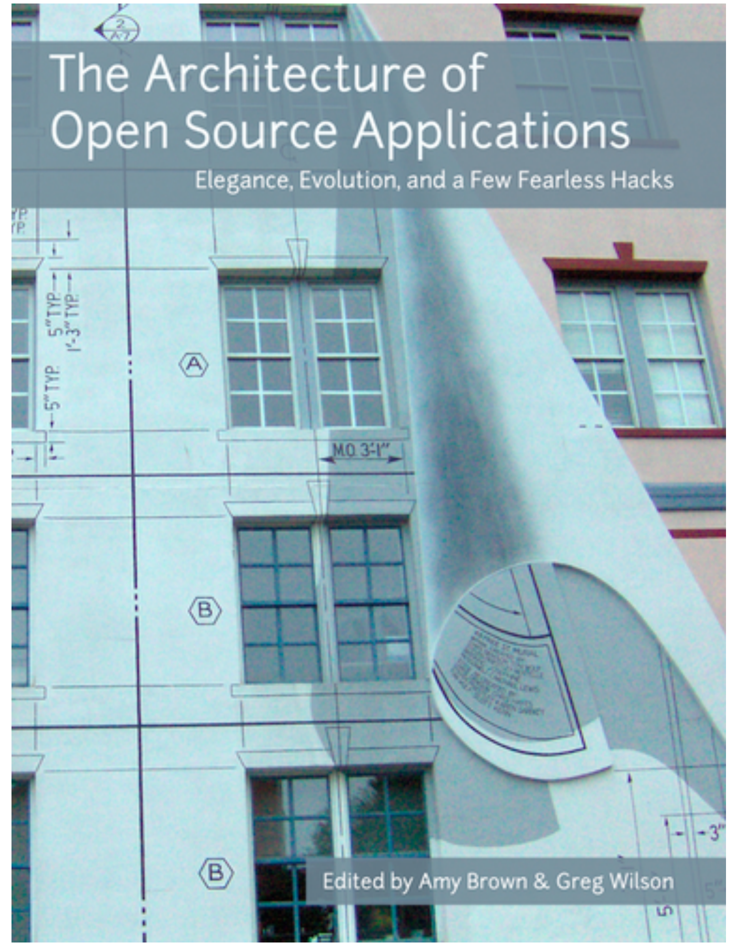
SQLAlchemy: an Architectural Retrospective

Front Matter

- This talk is loosely based on the SQLAlchemy chapter I'm writing for *The Architecture of Open Source Applications*
- http://www.aosabook.org/en/index.html



Introduction

- SQLAlchemy, the Database Toolkit for Python
- Introduced in 2005
- End-to-end system for working with the Python DBAPI
- Got early attention fast: fluent SQL, ORM with Unit of Work pattern

Part I - Philosophy

"Abstraction"

- When we talk about relational database tools, the term "database abstraction layer" is often used.
- What is implied by "Abstraction" ?
  - Conceal details of how data is stored and queried?
  - Should an abstraction layer conceal even that the database is relational ?
  - Should it talk to S3, MongoDB, DBM files just like a SQL database ?
  - In this definition, "abstraction" means "hiding".

Problems with "abstraction=hiding"

- SQL language involves "relations" (i.e. tables, views, SELECT statements) that can be sliced into subsets, intersected on attributes (i.e. joins)
- Ability to organize and query for data in a relational way is the primary feature of relational databases.
- Hiding it means you no longer have that capability.
- Why use a relational database then? Many alternatives now.
- We don't want "hiding". We want "automation"!

Automation

- Provide succinct patterns that automate the usage of lower level systems
- Establish single points of behavioral variance
- We still need to do work, know how everything works, design all strategies!
- But we work efficiently, instructing our tools to do the grunt work we give them.
- Use our **own** schema/design conventions, not someone else's

SQLAlchemy's Approach

- The developer must consider the relational form of the target data.
- Query and schema design decisions are all made by the developer. Tools don't make decisions.
- Provide a rich, detailed vocabulary to express these decisions
- Developer creates patterns and conventions based on this vocabulary.
- Opposite to the approach of providing defaults + ways to override some of them

An out of the box mapping

```
class User(Base):
    __tablename__ = 'user'
    id = Column(Integer, primary_key=True)
    username = Column(String(50), nullable=False)
    addresses = relationship("Address", backref="user",
                       cascade="all, delete-orphan")

class Address(Base):
    __tablename__ = 'address'
    id = Column(Integer, primary_key=True)
    user_id = Column(Integer, ForeignKey('user.id'),
                nullable=False)
    street = Column(String(50))
    city = Column(String(50))
    state = Column(CHAR(2))
    zip = Column(String(15))
```

Dealing with Verbosity

- But what about how verbose that was ?
  - Is that verbosity a problem when...
  - Your whole app has just the two classes ? No.
  - You have a large app, using those same patterns over and over again - yes.
  - Then we're writing a large app.   Large apps should have foundations!

Building a Foundation

Use a base that defines the conventions for all tables and classes

```
from sqlalchemy import Column, Integer
from sqlalchemy.ext.declarative import declarative_base

class Base(object):
    """Define the base conventions for
    all tables/classes."""

    @declared_attr
    def __tablename__(cls):
      """Table is named after the class name"""
      return cls.__name__.lower()

    id = Column(Integer, primary_key=True)
    """Surrogate primary key column named 'id'"""

Base = declarative_base(cls=Base)
```

Building a Foundation

Use functions to represent common idioms, like foreign key columns, datatypes that are common

```
def fk(tablename, nullable=False):
  """Define a convention for all foreign key columns.
   Just give it the table name."""

  return Column("%s_id" % tablename, Integer,
               ForeignKey("%s.id" % tablename),
               nullable=nullable)
```

Building a Foundation

Use prototypes and similar techniques for particular table structures that are common

```
class AddressPrototype(object):
  """Lots of objects will have an 'address'.  Let's
  build a prototype for it.'"""

  street = Column(String(50))
  city = Column(String(50))
  state = Column(CHAR(2))
  zip = Column(String(15))
```

Building a Foundation

Use mixins to define table/class attributes common to subsets of the domain model

```
class HasAddresses(object):
    """Define classes that have a collection of
    addresses via the AddressPrototype foundation."""

    @declared_attr
    def addresses(cls):
        cls.Address = type("%sAddress" % cls.__name__,
                (AddressPrototype, Base),
                {'%s_id' % cls.__tablename__:fk(cls.__tablename__)}
              )
        return relationship(cls.Address,
                                            backref=cls.__name__.lower(),
                                            cascade="all, delete-orphan")
```

Use the Foundation

With our conventions in place, the actual mapping for both user/address looks like this

```
from myapp.base import (
            HasAddresses, Base, Column, String
           )

class User(HasAddresses, Base):
  username = Column(String(50), nullable=False)

Address = User.Address
```

More Foundation

- More examples of convention-oriented "helpers", including pre-fab one_to_many()/many_to_one()/many_to_many() helpers, at http://techspot.zzzeek.org/2011/05/17/magic-a-new-orm/

Exposing Relational Constructs

- SQLAlchemy's querying system doesn't try to hide that a relational database is in use.
- Like "power steering" for SQL. Doesn't teach you how to drive!
- Developer should be very aware of the SQL being emitted. SQLAlchemy makes this easy via logging or "echo" flag.
- Just like your car has windows to see where you're going!

Exposing Relational Constructs - An example

Users on a certain street with no address in NYC - a hypothetical "relational-agnostic" way

```
my_user = User.\
            filter(addresses__street = '123 Green Street').\
            has_none(addresses__city = "New York")[0]

# obvious SQL from the above

SELECT * FROM user JOIN address ON user.id=address.user_id
WHERE address.street == '123 Green Street'
AND NOT EXISTS (
    SELECT * FROM address WHERE city='New York'
    AND user_id=user.id
)
```

Exposing Relational Constructs - An example

- Now I want:
  - Give me all households in New York with exactly two occupants where neither occupant has any residences outside of the city.
- Our model isn't terrifically optimized for this query, since the "address" rows are not normalized
- This query needs to be built relationally,referencing relational structures explicitly and building from the inside out
- This is why we like relational databases !

