Self-Organizing Systems

Lab Class

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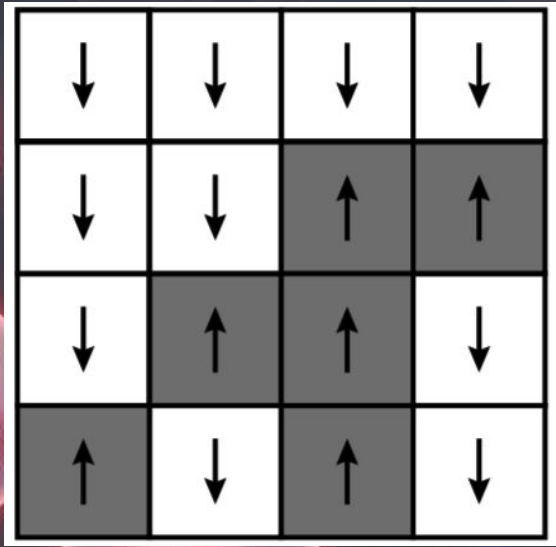
The Ising Model

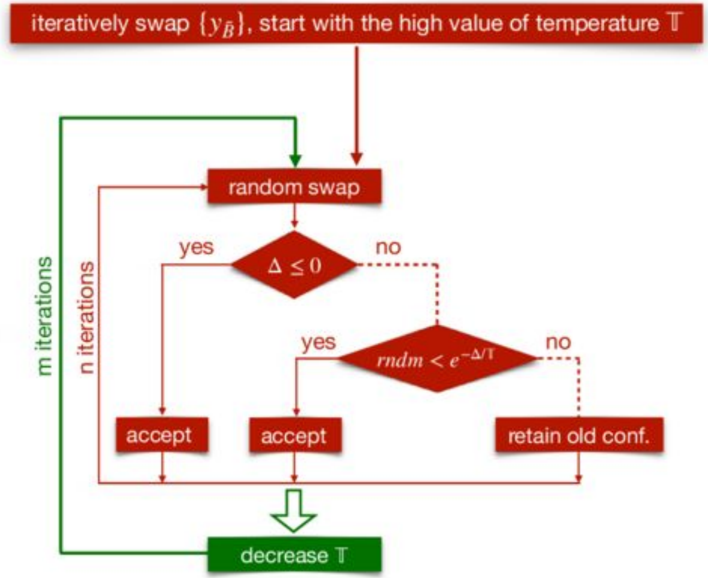
- A model from *statistical physics*
    - A branch of study - to understand the behavior of many particles. (avg., collective.m …)
    - Developed to explain the ferromagnetism
- Each node has either one of the spin
    - $s_i = \pm 1$ (i.e Up or Down respectively)
- Neighboring spins want to align (lower energy)
- Temperature introduces randomness (higher T → more disorder)
- Measures degree of alignment
    - $M = - \Sigma_i s_i$
- Each grid configuration has energy,
    - $E = - \Sigma_{(ij)} s_i s_j$, where ij denotes the two neighbouring grid nodes.
- Lower energy when neighbors have the same spin



Metropolis algorithm

This algorithm tries to minimize the overall energy by flipping a single spin each time step

1. Pick a random cell *i*
2. Compute energy change ΔE if its spin is flipped
3. Accept flip if:
   - ΔE≤ 0 (energy decreases),
   - ΔE> 0 with probability:
     a. A=exp(−ΔE/T)



A simple implementation of the Algorithm [1].

[1] https://www.researchgate.net/figure/mplementation-of-the-Metropolis-algorithm_fig1_383144284

Task Objectives

Requirements

- Implement Ising model with 100×100 **grid with periodic boundaries**.
- Initialize with random spins.
- Use Metropolis algorithm for evolution.
- Choose any programming language and T values.

Expected Outputs

- Plot grid world (spin configuration) at:
  - Initialization
  - Intermediate steps (for different T)
  - Late-stage equilibrium (if it attains)

Expected

- Run script → initializes grid → iterates Metropolis steps → outputs plots → Explanation.

Simulation Requirements

- Run Metropolis for 1,000,000 time steps for several temperatures T.
- Identify critical temperature $\mathbf{T_c}$.
- Highest T at which distant spins remain correlated (parallel).

What to Analyze

- Behavior at:
  - $T \ll T_c$ → strong alignment (ordered phase)
  - $T \approx T_c$ → phase transition
  - $T \gg T_c$ → random spins (disordered phase)

Plots to Include

- Grid world for the three temperature regimes.
- Energy vs. time
- Magnetization vs. time

Explain

- Transition near T_c is smooth/continuous, not a sudden jump.

The El Farol bar problem

Observer Controller Architecture

A neighborhood decides weekly whether to go to a small bar.

Rule:
- If **< 60%** go → *Not crowded* → *Good time*
- If **≥ 60%** go → *Crowded* → *Bad time*

Each person makes decisions **simultaneously** each week.

People only know:
- Their own experience last week
- Experiences of their 4 neighbors

Three possible experiences:

1. *Did not go*
2. *Went + Bad time*
3. *Went + Good time*

Naive behavior

- If last week was crowded → *don't go*
- If last week was not crowded → *go*

2) Anti-cyclical behavior

- If people had a good time → *don't go*
- If it was crowded → *go*

System Architecture (OC Architecture)

Observer - Controller (Psychologist)

- Monitors overall bar attendance percentage.
- Monitors ratio of naive vs anti-cyclical agents.
- Every time step:
    a. Chooses 1 person
    b. Switches their behavior type
        i. Naive → Anti-cyclical
        ii. Anti-cyclical → Naive
- Goal:
  Keep bar occupancy just below 60%, rarely exceeding it.

Grid Setup

- 50 × 50 = 2500 people
- Behaviors randomly assigned initially (naive vs anti-cyclical)
- Psychologist selects 1 person per time step
- Run 100 independent simulations

Outputs

1. Average behavior ratio over time
    - Fraction Naive vs Anti-cyclical
    - Extra behaviors in part b
        i. Keep it interesting - No - Always goes / Does not goes.
2. Average bar attendance ratio over time
3. **Plots**: 100 Independent runs (average)
    - Bar Visitors vs time
    - Behavior ratio vs time