CSE 331
Software Design & Implementation

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Fall 2022

Exceptions and Assertions

Outline

- General concepts about dealing with errors and failures
- Assertions: what, why, how
  - for things you believe will/should never happen
- Exceptions: what, how
  - how to throw, catch, and declare exceptions in Java
  - subtyping of exceptions
  - checked vs. unchecked exceptions
- Exceptions: why *in general*
  - for things you believe are bad and should rarely happen
  - and many other style issues
- Alternative with trade-offs: Returning special values
- Summary and review

Not all “errors” should be failures

Some “error” cases:

1. Misuse of your code
   - e.g., precondition violation
   - **should** be a failure (i.e., made visible to the user)

2. Errors in your code vs reasoning
   - e.g., representation invariant fails to hold
   - **should** be a failure

3. Unexpected resource problems
   - e.g., missing file, server offline, …
   - not an error in the sense above (... these are not bugs)
   - **should not** be a failure (i.e., do try to recover)

What to do when failing

Fail fast and fail friendly

Goal 1: *Prevent harm*

- stop before anything worse happens
- (do still need to perform cleanup: close open resources etc.)

Goal 2: *Give information about the problem*

- failing quickly helps localize the defect
- a good error message is important for debugging

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Square root

```
// requires: x >= 0
// returns: approximation to square root of x
public double sqrt(double x) {
  ...
}
```

Square root with assertion

```
// requires: x >= 0
// returns: approximation to square root of x
public double sqrt(double x) {
  assert x >= 0.0;
  double result;
  … compute result …
  assert Math.abs(result*result – x) < .0001;
  return result;
}
```

- These two assertions serve different purposes

(Note: the Java library Math.sqrt method returns NaN for x<0. We use different specifications in this lecture as examples.)

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Square root, specified for all inputs

```
// throws: NegativeArgumentException if x < 0
// returns: approximation to square root of x
public double sqrt(double x)
    throws NegativeArgumentException {
  if (x < 0)
    throw new NegativeArgumentException();
  …
}
```

- `throws` is part of a method signature: “it might happen”
  - comma-separated list
  - like @modifies, promises are in what is **not listed**
- `throw` is a statement that actually causes exception-throw
  - immediate control transfer [like `return` but different]

Using try-catch to handle exceptions

```
public double sqrt(double x)
    throws NegativeArgumentException
  …
```

Client code:

```
try {
  y = sqrt(…);
  ... other statements ...
} catch (NegativeArgumentException e) {
  e.printStackTrace(); // or other actions
}
```

- Handled by nearest *dynamically* enclosing **`try/catch`**
  - top-level default handler: print stack trace & crash

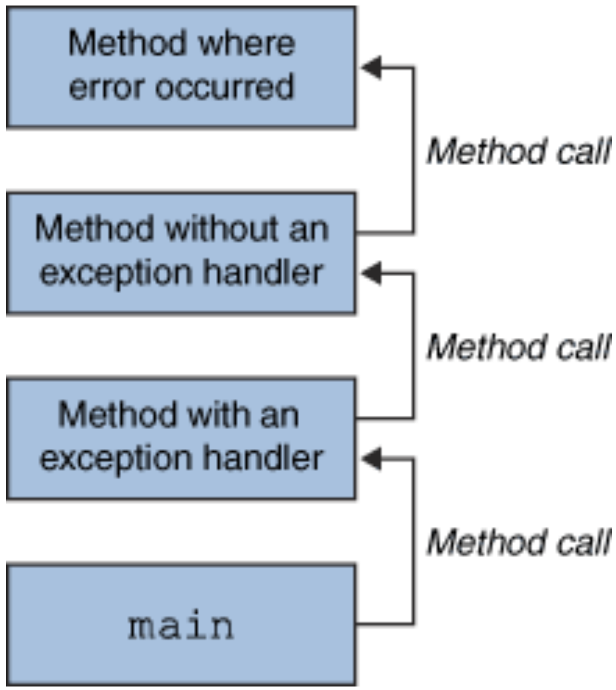
Catching with inheritance

```
try {
   code…
} catch (FileNotFoundException fnfe) {
   code to handle a file not found exception
} catch (IOException ioe) {
   code to handle any other I/O exception
} catch (Exception e) {
   code to handle any other exception
}
```

