UC Berkeley EECS
Lecturer SOE
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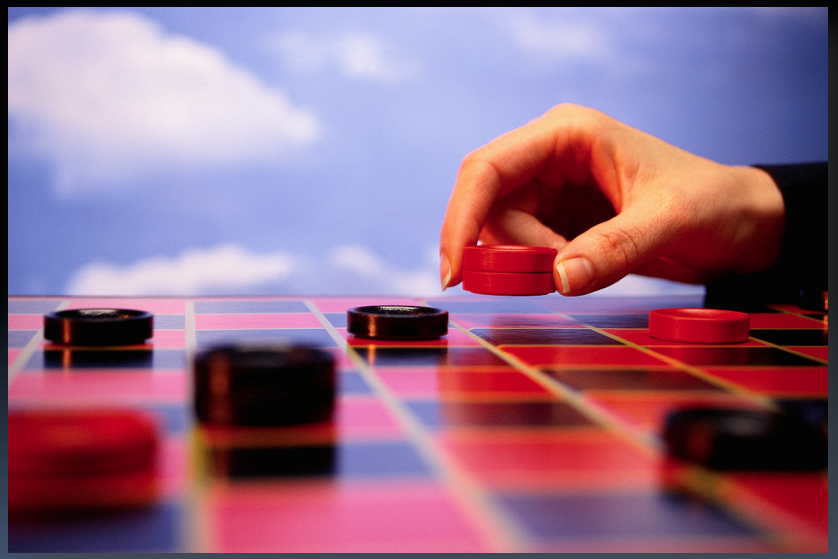
CS10
The Beauty and Joy of Computing

