CS10 : The Beauty and Joy of Computing

Lecture #16 : Computational Game Theory

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Summer Instructor
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CHECKERS SOLVED!

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…
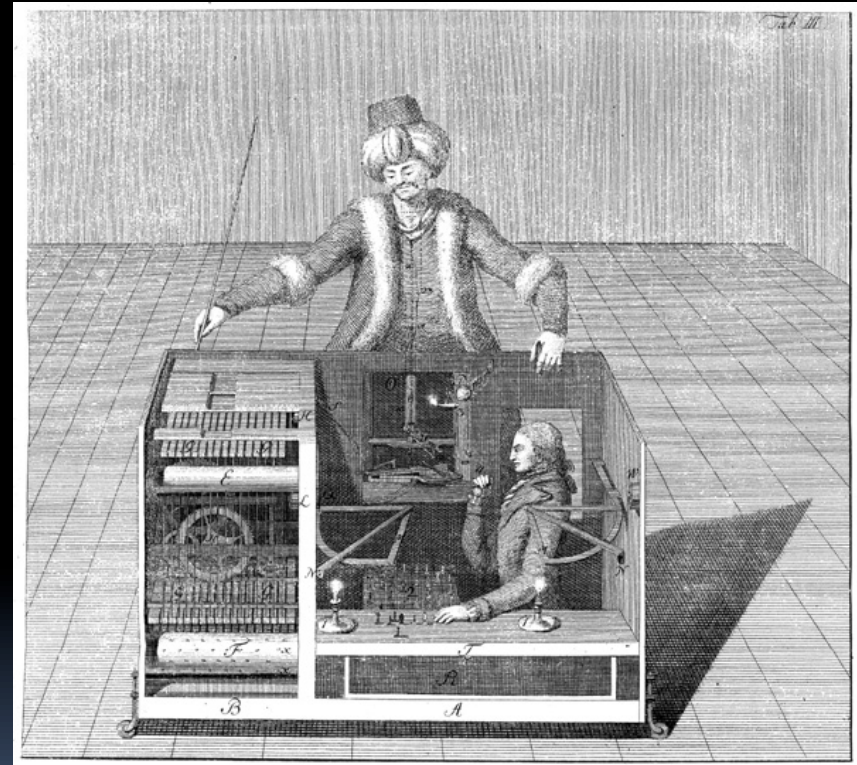
The Mechanical Turk (1770)

Claude Shannon's Paper (1950)

- **"Father of Information Theory"**
  - Digital computer and digital circuit design theory
  - 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 $< 2^{155} \sim 10^{46.7}$

Claude Shannon (1916-2001)

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

You Tube
Broadcast Yourself ™   Home Videos Channels Shows   Search

Deep Blue beat G. Kasparov in 1997

ENDGAME
CHALLENGING THE MASTERS

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 or 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)
    - 🟢 <u>Winning</u> (∃ losing child)
    - 🔴 <u>Losing</u> (All children winning)
    - 🟡 <u>Tieing</u> (!∃ losing child, but ∃ tieing child)
    - 🟡 <u>Drawing</u> (can't force a win or be forced to lose)
  - Remoteness
    - How long before game ends?

W

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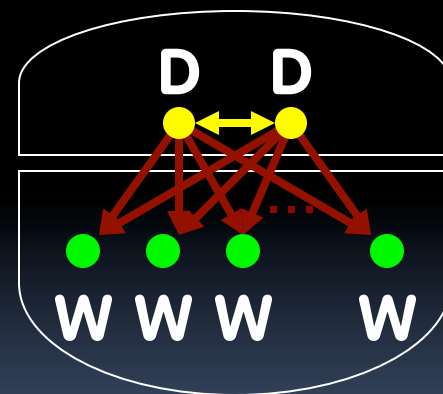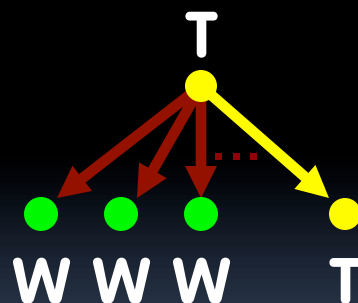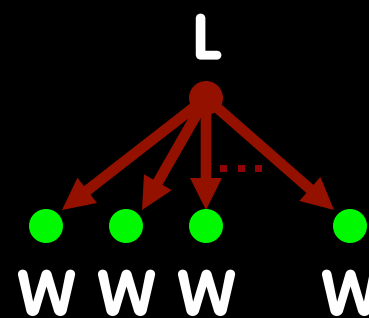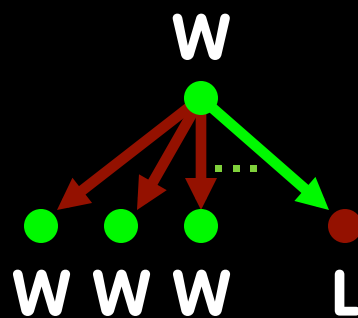
GamesCrafters

