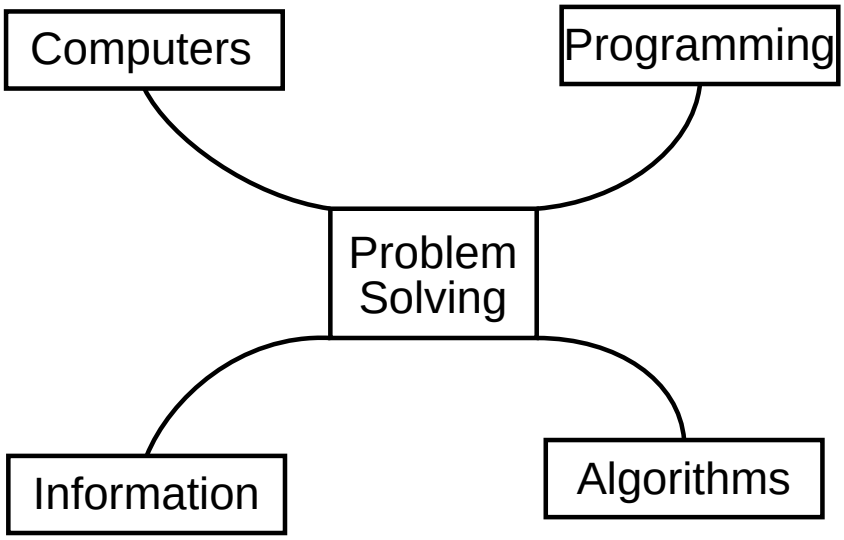
Reminder

- Midterm today at 6:00pm at MAASS 112

Review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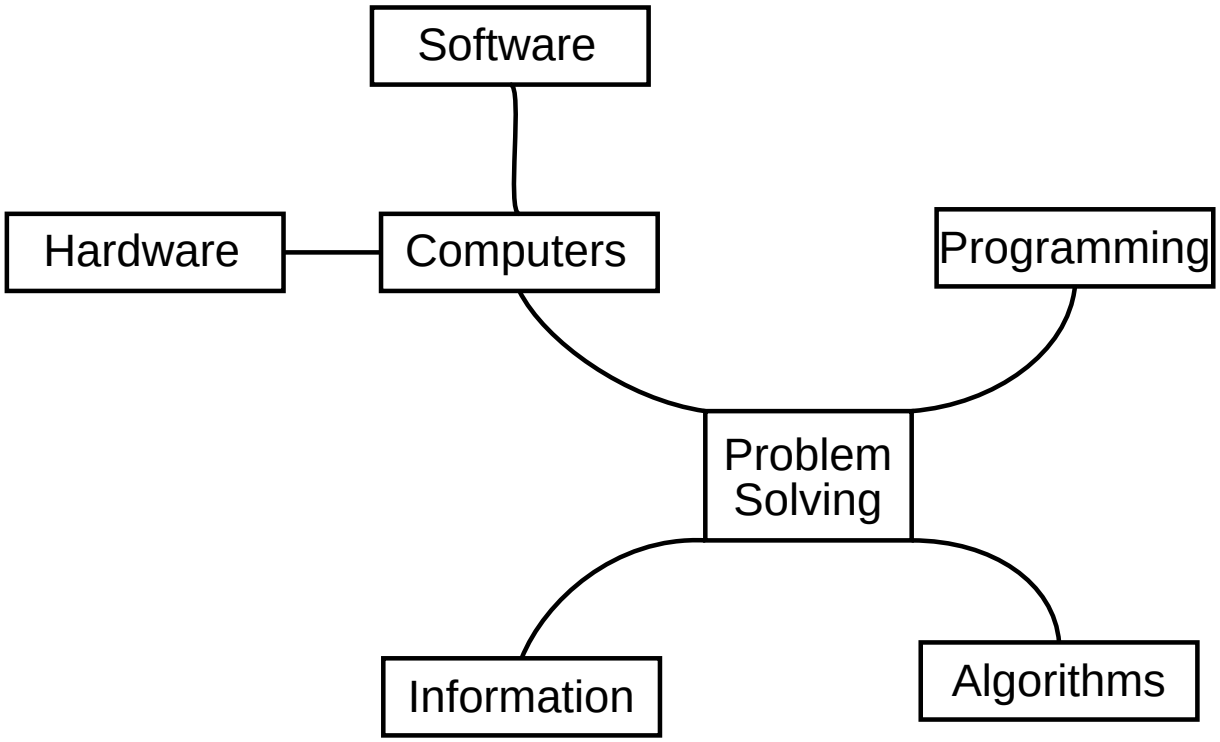
Review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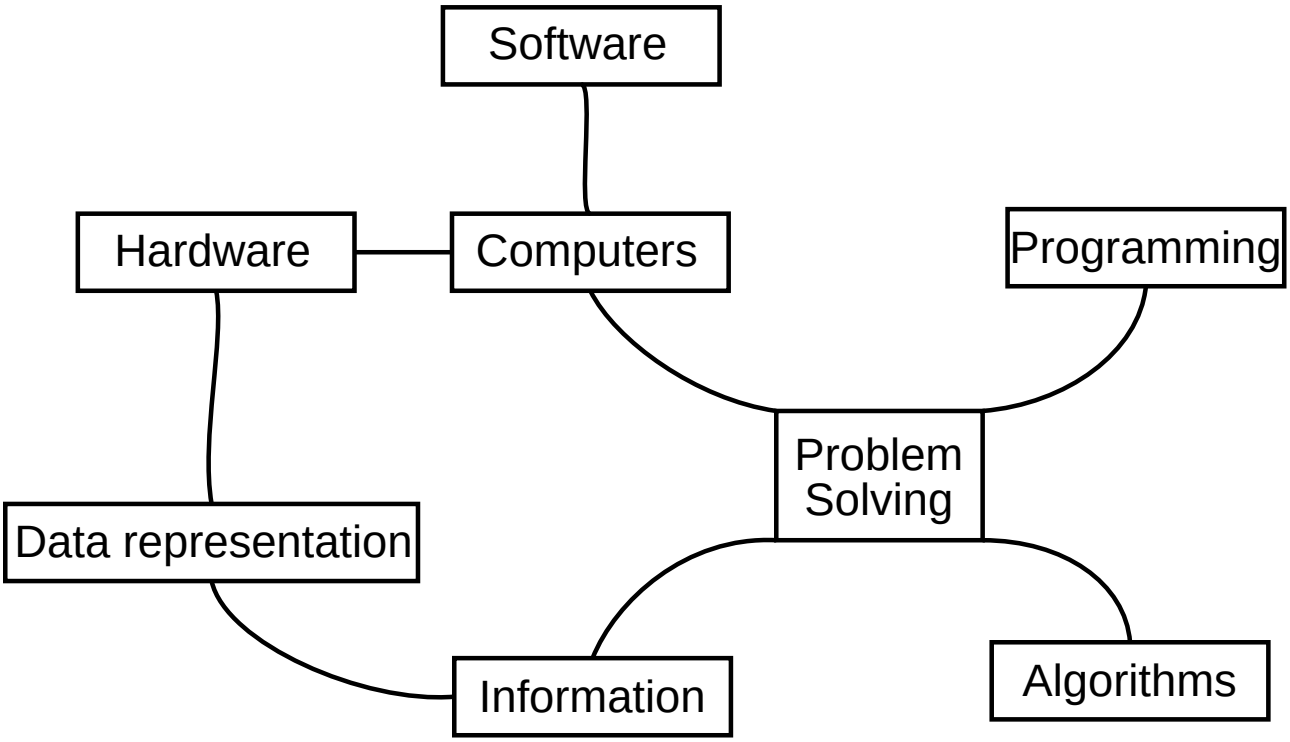
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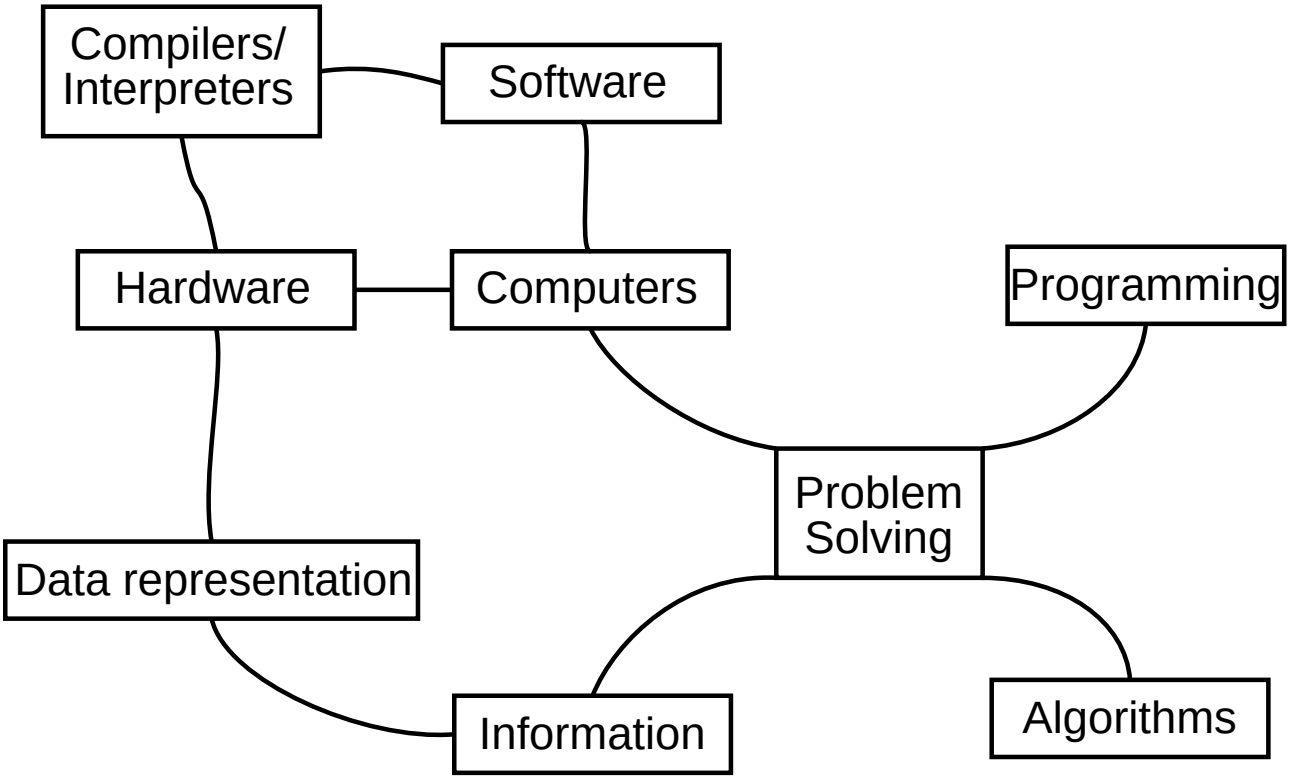
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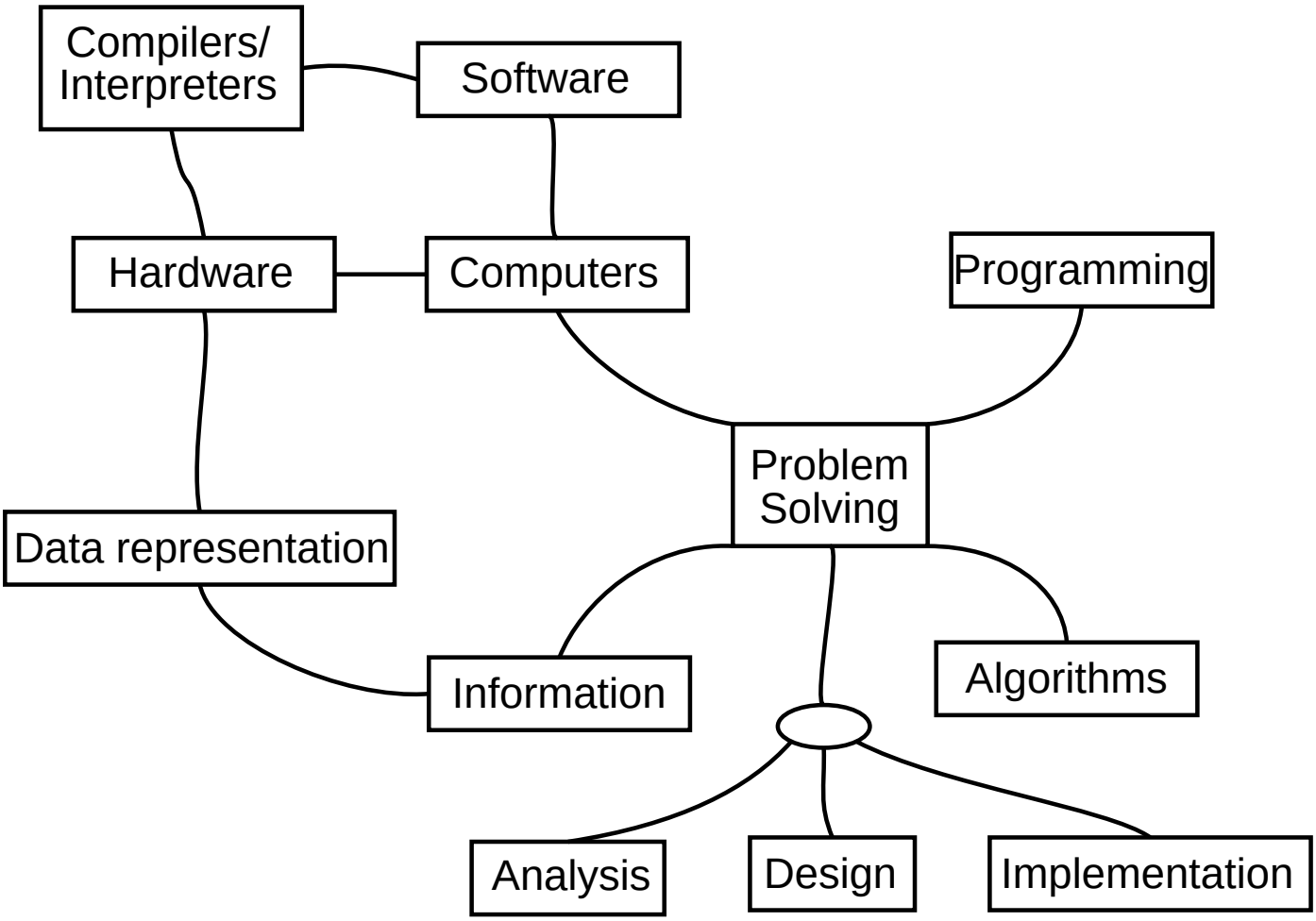
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Implementation

