

**Oat** is a set of programs for processing images, extracting object position information, and streaming data to disk and/or the network in real-time. Oat subcommands are independent programs that each perform a single operation but that can communicate through shared memory. This allows a user to chain operations together in arrangements suitable for particular context or tracking requirement. This architecture enables scripted construction of custom data processing chains. Oat is primarily used for real-time animal position tracking in the context of experimental neuroscience, but can be used in any circumstance that requires real-time object tracking.



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## Manual

Oat components are a set of programs that communicate through shared memory to capture, process, perform object detection within, and record video streams. Oat components act on two basic data types: **frames** and **positions**.

- **frame** - Video frame.
- **position** - 2D position.

Oat components are be chained together to realize custom data processing pipelines, with individual components executing largely in parallel. Processing pipelines can be split and merged while maintaining thread-safety and sample synchronization. For example, a script to detect the position of a single object in pre-recorded video file might look like this:

```
# Serve frames from a video file to the 'raw' stream
oat frameserve file raw -f ./video.mpg &

# Perform background subtraction on the 'raw' stream
# Serve the result to the 'filt' stream
oat framefilt bsub raw filt &

# Perform color-based object position detection on the 'filt' stream
# Serve the object position to the 'pos' stream
oat posidet hsv filt pos &

# Decorate the 'raw' stream with the detected position form the 'pos' stream
# Serve the decorated images to the 'dec' stream
oat decorate -p pos raw dec &

# View the 'dec' stream
oat view dec &

# Record the 'dec' and 'pos' streams to file in the current directory
oat record -i dec -p pos -f ./
```

This script has the following graphical representation:

```
frameserve --> framefilt --> posidet --> decorate ---> view
          \                               /          \
          -----> record
```

Generally, an Oat component is called in the following pattern:

```
oat <subcommand> [TYPE] [IO] [CONFIGURATION]
```

The `<subcommand>` indicates the component that will be executed. Components are classified according to their type signature. For instance, `framefilt` (frame filter) accepts a frame and produces a frame. `posifilt` (position filter) accepts a position and produces a position. `frameserve` (frame server) produces a frame, and so on. The `TYPE` parameter specifies a concrete type of transform (e.g. for the `framefilt` subcommand, this could be `bsub` for background subtraction). The `IO` specification indicates where the component will receive data from and to where the processed data should be published. The `CONFIGURATION` specification is used to provide parameters to shape the component's operation. Aside from command line options and switches, which are listed using the `--help` option for each subcommand, the user can often provide an external file containing a configuration table to pass parameters to a component. Some configuration parameters can only be specified using a configuration file. Configuration files are written in plain text using [TOML](#). A multi-component processing script can share a configuration file because each component accesses parameter information using a file/key pair, like so

```
[key]
parameter_0 = 1           # Integer
parameter_1 = true        # Boolean
parameter_2 = 3.14        # Double
parameter_3 = [1.0, 2.0, 3.0] # Array of doubles
```

or more concretely,

```
# Example configuration file for frameserve --> framefilt
[frameserve-par]
frame_rate = 30           # FPS
roi = [10, 10, 100, 100]  # Region of interest

[framefilt-par]
mask = "~/Desktop/mask.png" # Path to mask file
```

The type and sanity of parameter values are checked by Oat before they are used. Below, the type signature, usage information, available configuration parameters, examples, and configuration options are provided for each Oat component.

## Frame Server

**oat-frameserve** - Serves video streams to shared memory from physical devices (e.g. webcam or GIGE camera) or from file.

## Signature

**oat-frameview** --> frame

## Usage

Usage: frameserve [INFO]  
      or: frameserve TYPE SINK [CONFIGURATION]

### SINK

User-supplied name of the memory segment to publish frames to (e.g. raw).

### TYPE

wcam: Onboard or USB webcam.  
gige: Point Grey GigE camera.  
file: Stream video from file.

### INFO:

--help                           Produce help message.  
-v [ --version ]                Print version information.

### CONFIGURATION:

-c [ --config ] arg            Configuration file/key pair.  
-f [ --video-file ] arg        Path to video file if 'file' is selected as the  
                                 server TYPE.

## Configuration File Options

**TYPE = gige**

- **index=+int** User specified camera index. Useful in multi-camera imaging configurations.
- **fps=+float** Acquisition frame rate (Hz). Ignored if **trigger\_on=true**. If unspecified, then the maximum frame rate will be used.
- **exposure=float** Automatically adjust both shutter and gain to achieve given exposure (EV).
- **shutter=+float** Shutter time in milliseconds. Specifying **exposure** overrides this option.

