Testing

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Slides adapted from Dr. Hazel Campbell, Dr. Ken Wong

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Goal

- Does program P obey specification S?
  - What is P?
  - What is S?

Approaches

- Reasoning about the state model for P:
  - Typically, a huge number of states
  - Every practical technique must be inaccurate
  - Could *abstract* states
  - Could *sample* states
  - Or both

Approaches

- Abstraction:
  - Often used in static software analysis techniques
    - E.g., model checking P for some specific S
  - Techniques often pessimistically inaccurate
    - May report P is faulty when P is correct

Approaches

- Sampling:
  - Often used in dynamic analysis techniques
    - E.g., testing, profiling
  - Techniques often optimistically inaccurate
    - May report P is correct when P is faulty
    - Testing drives P through a sampling of states, but the samples may not generalize to actual situations

Software Defects

- Some terms:
  - Human *errors* can lead to *faults* in work products, which may cause *failures* when running the software
  - Can try to find faults through *testing*, reviews, proof, model checking, code analysis, etc.
  - Some avoid the term *bug*, since it implies something wandered into the code

Examples of Defects

- Actual behavior differing from expected:
  - Algorithmic
    - Code logic does not produce the proper output
  - Overload
    - Data structure unexpectedly filled completely
  - Performance
    - Violates service level agreement
  - Accuracy
    - Calculated result not to the desired level of accuracy
  - Timing
    - Race condition in coordinating concurrent processes

Failure

- AT&T failure (1990):
  - 114 switching nodes of their long-distance system crashed
  - The outage lasted for 9 h, 70 million calls went uncompleted
- Reason:
  - If a node crashes, it tells neighboring nodes to reroute traffic around it
  - A bug in handling this message caused the receiving node to also crash, etc.

Fault in Code

- Root cause:

```
do {
    switch (…) {
    case …:
        if (…) {
            …
            break;
        } else {
            …
        }
    …
    }
} while (…);
```

After expensive testing phase, a small change was made without again retesting

Why Test?

- Goals:
  - Verification
    - Check that requirements are satisfied
  - Not only to *confirm* normal behavior
    - Find problems to *refute* that the program is correct
  - Establish due diligence
    - Evidence in case of product liability litigation
  - Avoid regression
    - Prevent previous problems from reoccurring

Regression Testing

- Goal:
  - To avoid breaking things that should work
    - Collect, reuse, and re-run automated test cases
  - Do regression test after a change or fix
    - Re-run tests to check whether previously passing tests of the system now fail
    - E.g., old defect somehow became unfixed

Limits of Testing

- Issues:
  - A program cannot be tested completely
    - Too many inputs and path combinations to cover
  - Testing cannot find all defects
    - Cannot show their absence, just their presence
  - Challenging
    - Testing may be expensive and frustrating
    - Test code itself could add its own defects

Test-Driven Development

Automated Testing

- Purpose:
  - Write software to help test software
    - Automation essential to test-driven development and refactoring
- Limitations:
  - Manual testing still need to observe certain problems
    - E.g., strange noises from the speaker, flickering graphics

Automated Testing

- A good automated unit test:
  - Is simple to write and understand
    - Reduces the chance of defects in the test code
  - Runs quickly
    - Allows it to be re-run frequently while developing
  - Is isolated
    - Could run multiple unit tests in parallel
  - Shows exactly what went wrong if it fails
    - Reduce time spent in a debugger

