2IP15 Programming Methods

From Small to Large Programs

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Overview

- Guidelines for (functional) decomposition
- Dealing with errors in engineering
- Unit testing

Techniques (Methods)

- Product: strive for modular structure in software
- Process (way of working): Test-Driven Development (TDD)

  This is also modular: distinct steps/phases

Manage Complexity

Why?

Intellectual limits of human beings, concerning

- productivity
- memory
- communication
- accuracy
- ...

Techniques to Manage Complexity

- Divide & Conquer
- Separation of Concerns
- Decomposition
- Modularization
- Encapsulation
- Abstraction

All related

Abstraction

To abstract *from something*

- Ignore/suppress distinctions that are considered irrelevant
- Separate relevant from irrelevant details

Example: Identify fractions a/b and c/d ($b \neq 0 \neq d$) when $ad = bc$

2IT05: equivalence relation, equivalence class, quotient set

Abstract from *how* a subproblem is solved, through a specification

Abstract from *which* subproblem is solved, through parameters

Abstract from *how* a solution is used, through a specification

Abstraction Example: Assignment Rectangle (2IP65)

On **input** are **6 integers**, representing three points in a Cartesian co-ordinate system, for each point first the x- and then the y-coordinate.

The first two points designate a **rectangle** with axes-parallel sides.

The first point is the **top left corner** of the rectangle, the second point is the **bottom right corner**.

The program has to **decide** whether the third **point** is **inside the rectangle** (including the edges) or outside.

The program should **output** an **error message** if the rectangle is **ill-defined**, i.e., if the second point is not to the right of and below the first point. The program may assume that no other errors occur in the input.

Abstraction Example: Monolithic Solution, Variables

```
1  // Monolithic solution
2
3  import java.util.Scanner; // for input
4
5  class Rectangle1 {
6
7      Scanner scanner; // input source
8      int tlx; // top left x
9      int tly; // top left y
10     int brx; // bottom right x
11     int bry; // bottom right y
12     int px; // point x
13     int py; // point y
```

Abstraction Example: Monolithic Solution, Method

```
15      void doRectangle() {
16          scanner = new Scanner(System.in);
17          tlx = scanner.nextInt();
18          tly = scanner.nextInt();
19          brx = scanner.nextInt();
20          bry = scanner.nextInt();
21          px = scanner.nextInt();
22          py = scanner.nextInt();
23
24          if (tlx > brx || tly > bry) {
25              System.out.println("error");
26              return;
27          }
28          // tlx <= brx && tly <= bry
```

Abstraction Example: Monolithic Solution, Method

```
29          if (tlx <= px && px <= brx && tly <= py && py <= bry) {
30              System.out.println("inside");
31          } else {
32              System.out.println("outside");
33          }
34      }
```

Abstraction Example: Separate Methods, Top Level + Output

```
15      void doRectangle() {
16          scanner = new Scanner(System.in);
17          readInput();
18
19          if (! isValidRectangle()) {
20              System.out.println("error");
21              return;
22          }
23          // input rectangle is valid
24          if (isPointInsideRectangle()) {
25              System.out.println("inside");
26          } else {
27              System.out.println("outside");
28          }
29      }
```

Abstraction Example: Separate Methods, Input

```
31      // Read input into tlx, ..., py via scanner
32      void readInput() {
33          tlx = scanner.nextInt();
34          tly = scanner.nextInt();
35          brx = scanner.nextInt();
36          bry = scanner.nextInt();
37          px = scanner.nextInt();
38          py = scanner.nextInt();
39      }
```

Abstraction Example: Separate Methods, Calculations

```
41      // Returns whether tlx, ..., bry is a rectangle
42      boolean isValidRectangle() {
43          return tlx <= brx && tly <= bry;
44      }
45
46      // Returns whether px, py is inside rectangle tlx, ..., bry
47      boolean isPointInsideRectangle() {
48          return tlx <= px && px <= brx && tly <= py && py <= bry;
49      }
```

Abstraction Example: Parameterized Methods, Top Level

```
14      void doRectangle() {
15          readInput(new Scanner(System.in));
16
17          if (! isValidRectangle(tlx, tly, brx, bry)) {
18              System.out.println("error");
19              return;
20          }
21          // input rectangle is valid
22          if (isPointInsideRectangle(tlx, tly, brx, bry,
23                                     px, py)) {
24              System.out.println("inside");
25          } else {
26              System.out.println("outside");
27          }
28      }
```

