

CMSC 132: OBJECT-ORIENTED PROGRAMMING II



Recursive Algorithms

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Recursion

- Recursion is a strategy for solving problems
 - A procedure that calls itself
- Approach
 - If (problem instance is simple / trivial)
 - Solve it directly
 - Else
 - Simplify problem instance into **smaller** instance(s) of the original problem
 - Solve smaller instance using same algorithm
 - Combine solution(s) to solve original problem

Example – Factorial

- Factorial definition
 - $n! = n \times n-1 \times n-2 \times n-3 \times \dots \times 3 \times 2 \times 1$
 - $0! = 1$
- To calculate factorial of n
 - Base case
 - If $n = 0$, return 1
 - Recursive step
 - Calculate the factorial of $n-1$
 - Return $n \times$ (the factorial of $n-1$)
- Code

```
int fact ( int n ) {  
    if ( n == 0 )  
        return 1;                // base case  
    return n * fact(n-1);        // recursive step  
}
```

Properties

- Recursion relies on the call stack
 - State of current procedure is saved when procedure is recursively invoked
 - Every procedure invocation gets own stack space
 - Let's draw a diagram for factorial(4)
- Any problem solvable with recursion may be solved with iteration (and vice versa)
 - Use iteration with explicit stack to store state
 - Algorithm may be simpler for one approach

Recursion vs. Iteration

- Recursive algorithm

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

- Iterative algorithm

```
int fact ( int n ) {  
    int i, res;  
    res = 1;  
    for (i=n; i>0; i--) {  
        res = res * i;  
    }  
    return res;  
}
```

Recursive algorithm is closer to factorial definition

Examples

- Find → To **find** an element in an array
 - Base case
 - If array is empty, return false
 - Recursive step
 - If 1st element of array is given value, return true
 - Skip 1st element and **recur** on remainder of array
- Count Instances → To **count** # of elements in an array
 - Base case
 - If array is empty, return **0**
 - Recursive step
 - Skip 1st element and **recur** on remainder of array
 - Add **1** to result
- Some recursive problems require an auxiliary function
 - Auxiliary function → the one that actually is recursive
- **Example:** ArrayExamples.java

Examples

- Let's look at recursive solutions for operations on a linked list
 - Find
 - Count
 - Print list
 - Print list in reverse

Recursion vs. Iteration

- Iterative algorithms

- May be more efficient
 - No additional function calls
 - Run faster, use less memory

- Recursive algorithms

- Higher overhead
 - Time to perform function call
 - Memory for call stack
- May be simpler algorithm
 - Easier to understand, debug, maintain
- Natural for backtracking searches
- Suited for recursive data structures
 - Trees, graphs...

Making Recursion Work

- Designing a correct recursive algorithm
- Verify
 - Base case(s) is
 - Recognized correctly
 - Solved correctly
 - Recursive case
 - Solves 1 or more simpler subproblems
 - Can calculate solution from solution(s) to subproblems
 - Makes progress toward the base case
- Uses principle of **proof by induction**

Proof By Induction

- Mathematical technique
- A theorem is true for all $n \geq 0$ if
 - Base case
 - Prove theorem is true for $n = 0$, and
 - Inductive step
 - Assume theorem is true for n (inductive hypothesis)
 - Prove theorem must be true for $n+1$

Types of Recursion

- Tail recursion

- Has a recursive call as final action

- Example

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

- **Can easily transform to iteration (loop)**
 - In functional languages tail call elimination is often guaranteed by the language

Types of Recursion

- Non-tail recursion

- Example

```
int nontail( int n ) {  
    ...  
    x = nontail(n-1) ;  
    y = nontail(n-2) ;  
    z = x + y;  
    return z;  
}
```

- **Can transform to iteration using explicit stack**

Possible Problems – Infinite Loop

- Infinite recursion
 - If recursion not applied to simpler problem

```
int bad (int n) {  
    if (n == 0)  
        return 1;  
    return bad(n);  
}
```

- Infinite loop?
- Eventually halt when runs out of (stack) memory
 - Stack overflow

Possible Problems – Efficiency

- May perform excessive computation
 - If recomputing solutions for subproblems
- Example
 - Fibonacci numbers
 - $\text{fibonacci}(0) = 0$
 - $\text{fibonacci}(1) = 1$
 - $\text{fibonacci}(n) = \text{fibonacci}(n-1) + \text{fibonacci}(n-2)$
- **Example:** Fibonacci.java

