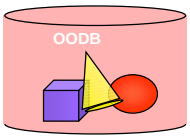
ODMG Object Programming Language Bindings

Objectives

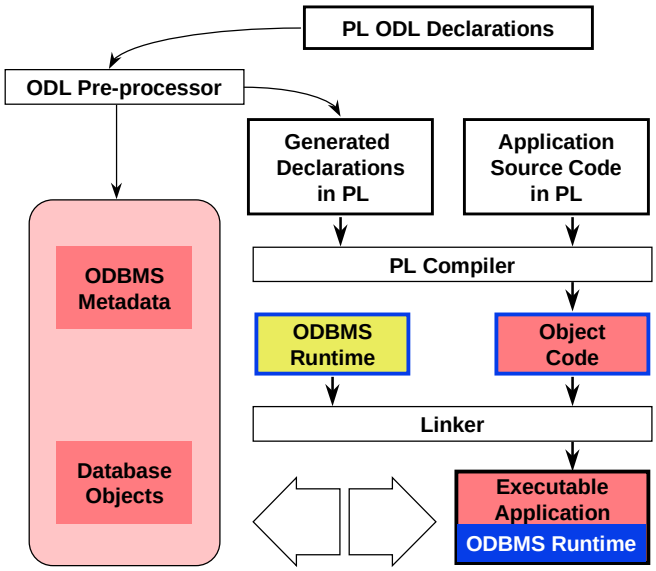
- Implement the abstract model
  - mapping concepts
  - mapping types
  - mapping collections
- Adapt the model whenever necessary
  - some concepts are not supported by the language
    - interface: in C++ ==> class
    - association: in C++ and Java ==> attributes of type Ref <T>
    - keys: in C++ and Java ==> no keys !
- Integrate the OQL Query Language

Benefits

- Extend programming language with persistent capability
  - migrate programming applications in memory to databases
  - manipulate object databases with standard programming language
- Provide to programming language database functionality:
  - querying
  - transactions
  - security
  - indexing, ...



Architecture



I) ODMG C++ BINDING

Design Principles

- Provide a C++ library where there is a unified type system across the programming language and the database
- The C++ binding maps the ODMG Object Model into C++ through a set of "persistence-capable" classes
  - Uses C++ template classes for implementation
  - Based on the smart pointer ("ref-based") approach
- Main Features
  - Mapping between ODMG types and C++ types
  - Access to Meta-schema
  - C++/OQL Coupling
- The OML/C++ is C++ compliant (i.e. standard C++ compilers)
  - Compatible with Standard Template Library (STL) + persistence

Persistence-capable Classes

- For each persistence-capable class *T*, a twin class *d_Ref*<*T*> is defined
  - Instances of a persistence-capable class behave like C++ pointers (but OIDs ≠ C++pointer)
  - Instances may contain built-in types, user-defined classes, or pointers to transient data accessible through C++ references during a transaction
- The C++ binding defines the class *d_Object* as the superclass of all persistence-capable classes
  - Persistence propagation by inheritance
  - Persistence declaration during creation time
- The notion of interface is implicit in ODMG C++ binding
  - interface: public part of C++ class definitions
  - implementation: protected and private parts of C++ class definitions

Persistence-capable Classes: An O2 Example

```
class Person:
  public d_Object {
  private:
    char* name;
    d_Ref<Person> spouse;
    d_Set<d_Ref<Person>>
      family;
  public:
    Person (char* name);
     ~Person();
};
```

Persistence-capable class

```
class Person: virtual public o2_root {
 private:
    char* name;
    d_Ref<Person> spouse
    d_Set<d_Ref<Person>> family;
 public:
    Person (char* name);
     ~Person();
 protected:
    virtual void o2_new();
    virtual void o2_read();
    virtual void o2_write();
.........
};
```

