Zebra
Aurora™ Vision

Aurora Vision Library 5.6

Aurora Vision Library Documentation

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1. Introduction

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Overview

Introduction

Aurora Vision Library is a machine vision library for C++ and .NET programmers. It provides a comprehensive set of functions for creating industrial image analysis applications – from standard-based image acquisition interfaces, through low-level image processing routines, to ready-made tools such as template matching, measurements or barcode readers. The main strengths of the product include the highest performance, modern design and simple structure making it easy to integrate with the rest of your code.

The scope of the library encompasses:

- **Image Processing**
  High performance, any-shape ROI operations for unary and binary image arithmetics, refinement, morphology, smoothing, spatial transforms, gradients, thresholding and color analysis.
- **Region Analysis**
  Robust processing of pixel sets that correspond to foreground objects: extraction, set arithmetics, refinement, morphology, skeletonization, spatial transformations, feature extraction and measurements.
- **Path Analysis**
  Subpixel-precise alternative to region analysis, particularly suitable for shape analysis. Provides methods for contour extraction, refinement, segmentation, smoothing, classification, global transformations, feature extraction and more.
- **Profiles**
  Auxiliary toolset for analysis of one-dimensional sequences of values, e.g. image sections or path-related distances.
- **Histograms**
  Auxiliary toolset for value distribution analysis.
- **Geometry 2D**
  Exhaustive toolset of geometric operations compatible with other parts of the library. Provides operations for measuring distances and angles, determining intersections, tangents and feature.
- **1D Edge Detection**
  Detection of edges, ridges and stripes (paired edges) by the means of 1D edge scanning, i.e. by extracting and analysing a profile along a specified path.
- **2D Edge Detection**
  Detection of edges by the means of 2D edge tracing, i.e. by extracting and refining locally maximal image gradients.
- **Fourier Analysis**
  Suitable both for educational experimentation and industrial application, this toolset provides methods for Fourier transform and image processing in the frequency domain.
- **Template Matching**
  Efficient, robust and easy to use methods for localizing objects using a gray-based or an edge-based model.
- **Barcodes**
  Detection and recognition of many types of 1D codes.
- **Datacodes**
  Detection and recognition of QR codes and DataMatrix codes.
- **Hough Transform**
  Detection of analytical shapes using the Hough transform.
- **Image Segmentation**
  Automated extraction of object regions using gray or edge information.
- **Multilayer Perceptron**
  Artificial neural networks.
- **Optical Character Recognition**
  Text recognition or validation, including dot print.
- **Shape Fitting**
  Subpixel-precise detection of analytical shapes, whose rough locations are known.

Relation between Aurora Vision Library and Aurora Vision Studio

Each function of the Aurora Vision Library is the basis for the corresponding filter available in **Aurora Vision Studio**. Therefore, it is possible (and advisable) to use the Aurora Vision Studio as a convenient, drag & drop prototyping tool, even if one intends to develop the final solution in C++ using Aurora Vision Library. Moreover, for extended information about how to use advanced image analysis techniques, one can refer to Machine Vision Guide from the documentation of **Aurora Vision Studio**.

In the table below we compare the ThresholdImage function with the ThresholdImage filter:

Aurora Vision Library:

```
void ThresholdImage
(
 const Image&   inImage,
 Optional<const Region&> inRoi,
 Optional<real>   inMinValue,
 Optional<real>   inMaxValue,
 real     inFuzziness,
 Image&     outMonoImage
);
```

Aurora Vision Studio:

Key Features

Performance

In Aurora Vision Library careful design of algorithms goes hand in hand with extensive hardware optimizations, resulting in performance that puts the library among the fastest in the world. Our implementations make use of **SSE instructions** and **parallel computations** on multicore processors.

Modern Design

All types of data feature **automatic memory management**, errors are handled explicitly with **exceptions** and **optional types** are used for type-safe special values. All functions are **thread-safe** and use **data parallelism** internally, when possible.

Consistency

The library is a simple collection of types and functions, provided as a single DLL file with appropriate headers. For maximum readability function follow consistent naming convention (e.g. the VERB + NOUN form as in: ErodeImage, RotateVector). All results are returned via reference output parameters, so that many outputs are always possible.

Example Program

A simple program based on the Aurora Vision Library may look as follows:

```
#include <AVL.h>

using namespace atl;
using namespace avl;

int main()
{
 try
 {
  InitLibrary();
  Image input, output;
  LoadImage("input.bmp", false, input);
  ThresholdImage(input, NIL, 128, NIL, 0, output);
  SaveImage(output, NIL, "output.bmp", false);
  return 0;
 }
 catch (const atl::Error&)
 {
  return -1;
 }
}
```

Please note that Aurora Vision Library is distributed with a set of example programs, which are available after installation.

Programming Conventions

Organization of the Library

Aurora Vision Library is a collection of C++ functions that process machine vision related types of data. Each function corresponds to a single data processing operation, e.g. DetectEdges_AsPaths performs a Canny-like 2D edge detection. As a data processing library, it is not particularly object-oriented. It does use, however, modern approach to C++ programming with automatic memory management, exception handling, thread safety and the use of templates where appropriate.

Namespaces

There are two namespaces used:

- **atl** – the namespace of types and functions related to Aurora Template Library.
- **avl** – the namespace of types and functions related to Aurora Vision Library as the whole.
- **avs** – Aurora Vision Studio Code Generator equivalents of Aurora Vision Library functions. Not recommended to use.

Enumeration Types

All enumeration types in Aurora Vision Library use C++0x-like namespaces, for example:

```
namespace EdgeFilter
{
    enum Type
    {
        Canny,
        Deriche,
        Lanser
    };
}
```

This has two advantages: (1) some identifiers can be shared between different enumeration types; (2) after typing "EdgeFilter::" IntelliSense will display all possible elements of the given enumeration type.

Example:

```
atl::Array<avl::Path> edges;
avl::Image image, gradientImage;

avl::DetectEdges_AsPaths(image, atl::NIL, avl::EdgeFilter::Canny,
                         2.0f, atl::NIL, 60.0f, 30.0f, atl::NIL, 30.0f, 0.0f, atl::NIL, 0.0f, edges, gradientImage);
```

Function Parameters

Contrary to standard C++ libraries, machine vision algorithms tend to have many parameters and often compute not single, but many output values. Moreover, diagnostic information is highly important for effective work of a machine vision software engineer. For these reasons, function parameters in Aurora Vision Library are organized as follows:

1. First come **input parameters**, which have "in" prefix.
2. Second come **output parameters**, which have "out" prefix and denote the results.
3. The last come **diagnostic output parameters**, which have "diag" prefix and contain information that is useful for optimizing parameters (not computed when the diagnostic mode is turned off).

For example, the following function invocation has a number of input parameters, a single output parameter (*edges*) and a single diagnostic output parameter (*gradientImage*).

```
atl::Array<avl::Path> edges;
avl::Image image, gradientImage;

avl::DetectEdges_AsPaths(image, atl::NIL, avl::EdgeFilter::Canny,
                         2.0f, atl::NIL, 60.0f, 30.0f, atl::NIL, 30.0f, 0.0f, atl::NIL, 0.0f, edges, gradientImage);
```

Diagnostic Output Parameters

Due to efficiency reasons the diagnostic outputs are only computed when the diagnostic mode is turned on. This can be done by calling:

```
avl::EnableAvlDiagnosticOutputs(true);
```

In your code you can check if the diagnostic mode is turned on by calling:

```
if (avl::GetAvlDiagnosticOutputsEnabled())
{
 //...
}
```

Optional Outputs

Due to efficiency reasons computation of some outputs can be skipped. In function TestImage user can inform function that computation of **outMonoImage** is not necessary and function can omit computation of this data.

the TestImage Header with last two optional parameters:

```
void avl::TestImage
(
 avl::TestImageId::Type inImageId,
 atl::Optional<avl::Image&> outRgbImage = atl::NIL,
 atl::Optional<avl::Image&> outMonoImage = atl::NIL
)
```

Example of using optional outputs:

```
avl::Image rgb, mono;

// Both outputs are computed
avl::TestImage(avl::TestImageId::Baboon, rgb, mono);

// Only RGB image is computed
avl::TestImage(avl::TestImageId::Baboon, rgb);

// Only mono image is computed
avl::TestImage(avl::TestImageId::Baboon, atl::NIL, mono);
```

In-Place Data Processing

Some functions can process data *in-place*, i.e. modifying the input objects instead of computing new ones. There are two approaches used for such functions:

1. Some filters, e.g. the image drawing routines, use "io" parameters, which work simultaneously as inputs and outputs. For example, the following function invocation draws red circles on the *image1* object:
   ```
   avl::DrawCircle(image1, circle, atl::NIL, avl::Pixel(255, 0, 0), style);
   ```
2. Some filters, e.g. image point transforms, can be given the same object on the input and on the output. For example, the following function invocation negates pixel values without allocating any additional memory:
   ```
   avl::NegateImage(image1, atl::NIL, image1);
   ```

Please note, that simple functions like NegateImage can be executed even 3 times faster in-place than when computing a new output object.

Work Cancellation

Most of long-working functions can be cancelled using CancelCurrentWork function. Cancellation technique is thread-safe, so function CancelCurrentWork can be called from different thread. If avl function was cancelled then atl::CancellationError is thrown.

To check cancellation status use the IsCurrentWorkCancelled or ThrowIfCurrentWorkCancelled functions.

```
void ProcessingThread()
{
 while (!avl::IsCurrentWorkCancelled())
 {
  std::cout << "Iteration start" << std::endl;
  avl::Delay(10000); // Function with cancellation support
  std::cout << "Iteration complete" << std::endl;
 }
 std::cout << "Processing thread stop" << std::endl;
}

int main()
{
 avl::InitLibrary();
 std::thread t {ProcessingThread};

 std::cout << "Press Enter to stop execution." << std::endl;
 std::cin.get();

 // Cancel work in ProcessingThread and in avl::Delay
 avl::CancelCurrentWork();

 t.join();

 return 0;
}
```

Library Initialization

For reasons related to efficiency and thread-safety, before any other function of the AVL library is called, the InitLibrary function should be called first:

```
int main()
{
 avl::InitLibrary();
 //...
}
```

Debug Preview

For diagnostic purposes it is useful to be able to preview Images and image based data primitives. You can achieve this by using functions from the Debug Preview category. They can be helpful in debugging programs and displaying both intermediate and final data.

```
avl::Image image;
avl::LoadImage("hello.png", false, image);

// Prepare the preview window
auto view = avl::DebugPreview::CreateView("My Preview Window");

// Show loaded image in new window.
avl::DebugPreview::SetViewImage(view, image);

// Wait until window is closed.
avl::DebugPreview::WaitForViewClose(view);
```

Aurora Template Library

Aurora Vision Library is based on the Aurora Template Library – a simplified counterpart of the C++ Standard Template Library, which avoids advanced templating techniques mainly by using raw pointers instead of abstract iterators. This makes Aurora Vision Library portable to embedded platforms, including the ones that do not support C++ templates fully.

Please note, that the following types should only be parametrized with fundamental types (int, float, etc.) or types from avl or atl namespace. Const and/or reference types are also allowed, as long as template type accepts such type (e.g. Array<T> cannot be parametrized with reference type).

Array<T>

The Array<T> type strictly corresponds to std::vector<T>. It is a random-access, sequential container with automatic memory reallocation when growing.

Here is a simplified version of the public interface is depicted: Array.h

Optional<T>

The Optional<T> type provides a consistent way of representing an optional value, something for which NULL pointers or special values (such as -1) are often used. Many APIs provide optional values using default values of parameters. This type is inspired by boost::optional<T> class from the Boost Library, but is designed mostly for input parameters, not only for function results.

In Aurora Vision Library it is used to represent optional regions of interest in image processing operations and many other input parameters that can be determined automatically when not provided by an user.

Documentation for this type is presented in Optional.h.

Sample use:

```
atl::Optional<avl::Point2D> p;
p = avl::Point2D(10, 25);        // normal value
p = atl::NIL;                 // NIL value
if (p != atl::NIL)
{
 avl::Point2D q = p.Get();    // access to a non-nil value
 p.Get().x = 15;          // direct access to a field
}
```

Conditional<T>

This type of data is especially used to determine invalid results. Many functions in C return special value as -1 or NULL when their result is invalid. Type Conditional<T> is very similar to Optional<T>, but it is mostly used in outputs.

Documentation for this type is presented in Conditional.h.

Sample use:

```
atl::Conditional<int> result;
avl::ParseInteger("Test1", avl::NumberSystemBase::Base_10, result); // Parsing textual data

if (result != atl::NIL)   // If textual data is not valid integer result has value atl::NIL
 printf("Valid integer.");
else
 printf("Invalid integer. Value: %d", result.Get());
```

Dummy<T>

Dummy<T> class is used to create a temporary object that will be released after its use. It is mostly used to create a temporary object to pass its reference to a function. Such temporary objects are helpful when not all values returned by a function are important and we don't plan to use them.

Sample use:

```
avl::Region region;
avl::Circle2D circle = avl::Circle2D(50.0f, 50.0f, 50.0f);

avl::CreateCircleRegion(circle, atl::NIL, 100, 100, region);

// Second parameter is not used.
avl::Segment2D minorAxis;
avl::RegionEllipticAxes(region, atl::Dummy<avl::Segment2D>(), minorAxis);

std::cout << "Minor axis length: " << minorAxis.Length();
```

2. Getting Started

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This is just a placeholder to silence warnings about broken link.

SDK Installation

Requirements

Aurora Vision Library is designed to be a part of applications working under control of the Microsoft Windows operating system. Supported versions are: 10 and 11, as well as the corresponding embedded editions.

To build an application using Aurora Vision Library, Microsoft Visual Studio environment is required. Supported versions are: 2015, 2017 and 2019.

Aurora Vision Library can be also used on Linux operating system with GCC compiler - for details consult Using SDK on Linux article.

Running the Installer

The installation process is required to copy the files to the proper folders and to set the environment variables used for building applications using Aurora Vision Library.

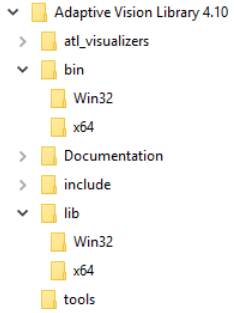
After the installation, a license for Aurora Vision Library product has to be loaded. It can be done with the *License Manager* tool available in the *Start Menu*.

To verify that the installation has been successful and the license works correctly, one can try to load, build and run example programs, which are available from the *Start Menu*.

SDK Directories

Aurora Vision Library is distributed as a set of header files (.h), dynamic (.dll) and static (.lib) libraries. The libraries (static and dynamic) are provided in versions for 32-bit and 64-bit system. The header files are common for both versions.

The picture below shows the structure of the directories containing headers and libraries included in Aurora Vision Library.



The directories (installed in the *Program Files* system folder) being a part of Aurora Vision Library are shortly described below.

- **atl_visualizers** – a directory containing the visualizers for Microsoft Visual Studio Debugger of Aurora Vision Library data types.
- **bin** – a directory containing dynamic linked library files (AVL.dll) for 32|64-bit applications. The libraries are common for all supported versions of Microsoft Visual Studio and for Debug|Release configurations. All the functions of Aurora Vision Library are included in the AVL.dll file.
- **Documentation** – a directory containing the documentation of Aurora Vision Library, including this document.
- **include** – a directory containing all header (.h) files for Aurora Vision Library. Every source code file that uses Aurora Vision Library needs the AVL.h header file (the main header file) to be included.
- **lib** – a directory containing static (.lib) libraries (AVL.lib) for 32|64-bit applications. The AVL.lib file has to be statically-linked into the program that uses Aurora Vision Library. It acts as an intermediary between the usage of Aurora Vision Library functions and the AVL.dll file. The programmer creating an application does not need to bother about DLL entry points and functions exported from the AVL.dll file. Aurora Vision Library is designed to be easy to use, so one only needs to link the AVL.lib file and can use all the functions from the AVL.dll just as easy as local functions.
- **tools** – a directory containing the *License Manager* tool helping the user to load the license for Aurora Vision Library to the developer's computer.
- **Examples** – a directory located in the *Public Documents* system folder (e.g. `C:\Users\Public\Documents\Aurora Vision Library 5.6\Examples` on Windows Vista/7) containing simple example solutions using Aurora Vision Library. The examples are a good way of learning, how to use Aurora Vision Library. They can be used as a base for more complicated programs as well. The shortcut to the Examples directory can be found in the *Start Menu* after the installation of Aurora Vision Library.

Library Architecture

Aurora Vision Library is split into four parts:

1. Aurora Vision Library - contains all functions for working with images.
2. Standard Library - contains all auxiliary functions like: file operations, XML editing or mathematical operations.
3. GenICam Library - contains all GenICam and GigEVision functions.
4. Third Party Library - contains functions of third-party hardware producers.

The usage of the library is possible only when including one of the following header files:

- AVL.h
- STD.h
- Genicam.h
- ThirdPartySdk.h

Environment and Paths

Aurora Vision Library uses the environment variable named `AVL_PATH5_6` (5_6 stands for the 5.6 version) in the building process. The variable points the directory with the headers and libraries needed in the compile time (.h files and AVL.lib) and in the run time (AVL.dll). Its value is typically set to `C:\Program Files (x86)\Aurora Vision\Aurora Vision Library 5.6`, but it can differ in other systems.

The projects using Aurora Vision Library should use the value of `AVL_PATH5_6` to resolve the locations of the header files and statically-linked `AVL.lib` file. Using an environment variable containing path makes the application source code more portable between computers. The `AVL_PATH5_6` path is typically used in the project settings of the compiler (Configuration Properties | C/C++ | General | Additional Include Directories) to find the header files, settings of the linker (Configuration Properties | Linker | General | Additional Library Directories) to find the proper version of the AVL.lib and in the configuration of Post-Build Event (Configuration Properties | Build Events | Post-Build Event | Command Line) to copy the proper version of the AVL.dll file to the output directory of the project. All the settings can be viewed in the simple example applications distributed with Aurora Vision Library.

Project Configuration

General Information

Aurora Vision Library is designed to be used as a part of C++ projects developed with Microsoft Visual Studio in versions 2015-2019.

Creating a New Project

Microsoft Visual Studio 2015, 2017 and 2019

Aurora Vision Library is provided with a project template. To create a new project using Aurora Vision Library, start Microsoft Visual Studio and choose the *File* | *New* | *Project...* command. The template called *AVL 5.6 Project* is available in the tab *Installed* | *Templates* | *Other Languages* | *Visual C++*.

Required Project Settings

All projects that use Aurora Vision Library need some specific values of the compiler and linker settings. If you want to use the Library in your existing project or you are manually configuring a new project, please apply the settings listed below:

- **Configuration Properties | General**
  - **Character Set** should be set to `Use Unicode Character Set`.
- **Configuration Properties | C/C++**
  - **General**
    - **Additional Include Directories** should contain the `$(AVL_PATH5_6)\include\` path.
- **Configuration Properties | Linker**
  - **General**
    - **Additional Library Directories** should contain the proper path to directory containing the AVL.lib file. The proper path is `$(AVL_PATH5_6)\lib\$(PlatformName)\` .
  - **Input**
    - **Additional Dependencies** should contain `AVL.lib` file.
- **Configuration Properties | Build Events**
  - **Post-Build Event**
    - **Command Line** should contain `copy "$(AVL_PATH5_6)\bin\$(PlatformName)\AVL.dll" "$(OutDir)"` call. This setting is not mandatory, but the application using Aurora Vision Library requires an access to the AVL.dll file and this is the easiest way to fulfill this requirement.

Including Headers

Every source code file that uses Aurora Vision Library needs the `#include <AVL.h>` directive. A proper path to the AVL.h file is set in the settings of the compiler (described above), so there is no need to use the full path in the directive.

Distributing Aurora Vision Library with Your Application

Once the application is ready, it is time for preparing a distribution package or an installer. There are two requirements that needs to be fulfilled:

- The final executable file of the application needs to have access to the proper version (used by *Win32* or *x64* configuration) of the AVL.dll file. Typically, the AVL.dll file should be placed in the same directory as the executable.
- The computer that the application will run on needs a valid license for the use of Aurora Vision Library product. Licenses can be managed with the License Manager application, that is installed with Aurora Vision Library Runtime package.
- A license file (*.avkey) can be also manually copied to the end user's machine without installing Aurora Vision Library Runtime. It must be placed in a subdirectory of the *AppData* system folder. The typical location for the license file is `C:\Users\%USERNAME%\AppData\Local\Aurora Vision\Licenses`. Remember that the license is valid per machine, so every computer that runs the application needs a separate license file.
- Alternatively to the (*.avkey) files we support USB Dongle licenses.

Using Library with CMake

Library ships with CMake configuration modules. It makes the project portable, and easy to compile for Windows, linux or Android. The minimum CMake version supported is 3.10 (for example shipped with Ubuntu bionic/18.04)

Quick Start

A simple template for CMakeLists.txt is presented below:

```
cmake_minimum_required(VERSION 3.10)
project(example)

find_package(
    AVL
    # for a specific version, uncomment the line below
    #5.3
    CONFIG
    REQUIRED
)

# copy binaries to build directory
copy_avl()

add_executable(
    # executable name
    example_exec
    # source files
    main.cpp
)

target_link_libraries(
    example_exec
    PUBLIC
    AVL
)

# install user executable
install(TARGETS example_exec)
# install ALL AVL libraries
install_avl()
```

One can also copy one of the CMake examples, and modify to your needs. For further cmake use refer to online documentation. Be aware that ubuntu 18.04 is the baseline distribution, so minimal CMake version is 3.10

Reference

package

CMake package is provided for windows installer and linux archive. Both should be usable after installation. Linux additionally ships with Android libraries. The library is only discoverable using CONFIG mode, so it's sensible to restrict find_package to that mode.

```
find_package(
    AVL
    # for a specific version, uncomment the line below
    #5.3
    CONFIG
    REQUIRED
)
```

On Android to use system installed AVL it is necessary to add CMAKE_FIND_ROOT_PATH_BOTH argument:

```
find_package(AVL CONFIG REQUIRED CMAKE_FIND_ROOT_PATH_BOTH)
```

Possible packages:

- AVL - full library
- AVL_Lite - lite library
- Weaver - deep learning inference library

install_avl

Install all AVL libraries when executing make install or ninja install or building INSTALL project in Visual Studio. It accepts a LIB argument to override default installation directory. It requires find_package(AVL...) call first.

```
find_package(AVL CONFIG REQUIRED)

install_avl()
```

By default it installs to ${CMAKE_INSTALL_PREFIX}/bin on Windows and ${CMAKE_INSTALL_PREFIX}/lib on Linux. When provided the LIB argument it installs to ${CMAKE_INSTALL_PREFIX}/${LIB_ARGUMENT}

```
install_avl(LIB "avl_directory")
```

Possible variants:

- install_avl()
- install_avl_lite()
- install_weaver()

copy_avl

Copy all AVL libraries when compiling targets that depend on AVL to binary directory. By default it's ${CMAKE_BINARY_DIR} or ${CMAKE_BINARY_DIR}/$<CONFIG> on Windows. It requires find_package(AVL...) call first.

```
find_package(AVL CONFIG REQUIRED)

copy_avl()
```

Possible variants:

- copy_avl()
- copy_avl_lite()
- copy_weaver()

Using Library on Linux

Requirements

Aurora Vision Library is designed to be used with GCC compiler on Linux x86_64 and embedded ARMv8-A systems. Currently gcc in version 9.3.1 is supported, and corresponding toolchains for embedded linux: arm-linux-gnueabihf-, aarch64-linux-gnu-. Custom build can be prepared upon the earlier contact with Aurora Vision team. The Aurora Vision Library is distributed as .tar.gz or .tar.xz archive. The library is compatible with Debian-like system, including - but not limited to - Ubuntu distributions.

Common prerequisites

Properly set locale on target computer is important. Non-existing locale will cause bugs and bad behavior. To list locale that exists on your computer use: `locale -a`, and currently set: `locale`. Remember that running your application as daemon (e.g. from systemd) may set different locale, than the one in your user terminal. Refer to your Linux distribution documentation.

To build example in simple manner, GNU Make tool and CMake is needed.

- Ubuntu 20.04/Debian 11 or newer:
  - Runtime:
    - package libc6 ≥ 2.31
    - package libudev1 ≥ 245.4
  - Development:
    - package g++ version ≥ 9.4.0
    - package make version ≥ 4.2.1
    - package cmake version ≥ 3.16.3
    - `sudo apt-get install cmake make g++`
  - Examples:
    - `sudo apt-get install libgtk-3-dev libsdl2-dev qtbase5-dev`
    - For UserFilter example, you will need avexecutor
- Rocky Linux 9/Fedora 31 (36 for QT)/OpenSUSE 15.3 or newer:
  - Runtime:
    - package glibc ≥ 2.30
    - package systemd ≥ 243.9
  - Development:
    - package gcc-c++ version ≥ 9.3.1
    - package make version ≥ 4.2.1
    - package cmake version ≥ 3.17.4
    - CentOS/Fedora: `dnf install gcc-c++ make cmake`
    - OpenSUSE: `zypper install gcc-c++ make cmake`
  - Examples:
    - CentOS/Fedora: `dnf install SDL2-devel qt5-qtbase-devel gtk3-devel`
    - OpenSUSE: `zypper install libSDL2-devel libqt5-qtbase-devel gtk3-devel`
- Generic:
  - Runtime:
    - libraries libc.so.6, libpthread.so.0, libm.so.6, libdl.so.2, librt.so.1, libgcc_s.so.1 from glibc version ≥ 2.30 or compatible (i.e. musl libc)
    - library libudev.so.1 from systemd version ≥ 243.9

Supported input devices

Vendor	x86_64	armv8
ximea	✓	✓
Allied Vision Vimba	✓	✓
Basler Pylon	✓	✓
LMI Gocator	✓	✓
AXIS	✓	✓
GenicamGenTL	✓	✓
Hilscher	✓	✓
OPCUA	✓	✓
SerialPort	✓	✓
NET SynView	✓	✓
Z4Sight	✓	✓
eBUS	✓	✓

Installation instructions

In unpacked directory call the install script. In example: `sudo ./install` This command will install the library to a proper directory in opt. It will also make the library visible to CMake find_package command.

Compilation instructions

Directory structure

Unpacked directory consists of following entries:

- examples/ - directory contains source files of example programs written with Aurora Vision Library
- include/ - this directory contains library header files
- lib/ - here the .so file with library is stored, along with any kits
- bin/ - directory for additional binaries, like Licensing tool.
- /README - instruction of library usage
- /sha512sum - checksums for all files in archive, check with `sha512sum --quiet -c sha512sum`
- /metadata.json - file containing information about the optimal target system, and library version
- /install - installation script
- /uninstall - uninstall script, will be copied to installation directory, where it can be safely used

Compilation

Using CMake

CMake is the recommended way to compile on linux, see documentation Using Library with CMake

Using Makefile or your custom build system

For compiling with Aurora Vision Library please remember to:

- add the include/ subdirectory to the compiler include directories: -I switch
- add the lib/ subdirectory to the linker directories: -L switch
- link with Aurora Vision Library: -lAVL
- use -rpath in linker options, LD_LIBRARY_PATH or LD_PRELOAD of libAVL.so file.
- link with dependencies: -lpthread -lrt -ldl

One can consult makefile in the examples/ directory to see how to compile and link with Aurora Vision Library.

Known compilation bugs

In case of the following linker errors: (or similar)

```
/usr/bin/ld: warning: libiconv.so, needed by lib/libAVL.so, not found (try using -rpath or -rpath-link)
lib/libAVL.so: undefined reference to `libiconv'
lib/build/libAVL.so: undefined reference to `libiconv_close'
lib/build/libAVL.so: undefined reference to `libiconv_open'
```

It is a known gnu linker bug, affecting versions older than 2.28 (e.g. in Ubuntu 16.04).
To solve the problem you can:

- Try a different linker (add for linking -fuse-ld=gold for gold or -fuse-ld=lld, consult your linux distribution manual)
- Link with the missing library (for example add -liconv)
- Update the linker (binutils 2.28 or newer)

Licensing and distribution

Licensing

File based licenses are supported on all Linux platforms. Dongle licenses depend on CodeMeter runtime. Currently Codemeter runtime is available for x86_64 and ARMV7-A. To develop and debug programs written with Aurora Vision Library, Library license has to be present. To run compiled binaries linked with Aurora Vision Library, LibraryRuntime license has to be present.

One can use license_manager from bin/ directory to list currently installed file or dongle licenses:
`license_manager list`
Red marked licenses are invalid, for example past the license date or installed license for the wrong machine (bad ID)

File License

To obtain license:

- In a terminal, on the target machine run `license_manager id` from bin/ directory
- Copy the printed Computer ID
- Use that Computer ID to get a .avkey file from User Area on www.adaptive-vision.com website.
- Download the key to the target machine
- Install the license by **one** of the following methods:
  - Run in terminal `license_manager install downloaded_file.avkey` (*Recommended*)
  - Copy the .avkey file next to executable, that is using Aurora Vision Library

Dongle License

Installed CodeMeter Runtime is required, as well as proper license available on plugged in dongle.

Download runtime package from WIBU website, section "CodeMeter User Runtime for Linux".
"Driver Only" (lite) version recommended for headless (no desktop GUI) installations. ARMV7-A is available under "CodeMeter User Additional Downloads" as "Raspberry PI" version

Distribution

To distribute program with Aurora Vision Library, one have to provide license (file or dongle - depending on system used) and the libavl.so. To provide the .so file, one can install SDK on target machine, but this will provide headers etc., which may be unwanted. In such case, the library file, with any used kits should be copied to suitable system directory, or the program has to be compiled with -rpath and relative path to the .so file. Third option is to provide a boot script, which will set LD_LIBRARY_PATH or LD_PRELOAD with libavl.so location.

Program development - general advise

The most convenient way to make programs with Aurora Vision Library for Linux is to develop vision algorithm using Aurora Vision Studio on Windows and then generating C++ code. This code can be further changed or interfaced with rest of the system and tested on Windows. Then, cross-compiler can be used to prepare Linux build, which will be provided to target machine. It is easy to organize work this way, because:

- developing vision algorithm using plain C++ is hard, troublesome and error prone, but Aurora Vision Studio makes it easy,
- programs written with Aurora Vision Library on Windows can be easily debugged using Microsoft Visual Studio thanks to provided debug visualizers and the Image Watch extensions to Microsoft Visual Studio,
- cross compilation using virtualization solution, like Vagrant, is easy and fast, and does not force developer to use two systems simultaneously.

Of course, the programs can be also developed on Linux machine directly. Then a dose of work should be put into writing good Makefile. Debugging can be done by GDB, but we do not provide debug symbols for Aurora Vision Library.

Runtime considerations

Some architectures might impose restrictions on libavl code. In this section we present pitfalls the user should be aware of.

Homogeneous Multiprocessor/SMP

There are many identical cores. One might have a problem when cores span across multiple physical CPUs, frequent on servers. The CPU's don't share CPU cache, so when execution of thread from CPUx/COREa is moved to CPUy/COREb, cache needs to be updated. It imposes time penalty. A workaround would be to pin threads to specific cores, (set affinity) or limit execution of libavl to specific number of cores on one physical CPU.

- use taskset linux command to limit execution on specific cores
- use OMP_PROC_BIND=TRUE environment variable to bind threads to cores they started on

Heterogeneous Multiprocessor

There are different kinds of processors the code runs on. Some examples are ARM big.LITTLE architecture, (where the cores mainly differ in maximum speed), or Tegra TX2 (where the cores serve different purpose). This kind of architecture might also suffer from Homogeneous Multiprocessor problems, but might suffer from different set of problems. One have to consider the cores are designed for low power and high performance, single threaded multithreaded optimized. Use the same solutions as in previous point, just take into account what type of algorithm will be executed.

Tegra TX2

This CPU is an example of Heterogeneous Multiprocessor architecture. It comprises of 6 cores: 2 Denver2 4 Cortex-A57. Denver2 core is designed for single thread performance, while Cortex-A57 for multithreaded. One can use both, but with thread binding, so threads are executed on the cores they started on. Limiting to one type of core might be beneficial when power consumption is a factor. Remember that thread binding might bind your application to core you did not want to use. Core 0 is Cortex-A57, core 1 and 2: Denver2, and cores 3-5: Cortex-A57. Core 0 is always active.

Using User Filters on Linux

Creating Studio project

First you should create Aurora Vision Studio project and add new User Filter library on Windows. Refer to Creating User Filters Studio article for details.

Implement and build your User Filter. Then in Aurora Vision Studio add it to program and use it as needed. Note that path to the User Filter should be relative to the project.

Building User Filter on Linux

On Linux install avexecutor. Copy source code of your User Filter to Linux. To build it using gcc, you will need to:

- add the avexecutor's include/ subdirectory to the compiler include directories: -I switch
- add the avexecutor's lib/x86_64-linux-gnu/ subdirectory to the linker directories: -L switch
- link with Aurora Vision Library Lite and UserFilters: -lAVL_Lite -lUserFilters
- signify we are building a shared library: -shared -fPIC
- set output name to .so: -o user_filter_library.so

Loading User Filter library from Studio program

Copy Studio project files to Linux. Put built .so User Filter library in directory relative to project files. Make sure the file name of User Filter selected on Windows (e.g. user_filter_library.dll) matches name of .so file. The file extension will be changed automatically by Console application.

Then the program can be started as usual: <path to Console application> <path to .avproj file>

Using AVL instead of AVL Lite

User Filter can alternatively be built using full AVL library. The process described above will need to be changed as follows:

- point compiler also to include and lib directories of AVL
- link with AVL instead of AVL_Lite: -lAVL
- copy libAVL.so from AVL directory to avexecutor/lib/x86_64-linux-gnu/ directory
- change #include to <AVL.h>
- remember to modify Visual Studio solution on Windows in a similar manner

3. Technical Issues

Table of content:

Interfacing with Other Libraries

Aurora Vision Library contains the avl::Image class which represents an image. This article describes how to create an avl::Image object with raw data acquired from cameras, and how to convert it to image structures specific to other libraries.

Aurora Vision Library provides a set of sample converters. To use it in your program you should include a specific header file which is available in Aurora Vision Library include directory (e.g. AVLConverters/AVL_OpenCV.h). The list below presents all the available converters:

- Euresys
- MFC
- MvAcquire
- OpenCV
- Pylon
- QT
- SynView

An example of using MFC converters can be found in the Aurora Vision Library directory in My Documents (Examples\MFC Examples). Below is shown also an OpenCV converter example.

Example: Converting Between avl::Image and OpenCV Mat

It is also possible to convert avl::Image to image structures from common libraries. The example code snippets below show how to convert an avl::Image object to other structures.

```
#include <opencv2/highgui/highgui.hpp>
#include <AVLConverters/AVL_OpenCV.h>

#include <AVL.h>

avl::Image inputImage, processedImage;
cv::Mat cvImage;

int thresholdValue, rotateAngle;

//image processing
void ProcessImage()
{
 avl::Image image1;
 avl::ThresholdImage(inputImage, atl::NIL, (float)thresholdValue, atl::NIL, 0.0, image1);
 avl::RotateImage(image1, (float)rotateAngle, avl::RotationSizeMode::Fit,
  avl::InterpolationMethod::Bilinear, false, processedImage);
}

// callback
void on_trackbar(int, void*)
{
 ProcessImage();

 avl::AvlImageToCVMat_Linked(processedImage, cvImage);
 cv::imshow("CV Result Window", cvImage);
}

int main(void)
{
 // Load AVL image
 avl::Image monoImage, rgbImage;
 avl::TestImage(avl::TestImageId::Lena, rgbImage, monoImage);
 avl::DownsampleImage(monoImage, 1, inputImage);
 thresholdValue = 128;
 rotateAngle = 0;

 // Create OpenCV Gui
 cv::namedWindow("Settings Window", 1);
 cv::resizeWindow("Settings Window", 300, 80);
 cv::createTrackbar("Threshold", "Settings Window", &thresholdValue, 255, on_trackbar);
 cv::createTrackbar("Rotate", "Settings Window", &rotateAngle, 360, on_trackbar);

 // set trackbar
 on_trackbar(0, 0);

 cv::waitKey(0);
 return 0;
}
```

Example: avl::Image from pointer to image data

It is also possible to create an avl::Image object using a pointer to image data, without copying memory blocks. This, however, requires compatible memory representations of images and proper information about the image being created has to be provided.

The constructor shown below should be used for this operation:

```
Image::Image(int width, int height, int pitch, PlainType::Type type, int depth, void* data,
 atl::Optional< const avl::Region& > inRoi = atl::NIL);
```

Please note that all of the XxxToXxx_Linked functions do not copy data and the user has to take care of freeing such data. See also the usage example in OpenCV converter above. Functions AvlImageToCVMat_Linked and CVMatToAvlImage_Linked do not copy data.

Displaying Images Directly on WinAPI/MFC Device Context (HDC)

For convenience, there is also a function that directly displays an image on a WinAPI device context (HDC). This function is defined in the header "AVLConverters/AVL_Winapi.h" as:

```
void DisplayImageHDC(HDC inHdc, avl::Image& inImage, float inZoomX = 1.0, float inZoomY = 1.0);
```

For sample program showing how to use this function, please refer to the official example in the "06 WinAPI tutorial" directory.

Loading Aurora Vision Studio Files (AVDATA)

Aurora Vision Studio has its own format for storing arbitrary objects - the AVDATA format. It is used for storing elements of the program (paths, regions etc.) automatically, or manually when using "Export to AVDATA file" option or the **SaveObject** and **LoadObject** generic filters.

Aurora Vision Library can load and save several types of objects in AVDATA format. This is done using dedicated functions, two corresponding for each supported type. The functions start with **Load** and **Save** and accept two parameters - a filename and an object reference - for loading or saving.

```
void LoadRegion
(
 const File& inFilename,  //:Name of the source file
 Region& outRegion  //:Deserialized output Region
);
```

```
void SaveRegion
(
 const Region& inRegion,  //:Region to be serialized
 const File& inFilename  //:Name of the target file
);
```

The supported types include:

- Region
- Profile
- Histogram
- SpatialMap
- EdgeModel
- GrayModel
- OcrMlpModel
- OcrSvmModel
- Image*

Because the **LoadImage** function is a more general mechanism for saving and loading images into common file formats (like BMP, JPG or PNG), the functions for loading and saving avl::Image as AVDATA are different:

```
void LoadImageObject
(
 const File& inFilename,  //:Name of the source file
 Image& outImage  //:Deserialized output Image
);
```

```
void SaveImageObject
(
 const Image& inImage,  //:Image to be serialized
 const File& inFilename  //:Name of the target file
)
```

Simple types like **Integer**, **Real** or **String** can be stored in files in textual form - by setting **inStreamMode** to *Text* when using **SaveObject** - this can be read by formatted input output in C/C++ (for example using functions from the scanf family).

Working with GenICam GenTL Devices

Introduction

GenICam GenTL is a standard that defines a software interface encapsulating a transport technology and that allows applications to communicate with general vision devices without prior knowledge of its communication protocol. GenTL supporting application (a GenTL consumer) is able to load a third party dynamic link library (a GenTL provider) that is a kind of a "driver" for a vision device. GenICam standard allows to overcome differences with communication protocols and technologies, and allows to handle different devices in same common way. However application still needs to be aware of differences in device capabilities and be prepared to cooperate with specific device class or device model.

Aurora Vision Library contains a built-in GenTL subsystem that helps and simplifies usage of a GenTL device in vision application. AVL GenTL subsystem helps in loading provider libraries, enumerating GenTL infrastructure, managing acquisition engine and frame buffers, converting image formats and implements GenAPI interface.

In order to be able to use a GenTL provider it needs to be properly registered (installed) in local system. Usually this task is performed by an installer supplied by a device vendor. Please note that a 32bit application requires a 32 bit provider library and a 64 bit application requires respectively a 64 bit provider library. A registered GenTL provider is characterized by a file with ".cti" extension. Path to cti library containing folder is stored in an environmental variable named "GENICAM_GENTL32_PATH" ("GENICAM_GENTL64_PATH" for 64 bit providers).

Basic Usage

Functions designed for GenTL support can be found in GenTL and GenApi categories. A basic application will first use a GenTL_OpenDevice function to open a device instance (to establish the connection) and to request a handle for further operations on the device. This handle can be than used with GenApi functions to access device specific configuration and manage them. When the device identifiers are not fully known, or can dynamically change at runtime a GenTL_FindDevices function can be first used to enumerate available GenTL devices.

To start streaming video out of configured device a GenTL_StartAcquisition function must be executed.

After this sequentially upcoming images can be retrieved with GenTL_ReceiveImage or GenTL_TryReceiveImage functions. Images will be stored in an input FIFO queue. Not retrieved images (on queue overflow) will be dropped starting from the oldest one. To stop image acquisition a GenTL_StopAcquisition function should be called. Image acquisition can be stopped and than started again multiple times for same device with eventual configuration change in between (some parameters can be locked for time of image streaming).

To release the device instance its handle need to be closed with GenTL_CloseHandle function.

Advanced Usage

When more information need to be known about GenTL environment its structure can be explored using GenTL_EnumLibraries, GenTL_GetLibraryDescriptor, GenTL_EnumLibraryInterfaces, GenTL_GetInterfaceDescriptor functions.

When extended information or configuration, specific for GenTL provider or transport technology need to be accessed, following functions can be considered: GenTL_OpenLibrarySystemModuleSettings, GenTL_OpenInterfaceModuleSettings, GenTL_OpenDeviceModuleSettings, GenTL_OpenDeviceStreamModuleSettings.

