Software Engineering I (02161)

Week 11

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Technical University of Denmark

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Contents

Design by Contract (DbC)

- Contracts
- Implementing DbC in Java
- Assertion vs Tests
- Invariants
- Inheritance
- Defensive Programming

Activity Diagrams

Summary of the course

What does this function do?

sort

```
public List<Integer> f(List<Integer> list) {
   if (list.size() <= 1) return list;

   int p = list.elementAt(0);

   List<Integer> l1 = new ArrayList<Integer>();
   List<Integer> l2 = new ArrayList<Integer>();
   List<Integer> l3 = new ArrayList<Integer>();

   g(p,list,l1,l2,l3);

   List<Integer> r = f(l1);

   r.addAll(l2);
   r.addAll(f(l3));

   return r;
}

public void g(int p, List<Integer> list,
               List<Integer> l1, List<Integer> l2, List<Integer> l3) {
   for (int i : list) {
      if (i < p) l1.add(i);
      if (i == p) l3.add(i);
      if (i > p) l2.add(i);
   }
}
```

What does this function do?

```
public void testEmpy() {
  int[] a = {};
  List<Integer> r = f(Array.asList(a));
  assertTrue(r.isEmpty());
}

public void testOneElement() {
  int[] a = { 3 };
  List<Integer> r = f(Array.asList(a));
  assertEquals(Array.asList(3),r);
}

public void testTwoElements() {
  int[] a = {2, 1};
  List<Integer> r = f(Array.asList(a));
  assertEquals(Array.asList(1,2),r);
}

public void testThreeElements() {
  int[] a = {2, 3, 1};
  List<Integer> r = f(Array.asList(a));
  assertEquals(Array.asList(1,2,3),r);
}
...
```

What does this function do?

Contract

```
List<Integer> sort(List<Integer> a)
```

Precondition: *a* is not **null**

Postcondition: For all *result*, *a* ∈ List<Integer>:

$\mathit{result} == f(a)$

if and only if

isSorted(result) and sameElements(a,result)

where

isSorted(a) if and only if

for all $0 \le i, j < a.\mathit{size}()$**:**

$i \le j$ **implies** $a.\mathit{get}(i) \le a.\mathit{get}(j)$

and

sameElements(a,b) if and only if

for all $i \in \mathit{Integer}$**:** $\mathit{count}(a, i) = \mathit{count}(b, i)$

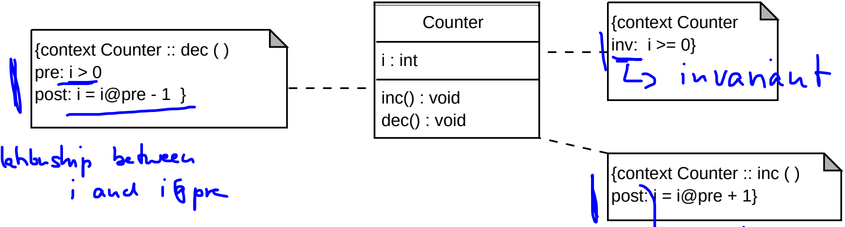
Design by contract

Contract between Caller and the Method

- Caller ensures precondition
- Method ensures postcondition

- Contracts spefify *what* instead of *how*

Example Counter



{context Counter :: dec ( )
pre: i > 0
post: i = i@pre - 1 }

Counter

i : int

inc() : void
dec() : void

{context Counter
inv: i >= 0}

↳ invariant

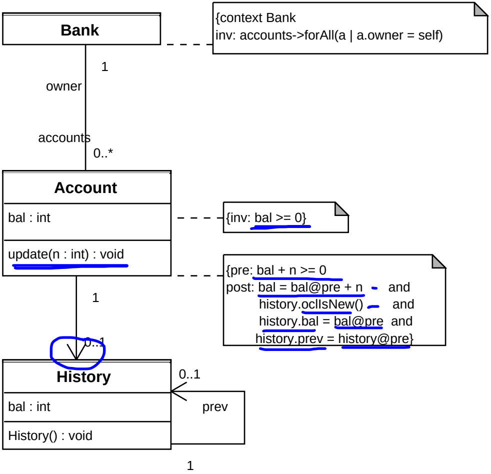
{context Counter :: inc ( )
post: i = i@pre + 1}

