eventsourcing Documentation

Release 6.0.0

John Bywater

Apr 23, 2018

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A library for event sourcing in Python.

CHAPTER 1

Overview

What is event sourcing? One definition suggests the state of an event-sourced application is determined by a sequence of events. Another definition has event sourcing as a persistence mechanism for domain driven design. Therefore, this library makes it easy to define, publish, persist, retrieve, project, and propagate the domain events of a software application.

It is common for the state of a software application to be distributed across a set of entities or aggregates. Therefore, this library provides infrastructure to support event sourcing the state of entities or aggregates in an application, and suggests a style for coding an application with event-sourced domain model entities or aggregates that have behaviour which triggers events.

This documentation provides: instructions for *installing* the package, highlights the main *features* of the library, describes the *design* of the software, the *infrastructure layer*, the *domain model layer*, the *application layer*, has information about *deployment*, and has some *background* information about the project.

This project is hosted on GitHub. Please register any issues, questions, and requests on GitHub.

1.1 Background

Although the event sourcing patterns are each quite simple, and they can be reproduced in code for each project, they do suggest cohesive mechanisms, for example applying and publishing the events generated within domain entities, storing and retrieving selections of the events in a highly scalable manner, replaying the stored events for a particular entity to obtain the current state, and projecting views of the event stream that are persisted in other models.

Therefore, quoting from Eric Evans' book about domain-driven design:

> *"Partition a conceptually COHESIVE MECHANISM into a separate lightweight framework. Particularly watch for formalisms for well-documented categories of algorithms. Expose the capabilities of the framework with an INTENTION-REVEALING INTERFACE. Now the other elements of the domain can focus on expressing the problem ('what'), delegating the intricacies of the solution ('how') to the framework."*

Inspiration:

- Martin Fowler's article on event sourcing

- Greg Young's discussions about event sourcing, and Event Store system
- Robert Smallshire's brilliant example on Bitbucket
- Various professional projects that called for this approach, for which I didn't want to rewrite the same things each time

See also:

- An introduction to event storming by a Steven Lowe
- **An Introduction to Domain Driven Design** by Dan Haywood
- Object-relational impedance mismatch page on Wikipedia
- From CRUD to Event Sourcing (Why CRUD is the wrong approach for microservices) by James Roper
- Event Sourcing and Stream Processing at Scale by Martin Kleppmann
- Data Intensive Applications with Martin Kleppmann
- The Path Towards Simplyfying Consistency In Distributed Systems by Caitie McCaffrey
- Kahn Process Networks page on Wikipedia

Citations:

- An Evaluation on Using Coarse grained Events in an Event Sourcing Context and its Effects Compared to Fine-grained Events by Brian Ye

1.2 Quick start

This section shows how to make a simple event sourced application using classes from the library. It shows the general story, which is elaborated over the following pages.

- *Define model*
- *Configure environment*
- *Run application*

Please use pip to install the library with the 'sqlalchemy' option.

```
$ pip install eventsourcing[sqlalchemy]
```

1.2.1 Define model

Define a domain model aggregate.

The class `World` defined below is a subclass of *`AggregateRoot`*.

The `World` has a property called `history`. It also has an event sourced attribute called `ruler`.

It has a command method called `make_it_so` which triggers a domain event of type `SomethingHappened` which is defined as a nested class. The domain event class `SomethingHappened` has a `mutate()` method, which happens to append triggered events to the history.

```
from eventsourcing.domain.model.aggregate import AggregateRoot
from eventsourcing.domain.model.decorators import attribute


class World(AggregateRoot):

    def __init__(self, ruler=None, **kwargs):
        super(World, self).__init__(**kwargs)
        self._history = []
        self._ruler = ruler

    @property
    def history(self):
        return tuple(self._history)

    @attribute
    def ruler(self):
        """A mutable event-sourced attribute."""

    def make_it_so(self, something):
        self.__trigger_event__(World.SomethingHappened, what=something)

    class SomethingHappened(AggregateRoot.Event):
        def mutate(self, obj):
            obj._history.append(self)
```

This class can be used and completely tested without any infrastructure.

Although every aggregate is a "little world", developing a more realistic domain model would involve defining attributes, command methods, and domain events particular to a concrete domain.

Basically, you can understand everything if you understand that command methods, such as `make_it_so()` in the example above, should not update the state of the aggregate directly with the results of their work, but instead trigger events using domain event classes which have `mutate()` methods that can update the state of the aggregate using the values given to the event when it was triggered. By refactoring the updating of the aggregate state, from the command method, to a domain event object class, triggered events can be stored and replayed to obtain persistent aggregates.

1.2.2 Configure environment

Generate cipher key (optional).

```
from eventsourcing.utils.random import encode_random_bytes

# Keep this safe.
cipher_key = encode_random_bytes(num_bytes=32)
```

Configure environment variables.

```
import os

# Optional cipher key (random bytes encoded with Base64).
os.environ['CIPHER_KEY'] = cipher_key

# SQLAlchemy-style database connection string.
os.environ['DB_URI'] = 'sqlite:///:memory:'
```

1.2.3 Run application

With the `SimpleApplication` from the library, you can create, read, update, and delete `World` aggregates that are persisted in the database identified above.

The code below demonstrates many of the features of the library, such as optimistic concurrency control, data integrity, and application-level encryption.

```
from eventsourcing.application.simple import SimpleApplication
from eventsourcing.exceptions import ConcurrencyError

# Construct simple application (used here as a context manager).
with SimpleApplication(persist_event_type=World.Event) as app:

    # Call library factory method.
    world = World.__create__(ruler='gods')

    # Execute commands.
    world.make_it_so('dinosaurs')
    world.make_it_so('trucks')

    version = world.__version__ # note version at this stage
    world.make_it_so('internet')

    # Assign to event-sourced attribute.
    world.ruler = 'money'

    # View current state of aggregate.
    assert world.ruler == 'money'
    assert world.history[2].what == 'internet'
    assert world.history[1].what == 'trucks'
    assert world.history[0].what == 'dinosaurs'

    # Publish pending events (to persistence subscriber).
    world.__save__()

    # Retrieve aggregate (replay stored events).
    copy = app.repository[world.id]
    assert isinstance(copy, World)

    # View retrieved state.
    assert copy.ruler == 'money'
    assert copy.history[2].what == 'internet'
    assert copy.history[1].what == 'trucks'
    assert copy.history[0].what == 'dinosaurs'

    # Verify retrieved state (cryptographically).
    assert copy.__head__ == world.__head__

    # Discard aggregate.
    world.__discard__()

    # Discarded aggregate is not found.
    assert world.id not in app.repository
    try:
        # Repository raises key error.
        app.repository[world.id]
    except KeyError:
```

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```
        pass
    else:
        raise Exception("Shouldn't get here")

    # Get historical state (at version from above).
    old = app.repository.get_entity(world.id, at=version)
    assert old.history[-1].what == 'trucks' # internet not happened
    assert len(old.history) == 2
    assert old.ruler == 'gods'

    # Optimistic concurrency control (no branches).
    old.make_it_so('future')
    try:
        old.__save__()
    except ConcurrencyError:
        pass
    else:
        raise Exception("Shouldn't get here")

    # Check domain event data integrity (happens also during replay).
    events = app.event_store.get_domain_events(world.id)
    last_hash = ''
    for event in events:
        event.__check_hash__()
        assert event.__previous_hash__ == last_hash
        last_hash = event.__event_hash__

    # Verify sequence of events (cryptographically).
    assert last_hash == world.__head__

    # Project application event notifications.
    from eventsourcing.interface.notificationlog import NotificationLogReader
    reader = NotificationLogReader(app.notification_log)
    notifications = reader.read()
    notification_ids = [n['id'] for n in notifications]
    assert notification_ids == [1, 2, 3, 4, 5, 6]

    # Check records are encrypted (values not visible in database).
    record_manager = app.event_store.record_manager
    items = record_manager.get_items(world.id)
    for item in items:
        assert item.originator_id == world.id
        assert 'dinosaurs' not in item.state
        assert 'trucks' not in item.state
        assert 'internet' not in item.state
```

1.3 Installation

Use pip to install the library from the Python Package Index.

```
$ pip install eventsourcing
```

If you want to use SQLAlchemy, then install the library with the 'sqlalchemy' option. Also install your chosen database driver.

```
$ pip install eventsourcing[sqlalchemy]
$ pip install psycopg2
```

Similarly, if you want to use Apache Cassandra, then please install with the 'cassandra' option.

```
$ pip install eventsourcing[cassandra]
```

Running the install command with again different options will just install the extra dependencies associated with that option. If you installed without any options, you can easily install optional dependencies later by running the install command again with the options you want.

1.4 Features

Event store — appends and retrieves domain events. Uses a sequenced item mapper with a record manager to map domain events to database records in ways that can be easily extended and replaced.

Data integrity — Sequences of events can be hash-chained, and the entire sequence of events checked for integrity. If the last hash can be independently validated, then so can the entire sequence. Events records can be encrypted with an authenticated encryption algorithm, so you cannot lose information in transit or at rest, or get database corruption without being able to detect it.

Optimistic concurrency control — can be used to ensure a distributed or horizontally scaled application doesn't become inconsistent due to concurrent method execution. Leverages any optimistic concurrency controls in the database adapted by the record manager.

Application-level encryption — encrypts and decrypts stored events, using a cipher strategy passed as an option to the sequenced item mapper. Can be used to encrypt some events, or all events, or not applied at all (the default).

Snapshotting — avoids replaying an entire event stream to obtain the state of an entity. A snapshot strategy is included which reuses the capabilities of this library by implementing snapshots as events.

Notifications and projections — reliable propagation of application events with pull-based notifications allows the application state to be projected accurately into replicas, indexes, view models, and other applications.

Process and systems — scalable event processing with application pipelines. Parallel pipelines are synchronised with causal dependencies. Runnable with single thread, multiprocessing on a single machine, and in a cluster of machines using the actor model.

Abstract base classes — suggest how to structure an event sourced application. The library has base classes for application objects, domain entities, entity repositories, domain events of various types, mapping strategies, snapshotting strategies, cipher strategies, etc. They are well factored, relatively simple, and can be easily extended for your own purposes. If you wanted to create a domain model that is entirely stand-alone (recommended by purists for maximum longevity), you might start by replicating the library classes.

Worked examples — a simple example application, with an example entity class, example domain events, and an example database table. Plus lots of examples in the documentation.

1.5 Design

The design of the library follows the layered architecture: interfaces, application, domain, and infrastructure.

The infrastructure layer encapsulates infrastructural services required by an event sourced application, in particular an event store.

The domain layer contains independent domain model classes. Nothing in the domain layer depends on anything in the infrastructure layer.

The application layer is responsible for binding domain and infrastructure, and has policies such as the persistence policy, which stores domain events whenever they are published by the model.

The example application has an example repository, from which example entities can be retrieved. It also has a factory method to create new example entities. Each repository has an event player, which all share an event store with the persistence policy. The persistence policy uses the event store to store domain events. Event players use the event store to retrieve the stored events, and the model mutator functions to project entities from sequences of events.

Functionality such as mapping events to a database, or snapshotting, is implemented as strategy objects, and injected into dependents by constructor parameter, making it easy to substitute custom classes for defaults.

The sequenced item persistence model allows domain events to be stored in wide variety of database services, and optionally makes use of any optimistic concurrency controls the database system may afford.

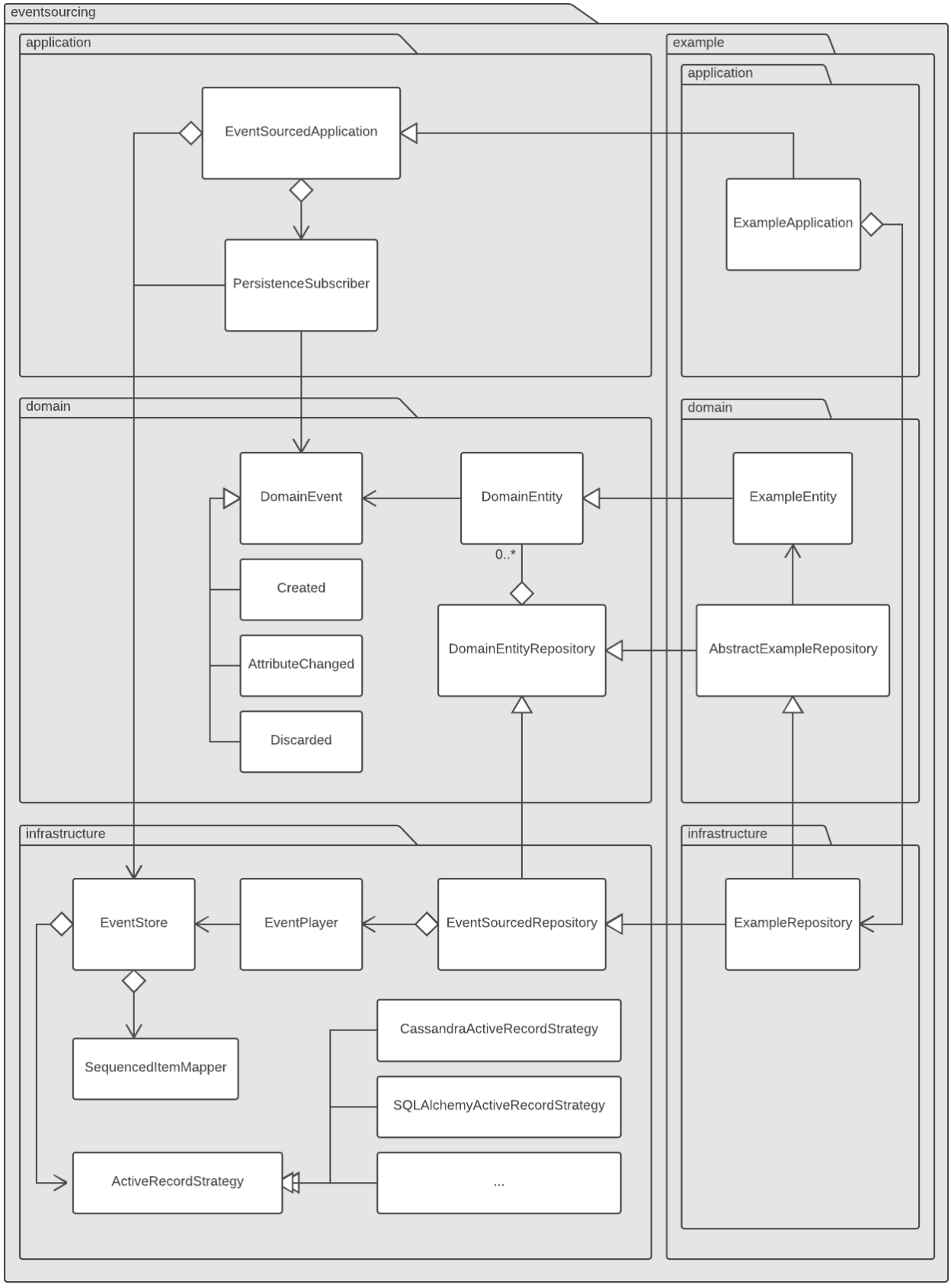
1.6 Infrastructure

The library's infrastructure layer provides a cohesive mechanism for storing events as sequences of items.

The entire mechanism is encapsulated by the library's `EventStore` class. The event store uses a sequenced item mapper and a record manager.

The sequenced item mapper converts objects such as domain events to sequenced items, and the record manager writes sequenced items to database records. The sequenced item mapper and the record manager operate by reflection off a common sequenced item type.

- *Sequenced item type*
  - *SequencedItem namedtuple*
  - *StoredEvent namedtuple*
- *Sequenced item mapper*
  - *Custom JSON transcoding*
  - *Application-level encryption*
- *Record managers*
  - *SQLAlchemy*
    - *SQLAlchemy dialects*
    - *MySQL*
    - *PostgreSQL*
    - *SQLite*
  - *Django ORM*
    - *Django backends*
  - *Contiguous record IDs*
  - *Cassandra*
  - *Sequenced item conflicts*
- *Event store*
  - *Optimistic concurrency control*


eventsourcing
application
example
application
EventSourcedApplication
ExampleApplication
PersistenceSubscriber
domain
domain
DomainEvent
DomainEntity
ExampleEntity
0..*
Created
AttributeChanged
Discarded
DomainEntityRepository
AbstractExampleRepository
infrastructure
infrastructure
EventStore
EventPlayer
EventSourcedRepository
ExampleRepository
SequencedItemMapper
CassandraActiveRecordStrategy
SQLAlchemyActiveRecordStrategy
ActiveRecordStrategy
...

- *Event store factory*
- *Timestamped event store*
  - *TimeUUIDs*

1.6.1 Sequenced item type

Sequenced item types are declared as named tuples (`namedtuple` from `collections`).

Below is an example of a sequenced item named tuple.

```
from collections import namedtuple

SequencedItem = namedtuple('SequencedItem', ['sequence_id', 'position', 'topic', 'data
↪'])
```

The fields can be named differently, however a suitable database table will have matching column names.

Whatever the names of the fields, the first field of a sequenced item will represent the identity of a sequence to which an item belongs. The second field will represent the position of the item in its sequence. The third field will represent a topic to which the item pertains. And the fourth field will represent the data associated with the item.

SequencedItem namedtuple

The library provides a sequenced item named tuple called *`SequencedItem`*.

```
from eventsourcing.infrastructure.sequenceditem import SequencedItem
```

Like in the example above, the library's `SequencedItem` namedtuple has four fields. The `sequence_id` identifies the sequence in which the item belongs. The `position` identifies the position of the item in its sequence. The `topic` identifies a dimension of concern to which the item pertains. The `data` holds the data associated with the item.

A sequenced item is just a tuple, and can be used as such. In the example below, a sequenced item happens to be constructed with a UUID to identify a sequence. The item has also been given an integer position value, it has a topic that happens to correspond to a domain event class in the library. The item's data is a JSON object in which `foo` is `bar`.

```
from uuid import uuid4

sequence1 = uuid4()

sequenced_item1 = SequencedItem(
    sequence_id=sequence1,
    position=0,
    topic='eventsourcing.domain.model.events#DomainEvent',
    data='{"foo":"bar"}',
)
```

As expected, the attributes of the sequenced item object are simply the values given when the object was constructed.

```
assert sequenced_item1.sequence_id == sequence1
assert sequenced_item1.position == 0
assert sequenced_item1.topic == 'eventsourcing.domain.model.events#DomainEvent'
assert sequenced_item1.data == '{"foo":"bar"}'
```

StoredEvent namedtuple

The library provides a sequenced item named tuple called `StoredEvent`. The attributes of the `StoredEvent` namedtuple are `originator_id`, `originator_version`, `event_type`, and `state`.

The `originator_id` is the ID of the aggregate that published the event, and is equivalent to `sequence_id` above. The `originator_version` is the version of the aggregate that published the event, and is equivalent to `position` above. The `event_type` identifies the class of the domain event that is stored, and is equivalent to `topic` above. The `state` holds the state of the domain event, and is equivalent to `data` above.

```
from eventsourcing.infrastructure.sequenceditem import StoredEvent

aggregate1 = uuid4()

stored_event1 = StoredEvent(
    originator_id=aggregate1,
    originator_version=0,
    event_type='eventsourcing.domain.model.events#DomainEvent',
    state='{"foo":"bar"}',
)
assert stored_event1.originator_id == aggregate1
assert stored_event1.originator_version == 0
assert stored_event1.event_type == 'eventsourcing.domain.model.events#DomainEvent'
assert stored_event1.state == '{"foo":"bar"}'
```

1.6.2 Sequenced item mapper

The event store uses a sequenced item mapper to map between sequenced items and application-level objects such as domain events.

The library provides a sequenced item mapper object class called `SequencedItemMapper`.

```
from eventsourcing.infrastructure.sequenceditemmapper import SequencedItemMapper
```

The `SequencedItemMapper` has a constructor arg `sequenced_item_class`, which defaults to the library's sequenced item named tuple `SequencedItem`.

```
sequenced_item_mapper = SequencedItemMapper()
```

The method `from_sequenced_item()` can be used to convert sequenced item objects to application-level objects.

```
domain_event = sequenced_item_mapper.from_sequenced_item(sequenced_item1)

assert domain_event.foo == 'bar'
```

The method `to_sequenced_item()` can be used to convert application-level objects to sequenced item named tuples.

```
assert sequenced_item_mapper.to_sequenced_item(domain_event).data == sequenced_item1.
↪data
```

If the names of the first two fields of the sequenced item named tuple (e.g. `sequence_id` and `position`) do not match the names of the attributes of the application-level object which identify a sequence and a position (e.g. `originator_id` and `originator_version`) then the attribute names can be given to the sequenced item mapper using constructor args `sequence_id_attr_name` and `position_attr_name`.

```
from eventsourcing.domain.model.events import DomainEvent

domain_event1 = DomainEvent(
    originator_id=aggregate1,
    originator_version=1,
    foo='baz',
)

sequenced_item_mapper = SequencedItemMapper(
    sequence_id_attr_name='originator_id',
    position_attr_name='originator_version'
)


assert domain_event1.foo == 'baz'

assert sequenced_item_mapper.to_sequenced_item(domain_event1).sequence_id ==␣
↪aggregate1
```

Alternatively, a sequenced item named tuple type that is different from the default `SequencedItem` namedtuple, for example the library's `StoredEvent` namedtuple, can be passed with the constructor arg `sequenced_item_class`.

```
sequenced_item_mapper = SequencedItemMapper(
    sequenced_item_class=StoredEvent
)

domain_event1 = sequenced_item_mapper.from_sequenced_item(stored_event1)

assert domain_event1.foo == 'bar', domain_event1
```

Since the alternative `StoredEvent` namedtuple can be used instead of the default `SequencedItem` namedtuple, so it is possible to use a custom named tuple. Which alternative you use for your project depends on your preferences for the names in the your domain events and your persistence model.

Please note, it is required of these application-level objects that the "topic" generated by `get_topic()` from the object class is resolved by `resolve_topic()` back to the same object class.

```
from eventsourcing.domain.model.events import Created
from eventsourcing.utils.topic import get_topic, resolve_topic

topic = get_topic(Created)
assert resolve_topic(topic) == Created
assert topic == 'eventsourcing.domain.model.events#Created'
```

Custom JSON transcoding

The `SequencedItemMapper` can be constructed with optional args `json_encoder_class` and `json_decoder_class`. The defaults are the library's `ObjectJSONEncoder` and `ObjectJSONDecoder` which can be extended to support types of value objects that are not currently supported by the library.

The code below extends the JSON transcoding to support sets.

```
from eventsourcing.utils.transcoding import ObjectJSONEncoder, ObjectJSONDecoder
```

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```
class CustomObjectJSONEncoder(ObjectJSONEncoder):
    def default(self, obj):
        if isinstance(obj, set):
            return {'__set__': list(obj)}
        else:
            return super(CustomObjectJSONEncoder, self).default(obj)


class CustomObjectJSONDecoder(ObjectJSONDecoder):
    @classmethod
    def from_jsonable(cls, d):
        if '__set__' in d:
            return cls._decode_set(d)
        else:
            return ObjectJSONDecoder.from_jsonable(d)

    @staticmethod
    def _decode_set(d):
        return set(d['__set__'])


customized_sequenced_item_mapper = SequencedItemMapper(
    json_encoder_class=CustomObjectJSONEncoder,
    json_decoder_class=CustomObjectJSONDecoder
)

domain_event = customized_sequenced_item_mapper.from_sequenced_item(
    SequencedItem(
        sequence_id=sequence1,
        position=0,
        topic='eventsourcing.domain.model.events#DomainEvent',
        data='{"foo":{"__set__":["bar","baz"]}}',
    )
)
assert domain_event.foo == set(["bar", "baz"])

sequenced_item = customized_sequenced_item_mapper.to_sequenced_item(domain_event)
assert sequenced_item.data.startswith('{"foo":{"__set__":["ba')
```

Application-level encryption

The `SequencedItemMapper` can be constructed with a symmetric cipher. If a cipher is given, then the `state` field of every sequenced item will be encrypted before being sent to the database. The data retrieved from the database will be decrypted and verified, which protects against tampering.

The library provides an AES cipher object class called `AESCipher`. It uses the AES cipher from the Python Cryptography Toolkit, as forked by the actively maintained PyCryptodome project.

The `AESCipher` class uses AES in GCM mode, which is a padding-less, authenticated encryption mode. Other AES modes aren't supported by this class, at the moment.

The `AESCipher` constructor arg `cipher_key` is required. The key must be either 16, 24, or 32 random bytes (128, 192, or 256 bits). Longer keys take more time to encrypt plaintext, but produce more secure ciphertext.

Generating and storing a secure key requires functionality beyond the scope of this library. However, the utils package does contain a function `encode_random_bytes()` that may help to generate a unicode key string, representing

random bytes encoded with Base64. A companion function `decode_random_bytes()` decodes the unicode key string into a sequence of bytes.

```
from eventsourcing.utils.cipher.aes import AESCipher
from eventsourcing.utils.random import encode_random_bytes, decode_random_bytes

# Unicode string representing 256 random bits encoded with Base64.
cipher_key = encode_random_bytes(num_bytes=32)

# Construct AES-256 cipher.
cipher = AESCipher(cipher_key=decode_random_bytes(cipher_key))

# Encrypt some plaintext (using nonce arguments).
ciphertext = cipher.encrypt('plaintext')
assert ciphertext != 'plaintext'

# Decrypt some ciphertext.
plaintext = cipher.decrypt(ciphertext)
assert plaintext == 'plaintext'
```

The `SequencedItemMapper` has constructor arg `cipher`, which can be used to pass in a cipher object, and thereby enable encryption.

```
# Construct sequenced item mapper to always encrypt domain events.
ciphered_sequenced_item_mapper = SequencedItemMapper(
    sequenced_item_class=StoredEvent,
    cipher=cipher,
)

# Domain event attribute ``foo`` has value ``'bar'``.
assert domain_event1.foo == 'bar'

# Map the domain event to an encrypted stored event namedtuple.
stored_event = ciphered_sequenced_item_mapper.to_sequenced_item(domain_event1)

# Attribute names and values of the domain event are not visible in the encrypted␣
↪``state`` field.
assert 'foo' not in stored_event.state
assert 'bar' not in stored_event.state

# Recover the domain event from the encrypted state.
domain_event = ciphered_sequenced_item_mapper.from_sequenced_item(stored_event)

# Domain event has decrypted attributes.
assert domain_event.foo == 'bar'
```

Please note, the sequence ID and position values are not encrypted, necessarily. However, by encrypting the state of the item within the application, potentially sensitive information, for example personally identifiable information, will be encrypted in transit to the database, at rest in the database, and in all backups and other copies.

1.6.3 Record managers

The event store uses a record manager to write sequenced items to database records.

The library has an abstract base class `AbstractActiveRecordManager` with abstract methods `append()` and `get_items()`, which can be used on concrete implementations to read and write sequenced items in a database.

A record manager is constructed with a `sequenced_item_class` and a matching `record_class`. The field names of a suitable record class will match the field names of the sequenced item named tuple.

SQLAlchemy

The library has a record manager for SQLAlchemy provided by the object class `SQLAlchemyRecordManager`.

To run the example below, please install the library with the 'sqlalchemy' option.

```
$ pip install eventsourcing[sqlalchemy]
```

The library provides record classes for SQLAlchemy, such as `IntegerSequencedRecord` and `StoredEventRecord`. The `IntegerSequencedRecord` class matches the default `SequencedItem` namedtuple. The `StoredEventRecord` class matches the alternative `StoredEvent` namedtuple. There is also a `TimestampSequencedRecord` and a `SnapshotRecord`.

The code below uses the namedtuple `StoredEvent` and the record class `StoredEventRecord`.

```
from eventsourcing.infrastructure.sqlalchemy.records import StoredEventRecord
```

Database settings can be configured using `SQLAlchemySettings`, which is constructed with a `uri` connection string. The code below uses an in-memory SQLite database.

```
from eventsourcing.infrastructure.sqlalchemy.datastore import SQLAlchemySettings

settings = SQLAlchemySettings(uri='sqlite:///:memory:')
```

To help setup a database connection and tables, the library has object class `SQLAlchemyDatastore`.

The `SQLAlchemyDatastore` is constructed with the `settings` object, and a tuple of record classes passed using the `tables` arg.

```
from eventsourcing.infrastructure.sqlalchemy.datastore import SQLAlchemyDatastore

datastore = SQLAlchemyDatastore(
    settings=settings,
    tables=(StoredEventRecord,)
)
```

Please note, if you have declared your own SQLAlchemy model `Base` class, you may wish to define your own record classes which inherit from your `Base` class. If so, if may help to refer to the library record classes to see how SQLALchemy ORM columns and indexes can be used to persist sequenced items.

The methods `setup_connection()` and `setup_tables()` of the datastore object can be used to setup the database connection and the tables.

```
datastore.setup_connection()
datastore.setup_tables()
```

As well as `sequenced_item_class` and a matching `record_class`, the `SQLAlchemyRecordManager` requires a scoped session object, passed using the constructor arg `session`. For convenience, the `SQLAlchemyDatabase` has a thread-scoped session facade set as its a `session` attribute. You may wish to use a different scoped session facade, such as a request-scoped session object provided by a Web framework.

With the database setup, the `SQLAlchemyRecordManager` can be constructed, and used to store events using SQLAlchemy.

```
from eventsourcing.infrastructure.sqlalchemy.manager import SQLAlchemyRecordManager

record_manager = SQLAlchemyRecordManager(
    sequenced_item_class=StoredEvent,
    record_class=StoredEventRecord,
    session=datastore.session,
    contiguous_record_ids=True,
    application_id=uuid4()
)
```

Sequenced items (or "stored events" in this example) can be appended to the database using the `append()` method of the record manager.

```
record_manager.append(stored_event1)
```

(Please note, since the position is given by the sequenced item itself, the word "append" means here "to add something extra" rather than the perhaps more common but stricter meaning "to add to the end of a document". That is, the database is deliberately not responsible for positioning a new item at the end of a sequence. So perhaps "save" would be a better name for this operation.)

All the previously appended items of a sequence can be retrieved by using the `get_items()` method.

```
results = record_manager.list_items(aggregate1)
```

Since by now only one item was stored, so there is only one item in the results.

```
assert len(results) == 1
assert results[0] == stored_event1
```

SQLAlchemy dialects

The databases supported by core SQLAlchemy dialects are Firebird, Microsoft SQL Server, MySQL, Oracle, PostgreSQL, SQLite, and Sybase. This library's infrastructure classes for SQLAlchemy have been tested with MySQL, PostgreSQL, and SQLite.

