Test driven programming

- What is it?
- Why does it matter in P3?

Additional help desk hours

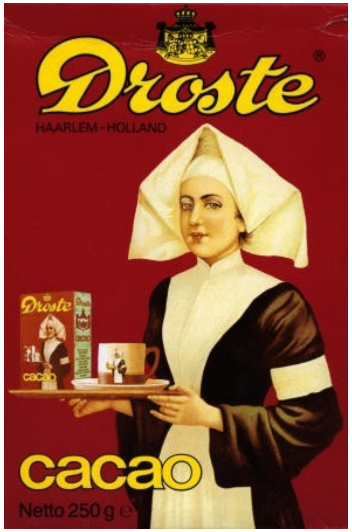
- 4-8 Sundays
- 4-6 Mondays
- 12-6 Thursdays
- 10-3 Fridays

Iclicker Question #1

What is the definition of recursion?

A. See recursion

Recursion



Chapter 5.4 in Rosen

Chapter 11 in Savitch

Preliminaries: programming as a contract

- Specifying what each method does
  - Specify it in a comment before method's header
- Precondition
  - What is assumed to be true before the method is executed
  - **Caller obligation**
- Postcondition
  - Specifies what will happen if the preconditions are met – what the method guarantees to the caller
  - **Method obligation**

Example

```
/*
 ** precondition:  n >= 0
 ** postcondition: return value satisfies:
 ** result == n!
*/
int factorial(int n) {


}
```

Enforcing preconditions

```
/*
 ** precondition:  n >= 0
 ** postcondition: return value satisfies:
 ** result == n!
*/
int factorial(int n) {
if (n < 0)
     throw new ArithmeticException("cannot
       compute factorial of a neg number!");

}
```

What about postconditions?

```
/*
 ** precondition:  n >= 0
 ** postcondition: return value satisfies:
 ** result == n!
*/
int factorial(int n) {
     assert result == n!;
}
```

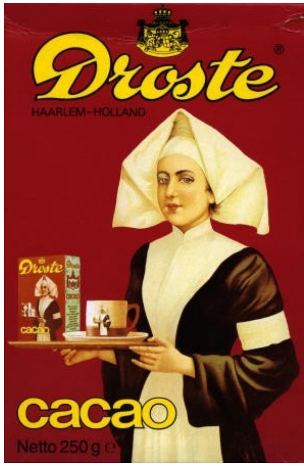
Java provides a mechanism called assertions to verify that postconditions hold

Enforcing preconditions

```
/*
 ** precondition:  x >= 0
 ** postcondition: return value satisfies:
 ** result * result == x
*/
double sqrt(double x) {
  if (x < 0)
     throw new ArithmeticException("you
       tried to take sqrt of a neg number!");

}
```

What does this method do?



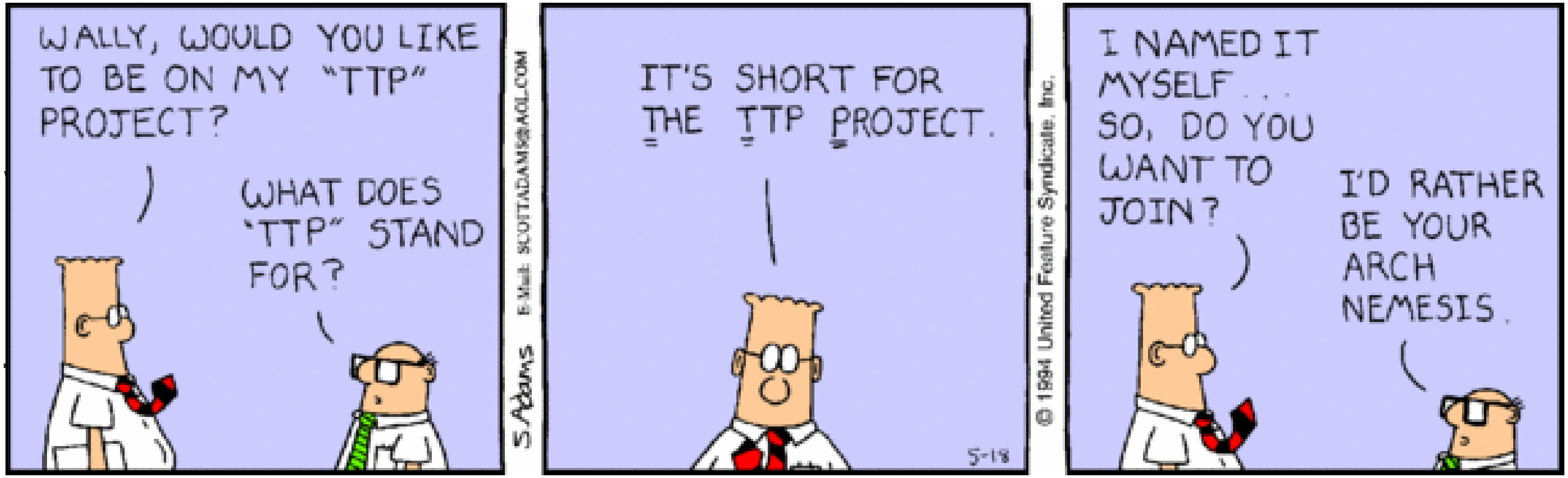

```
/**
* precondition n>0
* postcondition ??
*/
private void printStars(int n) {
    if (n == 1) {
        System.out.println("*");
    } else {
        System.out.print("*");
        printStars(n - 1);
    }
}
```

