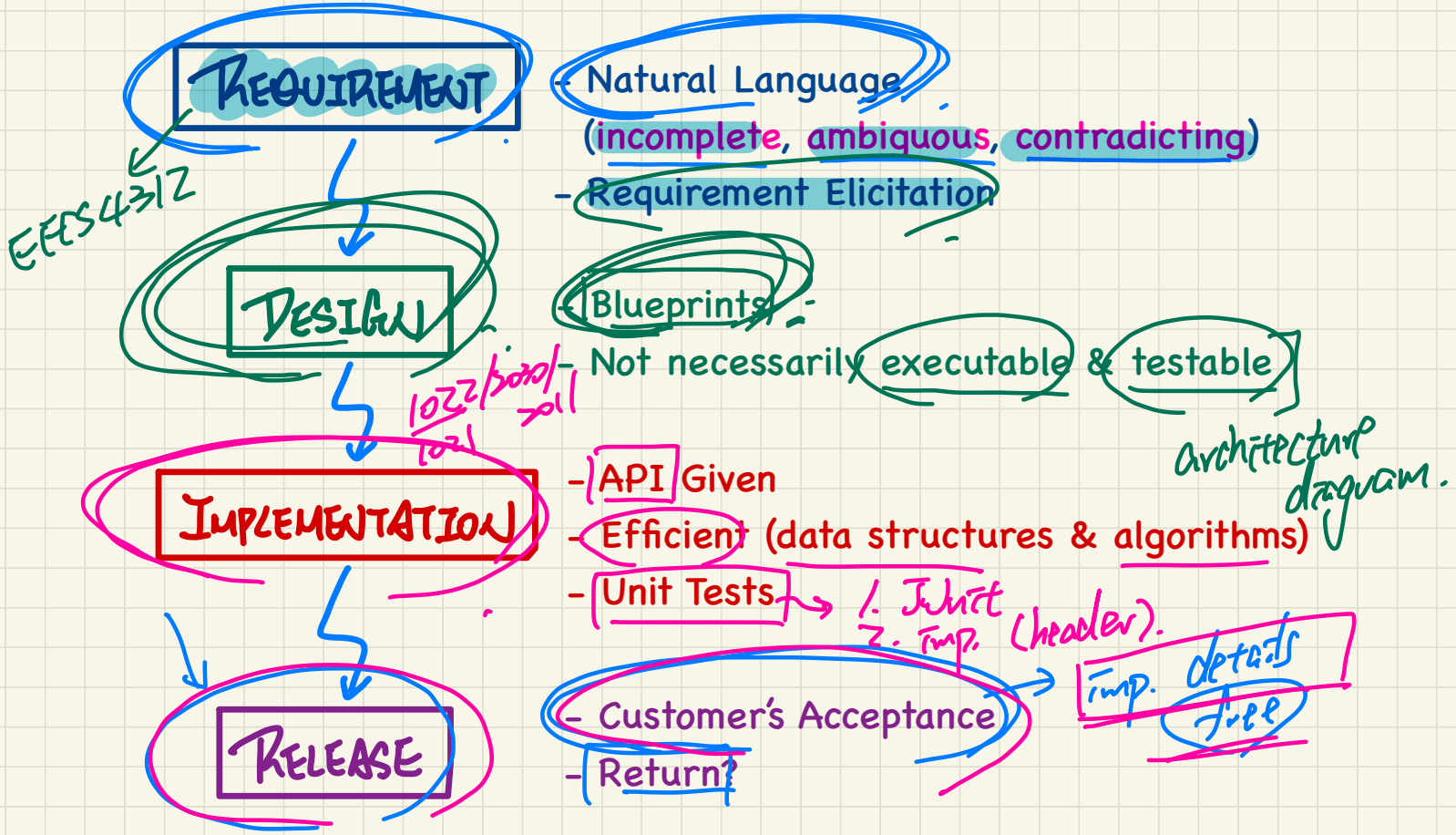
Lecture 1

Part 1

Design by Contract (DbC): Motivation & Terminology

Software Development Process



Informal Requirements

Incompleteness, Ambiguities, Contradictions

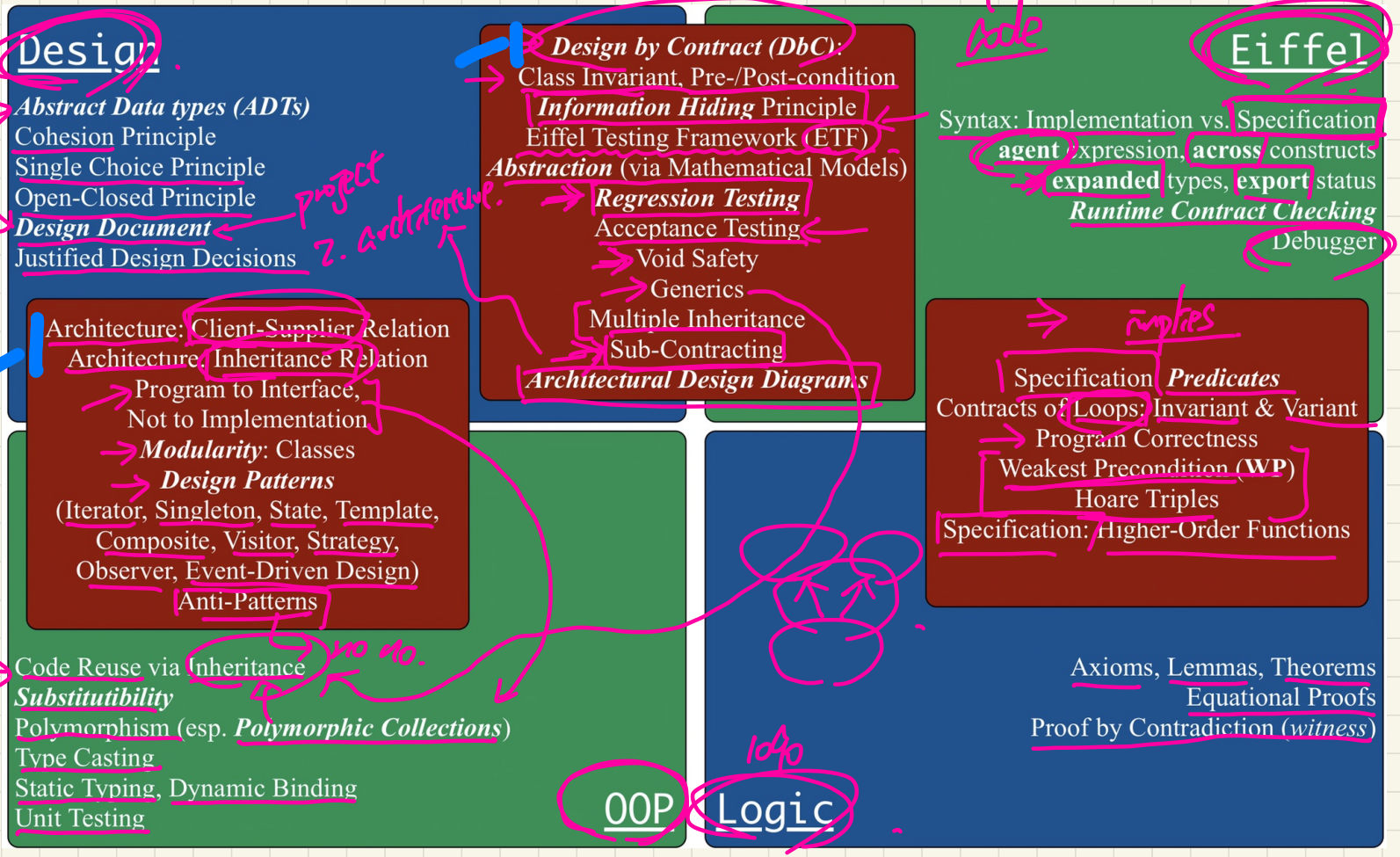
mobile web desktop.

