Object/Relational Mapping 2008: Hibernate and the Entity Data Model (EDM)

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Love of Objects

- Programmers love objects
- Objects are normally ephemeral
- Programming languages provide object persistence, but it is fragile
- Databases provide robust data persistence.
- So… need way to persist object data in the database
- Or think bigger: use data model across object-DB boundaries.
- But a central authority on an object model worries some people: not clearly agile.

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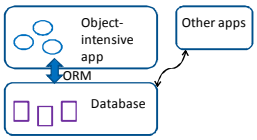
Object-Relational Mapping (ORM)

- A software system that shuttles data back and forth between database rows and objects
- Appears as a normal database user to the database
- Can share the database and tables with other apps



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Object-Relational Mapping

- Has a history, but widely adopted only since open-source Hibernate project started, 2001-2002.
- The Hibernate project [7] was founded and led by Gavin King, a Java/J2EE software developer, now part of JBoss. King wrote an excellent book [3].
- Microsoft has adopted a similar approach with EDM, Entity Data Model and its Entity Framework [1, 10]. V1 was released with Visual Studio SP1 in August.
- Both Hibernate and EDM support (or will support) multiple databases: Oracle, DB2, SQL Server, …

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Java Persistence Architecture (JPA)

- JPA is part of current JEE (previously J2EE), Sun's Java Enterprise Edition
- JPA is a standardized version of the Hibernate architecture
- EJB 3 (current Entity Java Beans) uses JPA for EJB persistence, i.e., persistence of "managed" objects
- JPA and EJB 3 are now available in major application servers: Oracle TopLink 11g, OpenJPA for WebSphere and WebLogic, Hibernate JPA for JBoss
- JPA can be used outside EJB 3 for persistence of ordinary objects, as Hibernate is used in this talk

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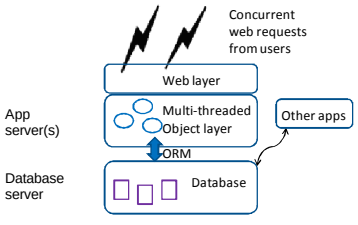
Current ORM Impetus: the web app

A web app, with its multi-threaded object layer, particularly needs help with the correct handling of persistent data



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Our Universe of Discourse

- Object-oriented web apps with database backed data
- Let's consider sites with
  - Possibly many application servers, where the objects live
  - A single database server with plenty of CPUs and disks
- Given today's fast machines and databases, this configuration scales up to many 100s of transactions/second (over 1 M Tx/hour)
- We will concentrate on common characteristics of Hibernate and EDM

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Outline of Presentation

-------Ask questions any time

- Schema mapping
- Entities and their identity
- Relationships
- Inheritance
- The Pizza Shop Example
- Sample code using entity objects
- Development tools, artifacts
- The ORM runtime system
- Transactions, performance
- Summary

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Data Modeling

- Three modeling methodologies:
  - We all know the venerable Chen E-R models for database schemas; the extended E-R models (EER) incorporate inheritance
  - The object modeling approach uses UML class diagrams, somewhat similar to EER
  - The tables of the database define the "physical" schema, itself a model of underlying resources
- The relationship between these models involves schema mapping, covered in last SIGMOD's keynote talk by Phil Bernstein[9]

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Even simple cases need help

- In the simplest case, a program object of class A has fields x, y, z and a table B has columns x, y, z
  - Each instance of A has a row in B and vice versa, via ORM
  - Are we done?
  - If x is a unique id, and x, y, and z are simple types, yes.
  - --Or some unique id in (x, y, z), possibly composite
- If no unique id in (x, y, z), the object still has its innate identity, but corresponding rows involve duplicate rows, against relational model rules
- So in practice, we add a unique id in this case:
- Class A1 has id, x, y, z and table B1 has id, x, y, z

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Persistent Objects & Identity

- A "persistent object" is an ordinary program object tied via ORM to database data for its long-term state
- The program objects come and go as needed
- Don't confuse this with language-provided persistence (Java/C#), a less robust mechanism
- Persistent objects have field-materialized identity
- It makes sense—Innate object identity depends on memory addresses, a short-lived phenomenon
- So long-lived objects (could be years…) have to be identified this way, it's not the database's fault