Build a query from the inside out

```
-- New York addresses that have two
-- occupants

SELECT street, city, zip FROM address
    WHERE city='New York'
    GROUP BY street, city, zip
    HAVING count(user_id) = 2
```

Build a query from the inside out

```
-- users who are different from each other

SELECT * FROM user AS u_1 JOIN
  user AS u_2 ON u_1.id > u_2.id
```

Build a query from the inside out

```
-- join them to their addresses, join addresses
-- to the two occupant NY addresses

SELECT * FROM user AS u_1 JOIN
  user AS u_2 ON u_1.id > u_2.id JOIN
  address AS a_1 ON u_1.id = a_1.user_id JOIN
  address AS a_2 ON u_2.id = a_2.user_id JOIN
  (SELECT street, city, zip FROM address
            WHERE city='New York'
            GROUP BY street, city, zip
            HAVING count(user_id) = 2
  ) AS two_occupant_ny ON (
     a_1.street=two_occupant_ny.street AND
     a_1.city=two_occupant_ny.city AND
     a_1.zip=two_occupant_ny.zip AND
     a_2.street=two_occupant_ny.street AND
     a_2.city=two_occupant_ny.city AND
     a_2.zip=two_occupant_ny.zip
  )
```

Build a query from the inside out

```
-- ... who don't have a house outside of New York

SELECT * FROM user AS u_1 JOIN
  user AS u_2 ON u_1.id > u_2.id JOIN
  address AS a_1 ON u_1.id = a_1.user_id JOIN
  address AS a_2 ON u_2.id = a_2.user_id JOIN
  (SELECT street, city, zip FROM address
            WHERE city='New York'
            GROUP BY street, city, zip
            HAVING count(user_id) = 2
  ) AS two_occupant_ny ON (
      a_1.street == two_occupant_ny.street AND
      a_1.city == two_occupant_ny.city AND
      a_1.zip == two_occupant_ny.zip AND
      a_2.street == two_occupant_ny.street AND
      a_2.city == two_occupant_ny.city AND
      a_2.zip == two_occupant_ny.zip
    ) AND NOT EXISTS (SELECT * FROM address WHERE
      city!='New York' AND
      user_id=u_1.id OR
      user_id=u_2.id)
```

Build a query from the inside out

- SQLAlchemy gives you this same "inside out" paradigm - you think in terms of SQL relations and joins in the same way as when constructing plain SQL.
- SQLAlchemy can then apply automated enhancements like eager loading, row limiting, further relational transformations

Build a `Query()` from the inside out

```
# New York addresses that have two
# occupants

two_occupant_ny = \
    Session.query(Address.street, Address.city, Address.zip).\
        filter(Address.city == 'New York').\
        group_by(Address.street, Address.city, Address.zip).\
        having(func.count(Address.user_id) == 2).\
        subquery()
```

Build a `Query()` from the inside out

```
# users who are different from each other

u_1, u_2 = aliased(User), aliased(User)

user_q = Session.query(u_1, u_2).\
        select_from(u_1).\
        join(u_2, u_1.id > u_2.id)
```

Build a `Query()` from the inside out

```
# join them to their addresses, join addresses
# to the two occupant NY addresses

a_1, a_2 = aliased(Address), aliased(Address)
user_q = user_q.\
            join(a_1, u_1.addresses).\
            join(a_2, u_2.addresses).\
            join(
                two_occupant_ny,
                and_(
                    a_1.street==two_occupant_ny.c.street,
                    a_1.city==two_occupant_ny.c.city,
                    a_1.zip==two_occupant_ny.c.zip,
                    a_2.street==two_occupant_ny.c.street,
                    a_2.city==two_occupant_ny.c.city,
                    a_2.zip==two_occupant_ny.c.zip,
                )
            )
```

Build a `Query()` from the inside out

```
# who don't have a house outside of New York

user_q = user_q.filter(
                ~exists([Address.id]).
                    where(Address.city != 'New York').\
                    where(or_(
                        Address.user_id==u_1.id,
                        Address.user_id==u_2.id
                    ))
            )
```

Build a `Query()` from the inside out

```
# pre-load all the Address objects for each
# User too !

user_q = user_q.options(
                joinedload(u_1.addresses),
                joinedload(u_2.addresses))
users = user_q.all()
```

What's it look like ?

```
SELECT user_1.id AS user_1_id, user_1.username AS user_1_username, user_2.id AS
user_2_id, user_2.username AS user_2_username, address_1.id AS address_1_id,
address_1.street AS address_1_street, address_1.city AS address_1_city, address_1.zip
AS address_1_zip, address_1.user_id AS address_1_user_id, address_2.id AS
address_2_id, address_2.street AS address_2_street, address_2.city AS address_2_city,
address_2.zip AS address_2_zip, address_2.user_id AS address_2_user_id
FROM user AS user_1
   JOIN user AS user_2 ON user_1.id > user_2.id
   JOIN address AS address_3 ON user_1.id = address_3.user_id
   JOIN address AS address_4 ON user_2.id = address_4.user_id
   JOIN (SELECT address.street AS street, address.city AS city, address.zip AS zip
     FROM address
     WHERE address.city = ? GROUP BY address.street, address.city, address.zip
     HAVING count(address.user_id) = ?) AS anon_1 ON address_3.street = anon_1.street
AND address_3.city = anon_1.city AND address_3.zip = anon_1.zip AND address_4.street =
anon_1.street AND address_4.city = anon_1.city AND address_4.zip = anon_1.zip
     LEFT OUTER JOIN address AS address_1 ON user_1.id = address_1.user_id
     LEFT OUTER JOIN address AS address_2 ON user_2.id = address_2.user_id
WHERE NOT (EXISTS (SELECT address.id
               FROM address WHERE address.city != ? AND (address.user_id = user_1.id
OR address.user_id = user_2.id)))

--params: ('New York', 2, 'New York')

# result !
User(name=u5, addresses=s1/New York/12345, s2/New York/12345, s3/New York/12345) /
User(name=u2, addresses=s2/New York/12345, s4/New York/12345, s5/New York/12345)
```

"Leaky Abstraction"

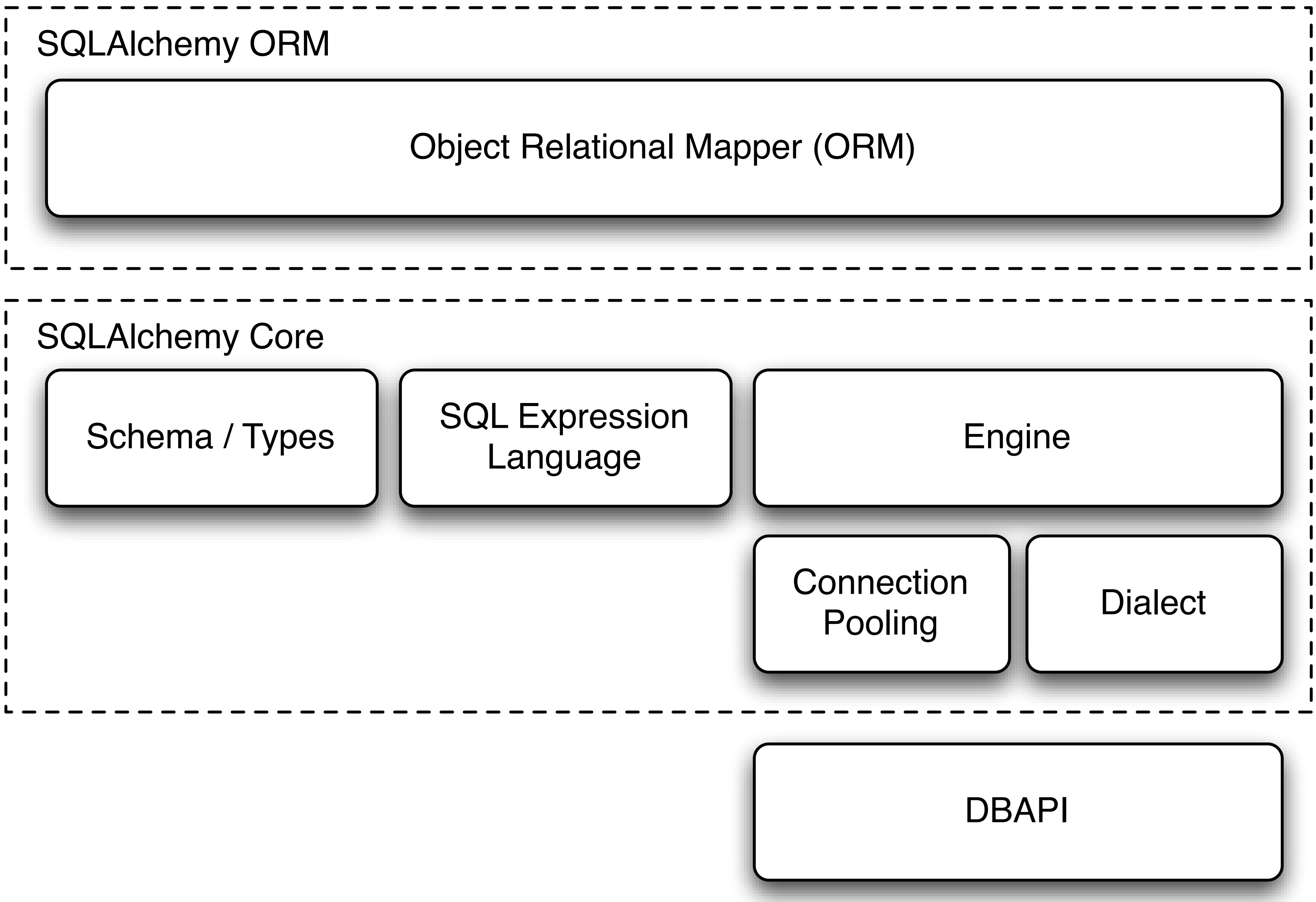
- Is this "leaky abstraction ?"
- You bet !
- Joel On Software - "All non-trivial abstractions, to some degree, are leaky."
- SQLAlchemy works with this reality up front to create the best balance possible.
- The goal is controlled automation, reduced boilerplate, succinct patterns of usage. **Not** "don't make me understand things".