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/

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**

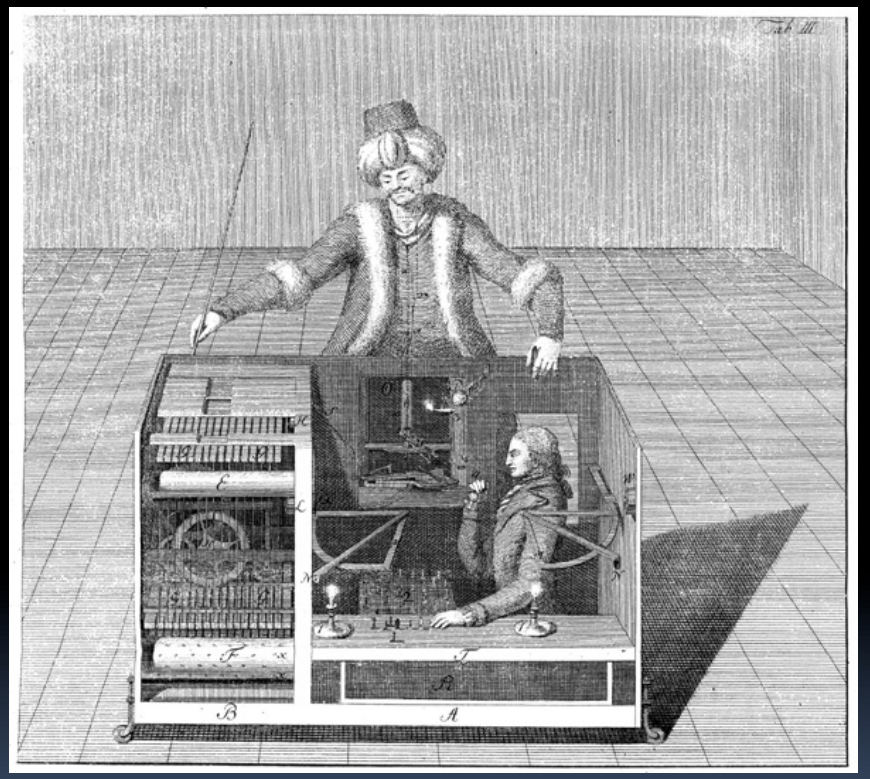
Computer Science … A UCB view

- **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
  - …

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 $< 2^{155} \sim 10^{46.7}$

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

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

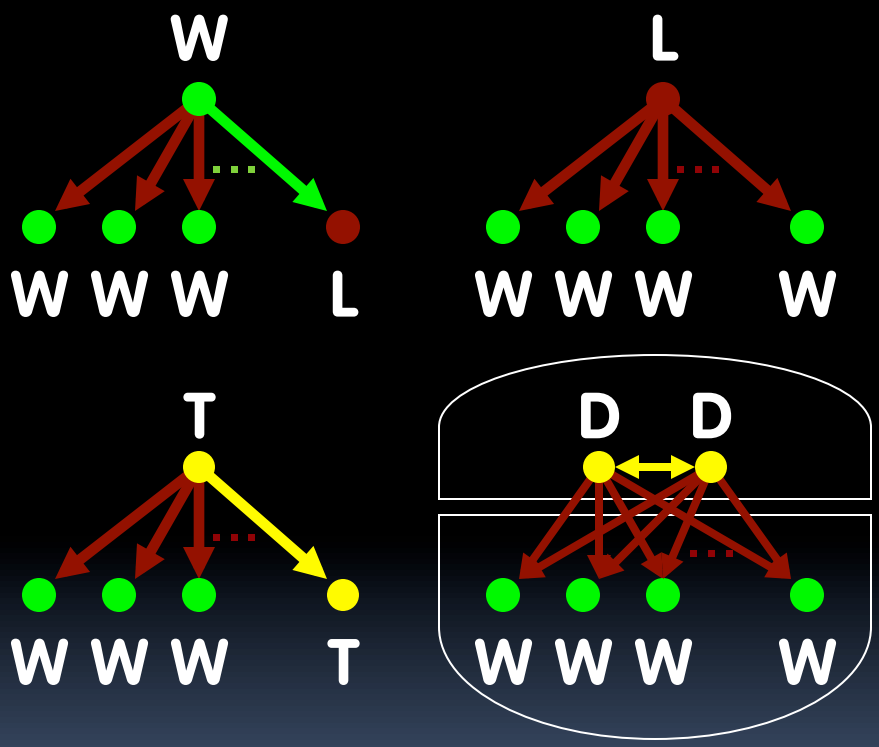
- von Neumann and Morgenstern's 1944 *Theory of Games and Economic Behavior*
- Matrix games
- Prisoner's dilemma, auctions
- Film : *A Beautiful Mind* (about John Nash)
- **Incomplete** info, simultaneous moves
- Goal: Maximize payoff

