Advanced Object-Oriented Programming

CPT204 – Lecture 6
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CPT204 Advanced Object-Oriented Programming

Lecture 6

Exception, Linked List 3

Welcome !

- Welcome to Lecture 6 !
- In this lecture we are going to
  - learn about null values
  - learn about exception
    - checked vs unchecked
    - handling exception
  - continue improving our homemade linked list, while learning about
    - copy constructor
    - shallow copy vs deep copy

Null References (1)

- In Java, references to objects and arrays can also take on the special value **null**, which means that the reference doesn't point to an object
  - Null values are an unfortunate hole in Java's type system

- Primitives cannot be null and the compiler will reject such attempts with **static errors**:

```
int size = null;      // illegal
double depth = null; // illegal
```

Null References (2)

- On the other hand, we can assign `null` to any non-primitive variable and the compiler happily accepts this code at compile time:

```
String name = null;
int[] points = null;
```

- But you'll get **errors at runtime** because you can't call any methods or use any fields with one of these references:

```
name.length()    // throws NullPointerException
points.length    // throws NullPointerException
```

Null References (3)

- Note that `null` is **not** the same as an empty string `""` or an empty array
  - On an empty string or empty array, you **can** call methods and access fields
  - The length of an empty array or an empty string is 0
  - The length of a string variable that points to null isn't anything: calling `length()` throws a `NullPointerException`

- Also note that arrays of non-primitives and collections like List might be non-`null` but contain `null` as a value:

```
String[] names = new String[] { null };
List<Double> sizes = new ArrayList<>();
sizes.add(null);
```

- These `null`s are likely to cause errors as soon as someone tries to use the contents of the collection!

Null Values (1)

- Null values are troublesome and unsafe, and in fact in most good Java programming, null values are ***implicitly disallowed*** in *parameters* and *return values*
  - so every method implicitly has a precondition on its object and array parameters that they be non-null, and
  - every method that returns an object or an array implicitly has a postcondition that its return value is non-null
  - if a method allows null values for a parameter, it should ***explicitly*** state it, or if it might return a null value as a result, it should ***explicitly*** state it

Null Values (2)

- There are extensions to Java that allow you to forbid null directly in the type declaration:

```
static boolean addAll(@NonNull List<T> list1, @NonNull List<T> list2)
```

where it can be checked automatically at compile time or runtime

- Google has their own discussion of null in Guava, the company's core Java libraries. The project explains:

> Careless use of `null` can cause a staggering variety of bugs. Studying the Google code base, we found that something like 95% of collections weren't supposed to have any null values in them, and having those **fail fast** rather than silently accept `null` would have been helpful to developers.
>
> Additionally, `null` is unpleasantly ambiguous. It's rarely obvious what a `null` return value is supposed to mean — for example, `Map.get(key)` can return `null` either because the value in the map is `null`, or the value is not in the map. Null can mean failure, can mean success, can mean almost anything. Using something other than `null` **makes your meaning clear**.

Exceptions

- Next, we discuss how to handle ***exceptional cases*** in a way that is safe from bugs and easy to understand

- A method's signature — its name, parameter types, return type — is a core part of its specification, and the signature may also include ***exceptions*** that the method may ***trigger***

Exceptions for Signaling Bugs

- We have already seen some exceptions in our Java programming so far, such as
  - `IndexOutOfBoundsException`, thrown when a list index `list.get(i)` is outside the valid range for the list `list`
  - `NullPointerException`, thrown when trying to call a method on a `null` object reference
- These exceptions generally ***indicate bugs in your code***, and the information displayed by Java when the exception is thrown can help you find and fix the bug
- `IndexOutOfBounds` and `NullPointerException` are probably the most common exceptions of this sort
- Other examples include:
  - `ArithmeticException`, thrown for arithmetic errors like integer division by zero
  - `NumberFormatException`, thrown by methods like `Integer.parseInt` if you pass in a string that cannot be parsed into an integer

Exceptions for Special Results (1)

- Exceptions are not just for signaling bugs
- They can be used to improve the structure of code that involves procedures with **special results**

- An unfortunately common way to handle special results is to return special values
- Lookup operations in the Java library are often designed like this:
  you get an index of -1 when expecting a positive integer, or a `null` reference when expecting an object
- This approach is OK if used sparingly, but it has two problems :
  - First, it's tedious to check the return value
  - Second, it's easy to forget to do it

Exceptions for Special Results (2)

- Also, it's not always easy to find *a special value*.

  Suppose we have a `BirthdayBook` class with a `lookup` method.

