

# A Better Eiffelstore Library

Bachelor Thesis

By: Roman Schmocker  
Supervised by: Marco Piccioni  
Prof. Dr. Bertrand Meyer

Student Number: 09-911-215



## **Abstract**

ABEL is a persistence library that unifies existing solutions under a simple and transparent API. The API fully supports the CRUD operations, transactions, and has some advanced features like result filtering based on some criteria.

The library contains a powerful framework with an object-relational mapping layer at the core that allows to adapt ABEL to basically any existing persistence solution.



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# Chapter 1

## Introduction

### 1.1 Introduction

The Eiffel language [2] [8] features a lot of different persistence libraries, and every solution has its own advantages and drawback. A database such as MySQL [3] for example is quite fast, but it comes at the expense of the object-relational impedance mismatch.[7] A serialization library on the other hand is easier to handle for the programmer, but its performance rapidly decreases for large data sets.

It is very hard to switch from one persistence solution to another, because all have their own interface. Even changing for example the database from MySQL to Oracle [4] is usually very hard to achieve, if only because their SQL dialects are different.

To overcome such problems we have developed a new library called ABEL, which is the acronym for “A better Eiffelstore library”. ABEL tries to unify existing persistence libraries under a simple and yet powerful API, which is completely transparent to the actual storage mechanism.

### 1.2 Overview

This thesis is basically splitted into two parts: The API tutorial and the technical documentation.

In the first part you will be introduced to the basic operations of the API, like the CRUD (Create, Read, Update, Delete) operations or transaction handling.

The second part is an introduction to the general architecture of ABEL and some selected topics like the object-relational mapping layer or the main interfaces for backend abstraction.

# Chapter 2

## API tutorial

### 2.1 Getting started

#### 2.1.1 The setup

In this little tutorial, we are using PERSON objects to show the usage of the API. In the source code below you will see that ABEL handles objects "as they are", meaning that you don't need to inherit from any specific class to make them persistent.

```
1 class PERSON

    create
4    make

    feature {NONE} -- Initialization
7
    make (first, last: STRING)
        -- Create a new person
10    do
        first_name := first
        last_name := last
13    age:= 0
    end

16 feature -- Basic operations

    celebrate_birthday
19    -- Increase age by 1
    do
        age:= age+1
```



```

22     end

    feature -- Access
25
        first_name: STRING
            -- First name of person
28        last_name: STRING
            -- Last name of person

31        age: INTEGER
            -- The person's age

34 end

```

**Listing 2.1:** The *PERSON* class

There are 3 very important classes in ABEL:

- The `CRUD_EXECUTOR` is, as the name suggests, responsible to execute CRUD commands. It is the core interface in ABEL and completely transparent to the actual storage backend.
- The `OBJECT_QUERY [G]` class is used to describe a read operation in ABEL. You can execute such a query in the `CRUD_EXECUTOR`. The result will be objects of type `G`.
- The deferred class `REPOSITORY` provides an abstraction to the actual storage mechanism. Every `CRUD_EXECUTOR` is attached to a specific `REPOSITORY`.

## 2.1.2 Initialization

To start using the library, we therefore first need to create a `REPOSITORY`. For this tutorial we will use a simple `IN_MEMORY_REPOSITORY`, which simulates a relational database but stores all values in memory. Although this repository will not give us any persistence, we use it here because initialization is very easy.

```

1 class TUTORIAL

    create
4     make

    feature {NONE} -- Initialization
7

```

```

make
-- Set up a simple in-memory repository
10  local
    repository: PS_IN_MEMORY_REPOSITORY
do
13  create repository.make
    create executor.make (repository)
end
16
feature

19  executor: PS_CRUD_EXECUTOR
    -- The CRUD executor used throughout the tutorial

22 end

```

*Listing 2.2: The TUTORIAL class*

We will use this class throughout the tutorial. You can assume that listings of Eiffel features are inside the TUTORIAL class, if they are not enclosed in another class declaration.

If you want to set up ABEL using a real persistence mechanism, you can read section 2.5, “Advanced Initialization.”

## 2.2 Basic operations

### 2.2.1 Query

A query for objects is done by creating a OBJECT\_QUERY [G] object and executing it in the CRUD\_EXECUTOR. The generic parameter G of the OBJECT\_QUERY instance denotes the type of objects that should be queried.

After a successful execution of the query, you can get the result through the iteration cursor OBJECT\_QUERY.result\_cursor. Having an iteration cursor as a result has several advantages, e.g. support for lazy loading or the across syntax, as you will see in the next example:

cite?

```

simple_query: LINKED_LIST [PERSON]
2  -- Query all person objects from the current repository
    local
        query: PS_OBJECT_QUERY [PERSON]
5  do
        create Result.make
        create query.make

```

```

8      executor.execute_query (query)

      across query as query_result
11     loop
        Result.extend (query_result.item)
      end
14   end

```

Usually the result of such a query is very big, and you are probably only interested in objects that meet a certain criteria, e.g. all persons of age 20. ABEL has a mechanism to support this kind of result filtering. You can read about it in section 2.3.

Please note that ABEL does not enforce any kind of order on a query result.

### 2.2.2 Insert and update

Inserting and updating an object is done through `CRUD_EXECUTOR.insert` (or `CRUD_EXECUTOR.update`, respectively):

```

1  simple_insert_and_update (a_person:PERSON)
    -- insert 'a_person' into the current repository
    do
4      executor.insert (a_person)
        a_person.celebrate_birthday
        executor.update (a_person)
7  end

```

### 2.2.3 Deletion

Deletion is done through the `CRUD_EXECUTOR.delete` feature, like shown in the following example:

```

    delete_person (name:STRING)
2    -- Delete the person called 'name'.
    local
        query: PS_OBJECT_QUERY[PERSON]
5    do
        -- First retrieve the person from the database
        create query.make
8        executor.execute_query (query)
        across query as query_result
        loop

```

```

11      if query_result.item.last_name.equals (name) then

        -- Now delete him
14      executor.delete (query_result.item)
        end
      end
17 end

```

There is another way to delete objects which uses a query and some matching criteria. You can read about it in section 2.3.3.

## 2.2.4 Recognizing Objects

ABEL keeps track of objects that have been inserted or queried. This is important because in case of an update or delete, ABEL needs to internally map the object in the current execution of the program to its specific entry in the database. Because of that, you can't update or delete an object that is not yet known to ABEL. As an example, the following two functions will fail:

```

1  failing_update
   -- Try and fail to update a new person object
   local
4    a_person:PERSON
   do
      create a_person.make ("Albo", "Bitossi")
7    executor.update (a_person)
      -- Results in a precondition violation
   end
10
   failing_delete (name:STRING)
   -- Try and fail to delete a new person object
13  local
      a_person:PERSON
   do
16    create a_person.make ("Albo", "Bitossi")
      executor.delete (a_person)
      -- Results in a precondition violation
19  end

```

Please note that there's another way to delete objects, described in Section 2.3.3, which doesn't have this restriction.

The `CRUD_EXECUTOR.is_persistent` feature can tell you if a specific object is known to ABEL and therefore has a link to its entry in the data-

base.

## 2.3 Advanced Queries

### 2.3.1 The query mechanism

As you already know, queries to the database are done by creating a new `OBJECT_QUERY` and letting it be executed by the `CRUD_EXECUTOR`. The generic parameter `G` of the `OBJECT_QUERY` instance determines the type of the objects that will be returned, including any conforming type (e.g. descendants of `G`).

ABEL will by default load an object completely, that means all objects that can be reached by following references will be loaded as well. There is a mechanism in ABEL that ensures that an object will not be loaded twice in a single query (see also section 2.4).

