Modul 3: Beyond Classical Search

Simulated Annealing

Masayu Leylia Khodra

KK IF – Teknik Informatika – STEI ITB

Inteligensi Buatan
(*Artificial Intelligence*)

bolehin pindah ke state tetangga yg lebih buruk dgn probabilitas tertentu yg semakin lama semakin menurun.

SA: Combining Completeness and Efficiency

tetangga cuman 1

Purely random walk

Hill-climbing

Complete search

Incomplete search (no "downhill" moves)

Extremely inefficient

Efficient, but can stuck on local maximum
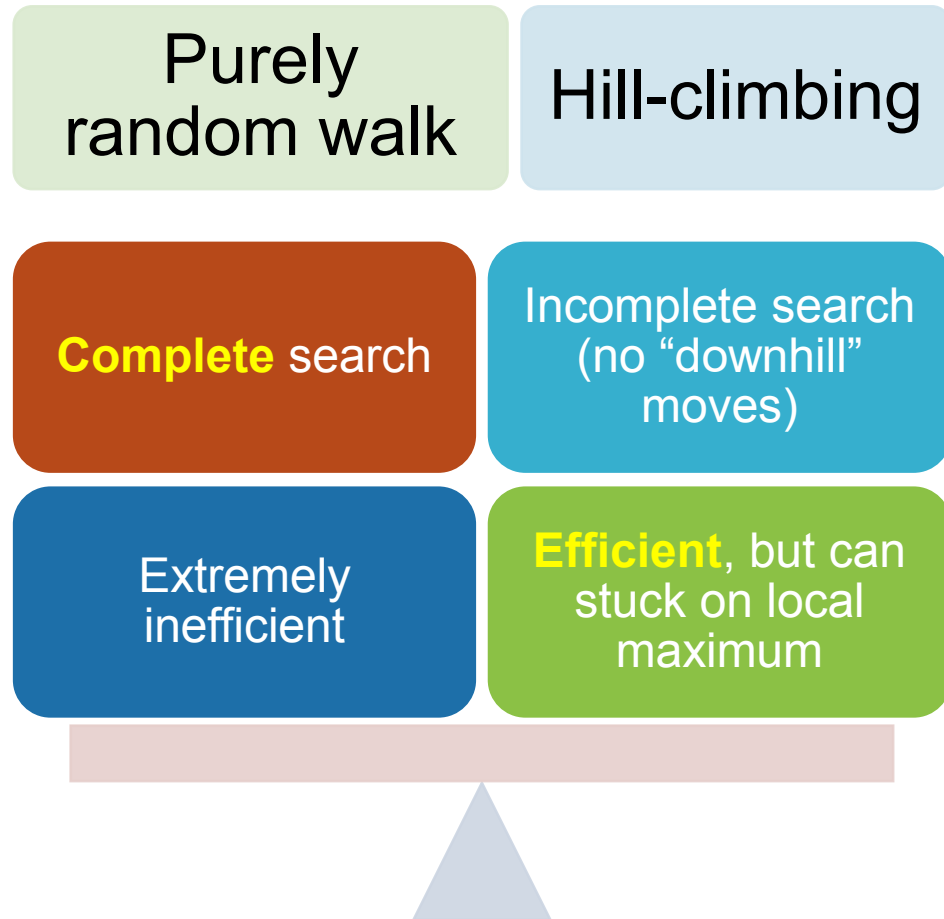
- Simulated annealing combines hill climbing (efficient) with a random walk (complete)
- Idea: escape local maxima by allowing some "bad" moves but gradually decrease their frequency
- Simulated annealing is a version of stochastic hill climbing where some downhill moves are allowed.
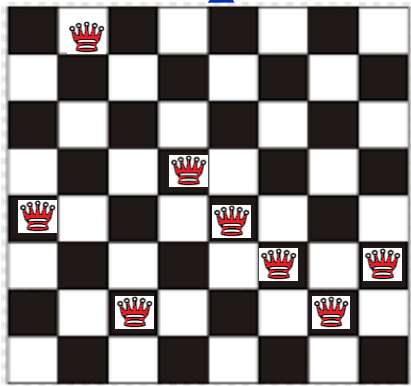
EDUNEX ITB

