Exceptions

EECS2030 E&F: Advanced
Object Oriented Programming
Fall 2024

CHEN-WEI WANG

Learning Outcomes

LASSONDE
SCHOOL OF ENGINEERING

This module is designed to help you learn about:

- <u>Caller</u> vs. <u>Callee</u> in a Method Invocation
- **_Error Handling_** via <u>Console</u> Message
- The **_Catch_**-or-**_Specify_** Requirement
- Example: To Handle or <u>Not</u> to Handle?
- **_Error Handling_** via <u>Exceptions</u>
- What to Do When an <u>Exception</u> is Thrown at <u>Runtime</u>
- More Examples on <u>Exception Handling</u>

Caller vs. Callee

- Within the body implementation of a method ({...}), we may call other methods.

```
1  class C1 {
2    void m1() {
3      C2 o = new C2();
4      o.m2(); /* static type of o is C2 */
5    }
6  }
```

- From **Line 4**, we say:
  - Method *C1.m1* (i.e., method m1 from class C1) is the *caller* of method *C2.m2*.
  - Method *C2.m2* is the *callee* of method *C1.m1*.

Stack of Method Calls

- Execution of a Java project *starts* from the `main` ***method*** of some class (e.g., CircleTester, BankApplication).
- Each line of *method call* involves the execution of that method's *body implementation*
  - That method's body implementation may also involve *method calls*, which may in turn involve more *method calls*, and *etc*.
  - It is typical that we end up with *a chain of method calls* !
  - We visualize this chain of method calls as a *call stack* . For example:
    - Account.withdraw   [*top* of stack; *latest* called]
    - Bank.withdrawFrom
    - BankApplication.main   [*bottom* of stack; *earliest* called]
  - The closer a method is to the *top* of the call stack, the *later* its call was made.

```
1  class Circle {
2    double radius;
3    Circle() { /* radius defaults to 0 */ }
4    void setRadius(double r) {
5      if ( r < 0 ) { System.out.println( "Invalid radius." ); }
6      else { radius = r; }
7    }
8    double getArea() { return radius * radius * 3.14; }
9  }
```

- A negative radius is considered as an *invalid input value* to method setRadius.
- What if the *caller* of Circle.setRadius passes a negative value for r?
  ◦ An error message is *printed to the console* (**Line 5**) to warn the *caller* of setRadius.
  ◦ However, printing an error message to the console *does not force* the *caller* of setRadius to stop and handle invalid values of r.

```
1    class CircleCalculator {
2     public static void main(String[] args) {
3       Circle c = new Circle();
4       c.setRadius( -10 );
5       double area = c.getArea();
6       System.out.println("Area: " + area);
7     }
8    }
```

- **L4**: *CircleCalculator.main* is **caller** of *Circle.setRadius*
- A negative radius is passed to setRadius in **Line 4**.
- The execution *always flows smoothly* from **Lines 4** to **Line 5**, *even when there was an error* message printed from **Line 4**.
- It is not feasible to check if there is any kind of error message printed to the console right after the execution of **Line 4**.
- **Solution:** A way to force *CircleCalculator.main*, **caller** of *Circle.setRadius*, to realize that things might go wrong.
    ⇒ When things do go wrong, immediate actions are needed.

Error Reporting via Consoles: Bank (1)

```java
class Account {
 int id; double balance;
 Account(int id) { this.id = id; /* balance defaults to 0 */ }
 void deposit(double a) {
   if ( a < 0 ) { System.out.println( "Invalid deposit." ); }
   else { balance += a; }
 }
 void withdraw(double a) {
   if ( a < 0 || balance - a < 0 ) {
     System.out.println( "Invalid withdraw." ); }
   else { balance -= a; }
 }
}
```

- A negative deposit or withdraw amount is *invalid*.
- When an *error* occurs, a message is *printed to the console*.
- However, printing error messages does not <u>force</u> the *caller* of
  Account.deposit or Account.withdraw to stop and
  handle invalid values of a.

