Software Architecture Exam

Spring Semester 2009
Prof. Dr. Bertrand Meyer
Date: 26 May 2009

Family name, first name: ....

Student number: ....

I confirm with my signature, that I was able to take this exam under regular circumstances and that I have read and understood the directions below.

Signature: ....

Directions:

- Exam duration: 120 minutes.
- Except for a dictionary you are not allowed to use any supplementary material.
- Use a pen (**not** a pencil)!
- Please write your student number onto **each** sheet.
- All solutions can be written directly onto the exam sheets. If you need more space for your solution ask the supervisors for a sheet of official paper. You are **not** allowed to use other paper.
- Only one solution can be handed in per question. Invalid solutions need to be crossed out clearly.
- Please write legibly! We will only correct solutions that we can read.
- Manage your time carefully (take into account the number of points for each question).
- Don't forget to add comments to features.
- Please **immediately** tell the supervisors of the exam if you feel disturbed during the exam.

Good luck!

Question	Number of possible points	Points
1	18	
2	20	
3	22	
4	16	

1 Multiple choice questions (18 points)

For each statement found below, indicate through a checkmark in the corresponding column whether it is false or true. For each statement, you can mark at most one square. A correctly set checkmark is worth 1 point, an incorrectly set checkmark is worth 0 points.

Example:

Which of the following statements are true and which are false for objects and classes of Eiffel?

True	False		Statement
☒	☐	a.	Classes exist only in the software text; objects exist only during the execution of the software.
☐	☒	b.	Each object is an instance of its generic class.
☐	☒	c.	An object is deferred if it has at least one deferred feature.

1.1 Which of the following statements are true and which are false for the Unified Modeling Language?

True	False		Statement
☐	☐	a.	A UML model is a set of classes and relations between them.
☐	☐	b.	The general semantics of the dependency relation is that if the independent entity changed, the dependent one may also change.
☐	☐	c.	State diagrams are intended for describing dynamic behavior of the system.
☐	☐	d.	An association between two classes on a class diagram means that they are different implementations of the same abstraction.
☐	☐	e.	Aggregation expresses the "part-of" relation, which means that the part is always created and destroyed together with the aggregate.
☐	☐	f.	In contrast to communication diagrams, on sequence diagrams not only the set of entities and relations between them matters, but also the spatial placement of elements.

1.2 Which of the following statements are true and which are false for the Eiffel exception mechanism?

True	False		Statement
☐	☐	a.	The execution of a rescue clause must in all cases re-establish the class invariant.
☐	☐	b.	If a retry succeeds, the program execution continues normally.
☐	☐	c.	If a rescue clause only contains a retry, then the retry will be executed at most once.
☐	☐	d.	If a rescue clause only contains a retry, then the retry will be repeatedly executed until there is no failure any more.
☐	☐	e.	If an exception is triggered in a routine that doesn't have a rescue clause, then the exception is passed to the caller.

1.3 If a software element C (client) needs a service from a software element S (supplier), the following four possibilities exist:

1. C must know the identity of S and S must know the identity of C.
2. C must know the identity of S, but S does not have to know the identity of C.
3. S must know the identity of C, but C does not have to know the identity of S.
4. Neither needs to know the identity of the other.

State which one of 1, 2, 3 or 4 applies to the following architecture styles:

1	**2**	**3**	**4**	**Statement**
☐	☐	☐	☐	a. Batch-sequential
☐	☐	☐	☐	b. Pipe-and-filter
☐	☐	☐	☐	c. Call-and-return
☐	☐	☐	☐	d. Event-based (Publish-Subscribe)
☐	☐	☐	☐	e. Blackboard
☐	☐	☐	☐	f. Hierarchically layered
☐	☐	☐	☐	g. Client-Server

2 Abstract Data Types and Design by Contract (20 Points)

2.1 Incompleteness in contracts (3 Points)

Tic-Tac-Toe game is played on a 3-by-3 board, which is initially empty. There are two players: a "cross" player and a "circle" player. They take turns; each turn changes exactly one cell on the board from empty to the symbol of the current player (cross or circle). The "cross" player always starts the game. The rules that define when the game ends and which player wins are omitted from the task for simplicity.