Relationship between
i and i@pre

pre : true

```
public T n(T1 a1, .., Tn an, Counter c)
   ...
   // Here the precondition of c has to hold
   // to fulfil the contract
   c.dec();
   // Before returning from dec, c has to ensure the
   // postcondition of dec
   ...
```

Bank example with constraints



Bank

1

owner

accounts

0..*

{context Bank
inv: accounts->forAll(a | a.owner = self)

Account

bal : int

update(n : int) : void

{inv: bal >= 0}

{pre: bal + n >= 0
post: bal = bal@pre + n and
history.oclIsNew() and
history.bal = bal@pre and
history.prev = history@pre}

1

0..1

History

bal : int

History() : void

0..1

prev

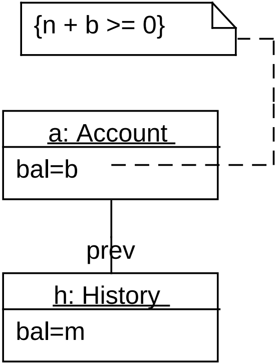
1

Update operation of Account

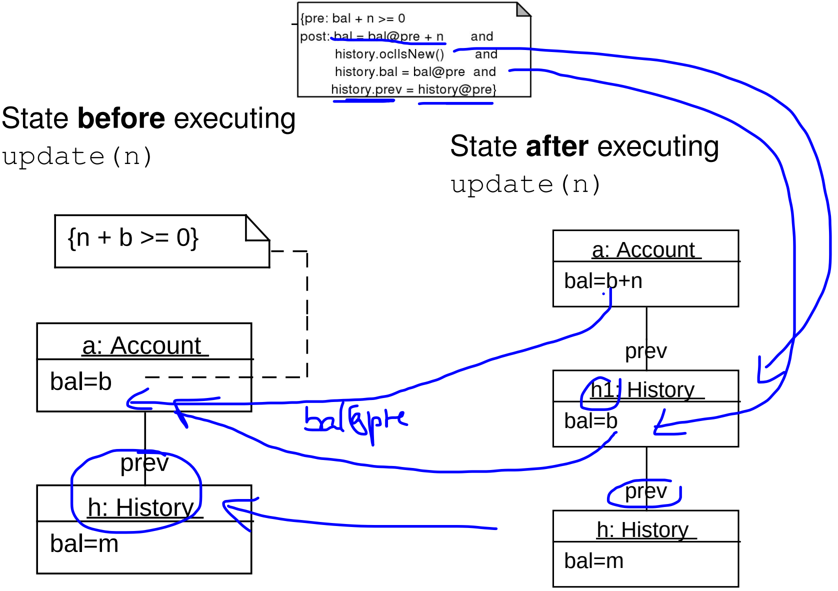
```
{pre: bal + n >= 0
post: bal = bal@pre + n       and
        history.oclIsNew()       and
        history.bal = bal@pre  and
        history.prev = history@pre}
```

State **before** executing

`update(n)`



Update operation of Account



{pre: bal + n >= 0
post: bal = bal@pre + n and
history.oclIsNew() and
history.bal = bal@pre and
history.prev = history@pre}

State **before** executing `update(n)`

{n + b >= 0}

a: Account
bal=b

prev

h: History
bal=m

State **after** executing `update(n)`

a: Account
bal=b+n

prev

h1: History
bal=b

prev

h: History
bal=m

bal@pre

Example

```
LibraryApp::addMedium(Medium m)
pre: adminLoggedIn
post: medium = medium@pre->including(m) and
        medium.library = this
```

adding an element
to a set

```
LibraryApp::search(String string) : List<Medium>
post: result = medium->select(m |
                    m.title.contains(string) or
                    m.autor.contains(string) or
                    m.signature.contains(string))
   medium = medium@pre
```

```
User::borrowMedium(Medium m)
pre: borrowedMedium->size < 10
         and m != null
         and not(borrowedMedium->exists(m’  | m’.isOverdue))
post: m.borrowDate = libApp.getDate() and
        borrowedMedium = borrowedMedium@pre->including(m)
```

Postcondition

Assume that `result` denotes the result of the function $f(x : double)$.

