The Beauty and Joy of Computing
Lecture #22: Computational Game Theory
2011-04-18

CHECKERS SOLVED IN 2007!
A 19-year project led by Prof. Jonathan Schaeffer, he used dozens (sometimes hundreds) of computers and AI to prove it is, in perfect play, a draw! This means that if two Gods were to play, nobody would ever win!

www.cs.ualberta.ca/~chinook/

Computer Science ... A UCB view

- CS research areas:
  - Artificial Intelligence
  - Biosystems & Computational Biology
  - Computer Architecture & Engineering
  - Database Management Systems
  - Graphics
  - Human-Computer Interaction
  - Operating Systems & Networking
  - Programming Systems
  - Scientific Computing
  - Security
  - Theory
  - ...

The Turk (1770)
- A Hoax!
- Built by Wolfgang von Kempelen
  - to impress the Empress
- Could play a strong game of Chess
  - Thanks to Master inside
- Toured Europe
  - Defeated Benjamin Franklin & Napoleon!
- Burned in an 1854 fire
  - Chessboard saved.

Claude Shannon's Paper (1950)
- The “Father of Information Theory”
  - Founded the digital computer
  - Defined fundamental limits on compressing/storing data
- Wrote “Programming a Computer for Playing Chess” paper in 1950
  - C. Shannon, Philos. Mag. 41, 256 (1950)
  - All chess programs today have his theories at their core
- His estimate of # of Chess positions called “Shannon #”
  - Now proved ≈ 432

Deep Blue vs Garry Kasparov (1997)
- Kasparov World Champ
- 1996 Tournament – Deep Blue
  - First game DB wins a classic!
  - But DB loses 3 and draws 2 to lose the 6-game match 4-2
  - In 1997 Deep Blue upgraded, renamed “Deeper Blue”
- 1997 Tournament – Deeper Blue
  - GK wins game 1
  - GK resigns game 2
  - even though it was drawn!
  - DB & GK draw games 3-5
  - Game 6 1997-05-11 (May 11)
    - Kasparov blunders in 7, loses in 11 moves. Loses tournament 2½ - 2½
    - GK accuses DB of cheating. No remark.
- Defining moment in AI history

Computational Game Theory
- History
- Definitions
  - Game Theory
  - What Games We Mean
  - Win, Lose, Tie, Draw
  - Weakly / Strongly Solving
- Gamesman
  - Dan’s Undergraduate R&D Group
  - Demo!
- Future
What is “Game Theory”?  

**Combinatorial**  
- Sprague and Grundy’s 1939 Mathematics and Games  
- Nim, Domineering, dots and boxes  
- Film: <last year in manslaughter>  
- Complete info, alternating moves  
- Goal: last move

**Computational**  
- R. C. Bell’s 1938 Board and Table Games from many Civilizations  
- Board games  
- Tic-Tac-Toe, Chess, Connect 4, Othello  
- Film: Searching for Bobby Fischer  
- Complete info, alternating moves  
- Goal: Variies

**Economic**  
- von Neumann and Morgenstern’s 1944 Theory of Games and Economic Behavior  
- Matrix games  
- Prisoner’s dilemma, auctions  
- Film: A Beautiful Mind (about John Nash)  
- Incomplete info, simultaneous moves  
- Goal: Maximize payoff

What “Board Games” do you mean?  

- No chance, such as dice or shuffled cards  
- Both players have complete information  
- No hidden information, as in Stratego & Magic  
- Two players (Left & Right) usually alternate moves  
- Repeat & skip moves ok  
- Simultaneous moves not ok  
- The game can end in a pattern, capture, by the absence of moves, or …

What’s in a Strong Solution  

- For every position  
  - Assuming alternating play  
  - Value …  
  - for player whose turn it is!  
  - Winning (3 losing child)  
  - Losing (all children winning)  
  - Tying (3 losing child, but 3 losing child)  
  - Drawing (can’t force a win or be forced to lose)  
  - Remoteness  
  - How long before game ends?

GamesCrafters  

- We strongly solve abstract strategy games and puzzles  
  - 70 games / puzzles in our system  
  - Allows perfect play against an opponent  
  - Ability to do a post-game analysis

What did you mean “strongly solve”?  

Weakly Solving A Game (Checkers)  

Log of Search Space Size

Thanks to Jonathan Schaeffer @ U Alberta for this slide…
Strong Solving Example: 1, 2, …, 10

- Rules (on your turn):
  - Running total = 0
- Rules (on your turn):
  - Add 1 or 2 to running total
- Goal
  - Be the FIRST to get to 10
- Example
  - Ana: “2 to make it 2”
  - Bob: “1 to make it 3”
  - Ana: “2 to make it 5”
  - Bob: “2 to make it 7” → photo
  - Ana: “1 to make it 8”
  - Bob: “2 to make it 10”! WIN!

Example: Tic-Tac-Toe

- Rules (on your turn):
  - Place your X or O in an empty slot on 3x3 board
- Goal
  - If your make 3-in-a-row first in any row / column / diag, win
  - Else if board is full with no 3-in-a-row, tie
- Misère is tricky
  - 3-in-row LOSES
  - Pair up and play now, then swap who goes first

Tick-Tack-Toe Answer Visualized!

- Recursive Values Visualization Image
- Misère Tic-tac-toe
  - Outer rim is position
  - Inner levels moves
  - Legend
    - Lose
    - Tie
    - Win

GamesCrafters

- Undergraduate Computational Game Theory Research Group
- 300 students since 2001
  - We now average 200 students
  - They work in teams of 2+
- Most return, take more senior roles (sub-group team leads)
  - Maximization (bottom-up solved)
  - Minimax (value, alpha beta pruning)
  - D4 (graphical interface work)
  - GPU (GPU computing)
  - Architecture (core)
  - New game ideas (add / refactor)
  - Documentation (games & code)

Connect 4 Solved, Online!

- We've just finished a solve of Connect 4!
- It took 30 Machines x 8 Cores x 1 weeks
- Win for the first player (go in the middle!)
  - 3, 5 = tie
  - 1, 2, 6, 7 = lose
- Come play online!

Future

- Board games are exponential
  - So has been the progress of the speed / capacity of computers
- Therefore, every few years, we only get to solve one more "puzzle"
- One by one, we're going to solve them and/or beat humans
  - E.g., Checkers, Go
- Strongly solving (GamesCrafters)
  - We visit EVERY position, and know value of EVERY position
  - E.g., Connect 4
- Weakly solving (Lexiv Albertz)
  - We know game's value by only visiting SOME positions, so we only know value of SOME positions
  - E.g., Checkers

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