

Design-by-Contract (DbC)

Readings: OOSC2 Chapter 11



EECS3311 M: Software Design
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Motivation: Catching Defects – Design or Implementation Phase?

- To minimize **development costs**, minimize *software defects*.
 - ∴ The cost of fixing defects *increases exponentially* as software progresses through the development lifecycle:
 - Requirements → *Design* → *Implementation* → Release
 - ∴ Catch defects **as early as possible**.

Design and architecture	Implementation	Integration testing	Customer beta test	Postproduct release
1X*	5X	10X	15X	30X

- Discovering *defects* after **release** costs up to 30 times more than catching them in the **design** phase.
- Choice of **design language** for your project is therefore of paramount importance.

Source: Minimizing code defects to improve software quality and lower development costs.

What This Course Is About

- Focus is *design*
 - *Architecture*: (many) *inter-related* modules
 - *Specification*: *precise* (functional) interface of each module
- For this course, having a prototypical, *working* implementation for your design suffices.
- A later *refinement* into more efficient data structures and algorithms is beyond the scope of this course.

[assumed from EECS2011, EECS3101]

∴ Having a suitable language for **design** matters the most.

Q: Is Java also a “good” **design** language?

A: Let’s first understand what a “good” **design** is.

Terminology: Contract, Client, Supplier

- A **supplier** implements/provides a service (e.g., microwave).
- A **client** uses a service provided by some supplier.
 - The client are required to follow certain instructions to obtain the service (e.g., supplier **assumes** that client powers on, closes door, and heats something that is not explosive).
 - If instructions are followed, the client would **expect** that the service does what is guaranteed (e.g., a lunch box is heated).
 - The client does not care how the supplier implements it.
- What then are the *benefits* and *obligations* of the two parties?

	<i>benefits</i>	<i>obligations</i>
CLIENT	obtain a service	follow instructions
SUPPLIER	assume instructions followed	provide a service

- There is a **contract** between two parties, violated if:
 - The instructions are not followed. [Client's fault]
 - Instructions followed, but service not satisfactory. [Supplier's fault]

Client, Supplier, Contract in OOP (1)

```
class Microwave {  
    private boolean on;  
    private boolean locked;  
    void power() {on = true;}  
    void lock() {locked = true;}  
    void heat(Object stuff) {  
        /* Assume: on && locked */  
        /* stuff not explosive. */  
    } }  
}
```

```
class MicrowaveUser {  
    public static void main(...) {  
        Microwave m = new Microwave();  
        Object obj = ???;  
        m.power(); m.lock();  
        m.heat(obj);  
    } }  
}
```

Method call `m.heat(obj)` indicates a client-supplier relation.

- **Client:** resident class of the method call [MicrowaveUser]
- **Supplier:** type of context object (or call target) `m` [Microwave]

Client, Supplier, Contract in OOP (2)

```
class Microwave {
    private boolean on;
    private boolean locked;
    void power() {on = true;}
    void lock() {locked = true;}
    void heat(Object stuff) {
        /* Assume: on && locked */
        /* stuff not explosive. */
    }
}
```

```
class MicrowaveUser {
    public static void main(...) {
        Microwave m = new Microwave();
        Object obj = ???;
        m.power(); m.lock();
        m.heat(obj);
    }
}
```

- The **contract** is *honoured* if:

Right **before** the method call:

- State of `m` is as assumed: `m.on==true` and `m.locked==ture`
- The input argument `obj` is valid (i.e., not explosive).

Right **after** the method call: `obj` is properly heated.

- If any of these fails, there is a **contract violation**.
 - `m.on` or `m.locked` is false ⇒ MicrowaveUser's fault.
 - `obj` is an explosive ⇒ MicrowaveUser's fault.
 - A fault from the client is identified ⇒ Method call will not start.
 - Method executed but `obj` not properly heated ⇒ Microwave's fault

What is a Good Design?

- A “good” design should *explicitly* and *unambiguously* describe the **contract** between **clients** (e.g., users of Java classes) and **suppliers** (e.g., developers of Java classes).
We such a contractual relation a **specification**.
- When you conduct *software design*, you should be guided by the “appropriate” contracts between users and developers.
 - Instructions to **clients** should *not be unreasonable*.
e.g., asking them to assemble internal parts of a microwave
 - Working conditions for **suppliers** should *not be unconditional*.
e.g., expecting them to produce a microwave which can safely heat an explosive with its door open!
 - You as a designer should strike proper balance between **obligations** and **benefits** of clients and suppliers.
e.g., What is the obligation of a binary-search user (also benefit of a binary-search implementer)? [The input array is sorted.]
 - Upon contract violation, there should be the fault of **only one side**.
 - This design process is called **Design by Contract (DbC)**.

A Simple Problem: Bank Accounts

Provide an object-oriented solution to the following problem:

REQ1: Each account is associated with the *name* of its owner (e.g., "Jim") and an integer *balance* that is always positive.

REQ2: We may *withdraw* an integer amount from an account.

REQ3: Each bank stores a list of *accounts*.

REQ4: Given a bank, we may *add* a new account in it.

REQ5: Given a bank, we may *query* about the associated account of a owner (e.g., the account of "Jim").

REQ6: Given a bank, we may *withdraw* from a specific account, identified by its name, for an integer amount.

Let's first try to work on **REQ1** and **REQ2** in Java.

This may not be as easy as you might think!

