

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

Introduction

Oat's design is influenced by the UNIX philosophy, suckless tools, and MEABench. Oat consists of a set of small, composable programs (called **components**). Components are equipped with standard interfaces that permit communication through shared memory to capture, process, and record video streams. Currently, Oat components act on two basic data types: **frames** and **positions**.

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

Oat components can be chained together to realize custom dataflow networks that operate on instances of the aforementioned datatypes, called **tokens**. Token processing pipelines can be split and merged while maintaining thread-safety and sample synchronization. The messaging library underlying the communication between Oat components has been optimized to reduce token copying. For instance, **frame** passing is performed using a zero-copy protocol. This means that passing **frames** between components in a user-configured processing network incurs almost no memory or CPU cost compared to the monolithic equivalent. Further, great care was taken during implementations of Oat components to minimize time spent in critical sections. This means that individual components execute largely in parallel, even when components are highly interdependent, facilitating efficient use of multi-core CPUs and GPU-based processing acceleration.

To get a feel for how Oat is used, here is a script to detect the position of a single object in pre-recorded video file:

```
# 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
# If an appropriately configured GPU is available, this process will
# use it
oat framefilt mog raw filt &

# Perform color-based object position detection on the 'filt' stream
# Serve the object position to the 'pos' stream. Allow parameter tuning
# through a simple GUI.
oat posidet hsv filt pos --tune &

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

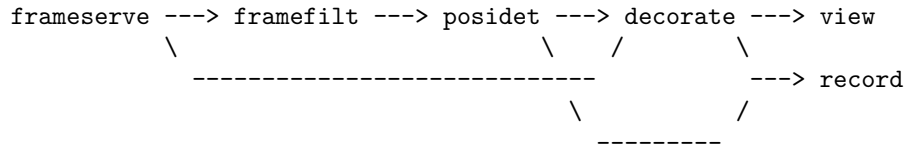
```
# View the 'dec' stream
```

```
oat view frame 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:



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

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

The **<component>** 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** component, 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. A description of a component's purpose, its available **TYPE**s and correct **IO** specification can be examined using the **--help** command line switch

```
oat <component> --help
```

The **CONFIGURATION** specification is used to provide parameters to shape the component's operation and are **TYPE**-specific. Information on program options for a particular concrete transform **TYPE** can be printed using

```
oat <component> <type> --help
```

In addition to command line input, all options can be specified using a configuration file which is provided to the program using the **-c** command line argument.

```
-c [ --config ] arg           Configuration file/key pair.
                               e.g. 'config.toml mykey'
```

For instance:

```
oat frameserve gige raw -c config.toml gige-config
```

The configuration file may contain many configuration tables that specify options for multiple oat programs. These tables are addressed using a key (**gige-config**) in the example above. 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-config]
frame_rate = 30           # FPS
roi = [10, 10, 100, 100] # Region of interest

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

These could then be used in a processing script as follows:

```
oat frameserve gige raw -c config.toml frameserve-config &
oat framefilt mask raw filt -c config.toml framefilt-config
```

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-frameserve --> frame`

Usage

Usage: `frameserve` [INFO]
 or: `frameserve` TYPE SINK [CONFIGURATION]
Serve frames to SINK.

INFO:

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

TYPE

`wcam`: Onboard or USB webcam.
`usb`: Point Grey USB camera.
`gige`: Point Grey GigE camera.
`file`: Video from file (*.mpg, *.avi, etc.).
`test`: Write-free static image server for performance testing.

SINK:

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

Configuration Options

TYPE = wcam

`-i [--index] arg` Camera index. Useful in multi-camera imaging configurations. Defaults to 0.
`-r [--fps] arg` Frames to serve per second. Defaults to 20.
`--roi arg` Four element array of unsigned ints, [x0,y0,width,height], defining a rectangular region of interest. Origin is upper left corner. ROI must fit within acquiredmat size. Defaults to full sensor size.

TYPE = gige and usb

`-i [--index] arg` Camera index. Defaults to 0. Useful in

-r [--fps] arg	multi-camera imaging configurations. Acquisition frame rate in Hz. Ignored if trigger-mode > -1 and enforce_fps=false. Defaults to the maximum frame rate.
-e [--enforce-fps]	If true, ensures that frames are produced at the fps setting bool retransmitting frames if the requested period is exceeded. This is sometimes needed in the case of an external trigger because PG cameras sometimes just ignore them. I have opened a support ticket on this, but PG has no solution yet.
-s [--shutter] arg	Shutter time in milliseconds. Defaults to auto.
-C [--color] arg	Pixel color format. Defaults to BRG. Values: GREY: 8-bit Greyscale image. BRG: 8-bit, 3-channel, BGR Color image.
-g [--gain] arg	Sensor gain value, specified in dB. Defaults to auto.
-S [--strobe-pin] arg	Hardware pin number on that a gate signal for the camera shutter is copied to. Defaults to 1.
-m [--trigger-mode] arg	Shutter trigger mode. Defaults to -1. Values: -1: No external trigger. Frames are captured in free-running mode at the currently set frame rate. 0: Standard external trigger. Trigger edge causes sensor exposure, then sensor readout to internal memory. 1: Bulb shutter mode. Same as 0, except that sensor exposure duration is determined by trigger active duration. 13: Low smear mode. Same as 0, speed of the vertical clock is increased near the end of the integration cycle. 14: Overlapped exposure/readout external trigger. Sensor exposure occurs during sensory readout to internal memory. This is the fastest option.
-p [--trigger-rising]	True to trigger on rising edge, false to trigger on falling edge. Defaults to true.
-t [--trigger-pin] arg	GPIO pin number on that trigger is sent to if external shutter triggering is used. Defaults

