

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-file] arg Configuration file.
-k [--config-key] arg Configuration key.
-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 -k 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 -k 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

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-file] arg Configuration file.

-k [--config-key] arg Configuration key.

-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.

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 -k 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-file] arg` Configuration file.
 `-k [--config-key] arg` Configuration key.

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 (pixels²)
- **max_area**=+double Maximum object area (pixels²)
- **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 -k 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
homo: 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-file] arg Configuration file.
-k [--config-key] arg Configuration key.

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/s²; e.g. pixels/s²).
- **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 = homo

- **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 -k kalman_config
```

Position combiner

`oat-posifilt` - Combine positions according to a specified operation.

Signature

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

Usage

TODO

Example

TODO

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

TODO

Example

TODO

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: XX.XX},
{header: [ {timestamp: YYYY-MM-DD-hh-mm-ss},
           {sample_rate_hz: Fs},
           {sources: [s1, s2, ..., sN]} ] },
{samples: [ [0, {Position1}, {Position2}, ..., {PositionN} ],
            [1, {Position1}, {Position2}, ..., {PositionN} ],
            :
            [T, {Position1}, {Position2}, ..., {PositionN} ] ] }
```

where each position object is defined as:

```
{TODO}
```

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:

| | |
|-------------------------------|----------------------------|
| <code>--help</code> | Produce help message. |
| <code>-v [--version]</code> | Print version information. |

CONFIGURATION:

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

Installation

Flycapture SDK (if Point-Grey camera is used)

- Go to [point-grey website](#)
- Download the FlyCapture2 SDK (version > 2.7.3)
- Extract the archive and use the `install_flycapture.sh` script to install the SDK on your computer.

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

Boost

```
wget http://sourceforge.net/projects/boost/files/boost/1.58.0/boost_1_58_0.tar.gz/download
tar -xf download
sudo cp -r boost_1_58_0 /opt
cd opt/boost_1_58_0/
sudo ./bootstrap.sh
sudo ./b2 --with-program_options --with_system --with_thread
```

OpenCV

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.

Note: To increase Oat's video visualization performance using `oat view`, you can build OpenCV with OpenGL support. This will open up significant processing bandwidth to other Oat components and make for faster processing pipelines. To compile OpenCV with OpenGL support, add the `-DWITH_OPENGL=ON` flag in the cmake command below. OpenCV will be build with OpenGL support if `OpenGL support: YES` appears in the cmake output text.

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

```
# Install dependencies
sudo apt-get install cmake git libgtk2.0-dev pkg-config libavcodec-dev libavformat-dev libswscale-dev
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
# Add -DWITH_CUDA=ON for CUDA support and -DWITH_OPENGL for OpenGL support
cmake -DCMAKE_BUILD_TYPE=RELEASE -DCMAKE_INSTALL_PREFIX=/usr/local ..
make
sudo make install
```

[RapidJSON](#) and [cpptoml](#)

Starting in the project root directory,

```
cd lib
./updatelibs.sh
```

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

PG POE 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

TODO

- [] Networked communication with clients that use extracted positional information
 - ~~Strongly prefer to consume JSON over something ad hoc, opaque and untyped~~
 - * EDIT: Position class is serialized to JSON object
 - Multiple clients
 - * Broadcast over UDP
 - * TCP/IP with thread for each client
- [] Cmake 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 cmake or doxygen
 - Windows build?
- [] Travis CI
 - Get it building using the improvements to CMake stated in last TODO item
- [] 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.
- [] shmem type checking by clients, exit gracefully in the case of incorrect type
- e.g. a framefilter tries to use a position filter as a SOURCE. In this case, the framefilter needs to realize that the SOURCE type is wrong and exit.
- [] Exception safety for all components
 - frameserve
 - ~~framefilt~~
 - ~~posidet~~
 - ~~posicom~~
 - ~~posifilt~~
 - ~~positest~~
 - ~~record~~
 - ~~view~~
 - ~~decorate~~

- [] Use smart pointers to ensure proper resource management.
 - ~~Start with **recorder**, which has huge amounts of heap allocated objects pointed to with raw pointers~~