mimoCoRB

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CHAPTER

ONE

MIMOCORB - MULTIPLE-IN MULTILE-OUT CONFIGURABLE RING BUFFER: OVERVIEW

mimoCoRB: multiple-in multiple-out Configurable Ring Buffer

The package **mimoCoRB** provides a central component of each data acquisition system needed to record and pre-analyse data from randomly occurring processes. Typical examples are waveform data as provided by detectors common in quantum mechanical measurements, or in nuclear physics, particle physics and astro particle physics, e. g. photo tubes, Geiger counters, avalanche photo-diodes or modern SiPMs.

The random nature of such processes and the need to keep read-out dead times low requires an input buffer for fast collection of data and an efficient buffer manager delivering a constant data stream to the subsequent processing steps. While a data source feeds data into the buffer, consumer processes receive the data to filter, reduce, analyze or simply visualize the recorded data. In order to optimally use the available resources, multi-core and multi-processing techniques must be applied. Data consumers may be obligatory ones, i. e. data acquisition pauses if all input buffers are full and an obligatory consumer is still busy processing. A second type of consumers (random consumers or "observers") receive an event copy from the buffer manager upon request, without interrupting the data acquisition process. Typical examples of random consumers are displays of a subset of the wave forms or of intermediate analysis results.

This project originated from an effort to structure and generalize data acquisition for several experiments in advanced physics laboratory courses at Karlsruhe Institute of Technology (KIT) and has been extensively tested unter Ubuntu Linux.

As a simple demonstration, we provide data from simulated signals as would be recorded by a detector for cosmic muons with four detection layers. Occasionally, such muons stop in an absorber between the 2nd and 3rd layer, where they decay at rest and emit a high-energetic electron recorded as a 2nd pulse in one or two of the detection layers. After data acquisition, a search for typical pulse shapes is performed and data with detected double pulses are selected and copied into a second buffer. A third buffer receives data in a reduced format which only contains the parameters of accepted pulses. These data and the wave forms of all double-pulses are finally stored on disk. Such an application is a very typical example of the general process of on-line data processing in modern physics experiments and may serve as a starting point for own projects.

1.1 Description of components

In order to decouple the random occurrence of "events" one needs a buffer capable of rapidly storing new incoming data and delivering a constant data stream to subsequent consumer processes. This is typically implemented as a first-in, first out ringbuffer providing storage space in memory for incoming data, which is released and overwritten by new data when all consuming processes have finished.

As digital filtering of incoming data may be very CPU intensive, multi-processing and multi-core capable components are needed to ensure sufficient compute power to process and analyze data. *mimoCoRB.mimo_buffer* implements such a buffer allowing multiple processes to read ("multiple out") or write ("multiple in") to a shared buffer space.

Because processing of the data, i.e. digital filtering, selection, compression and storage or real-time visualization of the data can be a complex workflow, buffers may be arranged in chains where one or several reader processes of a buffer write to one or several output buffer(s).

The central component takes care of memory management and access control provided by the class **newBuffer**. To control the data flow in a full data acquisition suite, three types of access are needed, implemented as **Writer**, **Reader** and **Observer** classes. Readers of the same type are grouped together for multi-processing of compute-intense tasks and form a Reader-group. Observers receive only a sub-set of the data and are mainly intended to be used for visual inspection or graphical representation of samples of the recorded or processed data.

Processes for data provisioning from front-end hardware or from other sources, like disk files, web streams or simulation, rely on the Writer class; similarly, processes reading data for filtering and transfer to subsequent buffers or to analyse, transform or extract data to storage media use the Reader class. Note that the buffer manager ensures that every slot assigned to a Reader (or a group of Readers) is actually processed; therefore, input to a buffer blocks if the buffer is filled up completely. The Writer class resumes data input as soon as a Reader or member of a Reader-group has finished processing and thus freed a slot in the buffer.

Multiprocessing is enabled by use of the *shared_memory* module of the *multiprocessing* package available since Python 3.8 for direct access to shared memory across processes. Other modules of the package (*Process*, *Lock*, *Event*, and *SimpleQueue* or *Queue*) are used to create and control sub-processes and for signalling and message or data exchange across processes.

The format of data stored in the buffers is based on structured *numpy* arrays with (configurable) field names and *numpy dtypes*. Each buffer entry is also associated with a unique number, a time stamp and a deadtime fraction to be provided by the initial data producer. The deadtime accounts for inefficiencies of the data acquisition due to processing in *mimoCoRB*. These metadata are set by the initial producer and must not be changed at a later stage in the processing chain.

1.2 Simple application example

An application example of *mimo_buffer* is shown below; it is also provided as a unit test. The set-up is as follows:

Two ring buffers are defined:

- input Buffer RB_1: 10 ch x 1024 slots (int32)
- output Buffer RB_2: 10 ch x 2 slots/ch (float64)

Simple data is filled into RB_1, copied and extended by a process writing data into RB_2, and finally a reader process to check integrity and completeness of the data. The most complex part of the code is in function *run_control()*, which demonstrates how to set up the buffers, define Reader and Writer instances and start the parallel processes for generating, processing and reading the data.

The example including comment lines for explanation is shown here:

```
import time
import unittest
import numpy as np
from multiprocessing import Process, Value
from mimocorb import mimo_buffer as bm

# global variables
N_requested = 1000  # number of data injections ("events")
Time_tick = 0.001   # time between events
Ncpu1 = 2           # number of parallel analyzer processes
```

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```
def data_generator(sink_dict):
  """writes continuously rising integers to buffer specified in sink_dict
  """
  sink = bm.Writer(sink_dict)
  n=0
  # inject data
  for x in range(N_requested):
      buffer = sink.get_new_buffer() # get new buffer and pass last item
      #  random wait for next data item
      time.sleep(-Time_tick*np.log(np.random.rand() ))
      # fill "data"
      n += 1
      buffer[:] = n
  # process last data item
  sink.process_buffer()

def analyzer(source_dict, sink_dict):
  """read from source and write first element and a time difference to sink
  """
  source = bm.Reader(source_dict)
  sink = bm.Writer(sink_dict)
  start_time = time.time()

  while True:
      input_data = source.get()
      output_data = sink.get_new_buffer()
      # process data
      output_data[0] = input_data[0]
      # mimick processing time
      time.sleep(2*Time_tick)
      output_data[1] = time.time() - start_time

      #
      sink.process_buffer()

def check_result(source_dict, res):
  """reads RB_2 and sum up the integer content

     sum is returned as shared memory Value-object
  """
  source = bm.Reader(source_dict)
  sum_rb = 0
  while True:
      input_data = source.get()
      res.value +=int(input_data[0])

def run_control():
  """Setup buffers, start processes and shut_down when 1st writer done
  """