-R [--roi] arg	to 0. Four element array of unsigned ints, [x0,y0,width,height], defining a rectangular region of interest. Origin is upper left corner. ROI must fit within acquired frame size. Defaults to full sensor size.
-b [--bin] arg	Two element array of unsigned ints, [bx,by], defining how pixels should be binned before transmission to the computer. Defaults to [1,1] (no binning).
-w [--white-balance] arg	Two element array of unsigned integers, [red,blue], used to specify the white balance. Values are between 0 and 1000. Only works for color sensors. Defaults to off.
-W [--auto-white-balance]	If specified, the white balance will be adjusted by the camera. This option overrides manual white-balance specification.

TYPE = file

-f [--video-file] arg	Path to video file to serve frames from.
-r [--fps] arg	Frames to serve per second.
--roi arg	Four element array of unsigned ints, [x0,y0,width,height], defining a rectangular region of interest. Origin is upper left corner. ROI must fit within acquired frame size. Defaults to full video size.

TYPE = test

-f [--test-image] arg	Path to test image used as frame source.
-C [--color] arg	Pixel color format. Defaults to BGR. Values: GREY: 8-bit Greyscale image. BGR: 8-bit, 3-channel, BGR Color image.
-r [--fps] arg	Frames to serve per second.
-n [--num-frames] arg	Number of frames to serve before exiting.

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 a frame source, 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 publish filtered frames to SINK.

INFO:

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

TYPE

bsub: Background subtraction
col: Color conversion
mask: Binary mask
mog: Mixture of Gaussians background segmentation.
undistort: Correct for lens distortion using lens distortion model.
thresh: Simple intensity threshold.

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).

Configuration Options

TYPE = bsub

-a [--adaptation-coeff] arg Scalar value, 0 to 1.0, specifying how quickly the new frames are used to update the background image. Default is 0, specifying no adaptation and a static background image that is never updated.
-f [--background] arg Path to background image used for

subtraction. If not provided, the first frame is used as the background image.

TYPE = mask

-f [--mask] arg 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

-a [--adaptation-coeff] arg Value, 0 to 1.0, specifying how quickly the statistical model of the background image should be updated. Default is 0, specifying no adaptation.

TYPE = undistort

-k [--camera-matrix] arg Nine element float array, [K11,K12,...,K33], specifying the 3x3 camera matrix for your imaging setup. Generated by oat-calibrate.
-d [--distortion-coeffs] arg Five to eight element float array, [x1,x2,x3,...], specifying lens distortion coefficients. Generated by oat-calibrate.

TYPE = thresh

-I [--intensity] arg Array of ints between 0 and 256, [min,max], specifying the intensity passband.

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  
# Change the underlying pixel color to single-channel GREY  
oat framefilt col raw gry -C GREY
```

```
# 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

token --> oat-view

Usage

Usage: view [INFO]
 or: view TYPE SOURCE [CONFIGURATION]
Graphical visualization of SOURCE stream.

INFO:

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

TYPE

 frame: Display frames in a GUI

SOURCE:

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

Configuration Options

TYPE = frame

 --control-endpoint arg ZMQ style endpoint specifier designating runtime control port: '<transport>://<host>:<port>'. For instance, 'tcp://*:5555' to specify TCP communication on port 5555. Or, for interprocess communication: '<transport>://<user-named-pipe>'. For instance 'ipc:///tmp/test.pipe'. Internally, this is used to construct a ZMQ REQ socket that that receives commands from oat-control. Defaults to ipc:///tmp/oatcomms.pipe.

 -r [--display-rate] arg Maximum rate, in Hz, at which the viewer is updated irrespective of its source's rate. If frames are supplied faster than this rate, they are ignored. Setting this to a reasonably low value prevents the viewer from consuming processing resources in order to update the

	display faster than is visually perceptible. Defaults to 30.
<code>-m [--min-max] arg</code>	2-element array of floats, [min,max], specifying the requested dyanmic range of the display. Pixel values below min will be mapped to min. Pixel values above max will be mapped to max. Others will be interpolated between min and max. Defaults to off.
<code>-f [--snapshot-path] arg</code>	The path to which in which snapshots will be saved. If a folder is designated, the base file name will be SOURCE. The time stamp of the snapshot will be prepended to the file name. Defaults to the current directory.

Example

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

# View frame stream named raw and specify that snapshots should be saved
# to the Desktop with base name 'snapshot'
oat view frame 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 detection on frames from SOURCE and publish object positions to SINK.