1) post: $\texttt{result}^2 = x$
2) post: $\texttt{result} = x^2$
3) post: $x^2 = \texttt{result}$
4) post: $x = \texttt{result}^2$

Which statements are correct: (multiple answers are possible)

a) 2 + 3 is the postcondition for the function computing the square of a number t 3 f 3
b) Only 2 is the postcondition for the function computing the square of a number t 1 f 5
c) 3 is the postcondition of the square root function t 2 f 6
e) 1 is the postcondition of the square root function t 5 f 0

Precondition

- Given the contract for a method $minmax(int[]array)$ in a class which has instance variables *min* and *max* of type int:

  pre: $array \neq null$ and $array.length > 0$
  post: $\forall i \in array : min \leq i \leq max$

- Which of the following statements is true: if the client calls *minmax* such the precondition is not satisfied

  a) A NullPointerException is thrown 2
  b) An IndexOutOfBoundsException is thrown 0
  c) Nothing happens 0
  t [✓ d) What happens depends on the implementation of minmax] 2

Implementing DbC with assertions

- Many languages have an assert construct: assert bexp;
- Contract for Counter::dec(i:int)

  Pre: $i > 0$

  Post: $i = i@pre - 1$

Implementing DbC with assertions

- Many languages have an assert construct: assert bexp;
- Contract for Counter::dec(i:int)

  Pre: $i > 0$

  Post: $i = i@pre - 1$

```
void dec() {
   assert i > 0; // Precondition
   int prei = i; // Remember the value of the counter
                 // to be used in the postcondition
   i--;
   assert i == prei-1; // Postcondition
}
```

Implementing DbC with assertions

- Many languages have an assert construct: assert bexp;
- Contract for Counter::dec(i:int)

  Pre: $i > 0$

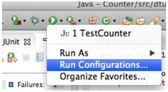
  Post: $i = i@pre - 1$

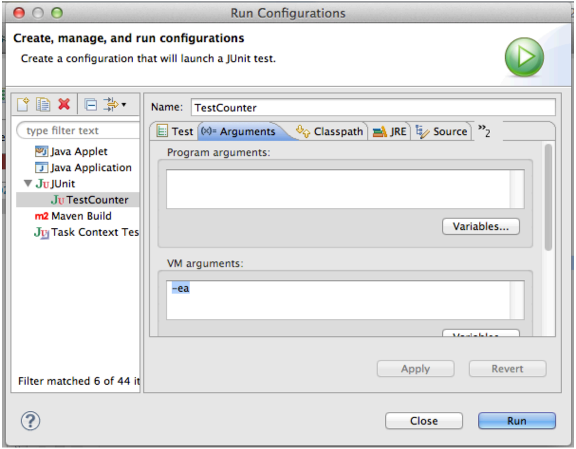
```
void dec() {
   assert i > 0; // Precondition
   int prei = i; // Remember the value of the counter
                 // to be used in the postcondition
   i--;
   assert i == prei-1; // Postcondition
}
```

- assert $\neq$ assertTrue

Important

- Assertion checking is switched off by default in Java
  1) `java -ea Main`
  2) In Eclipse





Name: TestCounter

VM arguments: -ea

Implementing DbC in Java

Pre: $args \neq null$ and $args.length > 0$

Post: $\forall n \in args : min \leq n \leq max$

```
public class MinMax {
  int min, max;

  public void minmax(int[] args) throws Error {
    assert args != null && args.length != 0;
    min = max = args[0];
    for (int i = 1; i < args.length; i++) {
      int obs = args[i];
      if (obs > max)
        max = obs;
      else if (min < obs)
        min = obs;
    }
    assert isBetweenMinMax(args);
  }

  private boolean isBetweenMinMax(int[] array) {
    boolean result = true;
    for (int n : array) {
      result = result && (min <= n && n <= max);
    }
    return result;
  }
```

Assertions

- Advantage
    - Postcondition is checked for each computation
    - Precondition is checked for each computation
- Disadvantage
    - Checking that a postcondition is satisfied can take as as much time as computing the result

    → Performace problems
    - Solution:
        - Assertion checking is switched on during debugging and testing and switched off in production systems
        - Only make assertions for precondition

