PyCBC:
a device independent approach to CBC analysis

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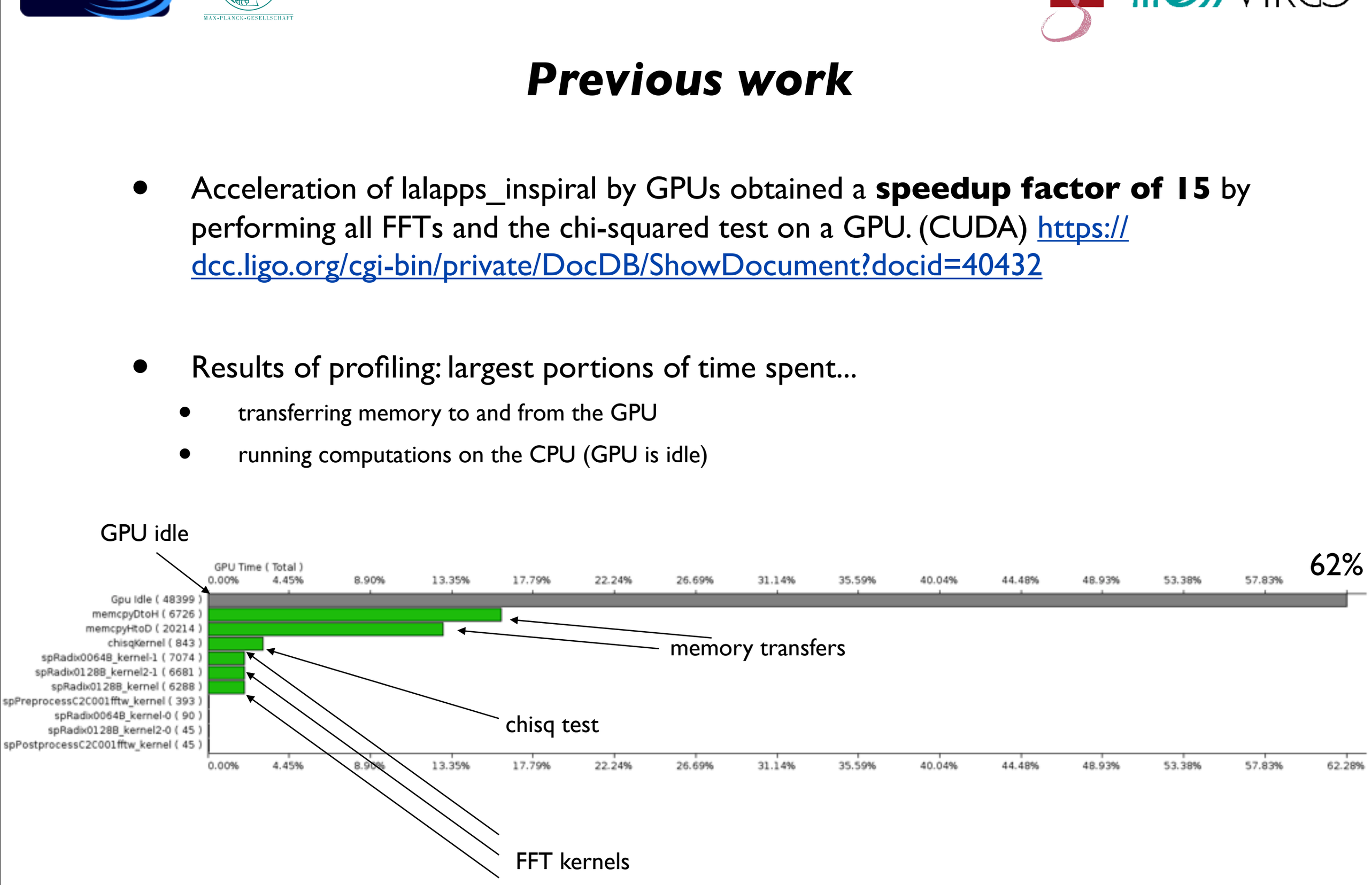
Previous work

- Acceleration of lalapps_inspiral by GPUs obtained a **speedup factor of 15** by performing all FFTs and the chi-squared test on a GPU. (CUDA) https://dcc.ligo.org/cgi-bin/private/DocDB/ShowDocument?docid=40432

- Results of profiling: largest portions of time spent...
  - transferring memory to and from the GPU
  - running computations on the CPU (GPU is idle)



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Previous work

- To optimize this, we need to implement more of the search engine (i.e., the whole hot loop) on the GPU.
  - the Budapest group has shown a possible **speedup factor of 92** by porting the search engine completely to the GPU. (OpenCl) http://www.grid.kfki.hu/twiki/bin/view/RmkiVirgo/GPU_inspiral

- Studying lalapps_inspiral, its procedural code structure and memory management do not meet the requirements of a sustainable framework for GPU accelerated CBC analysis.
  - necessary for targeting offline compute intensive searches (e.g., very large parameter spaces, coherent analyses, etc.)

