Design-by-Contract (Dbc)
Test-Driven Development (TDD)

Readings: OOSC2 Chapter 11

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Terminology: Contract, Client, Supplier

- A *supplier* implements/provides a service (e.g., microwave).
- A *client* uses a service provided by some supplier.
  - The client must 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 required (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	give instructions	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/src/2017/F/EECS3311/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

```java
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.

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?

- *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]
- 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.
  - It should be preferred to design your method by specifying the *preconditions* (i.e., *valid* inputs) it requires, rather than the *exceptions* (i.e., *erroneous* inputs) that it might trigger.
- 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

```
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; }
  }
```

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     }
```

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     }
```

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)

```
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 (¬ *preconditions*) appropriate?
- What if `amount == balance` when calling `withdraw`?

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

```
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.");
    }
```

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**).
- ∴ **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 `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 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

```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";
  }
```

Version 3: Why Better than Version 2?

```java
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? (1)

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*

```
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 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 { /* 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*.

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: The resulting balance of Jeremy is valid (150), but withdrawal was done via an *mistaken* increase. ⇒ 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 `divide(int x, int y)`?

    [**Result** $\times$ $y == x$]
  - Postcondition of `binarySearch(int x, int[] xs)`?

    [$x \in xs \Rightarrow$ **Result** $== x$]
- 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 textttwithdraw 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

	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*	Incorrect implementations do not necessarily result in a state that violates the class invariants.
V4	Deliberately changed `withdraw`'s implementation to be **incorrect**.	The incorrect implementation does not 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.

Version 5: 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
            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
            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

- 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.

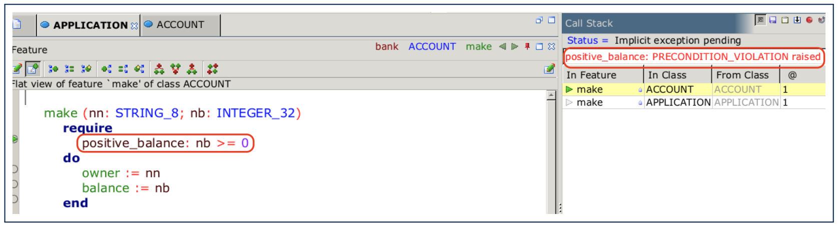
DbC in Eiffel: Precondition Violation (1.1)

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)



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
```

Status = Implicit exception pending

positive_balance: PRECONDITION_VIOLATION raised

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

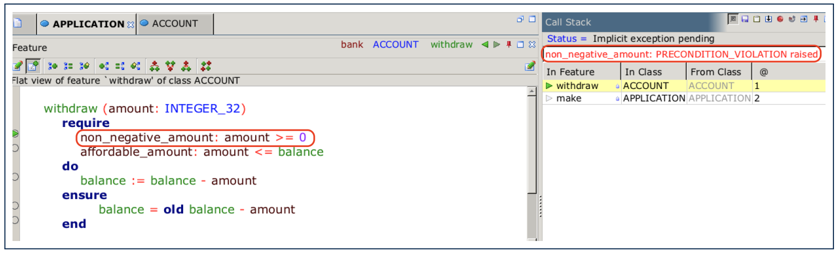
DbC in Eiffel: Precondition Violation (2.1)

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
    -- A precondition violation with tag "non_negative_amount"
    create {ACCOUNT} mark.make ("Mark", 100)
    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)



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
```

Status = Implicit exception pending

non_negative_amount: PRECONDITION_VIOLATION raised

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

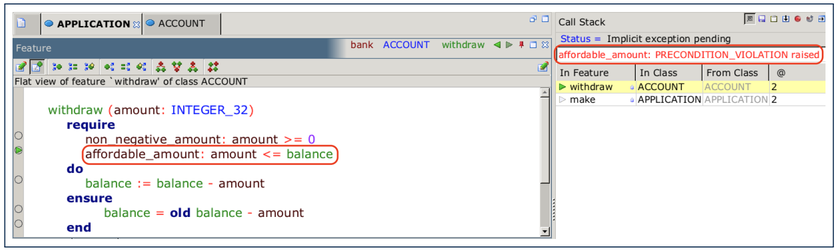
DbC in Eiffel: Precondition Violation (3.1)

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
    -- A precondition violation with tag "affordable_amount"
    create {ACCOUNT} tom.make ("Tom", 100)
    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)