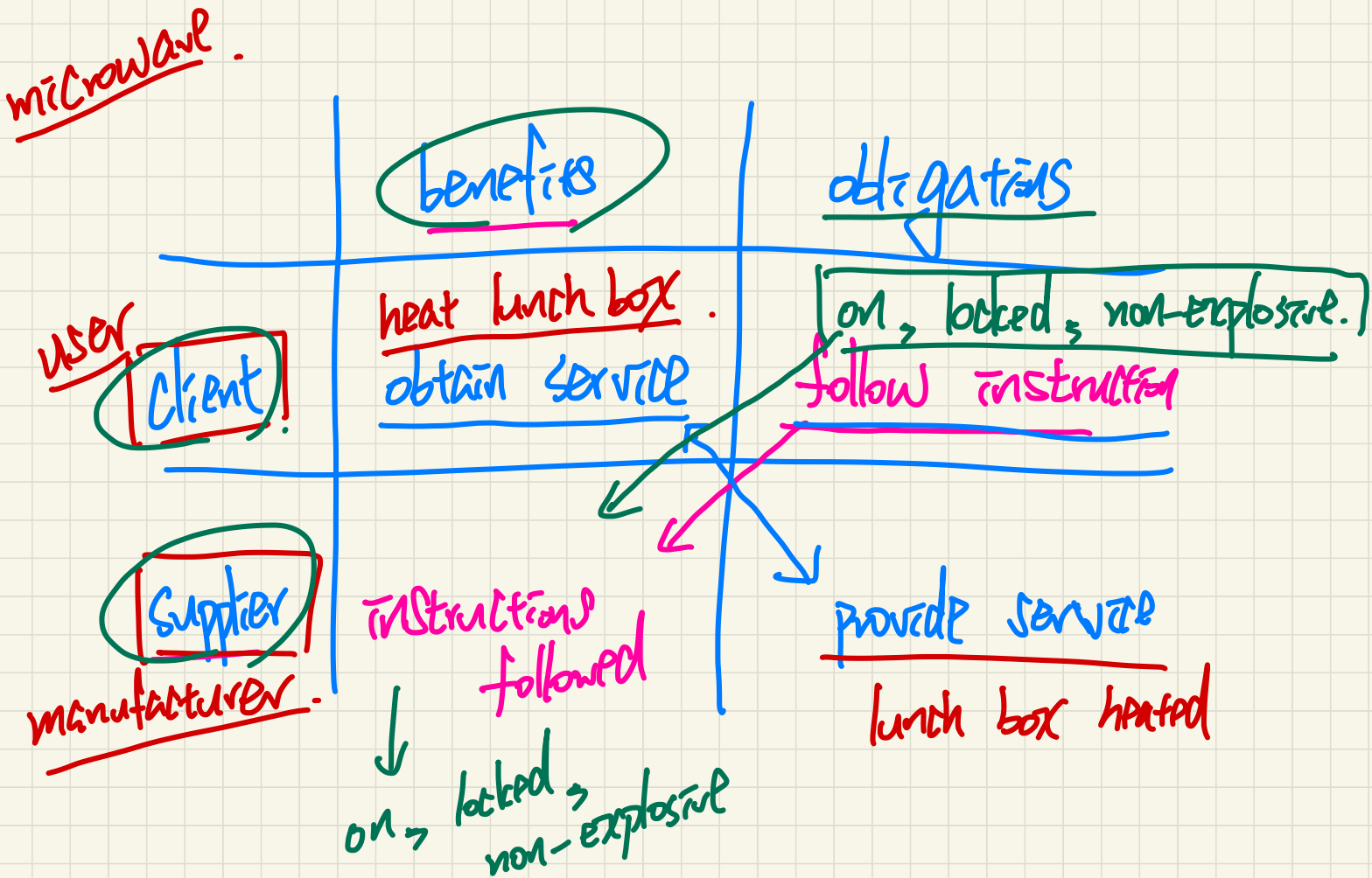
I'd like a working payment system.
Ideally, user can use it to pay their electricity bills and so on.
It should be easy to use and secure with a 4-phased authentication (face, touch, verification code, password).