Recursion

- **recursion**: The definition of an operation in terms of itself.
  - Solving a problem using recursion depends on solving smaller occurrences of the same problem.

- **recursive programming**: Writing methods that call themselves
  - directly or indirectly
  - An equally powerful substitute for *iteration* (loops)
  - But sometimes much more suitable for the problem

Recursive Acronyms



GNU — GNU's Not Unix

KDE — KDE Desktop Environment

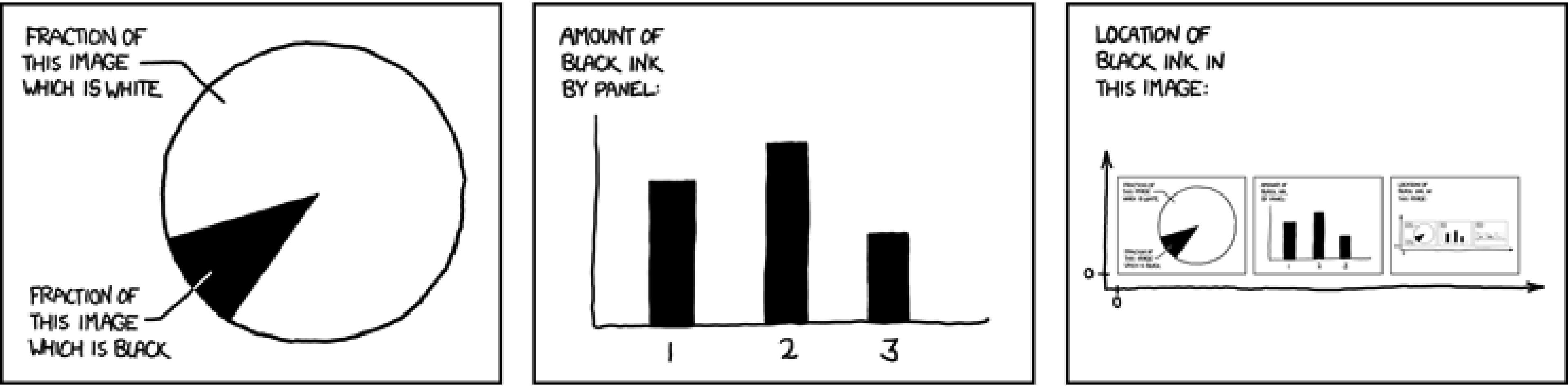
PHP - PHP: Hypertext Preprocessor

PNG — PNG's Not GIF (officially "Portable Network Graphics")

RPM — RPM Package Manager (originally "Red Hat Package Manager")

http://search.dilbert.com/comic/Ttp

More Recursion!