### 2.3.2 Criteria

You can filter your query results by setting criteria in the query object, using the `OBJECT_QUERY.set_criteria` feature. There are two types: predefined and agent criteria.

#### Predefined Criteria

Predefined criteria take an attribute name, an operator and a value. You can only use attributes that are of a basic type, like strings or numbers. During retrieval, ABEL checks the object's own value against the value set in the criterion, and filters objects that don't satisfy the criterion.

Most supported operators are pretty self-describing (see Listing 2.3). The likely exception is the "like"-operator, which does pattern-matching on strings. You can give the "like"-operator a pattern string as a value, which can contain the wildcard characters `*` and `?`. The asterisk stands for any number (including zero) of undefined characters, and the question mark means exactly one undefined character.

Not every type of attribute supports every operator. Valid combinations for each type are:

- Strings: `=`, `like`
- Any numeric value: `=`, `<`, `<=`, `>`, `>=`

- Booleans: =

Note that for performance reasons it is usually better to use predefined criteria, because they can be compiled to SQL and therefore the result will be filtered in the database.

## Agent Criteria

An agent criterion will filter the objects according to the result of an agent applied to them.

The criterion is initialized with an agent of type `PREDICATE [ANY, TUPLE [ANY]]`. There should be either an open target or a single open argument, and the type of the objects in the query result should conform to the agent's open operand.

## Creating criteria objects

The criteria instances are best created using the `CRITERION_FACTORY` class.

The main functions of the class are the following:

```

class
2  PS_CRITERION_FACTORY
  create
    default_create
5
  feature -- Creating a criterion

8  new alias "[]" (tuple: TUPLE [ANY]): PS_CRITERION
    -- This function creates a new criterion according to
    -- the tuple in the argument. The tuple should either
11  -- contain a single PREDICATE or three values with
    -- type [STRING, STRING, ANY]

14
    new_agent (a_predicate: PREDICATE [ANY, TUPLE [ANY]]):
      PS_CRITERION
      -- creates a criterion with an agent

17
    new_predefined (object_attribute: STRING;
      operator: STRING; value: ANY): PS_CRITERION
20  -- creates a predefined criterion

```

```

feature -- Operators
23   equals: STRING = "="

26   greater: STRING = ">"

    greater_equal: STRING = ">="
29   less: STRING = "<"

32   less_equal: STRING = "<="

    like_string: STRING = "like"
35
end

```

**Listing 2.3:** The *CRITERION\_FACTORY* interface

To create a new criterion, you basically have two possibilities. The first one is the more traditional one, using `CRITERION_FACTORY.new_agent` or `CRITERION_FACTORY.new_predefined`.

The second uses some syntactic sugar: The criterion is created with two brackets after the factory object, of which one is an overloaded operator and the other a tuple definition. It can be used for both types of criteria, and it is up to you to choose which approach you like best.

```

    create_criteria_traditional : PS_CRITERION
3   -- Create a new criteria using the traditional approach
    do

6       -- for predefined criteria
        Result :=
            factory.new_predefined ("age", factory.less, 5)
9
        -- for agent criteria
        Result :=
12        factory.new_agent (agent age_less_than (?, 5))
    end

15
    create_criteria_double_bracket : PS_CRITERION
    -- Create a new criteria using the double bracket syntax
18    do

```

```

-- for predefined criteria
21 Result:= factory["age", factory.less, 5]]

-- for agent criteria
24 Result := factory[agent age_less_than (?, 5)]]
end

27
age_less_than (person: PERSON; age: INTEGER): BOOLEAN
-- Just a little example agent
30 do
    Result:= person.age < age
end

```

## Combining criteria

If you want to set multiple criterion objects, you can combine them using the standard Eiffel keywords. For example, if you want to search for a person called “Albo Bitossi” with age  $\neq$  20, you can just create a criterion object for each of the constraints and combine them:

```

search_albo_bitossi : PS_CRITERION
3 -- Create a criterion object that searches for an Albo
  Bitossi which is not 20 years old
local
    first_name_criterion:PS_CRITERION
6    last_name_criterion: PS_CRITERION
    age_criterion: PS_CRITERION
do
9    first_name_criterion:=
      factory["first_name", factory.equals, "Albo" ]]

12    last_name_criterion :=
      factory["last_name", factory.equals, "Bitossi" ]]

15    age_criterion :=
      factory["age", factory.equals, 20 ]]

18 Result := first_name_criterion and last_name_criterion
    and not age_criterion

-- or a bit shorter

```



```

21      Result := factory[[ "first_name", "=", "Albo" ]]
           and factory[[ "last_name", "=", "Bitossi" ]]
           and not factory[[ "age", "=", 20 ]]
24  end

```

ABEL supports the three standard logical operators AND, OR and NOT. Their precedence is the same as in Eiffel, which means that NOT is stronger than AND, which in turn is stronger than OR.

### 2.3.3 Deletion queries

As already mentioned previously, there is another way to perform a deletion in the repository. When you call `CRUD_EXECUTOR.execute_deletion_query`, ABEL will delete all objects in the database that would have been retrieved by executing the query normally. You can look at the following example and compare it with its variation in the delete section 2.2.3

```

      delete_person (name:STRING)
      -- Delete 'name' using a deletion query.
3    local
           deletion_query: PS_OBJECT_QUERY[PERSON]
           criterion:PS_PREDEFINED_CRITERION
6    do
           create deletion_query.make
           create criterion.make ("last_name", "=", name)
9    deletion_query.set_criterion (criterion)
           executor.execute_deletion_query (deletion_query)
    end

```

It depends on the situation if you want to use deletion queries or a direct delete command. Usually, a direct command is better if you already have the object in memory, whereas deletion queries are nice to use if the object is not yet loaded from the database.

### 2.3.4 Tuple queries

So far, we've only looked at queries that return objects. However, in ABEL there is a second option to query data which returns tuples as a result. Consider an example where you just want to have a list of all last names of persons in the database. To load every object of type `PERSON` might lead to a very bad performance, especially if there is a big object graph attached to each person object.

To solve this problem, you can instead send a `TUPLE_QUERY` to the executor. The result is an iterator over a list of tuples in which the attributes of an object are collected. The order of these attributes is the one defined in `TUPLE_QUERY.projection`

```

1  print_all_last_names
   -- Print the last name of all PERSON objects
   local
4    query: PS_TUPLE_QUERY[PERSON]
      last_name_index: INTEGER
      single_result: TUPLE
7  do
      create query.make
      -- Find out at which position in the tuple the
        last_name is returned
10   last_name_index:= find_index_of_attribute("last_name")

      from
13     executor.execute_query (query)
      until
        query.result_cursor.after
16   loop
        single_result:= query.result_cursor.item
        print (single_result [last_name_index] )
19   end
   end

```

## Tuple queries and projections

By default, a `TUPLE_QUERY` will only return attributes which are of a basic type, so no references are followed during a retrieve. You can change this default by calling `TUPLE_QUERY.set_projection`, which expects an array of names of the attributes you would like to have. If you include an attribute name whose type is not a basic one, ABEL will actually retrieve and build the attribute object, and not just another tuple.