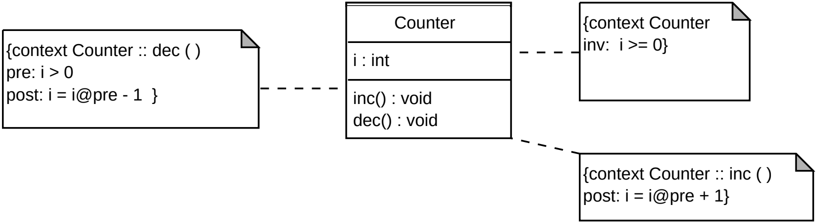
        → Preconditions are usually faster to check

        → Contract violations by the client are more difficult to find than postcondition violations (c.f. assertions vs tests)

Assertion vs. Tests

- Assertion
  - Check all computations (as long as assertion checking is switched on)
  - Check also for contract violations from the client (i.e. precondition violations)
- Tests
  - Only check test cases (concrete values)
  - Cannot check what happens if the contract is violated by the client

Invariants: Counter


{context Counter :: dec ( )
pre: i > 0
post: i = i@pre - 1 }

Counter

i : int

inc() : void
dec() : void

{context Counter
inv: i >= 0}

{context Counter :: inc ( )
post: i = i@pre + 1}

- Methods
  - assume that invariant holds
  - ensure invariants
- When does an invariant hold?
  - After construction
  - After each *public* method

Invariants

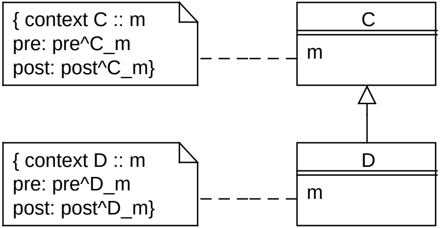
- Contstructor has to ensure invariant

```
public Counter() {
   i = 0;
   assert i >= 0;  // Invariant
}
```

- Operations ensure and assume invariant

```
void dec() {
   assert i >= 0; // Invariant
   assert i > 0; // Precondition
   int prei = i; // Remember the value of the counter
                 // to be used in the postcondition
   i--;
   assert i == prei-1; // Postcondition
   assert i >= 0; // Invariant
}
```

Contracts and inheritance



{ context C :: m
pre: pre^C_m
post: post^C_m}

{ context D :: m
pre: pre^D_m
post: post^D_m}

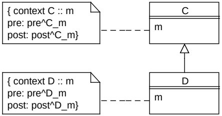
Contracts and Inheritance

Liskov / Wing Substitution principle:

At every place, where one can use objects of the superclass C, one can use objects of the subclass D

new C
new D

```
public T n(C c)
    ...
    // has to ensure Pre^C_m
    c.m();
    // n can rely Post^C_m
    ...
```


{ context C :: m
pre: pre^C_m
post: post^C_m}

{ context D :: m
pre: pre^D_m
post: post^D_m}

- Compare $t.n(newC())$ with $t.n(newD())$.

→ $Pre^C_m \implies Pre^D_m$ *weaker* precondition 1)

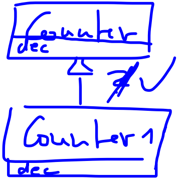
→ $Post^D_m \implies (Pre^C_m \implies Post^C_m)$ 2)
stronger postcondition

Counter vs. Counter1

Counter and Counter1 are identical with the exception of operation dec:

$i>0 \Longrightarrow true$

- Counter::dec
  - pre: $i > 0$
  - $(i>0) \Longrightarrow$ post: $i = i@pre - 1$
- Counter1::dec
  - pre: true
  - post: $(i@pre > 0) \Longrightarrow i = i@pre - 1$ and
    $(i@pre \leq 0) \Longrightarrow i = 0$



Which statement is true?

a) Counter is a subclass of Counter1

b) Counter1 is a subclass of Counter

c) There is no subclass relationship between Counter and Counter1

Defensive Programming

- Can one trust the client to ensure the precondition?