http://xkcd.com/688/

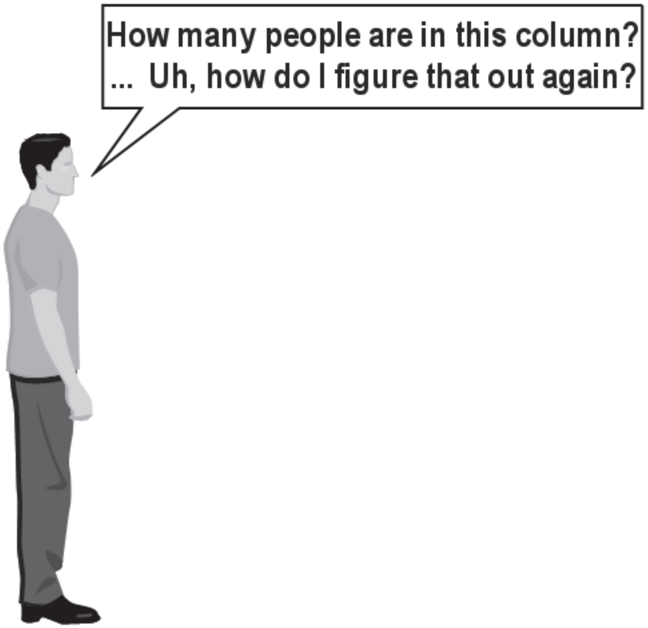
http://xkcd.com/981/

Why learn recursion?

- A different way of thinking about problems
- Can solve some problems better than iteration
- Leads to elegant, simple, concise code (when used well)
- Some programming languages ("functional" languages such as Scheme, ML, and Haskell) use recursion exclusively (no loops)

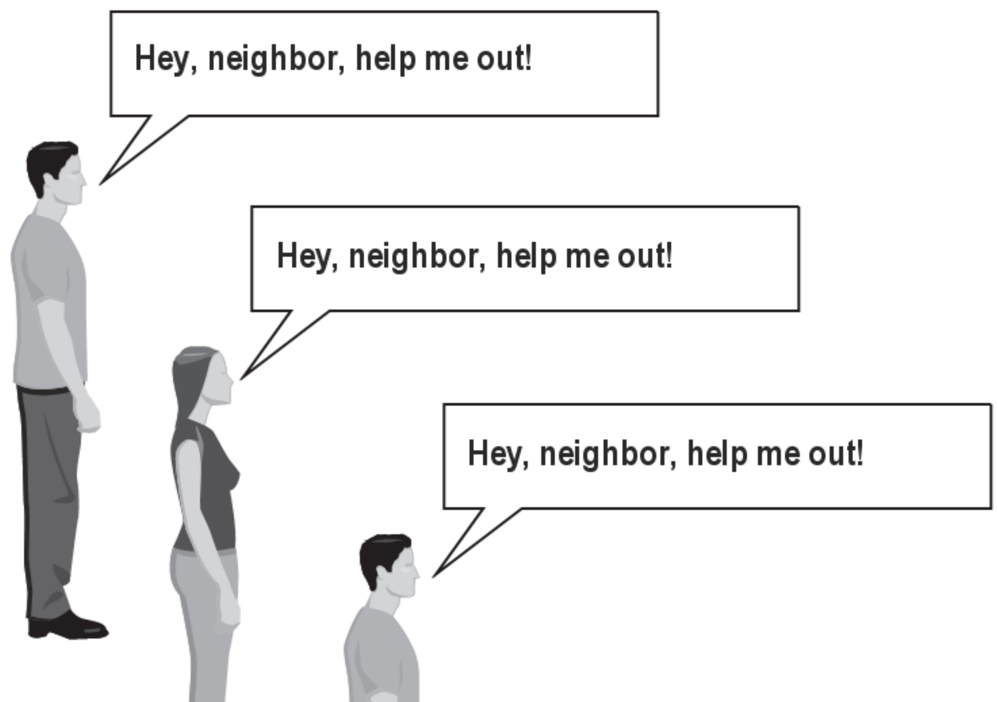
Exercise

- (To a student in the front row)
How many students are directly behind you?
  - We all have poor vision, and can only see the people right next to us. So you can't just look back and count.
  - But you are allowed to ask questions of the person behind you.
  - How can we solve this problem? (*recursively*)