  Here's one possible method signature:

```
class BirthdayBook {
    LocalDate lookup(String name) { ... }
}
```

  (`LocalDate` is part of the Java API)

- What should the method do if the birthday book *doesn't* have an entry for the person whose name is given?
  - we could return some *special date* that is not going to be used as a real date
  - bad programmers have been doing this for decades; they would return 9/9/99, for example, since it was obvious that no program written in 1960 would still be running at the end of the century

btw, they are wrong,
caused Y2K bug

Exceptions for Special Results (3)

- Here's a better approach: the method *throws an exception*:

```
LocalDate lookup(String name) throws NotFoundException {
    ...
    if ( ...not found... )
        throw new NotFoundException();
    ...
```

- The caller *handles* the exception with *a catch clause*, for example:

```
BirthdayBook birthdays = ...
try {
    LocalDate birthdate = birthdays.lookup("Alyssa");
    // we know Alyssa's birthday
} catch (NotFoundException nfe) {
    // her birthday was not in the birthday book
}
```

- Now there's no need for any special value, nor the checking associated with it

Exceptions for Special Results (3)

- Here's a better approach: the method *throws an exception*:

```
LocalDate lookup(String name) throws NotFoundException {
    ...
    if ( ...not found... )
        throw new NotFoundException();
    ...
```

advertise the exception in method's signature

the condition that triggers throwing exc

an **object** of type `NotFoundException` is thrown by lookup if date not found, method lookup execution then ends

- The caller *handles* the exception with *a catch clause*, for example:

```
BirthdayBook birthdays = ...
try {
    LocalDate birthdate = birthdays.lookup("Alyssa");
    // we know Alyssa's birthday
} catch (NotFoundException nfe) {
    // her birthday was not in the birthday book
}
```

method that throws exception is called inside try block here

codes here executed if lookup does not throw a `NotFoundException` object

codes here executed if lookup throws a `NotFoundException` object

- Now there's no need for any special value, nor the checking associated with it

In-Class Quiz 1

- We use `BirthdayBook` with the `lookup` method that `throws NotFoundException`
- Assume we have initialized the `birthdays` variable to point to a `BirthdayBook`, and that `"Makima"` is **not** in that birthday book
- What will happen with the following code:

```
try {
    LocalDate birthdate = birthdays.lookup("Makima");
}
System.out.println("done");
```

- ○ static error caused by incorrect syntax
- ○ static error caused by undeclared variable
- ○ dynamic error caused by `NotFoundException`
- ○ no errors and it prints `"done"`

In-Class Quiz 2

- We use `BirthdayBook` with the `lookup` method that `throws NotFoundException`
- Assume we have initialized the `birthdays` variable to point to a `BirthdayBook`, and that `"Makima"` is **not** in that birthday book
- What will happen with the following code:

```
try {
    LocalDate birthdate = birthdays.lookup("Makima");
} catch (NotFoundException nfe) {
    birthdate = LocalDate.now();
}
System.out.println("done");
```

  - static error caused by incorrect syntax
  - static error caused by undeclared variable
  - dynamic error caused by `NotFoundException`
  - no errors and it prints "done"

In-Class Quiz 3

- We use `BirthdayBook` with the `lookup` method that `throws NotFoundException`
- Assume we have initialized the `birthdays` variable to point to a `BirthdayBook`, and that `"Makima"` is **not** in that birthday book
- What will happen with the following code:

```
try {
    LocalDate birthdate = birthdays.lookup("Makima");
} catch (Exception NotFoundException) {
}
System.out.println("done");
```

- ○ static error caused by incorrect syntax
- ○ static error caused by undeclared variable
- ○ dynamic error caused by `NotFoundException`
- ○ no errors and it prints "done"

Exception Message (1)

- All exceptions may have a message associated with them in the constructor
  - to pass useful information about the cause of throwing the exception

```
LocalDate lookup(String name) throws NotFoundException {
    ...
    if ( ...not found... )
        throw new NotFoundException(name + "not found");
    ...
```

  - in the catch block, it is accessed by `getMessage()`

```
try {
    LocalDate birthdate = birthdays.lookup("Makima");
} catch (NotFoundException nfe) {
    System.err.println("birthdate of " + nfe.getMessage());
}
```

Exception Message (2)

- All exceptions may have a message associated with them in the constructor
  - if ***not*** provided in the constructor, the reference to the message string is `null`
  - this can result in confusing stack traces that start, for example:

```
birthday.NotFoundException: null
at birthday.BirthdayBook.lookup(BirthdayBook.java:42)
```

  - the `null` is misleading : in this case, it tells you the `NotFoundException` had no message string, **not that** a null value was responsible for the exception