- **gain=float** Sensor gain value. Specifying **exposure** overrides this option (dB).
- **white\_bal={red=+int, blue=+int}** White-balance specified as red/blue intensity values (0-1000).
- **roi={x\_offset=+int, y\_offset=+int, width=+int, height=+int}** Region of interest to extract from the camera or video stream (pixels).
- **trigger\_on=bool** True to use camera trigger, false to use software polling.
- **trigger\_rising=bool** True to trigger on rising edge, false to trigger on falling edge.
- **trigger\_mode=+int** Point-grey trigger mode. Common values are:
  - 0 - Standard external trigger. Trigger edge causes sensor exposure, then sensor readout to internal memory.
  - 1 - Blub shutter mode. Same as 0, except that sensor exposure duration is determined by trigger active duration.
  - 7 - Continuous internal trigger. No external trigger required, but not synchronized to an external clock.
  - 14 - Overlapped exposure/readout external trigger. Sensor exposure occurs during sensory readout to internal memory. This is the fastest external trigger mode.
- **trigger\_pin=+int** Hardware pin number on Point-grey camera that trigger is sent to.

**TYPE = file**

- **frame\_rate=float** Frame rate in frames per second
- **roi={x\_offset=+int, y\_offset=+int, width=+int, height=+int}** Region of interest to extract from the camera or video stream (pixels).

**TYPE = wcam - index=+int** User specified camera index. Useful in multi-camera imaging configurations.

## Examples

```
# Serve to the 'wraw' stream from a webcam
oat frameserve wcam wraw
```

```
# Stream to the 'graw' stream from a point-grey GIGE camera
# using the gige_config tag from the config.toml file
oat frameserve gige graw -c config.toml gige_config
```

```
# Serve to the 'fraw' stream from a previously recorded file
# using the file_config tag from the config.toml file
oat frameserve file fraw -f ./video.mpg -c config.toml file_config
```

## Frame Filter

**oat-framefilt** - Receive frames from named shared memory, filter, and publish to a second memory segment. Generally, used to pre-process frames prior to object position detection. For instance, **framefilt** could be used to perform background subtraction or application of a mask to isolate a region of interest.

## Signature

```
frame --> oat-framefilt --> frame
```

## Usage

Usage: **framefilt** [INFO]

or: **framefilt** TYPE SOURCE SINK [CONFIGURATION]

Filter frames from SOURCE and published filtered frames to SINK.

### TYPE

**bsub**: Background subtraction

**mask**: Binary mask

**mog**: Mixture of Gaussians background segmentation (Zivkovic, 2004)

### SOURCE:

User-supplied name of the memory segment to receive frames from (e.g. raw).

### SINK:

User-supplied name of the memory segment to publish frames to (e.g. filt).

### INFO:

**--help** Produce help message.

**-v [ --version ]** Print version information.

### CONFIGURATION:

**-c [ --config ] arg** Configuration file/key pair.

**-m [ --invert-mask ]** If using TYPE=mask, invert the mask before applying

## Configuration File Options

**TYPE = bsub**

- **background=string** Path to a background image to be subtracted from the SOURCE frames. This image must have the same dimensions as frames from SOURCE.

**TYPE = mask**

- **mask=string** Path to a binary image used to mask frames from SOURCE. SOURCE frame pixels with indices corresponding to non-zero value pixels in the mask image will be unaffected. Others will be set to zero. This image must have the same dimensions as frames from SOURCE.

**TYPE = mog**

- **learning\_coeff=+float** Value, 0 to 1.0, specifying how quickly the statistical model of the background image should be updated. Default is 0, specifying no adaptation.
- **gpu\_index=+int** Index of the GPU to use for performing background subtraction if Oat was compiled with CUDA support.

## Examples

```
# Receive frames from 'raw' stream
# Perform background subtraction using the first frame as the background
# Publish result to 'sub' stream
oat framefilt bsub raw sub

# Receive frames from 'raw' stream
# Apply a mask specified in a configuration file
# Publish result to 'roi' stream
oat framefilt mask raw roi -c config.toml mask-config
```



## Frame Viewer

**oat-view** - Receive frames from named shared memory and display them on a monitor. Additionally, allow the user to take snapshots of the currently displayed frame by pressing **s** while the display window is in focus.

## Signature

frame --> oat-view

## Usage

Usage: view [INFO]  
or: view SOURCE [CONFIGURATION]  
Display frame SOURCE on a monitor.

### SOURCE:

User-supplied name of the memory segment to receive frames from (e.g. raw).

### INFO:

--help                      Produce help message.  
-v [ --version ]            Print version information.

### CONFIGURATION:

-n [ --filename ] arg      The base snapshot file name.  
                            The timestamp of the snapshot will be prepended to  
                            this name.If not provided, the SOURCE name will be  
                            used.

-f [ --folder ] arg        The folder in which snapshots will be saved.

