Introduction to Software Engineering (ISAD1000)

Lecture 7: Modularity

Updated: 16th February, 2022

Discipline of Computing
School of Electrical Engineering, Computing and Mathematical Sciences (EECMS)

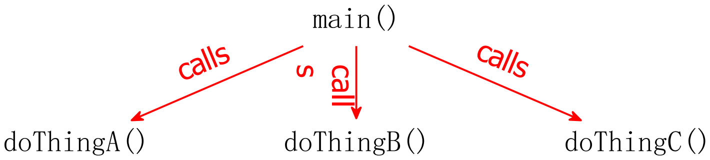
Outline

Design

- Design is a half-way step between requirements and coding.
- Uses many notations:
  - Pseudocode,
  - Structural diagrams,
  - Behavioural diagrams,
  - Tables.
- However, it also lives inside your code!
- Design is the *set of ideas* you have about how to satisfy the requirements.
- Some of these are big picture ideas; some are small details.

Modularity

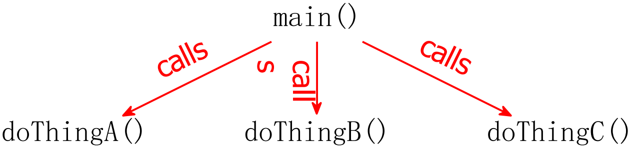
- A large part of design is about breaking things down.
  - What should the *parts* of your application be?
  - Divide and conquer – smaller problems are easier to overcome.
- We aim for *modularity*.
- Break up the software into self-contained pieces: methods, functions (and larger structures like "classes" and "packages").
  - A "module" is a specific Python concept.
  - *But*, more abstractly, it means any sub-part of a program.
- These pieces (modules) use one another:



Module Relationships/Dependencies

- Modules use each other to help accomplish tasks.
- Thus, modules depend on each other.
- Modules should hide their internal workings.
  - One module shouldn't need to "know" how other modules work.
  - More precisely, when writing/modifying a module, *you* shouldn't need to know how other modules work.
- It may not be obvious *why* this separation is a good idea...

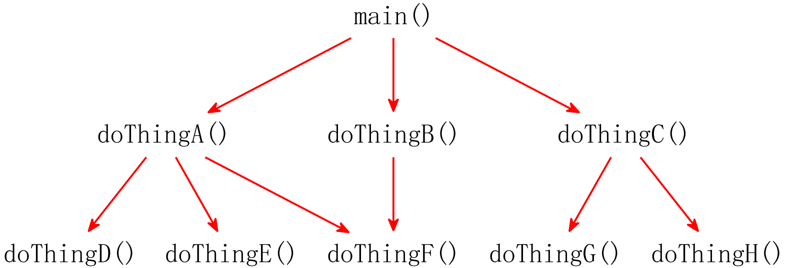
What is the Problem?



- Is it important to have these methods/functions at all?
- Is it important to give them well-defined responsibilities?

What is the Problem?

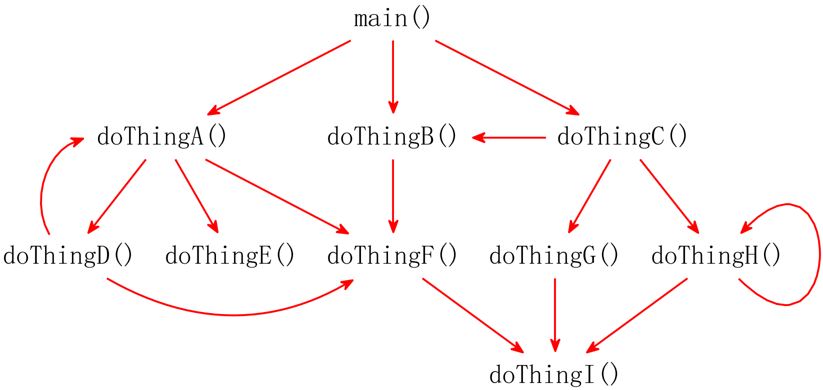
Programs can get larger:



- Painful to work with if you don't "divide and conquer" properly.
- So, ensure each method/function has a *single, well-defined responsibility*.

What is the Problem?

And programs can get more complex:



- When the relationships are complex anyway, you need all the "simplification skills" you can get!