Checked and Unchecked Exceptions (1)

- We've seen two different purposes for exceptions:
  - special results, and
  - bug detection

- As a general rule, you'll want to use **checked exceptions** to signal *special results* and **unchecked exceptions** to *signal bugs*

Checked and Unchecked Exceptions (2)

- ***Checked exceptions*** are called that because they are ***checked by the compiler***:
  - if a method might throw a checked exception, the possibility must be declared in its signature
    - `NotFoundException` would be a checked exception, and that's why the signature ends with `throws NotFoundException`
  - if a method calls another method that may throw a checked exception, it must either handle it (with try-catch), ***or*** declare the exception itself, since if it isn't caught locally it will be propagated up to callers

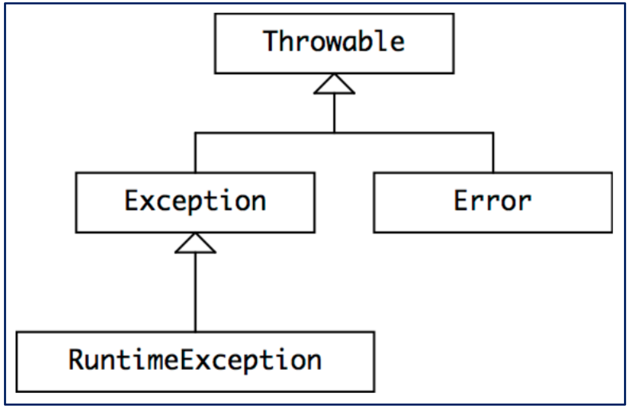
- So if you call `BirthdayBook`'s `lookup` method and *forget to handle* the `NotFoundException`, the compiler will **reject** your code
  - this is very useful, because it ensures that exceptions that are expected to occur will be handled

Checked and Unchecked Exceptions (3)

- ***Unchecked exceptions***, in contrast, are used to signal bugs
  - these exceptions are **not** expected to be handled by the code, except perhaps at the top level
  - we wouldn't want every method up the call chain to have to declare that it (might) throw all the kinds of bug-related exceptions that can happen at lower call levels: index out of bounds, null pointers, illegal arguments, assertion failures, etc
- As a result, for an unchecked exception the compiler will **not** check for `try-catch` or a `throws` declaration
  - Java *still allows* you to write a throws clause for an unchecked exception as part of a method signature, but this has ***no effect***, we don't recommend doing it

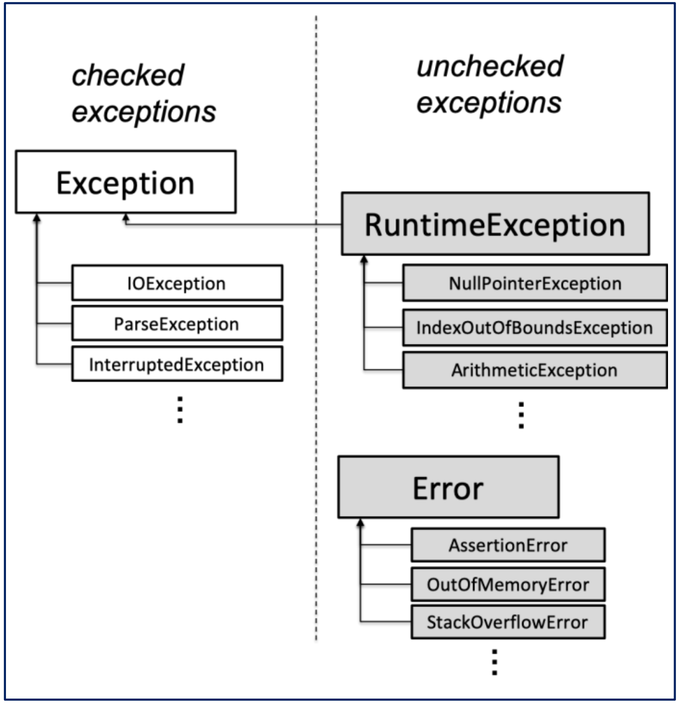
Java Exception Hierarchy

- To understand how Java decides whether an exception is checked or unchecked, let's look at the class hierarchy for Java exceptions
- **`Throwable`** is the class of objects that can be thrown or caught
    - `Throwable`'s implementation records a stack trace at the point where the exception was thrown, along with an optional string describing the exception
    - any object used in a `throw` or `catch` statement, or declared in the `throws` clause of a method, must be a subclass of `Throwable`