Abstraction Example: Parameterized Methods, Input

```
30      // Read input into global tlx, ..., py via scanner
31      void readInput(Scanner scanner) {
32          tlx = scanner.nextInt();
33          tly = scanner.nextInt();
34          brx = scanner.nextInt();
35          bry = scanner.nextInt();
36          px = scanner.nextInt();
37          py = scanner.nextInt();
38      }
```

Abstraction Example: Parameterized Methods, Calculations

```
40      // Returns whether tlx, ..., bry is a rectangle
41      boolean isValidRectangle(int tlx, int tly,
42                               int brx, int bry) {
43          return tlx <= brx && tly <= bry;
44      }
45
46      // Returns whether x, y is inside rectangle tlx, ..., bry
47      boolean isPointInsideRectangle(int tlx, int tly,
48                                     int brx, int bry,
49                                     int x, int y) {
50          return tlx <= x && x <= brx && tly <= y && y <= bry;
51      }
```

Abstraction Example: Parameterized Methods, Auxiliaries

```
47      // Returns whether tlx, ..., bry is a rectangle
48      boolean isValidRectangle(int tlx, int tly,
49                               int brx, int bry) {
50          return isDominated(tlx, tly, brx, bry);
51      }
52
53      // Returns whether x, y is inside rectangle tlx, ..., bry
54      boolean isPointInsideRectangle(int tlx, int tly,
55                                     int brx, int bry,
56                                     int x, int y) {
57          return isDominated(tlx, tly, x, y) &&
58                 isDominated(x, y, brx, bry);
59      }
60
61      // Returns whether ax, ay is dominated by bx, by
62      boolean isDominated(int ax, int ay, int bx, int by) {
63          return ax <= bx && ay <= by;
64      }
```

Abstraction Example (cont'd)

- Separate input, calculations, and output
- Parameterize methods

N.B. In this style, it is harder to parameterize `readInput` further, because Java has no output parameters, only return values. (No Java method with parameters `v, E` equivalent to `v := E` exists.)

`readInput()` could return an array, but then the indexing would be awkward. Separate classes for rectangles and points is the Java way.

Doing output could be separated from the top-level *coordination*, using a string result.

Advantages and Disadvantages of Divide & Conquer

- Advantages?
- Disadvantages?

Advantages of Divide & Conquer

- Enables solution of more complex problems
- Organizes communication about *solution* domain
- Facilitates parallel construction by a team
- Improves ability to plan work and track progress
- Improves verifiability (facilitates "getting it to work"):
  - Allows early review of design
  - Allows unit testing of separate components
  - Allows stepwise integration (avoiding a "big bang")
- Improves maintainability: changes affect few components
- Improves possibilities for reuse

Disdvantages of Divide & Conquer

- Top-level divisions are hard to make: can have big consequences

  Need experience and need to experiment (try alternatives)

- Separation often brings overhead (to cross boundary/interface)

  Also depends on implementation facilities (programming language)

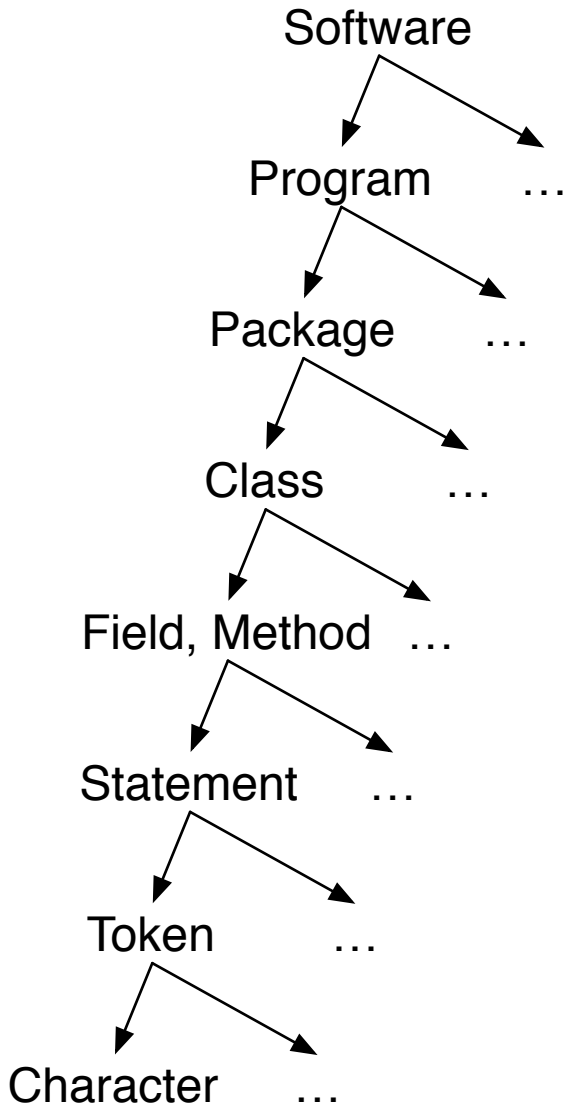
- The result looks bigger (overhead, again)