## Example

```
# View frame stream named raw  
oat view raw
```

  

```
# View frame stream named raw and specify that snapshots should be saved  
# to the Desktop with base name 'snapshot'  
oat view raw -f ~/Desktop -n snapshot
```

## Position Detector

`oat-posidet` - Receive frames from named shared memory and perform object position detection within a frame stream using one of several methods. Publish detected positions to a second segment of shared memory.

## Signature

`frame --> oat-posidet --> position`

## Usage

Usage: `posidet` [INFO]  
or: `posidet` TYPE SOURCE SINK [CONFIGURATION]  
Perform object position detection on frames from SOURCE.  
Publish detected object positions to SINK.

TYPE  
    `diff`: Difference detector (grey-scale, motion)  
    `hsv` : HSV detector (color)

SOURCE:  
    User-supplied name of the memory segment to receive frames from (e.g. `raw`).

SINK:  
    User-supplied name of the memory segment to publish detected positions to (e.g. `pos`).

INFO:  
    `--help`                               Produce help message.  
    `-v [ --version ]`                    Print version information.

CONFIGURATION:  
    `-c [ --config ] arg`                Configuration file/key pair.

## Configuration File Options

TYPE = `hsv`

- `tune=bool` Provide sliders for tuning hsv parameters
- `erode=+int` Candidate object erosion kernel size (pixels)
- `dilate=+int` Candidate object dilation kernel size (pixels)

- `min_area=+double` Minimum object area (pixels<sup>2</sup>)
- `max_area=+double` Maximum object area (pixels<sup>2</sup>)
- `h_thresholds={min=+int, max=+int}` Hue pass band
- `s_thresholds={min=+int, max=+int}` Saturation pass band
- `v_thresholds={min=+int, max=+int}` Value pass band

**TYPE = diff**

- `tune=bool` Provide sliders for tuning diff parameters
- `blur=+int` Blurring kernel size (normalized box filter; pixels)
- `diff_threshold=+int` Intensity difference threshold

### Example

```
# Use color-based object detection on the 'raw' frame stream
# publish the result to the 'cpos' position stream
# Use detector settings supplied by the hsv_config key in config.toml
oat posidet hsv raw cpos -c config.toml hsv_config

# Use motion-based object detection on the 'raw' frame stream
# publish the result to the 'mpos' position stream
oat posidet diff raw mpos
```

## Position Filter

**oat-posifilt** - Receive positions from named shared memory, filter, and publish to a second memory segment. Can be used to, for example, remove discontinuities due to noise or discontinuities in position detection with a Kalman filter or annotate categorical position information based on user supplied region contours.

## Signature

position --> oat-posifilt --> position

## Usage

Usage: posifilt [INFO]  
or: posifilt TYPE SOURCE SINK [CONFIGURATION]  
Filter positions from SOURCE and published filtered positions to SINK.

### TYPE

kalman: Kalman filter  
homography: homography transform  
region: position region label annotation

### SOURCE:

User-supplied name of the memory segment to receive positions from (e.g. rpos).

### SINK:

User-supplied name of the memory segment to publish positions to (e.g. rpos).

### INFO:

--help                                   Produce help message.  
-v [ --version ]                        Print version information.

### CONFIGURATION:

-c [ --config ] arg                    Configuration file/key pair.

## Configuration File Options

**TYPE** = kalman

- **dt=+float** Sample period (seconds).
- **timeout=+float** Time to perform position estimation detection with lack of updated position measure (seconds).

- **sigma\_accel**=+float Standard deviation of normally distributed, random accelerations used by the internal model of object motion (position units/s<sup>2</sup>; e.g. pixels/s<sup>2</sup>).
- **sigma\_noise**=+float Standard deviation of randomly distributed position measurement noise (position units; e.g. pixels).
- **tune**=bool Use the GUI to tweak parameters.

**TYPE = homography**

- **homography** = [[+float,+float,+float],[+float,+float,+float],[+float,+float,+float]], Homography matrix for 2D position (3x3; world units/pixel).

**TYPE = region**

- **<regions>**=[[+float, +float],[+float, +float],...,[+float, +float]] User-named region contours (pixels). Regions counters are specified as n-point matrices, [[x0, y0],[x1, y1],...,[xn, yn]], which define the vertices of a polygon. The name of the contour is used as the region label. For example, here is an octagonal region called CN and a tetragonal region called R0:

# These regions could be named anything...

```
CN = [[336.00, 272.50],
      [290.00, 310.00],
      [289.00, 369.50],
      [332.67, 417.33],
      [389.33, 413.33],
      [430.00, 375.33],
      [433.33, 319.33],
      [395.00, 272.00]]
```

```
R0 = [[654.00, 380.00],
      [717.33, 386.67],
      [714.00, 316.67],
      [655.33, 319.33]]
```

**Example**

```
# Perform Kalman filtering on object position from the 'pos' position stream
# publish the result to the 'kpos' position stream
# Use detector settings supplied by the kalman_config key in config.toml
oat posifilt kalman pos kfilt -c config.toml kalman_config
```

## Position Combiner

oat-posicom - Combine positions according to a specified operation.

