vallenae

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LIBRARY DOCUMENTATION

Extract and analyze Acoustic Emission measurement data.

The IO module *vallenae.io* enables reading (and writing) of Vallen Systeme SQLite database files:

- ***.pridb**: Primary database
- ***.tradb**: Transient data
- ***.trfdb**: Transient features

The remaining modules are system-independent and try to comprise the most common state-of-the-art algorithms in Acoustic Emission:

- *vallenae.features*: Extraction of Acoustic Emission features
- *vallenae.timepicker*: Timepicking algorithms for arrival time estimations

CHAPTER

ONE

IO

Read/write Vallen Systeme database and setup files.

1.1 Database classes

Classes to read/write pridb, tradb and trfdb database files.

> **Warning:** Writing is still experimental

PriDatabase(filename[, mode])	IO Wrapper for pridb database file.
TraDatabase(filename[, mode, compression])	IO Wrapper for tradb database file.
TrfDatabase(filename[, mode])	IO Wrapper for trfdb (transient feature) database file.

1.1.1 vallenae.io.PriDatabase

class vallenae.io.**PriDatabase**(*filename*, *mode='ro'*)

IO Wrapper for pridb database file.

Attributes

connected	Check if connected to SQLite database.
filename	Filename of database.

vallenae.io.PriDatabase.connected

property PriDatabase.**connected:** bool

Check if connected to SQLite database.

vallenae.io.PriDatabase.filename

property PriDatabase.**filename**: str

Filename of database.

Methods

__init__(filename[, mode])	Open pridb database file.
channel()	Get list of channels.
close()	Close database connection.
columns()	Columns of data table.
connection()	Get SQLite connection object.
create(filename)	Create empty pridb.
fieldinfo()	Read fieldinfo table.
globalinfo()	Read globalinfo table.
iread_hits(*[, channel, time_start, ...])	Stream hits with returned iterable.
iread_markers(*[, time_start, time_stop, ...])	Stream markers with returned iterable.
iread_parametric(*[, time_start, time_stop, ...])	Stream parametric data with returned iterable.
iread_status(*[, channel, time_start, ...])	Stream status data with returned iterable.
listen([existing, wait, query_filter])	Listen to database changes and return new records.
read(**kwargs)	Read all data set types (hits, markers, parametric data, status data) from pridb to Pandas DataFrame.
read_hits(**kwargs)	Read hits to Pandas DataFrame.
read_markers(**kwargs)	Read marker to Pandas DataFrame.
read_parametric(**kwargs)	Read parametric data to Pandas DataFrame.
read_status(**kwargs)	Read status data to Pandas DataFrame.
rows()	Number of rows in data table.
tables()	Get table names.
write_fieldinfo(field, info)	Write to fieldinfo table.
write_hit(hit)	Write hit to pridb.
write_marker(marker)	Write marker to pridb.
write_parametric(parametric)	Write parametric data to pridb.
write_status(status)	Write status data to pridb.

vallenae.io.PriDatabase.__init__

PriDatabase.**__init__**(*filename*, *mode='ro'*)

Open pridb database file.

Parameters

- **filename** (str) – Path to pridb database file
- **mode** (str) – Define database access: **"ro"** (read-only), **"rw"** (read-write), **"rwc"** (read-write and create empty database if it does not exist)

vallenae.io.PriDatabase.channel

PriDatabase.**channel**()

Get list of channels.

Return type
Set[int]

vallenae.io.PriDatabase.close

PriDatabase.**close**()

Close database connection.

vallenae.io.PriDatabase.columns

PriDatabase.**columns**()

Columns of data table.

Return type
Tuple[str, ...]

vallenae.io.PriDatabase.connection

PriDatabase.**connection**()

Get SQLite connection object.

Raises
RuntimeError – If connection is closed

Return type
Connection

vallenae.io.PriDatabase.create

static PriDatabase.**create**(*filename*)

Create empty pridb.

Parameters
filename (str) – Path to new pridb database file

vallenae.io.PriDatabase.fieldinfo

PriDatabase.**fieldinfo**()

Read fieldinfo table.

The fieldinfo table stores informations about columns of the data table (like units).

Return type
Dict[str, Dict[str, Any]]

Returns
Dict of column names and informations (again a dict)

vallenae.io.PriDatabase.globalinfo

PriDatabase.**globalinfo**()

Read globalinfo table.

Return type
Dict[str, Any]

vallenae.io.PriDatabase.iread_hits

PriDatabase.**iread_hits**(*, *channel=None*, *time_start=None*, *time_stop=None*, *set_id=None*, *query_filter=None*)

Stream hits with returned iterable.

Parameters

- **channel** (Union[None, int, Sequence[int]]) – None if all channels should be read. Otherwise specify the channel number or a list of channel numbers
- **time_start** (Optional[float]) – Start reading at relative time (in seconds). Start at beginning if *None*
- **time_stop** (Optional[float]) – Stop reading at relative time (in seconds). Read until end if *None*
- **set_id** (Union[None, int, Sequence[int]]) – Read by SetID
- **query_filter** (Optional[str]) – Optional query filter provided as SQL clause, e.g. "Amp > 5000 AND RiseT < 1000"

Return type
SizedIterable[*HitRecord*]

Returns
Sized iterable to sequential read hits

vallenae.io.PriDatabase.iread_markers

PriDatabase.**iread_markers**(*, *time_start=None*, *time_stop=None*, *set_id=None*, *query_filter=None*)

Stream markers with returned iterable.

Parameters

- **time_start** (Optional[float]) – Start reading at relative time (in seconds). Start at beginning if *None*
- **time_stop** (Optional[float]) – Stop reading at relative time (in seconds). Read until end if *None*
- **set_id** (Union[None, int, Sequence[int]]) – Read by SetID
- **query_filter** (Optional[str]) – Optional query filter provided as SQL clause, e.g. "Number > 11 AND Data LIKE '%TimeZone%'"

Return type
SizedIterable[*MarkerRecord*]

Returns
Sized iterable to sequential read markers

vallenae.io.PriDatabase.iread_parametric

PriDatabase.**iread_parametric**(*, *time_start=None*, *time_stop=None*, *set_id=None*, *query_filter=None*)

Stream parametric data with returned iterable.

Parameters

- **time_start** (Optional[float]) – Start reading at relative time (in seconds). Start at beginning if *None*
- **time_stop** (Optional[float]) – Stop reading at relative time (in seconds). Read until end if *None*
- **set_id** (Union[None, int, Sequence[int]]) – Read by SetID
- **query_filter** (Optional[str]) – Optional query filter provided as SQL clause, e.g. "PA0 >= -5000 AND PA0 < 5000"

Return type
SizedIterable[*ParametricRecord*]

Returns
Sized iterable to sequential read parametric data

vallenae.io.PriDatabase.iread_status

PriDatabase.**iread_status**(*, *channel=None*, *time_start=None*, *time_stop=None*, *set_id=None*, *query_filter=None*)

Stream status data with returned iterable.

Parameters

- **channel** (Union[None, int, Sequence[int]]) – None if all channels should be read. Otherwise specify the channel number or a list of channel numbers
- **time_start** (Optional[float]) – Start reading at relative time (in seconds). Start at beginning if *None*
- **time_stop** (Optional[float]) – Stop reading at relative time (in seconds). Read until end if *None*
- **set_id** (Union[None, int, Sequence[int]]) – Read by SetID
- **query_filter** (Optional[str]) – Optional query filter provided as SQL clause, e.g. "RMS < 300 OR RMS > 500"

Return type
SizedIterable[*StatusRecord*]

Returns
Sized iterable to sequential read status data

vallenae.io.PriDatabase.listen

PriDatabase.**listen**(*existing=False*, *wait=False*, *query_filter=None*)

Listen to database changes and return new records.

Parameters

- **existing** (bool) – Return already existing records
- **wait** (bool) – Wait for new records even if no acquisition (writer) is active. Otherwise the function returns after all records are read.
- **query_filter** (Optional[str]) – Optional query filter provided as SQL clause, e.g. "Time >= 100 AND Chan == 2"

Yields

New hit/marker/parametric/status data records

Return type

Iterable[Union[*HitRecord*, *MarkerRecord*, *ParametricRecord*, *StatusRecord*]]

vallenae.io.PriDatabase.read

PriDatabase.**read**(***kwargs*)

Read all data set types (hits, markers, parametric data, status data) from pridb to Pandas DataFrame.

Parameters

****kwargs** – Arguments passed to *iread_hits*, *iread_markers*, *iread_parametric* and *iread_status*

Return type

DataFrame

Returns

Pandas DataFrame with all pridb data set types

vallenae.io.PriDatabase.read_hits

PriDatabase.**read_hits**(***kwargs*)

Read hits to Pandas DataFrame.

Parameters

****kwargs** – Arguments passed to *iread_hits*

Return type

DataFrame

Returns

Pandas DataFrame with hit data

vallenae.io.PriDatabase.read_markers

PriDatabase.**read_markers**(***kwargs*)

Read marker to Pandas DataFrame.

Parameters
****kwargs** – Arguments passed to *iread_markers*

Return type
DataFrame

Returns
Pandas DataFrame with marker data

vallenae.io.PriDatabase.read_parametric

PriDatabase.**read_parametric**(***kwargs*)

Read parametric data to Pandas DataFrame.

Parameters
****kwargs** – Arguments passed to *iread_parametric*

Return type
DataFrame

Returns
Pandas DataFrame with parametric data

vallenae.io.PriDatabase.read_status

PriDatabase.**read_status**(***kwargs*)

Read status data to Pandas DataFrame.

Parameters
****kwargs** – Arguments passed to *iread_status*

Return type
DataFrame

Returns
Pandas DataFrame with status data

vallenae.io.PriDatabase.rows

PriDatabase.**rows**()

Number of rows in data table.

Return type
int

vallenae.io.PriDatabase.tables

PriDatabase.**tables**()

Get table names.

Return type
Set[str]

vallenae.io.PriDatabase.write_fieldinfo

PriDatabase.**write_fieldinfo**(*field*, *info*)

Write to fieldinfo table.

Parameters

- **field** (str) – Column name of data table
- **info** (Dict[str, Any]) – Dict of properties and values, e.g. {"Unit": "[Hz]"}

Raises
ValueError – If field is not a column of data table

vallenae.io.PriDatabase.write_hit

PriDatabase.**write_hit**(*hit*)

Write hit to pridb.

Caution: *HitRecord.set_id* is ignored and automatically incremented.

Parameters
hit (*HitRecord*) – Hit data set

Returns
Index (SetID) of inserted row

vallenae.io.PriDatabase.write_marker

PriDatabase.**write_marker**(*marker*)

Write marker to pridb.

Caution: *MarkerRecord.set_id* is ignored and automatically incremented.

Parameters
marker (*MarkerRecord*) – Marker data set

Returns
Index (SetID) of inserted row

vallenae.io.PriDatabase.write_parametric

PriDatabase.**write_parametric**(*parametric*)

Write parametric data to pridb.

Caution: *ParametricRecord.set_id* is ignored and automatically incremented.

Parameters
parametric (*ParametricRecord*) – Parametric data set

Returns
Index (SetID) of inserted row

vallenae.io.PriDatabase.write_status

PriDatabase.**write_status**(*status*)

Write status data to pridb.

Caution: *StatusRecord.set_id* is ignored and automatically incremented.

Parameters
status (*StatusRecord*) – Status data set

Returns
Index (SetID) of inserted row

1.1.2 vallenae.io.TraDatabase

class vallenae.io.**TraDatabase**(*filename*, *mode='ro'*, ***, *compression=False*)

IO Wrapper for tradb database file.

Attributes

connected	Check if connected to SQLite database.
filename	Filename of database.

vallenae.io.TraDatabase.connected

property TraDatabase.**connected**: bool

Check if connected to SQLite database.

vallenae.io.TraDatabase.filename

property TraDatabase.**filename**: str

Filename of database.

Methods

__init__(filename[, mode, compression])	Open tradb database file.
channel()	Get list of channels.
close()	Close database connection.
columns()	Columns of data table.
connection()	Get SQLite connection object.
create(filename)	Create empty tradb.
fieldinfo()	Read fieldinfo table.
globalinfo()	Read globalinfo table.
iread(*[, channel, time_start, time_stop, ...])	Stream transient data with returned Iterable.
listen([existing, wait, query_filter, raw])	Listen to database changes and return new records.
read(**kwargs)	Read transient data to Pandas DataFrame.
read_continuous_wave(channel[, time_start, ...])	Read transient signal of specified channel to a single, continuous array.
read_wave(trai[, time_axis, raw])	Read transient signal for a given TRAI (transient recorder index).
rows()	Number of rows in data table.
tables()	Get table names.
write(tra)	Write transient data to pridb.
write_fieldinfo(field, info)	Write to fieldinfo table.

vallenae.io.TraDatabase.__init__

TraDatabase.**__init__**(*filename*, *mode='ro'*, ***, *compression=False*)

Open tradb database file.

Parameters

- **filename** (str) – Path to tradb database file
- **mode** (str) – Define database access: **"ro"** (read-only), **"rw"** (read-write), **"rwc"** (read-write and create empty database if it does not exist)
- **compression** (bool) – Enable/disable FLAC compression data BLOBs for writing

vallenae.io.TraDatabase.channel

TraDatabase.**channel**()

Get list of channels.

Return type

Set[int]

vallenae.io.TraDatabase.close

TraDatabase.**close**()

Close database connection.

vallenae.io.TraDatabase.columns

TraDatabase.**columns**()

Columns of data table.

Return type
Tuple[str, ...]

vallenae.io.TraDatabase.connection

TraDatabase.**connection**()

Get SQLite connection object.

Raises
RuntimeError – If connection is closed

Return type
Connection

vallenae.io.TraDatabase.create

static TraDatabase.**create**(*filename*)

Create empty tradb.

Parameters
filename (str) – Path to new tradb database file

vallenae.io.TraDatabase.fieldinfo

TraDatabase.**fieldinfo**()

Read fieldinfo table.

The fieldinfo table stores informations about columns of the data table (like units).

Return type
Dict[str, Dict[str, Any]]

Returns
Dict of column names and informations (again a dict)

vallenae.io.TraDatabase.globalinfo

TraDatabase.**globalinfo**()

Read globalinfo table.

Return type
Dict[str, Any]

vallenae.io.TraDatabase.iread

TraDatabase.**iread**(*, *channel=None*, *time_start=None*, *time_stop=None*, *trai=None*, *query_filter=None*, *raw=False*)

Stream transient data with returned Iterable.

Parameters

- **channel** (Union[None, int, Sequence[int]]) – None if all channels should be read. Otherwise specify the channel number or a list of channel numbers
- **time_start** (Optional[float]) – Start reading at relative time (in seconds). Start at beginning if *None*
- **time_stop** (Optional[float]) – Stop reading at relative time (in seconds). Read until end if *None*
- **trai** (Union[None, int, Sequence[int]]) – Read data by TRAI (transient recorder index)
- **query_filter** (Optional[str]) – Optional query filter provided as SQL clause, e.g. "Pretrigger == 500 AND Samples >= 1024"
- **raw** (bool) – Return data as ADC values (int16). Default: *False*

Return type
SizedIterable[*TraRecord*]

Returns
Sized iterable to sequential read transient data

vallenae.io.TraDatabase.listen

TraDatabase.**listen**(*existing=False*, *wait=False*, *query_filter=None*, *raw=False*)

Listen to database changes and return new records.

Parameters

- **existing** (bool) – Return already existing records
- **wait** (bool) – Wait for new records even if no acquisition (writer) is active. Otherwise the function returns after all records are read.
- **query_filter** (Optional[str]) – Optional query filter provided as SQL clause, e.g. "TRAI >= 100 AND Samples >= 1024"
- **raw** (bool) – Return data as ADC values (int16). Default: *False*

Yields
New transient data records

Return type
Iterable[*TraRecord*]

vallenae.io.TraDatabase.read

TraDatabase.**read**(***kwargs*)

Read transient data to Pandas DataFrame.

Parameters
****kwargs** – Arguments passed to *iread*

Return type
DataFrame

Returns
Pandas DataFrame with transient data

vallenae.io.TraDatabase.read_continuous_wave

TraDatabase.**read_continuous_wave**(*channel*, *time_start=None*, *time_stop=None*, ***, *time_axis=True*, *show_progress=True*, *raw=False*)

Read transient signal of specified channel to a single, continuous array.

The signal is exactly cropped to the given time range. Time gaps are filled with 0's.

Parameters

- **channel** (int) – Channel number to read
- **time_start** (Optional[float]) – Start reading at relative time (in seconds). Start at beginning if *None*
- **time_stop** (Optional[float]) – Stop reading at relative time (in seconds). Read until end if *None*
- **time_axis** (bool) – Create the correspondig time axis. Default: *True*
- **show_progress** (bool) – Show progress bar. Default: *True*
- **raw** (bool) – Return data as ADC values (int16). Default: *False*

Return type
Union[Tuple[ndarray, ndarray], Tuple[ndarray, int]]

Returns

If *time_axis* is *True*

- Array with transient signal
- Time axis

If *time_axis* is *False*

- Array with transient signal
- Samplerate

vallenae.io.TraDatabase.read_wave

TraDatabase.**read_wave**(*trai*, *time_axis=True*, *, *raw=False*)

Read transient signal for a given TRAI (transient recorder index).

This method is useful in combination with *PriDatabase.read_hits*, that will store the TRAI in a DataFrame.

Parameters

- **trai** (int) – Transient recorder index (unique key between pridb and tradb)
- **time_axis** (bool) – Create the correspondig time axis. Default: *True*
- **raw** (bool) – Return data as ADC values (int16). Default: *False*

Return type
Union[Tuple[ndarray, ndarray], Tuple[ndarray, int]]

Returns

If time_axis is *True*

- Array with transient signal
- Time axis

If time_axis is *False*

- Array with transient signal
- Samplerate

vallenae.io.TraDatabase.rows

TraDatabase.**rows**()

Number of rows in data table.