- **Conclusion:** a redesign focused on transparent GPU acceleration (or future processing architectures) is needed

Requirements of a novel software framework for CBC analysis

- <u>Primary Requirements:</u>
  - flexible (easily reconfigurable from the top layer)
    - decouple algorithm from implementation
  - transparent processing on different architectures
  - transparent memory management
  - better readability (code shall be self explanatory ==> graph oriented processing framework)

- <u>Secondary Requirements:</u>
  - modularity and simple API
    - simple processing python objects (object oriented design)
    - new features are encapsulated in new objects or extensions of existing objects
    - robustness from unit tests
  - bindings to 3rd party libraries (e.g., lalsuite, fftw, numpy, etc.)
  - auto documentation (epydoc)

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People and sites involved in Pycbc development

- Albert Einstein Institute Hannover
  - Karsten Wiesner, Drew Keppel, Badri Krishnan
- Syracuse University
  - Duncan Brown, Alex Nitz,
- University of Wisconsin - Milwaukee
  - Adam Mercer
- Abilene Christian University
  - Josh Willis
- MTA KFKI RMKI Budapest
  - Bence Somhegyi, Gergely Debreczeni

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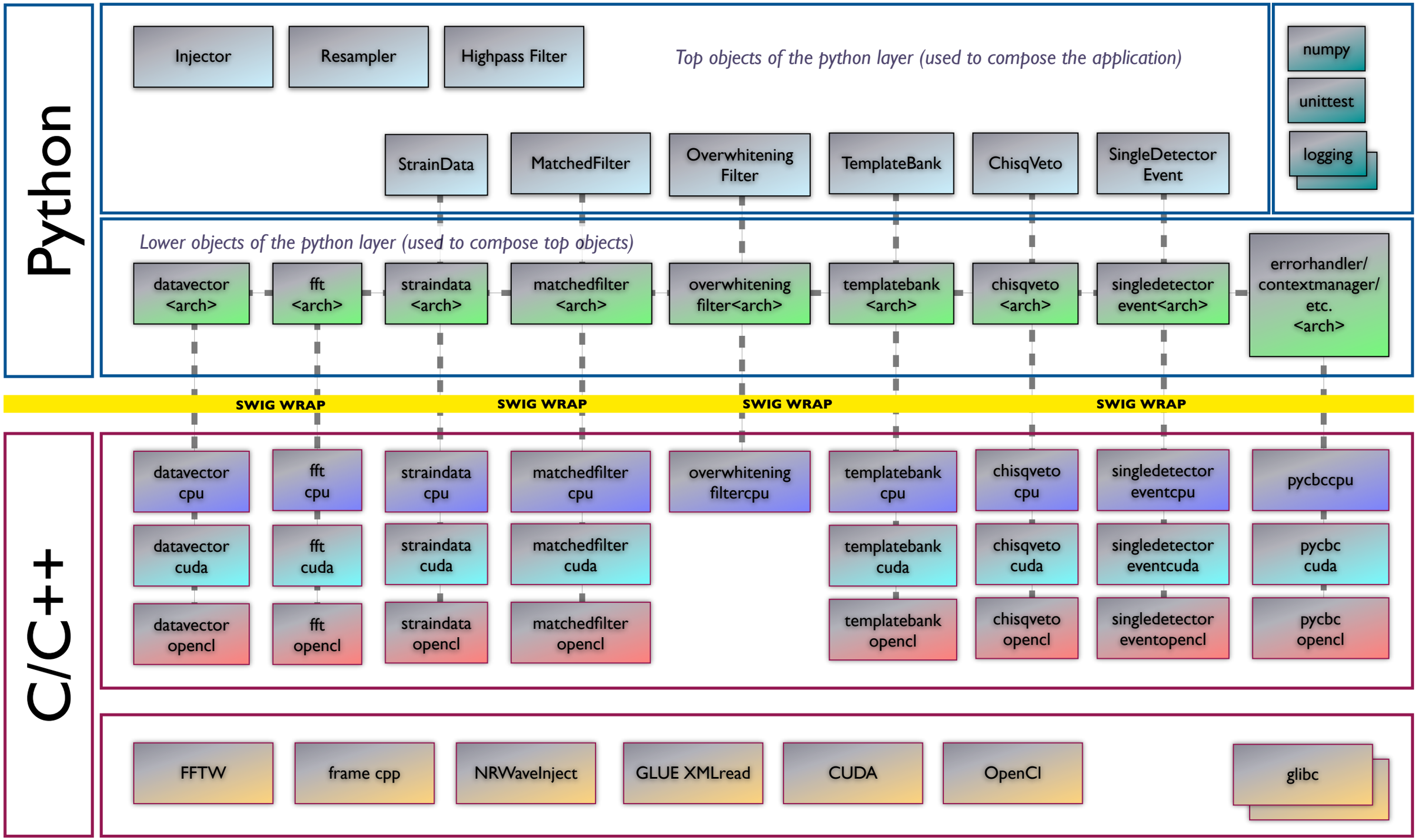
Pycbc Layers and packages