Below you will find an interface view of *GAME* class representing Tic-Tac-Toe games.

```
class GAME

create make

feature -- Initialization
  make
      -- Create an empty 3-by-3 board
    ensure
      cross_turn: next_turn = Cross
    end

feature -- Constants
  Empty: INTEGER is 0
  Cross: INTEGER is 1
  Circle: INTEGER is 2
      -- Symbolic constants for players and states of board cells

feature -- Access
```

```
  next_turn: INTEGER
      -- Player that will do the next turn

  item (i, j: INTEGER): INTEGER
      -- Value in the board cell (i, j)
    require
      i_in_bounds: i >= 1 and i <= 3
      j_in_bounds: j >= 1 and j <= 3
    ensure
      valid_value: Result = Empty or Result = Cross or Result = Circle
    end

feature -- Basic operations
  put_cross (i, j: INTEGER)
      -- Put cross into the cell (i, j)
    require
      cross_turn: next_turn = Cross
      i_in_bounds: i >= 1 and i <= 3
      j_in_bounds: j >= 1 and j <= 3
      empty: item (i, j) = Empty
    ensure
      cross_put: item (i, j) = Cross
      circle_turn: next_turn = Circle
    end

  put_circle (i, j: INTEGER)
      -- Put circle into the cell (i, j)
    require
      circle_turn: next_turn = Circle
      i_in_bounds: i >= 1 and i <= 3
      j_in_bounds: j >= 1 and j <= 3
      empty: item (i, j) = Empty
    ensure
      circle_put: item (i, j) = Circle
      cross_turn: next_turn = Cross
    end
invariant
  valid_player: next_turn = Cross or next_turn = Circle
end
```

The contract of this class is incomplete with respect to the game description given above. In which contract elements does the incompleteness reside? Express in natural language what the missing parts of the specification are. Give an example of a scenario that is allowed by the above contract, but should not happen in Tic-Tac-Toe:

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2.2 ADT GAME (10 Points)

Create an ADT that describes Tic-Tac-Toe games. The ADT functions should correspond one-to-one to the features of the *GAME* class above. The axioms of the ADT should be sufficiently complete, overcoming the incompleteness of the class contracts.

TYPES

GAME

FUNCTIONS

- *make* : . . . .
- *next_turn* : . . . .
- *item* : . . . .
- *put_cross* : . . . .
- *put_circle* : . . . .
- *Empty* : . . . .
- *Cross* : . . . .
- *Circle* : . . . .

PRECONDITIONS

P1 . . . .

P2 . . . .

P3 . . . .

AXIOMS

A1 . . . .

A2 . . . .

A3 . . . .

A4 . . . .

A5 . . . .

A6 ....

A7 ....

A8 ....

A9 ....

A10 ....

A11 ....

2.3 Proof of sufficient completeness (7 Points)

Prove that your specification is sufficiently complete.

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3 Design patterns I (22 Points)

Given is a class hierarchy that models a very simple forum system. It consists of three classes: class *FORUM_ENTITY*, class *POST* and class *THREAD* (see Listings 1, 2, and 3).

Question 1: The classes *FORUM_ENTITY*, *POST* and *THREAD* have been prepared for the implementation of a Visitor pattern, but they also implement a second pattern from the lecture. Which design pattern? Give its name.

. . . .

