Optimization Problems and Local Search

Russell and Norvig 4.3, 4.4

Optimization Problems
- Previously: systematic exploration of search space.
  - Path to goal is solution to problem
  - For some problems path is irrelevant.
    - Example: 8-queens

8 Queens

Stated as an optimization problem:
- State space: a board with 8 queens on it
- Objective/cost function: Number of pairs of queens that are attacking each other (quality of the state)

The Traveling Salesman Problem (TSP)

TSP: Given a list of cities and their pairwise distances, find a shortest possible tour that visits each city exactly once.

An optimal TSP tour through Germany’s 15 largest cities (one out of 14!/2)

13,509 cities and towns in the US that have more than 500 residents

http://www.tsp.gatech.edu/

Local Search

- Keep a “current” state, try to improve it by “locally” exploring the space of solutions
- Improve state by moving a queen to a position where fewer queens attack each other (neighboring state)
Greedy local search

- Problem: can get stuck in a local minimum (happens 86% of the time for the 8-queens problem).

Local minima vs. local maxima

- Local search: find a maximum or minimum of an objective function (cost function).
- Note: the local minima of a function $f(n)$ are the same as the maxima of $-f(n)$.

Hill-climbing

Apply successor function, and keep moves that improve the objective function

Hill-climbing

- Input: `problem`
- Local variables: `current`, a node.
- `neighbor`, a node.

```
function HILL-CLIMBING(problem) return a state that is a local maximum

current ← MAKE-NODE(INITIAL-STATE[problem])

loop do
neighbor ← a highest valued successor of current
if VALUE[neighbor] ≤ VALUE[current] then return STATE[current]
current ← neighbor
```

This flavor of hill-climbing is known as steepest ascent (steepest descent when the objective is minimization).

Need to consider:
- Choice of initial state
- Successor function

Solving TSP

Need to design a successor function that yields valid tours

A 2-opt move:

```
A
\[ u_1 \quad u_2 \quad u_3 \quad u_4 \quad u_5 \quad u_6 \]
```

3-opt

- Choose three edges from tour
- Remove them, and combine the three parts to a tour in the cheapest way to link them

Performing a 3-opt move

- Note that the six nodes come in pairs that are already connected: (A,B), (C,D), (E,F)
- Node ‘A’ can connect to:
  - Anything but ‘B’
  - Connecting it to D makes it a 2-Opt (OK)
  - 4 choices
- Node ‘B’ can connect to:
  - Cannot connect to ‘A’ or what ‘A’ connects to
  - Cannot connect to the other half of the pair that ‘A’ connects to.
  - 2 choices
- The final two nodes connect to each other
  - Eight legal possibilities (7 of which are novel)

Solving TSP (cont.)

- 3-opt moves lead to better local minima than 2-opt moves.
- The Lin-Kernighan algorithm (1973): a \( \lambda \)-opt move - efficiently constructs a successor that changes \( \lambda \) cities in a tour
- Often finds optimal solutions.

The Art of Local Search

- Hill-climbing (like A*) is a simple algorithm
- The art is in defining the successor function
  - More commonly called a neighborhood
  - Goal: avoid local minima
- The art in A* is defining the heuristic function

Variations

- Steepest ascent/descent: Successor is the neighbor with the largest increase/decrease in objective function.
- Stochastic hill-climbing
  - Random selection among the uphill moves.
  - The selection probability can vary with the steepness of the uphill move.
- First-choice hill-climbing
  - Stochastic hill climbing, generating successors randomly until a better one is found.
- Random-restart hill-climbing
  - Start several hill-climbing runs, each from a random initial state.

Random Restart

- Suppose that the probability of failure in a single try is \( P_f \)
- The probability of failure in \( k \) trials:
  \[
  P_f(k \text{ trials}) = (P_f)^k
  
  P_s(k \text{ trials}) = 1 - P_f(k \text{ trials}) = 1 - (P_f)^k
  
  The probability of success can be made arbitrarily close to 1 by increasing \( k \).

Why this won’t necessarily work

- NP-complete problems can have an exponential number of local minima.