- **A groups that <u>strongly solves</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"?
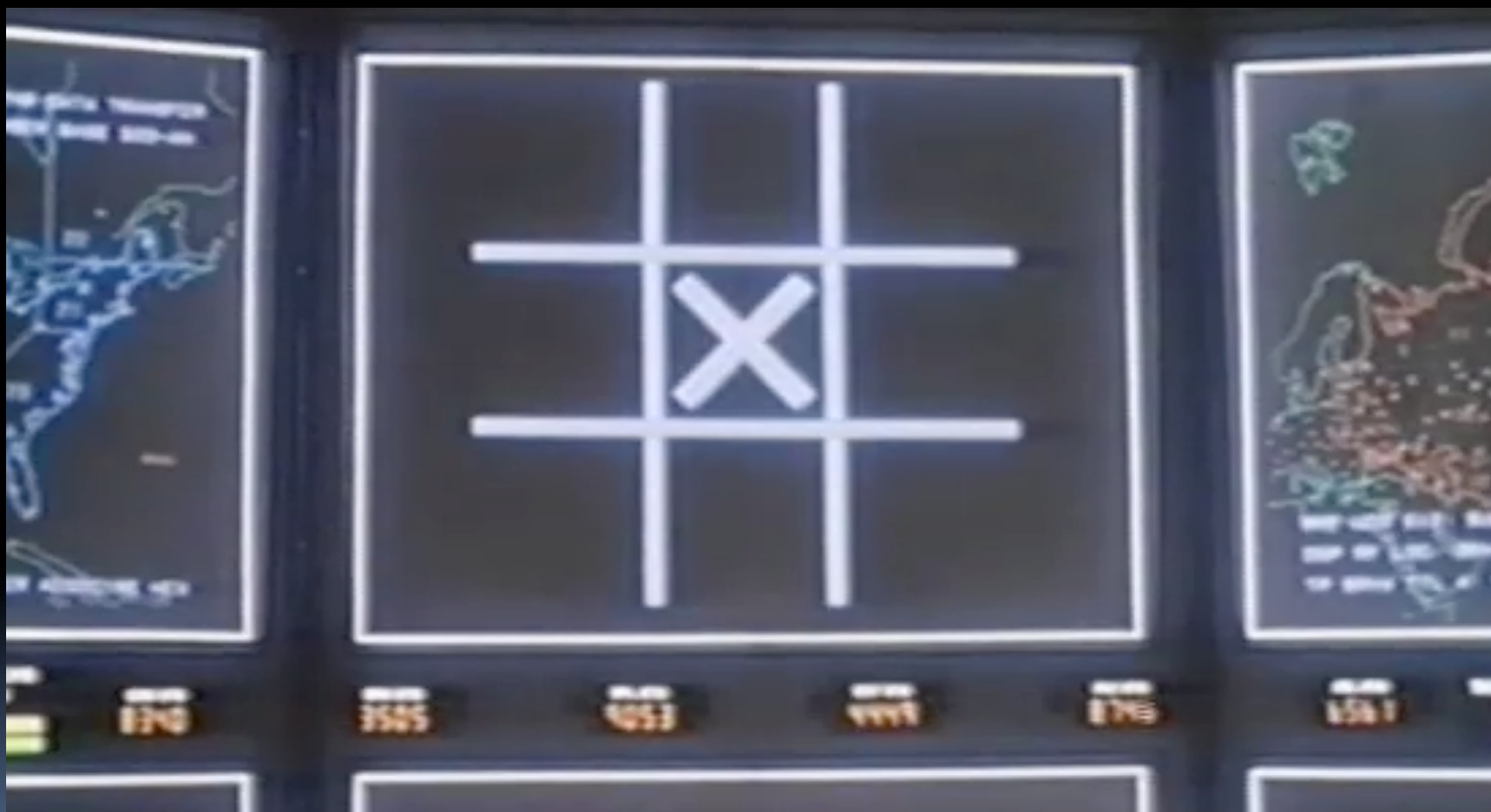
Wargames (1983)

