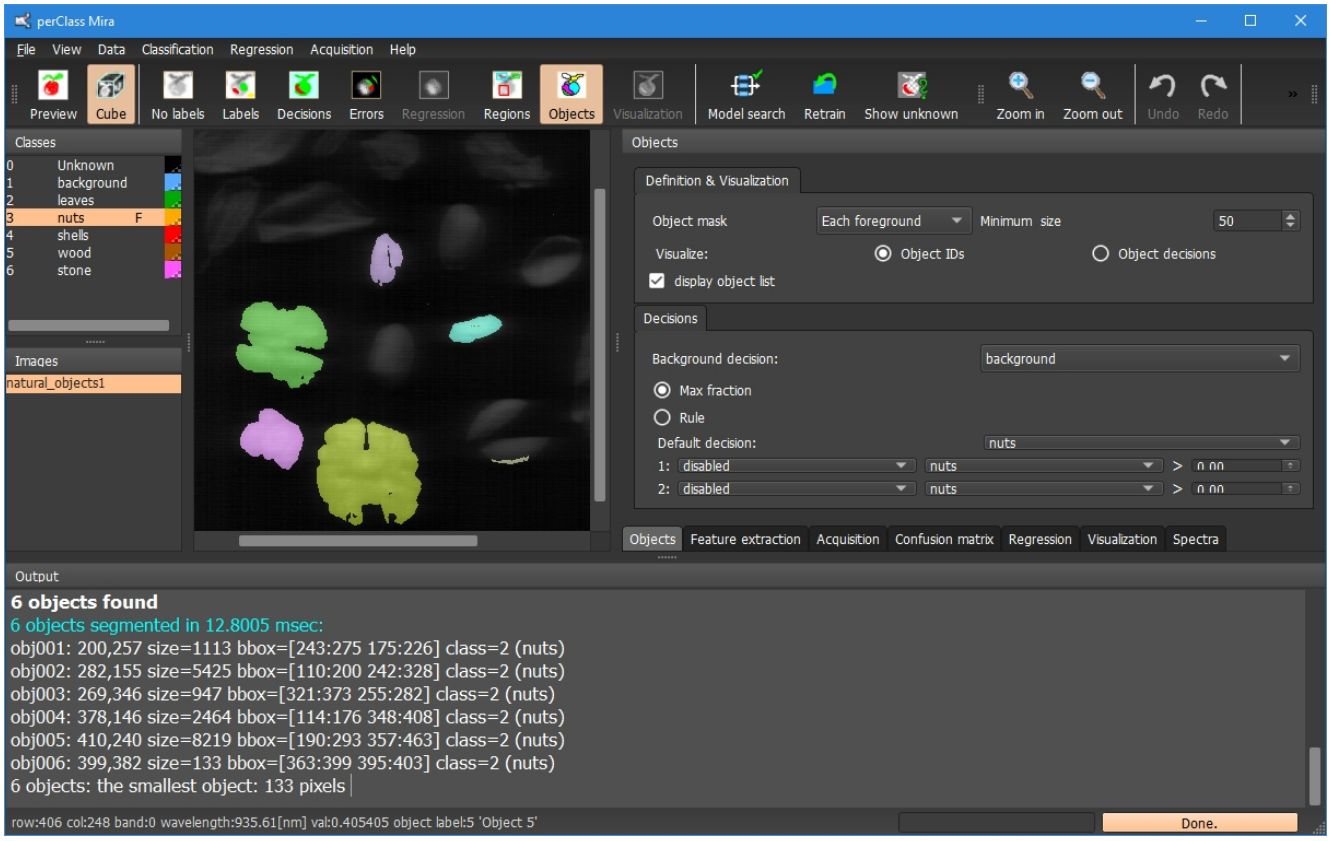
We may then click the *Objects* button in the toolbar. By default, each segmented object will be displayed with a different (random) color refering to its unique object id (index).




Object segmentation allows us to do several things:

## Display object details

We can see object details such as center of gravity positions, bounding boxes and sizes. Click on the *display object list* check box in the Object panel:



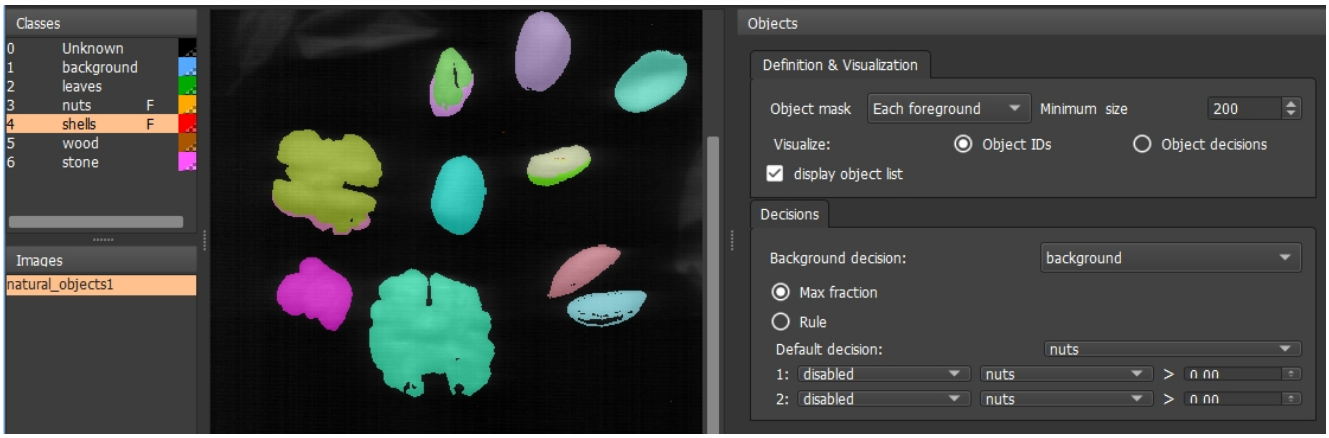

Note, that the minimum object size is displayed as well. Often, we wish to remove small objects from further analysis. We may do so by adjusting the minimum object size (50 pixels in the example above).

The displayed object information may be obrtained for live data stream using perClass Mira Runtime. This enables sorting applications where specific product or foreign objects are to be removed from the product stream.

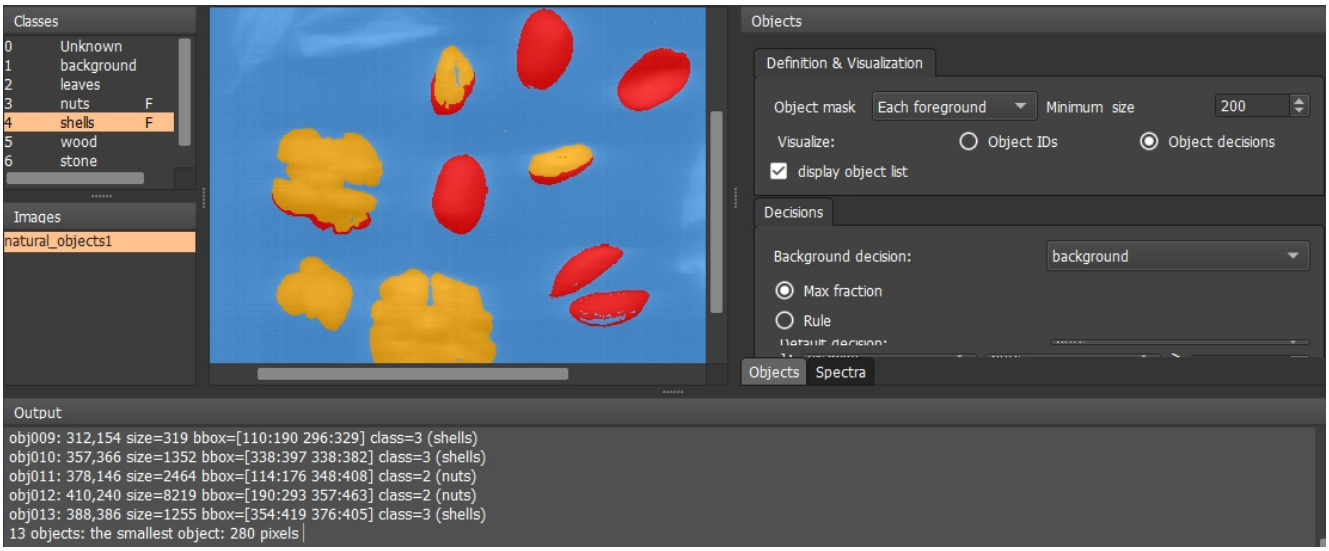
## Classify objects by content

Apart of object coordinates and size, we may also see its class. This refers to the per-object decision. In the simplest object detection use-case, each object belongs to one class.

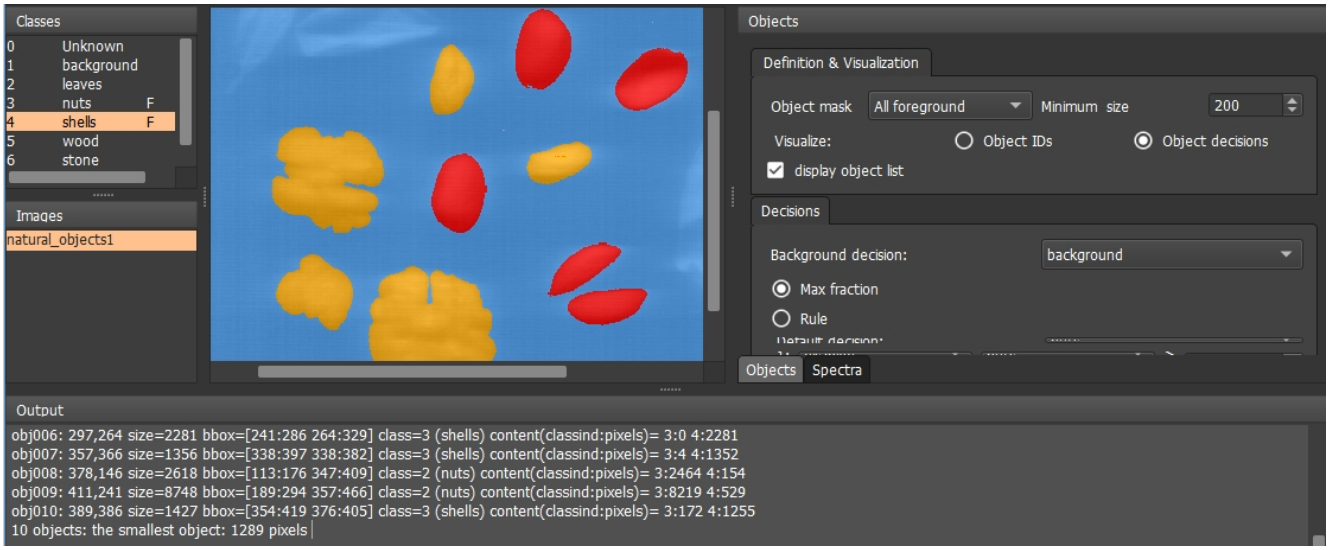
We can simultanously segment objects of multiple classes. We only need to flag the classes of interest as foreground. Note, that each class (nuts and shells) is segmented separately. Therefore, we can see objects of different colots




For each object, we can also render the per-object decision by clicking *Object decisions* in the Objects panel.




perClass Mira also provides an alternative object segmentation mode where multiple pixel decisions can occur within one object. This can be enabled by selecting *Object mask: All foreground*.
Note, that there are now only 10 objects segmented instead of 13. For each object, the number of pixels of each foreground class is also provided. The default decision uses majority voting.




## Next steps

We have seen how to visualize spectral images, define pixel classifiers and build object segmentation and classification solution.

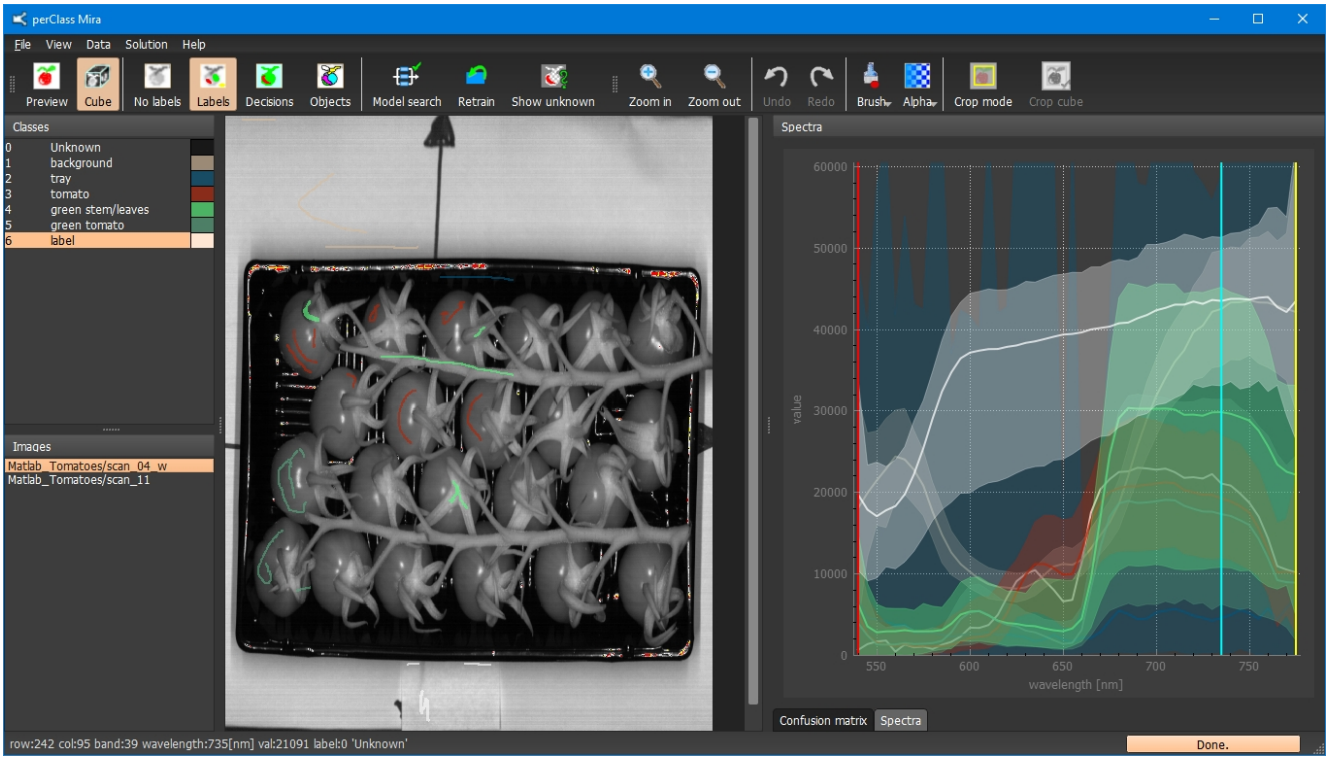
Possible next steps from here:

- You may wish to **extract information from the objects** and export it for external data analysis. For example, you may define custom spectral indices, measure and count objects or extract mean spectra per object. The information of interest may be extracted from a large number of scans in a batch mode and exported in Excel
- You may want to **apply the analysis on live data stream** from a spectral camera and build a specific sorting or quality control application
- You may wish to **estimate object quality** such as moisture content, protein content or similar using regression analysis
- You may wish to classify not only known types of materials but also **detect unknown materials and foreign obejcts**, different from examples seen in training.

# Performance optimization

When designing a classification system, one needs to understand its performance. perClass Mira provides a confusion matrix offering a detailed performance brake-down per class.
Confusion matrix highlights how labeled examples of different classes (ground truth) mapps to classifier output (decisions).

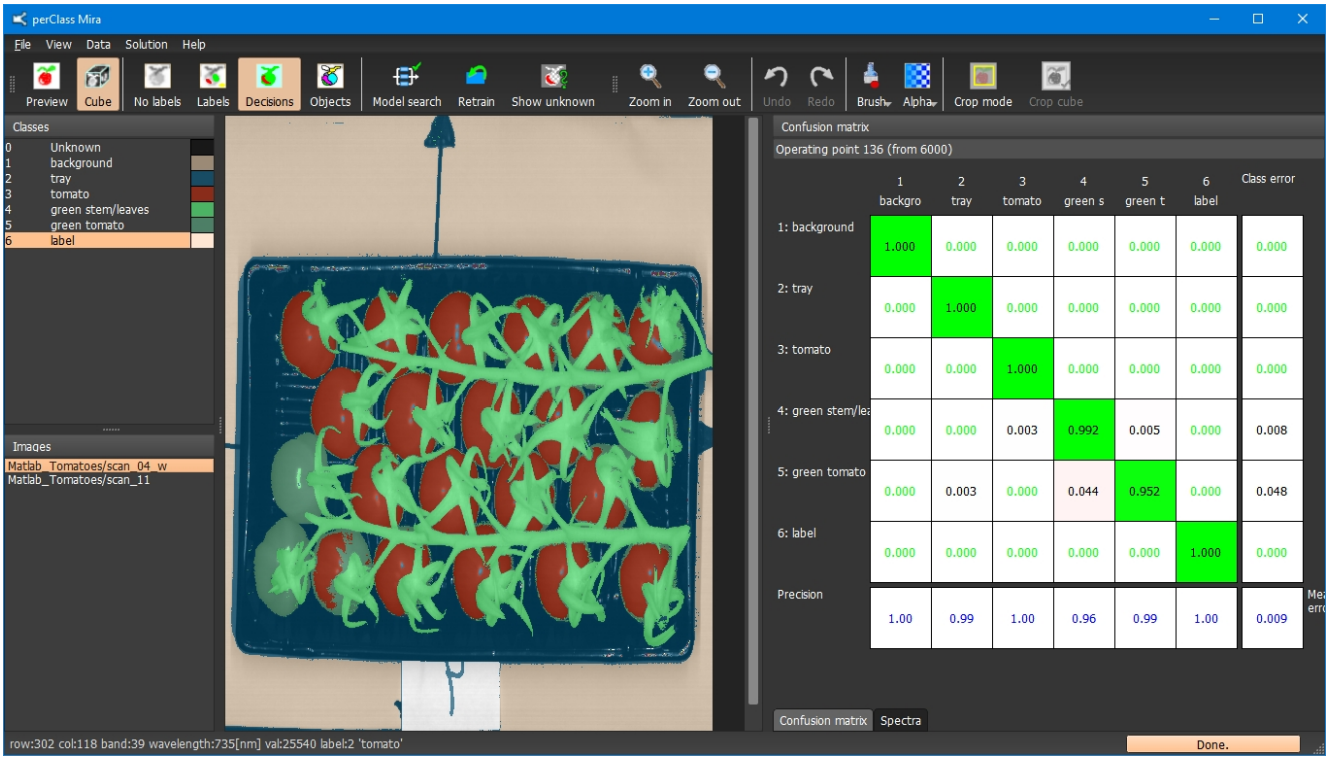
In this example, we have an image with a set of tomatoes in a box.




We have labeled six distinct classes.

When we build a classification model, we may switch to the *Confusion matrix* docked pannel.

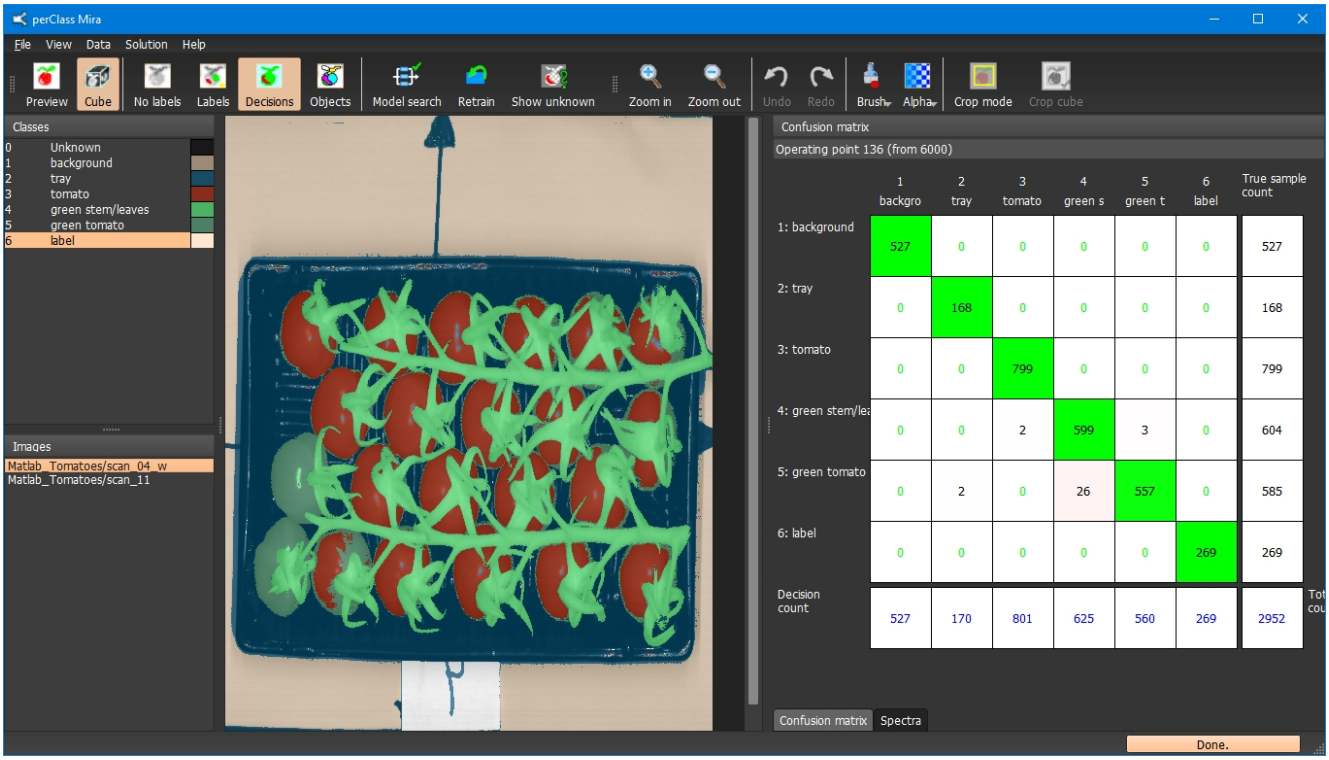
**TIP:** You may quickly switch to confusion matrix by pressing 'c' key and to spectral plot by pressing 's' key




The confusion matrix shows true class labels in rows and decisions in columns. Therefore, the diagonal represents correctly classifier examples and off-diagonal elements the errors.
By default, confusion matrix is normalized by sum of each row (total number of true class examples) to provide class errors.

To view the absolute, not normalized, values, toggle the *Show normalized matrix* command in the right-click

context menu or press Shift+N key.




The right-most column shows total number of class samples, or (on normalized confusion matrix) the per class error rate.
The last row shows number of decisions per class, or (on the normalized confusion matrix), the precisions. Precision is a total number of correctly classified samples dividied by the total decisions of this class. We wish to have precision of 1.00 which means that all each decision for this class is correct (pure).

Observing the confusion matrix in our example, we can see that the *green tomato* and *green stem/leaves* classes are not well separable. This probably caused by overlap of these classes in our data.

Although we cannot fully separate them, we may fine-tune the respective error trade-off. **perClass Mira provides fully interactive confusion matrix.**

We may right-click on any field of interest, for example the true *green tomato* vs *green stem/leaves.* The context menu shows a slider which may be used to tune the respective trade-off.
By moving the slider, we may see that the error is lowered and iage decisions change to reflect this new setting. Note that our statistical model does not change, we only tune the importance of specific class in our application. Therefore, the error removed from one confusion matrix field will move to another one. In our case, there will be higher error between true *green stem/leaves* and *green tomato* decision.


When exporting the trained model for execution using perClass Runtime, the current operating point (performance setting) is used. The deployed classifier should, therefore, reflect the situation in the confusion matrix.

## Performance constraints

To express application-specific rquirements perClass Mira allows definition of constraints in confusion matrix.

By double-clicking on any field of the matrix, we create respective constrain for the current value. For error (off-diagonal) elements the means that only solutions with error less or equal than current value are allowed.
For accuracies (diagonal) elements it is values higher or equal.


Each field with a constrain shows a small square in its left upper corner. Note, that due to equal sign in constrain definition our current solution does not change by creating a constrain. We only limit a subset of admissible solutions (see the text in the upper part of the confusion matrix widget showing that now 5178 solutions from the total 6000 are valid.)

We may install multiple constraints by double clicking. To remove a constrain, double click again.

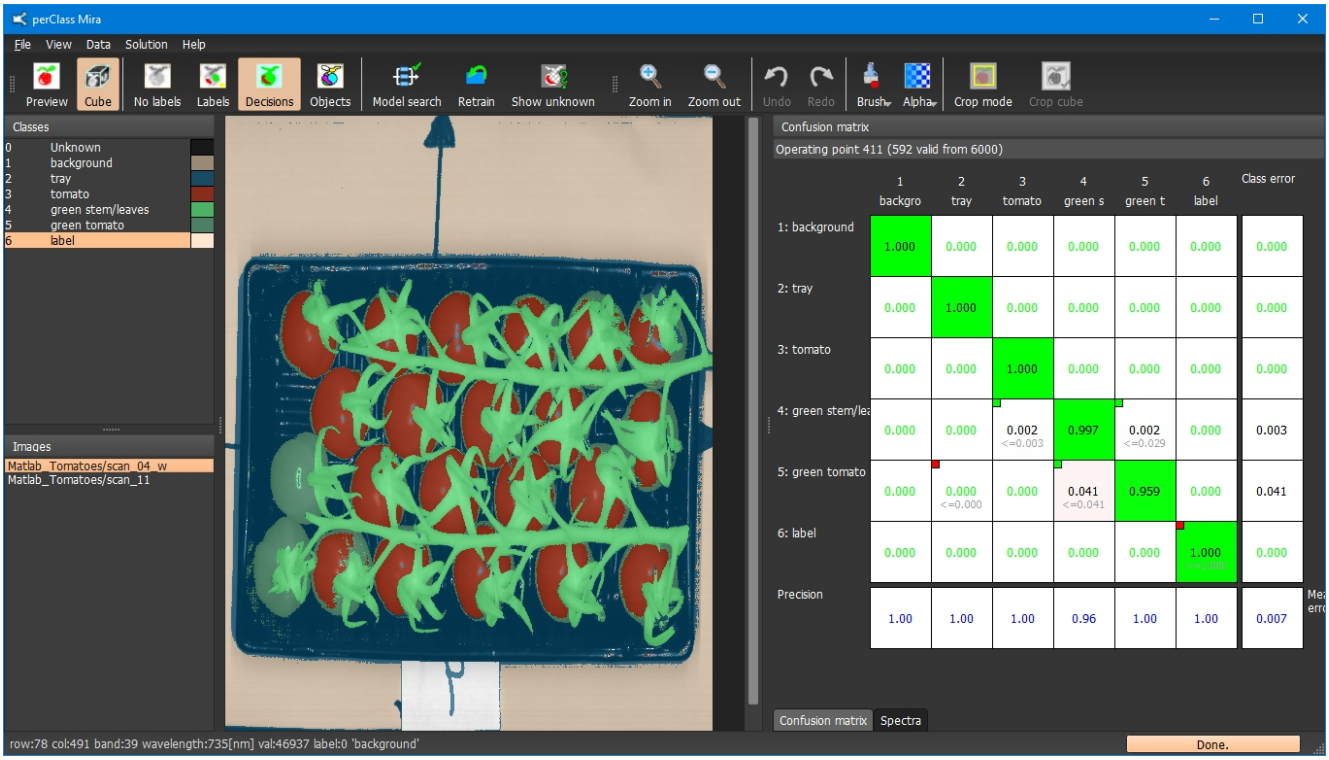
To change any constrain value, we may use Ctrl+mouse wheel on the specific field. This may lead to a new, better, operating point.

Note, that we may not minimize all errors simultaneously. Lowering the error between class 4 (*green stem/leaves*) and decision 5 (*green tomato*) the opposite error (class 5 vs decision 4) will increase. If we also install the constrain on class 5 vs decision 4 we may reach the situation where this constrain cannot be lowered further (by doing so, there would be no more solutions left). To explore fully these situations, constraints may be *disabled* by clicking on the small square in the left-upper corner. Only the constraints with green square are used in performance optimization, not the red square constraints.