Part II
Architectural Overview

The Core / ORM Dichotomy

- SQLAlchemy has two distinct areas
- Core
- Object Relational Mapper (ORM)

The Core / ORM Dichotomy



Core/ORM Dichotomy - Core

- All DBAPI interaction
- Schema description system (metadata)
- SQL expression system
- Fully usable by itself as the basis for any database-enabled application, other ORMs, etc.
- A Core-oriented application is schema-centric
- Biggest example of a custom Core-only persistence layer is Reddit

Core/ORM Dichotomy - ORM

- Built on top of Core. Knows nothing about DBAPI.
- Maps user-defined classes in terms of table metadata defined with core constructs
- Maintains a local set of in-Python objects linked to an ongoing transaction, passes data back and forth within the transactional scope,using a unit-of-work pattern.
- Data passed uses queries that ultimately are generated and emitted using the Core
- An ORM-oriented application is domain model centric.

Core/ORM Dichotomy - Pros

- ORM is built agnostic of SQL rendering / DBAPI details. All SQL/DBAPI behavior can be maintained and extended without any ORM details being involved
- Core concepts are exposed within the ORM, allowing one to "drop down" to more SQL/DBAPI-centric usages within the context of ORM usage
- Early ORM was able to be highly functional, as missing features were still possible via Core usage.

Core/ORM Dichotomy - Cons

- New users need to be aware of separation
- Performance. ORM and Core both have their own object constructs and method calls, leading to a greater number of objects generated, deeper call stacks. CPython is heavily impacted by function calls.
- Pypy hopes to improve this situation - SQLAlchemy is Pypy compatible
- Alex Gaynor hangs on #sqlalchemy-devel and runs our tests against Pypy constantly

Selected Architectural Highlights

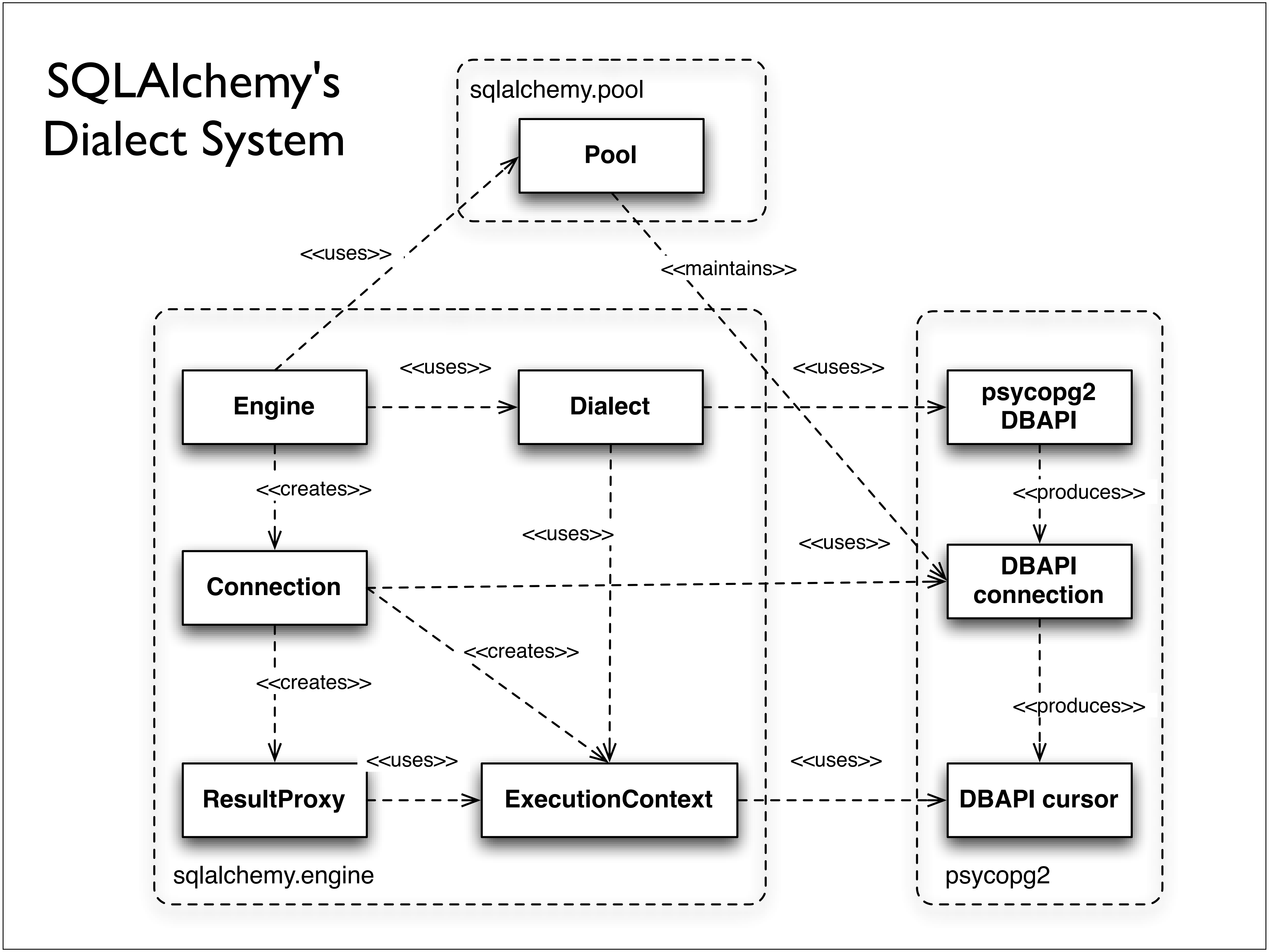
Taming the DBAPI

- DBAPI is the pep-249 specification for database interaction.
- Most Python database client libraries conform to the DBAPI specification.
- Lots of "suggestions", "guidelines", areas left open to interpretation
- Unicode, numerics, dates, bound parameter behavior, behavior of execute(), result set behavior, all have wide ranges of inconsistent behaviors.

