Design-by-Contract (DbC)

Readings: OOSC2 Chapters 6, 7, 8, 11

EECS3311 A & E: Software Design
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Learning Objectives

Upon completing this lecture, you are expected to understand:

1. *Design by Contract* (*DbC*): Motivation & Terminology
2. Supporting *DbC* (Java vs. Eiffel):
   Preconditions, *Postconditions*, *Class Invariants*
3. *Runtime Assertion Checking* of Contracts

Part 1

Design by Contract (DbC): Motivation & Terminology

Motivation: Catching Defects – When?

- To minimize *development costs*, minimize *software defects*.
- Software Development Cycle:

  Requirements → *Design* → *Implementation* → Release

  Q. Design or Implementation Phase?

  Catch defects *as early as possible*.

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

  ∵ The cost of fixing defects *increases exponentially* as software progresses through the development lifecycle.

- 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: IBM Report

What this Course Is About (1)

Design

Abstract Data types (ADTs)
Cohesion Principle
Single Choice Principle
Open-Closed Principle
Design Document
Justified Design Decisions

Architecture: Client-Supplier Relation
Architecture: Inheritance Relation
Program to Interface,
Not to Implementation
Modularity: Classes
Design Patterns
(Iterator, Singleton, State, Template,
Composite, Visitor, Strategy,
Observer, Event-Driven Design)
Anti-Patterns

Design by Contract (DbC):
Class Invariant, Pre-/Post-condition
Information Hiding Principle
Eiffel Testing Framework (ETF)
Abstraction (via Mathematical Models)
Regression Testing
Acceptance Testing
Void Safety
Generics
Multiple Inheritance
Sub-Contracting
Architectural Design Diagrams

Eiffel

Syntax: Implementation vs. Specification
agent expression, **across** constructs
expanded types, **export** status
Runtime Contract Checking
Debugger

Specification: ***Predicates***
Contracts of Loops: Invariant & Variant
Program Correctness
Weakest Precondition (**WP**)
Hoare Triples
Specification: Higher-Order Functions

Code Reuse via Inheritance
Substitutibility
Polymorphism (esp. ***Polymorphic Collections***)
Type Casting
Static Typing, Dynamic Binding
Unit Testing

OOP

Axioms, Lemmas, Theorems
Equational Proofs
Proof by Contradiction (*witness*)

Logic

What this Course Is About (2)

- 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 is 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* os the two parties?

	benefits	*obligations*
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 call 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)*.

Part 2.1

Supporting DbC in Java: Problem & 1st Attempt (No Contracts)

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 Java project archive (a zip file) here:

  `https://www.eecs.yorku.ca/~jackie/teaching/lectures/2020/F/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`

V1: An Account Class

```
public class AccountV1 {
      private String owner;
      private int balance;
      public String getOwner() { return owner; }
      public int getBalance() { return balance; }
      public AccountV1(String owner, int balance) {
            this.owner = owner; this.balance = balance;
      }
      public void withdraw(int amount) {
            this.balance = this.balance - amount;
      }
      public String toString() {
            return owner + "'s current balance is: " + balance;
      }
}
```

- 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.

V1: 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

V1: 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 $\boxed{\textbf{REQ2}}$
- Again a lack of contract between `BankAppV1` and `AccountV1`.

V1: Why Not a Good Design? (3)

```java
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`.

Part 2.2

Supporting DbC in Java:

2nd Attempt (Method Preconditions)

V1: 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 != 0`]
- Precond. of `binSearch(int x, int[] xs)`? [`xs` is sorted]
- Precond. of `topoSort(Graph g)`? [`g` is a DAG]

V1: 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 V2 by adding *exceptional conditions* (an *approximation* of *preconditions*) to the constructor and `withdraw` method of the `Account` class.

V2: Preconditions ≈ Exceptions

```
public class AccountV2 {
  public AccountV2(String owner, int balance) throws
      BalanceNegativeException
  {
    if( balance < 0 ) { /* negated precondition */
      throw new BalanceNegativeException(); }
    else { this.owner = owner; this.balance = balance; }
  }
  public void withdraw(int amount) throws
      WithdrawAmountNegativeException, WithdrawAmountTooLargeException {
    if( amount < 0 ) { /* negated precondition */
      throw new WithdrawAmountNegativeException(); }
    else if ( balance < amount ) { /* negated precondition */
      throw new WithdrawAmountTooLargeException(); }
    else { this.balance = this.balance - amount; }
  }
```

V2: Why Better than V1? (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*.

V2: Why Better than V1? (2.1)