Additional Requirements

When using GenTL subsystem of Aurora Vision Library a "Genicam_Kit.dll" file is required to be in range of application. This file (selected for 32/64 bit) can be found in Aurora Vision Library SDK "bin" directory.

Processing Images in Worker Thread

Introduction to the Problem

Aurora Vision Library is a C++ library, that is designed for efficient image processing in C++ applications. A typical application uses a single primary thread for the user interface and can optionally use additional worker threads for data processing without freezing the main window of the application. Images processing can be a time-consuming task, so performing it in a separate worker thread is recommended, especially for processing performed in continuous mode.

Processing images in a worker thread is asynchronous and it means that accessing the resources by the worker thread and the main thread has to be coordinated. Otherwise, both threads could access the same resource at the same time, what would lead to unpredictable data corruption. The typical resource that has to be protected to be thread-safe is the image buffer. Typically, the worker thread of the vision application has a loop. In this loop it grabs images from a camera and does some kind of processing. Images are stored in memory of a buffer as *avl::Image* data. The main thread (UI thread) presents the results of the processing and/or images from the camera. It has to be ensured that the images are not read by the UI thread and processed by the worker thread at the same time.

Please note that the GUI controls should never be accessed directly from the worker thread. To display the results of the worker thread processing in the GUI, a resource access control has to be used.

Example Application and Image Buffer Synchronization

This article does not present the rules of multithreaded programming. It only focuses on the most typical aspects of it, that can be met when writing applications with Aurora Vision Library. An example application that uses the main thread and the worker thread can be found among the examples distributed with Aurora Vision Library. It is called *MFC Simple Streaming* and the easiest way to open it is by opening *Examples* directory of Aurora Vision Library from the *Start Menu*. The application is located in *03 GigEVision tutorial* subdirectory. It is a good template for other vision applications processing images in a separate thread. It is written using *MFC*, but the basics of multithreading stay the same for all other technologies.

There are many techniques of synchronization of a shared resources access in a multithreading environment. Each of them is good as long as it protects the resources in all states that the application can be in and as long as it properly handles thrown exceptions, application closing etc.

In the example application, the main form of the application has a private field called *m_videoWorker* that represents the worker thread:

```
class ExampleDlg : public CDialog
{
private:
 (...)
 GigEVideoWorker m_videoWorker;
 (...)
}
```

The *GigEVideoWorker* class contains the image buffer:

```
class GigEVideoWorker
{
 (...)
private:
 avl::Image m_imageBuffer;
 (...)
}
```

This is the image buffer that contains the image received from the camera that needs to be protected from parallel access from worker thread and from the main thread that displays the image in the main form. The access synchronization is internally achieved using critical section and *EnterCriticalSection* and *LeaveCriticalSection* functions of the Windows operating system. When one thread calls the *GigEVideoWorker::LockResults()* function, it enters the critical section and no other thread can access the image buffer until the thread that got the lock calls *GigEVideoWorker::UnlockResults()*. When one thread enters the critical section, other threads that try to enter the critical section will be suspended (blocked) until the one leaves the critical section.

Using functions like *GigEVideoWorker::LockResults()* and *GigEVideoWorker::UnlockResults()* is a good choice for protecting the image buffer from accessing by multiple threads, but what if due to an error in the code the resource is locked but never unlocked? It can happen for example in a situation when an exception is thrown inside the critical section and the code lacks the *try/catch* statement in the function that locks and should unlock the resource. In the example application this problem has been resolved using the *RAII* programming idiom. *RAII* stands for *Resource Acquisition Is Initialization* and in short it means that the resource is acquired by creating the synchronization object and is released by destroying it. In the example application being described here, there is the class called *VideoWorkerResultsGuard*. It

exclusively calls the previously mentioned *GigEVideoWorker::LockResults()* and *GigEVideoWorker::UnlockResults()* functions in constructor and destructor. The instance of this *VideoWorkerResultsGuard* class is the synchronization object. The code of the class is listed below.

```
class VideoWorkerResultsGuard
{
private:
 GigEVideoWorker& m_object;

 VideoWorkerResultsGuard( const VideoWorkerResultsGuard& ); // = delete

public:
 explicit VideoWorkerResultsGuard( GigEVideoWorker& object )
 : m_object(object)
 {
  m_object.LockResults();
 }

 ~VideoWorkerResultsGuard()
 {
  m_object.UnlockResults();
 }
};
```

It can be easily seen that when the object of *VideoWorkerResultsGuard* is created, the thread that creates it calls the *LockResults()* function and by that it enters the critical section protecting the image buffer. When the object is destroyed, the thread leaves the critical section. Please note that the destructor of every object is automatically called in C++ when the automatic variable goes out of scope. It also covers the cases, when the variable goes out of scope because of the exception thrown from within of the critical section. Using *RAII* pattern allows programmer to easily synchronize the access to shared resources from multiple threads. When a thread needs to access a shared image buffer, it has to create the *VideoWorkerResultsGuard* object and destroy it (or let it be destroyed automatically when the object goes out of scope) when the access to the image buffer is no longer needed. The example usage of this synchronization looks as follows:

```
// Retrieve the results under lock.
{
 VideoWorkerResultsGuard guard(m_videoWorker);
 (...)
 avl::AVLImageToCImage(m_videoWorker.GetLastResultData(), width, height, false, m_lastImage);
 (...)
}
```

The method *GetLastResultData()* returns the reference to the shared image buffer. It can be safely used thanks to the usage of *VideoWorkerResultsGuard* object.

Notifications about Image Ready to Display

Another issue that needs to be considered in a typical application that processes images and uses a worker thread is notifying the main thread that the image processed by the worker thread is ready to display. Such notifications can be implemented in several ways. The one that has been used in the example application is using system function *PostMessage()*. When the worker thread has the image ready for presentation, it copies it to the *m_lastResultData* buffer (this is the protected one) and posts the notification message to the main window of the application:

```
//
// TODO: Compute the result data and put them in the shared buffer (just copy the source image).
//
m_lastResultData = m_imageBuffer;

// Send notification message
if (PostMessage(m_hNotificationWindow, m_notificationMessage, 0, NULL))
{
 m_lastResultProcessed = false;
}
```

The message is received by the main (UI) thread. Once it's received, the main thread acquires the access to the shared image buffer by creating the *VideoWorkerResultsGuard* object. Then, the image can be safely displayed.

The worker thread has a flag called *m_lastResultProcessed*. The flag set to *false* indicates that the notification about image ready to display had been posted to the main thread but the main thread has not processed (displayed) the image yet. The flag is set to false just after posting the notification message. The main thread sets the flag back to *true* using *NotificationGiveFeedback()* function:

```
void GigEVideoWorker::NotificationGiveFeedback( void )
{
 VideoWorkerResultsGuard guard(*this);
 m_lastResultProcessed = true;
}
```

Once the worker thread has sent the notification message, it can acquire and perform the next frame from the camera, but there's no point in sending the next notification until the previous is performed by the UI thread. Sending the new notifications without performing the old ones could lead to cumulating them in the messages queue of the main window. This is why the worker thread of the example application checks if the previous notification message has been performed and sends the next one only if the processing of the previous is finished:

```
if (m_lastResultProcessed && NULL != m_hNotificationWindow)
{
 // Create the result in shared buffers under lock.
 VideoWorkerResultsGuard guard(*this);
 (...)
}
```

Please note that the flag is also protected by the *VideoWorkerResultsGuard* synchronization object, so the

main thread cannot set it to *true* in the moment directly after the worker thread posted the notification message.

Issues of Multithreading

There are two primary issues to consider when using worker thread(s). The first one is destroying data by unsynchronized access from multiple threads and the second one is a deadlock that can appear when there are two (or more) resources to be synchronized.

Securing data integrity by the thread synchronization mechanisms has been shortly described in this article and is implemented in the example application distributed with Aurora Vision Library. As a rule of a thumb, please assume that every image that can be accessed from more then one thread should be protected by some kind of synchronization. We recommend the standard C++ *RAII* pattern as an easy to use and secure solution.

The example application described in this article contains only one resource – a critical section represented by the *VideoWorkerResultsGuard* class, but of course there may exist some applications where there is more then one resource to share. In such cases, the synchronization of the threads has to be implemented very carefully because there is a danger of deadlock that can be a result of bad implementation. If your application freezes (stops responding) and you have more then one synchronized resource, please review the synchronization code.

Troubleshooting

This article describes the most common problems that might appear when building and executing programs that use Aurora Vision Library.

Problems with Building

error LNK2019: unresolved external symbol _LoadImageA referenced in function
error C2039: 'LoadImageA' : is not a member of 'avl'

The problem is related to including the "windows.h" file. It defines a macro called *LoadImage*, which has the same name as one of the functions of Aurora Vision Library. Solution:

- Don't include both "windows.h" and "AVL.h" in a single compilation unit (cpp file).
- Use #undef LoadImage after including "windows.h".

error LNK1123: failure during conversion to COFF: file invalid or corrupt

If you encounter this problem, just disable the incremental linking (properties of the project | *Configuration Properties* | *Linker* | *General* | *Enable Incremental Linking*, set to *No (/INCREMENTAL:NO)*). This is a known issue of VS2010 and more information can be found on the Internet. Installing VS2010 Service Pack 1 is an alternative solution.

Exceptions Thrown in Run Time

Exception from the *avl* namespace is thrown

Aurora Vision Library uses exceptions to report errors in the run-time. All the exceptions are defined in *avl* namespace and derive from *avl::Error*. To solve the problem, add a *try/catch* statement and catch all *avl::Error* exceptions (or only selected derived type). Every *avl::Error* object has the *Message()* method which should provide you more detailed information about the problem. Remember that a good programming practice is catching C++ exceptions by a const reference.

```
try
{
    // your code here
}
catch (const atl::Error& er)
{
    cout << er.Message();
}
```

High CPU Usage When Running AVL Based Image Processing

When working with some AVL image processing functions it is possible that the reported CPU usage can reach 50~100% across all CPU cores even in situations when the actual workload does not justify that hight CPU utilization. This behavior is a side effect of a parallel processing back-end worker threads actively waiting for the next task. Although the CPU utilization is reported to be high those worker threads will not prevent other task to be executed when needed, so this behavior should not be a problem in most situations.

For situations when it is not desired this behavior can be changed (e.g. when profiling the application, performance testing or in any situation, when high CPU usage interfere with other system). To block the worker threads from idling for extended period of time the environment variable OMP_WAIT_POLICY must be set to the value PASSIVE, before the application is started:

```
set OMP_WAIT_POLICY=PASSIVE
```

This variable is checked when the DLLs are loaded, so setting it from the application code might not be effective.

Memory Leak Detection in Microsoft Visual Studio

When creating applications using Aurora Vision Library in Microsoft Visual Studio, it may be desirable to enable automated memory leak detection possible in Debug builds. The details of using this feature is described here: Finding Memory Leaks Using the CRT Library.

Some project types, notably MFC (Microsoft Foundation Classes) Windows application projects, have this mechanism enabled by default.

False Positives of Memory Leaks in AVL.dll

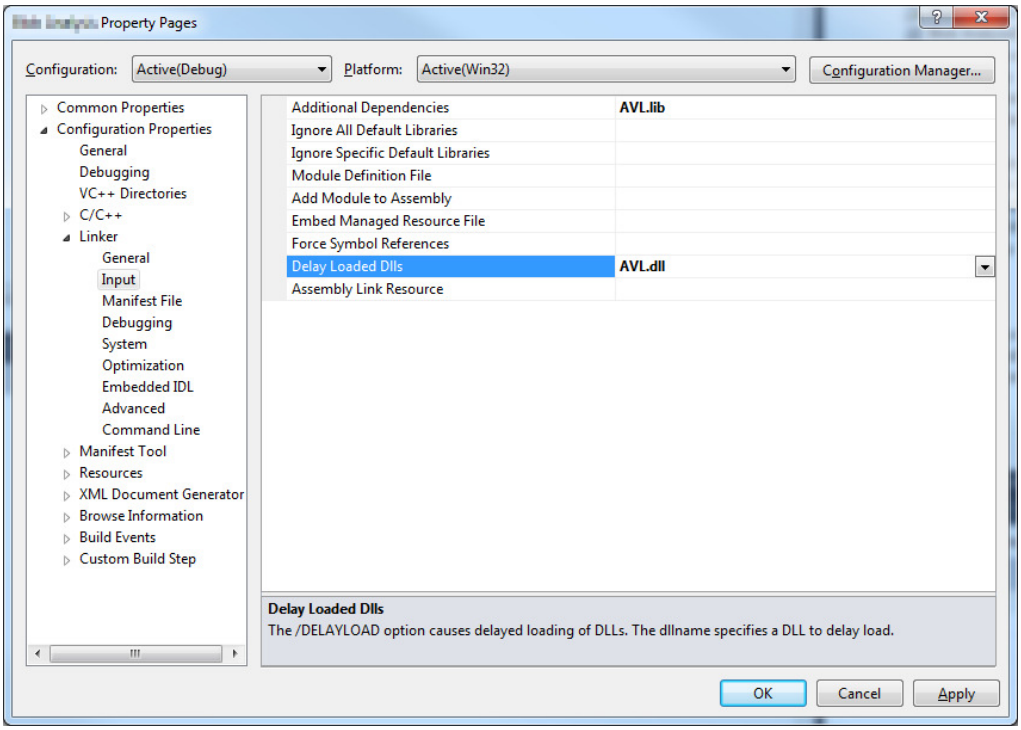
Using a default configuration, as described in Project Configuration can lead to false positives of memory leaks, which come from the AVL.dll library. The output of a finished program can look similar to the following:

```
(...)
The thread 'Win32 Thread' (0x898) has exited with code 0 (0x0).
The thread 'Win32 Thread' (0x168c) has exited with code 0 (0x0).
Detected memory leaks!
Dumping objects ->
{5573} normal block at 0x00453DB8, 8 bytes long.
 Data: <        > 01 00 00 00 00 00 00 00
{5572} normal block at 0x00453D68, 20 bytes long.
 Data: <D]NU         =E > 44 5D 4E 55 CD CD CD CD 02 00 00 00 B8 3D 45 00
{5571} normal block at 0x00453C18, 4 bytes long.
 Data: <X NU> 58 06 4E 55
(...)
```

These are not actual memory leaks, but internal resources of AVL.dll, which are not yet released when the memory leaks check is being run. Because there are many such allocated blocks reported, the actual memory leaks in your program can pass unnoticed.

Solution: Delayed Loading of AVL.dll

To avoid these false positives, AVL.dll should be configured to be delay loaded. This can be done in the Project Properties, under
Configuration Properties » Linker » Input:



Further Consequences

With this configuration, your program will not try to load AVL.dll until it uses the first function from Aurora Vision Library. This will be also connected with license checking.

The program will stop if AVL.dll is missing: if AVL.dll was not delay loaded, this would happen at start time (the program would refuse to run). This allows the program to work without AVL.dll, and use it only when it is available. The availability of AVL.dll can be checked beforehand, using LoadLibrary or LoadLibraryEx functions.

ATL Data Types Visualizers

Data Visualizers

Data visualizers present data during the debugging session in a human-friendly form. Microsoft Visual Studio allows users to write custom visualizers for C++ data. Aurora Vision Library is shipped with a set of visualizers for the most frequently used ATL data types: *atl::String*, *atl::Array*, *atl::Conditional* and *atl::Optional*.

Visualizers are automatically installed during installation of Aurora Vision Library and are ready to use, but they are also available at *atl_visualizers* subdirectory of Aurora Vision Library installation path.

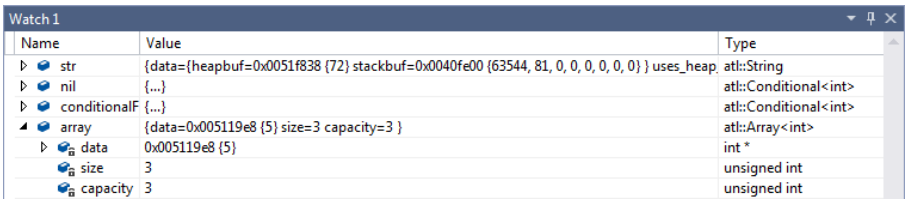
For more information about visualizers, please refer to the MSDN.

Example ATL data visualization

Please see the example variables definition below and their visualization without and with visualizers.

```
atl::String str = L"Hello world";
atl::Conditional nil = atl::NIL;
atl::Conditional conditionalFive = 5;
atl::Array array(3, 5);
```

Data preview without ATL visualizers installed:



The same data presented using AVL visualizers:

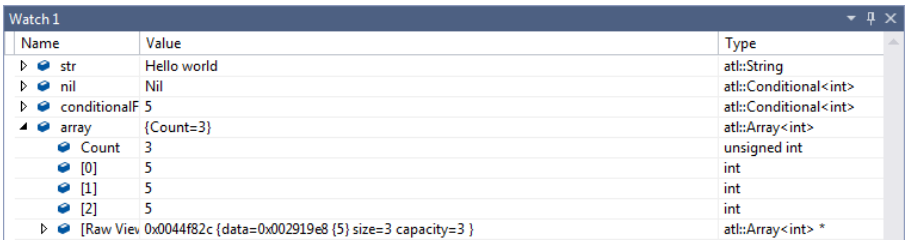


Image Watch extension

For Microsoft Visual Studio 2015, 2017 and 2019 an extension Image Watch is available. Image Watch allows to display images during debugging sessions in window similar to "Locals" or "Watch". To make Image Watch work correctly with *avl::Image* type, Aurora Vision Library installer provides avl::Image visualizer for Image Watch. If one have Image Watch extension and AVL installed, preview of images can be enabled by choosing "View->Other Windows->Image Watch" from Microsoft Visual Studio menu.

avl::Image description for Image Watch extension is included in *atl.natvis* file, which is stored in *atl_visualizers* folder in Aurora Vision Library installation directory. *atl.natvis* file is installed automatically during Aurora Vision Library installation.

When program is paused during debug session, all variables of type avl::Image can be displayed in Image Watch window, as shown below:

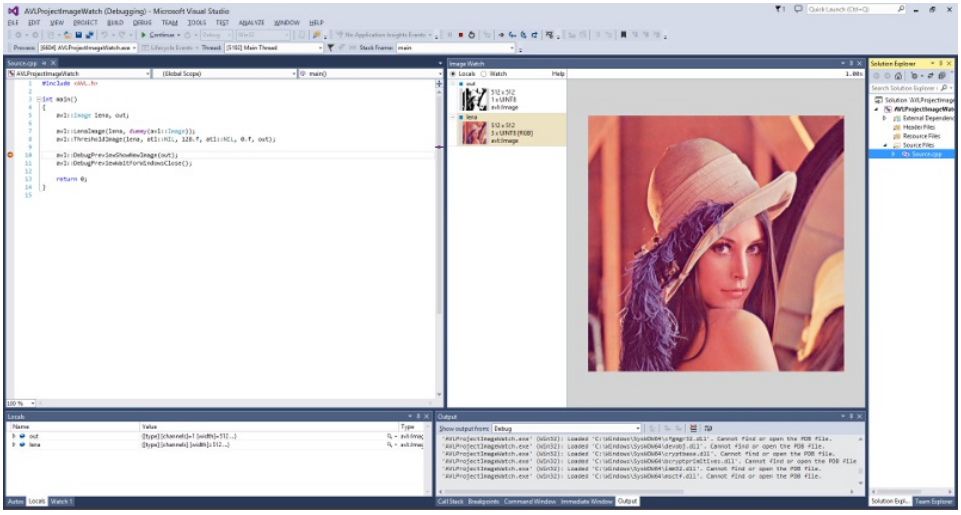


Image displayed inside Image Watch can be zoomed. When the close-up is large enough, decimal values of pixels' channel will be displayed. Hexadecimal values can be displayed instead, if appropriate option from context menu is selected.

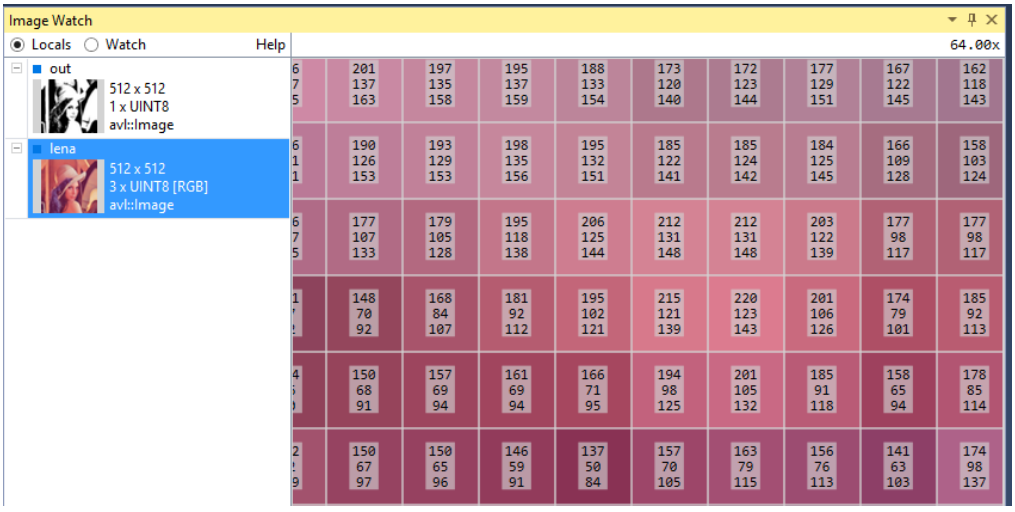


Image Watch is quite powerful tool - one can copy address of given pixel, ignore alpha channel and much more. All options are described in its documentation, which is accessible from the Image Watch site at:

- ImageWatch 2019 - for Microsoft Visual Studio 2019
- ImageWatch 2017 - for Microsoft Visual Studio 2017
- ImageWatch - for older versions of Microsoft Visual Studio

Optimizing Image Analysis for Speed

General Rules

Rule #1: Do not compute what you do not need.

- Use image resolution well fitted to the task. The higher the resolution, the slower the processing.
- Use the **inRoi** input of image processing functions to compute only the pixels that are needed in further processing steps.
- If several image processing operations occur in sequence in a confined region then it might be better to use CropImage at first.
- Do not overuse images of types other than UInt8 (8-bit).
- Do not use multi-channel images, when there is no color information being processed.
- If some computations can be done only once, move them before the main program loop, or even to a separate function.

Rule #2: Prefer simple solutions.

- Do not use Template Matching if more simple techniques as Blob Analysis or 1D Edge Detection would suffice.
- Prefer pixel-precise image analysis techniques (Region Analysis) and the *Nearest Neighbour* (instead of *Bilinear*) image interpolation.
- Consider extracting higher level information early in the program – for example it is much faster to process Regions than Images.

Rule #3: Mind the influence of the user interface.

- Note that displaying data in the user interface takes much time, regardless of the UI library used.
- Mind the Diagnostic Mode. Turn it off whenever you need to test speed. Diagnostic Mode can be turn off or on by EnableAvlDiagnosticOutputs function. One can check, if Diagnostic Mode is turned on by GetAvlDiagnosticOutputsEnabled function.
- Before optimizing the program, make sure that you know what really needs optimizing. Measure execution time or use a profiler.

Common Optimization Tips

Apart from the above general rules, there are also some common optimization tips related to specific functions and techniques. Here is a check-list:

- Template Matching: Prefer high pyramid levels, i.e. leave the **inMaxPyramidLevel** set to *atl::NIL*, or to a high value like between *4* and *6*.
- Template Matching: Prefer **inEdgePolarityMode** set not to Ignore and **inEdgeNoiseLevel** set to Low.
- Template Matching: Use as high values of the **inMinScore** input as possible.
- Template Matching: If you process high-resolution images, consider setting the **inMinPyramidLevel** to *1* or even *2*.
- Template Matching: When creating template matching models, try to limit the range of angles with the **inMinAngle** and **inMaxAngle** inputs.
- Template Matching: Consider limiting **inSearchRegion**. It might be set manually, but sometimes it also helps to use Region Analysis techniques before Template Matching.
- Do not use these functions in the main program loop: CreateEdgeModel1, CreateGrayModel, TrainOcr_MLP, TrainOcr_SVM.
- If you always transform images in the same way, consider functions from the Image Spatial Transforms Maps category instead of the ones from Image Spatial Transforms.
- Do not use image local transforms with arbitrary shaped kernels: DilateImage_AnyKernel, ErodeImage_AnyKernel, SmoothImage_Mean_AnyKernel. Consider the alternatives without the "_AnyKernel" suffix.
- SmoothImage_Median can be particularly slow. Use Gaussian or Mean smoothing instead, if possible.

Library-specific Optimizations

There are some optimization techniques that are available only in Aurora Vision Library and not in Aurora Vision Studio. These are:

In-Place Data Processing

See: In-Place Data Processing.

Re-use of Image Memory

Most image processing functions allocate memory for the output images internally. However, if the same object is provided in consecutive iterations and the dimensions of the images do not change, then the memory can be re-used without re-allocation. This is very important for the performance considerations, because re-allocation takes time which is not only significant, but also non-deterministic. Thus, it is highly advisable to move the image variable definition before the loop it is computed in:

```
// Slow code
while (...)
{
 Image image2;
 ThresholdImage(image1, atl::NIL, 128.0f, atl::NIL, 0.0f, image2);
}
```

```
// Fast code
Image image2;
while (...)
{
 ThresholdImage(image1, atl::NIL, 128.0f, atl::NIL, 0.0f, image2);
}
```

```
// Fast code (also in the first iteration)
Image image2(752, 480, PlainType::UInt8, 1, atl::NIL); // memory pre-allocation (dimensions must be known)
while (...)
{
 ThresholdImage(image1, atl::NIL, 128.0f, atl::NIL, 0.0f, image2);
}
```

Skipping Background Initialization

Almost all image processing functions of Aurora Vision Library have an optional **inRoi** parameter, which defines a region-of-interest. Outside this region the output pixels are initialized with zeros. Sometimes, when the rois are very small, the initialization might take significant time. If this is an internal operation and the consecutive operations do not read that memory, the initialization can be skipped by setting IMAGE_DIRTY_BACKGROUND flag in the output image. For example, this is how dynamic thresholding is implemented internally in AVL, where the out-of-roi pixels of the **blurred** image are not meaningful:

```
Image blurred;
blurred.AddFlags(IMAGE_DIRTY_BACKGROUND);
SmoothImage_Mean(inImage, inRoi, inSourceRoi, atl::NIL, KernelShape::Box, radiusX, radiusY, blurred);
ThresholdImage_Relative(inImage, inRoi, blurred, inMinRelativeValue, inMaxRelativeValue, inFuzziness, outMonoImage);
```

Library Initialization

Before you call any AVL function it is recommended to call the InitLibrary function first. This function is responsible for precomputing library's global data. If it is not used explicitly, it will be called within the first invocation of any other AVL function, taking some additional time.

Configuring Parallel Computing

The functions of Aurora Vision Library internally use multiple threads to utilize the full power of multi-core processors. By default they use as many threads as there are physical processors. This is the best setting for majority of applications, but in some cases another number of threads might result in faster execution. If you need maximum performance, it is advisable to experiment with the ControlParallelComputing function with both higher and lower number of threads. In particular:

- If the number of threads is **higher** than the number of physical processors, then it is possible to utilize the Hyper-Threading technology.
- If the number of threads is **lower** than the number of physical processors (e.g. 3 threads on a quad-core machine), then the system has at least one core available for background threads (like image acquisition, GUI or computations performed by other processes), which may improve its responsiveness.

Configuring Image Memory Pools

Among significant factors affecting function performance is memory allocation. Most of the functions available in Aurora Vision Library re-use their memory buffers between consecutive iterations which is highly beneficial for their performance. Some functions, however, still allocate temporary image buffers, because doing otherwise would make them less convenient in use. To overcome this limitation, there is the function ControlImageMemoryPools which can turn on a custom memory allocator for temporary images.

There is also a way to pre-allocate image memory before first iteration of the program starts. For this purpose use the InspectImageMemoryPools function at the end of the program, and – after a the program is executed – copy its **outPoolSizes** value to the input of a ChargeImageMemoryPools function executed at the beginning. In some cases this will improve performance of the first iteration of program.

Using GPGPU/OpenCL Computing

Some functions of Aurora Vision Library allow to move computations to an OpenCL capable device, like a graphics card, in order to speed up execution. After proper initialization, OpenCL processing is performed completely automatically by suitable functions without changing their use pattern. Refer to "Hardware Acceleration" section of the function documentation to find which functions support OpenCL processing and what are their requirements. Be aware that the resulting performance after switching to an OpenCL device may vary and may not always be a significant improvement relative to CPU processing. Actual performance of the functions must always be verified on the target system by proper measurements.

To use OpenCL processing in Aurora Vision Library the following is required:

- a processing device installed in the target system supporting OpenCL C language in version 1.1 or greater,
- a proper and up-to-date device driver installed in the system,
- a proper OpenCL runtime software provided by its vendor.

OpenCL processing is supported for example in the following functions: RgbToHsi, HsiToRgb, ImageCorrelationImage, DilateImage_AnyKernel.

To enable OpenCL processing in functions an AvsFilter_InitGPUProcessing function must be executed at the beginning of a program. Please refer to that function documentation for further information.

Deep Learning Training API

Note: This article is related to the C++ Deep Learning API for Feature Detection and Anomaly Detection techniques in 5.6 version only.

Table of contents:

Overview

The Deep Learning API provides a comprehensive framework for training and deploying Deep Learning models, focused on feature detection tasks. It offers an object-oriented interface that simplifies the complexities of configuring and managing Deep Learning operations. Whole API declaration is located in Api.h file. under avl namespace.

Namespaces

- avl: Main namespace containing all public-facing classes and types.

Classes and Types

avl::DetectFeaturesTraining

This is the primary class users should interact with for feature detection training. It is derived from TrainingBase and provides specialized methods and properties for configuring and managing feature detection tasks.

Constructors

```
DetectFeaturesTraining();
```

```
explicit DetectFeaturesTraining(const atl::String& url);
```

Configuration Methods

Training configuration can be performed in two ways:

1. **Via Set Methods:** Configuration can be done using methods like SetDevice, SetNetworkDepth, and other Set* methods. If a specific Set* method is not called, the default value will be used.
2. **Via JSON File:** Use the ParseConfigFromFile method to load configuration from a JSON file.

Enums

- SetType: Specifies the dataset role (Train, Valid, Test, Unknown).
- DeviceType: Defines the hardware device for training (CUDA, CPU).
- ModelTypeId: Identifies the model type (e.g., DetectFeatures, AnomalyDetection2SimilarityBased).

Functions

ParseConfigFromFile

Loads configuration from a JSON file.

```
void ParseConfigFromFile(const atl::String& jsonConfigFilePath);
```

Example of JSON file configuration below.

StartTraining

Begins the training process.

```
void StartTraining();
```

SaveModel

Saves the trained model to disk in two formats:

- A model state file (.pte) for internal use and training continuation
- A Weaver model file (.avdlmodel) for deployment in applications

Method Signatures

```
void SaveModel(const atl::Optional<atl::String>& modelDirectoryPath = atl::NIL, const bool overwritePreviousModel =
false);
void SaveModel(const char* modelDirectoryPath, const bool overwritePreviousModel = false);
```

Parameters

- modelDirectoryPath: Optional path to a directory where model files will be saved. If not provided (default), models are saved in the default directory: [current working directory]/Model/models/
- overwritePreviousModel: When set to true, any existing model files at the destination will be overwritten. When false (default), and model files exist, an error will be raised.

Helper Methods

After saving, you can retrieve the exact paths to the saved model files using:

- GetModelStateFilePath(): Returns the path to the .pte model state file
- GetModelWeaverFilePath(): Returns the path to the .avdlmodel Weaver model file

Usage Examples

```
// 1. Save to default location:
training.SaveModel();

// 2. Save to default location and overwrite existing files:
training.SaveModel(atl::NIL, true);

// 3. Save to custom location:
training.SaveModel("C:/My/Models/Path");

// 4. Save to custom location and overwrite existing files:
training.SaveModel("C:/My/Models/Path", true);

// 5. Get saved file paths:
std::cout << "Model State (.pte) saved to: " << training.GetModelStateFilePath().CStr8() << std::endl;
std::cout << "Weaver Model (.avdlmodel) saved to: " << training.GetModelWeaverFilePath().CStr8() << std::endl;
```

LoadModel

Loads a previously saved model state (.pte) file for inference.

Method Signatures

```
void LoadModel(const atl::String& modelFilePath);
void LoadModel(const char* modelFilePath);
```

Parameters

- modelFilePath: Path to a model state file (.pte) to load. The method will load the specified model file for inference operations.

Functionality

Loading a model allows you to:

- Perform inference on new images using a trained model

Usage Examples

```
// 1. Load a specific model file:
training.LoadModel("C:/My/Models/Path/model.pte");

// 2. Load using the path from a previous save operation (PTE file):
training.SaveModel();  // Save first
training.LoadModel(training.GetModelStateFilePath());  // Load the saved model
```

Important Notes

- This method loads only the model state (.pte) file used for training and inference within this API
- The Weaver model (.avdlmodel) files created by SaveModel() are for deployment in production applications
- After loading, the model is immediately ready for inference with InferAndGrade()

GetModelStateFilePath & GetModelWeaverFilePath

Helper methods to retrieve the paths of saved model files.

Method Signatures

```
atl::String GetModelStateFilePath();
atl::String GetModelWeaverFilePath();
```

Return Values

- GetModelStateFilePath(): Returns the full path to the saved model state file (.pte)
- GetModelWeaverFilePath(): Returns the full path to the saved Weaver model file (.avdlmodel)

Usage

These methods can be called only **after SaveModel()** to get the exact file paths where the models were saved:

```
training.SaveModel("./MyModels");
std::cout << "PTE model saved to: " << training.GetModelStateFilePath().CStr8() << std::endl;
std::cout << "Weaver model saved to: " << training.GetModelWeaverFilePath().CStr8() << std::endl;
```

InferAndGrade

Performs inference and grades the results. If the InferResultReceived method is overridden, it will be utilized during the inference process.

```
void InferAndGrade(
    const atl::String& imageFilePath,
    const Annotation& annotation,
    const atl::Optional<avl::Region>& roi = atl::NIL,
    const atl::Optional<atl::Array<atl::String>>& setNames = atl::NIL);
```

Parameters

- imageFilePath: Path to the image for inference.

- annotation: Annotation with class name (and optional region) used for grading or context.
- roi (optional): Region of interest. When omitted or atl::NIL, the full image is used.
- setNames (optional): Logical grouping / tag list for evaluation summary (e.g. custom test subsets).

Handling Events

To communicate with the user during training and inference, several events are available:

- TrainingProgressReceived(double progress): Called to update progress during training.
- InferResultReceived(const atl::Array<avl::Image>&): Invoked when inference results are available.

Usage Example

Below is an example demonstrating how to use the API for training a feature detection model:

```
#include "Api.h"
#include <iostream>

using namespace avl;

class MyTraining : public DetectFeaturesTraining
{
public:
 MyTraining()
 {
 }

 void TrainingProgressReceived(double progress) override
 {
  std::cout << "Progress: " << progress << std::endl;
 }

 void InferResultReceived(const atl::Array<avl::Image>& inferResultImages) override
 {
  (void)inferResultImages;
  //  for (const auto& inferResultImage : inferResultImages)
  // std::cout << "InferResult: " << "Width: " << inferResultImage.Width() <<, " Height: " <<
inferResultImage.Height() << std::endl;
 }
};

int main()
{
 MyTraining training;

 // Training dataset
 auto myTrainingSamples = atl::Array<atl::String>();
 myTrainingSamples.PushBack("Images/train/010.png");
 myTrainingSamples.PushBack("Images/train/011.png");
 myTrainingSamples.PushBack("Images/train/012.png");

 // Validation dataset
 auto myValidationSamples = atl::Array<atl::String>();
 myValidationSamples.PushBack("Images/valid/020.png");
 myValidationSamples.PushBack("Images/valid/021.png");
 myValidationSamples.PushBack("Images/valid/022.png");

 // Test dataset
 auto myTestSamples = atl::Array<atl::String>();
 myTestSamples.PushBack("Images/test/140.png");
 myTestSamples.PushBack("Images/test/141.png");
 myTestSamples.PushBack("Images/test/142.png");

 // Set names for samples used for infer and grade
 auto mySetNames = atl::Array<atl::String>();
 mySetNames.PushBack("my test set 1");
 mySetNames.PushBack("my test set 2");

 // Create a simple annotation mask for the training samples.
 atl::String myClassName = "thread";
 const int width = 648; // Example width and height, should match your training images
 const int height = 486;
 avl::Region myRegion(width, height);
 for (int y = height / 4; y < (height / 4 + height / 2); ++y)
  myRegion.Add(width / 4, y, (width / 4 + width / 2));
 auto myAnnotation = Annotation(myClassName, myRegion);

 // Set training configuration
 // MANUALLY:
 training.SetNetworkDepth(3);
 training.SetIterations(1);
 training.SetDevice(DeviceType::CUDA);
 training.SetToGrayscale(true);
 training.SetAugNoise(5.5);
 // training.SetClassNames(myClassName);  //Optional

 // Or from file:
 // training.ParseConfigFromFile("detect_features_config.json");

 // OPTIONAL:
 // training.Configure(); // Optional
 // training.GetConfig(); // Call `training.Configure();` before `training.GetConfig()` otherwise it will use default
config

 for (const auto& sample : myTrainingSamples)
  training.SetSample(sample, myAnnotation, SetType::Train);

 for (const auto& sample : myValidationSamples)
  training.SetSample(sample, myAnnotation, SetType::Valid);

 training.StartTraining();

 training.SaveModel();
 std::cout << "Model State (.pte) saved into file: " << training.GetModelStateFilePath().CStr8() << std::endl;
 std::cout << "Model Weaver (.avdlmodel) saved into file: " << training.GetModelWeaverFilePath().CStr8() << std::endl;

 // Load the model state for inference (use .pte file, not .avdlmodel)
 training.LoadModel(training.GetModelStateFilePath());

 for (const auto& sample : myTestSamples)
  training.InferAndGrade(sample, myAnnotation, atl::NIL, mySetNames);

 return 0;
}
```

JSON Configuration Example

Below is an example of JSON Configuration File for a feature detection model:

```
{
    "device": "cuda",
    "device_id": 0,
    "is_continuation": false,
    "network_depth": 3,
    "iterations": 2,
    "min_number_of_tiles": 6,
    "need_to_convert_samples": false,
    "stop.training_time_s": 0,
    "stop.validation_value": 0.0,
    "stop.stagnant_iterations": 0,
    "feature_size": 96,
    "aug.rotation": 0.0,
    "aug.scale.min": 1.0,
    "aug.scale.max": 1.0,
    "aug.shear.vertical": 0.0,
    "aug.shear.horizontal": 0.0,
    "aug.flip.vertical": false,
    "aug.flip.horizontal": false,
    "aug.noise": 2.0,
    "aug.blur": 0,
    "aug.luminance": 0.04,
    "aug.contrast": 0.0,
    "to_grayscale": false,
    "downsample": 2,
    "is_mega_tiling": false,
    "mega_tile_size": 128,
    "class_names": "thread",
    "adv.class_names_sep": ";"
}
```

Best Practices

- Use DetectFeaturesTraining for feature detection tasks instead of directly using TrainingBase.
- Extend DetectFeaturesTraining for custom behavior during training.
- Ensure balanced datasets for training and validation.
- Use callback methods to monitor training progress.

Limitations and Notes

- The ExportQuantizedModel method is not supported for DetectFeaturesTraining.
- Configuration can be done through property setters or by loading a JSON configuration file.
- SaveModel() creates two files: a .pte file for training/inference and a .avdlmodel file for deployment.
- LoadModel() only loads .pte files for inference operations within this API.
- Weaver model files (.avdlmodel) are intended for deployment in production applications, not for loading back into the training API.
- Provide an atl::Optional<avl::Region> ROI to limit inference processing area; pass atl::NIL (or omit parameter) to use the full image.
- An Annotation without a region is valid for tasks that don't require pixel masks.

4. Working with GigE Vision® Devices

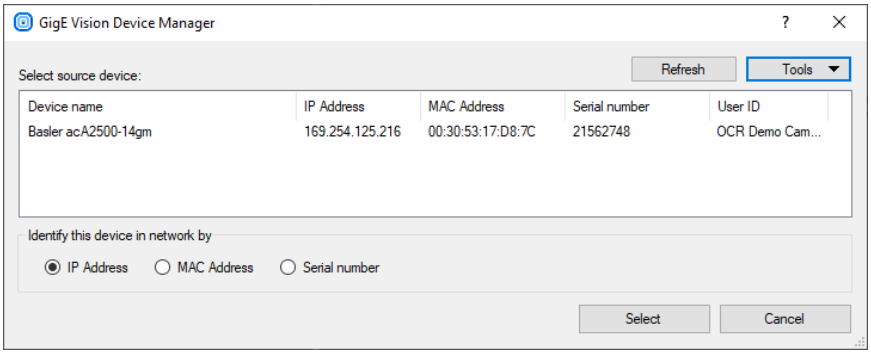
Table of content:

GigE Vision® Device Manager

The Device Manager is available as a separate tool in Aurora Vision Library SDK.

Device Manager Functions

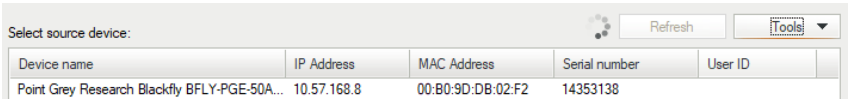
Typical state of the Device Manager is shown on image below. Note that the window may change its appearance depending on its purpose (like selecting a device address in a filter).