INFO:

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

TYPE

`aruco`: Aruco board pose estimation (any)
`diff`: Motion detector (mono)
`hsv`: HSV color thresholds (color)
`thresh`: Simple amplitude threshold (mono)
`rpg`: RPG pose estimator (any)

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 positions to (e.g. `pos`).

Configuration Options

TYPE = `aruco`

`-D [--dictionary] arg`

Aruco board dictionary to use for detection or printing when `-p` is defined. Dictionaries are defined by the size of each marker and the number of markers in the dictionary. These parameters are encoded by a string of the form:

`<Size>X<Size>_<Number of Markers>`

Values:

- 4X4_50 (default)
- 4X4_100
- 4X4_250
- 4X4_1000
- 5X5_50
- 5X5_100
- 5X5_250
- 5X5_1000
- 6X6_50
- 6X6_100
- 6X6_250
- 6X6_1000
- 7X7_50
- 7X7_100
- 7X7_250
- 7X7_1000

<p>-k [--camera-matrix] arg</p> <p>-d [--distortion-coeffs] arg</p> <p>-S [--board-size] arg</p> <p>-l [--length] arg</p> <p>-s [--separation] arg</p> <p>-R [--refine-detection]</p> <p>-p [--print]</p> <p>-P [--print-scale] arg</p>	<p>Nine element float array, [K11,K12,...,K33], specifying the 3x3 camera matrix for your imaging setup. Generated by oat-calibrate.</p> <p>Five to eight element float array, [x1,x2,x3,...], specifying lens distortion coefficients. Generated by oat-calibrate.</p> <p>Two element int array, [X,Y], specifying the dimensions of the Aruco board (the number of markers in the X and Y directions).</p> <p>Length, in meters, of each side of the square markers within the Aruco board.</p> <p>Separation, in meters, between each of the markers within the Aruco board.</p> <p>Perform a secondary marker location refinement step using knowledge of the board layout after initial marker detection is performed. Can lead to improved pose estimation robustness.</p> <p>Prior to performing position detection, print the specified Aruco marker to a PNG file, named 'board.png', in the current directory.</p> <p>The number of pixels to map to marker length to determine printing resolution. For instance, print-scale 50 indicates that each side of the marker will be 50 pixels. Defaults to 100.</p>
---	--

-t [--thresh-params] arg	Three element vector, [min,max,step], specifying threshold parameters for marker candidate detection. Min and max represent the interval where the thresholding window sizes (in pixels) are selected for adaptive thresholding. Step determines the granularity of increments between min and max. See cv::threshold() for details. Defaults to [3, 23, 10]
-t [--contour-params] arg	Two element vector, [min,max], specifying the minimum and maximum perimeter distance relative to the major dimension of the input frame in order for a detected contour to be considered a marker candidate. Defaults to [0.03, 4.0]. Note that a max=4.0 indicates that the marker can fill the entire frame.
-o [--min-corner-dist] arg	Float specifying the minimum distance between the corners of the same marker (expressed as rate relative the marker perimeter. Defaults to 0.05.
-O [--min-marker-dist] arg	Float specifying the minimum distance between the corners of different markers (expressed as rate relative the minimum candidate marker perimeter. Defaults to 0.05.
-b [--min-border-dist] arg	Float specifying the minimum absolute distance between a marker corner and the frame border (pixels). Defaults to 3.
-x [--pixels-per-cell] arg	Int specifying the number of pixels (length of a side) used to represent each black or white cell of the detected markers. A higher value may improve decoding accuracy at the cost of performance. Defaults to 4.
-B [--border-error-rate] arg	Fraction of board bits that can be white (erroneous) instead of black. Defaults to 0.35
-t [--tune]	If true, provide a GUI with sliders for tuning detection parameters.

TYPE = hsv

-H [--h-thresh] arg	Array of ints between 0 and 256, [min,max], specifying the hue passband.
-S [--s-thresh] arg	Array of ints between 0 and 256, [min,max], specifying the saturation passband.
-V [--v-thresh] arg	Array of ints between 0 and 256, [min,max],

specifying the value passband.

-e [--erode] arg Contour erode kernel size in pixels (normalized box filter).

-d [--dilate] arg Contour dilation kernel size in pixels (normalized box filter).

-a [--area] arg Array of floats, [min,max], specifying the minimum and maximum object contour area in pixels².

-t [--tune] If true, provide a GUI with sliders for tuning detection parameters.

TYPE = diff

-d [--diff-threshold] arg Intensity difference threshold to consider an object contour.

-b [--blur] arg Blurring kernel size in pixels (normalized box filter).

-a [--area] arg Array of floats, [min,max], specifying the minimum and maximum object contour area in pixels².

-t [--tune] If true, provide a GUI with sliders for tuning detection parameters.

TYPE = rpg

-M [--marker-positions] arg Nx3 element array of 3D marker positions in meters.

-T [--threshold] arg Detection threshold value, 0-256. Defaults to 100.

-s [--gauss-sigma] arg Sigma of Gaussian blur filter. Defaults to 0.6.

-a [--area] arg Array of floats, [min,max], specifying the minimum and maximum object contour area in pixels². Defaults to [10,200].