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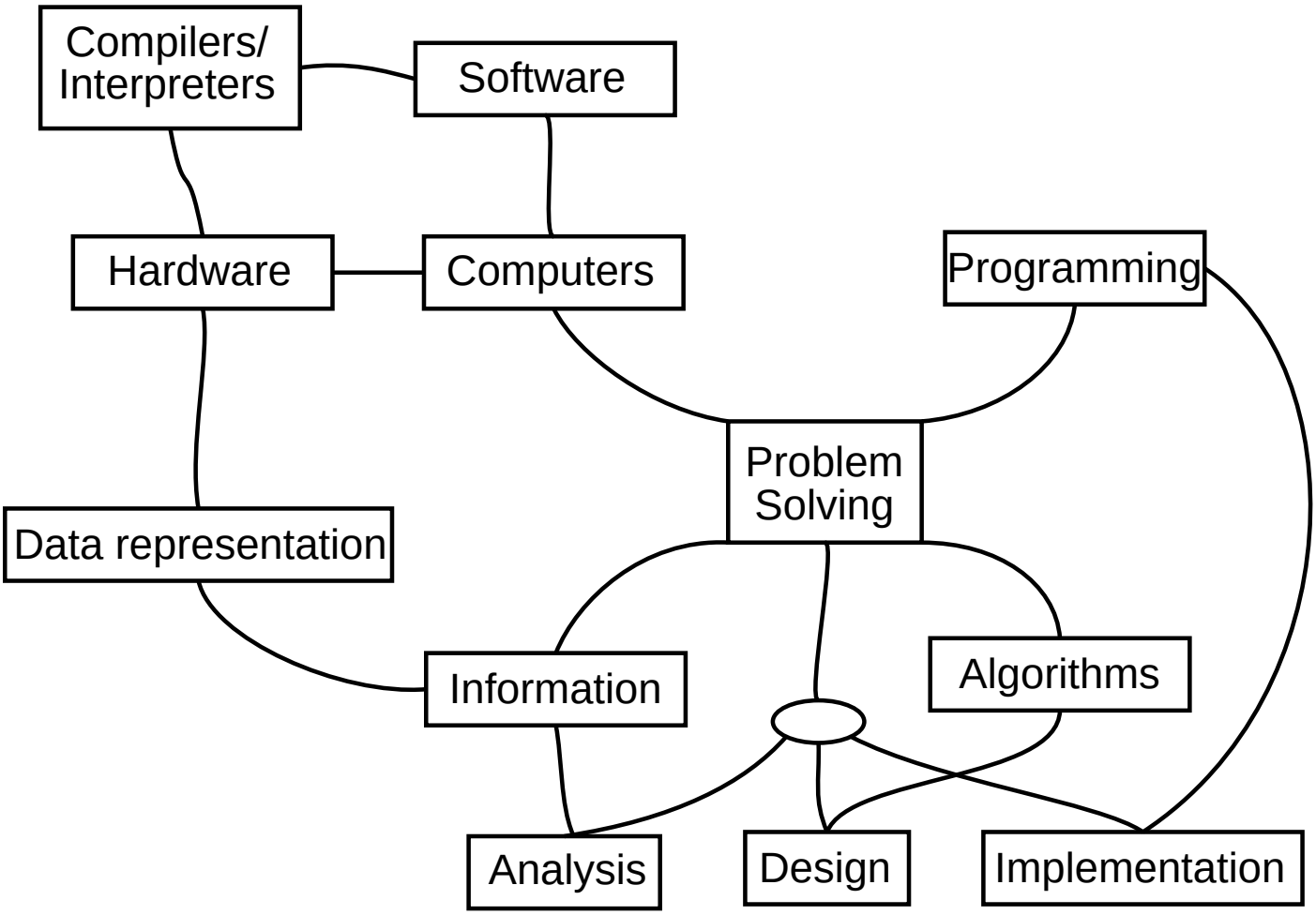
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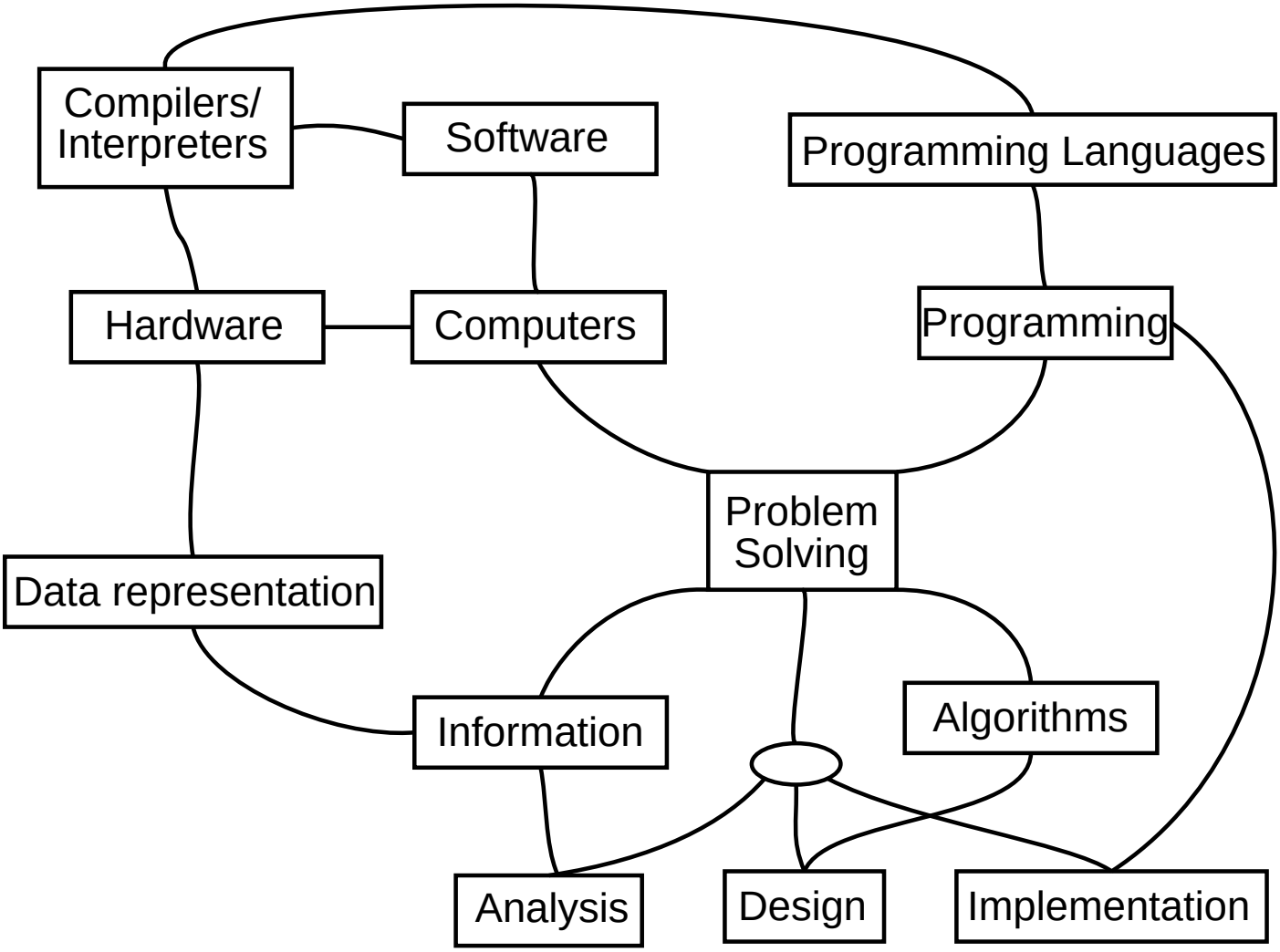
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Implementation