Listing 1: Class *FORUM_ENTITY*

```
deferred class FORUM_ENTITY

feature -- Access

  title : STRING
      -- Title of entity

  owner: STRING
      -- Username of person that initiated the thread/post

  output: STRING
      -- Textual description
    deferred
    end

feature -- Status report

  is_private : BOOLEAN
      -- Is entity read restricted ?

feature -- Element setting

  set_title_and_owner (t, o: STRING)
      -- Set 'title' to 't' and 'owner' to 'o'.
    require
      t_valid : t /= Void and then not t.is_empty
      o_valid : o /= Void and then not o.is_empty
    do
      title := t
      owner := o
    ensure
      title_set : t.is_equal (title)
      owner_set: o.is_equal (owner)
    end
```

```
set_private (b: BOOLEAN)
        -- Set 'is_private'.
    do
        is_private := b
    ensure
        is_private_set : is_private = b
    end

feature -- Basic operations

    process (v: VISITOR)
        -- Process 'Current' with visitor 'v'.
    require
        v_exists : v /= Void
    deferred
    end

end
```

Listing 2: Class *POST*

```
class POST inherit FORUM_ENTITY

create
    set_title_and_owner

feature -- Access

    text: STRING
        -- Message of post

feature -- Element change

    set_text (s: STRING)
        -- Set 'text' to 's'.
    require
        s_valid: s /= Void and then not s.is_empty
    do
        text := s
    ensure
        text_set : s. is_equal (text)
    end

feature -- Basic operations

    output: STRING
        -- Textual description
    do
        Result := "*********** POST ***********%NTitle: " + title +
            "%NOwner: " + owner + "%N"
        if text /= Void then
            Result := Result + text + "%N%N"
        end
    end

    process (v: VISITOR)
        -- Process 'Current' with visitor 'v'.
    do
        ..................................................................................
    end
end
```

Listing 3: Class *THREAD*

```
class THREAD inherit

  FORUM_ENTITY
    redefine
      set_title_and_owner
    end

create
  set_title_and_owner

feature -- Access

  contents: ARRAYED_LIST [FORUM_ENTITY]
      -- Contents of the thread

feature -- Element change

  set_title_and_owner (t, o: STRING)
      -- Set 'title' to 't' and 'owner' to 'o'.
    do
      Precursor (t, o)
      create contents.make (5)
    end

  add_entity (e: FORUM_ENTITY)
      -- Add 'e' to last position of 'contents'.
    require
      not_there: not contents.has (e)
    do
      contents.force (e)
    end

feature -- Basic operations

  output: STRING
      -- Textual description
    do
      Result := "*********** THREAD ***********%NTitle: " + title +
          "%NOwner: " + owner + "%N%N"
    end

  process (v: VISITOR)
      -- Process 'Current' with visitor 'v'.
    do
       ..............................................................................
    end
end
```

Question 2: Complete the implementation of the visitor pattern by filling in the missing lines in the classes *POST* and *THREAD* and by providing the code of *VISITOR* and *READ_VISITOR*. The main goal of *READ_VISITOR* is the generation of output for a hierarchy of threads and posts. It should show the following characteristics:

- The call *entity.process (v)* with *entity* of type *FORUM_ENTITY* and *v* of type *READ_VISITOR* should do a depth first traversal of the hierarchy attached to *entity*.

- During the traversal, it calls *output* on a visited entity if either (a) the entity is not private (see feature *is_private* of class *FORUM_ENTITY*) or (b) the *READ_VISITOR* has access to private entities (see feature *has_private_access* of class *READ_VISITOR*). The output is collected in the variable *last_output* of *READ_VISITOR*.

Listing 4: Class *VISITOR*

```
deferred class VISITOR
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end
```