## Tuple queries and criteria

As you can't use agents on tuples (because they expect an object and not a tuple), you are restricted to use predefined criteria in tuple queries. You can still combine them as usual. It is ok to include a criterion on an attribute that is not present in the projection list - these attributes will be

loaded internally to check if the object satisfies the criterion, but then they are discarded for the actual result.

```

1  print_last_names_of_20_year_old
   -- Print the last name of all PERSON objects with age=20
   local
4    query: PS_TUPLE_QUERY[PERSON]
   do
       create query.make
7
       -- Only return the last_name of persons
       query.set_projection (<<"last_name">>)
10
       -- Only return persons with age=20
       query.set_criterion (factory [["age", "=", 20]])
13
       from
           executor.execute_query (query)
16       until
           query.result_cursor.after
       loop
19         -- As we only have the last_name in the tuple,
           -- its index has to be 1
           print (query.result_cursor.item [1] )
22       end
   end

```

## 2.4 Dealing with references

In ABEL, a basic type is an object of type STRING, BOOLEAN, CHARACTER or any numeric object like REAL or INTEGER. The PERSON class has attributes that are of a basic type only, and those are stored together as a single unit in the database.

However, in Eiffel there's also the fact that an object can contain references to other objects. ABEL is able to handle these references by storing and reconstructing the whole object graph (An object graph is sloppily defined as all objects that can be reached by recursively following all references, starting at some root object).

Let's look at the new class CHILD:

```

1
class

```

```

    CHILD
4
    create
        make
7
    feature {NONE} -- Initialization

10    make (first, last: STRING)
        -- Create a new child
        do
13        first_name := first
            last_name := last
            age:= 0
16    end

    feature -- Access

19    celebrate_birthday
        -- Increase age by 1
22    do
        age:= age+1
    end

25    feature -- Status report

28    first_name: STRING
        -- First name of child
        last_name: STRING
31    -- Last name of child

        age: INTEGER
34    -- The child's age

    feature -- Parents

37    mother: detachable CHILD
        -- 'Current's mother

40    father: detachable CHILD
        -- 'Current's father

43    set_mother (a_mother: CHILD)
        -- Set the mother

```

```

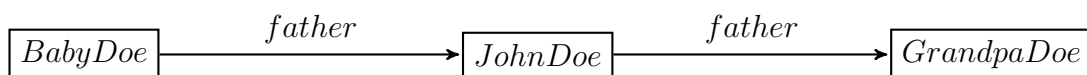
46     do
        mother:= a_mother
    end
49
    set_father (a_father: CHILD)
    -- Set the father
52     do
        father:= a_father
    end
55 end

```

**Listing 2.4:** The *CHILD* class

This adds in some complexity: Instead of having a single object, ABEL has to insert a *CHILD*'s mother and father as well, and if their parent attribute is attached as well it has to repeat again. The good news for you is that the examples above will work exactly the same.

However, there are some additional caveats to take into consideration. Let's consider a simple example with *CHILD* objects "Baby Doe", "John Doe" and "Grandpa Doe". From the name of the object instances you can already guess what the object graph looks like:



Now if you insert "Baby Doe" into the repository, ABEL will by default follow all references and insert every single object along the object graph, which means that "John Doe" and "Grandpa Doe" will be inserted as well. This is usually the desired behaviour, as objects are stored completely that way, but it also has some side effects:

- Assume an insert of "Baby Doe" has happened to an empty database. If you now query the database for *CHILD* objects, it will return exactly the same object graph as above, but the query result will actually have three items, as the object graph consists of three single *CHILD* objects.
- After you've inserted "Baby Doe", it has no effect if you insert "John Doe" or "Grandpa Doe" afterwards, because they have already been inserted through the first statement.

### 2.4.1 Updates

By default, ABEL does not follow references on updates. So for example the following statement has no effect on the database.

```
celebrate_fathers_birthday (a_child: CHILD)
2  -- Increase age of 'a_child's father
  require
    child_persistent: executor.is_persistent (a_child)
5  do
    a_child.father.celebrate_birthday

8  -- This won't have any effect
    executor.update (a_child)

11 -- however, it works that way
    executor.update (a_child.father)
  end
```

### 2.4.2 Going deeper

ABEL has no limits regarding the depth of an object graph, and it will detect and handle reference cycles correctly. You are welcome to test ABEL's capability with very complex objects, however please keep in mind that this will cause a big performance impact.

To overcome this problem, you can either use simple object structures, or you can tell ABEL to only load or store an object up to a certain depth. You can see how this is done in Section 3.2.2 in the technical documentation, where the whole concept of an object graphs and its depth is described more detailed.

## 2.5 Advanced Initialization

The in-memory repository we've used so far doesn't store data permanently. This is acceptable for testing or a tutorial, but not in a real application. Therefore, ABEL ships with repositories for a MySQL database and an SQLite database.

To use them, you currently have to assemble the parts that are needed. For MySQL, you need to create a `MYSQL_DATABASE` and `MYSQL_STRINGS` object. You need them to create the `GENERIC_LAYOUT_SQL_BACKEND`, which you need in turn to create the `RELATIONAL_REPOSITORY`.

The following little factory class show the process for either a MySQL or an SQLite [5] database:

```
2 class
  REPOSITORY_FACTORY

5 feature -- Connection details

  username:STRING = "tutorial"
8  password:STRING = "tutorial"

  db_name:STRING = "tutorial"
11 db_host:STRING = "127.0.0.1"
  db_port:INTEGER = 3306

14 sqlite_filename: STRING = "tutorial.db"

feature -- Factory methods
17
  create_mysql_repository: PS_RELATIONAL_REPOSITORY
    -- Create a MySQL repository
20  local
    database: PS_MYSQL_DATABASE
    mysql_strings: PS_MYSQL_STRINGS
23    backend: PS_GENERIC_LAYOUT_SQL_BACKEND
  do
    create database.make (username, password, db_name,
      db_host, db_port)
26    create mysql_strings
    create backend.make (database, strings)
    create Result.make (backend)
29  end

  create_sqlite_repository: PS_RELATIONAL_REPOSITORY
32  -- Create an SQLite repository
  local
    database: PS_SQLITE_DATABASE
    sqlite_strings: PS_SQLITE_STRINGS
35    backend: PS_GENERIC_LAYOUT_SQL_BACKEND
  do
38    create database.make (sqlite_filename)
    create sqlite_strings
    create backend.make (database, strings)
```

```

41      create Result.make (backend)
      end
end

```

That's all. You can now use the repository to create a `CRUD_EXECUTOR` and start programming on it. All examples from this tutorial work exactly the same, no matter if you use the `IN_MEMORY_REPOSITORY` or any of the database repositories.

## 2.6 Transaction handling

Every CRUD operation in ABEL is executed within a transaction. Transactions are created and committed implicitly, which has the advantage that - especially when dealing with complex object graphs - an object doesn't get "halfway inserted" in case of an error.

As a user, you also have the possibility to use transactions explicitly. This is done by manually creating an object of type `TRANSACTION` and using the `*_within_transaction` features in `CRUD_EXECUTOR`, instead of the normal ones. For convenience, there is a factory method for transactions built into the executor.

Let's consider an example where you want to update the age of every person by one:

```

1  update_ages
   -- Increase everyone's age by one
   local
4    query: PS_OBJECT_QUERY[PERSON]
    transaction: PS_TRANSACTION
   do
7    create query.make
    transaction := executor.new_transaction

10   executor.execute_query_within_transaction (query,
        transaction)

    across query as query_result
13   loop
        query_result.item.celebrate_birthday
        executor.update_within_transaction
16        (query_result.item, transaction)
    end

19   transaction.commit

```



```

-- It might be that the transaction has encountered an
  error at commit time:
22  if transaction.has_error then
    print ("Commit has not been successful")
    end
25  end

```

You can see here as well that a commit may fail, e.g. when a write conflict happened in the database. The errors are reported in the `TRANSACTION.has_error` attribute. In case of an error, all changes of the transaction are rolled back automatically.