  # Create ring buffers: #2: 10 channel, 2 value per channel
```

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```
  #    (1: buffer content; 2: time difference as int)
  #    d_type = [('chA', np.float)]  #not necessary: always the same type
  generator_buffer = bm.NewBuffer(10, 1, np.int32)
  eval_buffer = bm.NewBuffer(10, 2, np.float32)

  # create readers first
  source_dic_gen = generator_buffer.new_reader_group()
  source_dic_eval = eval_buffer.new_reader_group()

  # Create worker processes (correct sequence: first action as last)
  process_list = []
  #  evaluation to test ring buffer behavior
  result = Value('i', 0)   # int variable in shared meomry
  process_list.append(Process(target=check_result,
                              args=(source_dic_eval, result)))
  # data transfer between the 2 buffers: generator_buffer -> eval_buffer
  sink_dic_eval = eval_buffer.new_writer()
  # work with all cpu's requested
  number_of_workers = Ncpu1
  for i in range(number_of_workers):
      process_list.append(Process(target=analyzer,
                                  args=(source_dic_gen, sink_dic_eval)))

  # fill buffer (generator_buffer) with data first
  sink_dic_gen = generator_buffer.new_writer()
  process_list.append(Process(target=data_generator,
                              args=(sink_dic_gen,)))

  for p in process_list:
      p.start()

  run_active = True
  while run_active:
     run_active = False if process_list[-1].exitcode==0 else True
     time.sleep(0.1)  # wait
  time.sleep(0.1)  # some grace-time for readers to finish

  generator_buffer.shutdown()
  eval_buffer.shutdown()
  del generator_buffer, eval_buffer

  for p in process_list:
      p.join()

  return result.value

class RPTest(unittest.TestCase):

  def test_process(self):
      # start python test module and check result
      a = run_control()
      expected_result = N_requested*(N_requested+1)//2
```

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```
            # expected result: sum(i); i = 1, N_requested
      self.assertEqual(a, expected_result)