Return type
int

vallenae.io.TraDatabase.tables

TraDatabase.**tables**()

Get table names.

Return type
Set[str]

vallenae.io.TraDatabase.write

TraDatabase.**write**(*tra*)

Write transient data to pridb.

Parameters
tra (*TraRecord*) – Transient data set

Return type
int

Returns
Index (SetID) of inserted row

vallenae.io.TraDatabase.write_fieldinfo

TraDatabase.**write_fieldinfo**(*field*, *info*)
Write to fieldinfo table.

Parameters

- **field** (str) – Column name of data table
- **info** (Dict[str, Any]) – Dict of properties and values, e.g. {"Unit": "[Hz]"}

Raises
ValueError – If field is not a column of data table

1.1.3 vallenae.io.TrfDatabase

class vallenae.io.**TrfDatabase**(*filename*, *mode='ro'*)
IO Wrapper for trfdb (transient feature) database file.

Attributes

connected	Check if connected to SQLite database.
filename	Filename of database.

vallenae.io.TrfDatabase.connected

property TrfDatabase.**connected**: bool
Check if connected to SQLite database.

vallenae.io.TrfDatabase.filename

property TrfDatabase.**filename**: str
Filename of database.

Methods

__init__(filename[, mode])	Open trfdb database file.
close()	Close database connection.
columns()	Columns of data table.
connection()	Get SQLite connection object.
create(filename)	Create empty trfdb.
fieldinfo()	Read fieldinfo table.
globalinfo()	Read globalinfo table.
iread(*[, trai, query_filter])	Stream features with returned iterable.
listen([existing, wait, query_filter])	Listen to database changes and return new records.
read(**kwargs)	Read features to Pandas DataFrame.
rows()	Number of rows in data table.
tables()	Get table names.
write(feature_set)	Write feature record to trfdb.
write_fieldinfo(field, info)	Write to fieldinfo table.

vallenae.io.TrfDatabase.__init__

TrfDatabase.**__init__**(*filename*, *mode='ro'*)

Open trfdb database file.

Parameters

- **filename** (str) – Path to trfdb database file
- **mode** (str) – Define database access: **"ro"** (read-only), **"rw"** (read-write), **"rwc"** (read-write and create empty database if it does not exist)

vallenae.io.TrfDatabase.close

TrfDatabase.**close**()

Close database connection.

vallenae.io.TrfDatabase.columns

TrfDatabase.**columns**()

Columns of data table.

Return type

Tuple[str, ...]

vallenae.io.TrfDatabase.connection

TrfDatabase.**connection**()

Get SQLite connection object.

Raises
RuntimeError – If connection is closed

Return type
Connection

vallenae.io.TrfDatabase.create

static TrfDatabase.**create**(*filename*)

Create empty trfdb.

Parameters
filename (str) – Path to new trfdb database file

vallenae.io.TrfDatabase.fieldinfo

TrfDatabase.**fieldinfo**()

Read fieldinfo table.

The fieldinfo table stores informations about columns of the data table (like units).

Return type
Dict[str, Dict[str, Any]]

Returns
Dict of column names and informations (again a dict)

vallenae.io.TrfDatabase.globalinfo

TrfDatabase.**globalinfo**()

Read globalinfo table.

Return type
Dict[str, Any]

vallenae.io.TrfDatabase.iread

TrfDatabase.**iread**(*, *trai=None*, *query_filter=None*)

Stream features with returned iterable.

Parameters

- **trai** (Union[None, int, Sequence[int]]) – Read data by TRAI (transient recorder index)
- **query_filter** (Optional[str]) – Optional query filter provided as SQL clause, e.g. "FFT_CoG >= 150 AND CTP < 20"

Return type
SizedIterable[*FeatureRecord*]

Returns
Sized iterable to sequential read features

vallenae.io.TrfDatabase.listen

TrfDatabase.**listen**(*existing=False*, *wait=False*, *query_filter=None*)

Listen to database changes and return new records.

Parameters

- **existing** (bool) – Return already existing records
- **wait** (bool) – Wait for new records even if no acquisition (writer) is active. Otherwise the function returns after all records are read.
- **query_filter** (Optional[str]) – Optional query filter provided as SQL clause, e.g. "TRAI >= 100"

Yields
New feature records

Return type
Iterable[*FeatureRecord*]

vallenae.io.TrfDatabase.read

TrfDatabase.**read**(***kwargs*)

Read features to Pandas DataFrame.

Parameters
****kwargs** – Arguments passed to *iread*

Return type
DataFrame

Returns
Pandas DataFrame with features

vallenae.io.TrfDatabase.rows

TrfDatabase.**rows**()

Number of rows in data table.

Return type
int

vallenae.io.TrfDatabase.tables

TrfDatabase.**tables**()

Get table names.

Return type
Set[str]

vallenae.io.TrfDatabase.write

TrfDatabase.**write**(*feature_set*)

Write feature record to trfdb.

Parameters
feature_set (*FeatureRecord*) – Feature set

Return type
int

Returns
Index (trai) of inserted row

vallenae.io.TrfDatabase.write_fieldinfo

TrfDatabase.**write_fieldinfo**(*field*, *info*)

Write to fieldinfo table.

Parameters

- **field** (str) – Column name of data table
- **info** (Dict[str, Any]) – Dict of properties and values, e.g. {"Unit": "[Hz]"}

Raises
ValueError – If field is not a column of data table

All database classes implement two different interfaces to access data:

Standard `read_*`

Read data to pandas.DataFrame, e.g. with *PriDatabase.read_hits*

```
>>> pridb = vae.io.PriDatabase("./examples/steel_plate/sample.pridb")
>>> df = pridb.read_hits()  # save all hits to pandas dataframe
>>> df[["time", "channel"]]  # output columns hit and channel
             time  channel
set_id
10       3.992771        3
11       3.992775        2
12       3.992813        4
13       3.992814        1
```

Streaming `iread_*`

Iterate through the data row by row. This is a memory-efficient solution ideal for batch processing. The return types are specific typing.NamedTuple, see *Data types*.

Example with *PriDatabase.iread_hits*:

```
>>> pridb = vae.io.PriDatabase("./examples/steel_plate/sample.pridb")
>>> for hit in pridb.iread_hits():
...     print(f"time: {hit.time:0.4f}, channel: {hit.channel}")
...
time: 3.9928,   channel: 3
time: 3.9928,   channel: 2
time: 3.9928,   channel: 4
```

