CSE 331
Software Design & Implementation

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Exceptions and Assertions

(Slides by Mike Ernst and David Notkin)

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, many more
3. Unpredictable external problems
    Out of memory
    Missing file
    Memory corruption
How would you categorize these?
    Failure of a subcomponent
    No return value (e.g., list element not found, division by zero)

Avoiding errors

A precondition prohibits misuse of your code

- Adding a precondition weakens the spec

This ducks the problem

- Does not address errors in your own code
- Does not help others who are misusing your code

Removing the precondition requires specifying the behavior

- Strengthens the spec
- Example: specify that an exception is thrown

Defensive programming

Check

- precondition
- postcondition
- representation invariant
- other properties that you know to be true

Check statically via reasoning (& tools)

Check dynamically at run time via assertions

```
assert index >= 0;
assert size % 2 == 0 : "Bad size for " +
                               toString();
```

Write the assertions as you write the code

When *not* to use assertions

Don't clutter the code

```
x = y + 1;
assert x == y + 1;
```
// useless, distracting

Don't perform side effects

```
assert list.remove(x); // modifies behavior if disabled

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

Turn them off in rare circumstances (e.g., production code(?))

- "**`java -ea`**" runs Java with **a**ssertions **e**nabled
- "**`java`**" runs Java with assertions disabled (default)
- Most assertions should always be enabled

What to do when something goes wrong

Something goes wrong: an assertion fails (or would have failed if it were there)

Fail early, fail friendly

Goal 1: Give information about the problem

- To the programmer
  - A good error message is key!
- To the client code

Goal 2: Prevent harm from occurring

- 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)
  - External problem: no hope; just be informative
  - Internal problem: if you can fix, you can prevent

Square root without exceptions

```
// 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) {
  double result;
  ... // compute result
  assert (Math.abs(result*result – x) < .0001);
  return result;
}
```

Square root, specified for all inputs; Using try-catch

```
// 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();
  ...
}
```

Client code:

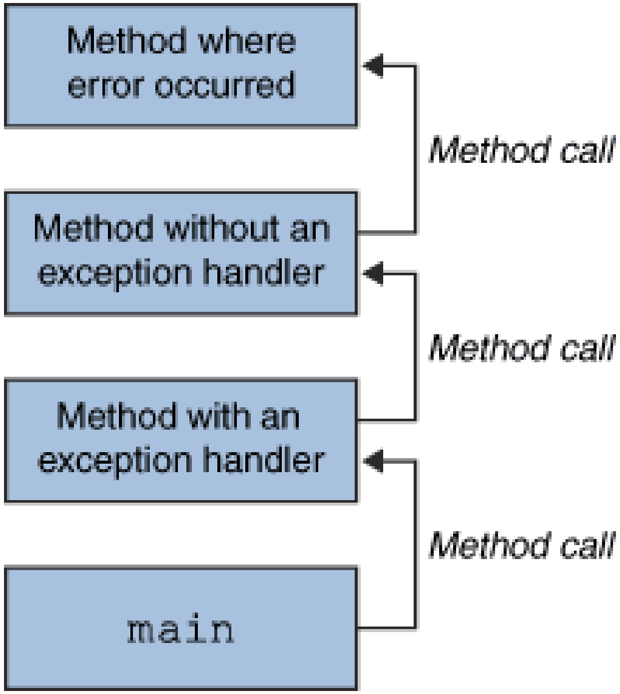
```
try {
  y = sqrt(-1);
} catch (IllegalArgumentException e) {
  e.printStackTrace(); // or take some other action
}
```

Handled by catch associated with nearest dynamically enclosing try

Top-level default handler: stack trace, program terminates

Throwing and catching

- At any time, your program has an active call stack of methods
  - The call stack is **not** the same as nesting of classes or packages or such – it reflects which methods called which methods during this specific execution
- When an exception is thrown, the JVM looks up the call stack until it finds a method with a matching catch block for it
  - If one is found, control jumps back to that method
  - If none is found, the program crashes
- Exceptions allow non-local error handling
  - A method many levels up the stack can handle a deep error



The finally block

```
try {
  code…
} catch (type name) {
    code… to handle the exception
} finally {
    code… to run after the try or catch finishes
}
```

finally is often used for common “clean-up” code

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

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);
}
```

How can clients know if a set of arguments to solveQuad is illegal?