Weakly Solving A Game (Checkers)

Workers:
positions to search

Master:
main line of
play to consider

Endgame
databases
(solved)
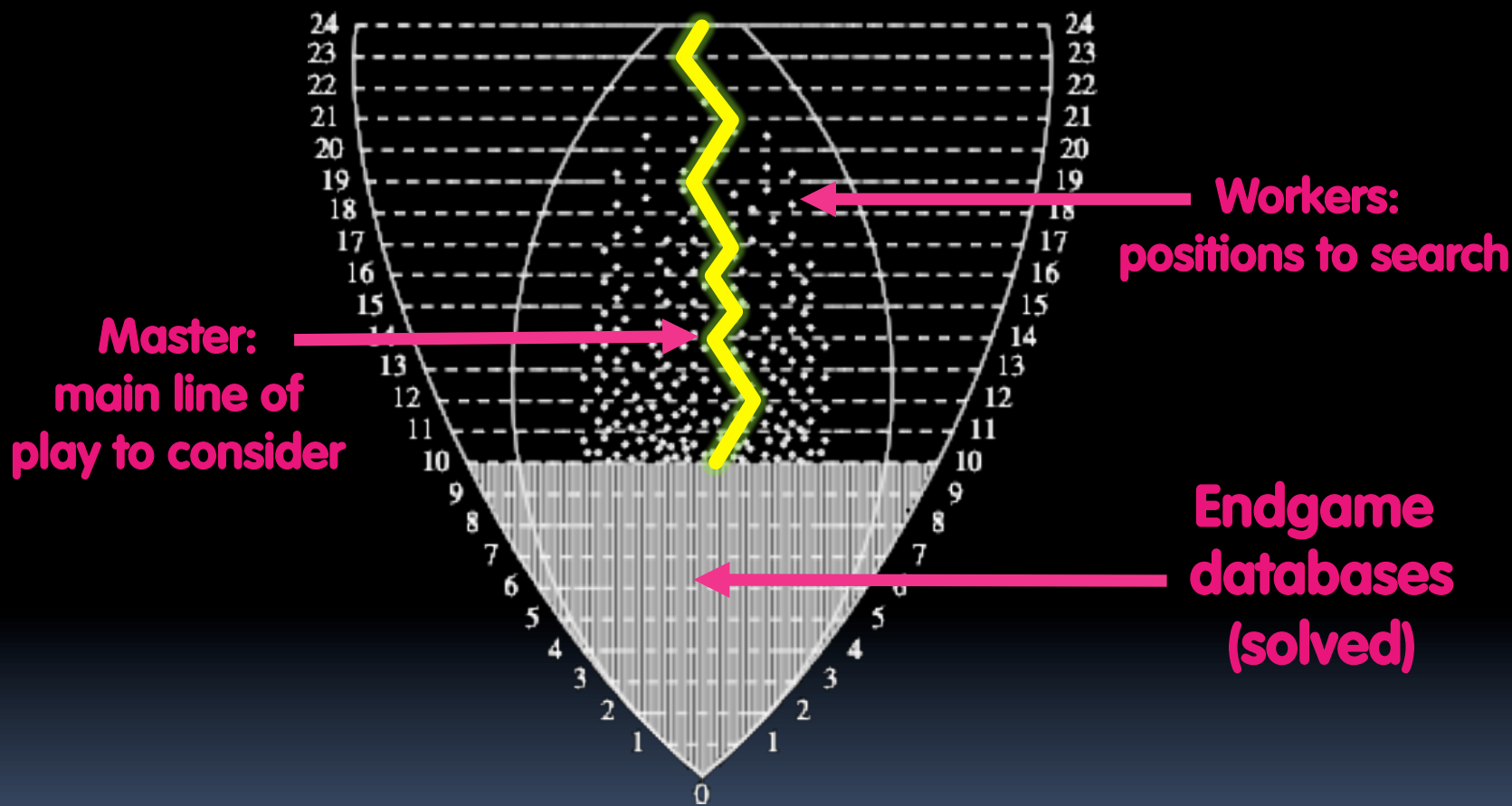
Log of Search Space Size