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```
time: 3.9928,   channel: 1
>>> type(hit)
<class 'vallenae.io.datatypes.HitRecord'>
```

1.2 Data types

Records of the database are represented as `typing.NamedTuple`. Each record implements a class method `from_sql` to init from a SQLite row dictionary (column name: value).

HitRecord(time, channel, param_id, ...[, ...])	Hit record in pridb (SetType = 2).
MarkerRecord(time, set_type, data[, number, ...])	Marker record in pridb (SetType = 4, 5, 6).
StatusRecord(time, channel, param_id, ...[, ...])	Status data record in pridb (SetType = 3).
ParametricRecord(time, param_id[, set_id, ...])	Parametric data record in pridb (SetType = 1).
TraRecord(time, channel, param_id, ...[, ...])	Transient data record in tradb.
FeatureRecord(trai, features)	Transient feature record in trfdb.

1.2.1 vallenae.io.HitRecord

class vallenae.io.**HitRecord**(*time: float*, *channel: int*, *param_id: int*, *amplitude: float*, *duration: float*, *energy: float*, *rms: float*, *set_id: int | None = None*, *threshold: float | None = None*, *rise_time: float | None = None*, *signal_strength: float | None = None*, *counts: int | None = None*, *trai: int | None = None*, *cascade_hits: int | None = None*, *cascade_counts: int | None = None*, *cascade_energy: int | None = None*, *cascade_signal_strength: int | None = None*)

Hit record in pridb (SetType = 2).

Attributes

amplitude	Peak amplitude in volts
cascade_counts	Summed counts of hits in the same hit-cascade
cascade_energy	Summed energy of hits in the same hit-cascade
cascade_hits	Total number of hits in the same hit-cascade
cascade_signal_strength	Summed signal strength of hits in the same hit-cascade # noqa
channel	Channel number
counts	Number of positive threshold crossings
duration	Hit duration in seconds
energy	Energy (EN 1330-9) in eu (1e-14 V^2s)
param_id	Parameter ID of table ae_params for ADC value conversion
rise_time	Rise time in seconds
rms	RMS of the noise before the hit in volts
set_id	Unique identifier for data set in pridb
signal_strength	Signal strength in nVs (1e-9 Vs)
threshold	Threshold amplitude in volts
time	Time in seconds
trai	Transient recorder index (foreign key between pridb and tradb)

vallenae.io.HitRecord.amplitude

HitRecord.**amplitude**: float

Peak amplitude in volts

vallenae.io.HitRecord.cascade_counts

HitRecord.**cascade_counts**: Optional[int]

Summed counts of hits in the same hit-cascade

vallenae.io.HitRecord.cascade_energy

HitRecord.**cascade_energy**: Optional[int]

Summed energy of hits in the same hit-cascade

vallenae.io.HitRecord.cascade_hits

HitRecord.**cascade_hits**: Optional[int]

Total number of hits in the same hit-cascade

vallenae.io.HitRecord.cascade_signal_strength

HitRecord.**cascade_signal_strength**: Optional[int]

Summed signal strength of hits in the same hit-cascade # noqa

vallenae.io.HitRecord.channel

HitRecord.**channel**: int

Channel number

vallenae.io.HitRecord.counts

HitRecord.**counts**: Optional[int]

Number of positive threshold crossings

vallenae.io.HitRecord.duration

HitRecord.**duration**: float

Hit duration in seconds

vallenae.io.HitRecord.energy

HitRecord.**energy**: float

Energy (EN 1330-9) in eu (1e-14 V^2s)

vallenae.io.HitRecord.param_id

HitRecord.**param_id**: int

Parameter ID of table ae_params for ADC value conversion

vallenae.io.HitRecord.rise_time

HitRecord.**rise_time**: Optional[float]

Rise time in seconds

vallenae.io.HitRecord.rms

HitRecord.**rms**: float

RMS of the noise before the hit in volts

vallenae.io.HitRecord.set_id

HitRecord.**set_id:** Optional[int]

Unique identifier for data set in pridb

vallenae.io.HitRecord.signal_strength

HitRecord.**signal_strength:** Optional[float]

Signal strength in nVs (1e-9 Vs)

vallenae.io.HitRecord.threshold

HitRecord.**threshold:** Optional[float]

Threshold amplitude in volts

vallenae.io.HitRecord.time

HitRecord.**time:** float

Time in seconds

vallenae.io.HitRecord.trai

HitRecord.**trai:** Optional[int]

Transient recorder index (foreign key between pridb and tradb)

Methods

__init__()	
count(value, /)	Return number of occurrences of value.
from_sql(row)	Create *HitRecord* from SQL row.
index(value[, start, stop])	Return first index of value.

vallenae.io.HitRecord.__init__

HitRecord.**__init__**()

vallenae.io.HitRecord.count

HitRecord.**count**(*value*, /)

Return number of occurrences of value.

vallenae.io.HitRecord.from_sql

classmethod HitRecord.**from_sql**(*row*)

Create *HitRecord* from SQL row.

Parameters
row (Dict[str, Any]) – Dict of column names and values

Return type
HitRecord

vallenae.io.HitRecord.index

HitRecord.**index**(*value*, *start=0*, *stop=9223372036854775807*, /)

Return first index of value.

Raises ValueError if the value is not present.

1.2.2 vallenae.io.MarkerRecord

class vallenae.io.**MarkerRecord**(*time: float*, *set_type: int*, *data: str*, *number: int | None = None*, *set_id: int | None = None*)

Marker record in pridb (SetType = 4, 5, 6).

A marker can have different meanings depending on its SetType:

- 4: label
- 5: datetime data set, as it is inserted whenever recording is started by software
- 6: a section start marker. E.g. new sections are started, if acquisition settings changed

Attributes

data	Content of marker (label text or datetime)
number	Marker number
set_id	Unique identifier for data set in pridb
set_type	Marker type (see above)
time	Time in seconds

vallenae.io.MarkerRecord.data

MarkerRecord.**data**: str

Content of marker (label text or datetime)

vallenae.io.MarkerRecord.number

MarkerRecord.**number**: Optional[int]

Marker number

vallenae.io.MarkerRecord.set_id

MarkerRecord.**set_id**: Optional[int]

Unique identifier for data set in pridb

vallenae.io.MarkerRecord.set_type

MarkerRecord.**set_type**: int

Marker type (see above)

vallenae.io.MarkerRecord.time

MarkerRecord.**time**: float

Time in seconds

Methods

__init__()	
count(value, /)	Return number of occurrences of value.
from_sql(row)	Create *MarkerRecord* from SQL row.
index(value[, start, stop])	Return first index of value.

vallenae.io.MarkerRecord.__init__

MarkerRecord.**__init__**()

vallenae.io.MarkerRecord.count

MarkerRecord.**count**(*value*, /)

Return number of occurrences of value.

vallenae.io.MarkerRecord.from_sql

classmethod MarkerRecord.**from_sql**(*row*)

Create *MarkerRecord* from SQL row.

Parameters
row (Dict[str, Any]) – Dict of column names and values

Return type
MarkerRecord

vallenae.io.MarkerRecord.index

MarkerRecord.**index**(*value*, *start=0*, *stop=9223372036854775807*, /)

Return first index of value.

Raises ValueError if the value is not present.

1.2.3 vallenae.io.StatusRecord

class vallenae.io.**StatusRecord**(*time: float*, *channel: int*, *param_id: int*, *energy: float*, *rms: float*, *set_id: int* | *None* = *None*, *threshold: float* | *None* = *None*, *signal_strength: float* | *None* = *None*)

Status data record in pridb (SetType = 3).

Attributes

channel	Channel number
energy	Energy (EN 1330-9) in eu (1e-14 V^2s)
param_id	Parameter ID of table ae_params for ADC value conversion
rms	RMS in volts
set_id	Unique identifier for data set in pridb
signal_strength	Signal strength in nVs (1e-9 Vs)
threshold	Threshold amplitude in volts
time	Time in seconds

vallenae.io.StatusRecord.channel

StatusRecord.**channel**: int
Channel number

vallenae.io.StatusRecord.energy

StatusRecord.**energy**: float
Energy (EN 1330-9) in eu (1e-14 V^2s)

vallenae.io.StatusRecord.param_id

StatusRecord.**param_id**: int
Parameter ID of table ae_params for ADC value conversion

vallenae.io.StatusRecord.rms

StatusRecord.**rms**: float
RMS in volts

vallenae.io.StatusRecord.set_id

StatusRecord.**set_id**: Optional[int]
Unique identifier for data set in pridb

vallenae.io.StatusRecord.signal_strength

StatusRecord.**signal_strength**: Optional[float]
Signal strength in nVs (1e-9 Vs)

vallenae.io.StatusRecord.threshold

StatusRecord.**threshold**: Optional[float]
Threshold amplitude in volts

vallenae.io.StatusRecord.time

StatusRecord.**time**: float
Time in seconds

Methods

__init__()	
count(value, /)	Return number of occurrences of value.
from_sql(row)	Create *StatusRecord* from SQL row.
index(value[, start, stop])	Return first index of value.

vallenae.io.StatusRecord.__init__

StatusRecord.**__init__**()

vallenae.io.StatusRecord.count

StatusRecord.**count**(*value*, */*)

Return number of occurrences of value.

vallenae.io.StatusRecord.from_sql

classmethod StatusRecord.**from_sql**(*row*)

Create *StatusRecord* from SQL row.

Parameters
row (Dict[str, Any]) – Dict of column names and values

Return type
StatusRecord

vallenae.io.StatusRecord.index

StatusRecord.**index**(*value*, *start=0*, *stop=9223372036854775807*, */*)

Return first index of value.

Raises ValueError if the value is not present.

1.2.4 vallenae.io.ParametricRecord

class vallenae.io.**ParametricRecord**(*time: float*, *param_id: int*, *set_id: int | None = None*, *pctd: int | None = None*, *pcta: int | None = None*, *pa0: int | None = None*, *pa1: int | None = None*, *pa2: int | None = None*, *pa3: int | None = None*, *pa4: int | None = None*, *pa5: int | None = None*, *pa6: int | None = None*, *pa7: int | None = None*)

Parametric data record in pridb (SetType = 1).

Attributes

pa0	Amplitude of parametric input 0 in volts
pa1	Amplitude of parametric input 1 in volts
pa2	Amplitude of parametric input 2 in volts
pa3	Amplitude of parametric input 3 in volts
pa4	Amplitude of parametric input 4 in volts
pa5	Amplitude of parametric input 5 in volts
pa6	Amplitude of parametric input 6 in volts
pa7	Amplitude of parametric input 7 in volts
param_id	Parameter ID of table ae_params for ADC value conversion
pcta	Analog hysteresis counter
pctd	Digital counter value
set_id	Unique identifier for data set in pridb
time	Time in seconds

vallenae.io.ParametricRecord.pa0

ParametricRecord.**pa0**: Optional[int]

Amplitude of parametric input 0 in volts

vallenae.io.ParametricRecord.pa1

ParametricRecord.**pa1**: Optional[int]

Amplitude of parametric input 1 in volts

vallenae.io.ParametricRecord.pa2

ParametricRecord.**pa2**: Optional[int]

Amplitude of parametric input 2 in volts

vallenae.io.ParametricRecord.pa3

ParametricRecord.**pa3**: Optional[int]

Amplitude of parametric input 3 in volts

vallenae.io.ParametricRecord.pa4

ParametricRecord.**pa4**: Optional[int]

Amplitude of parametric input 4 in volts

vallenae.io.ParametricRecord.pa5

ParametricRecord.**pa5:** Optional[int]
Amplitude of parametric input 5 in volts

vallenae.io.ParametricRecord.pa6

ParametricRecord.**pa6:** Optional[int]
Amplitude of parametric input 6 in volts

vallenae.io.ParametricRecord.pa7

ParametricRecord.**pa7:** Optional[int]
Amplitude of parametric input 7 in volts

vallenae.io.ParametricRecord.param_id

ParametricRecord.**param_id:** int
Parameter ID of table ae_params for ADC value conversion

vallenae.io.ParametricRecord.pcta

ParametricRecord.**pcta:** Optional[int]
Analog hysteresis counter

vallenae.io.ParametricRecord.pctd

ParametricRecord.**pctd:** Optional[int]
Digital counter value

vallenae.io.ParametricRecord.set_id

ParametricRecord.**set_id:** Optional[int]
Unique identifier for data set in pridb

vallenae.io.ParametricRecord.time

ParametricRecord.**time:** float
Time in seconds

Methods

__init__()	
count(value, /)	Return number of occurrences of value.
from_sql(row)	Create *ParametricRecord* from SQL row.
index(value[, start, stop])	Return first index of value.

vallenae.io.ParametricRecord.__init__

ParametricRecord.**__init__**()

vallenae.io.ParametricRecord.count

ParametricRecord.**count**(*value*, */*)

Return number of occurrences of value.

vallenae.io.ParametricRecord.from_sql

classmethod ParametricRecord.**from_sql**(*row*)

Create *ParametricRecord* from SQL row.

Parameters
row (Dict[str, Any]) – Dict of column names and values

Return type
ParametricRecord

vallenae.io.ParametricRecord.index

ParametricRecord.**index**(*value*, *start=0*, *stop=9223372036854775807*, */*)

Return first index of value.

Raises ValueError if the value is not present.

1.2.5 vallenae.io.TraRecord

class vallenae.io.**TraRecord**(*time: float*, *channel: int*, *param_id: int*, *pretrigger: int*, *threshold: float*, *samplerate: int*, *samples: int*, *data: ndarray*, *trai: int | None = None*, *rms: float | None = None*, *raw: bool = False*)

Transient data record in tradb.

Attributes

channel	Channel number
data	Transient signal in volts or ADC values if *raw* = *True*
param_id	Parameter ID of table tr_params for ADC value conversion
pretrigger	Pretrigger samples
raw	*data* is stored as ADC values (int16)
rms	RMS of the noise before the hit
samplerate	Samplerate in Hz
samples	Number of samples
threshold	Threshold amplitude in volts
time	Time in seconds
trai	Transient recorder index (foreign key between pridb and tradb)

vallenae.io.TraRecord.channel

TraRecord.**channel:** int

Channel number

vallenae.io.TraRecord.data

TraRecord.**data:** ndarray

Transient signal in volts or ADC values if *raw* = *True*

vallenae.io.TraRecord.param_id

TraRecord.**param_id:** int

Parameter ID of table tr_params for ADC value conversion

vallenae.io.TraRecord.pretrigger

TraRecord.**pretrigger:** int

Pretrigger samples

vallenae.io.TraRecord.raw

TraRecord.**raw:** bool

data is stored as ADC values (int16)

vallenae.io.TraRecord.rms

TraRecord.**rms**: Optional[float]
RMS of the noise before the hit

vallenae.io.TraRecord.samplerate

TraRecord.**samplerate**: int
Samplerate in Hz

vallenae.io.TraRecord.samples

TraRecord.**samples**: int
Number of samples

vallenae.io.TraRecord.threshold

TraRecord.**threshold**: float
Threshold amplitude in volts

vallenae.io.TraRecord.time

TraRecord.**time**: float
Time in seconds

vallenae.io.TraRecord.trai

TraRecord.**trai**: Optional[int]
Transient recorder index (foreign key between pridb and tradb)

Methods

__init__()	
count(value, /)	Return number of occurrences of value.
from_sql(row, *[, raw])	Create *TraRecord* from SQL row.
index(value[, start, stop])	Return first index of value.

vallenae.io.TraRecord.__init__

TraRecord.**__init__**()

vallenae.io.TraRecord.count

TraRecord.**count**(*value*, /)

Return number of occurrences of value.

vallenae.io.TraRecord.from_sql

classmethod TraRecord.**from_sql**(*row*, *, *raw=False*)

Create *TraRecord* from SQL row.

Parameters

- **row** (Dict[str, Any]) – Dict of column names and values
- **raw** (bool) – Provide *data* as ADC values (int16)

Return type

TraRecord

vallenae.io.TraRecord.index

TraRecord.**index**(*value*, *start=0*, *stop=9223372036854775807*, /)

Return first index of value.

Raises ValueError if the value is not present.

1.2.6 vallenae.io.FeatureRecord

class vallenae.io.**FeatureRecord**(*trai: int*, *features: Dict[str, float]*)

Transient feature record in trfdb.

Attributes

features	Feature dictionary (feature name -> value)
trai	Transient recorder index

vallenae.io.FeatureRecord.features

FeatureRecord.**features: Dict[str, float]**

Feature dictionary (feature name -> value)

vallenae.io.FeatureRecord.trai

FeatureRecord.**trai**: int

Transient recorder index

Methods

__init__()	
count(value, /)	Return number of occurrences of value.
from_sql(row)	Create *FeatureRecord* from SQL row.
index(value[, start, stop])	Return first index of value.

vallenae.io.FeatureRecord.__init__

FeatureRecord.**__init__**()

vallenae.io.FeatureRecord.count

FeatureRecord.**count**(*value*, /)

Return number of occurrences of value.

vallenae.io.FeatureRecord.from_sql

classmethod FeatureRecord.**from_sql**(*row*)

Create *FeatureRecord* from SQL row.

Parameters

row (Dict[str, Any]) – Dict of column names and values

Return type

FeatureRecord

vallenae.io.FeatureRecord.index

FeatureRecord.**index**(*value*, *start=0*, *stop=9223372036854775807*, /)

Return first index of value.

Raises ValueError if the value is not present.

1.3 Compression

Transient signals in the tradb are stored as BLOBs of 16-bit ADC values – either uncompressed or compressed (FLAC). Following functions convert between BLOBs and arrays of voltage values.

decode_data_blob(data_blob, data_format, ...)	Decodes (compressed) 16-bit ADC values from BLOB to array of voltage values.
encode_data_blob(data, data_format, ...[, raw])	Encodes array of voltage values to BLOB of 16-bit ADC values for memory-efficient storage.

1.3.1 vallenae.io.decode_data_blob

vallenae.io.**decode_data_blob**(*data_blob*, *data_format*, *factor_millivolts*, *, *raw=False*)

Decodes (compressed) 16-bit ADC values from BLOB to array of voltage values.

Parameters

- **data_blob** (bytes) – Blob from tradb
- **data_format** (int) –
  - 0: uncompressed
  - 2: FLAC compression
- **factor_millivolts** (float) – Factor from int16 representation to millivolts. Stored in tradb -> tr_params as 'TR_mV'
- **raw** (bool) – Return data as ADC values (np.int16), *factor_millivolts* will be ignored

Return type
ndarray

Returns
Array of voltage values or ADC values if *raw* is *True*

1.3.2 vallenae.io.encode_data_blob

vallenae.io.**encode_data_blob**(*data*, *data_format*, *factor_millivolts*, *, *raw=False*)

Encodes array of voltage values to BLOB of 16-bit ADC values for memory-efficient storage.

Parameters

- **data** (ndarray) – Array with voltage values
- **data_format** (int) –
  - 0: uncompressed
  - 2: FLAC compression
- **factor_millivolts** (float) – Factor from int16 representation to millivolts. Stored in tradb -> tr_params as 'TR_mV'
- **raw** (bool) – Provide *data* as ADC values (int16), *factor_millivolts* will be ignored

Return type
bytes

Returns
Data blob

CHAPTER

TWO

FEATURES

2.1 Acoustic Emission

peak_amplitude(data)	Compute maximum absolute amplitude.
peak_amplitude_index(data)	Compute index of peak amplitude.
is_above_threshold(data, threshold)	Checks if absolute amplitudes are above threshold.
first_threshold_crossing(data, threshold)	Compute index of first threshold crossing.
rise_time(data, threshold, samplerate[, ...])	Compute the rise time.
energy(data, samplerate)	Compute the energy of a hit.
signal_strength(data, samplerate)	Compute the signal strength of a hit.
counts(data, threshold)	Compute the number of positive threshold crossings of a hit (counts).
rms(data)	Compute the root mean square (RMS) of an array.

2.1.1 vallenae.features.peak_amplitude

vallenae.features.**peak_amplitude**(*data*)

Compute maximum absolute amplitude.

Parameters
data (ndarray) – Input array

Return type
float

Returns
Peak amplitude of the input array

2.1.2 vallenae.features.peak_amplitude_index

vallenae.features.**peak_amplitude_index**(*data*)

Compute index of peak amplitude.

Parameters
data (ndarray) – Input array

Return type
int

Returns
Index of peak amplitude

2.1.3 vallenae.features.is_above_threshold

vallenae.features.**is_above_threshold**(*data*, *threshold*)

Checks if absolute amplitudes are above threshold.

Parameters

- **data** (ndarray) – Input array
- **threshold** (float) – Threshold amplitude

Return type
bool

Returns
True if input array is above threshold, otherwise False

2.1.4 vallenae.features.first_threshold_crossing

vallenae.features.**first_threshold_crossing**(*data*, *threshold*)

Compute index of first threshold crossing.

Parameters

- **data** (ndarray) – Input array
- **threshold** (float) – Threshold amplitude

Return type
Optional[int]

Returns
Index of first threshold crossing. None if threshold was not exceeded

2.1.5 vallenae.features.rise_time

vallenae.features.**rise_time**(*data*, *threshold*, *samplerate*, *first_crossing=None*, *index_peak=None*)

Compute the rise time.

The rise time is the time between the first threshold crossing and the peak amplitude.

Parameters

- **data** (ndarray) – Input array (hit)
- **threshold** (float) – Threshold amplitude (in volts)
- **samplerate** (int) – Sample rate of the input array
- **first_crossing** (Optional[int]) – Precomputed index of first threshold crossing to save computation time
- **index_peak** (Optional[int]) – Precomputed index of peak amplitude to save computation time

Return type
float

2.1.6 vallenae.features.energy

vallenae.features.**energy**(*data*, *samplerate*)

Compute the energy of a hit.

Energy is the integral of the squared AE-signal over time (EN 1330-9). The unit of energy is eu. 1 eu corresponds to 1e-14 V^2s.

Parameters

- **data** (ndarray) – Input array (hit)
- **samplerate** (int) – Sample rate of input array in Hz

Return type
float

Returns
Energy of input array (hit)

2.1.7 vallenae.features.signal_strength

vallenae.features.**signal_strength**(*data*, *samplerate*)

Compute the signal strength of a hit.

Signal strength is the integral of the rectified AE-signal over time. The unit of Signal Strength is nVs (1e-9 Vs).

Parameters

- **data** (ndarray) – Input array (hit)
- **samplerate** (int) – Sample rate of input array in Hz

Return type
float

Returns
Signal strength of input array (hit)

2.1.8 vallenae.features.counts

vallenae.features.**counts**(*data*, *threshold*)

Compute the number of positive threshold crossings of a hit (counts).

Parameters

- **data** (ndarray) – Input array
- **threshold** (float) – Threshold amplitude

Return type
int

Returns
Number of positive threshold crossings

2.1.9 vallenae.features.rms

vallenae.features.**rms**(*data*)

Compute the root mean square (RMS) of an array.

Parameters
data (ndarray) – Input array

Return type
float

Returns
RMS of the input array

References

https://en.wikipedia.org/wiki/Root_mean_square

2.2 Conversion

amplitude_to_db(amplitude[, reference])	Convert amplitude from volts to decibel (dB).
db_to_amplitude(amplitude_db[, reference])	Convert amplitude from decibel (dB) to volts.

2.2.1 vallenae.features.amplitude_to_db

vallenae.features.**amplitude_to_db**(*amplitude*, *reference=1e-06*)

Convert amplitude from volts to decibel (dB).

Parameters

- **amplitude** (float) – Amplitude in volts
- **reference** (float) – Reference amplitude. Defaults to 1 µV for dB(AE)

Return type
float

Returns
Amplitude in dB(ref)

2.2.2 vallenae.features.db_to_amplitude

vallenae.features.**db_to_amplitude**(*amplitude_db*, *reference=1e-06*)

Convert amplitude from decibel (dB) to volts.

Parameters

- **amplitude_db** (float) – Amplitude in dB
- **reference** (float) – Reference amplitude. Defaults to 1 µV for dB(AE)

Return type
float

Returns
Amplitude in volts

CHAPTER

THREE

TIMERPICKER

The determination of signal arrival times has a major influence on the localization accuracy. Usually, arrival times are determined by the first threshold crossing (either fixed or adaptive). Following popular methods have been proposed in the past to automatically pick time of arrivals:

hinkley(arr[, alpha])	Hinkley criterion for arrival time estimation.
aic(arr)	Akaike Information Criterion (AIC) for arrival time estimation.
energy_ratio(arr[, win_len])	Energy ratio for arrival time estimation.
modified_energy_ratio(arr[, win_len])	Modified energy ratio method for arrival time estimation.

3.1 vallenae.timepicker.hinkley

vallenae.timepicker.**hinkley**(*arr*, *alpha=5*)

Hinkley criterion for arrival time estimation.

The Hinkley criterion is defined as the partial energy of the signal (cumulative square sum) with an applied negative trend (characterized by alpha).

The starting value of alpha is reduced iteratively to avoid wrong picks within the pre-trigger part of the signal. Usually alpha values are chosen to be between 2 and 200 to ensure minimal delay. The chosen alpha value for the Hinkley criterion influences the results significantly.

Parameters

- **arr** (ndarray) – Transient signal of hit
- **alpha** (int) – Divisor of the negative trend. Default: 5

Return type

Tuple[ndarray, int]

Returns

- Array with computed detection function
- Index of the estimated arrival time (max value)

References

- Molenda, M. (2016). Acoustic Emission monitoring of laboratory hydraulic fracturing experiments. Ruhr-Universität Bochum.
- van Rijn, N. (2017). Investigating the Behaviour of Acoustic Emission Waves Near Cracks: Using the Finite Element Method. Delft University of Technology.

3.2 vallenae.timepicker.aic

vallenae.timepicker.**aic**(*arr*)

Akaike Information Criterion (AIC) for arrival time estimation.

The AIC picker basically models the signal as an autoregressive (AR) process. A typical AE signal can be subdivided into two parts. The first part containing noise and the second part containing noise and the AE signal. Both parts of the signal contain non deterministic parts (noise) describable by a Gaussian distribution.

Parameters
arr (ndarray) – Transient signal of hit

Return type
Tuple[ndarray, int]

Returns

- Array with computed detection function
- Index of the estimated arrival time (max value)

References

- Molenda, M. (2016). Acoustic Emission monitoring of laboratory hydraulic fracturing experiments. Ruhr-Universität Bochum.
- Bai, F., Gagar, D., Foote, P., & Zhao, Y. (2017). Comparison of alternatives to amplitude thresholding for onset detection of acoustic emission signals. Mechanical Systems and Signal Processing, 84, 717-730.
- van Rijn, N. (2017). Investigating the Behaviour of Acoustic Emission Waves Near Cracks: Using the Finite Element Method. Delft University of Technology.

3.3 vallenae.timepicker.energy_ratio

vallenae.timepicker.**energy_ratio**(*arr*, *win_len=100*)

Energy ratio for arrival time estimation.

Method based on preceding and following energy collection windows.

Parameters

- **arr** (ndarray) – Transient signal of hit
- **win_len** (int) – Samples of sliding windows. Default: 100

Return type
Tuple[ndarray, int]

Returns

- Array with computed detection function
- Index of the estimated arrival time (max value)

References

- Han, L., Wong, J., & Bancroft, J. C. (2009). Time picking and random noise reduction on microseismic data. CREWES Research Report, 21, 1-13.

3.4 vallenae.timepicker.modified_energy_ratio

vallenae.timepicker.**modified_energy_ratio**(*arr*, *win_len=100*)

Modified energy ratio method for arrival time estimation.

The modifications improve the ability to detect the onset of a seismic arrival in the presence of random noise.

Parameters

- **arr** (ndarray) – Transient signal of hit
- **win_len** (int) – Samples of sliding windows. Default: 100

Return type
Tuple[ndarray, int]

Returns

- Array with computed detection function
- Index of the estimated arrival time (max value)

References

- Han, L., Wong, J., & Bancroft, J. C. (2009). Time picking and random noise reduction on microseismic data. CREWES Research Report, 21, 1-13.

CHAPTER

FOUR

EXAMPLES

A collection of examples how to read and analyse Acoustic Emission data.

4.1 Export to WAV (incremental)

Generate WAV files from tradb. We use the *vallenae.io.TraDatabase.read_continuous_wave* method to read the transient data as a continuous array.

This example reads and writes the data incrementally to handle big file sizes that don't fit into memory at once.

