CSE 331
Software Design & Implementation

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Exceptions and Assertions

(Based on slides by Mike Ernst, Dan Grossman, David Notkin, Hal Perkins)

Outline

- General concepts about dealing with errors and failures
- Assertions: what, why, how
  - For things you believe will/should never happen
- Exceptions: what, how *in Java*
  - How to throw, catch, and declare exceptions
  - 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

Failure causes

Partial failure is inevitable

- Goal: prevent complete failure
- Structure your code to be reliable and understandable

Some failure causes:

1. Misuse of your code
   - Precondition violation

2. Errors in your code
   - Bugs, representation exposure, …

3. Unpredictable external problems
   - Out of memory, missing file, …

What to do when something goes wrong

Fail early, fail friendly

Goal 1: *Give information about the problem*

- To the programmer – a good error message is key!
- To the client code: via exception or return-value or …

Goal 2: *Prevent harm*

Abort: inform a human

- Perform cleanup actions, log the error, etc.

Re-try:

- Problem might be transient

Skip a subcomputation:

- Permit rest of program to continue

Fix the problem?

- *Usually* infeasible to repair from an unexpected state

Avoiding errors

A precondition prohibits misuse of your code

- Adding a precondition weakens the spec

This ducks the problem of errors-will-happen

- Mistakes in your own code
- Misuse of your code by others

Removing a precondition requires specifying more behavior

- Often a good thing, but there are tradeoffs
- Strengthens the spec
- Example: specify that an exception is thrown

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Defensive programming

Check:

- Precondition
- Postcondition
- Representation invariant
- Other properties that you know to be true

Check *statically* via reasoning and tools

Check *dynamically* via assertions

```
assert index >= 0;
assert items != null : "null item list argument"
assert size % 2 == 0 : "Bad size for " +
                           toString();
```

- Write assertions as you write code
- Include descriptive messages

Enabling assertions

In Java, assertions can be enabled or disabled at runtime without recompiling

Command line:

`java –ea` runs code with assertions enabled

`java` runs code with assertions disabled (default)

Eclipse:

Select Run>Run Configurations… then add **`-ea`** to VM arguments under (x)=arguments tab

(These tool details were covered in section already)

When *not* to use assertions

Don't clutter the code with useless, distracting repetition

```
x = y + 1;
assert x == y + 1;
```

Don't perform side effects

```
assert list.remove(x); // won't happen if disabled

// Better:
boolean found = list.remove(x);
assert found;
```

Turn them off in rare circumstances (production code(?))

– Most assertions better left enabled

`assert` and **`checkRep()`**

CSE 331's **`checkRep()`** is another dynamic check

Strategy: use **`assert`** in **`checkRep()`** to test and fail with meaningful traceback/message if trouble found

- Be sure to enable asserts when you do this!

Asserts should be enabled always for CSE 331 projects

- We will enable them for grading

Expensive `checkRep()` tests

Detailed checks can be too slow in production

But complex tests can be very helpful, particularly during testing/debugging (let the computer find problems for you!)

No perfect answers; suggested strategy for **`checkRep`**:

- Create a static, global “debug” or “debugLevel” variable
- Run expensive tests when this is enabled
- Turn it off in graded / production code if tests are too expensive

Often helpful: put expensive / complex tests in separate methods and call as needed

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 very different purposes

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Square root, specified for all inputs