if __name__ == "__main__":
  unittest.main(verbosity=2)
#    print(process_buffer())
```

CHAPTER

TWO

ACCESS CLASSES IN THE MODULE *BUFFER_CONTROL*

To facilitate user interaction with the buffer manager a set of additional classes is provided in the module *buffer_control* to set-up and manage cascades of ringbuffers and the associated functions for filling, filtering and extracting data. These classes are also interesting for developers wanting to help improving the package.

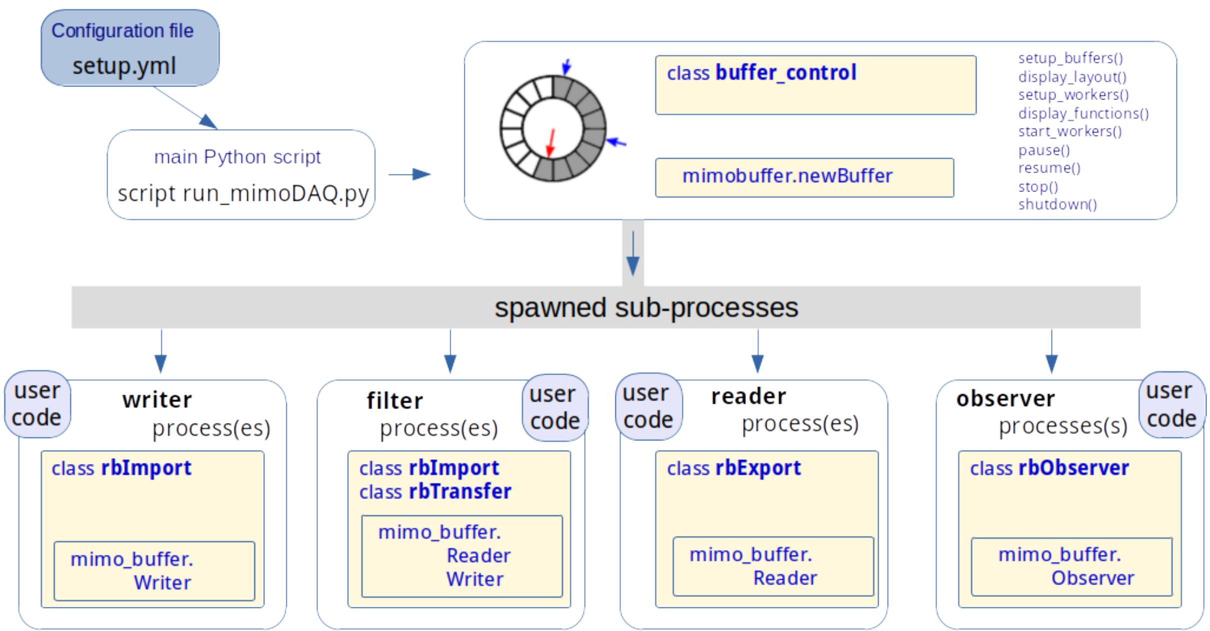
The classes are:

- ***class buffer_control***
  Set-up and management of ringbuffers and associated sub-processes. This is the overarching class with access to all created buffers and sub-processes.
- ***class rbImport***
  Read data from source (front-end like a PicoScope USB oscilloscope, of from file or simulation) and put data in a mimo_buffer. Data input is handled by a call of a user-supplied Python generator (i.e. via 'yield()') for data and metadata.
- ***class rbTransfer***
  Read data from a mimo_buffer, filter and/or reformat data and write to output mimo_buffer(s). Data is provided as the argument to a user-defined filter function returning *None* if data is to be discarded, a number if data is to be copied to another buffer, or - optionally - a list of transformed data records produced from processed input data. If such data are provided, a respective number of ringbuffers as destination must be configured.
- ***class rbExport***
  Read data from mimo_buffer and analyze (with user-supplied code), without writing to another ringbuffer. Data is expected to be provided by a Python generator in the __call__() method of the class yielding a tuple of data and metadata.
- ***class rbObserver***
  Deliver data from a buffer to an observer process. A tuple (data, metadata) is provided by a Python generator implemented in the __call__() method of the class.
- ***class rb_toTxtfile*:**
  Save mimo_buffer data to a file in csv-format. The header line of this file contains the keys of the respective columns, which are derived from the datatype of the structured ringbuffer array. Aliases for improved clarity can be provided in the configuration file.
- ***class rb_toParquetfile*:**
  Save mimo_buffer data to an archive in *tar* format; each data record is packed in Parquet format.
- ***class run_mimoDAQ***
  Setup and run a Data Acquisition suite with the mimoCoRB buffer manager. The layout of ringbuffers and associated functions are defined in a configuration file in *yaml* format. All configured functions are executed as worker processes in separate sub-processes and therefore optimal use is made of of multi-core architectures.

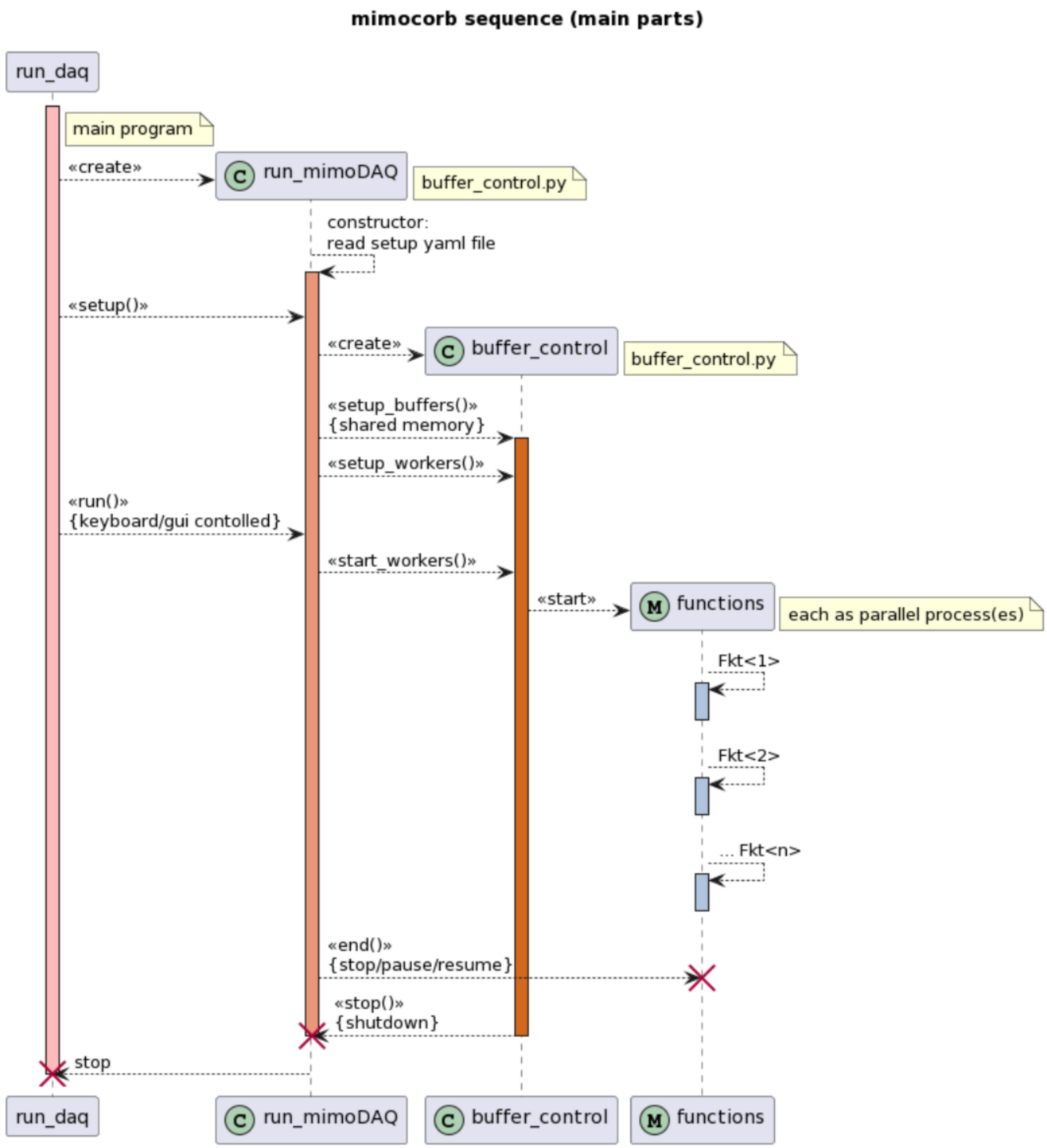
- **class** ***bufferinfoGUI*****:**
  A graphical interface showing buffer rates and status information and providing some control buttons interacting with the run_mimoDAQ class.