P ¬P

$P \wedge \neg P \equiv F$.

Roadmap of this Course




microwave.
benefits
obligations
on, locked, non-explosive.
heat lunch box.
obtain service
follow instructions
user
client
supplier
manufacturer.
instructions followed
provide service
lunch box heated
on, locked, non-explosive

Client vs. Supplier in OOP

```
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);
  } }
```

client class

client method

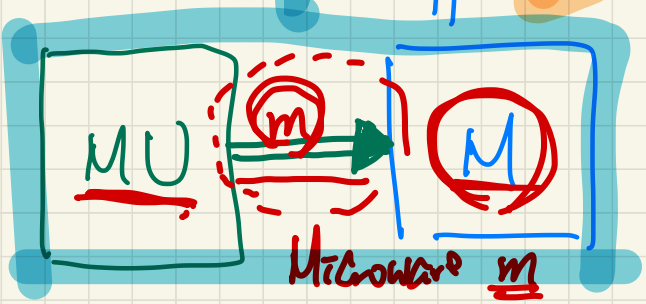
argument/input

context object

Microwave

supplier method

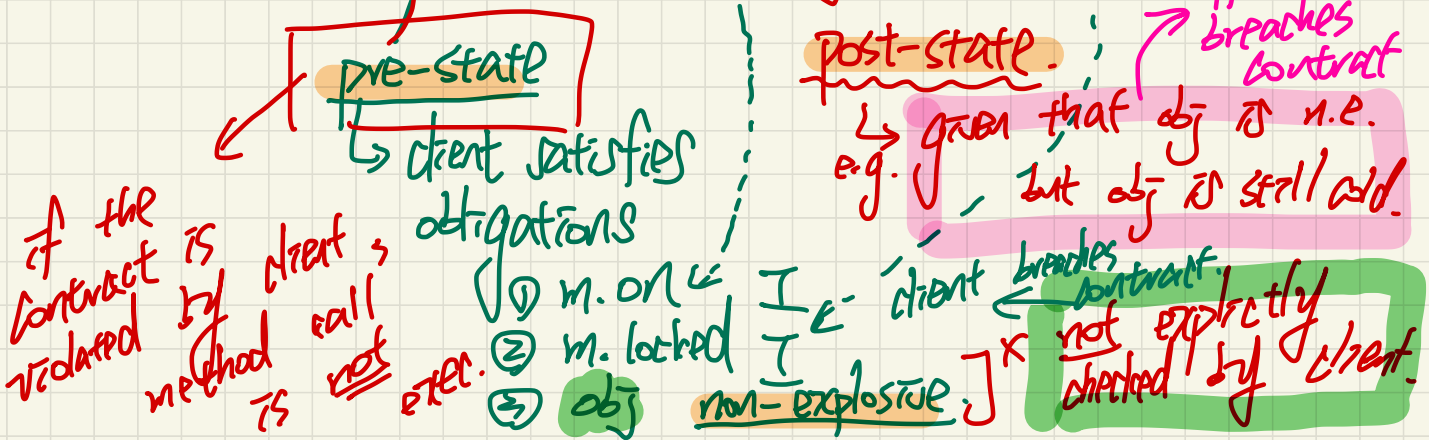
supplier class

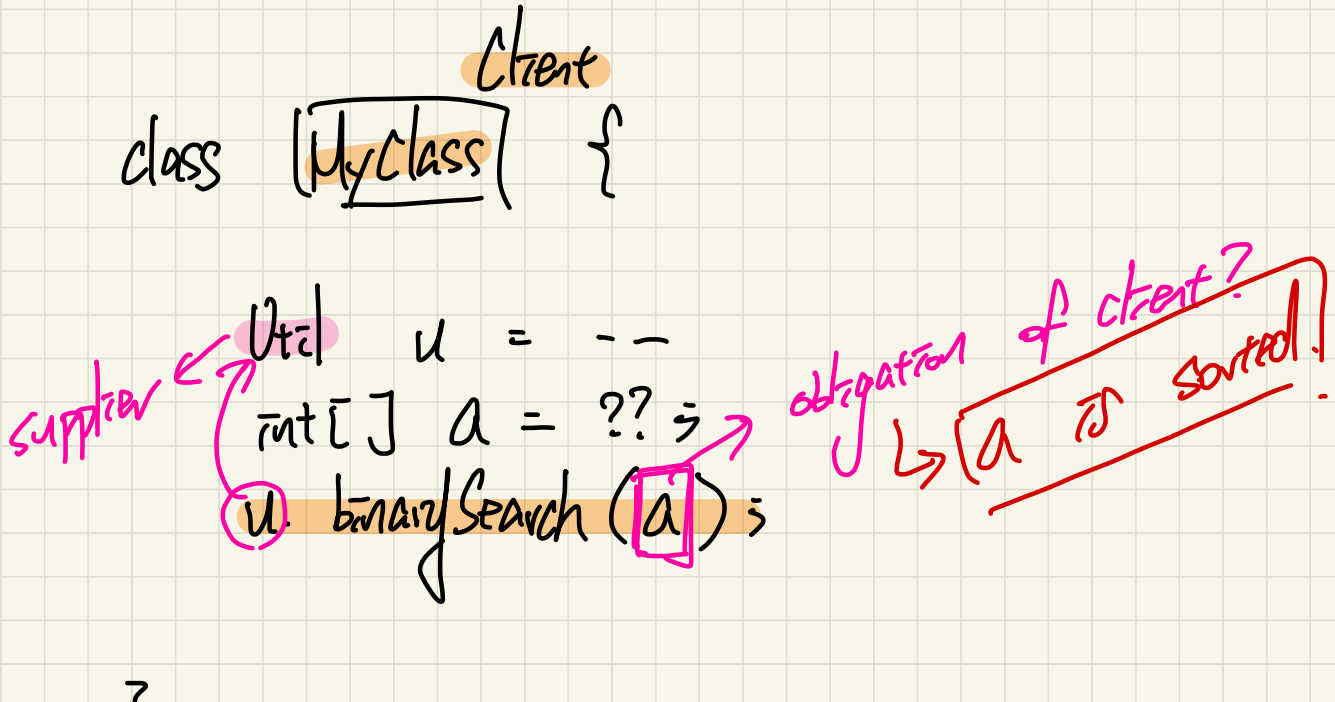


Contract Honoured?

```
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);
  } }
```




Client
class MyClass {
Util u = --
int[] a = ??;
u.binarySearch(a);
}
supplier
obligation of client?
↳ a is sorted!

Lecture 1

Part 2

Supporting DbC in Java:
Preconditions,
Class Invariant,
Postconditions

A Simple Design Problem: Bank Accounts

REQ1: Each account is associated with the *name* of its owner (e.g., `"Jim"`) and an integer *balance* that is always positive. > 0

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

Bank Accounts in Java: Version 1

Supplier

```
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 }
```

Bank Accounts in Java: Version 1 Critique (1)

```
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 }
```

supplier to blame
: interface doesn't specify input constraint

client to blame
: -10 is illegal.

Supplier

Client

```
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);
  }
}
```

post-state invalid

Console Output:

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

Bank Accounts in Java: Version 1 Critique (2)

```
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 }
```

supplier blame.

Supplier

Client

```
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);
```

invalid.

supplier.

```
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
```

client blame

Bank Accounts in Java: Version 1 Critique (3)

```
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 }
```

Supplier

Client

```
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);
```

supplier

```
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
```

Preconditions vs. Exceptions

$y != 0 \equiv \neg(y == 0)$

pre. exception

Service Conditions

```
/**
 * @pre y != 0
 */
divide(int x, int y) {
    ...
}
```

Error Conditions

```
/**
 * @throws DBZE if y == 0
 */
divide(int x, int y) throws DBZE {
    if (y == 0) {
        throw new DBZE()
    }
    ...
}
```

→ ¬P

P

¬P

Bank Accounts in Java: Version 2

```
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   }
```

fix: balance <= amount

AccountV2 acc = 100

acc.withdraw(100)

100

100

100 - 100

0

exception condition

what if balance == amount

missing case

precondition:

¬(balance < amount)

≡ balance >= amount

Any missing case?