MySQL

For MySQL, the Python package mysql-connector-python-rf can be used (licenced GPL v2). Please note, I had problems running this driver with Python 2.7 (unicode error when it raises exceptions).

```
$ pip install pymysql-connector-python-rf
```

The `uri` for MySQL used with this driver would look something like this.

```
mysql+pymysql://username:password@localhost/eventsourcing
```

Alternatively for MySQL, the Python package mysqlclient can be used (also licenced GPL v2). I didn't have problems using this driver with Python 2.7.

```
$ pip install mysqlclient
```

The `uri` for MySQL used with this driver would look something like this.

```
mysql+mysqldb://username:password@localhost/eventsourcing
```

Another alternative is PyMySQL. It has a BSD licence.

```
$ pip install PyMySQL
```

The `uri` for MySQL used with this driver would look something like this.

```
mysql+pymysql://username:password@localhost/eventsourcing
```

PostgreSQL

For PostgreSQL, the Python package psycopg2 can be used.

```
$ pip install psycopg2
```

The `uri` for PostgreSQL used with this driver would look something like this.

```
postgresql+psycopg2://username:password@localhost:5432/eventsourcing
```

SQLite

SQLite is shipped with core Python packages, so nothing extra needs to be installed.

The `uri` for a temporary SQLite database might look something like this.

```
sqlite:///tmp/eventsourcing.db
```

Please note, the library's SQLAlchemy insfrastructure defaults to using an in memory SQLite database, which is the fastest way to run the library, and is recommended as a convenience for development.

Django ORM

The library has a record manager for the Django ORM provided by `DjangoRecordManager` class.

To run the example below, please install the library with the 'django' option.

```
$ pip install eventsourcing[django]
```

For the `DjangoRecordManager`, the `IntegerSequencedRecord` from `eventsourcing.infrastructure.django.models` matches the `SequencedItem` namedtuple. The `StoredEventRecord` from the same module matches the `StoredEvent` namedtuple. There is also a `TimestampSequencedRecord` and a `SnapshotRecord`. These are all Django models.

The package `eventsourcing.infrastructure.django` is a little Django app. To involve its models in your Django project, simply include the application in your project's list of `INSTALLED_APPS`.

```
INSTALLED_APPS = [
    'django.contrib.admin',
    'django.contrib.auth',
    'django.contrib.contenttypes',
    'django.contrib.sessions',
    'django.contrib.messages',
```

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```
    'django.contrib.staticfiles',
    'eventsourcing.infrastructure.django'
]
```

Alternatively, import or write the classes you want into one of your own Django app's `models.py`.

The Django application at `eventsourcing.infrastructure.django` has database migrations that will add four tables, one for each of the record classes mentioned above. So if you use the application directly in `INSTALLED_APPS` then the app's migrations will be picked up by Django.

If, instead of using the app directly, you import some of its model classes into your own application's `models.py`, you will need to run `python manage.py makemigrations` before tables for event sourcing can be created by Django. This way you can avoid creating tables you won't use.

The library has a little Django project for testing the library's Django app, it is used in this example to help run the library's Django app.

```
import os

os.environ['DJANGO_SETTINGS_MODULE'] = 'eventsourcing.tests.djangoproject.
↪djangoproject.settings'
```

This Django project is simply the files that `django-admin.py startproject` generates, with the SQLite database set to be in memory, and with the library's Django app added to the `INSTALLED_APPS` setting.

With the environment variable `DJANGO_SETTINGS_MODULE` referring to the Django project, Django can be started. If you aren't running tests with the Django test runner, you may need to run `django.setup()`.

```
import django

django.setup()
```

Before using the database, make sure the migrations have been applied, so the necessary database tables exist.

An alternative to `python manage.py migrate` is the `call_command()` function, provided by Django. If you aren't running tests with the Django test runner, this can help e.g. to setup an SQLite database in memory before each test by calling it in the `setUp()` method of a test case.

```
from django.core.management import call_command

call_command('migrate', verbosity=0, interactive=False)
```

So long as a table exists for its record class, the `DjangoRecordManager` can be used to store events using the Django ORM.

```
from eventsourcing.infrastructure.django.manager import DjangoRecordManager
from eventsourcing.infrastructure.django.models import StoredEventRecord

django_record_manager = DjangoRecordManager(
    record_class=StoredEventRecord,
    sequenced_item_class=StoredEvent,
    contiguous_record_ids=True
)

results = django_record_manager.list_items(aggregate1)
assert len(results) == 0
```

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```
django_record_manager.append(stored_event1)

results = django_record_manager.list_items(aggregate1)
assert results[0] == stored_event1
```

Django backends

The supported Django backends are PostgreSQL, MySQL, SQLite, and Oracle. This library's Django infrastructure classes have been tested with PostgreSQL, MySQL, SQLite.

Contiguous record IDs

The `contiguous_record_ids` argument, used in the examples above, is optional, and is by default `False`. If set to a `True` value, and if the record class has an ID field, then the records will be inserted (using an "insert select from" query) that generates a table of records with IDs that form a contiguous integer sequence.

Application events recorded in this way can be accurately followed as a single sequence without overbearing complexity to mitigate gaps and race conditions. This feature is only available on the relational record managers (Django and SQLAlchemy, not Cassandra).

If the record ID is merely auto-incrementing, as it is when the the library's integer sequenced record classes are used without this feature being enabled, then gaps could be generated. Whenever there is contention in the aggregate sequence (record ID) that causes the unique record ID constraint to be violated, the transaction will being rolled back, and an ID that was issued was could be discarded and lost. Other greater IDs may already have been issued. The complexity for followers is that a gap may be permanent or temporary. It may be that a gap is eventually filled by a transaction that was somehow delayed. Although some database appear to have auto-incrementing functionaliuty that does not lead to gaps even with transactions being rolled back, I don't understand when this happens and when it doesn't and so feel unable to reply on it, at least at the moment. It appears to be an inherently unreliable situation that could probably be mitigated satisfactorily by followers if they need to project the application events accurately, but only with increased complexity.

Each relational record manager has a raw SQL query with an "insert select from" statement. If possible, the raw query is compiled when the record manager object is constructed. When a record is inserted, the new field values are bound to the raw query and executed within a transaction. When executed, the query firstly selects the maximum ID from all records currently existing in the table (as visible in its transaction), and then attempts to insert a record with an ID value of the max existing ID plus one (the next unused ID). The record table must have a unique constraint for the ID, so that records aren't overwritten by this query. The record ID must also be indexed, so that the max value can be identified efficiently. The b-tree commonly used for databases indexes supports this purpose well. The transaction isolation level must be at least "read committed", which is true by default for MySQL and PostgreSQL.

Any resulting contention in the record ID will raise an exception so that the query can be retried. The library exception class `RecordConflictError` will be raised.

Cassandra

The library has a record manager for Apache Cassandra provided by the `CassandraRecordManager` class.

```
from eventsourcing.infrastructure.cassandra.manager import CassandraRecordManager
```

To run the example below, please install the library with the 'cassandra' option.

```
$ pip install eventsourcing[cassandra]
```

It takes a while to build the driver. If you want to do that last step quickly, set the environment variable CASS_DRIVER_NO_CYTHON.

```
$ CASS_DRIVER_NO_CYTHON=1 pip install eventsourcing[cassandra]
```

For the CassandraRecordManager, the IntegerSequencedRecord from eventsourcing.infrastructure.cassandra.models matches the SequencedItem namedtuple. The StoredEventRecord from the same module matches the StoredEvent namedtuple. There is also a TimestampSequencedRecord, a TimeuuidSequencedRecord, and a SnapshotRecord.

The CassandraDatastore and CassandraSettings can be used in the same was as SQLAlchemyDatastore and SQLAlchemySettings above. Please investigate library class *CassandraSettings* for information about configuring away from default settings.

```
from eventsourcing.infrastructure.cassandra.datastore import CassandraDatastore,␣
↪CassandraSettings
from eventsourcing.infrastructure.cassandra.records import StoredEventRecord

cassandra_datastore = CassandraDatastore(
    settings=CassandraSettings(),
    tables=(StoredEventRecord,)
)
cassandra_datastore.setup_connection()
cassandra_datastore.setup_tables()
```

With the database setup, the CassandraRecordManager can be constructed, and used to store events using Apache Cassandra.

```
from eventsourcing.infrastructure.cassandra.manager import CassandraRecordManager

cassandra_record_manager = CassandraRecordManager(
    record_class=StoredEventRecord,
    sequenced_item_class=StoredEvent,
)

results = cassandra_record_manager.list_items(aggregate1)
assert len(results) == 0

cassandra_record_manager.append(stored_event1)

results = cassandra_record_manager.list_items(aggregate1)
assert results[0] == stored_event1

cassandra_datastore.drop_tables()
cassandra_datastore.close_connection()
```

Sequenced item conflicts

It is a common feature of the record manager classes that it isn't possible successfully to append two items at the same position in the same sequence. If such an attempt is made, a RecordConflictError will be raised.

```
from eventsourcing.exceptions import RecordConflictError

# Fail to append an item at the same position in the same sequence as a previous item.
try:
    record_manager.append(stored_event1)
```

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```
except RecordConflictError:
    pass
else:
    raise Exception("RecordConflictError not raised")
```

This feature is implemented using optimistic concurrency control features of the underlying database. With SQLAlchemy, a unique constraint is used that involves both the sequence and the position columns. The Django ORM strategy works in the same way.

With Cassandra the position is the primary key in the sequence partition, and the "IF NOT EXISTS" feature is applied. The Cassandra database management system implements the Paxos protocol, and can thereby accomplish linearly-scalable distributed optimistic concurrency control, guaranteeing sequential consistency of the events of an entity despite the database being distributed. It is also possible to serialize calls to the methods of an entity, but that is out of the scope of this package — if you wish to do that, perhaps something like an actor framework or Zookeeper might help.

1.6.4 Event store

The library's `EventStore` provides an interface to the library's cohesive mechanism for storing events as sequences of items, and can be used directly within an event sourced application to append and retrieve its domain events.

The `EventStore` is constructed with a sequenced item mapper and an record manager, both are discussed in detail in the sections above.

```
from eventsourcing.infrastructure.eventstore import EventStore

event_store = EventStore(
    sequenced_item_mapper=sequenced_item_mapper,
    record_manager=record_manager,
)
```

The event store's `append()` method can append a domain event to its sequence. The event store uses the `sequenced_item_mapper` to obtain a sequenced item named tuple from a domain events, and it uses the `record_manager` to write a sequenced item to a database.

In the code below, a `DomainEvent` is appended to sequence `aggregate1` at position `1`.

```
event_store.append(
    DomainEvent(
        originator_id=aggregate1,
        originator_version=1,
        foo='baz',
    )
)
```

The event store's method `get_domain_events()` is used to retrieve events that have previously been appended. The event store uses the `record_manager` to read the sequenced items from a database, and it uses the `sequenced_item_mapper` to obtain domain events from the sequenced items.

```
results = event_store.get_domain_events(aggregate1)
```

Since by now two domain events have been stored, so there are two domain events in the results.

```
assert len(results) == 2
```

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```
assert results[0].foo == 'bar'
assert results[1].foo == 'baz'
```

The optional arguments of `get_domain_events()` can be used to select some of the items in the sequence.

The `lt` arg is used to select items below the given position in the sequence.

The `lte` arg is used to select items below and at the given position in the sequence.

The `gte` arg is used to select items at and above the given position in the sequence.

The `gt` arg is used to select items above the given position in the sequence.

The `limit` arg is used to limit the number of items selected from the sequence.

The `is_ascending` arg is used when selecting items. It affects how any `limit` is applied, and determines the order of the results. Hence, it can affect both the content of the results and the performance of the method.

```
# Get events below and at position 0.
result = event_store.get_domain_events(aggregate1, lte=0)
assert len(result) == 1, result
assert result[0].foo == 'bar'

# Get events at and above position 1.
result = event_store.get_domain_events(aggregate1, gte=1)
assert len(result) == 1, result
assert result[0].foo == 'baz'

# Get the first event in the sequence.
result = event_store.get_domain_events(aggregate1, limit=1)
assert len(result) == 1, result
assert result[0].foo == 'bar'

# Get the last event in the sequence.
result = event_store.get_domain_events(aggregate1, limit=1, is_ascending=False)
assert len(result) == 1, result
assert result[0].foo == 'baz'
```

Optimistic concurrency control

It is a feature of the event store that it isn't possible successfully to append two events at the same position in the same sequence. This condition is coded as a `ConcurrencyError` since a correct program running in a single thread wouldn't attempt to append an event that it had already successfully appended.

```
from eventsourcing.exceptions import ConcurrencyError

# Fail to append an event at the same position in the same sequence as a previous␣
↪event.
try:
    event_store.append(
        DomainEvent(
            originator_id=aggregate1,
            originator_version=1,
            foo='baz',
        )
    )
except ConcurrencyError:
```

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```
    pass
else:
    raise Exception("ConcurrencyError not raised")
```

This feature depends on the behaviour of the record manager's `append()` method: the event store will raise a `ConcurrencyError` if a `RecordConflictError` is raised by its record manager.

If a command fails due to a concurrency error, the command can be retried with the lastest state. The `@retry` decorator can help code retries on commands.

```
from eventsourcing.domain.model.decorators import retry

errors = []

@retry(ConcurrencyError, max_attempts=5)
def set_password():
    exc = ConcurrencyError()
    errors.append(exc)
    raise exc

try:
    set_password()
except ConcurrencyError:
    pass
else:
    raise Exception("Shouldn't get here")

assert len(errors) == 5
```

This feature avoids the sequence of records being corrupted due to concurrent threads operating on the same aggregate. However, the result is that success of appending an event in such circumstances is only probabilistic with respect to concurrency conflicts. Concurrency conflicts can be avoided if all commands for a single aggregate are executed in series, for example by treating each aggregate as an actor within an actor framework, or with locks provided by something like Zookeeper.

Event store factory

As a convenience, the library function `construct_sqlalchemy_eventstore()` can be used to construct an event store that uses the SQLAlchemy classes.

```
from eventsourcing.infrastructure.sqlalchemy import factory

event_store = factory.construct_sqlalchemy_eventstore(
    session=datastore.session,
    application_id=uuid4(),
    contiguous_record_ids=True,
)
```

By default, the event store is constructed with the `StoredEvent` sequenced item named tuple, and the record class `StoredEventRecord`. The optional args `sequenced_item_class` and `record_class` can be used to construct different kinds of event store.

Timestamped event store

The examples so far have used an integer sequenced event store, where the items are sequenced by integer version.

The example below constructs an event store for timestamp-sequenced domain events, using the library record class `TimestampSequencedRecord`.

```
from uuid import uuid4

from eventsourcing.infrastructure.sqlalchemy.records import TimestampSequencedRecord
from eventsourcing.utils.times import decimaltimestamp

# Setup database table for timestamped sequenced items.
datastore.setup_table(TimestampSequencedRecord)

# Construct event store for timestamp sequenced events.
timestamped_event_store = factory.construct_sqlalchemy_eventstore(
    sequenced_item_class=SequencedItem,
    record_class=TimestampSequencedRecord,
    sequence_id_attr_name='originator_id',
    position_attr_name='timestamp',
    session=datastore.session,
)

# Construct an event.
aggregate_id = uuid4()
event = DomainEvent(
    originator_id=aggregate_id,
    timestamp=decimaltimestamp(),
)

# Store the event.
timestamped_event_store.append(event)

# Check the event was stored.
events = timestamped_event_store.get_domain_events(aggregate_id)
assert len(events) == 1
assert events[0].originator_id == aggregate_id
assert events[0].timestamp < decimaltimestamp()
```

Please note, optimistic concurrent control doesn't work with timestamped sequenced items to maintain consistency of a domain entity, because each event is likely to have a unique timestamp, and so branches can occur without restraint. Optimistic concurrency control will prevent one timestamp sequenced event from overwritting another. For this reason, although domain events are usefully timestamped, it is not a very good idea to store the events of an entity or aggregate as timestamp-sequenced items. Timestamp-sequenced items are useful for storing events that are logically independent of others, such as messages in a log, things that do not risk causing a consistency error due to concurrent operations. It remains that timestamp sequenced items can happen to occur at the same timestamp, in which case there would be a concurrency error exception, and the event could be retried with a later timestamp.

TimeUUIDs

If throughput is so high that such conflicts are too frequent, the library also supports sequencing items by TimeUUID, which includes a random component that makes it very unlikely two events will conflict. This feature currently works with Apache Cassandra only. Tests exist in the library, other documentation is forthcoming.

1.7 Domain model

The library's domain layer has base classes for domain events and entities. These classes show how to write a domain model that uses the library's event sourcing infrastructure. They can also be used to develop an event-sourced application as a domain driven design.

- *Domain events*
  - *Publish-subscribe*
  - *Event library*
  - *Custom events*
- *Domain entities*
  - *Entity library*
  - *Naming style*
  - *Entity events*
  - *Factory method*
  - *Triggering events*
  - *Data integrity*
  - *Discarding entities*
  - *Custom entities*
  - *Custom attributes*
  - *Custom commands*
  - *Custom events*
- *Aggregate root*

1.7.1 Domain events

The purpose of a domain event is to be published when something happens, normally the results from the work of a command. The library has a base class for domain events called `DomainEvent`.

Domain events can be freely constructed from the `DomainEvent` class. Attributes are set directly from the constructor keyword arguments.

```
from eventsourcing.domain.model.events import DomainEvent

domain_event = DomainEvent(a=1)
assert domain_event.a == 1
```

The attributes of domain events are read-only. New values cannot be assigned to existing objects. Domain events are immutable in that sense.

```
# Fail to set attribute of already-existing domain event.
try:
    domain_event.a = 2
```

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```
except AttributeError:
    pass
else:
    raise Exception("Shouldn't get here")
```

Domain events can be compared for equality as value objects, instances are equal if they have the same type and the same attributes.

```
DomainEvent(a=1) == DomainEvent(a=1)

DomainEvent(a=1) != DomainEvent(a=2)

DomainEvent(a=1) != DomainEvent(b=1)
```

Publish-subscribe

Domain events can be published, using the library's publish-subscribe mechanism.

The `publish()` function is used to publish events. The `event` arg is required.

```
from eventsourcing.domain.model.events import publish

publish(event=domain_event)
```

The `subscribe()` function is used to subscribe a `handler` that will receive events.

The optional `predicate` arg can be used to provide a function that will decide whether or not the subscribed handler will actually be called when an event is published.

```
from eventsourcing.domain.model.events import subscribe

received_events = []

def receive_event(event):
    received_events.append(event)

def is_domain_event(event):
    return isinstance(event, DomainEvent)

subscribe(handler=receive_event, predicate=is_domain_event)

# Publish the domain event.
publish(domain_event)

assert len(received_events) == 1
assert received_events[0] == domain_event
```

The `unsubscribe()` function can be used to stop the handler receiving further events.

```
from eventsourcing.domain.model.events import unsubscribe

unsubscribe(handler=receive_event, predicate=is_domain_event)

# Clean up.
del received_events[:]  # received_events.clear()
```

Event library

The library has a small collection of domain event subclasses, such as `EventWithOriginatorID`, `EventWithOriginatorVersion`, `EventWithTimestamp`, `EventWithTimeuuid`, `Created`, `AttributeChanged`, `Discarded`.

Some of these classes provide useful defaults for particular attributes, such as a `timestamp`. Timestamps can be used to sequence events.

```
from eventsourcing.domain.model.events import EventWithTimestamp
from eventsourcing.domain.model.events import EventWithTimeuuid
from decimal import Decimal
from uuid import UUID

# Automatic timestamp.
assert isinstance(EventWithTimestamp().timestamp, Decimal)

# Automatic UUIDv1.
assert isinstance(EventWithTimeuuid().event_id, UUID)
```

Some classes require particular arguments when constructed. The `originator_id` can be used to identify a sequence to which an event belongs. The `originator_version` can be used to position the event in a sequence.

```
from eventsourcing.domain.model.events import EventWithOriginatorVersion
from eventsourcing.domain.model.events import EventWithOriginatorID
from uuid import uuid4

# Requires originator_id.
EventWithOriginatorID(originator_id=uuid4())

# Requires originator_version.
EventWithOriginatorVersion(originator_version=0)
```

Some are just useful for their distinct type, for example in subscription predicates.

```
from eventsourcing.domain.model.events import Created, AttributeChanged, Discarded

def is_created(event):
    return isinstance(event, Created)

def is_attribute_changed(event):
    return isinstance(event, AttributeChanged)

def is_discarded(event):
    return isinstance(event, Discarded)

assert is_created(Created()) is True
assert is_created(Discarded()) is False
assert is_created(DomainEvent()) is False

assert is_discarded(Created()) is False
assert is_discarded(Discarded()) is True
assert is_discarded(DomainEvent()) is False

assert is_domain_event(Created()) is True
assert is_domain_event(Discarded()) is True
assert is_domain_event(DomainEvent()) is True
```

Custom events

Custom domain events can be coded by subclassing the library's domain event classes.

Domain events are normally named using the past participle of a common verb, for example a regular past participle such as "started", "paused", "stopped", or an irregular past participle such as "chosen", "done", "found", "paid", "quit", "seen".

```
class SomethingHappened(DomainEvent):
    """
    Published whenever something happens.
    """
```

It is possible to code domain events as inner or nested classes.

```
class Job(object):

    class Seen(EventWithTimestamp):
        """
        Published when the job is seen.
        """

    class Done(EventWithTimestamp):
        """
        Published when the job is done.
        """
```

Inner or nested classes can be used, and are used in the library, to define the domain events of a domain entity on the entity class itself.

```
seen = Job.Seen(job_id='#1')
done = Job.Done(job_id='#1')

assert done.timestamp > seen.timestamp
```

So long as the entity event classes inherit ultimately from library class `QualnameABC`, which `DomainEvent` does, the utility functions `get_topic()` and `resolve_topic()` can work with domain events defined as inner or nested classes in all versions of Python. These functions are used in the `DomainEntity.Created` event class, and in the infrastructure class `SequencedItemMapper`. The requirement to inherit from `QualnameABC` actually only applies when using nested classes in Python 2.7 with the utility functions `get_topic()` and `resolve_topic()`. Events classes that are not nested, or that will not be run with Python 2.7, do not need to inherit from `QualnameABC` in order to work with these two functions (and hence the library domain and infrastructure classes which use those functions).

1.7.2 Domain entities

A domain entity is an object that is not defined by its attributes, but rather by a thread of continuity and its identity. The attributes of a domain entity can change, directly by assignment, or indirectly by calling a method of the object.

The library has a base class for domain entities called `DomainEntity`, which has an `id` attribute.

```
from eventsourcing.domain.model.entity import DomainEntity

entity_id = uuid4()

entity = DomainEntity(id=entity_id)
```

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```
assert entity.id == entity_id
```

Entity library

The library also has a domain entity class called `VersionedEntity`, which extends the `DomainEntity` class with a `__version__` attribute.

```
from eventsourcing.domain.model.entity import VersionedEntity

entity = VersionedEntity(id=entity_id, __version__=1)

assert entity.id == entity_id
assert entity.__version__ == 1
```

The library also has a domain entity class called `TimestampedEntity`, which extends the `DomainEntity` class with attributes `__created_on__` and `__last_modified__`.

```
from eventsourcing.domain.model.entity import TimestampedEntity

entity = TimestampedEntity(id=entity_id, __created_on__=123)

assert entity.id == entity_id
assert entity.__created_on__ == 123
assert entity.__last_modified__ == 123
```

There is also a `TimestampedVersionedEntity` that has `id`, `__version__`, `__created_on__`, and `__last_modified__` attributes.

```
from eventsourcing.domain.model.entity import TimestampedVersionedEntity

entity = TimestampedVersionedEntity(id=entity_id, __version__=1, __created_on__=123)

assert entity.id == entity_id
assert entity.__created_on__ == 123
assert entity.__last_modified__ == 123
assert entity.__version__ == 1
```

A timestamped, versioned entity is both a timestamped entity and a versioned entity.

```
assert isinstance(entity, TimestampedEntity)
assert isinstance(entity, VersionedEntity)
```

Naming style

The double leading and trailing underscore naming style, seen above, is used consistently in the library's domain entity and event base classes for attribute and method names, so that developers can begin with a clean namespace. The intention is that the library functionality is included in the application by aliasing these library names with names that work within the project's ubiquitous language.

This style breaks PEP8, but it seems worthwhile in order to keep the "normal" Python object namespace free for domain modelling. It is a style used by other libraries (such as SQLAlchemy and Django) for similar reasons.

The exception is the `id` attribute of the domain entity base class, which is assumed to be required by all domain entities (or aggregates) in all domains.

Entity events

The library's domain entity classes have domain events defined as inner classes: `Event`, `Created`, `AttributeChanged`, and `Discarded`.

```
DomainEntity.Event
DomainEntity.Created
DomainEntity.AttributeChanged
DomainEntity.Discarded
```

The domain event class `DomainEntity.Event` is a super type of the others. The others also inherit from the library base classes `Created`, `AttributeChanged`, and `Discarded`. All these domain events classes are subclasses of `DomainEvent`.

```
assert issubclass(DomainEntity.Created, DomainEntity.Event)
assert issubclass(DomainEntity.AttributeChanged, DomainEntity.Event)
assert issubclass(DomainEntity.Discarded, DomainEntity.Event)

assert issubclass(DomainEntity.Created, Created)
assert issubclass(DomainEntity.AttributeChanged, AttributeChanged)
assert issubclass(DomainEntity.Discarded, Discarded)

assert issubclass(DomainEntity.Event, DomainEvent)
```

These entity event classes can be freely constructed, with suitable arguments.

All events need an `originator_id`. Events of versioned entities also need an `originator_version`. Events of timestamped entities generate a current `timestamp` value, unless one is given. `Created` events also need an `originator_topic`. The other events need an `__previous_hash__`. `AttributeChanged` events also need `name` and `value`.

All the events of `DomainEntity` use SHA-256 to generate an `event_hash` from the event attribute values when constructed for the first time. Events can be chained together by constructing each subsequent event to have its `__previous_hash__` as the `event_hash` of the previous event.

```
from eventsourcing.utils.topic import get_topic

entity_id = UUID('b81d160d-d7ef-45ab-a629-c7278082a845')

created = VersionedEntity.Created(
    originator_version=0,
    originator_id=entity_id,
    originator_topic=get_topic(VersionedEntity)
)

attribute_a_changed = VersionedEntity.AttributeChanged(
    name='a',
    value=1,
    originator_version=1,
    originator_id=entity_id,
    __previous_hash__=created.__event_hash__,
)

attribute_b_changed = VersionedEntity.AttributeChanged(
    name='b',
    value=2,
    originator_version=2,
    originator_id=entity_id,
```

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```
    __previous_hash__=attribute_a_changed.__event_hash__,
)

entity_discarded = VersionedEntity.Discarded(
    originator_version=3,
    originator_id=entity_id,
    __previous_hash__=attribute_b_changed.__event_hash__,
)
```

The events have a `__mutate__()` function, which can be used to mutate the state of a given object appropriately.

For example, the `DomainEntity.Created` event mutates to an entity instance. The class that is instantiated is determined by the `originator_topic` attribute of the `DomainEntity.Created` event.

A domain event's `__mutate__()` method normally requires an `obj` argument, but that is not required for `DomainEntity.Created` events. The default is `None`, but if a value is provided it must be callable that returns an object, such as a domain entity class. If a domain entity class is provided, the `originator_topic` will be ignored.

```
entity = created.__mutate__()

assert entity.id == entity_id
```

As another example, when a versioned entity is mutated by an event of the `VersionedEntity` class, the entity version number is set to the event `originator_version`.

```
assert entity.__version__ == 0

entity = attribute_a_changed.__mutate__(entity)
assert entity.__version__ == 1
assert entity.a == 1

entity = attribute_b_changed.__mutate__(entity)
assert entity.__version__ == 2
assert entity.b == 2
```

Similarly, when a timestamped entity is mutated by an event of the `TimestampedEntity` class, the `__last_modified__` attribute of the entity is set to have the event's `timestamp` value.

Factory method

The `DomainEntity` has a class method `__create__()` which can return new entity objects. When called, it constructs the `Created` event of the concrete class with suitable arguments such as a unique ID, and a topic representing the concrete entity class, and then it projects that event into an entity object using the event's `__mutate__()` method. Then it publishes the event, and then it returns the new entity to the caller. This technique works correctly for subclasses of both the entity and the event class.

```
entity = DomainEntity.__create__()
assert entity.id
assert entity.__class__ is DomainEntity


entity = VersionedEntity.__create__()
assert entity.id
assert entity.__version__ == 0
```

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```
assert entity.__class__ is VersionedEntity


entity = TimestampedEntity.__create__()
assert entity.id
assert entity.__created_on__
assert entity.__last_modified__
assert entity.__class__ is TimestampedEntity


entity = TimestampedVersionedEntity.__create__()
assert entity.id
assert entity.__created_on__
assert entity.__last_modified__
assert entity.__version__ == 0
assert entity.__class__ is TimestampedVersionedEntity
```

Triggering events

Commands methods will construct, apply, and publish events, using the results from working on command arguments. The events need to be constructed with suitable arguments.

To help trigger events in an extensible manner, the `DomainEntity` class has a method called `__trigger_event__()`, that is extended by subclasses in the library, which can be used in command methods to construct, apply, and publish events with suitable arguments. The events' `__mutate__()` methods update the entity appropriately.

For example, triggering an `AttributeChanged` event on a timestamped, versioned entity will cause the attribute value to be updated, but it will also cause the version number to increase, and it will update the last modified time.

```
entity = TimestampedVersionedEntity.__create__()
assert entity.__version__ == 0
assert entity.__created_on__ == entity.__last_modified__

# Trigger domain event.
entity.__trigger_event__(entity.AttributeChanged, name='c', value=3)

# Check the event was applied.
assert entity.c == 3
assert entity.__version__ == 1
assert entity.__last_modified__ > entity.__created_on__
```

The command method `__change_attribute__()` triggers an `AttributeChanged` event. In the code below, the attribute `full_name` is set to 'Mr Boots'. A subscriber receives the event.

```
subscribe(handler=receive_event, predicate=is_domain_event)
assert len(received_events) == 0

entity = VersionedEntity.__create__(entity_id)

# Change an attribute.
entity.__change_attribute__(name='full_name', value='Mr Boots')

# Check the event was applied.
assert entity.full_name == 'Mr Boots'
```

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```
# Check two events were published.
assert len(received_events) == 2

first_event = received_events[0]
assert first_event.__class__ == VersionedEntity.Created
assert first_event.originator_id == entity_id
assert first_event.originator_version == 0

last_event = received_events[1]
assert last_event.__class__ == VersionedEntity.AttributeChanged
assert last_event.name == 'full_name'
assert last_event.value == 'Mr Boots'
assert last_event.originator_version == 1

# Check the event hash is the current entity head.
assert last_event.__event_hash__ == entity.__head__

# Clean up.
unsubscribe(handler=receive_event, predicate=is_domain_event)
del received_events[:]  # received_events.clear()
```

Data integrity

Domain events that are triggered in this way are hash-chained together by default.

The state of each event, including the hash of the last event, is hashed using SHA-256. Before an event is applied to an entity, it is validated in itself (the event hash represents the state of the event) and as a part of the chain (the previous event hash is included in the next event state). If the sequence of events is accidentally damaged in any way, then a `DataIntegrityError` will almost certainly be raised from the domain layer when the sequence is replayed.