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 …

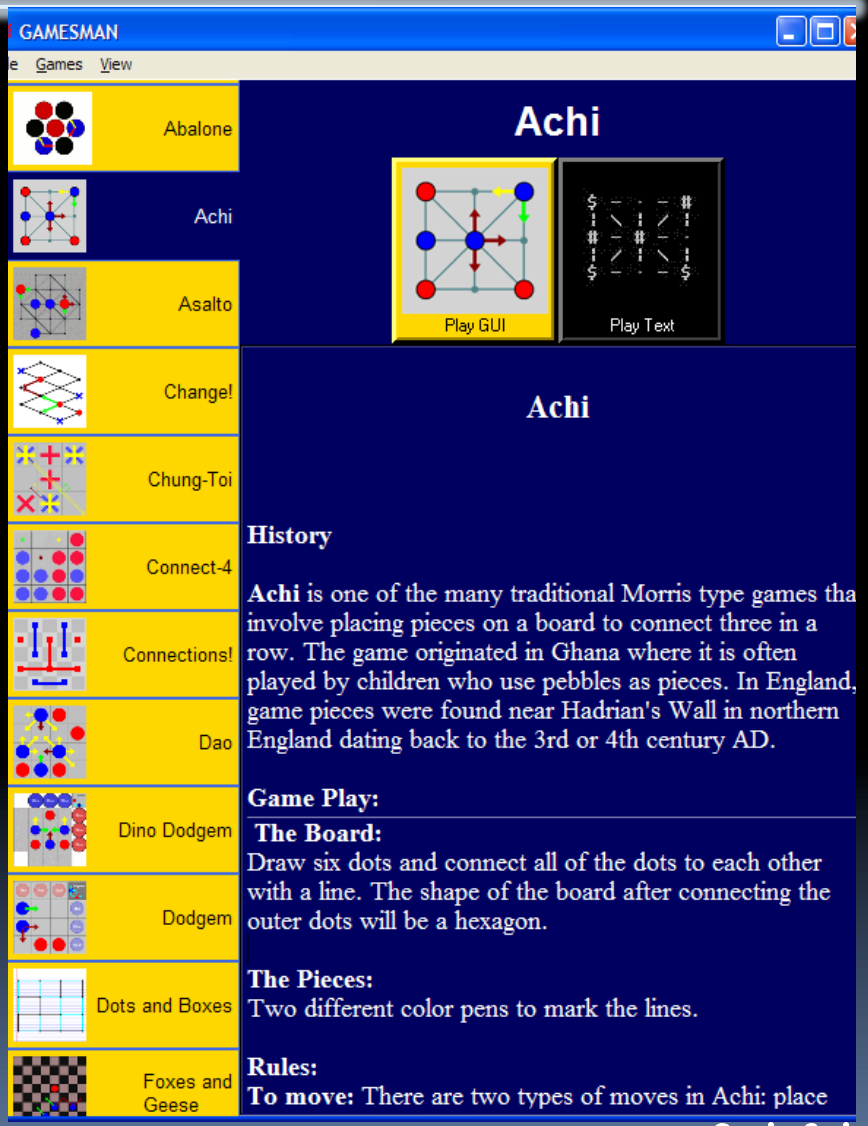
What's in a Strong Solution

- **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?