At first the manager will search local network for active devices. All found devices will be shown in list with the following information: manufacturer name and device name, current IP address, network interface hardware address (MAC address), serial number (if supported), user specified name (saved in the device memory; if supported by device). Informations like MAC address and serial number should be printed on the device casing for easy identification. Sometimes, when a device has more than one interface, is may appear in list more that once. In this situation every entry in the list identifies another device feature.

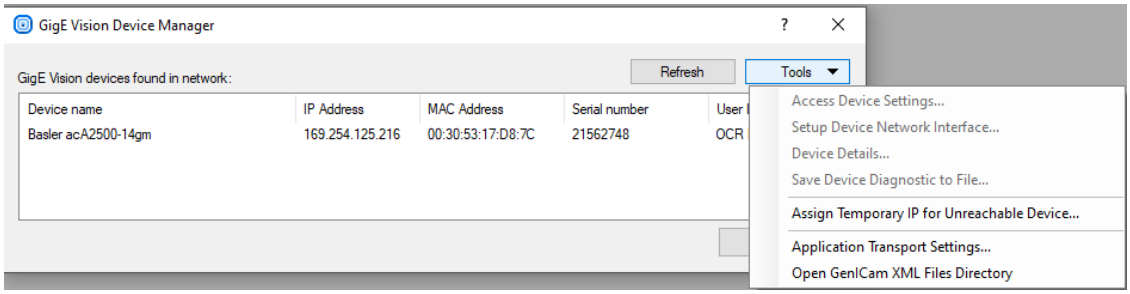
Refresh

Refresh button performs a new search in the network. Use this function when the network configuration has been changed, a new device has been plugged in or when your device has not been found at startup.



Tools

Tools button opens a menu with functions designed for device configuration. Some of these functions are device dependant and require the user to selected a device on the list first (they are also available in a device context menu).



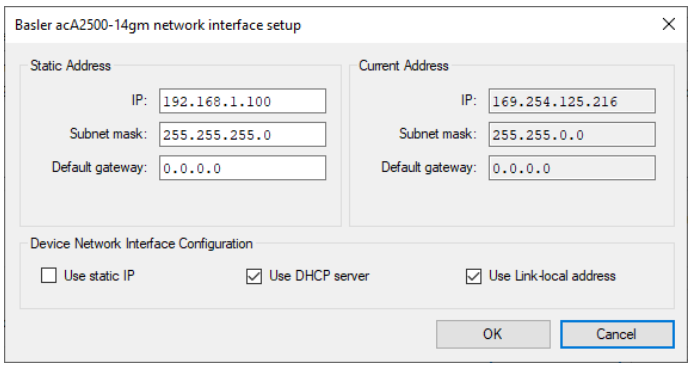
Tool: Access Device Settings...

This tool allows to access device-specific parameters prepared by its manufacturer and available through GenICam interface.

See: Device Settings Editor

Tool: Setup Device Network Interface...

This tool is intended to manage network configuration of a device network adapter.



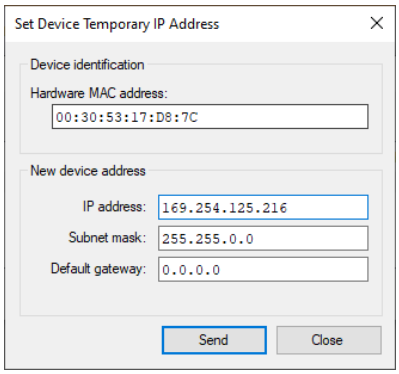
- **Static address** – this field allows to set a static (persistent) network configuration saved in device non-volatile memory. Use this setting when the device is identified by IP address that cannot change or when automatic address configuration is not available. This field has no effect when *Use static IP* field is not checked.
- **Current address** – this read-only field shows current network configuration of a device, for example the address assigned to it by a DHCP server.

- **Device IP configuration** – this field allows to activate or deactivate specified methods of acquiring addresses by a device on startup. Some of this options can be not available (grayed) when the device is not supporting specified mode.
  - **Use static IP** – Device will use address specified in *Static address* field.
  - **Use DHCP server** – When a DHCP server is available in the network, devices will acquire automatically assigned address from it.
  - **Use Link-local address** – When there is no other method available a device will try to find a free address from 169.254.-.- range. When using this method (for example on a direct connection between the device and a computer) the device will take significantly more time to become available in network after startup.

After clicking OK the new configuration will be send to a device. Configuration can be changed only when the device is not used by another application and/or is not streaming video. New configuration may be not available until the device is restarted or reconnected.

Tool: Assign Temporary IP for Unreachable Device

This tool is intended for situations when a device cannot be accessed because of its invalid or unspecified network configuration (note that this should be a very rare case and usually the device should appear in list). The tool allows to immediately change network address of an idle device (thus realizing GigE Vision® FORCE IP function).



This tool requires a user to specify device hardware network adapter MAC address (should be printed on device casing). After that a new IP configuration can be specified. The address can be changed only when the device is idle (is not connected to other application and not streaming video). The new address will be available immediately after successful send operation.

Tool: Application Transport Settings...

This tool allows to access and edit application settings related with driver transport layer, like connection attempts and timeouts. Settings are saved and used at whole application level. Changes affects only newly opened connections.

Changes made in Device Manager application does not affect applications based on Aurora Vision Library. Application must set up its transport layer configuration individually (see GigEVision_OpenSystemConfiguration).

Tool: Open GenICam XML Directory

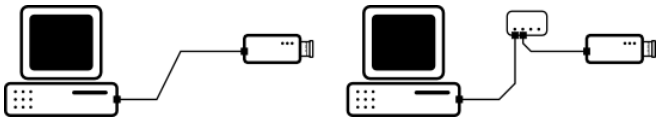
GigE Vision® devices are implementing GenICam standard. GenICam standard requires that a device must be described by a special XML file that defines all device parameters and capabilities. This file is usually obtained automatically by the application from the device memory or from manufacturer's internet web page. Sometimes the XML file can be supplied by manufacturer on a separate disk. Aurora Vision Studio and Aurora Vision Executor use a special directory for these files which is located in the user data directory. Use this tool to open that directory.

Device description files should be copied into this directory without changing their name, extension and content. File can also be supplied as a ZIP archive – do not decompress such file nor change its extension.

Connecting Devices

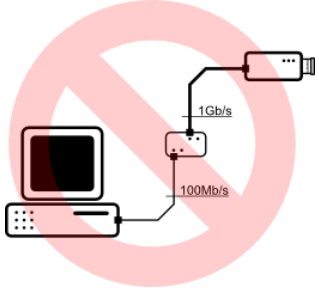
Connecting a GigE Vision device to a computer means plugging both into the same Ethernet network.

It is recommended that the connection is as simple as possible. To achieve best performance use direct connection with a crossed Ethernet cable or connect the camera and the computer to the same Ethernet switch (without any other heavy traffic routed through the same switch).



The device and the computer must reside in a single local area network and must be set up for the same subnet.

GigE Vision® is designed for 1 Gb/s networks, but it is also possible to use 100 Mb/s connection as long as the entire network connection have an uniformed speed (some custom device configuration might be required when the device is not able to detect connection speed automatically). It is recommended however to avoid connecting a device to a network link which is faster than the maximum throughput of the whole network route. Such configurations require manual setting of the device's transmission speed limit.



Firewall Issues

GigE Vision® protocol produces a specific type of traffic that is not *firewall friendly*. Typical firewall software is unable to recognize that video streaming traffic is initialized by a local application and will block this connection. Aurora Vision's GigE driver attempts to overcome this problem using *firewall traversal mechanism*, but not all devices support this.

It is thus required to enable incoming traffic on all UDP ports for Aurora Vision Studio and Aurora Vision Executor in a firewall on your local computer.

For information how to enable such traffic in Windows Firewall see: Enabling Traffic in Firewall.

Configuring IP Address of a Device

In most situations a GigE Vision device is able to automatically obtain an IP address without user action (using DHCP server or automatic local link address). It is however recommended to set a static IP address for both local network card and device whenever possible. In some cases (e.g. when preparing the device for operation in an industrial network) it might be required to access and set/change the device's network configuration for a proper static IP address. Most suitable for this purpose will be a software and a documentation provided by the device manufacturer. When these are not available Aurora Vision Studio offers universal configuration tools available from the GigE Vision Device Manager (see: Device Manager section).

Packet Size

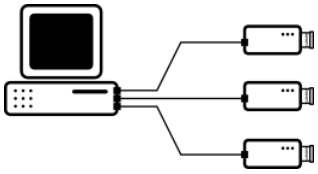
Network video stream is divided into packets of a specified size. The packet size is limited by the Ethernet standard but some network cards support an extension called *jumbo packet* that increases allowed packet size. Because a connection is more efficient when the packet size is bigger, the application will attempt to negotiate biggest possible network packet size for current connection, taking advantage of enabled jumbo packets.

For information how to enable jumbo packets see: Enabling Jumbo Packets

Connecting Multiple Devices to a Single Computer

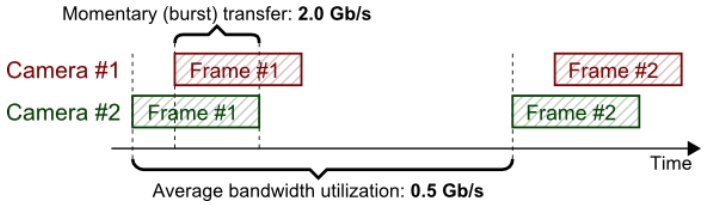
It is possible to connect multiple GigEVision cameras to a single computer and to perform image processing based on multiple video streams (e.g. observing objects from multiple sides), however it can introduce multiple technical challenges that must be considered.

For the best performance it is recommended to connect all devices directly to the computer using multiple gigabit network cards:



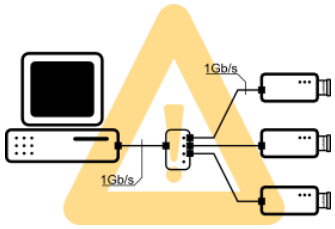
In such configuration it is required for the computer hardware to handle concurrent gigabit streams at once. Even when separate network cards are able to receive the network streams there still may be problems for the computer hardware to transfer data from the network adapters to the system memory. Attention must be paid when choosing hardware for such applications. When given requirements are not met the system may observe excessive packets loss leading to the video stream frames loss.

Even when the cameras framerate is low and the resulting average network throughput is relatively low the system still **may drop packets during network bursts** when the momentary data transfer exceeds the system capabilities. Such burst may appear when multiple cameras transmit a single frame at the same time. By default GigEVision camera is transferring a single frame with maximum available speed and lowering framerate is only increasing the gaps between frame transfers:



Although diagnostic tools will report network throughput utilization to be well below system limits it is still possible for short burst transfers to temporary exceed the system limits resulting in packets drop. To overcome such problems it is required to not only ensure camera framerates to be below proper limit, but also to limit the maximum network transfer speed of the device network adapters. Refer to the device documentation for details about how to limit the network transfer speed in specific device. Usually this can be achieved by decreasing value of parameters such as *DeviceLinkThroughputLimit* or *StreamBytesPerSecond* (in bytes per second), or by introducing delays in between the network packets by increasing parameters such as *PacketDelay*, *InterPacketDelay* or *GevSCPD* (measured in internal device timer ticks - must be calculated individually for device using device timer frequency).

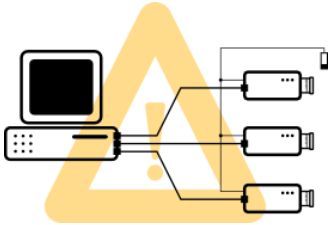
Above requirements are especially important when cameras are connected to the computer using a single network card and a shared network switch:

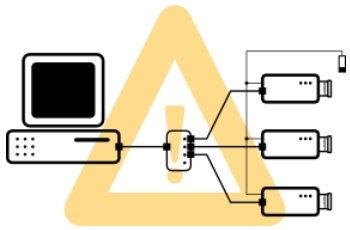


Special care must be taken to assure that all the cameras connected to the switch (when all transmitting at once) do not exceed transfer limits of the connection between the switch and the computer, both average transfer (by limiting the framerate) as well as temporary burst transfer (by limiting network transfer speed). Network switch will attempt to handle burst transfers by storing the packets in its internal buffer and transmitting packets stored in the buffer after the burst, but when the amount of data in burst transfer exceeds the buffer size the network packets will be dropped. Thus it is required for the switch buffer to be large enough to store all camera frames captured at once, or to limit transmission speed for the switch buffer to not overflow.

It is important to note that **the maximum performance of the multi-camera system with shared network switch is limited by the throughput of the link between the switch and the computer**, and usually it will not be possible to achieve the maximum framerate and/or resolution of the cameras.

A common case of using multiple cameras at once is to capture multiple photos of a object from a single trigger source (with synchronous triggering):

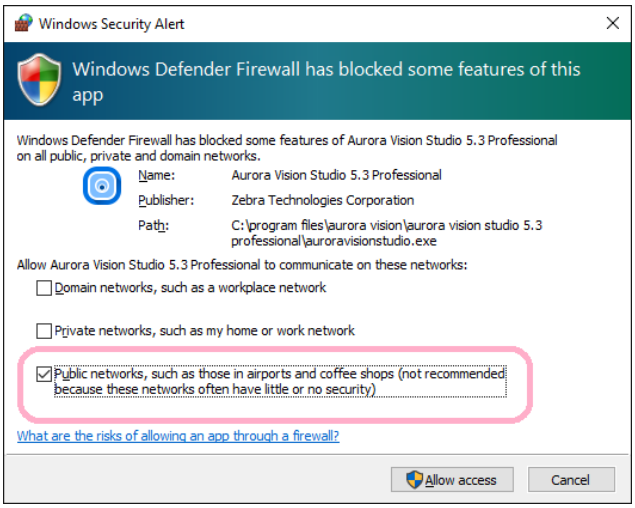




All above recommendations must be considered for such configuration. Because under synchronous triggering all the cameras will always be transferring images at the same time the problem of momentary burst transfer is especially present. Care must be taken to limit the maximum network transmission speed in the cameras to the system limits and to give enough time between trigger events for the cameras to finish the transfer.

Enabling Traffic in Firewall

Standard windows firewall or other active firewall applications should prompt for confirmation on enabling incoming traffic upon first access to the device. Sample prompt message from standard Windows 7 Firewall is shown on the image bellow.



Please note that **a device connected directly to computer's network adapter** in Windows Vista and Windows 7 will become an element of an unidentified network. Such device will be treated by default as **Public network**. In order to communicate with such a device you must allow for traffic also in Public networks as shown on the above image.

Clicking on *Allow access* will enable application to stream video from a device. Because of a delay caused by the firewall dialog first run of a program may fail with a timeout error. In such situations just try running program again after enabling access.

For information about changing settings of your firewall application search how to allow a program to communicate through this firewall in a Windows help or a third party application manual. GigE Vision® driver requires that incoming traffic is enabled on all UDP ports for application.

Enabling Jumbo Packets

Introduction

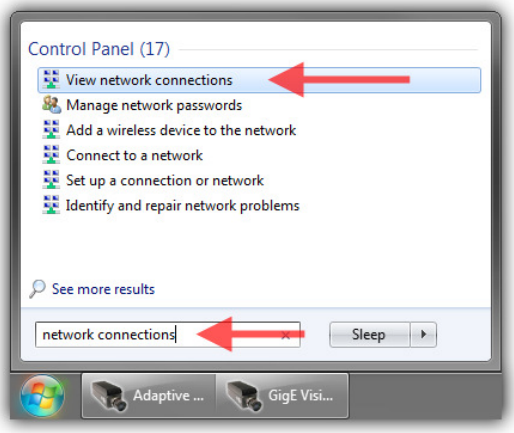
Jumbo Packet is an extension of network devices that allows for transmission of packets bigger than 1.5kB. Enabling Jumbo Packets can significantly increase video streaming performance.

Note that not all network devices support Jumbo Packets. To activate a big packet size, all devices from a network adapter through network routing equipment to a camera device must support and have enabled big packet sizes. Most suitable situation for using Jumbo Packets is when the device is connected directly to computer's network adapter with a crossed Ethernet cable.

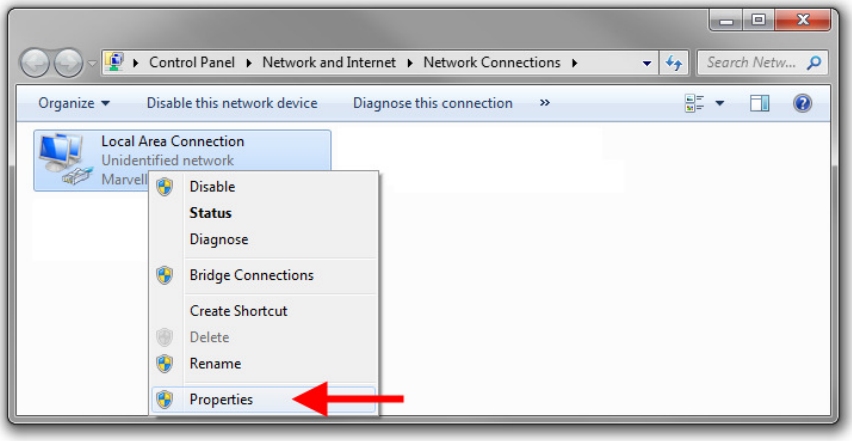
Do not enable Jumbo Packets when the device is connected through complicated network infrastructure with more that one routing path as maximum allowed packet sizes detected at application start can change later in the process.

Enabling Jumbo Packets in Windows Vista/7

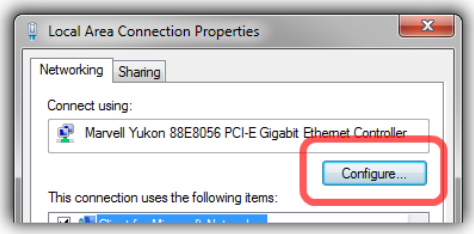
1. Open network connections applet from the control panel.



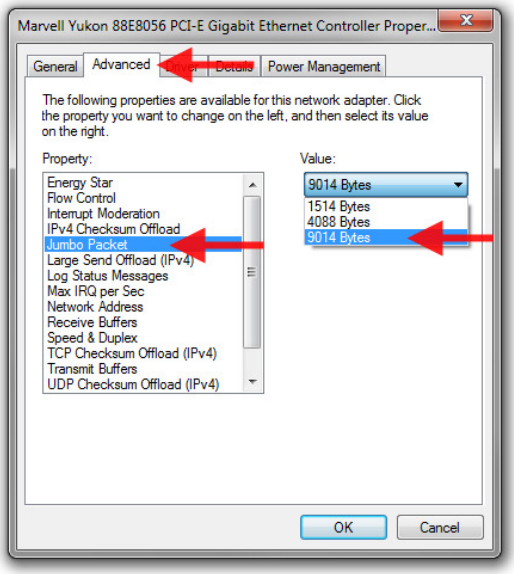
2. Right click a network adapter that have a connection with a device and open its properties (an administrator password may be needed).



3. In network adapter's properties click on *Configure*.



4. From Advanced tab select *Jumbo Packet* property and increase its value up to 9014 Bytes (9k Bytes). This step might look differently depending on the network card vendor. For some vendors this property might have different similar name (e.g. *Large Packet*). When there is no property for enabling/setting large packet size this card does not support jumbo packets.

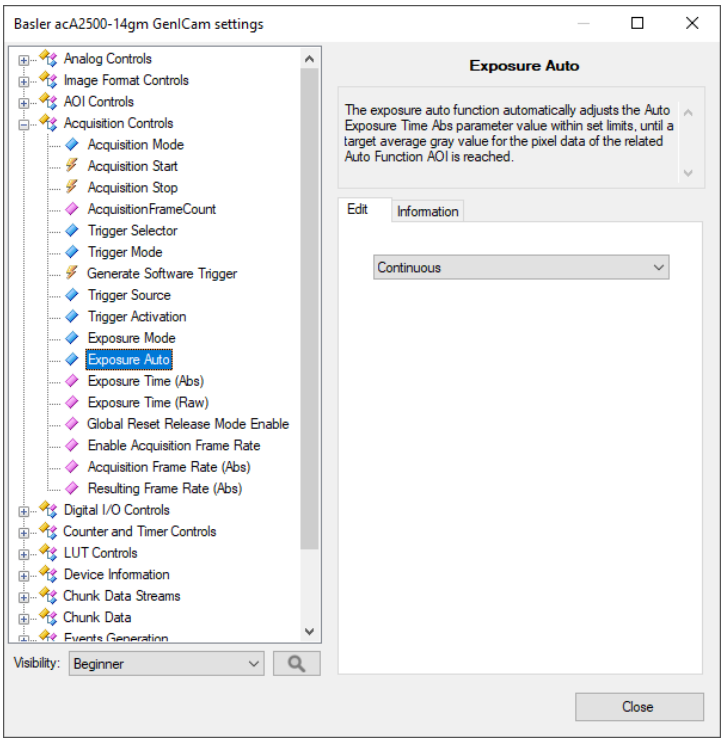


5. Click OK.

Device Settings Editor

GigE Vision® compliant devices are implementing GenICam standard that describes camera internal parameters and a way how to access them. Device Manager allows a user to access and edit device settings through a Settings Editor tool (available from *Tools » Access Device Settings*).

Example appearance of the Device Settings Editor is shown on the image below.



On the left side of the window is a tree representation of device parameters split into categories. All these parameters and their organization is device dependent, which means that different devices can produce different sets of parameters, with different meanings. Parameter's friendly name and a brief explanation (also provided by a device) is shown on the right side of the window after the parameter is highlighted in tree. For more information about specific parameter functions refer to a device documentation.

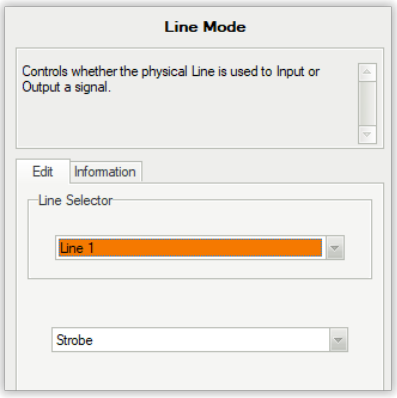
When editing selected parameter is possible and supported, an editor of the parameter value will be displayed below its explanation. Different editors are provided for the following parameter types:

- **Integer** - Plain number or hexadecimal number (indicated by *Hex* label on the left side of the text box). Values are limited by their maximum, minimum and allowed step. Numbers that does not fulfill this rules are corrected automatically upon confirmation. After clicking on *Save* button (or pressing *Enter*) new value will be validated and sent to the device.
- **Float** - Real number with fractional part. Values are limited by their maximum and minimum. Numbers that do not match this range are corrected automatically upon confirmation. A parameter can also have suggested step added after clicking in *+/-* buttons. After clicking on *Save* button (or pressing Enter) new value will be validated and sent to the device.
- **String** - Text of a limited length.
- **Boolean** - Single Yes/No value represented by check box. A value is sent to the device immediately after check state is changed.
- **Enumeration** - Parameter that accepts one of several predefined values. Predefined values are represented as list of their friendly names. Parameter is edited by choosing one of its values from a drop-down list. New values are sent to the device immediately after their selection in the list.
- **Command** - This is a special parameter that is represented only by a single button. Clicking on button will execute related activity in the device (for example Saving current parameter set to non-volatile memory).

Depending on situation, editor can be disabled (grayed), which means that this parameter is currently locked (for example parameter describing image format when the camera streaming is active). Editor can be read only (Save button grayed, grayed drop-down list or unchangeable check-box), which means that this parameter is read-only (for example informational parameters like manufacturer name).

Instead of an editor can there also be a displayed text: **"This parameter is currently not available"**. This means that the parameter can not be accessed or edited in the current device state or due to other parameter states. For example parameter describing acquisition frame rate value, when the user selection of frame rate is disabled (by parameter like *Enable Acquisition Framerate*).

Sometimes with the parameter editor displayed will be an additional editor, named selector.



In such situation selected parameter is connected with one of categories (slots) described by selector. In the example on the above image, parameter is determining whether the physical Line is used to Input or Output a signal. This device has two lines and both have its own separate values to choose from. Selector will pick which line we want to edit and bottommost editor will change it purpose. This means that there are actually two different *Line Modes* parameters in device.

Please note that selector will not always be displayed above editor. You must follow a device documentation and search parameters tree for selectors and other parameters on which this parameter is dependent.

The Device Settings Editor can be used to identify device capabilities and descriptions or to set up a new device. Device Editor can be also used when a program is running and the camera is streaming. In this situation changes should be immediately visible in the camera output.

Settings Editor gives a user an unlimited access to the device parameters and, **when used improperly, can put device in an invalid state** in which the device will become inaccessible by applications or can cause transitional errors in the program execution.

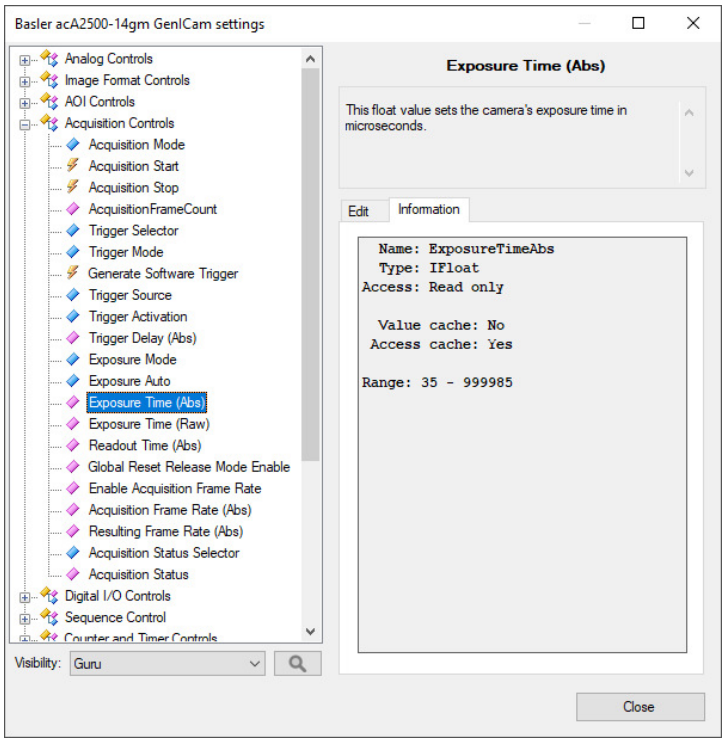
Saving Device Configuration

Most parameters available in the Settings Editor are stored by devices in a volatile memory and will be lost (reset to default) after device reset or power down.

A device should offer functions to save parameters set in *Configuration Sets* section of parameters tree. Refer to a device documentation for more information about configuration set saving and loading.

Parameter Information

Settings editor can also show information about selected parameter (by switching the tab on right side of the window).



In this mode the window appearance is changed. Instead of editors, on the right side of the window displayed are useful informations for a program developer, including:

- **Name** - parameter internal name. Note that parameter tree and descriptions are using human friendly name, not parameter ID. This field shows a proper parameter ID that must be used in parameter get/set functions.
- **Type** - parameter type name. This type must be consistent with the filter value type.
- **Access** - allowed access to parameter. Parameter must be writable to be set by program.
- **Range** - for numeric parameters this field shows the allowed range. Range of some parameters can change dynamically during its operation.
- **Value cache** - when GenAPI cache is enabled this field indicates if device allows to store this parameter value in local memory to reduce network operations.
- **Access cache** - when GenAPI cache is enabled this field indicates if device allows to store access mode of this parameter in local memory to reduce network operations on controlling parameter accessibility.
- **Available entries** - for enumeration parameters this field will list currently available values for a parameter. The field shows proper internal IDs that should be used when setting the parameter (note that editor's drop-down lists are using human friendly names).

Known Issues

In this section you will find solutions to known issues that we have came across while testing communication between Aurora Vision products and different camera models through GigE Vision.

Table of Contents

The Imaging Source cameras

There might be problems with image acquisition from The Imaging Source cameras through GigE. It's caused by the implementation (regarding caching and packet size) of GigE Vision standard in those cameras and as a result no image can be seen in Aurora Vision Studio (the previews are empty during program execution).

To resolve this issue, a camera restart (this has to be done only once, after you encounter the problem with image acquisition) and changing some parameters in Aurora Vision GenAPI configuration are required. Parameters which should be changed are:

- Enable *GenAPI Cache* (should be set to *False*),
- Disable *Packet Size Negotiation* (should be set to *True*),
- Enable *Constant Packet Size* (should be set to *False*).

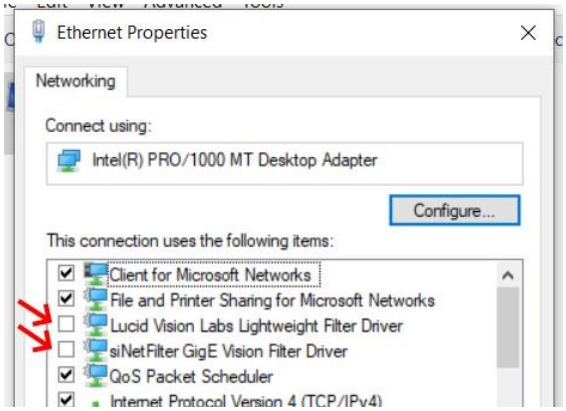
In order to change these parameters, you should (before opening device connection) open library configuration with function GigEVision_OpenSystemConfiguration, and set the following parameters (please note that these parameters have to be set separately for each application)by using GenApi function:

- GevAppTLEnableGenApiCache (Boolean) to False
- GevAppTLDisablePacketSizeNegotiation (Boolean) to True
- GevAppTLEnableConstantPacketSize (Boolean) to False

Basic Troubleshooting

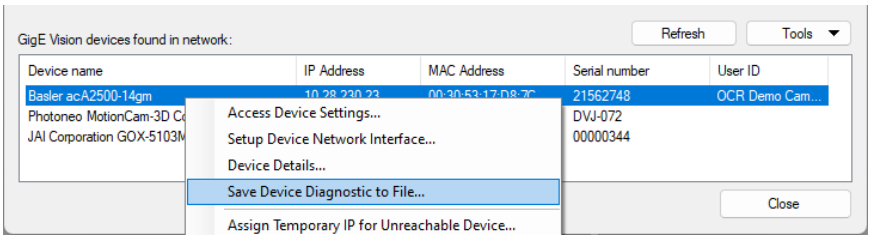
If a GigEVision device is connected, but the image cannot be acquired, please follow the steps below.

1. If the camera settings have been changed, set the default value for each changed parameter.
2. Check if there is no other software that uses the camera in the background. If there is, close it.
3. Check the camera connection. Connect the device directly to the PC if possible. If not, simplify the connection as much as possible. If there is any managed switch, check its settings.
4. If possible, use stable power supply (not PoE).
5. Set static IP address for both the camera and the PC. More information can be found here.
6. Enable Traffic in Firewall. More information can be found here.
7. Turn off Third-party Network Card Drivers.



8. Enable Jumbo Packets. More information can be found here.
9. Update PC Network Card Driver.

If after following all the steps the issue still appears, open GigE Vision Device Manager, right-click on the issued camera, choose ***Save Device Diagnostic to File***, and send the created file to the Technical Support Team.



5. Machine Vision Guide

Table of content:

Image Processing

Introduction

There are two major goals of Image Processing techniques:

1. To enhance an image for better human perception
2. To make the information it contains more salient or easier to extract

It should be kept in mind that in the context of computer vision only the second point is important. Preparing images for human perception is not part of computer vision; it is only part of information visualization. In typical machine vision applications this comes only at the end of the program and usually does not pose any problem.

The first and the most important advice for machine vision engineers is: **avoid image transformations designed for human perception when the goal is to extract information**. Most notable examples of transformations that are not only not interesting, but can even be highly disruptive, are:

- JPEG compression (creates artifacts not visible by human eye, but disruptive for algorithms)
- CIE Lab and CIE XYZ color spaces (specifically designed for human perception)
- Edge enhancement filters (which improve only the "apparent sharpness")
- Image thresholding performed before edge detection (precludes sub-pixel precision)

Examples of image processing operations that can really improve information extraction are:

- Gaussian image smoothing (removes noise, while preserving information about local features)
- Image morphology (can remove unwanted details)
- Gradient and high-pass filters (highlight information about object contours)
- Basic color space transformations like HSV (separate information about chromaticity and brightness)
- Pixel-by-pixel image composition (e.g. can highlight image differences in relation to a reference image)

Regions of Interest

The image processing tools provided by Aurora Vision have a special *inRoi* input (of Region type), that can limit the spatial scope of the operation. The region can be of any shape.

An input image and the inRoi.

Result of an operation performed within inRoi.

Remarks:

- The output image will be black outside of the *inRoi* region.
- To obtain an image that has its pixels modified in *inRoi* and copied outside of it, one can use the ComposeImages filter.
- The default value for *inRoi* is *Auto* and causes the entire image to be processed.
- Although *inRoi* can be used to significantly speed up processing, it should be used with care. The performance gain may be far from proportional to the *inRoi* area, especially in comparison to processing the entire image (*Auto*). This is due to the fact, that in many cases more SSE optimizations are possible when *inRoi* is not used.

Some filters have a second region of interest called *inSourceRoi*. While *inRoi* defines the range of pixels that will be written in the output image, the *inSourceRoi* parameter defines the range of pixels that can be read from the input image.

Image Boundary Processing

Some image processing filters, especially those from the Image Local Transforms category, use information from some local neighborhood of a pixel. This causes a problem near the image borders as not all input data is available. The policy applied in our tools is:

- Never assume any specific value outside of the image, unless specifically defined by the user.
- If only partial information is available, it is better not to detect anything, than detect something that does not exist.

In particular, the filters that use information from a local neighborhood just use smaller (cropped) neighbourhood near the image borders. This is something, however, that has to be taken into account, when relying on the results – for example results of the smoothing filters can be up to 2 times less smooth at the image borders (due to half of the neighborhood size), whereas results of the morphological filters may "stick" to the image borders. If the highest reliability is required, the general rule is: **use appropriate regions of interest to ignore image processing results that come from incomplete information** (near the image borders).

Toolset

Image Combinators

The filters from the Image Combinators category take two images and perform a pixel-by-pixel transformation into a single image. This can be used for example to highlight differences between images or to normalize brightness – as in the example below:

Input image with high reflections.

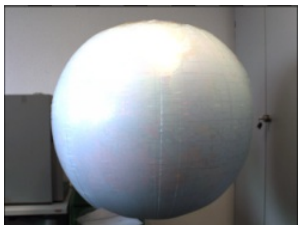


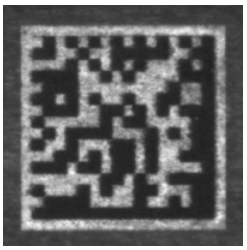
Image of the reflections (calibrating).

The result of applying DivideImages with inScale = 128 (inRoi was used).

Image Smoothing

The main purpose of the image smoothing filters (located in the Image Local Transforms category) is removal of noise. There are several different ways to perform this task with different trade-offs. On the example below three methods are presented:

1. Mean smoothing – simply takes the average pixel value from a rectangular neighborhood; it is the fastest method.
2. Median smoothing – simply takes the median pixel value from a rectangular neighborhood; preserves edges, but is relatively slow.
3. Gauss smoothing – computes a weighted average of the pixel values with Gaussian coefficients as the weights; its advantage is isotropy and reasonable speed for small kernels.



Input image with some noise.

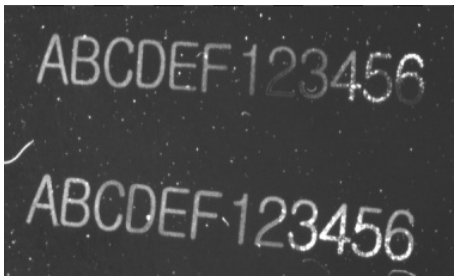
Result of applying SmoothImage_Mean.

Result of applying SmoothImage_Gauss.

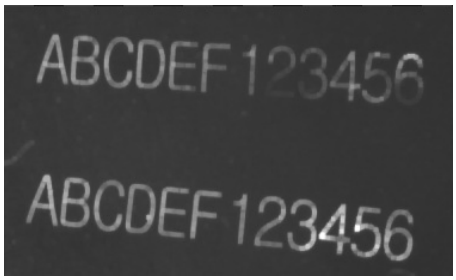
Result of applying SmoothImage_Median.

Image Morphology

Basic morphological operators – DilateImage and ErodeImage – transform the input image by choosing maximum or minimum pixel values from a local neighborhood. Other morphological operators combine these two basic operations to perform more complex tasks. Here is an example of using the OpenImage filter to remove salt and pepper noise from an image:



Input image with salt-and-pepper noise.



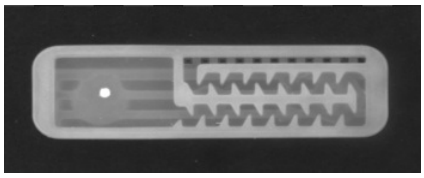
Result of applying OpenImage.

Gradient Analysis

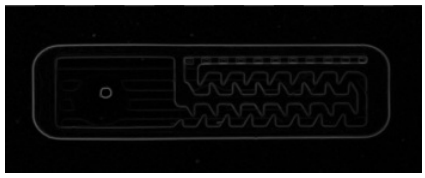
An image gradient is a vector describing direction and magnitude (strength) of local brightness changes. Gradients are used inside of many computer vision tools – for example in object contour detection, edge-based template matching and in barcode and DataMatrix detection.

Available filters:

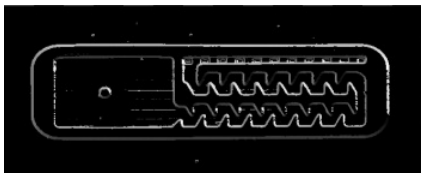
- GradientImage – produces a 2-channel image of signed values; each pixel denotes a gradient vector.
- GradientMagnitudeImage – produces a single channel image of gradient magnitudes, i.e. the lengths of the vectors (or their approximations).
- GradientDirAndPresenceImage – produces a single channel image of gradient directions mapped into the range from 1 to 255; 0 means no significant gradient.



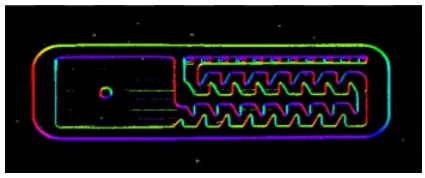
An input image.



Result of GradientMagnitudeImage.



Result of GradientDirAndPresenceImage.



Diagnostic output of GradientImage showing hue-coded directions.

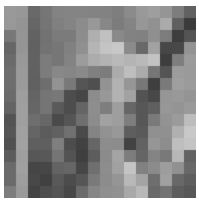
Spatial Transforms

Spatial transforms modify an image by changing locations, but not values, of pixels. Here are sample results of some of the most basic operations:

Result of MirrorImage.

Result of RotateImage.

Result of ShearImage.



Result of DownsampleImage.

Result of TransposeImage.

Result of TranslateImage.

Result of CropImage.

Result of UncropImage applied to the result of CropImage.

There are also interesting spatial transform tools that allow to transform a two dimensional vision problem into a 1.5-dimensional one, which can be very useful for further processing:

An input image and a path.

Result of ImageAlongPath.

Spatial Transform Maps

The spatial transform tools perform a task that consist of two steps for each pixel:

1. compute the destination coordinates (and some coefficients when interpolation is used),
2. copy the pixel value.

In many cases the transformation is constant – for example we might be rotating an image always by the same angle. In such cases the first step – computing the coordinates and coefficients – can be done once, before the main loop of the program. Aurora Vision provides the Image Spatial Transforms Maps category of filters for exactly that purpose. When you are able to compute the transform beforehand, storing it in the SpatialMap type, in the main loop only the RemapImage filter has to be executed. This approach will be much faster than using standard spatial transform tools.

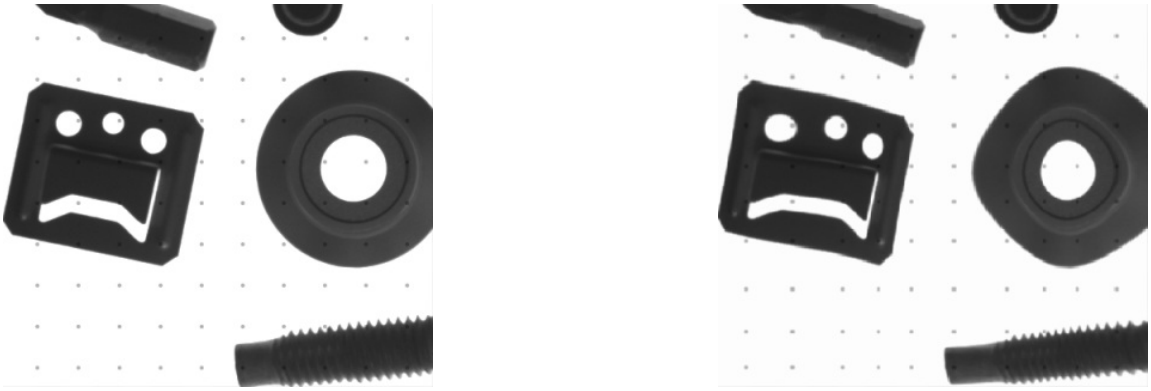
The SpatialMap type is a map of image locations and their corresponding positions after given geometric transformation has been applied.