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();
  }
}

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

Exception chaining:

```
throw new NotRealException(e);
```

Exceptions as non-local control flow

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

Not common – you'd better have a good reason for this

Informing the client of a problem

Special value

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

Problems with using special value

- Hard to distinguish from real results
- Error-prone: what if the programmer forgets to check result?
  - The value should not be legal – should cause a failure later
- Ugly
- Less efficient

A better solution: exceptions

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
- Unpredictable or unpreventable by client

Handling exceptions

Failures

- Usually can’t recover
- If the condition is not checked, the exception propagates up the stack
- The top-level handler prints the stack trace

Special results

- Take special action and continue computing
- Should always check for this condition
- Should handle locally

Why catch exceptions locally?

Failure to catch exceptions violates modularity

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

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

Better alternative: catch it and throw it 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

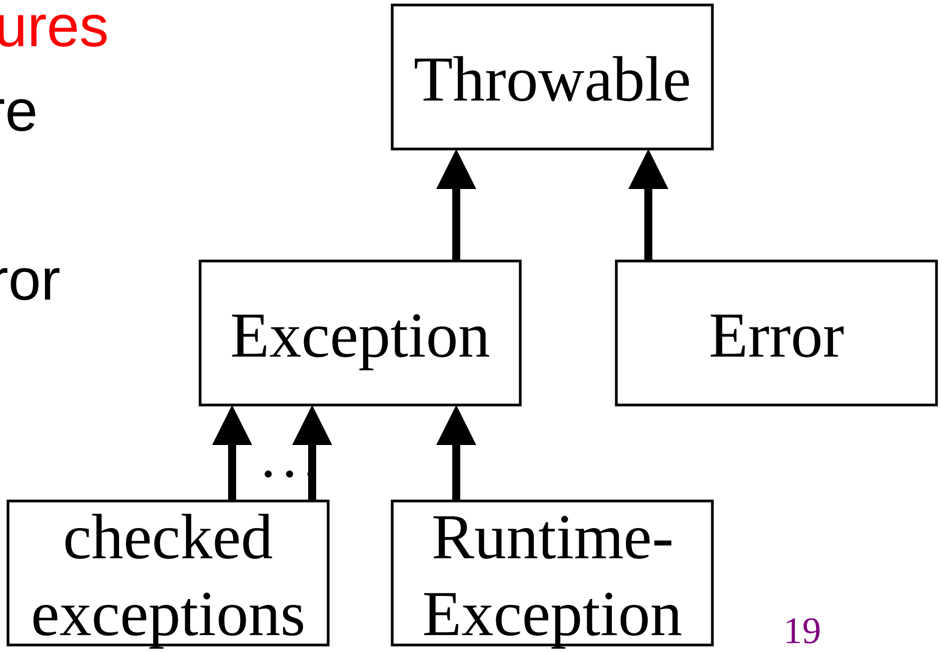
Java exceptions for failures and for special cases