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Persistent Objects need tracking

- We want only one copy of each unique object in use by an app, a basic idea of OO programming
- Each persistent object has a unique id
- We can no longer can depend on object location in memory to ensure non-duplication
- So we have a harder problem than before—need an active agent tracking objects
- This agent is part of ORM's runtime system
- The ORM uses hashing to keep track of ids, detect duplicates

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ORM Entities

- Like E/R entities, ORM entities model collections of real-world objects of interest to the app
- Entities have properties/attributes of database datatypes
- Entities participate in relationships—see soon (but relationships are not "first class" objects, have no attributes)
- Entities have unique ids consisting of one or more properties
- Entity instances (AKA entities) are persistent objects of persistent classes
- Entity instances correspond to database rows of matching unique id

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Value Objects

- In fact, persistent objects can be entities or value objects
- Value objects can represent E/R composite attributes and multi-valued attributes
- Example: one address consisting of several address attributes for a customer.
- Programmers want an object for the whole address, hanging off the customer object
- Value objects provide details about some entity, have lifetime tied to their entity, don't need own unique id
- Value objects are called Hibernate "components", EDM "complex types"
- We'll only discuss entities for persistent objects
- For this presentation, persistent object = entity object

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Creating Unique IDs

- A new entity object needs a new id, and the database is holding all the old rows, so it is the proper agent to assign it
- Note this can't be done with standard SQL insert, which needs predetermined values for all columns
- Every production database has a SQL extension to do this
  - Oracle's sequences
  - SQL Server's auto-increment datatype
  - …
- The ORM system coordinates with the database to assign the id, in effect standardizing an extension of SQL
- Keys obtained this way have no meaning, are called "surrogate keys"
- Natural keys can be used instead if they are available.

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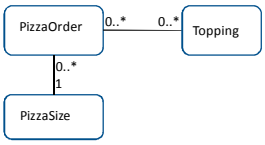
Entity Model



- Uses UML-like diagrams to express object models that can be handled by this ORM methodology
- Currently handles only binary relationships between entities, expects foreign keys for them in database schema
- Has a SQL-like query language that can deliver entity objects and entity object graphs
- Supports updates and transactions

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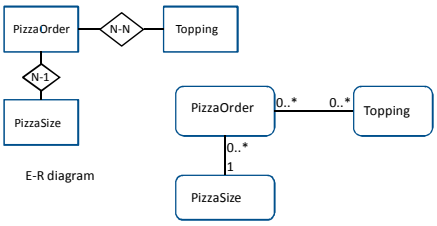
Classic Relationships

A PizzaOrder has a PizzaSize and a set of Toppings



E-R diagram

UML class diagram or entity model: no big diamonds, type of relationship is inferred from cardinality markings

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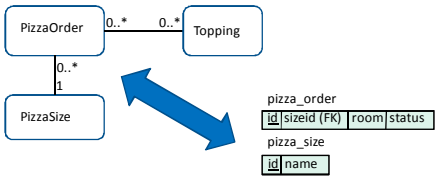
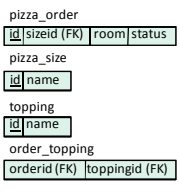
Classic Relationships

Schema mapping, entities to tables and vice versa





Needed database schema: has one table for each entity, plus a link table for N-N relationship

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Inheritance

- Example: generalize Topping to PizzaOption, to allow other options in the future:
  - Topping ISA PizzaOption
  - Shape ISA PizzaOption, …
- Then a PizzaOrder can have a collection of PizzaOptions
  - We can process the PizzaOptions generically, but when necessary, be sensitive to their subtype: Topping or Shape
  - It is important to have "polymorphic associations", such as PizzaOrder to PizzaOption, that deliver the right subtype object when followed.
- Inheritance is supported directly in Java, C#, etc., ISA "relationship"
- Inheritance is not native to RDBs, but part of EER, extended entity-relationship modeling, long-known schema-mapping problem

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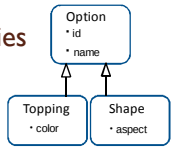
Inheritance Hierarchies