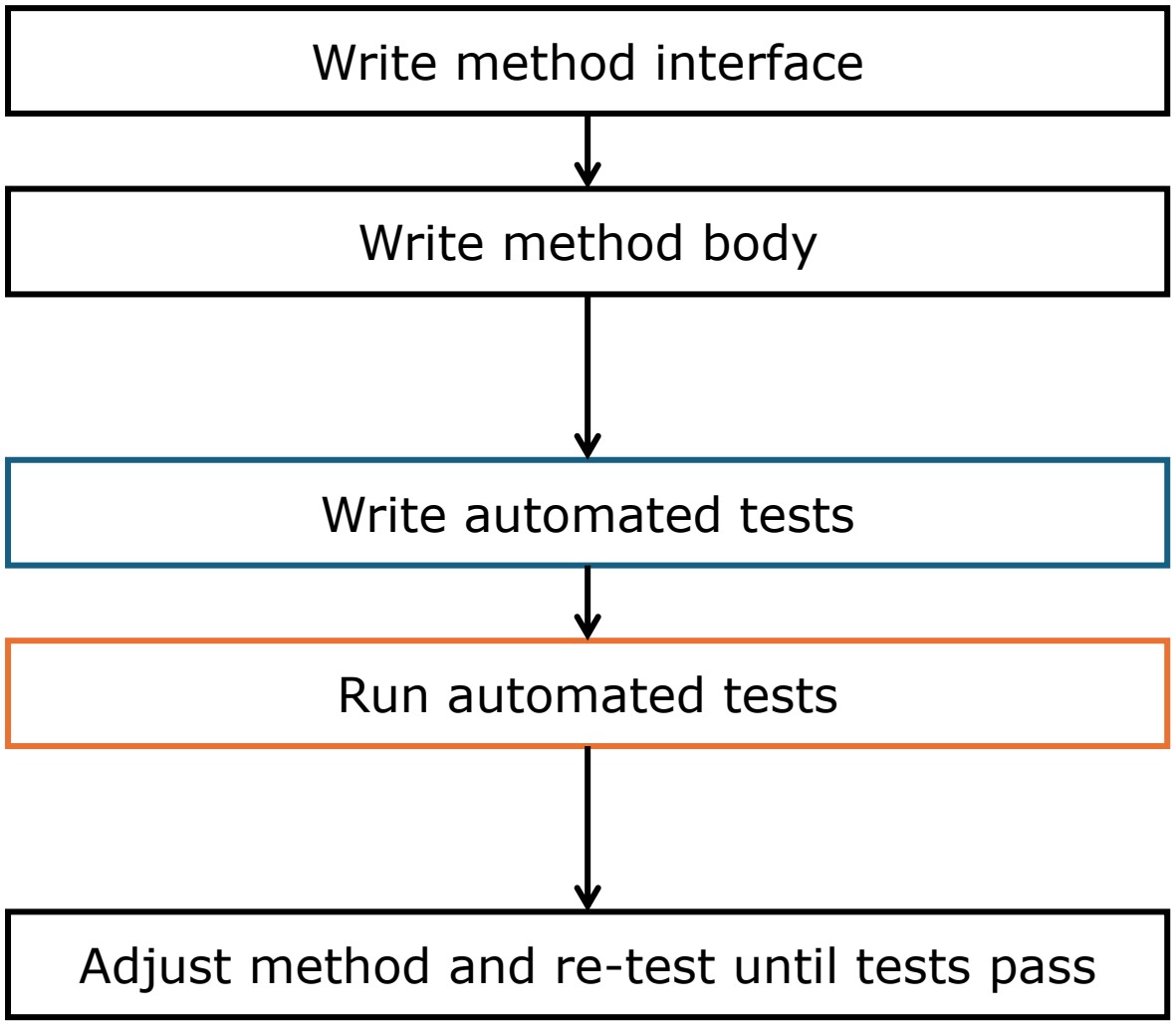
Automated Testing

- “Whenever you are tempted to type something into a print statement or a debugger expression, write it as a test instead.” — Martin Fowler