-w [--width-height-dist] arg Minimum ratio of width-to-height of a bounding box around a detected blob. Ideally the ratio of the width to the height of the bounding rectangle should be 1. Defaults to 0.5.

-c [--circ-dist] arg Maximum allowable distortion, 0 to 1.0, of a bounding box around the detected blob, calculated as the area of the blob divided by pi times half the height or half the width of the bounding rectangle. Defaults to 0.5.

-b [--back-proj-tol] arg Maximum allowable back projection tolerance, in pixels, to consider a projected point to

	correspond to the detected point in the captured image. Defaults to 5.
-n [--nn-pixel-tol] arg	Tolerance, in pixels, that determines the correspondences between the LEDs and the detections in the image when predicting the position of the LEDs in the image. Defaults to 7.
-C [--pose-cert-thresh] arg	Minimum ratio of how many of the back-projected points must be within the 'back-proj-tol' for a correspondence between the LEDs and the detections to be correct. Defaults to 0.75.
-p [--pose-corr-thresh] arg	Minimum correspondence ratio, 0 to 1.0, to continue with smart pose estimation rather than brute-force correspondence search. Defaults to 0.7.
-r [--roi-border] arg	Thickness of the border (in pixels) around the predicted area of the LEDs in the image that defines the region of interest for image detection of the LEDs in the next frame. Defaults to 20.
-k [--camera-matrix] arg	Nine element float array, [K11,K12,...,K33], specifying the 3x3 camera matrix for your imaging setup. Generated by oat-calibrate.
-d [--distortion-coeffs] arg	Five to eight element float array, [x1,x2,x3,...], specifying lens distortion coefficients. Generated by oat-calibrate.
-t [--tune]	if true, provide a gui with sliders for tuning detection parameters.

TYPE = thresh

-T [--thresh] arg	Array of ints between 0 and 256, [min,max], specifying the intensity passband.
-e [--erode] arg	Contour erode kernel size in pixels (normalized box filter).
-d [--dilate] arg	Contour dilation kernel size in pixels (normalized box filter).
-a [--area] arg	Array of floats, [min,max], specifying the minimum and maximum object contour area in pixels ² .
-t [--tune]	If true, provide a GUI with sliders for tuning detection parameters.

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 Generator

oat-posigen - Generate positions for testing downstream components. Publish generated positions to shared memory.

Signature

oat-posigen --> position

Usage

Usage: **posigen** [INFO]
or: **posigen** TYPE SINK [CONFIGURATION]
Publish generated positions to SINK.

INFO:

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

TYPE

rand2D: Randomly accelerating 2D Position

SINK:

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

Configuration Options

TYPE = rand2D

-r [--rate] arg	Samples per second. Defaults to as fast as possible.
-n [--num-samples] arg	Number of position samples to generate and serve. Defaults to approximately infinite.
-R [--room] arg	Array of floats, [x0,y0,width,height], specifying the boundaries in which generated positions reside. The room has periodic boundaries so when a position leaves one side it will enter the opposing one.
-a [--sigma-accel] arg	Standard deviation of normally-distributed random accelerations

Example

```
# Publish randomly moving positions to the 'pos' position stream  
oat posigen rand2D pos
```

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 publish filtered positions to SINK.

INFO:

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

TYPE

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

SOURCE:

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

SINK:

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

Configuration Options

TYPE = kalman

--dt arg Kalman filter time step in seconds.
-T [--timeout] arg Seconds to perform position estimation detection with lack of position measure. Defaults to 0.
-a [--sigma-accel] arg Standard deviation of normally distributed, random accelerations used by the internal model of object motion (position units/s²; e.g. pixels/s²).
-n [--sigma-noise] arg Standard deviation of randomly distributed position measurement noise (position units; e.g. pixels).

```

-t [ --tune ]                If true, provide a GUI with sliders for tuning
                              filter parameters.

TYPE = homography

-H [ --homography ] arg      A nine-element array of floats, [h11,h12,...,h33],
                              specifying a 3x3 homography matrix for 2D position.
                              Can be produced by oat-calibrate homography.

TYPE = region

--regions arg                NOTE: Regions can only be specified in a config file.
                              Regions contours are specified as n-point matrices,
                              [[x0, y0],[x1, y1],...,[xn, yn]], which define the
                              vertices of a polygon:

                              <region> = [[+float, +float],
                                           [+float, +float],
                                           ...
                                           [+float, +float]]

The name of the contour is used as the region label
(10 characters max). For example, here is an
octagonal region called CN and a tetragonal region
called R0:

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 and Publish combined position to SINK

INFO:

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

TYPE

mean: Geometric mean of positions

SOURCES:

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

SINK:

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

Configuration Options

TYPE = mean

```
-h [ --heading-anchor ] arg  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

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).

INFO:

```

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

```

CONFIGURATION:

```

-c [ --config ] arg      Configuration file/key pair.
                           e.g. 'config.toml mykey'
--control-endpoint arg    ZMQ style endpoint specifier designating
                           runtime control port: '<transport>://<host>:<port>'. For instance, 'tcp://*:5555' to
                           specify TCP communication on port 5555. Or,
                           for interprocess communication:
                           '<transport>://<user-named-pipe>'. For
                           instance 'ipc:///tmp/test.pipe'. Internally,
                           this is used to construct a ZMQ REQ socket
                           that that receives commands from oat-control.