- Both Hibernate and EDM can handle inheritance hierarchies and polymorphic associations to them
- Both Hibernate and EDM provide single-table and multiple-tables per hierarchy solutions
  - Single-table: columns for all subtypes, null values if not appropriate to row's subtype
  - Multiple-table: table for common (superclass) properties, table for each subclass for its specific properties, foreign key to top table
  - Also hybrid: common table plus separate tables for some subclasses

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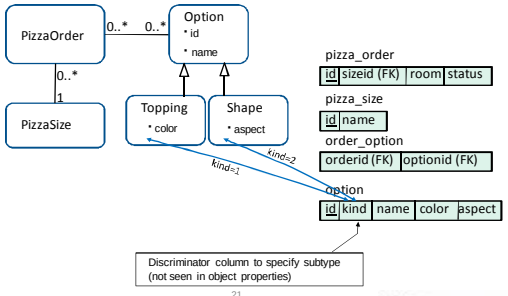
Inheritance Mapping (single table)



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Inheritance using a single table

- The discriminator column (here "kind") is handled by the O/R layer and does not show in the object properties
- The hierarchy can have multiple levels
- Single-table approach is usually the best performing way
- But we have to give up non-null DB constraints for subtype-specific properties
- Alternatively, use multiple tables…

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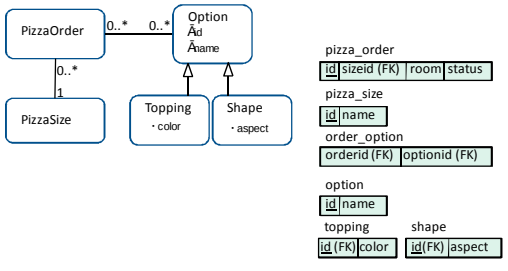
Inheritance Mapping (3 tables)



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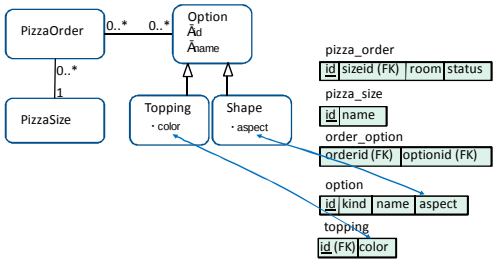
Inheritance Mapping (hybrid)



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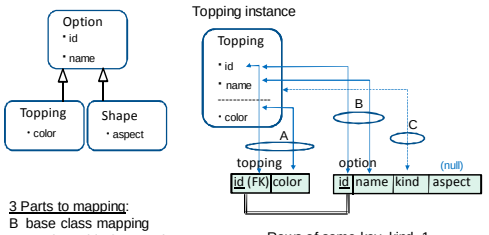
A Mapping dissected



3 Parts to mapping:
B base class mapping
A topping table for Topping
C option table for Topping
Together, 2-way mapping

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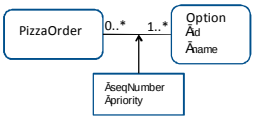
Example of an object model that doesn't fit current ORM



- Case of attributes of the N-N relationship
- We know how to do this in the database…
- We can introduce a new entity in the middle but lose crispness
- Related to problem of ternary relations, also missing

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The Pizza Shop Example

- Free pizza for students in a dorm
- Student can:
  - Choose toppings, size, order by room number
  - Check on orders by room number
- Admin can:
  - Add topping choices, sizes
  - Mark the oldest pizza order "done"
- Available at www.cs.umb.edu/~eoneil/orm

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The Pizza Shop Example

- Implemented using Hibernate and Microsoft EDM: same architecture, similar code, same database schema
- Implemented as client-server app and web app: only the top-level code changes
  - Client-server means all the app code runs on the client, with network connection to DB
  - Web app means all the app code runs on the web server/app server, clients use browser, DB can be on another server.
- Transactions are explicitly coded, not using container-managed transactions (EJB/COM+ Serviced Components)

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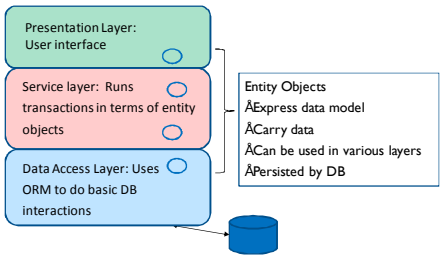
The Pizza Shop: layers



