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
  - \( n! = n \times (n-1) \times (n-2) \times (n-3) \times \ldots \times 3 \times 2 \times 1 \)
  - \( 0! = 1 \)

- 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
  
  ```c
  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

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

Recursive algorithm is closer to factorial definition

• Iterative algorithm

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

• Notice we can use the ?: operator for the implementation of some of these methods
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

```java
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
    - fibonacci(0) = 0
    - fibonacci(1) = 1
    - fibonacci(n) = fibonacci(n-1) + fibonacci(n-2)
  - Example: Fibonacci.java
Possible Problems – Efficiency

• Recursive algorithm to calculate $\text{fibonacci}(n)$
  • If $n$ is 0 or 1, return 1
  • Else compute $\text{fibonacci}(n-1)$ and $\text{fibonacci}(n-2)$
  • Return their sum
• Simple algorithm $\Rightarrow$ exponential time $O(2^n)$
  • Computes $\text{fibonacci}(1)$ $2^n$ 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×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