



# ARO Project 2021

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# Introduction

The ARO Project is a program to find a sufficiently optimal series of images for spatial light modulators (SLMs) to generate a high intensity signal image from a camera. The program offers three algorithms to achieve this; sequential (brute-force), simple genetic algorithm, and micro genetic algorithm. Through the graphical user interface (GUI), a user can configure various parameters for the camera, SLMs, optimization process (how many generations, bin size for images, etc.), and the kind of outputs during/after the optimization. The program also uses multithreading to increase efficiency towards finding results and enable the ability to abort optimization. There are two alternative builds of the program for using two different camera SDKs, one being Spinnaker and the other PICam. Both are developed and built within one Visual Studio project entitled “ARO\_Project”.

The purpose of this document is to be a companion piece to the code implementation and elaborate on the project and its components as it currently is, to help in understanding and assist in further developments by providing a high-level look at the implementation and providing details that may be easily missed or misunderstood when looking over the code alone. The goal is to have this one document encapsulate everything to an acceptable degree to also help reduce the strain of searching through various files or being uncertain if a document is “up to date” with the others. Other documentation files may still be beneficial, but shouldn’t be required additional readings for what the project is at the time of this document’s writing. However it will assume that you have access to the code and that you are dedicating time to look over it as well.

## Section 1: Libraries & Frameworks

Besides various standard libraries provided by C++ (string, algorithm, thread, etc.), there are other vital tools used in the project's implementation. Packages are used for handling both the graphical user interface (GUI), make tasks such as image processing or display easier, and to interface with the hardware being used (a camera and SLMs). The following is a brief overview of what is used to help introduce the project implementation.

For the GUI, the Microsoft Foundation Class (MFC) framework is used and is where a user will be able to configure then run/stop the optimization process. This is done with a group of dialogs within a main dialog that help encapsulate the various kinds of settings available and handle the properties/events that occur within. In the GUI presentation, these subdialogs are contained within a window that can be changed with selecting tabs. The main dialog is where the control for selecting, starting, and stopping the optimization process can be found along with a few additional options such as save/load settings and enabling multithreading.

For interfacing with the spatial light modulators (SLMs), the Blink\_PCle SDK is used. To make the interactions more portable and easier to manage, all interactions with this SDK are contained within the SLMController class. An additional class SLM\_Board helps in tracking the properties of each board that are found connected at startup. Provided LUT files can be located in C:\BLINK\_PCle\LUT\_Files of ASLAnderson machine if not in the project contents itself. By default the boards use "linear.lut".

Some tasks involving the managing of images are handled with the usage of OpenCV. This includes the method of saving images and providing separate window displays of the camera and SLMs to the user during optimization. These displays are encapsulated with CameraDisplay, but this library is also used in Optimization and various other parts of the project. The current version being used is 2.08, but it can be updated to more recent versions easily enough as the implementation usage is basic and mostly relying on the matrix data type.

For the camera interactions (configuring and receiving image data) there are two libraries available with the build using one depending on the desired version. The first version is Spinnaker and is the older one used. The other is PICam and is a newer additional option in the project. These two SDKs are not used concurrently, with the implementation having distinct versions of CameraController and ImageController to wrap interactions with the SDKs. To change versions, you must build a separate executable with a change in CameraController.h in whether USE\_PICAM and USE\_SPINNAKER is defined. Attempting to use both will run into an explicit build error.

In the ASLAnderson machine at ASL, additional resources for Spinnaker can be found in "C:\Program Files\Point Grey Research\Spinnaker2013". For PICam it is in "C:\Program Files\Princeton Instruments\PICam". Examples for PICam implementation provided by Princeton Instruments can be found in "C:\Users\Public\Documents\Princeton Instruments\Picam\Samples\source code".

For more details on the classes that use these SDKs and others, refer to [Section 3: Classes](#).

## Section 2: User Guide

*The goal of this section is to serve as a kind of “User’s Manual”, identifying the various features, options, and output to be expected in the current program. This will not consider implementation or similar details and will be left to the other sections. A shorter description of the program’s layout (as it is more intended to be a quick orientation and not a thorough guide) can be found in [Section 3](#).*

### Section 2-1: Startup & Main GUI

When starting up the application, two windows will be generated. The first is a console window which will provide verbose text information and also will always provide updates during optimization. The second, smaller, window is the GUI interface which will be where you can configure the setup and start/stop the optimization process for given boards. This GUI is structured so that some prominent options are always available while more specific parameters are contained in subject-based tabbed windows. The rest of this section will go over the main GUI that is not encapsulated in one of these tabbed windows.

On the top row are “Save Settings” and “Load Settings”, when configuring a setup you can use these two options to save or load them. When saving, the parameters are saved in a readable configuration file that can be edited with a simple text editor if needed. When loading from a file, it will attempt to assign all LUT files to all the boards that existed when being saved and will give a warning if there are failures to do so. The configuration files will not contain the LUT file data, so be sure to have those in the same file path as when saving. The console window will also provide updates during the loading as well. When making changes, be sure to save before closing as there are no warnings to save them.

Next to the settings options is a checkbox for enabling multithreading. When enabled, running a genetic algorithm will utilize multithreading with the exact number of the threads dependent on the parameters within Optimization Settings. Generally, enabling multithreading will lead to a faster run of the algorithm. The iterative algorithm does not use any multithreading however, so for that choice there will be no difference.

Below these options are 4 buttons, with 3 of them being labeled for choosing an optimization algorithm to use and the right-most labeled “Start Optimization”. uGA and SGA are the two provided genetic algorithms, and IA is the iterative algorithm. If none of the algorithms have been selected yet, the start button is disabled. After selecting an algorithm, you may start the algorithm by pressing the start button. Once started, the start button becomes the abort button in case that is needed during the run to safely stop.

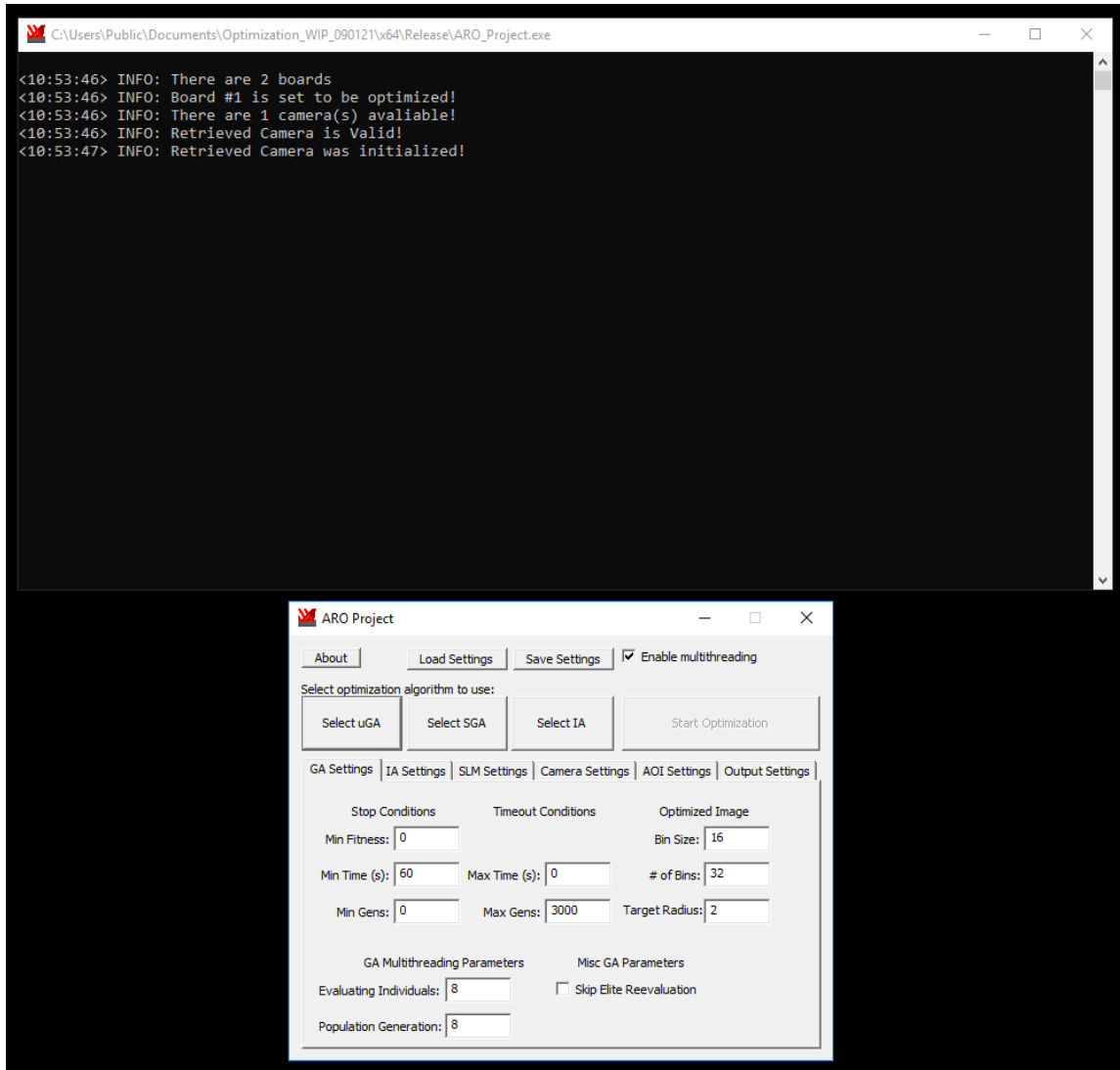


Figure 2.1. Start up with 2 SLM boards and 1 Camera connected with the tabbed window open to GA Settings.

## Section 2-2: Optimization Settings (GA & IA)

*Parameters are given within their categories*

**Stop Conditions:** All these conditions must be met before ending the algorithm's run.

- **Min Fitness** - The minimum average intensity within the target radius of the camera image to achieve.
- **Min Time** - The minimum amount of real-world time the genetic algorithm must run in seconds.
- **Min Gens** - The minimum number of generations the genetic algorithm must perform.

**Timeout Conditions:** If any conditions are reached, the algorithm will end regardless of results.

- *Max Time* - The maximum amount of real-world time the genetic algorithm is allowed to run in seconds. Set to 0 for indefinite.
- *Max Gens* - The maximum number of generations the genetic algorithm is allowed to perform. Set to 0 for indefinite.

**Optimized Image:** These determine the characteristics of the optimized SLM image(s).

- *Bin Size* - Size of a given bin in the SLM image for optimization.
- *# of Bins* - The square dimension of the resolution of the SLM image for optimization (example: a value of 10 would have 100 bins).
- *Target Radius* - The radius from the center of the camera image (in pixels) that will be considered for increasing intensity, the rest of the camera image will be ignored in the evaluation.
- *Phase Resolution (IA Only)* - The step-size within a bin to find an optimal value.

**GA Multithreading Parameters:** Determine the number of threads used if multithreading.

- *Evaluating Individuals* - Number of threads to use when performing the evaluation process of the individuals in a pool.
- *Population Generation* - Number of threads to use when performing the genetic crossover/breeding process in a population pool in a generation.

**Misc GA Parameters:** A section for other parameters, currently only has one.

- *Skip Elite Reevaluation* - If toggled, during evaluation of individuals in a generation it will skip those that have already been assigned a fitness (the elites that were carried over).

## Section 2-3: Camera Settings

Two subwindows will be described in this section

**Camera Settings:** General parameter settings for the camera, some are currently supported in the Spinnaker version

- *Frames Per Second (Spinnaker Version)* - The rate the camera acquires images.
- *Initial Exposure Time* - The initial exposure time the camera uses when getting images (in microseconds). If the resulting image is too high during the run of the algorithm, it may reduce it during runtime.
- *Gamma Value (Spinnaker Version)* - The gamma intensity of the image data, separate from the exposure time.

**AOI Settings:** A subset given in a separate subwindow, for the Area of Interest in the camera.

- *AOI Control Parameters* - Four fields to set the width/height and offsets for the AOI
- *Center AOI* - Takes current width/height and sets to have contents in center of camera's larger view window.
- *Max Image Size* - Sets the AOI to be the entire camera image view window.



## Section 2-4: SLM Settings

Within SLM Settings window, in the top-left the user may choose from a list a connected SLM to configure. As an option, checking “Set All” will have any further adjustments within SLM Settings be applied to all the boards.

- *Optimize this board* - Check this to include this board to be used in optimization.
- *Turn power ON/OFF* - Power button for the selected SLM
- *Set LUT* - Browse and select a LUT file (default filter for .lut extension), updates current assignment path in SLM settings.

## Section 2-5: Output Settings

**Output Folder:** A field-box and browse button to set a path to a folder where all file outputs will be made to.

### Runtime Displays:

- *Display Camera* - Output to the screen as a separate window the best camera image during optimization runtime (for GAs, this will be updated in every generation).
- *Display SLM* - Output to the screen as separate window(s) the best SLM image(s) during optimization runtime (for GAs, this will be updated in every generation).