Defensive Programming

- Can one trust the client to ensure the precondition?
- Defensive Programming: don’t trust the client

```
void dec() { if (i > 0) { i--; } }
```

Defensive Programming

- Can one trust the client to ensure the precondition?
- Defensive Programming: don't trust the client

```
void dec() { if (i > 0) { i--; } }
```

- New Contract: No requirement for the client
  - Method has to ensure it works with any argument

    pre: true

    post: $(i@pre > 0) \implies (i = i@pre - 1)$ and
    $(i@pre \leq 0) \implies (i = 0)$

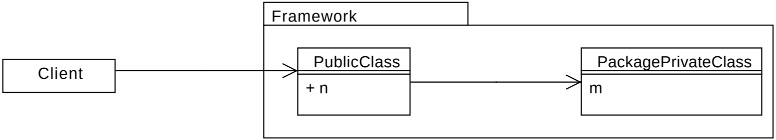
Defensive Programming

- Can one trust the client to ensure the precondition?
- Defensive Programming: don't trust the client

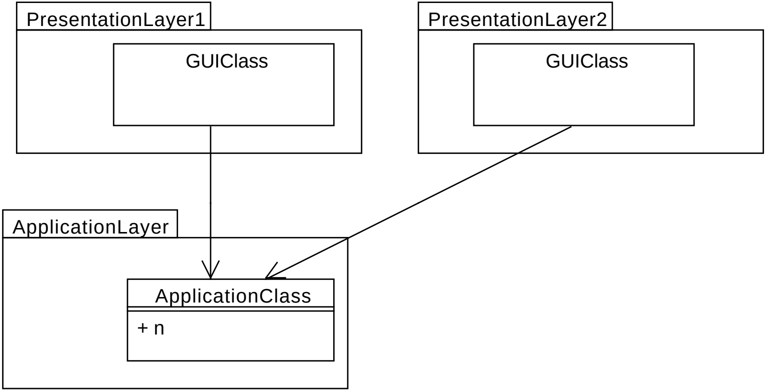
```
void dec() { if (i > 0) { i--; } }
```

- New Contract: No requirement for the client
  - Method has to ensure it works with any argument
    pre: true
    post: $(i@pre > 0) \implies (i = i@pre - 1)$ and
    $(i@pre \leq 0) \implies (i = 0)$
- Or, using *under specification*
  pre: true
  post: $(i@pre > 0) \implies (i = i@pre - 1)$

Defensive Programming



Defensive Programming



Defensive Programming

Given method contracts 1)

```
LibraryApp::addMedium(Medium m)
pre: adminLoggedIn
post: medium = medium@pre->including(m) and
        medium.library = this)
```

and 2)

```
LibraryApp::addMedium(Medium m)
post: adminLoggedIn implies
            medium = medium@pre->including(m) and
           medium.library = this)
```

Which statement is correct?

a) 1) uses defensive programming

b) 2) uses defensive programming

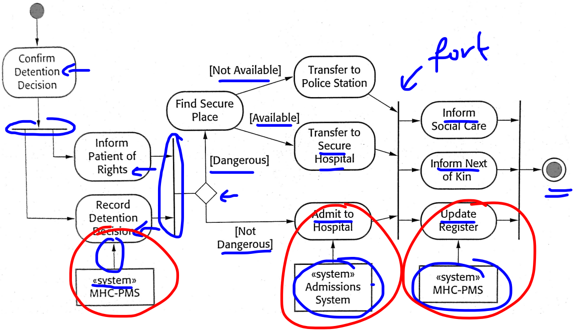
Contents

Design by Contract (DbC)