Best practice procedure:

- Install constraints of interest by double-clicking
- Tune the constraints' values using Ctrl+mouse wheel
- If the errors cannot be lowered further as desired:
  - either increase value of other constraints (Ctrl+mouse wheel)
  - or disable other constraints and lower the error value of the more important ones

Example of multiple constraints:



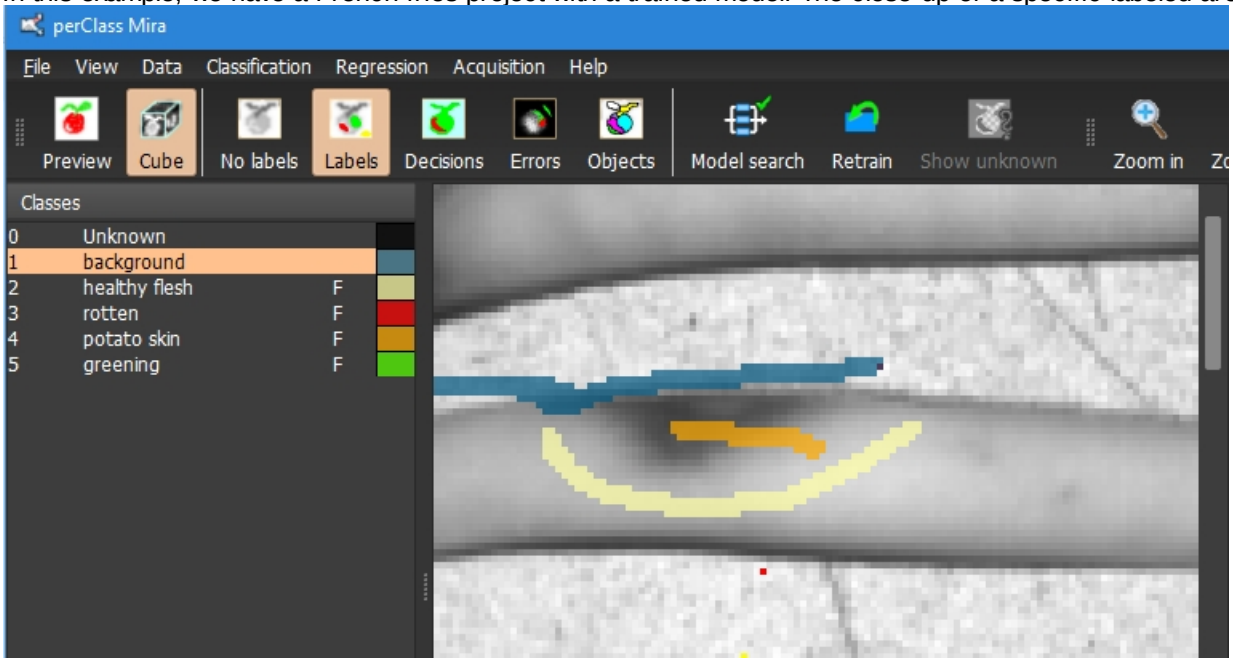

Note, that re-training a model does not change the optimization options (operating poionts) only updates the model and selects one of existing points.
When selecting a new model via *Model search*, also new set of operating points (solutions) are created.

In both cases, there may be no solution that fulfills all enabled constraints. In this situation, all constraints are disabled. You may re-enable some of them and/or update value of others to find a desired solution.

## Error visualization

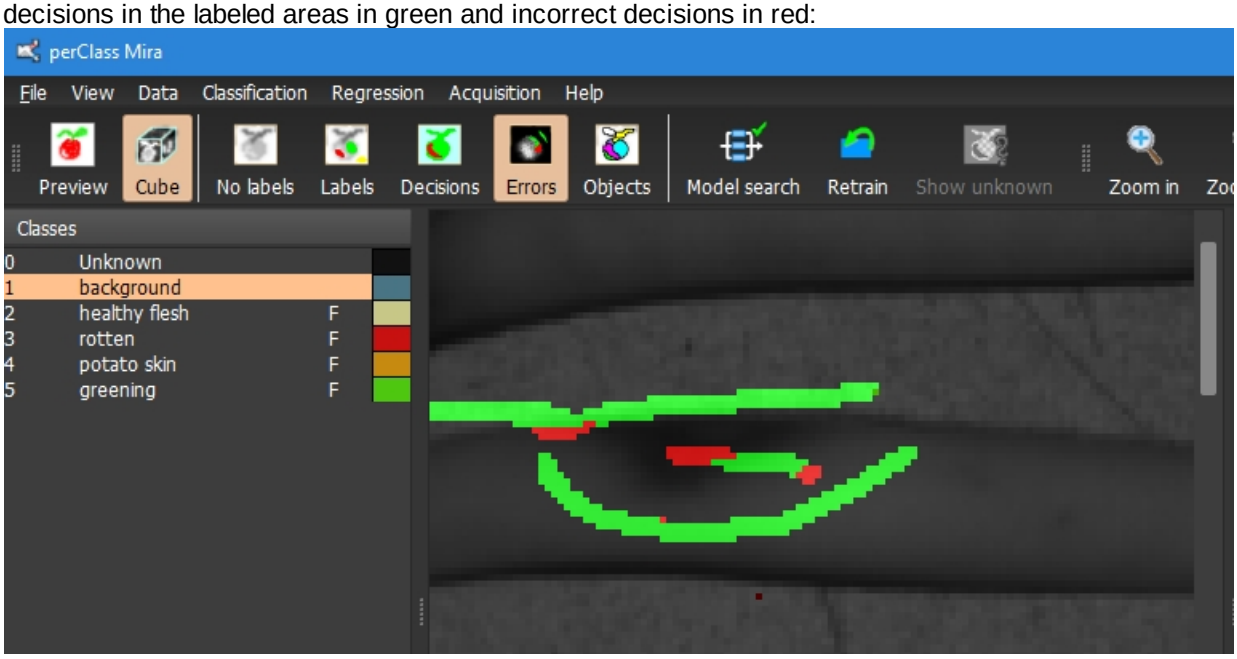
perClass Mira 2.0 brings error visualization. It enables the user to understand where the classiifer fails and facilitates the model improvements.

In this example, we have a French fries project with a trained model. The close-up of a specific labeled area:



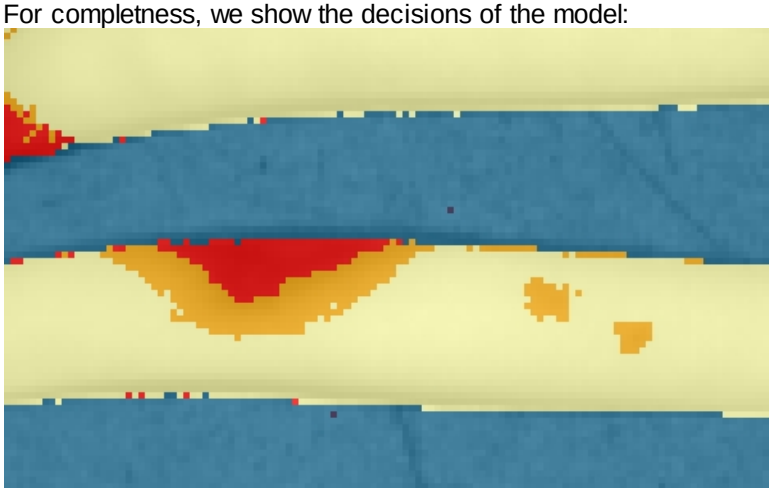

When we select the *Errors* mode in the toolbar (or press E key), the visualization will highlight correct model

decisions in the labeled areas in green and incorrect decisions in red:




We can see, that there are three regions where the current model misclassifies the labeled information.

For completness, we show the decisions of the model:



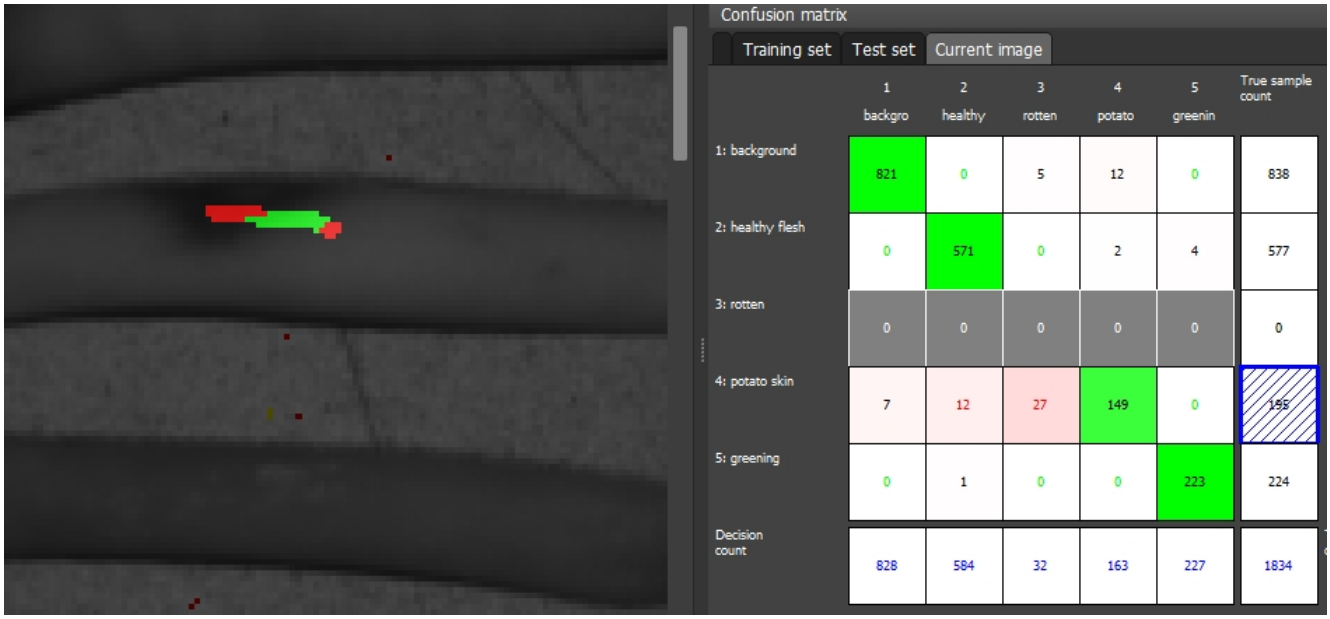
It is clear that the central area is classified as rotten while our middle label stroke assigns it to the *potato skin* class.
The background label stroke also reaches into the potato piece resulting into incorrect classification.

## Interactive error visualization in image confusion matrix

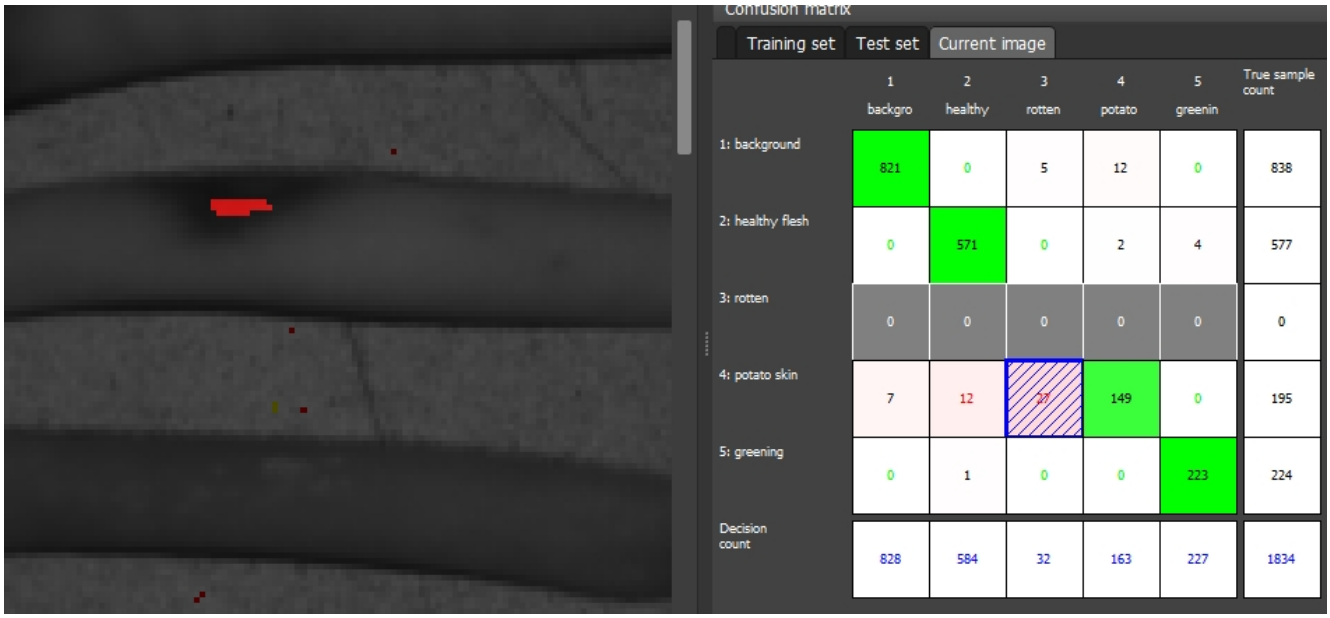
By default, the error mode shows all labeled pixels in an image. In order to gain deeper insight into model performance, it is possible to limit the visualization to specific type of errors in a confusion matrix.

Hovering the mouse over the *image confusion matrix*, we visualize only the corresponding subset of pixels.

Using the French fries example from previous page, we visualize only examples labeled a *potato skin:*




When we move the mouse to the entry *potato skin - rotten* (the value of 27), we can quickly identify the part of the stroke where the current models mislabels skin as rot defect.



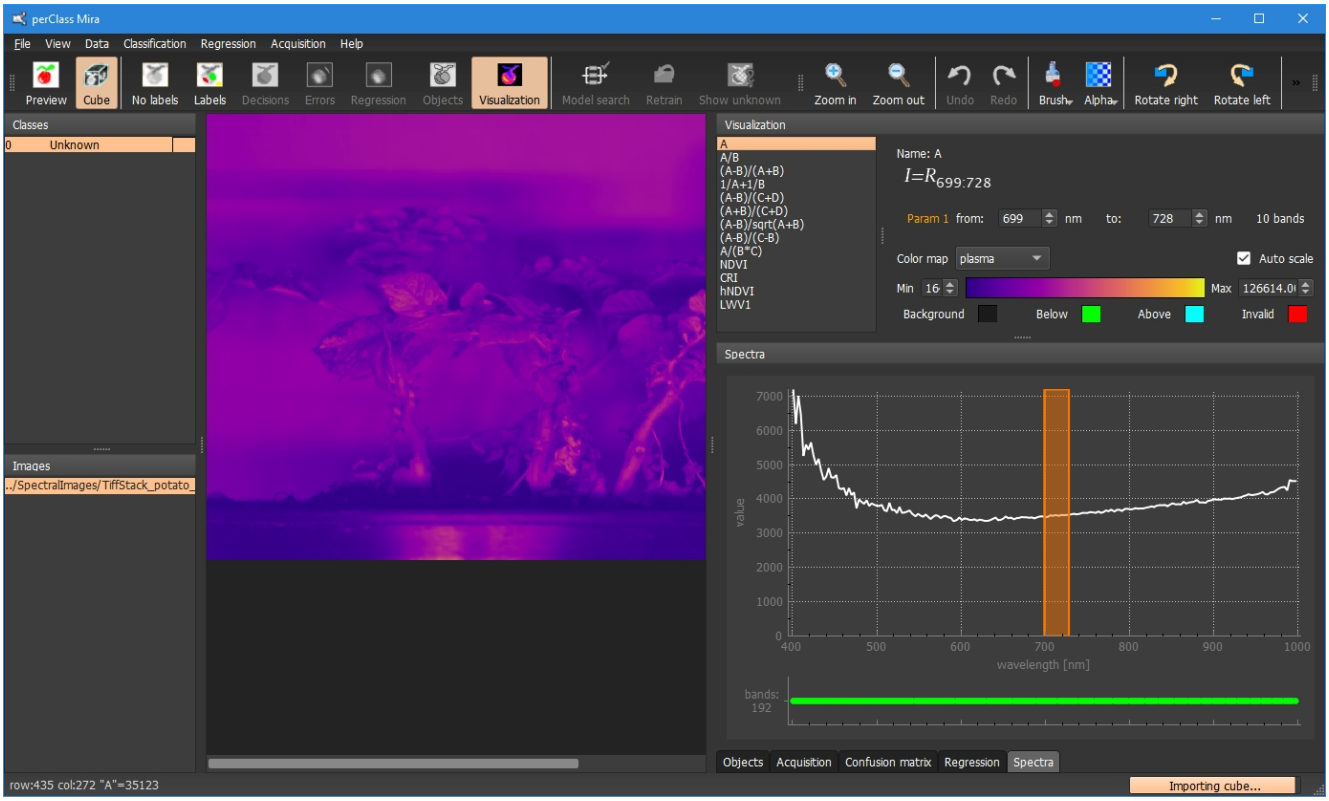

**Important:** Please note, that the green/red pixel visualization corresponds to the current model. There may be several reasons why we observe incorrect labeling in the left part of the stroke:

1. Our labeling may not be precise and the error suggests which part is incorrectly labeled. In this most common case, removing the *potato skin* on the left and the right end of the stroke would be advisable to improve the trainng labels. Leaving incorrect labels confuses machine learning models.
2. If we observe model errors when inspecting a test image (unused in model building), it may be that the areas highlighted as errors are, in fact, valid examples not represented in the training set. In such a case, it is advisable to include similar material examples to our training set.

## Visualization

perClass Mira provides an interactive visualization tool that allows us to quickly show bands or band ranges but also results of more complex common equations such as NDVI.

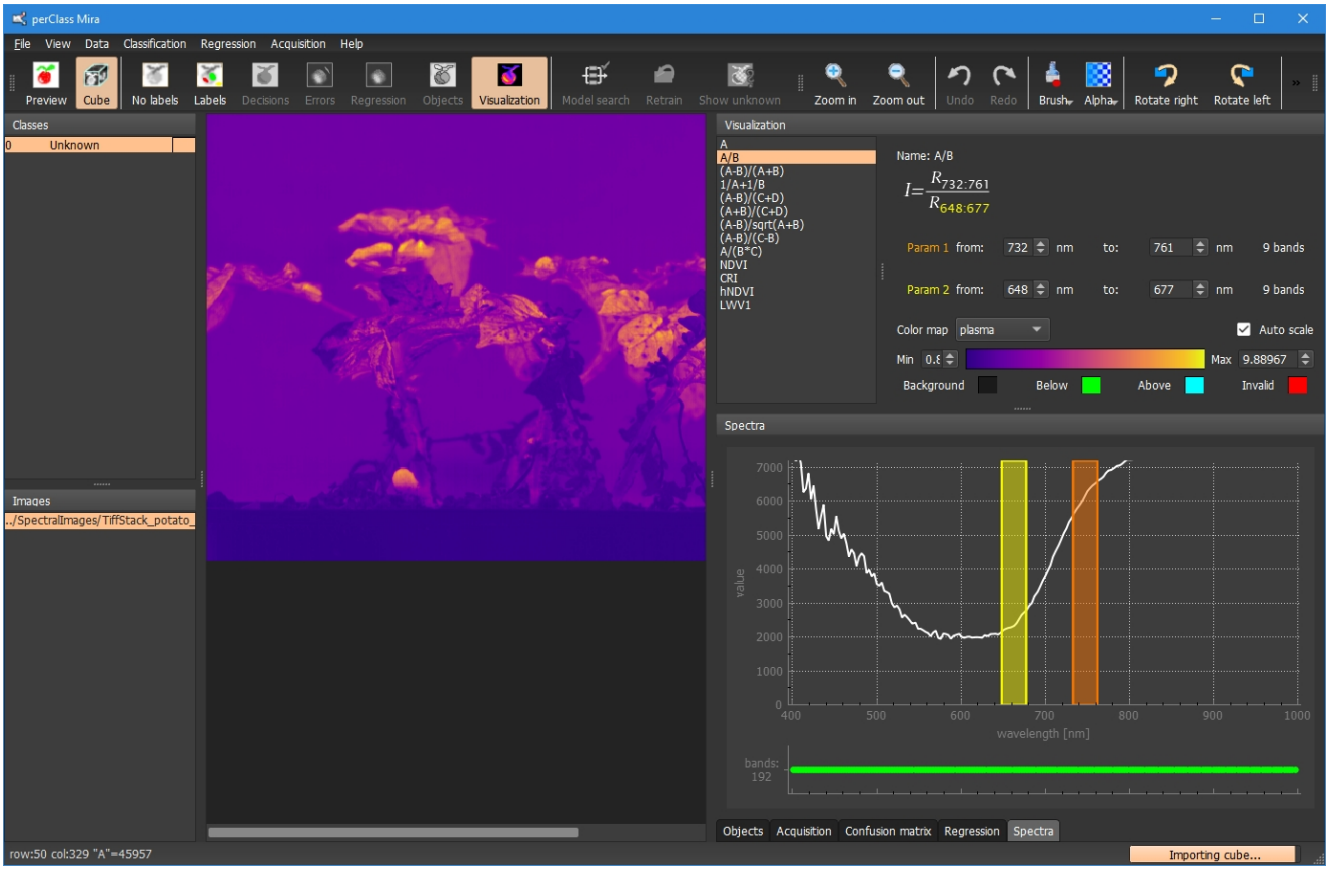
The functionality is configurable in a separate *Visualization* pannel. As the visualization equations are defined in terms on spectral bands or band ranges, it is useful to place both *Visualization* and *Spectra* pannels next to each other, as shown on the screenshot:




The *Visualization* pannel lists number of common equations at its left side. When an equation is selected, details are shown on the right.

In our example, only a single band or band range is shown. Note, that the band range is represented by a rectangle in the spectral plot.

Equations may have multiple parameters. For example, if we select A/B equation, we will compute ratio of values of the two bands or band ranges per pixel. Parameters may be changed by defining minimum and maximum wavelengths in nanometers or simply by dragging the corresponding rectangles in the spectral plot.

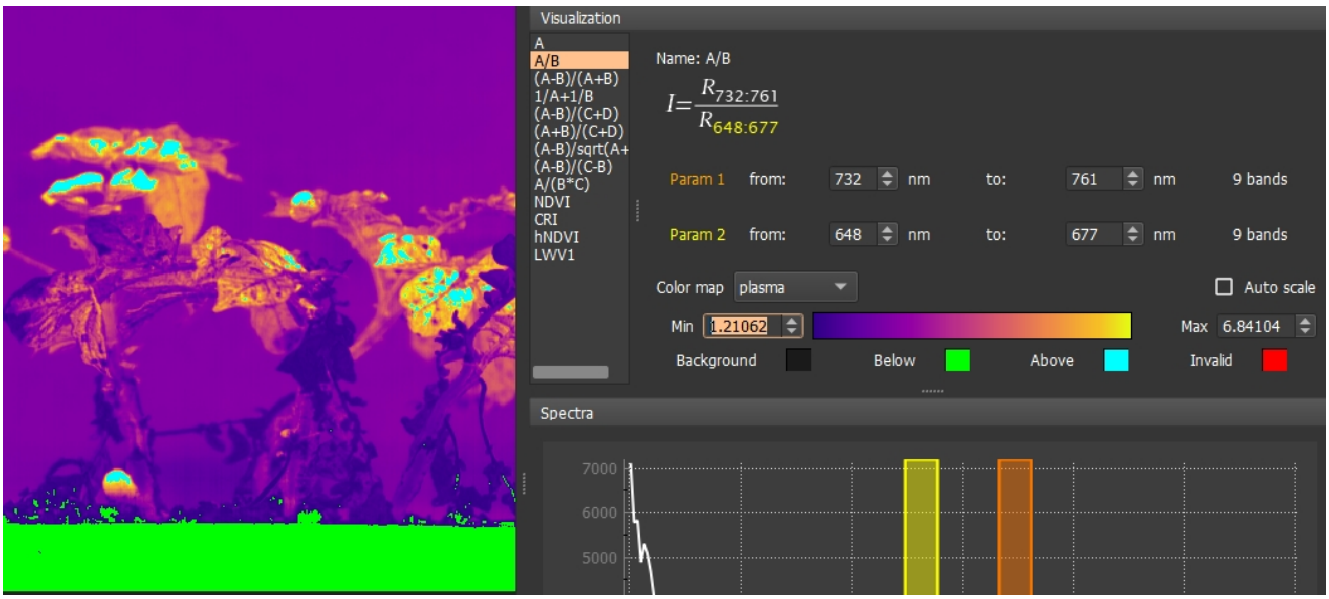



## Scalling

Visualization output is, by default, auto-scaled based on min and max values of the entire image.

We may switch the auto-scale using the check box or by directly adjusting min and max value.

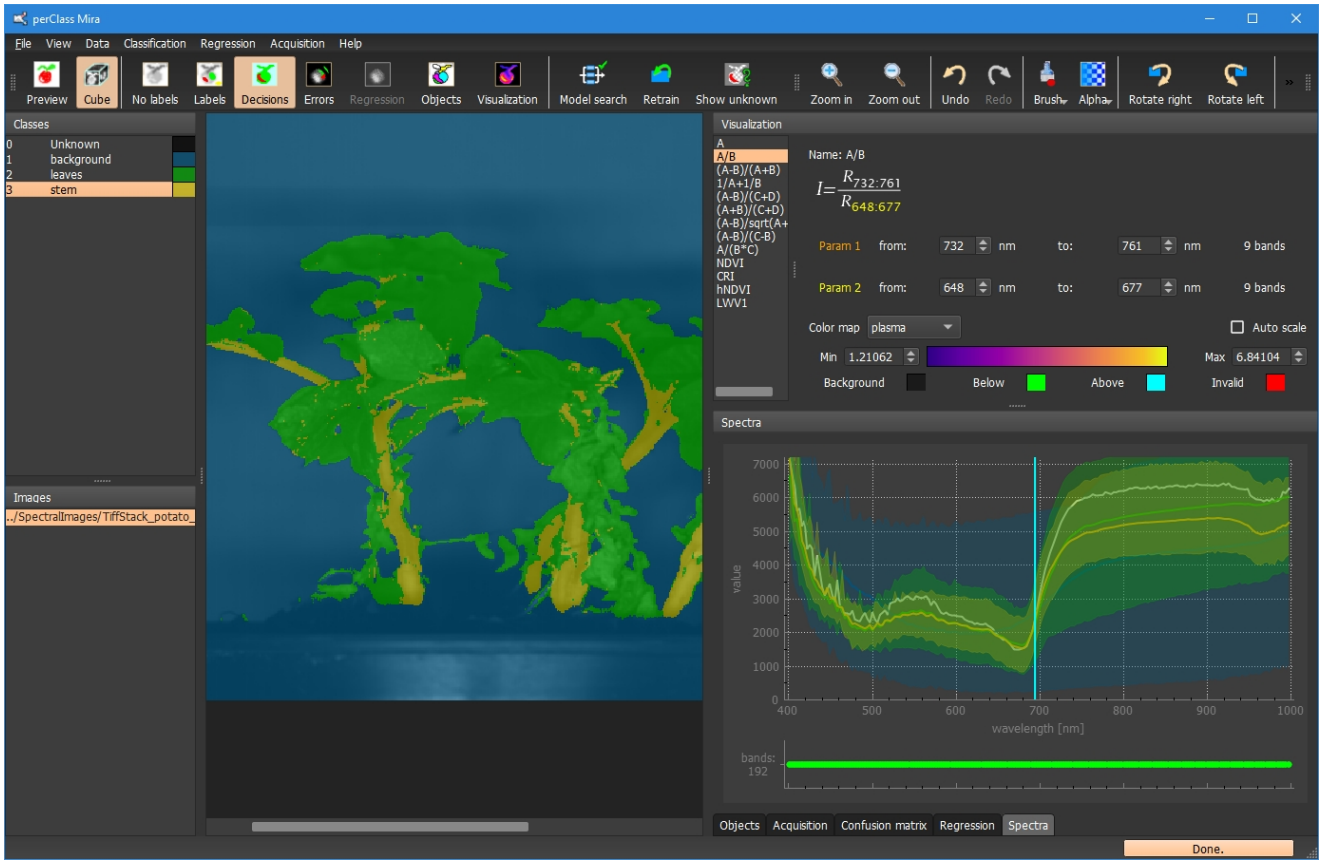
The pixels out of range are rendered using below/above colors, respectively:



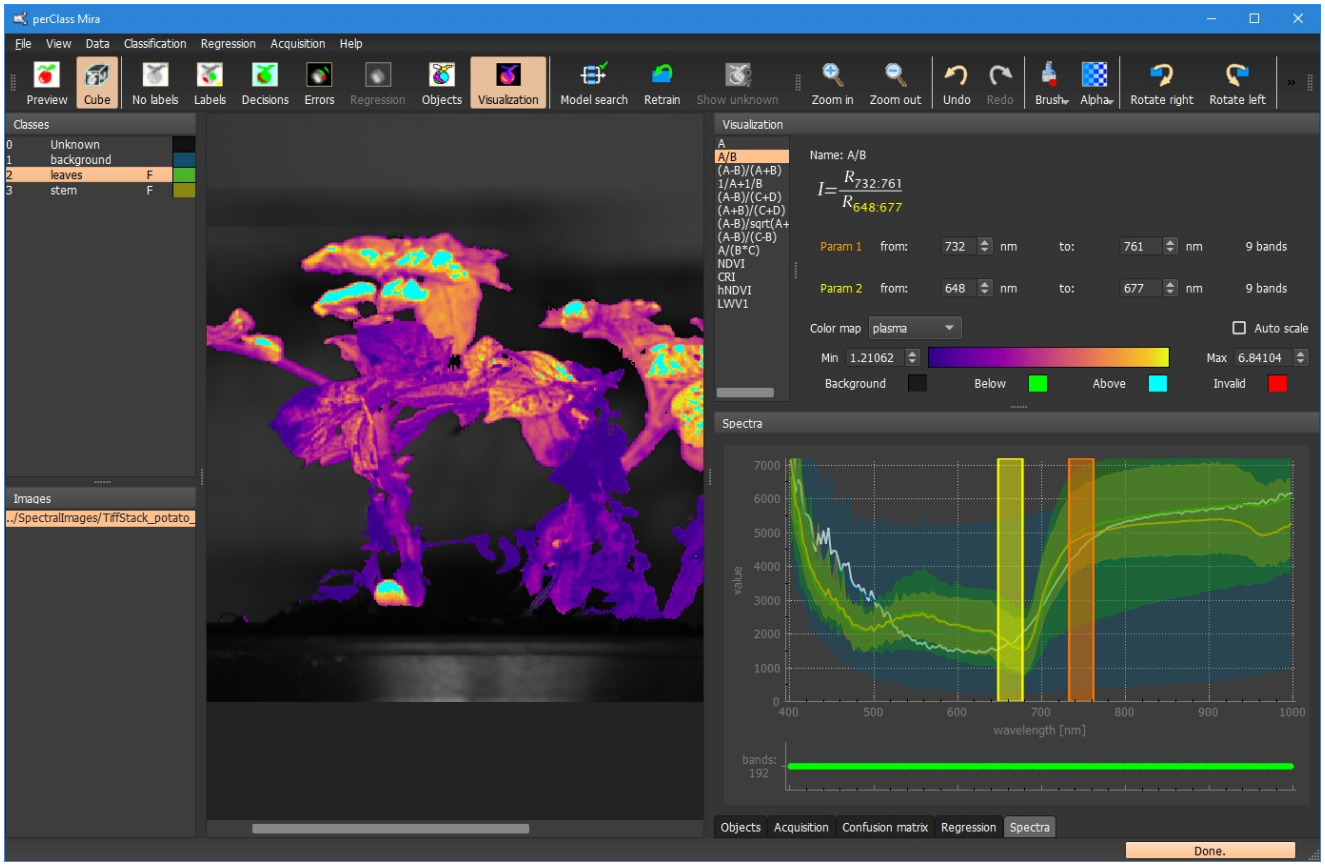

## Constraining visualization to foreground

Typically, we are not interested in spectral index value for the entire image but only for objects of interest. For example, in plant phenotyping, we want to characterize plant health using NDVI index.