```java
public class BankAppV2 {
  public static void main(String[] args) {
    System.out.println("Create an account for Mark with balance 100:");
    try {
      AccountV2 mark = new AccountV2("Mark", 100);
      System.out.println(mark);
      System.out.println("Withdraw -1000000 from Mark's account:");
      mark.withdraw(-1000000);
      System.out.println(mark);
    }
    catch (BalanceNegativeException bne) {
      System.out.println("Illegal negative account balance.");
    }
    catch (WithdrawAmountNegativeException wane) {
      System.out.println("Illegal negative withdraw amount.");
    }
    catch (WithdrawAmountTooLargeException wane) {
      System.out.println("Illegal too large withdraw amount.");
    }
```

V2: Why Better than V1? (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.
```

- **L8**: 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 *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!!

V2: Why Better than V1? (3.1)

```
public class BankAppV2 {
  public static void main(String[] args) {
    System.out.println("Create an account for Tom with balance 100:");
    try {
      AccountV2 tom = new AccountV2("Tom", 100);
      System.out.println(tom);
      System.out.println("Withdraw 150 from Tom's account:");
      tom.withdraw(150);
      System.out.println(tom);
    }
    catch (BalanceNegativeException bne) {
      System.out.println("Illegal negative account balance.");
    }
    catch (WithdrawAmountNegativeException wane) {
      System.out.println("Illegal negative withdraw amount.");
    }
    catch (WithdrawAmountTooLargeException wane) {
      System.out.println("Illegal too large withdraw amount.");
    }
```

V2: Why Better than V1? (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.
```

- **L8**: 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 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!!

V2: Why Still Not a Good Design? (1)

```
public class AccountV2 {
  public AccountV2(String owner, int balance) throws
      BalanceNegativeException
  {
    if( balance < 0 ) { /* negated precondition */
      throw new BalanceNegativeException(); }
    else { this.owner = owner; this.balance = balance; }
  }
  public void withdraw(int amount) throws
      WithdrawAmountNegativeException, WithdrawAmountTooLargeException {
    if( amount < 0 ) { /* negated precondition */
      throw new WithdrawAmountNegativeException(); }
    else if ( balance < amount ) { /* negated precondition */
      throw new WithdrawAmountTooLargeException(); }
    else { this.balance = this.balance - amount; }
  }
```

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

V2: Why Still Not a Good Design? (2.1)

```java
public class BankAppV2 {
  public static void main(String[] args) {
    System.out.println("Create an account for Jim with balance 100:");
    try {
      AccountV2 jim = new AccountV2("Jim", 100);
      System.out.println(jim);
      System.out.println("Withdraw 100 from Jim’s account:");
      jim. withdraw(100) ;
      System.out.println(jim);
    }
    catch (BalanceNegativeException bne) {
      System.out.println("Illegal negative account balance.");
    }
    catch (WithdrawAmountNegativeException wane) {
      System.out.println("Illegal negative withdraw amount.");
    }
    catch (WithdrawAmountTooLargeException wane) {
      System.out.println("Illegal too large withdraw amount.");
    }
```

V2: 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**).
- ∴ **L13** of `AccountV2` should be `balance <= amount`.

Part 2.3

Supporting DbC in Java:
3^{rd} Attempt (Class Invariants)

V2: 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 `CSMajoarStudent`? [`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 $\boxed{\text{V3}}$ by adding *assertions* to the end of constructor and `withdraw` method of the `Account` class.

V3: Class Invariants ≈ Assertions

```java
public class AccountV3 {
  public AccountV3(String owner, int balance) throws
      BalanceNegativeException
  {
    if(balance < 0) { /* negated precondition */
      throw new BalanceNegativeException(); }
    else { this.owner = owner; this.balance = balance; }
    assert this.getBalance() > 0 : "Invariant:  positive balance";
  }
  public void withdraw(int amount) throws
      WithdrawAmountNegativeException, WithdrawAmountTooLargeException {
    if(amount < 0) { /* negated precondition */
      throw new WithdrawAmountNegativeException(); }
    else if (balance < amount) { /* negated precondition */
      throw new WithdrawAmountTooLargeException(); }
    else { this.balance = this.balance - amount; }
    assert this.getBalance() > 0 : "Invariant:  positive balance";
  }
```

V3: Why Better than V2?

```
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            * V2: 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*.

V3: Why Still Not a Good Design?