Activity Diagrams

Summary of the course

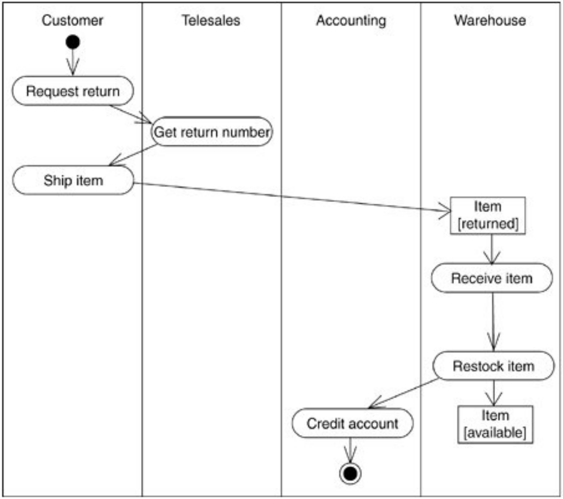
Activity Diagram: Business Processes



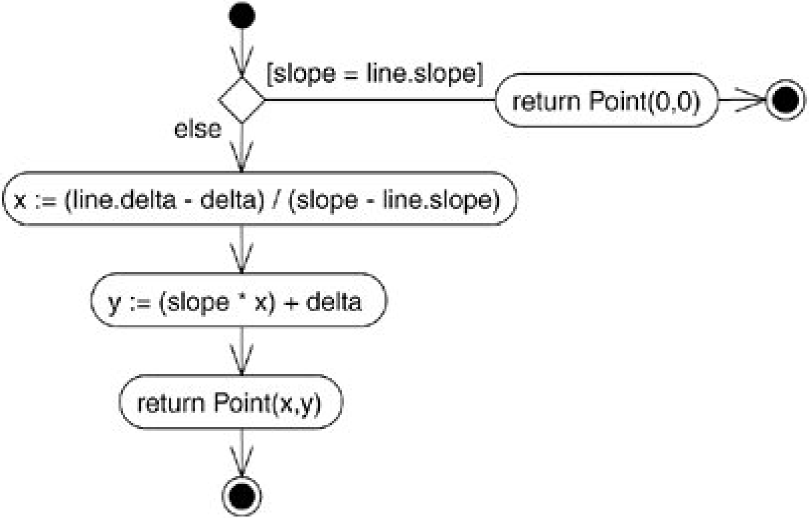
- Describe the *context* of the system
- Helps finding the requirements of a system
  - modelling business processes leads to suggestions for possible systems and ways how to interact with them
  - Software systems need to fit in into existing business processes

Activity Diagram Example Workflow

Swimlane



Activity Diagram Example Operation

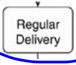


UML Activity Diagrams

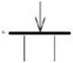
- Focus is on *control flow* and *data flow*
- Good for showing *parallel/concurrent* control flow
- Purpose
  - Model business processes
  - Model workflows
  - Model single operations
- Literature: UML Distilled by Martin Fowler

Activity Diagram Concepts

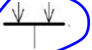
- *Actions*



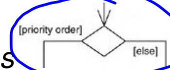
  - ~~Are~~ Can be atomic or can be composite .
  - E.g Sending a message, doing some computation, raising an exception, . . .
    - UML has approx. 45 Action types
- *Concurrency*
  - Fork: Creates concurrent flows



    - Can be true concurrency
    - Can be interleaving
  - Join: Synchronisation of concurrent activities

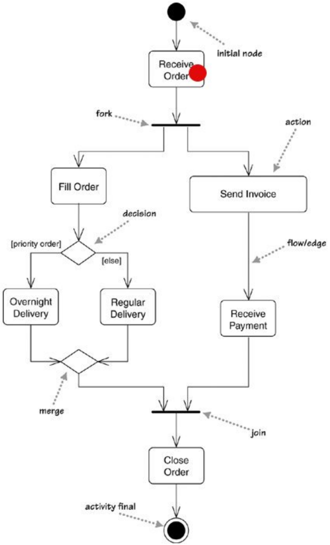


    - Wait for all concurrent activities to finish (based on token semantics)



- *Decisions*
  - Notation: Diamond with conditions on outgoing transitions
  - `else` denotes the transition to take if no other condition is satisfied

Activity Diagrams Execution



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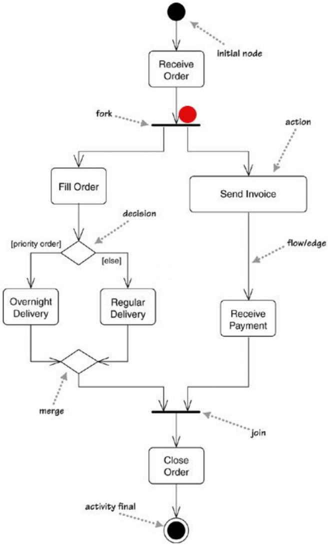

