Exceptions and assertions

CSE 331
University of Washington

Michael Ernst

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

   Memory corruption

Using the above categorization, how would you categorize these?

- Failure of a subcomponent
- No return value (e.g., list element not found, division by zero)

What to do when something goes wrong

Fail early, fail friendly

Goal 1: Give information about the problem

- To the programmer
- To the client code and/or human user

Goal 2: Prevent harm from occurring

- Abort: halt/crash the program
  - Prevent computation (continuing could be bad or good)
  - 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

Avoiding blame for failures

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
- “Partial spec” vs. “complete spec” (neither is better)

Defensive programming: prevent or detect errors

Check

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

Check statically via reasoning and tools

Check dynamically at run time via assertions

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

Write the assertions as you write the code

Descriptive message is optional

Outline

⇒Assertions

- Exceptions
- Designing with exceptions

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;
```

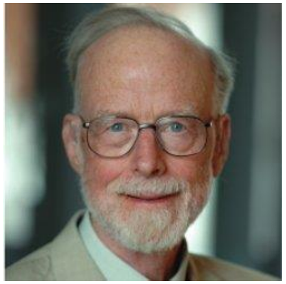
How can you test at run time whether assertions are enabled? Why would you want to do this?

Disabling assertions

Most assertions are better left enabled

- Prevents downstream problems
- Early indication of trouble eases debugging
- The cost is worth it during testing and debugging!

> "What would we think of a sailor who wears his lifejacket when training on dry land, but takes it off as soon as he goes to sea?"
> Sir C.A.R. Hoare, *Hints on Programming Language Design*, 1974



The user controls whether Java assertions run

`java -ea` runs Java with **a**ssertions **e**nabled

`java` runs Java with assertions disabled (default ☹)

A reason to use an assertion library

Turn off expensive assertions in CPU-limited production runs

- Common approach: guard expensive assertions (maybe including **`checkRep()`**) by static variable **`debug`**
- Set **`debug`** to false in production / graded code

Square root

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



}
```

Square root with assertion

java.lang.Math.sqrt returns NaN for argument < 0.
We use different specs as examples.

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

Compare to:

```
if (x < 0)
    throw new IllegalArgumentException();
```

No difference!

What is the purpose of each assertion?

Outline

- Assertions

⇒Exceptions

- Designing with exceptions

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();
  ...
}
```

Throwing an exception causes immediate control transfer

- Like **`return`** but different

True subtyping for throws clauses:

- Subclass method throws fewer more specific exceptions

Compiler does not enforce true subtyping

Using try-catch to handle exceptions

```
public double sqrt(double x) throws IllegalArgumentException
```

A thrown exception is handled by the `catch` associated with the nearest *dynamically enclosing* `try`

<u>Client code:</u>

```
try {
  field = sqrt(-1);
} catch (IllegalA…E… e) {
  ... take some action ...
}
```

<u>Client code:</u>

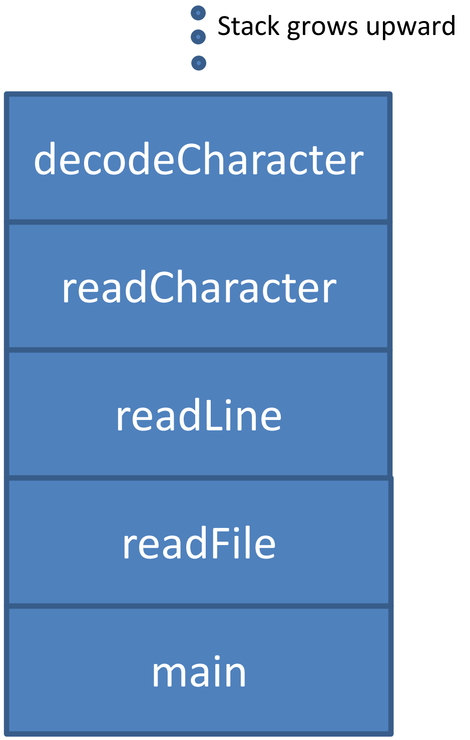
```
try {
  foo();
} catch (IllegalA…E… e) {
  ... take some action ...
}

void foo() {
  field = sqrt(-1);
}
```

Top-level default handler around `main()`: stack trace, program terminates

Throwing and catching

- At run time, Java maintains a call stack of methods that are currently executing
  - Dynamic from method calls during execution
  - Has no relation to static nesting of classes, packages, etc.
- When an exception is thrown, control transfers to the nearest method with a matching (= supertype) **`catch`** block
  - If none is found, top-level handler
    - Print stack trace, terminate program
- Exceptions allow non-local error handling
  - A method many levels up the stack can handle a deep error



The first matching `catch` clause executes

