UCLA

Simulated Annealing

NANOCAD LAB

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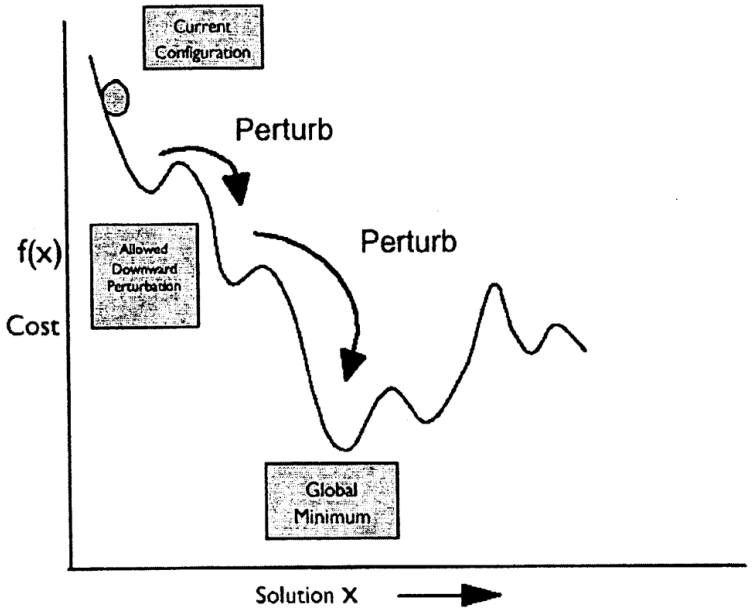
What is Simulated Annealing?

- Probabilistic method for finding global minimum of a cost function
- Motivation from combinatorial optimization problems
  - i.e. traveling salesman problem (TSP)
- Heuristics algorithms often terminate in a local minima
- New States are characterized by a cost function:
  - Always accept new state if new cost is lower
  - State with increase in cost are accepted based on a controlling parameter (T).

"Hill-Climbing"



- Cost-increasing moves are allowed depending on the current state
- An algorithm that is similar to annealing in solids
  - a technique involving heating and controlled cooling of a material to increase the size of its crystal

Parameters

- Initial configuration
- A transition or generation function to find a neighbor as next candidate
- A cost function
- An Evaluation Criterion
  - i.e. $y = \exp(-\frac{c(j) - c(i)}{T})$
- A Stop Criterion
  - i.e. value of cost function remained unchanged at the end of certain consecutive configuration

Temperature Parameter

- Initial temperature[1]
  - Exploration of the configuration space is performed to determine “σ”
  - k is determined by assuming a normal distribution and temperature high enough to accept with probability P a configuration whose cost is 3σ worst than current configuration