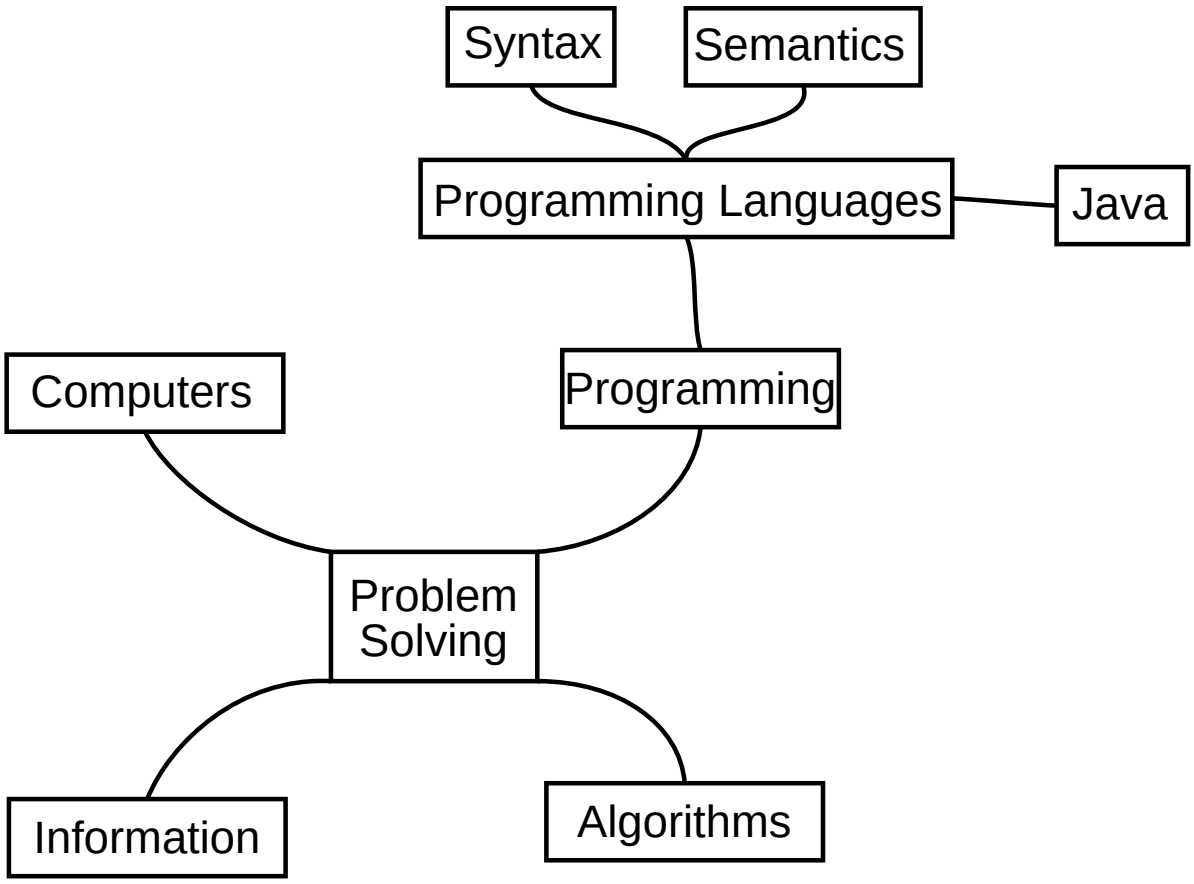
Problem solving

- Clear statement of the problem
- Analysis (of the problem)
- Design
- Implementation
- Testing / Verification
- Maintenance

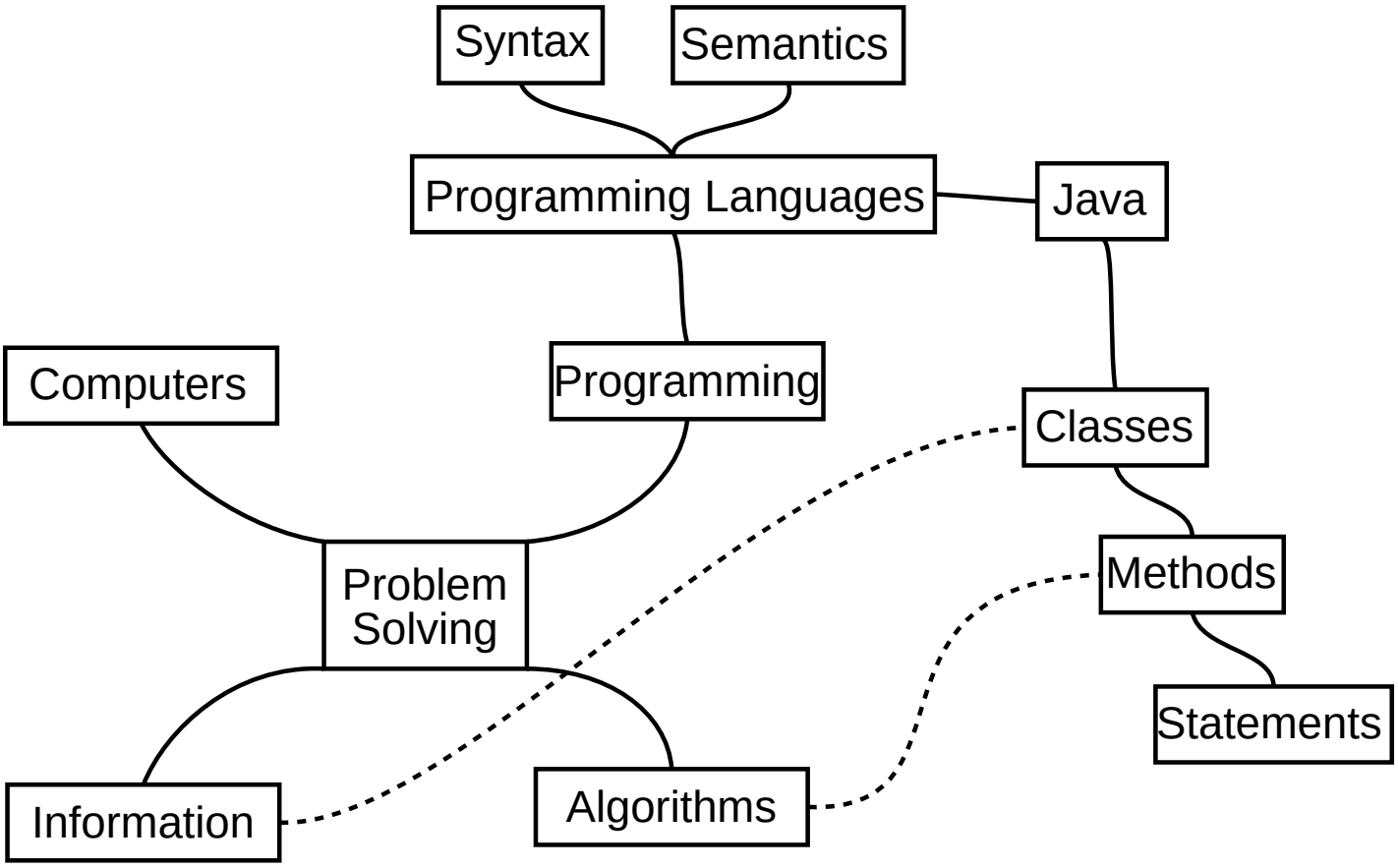
Analysis

- Goal: to obtain a precise understanding the problem
- Things to do in analysis:
  - Determine inputs and outputs
  - Determine general and specific requirements
  - Make or obtain precise definitions of concepts involved
  - Determine the relevant information to the problem
  - Determine the relationship between different elements or pieces of information of the problem
  - Make explicit any relevant assumptions