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
```

Status = Implicit exception pending

affordable_amount: PRECONDITION_VIOLATION raised

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

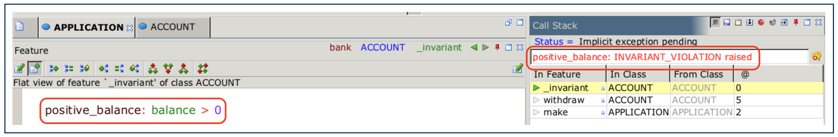
DbC in Eiffel: Class Invariant Violation (4.1)

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
    -- A class invariant violation with tag "positive_balance"
    create {ACCOUNT} tom.make ("Jim", 100)
    jim.withdraw(100)
  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)



Flat view of feature `_invariant' of class ACCOUNT

```
positive_balance: balance > 0
```

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

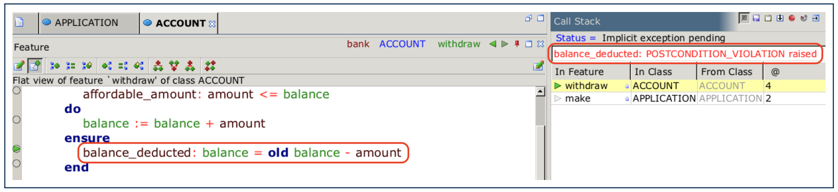
DbC in Eiffel: Class Invariant Violation (5.1)

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
    -- Change withdraw in ACCOUNT to: balance := balance + amount
    -- A postcondition violation with tag "balance_deducted"
    create {ACCOUNT} jeremy.make ("Jeremy", 100)
    jeremy.withdraw(150)
    -- Change withdraw in ACCOUNT back to: balance := balance - amount
  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: Class Invariant Violation (5.2)



Flat view of feature `withdraw' of class ACCOUNT