Possible Problems – Efficiency

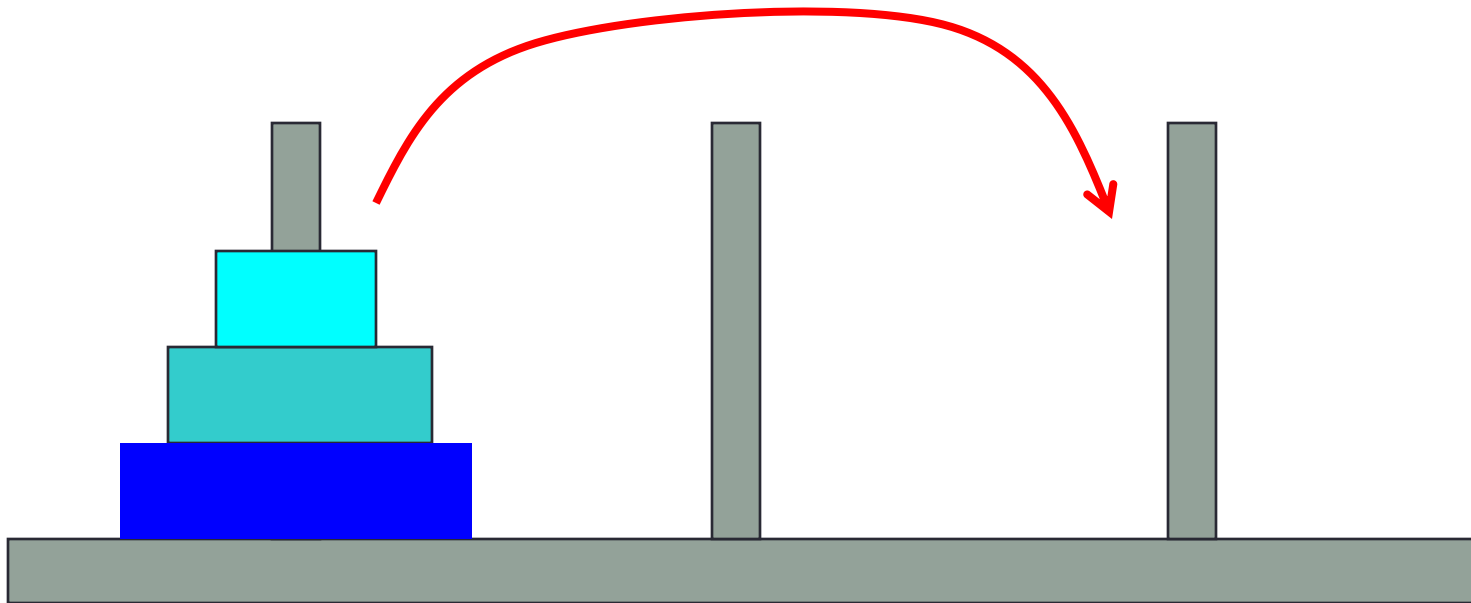
- Recursive algorithm to calculate fibonacci(n)
 - If n is 0 or 1, return 1
 - Else compute fibonacci(n-1) and fibonacci(n-2)
 - Return their sum
- Simple algorithm $\Rightarrow$ exponential time $O(2^n)$
 - Computes fibonacci(1) 2^n times
- Can solve efficiently using
 - Iteration
 - Dynamic programming
 - Will examine different algorithm strategies later...

Examples of Recursive Algorithms

- Towers of Hanoi
- Binary search
- Quicksort
- N-queens
- Fractals

Example – Towers of Hanoi

- Problem
 - Move stack of disks between pegs
 - Can only move top disk in stack
 - Only allowed to place disk on top of larger disk