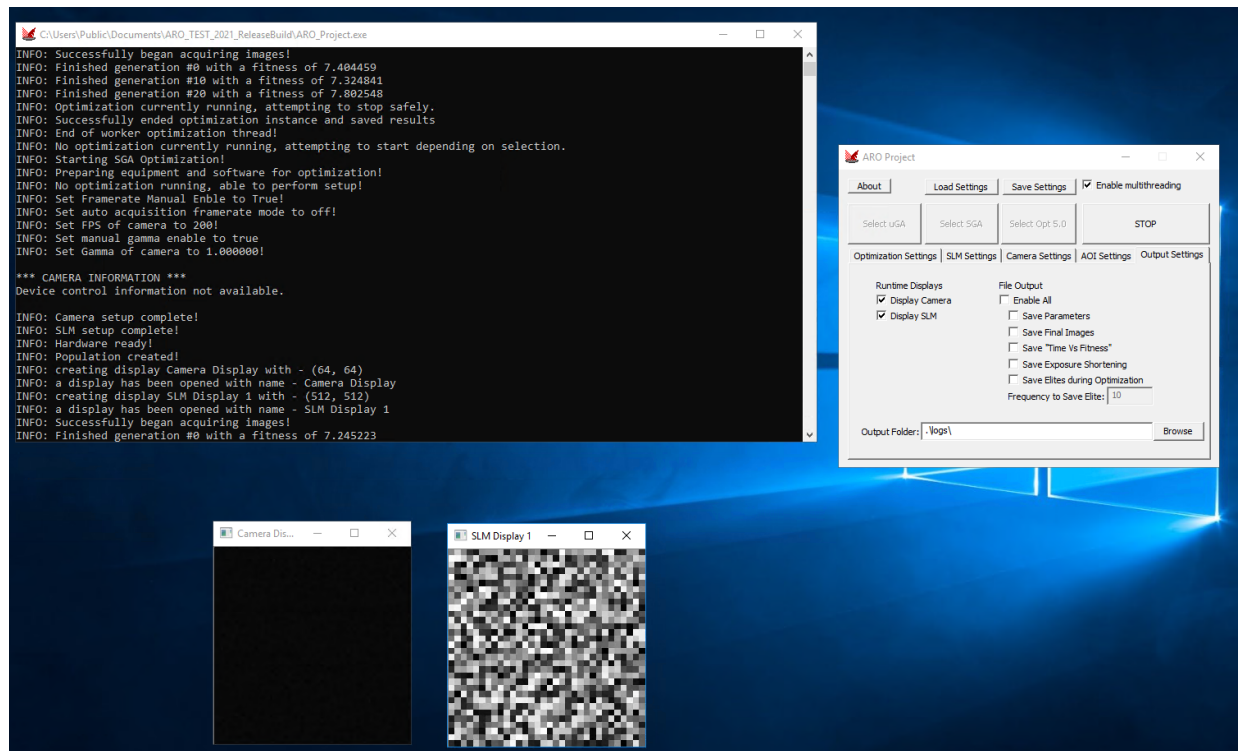


Figure 2.2. Test Demo of Optimization in Process with toggled Image Displays

**File Output:**

- *Enable All* - Shortcut to enable all file outputs that also are listed as separate toggles.
- *Save Parameters* - When running optimization will save the current setup as both a config file that can be loaded and an additional verbose text file.
- *Save Final Images* - Save the resulting optimized camera and SLM images in bitmap format. If a timeout condition occurs, it will not save the resulting images.
- *Save "Time Vs Fitness"* - Records the time performance of the program during optimization run.
- *Save Exposure Shortening* - Logs when exposure was shortened from initial during the optimization run.
- *Save Elites during Optimization* - Save camera and SLM images during optimization run to observe change over optimization run at a later time.
- *Frequency to Save Elite* - If saving elites during optimization, the frequency by generation to save the progress (example: input of 10 would save every 10 generations).

**File Format Details:**

*All files are prefixed with a timestamp containing date and time down to seconds, followed by algorithm name (for example the simple genetic algorithm will have files prefixed with "SGA").*

If *Save "Time Vs Fitness"* is toggled, 2 files will be produced after running the optimization algorithm.

The first is entitled "time\_vs\_fitness.txt" and contains in a row the following:

- Time elapsed since start in milliseconds
- Fitness of current individual that has been evaluated
- Exposure time, and the ratio of it compared to the initial exposure time.

The second is focused on performance of parts of the algorithm and is entitled "timePerformance.csv".

- In the top row along with header info is also a record of the thread counts given by the GUI parameters (as described in [Optimization Settings](#)), this is to help track if considering the impact multithreading has on performance between runs.
- Each row has the following info:
  - Current generation
  - Time (in microseconds) to evaluate the pool of individuals
  - Time (in microseconds) to perform genetic crossover/breeding to produce new pool.
  - Overall time (in microseconds) to process the entire generation. This is expected to be approximately (but slightly greater as it includes the other outputs) equal to the sum of the previous recorded times.
- At the bottom of the file is a record of the overall time of the run in microseconds.

## Section 3: Program Walkthrough

In this section we will be giving a quick overview over the program's appearance and behavior as given by the user through the GUI. This is to help give an orientation to the layout before going deeper into the implementation. It is assumed that the reader has not read Section 2 which goes over the program and its outputs. This guide will be going through the Spinnaker version (the only difference to the user may be the options available in Camera Settings).

When starting the program, two windows are created. One is a console window that gives helpful verbose info while running, the other is the GUI window where the user will make interactions to configure, then start/stop the optimization process. Figure 3.1 shows the application windows at startup.

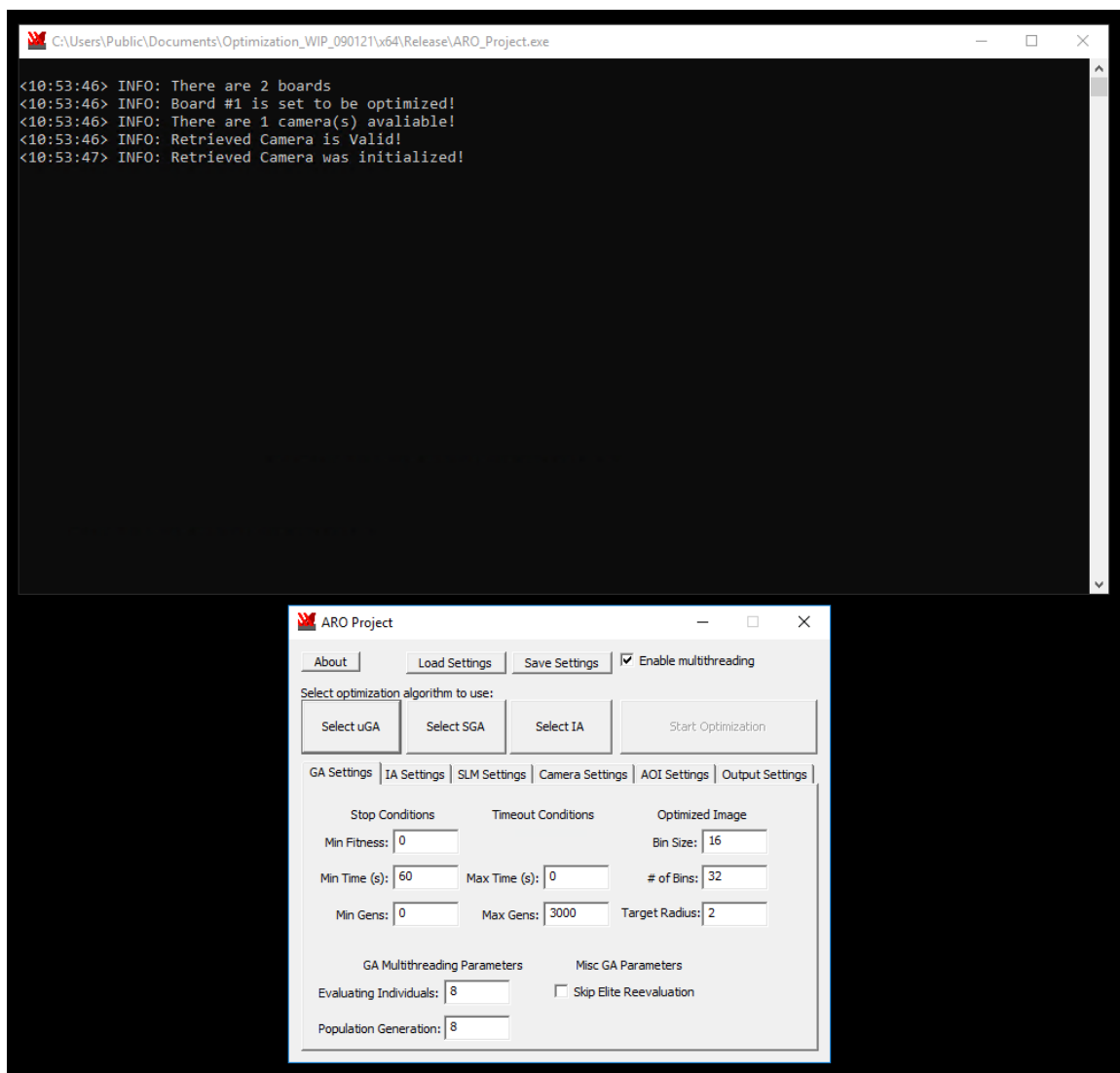


Figure 3.1. Main Windows, Console (left) and main GUI (right)

Since the console window does not provide any means of input, for the remainder of this guide we will be focusing on the GUI window which Figure 3.2 will provide a more focused view

of. Note that the majority of the window contains a tabbed sub-window with 6 tabs for the following categorized settings; G, IA, SLM, Camera, AOI (Area of Interest which may also be known as Region of Interest, ROI), and Output. Above this tab window are 7 buttons and 1 checkbox encompassed into 2 rows. The bottom row contains buttons for selecting an optimization algorithm and start/stop the selected optimization (initially on startup the start/stop button is disabled as no algorithm has been chosen). The top row has an about button, load/save settings, and the toggle to enable the usage of multiple threads or not for our optimization. Note that the optimization is run on a separate worker thread from the GUI so that the stop button will work regardless of this toggle. When the optimization is running, the only interactions available in the GUI is the stop and about buttons.

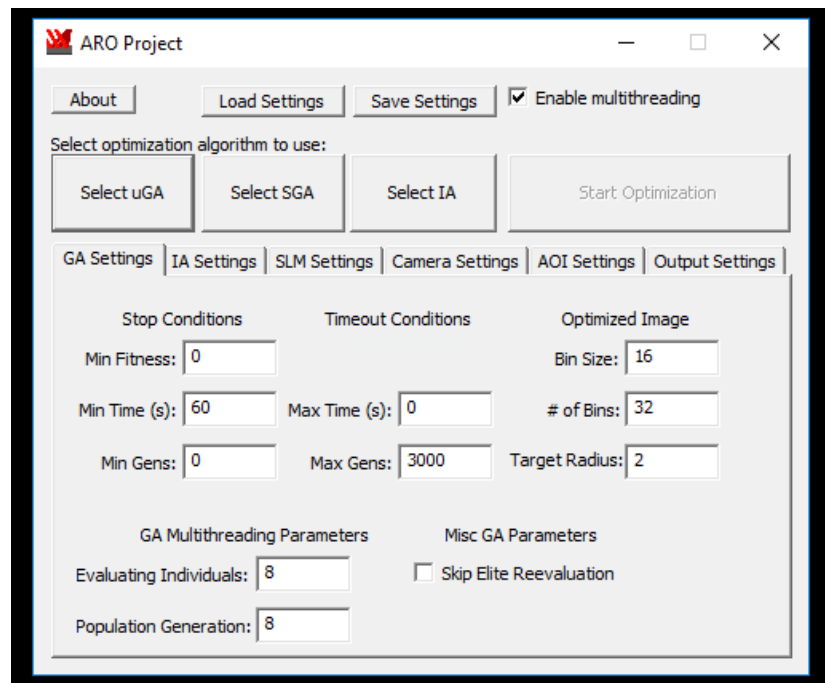


Figure 3.2. The Main GUI Window with Focus on Optimization Settings

The tab window is initially focused on GA settings, and within it there is access to various fields relating to stop/timeout conditions for the genetic algorithms and fields for the desired optimized image. Below these fields is a toggle that when enabled will skip elites in a pool from being evaluated (as they already have been) to attempt speeding the optimization process. To the bottom right are two fields that when multithreading is enabled will set the number of threads that the two multithreaded tasks will utilize. The default value in the fields is dependent on the number of logical processors on the CPU but it is valid to try and exceed the count. Refer to [Section 4-3](#) for more details regarding the current implementation of multithreading behavior.

The next window is IA settings, it is for parameters that are for the iterative algorithm. It is much simpler with essentially the same content as the “Optimized Image” parameters under GA, but with an added phase resolution that impacts the precision of bin values it iterates through to find the optimal number. Although it has the same impact, the bin size, # of bins, and target radius parameters between GA and IA are not shared and are adjustable separately.

Figure 3.3 provides a quick look into the about button. When clicked it produces a new child window that provides some details on the application and an OK button to close (the top-right close button of the about window also works). This window must be closed in order to be able to refocus on the main GUI window again.

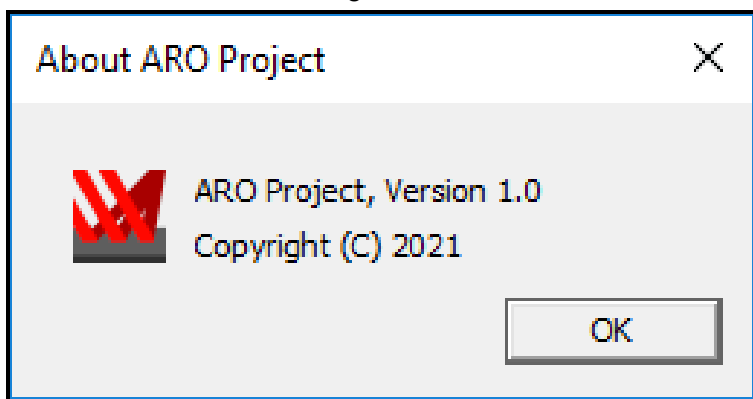


Figure 3.3. About Window Created by Clicking on About Button

Back to the tabs, the next tab is SLM Settings. Within these settings are the available configuration options for the Spatial Light Modulators (SLMs). Initially all the boards are powered off and given a LUT file path as "linear.LUT". Figure 3.4.1 shows the current layout, note that there is a LUT file path display which is not editable, instead the method of changing LUT file is by clicking on the "Set LUT" button. Figure 3.4.2 shows the window created to select a LUT file, which by default filters out files to only show ones with a LUT extension (though the user can adjust to show all files if needed).