### Signature

```
position 0 --> |
position 1 --> |
      :       | oat-posicom --> position
position N --> |
```

### Usage

Usage: posicom [INFO]  
or: posicom TYPE SOURCES SINK [CONFIGURATION]  
Combine positional information from two or more SOURCES.  
Publish combined position to SINK.

#### TYPE

mean: Geometric mean of SOURCE positions

#### SOURCES:

User-supplied position source names (e.g. pos1 pos2).

#### SINK:

User-supplied position sink name (e.g. pos).

#### INFO:

--help	Produce help message.
-v [ --version ]	Print version information.

#### CONFIGURATION:

-c [ --config ] arg	Configuration file/key pair.
---------------------	------------------------------

## Configuration File Options

**TYPE = mean**

- **heading\_anchor=+int** Index of the SOURCE position to use as an anchor when calculating object heading. In this case the heading equals the mean directional vector between this anchor position and all other SOURCE positions. If unspecified, the heading is not calculated.

## Example

```
# Generate the geometric mean of 'pos1' and 'pos2' streams
# Publish the result to the 'com' stream
oat posicom mean pos1 pos2 com
```

## Frame Decorator

oat-decorate - Annotate frames with sample times, dates, and/or positional information.

## Signature

```
      frame --> |
position 0 --> |
position 1 --> | oat-decorate --> frame
      :         |
position N --> |
```

## Usage

Usage: decorate [INFO]

or: decorate SOURCE SINK [CONFIGURATION]

Decorate the frames from SOURCE, e.g. with object position markers and sample number. Publish decorated frames to SINK.

### SOURCE:

User-supplied name of the memory segment from which frames are received (e.g. raw).

### SINK:

User-supplied name of the memory segment to publish frames to (e.g. out).

### OPTIONS:

#### INFO:

--help	Produce help message.
-v [ --version ]	Print version information.

#### CONFIGURATION:

-p [ --position-sources ] arg	The name of position server(s) used to draw object position markers.
-------------------------------	--

<code>-t [ --timestamp ]</code>	Write the current date and time on each frame.
<code>-s [ --sample ]</code>	Write the frame sample number on each frame.
<code>-S [ --sample-code ]</code>	Write the binary encoded sample on the corner of each frame.
<code>-R [ --region ]</code>	Write region information on each frame if there is a position stream that contains it.

## Example

```
# Add textual sample number to each frame from the 'raw' stream
oat decorate raw -s

# Add position markers to each frame from the 'raw' stream to indicate
# objection positions for the 'pos1' and 'pos2' streams
oat decorate raw -p pos1 pos2
```



## Recorder

`oat-record` - Save frame and position streams to file.

- **frame** streams are compressed and saved as individual video files ( [H.264](#) compression format AVI file).
- **position** streams are combined into a single [JSON](#) file. Position files have the following structure:

```
{oat-version: X.X},
{header: {timestamp: YYYY-MM-DD-hh-mm-ss},
        {sample_rate_hz: X.X},
        {sources: [ID_1, ID_2, ..., ID_N]} }
{samples: [ [0, {Position1}, {Position2}, ..., {PositionN} ],
            [1, {Position1}, {Position2}, ..., {PositionN} ],
            :
            [T, {Position1}, {Position2}, ..., {PositionN} ] ] }
```

where each position object is defined as:

{ ID: String,	A string matching an ID from the header sources
unit: String,	Enum specifying length units (0=pixels, 1=meters)
pos_ok: Bool,	Boolean indicating if position is valid
pos_xy: [Double, Double],	Position x,y values
vel_ok: Bool,	Boolean indicating if velocity is valid
vel_xy: [Double, Double],	Velocity x,y values
head_ok: Bool,	Boolean indicating if heading is valid
head_xy: [Double, Double],	Heading x,y values
reg_ok: Bool,	Boolean indicating if region tag is valid
reg: String }	Region tagk

Data fields are only populated if the values are valid. For instance, in the case that only object position is valid, and the object velocity, heading, and region information are not calculated, an example position data point would look like this:

```
{ ID: "Example",
  unit: 0,
  pos_ok: True,
  pos_xy: [300.0, 100.0],
  vel_ok: False,
  head_ok: False,
  reg_ok: False }
```

All streams are saved with a single recorder have the same base file name and save location (see usage). Of course, multiple recorders can be used in parallel to (1) parallelize the computational load of video compression, which tends to be quite intense and (2) save to multiple locations simultaneously.