The hash of the last event applied to an entity is available as an attribute called `__head__`.

```
# Entity's head hash is determined exclusively
# by the entire sequence of events and SHA-256.
assert entity.__head__ ==
↪'ae7688000c38b2bd504b3eb3cd8e015144dd9a3c4992951c87cef9cce047f86c'

# Entity's head hash is simply the event hash
# of the last event that mutated the entity.
assert entity.__head__ == last_event.__event_hash__
```

A different sequence of events will almost certainly result a different head hash. So the entire history of an entity can be verified by checking the head hash. This feature could be used to protect against tampering.

The hashes can be salted by setting environment variable `SALT_FOR_DATA_INTEGRITY`, perhaps with random bytes encoded as Base64.

```
from eventsourcing.utils.random import encode_random_bytes

# Keep this safe.
salt = encode_random_bytes(num_bytes=32)

# Configure environment (before importing library).
import os
os.environ['SALT_FOR_DATA_INTEGRITY'] = salt
```

Discarding entities

The entity method `__discard__()` can be used to discard the entity, by triggering a `Discarded` event, after which the entity is unavailable for further changes.

```
from eventsourcing.exceptions import EntityIsDiscarded

entity.__discard__()

# Fail to change an attribute after entity was discarded.
try:
    entity.__change_attribute__('full_name', 'Mr Boots')
except EntityIsDiscarded:
    pass
else:
    raise Exception("Shouldn't get here")
```

Custom entities

The library entity classes can be subclassed.

```
class User(VersionedEntity):
    def __init__(self, full_name, *args, **kwargs):
        super(User, self).__init__(*args, **kwargs)
        self.full_name = full_name
```

Subclasses can extend the entity base classes, by adding event-based properties and methods.

Custom attributes

The library's `@attribute` decorator provides a property getter and setter, which will triggers an `AttributeChanged` event when the property is assigned. Simple mutable attributes can be coded as decorated functions without a body, such as the `full_name` function of `User` below.

```
from eventsourcing.domain.model.decorators import attribute


class User(VersionedEntity):

    def __init__(self, full_name, *args, **kwargs):
        super(User, self).__init__(*args, **kwargs)
        self._full_name = full_name

    @attribute
    def full_name(self):
        """Full name of the user."""
```

In the code below, after the entity has been created, assigning to the `full_name` attribute causes the entity to be updated. An `AttributeChanged` event is published. Both the `Created` and `AttributeChanged` events are received by a subscriber.

```
assert len(received_events) == 0
subscribe(handler=receive_event, predicate=is_domain_event)

# Publish a Created event.
```

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```
user = User.__create__(full_name='Mrs Boots')

# Publish an AttributeChanged event.
user.full_name = 'Mr Boots'

assert len(received_events) == 2
assert received_events[0].__class__ == VersionedEntity.Created
assert received_events[0].full_name == 'Mrs Boots'
assert received_events[0].originator_version == 0
assert received_events[0].originator_id == user.id

assert received_events[1].__class__ == VersionedEntity.AttributeChanged
assert received_events[1].value == 'Mr Boots'
assert received_events[1].name == '_full_name'
assert received_events[1].originator_version == 1
assert received_events[1].originator_id == user.id

# Clean up.
unsubscribe(handler=receive_event, predicate=is_domain_event)
del received_events[:]  # received_events.clear()
```

Custom commands

The entity base classes can be extended with custom command methods. In general, the arguments of a command will be used to perform some work. Then, the result of the work will be used to trigger a domain event that represents what happened. Please note, command methods normally have no return value.

For example, the `set_password()` method of the `User` entity below is given a raw password. It creates an encoded string from the raw password, and then uses the `__change_attribute__()` method to trigger an `AttributeChanged` event for the `_password` attribute with the encoded password.

```
from eventsourcing.domain.model.decorators import attribute


class User(VersionedEntity):

    def __init__(self, *args, **kwargs):
        super(User, self).__init__(*args, **kwargs)
        self._password = None

    def set_password(self, raw_password):
        # Do some work using the arguments of a command.
        password = self._encode_password(raw_password)

        # Change private _password attribute.
        self.__change_attribute__('_password', password)

    def check_password(self, raw_password):
        password = self._encode_password(raw_password)
        return self._password == password

    def _encode_password(self, password):
        return ''.join(reversed(password))
```

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```
user = User(id='1', __version__=0)

user.set_password('password')
assert user.check_password('password')
```

Custom events

Custom events can be defined as inner or nested classes of the custom entity class. In the code below, the entity class `World` has a custom event called `SomethingHappened`.

Custom event classes can extend the `__mutate__()` method, so it affects entities in a way that is specific to that type of event. More conveniently, event classes can implement a `mutate()` method, which avoids the need to call the super method and return the obj. For example, the `SomethingHappened` event class has a `mutate()` method which simply appends the event object to the entity's `history` attribute.

Custom events are normally triggered by custom commands. In the example below, the command method `make_it_so()` triggers the custom event `SomethingHappened`.

```
from eventsourcing.domain.model.decorators import mutator

class World(VersionedEntity):

    def __init__(self, *args, **kwargs):
        super(World, self).__init__(*args, **kwargs)
        self.history = []

    def make_it_so(self, something):
        # Do some work using the arguments of a command.
        what_happened = something

        # Trigger event with the results of the work.
        self.__trigger_event__(World.SomethingHappened, what=what_happened)

    class SomethingHappened(VersionedEntity.Event):
        """Published when something happens in the world."""
        def mutate(self, obj):
            obj.history.append(self)
```

A new world can now be created, using the `__create__()` method. The command `make_it_so()` can be used to make things happen in this world. When something happens, the history of the world is augmented with the new event.

```
world = World.__create__()

world.make_it_so('dinosaurs')
world.make_it_so('trucks')
world.make_it_so('internet')

assert world.history[0].what == 'dinosaurs'
assert world.history[1].what == 'trucks'
assert world.history[2].what == 'internet'
```

1.7.3 Aggregate root

Eric Evans' book Domain Driven Design describes an abstraction called "aggregate":

> *"An aggregate is a cluster of associated objects that we treat as a unit for the purpose of data changes. Each aggregate has a root and a boundary."*

Therefore,

> *"Cluster the entities and value objects into aggregates and define boundaries around each. Choose one entity to be the root of each aggregate, and control all access to the objects inside the boundary through the root. Allow external objects to hold references to the root only."*

In this situation, one aggregate command may result in many events. In order to construct a consistency boundary, we need to prevent the situation where other threads pick up only some of the events, but not all of them, which could present the aggregate in an inconsistent, or unusual, and perhaps unworkable state.

In other words, we need to avoid the situation where some of the events have been stored successfully but others have not been. If the events from a command were stored in a series of independent database transactions, then some would be written before others. If another thread needs the aggregate and gets its events whilst a series of new event are being written, it would not receive some of the events, but not the events that have not yet been written. Worse still, events could be lost due to an inconvenient database server problem, or sudden termination of the client. Even worse, later events in the series could fall into conflict because another thread has started appending events to the same sequence, potentially causing an incoherent state that would be difficult to repair.

Therefore, to implement the aggregate as a consistency boundary, all the events from a command on an aggregate must be appended to the event store in a single atomic transaction, so that if some of the events resulting from executing a command cannot be stored then none of them will be stored. If all the events from an aggregate are to be written to a database as a single atomic operation, then they must have been published by the entity as a single list.

The library has a domain entity class called *AggregateRoot* that can be useful in a domain driven design, especially where a single command can cause many events to be published. The `AggregateRoot` entity class extends `TimestampedVersionedEntity`. It overrides the `__publish__()` method of the base class, so that triggered events are published only to a private list of pending events, rather than directly to the publish-subscribe mechanism. It also adds a method called `__save__()`, which publishes all pending events to the publish-subscribe mechanism as a single list.

It can be subclassed by custom aggregate root entities. In the example below, the entity class `World` inherits from `AggregateRoot`.

```
from eventsourcing.domain.model.aggregate import AggregateRoot


class World(AggregateRoot):
    """
    Example domain entity, with mutator function on domain event.
    """
    def __init__(self, *args, **kwargs):
        super(World, self).__init__(*args, **kwargs)
        self.history = []

    def make_things_so(self, *somethings):
        for something in somethings:
            self.__trigger_event__(World.SomethingHappened, what=something)

    class SomethingHappened(AggregateRoot.Event):
        def mutate(self, obj):
            obj.history.append(self)
```

The `World` aggregate root has a command method `make_things_so()` which publishes `SomethingHappened` events. The `mutate()` method of the `SomethingHappened` class simply appends the event (`self`) to the aggregate object `obj`.

We can see the events that are published by subscribing to the handler `receive_events()`.

```
assert len(received_events) == 0
subscribe(handler=receive_event)

# Create new world.
world = World.__create__()
assert isinstance(world, World)

# Command that publishes many events.
world.make_things_so('dinosaurs', 'trucks', 'internet')

# State of aggregate object has changed
# but no events have been published yet.
assert len(received_events) == 0
assert world.history[0].what == 'dinosaurs'
assert world.history[1].what == 'trucks'
assert world.history[2].what == 'internet'
```

Events are pending, and will not be published until the `__save__()` method is called.

```
# Has pending events.
assert len(world.__pending_events__) == 4

# Publish pending events.
world.__save__()

# Pending events published as a list.
assert len(received_events) == 1
assert len(received_events[0]) == 4

# No longer any pending events.
assert len(world.__pending_events__) == 0

# Clean up.
unsubscribe(handler=receive_event)
del received_events[:]  # received_events.clear()
```

1.8 Application

The application layer combines objects from the domain and infrastructure layers.

- *Overview*
- *Simple application*
- *Custom application*
  - *Run the code*
  - *Stored events*

- *Sequenced items*
- *Database records*
- *Close*

1.8.1 Overview

An application object normally has repositories and policies. A repository allows aggregates to be retrieved by ID, using a dictionary-like interface. Whereas aggregates implement commands that publish events, policies subscribe to events and execute commands.

An application can be understood by understanding its policies, aggregates, commands, and events.

An application object can have methods ("application services") which provide a relatively simple interface for client operations, hiding the complexity and usage of the application's domain and infrastructure layers.

Application services can be developed outside-in, with a test- or behaviour-driven development approach. A test suite can be imagined as an interface that uses the application. Interfaces are outside the scope of the application layer.

To run the examples below, please install the library with the 'sqlalchemy' option.

```
$ pip install eventsourcing[sqlalchemy]
```

1.8.2 Simple application

The library provides a simple application class `SimpleApplication` which can be constructed directly.

Its `uri` attribute is an SQLAlchemy-style database connection string. An SQLAlchemy thread-scoped session facade will be setup using the `uri` value.

```
uri = 'sqlite:///:memory:'
```

As you can see, this example is using SQLite to manage an in memory relational database. You can change `uri` to any valid connection string.

Here are some example connection strings: for an SQLite file; for a PostgreSQL database; or for a MySQL database. See SQLAlchemy's create_engine() documentation for details. You may need to install drivers for your database management system (such as `psycopg2` for PostreSQL or `pymysql` or even `mysql-connector-python-rf` for MySQL).

```
# SQLite with a file on disk.
sqlite:////tmp/mydatabase

# PostgreSQL with psycopg2.
postgresql+psycopg2://scott:tiger@localhost:5432/mydatabase

# MySQL with pymysql.
mysql+pymysql://scott:tiger@hostname/dbname

# MySQL with mysql-connector-python-rf.
mysql+sqlconnector://scott:tiger@hostname/dbname
```

Encryption is optionally enabled in `SimpleApplication` with a suitable AES key (16, 24, or 32 random bytes encoded as Base64).

```
from eventsourcing.utils.random import encode_random_bytes

# Keep this safe (random bytes encoded with Base64).
cipher_key = encode_random_bytes(num_bytes=32)
```

These values can be given to the application object as constructor arguments `uri` and `cipher_key`. Alternatively, the `uri` value can be set as environment variable `DB_URI`, and the `cipher_key` value can be set as environment variable `CIPHER_KEY`.

```
from eventsourcing.application.simple import SimpleApplication
from eventsourcing.domain.model.aggregate import AggregateRoot

app = SimpleApplication(
    uri='sqlite:///:memory:',
    cipher_key=cipher_key,
    persist_event_type=AggregateRoot.Event,
)
```

Instead of providing a URI, an already existing SQLAlchemy session can be passed in, using constructor argument `session`. For example, a session object provided by a framework extension such as Flask-SQLAlchemy could be passed to the application object.

Once constructed, the `SimpleApplication` will have an event store, provided by the library's `EventStore` class, for which it uses the library's infrastructure classes for SQLAlchemy.

```
app.event_store
```

The `SimpleApplication` uses the library function `construct_sqlalchemy_eventstore()` to construct its event store, for integer-sequenced items with SQLAlchemy.

To use different infrastructure for storing events, subclass the `SimpleApplication` class and override the method `setup_event_store()`. You can read about the available alternatives in the *infrastructure layer* documentation.

The `SimpleApplication` also has a persistence policy, provided by the library's `PersistencePolicy` class.

```
app.persistence_policy
```

The persistence policy appends domain events of type *persist_event_type* to its event store whenever they are published.

The `SimpleApplication` also has a repository, an instance of the library's `EventSourcedRepository` class.

```
app.repository
```

Both the repository and persistence policy use the event store.

The aggregate repository is generic, and can retrieve all aggregates in an application, regardless of their class.

The example below uses the `AggregateRoot` class directly to create a new aggregate object that is available in the application's repository.

```
obj = AggregateRoot.__create__()
obj.__change_attribute__(name='a', value=1)
assert obj.a == 1
obj.__save__()

# Check the repository has the latest values.
copy = app.repository[obj.id]
```

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```
assert copy.a == 1

# Check the aggregate can be discarded.
copy.__discard__()
assert copy.id not in app.repository

# Check optimistic concurrency control is working ok.
from eventsourcing.exceptions import ConcurrencyError
try:
    obj.__change_attribute__(name='a', value=2)
    obj.__save__()
except ConcurrencyError:
    pass
else:
    raise Exception("Shouldn't get here")
```

Because of the unique constraint on the sequenced item table, it isn't possible to branch the evolution of an entity and store two events at the same version. Hence, if the entity you are working on has been updated elsewhere, an attempt to update your object will cause a `ConcurrencyError` exception to be raised.

Concurrency errors can be avoided if all commands for a single aggregate are executed in series, for example by treating each aggregate as an actor, within an actor framework.

The `SimpleApplication` has a `notification_log` attribute, which can be used to follow the application events as a single sequence.

```
# Follow application event notifications.
from eventsourcing.interface.notificationlog import NotificationLogReader
reader = NotificationLogReader(app.notification_log)
notification_ids = [n['id'] for n in reader.read()]
assert notification_ids == [1, 2, 3], notification_ids

# - create two more aggregates
obj = AggregateRoot.__create__()
obj.__save__()

obj = AggregateRoot.__create__()
obj.__save__()

# - get the new event notifications from the reader
notification_ids = [n['id'] for n in reader.read()]
assert notification_ids == [4, 5], notification_ids
```

1.8.3 Custom application

The `SimpleApplication` class can be extended.

The example below shows a custom application class `MyApplication` that extends `SimpleApplication` with application service `create_aggregate()` that can create new `CustomAggregate` entities.

```
class MyApplication(SimpleApplication):
    def __init__(self, **kwargs):
        super(MyApplication, self).__init__(
            persist_event_type=CustomAggregate.Event, **kwargs)
```

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```
    def create_aggregate(self, a):
        return CustomAggregate.__create__(a=1)
```

The application code above depends on an entity class called `CustomAggregate`, which is defined below. It extends the library's `AggregateRoot` entity with an event sourced, mutable attribute `a`.

```
from eventsourcing.domain.model.decorators import attribute

class CustomAggregate(AggregateRoot):
    def __init__(self, a, **kwargs):
        super(CustomAggregate, self).__init__(**kwargs)
        self._a = a

    @attribute
    def a(self):
        """Mutable attribute a."""
```

For more sophisticated domain models, please read about the custom entities, commands, and domain events that can be developed using classes from the library's *domain model layer*.

Run the code

The custom application object can be constructed.

```
# Construct application object.
app = MyApplication(uri='sqlite:///:memory:')
```

The application service aggregate factor method `create_aggregate()` can be called.

```
# Create aggregate using application service, and save it.
aggregate = app.create_aggregate(a=1)
aggregate.__save__()
```

Existing aggregates can be retrieved by ID using the repository's dictionary-like interface.

```
# Aggregate is in the repository.
assert aggregate.id in app.repository

# Get aggregate using dictionary-like interface.
aggregate = app.repository[aggregate.id]

assert aggregate.a == 1
```

Changes to the aggregate's attribute `a` are visible in the repository once pending events have been published.

```
# Change attribute value.
aggregate.a = 2
aggregate.a = 3

# Don't forget to save!
aggregate.__save__()

# Retrieve again from repository.
aggregate = app.repository[aggregate.id]
```

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```
# Check attribute has new value.
assert aggregate.a == 3
```

The aggregate can be discarded. After being saved, a discarded aggregate will no longer be available in the repository.

```
# Discard the aggregate.
aggregate.__discard__()

# Check discarded aggregate no longer exists in repository.
assert aggregate.id not in app.repository
```

Attempts to retrieve an aggregate that does not exist will cause a `KeyError` to be raised.

```
# Fail to get aggregate from dictionary-like interface.
try:
    app.repository[aggregate.id]
except KeyError:
    pass
else:
    raise Exception("Shouldn't get here")
```

Stored events

It is always possible to get the domain events for an aggregate, by using the application's event store method `get_domain_events()`.

```
events = app.event_store.get_domain_events(originator_id=aggregate.id)
assert len(events) == 4

assert events[0].originator_id == aggregate.id
assert isinstance(events[0], CustomAggregate.Created)
assert events[0].a == 1

assert events[1].originator_id == aggregate.id
assert isinstance(events[1], CustomAggregate.AttributeChanged)
assert events[1].name == '_a'
assert events[1].value == 2

assert events[2].originator_id == aggregate.id
assert isinstance(events[2], CustomAggregate.AttributeChanged)
assert events[2].name == '_a'
assert events[2].value == 3

assert events[3].originator_id == aggregate.id
assert isinstance(events[3], CustomAggregate.Discarded)
```

Sequenced items

It is also possible to get the sequenced item namedtuples for an aggregate, by using the method `get_items()` of the event store's record manager.

```
items = app.event_store.record_manager.list_items(aggregate.id)
assert len(items) == 4
```

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```
assert items[0].originator_id == aggregate.id
assert items[0].event_type == 'eventsourcing.domain.model.aggregate#AggregateRoot.
↪Created'
assert '"a":1' in items[0].state, items[0].state
assert '"timestamp":' in items[0].state

assert items[1].originator_id == aggregate.id
assert items[1].event_type == 'eventsourcing.domain.model.aggregate#AggregateRoot.
↪AttributeChanged'
assert '"name":"_a"' in items[1].state
assert '"timestamp":' in items[1].state

assert items[2].originator_id == aggregate.id
assert items[2].event_type == 'eventsourcing.domain.model.aggregate#AggregateRoot.
↪AttributeChanged'
assert '"name":"_a"' in items[2].state
assert '"timestamp":' in items[2].state

assert items[3].originator_id == aggregate.id
assert items[3].event_type == 'eventsourcing.domain.model.aggregate#AggregateRoot.
↪Discarded'
assert '"timestamp":' in items[3].state
```

In this example, the `cipher_key` was not set, so the stored data is visible.

Database records

Of course, it is also possible to just use the record class directly to obtain records. After all, it's just an SQLAlchemy ORM object.

```
app.event_store.record_manager.record_class
```

The `orm_query()` method of the SQLAlchemy record manager is a convenient way to get a query object from the session for the record class.

```
event_records = app.event_store.record_manager.orm_query().all()

assert len(event_records) == 4
```

Close

If the application isn't being used as a context manager, then it is useful to unsubscribe any handlers subscribed by the policies (avoids dangling handlers being called inappropriately, if the process isn't going to terminate immediately, such as when this documentation is tested as part of the library's test suite).

```
# Clean up.
app.close()
```

1.9 Snapshotting

Snapshots provide a fast path for obtaining the state of an entity or aggregate that skips replaying some or all of the entity's events.

If the library repository class `EventSourcedRepository` is constructed with a snapshot strategy object, it will try to get the closest snapshot to the required version of a requested entity, and then replay only those events that will take the snapshot up to the state at that version.

Snapshots can be taken manually. To automatically generate snapshots, a snapshotting policy can take snapshots whenever a particular condition occurs, for example after every ten events.

- *Domain*
- *Application*
- *Run the code*

1.9.1 Domain

To avoid duplicating code from the previous sections, let's use the example entity class *`Example`* and its factory function *`create_new_example()`* from the library.

```
from eventsourcing.example.domainmodel import Example, create_new_example
```

1.9.2 Application

The library class *`SnapshottingApplication`*, extends *`SimpleApplication`* by setting up infrastructure for snapshotting, such as a snapshot store, a dedicated table for snapshots, and a policy to take snapshots every so many events. It is recommended not to co-mingle saved snapshots with the entity event sequence. It can also make sense to use a completely separate table for snapshot records, especially if the table of domain events is also being used as application log (e.g. it has an auto-incrementing integer primary key column).

```
from eventsourcing.application.simple import SnapshottingApplication
```

1.9.3 Run the code

In the example below, snapshots of entities are taken every `period` number of events.

```
with SnapshottingApplication(period=2) as app:

    # Create an entity.
    entity = create_new_example(foo='bar1')

    # Check there's no snapshot, only one event so far.
    snapshot = app.snapshot_strategy.get_snapshot(entity.id)
    assert snapshot is None

    # Change an attribute, generates a second event.
    entity.foo = 'bar2'
```

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```
    # Check the snapshot.
    snapshot = app.snapshot_strategy.get_snapshot(entity.id)
    assert snapshot.state['_foo'] == 'bar2'

    # Check can recover entity using snapshot.
    assert entity.id in app.repository
    assert app.repository[entity.id].foo == 'bar2'

    # Check snapshot after five events.
    entity.foo = 'bar3'
    entity.foo = 'bar4'
    entity.foo = 'bar5'
    snapshot = app.snapshot_strategy.get_snapshot(entity.id)
    assert snapshot.state['_foo'] == 'bar4'

    # Check snapshot after seven events.
    entity.foo = 'bar6'
    entity.foo = 'bar7'
    assert app.repository[entity.id].foo == 'bar7'
    snapshot = app.snapshot_strategy.get_snapshot(entity.id)
    assert snapshot.state['_foo'] == 'bar6'

    # Check snapshot state is None after discarding the entity on the eighth event.
    entity.__discard__()
    assert entity.id not in app.repository
    snapshot = app.snapshot_strategy.get_snapshot(entity.id)
    assert snapshot.state is None

    try:
        app.repository[entity.id]
    except KeyError:
        pass
    else:
        raise Exception('KeyError was not raised')

    # Get historical snapshots.
    snapshot = app.snapshot_strategy.get_snapshot(entity.id, lte=2)
    assert snapshot.state['___version__'] == 1  # one behind
    assert snapshot.state['_foo'] == 'bar2'

    snapshot = app.snapshot_strategy.get_snapshot(entity.id, lte=3)
    assert snapshot.state['___version__'] == 3
    assert snapshot.state['_foo'] == 'bar4'

    # Get historical entities.
    entity = app.repository.get_entity(entity.id, at=0)
    assert entity.__version__ == 0
    assert entity.foo == 'bar1', entity.foo

    entity = app.repository.get_entity(entity.id, at=1)
    assert entity.__version__ == 1
    assert entity.foo == 'bar2', entity.foo

    entity = app.repository.get_entity(entity.id, at=2)
    assert entity.__version__ == 2
    assert entity.foo == 'bar3', entity.foo
```

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```
    entity = app.repository.get_entity(entity.id, at=3)
    assert entity.__version__ == 3
    assert entity.foo == 'bar4', entity.foo
```

1.10 Notifications

This section discusses how to use notifications to propagate the domain events of an application.

If the domain events of an application can somehow be placed in a sequence, then the sequence of events can be propagated as a sequence of notifications.

- *Three options*
  - *Bounded context controls notifications*
- *Application sequence*
  - *Timestamps*
  - *Integers*
  - *Record managers*
  - *BigArray*
- *Notification logs*
- *Local notification logs*
  - *RecordManagerNotificationLog*
  - *Notification records*
  - *BigArrayNotificationLog*
- *Remote notification logs*
  - *NotificationLogView*
  - *Notification API*
  - *RemoteNotificationLog*
- *Notification log reader*

1.10.1 Three options

Vaughn Vernon suggests in his book Implementing Domain Driven Design:

> *"at least two mechanisms in a messaging solution must always be consistent with each other: the persistence store used by the domain model, and the persistence store backing the messaging infrastructure used to forward the Events published by the model. This is required to ensure that when the model's changes are persisted, Event delivery is also guaranteed, and that if an Event is delivered through messaging, it indicates a true situation reflected by the model that published it. If either of these is out of lockstep with the other, it will lead to incorrect states in one or more interdependent models"*

He continues by describing three options. The first option is to have the messaging infrastructure and the domain model share the same persistence store, so changes to the model and insertion of new messages commit in the same local transaction.

The second option is to have separate datastores for domain model and messaging but have a two phase commit, or global transaction, across the two.

The third option is to have the bounded context control notifications. The simple logic of an ascending sequence of integers can allow others to progress along an application's sequence of events. It is also possible to use timestamps.

The first option implies that each event sourced application functions cohesively also as a messaging service. Assuming that "messaging service" means an AMQP system, it seems impractical in a small library such as this to implement an AMQP broker, something that works with all of the library's record manager classes. However, perhaps if Kafka could be adapted as a record manager, it could be used both to persist and propagate events.

The second option, which is similar to the first, involves using a separate messaging infrastructure within a two-phase commit, which could be possible, but seems unattractive. At least RabbitMQ can't participate in a two-phase commit.

The third option is pursued below.

Bounded context controls notifications

The third option doesn't depend on messaging infrastructure, but does involve "notifications". If the events of an application can be placed in a sequence, the sequence of events can be presented as a sequence of notifications, with notifications being propagated in a standard way. For example, notifications could be presented by a server, and clients could pull notifications they don't have, in linked sections, perhaps using a standard format and standard protocols.

Pulling new notifications could resume whenever a "prompt" is received via an AMQP system. This way, the client doesn't have the latency or intensity of a polling interval, the messaging infrastructure doesn't need to deliver messages in order (which AMQP messaging systems don't normally provide), and message size is minimised.

If the "substantive" changes enacted by a receiver are stored atomically with the position in the sequence of notifications, the receiver can resume by looking at the latest record it has written, and from that record identify the next notification to consume. This is obvious when considering pure replication of a sequence of events. But in general, by storing in the produced sequence the position of the receiver in the consumed sequence, and using optimistic concurrency control when records are inserted in the produced sequence, at least from the point of view of consumers of the produced sequence, "exactly once" processing can be achieved. Redundant (concurrent) processing of the same sequence would then be possible, which may help to avoid interruptions in processing the application's events.

If placing all the events in a single sequence is restrictive, then perhaps partitioning the application notifications may offer a scalable approach. For example, if each user has one partition, each notification sequence would contain all events from the aggregates pertaining to one user. So that the various sequences can be discovered, it would be useful to have a sequence in which the creation of each partition is recorded. The application could then be scaled by partition. (Please note, the library doesn't currently support partitioning the aggregates of an application.)

If partitioning the aggregates of application is restrictive, then it would also be possible to have a notification sequence for each aggregate; in this case, the events would already have been placed in a sequence and so they could be presented directly as notifications. But as aggregates come and go, the overhead of keeping track of the notification sequences may become restrictive. (Please note, the library doesn't currently support notifications for individual aggregates.)

An alternative to sequencing events individually would be to sequence the lists of events published when saving the pending events of an aggregate (see `AggregateRoot`), so that in cases where it is feasible to place all the commands in a sequence, it would also be feasible to place the resulting lists of events in a sequence, assuming the number of such lists is less than or equal to the number of commands. Sequencing the lists would allow these little units of coherence to be propagated, which may be useful in some cases. (Please note, the library doesn't currently support notifications for lists of events.)

Before continuing with code examples below, we need to setup an event store.

```
from uuid import uuid4

from eventsourcing.application.policies import PersistencePolicy
from eventsourcing.domain.model.entity import DomainEntity
from eventsourcing.infrastructure.eventstore import EventStore
from eventsourcing.infrastructure.repositories.array import BigArrayRepository
from eventsourcing.infrastructure.sequenceditem import StoredEvent
from eventsourcing.infrastructure.sequenceditemmapper import SequencedItemMapper
from eventsourcing.infrastructure.sqlalchemy.datastore import SQLAlchemyDatastore,␣
↪SQLAlchemySettings
from eventsourcing.infrastructure.sqlalchemy.manager import SQLAlchemyRecordManager
from eventsourcing.infrastructure.sqlalchemy.records import StoredEventRecord

# Setup the database.
datastore = SQLAlchemyDatastore(
    settings=SQLAlchemySettings(),
    tables=[StoredEventRecord],
)
datastore.setup_connection()
datastore.setup_tables()

# Setup the record manager.
record_manager = SQLAlchemyRecordManager(
    session=datastore.session,
    record_class=StoredEventRecord,
    sequenced_item_class=StoredEvent,
    contiguous_record_ids=True,
    application_id=uuid4(),
)

# Setup a sequenced item mapper.
sequenced_item_mapper = SequencedItemMapper(
    sequenced_item_class=StoredEvent,
)

# Setup the event store.
event_store = EventStore(
    record_manager=record_manager,
    sequenced_item_mapper=sequenced_item_mapper
)

# Set up a persistence policy.
persistence_policy = PersistencePolicy(
    event_store=event_store,
    event_type=DomainEntity.Event
)
```

Please note, the `SQLAlchemyRecordManager` is has its `contiguous_record_ids` option enabled.

The infrastructure classes are explained in other sections of this documentation.

1.10.2 Application sequence

The fundamental concern here is to propagate the events of an application without events being missed, duplicated, or jumbled.

The events of an application sequence could be sequenced with either timestamps or integers. Sequencing the appli-

cation events by timestamp is supported by the relational timestamp sequenced record classes, in that their position column is indexed. However, the notification logs only work with integer sequences.

Sequencing with integers involves generating a sequence of integers, which is easy to follow, but can limit the rate at which records can be written. Using timestamps allows records to be inserted independently of others, but timestamps can cause uncertainty when following the events of an application.

If an application's domain model involves the library's `AggregateRoot` class, which publishes all pending events together as a list, rather than inserting each event, it would be possible to insert the lists of events into the application sequence as a single entry. This may reduce the number of inserts into the application sequence. The lists could be sequenced by timestamp or integer. Timestamps may allow the greatest write-speed. (This approach currently hasn't been explored any further, but it should be.)

Timestamps

If time itself was ideal, then timestamps would be ideal. Each event could then have a timestamp that could be used to index and iterate through the events of the application. However, there are many clocks, and each runs slightly differently from the others.

If the timestamps of the application events are created by different clocks, then it is possible to write events in an order that creates consistency errors when reconstructing the application state. Hence it is also possible for new records to be written with a timestamp that is earlier than the latest one, which makes following the application sequence tricky.

