CMSC 132: Object-Oriented Programming II

Algorithm Strategies

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General Concepts

Algorithm strategy
- Approach to solving a problem
- May combine several approaches

Algorithm structure
- Iterative $\implies$ execute action in loop
- Recursive $\implies$ reapply action to subproblem(s)

Problem type
Problem Type

- **Satisfying**
  - Find any satisfactory solution
  - Example → Find path from A to F

- **Optimization**
  - Find best solution (vs. cost metric)
  - Example → Find shortest path from A to E
Some Algorithm Strategies

- Recursive algorithms
- Backtracking algorithms
- Divide and conquer algorithms
- Dynamic programming algorithms
- Greedy algorithms
- Brute force algorithms
- Branch and bound algorithms
- Heuristic algorithms
Recursive Algorithm

Based on reapplying algorithm to subproblem

Approach

1. Solves base case(s) directly
2. Recurs with a simpler subproblem
3. May need to combine solution(s) to subproblems
Backtracking Algorithm

Based on depth-first recursive search

Approach

1. Tests whether solution has been found
2. If found solution, return it
3. Else for each choice that can be made
   a) Make that choice
   b) Recur
   c) If recursion returns a solution, return it
4. If no choices remain, return failure

Tree of alternatives → search tree
Backtracking Algorithm – Reachability

Find path in graph from A to F

1. Start with currentNode = A
2. If currentNode has edge to F, return path
3. Else select neighbor node X for currentNode
   - Recursively find path from X to F
     - If path found, return path
     - Else repeat for different X
   - Return false if no path from any neighbor X
Backtracking Algorithm – Path Finding

Search tree

- A → B
- A → C
- A → D
- A → B → C
- A → D → C
- A → B → E
- A → C → E
- A → D → F
- A → B → C → E
- A → D → C → E
Backtracking Algorithm – Map Coloring

- Color a map using four colors so adjacent regions do not share the same color.

- Coloring map of countries
  - If all countries have been colored return success
  - Else for each color c of four colors and country n
    - If country n is not adjacent to a country that has been colored c
      - Color country n with color c
      - Recursively color country n+1
      - If successful, return success
  - Return failure

- Map from wikipedia –
  http://upload.wikimedia.org/wikipedia/commons/thumb/a/a5/Map_of_USA_with_state_names.svg/650px-Map_of_USA_with_state_names.svg.png
Divide and Conquer

Based on dividing problem into subproblems

Approach

1. Divide problem into smaller subproblems
   - Subproblems must be of same type
   - Subproblems do not need to overlap
2. Solve each subproblem recursively
3. Combine solutions to solve original problem

Usually contains two or more recursive calls
Divide and Conquer – Sorting

- **Quicksort**
  - Partition array into **two parts** around pivot
  - Recursively quicksort each part of array
  - Concatenate solutions

- **Mergesort**
  - Partition array into **two parts**
  - Recursively mergesort each half
  - Merge two sorted arrays into single sorted array
Dynamic Programming Algorithm

- Based on remembering past results

**Approach**

1. Divide problem into smaller subproblems
   - Subproblems must be of same type
   - Subproblems must overlap

2. Solve each subproblem recursively
   - May simply look up solution (if previously solved)

3. Combine solutions into to solve original problem

4. Store solution to problem

- Generally applied to optimization problems
Fibonacci Algorithm

Fibonacci numbers

- $\text{fibonacci}(0) = 1$
- $\text{fibonacci}(1) = 1$
- $\text{fibonacci}(n) = \text{fibonacci}(n-1) + \text{fibonacci}(n-2)$

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 $O(2^n)$
Dynamic Programming – Fibonacci

Dynamic programming version of fibonacci(n)
- If n is 0 or 1, return 1
- Else solve fibonacci(n-1) and fibonacci(n-2)
  - Look up value if previously computed
  - Else recursively compute
- Find their sum and store
- Return result