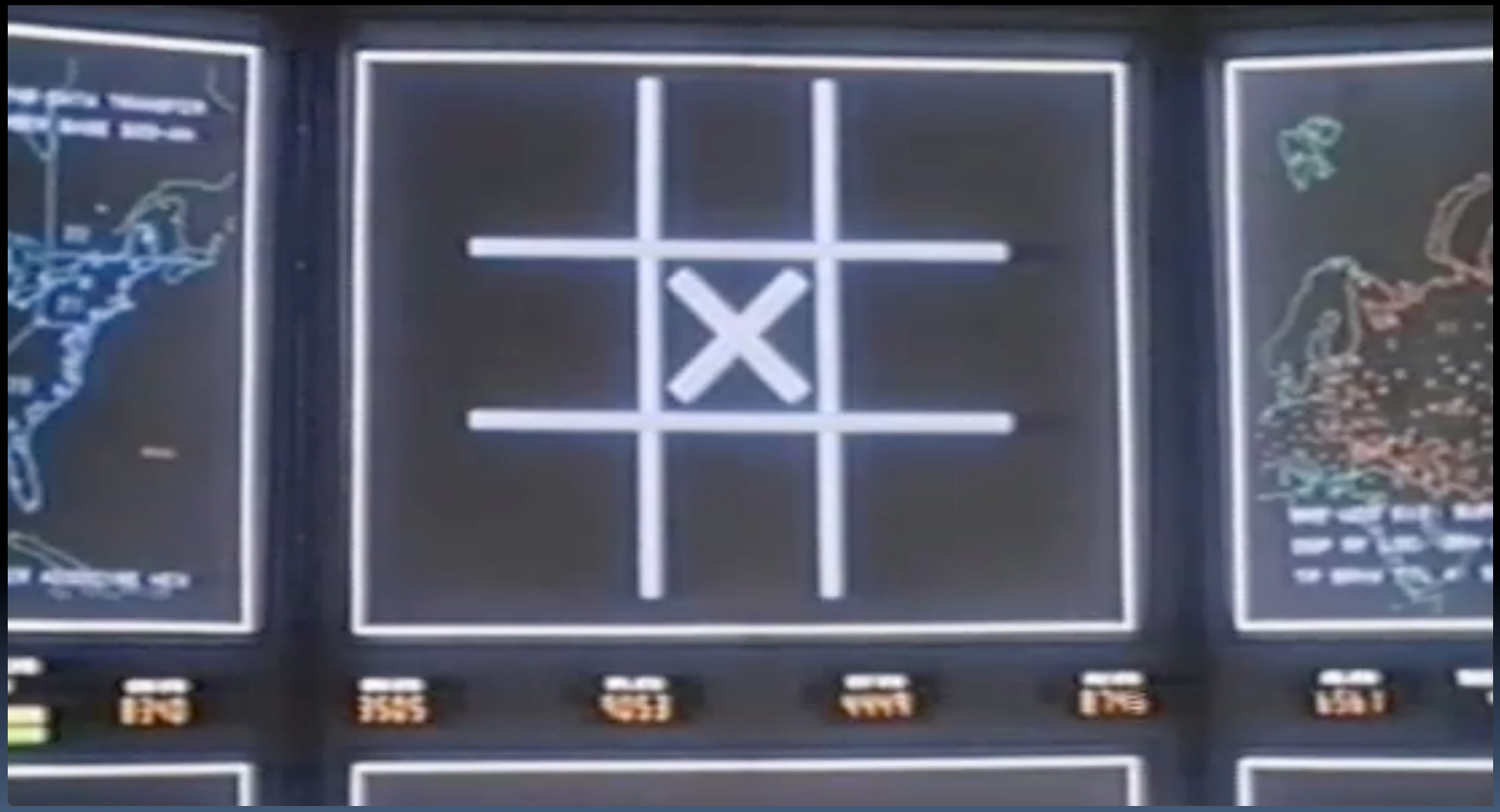


GamesCrafters

- **We <u>strongly solve</u> 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)

Peer Instruction

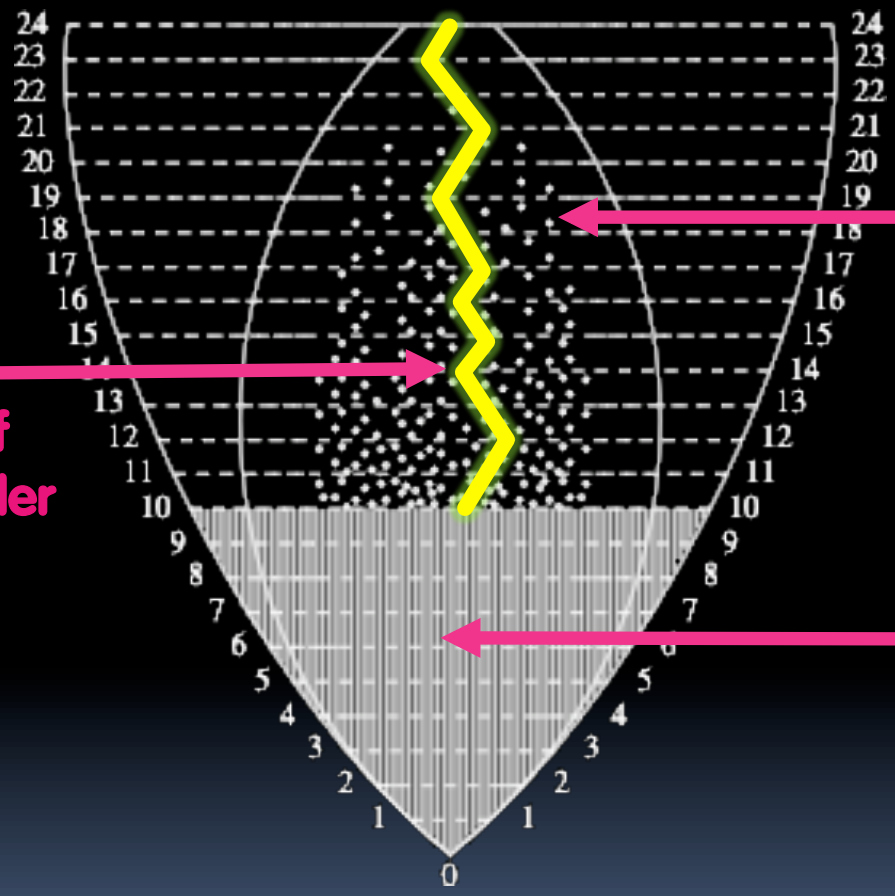
1. Every year computer power (speed, storage) is growing exponentially, so eventually they'll be able to strongly solve the world's board games.