```
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
}
```

e.g., `SocketException`

e.g., `ArithmeticException`

The `finally` block

- **`finally`** body is always executed
  - Whether an exception is thrown or not
  - If an exception was thrown, the exception continues being thrown after the **`finally`** block executes
- Useful for "clean-up" code, re-establishing invariants, …

```
FileWriter out = null;
try {
  out = new FileWriter(...);
  ... write to out; may throw IOException
} finally {
  if (out != null) {
    out.close();
  }
}
```

Better style: try-with-resources

A try statement can have **`catch`** blocks and/or a **`finally`** block

Calling a method that might throw an exception

```
public double sqrt(double x) throws IllegalArgumentException;

// returns: x such that ax^2 + bx + c = 0

double solveQuad(double a, double b, double c) {


  return (-b + sqrt(b*b - 4*a*c)) / (2*a);
}
```

The compiler rejects this code.
How can we fix it?

Declaring an exception

```
public double sqrt(double x) throws IllegalArgumentException;

// 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);
}
```

Uninformative to clients:

`solveQuad(1,0,1)` ⇒ "-4 is less than zero"

Why handle exceptions locally?

Failure to catch exceptions may violate modularity

- Call chain: A → IntegerSet.insert → 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"

Maybe 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

```
public double sqrt(double x) throws IllegalArgumentException;

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

Note: clients don't know whether a set of arguments to **solveQuad** is legal or illegal

Exception chaining

```
public double sqrt(double x) throws IllegalArgumentException;

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

Useful mostly for debugging

Note: clients don't know whether a set of arguments to `solveQuad` is legal or illegal

Exceptions as non-local control

Execute **`procElt`** on (x, y) pairs, until **`procElt`** returns true

```
…
boolean finished = false;
for (int x : xIter) {
  for (int y : xIter) {
    if (procElt(x, y)) {
      finished = true;
      break; // y loop
    }
  }
  if (finished) {
    break; // x loop
  }
}
… rest of method
```

```
…
try {
  for (int x : xIter) {
    for (int y : yIter) {
      if (procElt(x, y)) {
        throw new Finished();
      }
    }
  }
} catch (Finished f) {
 // nothing to do
}
… rest of method
```

Exceptions as non-local control

Execute **procElt** on (x, y) pairs, until **procElt** returns true

```
…
boolean finished = false;
xloop:
for (int x : xIter) {
   for (int y : xIter) {
      if (procElt(x, y)) {
         break xloop;
      }
   }
}
… rest of method
```

```
void procMatrix() {
   for (int x : xIter) {
      for (int y : xIter) {
         if (procElt(x, y)) {
            return;
         }
      }
   }
}