Dynamic programming algorithm \( \Rightarrow O(n) \) time
- Since solving fibonacci(n-2) is just looking up value
Dynamic Programming – Shortest Path

Dijkstra’s Shortest Path Algorithm

\[ S = \emptyset \]
\[ C[X] = 0 \]
\[ C[Y] = \infty \text{ for all other nodes} \]

while ( not all nodes in \( S \) )

    find node \( K \) not in \( S \) with smallest \( C[K] \)
    add \( K \) to \( S \)
    for each node \( M \) not in \( S \) adjacent to \( K \)
        \[ C[M] = \min ( C[M], C[K] + \text{cost of (K,M)} ) \]

Stores results of smaller subproblems
Greedy Algorithm

- Based on trying best current (local) choice

Approach

- At each step of algorithm
- Choose best local solution

Avoid backtracking, exponential time $O(2^n)$

Hope local optimum lead to global optimum

Example: Coin System

- Coins – 30 20 15 1
- Find minimum number of coins for 40
- Greedy Algorithm fails
Greedy Algorithm – Shortest Path (A to E)

Example

Choose lowest-cost neighbor

A → B

A → B → E

Cost ⇒ 6

Does not yield overall (global) shortest path
Greedy Algorithm – MST

Kruskal’s Minimal Spanning Tree Algorithm

sort edges by weight (from least to most)

tree = ∅

for each edge (X,Y) in order

if it does not create a cycle

add (X,Y) to tree

stop when tree has N–1 edges

Picks best local solution at each step
Brute Force Algorithm

Based on trying all possible solutions

Approach

- **Generate and evaluate possible solutions until**
  - Satisfactory solution is found
  - Best solution is found (if can be determined)
  - All possible solutions found

- Return best solution
- Return failure if no satisfactory solution

Generally most expensive approach
Brute Force Algorithm – Shortest Path

Example

- A → B
- A → C
- A → D

- A → B → C
- A → D → C

- A → B → E
- A → C → E
- A → D → F

- A → B → C → E
- A → D → C → E

Examines all paths in graph
Brute Force Algorithm – TSP

Traveling Salesman Problem (TSP)
- Given weighted undirected graph (map of cities)
- Find lowest cost path visiting all nodes (cities) once
- No known polynomial-time general solution

Brute force approach
- Find all possible paths using recursive backtracking
- Calculate cost of each path
- Return lowest cost path
- Complexity $O(n!)$
Branch and Bound Algorithm

Based on limiting search using current solution

Approach

- Track best current solution found
- Eliminate (prune) partial solutions that can not improve upon best current solution

Reduces amount of backtracking

- Not guaranteed to avoid exponential time $O(2^n)$
Branch & Bound Alg. – Shortest Path

**Example**

A → B
A → C
A → D

**Cost**
A → B → E: 6
A → C → E: 5

**Pruned paths beginning with A → B → C & A → D**
Branch and Bound – TSP

Branch and bound algorithm for TSP

- Find possible paths using recursive backtracking
- Track cost of best current solution found
- Stop searching path if cost > best current solution found
- Return lowest cost path

If good solution found early, can reduce search

May still require exponential time $O(2^n)$
Heuristic Algorithm

- Based on trying to guide search for solution
- Heuristic $\Rightarrow$ “rule of thumb”

Approach

- Generate and evaluate possible solutions
  - Using “rule of thumb”
  - Stop if satisfactory solution is found

- Can reduce complexity
- Not guaranteed to yield best solution
Heuristic – Shortest Path

Example

Try only edges with cost < 5

Worked…in this case
Heuristic Algorithm – TSP

- Heuristic algorithm for TSP
  - Find possible paths using recursive backtracking
    - Search 2 lowest cost edges at each node first
  - Calculate cost of each path
  - Return lowest cost path from first 100 solutions
- Not guaranteed to find best solution
- Heuristics used frequently in real applications
Summary

- Wide range of strategies
- Choice depends on
  - Properties of problem
  - Expected problem size
  - Available resources