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

	12
a)	FF
b)	FT
c)	TF
d)	TT

Thanks to Jonathan Schaeffer @ U Alberta for this slide…

Weakly Solving A Game (Checkers)



Workers: positions to search

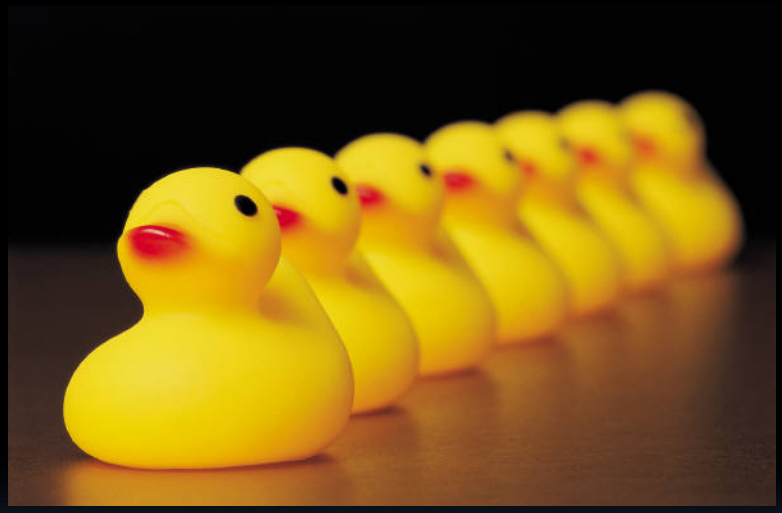
Master: main line of play to consider

Endgame databases (solved)

Log of Search Space Size

Strong Solving Example: 1,2,…,10

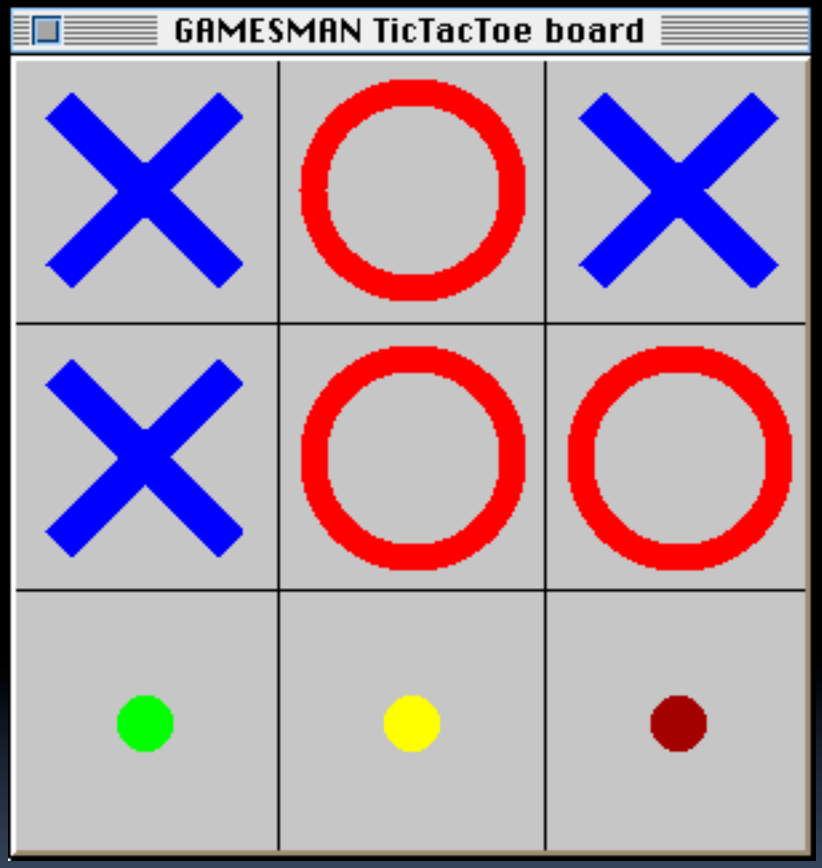
- **Rules (on your turn):**
  - Running total = 0
- **Rules (on your turn):**
  - Add 1 or 2 to running total
- **Goal**
  - Be the FIRST to get to 10
- **Example**
  - Ana: "2 to make it 2"
  - Bob: "1 to make it 3"
  - Ana: "2 to make it 5"
  - Bob: "2 to make it 7" → photo
  - Ana: "1 to make it 8"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