```

Defaults to ipc:///tmp/oatcomms.pipe.

<code>-p [--position-sources] arg</code>	The name of position SOURCE(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.
<code>-h [--history]</code>	Display position history.
<code>-i [--invert-font]</code>	Invert font color.

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 saved to separate JSON file. Optionally, they can be saved to numpy binary files. JSON position files have the following structure:

```
{
  oat-version: X.X,
  header: {
    timestamp: YYYY-MM-DD-hh-mm-ss,
    sample_rate_hz: X.X
  },
  positions: [
    position,
    position,
    ...,
    position
  ]
}
```

where each **position** object is defined as:

```
{
  tick: Int,           | Sample number
  usec: Int,           | Microseconds associated with current sample number
  unit: Int,           | 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 tag
}
```

When using JSON and the **consise-file** option is specified, 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:

```
{ tick: 501,
  usec: 50100000,
  unit: 0,
```

```

pos_ok: True,
pos_xy: [300.0, 100.0],
vel_ok: False,
head_ok: False,
reg_ok: False }

```

When using binary file format, position entries occupy single elements of a numpy structured array with the following `dtype`:

```

[('tick', '<u8'),
 ('usec', '<u8'),
 ('unit', '<i4'),
 ('pos_ok', 'i1'),
 ('pos_xy', '<f8', (2,)),
 ('vel_ok', 'i1'),
 ('vel_xy', '<f8', (2,)),
 ('head_ok', 'i1'),
 ('head_xy', '<f8', (2,)),
 ('reg_ok', 'i1'),
 ('reg', 'S10')]

```

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 (3) to save the same data stream multiple times in different formats.

Signature

```

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

```

Usage

```

Usage: record [INFO]
      or: record [CONFIGURATION]
Record any Oat token source(s).

```

INFO:

```

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

```

CONFIGURATION:

-c [--config] arg	Configuration file/key pair. e.g. 'config.toml mykey'
--control-endpoint arg	ZMQ style endpoint specifier designating runtime control port: '<transport>://<host>:<port>'. For instance, 'tcp://*:5555' to specify TCP communication on port 5555. Or, for interprocess communication: '<transport>://<user-named-pipe>'. For instance 'ipc:///tmp/test.pipe'. Internally, this is used to construct a ZMQ REQ socket that that receives commands from oat-control. Defaults to ipc:///tmp/oatcomms.pipe.
-s [--frame-sources] arg	The names of the FRAME SOURCES that supply images to save to video.
-p [--position-sources] arg	The names of the POSITION SOURCES that supply object positions to be recorded.
-n [--filename] arg	The base file name. If not specified, defaults to the SOURCE name.
-f [--folder] arg	The path to the folder to which the video stream and position data will be saved. If not specified, defaults to the current directory.
-d [--date]	If specified, YYYY-MM-DD-hh-mm-ss_ will be prepended to the filename.
-o [--allow-overwrite]	If set and save path matches and existing file, the file will be overwritten instead of a incremental numerical index being appended to the file name.
-F [--fourcc] arg	Four character code (https://en.wikipedia.org/wiki/FourCC) used to specify the codec used for AVI video compression. Must be specified as a 4-character string (see http://www.fourcc.org/codecs.php for possible options). Not all valid FOURCC codes will work: it must be implemented by the low level writer. Common values are 'DIVX' or 'H264'. Defaults to 'None' indicating uncompressed video.
-b [--binary-file]	Position data will be written as numpy data file (version 1.0) instead of JSON. Each position data point occupies a single entry in a structured numpy array. Individual position characteristics are described in the

<p><code>-c [--concise-file]</code></p>	<p>arrays dtype.</p> <p>If set and using JSON file format, indeterminate position data fields will not be written e.g. <code>pos_xy</code> will not be written even when <code>pos_ok = false</code>. This means that position objects will be of variable size depending on the validity of whether a position was detected or not, potentially complicating file parsing.</p>
---	---

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 -s raw

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

# Save the pos stream twice, one binary and one JSON file, in the current
# directory
oat record -p pos &
oat record -p pos -b
```

Position Socket

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

Signature

`position --> oat-posisock`

Usage

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

INFO:

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

TYPE:

`std`: Asynchronous position dump to stdout.
`pub`: Asynchronous position publisher over ZMQ socket.
 Publishes positions without request to potentially many subscribers.
`rep`: Synchronous position replier over ZMQ socket.
 Sends positions in response to requests from a single endpoint. Several transport/protocol options. The most useful are `tcp` and `interprocess (ipc)`.
`udp`: Asynchronous, client-side, unicast user datagram protocol over a traditional BSD-style socket.

SOURCE:

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

Configuration Options

TYPE = std

`-p [--pretty-print]` If true, print formatted positions to the command line.

TYPE = pub

`-e [--endpoint] arg` ZMQ-style endpoint. For TCP: '`<transport>://<host>:<port>`'. For instance,

'tcp://*:5555'. Or, for interprocess communication:
'<transport>:///<user-named-pipe>'. For instance
'ipc:///tmp/test.pipe'.

TYPE = rep

-e [--endpoint] arg ZMQ-style endpoint. For TCP:
 '<transport>://<host>:<port>'. For instance,
 'tcp://*:5555'. Or, for interprocess communication:
 '<transport>:///<user-named-pipe>'. For instance
 'ipc:///tmp/test.pipe'.

type = udp

-h [--host] arg Host IP address of remote device to send positions
 to. For instance, '10.0.0.1'.
-p [--port] arg Port number of endpoint on remote device to send
 positions to. For instance, 5555.

Example