Playing the Various Versions in Java

- **Download** the project archive (a zip file) here:
<http://www.eecs.yorku.ca/~jackie/teaching/lectures/2019/W/EECS3311/codes/DbCIntro.zip>
- Follow this tutorial to learn how to **import** an project archive into your workspace in Eclipse:
<https://youtu.be/h-rgdQZg2qY>
- Follow this tutorial to learn how to **enable** assertions in Eclipse:
<https://youtu.be/OEgRV4a5Dzg>

Version 1: An Account Class

```
1 public class AccountV1 {
2     private String owner;
3     private int balance;
4     public String getOwner() { return owner; }
5     public int getBalance() { return balance; }
6     public AccountV1(String owner, int balance) {
7         this.owner = owner; this.balance = balance;
8     }
9     public void withdraw(int amount) {
10        this.balance = this.balance - amount;
11    }
12    public String toString() {
13        return owner + "'s current balance is: " + balance;
14    }
15 }
```

- Is this a good design? Recall **REQ1**: Each account is associated with ... an integer balance that is *always positive*.
- This requirement is *not* reflected in the above Java code.

Version 1: Why Not a Good Design? (1)

```
public class BankAppV1 {  
    public static void main(String[] args) {  
        System.out.println("Create an account for Alan with balance -10:");  
        AccountV1 alan = new AccountV1("Alan", -10);  
        System.out.println(alan);  
    }  
}
```

Console Output:

```
Create an account for Alan with balance -10:  
Alan's current balance is: -10
```

- Executing `AccountV1`'s constructor results in an account object whose **state** (i.e., values of attributes) is *invalid* (i.e., Alan's balance is negative). ⇒ Violation of **REQ1**
- Unfortunately, both client and supplier are to be blamed: `BankAppV1` passed an invalid balance, but the API of `AccountV1` does not require that! ⇒ A lack of defined contract

Version 1: Why Not a Good Design? (2)

```
public class BankAppV1 {  
    public static void main(String[] args) {  
        System.out.println("Create an account for Mark with balance 100:");  
        AccountV1 mark = new AccountV1("Mark", 100);  
        System.out.println(mark);  
        System.out.println("Withdraw -1000000 from Mark's account:");  
        mark.withdraw(-1000000);  
        System.out.println(mark);  
    }  
}
```

```
Create an account for Mark with balance 100:  
Mark's current balance is: 100  
Withdraw -1000000 from Mark's account:  
Mark's current balance is: 1000100
```

- Mark's account state is always valid (i.e., 100 and 1000100).
- Withdraw amount is never negative! ⇒ Violation of **REQ2**
- Again a lack of contract between BankAppV1 and AccountV1.

Version 1: Why Not a Good Design? (3)

```
public class BankAppV1 {  
    public static void main(String[] args) {  
        System.out.println("Create an account for Tom with balance 100:");  
        AccountV1 tom = new AccountV1("Tom", 100);  
        System.out.println(tom);  
        System.out.println("Withdraw 150 from Tom's account:");  
        tom.withdraw(150);  
        System.out.println(tom);  
    }  
}
```

```
Create an account for Tom with balance 100:  
Tom's current balance is: 100  
Withdraw 150 from Tom's account:  
Tom's current balance is: -50
```

- Withdrawal was done via an “appropriate” reduction, but the resulting balance of Tom is *invalid*. ⇒ Violation of **REQ1**
- Again a lack of contract between BankAppV1 and AccountV1.

Version 1: How Should We Improve it? (1)

Preconditions of a method specify the precise circumstances under which that method can be executed.

- Precond. of `divide(int x, int y)`? $[y \neq 0]$
- Precond. of `binSearch(int x, int[] xs)`? $[xs \text{ is sorted}]$
- Precond. of `topoSort(Graph g)`? $[g \text{ is a DAG}]$

Version 1: How Should We Improve it? (2)

The best we can do in Java is to encode the *logical negations* of preconditions as *exceptions*:

- `divide(int x, int y)`
throws `DivisionByZeroException` when `y == 0`.
- `binSearch(int x, int[] xs)`
throws `ArrayNotSortedException` when `xs` is *not* sorted.
- `topoSort(Graph g)`
throws `NotDAGException` when `g` is *not* directed and acyclic.
- Design your method by specifying the *preconditions* (i.e., *service* conditions for *valid* inputs) it requires, not the *exceptions* (i.e., *error* conditions for *invalid* inputs) for it to fail.
- Create Version 2 by adding *exceptional conditions* (an *approximation* of *preconditions*) to the constructor and `withdraw` method of the `Account` class.

Version 2: Added Exceptions to Approximate Method Preconditions

```
1 public class AccountV2 {
2     public AccountV2(String owner, int balance) throws
3         BalanceNegativeException
4     {
5         if( balance < 0 ) { /* negated precondition */
6             throw new BalanceNegativeException(); }
7         else { this.owner = owner; this.balance = balance; }
8     }
9     public void withdraw(int amount) throws
10        WithdrawAmountNegativeException, WithdrawAmountTooLargeException {
11        if( amount < 0 ) { /* negated precondition */
12            throw new WithdrawAmountNegativeException(); }
13        else if ( balance < amount ) { /* negated precondition */
14            throw new WithdrawAmountTooLargeException(); }
15        else { this.balance = this.balance - amount; }
16    }
```


Version 2: Why Better than Version 1? (1)

```
1 public class BankAppV2 {  
2     public static void main(String[] args) {  
3         System.out.println("Create an account for Alan with balance -10:");  
4         try {  
5             AccountV2 alan = new AccountV2("Alan", -10);  
6             System.out.println(alan);  
7         }  
8         catch (BalanceNegativeException bne) {  
9             System.out.println("Illegal negative account balance.");  
10        }
```

```
Create an account for Alan with balance -10:  
Illegal negative account balance.
```

L6: When attempting to call the constructor `AccountV2` with a negative balance `-10`, a `BalanceNegativeException` (i.e., *precondition* violation) occurs, *preventing further operations upon this invalid object.*