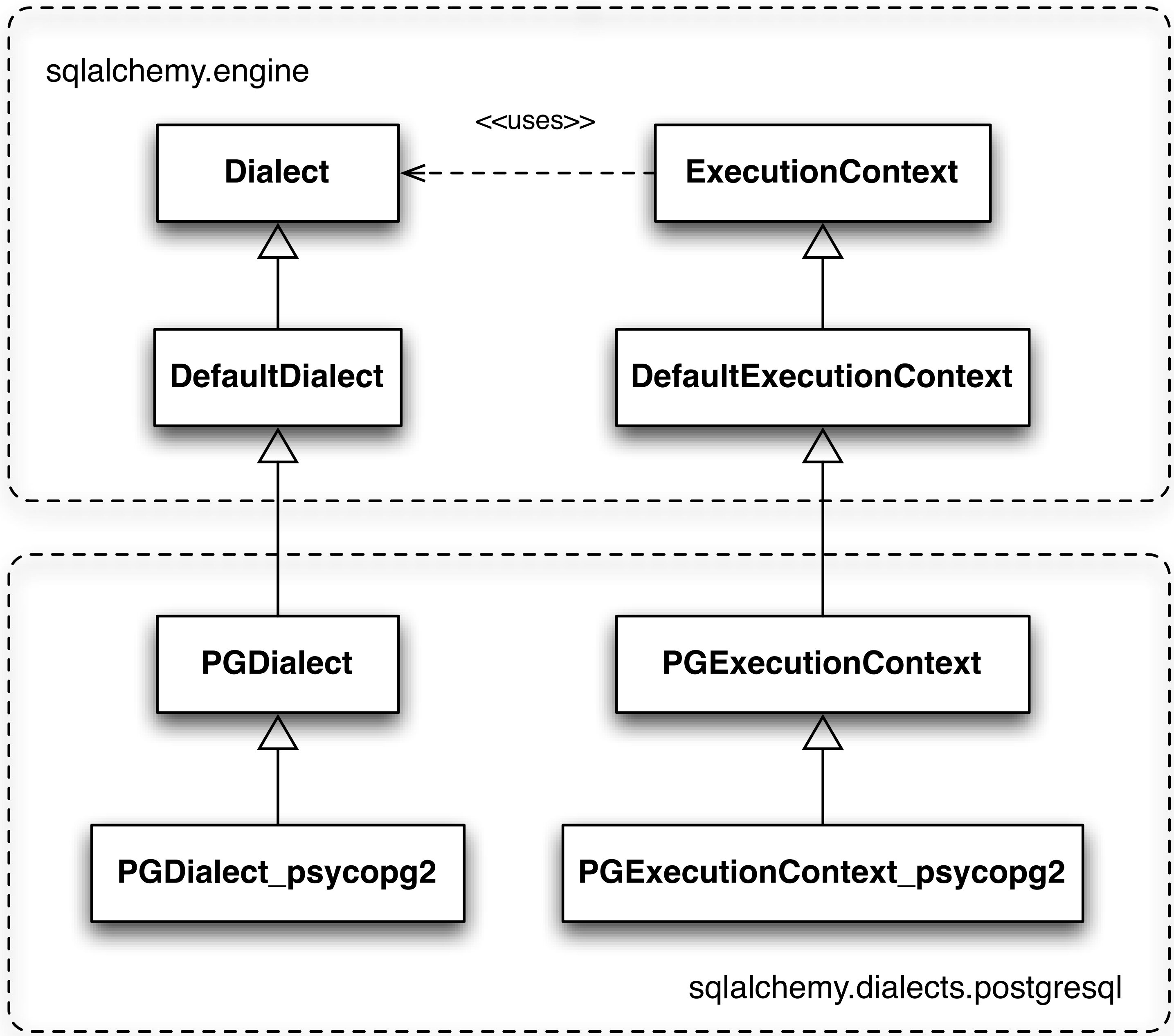
SQLAlchemy's Dialect System

A rudimentary SQLAlchemy Engine interaction

```
engine = create_engine(
                "postgresql://user:pw@host/dbname")

connection = engine.connect()

result = connection.execute(
            "select * from user_table where name=?",
            "jack")

print result.fetchall()
connection.close()
```

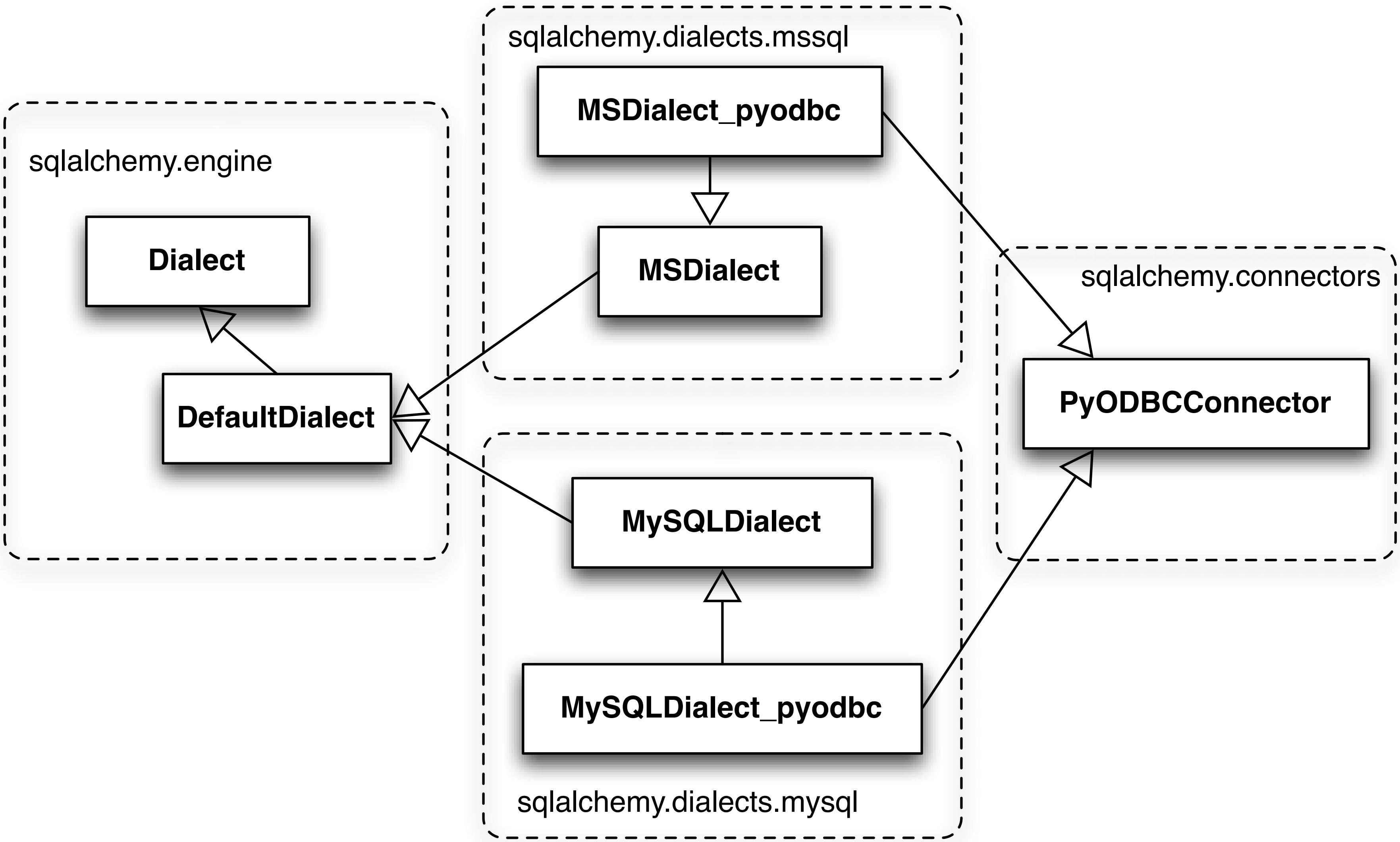

SQLAlchemy's
Dialect System
sqlalchemy.pool
Pool
<<uses>>
<<maintains>>
Engine
<<uses>>
Dialect
<<uses>>
psycopg2
DBAPI
<<creates>>
<<uses>>
<<produces>>
<<uses>>
Connection
DBAPI
connection
<<creates>>
<<creates>>
<<produces>>
<<uses>>
<<uses>>
ResultProxy
ExecutionContext
DBAPI cursor
sqlalchemy.engine
psycopg2

Dealing with database and DBAPI Variability



Two levels of variance

DBAPIs with Multiple Backends



SQL Expression Constructs

- Wasn't clear in the early days how SQL expressions should be constructed
- Strings ? Hibernate HQL ?
- statement.addWhereClause(isGreaterThan(x, 5)) ?
- ...
- Ian Bicking's SQLObject has a great idea !! Let's do that !

SQLBuilder

We can use Python expressions and overload operators!

```
from sqlobject.sqlbuilder import EXISTS, Select

select = Test1.select(EXISTS(Select(Test2.q.col2,
          where=(Test1.q.col1 == Test2.q.col2))))
```

Operator Overloading

This expression does not produce True or False

```
column('a') == 2
```

Operator Overloading

Instead, __eq__() is overloaded so it's equivalent to...

```
column('a') == 2

from sqlalchemy.sql.expression import \
                           _BinaryExpression
from sqlalchemy.sql import column, bindparam
from sqlalchemy.operators import eq

_BinaryExpression(
    left=column('a'),
    right=bindparam('a', value=2, unique=True),
    operator=eq
)
```