7 ducks (out of 10)

Example: Tic-Tac-Toe

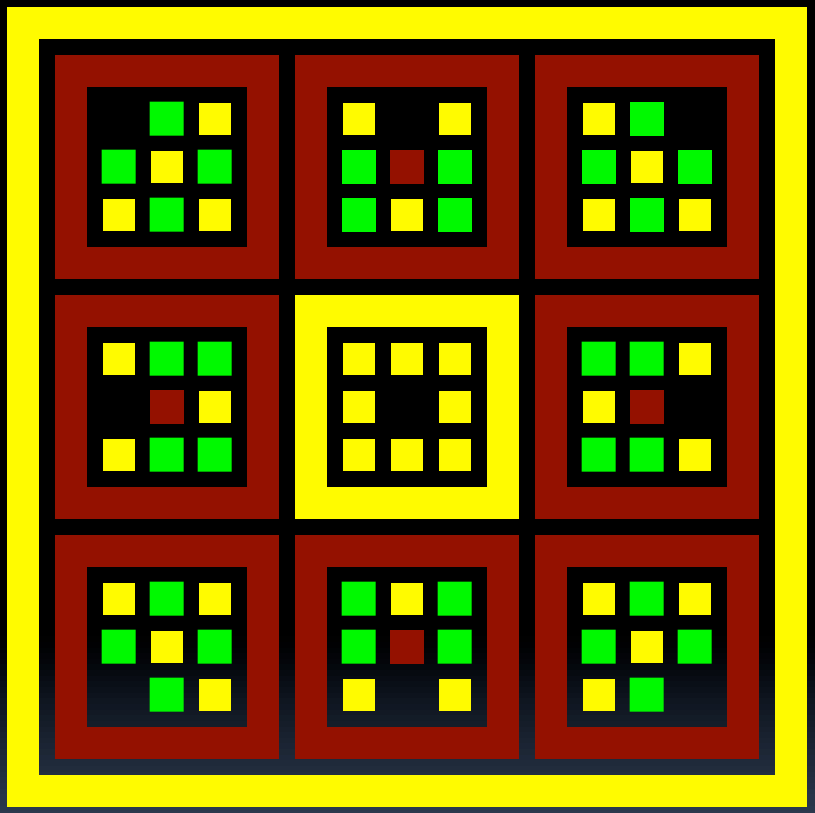
- **Rules (on your turn):**
  - Place your X or O in an empty slot on 3x3 board
- **Goal**
  - If your make 3-in-a-row first in any row / column / diag, win
  - Else if board is full with no 3-in-row, tie
- **Misére is tricky**
  - 3-in-row LOSES
  - Pair up and play now, then swap who goes 1st



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!

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

174089650659031927907188238070564367946602724950263541194828118706801051676184649841162792889887149386120969888163207806137549871813550931295148033696605728930754681805976603

Go's search space ~ 3^{361}