Listing 5: Class *READ_VISITOR*

```
class READ_VISITOR inherit VISITOR

create
  make

feature -- Initialization

  make (b: BOOLEAN)
      -- Initialize and set flag for reading private threads and posts.
    do
      last_output := ""
      has_private_access := b
    ensure
      output_exists: last_output /= Void
      private_access_set: has_private_access = b
    end

feature -- Access

  last_output: STRING

feature -- Status report

  has_private_access: BOOLEAN

feature {FORUM_ENTITY} -- Basic operations

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end
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Question 3: Listing 6 shows the root class *APPLICATION* of a system that provides a user interface to log in and out of the system and print the hierarchy of threads and posts. The feature *prepare* reads a hierarchy of threads and posts from a file (contents are omitted). Redesign the class to use a pattern that helps removing the case distinctions between a logged in user and an anonymous user found in the features *login*, *logout* and *read_entity*.

What pattern would you use? Give its name. ....

Draw a diagram of the involved classes and list the names of all their features. A partial version of *APPLICATION* is given as a starting point. Explain in a couple of sentences how the involved classes interact and why the case distinctions disappear.

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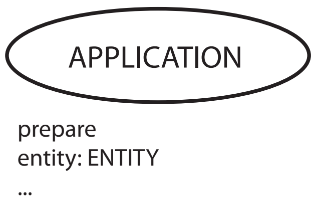

Listing 6: Class *APPLICATION*

```
class APPLICATION

create
  make

feature -- Access

  is_logged_in : BOOLEAN
      -- Is user logged in?

  entity: FORUM_ENTITY
      -- Top level entity

  username: STRING
      -- Username of logged in user (may be void)

feature -- Basic operations

  login
      -- Log in if not already logged in.
    do
      if not is_logged_in then
        io.put_string ("Username: ")
        io.read_word
        if not io.last_string.is_empty then
          username := io.last_string
          is_logged_in := True
        else
          io.put_string ("Username invalid")
        end
      else
        io.put_string ("You have to logout first.")
      end
    ensure
      username_set: username /= Void
    end

  logout
      -- Log out if logged in.
    do
      if not is_logged_in then
        io.put_string ("You have to login first.")
      else
        username := Void
        is_logged_in := False
      end
    ensure
      username_set: username = Void
    end

  read_entity
      -- Read entity contents.
    local
      v: READ_VISITOR
    do
      if is_logged_in then
        create v.make (True)
      else
        create v.make (False)
      end
      entity.process (v)
```

```
        io.put_string (v.last_output)
    end

feature -- Initialization

  make is
      -- Run application.
    local
      c: CHARACTER
    do
      prepare
      from
        io.put_string ("%N>")
        io.read_character
        c := io.last_character
      until
        c = 'q'
      loop
        inspect c
        when 'i' then
          login
        when 'o' then
          logout
        when 'r' then
          read_entity
        else
          if c.is_alpha then
            io.put_string ("Available commands: %Ni: login%No: logout%Nr:
                read entity%Nq: quit%N")
          end
        end
        if c.is_alpha then
          io.put_string ("%N>")
        end
        io.read_character
        c := io.last_character
      end
    end

feature {NONE} -- Implementation

  prepare
      -- Fill some threads and posts.
    local
      top, sub1, sub2: THREAD
      p: POST
    do
      -- Implementation removed to improve readability.
    ensure
      entity_exists : entity /= Void
    end

end
```

4 Design Patterns II (16 Points)

A company selling furniture has an interactive program to show customers what a furnished room would look like. Furniture pieces can be added and removed from the room, and these actions can be undone and redone. Here is a typical top-level interaction with the system:

```
class SAMPLE_SYSTEM_USE

feature

    interaction
            -- A sample client interaction.
        local
            room: ROOM
            chair_handle: INTEGER
            desk_handle: INTEGER
        do
            create room.make_with_furniture_factory (create {
                DIRECTX_FURNITURE_FACTORY})
            room.add_chair (create {COORDINATE}.make (14, 10))
            chair_handle := room.added_chair_id
            room.add_desk (create {COORDINATE}.make (1, 20))
            desk_handle := room.added_desk_id
            room.remove_chair (chair_handle)
            room.undo
            room.redo
        end

end
```

The room uses an abstract factory (an instance of FURNITURE_FACTORY) to create furniture pieces (instances of CHAIR and DESK). Assume the following classes:

```
deferred class
    FURNITURE_FACTORY

feature

    make_chair (c: COORDINATE)
        deferred
        ensure
            made_chair /= Void
        end

    make_desk (c: COORDINATE)
        deferred
        ensure
            made_desk /= Void
        end

    made_chair: CHAIR
            -- The last made chair.

    made_desk: DESK
            -- The last made desk.

end
```

```
deferred class
    FURNITURE_PIECE

feature
    coordinate: COORDINATE

end
```

```
class
    DESK

inherit
    FURNITURE_PIECE

-- Implementation omitted.

end
```

```
class
    CHAIR

inherit
    FURNITURE_PIECE

-- Implementation omitted.

end
```

Your task is to implement the command pattern that supports the undo-redo mechanism by filling in code in classes ROOM, ADD_ACTION and REMOVE_ACTION. Since these classes cooperate closely, it's a good idea to study them carefully before writing the code. Some features of classes LINKED_LIST and STACK that you might find useful are shown at the end.

```
deferred class
    ACTION

feature

    perform
        deferred
        end

    unperform
        deferred
        end

end
```

```
class
    ADD_ACTION

inherit
    ACTION

create
    make

feature
    make (n: INTEGER; fp: FURNITURE_PIECE; l: LIST [TUPLE [id: INTEGER; f:
            FURNITURE_PIECE]])
            -- Initialize an add-action into 'l' of 'fp' with ID 'n'.
        require
            furniture_list_exists : l /= Void
        do
            piece_number := n
            furniture_piece := fp
            furniture_list := l
        end

```

```
    perform
            -- Add the furniture piece to the room.
        do

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        end

    unperform
            -- Undo the last 'perform'.
        do
            furniture_list.prune_all ([piece_number, furniture_piece])
        end

feature {NONE} -- Implementation
    piece_number: INTEGER
    furniture_piece: FURNITURE_PIECE
    furniture_list: LIST [TUPLE [id: INTEGER; f: FURNITURE_PIECE]]
            -- The room's contents.

invariant
    furniture_list_exists: furniture_list /= Void

end
```

```
class
    REMOVE_ACTION

inherit
    ACTION

create
    make

feature
    make (n: INTEGER; l: LIST [TUPLE [id: INTEGER; f: FURNITURE_PIECE]])
            -- Initialize an action to remove a furniture piece with ID 'n' from 'l'.
        require
            furniture_list_exists: l /= Void
        do
            piece_number := n
            furniture_list := l
        end

    perform
            -- Remove the furniture piece from the room, if possible.
        local
            found: BOOLEAN
            furniture_item: TUPLE [n: INTEGER; fp: FURNITURE_PIECE]
        do
            from
                furniture_list.start
                furniture_piece := Void
            until
                found or else furniture_list.off
            loop
```

```
                    furniture_item := furniture_list.item
                    if furniture_item.n = piece_number then
                        furniture_piece := furniture_item.fp
                        furniture_list.remove
                        found := True
                    end
                    if not found then
                        furniture_list.forth
                    end
                end
            end

        unperform
                -- Undo the last 'perform'.
            do

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            end

    feature {NONE} -- Implementation
        piece_number: INTEGER
        furniture_piece: FURNITURE_PIECE
        furniture_list: LIST [TUPLE [id: INTEGER; f: FURNITURE_PIECE]]
                -- The room's contents.

    invariant
        furniture_list_exists: furniture_list /= Void

    end
```

```
    class
        ROOM

    create
        make_with_furniture_factory

    feature

        make_with_furniture_factory (f: FURNITURE_FACTORY)
                -- Create an empty room.
            require
                factory_exists: f /= Void
            do
                furniture_factory := f
                create {LINKED_LIST [TUPLE [INTEGER, FURNITURE_PIECE]]}
                    furniture_list.make
                furniture_list.compare_objects
                    -- Use object rather than reference comparison for elements.
                id_counter := 1
```