Version 2: Why Better than Version 1? (2.1)

```
1 public class BankAppV2 {
2     public static void main(String[] args) {
3         System.out.println("Create an account for Mark with balance 100:");
4         try {
5             AccountV2 mark = new AccountV2("Mark", 100);
6             System.out.println(mark);
7             System.out.println("Withdraw -1000000 from Mark's account:");
8             mark.withdraw(-1000000);
9             System.out.println(mark);
10        }
11        catch (BalanceNegativeException bne) {
12            System.out.println("Illegal negative account balance.");
13        }
14        catch (WithdrawAmountNegativeException wane) {
15            System.out.println("Illegal negative withdraw amount.");
16        }
17        catch (WithdrawAmountTooLargeException wane) {
18            System.out.println("Illegal too large withdraw amount.");
19        }
20    }
21 }
```

Version 2: Why Better than Version 1? (2.2)

Console Output:

```
Create an account for Mark with balance 100:  
Mark's current balance is: 100  
Withdraw -1000000 from Mark's account:  
Illegal negative withdraw amount.
```

- **L9:** When attempting to call method `withdraw` with a positive but too large amount 150, a `WithdrawAmountTooLargeException` (i.e., **precondition** violation) occurs, *preventing the withdrawal from proceeding*.
- We should observe that *adding preconditions* to the supplier `BankV2`'s code forces the client `BankAppV2`'s code to *get complicated by the try-catch statements*.
- Adding clear contract (*preconditions* in this case) to the design **should not** be at the cost of complicating the client's code!!

Version 2: Why Better than Version 1? (3.1)

```
1 public class BankAppV2 {
2     public static void main(String[] args) {
3         System.out.println("Create an account for Tom with balance 100:");
4         try {
5             AccountV2 tom = new AccountV2("Tom", 100);
6             System.out.println(tom);
7             System.out.println("Withdraw 150 from Tom's account:");
8             tom.withdraw(150);
9             System.out.println(tom);
10        }
11        catch (BalanceNegativeException bne) {
12            System.out.println("Illegal negative account balance.");
13        }
14        catch (WithdrawAmountNegativeException wane) {
15            System.out.println("Illegal negative withdraw amount.");
16        }
17        catch (WithdrawAmountTooLargeException wane) {
18            System.out.println("Illegal too large withdraw amount.");
19        }
20    }
21 }
```

Version 2: Why Better than Version 1? (3.2)

Console Output:

```
Create an account for Tom with balance 100:  
Tom's current balance is: 100  
Withdraw 150 from Tom's account:  
Illegal too large withdraw amount.
```

- **L9:** When attempting to call method `withdraw` with a negative amount `-1000000`, a `WithdrawAmountNegativeException` (i.e., **precondition** violation) occurs, *preventing the withdrawal from proceeding*.
- We should observe that due to the *added preconditions* to the supplier `BankV2`'s code, the client `BankAppV2`'s code is forced to *repeat the long list of the try-catch statements*.
- Indeed, adding clear contract (*preconditions* in this case) **should not** be at the cost of complicating the client's code!!

Version 2: Why Still Not a Good Design? (1)

```
1 public class AccountV2 {
2     public AccountV2(String owner, int balance) throws
3         BalanceNegativeException
4     {
5         if( balance < 0 ) { /* negated precondition */
6             throw new BalanceNegativeException(); }
7         else { this.owner = owner; this.balance = balance; }
8     }
9     public void withdraw(int amount) throws
10        WithdrawAmountNegativeException, WithdrawAmountTooLargeException {
11        if( amount < 0 ) { /* negated precondition */
12            throw new WithdrawAmountNegativeException(); }
13        else if ( balance < amount ) { /* negated precondition */
14            throw new WithdrawAmountTooLargeException(); }
15        else { this.balance = this.balance - amount; }
16    }
```

- Are all the *exception* conditions (\neg *preconditions*) appropriate?
- What if amount == balance when calling withdraw?

Version 2: Why Still Not a Good Design? (2.1)

```
1 public class BankAppV2 {
2     public static void main(String[] args) {
3         System.out.println("Create an account for Jim with balance 100:");
4         try {
5             AccountV2 jim = new AccountV2("Jim", 100);
6             System.out.println(jim);
7             System.out.println("Withdraw 100 from Jim's account:");
8             jim.withdraw(100);
9             System.out.println(jim);
10        }
11        catch (BalanceNegativeException bne) {
12            System.out.println("Illegal negative account balance.");
13        }
14        catch (WithdrawAmountNegativeException wane) {
15            System.out.println("Illegal negative withdraw amount.");
16        }
17        catch (WithdrawAmountTooLargeException wane) {
18            System.out.println("Illegal too large withdraw amount.");
19        }
20    }
21 }
```

Version 2: Why Still Not a Good Design? (2.2)

```
Create an account for Jim with balance 100:  
Jim's current balance is: 100  
Withdraw 100 from Jim's account:  
Jim's current balance is: 0
```

L9: When attempting to call method `withdraw` with an amount 100 (i.e., equal to Jim's current balance) that would result in a **zero** balance (clearly a violation of **REQ1**), there should have been a *precondition* violation.

Supplier `AccountV2`'s *exception* condition `balance < amount` has a *missing case* :

- Calling `withdraw` with `amount == balance` will also result in an invalid account state (i.e., the resulting account balance is **zero**).
- \therefore **L13** of `AccountV2` should be `balance <= amount`.

Version 2: How Should We Improve it?