```
Export channel 1 to /tmp/tmp7tkuetjt/bearing_plain_ch1.wav
Generated WAV files:
/tmp/tmp7tkuetjt/bearing_plain_ch1.wav
```

```
from pathlib import Path
from tempfile import TemporaryDirectory
from typing import Optional

import vallenae as vae
from soundfile import SoundFile

HERE = Path(__file__).parent if "__file__" in locals() else Path.cwd()


def export_wav_incremental(
    filename_wav: Path,
    tradb: vae.io.TraDatabase,
    channel: int,
    time_start: Optional[float] = None,
    time_stop: Optional[float] = None,
    time_block: int = 1,
):
    """
    Export data from tradb to a WAV file.
```

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```
    Args:
        filename_wav: Path to the generated WAV file
        tradb: `TraDatabase` instance
        channel: Channel number
        time_start: Start reading at relative time (in seconds). Start at beginning if
↪`None`
        time_start: Stop reading at relative time (in seconds). Read until end if `None`
        time_block: Block size in seconds
    """
    con = tradb.connection()
    if time_start is None:
        time_start = 0
    if time_stop is None:
        time_stop = con.execute("SELECT MAX(Time) FROM view_tr_data").fetchone()[0]

    samplerates = con.execute("SELECT DISTINCT(SampleRate) FROM tr_data").fetchone()
    assert len(samplerates) == 1
    samplerate = samplerates[0]

    blocks = int((time_stop - time_start) // time_block + 1)
    with SoundFile(filename_wav, "w", samplerate=samplerate, channels=1, subtype="PCM_16
↪") as f:
        for block in range(blocks):
            time_block_start = time_start + block * time_block
            time_block_stop = min(time_start + (block + 1) * time_block, time_stop)
            y, _ = tradb.read_continuous_wave(
                channel=channel,
                time_start=time_block_start,
                time_stop=time_block_stop,
                time_axis=False,
                show_progress=False,
                raw=True,  # read as ADC values (int16)
            )
            f.write(y)
            f.flush()


def main():
    filename_tradb = HERE / "bearing" / "bearing_plain.tradb"
    # use a temporary file for this example
    with TemporaryDirectory() as tmpdir:
        with vae.io.TraDatabase(filename_tradb) as tradb:
            for channel in tradb.channel():
                filename_wav = Path(tmpdir) / f"{filename_tradb.stem}_ch{channel}.wav"
                print(f"Export channel {channel} to {filename_wav}")
                export_wav_incremental(
                    filename_wav=filename_wav,
                    tradb=tradb,
                    channel=channel,
                    time_start=0,  # read from t = 0 s
                    time_stop=None,  # read until end if None
                    time_block=1,  # read/write in block sizes of 1 s
```

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```
                )

        # list all generated wav files
        print("Generated WAV files:")
        for file in Path(tmpdir).iterdir():
            print(file)


if __name__ == "__main__":
    main()
```

Total running time of the script: (0 minutes 0.059 seconds)

4.2 Read pridb

```
from pathlib import Path

import matplotlib.pyplot as plt
import vallenae as vae

HERE = Path(__file__).parent if "__file__" in locals() else Path.cwd()
PRIDB = HERE / "steel_plate" / "sample.pridb"
```

4.2.1 Open pridb

```
pridb = vae.io.PriDatabase(PRIDB)

print("Tables in database: ", pridb.tables())
print("Number of rows in data table (ae_data): ", pridb.rows())
print("Set of all channels: ", pridb.channel())
```

```
Tables in database:  {'ae_data', 'ae_fieldinfo', 'data_integrity', 'acq_setup', 'ae_
↪markers', 'ae_params', 'ae_globalinfo'}
Number of rows in data table (ae_data):  18
Set of all channels:  {1, 2, 3, 4}
```

4.2.2 Read hits to Pandas DataFrame

```
df_hits = pridb.read_hits()
# Print a few columns
print(df_hits[["time", "channel", "amplitude", "counts", "energy"]])
```

```
Hits:   0%|          | 0/4 [00:00<?, ?it/s]
Hits: 100%|| 4/4 [00:00<00:00, 7660.83it/s]
            time  channel  amplitude  counts        energy
set_id
```

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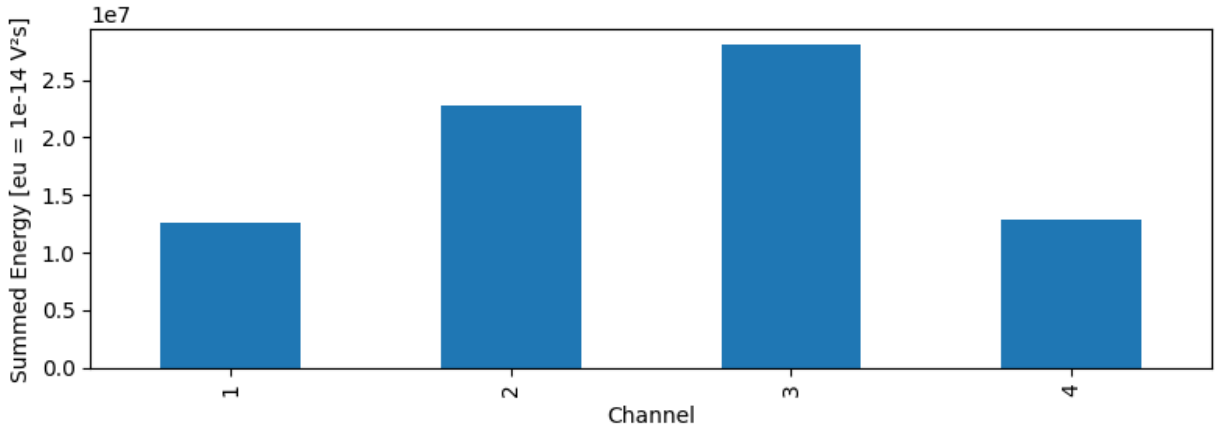
```
10      3.992771        3   0.046539    2180  2.799510e+07
11      3.992775        2   0.059621    2047  2.276279e+07
12      3.992813        4   0.034119    1854  1.286700e+07
13      3.992814        1   0.029115    1985  1.265275e+07
```

4.2.3 Query Pandas DataFrame

DataFrames offer powerful features to query and aggregate data, e.g. plot summed energy per channel

```
ax = df_hits.groupby("channel").sum()["energy"].plot.bar(figsize=(8, 3))
ax.set_xlabel("Channel")
ax.set_ylabel("Summed Energy [eu = 1e-14 V²s]")
plt.tight_layout()
plt.show()
```



4.2.4 Read markers

```
df_markers = pridb.read_markers()
print(df_markers)
```

```
Marker:   0%|          | 0/5 [00:00<?, ?it/s]
Marker: 100%|| 5/5 [00:00<00:00, 14354.22it/s]
          time  set_type                                          data  number
set_id
1         0.00         6                                                     1
2         0.00         4                                  10:52 Resume       1
3         0.00         5                       2019-09-20 10:54:52    <NA>
4         0.00         4  TimeZone: +02:00 (W. Europe Standard Time)       2
18      100.07         4                                  10:56 Suspend       3
```

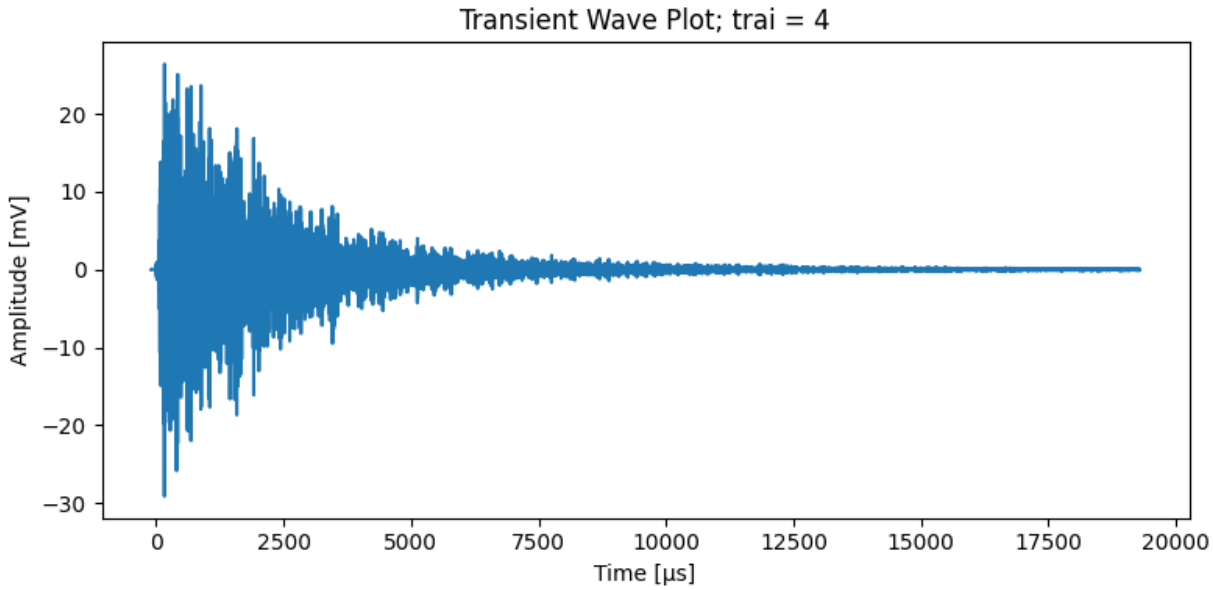
4.2.5 Read parametric data

```
df_parametric = pridb.read_parametric()
print(df_parametric)
```

```
Parametric:   0%|          | 0/9 [00:00<?, ?it/s]
Parametric: 100%|| 9/9 [00:00<00:00, 13842.59it/s]
        time  param_id  pctd  pcta
set_id
5       0.00         1     0     0
6       1.00         1     0     0
7       2.00         1     0     0
8       3.00         1     0     0
9       3.99         1     0     0
14      4.00         1     0     0
15      5.00         1     0     0
16      6.00         1     0     0
17      6.45         1     0     0
```

Total running time of the script: (0 minutes 0.217 seconds)

4.3 Read and plot transient data




```
from pathlib import Path

import matplotlib.pyplot as plt
import vallenae as vae

HERE = Path(__file__).parent if "__file__" in locals() else Path.cwd()
TRADB = HERE / "steel_plate" / "sample_plain.tradb"  # uncompressed
```

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```
TRAI = 4  # just an example, no magic here


def main():
    # Read waveform from tradb
    with vae.io.TraDatabase(TRADB) as tradb:
        y, t = tradb.read_wave(TRAI)

    y *= 1e3  # in mV
    t *= 1e6  # for µs

    # Plot waveforms
    plt.figure(figsize=(8, 4), tight_layout=True)
    plt.plot(t, y)
    plt.xlabel("Time [µs]")
    plt.ylabel("Amplitude [mV]")
    plt.title(f"Transient Wave Plot; trai = {TRAI}")
    plt.show()


if __name__ == "__main__":
    main()
```

Total running time of the script: (0 minutes 0.269 seconds)

4.4 Timepicker

Following example showcases the results of different timepicking methods. For more informations, please refer to the functions documentation (*vallenae.timepicker*).

```
import time
from pathlib import Path

import matplotlib.pyplot as plt
import vallenae as vae

HERE = Path(__file__).parent if "__file__" in locals() else Path.cwd()
TRADB = HERE / "steel_plate" / "sample_plain.tradb"
TRAI = 4
SAMPLES = 2000
```

4.4.1 Read waveform from tradb

```
tradb = vae.io.TraDatabase(TRADB)

y, t = tradb.read_wave(TRAI)
# crop first samples
t = t[:SAMPLES]
y = y[:SAMPLES]
# unit conversion
t *= 1e6  # convert to µs
y *= 1e3  # convert to mV
```

4.4.2 Prepare plotting with time-picker results

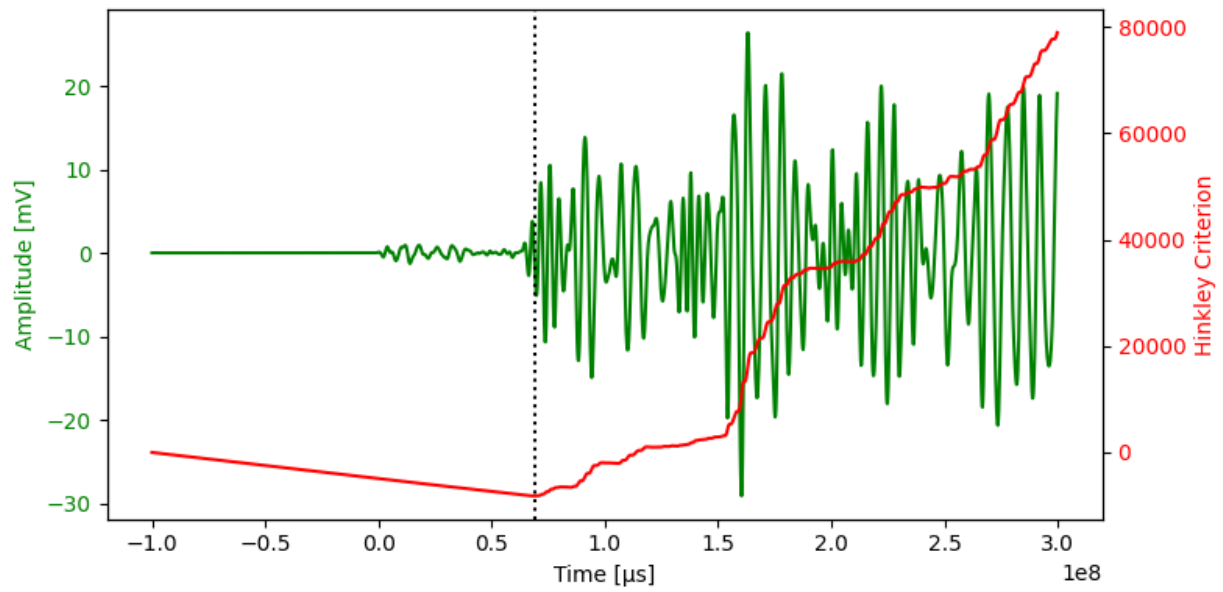
```
def plot(t_wave, y_wave, y_picker, index_picker, name_picker):
    _, ax1 = plt.subplots(figsize=(8, 4), tight_layout=True)
    ax1.set_xlabel("Time [µs]")
    ax1.set_ylabel("Amplitude [mV]", color="g")
    ax1.plot(t_wave, y_wave, color="g")
    ax1.tick_params(axis="y", labelcolor="g")

    ax2 = ax1.twinx()
    ax2.set_ylabel(f"{name_picker}", color="r")
    ax2.plot(t_wave, y_picker, color="r")
    ax2.tick_params(axis="y", labelcolor="r")

    plt.axvline(t_wave[index_picker], color="k", linestyle=":")
    plt.show()
```

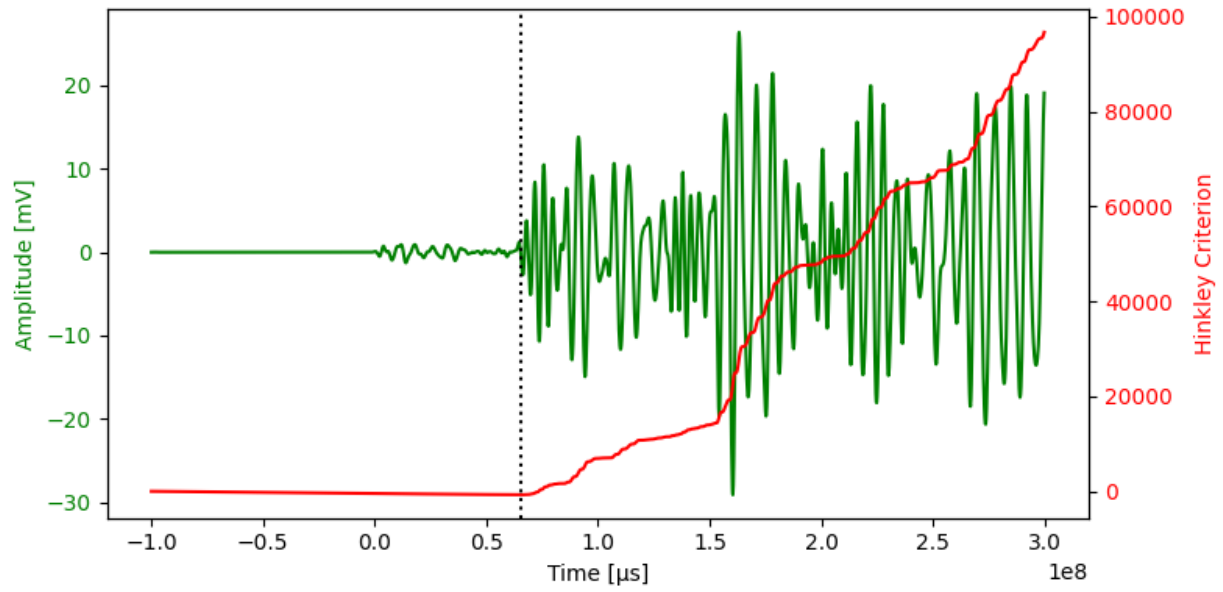
4.4.3 Hinkley Criterion

```
hc_arr, hc_index = vae.timepicker.hinkley(y, alpha=5)
plot(t, y, hc_arr, hc_index, "Hinkley Criterion")
```