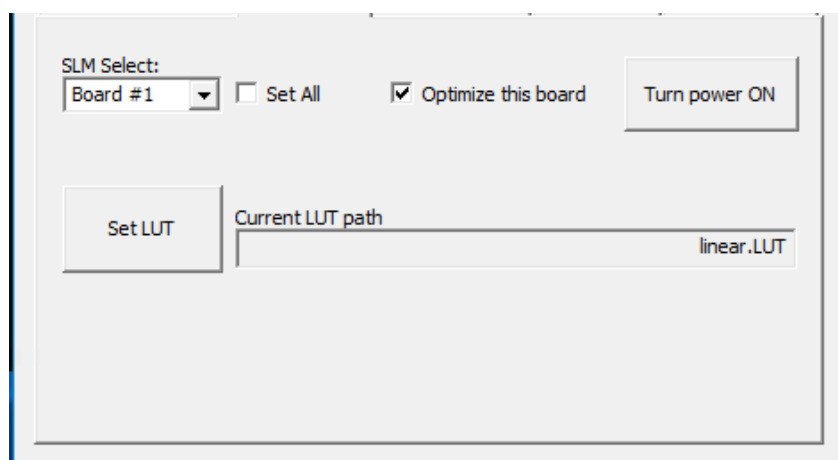


Figure 3.4.1. SLM Settings Window with Default Values

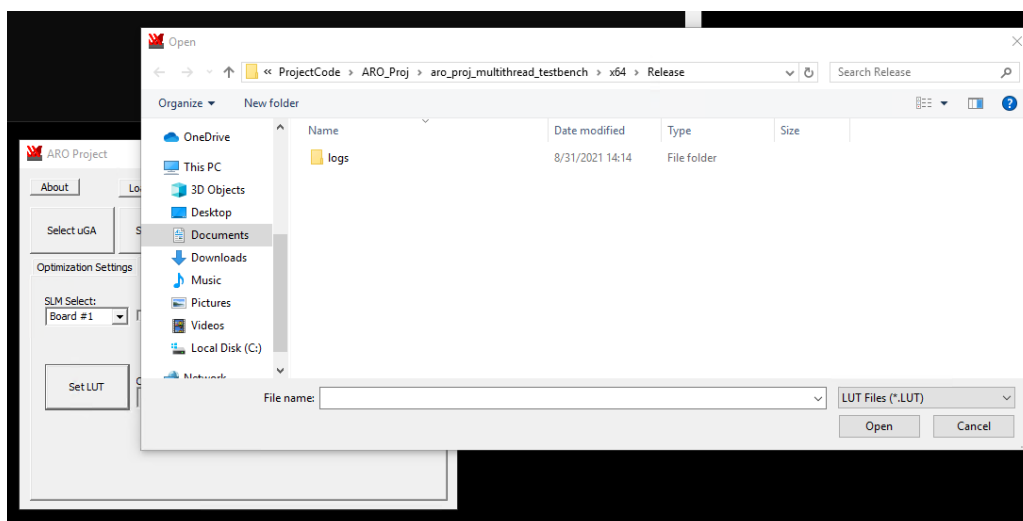


Figure 3.4.2. Selecting a LUT file to Set

In the top left is a SLM Select drop down list, this is updated at startup with the total number of boards connected and is for choosing which board to configure. If “Set All” is toggled, the current selection is ignored and all future changes will be applied to all the boards instead.

For the currently selected board(s) there is a toggle to include it for the next optimization run. By default at startup, the first board is enabled with the others (if there are any) disabled. The user may set more than one board to be optimized. If all the boards are disabled, the optimization will not run since there are no boards to optimize with.

The following two tabs (Camera and AOI) are the simplest as they feature relatively straightforward fields and buttons relating to configuring the camera and its area of interest (a subfield of the camera’s image range that we are focused on which reduces the amount of data moving around and allowing higher frame rates). The Camera settings offers the means of adjusting exposure time, frame rate (which may be separate from exposure and is how fast it acquires images in Spinnaker and also applied to the SLMs), and gamma. The AOI Setting has fields for setting the area of interest’s dimensions and offset to choose where to get the image data from and two buttons to center the given dimensions into the camera’s view or set the area of interest to be the entire view dimensions of the camera.

The final tab is Output Settings and is shown in Figure 3.5. This window is where configurations made to the kinds of outputs made during or after optimization can be selected and where to output them to (the default location being a local logs folder). The toggles are separated into two columns; “Runtime Displays” and “File Output”.

The first column allows enabling/disabling the displays generated to show current best camera and SLM images in a generation (shown when running the optimization). The second column provides selections to enable specific files types to be outputted and reviewed later with the first toggle being an enable all option. When this toggle is checked, the following toggles are disabled to help communicate that adjusting the toggles would not change anything (as they are all enabled). At the bottom row there is a field to adjust the frequency that saving elites are made, this is only available if the toggle “Save Elites during Optimization” is enabled (the enable

all option will also make this available). By default all file outputs are enabled (via the enable all button).

The bottom of this window shows the settings for where to store the file outputs. The user may either edit directly in this field or use the “Browse” button to open a folder selection window and set the path through that.

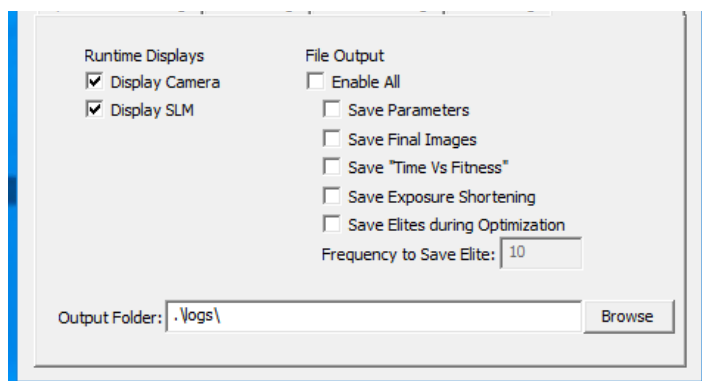


Figure 3.5. Output Settings

The final element of the GUI to show before demoing the optimization behavior is the tooltips feature. If the user wishes to have more details regarding a component, they simply hover over it and a text box below the cursor will appear. Figure 3.6 shows this in action with the “Frequency to Save Elite” field (note that you cannot see the cursor due to the capture software, to the user it is hovering over the box field containing the value 10).

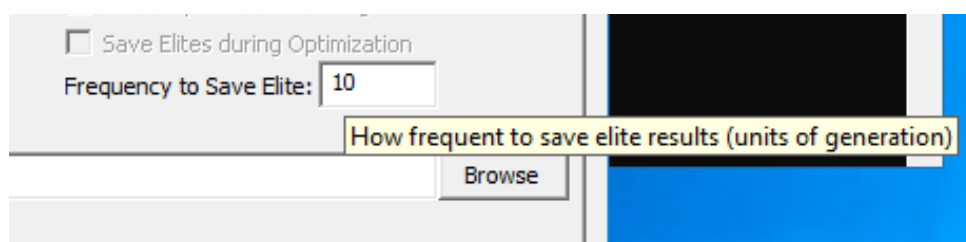


Figure 3.6. Tooltips Display for Multi-SLM with Green Highlight of Area Hovered.

With all major elements of the GUI covered, we will now show the user side experience of running an optimization algorithm. Figure 3.7 shows an example of what the user would see when performing an optimization (in this case SGA). The start button in the main GUI is now relabeled “STOP” and when pressed will attempt to safely end the optimization prematurely. The console window outputs information (in this demo I’ve stopped and started the optimization again and this is shown in the console log). With the display camera and display SLM toggled, two additional windows are created to show the current best. These windows in Figure 3.7 are near the bottom (but can be moved around like the other windows) with the left one being the camera image and the other the SLM. If more than one SLM is being optimized, additional displays for each SLM will be created. Note that this was a test run where the laser was not active (only demoing the program itself) and so the camera image would be largely black (as there would be no light from the laser). When the optimization is finished, these windows are



closed automatically and the stop button is reset to “Start Optimization”. Unlike when starting the program, the start button is still enabled as the previously selected algorithm is remembered as selected.

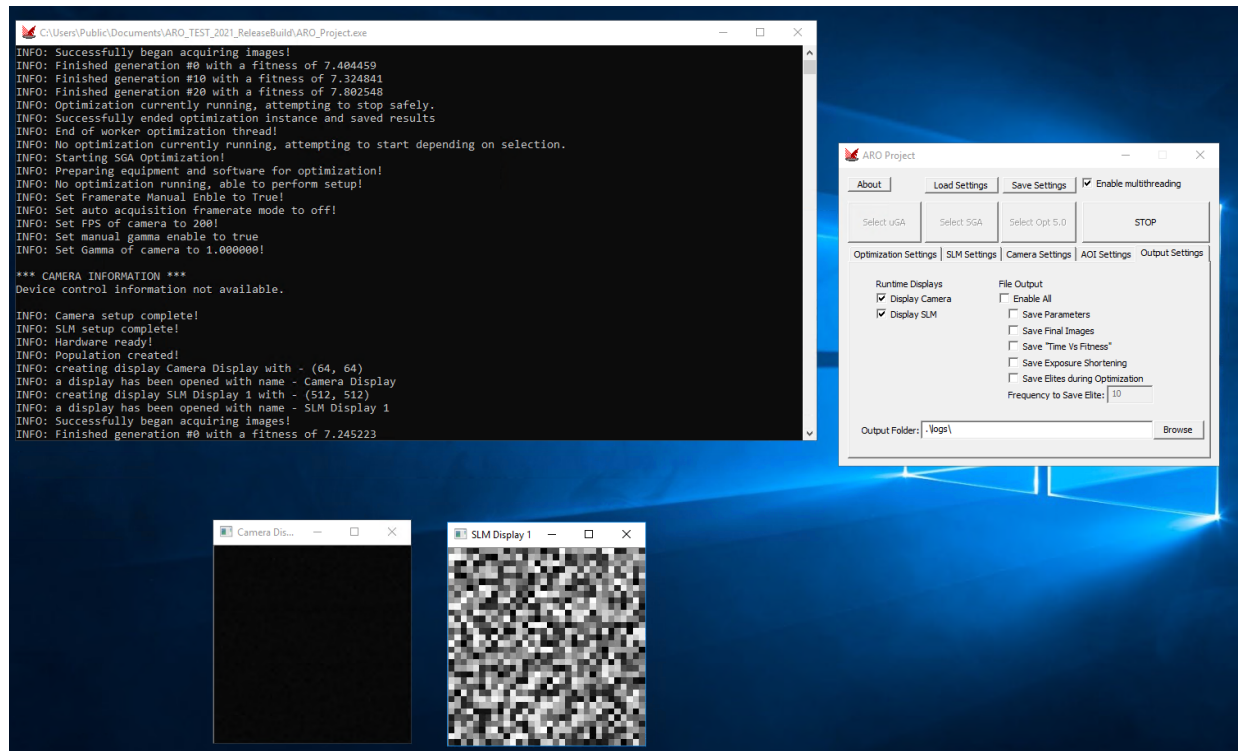


Figure 3.7. Test Demo of Optimization in Process with Newly Created Image Displays



## Section 4: Classes

Refer to [Figure A.1 in Appendix A](#) for a high level diagram that illustrates the relationships of the classes implemented within the project space.

This section elaborates on notable classes that are implemented in this project. Rather than giving details on every property and method, the goal is to provide a contextual explanation to the class' role so that when looking over the code you will have some initial background knowledge on what they are and their general role.

### ARO\_App

This class is the entry point for launching the application using MFC and relies on MainDialog. Unless there are some major changes to be made this can be largely left alone as the GUI will be configured through the dialog classes themselves.

## Section 4-1: User Interface Dialogs Classes

This subsection covers the dialog for the GUI classes and their roles. The general structure of them having been constructed from the MFC setup and generation process provided by Visual Studio.

### MainDialog

This dialog class is responsible for the main GUI window. Besides a few input components it's main purpose is to manage application resources of the program and provide access to the sub dialogs through a tab window.

The most prominent element available in the MainDialog (besides the previously mentioned tab window) is the ability to select and start/stop the optimization process. The MainDialog is also where the option to save/load settings is available (this feature uses file i/o with preference to .cfg file extension with an order-dependent and syntax specific file reading process that is implemented in the distinct file OutputSettings.cpp) and the option to enable multithreading or not. The Optimization class has a pointer to this dialog as a means of accessing the entire GUI to draw current values from and determine if the stop button has been pressed or not.

### AOIControlDialog & CameraControlDialog

These two sub dialogs are what manages various configurations for the camera being used. AOIControlDialog is specific to setting the area of interest of the camera image to draw data from (rather than taking the entire view the camera has) with additional options to make setting AOI easier (centering and getting full image size buttons). CameraControlDialog provides the other options available to configuring the camera, currently that is the framerate, initial exposure time (separate from framerate), and gamma value. These values are used by the CameraController class and are accessed by it when starting the optimization process.