```
            create {LINKED_STACK [ACTION]} undoable_action_stack.make
            create {LINKED_STACK [ACTION]} redoable_action_stack.make
        ensure
            room_empty: furniture_piece_count = 0
        end

    add_chair (c: COORDINATE)
            -- Add a chair to the room at coordinate 'c'.
        local
            add_action: ADD_ACTION
            chair: CHAIR
        do
            furniture_factory.make_chair (c)
            chair := furniture_factory.made_chair

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            added_chair_id := id_counter
            id_counter := id_counter + 1
        ensure
            added_chair: furniture_piece_count = old furniture_piece_count + 1
        end

    add_desk (c: COORDINATE)
            -- Add a desk to the room.
        local
            add_action: ADD_ACTION
            desk: DESK
        do
            -- Implementation not shown.
        ensure
            added_desk: furniture_piece_count = old furniture_piece_count + 1
        end

    remove_chair (n: INTEGER)
            -- Remove chair with id 'n' from the room.
            -- Do nothing if the chair is not inside the room.
        local
            remove_action: REMOVE_ACTION
        do

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```

```
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    ensure
        possibly_removed_chair: furniture_piece_count <= old furniture_piece_count
    end

remove_desk (n: INTEGER)
        -- Remove desk with id 'n' from the room.
        -- Do nothing if the desk is not inside the room.
    local
        remove_action: REMOVE_ACTION
    do
        create remove_action.make (n, furniture_list)
        remove_action.perform
        undoable_action_stack.put (remove_action)
        redoable_action_stack.wipe_out
    ensure
        possibly_removed_desk: furniture_piece_count <= old furniture_piece_count
    end

undo
        -- Undo the last add or remove action.
    local
        action: ACTION
    do
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    end
```

```
    redo
            -- Redo the last undone action.
        local
            action: ACTION
        do
            if not redoable_action_stack.is_empty then
                action := redoable_action_stack.item
                redoable_action_stack.remove
                action.perform
                undoable_action_stack.put (action)
            end
        end

    added_chair_id: INTEGER
            -- A handle for the last added chair.

    added_desk_id: INTEGER
            -- A handle for the last added desk.

    furniture_piece_count: INTEGER
            -- The number of furniture pieces inside.
        do
            Result := furniture_list.count
        end

feature {NONE} -- Implementation
    furniture_factory: FURNITURE_FACTORY
    furniture_list: LIST [TUPLE [INTEGER, FURNITURE_PIECE]]
    id_counter: INTEGER
            -- Internal counter to provide handles to created furniture pieces.
    undoable_action_stack: STACK [ACTION]
            -- Stack storing done actions that can be undone.
    redoable_action_stack: STACK [ACTION]
            -- Stack storing undone actions that can be redone.

invariant
    furniture_factory_exists: furniture_factory /= Void
    furniture_list_exists: furniture_list /= Void
    undoable_action_stack_exists: undoable_action_stack /= Void
    redoable_action_stack_exists: redoable_action_stack /= Void

end
```

```
class
    LINKED_LIST [G]

feature -- General operations.

    force (v: G)
            -- Add 'v' to end.
        require
            extendible: extendible
        ensure
            new_count: count = old count + 1
            item_inserted: has (v)

    prune_all (v: G)
            -- Remove all occurrences of 'v'.

feature -- Cursor-based operations.

    start
```

```
            -- Move cursor to first position.

    off: BOOLEAN
            -- Is there no current item?

    forth
            -- Move cursor to next position.

    item
            -- Item at the current cursor position.

    remove
            -- Remove item at current cursor position.
            -- Move cursor to next position.

-- Other features omitted.

end
```

```
class
    STACK [G]

feature

    put (v: G)
            -- Push 'v' onto top.
        ensure
            item_pushed: item = v


    remove
            -- Remove the top item.


    wipe_out
            -- Remove all items.
        ensure
            wiped_out: is_empty


    item: G
            -- The top element of the stack.


    is_empty: BOOLEAN
            -- Is the stack empty?

-- Other features omitted.

end
```