Twin class in O2

Mapping the ODMG Object Model into C++

ODMG		C++
structure		*struct/class*
class C		*d_Ref<C>*
set<T> bag<T>		*d_Set<Φ(T)> d_Bag<Φ(T)>*
array<T>		*Φ(T)[]* or *d_Array<Φ(T)>*
relationship T		*d_Rel_Ref<Φ(T)>*
relationship set<T>		*d_Rel_Set<Φ(T)>*
extent of class T	Φ	*d_Extent <Φ(T)>*
keys		*not supported*
exception handling		*C++ exception mechanism*
collection		*abstract template class*
named operations		*C++ function members*
create, delete		*constructor, destructor*
basic type T		*d_T: d_String, d_Time, d_Date, d_Boolean,*

ODMG C++ ODL

- The database schema is derived from the C++ class hierarchy
- All primitive C++ data types are explicitly supported except: unions, bit fields, and references
  - Objects may refer others only through a smart pointer called d_Ref
- Several predefined structured literal types are provided, including:
  - d_String, d_Interval, d_Date, d_Time, d_Timestamp
- A number of basic fixed-length types is also supported
- There is a list of parameterized collection classes:
  - d_Set, d_Bag, d_List, d_Varray, d_Dictionary
- C++ interpretation of the ODMG relationships
- The class d_Extent<T> provides an interface to the extent for a persistence-capable class T

C++ ODL Basic Types

Basic Type	Range	Description
d_Short	16 bits	signed integer
d_Long	32 bits	signed integer
d_UShort	16 bits	unsigned integer
d_ULong	16 bits	unsigned integer
d_Float	32 bits	single precision
d_Double	64 bits	double precision
d_Char	8 bits	ASCII
d_Octet	8 bits	no interpretation
d_Boolean	d_True,D_False	

C++ ODL d_Ref

- A d_Ref is parameterized by the type of the referenced object

```
d_Ref<Professor>    profP;
d_Ref<Department> deptRef;
profP->grant_tenure();
deptRef = profP->dept;
```

- d_Ref is defined as a class template:

```
template <class T> class d_Ref {.....}
```

- d_Ref <T> can be converted into d_Ref_Any, in order to support a reference to any type, similar to that of void *
- Operators == and != are defined to compare the objects referenced, rather than memory addresses (shallow copy semantics)
- The dereferencing operator (→) is used to access members of the persistent object "addressed" by the specific reference

C++ ODL Collections

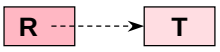
- d_Set, d_Bag, d_List, d_Varray, d_Dictionary are subclass of d_Collection
- The collections classes are delivered as templates:

```
template <class T> d_Collection : public d_Object
template <class T> d_Set : public d_Collection
```

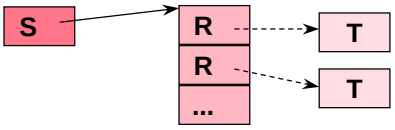
- Elements therein are accessed through iterators
- Elements to be inserted in a collection must define:
  - default ctor, copy ctor, dtor, assignment op, and equality op;
  - types requiring ordering must also provide the less-than op

C++ ODL Collections: Examples

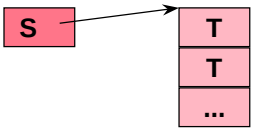
d_Ref<T>



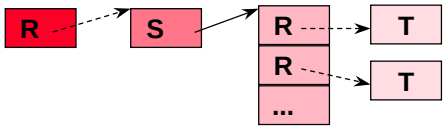
d_Set<d_Ref<T> >



d_Set<T>



d_Ref<d_Set<d_Ref<T> > >



C++ ODL Relationships

- Declaring various types of relationships between classes
  - 1-1: d_Rel_Ref
  - 1-n: d_Rel_Set or d_Rel_List and d_Rel_Ref
  - m-n: d_Rel_Set or d_Rel_List and d_Rel_Set or d_Rel_List
- Relationships are also implemented with class templates

```
template < class T, const char* Member> class d_Rel_Ref :
                    public d_Ref <T>
template < class T, const char* Member> class d_Rel_Set :
                    public d_Set < d_Ref <T>>
template < class T, const char* Member> class d_Rel_List :
                    public d_list < d_Ref <T>>
```