```
      affordable_amount: amount <= balance
    do
      balance := balance + amount
    ensure
      balance_deducted: balance = old balance - amount
    end
```

Status = Implicit exception pending

balance_deducted: POSTCONDITION_VIOLATION raised

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

TDD: Test-Driven Development (1)

- How we have tested the software so far:
  - Executed each test case **manually** (by clicking `Run` in EStudio).
  - Compared **with our eyes** if ***actual results*** (produced by program) match ***expected results*** (according to requirements).
- Software is subject to numerous revisions before delivery.

  ⇒ Testing manually, repetitively, is tedious and error-prone.

  ⇒ We need *automation* in order to be cost-effective.
- *Test-Driven Development*
  - **Test Case**: Expected ***working*** scenario (**expected** outcome) or ***problematic*** scenario (**expected** contract violation).
  - As soon as your code becomes *executable* (with **a unit of functionality** completed), start translating relevant test cases into an executable form and execute them.
  - **Test Suite**: Collection of test cases.

    ⇒ A test suite is supposed to measure "correctness" of software.

    ⇒ The larger the suite, the more confident you are.

TDD: Test-Driven Development (2)

- The *ESpec* (Eiffel Specification) library is a framework for:
  - Writing and accumulating ***test cases***

    Each list of *relevant test cases* is grouped into an `ES_TEST` class, which is just an Eiffel class that you can execute upon.
  - Executing the ***test suite*** whenever software undergoes a change

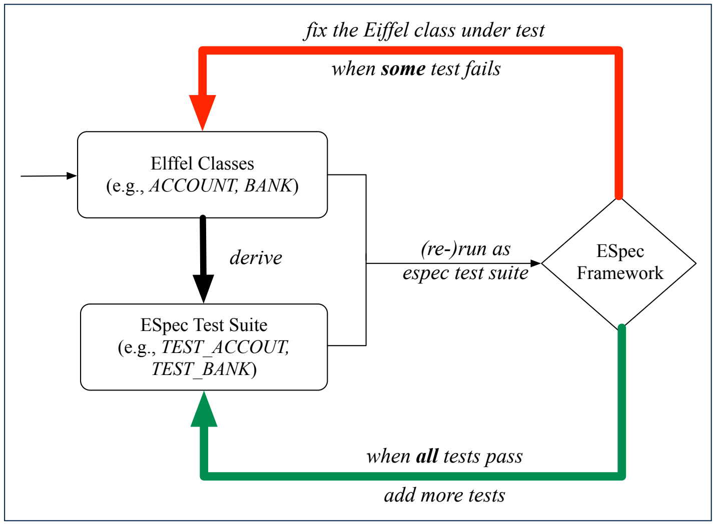
    e.g., a bug fix

    e.g., extension of a new functionality
- ESpec tests are *helpful client* of your classes, which may:
  - Either attempt to use a feature in a ***legal*** way (i.e., ***satisfying*** its precondition), and report:
    - ***Success*** if the result is as expected
    - ***Failure*** if the result is ***not*** as expected:

      e.g., state of object has not been updated properly

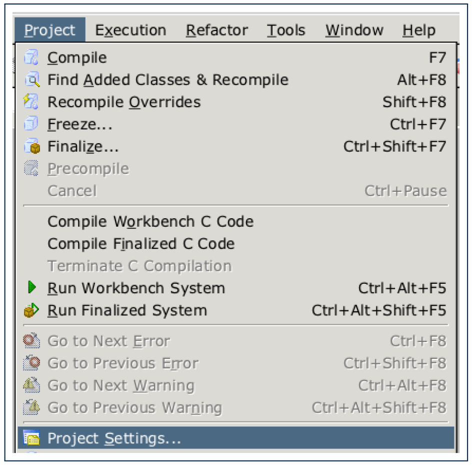
      e.g., a ***postcondition violation*** or ***class invariant violation*** occurs
  - Or attempt to use a feature in an ***illegal*** way (e.g., ***not satisfying*** its precondition), and report:
    - ***Success*** if precondition violation occurs.
    - ***Failure*** if precondition violation does ***not*** occur.

TDD: Test-Driven Development (3)



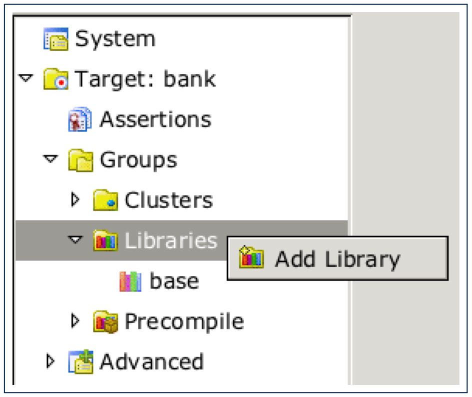
Adding the ESpec Library (1)

Step 1: Go to Project Settings.


Project
Execution
Refactor
Tools
Window
Help
Compile F7
Find Added Classes & Recompile Alt+F8
Recompile Overrides Shift+F8
Freeze... Ctrl+F7
Finalize... Ctrl+Shift+F7
Precompile
Cancel Ctrl+Pause
Compile Workbench C Code
Compile Finalized C Code
Terminate C Compilation
Run Workbench System Ctrl+Alt+F5
Run Finalized System Ctrl+Alt+Shift+F5
Go to Next Error Ctrl+F8
Go to Previous Error Ctrl+Shift+F8
Go to Next Warning Ctrl+Alt+F8
Go to Previous Warning Ctrl+Alt+Shift+F8
Project Settings...

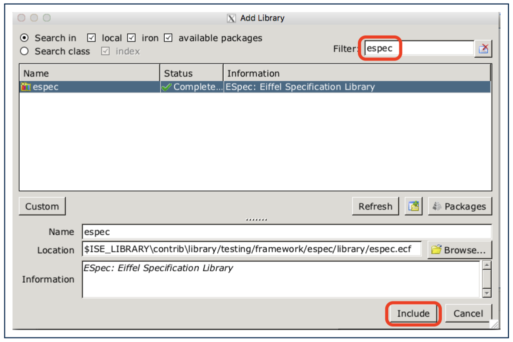
Adding the ESpec Library (2)

Step 2: Right click on `Libraries` to add a library.



Adding the ESpec Library (3)

Step 3: Search for `espec` and then include it.



● Search in ☑ local ☑ iron ☑ available packages
○ Search class ☑ index
Filter: espec

Name	Status	Information
espec	✓ Complete...	ESpec: Eiffel Specification Library

Name: espec
Location: $ISE_LIBRARY\contrib\library/testing/framework/espec/library/espec.ecf
Information: *ESpec: Eiffel Specification Library*

This will make two classes available to you:

- `ES_TEST` for adding test cases
- `ES_SUITE` for adding instances of `ES_TEST`.
  - To run, an instance of this class must be set as the `root`.

`ES_TEST`: Expecting to Succeed (1)