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

- From V2: *exceptions* encoding **negated** *preconditions*
- From V3: *assertions* encoding the *class invariants*

```java
public class AccountV3 {
  public void withdraw(int amount) throws
     WithdrawAmountNegativeException, WithdrawAmountTooLargeException {
    if( amount < 0 ) { /* negated precondition */
      throw new WithdrawAmountNegativeException(); }
    else if ( balance < amount ) { /* negated precondition */
      throw new WithdrawAmountTooLargeException(); }
    else { this.balance = this.balance - amount; }
    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 V4, where deliberately mistakenly implement `withdraw`.

Supporting DbC in Java:
4^{th} Attempt (Faulty Implementation)

V4: `withdraw` implemented incorrectly? (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 { /* WRONT 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*.

V4: `withdraw` implemented incorrectly? (2)

```java
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      * V2: 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. ⇒ Violation of **REQ2**

Part 2.5

Supporting DbC in Java:
5th Attempt (Method Postconditions)

V4: 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)`?

    $$[\ \textbf{Result} \times y == x\ ]$$

  - Postcondition of `boolean binSearch(int x, int[] xs)`?

    $$[\ x \in xs \iff \textbf{Result}\ ]$$

- 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 $\boxed{\text{V5}}$ by adding *assertions* to the end of `withdraw` method of the `Account` class.

V5: Postconditions ≈ Assertions

```
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**.

V5: Why Better than V4?

```
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            * V2: 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*.

Part 2.6

Supporting DbC:
Java vs. Eiffel

Evolving from V1 to V5

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

- 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.

V5: Contract between Client and Supplier

	benefits	*obligations*
`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

	benefits	*obligations*
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 Command

```
some_command (x: SOME_TYPE_1; y: SOME_TYPE_2)
   -- 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***

DbC in Eiffel: Anatomy of a Query