Additionally, the Image Spatial Transforms Maps category provides several filters that can be used to flatten the curvature of a physical object. They can be used for e.g. reading labels glued onto curved surfaces. These filters model basic 3D objects:

1. **Cylinder** (CreateCylinderMap) – e.g. flattening of a bottle label.
2. **Sphere** (CreateSphereMap) – e.g. reading a label from light bulb.
3. **Box** (CreatePerspectiveMap_Points or CreatePerspectiveMap_Path) – e.g. reading a label from a box.
4. **Circular objects (polar transform)** (CreateImagePolarTransformMap) – e.g. reading a label wrapped around a DVD disk center.

Example of remapping of a spherical object using CreateSphereMap and RemapImage. Image before and after remapping.

Furthermore custom spatial maps can be created with ConvertMatrixMapsToSpatialMap.



An example of custom image transform created with ConvertMatrixMapsToSpatialMap. Image before and after remapping.

Image Thresholding

The task of Image Thresholding filters is to classify image pixel values as foreground (white) or background (black). The basic filters ThresholdImage and ThresholdToRegion use just a simple range of pixel values – a pixel value is classified as foreground iff it belongs to the range. The ThresholdImage filter just transforms an image into another image, whereas the ThresholdToRegion filter creates a region corresponding to the foreground pixels. Other available filters allow more advanced classification:

- ThresholdImage_Dynamic and ThresholdToRegion_Dynamic use average local brightness to compensate global illumination variations.
- ThresholdImage_RGB and ThresholdToRegion_RGB select pixel values matching a range defined in the RGB (the standard) color space.
- ThresholdImage_HSx and ThresholdToRegion_HSx select pixel values matching a range defined in the HSx color space.
- ThresholdImage_Relative and ThresholdToRegion_Relative allow to use a different threshold value at each pixel location.

Input image with uneven light.

Result of ThresholdImage – the bars can not be recognized.

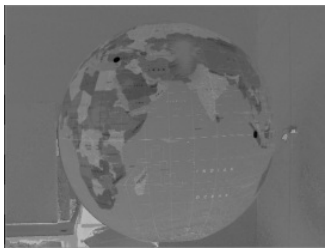
Result of ThresholdImage_Dynamic – the bars are correct.

There is also an additional filter SelectThresholdValue which implements a number of methods for automatic threshold value selection. It should, however, be used with much care, because there is no universal method that works in all cases and even a method that works well for a particular case might fail in special cases.

Image Pixel Analysis

When reliable object detection by color analysis is required, there are two filters that can be useful: ColorDistance and ColorDistanceImage. These filters compare colors in the RGB space, but internally separate analysis of brightness and chromaticity. This separation is very important, because in many cases variations in brightness are much higher than variations in chromaticity. Assigning more significance to the latter (high value of the *inChromaAmount* input) allows to detect areas having the specified color even in presence of highly uneven illumination:

Input image with uneven light.



Result of ColorDistanceImage for the red color with inChromaAmount = 1.0. Dark areas correspond to low color distance.

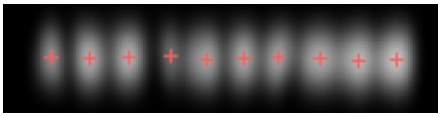
Result of thresholding reveals the location of the red dots on the globe.

Image Features

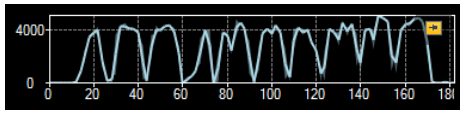
Image Features is a category of image processing tools that are already very close to computer vision – they transform pixel information into simple higher-level data structures. Most notable examples are: ImageLocalMaxima which finds the points at which the brightness is locally the highest, ImageProjection which creates a profile from sums of pixel values in columns or in rows, ImageAverage which averages pixel values in the entire region of interest. Here is an example application:

Input image with digits to be segmented.

Result of preprocessing with CloseImage.



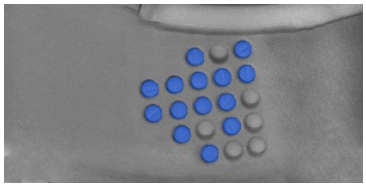
Digit locations extracted by applying SmoothImage_Gauss and ImageLocalMaxima.



Profile of the vertical projection revealing regions of digits and the boundaries between them.

Blob Analysis

Introduction



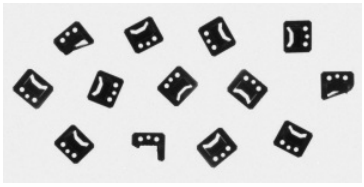
Blob Analysis is a fundamental technique of machine vision based on analysis of consistent image regions. As such it is a tool of choice for applications in which the objects being inspected are clearly discernible from the background. Diverse set of Blob Analysis methods allows to create tailored solutions for a wide range of visual inspection problems.

Main advantages of this technique include high flexibility and excellent performance. Its limitations are: clear background-foreground relation requirement (see Template Matching for an alternative) and pixel-precision (see 1D Edge Detection for an alternative).

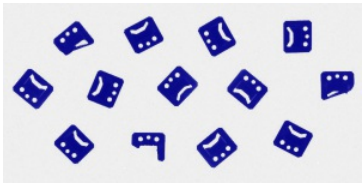
Concept

Let us begin by defining the notions of *region* and *blob*.

- *Region* is any subset of image pixels. In Aurora Vision Studio regions are represented using Region data type.
- *Blob* is a connected region. In Aurora Vision Studio blobs (being a special case of region) are represented using the same Region data type. They can be obtained from any region using a single SplitRegionIntoBlobs filter or (less frequently) directly from an image using image segmentation filters from category Image Analysis techniques.



An example image.



Region of pixels darker than 128.

Decomposition of the region into array of blobs.

The basic scenario of the Blob Analysis solution consists of the following steps:

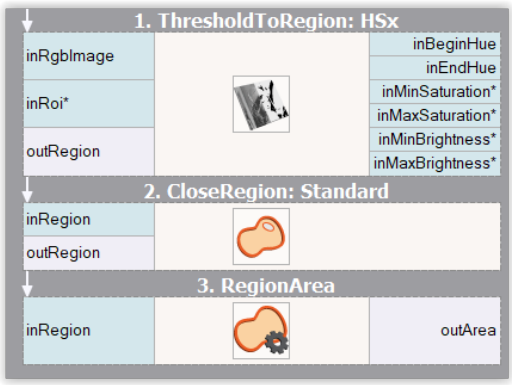
1. **Extraction** - in the initial step one of the Image Thresholding techniques is applied to obtain a region corresponding to the objects (or single object) being inspected.
2. **Refinement** - the extracted region is often flawed by noise of various kind (e.g. due to inconsistent lightning or poor image quality). In the Refinement step the region is enhanced using region transformation techniques.
3. **Analysis** - in the final step the refined region is subject to measurements and the final results are computed. If the region represents multiple objects, it is split into individual blobs each of which is inspected separately.

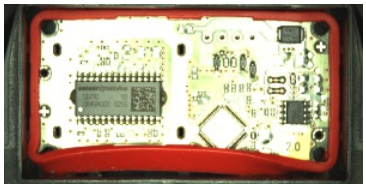
Examples

The following examples illustrate the general schema of Blob Analysis algorithms. Each of the techniques represented in the examples (thresholding, morphology, calculation of region features, etc.) is inspected in detail in later sections.

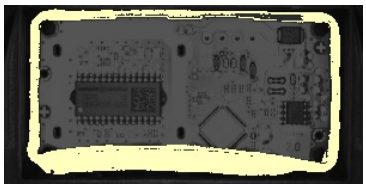
Rubber Band

In this, idealized, example we analyze a picture of an electronic device wrapped in a rubber band. The aim here is to compute the area of the visible part of the band (e.g. to decide whether it was assembled correctly).

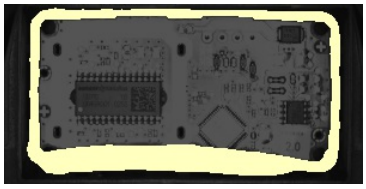




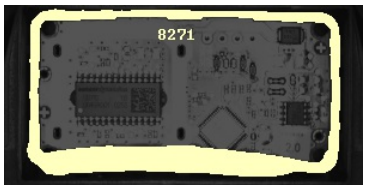
Initial image



Extraction



Refinement



Results

In this case each of the steps: Extraction, Refinement and Analysis is represented by a single filter.

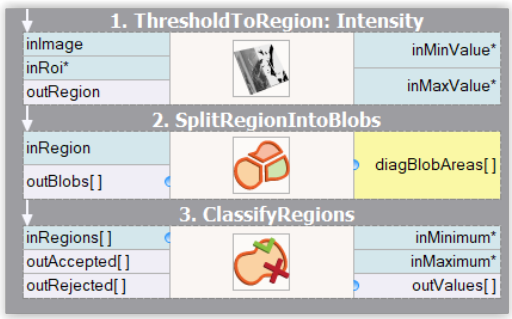
Extraction - to obtain a region corresponding to the red band a Color-based Thresholding technique is applied. The ThresholdToRegion_HSx filter is capable of finding the region of pixels of given color characteristics - in this case it is targeted to detect red pixels.

Refinement - the problem of filling the gaps in the extracted region is a standard one. Classic solutions for it are the region morphology techniques. Here, the CloseRegion filter is used to fill the gaps.

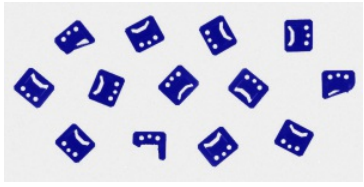
Analysis - finally, a single RegionArea filter is used to compute the area of the obtained region.

Mounts

In this example a picture of a set of mounts is inspected to identify the damaged ones.

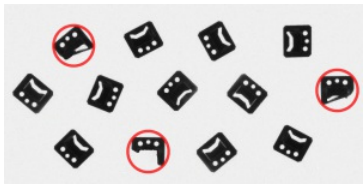


Input image



Extraction

Analysis



Results

Extraction - as the lightning in the image is uniform, the objects are consistently dark and the background is consistently bright, the extraction of the region corresponding to the objects is a simple task. A basic ThresholdToRegion filter does the job, and does it so well that no **Refinement** phase is needed in this example.

Analysis - as we need to analyze each of the blobs separately, we start by applying the SplitRegionIntoBlobs filter to the extracted region.

To distinguish the bad parts from the correct parts we need to pick a property of a region (e.g. area, circularity, etc.) that we expect to be high for the good parts and low for the bad parts (or conversely). Here, the area would do, but we will pick a somewhat more sophisticated rectangularity feature, which will compute the similarity-to-rectangle factor for each of the blobs.

Once we have chosen the rectangularity feature of the blobs, all that needs to be done is to feed the regions to be classified to the ClassifyRegions filter (and to set its **inMinimum** value parameter). The blobs of too low rectangularity are available at the **outRejected** output of the classifying filter.

Extraction

There are two techniques that allow to extract regions from an image:

- **Image Thresholding** - commonly used methods that compute a region as a set of pixels that meet certain condition dependent on the specific operator (e.g. region of pixels brighter than given value, or brighter than the average brightness in their neighborhood). Note that the resulting data is always a single region, possibly representing numerous objects.
- **Image Segmentation** - more specialized set of methods that compute a set of blobs corresponding to areas in the image that meet certain condition. The resulting data is always an array of connected regions (blobs).

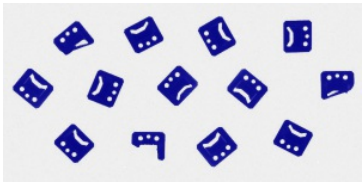
Thresholding

Image Thresholding techniques are preferred for common applications (even those in which a set of objects is inspected rather than a single object) because of their simplicity and excellent performance. In Aurora Vision Studio there are six filters for image-to-region thresholding, each of them implementing a different thresholding method.

Brightness-based (basic)	ThresholdToRegion: inImage, inRoi, outRegion → inMinValue, inMaxValue	ThresholdToRegion_Dynamic: inImage, inRoi, inSourceRoi, diagBaseImage, outRegion → inMinRelativeValue, inMaxRelativeValue
Brightness-based (additional)	ThresholdToRegion_Relative: inImage, inRoi, inBaseImage, outRegion → inMinRelativeValue, inMaxRelativeValue	
Color-based	ThresholdToRegion_RGB: inRgbImage, inRoi, outRegion → inMinRed, inMaxRed, inMinGreen, inMaxGreen, inMinBlue, inMaxBlue, inMinAlpha, inMaxAlpha	ThresholdToRegion_HSx: inRgbImage, inRoi, diagHSxImage, outRegion → inBeginHue, inEndHue, inMinSaturation, inMaxSaturation, inMinBrightness, inMaxBrightness

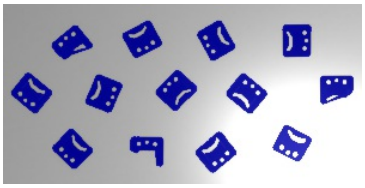
Classic Thresholding

ThresholdToRegion simply selects the image pixels of the specified brightness. It should be considered a basic tool and applied whenever the intensity of the inspected object is constant, consistent and clearly different from the intensity of the background.



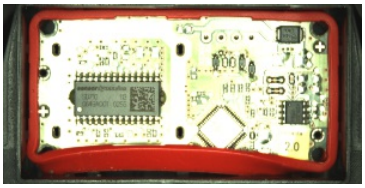
Dynamic Thresholding

Inconsistent brightness of the objects being inspected is a common problem usually caused by the imperfections of the lightning setup. As we can see in the example below, it is often the case that the objects in one part of the image actually have the same brightness as the background in another part of the image. In such case it is not possible to use the basic ThresholdToRegion filter and ThresholdToRegion_Dynamic should be considered instead. The latter selects image pixels that are *locally* bright/dark. Specifically - the filter selects the image pixels of the given *relative local brightness* defined as the difference between the pixel intensity and the average intensity in its neighborhood.

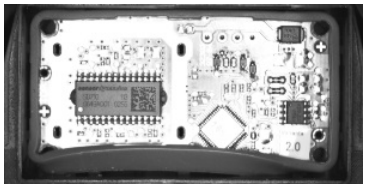


Color-based Thresholding

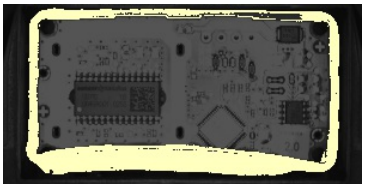
When inspection is conducted on color images it may be the case that despite a significant difference in color, the brightness of the objects is actually the same as the brightness of their neighborhood. In such case it is advisable to use Color-based Thresholding filters: ThresholdToRegion_RGB, ThresholdToRegion_HSx. The suffix denote the color space in which we define the desired pixel characteristic and not the space used in the image representation. In other words - both of these filters can be used to process standard RGB color image.



An example image.



Mono equivalent of the image depicting brightness of its pixels.

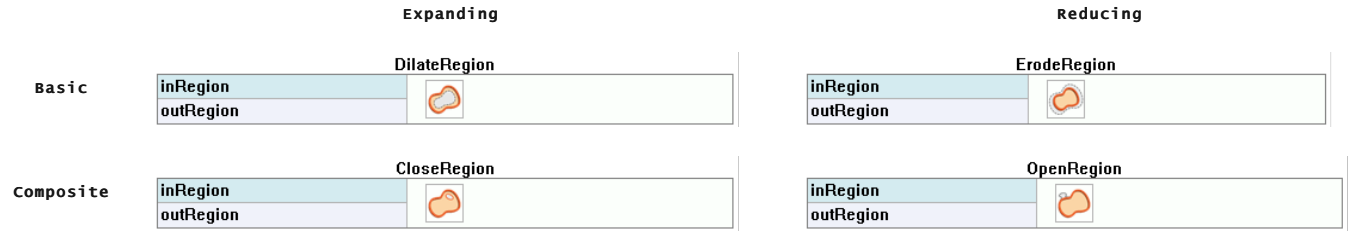


Result of the color-based thresholding targeted at red pixels.

Refinement

Region Morphology

Region Morphology is a classic technique of region transformation. The core concept of this toolset is the usage of a *structuring element* also known as the *kernel*. The kernel is a relatively small shape that is repeatedly centered at each pixel within dimensions of the region that is being transformed. Every such pixel is either added to the resulting region or not, depending on operation-specific condition on the minimum number of kernel pixels that have to overlap with actual input region pixels (in the given position of the kernel). See description of **Dilation** for an example.



Dilation and Erosion

Dilation is one of two basic morphological transformations. Here each pixel **P** within the dimensions of the region being transformed is added to the resulting region if and only if the structuring element centered at **P** overlaps with *at least* one pixel that belongs to the input region. Note that for a circular kernel such transformation is equivalent to a uniform expansion of the region in every direction.

Erosion is a dual operation of **Dilation**. Here, each pixel **P** within the dimensions of the region being transformed is added to the resulting region if and only if the structuring element centered at **P** is *fully contained* in the region pixels. Note that for a circular kernel such transformation is equivalent to a uniform reduction of the region in every direction.

Closing and Opening

The actual power of the **Region Morphology** lies in its *composite operators* - **Closing** and **Opening**. As we may have recently noticed, during the blind region expansion performed by the **Dilation** operator, the gaps in the transformed region are filled in. Unfortunately, the expanded region no longer corresponds to the objects being inspected. However, we can apply the **Erosion** operator to bring the expanded region back to its original boundaries. The key point is that the gaps that were completely filled during the dilation will stay filled after the erosion. The operation of applying **Erosion** to the result of **Dilation** of the region is called **Closing**, and is a tool of choice for the task of filling the gaps in the extracted region.

Opening is a dual operation of **Closing**. Here, the region being transformed is initially eroded and then dilated. The resulting region preserves the form of the initial region, with the exception of thin/small parts, that are removed during the process. Therefore, **Opening** is a tool for removing the thin/outlying parts from a region. We may note that in the example below, the **Opening** does the - otherwise relatively complicated - job of finding the segment of the rubber band of excessive width.

Other Refinement Methods

Analysis

Once we obtain the region that corresponds to the object or the objects being inspected, we may commence the analysis - that is, extract the information we are interested in.

Region Features

Aurora Vision Studio allows to compute a wide range of numeric (e.g. area) and non-numeric (e.g. bounding circle) region features. Calculation of the measures describing the obtained region is often the very aim of applying the blob analysis in the first place. If we are to check whether the rectangular packaging box is deformed or not, we may be interested in calculating the *rectangularity factor* of the packaging region. If we are to check if the chocolate coating on a biscuit is broad enough, we may want to know the *area* of the coating region.

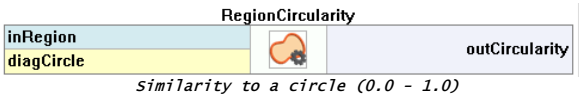
It is important to remember, that when the obtained region corresponds to multiple image objects (and we want to inspect each of them separately), we should apply the SplitRegionIntoBlobs filter before performing the calculation of features.

Numeric Features

Each of the following filters computes a number that expresses a specific property of the region shape.

Annotations in brackets indicate the range of the resulting values.

Size of the region (0 - ∞)

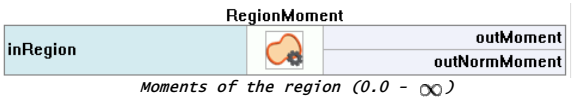


Similarity to a circle (0.0 - 1.0)

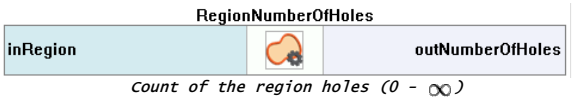
Similarity to own convex hull (0.0 - 1.0)

Similarity to a rectangle (0.0 - 1.0)

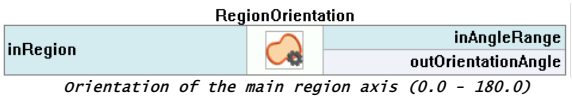
Similarity to a line (0.0 - ∞)



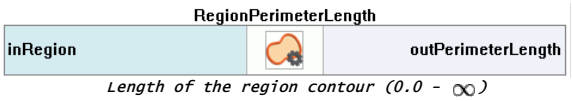
Moments of the region (0.0 - ∞)



Count of the region holes (0 - ∞)



Orientation of the main region axis (0.0 - 180.0)



Length of the region contour (0.0 - ∞)

Non-numeric Features

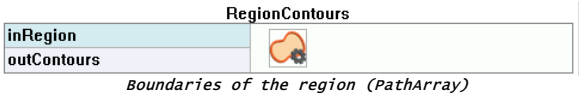
Each of the following filters computes an object related to the shape of the region. Note that the primitives extracted using these filters can be made subject of further analysis. For instance, we can extract the holes of the region using the RegionHoles filter and then measure their areas using the RegionArea filter.

Annotations in brackets indicate Aurora Vision Studio's type of the result.

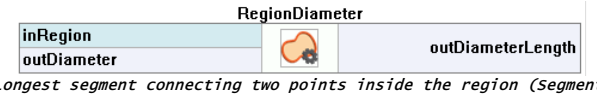
Smallest axis-aligned rectangle containing the region (Box)

Smallest circle containing the region (Circle2D)

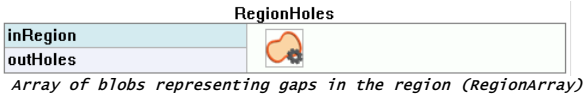
Smallest any-orientation rectangle containing the region (Rectangle2D)



Boundaries of the region (PathArray)



Longest segment connecting two points inside the region (Segment2D)

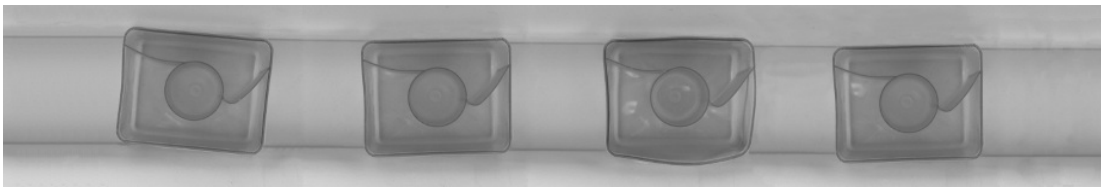


Array of blobs representing gaps in the region (RegionArray)

Skeleton of the region (PathArray)

Case Studies

Capsules

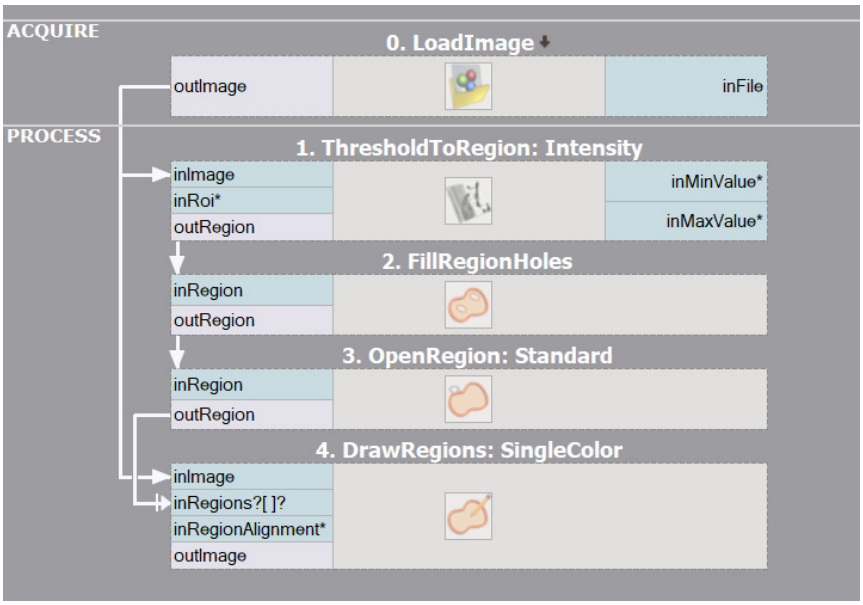


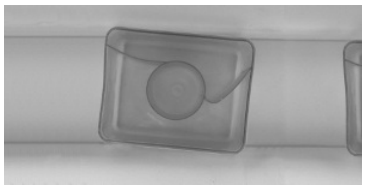
In this example we inspect a set of washing machine capsules on a conveyor line. Our aim is to identify the deformed capsules.

We will proceed in two steps: we will commence by designing a simple program that, given picture of the conveyor line, will be able to identify the region corresponding to the capsule(s) in the picture. In the second step we will use this program as a building block of the complete solution.

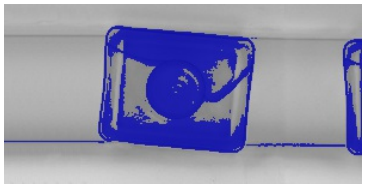
FindRegion Routine

In this section we will develop a program that will be responsible for the **Extraction** and **Refinement** phases of the final solution. For brevity of presentation in this part we will limit the input image to its initial segment.

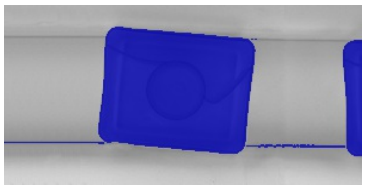




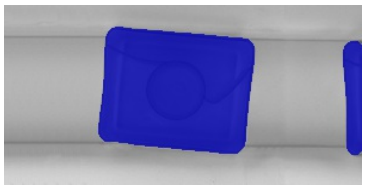
Initial image



ThresholdToRegion



FillRegionHoles



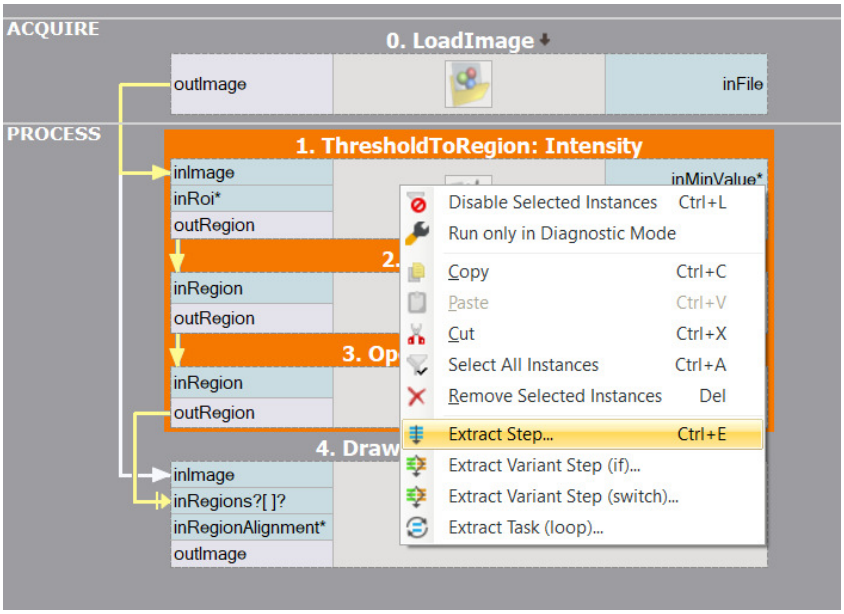
OpenRegion

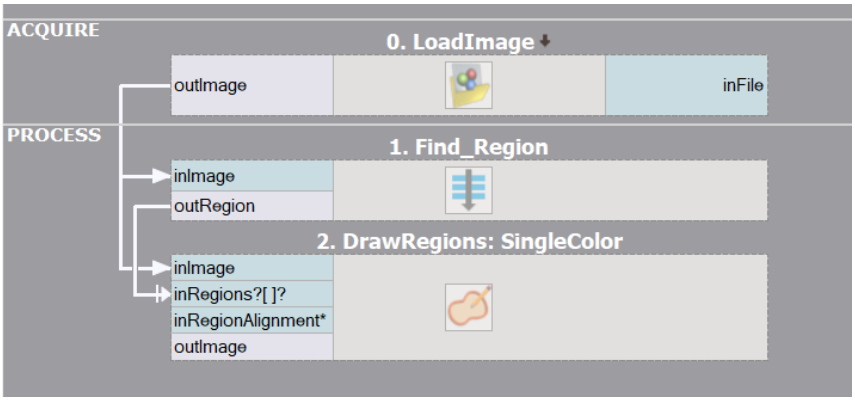
After a brief inspection of the input image we may note that the task at hand will not be trivial - the average brightness of the capsule body is similar to the intensity of the background. On the other hand the border of the capsule is consistently darker than the background. As it is the border of the object that bears significant information about its shape we may use the basic ThresholdToRegion filter to extract the darkest pixels of the image with the intention of filling the extracted capsule border during further refinement.

The extracted region certainly requires such refinement - actually, there are two issues that need to be addressed. We need to fill the shape of the capsule and eliminate the thin horizontal stripes corresponding to the elements of the conveyor line setup. Fortunately, there are fairly straightforward solutions for both of these problems.

FillRegionHoles will extend the region to include all pixels enclosed by present region pixels. After the region is filled all that remains is the removal of the thin conveyor lines using the classic OpenRegion filter.

Our routine for **Extraction** and **Refinement** of the region is ready. As it constitutes a continuous block of filters performing a well defined task, it is advisable to encapsulate the routine inside a function to enhance the readability of the soon-to-be-growing program.

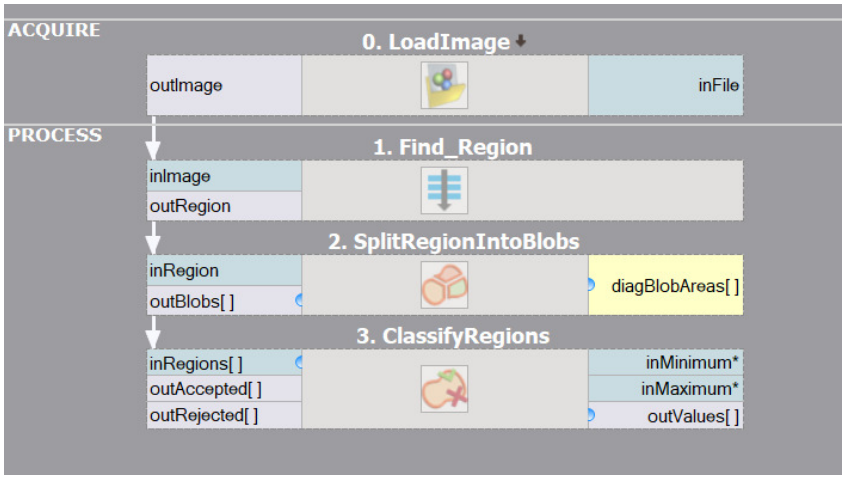




Complete Solution

Our program right now is capable of extracting the region that directly corresponds to the capsules visible in the image. What remains is to inspect each capsule and classify it as a correct or deformed one.

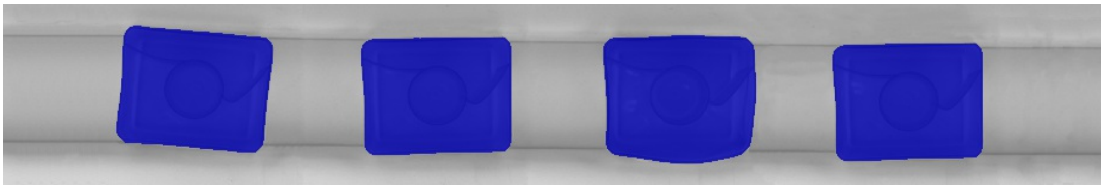
As we want to analyze each capsule separately, we should start with decomposition of the extracted region into an array of connected components (blobs). This common operation can be performed using the straightforward SplitRegionIntoBlobs filter.



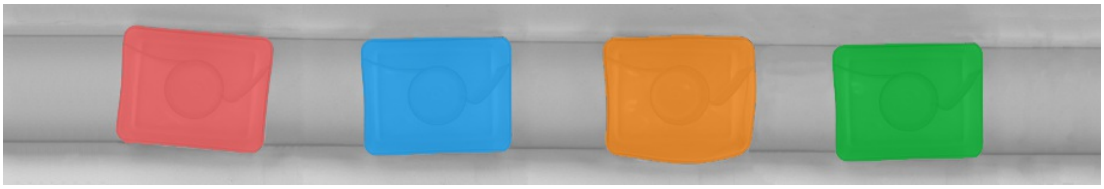
We are approaching the crucial part of our solution - how are we going to distinguish correct capsules from deformed ones? At this stage it is advisable to have a look at the summary of numeric region features provided in **Analysis** section. If we could find a numeric region property that is correlated with the nature of the problem at hand (e.g. it takes low values for a correct capsules and high values for a deformed one, or conversely), we would be nearly done.

Rectangularity of a shape is defined as the ratio between its area and area of its smallest enclosing rectangle - the higher the value, the more the shape of the object resembles a rectangle. As the shape of a correct capsule is almost rectangular (it is a rectangle with rounded corners) and clearly *more* rectangular than the shape of deformed capsule, we may consider using rectangularity feature to classify the capsules.

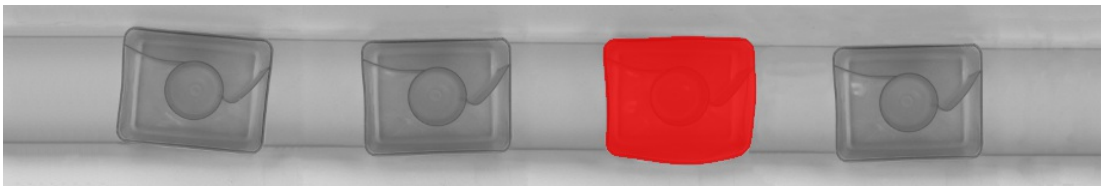
Having selected the numeric feature that will be used for the classification, we are ready to add the ClassifyRegions filter to our program and feed it with data. We pass the array of capsule blobs on its **inRegions** input and we select Rectangularity on the **inFeature** input. After brief interactive experimentation with the *inMinimum* threshold we may observe that setting the minimum rectangularity to 0.95 allows proper discrimination of correct (available at **outAccepted**) and deformed (**outRejected**) capsule blobs.



Region extracted by the FindRegion routine.



Decomposition of the region into individual blobs.



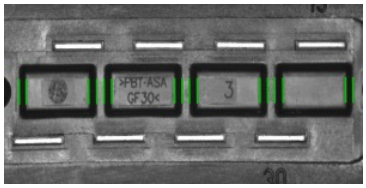
Blobs of low rectangularity selected by ClassifyRegions filter.

1D Edge Detection

Introduction

1D Edge Detection (also called *1D Measurement*) is a classic technique of machine vision where the information about image is extracted from one-dimensional profiles of image brightness. As we will see, it can be used for measurements as well as for positioning of the inspected objects.

Main advantages of this technique include sub-pixel precision and high performance.



Concept

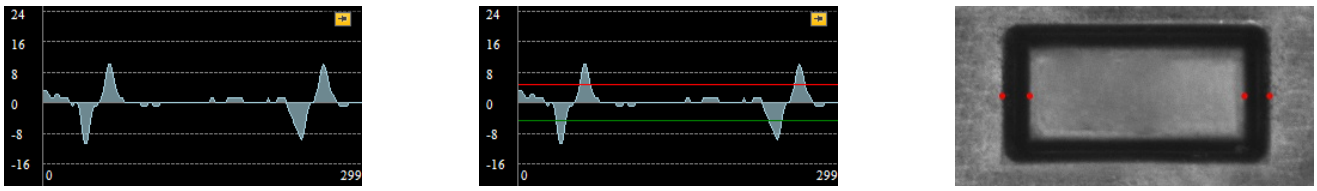
The 1D Edge Detection technique is based on an observation that any edge in the image corresponds to a rapid brightness change in the direction perpendicular to that edge. Therefore, to detect the image edges we can scan the image along a path and look for the places of significant change of intensity in the extracted brightness profile.

The computation proceeds in the following steps:

1. **Profile extraction** – firstly the profile of brightness along the given path is extracted. Usually the profile is smoothed to remove the noise.
2. **Edge extraction** – the points of significant change of profile brightness are identified as *edge points* – points where perpendicular edges intersect the scan line.
3. **Post-processing** – the final results are computed using one of the available methods. For instance ScanSingleEdge filter will select and return the strongest of the extracted edges, while ScanMultipleEdges filter will return all of them.

Example

The image is scanned along the path and the brightness profile is extracted and smoothed.



Brightness profile is differentiated. Notice four peaks of the profile derivative which correspond to four prominent image edges intersecting the scan line. Finally the peaks stronger than some selected value (here minimal strength is set to 5) are identified as edge points.

Filter Toolset

Basic toolset for the 1D Edge Detection-based techniques scanning for edges consists of 9 filters each of which runs a single scan along the given path (**inScanPath**). The filters differ on the structure of interest (edges / ridges / stripes (edge pairs)) and its cardinality (one / any fixed number / unknown number).

Edges

Single Result

ScanSingleEdge

inImage	outEdge.Point
inScanPath	outEdge.Magnitude
inScanPathAlignment	outBrightnessProfile
outAlignedScanPath	outResponseProfile

Multiple Results

ScanMultipleEdges

inImage	outEdges.Point
inScanPath	outEdges.Magnitude
inScanPathAlignment	outBrightnessProfile
outAlignedScanPath	outResponseProfile

Fixed Number of Results

ScanExactlyNEdges

inImage	outEdges.Point
inScanPath	outEdges.Magnitude
inScanPathAlignment	outBrightnessProfile
outAlignedScanPath	outResponseProfile

Stripes

Single Result

ScanSingleStripe

inImage	outStripe.Width
inScanPath	
inScanPathAlignment	outBrightnessProfile
outStripe	
outAlignedScanPath	outResponseProfile

Multiple Results

ScanMultipleStripes

inImage	outStripes.Width
inScanPath	
inScanPathAlignment	outBrightnessProfile
outStripes	
outAlignedScanPath	outResponseProfile

Fixed Number of Results

ScanExactlyNStripes

inImage	outStripes.Width
inScanPath	
inScanPathAlignment	outBrightnessProfile
outStripes	
outAlignedScanPath	outResponseProfile

Ridges

Single Result

ScanSingleRidge

inImage	outRidge.Point
inScanPath	outRidge.Magnitude
inScanPathAlignment	outBrightnessProfile
outAlignedScanPath	outResponseProfile

Multiple Results

ScanMultipleRidges

inImage	outRidges.Point
inScanPath	outRidges.Magnitude
inScanPathAlignment	outBrightnessProfile
outAlignedScanPath	outResponseProfile

Fixed Number of Results

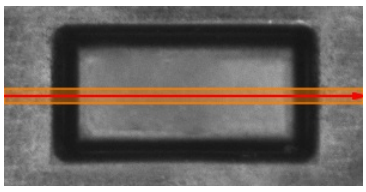
ScanExactlyNRidges

inImage	outRidges.Point
inScanPath	outRidges.Magnitude
inScanPathAlignment	outBrightnessProfile
outAlignedScanPath	outResponseProfile

Note that in Aurora Vision Library there is the **CreateScanMap** function that has to be used before a usage of any other 1D Edge Detection function. The special function creates a scan map, which is passed as an input to other functions considerably speeding up the computations.

Parameters

Profile Extraction

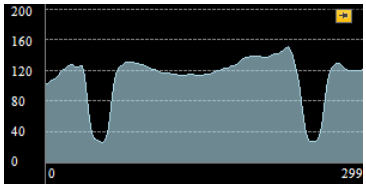


In each of the nine filters the brightness profile is extracted in exactly the same way. The stripe of pixels along **inScanPath** of width **inScanWidth** is traversed and the pixel values across the path are accumulated to form one-dimensional profile. In the picture on the right the stripe of processed pixels is marked in orange, while **inScanPath** is marked in red.

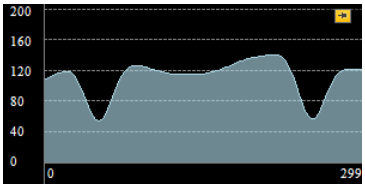
The extracted profile is smoothed using Gaussian smoothing with standard deviation of **inSmoothingStdDev**. This parameter is important for the robustness of the computation - we should pick the value that is high enough to eliminate noise that could introduce false / irrelevant extrema to the profile derivative, but low enough to preserve the actual edges we are to detect.

The **inSmoothingStdDev** parameter should be adjusted through interactive experimentation using **outBrightnessProfile** output, as demonstrated below.

*Too low **inSmoothingStdDev** - too much noise*

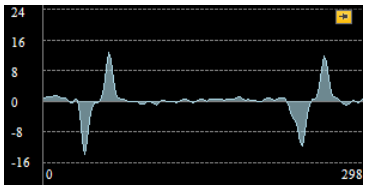


*Appropriate **inSmoothingStdDev** - low noise, significant edges are preserved*



*Too high **inSmoothingStdDev** - significant edges are attenuated*

Edge Extraction

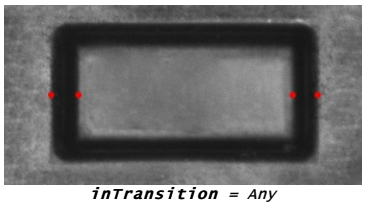


After the brightness profile is extracted and refined, the derivative of the profile is computed and its local extrema of magnitude at least **inMinMagnitude** are identified as edge points. The **inMinMagnitude** parameter should be adjusted using the **outResponseProfile** output.