In perClass Mira, we can easily construct a classification model for leaves and stem of the plant.




When we flag only the classes of interest as foreground, the visualization will be applied only to the respective pixels.




Note that also data auto-scaling will also use only foreground pixels. This allows us to avoid reflections or

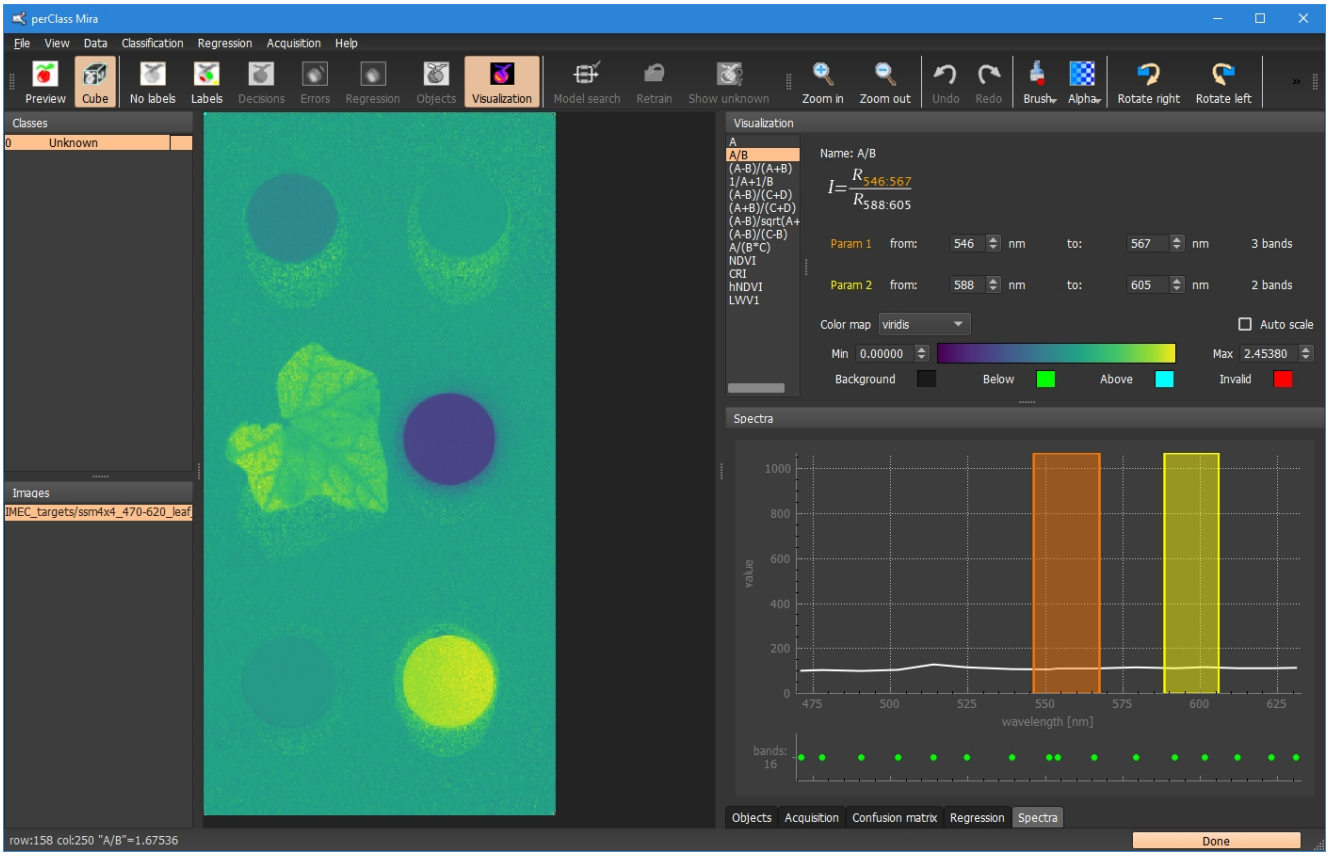
uninformative areas of the background.

## Mapping wavelengths to cube bands

Visualization parameters are defined by wavelengths or wavelength ranges in nanometers.

Next to each parameter, we may see indication how many bands are covered by its definition.

In this example, we can see a spectral cube from a sensor with 16 spectral bands.

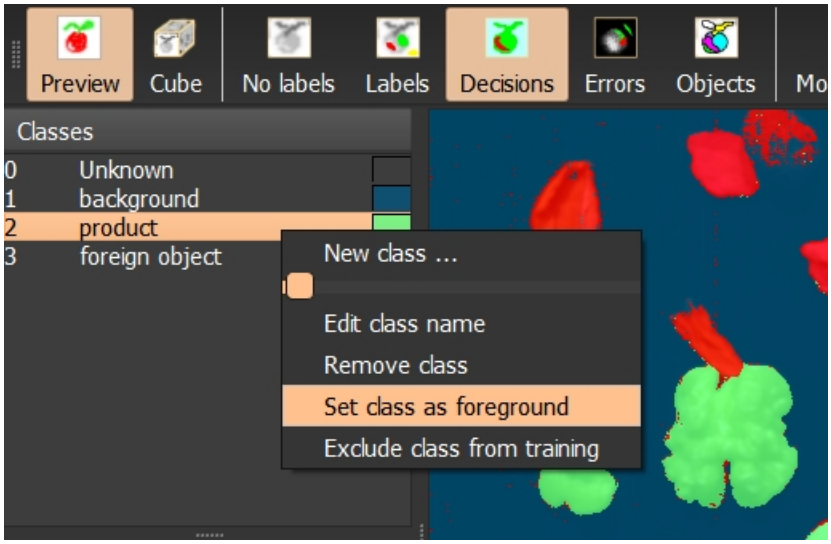



If there are no bands available to fit the parameter definition, the visualization output is rendered as "invalid", by default in red.

## Object segmentation

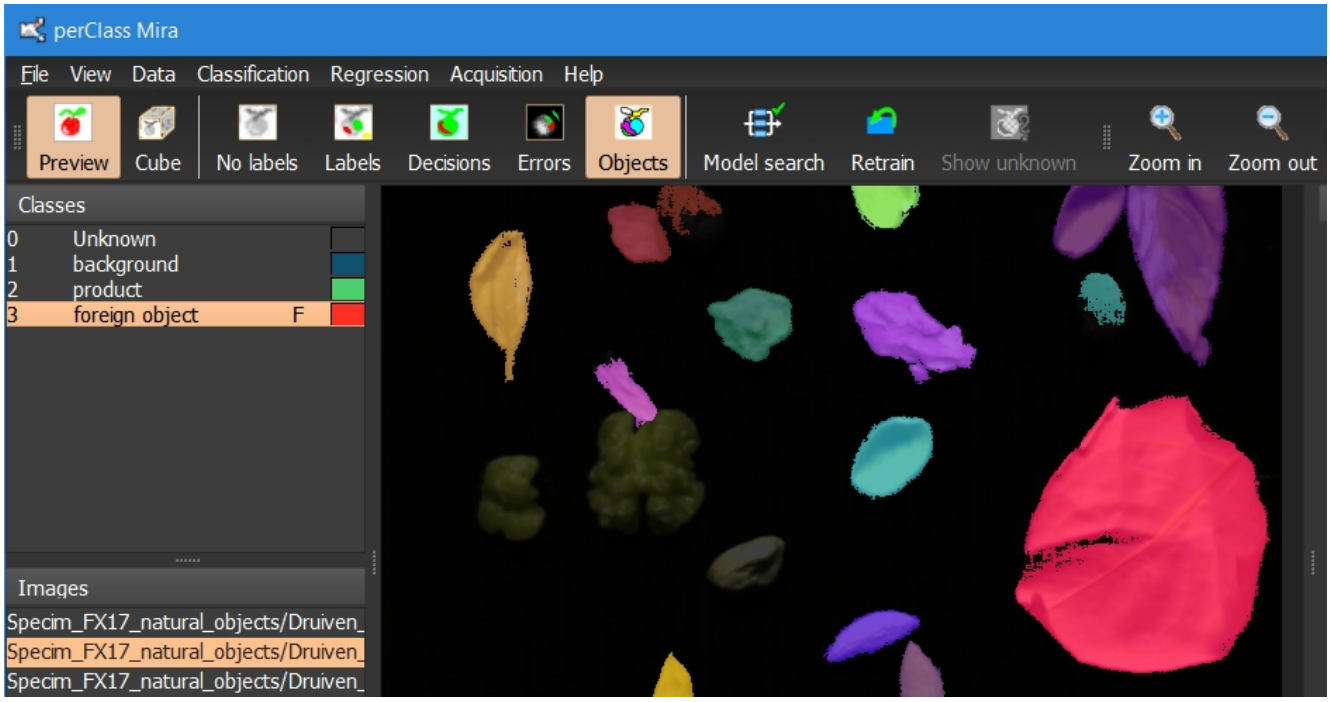
Apart of pixel classification perClass Mira provides object segmentation. In order to segment objects (connected components), one needs to set one or more classes as "foreground":

1. In the class list, use right click to open the context menu on the desired class and select *Set class as foreground* (or press F key)




2. On the toolbar, press the *Objects* button (or press O key)

Selected class/classes will be segmented out and each connected component will be visualized with a randomly selected color.

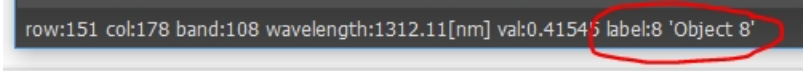



You may notice that small objects got removed from the segmentation result. The minimum size of accepted objects is adjustable in the Objects pannel or via *Classification* / *Set minimum objects size* menu.

## Object labels and object decisions

By default, object segmentation shows object labels. This means, that each connected component is assigned into a unique category.

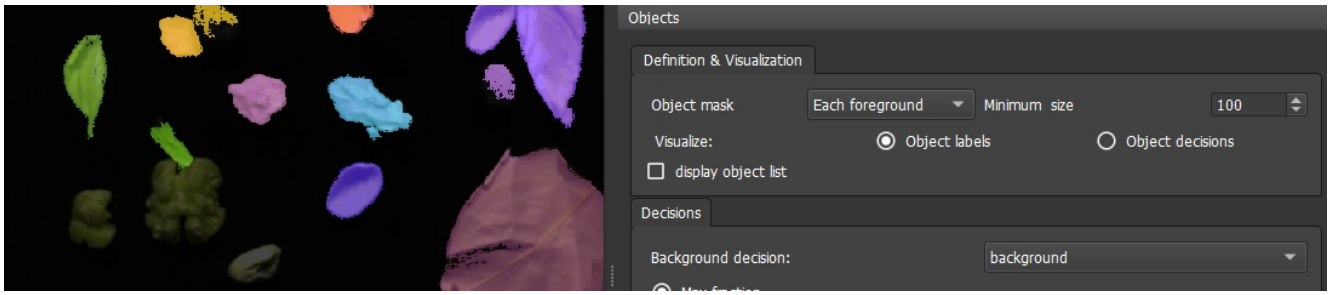
When hovering the mouse over the objects, the object label is displayed on the status bar.



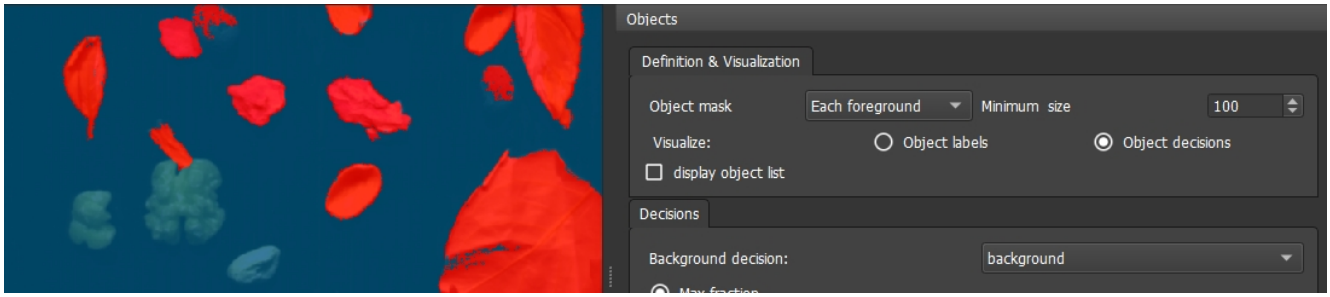

The object pannel provides more options on how to deal with detected objects.

Instead of object labels, we may visualize **object decisions**. It means, that each object is assigned into one of the user-defined classes.

Object labels output:



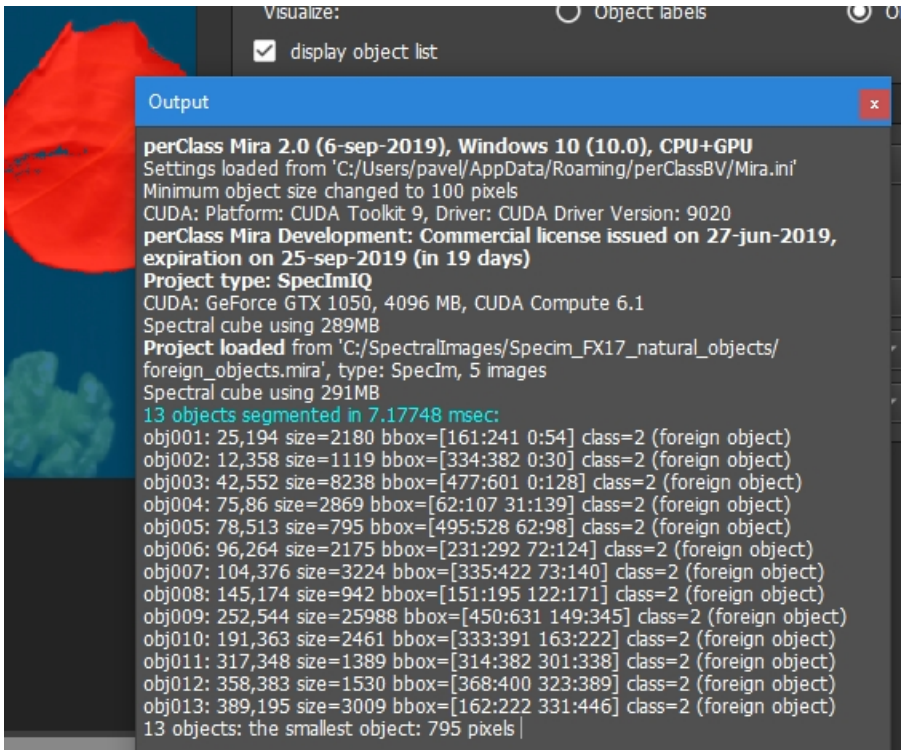

Object decisions output (when only the *foreign object* class is considered as foreground):




Note, that multiple classes may be considered as foreground. In such a case, perClass Mira can handle touching objects of different classes.

## Displaying object list

Object list can be displayed in the output window by enabling the *Display object list* check box.




The object list summrizes:

- object label
- center of gravity (row, column)
- size in pixels

- bounding box (columns, rows)
- class

This information can be delivered by perClass Mira Runtime processing a live stream of spectral data.

## Object modes

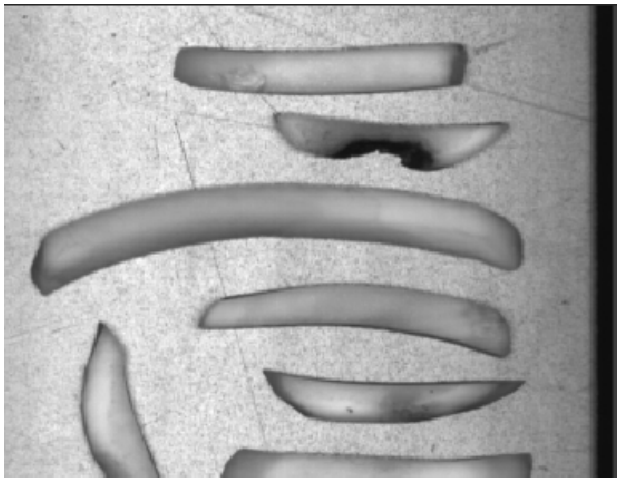
perClass Mira offers two object-definition modes, depending on the mask construction process:

1. **Object mask: Each foreground**. Each object is composed of a single class (or material). Example: Object is either a nut or a shell or a stone. This approach results in **object detection useful in sorting applications**.
2. **Object mask: All foregrounds**. An object is composed of multiple materials (classes). For example, potato chips sorting needs to remove potato pieces (objects) that contain any rotten or green part. In general, this approach is fitting to **object classification use-cases**

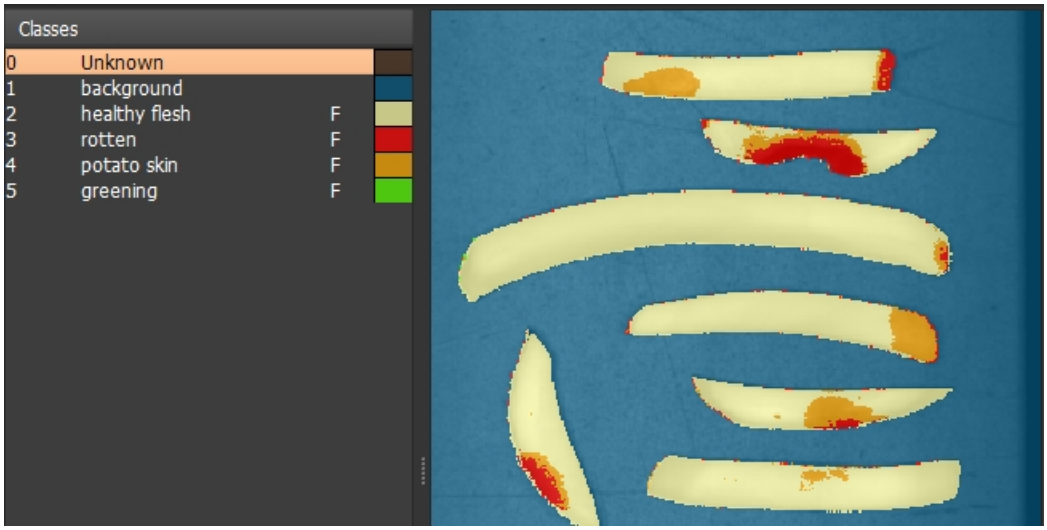
### Example of both modes on a French fries data set

Pieces of French fries are to be sorted to remove objects containing defects. Within each piece of a potato, there can be healthy potato flesh or skin (both OK for the consumer) but also rot or greening defects than must be avoided.

#### *Single band image*



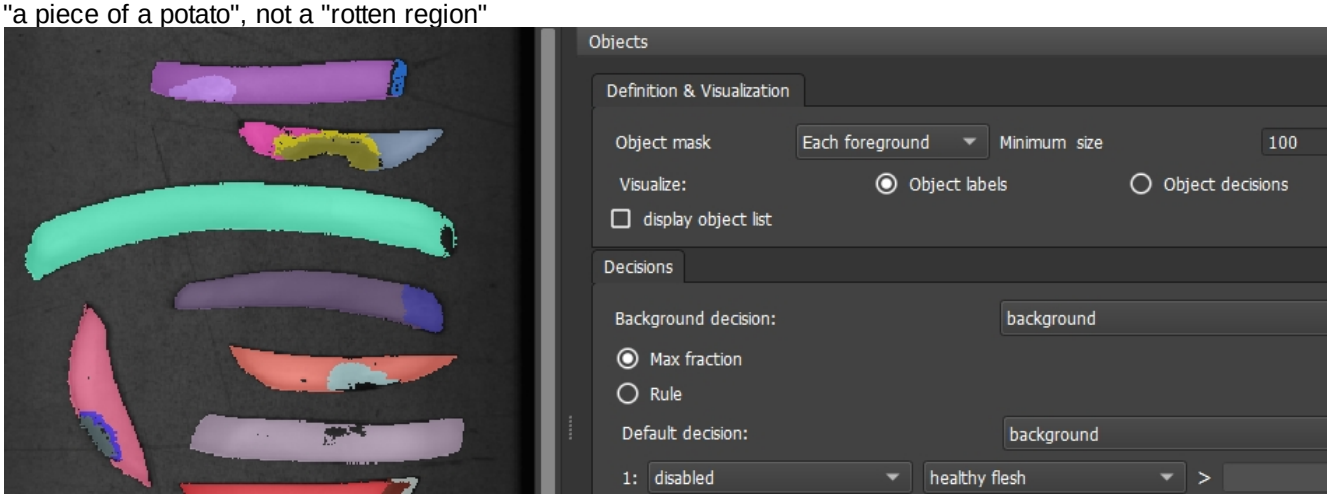
### Decisions of a classifier




### Object definition with "mask by each foreground" mode

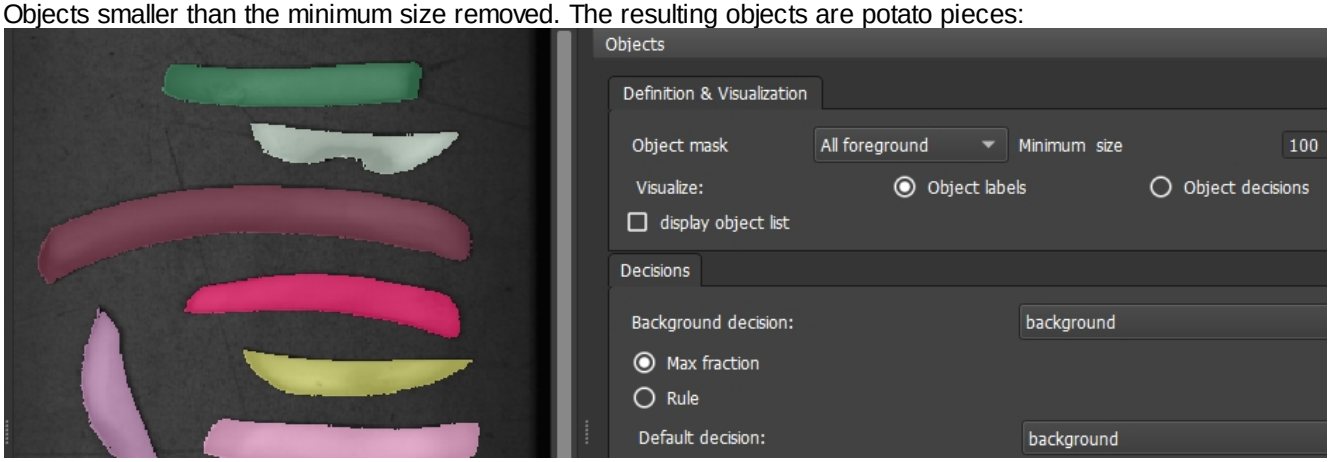
Using the "Each foreground" setting, each foreground class (healthy, skin, rot and green) is handled separately.

Small objects are removed. The resulting object labels will show a colorful patchwork of individual regions.
This approach does not help us to build a sorting problem as "an object" in the French fries sorting application is "a piece of a potato", not a "rotten region"




## Object definition with "mask by all foreground" mode

Using the "All foreground" approach, a union of all foreground classes is considered as a mask for segmentation. Objects smaller than the minimum size removed. The resulting objects are potato pieces:




# Object classification

Object classification use-case based on "All foreground" masking allows us to define specific way how to decide class on individual objects. The object pannel provides two approaches:

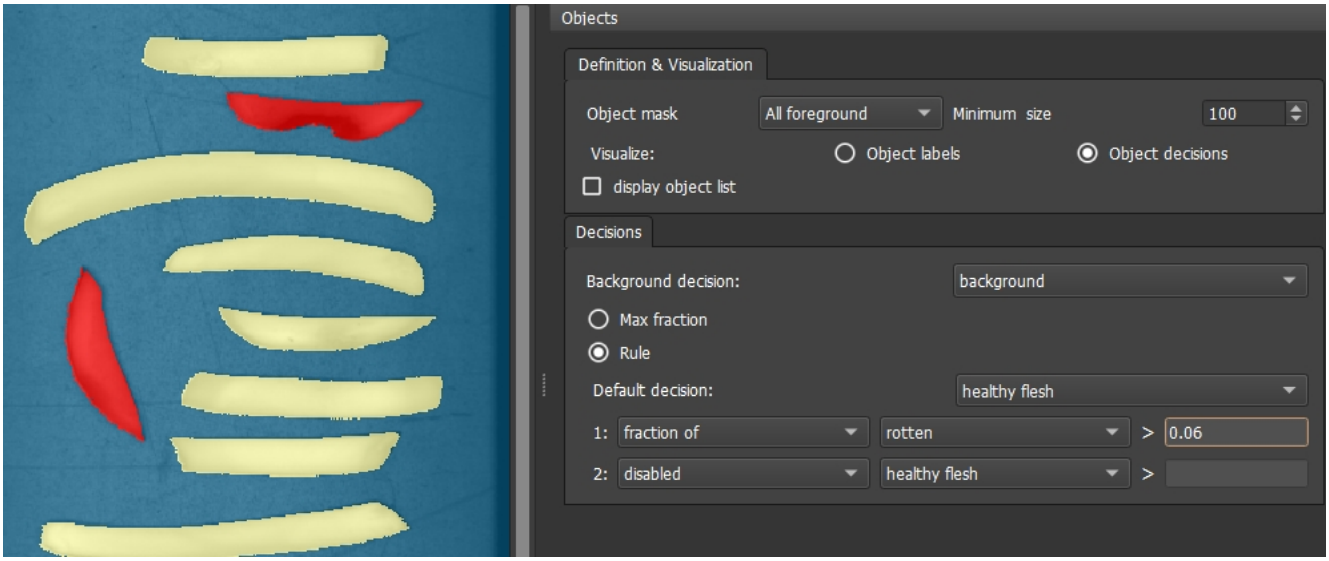
1. Maximum fraction (majority voting)
2. Rule-based classification

## Maximum fraction object classification

Object is classified to a foreground class with the highest number of pixels within an object. Background is assigned to a class defined by the "*Background class"* combo box.
This option is useful in situations where we distinguish several spectrally different classes but the entire object is either one or the other. For example, in a fruit sorting application, we may train a "*firm fruit*" and *hard fruit* classes. The maximum fraction object classifier assigns the fruit piece to the most frequent class.

## Rule-based object classification

In some sorting use-cases, the presence of even small amount or fraction of a specific class mandates rejection of an object. For example, more than 6% or a rotten potato may result in a piece rejection as defective. Object pannel allows us to define rules based on size (in pixels) or fraction (0..1) of an object.
The default decision is also available. It is applicable when no other rules trigger on a given object.




# Feature extraction

perClass Mira allows us to extract information from spectral images. The information such as mean spectra or spectral index can be extracted from objects or from image regions. It can be exported in different ways and used for further analysis. The feature extraction is performed from all selected images in a batch fashion.