Maintenance

- The final stage in the life of a software project.
- Occurs *after* the software is released or delivered to the client.
- The word "maintenance" is slightly misleading:
  - Hardware maintenance means fixing/replacing parts that become faulty or damaged over time.
  - This doesn't happen to software, which is just information.
  - If you find a software fault, that fault was *always there* (since at least the last modification, and often long before).
- There are good reasons to perform maintenance:
  - Corrective maintenance – fixing faults.
  - Perfective maintenance – improving or adding functionality.
  - Adaptive maintenance – updating the software for changing circumstances.

Lehman's Laws

- Meir Lehman proposed 5 laws, based on observations of software projects.
  - These are "laws" in the scientific sense.
  - They are a statement of the way things are, *not* guidelines for how things should be.
- We'll focus on the first two:
  1. **Continuing change** – a useful program either undergoes continual change/evolution, or becomes progressively less useful.
  2. **Increasing complexity** – as a program changes/evolves, its design complexity increases and its structure deteriorates, unless extra work is done to compensate.
- The other three laws relate to the ability to measure and predict the course of a large software project, independently of the actual work that needs to be done.

Refactoring

- Modifying your code without changing its functionality.
- Why?
  - To improve maintainability, and so counteract Lehman's 2nd law (increasing complexity).
  - To increase design flexibility, paving the way for future functionality to be added.
- Refactoring involves some redesign work.
  - It's not just about adjusting spacing, variable names, etc.
  - You choose a different, more *elegant*, more *logical* design.
- Often means:
  - Splitting up modules.
  - Combining separate modules into one.
  - Moving parts of one module into another.
  - Changing the way two modules communicate.
  - Eliminating redundant code.

Regression Testing

- Modifying working code always carries a risk.
- You could introduce a new fault.
  - Called a *regression*.
  - Your program regresses from working to faulty.
- *Regression testing* checks whether this has happened.
  - Test-Driven Development makes it easy.
  - Most of your test code should still work with the modified production code.
  - Update any out-of-date test code.
  - Run the tests.
  - If anything breaks that was previously working, you have a regression.
  - Fix it!
- Now we'll get back to design.

Coupling

- In FOP/PDI/OOPD, you learn that programs are broken down into several methods/functions.
  - In fact, even small programs have dozens of methods/functions.
  - Large programs have thousands.
- Methods/functions (and larger structures) interact in various ways, most obviously by "calling" each other. e.g.
  - `calcDaysInMonth()` must know if a given year is a leap year.
  - `calcDaysInMonth()` calls `isLeapYear()` to find out.
  - Thus, `calcDaysInMonth()` *depends* on `isLeapYear()`.
  - (`isLeapYear()` might also be called elsewhere in the same program.)
- But this isn't the only way that methods/functions can interact.

Degree of Coupling

- Not all coupling is equal.
  - Some coupling is looser/lower.
  - Some coupling is tighter/higher.
- We prefer it to be as loose as possible.
  - The loosest coupling is no coupling at all.
  - However, *some* coupling is essential, or the program will become logically impossible to write.
- Where high coupling exists between two modules, the contents of one have very significant effects on the other.
  - Working with tightly-coupled modules is difficult.
  - You must understand both at once, rather than one-at-a-time.
  - This makes it more time consuming (and expensive) to write, test, inspect or modify the code.
  - So, avoid high coupling!

Calls

- Calls are the most obvious and common form of coupling.
- A call (a.k.a an *invocation*) is a very specific event.
- e.g. when `calcDaysInMonth()` calls `isLeapYear()`:
  1. `calcDaysInMonth()` pauses.
  2. The year is passed from `calcDaysInMonth()` to `isLeapYear()`.
  3. `isLeapYear()` performs its calculation.
  4. The result is returned back to `calcDaysInMonth()`.
  5. `calcDaysInMonth()` resumes from where it left off.
  6. `calcDaysInMonth()` receives the return value and uses it in its own calculations.
- Parameters and return values makes the coupling slightly higher (than not having them).
  - We generally can't avoid this (without doing something much worse).
  - But it is possible to have *too many* parameters.
  - More than about 6 is a warning sign.