- A **`SocketException`** would match the second block
- An **`ArithmeticException`** would match the third block
- (Subsequent catch blocks need not be supertypes like this)

Throwing and catching

- Executing program has a stack of currently executing methods
  - dynamic: reflects runtime order of method calls
  - no relation to static nesting of classes, packages, etc.
- When an exception is thrown, control transfers to nearest method with a *matching* catch block
  - if none found, top-level handler used
- Exceptions allow *non-local* error handling
  - a method many levels up the stack can handle a deep error



Code Paths with Exceptions

Three potential paths through the code below:

```
try {
  y = foo(…);
  … more code …
} catch (Type name) {
  … code to handle the exception …
}
```

1. sqrt returns normally
2. sqrt throws an exception caught by this catch
3. sqrt throws an exception not caught here

The `finally` block

`finally` block is always executed

- whether an exception is thrown or not

```
try {
  y = foo(…);
  … more code …
} catch (Type name) {
  … code to handle the exception …
} finally {
  … code to run after the try or catch finishes
}
```

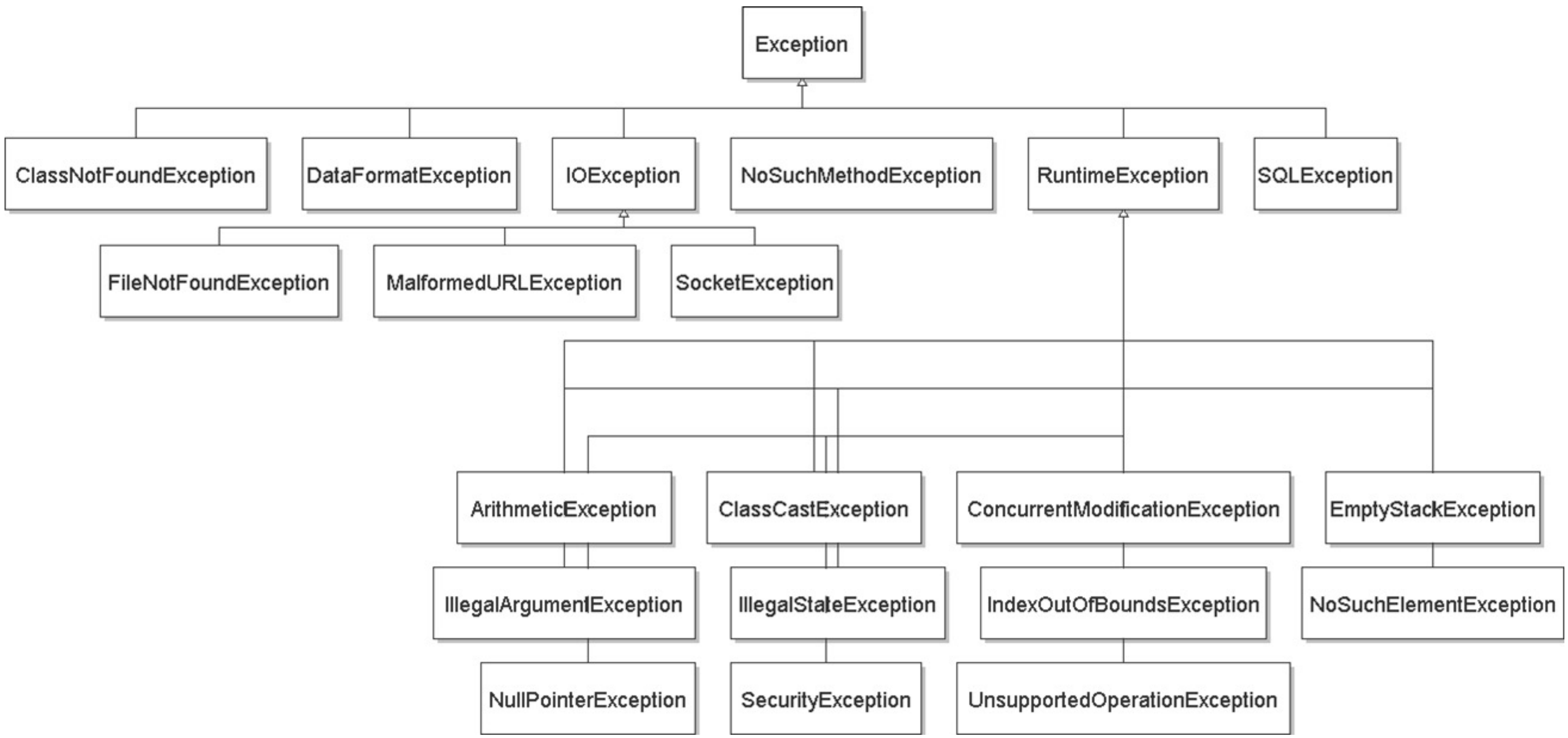
What `finally` is for

`finally` is used for common “must-always-run” or “clean-up” code

- avoids duplicated code in catch branch[es] and after