Neighbor: One Random Successor of Current
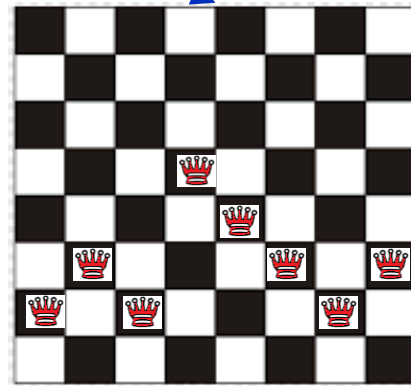
Current State: h=-17
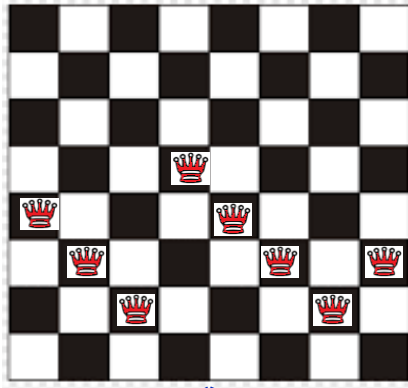
56 possible random successor

Better neighbor: h=-12

Worse neighbor: h=-18

- Stochastic hill-climbing:
  - Only move to better neighbor, and skip worse neighbor.

- Simulated annealing:
  - move to better neighbor, and allow move to worse neighbor that has probability

$$e^{\Delta E / T}$$

nilai/utilitas state tetangga terpilih − nilai/utilitas state sekarang.

temperatur

prob.

T ↑, nilai e jd makin besar. karena ΔE negatif

hanya digunakan ketika state tetangga yg dibangkitkan lebih buruk.

EDUNEX ITB

Simulated Annealing

ΔE selalu negatif karena dia lebih buruk. (handwritten)

https://id.m.wikipedia.org/wiki/Berkas:Annealing_a_silver_strip.JPG

Annealing: heat (metal or glass) and allow it to cool slowly, in order to remove internal stresses and toughen it.

- T is the "temperature" of annealing that gradually decreases.
- $\Delta E = neighbor.value - current.value$
- If better neighbor ($\Delta E > 0$): move to neighbor (stochastic HC)

  kalo lebih > 0 pasti pindah (handwritten)

- If worse neighbor ($\Delta E < 0$): probability move $e^{\Delta E / T}$
  - When T is high (e.g. $\Delta E = -5$, T=100, prob=0.95), there is a lot of random motion ➔ random walk
  - When T approaches 0 (e.g. $\Delta E = -5$, T=1, prob=0.007), randomness is decreased ➔ stochastic hill climbing.

EDUNEX ITB

Simulated Annealing (Russel & Norvig, 2010)

function SIMULATED-ANNEALING(*problem*, *schedule*) **returns** a solution state
    inputs: *problem*, a problem
             schedule, a mapping from time to "temperature"

    current ← MAKE-NODE(*problem*.INITIAL-STATE)
    for $t = 1$ **to** ∞ **do**
        $T \leftarrow schedule(t)$
        if $T = 0$ **then return** *current*
        next ← a randomly selected successor of *current*
        $\Delta E \leftarrow next.\text{VALUE} - current.\text{VALUE}$
        if $\Delta E > 0$ **then** *current* ← *next*
        else *current* ← *next* only with probability $e^{\Delta E/T}$

Handwritten annotations:

- beres artinya (celesai).
- Terminates T=0
- T: temperature as a function of time t
- Move to better neighbor (stochastic HC)
- allowing some "bad" moves, depends on probability
- pindah/ enggak tergantung sama probability
- pendekatan.
- set threshold probability.
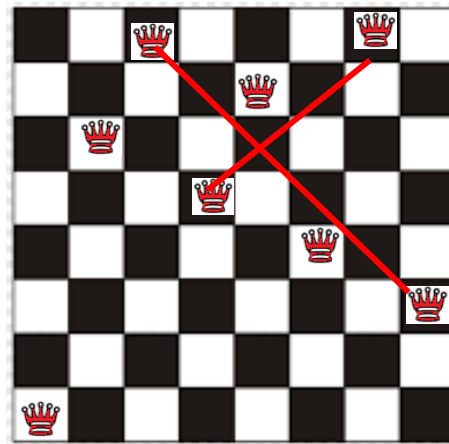- bangkitkan nilai random dari 0-1.