Global Variables (or Public Fields)

- Normal ("local") variables only exist within a particular method/function.
- Global variables exist outside any method/function.
- They can be accessed directly from anywhere.
- Lazy programmers use them as a short-cut.
  - "How can data get from `doThingA()` to `doThingB()`?"
  - "Ah ha! A global variable!"
  - Yes, but you will live to regret it.
- Global variables create tight (high) coupling between modules.
- The modules don't even refer to each other, making the coupling very difficult to see.
  - But it's there. Changes made to one module, in terms of how it uses the global variable, will affect all other modules that use it.

Global Variable Example

Java

```java
public class GlobalVariableExample
{
    public int x;        // Global variables (or technically
    public int xSquared; // "public fields" in Java).

    public static void main(String[] args)
    {
        x = ...; // Input a value from the user
        square();
        outputResult();
    }
    public static void square() {
        xSquared = x * x;
    }
    public static void outputResult() {
        System.out.println(xSquared);
    }
}
```

Global Variable Example

Python

```
def square():
    global x             # Note: "global x" allows a function
    global xSquared      # to modify global variable x. You
    xSquared = x * x     # technically don't need it simply
                         # to read a global variable.
def outputResult():
    global xSquared      # Having told you how to do this...
    print(xSquared)      # don't!

if __name__ == "__main__":
    x = int(input())
    square()
    outputResult()
```

Global Variable Discussion

- In the previous example:
  - The main/top-level code is coupled to `square()` via the global variable `x`.
  - `square()` and `outputResult()` are coupled via the global variable `xSquared`.
- What's wrong with this?
- Problems arise when we want to *modify* the code (maybe to extend the functionality).
- Global variables are a minefield.
  - It's easier to make mistakes, and harder to fix them.
  - You can't easily the consequences of what you're about to do, because the global variables connect things without telling you that they're connected.

Global Variables Increase Complexity!

- Say we want to **square two numbers and add them.**
- *With* global variables:

```java
x = ...; // Input 1st value
square();
int result1 = xSquared;
x = ...; // Input 2nd value
square();
int result2 = xSquared;
int result = result1 + result2;
```

- *Without* global variables:

```java
int x = ...; // Input 1st value
int y = ...; // Input 2nd value
result = square(x) + square(y);
```

Global Variables Increase Complexity!

- Say we want to **square two numbers and add them.**
- *With* global variables:

```python
x = ...   # Input 1st value
square()
result1 = xSquared
x = ...   # Input 2nd value
square()
result2 = xSquared
result = result1 + result2
```

- *Without* global variables:

```python
x = ...   # Input 1st value
y = ...   # Input 2nd value
result = square(x) + square(y)
```

Global Variable Are Messy

- If `x` is global, then we can't do this:

```
x = ...
y = ...
square() # Both calls to square() will use x, and not y.
square()
```

- We can't fix it like this either:

```
x = ...
x = ... # This just overwrites the first value of x.
square()
square()
```

- A similar problem applies to the `xSquared` variable.

Removing Global Variables

- Global variables can be removed by converting them into:
  - Parameters, when a method/function needs to import information;
  - Return values, where a method/function needs to export information;
  - Or both (if it was both reading and modifying a single global variable).

Removing Global Variables

Java

```
public class NoMoreGlobalVariables
{
    ~~public  int  x;~~
    ~~public int xSquared;~~
    public static void main(String[] args)
    {
        int x = ...; // Input a value from the user
        int xSquared = square(x);
        outputResult(xSquared);
    }
    public static int square(int x) {
        return x * x;
    }
    public static void outputResult(xSquared) {
        System.out.println(xSquared);
    }
}
```

Removing Global Variables

Python

```
def square(x):
    ~~global x~~
    ~~global xSquared~~
             x * x

def outputResult(         ):
    ~~global xSquared~~
    print(xSquared)

if __name__ == "__main__":
    x = int(input())
                 square( )
    outputResult(         )
```

Control Flags

- Parameters are supposed to provide data needed to perform an operation.
- Sometimes, a parameter is nothing but a way of choosing between different operations – a control flag.
  - Often a boolean, but could actually have any type.
- When this happens, the call*er* method/function and call*ed* method/function are more tightly coupled than usual.
- The caller is not just using the called, but some *subcomponent* of the called.
- The caller depends (at least partly) on the inner workings of the called.