Note: layers are not required by ORM, they are just a good idea for such apps

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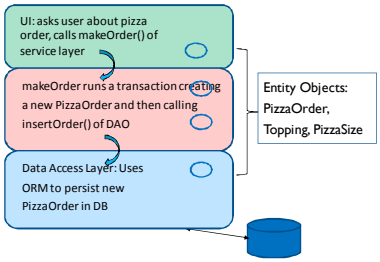
The Pizza Shop: objects, calls



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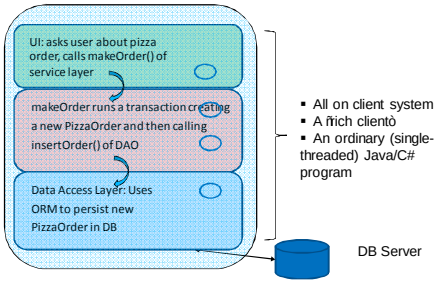
The Pizza Shop: Client-server



- All on client system
- A ñrich clientò
- An ordinary (single-threaded) Java/C# program

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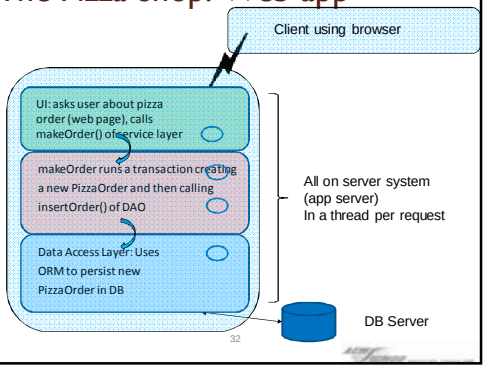
The Pizza Shop: Web app



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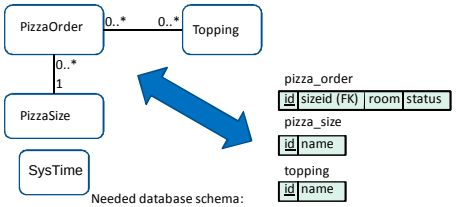
Pizza Shop Entities, Mapping



Needed database schema: has one table for each entity, plus a link table for N-N relationship

pizza_order: id | sizeid (FK) | room | status

pizza_size: id | name

topping: id | name

order_topping: orderid (FK) | toppingid (FK)

sys_time: id | current_day | report_day

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Entity Objects: ideally POJOs/POCOs

- POJO=plain old Java object, POCO=plain old CLR object (C#, etc., CLR= Common Language Runtime of .NET)
  - No special methods need to be implemented
  - Objects are created with normal "new", not some required factory
- Compare to EJB2 Entity Java Bean, COM "managed" objects: these are hard to unit-test, tend to be "heavy-weight"
- EDM: entity objects are POCOs in some ways, but need to extend system class EntityObject, and implement certain methods. Version 2 of EDM is expected to improve this.
- Hibernate: entity objects are POJOs, with no required superclass. All they need is a no-args constructor.

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Example Simple POJO with properties id and sizeName

```
public class PizzaSize {
    private int id;
    private String sizeName;
    public PizzaSize () {}
    public int getId() { return this.id;}
    public String getSizeName() { return
                        this.sizeName;}
    public void setSizeName(String sizeName) {
        this.sizeName = sizeName;
    }
…   // equals, hashCode, other methods
}
```

Private fields for properties

No-args constructor
Getter for id: ñidòis a read-only property ñ

Getter and setter for sizeName: ñsizeNameò is a read-write property

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Example Simple POCO

Note: C# has handy property-specific syntax

```
public class PizzaSize
{
   private int _ID;
   private string _SizeName;
   public int ID {
        get  { return this._ID;}
   }
   public string SizeName {
        get  { return this._SizeName;}
        set  { this._SizeName = value;}
   }
  … // other methods
}
```

Private fields for properties

Getter for id: ñidòis a read-only property

Getter and setter for sizeName: ñsizeNameò is a read-write property

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Hibernate entity POJO with Relationships (can be generated)

```
public class PizzaOrder {
    // Fields, constructors, property getters, setters
    // as in simple POJO
    public PizzaSize getPizzaSize() { return this.pizzaSize;}
    public void setPizzaSize(PizzaSize pizzaSize) {
        this.pizzaSize = pizzaSize;
    }
    public Set<Topping> getToppings() {
        return this.toppings;
    }
…
}
```