EDUNEX ITB

Move to Worse State

Current State: h=-1
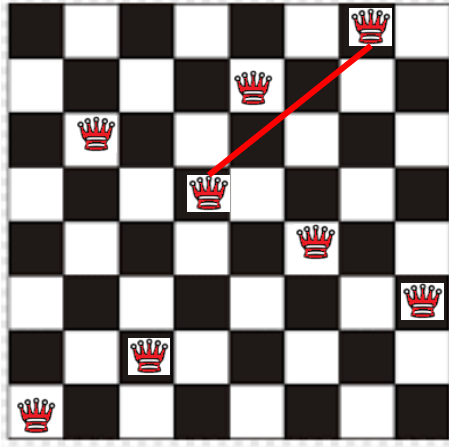
Column: C3
Row: 2➔8

$$current \leftarrow next \text{ only with probability } e^{\Delta E/T}$$

Compare to static value:
move probability > 0.5
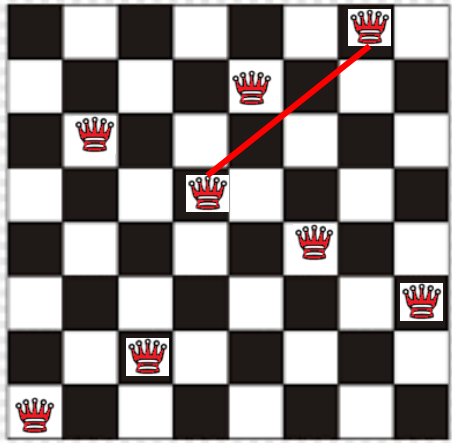
Compare to random value:
move probability > random(0,1)

Next: h=-2, T=10
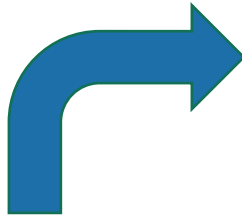$\Delta E<0$: prob=$e^{(-2-(-1))/10}$=$e^{-0.1}$ =0.9

EDUNEX ITB

Simulated Annealing: Illustration

Current State: h=-1

Column: C3
Row: 2➜8

Column: C4
Row: 5➜3

Next: h=-2, T=10
Prob=$e^{(-2-(-1))/10}$=$e^{-0.1}$ =0.9
Current ← next
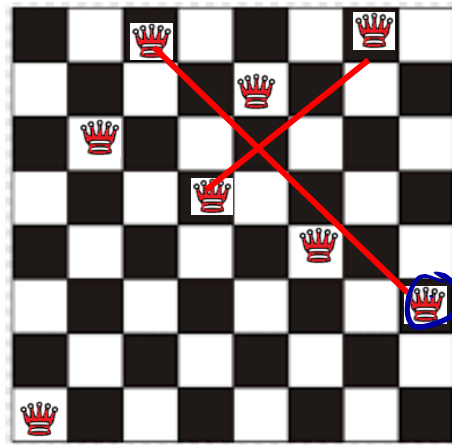
Next: h=-1
Current ← next
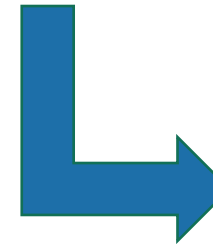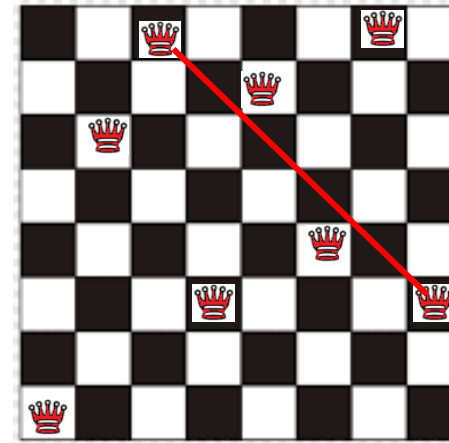
Column: C8
Row: 3➜5