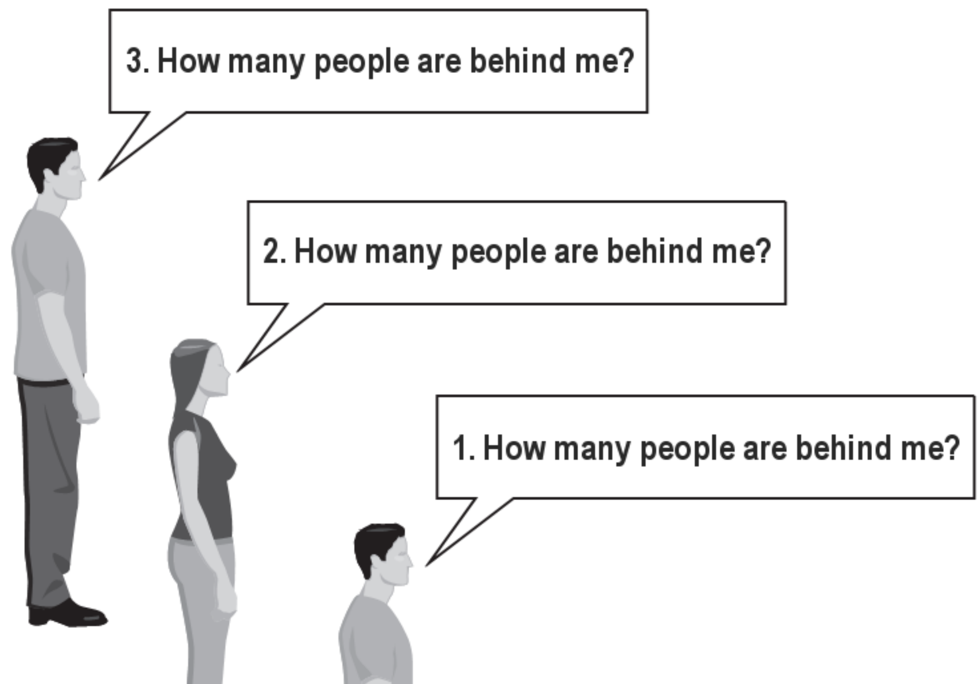
The idea

- Recursion is all about breaking a big problem into smaller occurrences of that same problem.
  - Each person can solve a small part of the problem.
    - What is a small version of the problem that would be easy to answer?
    - What information from a neighbor might help you?



Recursive algorithm

- Number of people behind me:
  - If there is someone behind me,
    ask him/her how many people are behind him/her.
    - When they respond with a value **N**, then I will answer **N + 1**.
  - If there is nobody behind me, I will answer **0**.



Recursive structures

- A directory has
  - files

  and
  - (sub) directories
- An expression has   a*b + c*d
  - operators
  - operands, which are
    - variables
    - constants
    - (sub) expressions

Expressions represented by trees

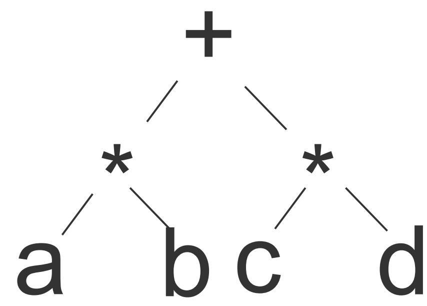
- A **tree** is
  - a node

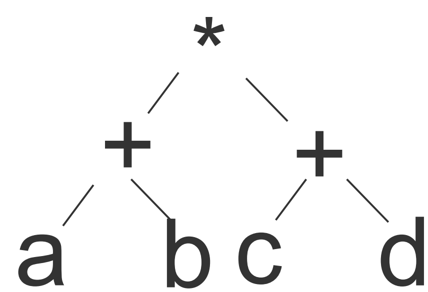
  with
  - zero or more sub **trees**

examples:

a*b + c*d

(a+b)*(c+d)





Structure of recursion

- Each of these examples has
  - recursive parts (directory, expression, tree)
  - non recursive parts (file, variables, nodes)

- Always need non recursive parts. Why?

- Same goes for recursive algorithms.

Cases

- Every recursive algorithm has at least 2 cases:
  - **base case**: A simple instance that can be answered directly.
  - **recursive case**: A more complex instance of the problem that cannot be directly answered, but can instead be described in terms of smaller instances.
  - Can have more than one base or recursive case, but all have at least one of each.
  - A crucial part of recursive programming is identifying these cases.