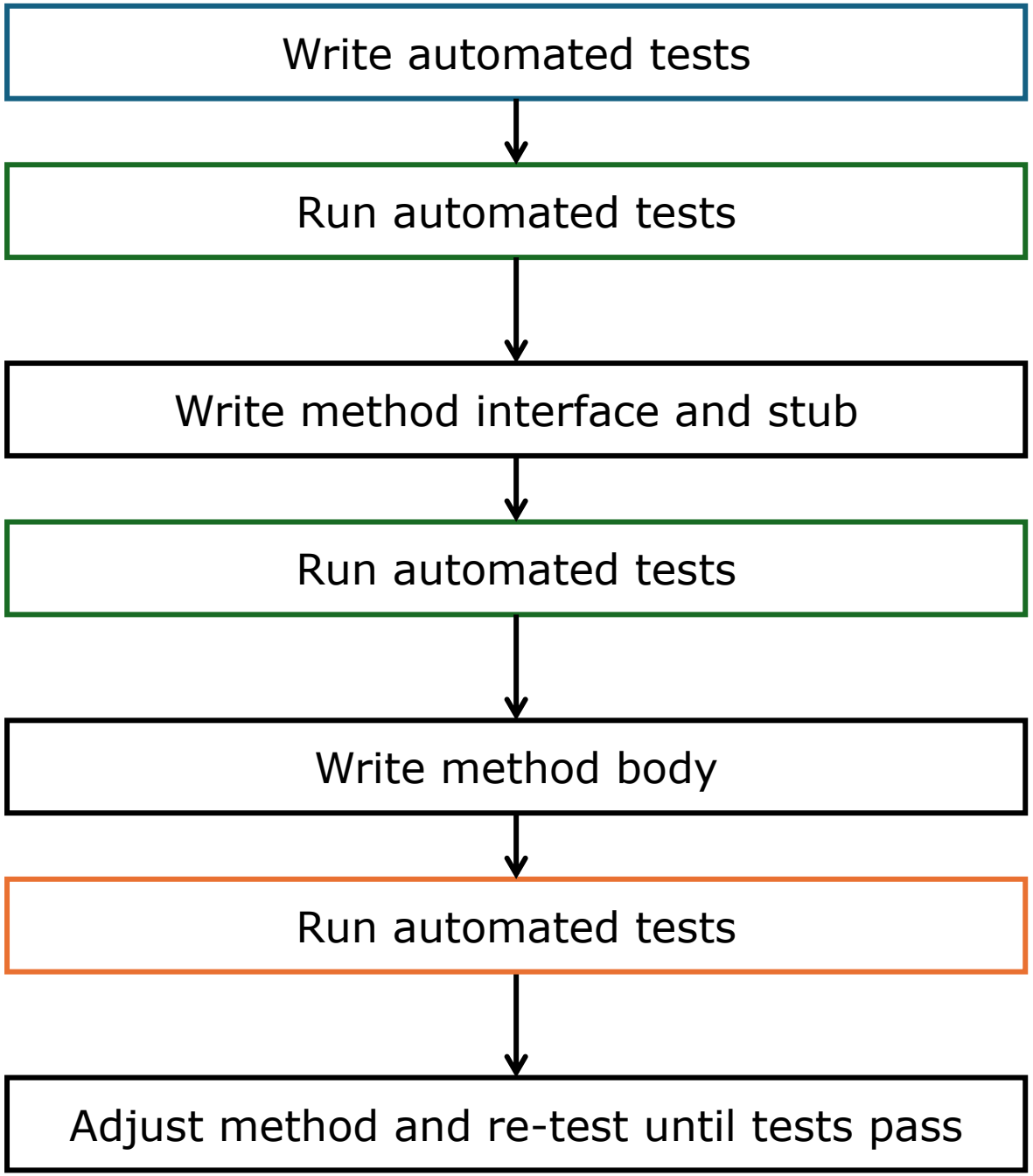
Test-Driven Development

- Idea:
  - If testing is so useful, let's write the tests first
  - These automated tests capture *code-level requirements* to be satisfied
  - Once code is written so that these tests pass, then these requirements are met

Traditional development



Test-first or test-driven development



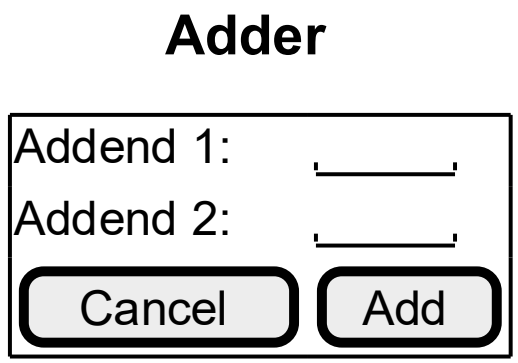
State-Based Testing

State-Based Testing

- Steps:
  - Set up software into a known state
    - E.g., initialize variables
  - Trigger transitions to cause state changes
    - E.g., call methods to change variables
    - E.g., interact with the user interface
  - Verify the actual arrived state is expected
    - E.g., see if actual values in variables meet expectations