A "jitter buffer" can be used, otherwise any events timestamped by a relatively retarded clock, and hence positioned behind events that were inserted earlier, could be missed. The delay, or the length of the buffer, must be greater than the differences between clocks, but how do we know for sure what is the maximum difference between the clocks?

Of course, there are lots of remedies. Clocks can be synchronised, more or less. A timestamp server could be used, and hybrid monotonically increasing timestamps can implemented. Furthermore, the risk of simultaneous timestamps can be mitigated by using a random component to the timestamp, as with UUID v1 (which randomizes the order of otherwise "simultaneous" events).

These techniques (and others) are common, widely discussed, and entirely legitimate approaches to the complications encountered when using timestamps to sequence events. The big advantage of using timestamps is that you don't need to generate a sequence of integers, and applications can be distributed and scaled without performance being limited by a fragile single-threaded auto-incrementing integer-sequence bottleneck.

In support of this approach, the library's relational record classes for timestamp sequenced items. In particular, the `TimestampSequencedRecord` classes for SQLAlchemy and Django index their position field, which is a timestamp, and so this index can be used to get all application events ordered by timestamp. If you use this class in this way, make sure your clocks are in sync, and query events from the last position until a time in the recent past, in order to implement a jitter buffer.

Todo: Code example.

(An improvement could be to have a timestamp field that is populated by the database server, and index that instead of the application event's timestamp which would vary according to the variation between the clock of application servers. Code changes and other suggestions are always welcome.)

Integers

To reproduce the application's sequence of events perfectly, without any risk of gaps or duplicates or jumbled items, or race conditions, we can generate and then follow a contiguous sequence of integers. It is also possible to generate and follow a non-contiguous sequence of integers, but the gaps will need to be negotiated, by guessing how long an unusually slow write would take to become visible, since such gaps could be filled in the future.

The library's relational record managers with record classes that have an indexed integer ID column. Record IDs are used to place all the application's event records in a single sequence. This technique is recommended for enterprise

applications, and at least the earlier stages of more ambitious projects. There is an inherent limit to the rate at which an application can write events using this technique, which essentially follows from the need to write events in series. The rate limit is the reciprocal of the time it takes to write one event record, which depends on the insert statement.

By default, these library record classes have an auto-incrementing ID, which will generate an increasing sequence as records are inserted, but which may have gaps if an insert fails. Optionally, the record managers can also can be used to generate contiguous record IDs, with an "insert select from" SQL statement that, as a clause in the insert statement, selects the maximum record ID from the visible table records. Since it is only possible to extend the sequence, the visible record IDs will form a contiguous sequence, which is the easiest thing to follow, because there is no possibility for race conditions where events appear behind the last visible event. The "insert select from" statement will probably be slower than the default "insert values" and the auto-incrementing ID, and only one of many concurrent inserts will be successful. Exceptions from concurrent inserts could be mitigated with retried, and avoided entirely by serialising the inserts with a queue, for example in an actor framework. Although this will smooth over spikes, and unfortunate coincidences will be avoided, the continuous maximum throughput will not be increased, a queue will eventually reach a limit and a different exception will be raised.

Given the rate limit, it could an application quite a long time to fill up a well provisioned database table. Nevertheless, if the rate of writing or the volume of domain event records in your system inclines you towards partitioning the table of stored events, or if anyway your database works in this way (e.g. Cassandra), then the table would need to be partitioned by sequence ID so that the aggregate performance isn't compromised by having its events distributed across partitions, which means maintaining an index of record IDs across such partitions, and hence sequencing the events of an application in this way, will be problematic.

To proceed without an indexed record ID column, the library class `BigArray` can be used to sequence all the events of an application. This technique can be used as an alternative to using a native database index of record IDs, especially in situations where a normal database index across all records is generally discouraged (e.g. in Cassandra), or where records do not have an integer ID or timestamp that can be indexed (e.g. all the library's record classes for Cassandra, and the `IntegerSequencedNoIDRecord` for SQLAlchemy, or when storing an index for a large number of records in a single partition is undesirable for infrastructure or performance reasons, or is not supported by the database.

The `BigArray` can be used to construct both contiguous and non-contiguous integer sequences. As with the record IDs above, if each item is positioned in the next position after the last visible record, then a contiguous sequence is generated, but at the cost of finding the last visible record. However, if a number generator is used, the rate is limited by the rate at which numbers can be issued, but if inserts can fail, then numbers can be lost and the integer sequence will have gaps.

Record managers

A relational record manager can function as an application sequence, especially when its record class has an ID field, and more so when the `contiguous_record_ids` option is enabled. This technique ensures that whenever an entity or aggregate command returns successfully, any events will already have been simultaneously placed in both the aggregate's and the application's sequence. Importantly, if inserting an event hits a uniqueness constraint and the transaction is rolled back, the event will not appear in either sequence.

This approach provides perfect accuracy with great simplicity for followers, but it has a maximum total rate at which records can be written into the database. In particular, the `contiguous_record_ids` feature executes an "insert select from" SQL statement that generates contiguous record IDs when records are inserted, on the database-side as a clause in the insert statement, by selecting the maximum existing ID in the table, adding one, and inserting that value, along with the event data.

Because the IDs must be unique, applications may experience the library's `ConcurrencyError` exception if they happen to insert records simultaneously with others. Record ID conflicts are retried a finite number of times by the library before a `ConcurrencyError` exception is raised. But with a load beyond the capability of a service, increased congestion will be experienced by the application as an increased frequency of concurrency errors.

Please note, without the `contiguous_record_ids` feature enabled, the ID columns of library record classes should be merely auto-incrementing, and so the record IDs can anyway be used to get all the records in the order they were written. However, auto-incrementing the ID can lead to a sequence of IDs that has gaps, a non-contiguous sequence, which could lead to race conditions and missed items. The gaps would need to be negotiated, which is relatively complicated. To keep things relatively simple, a record manager that does not have the `contiguous_record_ids` feature enabled cannot be used with the library's `RecordManagerNotificationLog` class (introduced below). If you want to sequence the application events with a non-contiguous sequence, then you will need to write something that can negotiate the gaps.

To use contiguous IDs to sequence the events of an application, simply use a relational record manager with an `IntegerSequencedRecord` that has an ID, such as the `StoredEventRecord` record class, and with a True value for its `contiguous_record_ids` constructor argument. The `record_manager` above was constructed in this way. The records can be then be obtained using the `get_notifications()` method of the record manager. The record IDs will form a contiguous sequence, suitable for the `RecordManagerNotificationLog`.

```
from eventsourcing.domain.model.entity import VersionedEntity

notifications = record_manager.get_notifications()

assert len(notifications) == 0, notifications

first_entity = VersionedEntity.__create__()

notifications = record_manager.get_notifications(start=0, stop=5)

assert len(notifications) == 1, notifications
```

The local notification log class `RecordManagerNotificationLog` (see below) can adapt record managers, presenting the application sequence as notifications in a standard way.

BigArray

This is a long section, and can be skipped if you aren't currently required to scale beyond the limits of a database table that has indexed record IDs.

To support ultra-high capacity requirements, the application sequence must be capable of having a very large number of events, neither swamping an individual database partition (in Cassandra) nor distributing things across table partitions without any particular order so that iterating through the sequence is slow and expensive. We also want the application log effectively to have constant time read and write operations for normal usage.

The library class *`BigArray`* satisfies these requirements quite well, by spanning across many such partitions. It is a tree of arrays, with a root array that stores references to the current apex, with an apex that contains references to arrays, which either contain references to lower arrays or contain the items assigned to the big array. Each array uses one database partition, limited in size (the array size) to ensure the partition is never too large. The identity of each array can be calculated directly from the index number, so it is possible to identify arrays directly without traversing the tree to discover entity IDs. The capacity of base arrays is the array size to the power of the array size. For a reasonable size of array, it isn't really possible to fill up the base of such an array tree, but the slow growing properties of this tree mean that for all imaginable scenarios, the performance will be approximately constant as items are appended to the big array.

Items can be appended to a big array using the `append()` method. The append() method identifies the next available index in the array, and then assigns the item to that index in the array. A *`ConcurrencyError`* will be raised if the position is already taken.

The performance of the `append()` method is proportional to the log of the index in the array, to the base of the array size used in the big array, rounded up to the nearest integer, plus one (because of the root sequence that tracks the apex). For example, if the sub-array size is 10,000, then it will take only 50% longer to append the 100,000,000th item

to the big array than the 1st one. By the time the 1,000,000,000,000th index position is assigned to a big array, the `append()` method will take only twice as long as the 1st.

That's because the default performance of the `append()` method is dominated by the need to walk down the big array's tree of arrays to find the highest assigned index. Once the index of the next position is known, the item can be assigned directly to an array. The performance can be improved by using an integer sequence generator, but departing from using the current max ID risks creating gaps in the sequence of IDs.

```
from uuid import uuid4
from eventsourcing.domain.model.array import BigArray
from eventsourcing.infrastructure.repositories.array import BigArrayRepository


repo = BigArrayRepository(
    event_store=event_store,
    array_size=10000
)

big_array = repo[uuid4()]
big_array.append('item0')
big_array.append('item1')
big_array.append('item2')
big_array.append('item3')
```

Because there is a small duration of time between checking for the next position and using it, another thread could jump in and use the position first. If that happens, a *ConcurrencyError* will be raised by the *BigArray* object. In such a case, another attempt can be made to append the item.

Items can be assigned directly to a big array using an index number. If an item has already been assigned to the same position, a concurrency error will be raised, and the original item will remain in place. Items cannot be unassigned from an array, hence each position in the array can be assigned once only.

The average performance of assigning an item is a constant time. The worst case is the log of the index with base equal to the array size, which occurs when containing arrays are added, so that the last highest assigned index can be discovered. The probability of departing from average performance is inversely proportional to the array size, since the the larger the array size, the less often the base arrays fill up. For a decent array size, the probability of needing to build the tree is very low. And when the tree does need building, it doesn't take very long (and most of it probably already exists).

```
from eventsourcing.exceptions import ConcurrencyError

assert big_array.get_next_position() == 4

big_array[4] = 'item4'
try:
    big_array[4] = 'item4a'
except ConcurrencyError:
    pass
else:
    raise
```

If the next available position in the array must be identified each time an item is assigned, the amount of contention will increase as the number of threads increases. Using the `append()` method alone will work if the time period of appending events is greater than the time it takes to identify the next available index and assign to it. At that rate, any contention will not lead to congestion. Different nodes can take their chances assigning to what they believe is an unassigned index, and if another has already taken that position, the operation can be retried.

However, there will be an upper limit to the rate at which events can be appended, and contention will eventually lead to congestion that will cause requests to backup or be spilled.

The rate of assigning items to the big array can be greatly increased by factoring out the generation of the sequence of integers. Instead of discovering the next position from the array each time an item is assigned, an integer sequence generator can be used to generate a contiguous sequence of integers. This technique eliminates contention around assigning items to the big array entirely. In consequence, the bandwidth of assigning to a big array using an integer sequence generator is much greater than using the `append()` method.

If the application is executed in only one process, for example during development, the number generator can be a simple Python object. The library class *SimpleIntegerSequenceGenerator* generates a contiguous sequence of integers that can be shared across multiple threads in the same process.

```
from eventsourcing.infrastructure.integersequencegenerators.base import␣
↪SimpleIntegerSequenceGenerator

integers = SimpleIntegerSequenceGenerator()
generated = []
for i in integers:
    if i >= 5:
        break
    generated.append(i)

expected = list(range(5))
assert generated == expected, (generated, expected)
```

If the application is deployed across many nodes, an external integer sequence generator can be used. There are many possible solutions. The library class *RedisIncr* uses Redis' INCR command to generate a contiguous sequence of integers that can be shared be processes running on different nodes.

Using Redis doesn't necessarily create a single point of failure. Redundancy can be obtained using clustered Redis. Although there aren't synchronous updates between nodes, so that the INCR command may issue the same numbers more than once, these numbers can only ever be used once. As failures are retried, the position will eventually reach an unassigned index position. Arrangements can be made to set the value from the highest assigned index. With care, the worst case will be an occasional slight delay in storing events, caused by switching to a new Redis node and catching up with the current index number. Please note, there is currently no code in the library to update or resync the Redis key used in the Redis INCR integer sequence generator.

```
from eventsourcing.infrastructure.integersequencegenerators.redisincr import RedisIncr

integers = RedisIncr()
generated = []
for i in integers:
    generated.append(i)
    if i >= 4:
        break

expected = list(range(5))
assert generated == expected, (generated, expected)
```

The integer sequence generator can be used when assigning items to the big array object.

```
big_array[next(integers)] = 'item5'
big_array[next(integers)] = 'item6'

assert big_array.get_next_position() == 7
```

Items can be read from the big array using an index or a slice.

The performance of reading an item at a given index is always constant time with respect to the number of the index. The base array ID, and the index of the item in the base array, can be calculated from the number of the index.

The performance of reading a slice of items is proportional to the size of the slice. Consecutive items in a base array are stored consecutively in the same database partition, and if the slice overlaps more than base array, the iteration proceeds to the next partition.

```
assert big_array[0] == 'item0'
assert list(big_array[5:7]) == ['item5', 'item6']
```

The big array can be written to by a persistence policy. References to events could be assigned to the big array before the domain event is written to the aggregate's own sequence, so that it isn't possible to store an event in the aggregate's sequence that is not already in the application sequence. To do that, construct the application logging policy object before the normal application persistence policy. Also, make sure the application log policy excludes the events published by the big array (otherwise there will be an infinite recursion). If the event fails to write, then the application sequence will have a dangling reference, which followers will have to cope with.

Alternatively, if the database supports transactions across different tables (not Cassandra), the big array assignment and the event record insert can be done in the same transaction, so they both appear or neither does. This will help to avoid some complexity for followers. The library currently doesn't have any code that writes to both in the same transaction.

Todo: Code example of policy that places application domain events in a big array.

If the big array item is not assigned in the same separate transaction as the event record is inserted, commands that fail to insert the event record after the event has been assigned to the big array (due to an operation error or a concurrency error) should probably raise an exception, so that the command is seen to have failed and so may be retried. An event would then be in the application sequence but not in the aggregate sequence, which is effectively a dangling reference, one that may or may not be satisfied later. If the event record insert failed due to an operational error, and the command is retried, a new event at the same position in the same sequence may be published, and so it would appear twice in the application sequence. And so, whilst dangling references in the application log can perhaps be filtered out by followers after a delay, care should be taken by followers to deduplicate events.

It may also happen that an item fails to be assigned to the big array. In this case, an ID that was issued by an integer sequence generator would be lost. The result would be a gap, that would need to be negotiated by followers.

If writing the event to its aggregate sequence is successful, then it is possible to push a notification about the event to a message queue. Failing to push the notification perhaps should not prevent the command returning normally. Push notifications could also be generated by another process, something that pulls from the application log, and pushes notifications for events that have not already been sent.

Since we can imagine there is quite a lot of noise in the sequence, it may be useful to process the application sequence within the context by constructing another sequence that does not have duplicates or gaps, and then propagating that sequence.

The local notification log class `BigArrayNotificationLog` (see below) can adapt big arrays, presenting the assigned items as notifications in a standard way. Gaps in the array will result in notification items of `None`. But where there are gaps, there can be race conditions, where the gaps are filled. Only a contiguous sequence, which has no gaps, can exclude gaps being filled later.

Please note: there is an unimplemented enhancement which would allow this data structure to be modified in a single transaction, because the new non-leaf nodes can be determined from the position of the new leaf node, however currently a less optimal approach is used which attempts to add all non-leaf nodes and carries on in case of conflicts.

1.10.3 Notification logs

As described in Implementing Domain Driven Design, a notification log presents a sequence of notification items in linked sections.

Sections are obtained from a notification log using Python's "square brackets" sequence index syntax. The key is a section ID. A special section ID called "current" can be used to obtain a section which contains the latest notification

(see examples below).

Each section contains a limited number items, the size is fixed by the notification log's `section_size` constructor argument. When the current section is full, it is considered to be an archived section.

All the archived sections have an ID for the next section. Similarly, all sections except the first have an ID for the previous section.

A client can get the current section, go back until it reaches the last notification it has already received, and then go forward until all existing notifications have been received.

The section ID numbering scheme follows Vaughn Vernon's book. Section IDs are strings: a string formatted with two integers separated by a comma. The integers represent the first and last number of the items included in a section.

The classes below can be used to present a sequence of items, such the domain events of an application, in linked sections. They can also be used to present other sequences for example a projection of the application sequence, where the events are rendered in a particular way for a particular purpose, such as analytics.

A local notification log could be presented by an API in a serialized format e.g. JSON or Atom XML. A remote notification log could then access the API and provide notification items in the standard way. The serialized section documents could then be cached using standard cacheing mechanisms.

1.10.4 Local notification logs

RecordManagerNotificationLog

A relational record manager can be adapted by the library class *RecordManagerNotificationLog*, which will then present the application's events as notifications.

The `RecordManagerNotificationLog` is constructed with a `record_manager`, and a `section_size`.

```
from eventsourcing.interface.notificationlog import RecordManagerNotificationLog

# Construct notification log.
notification_log = RecordManagerNotificationLog(record_manager, section_size=5)

# Get the "current" section from the record notification log.
section = notification_log['current']
assert section.section_id == '6,10', section.section_id
assert section.previous_id == '1,5', section.previous_id
assert section.next_id == None
assert len(section.items) == 4, len(section.items)

# Get the first section from the record notification log.
section = notification_log['1,5']
assert section.section_id == '1,5', section.section_id
assert section.previous_id == None, section.previous_id
assert section.next_id == '6,10', section.next_id
assert len(section.items) == 5, section.items
```

The sections of the record notification log each have notification items that reflect the recorded domain event. The items (notifications) in the sections from `RecordManagerNotificationLog` are Python dicts with three key-values: `id`, `topic`, and `data`.

The record manager uses its `sequenced_item_class` to identify the actual names of the record fields containing the topic and the data, and constructs the notifications (the dicts) with the values of those fields. The notification's data is simply the record data, so if the record data was encrypted, the notification data will also be encrypted. The keys of the event notification do not reflect the sequenced item class being used in the record manager.

The `topic` value can be resolved to a Python class, such as a domain event class. An object instance, such as a domain event object, can then be reconstructed using the notification's `data`.

In the code below, the function `resolve_notifications` shows how that can be done (this function doesn't exist in the library).

```
def resolve_notifications(notifications):
    return [
        sequenced_item_mapper.from_topic_and_data(
            topic=notification['event_type'],
            data=notification['state']
        ) for notification in notifications
    ]

# Resolve a section of notifications into domain events.
domain_events = resolve_notifications(section.items)

# Check we got the first entity's "created" event.
assert isinstance(domain_events[0], VersionedEntity.Created)
assert domain_events[0].originator_id == first_entity.id
```

If the notification data was encrypted by the sequenced item mapper, the sequence item mapper will decrypt the data before reconstructing the domain event. In this example, the sequenced item mapper does not have a cipher, so the notification data is not encrypted.

The library's `SimpleApplication` has a `notification_log` that uses this `RecordManagerNotificationLog` class.

Notification records

An application could write separate notification records and event records. Having separate notification records allows notifications to be arbitrarily and therefore evenly distributed across a variable set of notification logs.

The number of logs could governed automatically by a scaling process so the cadence of each notification log is actively controlled to a constant level.

Todo: Merge these paragraphs, remove repetition (params below were moved from projections doc).

When an application has one notification log, any causal ordering between events will preserved in the log: you won't be informed that something changed without previously being informed that it was created. But if there are many notification logs, then it would be possible to record casual ordering between events: the notifications recorded for the last events that were applied to the aggregates used when triggering new events can be included in the notifications for the new events. This avoids downstream needing to: serialise everything in order to recover order e.g. by merge sorting all logs by timestamp; partitioning the application state; or to ignore causal ordering. For efficiency, prior events that were notified in the same log wouldn't need to be included. So it would make sense for all the events of a particular aggregate to be notified in the same log, but if necessary they could be distributed across different notification logs without downstream processing needing to incoherent or bottle-necked. To scale data, it might become necessary to fix an aggregate to a notification log, so that many databases can be used with each having the notification records and the event records together (and any upstream notification tracking records) so that atomic transactions for these records are still workable.

If all events in a process are placed in the same notification log sequence, since a notification log will need to be processed in series, the throughput is more or less limited by the rate at which a sequence can be processed by a single thread. To scale throughput, the application event notifications could be distributed into many different notification logs, and a separate operating system process (or thread) could run concurrently for each log. A set of notification logs could be processed by a single thread, that perhaps takes one notification in turn from each log, but with parallel processing, total throughput could be proportional to the number of notification logs used to propagate the domain events of an application.

Causal ordering can be maintained across the logs, so long as each event notification references the notifications for the last event in all the aggregates that were required to trigger the new events. If a notification references a notification in another log, then the processing can wait until that other notification has been processed. Hence notifications do not need to include notifications in the same log, as they will be processed first. On the other hand, if all notifications include such references to other notifications, then a notification log could be processed in parallel: since it is unlikely that each notification in a log depends on its immediate predecessor, wherever a sub-sequence of notifications all depend on notifications that have already been processed, those notifications could perhaps be processed concurrently.

There will be a trade-off between evenly distributing events across the various logs and minimising the number of causal ordering that go across logs. A simple and probably effective rule would be to place all the events of one aggregate in the same log. But it may also help to partition the aggregates of an application by e.g. user, and place the events of all aggregates created by a user in the same notification log, since they are perhaps most likely to be causally related. This mechanism would allow the number of logs to be increased and decreased, with aggregate event notifications switching from one log to another and still be processed coherently.

Todo: Define notification records in SQLAlchemy: application_id, pipeline_id, record_id, originator_id, originator_version with unique index on (application_id, log_id, record_id) and unique index on (originator_id, originator_version). Give notification record class to record manager. Change manager to write a notification record for each event. Maybe change aggregate __save__() method to accept other records, which could be used to save a tracking record. Use with an event record class that also has (application_id) column.

BigArrayNotificationLog

You can skip this section if you skipped the section about BigArray.

A big array can be adapted by the library class *BigArrayNotificationLog*, which will then present the items assigned to the array as notifications.

The `BigArrayNotificationLog` is constructed with a `big_array`, and a `section_size`.

```
from eventsourcing.interface.notificationlog import BigArrayNotificationLog

# Construct notification log.
big_array_notification_log = BigArrayNotificationLog(big_array, section_size=5)

# Get the "current "section from the big array notification log.
section = big_array_notification_log['current']
assert section.section_id == '6,10', section.section_id
assert section.previous_id == '1,5', section.previous_id
assert section.next_id == None
assert len(section.items) == 2, len(section.items)

# Check we got the last two items assigned to the big array.
assert section.items == ['item5', 'item6']

# Get the first section from the notification log.
section = big_array_notification_log['1,10']
assert section.section_id == '1,5', section.section_id
assert section.previous_id == None, section.previous_id
assert section.next_id == '6,10', section.next_id
assert len(section.items) == 5, section.items

# Check we got the first five items assigned to the big array.
assert section.items == ['item0', 'item1', 'item2', 'item3', 'item4']
```

Please note, for simplicity, the items in this example are just strings ('item0' etc). If the big array is being used to sequence the events of an application, it is possible to assign just the item's sequence ID and position, and let followers get the actual event using those references.

Todo: Fix problem with not being able to write all of big array with one SQL expression, since it involves constructing the non-leaf records. Perhaps could be more precise about predicting which non-leaf records need to be inserted so that we don't walk down from the top each time discovering whether or not a record exists. It's totally predictable, but the code is cautious. But it would be possible to identify all the new records and add them. Still not really possible to use "insert select max", but if each log has it's own process, then IDs can be issued from a generator, initialised from a query, and reused if an insert fails so the sequence is contiguous.

1.10.5 Remote notification logs

The RESTful API design in Implementing Domain Driven Design suggests a good way to present the notification log, a way that is simple and can scale using established HTTP technology.

This library has a pair of classes that can help to present a notification log remotely.

The `RemoteNotificationLog` class has the same interface for getting sections as the local notification log classes described above, but instead of using a local datasource, it requests serialized sections from a Web API.

The `NotificationLogView` class serializes sections from a local notification log, and can be used to implement a Web API that presents notifications to a network.

Alternatively to presenting domain event data and topic information, a Web API could present only the event's sequence ID and position values, requiring clients to obtain the domain event from the event store using those references. If the notification log uses a big array, and the big array is assigned with only sequence ID and position values, the big array notification log could be used directly with the `NotificationLogView` to notify of domain events by reference rather than by value. However, if the notification log uses a record manager, then a notification log adapter would be needed to convert the events into the references.

If a notification log would then receive and would also return only sequence ID and position information to its caller. The caller could then proceed by obtaining the domain event from the event store. Another adapter could be used to perform the reverse operation: adapting a notification log that contains references to one that returns whole domain event objects. Such adapters are not currently provided by this library.

NotificationLogView

The library class *`NotificationLogView`* presents sections from a local notification log, and can be used to implement a Web API.

The `NotificationLogView` class is constructed with a local `notification_log` object and an optional `json_encoder_class` (which defaults to the library's. `ObjectJSONEncoder` class, used explicitly in the example below).

The example below uses the record notification log, constructed above.

```
import json

from eventsourcing.interface.notificationlog import NotificationLogView
from eventsourcing.utils.transcoding import ObjectJSONEncoder, ObjectJSONDecoder

view = NotificationLogView(
    notification_log=notification_log,
    json_encoder_class=ObjectJSONEncoder
)

section_json, is_archived = view.present_section('1,5')

section_dict = json.loads(section_json, cls=ObjectJSONDecoder)
```

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```
assert section_dict['section_id'] == '1,5'
assert section_dict['next_id'] == '6,10'
assert section_dict['previous_id'] == None
assert section_dict['items'] == notification_log['1,5'].items
assert len(section_dict['items']) == 5

item = section_dict['items'][0]
assert item['id'] == 1
assert '__event_hash__' in item['state']
assert item['event_type'] == 'eventsourcing.domain.model.entity#VersionedEntity.
↪Created'

assert section_dict['items'][1]['event_type'] == 'eventsourcing.domain.model.array
↪#ItemAssigned'
assert section_dict['items'][2]['event_type'] == 'eventsourcing.domain.model.array
↪#ItemAssigned'
assert section_dict['items'][3]['event_type'] == 'eventsourcing.domain.model.array
↪#ItemAssigned'
assert section_dict['items'][4]['event_type'] == 'eventsourcing.domain.model.array
↪#ItemAssigned'

# Resolve the notifications to domain events.
domain_events = resolve_notifications(section_dict['items'])

# Check we got the first entity's "created" event.
assert isinstance(domain_events[0], VersionedEntity.Created)
assert domain_events[0].originator_id == first_entity.id
```

Notification API

A Web application could identify a section ID from an HTTP request path, and respond by returning an HTTP response with JSON content that represents that section of a notification log.

The example uses the library's `NotificationLogView` to serialize the sections of the record notification log (see above).

```
def notification_log_wsgi(environ, start_response):

    # Identify section from request.
    section_id = environ['PATH_INFO'].strip('/')

    # Construct notification log view.
    view = NotificationLogView(notification_log)

    # Get serialized section.
    section, is_archived = view.present_section(section_id)

    # Start HTTP response.
    status = '200 OK'
    headers = [('Content-type', 'text/plain; charset=utf-8')]
    start_response(status, headers)

    # Return body.
    return [(line + '\n').encode('utf8') for line in section.split('\n')]
```

A more sophisticated application might include an ETag header when responding with the current section, and a Cache-Control header when responding with archived sections.

A more standard approach would be to use Atom (application/atom+xml) which is a common standard for producing RSS feeds and thus a great fit for representing lists of events, rather than `NotificationLogView`. However, just as this library doesn't (currently) have any code that generates Atom feeds from domain events, there isn't any code that reads domain events from atom feeds. So if you wanted to use Atom rather than `NotificationLogView` in your API, then you will also need to write a version of `RemoteNotificationLog` that can work with your Atom API.

RemoteNotificationLog

The library class *`RemoteNotificationLog`* can be used in the same way as the local notification logs above. The difference is that rather than accessing a database using a `BigArray` or record manager, it makes requests to an API.

The `RemoteNotificationLog` class is constructed with a `base_url`, a `notification_log_id` and a `json_decoder_class`. The JSON decoder must be capable of decoding JSON encoded by the API. Hence, the JSON decoder must match the JSON encoder used by the API.

The default `json_decoder_class` is the library's `ObjectJSONDecoder`. This encoder matches the default `json_encoder_class` of the library's `NotificationLogView` class, which is the library's `ObjectJSONEncoder` class. If you want to extend the JSON encoder classes used here, just make sure they match, otherwise you will get decoding errors.

The `NotificationLogReader` can use the `RemoteNotificationLog` in the same way that it uses a local notification log object. Just construct it with a remote notification log object, rather than a local notification log object, then read notifications in the same way (as described above).

If the API uses a `NotificationLogView` to serialise the sections of a local notification log, the remote notification log object functions effectively as a proxy for a local notification log on a remote node.

```
from eventsourcing.interface.notificationlog import RemoteNotificationLog

remote_notification_log = RemoteNotificationLog("base_url")
```

If a server were running at "base_url" the `remote_notification_log` would function in the same was as the local notification logs described above, returning section objects for section IDs using the square brackets syntax.

If the section objects were created by a `NotifcationLogView` that had the `notification_log` above, we could obtain all the events of an application across an HTTP connection, accurately and without great complication.

See `test_notificationlog.py` for an example that uses a Flask app running in a local HTTP server to get notifications remotely using these classes.

1.10.6 Notification log reader

The library object class *`NotificationLogReader`* effectively functions as an iterator, yielding a continuous sequence of notifications that it discovers from the sections of a notification log, local or remote.

A notification log reader object will navigate the linked sections of a notification log, backwards from the "current" section of the notification log, until reaching the position it seeks. The position, which defaults to `0`, can be set directly with the reader's `seek()` method. Hence, by default, the reader will navigate all the way back to the first section.

After reaching the position it seeks, the reader will then navigate forwards, yielding as a continuous sequence all the subsequent notifications in the notification log.

As it navigates forwards, yielding notifications, it maintains position so that it can continue when there are further notifications. This position could be persisted, so that position is maintained across invocations, but that is not a feature of the `NotificationLogReader` class, and would have to be added in a subclass or client object.

The `NotificationLogReader` supports slices. The position is set indirectly when a slice has a start index.

All the notification logs discussed above (local and remote) have the same interface, and can be used by `NotificationLogReader` progressively to obtain unseen notifications.

The example below happens to yield notifications from a big array notification log, but it would work equally well with a record notification log, or with a remote notification log.

Todo: Maybe just use "obj.read()" rather than "list(obj)", so it's more file-like.