  But it has explicit structure (there is a price to that)

- Functions cannot be specified/designed/implemented in *isolation*

  They need to be considered in related groups (cf. class)

Divide & Conquer Applies to Multiple Levels



Guidelines for Functional Decomposition

- Maximize cohesion

  Cohesion = measure of relatedness of 'things' *inside* a 'module'

  Keep related things together; separate unrelated things

- Minimize coupling, also stated as minimize dependency

  Coupling = measure of connectedness *between* 'modules'

  Interface of a 'module' concerns all its external connections

  Consider both *number and nature of dependencies*:

  ++ via parameter

  □ use constant, type, (variable,) method defined elsewhere

  −− implicit common 'knowledge' (file name in string literal)

Guidelines for Functional Decomposition (cont'd)

- Each 'function' should solve a single well-defined problem

  Single Responsibility Principle: SRP

- If specification is difficult to provide, then something is wrong
- Specify on the right level of data abstraction!
- Limit the size of the interface, i.e., number of parameters

  Possibly combine parameters (in a new class, representing a new concept, raising the level of abstraction)

Guidelines for Functional Decomposition (cont'd)

- Each problem should be solved in one place only

  Don't Repeat Yourself: DRY

- Avoid code duplication, a.k.a. code clones
- Copy-Paste-Edit is a bad way to reuse code (why?)
- Use parameters to unify similar code

Guidelines for Functional Decomposition (cont'd)

- Each 'function' should have a small implementation
- No more than a (few) dozen lines, with limited nesting depth
- Nested control structures should invite further subdivision, especially nested loops
- Cyclomatic complexity is a good metric

  Checkstyle measures this and warns when above 10
- If it is above 8, consider subdivision, a.k.a. Refactoring

  NetBeans can assist:
  Select code, right-click, Refactor > Introduce Method...

Further Abstraction Example

Assignment *Rectangle* (2IP65)

```
process(int tlx, int tly, int brx, int bry, int x, int y)
```

Group parameters to form `Point` and `Rectangle`:

```
boolean contains(Rectangle r, Point p) { ... }
```

or in **class** `Rectangle`:

```
/** @return whether this contains p (incl. boundary) */
boolean contains(Point p) { ... }

Rectangle r; Point p; ... r.contains(p) ...; ...
```

Generalization

- Consider possibilities for generalization: solving a more general problem than (initially) required.

  Generalization improves (re)usability and insight.
  It can also simplify solution!

- Generalize by means of parameters, not via global variables.

  Parameters abstract from the identity of the data operated on.

  Code duplication should invite refactoring by parameterization.

- Decomposing a problem into simpler versions of itself gives rise to recursion.

- Weigh benefits against costs: too general makes use costly.

Generalization Example

How many regions arise when space is cut by five arbitrary planes?

'Arbitrary': No parallel planes; every three planes intersect in 1 point.

Parameterize on number of planes N

Parameterize on dimension D of 'space' to be divided:
$D = 1 \rightarrow$ line, $D = 2 \rightarrow$ plane, $D = 3 \rightarrow$ space

$$
\begin{array}{rcl}
R(D,N) & \stackrel{\text{def}}{=} & \#\text{ regions when } D\text{-space cut by } N \text{ arbitrary } D-1\text{-spaces} \\
R(D,0) & = & 1 \quad \text{(when not divided)} \\
R(1,N) & = & N+1 \quad \text{(a line divided by } N \text{ points)} \\
R(D,N) & = & R(D,N-1) + R(D-1,N-1) \quad \text{if } 2 \leq D \text{ and } 1 \leq N \\
R(3,5) & = & 26
\end{array}
$$