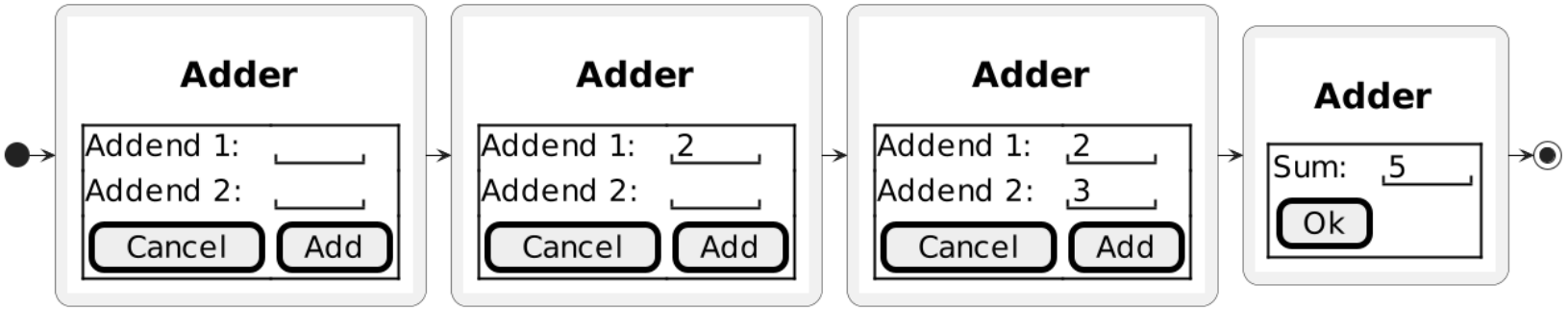
Black Box Testing

- Testing, without seeing the code:



Black Box Testing

- Expected behavior:



  - Deviations from the expected interaction?

Black Box Testing

- Tips:
  - Want be systematic about what to test
    - E.g., focus on the adder functionality for now
  - Avoid redundant tests
    - Too easy to keep adding meaningless extra tests
  - Determine *equivalence classes* of tests

Black Box Testing

- Equivalence classes:
  - Each test inside an equivalence class checks the “same thing”
  - If a test inside the class will catch a defect, the other tests probably also will
  - If a test inside the class will not catch a defect, the other tests probably also will not
  - Keep only a few tests in each class, as representatives

Black Box Testing

- Example test cases:
  - Be systematic about what to test, not knowing the internal code

	Addends	Sum	Description (also check commutative)
2	3	5	Something simple
99	99	198	Large positive pair
99	-14	85	Large positive plus negative
99	16	115	Large positive plus positive
-99	-99	-198	Large negative pair
-99	-14	-113	Large negative plus negative
-99	16	-83	Large negative plus positive
-99	99	0	Large positive plus large negative
9	9	18	Largest single digit positive pair

Black Box Testing

- Example test cases:
  - Guessing at internal algorithm or representation

	Addends	Sum	Description (also check commutative)
0	0	0	All zero special case
0	23	23	Zero plus positive
-78	0	-78	Negative plus zero
127	127	254	Max signed bytes
-128	127	-1	Min and max signed bytes
-128	-128	-256	Min signed bytes
2147483647	2147483647		Max signed integers
-2147483648	2147483647	-1	Min and max signed integers
-2147483648	-2147483648		Min signed integers

Black Box Testing

- Example test cases:
  - Data input from fields in user interface

	Addends	Sum	Category (also check commutative)
4/3	2		Expression
$2	$2		Currency symbols
+5	3		Addition sign
(9)	9		Parentheses around negatives
l	1		Lower case letter l
O	0		Upper case letter O
<tab>	<tab>		No input
1.2	5		Decimal
A	b		Invalid characters

Black Box Testing

- Example test cases:
  - And even more user interface explorations
    - Editing with delete, backspace, cursor keys, etc.
    - Using F1, escape, and control characters
    - Vary timing of data entry

Testing Strategies

- Big-bang strategy:
  - Test thoroughly only after the whole system is put together
  - Pro(?)
    - "Project almost finished, only testing left"
  - Cons
    - Hard to pinpoint the cause of a failure

Testing Strategies

- Top-down incremental strategy:
  - Implement/test the highest-level modules first
    - Provide stubs for lower-level functionality not yet implemented
    - Higher-level modules are the test drivers
- Bottom-up incremental strategy:
  - Implement/test the lowest-level modules first
    - Need to write test drivers

Testing Techniques

- Creating good tests:
  - Test every error message
    - Error-handling code tends to be weaker
  - Test under other configurations
    - Programmers are biased to their own setup

Design for Testing

Good Software Design

- Software should be flexible:
  - Easy to change to respond to new needs
  - Easy to understand
  - Easy to extend, without exploding complexity
- Software should be testable:
  - Easy to construct the units
  - Easy to set up units into desired state
  - Easy to drive code and witness effects

Example Bad Design 1

```
/**
 * Process photo album requests,
 * parse user preferences,
 * apply image transformations,
 * assemble images into albums,
 * deliver results to users
 */

public class PhotoAlbumServer {

    … // lots of code

}
```