```
from eventsourcing.interface.notificationlog import NotificationLogReader

# Construct log reader.
reader = NotificationLogReader(notification_log)

# The position is zero by default.
assert reader.position == 0

# The position can be set directly.
reader.seek(10)
assert reader.position == 10

# Reset the position.
reader.seek(0)

# Read all existing notifications.
all_notifications = reader.read_list()
assert len(all_notifications) == 9

# Resolve the notifications to domain events.
domain_events = resolve_notifications(all_notifications)

# Check we got the first entity's created event.
assert isinstance(domain_events[0], VersionedEntity.Created)
assert domain_events[0].originator_id == first_entity.id

# Check the position has advanced.
assert reader.position == 9

# Read all subsequent notifications (should be none).
subsequent_notifications = list(reader)
assert subsequent_notifications == []

# Publish two more events.
VersionedEntity.__create__()
VersionedEntity.__create__()

# Read all subsequent notifications (should be two).
subsequent_notifications = reader.read_list()
assert len(subsequent_notifications) == 2

# Check the position has advanced.
assert reader.position == 11

# Read all subsequent notifications (should be none).
```

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```
subsequent_notifications = reader.read_list()
len(subsequent_notifications) == 0

# Publish three more events.
VersionedEntity.__create__()
VersionedEntity.__create__()
last_entity = VersionedEntity.__create__()

# Read all subsequent notifications (should be three).
subsequent_notifications = reader.read_list()
assert len(subsequent_notifications) == 3

# Check the position has advanced.
assert reader.position == 14

# Resolve the notifications.
domain_events = resolve_notifications(subsequent_notifications)
last_domain_event = domain_events[-1]

# Check we got the last entity's created event.
assert isinstance(last_domain_event, VersionedEntity.Created), last_domain_event
assert last_domain_event.originator_id == last_entity.id

# Read all subsequent notifications (should be none).
subsequent_notifications = reader.read_list()
assert subsequent_notifications == []

# Check the position has advanced.
assert reader.position == 14
```

The position could be persisted, and the persisted value could be used to initialise the reader's position when reading is restarted.

In this way, the events of an application can be followed with perfect accuracy and without lots of complications. This seems to be an inherently reliable approach to following the events of an application.

```
# Clean up.
persistence_policy.close()
```

1.11 Projections

A projection is a function of application state. If the state of an application is event sourced, projections can operate by processing the events of an application. There are lots of different kinds of projection.

- *Overview*
- *Subscribing to events*
- *Tracking notification logs*
  - *Application state replication*
  - *Index of email addresses*

1.11.1 Overview

Projected state can be updated by direct event subscription, or by following notification logs that propagate the events of an application. Notification logs are described in the previous section.

Notifications in a notification log can be pulled. Pulling notifications can be prompted periodically, prompts could also be pushed onto a message bus. Notifications could by pushed onto the message bus, but if order is lost, the projection will need to refer to the notification log.

Projections can track the notifications that have been processed: the position in an upstream notification log can be recorded. The position can be recorded as a value in the projected application state, if the nature of the projection lends itself to be used also to track notifications. Alternatively, the position in the notification log can be recorded with a separate tracking record.

Projections can update more or less anything. To be reliable, the projection must write in the same atomic database transaction all the records that result from processing a notification. Otherwise it is possible to track the position and fail to update the projection, or vice versa.

Since projections can update more or less anything, they can also call command methods on event sourced aggregates. The important thing is for any new domain events that are triggered by the aggregates to be recorded in the same database transaction as the tracking records. For reliability, if these new domain events are also placed in a notification log, then the tracking record and the domain event records and the notification records can be written in the same database transaction. A projection that operates by calling methods on aggregates and recording events with notifications, can be called an "application process".

1.11.2 Subscribing to events

The library function *subscribe_to()* can be used to decorate functions, so that the function is called each time a matching event is published by the library's pub-sub mechanism.

The example below, which is incomplete because the `TodoView` is not defined, suggests that record `TodoView` can be created whenever a `Todo.Created` event is published. Perhaps there's a `TodoView` table with an index of todo titles, or perhaps it can be joined with a table of users.

```
from eventsourcing.domain.model.decorators import subscribe_to
from eventsourcing.domain.model.entity import DomainEntity


class Todo(DomainEntity):
    class Created(DomainEntity.Created):
        pass

@subscribe_to(Todo.Created)
def new_todo_projection(event):
    todo = TodoView(id=event.originator_id, title=event.title, user_id=event.user_id)
    todo.save()
```

It is possible to access aggregates and other views when updating a view, especially to avoid bloating events with redundant information that might be added to avoid such queries. Transactions can be used to insert related records, building a model for a view.

It is possible to use the decorator in a downstream application which republishes domain events perhaps published by an original application that uses messaging infrastructure such as an AMQP system. The decorated function would be called synchronously with the republishing of the event, but asynchronously with respect to the original application.

A naive projection might consume events as they are published and update the projection without considering whether the event was a duplicate, or if previous events were missed. The trouble with this approach is that, without further modification, without referring to a fixed sequence and maintaining position in that sequence, there is no way to

recover when events have been missed. If the projection somehow fails to update when an event is received, then the event will be lost forever to the projection, and the projection will be forever inconsistent.

Of course, it is possible to follow a fixed sequence of events, for example by tracking notification logs.

1.11.3 Tracking notification logs

If the events of an application are presented as a sequence of notifications, then the events can be projected using a notification reader to pull unseen items.

Getting new items can be triggered by pushing prompts to e.g. an AMQP messaging system, and having the remote components handle the prompts by pulling the new notifications.

To minimise load on the messaging infrastructure, it may be sufficient simply to send an empty message, thereby prompting receivers to pull new notifications. This may reduce latency or avoid excessive polling for updates, but the benefit would be obtained at the cost of additional complexity. Prompts that include the position of the notification in its sequence would allow a follower to know when it is being prompted about notifications it already pulled, and could then skip the pulling operation.

If an application has partitioned notification logs, they could be consumed concurrently.

If a projection creates a sequence that it appends to at least once for each notification, the position in the notification log can be tracked as part of the projection's sequence. Tracking the position is important when resuming to process the notifications. An example of using the projection's sequence to track the notifications is replication (see example below). However, with this technique, something must be written to the projection's sequence for each notification received. That can be tolerated by writing "null" records that extend the sequence without spoiling the projections, for example in the event sourced index example below, random keys are inserted instead of email addresses to extend the sequence.

An alternative which avoids writing unnecessarily to a projection's sequence is to separate the concerns, and write a tracking record for each notification that is consumed, and then optionally any records created for the projection in response to the notification.

A tracking record can simply have the position of a notification in a log. If the notifications are interpreted as commands, then a command log could function effectively to track the notifications, so long as one command is written for each notification (which might then involve "null" commands). For reliability, the tracking records need to be written in the same atomic database transaction as the projection records.

The library's `Process` class uses tracking records.

Application state replication

Using event record notifications, the state of an application can be replicated perfectly. If an application can present its event records as a notification log, then a "replicator" can read the notification log and write copies of the original records into a replica's record manager.

In the example below, the `SimpleApplication` class is used, which has a `RecordManagerNotificationLog` as its `notification_log`. Reading this log, locally or remotely, will yield all the event records persisted by the `SimpleApplication`. The `SimpleApplication` uses a record manager with contiguous record IDs which allows it to be used within a record manager notification log object.

A record manager notification log object represents records as record notifications. With record notifications, the ID of the record in the notification is used to place the notification in its sequence. Therefore the ID of the last replicated record is used to determine the current position in the original application's notification log, which gives "exactly once" processing.

```
from eventsourcing.application.simple import SimpleApplication
from eventsourcing.exceptions import ConcurrencyError
from eventsourcing.domain.model.aggregate import AggregateRoot
from eventsourcing.interface.notificationlog import NotificationLogReader,␣
↪RecordManagerNotificationLog


# Define record replicator.
class RecordReplicator(object):
    def __init__(self, notification_log, record_manager):
        self.reader = NotificationLogReader(notification_log)
        self.manager = record_manager
        # Position reader at max record ID.
        self.reader.seek(self.manager.get_max_record_id() or 0)

    def pull(self):
        for notification in self.reader.read():
            record = self.manager.record_class(**notification)
            self.manager._write_records([record])


# Construct original application.
original = SimpleApplication(persist_event_type=AggregateRoot.Event)

# Construct replica application.
replica = SimpleApplication()

# Construct replicator.
replicator = RecordReplicator(
    notification_log=original.notification_log,
    record_manager=replica.event_store.record_manager
)

# Publish some events.
aggregate1 = AggregateRoot.__create__()
aggregate1.__save__()
aggregate2 = AggregateRoot.__create__()
aggregate2.__save__()
aggregate3 = AggregateRoot.__create__()
aggregate3.__save__()

assert aggregate1.__created_on__ != aggregate2.__created_on__
assert aggregate2.__created_on__ != aggregate3.__created_on__

# Check aggregates not in replica.
assert aggregate1.id in original.repository
assert aggregate1.id not in replica.repository
assert aggregate2.id in original.repository
assert aggregate2.id not in replica.repository
assert aggregate3.id in original.repository
assert aggregate3.id not in replica.repository

# Pull records.
replicator.pull()

# Check aggregates are now in replica.
assert aggregate1.id in replica.repository
```

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```
assert aggregate2.id in replica.repository
assert aggregate3.id in replica.repository

# Check the aggregate attributes are correct.
assert aggregate1.__created_on__ == replica.repository[aggregate1.id].__created_on__
assert aggregate2.__created_on__ == replica.repository[aggregate2.id].__created_on__
assert aggregate3.__created_on__ == replica.repository[aggregate3.id].__created_on__

# Create another aggregate.
aggregate4 = AggregateRoot.__create__()
aggregate4.__save__()

# Check aggregate exists in the original only.
assert aggregate4.id in original.repository
assert aggregate4.id not in replica.repository

# Resume pulling records.
replicator.pull()

# Check aggregate exists in the replica.
assert aggregate4.id in replica.repository

# Terminate replicator (position in notification sequence is lost).
replicator = None

# Create new replicator.
replicator = RecordReplicator(
    notification_log=original.notification_log,
    record_manager=replica.event_store.record_manager
)

# Create another aggregate.
aggregate5 = AggregateRoot.__create__()
aggregate5.__save__()

# Check aggregate exists in the original only.
assert aggregate5.id in original.repository
assert aggregate5.id not in replica.repository

# Pull after replicator restart.
replicator.pull()

# Check aggregate exists in the replica.
assert aggregate5.id in replica.repository

# Setup event driven pulling. Could prompt remote
# readers with an AMQP system, but to make a simple
# demonstration just subscribe to local events.

@subscribe_to(AggregateRoot.Event)
def prompt_replicator(_):
    replicator.pull()

# Now, create another aggregate.
aggregate6 = AggregateRoot.__create__()
aggregate6.__save__()
assert aggregate6.id in original.repository
```

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```
# Check aggregate was automatically replicated.
assert aggregate6.id in replica.repository

# Clean up.
original.close()
replica.close()
```

For simplicity in the example, the notification log reader uses a local notification log in the same process as the events originated. Perhaps it would be better to run a replication job away from the application servers, on a node remote from the application servers, away from where the domain events are triggered. A local notification log could be used on a worker-tier node that can connect to the original application's database. It could equally well use a remote notification log without compromising the accuracy of the replication. A remote notification log, with an API service provided by the application servers, would avoid the original application database connections being shared by countless others. Notification log sections can be cached in the network to avoid loading the application servers with requests from a multitude of followers.

Since the replica application uses optimistic concurrency control for its event records, it isn't possible to corrupt the replica by attempting to write the same record twice. Hence jobs can pull at periodic intervals, and at the same time message queue workers can respond to prompts pushed to AMQP-style messaging infrastructure by the original application, without needing to serialise their access to the replica with locks: if the two jobs happen to collide, one will succeed and the other will encounter a concurrency error exception that can be ignored.

The replica could itself be followed, by using its notification log. Although replicating replicas indefinitely is perhaps pointless, it suggests how notification logs can be potentially be chained with processing being done at each stage.

For example, a sequence of events could be converted into a sequence of commands, and the sequence of commands could be used to update an event sourced index, in an index application. An event that does not affect the projection can be recorded as "noop", so that the position is maintained. All but the last noop could be deleted from the command log. If the command is committed in the same transaction as the events resulting from the command, then the reliability of the arbitrary projection will be as good as the pure replica. The events resulting from each commands could be many or none, which shows that a sequence of events can be projected equally reliably into a different sequence with a different length.

Index of email addresses

This example is similar to the replication example above, in that notifications are tracked with the records of the projected state. In consequence, an index entry is added for each notification received, which means progress can be made along the notification log even when the notification doesn't imply a real entry in the index.

```
import uuid

from eventsourcing.application.simple import SimpleApplication
from eventsourcing.exceptions import ConcurrencyError
from eventsourcing.domain.model.aggregate import AggregateRoot
from eventsourcing.interface.notificationlog import NotificationLogReader,␣
↪RecordManagerNotificationLog

# Define domain model.
class User(AggregateRoot):
    def __init__(self, *arg, **kwargs):
        super(User, self).__init__(*arg, **kwargs)
        self.email_addresses = {}

    class Event(AggregateRoot.Event):
```

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```
        pass

    class Created(Event, AggregateRoot.Created):
        pass

    def add_email_address(self, email_address):
        self.__trigger_event__(User.EmailAddressAdded, email_address=email_address)

    class EmailAddressAdded(Event):
        def mutate(self, aggregate):
            email_address = User.EmailAddress(self.email_address)
            aggregate.email_addresses[self.email_address] = email_address

    def verify_email_address(self, email_address):
        self.__trigger_event__(User.EmailAddressVerified, email_address=email_address)

    class EmailAddressVerified(Event):
        def mutate(self, aggregate):
            aggregate.email_addresses[self.email_address].is_verified = True

    class EmailAddress(object):
        def __init__(self, email_address):
            self.email_address = email_address
            self.is_confirmed = False

class IndexItem(AggregateRoot):
    def __init__(self, index_value=None, *args, **kwargs):
        super(IndexItem, self).__init__(*args, **kwargs)
        self.index_value = index_value

    class Event(AggregateRoot.Event):
        pass

    class Created(Event, AggregateRoot.Created):
        pass


def uuid_from_url(url):
    return uuid.uuid5(uuid.NAMESPACE_URL, url.encode('utf8') if bytes == str else url)


# Define indexer.
class Indexer(object):
    class Event(AggregateRoot.Event):
        pass
    class Created(AggregateRoot.Created):
        pass
    def __init__(self, notification_log, record_manager):
        self.reader = NotificationLogReader(notification_log)
        self.manager = record_manager
        # Position reader at max record ID.
        # - this can be generalised to get the max ID from many
        #   e.g. big arrays so that many notification logs can
        #   be followed, consuming a group of notification logs
        #   would benefit from using transactions to set records
        #   in a big array per notification log atomically with
        #   inserting the result of combining the notification log
```

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```
        #   because processing more than one stream would produce
        #   a stream that has a different sequence of record IDs
        #   which couldn't be used directly to position any of the
        #   notification log readers
        # - if producing one stream from many can be as reliable as
        #   replicating a stream, then the unreliability will be
        #   caused by interoperating with systems that just do push,
        #   but the push notifications could be handled by adding
        #   to an application partition sequence, so e.g. all bank
        #   payment responses wouldn't need to go in the same sequence
        #   and therefore be replicated with mostly noops in all application
        #   partitions, or perhaps they could initially go in the same
        #   sequence, and transactions could used to project that into
        #   many different sequences, in order words splitting the stream
        #   (splitting is different from replicating many time). When splitting
        #   the stream, the splits's record ID couldn't be used to position to␣
↪splitter
        #   in the consumed notification log, so there would need to be a command
        #   log that tracks the consumed sequence whose record IDs can be used to␣
↪position
        #   the splitter in the notification log, with the commands
        #   defining how the splits are extended, and everything committed in a␣
↪transaction
        #   so the splits are atomic with the command log
        # Todo: Bring out different projectors: splitter (one-many), combiner (many-
↪one), repeater (one-one).
        self.reader.seek(self.manager.get_max_record_id() or 0)

    def pull(self):
        # Project events into commands for the index.
        for notification in self.reader.read():

            # Construct index items.
            # Todo: Be more careful, write record with an ID explicitly,
            # (walk the event down the stack explicity, and then set the ID)
            # so concurrent processing is safe. Providing the ID also avoids
            # the cost of computing the next record ID.
            # Alternatively, construct, execute, then record index commands in a big␣
↪array.
            # Could record commands in same transaction as result of commands if␣
↪commands are not idempotent.
            # Could use compaction to remove all blank items, but never remove the␣
↪last record.
            if notification['event_type'].endswith('User.EmailAddressVerified'):
                event = original.event_store.sequenced_item_mapper.from_topic_and_
↪data(
                    notification['event_type'],
                    notification['state'],
                )
                index_key = uuid_from_url(event.email_address)
                index_value = event.originator_id
            else:
                index_key = uuid.uuid4()
                index_value = ''

            # Todo: And if we can't create new index item, get existing and append␣
↪value.
```

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```
            index_item = IndexItem.__create__(originator_id=index_key, index_
↪value=index_value)
            index_item.__save__()


# Construct original application.
original = SimpleApplication(persist_event_type=User.Event)

# Construct index application.
index = SimpleApplication(persist_event_type=IndexItem.Event)

# Setup event driven indexing.
indexer = Indexer(
    notification_log=original.notification_log,
    record_manager=index.event_store.record_manager
)

@subscribe_to(User.Event)
def prompt_indexer(_):
    indexer.pull()

user1 = User.__create__()
user1.__save__()
assert user1.id in original.repository
assert user1.id not in index.repository

user1.add_email_address('me@example.com')
user1.__save__()

index_key = uuid_from_url('me@example.com')
assert index_key not in index.repository

user1.verify_email_address('me@example.com')
user1.__save__()
assert index_key in index.repository
assert index.repository[index_key].index_value == user1.id

assert uuid_from_url(u'mycat@example.com') not in index.repository

user1.add_email_address(u'mycat@example.com')
user1.verify_email_address(u'mycat@example.com')
user1.__save__()

assert uuid_from_url(u'mycat@example.com') in index.repository

assert user1.id in original.repository
assert user1.id not in index.repository
```

Todo: Projection into a timeline view?

Todo: Projection into snapshots (policy determines when to snapshot)?

Todo: Projection for data analytics?

Todo: Concurrent processing of notification logs, respecting causal relations.

Todo: Order reservation payments, system with many processes and many notification logs.

Todo: Single process with single log.

Todo: Single process with many logs.

Todo: Many processes with one log each.

Todo: Many processes with many logs each (static config).

Todo: Many processes with many logs each (dynamic config).

Todo: Single process with state machine semantics (whatever they are)?

1.12 Process and system

This section is about process applications. A process application is a projection into an event sourced application. A system of process applications can be constructed by linking applications together in a pipeline.

Reliability is the most important concern in this section. A process is considered to be reliable if its product is entirely unaffected (except in being delayed) by a sudden termination of the process happening at any time. The only trick is remembering that, in general, production is determined by consumption with recording. In particular, if the consumption and the recording are reliable, then the product of the process is bound to be reliable.

This definition of the reliability of a process doesn't include availability. Infrastructure unreliability may cause processing delays. Disorderly environments shouldn't cause disorderly processing. The other important concerns discussed in this section are scalability and maintainability.

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    - *Notification tracking*
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    - *Single threaded*
    - *Multiprocessing*
    - *Single pipeline*

        * *Multiple pipelines*
        * *Actor model*
        * *Pool of workers*
    - *Integration with APIs*

Please note, the code presented in the example below works only with the library's SQLAlchemy record manager. Django support is planned, but not yet implemented. Support for Cassandra is being considered but applications will probably be simple replications of application state, due to the limited atomicity of Cassandra's lightweight transactions. Cassandra could be used to archive events written firstly into a relational database. Events could be removed from the relational database before storage limits are encountered. Events missing in the relational database could be sourced from Cassandra.

1.12.1 Overview

Process application

The library's process application class `Process` functions as a projection into an event-sourced application. Applications and projections are discussed in previous sections. The `Process` class extends `SimpleApplication` by also reading notification logs and writing tracking records. A process application also has a policy that defines how it will respond to domain events it reads from notification logs.

Notification tracking

A process application consumes events by reading domain event notifications from its notification log readers. The events are retrieved in a reliable order, without race conditions or duplicates or missing items. Each notification in a notification log has a unique integer ID, and the notification log IDs form a contiguous sequence.

To keep track of its position in the notification log, a process application will create a new tracking record for each event notification it processes. The tracking records determine how far the process has progressed through the notification log. The tracking records are used to set the position of the notification log reader when the process is commenced or resumed.

Policies

A process application will respond to events according to its policy. Its policy might do nothing in response to one type of event, and it might call an aggregate command method in response to another type of event. If the aggregate method triggers new domain events, they will be available in its notification log for others to read.

There can only be one tracking record for each notification. Once the tracking record has been written it can't be written again, and neither can any new events unfortunately triggered by duplicate calls to aggregate commands (which may not be idempotent). If an event can be processed at all, then it will be processed exactly once.

Whatever the policy response, the process application will write one tracking record for each notification, along with new stored event and notification records, in an atomic database transaction.

Atomicity

A process application is as reliable as the atomicity of its database transactions, just like a ratchet is as strong as its teeth (notification log) and pawl (tracking records).

If some of the new records can't be written, then none are. If anything goes wrong before all the records have been written, the transaction will abort, and none of the records will be written. On the other hand, if a tracking record is written, then so are any new event records, and the process will have fully completed an atomic progression.

The atomicity of the recording and consumption determines the production as atomic: a continuous stream of events is processed in discrete, sequenced, indivisible units. Hence, interruptions can only cause delays.

System of processes

The library class `System` can be used to define a system of process applications, independently of scale.

In a system, one process application can follow another. One process can follow two other processes in a slightly more complicated system. A system could be just one process following itself.

Scale-independence

The system can run at different scales, but the definition of the system is independent of scale.

A system of process applications can run in a single thread, with synchronous propagation and processing of events. This is intended as a development mode.

A system can also run with multiple operating system processes, with asynchronous propagation and processing of events. Having an asynchronous pipeline means events at different stages can be processed at the same time. This could be described as "diachronic" parallelism, like the way a pipelined CPU core has stages. This kind of parallelism can improve throughput, up to a limit provided by the number of steps required by the domain. The reliability of the sequantial processing allows one to write a reliable "saga" or a "process manager". In other words, a complicated sequence involving different aggregates, and perhaps different bounded contexts, can be implemented reliably without long-lived transactions.

To scale the system further, a system of process applications can run with parallel instances of the pipeline expressions, just like the way an operating system can use many cores (pipelines) processing instruction in parallel. Having parallel pipelines means that many events can be processed at the same stage at the same time. This "synchronic" parallelism allows a system to take advantage of the scale of its infrastructure.

Causal dependencies

If an aggregate is created and then updated, the second event is causally dependent on the first. Causal dependencies between events can be detected and used to synchronise the processing of parallel pipelines downstream. Downstream processing of one pipeline can wait for an event to be processed in another.

In the process applications, the causal dependencies are automatically inferred by detecting the originator ID and version of aggregates as they are retrieved. The old notifications are referenced in the first new notification. Downstream can then check all causal dependencies have been processed, using its tracking records.

In case there are many dependencies in the same pipeline, only the newest dependency in each pipeline is included. By default in the library, only dependencies in different pipelines are included. If causal dependencies from all pipelines were included in each notification, each pipeline could be processed in parallel, to an extent limited by the dependencies between the notifications.

Kahn process networks

Because a notification log and reader functions effectively as a FIFO, a system of determinate process applications can be recognised as a Kahn Process Network (KPN).

Kahn Process Networks are determinate systems. If a system of process applications happens to involve processes that are not determinate, or if the processes split and combine or feedback in a random way so that nondeterminacy is introduced by design, the system as a whole will not be determinate, and could be described in more general terms as "dataflow" or "stream processing".

Whether or not a system of process applications is determinate, the processing will be reliable (results unaffected by infrastructure failures).

High performance or "real time" processing could be obtained by avoiding writing to a durable database and instead running applications with an in-memory database.

Process manager

A process application, specifically an aggregate combined with a policy in a process application, could function effectively as a "saga", or "process manager", or "workflow manager". That is, it could effectively control a sequence of steps involving other aggregates in other bounded contexts, steps that might otherwise be controlled with a "long-lived transaction". It could 'maintain the state of the sequence and determine the next processing step based on intermediate results' (quote from Enterprise Integration Patterns). Exceptional "unhappy path" behaviour can be implemented as part of the logic of the application.

1.12.2 Example

The example below is suggestive of an orders-reservations-payments system. The system automatically processes a new Order by making a Reservation, and then a Payment; facts registered with the Order as they happen.

The behaviour of the system is entirely defined by the combination of the aggregates and the policies of its process applications. This allows highly maintainable code, code that is easily tested, easily understood, easily changed.

Below, the "orders, reservations, payments" system is run: firstly as a single threaded system; then with multiprocessing using a single pipeline; and finally with both multiprocessing and multiple pipelines.

Aggregates

In the code below, event-sourced aggregates are defined for orders, reservations, and payments. The `Order` class is for "orders". The `Reservation` class is for "reservations". And the `Payment` class is for "payments".

In the model below, an order can be created. A new order can be set as reserved, which involves a reservation ID. Having been created and reserved, an order can be set as paid, which involves a payment ID.

```
from eventsourcing.domain.model.aggregate import AggregateRoot


class Order(AggregateRoot):
    def __init__(self, command_id=None, **kwargs):
        super(Order, self).__init__(**kwargs)
        self.command_id = command_id
        self.is_reserved = False
        self.is_paid = False

    class Event(AggregateRoot.Event):
        pass

    class Created(Event, AggregateRoot.Created):
        def __init__(self, **kwargs):
            assert 'command_id' in kwargs, kwargs
```

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```
            super(Order.Created, self).__init__(**kwargs)

    class Reserved(Event):
        def mutate(self, order):
            order.is_reserved = True
            order.reservation_id = self.reservation_id

    class Paid(Event):
        def mutate(self, order):
            order.is_paid = True
            order.payment_id = self.payment_id

    def set_is_reserved(self, reservation_id):
        assert not self.is_reserved, "Order {} already reserved.".format(self.id)
        self.__trigger_event__(
            Order.Reserved, reservation_id=reservation_id
        )

    def set_is_paid(self, payment_id):
        assert not self.is_paid, "Order {} already paid.".format(self.id)
        self.__trigger_event__(
            self.Paid, payment_id=payment_id, command_id=self.command_id
        )
```

A reservation can also be created. A reservation has an `order_id`.

```
class Reservation(AggregateRoot):
    def __init__(self, order_id, **kwargs):
        super(Reservation, self).__init__(**kwargs)
        self.order_id = order_id

    class Created(AggregateRoot.Created):
        pass
```

Similarly, a payment can be created. A payment also has an `order_id`.

```
class Payment(AggregateRoot):
    def __init__(self, order_id, **kwargs):
        super(Payment, self).__init__(**kwargs)
        self.order_id = order_id

    class Created(AggregateRoot.Created):
        pass
```

As shown in previous sections, the behaviours of this domain model can be fully tested with simple test cases, without involving any other components.

Commands

Commands have been discussed so far as methods on aggregate objects. Here, system commands are introduced, as event sourced aggregates. System command aggregates can be created, and set as "done". A commands process application can be followed by other applications. This provides a standard interface for system input.

In the code below, the system command class `CreateNewOrder` is defined using the library `Command` class. The `Command` class extends the `AggregateRoot` class with a method `done()` and a property `is_done`.

The `CreateNewOrder` class extends the library's `Command` class with an event sourced `order_id` attribute, which will be used to associate the commands objets with the orders created by the system in response.

```
from eventsourcing.domain.model.command import Command
from eventsourcing.domain.model.decorators import attribute


class CreateNewOrder(Command):
    @attribute
    def order_id(self):
        pass
```

A `CreateNewOrder` command can be assigned an order ID. Its `order_id` is initially `None`.

The behaviour of a system command aggregate can be fully tested with simple test cases, without involving any other components.

```
from uuid import uuid4

def test_create_new_order_command():
    # Create a "create new order" command.
    cmd = CreateNewOrder.__create__()

    # Check the initial values.
    assert cmd.order_id is None
    assert cmd.is_done is False

    # Assign an order ID.
    order_id = uuid4()
    cmd.order_id = order_id
    assert cmd.order_id == order_id

    # Mark the command as "done".
    cmd.done()
    assert cmd.is_done is True

    # Check the events.
    events = cmd.__batch_pending_events__()
    assert len(events) == 3
    assert isinstance(events[0], CreateNewOrder.Created)
    assert isinstance(events[1], CreateNewOrder.AttributeChanged)
    assert isinstance(events[2], CreateNewOrder.Done)


# Run the test.
test_create_new_order_command()
```

One advantage of having distinct commands is that a new version of the system can be verified by checking the same commands generates the same state as the old version.

Processes

A process application has a policy. The policy may respond to a domain event by calling a command method on an aggregate.

The orders process responds to new commands by creating a new `Order`. It responds to new reservations by setting an `Order` as reserved. And it responds to a new `Payment`, by setting an `Order` as paid.

```
from eventsourcing.application.process import Process
from eventsourcing.utils.topic import resolve_topic


class Orders(Process):
    persist_event_type=Order.Event

    @staticmethod
    def policy(repository, event):
        if isinstance(event, Command.Created):
            command_class = resolve_topic(event.originator_topic)
            if command_class is CreateNewOrder:
                return Order.__create__(command_id=event.originator_id)

        elif isinstance(event, Reservation.Created):
            # Set the order as reserved.
            order = repository[event.order_id]
            assert not order.is_reserved
            order.set_is_reserved(event.originator_id)

        elif isinstance(event, Payment.Created):
            # Set the order as paid.
            order = repository[event.order_id]
            assert not order.is_paid
            order.set_is_paid(event.originator_id)
```

The reservations process application responds to an `Order.Created` event by creating a new `Reservation` aggregate.

```
class Reservations(Process):
    @staticmethod
    def policy(repository, event):
        if isinstance(event, Order.Created):
            return Reservation.__create__(order_id=event.originator_id)
```

The payments process application responds to an `Order.Reserved` event by creating a new `Payment`.

```
class Payments(Process):
    @staticmethod
    def policy(repository, event):
        if isinstance(event, Order.Reserved):
            return Payment.__create__(order_id=event.originator_id)
```

Additionally, the library class `CommandProcess` is extended by defining a policy that responds to `Order.Created` events by setting the `order_id` on the command. It also responds to `Order.Paid` events by setting the command as done.

```
from eventsourcing.application.command import CommandProcess
from eventsourcing.domain.model.decorators import retry
from eventsourcing.exceptions import OperationalError, RecordConflictError


class Commands(CommandProcess):
    @staticmethod
    def policy(repository, event):
        if isinstance(event, Order.Created):
            cmd = repository[event.command_id]
```

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```
            cmd.order_id = event.originator_id
        elif isinstance(event, Order.Paid):
            cmd = repository[event.command_id]
            cmd.done()

    @staticmethod
    @retry((OperationalError, RecordConflictError), max_attempts=10, wait=0.01)
    def create_new_order():
        cmd = CreateNewOrder.__create__()
        cmd.__save__()
        return cmd.id
```

The `@retry` decorator here protects against any contention writing to the `Commands` notification log.

Please note, the `__save__()` method of aggregates shouldn't be called in a process policy, because pending events from both new and changed aggregates will be automatically collected by the process application after its `policy()` method has returned. To be reliable, a process application needs to commit all the event records atomically with a tracking record, and calling `__save__()` will instead commit events in a separate transaction. Policies should normally return new aggregates to the caller, but do not need to return existing aggregates that have been accessed or changed.

Tests

Process policies are just functions, and are easy to test.

In the orders policy test below, an existing order is marked as reserved because a reservation was created. The only complication comes from needing to prepare at least a fake repository and a domain event, given as required arguments when calling the policy in the test. If the policy response depends on already existing aggregates, they will need to be added to the fake repository. A Python dict can function effectively as a fake repository in such tests. It seems simplest to directly use the model domain event classes and aggregate classes in these tests, rather than coding test doubles.