**IMPORTANT:** The CameraControlDialog's frame rate field is also accessed by SLMController to set the SLM framerate and attempt to match the camera's.

## GA\_ControlDialog

This subdialog is where the configuration options for optimization parameters for the genetic algorithms.

## IA\_ControlDialog

This subdialog is where the configuration options for optimization parameters for the iterative algorithm specifically. Because of the comparatively simpler setup, the only addition here is the inclusion of phase resolution. Although there are similar parameters for optimizing image, the fields are not set to be identical. Due to this arrangement, when the Camera Controller draws from the GUI it depends on the current selected algorithm to choose the appropriate dialog.

## SLMControlDialog

This subdialog is where the user can configure the SLMs. It is also where the option to optimize more than one SLM is available. This dialog also provides the behavior in attempting to write a LUT file with a GUI-based response to if an error occurs to attempt a retry.

A notable element is the LUT path display which is updated to show the current board's LUT path, this component is ignored by the SLMController as it is assumed the SLM\_Board's property is the most accurate (they should be matching). To make this more clear that this is not an input field, the display is disabled from interactivity.

## OutputControlDialog

This subdialog manages the toggle of various outputs that the user may want to have made while the optimization process is running.

A note about the output is that all files when optimization is done should be named with a timestamp that should prevent the risk of overwriting multiple runs in the same output folder (this is done within the Optimization sub-classes). Also the enable all option does not change the state of the sub-toggles made within (just disabled from access). Thus when referring to the toggles it is important to check both the enable all and the relevant sub-toggle, not just the sub-toggle.

## Section 4-2: Utility Classes

These classes are used in the program as helpful tools. Note that in older documentation there was also a "Utility" class that contained various helpful static functions. This "Utility class" has been remade into a namespace providing the same functions.

## ImageScaler

A class to contain the properties and scaling method to translate an image of one size to another. This is used to translate a desired image with a given resolution to one that will properly fit an SLM board. The optimized image parameters in Optimization Settings is accessed by this class.

## CameraDisplay

A simple container to help in displaying a given image to a distinct window using the OpenCV library. You can set the dimensions of the window and update with a raw pointer to the data that is then to update the display. Although the name is “CameraDisplay”, this class is used to display both Camera and SLM images (as this class only interacts with image data and not the hardware for either).

## TimeStampGenerator

This class when constructed gives how much time has elapsed since then. This is used by the optimization process to both compare against a stop condition and also to output time elapsed in performance outputs.

## BetterRandom

This project’s randomizer (instead of standard rand()) as a more evenly distributed randomizer. Used most notably in the genetic algorithms to generate random individuals and perform crossovers. The usage is similar to the standard rand with the need to initialize before usage.

## ThreadPool

When multithreading is enabled for the genetic algorithms, the multithreaded approach uses a persistent pool of threads that are given a queue of “jobs” to execute in parallel. This reduces the overhead required during the optimization and is what makes the multithreading notably more efficient as a result. The number of threads in the pool is at most the number of logical processors on the CPU, but if the number of threads for both evaluating individuals and the genetic algorithm are less than that then the pool will be equal to the greater of the two. For example, if the CPU has 8 logical processors but evaluating individuals is set to 2 and population generation is 6, then the pool will have 6 threads. If the number of evaluating individuals is instead 10, the number of created threads is capped at 8.

## Section 4-3: Equipment Classes

These classes are what are responsible for accessing and managing the hardware equipment.

## SLMController

The wrapper for interacting with the Blink\_PCle SDK for controlling the Spatial Light Modulators (SLMs). Wherever interactions with the SLMs are required this should be made accessible rather than interacting with Blink to increase portability of the project in case a different SDK is desired to be used in the future similar to how CameraController has two versions. A note about Blink is that the boards follow 1-based indexing (1 is start as opposed to 0 in an array), so when iterating or accessing specific boards be sure that the right value is used. SLM\_Board should contain an accurate id value that would be better used when accessing a board through Blink than using the position it resides in under SLMController's board vector.

## SLM\_Board

Simple class to encapsulate tracking data for the state of the SLM boards connected. Includes (but not limited to) image dimensions of the board, a string for the current assigned LUT file, and the current power state (which isn't available from Blink directly, rather is updated whenever the power setting is updated in SLMController). SLMController holds a vector of pointers to these boards. During optimization, the Optimization class holds a vector of pointers to the boards that are set to be optimized that are taken from SLMController. It is important to not delete the board data after optimization as SLMController does not reinitialize the data and the vector holding optimizing boards is not a deep copy from the vector holding all the boards. The board\_id property is the board index according to Blink and is important should be used rather than array indexes when writing to reduce chances of discrepancies in values.

## CameraController

The wrapper for interacting with the chosen camera SDK (Spinnaker or PICam). Regardless of SDK chosen, CameraController provides the means of configuring the camera accordingly and in acquiring the image data that is contained within ImageController.

At the start of an optimization, call *setupCamera()* to connect with the camera and apply current camera settings according to the UI. The *shutdownCamera()* is called to release resources for the camera and should be called when done with the camera (which is not when done with optimization as it may be started again later in the GUI). The methods *startCamera()* and *stopCamera()* to manage the acquisition from running or not. These are called by the optimizations so that the camera isn't actively acquiring images when not optimizing.

For Spinnaker some hard coded settings are for acquisition with "Continuous Mode" and the buffer to "Newest Only" so that we can acquire the most recent image at a later point.

PICam operates somewhat differently, with different available parameters and setup. Unlike Spinnaker, it does not rely on a nodemap to access and set these parameters but instead a variety of PicamParameter defined enumerated values. Changes made to parameters are done on a virtual camera, and only after calling the commit parameters method will the changes be applied to hardware. The basic/default approach involves finite acquisition, for indefinite it requires setting the readout to 0, setting up a user-defined buffer, then calling for wait on acquisition update for new data. The readout is currently set to full frame as we are interested

in most recent frame and may be some time for the next frame. The camera is configured to readout a full-frame at a time. Because a given acquisition may contain more than one frame in the buffer readout and we are only interested in the most recent for an individual, we must navigate through the buffer to get the most recent one.

## ImageController

This wraps all the interactions with the chosen camera SDK in the context of image data itself (this is most important for Spinnaker as it has its own ImagePtr class that is used). This class is used in the optimization to hold an image data that can be accessed or saved at a later point. The ImageController is also what provides the means of saving images. Like CameraController, there are alternate versions between Spinnaker and PICam. However the PICam version itself does not directly interact with PICam as it deals with direct readout image data to perform a deep copy from. This makes it somewhat simpler than Spinnaker's if it weren't for the additional fact that for PICam we must also convert the image pixel-format from 16-bit to 8-bit as PICam doesn't offer an 8-bit format for the readout.

## Section 4-4: Optimization Classes

These classes are specifically related to the optimization algorithms. The child classes are not covered as those are responsible largely for implementing virtual methods which are different depending on the algorithm.

### Individual

This class holds the properties and behaviors for a given individual in the genetic algorithms. It has a pointer to a vector that holds the image data to be written to an SLM and is being optimized and a variable to hold the resulting fitness determined by the average intensity within a centered circle with given radius. This fitness is initially set to -1 (something that should be invalid as absolute darkness ought to be 0) as a means of identifying if this individual has been evaluated or not.

### Population

Holds a pool of individuals that represent a generation and provides the means of implementing the genetic steps of producing a new generation. The base Population class is virtual and relies on the implementation to be provided from the two child classes; SGA\_Population and uGA\_Population.

For the process of generating the next generation for SGA and uGA, refer to [Figures A.4 and A.5 in Appendix A](#). These figures also note where multithreading is utilized (though multithreading if enabled is also used in the initialization of the first generation as well in the class's constructor). These threads are managed using the thread pool class provided by the GA\_Optimization class. The Population class also holds a pointer array to BetterRandom objects, one instance for each thread.

## Optimization

Encapsulates the higher level properties and behaviors for an optimization algorithm along with declarations for the setup, output, and release of resources as well as various properties. The base Optimization class has 4 virtual methods that are relied on by the child classes to implement. The implementations of the optimization algorithms are made in child classes for each algorithm available (BruteForce, SGA, and uGA). For the genetic algorithm, a class “GA\_Optimization” inherits from this class that the final child genetic algorithm based classes use. The process of generating a pool and the next generation are dependent on the Population’s implementation and are included in the associated child classes as properties. For the genetic algorithms there is a population for each board (for example, if two boards are set to be optimized then two populations are created and don’t share individuals).

The virtual methods are the following; *setupInstanceVariables*, *shutdownOptimizationInstance*, *runIndividual*, and *runOptimization*. The first two methods are to be responsible for initializing and releasing properties such as the population and current generation count. These are implemented within the child classes to set up the specific instance appropriately and set the populations (for the GAs) to the correct type. The method *runIndividual* is implemented by the GAs to perform the process of evaluating an individual in a pool (refer to [Figure A.3 in Appendix A](#) in how that is done), while for the BruteForce algorithm the *runIndividual* is for optimizing a given board. The method *runOptimization* is a higher level function to encapsulate the total behavior of optimization and uses the previously mentioned methods to perform the algorithm.

## GA\_Optimization

Inheriting from Optimization, this class is a base class for genetic algorithm behavior specifically. It implements *runOptimization* and *runIndividual* as well as setting up a pointer to populations to use. This is inherited from uGA and SGA Optimization classes as a way to reduce code duplication as both algorithms have the same approach for running the optimization and evaluating a given individual. Because the brute force algorithm has no means of using multithreading, this virtual class also adds the properties for multithreading with defined mutexes and a pointer to threadPool class.

For information on the process of optimization in the genetic algorithms, refer to [Figures A.2 and A.3 in Appendix A](#) for *runOptimization* and *runIndividual* respectively. These figures also note where multithreading is utilized during optimization. [Figures A.4 and A.5](#) will give insight to the process of creating the next generation for the two algorithms.

## Section 5: Notes For Working on the Project

The goal of this section is to help starting on developing for this project by exploring areas that may not be most intuitive or familiar which may not be easily found through looking in the code alone.

### Section 5-1: Visual Studio Configuration

This project has been built using Visual Studio 2013, and with this a number of configurations have been made. Importantly is the linkage to the [mentioned libraries in Section 1](#) which is also different between Debug and Release builds as the specific files used change from debug version to a release. For this project you will also require Blink\_PICl, OpenCV, and Spinnaker (or PICam) installed to access their libraries. The author of this document [Andrew O’Kins] had the experience of adding PICam and fixing linkage issues but not configuring all the settings, so this section is not a guarantee that everything is configured correctly if starting from scratch (sincere apologies if you are in that situation).

To modify the libraries being linked to, first open the project properties window by going under the Project tab. In Figure 5.1 this is “ARO\_Project Properties...”.

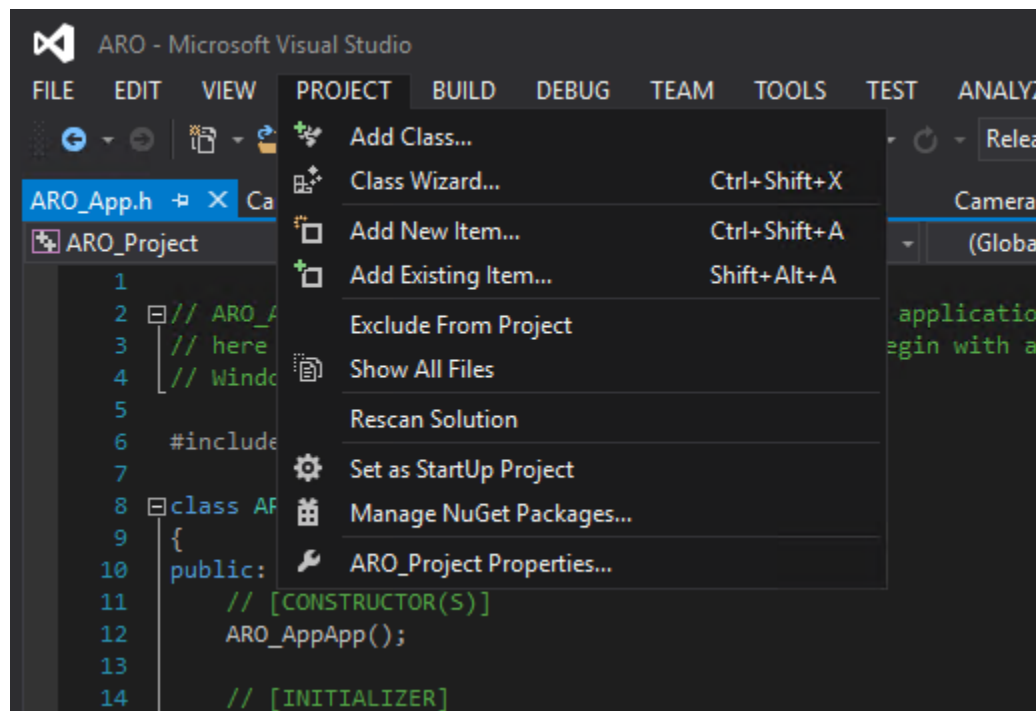


Figure 5.1 Project Properties Drop-Down Menu

The window displayed will provide the means of configuring the build properties for both Debug and Release version. When making changes to libraries, be sure to properly update both versions appropriately. Figure 5.2 shows the window with configuring debug and the VC++



directories properties selected. The highlighted row is where you will want to have included a path to the libraries being used.