Example Bad Design 1

- Poor flexibility:
  - Difficult to extract and reuse parts
  - Complex to add new features
  - Instance variables are “global”
- Poor testability:
  - Only end-to-end testing possible
  - Need golden results files for every combination of preference settings and image transformations

Improved Design 1

- Use separation of concerns:
  - RequestHandler class
  - UserPreferencesReader class
  - UserPreferencesParser class
  - ImageEffect class
  - ImageTransformer class
  - …

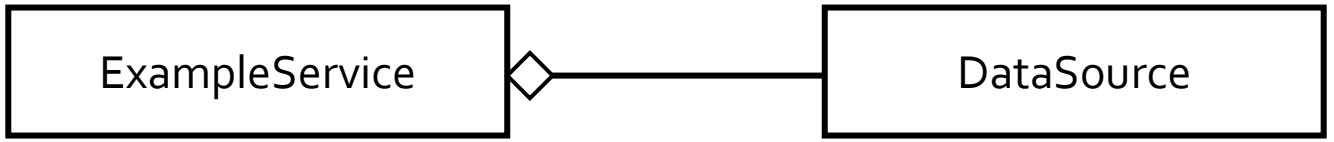
Improved Design 1

- Better flexibility:
  - Uses object-oriented design
  - Easier to understand smaller, separate units
- Better testability:
  - More focused tests of each unit
  - Test fixtures easier to provide for each unit
  - Easier to check results

Forming Dependencies

```
public class ExampleService {
    private DataSource theDataSource;
    …

    public ExampleService( … ) {
        theDataSource = new DataSource( … );
        …
    }

    public void doService() {
        …
        … = theDataSource.getInfo();
        …
    }
    …
}
```