```
# Reply to requests for positions from the 'pos' stream to port 5555 using TCP
oat posisock rep pos -e tcp://*:5555

# Asynchronously publish positions from the 'pos' stream to port 5556 using TCP
oat posisock pub pos -e tcp://*:5556

# Dump positions from the 'pos' stream to stdout
oat posisock std pos
```

Buffer

oat-buffer - A first in, first out (FIFO) token buffer that can be use to decouple asynchronous portions of a data processing network. An example of this is the case when a precise external clock is used to govern image acquisition via a physical trigger line. In this case, ‘hickups’ in the data processing network following the camera should not cause the camera to skip frames. Of course, there is no free lunch: if the processing pipline cannot keep up with the external clock on average, then the buffer will eventually fill and overflow.

Signatures

position --> oat-buffer --> position

frame --> oat-buffer --> frame

Usage

Usage: buffer [INFO]

or: buffer TYPE SOURCE SINK [CONFIGURATION]

Place tokens from SOURCE into a FIFO. Publish tokens in FIFO to SINK.

INFO:

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

TYPE

frame: Frame buffer
pos2D: 2D Position buffer

SOURCE:

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

SINK:

User-supplied name of the memory segment to publish tokens to (e.g. output).

Example

Acquire frames on a gige camera driven by an exnternal trigger

oat frameserve gige raw -c config.toml gige-trig

Buffer the frames separate asynchronous sections of the processing network

oat buffer frame raw buff

Filter the buffered frames and save

```
oat framefilt mog buff filt
oat record -f ~/Desktop/ -p buff filt
```

In the above example, one must be careful to fully separate the network across the buffer boundary in order for it to provide any functionality. For instance, if we changed the record command to the following

```
oat record -f ~/Desktop/ -p raw filt
```

Then the buffer would do nothing since the raw token stream must be synchronous with the recorder, which bypasses the buffer. In this case, the buffer is just wasting CPU cycles. Here is a graphical representation of the first configuration where the `oat-buffer` is used properly. The synchronization boundary is shown using vertical lines.

```

      |
frameserve --> buffer --> framefilt --> record
      |      \                /
      |      -----

```

In the second configuration, the connection from frameserve to record breaks the synchronization boundary.

```

      |
frameserve --> buffer --> framefilt --> record
      \      |                /
      ----|-----

```

Calibrate

oat-calibrate - Interactive program used to generate calibration parameters for an imaging system that can be used to parameterize **oat-framefilt** and **oat-posifilt**. Detailed usage instructions are displayed upon program startup.

Signature

frame --> oat-calibrate

Usage

Usage: calibrate [INFO]
 or: calibrate TYPE SOURCE SINK [CONFIGURATION]
Camera calibration and homography generation routines.

INFO:

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

TYPE

 camera: Generate calibration parameters (camera matrix and distortion coefficients).
 homography: Generate homography transform between pixels and world units.

SOURCE:

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

Configuration Options

TYPE = camera

-k [--calibration-key] arg	The key name for the calibration entry that will be inserted into the calibration file. e.g. 'camera-1-homography'
-f [--calibration-path] arg	The calibration file location. If not is specified, defaults to './calibration.toml'. If a folder is specified, defaults to '<folder>/calibration.toml'. . If a full path including file in specified, then it will be that path without modification.
-s [--chessboard-size] arg	Int array, [x,y], specifying the number of inside corners in the horizontal and vertical demensions of the chessboard used for

calibration.

-w [--square-width] arg The length/width of a single chessboard square in meters.

TYPE = homography

-k [--calibration-key] arg The key name for the calibration entry that will be inserted into the calibration file. e.g. 'camera-1-homography'

-f [--calibration-path] arg The calibration file location. If not is specified, defaults to './calibration.toml'. If a folder is specified, defaults to '<folder>/calibration.toml'. If a full path including file is specified, then it will be that path without modification.

-m [--method] arg Homography estimation method. Defaults to 0.

Values:

- 0: RANSAC-based robust estimation method (automatic outlier rejection).
- 1: Best-fit using all data points.
- 2: Compute the homography that fits four points. Useful when frames contain known fiducial marks.

Kill

`oat-kill` - Issue SIGINT to all running Oat processes started by the calling user. A side effect of Oat's architecture is that components can become orphaned in certain circumstances: abnormal termination of attached sources or sinks, running pure sources in the background and forgetting about them, etc. This utility will gracefully interrupt all currently running oat components.

Usage

Usage: `kill`

Example

