Pedagogical Possibilities for the 2048 Puzzle Game

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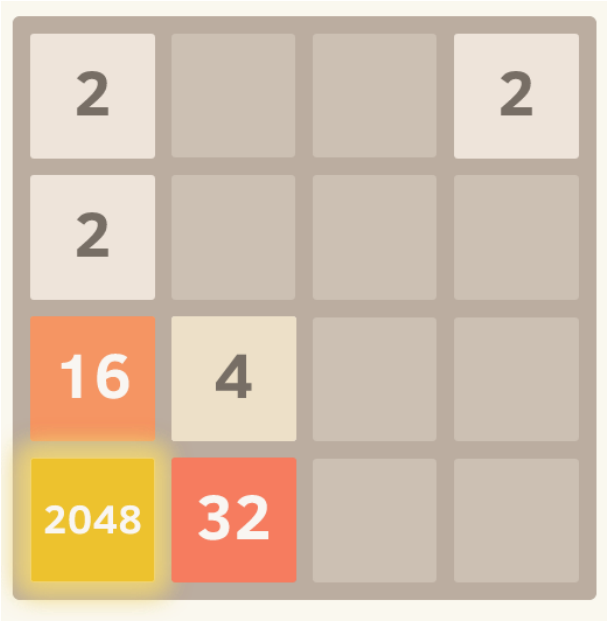
Outline

- Introduction to the 2048 Game
- Sample 2048 Assignments
- The Importance of Sharing Assignments
- Wanted: High Fun/SLOC Assignments

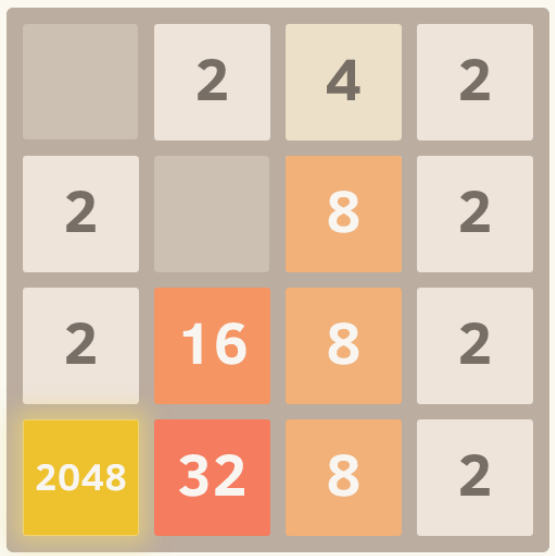
What is 2048?

- 4-by-4 square grid partially filled with tiles labeled with powers of 2.
- Primary goal: merge tiles in order to create a tile labeled 2048 (2^{11})
- Secondary goal: achieve higher scores and higher tiles.
- Initial board has 2 randomly generated tiles.
  - Uniformly random position
  - Values 2 (with probability .9) or 4.