```
some_query (x: SOME_TYPE_1; y: SOME_TYPE_2): SOME_RT
    -- Description of the query.
  require
    -- List of tagged boolean expressions for preconditions
  local
    -- List of local variable declarations
  do
    -- List of instructions as implementation
   Result := ...
  ensure
    -- List of tagged boolean expressions for postconditions
  end
```

- Each query has a predefined variable **`Result`**.
- Implicitly, you may think of:
  - First line of the query declares `Result: SOME_RT`
  - Last line of the query return the value of **`Result`**.

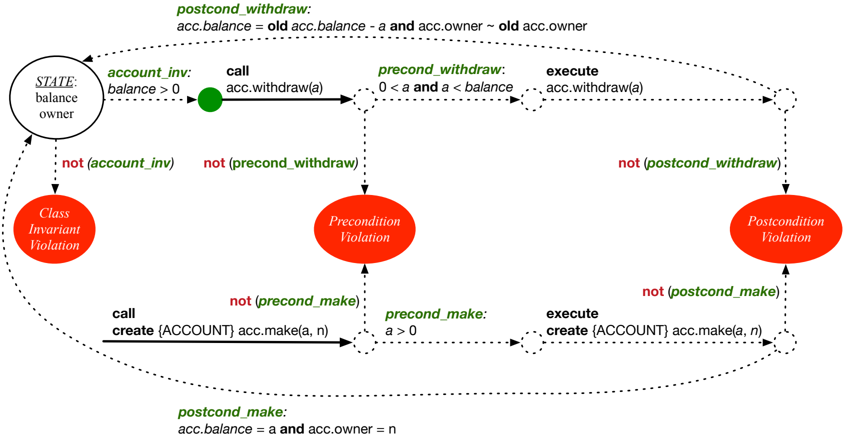
    ⇒ Manipulate **`Result`** so that its last value is the desired result.

Part 3

DbC in Eiffel: Runtime Checking

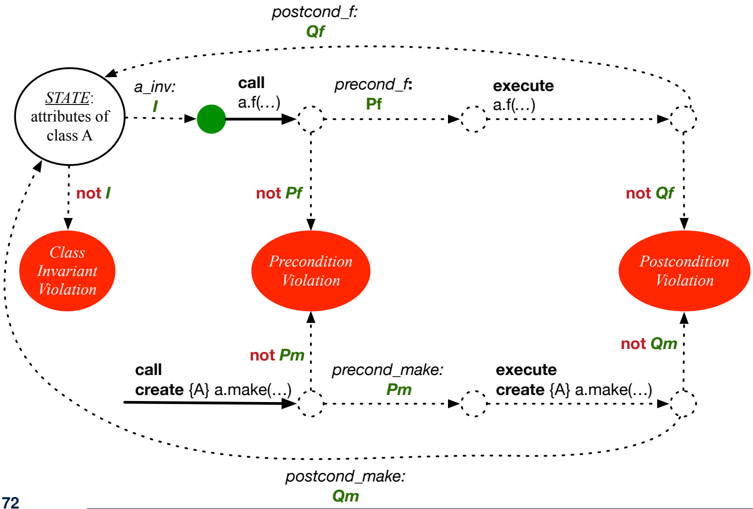
Runtime Monitoring of Contracts (1)

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 $\boxed{\text{before}}$ 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 $\boxed{old\_balance := balance}$
- Right $\boxed{\text{after}}$ 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.

Experimenting Contract Violations in Eiffel

- **Download** the Eiffel project archive (a zip file) here:

  `https://www.eecs.yorku.ca/~jackie/teaching/lectures/2020/F/EECS3311/codes/DbCIntroEiffel.zip`

- Unzip and compile the project in Eiffel Studio.
- Follow the in-code comments to re-produce the various ***contract violations*** and understand from the ***stack trace*** how they occur.

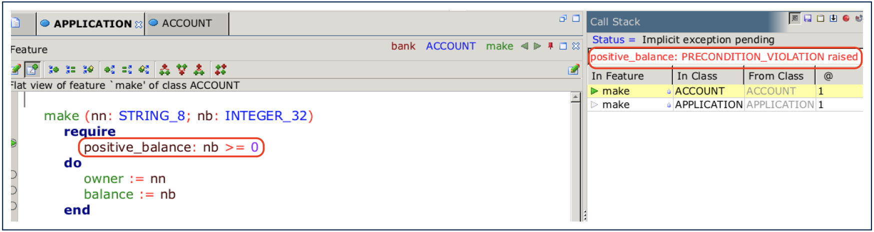
DbC in Eiffel: Precondition Violation (1.1)

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)



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

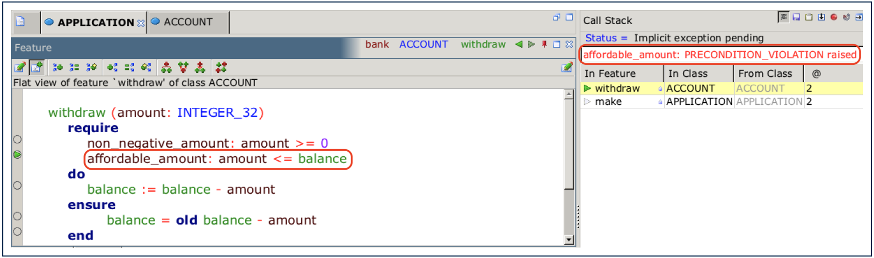
DbC in Eiffel: Precondition Violation (3.1)

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)



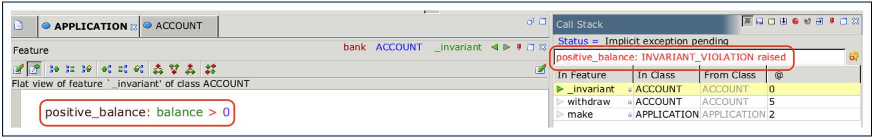
DbC in Eiffel: Class Invariant Violation (4.1)

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)



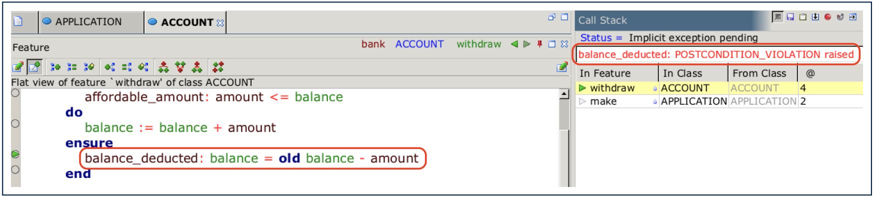
DbC in Eiffel: Postcondition Violation (5.1)

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)



Beyond this lecture...

1. Review your Lab0 tutorial about how DbC is supported in Eiffel.
2. Explore in Eclipse how *contract* checks are *manually-coded*:

   `https://www.eecs.yorku.ca/~jackie/teaching/lectures/2020/F/EECS3311/codes/DbCIntro.zip`
3. Recall the 4th requirement of the bank problem (see here):

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

   Design the header of this `add` method, implement it, and encode proper pre-condition and ***post-condition*** for it.

   Q. What postcondition can you think of? Does it require any skill from EECS1090? What attribute value(s) do you need to manually store in the ***pre-state***?
4. 3 short courses which will help your labs and project:
   - Eiffel Syntax: here.
   - Common Syntax/Type Errors in Eiffel: here.
   - Drawing Design Diagrams: here.

Index (1)

Index (2)

Index (3)

Index (4)

Index (5)

Index (6)