Example SQL Expression

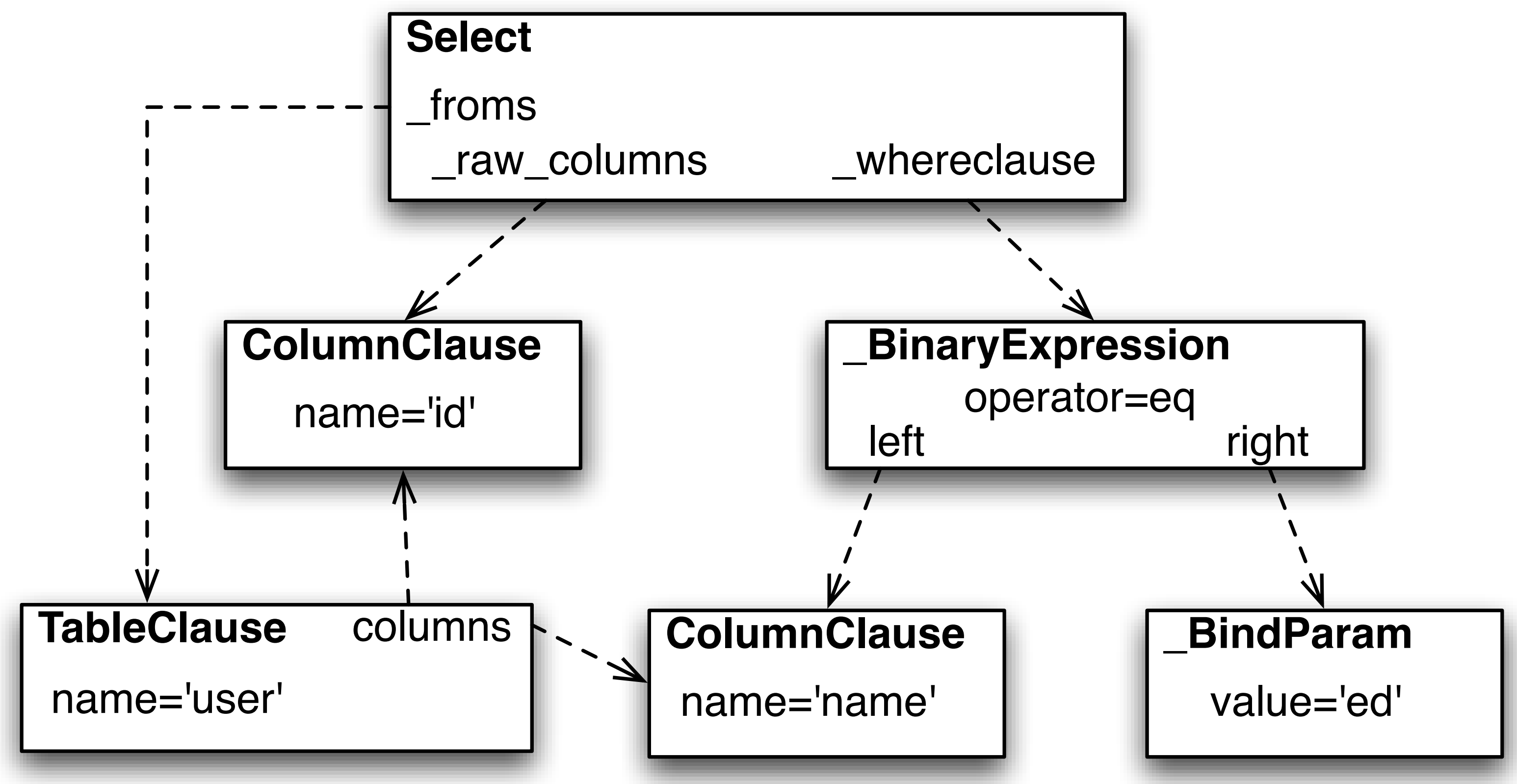
Statement:

```
SELECT id FROM user WHERE name = ?
```

SQL Expression:

```
from sqlalchemy import select

stmt = select([user.c.id]).where(user.c.name=='ed')
```

Example SQL Expression



Intro to Mapping

In original SQLAlchemy, mappings looked like this: first define "table metadata":

```
from sqlalchemy import (MetaData, String, Integer, CHAR,
                        Column, Table, ForeignKey)

metadata = MetaData()
user = Table('user', metadata,
         Column('id', Integer, primary_key=True),
         Column('name', String(50), nullable=False)
)

address = Table('address', metadata,
         Column('id', Integer, primary_key=True),
         Column('user_id', Integer, ForeignKey('user.id'),
                                           nullable=False)
         Column('street', String(50)),
         Column('city', String(50)),
         Column('state', CHAR(2)),
         Column('zip', String(14))
```

Intro to Mapping

... then, define classes and "map" them to the tables using the `mapper()` function:

```
from sqlalchemy.orm import mapper, relationship

class User(object):
   def __init__(self, name):
        self.name = name

class Address(object):
   def __init__(self, street, city, state, zip):
        self.street = street
        self.city = city
        self.state = state
        self.zip = zip

mapper(User, user, properties={
    'addresses':relationship(Address)
})

mapper(Address, address)
```

This strict separation of database metadata and class definition, linked by the also separate `mapper()` step, we now call *classical* mapping.

Declarative Mapping

In modern SQLAlchemy, we usually use the Declarative system to "declare" Table metadata and class mapping at the same time...

```
from sqlalchemy.ext.declarative import declarative_base

Base = declarative_base()

class User(Base):
  __tablename__ = 'user'
  id = Column(Integer, primary_key=True)
  name = Column(String(50), nullable=False)
  addresses = relationship("Address")

class Address(Base):
  __tablename__ = 'address'
  id = Column(Integer, primary_key=True)
  user_id = Column(Integer, ForeignKey('user.id'),
              nullable=False)
  # ...
```

Declarative Mapping

... or at least, the class definition and mapping. Table metadata can still be separate...

```
class User(Base):
  __table__ = user
  addresses = relationship("Address", backref="user",
                     cascade="all, delete-orphan")

class Address(Base):
  __table__ = address
```

Declarative Mapping

... or inline like this if preferred

```
class User(Base):
  __table__ = Table('user', Base.metadata,
        Column('id', Integer, primary_key=True),
        Column('name', String(50), nullable=False)
  )

  addresses = relationship("Address", backref="user",
                   cascade="all, delete-orphan")

class Address(Base):
  __table__ = Table('address', Base.metadata,
        Column('id', Integer, primary_key=True),
        Column('user_id', Integer, ForeignKey('user.id'),
                           nullable=False),
        # ...
        )
```

What do classical mapping, declarative mapping, declarative with `__table__` etc. all have in common ?

They all create a `mapper()` and instrument the class in the identical way!

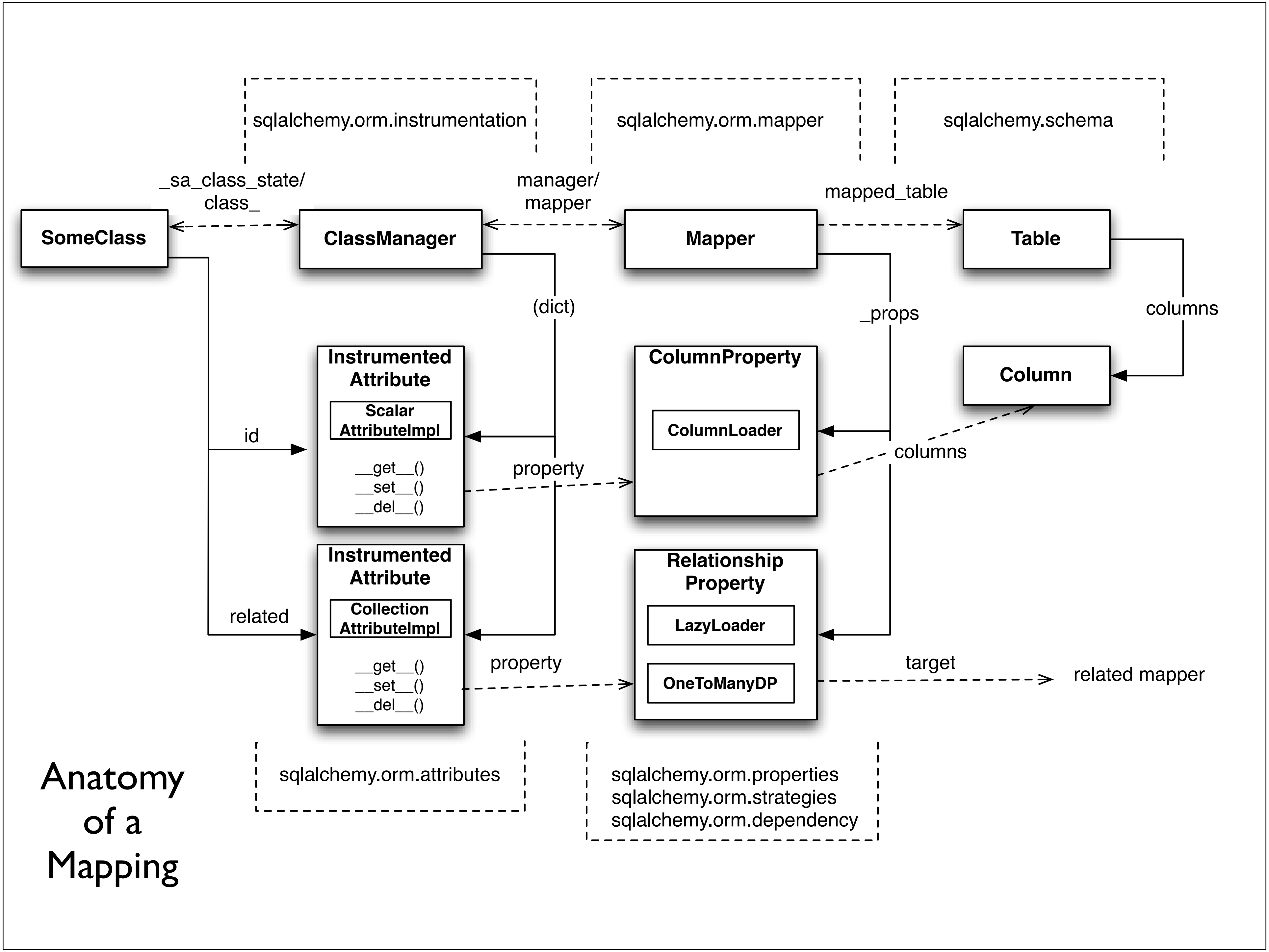
The `mapper()` Object for the `User` class

```
>>> from sqlalchemy.orm import class_mapper
>>> class_mapper(User)
<Mapper at 0x1267970; User>
```

They all create a `mapper()` and instrument the class in the identical way!