You can also abort a transaction manually by calling `TRANSACTION.rollback`.

## 2.6.1 Transaction isolation levels

ABEL supports the four standard transaction isolation levels found in most database systems:

- Read Uncommitted
- Read Committed
- Repeatable Read
- Serializable

The different levels are defined in the “enum class” `TRANSACTION_ISOLATION_LEVEL`.

You can set a transaction isolation level using the feature `REPOSITORY.set_transaction_isolation_level`. The default transaction isolation level of ABEL is defined by the actual storage backend.

Please note: Not every backend supports all isolation levels. Therefore a backend can also use a higher isolation level than you actually instruct it to use, but it is not allowed to use a lesser isolation level.

## 2.7 Error handling

As ABEL is dealing with IO and databases, runtime errors may happen. ABEL will in general raise exceptions in case of an error and expose the error to the library user as an `ERROR` object. ABEL distinguishes between two different kinds of errors.

- **Fatal errors:** Irrecoverable errors happening in a scenario like a broken connection or an integrity constraint violation in the database. The usual measure is to rollback the current transaction and raise an exception. If you catch the exception in a rescue clause and manage to resolve the problem, you can continue using ABEL.
- **Resolvable failures:** Those are not really visible to the user, because no exception is raised when they occur. A typical example is a conflict between two transactions. ABEL will detect the failure and, in case of implicit transaction management, retry.

If you use explicit transaction management, it will just doom the current transaction to fail at commit time.

ABEL represents errors as objects, and all specific error classes inherit from the deferred class `ERROR`. The following list shows all errors that can happen at runtime.

If not explicitly stated otherwise, the errors in this lists belong to the first category (Fatal errors).

- `CONNECTION_PROBLEM`: A broken internet link, or a deleted serialization file.
- `TRANSACTION_CONFLICT`: A write conflict between two transactions. This is a resolvable failure.
- `UNRESOLVABLE_TRANSACTION_CONFLICT`: A conflict in implicit transaction management that doesn't resolve even after a retry
- `ACCESS_RIGHT_VIOLATION`: Insufficient privileges in database, or no write permission to serialization file.
- `INTERNAL_ERROR`: Any error happening inside the library, like a failed SQL compilation.
- `GENERAL_ERROR`: Anything that doesn't fit into one of the categories above.

Please note that this list isn't complete yet. ABEL first needs to get in a releasable state.

If you want to handle an error, you have to add a rescue clause somewhere in your code. You can get the actual error from the `CRUD_EXECUTOR.error` or `TRANSACTION.error` feature or - as `ERROR` inherits from

DEVELOPER\_EXCEPTION - by performing an object test on Eiffel's EXCEPTION\_MANAGER.last\_exception.

For your convenience, there is a visitor pattern for all ABEL error types. You can just implement the appropriate functions and use it for your error handling code.

The following code shows an example. Note that there's some pseudocode inside, and only important features are shown:

```
2 class
  MY_PRIVATE_VISITOR
inherit
5   PS_ERROR_VISITOR

feature
8   shall_retry: BOOLEAN
      -- Should my client retry the operation?

11  visit_access_right_violation (
      error: PS_ACCESS_RIGHT_VIOLATION)
      -- Visit an access right violation error
14  do
      add_some_privileges
      shall_retry:=True
17  end

      visit_connection_problem (error: PS_CONNECTION_PROBLEM)
20  -- Visit a connection problem error
      do
      notify_user_of_abort
23  shall_retry:=False
      end
end
26

class
29  TUTORIAL

feature
32  my_visitor: MY_PRIVATE_VISITOR
      -- A user-defined visitor to react to an error
35
```

```

    executor: PS_CRUD_EXECUTOR
    -- The CRUD executor used throughout the tutorial
38
    do_something_with_error_handling
    -- Perform some operations. Deal with errors in case of
    a problem
41    do
        -- Some complicated operations
    rescue
44        my_visitor.visit (executor.error)
        if my_visitor.shall_retry then
            retry
47        else
            -- The exception propagates upwards, and maybe
            -- another feature can handle it
50        end
    end
end

```

# Chapter 3

## Technical documentation

### 3.1 Architecture overview

The ABEL library can be splitted into a frontend and a backend part. The frontend provides the main API, which is completely agnostic of the actual storage engine, whereas the backend provides a framework and some implementations to adapt ABEL to a specific storage engine. The boundary between Backend and Frontend can be drawn straight through the deferred class `REPOSITORY`.

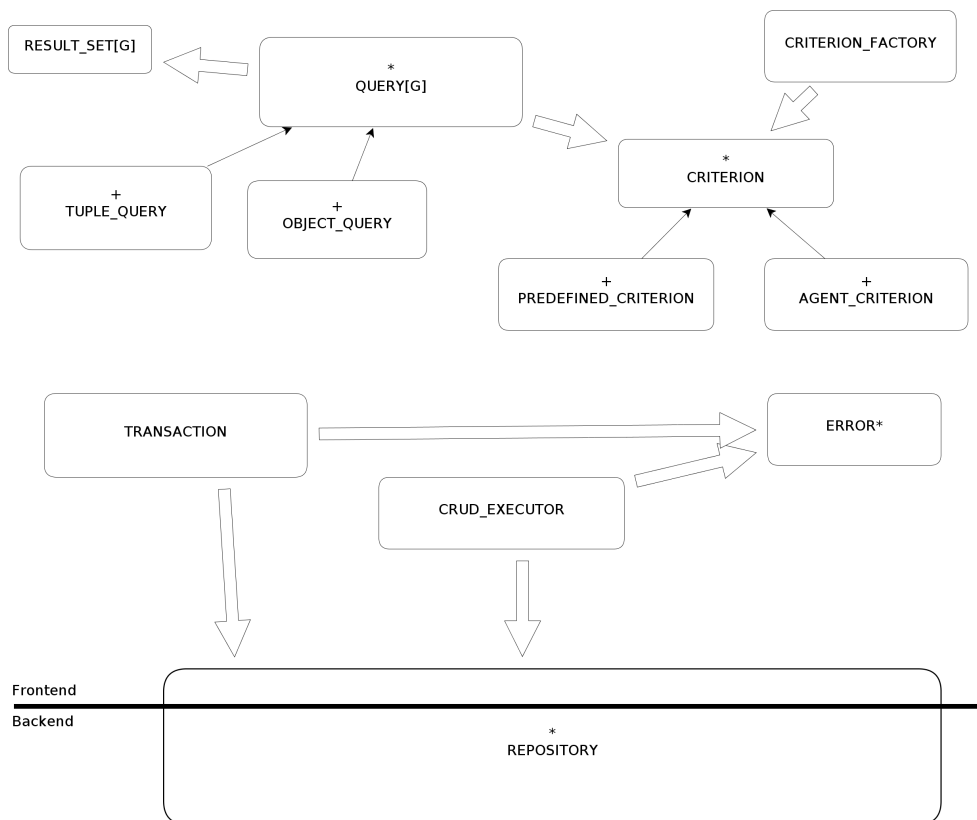
#### 3.1.1 Frontend

If you've read the previous part of the documentation, then you should be quite familiar now with the frontend. The main classes are:

- `CRUD_EXECUTOR`: Provides features for CRUD operations, and does some error handling for transaction conflicts.
- `QUERY`: Collects information like the Criteria, Projection, and (through its generic parameter) the type of the object to be retrieved. It doesn't do anything by itself.
- `TRANSACTION`: Represents a transaction, and is responsible to internally propagate errors. It provides the features commit and roll-back, but internally it relies on `REPOSITORY` to execute them.
- `CRITERION`: Its descendants provide a filtering function for retrieved objects, and it has builtin functions to generate a tree of criteria using the overloaded logical operators.