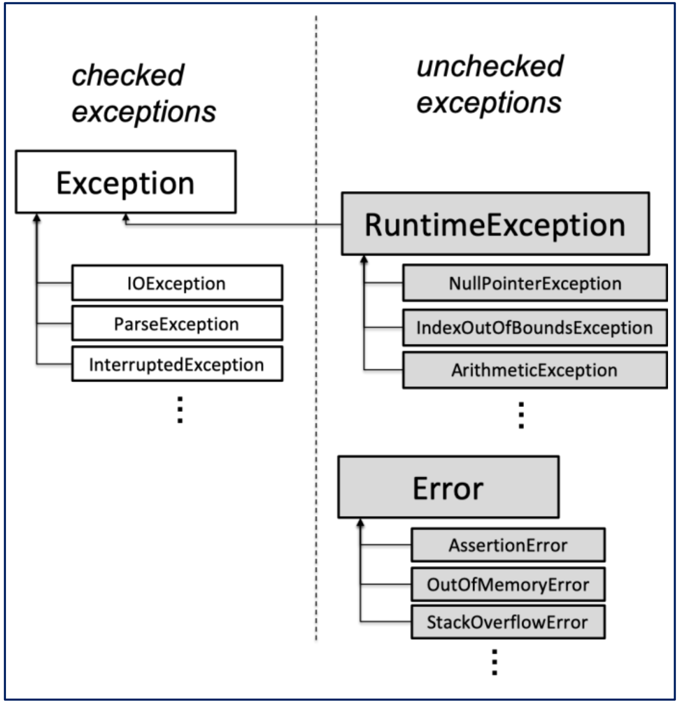
Checked vs Unchecked Exception in Java (1)

- `Exception` is the normal base class of **checked exceptions**
- The compiler applies ***static checking*** to methods using these exceptions
  - A checked exception ***must*** either be caught or declared when it's possible for it to be thrown



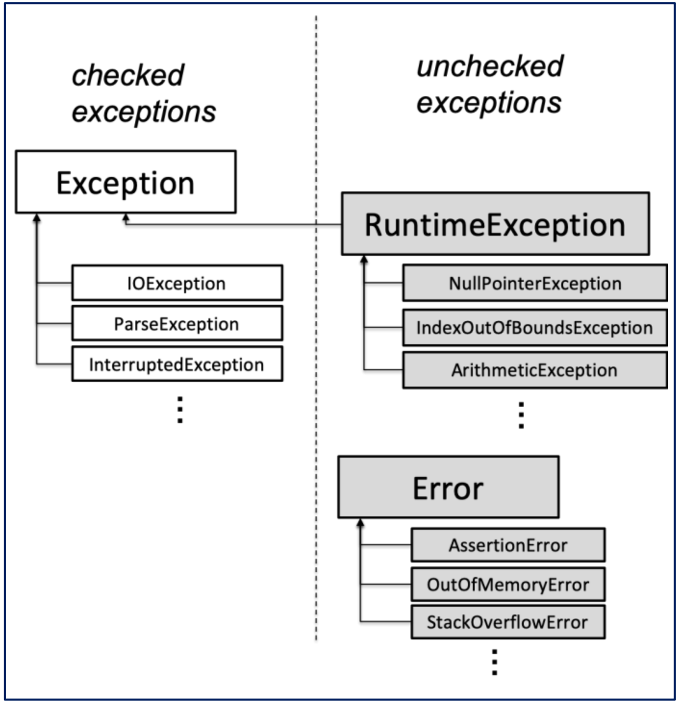
Checked vs Unchecked Exception in Java (2)

- However, **`RuntimeException`** and its subclasses are **unchecked exceptions**
- `RuntimeException` and its subclasses ***don't have to*** be declared in the throws clause of a method that throws them,
  - and ***don't have to*** be caught or declared by a caller of such a method



Checked vs Unchecked Exception in Java (3)