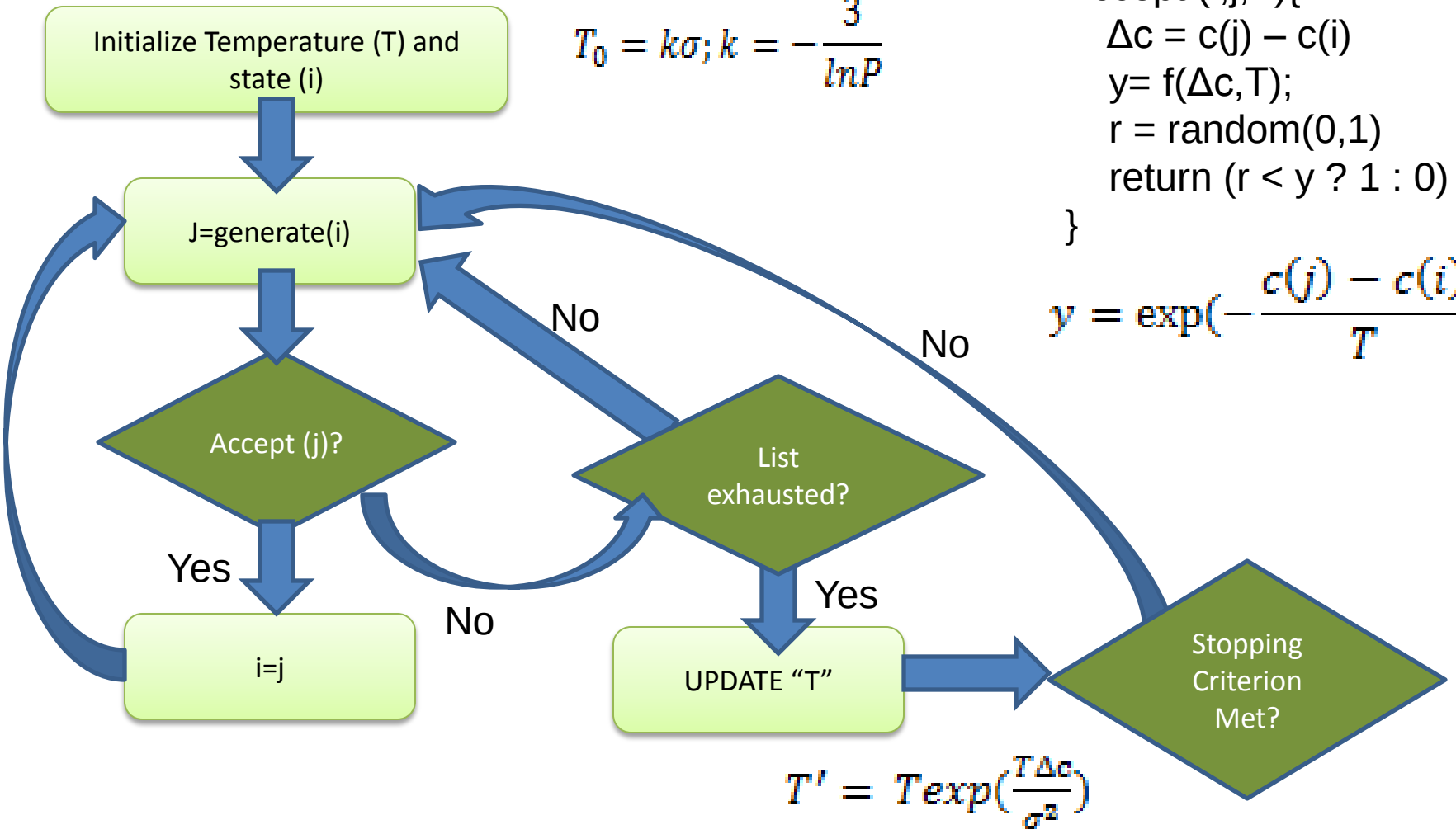
$$T_0 = k\sigma; k = -\frac{3}{lnP}$$

- Temperature decrement[2]
  - Method used the so-called annealing curve, a plot of the average cost versus the log of the temperature value

$$T' = T exp(\frac{T\Delta c}{\sigma^2})$$

1) S. White, “Concepts of Scale in Simulated Annealing,” (1984).
2) M. Huang, F. Romeo, A. Sangiovanni-Vincentelli, “An Efficient General Cooling Schedule for Simlated Annelaing,” (1986).

Pseudo-Code



$$T_0 = k\sigma; k = -\frac{3}{lnP}$$

```
Accept (i,j,T){
    Δc = c(j) – c(i)
    y= f(Δc,T);
    r = random(0,1)
    return (r < y ? 1 : 0)
}
```

$$y = \exp(-\frac{c(j) - c(i)}{T})$$

$$T' = T exp(\frac{T\Delta c}{\sigma^2})$$

Applications of Simulated Annealing

- Combinatorial optimizations
  - Traveling Salesperson (TSP)
- Computer-aided circuit design
  - Placement and Routing
- Image Processing
- Numerical Analysis
- Among others…

Summary

- Simulated Annealing allow hill-climbing move to avoid local minima
- The ‘temperature’ play a crucial role in accepting cost-increasing states
- Algorithm speed is affected by:
  - Initial temperature
  - # of configurations within each temperature
  - Temperature rate of decrease

Example Applet and References

- Simulated Annealing applet of Traveling Salesperson
  - http://www.heatonresearch.com/articles/64/page1.html

- References
  - Carl Sechen, VLSI Placement and Global Routing Using Simulated Annealing, Boston: Kluwer Academic Publisher, 1988
  - Dimitris Bertsimas and John Tsitsiklis, Simulated Annealing, Statistical Science, 1993, Vol. 8, No. 1, 10-15

Thank You for your Attention~!