Bank Accounts in Java: Version 2 Critique (1)

Compared with Version 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   }
```

-10

-10

bypassed.

Supplier

Client

```
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     }
```

imp. of AccountV2 not appr.

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

Bank Accounts in Java: Version 2 Critique (2)

Compared with Version 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   }
```

Supplier

Client

```
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     }
```

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.
```

Bank Accounts in Java: Version 2 Critique (3)

Compared with Version 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   }
```

Supplier

by passed

Client

```
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     }
```

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.
```

Bank Accounts in Java: Version 2 Critique (4)

Supplier

```
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   }
```

Client

```
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     }
```

Requirement

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

Console Output

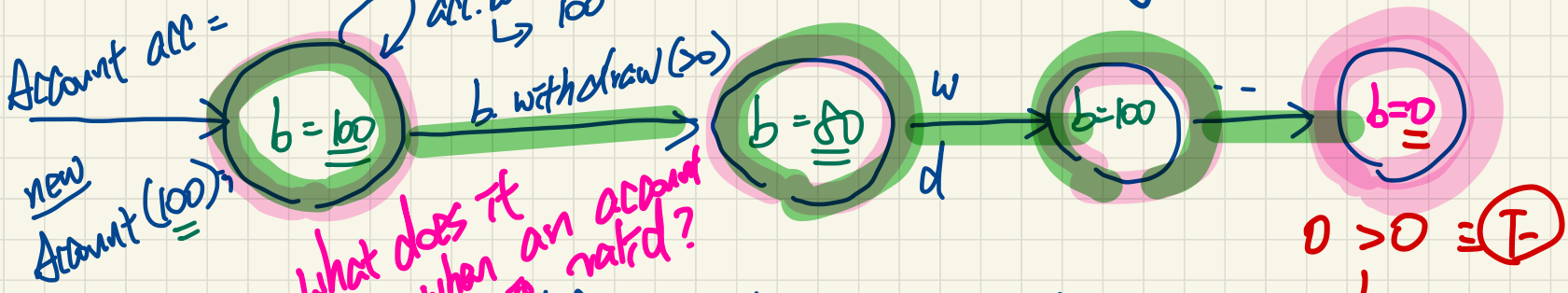
```
Create an account for Jim with balance 100:
Jim's current balance is: 100
Withdraw 100 from Jim's account:
Jim's current balance is: 0
```

Class Invariant

valid

circle
state : values of attributes

transitions: mutator method call which intend to modify state
arrows



Invariant → what does it mean when an account is valid?

acc.balance >0

lifetime of account object

Bank Accounts in Java: Version 3

```
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() > X : "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() > X : "Invariant:  positive balance";
18   }
```

R1

100

R2

100

Change: $b > 100$ → multiple places affected (single choice principle).

Bank Accounts in Java: Version 3 Critique (1)

Compared with Version 2

```
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   }
```

100 b=100 0 0 > 0 F.

Supplier

Client

```
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); b=0
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
```

Bank Accounts in Java: Version 3 Critique (2)

```
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"; }
```

≈ preconditions (obligations for clients)

≈ invariant (obligation for supplier)

When the amount is neither negative nor too large,

is there any obligation on the supplier of withdraw?

Bank Accounts in Java: Version 4

with an evil supplier

```
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"; }
```

faulty

Invariant : is this contract "good" enough to signal an error at runtime?

Bank Accounts in Java: Version 4 Critique