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Code example: Application layer of the test prototype

```
import sys
import random

# preliminary hard coded path to packages
sys.path.append('/Users/kawies/dev/src/pycbc')

from pycbc.pycbc import CPUDeviceContext as ProcessingTargetContext

from pycbc.straindata.straindata_cpu import StrainDataCpu as StrainData
from pycbc.templatebank.templatebank_cpu import TemplateBankCpu as TemplateBank
from pycbc.matchedfilter.matchedfilter_cpu import MatchedFilterCpu as
MatchedFilter
from pycbc.chisqveto.chisqveto_cpu import ChisqVetoCpu as ChisqVeto
from pycbc.singledetectorevent.singledetectorevent_cpu import
SingleDetectorEventCpu as SingleDetectorEvent
from pycbc.datavector.datavectorcpu import real_vector_single_t as
SnrResultTimeSeries

import logging

logging.basicConfig(level=logging.DEBUG,
                    format='%(name)s %(asctime)s %(levelname)s %(message)s',
                    filename='pycbc_min_pipeline.log',
                    filemode='w')

logger= logging.getLogger('pycbc.main_script')


start_message = 'Starting pycbc single detector minimal pipeline ...'
logger.debug(start_message)
print start_message

# setup straindata
search_time = 128 # typ design spec: 2048
sample_freq = 256 # typ design spec: 4096
length =      search_time * sample_freq
segments = 15
gps_start_time= 871147532
gps_end_time= gps_start_time + search_time
interferometer = "H1"

# setup chisq veto
chisq_bins = 16

# setup event finder
snr_threshold = 5.5

with ProcessingTargetContext(1) as context:

    strain_data = StrainData(gps_start_time, gps_end_time,
                        segments, sample_freq,
                        interferometer, context)

    # initialize straindata w/ noise
    for i in range(length):
        tmp = random.uniform(-1,1)
        strain_data.time_series[i] = tmp

    # convert straindata to single precision
    strain_data.convert_to_single_preci()

    # segmenting straindata and transform into frequency domain
    strain_data.perform_fft_segments()

    # transfer straindata to appropriate memory space on target device
    strain_data.render()

    # create 5 templates (testing the iterator of TemplateBank)
    bank = TemplateBank(5, strain_data.segments_length,
                           strain_data.segments_delta_x, context)
    logger.debug("instantiated TemplateBank w/ waveform length: {0}"
                 .format(bank.waveform_length))

    # create matched filter (only generate_snr() has to be implemented
    # for the minimal pipeline)
    matched_filter = MatchedFilter(strain_data.segments_length, context)
    logger.debug("instantiated MatchedFilter w/ length: {0}".format
    (matched_filter.length))

    # instantiate result vectors
    snr = SnrResultTimeSeries(strain_data.segments_length,
                              strain_data.segments_delta_x, context)
    logger.debug("instantiated SnrResultTimeSeries as {0}".format(repr(snr)))

    # instantiate chisq_veto
    chisq_veto = ChisqVeto(strain_data.segments_length, chisq_bins, context)
    logger.debug("instantiated ChisqVeto as {0}".format(repr(chisq_veto)))

    # instantiate event finder
    events = SingleDetectorEvent(snr_threshold, context)
    logger.debug("instantiated SingleDetectorEvent as {0}".format(repr(events)))

    # filter the data against the template bank
    for template in bank:
        htilde = bank.perform_generate_waveform(template)
        for stilde in strain_data:
            matched_filter.perform_generate_snr(stilde, htilde, snr)
            if matched_filter.max() > snr_threshold:
                chisq = chisq_veto.generate_chisq(snr, qtilde)
                events.find_events(snr, chisq)

    # cluster the events across the template bank
    events.cluster_events(0.1)
    events.write("/path/to/output.xml")

    # leaving the ProccessingTargetContext NOW (destroy the device context)
    ###########################################################################

end_message = '... end of pycbc single detector minimal pipeline.'
logger.debug(end_message)
print end_message
```