Base and Recursive Cases: Example

```
public void printStars(int n) {
    if (n == 1) {
        // base case; print one star
        System.out.println("*");
    } else {
        // recursive case; print one more star
        System.out.print("*");
        printStars(n - 1);
    }
}
```

Recursion Zen

- An even simpler, base case is `n=0`:

```
public void printStars(int n) {
    if (n == 0) {
        // base case; end the line of output
        System.out.println();
    } else {
        // recursive case; print one more star
        System.out.print("*");
        printStars(n - 1);
    }
}
```

  - **Recursion Zen**: The art of identifying the best set of cases for a recursive algorithm and expressing them elegantly.

Everything recursive can be done non-recursively

```
// Prints a line containing a given number of stars.
// Precondition: n >= 0
public void printStars(int n) {
    for (int i = 0; i < n; i++) {
        System.out.print("*");
    }
    System.out.println();
}
```

IC Question #1

What is a precondition for a method?

A. Method obligation
B. What is assumed to be true after the method is executed
C. Caller obligation
D. The digital signature

IC Question #1 Answer

What is a precondition for a method?

A. Method obligation
B. What is assumed to be true after the method is executed
C. Caller obligation
D. The digital signature

IC Question #2

What is the base case of a recursive method?

A. A simple instance that can be answered directly.
B. A more complex instance of the problem that cannot be directly answered, but can instead be described in terms of smaller instances.
C. The optional part of the recursive method

IC Question #2 Answer

What is the base case of a recursive method?

A. A simple instance that can be answered directly.
B. A more complex instance of the problem that cannot be directly answered, but can instead be described in terms of smaller instances.
C. The optional part of the recursive method

IC Question #3

What is the recursive case of a recursive method?

A. A simple instance that can be answered directly.
B. A more complex instance of the problem that cannot be directly answered, but can instead be described in terms of smaller instances.
C. The optional part of the recursive method

IC Question #3 Answer

What is the recursive case of a recursive method?

A. A simple instance that can be answered directly.
B. A more complex instance of the problem that cannot be directly answered, but can instead be described in terms of smaller instances.
C. The optional part of the recursive method

Let's look at some code

- SimpleRecursion

IC Question #1

What is a postcondition for a method?

A. Method obligation
B. What is assumed to be true before the method is executed
C. Caller obligation
D. The digital signature

IC Question #1 Answer

What is a postcondition for a method?

A. Method obligation
B. What is assumed to be true before the method is executed
C. Caller obligation
D. The digital signature

Computing the maximum of an array

We would like to compute the maximum of the elements in an array.

Need to identify base case and recursive case, and what to do in each.

Computing the maximum of an array

The idea:

Base case: array of size 1: return the element

Recursive case: compute maximum of two numbers – the first element, and the maximum of the rest of the array

Exercise

- Let's write a method `reverseLines(Scanner scan)` that reads lines using the scanner and prints them in reverse order.
  - Use recursion without using loops.
  - Example input:

    ```
    this
    is
    fun
    no?
    ```

    → Expected output:

    ```
    no?
    fun
    is
    this
    ```

  - What are the cases to consider?
    - How can we solve a small part of the problem at a time?
    - What is a file that is very easy to reverse?

Reversal pseudocode

- Reversing the lines of a file:
  - Read a line L from the file.
  - Print the rest of the lines in reverse order.
  - Print the line L.

- If only we had a way to reverse the rest of the lines of the file....

Reversal solution

```
public void reverseLines(Scanner input) {
    if (input.hasNextLine()) {
        // recursive case
        String line = input.nextLine();
        reverseLines(input);
        System.out.println(line);
    }
}
```

- Where is the base case?

Tracing our algorithm

- **Call stack**: The method invocations active at any given time.

```
public void reverseLines(Scanner input) {
    if (input.hasNextLine()) {
```

```
public void reverseLines(Scanner input) {
    if (input.hasNextLine()) {
```

```
public void reverseLines(Scanner input) {
    if (input.hasNextLine()) {
```

```
public void reverseLines(Scanner input) {
    if (input.hasNextLine()) {
```

```
public void reverseLines(Scanner input) {
    if (input.hasNextLine()) {   // false
        ...
    }
}
```

output:

```
no?
fun
is
this
```

input file:

```
this
is
fun
no?
```

Recursive power example

- Write a method that computes x^n.