- **Even without** fixing this insufficient *precondition*, we could have avoided the above scenario by *checking at the end of each method that the resulting account is valid*.
 - ⇒ We consider the condition `this.balance > 0` as **invariant** throughout the lifetime of all instances of `Account`.
- **Invariants** of a class specify the precise conditions which all instances/objects of that class must satisfy.
 - Inv. of `CSMajorStudent`? [`gpa >= 4.5`]
 - Inv. of `BinarySearchTree`? [in-order trav. → sorted key seq.]
- The best we can do in Java is encode invariants as *assertions*:
 - `CSMajorStudent: assert this.gpa >= 4.5`
 - `BinarySearchTree: assert this.inOrder() is sorted`
 - Unlike exceptions, assertions are not in the class/method API.
- Create **Version 3** by adding *assertions* to the end of constructor and `withdraw` method of the `Account` class.

Version 3: Added Assertions to Approximate Class Invariants

```
1 public class AccountV3 {
2     public AccountV3(String owner, int balance) throws
3         BalanceNegativeException
4     {
5         if(balance < 0) { /* negated precondition */
6             throw new BalanceNegativeException(); }
7         else { this.owner = owner; this.balance = balance; }
8         assert this.getBalance() > 0 : "Invariant: positive balance";
9     }
10    public void withdraw(int amount) throws
11        WithdrawAmountNegativeException, WithdrawAmountTooLargeException {
12        if(amount < 0) { /* negated precondition */
13            throw new WithdrawAmountNegativeException(); }
14        else if (balance < amount) { /* negated precondition */
15            throw new WithdrawAmountTooLargeException(); }
16        else { this.balance = this.balance - amount; }
17        assert this.getBalance() > 0 : "Invariant: positive balance";
18    }
```

Version 3: Why Better than Version 2?

```
1 public class BankAppV3 {  
2     public static void main(String[] args) {  
3         System.out.println("Create an account for Jim with balance 100:");  
4         try { AccountV3 jim = new AccountV3("Jim", 100);  
5             System.out.println(jim);  
6             System.out.println("Withdraw 100 from Jim's account:");  
7             jim.withdraw(100);  
8             System.out.println(jim); }  
9         /* catch statements same as this previous slide:  
10        * Version 2: Why Still Not a Good Design? (2.1) */
```

```
Create an account for Jim with balance 100:  
Jim's current balance is: 100  
Withdraw 100 from Jim's account:  
Exception in thread "main"
```

java.lang.AssertionError: Invariant: positive balance

L8: Upon completion of `jim.withdraw(100)`, Jim has a **zero** balance, an assertion failure (i.e., **invariant** violation) occurs, *preventing further operations on this invalid account object.*

Version 3: Why Still Not a Good Design?

Let's review what we have added to the method `withdraw`:

- From **Version 2**: *exceptions* encoding **negated preconditions**
- From **Version 3**: *assertions* encoding the *class invariants*

```
1 public class AccountV3 {
2     public void withdraw(int amount) throws
3         WithdrawAmountNegativeException, WithdrawAmountTooLargeException {
4         if( amount < 0 ) { /* negated precondition */
5             throw new WithdrawAmountNegativeException(); }
6         else if ( balance < amount ) { /* negated precondition */
7             throw new WithdrawAmountTooLargeException(); }
8         else { this.balance = this.balance - amount; }
9         assert this.getBalance() > 0 : "Invariant: positive balance"; }
```

However, there is **no contract** in `withdraw` which specifies:

- Obligations of supplier (`AccountV3`) if preconditions are met.
 - Benefits of client (`BankAppV3`) after meeting preconditions.
- ⇒ We illustrate how problematic this can be by creating

Version 4, where deliberately mistakenly implement `withdraw`.

Version 4: What If the Implementation of `withdraw` is Wrong? (1)

```
1 public class AccountV4 {
2     public void withdraw(int amount) throws
3         WithdrawAmountNegativeException, WithdrawAmountTooLargeException
4     { if(amount < 0) { /* negated precondition */
5         throw new WithdrawAmountNegativeException(); }
6     else if (balance < amount) { /* negated precondition */
7         throw new WithdrawAmountTooLargeException(); }
8     else { /* WRONG IMPLEMENTATION */
9         this.balance = this.balance + amount; }
10    assert this.getBalance() > 0 :
11        owner + "Invariant: positive balance"; }
```

- Apparently the implementation at **L11** is **wrong**.
- Adding a positive amount to a valid (positive) account balance would not result in an invalid (negative) one.
⇒ The **class invariant** will **not** catch this flaw.
- When something goes wrong, a good **design** (with an appropriate **contract**) should report it via a **contract violation**.

Version 4: What If the Implementation of `withdraw` is Wrong? (2)

```
1 public class BankAppV4 {
2     public static void main(String[] args) {
3         System.out.println("Create an account for Jeremy with balance 100:");
4         try { AccountV4 jeremy = new AccountV4("Jeremy", 100);
5             System.out.println(jeremy);
6             System.out.println("Withdraw 50 from Jeremy's account:");
7             jeremy.withdraw(50);
8             System.out.println(jeremy); }
9         /* catch statements same as this previous slide:
10        * Version 2: Why Still Not a Good Design? (2.1) */
```

```
Create an account for Jeremy with balance 100:
Jeremy's current balance is: 100
Withdraw 50 from Jeremy's account:
Jeremy's current balance is: 150
```

L7: Resulting balance of Jeremy is valid ($150 > 0$), but withdrawal was done via an *mistaken* increase. \Rightarrow Violation of **REQ2**

Version 4: How Should We Improve it?

- **Postconditions** of a method specify the precise conditions which it will satisfy upon its completion.
 - This relies on the assumption that right before the method starts, its preconditions are satisfied (i.e., inputs valid) and invariants are satisfied (i.e., object state valid).
 - Postcondition of `double divide(int x, int y)`?

$$[\text{Result} \times y == x]$$
 - Postcondition of `boolean binSearch(int x, int[] xs)`?

$$[x \in xs \iff \text{Result}]$$
- The best we can do in Java is, similar to the case of invariants, encode postconditions as *assertions*.
 - But again, unlike exceptions, these assertions will not be part of the class/method API.
- Create Version 5 by adding *assertions* to the end of `withdraw` method of the `Account` class.

