Dynamic Programming

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Background

Richard Bellman pioneered Dynamic Programming in the 50's

Dynamic Programming works via the Principle of Optimality:
An optimal sequence of decisions is obtained iff each subsequence of decisions is optimal.

I.e. we can build large optimization solutions out of small optimization solutions.

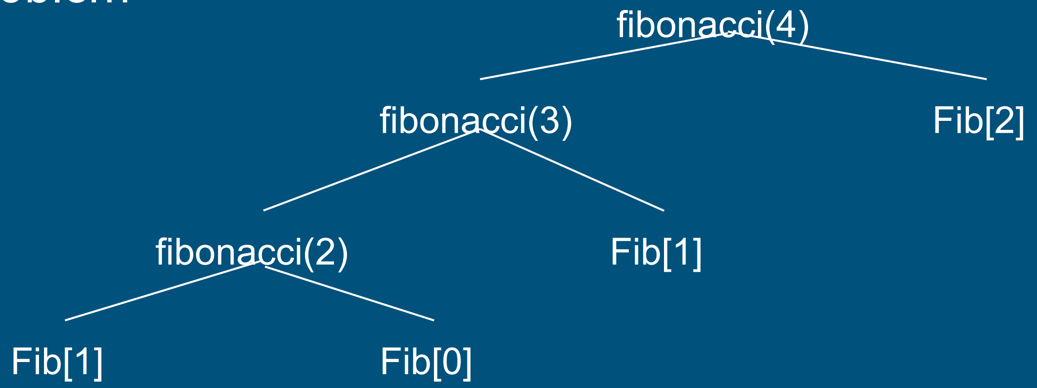
Intro

Dynamic Programming is decomposing a problem into subproblems whose solutions are stored for later use.

The two biggest categories of Dynamic Programming are top-down and bottom-up.

Top-Down

- Starting with the large problem, decompose it into smaller problems
- Compute and store the solution to the smaller problems if they haven't been computed yet
- Use the solutions to the subproblems to compute the solution to the large problem



Top-Down Example

```
int marker = 1;
arr[]; arr[0] = 0; arr[1] = 1;

topDownFib(int n){
    if(n > marker){
        int temp = topDownFib(n-1)+topDownFib(n-2);
        marker = n;
        arr[n] = temp;
    }
    return arr[n];
}
```

Bottom-Up

Combine the solutions to small subproblems to obtain the solutions to subproblems of increasing size. Continue in this fashion until we arrive at the solution to the original problem.

fibonacci(3) =>

Fib[0] = 0
Fib[1] = 1
Fib[2] = Fib[1] + Fib[2] = 1
Fib[3] = Fib[2] + Fib[1] = 2

Bottom-Up Example

```
int marker = 1; //the highest index we’ve calculated so far
HashMap<Integer, Integer> map; //Add 0 at 0th index and 1 at 1st index

bottomUpFib(int n) {
	if (n > marker) {
		int i = marker;
			for (; i < n ; i ++) {
				map.add(i+1, map.get(i-1) + map.get(i-2));
			}
			marker = n;
		}
	return map.get(n);
}
```

Top-Down vs Bottom-Up

- Top-down has recursive overhead

- Bottom-up may compute more sub-problems than necessary.

Theoretical Computer Science

Theoretical Computer Science concerns itself with three chief categories:

- Algorithm Design
- Algorithm Analysis
- Modes of Computation

Dynamic Programming is part of Algorithm Design

- Optimization Algorithm
  - Speed vs. Memory

Current Theory

- Increased speed
- Limited by difficulty in decomposing a large problem into smaller subproblems
- Favors objects that are linearly ordered and cannot be rearranged
  - Characters in a string, matrices in a chain, left-to-right order of leaves in a search tree
- Problems evaluating subproblems in an efficient order
- Uses more memory

Exercise

Try and think of a problem where the dynamic programming approach would be useful. The problem doesn't necessarily need to be framed in terms of coding and computers.

Discuss with your table for a minute (or so).

(Hint: what's a problem where it's worth remembering the answer once in awhile?)

Real-World Application I

- Bioinformatics
    - Interdisciplinary field that develops methods and software tools for understanding biological data
        - DNA/RNA Sequence Alignment
- Control Theory
    - Interdisciplinary branch of engineering and mathematics that deals with the behavior of dynamic systems with inputs and how their behavior is modified by feedback
        - AI computing approaches

Real-World Application II

- Information Theory
    - Studies the quantification, storage, and communication of information
        - Cryptography
        - Gambling
- Operations Research
    - Deals with the application of advanced analytical methods to help make better decisions
        - Optimal search
        - Routing
        - Scheduling
- Computer Science

Real-World Application III

- Diff Algorithm
  - Reports differences between two files, expressed as a minimal list of line changes to bring either file into agreement with the other
    - Solves the longest common subsequence problem to find the lines that do not change between files
- Viterbi Algorithm
  - Decodes convolutional codes used in both CDMA and GSM digital cellular, dial-up modems, satellite, deep-space communications, and 802.11 wireless LANs
    - Decoding algorithm for convolutional codes over noisy digital communication links
    - Commonly used in speech recognition, speech synthesis, diarization, keyword spotting, computational linguistics, and bioinformatics

Real-World Application IV

- Smith-Waterman Algorithm
  - Performs local sequence alignment for determining similar regions between two strings or nucleotide or protein sequences
  - Compares segments for all possible lengths and optimizes the similarity measure
- Bellman-Ford Algorithm
  - Detects a negative cycle if any exists in a weighted digraph
  - Finds the shortest simple path if no negative cycles exist
- Cocke-Kasami-Younger Algorithm
  - Parsing algorithm for context-free grammars given in Chomsky Normal Form

Ongoing Research I

- Researchers at MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL) working on parallelize algorithms that utilize dynamic programming called Bellmania
- Programs run on multicore chips
- Operate up to 11 times faster than other parallel processing technique

Ongoing Research II

- Limitations
  - Typically 10 times longer than single-core version
  - Individual lines of code are more complex
    - So complex that errors occur
  - Problems efficiently accessing the stored solutions in parallel
    - Memory management more complex

Backup Exercise

Works Cited

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