Chapter3

Heuristic Search Techniques

(Cont….)

Simulated Annealing

- It is an algorithm which helps us reach a global optimum of a multi-dimensional function despite the presence of several hills and valleys
- It is evolutionary in the sense that unlike traditional optimization techniques like random walk or hill climbing it will not get stuck at a local maximum
- Imagine you are standing in a place and you need to reach the highest point. you can look around you and if you see a place with a higher height than the ground you are standing, you move to that place, keep repeating this and you eventually reach a point where you cannot see a higher point. This technique is called hill climbing

Simulated Annealing

- **Problem: You might not be standing at the highest point, and you might not be able to see a higher point from where you are standing. you might have been able to observe a higher point if you where standing at some other point**
- **Simulated annealing takes the risk of occasionally moving to a lower point so that the chances of missing out on seeing a higher point are reduced**
- **Initially it is willing to take risks of jumping to lower points, however as time passes, it is less willing to jump to lower point and eventually terminates**
- **This idea lower the chances of getting caught at local maxima, plateau or ridge**

Simulated Annealing

- Change in terminology:

  heuristic function→ objective function

  Goal: Minimize objective function value

- Process of valley descending rather than hill climbing

Annealing

- Physical substances such as metals are melted (raised to high temperature-energy levels) and then gradually cooled until some solid state is reached

  Goal: produce minimal energy state

- Physical substances usually move from higher energy configurations to lower ones, so the valley descending occurs naturally

Simulated Annealing

- But, there is some probability that a transition to a higher energy state will occur

$$P = e^{-(-\delta E / kt)}$$

Where,

δE: Change in energy level

T : Temperature

k : Boltzmann's constant

- Probability that an uphill move will be made, decreases as the temp decreases

Simulated Annealing

T: 10,000	99.99990%
1000	99.9905%
100	99.99000%
10	90.04%
5	81.87%
3	71.89%
2	60.65%
1	36.78%

- **Moves are more likely during the beginning of the process when the temperature is high and they become less likely at the end, as the temperature becomes less**

  Downhill moves→ anytime

  Upward moves→ during initial time

Simulated Annealing

- Annealing Schedule:
  - Rate at which the system is cooled
- Metal heated to a sufficiently high temperature and all we want to do is cool the metal down
- Cooling can be done by two approaches
  - Hastily approach
  - Gradual approach
- These properties of physical annealing can be used to define an analogous process of simulated annealing

Simulated Annealing

- In analogous process…..
- δE is the change in the value of objective function
- k describes the correspondence between the units of temperature & unit of energy E & T are artificial, we drop ‘k’

$$p' = e^{-(-\delta E / kt)}$$

- Need to choose a schedule of value T

Simulated Annealing

- How Simulated Annealing is different than Hill Climbing?
  - The annealing schedule must be maintained
  - Move to worst/bad/poor states may be accepted
  - Maintains state ‘best state found so far’

Relationship between Physical Annealing and Simulated Annealing

Thermodynamic Simulation	**Combinatorial Optimisation**
System States	Feasible Solutions
Energy	Cost
Change of State	Neighbouring Solutions
Temperature	Control Parameter
Frozen State	Heuristic Solution

Simulated Annealing

Algorithm:

1. **Evaluate the initial state: If it is also a goal state, return it and quit. otherwise continue with initial state as current state**
2. **Initialize BEST-SO-FAR to the current state**
3. **Initialize 'T' according to annealing schedule**
4. **Loop until a solution is found or until there are no new operators left to be applied in the current state**
   a) **Select an operator that has not yet been applied to the current state and apply it to produce a new state**
   b) **Evaluate the new state**

      δE = (Value of current) – (Value of new state)

Simulated Annealing

- If the new state is goal state, return it & quit
- else if it is better than current state, make it the current state also set BEST-SO-FAR to this new state
- If it is not better than current state, then make it the current state with probability p’

c) Revise T as necessary according to annealing schedule

5. Return BEST-SO-FAR as the answer

Application of Simulated Annealing

- To solve problems in which the number of moves from a given state is very large [More permutations/ combinations]
  - Job scheduling
  - Time table management
  - TSP, etc…