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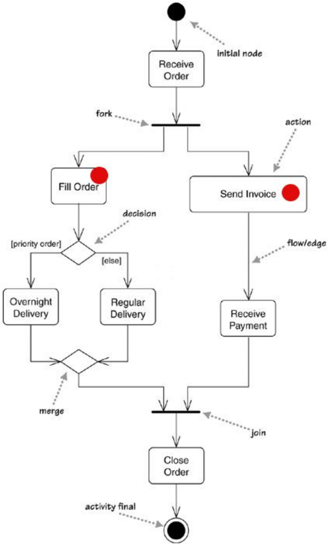

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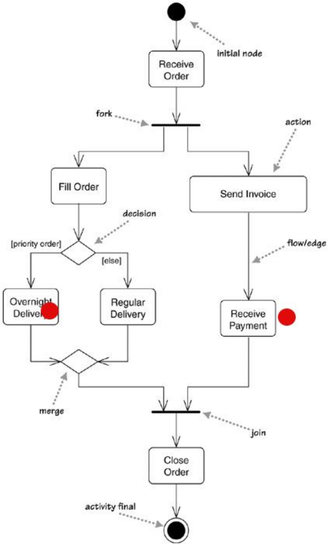

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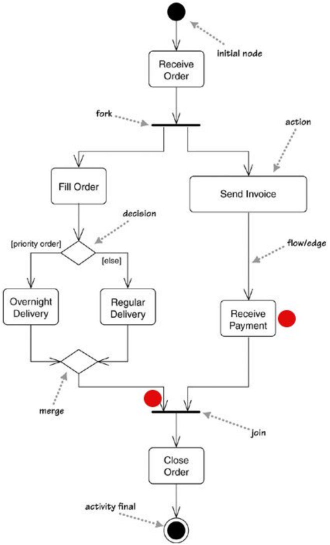
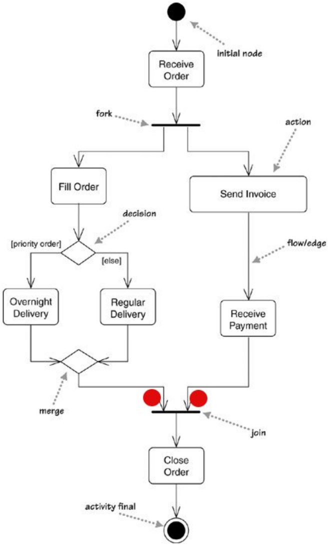


Activity Diagrams Execution



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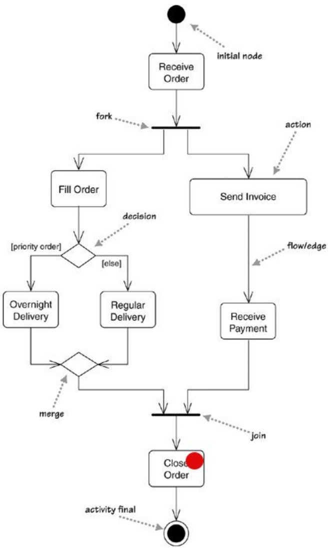

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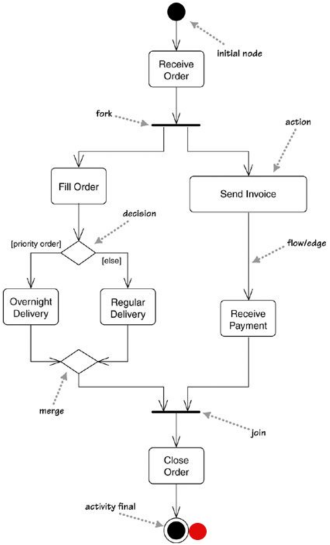
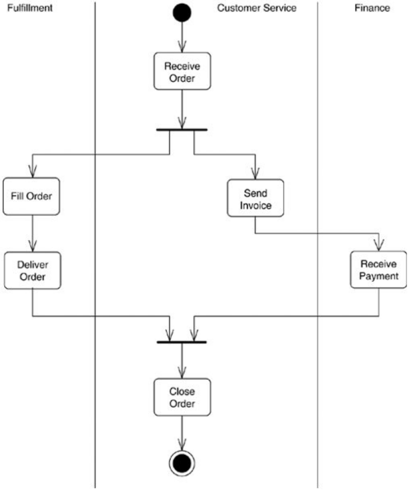
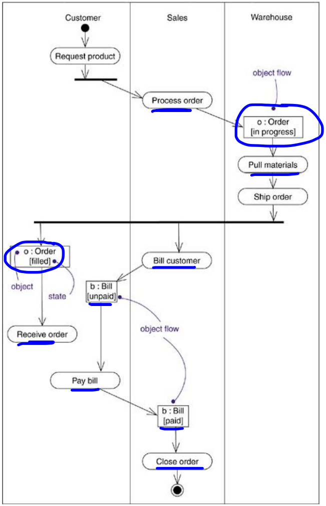