Control Flags – Example

Java

```java
public static String formatTimeDate(int one, int two,
                                    int three, boolean isDate) {
    String s;
    if(isDate) {
        s = one + "/" + two + "/" + three;
    }
    else {
        s = one + ":" + two + ":" + three;
    }
    return s
}

public static void printDate() {
    int day, month, year;
    ... // Input values for day, month, year
    System.out.println(formatTimeDate(day, month, year, true));
}
```

Control Flags – Example

Python

```python
def formatTimeDate(one, two, three, isDate):
    if isDate:
        s = str(one) + "/" + str(two) + "/" + str(three)

    else:
        s = str(one) + ":" + str(two) + ":" + str(three)

    return s

def printDate():
    ... # Input values for day, month, year
    print(formatTimeDate(day, month, year, True))
```

Control Flags – Discussion

- In the previous example, `formatTimeDate()` has a control flag parameter `isDate`.
  - If `isDate` is true, we format a date.
  - If `isDate` is false, we format a time.
  - `isDate` itself is not really data. It has no purpose other than to join together two unconnected tasks.
- `printDate()` really depends on *one half* of `formatTimeDate()`.
  - This is actually a tighter coupling arrangement, because `printDate()` has to "know" about time formatting, even though that's not needed.
- A better solution would be to:
  - Split `formatTimeDate()` into `formatTime()` and `formatDate()`.
  - Have `printDate()` call only `formatDate()`.
  - Thus, eliminate the control flag altogether.

Refactoring Control Flags

Java

```java
public static String formatTime(int hr, int min, int sec)
{
    return hr + ":" + min + ":" + sec;
}

public static String formatDate(int day, int month, int year)
{
    return day + "/" + month + "/" + year;
}

public static void printDate()
{
    int day, month, year;
    ... // Input values for day, month, year
    System.out.println(formatTimeDate(day, month, year, true)
                       formatDate(day, month, year));
}
```

Refactoring Control Flags

Python

```python
def formatTime(hr, minute, sec):
    return str(hr) + ":" + str(minute) + ":" + str(sec)

def formatDate(day, month, year):
    return str(day) + "/" + str(month) + "/" + str(year)

def printDate():
    ... # Input values for day, month, year
    print(formatTimeDate(day, month, year, True)
          formatDate(day, month, year))
```

Cohesion

- *Cohesion* is the extent to which a single module does one well-defined task.
- We want to *maximise* cohesion (just as we want to minimise coupling).
- High cohesion leads to more efficient use of your mental resources.
  - If a module has one well-defined purpose, it will be easier to understand.
  - If it's easier to understand, it will be faster to write, test, inspect and modify.

Coupling vs. Cohesion

- Good (low/loose) coupling and good (high) cohesion go hand-in-hand.
- Good coupling and cohesion are facets of modularity.
- Improve one, and you often improve the other as well.
- If one is bad, the other tends to be bad as well.
- How to tell the difference?
  - Cohesion deals with tasks done *within* a *single* module.
  - Coupling deals with connections *between two* modules.
  - "Couple" literally means two – that's how you remember which is which.

Control Flags (Again)

- Control flags may also indicate low cohesion – where a method/function performs more than one distinct task.

Java
```java
public static String formatTimeDate(int one, int two,
                                    int three, boolean isDate) {
    String s;
    if(isDate) {
        s = one + "/" + two + "/" + three;
    }
    else {
        s = one + ":" + two + ":" + three;
    }
    return s
}
```

- `formatTimeDate()` formats dates, and formats times.
- These tasks are similar, but *not really* a single responsibility.

Control Flags (Again)

- Control flags may also indicate low cohesion – where a method/function performs more than one distinct task.

Python

```python
def formatTimeDate(one, two, three, isDate):
    if isDate:
        s = str(one) + "/" + str(two) + "/" + str(three)

    else:
        s = str(one) + ":" + str(two) + ":" + str(three)

    return s
```

- `formatTimeDate()` formats dates, and formats times.
- These tasks are similar, but *not really* a single responsibility.

Sequential Tasks

- A poorly-cohesive method/function could also be doing several things *in sequence*.
  - It doesn't always have to involve a control flag and an `if` statement.
  - It could simply do *all* of the tasks.
- This is still bad, and the method/function should still be split up as before.