You can see that the main objective of the frontend is to provide an easy to use, backend-agnostic API and to collect any information the backend needs.

The class diagram provides an overview over the frontend. Note that this diagram only shows the most important classes and their relations.



**Figure 3.1:** The main frontend classes and their relations.

### 3.1.2 Backend

The frontend needs a repository which is specific to a persistence library, and the backend part provides a framework to implement these repositories (in cluster Framework). There are also some already predefined repositories inside the backend (cluster Backends), like the IN\_MEMORY\_REPOSITORY.

## The framework layers

The framework is built of several layers, with each layer being more specific to a persistence mechanism as it goes down.

The uppermost layer is the `REPOSITORY` class. It provides a very high level of abstraction, as it deals with normal Eiffel objects that may reference a lot of other objects.

One level below you can find the object-relational mapping layer. It is responsible to take an object graph apart into its pieces and generate a plan for the write operations. It is also responsible to build an object graph from its pieces during object retrieval. This layer is described more precisely in the next section 3.2.

On the next level there is the `BACKEND_STRATEGY` layer. Its task is to map the object pieces generated before to a specific storage engine, e.g. a database with some table layout.

The lowest level of abstraction is only significant for databases that understand SQL. It provides a set of wrapper classes that hide connection details and error handling, and it has a features to execute SQL and retrieve the result in a standardized way.

## Important data structures

The key data structure in the framework is the `OBJECT_IDENTIFICATION_MANAGER`. It maintains a weak reference to every object that has been queried or inserted before and assigns a repository-wide unique number to it (called the `object_identifier`). It is, for example, responsible for the fact that the update fails in section 2.2.4, “Recognizing Objects.”

Another important datastructure is the `KEY_POID_TABLE`, which maps the objects `object_identifier` to the primary key of the corresponding entry in the database.

## Transactions

Although not directly visible, transactions play an important role in the backend. Every operation internally runs inside a transaction, and almost every part in the backend is aware of transactions. For example, the two important data structures described above have to provide some kind of rollback mechanism, and ideally all ACID properties as well.

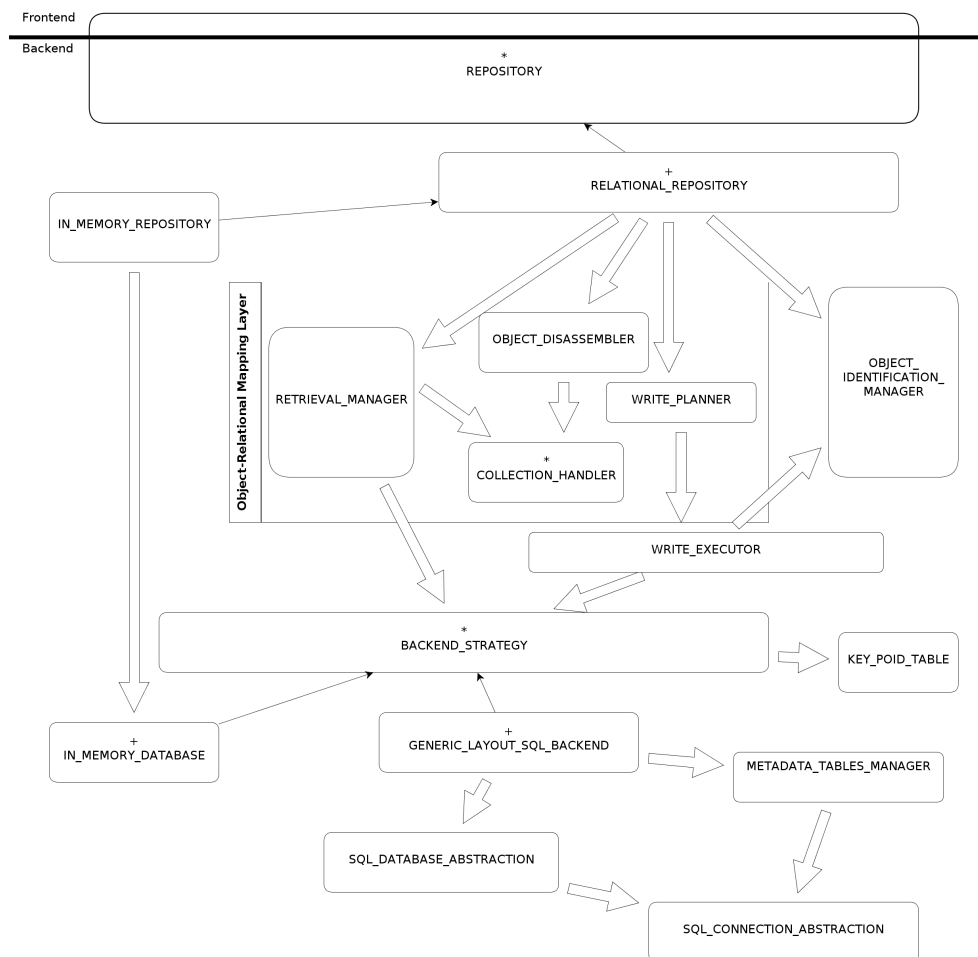
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Another important task of transactions is error propagation within the backend. If for example an SQL statement fails because of some integrity constraint violation, then the database wrapper can set the error field in

the current transaction instance and raise an exception. As the exception propagates upwards, every layer in the backend can do the appropriate steps to bring the library back in a consistent state, using the transaction with the error inside to decide its actions.

## Class diagram

To visualize the whole structure, there is a class diagram that shows the most important classes and concepts of the framework. You can also see the `IN_MEMORY_DATABASE` and `GENERIC_LAYOUT_SQL_BACKEND`, which are two implementations of the `BACKEND_STRATEGY`.



**Figure 3.2:** The main backend classes and their relations.



## 3.2 Object-relational Mapping

The object-relational mapping layer (abbreviated as ORM layer) lies between the REPOSITORY and the BACKEND\_STRATEGY. It consists of four main classes doing the actual work, and a set of helper classes to represent an object graph.

All object graph representation classes are in “framework/object\_graph\_representation”. Beside representation of an object graph, they are also used to describe a write operation in the BACKEND\_STRATEGY. The most important helper classes are:

- BASIC\_ATTRIBUTE\_PART represents an object of a basic type
- COLLECTION\_PART represents a collection, e.g. an instance of SPECIAL.
- SINGLE\_OBJECT\_PART: represents an Eiffel object that is neither a basic type nor a collection.