- Creating, traversing and updating relationships using C++ OML

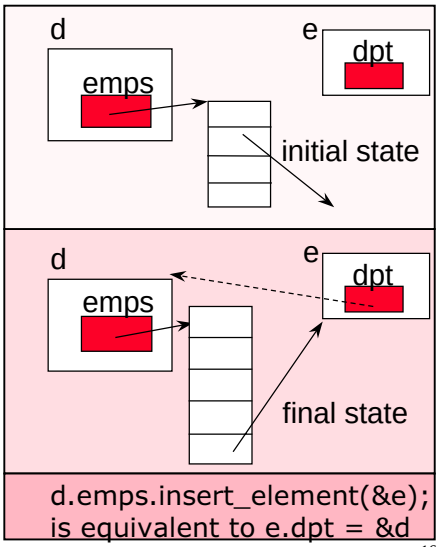
C++ ODL Relationships: Example

```
extern const char _dpt[],_emps[];

class Department {
  d_Rel_Set <Employee,_dpt> emps;
};

class Employee {
  d_Rel_Ref <Department,_emps> dpt;
};

const char _dpt[] = "dpt";
const char _emps[] = "emps";
```



C++ ODL d_Extent<T>

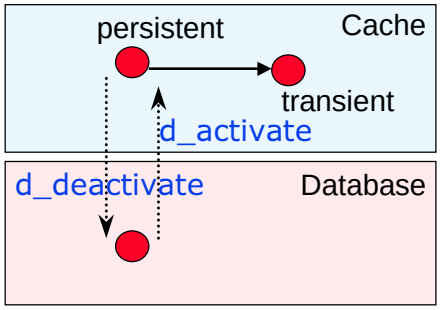
- The class d_Extent<T> provides an interface to the extent of a persistence capable class T in the C++ binding
- The database schema definition contains a parameter for each persistent class specifying whether the ODBMS should maintain the extent for the class
- The content of this class is automatically maintained by the ODBMS
- The class includes optional support for polymorphism
- Comparison and set operations are not defined for this class

ODMG C++ OML

- Object creation
- Object deletion
- Object modification
- Object naming
- Manipulating collections
- C++/OQL

Database and Memory Cache

- The d_Object class allows the type definer to specify when a class is capable of having persistent, as well as transient instances
- Pointers to transient objects in a newly retrieved persistent object must be initialized by the application
- When a persistent object is committed, the ODBMS sets its embedded d_Refs to transient objects to null
- Binding-specific member functions d_activate and d_deactivate called when a persistent object enters, or exits respectively the application cache

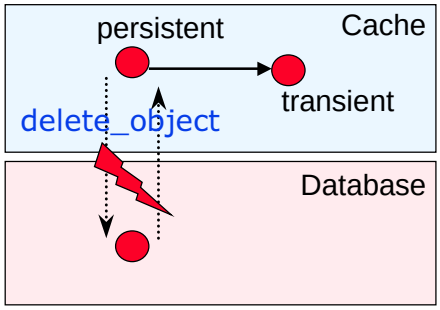


Object Creation

- Whether an object is transient or persistent is decided at creation time
- Objects are created with the new operator, overloaded to accept arguments specifying object lifetime
  - transient object
    void * operator new(size_t)
  - persisted object to be placed "near" the clustering object
    void *operator new(const d_Ref_Any &clustering, const char *typename)
  - persistent object to be placed in the database (unspecified clustering)
    void * operator new (d_Database *database, const char *typename)
- Examples:
  - d_Ref <Person> adam = new (&base) Person;
  - d_Ref <Person> eve = new (adam) Person;