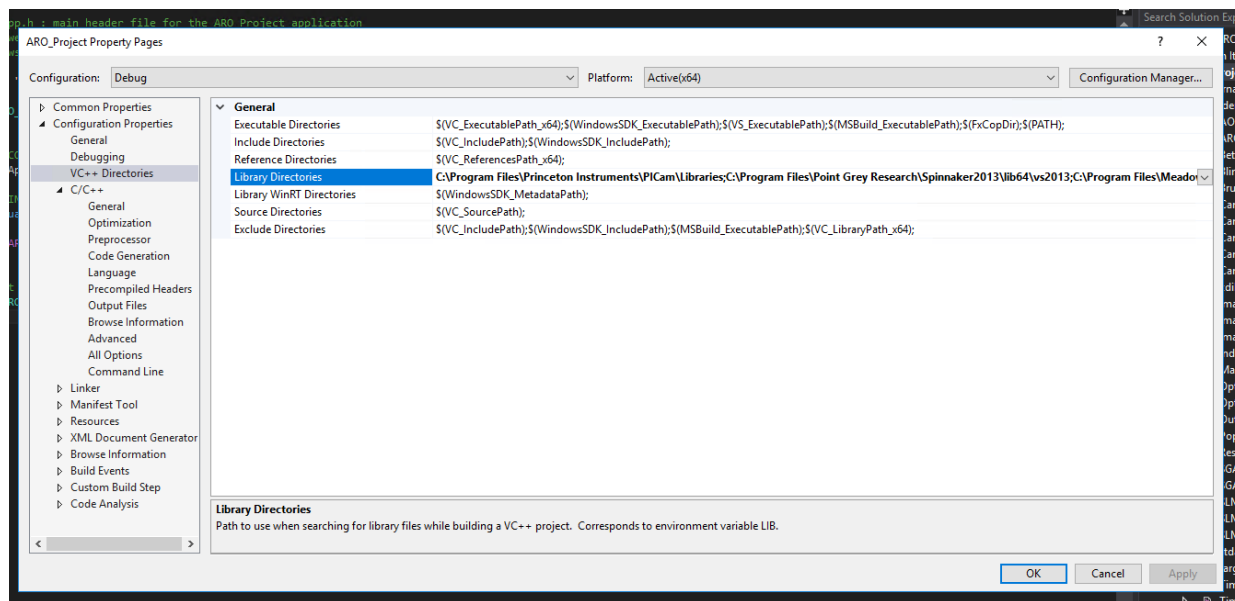


Figure 5.2 Debug Project Properties Focus on Library Directories Setting

There is more that will also need to be adjusted if you want to include new libraries and build. You will want to add the appropriate paths to the Include folder for accessing the files that you want (and will help intellisense know if you have your code right). This is under C/C++ and in General, Figure 5.3 shows this field is the top row.

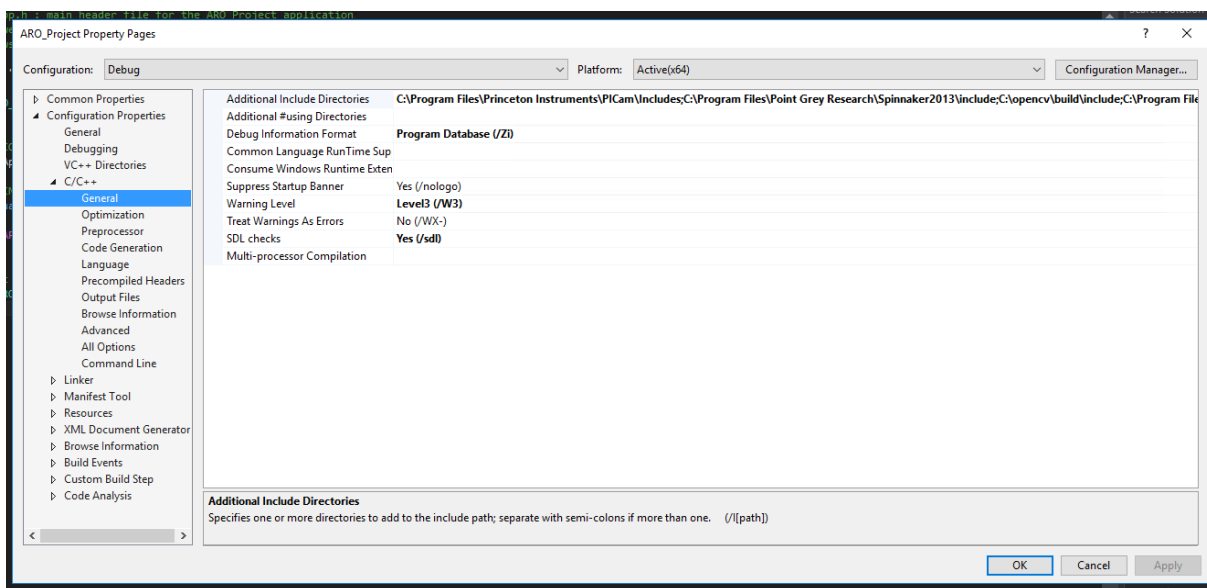


Figure 5.3. Debug Project Properties Focus on Include Directories Setting



It's not over yet! There's still a few places to set things up in. Another location is the linker where you will need to set it so that the linker will connect to the libraries too (so that it will actually compile right). These will have similar paths as the VC++ setting as shown in Figure 5.4.

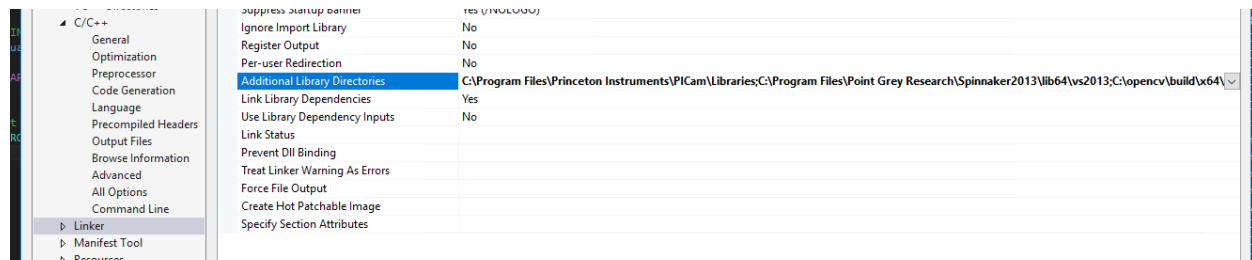


Figure 5.4 Linker Project Properties

The final area is to connect our dependencies to the appropriate .lib files that the executable will be using. This is under Linker -> Input and should be the top row. These aren't file paths but rather the file names. This is where you will want to make sure that the Debug and Release versions are set up correctly as there are library files for either debug or release version and having it misconfigured could lead to errors. Debug library files typically end with a 'd' in the name. Figure 5.5a shows an example of the Debug dependencies setup and Figure 5.5b shows the Release dependencies setup. Note the difference for OpenCV lib file being "opencv\_core248.lib" for the Release configuration and "opencv\_core248d.lib" for the Debug configuration.

Additional Dependencies Picam.lib;opencv\_core248d.lib;opencv\_imgproc248d.lib;opencv\_highgui248d.lib;Blink\_SDK.lib;Spinnakerd\_\$(PlatformToolset).lib;%(AdditionalDependencies)

Figure 5.5a Dependencies for the Debug Build

Additional Dependencies Picam.lib;opencv\_core248.lib;opencv\_imgproc248.lib;opencv\_highgui248.lib;Blink\_SDK.lib;Spinnakerd\_\$(PlatformToolset).lib;%(AdditionalDependencies)

Figure 5.5b Dependencies for the Release Build

If these fields are all updated properly, the libraries should now be properly set up and connected and you should be good to go with using them. You may need to restart Visual Studio to have intellisense work properly.

## Section 5-2: Modifying the GUI

### Editing GUI Components and Layout

Visual Studio provides a means of modifying the MFC GUI with a streamlined process by using the Resource View. Through the Resource View you can select a dialog to modify and then with simple drag and drop be able to move current elements within the dialog and add/remove elements. Adding/Removing elements is more involved but straightforward. When adding to the resource layout, drag the desired element from the toolbox window to the resource editor and be sure to edit the ID to something unique and identifiable under the Properties

window. Figure 5.6 gives an example of the resource view on one of the sub dialogs. The window to the right is the properties of a selected element. Notice to the left edge a 90-degree rotated button labeled “ToolBox”, click on this to get a list of component types that you can drag-and-drop to then add. To edit the ID, simply click on the ID field in the properties window and type it in (it will be added as a defined value in resource.h). For labels, change the Caption field. If your element is a number field, it’s recommended to set that it only accepts numbers.

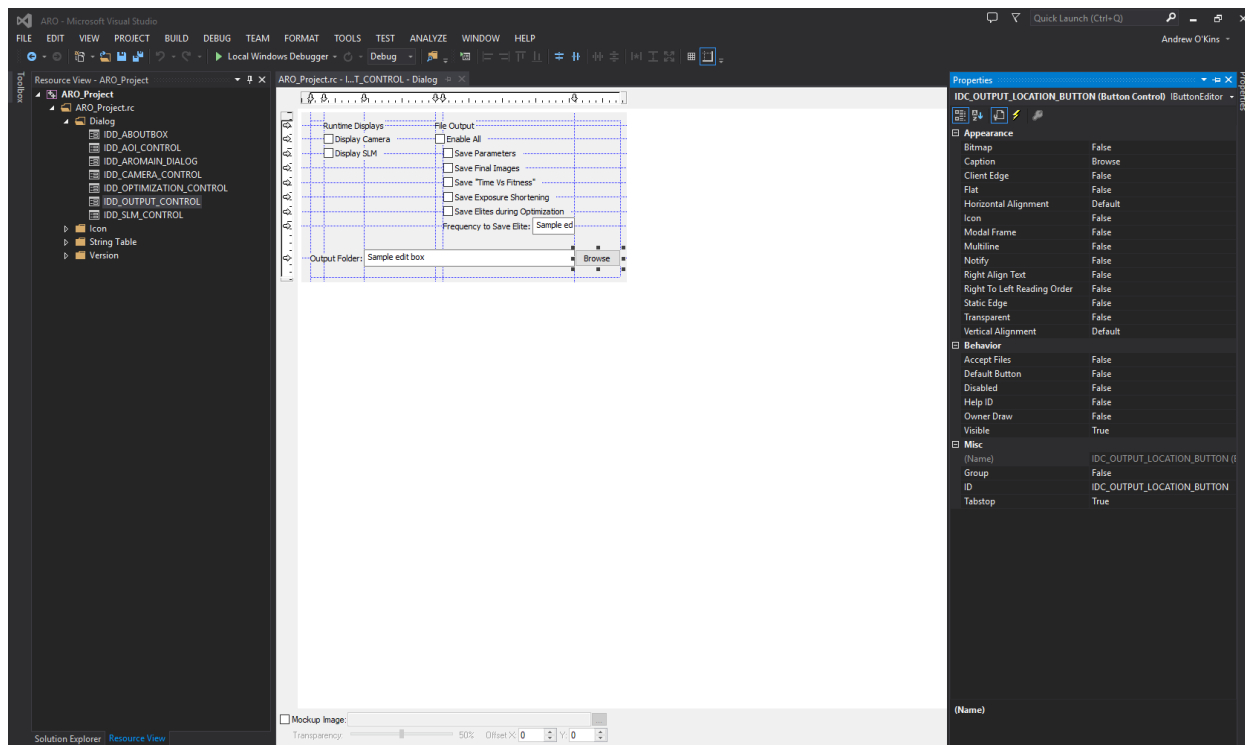


Figure 5.6 Resource View in Visual Studio

When ready to add the element as something that you can interact with in the code (such as a new checkbox), right click on the element to get a dropdown menu on your options which is shown in an example checkbox in Figure 5.7.

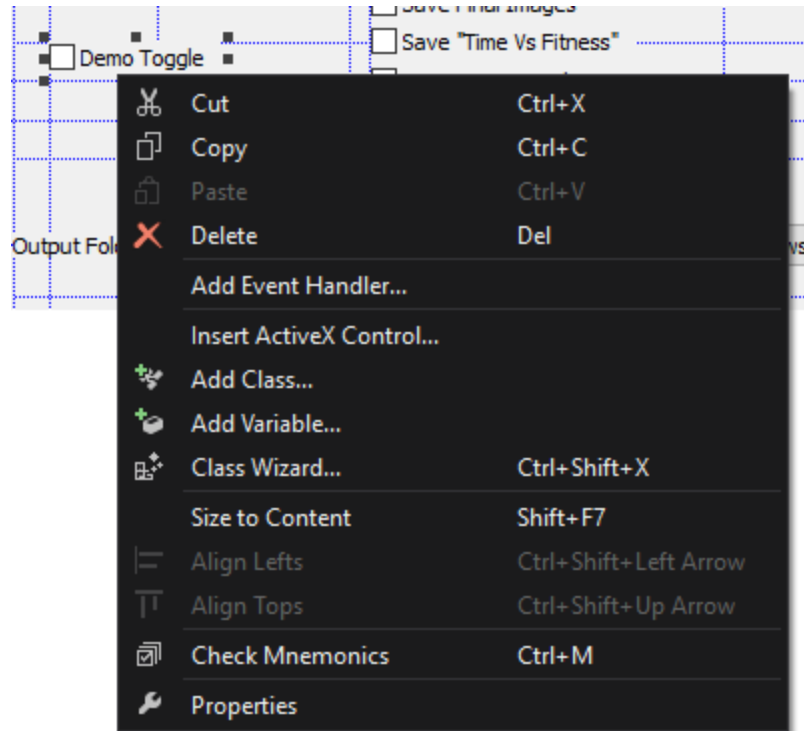


Figure 5.7 Available Options when Right-Clicking on an Element in Resource View

Two notable options to consider are “Add Variable...” and “Add Event Handler...”. If you select the add variable option, a window like in Figure 5.8 will appear and allow you to set up a variable that will be associated with the element you’ve created. Give it a variable name and ideally also a comment, typically Visual Studio will get the type and other parts as you need it so don’t worry too much about them unless you’re looking for something more specific or non-default. When you select Finish, the variable will be automatically added to your dialog and be ready to go. You will just need to give it a default value within *MainDialog::setDefaultUI()* and use it accordingly from then on.