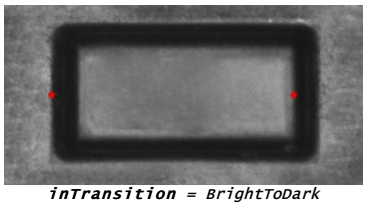
The picture on the right depicts an example **outResponseProfile** profile. In this case the significant extrema vary in magnitude from 11 to 13, while the magnitude of other extrema is lower than 3. Therefore any **inMinMagnitude** value in range (4, 10) would be appropriate.

Edge Transition

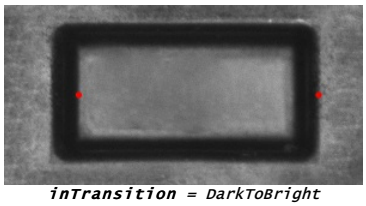
Filters being discussed are capable of filtering the edges depending on the kind of transition they represent - that is, depending on whether the intensity changes from bright to dark, or from dark to bright. The filters detecting individual edges apply the same condition defined using the **inTransition** parameter to each edge (possible choices are *bright-to-dark*, *dark-to-bright* and *any*).



***inTransition** = Any*



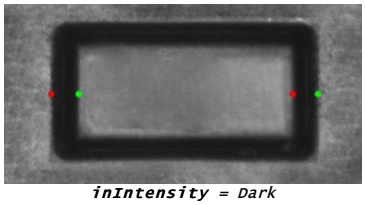
***inTransition** = BrightToDark*



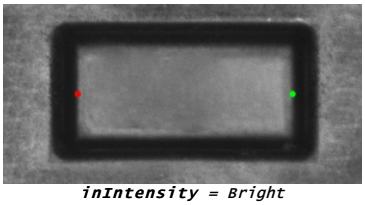
***inTransition** = DarkToBright*

Stripe Intensity

The filters detecting stripes expect the edges to alternate in their characteristics. The parameter **inIntensity** defines whether each stripe should bound the area that is brighter, or darker than the surrounding space.



***inIntensity** = Dark*



***inIntensity** = Bright*

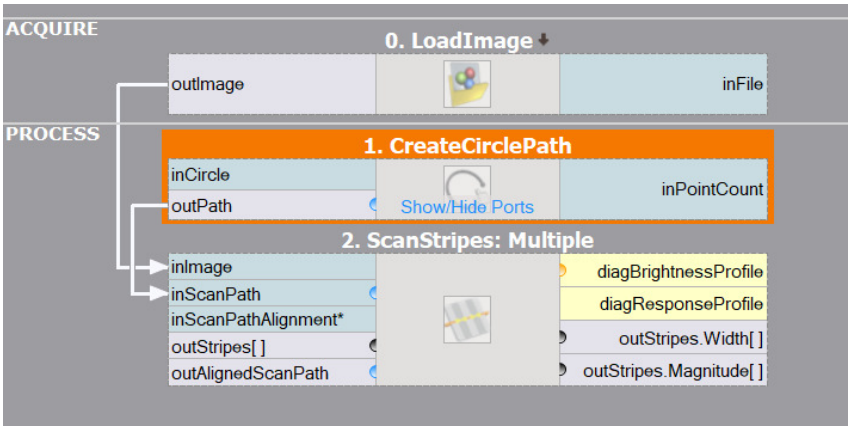
Case Study: Blades

Assume we want to count the blades of a circular saw from the picture.

We will solve this problem running a single 1D Edge Detection scan along a circular path intersecting the blades, and therefore we need to produce appropriate circular path. For that we will use a straightforward CreateCirclePath filter. The built-in editor will allow us to point & click the required **inCircle** parameter.

The next step will be to pick a suitable measuring filter. Because the path will alternate between dark blades and white background, we will use a filter that is capable of measuring stripes. As we do not now how many blades there are on the image (that is what we need to compute), the ScanMultipleStripes filter will be a perfect choice.

We expect the measuring filter to identify each blade as a single stripe (or each space between blades, depending on our selection of **inIntensity**), therefore all we need to do to compute the number of blades is to read the value of the **outStripes.Count** property output of the measuring filter.



The program solves the problem as expected (perhaps after increasing the **inSmoothingStdDev** from default of 0.6 to bigger value of 1.0 or 2.0) and detects all 30 blades of the saw.

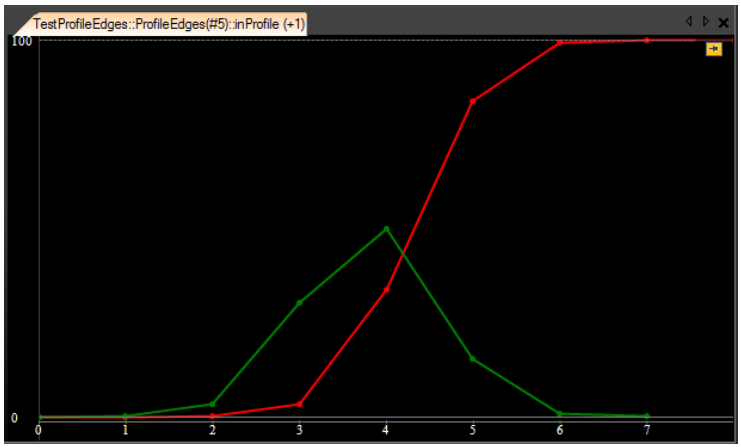
1D Edge Detection – Subpixel Precision

Introduction

One of the key strengths of the 1D Edge Detection tools is their ability do detect edges with precision higher than the pixel grid. This is possible, because the values of the derivative profile (of pixel values) can be interpolated and its maxima can be found analytically.

Example: Parabola Fitting

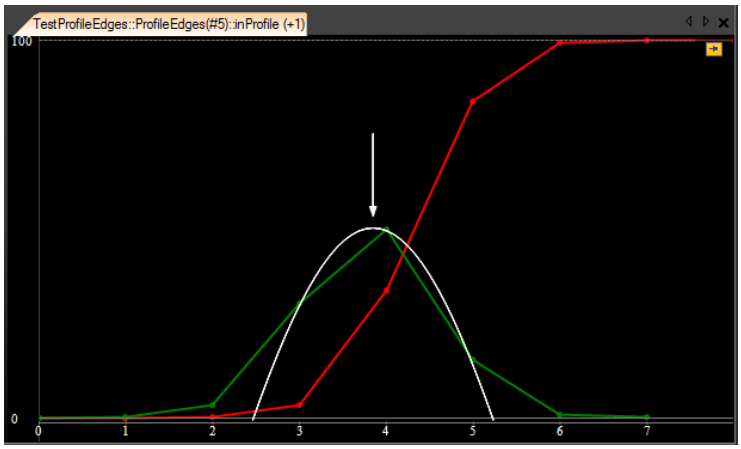
Let us consider a sample profile of pixel values corresponding to an edge (red):



Sample edge profile (red) and its derivative (green). Please note, that the derivative is shifted by 0.5.

The steepest segment is between points 4.0 and 5.0, which corresponds to the maximum of the derivative (green) at 4.5. Without the subpixel precision the edge would be found at this point.

It is, however, possible to consider information about the values of the neighbouring profile points to extract the edge location with higher precision. The simplest method is to fit a parabola to three consecutive points of the derivative profile:



Fitting a parabola to three consecutive points.

Now, the edge point we are looking for can be taken from the maximum of the parabola. In this case it will be 4.363, which is already a subpixel-precise result. This precision is still not very high, however. We know it from an experiment – this particular profile, which we are considering in this example, has been created from a perfect gaussian edge located at the point 430 and downsampled 100 times to simulate a camera looking at an edge at the point 4.3. The error that we got, is 0.063 px. From other experiments we know that in the worst case it can be up to 1/6 px.

Advanced: Methods Available in Aurora Vision

More advanced methods can be used that consider not three, but four consecutive points and which employ additional techniques to assure the highest precision in presence of noise and other practical edge distortions. In Aurora Vision Studio they are available in a form of 3 different profile interpolation methods:

- *Linear* – the simplest method that results in pixel-precise results,
- *Quadratic3* – an improved fitting of parabola to 3 consecutive points,

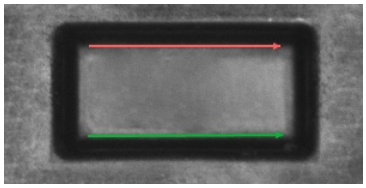
- *Quadratic4* – an advanced method that fits parabola to 4 consecutive points.

The precision of these methods on perfect gaussian edges is respectively: 1/2 px, 1/6 px and 1/23 px. It has to be added, however, that the *Quadratic4* method differs significantly in its performance on edges which are only slightly blurred – when the image quality is close to perfect, the precision can be even higher than 1/50 px.

Shape Fitting

Introduction

Shape Fitting is a machine vision technique that allows for precise detection of objects whose shapes and rough positions are known in advance. It is most often used in measurement applications for establishing line segments, circles, arcs and paths defining the shape that is to be measured.



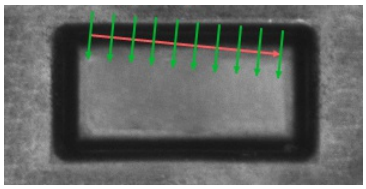
As this technique is derived from 1D Edge Detection, its key advantages are similar – including sub-pixel precision and high performance.

Concept

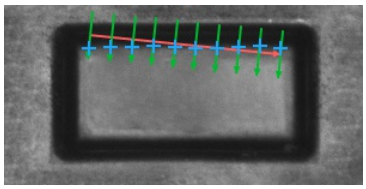
The main idea standing behind Shape Fitting is that a continuous object (such as a circle, an arc or a segment) can be determined using a finite set of points belonging to it. These points are computed by means of appropriate 1D Edge Detection filters and are then combined together into a single higher-level result.

Thus, a single Shape Fitting filter's work consists of the following steps:

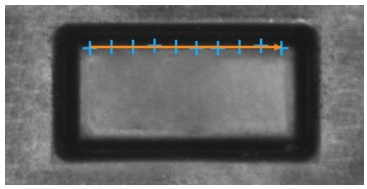
1. **Scan segments preparation** – a series of segments is prepared. The number, length and orientations of the segments are computed from the filter's parameters.
2. **Points extraction** – points that should belong to the object being fitted are extracted using (internally) a proper 1D Edge Detection filter (e.g. ScanSingleEdge in FitCircleToEdges) along each of the scan segments as the scan path.
3. **Object fitting** – the final result is computed with the use of a technique that allows fitting an object to a set of points. In this step, a filter from Geometry 2D Fitting is internally used (e.g. FitCircleToPoints in FitCircleToEdges). An exception to the rule is path fitting. No Geometry 2D Fitting filter is needed there, because the found points serve themselves as the output path characteristic points.



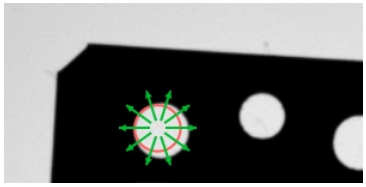
*The scan segments are created according to the fitting field and other parameters (e.g. **inScanCount**).*



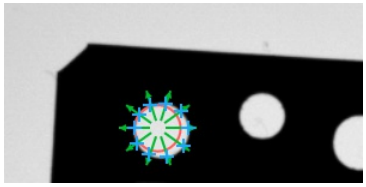
ScanSingleEdge (or another proper 1D Edge Detection filter) is performed.



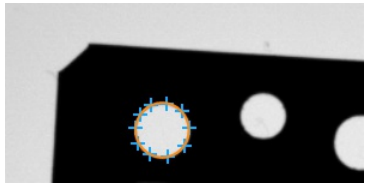
A segment is fitted to the obtained points.



*The scan segments are created according to the fitting field and other parameters (e.g. **inScanCount**).*



ScanSingleEdge (or another proper 1D Edge Detection filter) is performed.



A segment is fitted to the obtained points.

Toolset

The typical usage of the shape fitting method encompasses two distinct functions. One of the **CreateObjectFittingMap** functions (e.g. **CreateCircleFittingMap**) has to be used before any other Shape Fitting function. The special functions create a fitting map consisting of the scan segments. The fitting map is then passed as an input to other functions and, because it generally must be created only once for a whole series of fitting, this strategy speeds up the computations considerably. However, the fitting map must be created before every fitting when **inFittingFieldAlignment** parameter of the **CreateObjectFittingMap** function is not *Nil*.

A sample program is shown below:

```
// Precompute CircleFittingMap before loop.
avl::CreateCircleFittingMap
(
 sampleImage,
 CircleFittingField(expectedCircle, 20.0f),
 NIL,
 10,
 1,
 SamplingParams(InterpolationMethod::Bilinear, 1.0f, atl::NIL),
 circleFittingMap
);

while (true)
{
 Image image;
 atl::Conditional<avl::Circle2D> outCircle;

 GetImageFromCamera(image);  // Get images from a camera.

 avl::FitCircleToEdges   // Perform fitting.
 (
  image,
  circleFittingMap,
  EdgeScanParams(),
  Selection::Best,
  NIL,
  0.1f,
  CircleFittingMethod::AlgebraicPratt,
  NIL,
  outCircle
 );

 if (outCircle != NIL)
 {
  // Process results.
 }
}
```

Parameters

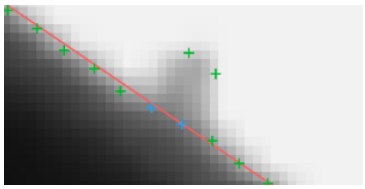
Because of the internal use of 1D Edge Detection filters and Geometry 2D Fitting filters, all parameters known from them are also present in Shape Fitting filters interfaces.

Beside these, there are also a few parameters specific to the subject of shape fitting. The **inScanCount** parameter controls the number of the scan segments. However, not all of the scans have to succeed in order to regard the whole fitting process as being successful. The **inMaxIncompleteness** parameter determines what fraction of the scans may fail.

*FitCircleToEdges performed on the sample image with **inMaxIncompleteness** = 0.25. Although two scans have ended in failure, the circle has been fitted successfully.*

The path fitting functions have some additional parameters, which help to control the output path shape. These parameters are:

- **inMaxDeviationDelta** – it defines the maximal allowed difference between deviations of consecutive points of the output path from the corresponding input path points; if the difference between deviations is greater, the point is considered to be not found at all.
- **inMaxInterpolationLength** – if some of the scans fail or if some of found points are classified to be wrong according to another control parameters (e.g. **inMaxDeviationDelta**), output path points corresponding to them are interpolated depending on points in their nearest vicinity. No more than **inMaxInterpolationLength** consecutive points can be interpolated, and if there exists a longer series of points that would have to be interpolated, the fitting is considered to be unsuccessful. The exception to this behavior are points which were not found on both ends of the input path. Those are not part of the result at all.



*FitPathToEdges performed on the sample image with **inMaxDeviationDelta** = 2 and **inMaxInterpolationLength** = 3. Blue points are the points that were interpolated. If **inMaxInterpolationLength** value was less than 2, the fitting would have failed.*

Template Matching

Introduction

Template Matching is a high-level machine vision technique that identifies the parts on an image that match a predefined template. Advanced template matching algorithms allow to find occurrences of the template regardless of their orientation and local brightness.

Template Matching techniques are flexible and relatively straightforward to use, which makes them one of the most popular methods of object localization. Their applicability is limited mostly by the available computational power, as identification of big and complex templates can be time-consuming.

Concept

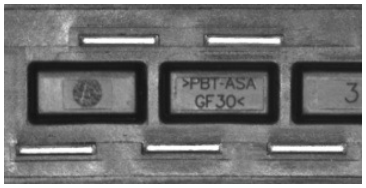
Template Matching techniques are expected to address the following need: provided a reference image of an object (the *template image*) and an image to be inspected (the *input image*) we want to identify all *input image* locations at which the object from the *template image* is present. Depending on the specific problem at hand, we may (or may not) want to identify the rotated or scaled occurrences.

We will start with a demonstration of a naive Template Matching method, which is insufficient for real-life applications, but illustrates the core concept from which the actual Template Matching algorithms stem from. After that we will explain how this method is enhanced and extended in advanced **Grayscale-based Matching** and **Edge-based Matching** routines.

Naive Template Matching

Imagine that we are going to inspect an image of a plug and our goal is to find its pins. We are provided with a *template image* representing the reference object we are looking for and the *input image* to be inspected.

Template image



Input image

We will perform the actual search in a rather straightforward way – we will position the *template* over the image at every possible location, and each time we will compute some numeric measure of similarity between the template and the image segment it currently overlaps with. Finally we will identify the positions that yield the best similarity measures as the probable template occurrences.

Image Correlation

One of the subproblems that occur in the specification above is calculating the *similarity measure* of the aligned template image and the overlapped segment of the input image, which is equivalent to calculating a similarity measure of two images of equal dimensions. This is a classical task, and a numeric measure of image similarity is usually called *image correlation*.

Cross-Correlation

The fundamental method of calculating the image correlation is so called *cross-correlation*, which essentially is a simple sum of pairwise multiplications of corresponding pixel values of the images.

Though we may notice that the correlation value indeed seems to reflect the similarity of the images being compared, cross-correlation method is far from being robust. Its main drawback is that it is biased by changes in global brightness of the images - brightening of an image may sky-rocket its cross-correlation with another image, even if the second image is not at all similar.

Image1	Image2	Cross-Correlation
		19404780
		23316890
		24715810

$$\text{Cross-Correlation}(\text{Image1}, \text{Image2}) = \sum_{x,y} \text{Image1}(x,y) \times \text{Image2}(x,y)$$

Normalized Cross-Correlation

Normalized cross-correlation is an enhanced version of the classic *cross-correlation* method that introduces two improvements over the original one:

- The results are invariant to the global brightness changes, i.e. consistent brightening or darkening of either image has no effect on the result (this is accomplished by subtracting the mean image brightness from each pixel value).
- The final correlation value is scaled to [-1, 1] range, so that NCC of two identical images equals 1.0, while NCC of an image and its negation equals -1.0.

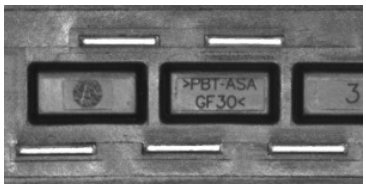
Image1	Image2	NCC
		-0.417
		0.553
		0.844

$$\text{NCC}(\text{Image1}, \text{Image2}) = \frac{1}{N\sigma_1\sigma_2} \sum_{x,y} (\text{Image1}(x,y) - \overline{\text{Image1}}) \times (\text{Image2}(x,y) - \overline{\text{Image2}})$$

Template Correlation Image

Let us get back to the problem at hand. Having introduced the Normalized Cross-Correlation - robust measure of image similarity - we are now able to determine how well the template fits in each of the possible positions. We may represent the results in a form of an image, where brightness of each pixels represents the NCC value of the template positioned over this pixel (black color representing the minimal correlation of -1.0, white color representing the maximal correlation of 1.0).

Template image



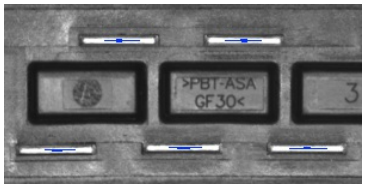
Input image

Template correlation image

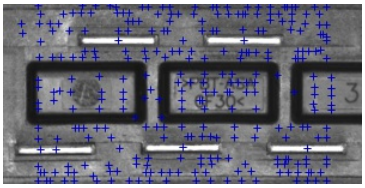
Identification of Matches

All that needs to be done at this point is to decide which points of the *template correlation image* are good enough to be considered actual matches. Usually we identify as matches the positions that (simultaneously) represent the template correlation:

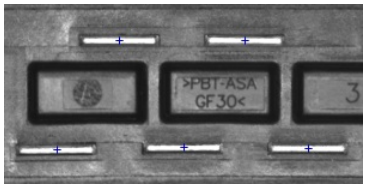
- stronger that some predefined threshold value (i.e stronger that 0.5)
- locally maximal (stronger that the template correlation in the neighboring pixels)



Areas of template correlation above 0.75

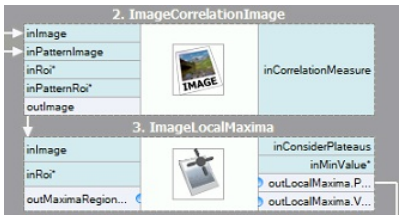


Points of locally maximal template correlation



Points of locally maximal template correlation above 0.75

Summary



It is quite easy to express the described method in Aurora Vision Studio - we will need just two built-in filters. We will compute the template correlation image using the ImageCorrelationImage filter, and then identify the matches using ImageLocalMaxima - we just need to set the **inMinValue** parameter that will cut-off the weak local maxima from the results, as discussed in previous section.

Though the introduced technique was sufficient to solve the problem being considered, we may notice its important drawbacks:

- Template occurrences have to preserve the orientation of the reference template image.
- The method is inefficient, as calculating the template correlation image for medium to large images is time consuming.

In the next sections we will discuss how these issues are being addressed in advanced template matching techniques: **Grayscale-based Matching** and **Edge-based Matching**.

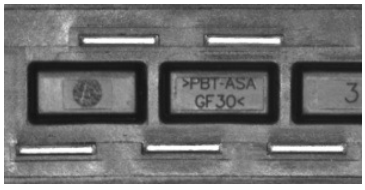
Grayscale-based Matching, Edge-based Matching

Grayscale-based Matching is an advanced Template Matching algorithm that extends the original idea of correlation-based template detection enhancing its efficiency and allowing to search for template occurrences regardless of its orientation. **Edge-based Matching** enhances this method even more by limiting the computation to the object edge-areas.

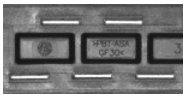
In this section we will describe the intrinsic details of both algorithms. In the next section (**Filter toolset**) we will explain how to use these techniques in Aurora Vision Studio.

Image Pyramid

Image Pyramid is a series of images, each image being a result of downsampling (scaling down, by the factor of two in this case) of the previous element.



Level 0 (input image)



Level 1

Level 2

Pyramid Processing

Image pyramids can be applied to enhance the efficiency of the correlation-based template detection. The important observation is that the template depicted in the reference image usually is still discernible after significant downsampling of the image (though, naturally, fine details are lost in the process). Therefore we can identify match candidates in the downsampled (and therefore much faster to process) image on the highest level of our pyramid, and then repeat the search on the lower levels of the pyramid, each time considering only the template positions that scored high on the previous level.

At each level of the pyramid we will need appropriately downsampled picture of the reference template, i.e. both input image pyramid and template image pyramid should be computed.

Level 0 (template reference image)

Level 1

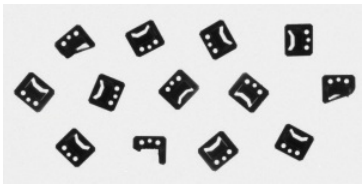
Level 2

Grayscale-based Matching

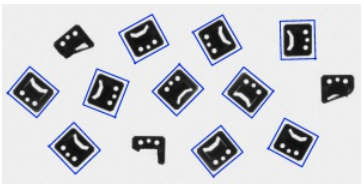
Although in some of the applications the orientation of the objects is uniform and fixed (as we have seen in the plug example), it is often the case that the objects that are to be detected appear rotated. In Template Matching algorithms the classic pyramid search is adapted to allow *multi-angle* matching, i.e. identification of rotated instances of the template.

This is achieved by computing not just one *template image* pyramid, but a set of pyramids - one for each possible rotation of the template. During the pyramid search on the input image the algorithm identifies the pairs *(template position, template orientation)* rather than sole template positions. Similarly to the original schema, on each level of the search the algorithm verifies only those *(position, orientation)* pairs that scored well on the previous level (i.e. seemed to match the template in the image of lower resolution).

Template image



Input image



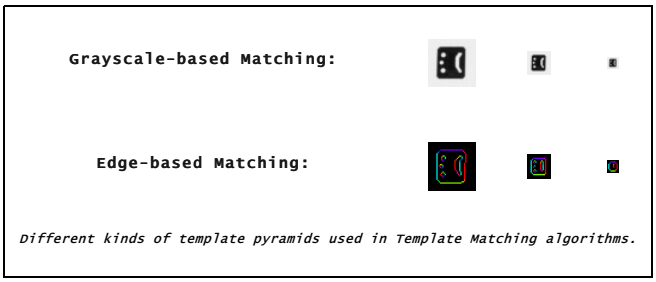
Results of multi-angle matching

The technique of pyramid matching together with *multi-angle* search constitute the **Grayscale-based Template Matching** method.

Edge-based Matching

Edge-based Matching enhances the previously discussed Grayscale-based Matching using one crucial observation - that the shape of any object is defined mainly by the shape of its edges. Therefore, instead of matching of the whole template, we could extract its edges and match only the nearby pixels, thus avoiding some unnecessary computations. In common applications the achieved speed-up is usually significant.

Matching object edges instead of an object as a whole requires slight modification of the original pyramid matching method: imagine we are matching an object of uniform color positioned over uniform background. All of object edge pixels would have the same intensity and the original algorithm would match the object anywhere wherever there is large enough blob of the appropriate color, and this is clearly not what we want to achieve. To resolve this problem, in Edge-based Matching it is the *gradient direction* (represented as a color in HSV space for the illustrative purposes) of the edge pixels, not their intensity, that is matched.



Different kinds of template pyramids used in Template Matching algorithms.

Filter Toolset

Aurora Vision Studio provides a set of filters implementing both **Grayscale-based Matching** and **Edge-based Matching**. For the list of the filters see Template Matching filters.

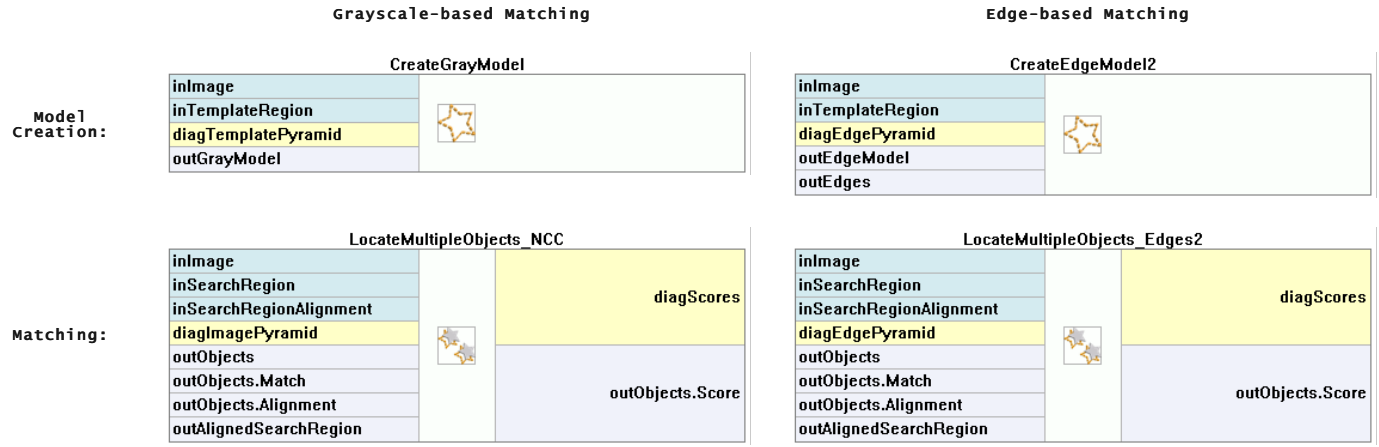
As the template image has to be preprocessed before the pyramid matching (we need to calculate the template image pyramids for all possible rotations and scales), the algorithms are split into two parts:

- **Model Creation** - in this step the *template image* pyramids are calculated and the results are stored in a *model* - atomic object representing all the data needed to run the pyramid matching.
- **Matching** - in this step the *template model* is used to match the template in the *input image*.

Such an organization of the processing makes it possible to compute the *model* once and reuse it multiple times.

Available Filters

For both Template Matching methods two filters are provided, one for each step of the algorithm.



Please note that the use of CreateGrayModel and CreateEdgeModel2 filters will only be necessary in more advanced applications. Otherwise it is enough to use a single filter of the **Matching** step and create the *model* by setting the *inGrayModel* or *inEdgeModel* parameter of the filter. The CreateEdgeModel2 and LocateMultipleObjects_Edges2 filters are preferred over CreateEdgeModel1 and LocateMultipleObjects_Edges1 because they are newer, more advanced versions with more capabilities.

The main challenge of applying the Template Matching technique lies in careful adjustment of filter parameters, rather than designing the program structure.

Advanced Application Schema

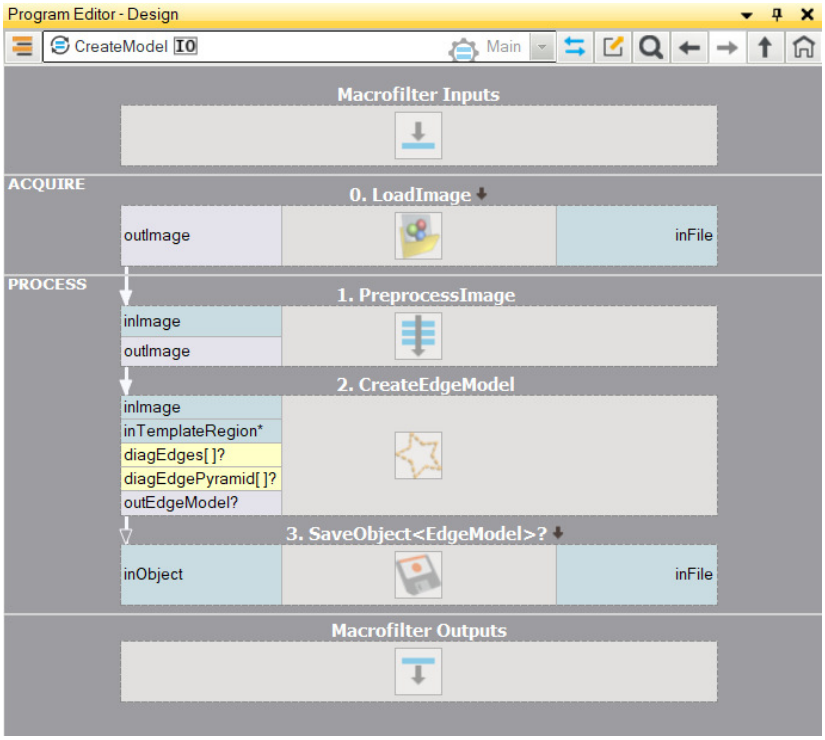
There are several kinds of advanced applications, for which the interactive GUI for Template Matching is not enough and the user needs to use the CreateGrayModel or CreateEdgeModel2 filter directly. For example:

1. When creating the model requires non-trivial image preprocessing.
2. When we need an entire array of models created automatically from a set of images.
3. When the end user should be able to define his own templates in the runtime application (e.g. by making a selection on an input image).

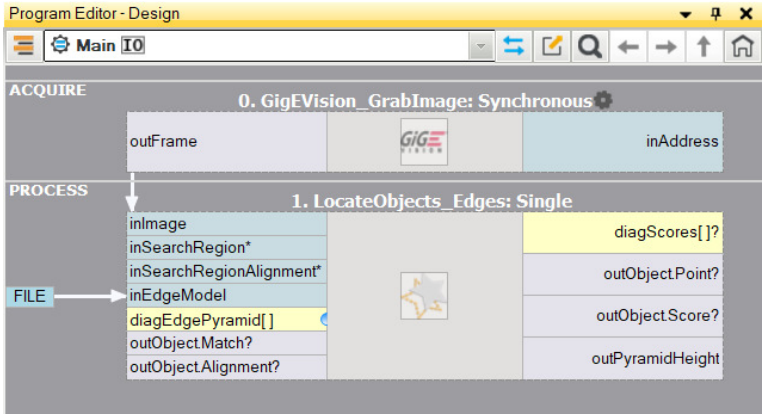
Schema 1: Model Creation in a Separate Program

For the cases 1 and 2 it is advisable to implement model creation in a separate *Task* macrofilter, save the model to an AVDATA file and then link that file to the input of the matching filter in the main program:

Model Creation:



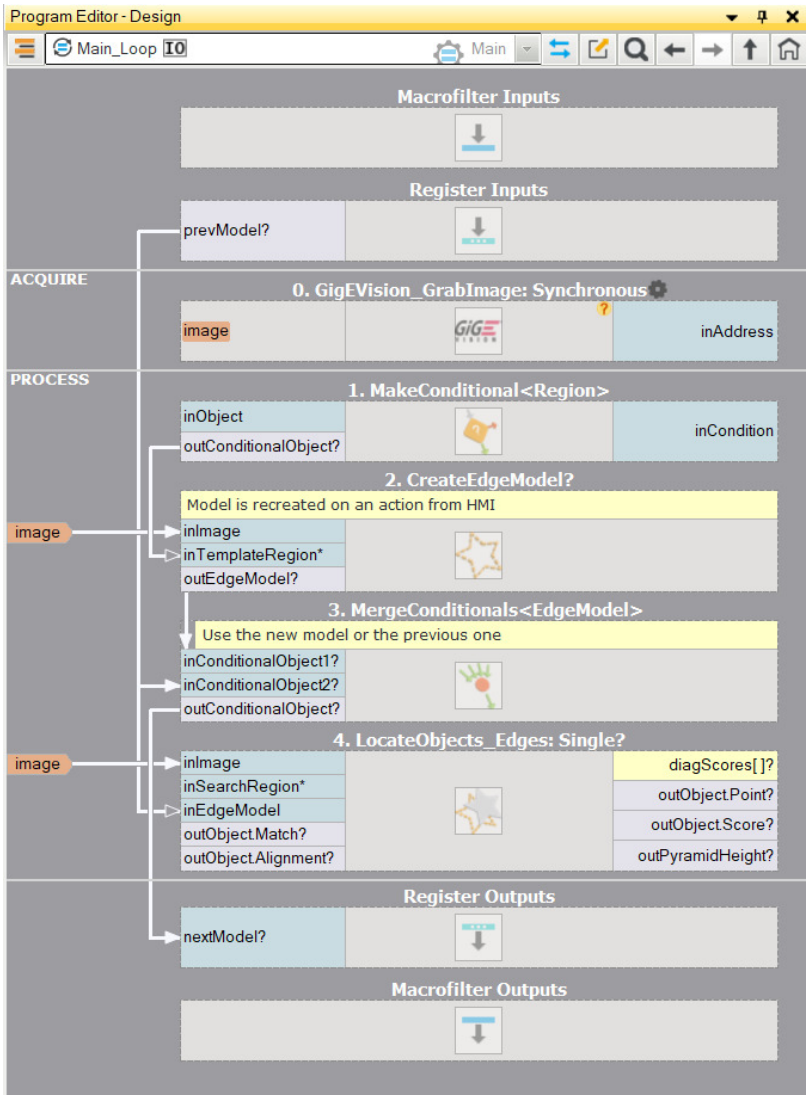
Main Program:



When this program is ready, you can run the "CreateModel" task as a program at any time you want to recreate the model. The link to the data file on the input of the matching filter does not need any modifications then, because this is just a link and what is being changed is only the file on disk.

Schema 2: Dynamic Model Creation

For the case 3, when the model has to be created dynamically, both the model creating filter and the matching filter have to be in the same task. The former, however, should be executed conditionally, when a respective HMI event is raised (e.g. the user clicks an ImpulseButton or makes some mouse action in a VideoBox). For representing the model, a register of EdgeModel2? type should be used, that will store the latest model. Here is an example realization with the model being created from a predefined box on an input image when a button is clicked in the HMI:



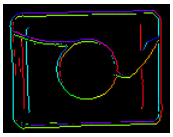
Model Creation

Height of the Pyramid

The **inMaxPyramidLevel** parameter determines the number of levels of the pyramid matching and should be set to the largest number for which the template is still recognizable on the highest pyramid level. This value should be selected through interactive experimentation using the diagnostic output **diagTemplatePyramid** (Grayscale-based Matching) or **diagEdgePyramid** (Edge-based Matching).

The **inMinPyramidLevel** parameter determines the lowest pyramid level that is generated during creation phase and the lowest pyramid level that the occurrences are tracked to during location phase. If the parameter is set to lower value in location than in creation, the missing levels are generated dynamically by the locating filter. This approach leads to much faster creation, but a bit slower location.

In the following example the **inMaxPyramidLevel** value of 4 would be too high (for both methods), as the structure of the template is entirely lost on this level of the pyramid. Also the value of 3 seems a bit excessive (especially in case of Edge-based Matching) while the value of 2 would definitely be a safe choice.

	Level 0	Level 1	Level 2	Level 3	Level 4
Grayscale-based Matching (diagTemplatePyramid):					
Edge-based Matching (diagEdgePyramid):					

Angle Range

The **inMinAngle**, **inMaxAngle** parameters determine the range of template orientations that will be considered in the matching process. For instance (values in brackets represent the pairs of **inMinAngle**, **inMaxAngle** values):

- (-180.0, 180.0): all rotations are considered (default value)
- (-15.0, 15.0): the template occurrences are allowed to deviate from the reference template orientation at most by 15.0 degrees (in each direction)
- (0.0, 0.0): the template occurrences are expected to preserve the reference template orientation

Wide range of possible orientations introduces significant amount of overhead (both in memory usage and computing time), so it is advisable to limit the range whenever possible, especially if different scales are also involved. The number of rotations created can be further manipulated with

inAnglePrecision parameter. Decreasing it results in smaller models and smaller execution times, but can also lead to objects that are slightly less accurate.

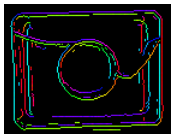
Scale Range

The **inMinScale**, **inMaxScale** parameters determine the range of template scales that will be considered in the matching process. It enables locating objects that are slightly smaller or bigger than the object used during model creation.

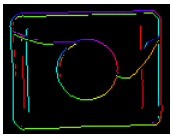
Wide range of possible scales introduces significant amount of overhead (both in memory usage and computing time), so it is advisable to limit the range whenever possible. The number of scales created can be further manipulated with **inScalePrecision** parameter. Decreasing it results in smaller models and smaller execution times, but can also lead to objects that are slightly less accurate.

Edge Detection Settings (only Edge-based Matching)

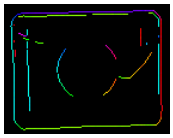
The **inEdgeThreshold**, **inEdgeHysteresis** parameters of CreateEdgeModel2 filter determine the settings of the hysteresis thresholding used to detect edges in the template image. The lower the **inEdgeThreshold** value, the more edges will be detected in the template image. These parameters should be set so that all the significant edges of the template are detected and the amount of redundant edges (noise) in the result is as limited as possible. Similarly to the pyramid height, edge detection thresholds should be selected through interactive experimentation using the **outEdges** output and the diagnostic output **diagEdgePyramid** - this time we need to look only at the picture at the lowest level.



(15.0, 30.0) - excessive amount of noise



(40.0, 60.0) - OK



(60.0, 70.0) - significant edges lost

The CreateEdgeModel2 filter will not allow to create a model in which no edges were detected at the top of the pyramid (which means not only *some* significant edges were lost, but all of them), yielding an error in such case. Whenever that happens, the height of the pyramid, or the edge thresholds, or both, should be reduced.

Matching

The **inMinScore** parameter determines how permissive the algorithm will be in verification of the match candidates - the higher the value the less results will be returned. This parameter should be set through interactive experimentation to a value low enough to assure that all correct matches will be returned, but not much lower, as too low value slows the algorithm down and may cause false matches to appear in the results.

Tips and Best Practices

How to Select a Method?

For vast majority of applications the **Edge-based Matching** method will be both more robust and more efficient than **Grayscale-based Matching**. The latter should be considered only if the template being considered has smooth color transition areas that are not defined by discernible edges, but still should be matched.

How to even further upgrade the results of Edge-based Matching?

You can use EnhanceMultipleObjectMatches filter or EnhanceSingleObjectMatch filter to fine-tune the results. A great example of usage is presented in the CreateGoldenTemplate2 filter.

Using Local Coordinate Systems

Introduction

Local coordinate systems provide a convenient means for inspecting objects that may appear at different positions on the input image. Instead of denoting coordinates of geometrical primitives in the absolute coordinate system of the image, local coordinate systems make it possible to use coordinates local to the object being inspected. In an initial step of the program the object is located and a local coordinate system is set accordingly. Other tools can then be configured to work within this coordinate system, and this makes them independent of the object translation, rotation and scale.

Two most important notions here are:

- **CoordinateSystem2D** – a structure consisting of *Origin* (Point2D), *Angle* (real number) and *Scale* (real number), defining a relative Cartesian coordinate system with its point (0, 0) located at the *Origin* point of the parent coordinate system (usually an image).
- **Alignment** – the process of transforming geometrical primitives from a local coordinate system to the coordinates of an image (absolute), or data defining such transformation. An alignment is usually represented with the **CoordinateSystem2D** data type.

Creating a Local Coordinate System

There are two standard ways of setting a local coordinate system:

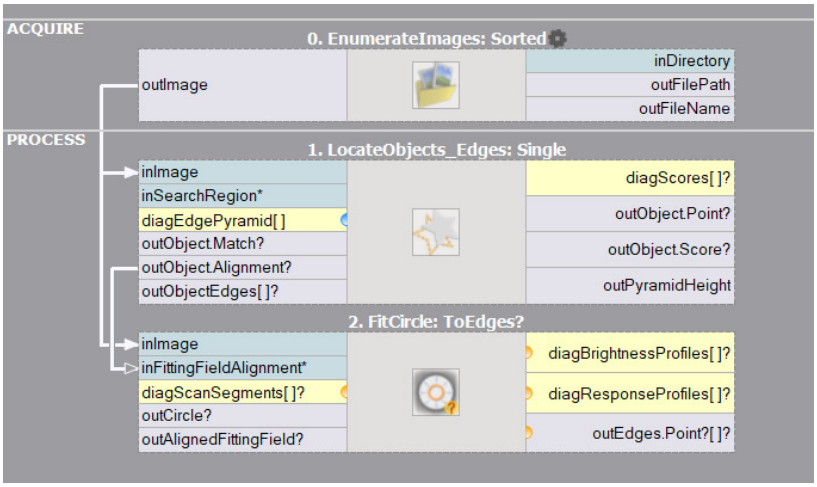
1. With Template Matching filters it is straightforward as the filters have **outObjectAlignment(s)** outputs, which provide local coordinate systems of the detected objects.
2. With one of the CreateCoordinateSystem functions, which allow for creating local coordinate systems manually at any location, and with any rotation and scale. In most typical scenarios of this kind, the objects are located with 1D Edge Detection, Shape Fitting or Blob Analysis tools.