Swimlanes / Partitions

- Swimlanes show **who** is performing an activity

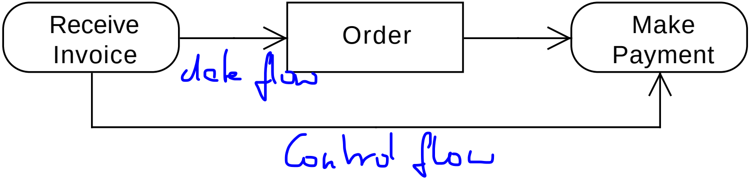


Objectflow example

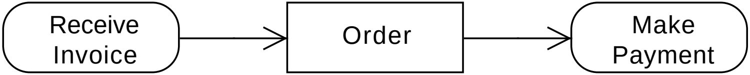


Data flow and Control flow

- *Data flow* and *control flow* are shown:



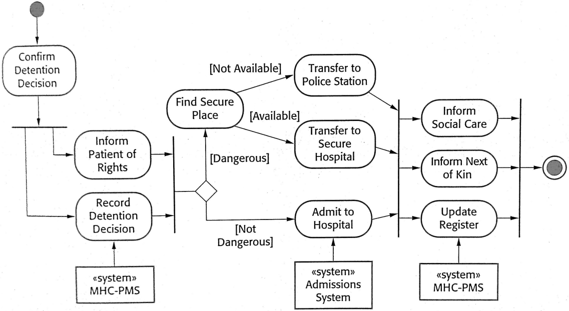
- Control flow can be omitted if implied by the data flow:

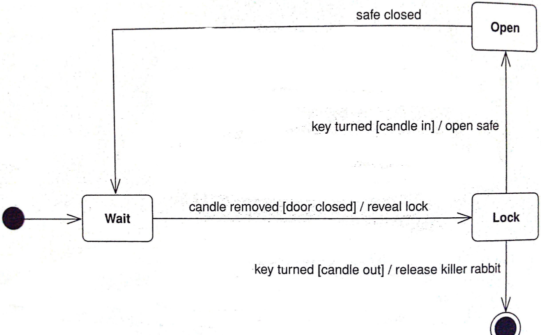


Use of Activity Diagrams

- Emphasise on concurrent/parallel execution
- Requirements phase
    - To model business processes / workflows to be automated
- Design phase
    - Show the semantics of one operation
        - Close to a graphic programming language

Activity Diagram vs State Machines




safe closed
Open
key turned [candle in] / open safe
Wait
candle removed [door closed] / reveal lock
Lock
key turned [candle out] / release killer rabbit

Contents

Design by Contract (DbC)

Activity Diagrams

Summary of the course

What did you learn?

- Requirements: Use Cases, User Stories, Use Case Diagrams
- Testing: Systematic Tests, Test-Driven Development
- System Modelling: Class Diagram, Sequence Diagrams, State Machines, Activity Diagrams
- Design: CRC cards, Refactoring, Layered Architecture, Design Principles, Design Patterns
- Software Development Process: Agile Processes, Project Planning
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- Don’t forget the course evaluation

Plan for next weeks

- Week 12: No lecture. Focus on examination proect.
  - Exercises from 13:00 – 15:00
- Week 13: 12.5., 13:00 – 17:00: 10 min demonstrations of the software
  1. Show that all automatic tests run
  2. TA chooses one use case
     - 2.a Show the systematic tests for that use case
     - 2.b Execute the systematic test **manually**
  - Schedule will be published this week