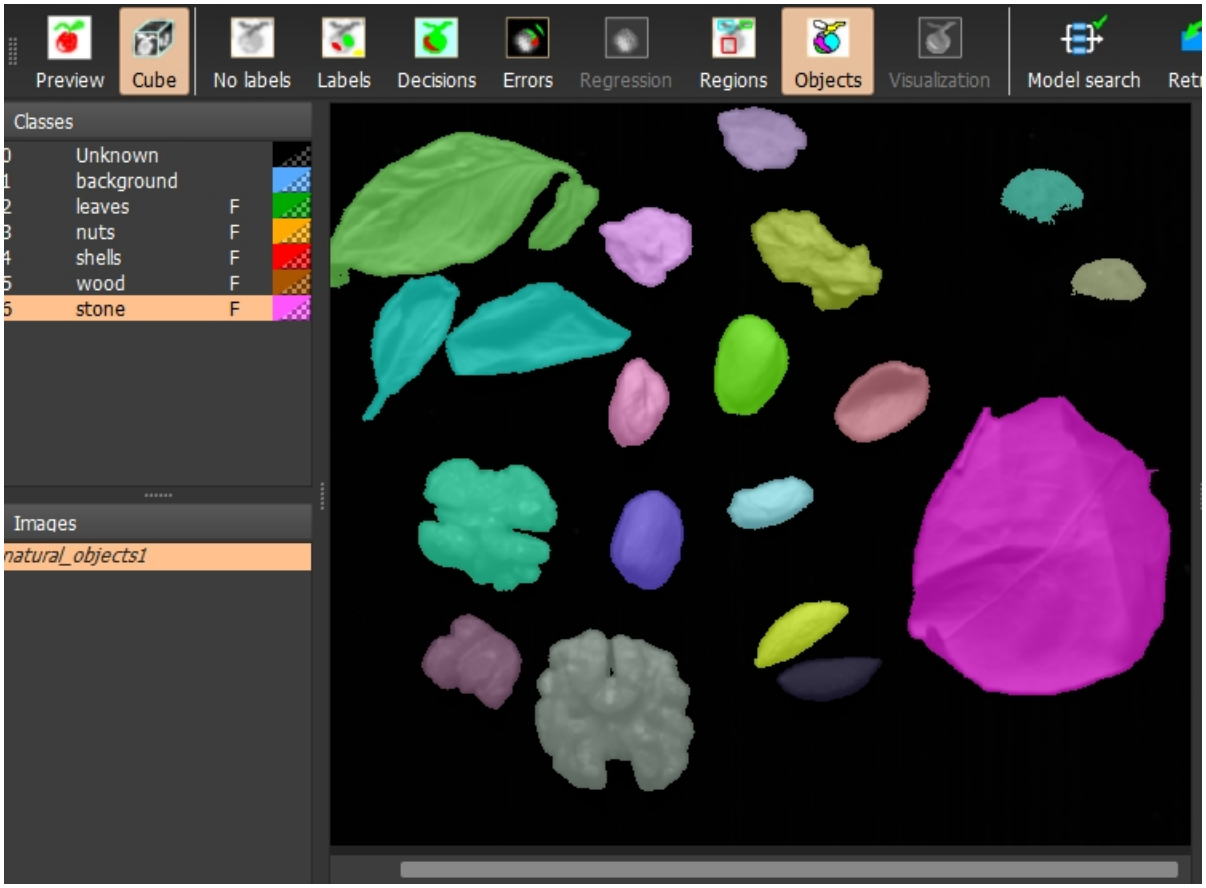
## Location of information to be extracted

Infrormation can be extracted from different **locations**:

- from objects computed by object segmentation
- from regions manually-defined in each image
- from regions manually-defined in a single "template" image

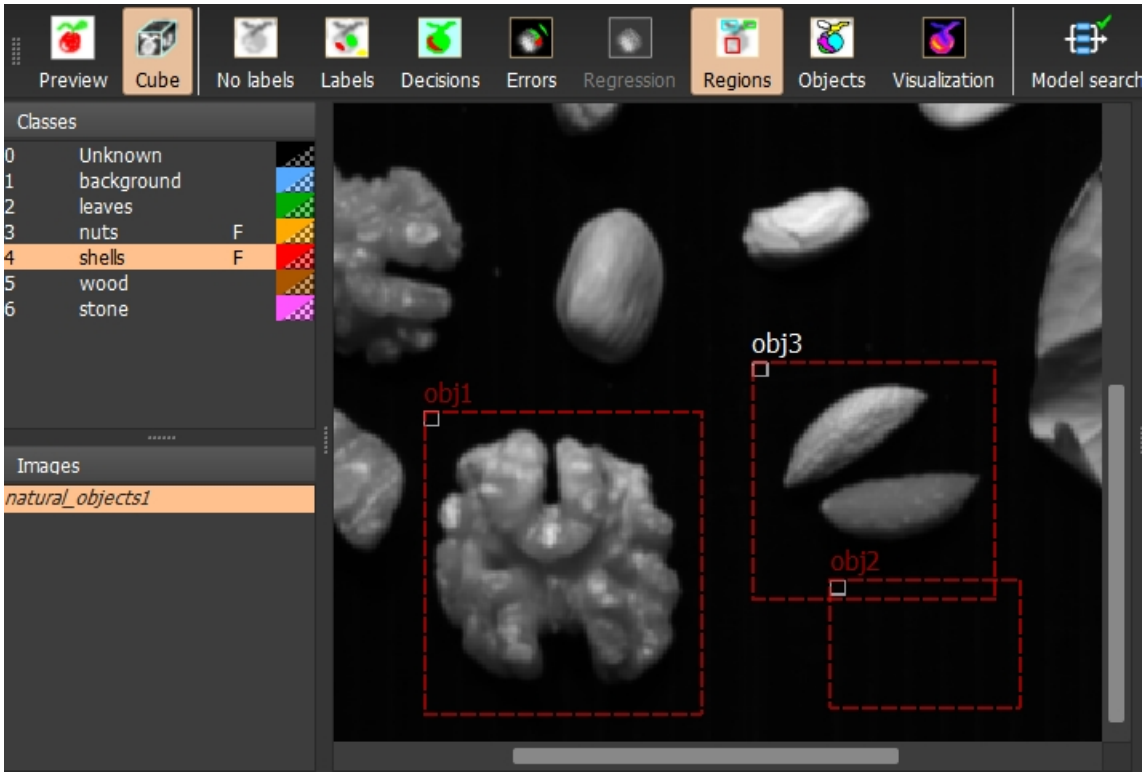
### *Objects computed by object segmentation*

This option referes to objects segmented out using connected component analysis.




## *Manually defined regions in each image*

The *Regions* mode allows us to define rectangular areas (regions) where the information is extracted.

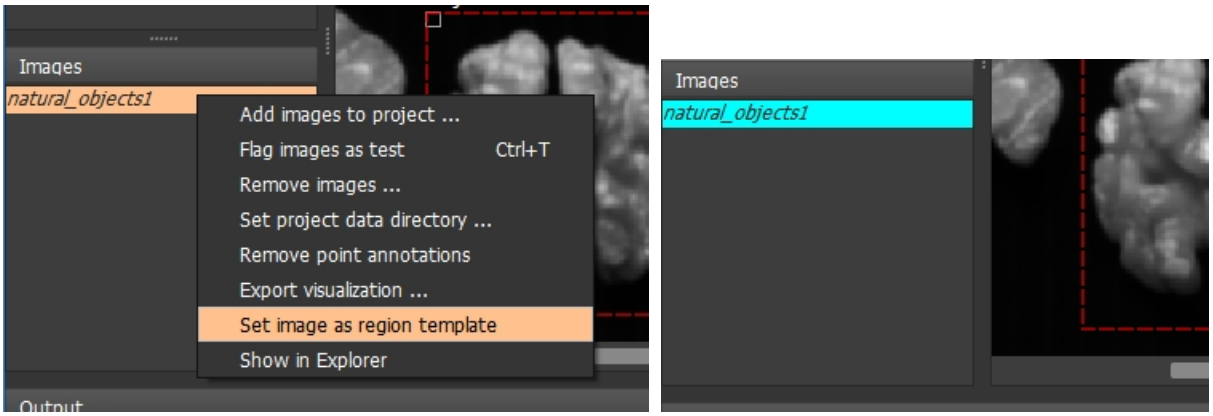



## *Manually defined regions in a template image*

In order to extract information from regions in new, previously unseen, images, we may define one image as a

template used for region definition. This is useful in situations where the image locations are fixed in each scan, e.g. a germination grid or plant location.

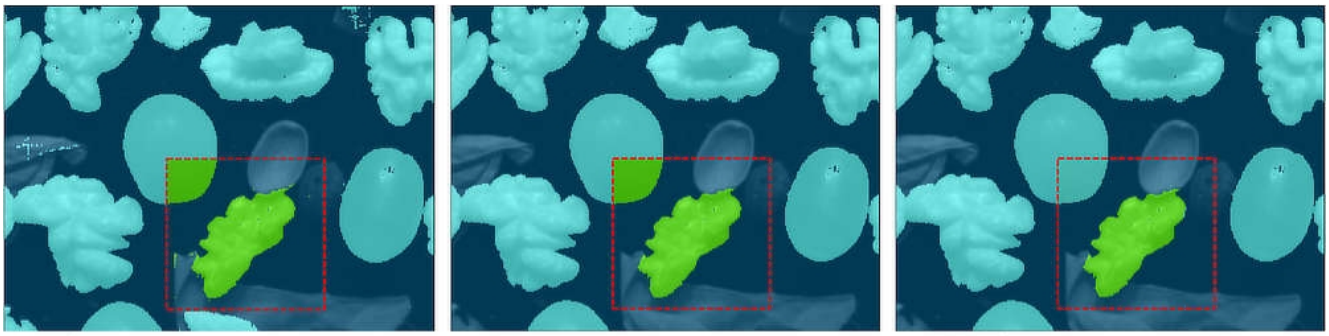
We may set an image as a template via the right-click contect menu. The image will be displayed in a bright blue color.




## What is being extracted

There are three different options defining what exact pixels are included in data representation extraction:

- **All foreground pixels inside a region.** This includes any isolated pixels of the foreground class(es)
- **All object pixels inside a region.** Based on the minimum object size, defined in *Objects* panel, the smaller objects are excluded.Only the pixels of large-enough objects are included.
- **Pixels of objects with centroids inside a region.** The pixels of objects with a center of gravity outiside our reagon are excluded. Note the part of the round object entering top-left corner of our red region. It is now excluded from processing because the centroid of the round object is outside of the red rectangle. This option is useful to include only the principal objects.



*All foreground pixels inside a region* *All object pixels inside a region* *Pixels of objects with centroids inside a region*

## Feature extraction types

Different types of information can be extracted:

- Mean spectra
- Spectral index mean
- Spectral index histogram
- Foreground pixel count
- Class fraction
- Regression output

### Mean spectrum

# Mean spectra

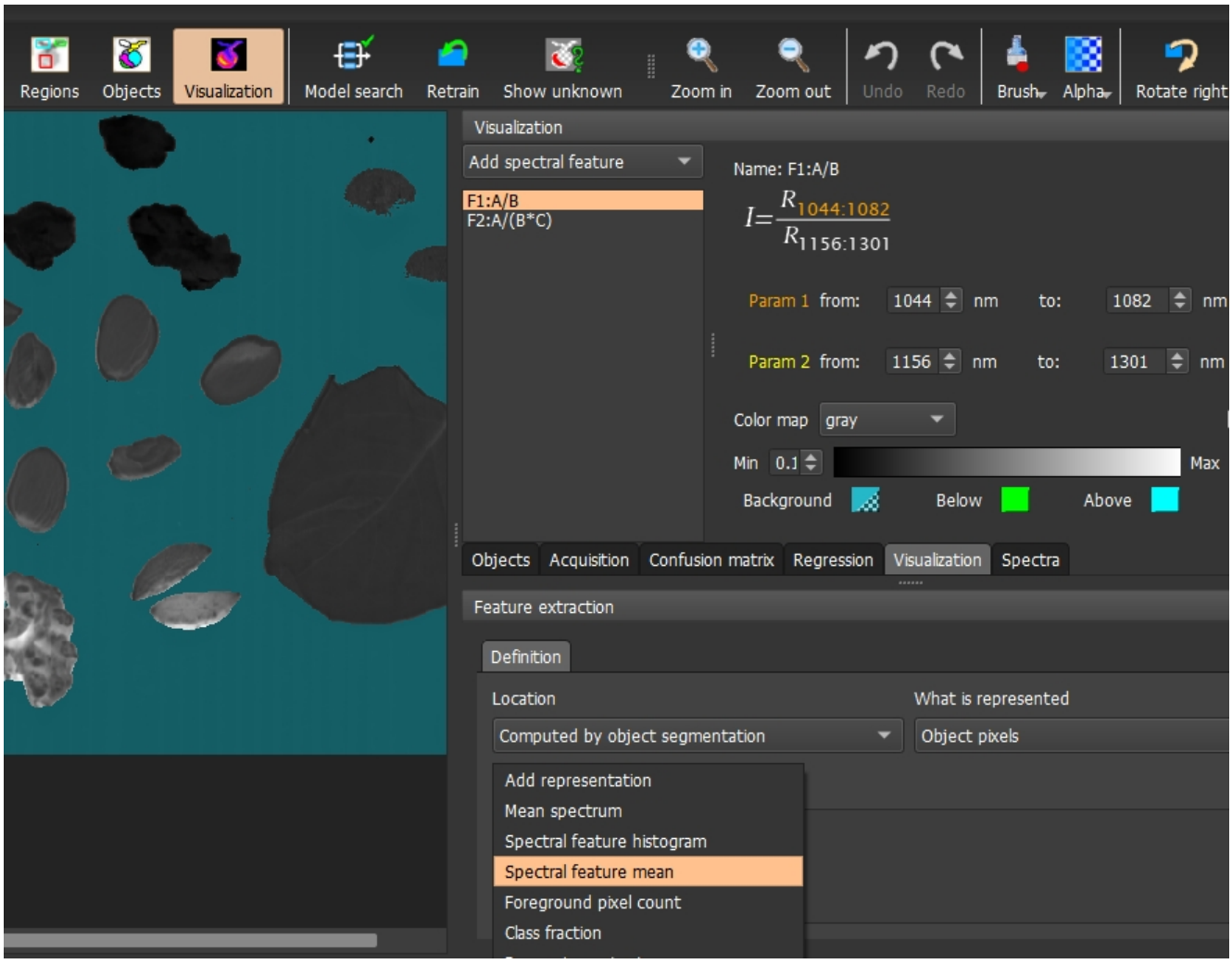
Single mean spectrum for each object or region is extracted.

### Spectral index mean

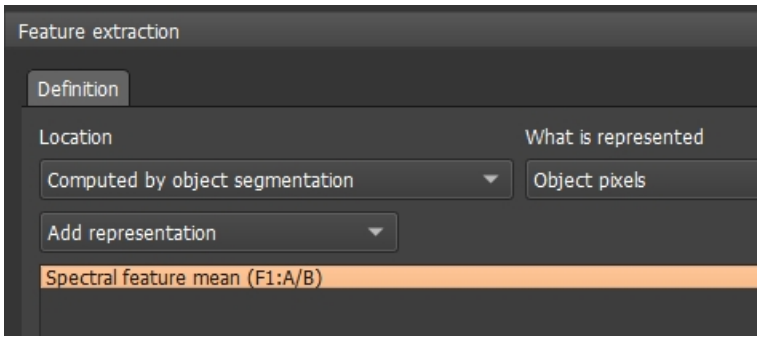
# Spectral index mean

Mean of a spectral index for each object or region is extracted. This is a single scalar value per object/region.

We need to first select the spectral index of interest in the *Visualization* panel. Then, we may select the 'Spectral index mean' option in the *Feature extraction* panel.

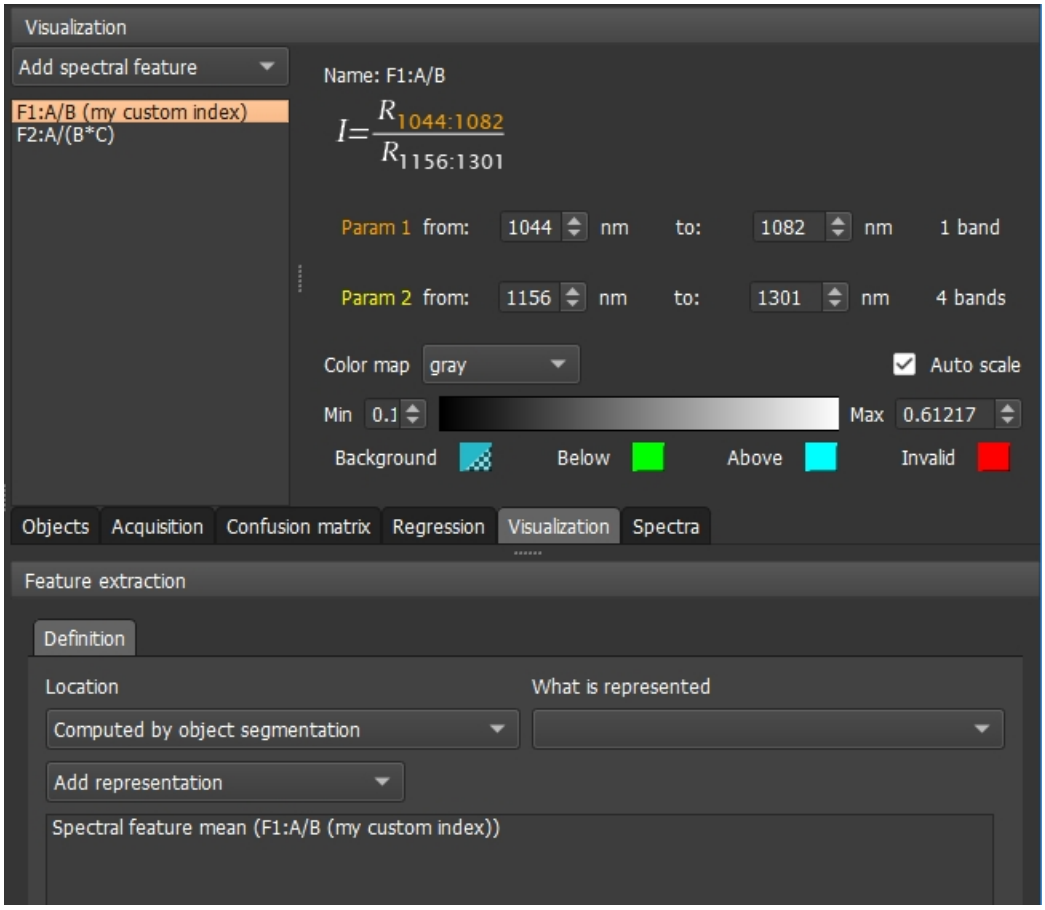



The feature name then refers to the selected spectral index.




Note, that if we rename the spectral index name (vis right-click and *Rename spectral index* in the visualization

list), the name of the extracted feature is updated.




If we remove the spectral index, the feature remains defined. However, when trying to export features an error message will appear.

### Spectral index histogram

# Spectral index histogram

A histogram of a selected spectral index is extracted for each object. By default, the histogram contains 20 bins. The min and max bounds are defined by the spectral index bounds.
The histogram bounds are defined at the moment of computing/exporting the representation from the spectral index min/max bounds, not at the moment of feature extractor definintion. Therefore, you are free to adjust the spectral bounds at any moment.

Note, that if the *Auto scale* of spectral index is enabled, the min and max value depends on the currently selected image. In order to use the extracted spectral index histogram in further data analysis, the same bounds should be used for all images in the extracted data set. The min and max bounds are provided in the exported Excel or XML files for user to inspect.

### Foreground pixel count

# Foreground pixel count

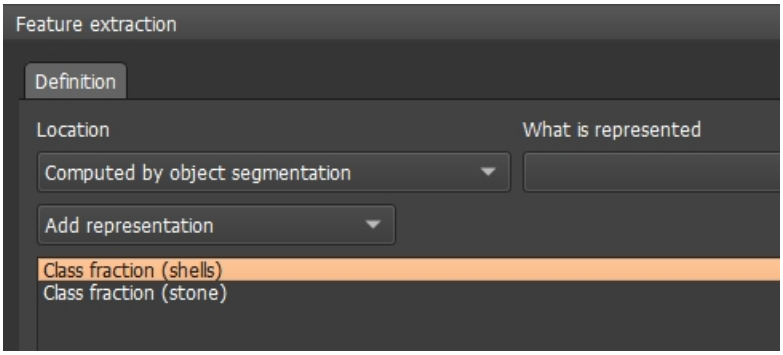
This is the number of pixels used in the analysis of a specific obejct or region.

### Class fraction

# Class fraction

This is the fraction of pixels of a selected class from the entire object/region. The feature extractor name then

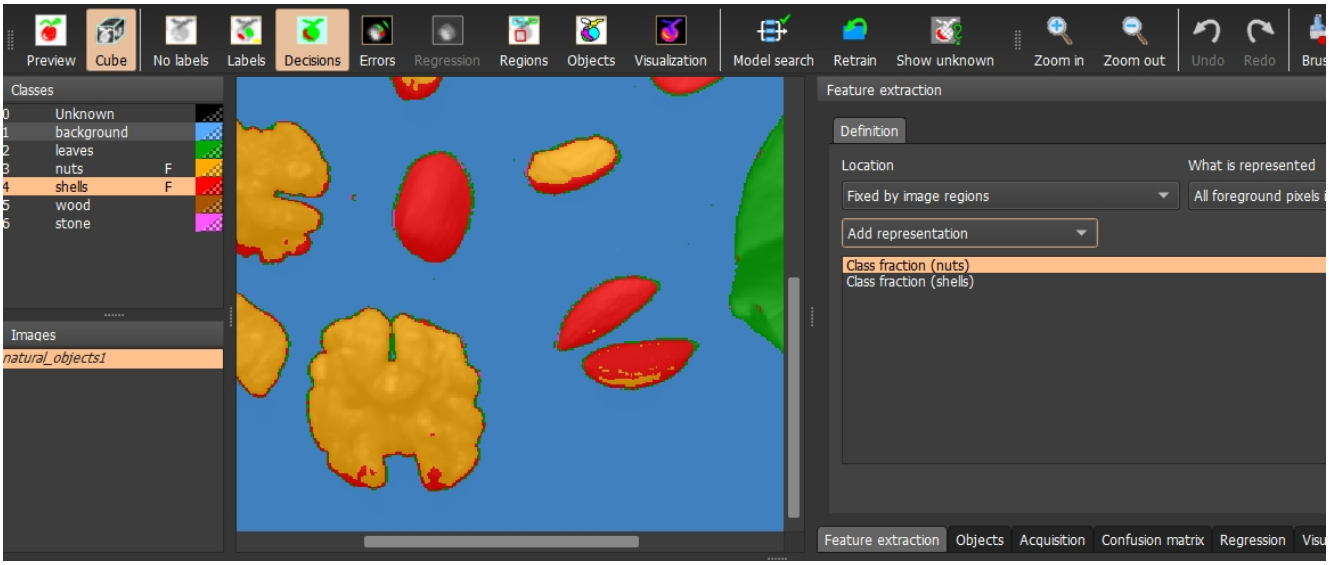
referes to the class selected at the moment of definition.



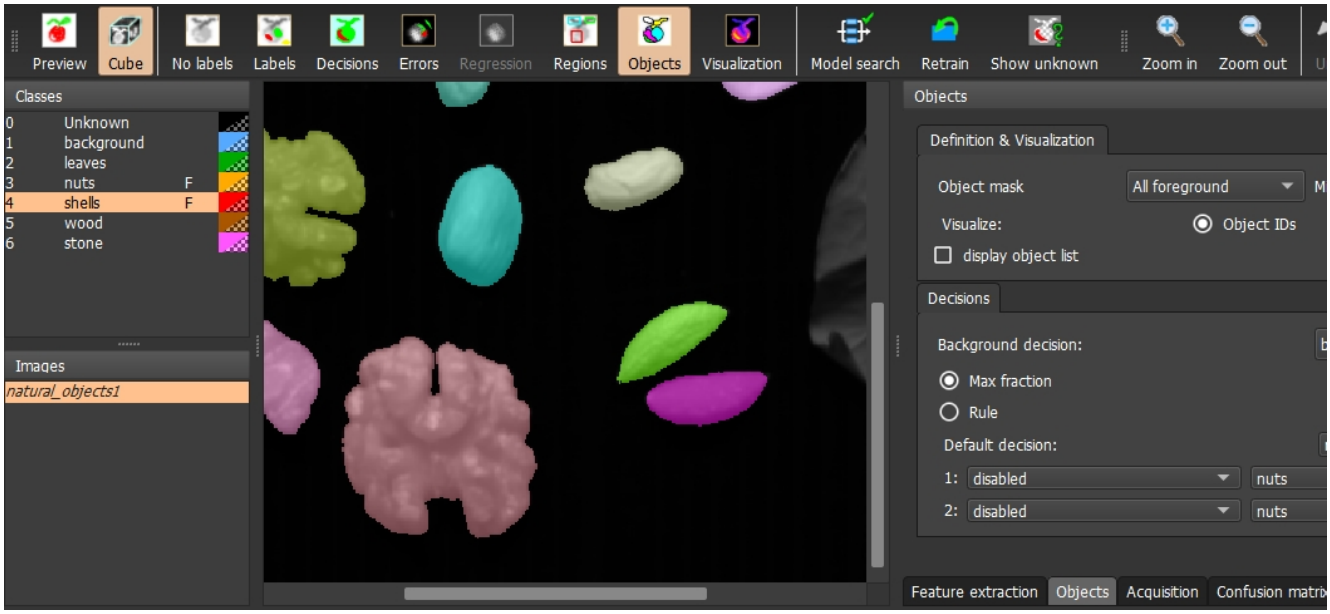

The class fraction is useful in combination with 'All foreground' segmentation mask i.e. in situations where we select multiple foregrounds and define an object as a union of foreground classes. The class fraction then provides the insight in object composition. For example, what is a fraction of disease or defect in a plant or product.

Here is an example on natural objects. We are interested in fraction of *nuts* and *shells* classes:

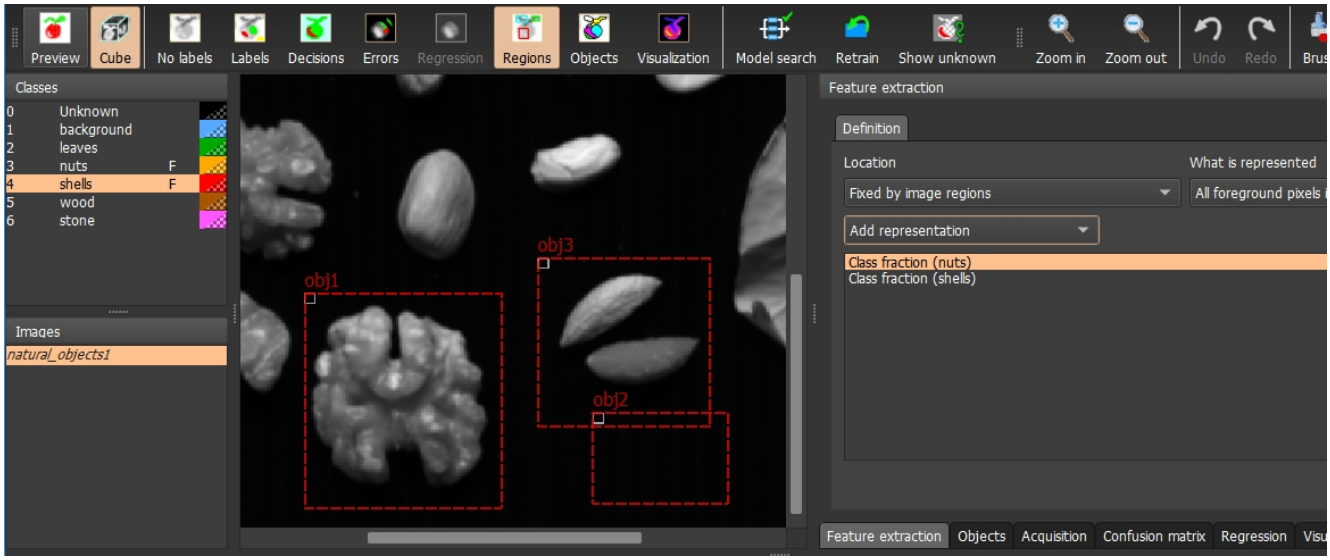
The pixel decisions:




The object segmentation defines 'All foreground' mask. As the foreground is only *nuts* and *shells*, the leaf is missing.




The region definition:




The information extracted and exported to Excel file:

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | | | | | | | | | | | |
| 6 | | Object location | Fixed by image regions | | | | | | | | |
| 7 | | What is represented | All foreground pixels | | | | | | | | |
| 8 | | | | | | | | | | Class fraction (nuts) | Class fraction (shells) |
| 9 | Image | | Object | Bounding box | | | | Content | | | |
| 10 | Index | name | name | Column | Row | Width | Height | present | pixels | | |
| 11 | | | | | | | | | | | |
| 12 | 1 | natural_objects1 | obj1 | 186 | 351 | 117 | 128 | TRUE | 8748 | 0.939529 | 0.060471 |
| 13 | 1 | natural_objects1 | obj2 | 359 | 423 | 80 | 53 | FALSE | 0 | | |
| 14 | 1 | natural_objects1 | obj3 | 326 | 330 | 102 | 100 | TRUE | 2783 | 0.063241 | 0.936759 |

Note, that the fraction of nuts and shells sums to one as these were the only two foreground classes. Also note, that the object 2 does not contain any foreground pixel. The extracted features are, therefore, missing.

The important advantage of extracting information from regions and not computed objects is exactly the ability to detect missing information in a specific image location. This allows us, for example, to detect that a seed in a specific grid well did not germinate.

## Regression output

# Regression output

The mean regression output per object or region is extarcted. It is defined for a specific regression variable selected in the *Regression* panel's *Variables* tab.