These classes shield much of the complexity from the user, who can thus concentrate on writing the pieces of code need to acquire and process the data. The access classes expect as input lists of dictionaries with the parameters of buffers to read from (**source_list**), to write to (**sink_list**) or to observe (**observe_list**). An additional dictionary (**config_dict**) provides the parameters needed for the specific functionality, for example names of functions to read, filter or manipulate data or the names of target files. The interface for passing data between the user-defined functions and ringbuffers relies on Python generators (i.e. the *yield* instruction).

The overarching class **buffer_control** provides methods to setup buffers and worker processes and to control the data acquisition process. The methods collected in the class *run_mimoDAQ*, in particular the function **run_mimoDAQ**, contains the code needed to run a real example of a data-acquisition suite defined in a configuration file specifying the associated, user-defined functions for data provisioning, filtering and storage. *run_mimoDAQ* is controlled either by keyboard commands of from a graphical user interface; pre-defined conditions on the total number of events processed, the duration of the data taking run or finishing of the writer process to the first buffer due to source exhaustion can also be defined to end data taking. The class structure and dependencies are shown in the figure below.



A sequence diagram of a a typical application, shown below, illustrates illustrates the interplay and dependencies of the classes described above. The script *run_daq.py* creates an instance of *run_mimoDAQ* and starts its *run()*-method. The interction with the user-supplied filter functions is handled by methods of the class *buffer_control*.



For complex setups and longer data-taking periods it is important to gain a quick overview of the status of all buffers and to monitor long-term stability. Therefore, a graphical display with the processing rate of all buffers is provided by the class **bufferinfoGUI**. A text window receives frequent updates of the number of events processed by each buffer and of the buffer fill-levels. Klickable control buttons send information via a dedicated command queue to the calling process *run_mimoDAQ* and enable pausing, resuming and controlled ending of the data-acquisition processes.

The suggested structure of the project work-space for mimiCoRB applications is as follows:

```
|--> <user working directory>       # the main configuration script resides here
                |
```

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```
                  | --> modules     # project-specific, user-supplied python code
                  | --> config      # configuration files in yaml format
                  | --> target      # output of data-acquisition run(s)
```

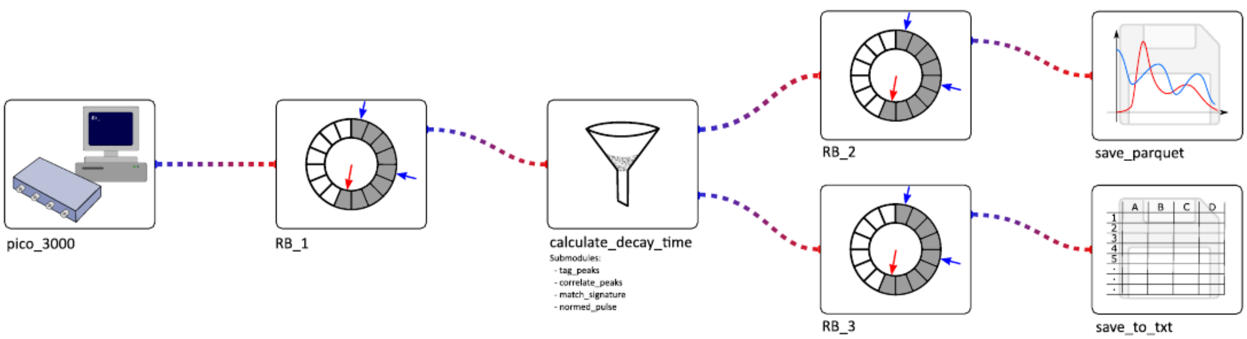
For illustration and as a starting point for own applications, a stand-alone example is provided as part of the package, as described in the following section.