```
def test_orders_policy():
    # Prepare repository with a real Order aggregate.
    order = Order.__create__(command_id=None)
    repository = {order.id: order}

    # Check order is not reserved.
    assert not order.is_reserved

    # Process reservation created.
    with Orders() as orders:
        event = Reservation.Created(originator_id=uuid4(), originator_topic='', order_
↪id=order.id)
        orders.policy(repository=repository, event=event)

    # Check order is reserved.
    assert order.is_reserved


# Run the test.
test_orders_policy()
```

In the payments policy test below, a new payment is created because an order was reserved.

```
def test_payments_policy():

    # Prepare repository with a real Order aggregate.
    order = Order.__create__(command_id=None)
    repository = {order.id: order}

    # Check payment is created whenever order is reserved.
    with Payments() as payments:
        event = Order.Reserved(originator_id=order.id, originator_version=1)
        payment = payments.policy(repository=repository, event=event)

    assert isinstance(payment, Payment), payment
    assert payment.order_id == order.id


# Run the test.
test_payments_policy()
```

It isn't necessary to return changed aggregates from the policy. The test will already have a reference to the aggregate, since it will have constructed the aggregate before passing it to the policy in the fake repository, so the test will already be in a good position to check that already existing aggregates are changed by the policy as expected. The test gives a `repository` to the policy, which contains the `order` aggregate expected by the policy.

System

A system of process applications can be defined using one or many pipeline expressions.

The expression `A | A` would have a process application class called `A` following itself. The expression `A | B | C` would have `A` followed by `B` and `B` followed by `C`. This can perhaps be recognised as the "pipes and filters" pattern, where the process applications function effectively as the filters.

In this example, firstly the `Orders` process will follow the `Commands` process so that orders can be created. The `Commands` process will follow the `Orders` process, so that commands can be marked as done when processing is complete.

```
commands_pipeline = Commands | Orders | Commands
```

Similarly, the `Orders` process and the `Reservations` process will follow each other. Also the `Orders` and the `Payments` process will follow each other.

```
reservations_pipeline = Orders | Reservations | Orders
payments_pipeline = Orders | Payments | Orders
```

The orders-reservations-payments system can be defined using these pipeline expressions.

```
from eventsourcing.application.system import System

system = System(
    commands_pipeline,
    reservations_pipeline,
    payments_pipeline
)
```

This is equivalent to a system defined with the following single pipeline expression.

```
system = System(
    Commands | Orders | Reservations | Orders | Payments | Orders | Commands
)
```

Although a process application class can appear many times in the pipeline expressions, there will only be one instance of each process when the pipeline system is instantiated. Each application can follow one or many applications, and can be followed by one or many applications.

State is propagated between process applications through notification logs only. This can perhaps be recognised as the "bounded context" pattern. Each application can access only the aggregates it has created. For example, an `Order` aggregate created by the `Orders` process is available in neither the repository of `Reservations` nor the repository of `Payments`. That is because if an application could directly use the aggregates of another application, processing could produce different results at different times, and in consequence the processing wouldn't be reliable. If necessary, a process application could replicate the state of an aggregate within its own context in an application it is following, by projecting its events as they are read from an upstream notification log.

Single threaded

If the `system` object is used as a context manager, the process applications will run in a single thread in the current process. Events will be processed with synchronous handling of prompts, so that policies effectively call each other recursively.

In the code below, the `system` object is used as a context manager. When used in this way, by default the process applications will share an in-memory SQLite database.

```
with system:
    # Create new order command.
    cmd_id = system.commands.create_new_order()

    # Check the command has an order ID and is done.
    cmd = system.commands.repository[cmd_id]
    assert cmd.order_id
    assert cmd.is_done

    # Check the order is reserved and paid.
    order = system.orders.repository[cmd.order_id]
    assert order.is_reserved
    assert order.is_paid

    # Check the reservation exists.
    reservation = system.reservations.repository[order.reservation_id]

    # Check the payment exists.
    payment = system.payments.repository[order.payment_id]
```

Basically, given the system is running, when a "create new order" command is created, then the command is done, and an order has been both reservered and paid.

Everything happens synchronously, in a single thread, so that by the time `create_new_order()` has returned, the system has already processed the command, which can be retrieved from the "commands" repository.

Running the system with a single thread and an in-memory database is useful when developing and testing a system of process applications, because it runs very quickly and the behaviour is very easy to follow.

Multiprocessing

The example below shows the same system of process applications running in different operating system processes, using the library's `Multiprocess` class, which uses Python's `multiprocessing` library.

Running the system with multiple operating system processes means the different processes are running concurrently, so that as the payment is made for one order, another order might get reserved, whilst a third order is at the same time created.

In this example, the process applications share a MySQL database.

```
import os

os.environ['DB_URI'] = 'mysql+pymysql://{}:{}@{}/eventsourcing'.format(
    os.getenv('MYSQL_USER', 'root'),
    os.getenv('MYSQL_PASSWORD', ''),
    os.getenv('MYSQL_HOST', '127.0.0.1'),
)
```

The process applications could each use their own separate database. If the process applications were using different databases, upstream notification logs would need to be presented in an API, so that downstream could read notifications from a remote notification log, as discussed in the section about notifications (using separate databases is not currently supported by the `Multiprocess` class).

The MySQL database needs to be created before running the next bit of code.

```
$ mysql -e "CREATE DATABASE eventsourcing;"
```

Before starting the system's operating system processes, let's create a `CreateNewOrder` command using the `create_new_order()` method on the `Commands` process (defined above). Because the system isn't yet running, the command remains unprocessed.

```
with Commands(setup_tables=True) as commands:

    # Create a new command.
    cmd_id = commands.create_new_order()

    # Check command exists in repository.
    assert cmd_id in commands.repository

    # Check command is not done.
    assert not commands.repository[cmd_id].is_done
```

The database tables for storing events and tracking notification were created by the code above, because the `Commands` process was constructed with `setup_tables=True`, which is by default `False` in the `Process` class.

Single pipeline

The code below uses the library's `Multiprocess` class to run the `system`. It starts one operating system process for each process application in the system, which in this example will give four child operating system processes.

```
from eventsourcing.application.multiprocess import Multiprocess

multiprocessing_system = Multiprocess(system)
```

The operating system processes can be started by using the `multiprocess` object as a context manager. The unprocessed commands will be processed shortly after the various operating system processes have been started.

```
# Check the unprocessed command gets processed eventually.
@retry((AssertionError, KeyError), max_attempts=100, wait=0.5)
def assert_command_is_done(repository, cmd_id):
    assert repository[cmd_id].is_done

# Process the command.
with multiprocessing_system, Commands() as commands:
    assert_command_is_done(commands.repository, cmd_id)
```

The process applications read their upstream notification logs when they start, so the unprocessed command is picked up and processed immediately.

Multiple pipelines

The system can run with multiple instances of the system's pipeline expressions. Running the system with parallel pipelines means that each process application in the system can process many events at the same time.

In the example below, there are three parallel pipeline instances, which gives twelve child operating system processes. All the operating system processes share the same MySQL database.

```
num_pipelines = 3
```

Pipelines have integer IDs. In this example, the pipeline IDs are `[0, 1, 2]`.

```
pipeline_ids = range(num_pipelines)
```

It would be possible to run the system with e.g. pipelines 0-7 on one machine, pipelines 8-15 on another machine, and so on.

The `pipeline_ids` are given to the `Multiprocess` object.

```
multiprocessing_system = Multiprocess(system, pipeline_ids=pipeline_ids)
```

Below, five orders are processed in each pipeline.

```
num_orders_per_pipeline = 5

with multiprocessing_system, Commands() as commands:

    # Create new orders.
    command_ids = []
    for _ in range(num_orders_per_pipeline):
        for pipeline_id in pipeline_ids:

            # Change the pipeline for the command.
            commands.change_pipeline(pipeline_id)

            # Create a "create new order" command.
            cmd_id = commands.create_new_order()
            command_ids.append(cmd_id)

    # Check all commands are eventually done.
    for i, command_id in enumerate(command_ids):
        assert_command_is_done(commands.repository, command_id)
```

Especially if cluster scaling is automated, it would be useful for processes to be distributed automatically across the cluster. Actor model seems like a good foundation for such automation.

Actor model

beta

An Actor model library, in particular the Thespian Actor Library, can be used to run a pipelined system of process applications as actors.

```
from eventsourcing.application.actors import Actors

actors = Actors(system, pipeline_ids=pipeline_ids)

with actors, Commands() as commands:

    # Create new orders.
    command_ids = []
    for _ in range(num_orders_per_pipeline):
        for pipeline_id in pipeline_ids:

            # Change the pipeline for the command.
            commands.change_pipeline(pipeline_id)

            # Create a "create new order" command.
            cmd_id = commands.create_new_order()
            command_ids.append(cmd_id)

    # Check all commands are eventually done.
    for i, command_id in enumerate(command_ids):
        assert_command_is_done(commands.repository, command_id)
```

An Thespian "system base" other than the default "simple system base" can be started by using the functions `start_multiproc_tcp_base_system()` or `start_multiproc_queue_base_system()`. In these cases, the system actors will started in separate operating system processes. Otherwise they will all run by sending messages recursively. The base system can be shutdown by calling `shutdown()` on the `actors` object.

The system actors can be started by calling the `start()` method of `actors`. The system actors can be stopped by calling the `close()` method on `actors`.

If `actors` is used as a context manager, the `start()` method will be called when the context manager enters. The `close()` method will be called when the context manager exits, but by default the `shutdown()` method will not be called. If `actors` is constructed with `shutdown_on_exit=True`, which is `False` by default, then `shutdown()` will also be called when the context manager exits.

These methods can be used separately. A script can be called to initialise the base system. Another script can start the system actors. Another script can be called to send system commands, so that the system actors actually do some work. Another script can be used to shutdown the system actors. And another can be used to shutdown the base system. That may help operations. Please refer to the Thespian documentation for more information about dynamic source loading.

Pool of workers

An alternative to having a thread dedicated to every process application for each pipeline, the prompts could be sent to via a queue to a pool of workers, which change pipeline and application according to the prompt. Causal dependencies

would be needed for all notifications, which is not the library default. The library does not currently support processing events with a pool of workers.

1.12.3 Integration with APIs

Integration with systems that present a server API or otherwise need to be sent messages (rather than using notification logs), can be integrated by responding to events with a policy that uses a client to call the API or send a message. However, if there is a breakdown during the API call, or before the tracking record is written, then to avoid failing to make the call, it may happen that the call is made twice. If the call is not idempotent, and is not otherwise guarded against duplicate calls, there may be consequences to making the call twice, and so the situation cannot really be described as reliable.

If the server response is asynchronous, any callbacks that the server will make could be handled by calling commands on aggregates. If callbacks might be retried, perhaps because the handler crashes after successfully calling a command but before returning successfully to the caller, unless the callbacks are also tracked (with exclusive tracking records written atomically with new event and notification records) the aggregate commands will need to be idempotent, or otherwise guarded against duplicate callbacks. Such an integration could be implemented as a separate "push-API adapter" process, and it might be useful to have a generic implementation that can be reused, with documentation describing how to make such an integration reliable, however the library doesn't currently have any such adapter process classes or documentation.

1.13 Deployment

This section gives an overview of the concerns that arise when using an eventsourcing application in Web applications and task queue workers. There are many combinations of frameworks, databases, and process models. The complicated aspect is setting up the database configuration to work well with the framework. Your event sourcing application can be constructed just after the database is configured, and before requests are handled.

Please note, unlike the code snippets in the other examples, the snippets of code in this section are merely suggestive, and do not form a complete working program. For a working example using Flask and SQLAlchemy, please refer to the library module `eventsourcing.example.interface.flaskapp`, which is tested both stand-alone and with uWSGI.

- *Application object*
  - *Lazy initialization*
- *Database connection*
  - *SQLAlchemy*
  - *Cassandra*
- *Web interfaces*
  - *uWSGI*
  - *Flask*
    - *Flask with SQLAlchemy*
    - *Flask with Cassandra*
  - *Django*
    - *Django ORM*

        * *Django with Cassandra*
    - *Zope*
        * *Zope with SQLAlchemy*
- *Task queues*
    - *Celery*
    - *Redis Queue*

1.13.1 Application object

In general you need one, and only one, instance of your application object in each process. If your eventsourcing application object has any policies, for example if is has a persistence policy that will persist events whenever they are published, then constructing more than one instance of the application causes the policy event handlers to be subscribed more than once, so for example more than one attempt will be made to save each event, which won't work.

To make sure there is only one instance of your application object in each process, one possible arrangement (see below) is to have a module with two functions and a variable. The first function constructs an application object and assigns it to the variable, and can perhaps be called when a module is imported, or from a suitable hook or signal designed for setting things up before any requests are handled. A second function returns the application object assigned to the variable, and can be called by any views, or request or task handlers, that depend on the application's services.

Although the first function below must be called only once, the second function can be called many times. The example functions below have been written relatively strictly so that, when it is called, the function `init_application()` will raise an exception if it has already been called, and `get_application()` will raise an exeception if `init_application()` has not already been called.

```
from eventsourcing.application.simple import SimpleApplication


def construct_application(**kwargs):
    return SimpleApplication(**kwargs)


_application = None


def init_application(**kwargs):
    global _application
    if _application is not None:
        raise AssertionError("init_application() has already been called")
    _application = construct_application(**kwargs)


def get_application():
    if _application is None:
        raise AssertionError("init_application() must be called first")
    return _application
```

The expected behaviour is demonstrated below.

```
try:
    get_application()
```

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```
except AssertionError:
    pass
else:
    raise Exception("Shouldn't get here")

init_application()

get_application()
```

As an aside, if you will use these function also in your test suite, and your test suite needs to set up the application more than once, you will also need a `close_application()` function that closes the application object, unsubscribing any handlers, and resetting the module level variable so that `init_application()` can be called again. If doesn't really matter if you don't close your application at the end of the process lifetime, however you may wish to close any database or other connections to network services.

```
def close_application():
    global _application
    if _application is not None:
        _application.close()
        _application = None
```

The expected behaviour is demonstrated below.

```
close_application()
close_application()
```

Lazy initialization

An alternative to having separate "init" and "get" functions is having one "get" function that does lazy initialization of the application object when first requested. With lazy initialization, the getter will first check if the object it needs to return has been constructed, and will then return the object. If the object hasn't been constructed, before returning the object it will construct the object. So you could use a lock around the construction of the object, to make sure it only happens once. After the lock is obtained and before the object is constructed, it is recommended to check again that the object wasn't constructed by another thread before the lock was acquired.

```
import threading

lock = threading.Lock()

def get_application():
    global _application
    if _application is None:
        lock.acquire()
        try:
            # Check again to avoid a TOCTOU bug.
            if _application is None:
                _application = construct_application()
        finally:
            lock.release()
    return _application


get_application()
get_application()
```

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```
get_application()

close_application()
```

1.13.2 Database connection

Typically, your eventsourcing application object will be constructed after its database connection has been configured, and before any requests are handled. Views or tasks can then safely use the already constructed application object.

If your eventsourcing application depends on receiving a database session object when it is constructed, for example if you are using the SQLAlchemy classes in this library, then you will need to create a correctly scoped session object first and use it to construct the application object.

On the other hand, if your eventsourcing application does not depend on receiving a database session object when it is constructed, for example if you are using the Cassandra classes in this library, then you may construct the application object before configuring the database connection - just be careful not to use the application object before the database connection is configured otherwise your queries just won't work.

Setting up connections to databases is out of scope of the eventsourcing application classes, and should be set up in a "normal" way. The documentation for your Web or worker framework may describe when to set up database connections, and your database documentation may also have some suggestions. It is recommended to make use of any hooks or decorators or signals intended for the purpose of setting up the database connection also to construct the application once for the process. See below for some suggestions.

SQLAlchemy

SQLAlchemy has very good documentation about constructing sessions. If you are an SQLAlchemy user, it is well worth reading the documentation about sessions in full. Here's a small quote:

> *Some web frameworks include infrastructure to assist in the task of aligning the lifespan of a Session with that of a web request. This includes products such as Flask-SQLAlchemy for usage in conjunction with the Flask web framework, and Zope-SQLAlchemy, typically used with the Pyramid framework. SQLAlchemy recommends that these products be used as available.*
>
> *In those situations where the integration libraries are not provided or are insufficient, SQLAlchemy includes its own "helper" class known as scoped_session. A tutorial on the usage of this object is at Contextual/Thread-local Sessions. It provides both a quick way to associate a Session with the current thread, as well as patterns to associate Session objects with other kinds of scopes.*

The important thing is to use a scoped session, and it is better to have the session scoped to the request or task, rather than the thread, but scoping to the thread is ok.

As soon as you have a scoped session object, you can construct your eventsourcing application.

Cassandra

Cassandra connections can be set up entirely independently of the application object.

1.13.3 Web interfaces

uWSGI

If you are running uWSGI in prefork mode, and not using a Web application framework, please note that uWSGI has a postfork decorator which may help.

Your "wsgi.py" file can have a module-level function decorated with the `@postfork` decorator that initialises your eventsourcing application for the Web application process after child workers have been forked.

```
from uwsgidecorators import postfork

@postfork
def init_process():
    # Set up database connection.
    database = {}
    # Construct eventsourcing application.
    init_application()
```

Other decorators are available.

Flask

Flask with SQLAlchemy

If you wish to use eventsourcing with Flask and SQLAlchemy, then you may wish to use Flask-SQLAlchemy. You just need to define your record class(es) using the model classes from that library, and then use it instead of the library classes in your eventsourcing application object, along with the session object it provides.

The docs snippet below shows that it can work simply to construct the eventsourcing application in the same place as the Flask application object.

The Flask-SQLAlchemy class *SQLAlchemy* is used to set up a session object that is scoped to the request.

```
from flask import Flask
from flask_sqlalchemy import SQLAlchemy
from sqlalchemy_utils.types.uuid import UUIDType


# Construct Flask application.
application = Flask(__name__)
application.config['SQLALCHEMY_DATABASE_URI'] = 'sqlite://'
application.config['SQLALCHEMY_TRACK_MODIFICATIONS'] = False

# Construct Flask-SQLAlchemy object.
db = SQLAlchemy(application)

# Define database table using Flask-SQLAlchemy library.
class StoredEventRecord(db.Model):
    __tablename__ = 'integer_sequenced_items'

    id = db.Column(db.BigInteger().with_variant(db.Integer, "sqlite"), primary_
↪key=True)

    # Sequence ID (e.g. an entity or aggregate ID).
    originator_id = db.Column(UUIDType(), nullable=False)
```

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```
    # Position (index) of item in sequence.
    originator_version = db.Column(db.BigInteger(), nullable=False)

    # Topic of the item (e.g. path to domain event class).
    event_type = db.Column(db.String(255))

    # State of the item (serialized dict, possibly encrypted).
    state = db.Column(db.Text())

    # Index.
    __table_args__ = db.Index('index', 'originator_id', 'originator_version',␣
↪unique=True),


# Construct eventsourcing application with Flask-SQLAlchemy table and session.
@application.before_first_request
def before_first_request():
    init_application(
        session=db.session,
        stored_event_record_class=StoredEventRecord,
    )
```

For a working example using Flask and SQLAlchemy, please refer to the library module *eventsourcing.example.interface.flaskapp*, which is tested both stand-alone and with uWSGI. The Flask application method "before_first_request" is used to decorate an application object constructor, just before a request is made, so that the module can be imported by the test suite, without immediately constructing the application.

Flask with Cassandra

The Cassandra Driver FAQ has a code snippet about establishing the connection with the uWSGI *postfork* decorator, when running in a forked mode.

```
from flask import Flask
from uwsgidecorators import postfork
from cassandra.cluster import Cluster

session = None
prepared = None

@postfork
def connect():
    global session, prepared
    session = Cluster().connect()
    prepared = session.prepare("SELECT release_version FROM system.local WHERE key=?")

app = Flask(__name__)

@app.route('/')
def server_version():
    row = session.execute(prepared, ('local',))[0]
    return row.release_version
```

The Flask-Cassandra project serves a similar function to Flask-SQLAlchemy.

Django

When deploying an event sourcing application with Django, just remember that there must only be one instance of the application in any given process, otherwise its subscribers will be registered too many times. There are perhaps three different processes to consider. Firstly, running the test suite for your Django project or app. Secondly, running the Django project with WSGI (or equivalent). Thirdly, running the Django project from a task queue worker, such as RabbitMQ.

For the first case, if your application needs to be created fresh for each test, it is recommended to have a base test case class, which initialises the application during `setUp()` and closes the application during `tearDown()`. Another option is to use a yield fixture in pytest with the application object yielded whilst acting as a context manager. Just make sure the application is constructed once, and then closed if it is constructed again.

Of course if you only have one application object to test, then you could perhaps just create it at the start of the test suite. If so, closing the application doesn't matter, because no other application object will be created before the process ends.

For the second case, it is recommended to construct the application object from the project's `wsgi.py` file, which doesn't get used when running Django from a test suite, or from a task queue worker. Views can then get the application object freely. Closing the application doesn't matter, because it will be used until the process ends.

For the third case, it is recommended to construct the application in a suitable signal from the task queue framework, so that the application is constructed before request threads begin. Jobs can then get the application object freely. Closing the application doesn't matter, because it will be used until the process ends.

In each case, to make things very clear for other developers of your code, it is recommended to construct the application object with a module level function called `init_application()` that assigns to a module level variable, and then obtain the application object with another module level function called `get_application()`, which raises an exception if the application has not been constructed.

Django ORM

If you wish to use eventsourcing with Django ORM, the simplest way is having your application's event store use this library's `DjangoRecordManager`, and making sure the record classes (Django models) are included in your Django project. See *infrastructure doc* for more information.

The independent project djangoevents by Applause is a Django app that provides a more integrated approach to event sourcing in a Django project. It also uses the Django ORM to store events. Using djangoevents is well documented in its README file. It adds some nice enhancements to the capabilities of this library, and shows how various components can be extended or replaced. Please note, the djangoevents project currently works with a much older version of this library which isn't recommended for new projects.

Django with Cassandra

If you wish to use eventsourcing with Django and Cassandra, regardless of any event sourcing, you may wish to use Django-Cassandra. The library's Cassandra classes use the Cassandra Python library which the Django-Cassandra project integrates into Django. So you can easily develop an event sourcing application using the capabilities of this library, and then write views in Django, and use the Django-Cassandra project as a means of integrating Django as an Web interface to an event sourced application that uses Cassandra.

It's also possible to use this library directly with Django and Cassandra. You just need to configure the connection and initialise the application before handling requests in a way that is correct for your configuration (which is what Django-Cassandra tries to make easy).

Zope

Zope with SQLAlchemy

The Zope-SQLAlchemy project serves a similar function to Flask-SQLAlchemy.

1.13.4 Task queues

This section contains suggestions about using an eventsourcing application in task queue workers.

Celery

Celery has a worker_process_init signal decorator, which may be appropriate if you are running Celery workers in prefork mode. Other decorators are available.

Your Celery tasks or config module can have a module-level function decorated with the `@worker-process-init` decorator that initialises your eventsourcing application for the Celery worker process.

```
from celery.signals import worker_process_init

@worker_process_init.connect
def init_process(sender=None, conf=None, **kwargs):
    # Set up database connection.
    database = {}
    # Construct eventsourcing application.
    init_application()
```

As an alternative, it may work to use decorator `@task_prerun` with a getter that supports lazy initialization.

```
from celery.signals import task_prerun
@task_prerun.connect
def init_process(*args, **kwargs):
    get_appliation(lazy_init=True)
```

Once the application has been safely initialized once in the process, your Celery tasks can use function `get_application()` to complete their work. Of course, you could just call a getter with lazy initialization from the tasks.

```
from celery import Celery

app = Celery()

# Use Celery app to route the task to the worker.
@app.task
def hello_world():
    # Use eventsourcing app to complete the task.
    app = get_application()
    return "Hello World, {}".format(id(app))
```

Again, the most important thing is configuring the database, and making things work across all modes of execution, including your test suite.

Redis Queue

Redis queue workers are quite similar to Celery workers. You can call `get_application()` from within a job function. To fit with the style in the RQ documentation, you could perhaps use your eventsourcing application as a context manager, just like the Redis connection example.

1.14 Release notes

It is the aim of the project that releases with the same major version number are backwards compatible, within the scope of the documented examples. New major versions indicate a backward incompatible changes have been introduced since the previous major version.

Version 4.x series was released after quite a lot of refactoring made things backward-incompatible. Object namespaces for entity and event classes was cleaned up, by moving library names to double-underscore prefixed and postfixed names. Domain events can be hashed, and also hash-chained together, allowing entity state to be verified. Created events were changed to have originator_topic, which allowed other things such as mutators and repositories to be greatly simplified. Mutators are now by default expected to be implemented on entity event classes. Event timestamps were changed from floats to decimal objects, an exact number type. Cipher was changed to use AES-GCM to allow verification of encrypted data retrieved from a database.

Also, the record classes for SQLAlchemy were changed to have an auto-incrementing ID, to make it easy to follow the events of an application, for example when updating view models, without additional complication of a separate application log. This change makes the SQLAlchemy library classes ultimately less "scalable" than the Cassandra classes, because an auto-incrementing ID must operate from a single thread. Overall, it seems like a good trade-off for early-stage development. Later, when the auto-incrementing ID bottleneck would otherwise throttle performance, "scaling-up" could involve switching application infrastructure to use a separate application log.

Also, support for Django ORM was added in version 4.1.0.

Version 3.x series was a released after quite of a lot of refactoring made things backwards-incompatible. Documentation was greatly improved, in particular with pages reflecting the architectural layers of the library (infrastructure, domain, application).

Version 2.x series was a major rewrite that implemented two distinct kinds of sequences: events sequenced by integer version numbers and events sequenced in time, with an archetypal "sequenced item" persistence model for storing events.

Version 1.x series was an extension of the version 0.x series, and attempted to bridge between sequencing events with both timestamps and version numbers.

Version 0.x series was the initial cut of the code, all events were sequenced by timestamps, or TimeUUIDs in Cassandra, because the project originally emerged whilst working with Cassandra.

1.15 Module docs

This document describes the packages, modules, classes, functions and other code details of the library.

- genindex
- modindex

1.15.1 eventsourcing

The eventsourcing package contains packages for the application layer, the domain layer, the infrastructure layer, and the interface layer. There is also a module for exceptions, an example package, and a utils package.

application

The application layer brings together the domain and infrastructure layers.

base

class eventsourcing.application.base.**ApplicationWithEventStores**(*entity_record_manager=None*, *log_record_manager=None*, *snapshot_record_manager=None*, *always_encrypt=False*, *cipher=None*)

Bases: object

Event sourced application object class.

Can construct event stores using given database records. Supports three different event stores: for log events, for entity events, and for snapshot events.

close()

construct_event_store(*event_sequence_id_attr*, *event_position_attr*, *record_manager*, *always_encrypt=False*, *cipher=None*)

construct_sequenced_item_mapper(*sequenced_item_class*, *event_sequence_id_attr*, *event_position_attr*, *json_encoder_class=<class 'eventsourcing.utils.transcoding.ObjectJSONEncoder'>*, *json_decoder_class=<class 'eventsourcing.utils.transcoding.ObjectJSONDecoder'>*, *always_encrypt=False*, *cipher=None*)

class eventsourcing.application.base.**ApplicationWithPersistencePolicies**(***kwargs*)

Bases: *eventsourcing.application.base.ApplicationWithEventStores*

close()

construct_entity_persistence_policy()

construct_log_persistence_policy()

construct_snapshot_persistence_policy()

policies

class eventsourcing.application.policies.**PersistencePolicy**(*event_store*, *event_type=None*)

Bases: object

Stores events of given type to given event store, whenever they are published.

close()

is_event(*event*)

store_event(*event*)

class eventsourcing.application.policies.**SnapshottingPolicy**(*repository*, *period=2*)

Bases: object

close()

condition(*event*)

take_snapshot(*event*)

simple

class eventsourcing.application.simple.**SimpleApplication**(*name=''*, *persistence_policy=None*, *persist_event_type=None*, *uri=None*, *pool_size=5*, *session=None*, *cipher_key=None*, *sequenced_item_class=None*, *stored_event_record_class=None*, *setup_table=True*, *contiguous_record_ids=True*, *pipeline_id=-1*, *notification_log_section_size=None*)

Bases: object

change_pipeline(*pipeline_id*)

close()

construct_event_store(*application_id*, *pipeline_id*)

construct_repository(*event_store*, ***kwargs*)

drop_table()

persist_event_type = None

session

setup_cipher(*cipher_key*)

setup_datastore(*session*, *uri*, *pool_size=5*)

setup_event_store()

setup_persistence_policy(*persist_event_type*)

setup_repository(***kwargs*)

setup_table()

class eventsourcing.application.simple.**SnapshottingApplication**(*period=10*, *snapshot_record_class=None*, ***kwargs*)

Bases: *eventsourcing.application.simple.SimpleApplication*

close()

setup_event_store()

setup_persistence_policy(*persist_event_type*)

setup_repository(***kwargs*)

setup_table()

domain.model

The domain layer contains a domain model, and optionally services that work across different entities or aggregates.

The domain model package contains classes and functions that can help develop an event sourced domain model.

aggregate

Base classes for aggregates in a domain driven design.

class eventsourcing.domain.model.aggregate.**AggregateRoot**(***kwargs*)
Bases: *eventsourcing.domain.model.entity.TimestampedVersionedEntity*

Root entity for an aggregate in a domain driven design.

class AttributeChanged(*originator_version*, ***kwargs*)
Bases: eventsourcing.domain.model.aggregate.Event, eventsourcing.domain.model.entity.AttributeChanged

Published when an AggregateRoot is changed.

class Created(*originator_version=0*, ***kwargs*)
Bases: eventsourcing.domain.model.aggregate.Event, eventsourcing.domain.model.entity.Created

Published when an AggregateRoot is created.

class Discarded(*originator_version*, ***kwargs*)
Bases: eventsourcing.domain.model.aggregate.Event, eventsourcing.domain.model.entity.Discarded

Published when an AggregateRoot is discarded.

class Event(*originator_version*, ***kwargs*)
Bases: eventsourcing.domain.model.entity.Event

Supertype for aggregate events.