Using a Local Coordinate System

After a local coordinate system is created it can be used in the subsequent image analysis tools. The high level tools available in Aurora Vision Studio have an **inAlignment** (or similar) input, which just needs to be connected to the port of the created local coordinate system. At this point, you should first run the program at least to the point where the coordinate system is computed, and then the geometrical primitives you will be defining on other inputs, will be automatically aligned with the position of the inspected object.

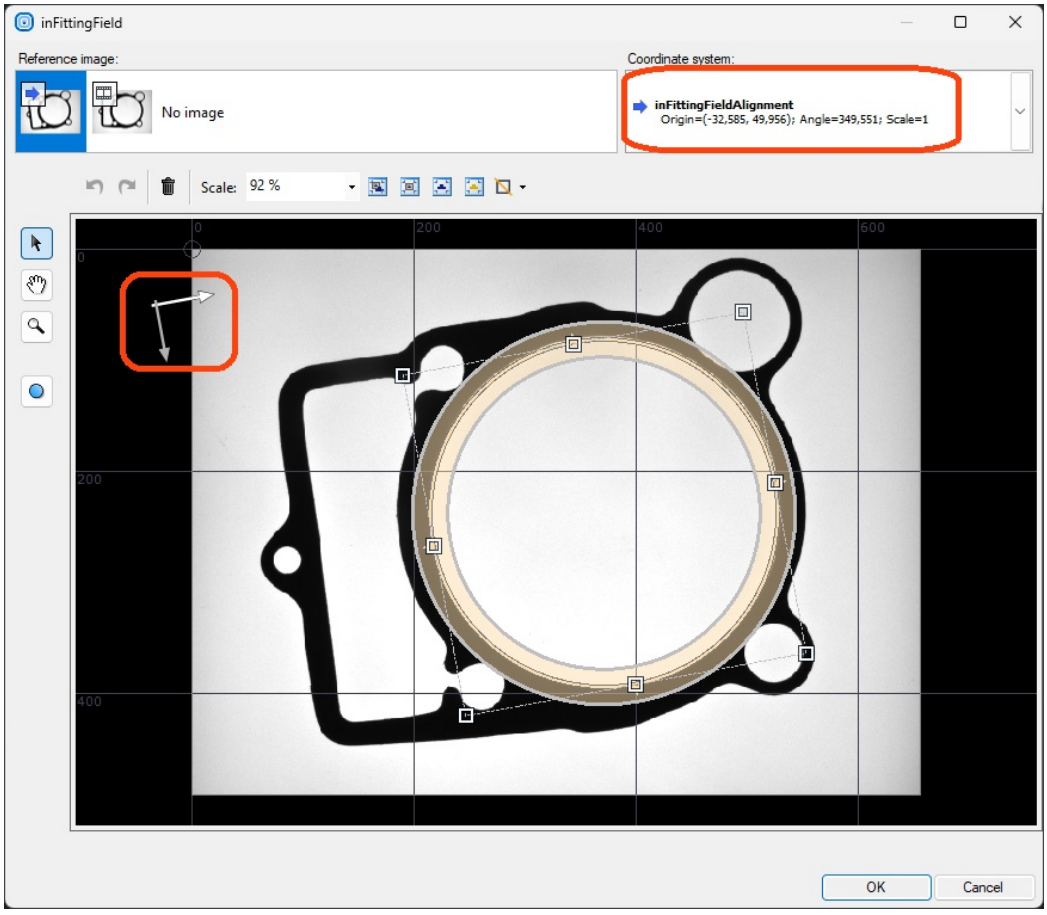
Example 1: Alignment from Template Matching

To use object alignment from a Template Matching filter, you need to connect the **Alignment** ports:



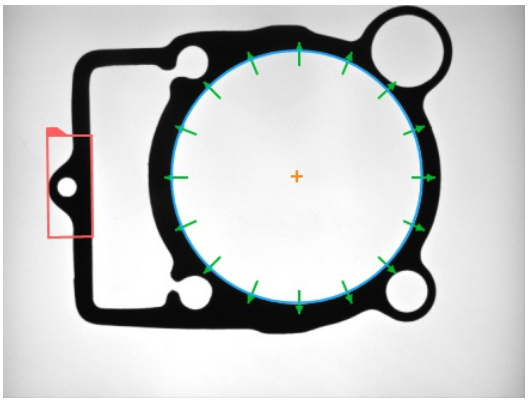
Template Matching and an aligned circle fitting.

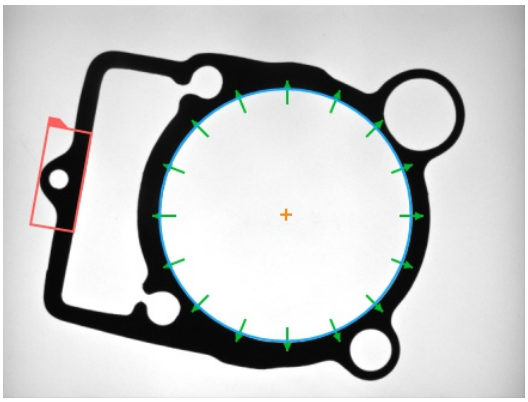
When you execute the template matching filter and enter the editor of the **inFittingField** input of the FitCircleToEdges filter, you will have the local coordinate system already selected (you can also select it manually) and the primitive you create will have relative coordinates:



Editing an expected circle in a local coordinate system.

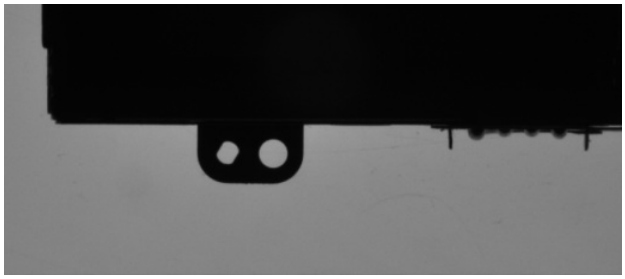
During program execution this geometrical primitive will be automatically aligned with the object position. Moreover, you will be able to adjust the input primitive in the context of any input image, because they will be always displayed aligned. Here are example results:





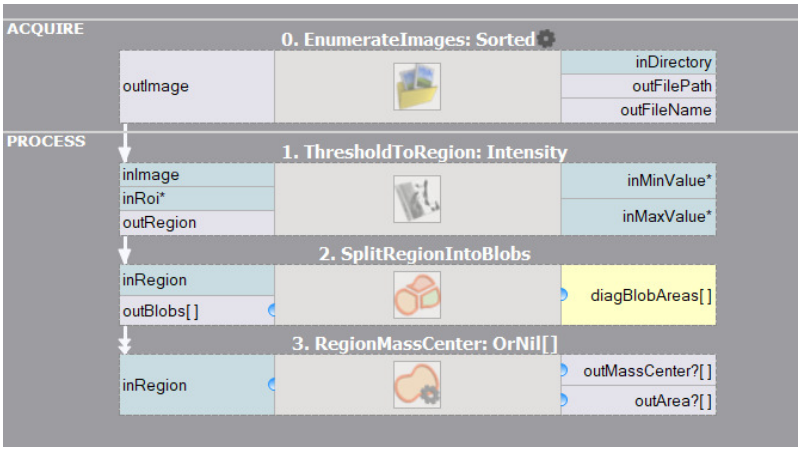
Example 2: Alignment from Blob Analysis

In many applications objects can be located with methods simpler and faster than Template Matching – like 1D Edge Detection, Shape Fitting or Blob Analysis. In the following example we will show how to create a local coordinate system from two blobs:

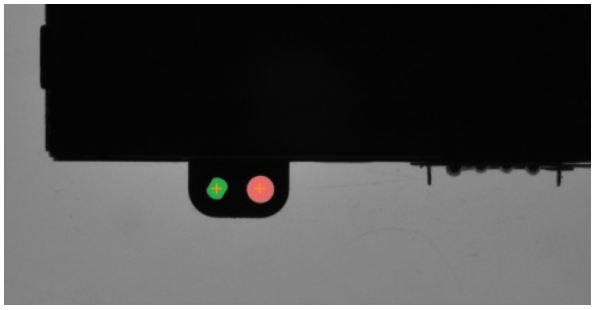


Two holes clearly define the object location.

In the first step we detect the blobs (see also: Blob Analysis) and their centers:

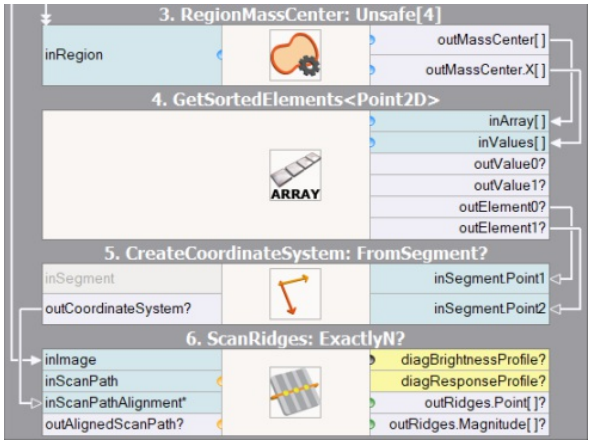


Filters detecting blobs and their centers.

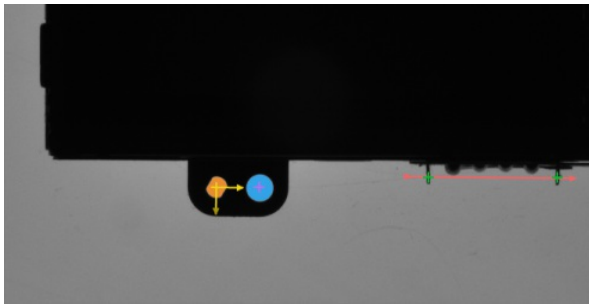


The result of blob detection.

In the second step we sort the centers by the X coordinate and create a coordinate system "from segment" defined by the two points (CreateCoordinateSystemFromSegment). The segment defines both the origin and the orientation. Having this coordinate system ready, we connect it to the **inScanPathAlignment** input of ScanExactlyNRidges, which will measure the distance between two insets. The measurement will work correctly irrespective of the object position (mind the expanded structure inputs and outputs):



Filters creating a coordinate systems and performing an aligned measurement.



Created local coordinate system and an aligned measurement.

Manual Alignment

In some cases the filter you will need to use with a local coordinate system will have no appropriate **inAlignment** input. In such cases the solution is to transform the primitive manually with filters like AlignPoint, AlignCircle, AlignRectangle. These filters accept a geometrical primitive defined in a local coordinate system, and the coordinate system itself, and return the same primitive, but with absolute coordinates, i.e. aligned to the coordinate system of an image.

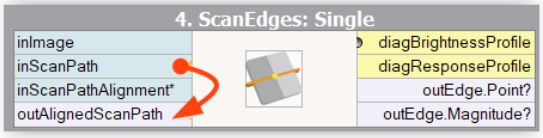
A very common case is with ports of type Region, which is pixel-precise and, while allowing for creation of arbitrary shapes, cannot be directly transformed. In such cases it is advisable to use the CreateRectangleRegion filter and define the region-of-interest at **inRectangle**. The filter, having also the **inRectangleAlignment** input connected, will return a region properly aligned with the related object position. Some ready-made tools, e.g. CheckPresence_Intensity, use this approach internally.

Not Mixing Local Coordinate Systems

It is important to keep in mind that geometrical primitives that appear in different places of a program may belong to different coordinate systems. When such different objects are combined together (e.g. with a filter like SegmentSegmentIntersection) or placed on a single data preview, the results will be meaningless or at least confusing. Thus, only objects belonging to the same coordinate system should be combined. In particular, when placing primitives on a preview on top of an image, only aligned primitives (with absolute coordinates) should be used.

As a general rule, image analysis filters of Aurora Vision Studio accept primitives in local coordinate systems on inputs, but outputs are always

aligned (i.e. in the absolute coordinate system). In particular, many filters that align input primitives internally also have outputs that contain the input primitive transformed to the absolute coordinate system. For example, the ScanSingleEdge filters has a **inScanPath** input defined in a local coordinate system and a corresponding **outAlignedScanPath** output defined in the absolute coordinate system:

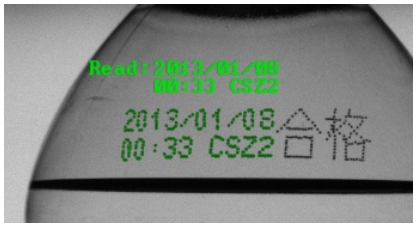


*The ScanSingleEdge filter with a pair of ports: **inScanPath** and **outAlignedScanPath**, belonging to different coordinate systems.*

Optical Character Recognition - traditional method

Introduction

Optical Character Recognition (OCR) is a machine vision task consisting in extracting textual information from images.



Result of data extraction using OCR.

State of the art techniques for OCR offer high accuracy of text recognition and invulnerability to medium grain graphical noises. They are also applicable for recognition of characters made using dot matrix printers. This technology gives satisfactory results for partially occluded or deformed characters.

Please be informed that this article is referring to the traditional OCR method. Nowadays, we strongly recommend using Deep Learning OCR tools, which are much faster and more efficient than the traditional ones in many cases. You can find more information about the Deep Learning tools here.

Efficiency of the traditional recognition process mostly depends on the quality of text segmentation results. Most of the recognition cases can be done using a provided set of recognition models. In other cases a new recognition model can be easily prepared.

Concept

OCR technology is widely used for automatic data reading from various sources. It is especially used to gather data from documents and printed labels.

In the first part of this manual usage of high level filters will be described.

The second part of this manual shows how to use standard OCR models provided with Aurora Vision Studio. It also shows how to prepare an image to get best possible results of recognition.

The third part describes the process of preparing and training OCR models.

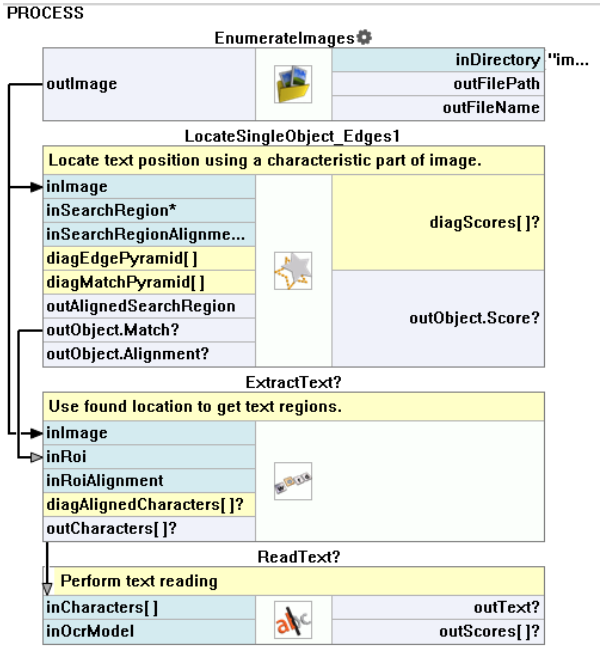
The last part presents an example program that reads text from images.

Using high level Optical Character Recognition filters

Aurora Vision Studio offers a convenient way to extract a text region from an image and then read it using a trained OCR classifier.

The typical OCR application consists of the following steps:

1. **Find text position** - locate the text position using template matching,
2. **Extract text** - use the filter ExtractText to distinct the text form the background and perform its segmentation,
3. **Read text** - recognizing the extracted characters with the ReadText filter.



Example OCR application using high level filters.

Details on Optical Character Recognition technique

Reading text from images

In order to achieve the most accurate recognition it is necessary to perform careful text extraction and segmentation. The overall process of acquiring text from images consists of the following steps:

1. Getting text location,
2. Extracting text from the background,
3. Segmenting text,
4. Using prepared OCR models,
5. Character recognition,
6. Interpreting results,
7. Verifying results.

The following sections will introduce methods used to detect and recognize text from images. For better understanding of this guide the reader should be familiar with basic blob analysis techniques.

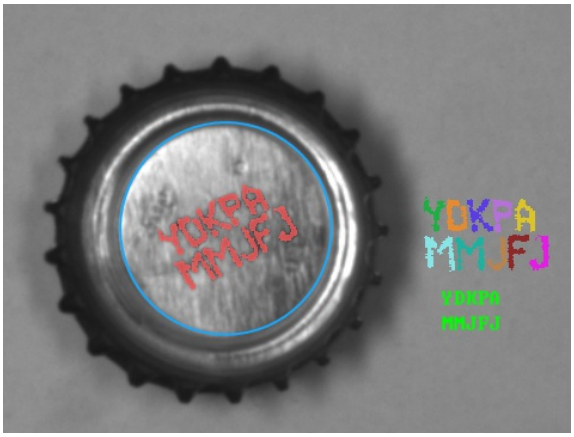
Getting text location

In general, text localization tasks can be divided into three cases:

1. The location of text is fixed and it is described by boxes called masks. For example, the personal identification card is produced according to the formal specification. The location of each data field is known. A well calibrated vision system can take images in which the location of the text is almost constant.

An example image with text masks.

2. Text location is not fixed, but it is related to a characteristic element on the input images or to a special marker (an optical mark). To get the location of the text the optical mark has to be found. This can be done with template matching, 1D edge detection or other technique.
3. The location of text is not specified, but characters can be easily separated from the background with image thresholding. The correct characters can then be found with blob analysis techniques.

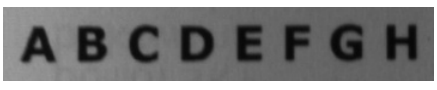


Getting text from a bottle cap.

When the text location is specified, the image under analysis must be transformed to make text lines parallel to the X-axis. This can be done with RotateImage, CropImageToRectangle or ImageAlongPath filters.

Extracting text from the background

A major complication during the process of text extraction may be uneven light. Some techniques like light normalization or edge sharpening can help in finding characters. The example of light normalization can be found in the example project *Examples\Tablets*. The presentation of image sharpening using the Fourier transform can be found in the *Examples\Fourier* example.

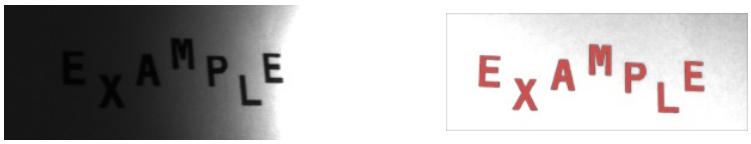


Original image.

Image after light normalization.

Image after low-frequency image damping using the Fourier transform.

Text extraction is based on image binarization techniques. To extract characters, filters like ThresholdToRegion and ThresholdToRegion_Dynamic can be used. In order to avoid recognizing regions which do not include characters, it is advisable to use filters based on blob area.



Sample images with uneven light.

Results of ThresholdToRegion and ThresholdToRegion_Dynamic on images with uneven light.

At this point the extracted text region is prepared for segmentation.

Segmenting text

Text region segmentation is a process of splitting a region into lines and individual characters. The recognition step is only possible if each region contains a single character.

Firstly, if there are multiple lines of text, separation into lines must be performed. If the text orientation is horizontal, simple region dilation can be used followed by splitting the region into blobs. In other cases the text must be transformed, so that the lines become horizontal.

The process of splitting text into lines using region morphology filters.

When text text lines are separated, each line must be split into individual characters. In a case when characters are not made of diacritic marks and characters can be separated well, the filter SplitRegionIntoBlobs can be used. In other cases the filter SplitRegionIntoExactlyNCharacters or SplitRegionIntoMultipleCharacters must be used.

Character segmentation using SplitRegionIntoBlobs.

Character segmentation using SplitRegionIntoMultipleCharacters.

Next, the extracted characters will be translated from graphical representation to textual representation.

Using prepared OCR models

Standard OCR models are typically located in the disk directory *C:\ProgramData\Aurora Vision\{Aurora Vision Product Name}\PretrainedFonts*.

The table below shows the list of available font models:

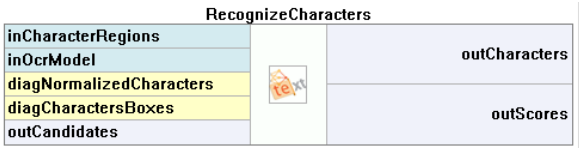
Font name	Font typeface	Set name	Characters
OCRA	monospaced	AZ	ABCDEFGHIJKLMNOPQRSTUVWXYZ.-/
		AZ_small	abcdefghijklmnopqrstuvwxyz.-/
		09	0123456789.-/+
		AZ09	ABCDEFGHIJKLMNOPQRSTUVWXYZ0123456789.-/+
OCRB	monospaced	AZ	ABCDEFGHIJKLMNOPQRSTUVWXYZ.-/
		AZ_small	abcdefghijklmnopqrstuvwxyz.-/
		09	0123456789.-/+
		AZ09	ABCDEFGHIJKLMNOPQRSTUVWXYZ0123456789.-/+
MICR	monospaced	ABC09	ABC0123456789
Computer	monospaced	AZ	ABCDEFGHIJKLMNOPQRSTUVWXYZ.-/
		AZ_small	abcdefghijklmnopqrstuvwxyz.-/
		09	0123456789.-/+
		AZ09	ABCDEFGHIJKLMNOPQRSTUVWXYZ0123456789.-/+
DotMatrix	monospaced	AZ	ABCDEFGHIJKLMNOPQRSTUVWXYZ+-./
		AZ09	ABCDEFGHIJKLMNOPQRSTUVWXYZ+-01234556789./
		09	01234556789.+-/
Regular	proportional	AZ	ABCDEFGHIJKLMNOPQRSTUVWXYZ.-/
		AZ_small	abcdefghijklmnopqrstuvwxyz.-/
		09	0123456789.-/+
		AZ09	ABCDEFGHIJKLMNOPQRSTUVWXYZ0123456789.-/+

Character recognition

Aurora Vision Library offers two types of character classifiers:

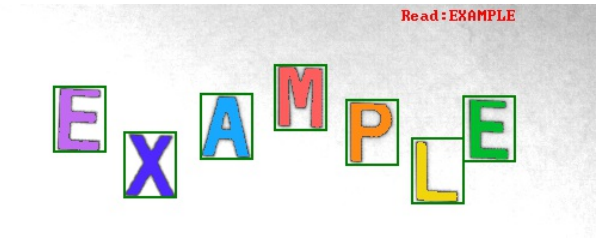
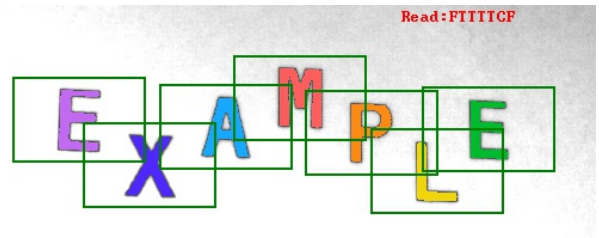
1. Classifier based on multi-layer perceptron (MLP).
2. Classifier based on support vector machines (SVM).

Both of the classifiers are stored in the OcrModel type. To get a text from character regions use the RecognizeCharacters filter, shown on the image below:



The first and the most important step is to choose the appropriate character normalization size. The internal classifier recognizes characters using their normalized form. More information about character normalization process will be provided in the section describing the process of classifier training.

The character normalization allows to classify characters with different sizes. The parameter **inCharacterSize** defines the size of a character before the normalization. When the value is not provided, the size is calculated automatically using the character bounding box.

Character presentation	Characters after normalization	Description
		The appropriate character size is chosen.
		The size of character is too small.
		Too much information about a character is lost because of too large size has been selected .

Next, character sorting order must be chosen. The default order is from left to right.

If the input text contains spaced characters, the value of **inMinSpaceWidth** input must be set. This value indicates the minimal distance between two characters between which a space will be inserted.

Character recognition provides the following information:

1. the read text as a string (**outCharacters**),
2. an array of character recognition scores (**outScores**),
3. an array of recognition candidates for each character (**outCandidates**).

Interpreting results

The table below shows recognition results for characters extracted from the example image. An unrecognized character is colored in red.

Original character	Recognized character	Score	Candidates (character and accuracy)	
	(outCharacters)	(outScores)	(outCandidates)	
E	E	1.00	E: 1.00	
X	X	1.00	X: 1.00	
A	A	1.00	A: 1.00	
M	M	1.00	M: 1.00	
P	**R**	0.50	R: 0.90	B: 0.40
L	L	1.00	L: 1.00	
E	E	1.00	E: 1.00	

In this example the letter *P* was not included in the training set. In effect, the OCR model was unable to recognize the representation of the *P* letter. The internal classifier was trying to select most similar known character.

Verifying results

After reading result should be check if text follows constraints. It can be done using simple string manipulation.

Preparation of the OCR models

An OCR model consists of an internal statistical tool called a classifier and a set of character data. There are two kinds of classifiers used to recognize characters. The first classifier type is based on the multilayer perceptron classifier (MLP) and the second one uses support vector machines (SVM). For further details please refer to the documentation of the MLP_Init and the SVM_Init filters. Each model must be trained before it can be used.

The process of OCR model training consists of the following steps:

1. preparation of the training data set,
2. selection of the normalization size and character features,
3. setup of the OCR model,
4. training of the OCR model,
5. saving results to a file.

When these steps are performed, the model is ready to use.

Preparation of the training data set

Each classifier needs character samples in order to begin the training process. To get the best recognition accuracy, the training character samples should be as similar as possible to those which will be provided for recognition. There are two possible ways to obtain sample characters: (1)

extraction of characters from real images or (2) generation of artificial characters using computer fonts.

In the perfect world the model should be trained using numerous real samples. However, sometimes it can be difficult to gather enough real character samples. In this case character samples should be generated by deforming the available samples. A classifier which was trained on a not big enough data set can focus only on familiar character samples at the same time failing to recognize slightly modified characters.

Synthetic characters generated by means of a computer font.

Character samples acquired from a real usage.

Example operations which are used to create new character samples:

1. region rotation (using the RotateRegion filter),
2. shearing (ShearRegion),
3. dilatation and erosion (DilateRegion, ErodeRegion),
4. addition of a noise.

The set of character samples deformed by: the region rotation, morphological transforms, shearing and noises.

Note: Adding too many deformed characters to a training set will increase the training time of a model.

Note: Excessive deformation of character shape can result in classifier inability to recognize the learnt character base. For example: if the training set contains a *C* character with too many noises, it can be mistaken for *O* character. In this case the classifier will be unable to determine the base of a newly provided character.

Each character sample must be stored in a structure of type CharacterSample. This structure consists of a character region and its textual representation. To create an array of character samples use the MakeCharacterSamples filter.

Selection of normalization size and character features

The character normalization allows for reduction of the amount of data used in the character classification. The other aim of normalization is to enable the classification process to recognize characters of various sizes.

During normalization each character is resized into a size which was provided during the model initialization. All further classifier operations will be performed on the resized (normalized) characters.

Various size characters before and after the normalization process.

Selection of too large normalization size will increase training time of the OCR classifier. On the other hand, too low size will result in loss of important character details. The selected normalization size should be a compromise between classification time and the accuracy of recognition. For the best results, a character size after normalization should be similar to its size before normalization.

During the normalization process some character details will be lost, e.g. the aspect ratio of a character. In the training process, some additional information can be added, which can compensate for the information loss in the normalization process. For further information please refer to the documentation of the TrainOcr_MLP filter.

Training of the OCR model

There are two filters used to train each type of an OCR classifier. These filters require parameters which describe the classifier training process.

Training of MLP classifier using TrainOcr_MLP.

Training of SVM classifier using TrainOcr_SVM.

Saving the training results

After successful classifier training the results should be saved for future use. The function SaveOcrModel should be used.

Camera Calibration and World Coordinates

Camera Calibration

Camera calibration, also known as camera resectioning, is a process of estimating parameters of a camera model: a set of parameters that describe the internal geometry of image capture process. Accurate camera calibration is is essential for various applications, such as multi-camera setups where images relate to each other, removing geometric distortions due to lens imperfections, or precise measurement of real-world geometric properties (positions, distances, areas, straightness, etc.).

The model to be used is chosen depending on the camera type (e.g. projective camera, telecentric camera, line scan camera) and accuracy requirements. In a case of a standard projective camera, the model (known as pinhole camera model) consists of focal length, principal point location and distortion parameters.

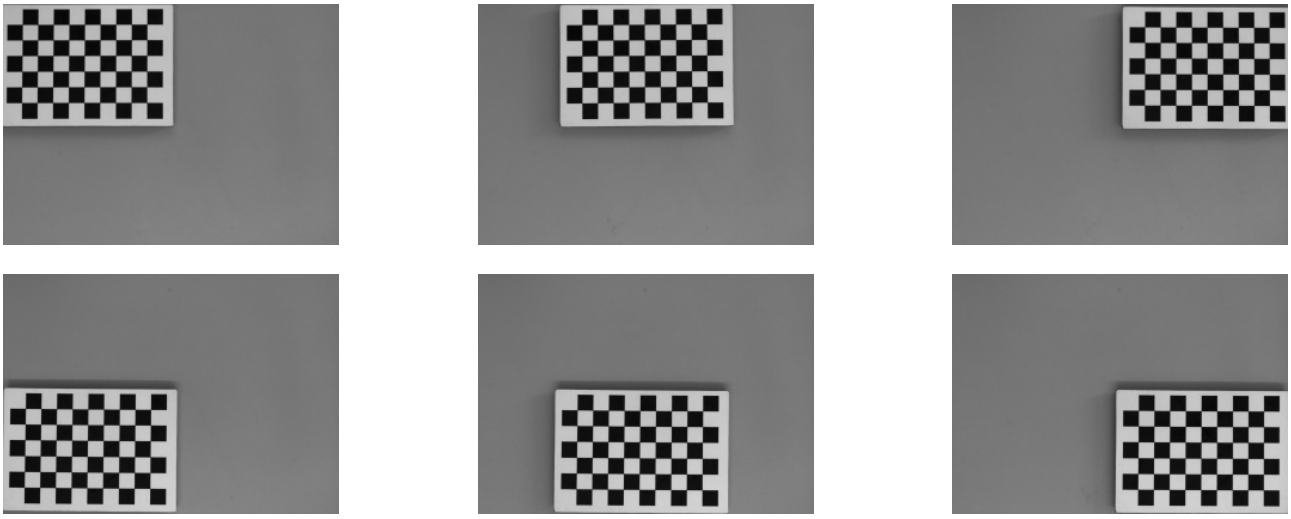
A few distortion model types are supported. The simplest - divisional - supports most use cases and has predictable behaviour even when calibration data is sparse. Higher order models can be more accurate, however they need a much larger dataset of high quality calibration points, and are usually needed for achieving high levels of positional accuracy across the whole image - order of magnitude below 0.1 pix. Of course this is only a rule of thumb, as each lens is different and there are exceptions.

The area scan camera models (pinhole or telecentric) contain only *intrinsic* camera parameters, and so it does not change with camera repositioning, rotations, etc. Thanks to that, there is no need for camera calibration in the production environment, the camera can be calibrated beforehand. As soon as the camera has been assembled with the lens and lens adjustments (zoom/focus/f-stop rings) have been tightly locked, the calibration images can be taken and camera calibration performed. Of course any modifications to the camera-lens setup void the calibration parameters, even apparently minor ones such as removing the lens and putting it back on the camera in seemingly the same position.

On the other hand the line scan model contains parameters of whole imaging setup, i.e. camera and a moving element (usually a conveyor belt). Such approach, in contrast with area scan camera calibration, is necessary as the moving element of line scan camera system is tightly bound within the image acquisition geometry.

Camera model can be directly used to obtain an *undistorted* image (an image, which would have been taken by a camera with the same basic parameters, but without lens distortion present), however for most use cases the camera calibration is just a prerequisite to some other operation. For example, when camera is used for inspection of planar surfaces (or objects lying on such surface), the camera model is needed to perform a *World Plane* calibration (see *World Plane - measurements and rectification* section below).

In Aurora Vision Studio user will be prompted by a GUI when a camera calibration is needed to be performed. Alternatively, filters responsible for camera calibration may be used directly: CalibrateCamera_Pinhole, CalibrateCamera_Telecentric, CalibrateCamera_LineScan.



A set of grid pictures for basic calibration. Note that high accuracy applications require denser grids and higher amount of pictures. Also note that all grids are perpendicular to the optical axis of the camera, so the focal length won't be calculated by the filter.

World Plane - Measurements and Rectification

Vision systems which are concerned with observation and inspection of planar (flat) surfaces, or objects lying on such surfaces (e.g. conveyor belts) can take advantage of the *image to world plane transform* mechanism of Aurora Vision Studio, which allows for:

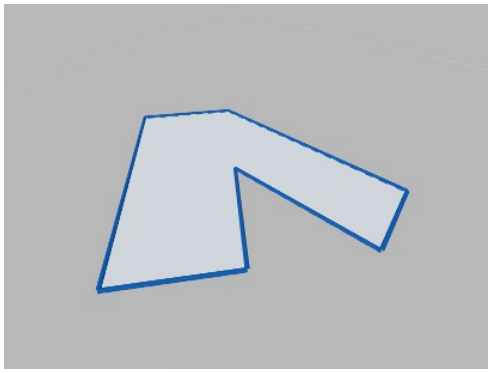
- Calculation of real world coordinates from locations on original image. This is crucial, for example, for interoperability with external devices, such as industrial robots. Suppose a object is detected on the image, and its location needs to be transmitted to the robot. The detected object location is given in image coordinates, however the robot is operating in real world with different coordinate system. A common coordinate system is needed, defined by a *world plane*.
- Image *rectification* onto the *world plane*. This is needed when performing image analysis using original image is not feasible (due to high degree of lens and/or perspective distortion). The results of analysis performed on a rectified image can also be transformed to real-world coordinates defined by a world plane coordinate system. Another use case is a multi-camera system – *rectification* of images from all the cameras onto common *world plane* gives a simple and well defined relation between those rectified images, which allows for easy superimposing or mosaic stitching.

The image below shows the image coordinate system. Image coordinates are denoted in pixels, with the origin point (0, 0) corresponding to the top-left corner of the image. The X axis starts at the left edge of an image and goes towards the right edge. The Y axis starts at the top of the image towards image bottom. All image pixels have nonnegative coordinates.

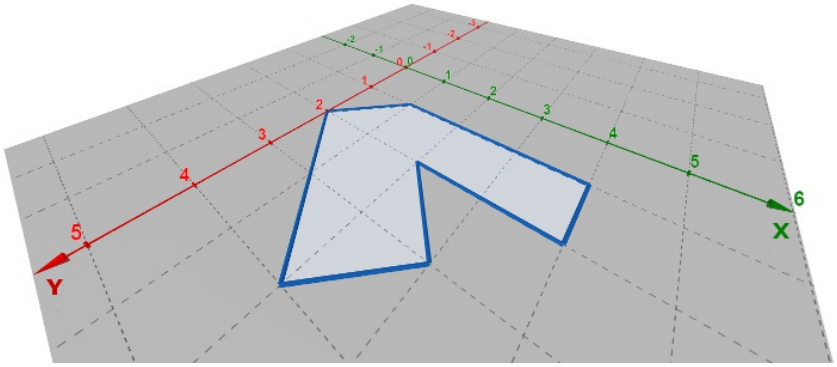
Directions and pixel positions in image coordinates.

The *world plane* is a distinguished flat surface, defined in the real 3D world. It may be arbitrarily placed with respect to the camera. It has a defined origin position and XY axes.

Images below present the concept of a *world plane*. First image presents an original image, as captured by a camera that has not been mounted quite straight above the object of interest. The second image presents a *world plane*, which has been aligned with the surface on which the object is present. This allows for either calculation of world coordinates from pixel locations on original image, or image rectification, as shown on the next images.



Object of interest as captured by an imperfectly positioned camera.



World plane coordinate system superimposed onto the original image.

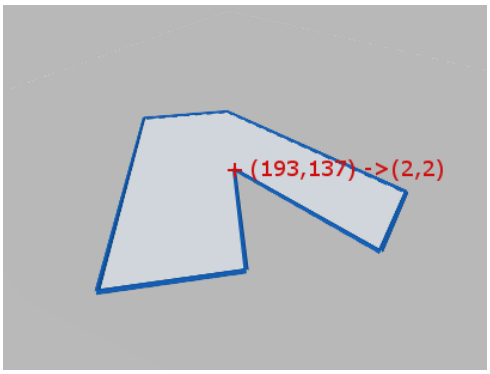


Image to world plane coordinate calculation.

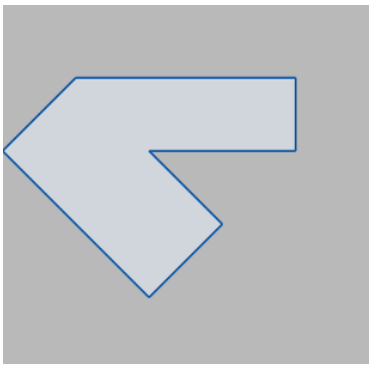


Image rectification, with cropping to an area from point (0,0) to (5,5) in world coordinates.

In order to use the *image to world plane transform* mechanism of Aurora Vision Studio, appropriate UI wizards are supplied:

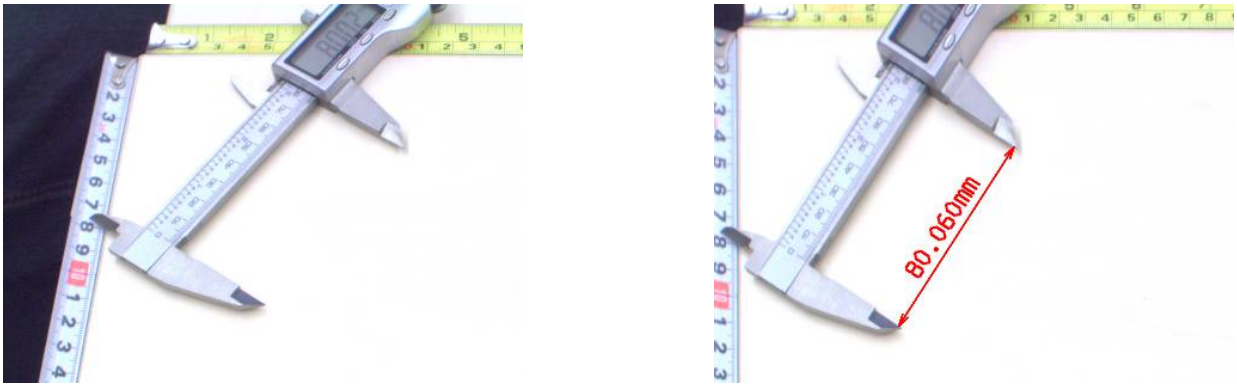
- For calculation of real world coordinates from locations on original image – use a wizard associated with the **inTransform** input of ImagePointToWorldPlane filter (or other from ImageObjectsToWorldPlane group).
- For image *rectification* onto the *world plane* – use a wizard associated with the **inRectificationMap** input of RectifyImage filter.

Although using UI wizards is the recommended course of action, the most complicated use cases may need a direct use of filters, in such a case following steps are to be performed:

1. Camera calibration – this step is highly recommended to achieve accurate results, although not strictly necessary (e.g. when lens distortion errors are insignificant).
2. World plane calibration – the CalibrateWorldPlane_* filters compute a RectificationTransform, which represents *image to world plane relation*
3. The *image to world plane relation* then can be used to:
   - Calculate of real world coordinates from locations on original image, and vice versa, see ImagePointToWorldPlane, WorldPlanePointToImage or similar filters (from ImageObjectsToWorldPlane or WorldPlaneObjectsToImage groups).
   - Perform image *rectification* onto the world plane, see CreateRectificationMap_* filters.

There are different use cases of world coordinates calculation and image rectification:

- Calculating world coordinates from pixel locations on original image without image rectification. This approach uses transformation output for example by CalibrateWorldPlane_* to calculate real world coordinates with ImageObjectsToWorldPlane_*
- Second scenario is very similar to the first one with the difference of using image rectification. In this case, after performing analysis on an rectified image (i.e. image remapped by RectifyImage), the locations can be transformed to a common coordinate system given by the world plane by using the *rectified image to world plane* relation. It is given by auxiliary output **outRectifiedTransform** of RectifyImage filter. Notice that the *rectified image to world plane* relation is different than *original image to world plane* relation.
- Last use case is to perform image rectification and rectified image analysis without its features recalculation to real world coordinates.



Example of taking world plane measurements on the rectified image. Left: original image, as captured by a camera, with mild lens distortion. Right: rectified image with annotated length measurement.

Notes:

- *Image to world plane transform* is still a valid mechanism for telecentric cameras. Is such a case, the image would be related to world plane by an affine transform.
- Camera distortion is automatically accounted for in both world coordinate calculations and image rectification.
- The spatial map generated by CreateRectificationMap_* filters can be thought of as a map performing *image undistortion* followed by a *perspective removal*.