Next: h=0
Current ← next

stop
pas 0

EDUNEX ITB
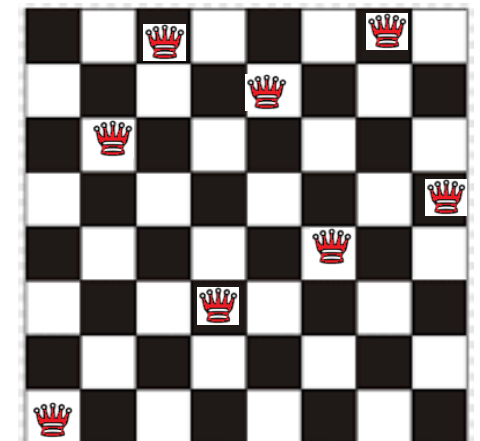
Application: Simulated Annealing for Paraphrase
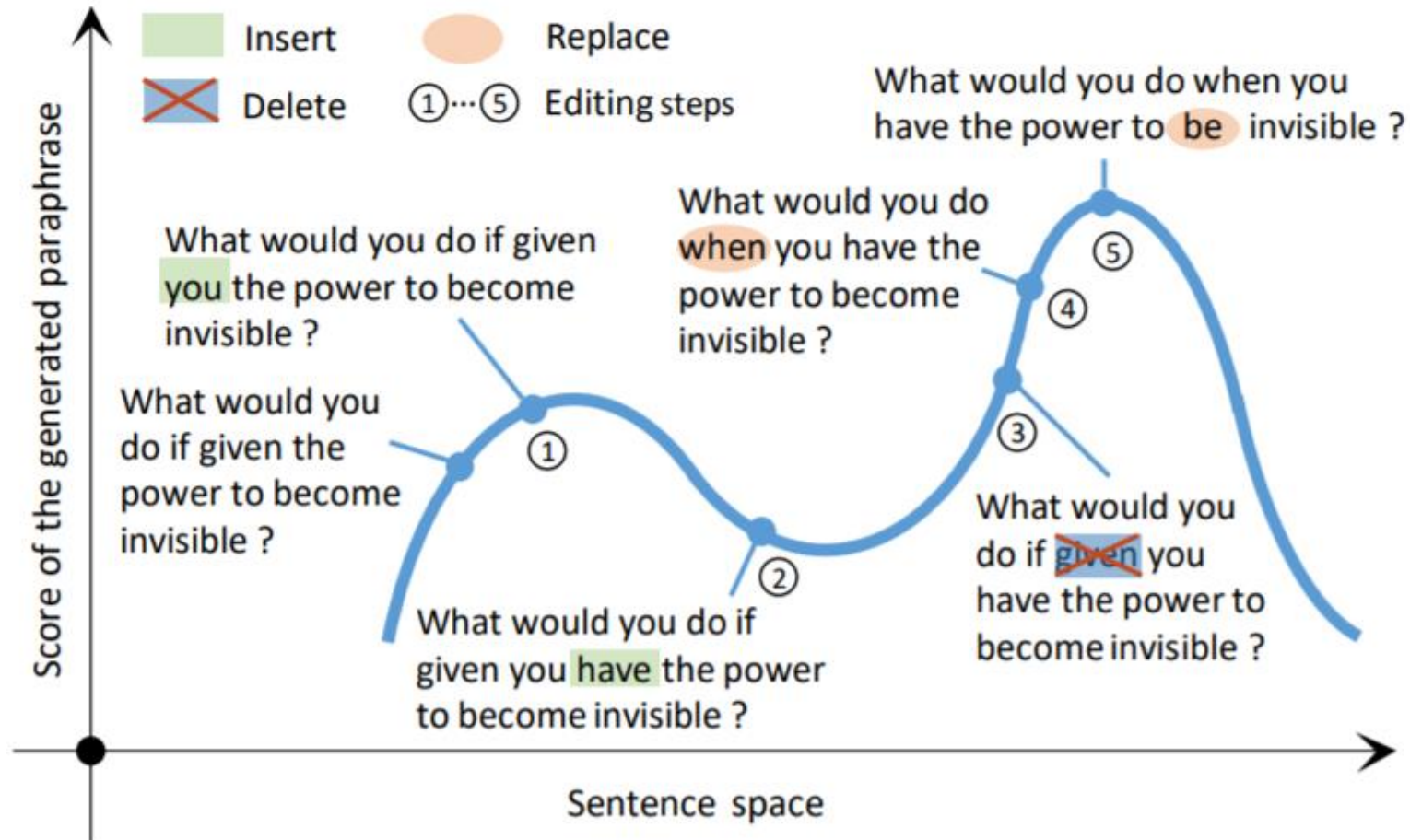
Liu, X., Mou, L., Meng, F., Zhou, H., Zhou, J., & Song, S. (2020). Unsupervised paraphrasing by simulated annealing. Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics, pages 302–312 July 5 - 10, 2020. c 2020 Association for Computational Linguistics. *arXiv preprint arXiv:1909.03588.*

Properties of simulated annealing search

One can prove: If T decreases slowly enough, then simulated annealing search will find a global optimum with probability approaching 1

Widely used in VLSI layout, airline scheduling, etc

Summary: Simulated Annealing

Simulated annealing is a version of stochastic hill climbing where some downhill moves are allowed.

If T decreases slowly enough, then simulated annealing search will find a global optimum with probability approaching 1

Next:

- Genetic Algorithm

EDUNEX ITB

THANK YOU