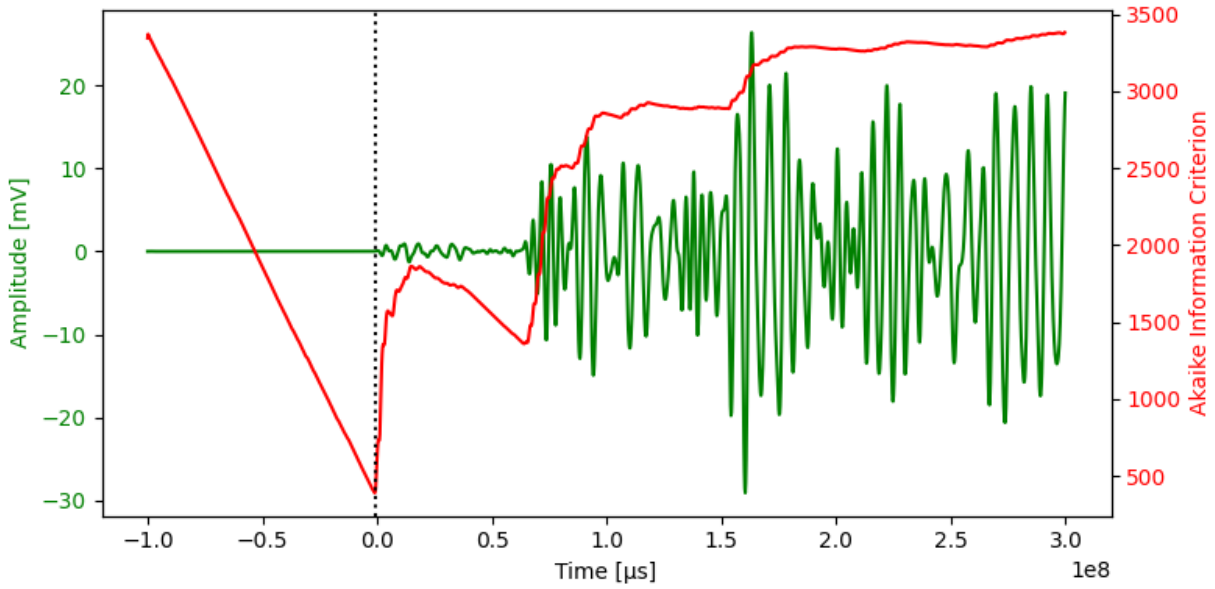
The negative trend correlates to the chosen alpha value and can influence the results strongly. Results with **alpha = 50** (less negative trend):

```
hc_arr, hc_index = vae.timepicker.hinkley(y, alpha=50)
plot(t, y, hc_arr, hc_index, "Hinkley Criterion")
```



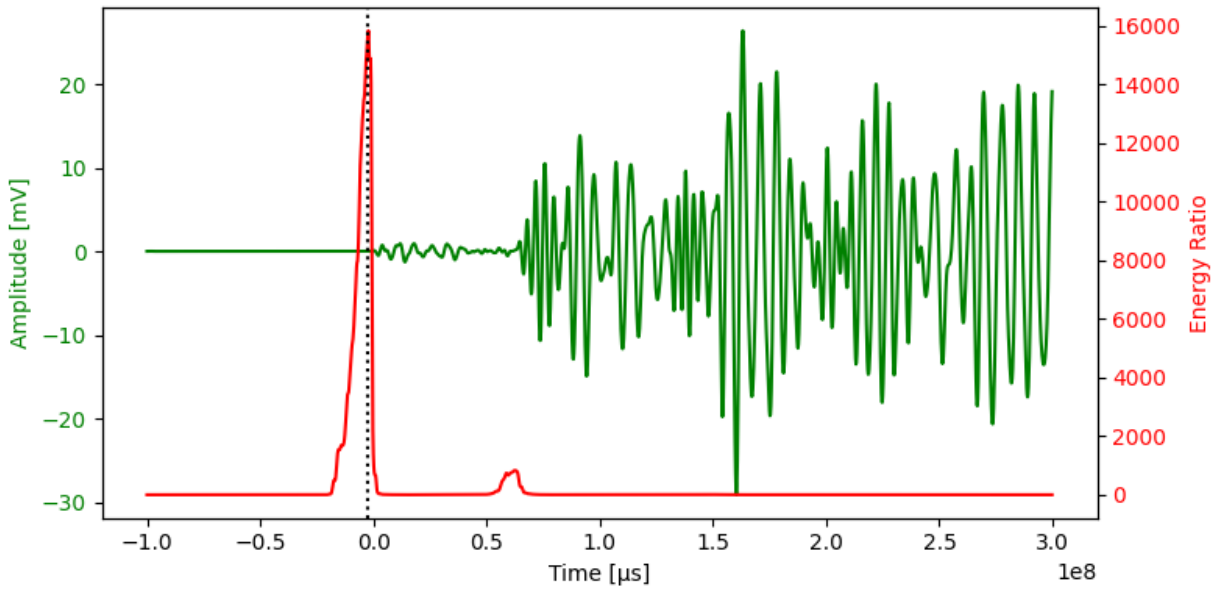
4.4.4 Akaike Information Criterion (AIC)

```
aic_arr, aic_index = vae.timepicker.aic(y)
plot(t, y, aic_arr, aic_index, "Akaike Information Criterion")
```



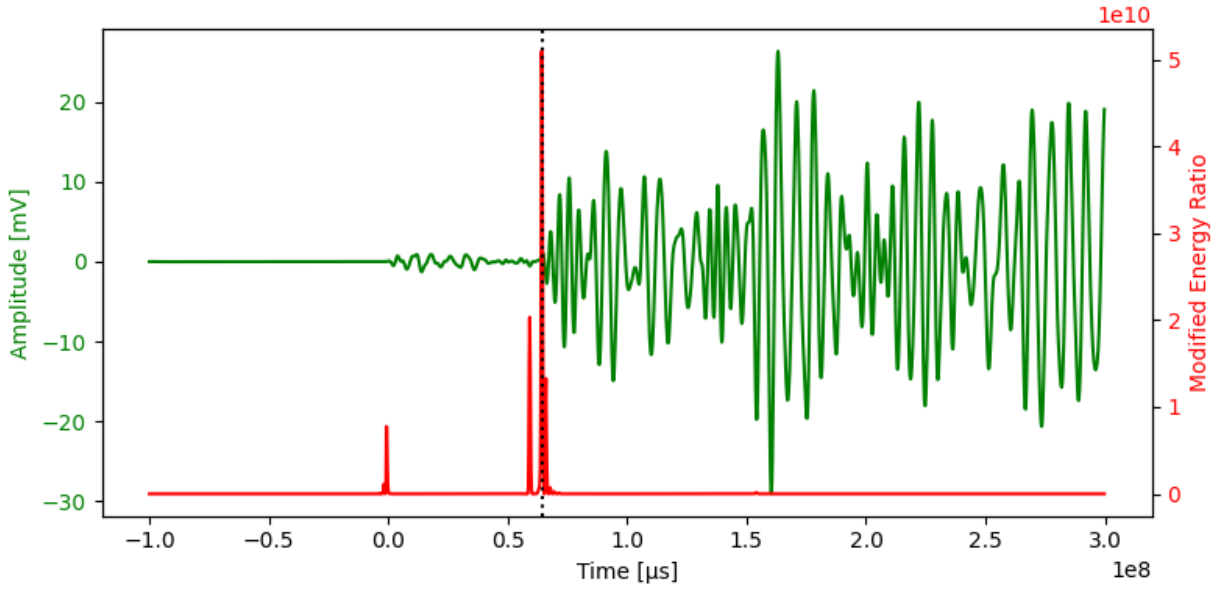
4.4.5 Energy Ratio

```
er_arr, er_index = vae.timepicker.energy_ratio(y)
plot(t, y, er_arr, er_index, "Energy Ratio")
```



4.4.6 Modified Energy Ratio

```
mer_arr, mer_index = vae.timepicker.modified_energy_ratio(y)
plot(t, y, mer_arr, mer_index, "Modified Energy Ratio")
```



4.4.7 Performance comparison

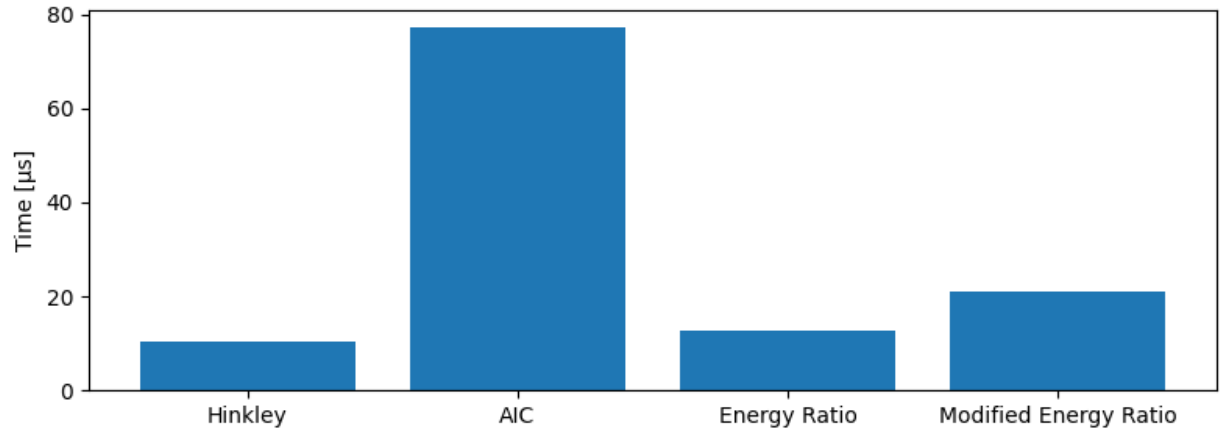
All timepicker implementations are using Numba for just-in-time (JIT) compilations. Usually the first function call is slow, because it will trigger the JIT compiler. To compare the performance to a native or numpy implementation, the average of multiple executions should be compared.

```
def timeit(func, loops=100):
    time_start = time.perf_counter()
    for _ in range(loops):
        func()
    return 1e6 * (time.perf_counter() - time_start) / loops  # elapsed time in µs

timer_results = {
    "Hinkley": timeit(lambda: vae.timepicker.hinkley(y, 5)),
    "AIC": timeit(lambda: vae.timepicker.aic(y)),
    "Energy Ratio": timeit(lambda: vae.timepicker.energy_ratio(y)),
    "Modified Energy Ratio": timeit(lambda: vae.timepicker.modified_energy_ratio(y)),
}

for name, execution_time in timer_results.items():
    print(f"{name}: {execution_time:0.3f} µs")

plt.figure(figsize=(8, 3), tight_layout=True)
plt.bar(timer_results.keys(), timer_results.values())  # noqa: SIM911
plt.ylabel("Time [µs]")
plt.show()
```




```
Hinkley: 10.551 µs
AIC: 77.192 µs
Energy Ratio: 12.600 µs
Modified Energy Ratio: 20.961 µs
```

Total running time of the script: (0 minutes 3.184 seconds)

4.5 Timepicker batch processing

Following examples shows how to stream transient data row by row, compute timepicker results and save the results to a feature database (trfdb).

```
from pathlib import Path
from shutil import copyfile
from tempfile import gettempdir

import matplotlib.pyplot as plt
import pandas as pd
import vallenae as vae

HERE = Path(__file__).parent if "__file__" in locals() else Path.cwd()
TRADB = HERE / "steel_plate" / "sample_plain.tradb"
TRFDB = HERE / "steel_plate" / "sample.trfdb"
TRFDB_TMP = Path(gettempdir()) / "sample.trfdb"
```

4.5.1 Open tradb (readonly) and trfdb (readwrite)

```
copyfile(TRFDB, TRFDB_TMP)  # copy trfdb, so we don't overwrite it

tradb = vae.io.TraDatabase(TRADB)
trfdb = vae.io.TrfDatabase(TRFDB_TMP, mode="rw")  # allow writing
```

4.5.2 Read current trfdb

```
print(trfdb.read())
```

```
Trf:   0%|          | 0/4 [00:00<?, ?it/s]
Trf: 100%|| 4/4 [00:00<00:00, 27369.03it/s]
         FFT_CoG     FFT_FoM         PA  ...  CTP          FI          FR
trai                                     ...
1     147.705078  134.277344  46.483864  ...   11  222.672058  110.182449
2     144.042969  139.160156  59.450512  ...   35  182.291672   98.019981
3     155.029297  164.794922  33.995209  ...   55  155.191879   95.493233
4     159.912109  139.160156  29.114828  ...   29  181.023727  101.906227

[4 rows x 8 columns]
```

4.5.3 Compute arrival time offsets with different timepickers

To improve localisation, time of arrival estimates using the first threshold crossing can be refined with timepickers. Therefore, arrival time offsets between the first threshold crossings and the timepicker results are computed.

```
def dt_from_timepicker(timepicker_func, tra: vae.io.TraRecord):
    # Index of the first threshold crossing is equal to the pretrigger samples
    index_ref = tra.pretrigger
    # Only analyse signal until peak amplitude
    index_peak = vae.features.peak_amplitude_index(tra.data)
    data = tra.data[:index_peak]
    # Get timepicker result
    _, index_timepicker = timepicker_func(data)
    # Compute offset in µs
    return (index_timepicker - index_ref) * 1e6 / tra.samplerate
```

Transient data is streamed from the database row by row using *vallenae.io.TraDatabase.iread*. Only one transient data set is loaded into memory at a time. That makes the streaming interface ideal for batch processing. The timepicker results are saved to the trfdb using *vallenae.io.TrfDatabase.write*.

```
for tra in tradb.iread():
    # Calculate arrival time offsets with different timepickers
    feature_set = vae.io.FeatureRecord(
        trai=tra.trai,
        features={
            "ATO_Hinkley": dt_from_timepicker(vae.timepicker.hinkley, tra),
            "ATO_AIC": dt_from_timepicker(vae.timepicker.aic, tra),
            "ATO_ER": dt_from_timepicker(vae.timepicker.energy_ratio, tra),
            "ATO_MER": dt_from_timepicker(vae.timepicker.modified_energy_ratio, tra),
        }
    )
    # Save results to trfdb
    trfdb.write(feature_set)
```

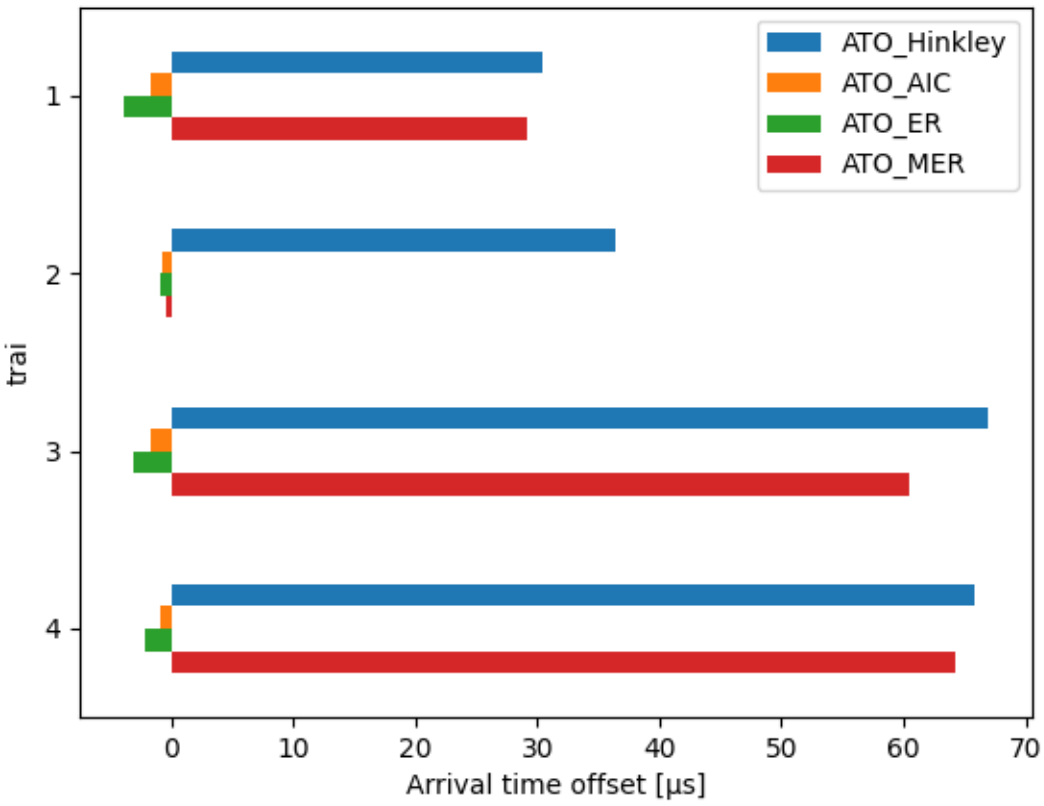
4.5.4 Read results from trfdb

```
print(trfdb.read().filter(regex="ATO"))
```

```
Trf:   0%|          | 0/4 [00:00<?, ?it/s]
Trf: 100%|| 4/4 [00:00<00:00, 80273.76it/s]
      ATO_Hinkley  ATO_AIC  ATO_ER  ATO_MER
trai
1            30.4     -1.8    -4.0     29.2
2            36.4     -0.8    -1.0     -0.4
3            67.0     -1.8    -3.2     60.4
4            65.8     -1.0    -2.2     64.2
```

4.5.5 Plot results

```
ax = trfdb.read()[["ATO_Hinkley", "ATO_AIC", "ATO_ER", "ATO_MER"]].plot.barh()
ax.invert_yaxis()
ax.set_xlabel("Arrival time offset [µs]")
plt.show()
```




```
Trf:   0%|          | 0/4 [00:00<?, ?it/s]
Trf: 100%|| 4/4 [00:00<00:00, 87838.83it/s]
```