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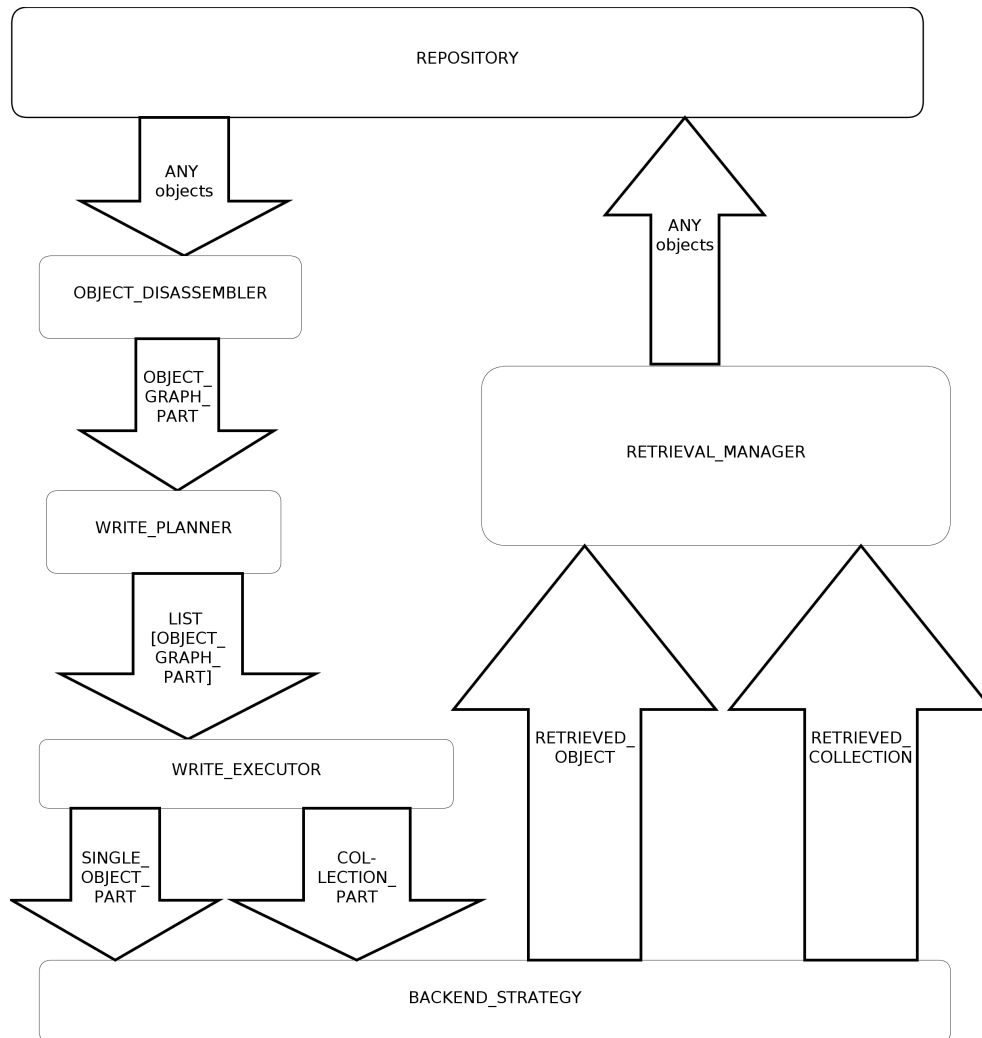
All these classes inherit from a deferred class OBJECT\_GRAPH\_PART. They have a builtin iteration cursor, and they share the concept of a dependency: If an object graph part X is dependent on another part Y, then it means for example that Y has to be inserted first, because X needs its primary key as a foreign key in the database.

The four classes listed here are the ones that do the actual work:

- The OBJECT\_DISASSEMBLER is responsible to create the explicit object graph representation.
- The WRITE\_PLANNER is responsible to generate a total order on all write operations, taking care of the dependency issues.
- The RETRIEVAL\_MANAGER builds objects from the parts that it gets from the backend, and takes care that the complete object graph gets loaded.
- The COLLECTION\_HANDLER, or rather its descendants, add collection handling support to the basic ORM layer. You need at least one handler for SPECIAL, but you can add handlers for other collection as well.

The graph visualizes the process and shows the intermediate representation of data in the object-relational mapping layer.

The object writing part is a bit more complex than the reading part, because of the dependency issue.



*Figure 3.3: The different intermediate representations of data.*

### 3.2.1 Collection handling

You can extend the ORM algorithm to include collections. A collection is usually mapped differently from a normal object in the backend, e.g. through a M:N-relation table. You need at least one handler for SPECIAL, because of its peculiarity that it doesn't have a fixed amount of fields, but you can include any other collection, e.g. a LIST or an ARRAY.

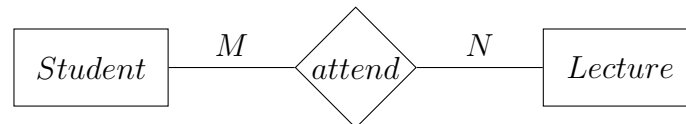
There are two types of collections you can create within a handler. The RELATIONAL\_COLLECTION is intended for a case when you have a typical database layout, with tables for a specific class and relations stored either with in the referenced object table (1:N-Relations) or inside their own

table (M:N-Relations). The `OBJECT_COLLECTION` is intended for a scenario where you can store collections in a separate table, having their own primary key, and with the collection owner using this key as a foreign key.

The following diagrams shows an example entity-relationship model for each type of collection:



**Figure 3.4:** An ER-model where an `OBJECT_COLLECTION` can be used.



**Figure 3.5:** An ER-model where a `RELATIONAL_COLLECTION` with M:N mapping can be used.



**Figure 3.6:** An ER-model where a `RELATIONAL_COLLECTION` with 1:N mapping can be used.

Note that the choice of the collection has an effect in the object-relational mapping layer already:

- An `OBJECT_COLLECTION` is handled like a `SINGLE_OBJECT_PART`: The owner of the collection object depends on the collection, and the collection depends on all items that it references.
- A `RELATIONAL_COLLECTION` in an M:N mapping mode depends on both the collection owner and all items that it references, but the owner does not depend on its collection. This comes from the fact that you need both a foreign key of the owner and the collection items to insert a row in a M:N-relation table
- A `RELATIONAL_COLLECTION` in an 1:N mapping mode actually isn't forwarded to the backend at all. Instead, for each collection item there is a dependency added to the collection owner. Again, this comes from the normal practice in database layouts for 1:N relations.

If you use one of the predefined backends, you usually don't have to care about collection handlers. They become important however if you want to adapt ABEL to a custom database layout, as you can see in section 3.5.2.

Please note that the framework itself does not provide any collection handler, and inserting a SPECIAL object without setting an appropriate handler will result in a runtime crash. However, there is a SPECIAL handler shipped with the predefined backends, and for example the IN\_MEMORY\_REPOSITORY makes use of it.

### 3.2.2 Object graph settings

First, let's define the object graph more exactly, using graph theory. A vertex in the graph corresponds to an object, and a reference is a directed edge.

The (global) object graph is the web of objects and references as it is currently in main memory.

An object Y can be reached from another object X if there is a path between X and Y, i.e. Y is in the transitive closure of X.

The object graph of an object X is the induced subgraph of the global object graph that contains all vertices that can be reached from X.

The level of an object Y in the object graph of X is the length of the shortest path from X to Y.

Using these definitions we can now describe how ABEL handles object graphs, and how you can tweak the default settings to increase performance.

Every operation in ABEL has its own depth parameter (defined in OBJECT\_GRAPH\_SETTINGS), which has the following effect: Each operation will only handle the objects when the following condition holds:

$$level(object) < depth$$

Now, let's put this in a context: You already know that the insert and retrieve features handle the complete object graph of an object. In fact, the depth for both functions is Infinity by default.

On the other hand, the update or delete operations only handle first object they get, and don't care about the object graph. Their depth is defined as exactly 1, which means that only an object with a level of 0 satisfies the condition above. The only object with level 0 is in fact the root object of an object graph.

To fully understand the behaviour of ABEL, we also have to look at what happens when the algorithm reaches the “last” object, i.e. when the condition  $level + 1 = depth$  holds. In that case the object with all basic attributes gets inserted/updated, but references only get written if the referenced object is already persistent. If it isn’t persistent, then in a later retrieval operation the reference will be Void.

You can change the depth of the individual operations in `REPOSITORY.default_object_graph`. Please keep in mind that this is a dangerous operation, as a not fully retrieved or inserted object will contain Void references even in a void-safe environment, and a partially loaded object may also violate its invariant.