Version 5: Added Assertions to Approximate Method Postconditions

```
1 public class AccountV5 {
2     public void withdraw(int amount) throws
3         WithdrawAmountNegativeException, WithdrawAmountTooLargeException {
4         int oldBalance = this.balance;
5         if(amount < 0) { /* negated precondition */
6             throw new WithdrawAmountNegativeException(); }
7         else if (balance < amount) { /* negated precondition */
8             throw new WithdrawAmountTooLargeException(); }
9         else { this.balance = this.balance - amount; }
10        assert this.getBalance() > 0 : "Invariant: positive balance";
11        assert this.getBalance() == oldBalance - amount :
12            "Postcondition: balance deducted"; }
```

A postcondition typically relates the pre-execution value and the post-execution value of each relevant attribute (e.g., balance in the case of withdraw).

⇒ Extra code (**L4**) to capture the pre-execution value of balance for the comparison at **L11**.

Version 5: Why Better than Version 4?

```
1 public class BankAppV5 {
2     public static void main(String[] args) {
3         System.out.println("Create an account for Jeremy with balance 100:");
4         try { AccountV5 jeremy = new AccountV5("Jeremy", 100);
5             System.out.println(jeremy);
6             System.out.println("Withdraw 50 from Jeremy's account:");
7             jeremy.withdraw(50);
8             System.out.println(jeremy); }
9         /* catch statements same as this previous slide:
10        * Version 2: Why Still Not a Good Design? (2.1) */
```

```
Create an account for Jeremy with balance 100:
Jeremy's current balance is: 100
Withdraw 50 from Jeremy's account:
Exception in thread "main"
```

java.lang.AssertionError: Postcondition: balance deducted

L8: Upon completion of `jeremy.withdraw(50)`, Jeremy has a wrong balance 150, an assertion failure (i.e., **postcondition** violation) occurs, *preventing further operations on this invalid account object.*

Evolving from Version 1 to Version 5

	<i>Improvements</i> Made	Design <i>Flaws</i>
V1	–	Complete lack of Contract
V2	Added exceptions as <i>method preconditions</i>	Preconditions not strong enough (i.e., with missing cases) may result in an invalid account state.
V3	Added assertions as <i>class invariants</i>	Incorrect implementations do not necessarily result in a state that violates the class invariants.
V4	Deliberately changed <code>withdraw</code> 's implementation to be incorrect .	The incorrect implementation does not result in a state that violates the class invariants.
V5	Added assertions as <i>method postconditions</i>	–

- In Versions 2, 3, 4, 5, **preconditions** approximated as *exceptions*.
 - ⊙ These are **not preconditions**, but their **logical negation**.
 - ⊙ Client `BankApp`'s code **complicated** by repeating the list of `try-catch` statements.
- In Versions 3, 4, 5, **class invariants** and **postconditions** approximated as *assertions*.
 - ⊙ Unlike exceptions, these assertions will **not appear in the API** of `withdraw`. Potential clients of this method **cannot know**: **1**) what their benefits are; and **2**) what their suppliers' obligations are.
 - ⊙ For postconditions, **extra code** needed to capture pre-execution values of attributes.

Version 5: Contract between Client and Supplier

	<i>benefits</i>	<i>obligations</i>
BankAppV5.main (CLIENT)	balance deduction positive balance	amount non-negative amount not too large
BankV5.withdraw (SUPPLIER)	amount non-negative amount not too large	balance deduction positive balance

	<i>benefits</i>	<i>obligations</i>
CLIENT	postcondition & invariant	precondition
SUPPLIER	precondition	postcondition & invariant

DbC in Java

DbC is possible in Java, but not appropriate for your learning:

- **Preconditions** of a method:

Supplier

- Encode their logical negations as exceptions.
- In the **beginning** of that method, a list of `if`-statements for throwing the appropriate exceptions.

Client

- A list of `try-catch`-statements for handling exceptions.

- **Postconditions** of a method:

Supplier

- Encoded as a list of assertions, placed at the **end** of that method.

Client

- All such assertions do not appear in the API of that method.

- **Invariants** of a class:

Supplier

- Encoded as a list of assertions, placed at the **end** of **every** method.

Client

- All such assertions do not appear in the API of that class.

DbC in Eiffel: Supplier

DbC is supported natively in Eiffel for **supplier**:

```
class ACCOUNT
create
    make
feature -- Attributes
    owner : STRING
    balance : INTEGER
feature -- Constructors
    make(nn: STRING; nb: INTEGER)
        require -- precondition
            positive_balance: nb > 0
        do
            owner := nn
            balance := nb
        end
feature -- Commands
    withdraw(amount: INTEGER)
        require -- precondition
            non_negative_amount: amount > 0
            affordable_amount: amount <= balance -- problematic, why?
        do
            balance := balance - amount
        ensure -- postcondition
            balance_deducted: balance = old balance - amount
        end
invariant -- class invariant
    positive_balance: balance > 0
end
```

DbC in Eiffel: Contract View of Supplier

Any potential **client** who is interested in learning about the kind of services provided by a **supplier** can look through the **contract view** (without showing any implementation details):

```
class ACCOUNT
create
  make
feature -- Attributes
  owner : STRING
  balance : INTEGER
feature -- Constructors
  make(nn: STRING; nb: INTEGER)
    require -- precondition
      positive_balance: nb > 0
    end
feature -- Commands
  withdraw(amount: INTEGER)
    require -- precondition
      non_negative_amount: amount > 0
      affordable_amount: amount <= balance -- problematic, why?
    ensure -- postcondition
      balance_deducted: balance = old balance - amount
    end
invariant -- class invariant
  positive_balance: balance > 0
end
```

DbC in Eiffel: Anatomy of a Class

```
class SOME_CLASS
create
  -- Explicitly list here commands used as constructors
feature -- Attributes
  -- Declare attribute here
feature -- Commands
  -- Declare commands (mutators) here
feature -- Queries
  -- Declare queries (accessors) here
invariant
  -- List of tagged boolean expressions for class invariants
end
```

- Use feature clauses to group attributes, commands, queries.
- Explicitly declare list of commands under create clause, so that they can be used as class constructors.