```
# Interrupt all currently running oat components  
oat kill
```

Clean

oat-clean - Programmer's utility for cleaning shared memory segments after following abnormal component termination. Not required unless a program terminates without cleaning up shared memory. If you are using this for things other than development, then please submit a bug report.

Usage

Usage: **clean** [INFO]
 or: **clean** NAMES [CONFIGURATION]
Deallocate the named shared memory segments specified by NAMES.

INFO:

--help	Produce help message.
-v [--version]	Print version information.
-q [--quiet]	Quiet mode. Prevent output text.
-l [--legacy]	Legacy mode. Append "_sh_mem" to input NAMES before removing.

Example

```
# Remove raw and filt blocks from shared memory after abnormal termination of  
# some components that created them  
oat clean raw filt
```

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:

```
-DUSE_FLYCAP=Off // Compile with support for Point Grey Cameras
-DBUILD_DOCS=Off // Generate Doxygen documentation
```

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 (once you start a new terminal):

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

If you get runtime link errors when you try to run an Oat program such as `>error while loading shared libraries: libboost_program_options.so.1.60.0` then you need to add the following entry to your `.bashrc`

```
export LD_LIBRARY_PATH=</path/to/boost>/stage/lib:$LD_LIBRARY_PATH
```

Dependencies

License compatibility

Oat is licensed under the GPLv3.0. Its dependencies' licenses are shown below:

- Eigen3: MPL
- Flycapture SDK: NON-FREE specialized license (This is an optional package. If you compile without Flycapture support, you can get around

this. Also, see the `GigE interface cleanup` entry in the TODO section for a potentially free alternative.)

- OpenCV: BSD
- ZeroMQ: LGPLv3.0
- Boost: Boost software license
- cptoml: Some kind of Public Domain Dedication
- RapidJSON: BSD
- Catch: Boost software license

These licenses do not violate the terms of Oat's license. If you feel otherwise please submit an bug report.

Eigen

Eigen is a template library for linear algebra that is required by some Oat component types:

- `oat-posidet rpg`

To build these component sub-types, you must install Eigen. Eigen can be obtained either from its source repo or via snapshot download [here](#).

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 ≥ 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 --with-filesystem
cd ..
sudo mv boost* /opt
```

Finally, if you are getting runtime linking errors, you will need to place the following in `.bashrc`

```
export LD_LIBRARY_PATH=<path to boost root directory>/stage/lib:$LD_LIBRARY_PATH
```

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, first install dependencies:

```
sudo apt-get install libgtkglext1 libgtkglext1-dev
```

Then, 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 and OpenGL support, the performance benefits will be automatic, no compiler options need to be set for Oat.

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 **carefully** read the installation instructions since it is a multistep process. Here are some additional hints that worked for me:
- 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 + Alt + F1`, and killing the X-server via `sudo service lightdm stop` (or equivalent), and running the runfile with root privileges.
- I have had the most success on systems that do not use GNOME or other fancy desktop environments. The install on lubunut, which uses LXDE as its desktop environment, was especially smooth.
- 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 have getting a `cv::exception` complaining that about `code=30(cudaErrorUnknown) "cudaGetDeviceCount(&device_count)"` or similar, run the affected command as root one time.

If OpenCV is compiled with CUDA support, the CUDA-enabled portions of the Oat codebase will be enabled automatically. No compile flags are required.

Note: GUI functionality is enhanced 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
```

The you can compile OpenCV using QT support by adding `-DWITH_QT=ON` flag to the cmake command below. QT functionality will then be used by Oat automatically.

Finally, to compile and install OpenCV:

```
# Install OpenCV's dependencies
sudo apt-get install build-essential # Compiler
sudo apt-get install cmake git # For building opencv and Oat
sudo apt-get install libgtk2.0-dev pkg-config libavcodec-dev libavformat-dev libswscale-dev
sudo apt-get install libv4l-dev # Allows changing frame rate with webcams
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/3.1.0.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 -DWITH_LIBV4L=ON -DCMAKE_BUILD_TYPE=RELEASE -DCMAKE_INSTALL_PREFIX=/usr/local ..

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

ZeroMQ

ZeroMQ is required by the following Oat components:

- oat-record
- oat-posisock

Download, compile, and install ZeroMQ as follows:

```
wget http://download.zeromq.org/zeromq-4.1.4.tar.gz -O tarzmq
tar -xf tarzmq
cd ./zeromq*
```

```
./configure --without-libsodium
make
sudo make install
sudo ldconfig
```

Additionally, you will need to download the ZeroMQ C++ binding (this is just a single header file) and place it somewhere that your compiler will find it.

```
wget https://raw.githubusercontent.com/zeromq/cppzmq/master/zmq.hpp
sudo mv zmq.hpp /usr/local/include/
```

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`

Performance

Oat is designed for use in real-time video processing scenarios. This boils down the following definition

The average execution time for an Oat dataflow network must not exceed the camera(s) image transfer period

If this condition is not met, then frames will eventually be dropped. There is no way around this. The guts of Oat consist of a simple, but very efficient message passing library that links together processing routines taken from a variety of sources (some written by me, some by third party projects such as OpenCV). The speed of each processing step is determined both by its computational complexity and deftness of implementation, both of which can vary quite a lot for different components. To see some rudimentary performance numbers for Oat components in isolation, have a look at these numbers. There is definitely room for optimization for some components. And, several components that are ripe for GPU implementation do not have one yet. This comes down to free time.