Extraction of Calibration Grids

Both *camera calibration* and *image to world plane transform* calculation use extracted *calibration grids* in the form of array of image points with grid indices, i.e. annotated points.

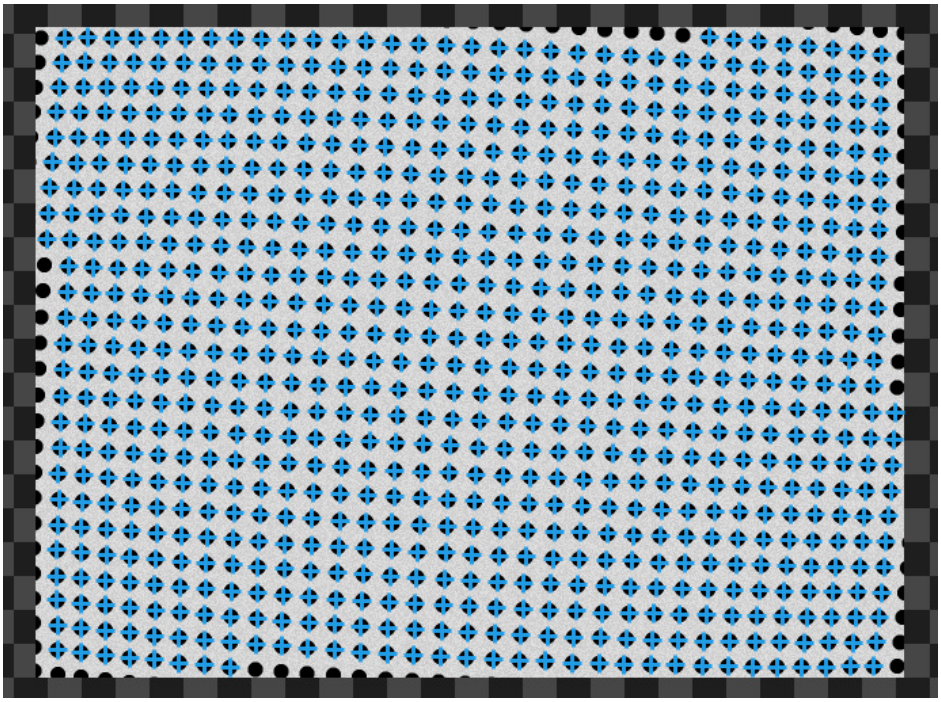
Note that the real-world coordinates of the grids are 2D, because the relative z coordinate of any point on the flat grid is 0.

Aurora Vision Studio provides extraction filters for a few standard grid formats (see: DetectCalibrationGrid_Chessboard and DetectCalibrationGrid_Circles).

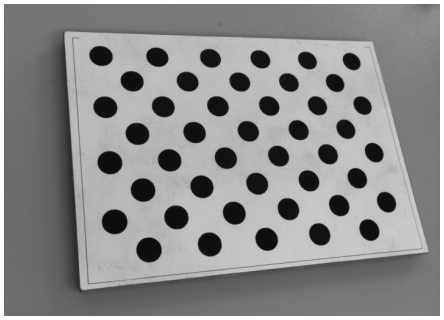
Using custom grids requires a custom solution for extracting the image point array. If the custom grid is a rectangular grid, the AnnotateGridPoints filter may be used to compute annotations for the image points.

Note that the most important factor in achieving high accuracy results is the precision and accuracy of extracted calibration points. The calibration grids should be as flat and stiff as possible (cardboard is not a proper backing material, thick glass is perfect). Take care of proper conditions when taking the calibration images: minimize motion blur by proper camera and grid mounts, prevent reflections from the calibration surface (ideally use diffusion lighting). When using a custom calibration grid, make sure that the points extractor can achieve subpixel precision. Verify that measurements of the real-world grid coordinates are accurate. Also, when using a chessboard calibration grid, make sure that the whole calibration grid is visible in the image. Otherwise, it will not be detected because the detection algorithm requires a few pixels wide quiet zone around the chessboard. Pay attention to the number of columns and rows, as providing misleading data may make the algorithm work incorrectly or not work at all.

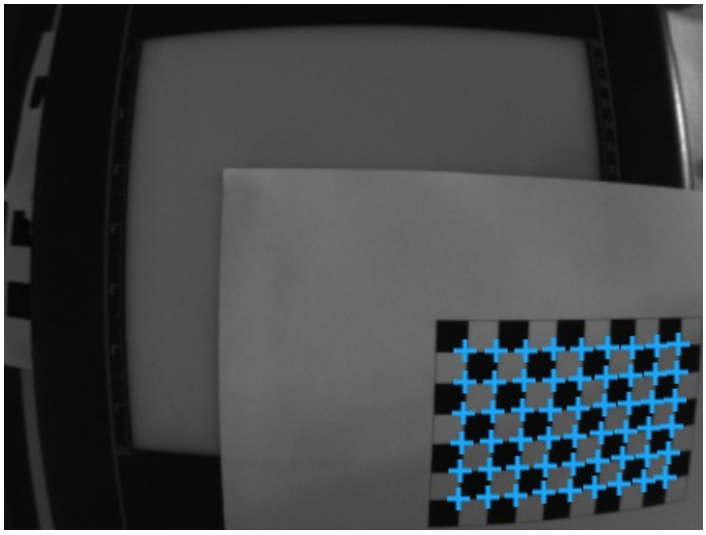
The recommended calibration grid to use in Aurora Vision Studio is a circles grid, see DetectCalibrationGrid_Circles. Optimal circle radius may vary depending on exact conditions, however a good rule of thumb is 10 pixels (20 pixel diameter). Smaller circles tend to introduce positioning jitter. Bigger circles lower the total amount of calibration points and suffer from geometric inaccuracies, especially when lens distortion and/or perspective is noticeable. Note: it is important to use a symmetric board as shown in the image below. Asymmetric boards are currently not supported.



Symmetric circle grid is the recommended one to use in Aurora Vision Studio.



Unsupported asymmetric circle grid.



Detected chessboard grid, with image point array marked.

Application Guide – Image Stitching

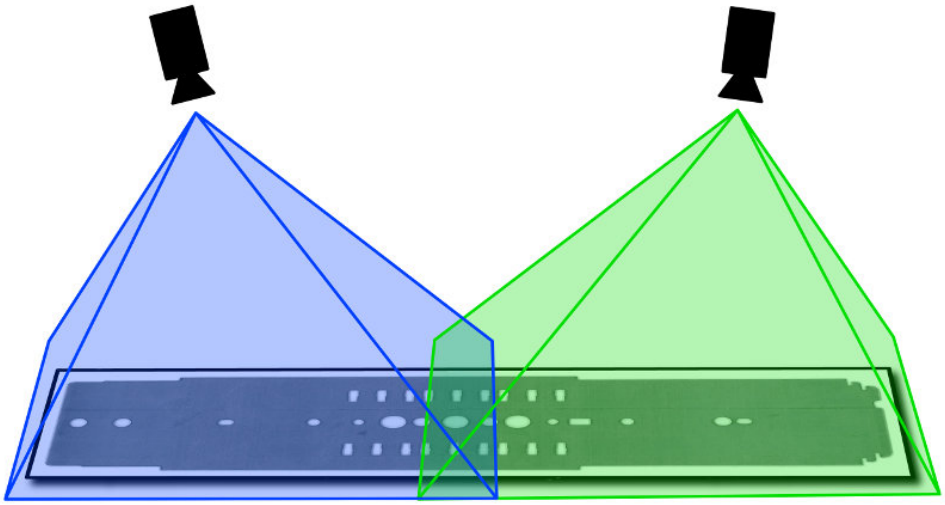
Seamless image stitching in multiple camera setup is, in its essence, an image rectification onto the world plane.

Note that high quality stitching requires a vigilant approach to the calibration process. Each camera introduces both lens distortion as well as perspective distortion, as it is never positioned perfectly perpendicular to the analyzed surface. Other factors that need to be taken into account are the camera-object distance, camera rotation around the optical axis, and image overlap between cameras.

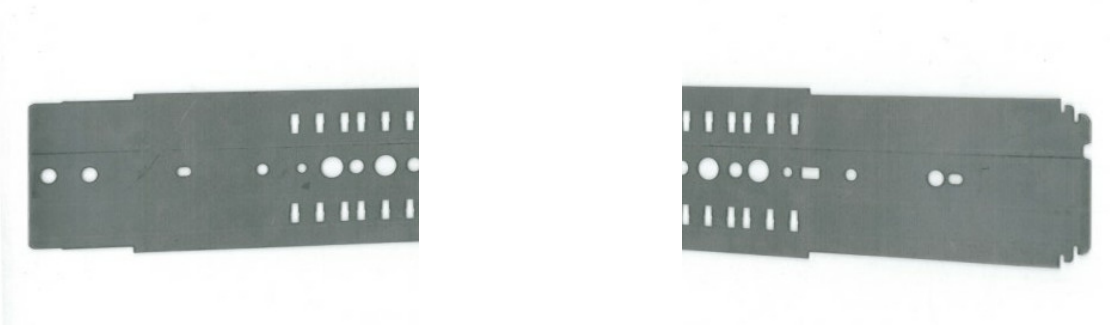
The process consists of two main steps. First, each camera is calibrated to produce a partial, rectified image. Then all partial images are simply merged using the JoinImages filter.

Image stitching procedure can be outlined as follows:

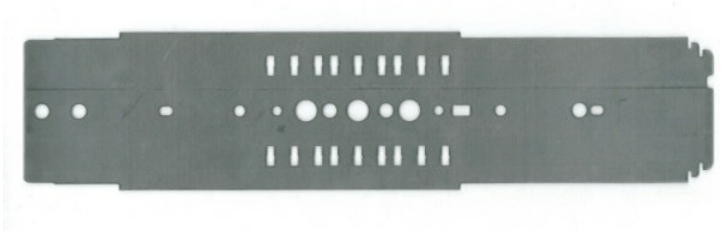
- Cover the inspection area with two or more cameras. Make sure that fields of view of individual cameras overlap a bit.
- Place a calibration grid onto the inspection area. For each camera, capture the image of a part of the calibration grid. The grid defines a world coordinate system used for stitching, and so it should contain some markers from which the coordinates of world plane points will be identifiable for each camera.
- Define the world coordinate extents for which each camera will be responsible. For example, lets define that camera 1 should cover area from 100 to 200 in X, and from -100 to 100 in Y coordinate; camera 2 - from 200 to 300 in X, and from -100 to 100 in Y.
- For each camera, use a wizard associated with the **inRectificationMap** input of RectifyImage filter to setup the image rectification. Use the captured image for camera calibration and world to image transform. Use the defined world coordinate extents to setup the rectification map generation (select "world bounding box" mode of operation). Make sure that the world scale for rectification is set to the same fixed value for all images.
- Use the JoinImages appropriately to merge outputs of RectifyImage filters.



A multi-camera setup for inspection of a flat object.



Input images, as captured by cameras.



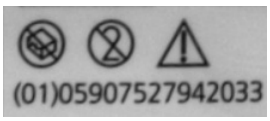
Stitching result.

Golden Template

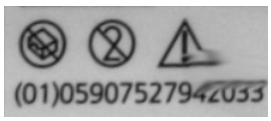
Golden Template technique performs a pixel-to-pixel comparison of two images. This technique is especially useful when the object's surface or object's shape is very complex.

Aurora Vision Studio offers three ways of performing the golden template comparison.

- **Comparison based on pixels intensity** - it can be achieved using the CompareGoldenTemplate_Intensity. In this method two images are compared pixel-by-pixel and the defect is classified based on a difference between pixels intensity. This technique is especially useful in finding defects like smudges, scratches etc.



Golden template



Defected object

Found defects

Example usage of Golden Template technique using the pixels intensity based comparison.

- **Comparison based on objects edges** - this method is very useful when defects may occur on the edge of the object and pixel comparison may fail due to different light reflections or the checking the object surface is not necessary. For matching object's edges use the CompareGoldenTemplate_Edges filter.

Golden template

Defected object

Found defects

Example usage of Golden Template technique using the edges comparison.

- **Second version of the comparison based on objects edges** - this method uses more than one image to create the model for the inspection. Due to that it is not vulnerable to pixel-sized errors and displacements. Advanced tips on how to use its parameters are located here: CompareGoldenTemplate2.

How To Use

Golden template is a previously prepared image which is used to compare image from the camera. This robust technique allows us to perform quick comparison inspection but some conditions must be met:

- stable light conditions,
- position of the camera and the object must be still,
- precise object positioning

Most applications use the Template Matching technique for finding objects and then matched rectangle is compared. Golden template image and image to compare must have this same dimensions. To get best results filter CropImageToRectangle should be used. Please notice that filter CropImageToRectangle performs cropping using a real values and it has sub-pixel precision.

Deep Learning

Note: The following article concerns the functionalities related to another product: **Deep Learning Add-on**. More information are available here.

Table of contents:

1. Introduction

Deep Learning is a breakthrough machine learning technique in computer vision. It learns from training images provided by the user and can automatically generate solutions for a wide range of image analysis applications. Its key advantage, however, is that it is able to solve many of the applications which have been too difficult for traditional, rule-based algorithms of the past. Most notably, these include inspections of objects with high variability of shape or appearance, such organic products, highly textured surfaces or natural outdoor scenes. What is more, when using ready-made products, such as our Aurora Vision Deep Learning, the required programming effort is reduced almost to zero. On the other hand, deep learning is shifting the focus to working with data, taking care of high quality image annotations and experimenting with training parameters – these elements actually tend to take most of the application development time these days.

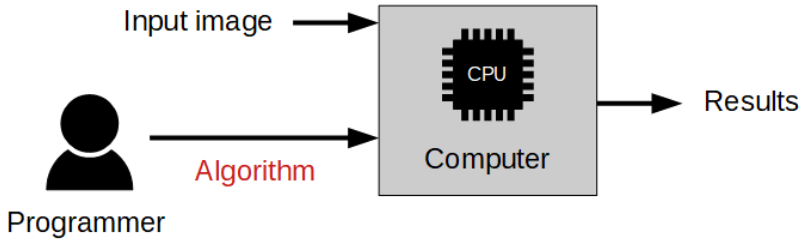
Typical applications are:

- detection of surface and shape defects (e.g. cracks, deformations, discoloration),
- detecting unusual or unexpected samples (e.g. missing, broken or low-quality parts),
- identification of objects or images with respect to predefined classes (i.e. sorting machines),
- location, segmentation and classification of multiple objects within an image (i.e. bin picking),
- product quality analysis (including fruits, plants, wood and other organic products),
- location and classification of key points, characteristic regions and small objects,
- optical character recognition.

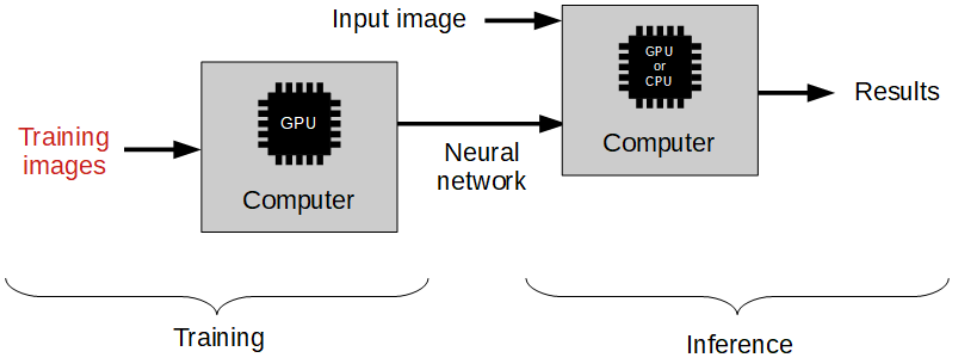
The use of deep learning functionality includes two stages:

1. Training – generating a model based on features learned from training samples,
2. Inference – applying the model on new images in order to perform the actual machine vision task.

The difference to the traditional image analysis approach is presented in the diagrams below:



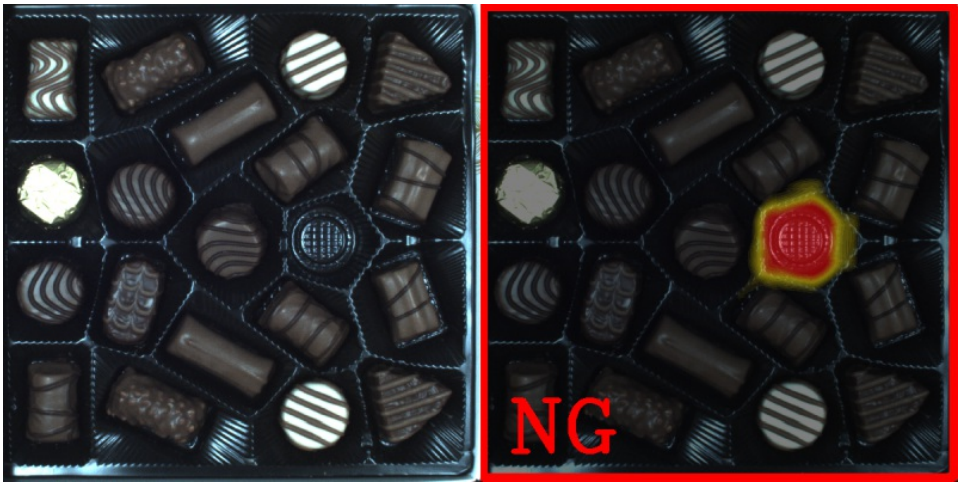
Traditional approach: The algorithm must be designed by a human specialist.



Machine learning approach: We only need to provide a training set of labeled images.

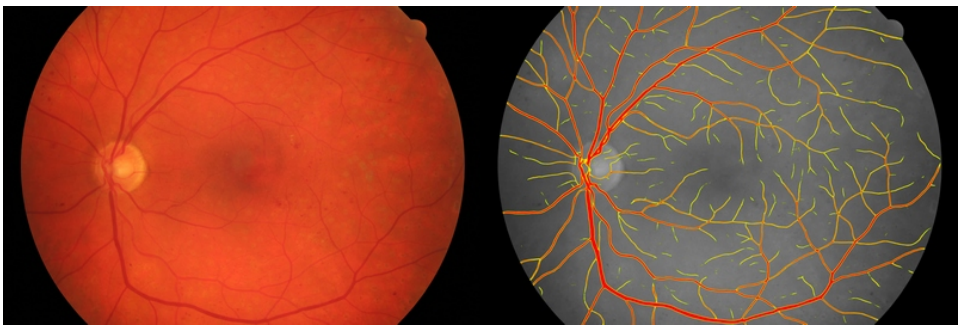
Overview of Deep Learning Tools

1. Anomaly Detection - this technique is used to detect anomalous (unusual or unexpected) samples. It only needs a set of fault-free samples to learn the model of normal appearance. Optionally, several faulty samples can be added to better define the threshold of tolerable variations. This tool is useful especially in cases where it is difficult to specify all possible types of defects or where negative samples are simply not available. The output of this tool are: a classification result (normal or faulty), an abnormality score and a (rough) heatmap of anomalies in the image.



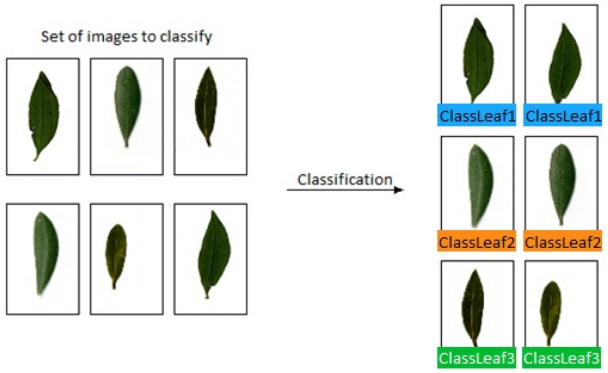
An example of a missing object detection using AvsFilter_DL_DetectAnomalies2 tool.
Left: The original image with a missing element. Right: The classification result with a heatmap of anomalies.

2. Feature Detection - this technique is used to precisely segment one or more classes of pixel-wise features within an image. The pixels belonging to each class must be marked by the user in the training step. The result of this technique is an array of probability maps for every class.



An example of image segmentation using AvsFilter_DL_DetectFeatures tool.
Left: The original image of the fundus. Right: The segmentation of blood vessels.

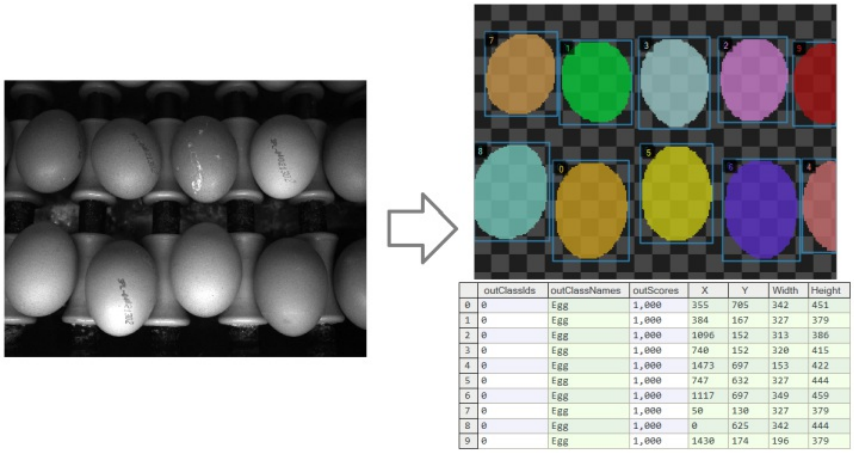
3. Object Classification – this technique is used to identify an object in a selected region with one of user-defined classes. First, it is necessary to provide a training set of labeled images. The result of this technique is: the name of detected class and a classification confidence level.



An example of object classification using AvsFilter_DL_ClassifyObject tool.

4. Instance Segmentation (deprecated) – this technique is used to locate, segment and classify one or multiple objects within an image. The training requires the user to draw regions corresponding to objects in an image and assign them to classes. The result is a list of detected objects – with their bounding boxes, masks (segmented regions), class IDs, names and membership probabilities.

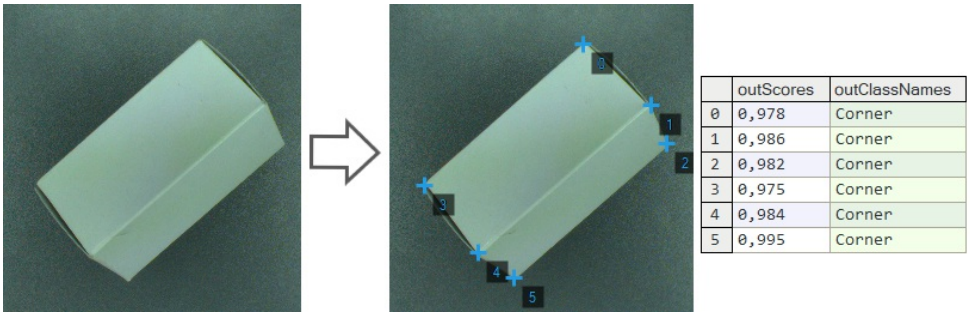
> **Warning:** The **Instance Segmentation** model is trainable in 5.3 and older versions only. In more recent releases, the models can be only inferred.



	outClassIds	outClassNames	outScores	X	Y	Width	Height
0	0	Egg	1,000	355	705	342	451
1	0	Egg	1,000	384	167	327	379
2	0	Egg	1,000	1096	152	313	386
3	0	Egg	1,000	740	152	320	415
4	0	Egg	1,000	1473	697	153	422
5	0	Egg	1,000	747	632	327	444
6	0	Egg	1,000	1117	697	349	459
7	0	Egg	1,000	50	130	327	379
8	0	Egg	1,000	0	625	342	444
9	0	Egg	1,000	1430	174	196	379

An example of instance segmentation using AvsFilter_DL_SegmentInstances_Deprecated tool. Left: The original image. Right: The resulting list of detected objects.

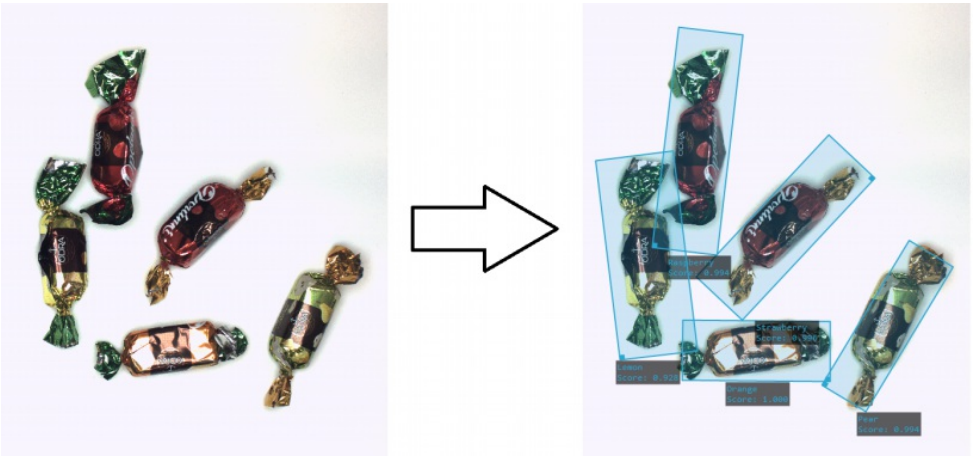
5. Point Location – this technique is used to precisely locate and classify key points, characteristic parts and small objects within an image. The training requires the user to mark points of appropriate classes on the training images. The result is a list of predicted point locations with corresponding class predictions and confidence scores.



	outScores	outClassNames
0	0,978	Corner
1	0,986	Corner
2	0,982	Corner
3	0,975	Corner
4	0,984	Corner
5	0,995	Corner

An example of point location using AvsFilter_DL_LocatePoints tool. Left: The original image. Right: The resulting list of detected points.

6. Object Location – this technique is used to locate and classify one or multiple objects within an image. In this tool, a user needs to draw rectangles bounding the objects in the scene and specify their classes. The result of this technique is a list of rectangles bounding the predicted objects with corresponding class predictions and confidence scores.

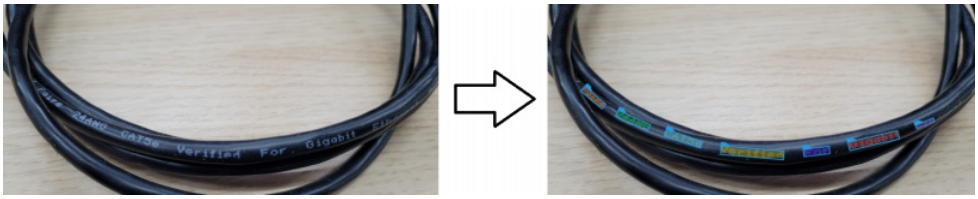


An example of instance segmentation using AvsFilter_DL_LocateObjects tool. Left: The original image. Right: The resulting list of detected objects.

7. Reading Characters – this technique is used to locate and recognize characters within an image. The result is a list of found characters.

An example of optical character recognition using AvsFilter_DL_ReadCharacters tool. Left: The original image. Right: The image with the recognized characters drawn.

8. Locating Text – this technique is used to locate text within an image. The result is an array of found located rectangles.



An example of locating text using AvsFilter_DL_LocateText tool. Left: The original image. Right: The image with the found text regions.

Basic Terminology

You do not need to have the specialistic scientific knowledge to develop your deep learning solutions. However, it is highly recommended to understand the basic terminology and principles behind the process.

Deep neural networks

Aurora Vision provides access to several standardized deep neural networks architectures created, adjusted and tested to solve industrial machine vision tasks. Each of the networks is a set of trainable convolutional filters and neural connections which can model complex transformations of an image with the goal to extract relevant features and use them to solve a particular problem. However, these networks are useless without proper amount of good quality data provided for training process. This documentation presents necessary practical hints on creating an effective deep learning model.

Depth of a neural network

Due to various levels of task complexity and different expected execution times, the users can choose one of five available network depths. The **Network Depth** parameter is an abstract value defining the memory capacity of a neural network (i.e. the number of layers and filters) and the ability to solve more complex problems. The list below gives hints about selecting the proper depth for a task characteristics and conditions.

1. Low depth (value 1-2)
    - A problem is simple to define.
    - A problem could be easily solved by a human inspector.
    - A short time of execution is required.
    - Background and lighting do not change across images.
    - Well-positioned objects and good quality of images.
2. Standard depth (default, value 3)
    - Suitable for a majority of applications without any special conditions.
    - A modern CUDA-enabled GPU is available.
3. High depth (value 4-5)
    - **A big amount of training data is available.**
    - A problem is hard or very complex to define and solve.
    - Complicated irregular patterns across images.
    - Long training and execution times are not a problem.
    - A large amount of GPU RAM (≥4GB) is available.
    - Varying background, lighting and/or positioning of objects.

Tip: Test your solution with a lower depth first, and then increase it if needed.

Note: A higher network depth will lead to a significant increase in memory and computational complexity of training and execution.

Data division

While training the model, we use one set of images to estimate the network weights. This set is called **training** data and should reflect the problem as well as possible (e.g., in the case of object classification, representants for all considered classes should be present in this set).

To be sure that the learned model generalizes well, or in other words can give similar results with newly seen data, we need to prepare **validation**

data, too. This second set should contain a small number of representative images to the learned problem. A rule of a thumb says, that its size should be 10% of the training data set size and have a good representation of all problems (e.g., at least one image for each class in the case of object classification should be present in validation data).

The images loaded to Deep Learning Editor must be assigned to one of those two datasets before training procedure can follow.

When the amount of data is large, one may want to simulate how the trained model will work on images not used during the training (it allows checking the performance accessible during the inference). In such a case, assign images to **test** data.

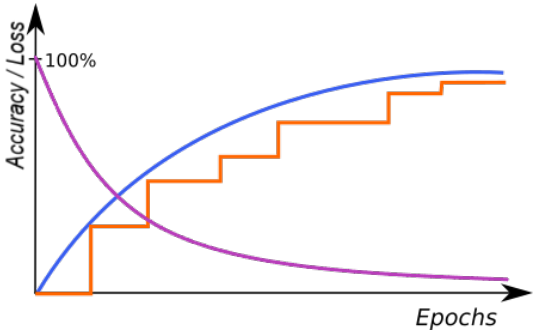
Training process

Model training is an iterative process of updating neural network weights based on the training data. One **iteration** involves some number of steps (determined automatically), each step consists of the following operations:

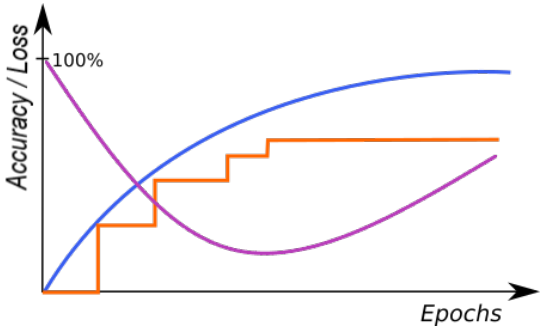
1. selection of a small subset (**batch**) of training samples,
2. calculation of an error measure for these samples,
3. updating the weights to achieve lower error for these samples.

At the end of each iteration, the current model is evaluated on a separate set of validation samples selected before the training process. Depending on the tool, validation set can be automatically chosen from the training samples, or selected by the user. It is used to simulate how neural network would work with real images not used during training. Only the set of network weights corresponding with the best validation score at the end of training is saved as the final solution. Monitoring the training, validation and loss score (blue, orange and purple lines in the figures below) in consecutive iterations gives fundamental information about the progress:

1. Training and validation scores are improving and loss score is decreasing – keep training, the model can still improve.
2. Training and validation scores has stopped improving and loss score is decreasing – keep training for a few iterations more and stop if there is still no change.
3. Loss score is improving – you can stop training, model has probably started **overfitting** to your training data (remembering exact samples rather than learning rules about features). It may also be caused by too small amount of diverse samples or too low complexity of the problem for a network selected (try lower **Network Depth**).



An example of correct training.



A graph characteristic for network overfitting.

The above graphs represent training progress in the Deep Learning Editor. The blue line indicates performance on the training samples, the orange line represents performance on the validation samples and the purple line represents the loss function. Please note the blue line is plotted more frequently than the orange line as validation performance is verified only at the end of each iteration.

Stopping Conditions

The user can stop the training manually by clicking the **Stop** button. Alternatively, it is also possible to set one or more stopping conditions:

1. **Iteration Count** – training will stop after a fixed number of iterations.
2. **Iterations without Improvement** – training will stop when the best validation score was not improved for a given number of iterations.
3. **Time** – training will stop after a given number of minutes has passed.
4. **Validation Accuracy** or **Validation Error** – training will stop when the validation score reaches a given value.

Preprocessing

To adjust performance to a particular task, the user can apply some additional transformations to the input images before training starts:

1. **Downsample** – reduction of the image size to accelerate training and execution times, at the expense of lower level of details possible to detect. Increasing this parameter by 1 will result in downsampling by the factor of 2 over both image dimension.
2. **Convert to Grayscale** – while working with problems where color does not matter, you can choose to work with monochrome versions of images.

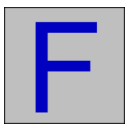
Augmentation

In case when the number of training images can be too small to represent all possible variations of samples, it is recommended to use data augmentations that add artificially modified samples during training. This option will also help avoiding overfitting.

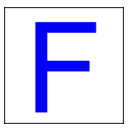
Below is a description of the available augmentations and examples of the corresponding transformations:

1. **Luminance** – change brightness of samples by a random percentage (between -ParameterValue and +ParameterValue) of pixel values (0-255). For a given augmentation values, samples as below can be added to the training set.

Luminance=-50.

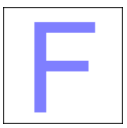


Luminance=-25.



Original image.

Luminance=25.

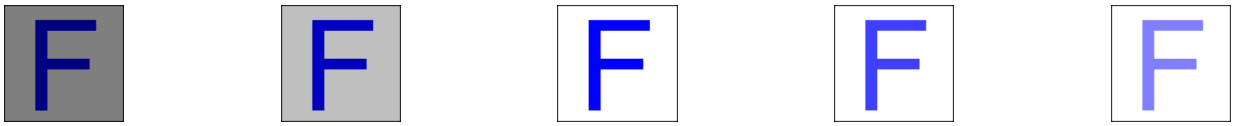


Luminance=50.

2. **Contrast** – difference in brightness or color between elements of an image. This parameter enhances the network to recognize details more effectively. It is specified by a single float value that defines the range of contrast adjustments as (-contrast, contrast). These values can range from -50% to 50%, where 0% indicates no change, 50% represents the maximum increase in contrast, and -50% signifies the maximum decrease in contrast. The default setting is 0%. For instance, if a 20% value is chosen, the contrast change applied to an image will be randomly selected from a range of -20% to 20% and incorporated into the training set.

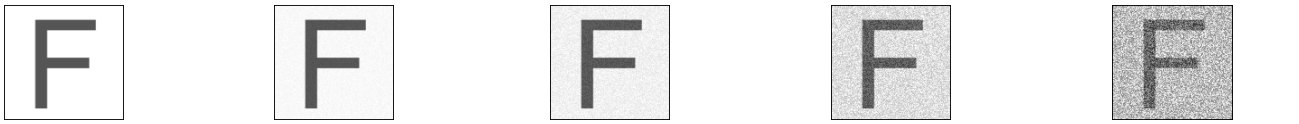
Contrast=-50%. *Contrast=-20%.* *Original image (0%).* *Contrast=20%.* *Contrast=50%.*

3. **Brightness** – increase the brightness of samples by multiplying pixel values. This parameter is introduced instead of **Luminance** in some of Deep Learning tools.

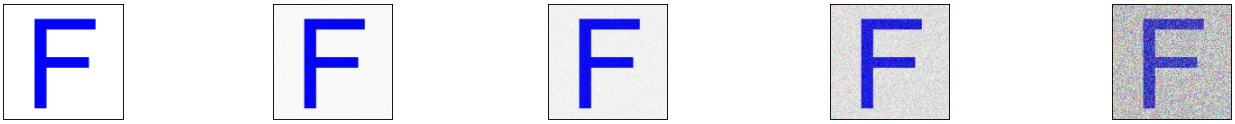


Brightness=0.2. *Brightness=0.5.* *Original image.* *Brightness=1.5.* *Brightness=1.8.*

4. **Noise** – modify samples with uniform noise. Value of each channel and pixel is modified separately, by random percentage (between -ParameterValue and +ParameterValue) of pixel values (0-255). Please note that choosing an appropriate augmentation value should depend on the size of the feature in pixels. Larger value will have a much greater impact on small objects than on large objects. For a tile with the feature "F" with the size of 130x130 pixels and a given augmentation values, samples as below can be added to the training set.:

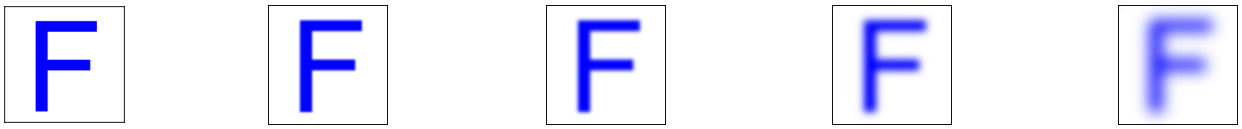


Original grayscale image. *Grayscale image. Noise=4.* *Grayscale image. Noise=10.* *Grayscale image. Noise=25.* *Grayscale image. Noise=50.*



Original RGB image. *RGB image. Noise=4.* *RGB image. Noise=10.* *RGB image. Noise=25.* *RGB image. Noise=50.*

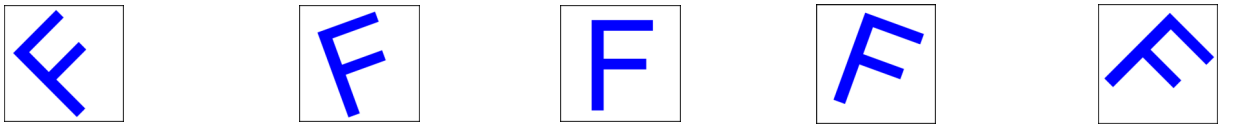
5. **Gaussian Blur** – blur samples with a kernel of a size randomly selected between 0 and the provided maximum kernel size. Please note that choosing an appropriate Gaussian Blur Kernel Size should depend on the size of the feature in pixels. Larger kernel sizes will have a much greater impact on small objects than on large objects. For a tile with the feature "F" with the size of 130x130 pixels and a given augmentation values, samples as below can be added to the training set.:



Original image. *Gaussian Blur=5.* *Gaussian Blur=10.* *Gaussian Blur=25.* *Gaussian Blur=50.*

6. **Rotation** – rotate samples by a random angle between -ParameterValue and +ParameterValue. Measured in degrees.

In Detect Features, Locate Points and Detect Anomalies, for a tile with the feature "F" and given augmentation values, samples as below can be added to the training set.



Tile rotation=-45°. *Tile rotation=-20°.* *Original tile.* *Tile rotation=20°.* *Tile rotation=45°.*

In Classify Object and Segment Instances, for an image with the feature "F" and given augmentation values, samples as below can be added to the training set.

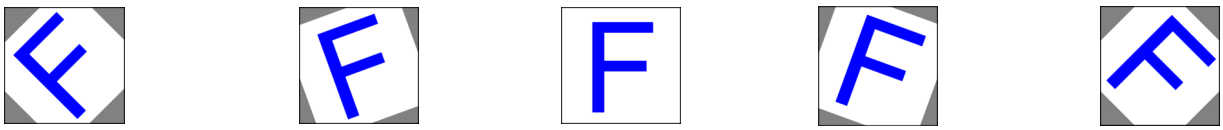
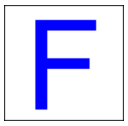
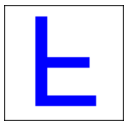


Image rotation=-45°. *Image rotation=-20°.* *Original image.* *Image rotation=20°.* *Image rotation=45°.*

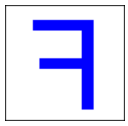
7. **Flip Up-Down** – reflect samples along the X axis.
8. **Flip Left-Right** – reflect samples along the Y axis.



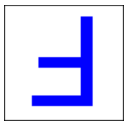
No flips.



Up-Down flip.



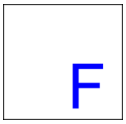
Left-Right flip.



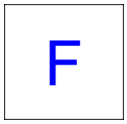
Both flips.

9. **Relative Translation** – translate samples by a random shift, defined as a percentage (between -ParameterValue and +ParameterValue) of the tile. Works independently in both X and Y dimensions.

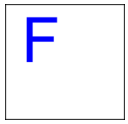
In Locate Points, for a tile with the feature "F" and given augmentation values, samples as below can be added to the training set.



Tile translation x=20%, y=20%.



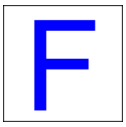
Original tile.



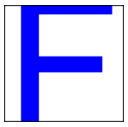
Tile translation x=-20%, y=-20%.

10. **Scale** – resize samples relatively to their original size by a random percentage between the provided minimum scale and maximum scale.

Resize=50%.



Original image.

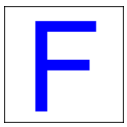


Resize=150%.

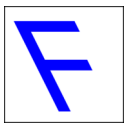
11. **Horizontal Shear** – shear samples horizontally by an angle between -ParameterValue and +ParameterValue. Measured in degrees.

In Detect Features, Locate Points and Detect Anomalies, for a tile with the feature "F" and given augmentation values, samples as below can be added to the training set.

Horizontal Shear=-30.