Apart from the depth, there are some other settings as well, i.e. what ABEL should do if it finds an already persistent object along the object graph of a new object to insert, or vice versa.

### 3.3 Backend abstraction

The framework provides some very flexible interfaces to be able to support many different storage engines. The three main levels of abstraction are the `REPOSITORY`, the `BACKEND_STRATEGY` and the database wrapper classes.

#### 3.3.1 REPOSITORY

The deferred class `REPOSITORY` provides the highest level of abstraction. It deals with raw Eiffel objects including their complete object graph. It provides a good interface to wrap a persistence mechanism that provides a similarly high level of abstraction, like for example db4o [1].

The `RELATIONAL_REPOSITORY` is the main implementation of this interface. It uses the ORM layer and a `BACKEND_STRATEGY` and is therefore the default repository for persistence libraries which are wrapped through `BACKEND_STRATEGY`.

#### 3.3.2 BACKEND\_STRATEGY

The second important interface is the deferred class `BACKEND_STRATEGY`. This layer only deals with one object graph part at once, either a single object or a collection. It is responsible to map these to the actual persistence mechanism, which is usually a specific layout in a database.

Its use however is not restricted to relational databases. The `IN_MEMORY_DATABASE` for example implements this interface to provide a fake storage engine useful for testing, and it is planned to wrap the serialization libraries using this abstraction.

### 3.3.3 Database wrapper

The last layer of abstraction is a set of wrappers to a database. It consists of three deferred classes:

- The `SQL_DATABASE_ABSTRACTION` represents a database. Its main task is to acquire or release a `SQL_CONNECTION_ABSTRACTION`.
- The `SQL_CONNECTION_ABSTRACTION` represents a single connection. It has to forward SQL statements to the database and represent the result in an iteration cursor of `SQL_ROW_ABSTRACTIONS`. Another important task is to map database specific error messages to `ABEL_ERROR` instances.
- The `SQL_ROW_ABSTRACTION` represents a single row in the result of an SQL query.

The wrapper is very useful if you want to easily swap e.g. from a MySQL database to SQLite

However, keep in mind that the abstraction is not perfect. For example, the wrapper doesn't care about the different SQL variations, as it just forwards the statements to the database.

To overcome this problem, you can put all SQL statements in your implementation of `BACKEND_STRATEGY` into a separate class, and generally stick to standard SQL as much as possible.

## 3.4 Extensions

Due to its very flexible abstraction mechanism, you can easily extend ABEL with features like client-side transaction management or `ESCHER` [9] integration.

The general pattern on how to do this is quite simple: You can implement a `BACKEND_STRATEGY` which uses another instance of `BACKEND_STRATEGY`, but does some processing on the intermediate result. That way you can add:

- Filter support for some non-persistent attributes by removing them from the `OBJECT_GRAPH_PART` during a write, and adding a default value during retrieval.
- `ESCHER` support by checking on the version attribute during a retrieval, and calling the conversion function if necessary.
- Client-side transaction management by using a multiversion concurrency control mechanism and delaying write operations until you can definitely commit.
- Caching of objects by using an `IN_MEMORY_DATABASE` alongside the actual backend.
- An instance that does correctness checks, e.g. by routing the calls to two different backends and comparing if the results are the same.
- Anything else you can imagine...

The really nice thing is that you can add extensions without really adding complexity to the core of ABEL, and it works for all possible implementations of `BACKEND_STRATEGY` at once.

## 3.5 Database adaption

The `BACKEND_STRATEGY` interface allows to adapt the framework to many database layouts. Shipped with the library is a backend that uses a generic database layout which can handle every type of object. It is explained in the next section.

You can also adapt ABEL to your very own private database layout. An example on how to do this is shown in section 3.5.2.

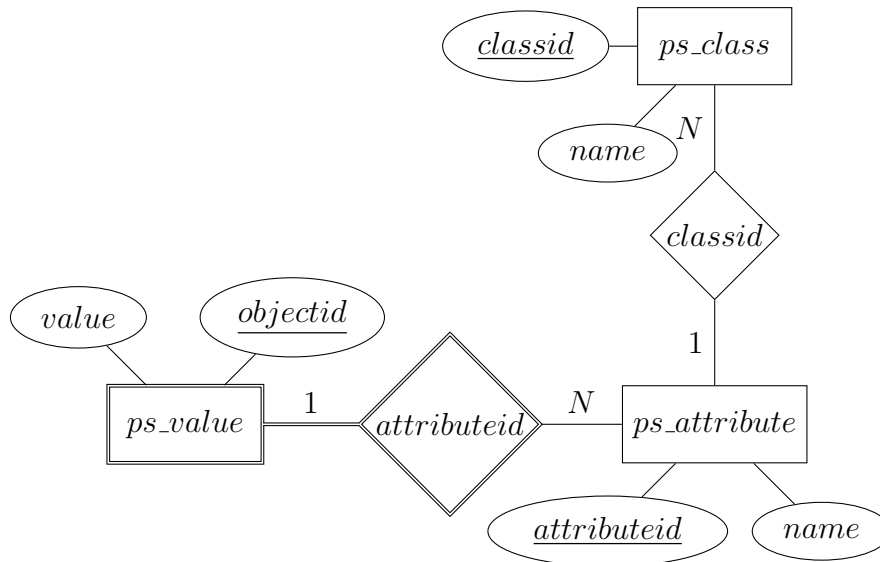
### 3.5.1 The generic layout backend

The database layout is based upon metadata of the class. It is very flexible and allows for any type of objects to be inserted. The layout is a modified version from the suggestion in Scott W. Ambler's article "Mapping Objects to Relational Databases" [6].

The ER-model in the diagram is in fact a simplified view. The real model uses another relationship between value and class to determine the runtime type of a value, which is required in some special cases.

The predefined backend located in "backends/generic\_database\_layout" folder

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**Figure 3.7:** The ER-Model of the generic database layout.

Eiffel objects to this layout.

It is split into three classes:

- The METADATA\_TABLES\_MANAGER is responsible to read and write tables “ps\_class” and “ps\_attribute”.
- The GENERIC\_LAYOUT\_SQL\_BACKEND, which actually implements BACKEND\_STRATEGY, is responsible to write and read the ps\_value table
- The GENERIC\_LAYOUT\_SQL\_STRINGS collects all SQL statements. Its descendants adapt the statements to a specific database if there is an incompatibility.

The functionality of the metadata table manager is quite easy: It just caches table ps\_class and ps\_attribute in memory and provides features to get the primary key of an attribute or a class. If the class is not present in the database, then it will insert it and return the new primary key.

Using the table manager, the GENERIC\_LAYOUT\_SQL\_BACKEND has all information to perform a write operation: The attribute value in the SINGLE\_OBJECT\_PART, the attribute foreign key from the METADATA\_TABLES\_MANAGER, and the object primary key either stored in the KEY\_POID\_TABLE or generated during an insert.

The retrieval operation is similar. First, the backend gets all attribute primary keys of a specific class from the table manager, and then it ex-



ecutes an SQL query to retrieve all values whose attribute foreign keys match the ones retrieved before. The backend can also sort the result by the object primary key, such that attributes of the same object are grouped together.