Checked exceptions for special cases

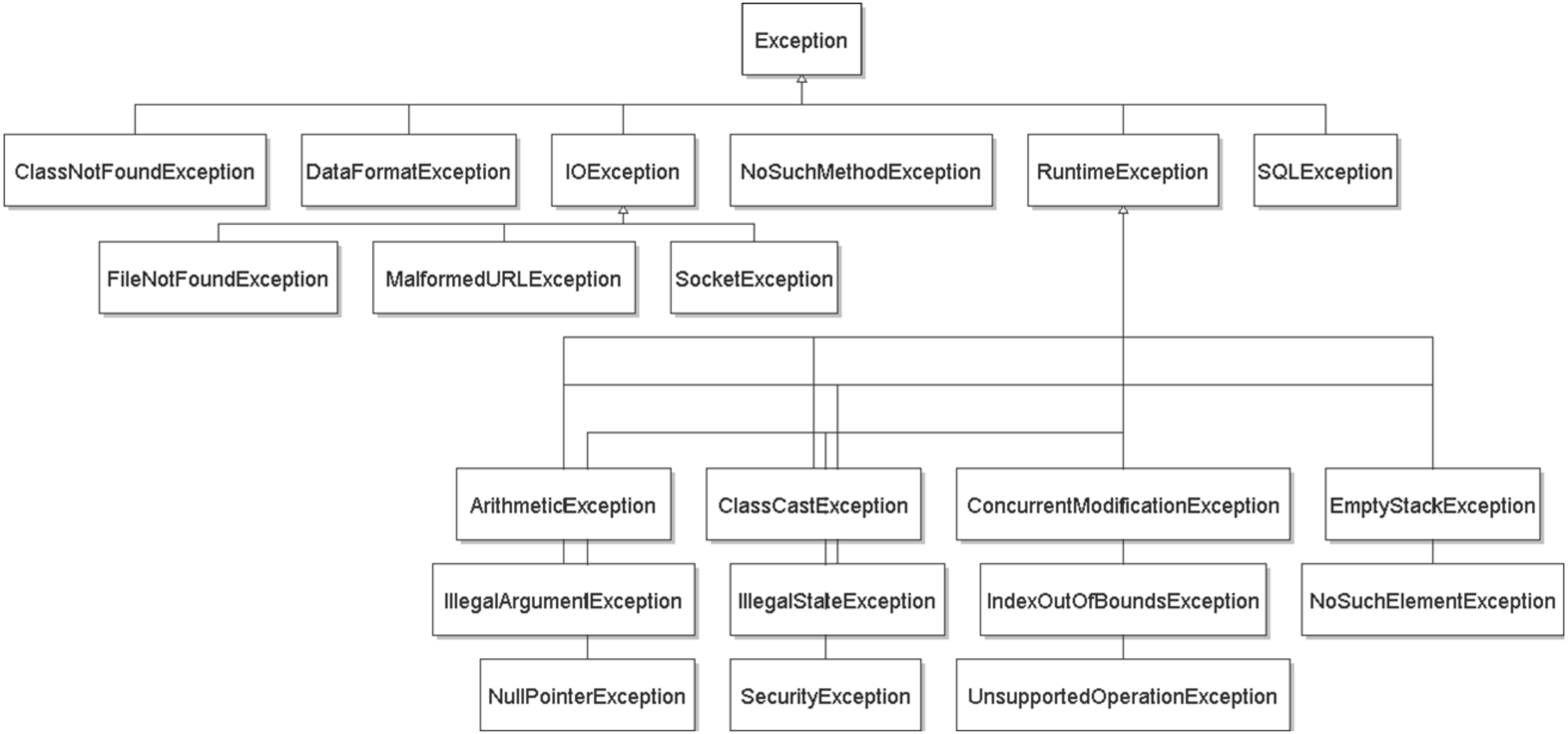
- Library: must declare in signature
- Client: must either catch or declare
    - Even if you can prove it will never happen at run time
- There is guaranteed to be a dynamically enclosing catch

Unchecked exceptions for failures

- Library: no need to declare
- Client: no need to catch
- RuntimeException and Error
    - and their subclasses



exception hierarchy



Catching with inheritance

```
try {
  code…
} catch (FileNotFoundException fnfe) {
    code… to handle the 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

Avoid proliferation of checked exceptions

Unchecked exceptions are better if clients will usually write code that ensures the exception will not happen

- There is a convenient and inexpensive way to avoid it
- The exception reflects unanticipatable failures

Otherwise use a checked exception

- Must be caught and handled – prevents program defects
- Checked exceptions should be locally caught and handled
- Checked exceptions that propagate long distances suggests bad design (failure of modularity)

Java sometimes uses null (or NaN, etc.) as a special value

- Acceptable if used judiciously, carefully specified
- Easy to forget to check

Don’t ignore exceptions

- Effective Java Tip #65: Don't ignore exceptions

- An empty catch block is (a common) poor style – often done to get code to compile or hide an error

```
try {
  readFile(filename);
} catch (IOException e) {}  // do nothing on error
```

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

```
} catch (IOException e) {
  e.printStackTrace();    // just in case
}
```

Exceptions in 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

Avoid preconditions because
- Caller may violate precondition
- Program can fail in an uninformative or dangerous way
- Want program to fail as early as possible

How do preconditions and exceptions differ, for the client?

Exceptions in review, continued

Use checked exceptions most of the time

Handle exceptions sooner rather than later

Not all exceptions are errors

- A program structuring mechanism with non-local jumps (expensive, should be rare)
- Used for exceptional (unpredictable) circumstances

Also see Bloch's *Effective Java*, ch. 9