## Regression

Regression modeling is used to estimate a numerical value instead of making a decision. It is often adopted in quality estimation.

perClass Mira implements object-centered regression modelling. Individual objects can be annotated with numerical meta-data. A regression model is build that can be applied to a new object.
This enables practical applications such as:

- Estimate brix (sugar) content in a tomato
- Estimate a dry-matter content of a plant leaf
- Estimate moisture content in biscuits

### Regression example: Powder mixture

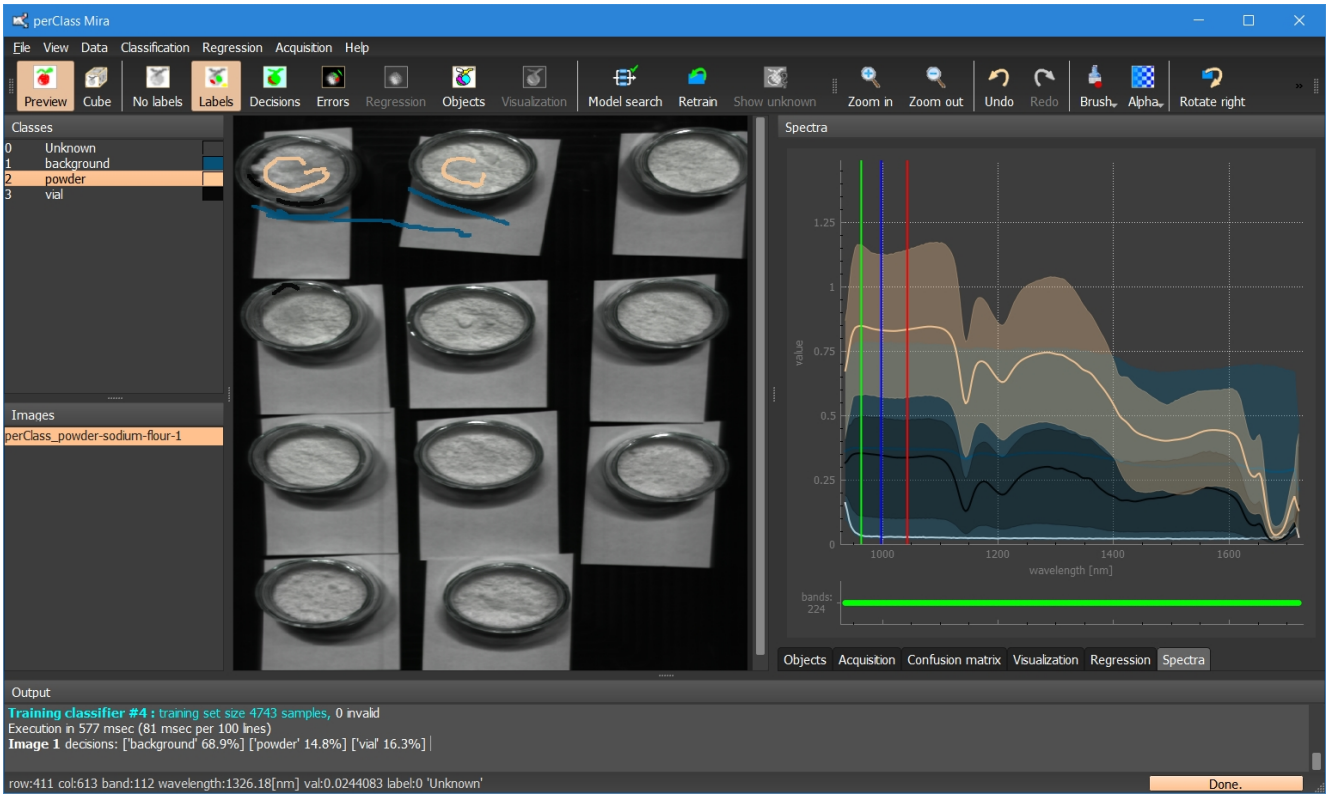
In this example, we will use a mixture of sodium carbonate and flour. A set of vials with different mixing proportions is scanned using Specim FX17 camera in the range between 900 and 1700nm.

In order to estimate mixing proportion we:

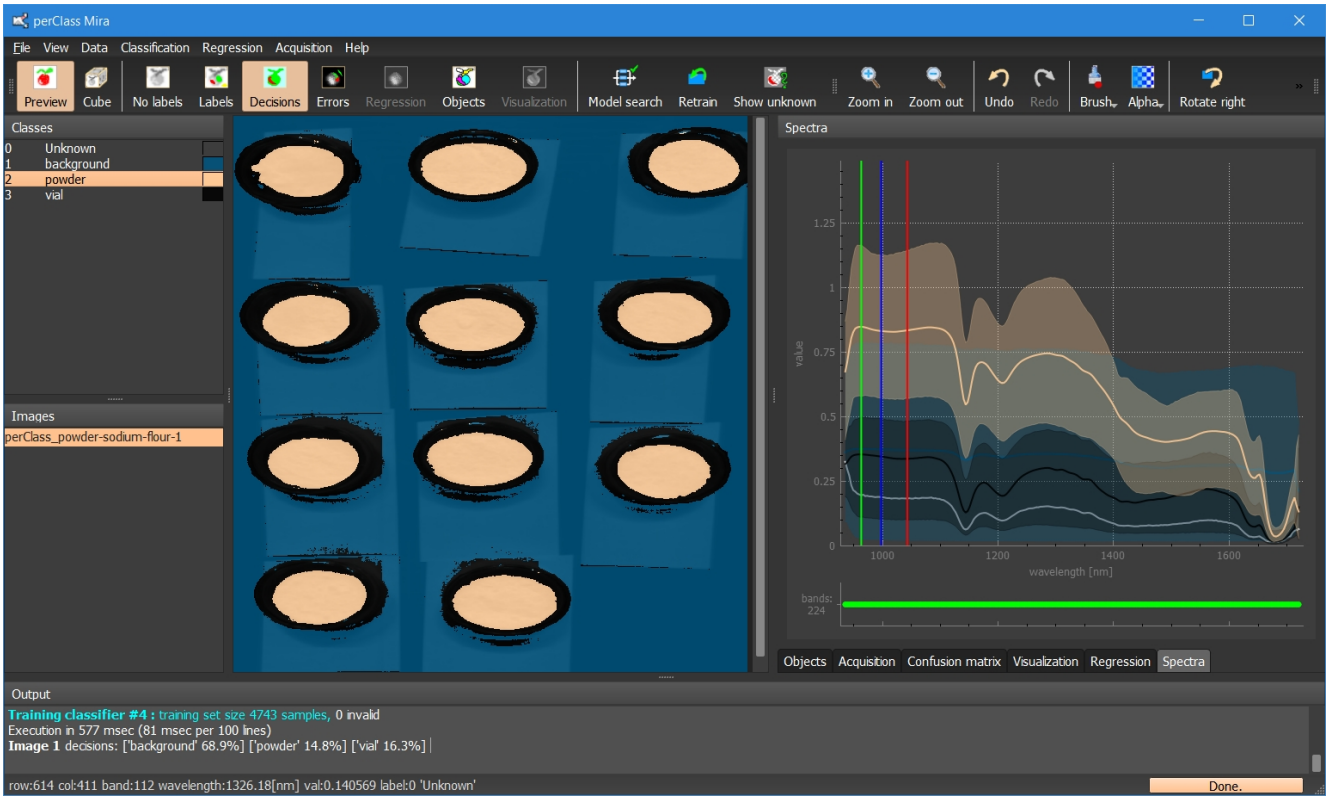
1. Build a classification model that identifies area of interest for regression
2. Define the class of interest as foreground so that objects can be segmented out
3. Annotate number of objects with known ground-truth values for regression
4. Build a regression model
5. Flag some of the images for testing only to judge generalization performance
6. Improve the model
7. Apply the solution to a new hyperspectral scan (objects get identified and for each a value is estimated)

## Step 1: Pixel classifier

**Step 1:** We build a pixel classifier separating the powder from the background and vials

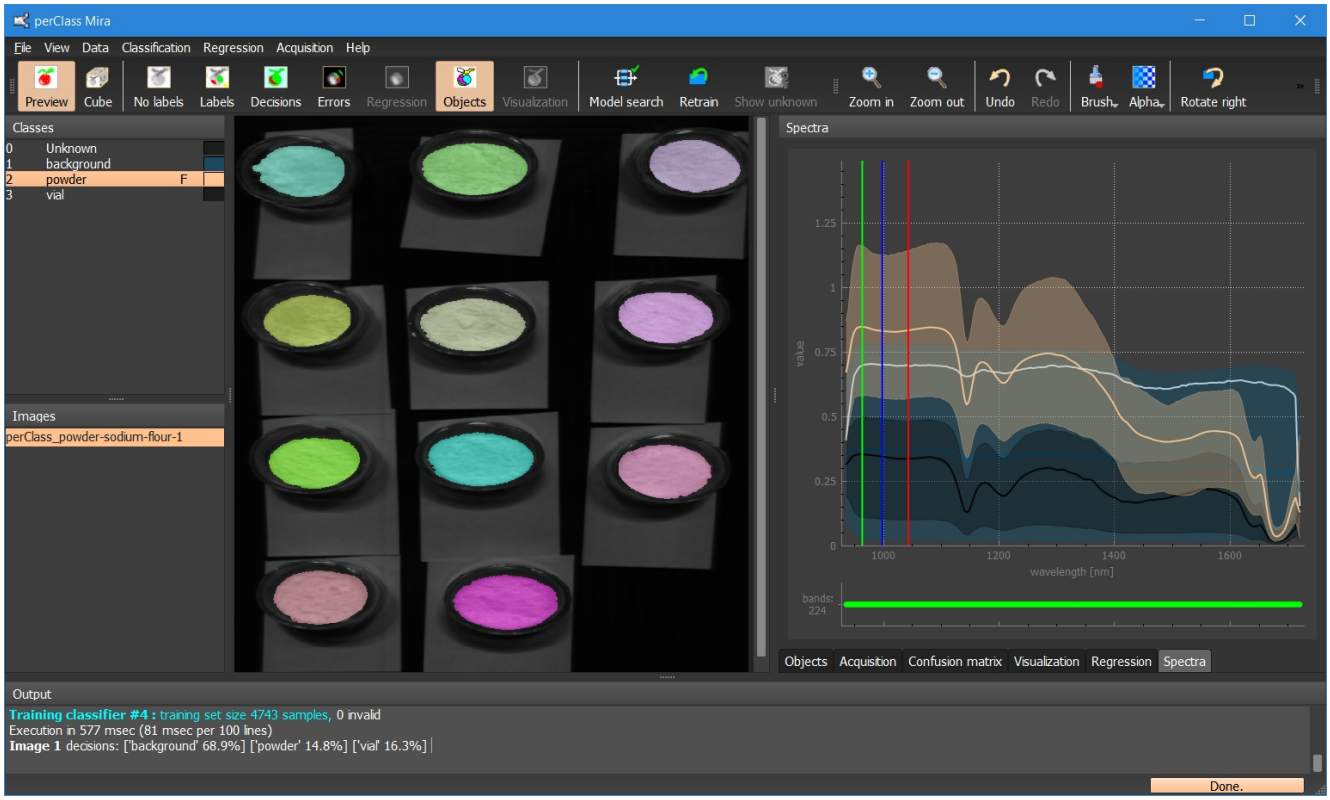



Decisions:




## Step 2: Object segmentation

We now need to flag the "powder" class as foreground (by right-clicking on the class name in the class list and selecting *Set class as foreground* or by pressing 'F' key)



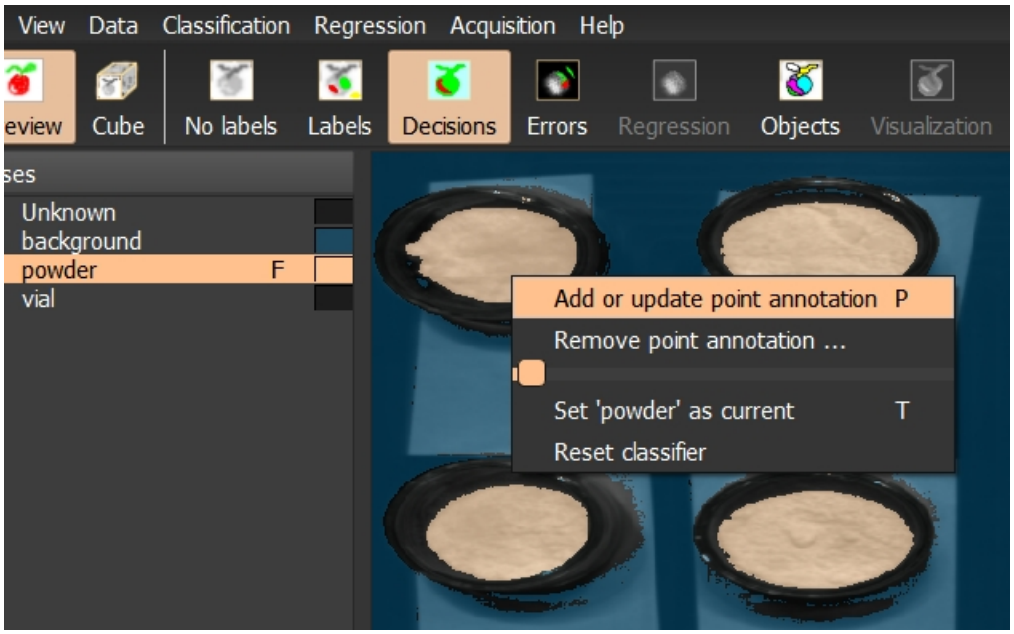

## Step 3: Point annotation

In order to build a regression model, we need extra annotation connecting known ground-truth numerical values to objects.

In our case, we know for each vial what mixing proportion is present. We will use percentage of Sodium as the numeric target.

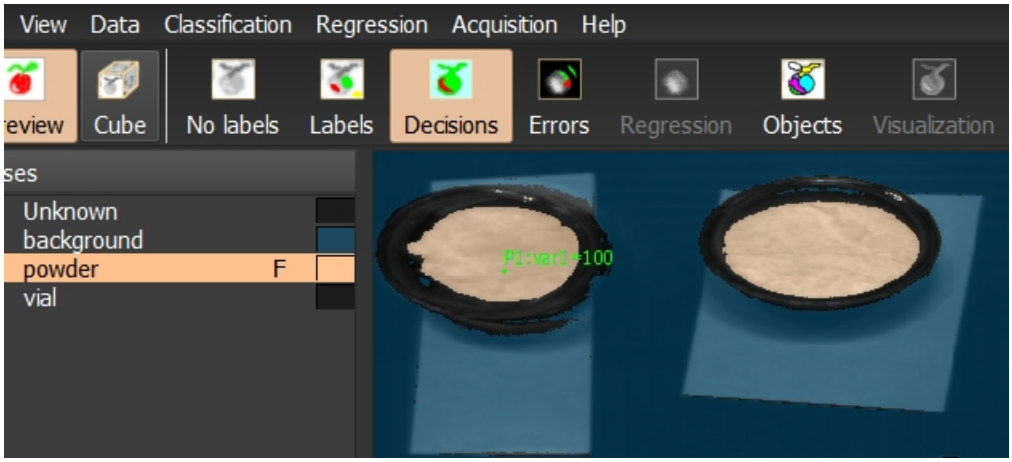
Because the regression modelling is performed on the object level, we need sufficient number of annotated objects. How many exactly are needed will depend on the project. The best guidance is by building the regression model and comparing its performance on the training and test subset of objects.We will discuss construction of a test set further in our example.

We can add a point annotation by right-click and *Add or update point annotation* command:




A dialog will appear where we can enter numeric value.

A new point will appear at the location indicating the value.

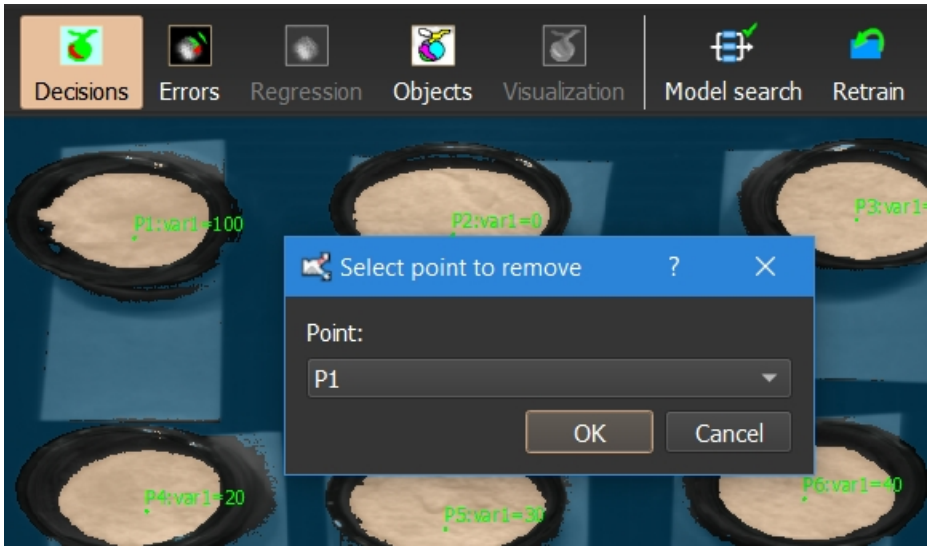



In order to edit the point, move mouse over it and use the same context menu item.

Point annotations need to be placed inside the objects in order to be used for regression. You may drag the point to adjust its position.

### Step 3a: Removing point annotations

To delete points use *Remove point annotation* command. A dialog will appear with a list of points in the current image.




Each point has a unique number that is identifying him in the project.

In order to remove all points in an image, use *Remove all point annotations* from the *Regression* menu.

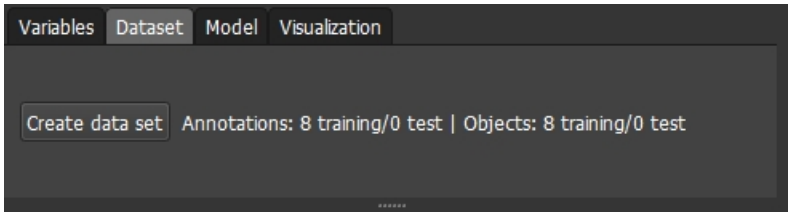
**TIP:** If you wish to remove points in several images, simply select the images (holding shift for continuous selection or Ctrl for arbitrary selection) and use the same command.

## Step 4: Build regression model

In order to build a regression model, use *Model search* button in the regression panel.


The regression plot will show true (horizontal axis) versus predicted (vertical axis) values for each object.

On the *Dataset* tab, details on the annotations and objects are listed. Annotations refer to placed point annotations while objects to the number of point annotations representing specific objects used for training or as independent test set. We can only train a regression model, if there are training objects listed. If you move any of the annotation points out of its object and click *Retrain model* button in *Model* tab, you will see one point (object) disappearing.




On the *Visualization* tab, you may adjust minimum and maximum value or scale the plot to fit.

To improve regression, we may change data preprocessing. By clicking *Preprocessing* button, a dialog opens with a list of options.
By default, no preprocessing is applied. We may also select spectral smoothing, 1st or 2nd derivative with different window sizes (in bands).
After changing preprocessing, it is necessary to explicitly retrain the regression model.

## Step 5: Adding test examples

To properly validate performance of regression models, we need to apply the regression model to objects unseen in training.

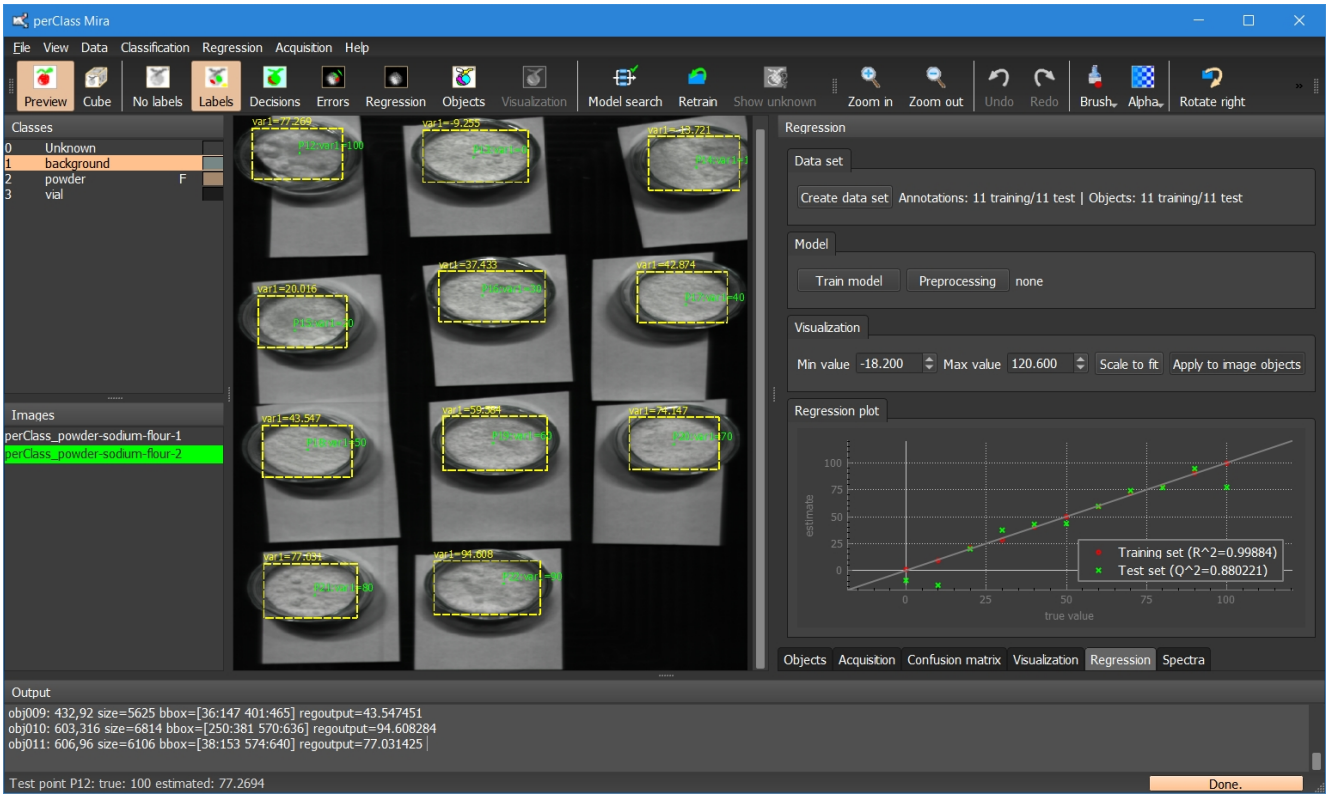
In perClass Mira, we may flag images for testing only (right-click in the image list or press Ctrl+T when image is selected). Test images are displayed in green.
We still need to place object annotations on the test images, because we need the ground-truth to compare with estimated values.

In this example, we added a new scan, annotated the vials with proper ground truth. Then, we recreated the data

set by clicking *Create data set* in Regression pannel. Note, that 11 objects are listed for testing.

We then retrained our model. The regression plot shows a new set of green points referring to the test objects. The red points always refer only to the training objects.

Finally, we clicked on *Apply to image object* button. This applies our pixel classifier to the image, segmented objects and applies our regression model to each one. The result (estimated fraction of sodium) is displayed next to the yellow bounding box.




Although there is a good match of the regression trend, estimated values for two test points fall far from the ground truth. We may hover the mouse over the points in the regression plot to inspect which point is the closest to the mouse. The point number, ground truth and the estimated value are listed in the status bar at the bottom of the window.

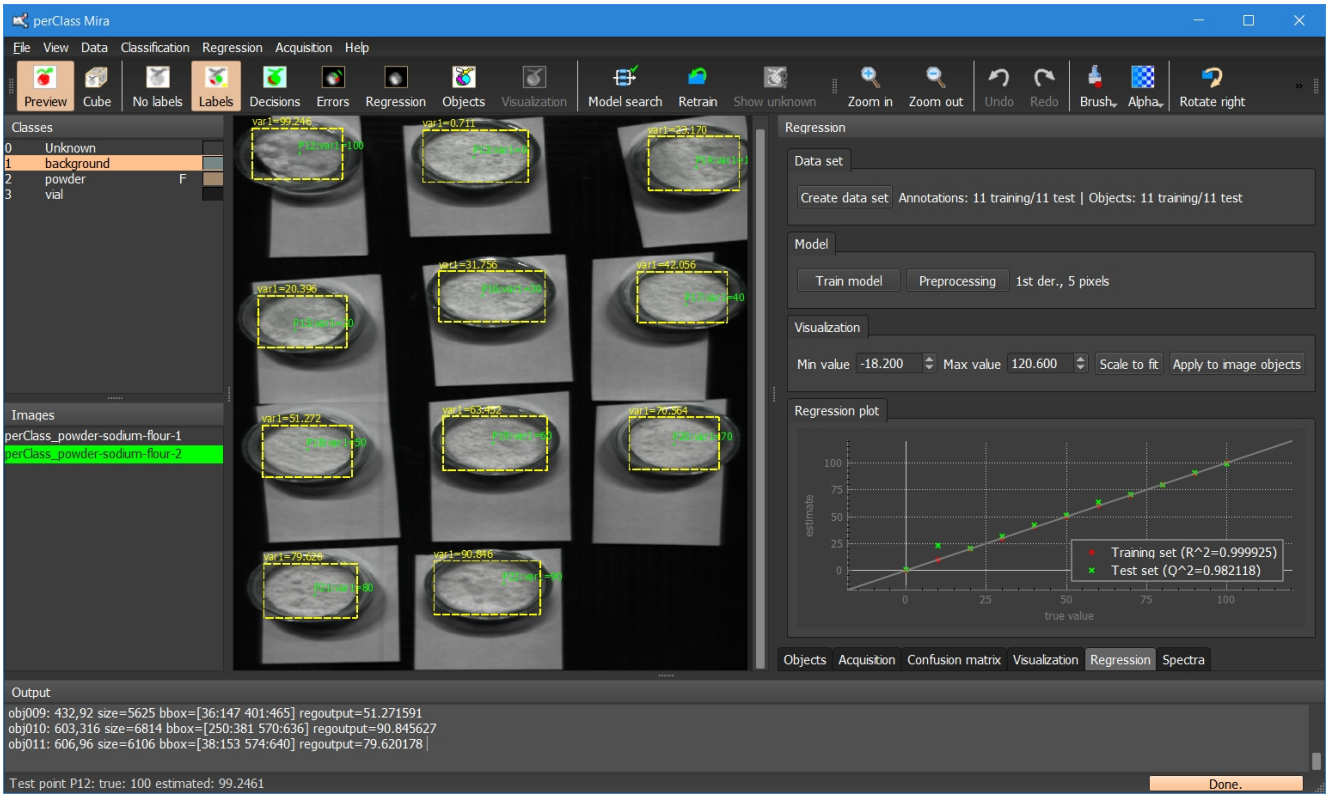
We were placing the mouse pointer over the green point in the upper right part of the plot. We can see that the marker refers to point P12 with the true fraction of 100 and the estimated value of 77.2. Note the corresponding object in the left upper corner of our scan - the bounding box shows the same 77.2 estimated value.

## Improving regression models

How do we improve regression model model?

## *Preprocessing*

For example, we may preprocess spectral data. In our example, we may use 1st spectral derivative and retrain the model. Updated model shows better fit:




perClass Mir provides R^2 and Q^2 statistics quantifying model fit in the regression plot legend. The R^2 refers to training objects and Q^2 to test objects. Our goal is to get as good test set fit as possible, meaning the highest Q^2 statistic.

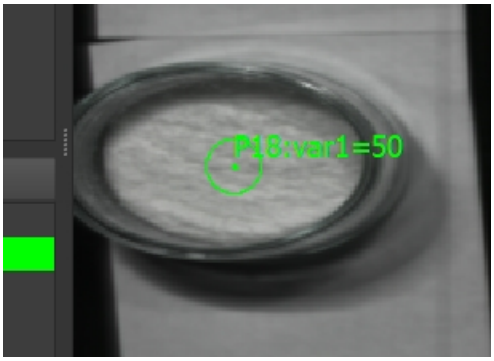
## *Feature subset*

In some problems, it may be beneficial to avoid certain parts of spectrum in regression modeling. Typically, start and end of the spectral range exhibit higher noise and may be better avoided. We may simply select desired set of bands in the spectral pannel.

perClass Mira allows to use different feature subset for the pixel classifier and different for the regressor. Both models adopt the selected bands when trained.

## *Limiting spatial neighborhood*

In non-homogeneous objects, it may be useful to limit the object area used for building regression model. We may do that by defining "point radius". Use the *Set point radius* command from *Regression* menu. By default, the radius is 0 which means that all spectral of each object are used to build regression model. By limiting the radius to, for example 12 pixels, only the spectra inside the displayed circle will be utilized.