Adding an event handler is useful for if you want to do something when the user does something (usually like when the element is clicked on). Figure 5.9 shows the add event handler window and is similar to the add variable except it generates an empty function for you to write code into that is called when the event occurs. A note to be careful with is that the event handler does not have to be within the same dialog class the associated component is being used in (or even a dialog class at all for that matter) so make sure that it is where you want/need it to be.

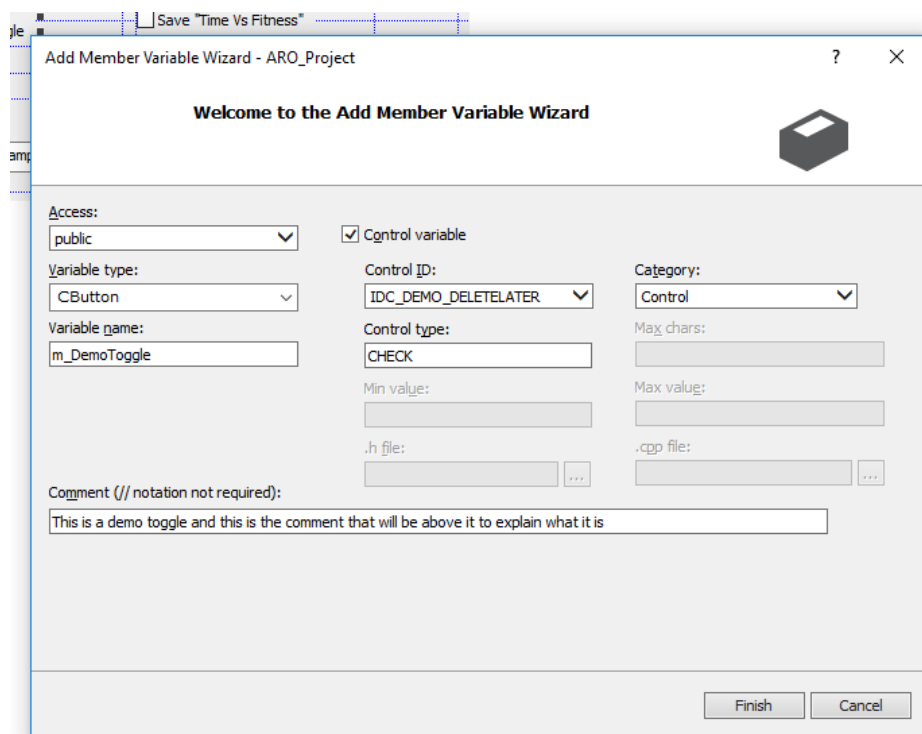


Figure 5.8 Adding Variable Window with Demo Toggle

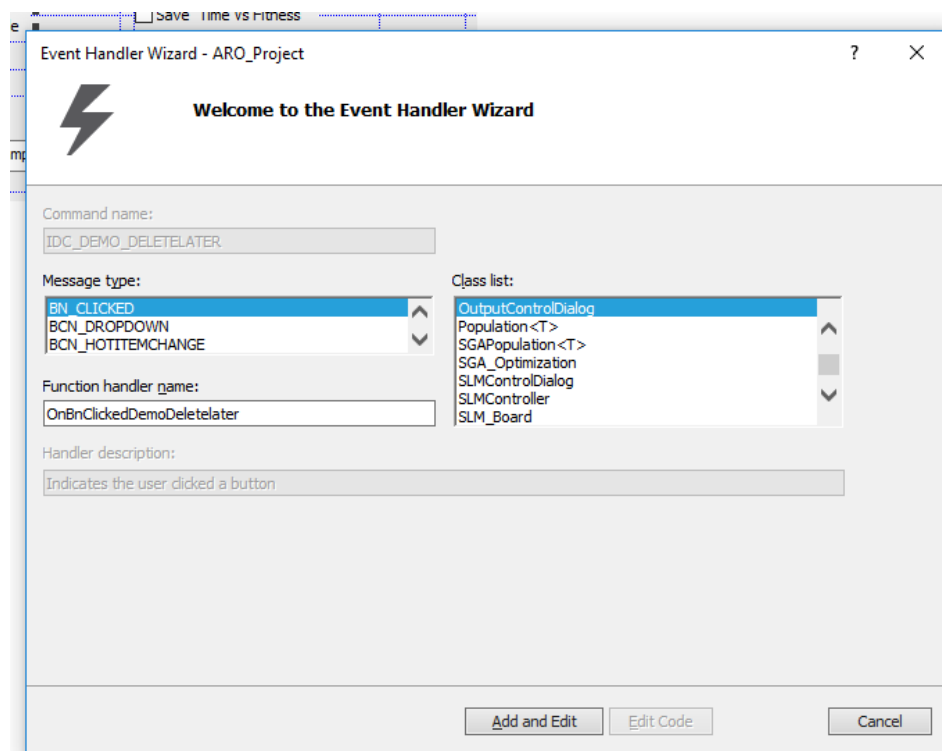


Figure 5.9 Adding Event Handler with Demo Toggle

Removing elements is equally straightforward, with the steps being to simply delete the component in both resource view and in the code (which may be more time consuming as it won't be auto-removed the same way it can be auto-added to the class). Note: when removing elements from resource view, it will not remove it from the code and vice-versa (unless you went into the resource file and edited it directly).

Whenever adding or removing elements, it is important to [consider the save and load feature](#) as you will have to add/remove the variables appropriately there as well. It is also highly recommended to add a tooltip to provide additional details to this component. To do this, go into the implementation file for the dialog that the component is in and look under its *OnInitDialog*. To add the tooltip, use the `m_mainToolTips` property and call *AddTool* with arguments *GetDlgItem()* (with the ID of the component) and a c-string that will be what the tooltip says.

## Creating a New Tab Window (subdialog class)

In the case of needing to have an entirely new category of settings (or something else in the same tab window), you will need to create a Dialog class that is then added to the tab list. This is a bit more involved but can be done with relative ease.

First you will need to create the resource dialog. Go into Resource View and add a new Dialog (right clicking in the Resource View and selecting "Insert Dialog" will work as shown in Figure 5.10.1 (or if you choose "Add Resource" a window like in Figure 5.10.2 will appear to choose Dialog from) as. This will create a new Dialog that we can use to add new elements too. The first recommended step is to right click on the dialog and select "Properties" to open up the Properties window for it (similar to a component) and set Border to "None" and update the name/ID to something more descriptive (in this example I'm calling it `IDD_NEW_TABDIALOG`). Should look something like Figure 5.11 now.

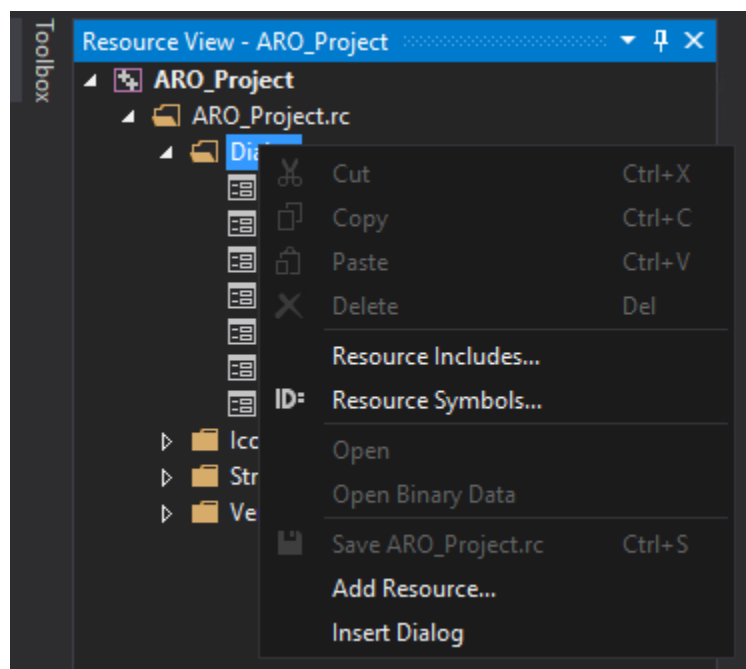


Figure 5.10.1. Inserting New Dialog into Resource View

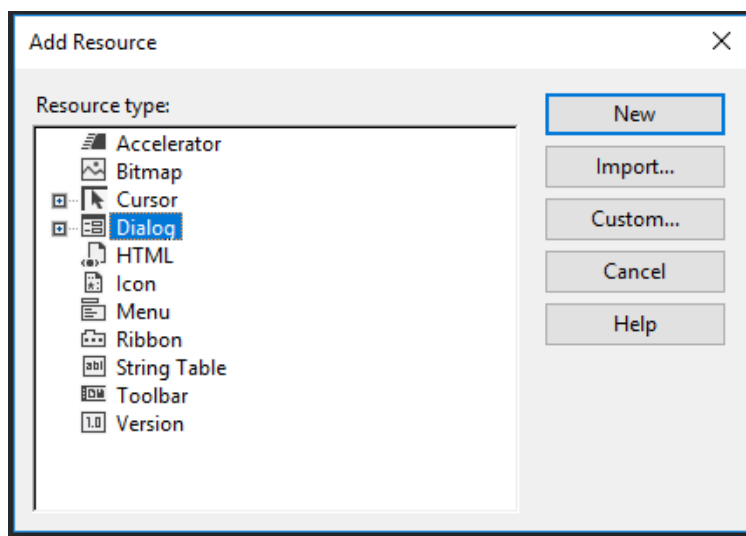


Figure 5.10.2. Add Resource Menu to Insert New Dialog From

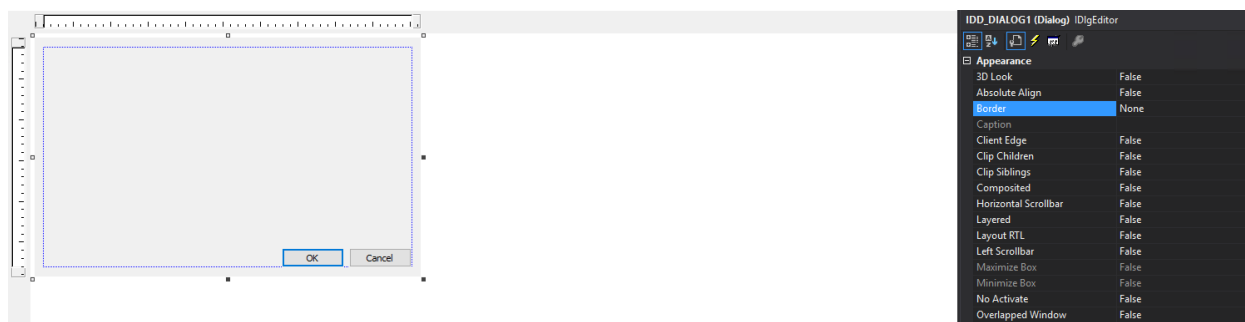


Figure 5.11 New Dialog with No Border

The next step is to now create a class that can use this new dialog window and be contained in the tab window. To do this, right click on the dialog and select “Add Class...”. Figure 5.12 shows the window that will appear, set the name of the class and when finished it will generate the header and implementation files for it automatically for you to work in. However to properly implement the class you will need to add some things. Most importantly you need to add the necessary includes for it to compile and use the resources. Figure 5.13 shows the includes made in the header of the new class and the general appearance of the class, you may need to restart Visual Studio for intellisense to not throw warnings with the new IDD. To include it into the main dialog you will also have to add the new header file into the MainDialog’s includes before adding it into the implementation.