Attributes are "instrumented" - when using Declarative, this replaces the `Column` object originally placed in the class for the "username" attribute.

```
>>> User.username
<sqlalchemy.orm.attributes.InstrumentedAttribute
object at 0x1267c50>
```


sqlalchemy.orm.instrumentation
sqlalchemy.orm.mapper
sqlalchemy.schema
_sa_class_state/
class_
manager/
mapper
mapped_table
SomeClass
ClassManager
Mapper
Table
(dict)
_props
columns
Instrumented
Attribute
Scalar
AttributeImpl
__get__()
__set__()
__del__()
ColumnProperty
ColumnLoader
Column
id
property
columns
Instrumented
Attribute
Collection
AttributeImpl
__get__()
__set__()
__del__()
Relationship
Property
LazyLoader
OneToManyDP
related
property
target
related mapper
sqlalchemy.orm.attributes
sqlalchemy.orm.properties
sqlalchemy.orm.strategies
sqlalchemy.orm.dependency
Anatomy
of a
Mapping

Fun facts about Declarative

- A "SQLObject"-like declarative layer was always planned, since the beginning. It was delayed so that focus could be placed on classical mappings first.
- An early extension, `ActiveMapper`, was introduced and later superseded by **Elixir** - a declarative layer that redefined basic mapping semantics.
- Declarative was introduced as a "one click away from classical mapping" system, which retains standard SQLA constructs - only rearranging how they are combined.
- zzzeek had to be convinced by Chris Withers to support Declarative "mixins" - thanks Chris !

Unit of Work

- Unit of work's job is to find all pending data changes in a particular Session, and emit them to the database.
- (the Session is an in-memory "holding zone" for the mapped objects we're working with)
- Organizes pending changes into commands which emit batches of INSERT, UPDATE, DELETE statements
- Organizes the statement batches such that dependent statements execute after their dependencies
- In between blocks of statements, data is synchronized from the result of a completed statement into the parameter list of another yet to be executed.

Unit of work example

```
from sqlalchemy.orm import Session

session = Session(bind=some_engine)

session.add_all([
    User(name='ed'),
    User(name='jack', addresses=[address1, address2])
])

# force a flush
session.flush()
```

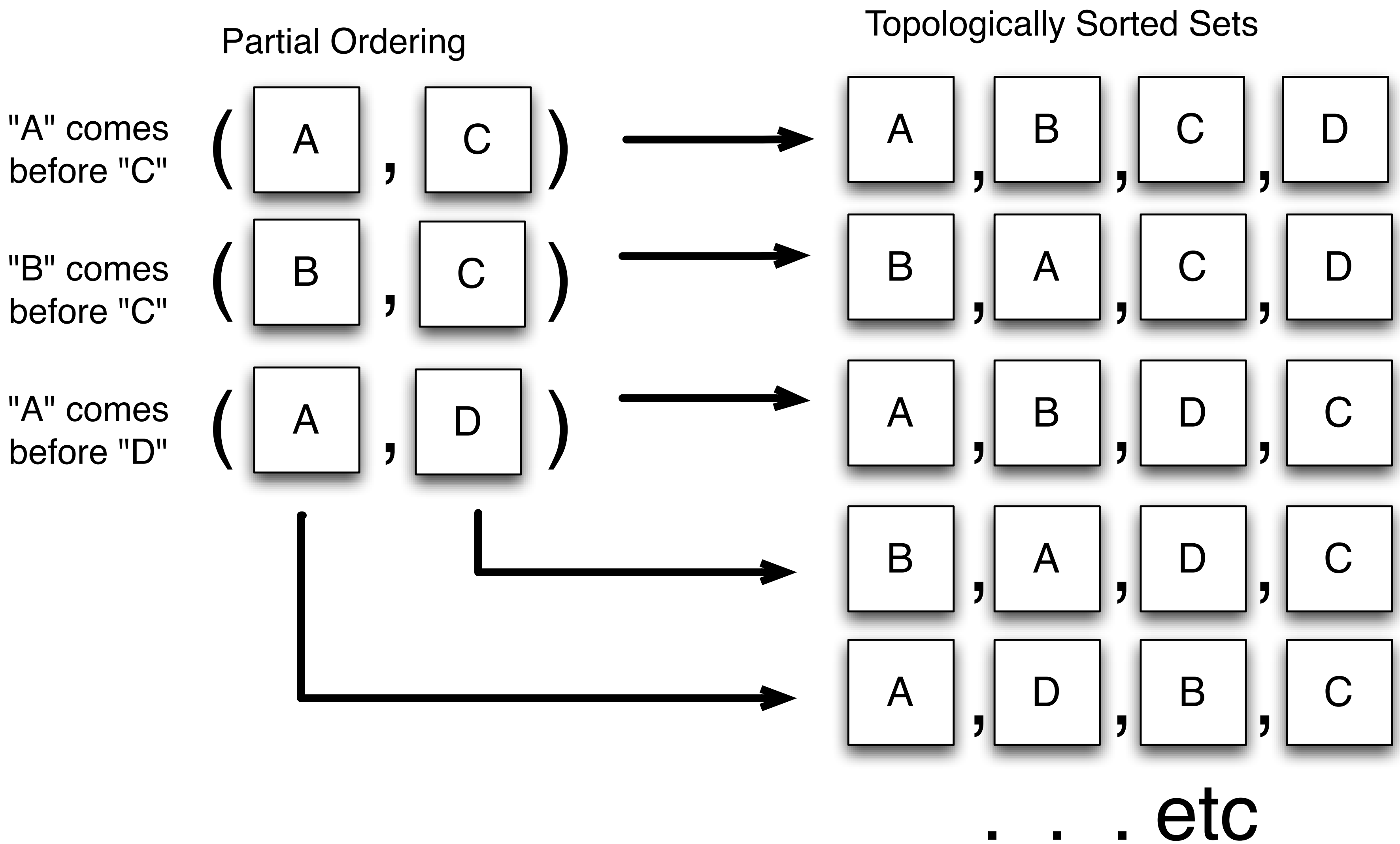
Unit of work example

```
-- INSERT statements
BEGIN (implicit)
INSERT INTO user (name) VALUES (?)
('ed',)
INSERT INTO user (name) VALUES (?)
('jack',)


-- statements are batched if primary key already present
INSERT INTO address (id, user_id, street, city, state, zip) VALUES
(?, ?, ?, ?, ?, ?)
((1, 2, '350 5th Ave.', 'New York', 'NY', '10118'), (2, 2, '900
Market Street', 'San Francisco', 'CA', '94102'))
```

Dependency Sorting

- The core concept used by the UOW is the **topological sort.**
- In this sort, an ordering is produced which is compatible with a "partial ordering" - pairs of values where one must come before the other.

