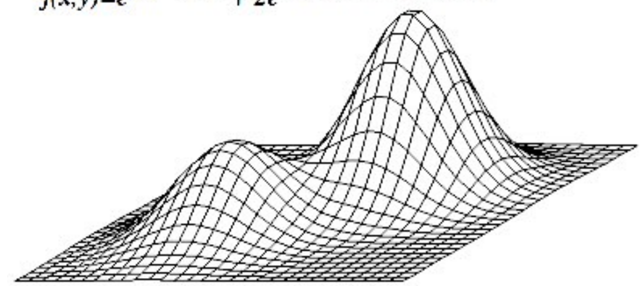
Advanced Search Algorithms I: Simulated Annealing

CSE 415: Introduction to Artificial Intelligence
University of Washington
Winter, 2018

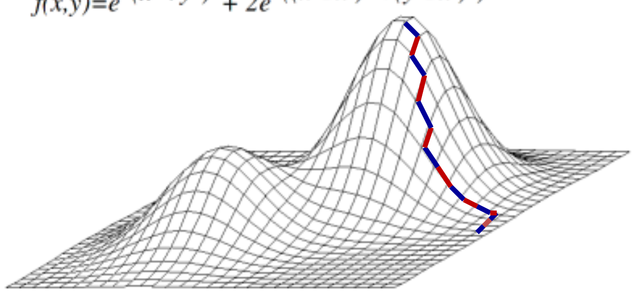
Hill Climbing

$$f(x,y)=e^{-(x^2+y^2)} + 2e^{-((x-1.7)^2+(y-1.7)^2)}$$



Hill Climbing (cont.)

$$f(x,y)=e^{-(x^2+y^2)} + 2e^{-((x-1.7)^2+(y-1.7)^2)}$$



Hill Climbing (cont.)

Assumptions:
Each state maps to a well-defined “height.”

Method:
At each step, choose the move that results in the state having the greatest height.

Similar to:
Greedy algorithms.
Gradient ascent or descent or steepest ascent or descent (in continuous state spaces)

Hill Climbing (cont.)

Major limitation:

Can get stuck in a local optimum (e.g., a lesser peak).

Simulated Annealing

Like probabilistic hill climbing.
Allows for the possibility of escaping from local optima.

Optimum means "lowest potential energy" state.

S.A. is based on an analogy to a metallurgical process called annealing.

S.A. (cont.)

Problem structure for simulated annealing:

We have an energy function

$$E: S \rightarrow \Re^+$$

that assigns to each state a nonnegative real number.

S.A. – The Method

In state s having energy z, randomly select an operator whose precondition is satisfied.
Apply it to create a state s' having energy z'. If $z' \leq z$, then accept s' as the new current state.
But if $z' > z$, randomly choose to accept s' with probability p, where

$$p = e^{-(z'-z)/kT}$$

T is the "temperature" which starts high and gradually is reduced to 0.

S.A. Typical Problem Structure

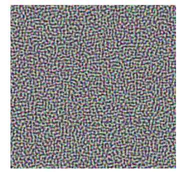
Problem structure for simulated annealing:

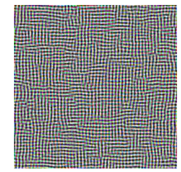
Often: the state space is a cartesian product of many subspaces each of which corresponds to a state variable.

S.A. Example

"Crystallization" in a digital image.
Each pixel corresponds to a separate state variable.
Start with a random image. Use an energy function that gives low energy to similar pixels being adjacent and low energy when pixels at a slight distance are different, but higher energy in the other situations.

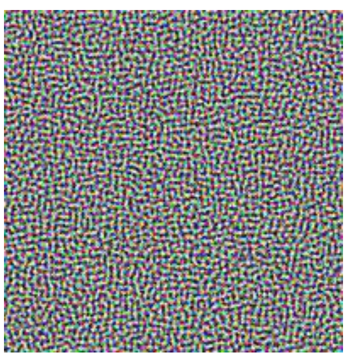
http://en.wikipedia.org/wiki/Simulated_annealing
Results using fast and slow cooling schedules:

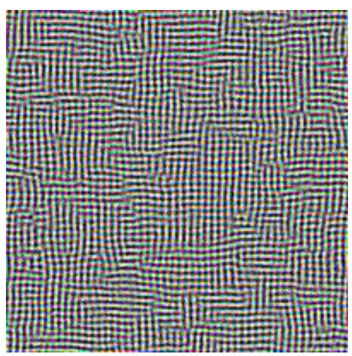




S.A. Example (enlargements)

Fast **Slow**





S. A. Example 2

Travelling Salesman Problem
Demonstration applet at:

http://www.heatonresearch.com/articles/64/page1.html