N-1 relationship to PizzaSize

N-N relationship to Topping

Standard collection type

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EDM entity with Relationships (generated code)

Note: italics indicate pseudocode

```
public partial class PizzaOrder:
   global::System.Data.Objects.DataClasses.EntityObject
{  // Fields, constructors, property getters, setters
   // setters have code to report property change
   public PizzaSize PizzaSize
     {
       get  { return PizzaSize object from superclass RelationshipManager; }
       set  { set value in superclass RelationshipManager; }
     }
   public global::System.Data.Objects.DataClasses.EntityCollection<Topping>
        Topping
     {
       get  {  return EntityCollection<Topping> from superclass's
                RelationshipManager; }
     }
…
}
```

←superclass

N-1 relationship to PizzaSize

N-N relationship to Topping

Special collection type, with familiar API

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Sample code using entity objects

Just "dot through" the N-1 relationship: an order has a unique PizzaSize object bound to it

```
order.getSize().getSizeName() //Hibernate/Java
order.Size.SizeName           // EDM/C#
```

The N-N relationship to Toppings: an order has a collection of Toppings:

```
for (Topping t: order.getToppings())   //Hibernate/Java
   // do something with t
foreach (Topping t in order.Topping)   // EDM/C#
  // do something with t
```

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Sample Code: persist new object

Hibernate:

```
session.persist(order);
```

Later, after commit, or optional earlier

`session.flush()`, order id is valid

EDM:

```
context.AddObject("PizzaOrder", order);
```

Later, after `context.SaveChanges()`, order id is valid

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Sample code for a "finder"

To get PizzaOrder objects for a certain room and day, including available Toppings (and PizzaSize) for each

Hibernate HQL: Toppings available in a lazy way

```
List<PizzaOrder> orders =
   session.createQuery("from PizzaOrder o
    where o.roomNumber = "+ roomNumber +
    " and o.day = " + day ).list();
```

EDM Entity SQL: Toppings available by explicit request here:

```
List<PizzaOrder> orders = new ObjectQuery<PizzaOrder>("select
   value o from PizzaEntities.PizzaOrder as o
    where o.RoomNumber = " + roomNumber +
    " and o.Day = " + day, context).
   Include("Topping").Include("PizzaSize").ToList();
```

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Hibernate lazy fetch

- In the finder query, Hibernate returns PizzaOrder objects with a "proxy" for the associated PizzaSize and a "collection wrapper" for the Toppings collection
- As long as the runtime system is still alive, first access to such an association results in a DB hit for the actual data
- First access after the runtime is shut down results in an exception: it's too late to be lazy
- This default strategy can be overridden in the mapping file: lazy="false" for PizzaOrder's Toppings, for example.
- EDM: no implicit database access, so need to code what you need

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More queries: some joins

- Example: Find all pizza orders for today (order's day matches sys_time's current_day). No relationship for this, so no connections in the object graph.
- Note no mapped association on day, so no handy collection of object references to use. Use a join…
  - EDM Entity SQL:
    "select value o from PizzaEntities.PizzaOrder as o join PizzaEntities.SysTime as t on o.Day = t.CurrentDay"
  - EDM LINQ: language-integrated query
    List<PizzaOrder> l = (from o in context.PizzaOrder join s in context.SysTime on o.Day equals s.CurrentDay select o).ToList(); // no quotes! C# knows query syntax and does type checking
  - HQL:
    "select o from PizzaOrder o, SysTime t where o.day = t.currentDay"

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More query features

- Group by, having, order by
- Parameterized queries
- Pairs of objects returned, etc.
- Scalars and aggregates
- Build up queries using methods
- Hibernate: direct SQL queries
- stored procedures
- Control of fetch strategies

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Entity objects in two layers

Service layer

- Create context and transaction
- Call DAO to get entity objects to work on
- Or Call DAO to add objects
- Or Call objects' own methods
- EDM: context.SaveChanges()/ Hibernate: session.flush() (can be done automatically)
- Commit transaction, drop context