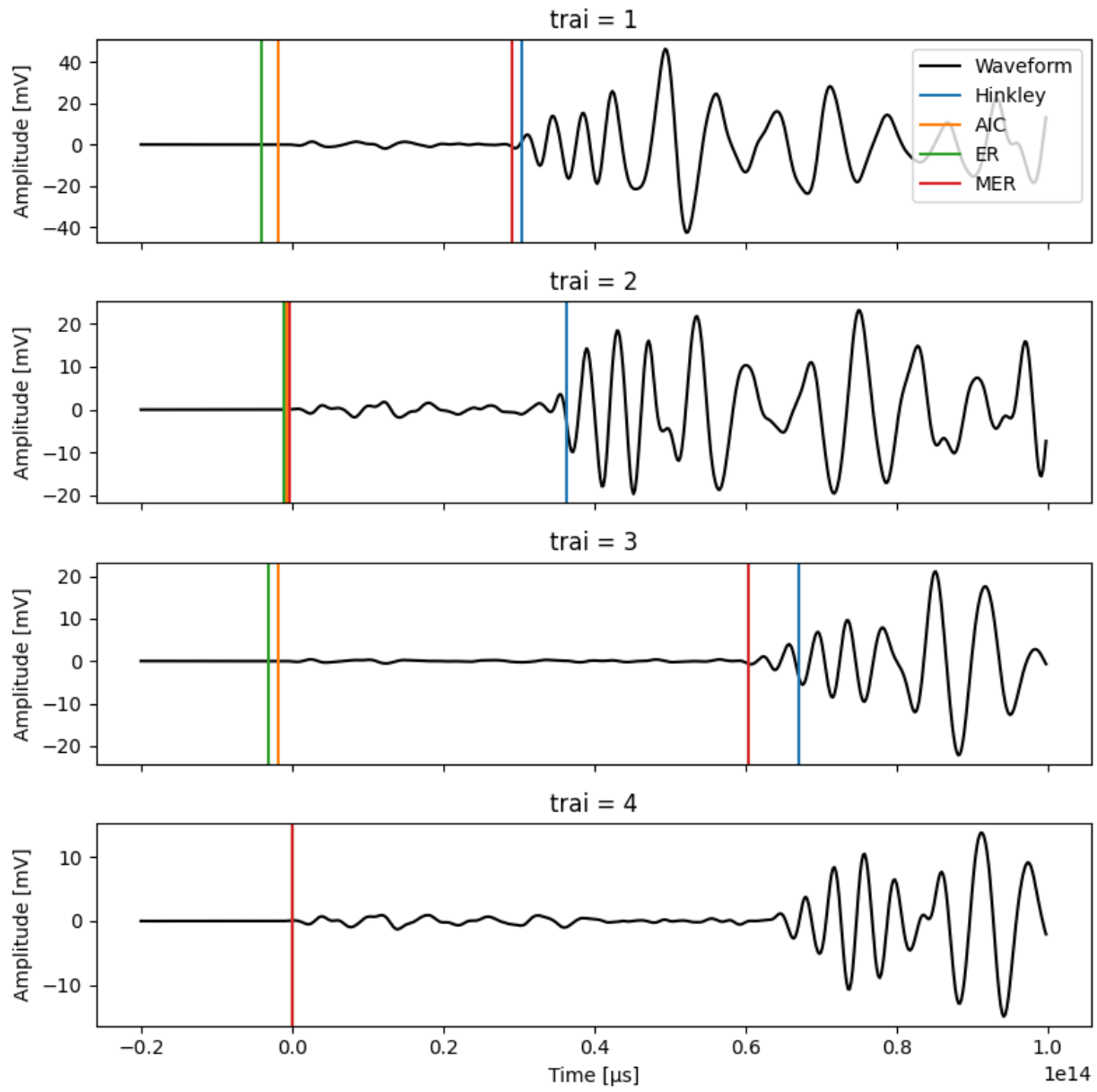
4.5.6 Plot waveforms and arrival times

```
_, axes = plt.subplots(4, 1, tight_layout=True, figsize=(8, 8))
for row, ax in zip(trfdb.read().itertuples(), axes):
    trai = row.Index

    # read waveform from tradb
    y, t = tradb.read_wave(trai)

    # plot waveform
    ax.plot(t[400:1000] * 1e6, y[400:1000] * 1e3, "k")  # crop and convert to µs/mV
    ax.set_title(f"trai = {trai}")
    ax.set_xlabel("Time [µs]")
    ax.set_ylabel("Amplitude [mV]")
    ax.label_outer()
    # plot arrival time offsets
    ax.axvline(row.ATO_Hinkley, color="C0")
    ax.axvline(row.ATO_AIC, color="C1")
    ax.axvline(row.ATO_ER, color="C2")
    ax.axvline(row.ATO_MER, color="C3")

axes[0].legend(["Waveform", "Hinkley", "AIC", "ER", "MER"])
plt.show()
```




```
Trf:   0%|          | 0/4 [00:00<?, ?it/s]
Trf: 100%|| 4/4 [00:00<00:00, 68200.07it/s]
```

4.5.7 Use results in VisualAE

The computed arrival time offsets can be directly used in VisualAE. We only need to specify the unit. VisualAE requires them to be in µs. Units and other column-related meta data is saved in the *trf_fieldinfo* table. Field infos can be retrieved with *vallenae.io.TrfDatabase.fieldinfo*:

```
print(trfdb.fieldinfo())
```

```
{'FFT_CoG': {'SetTypes': 2, 'Unit': '[kHz]', 'LongName': 'F(C.o.Gravity)', 'Description
↪': 'Center of gravity of spectrum', 'ShortName': None, 'FormatStr': None}, 'FFT_FoM': {
↪'SetTypes': 2, 'Unit': '[kHz]', 'LongName': 'F(max. Amp.)', 'Description': 'Frequency␣
↪of maximum of spectrum', 'ShortName': None, 'FormatStr': None}, 'PA': {'SetTypes': 8,
↪'Unit': '[mV]', 'LongName': 'Peak Amplitude', 'Description': None, 'ShortName': None,
↪'FormatStr': None}, 'RT': {'SetTypes': 8, 'Unit': '[µs]', 'LongName': 'Rise Time',
↪'Description': None, 'ShortName': None, 'FormatStr': None}, 'Dur': {'SetTypes': 8,
↪'Unit': '[µs]', 'LongName': 'Duration (available)', 'Description': None, 'ShortName':␣
↪None, 'FormatStr': None}, 'CTP': {'SetTypes': 8, 'Unit': None, 'LongName': 'Cnts to␣
↪peak', 'Description': None, 'ShortName': None, 'FormatStr': '#'}, 'FI': {'SetTypes': 8,
↪ 'Unit': '[kHz]', 'LongName': 'Initiation Freq.', 'Description': None, 'ShortName':␣
↪None, 'FormatStr': None}, 'FR': {'SetTypes': 8, 'Unit': '[kHz]', 'LongName':
↪'Reverberation Freq.', 'Description': None, 'ShortName': None, 'FormatStr': None}}
```

Show results as table:

```
print(pd.DataFrame(trfdb.fieldinfo()))
```

```
                                FFT_CoG  ...                   FR
SetTypes                              2  ...                    8
Unit                              [kHz]  ...                [kHz]
LongName                 F(C.o.Gravity)  ...  Reverberation Freq.
Description  Center of gravity of spectrum  ...                 None
ShortName                           None  ...                 None
FormatStr                           None  ...                 None

[6 rows x 8 columns]
```

Write units to trfdb

Field infos can be written with *vallenae.io.TrfDatabase.write_fieldinfo*:

```
trfdb.write_fieldinfo("ATO_Hinkley", {"Unit": "[µs]", "LongName": "Arrival Time Offset␣
↪(Hinkley)"})
trfdb.write_fieldinfo("ATO_AIC", {"Unit": "[µs]", "LongName": "Arrival Time Offset (AIC)
↪"})
trfdb.write_fieldinfo("ATO_ER", {"Unit": "[µs]", "LongName": "Arrival Time Offset (ER)"})
trfdb.write_fieldinfo("ATO_MER", {"Unit": "[µs]", "LongName": "Arrival Time Offset (MER)
↪"})

print(pd.DataFrame(trfdb.fieldinfo()).filter(regex="ATO"))
```

```
                           ATO_Hinkley  ...                   ATO_MER
SetTypes                          None  ...                      None
```

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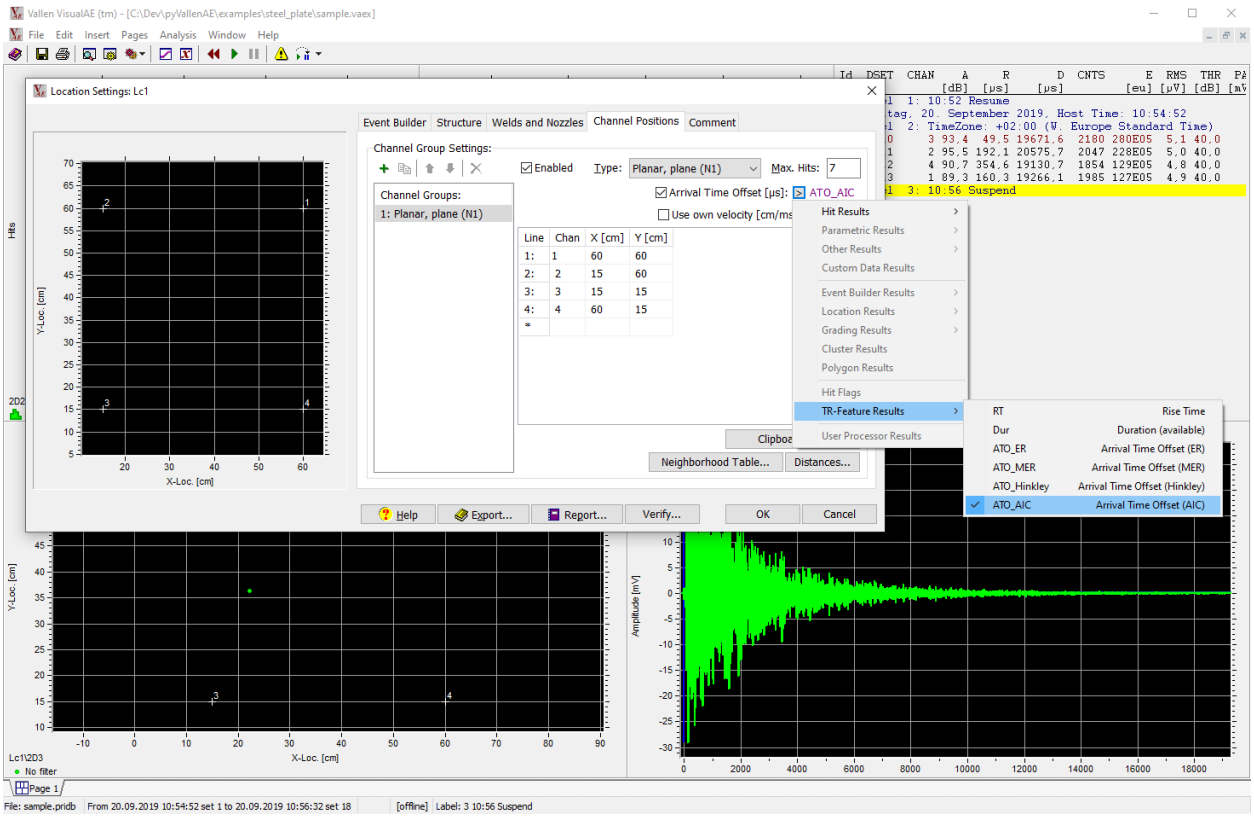
```
Unit                                    [µs]  ...                                    [µs]
LongName     Arrival Time Offset (Hinkley)  ...  Arrival Time Offset (MER)
Description                             None  ...                                    None
ShortName                               None  ...                                    None
FormatStr                               None  ...                                    None

[6 rows x 4 columns]
```

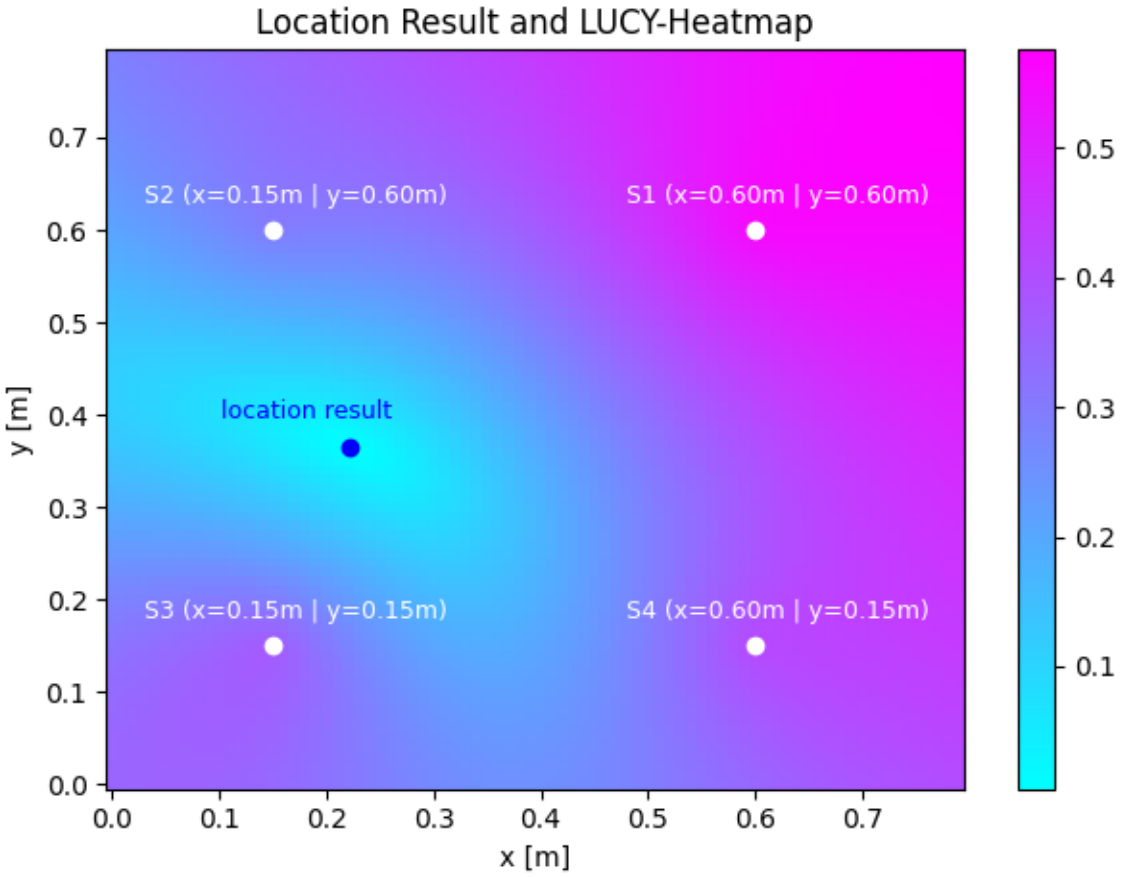
Load results in VisualAE

Time arrival offsets can be specified in the settings of *Location Processors - Channel Positions - Arrival Time Offset*. (Make sure to rename the generated trfdb to match the filename of the pridb.)



Total running time of the script: (0 minutes 0.834 seconds)

4.6 Localisation




```
Hits:   0%|          | 0/4 [00:00<?, ?it/s]
Hits: 100%|| 4/4 [00:00<00:00, 9310.33it/s]
Runtime for 1 call to differential_evolution(): 0.6603 s
             message: Optimization terminated successfully.
             success: True
                 fun: 0.001115889206067505
                   x: [ 2.217e-01  3.657e-01]
                 nit: 101
                nfev: 8175
          population: [[ 2.216e-01  3.657e-01]
                       [ 2.216e-01  3.657e-01]
                       ...
                       [ 2.219e-01  3.655e-01]
                       [ 2.218e-01  3.656e-01]]
 population_energies: [ 1.116e-03  1.118e-03 ...  1.144e-03  1.127e-03]
                 jac: [-7.818e-04  8.985e-04]
```

```python
import math
import time
from pathlib import Path
from typing import Dict, Optional, Tuple
from xml.etree import ElementTree

import matplotlib.pyplot as plt
import numpy as np
import vallenae as vae
from numba import f8, njit
from numpy.linalg import norm
from scipy.optimize import differential_evolution

HERE = Path(__file__).parent if "__file__" in locals() else Path.cwd()
PRIDB = HERE / "steel_plate" / "sample.pridb"
SETUP = HERE / "steel_plate" / "sample.vaex"
NUMBER_SENSORS = 4


@njit(f8(f8[:], f8, f8[:, :], f8[:]))
def lucy_error_fun(
    test_pos: np.ndarray,
    speed: float,
    sens_poss: np.ndarray,
    measured_delta_ts: np.ndarray,
) -> float:
    """
    Implementation of the LUCY computation in 2D as documented in
    the Vallen online help.

    Args:
        test_pos: Emitter position to test.
        speed: Assumed speed of sound in a plate-like structure.
        sens_poss: Sensor positions, often a 4x2 array, has to match
            the sorting of the delta-ts.
        measured_delta_ts: The measured time differences in seconds, has to
            match the order of the sensor positions.

    Returns:
        The LUCY value as a float. Ideally 0, in practice never 0, always positive.
    """
    m = len(measured_delta_ts)
    n = m + 1
    measured_delta_dists = speed * measured_delta_ts
    theo_dists = np.zeros(n)
    theo_delta_dists = np.zeros(m)
    for i in range(n):
        theo_dists[i] = norm(test_pos - sens_poss[i, :])
    for i in range(m):
        theo_delta_dists[i] = theo_dists[i + 1] - theo_dists[0]

    # LUCY definition taken from the vallen online help:
    return norm(theo_delta_dists - measured_delta_dists) / math.sqrt(n - 1)
```

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```
def get_channel_positions(setup_file: str) -> Dict[int, Tuple[float, float]]:
    tree = ElementTree.parse(setup_file)
    nodes = tree.getroot().findall(".//ChannelPos")
    if nodes is None:
        raise RuntimeError("Can not retrieve channel positions from %s", setup_file)
    return {
        int(elem.get("Chan")): (float(elem.get("X")), float(elem.get("Y")))  # type:␣
↪ignore
        for elem in nodes if elem is not None
    }


def get_velocity(setup_file: str) -> Optional[float]:
    tree = ElementTree.parse(setup_file)
    node = tree.getroot().find(".//Location")
    if node is not None:
        velocity_str = node.get("Velocity")
        if velocity_str is not None:
            return float(velocity_str) * 1e3  # convert to m/s
    raise RuntimeError("Can not retrieve velocity from %s", setup_file)


def main():
    # Consts plotting
    text_delta_y = 0.03
    text_delta_x = -0.12

