Computer Science I

Recursion

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Outline

1. Introduction
2. Designing Recursive Functions
3. Avoiding Recursion

Part I: Introduction

Challenge

Challenge: write code to count down from 10 to 1 *without* using a loop.

Challenge

```
1  void countDown(int n) {
2
3    if(n < 0) {
4      printf("Error: cannot count down from negatives!");
5    } else if(n == 0) {
6      printf("Blast Off\n");
7    } else {
8      printf("%d\n", n);
9      countDown(n-1);
10   }
11   return;
12 }
```

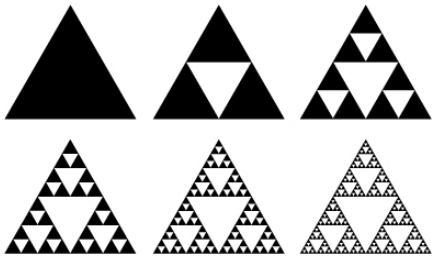
Recursion

- *Recursion* is when something is defined in terms of itself
- Mathematics: recurrence relations, Fibonacci Sequence

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

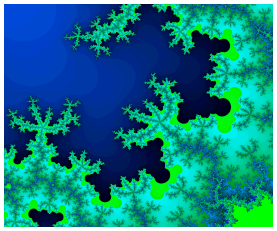
$$1,\ 1,\ 2,\ 3,\ 5,\ 8,\ 13,\ 21,\ 34,\ 55 \tag{1}$$

Fractals



Serpinski Triangles

Fractals



Mandelbrot Set

Recursive Functions

- A *recursive function* is a function that makes one or more "recursive calls" to itself
- Generally recursive calls pass in different parameter values
- More generally: divide-and-conquer style problem solving

Part II: Writing Recursive Functions

Recursion

In general, every recursive function must have:

1. A *base case* – a condition after which the recursion stops
2. Each recursive call must make progress toward the base case
3. Corner cases may need to be handled separately

Thinking Recursively

- A recursive solution requires you to think about a general "case"
- Similar to loops: at the i-th iteration what do you do?
- Given the input, how do you *divide-and-conquer* it?

Examples

- Write a recursive function to compute the fibonacci sequence
- Write a recursive function to find the largest element in an array of integers (simulate a traditional loop)
- Write a recursive, *divide-and-conquer*-style function to sum the elements in an array of integers

Fibonacci Solution

```
int fibonacci(int n) {

  if(n < 1) {
    return -1;
  } else if(n == 1 || n == 2) {
    return 1;
  } else {
    return fibonacci(n-1) + fibonacci(n-2);
  }

}
```

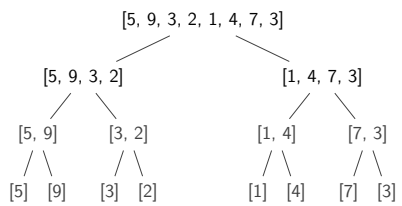
Largest Element Solution

```
int largestElement(const int *arr, int largest, int index) {
  if(index < 0) {
    return largest;
  } else {
    if(arr[index] > largest) {
      return largestElement(arr, arr[index], index-1);
    } else {
      return largestElement(arr, largest, index-1);
    }
  }
}
```

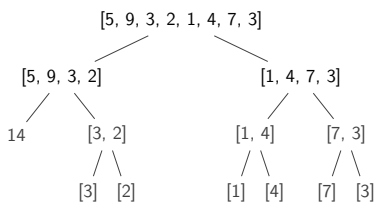
Summation Solution

```
int recursiveSum(const int *arr, int l, int r) {
  if(l > r) {
    return 0;
  } else if(l == r) {
    return arr[l];
  } else {
    int m = (l + r) / 2;
    return recursiveSum(arr, l, m) + recursiveSum(arr, m+1, r);
  }
}
```

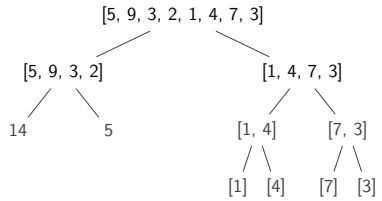
Divide & Conquer



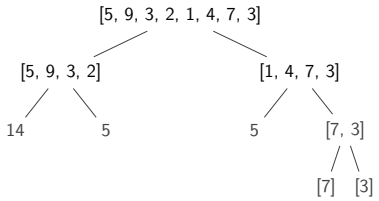
Divide & Conquer



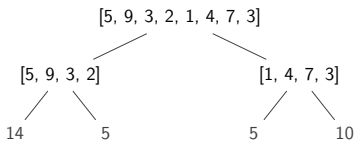
Divide & Conquer



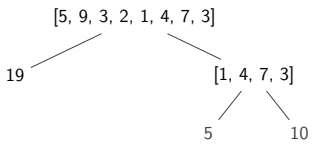
Divide & Conquer



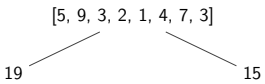
Divide & Conquer



Divide & Conquer



Divide & Conquer



Divide & Conquer

Part III: Avoiding Recursion

Recursion: Advantages

- Recursion can be a useful problem solving technique
- Divide & Conquer strategies are generally presented as recursive
- Functional programming languages (Lisp, Haskell) use recursion as a fundamental control flow mechanism

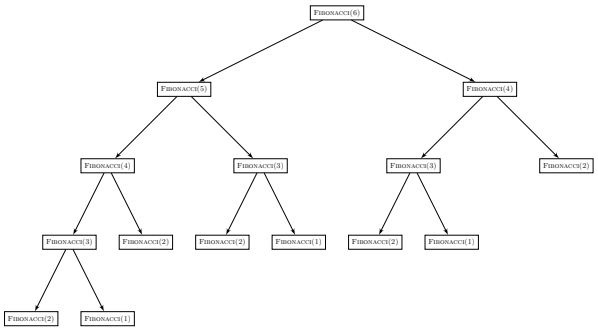
Recursion: Disadvantages

- In practice, recursion is not necessary: any (computable) recursive function can be rewritten using a loop and/or smart data structure
- Many style guides discourage or forbid the use of recursion
- Recursive functions can "abuse" the program stack by creating and destroying many stack frames
- Deep recursion risks *stack overflow*
- Demonstration

Recursion: Disadvantages

- Recursion can be extremely inefficient when not done properly
- Perfect example: Fibonacci code
- The same computations are performed over and over multiple times
- Computation Tree

Computation Tree



Mitigating Problems with Recursion

- Alternative solution: *memoization*
- Cache values so they can be reused (and not recomputed)
- Each recursive call checks to see if the value has been computed
- If yes: use it (avoid further recursion)
- If no: pay for the recursion, but store the answer
- Demonstration