Error Reporting via Consoles: Bank (2)

```
1   class Bank {
2     Account[] accounts; int numberOfAccounts;
3     Bank(int id) { ... }
4     void withdrawFrom(int id, double a) {
5       for(int i = 0; i < numberOfAccounts; i ++) {
6         if(accounts[i].id == id) {
7           accounts[i].withdraw( a );
8         }
9       } /* end for */
10    } /* end withdraw */
11  }
```

- **L7**: *Bank.withdrawFrom* is caller of *Account.withdraw*
- What if in **Line 7** the value of a is negative?
  Error message Invalid withdraw printed from method
  Account.withdraw to console.
- Impossible to <u>force</u> *Bank.withdrawFrom*, the caller of
  Account.withdraw, to stop and handle invalid values of a.

```
1   class BankApplication {
2     pubic static void main(String[] args) {
3       Scanner input = new Scanner(System.in);
4       Bank b = new Bank(); Account acc1 = new Account(23);
5       b.addAccount(acc1);
6       double a = input.nextDouble();
7       b.withdrawFrom(23, a );
8       System.out.println("Transaction Completed.");
9   }
```

- There is a chain of method calls:
  - **BankApplication.main** calls **Bank.withdrawFrom**
  - **Bank.withdrawFrom** calls **Account.withdraw**.
- The actual update of balance occurs at the Account class.
  - What if in **Line 7** the value of a is negative?

    Invalid withdraw printed from **Bank.withdrawFrom**,
    originated from **Account.withdraw** to console.
  - However, impossible to <u>stop</u> **BankApplication.main** from
    continuing to execute **Line 8**, printing Transaction Completed.
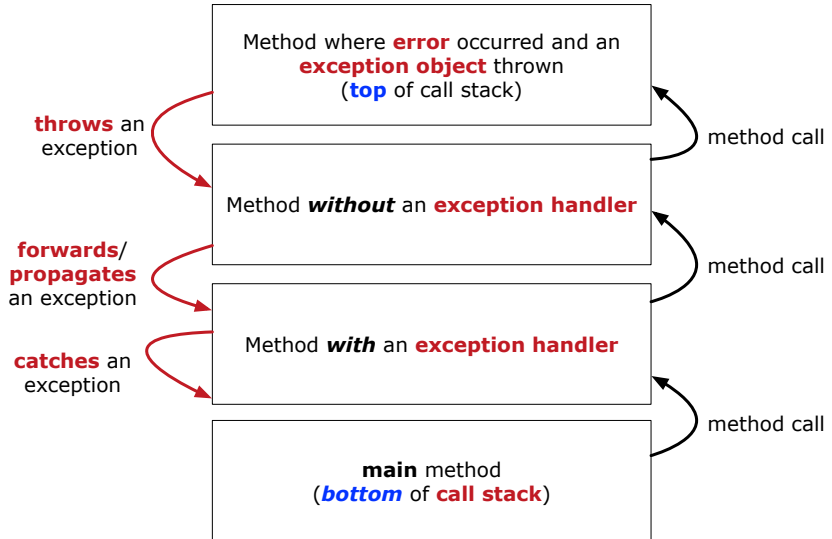- **Solution:** Define error checking only once and let it *propagate*.

What is an Exception?

- An *exception* is an *event*, which
  - occurs during the *execution of a program*
  - *disrupts the normal flow* of the program's instructions
- When an error occurs within a method:
  - the method throws an exception:
    - first creates an *exception object*
    - then hands it over to the *runtime system*
  - the exception object contains information about the error:
    - type   [e.g., `NegativeRadiusException`]
    - the state of the program when the error occurred

What to Do When an Exception Is Thrown?