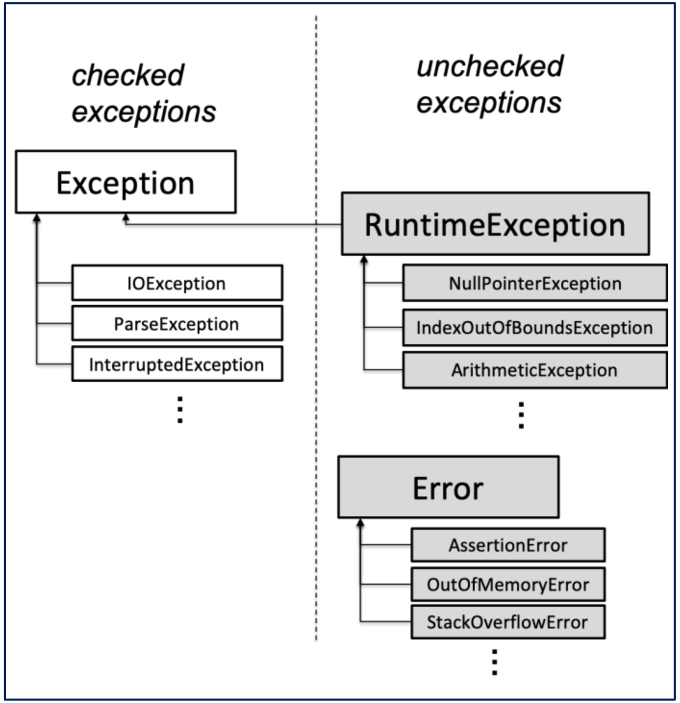
- In addition, **`Error`** and its subclasses are also **unchecked exceptions**
- This part of the hierarchy is reserved for errors produced by the Java runtime system, such as `StackOverflowError` and `OutOfMemoryError`
- For some reason `AssertionError` also extends `Error`, even though it indicates a bug in user code, not in the runtime
- Errors should be considered unrecoverable, and should ***not*** be caught by your code



Creating Exception

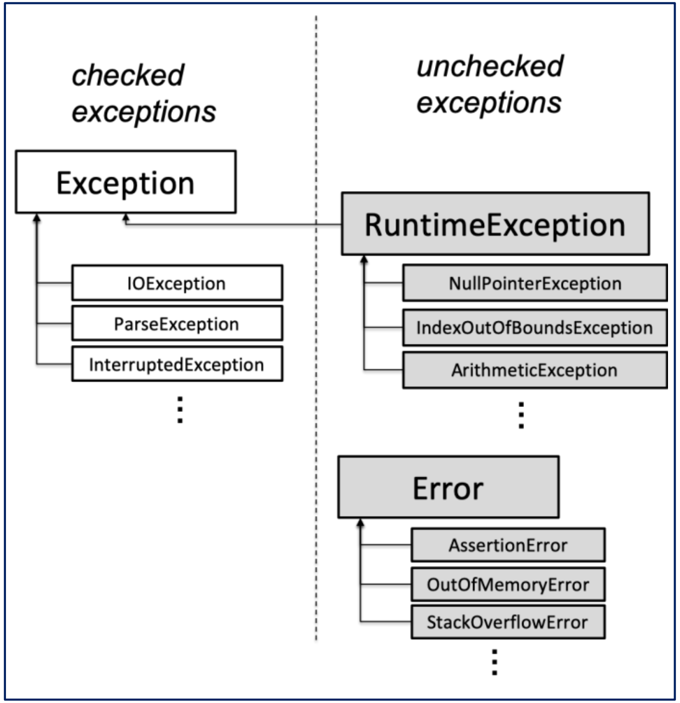
- When you define your own exceptions, ***you should either subclass*** **`Exception`** to make it an ***checked exception***,
  - ***or*** subclass **`RuntimeException`** to make it ***unchecked exception***

- ***Don't*** subclass `Error` or `Throwable`, because these are reserved by Java itself