## Signature

```
position 0 --> |
position 1 --> |
:              |
position N --> | oat-record
                |
    frame 0 --> |
    frame 1 --> |
    :           |
    frame N --> |
```

## Usage

```
Usage: record [OPTIONS]
       or: record [CONFIGURATION]
```

### OPTIONS:

```
--help           Produce help message.
-v [ --version ] Print version information.
```

### CONFIGURATION:

```
-n [ --filename ] arg  The base file name to which to source name will
                        be appended
-f [ --folder ] arg    The path to the folder to which the video
                        stream and position information will be saved.
                        If specified, YYYY-MM-DD-hh-mm-ss_ will be
                        prepended to the filename.
-p [ --positionsources ] arg The name of the server(s) that supply object
                        position information. The server(s) must be of
                        type SMServer<Position>
-i [ --imagesources ] arg The name of the server(s) that supplies images
                        to save to video. The server must be of type
                        SMServer<SharedCVMatHeader>
```

## Example

```
# Save positional stream 'pos' to current directory
oat record -p pos

# Save positional stream 'pos1' and 'pos2' to current directory
oat record -p pos1 pos2

# Save positional stream 'pos1' and 'pos2' to Desktop directory and
# prepend the timestamp to the file name
oat record -p pos1 pos2 -d -f ~/Desktop

# Save frame stream 'raw' to current directory
oat record -i raw

# Save frame stream 'raw' and positional stream 'pos' to Desktop
# directory and prepend the timestamp and 'my_data' to each filename
oat record -i raw -p pos -d -f ~/Desktop -n my_data
```

## Position Network Socket

oat-posisock - Stream detected object positions to the network in either client or server configurations.

## Signature

position --> oat-posisock

## Usage

Usage: posisock [OPTIONS]  
or: posisock TYPE SOURCE [CONFIGURATION]  
Send positions from SOURCE to a remote endpoint.

TYPE  
udp: User datagram protocol.

## OPTIONS:

INFO:  
--help                                   Produce help message.  
-v [ --version ]                        Print version information.

CONFIGURATION:  
-h [ --host ] arg                       Remote host to send positions to.  
-p [ --port ] arg                       Port on which to send positions.  
--server                                 Server-side socket synchronization. Position data packets are sent whenever requested by a remote client. TODO: explain request protocol...  
-c [ --config ] arg                     Configuration file/key pair.

## Example

TODO

## Installation

First, ensure that you have installed all dependencies required for the components and build configuration you are interested in using. For more information on dependencies, see the [dependencies](#) section below. To compile and install Oat, starting in the top project directory, create a build directory, navigate to it, and run cmake on the top-level CMakeLists.txt like so:

```
mkdir release
cd release
cmake -DCMAKE_BUILD_TYPE=Release [CMAKE OPTIONS] ..
make
make install
```

If you just want to build a single component, individual components can be built using `make [component-name]`, e.g. `make oat-view`. Available cmake options and their default values are:

```
-DOAT_USE_FLYCAP=Off // Compile with support for Point Grey Cameras
-DOAT_USE_OPENGL=Off // Compile with support for OpenGL rendering
-DOAT_USE_CUDA=Off   // Compile with NVIDIA GPU accelerated processing
```

If you had to install Boost from source, you must let cmake know where it is installed via the following switch. Obviously, provide the correct path to the installation on your system.

```
-DBOOST_ROOT=/opt/boost_1_59_0
```

To complete installation, add the following to your `.bashrc` or equivalent. This makes Oat commands available within your user profile:

```
# Make Oat commands available to user
eval "$(path/to/Oat/oat/bin/oat init -)"
```

## Dependencies

### Flycapture SDK

The FlyCapture SDK is used to communicate with Point Grey digital cameras. It is not required to compile any Oat components. However, the Flycapture SDK is required if a Point Grey camera is to be used with the `oat-frameserve` component to acquire images. If you simply want to process pre-recorded files or use a web cam, e.g. via

```
oat-frameserve file raw -f video.mpg
oat-frameserve wcam raw
```

then this library is *not* required.

To install the Point Grey SDK:

- Go to [point-grey website](#)
- Download the FlyCapture2 SDK (version  $\geq 2.7.3$ ). Annoyingly, this requires you to create an account with Point Grey.
- Extract the archive and use the `install_flycapture.sh` script to install the SDK on your computer and run

```
tar xf flycapture.tar.gz
cd flycapture
sudo ./install_flycapture
```

## Boost

The [Boost libraries](#) are required to compile all Oat components. You will need to install versions  $\geq 1.56$ . To install Boost, use APT or equivalent,

```
sudo apt-get install libboost-all-dev
```

If you are using an Ubuntu distribution older than Wily Werewolf, Boost will be too old and you will need to install from source via

```
# Install latest boost
wget http://sourceforge.net/projects/boost/files/latest/download?source=files -O tarboost
tar -xf tarboost
cd ./boost*
./bootstrap.sh
./b2 --with-program_options --with-system --with-thread
cd ..
sudo mv boost* /opt
```

## OpenCV

[opencv](#) is required to compile the following oat components:

- oat-frameserve
- oat-framefilt
- oat-view
- oat-record

- `oat-posidet`
- `oat-posifilt`
- `oat-decorate`
- `oat-positest`

**Note:** OpenCV must be installed with ffmpeg support in order for offline analysis of pre-recorded videos to occur at arbitrary frame rates. If it is not, gstreamer will be used to serve from video files at the rate the files were recorded. No cmake flags are required to configure the build to use ffmpeg. OpenCV will be built with ffmpeg support if something like

```
-- FFMPEG:          YES
-- codec:           YES (ver 54.35.0)
-- format:          YES (ver 54.20.4)
-- util:            YES (ver 52.3.0)
-- swscale:         YES (ver 2.1.1)
```

appears in the cmake output text. The dependencies required to compile OpenCV with ffmpeg support, can be obtained as follows:

#### TODO

**Note:** To increase Oat's video visualization performance using `oat view`, you can build OpenCV with OpenGL and/or OpenCL support. Both will open up significant processing bandwidth to other Oat components and make for faster processing pipelines. To compile OpenCV with OpenGL and OpenCL support, add the `-DWITH_OPENGL=ON` and the `-DWITH_OPENCL=ON` flags to the cmake command below. OpenCV will be build with OpenGL and OpenCL support if `OpenGL support: YES` and `Use OpenCL: YES` appear in the cmake output text. If OpenCV is compiled with OpenCL support, the performance benefits will be automatic. For OpenGL, you need to set a flag when building Oat to see the performance gains. See the [Installation](#) section for details.

**Note:** If you have [NVIDIA GPU that supports CUDA](#), you can build OpenCV with CUDA support to enable GPU accelerated video processing. To do this, will first need to install the [CUDA toolkit](#). Be sure to read the [installation instructions](#) since it is a multistep process. Here are some additional hints that worked for me:

- I have found that its quite difficult to get NVIDIA drivers new enough to support CUDA Toolkit 7.5 to work on my system. If you have this problem, use version 7.0.
- I have found that installing the toolkit via 'runfile' to be the most painless. To do this you will need to switch your system to text mode using `Ctrl + Shift + F1`, and killing the X-server via `sudo service lightdm stop` (or equivalent), and running the runfile with root privileges.

- Do **not** install the nvidia drivers along with the CUDA toolkit installation. I found that (using ubuntu 14.04) this causes all sorts of issues with X, cinnamon, etc, to the point where I could not even boot my computer into anything but text mode. Instead, install the NVIDIA drivers using either the package manager (`nvidia-current`) or even more preferably, using the `[device-drivers]` (<http://askubuntu.com/a/476659>) program or equivalent.
- If you are getting a `cv::exception` complaining that about `code=30(cudaErrorUnknown) "cudaGetDeviceCount(&device_count)"` or similar, run the affected command as [root one time](#).

To compile OpenCV with CUDA support, add the `-DWITH_CUDA=ON` flag in the cmake command below.

**Note:** GUI functionality in OpenCV is compiled with Qt support. You can build OpenCV with Qt by first installing the [Qt SDK](#) and these dependencies:

```
# Additional dependencies for integrated QT with OpenGL
sudo apt-get install libqt5opengl5 libqt5opengl5-dev
```

Then you can compile OpenCV using QT support by adding `-DWITH_QT=ON` flag to the cmake command below.

Finally, to compile and install OpenCV:

```
# Install OpenCV's dependencies
sudo apt-get install build-essential # Compiler
sudo apt-get install cmake git libgtk2.0-dev pkg-config libavcodec-dev libavformat-dev libswscale-dev
sudo apt-get install python-dev python-numpy libtbb2 libtbb-dev libjpeg-dev libpng-dev libtiff-dev
sudo apt-get install # ffmpeg support [TODO]
sudo apt-get install # OpenGL support [TODO]
sudo ldconfig -v

# Get OpenCV
wget https://github.com/Itseez/opencv/archive/3.0.0-rc1.zip -O opencv.zip
unzip opencv.zip -d opencv

# Build OpenCV
cd opencv/opencv-3.0.0-rc1
mkdir release
cd release

# Run cmake to generate Makefile
# Add -DWITH_CUDA=ON for CUDA support and -DWITH_OPENGL for OpenGL support
cmake -DCMAKE_BUILD_TYPE=RELEASE -DCMAKE_INSTALL_PREFIX=/usr/local ..
```



```
# Build the project and install  
make  
sudo make install
```

## RapidJSON, cpptoml, and Catch

These libraries are installed automatically by cmake during the build process.