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

- `throws` is part of a method signature: "it might happen"
  - Comma-separated list
- `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 IllegalArgumentException
  …
```

Client code:

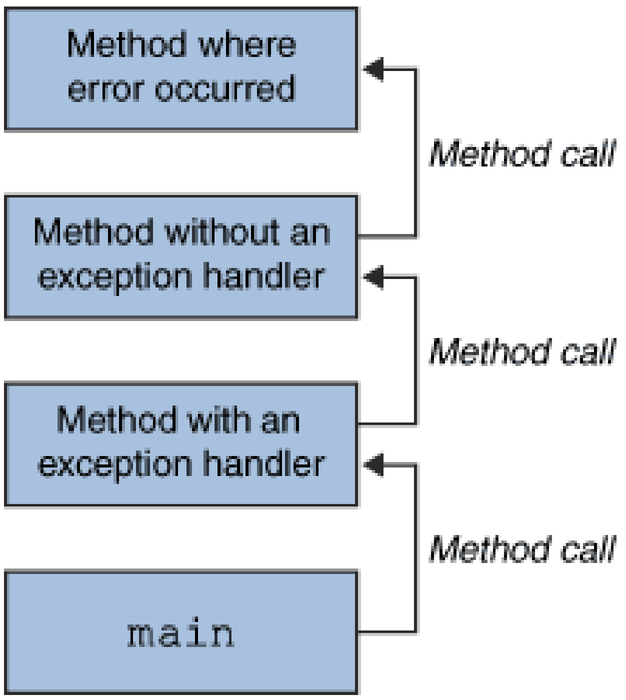
```
try {
  y = sqrt(…);
} catch (IllegalArgumentException e) {
  e.printStackTrace(); //and/or take other actions
}
```

Handled by nearest *dynamically* enclosing **`try/catch`**

- Top-level default handler: stack trace, program terminates

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 prints stack trace and terminates
- Exceptions allow *non-local* error handling
  - A method many levels up the stack can handle a deep error

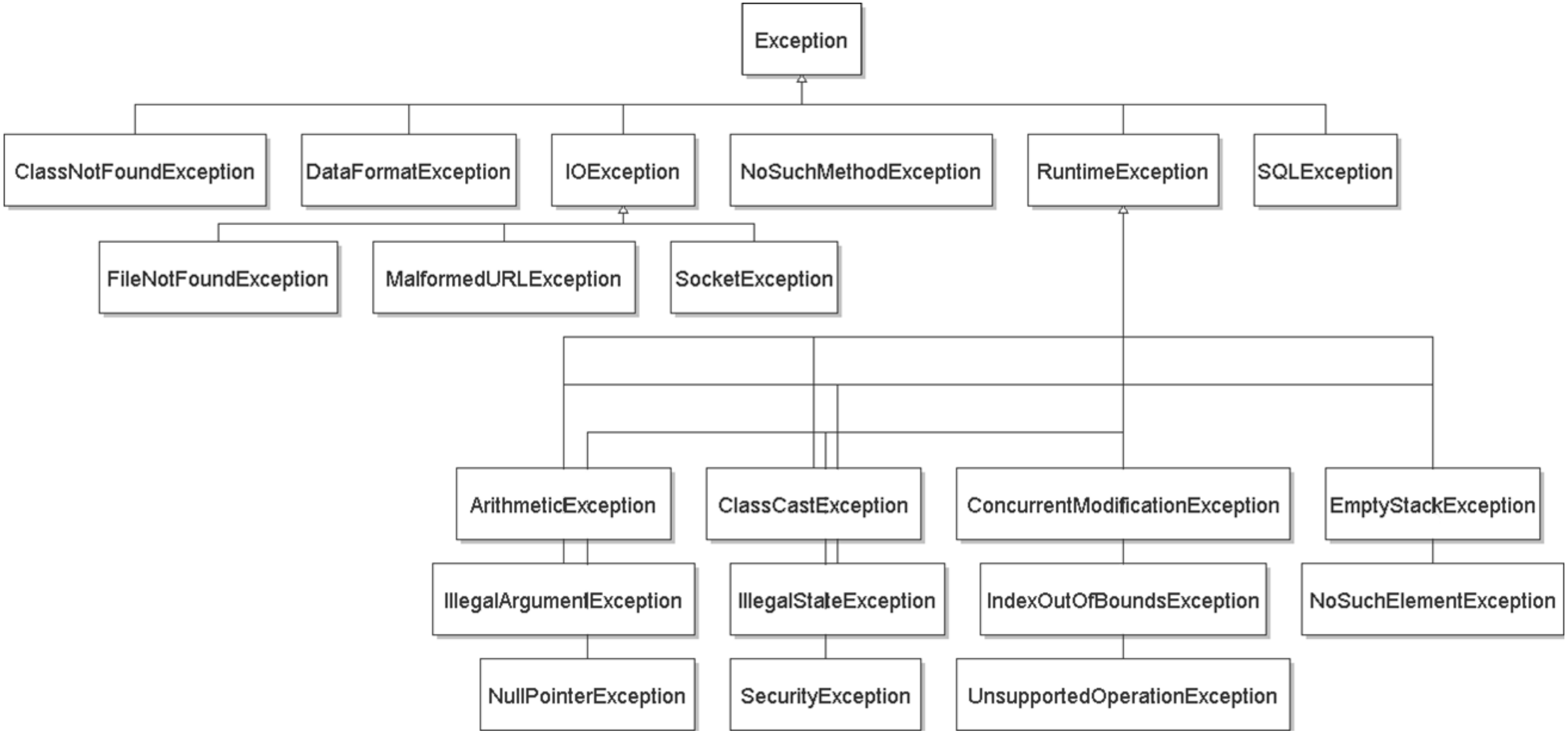


Catching with inheritance