One approach is that the class makes what it depends on

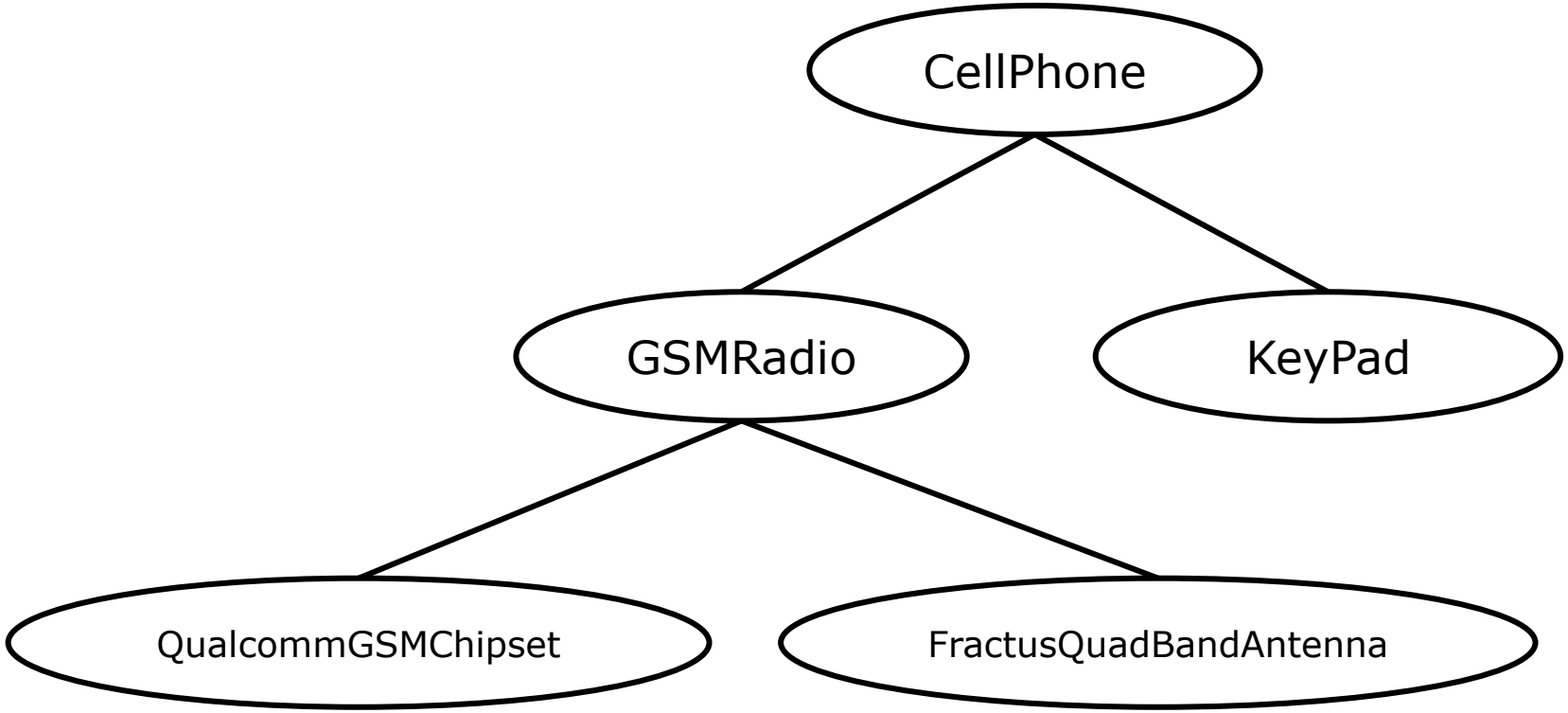


“Dependency Injection”

```
public class ExampleService {
    private DataSource theDataSource;
    …

    public ExampleService(
        DataSource aDataSource ) {

        theDataSource = aDataSource;
        …
    }

    public void doService() {
        …
        … = theDataSource.getInfo();
        …
    }
    …
}
```

Alternatively, construct what this class depends on outside the class

System Assembly



System Assembly without DI

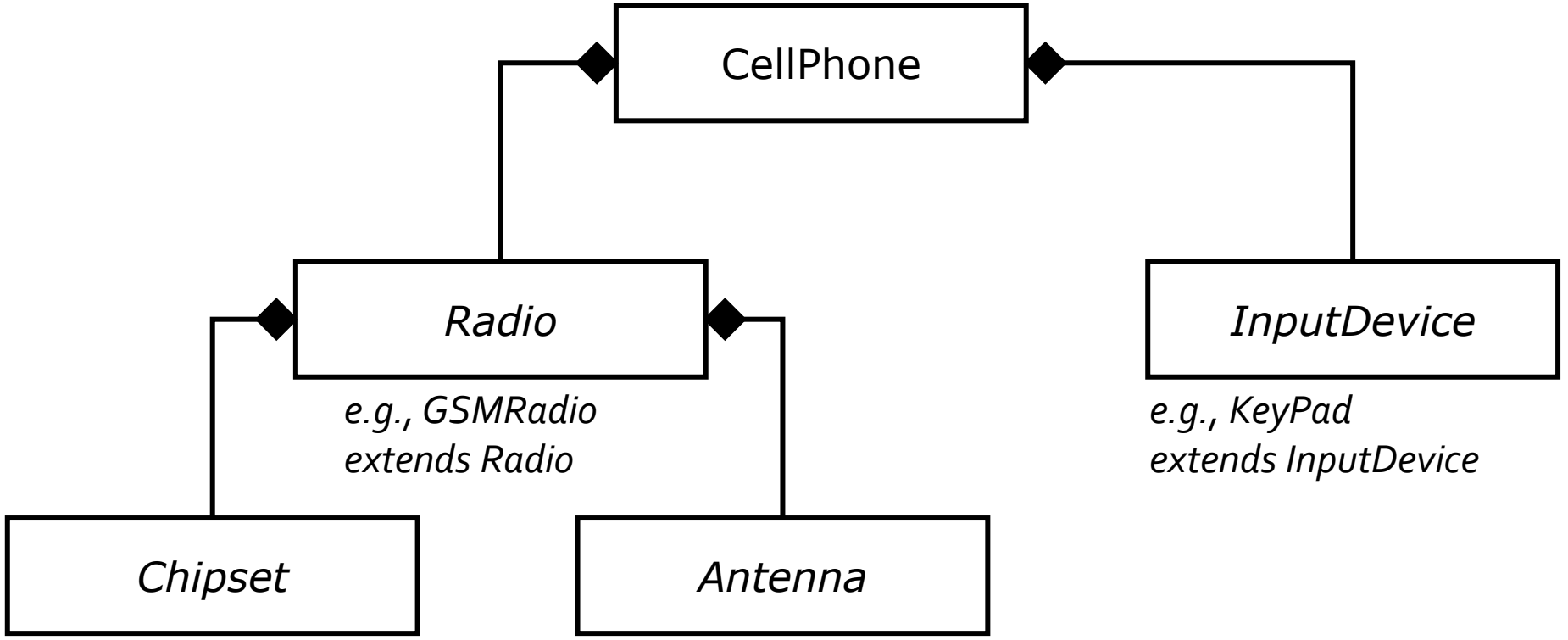
- ```
  public class CellPhone {
      …
      public CellPhone() {
          radio = new GSMRadio();
          inputDevice = new KeyPad();
          …
      }
  }
  ```
- ```
  public class GSMRadio {
      …
      public GSMRadio() {
          chipset = new QualcommGSMChipset();
          antenna = new FractusQuadBandAntenna();
      }
  }
  ```
- ```
  CellPhone phone = new CellPhone();
  // fully assembled
  ```
  ```

System Assembly without DI

- Poor flexibility:
  - Difficult to change and plug in parts
    - For different radio, different input device, etc.
- Poor testability:
  - Can’t supply test versions of parts
    - Stuck with given parts
  - Entire aggregate is constructed
    - Could be expensive

System Assembly with DI