Typical Purposes of 'Functions'

- Input, calculate, output
- Parse, convert, format
- De-nest (disentangle) control structures
- Initialize, query, update, finalize
- Check condition
- Create, delete
- Coordinate activities, handle events
- Abstract from the way data is represented

'Function' Names, Parameter Order

- Use verb-plus-noun, but avoid overly general words: `processInput`

  Do not include the object name that **`this`** refers to

  In **`class`** `Document` do not name a method `printDocument`

- Function name should reflect returned value

- Procedure name should reflect postcondition

- Short parameter names facilitate writing of specifications

- Parameter order: 1 input-only, 2 input-and-output, 3 output-only (status and error information last).

Engineering gone wrong

Do you know examples of engineering 'inconveniences' and disasters?

Were you ever the victim of an engineering mistake?

Did you ever make an engineering mistake? How about BIG ones?

What is the most memorable engineering mistake you made?

Terminology: IEEE Classification

Failure: product deviates from requirements during use/operation

Defect, fault: anomaly in a product that can somehow (eventually) lead to a failure; product can be any artifact (e.g. a design document)

Mistake: human action ("slip") causing a fault

Error: difference between actual and specified/expected result

These notions assume existence of requirements/specification/contract as a frame of reference, which needs to be established in advance

N.B. Beautiful versus ugly: an opinion, not an error

Economy of Defects

- The longer a defect is undiscovered, the higher its cost: grows exponentially in distance between injection and elimination.
- Defects decrease the predictability of a project: cost (time) of defect localization and repair are extremely variable.
- Defects concern risks, i.e. uncertainty; product could be defect-free at once, but defects are likely.
- The likelihood of defects increases rapidly with higher system complexity.

Kinds of Mistakes

There are many different kinds of mistakes, such as

- Misunderstanding a customer
- Misinterpreting a written requirement
- Overlooking a case in analyzing the requirements
- Adopting an incorrect algorithm
- Making an unwarranted assumption when implementing a method
- Making a typing error (typo) when entering code

No single method can cure all this.

Dealing with Mistakes

1. Admit that people make mistakes and inject defects: awareness
2. Prevent them as much as possible
3. Minimize consequences: fault tolerance, defensive programming
4. Detect presence of defects as early as possible
5. Localize defects
6. Repair defects
7. Trace them: root causes and possible other consequences
8. Learn from them: improve the process and tools

Awareness

Robert N. Britcher in *The Limits of Software* (Addison-Wesley, 1999):

"Programmers [Engineers] will always make errors. No advance in formal [methods] will ... prevail over human fallibility.

[T]here are two approaches to software errors:

- one accepts them as inevitable and steers work toward removing faults that errors produce;
- the other ignores errors, the resulting faults, and the failures they may cause, and replaces testing, discovery, and repair with legal and business maneuvers."

Legal actions and sanctions against engineers do not help either. (On the contrary ...)

Preventing Defects (or instant detection and repair)

- Impossible to do for 100%, but prevention offers the biggest gains
- Every defect not prevented adds work (cost)
- Remove sources for mistakes (e.g., improve syntax of prog. lang., use better tools: editor with syntax highlighting, . . .)
- Always work neatly, also on prototypes, test software, . . .
- Use checklists and standards
- Work in pairs
- "Think before you act"

Detecting Defects

- Reviewing:
  - Examine an artifact *with the intent of finding defects*.
  - Can be done early in the development process.
  - Often localizes the defects as well.
  - Can and should also be applied to code.
- Testing:
  - Use a product systematically *with the intent of finding defects*.
  - Works through *failures*; does not localize underlying defects.
  - Requires a working product (part).

Reviewing and testing complement each other.

Limits of Testing

Testing in itself does not create quality; it is a *measure* of quality.

Edsger W. Dijkstra (CACM, 1972; winner of Turing Award 1972):

> "Program testing can be a very effective way to show the presence of bugs, but it is hopelessly inadequate for showing their absence."

Dijkstra's advice: Prove mathematically that an artifact has required properties. Ideally: let proof development drive the design, leading to Correctness by Construction.

Removing Defects

Testing and debugging are two very different activities

Testing: The process of systematically executing software with the intent of *detecting* the *presence of defects*.

Debugging: The process of localizing, diagnosing, and correcting *detected defects*.