DAO

- Run query for objects or scalar results
- Add new objects

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Entity Objects can do more

- So far, entity objects carry data to/from database
- i.e, represent persistent *data*
- But objects should have related behavior too
- No problem: add methods to entity classes
- Suppose app needs to compute optimal ordering of toppings for building pizza
- List<Topping> x.getToppingsInBuildOrder()
- This should be method of PizzaOrder, an entity

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Adding business methods to the entity classes

- Hibernate: relatively simple entity classes, can expand as needed
- EDM: generated code for entity classes: how can we add to it?
- Partial classes of C# come to the rescue:
  - Generated code for PizzaOrder provides data methods in one partial class for PizzaOrder
  - We code business methods in another partial class for PizzaOrder, in another source file.
  - Compiler puts them together

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"Rich" Domain model

- Domain classes (entities) manage their persistent data, and "rich" ones also provide app-related actions on their data
- Idea of DDD, domain-driven design (Fowler[13], Evans[14], 2004)
- Service layer coordinates actions *between* entities as needed for transactional actions
- Service layer should be thin, delimiting transactions and calling on domain classes for most of the work
- Data-only entities dubbed "anemic domain model"

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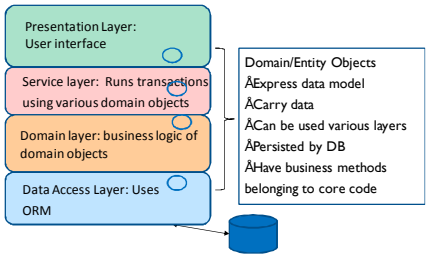
The Pizza Shop: layers refined



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Development Tools

Goal of using GUI to incrementally build a data model is doable, coming, will be great
Example: EDM data model display:

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Development Tools

- The tools
  - Can turn the entity model into program classes
  - Can turn the entity model into database schema
  - Or turn database schema into an entity model
  - Or turn a set of classes into an entity model
- Pizza Shop is simple enough to be specified by database schema + one execution of tool
- For complex systems, you need to work with the XML mapping files to get the full use of these systems today. (Or use Hibernate/JPA source annotations instead of XML.)
- Luckily, only elementary XML is needed, let's look at some files…

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XML: Hibernate PizzaSize

```
<?xml version="1.0"?>
<!DOCTYPE hibernate-mapping PUBLIC "-//Hibernate/Hibernate Mapping DTD 3.0//ENö
    "http://hibernate.sourceforge.net/hibernate-mapping-3.0.dtd">
<hibernate-mapping>
  <class name="pizza.domain.PizzaSize" table="PIZZA_SIZE">
    <id name="id" type="int">
      <column name="ID" />
      <generator class="native" />
    </id>
    <property name="sizeName" type="string">
      <column name="SIZE_NAME" length="30" not-null="true" unique="true" />
    </property>
  </class>
</hibernate-mapping>
```

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XML for EDM PizzaSize: 3 parts

```
<EntityType Name="PizzaSize">
    <Key><PropertyRef Name="ID" /></Key>
    <Property Name="ID" Type="Int32" Nullable="false" />
    <Property Name="SizeName" Type="String" Nullable="false" MaxLength="50" />
    <NavigationProperty Name="PizzaOrder" Relationship = "PizzaModel.FK_PizzaOrder_PizzaSize"
                FromRole="PizzaSize" ToRole="PizzaOrder" />
</EntityType> …
<EntityType Name="PizzaSize">
    <Key><PropertyRef Name="ID" /></Key>
    <Property Name="ID" Type="int" Nullable="false" StoreGeneratedPattern="Identity" />
    <Property Name="SizeName" Type="nvarchar" Nullable="false" MaxLength="50" />
</EntityType> …
<EntityTypeMapping TypeName="IsTypeOf(PizzaModel.PizzaSize)">
    <MappingFragment StoreEntitySet="PizzaSize">
        <ScalarProperty Name="ID" ColumnName="ID" />
        <ScalarProperty Name="SizeName" ColumnName="SizeName" />
    </MappingFragment>
</EntityTypeMapping>
```

