The game had been tense, but friendly enough. Then Steve tried to annex Portugal, and the room became decidedly chillier.
Project 1

- Show expanded nodes?
  - isGoalState() can use visitedList to drawExpandedCells
Games

- Games vs. Game Theory?
- Difference from search?
- Use GAs?
Game Playing State-of-the-Art

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- **Jeopardy:** Watson

- **Pacman:**?
Adversarial Search?
Game Playing

- Many different kinds of games!

- Axes:
  - Deterministic or stochastic?
  - One, two, or more players?
  - Perfect information (can you see the state)?

- Want algorithms for calculating a strategy (policy) which recommends a move in each state
Deterministic Games

- Many possible formalizations, one is:
  - States: $S$ (start at $s_0$)
  - Players: $P=\{1\ldots N\}$ (usually take turns)
  - Actions: $A$ (may depend on player / state)
  - Transition Function: $S \times A \rightarrow S$
  - Terminal Test: $S \rightarrow \{t,f\}$
  - Terminal Utilities: $S \times P \rightarrow \mathbb{R}$

- Solution for a player is a policy: $S \rightarrow A$
Deterministic Single-Player?

- Deterministic, single player, perfect information:
  - Know the rules
  - Know what actions do
  - Know when you win
  - E.g. Freecell, 8-Puzzle, Rubik’s cube
- … it’s just search!
- Slight reinterpretation:
  - Each node stores a value: the best outcome it can reach
  - This is the maximal outcome of its children (the max value)
  - Note that we don’t have path sums as before (utilities at end)
- After search, can pick move that leads to best node
Adversarial Games

- Deterministic, zero-sum games:
  - Tic-tac-toe, chess, checkers
  - One player maximizes result
  - The other minimizes result

- Minimax search:
  - A state-space search tree
  - Players alternate turns
  - Each node has a minimax value: best achievable utility against a rational adversary

Minimax values: computed recursively

Terminal values: part of the game
Computing Minimax Values

- Two recursive functions:
  - max-value maxes the values of successors
  - min-value mins the values of successors

```python
def value(state):
    if the state is a terminal state: return the state’s utility
    if the next agent is MAX: return max-value(state)
    if the next agent is MIN: return min-value(state)

def max-value(state):
    initialize max = -\infty
    for each successor of state:
        compute value(successor)
        update max accordingly
    return max
```
Minimax Example
Tic-tac-toe Game Tree

MAX (X)

MIN (O)

MAX (X)

MIN (O)

TERMINAL

Utility

-1

0

+1
Minimax Properties

- Optimal against a perfect player. Otherwise?

- Time complexity?
  - $O(b^m)$

- Space complexity?
  - $O(bm)$

- For chess, $b \approx 35$, $m \approx 100$
  - Exact solution is completely infeasible
  - But, do we need to explore the whole tree?