Review


Syntax
Semantics
Programming Languages
Java
Computers
Programming
Problem Solving
Information
Algorithms

Review


Syntax
Semantics
Programming Languages
Java
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Classes
Problem Solving
Methods
Statements
Information
Algorithms

Statements

- Variable declarations
- Assignment
- Conditionals
- Loops
- Method calls

Statements

- Variables
  - A variable is a memory cell with a name (identifier)
  - A variable can change its value
  - A variable has a *data type*
  - Variable declaration

```
type identifier;
type identifier = expression;
type id1, id2, id3;
type id1 = e1, id2 = e2, id3 = e3;
```

  - The type of a variable can be
    - Primitive (e.g. int, boolean, etc.)
    - User-defined (i.e. a class)

Statements

- Assignment
  - Changes the value of a variable

    variable = *expression*;

  - Expressions:
    * arithmetic: int type
    * boolean
    * string

Statements

- Conditionals: making decisions
  - if

```
if (condition)
  statement_or_block;
```

  - if-else

```
if (condition)
  statement_or_block1;
else
  statement_or_block2;
```

  - switch

```
switch(int_or_char_expr) {
  case int_or_char_expr1: statements1;
  case int_or_char_expr2: statements2;
  ...
  default: statementsn;
}
```

Statements

- Loops: Repetition
  - while

```
while (condition)
  statement_or_block;
```

  - do-while

```
do
  statement_or_block
while(condition);
```

  - for

```
for (init; condition; statement)
  statement_or_block;
```

Statements

- Method calls
  - normal

    objectreference.*methodname*(*arg1*, *arg2*, ..., *argn*

  - static

    classname.*methodname*(*arg1*, *arg2*, ..., *argn*)

- Messages to self

  methodname(*arg1*, *arg2*, ..., *argn*)
  this.*methodname*(*arg1*, *arg2*, ..., *argn*)

Control-flow

- Statements are executed sequentially
- The order in which statements appear matters

```
int x;
x = 8;
x = x + 3;
if (x >= 10) {
  System.out.println(“OK”);
}
else {
  System.out.println(“Error”);
}
```

Control-flow

- Statements are executed sequentially
- The order in which statements appear matters

```
int x;
x = 8;
if (x >= 10) {
  System.out.println(“OK”);
}
else {
  System.out.println(“Error”);
}
x = x + 3;
```

Control-flow

- Loops
- Termination: a loop may fail to terminate

```
int i;
i = 0;
while (i < 10) {
  System.out.print(i);
}
```

- To terminate, the body of the loop must have some "advance" statements, i.e. statements which will eventually make the condition false.

```
int i;
i = 0;
while (i < 10) {
  System.out.print(i);
  i++;
}
```

Classes and objects

- Objects are composite data that can react to messages
- Classes define the structure and behaviour of objects
- Objects are not classes
  - A class is a data type
  - An object is an instance of a class

Classes and objects

- Defining classes
  - Attributes (instance variables): characteristics of the objects
  - Methods: how objects react to messages
- Using classes
  - Creating objects
  - Accessing attributes
  - Invoking (calling) methods: sending messages

Classes and objects

- Defining classes:

```
public class ClassName {
  // Attribute definitions
  // Method definitions
}
```

- Defining attributes:

```
type identifier;
```

Note: different classes can have attributes with the same name

Classes and objects

- Defining methods:
  - normal

```
type name(type1 p1, type2 p2, ..., typen pn)
{
  list_of_statements;
}
```

  - static

```
static type name(type1 p1, type2 p2, ..., typen
{
  list_of_statements;
}
```

Note: different classes can have methods with the same name

Classes and objects

- Using classes:
  - Creating objects:
    type objectreference;
    objectreference = new *type*(*args*);
    where *type* is a class.

- Accessing attributes:

  objectreference.*attributename*

  only if the attribute is defined in *objectreference*'s class.

- Calling methods:

  objectreference.*methodname*(*arg1*,*arg2*,...,*argn*)

  only if the method is defined in *objectreference*'s class, and the types of the arguments are the same as the types of the parameters.

Methods calls

- If class A is defined as

```
class A {
  void m() { ... }
}
```

- and a variable x has a reference to an A object:

```
A x;
x = new A();
```

- then method m can be applied to x

```
x.m();
```

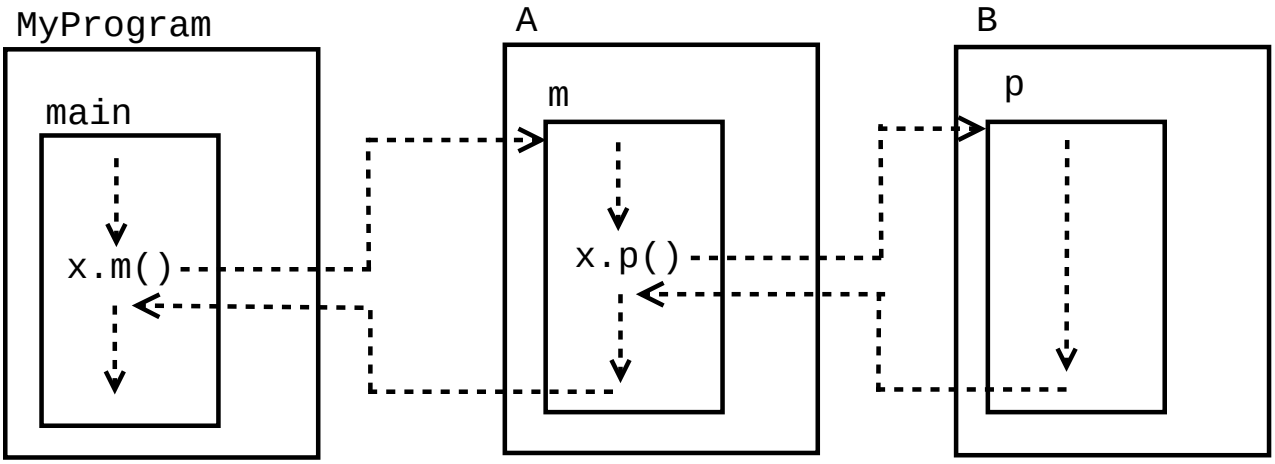
- But if method p is not defined in A, it cannot be applied to x

```
x.p(); // Error
```

Method calls

- Control flow
- Frames and parameter passing
- Access to variables
  - Parameters
  - Local variables
  - Object attributes
- Static methods
- Static variables
- Recursive methods

Methods calls: control flow

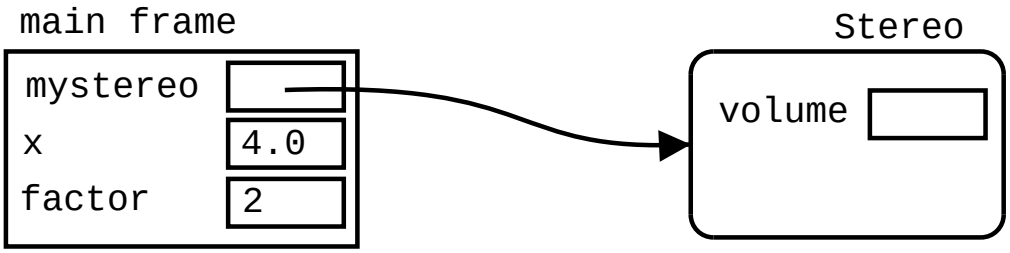


Methods calls: parameter passing

```
public class Stereo {
    double volume;
    void set_volume(double v)
    {
        volume = v;
    }
    double get_volume()
    {
        return volume;
    }
}
public class SoundSystem {
    public static void main(String[] args)
    {
        Stereo mystereo = new Stereo();
        double x, factor = 2;
        System.out.println("Testing...");
        x = 4.0;
        mystereo.set_volume( x * factor );
        System.out.println(mystereo.get_volume());
    }
}
```