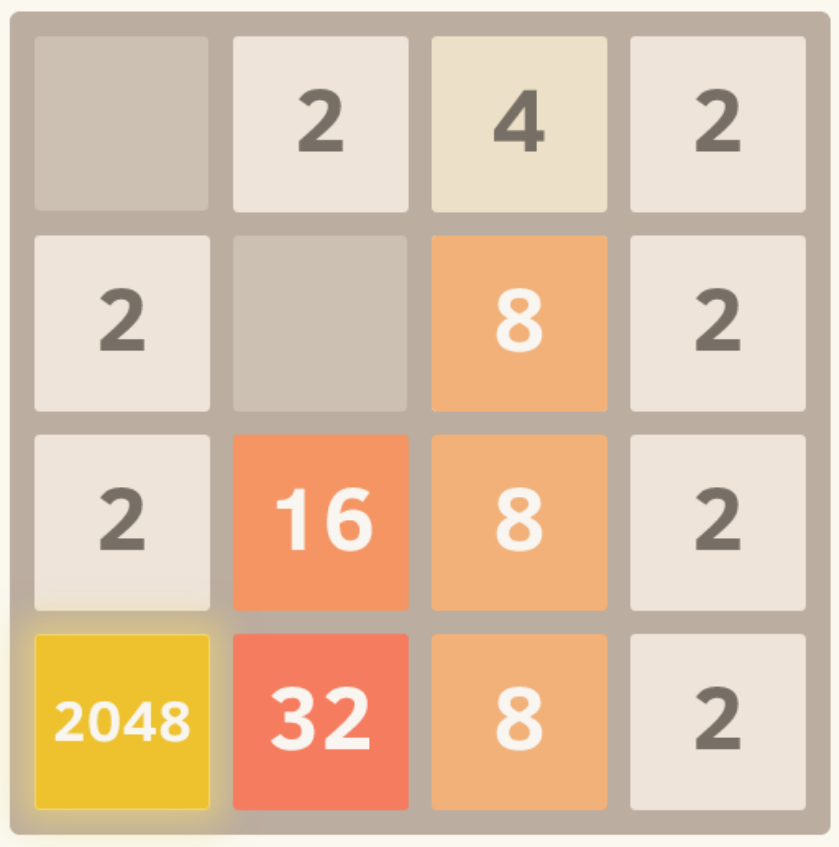


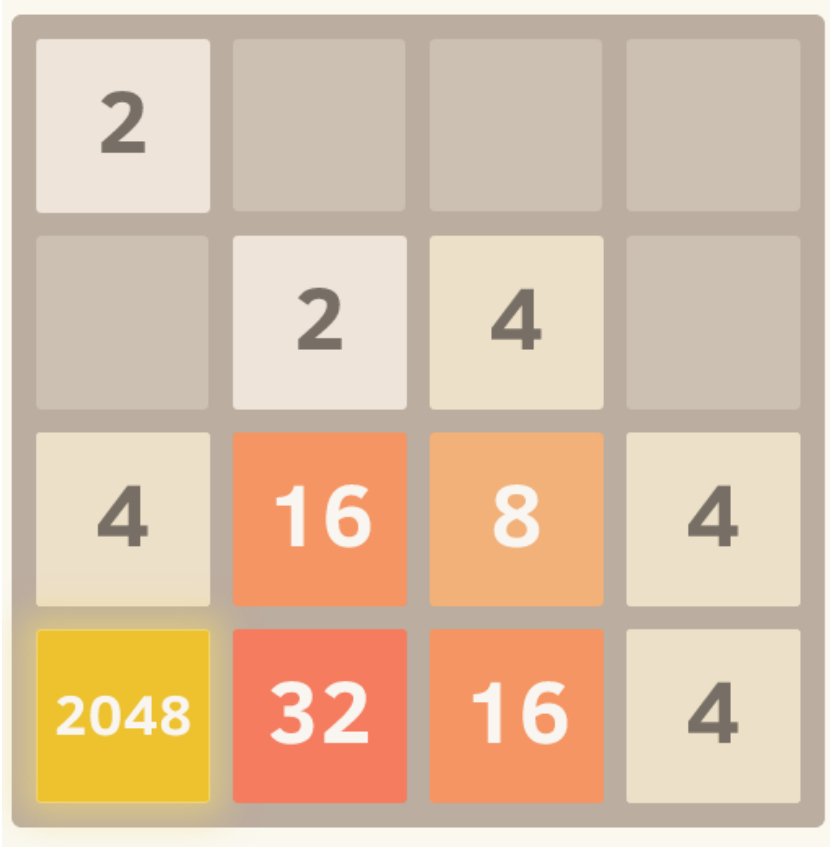
2048 Turn

- Move left, right, up, or down, if it results in a *change* to the grid.
  - Change can be from tile sliding, and/or
  - merging same number tiles by sliding them together along a row/column line.
- No legal move → game over.
- Player chooses a direction along a line:
  - All tiles merge and slide in that direction if possible.
  - From the front to the back, successive identical tile pairs merge into a new tile with their sum.
  - (Merged tiles cannot merge again in the same movement.)
  - All tiles slide as far as possible in the direction of motion.



Downward Move Example





How can 2048 be useful to CS Ed?

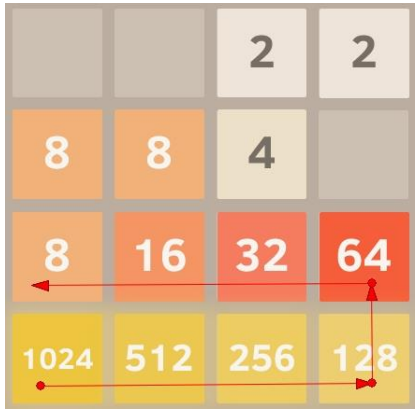
- CS1, CS2: Modeling
  - 1D, 2D array, iteration exercise
  - Queue exercise
- CS1/CS2: MC Simulation
- AI
  - Heuristic evaluation
  - Search (Expectimax, etc.)

Modeling

- Given a 4-by-4 puzzle grid,
  - Is the game over?
  - Can the player legally move in a given direction?
  - What are the legal directions of motion?
- Given a single line of tiles, compute the result of a move towards the front of that line.
- Given a 4-by-4 puzzle grid,
  - Compute the result of a move in a given direction.

Heuristic Evaluation

- Score one's preference for a given board.
- For non-AI students, the instructor can supply search code using student heuristics.
- How much should one value:
  - … having our maximum value tile in a corner?
  - … monotonicity along a snake-like path?
  - … monotonicity along any line?
  - … the maximum tile of a line along an edge?
  - … adjacent identical tiles?
  - … empty cells?
- Such open-ended assignments encourage creativity and deeper problem-solving engagement.