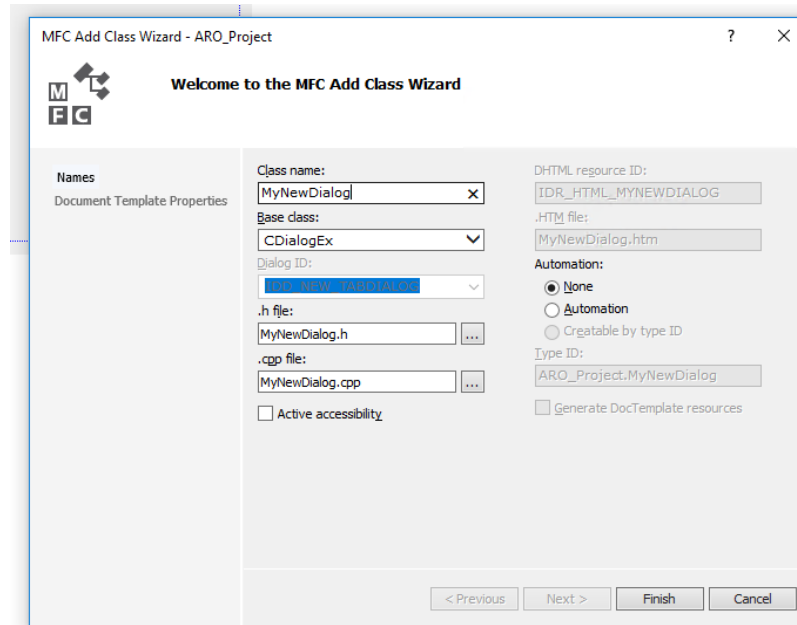


Figure 5.12 Creating a Dialog Class Window

```

1  #pragma once
2
3  #include "resource.h"
4  #include "afxwin.h"
5
6
7  // MyNewDialog dialog
8
9  class MyNewDialog : public CDialogEx
10 {
11     DECLARE_DYNAMIC(MyNewDialog)
12
13 public:
14     MyNewDialog(CWnd* pParent = NULL); // standard constructor
15     virtual ~MyNewDialog();
16
17     // Dialog Data
18     enum { IDD = IDD_NEW_TABDIALOG };
19
20 protected:
21     virtual void DoDataExchange(CDataExchange* pDX); // DDX/DDV support
22
23     DECLARE_MESSAGE_MAP()
24 };
25

```

Figure 5.13 The New Dialog Class Header

The next step is to incorporate this dialog into the tab window. Add the dialog as a public property of MainDialog's, then go into MainDialog's implementation file and into *OnInitDialog*. Add the tab heading into the headings array and increment the for loop to insert it into the *m\_TabControl* property. Followed by creating the window with *Create([ID OF NEW DIALOG], &m\_TabControl)* and use the *rect* variable to define the dimensions. The final critical step is to add the dialog in *OnTcnSelchangeTab1* which is responsible for handling the tab showing the windows. Simple add a new case number for where the new dialog is and set it to update *m\_pwndShow* (failure to do so will give a warning message when trying to run the program and the new window won't work).

For tooltips, this is implemented manually. Go into the header of your new dialog class and add a *CToolTipCtrl* property, declaration for *virtual BOOL PreTranslateMessage(MSG\**

*pMsg*), and another declaration for *virtual BOOL OnInitDialog()*. Then go into the implementation file and add the following:

1. In constructor initialize the *CToolTipCtrl* property (if pointer set it to a new one)
2. Implement the setup for the tooltip controller within *OnInitDialog*
  - a. Call your tooltip controller's *Create* with *this* (pointer to your dialog's instance) as parent window.
  - b. Add tools to your tooltips, using *GetDlgItem* with arguments of the IDs of your components and text for the tooltip.
  - c. Call the tooltip controller's *Activate* with *this*
  - d. Return *CDialogEx::OnInitDialog()* so it also does all the default stuff
3. Implement *PreTranslateMessage(MSG\* pMsg)*
  - a. Call your tooltip controllers *RelayEvent()* with argument being *pMsg*
  - b. Return *Cdialog::PreTranslateMessage(pMsg)* so it does all the default stuff.
4. Properly deallocate the tooltip controller within the dialog's destructor (if pointer call delete).

The dialog should now be added to the program and have tooltips working. For more about adding/changing its components refer to the other subsections. With a new dialog tab, you likely will also need to increase the width of the main dialog window so as to have room for the new tab. This will only require changing the width of content in the main dialog, the sub-dialogs don't need to also be widened but they also won't utilize the extra space either.

## Changing Default Values

Changing the default values (what the contents are in load up) for most of the GUI elements is pretty straightforward. All you have to do is go into the *MainDialog*'s *setDefaultUI()* and set the value to the component there. This method is called within *OnInitDialog* and can be used to set the default values for all the sub-dialogs too.

## Considering the Save / Load Feature and New Changes in Elements

The save and load ability is pretty simple, so it is simple to modify but also means that you will need to be careful and make sure it is kept up to date when changing what elements are in the GUI (especially adding new ones as it won't capture them). The save/load behaviors are kept separate in their own *SettingsOutput.cpp* file to help reduce the size of *MainDialog.cpp* (the main implementation file for the *MainDialog* class) for better navigation.

As mentioned in [Editing GUI Components and Layout](#), when removing elements you will have to be sure to remove references to the variables that no longer exist here. In the case of adding them, you will need to both add references to it in saving settings and loading them.

For loading settings, have the name of your variable (doesn't have to be the same as the code, just consistent) added in the conditions within *MainDialog::setValueByName()* and assign the input value accordingly to the element. I [Andrew O'Kins] recommend keeping the variables within a specific dialog grouped together to help in readability and tracking if there are variables missing or not. Unrecognized added variables can be more easily detected by attempting to



load a generated file as it should output onto the console window the names of any unrecognized variable names.

For saving the settings, you will need to add it within the method *MainDialog::saveUtoFile()* following the syntax [variable name]=[value converted to string]. In the case of booleans (such as from checkboxes), I recommend using “true” and “false” for readability in the save file and when reading defaulting to false if not “true” (though that is up to your judgement on what would be better to default on for a given property). As long as you keep things consistent within the syntax you should be good to go. If you wanted to add comments within the save file (such as categories), the comment syntax is starting the line with “#”.

## Section 5-3: Multithreading Management

Multithreading is made possible with two libraries, the standard thread library provided by C++11 and threading tools provided by MFC. The usage of threading in MFC is to launch the optimization and enable the ease of interactions with the GUI during the optimization for important features like the stop button. When the start button is pressed, it launches a thread with the method *optThreadMethod* and the main dialog passed in as the argument. This thread identifies the algorithm to use and runs it accordingly. If an optimization is identified as already running, the button instead acts as a stop button and will notify the algorithm to stop prematurely.

For the optimization itself, the multithreading is available to be used for two tasks; evaluating individuals (*runIndividual*) and the process of creating new individuals in the pool (within *nextGeneration*). To do this, a thread pool is created and managed in the *ThreadPool* class. The number of thread pools is equivalent to either the number of logical processors on the CPU or (if less) the max number of assigned threads for evaluating individuals or creating new individuals.

The approach with a thread pool is to have a set of persistent threads that wait for jobs to be executed, when a job is added to the queue only one thread will perform that job while the others (if not already busy with their own) will wait for additional jobs. The current class is very simplistic, with once the thread pool is created it remains at its size until destruction and the only open means of interface is to add jobs or wait until all jobs (both actively doing and in the queue) are done. The jobs assignable is also very restricted, with it only supporting void type functions with no inputs (so to get by this, use `std::bind`).

With this implementation, in effect for the multithreading fields in the GUI after initialization of the *ThreadPool* it is used to impact the number of jobs given to the pool, thus controlling the number of threads being used for the higher-level task. For example, setting the evaluation of individuals to 2 threads will have it create 2 jobs for the pool to work on, thus limiting the number of threads being used for the task to 2. As a result, during optimization the number of threads being “used” with the queued jobs may not be the same as actual runtime threads performing all the tasks if the number exceeds hardware.

This document will not go more in-detail on the multithreading implementation, as it will assume that either the reader is already familiar with general multithreading concepts or

otherwise this document may just be reiterating general concepts that are not specific to ARO and may be better explained in other resources.