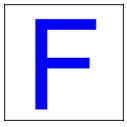
Original tile.



Horizontal Shear=30.

In Classify Object and Segment Instances, for an image with the feature "F" and given augmentation values, samples as below can be added to the training set.

Horizontal Shear=-30.

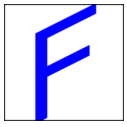


Original image.

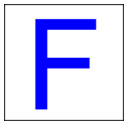
Horizontal Shear=30.

12. **Vertical Shear** – analogous to Horizontal Shear.

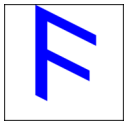
In Detect Features, Locate Points, and Detect Anomalies, for a tile with the feature "F" and given augmentation values, samples as below can be added to the training set.



Vertical Shear=-30.



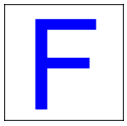
Original tile.



Vertical Shear=30.

In Classify Object and Segment Instances, for an image with the feature "F" and given augmentation values, samples as below can be added to the training set.

Vertical Shear=-30.



Original image.

Vertical Shear=30.

Warning: the choice of augmentation options depends only on the task we want to solve. Sometimes they might be harmful for quality of a solution. For a simple example, the Rotation should not be enabled if rotations are not expected in a production environment. Enabling augmentations also increases the network training time (but does not affect execution time!)

2. Anomaly Detection

Warning: The AvsFilter_DL_DetectAnomalies1 model is trainable in 5.3 and older versions only. In more recent releases, the models can only be used for inference.

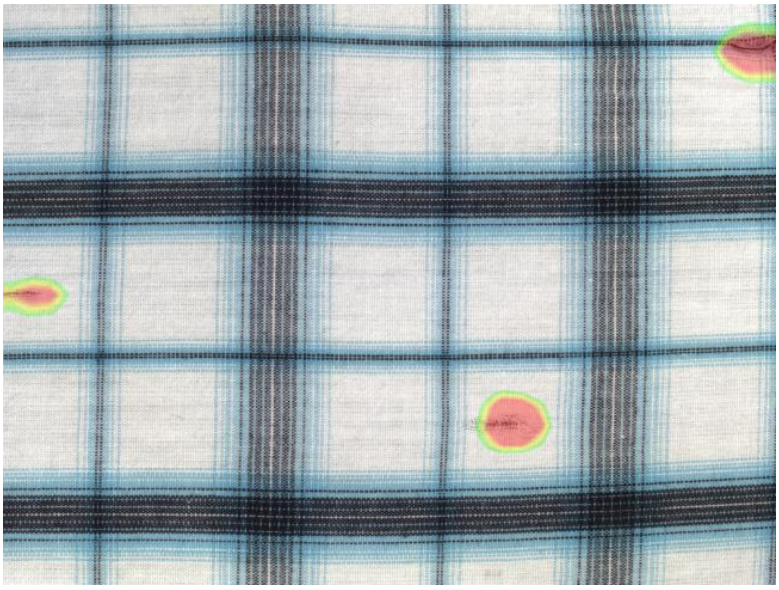
Aurora Vision Deep Learning provides two ways of defect detection:

- AvsFilter_DL_DetectAnomalies2 Golden Template
- AvsFilter_DL_DetectAnomalies2 Similarity-Based

The AvsFilter_DL_DetectAnomalies2 **Golden Template** is an appropriate method for positioned objects with complex details. The tool divides the images into regions and creates a separate model for each region. The tool has the **Texture Mode** dedicated for texture defects detection. It can be used for plain surfaces or the ones with a simple pattern.

The AvsFilter_DL_DetectAnomalies2 **Similarity-Based** is a good general-purpose technique that can handle detailed as well as simple datasets. The tool operates by first assembling a collection of normal features during training and then by comparing observed image segments against this collection during inference to assess normality.

To sum up, while choosing the tool for anomaly detection, first check the **Similarity-Based** approach. If the model isn't producing sufficiently accurate defect localizations, please try the **Golden Template** approach.



An example of textile defect detection using the AvsFilter_DL_DetectAnomalies2.

Parameters

- **Max Translation** is related to the AvsFilter_DL_DetectAnomalies2 **Golden Template** approach. It is the maximal position change tolerance. If the parameter increases, the working area of a small model enlarges and the number of the created small models decreases.
- **Model Complexity** (or just Complexity) is related to the AvsFilter_DL_DetectAnomalies2 approach. Greater value may improve model effectiveness, especially for complex objects, at the expense of memory usage and interference time.

Metrics

Measuring accuracy of anomaly detection tools is a challenging task. The most straightforward approach is to calculate the Recall/Precision/F1 measures for the whole images (classified as GOOD or BAD, without looking at the locations of the anomalies). Unfortunately, such an approach is not very reliable due to several reasons, including: (1) when we have a limited number of test images (like 20), the scores will vary a lot (like Δ=5%) when just one case changes; (2) very frequently the tools we test will find random false anomalies, but will not find the right ones - and still will get high scores as the image as a whole is considered correctly classified. Thus, it may be tempting to use annotated anomaly regions and calculate the per-pixel scores. However, this would be too fine-grained. For anomaly detection tasks we do not expect the tools to be necessarily very accurate in terms of the location of defects. Individual pixels do not matter much. Instead, we expect that the anomalies are detected "more or less" at the right locations. As a matter of fact, some tools which are not very accurate in general (especially those based on auto-encoders) will produce relatively accurate outlines for the anomalies they find, while the methods based on one-class classification will usually perform better in general, but the outlines they produce will be blurred, too thin or too thick.

For these reasons, we introduced an intermediate approach to calculation of Recall. Instead of using the per-image or the per-pixel methods, we use a per-region one. Here is how we calculate Recall:

- For each anomaly region we check if there is any single pixel in the heatmap above the threshold. If it is, we increase **TP** (the number of True Positives) by one. Otherwise, we increase **FN** (the number of False Negatives) by one.
- Then we use the formula:

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

The above method works for Recall, but cannot be directly applied to the calculation of Precision. Thus, for Precision we use a per-pixel approach, but it also comes with its own difficulties. First issue is that we often find ourselves having a lot of GOOD samples and a very limited set of BAD testing cases. This means unbalanced testing data, which in turn means that the Precision metric is highly affected with the overwhelming quantity of GOOD samples. The more GOOD samples we have (at the same amount of BAD samples), the lower Precision will be. It may be actually very low, often not reflecting the true performance of the tool. For that reason, we need to incorporate balancing into our metrics.

A second issue with Precision in real-world projects is that False Positives tend to naturally occur within BAD images, outside of the marked anomaly regions. This happens for several reasons, but is repeatable among different projects. Sometimes if there is a defect, it often means that something was broken and other parts of the object may be slightly affected too, sometimes in a visible way, sometimes with a level of ambiguity. And quite often the objects under inspection simply get affected by the process of artificially introducing defects (like someone is touching a piece of fabric and accidentally causes wrinkles that would normally not occur). For this reason, we calculate the per-pixel False Negatives only on GOOD images.

The complete procedure for calculation of Precision is:

- We calculate the average **pp_TP** (the number of per-pixel True Positives) across all BAD testing samples.
- We calculate the average **pp_FP** (the number of per-pixel False Positives) across all GOOD testing samples.

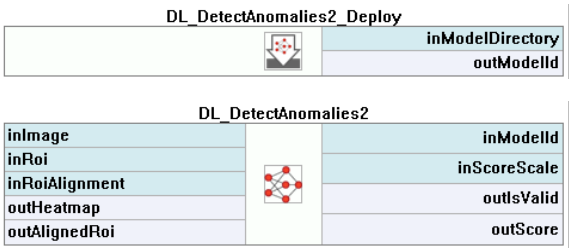
- Then we use the formula:

$$Precision = \frac{\overline{pp\_TP}}{\overline{pp\_TP} + \overline{pp\_FP}}$$

Finally we calculate the F1 score in the standard way, for practical reasons neglecting the fact that the Recall and Precision values that we unify were calculated in different ways. We believe that this metric is best for practical applications.

Model Usage

In Detect Anomalies 2 variant, a model should be loaded with AvsFilter_DL_DetectAnomalies2_Deploy prior to executing it with AvsFilter_DL_DetectAnomalies2. Alternatively, model can be loaded directly by AvsFilter_DL_DetectAnomalies2 filter, but it will then require time-consuming initialization in the first program iteration.



Running Aurora Vision Deep Learning Service simultaneously with these filters is discouraged as it may result in degraded performance or errors.

3. Feature Detection (segmentation)

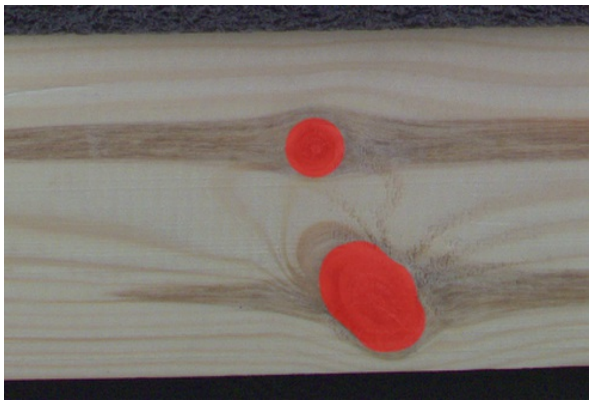
This technique is used to detect pixel-wise regions corresponding to defects or – in a general sense – to any image features. A feature here may be also something like the roads on a satellite image or an object part with a characteristic surface pattern. Sometimes it is also called pixel labeling as it assigns a class label to each pixel, but it does not separate instances of objects.

Training Data

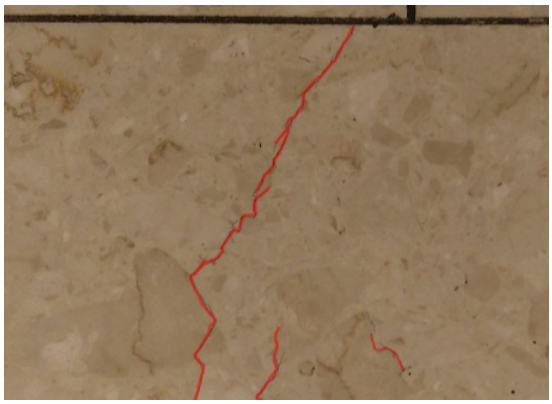
Images used for training can be of different sizes and can have different ROIs defined. However, it is important to ensure that the scale and the characteristics of the features are consistent with that of the production environment.

Each and every feature should be marked on all training images, or the ROI should be limited to include only marked defects. Incompletely or inconsistently marked features are one of the main reasons of poor accuracy. REMEMBER: If you leave even a single piece of some feature not marked, it will be used as a negative sample and this will highly confuse the training process!

The marking precision should be adjusted to the application requirements. The more precise marking the better accuracy in the production environment. While marking with low precision it is better to mark features with some excess margin.



An example of wood knots marked with low precision.



An example of tile cracks marked with high precision.

Multiple classes of features

It is possible to detect many classes of features separately using one model. For example, road and building like in the image below. Different features may overlap but it is usually not recommended. Also, it is not recommended to define more than a few different classes in a single model. On the other hand, if there are two features that may be mutually confusing (e.g. roads and rivers), it is recommended to have separate classes for them and mark them, even if one of the classes is not really needed in the results. Having the confusing feature clearly marked (and not just left as the background), the neural network will focus better on avoiding misclassification.

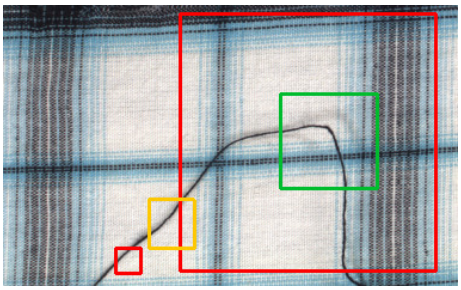
An example of marking two different classes (red roads and yellow buildings) in the one image.

Patch (Feature) Size

Detect Features is an end-to-end segmentation tool which works best when analysing an image in a medium-sized square window. The size of this window is defined by the Feature Size parameter. It should be not too small, and not too big. Typically much bigger than the size (width or diameter) of the feature itself, but much less than the entire image. In a typical scenario the value of 96 or 128 works quite well.

Performance Tip 1: a larger Feature Size increases the training time and requires more GPU memory and more training samples to operate effectively. When Feature Size exceeds 128 pixels and still looks too small, it is worth considering the **Downsample** option.

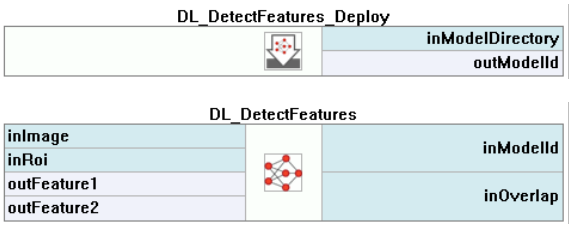
Performance Tip 2: if the execution time is not satisfying you can set the inOverlap filter input to False. It should speed up the inspection by 10-30% at the expense of less precise results.



Examples of Feature Size: too large or too small (red), maybe acceptable (yellow) and good (green). Remember that this is just an example and may vary in other cases.

Model Usage

A model should be loaded with AvsFilter_DL_DetectFeatures_Deploy filter before using AvsFilter_DL_DetectFeatures filter to perform segmentation of features. Alternatively, the model can be loaded directly by AvsFilter_DL_DetectFeatures filter, but it will result in a much longer time of the first iteration.



Running Aurora Vision Deep Learning Service simultaneously with these filters is discouraged as it may result in degraded performance or errors.

Parameters:

- To limit the area of image analysis you can use **inRoi** input.
- To shorten feature segmentation process you can disable **inOverlap** option. However, in most cases, it decreases segmentation quality.
- Feature segmentation results are passed in a form of bitmaps to **outHeatmaps** output as an array and **outFeature1**, **outFeature2**, **outFeature3** and **outFeature4** as separate images.

Due to the lack of context on the image border, correctly detecting objects at the image edges is problematic. Therefore, the heatmaps returned by the network focus on the image content beyond the edges without analysing the data located on the image border. When the **inRoi** is applied, the border is removed from the selected image region.

4. Object Classification

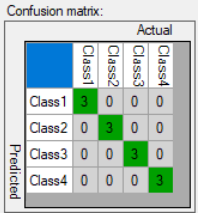
This technique is used to identify the class of an object within an image or within a specified region.

The Principle of Operation

During the training phase, the object classification tool learns representation of user defined classes. The model uses generalized knowledge gained from samples provided for training, and aims to obtain good separation between the classes.

Result of classification after training.

After a training process is completed, the user is presented with a confusion matrix. It indicates how well the model separated the user defined classes. It simplifies identification of model accuracy, especially when a large number of samples has been used.



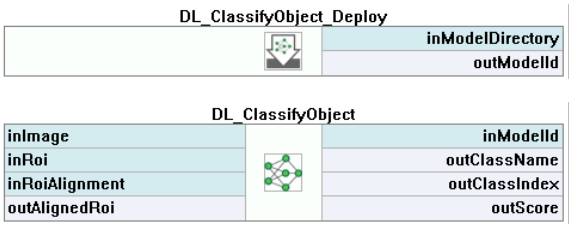
Confusion matrix presents correct (diagonal) and incorrect assignment of samples to the user defined classes.

Training Parameters

In addition to the default training parameters (list of parameters available for all Deep Learning algorithms), the AvsFilter_DL_ClassifyObject tool provides a **Detail Level** parameter which enables control over the level of detail needed for a particular classification task. For majority of cases the default value of 1 is appropriate, but if images of different classes are distinguishable only by small features (e.g. granular materials like flour and salt), increasing value of this parameter may improve classification results.

Model Usage

A model should be loaded with AvsFilter_DL_ClassifyObject_Deploy filter before using AvsFilter_DL_ClassifyObject filter to perform classification. Alternatively, model can be loaded directly by AvsFilter_DL_ClassifyObject filter, but it will result in a much longer time of the first iteration.



Running Aurora Vision Deep Learning Service simultaneously with these filters is discouraged as it may result in degraded performance or errors.

Parameters:

- To limit the area of image analysis you can use **inRoi** input.
- Classification results are passed to **outClassName** and **outClassIndex** outputs.
- The score value **outScore** indicates the confidence of classification.

5. Instance Segmentation (deprecated)

Warning: The **Instance Segmentation** model is trainable in 5.3 and older versions only. In more recent releases, the models can be only inferred.

This technique is used to locate, segment and classify one or multiple objects within an image. The result of this technique are lists with elements describing detected objects – their bounding boxes, masks (segmented regions), class IDs, names and membership probabilities.

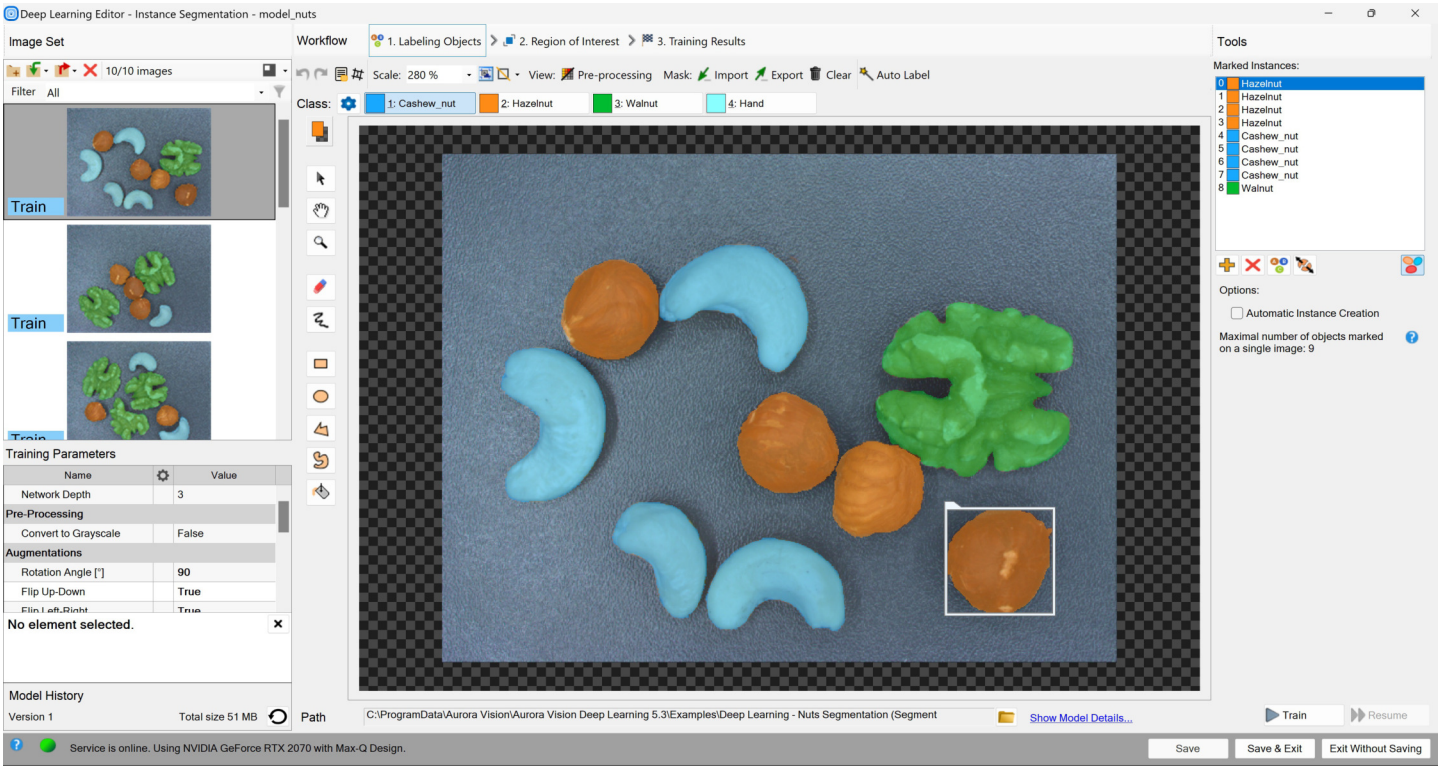
Note that in contrary to feature detection technique, instance segmentation detects individual objects and may be able to separate them even if they touch or overlap. On the other hand, instance segmentation is not an appropriate tool for detecting features like scratches or edges which may possibly have no object-like boundaries.

Original image.

Visualized instance segmentation results.

Training Data

The training phase requires the user to draw regions corresponding to objects on an image and assign them to classes.



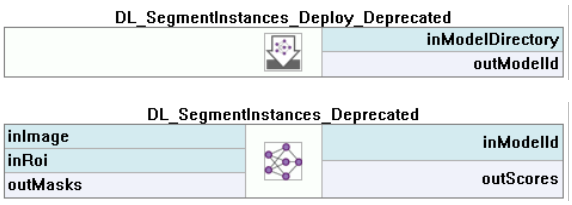
Editor for marking objects.

Training Parameters

Instance segmentation training adapts to the data provided by the user and does not require any additional training parameters besides the default ones.

Model Usage

A model should be loaded with AvsFilter_DL_SegmentInstances_Deploy_Deprecated filter before using AvsFilter_DL_SegmentInstances_Deprecated filter to perform classification. Alternatively, model can be loaded directly by AvsFilter_DL_SegmentInstances_Deprecated filter, but it will result in a much longer time of the first iteration.



Running Aurora Vision Deep Learning Service simultaneously with these filters is discouraged as it may result in degraded performance or errors.

Parameters:

- To limit the area of image analysis you can use **inRoi** input.
- To set minimum detection score **inMinDetectionScore** parameter can be used.
- Maximum number of detected objects on a single image can be set with **inMaxObjectsCount** parameter. By default it is equal to the maximum number of objects in the training data.
- Results describing detected objects are passed to following outputs:
  - bounding boxes: **outBoundingBoxes**,
  - class IDs: **outClassIds**,
  - class names: **outClassNames**,
  - classification scores: **outScores**,
  - masks: **outMasks**.

6. Point Location

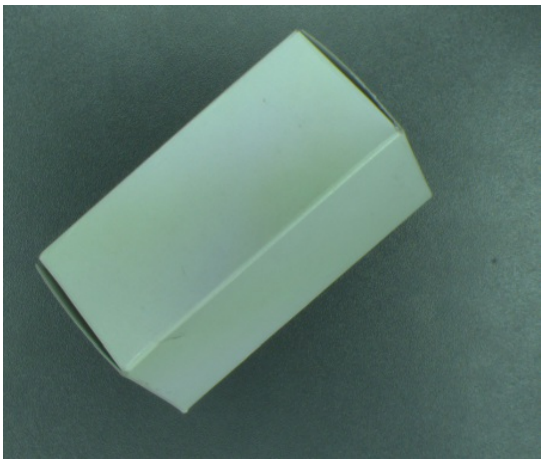
This technique is used to precisely locate and classify key points, characteristic parts and small objects within an image. The result of this technique is a list of predicted point locations with corresponding class predictions and confidence scores.

When to use point location instead of instance segmentation:

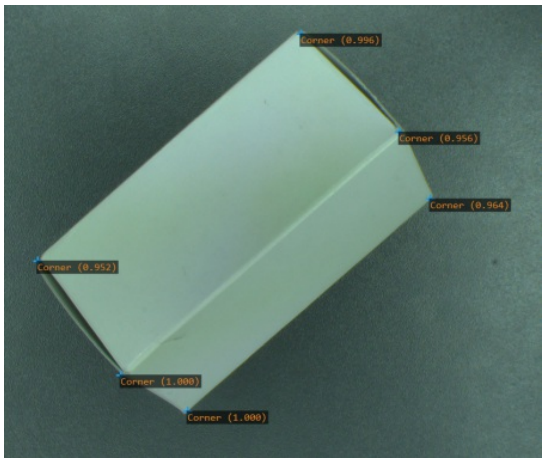
- precise location of key points and distinctive regions with no strict boundaries,
- location and classification of objects (possibly very small) when their segmentation masks and bounding boxes are not needed (e.g. in object counting).

When to use point location instead of feature detection:

- coordinates of key points, centroids of characteristic regions, objects etc. are needed.



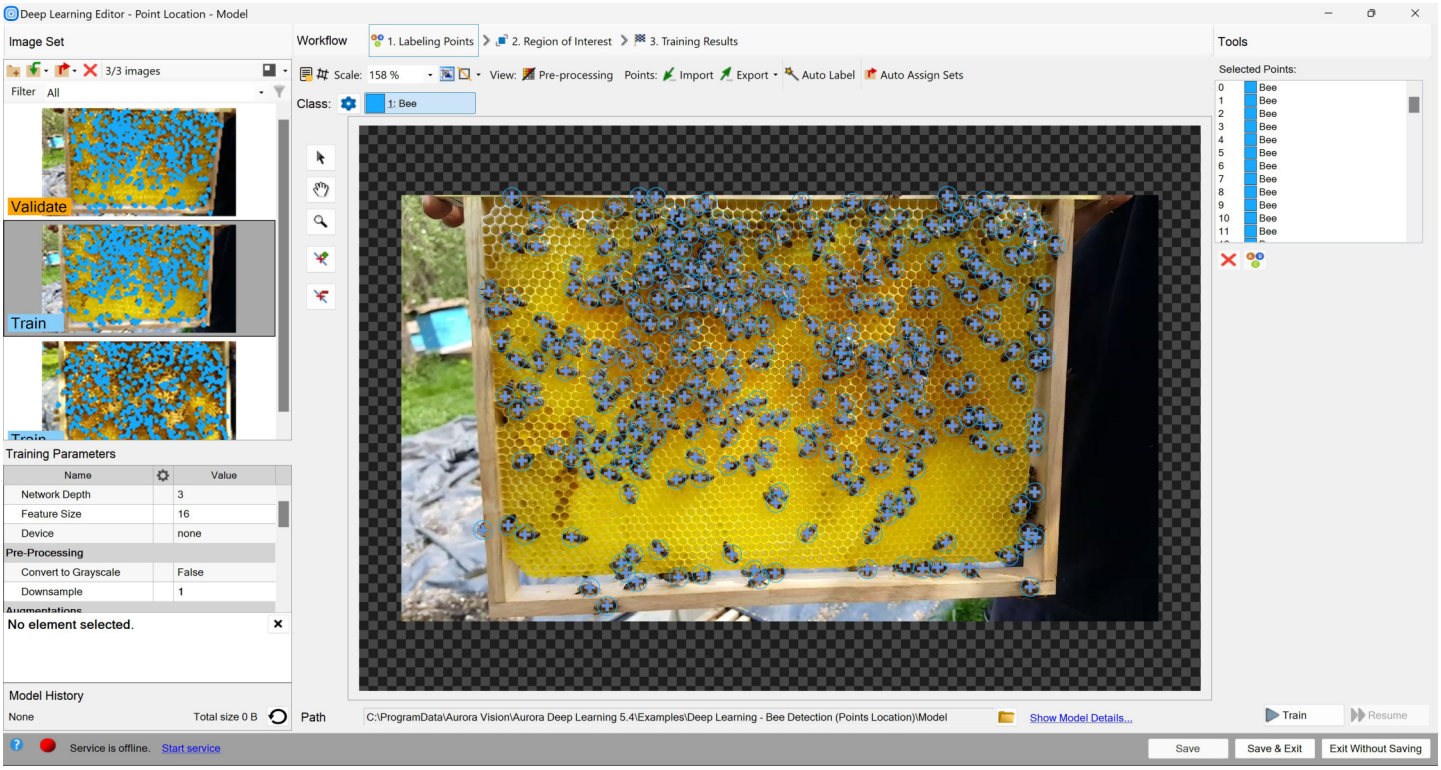
Original image.



Visualized point location results.

Training Data

The training phase requires the user to mark points of appropriate classes on the training images.



Editor for marking points.

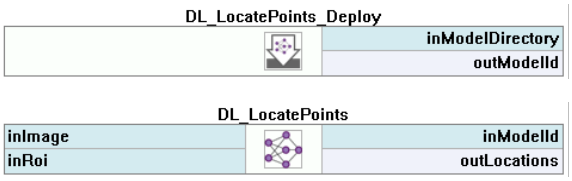
Feature Size

In the case of the Point Location tool, the Feature Size parameter corresponds to the size of an object or characteristic part. If images contain objects of different scales, it is recommended to use a Feature Size slightly larger than the average object size, although it may require experimenting with different values to achieve the best possible results.

Performance tip: a larger feature size increases the training time and needs more memory and training samples to operate effectively. When feature size exceeds 64 pixels and still looks too small, it is worth considering the **Downsample** option.

Model Usage

A model should be loaded with AvsFilter_DL_LocatePoints_Deploy filter before using AvsFilter_DL_LocatePoints filter to perform point location and classification. Alternatively, model can be loaded directly by AvsFilter_DL_LocatePoints filter, but it will result in a much longer time of the first iteration.



Running Aurora Vision Deep Learning Service simultaneously with these filters is discouraged as it may result in degraded performance or errors.

Parameters:

- To limit the area of image analysis you can use **inRoi** input.
- To set minimum detection score **inMinDetectionScore** parameter can be used.

- **inMinDistanceRatio** parameter can be used to set minimum distance between two points to be considered as different. The distance is computed as MinDistanceRatio * FeatureSize. If the value is not enabled, the minimum distance is based on the training data.
- To increase detection speed but with potentially slightly worse precision **inOverlap** can be set to False.
- Results describing detected points are passed to following outputs:
  - point coordinates: **outLocations**,
  - class IDs: **outClassIds**,
  - class names: **outClassNames**,
  - classification scores: **outScores**.

7. Locating objects

This technique is used to locate and classify one or multiple objects within an image. The result of this technique is a list of rectangles bounding the predicted objects with corresponding class predictions and confidence scores.

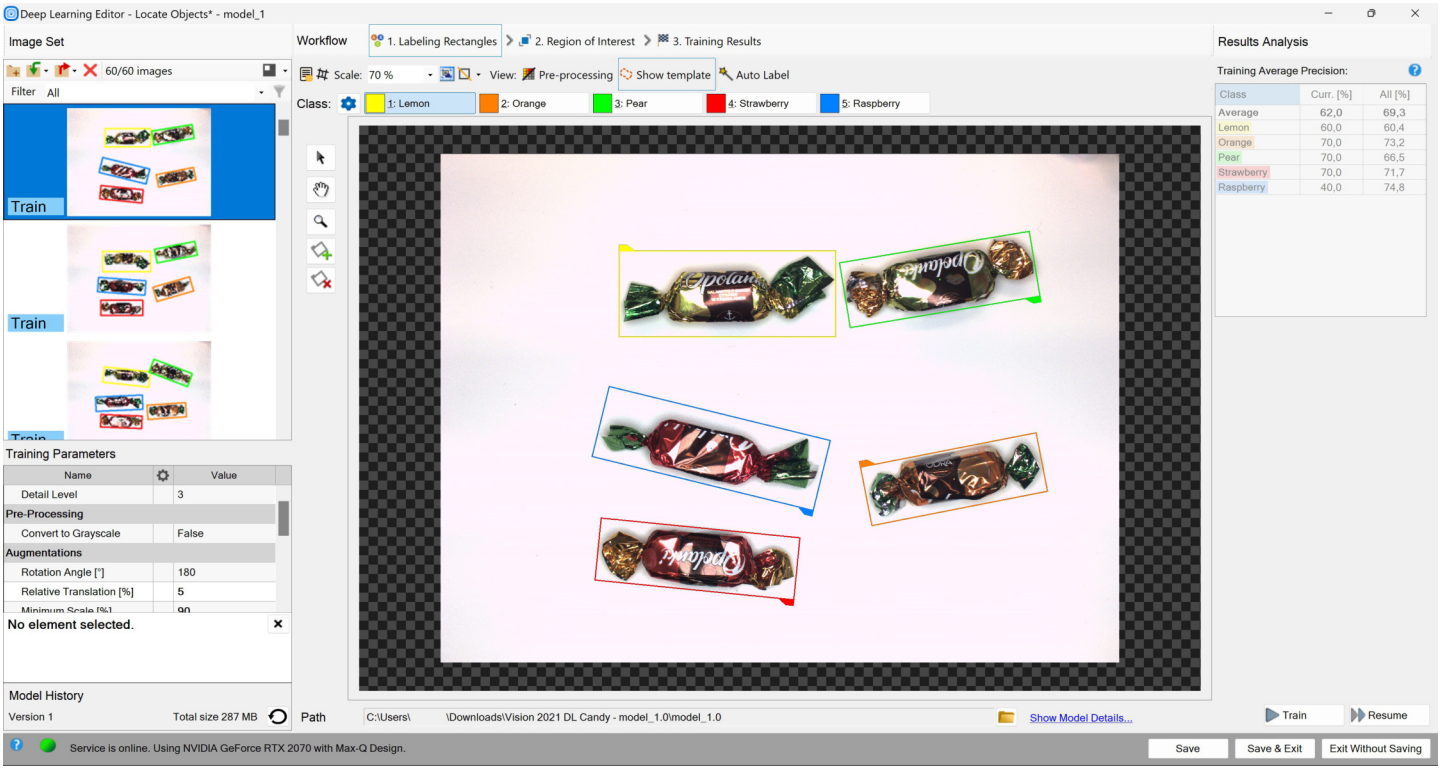
The tool returns the rectangle region containing the predicted objects and showing their approximate location and orientation, but it doesn't return the precise position of the key points of the object or the segmented region. It is an intermediate solution between the Point Location and the Instance Segmentation.

Original image.

Visualized object location results.

Training Data

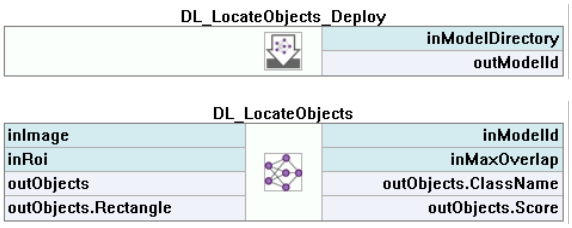
The training phase requires the user to mark rectangles bounding objects of appropriate classes on the training images.



Editor for marking objects.

Model Usage

A model should be loaded with AvsFilter_DL_LocateObjects_Deploy filter before using AvsFilter_DL_LocateObjects filter to perform object location and classification. Alternatively, model can be loaded directly by AvsFilter_DL_LocateObjects filter, but it will result in a much longer time of the first iteration.



Running Aurora Vision Deep Learning Service simultaneously with these filters is discouraged as it may result in degraded performance or errors.

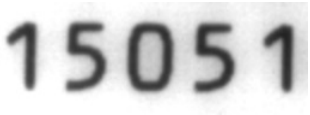
Parameters:

- To limit the area of image analysis you can use **inRoi** input.
- To set minimum detection score **inMinDetectionScore** parameter can be used.
- Results describing detected objects are passed to the object output: **outObjects**.

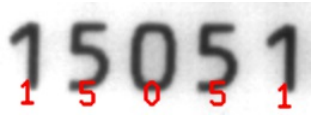
8. Reading Characters

This technique is used to locate and recognize characters within an image. The result is a list of found characters.

This tool uses a pretrained model and cannot be trained.



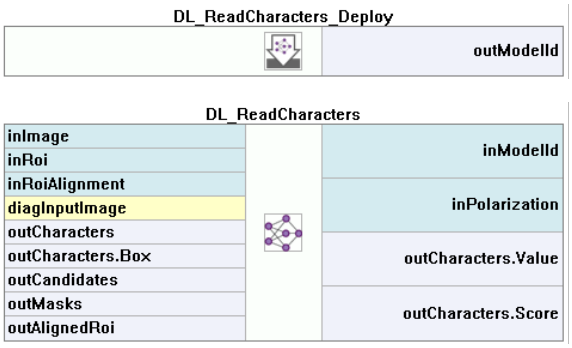
Original image.



Visualized results of the OCR tool.

Model Usage

A model should be loaded with the AvsFilter_DL_ReadCharacters_Deploy filter before using the AvsFilter_DL_ReadCharacters filter to perform recognition. Alternatively, a model can be loaded directly by the AvsFilter_DL_ReadCharacters filter, but it may result in a longer time of the first iteration.



Running the Aurora Vision Deep Learning Service simultaneously with these filters is discouraged as it may result in degraded performance or errors.

Parameters:

- To limit the area of the image analysis and/or to set a text orientation you can use the **inRoi** input.
- You can set one of the available pretrained model types in the AvsFilter_DL_ReadCharacters_Deploy filter using the inPretrainedModelType input or, in the AvsFilter_DL_ReadCharacters filter, using the inModelID/PretrainedModel input. Differences between the various model types are elaborated upon here.
- The average size (in pixels) of characters in the analysed area should be set with the **inCharHeight** parameter. Here you can learn more about the relation between the inCharRange input value and the type of model that you selected.
- To improve the detection/recognition accuracy for a font with exceptionally thin or wide contours you can use the**inWidthScale** input. To some extent, it may also help in case of characters positioned very close to each other.
- To filter false positive results near true characters use **inCharSpacing** parameter.
- To limit or increase the set of recognized characters (e.g. to exclude digits or to include punctuation marks) use the **inCharRange** parameter.
- To filter results by polarity and contrast use **inPolarization** and **inContrastThreshold** parameters.
- To remove results at the edge of ROI **inRemoveBoundaryCharacters** parameter.

To postprocess results of AvsFilter_DL_ReadCharacters you can use MergeCharactersIntoLines filter.

- To get string by connection **outCharacters**
- To match known **inPattern** use grammar rules

9. Locating Text

This technique is used to locate text within an image. The result is an array of found located rectangles.

This tool uses a pretrained model and cannot be trained.

Original image.

Visualized text location results, with orientation marked at origin.

Model Usage

A model should be loaded with the AvsFilter_DL_LocateText_Deploy filter before using the AvsFilter_DL_LocateText filter to perform recognition. Alternatively, model can be loaded directly by the AvsFilter_DL_LocateText filter, but it may result in a longer time of the first iteration.

Running Aurora Vision Deep Learning Service simultaneously with these filters is discouraged as it may result in degraded performance or errors.

Parameters:

- To limit the area of image analysis you can use the **inRoi** input.
- You can set one of the available pretrained model types in the AvsFilter_DL_LocateText filter using the inModelID/PretrainedModel input. Differences between the various model types are elaborated upon here.
- The average size (in pixels) of characters in the analysed area should be set with the **inCharHeight** parameter. Here you can learn more about the relation between the inCharRange input value and the type of model that you selected.
- To improve the detection accuracy for a font with exceptionally thin or wide contours you can use the **inWidthScale** input. To some extent, it may also help in case of characters positioned very close to each other.
- To set the minimum area value threshold for detection, **inMinTextArea** parameter can be used.

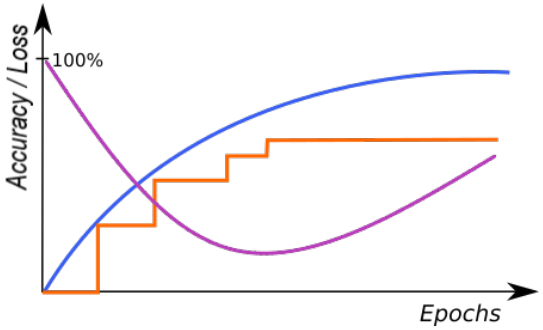
10. Troubleshooting

Below you will find a list of most common problems.

1. Network overfitting

A situation when a network loses its ability to generalize over available problems and focuses only on training data.

Symptoms: during training, the loss graph starts rising, the validation graph stops at one level and training graph continues to rise. Defects on training images are marked very precisely, but defects on new images are marked poorly.



A graph characteristic for network overfitting.

Causes:

- The number of test samples is too small.
- Training time is too long.

Possible solutions:

- Provide more real samples of different objects.
- Use more augmentations.
- Reduce Network Depth.

2. Susceptibility to changes in lighting conditions

Symptoms: network is not able to process images properly when even minor changes in lighting occur.

Causes:

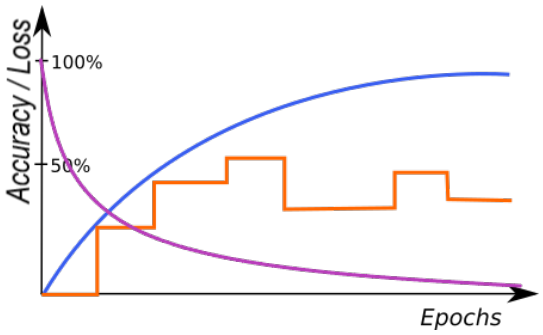
- Samples with variable lighting were not provided.

Solution:

- Provide more samples with variable lighting.
- Enable "Luminance" option for automatic lighting augmentation.

3. No progress in network training

Symptoms – even though the training time is optimal, there is no visible training progress.



Training progress with contradictory samples.

Causes:

- The number of samples is too small or the samples are not variable enough.
- Image contrast is too small.
- The chosen network architecture is too small.
- There is contradiction in defect masks.

Solution:

- Modify lighting to expose defects.
- Remove contradictions in defect masks.

Tip: Remember to mark all defects of a given type on the input images or remove images with unmarked defects. Marking only a part of defects of a given type may negatively influence the network learning process.

4. Training/sample evaluation is very slow

Symptoms – training or sample evaluation takes a lot of time.

Causes:

- Resolution of the provided input images is too high.
- Fragments that cannot possibly contain defects are also analyzed.

Solution:

- Enable "Downsample" option to reduce the image resolution.
- Limit ROI for sample evaluation.
- Use lower Network Depth

See Also

- Deep Learning training API documentation - instruction how to perform training of Deep Learning models (5.3 and older version only).

Zebra
Aurora™ Vision

This article is valid for version 5.6.1