  $x^n = x * x * x * \ldots * x$ (n times)

- An iterative solution:

```
public int pow(int x, int n) {
    int product = 1;
    for (int i = 0; i < n; i++) {
        product = product * x;
    }
    return product;
}
```

Exercise solution

```
// Returns base ^ exponent.
// Precondition: exponent >= 0
public int pow(int x, int n) {
    if (n == 0) {
        // base case; any number to 0th power is 1
        return 1;
    } else {
        // recursive case:  x^n = x * x^(n-1)
        return x * pow(x, n-1);
    }
}
```

How recursion works

- Each call sets up a new instance of all the parameters and the local variables
- When the method completes, control returns to the method that invoked it (which might be another invocation of the same method)

```
pow(4, 3) = 4 * pow(4, 2)
          = 4 * 4 * pow(4, 1)
          = 4 * 4 * 4 * pow(4, 0)
          = 4 * 4 * 4 * 1
          = 64
```

Activation records

- **Activation record**: memory that Java allocates to store information about each running method
  - return point ("RP"), argument values, local variables
  - Java stacks up the records as methods are called (call stack); a method's activation record exists until it returns
  - Eclipse debug draws the act. records and helps us *trace* the behavior of a recursive method

```
 _____________________________________________
| x   = [ 4 ]          n = [ 0 ] | pow(4, 0)
|_RP  = [pow(4,1)]_______________|
| x   = [ 4 ]          n = [ 1 ] | pow(4, 1)
|_RP  = [pow(4,2)]_______________|
| x   = [ 4 ]          n = [ 2 ] | pow(4, 2)
|_RP  = [pow(4,3)]_______________|
| x   = [ 4 ]          n = [ 3 ] | pow(4, 3)
|_RP  = [main]___________________|
|________________________________| main
```

Infinite recursion

- A method with a missing or badly written base case can causes **infinite recursion**

```
public int pow(int x, int y) {
    return x * pow(x, y - 1);  // Oops! No base case
}

pow(4, 3) = 4 * pow(4, 2)
          = 4 * 4 * pow(4, 1)
          = 4 * 4 * 4 * pow(4, 0)
          = 4 * 4 * 4 * 4 * pow(4, -1)
          = 4 * 4 * 4 * 4 * 4 * pow(4, -2)
          = ... crashes: Stack Overflow Error!
```

An optimization

- Notice the following mathematical property:

$$3^{12} = (3^2)^6 = (9)^6 = (81)^3 = 81 * (81)^2$$

  - We can use it to improve our `pow` method!
  - What is the "trick"?
  - How can we incorporate this optimization into our `pow` method?
  - What is the benefit?

Exercise solution 2

```
// Returns base ^ exponent.
// Precondition: exponent >= 0
public int pow(int base, int exponent) {
    if (exponent == 0) {
        // base case; any number to 0th power is 1
        return 1;
    } else if (exponent % 2 == 0) {
        // recursive case 1:  x^y = (x^2)^(y/2)
        return pow(base * base, exponent / 2);
    } else {
        // recursive case 2:  x^y = x * x^(y-1)
        return base * pow(base, exponent - 1);
    }
}
```

IC Question #2

In a recursive method, when the method completes, control returns to where?

A. The calling method
B. The next iteration of the recursive method
C. The parent process
D. The child process

IC Question #2 Answer

In a recursive method, when the method completes, control returns to where?

A. The calling method
B. The next iteration of the recursive method
C. The parent process
D. The child process

IC Question #3

What is an activation record?

A. Global memory
B. Memory specific to setting up and initializing a program
C. Memory allocated for information about each running method
D. The call stack

IC Question #3 Answer

What is an activation record?

A. Global memory
B. Memory specific to setting up and initializing a program
C. Memory allocated for information about each running method
D. The call stack

IC Question #4

When is an activation record released?

A. When the process terminates
B. When the method is invoked
C. When the process is created
D. When the method returns

IC Question #4

When is an activation record released?

A. When the process terminates
B. When the method is invoked
C. When the process is created
D. When the method returns