Method invocation: Memory structure

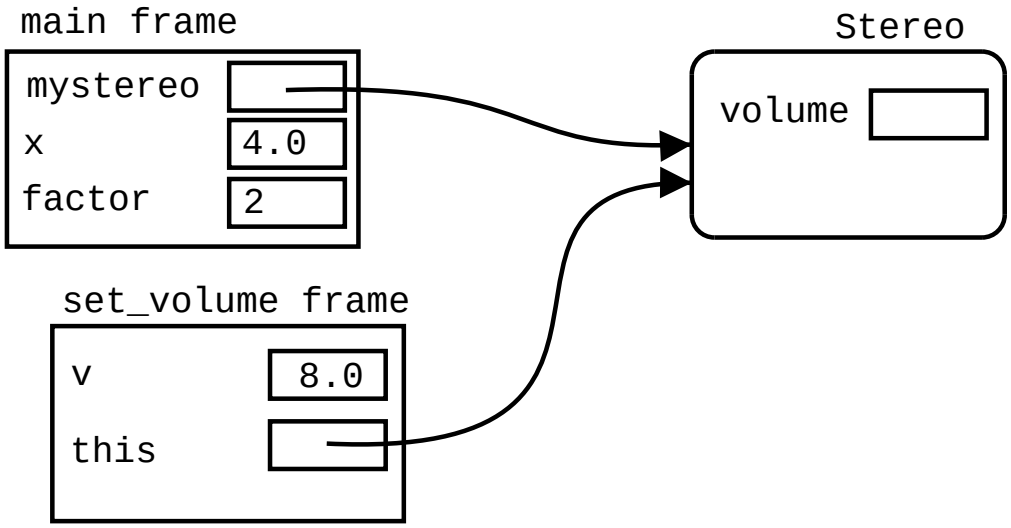
Before calling `mystereo.set_volume(x*factor)`



First its arguments (`x*factor`) are evaluated:
Evaluating `x*factor` in the main frame results in `8.0`

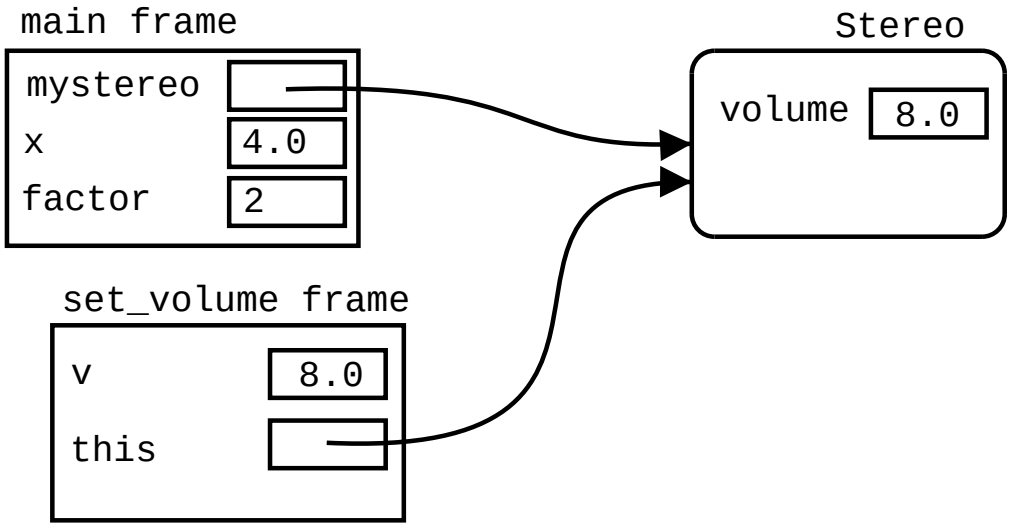
Method invocation: Memory structure

A frame for set_volume is created, and
the argument is assigned to the parameter: `v = 8.0;`



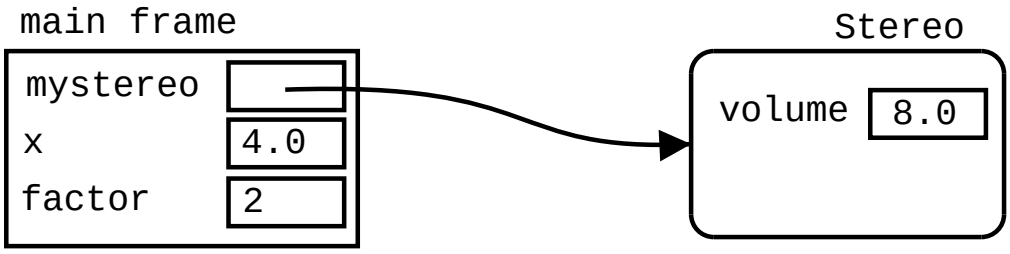
Method invocation: Memory structure

The current method (main) is suspended, and
the body of the called method (set_volume) is executed
in the context of the current frame (the set_volume frame):



Method invocation: Memory structure

Finally the called method frame is discarded, and computation of the calling method (main) is resumed in the instruction immediately after the method call.



Static methods

- Static methods have no direct effect on objects
- When calling a static method, the frame does not have a "this" reference
- Therefore they cannot access any object attributes
- They can access only:
  - Parameters
  - Local variables
  - static variables (shared between all objects in the class)
- Non-static methods can access both static and non-static methods and variables
- Static methods cannot access non-static methods and non-static instance variables

Objects as first class values

- Objects can be passed as parameters and returned as values

```
public class Rabbit {
  void jump() { ... }
}
public class Cage {
  void shake(Rabbit a)
  {
    a.jump();
  }
  Rabbit create()
  {
    return new Rabbit();
  }
}
```

...elsewhere...

```
Rabbit bugs = new Rabbit();
Cage c = new Cage();
c.shake(bugs);
Rabbit wester = c.create();
```

Objects as first class values

- Objects can be attibutes of other objects

```
public class Rabbit {
  void jump() { ... }
}
public class Cage {
  Rabbit my_rabbit;
  void put(Rabbit a)
  {
    my_rabbit = a;
  }
  Rabbit get()
  {
    return my_rabbit;
  }
}
```

...elsewhere...

```
Rabbit bugs = new Rabbit();
Cage c = new Cage();
c.put(bugs);
Rabbit wester = c.get();
```

Methods: divide and conquer

If a problem is too complex, then its solution should be done by dividing the problem into smaller subproblems, and solving each subproblem in a separate method. The solution to the entire problem is then achieved by combining the solutions of the subproblems (by calling the necessary methods.)

Methods: *reusable* abstractions

- A method can be reused in different contexts
- Calling a method is "the same" as substituting its body in place of its call (replacing the parameters by the actual arguments,) but
- If we define a method, we can simply call it from more than one context without having to do copy and paste.

Methods: reusable abstractions

Determining whether n is a prime number or not:

```
boolean result;
int i;

result = true;
i = 2;
while (i < n && result) {
  if (n % i == 0) {
    result = false;
  }
  i++;
}
```

Methods: reusable abstractions

```
public class MyMathProcedures {
  static void print_primes(int m)
  {
    boolean result;
    int n;

    n = 1;
    while (n <= m) {

      // Find out if n is prime...
      if (result)
        System.out.println(n);
      n++;
    }
  }
}
```

Methods: reusable abstractions

```
public class MyMathProcedures {
  static void print_primes(int m)
  {
    boolean result;
    int i, n;

    n = 1;
    while (n <= m) {
      result = true;
      i = 2;
      while (i < n && result) {
        if (n % i == 0) {
          result = false;
        }
        i++;
      }
      if (result)
        System.out.println(n);
      n++;
    }
  }
}
```

Methods: reusable abstractions

```
public class MyMathProcedures {
  static boolean is_prime(int n)
  {
    boolean result;
    int i;

    result = true;
    i = 2;
    while (i < n && result) {
      if (n % i == 0) {
        result = false;
      }
      i++;
    }
    return result;
  }
  //... rest of the class
}
```

Methods: reusable abstractions

```
public class MyMathProcedures {
  static void print_primes(int m)
  {
    boolean result;
    int i, n;

    n = 1;
    while (n <= m) {
      result = true;
      i = 2;
      while (i < n && result) {
        if (n % i == 0) {
          result = false;
        }
        i++;
      }
      if (result)
        System.out.println(n);
      n++;
    }
  }
}
```

Methods: reusable abstractions

```
public class MyMathProcedures {
  static boolean is_prime(int n) { ... }

  static void print_primes(int m)
  {
    boolean result;
    int n;

    n = 1;
    while (n <= m) {
      result = is_prime(n);
      if (result)
        System.out.println(n);
      n++;
    }
  }
}
```

Methods: reusable abstractions

```
public class MyMathProcedures {
  static boolean is_prime(int n) { ... }

  static void print_primes(int m)
  {
    int n;

    n = 1;
    while (n <= m) {
      if (is_prime(n))
        System.out.println(n);
      n++;
    }
  }
}
```

Methods: reusable abstractions

Problem: given three numbers, determine whether all of them are prime or their sum is prime

Methods: reusable abstractions

```
public class MyMathProcedures {
  static boolean is_prime(int n) { ... }

  static void threenumbers(int a, int b, int c)
  {
    if (is_prime(a) && is_prime(b) && is_prime(c)
       || is_prime(a+b+c)) {
      return true;
    }
    return false;
  }
}
```

Methods: reusable abstractions

```
public class MyMathProcedures {
  static boolean is_prime(int n) { ... }

  static void threenumbers(int a, int b, int c)
  {
    return (is_prime(a) && is_prime(b) && is_prime(
         || is_prime(a+b+c));
  }
}
```