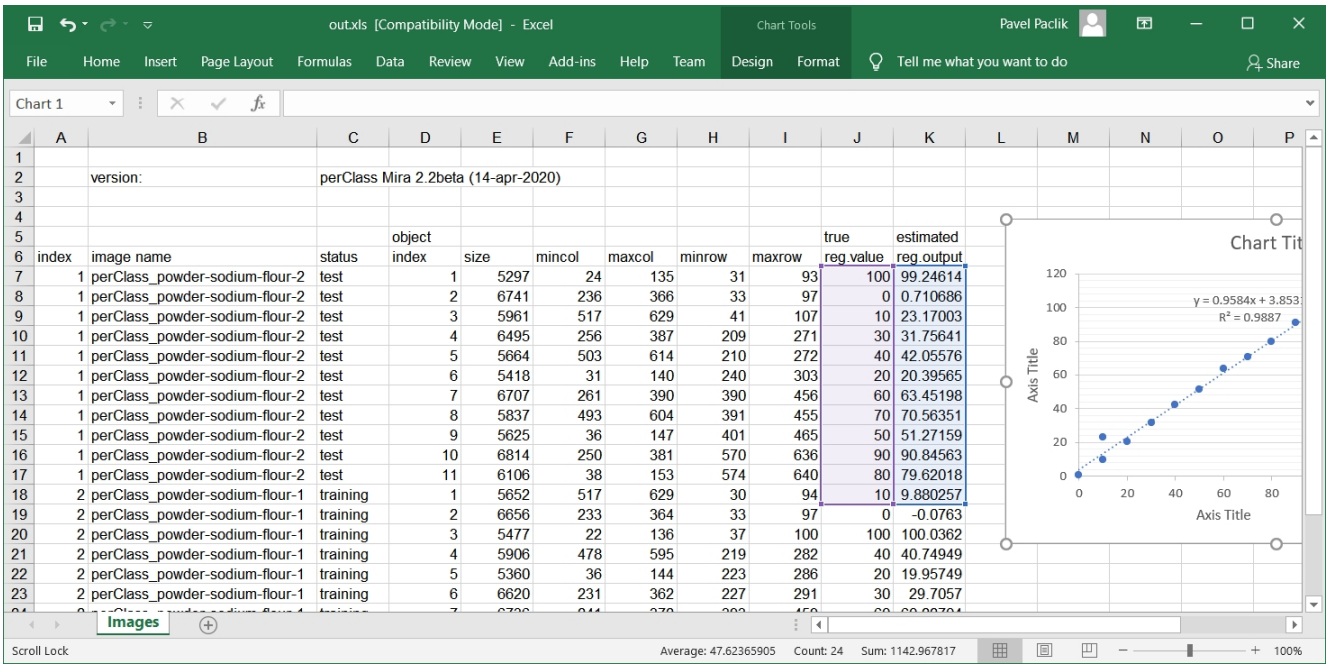

When point radius is adjusted, regression data set needs to be re-created with *Create data set* button.

Note, that the point radius is applied only in building the training and test sets. When applying the model to a new image using *Apply to new image* entire object is used.

## Exporting regression results to Excel

For selected images, regression results may be exported to Excel. Select *File* menu, *Export - Export regression results* command.

For each selected image, all detected objects are reported with their indices, sizes, bounding box and true/estimated regression values.



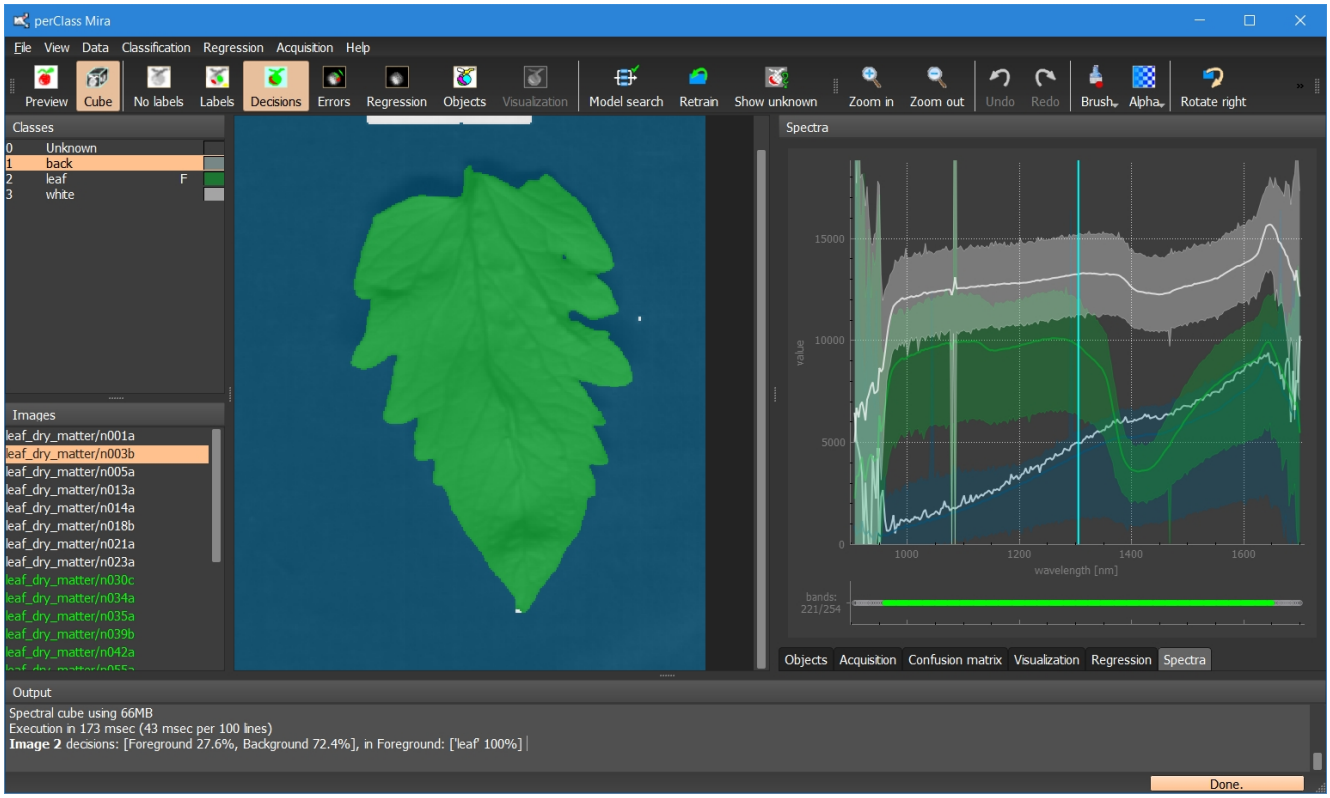

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | |
| 2 | | version: | perClass Mira 2.2beta (14-apr-2020) | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | |
| 5 | | | | object | | | | | | true | estimated | | | | | |
| 6 | index | image name | status | index | size | mincol | maxcol | minrow | maxrow | reg.value | reg.output | | | | | |
| 7 | 1 | perClass_powder-sodium-flour-2 | test | 1 | 5297 | 24 | 135 | 31 | 93 | 100 | 99.24614 | | | | | |
| 8 | 1 | perClass_powder-sodium-flour-2 | test | 2 | 6741 | 236 | 366 | 33 | 97 | 0 | 0.710686 | | | | | |
| 9 | 1 | perClass_powder-sodium-flour-2 | test | 3 | 5961 | 517 | 629 | 41 | 107 | 10 | 23.17003 | | | | | |
| 10 | 1 | perClass_powder-sodium-flour-2 | test | 4 | 6495 | 256 | 387 | 209 | 271 | 30 | 31.75641 | | | | | |
| 11 | 1 | perClass_powder-sodium-flour-2 | test | 5 | 5664 | 503 | 614 | 210 | 272 | 40 | 42.05576 | | | | | |
| 12 | 1 | perClass_powder-sodium-flour-2 | test | 6 | 5418 | 31 | 140 | 240 | 303 | 20 | 20.39565 | | | | | |
| 13 | 1 | perClass_powder-sodium-flour-2 | test | 7 | 6707 | 261 | 390 | 390 | 456 | 60 | 63.45198 | | | | | |
| 14 | 1 | perClass_powder-sodium-flour-2 | test | 8 | 5837 | 493 | 604 | 391 | 455 | 70 | 70.56351 | | | | | |
| 15 | 1 | perClass_powder-sodium-flour-2 | test | 9 | 5625 | 36 | 147 | 401 | 465 | 50 | 51.27159 | | | | | |
| 16 | 1 | perClass_powder-sodium-flour-2 | test | 10 | 6814 | 250 | 381 | 570 | 636 | 90 | 90.84563 | | | | | |
| 17 | 1 | perClass_powder-sodium-flour-2 | test | 11 | 6106 | 38 | 153 | 574 | 640 | 80 | 79.62018 | | | | | |
| 18 | 2 | perClass_powder-sodium-flour-1 | training | 1 | 5652 | 517 | 629 | 30 | 94 | 10 | 9.880257 | | | | | |
| 19 | 2 | perClass_powder-sodium-flour-1 | training | 2 | 6656 | 233 | 364 | 33 | 97 | 0 | -0.0763 | | | | | |
| 20 | 2 | perClass_powder-sodium-flour-1 | training | 3 | 5477 | 22 | 136 | 37 | 100 | 100 | 100.0362 | | | | | |
| 21 | 2 | perClass_powder-sodium-flour-1 | training | 4 | 5906 | 478 | 595 | 219 | 282 | 40 | 40.74949 | | | | | |
| 22 | 2 | perClass_powder-sodium-flour-1 | training | 5 | 5360 | 36 | 144 | 223 | 286 | 20 | 19.95749 | | | | | |
| 23 | 2 | perClass_powder-sodium-flour-1 | training | 6 | 6620 | 231 | 362 | 227 | 291 | 30 | 29.7057 | | | | | |

## Importing annotations from Excel

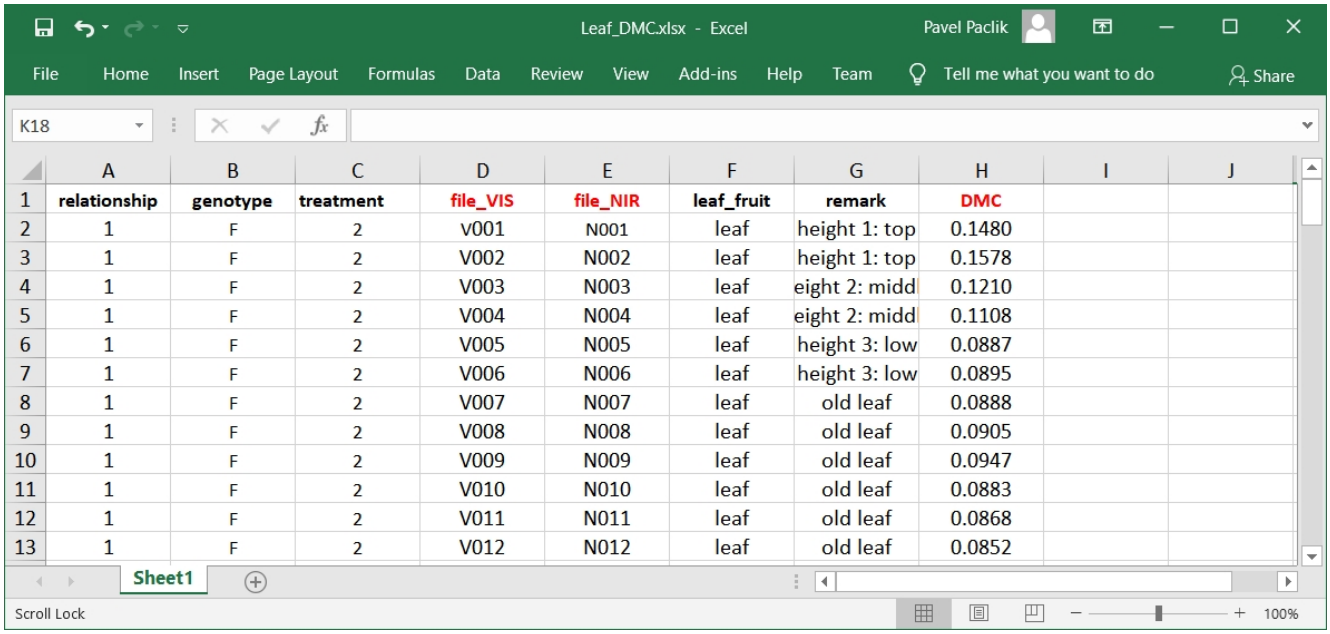
In many regression problems, large number of annotated objects is needed to build good models. perClass Mira provides import of point annotations from Excel.

To demonstrate, we will use a different data set with leaves. The goal is to estimate dry-matter-content (DMC) per leaf.

We have added several scans to perClass Mira project and build a pixel classifier separating leaf from background. The "leaf" class is flagged as foreground.



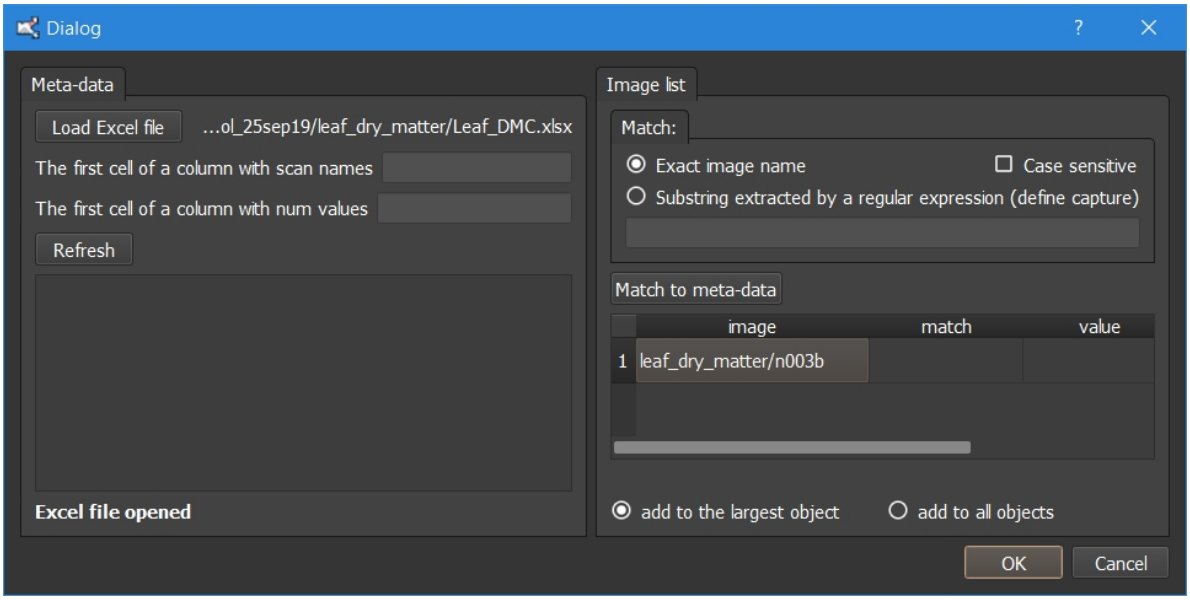

The ground-truth annotation is available in a separate Excel file:




| | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | relationship | genotype | treatment | file_VIS | file_NIR | leaf_fruit | remark | DMC | | |
| 2 | 1 | F | 2 | V001 | N001 | leaf | height 1: top | 0.1480 | | |
| 3 | 1 | F | 2 | V002 | N002 | leaf | height 1: top | 0.1578 | | |
| 4 | 1 | F | 2 | V003 | N003 | leaf | eight 2: midd | 0.1210 | | |
| 5 | 1 | F | 2 | V004 | N004 | leaf | eight 2: midd | 0.1108 | | |
| 6 | 1 | F | 2 | V005 | N005 | leaf | height 3: low | 0.0887 | | |
| 7 | 1 | F | 2 | V006 | N006 | leaf | height 3: low | 0.0895 | | |
| 8 | 1 | F | 2 | V007 | N007 | leaf | old leaf | 0.0888 | | |
| 9 | 1 | F | 2 | V008 | N008 | leaf | old leaf | 0.0905 | | |
| 10 | 1 | F | 2 | V009 | N009 | leaf | old leaf | 0.0947 | | |
| 11 | 1 | F | 2 | V010 | N010 | leaf | old leaf | 0.0883 | | |
| 12 | 1 | F | 2 | V011 | N011 | leaf | old leaf | 0.0868 | | |
| 13 | 1 | F | 2 | V012 | N012 | leaf | old leaf | 0.0852 | | |

To import object annotation from this Excel file, we need to match scan name to dry-matter-content (DMC) value.

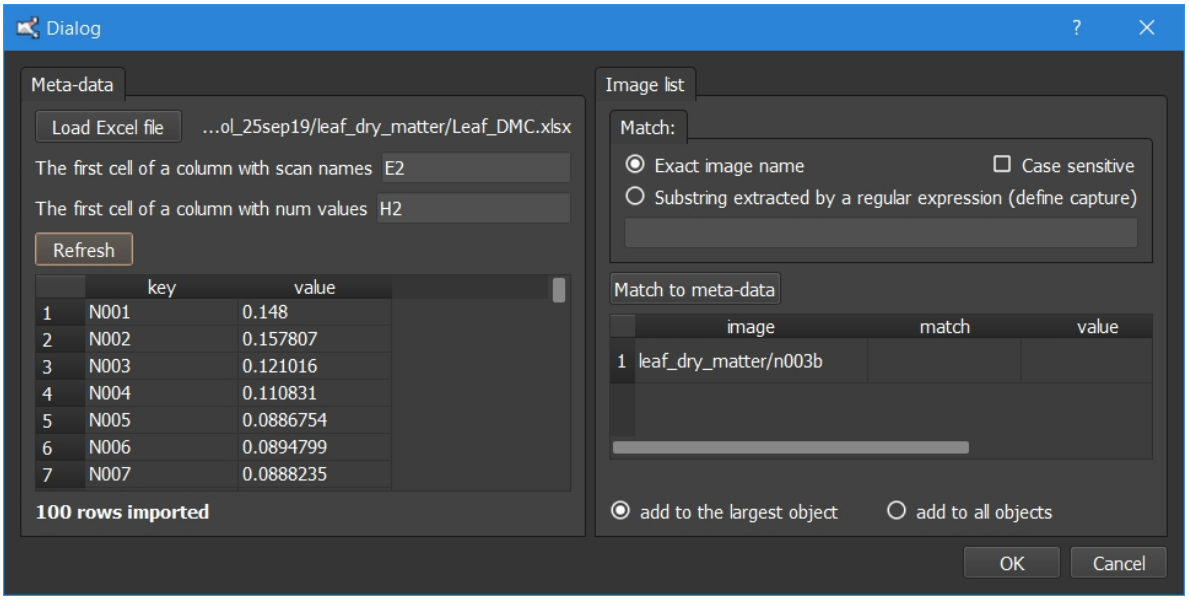
We will select *Import point meta-data* from *Regression* menu. A dialog will appear:




We have pressed *Load Excel file* button and selected the file containing meta-data.

Now we need to specify the first cell of a column containing scan names and numerical values.

In our example, it will be E2 for scan names and H2 for numerical values, respectively. We can then click on *Refresh* button. scan-value pairs will load in the meta-data pannel on the left.




Now we need to match scan names of selected images (single **leaf_dry_matter/n003b** image in our example) to the meta-data values.

**In a simple situation**, where the file name exactly matches the field in the Excel file, we can keep the default *Exact image name* option and press *Match to meta-data* button.

Often, the scan names contain additional characters: For example, we have the enclosing directory name ('leaf_dry_matter/') before the scan name and also extra letter after.

In perClass Mira, we can use regular expression to extract the scan name only. Regular expression is a text pattern decribing how to match or extract substring from a string.

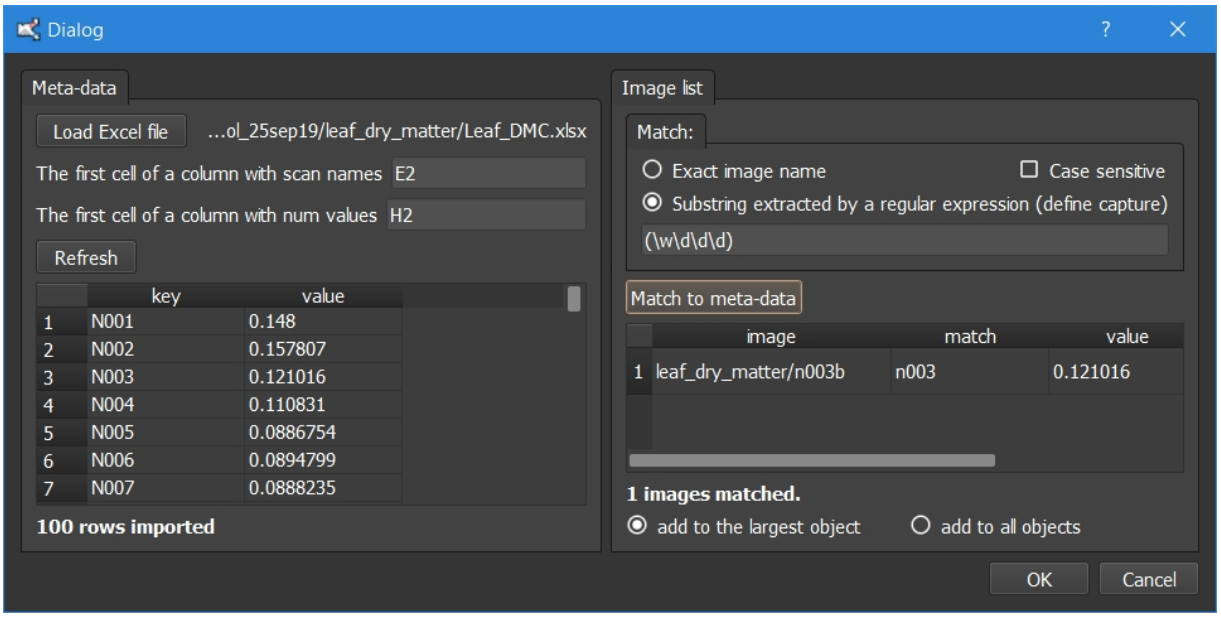
If you are not familiar with regular expressions, simply update your Excel file to list exact scan names. **TIP:** If you set the top-level data directory exactly above the scans, you will not see the enclosing directory as a part of the scan name ("leaf_dry_matter" in our example). This will simplify the task.

In our situation, we use a regular expression: **(\w\d\d\d)**

This means: There is a letter (\w) followed by three digits (\d). The parentheses are defining a "capture" i.e. part of the string returned. We need the parentheses to capture the scan name without the trailing letter.

To make sure this pattern does not match anywhere earlier, we could also use: **leaf_dry_matter/(\w\d\d\d)**

We click on *Match to meta-data* button and see that our selected image is matched to 0.121016:




Now we can press OK. By default, a point annotation will be created inside the largest object in the scan. We can also annotate all objects (larger than minimum object size).

Note, that the existing point annotations are not removed automatically. If needed, you can remove point annotations from the images prior to import, as described here.

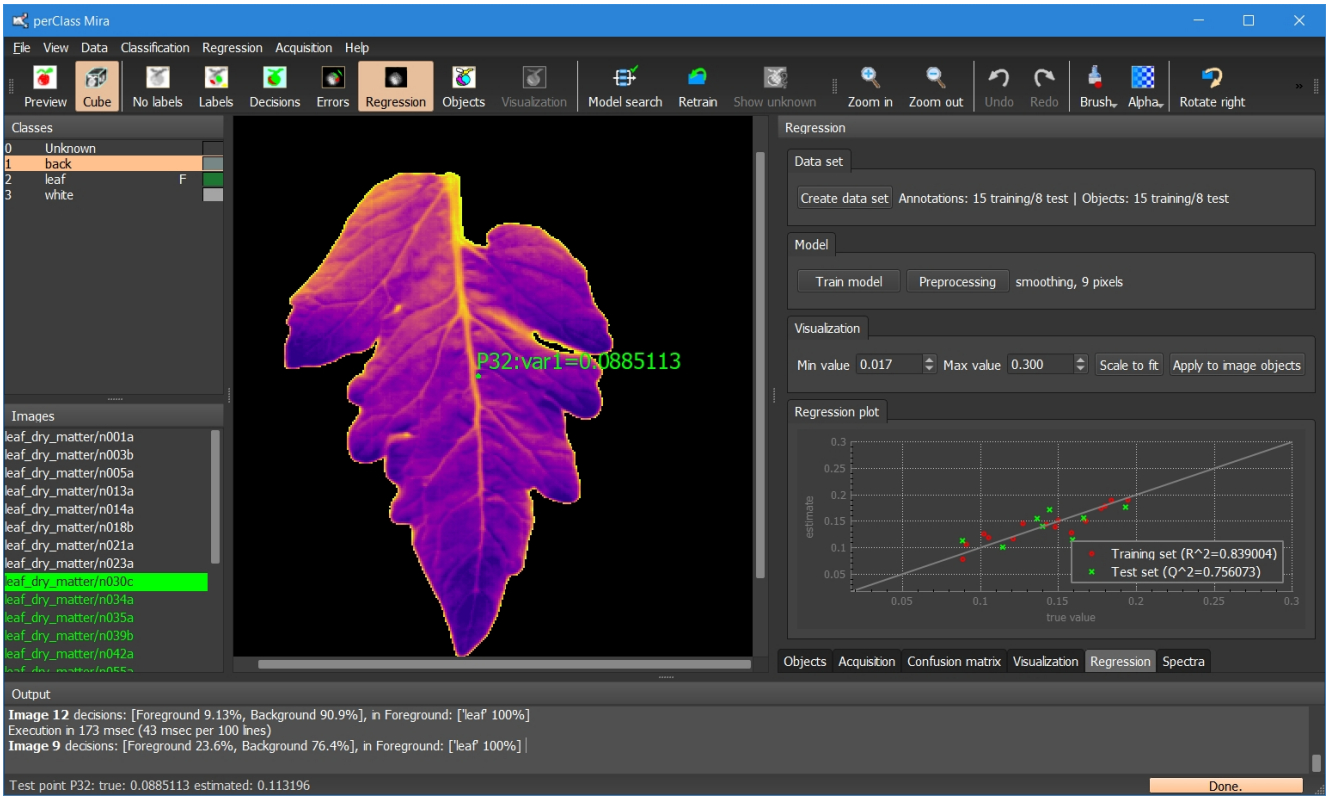
Naturally, the import dialog can process multiple scans at once. To do that, just select desired scans in the image list.

The import dialog remembers the settings in one perClass Mira session. So you may just return to it later and annotate several more images from the same Excel file with one click.

## Per-pixel regression output

Apart of per-object regression, perClass Mira also provides per-pixel regression output.

When a regression model is trained, press the *Regression* button on the toolbar.



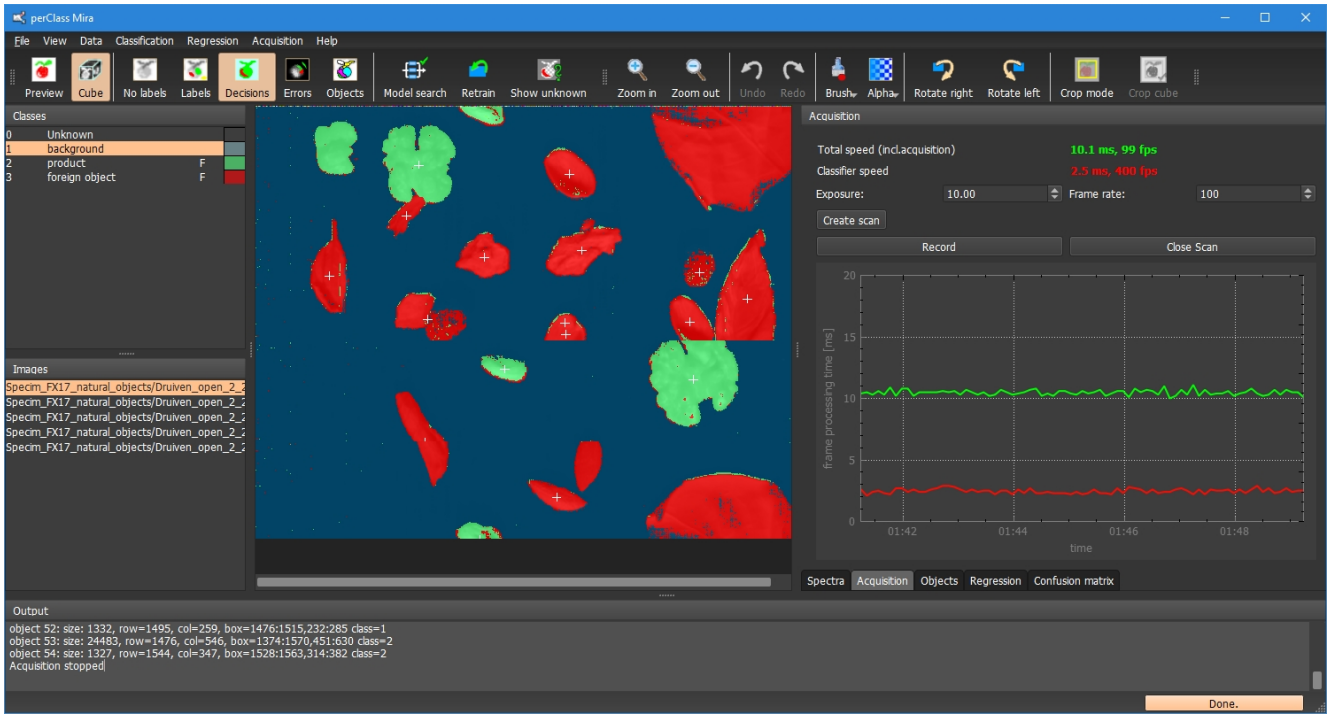

The image shows a false-color representation in the minimum and maximum value range defined by the values in the *Regression* pannel.