- ```
  public class CellPhone {
      …
      public CellPhone( Radio radio,
          InputDevice inputDevice ) {

          this.radio = radio;
          this.inputDevice = inputDevice;
      }
      …
  }
  ```
- ```
  public class GSMRadio extends Radio {
      …
      public GSMRadio( Chipset chipset,
          Antenna antenna ) {

          this.chipset = chipset;
          this.antenna = antenna;
      }
  }
  ```

System Assembly with DI

- ```
  // in some high-level class

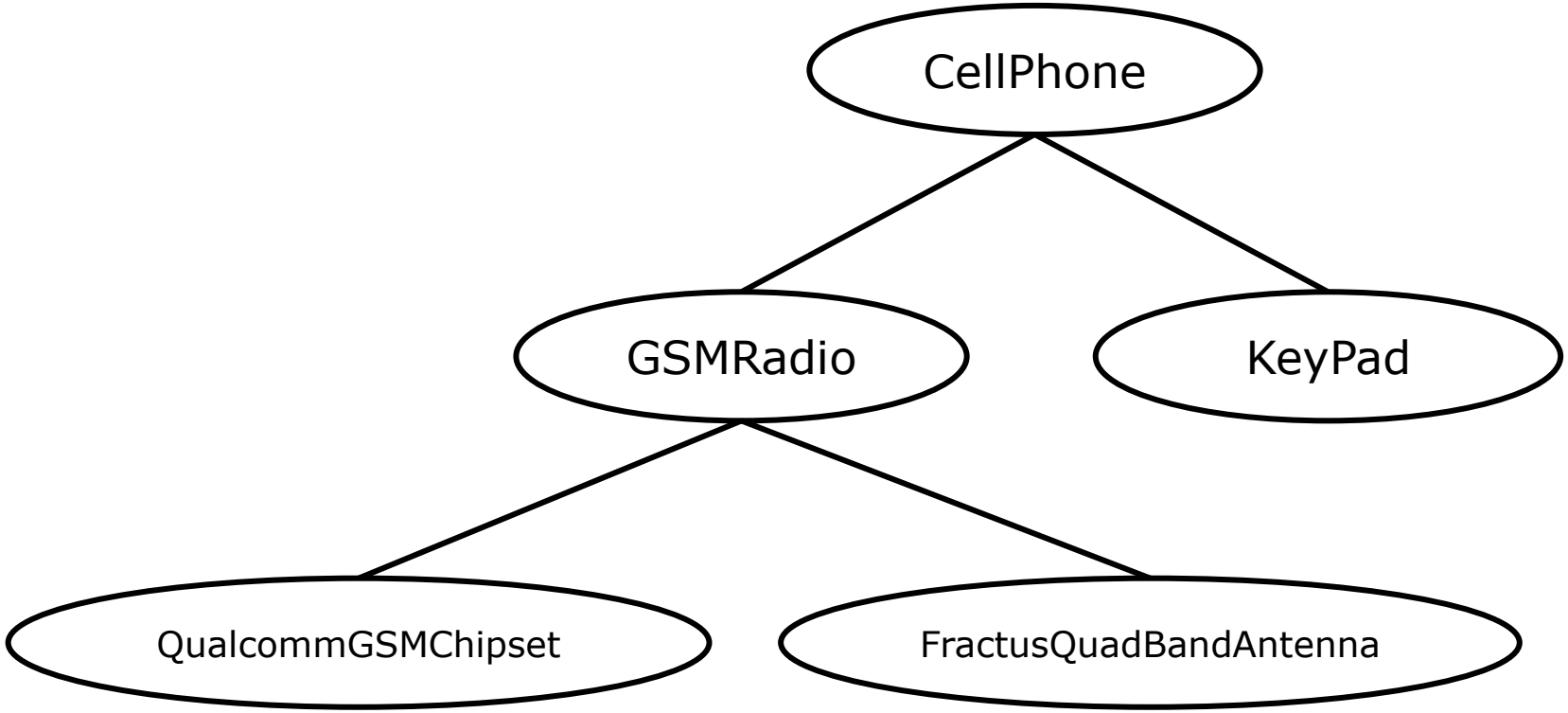
  CellPhone phone = new CellPhone(
      new GSMRadio(
          new QualcommGSMChipset(),
          new FractusQuadBandAntenna()
      ),
      new KeyPad()
  );
  ```

Separates out "dependency resolution" from the constituent classes
  ```