- After a method *throws an exception*, the *runtime system* searches the corresponding `call stack` for a method that contains a block of code to *handle* the exception.
  - This block of code is called an `exception handler`.
    - An exception handler is **appropriate** if the *type* of the *exception object thrown* matches the *type* that can be handled by the handler.
    - The exception handler chosen is said to *catch* the exception.
  - The search goes from the *top* to the *bottom* of the call stack:
    - The method in which the *error* occurred is searched first.
    - The *exception handler* is not found in the current method being searched ⇒ Search the method that calls the current method, and *etc*.
    - When an appropriate *handler* is found, the *runtime system* passes the exception to the handler.
  - The *runtime system* searches all the methods on the `call stack` without finding an **appropriate** *exception handler*
    ⇒ The program terminates and the exception object is directly "thrown" to the console!

Method where **error** occurred and an **exception object** thrown (**top** of call stack)

throws an exception

method call

Method *without* an **exception handler**

forwards/ **propagates** an exception

method call

Method *with* an **exception handler**

catches an exception

method call

main method (*bottom* of **call stack**)

The Catch or Specify Requirement (1)

Code (e.g., a method call) that might throw certain exceptions must be enclosed by one of the two ways:

1. The "Catch" Solution: A `try` statement that *catches* and *handles* the *exception*

(**without** propagating that exception to the method's *caller*).

```
main(...) {
  Circle c = new Circle();
  try {
    c.setRadius(-10);
  }
  catch(NegativeRaidusException e) {
    ...
  }
}
```

Code (e.g., a method call) that might throw certain exceptions must be enclosed by one of the two ways:

2. The "Specify" Solution: A method that specifies as part of its *header* that it may (or may not) **_throw_** the **_exception_** (which will be thrown to the method's **_caller_** for handling).

```
class Bank {
  Account[] accounts; /* attribute */
  void withdraw (double amount)
     throws InvalidTransactionException {
    ...
    accounts[i].withdraw(amount);
    ...
  }
}
```

Example: to Handle or Not to Handle? (1.1)

LASSONDE
SCHOOL OF ENGINEERING

Consider the following three classes:

```
class A {
  ma(int i) {
    if(i < 0) { /* Error */ }
    else { /* Do something. */ }
  } }
```

```
class B {
  mb(int i) {
    A oa = new A();
    oa.ma(i); /* Error occurs if i < 0 */
  } }
```
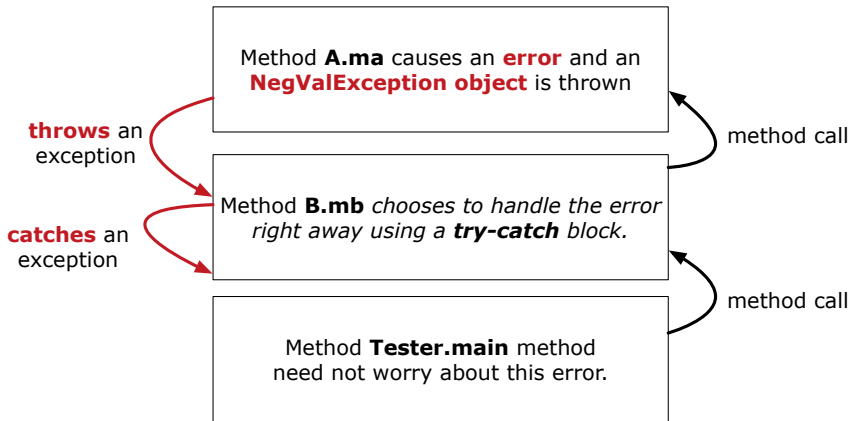
```
class Tester {
  public static void main(String[] args) {
    Scanner input = new Scanner(System.in);
    int i = input.nextInt();
    B ob = new B();
    ob.mb(i); /* Where can the error be handled?  */
  } }
```

• We assume the following kind of error for negative values:

```
class NegValException extends Exception {
  NegValException(String s) { super(s); }
}
```

• The above kind of exception may be thrown by calling A.ma.

• We will see three kinds of possibilities of handling this exception:

> **Version 1**:
> Handle it in B.mb
> **Version 2**:
> Pass it from B.mb and handle it in Tester.main
> **Version 3**:
> Pass it from B.mb, then from Tester.main, then throw it to the console.

