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
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
  - All chess programs today have his theories at their core
  - His estimate of # of Chess positions called “Shannon #”
    - Now proved < $2^{155} \sim 10^{46.7}$
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
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

- **Achi** is one of the many traditional Morris type games that involve placing pieces on a board to connect three in a row. The game originated in Ghana where it is often played by children who use pebbles as pieces. In England, game pieces were found near Hadrian's Wall in northern England dating back to the 3rd or 4th century AD.
What did you mean “strongly solve”? 

Wargames (1983)
Peer Instruction

1. Every year computer power (speed, storage) is growing exponentially, so eventually they’ll be able to strongly solve the world’s board games.

2. I’m happy when a game is strongly solved.

   a) FF
   b) FT
   c) TF
   d) TT
Weakly Solving A Game (Checkers)

Log of Search Space Size

Master: main line of play to consider

Workers: positions to search

Endgame databases (solved)
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!
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

- **Misère is tricky**
  - 3-in-row LOSES
  - Pair up and play now, then swap who goes 1st
Tic-Tac-Toe Answer Visualized!

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

Misère Tic-Tac-Toe 2-ply Answer
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)

Garcia, Spring 2011
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 “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

Strongly solving arguments:

- E.g., Go: 17408965065903192790718
- 8238070564367946602724
- 950263541194828118706801
- 05167618464984116279288
- 98871493861209698881632
- 07806137549871813550931
- 2951480336966057289307
- 5468180597603

Go’s search space $\sim 3^{361}$