```
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

Exception Hierarchy



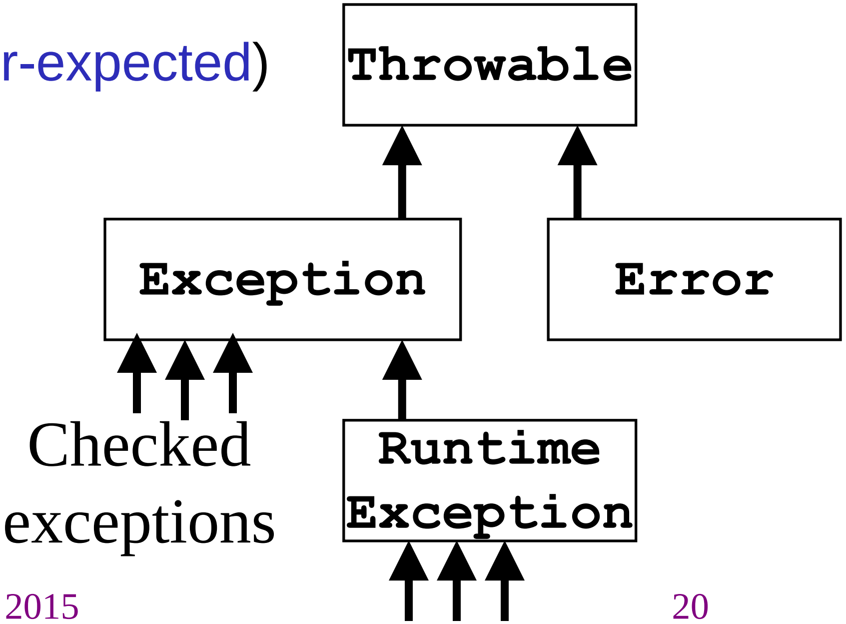
Java's checked/unchecked distinction

Checked exceptions (*style*: for *special 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"
- There is guaranteed to be a dynamically enclosing catch

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

- Library: No need to declare
- Client: No *need* to catch
- Subclasses of **`RuntimeException`** and **`Error`**



Checked vs. unchecked

- No perfect answer to “should possible exceptions thrown” be part of a method signature
  - So Java provided both
- Advantages to checked exceptions:
  - Static checking of callee ensures no other checked exceptions get thrown
  - Static checking of caller ensures caller does not forget to check
- Disadvantages:
  - Impedes implementations and overrides
  - Often in your way when prototyping
  - Have to catch or declare even in clients where the exception is not possible

The `finally` block

`finally` block is always executed

- Whether an exception is thrown or not

```
try {
  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();
}
```

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Propagating an exception

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

Aside: How can clients know if a set of arguments
to **`solveQuad`** is illegal?

Why catch exceptions locally?

Failure to catch exceptions usually violates modularity

- Call chain: A $\rightarrow$ IntegerSet.insert $\rightarrow$ IntegerList.insert
- IntegerList.insert throws some exception
  - Implementer of IntegerSet.insert knows how list is being used
  - Implementer of A may not even know that IntegerList exists

Method on the stack may think that it is handling an exception raised by a different call

Better 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 (IllegalArgumentException 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); }
}
```

Exceptions as non-local control flow

```
void compile() {
  try {
    parse();
    typecheck();
    optimize();
    generate():
  } catch (RuntimeException e) {
    Logger.log("Failed: " + e.getMessage());
  }
}
```

– Not common – usually bad style, particularly at small scale
– Java/C++, etc. exceptions are expensive if thrown/caught
– Reserve exceptions for exceptional conditions

Two distinct uses of exceptions

- Failures
  - Unexpected
  - Should be rare with well-written client and library
  - Can be the client's fault or the library's
  - Usually unrecoverable

- Special results
  - Expected but not the common case
  - Unpredictable or unpreventable by client

Handling exceptions

- Failures
  - Usually can’t recover
  - If condition not checked, exception propagates up the stack
  - The top-level handler prints the stack trace
  - Unchecked exceptions the better choice (else many methods have to declare they could throw it)

- Special results
  - 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 (encourages local handling)

Don’t ignore exceptions

Effective Java Tip #65: Don't ignore exceptions

Empty catch block is (common) poor style – often done to get code to compile despite checked exceptions

- Worse reason: to silently hide an error

```
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:

- For a normal-ish, common case, it “is” the result
- Less verbose clients 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

- Up for debate if **`indexOf`** not-present-value is exceptional

Special values in C/C++/others

- For errors and exceptional conditions in Java, use exceptions!
- But C doesn't have exceptions and some C++ projects avoid them
- Over decades, a common idiom has emerged
  - Error-prone but you can get used to it ☹
  - Affects how you read code
  - Put "results" in "out-parameters"
  - Result is a boolean (int in C) to indicate success or failure

```
type result;
if(!computeSomething(&result)) { … return 1; }
// no "exception", use result
```

- Bad, but less bad than error-code-in-global-variable

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Exceptions: review

Use an exception when
- Used in a broad or unpredictable context
- Checking the condition is feasible

Use a precondition when
- Checking would be prohibitive
  - E.g., requiring that a list be sorted
- Used in a narrow context in which calls can be checked

Use a special value when
- It is a reasonable common-ish situation
- Clients are likely (?) to remember to check for it

Use an assertion for internal consistency checks that should not fail

Exceptions: review, continued

Use *checked* exceptions most of the time

- Static checking is helpful

But maybe avoid checked exceptions if possible for many callers to *guarantee* exception cannot occur

Handle exceptions sooner rather than later

Not all exceptions are errors

- Example: File not found

Good reference: Effective Java, Chapter 9

- A whole chapter? Exception-handling design matters!