Java

```java
public static String[] formatTimeDate(int one,
                                      int two, int three) {
    String[] s = new String[2];
    s[0] = one + "/" + two + "/" + three;
    s[1] = one + ":" + two + ":" + three;
    return s;  // Return an array containing both results
}
```

Sequential Tasks

- A poorly-cohesive method/function could also be doing several things *in sequence*.
  - It doesn't always have to involve a control flag and an `if` statement.
  - It could simply do *all* of the tasks.
- This is still bad, and the method/function should still be split up as before.

Python

```python
def formatTimeDate(one, two, three):
    s0 = str(one) + "/" + str(two) + "/" + str(three)
    s1 = str(one) + ":" + str(two) + ":" + str(three)
    return (s0, s1)  # Return a tuple containing both results
```

Relatedness of Tasks

- Even among methods/functions that perform multiple tasks, there are varying levels of cohesion.
- The degree of cohesion depends on how related the tasks are to each other:
  - Completely unrelated – extremely low (essentially zero) cohesion.
  - Superficially related by name or some ad hoc category.
  - Related by time – the tasks must be performed at about the same time, perhaps in a particular order.
  - Related by data – the tasks all use the same data, perhaps data produced by each other.

Different Data

- If distinct parts of a method/function use different data, it probably has poor cohesion.

Java

```java
public static void checkAgeAndPostcode(int age, int postcode)
{
    if(0 <= age && age <= 130) {
        System.out.println("Valid age");
    }
    else {
        System.out.println("Invalid age");
    }
    if(1000 <= postcode && postcode < 10000) {
        System.out.println("Valid postcode");
    }
    else {
        System.out.println("Invalid postcode");
    }
}
```

Different Data

- If distinct parts of a method/function use different data, it probably has poor cohesion.

Python

```python
def checkAgeAndPostcode(age, postcode):
    if 0 <= age <= 130:
        print("Valid age")
    else:
        print("Invalid age")

    if 1000 <= postcode < 10000:
        print("Valid postcode")
    else:
        print("Invalid postcode")
```

Different Data – Discussion

- `checkAgeAndPostcode()` has two parts that work with different data.
- Therefore, it is clearly performing two different tasks – low cohesion.
- Why is this bad?
  - What if you want to check *only* the age, or *only* the postcode?
  - You can't do it with this method/function.
  - If there were *two separate* methods/functions, you could.

Refactoring to Improve Cohesion

If a module performs several unrelated tasks, break it up:

Java

```java
public static void checkAge(int age) {
    if(0 <= age && age <= 130) {
        System.out.println("Valid age");
    } else {
        System.out.println("Invalid age");
    }
}

public static void checkPostcode(int postcode) {
    if(1000 <= postcode && postcode < 10000) {
        System.out.println("Valid postcode");
    } else {
        System.out.println("Invalid postcode");
    }
}
```

Refactoring to Improve Cohesion

If a module performs several unrelated tasks, break it up:

Python

```python
def checkAge(age):
    if 0 <= age <= 130:
        print("Valid age")
    else:
        print("Invalid age")

def checkPostcode(postcode):
    if 1000 <= postcode < 10000:
        print("Valid postcode")
    else:
        print("Invalid postcode")
```

Refactoring to Improve Cohesion (continued)

Find where you called the original method/function:

```
checkAgeAndPostcode(someAge, somePostcode)
```

And break up the call(s) as well:

```
checkAge(someAge)
checkPostcode(somePostcode)
```

- This won't affect the functionality.
- It *will* improve cohesion (and hence flexibility, maintainability, etc.).

Redundancy (or Repetition or Duplication)

- Good software design seeks to avoid redundancy, repetition, duplication, repetition, repetition and redundancy.
- Code is redundant if it performs a task that is already performed by another piece of code.
- Redundancy is good in hardware:
  - Physical things wear out over time and become faulty.
  - Duplication of physical parts can improve reliability.
  - Unlikely that they will all fail simultaneously.
- Redundancy is (usually) bad in software:
  - Software *does not* wear out over time.
  - Duplicate software systems are guaranteed to fail simultaneously (under the same conditions).
  - Redundancy increases complexity without any benefit.
- The opposite of redundancy is *reuse*.