- avoids having to catch all exceptions

```
try {
  // ... write to out;  might throw exception
} catch (IOException e) {
  System.out.println("Caught IOException: "
                     + e.getMessage());
} finally {
  out.close();
}
```

(Abridged) Exception Hierarchy



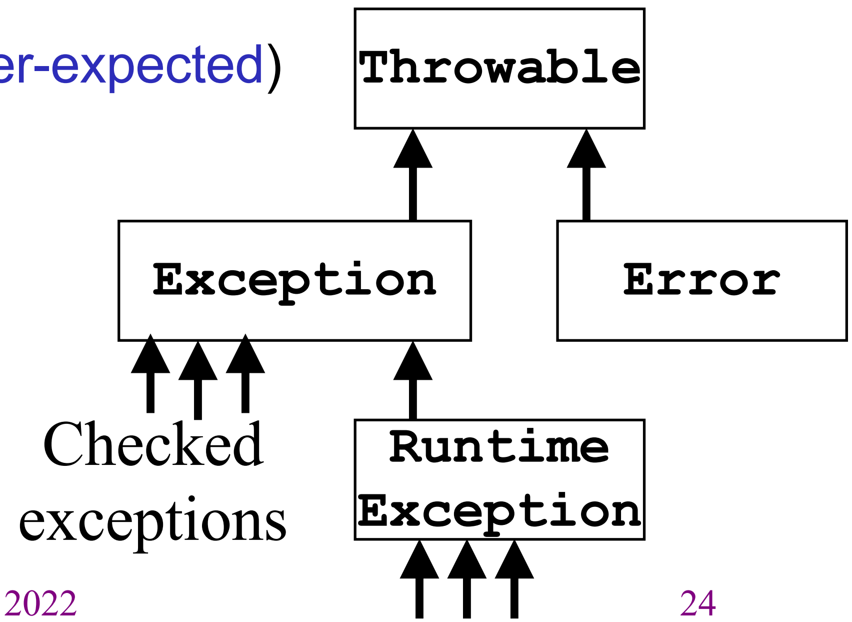
Java's checked/unchecked distinction

Checked exceptions (*style*: for *special cases / abnormal cases*)

- **callee** must declare in signature (else type error)
- **client** must either catch or declare (else type error)
  - even if you can prove it will never happen at run time, the type system does not "believe you"
- guaranteed to be a matching enclosing catch *at runtime*

Unchecked exceptions (*style*: for never-expected)

- **library** has no need to declare
- **client** has no need to catch
- these are subclasses of:
  - **`RuntimeException`**
  - **`Error`** (rarely caught)



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Two distinct uses of exceptions

- Errors that should be failures
  - unexpected (ideally, should not happen at all)
  - should be rare with high quality client and library
  - can be the client's fault or the library's
  - often unrecoverable

- Special cases (a.k.a. exceptional cases)
  - expected, just not the common case
  - possibly unpredictable or unpreventable by client