### 3.5.2 Adaption to a custom database layout

Adapting ABEL to a custom database layout needs two steps:

- Implement a BACKEND\_STRATEGY for your layout
- Implement COLLECTION\_HANDLERS for all collections that need to be mapped relationally

Let's consider a very simple example with only two classes:

```
1 class PERSON

    feature
4   name: STRING

    items_owned: LINKED_LIST [ITEM]
7 end

10 class ITEM

    feature
13  value: INTEGER

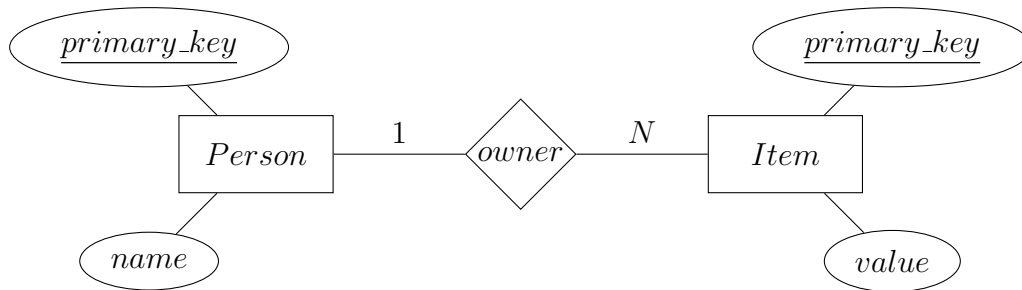
end
```

*Listing 3.1: Example classes*

In the database, there is table Person with columns primary\_key and name, and table Item with columns primary\_key, item, and a foreign key owner to Person.

In this setup, you only need a relational collection handler for LINKED\_LIST which always has to be 1:N mapped. Therefore, the implementation of the (only) collection handler is very simple:

```
class
    LINKED_LIST_HANDLER
3 inherit
    PS_COLLECTION_HANDLER [LINKED_LIST [ITEM] ]
```



**Figure 3.8:** The example ER-Model.

### feature

```

6   create_object_graph_part (
      obj: PS_OBJECT_IDENTIFIER_WRAPPER;
9   ref_owner: PS_OBJECT_GRAPH_PART;
      attr_name: STRING;
      mode: PS_WRITE_OPERATION)
12  : PS_RELATIONAL_COLLECTION_PART [LINKED_LIST[ITEM]]
      -- Create a new part, but don't disassemble
      do
15      create Result.make (obj, ref_owner, attr_name, mode,
          Current)
      end

18  is_in_relational_storage_mode (a_collection:
      PS_COLLECTION_PART[LINKED_LIST[ITEM]]): BOOLEAN = True
      -- Is 'a_collection' stored in relational mode?

21  is_1_to_n_mapped (a_collection: PS_COLLECTION_PART[
      LINKED_LIST[ITEM]]): BOOLEAN = True
      -- Is 'a_collection' stored relationally in a 1:N
      mapping?

24  end
  
```

**Listing 3.2:** The collection handler for LINKED\_LIST

The implementation of BACKEND.STRATEGY is quite straightforward as well. You just have to distinguish between PERSON and ITEM objects and insert them in the corresponding table.

Please remember that the object-relational mapping layer adds an attribute with name “items\_owned” to the ITEM object, which is the default

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behaviour for 1:N relations. This especially means that you don't need to implement the relational collection write operations.

The following code listing shows the insert feature in pseudocode:

```

class
2  MY_SIMPLE_BACKEND
  inherit
    PS_BACKEND_STRATEGY
5 feature

    insert (an_object:PS_SINGLE_OBJECT_PART; a_transaction:
        PS_TRANSACTION)
8    -- Inserts the object into the database
    do
        if an_object is a PERSON object then
11        database.execute_sql ("INSERT INTO person (name)
            VALUES " + an_object.get_value ("name"))
            key_mapper.add_entry (an_object, database.execute_sql
                ( "Get last autoincremented primary key of Person
                    ")
            )
        else
14        -- The ORM layer has added an attribute 'items_owned'
            in ITEM
            foreign_key:= key_mapper.primary_key_of (an_object.
                get_value ("items_owned"))
            database.execute_sql ("INSERT INTO item (value, owner
                ) VALUES " + an_object.get_value ("value") +
                foreign_key)
17        key_mapper.add_entry (an_object, database.execute_sql
            ("Get last autoincremented primary key of Item")
        )
    end
end

20

    key_mapper: PS_KEY_POID_TABLE
23    -- Maps object identifiers to primary keys

end

```

**Listing 3.3:** The collection handler for LINKED\_LIST

During a retrieval operation, you similarly have to select your values from the correct table.

Please note that you need the retrieve\_relational\_collection feature here.

# Chapter 4

## Conclusions

### 4.1 Conclusions

In this thesis, we have developed a software library to access different persistence mechanism. The library features a simple yet powerful programming interface, which is completely agnostic of the actual backend.

Below the API we developed a very flexible framework to adapt ABEL to a lot of existing storage engines. The framework includes a reusable object-relational mapping layer, a database library wrapper, and some interfaces for extension and customization.

Based on this framework we have developed an in-memory backend which is useful for testing, and a test suite that is mostly independent of the actual backend.

Furthermore, we have developed a backend that uses a generic database layout for storing objects, working both for MySQL and SQLite databases.

### 4.2 Current limitations

- Due to a limitation in INTERNAL, inheritance is not properly supported. This especially means that a query of an object of class G will not return descendants of G.
- If you adapt ABEL to a custom database layout, it can only handle object types that have corresponding tables in the database.
- If a custom database layout isn't well designed, e.g. if there are redundancies, you might get into trouble when trying to adapt ABEL to it.

- Some basic types are not fully supported:
  - REALs have a rounding error
  - STRING\_32 is converted to STRING\_8, which distorts them sometimes.
  - CHARACTER is converted to INTEGER for storage. This is usually fine, but in custom database layouts it results in a type mismatch.
- The generic database layout backend doesn't support SPECIAL yet (or collections in general).
- The library completely lacks any performance optimization.
- The retrieval operation in the object-relational mapping doesn't support the depth parameter.
- The error representation is not complete.

## 4.3 Future work

**Ordering** At the moment, a query result has no defined order. A mechanism to enforce an order in the result set might be useful.

**Update Query** With the current API you can only do an update if the object has been retrieved or inserted before. Another way to do update operations could use a QUERY instead, but you also need some new mechanism to be able to say which attributes should be updated with a new value.

**Performance** Currently there is no optimization in ABEL, and there is a lot that can be done in this area:

- Compile PREDEFINED\_CRITERIA to SQL in order to get smaller results.
- Add support for lazy loading in the generic database layout implementation by using SQL cursors instead of normal select statements.
- Use prepared statements and maybe even stored procedures instead of normal SQL statements.

- Optimize ABEL by trying to reduce network round trip times to a minimum.
- Finding and fixing performance bottlenecks in the code with the help of a profiler

**Adaptor Framework** Adaption to a specific layout is a tedious task at the moment, as everything has to be hardcoded. It would be much easier if you could just define a mapping from classes to tables and attribute names to column names, and the framework takes care of the rest. As an extension this mapping could be defined in an XML file.

**Backends** Extend ABEL to support more backends, e.g.

- A serialization library
- An object database like db4o
- EiffelStore
- A NoSQL database like CouchDB

**Inheritance** ABEL needs proper inheritance support as soon as the required features in INTERNAL get implemented.

**Transaction management** Some backends, e.g. the in-memory backend or the serialization library, don't support transactions. Therefore it would be nice to implement local transaction management for these libraries by using multiversion concurrency control at the BACK-END\_STRATEGY level.

**ESCHER** At the moment, the behaviour of ABEL is undefined in case of a version mismatch between the type of stored objects and their current runtime type. An integration of ESCHER into the ABEL framework would help detecting a version mismatch and, if possible, correct it immediately.

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