**TIP:** Inspect predicted value per pixel by hovering the mouse over the image.

As with other visualizations, regression rendering can be exported for selected images using *Export visualization* command in image-list right-click context menu.

## Live data acquisition

Live acquisition functionality allows users with Specim cameras and Specsensor SDK installed apply models directly on data stream from a camera or a file via filereader interface.



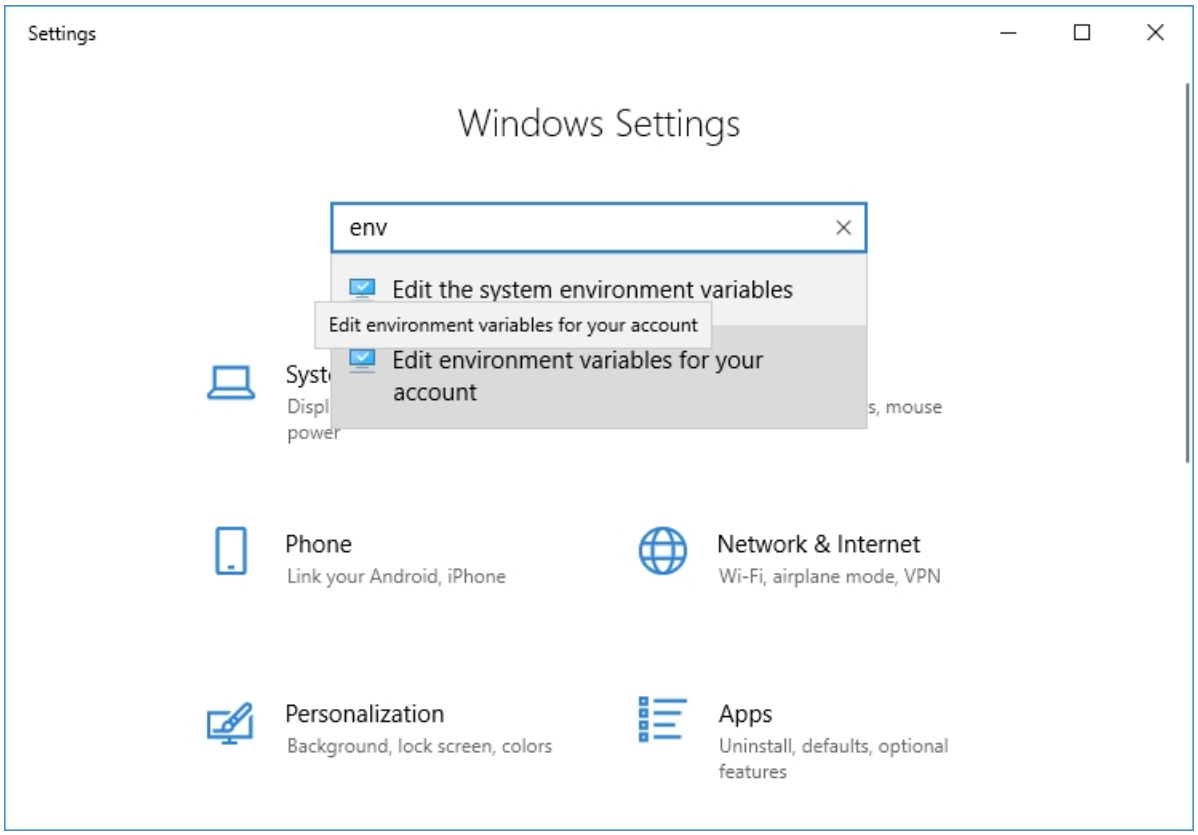

## Installation of Specsensor SDK

Specim Specsensor SDK needs to be installed on the system running perClass Mira.

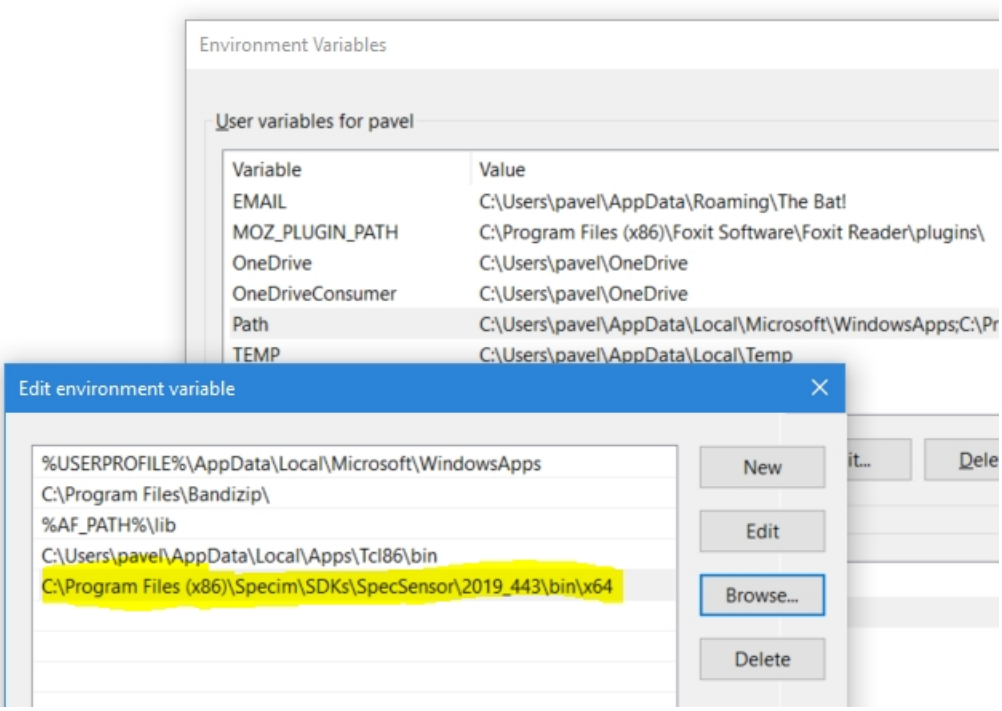
The Specsensor version needs to be at least 2018_415 (if you still use 2017 SDK release, please update). In general, it is adviceable to update to the latest Specsensor release.

After Specsensor installation, make sure that the system Path environment variable contains the path to Specsensor

1. Open System Settings dialog




2. Open *"Edit environmental variables for your account"* dialog

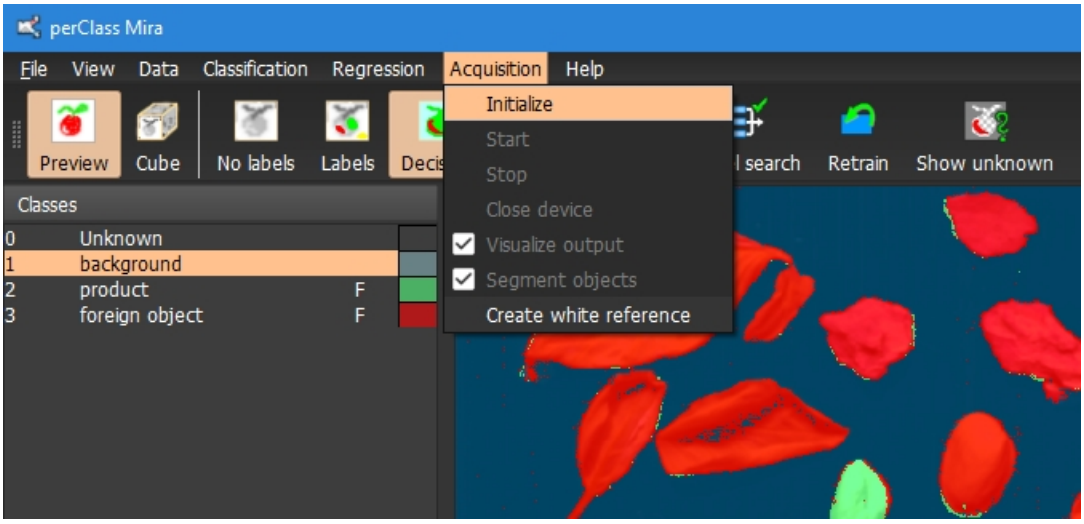



3. Make sure the path to points to the bin\x64 sub directory of the SDK

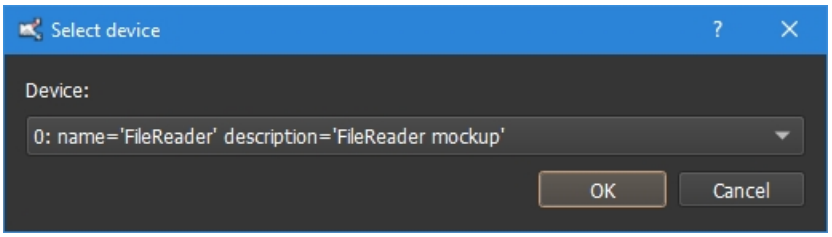
Restart of the machine is not needed, only restart of perClass Mira application.

## Initializing acquisition

1. Create or open a Specim FX project
2. Train a classifier (a model must exist in order to process live data)
3. In the *Acquisition* menu, select *Initialize*

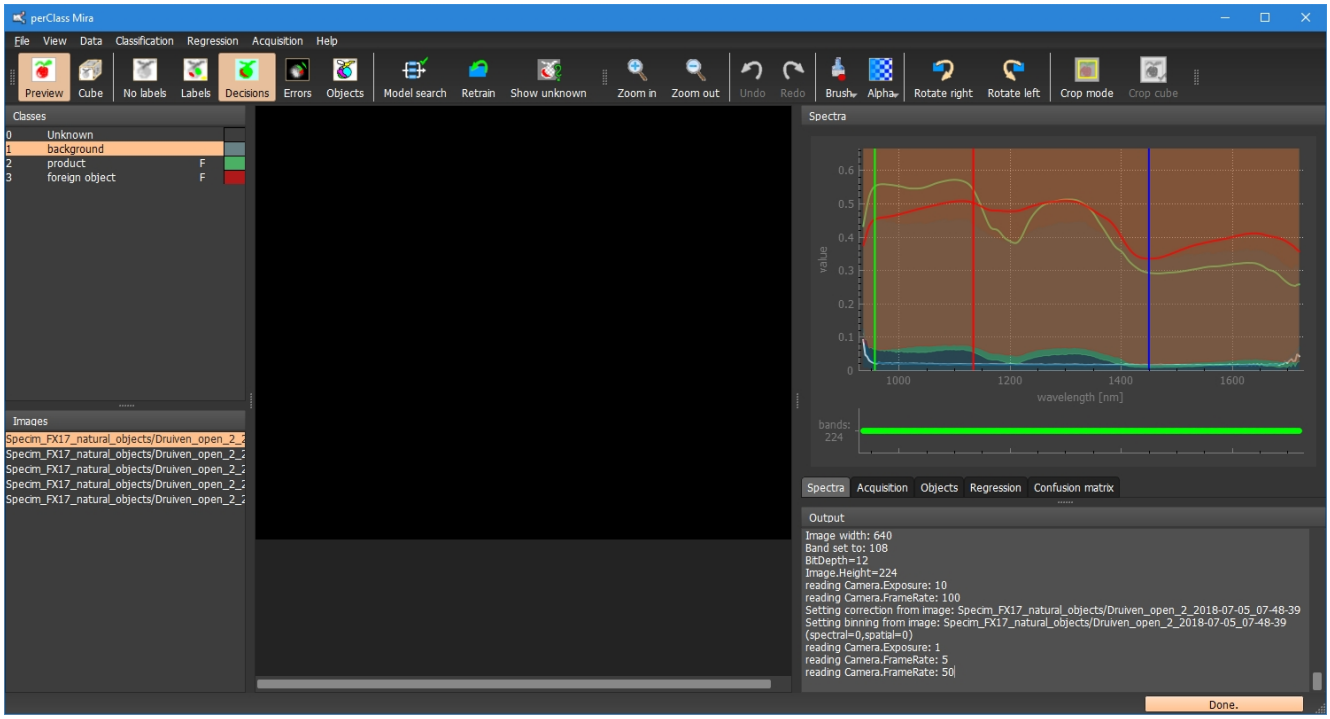



4. A dialog will appear listing all available devices accessible to Specsensor SDK



5. Select the camera or the FileReader interface and click OK
6. If using FileReader an Open File dialog will appear where you can point to the **raw spectral cube** simmulating sensor acquisition stream. Select an existing Specim FX scan directory and the raw cube header file under the capture sub-directory

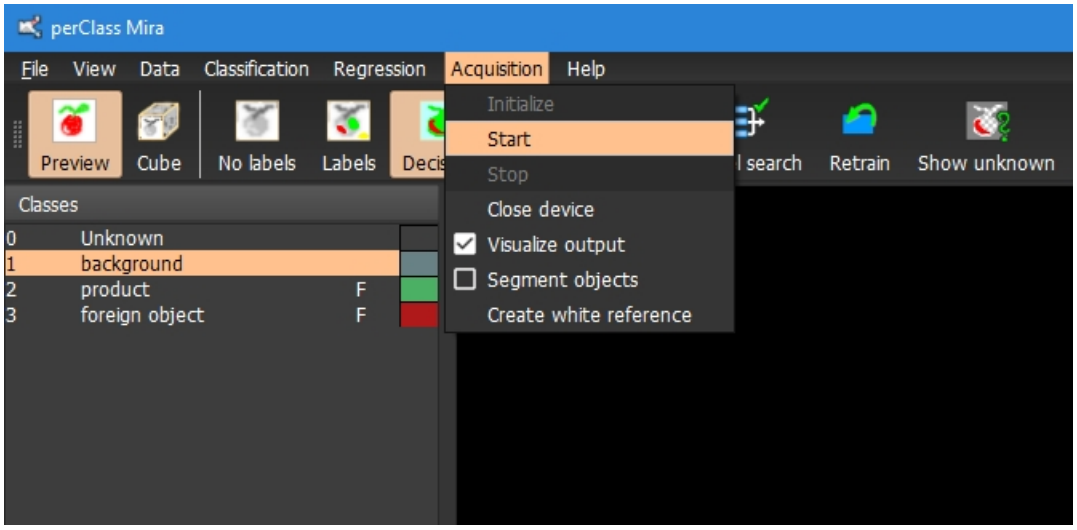
7. The window should show an empty buffer



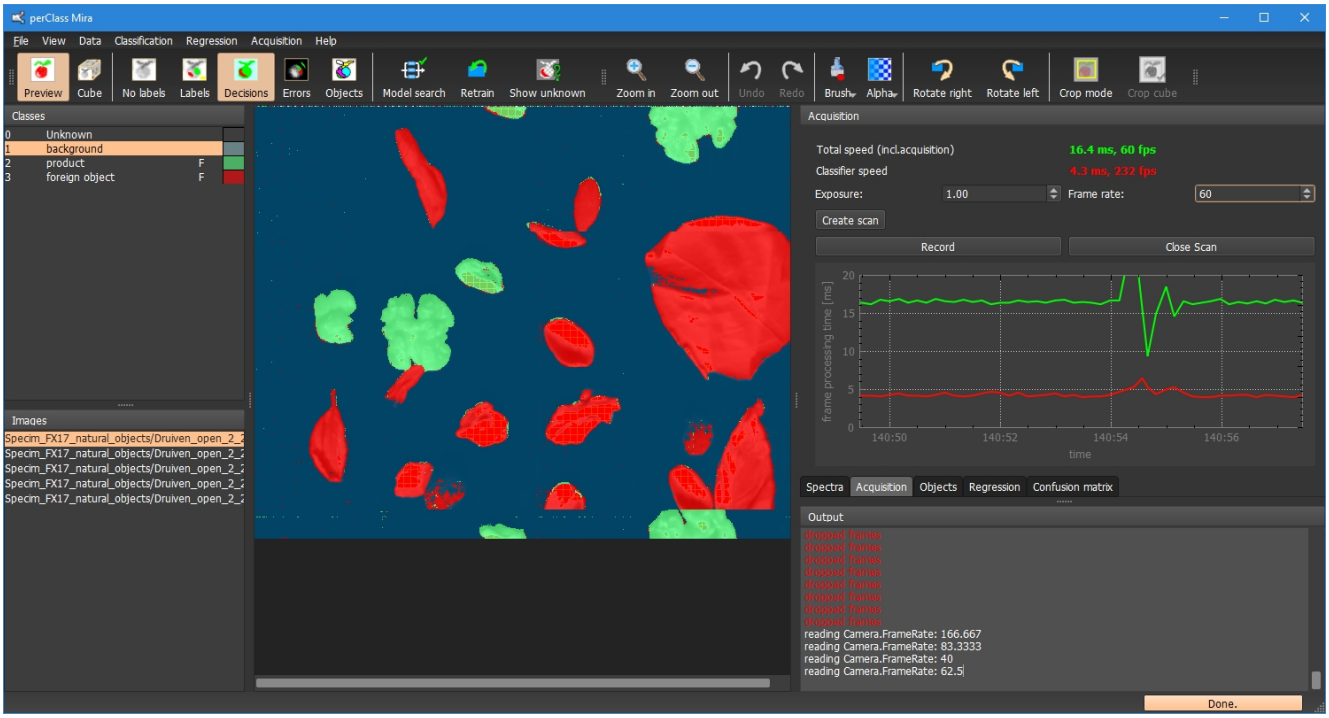

8. Process the data stream can now be started

## Live data processing

Select *Start* in *Acquisition* menu.




You should see new acquisition arriving in the window




On the right side of the screenshot you can see opened acquisition pannel. It shows the speed of the classifier in red and the total speed of the system in green.

You can change the exposure and frame rate of the sensor from the pannel. By increasing the frame rate, you can speed up acquisition. If the classifier cannot process data at a given speed, you will see red message in the output window pointing out that frames are dropping.

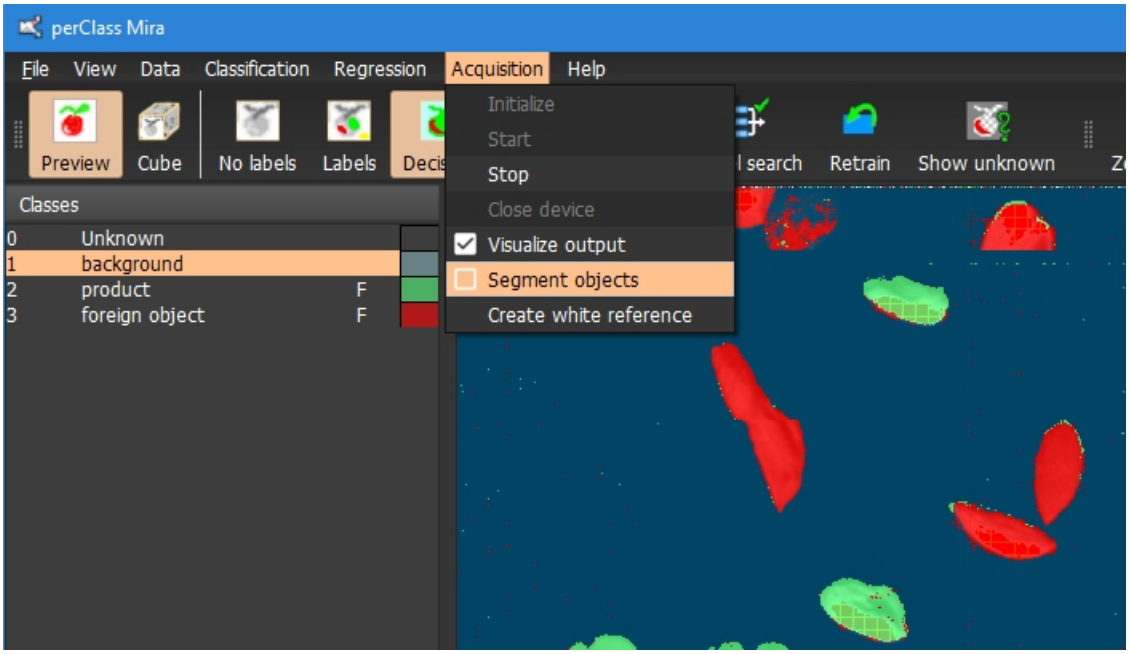
**Please note that some combinations of exposure and frame rate are invalid i.e. you cannot have high frame rate and high exposure at the same time.**

## Segmenting out objects

To segment objects on the live data stream:

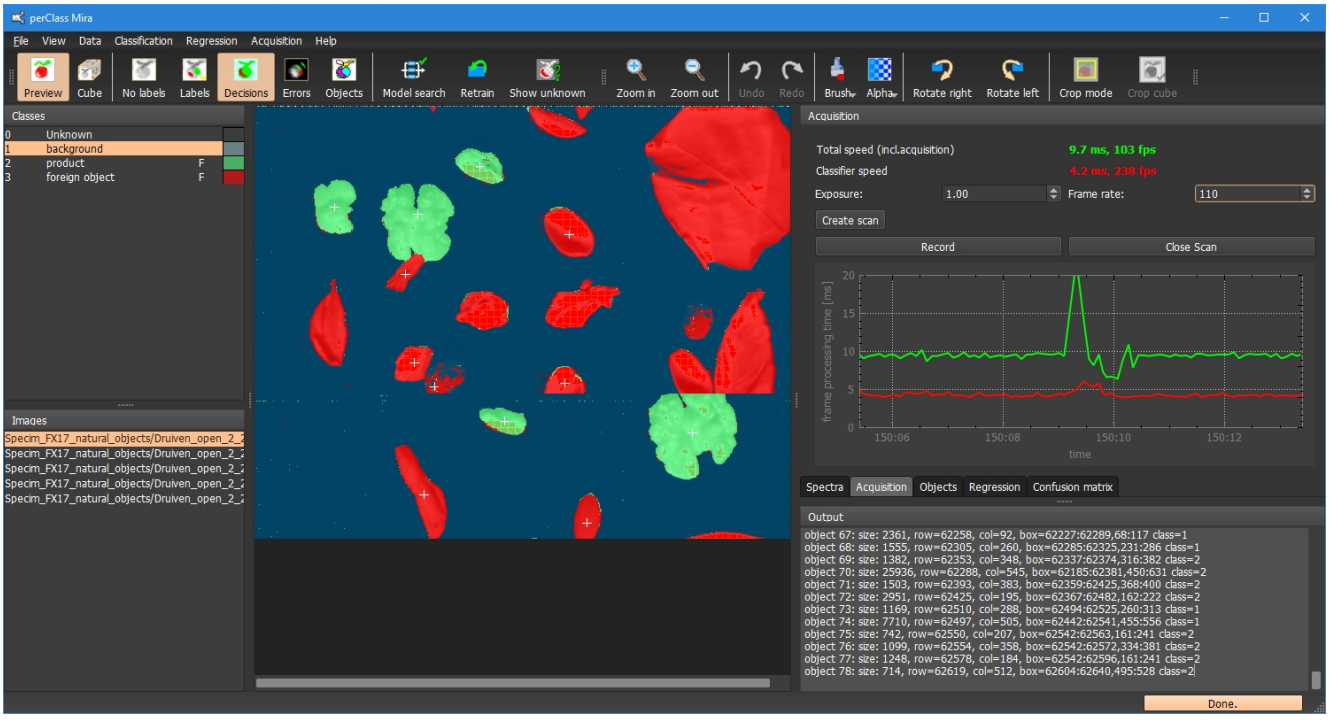
1. Make sure that one or more classes are flagged as foreground in the class list

2. Switch on *Segment objects* in the *Acquisition* menu




Segmented objects will be marked with crosses at their center of gravity.

The output windows also shows object sizes, bounding boxes and classes (if multiple classes are used fot segmentation)




The same per-object information is accessible from perClass Mira Runtime API from custom applications.

## Closing live acquisition mode

Use *Stop* and *Close device* in the *Acquisition* menu to disable acquisition mode.

# Reference information

## Project types

perClass Mira offers several project types:

### *1. Cubert UH185*

- Images are represented by multi-layer tiff files
- User needs to point to .cu3 file (50x50 spatial pixels)
- High-resolution panchromatic image is used for preview
- Multiple files can be loaded at once

### *2. Cubert ENVI*

- Images are ENVI cubes saved from Cubert Utils
- This project type can be used for upsampled cubes from UH185 or Ultris

### *3. Cubert Tiff*

- Images are native multi-layer tiff files from Cubert Ultris or UH185
- Preview is generated from the spectral cube

### *4. IMEC*

- Images are ENVI cubes
- User needs to point to .hdr files
- It is assumed, that the data cube is stored in a file with the same name as .hdr file and with .raw extension
- There is no preview image expected

### *5. Headwall*

- Images are ENVI cubes
- User needs to point to .hdr files
- It is assumed, that the data cube is stored in a file with the same name as .hdr file and without any extension
- No preview

### *6. Hyspex*

- Images are ENVI cubes
- User needs to point to .hdr files
- It is assumed, that the data cube is stored in a file with the same name as .hdr file and without any extension
- A preview in a jpeg file is assumed to be available

### *7. Matlab*

- Images are stored in .mat files
- Data cube is a 3D matrix in uint8, uint16, single or double precision
- User may select which variable to use upon load of the first image
- Optionally, a wavelength vector in single or double precision may be provided

### *8. SpecIm FX (LUMO scanner)*

- Images are ENVI files
- User needs to point to the entire directory saved from LUMO scanner
- Preview image is assumed to be present
- Raw image cube is loaded and corrected by included white and dark standard images

### *9. SpecIm iQ (iQ Studio)*

- Images are ENVI files

- User needs to point to the specific .hdr file representing already corrected cube (such as the reflectance cube in results directory)
- No preview is assumed
- Spectral cube is assumed to have .raw extension

### *10. Tiff stack*

- A scan is a directory with individual band images in .tiff format
- Specific band image naming is expected (example: 231001_1_ch_0007_w_0419.tif - the scan name 231001_1, the 1-based channel index 7 and the wavelength in nm is 419)

### *11. Senop*

- ENVI images with .dat extension for the spectral cube
- No reflectance correction is applied

### *12. Silios*

- Native TIF files saved by Silios acquisition software are suported
- Scans are loaded as is, no correction is applied
- The text file, stored from Silios acquisition in the same directory as scans, is used to read wavelength information
- only multispectral bands are loaded, not the panchromatic band

## Supported image formats

Supported image formats in perClass Mira are:

### *ENVI Files*

- BIL, BIP or BSQ layout
- uint8, int16, uint16, single or double precision float
- Support for header offset
- Wavelengths are loaded from the wavelength field

### *Matlab*

- 3D cubes as uint8, uint16, float/single and double precision
- BSQ layout is assumed with two spatial dimensions followed by the spectral dimension
- Separate vector of wavelengths in single or double precision can be provided when loading the first image to use proper wavelength range in nanometers.

### *TiffStack*

- Image is a directory with a stack of tiff images, each representing one band.
- Channel index and wavelength is stored in a file-name
- Example: Band image for 7th channel (1-based indexing) representing wavelength 419nm. The first part of the filename is the image name (also the name of the directory)
    - `231001_1_ch_0007_w_0419.tif`

## Image zoom

- To zoom, use + and - toolbar buttons
- Alternative is to hold *Ctrl* key and use the mouse scroll-wheel

## Keyboard shortcuts

### *In image view:*

| | |
|---|---|
| Ctrl+n | new class, ask name |
| n | new class, fill automatic name |
| 0 (zero) | set "Unknown" class as current (removing labels) |
| 1..9 | set specific class as current |
| +/- | zoom increase/decrease |
| Ctrl+1 | zoom 100% |
| PgUp/PgDown | select next/previous spectral band |
| Ctrl+s | save project |
| Space | switch to the last label layer |
| Ctrl+Space | switch between preview and spectral cube |
| . (dot) | randomly change color of class under cursor |
| t | set class under cursor as current |
| m | run model search |
| r | retrain algorithm found in the last model search |
| shift-r | re-run the existing classifier on the image (to measure execution speed) |
| u | show data unseen in training (active learning) |
| shift+l | switch to no labels mode |
| l | switch to label mode |
| d | switch to decisions mode |
| e | switch to errors mode |
| o | find connected components (objects) |
| F1 | open help |
| F11 | toggle full screen mode |
| hold mouse & move | paint using current class |
| Shift+hold mouse | paint removing labels under cursor |
| Ctrl+mouse wheel | zoom image |
| c | switch to confusion matrix |
| s | switch to spectral plot |
| x | mark class as excluded from training |
| b | mark class as background (for object definition) |

### *In spectral plot (after clicking on spectral plot)*

| | |
|---|---|
| up/down | increase/decrease max display value |
| right/left | select next/previous spectral band |
| Shift+mouse wheel | select next/previous spectral band |

### *In confusion matrix*

| | |
|---|---|
| Double click | add or remove constrain |
| Ctrl+mouse wheel | adjust constrain value live |
| Shift+N | toggle between normalized confusion matrix and absolute values (sample counts) |
| ] (square bracket) | next valid solution |
| [ | previous valid solution |

# perClass Mira Runtime API

### *Initialization and cleanup*

- `mira_Init`
- `mira_Release`

### *Error handling*

- `mira_GetErrorCode`
- `mira_GetErrorMsg`

### *Computational device selection*

- `mira_RefreshDeviceList`
- `mira_GetDeviceCount`
- `mira_GetDeviceName`
- `mira_SetDevice`

### *Loading model*

- `mira_LoadModel`
- `mira_LoadCorrection`

### *Data processing - querrying input data parameters*

- `mira_GetInputWidth`
- `mira_SetInputWidth`
- `mira_GetInputHeight`
- `mira_GetInputBands`
- `mira_GetInputDataType`
- `mira_GetInputDataLayout`

### *Data processing*

- `mira_SetSegmentation`
- `mira_StartAcquisition`
- `mira_ProcessFrame`
- `mira_ProcessCube`
- `mira_StopAcquisition`
- `mira_SaveImage`

### *Processing results*

#### *Pixel classification*

- `mira_GetFrameDecisions`
- `mira_GetDecCount`
- `mira_GetDecName`
- `mira_GetDecColor`

#### *Object segmentation*

- `mira_GetMaskType`
- `mira_GetObjCount`
- `mira_GetObjDataInt`

- **mira_GetObjDataClassSize**
- **mira_GetObjDataClassFrac**
- **mira_SetMinObjSize**

***Regression***

- **mira_GetRegVarCount**
- **mira_GetRegVarName**
- **mira_GetObjDataRegOutput**
- **mira_GetFrameRegOutputVar**

## mira_Init

Initialize runtime environment.

```
mrkernel* mira_Init(const char* path)
```

*Input:* Path to a directory with a license file
*Output:* Runtime environment pointer

*Description:*

The mira_Init function initializes runtime environment. It returns a pointer used for any other API function that interacts with the runtime.
The input is a path to a directory where a license file with .lic extension can be found. Pass "." for the current directory.