Topological Sort

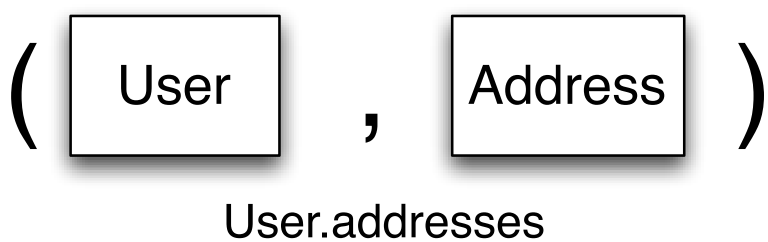


The Dependency Graph

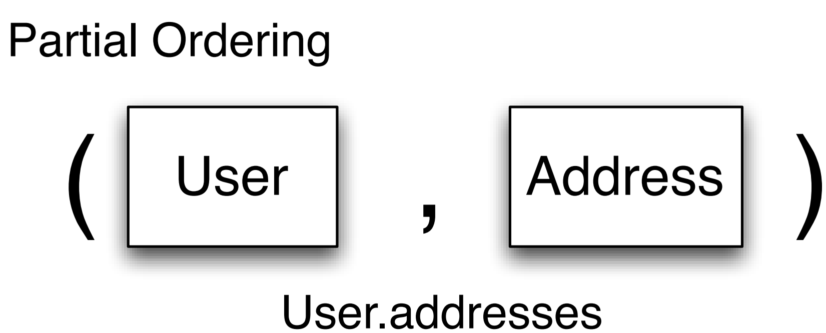
- The Unit of Work sees the mapping configuration as a "dependency graph" - `Mapper` objects represent nodes, `relationship()` objects represent edges.
- For each "edge", the `Mapper` on the right is dependent on the `Mapper` on the left
- A dependency usually corresponds to mapper B's table having a foreign key to that of mapper A
- These pairs of `Mapper` objects form the "partial ordering" passed to the topological sort