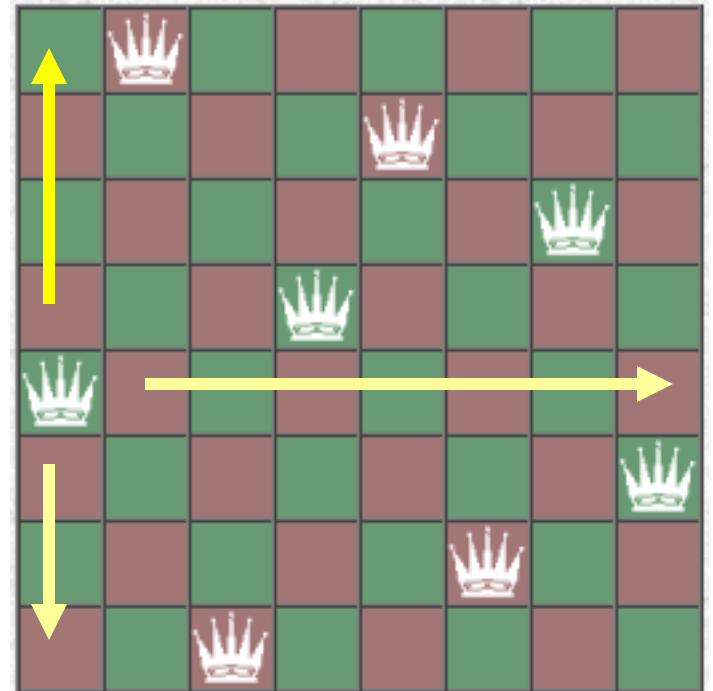
Example – Towers of Hanoi

- To move a stack of n disks from peg X to Y
 - Base case
 - If $n = 1$, move disk from X to Y
 - Recursive step
 - Move top $n-1$ disks from X to 3rd peg
 - Move bottom disk from X to Y
 - Move top $n-1$ disks from 3rd peg to Y

Iterative algorithm would take much longer to describe!

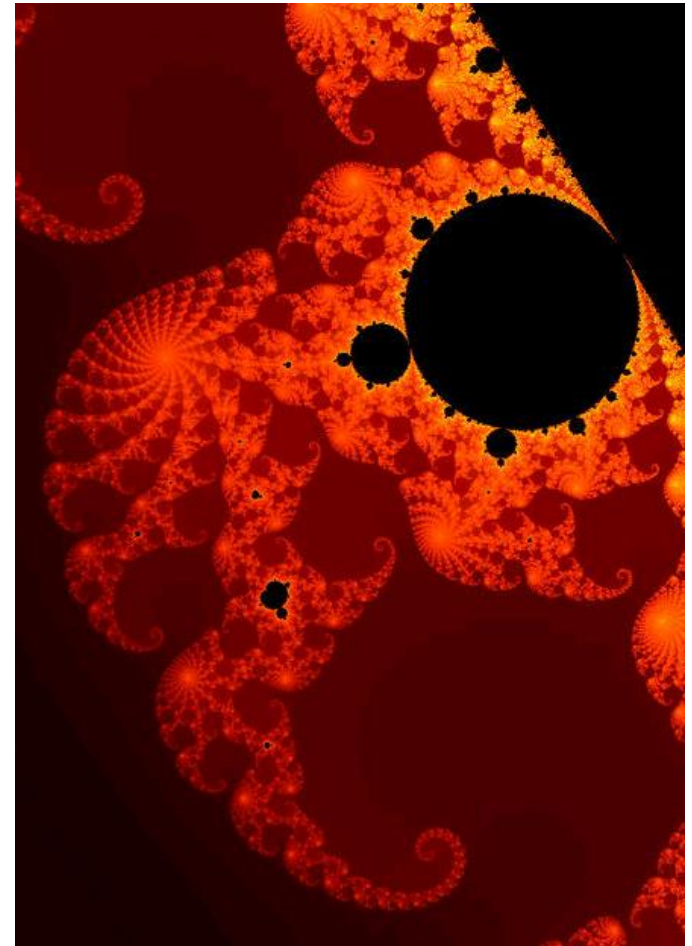
N-Queens

- Goal
 - Place queens on a board such that every row and column contains one queen, but no queen can attack another queen
- Recursive approach
 - To place queens on $N \times N$ board
 - Assume you've already placed K queens



Fractals

- Goal
 - Construct shapes using a simple recursive definition with a natural appearance
- Properties
 - Appears similar at all scales of magnification
 - Therefore “infinitely complex”
 - Not easily described in Euclidean geometry



Mandelbrot Set