Exceptions and Assertions

(Based on slides by Mike Ernst, 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

```java
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

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

Don’t perform side effects

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

// Better:
```java
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

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

```java
// 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

Square root, specified for all inputs

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

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Using try-catch to handle exceptions

```java
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

```java
try {
    code...
    y = sqrt(...);
} catch (FileNotFoundException fnfe) {
    code to handle a file not found exception
} catch (IOException ioe) {
    code to handle any other I/O exception
    e.printStackTrace(); //and/or take other actions
} 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
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 callee ensures no other checked exceptions get thrown
  - Static checking 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

```java
try {
    code...
} catch (Type name) {
    code... to handle the exception
} finally {
    code... to run after the try or catch finishes
}
```

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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 → IntegerSet.insert → 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 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

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

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

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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
    ```java
    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!