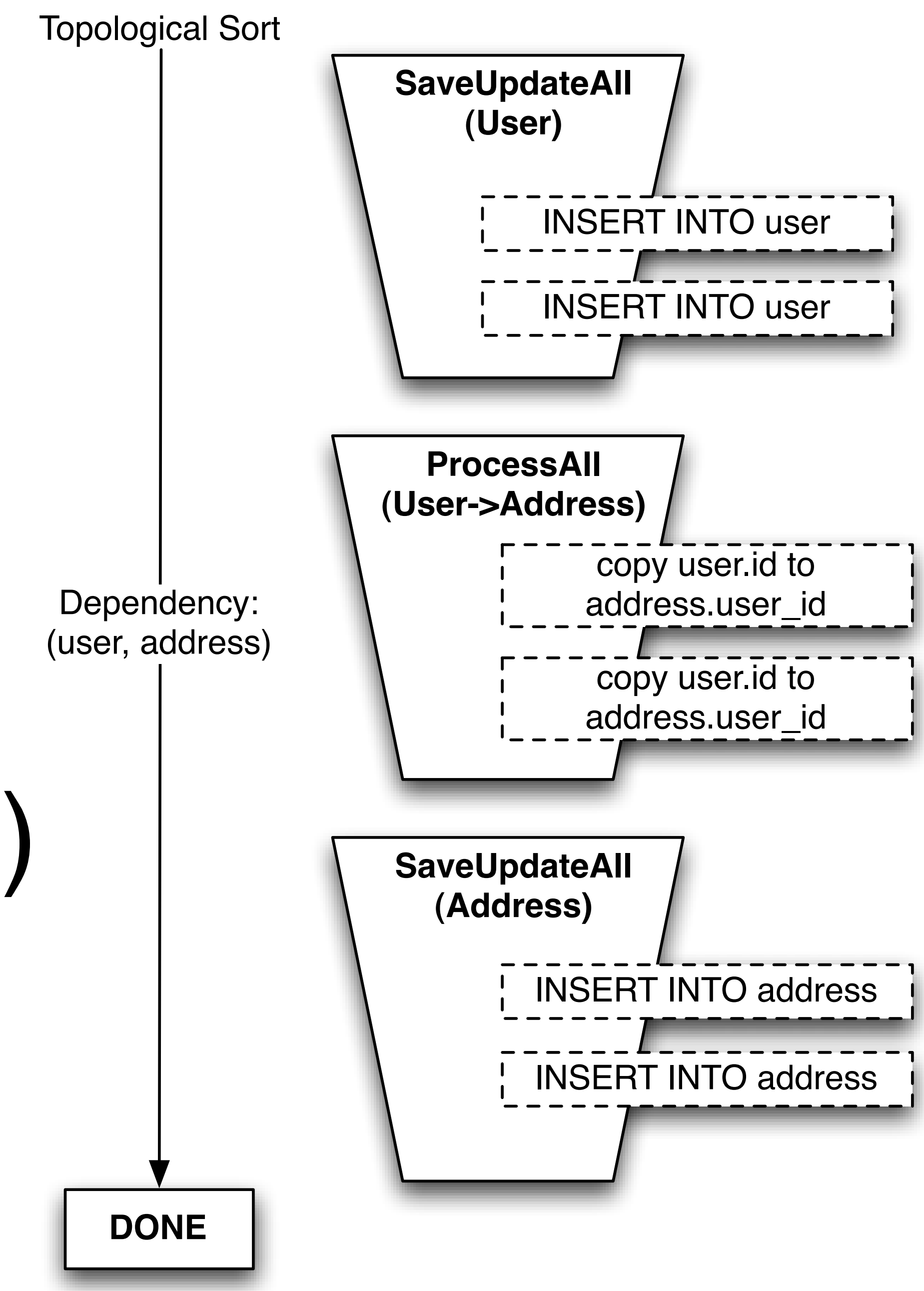
Unit of work sorting per-mapper

Partial Ordering



Unit of work sorting per-mapper



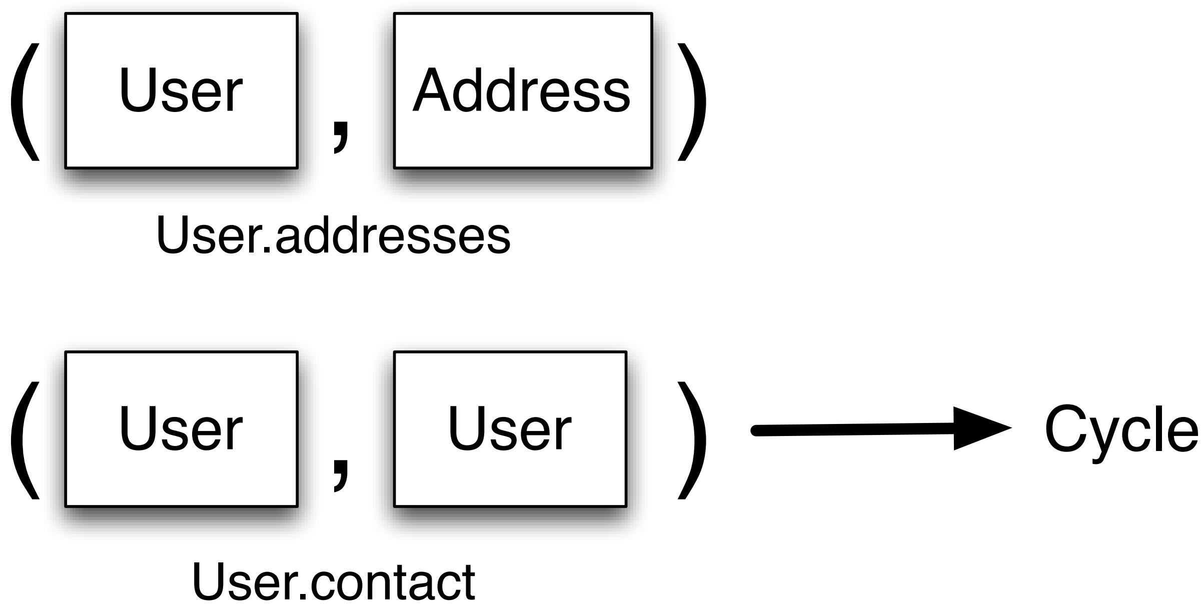


UOW - Cycle Resolution

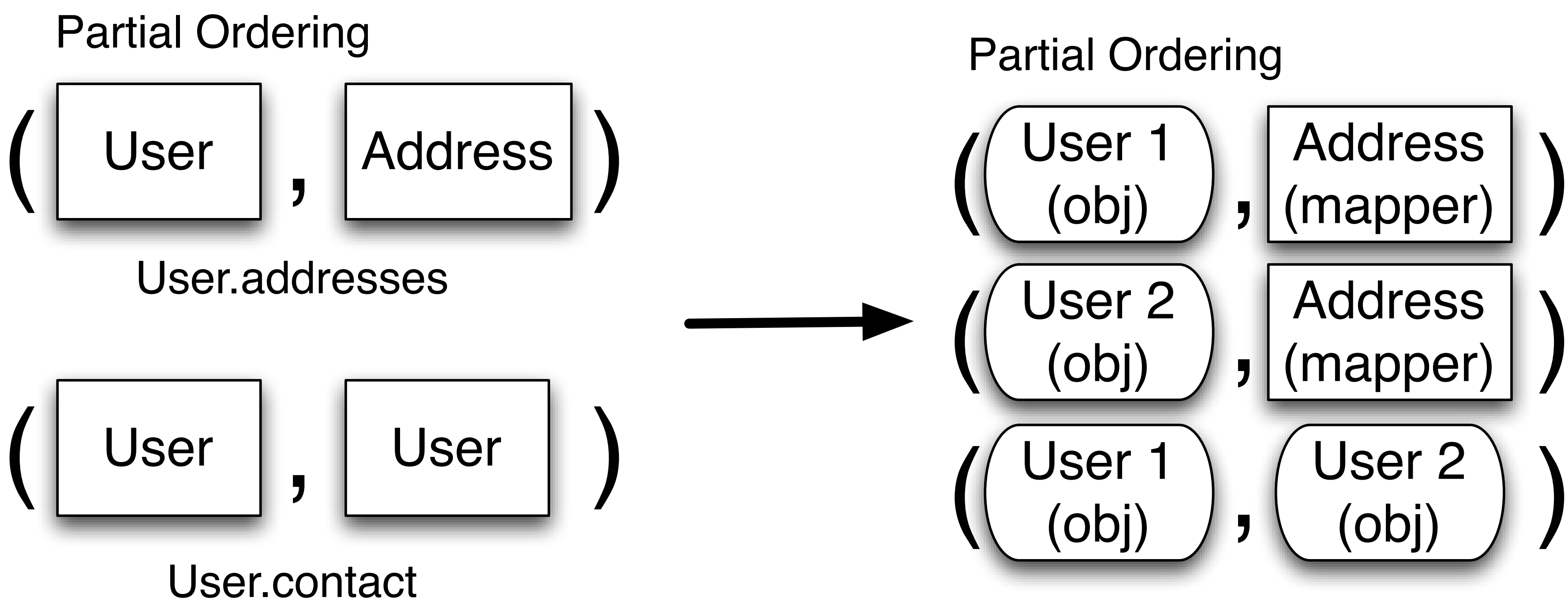
- A cycle forms when a mapper is dependent on itself, or on another mapper that's ultimately dependent on it.
- Those portions of the dependency graph with cycles are broken into inter-object sorts.
- I used a function on Guido's blog to detect the cycles.
- Rationale - don't waste time sorting individual items if we don't need it !

Unit of work sorting per-row

Partial Ordering

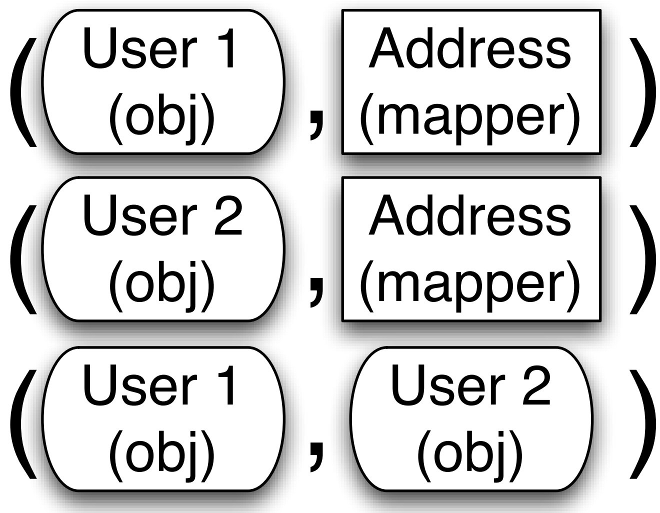


Unit of work sorting per-row

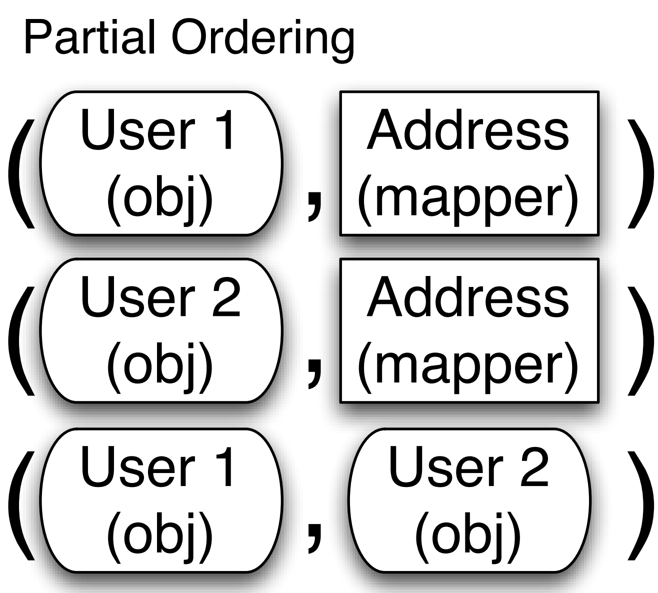


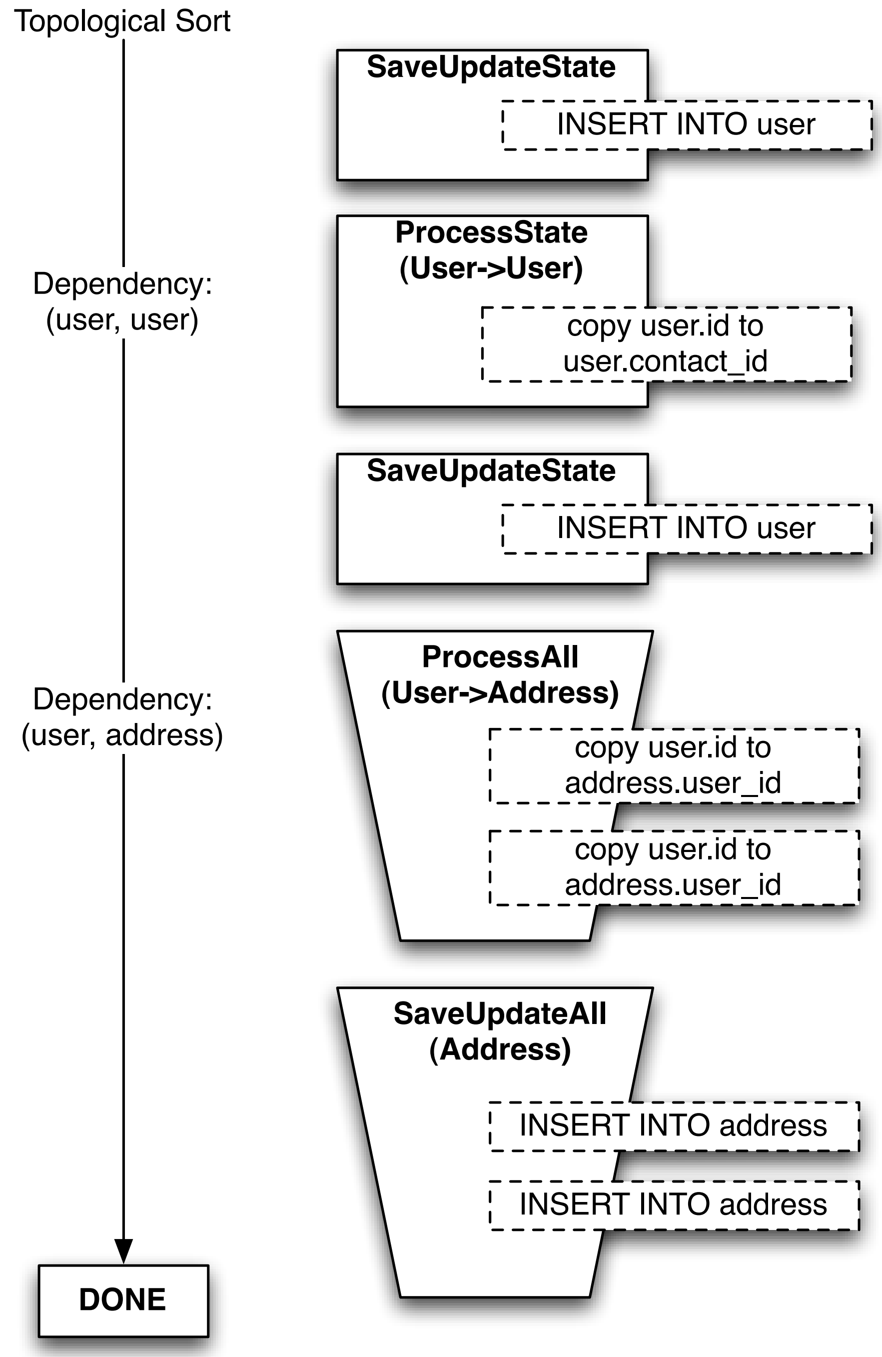
Unit of work sorting per-row

Partial Ordering



Unit of work sorting per-row





SQLAlchemy

We're done !
Hope this was enlightening.

http://www.sqlalchemy.org