[See the groups panel in Eiffel Studio.]

- The **class invariant invariant** clause may be omitted:
 - There's no class invariant: any resulting object state is acceptable.
 - The class invariant is equivalent to writing **invariant true**

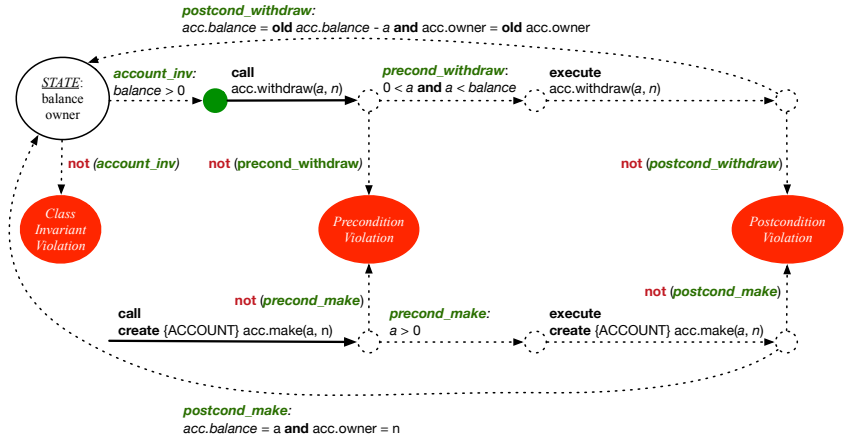
DbC in Eiffel: Anatomy of a Feature

```
some_command
  -- Description of the command.
  require
    -- List of tagged boolean expressions for preconditions
  local
    -- List of local variable declarations
  do
    -- List of instructions as implementation
  ensure
    -- List of tagged boolean expressions for postconditions
  end
```

- The **precondition** *require* clause may be omitted:
 - There's no precondition: any starting state is acceptable.
 - The precondition is equivalent to writing `require true`
- The **postcondition** *ensure* clause may be omitted:
 - There's no postcondition: any resulting state is acceptable.
 - The postcondition is equivalent to writing `ensure true`

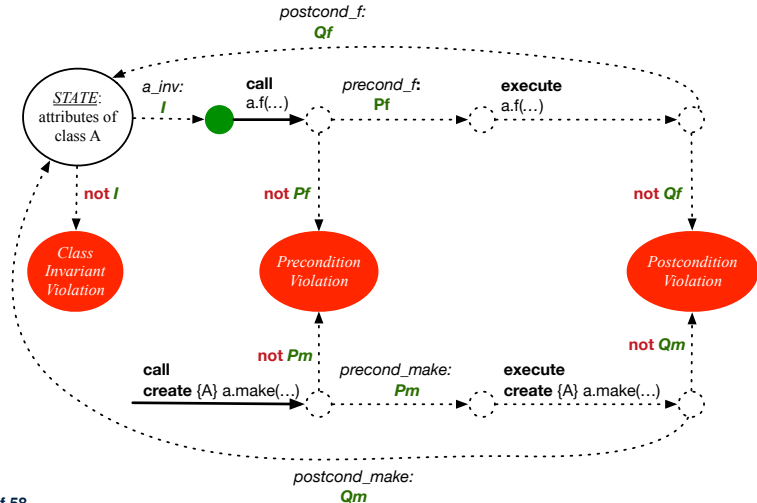
Runtime Monitoring of Contracts (1)

In the specific case of `ACCOUNT` class with creation procedure `make` and command `withdraw`:



Runtime Monitoring of Contracts (2)

In general, class C with creation procedure cp and any feature f :



Runtime Monitoring of Contracts (3)

- All **contracts** are specified as **Boolean expressions**.
- Right **before** a feature call (e.g., `acc.withdraw(10)`):
 - The current state of `acc` is called the **pre-state**.
 - Evaluate feature `withdraw`'s **pre-condition** using current values of attributes and queries.
 - **Cache** values (**implicitly**) of all expressions involving the **old** keyword in the **post-condition**.
e.g., cache the value of **old balance** via `old_balance := balance`
- Right **after** the feature call:
 - The current state of `acc` is called the **post-state**.
 - Evaluate class `ACCOUNT`'s **invariant** using current values of attributes and queries.
 - Evaluate feature `withdraw`'s **post-condition** using both current and **"cached"** values of attributes and queries.