2.1 Application example

The subdirectory *examples/* contains a rather complete application use case. It runs stand-alone and uses as input simulated waveform data of short pulses in a scintillator detector. The simulated physics process corresponds to signatures produced by cosmic muons. Of particular interest in this case are (rare) signatures with a double-pulse structure, where the first pulse originates from a detected muon and the second one from a decay electron of a muon that has been stopped in or near a detection layer.

Examples of code snippets and configuration data are provided in the subdirectories *examples/modules/* and *examples/config/*, respectively. Waveform data, as provided by, for example, a multi-channel digital oscilloscope, are generated and filled into the first one of a cascaded set of three ringbuffers. The raw data are analyzed, and accepted data with a double-pulse signature are selected and directly passed on to a second ringbuffer. A third buffer contains only the information on found signal pulses; a result file in *csv* format contains the data extracted from this buffer. Configuration files and the recorded data files are stored in the subdirectory *examples/target/<projectname>_<date_and_time>*.

A graphical representation of the set-up is shown in the figure below [source: Master's Thesis Christoph Mayer, ETP 2022]. Note that the oscilloscope is replaced by a signal simulation in the provided example.



The buffer layout and the associated functions are defined in the main configuration file *simulsource_setup.py*, which serves as the input to the execution script *run_daq.py* in the top-level directory of the package. The *python* files *simulation_source.py*, *liftime_filter.py* and *save_files.py* contain the user code for data generation, analysis and filtering and extraction of the finally accepted data to disk files. The *.yaml* files *simulation_config.yaml* and *save_lifetimes.yaml* contain configurable parameters provided to these functions.

This example is executed form the directory *examples/* by entering:

> *../run_daq.py simulsource_setup.yaml*

The code needed to run a data acquisition based on the package *mimocorb.buffer_control.run_mimoDAQ* is shown here:

```python
# script run_daq.py

from mimocorb.buffer_control import run_mimoDAQ
daq = run_mimoDAQ()
```

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```
daq.setup()
daq.run()
```

The input *yaml* file for the example provided as part of the package looks as follows:

```
#  Application example for mimoCoRB
#  --------------------------------

RingBuffer:
  # define ring buffers
  - RB_1:
      # raw input data buffer (waveforms from PicoScope, file_source or simulation_
↪source)
      number_of_slots: 128
      channel_per_slot: 4250
      data_type:
          1: ['chA', "float64"]
          2: ['chB', "float64"]
          3: ['chC', "float64"]
          4: ['chD', "float64"]
  - RB_2:
      # buffer with accepted signatures (here double-pulses)
      number_of_slots: 128
      channel_per_slot: 4250
      data_type:
          1: ['chA', "float64"]
          2: ['chB', "float64"]
          3: ['chC', "float64"]
          4: ['chD', "float64"]
  - RB_3:
      # buffer with pulse parameters (derived from waveforms)
      number_of_slots: 32
      channel_per_slot: 1
      data_type:
          1: ['decay_time', "int32"]
          3: ['1st_chA_h', "float64"]
          4: ['1st_chB_h', "float64"]
          5: ['1st_chC_h', "float64"]
          6: ['1st_chA_p', "int32"]
          7: ['1st_chB_p', "int32"]
          8: ['1st_chC_p', "int32"]
          9: ['1st_chA_int', "float64"]
          10: ['1st_chB_int', "float64"]
          11: ['1st_chC_int', "float64"]
          12: ['2nd_chA_h', "float64"]
          13: ['2nd_chB_h', "float64"]
          14: ['2nd_chC_h', "float64"]
          15: ['2nd_chA_p', "int32"]
          16: ['2nd_chB_p', "int32"]
          17: ['2nd_chC_p', "int32"]
          18: ['2nd_chA_int', "float64"]
          19: ['2nd_chB_int', "float64"]
```

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```
        20: ['2nd_chC_int', "float64"]
        21: ['1st_chD_h', "float64"]
        22: ['1st_chD_p', "int32"]
        23: ['1st_chD_int', "float64"]
        24: ['2nd_chD_h', "float64"]
        25: ['2nd_chD_p', "int32"]
        26: ['2nd_chD_int', "float64"]

Functions:
  # define functions and assignments
  - Fkt_main:
      config_file: "config/simulation_config.yaml"
  - Fkt_1:
       file_name: "modules/simulation_source"
       fkt_name: "simulation_source"
       num_process: 1
       RB_assign:
           RB_1: "write"
  - Fkt_2:
       file_name: "modules/lifetime_filter"
       fkt_name: "calculate_decay_time"
       num_process: 2
       RB_assign:
           RB_1: "read"     # input
           RB_2: "write"    # waveform to save (if double pulse was found)
           RB_3: "write"    # pulse data
  - Fkt_3:
      file_name: "modules/save_files"
      fkt_name: "save_to_txt"
      config_file: "config/save_lifetime.yaml"
      num_process: 1
      RB_assign:
           RB_3: "read"     # pulse data
  - Fkt_4:
      file_name: "modules/save_files"
      fkt_name: "save_parquet"
      num_process: 1
      RB_assign:
           RB_2: "read"     # waveform to save
```

The configuration file referenced in the line *config_file: "config/simulation_config.yaml"* provides the information needed by the user-supplied functions.

The example coming with this package contains two more convenience functions, one for an observer process displaying a random sample of waveforms in an oscilloscope display, and a second one for on-line analysis and histogramming of buffer data. The addendum to the configuration looks as follows:

```
- Fkt_5:
     file_name: "modules/plot_waveform"
     fkt_name: "plot_waveform"
     num_process: 1
     RB_assign:
          RB_2: "observe"  # double pulse waveform
```

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```
- Fkt_6:
    file_name: "modules/plot_histograms"
    fkt_name: "plot_histograms"
    num_process: 1
    RB_assign:
       RB_3: "read"  # pulse parameters
```

These additional functions rely on the modules *mimocorb.plot_buffer* and *mimocorb.histogram_buffer*, which provide animated displays of waveforms similar to an oscilloscope and a histogram package for life-updates of frequency distributions of scalar variables. Configuration parameters needed for the functions associated to the ringbuffers can either be specified as a *yaml* block under a keyword in the general configuration file that is assigned to the function *Fkt_main* in the example above. Alternatively, a dedicated configuration file can be specified in a separate *yaml* file, as is done for function *Fkt_3* in the example. This latter feature is particularly useful if the same function code is used to handle data from different buffers, e.g. writing buffer contents to a file in *csv* format.

The functions are started as sub-processes and have a unique interface. Lists of dictionaries provide the necessary information to connect to the buffer manager via the *Writer*, *Reader* or *Observer* classes of the package. This information comprises the pointer to the shared buffer manager as well as pointers to instances of the functions *Event()* or *Queue()* from the multiprocessing package to enable communication and data transfers across processes. A further dictionary (*config_dict*) provides the function-specific parameters discussed previously. The keyword dictionary *rb_info* specifies whether writer, reader or observer functionality is required. It contains a copy of the ring-buffer assignment block („RB_assign:") from the main setup file on function level. Its purpose is to facilitate the ring-buffer access part within a function or class. The function interface looks as follows:

```
def <function_name>(
  source_list=None, sink_list=None, observe_list=None, config_dict=None, **rb_info):
```

This interface must be respected by any user function. The argument list must also be passed to instances of the access classes *rbImort*, *rbExport*, *rbTransfer* or *rbObserve*. An example of a user fuction in the directory *modules/* to write bufer data to a text file is shown below:

```
"""Module save_files to handle file I/O for data in txt and parquet format

   This module relies on classes in mimocorb.buffer_control
"""
from mimocorb.buffer_control import rb_toTxtfile, rb_toParquetfile
def save_to_txt(source_list=None, sink_list=None, observe_list=None, config_dict=None,␣
↪**rb_info):
    sv = rb_toTxtfile(source_list=source_list, config_dict=config_dict, **rb_info)
    sv()
```

Examples showing how to implement user-supplied functions to interact with *mimiCoRB* are provided in the subdirectory *examples/* of the *mimiCoRB* package. The example described above is defined in the configuration file *simul_source_setup.yam*; a more complex case with two streams going to different output buffers and files is specified in the file simul_spin_setup.yaml. Starting this example with > *../run_daq.py simul_spin_setup.yaml* leads to the following terminal output:

```
*==* script ../run_daq.py running

 4 buffers created...  List of buffers
 RB_1 128 4250
 RB_2 128 4250
 RB_3 32 1
```

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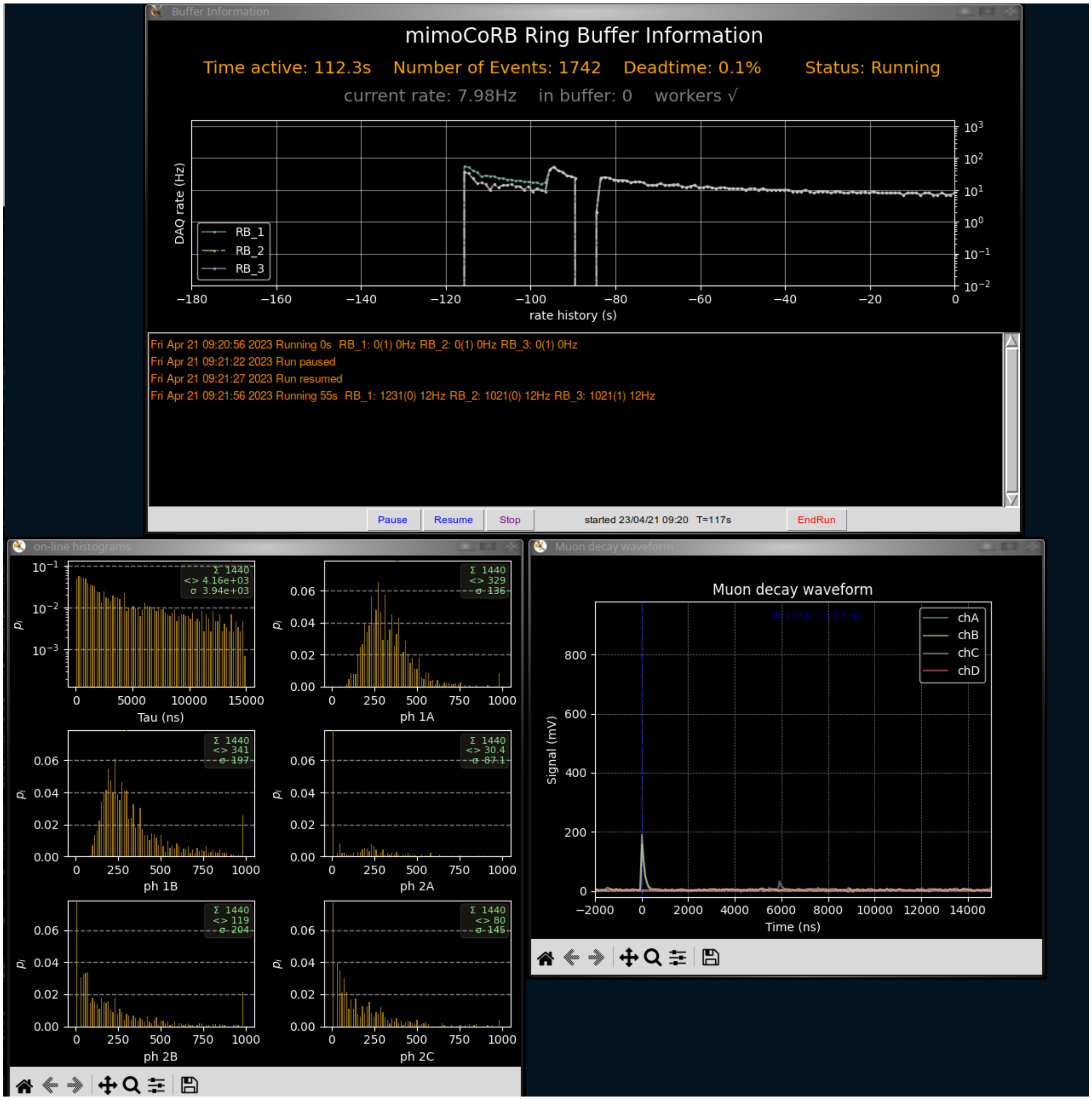
```
RB_4 32 1
List of functions
FKT_1 simulation_source (1)   {'RB_1': 'write'}
FKT_2 calculate_decay_time (2)   {'RB_1': 'read', 'RB_2': 'write', 'RB_3': 'write', 'RB_
↪4': 'write'}
FKT_3 save_to_txt (1)   {'RB_3': 'read'}
FKT_4 save_to_txt (1)   {'RB_4': 'read'}
FKT_5 save_parquet (1)   {'RB_2': 'read'}
FKT_6 plot_waveform (1)   {'RB_2': 'observe'}
FKT_7 plot_histograms (1)   {'RB_3': 'read'}
FKT_8 plot_histograms (1)   {'RB_4': 'read'}