Example: to Handle or Not to Handle? (2.1) LASSONDE

SCHOOL OF ENGINEERING

Version 1: Handle the exception in `B.mb`.

```
class A {
  ma(int i) throws NegValException {
    if(i < 0) { throw new NegValException("Error."); }
    else { /* Do something. */ }
  } }
```

```
class B {
  mb(int i) {
    A oa = new A();
    try { oa.ma(i); }
    catch(NegValException nve) { /* Do something. */ }
  } }
```
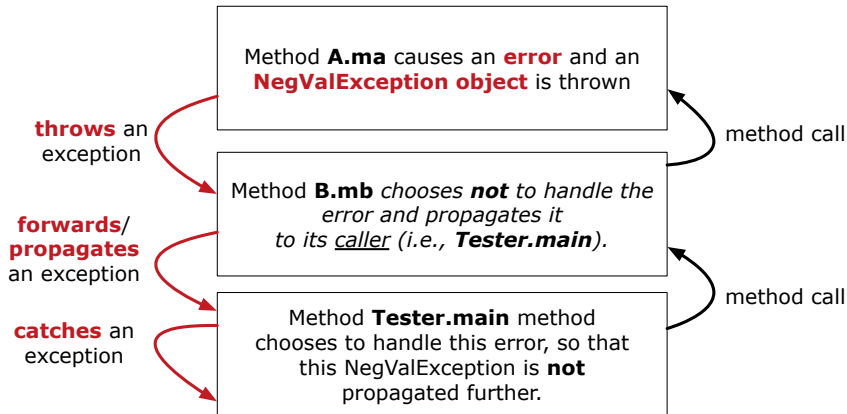
```
class Tester {
  public static void main(String[] args) {
    Scanner input = new Scanner(System.in);
    int i = input.nextInt();
    B ob = new B();
    ob.mb(i); /* Error, if any, would have been handled in B.mb. */
  } }
```

Version 1: Handle the exception in `B.mb`.

Method **A.ma** causes an **error** and an **NegValException object** is thrown

throws an exception

method call

Method **B.mb** *chooses to handle the error right away using a **try-catch** block.*

catches an exception

method call

Method **Tester.main** method need not worry about this error.

Example: to Handle or Not to Handle? (3.1) LASSONDE

SCHOOL OF ENGINEERING

Version 2: Handle the exception in `Tester.main`.
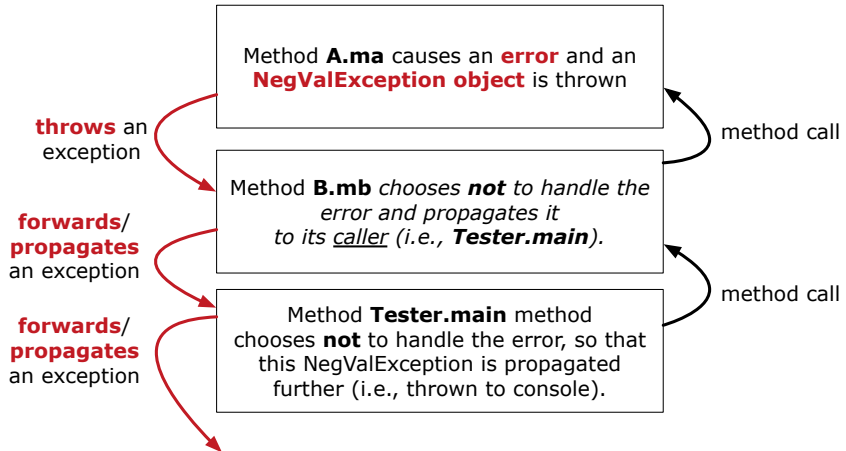
```java
class A {
  ma(int i) throws NegValException {
    if(i < 0) { throw new NegValException("Error."); }
    else { /* Do something. */ }
  } }
```

```java
class B {
  mb(int i) throws NegValException {
    A oa = new A();
    oa.ma(i);
  } }
```

```java
class Tester {
  public static void main(String[] args) {
    Scanner input = new Scanner(System.in);
    int i = input.nextInt();
    B ob = new B();
    try { ob.mb(i); }
    catch(NegValException nve) { /* Do something. */ }
  } }
```

Version 2: Handle the exception in `Tester.main`.