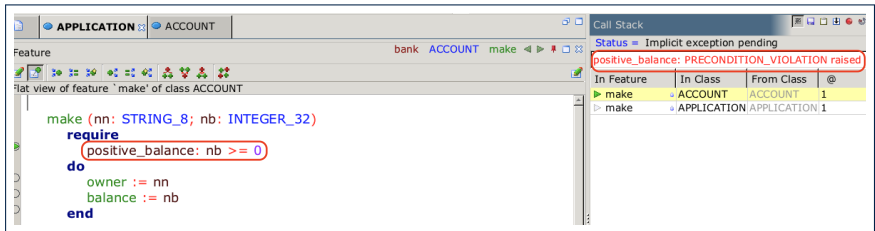
DbC in Eiffel: Precondition Violation (1.1)

The **client** need not handle all possible contract violations:

```
class BANK_APP
inherit
  ARGUMENTS
create
  make
feature -- Initialization
  make
    -- Run application.
local
  alan: ACCOUNT
do
  -- A precondition violation with tag "positive_balance"
  create {ACCOUNT} alan.make ("Alan", -10)
end
end
```

By executing the above code, the runtime monitor of Eiffel Studio will report a **contract violation** (precondition violation with tag "positive_balance").

DbC in Eiffel: Precondition Violation (1.2)



Feature bank ACCOUNT make

Flat view of feature 'make' of class ACCOUNT

```
make (nn: STRING_8; nb: INTEGER_32)
  require
    positive_balance: nb >= 0
  do
    owner := nn
    balance := nb
  end
```

Call Stack

Status = Implicit exception pending

positive_balance: PRECONDITION_VIOLATION raised

In Feature	In Class	From Class	@
▶ make	ACCOUNT	ACCOUNT	1
▶ make	APPLICATION	APPLICATION	1

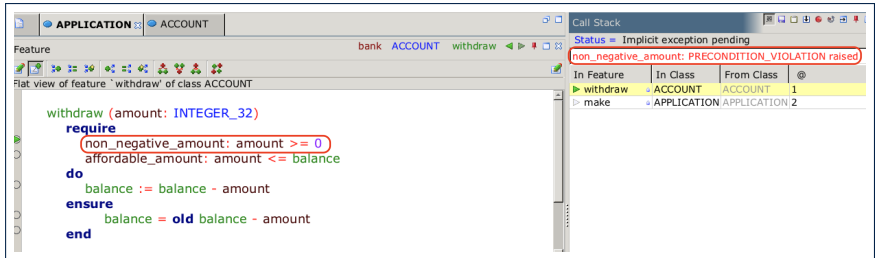
DbC in Eiffel: Precondition Violation (2.1)

The **client** need not handle all possible contract violations:

```
class BANK_APP
inherit
  ARGUMENTS
create
  make
feature -- Initialization
  make
    -- Run application.
local
  mark: ACCOUNT
do
  create {ACCOUNT} mark.make ("Mark", 100)
  -- A precondition violation with tag "non_negative_amount"
  mark.withdraw(-1000000)
end
end
```

By executing the above code, the runtime monitor of Eiffel Studio will report a **contract violation** (precondition violation with tag "non_negative_amount").

DbC in Eiffel: Precondition Violation (2.2)



APPLICATION ACCOUNT

Feature bank ACCOUNT withdraw

Flat view of feature 'withdraw' of class ACCOUNT

```
withdraw (amount: INTEGER_32)
  require
    non_negative_amount: amount >= 0
    affordable_amount: amount <= balance
  do
    balance := balance - amount
  ensure
    balance = old balance - amount
end
```

Call Stack

Status = Implicit exception pending

non_negative_amount: PRECONDITION_VIOLATION raised

In Feature	In Class	From Class	@
withdraw	ACCOUNT	ACCOUNT	1
make	APPLICATION	APPLICATION	2

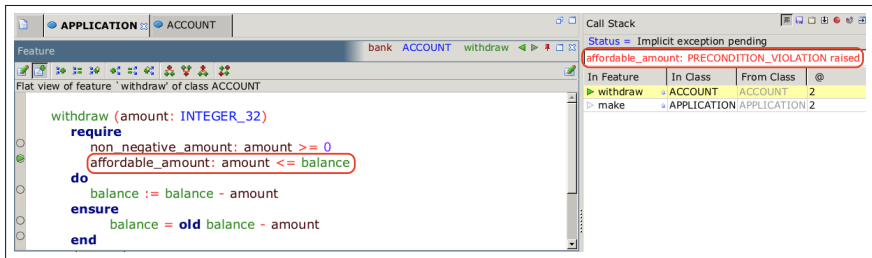
DbC in Eiffel: Precondition Violation (3.1)

The **client** need not handle all possible contract violations:

```
class BANK_APP
inherit
  ARGUMENTS
create
  make
feature -- Initialization
  make
    -- Run application.
local
  tom: ACCOUNT
do
  create {ACCOUNT} tom.make ("Tom", 100)
  -- A precondition violation with tag "affordable_amount"
  tom.withdraw(150)
end
end
```

By executing the above code, the runtime monitor of Eiffel Studio will report a **contract violation** (precondition violation with tag "affordable_amount").

DbC in Eiffel: Precondition Violation (3.2)



APPLICATION ACCOUNT

Feature bank ACCOUNT withdraw

Flat view of feature 'withdraw' of class ACCOUNT

```
withdraw (amount: INTEGER_32)
  require
    non_negative_amount: amount >= 0
    affordable_amount: amount <= balance
  do
    balance := balance - amount
  ensure
    balance = old balance - amount
  end
```

Call Stack

Status = Implicit exception pending

affordable_amount: PRECONDITION_VIOLATION raised

In Feature	In Class	From Class	@
withdraw	ACCOUNT	ACCOUNT	2
make	APPLICATION	APPLICATION	2

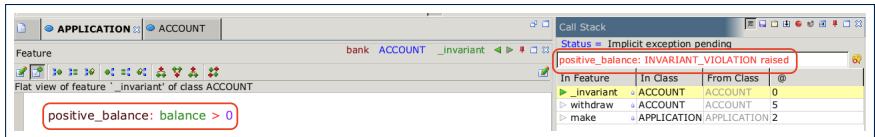
DbC in Eiffel: Class Invariant Violation (4.1)

The **client** need not handle all possible contract violations:

```
class BANK_APP
inherit
  ARGUMENTS
create
  make
feature -- Initialization
  make
    -- Run application.
local
  jim: ACCOUNT
do
  create {ACCOUNT} tom.make ("Jim", 100)
  jim.withdraw(100)
  -- A class invariant violation with tag "positive_balance"
end
end
```

By executing the above code, the runtime monitor of Eiffel Studio will report a **contract violation** (class invariant violation with tag "positive_balance").