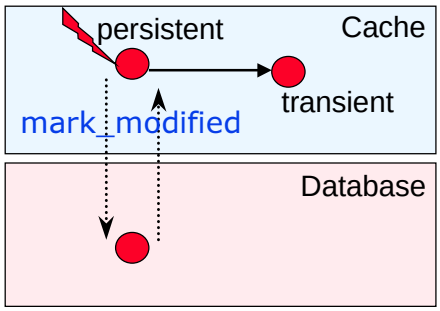
Object Deletion

- Deleting a persistent object is done with the operation delete_object(), which is a member function of the d_Ref class
- The effect of the delete operation is to cut the link between the referenced object in memory and the corresponding object into the database
- The definitive deletion is subject to transaction commit



Object Modification

- When a persistent object is brought into memory, its initial state is identical to the database state
- In memory, the state is modified by updating properties or by invoking operations on it, as regular C++ ops
- To inform the runtime ODBMS that the state has been modified we need a special function mark_modified of class d_Object
  - In some implementations, it is possible to detect that the state of an object has been modified
- The ODBMS updates the database at transaction commit time



Object Naming & d_Database Class

- To retrieve objects in a database we need persistent names
  - These names are the root of the persistency
- A name can identify a unique object or a collection of objects
  - Object names can be assigned and modified at run-time
- The facility for naming is related with the class d_Database
  - Objects of this class are transient and their semantics do not include actual database creation
  - Other supported operations include opening and closing an existing database

Examples of Object Naming

```
d_Session session;
d_Database base;
d_Transaction trans;
session.set_default_env;
session.begin(argc, argv);
base.open("origin");
trans.begin( );
d_Ref<Person>
 adam=new(&base) Person("adam");
base.set_object_name(adam,"adam");
trans.commit;
base.close( );
session.end( );
```

```
.....
session.set_default_env;
session.begin(argc,argv);
base.open("origin");
trans.begin( );
adam=base.lookup_object("adam”);
d_Ref<Person>
  eve=new (&base) Person ("eve");
adam -> spouse = eve;
d_Ref <Person>
  cain=new (&base) Person ("cain");
adam->family.insert_element (cain);
trans.commit;
base.close( );
session.end( );
```

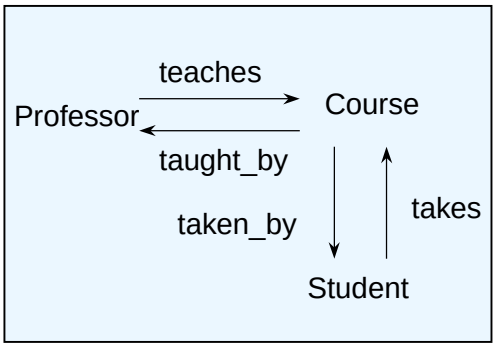
Iterating on Collections

- To iterate on collections a template class d_Iterator<T> is defined
- Iterators can be obtained though the create_iterator method defined in the class d_Collection
- The get_element function return the value of the currently "pointed-to" element in the collection (if any)
- The next function checks the end of iteration, advancing the iterator and returning the current element
- Iterators mean great flexibility:
  - collection type independence
  - element type independence
  - generality and reusability

```
d_Iterator <d_Ref<Person>> iter=
   adam->family.create_iterator ( );
d_Ref <Person>  s;
while (iter.next (s)) {
            .....
}
```


OQL Embedded in C++

- Queries are supported in two forms: collections vs database
- Directed queries on collections
  - made through the query method of collection classes
  - they require as parameter the query predicate in a string; the syntax is that of the OQL *where* clause
  - the result is returned in a second collection class
- Queries on the database
  - first an object of type d_OQL_Query must be constructed
  - then the query must be executed with the d_oql_execute function



Query Examples

```
d_Set < d_Ref < Student > > Students, mathematicians, old;

Students.query (mathematicians,
                "exists c in this.takes: c.subject = 'Math' ");

d_OQL_Query  q1( "select s
                  from  s in $1
                  where exists c in s.taken_by:
                     s.age > c.taught_by.age");

query = q1 << Students;
d_oql_execute ( query, old );
query = q1 << others;
d_oql_execute ( query, old);
```