Methods: reusable abstractions

```
public class MyMathProcedures {
  static boolean is_prime(int n) { ... }

  static void threenumbers(int a, int b, int c)
  {
    boolean result1, result2, result3, result4;
    int i;

    result1 = true;
    i = 2;
    while (i < a && result1) {
      if (a % i == 0) {
        result1 = false;
      }
      i++;
    }
    result2 = true;
    i = 2;
    while (i < b && result2) {
      if (b % i == 0) {
        result2 = false;
```

```
        }
        i++;
      }
      result3 = true;
      i = 2;
      while (i < c && result3) {
        if (c % i == 0) {
          result3 = false;
        }
        i++;
      }
      result4 = true;
      i = 2;
      while (i < a+b+c && result4) {
        if ((a+b+c) % i == 0) {
          result4 = false;
        }
        i++;
      }
      return result1 && result2 && result3 || result
    }
  }
```

Methods: reusable abstractions

```
public class MyMathProcedures {
  static boolean is_prime(int n)
  {
    boolean result;
    int i;

    result = true;
    i = 2;
    while (i < Math.sqrt(n) && result) {
      if (n % i == 0) {
        result = false;
      }
      i++;
    }
    return result;
  }
  //... rest of the class
}
```

Recursion

- A recursive method is a method that calls itself (directly or indirectly.)
- A recursive definition is a definition of something in terms of itself
- Some recursive definitions don't make sense, (e.g. from Webster's: growl: to utter a growl), but others do
- For example:
  - A *list of numbers* is either:
    * A single number, or
    * A number followed by a list of numbers.
  - For example:
    * 5 is a list of numbers
    * 7, 5 is a list of numbers (because 5 is a list)
    * 6, 7, 5 is a list of numbers (because 7, 5 is a list)
    * 8, 6, 7, 5 is a list of numbers (because 6, 7, 5 is a list)

Recursive functions

- Factorial: the factorial of a natural number n, written $n!$ is the multiplication of the first n positive integers, i.e.

$$n! = 1 \cdot 2 \cdot 3 \cdot ... \cdot (n-2) \cdot (n-1) \cdot n \qquad (1)$$

But note that

$$1 \cdot 2 \cdot 3 \cdot ... \cdot (n-2) \cdot (n-1) = (n-1)! \qquad (2)$$

So by (1) and (2) we get

$$n! = (n-1)! \cdot n \qquad (3)$$

But we have to assume a "base case", by defining

$$0! = 1 \qquad (4)$$

Recursive functions (contd.)

Hence, (3) and (4) together gives us an alternative, and recursive definition of (1):

$$n! = \begin{cases} 1 & \text{if } n = 0 \\ (n-1)! \cdot n & \text{otherwise} \end{cases}$$

This can be implemented as a static recursive method:

```
static int factorial(int n)
{
    if (n == 0) {
        return 1;
    }
    return factorial(n-1)*n;
}
```

Execution of recursive methods

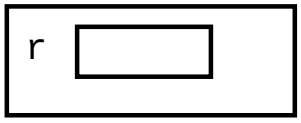
Consider the following client for this factorial function:

```
int r;
r = factorial(4);
```

Its execution proceeds as follows:

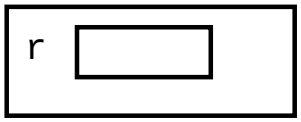
This is executed in some frame:

Some frame

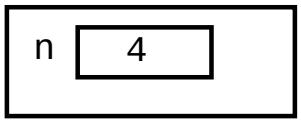


When we call `factorial(4);` a new frame for the method is created:

Some frame



factorial frame

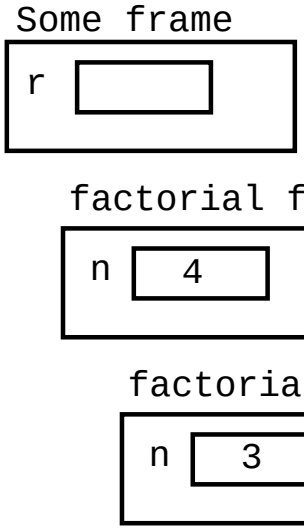


We execute the body of factorial; n is not 0 so we execute

```
return factorial(n-1)*n;
```

which in this frame is the same as

```
return factorial(4-1)*4;
```



pending computation:

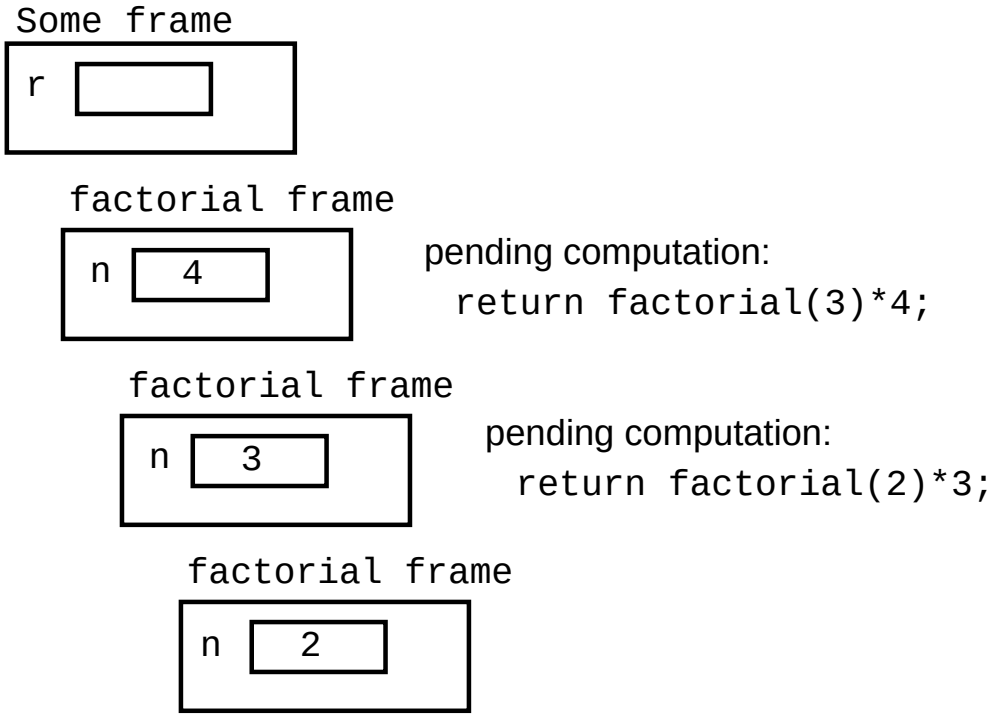
```
return factorial(3)*4;
```

Again, we execute the body of factorial;
again, n is not 0 so we execute

```
return factorial(n-1)*n;
```

which in this frame is the same as

```
return factorial(3-1)*3;
```

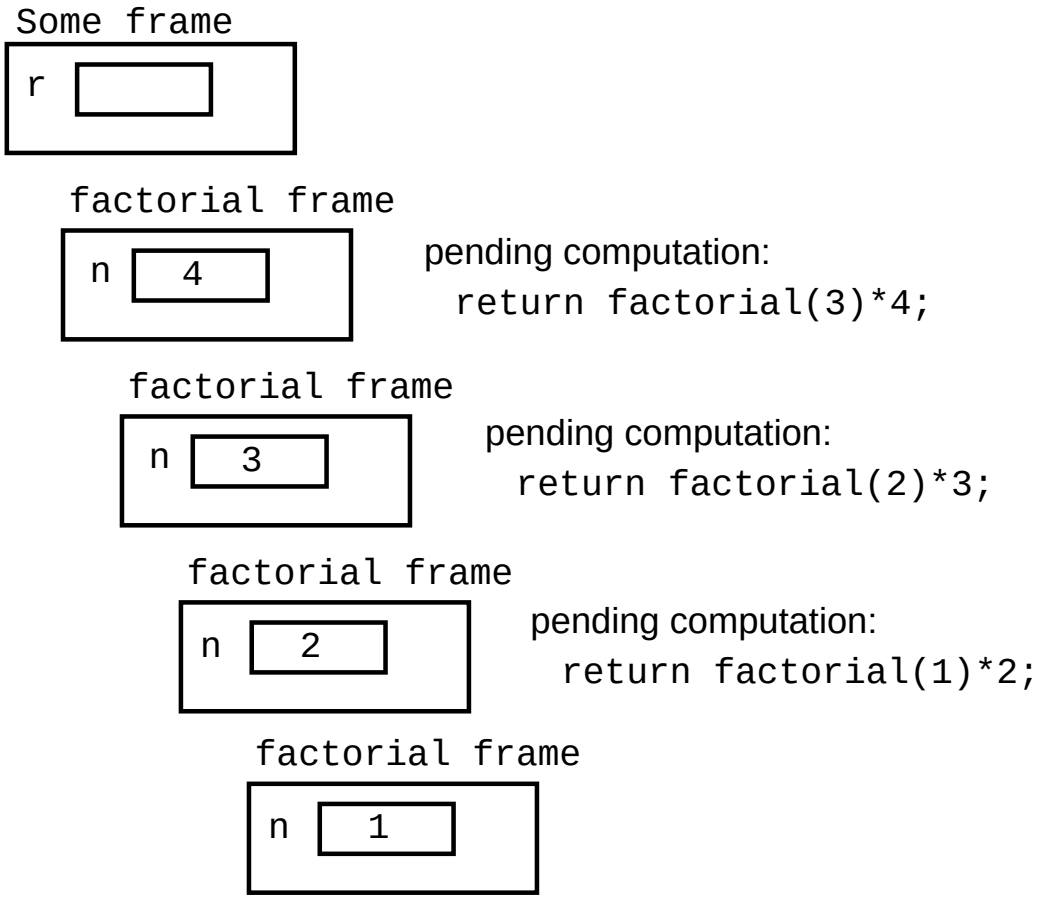


Again, we execute the body of factorial;
again, n is not 0 so we execute

```
return factorial(n-1)*n;
```