[RapidJSON](#) is required by the following Oat components:

- oat-record
- oat-posisock

[cpptoml](#) is required by the following Oat components:

- oat-frameserve
- oat-framefilt
- oat-posidet
- oat-posifilt
- oat-posicom
- oat-positest

[Catch](#) is required to make and run tests using `make test`

## Setting up a Point-grey PGE camera in Linux

`oat-frameserve` supports using Point Grey GIGE cameras to collect frames. I found the setup process to be straightforward and robust, but only after cobbling together the following notes.

### Camera IP Address Configuration

First, assign your camera a static IP address. The easiest way to do this is to use a Windows machine to run the Point Grey ‘GigE Configurator’. If someone knows a way to do this without Windows, please tell me. An example IP Configuration might be:

- Camera IP: 192.168.0.1
- Subnet mask: 255.255.255.0
- Default gateway: 192.168.0.64

## Point Greg GigE Host Adapter Card Configuration

Using network manager or something similar, you must configure the IPv4 configuration of the GigE host adapter card you are using to interface the camera with your computer.

- First, set the ipv4 method to **manual**.
- Next, you must configure the interface to (1) have the same network prefix and (2) be on the same subnet as the camera you setup in the previous section.
  - Assuming you used the camera IP configuration specified above, your host adapter card should be assigned the following private IPv4 configuration:
    - \* POE gigabit card IP: 192.168.0.100
    - \* Subnet mask: 255.255.255.0
    - \* DNS server IP: 192.168.0.1
- Next, you must enable jumbo frames on the network interface. Assuming that the camera is using **eth2**, then entering

```
sudo ifconfig eth2 mtu 9000
```

into the terminal will enable 9000 MB frames for the **eth2** adapter. - Finally, to prevent image tearing, you should increase the amount of memory Linux uses for network receive buffers using the **sysctl** interface by typing

```
sudo sysctl -w net.core.rmem_max=1048576 net.core.rmem_default=1048576
```

into the terminal. *In order for these changes to persist after system reboots, the following lines must be added to the bottom of the **/etc/sysctl.conf** file:*

```
net.core.rmem_max=1048576
net.core.rmem_default=1048576
```

## Multiple Cameras

- If you have two or more cameras/host adapter cards, they can be configured as above but *must exist on a separate subnets*. For instance, we could repeat the above configuration steps for a second camera/host adapter card using the following settings:
  - Camera Configuration:

- \* Camera IP: 192.168.1.1
- \* Subnet mask: 255.255.255.0
- \* Default gateway: 192.168.1.64
- Host adapter configuration:
  - \* POE gigabit card IP: 192.168.1.100
  - \* Subnet mask: 255.255.255.0
  - \* DNS server IP: 192.168.1.1

## Example

Below is an example network adapter and camera configuration for a two-camera imaging system provided by [Point Grey](#). It consists of two Blackfly GigE cameras (Point Grey part number: BFLY-PGE-09S2C) and a single dual-port POE GigE adapter card (Point Grey part number: GIGE-PCIE2-2P02).

### Camera 0

- Adapter physical connection (looking at back of computer)

```

RJ45 -----
      |       |
L [  [ ]    [x]  ] R

```

- Adapter Settings
  - Model: Intel 82574L Gigabit Network Connection
  - MAC: 00:B0:9D:DB:D9:63
  - MTU: 9000
  - DHCP: Disabled
  - IP: 192.168.0.100
  - Subnet mask: 255.255.255.0
- Camera Settings
  - Model: Blackfly BFLY-PGE-09S2C
  - Serial No.: 14395177
  - IP: 192.168.0.1 (Static)
  - Subnet mask: 255.255.255.0
  - Default GW: 0.0.0.0
  - Persistent IP: Yes

## Camera 1

- Adapter physical connection (looking at back of computer)

```
RJ45  -----  
      |         |  
L [  [x]      [ ]  ] R
```

- Adapter Settings
  - Model: Intel 82574L Gigabit Network Connection
  - MAC: 00:B0:9D:DB:A7:29
  - MTU: 9000
  - DHCP: Disabled
  - IP: 192.168.1.100
  - Subnet mask: 255.255.255.0
- Camera Settings
  - Model: Blackfly BFLY-PGE-09S2C
  - IP: 192.168.1.1 (Static)
  - Subnet mask: 255.255.255.0
  - Default GW: 0.0.0.0
  - Persistent IP: Yes