```
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 { /* CORRECT IMPLEMENTATION */
9        this.balance = this.balance + amount; }
10   assert this.getBalance() >= 0 :
11     owner + "Invariant: positive balance"; }
```

Supplier

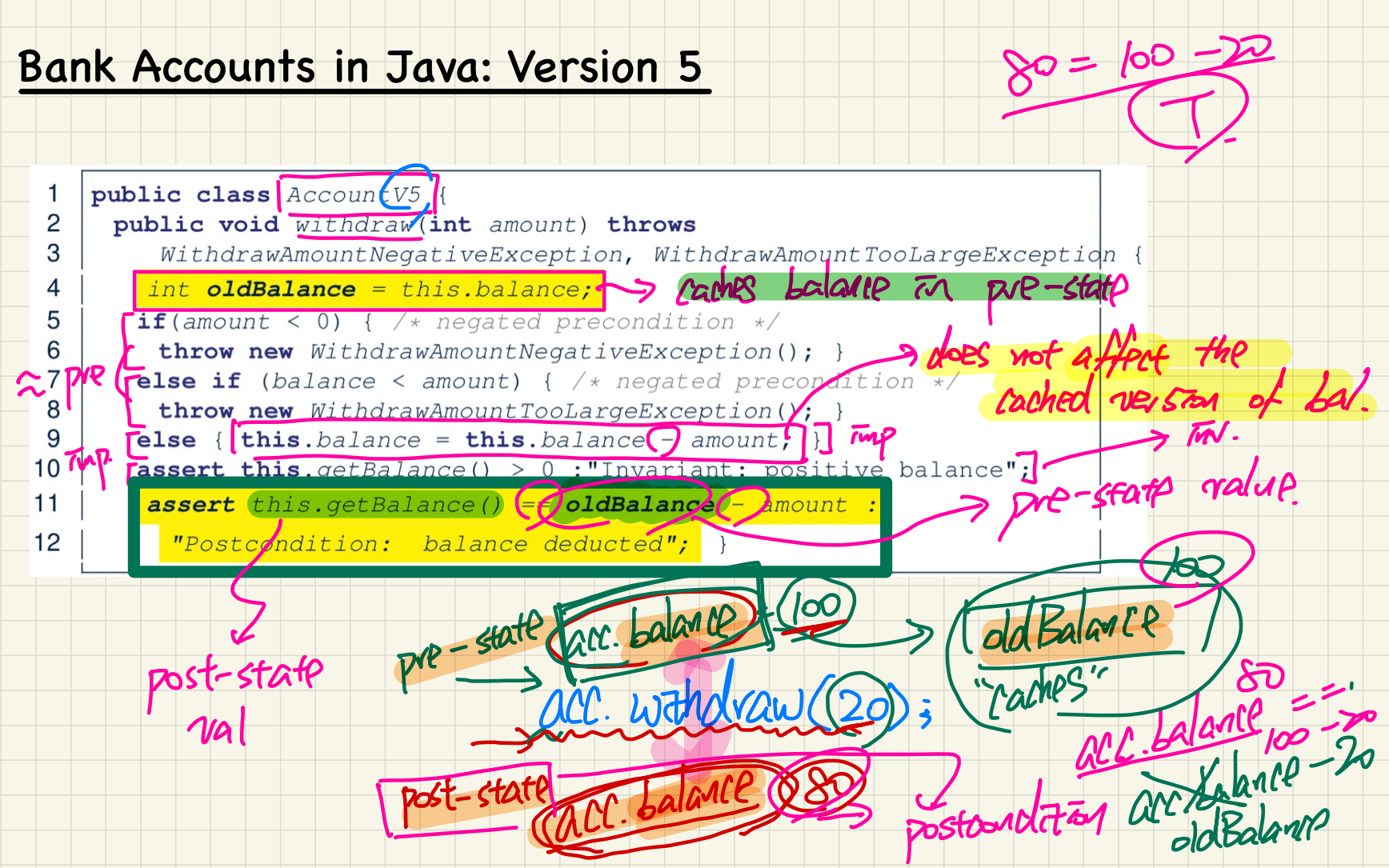
Client

```
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
```

Bank Accounts in Java: Version 5

```
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"; }
```



Bank Accounts in Java: Version 5 Critique

Compared with Version 4

Supplier

```
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"; }
```

Client

```
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
```

Design by Contract in Java

```
public class AccountV5 {
  public void withdraw(int amount) throws
      WithdrawAmountNegativeException, WithdrawAmountTooLargeExceptio
    int oldBalance = this.balance;
    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";
    assert this.getBalance() == oldBalance - amount :
      "Postcondition:  balance deducted"; }
```

C.I. Private

Supplier

Client

```
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.");
  }
```

Design by Contract in Eiffel

Contract View