which in this frame is the same as

```
return factorial(2-1)*2;
```

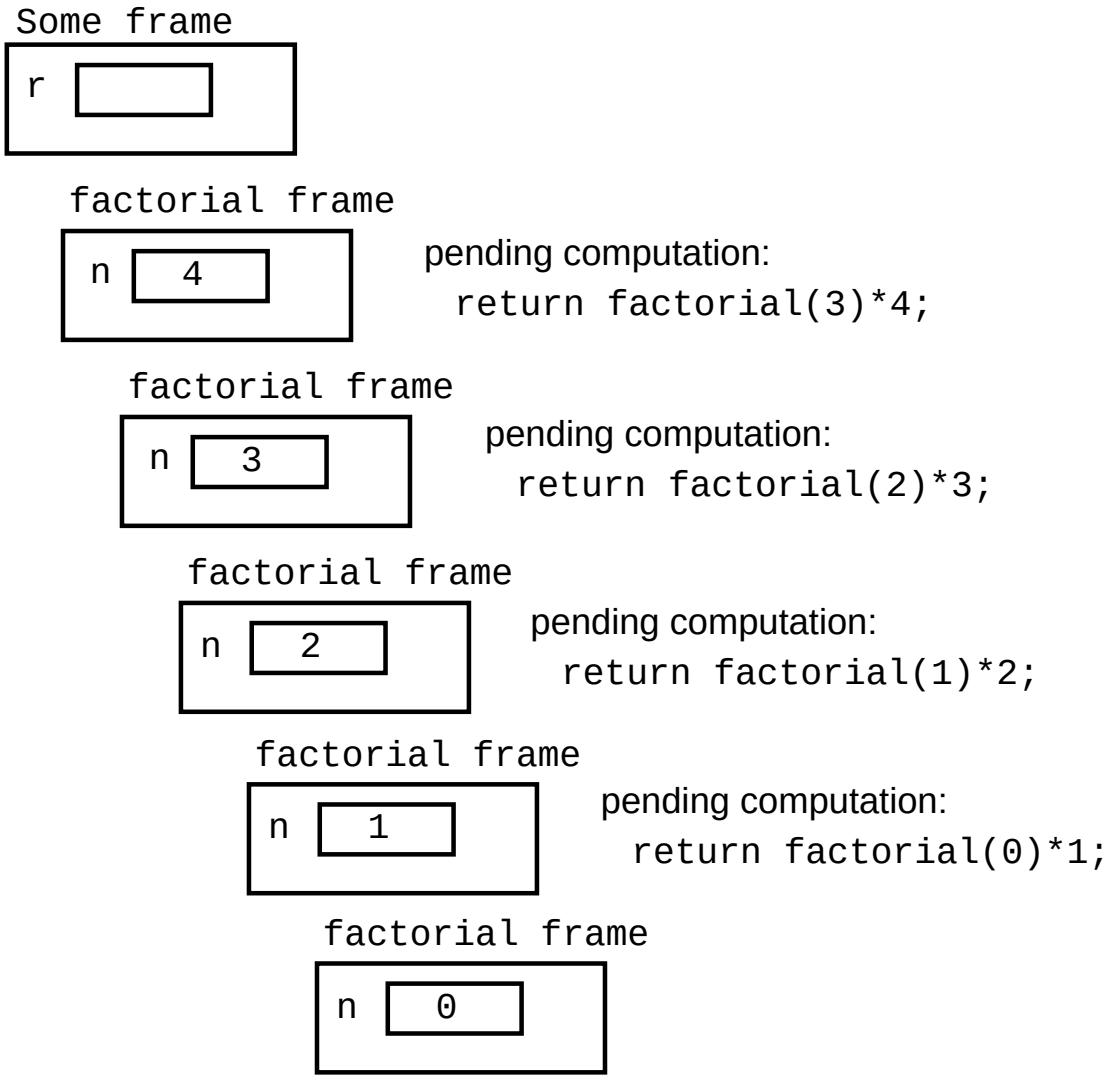


Again, we execute the body of factorial;
again, n is not 0 so we execute

```
return factorial(n-1)*n;
```

which in this frame is the same as

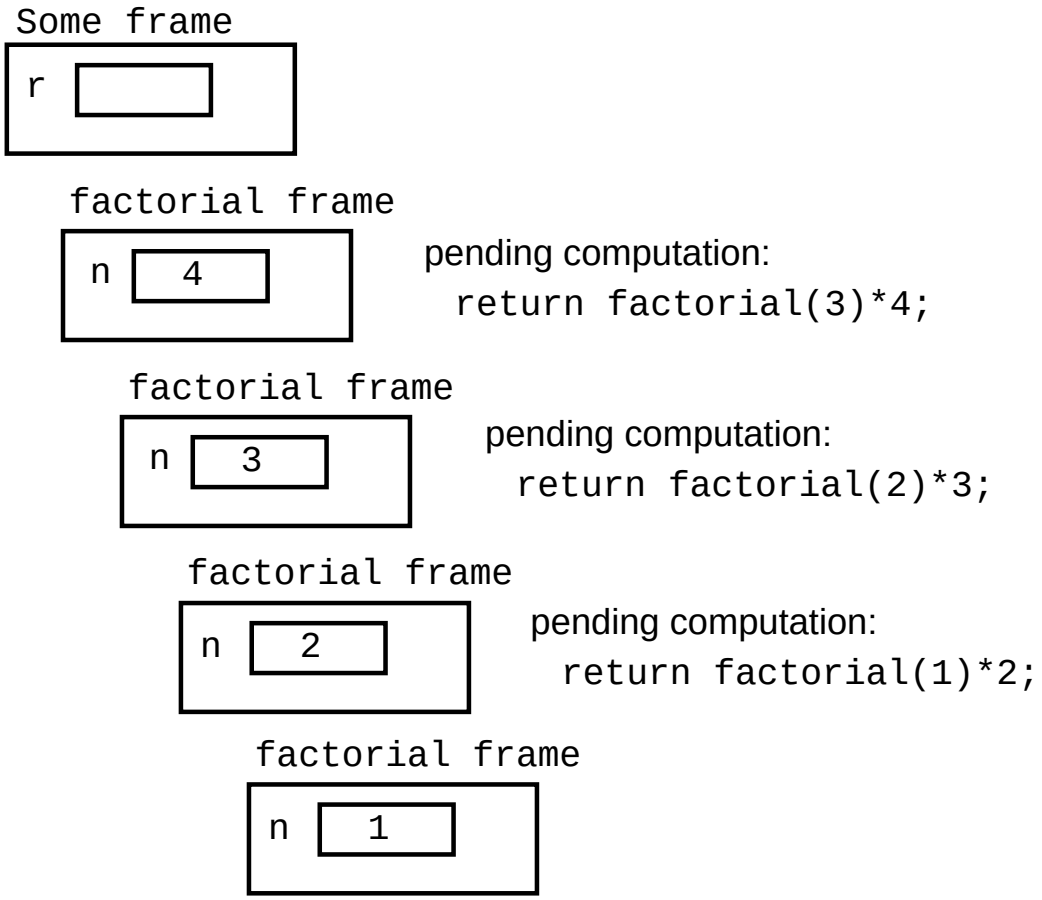
```
return factorial(1-1)*1;
```



Now, we have reached the base case, and n is 0, so we execute:

```
return 1;
```

We get rid of the frame, and pass the returned value to the caller



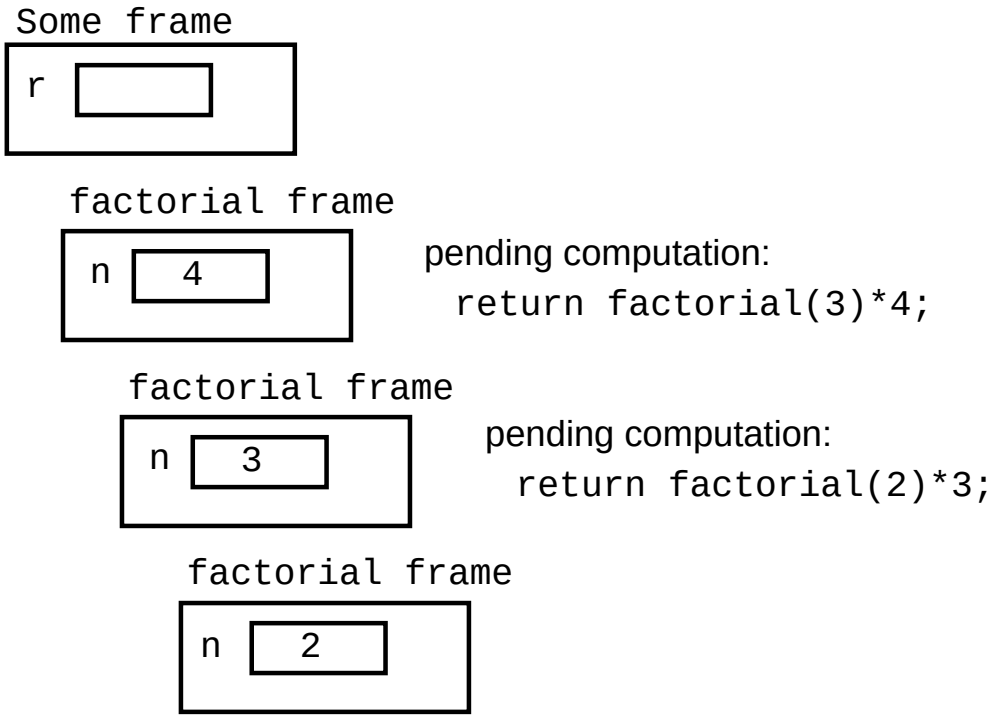
The pending computation here was:

```
return factorial(0)*1;
```

and the method called `factorial(0)`
returned 1, so this pending computation is now:

```
return 1*1;
```