After initialization, `mira_GetErrorMsg` provides welcome string listing software version or error message.

*Example:*

```
mrkernel* pmr=mira_Init(".");
printf("Init: %s", mira_GetErrorMsg(pmr));
if( pmr==NULL ) return;
```

## Error codes

-101 Passing NULL pointer
-102 mira_GetDeviceName: Device index out of bounds
-103 mira_StartAcquisition: Project not loaded
-104 mira_StartAcquisition: Classifier model not loaded

-110 mira_LoadModel: Error loading model from file
-111 mira_LoadModel: Wrong file format
-112 mira_LoadModel: Internal error when loading
-113 mira_LoadModel: File cannot be opened

-120 mira_saveImage: Label image does not exist

-130 mira_LoadCorrection: Loading meta-data from the correction scan failed.
-131 mira_LoadCorrection: Error loading dark reference data
-132 mira_LoadCorrection: Dark and White reference images have different width or band count.
-134 mira_LoadCorrection: Both dark and white reference scans need to be loaded.
-135 mira_LoadCorrection: Reference file not present
-136 mira_LoadCorrection: Unsupported data layout or data type

-140 Error switching to the computation device
-141 mira_RefreshDeviceList: Error setting CUDA backend
-142 mira_RefreshDeviceList: Error setting OpenCL backend
-143 mira_RefreshDeviceList: listNVIDIA and listOpenCL must be specified as 0 or 1 values

-150 Feature does not exist
-151 Wrong feature type requested

-160 Max number of objects per frame reached
-161 mira_GetObjData*: Object index out of bounds
-162 mira_GetObjData*: Class index out of bounds (0..9)
-163 mira_GetObjDataClassSize: Segmentation not set to required 'All foreground' mode.
-164 mira_GetMaskType: Object segmetation not defined

-170 mira_StartAcquisition: Acquisition already running
-171 mira_StopAcquisition: Acquisition not running
-172 mira_StartAcquisition: Object segmentation cannot proceed

-180 mira_GetDecName: Decision index out of bounds

-190 mira_SetForegroundClass: Foreground class index out of bounds

-201 mira_ProcessCube: Line-scan project type cannot process cubes
-202 mira_StartAcquisition: Label image dimension mismatch

-203 mira_ProcessCube: Missing image geometry description

-204 mira_ProcessFrame: Line-scan processing requires BIL layout

-205 mira_GetInputDataLayout: Undefined data layout
-206 mira_GetInputDataType: Undefined data type

-207 mira_ProcessCube: Unsupported project type

-208 mira_ProcessFrame: Unsupported data type
-208 mira_ProcessCube: Unsupported data type or data layout

## mira_GetVersion

Return runtime version

```
const char* mira_GetVersion()
```

*Input:* None

*Output:* Version string

*Description:*
`mira_GetVersion` returns version string together with the release date. For example "2.1 26-mar-2020".

## mira_GetErrorCode

Return error code

```
int mira_GetErrorMsg(mrkernel* pmr)
```

*Input:* Runtime environment pointer

*Output:* Error code

*Description:*
`mira_GetErrorCode` returns error code. For a specific string description, `mira_GetErrorMsg`

## mira_GetErrorMsg

Returns error message.

```
const char* mira_GetErrorMsg(mrkernel* pmr)
```

*Input:* Runtime environment pointer

*Output:* Error message string

*Description:*
`mira_GetErrorMsg` returns error message as string. For a specific error code, use `mira_GetErrorCode`

## mira_RefreshDeviceList

Returns error message.

```
int mira_RefreshDeviceList(mrkernel *pmr,int listNVIDIA,int listOpenCL)
```

*Input:*

- Runtime environment pointer pmr
- Flag whether to search for and list NVIDIA devices (0: no, 1: yes)
- Flag whether to search for and list OpenCL devices (0: no, 1: yes)

*Output:* Result: MIRA_OK or error code

*Description:*
`mira_RefreshDeviceList` searches for computational devices (NVIDIA or OpenCL). After calling `mira_RefreshDeviceList`, one can get device count using `mira_GetDeviceCount` and names with `mira_GetDeviceName`.

*Example:*

```
    MIRA_CHECK( mira_RefreshDeviceList(pmr,1,0) );
    const int devCount=mira_GetDeviceCount(pmr);
    printf("\n%d devices:\n",devCount);
    for(int i=0;i<devCount;i++) {
        printf("%d : %s\n",i, mira_GetDeviceName(pmr,i));
    }
    int deviceInd=atoi(argv[1]);
    MIRA_CHECK( mira_SetDevice(pmr,deviceInd) );
    printf("Device selected: %d '%
s'\n",deviceInd,mira_GetDeviceName(pmr,deviceInd));
```

The `MIRA_CHECK` macro checks the output result. If error occurs, the program flow is terminated. See perclass_mira.h definition.

## mira_GetDeviceCount

Returns the number of GPU devices found

```
int mira_GetDeviceCount(mrkernel* pmr)
```

*Input:* Runtime environment pointer

*Output:* Number of devices found

*Description:*
`mira_GetDeviceCount` returns the number of devices found by `mira_RefreshDeviceList`.

## mira_GetDeviceName

Returns the name of a specific computational device

```
const char* mira_GetDeviceName(mrkernel* pmr,int deviceInd)
```

*Input:*

- Runtime environment pointer
- Device index

*Output:* String name of a device

*Description:*
`mira_GetDeviceName` returns the name for a specific device. Before using `mira_GetDeviceName` or `mira_GetDeviceCount`, the device list needs to be constructed by `mira_RefreshDeviceList`.

## mira_SetDevice

Sets specific computational device

```
int mira_SetDevice(mrkernel* pmr,int deviceInd)
```

*Input:*

- Runtime environment pointer
- Device index

*Output:* Result code (MIRA_OK or error)

*Description:*
`mira_SetDevice` sets specific computational device. The device list needs to be constructed by `mira_RefreshDeviceList`.

*Example:*

```
    MIRA_CHECK( mira_RefreshDeviceList(pmr,1,0) );
    const int devCount=mira_GetDeviceCount(pmr);
    printf("\n%d devices:\n",devCount);
    for(int i=0;i<devCount;i++) {
        printf("%d : %s\n",i, mira_GetDeviceName(pmr,i));
    }
    int deviceInd=atoi(argv[1]);
    MIRA_CHECK( mira_SetDevice(pmr,deviceInd) );
    printf("Device selected: %d '%
s'\n",deviceInd,mira_GetDeviceName(pmr,deviceInd));
```

The `MIRA_CHECK` macro checks the output result. If error occurs, the program flow is terminated. See perclass_mira.h definition.

## mira_LoadModel

Loads classification model

```
int mira_LoadModel(mrkernel *pmr, const char* filename)
```

*Input:*

- Runtime environment pointer
- Filename (.mira project file)

*Output:* Result code (MIRA_OK or error)

*Description:*
`mira_LoadModel` loads a classification model from .mira project file.

## mira_LoadCorrection

Loads white and dark correction data from disk

```
int mira_LoadCorrection(mrkernel *pmr, const char* dirname, const char *scanname);
```

*Input:*

- Runtime environment pointer
- Dirname - a name of a directory containing a scan directory
- Scanname - a name of a scan directory

*Output:* Result code (MIRA_OK or error)

*Description:*

**For Headwall project type:**
Correction information is assumed to be in whiteReference and darkReference scans. To load references, pass the path to a directory containing the whiteReference and darkReference ENVI scans. The third argument is NULL.

Header files must have .hdr extensions. Both spectral cubes can have arbitrary extensions. Reference cubes must be in BIL data layout. Both uint16 and float data types are supported.

Example:
```
res = mira_LoadCorrection(pmr,"path_to_dir_with_references",NULL);
```

In this way, both reference files are loaded at the same time.

**For Specim project type:**
`mira_LoadCorrection` loads dark and white correction information from `dirname` directory. The assumption is the a scanname is a name of a directory inside the dirname directory and that it conforms Specim LUMO scanner directory structure. This means that inside scanname directory is a capture sub-directory. Inside the capture sub-dir, the following files are needed:

- WHITEREF_scanname.hdr
- WHITEREF_scanname.raw
- DARKREF_scanname.hdr
- DARKREF_scanname.raw
- scanname.hdr

The scanname.hdr defines wavelengths, band cound and pixel count of a scan. Note, that the scanname.raw is not needed when loading correction.

All ENVI cubes are supposed to be in BIL data layout and use uint16 data type.

If `mira_LoadCorrection` is not called, the assumption is that the input data stream is already reflectance corrected and in float data type. This can be checked using mira_GetInputDataType.

## mira_SetMinObjSize

Set the minimum object size for segmentation

```
int mira_SetMinObjSize(mrkernel *pmr,int minSize);
```

*Input:*

- Runtime environment pointer
- minSize - minimum object size in pixels

*Output:* Result code (MIRA_OK or error)

*Description:*
`mira_SetMinObjSize` sets the minimum object size in pixels. Objects with size larger or equal than minSize are reported.

## mira_SetSegmentation

Set the minimum object size for segmentation

```
int mira_SetSegmentation(mrkernel *pmr,int enable);
```

*Input:*

- Runtime environment pointer
- enable - flag is to enable (1) or disable (0) object segmenttion

*Output:* Result code (MIRA_OK or error)

*Description:*
`mira_SetSegmentation` enables or disables object segmentation. For all type of projects it is disabled by default (Note: before 2.3, it was enabled by default for line-scan projects).. Use before starting the acquisition. Note, that the model needs to have some class or classes flagged as foreground to perform segmentation.

## mira_GetInputWidth

Get the expected width of the input image stream

```
int mira_GetInputWidth(mrkernel* pmr);
```

*Input:*

- Runtime environment pointer

*Output:* Input image width if > 0 or an error code if < 0

The image width in the line scan use case is the number of pixels of one line i.e. the pixels across the belt.

## mira_SetInputWidth

Set the width of the input image stream

```
int mira_SetInputWidth(mrkernel* pmr, int width);
```

*Input:*

- Runtime environment pointer
- Input width of the data stream

*Output:* Result code (MIRA_OK or error)

Input width of the data stream may be set manually. The width overrules the setting in the loaded project.

## mira_GetInputHeight

Get the expected height of the input image stream

```
int mira_GetInputHeight(mrkernel* pmr);
```

*Input:*

- Runtime environment pointer

*Output:* Input image height if > 0 or an error code if < 0

This call is only meaningful in snapshot use-case where entire spectral cube is to be processed with mira_ProcessCube function.

## mira_GetInputBands

Get the expected number of spectral bands of the input image stream

```
int mira_GetInputBands(mrkernel* pmr);
```

*Input:*

- Runtime environment pointer

*Output:* Input band count if > 0 or an error code if < 0

This call returns the number of spectral bands expected in each pixel.

## mira_GetInputDataType

Get the expected data type in the input image stream

```
int mira_GetInputDataType(mrkernel* pmr);
```

*Input:*

- Runtime environment pointer

*Output:* Input data type if >= 0 or an error code if < 0

```
MIRA_DATATYPE_UNKNOWN  0
MIRA_DATATYPE_UINT16   1
MIRA_DATATYPE_FLOAT    2
MIRA_DATATYPE_UINT8    3
```

This call returns the data type expected in the input image stream based on the loaded model.

## mira_GetInputDataLayout

Get the expected data layout of the input image stream

```
int mira_GetInputDataLayout(mrkernel* pmr);
```

*Input:*

- Runtime environment pointer

*Output:* Input data layout if >= 0 or an error code if < 0

```
MIRA_DATALAYOUT_UNKNOWN  0
MIRA_DATALAYOUT_BIP      1      /* spectrum-by-spectrum (dimensions: bands-width-height) */
MIRA_DATALAYOUT_BIL      2      /* frame-by-frame (dimensions: width-bands-height) */
MIRA_DATALAYOUT_BSQ      3      /* spatial frame by frame (dimensions: width-height-bands) */
```

This call returns the data layout expected in the input image stream based on the loaded model.

## mira_GetMaskType

Get the mask type of the loaded object segmentation model

```
int mira_GetMaskType(mrkernel* pmr);
```

*Input:*

- Runtime environment pointer

*Output:* Input data layout if >= 0 or an error code if < 0

MIRA_MASK_EACH_FOREGROUND 1
MIRA_MASK_ALL_FOREGROUND 2

This call returns the mask type for the loaded model. The 'each-foreground' type is used for single material per object situations (object detection). The 'all-foreground' mask is used for complex objects composed of multiple materials where the union of classes defines object mask (object classification). An example: A potato can have healthy flesh or rotten defect - these are the trained classes. The segmentation mask is set of 'all-foreground' and, therefore, entire piece of potato is segmented out. For each object, perClass Mira Runtime provides pixel count for each foreground class. This allows object sorting based on composition.

## mira_StartAcquisition

Starts the acquisition

```
int mira_StartAcquisition(mrkernel* pmr)
```

*Input:*

- Runtime environment pointer

*Output:* Result code (MIRA_OK or error)

*Description:*
`mira_StartAcquisition` starts the acquisition process. Computational device must be defined, model loaded and correction information defined.
Individual frames can then be processed using `mira_ProcessFrame`

## mira_ProcessFrame

Process a single individual raw spectral frame from a line-scan camera

```
int mira_ProcessFrame(mrkernel* pmr, void* pData);
```

*Input:*

- Runtime environment pointer
- Pointer to external buffer with raw spectral frame data

*Output:* Result code (MIRA_OK or error)

*Description:*
`mira_ProcessFrame` passes data of a raw spectral frame from a line-scan camera. Acquisition process need to be running (started using `mira_StartAcquisition`).
The input data stream from a line scan camera is expected to be in BIL layout (pixels on the spatial line times spectral bands). The expected geometry and data type are defined by the loaded solution. This information can be queried by the `mira_GetInputWidth`, `mira_GetInputBands`, and `mira_GetInputDataType`.

After a frame is processed, per-pixel decisions may be read out using `mira_GetFrameDecisions` or object information extracted using `mira_GetObj*` functions.

## mira_ProcessCube

Process a single spectral cube

```
int mira_ProcessCube(mrkernel* pmr, void* pData);
```

*Input:*

- Runtime environment pointer

- Pointer to external buffer with raw spectral frame data

*Output:* Result code (MIRA_OK or error)

*Description:*
`mira_ProcessCube` passes data of a entire spectral cube. Acquisition process need to be running (started using `mira_StartAcquisition`).
The expected geometry and data type are defined by the loaded solution. This information can be queried by the `mira_GetInputHeight`, `mira_GetInputWidth`, `mira_GetInputBands`, `mira_GetInputDataLayout` and `mira_GetInputDataType`.

After a cube is processed, per-pixel decisions may be read out using `mira_GetFrameDecisions` or object information extracted using `mira_GetObj*` functions.

## mira_StopAcquisition

Starts the acquisition

```
int mira_StopAcquisition(mrkernel* pmr)
```

*Input:*

- Runtime environment pointer

*Output:* Result code (MIRA_OK or error)

*Description:*
`mira_StopAcquisition` stops the acquisition process. Statistics on number of processed frames, speed per frame and frame-rate is available via a subsequent `mira_GetErrorMsg` call.

*Example:*
```
Average alg time: 2.79676 ms/frame (357.557 fps), processed 1500 frames, first 500 skipped for warm-up.
```

## mira_GetFrameDecisions

Returns a pointer to pixel decisions on the last processed line

```
const unsigned char *mira_GetFrameDecisions(mrkernel* pmr);
```

*Input:*

- Runtime environment pointer

*Output:* Pointer to decisions on the last processed line

*Description:*
`mira_GetFrameDecisions` returns pointer to decisions at the last processed line. The values are zero-based indices. Class name corresponding to each index can be obtained using `mira_GetDecName`

## mira_GetDecCount

Returns the number of decisions provided by the classifier

```
int mira_GetDecCount(mrkernel* pmr);
```

*Input:*

- Runtime environment pointer

*Output:* Number of decisions provided by the classifier

*Description:*
`mira_GetDecCount` returns the number of decisions provided by the classifier. The decision index, returned for each pixel by `mira_GetFrameDecisions` is a value smaller than decision count (zero-based indexing).

## mira_GetRegVarCount

Returns the number of regression variables available by the regression model

```
int mira_GetRegVarCount(mrkernel* pmr);
```

*Input:*

- Runtime environment pointer

*Output:* Number of regression variables provided by the project

*Description:*
`mira_GetRegVarCount` returns the number of regression variables provided by the project. The `mira_GetRegVarName` function can be then used to obtain specific variable names.

If the project does not contain any trained regression model, zero is returned. Therefore, this function can be used to check whether regression modeling is enabled in the project.

## mira_GetRegVarName

Returns regression variable name given its index

```
const char* mira_GetRegVarName(mrkernel* pmr,int regVarInd);
```

*Input:*

- Runtime environment pointer
- Regression variable index (0 to the count returned by mira_GetRegVarCount - 1)

*Output:* String name of a regression variable

*Description:*
`mira_GetRegVarName` returns the name for a specific regression variable.

*Example:*

```
    varCount=mira_GetRegVarCount(pmr);
    if( varCount>0 ) {
        /* regression variables */
        printf("\nregression vars:\n");
        for(int i=0;i<varCount;i++) {
            printf("%d : %s\n",i,mira_GetRegVarName(pmr,i));
        }
    }
```

*Output*:

```
regression vars:
0 : brix
1 : acidity
```

## mira_GetObjDataRegOutput

Read information on segmented out objects

```
int mira_GetObjDataRegOutput(mrkernel* pmr, int entryInd, const float**
ppObjData);
```

*Input:*

- Runtime environment pointer
- entryID - zero-based index of an object

- ppObjData - pointer to a pointer to a table with regression results per object (floating point_

*Output:* Result (MIRA_OK or error)

*Description:*
`mira_GetObjDataRegOutput` provides per-object regression output. The second parameter `entryInd` is a zero-based object index (0..number of objects found -1). The third parameter `ppObjData` represents regression values for a given object. The example below illustrates that we declare a pointer to float called pObjData and initialize its value to NULL. In an acquisition loop, after processing a frame, if an object is found, we call `mira_GetObjDataInt` in a for loop extracting object information.
When we wish to access regression information for a given object, we use the **`mira_GetObjDataRegOutput`** function. We pass **the address** of the pObjData to the `mira_GetObjDataInt`, not the pointer itself. The actual regression value can be accessed using `pRegData[v]`, where `v` is the zero-based regression variable index. No memory allocation is needed on the side of user code.

*Example*:

```
     int objCount=0;

     const int varCount=mira_GetRegVarCount(pmr);

     float* pRegData=NULL;

    while( frameInd<frames ) {
       res=mira_ProcessFrame(pmr,ptrf);

       objCount=mira_GetObjCount(pmr);

       if( objCount>0 ) {
            for(int i=0;i<objCount;i++) {
                /* we pass address of a pointer to receive object table
                   allocated by the runtime */

                mira_GetObjDataInt(pmr,i,&pObjData);

                /* pObjData allows us to access object details */
                printf("\n obj%d : %d,d ",
                       pObjData[MIRA_OBJECT_ID],
                       pObjData[MIRA_OBJECT_FRAME],    /* along the belt */
                       pObjData[MIRA_OBJECT_POS] );    /* across the belt */

                if( varCount>0 && mira_GetObjDataRegOutput(pmr,i,&pRegData)
==MIRA_OK ) {
                       printf("\t reg:");
                       for(int v=0;v<varCount;v++) {
                           printf(" %3.3f ",pRegData[v]);
                       }
                }

            } /* end of for loop */
        } /* end of if objects */
    } /* end of frame acquisiion */
```

## mira_GetFrameRegOutputVar

Returns a pointer to pixel decisions on the last processed line

```
const float *mira_GetFrameRegOutputVar(mrkernel* pmr, int varInd, int
maskBackground, float maskVal);
```

*Input:*

- Runtime environment pointer
- regression variable index
- flag specifying if background should be masked
- masking value put on background pixels (if maskBackground==1)

*Output:* Pointer to per-pixel floating point regression value for the frame

*Description:*
`mira_GetFrameRegOutputVar` returns pointer to floating point regression values at the last processed line. The pointer can be dereferenced for each pixel of the processed line (from 0 to InputDataWidth-1 inclusive). The output is provided for a regression variable defined by the index given in the second parameter). The third parameter specifies if background pixels should be masked (mackBackground==1) or not (maskBackground==0). If masking is requested, the last paramer specifies floating point value copied into all background pixels. The masking procedure simplifies post-processing of the per-pixel regression output.

## mira_GetDecName

Returns decision (class) name given decision index

```
const char* mira_GetDecName(mrkernel* pmr,int decInd);
```

*Input:*

- Runtime environment pointer
- Decision index (0 to number of decisions - 1)

*Output:* String name of a class (decision)

*Description:*
`mira_GetDecName` returns the name for a specific decision index.

*Example:*

```
    printf("classifier decisions:\n");
    const int decCount=mira_GetDecCount(pmr);
    for(int i=0;i<decCount;i++) {
        printf("%d : %s\n",i,mira_GetDecName(pmr,i));
    }
```

*Output*:

```
classifier decisions:
0 : background
1 : product
2 : foreign object
```

## mira_GetDecColor

Returns R,G,B color of a given decision

```
const char* mira_GetDecColor(mrkernel* pmr,int decInd,unsigned char* R,unsigned
char* G,unsigned char* B);
```

*Input:*

- Runtime environment pointer
- Decision index (0 to number of decisions - 1)
- pointer to red, green and blue color

*Output:* String name of a class (decision)

*Description:*
`mira_GetDecColor` returns R,G, and B colors for a given decision

## mira_GetObjCount

Returns the number of objects found after processing a frame

```
int mira_GetObjCount(mrkernel* pmr);
```

*Input:*

- Runtime environment pointer

*Output:* Number of objects found after processing a given frame

*Description:*
`mira_GetObjCount` returns the number of objects found after processing a given frame. If non-zero, the object information can be read using `mira_GetObjData*` funcitons, see this example.
Note, that the object-specific information is replaced after next frame processing.

## mira_GetObjDataInt

Read information on segmented out objects

```
int mira_GetObjDataInt(mrkernel* pmr, int entryInd, int** ppObjData);
```

*Input:*

- Runtime environment pointer
- entryID - zero-based index of an object
- ppObjData - pointer to a pointer to a table with object information

*Output:* Result (MIRA_OK or error)

*Description:*
`mira_GetObjDataInt` returns details on a specific object found. The first parameter is a zero-based object index (0..number of objects found -1). The second parameter represents an object table. The example below illustrates that we declare a pointer to int called pObjData and initialize its value to NULL. In an acquisition loop, after processing a frame, if an object is found, we call `mira_GetObjDataInt` in a for loop extracting object information. Note, that we pass address of the pObjData to the `mira_GetObjDataInt.`

*The object table:*

| | | |
|---|---|---|
| MIRA_OBJECT_ID | 0 | Unique object identifier |
| MIRA_OBJECT_FRAME | 1 | Frame index for the object centroid |
| MIRA_OBJECT_POS | 2 | Position of the object centroid across the belt |
| MIRA_OBJECT_MINFRAME | 3 | Bounding box coordinates: |
| MIRA_OBJECT_MAXFRAME | 4 | |
| MIRA_OBJECT_MINCOL | 5 | |
| MIRA_OBJECT_MAXCOL | 6 | |
| MIRA_OBJECT_SIZE | 7 | Object size in pixels |
| MIRA_OBJECT_CLASS | 8 | Object class index |

Example:

```
    int objCount=0;
    int* pObjData=NULL; /* pointer to object table data */
    while( frameInd<frameCount ) {

        mira_ProcessFrame(pmr,pFrame);

        objCount=mira_GetObjCount(pmr);
        if( objCount>0 ) {
            for(int i=0;i<objCount;i++) {
                /* we pass address of a pointer to receive object table
                   allocated by the runtime */
```

```
                mira_GetObjDataInt(pmr,i,&pObjData);

                /* pObjData allows us to access object details */
                printf("\n obj%d : %d,d ",
                       pObjData[MIRA_OBJECT_ID],
                       pObjData[MIRA_OBJECT_FRAME],    /* along the belt */
                       pObjData[MIRA_OBJECT_POS] );    /* across the belt */
            } /* end of for loop */
        } /* end of if objects */
    } /* end of frame acquisiion */
```

## mira_GetObjDataClassSize

For complex object segmentation, returns number of class pixels wihtin the obejct

```
int mira_GetObjDataClassSize(mrkernel* pmr, int entryInd, int classInd);
```

*Input:*

- Runtime environment pointer
- entryInd - Object index (zero-based)
- classInd - Class index (zero-based)

*Output:* Number of pixels of specific class within specific object or error

*Description:*
`mira_GetObjDataClassSize` returns the number of pixels of specific class within an object. This function is applicable when object segmentation mask is defined as "all foregound" i.e. when complex objects are segmented.

## mira_GetObjDataClassFrac

For complex object segmentation, returns the fraction of class pixels wihtin the obejct

```
float mira_GetObjDataClassFrac(mrkernel* pmr, int entryInd, int classInd)
```

*Input:*

- Runtime environment pointer
- entryInd - Object index (zero-based)
- classInd - Class index (zero-based)

*Output:* Fraction (0.0 to 1.0) inclusive of pixels of specific class within specific object or error code

*Description:*
`mira_GetObjDataClassFrac` returns the fraction of specific class within an object. This function is applicable when object segmentation mask is defined as "all foregound" i.e. when complex objects are segmented.
If error occurs the negative error code value is returned.

## mira_SaveImage

Save internal segmentation buffer as PNG image

```
int mira_SaveImage(mrkernel* pmr,const char* filename)
```

*Input:*

- Runtime environment pointer
- Filename

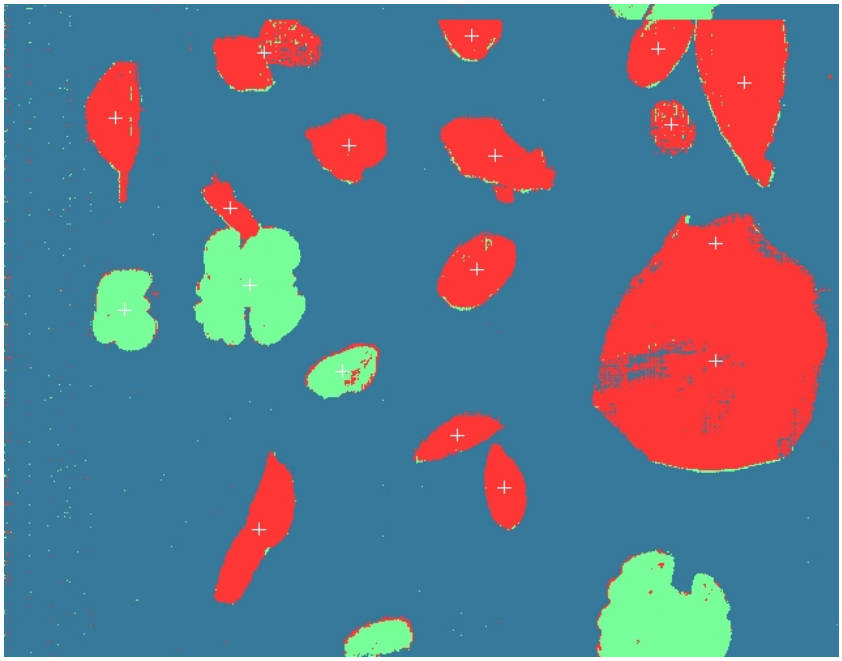
*Output:* Result (MIRA_OK or error)

*Description:*
`mira_SaveImage` saves internal segmentation buffer into a PNG file. It is intended as a quick visualization of what the classifier can "see" in a deployed system.
Segmented objects are highligted by white crosses.

*Example:*

```
MIRA_CHECK( mira_StopAcquisition(pmr) );
printf("\n %s",mira_GetErrorMsg(pmr));
/* We can save the content of the internal buffer. */
mira_SaveImage(pmr,"out.png");
mira_Release(pmr);
```

*Output:* Content of out.png file



## mira_Release

Release runtime internal session and clean resources.

```
void mira_Release(mrkernel* pmr)
```

*Input:*

- Runtime environment pointer

*Output:* None

*Description:*
`mira_Release` end the session and releases all memory allocated by the runtime.