```
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
```

```
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
            do
                  balance := balance - amount
            ensure -- postcondition
                  balance_deducted: balance = old balance - amount
            end
invariant -- class invariant
      positive_balance: balance > 0
end
```

imp.

imp.

Implementation View

Lecture 1

Part 3

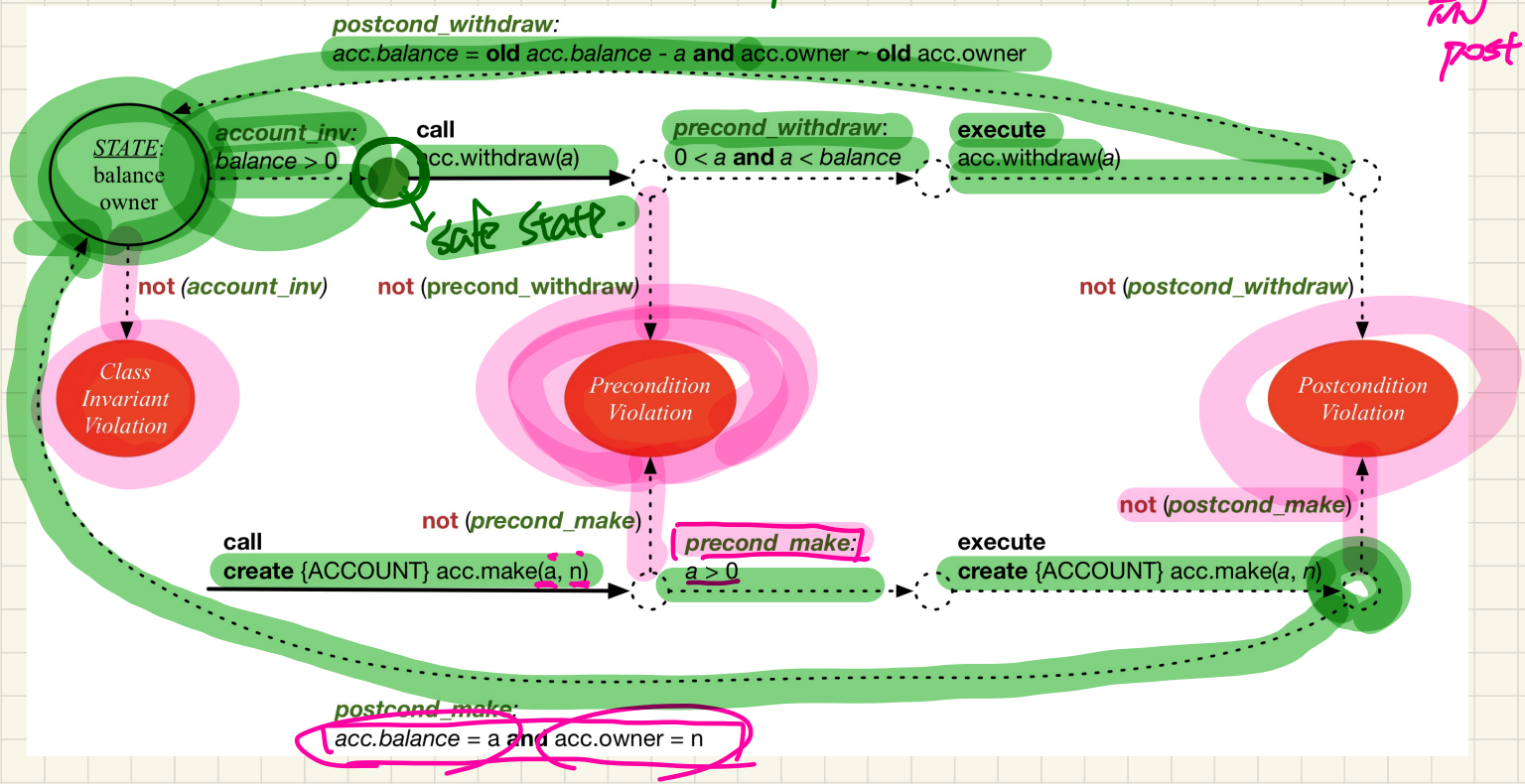
DbC in Eiffel: Runtime Contract Checking

Design by Contract in Eiffel

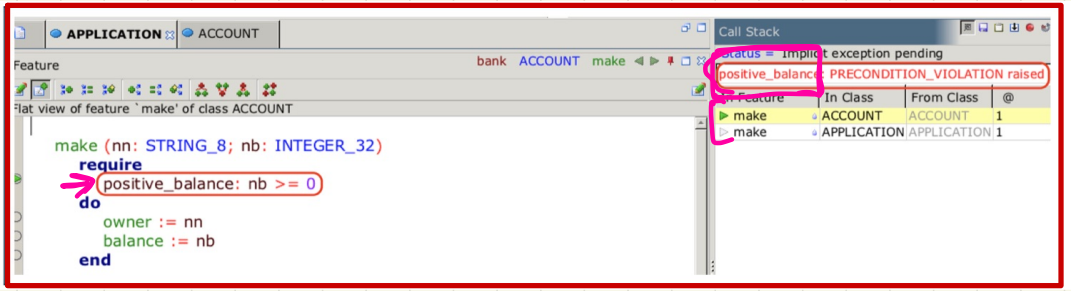
Implementation View

```
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
            ensure
                  init: balance = nb and owner = nn
feature -- Commands
      withdraw(amount: INTEGER)
            require -- precondition
                  non_negative_amount: amount > 0
                  affordable_amount: amount <= balance -- problematic
            do
                  balance := balance - amount
            ensure -- postcondition
                  balance_deducted: balance = old balance - amount
            end
invariant -- class invariant
      positive_balance: balance > 0
end
```

Runtime Monitoring of Contracts



Precondition Violation: positive_balance



Supplier

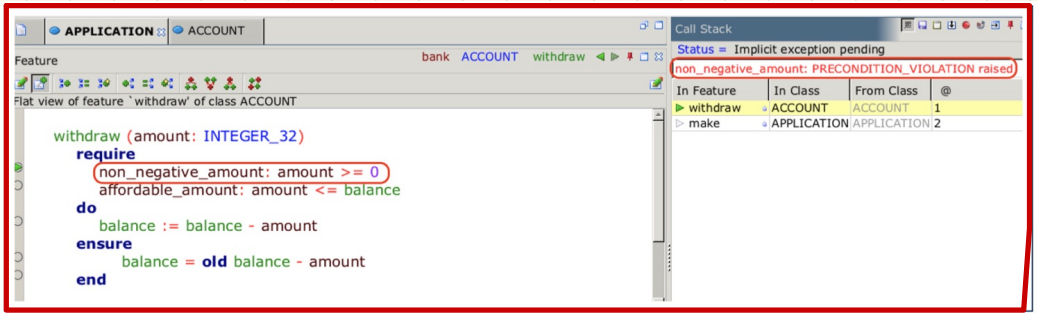
```
class ACCOUNT
create
      make
feature -- Attributes
      owner : STRING
      balance : INTEGER
feature -- Constructors
      make(nn: STRING; nb: INTEGER)
            require -- precondition
                  positive_balance: nb > 0
            end
feature -- Commands
      withdraw(amount: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