Method **A.ma** causes an **error** and an **NegValException object** is thrown

throws an exception

method call

Method **B.mb** *chooses **not** to handle the error and propagates it to its <u>caller</u> (i.e., **Tester.main**).*

forwards/ **propagates** an exception

method call

Method **Tester.main** method chooses to handle this error, so that this NegValException is **not** propagated further.

catches an exception

Version 3: Handle in neither of the classes.

```
class A {
  ma(int i) throws NegValException {
    if(i < 0) { throw new NegValException("Error."); }
    else { /* Do something. */ }
  } }
```

```
class B {
  mb(int i) throws NegValException {
    A oa = new A();
    oa.ma(i);
  } }
```

```
class Tester {
  public static void main(String[] args) throws NegValException {
    Scanner input = new Scanner(System.in);
    int i = input.nextInt();
    B ob = new B();
    ob.mb(i);
  } }
```

Version 3: Handle in neither of the classes.

Method **A.ma** causes an **error** and an **NegValException object** is thrown

throws an
exception

method call

Method **B.mb** *chooses **not** to handle the
error and propagates it
to its <u>caller</u> (i.e., **Tester.main**).*

forwards/
propagates
an exception

method call

Method **Tester.main** method
chooses **not** to handle the error, so that
this NegValException is propagated
further (i.e., thrown to console).

forwards/
propagates
an exception

```
public class InvalidRadiusException extends Exception {
 public InvalidRadiusException(String s) {
   super(s);
 }
}
```

- A new kind of Exception: InvalidRadiusException
- For any method that can have this kind of error, we declare at that method's *header* that it may *throw* an InvalidRaidusException object.

```
class Circle {
  double radius;
  Circle() { /* radius defaults to 0 */ }
  void setRadius(double r) throws InvalidRadiusException {
    if (r < 0) {
      throw new InvalidRadiusException("Negative radius.");
    }
    else { radius = r; }
  }
  double getArea() { return radius * radius * 3.14; }
}
```

- As part of the *header* of setRadius, we declare that it may *throw* an InvalidRadiusException object at runtime.
- Any method that calls setRadius will be forced to *deal with this potential error* .

```
1   class CircleCalculator1 {
2    public static void main(String[] args) {
3      Circle c = new Circle();
4      try {
5        c.setRadius(-10);
6        double area = c.getArea();
7        System.out.println("Area: " + area);
8      }
9      catch(InvalidRadiusException e) {
10       System.out.println(e);
11     }
12   } }
```

- **Lines 6** is forced to be wrapped within a *try-catch* block, since it may *throw* an InvalidRadiusException object.

- If an InvalidRadiusException object is thrown from **Line 6**, then the normal flow of execution is *interrupted* and we go to the catch block starting from **Line 9**.

Exercise: Extend `CircleCalculator1`: repeatedly prompt for a new radius value until a valid one is entered (i.e., the `InvalidRadiusException` does not occur).

```
Enter a radius:
-5
Radius -5.0 is invalid, try again!
Enter a radius:
-1
Radius -1.0 is invalid, try again!
Enter a radius:
5
Circle with radius 5.0 has area: 78.5
```

```
1   public class CircleCalculator2 {
2     public static void main(String[] args) {
3       Scanner input = new Scanner(System.in);
4       boolean inputRadiusIsValid = false;
5       while(!inputRadiusIsValid) {
6         System.out.println("Enter a radius:");
7         double r = input.nextDouble();
8         Circle c = new Circle();
9         try { c.setRadius(r);
10             inputRadiusIsValid = true;
11            System.out.print("Circle with radius " + r);
12            System.out.println(" has area: "+ c.getArea()); }
13        catch(InvalidRadiusException e) { print("Try again!"); }
14      } } }
```