__publish__(*event*)
Appends event to internal collection of pending events.

__save__()
Publishes pending events for others in application.

array

A kind of collection, indexed by integer. Doesn't need to replay all events to exist.

class eventsourcing.domain.model.array.**AbstractArrayRepository**(*array_size=10000*, **args*, ***kwargs*)
Bases: *eventsourcing.domain.model.entity.AbstractEntityRepository*

Repository for sequence objects.

__getitem__(*array_id*)
Returns sequence for given ID.

class eventsourcing.domain.model.array.**AbstractBigArrayRepository**
Bases: *eventsourcing.domain.model.entity.AbstractEntityRepository*

Repository for compound sequence objects.

__getitem__(*array_id*)
Returns sequence for given ID.

subrepo
Sub-sequence repository.

class eventsourcing.domain.model.array.**Array**(*array_id*, *repo*)
Bases: object

__getitem__(*item*)
Returns item at index, or items in slice.

__len__()
Returns length of array.

__setitem__(*index*, *item*)
Sets item in array, at given index.

Won't overrun the end of the array, because the position is fixed to be less than base_size.

append(*item*)
Sets item in next position after the last item.

get_item_assigned(*index*)

get_items_assigned(*start_index=None*, *stop_index=None*, *limit=None*, *is_ascending=True*)

get_last_item_and_next_position()

get_next_position()

class eventsourcing.domain.model.array.**BigArray**(*array_id*, *repo*)
Bases: *eventsourcing.domain.model.array.Array*

A virtual array holding items in indexed positions, across a number of Array instances.

Getting and setting items at index position is supported. Slices are supported, and operate across the underlying arrays. Appending is also supported.

BigArray is designed to overcome the concern of needing a single large sequence that may not be suitably stored in any single partiton. In simple terms, if events of an aggregate can fit in a partition, we can use the same size partition to make a tree of arrays that will certainly be capable of sequencing all the events of the application in a single stream.

With normal size base arrays, enterprise applications can expect read and write time to be approximately constant with respect to the number of items in the array.

The array is composed of a tree of arrays, which gives the capacity equal to the size of each array to the power of the size of each array. If the arrays are limited to be about the maximum size of an aggregate event stream (a large number but not too many that would cause there to be too much data in any one partition, let's say 1000s to be safe) then it would be possible to fit such a large number of aggregates in the corresponding BigArray, that we can be confident it would be full.

Write access time in the worst case, and the time to identify the index of the last item in the big array, is proportional to the log of the highest assigned index to base the underlying array size. Write time on average, and read time given an index, is constant with respect to the number of items in a BigArray.

Items can be appended in log time in a single thread. However, the time between reading the current last index and claiming the next position leads to contention and retries when there are lots of threads of execution all attempting to append items, which inherently limits throughput.

Todo: Not possible in Cassandra, but maybe do it in a transaction in SQLAlchemy?

An alternative to reading the last item before writing the next is to use an integer sequence generator to generate a stream of integers. Items can be assigned to index positions in a big array, according to the integers that are issued. Throughput will then be much better, and will be limited only by the rate at which the database can have events written to it (unless the number generator is quite slow).

An external integer sequence generator, such as Redis' INCR command, or an auto-incrementing database column, may constitute a single point of failure.

__len__()
Returns length of array.

calc_parent(*i*, *j*, *h*)
Returns get_big_array and end of span of parent sequence that contains given child.

calc_required_height(*n*, *size*)

create_array_id(*i*, *j*)

get_item(*position*)

get_last_array()
Returns last array in compound.

Return type CompoundSequenceReader

get_last_item_and_next_position()

get_slice(*start*, *stop*)

class eventsourcing.domain.model.array.**ItemAssigned**(*item*, *index*, **args*, ***kwargs*)
Bases: eventsourcing.domain.model.entity.Event

Occurs when an item is set at a position in an array.

index

item

collection

Decorators useful in domain models based on the classes in this library.

eventsourcing.domain.model.decorators.**attribute**(*getter*)
When used as a method decorator, returns a property object with the method as the getter and a setter defined to call instance method change_attribute(), which publishes an AttributeChanged event.

eventsourcing.domain.model.decorators.**mutator**(*arg=None*)
Structures mutator functions by allowing handlers to be registered for different types of event. When the decorated function is called with an initial value and an event, it will call the handler that has been registered for that type of event.

It works like singledispatch, which it uses. The difference is that when the decorated function is called, this decorator dispatches according to the type of last call arg, which fits better with reduce(). The builtin Python

function reduce() is used by the library to replay a sequence of events against an initial state. If a mutator function is given to reduce(), along with a list of events and an initializer, reduce() will call the mutator function once for each event in the list, but the initializer will be the first value, and the event will be the last argument, and we want to dispatch according to the type of the event. It happens that singledispatch is coded to switch on the type of the first argument, which makes it unsuitable for structuring a mutator function without the modifications introduced here.

The other aspect introduced by this decorator function is the option to set the type of the handled entity in the decorator. When an entity is replayed from scratch, in other words when all its events are replayed, the initial state is None. The handler which handles the first event in the sequence will probably construct an object instance. It is possible to write the type into the handler, but that makes the entity more difficult to subclass because you will also need to write a handler for it. If the decorator is invoked with the type, when the initial value passed as a call arg to the mutator function is None, the handler will instead receive the type of the entity, which it can use to construct the entity object.

```
class Entity(object):
    class Created(object):
        pass

@mutator(Entity)
def mutate(initial, event):
    raise NotImplementedError(type(event))

@mutate.register(Entity.Created)
def _(initial, event):
    return initial(**event.__dict__)

entity = mutate(None, Entity.Created())
```

eventsourcing.domain.model.decorators.**random**() → x in the interval [0, 1).

eventsourcing.domain.model.decorators.**retry**(*exc=<class 'Exception'>*, *max_attempts=1*, *wait=0*)

eventsourcing.domain.model.decorators.**subscribe_to**(**event_classes*)

Decorator for making a custom event handler function subscribe to a certain class of event.

The decorated function will be called once for each matching event that is published, and will be given one argument, the event, when it is called. If events are published in lists, for example the AggregateRoot publishes a list of pending events when its __save__() method is called, then the decorated function will be called once for each event that is an instance of the given event_class.

Please note, this decorator isn't suitable for use with object class methods. The decorator receives in Python 3 an unbound function, and defines a handler which it subscribes that calls the decorated function for each matching event. However the method isn't called on the object, so the object instance is never available in the decorator, so the decorator can't call a normal object method because it doesn't have a value for 'self'.

event_class: type used to match published events, an event matches if it is an instance of this type

The following example shows a custom handler that reacts to Todo.Created event and saves a projection of a Todo model object.

```
@subscribe_to(Todo.Created)
def new_todo_projection(event):
    todo = TodoProjection(id=event.originator_id, title=event.title)
    todo.save()
```

entity

Base classes for domain entities of different kinds.

The entity module provides base classes for domain entities.

class eventsourcing.domain.model.entity.**AbstractEntityRepository**
Bases: *eventsourcing.domain.model.entity.AbstractEventPlayer*

__contains__(*entity_id*)
Returns True or False, according to whether or not entity exists.

__getitem__(*entity_id*)
Returns entity for given ID.

event_store
Returns event store object used by this repository.

get_entity(*entity_id*, *at=None*)
Returns entity for given ID.

take_snapshot(*entity_id*, *lt=None*, *lte=None*)
Takes snapshot of entity state, using stored events. :return: Snapshot

class eventsourcing.domain.model.entity.**AbstractEventPlayer**
Bases: object

class eventsourcing.domain.model.entity.**DomainEntity**(*id*)
Bases: *eventsourcing.domain.model.events.QualnameABC*

Base class for domain entities.

class AttributeChanged(***kwargs*)
Bases: eventsourcing.domain.model.entity.Event, *eventsourcing.domain.model.events.AttributeChanged*

Published when a DomainEntity is discarded.

class Created(*originator_topic*, ***kwargs*)
Bases: eventsourcing.domain.model.entity.Event, *eventsourcing.domain.model.events.Created*

Published when an entity is created.

originator_topic

class Discarded(***kwargs*)
Bases: *eventsourcing.domain.model.events.Discarded*, eventsourcing.domain.model.entity.Event

Published when a DomainEntity is discarded.

class Event(***kwargs*)
Bases: *eventsourcing.domain.model.events.EventWithOriginatorID*, *eventsourcing.domain.model.events.DomainEvent*

Supertype for events of domain entities.

__check_obj__(*obj*)
Checks obj state before mutating.

__assert_not_discarded__()
Raises exception if entity has been discarded already.

__change_attribute__(*name*, *value*)
Changes named attribute with the given value, by triggering an AttributeChanged event.

__discard__()
Discards self, by triggering a Discarded event.

__publish__(*event*)
Publishes given event for subscribers in the application.

Parameters **event** – domain event or list of events

__publish_to_subscribers__(*event*)
Actually dispatches given event to publish-subscribe mechanism.

Parameters **event** – domain event or list of events

__trigger_event__(*event_class*, ***kwargs*)
Constructs, applies, and publishes a domain event.

id
Entity ID allows an entity instance to be referenced and distinguished from others, even though its state may change over time.

class eventsourcing.domain.model.entity.**TimestampedEntity**(*__created_on__=None*, ***kwargs*)

Bases: *eventsourcing.domain.model.entity.DomainEntity*

class AttributeChanged(***kwargs*)
Bases: eventsourcing.domain.model.entity.Event, eventsourcing.domain.model.entity.AttributeChanged

Published when a TimestampedEntity is changed.

class Created(*originator_topic*, ***kwargs*)
Bases: eventsourcing.domain.model.entity.Created, eventsourcing.domain.model.entity.Event

Published when a TimestampedEntity is created.

class Discarded(***kwargs*)
Bases: eventsourcing.domain.model.entity.Event, eventsourcing.domain.model.entity.Discarded

Published when a TimestampedEntity is discarded.

class Event(***kwargs*)
Bases: eventsourcing.domain.model.entity.Event, *eventsourcing.domain.model.events.EventWithTimestamp*

Supertype for events of timestamped entities.

__mutate__(*obj*)
Update obj with values from self.

class eventsourcing.domain.model.entity.**TimestampedVersionedEntity**(*__created_on__=None*, ***kwargs*)

Bases: *eventsourcing.domain.model.entity.TimestampedEntity*, *eventsourcing.domain.model.entity.VersionedEntity*

class AttributeChanged(*originator_version*, ***kwargs*)
Bases: eventsourcing.domain.model.entity.Event, eventsourcing.domain.model.entity.AttributeChanged, eventsourcing.domain.model.entity.AttributeChanged

Published when a TimestampedVersionedEntity is created.

class Created(*originator_version=0*, ***kwargs*)
Bases: eventsourcing.domain.model.entity.Created, eventsourcing.domain.model.entity.Created, eventsourcing.domain.model.entity.Event

Published when a TimestampedVersionedEntity is created.

class Discarded(*originator_version*, ***kwargs*)
Bases: eventsourcing.domain.model.entity.Event, eventsourcing.domain.model.entity.Discarded, eventsourcing.domain.model.entity.Discarded

Published when a TimestampedVersionedEntity is discarded.

class Event(*originator_version*, ***kwargs*)
Bases: eventsourcing.domain.model.entity.Event, eventsourcing.domain.model.entity.Event

Supertype for events of timestamped, versioned entities.

class eventsourcing.domain.model.entity.**TimeuuidedEntity**(*event_id*, ***kwargs*)
Bases: *eventsourcing.domain.model.entity.DomainEntity*

class eventsourcing.domain.model.entity.**TimeuuidedVersionedEntity**(*event_id*, ***kwargs*)
Bases: *eventsourcing.domain.model.entity.TimeuuidedEntity*, *eventsourcing.domain.model.entity.VersionedEntity*

class eventsourcing.domain.model.entity.**VersionedEntity**(*__version__=None*, ***kwargs*)
Bases: *eventsourcing.domain.model.entity.DomainEntity*

class AttributeChanged(*originator_version*, ***kwargs*)
Bases: eventsourcing.domain.model.entity.Event, eventsourcing.domain.model.entity.AttributeChanged

Published when a VersionedEntity is changed.

class Created(*originator_version=0*, ***kwargs*)
Bases: eventsourcing.domain.model.entity.Created, eventsourcing.domain.model.entity.Event

Published when a VersionedEntity is created.

class Discarded(*originator_version*, ***kwargs*)
Bases: eventsourcing.domain.model.entity.Event, eventsourcing.domain.model.entity.Discarded

Published when a VersionedEntity is discarded.

class Event(*originator_version*, ***kwargs*)
Bases: *eventsourcing.domain.model.events.EventWithOriginatorVersion*, eventsourcing.domain.model.entity.Event

Supertype for events of versioned entities.

__check_obj__(*obj*)
Extended superclass method by checking the event's originator version follows (1 +) this entity's version.

__trigger_event__(*event_class*, ***kwargs*)
Triggers domain event with entity's next version number.

events

Base classes for domain events of different kinds.

class eventsourcing.domain.model.events.**AttributeChanged**(**kwargs)
Bases: *eventsourcing.domain.model.events.DomainEvent*

Can be published when an attribute of an entity is created.

name

value

class eventsourcing.domain.model.events.**Created**(**kwargs)
Bases: *eventsourcing.domain.model.events.DomainEvent*

Can be published when an entity is created.

class eventsourcing.domain.model.events.**Discarded**(**kwargs)
Bases: *eventsourcing.domain.model.events.DomainEvent*

Published when something is discarded.

class eventsourcing.domain.model.events.**DomainEvent**(**kwargs)
Bases: *eventsourcing.domain.model.events.QualnameABC*

Base class for domain events.

Implements methods to make instances read-only, comparable for equality, have recognisable representations, and hashable.

__eq__(*other*)
Tests for equality of two event objects.

__hash__()
Computes a Python integer hash for an event, using its event hash string if available.

Supports equality and inequality comparisons.

__init__(**kwargs)
Initialises event attribute values directly from constructor kwargs.

__mutate__(*obj*)
Update obj with values from self.

Can be extended, but subclasses must call super method, and return an object.

Parameters **obj** – object to be mutated

Returns mutated object

__ne__(*other*)
Negates the equality test.

__repr__()
Returns string representing the type and attribute values of the event.

__setattr__(*key*, *value*)
Inhibits event attributes from being updated by assignment.

mutate(*obj*)
Convenience for use in custom models, to update obj with values from self without needing to call super method and return obj (two extra lines).

Can be overridden by subclasses. Any value returned by this method will be ignored.

Please note, subclasses that extend mutate() might not have fully completed that method before this method is called. To ensure all base classes have completed their mutate behaviour before mutating an event in a concrete class, extend mutate() instead of overriding this method.

Parameters **obj** – object to be mutated

exception eventsourcing.domain.model.events.**EventHandlersNotEmptyError**
Bases: Exception

class eventsourcing.domain.model.events.**EventWithOriginatorID**(*originator_id*, ***kwargs*)
Bases: *eventsourcing.domain.model.events.DomainEvent*

originator_id

class eventsourcing.domain.model.events.**EventWithOriginatorVersion**(*originator_version*, ***kwargs*)
Bases: *eventsourcing.domain.model.events.DomainEvent*

For events that have an originator version number.

originator_version

class eventsourcing.domain.model.events.**EventWithTimestamp**(*timestamp=None*, ***kwargs*)
Bases: *eventsourcing.domain.model.events.DomainEvent*

For events that have a timestamp value.

timestamp

class eventsourcing.domain.model.events.**EventWithTimeuuid**(*event_id=None*, ***kwargs*)
Bases: *eventsourcing.domain.model.events.DomainEvent*

For events that have an UUIDv1 event ID.

event_id

class eventsourcing.domain.model.events.**Logged**(***kwargs*)
Bases: *eventsourcing.domain.model.events.DomainEvent*

Published when something is logged.

class eventsourcing.domain.model.events.**QualnameABC**
Bases: object

Base class that introduces __qualname__ for objects in Python 2.7.

class eventsourcing.domain.model.events.**QualnameABCMeta**
Bases: abc.ABCMeta

Supplies __qualname__ to object classes with this metaclass.

eventsourcing.domain.model.events.**assert_event_handlers_empty**()

eventsourcing.domain.model.events.**clear_event_handlers**()

eventsourcing.domain.model.events.**create_timesequenced_event_id**()

eventsourcing.domain.model.events.**publish**(*event*)

eventsourcing.domain.model.events.**subscribe**(*handler*, *predicate=None*)

eventsourcing.domain.model.events.**unsubscribe**(*handler*, *predicate=None*)

snapshot

Snapshotting is implemented in the domain layer as an event.

class eventsourcing.domain.model.snapshot.**AbstractSnapshop**
Bases: object

originator_id
ID of the snapshotted entity.

originator_version
Version of the last event applied to the entity.

state
State of the snapshotted entity.

topic
Path to the class of the snapshotted entity.

class eventsourcing.domain.model.snapshot.**Snapshot**(*originator_id*, *originator_version*, *topic*, *state*)
Bases: *eventsourcing.domain.model.events.EventWithTimestamp*, *eventsourcing.domain.model.events.EventWithOriginatorVersion*, *eventsourcing.domain.model.events.EventWithOriginatorID*, *eventsourcing.domain.model.snapshot.AbstractSnapshop*

state
State of the snapshotted entity.

topic
Path to the class of the snapshotted entity.

timebucketedlog

Time-bucketed logs allow a sequence of the items that is sequenced by timestamp to be split across a number of different database partitions, which avoids one partition becoming very large (and then unworkable).

class eventsourcing.domain.model.timebucketedlog.**MessageLogged**(*message*, *originator_id*)
Bases: *eventsourcing.domain.model.events.EventWithTimestamp*, *eventsourcing.domain.model.events.EventWithOriginatorID*, *eventsourcing.domain.model.events.Logged*

message

class eventsourcing.domain.model.timebucketedlog.**Timebucketedlog**(*name*, *bucket_size=None*, ***kwargs*)
Bases: *eventsourcing.domain.model.entity.TimestampedVersionedEntity*

class BucketSizeChanged(*originator_version*, ***kwargs*)
Bases: eventsourcing.domain.model.timebucketedlog.Event, eventsourcing.domain.model.entity.AttributeChanged

class Event(*originator_version*, ***kwargs*)
Bases: eventsourcing.domain.model.entity.Event

Supertype for events of time-bucketed log.

class Started(*originator_version=0*, ***kwargs*)
Bases: eventsourcing.domain.model.entity.Created, eventsourcing.domain.model.timebucketedlog.Event

append_message(*message*)

bucket_size

name

started_on

class eventsourcing.domain.model.timebucketedlog.**TimebucketedlogRepository**
Bases: *eventsourcing.domain.model.entity.AbstractEntityRepository*

get_or_create(*log_name*, *bucket_size*)
Gets or creates a log.

Return type *Timebucketedlog*

eventsourcing.domain.model.timebucketedlog.**bucket_duration**(*bucket_size*)

eventsourcing.domain.model.timebucketedlog.**bucket_starts**(*timestamp*, *bucket_size*)

eventsourcing.domain.model.timebucketedlog.**make_timebucket_id**(*log_id*, *timestamp*, *bucket_size*)

eventsourcing.domain.model.timebucketedlog.**next_bucket_starts**(*timestamp*, *bucket_size*)

eventsourcing.domain.model.timebucketedlog.**previous_bucket_starts**(*timestamp*, *bucket_size*)

eventsourcing.domain.model.timebucketedlog.**start_new_timebucketedlog**(*name*, *bucket_size=None*)

eventsourcing.domain.model.timebucketedlog.**timestamp_from_datetime**(*dt*)

infrastructure

The infrastructure layer adapts external devices in ways that are useful for the application, such as the way an event store encapsulates a database.

base

Abstract base classes for the infrastructure layer.

class eventsourcing.infrastructure.base.**AbstractSequencedItemRecordManager**(*record_class*, *sequenced_item_class=<'eventsourcing.infrastructure.sequencedcontiguous_record_ids=False*, *application_id=None*, *pipeline_id=-1*)

Bases: object

all_sequence_ids()
Returns all sequence IDs.

append(*sequenced_item_or_items*)
Writes sequenced item into the datastore.

delete_record(*record*)
Removes permanently given record from the table.

from_record(*record*)
Constructs and returns a sequenced item object, from given ORM object.

get_field_kwargs(*item*)

get_item(*sequence_id*, *position*)
Gets sequenced item from the datastore.

get_items(*sequence_id*, *gt=None*, *gte=None*, *lt=None*, *lte=None*, *limit=None*, *query_ascending=True*, *results_ascending=True*)
Returns sequenced items.

get_notifications(*start=None*, *stop=None*, **args*, ***kwargs*)
Returns records sequenced by notification ID, from application, for pipeline, in given range.

get_records(*sequence_id*, *gt=None*, *gte=None*, *lt=None*, *lte=None*, *limit=None*, *query_ascending=True*, *results_ascending=True*)
Returns records for a sequence.

list_items(**args*, ***kwargs*)

list_sequence_ids()

raise_index_error(*position*)

raise_operational_error(*e*)

raise_record_integrity_error(*e*)

raise_sequenced_item_conflict()

to_record(*sequenced_item*)
Constructs and returns an ORM object, from given sequenced item object.

class eventsourcing.infrastructure.base.**AbstractTrackingRecordManager**

Bases: object

get_max_record_id(*application_name*, *upstream_application_name*, *pipeline_id*)
Returns maximum record ID for given application name.

record_class
Returns tracking record class.

class eventsourcing.infrastructure.base.**RelationalRecordManager**(**args*, ***kwargs*)
Bases: *eventsourcing.infrastructure.base.AbstractSequencedItemRecordManager*

_prepare_insert(*tmpl*, *record_class*, *field_names*, *placeholder_for_id=False*)
Compile SQL statement with placeholders for bind parameters.

_write_records(*records*, *tracking_kwargs=None*)
Actually creates records in the database. :param tracking_kwargs:

append(*sequenced_item_or_items*)
Writes sequenced item into the datastore.

get_max_record_id()
Return maximum ID of existing records.

get_record_table_name(*record_class*)
Returns table name - used in raw queries.

Return type str

insert_select_max
SQL statement that inserts records with contiguous IDs, by selecting max ID from indexed table records.

insert_tracking_record
SQL statement that inserts tracking records.

insert_values
SQL statement that inserts records without ID.

to_records(*sequenced_item_or_items*)

tracking_record_class = None

tracking_record_field_names = ['application_id', 'upstream_application_id', 'pipeline_

write_records(*records*, *tracking_kwargs=None*)
Calls _write_records() implemented by concrete classes.

Parameters **tracking_kwargs** –

cassandra

Classes for event sourcing with Apache Cassandra.

class eventsourcing.infrastructure.cassandra.datastore.**CassandraDatastore**(*tables*, **args*, ***kwargs*)
Bases: *eventsourcing.infrastructure.datastore.Datastore*

close_connection()
Drops connection to a datastore.

drop_table(**_*)

drop_tables()
Drops tables used to store events.

setup_connection()
Sets up a connection to a datastore.

setup_tables()
Sets up tables used to store events.

truncate_tables()
Truncates tables used to store events.

class eventsourcing.infrastructure.cassandra.datastore.**CassandraSettings**(*hosts=None*, *port=None*, *protocol_version=None*, *default_keyspace=None*, *consistency=None*, *replication_factor=None*, *username=None*, *password=None*)

Bases: *eventsourcing.infrastructure.datastore.DatastoreSettings*

CONSISTENCY_LEVEL = 'LOCAL_QUORUM'

DEFAULT_KEYSPACE = 'eventsourcing'

HOSTS = ['127.0.0.1']

PORT = 9042

PROTOCOL_VERSION = 3

REPLICATION_FACTOR = 1

class eventsourcing.infrastructure.cassandra.factory.**CassandraInfrastructureFactory**(*record_m*
se-
*quenced_*
in-
te-
ger_sequ
times-
tamp_seq
snap-
shot_reco
con-
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tion_id=N
*pipeline_*
1)

Bases: eventsourcing.infrastructure.factory.InfrastructureFactory

integer_sequenced_record_class
alias of eventsourcing.infrastructure.cassandra.records.IntegerSequencedRecord

record_manager_class
alias of *eventsourcing.infrastructure.cassandra.manager.CassandraRecordManager*

snapshot_record_class
alias of eventsourcing.infrastructure.cassandra.records.SnapshotRecord

timestamp_sequenced_record_class
alias of eventsourcing.infrastructure.cassandra.records.TimestampSequencedRecord

class eventsourcing.infrastructure.cassandra.manager.**CassandraRecordManager**(*record_class*, *sequenced_item_class='eventsourcing.infrastructure.seq*, *contiguous_record_ids=Fals*, *application_id=None*, *pipeline_id=-1*)

Bases: *eventsourcing.infrastructure.base.AbstractSequencedItemRecordManager*

all_sequence_ids()
Returns all sequence IDs.

append(*sequenced_item_or_items*)
Writes sequenced item into the datastore.

delete_record(*record*)
Removes permanently given record from the table.

filter(***kwargs*)

get_item(*sequence_id*, *position*)
Gets sequenced item from the datastore.

get_notifications(*start=None*, *stop=None*, **args*, ***kwargs*)
Returns records sequenced by notification ID, from application, for pipeline, in given range.

get_records(*sequence_id*, *gt=None*, *gte=None*, *lt=None*, *lte=None*, *limit=None*, *query_ascending=True*, *results_ascending=True*)
Returns records for a sequence.

datastore

Base classes for concrete datastore classes.

class eventsourcing.infrastructure.datastore.**Datastore**(*settings*)
Bases: object

close_connection()
Drops connection to a datastore.

drop_tables()
Drops tables used to store events.

setup_connection()
Sets up a connection to a datastore.

setup_tables()
Sets up tables used to store events.

truncate_tables()
Truncates tables used to store events.

exception eventsourcing.infrastructure.datastore.**DatastoreConnectionError**
Bases: *eventsourcing.infrastructure.datastore.DatastoreError*

exception eventsourcing.infrastructure.datastore.**DatastoreError**
Bases: Exception

class eventsourcing.infrastructure.datastore.**DatastoreSettings**
Bases: object

Base class for settings for database connection used by a stored event repository.

exception eventsourcing.infrastructure.datastore.**DatastoreTableError**
Bases: *eventsourcing.infrastructure.datastore.DatastoreError*

django

A Django application for event sourcing with the Django ORM.

class eventsourcing.infrastructure.django.manager.**DjangoRecordManager**(**args*, ***kwargs*)
Bases: *eventsourcing.infrastructure.base.RelationalRecordManager*

_prepare_insert(*tmpl*, *record_class*, *field_names*, *placeholder_for_id=False*)
With transaction isolation level of "read committed" this should generate records with a contiguous sequence of integer IDs, using an indexed ID column, the database-side SQL max function, the insert-select-from form, and optimistic concurrency control.

all_sequence_ids()
Returns all sequence IDs.

delete_record(*record*)
Permanently removes record from table.

get_item(*sequence_id*, *position*)
Gets sequenced item from the datastore.

get_max_record_id()
Return maximum ID of existing records.

get_notifications(*start=None*, *stop=None*, **args*, ***kwargs*)
Returns all records in the table.

get_record_table_name(*record_class*)
Returns table name from SQLAlchemy record class.

get_records(*sequence_id*, *gt=None*, *gte=None*, *lt=None*, *lte=None*, *limit=None*, *query_ascending=True*, *results_ascending=True*)
Returns records for a sequence.

eventplayer

Base classes for event players of different kinds.

class eventsourcing.infrastructure.eventplayer.**EventPlayer**(*event_store*, *snapshot_strategy=None*, *use_cache=False*, *mutator_func=None*)
Bases: *eventsourcing.domain.model.entity.AbstractEventPlayer*

event_store

static mutate(*initial*, *event*)

replay_events(*initial_state*, *domain_events*)
Evolves initial state using the sequence of domain events and a mutator function.

eventsourcedrepository

Base classes for event sourced repositories (not abstract, can be used directly).

class eventsourcing.infrastructure.eventsourcedrepository.**EventSourcedRepository**(*event_store*, *snapshot_strategy=*
use_cache=Fa
mutator_func=Non
Bases: *eventsourcing.infrastructure.eventplayer.EventPlayer*, *eventsourcing.domain.model.entity.AbstractEntityRepository*

__contains__(*entity_id*)
Returns a boolean value according to whether entity with given ID exists.

__getitem__(*entity_id*)
Returns entity with given ID.

get_entity(*entity_id*, *at=None*)
Returns entity with given ID, optionally until position.

replay_entity(*entity_id*, *gt=None*, *gte=None*, *lt=None*, *lte=None*, *limit=None*, *initial_state=None*, *query_descending=False*)
Reconstitutes requested domain entity from domain events found in event store.

take_snapshot(*entity_id*, *lt=None*, *lte=None*)
Takes a snapshot of the entity as it existed after the most recent event, optionally less than, or less than or equal to, a particular position.

eventstore

The event store provides the application-level interface to the event sourcing persistence mechanism.

class eventsourcing.infrastructure.eventstore.**AbstractEventStore**
Bases: object

Abstract base class for event stores. Defines the methods expected of an event store by other classes in the library.

all_domain_events()
Returns all domain events in the event store.

append(*domain_event_or_events*)
Put domain event in event store for later retrieval.

get_domain_event(*originator_id*, *position*)
Returns a single domain event.

get_domain_events(*originator_id*, *gt=None*, *gte=None*, *lt=None*, *lte=None*, *limit=None*, *is_ascending=True*, *page_size=None*)
Returns domain events for given entity ID.

get_most_recent_event(*originator_id*, *lt=None*, *lte=None*)
Returns most recent domain event for given entity ID.

class eventsourcing.infrastructure.eventstore.**EventStore**(*record_manager*, *sequenced_item_mapper*)
Bases: *eventsourcing.infrastructure.eventstore.AbstractEventStore*

Event store appends domain events to stored sequences. It uses a record manager to map named tuples to database records, and it uses a sequenced item mapper to map named tuples to application-level objects.

__init__(*record_manager*, *sequenced_item_mapper*)
Initialises event store object.

Parameters

- **record_manager** – record manager
- **sequenced_item_mapper** – sequenced item mapper

all_domain_events()
Yields all domain events in the event store.

append(*domain_event_or_events*)
Appends given domain event, or list of domain events, to their sequence.

Parameters **domain_event_or_events** – domain event, or list of domain events

get_domain_event(*originator_id*, *position*)
Gets a domain event from the sequence identified by *originator_id* at position *eq*.

Parameters

- **originator_id** – ID of a sequence of events
- **position** – get item at this position

Returns domain event

get_domain_events(*originator_id*, *gt=None*, *gte=None*, *lt=None*, *lte=None*, *limit=None*, *is_ascending=True*, *page_size=None*)
Gets domain events from the sequence identified by *originator_id*.