Pycbc signal processing graphs

- Shows processing graph from the application programmers viewpoint
- Shows how functions and kernels are called and where they live (layers)
- Shows how data flows
- Shows memory objects
  - Where they live
  - Who is the owner
  - Which kind of data do they hold
  - How long they live

Pycbc signal processing graph for very early test prototype

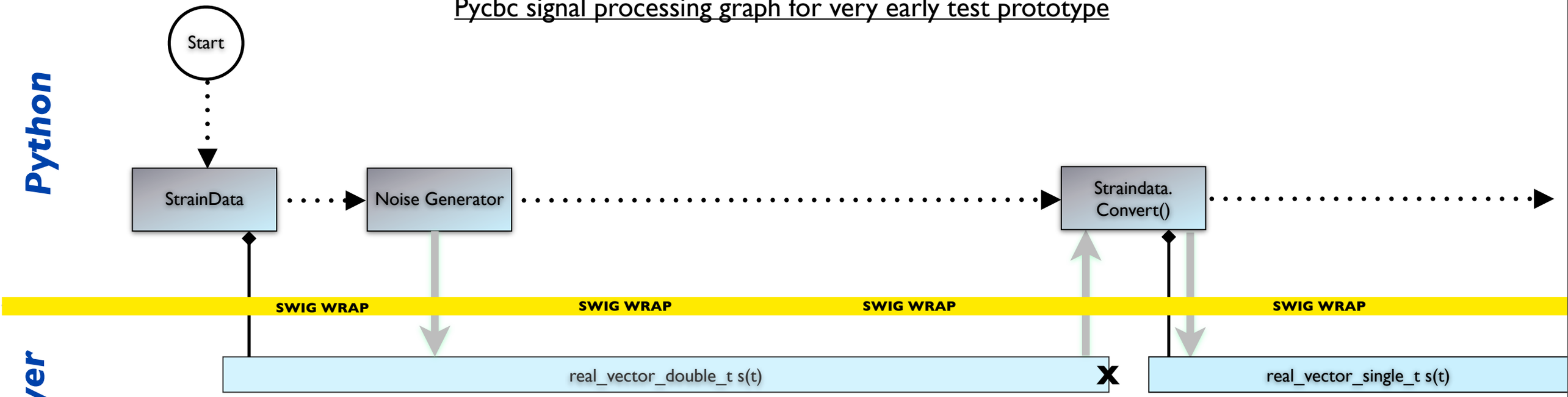
Python

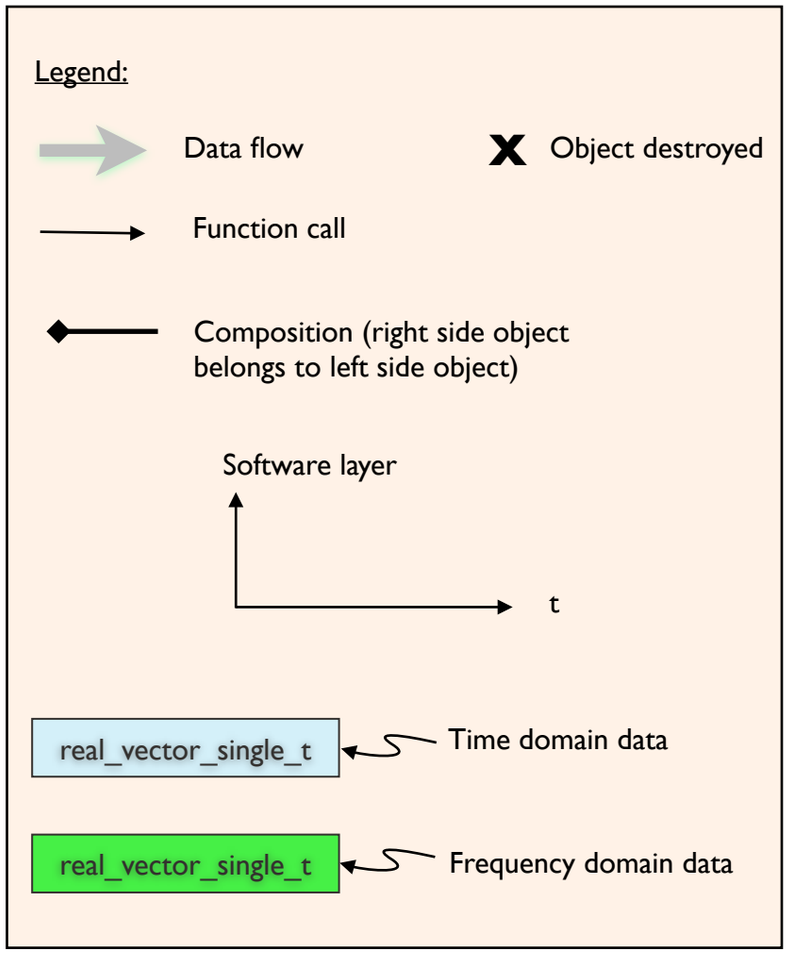
clayer

GPU

Lal

files





Pycbc signal processing graph for very early test prototype

Python

layer

GPU

GLUE/ Lal

files

one fixed equal mass system 2 * 1.4 M

Straindata. Segmenting()

TemplateBank

Straindata. DataTransfer()

SWIG WRAP

