CS10
The Beauty and Joy of Computing

Lecture #22 : Computational Game Theory

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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/

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

www.eecs.berkeley.edu/Research/Areas/

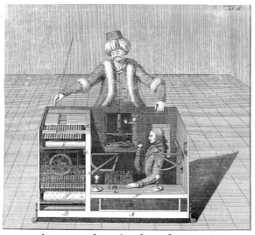
Computer Science … A UCB view

- 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
  - …

en.wikipedia.org/wiki/The_Turk

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…

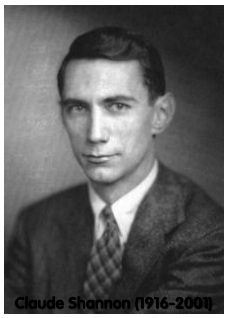


The Mechanical Turk (1770)

en.wikipedia.org/wiki/Claude_Shannon#Shannon.27s_computer_chess_program

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 < 2^{155} ~ $10^{46.7}$



Claude Shannon (1916-2001)

en.wikipedia.org/wiki/Deep_Blue_(chess_computer)

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 draw!
  - DB & GK draw games 3-5
  - Game 6 : 1997-05-11 (May 11th)
    - Kasparov blunders move 7, loses in 19 moves. Loses tournament 3 ½ - 2 ½
    - GK accuses DB of cheating. No rematch.
- Defining moment in AI history

IBM's Deep Blue vs Garry Kasparov

www.cs.berkeley.edu/~ddgarcia/eyawtkagtbwata

What is "Game Theory"?

Combinatorial
- Sprague and Grundy's 1939 Mathematics and Games
- Board games
- Nim, Domineering, dots and boxes
- Film: *Last Year in Marienbad*
- Complete info, alternating moves
- Goal: Last move

Computational
- R. C. Bell's 1988 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: Varies**

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?

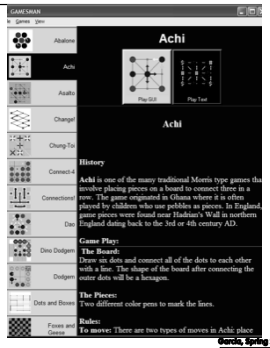
- **No chance, such as dice or shuffled cards**
- **Both players have complete information**
  - No hidden information, as in Stratego & Magic
- **Two players (Left & Right) usually alternate moves**
  - Repeat & skip moves ok
  - Simultaneous moves not ok
- **The game can end in a pattern, capture,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

What's in a Strong Solution

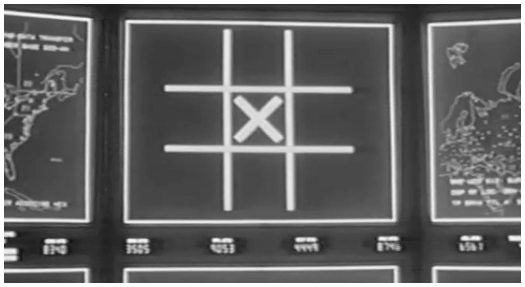
- **For every position**
  - Assuming alternating play
  - Value … (for player whose turn it is)
    - Winning (∃ losing child)
    - Losing (All children winning)
    - Tieing (!∃ losing child, but ∃ tieing child)
    - Drawing (can't force a win or be forced to lose)
  - Remoteness
    - How long before 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



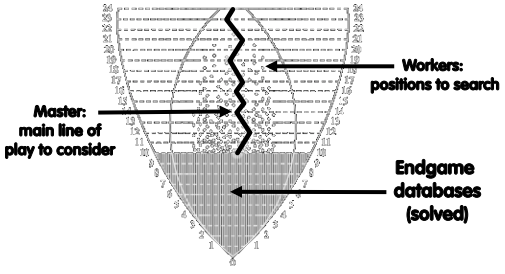
What did you mean "strongly solve"?



Wargames (1983)

Thanks to Jonathan Schaeffer @ U Alberta for this slide…

Weakly Solving A Game (Checkers)



Log of Search Space Size

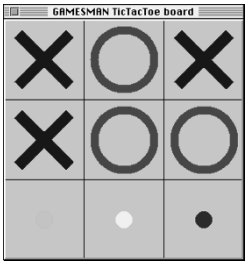
Strong Solving Example: 1,2,…,10

- **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" I WIN!

7 ducks (out of 10)

Example: Tic-Tac-Toe

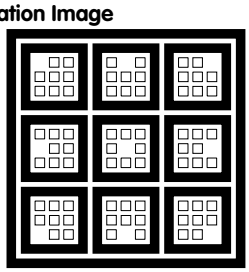
- **Rules (on your turn):**
  - Place your X or O in an empty slot on 3x3 board
- **Goal**
  - If your make 3-in-a-row first in any row / column / diag, win
  - Else if board is full with no 3-in-row, tie
- **Misére is tricky**
  - 3-in-row LOSES
  - Pair up and play now, then swap who goes 1st



Values Visualization for Tic-Tac-Toe

Tic-Tac-Toe Answer Visualized!

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



Misére Tic-Tac-Toe 2-ply Answer

`GamesCrafters.berkeley.edu`

GamesCrafters

- **Undergraduate Computational Game Theory Research Group**
- **300 students since 2001**
  - We now average 20/semester!
  - They work in teams of 2+
- **Most return, take more senior roles (sub-group team leads)**
  - Maximization (bottom-up solve)
  - Oh, DeepaBlue (parallelization)
  - GUI (graphical interface work)
  - Retro (GUI refactoring)
  - Architecture (core)
  - New/ice Games (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!**

`Gamescrafters.berkeley.edu`

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 "ply"
- **One by one, we're going to solve them and/or beat humans**
  - We'll never solve some
    - E.g., hardest game : Go
- **Strongly solving (GamesCrafters)**
  - We visit EVERY position, and know value of EVERY position
  - E.g., Connect 4
- **Weakly solving (Univ Alberta)**
  - We prove game's value by only visiting SOME positions, so we only know value of SOME positions
  - E.g., Checkers

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Go's search space ~ 3^{361}