System Assembly with DI



Could have other subclasses beyond these examples

System Assembly with DI



The bottom-up assembly process instantiates the children and inserts them into the parents

Example Bad Design 2

```
public class User {
    private Preferences prefs;

    public User( File prefFile ) {
        prefs = parseFile( prefFile );
        …
    }
    public void doSomething() {
        … // use prefs
    }
    …
    private Preferences parseFile( File prefFile ) {
        …
        aPrefs = new Preferences( … );
        … // setup prefs
        return aPrefs;
    }
}
```

Example Bad Design 2

- Poor flexibility:
  - Changing preferences requires changing User
    - File format changes
  - Difficult to reuse User
    - Embedded preference file reading and parsing
- Poor testability:
  - Tests that deal with files are slow
  - Need test file for each preference combination

Improved Design 2

```
class User {
    private Preferences prefs;

    public User( Preferences prefs ) {
        this.prefs = prefs;
        …
    }
    public void doSomething() {
        … // use prefs
    }
    …
}
```

Dependency injection

Improved Design 2

- Better flexibility:
  - No change to User if file format changes
  - Preferences not limited to be made from files
- Better testability:
  - Can run fast
    - Pass in mock or fake Preferences object

“Mock Object”

```
public class UserTest {
    …
    public void testdoSomething() {

        // MockPreferences extends Preferences,
        // but is overridden with canned settings
        // (no test preference file needed)

        Preferences mockPrefs =
            new MockPreferences();

        User aUser = new User( mockPrefs );

        aUser.doSomething();
        …

        mockPrefs.assertNoChange();
    }
}
```

Example Bad Design 3

- Situation:
  - Many pieces of information are needed by classes throughout the system
  - But each class needs just one or a few items
  - How to provide this information to the consumers?

Example Bad Design 3

- Typical approaches:
  - Consumers get the data they need,
  - Make the data global,
  - Pass around a context object, or
  - Put the data in widely known and used classes

Example Bad Design 3

```
public class Account {
    …
    public Account( User user ) {
        this.country =
user.getPreferences().getLocation().getCountry();
        …
    }
    …
}
```

Example Bad Design 3

- Poor flexibility:
  - Method parameters do not show what the method really needs
  - Code "locks in" the structure it walks
- Poor testability:
  - Test needs to recreate this structure

Example Bad Design 3

```
public void testSomethingForAccount() {
    // set up for test

    Country country = new Country( “Canada” );

    Location location = new Location();
    location.setCountry( country );

    Preferences prefs = new Preferences();
    prefs.setLocation( location );

    User user = new User( prefs );

    Account account = new Account( user );

    … // test Canadian account
}
```

Test code should be simple (less likely to have defects)

Improved Design 3

```
• public void testSomethingForAccount() {

      Country country = new Country( “Canada” );

      // redesigned constructor
      // (requires only what is needed)
      Account account = new Account( country );

      … // test Canadian account
  }
```

More Information

- Books:
  - Test-Driven Development
    - K. Beck
    - Addison-Wesley, 2003
  - Testing Computer Software
    - C. Kaner, J. Falk, H. Q. Nguyen
    - Wiley, 1999
  - Lessons Learned in Software Testing
    - C. Kaner, J. Bach, B. Pettichord
    - Wiley, 2002
  - Flexible Design? Testable Design? You Don't Have to Choose!
    - R. Rufer and T. Bialik

More Information

- Links:
  - Cause of AT&T Network Failure
    - http://catless.ncl.ac.uk/Risks/9.62.html#subj2
  - The Way of Testivus
    - http://www.agitar.com/downloads/TheWayOfTestivus.pdf
  - JUnit Resources for Test-Driven Development
    - https://junit.org/junit5/