## Appendix A: Diagrams

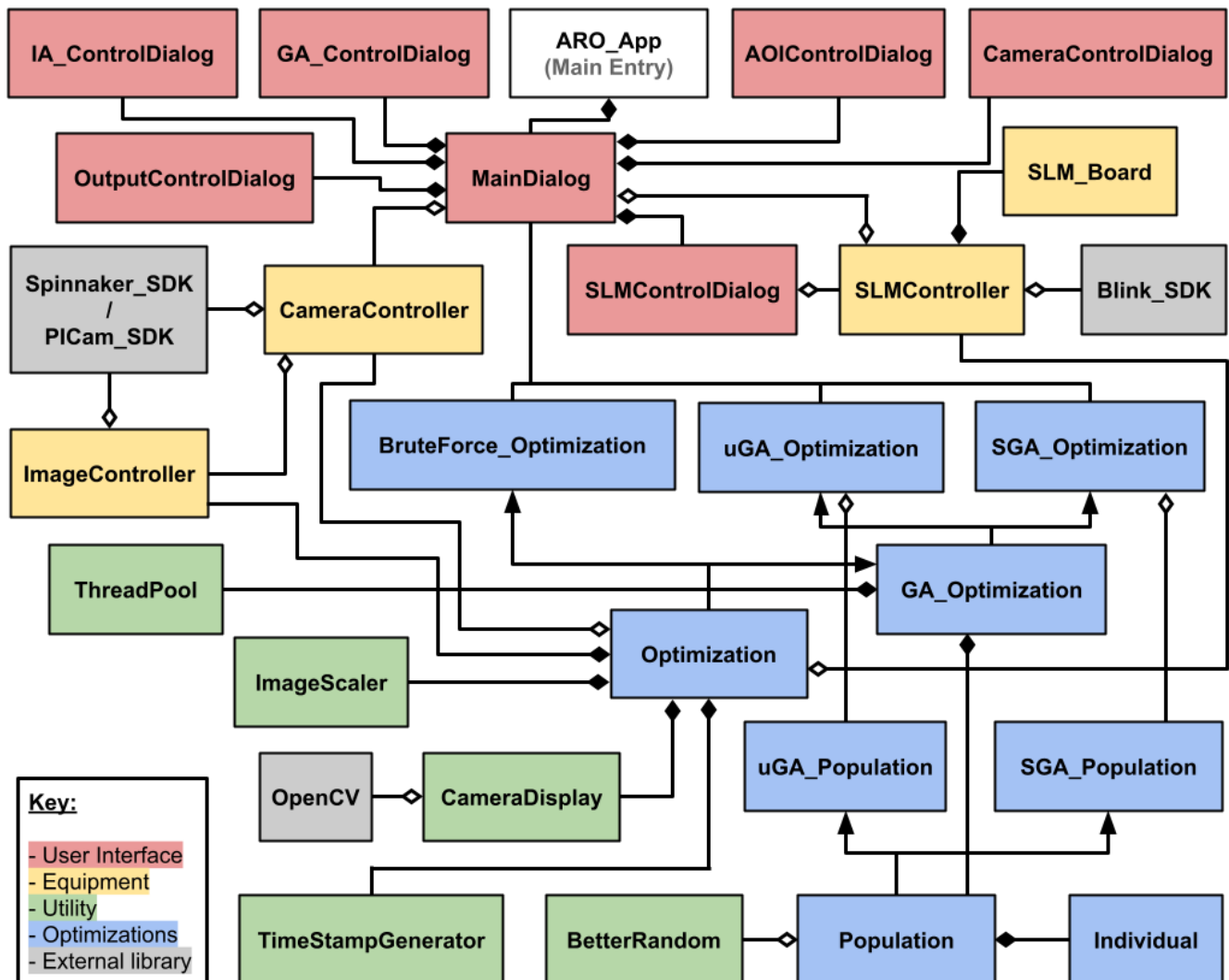


Figure A.1. High-Level UML Diagram Illustrating Class Relationships

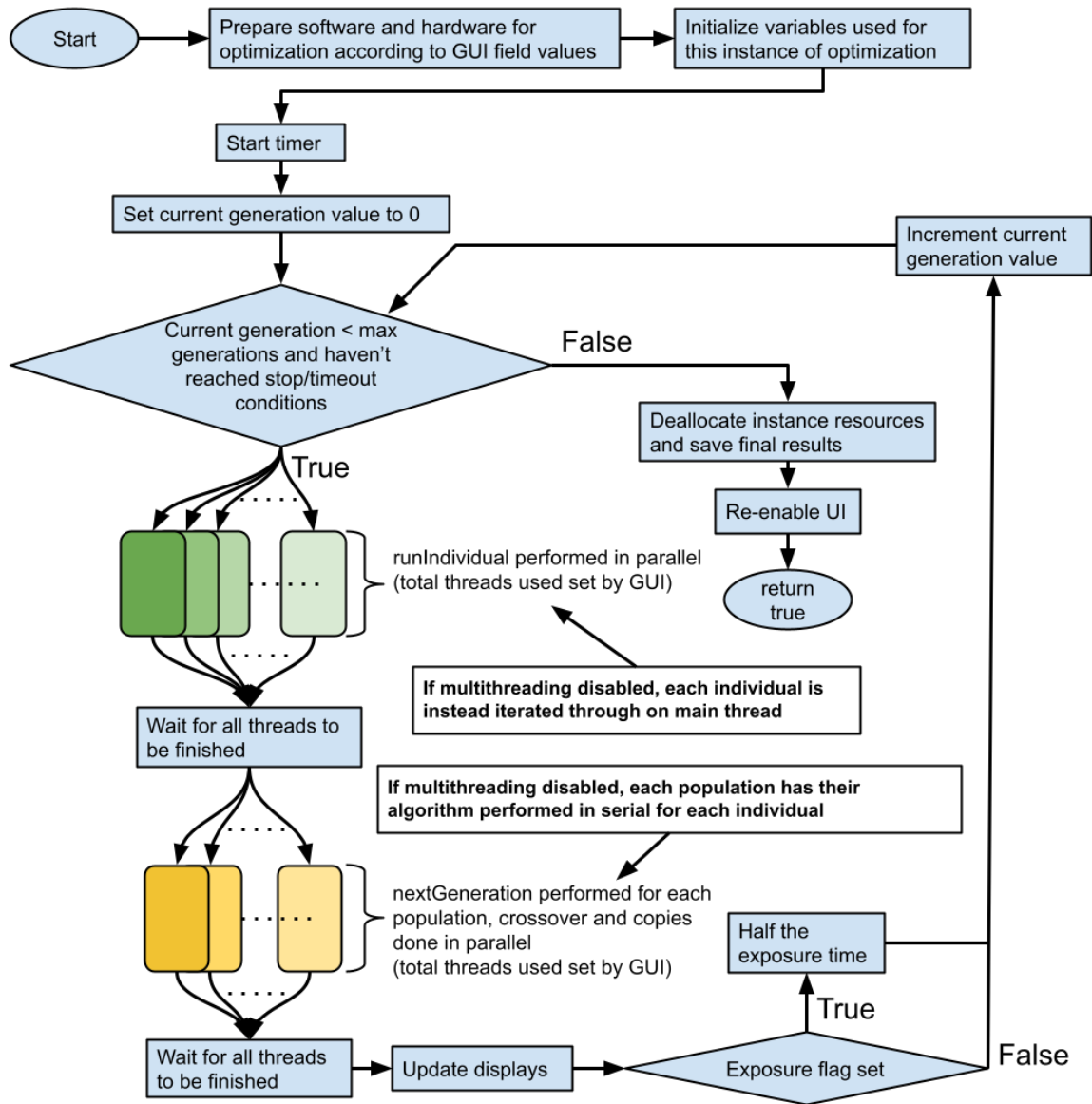


Figure A.2. High-Level Flowchart of GA Optimization Process

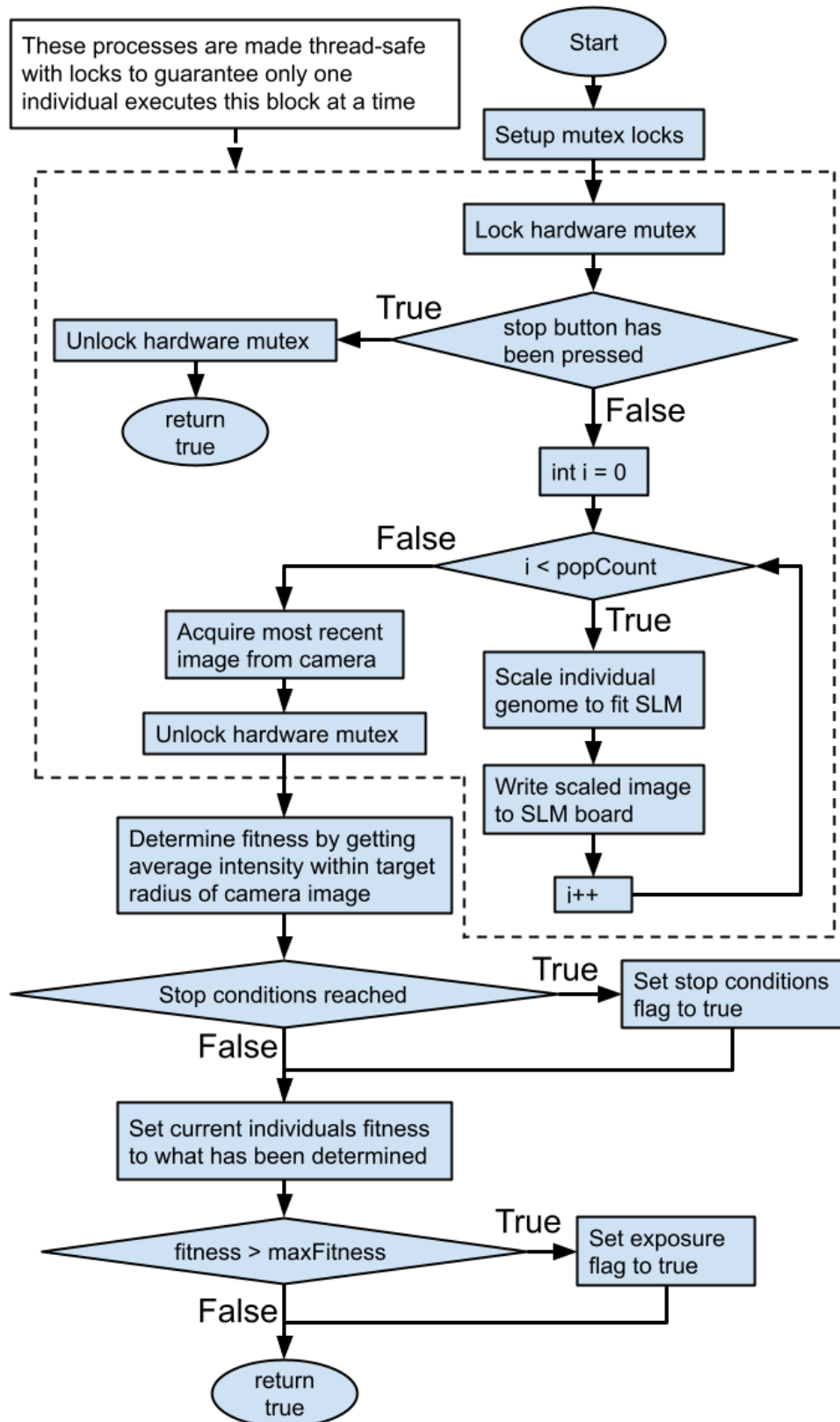


Figure A.3. Flowchart of SGA and uGA Process of Evaluating an Individual

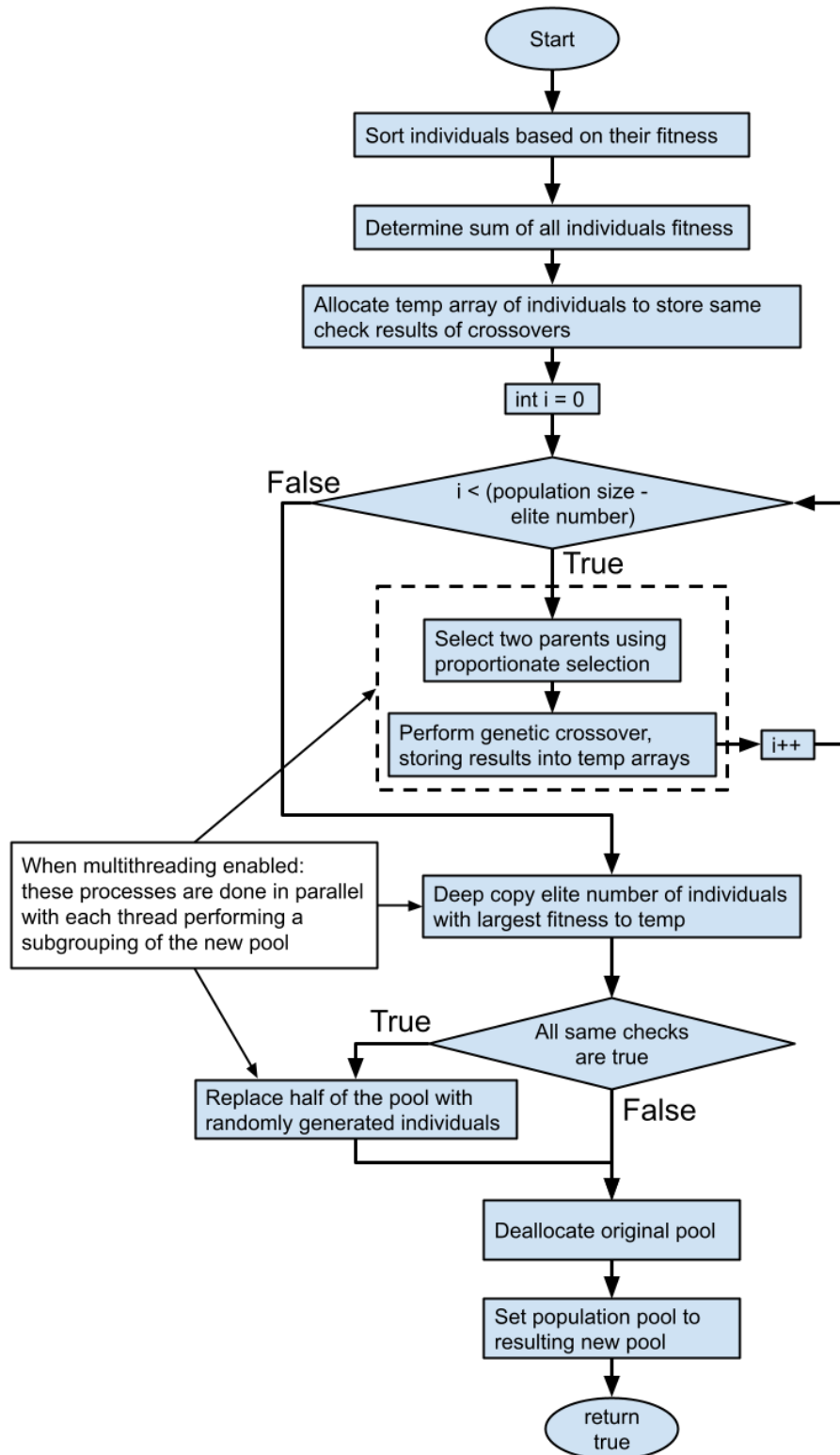


Figure A.4. Flowchart of Generating New Generation in SGA

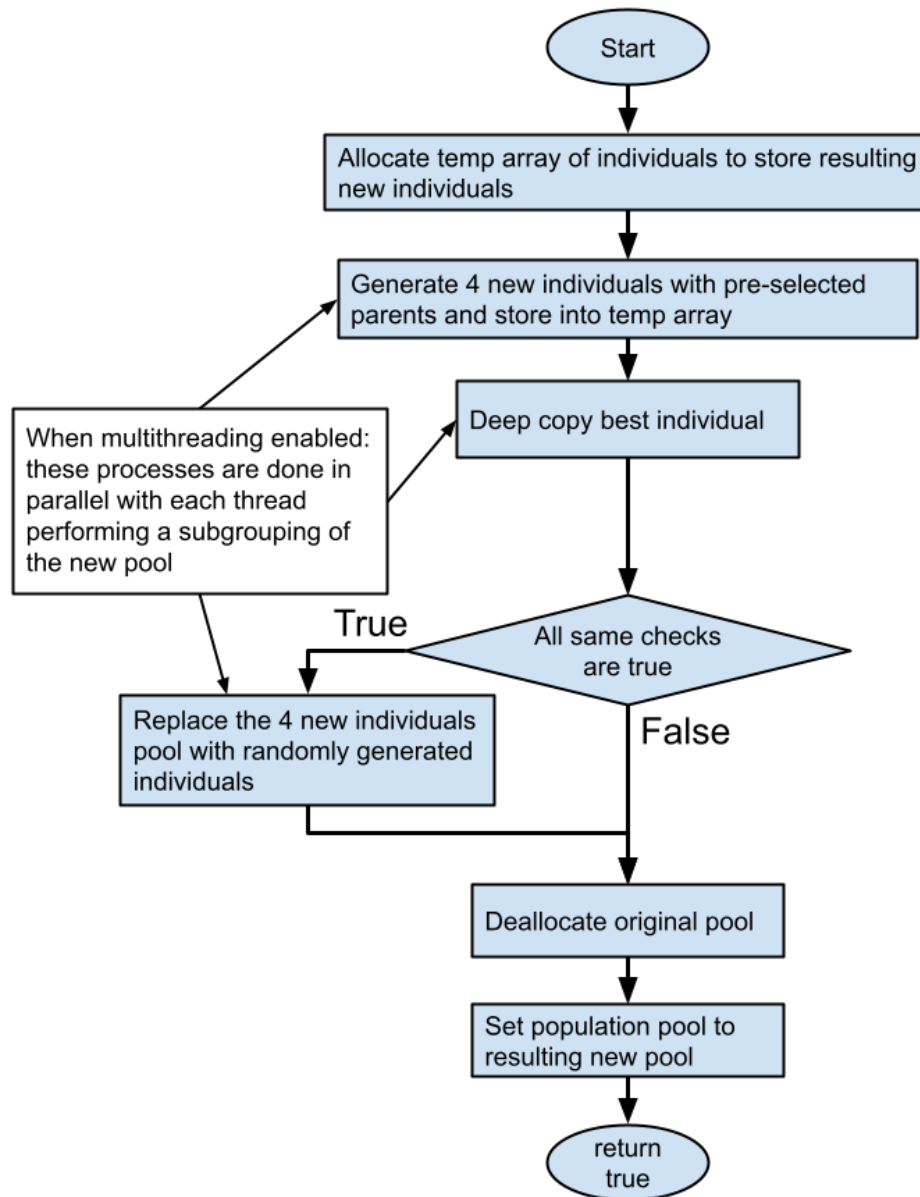


Figure A.5. Flowchart of Generating New Generation in uGA

## Appendix B: Additional Resources

Below are various links that will prove useful resources when working on the project:

Spinnaker C++ Programmer's Manual

<http://softwareservices.flir.com/Spinnaker/latest/index.html>

PICam 5.x Programmer's Manual

<https://www.princetoninstruments.com/wp-content/uploads/2020/04/PICAM-5.x-Programmers-Manual-Issue-8-4411-0161-2.pdf>

Meadowlark Optics Spatial Light Modulators User Manual

(contains documentation for Blink\_PCl e SDK)

<https://preview-assets-us-01.kc-usercontent.com/210eb585-dc2c-0008-b663-73b9ea5cff38/aab827a2-3e9c-4a2f-990d-70e0b6f328aa/1920%20PCle%20User%20Manual.pdf>

OpenCV Documentation & Tutorials

<https://docs.opencv.org/4.5.2/index.html>

Resources within this document (logo & diagrams) should be made available in the project folder within the subfolder "Documentation Resources".

If you have additional questions regarding this document, you can contact the author [Andrew O'Kins] by email at [andrewokins@gmail.com](mailto:andrewokins@gmail.com).