…
procMatrix();
… rest of method
```

;

Procedural abstraction can improve code structure. Also gives a name to logical chunks of code.

Reserve exceptions for exceptional conditions

Outline

- Assertions
- Exceptions

⇒Designing with exceptions

Informing the client of a problem

Special value

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

Problems with using a special value

- No special value may be available
- Error-prone: the programmer may forget to check result
  - Causes wrong computation and more obscure failure later
- Verbose – handle at each call, up the stack
  - A positive: Clients can omit handling if they prove the special value is impossible
- Less efficient

A better solution: exceptions

Types of exceptional outcomes.
Is it expected? What can the client do?

- Errors
  - Unexpected
    - Can be the client's fault or the library's
    - Should be rare with well-written client and library
  - Usually unrecoverable
- Special cases
  - Expected – client knows it is a possibility
    - Unpredictable or unpreventable by client
      - If client knows the result, no need to make the call
    - Not easy to prevent/ignore with a precondition
  - Client can and *should* do something about it

Handling exceptions

Errors

- Client usually can’t recover
- Exception propagates to callees

Special cases

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

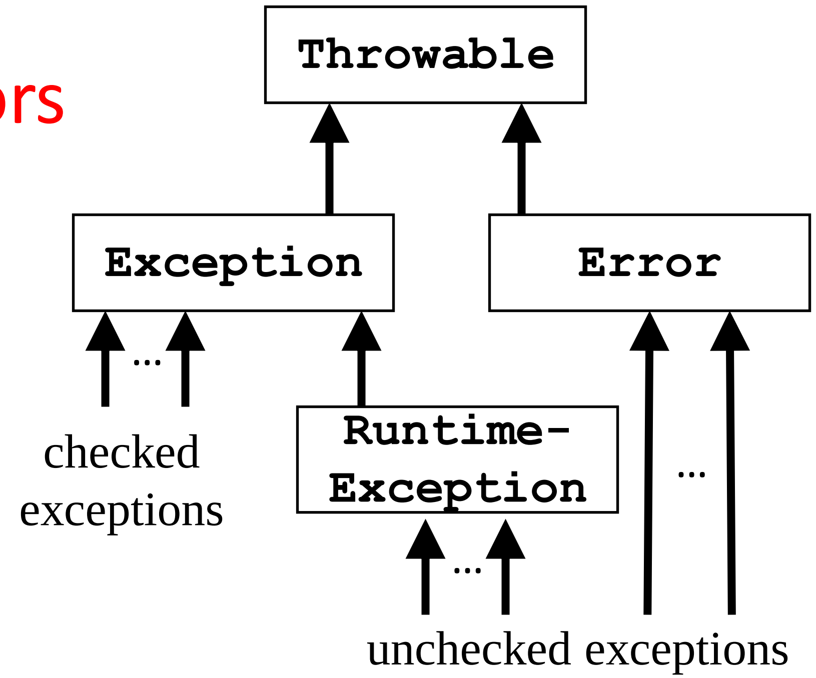
Java exceptions for errors and for special cases

Unchecked exceptions for errors

Library: no need to declare

Client: no need to catch

`RuntimeException`, **`Error`**, and their subclasses



Checked exceptions for special cases

Library: must declare in signature (compiler-enforced)

Client: must either catch or declare (compiler-enforced)

Even if you can prove it will never happen at run time

There is guaranteed to be a dynamically enclosing catch

Checked vs. unchecked exceptions

Unchecked exceptions for errors

- Use if (some) clients can ensure the exception will not happen
- It would be verbose & irritating if clients had to write a `catch` block nonetheless

Checked exception for special cases

- Static (compiler) checking ensures the caller handles it – can't forget
- Prevents program defects
- Annoying while prototyping
- Can't omit handling even if you know it cannot happen

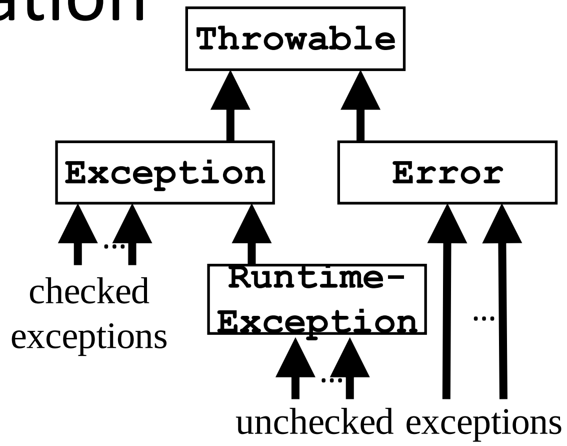
Checked exceptions have a lot of haters

If a library may throw a checked exception, the client *must* have a catch or throws clause

- Prevents program defects
- Can't omit handling even if you know it cannot happen
- Annoying while prototyping

My take: Good idea, poor implementation

- Weird class hierarchy
- Unintuitive name "checked"
- Some classes are in wrong category



Don’t ignore exceptions

- An empty catch block is poor style
  - often done to hide an error or get code to compile

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

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

```
} catch (IOException e) {
  e.printStackTrace();     // be informative
  System.exit(1);          // exit if appropriate
}
```

Exceptions and specifications

How do these specs differ, for the client?

Use an exception (complete specification) when
- Used in a broad or unpredictable context
- Checking the condition in the library is feasible

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

Avoid preconditions in public APIs because
- Caller may violate precondition
- Program can fail in an uninformative or dangerous way

Exceptions in review

Use checked exceptions most of the time

Static checking is useful

Use unchecked exceptions if

- callers can guarantee the exception cannot occur, or
- callers can’t do anything about it

Not all exceptions are due to program defects

Example: File not found

A program structuring mechanism with non-local jumps

Used for exceptional (unpredictable) circumstances

Make implementation fail as early as possible

Handle exceptions sooner rather than later

Also see Bloch’s *Effective Java*, chapter 9