Queries on the Database

- d_oql_execute returns either a collection, or an iterator on a collection (both are type-checked)
- queries can be constructed incrementally (using <<)
- queries can be parameterized
  - parameters in the query string are signified with $i
  - the shift-left operator (<<) is used to provide values as right-hand operands
  - the clear method re-initializes the query, so that it can be reused with different values
  - upon successful execution of a query the values are automatically cleared

Schema Access

- The ODMG database schema can be accessed through appropriate interfaces defined in the C++ binding
- The schema-access API is in effect an object-oriented framework
- C++ specific ODL extensions are included in the schema-access API (the C++ ODL is a superset of the ODMG ODL)
- Currently only the *read* interface is defined; the *write* interface is vendor-dependent
- Schema access is necessary not only for inspecting a database schema, but also for manipulating it at run-time (e.g. extents)

The ODMG Schema Access Class Hierarchy

```
- d_Scope
- d_Meta_Object
    |- d_Module [d_Scope]
    |- d_Type
    |  |- d_Class [d_Scope]
    |  |- d_Ref_Type
    |  |- d_Collection_Type
    |  |   \- d_Keyed_Collection_Type
    |  |- d_Primitive_Type
    |  |   \- d_Enumeration_Type [d_Scope]
    |  |- d_Structure_Type [d_Scope]
    |  \- d_Alias_Type
    |- d_Property
    |  |- d_Relationship
    |  \- d_Attribute
    |- d_Operation [d_Scope]
    |- d_Exception
    |- d_Parameter
    \- d_Constant
- d_Inheritance
```

II) ODMG Java BINDING

Main Features

- Unified type system between the Java language and the database
  - No modifications to Java syntax
- Java classes can be made persistence-capable
  - importation: Java classes ⇒ ODMG ODL
  - exportation: ODMG ODL ⇒ Java classes
- Automatic storage management semantics of Java
  - transient, dynamic persistency
- Transparent access and update to the database
- Collections
- Query facilities

Persistency

- Persistency is by reachability from persistent roots
  - All the persistent objects are directly or transitively attached to the persistent root
- At commit time if an object is connected to a persistent root then the object is written automatically into the database
- The class Database allows to define persistent roots and to retrieve them:
  - bind (Object, String) // give a name
  - lookup (String) // retrieve an object by its name

Retrieving and Creating Objects: Example

```
Database base = new Database;
base.open ("origin");
Transaction trans = new Transaction;
trans.begin ( );
Person adam = new Person ("adam");
base.bind (adam, "adam");
trans.commit ( );
base.close ( );
```

```
Database base = new Database;
base.open ("origin");
Transaction trans = new Transaction;
trans.begin ( );
Person adam = base.lookup("adam");
Person eve = new Person ("eve");
Person cain = new Person ("cain");
adam.spouse = eve;
adam.family.insertElement(cain);
trans.commit ( );
base.close ( );
```

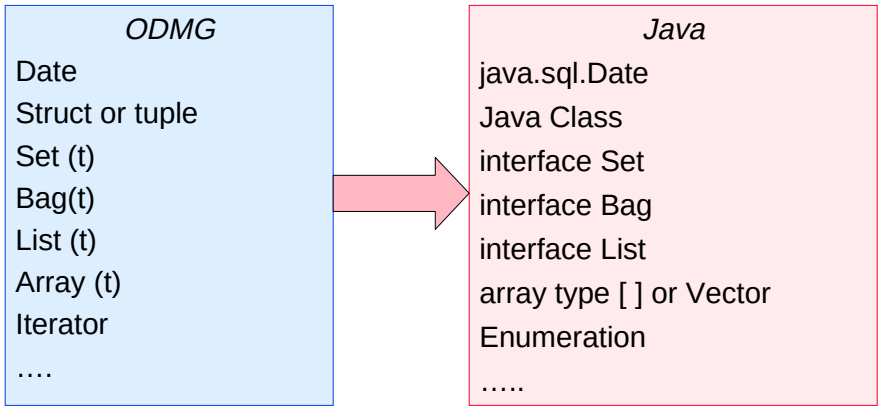
Interface Database

```
public class Database {
        public static Database open ( String name)
                throws ODMGException;
        public void close ( )
                throws ODMGException;
        public void bind (Object obj, String name);
        public Object lookup (String name)
                throws ObjectNaneNotFoundException;
}
```