```
1  class TEST_ACCOUNT
2  inherit ES_TEST
3  create make
4  feature -- Add tests in constructor
5    make
6      do
7        add_boolean_case (agent test_valid_withdraw)
8      end
9  feature -- Tests
10   test_valid_withdraw: BOOLEAN
11     local
12       acc: ACCOUNT
13     do
14       comment("Test a valid withdrawal.")
15       create {ACCOUNT} acc.make ("Alan", 100)
16       Result := acc.balance = 100
17       check Result end
18       acc.withdraw (20)
19       Result := acc.balance = 80
20     end
21 end
```

`ES_TEST`: Expecting to Succeed (2)

- **L2**: A test class is a subclass of `ES_TEST`.
- **L10 – 20** define a `BOOLEAN` test *query*. At runtime:
  - ***Success***: Return value of `test_valid_withdraw` (final value of variable **`Result`**) evaluates to *true* upon its termination.
  - ***Failure***:
    - The return value evaluates to *false* upon termination; or
    - Some contract violation (which is *unexpected*) occurs.
- **L7** calls feature `add_boolean_case` from `ES_TEST`, which expects to take as input a *query* that returns a Boolean value.
  - We pass *query* `test_valid_withdraw` as an input.
  - Think of the keyword `agent` acts like a function pointer.
    - `test_invalid_withdraw` alone denotes its return value
    - **`agent`** `test_invalid_withdraw` denotes address of *query*
- **L14**: Each test feature ***must*** call **`comment(...)`** (inherited from `ES_TEST`) to include the description in test report.
- **L17**: Check that *each* intermediate value of `Result` is ***true***.

ES_TEST: Expecting to Succeed (3)

- Why is the `check Result end` statement at **L7** necessary?
  - When there are two or more *assertions* to make, some of which (except the last one) may ***temporarily falsify*** return value **Result**.
  - As long as the last *assertion* assigns ***true*** to **Result**, then the entire *test query* is considered as a ***success***.

    ⇒ A ***false positive*** is possible!
- For the sake of demonstrating a false positive, imagine:
  - Constructor `make` ***mistakenly*** deduces 20 from input amount.
  - Command `withdraw` ***mistakenly*** deducts nothing.

```
1  test_query_giving_false_positive: BOOLEAN
2    local acc: ACCOUNT
3    do comment("Result temporarily false, but finally true.")
4        create {ACCOUNT} acc.make ("Jim", 100) -- balance set as 80
5        Result := acc.balance = 100 -- Result assigned to false
6        acc.withdraw (20) -- balance not deducted
7        Result := acc.balance = 80 -- Result re-assigned to true
8        -- Upon termination, Result being true makes the test query
9        -- considered as a success ==> false positive!
10   end
```

Fix? [insert ***check Result end***] between **L6** and **L7**.

ES_TEST: Expecting to Fail (1)

```
1   class TEST_ACCOUNT
2   inherit ES_TEST
3   create make
4   feature -- Add tests in constructor
5     make
6       do
7         add_violation_case_with_tag (
8           "non_negative_amount", agent test_invalid_withdraw)
9       end
10  feature -- Tests
11    test_invalid_withdraw
12      local
13        acc: ACCOUNT
14      do
15        comment("Test an invalid withdrawal.")
16        create {ACCOUNT} acc.make ("Mark", 100)
17        -- Precondition Violation
18        -- with tag "non_negative_amount" is expected.
19        Result := acc.withdraw (-1000000)
20      end
21  end
```

ES_TEST: Expecting to Fail (2)

- **L2**: A test class is a subclass of `ES_TEST`.
- **L11 – 20** define a test *command*. At runtime:
  - ***Success***: A precondition violation (with tag `"non_negative_amount"`) occurs at **L19** before its termination.
  - ***Failure***:
    - No contract violation with the expected tag occurs before its termination; or
    - Some other contract violation (with a different tag) occurs.
- **L7** calls feature `add_violation_case_with_tag` from `ES_TEST`, which expects to take as input a *command*.
  - We pass *command* `test_invalid_withdraw` as an input.
  - Think of the keyword `agent` acts like a function pointer.
    - `test_invalid_withdraw` alone denotes a call to it
    - `agent test_invalid_withdraw` denotes address of *command*
- **L15**: Each test feature ***must*** call `comment(...)` (inherited from `ES_TEST`) to include the description in test report.

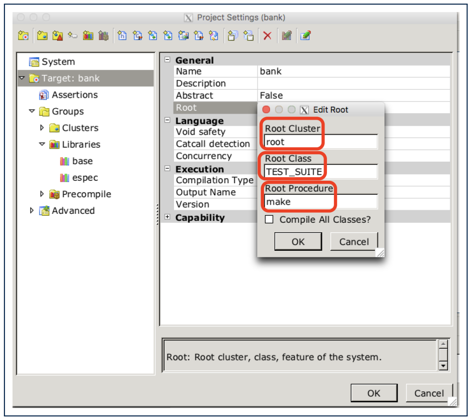
ES_SUITE: Collecting Test Classes