We get rid of the frame, and pass the returned value to the caller



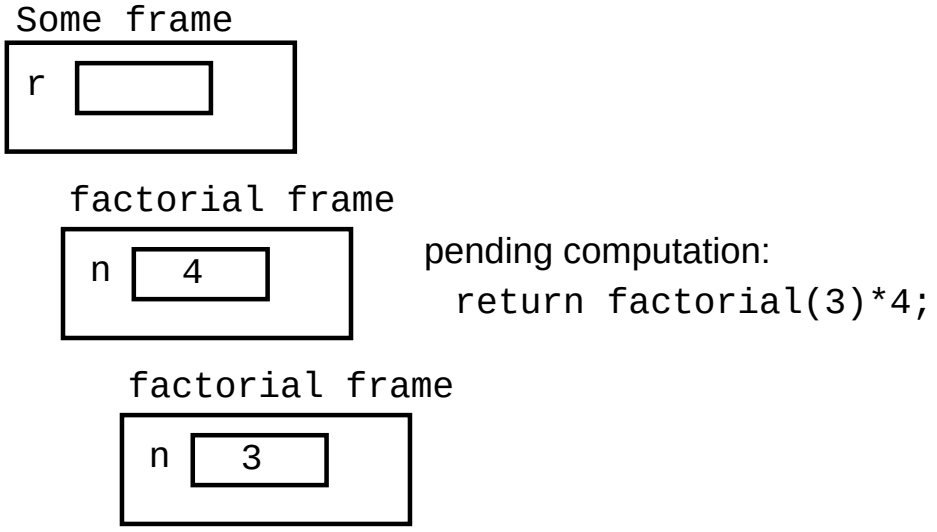
The pending computation here was:

```
return factorial(1)*2;
```

and the method called `factorial(1)`
returned 1, so this pending computation is now:

```
return 1*2;
```

We get rid of the frame, and pass the returned value to the caller



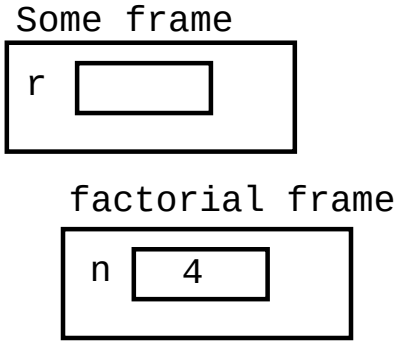
The pending computation here was:

```
return factorial(2)*3;
```

and the method called `factorial(2)`
returned 2, so this pending computation is now:

```
return 2*3;
```

We get rid of the frame, and pass the returned value to the caller



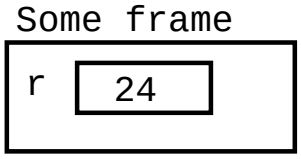
The pending computation here was:

```
return factorial(3)*4;
```

and the method called `factorial(3)`
returned 6, so this pending computation is now:

```
return 6*4;
```

We get rid of the frame, and pass the returned value to the caller



The pending computation here was:

```
r = factorial(4);
```

which returned 24, so this pending computation is now:

```
r = 24;
```

Recursion on other types

- Problem: given a string s, return the reverse of the string

- Analysis:
  - Notation:
    - $\mathsf{rev}(s)$ is the reverse of s
    - s_i is the i-th character of s
    - $\mathsf{len}(s)$ is the length of s
    - $\mathsf{rest}(s)$ is the string s without its first character s_0 (i.e. $\mathsf{rest}(s) = s_1 s_2 ... s_n$ where $n = \mathsf{len}(s) - 1$)
  - Formal definition of reverse:

$$\mathsf{rev}(s) = \begin{cases} \text{“”} & \text{if } s = \text{“”} \\ \mathsf{rev}(\mathsf{rest}(s)) + s_0 & \text{otherwise} \end{cases}$$

Reverse (contd.)

- For example:

$$
\begin{aligned}
\mathsf{rev}(\text{“}abcd\text{”}) &= \mathsf{rev}(\text{“}bcd\text{”}) +' a' \\
&= (\mathsf{rev}(\text{“}cd\text{”}) +' b') +' a' \\
&= ((\mathsf{rev}(\text{“}d\text{”}) +' c') +' b') +' a' \\
&= (((\mathsf{rev}(\text{“”}) +' d') +' c') +' b') +' a' \\
&= (((\text{“”} +' d') +' c') +' b') +' a' \\
&= ((\text{“}d\text{”} +' c') +' b') +' a' \\
&= (\text{“}dc\text{”} +' b') +' a' \\
&= \text{“}dcb\text{”} +' a' \\
&= \text{“}dcba\text{”}
\end{aligned}
$$

Reverse (contd.)

```
public class MoreStringOperations {
  static String reverse(String s)
  {
    if (s.equals(“”)) {
      return “”;
    }
    return reverse(rest(s))+s.charAt(0);
  }
  static String rest(String s)
  {
    String result =“”;
    int i = 1;
    while (i < s.length()) {
      result = result + s.charAt(i);
      i++;
    }
    return result;
  }
}
```

Double recursion

- Problem: Compute the n-th Fibonacci number
- Analysis: The Fibonacci sequence 1, 1, 2, 3, 5, 8, 13, 21, 34, ...is defined by:

$$fib(n) = \begin{cases} 1 & \text{if } n \leqslant 2 \\ fib(n-1) + fib(n-2) & \text{otherwise} \end{cases}$$

- Implementation:

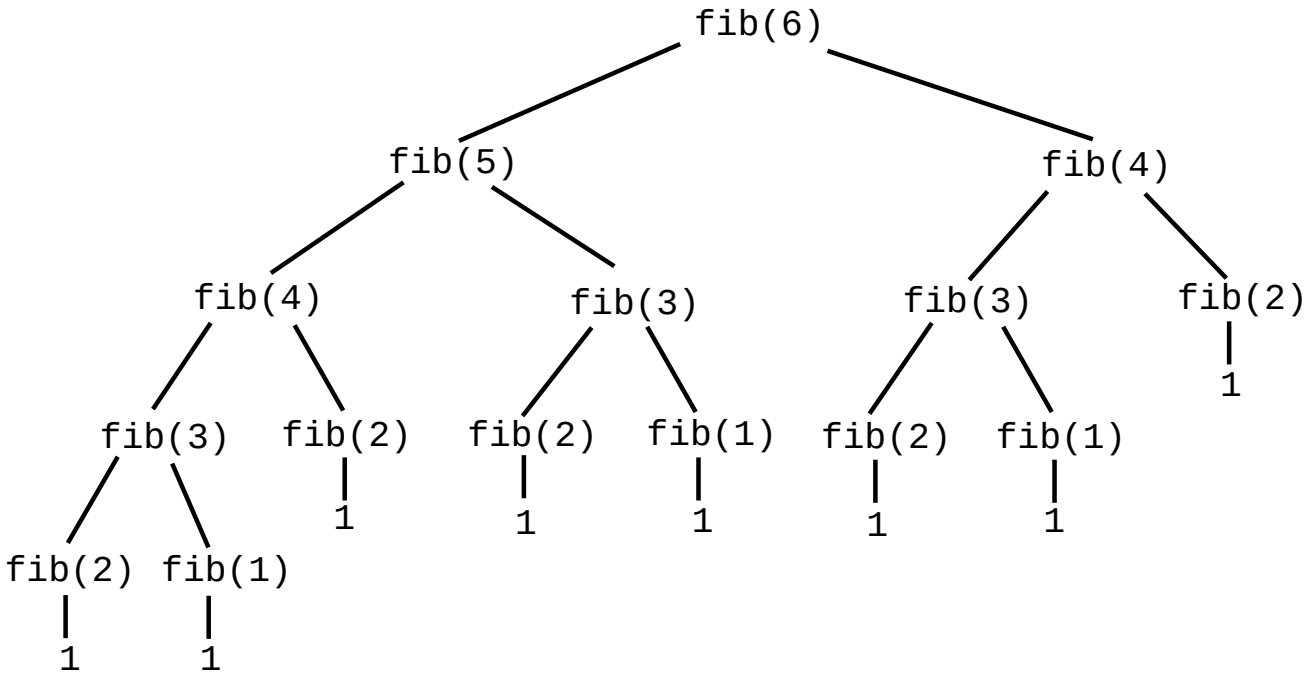
```
static int fib(int n)
{
    if (n <= 2) {
        return 1;
    }
    return fib(n-1)+fib(n-2);
}
```

Iteration vs recursion

- Iterative solution to the Fibonacci problem:

```
static int fib(int n)
{
    int a, b, c, i;
    a = 1;
    b = 1;
    c = 1;
    i = 3;
    while (i <= n) {
        c = a + b;
        a = b;
        b = c;
        i++;
    }
    return c;
}
```

Execution trees



Method overloading

- There can be several (static or not) methods with the same name...
- ...but the type or number of parameters must be different

Example

```
public class A {
  void f(int x)
  {
    System.out.println(“one: ”+x)
  }
  void f(boolean x)
  {
    System.out.println(“two: ”+x)
  }
}
public class B {
  void g()
  {
    A u = new A();
    u.f(5);
    u.f(false);
  }
}
```

Same for static methods

```
public class A {
  static void f(int x)
  {
    System.out.println("one: "+x)
  }
  static void f(boolean x)
  {
    System.out.println("two: "+x)
  }
}
public class B {
  void g()
  {
    A.f(5);
    A.f(false);
  }
}
```

The end