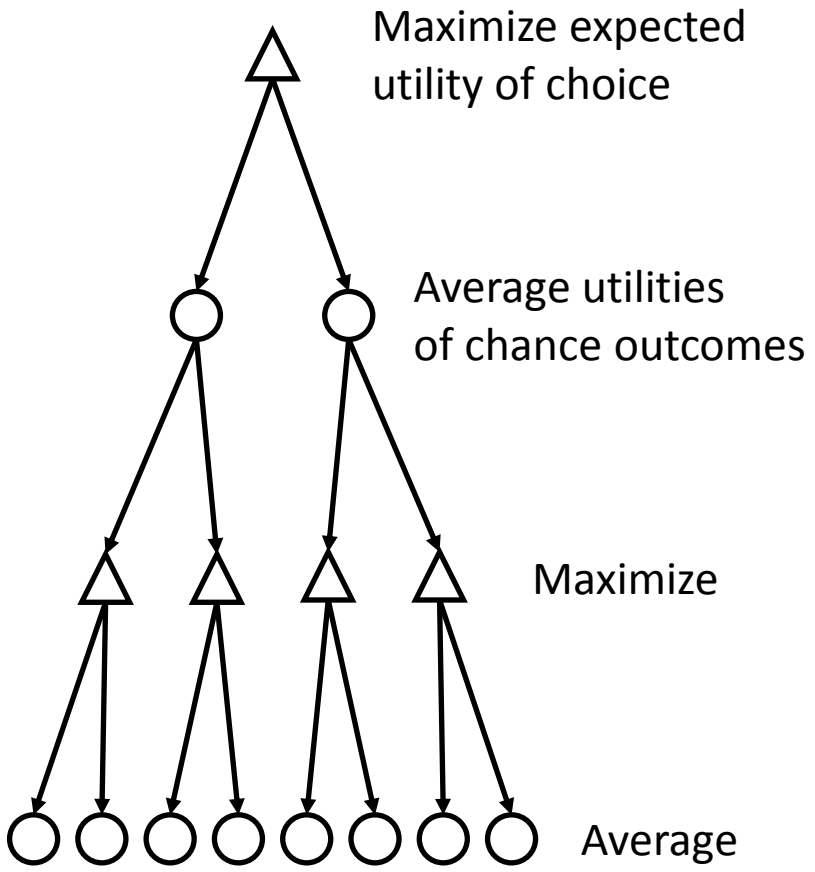


Simple Game Play

- Greedy – Pick the move that immediately (before random tile generation) yields the grid with the maximum heuristic evaluation
- Monte Carlo:
  - After each possible play,
    - For a fixed number of trials (e.g. 1000):
      - Simulate *n* (e.g. 2) moves (after *n* random tile generations) and accumulate the heuristic evaluation of the final resulting state.
    - Divide by the number of trials to get an avg. heuristic value.
  - Choose move with the maximum avg. heuristic value.

Advanced Game Play

- Choice node and chance nodes?
  - → **Expectimax**
  - Maximize at choice nodes, average at chance nodes
  - Evaluate heuristic at depth cutoff
  - Chance sampling: Average over a *sample* rather than all possible chance events
- Monte Carlo Tree Search



Performance Results

Algorithm	Median Score	Mean Score	Std. Dev.	Max. Tile	Median Tile
random	1028	1075	512	256	128
simple greedy	3326	3620	1708	1024	256
simple Monte Carlo (depth 3)	14586	14295	6592	2048	1024
expectimax (depth 2)	14398	14241	6717	2048	1024
expectimax (depth 3)	27132	25270	10429	4096	2048
10-sample expectimax (depth 2)	14496	14623	7096	4096	1024
10-sample expectimax (depth 3)	27052	24883	10106	4096	2048

- Simple Monte Carlo can achieve the 2048 tile.
- Chance sampling provides significant speedup with comparable performance.

Why is Nifty Nifty?

- Nifty Assignments sessions (http://nifty.stanford.edu) and spin-offs, e.g. Model AI Assignments (http://modelai.gettysburg.edu)
- Experiential learning is deep learning
- Model, well-designed, applied assignments form the foundation of experiential learning.
- Model assignments take significant time, effort, expertise, and revision to develop.
- Sharing such assignments through repositories aids the efficient advancement of CS education.

What Not to Assign

- Motivating question #1: Why *isn't* a Chess game a good intro CS assignment?
  - Complex rules (e.g. moves, en passant, castling) are often a distraction from the lesson.
- Motivating question #2: Why *isn't* Tic-tac-toe my favorite intro CS assignment?
  - Tic-tac-toe is boring once you know the strategy.

Wanted: High Fun/SLOC Assignments

- The best game/puzzle assignments:
  - Require few source-lines-of-code to model (simple)
  - Are **fun** and interesting, offering an experience worth revisiting (→satisfaction) and sharing (→promotion)
- Examples: Breakthrough, Connect6, Pig, Nim Games (Subtraction, 3-Pile Nim, Chomp), 2048
- I would be interested in your best examples as well!

Conclusion

- 2048 offers many good exercises for CS1 through advanced AI.
  - Modeling assignments are suitable for CS1.
  - Simple AI yields satisfying results.
- Sharing exercises for deep, experiential learning is worth our effort.
- Wanted: High Fun/SLOC Assignments!