Debugging is a time consuming and unpredictable process.

(Debugging is addressed later in the course . . .)

Testing Terminology

Test case :

- has a purpose (motivation);
- controls activation and input;
- observes response and output;
- decides on pass/fail based on expected (specified) result.

What input(s) to offer?

What result(s) to inspect?

How to decide on pass/fail?

JUnit: Automated Unit Testing Framework

JUnit: organizes code for test cases, runs them, reports results
N.B. Use JUnit 4.x, *not* JUnit 3.8.x

Each test case is coded in a method: `@Test public void ...()`

Explain purpose of test case in (javadoc) comment

Checking and reporting: `assertTrue`, `assertEquals`, `fail`, ...

Auxiliary methods: **`private`**

Can also test for required exceptions: no/wrong exception → failure
`@Test(expected = NullPointerException.class)`

JUnit: Execution

```
 1 import static org.junit.Assert.*;
 2 import org.junit.After;
 3 import org.junit.Before;
 4 import org.junit.Test;
 5
 6 public class MyTest {
 7     ... // global variables defining a 'test fixture'
 8     @Before protected void setUp() { /* initialize fixture */ }
 9     @After protected void tearDown() { /* finalize fixture */ }
10     @Test public void testCase1() { /* code for test case 1 */ }
11     @Test public void testCase2() { /* code for test case 2 */ }
12 }
```

Executes:

```
setUp(); testCase1(); tearDown();
setUp(); testCase2(); tearDown();
```

JUnit: Execution

N.B. The execution order of test cases is not predetermined!
Test cases should be independently executable.

JUnit and DrJava

Help > Testing using JUnit

File > New JUnit Test Case...

Tools > Test Current Document

Test (between Run and JavaDoc in top button bar)

JUnit and NetBeans

See NetBeans IDE Sample Java Project *Anagrams* (via New Project).

Help > Javadoc References > JUnit 4.10 (or via 'More Javadoc...')

Right-click Java file in NetBeans project: Tools > Create JUnit Tests

File > New File... > JUnit > ...

Run > Test Project

Right-click project: Test

Approaches to Selecting Input for Test Cases

Black-box, or test-to-specifications, or functional:

Checks the functionality of the software.

Consider specification/requirements only. Ignore code.

Glass-box, or test-to-code, or structural:

Checks the internal logic of the software.

Consider code only. Ignore specification/requirements.

Techniques for Constructing Test Cases

- Boundary analysis: pick values on and near boundaries
- Equivalence classes: pick a case from every equivalence class
- Statement, branch, and path coverage
- Random input (should be reproducible through seeding)

Coverage: Example

```
if (C) { v = 1; }
if (D) { w = 2; }
else { w = 3; }
```

5 (!) statements, $2 + 2$ branches, $2 * 2$ paths

Test Cases				Coverage		
1	2	3	4	Statement	Branch	Path
$\neg C, \neg D$				60%	50%	25%
C, D				80%	50%	25%
C, D	$C, \neg D$			100%	75%	50%
C, D	$\neg C, \neg D$			100%	100%	50%
C, D	$C, \neg D$	$\neg C, D$	$\neg C, \neg D$	100%	100%	100%

How to Decide on Pass/Fail

- Select trivial or highly structured input with known output
- 'Manually' determine expected output
- Check correctness of output via 'inverse' process;
  e.g. check whether a list is a sorted permutation of the input, rather than comparing it to a sorted version of the input;
  this is a must when input does not uniquely determine output
- Use alternate implementation to compute expected output;
  e.g. using a slower but simpler algorithm
- Cross check consistency of implementation;
  e.g. check whether sorting a list and sorting a permutation of that same list yield the same output

Testing Advice

- Develop test cases before coding (Test-Driven Development):
  Forces you to consider contracts and to use interfaces *before* implementing them; can test immediately *after* implementing.
- Code & test incrementally (not everything together at once).
- Code & test simple parts first.
- Use assertions (built-in tests; "fail early"):
  Test pre- and post-conditions, and 'can't-happen' cases.
- Automate testing.
- Keep test software, data, motivation, and results.
- Re-test after making changes (regression testing).

Submitting Work for Assignments in peach^3

- Name
- ID number
- Date
- Cut line `--8<--`

Summary

- Guidelines for (functional) decomposition
- Dealing with errors in engineering
- Unit testing