If anyone wants to try there hand at making some of the bottleneck components faster, please get in touch.

Outside of code optimization, there are a few things a user should be aware of to make efficient use of Oat, which are listed below.

Frames are slow

The first thing to know is that working with **frames** is orders of magnitude slower than working with **positions**. Therefore, minimizing the number of processing steps operating on **frames** is a good way to reduce computational requirements. Processing on **positions** is in the noise in comparison.

Parallelism

Increasing the number of components in your chain does not necessarily cause an appreciable an increase in processing time because Oat components run in parallel. Instead, up to the limit of the number of hyperthreads/GPU resources your computer supports, the slowest component in a dataflow network will largely determine the speed of the processing rather than the number of components within the processing network.

Resolution

Do you really need that 10 MP camera? Recall that increases in sensor resolution cause a power 2 increase in then number of pixels you need to smash into RAM, process, write to disk, and, probably, post process. Its really best to use the lowest resolution camera that suites your needs, both for the sake of real-time processing in Oat and your future sanity when trying to deal with those 30 GB video files.

Hard-disk

If you are saving video, then the write speed of your hard disk can become the limiting factor in a processing network. To elaborate, I'm just quoting my response to this issue:

Q: I also ran into an issue with RAM and encoding. I have 8 GB, and they fill up within about 20 seconds, then goes into swap.

A: I suspect the following is the issue:

$$(22 \text{ FPS} * 5 \text{ MP} * 24 \text{ bits/pixel}) / (8 \text{ bits/ byte}) = 330 \text{ MB/sec}$$

This (minus compression, which I'm admittedly ignoring, but is probably made up for by the time it takes to do the compression...) is the requisite write speed (in actuality, not theoretically) of your hard disk in order not to get memory overflow.

8 GB / 0.330 GB \approx 24 seconds.

The RAM is filling because your hard disk writes are not occurring fast enough. Oat is pushing frames to be written into a FIFO in main memory that the recorder thread is desperately trying to write to disk. Getting more RAM will just make the process persist for a bit longer before failing. I would get an SSD for streaming video to and then transfer those videos to a slower long term storage after recording.

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 Grey 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
```

These settings can then be reloaded after reboot using

```
sudo sysctl -p
```

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 Camera Configuration

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
 - Serial No.:

- IP: 192.168.1.1 (Static)
- Subnet mask: 255.255.255.0
- Default GW: 0.0.0.0
- Persistent IP: Yes

TODO

- [] Unit and stress testing
 - Unit tests for `libshmemdf`
 - * ~~Nominal data types, T~~
 - * Specializations for `Frames`
 - 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 synchronization is maintained, graceful exits, etc
- [] Position type correction and generalization to 3D pose
 - ~~It might be a good idea to generalize the concept of a position to a multi-positional element~~
 - ~~For things like the `oat-decorate`, `oat-posicom`, and potentially `oat-detect`, this could increase performance and decrease user script complexity if multiple targets common detection features needed to be tracked at once.~~
 - ~~Down side is that it potentially increases code complexity and would require a significant refactor.~~
 - ~~Additionally, position detection might no longer be stateless. E.g. think of the case when two detected objects cross paths. In order to ID the objects correctly in subsequent detections, the path of the objects would need to be taken into account (and there is not guarantee this result will be correct...). A potential work around is to have IDed ‘position groups’ with anonymous position members. This would get us back to stateless detection. However, it would make the concept of position combining hard to define (although that is even true now is just a design choice, really).~~
 - ~~EDIT: Additionally, there should certainly not be `Position2D` vs `Position3D`. Only `Position` which provides 3d specification with Z axis defaulting to 0.~~
 - ~~EDIT: In fact, positions should simply be generalize two a 3D pose. I’ve started a branch to do this.~~
- [] `oat-framefilt undistort`
 - Very slow. Needs an OpenGL or CUDA implementation
 - User supplied frame rotation occurs in a separate step from undistortion. Very inefficient. Should be able to combine rotation with camera matrix to make this a lot faster.
 - ~~EDIT: Also should provide an `oat-posifilt` version which only applies undistortion to position rather than the entire frame.~~
- [] Should components always involve a user IO thread?
 - For instance, some generalization of `oat-record ... --interactive`
 - For instance, it would be nice if PURE SINKs (e.g. `oat frameserve`) could have their sample clock reset via user input, without having to restart the program.

- For instance, it would be nice to be able to re-acquire the background image in `oat-framefilt bsub` without have to restart the program.
- Where should this come from? Command line input?
- EDIT: Shea and I have been brainstorming ways to use unix sockets to allow general runtime control of oat components. This will doing things like easy, in general.
- [] Add position history toggle in `oat-decorate`
 - Answer will come with solution to TODO above this one.
- [] Type deduction in `shmem Tokens`
 - Sources should have a static method for checking the token type of a given address.