- At **L7**, if the user's input value is:
  - Non-Negative: **L8** – **L12**.   [inputRadiusIsValid set *true*]
  - Negative: **L8**, **L9**, **L13**.   [inputRadiusIsValid remains *false*]

```
public class InvalidTransactionException extends Exception {
  public InvalidTransactionException(String s) {
    super(s);
  }
}
```

- A new kind of Exception:
  InvalidTransactionException
- For any method that can have this kind of error, we declare at
  that method's *header* that it may *throw* an
  InvalidTransactionException object.

```
class Account {
 int id; double balance;
 Account() { /* balance defaults to 0 */ }
 void withdraw(double a) throws InvalidTransactionException {
   if (a < 0 || balance - a < 0) {
     throw new InvalidTransactionException("Invalid withdraw."); }
   else { balance -= a; }
 }
}
```

- As part of the *header* of `withdraw`, we declare that it may *throw* an `InvalidTransactionException` object at runtime.
- Any method that calls `withdraw` will be forced to *deal with this potential error* .

```
class Bank {
 Account[] accounts; int numberOfAccounts;
 Account(int id) { ... }
 void withdraw(int id, double a)
    throws InvalidTransactionException {
  for(int i = 0; i < numberOfAccounts; i ++) {
    if(accounts[i].id == id) {
     accounts[i].withdraw(a);
    }
  } /* end for */ } /* end withdraw */ }
```

- As part of the *header* of withdraw, we declare that it may *throw* an InvalidTransactionException object.

- Any method that calls withdraw will be forced to *deal with this potential error* .

- We are *propagating* the potential error for the right party (i.e., BankApplication) to handle.

```
1   class BankApplication {
2    pubic static void main(String[] args) {
3      Bank b = new Bank();
4      Account acc1 = new Account(23);
5      b.addAccount(acc1);
6      Scanner input = new Scanner(System.in);
7      double a = input.nextDouble();
8      try {
9        b.withdraw(23, a);
10       System.out.println(acc1.balance); }
11     catch (InvalidTransactionException e) {
12       System.out.println(e); } } }
```

- **Lines 9** is forced to be wrapped within a *try-catch* block, since it may *throw* an InvalidTransactionException object.

- If an InvalidTransactionException object is thrown from **Line 9**, then the normal flow of execution is interrupted and we go to the catch block starting from **Line 11**.

More Examples (1)

```java
double r = ...;
double a = ...;
try{
  Bank b = new Bank();
  b.addAccount(new Account(34));
  b.deposit(34, 100);
  b.withdraw(34, a);
  Circle c = new Circle();
  c.setRadius(r);
  System.out.println(r.getArea());
}
catch(NegativeRadiusException e) {
  System.out.println(r + " is not a valid radius value.");
  e.printStackTrace();
}
catch(InvalidTransactionException e) {
  System.out.println(r + " is not a valid transaction value.");
  e.printStackTrace();
}
```

The Integer class supports a method for parsing Strings:

```
public static int parseInt(String s)
                throws NumberFormatException
```

e.g., Integer.parseInt("23") returns 23

e.g., Integer.parseInt("twenty-three") throws a
NumberFormatException

Write a fragment of code that prompts the user to enter a string
(using nextLine from Scanner) that represents an integer.

If the user input is not a valid integer, then prompt them to enter
again.

```
Scanner input = new Scanner(System.in);
boolean validInteger = false;
while (!validInteger) {
  System.out.println("Enter an integer:");
  String userInput = input.nextLine();
  try {
    int userInteger = Integer.parseInt(userInput);
    validInteger = true;
  }
  catch(NumberFormatException e) {
    System.out.println(userInput + " is not a valid integer.");
    /* validInteger remains false */
  }
}
```

- Practice creating a new *exception* class upon a method throwing it in the body of implementation (e.g., InvalidRadiusException, InvalidTransactionException).
- Play with the source code:
  - ExceptionsCircleAndBank.zip
  - ExceptionsToHandleOrNotToHandle.zip

  Tip. Change input values so as to explore, in Eclipse *debugger*, possible (*normal* vs. *abnormal*) *execution paths* .

Beyond this lecture. . .