Conceptual schema

Storage schema

Mapping

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EDM XML for Association

```
<EntityType Name="PizzaSize">
    <Property …>
    <NavigationProperty Name="PizzaOrder"
        Relationship = "PizzaModel.FK_PizzaOrder_PizzaSize"
            FromRole="PizzaSize" ToRole="PizzaOrder" />
</EntityType>
<Association Name="FK_PizzaOrder_PizzaSize">
    <End Role="PizzaSize" Type="PizzaModel.PizzaSize" Multiplicity="1" />
    <End Role="PizzaOrder" Type="PizzaModel.PizzaOrder" Multiplicity="*" />
</Association> …
<Association Name="FK_PizzaOrder_PizzaSize">
    <End Role="PizzaSize" Type="PizzaModel.Store.PizzaSize" Multiplicity="1" />
    <End Role="PizzaOrder" Type="PizzaModel.Store.PizzaOrder" Multiplicity="*" />
    <ReferentialConstraint>
        <Principal Role="PizzaSize"><PropertyRef Name="ID" /></Principal>
        <Dependent Role="PizzaOrder"><PropertyRef Name="SizeID" /></Dependent>
    </ReferentialConstraint>
</Association>
```

Conceptual schema

Storage schema

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The Entity Context

- Hibernate Session, EDM ObjectContext, seen as "session" and "context" variables in previous code.
- Belongs to one thread as its object cache, usually for one transaction lifetime, one request-response cycle.
- Usually defers updates to the database to end of transaction
- Ensures only one entity object for each id
- As a cache, avoids some rereads (loads by id) of database, preventing some repeated-read anomalies if running at lower isolation level.
- Caching: the database itself has the definitive cache, global to all apps using it…

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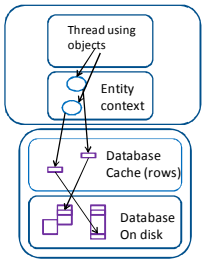
The Entity Context at work



1. Thread creates entity context, starts transaction
2. Accesses entity objects
3. Commits
4. Drops entity context
5. Uses (reads) entity objects outside context

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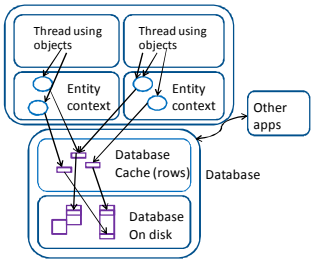
The Entity Contexts & the DB cache Under Concurrent Access



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Entity Object Life Cycle

- Birth: as a POJO or (semi) POCO, unconnected to the context
- Or read in by query, so already connected to context
- Possibly modified by app
- If new, needs addition to context: save()/AddObject()
- By commit, its updates are saved to DB
- Lives on after context dropped, useful for results display
- Can be reattached to new context, but not covered here
- Normally, abandoned soon, garbage-collected

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Queries and the object cache

- When a query delivers entity objects, the id's may already be in the cache
- Need to avoid duplicates, preserve app's changes
- Hibernate flushes changes to DB before query by default
- EDM, by default, preserves the older object of a certain id, avoiding some DB writes at this point
- But tricky: need to flush changes affecting search conditions to maintain query correctness.

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Transactions

- Hibernate and EDM are designed for transactional apps
- Both support transactions involving single or multiple DBs/resource managers, via JTA or DTC for distributed case
  (JTA=Java Transaction API, DTC= Microsoft's Distributed Transaction Coordinator)
- Both support both explicit transactions and container-managed transactions
- We're considering simple case of single DB, explicit transactions
- Still have choice in isolation level, mainly:
  - Read-committed (RC)
  - Read-committed with ORM-coordinated versioning
  - Serializable (SR)

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Transactions

- RC, SR have usual meaning, handled in DB
- Also Snapshot Isolation for some DBs
- Pizza project uses SR, but easy to change
- RC often not enough, but RC + versioning is attractive
- Versioning by ORM provides "optimistic CC":
  - Context remembers original object state, or row version if supported by DB
  - For changed objects, compares saved vs. current DB state at commit-time, throws an exception if changed
  - Avoids lost updates otherwise possible with RC
  - Refresh action available to help with retries