SWIG WRAP

SWIG WRAP

SWIG WRAP

_vector_single_t s(t)

[typ. 15 segments freq data from typ 256s timedomain data -> (N=2^20)] complex_vector_single_t stilde(f) (Python list of datavector_cpu)

FFTs of overlapping input data

render

[ ] complex_vector_single_t stilde(f)

Pycbc signal processing graph for very early test prototype

Python

for 5 templates in bank:

one waveform

TemplateBank

for 15 Segments in data:

MatchedFilter

If(max>thresh)

SWIG WRAP

SWIG WRAP

SWIG WRAP

SWIG WRAP

clayer

[] complex_vector_single_t stilde(f) (Python list of datavector_cuda)

complex_vector_single_t htilde

GPU

Generate_snr

Find_maximum

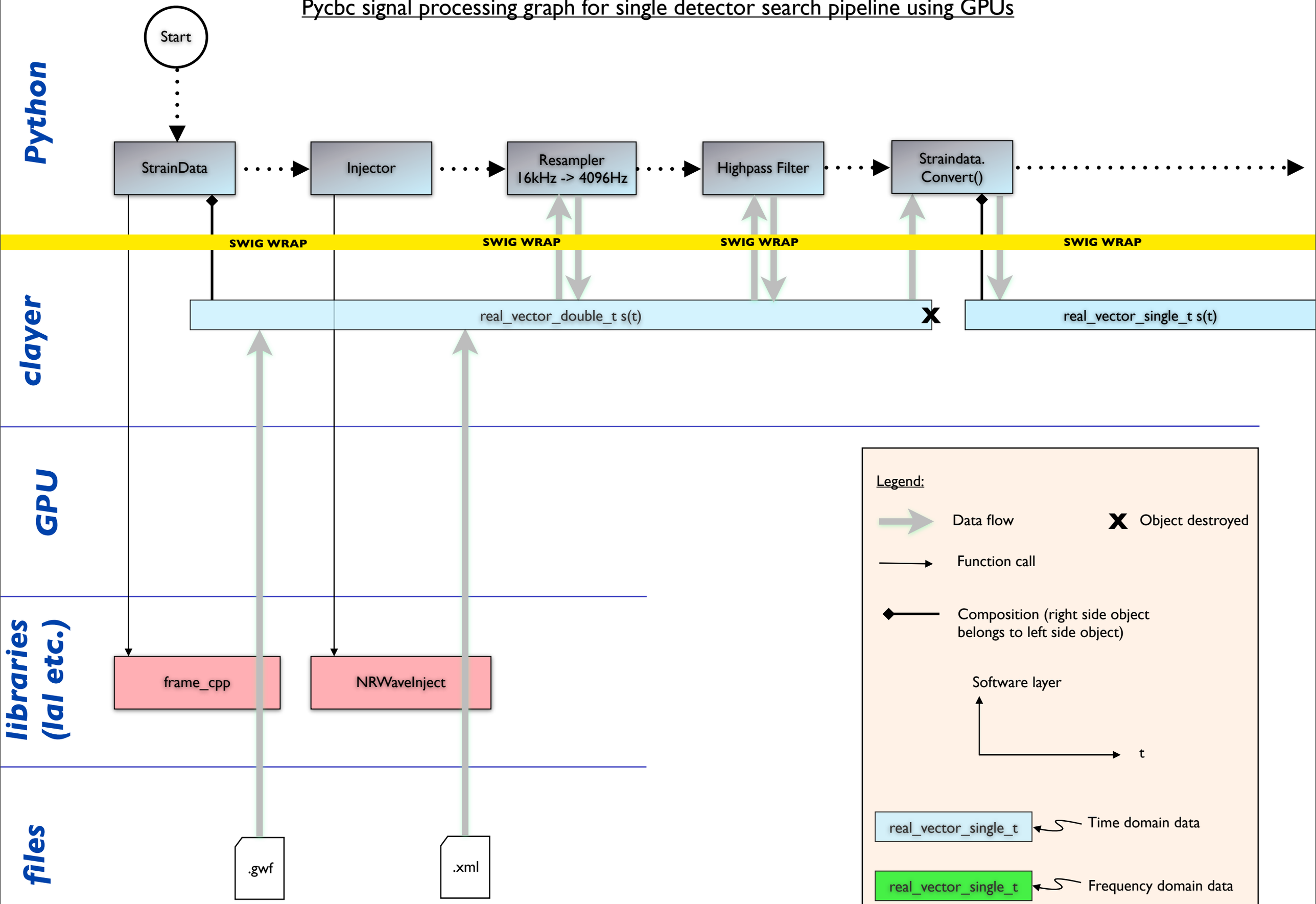
complex_vector_single_t qtilde (snr tilde)