Primitive Java Types

Basic Type	Description
integer short long float boolean char, byte, string	Integer class Short class Long class Float class Boolean class Char class

Mapping from ODMG to Java



ODMG Java OML

- Same Java syntax for manipulating persistent or transient objects
- Object creation is done with the new operator
  - If an object type intermixes persistent data and transient data only persistent data is loaded in memory, transient data is set to default
- There is no object deletion since persistency is by reachability
- Modification of objects is done with standard Java operations
  - At commit time modifications are written back automatically
- Collection interfaces
  - Collection, Set, Bag, List
- The interface Transaction provides standard operations as: begin( ), commit( ), abort( )
  - Operations are also defined for using the possibility of multithreading in Java, such operations are: join, current, etc.
- Java/OQL Coupling
  - similar to the C++ binding; bind is used instead of <<

Interface Collection

```
public interface Collection {
        public int size ( );
        public boolean isEmpty ( );
        public removeElement ( );
        .........
        public Collection query (String predicate);
}
```


Interface Set

```
public interface Set extends Collection {
        public Set union (Set otherSet);
        public Set intersection (Set otherSet);
        .......
        public boolean properSubsetOf (Set otherSet);
        .......
}
```

Interface List

```
public interface List extends Collection {
        public void add (int index, Object obj)
                throws ArrayIndexOutOfBounds;
        public void put (int index, Object obj)
                throws ArrayIndexOutOfBounds;
        ........
        public Object get (int index)
                throws ArrayIndexOutOfBounds;
        public List concat (List other);

}
```


OQL Embedded in Java

- Directed queries on collections
  - Filtering a collection with the operation query defined in the interface Collection
- Example :

  SetOfObject mathematicians;

  mathematicians = Students.query("exists c in this.takes: c.subject='Math' ");

- Queries on the database
  - Using the class OQLQuery (String question) and the operations bind(Object parameter) and execute()
- Example :

  Set Students, young;

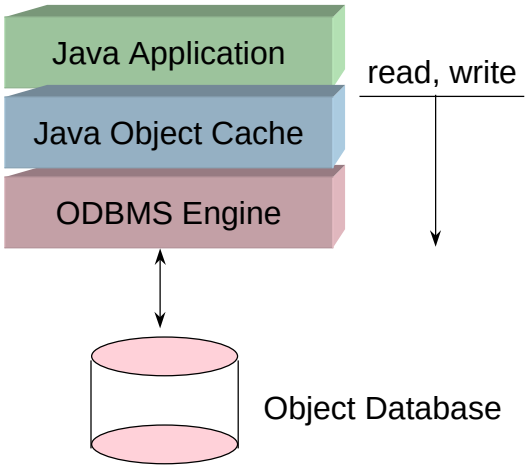
  OQLQuery q1;

  q1 = new OQLQuery ("select s from s in $1 where s.age = $2");

  q1.bind(Students); q1.bind(25);

  young = (Set) q1.execute ( );

General Architecture



Conclusion

- Java is well adapted to become a database programming language
- Some features of the ODMG model are not supported:
  - Relationships & collections are not parameterized by a type or a class
  - Extents & Keys
- The concepts of Java interface and implementation allow the possibility to define very powerful implementations for Set and List with HashSet, ArraySet, ArrayList, LinkedList, etc.

V) REFERENCES

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