## TODO

- [ ] Networked communication with remote endpoints that use extracted positional information
  - ~~Strongly prefer to consume JSON over something opaque and untyped~~
  - ~~UDP~~
    - \* ~~Client version (sends data without request)~~
    - \* ~~Server version (pipeline is heldup by client position requests)~~
  - TCP/IP
    - \* Client version (sends data without request)
    - \* Server version (pipeline is heldup by client position requests)
  - Broadcast
    - \* Client version (sends data without request)
  - Move to ZMQ sockets?
- [ ] Build improvements
  - ~~Global build script to make all of the programs in the project~~
  - ~~CMake managed versioning~~
  - ~~Option for building with/without point-grey support~~
  - ~~Author/project information injection into source files using either emake or doxygen~~
  - Detect if OpenCV was compiled with OpenGL or CUDA and automatically set `-DOAT_USE_OPENGL` and `-DOAT_USE_CUDA` accordingly
  - ~~Put boost in a more standard location~~
    - \* EDIT: compiles with v1.54, which is provided in package manager.
  - ~~Clang build?~~
  - Windows build?
- [ ] Travis CI
  - Get it building using the improvements to CMake stated in last TODO item
- [ ] Unit and stress testing
  - Unit tests for `libshmemdf`
    - \* ~~Nominal data types, T~~
    - \* Specializations for `SharedCVMat`
  - Stress tests for data processing chains
    - \* I need to come up with a series of scripts that configure and run components in odd and intensive, but legal, ways to ensure sample sychronization is maintianed, graceful exits, etc
- [ ] Frame and position server sample synchronization

- [ ] Dealing with dropped frames
  - \* Right now, I poll the camera for frames. This is fine for a file, but not necessarily for a physical camera whose acquisitions is governed by an external, asynchronous clock
  - \* Instead of polling, I need an event driven frame server. In the case of a dropped frame, the server **must** increment the sample number, even if it does not serve the frame, to prevent offsets from occurring.
  - \* EDIT: `libshmndf` and `oat::Frame` allow the sample number to be incremented and travel with the frame, even if the frame is dropped. This means that samples should be able to maintain accuracy even when frames are discarded due to buffer overflow
- [ ] Pull-based synchronization with remote client.
  - \* By virtue of the synchronization architecture I'm using to coordinate samples between SOURCE and SINK components, I get both push and pull based processing chain updates for free. This means if I use `oat-posisock` in server mode, and it blocks until a remote client requests a position, then the data processing chain update will be synchronized to these remote requestions. The exception are **pure** SOURCE components, which have internal ring-buffers (`oat-frameserve` and `oat-positest`). These components will fill their internal buffers at a rate driven by their internal clock regardless of remote requests for data processing chain updates. If remote synchronization is required, this is undesirable.
  - \* Ideally, the synchronization and buffering architecture of **pure** SOURCE components should be dependent on some globally enforced synchronization strategy. This might be accomplished via the creation of a master, read only clock, existing in shm, that dictates synchronization strategy and keeps time. Instead of each **pure** SOURCE keeping its own, asynchronous clock (e.g. if two cameras are started at different times, they can have different absolute sample numbers at the same real-world time), this central clock would be in charge. This would obviate all issues I'm having with sample number propagation through multi-SOURCE components.
- In anycase, the **pure** SOURCE components, especially `oat-frameserve`, are by far the most primitive components in the project at this point and need refactoring to deal with these two issues in a reasonable way.
- [ ] In line with the comments above about central clock management, it might also be better to have a central anonymous shared memory management. Instead of creating a named shared block that can potentially be stranded in the case of a program crash, a central program to manage all the shared blocks and the clock could be smarter about shm allocation/freeing.

- There could be, for instance, a directed adjacency list to describe a data processing graph stored in shmem.
- [ ] GigE interface cleanup
  - The PGGigEcam class is a big mess. It has tons of code redundancy.
  - Additionally, it needs to be optimized for performance. Are their unnecessary copies of images being made during conversion from PG Image to cv::Mat? Can I employ some move casts to help?
    - \* EDIT: shmemdf takes care of this.
  - There are a couple examples of GigE interfaces in OpenCV targeting other 3rd party APIs: `modules/videoio/src/cap_giganetix.cpp` and `opencv/modules/videoio/src/cap_pvapi.cpp`. I don't know that these are great pieces of code, but I should at least use them for inspiration.
  - `oat-frameserve gige` lacks the ability to set FPS in free running (non-triggered mode)
- [ ] Exception safety for all components and libs
  - `frameserve`
  - `framefilt`
  - `posidet`
  - `posicom`
  - `posifilt`
  - `positest`
  - `record`
  - `view`
  - `decorate`
- [ ] Decorator is primitive
  - Size of position markers, sample numbers, etc do not change with image resolution
  - How are multi-region tags displayed using the -R option?
- [ ] Something is wrong with sample synchronization
  - When working with Jennie's data, we found that position samples were being recorded multiple times - they had the same sample number and position info. Seems to be very intermittent, but points to a serious issue with sample synchronization. It seems likely this occurring in the recorder component due to its multithreaded implementation.
  - With `libshmemdf`, sample numbers now travel with samples. I need to use this to implement `asserts` in each component that (1) check that samples increase monotonically (buffer overflows means that samples can be skipped, so unary incrementation is not a given) and (2) that multisource components are dealing with synchronized

sample numbers when pull-based synchronization strategy is enforced  
(no external clock driving acquisition, so no chance for buffer overrun).