FFT

real_vector_single_t q (snr)

```
# filter the data against the template bank
for template in bank:
    htilde = bank.perform_generate_waveform(template)
    for stilde in strain_data:
        matched_filter.perform_generate_snr(snr, stilde, htilde)
        matched_filter.perform_find_max(max, snr)
```

Pycbc signal processing graph for single detector search pipeline using GPUs



Pycbc signal processing graph for single detector search pipeline using GPUs

Python

[typ. 10^3] ParameterSpace

Straindata. Segmenting()

Overwhitening Filter

Straindata *= Overw.-Filt

TemplateBank

TemplateBank. PreConditionData()

Overwhiten render()

Straindata. render()

SWIG WRAP

SWIG WRAP

SWIG WRAP

SWIG WRAP

_vector_single_t s(t)

[typ. 15 segments freq data from typ 256s timedomain data -> (N=2^20)] complex_vector_single_t stilde(f) (Python list of datavector_cpu)

FFTs of overlapping input data

real_vector_single_t 1/Sn(f) alias inverse PSD alias overwhitening filter N=2^20

median - inverse

__mul()

render

render

IFFT - truncate - FFT (inplace)

[ ] complex_vector_single_t stilde(f)

real_vector_single_t 1/Sn(f)

GLUE XMLread

.xml

clay

GPU

GLUE/ Lal

files

Pycbc signal processing graph for single detector search pipeline using GPUs

Python

GPU

clayer

```
for template in bank:
```

```
for stilde in data:
```

[ ] mParameterSpace

TemplateBank

ChisqVeto

MatchedFilter

If(max>thresh)

ChisqVeto

SingleDetector Event

SWIG WRAP

SWIG WRAP

SWIG WRAP

SWIG WRAP

[] complex_vector_single_t stilde(f) (Python list of datavector_cuda)

real_vector_single_t 1/Sn(f) (N=2^20)

Generate_filter_waveform

complex_vector_single_t htilde

Compute_freq_bins

complex_vector_single_t qtilde bin (snr tilde)

Generate_snr

Find_maximum

Generate_chisq

Find_Events

complex_vector_single_t qtilde (snr tilde)

real_vector_single_t (chisq)

FFT

real_vector_single_t q (snr)

```
# filter the data against the template bank
for template in bank:
    bank.generate_filter_waveform(template)
    chisq.compute_frequency_bins(template.htilde, gpu_data.overwhitenf)
    for stilde in gpu_data.strain:
        matched_filter.perform_generate_snr(snr, stilde, htilde)
        if matched_filter.max() > 5.5:
            chisq = chisq_veto.generate_chisq(snr, qtilde)
            events.find_events(snr, chisq)

# cluster the events across the template bank
events.cluster_events(0.1)
events.write( "/path/to/output.xml" )
```

Pycbc signal processing graph for single detector search pipeline using GPUs