Handling exceptions

- Errors that should be failures
  - usually can't recover
  - unchecked exceptions the better choice (avoids much work)
  - if condition not checked, exception propagates up the stack
    - top-level handler prints the stack trace

- Special cases
  - take special action and continue computing
  - should always check for this condition
  - should handle locally by code that knows how to continue
  - checked exceptions the better choice

Checked vs. unchecked

- No perfect answer to the question "should clients be forced to catch (or declare they throw) this exception?"
  - Java provided both options
- Advantages to checked exceptions:
  - Static checking of callee: only declared exceptions are thrown
  - Static checking of caller: exception is caught or declared
- Disadvantages:
  - impedes implementations and overrides (can't add exceptions)
    - prevents truly giving *no promises* when @requires is false
  - often in your way when prototyping
  - have to catch or declare even if the exception is not possible

Propagating an exception

```
// returns: x such that ax^2 + bx + c = 0
// throws: NegativeArgumentException if no real soln exists
double solveQuad(double a, double b, double c)
    throws NegativeArgumentException {
  // No need to catch exception thrown by sqrt
  return (-b + sqrt(b*b - 4*a*c)) / (2*a);
}
```

Aside: does "**negative argument**" make sense to the caller?

Why catch exceptions locally?

Problems:

1. Failure to catch exceptions often violates modularity
   - call chain: A `->` IntSet.insert `->` IntList.insert
   - IntList.insert throws some exception
     - implementer of IntSet.insert knows how list is being used
     - implementer of A may not even know that IntList exists
2. Possible that a method on the stack may think that it is handling an exception raised by a different call

Alternative: catch it and throw again
   - "chaining" or "translation"
   - do this even if the exception is better handled up a level
   - makes it clear to reader of code that it was not an omission

Exception translation

```
// returns: x such that ax^2 + bx + c = 0
// throws: NotRealException if no real solution exists
double solveQuad(double a, double b, double c)
                                       throws NotRealException {
  try {
    return (-b + sqrt(b*b - 4*a*c)) / (2*a);
  } catch (NegativeArgumentException e) {
    throw new NotRealException(); // "chaining"
  }
}

class NotRealException extends Exception {
  NotRealException() { super(); }
  NotRealException(String message) { super(message); }
  NotRealException(Throwable cause) { super(cause); }
  NotRealException(String msg, Throwable c) { super(msg, c); }
}
```

Don’t ignore exceptions

Effective Java Tip: Don't ignore exceptions

Empty catch block is poor style

sometimes okay inside of an exception handler

```
try {
  readFile(filename);
} catch (IOException e) {}  // silent failure
```

At a minimum, print out the exception so you know it happened

- and exit if that’s appropriate for the application

```
} catch (IOException e) {
  e.printStackTrace();
  System.exit(1);
}
```

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Informing the client of a problem

Special value:

- `null` for `Map.get`
- `-1` for `indexOf`
- `NaN` for `sqrt` of negative number

Advantages:

- can be less verbose than try/catch machinery

Disadvantages:

- error-prone: callers forget to check, forget spec, etc.
- need "extra" result: doesn't work if every result could be real
    - example: if a map could store `null` keys
- has to be propagated manually one call at a time

General Java style advice: exceptions for exceptional conditions

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Exceptions: review

Use an assertion for internal consistency checks that should not fail

- when checking at runtime is possible

Use <u>only</u> a precondition when

- used in a context in which calls can be checked via reasoning
- but checking at runtime would be prohibitive
  - e.g., requiring that a list be sorted

Use an exception when

- used in a dynamic / unpredictable context (client can't predict)
- for exceptional cases only

Use a special value when

- it is a common case (not really exceptional)
- clients are likely (?) to remember to check for it

Exceptions: review, continued

Use *checked* exceptions most of the time
- static checking is helpful! (**tools**, inspection, & testing)

Avoid checked exceptions if there is probably no way to recover

Handle exceptions sooner rather than later

Good reference: Effective Java chapter
- a whole chapter: exception-handling design matters!