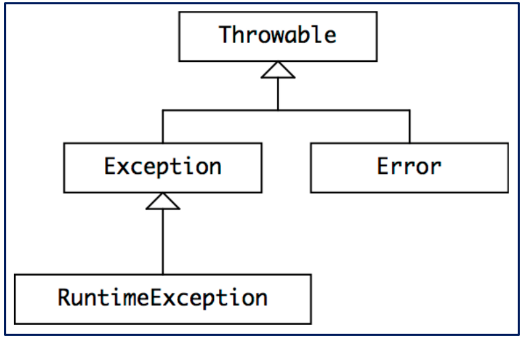
Catching Exception

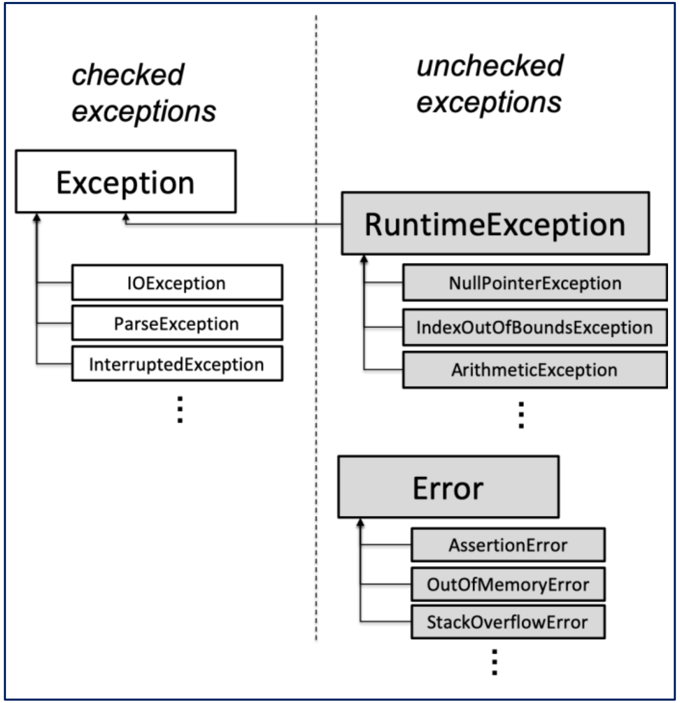
- When you catch an exception with a `try-catch` statement, you should catch the most specific exception class possible
- If you are expecting a `FileNotFoundException`, that’s what your catch statement should use
- Catching a broad class of exceptions, like `Exception` or `RuntimeException` or `Error`, is not safe from bugs or ready for change
  - because it catches ***every*** possible subclass of these exceptions, which may interfere with static checking and hide bugs



Java Exception Hierarchy

- One of the *confusing aspects* of the Java exception hierarchy is that `RuntimeException` is itself a subclass of `Exception`
- So the whole `Exception` family includes ***both*** *checked* exceptions (its direct descendants) ***and*** *unchecked* exceptions (the `RuntimeException` branch of the family)
- But `Error` is ***not*** a subclass of `Exception`, so all the *unchecked* `Error`-like exceptions are outside the `Exception` family





Exception Design Considerations (1)

- The rule we have given — use checked exceptions for special results (i.e., anticipated situations), and unchecked exceptions to signal bugs (unexpected failures) — makes sense, but it isn't the end of the story

- Exceptions in Java aren't as lightweight as they might be
  - They are expensive!

- Aside from the performance penalty, exceptions in Java incur another (more serious) cost: they're a pain to use, in both method design and method use
  - If you design a method to have its own (new) exception, you have to create a new class for the exception
  - If you call a method that can throw a checked exception, you have to wrap it in a try-catch statement (*even* if you know the exception will never be thrown)

Exception Design Considerations (2)

- Suppose, for example, you're designing a queue
  - Should *popping* the queue throw a checked exception when the queue is empty?
  - Suppose you want to support a style of programming in the client in which the queue is popped in a loop, until the exception is thrown
  - So you choose *a checked exception*
  - Now some client wants to use the method in a context in which, immediately prior to popping, the client *tests* whether the queue is empty and *only pops if it isn't*
  - That client will ***still need*** to wrap the call in a try-catch statement!

Exception Design Considerations (3)

- This suggests a more refined rule:
  - You should use an ***unchecked exception*** only to signal an *unexpected failure* (i.e. a bug),
    or if you *expect* that clients will *usually write code that ensures the exception will not happen*, because there is a convenient and inexpensive way to avoid the exception
  - Otherwise you should use a ***checked exception***

Exception Design Considerations (4)

- Here are some examples of applying this rule :
    - `Queue.pop()` throws an ***unchecked*** `EmptyQueueException` when the queue is empty
        - because it's reasonable to expect the caller to *avoid* this with a call like `Queue.size()` or `Queue.isEmpty()`
    - `Url.getWebPage()` throws a ***checked*** `IOException` when it can't retrieve the web page
        - because it's not easy for the caller to *prevent* this

Exception Design Considerations (5)

- `int integerSquareRoot(int x)` throws a ***checked*** `NotPerfectSquareException` when x has no integral square root,
  - because testing whether x is a perfect square is *just as hard* as finding the actual square root, so it's *not reasonable* to expect the caller to *prevent* it

- The cost of using exceptions in Java is one reason that many Java API's use the `null` reference as a special value
  - it's not a terrible thing to do, so long as it's done judiciously, and carefully specified

Declare Exceptions in Specification (1)

- Since an exception is a possible output from a method, it may have to be described in the postcondition for the method
- The Java way of documenting an exception as a postcondition is a `@throws` clause in the Javadoc comment
    - Recall that Java may also require the exception to be included in the method signature, using a `throws` declaration

- Exceptions that **signal a special result** (checked or unchecked) are always documented with a Javadoc **`@throws`** clause, specifying the conditions under which that special result occurs

Declare Exceptions in Specification (2)