Parameters

- **originator_id** – ID of a sequence of events
- **gt** – get items after this position

- **gte** – get items at or after this position
- **lt** – get items before this position
- **lte** – get items before or at this position
- **limit** – get limited number of items
- **is_ascending** – get items from lowest position
- **page_size** – restrict and repeat database query

Returns list of domain events

get_most_recent_event(*originator_id*, *lt=None*, *lte=None*)
Gets a domain event from the sequence identified by *originator_id* at the highest position.

Parameters

- **originator_id** – ID of a sequence of events
- **lt** – get highest before this position
- **lte** – get highest at or before this position

Returns domain event

iterator_class
alias of *eventsourcing.infrastructure.iterators.SequencedItemIterator*

to_sequenced_item(*domain_event_or_events*)
Maps domain event to sequenced item namedtuple.

Parameters **domain_event_or_events** – application-level object (or list)

Returns namedtuple: sequence item namedtuple (or list)

integersequencegenerators

Different ways of generating sequences of integers.

class eventsourcing.infrastructure.integersequencegenerators.base.**AbstractIntegerSequenceGe**
Bases: object

__next__()
Returns the next item in the container.

next()
Python 2.7 version of the iterator protocol.

class eventsourcing.infrastructure.integersequencegenerators.base.**SimpleIntegerSequenceGene**
Bases: *eventsourcing.infrastructure.integersequencegenerators.base.AbstractIntegerSequenceGenerator*

class eventsourcing.infrastructure.integersequencegenerators.redisincr.**RedisIncr**(*redis=None*, *key=None*)
Bases: *eventsourcing.infrastructure.integersequencegenerators.base.AbstractIntegerSequenceGenerator*

Generates a sequence of integers, using Redis' INCR command.

Maximum number is 2**63, or 9223372036854775807, the maximum value of a 64 bit signed integer.

iterators

Different ways of getting sequenced items from a datastore.

class eventsourcing.infrastructure.iterators.**AbstractSequencedItemIterator**(*record_manager*, *sequence_id*, *page_size=None*, *gt=None*, *gte=None*, *lt=None*, *lte=None*, *limit=None*, *is_ascending=True*)

Bases: object

DEFAULT_PAGE_SIZE = 1000

__iter__()
Yields a continuous sequence of items.

_inc_page_counter()
Increments the page counter.

Each query result as a page, even if there are no items in the page. This really counts queries.

- it is easy to divide the number of events by the page size if the "correct" answer is required
- there will be a difference in the counts when the number of events can be exactly divided by the page size, because there is no way to know in advance that a full page is also the last page.

_inc_query_counter()
Increments the query counter.

class eventsourcing.infrastructure.iterators.**GetEntityEventsThread**(*record_manager*, *sequence_id*, *gt=None*, *gte=None*, *lt=None*, *lte=None*, *page_size=None*, *is_ascending=True*, **args*, ***kwargs*)

Bases: threading.Thread

run()
Method representing the thread's activity.

You may override this method in a subclass. The standard run() method invokes the callable object passed to the object's constructor as the target argument, if any, with sequential and keyword arguments taken from the args and kwargs arguments, respectively.

class eventsourcing.infrastructure.iterators.**SequencedItemIterator**(*record_manager*, *sequence_id*, *page_size=None*, *gt=None*, *gte=None*, *lt=None*, *lte=None*, *limit=None*, *is_ascending=True*)

Bases: *eventsourcing.infrastructure.iterators.AbstractSequencedItemIterator*

__iter__()

Yields a continuous sequence of items from "pages" of sequenced items retrieved using the record manager.

class eventsourcing.infrastructure.iterators.**ThreadedSequencedItemIterator**(*record_manager*, *sequence_id*, *page_size=None*, *gt=None*, *gte=None*, *lt=None*, *lte=None*, *limit=None*, *is_ascending=True*)

Bases: *eventsourcing.infrastructure.iterators.AbstractSequencedItemIterator*

start_thread()

repositories

Repository base classes for entity classes defined in the library.

class eventsourcing.infrastructure.repositories.array.**ArrayRepository**(*array_size=10000*, **args*, ***kwargs*)

Bases: *eventsourcing.domain.model.array.AbstractArrayRepository*, *eventsourcing.infrastructure.eventsourcedrepository.EventSourcedRepository*

class eventsourcing.infrastructure.repositories.array.**BigArrayRepository**(*array_size=10000*, **args*, ***kwargs*)

Bases: *eventsourcing.domain.model.array.AbstractBigArrayRepository*, *eventsourcing.infrastructure.eventsourcedrepository.EventSourcedRepository*

subrepo

Sub-sequence repository.

subrepo_class

alias of *ArrayRepository*

class eventsourcing.infrastructure.repositories.collection_repo.**CollectionRepository**(*event_st snap- shot_str use_cac mu- ta- tor_func*

Bases: *eventsourcing.infrastructure.eventsourcedrepository.EventSourcedRepository*, eventsourcing.domain.model.collection.AbstractCollectionRepository

Event sourced repository for the Collection domain model entity.

class eventsourcing.infrastructure.repositories.timebucketedlog_repo.**TimebucketedlogRepo**(*ev sn sh us m ta to*

Bases: *eventsourcing.infrastructure.eventsourcedrepository.EventSourcedRepository*, *eventsourcing.domain.model.timebucketedlog.TimebucketedlogRepository*

Event sourced repository for the Example domain model entity.

sequenceditem

The persistence model for storing events.

class eventsourcing.infrastructure.sequenceditem.**SequencedItem**(*sequence_id*, *position*, *topic*, *data*)

Bases: tuple

__getnewargs__()
Return self as a plain tuple. Used by copy and pickle.

static __new__(*_cls*, *sequence_id*, *position*, *topic*, *data*)
Create new instance of SequencedItem(sequence_id, position, topic, data)

__repr__()
Return a nicely formatted representation string

_asdict()
Return a new OrderedDict which maps field names to their values.

classmethod _make(*iterable*, *new=<built-in method __new__ of type object at 0xa385c0>*, *len=<built-in function len>*)
Make a new SequencedItem object from a sequence or iterable

_replace(***kwds*)
Return a new SequencedItem object replacing specified fields with new values

data
Alias for field number 3

position
Alias for field number 1

sequence_id
Alias for field number 0

topic
Alias for field number 2

class eventsourcing.infrastructure.sequenceditem.**SequencedItemFieldNames**(*sequenced_item_class*)
Bases: object

data

other_names

position

sequence_id

topic

class eventsourcing.infrastructure.sequenceditem.**StoredEvent**(*originator_id*, *originator_version*, *event_type*, *state*)
Bases: tuple

__getnewargs__()
Return self as a plain tuple. Used by copy and pickle.

static __new__(*_cls*, *originator_id*, *originator_version*, *event_type*, *state*)
Create new instance of StoredEvent(originator_id, originator_version, event_type, state)

__repr__()
Return a nicely formatted representation string

_asdict()
Return a new OrderedDict which maps field names to their values.

classmethod _make(*iterable*, *new=<built-in method __new__ of type object at 0xa385c0>*, *len=<built-in function len>*)
Make a new StoredEvent object from a sequence or iterable

_replace(***kwds*)
Return a new StoredEvent object replacing specified fields with new values

event_type
Alias for field number 2

originator_id
Alias for field number 0

originator_version
Alias for field number 1

state
Alias for field number 3

sequenceditemmapper

The sequenced item mapper maps sequenced items to application-level objects.

class eventsourcing.infrastructure.sequenceditemmapper.**AbstractSequencedItemMapper**
Bases: object

from_sequenced_item(*sequenced_item*)
Return domain event from given sequenced item.

to_sequenced_item(*domain_event*)
Returns sequenced item for given domain event.

class eventsourcing.infrastructure.sequenceditemmapper.**SequencedItemMapper**(*sequenced_item_class='eventsourcing.infrastructure.sequenced*, *sequence_id_attr_name=None*, *position_attr_name=None*, *json_encoder_class=None*, *json_decoder_class=None*, *cipher=None*, *other_attr_names=()*)

Bases: *eventsourcing.infrastructure.sequenceditemmapper.AbstractSequencedItemMapper*

Uses JSON to transcode domain events.

construct_item_args(*domain_event*)
Constructs attributes of a sequenced item from the given domain event.

construct_sequenced_item(*item_args*)

from_sequenced_item(*sequenced_item*)
Reconstructs domain event from stored event topic and event attrs. Used in the event store when getting domain events.

from_topic_and_data(*topic*, *data*)

to_sequenced_item(*domain_event*)
Constructs a sequenced item from a domain event.

eventsourcing.infrastructure.sequenceditemmapper.**reconstruct_object**(*obj_class*, *obj_state*)

snapshotting

Snapshotting avoids having to replay an entire sequence of events to obtain the current state of a projection.

class eventsourcing.infrastructure.snapshotting.**AbstractSnapshotStrategy**
Bases: object

get_snapshot(*entity_id*, *lt=None*, *lte=None*)
Gets the last snapshot for entity, optionally until a particular version number.

Return type *Snapshot*

take_snapshot(*entity_id*, *entity*, *last_event_version*)
Takes a snapshot of entity, using given ID, state and version number.

Return type *AbstractSnapshop*

class eventsourcing.infrastructure.snapshotting.**EventSourcedSnapshotStrategy**(*event_store*)
Bases: *eventsourcing.infrastructure.snapshotting.AbstractSnapshotStrategy*

Snapshot strategy that uses an event sourced snapshot.

get_snapshot(*entity_id*, *lt=None*, *lte=None*)
Gets the last snapshot for entity, optionally until a particular version number.

Return type *Snapshot*

take_snapshot(*entity_id*, *entity*, *last_event_version*)
Takes a snapshot by instantiating and publishing a Snapshot domain event.

Return type *Snapshot*

eventsourcing.infrastructure.snapshotting.**entity_from_snapshot**(*snapshot*)
Reconstructs domain entity from given snapshot.

sqlalchemy

Classes for event sourcing with SQLAlchemy.

class eventsourcing.infrastructure.sqlalchemy.datastore.**SQLAlchemyDatastore**(*base=<class 'sqlalchemy.ext.decla tables=None, connection_strategy='plain' session=None, **kwargs*)

Bases: *eventsourcing.infrastructure.datastore.Datastore*

close_connection()
Drops connection to a datastore.

drop_table(*table*)

drop_tables()
Drops tables used to store events.

is_sqlite()

session

setup_connection()
Sets up a connection to a datastore.

setup_table(*table*)

setup_tables(*tables=None*)
Sets up tables used to store events.

truncate_tables()
Truncates tables used to store events.

class eventsourcing.infrastructure.sqlalchemy.datastore.**SQLAlchemySettings**(*uri=None*, *pool_size=5*)

Bases: *eventsourcing.infrastructure.datastore.DatastoreSettings*

class eventsourcing.infrastructure.sqlalchemy.factory.**SQLAlchemyInfrastructureFactory**(*session *args, **kwa*

Bases: eventsourcing.infrastructure.factory.InfrastructureFactory

construct_record_manager(***kwargs*)

integer_sequenced_record_class
alias of *eventsourcing.infrastructure.sqlalchemy.records.IntegerSequencedWithIDRecord*

record_manager_class
alias of *eventsourcing.infrastructure.sqlalchemy.manager.SQLAlchemyRecordManager*

snapshot_record_class
alias of *eventsourcing.infrastructure.sqlalchemy.records.SnapshotRecord*

timestamp_sequenced_record_class
alias of *eventsourcing.infrastructure.sqlalchemy.records.TimestampSequencedNoIDRecord*

eventsourcing.infrastructure.sqlalchemy.factory.**construct_sqlalchemy_eventstore**(*session*, *sequenced_item_c*, *sequence_id_attr*, *position_attr_name*, *json_encoder_c*, *json_decoder_c*, *cipher=None*, *record_class=N*, *contiguous_record_ids*, *application_id=None*, *pipeline_id=-1*)

class eventsourcing.infrastructure.sqlalchemy.manager.**SQLAlchemyRecordManager**(*session*, **args*, ***kwargs*)

Bases: *eventsourcing.infrastructure.base.RelationalRecordManager*

_prepare_insert(*tmpl*, *record_class*, *field_names*, *placeholder_for_id=False*)
With transaction isolation level of "read committed" this should generate records with a contiguous sequence of integer IDs, assumes an indexed ID column, the database-side SQL max function, the insert-select-from form, and optimistic concurrency control.

all_sequence_ids()
Returns all sequence IDs.

delete_record(*record*)
Permanently removes record from table.

filter_by(***kwargs*)

get_item(*sequence_id*, *position*)
Gets sequenced item from the datastore.

get_max_record_id()
Return maximum ID of existing records.

get_notifications(*start=None*, *stop=None*, **args*, ***kwargs*)
Returns records sequenced by notification ID, from application, for pipeline, in given range.

get_pipeline_and_notification_id(*sequence_id*, *position*)

get_record(*sequence_id*, *position*)

get_record_table_name(*record_class*)
Returns table name - used in raw queries.

Return type str

get_records(*sequence_id*, *gt=None*, *gte=None*, *lt=None*, *lte=None*, *limit=None*, *query_ascending=True*, *results_ascending=True*)
Returns records for a sequence.

orm_query()

tracking_record_class
alias of *eventsourcing.infrastructure.sqlalchemy.records.NotificationTrackingRecord*

class eventsourcing.infrastructure.sqlalchemy.manager.**TrackingRecordManager**(*session*)
Bases: *eventsourcing.infrastructure.base.AbstractTrackingRecordManager*

get_max_record_id(*application_name*, *upstream_application_name*, *pipeline_id*)
Returns maximum record ID for given application name.

has_tracking_record(*application_id*, *upstream_application_name*, *pipeline_id*, *notification_id*)

record_class
alias of *eventsourcing.infrastructure.sqlalchemy.records.NotificationTrackingRecord*

class eventsourcing.infrastructure.sqlalchemy.records.**IntegerSequencedNoIDRecord**(***kwargs*)
Bases: sqlalchemy.ext.declarative.api.Base

__init__(***kwargs*)
A simple constructor that allows initialization from kwargs.

Sets attributes on the constructed instance using the names and values in `kwargs`.

Only keys that are present as attributes of the instance's class are allowed. These could be, for example, any mapped columns or relationships.

data

position

sequence_id

topic

eventsourcing.infrastructure.sqlalchemy.records.**IntegerSequencedRecord**
alias of *eventsourcing.infrastructure.sqlalchemy.records.IntegerSequencedWithIDRecord*

class eventsourcing.infrastructure.sqlalchemy.records.**IntegerSequencedWithIDRecord**(***kwargs*)
Bases: sqlalchemy.ext.declarative.api.Base

__init__(***kwargs*)
A simple constructor that allows initialization from kwargs.

Sets attributes on the constructed instance using the names and values in `kwargs`.

Only keys that are present as attributes of the instance's class are allowed. These could be, for example, any mapped columns or relationships.

data

id

position

sequence_id

topic

class eventsourcing.infrastructure.sqlalchemy.records.**NotificationTrackingRecord**(***kwargs*)
Bases: sqlalchemy.ext.declarative.api.Base

__init__(***kwargs*)
A simple constructor that allows initialization from kwargs.

Sets attributes on the constructed instance using the names and values in `kwargs`.

Only keys that are present as attributes of the instance's class are allowed. These could be, for example, any mapped columns or relationships.

application_id

notification_id

pipeline_id

upstream_application_id

class eventsourcing.infrastructure.sqlalchemy.records.**SnapshotRecord**(***kwargs*)
Bases: sqlalchemy.ext.declarative.api.Base

__init__(***kwargs*)
A simple constructor that allows initialization from kwargs.

Sets attributes on the constructed instance using the names and values in `kwargs`.

Only keys that are present as attributes of the instance's class are allowed. These could be, for example, any mapped columns or relationships.

data

position

sequence_id

topic

class eventsourcing.infrastructure.sqlalchemy.records.**StoredEventRecord**(***kwargs*)
Bases: sqlalchemy.ext.declarative.api.Base

__init__(***kwargs*)
A simple constructor that allows initialization from kwargs.

Sets attributes on the constructed instance using the names and values in `kwargs`.

Only keys that are present as attributes of the instance's class are allowed. These could be, for example, any mapped columns or relationships.

application_id

causal_dependencies

event_type

id

originator_id

originator_version

pipeline_id

state

class eventsourcing.infrastructure.sqlalchemy.records.**TimestampSequencedNoIDRecord**(***kwargs*)
Bases: sqlalchemy.ext.declarative.api.Base

__init__(***kwargs*)
A simple constructor that allows initialization from kwargs.

Sets attributes on the constructed instance using the names and values in `kwargs`.

Only keys that are present as attributes of the instance's class are allowed. These could be, for example, any mapped columns or relationships.

data

position

sequence_id

topic

eventsourcing.infrastructure.sqlalchemy.records.**TimestampSequencedRecord**
alias of *eventsourcing.infrastructure.sqlalchemy.records.TimestampSequencedNoIDRecord*

class eventsourcing.infrastructure.sqlalchemy.records.**TimestampSequencedWithIDRecord**(***kwarg*
Bases: sqlalchemy.ext.declarative.api.Base

__init__(***kwargs*)
A simple constructor that allows initialization from kwargs.

Sets attributes on the constructed instance using the names and values in `kwargs`.

Only keys that are present as attributes of the instance's class are allowed. These could be, for example, any mapped columns or relationships.

data

id

position

sequence_id

topic

timebucketedlog_reader

Reader for timebucketed logs.

class eventsourcing.infrastructure.timebucketedlog_reader.**TimebucketedlogReader**(*log*, *event_store*, *page_size=50*)
Bases: object

get_events(*gt=None*, *gte=None*, *lt=None*, *lte=None*, *limit=None*, *is_ascending=False*, *page_size=None*)

get_messages(*gt=None*, *gte=None*, *lt=None*, *lte=None*, *limit=None*, *is_ascending=False*, *page_size=None*)

eventsourcing.infrastructure.timebucketedlog_reader.**get_timebucketedlog_reader**(*log*, *event_store*)

Return type *TimebucketedlogReader*

interface

The interface layer uses an application to service client requests.

notificationlog

Notification log is a pull-based mechanism for updating other applications.

class eventsourcing.interface.notificationlog.**AbstractNotificationLog**

Bases: object

Presents a sequence of sections from a sequence of notifications.

__getitem__(*section_id*)

Get section of notification log.

Return type *Section*

class eventsourcing.interface.notificationlog.**BigArrayNotificationLog**(*big_array*, *section_size*)

Bases: *eventsourcing.interface.notificationlog.LocalNotificationLog*

get_items(*start*, *stop*, *next_position=None*)

Returns items for section.

Return type list

get_next_position()

Returns items for section.

Return type int

class eventsourcing.interface.notificationlog.**LocalNotificationLog**(*section_size=None*)

Bases: *eventsourcing.interface.notificationlog.AbstractNotificationLog*

Presents a sequence of sections from a sequence of notifications.

static format_section_id(*first_item_number*, *last_item_number*)

get_items(*start*, *stop*, *next_position=None*)

Returns items for section.

Return type list

get_next_position()

Returns items for section.

Return type int

class eventsourcing.interface.notificationlog.**NotificationLogReader**(*notification_log*)

Bases: object

next()
Python 2.7 version of the iterator protocol.

read(*advance_by=None*)

read_items(*stop_index=None*, *advance_by=None*)

read_list(*advance_by=None*)

seek(*position*)

class eventsourcing.interface.notificationlog.**NotificationLogView**(*notification_log*, *json_encoder_class=None*)

Bases: object

present_section(*section_id*)

class eventsourcing.interface.notificationlog.**RecordManagerNotificationLog**(*record_manager*, *section_size*)

Bases: *eventsourcing.interface.notificationlog.LocalNotificationLog*

get_end_position()

get_items(*start*, *stop*, *next_position=None*)
Returns items for section.

Return type list

get_next_position()
Returns items for section.

Return type int

class eventsourcing.interface.notificationlog.**RemoteNotificationLog**(*base_url*, *json_decoder_class=None*)

Bases: *eventsourcing.interface.notificationlog.AbstractNotificationLog*

deserialize_section(*section_json*)

get_json(*section_id*)

get_resource(*doc_url*)

make_notification_log_url(*section_id*)

class eventsourcing.interface.notificationlog.**Section**(*section_id*, *items*, *previous_id=None*, *next_id=None*)

Bases: object

Section of a notification log.

Contains items, and has an ID.

May also have either IDs of previous and next sections of the notification log.

utils

The utils package contains common functions that are used in more than one layer.

cipher

class eventsourcing.utils.cipher.aes.**AESCipher**(*cipher_key*)
Bases: object

Cipher strategy that uses Crypto library AES cipher in GCM mode.

__init__(*cipher_key*)
Initialises AES cipher strategy with cipher_key.

Parameters **cipher_key** – 16, 24, or 32 random bytes

decrypt(*ciphertext*)
Return plaintext for given ciphertext.

encrypt(*plaintext*)
Return ciphertext for given plaintext.

time

eventsourcing.utils.times.**datetime_from_timestamp**(*t*)
Returns a datetime from a decimal UNIX timestamp.

Parameters **t** – timestamp, either Decimal or float

Returns datetime.datetime object

eventsourcing.utils.times.**decimaltimestamp**(*t=None*)
A UNIX timestamp as a Decimal object (exact number type).

Returns current time when called without args, otherwise converts given floating point number t to a Decimal with 9 decimal places.

Parameters **t** – Floating point UNIX timestamp ("seconds since epoch").

Returns A Decimal with 6 decimal places, representing the given floating point or the value returned by time.time().

eventsourcing.utils.times.**decimaltimestamp_from_uuid**(*uuid_arg*)
Return a floating point unix timestamp.

Parameters **uuid_arg** –

Returns Unix timestamp in seconds, with microsecond precision.

Return type float

eventsourcing.utils.times.**timestamp_long_from_uuid**(*uuid_arg*)
Returns an integer value representing a unix timestamp in tenths of microseconds.

Parameters **uuid_arg** –

Returns Unix timestamp integer in tenths of microseconds.

Return type int

topic

eventsourcing.utils.topic.**get_topic**(*domain_class*)
Returns a string describing a class.

Args: domain_class: A class.

Returns: A string describing the class.

eventsourcing.utils.topic.**resolve_attr**(*obj*, *path*)
A recursive version of getattr for navigating dotted paths.

Args: obj: An object for which we want to retrieve a nested attribute. path: A dot separated string containing zero or more attribute names.

Returns: The attribute referred to by obj.a1.a2.a3...

Raises: AttributeError: If there is no such attribute.

eventsourcing.utils.topic.**resolve_topic**(*topic*)
Return class described by given topic.

Args: topic: A string describing a class.

Returns: A class.

Raises: TopicResolutionError: If there is no such class.

transcoding

class eventsourcing.utils.transcoding.**ObjectJSONDecoder**(*object_hook=None*, ***kwargs*)
Bases: json.decoder.JSONDecoder

classmethod from_jsonable(*d*)

class eventsourcing.utils.transcoding.**ObjectJSONEncoder**(*sort_keys=True*, **args*, ***kwargs*)
Bases: json.encoder.JSONEncoder

default(*obj*)
Implement this method in a subclass such that it returns a serializable object for o, or calls the base implementation (to raise a TypeError).

For example, to support arbitrary iterators, you could implement default like this:

```
def default(self, o):
    try:
        iterable = iter(o)
    except TypeError:
        pass
    else:
        return list(iterable)
    # Let the base class default method raise the TypeError
    return JSONEncoder.default(self, o)
```

eventsourcing.utils.transcoding.**json_dumps**(*obj*, *cls=None*)

eventsourcing.utils.transcoding.**json_loads**(*s*, *cls=None*)

exceptions

A few exception classes are defined by the library to indicate particular kinds of error.

exception eventsourcing.exceptions.**ArrayIndexError**
Bases: IndexError, *eventsourcing.exceptions.EventSourcingError*

Raised when appending item to an array that is full.

exception eventsourcing.exceptions.**CausalDependencyFailed**
Bases: *eventsourcing.exceptions.EventSourcingError*

Raised when a causal dependency fails (after its tracking record not found).

exception eventsourcing.exceptions.**ConcurrencyError**
Bases: *eventsourcing.exceptions.RecordConflictError*

Raised when a record conflict is due to concurrency.

exception eventsourcing.exceptions.**ConsistencyError**
Bases: *eventsourcing.exceptions.EventSourcingError*

Raised when applying an event stream to a versioned entity.

exception eventsourcing.exceptions.**DataIntegrityError**
Bases: ValueError, *eventsourcing.exceptions.EventSourcingError*

Raised when a sequenced item data is damaged (hash doesn't match data)

exception eventsourcing.exceptions.**DatasourceSettingsError**
Bases: *eventsourcing.exceptions.EventSourcingError*

Raised when an error is detected in settings for a datasource.

exception eventsourcing.exceptions.**EntityIsDiscarded**
Bases: AssertionError

Raised when access to a recently discarded entity object is attempted.

exception eventsourcing.exceptions.**EntityVersionNotFound**
Bases: *eventsourcing.exceptions.EventSourcingError*

Raise when accessing an entity version that does not exist.

exception eventsourcing.exceptions.**EventHashError**
Bases: *eventsourcing.exceptions.DataIntegrityError*

Raised when an event's seal hash doesn't match the hash of the state of the event.

exception eventsourcing.exceptions.**EventRecordNotFound**
Bases: *eventsourcing.exceptions.EventSourcingError*

Raised when an event record is not found.

exception eventsourcing.exceptions.**EventSourcingError**
Bases: Exception

Base eventsourcing exception.

exception eventsourcing.exceptions.**HeadHashError**
Bases: *eventsourcing.exceptions.DataIntegrityError*, *eventsourcing.exceptions.MismatchedOriginatorError*

Raised when applying an event with hash different from aggregate head.

exception eventsourcing.exceptions.**MismatchedOriginatorError**
Bases: *eventsourcing.exceptions.ConsistencyError*

Raised when applying an event to an inappropriate object.

exception eventsourcing.exceptions.**MutatorRequiresTypeNotInstance**
Bases: *eventsourcing.exceptions.ConsistencyError*

Raised when mutator function received a class rather than an entity.

exception eventsourcing.exceptions.**OperationalError**
Bases: *eventsourcing.exceptions.EventSourcingError*

Raised when an operational error is encountered.

exception eventsourcing.exceptions.**OriginatorIDError**
Bases: *eventsourcing.exceptions.MismatchedOriginatorError*

Raised when applying an event to the wrong entity or aggregate.

exception eventsourcing.exceptions.**OriginatorVersionError**
Bases: *eventsourcing.exceptions.MismatchedOriginatorError*

Raised when applying an event to the wrong version of an entity or aggregate.

exception eventsourcing.exceptions.**ProgrammingError**
Bases: *eventsourcing.exceptions.EventSourcingError*

Raised when programming errors are encountered.

exception eventsourcing.exceptions.**PromptFailed**
Bases: *eventsourcing.exceptions.EventSourcingError*

Raised when prompt fails.

exception eventsourcing.exceptions.**RecordConflictError**
Bases: *eventsourcing.exceptions.EventSourcingError*

Raised when database raises an integrity error.

exception eventsourcing.exceptions.**RepositoryKeyError**
Bases: KeyError, *eventsourcing.exceptions.EventSourcingError*

Raised when using entity repository's dictionary like interface to get an entity that does not exist.

exception eventsourcing.exceptions.**TimeSequenceError**
Bases: *eventsourcing.exceptions.EventSourcingError*

Raised when a time sequence error occurs e.g. trying to save a timestamp that already exists.

exception eventsourcing.exceptions.**TopicResolutionError**
Bases: *eventsourcing.exceptions.EventSourcingError*

Raised when unable to resolve a topic to a Python class.

exception eventsourcing.exceptions.**TrackingRecordNotFound**
Bases: *eventsourcing.exceptions.EventSourcingError*

Raised when a tracking record is not found.

example

A simple, unit-tested, event sourced application.

application

class eventsourcing.example.application.**ExampleApplication**(***kwargs*)
Bases: *eventsourcing.application.base.ApplicationWithPersistencePolicies*

Example event sourced application with entity factory and repository.

create_new_example(*foo=''*, *a=''*, *b=''*)
Entity object factory.

eventsourcing.example.application.**close_example_application**()
Shuts down single global instance of application.

To be called when tearing down, perhaps between tests, in order to allow a subsequent call to init_example_application().

eventsourcing.example.application.**construct_example_application**(***kwargs*)
Application object factory.

eventsourcing.example.application.**get_example_application**()
Returns single global instance of application.

To be called when handling a worker request, if required.

eventsourcing.example.application.**init_example_application**(***kwargs*)
Constructs single global instance of application.

To be called when initialising a worker process.

domainmodel

class eventsourcing.example.domainmodel.**AbstractExampleRepository**
Bases: *eventsourcing.domain.model.entity.AbstractEntityRepository*

class eventsourcing.example.domainmodel.**Example**(*foo=''*, *a=''*, *b=''*, ***kwargs*)
Bases: *eventsourcing.domain.model.entity.TimestampedVersionedEntity*

An example event sourced domain model entity.

class AttributeChanged(*originator_version*, ***kwargs*)
Bases: eventsourcing.example.domainmodel.Event, eventsourcing.domain.model.entity.AttributeChanged

Published when an Example is created.

class Created(*originator_version=0*, ***kwargs*)
Bases: eventsourcing.example.domainmodel.Event, eventsourcing.domain.model.entity.Created

Published when an Example is created.

class Discarded(*originator_version*, ***kwargs*)
Bases: eventsourcing.example.domainmodel.Event, eventsourcing.domain.model.entity.Discarded

Published when an Example is discarded.

class Event(*originator_version*, ***kwargs*)
Bases: eventsourcing.domain.model.entity.Event

Supertype for events of example entities.

class Heartbeat(*originator_version*, ***kwargs*)
Bases: eventsourcing.example.domainmodel.Event, eventsourcing.domain.model.entity.Event

Published when a heartbeat in the entity occurs (see below).

mutate(*obj*)
Update obj with values from self.

a
An example attribute.

b
Another example attribute.

beat_heart(*number_of_beats=1*)

count_heartbeats()

foo
An example attribute.

eventsourcing.example.domainmodel.**create_new_example**(*foo=''*, *a=''*, *b=''*)
Factory method for example entities.

Return type *Example*

infrastructure

class eventsourcing.example.infrastructure.**ExampleRepository**(*event_store*, *snapshot_strategy=None*, *use_cache=False*, *mutator_func=None*)
Bases: *eventsourcing.infrastructure.eventsourcedrepository.EventSourcedRepository*, *eventsourcing.example.domainmodel.AbstractExampleRepository*

Event sourced repository for the Example domain model entity.

interface

class eventsourcing.example.interface.flaskapp.**IntegerSequencedItem**(***kwargs*)
Bases: sqlalchemy.ext.declarative.api.Model

__init__(***kwargs*)
A simple constructor that allows initialization from kwargs.

Sets attributes on the constructed instance using the names and values in `kwargs`.

Only keys that are present as attributes of the instance's class are allowed. These could be, for example, any mapped columns or relationships.

data

id

position

sequence_id

topic

eventsourcing.example.interface.flaskapp.**hello**()

eventsourcing.example.interface.flaskapp.**init_example_application_with_sqlalchemy**()

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