Client

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

Precondition Violation:

non_negative_amount



Supplier

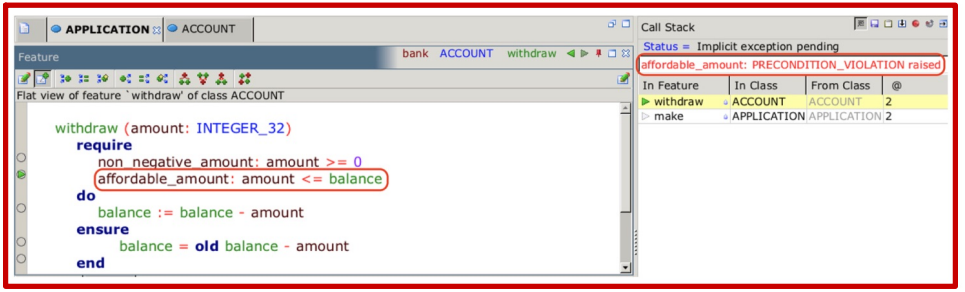
```
class ACCOUNT
create
	make
feature -- Attributes
	owner : STRING
	balance : INTEGER
feature -- Constructors
	make(nn: STRING; nb: INTEGER)
		require -- precondition
			positive_balance: nb > 0
		end
feature -- Commands
	withdraw(amount: INTEGER)
		require -- precondition
			non_negative_amount: amount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

Client

```
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 "nc
    mark.withdraw(-1000000)
  end
end
```

Precondition Violation:

affordable_amount



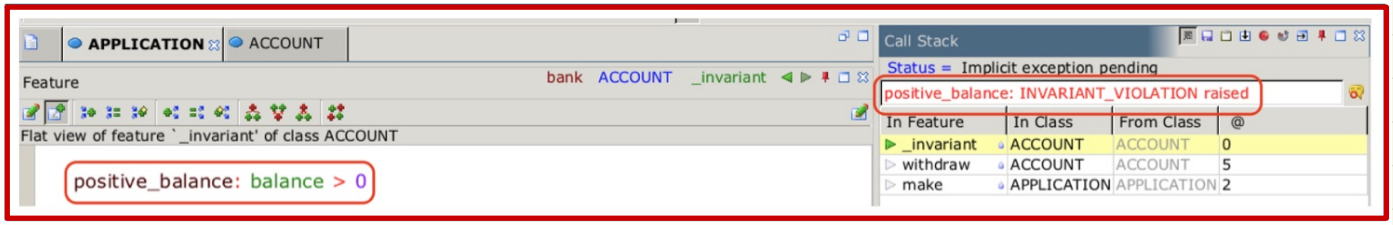
Supplier

```
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 -- problema
		ensure -- postcondition
			balance_deducted: balance = old balance - amount
		end
invariant -- class invariant
	positive_balance: balance > 0
end
```

Client

```
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 "
    tom.withdraw(150)
  end
end
```

Class Invariant Violation: positive_balance



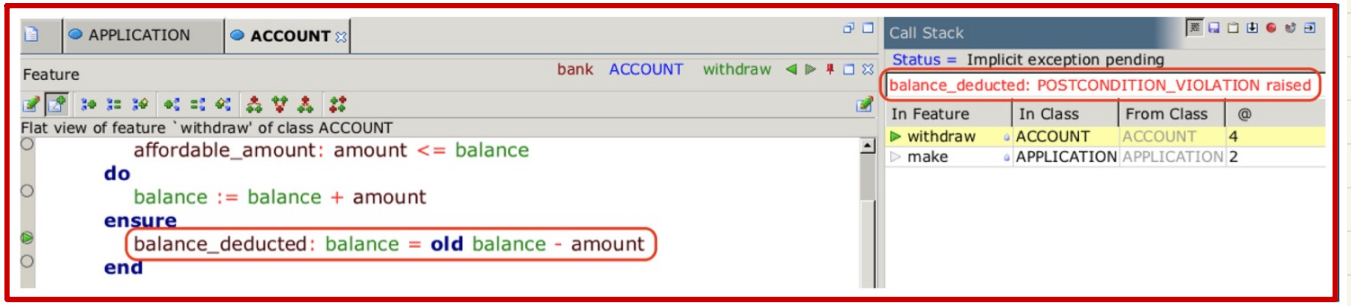
Supplier

```
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 -- problema
            ensure -- postcondition
                  balance_deducted: balance = old balance - amount
            end
invariant -- class invariant
      positive_balance: balance > 0
end
```

Client

```
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
```

Postcondition Violation: balance_deducted



Supplier

```
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 -- problema
            ensure -- postcondition
                  balance_deducted: balance = old balance - amount
            end
invariant -- class invariant
      positive_balance: balance > 0
end
```

Client

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

Runtime Monitoring of Contracts