- For a **checked exception**, Java also requires the exception to be mentioned in a throws declaration in the method signature
- For example, suppose `NotPerfectSquareException` were a checked exception; You would need to mention it in both `@throws` in the Javadoc and `throws` in the method signature:

```
/**
* Compute the integer square root.
* @param x value to take square root of
* @return square root of x
* @throws NotPerfectSquareException if x is not a perfect square
*/
int integerSquareRoot(int x) throws NotPerfectSquareException
```

Declare Exceptions in Specification (3)

- For an **unchecked exception** that signals a special result, Java allows but doesn't't require the throws clause; but it is better to omit the exception from the throws clause in this case, to avoid misleading a human programmer into thinking that the exception is checked
- For example, suppose you defined `EmptyQueueException` as an unchecked exception, then you should document it with `@throws`, but **not** include it in the method signature:

```java
/**
* Pops a value from this queue.
* @return next value in the queue, and removes the value from the queue
* @throws EmptyQueueException if this queue is empty
*/
int pop()
```

Declare Exceptions in Specification (4)

- Exceptions that **signal unexpected failures** – bugs in either the client or the implementation – are not part of the postcondition of a method, so they should **not** appear in either `@throws` or `throws`
- For example, `NullPointerException` *need never be* mentioned in a spec
  - an implicit precondition already disallows null values, which means that a valid implementation is free to throw it without any warning if a client ever passes a null value
- So this spec, for example, *never* mentions `NullPointerException`:

```
/**
 * @param list list of strings to convert to lower case
 * @return new list t, same length as list,
 *         where t[i] is list[i] converted to lowercase for all valid indices i
 */
static List<String> toLowerCase(List<String> list)
```

Abuse of Exceptions (1)

- Consider the following example from Effective Java, Joshua Bloch:

```
try {
    int i = 0;
    while (true)
        a[i++].f();
} catch (ArrayIndexOutOfBoundsException e) { }
```

- What does this code do?

  It is not at all obvious from inspection, and that's reason enough not to use it
  - The infinite loop terminates by throwing, catching, and ignoring an `ArrayIndexOutOfBoundsException` when it attempts to access the first array element outside the bounds of the array

Abuse of Exceptions (2)

- It is supposed to be equivalent to:

```
for (int i = 0; i < a.length; i++) {
    a[i].f();
}
```

- Or (using appropriate type `T`) to:

```
for (T x : a) {
    x.f();
}
```

- The exception-based idiom, Bloch writes:
  - … is a misguided attempt to improve performance based on the **faulty reasoning** that, since the VM checks the bounds of array accesses, the normal loop termination test (`i < a.length`) is redundant and should be avoided

Abuse of Exceptions (3)

- However, because exceptions in Java are designed for use only under exceptional circumstances, few, if any, JVM implementations attempt to optimize their performance
  - On a typical machine, the exception-based idiom runs 70 times slower than the standard one when looping from 0 to 99

- Much worse than that, the exception-based idiom is not even guaranteed to work!
  - Suppose the computation of `f()` in the body of the loop contains a bug that results in an out-of-bounds access to some unrelated array
  - What happens?
  - If a *reasonable loop idiom* were used, the bug would generate an uncaught exception, resulting in immediate thread termination with a full stack trace
  - If the *misguided exception-based loop* were used, the bug-related exception would be caught and misinterpreted as a normal loop termination!

Copy Constructor

- Copy constructor is a special constructor that takes as input another object of the same type and create a new object that is a copy of the input
  - the other object is usually called `other`
  - a copy here for a data structure usually means having the same elements

- Let us create a copy constructor for our running example, `SLList<T>`

Shallow Copy

- Suppose you code the Copy Constructor for `SLList<T>` as below

```
// Shallow Copy
// NOT what we want !
public SLList(SLList<T> other) {
    sentinel = other.sentinel;
    size = other.size;
}
```

you simply set the sentinel to point to other's sentinel and copy the size

- This is called **shallow copy** or **aliasing**
- Not what we want, because we want to create a new copy
  - while this is just having a new pointer to the old object, other
  - viewed another way, this is just giving the old object a new name / alias

Deep Copy

- What we want is to create an entirely new `SLList<T>`, with the exact same items as other
- This is called **deep copy**
  - The input and the copy output should be different objects
  - If you change other, the new `SLList<T>` you created should **not** change as well