Running 260s RB_1: 76409(0) 302Hz RB_2: 6118(0) 19Hz RB_3: 2952(1) 9.99Hz RB_4: 3166(1)␣
↪8.99Hz
```

A screenshot of a data-acquisition run with input from simulated data is shown in the figure below.


mimoCoRB Ring Buffer Information
Time active: 112.3s
Number of Events: 1742
Deadtime: 0.1%
Status: Running
current rate: 7.98Hz
in buffer: 0
workers √
DAQ rate (Hz)
rate history (s)
RB_1
RB_2
RB_3
Fri Apr 21 09:20:56 2023 Running 0s RB_1: 0(1) 0Hz RB_2: 0(1) 0Hz RB_3: 0(1) 0Hz
Fri Apr 21 09:21:22 2023 Run paused
Fri Apr 21 09:21:27 2023 Run resumed
Fri Apr 21 09:21:56 2023 Running 55s RB_1: 1231(0) 12Hz RB_2: 1021(0) 12Hz RB_3: 1021(1) 12Hz
Pause
Resume
Stop
started 23/04/21 09:20 T=117s
EndRun
Tau (ns)
ph 1A
ph 1B
ph 2A
ph 2B
ph 2C
Muon decay waveform
Signal (mV)
Time (ns)
chA
chB
chC
chD

CHAPTER THREE

MODULE DOCUMENTATION

mimo-ringbuffer:

Module implementing a multiple-in multiple-out ringbuffer appropriate for multi-core multiprocessing.

The ringbuffer creation and management is handled by the class `NewBuffer`. Buffer access is managed by the``Reader``, `Writer` and `Observer` classes.

classes:

- NewBuffer: create a new ringbuffer, assign writer(s) and reader(s) or observer(s)

  methods:

  – new_writer
  – new_reader_group
  – new_observer
  – buffer_staus

- Writer: write elements into a ringbuffer
- Reader: read all elements from a ringbuffer
- Observer: read selected elements from a ringbuffer.

class `mimocorb.mimo_buffer.`**`NewBuffer`**(*number_of_slots*, *values_per_slot*, *dtype*, *debug=False*)

Class to create a new ringbuffer object according to the 'FIFO' principle (first-in first-out).

Memory shares, IPC queues, lock and event objects as well as background threads are defined for the multiprocessing ringbuffer management. Methods are provided to build the setup dictionaries (necessary parameter objects) for the `Reader`, `Writer` or `Observer` instances, respectively. Further, methods are provided to allow an index processing (e.g. listeners) and to pause data processing.

Index processing overview: to achieve a proper handling for writing and reading data into a ringbuffer slot regarding the possible definition of more than one reader for a ringbuffer (multiprocessing mode on function level) the determination of the correct slot index is essential. For a `Writer` or `Reader` two SimpleQueues are defined, respectively. In principle one queue contains the index to be used next and the other the index just processed. An `Observer` is treated in a simpler way by using an own global index variable for each instance.

The queues are passed via the setup dictionary to the corresponding Reader or Writer instance, respectively, and processed there. In addition, the buffer manager provides methods to control the index determination (_writer/_reader/_observer_queue_listener()), started in own threads.

Writer index:

- writer_empty_queue: contains the slot numbers (initially filled); defines the next free ringbuffer slot.
  – fetched (removed) in the class Writer -> get_new_buffer()

  - last processed slot number is refilled in _increment_reader_pointer()
- writer_filled_queue: empty; contains the last processed slot number (distributed to all defined readers).
  - process_buffer()

Reader index:

- manually incremented in _increment_reader_pointer() via global variable read_pointer
- done_queue: empty; already processed slot number
- fetched in _reader_queue_listener()
- filled in the class Reader -> get() via the global variable _last_get_index
- todo_queue: empty; slot number to be processed next
- fetched in the class Reader -> get()
- filled in _writer_queue-listener (within the list reader_todo_queue_list)

Observer index:

- the global variable obs_pointer is used; it is an early copy of the write_pointer variable
  - defined in _writer_queue_listener()
  - directly used as index in _observeQ_listener()

important methods:

- __init__() constructor to create a new 'FIFO' ringbuffer
- new_writer() create new writer
- new_reader_group() create reader group
- new_observer() create observer
- buffer_status() display status: event count, processing rate, occupied slots
- pause() disable writer(s) to ringbuffer
- resume() (re-)enable writers
- set_ending() stop data-taking (gives processes time to finish before shutdown)
- close() release shared memory
- shutdown() end connected processes, delete ringbuffer

buffer_status()

Processing Rate and approximate number of free slots in this ringbuffer. This method is meant for user information purposes only, as the result may not be completely accurate due to race conditions.

Returns
cumulative event count, number of free slots, processing rate, average deadtime

Return type
tuple

`new_observer()`

Method to create a new (Queue based) observer.

Method: a copy of the most recent data (latest write_pointer) is transferred via a Queue whenever the Queue (of size 1) is empty. Sending data through the Queue is handled in a sparate thread

Returns
The `setup_dict` object passed to an `Observer`-instance to give access to the data Queue defined for this ringbuffer.

Return type
dict

`new_reader_group()`

Method to create a new reader group. The processing workload of a group can be distributed to multiple processes by using the same setup dictionary (`setup_dict`) defined for a `Reader`-object. Each ringbuffer element is processed by one reader group process. It's possible to create multiple reader groups per ringbuffer, where each reader group gets every element written to the ringbuffer. If a reader group is created, at least one `Reader`-class instance MUST steadily call its `get()` method to prevent the ringbuffer from blocking and to allow a safe shutdown.

Returns
The `setup_dict` object passed to a `Reader`-instance to grant read access to this ringbuffer.

Return type
dict

`new_writer()`

Method to create a new writer. It is possible to create multiple writers and simply share a setup dictionary definition between different `Writer`-instances (analogues to the behavior of the `new_reader_group`).

Returns
The `setup_dict` object passed to a `Writer`-instance to grant write access to this ringbuffer.

Return type
dict

`pause()`

Disable writing to ringbuffer (paused)

`resume()`

(Re)enable writing to ringbuffer (resume)

`set_ending()`

Stop data flow (before shut-down)

`shutdown()`

Shut down the ringbuffer(s): close background threads, terminate associated processes and release the shared memory definitions.

Affect processes using a `Reader`, `Writer` or `Observer` instance to a ringbuffer.

A 'trickle down' approach is used to have as few ringbuffer elements as possible unprocessed. This may not work correctly with more complex signal analysis chains. So always make sure to shut down the ringbuffers in data flow order (start with first element of the chain, the ringbuffer closest to the signal source).

CAUTION! If there are loops in the signal analysis chain, this method may end in an infinite loop!

class mimocorb.mimo_buffer.**Observer**(*setup_dict*)

Class for reading selected elements from a ringbuffer via q multiprocessing Queue

The data transfer is implemented via a multiprocessing Queue and interfaces with the ringbuffer manager (`NewBuffer`-class).

get()

Get latest element from buffer: metadata and data

As new data is provided and transferred as soon as data is read from the Queue, the get() method must not be called too frequentls

class mimocorb.mimo_buffer.**Reader**(*setup_dict*)

Class to read elements from a ringbuffer (multiple-out part).

Ringbuffer elements are structured NumPy arrays and strictly **read-only**. The returned array won't change until the next `Reader.get()` call is performed, blocking the ringbuffer element for the time being. A program design processing the ringbuffer content has to call the `Reader.get()`-method in a way that minimizes the ringbuffer lock time.

methods:

- get()
- get_metadata():

data_available()

Method to check for new data and avoid blocking of consumers

get()

Get a new element from the ringbuffer. The last element obtained by calling this function is marked as "processing is done". No memory views of old elements may be accessed after calling this function (memory might change, be corrupted or be inconsistent). This function blocks if there are no new elements in the ringbuffer.

Raises

SystemExit – When the `shutdown()`-method of the `NewBuffer` object has been called, a SystemExit is raised which terminates the process.

Returns

One element (structured numpy.ndarray) of the ringbuffer as specified in the `NewBuffer()-dtype`-object.

Return type

numpy.ndarray

get_metadata()

Get the metadata defined for a ringbuffer element of the `Reader.get()`-method.

Returns

Currently a 3-tuple is returned with `(counter, timestamp , deadtime)` which is assigned to the latest element of the ringbuffer. The content of these variables is filled by the `Writer`-process. The current convention is:

- counter (int): a unique, 0 based, consecutive integer referencing this element
- timestamp (float): the UTC timestamp
- **deadtime (float): In a live-data environment, the dead time of the first**
  writer in the analyses chain. This is meant to be the fraction of dead time to active data

capturing time (so 0.0 = no dead time whatsoever; 0.99 = only 1% of the time between this and the last element was spent with active data capturing)

Return type
tuple

`class mimocorb.mimo_buffer.Writer(`*setup_dict*`)`

Class to write elements into a ringbuffer (multiple-in part).

Ringbuffer elements are structured NumPy arrays. Writing is triggered by a call of `Writer.process_buffer()` or at the next call of `Writer.get_new_buffer()`. The ringbuffer element is blocked while writes to the NumPy array are permitted. A program design processing the ringbuffer content has to call the `Writer.process_buffer()` or `Writer.get_new_buffer()`-methods in a way that minimizes the ringbuffer lock time.

methods:

- get_new_buffer()
- set_metadata()
- process_buffer()

`get_new_buffer()`

Get a new free element in the ringbuffer.
The last element obtained by calling this function is marked as "ready to be processed". No memory views of old elements may be accessed after calling this function. This function blocks if there are no free elements in the ringbuffer and always returns a valid NumPy array that can be written to.

Raises
`SystemExit` – When the `shutdown()`-method of the `NewBuffer` object has been called, a SystemExit is raised which terminates the process.

Returns
One free ringbuffer element (structured numpy.ndarray) as specified in the `NewBuffer()-dtype`-object. Free elements may contain older data, but they can be safely overwritten.

Return type
numpy.ndarray

`process_buffer()`

Mark the current ringbuffer element as "ready to be processed".

The content of the array MUST NOT be changed after calling this function. If there is no current element, nothing happens. As the ringbuffer element is blocked while writing to the NumPy array it is recommended to call `Writer.process_buffer()` as soon as possible to minimize the ringbuffer lock time.

`set_metadata(`*counter*, *timestamp*, *deadtime*`)`

Set the metadata defined for the current ringbuffer element. If there is no current ringbuffer element (e.g. because `process_buffer()` has been called or `get_new_buffer()` has not been called yet), nothing happens. Copying metadata from a `Reader` to a `Writer` object (here called `source` and `sink`) can be done with:

```
sink.set_metadata(*source.get_metadata())
```

Parameters

- **counter** (*integer (np.longlong)*) – a unique, 0 based, consecutive integer referencing this element

- **timestamp** (*float (np.float64)*) – the UTC timestamp
- **deadtime** (*float (np.float64)*) – In a live-data environment, the dead time of the first writer in the analyses chain. This is meant to be the fraction of dead time to active data capturing time (so 0.0 = no dead time whatsoever; 0.99 = only 1% of the time between this and the last element was spent with active data capturing)

Collection of classes to set-up, manage and access ringbuffers and associated functions

class mimocorb.buffer_control.**buffer_control**(*buffers_dict*, *functions_dict*, *output_directory*)

Set-up and management ringbuffers and associated sub-processes

Class methods:

- setup_buffers()
- setup_workers()
- start_workers()
- pause()
- resume()
- shutdown()

display_functions()

Print list of functions and buffer associations

display_layout()

Print list of buffers

pause()

Pause data acquisition

resume()

Re-enable data acquisition after pause

setup_workers()

Set up all the (parallel) worker functions

shutdown()

Delete buffers, stop processes by calling the shutdown()-Method of the buffer manager

start_workers()

start all of the (parallel) worker functions

stop()

stop writing and reading data, allow processes to finish

class mimocorb.buffer_control.**rbExport**(*source_list=None*, *config_dict=None*, ***rb_info*)

Read data from buffer and send to requesting client (via Python yield()). Data are provided by a generator function yielding data and metadata in the __call__() method of the class.

class mimocorb.buffer_control.**rbImport**(*sink_list=None*, *config_dict=None*, *ufunc=None*, ***rb_info*)

Read data from external source (e.g. front-end device, file, simulation, etc.) and put data in mimo_buffer. Data is read by calling a user-supplied generator function for data and metadata.

class mimocorb.buffer_control.**rbObserver**(*observe_list=None*, *config_dict=None*, ***rb_info*)

Deliver data from buffer to an observer process. A tuple (data, metadata) is provided by a generator function (i.e. via yield()) implemented in the __call__() method of the class.

`class mimocorb.buffer_control.rbTransfer(source_list=None, sink_list=None, config_dict=None, ufunc=None, **rb_info)`

Read data from input buffer, filter data and write to output buffer(s) Data is provided as the argument to a user-defined filter function returing None if data is to be rejected, a number if data is to be copied to another buffer, or a list of processed input data write to additional buffers.

Args:

- buffer configurations (only one source and severals sinks, no observers!)
- function ufunc() must return
  - None if data to be rejected,
  - int if only raw data to be copied to sink[0]
  - list of parameterized data to be copied to sinks[]

Action:

store accepted data in buffers

`class mimocorb.buffer_control.rbWSObserver(observe_list=None, config_dict=None, **rb_info)`

Deliver data from buffer to an observer process

`class mimocorb.buffer_control.rb_toParquetfile(source_list=None, config_dict=None, **rb_info)`

Save data a set of parquet-files packed as a tar archive

`class mimocorb.buffer_control.rb_toTxtfile(source_list=None, config_dict=None, **rb_info)`

Save data to file in csv-format

`class mimocorb.buffer_control.run_mimoDAQ(verbose=2)`

Setup and run Data Aquisition suite with mimoCoRB buffer manager

The layout of ringbuffers and associated functions is defined in a configuration file in yaml format.

Functions:

- setup()
- run()
- end()

Data acquisition stops when either of the following conditions is met:

- number of requested events processed
- requested run-time reached
- inuput source exhausted
- end command issued from Keyboard or graphical interface

`end(twait=3.0)`

clean shutdown of daq suite

Arg:

twait: waiting time for processes to finish before shutdown

`keyboard_input(cmd_queue)`

Read keyboard input and send to Queeu, runing as background-thread to avoid blocking

class tc

define terminal color codes

bufferInfoGUI Graphical display of buffer status

code adapted from https://github.com/GuenterQuast/picoDAQ

`mimocorb.bufferinfoGUI.`**`bufferinfoGUI`**(*Qcmd*, *Qlog*, *Qinfo*, *RBnames=['RB_1']*, *maxRate=100.0*, *interval=1000.0*)

Show Buffer Manager logging messages and rate history and command buttons

Parameters

- **Qcmd** – multiprocessing.Queue for command passing to calling process
- **Qlog** – multiprocessing.Queue() for logging-info
- **Qinfo** – multiprocessing.Queue() for status info
- **RBnames** – list, buffer names, used as line labels
- **maxrate** – maximum rate for y-axis
- **interval** – update interval for graphics in ms

class `mimocorb.bufferinfoGUI.`**`plot_bufferinfo`**(*Q*, *RBnames*, *maxRate=1500.0*, *interval=1000.0*)

display statistics from Buffer Manager

uses multiprocessing.Queue() to display buffer information: total number of events, data acquisition rate, buffer filling level

Parameters

- **Q** – multiprocessing.Queue() for status info
- **RBnames** – list, buffer names, used as line labels
- **maxrate** – maximum rate for y-axis
- **interval** – graphics update interval in ms

plot_buffer Collection of classes with graphics functions to plot buffer data

The class animWaveFormPlotter is used by the class plotBuffer(). The _call__() method of this latter class is the entry point to the package.

class `mimocorb.plot_buffer.`**`animWaveformPlotter`**(*conf_dict=None*, *dtypes=None*, *fig=None*)

Oscilloscope-like display of wave from buffer data

The __call__ method of this class receives input data and updates and redraws only the new elements of the figure created in __init__

`init`()

plot initial line objects to be animated

class `mimocorb.plot_buffer.`**`plot_buffer`**(*source_list=None*, *sink_list=None*, *observe_list=None*, *config_dict=None*, ***rb_info*)

Plot data using a mimiCoRB Observer

histogram_buffer collection of classes to produce histograms

Show animated histogram(s) of scalar buffer variable(s)

Because this process runs as a ‘Reader’ process, the plotting function is executed as a background task in order to avoid blockingn of the main task.

The entry point is either the __call__() function of class histogram_buffer, which connects to a mimocorb buffer via the rbExport class, or directly the function plot_Histograms(), which receives data to be histogrammed via a multiprocessing Queue().

code adapted from https://github.com/GuenterQuast/picoDAQ

`class mimocorb.histogram_buffer.`**`animHists`**`(`*Hdescr*, *name='Histograms'*, *fig=None*`)`

display histograms, as normalised frequency distibutions

`class mimocorb.histogram_buffer.`**`histogram_buffer`**`(`*source_list=None*, *sink_list=None*, *observe_list=None*, *config_dict=None*, ***rb_info*`)`

Produce Histograms of (scalar) variables in buffer.

Read data from mimiCoRB buffer using the interface class mimo_control.rbExport and show histograms of scalar variables selected in the configuration dictionary

Plotting is done by means of the class plot_Histograms() running as background process

Parameters

- **`input`** – configuration dictionaries
- **`config_dict`** – must contain a block with name 'histograms', formatted as

  <name>: [<min>, <max>, <nbins>, <ymax>, <label>, <0/1 for lin/log>]

`mimocorb.histogram_buffer.`**`plot_Histograms`**`(`*Q*, *Hdescripts*, *interval*, *name='Histograms'*`)`

show animated histogram(s)

Args:

- Q: multiprocessing.Queue()
- Hdescripts: list of histogram descriptors, where each descriptor is a list:
  - min: minimum value
  - max: maximum value
  - nbins: nubmer of bins
  - ymax: scale factor for highest bin (1. = 1/Nbins)
  - name: name of the quantity being histogrammed
  - type: 0 linear, 1 for logarithmic y scale
- interval: time (in s) between updates
- name: name of histogram window

rb_unittest: application example for mimo_buffer

This code may serve as a very basic starting point for own projects

Set-up: 2 ring buffers are defined:

- input Buffer RB_1: 10 ch x 1024 slots (int32)
- output Buffer RB_2: 10 ch x 2 slots/ch (float64)

simulation_source: Generate simulated wave form data `simulation_source.`**`simulation_source`**(*source_list=None*, *sink_list=None*, *observe_list=None*, *config_dict=None*, ***rb_info*)

Generate simulated data and pass data to buffer

The class mimocorb.buffer_control/rbImport is used to interface to the newBuffer and Writer classes of the package mimoCoRB.mimo_buffer

Parameters

`config_dict` – configuration dictionary

- events_required: number of events to be simulated or 0 for infinite
- sleeptime: (mean) time between events
- random: random time between events according to a Poission process
- number_of_samples, sample_time_ns, pretrigger_samples and analogue_offset describe the waveform data to be generated (as for oscilloscope setup)

Internal parameters of the simulated physics process (the decay of a muon) are (presently) not exposed to user.

Module **lifetime_filter**

This (rather complex) module filters waveform data to search for valid signal pulses in the channel data. The goal is to clearly identify coincidences of signals in different layers (indiating the passage of a cosmic ray particle, a muon) and find double-pulse signatures that a muon was stopped in or near a detection layer where the resulting decay-electron produced a delayed pulse. The time difference between the initial and the delayed pulses is the individual lifetime of the muon.

Wave forms passing this filter-criterion an passed on to a new buffer; the decay time and the properties of the signal pulses (height, integral and postition in time) are written to another buffer.

The relevant configuration parameters can be found in the section *calculate_decay_time:* of the configuration file.

`lifetime_filter.`**`calculate_decay_time`**(*source_list=None*, *sink_list=None*, *observe_list=None*, *config_dict=None*, ***rb_info*)

Calculate decay time as time between double pulses

Input:

pulse wave forms

Returns:

None if failed, int or list of pulse parameters if successful

Note: output produced when filter is passed depends on number of defined sinks:

- one sink: input data
- two sinks: input data and double-pulse parameters
- three sinks: input data and double-pulse parameters separately for upwards and for downwards going decay electrons

plot: plotting waveforms from buffer using mimoCoRB.buffer_control.OberserverData

`plot_waveform.`**`plot_waveform`**(*source_list=None*, *sink_list=None*, *observe_list=None*, *config_dict=None*, ***rb_info*)

Plot waveform data from mimiCoRB buffer

Parameters

`input` – configuration dictionary

- plot_title: graphics title to be shown on graph

- min_sleeptime: time between updates
- sample_time_ns, channel_range, pretrigger_samples and analogue_offset describe the waveform data as for oscilloscope setup

plot_histograms: histogram variable(s) from buffer using mimoCoRB.histogram_buffer

`plot_histograms.`**`plot_histograms`**`(`*source_list=None*, *sink_list=None*, *observe_list=None*, *config_dict=None*, ***rb_info*`)`

Online display of histogram(s) of variable(s) from mimiCoRB buffer

Parameters
`input` – configuration dictionary

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