    # Consts LUCY grid
    grid_delta = 0.01
    location_search_bounds = [(0.0, 0.80), (0.0, 0.80)]

    # Read from pridb
    pridb = vae.io.PriDatabase(PRIDB)
    hits = pridb.read_hits()
    pridb.close()

    channel_order = hits["channel"].to_numpy()
    arrival_times = hits["time"].to_numpy()
    delta_ts = (arrival_times - arrival_times[0])[1:]

    # Get localisation parameters from .vaex file
    velocity = get_velocity(SETUP)
    pos_dict = get_channel_positions(SETUP)

    # Order sensor positions by hit occurence
    pos_ordered = np.array([pos_dict[ch] for ch in channel_order])

    # Compute heatmap
    def lucy_instance_2args(x, y):
        return lucy_error_fun(np.array([x, y]), velocity, pos_ordered, delta_ts)
```

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```
    x_range = np.arange(location_search_bounds[0][0], location_search_bounds[0][1], grid_
↪delta)
    y_range = x_range
    x_grid, y_grid = np.meshgrid(x_range, y_range)
    z_grid = np.vectorize(lucy_instance_2args)(x_grid, y_grid)

    # Plot heatmap
    plt.figure(tight_layout=True)
    plt.pcolormesh(x_grid, y_grid, z_grid, cmap="cool")
    plt.colorbar()
    plt.title("Location Result and LUCY-Heatmap")
    plt.xlabel("x [m]")
    plt.ylabel("y [m]")

    # Compute location
    def lucy_instance_single_arg(pos):
        return lucy_error_fun(pos, velocity, pos_ordered, delta_ts)

    start = time.perf_counter()
    # These are excessive search / overkill parameters:
    location_result = differential_evolution(
        lucy_instance_single_arg,
        location_search_bounds,
        popsize=40,
        polish=True,
        strategy="rand1bin",
        recombination=0.1,
        mutation=1.3,
    )
    end = time.perf_counter()
    print(f"Runtime for 1 call to differential_evolution(): {(end - start):0.4} s")
    print(location_result)

    # Plot location result
    x_res = location_result.x[0]
    y_res = location_result.x[1]
    plt.plot([x_res], [y_res], "bo")
    plt.text(
        x_res + text_delta_x,
        y_res + text_delta_y,
        "location result",
        fontsize=9,
        color="b",
    )

    # Plot sensor positions
    for channel, (x, y) in pos_dict.items():
        text = f"S{channel} (x={x:0.2f}m | y={y:0.2f}m)"
        plt.scatter(x, y, marker="o", color="w")
        plt.text(x + text_delta_x, y + text_delta_y, text, fontsize=9, color="w")
```

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```
    plt.show()


if __name__ == "__main__":
    main()
```

Total running time of the script: (0 minutes 1.836 seconds)

4.7 Go fast with multiprocessing

The streaming interfaces with iterables allow efficient batch processing as shown *here*. But still only one core/thread will be utilized. We will change that will multiprocessing.

Following example shows a batch feature extraction procedure using multiple CPU cores.

```
import multiprocessing
import os
import time
from itertools import cycle
from pathlib import Path
from typing import Iterable

import matplotlib.pyplot as plt
import vallenae as vae

HERE = Path(__file__).parent if "__file__" in locals() else Path.cwd()
TRADB = HERE / "steel_plate" / "sample_plain.tradb"
```

4.7.1 Prepare streaming reads

Our sample tradb only contains four data sets. That is not enough data for demonstrating batch processing. Therefore, we will simulate more data by looping over the data sets with following generator/iterable:

```
def tra_generator(loops: int = 1000) -> Iterable[vae.io.TraRecord]:
    with vae.io.TraDatabase(TRADB) as tradb:
        for loop, tra in enumerate(cycle(tradb.iread())):
            if loop > loops:
                break
            yield tra
```

4.7.2 Define feature extraction function

A simple function from the module `_feature_extraction` is applied to all data sets and returns computed features. The function is defined in another module to work with `multiprocessing.Pool`: https://bugs.python.org/issue25053

```
from _feature_extraction import feature_extraction  # noqa
```

4.7.3 Compute with single thread/core

Note: The examples are executed on the CI / readthedocs server with limited resources. Therefore, the shown computation times and speedups are below the capability of modern machines.

Run computation in a single thread and get the time:

```
def time_elapsed_ms(t0):
    return 1000.0 * (time.perf_counter() - t0)

if __name__ == "__main__":  # guard needed for multiprocessing on Windows
    time_start = time.perf_counter()
    for tra in tra_generator():
        results = feature_extraction(tra)
        # do something with the results
    time_single_thread = time_elapsed_ms(time_start)

    print(f"Time single thread: {time_single_thread:.2f} ms")
```

```
Time single thread: 1239.29 ms
```

4.7.4 Compute with multiple processes/cores

First get number of available cores in your machine:

```
print(f"Available CPU cores: {os.cpu_count()}")
```

```
Available CPU cores: 2
```

But how can we utilize those cores? The common answer for most programming languages is multithreading. Threads run in the same process and heap, so data can be shared between them (with care). Sadly, Python uses a global interpreter lock (GIL) that locks heap memory, because Python objects are not thread-safe. Therefore, threads are blocking each other and no speedups are gained by using multiple threads.

The solution for Python is multiprocessing to work around the GIL. Every process has its own heap and GIL. Multiprocessing will introduce overhead for interprocess communication and data serialization/deserialization. To reduce the overhead, data is sent in bigger chunks.

Run computation on 4 cores with chunks of 128 data sets and get the time / speedup:

```
if __name__ == "__main__":  # guard needed for multiprocessing on Windows
    with multiprocessing.Pool(4) as pool:
        time_start = time.perf_counter()
```

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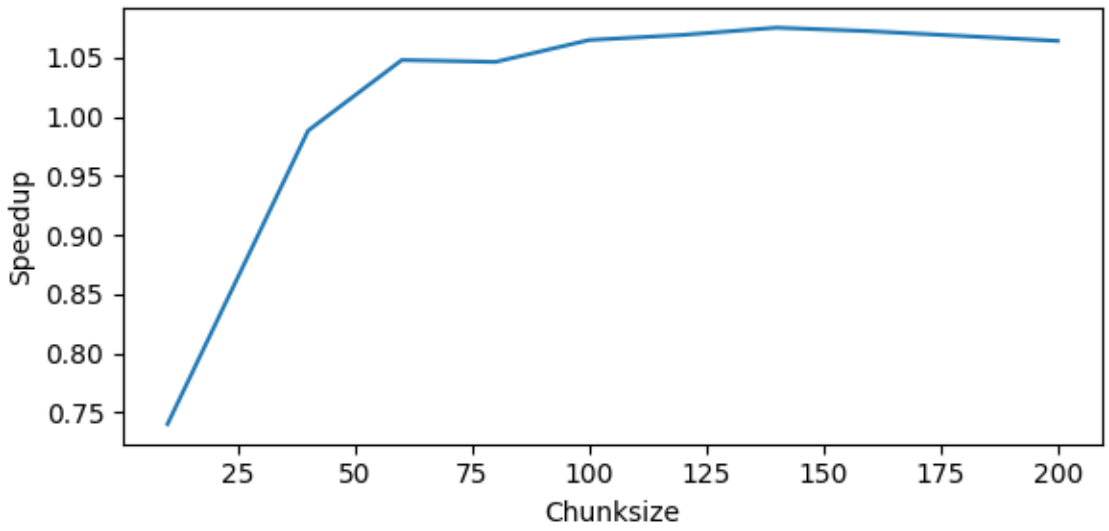
```
        for _results in pool.imap(feature_extraction, tra_generator(), chunksize=128):
            pass  # do something with the results
        time_multiprocessing = time_elapsed_ms(time_start)

    print(f"Time multiprocessing: {time_multiprocessing:.2f} ms")
    print(f"Speedup: {(time_single_thread / time_multiprocessing):.2f}")
```

```
Time multiprocessing: 1295.64 ms
Speedup: 0.96
```

Variation of the chunksize

Following results show how the chunksize impacts the overall performance. The speedup is measured for different chunksizes and plotted against the chunksize:

```
if __name__ == "__main__":  # guard needed for multiprocessing on Windows
    chunksizes = (10, 40, 60, 80, 100, 120, 140, 160, 200)
    speedup_chunksizes = []
    with multiprocessing.Pool(4) as pool:
        for chunksize in chunksizes:
            time_start = time.perf_counter()
            for _results in pool.imap(feature_extraction, tra_generator(),␣
↪chunksize=chunksize):
                pass  # do something with the results
            speedup_chunksizes.append(time_single_thread / time_elapsed_ms(time_start))

    plt.figure(tight_layout=True, figsize=(6, 3))
    plt.plot(chunksizes, speedup_chunksizes)
    plt.xlabel("Chunksize")
    plt.ylabel("Speedup")
    plt.show()
```



Total running time of the script: (0 minutes 14.106 seconds)

4.8 Custom feature extraction

Following examples shows how to compute custom features and save them in the transient feature database (trfdb) to visualize them in VisualAE.

The feature extraction can be live during acquisition. VisualAE will be notified, that a writer to the trfdb is active and waits for the features to be computed. Therefore, the computed features can be visualized in real time.

```
from pathlib import Path
from tempfile import gettempdir

import matplotlib.pyplot as plt
import numpy as np
import vallenae as vae

HERE = Path(__file__).parent if "__file__" in locals() else Path.cwd()
PRIDB = HERE / "bearing" / "bearing.pridb"
TRADB = HERE / "bearing" / "bearing_plain.tradb"
# TRFDB = HERE / "bearing" / "bearing.trfdb"
TRFDB_TMP = Path(gettempdir()) / "bearing_custom.trfdb"  # use a temp file for demo
```

4.8.1 Custom feature extraction algorithms

```
def rms(data: np.ndarray) -> float:
    """Root mean square (RMS)."""
    return np.sqrt(np.mean(data ** 2))


def crest_factor(data: np.ndarray) -> float:
    """Crest factor (ratio of peak amplitude and RMS)."""
    return np.max(np.abs(data)) / rms(data)


def spectral_peak_frequency(spectrum_: np.ndarray, samplerate: int) -> float:
    """
    Peak frequency in a spectrum.

    Args:
        spectrum: FFT amplitudes
        samplerate: Sample rate of the spectrum in Hz

    Returns:
        Peak frequency in Hz
    """
    def bin_to_hz(samplerate: int, samples: int, index: int):
        return 0.5 * samplerate * index / (samples - 1)

    peak_index = np.argmax(spectrum_)
    return bin_to_hz(samplerate, len(spectrum_), peak_index)
```

4.8.2 Open tradb and trfdb

```
tradb = vae.io.TraDatabase(TRADB)
trfdb = vae.io.TrfDatabase(TRFDB_TMP, mode="rwc")
```

Helper function to notify VisualAE, that the transient feature database is active/closed

```
def set_file_status(trfdb_: vae.io.TrfDatabase, status: int):
    """Notify VisualAE that trfdb is active/closed."""
    trfdb_.connection().execute(
        f"UPDATE trf_globalinfo SET Value = {status} WHERE Key == 'FileStatus'"
    )
```

4.8.3 Read tra records, compute features and save to trfdb

The *vallenae.io.TraDatabase.listen* method will read the tradb row by row and can be used during acquisition. Only if the acquisition is closed and no new records are available, the function returns.

```
set_file_status(trfdb, 2)  # 2 = active

for tra in tradb.listen(existing=True, wait=False):
    spectrum = np.fft.rfft(tra.data)
    features = vae.io.FeatureRecord(
        trai=tra.trai,
        features={
            "RMS": rms(tra.data),
            "CrestFactor": crest_factor(tra.data),
            "SpectralPeakFreq": spectral_peak_frequency(spectrum, tra.samplerate),
        }
    )
    trfdb.write(features)

set_file_status(trfdb, 0)  # 0 = closed
```

Write field infos to trfdb

Field infos can be written with *vallenae.io.TrfDatabase.write_fieldinfo*:

```
trfdb.write_fieldinfo("RMS", {"Unit": "[V]", "LongName": "Root mean square"})
trfdb.write_fieldinfo("CrestFactor", {"Unit": "[]", "LongName": "Crest factor"})
trfdb.write_fieldinfo("SpectralPeakFreq", {"Unit": "[Hz]", "LongName": "Spectral peak␣
↪frequency"})
```

4.8.4 Read results from trfdb

```
df_trfdb = trfdb.read()
print(df_trfdb)
```

```
Trf:   0%|          | 0/490 [00:00<?, ?it/s]
Trf: 100%|| 490/490 [00:00<00:00, 1920756.04it/s]
           RMS  CrestFactor  SpectralPeakFreq
trai
1     0.000129     3.684550           63800.0
2     0.000134     3.843248           65500.0
3     0.000108     3.906766           58500.0
4     0.000115     3.876217           58000.0
5     0.000106     3.548410           72000.0
...        ...          ...               ...
486   0.000006     3.624268          162900.0
487   0.000006     3.486689          250000.0
488   0.000006     3.530853          164100.0
489   0.000006     4.059815          174000.0
490   0.000006     3.545406          164700.0

[490 rows x 3 columns]
```

4.8.5 Plot AE features and custom features

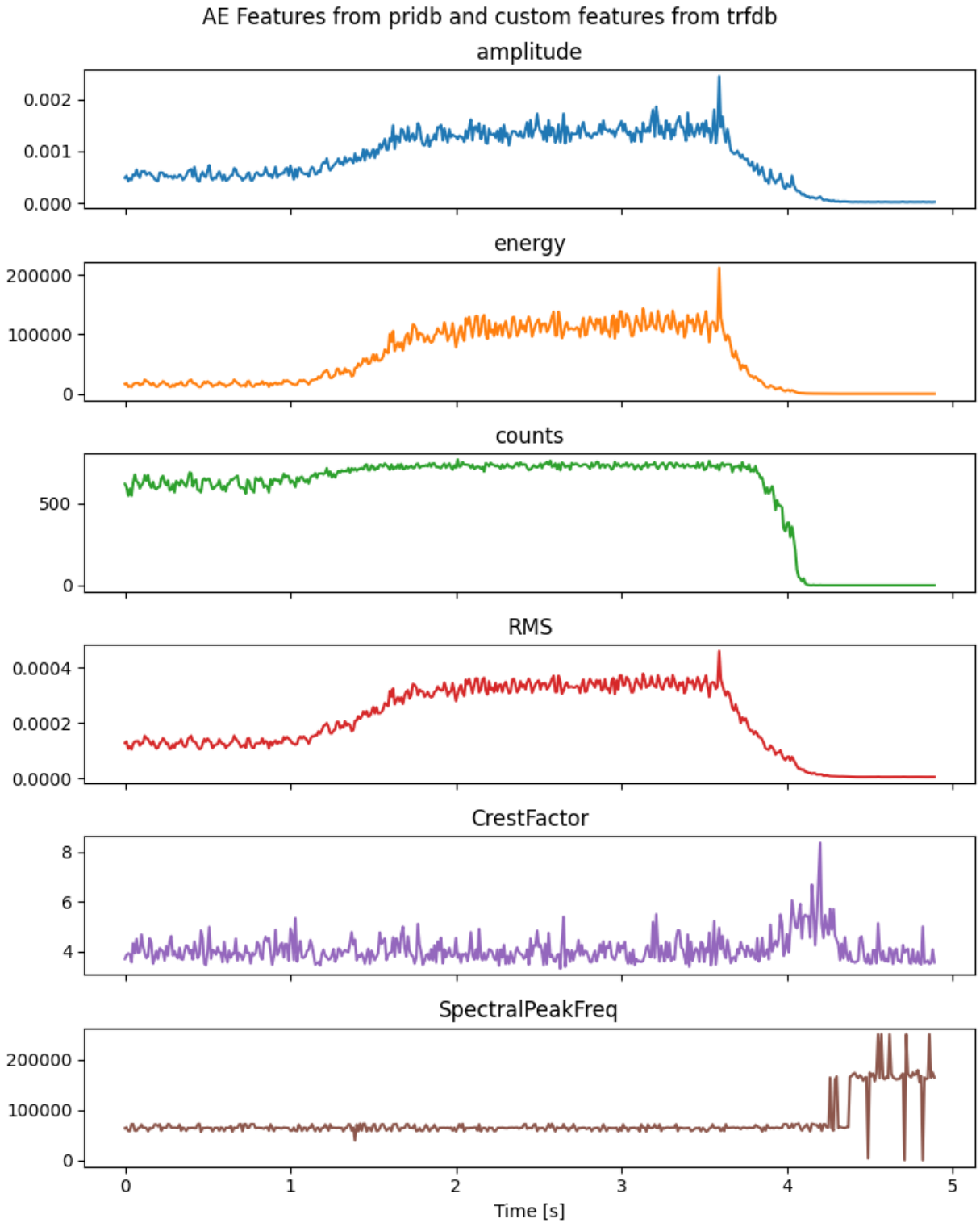
Read pridb and join it with trfdb:

```
with vae.io.PriDatabase(PRIDB) as pridb:
    df_pridb = pridb.read_hits()

df_combined = df_pridb.join(df_trfdb, on="trai", how="left")
print(df_combined)
```

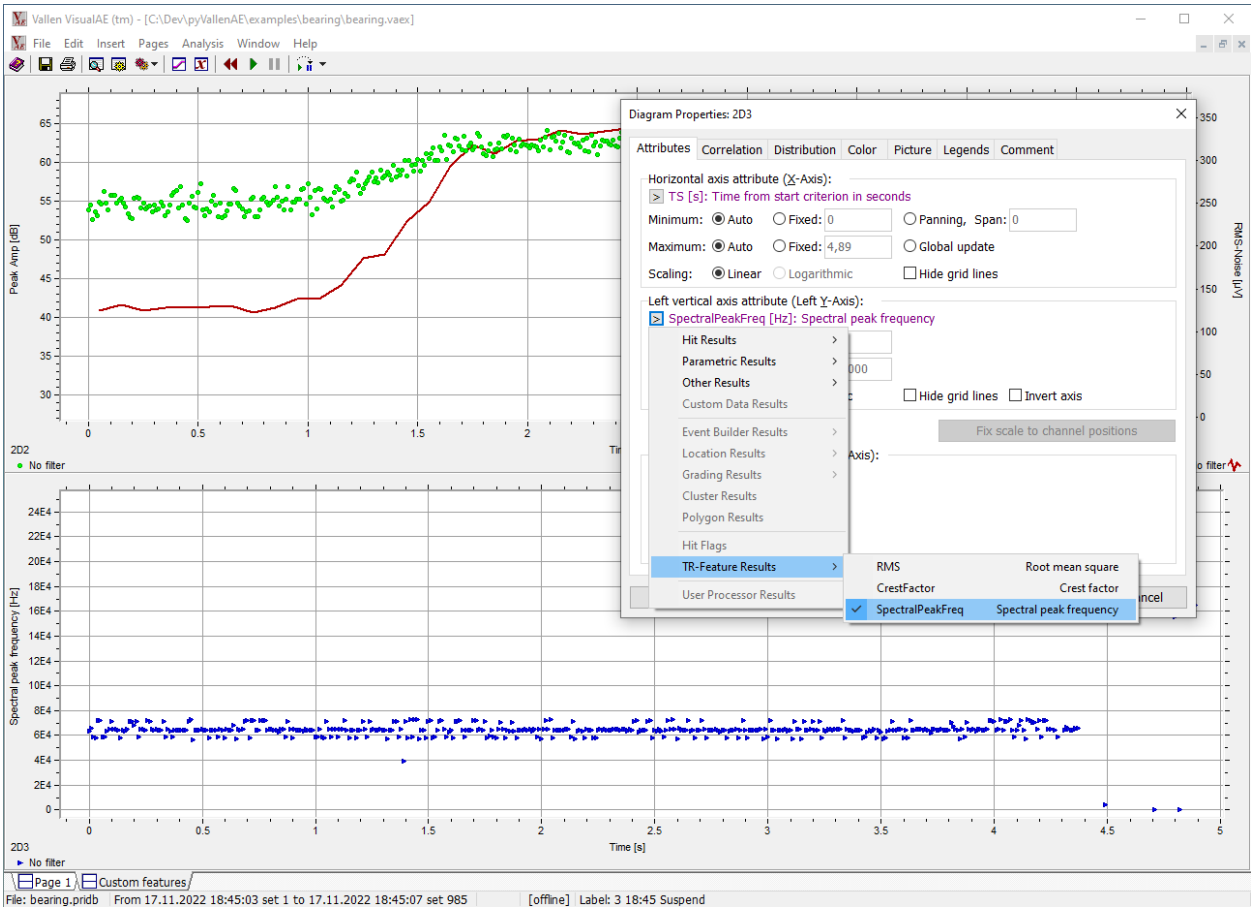
```
Hits:   0%|          | 0/490 [00:00<?, ?it/s]
Hits: 100%|| 490/490 [00:00<00:00, 100849.35it/s]
        time  channel  param_id  ...       RMS  CrestFactor  SpectralPeakFreq
set_id                           ...
6       0.00        1         2  ...  0.000129     3.684550           63800.0
8       0.01        1         2  ...  0.000134     3.843248           65500.0
10      0.02        1         2  ...  0.000108     3.906766           58500.0
12      0.03        1         2  ...  0.000115     3.876217           58000.0
14      0.04        1         2  ...  0.000106     3.548410           72000.0
...      ...      ...       ...  ...       ...          ...               ...
976     4.85        1         2  ...  0.000006     3.624268          162900.0
978     4.86        1         2  ...  0.000006     3.486689          250000.0
980     4.87        1         2  ...  0.000006     3.530853          164100.0
982     4.88        1         2  ...  0.000006     4.059815          174000.0
984     4.89        1         2  ...  0.000006     3.545406          164700.0

[490 rows x 15 columns]
```

Plot joined features from pridb and trfdb

```
features = [
    # from pridb
    "amplitude",
    "energy",
    "counts",
    # from trfdb - custom
    "RMS",
    "CrestFactor",
    "SpectralPeakFreq",
]
df_combined.plot(
    x="time",
    y=features,
    xlabel="Time [s]",
    title=features,
    legend=False,
    subplots=True,
    figsize=(8, 10),
)
plt.suptitle("AE Features from pridb and custom features from trfdb")
plt.tight_layout()
plt.show()
```


AE Features from pridb and custom features from trfdb
amplitude
0.002
0.001
0.000
energy
200000
100000
0
counts
500
0
RMS
0.0004
0.0002
0.0000
CrestFactor
8
6
4
SpectralPeakFreq
200000
100000
0
0
1
2
3
4
5
Time [s]

4.8.6 Display custom features in VisualAE



Total running time of the script: (0 minutes 0.915 seconds)

4.9 Spectrogram

Generate spectrogram from tradb. The *vallenae.io.TraDatabase.read_continuous_wave* method is used to read the transient data as a continuous array.

```
from pathlib import Path

import matplotlib.pyplot as plt
import numpy as np
import vallenae as vae
from matplotlib.colors import LogNorm
from scipy import signal

HERE = Path(__file__).parent if "__file__" in locals() else Path.cwd()
TRADB = HERE / "bearing" / "bearing_plain.tradb"
```

4.9.1 Read transient data as continous array

The signal is exactly cropped to the given time range (*time_start*, *time_stop*). Time gaps are filled with 0's.

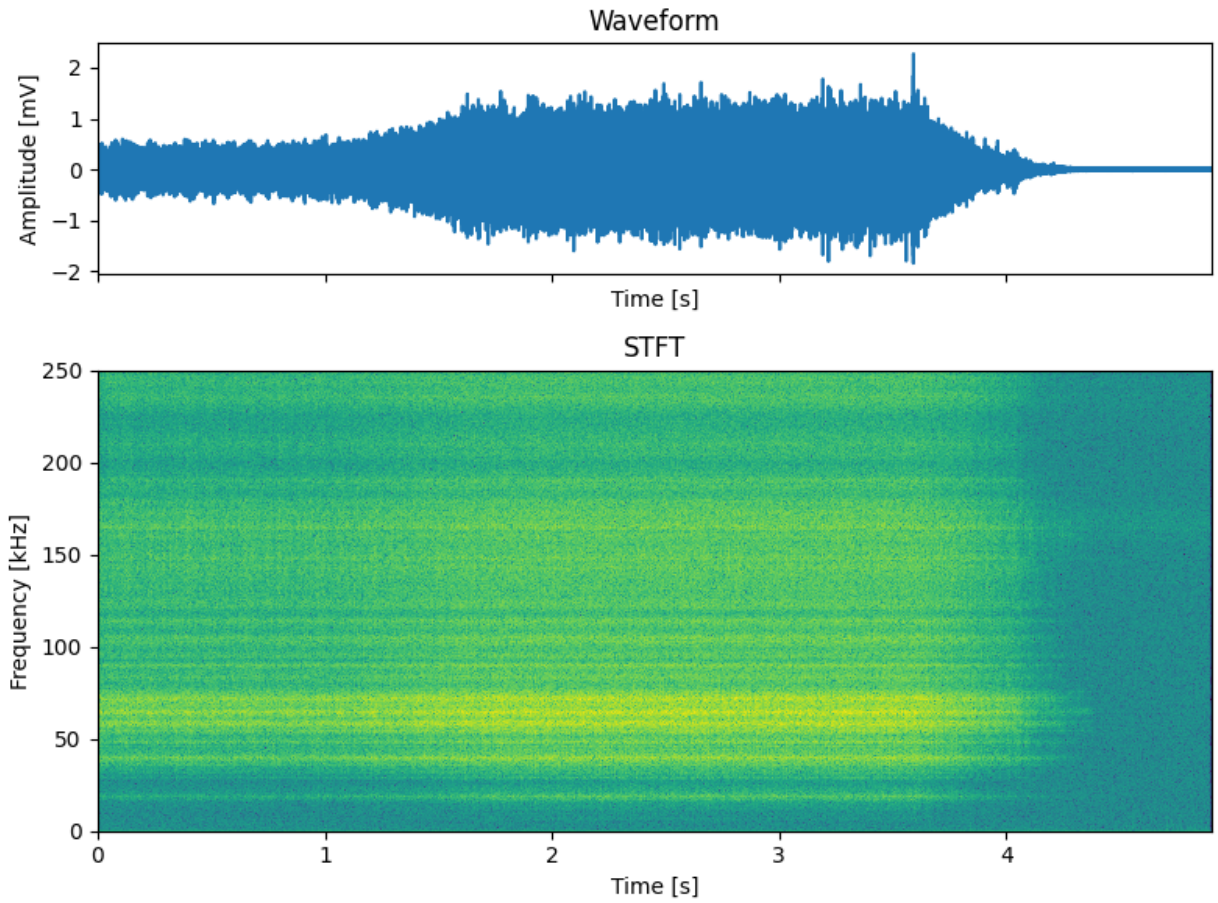
```
with vae.io.TraDatabase(TRADB) as tradb:
    y, fs = tradb.read_continuous_wave(
        channel=1,
        time_start=None,
        time_stop=None,
        time_axis=False,  # return samplerate instead of time axis
        show_progress=False,
    )
    t = np.arange(0, len(y)) / fs  # generate time axis
```

4.9.2 Compute Short-Time Fourier Transform (STFT)

```
nfft = 4096
noverlap = 2048
fz, tz, zxx = signal.stft(y, fs=fs, window="hann", nperseg=nfft, noverlap=noverlap)
```

4.9.3 Plot time data and spectrogram

```
fig, ax = plt.subplots(
    nrows=2,
    sharex=True,
    figsize=(8, 6),
    tight_layout=True,
    gridspec_kw={"height_ratios": (1, 2)},
)
ax[0].plot(t, y * 1e3)
ax[0].set(xlabel="Time [s]", ylabel="Amplitude [mV]", title="Waveform")
ax[1].pcolormesh(tz, fz / 1e3, np.abs(zxx), norm=LogNorm())
ax[1].set(xlabel="Time [s]", ylabel="Frequency [kHz]", title="STFT")
plt.show()
```



Total running time of the script: (0 minutes 2.220 seconds)

4.10 Export to WAV

Generate WAV files from tradb. We use the *vallenae.io.TraDatabase.read_continuous_wave* method to read the transient data as a continuous array.

The signal can optionally be decimated to reduce the size of the generated WAV files (using the `scipy.signal.decimate` function).

```
Export channel 1 to /tmp/tmpd3z4xw7g/bearing_plain_ch1.wav
Generated WAV files:
/tmp/tmpd3z4xw7g/bearing_plain_ch1.wav
```

```
from pathlib import Path
from tempfile import TemporaryDirectory
from typing import Optional
```

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```
import numpy as np
import vallenae as vae
from scipy import signal
from scipy.io import wavfile

HERE = Path(__file__).parent if "__file__" in locals() else Path.cwd()


def export_wav(
    filename_wav: Path,
    tradb: vae.io.TraDatabase,
    channel: int,
    time_start: Optional[float] = None,
    time_stop: Optional[float] = None,
    decimation_factor: int = 1,
):
    """
    Export data from tradb to a WAV file.

    Args:
        filename_wav: Path to the generated WAV file
        tradb: `TraDatabase` instance
        channel: Channel number
        time_start: Start reading at relative time (in seconds). Start at beginning if␣
↪`None`
        time_start: Stop reading at relative time (in seconds). Read until end if `None`
        decimation_factor: Decimate signal with given factor
    """
    y, fs = tradb.read_continuous_wave(
        channel=channel,
        time_start=time_start,
        time_stop=time_stop,
        time_axis=False,
        show_progress=False,
        raw=True,  # read as ADC values (int16)
    )

    if decimation_factor > 1:
        y = signal.decimate(y, decimation_factor).astype(np.int16)
        fs //= decimation_factor

    wavfile.write(filename_wav, fs, y)


def main():
    filename_tradb = HERE / "bearing" / "bearing_plain.tradb"

    # use a temporary file for this example
    with TemporaryDirectory() as tmpdir:
        with vae.io.TraDatabase(filename_tradb) as tradb:
            for channel in tradb.channel():
```

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```
                filename_wav = Path(tmpdir) / f"{filename_tradb.stem}_ch{channel}.wav"
                print(f"Export channel {channel} to {filename_wav}")
                export_wav(
                    filename_wav=filename_wav,
                    tradb=tradb,
                    channel=channel,
                    time_start=0,  # read from t = 0 s
                    time_stop=None,  # read until end if None
                    decimation_factor=5,  # custom decimation factor
                )

        # list all generated wav files
        print("Generated WAV files:")
        for file in Path(tmpdir).iterdir():
            print(file)


if __name__ == "__main__":
    main()
```

Total running time of the script: (0 minutes 0.094 seconds)

CHAPTER

FIVE

CHANGELOG

All notable changes to this project will be documented in this file.

The format is based on Keep a Changelog, and this project adheres to Semantic Versioning.

5.1 Unreleased

5.2 0.9.0 - 2024-02-14

5.2.1 Added

- Example for incremental WAV export
- Python 3.12 support

5.3 0.8.0 - 2023-07-13

5.3.1 Added

- Flag `TraRecord.raw` if data is stored as ADC values (int16)
- Flag `raw` for `TraDatabase` read methods to read data as ADC values:
  - `TraDatabase.iread`
  - `TraDatabase.read`
  - `TraDatabase.read_wave`
  - `TraDatabase.read_continuous_wave`
  - `TraDatabase.listen`
- Bearing example data
- Spectrogram example
- WAV export example using the new `raw` flag
- CI for Python 3.11

5.3.2 Changed

- Remove scipy dependency (only needed for examples)
- Migrate from setuptools to hatch (replace `setup.py` with `pyproject.toml`)

5.3.3 Fixed

- Multiprocessing example for Windows

5.4 0.7.0 - 2022-11-10

5.4.1 Added

- Example for custom feature extraction
- PyInstaller hook
- CI for Python 3.10

5.4.2 Changed

- Make Numba dependency optional (fallback timepicker implementations with NumPy)

5.4.3 Fixed

- Counts computations (first sample above threshold is not a count)

5.5 0.6.0 - 2021-09-02

5.5.1 Added

- CI for Python 3.9

5.5.2 Changed

- Remove superfluous `data_format` field from `TraRecord` data type

5.6 0.5.4 - 2021-05-25

5.6.1 Fixed

- Limit number of buffered records in `listen` methods
- Time axis rounding errors, e.g. for `TraDatabase.read_wave` with `time_axis=True`

5.7 0.5.3 - 2021-05-04

5.7.1 Fixed

- SQLite URI for absolute linux paths

5.8 0.5.2 - 2021-05-04

5.8.1 Fixed

- SQLite URI for special characters (#, ?)

5.9 0.5.1 - 2021-03-25

5.9.1 Fixed

- Buffering of SQL results in `listen` methods to allow SQL queries in between

5.10 0.5.0 - 2021-03-18

5.10.1 Added

- Query filter parameter to `TrfDatabase.read` and `TrfDatabase.iread`
- `listen` method for `PriDatabase`, `TraDatabase` and `TrfDatabase` to retrieve new records live

5.10.2 Changed

- Order feature records by TRAI for `TrfDatabase.read` and `TrfDatabase.iread`

5.11 0.4.0 - 2021-02-14

5.11.1 Added

- CI with GitHub actions on Linux, MacOS and Windows
- Workflow with GitHub actions to publish to PyPI on new releases
- `pyproject.toml` as the main config file for pylint, pytest, tox, coverage, ...

5.11.2 Changed

- Return exact time range with `TraDatabase.read_continuous_wave`
- Return "absolute" time axis with `TraDatabase.read_continuous_wave` (instead of starting at t = 0 s)

5.11.3 Fixed

- Fix database close if exception raised in `__init__` (e.g. file not found)
- Example `ex6_multiprocessing` for MacOS
- Find lower/upper bounds for same values (times) in binary search (used by `TraDatabase.iread`)
- Stop condition for `time_stop` in `TraDatabase.iread`
- Use TRAI for `TraDatabase.iread` as a time sorted index for binary search (SetID is not!)
- Check for empty time ranges in `TraDatabase.iread`

5.12 0.3.0 - 2020-11-05

5.12.1 Added

- Query filter for pridb/tradb (i)read functions

5.13 0.2.4 - 2020-11-01

5.13.1 Fixed

- SQL schemas for pridb/tradb/trfdb creation, add fieldinfos

5.14 0.2.3 - 2020-09-01

5.14.1 Fixed

- AIC timepicker
- Add threshold for monotonic time check (1 ns) to ignore rounding issues
- Suppress exception chaining

5.15 0.2.2 - 2020-07-10

5.15.1 Added

- Database classes are now pickable and can be used in multiprocessing
- SQLite transactions for all writes
- Faster blob encoding (`vallenae.io.encode_data_blob`)
- Faster RMS computation with Numba (`vallenae.features.rms`)

5.15.2 Fixed

- Catch possible global_info table parsing errors

5.16 0.2.1 - 2020-02-10

5.16.1 Fixed

- Examples outputs if not run as notebook
- Out-of-bound time_start, time_stop with SQL binary search
- Optional signal strength for e.g. spotWave data acquisition

5.17 0.2.0 - 2020-02-06

5.17.1 Added

- Database creation with `mode="rwc"`, e.g. `vallenae.io.PriDatabase.__init__`

5.17.2 Fixed

- Number field in `vallenae.io.MarkerRecord` optional
- Scaling of parametric inputs optional
- Keep column order of query if new columns are added to the database
- Return array with float32 from `vallenae.io.TraDatabase.read_continuous_wave` (instead of float64)

5.18 0.1.0 - 2020-01-24

Initial public release

CHAPTER

SIX

INDICES AND TABLES

- genindex
- modindex

PYTHON MODULE INDEX

V

INDEX

Symbols

A

C

D

E

F

V

W