SLList<T> Copy Constructor

- Here is the copy constructor for `SLList<T>` that correctly uses deep copy

```java
/** Creates a (deep) copy SLList of other. */
public SLList(SLList<T> other) {
    sentinel = new Node( i: null,  n: null);
    size = 0;

    Node p = sentinel;
    Node q = other.sentinel;
    while (q.next != null) {
        p.next = new Node(q.next.item,  n: null);
        p = p.next;
        q = q.next;
        size += 1;
    }
}
```

start with an empty list

create a new node and copy from other one-by-one

SLList<T> Copy Constructor 2

- Another way is to use methods that we have previously defined!

```java
/** Creates a (deep) copy SLList of other. */
public SLList(SLList<T> other) {
    this();

    Node q = other.sentinel;
    while (q.next != null) {
        this.addLast(q.next.item);
        q = q.next;
    }
}
```

call the empty constructor

use addLast to add the item from other one-by-one

NullPointerException

- If we try to copy a null, we will get a `NullPointerException`

```
// NullPointerException
SLList<String> listStr1 = null;
SLList<String> listStr2 = new SLList<>(listStr1);
listStr2.printList();
```

`NullPointerException` thrown when it tries to access sentinel of `null`

Unchecked IllegalArgumentException

- We can avoid that by using an unchecked exception `IllegalArgumentException`

```java
/**
 * Creates a deep copy SLList of other.
 * @param other an SLList object
 * @throws IllegalArgumentException if other is null
 */
public SLList(SLList<T> other) {

    if (other == null) {
        throw new IllegalArgumentException("other is null");
    }

    sentinel = new Node( i: null,  n: null);
    size = 0;

    Node p = sentinel;
    Node q = other.sentinel;
    while (q.next != null) {
        this.addLast(q.next.item);
        q = q.next;
    }
}
```

no need to advertise

check the throwing condition

pass a message

Catching IllegalArgumentException

- The exception can be caught in `main`
  - note that without try-catch the code still compiles, since we use an unchecked exception

```java
// Try-Catch IllegalArgumentException
SLList<String> listStr1 = null;
try {
    SLList<String> listStr2 = new SLList<>(listStr1);
} catch (IllegalArgumentException iae) {
    System.out.println("Copy failed, " + iae.getMessage());
}
```

print a message to help identify why the exception happened

Test Exception is Thrown

- We can use try-catch in JUnit and test for the string output
- Alternatively, we can test as follows:

use the optional 'expected' attribute of Test annotation

```
@Test(expected = IllegalArgumentException.class)
public void testIllegalArgumentExceptionNullCopy() {
    SLList<String> listStr1 = null;
    SLList<String> listStr2 = new SLList<>(listStr1);
}
```

Checked EmptySLListException

- Say we don't allow copy from an empty SLList, and want to enforce it
- We define our own checked exception :

```java
public class EmptySLListException extends Exception {

    private String name;

    public EmptySLListException (String name) {
        super(name);
        this.name = name;
    }

    @Override
    public String getMessage() {
        return name + " is empty, " + super.getMessage();
    }

}
```

inherit `Exception` functionality

pass the parameter to `Exception`

override the `getMessage()` method of `Exception`

call the overriden `getMessage()` method of `Exception`

Throws EmptySLListException

```java
/**
 * Creates a deep copy SLList of other.
 * @param other an SLList object
 * @throws IllegalArgumentException if other is null
 * @throws EmptySLListException if other is empty
 */
public SLList(SLList<T> other) throws EmptySLListException {

    if (other == null) {
        throw new IllegalArgumentException("other is null");
    }

    if (other.size() == 0) {
        throw new EmptySLListException("other");
    }

    sentinel = new Node( i: null,  n: null);
    size = 0;

    Node p = sentinel;
    Node q = other.sentinel;
    while (q.next != null) {
        this.addLast(q.next.item);
        q = q.next;
    }
}
```

must advertise

pass the parameter name

Gotta catch 'em all

```
// Try-Catch IllegalArgumentException and EmptySLListException
SLList<String> listStr1 = new SLList<>();
try {
    SLList<String> listStr2 = new SLList<>(listStr1);
} catch (IllegalArgumentException iae) {
    System.out.println("Copy failed, " + iae.getMessage());
} catch (EmptySLListException ese) {
    System.out.println("Cannot copy, " + ese.getMessage());
}
```

must handle the checked exception (since we don't throw it)

try by yourself if you set EmptySLListException to be unchecked!

Thank you for your attention !

- In this lecture, you have learned to:
  - use or not use null values
  - know the difference between checked and unchecked exceptions in Java
  - use exceptions to signal special results
  - write a copy constructor doing deep copy

- Please continue to Lecture Quiz 6 and Lab 6:
  - to do Lab Exercise 6.1 - 6.3, and
  - to do Exercise 6.1 - 6.3