Benefits of Reuse

- Redundancy increases the amount of code unnecessarily.
- All else being equal, a small system is better than a large one.
  - Easier to test – fewer test cases.
  - Easier to inspect – less material to review.
  - Less fault-prone – less opportunity for making mistakes.
  - Easier to maintain – less to understand.
- Some systems *must* be large, because their requirements are large, but they should not be any larger than necessary.
- Software engineers don't get paid per line of code.
  - (If they do, the project is doomed to be a catastrophe of useless, incompehensible code.)
- As a software engineer, some of your best work may be *removing* code, rather than adding more of it!

But But But...

- You may be thinking:
  - "Those test cases I've been writing seem awfully repetitive."
- Yes, they do!
- We briefly mentioned how to use loops and arrays to avoid that sort of repetition.
- However, some repetition is indeed unavoidable, due to:
  - The nature of the language.
  - The development environment.
  - The standards set by your organisation.
- Zero repetition is the "unobtainium" of software design.

Refactoring Redundancy – Reusing Modules

- We always try our best to minimise redundancy.
- If modules A and B perform exactly the same task:
  - One should be deleted; e.g. B.
  - Any other modules using B should instead use A.
- If module A is a superset of module B:
  - The duplication should be deleted from A.
  - Module A should instead *use* module B (rather than duplicate it).
- If modules A and B (and maybe even C, D, etc.) perform overlapping tasks:
  - Identify the overlapping code.
  - Delete it from both A and B (and C, D, etc. if applicable).
  - Create a new module Z, containing the overlapping code.
  - Have the other modules use module Z.

Supersets

Java
```java
public static boolean checkValid(int x) {
    return 0 <= x && x < 100;
}
public static void printIfValid(int number) {
    if(number >= 0 && number < 100)
        System.out.println(number);
    }                          // Notice that the two highlighted
}                              // sections are equivalent.
```

Refactor `printIfValid()` to call `checkValid()`:

Java
```java
public static void printIfValid(int number) {
    if(~~number >= 0 && number < 100~~ checkValid(number))
        System.out.println(number);
    }
}
```

Supersets

```python
def checkValid(x):
    return 0 <= x < 100

def printIfValid(number):
    if number >= 0 and number < 100:
        print(number)           # Notice that the two highlighted
                                # sections are equivalent.
```

Refactor `printIfValid()` to call `checkValid()`:

```python
def printIfValid(number):
    if number >= 0 and number < 100 checkValid(number):
        print(number)
```

Common Tasks

Java

```java
public static void printSpecial(double x, double y) {
    if(3 * x * x * y * (x - y) > 0.0) {
        System.out.println("(" + x + "," + y + ")");
    }
}

public static double getNM() {
    double n = 0.0;
    double m = 0.0;
    while(n <= 0.0 || m <= 0.0) {
        n = ...; // Input n value
        m = ...; // Input m value
    }
    return (n - m) * m * n * 3 * n;
}
```

- Remove the common code, and put it in a new method.

Common Tasks

Python

```python
def printSpecial(x, y):
    if 3 * x * x * y * (x - y) > 0.0:
        print(x, y)

def getNM():
    n = 0.0
    m = 0.0
    while n <= 0.0 or m <= 0.0:
        n = float(input())
        m = float(input())
    return (n - m) * m * n * 3 * n
```

- Remove the common code, and put it in a new function.

Common Tasks Refactored

Java

```
public static double calcXY(double x, double y) {
    return 3 * x * x * y * (x - y);
}                                  // new method

public static void printSpecial(double x, double y) {
    if(            ) {
        System.out.println("(" + x + "," + y + ")");
    }
}

public static double getNM() {
    double n = 0.0;
    double m = 0.0;
    while(n <= 0.0 || m <= 0.0) {...}
    return            ;
}
```

Common Tasks Refactored

Python

```
def calcXY(x, y): # new function
    return 3 * x * x * y * (x - y)

def printSpecial(x, y):
    if              > 0:
        print(x, y)

def getNM():
    n = 0.0
    m = 0.0
    while n <= 0.0 or m <= 0.0:
        ...
    return
```

Reuse and Coupling

- Reuse (a good thing) actually increases coupling (a bad thing).
- A slight paradox, or rather a balancing act.
  - Sensible reuse does not cause *undue* coupling.
  - Sensible coupling does not cause *undue* redundancy.
- If you're *not* sensible, you might:
  - See duplication where there isn't any.
  - Try to "reuse" things that are not applicable.

  These will increase coupling unnecessarily (and possibly also reduce cohesion).

That's all for now!