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Conversations

- So far, each request has had one transaction, good enough for Pizza Shop
- Some actions perceived as a unit to the user are made up of several requests
- Example: Read a current bid amount, let user decide on new bid, then make the new bid
- Two DB transactions here, since no DB transaction should span the think time
- The two transactions are related: a "conversation" or "session" or "business transaction" with one user

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Conversations

- Example Conversation: Look at bid, think, update bid
- Someone else can slip in a bid update between my look and update
- One solution: make my bid update contingent on the bid amount still being what I saw before, abort second transaction if not
- This is versioning again, now used across multiple system transactions in the same context

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Conversations and Sessions

- We're thinking about a context spanning several requests of a conversation so it can do version checking

  ----|---look----|----------think----------|--update--|----

  Tx1:10 ms 2 min Tx2:10 ms
- Expensive in memory, however, since the context must be kept alive between requests, while the user thinks: above 20 ms vs 2020 ms, factor of 100
- Rather than holding a whole context for a conversation, we can condense it down to a usually-small dataset as part of "session data", save nearly a factor of 100
- This can be held in the common database, but as unshared data, has other possibilities too

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Performance & Scalability: Assumptions

- One database server with plenty of memory
- Warm data is in DB server's cache
- One or multiple application servers
- No shared mutable data on app servers
- All shared mutable data is in the database
- DB server's cache data is fast to access over a local network
- Standard use of pooled DB connections to avoid connection-setup delays

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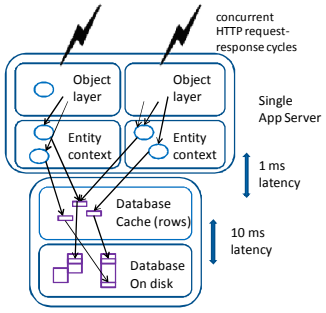
Web app, small site



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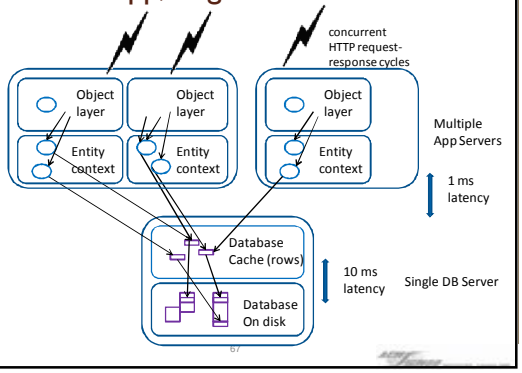
Web app, larger site



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Second-level caching

- If this simple design is maxing out, say with 1000s of Tx/sec
  - And is not sharing DB with other apps
  - And specifically is overwhelming the DB
- Can try second-level caching to offload the DB
- Example: JBoss Cache, a transactional replicated distributed cache
- i.e, can handle case of multiple app servers
- Involves more configuration, tuning, not easy
- Hopefully plenty of money for consultants at this point

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Summary

- Relational technology continues to prove its worth, and ORM is using it in full
- Only one deficiency of SQL 92 uncovered: standard way to generate new unique id
- The object-relational impedance mismatch has been largely overcome
- No textbooks yet, little academic work: Hibernate semantics are "example-driven"…
- See sources, run web app (Hibernate version) at www.cs.umb.edu/~eoneil/orm

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Bibliography

In proceedings (subset):

[1] Adya, Atul, Blakely, Jose, Melnik, Sergey, Meralidhar, S., and the ADO.NET Team, 2007, Anatomy of the ADO.NET Entity Framework, In Proceedings of SIGMOD 2007, ACM Press, New York, NY.

[3] Bauer, Christian, King, Gavin 2006 Java Persistence with Hibernate, Manning

[5] Bernstein, Phil, Melnik, Sergey. 2007 Model Management 2.0—Manipulating Richer Mappings. In Proceedings of SIGMOD 2007, ACM Press, New York, NY, 1-12.

[7] Hibernate, http://www.hibernate.org

[10] MSDN Library, 2006 The ADO.NET Entity Framework Overview, http://msdn2.microsoft.com/en-us/library/aa697427(VS.80).aspx

Added:

[13] Fowler, Martin 2003 Patterns of Enterprise Application Architecture, Addison-Wesley

[14] Evans, Eric 2004 Domain-Driven Design, Addison-Wesley

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