```
1   class TEST_SUITE
2   inherit ES_SUITE
3   create make
4   feature -- Constructor for adding test classes
5     make
6       do
7         add_test (create {TEST_ACCOUNT}.make)
8         show_browser
9         run_espec
10      end
11  end
```

- **L2**: A test suite is a subclass of `ES_SUITE`.
- **L7** passes an **anonymous** object of type `TEST_ACCOUNT` to `add_test` inherited from `ES_SUITE`).
- **L8 & L9** have to be entered in this order!

Running ES_SUITE (1)

Step 1: Change the *root class* (i.e., entry point of execution) to be TEST_SUITE.


Project Settings (bank)

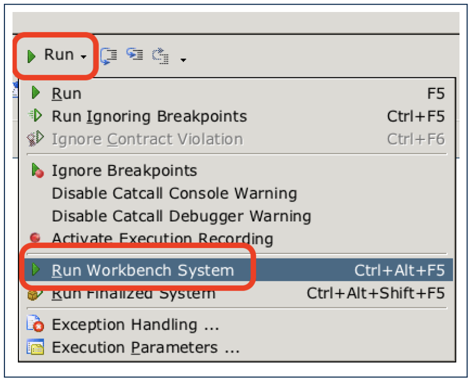
General
Name: bank
Description:
Abstract: False

Edit Root
Root Cluster: root
Root Class: TEST_SUITE
Root Procedure: make
□ Compile All Classes?

Root: Root cluster, class, feature of the system.

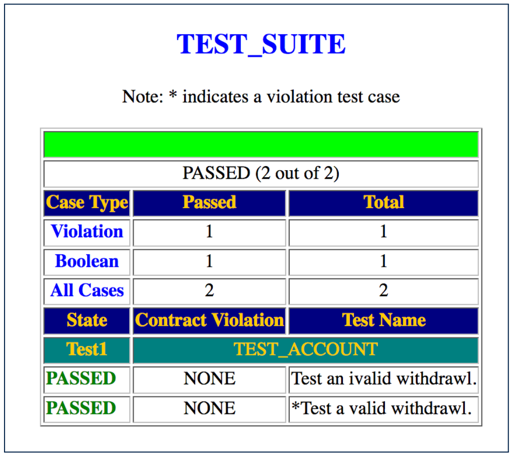
Running ES_SUITE (2)

Step 2: Run the **Workbench System**.


Run
Run F5
Run Ignoring Breakpoints Ctrl+F5
Ignore Contract Violation Ctrl+F6
Ignore Breakpoints
Disable Catcall Console Warning
Disable Catcall Debugger Warning
Activate Execution Recording
Run Workbench System Ctrl+Alt+F5
Run Finalized System Ctrl+Alt+Shift+F5
Exception Handling ...
Execution Parameters ...

Running ES_SUITE (3)

Step 3: See the generated test report.


TEST_SUITE

Note: * indicates a violation test case

PASSED (2 out of 2)		
Case Type	Passed	Total
Violation	1	1
Boolean	1	1
All Cases	2	2
State	Contract Violation	Test Name
Test1	TEST_ACCOUNT	
PASSED	NONE	Test an ivalid withdrawl.
PASSED	NONE	*Test a valid withdrawl.

Beyond this lecture...

- Study this tutorial series on DbC and TDD:
  https://www.youtube.com/playlist?list=PL5dxAmCmjv_6r5VfzCQ5bTznoDDgh__KS

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