DbC in Eiffel: Class Invariant Violation (4.2)



APPLICATION ACCOUNT

Feature bank ACCOUNT _invariant

Flat view of feature '_invariant' of class ACCOUNT

positive_balance: balance > 0

Call Stack

Status = Implicit exception pending

positive_balance: INVARIANT_VIOLATION raised

In Feature	In Class	From Class	@
▶ _invariant	ACCOUNT	ACCOUNT	0
▶ withdraw	ACCOUNT	ACCOUNT	5
▶ make	APPLICATION	APPLICATION	2

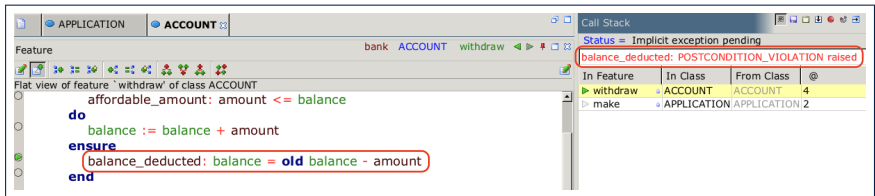
DbC in Eiffel: Postcondition Violation (5.1)

The **client** need not handle all possible contract violations:

```
class BANK_APP
inherit ARGUMENTS
create make
feature -- Initialization
    make
        -- Run application.
    local
        jeremy: ACCOUNT
    do
        -- Faulty implementation of withdraw in ACCOUNT:
        -- balance := balance + amount
        create {ACCOUNT} jeremy.make ("Jeremy", 100)
        jeremy.withdraw(150)
        -- A postcondition violation with tag "balance_deducted"
    end
end
```

By executing the above code, the runtime monitor of Eiffel Studio will report a **contract violation** (postcondition violation with tag "balance_deducted").

DbC in Eiffel: Postcondition Violation (5.2)



The screenshot displays the Eiffel IDE interface. The main editor shows the flat view of the 'withdraw' feature of the 'ACCOUNT' class. The code includes a precondition, a 'do' block, and an 'ensure' block. A red circle highlights the postcondition: `balance_deducted: balance = old balance - amount`. The 'Call Stack' window on the right shows the current status as 'Implicit exception pending' and a message: 'balance_deducted: POSTCONDITION_VIOLATION raised'. Below this, a table lists the call stack entries.

In Feature	In Class	From Class	@
▶ withdraw	ACCOUNT	ACCOUNT	4
▶ make	APPLICATION	APPLICATION	2

Index (1)

- Motivation: Catching Defects – Design or Implementation Phase?**
- What This Course Is About**
- Terminology: Contract, Client, Supplier**
- Client, Supplier, Contract in OOP (1)**
- Client, Supplier, Contract in OOP (2)**
- What is a Good Design?**
- A Simple Problem: Bank Accounts**
- Playing with the Various Versions in Java**
- Version 1: An Account Class**
- Version 1: Why Not a Good Design? (1)**
- Version 1: Why Not a Good Design? (2)**
- Version 1: Why Not a Good Design? (3)**
- Version 1: How Should We Improve it? (1)**

Index (2)

Version 1: How Should We Improve it? (2)

**Version 2: Added Exceptions
to Approximate Method Preconditions**

Version 2: Why Better than Version 1? (1)

Version 2: Why Better than Version 1? (2.1)

Version 2: Why Better than Version 1? (2.2)

Version 2: Why Better than Version 1? (3.1)

Version 2: Why Better than Version 1? (3.2)

Version 2: Why Still Not a Good Design? (1)

Version 2: Why Still Not a Good Design? (2.1)

Version 2: Why Still Not a Good Design? (2.2)

Version 2: How Should We Improve it?

**Version 3: Added Assertions
to Approximate Class Invariants**

Index (3)

- Version 3: Why Better than Version 2?
- Version 3: Why Still Not a Good Design?
- Version 4: What If the
Implementation of `withdraw` is Wrong? (1)
- Version 4: What If the
Implementation of `withdraw` is Wrong? (2)
- Version 4: How Should We Improve it?
- Version 5: Added Assertions
to Approximate Method Postconditions
- Version 5: Why Better than Version 4?
- Evolving from Version 1 to Version 5
- Version 5:
Contract between Client and Supplier
- DbC in Java
- DbC in Eiffel: Supplier

Index (4)

DbC in Eiffel: Contract View of Supplier

DbC in Eiffel: Anatomy of a Class

DbC in Eiffel: Anatomy of a Feature

Runtime Monitoring of Contracts (1)

Runtime Monitoring of Contracts (2)

Runtime Monitoring of Contracts (3)

DbC in Eiffel: Precondition Violation (1.1)

DbC in Eiffel: Precondition Violation (1.2)

DbC in Eiffel: Precondition Violation (2.1)

DbC in Eiffel: Precondition Violation (2.2)

DbC in Eiffel: Precondition Violation (3.1)

DbC in Eiffel: Precondition Violation (3.2)

DbC in Eiffel: Class Invariant Violation (4.1)

DbC in Eiffel: Class Invariant Violation (4.2)

Index (5)

DbC in Eiffel: Postcondition Violation (5.1)

DbC in Eiffel: Postcondition Violation (5.2)