Strong Solving Example: 1,2,…,10

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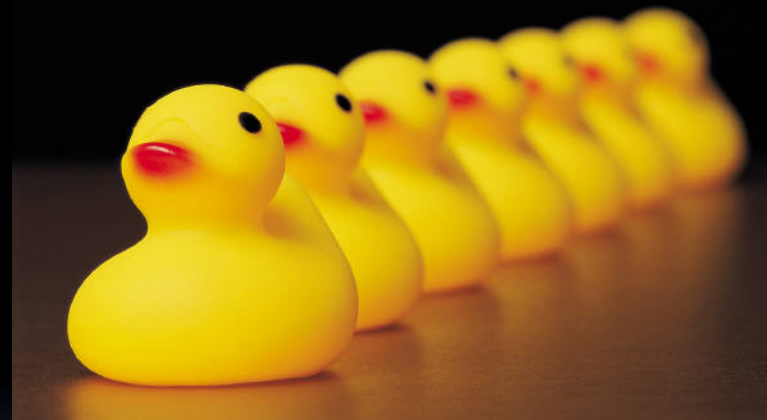- **Rules (on your turn):**
  - Add 1 or 2 to running total
- **Goal**
  - Be the FIRST to get to 10
- **Example**
  - Ana: "2 to make it 2"
  - Bob: "1 to make it 3"
  - Ana: "2 to make it 5"
  - Bob: "2 to make it 7" → photo
  - Ana: "1 to make it 8"
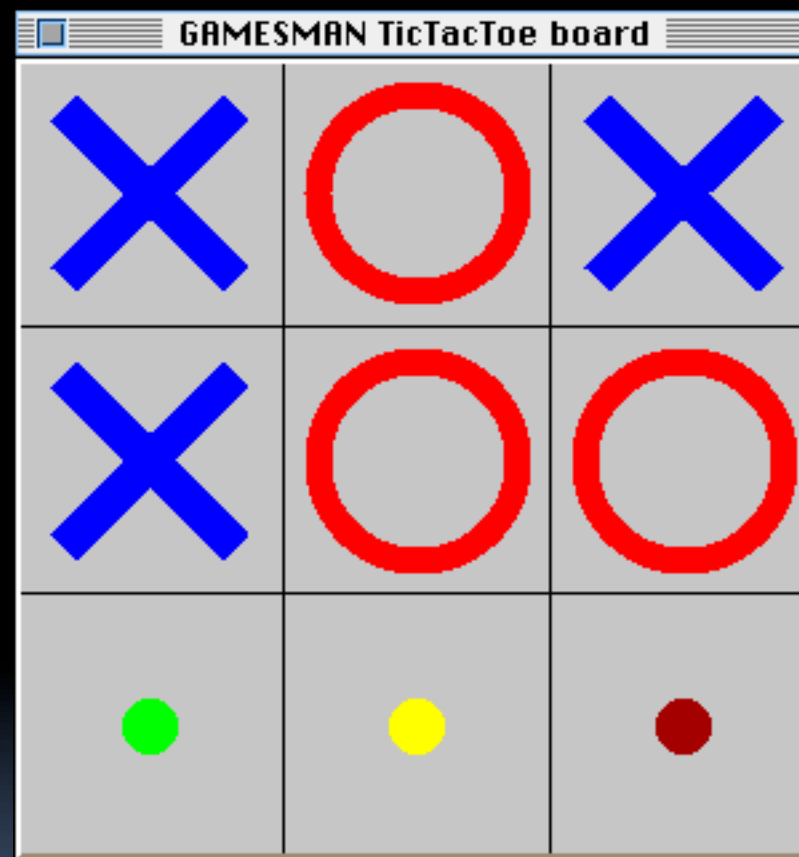 - Bob: "2 to make it 10" I WIN!

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 <u>first</u> 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

GAMESMAN TicTacToe board
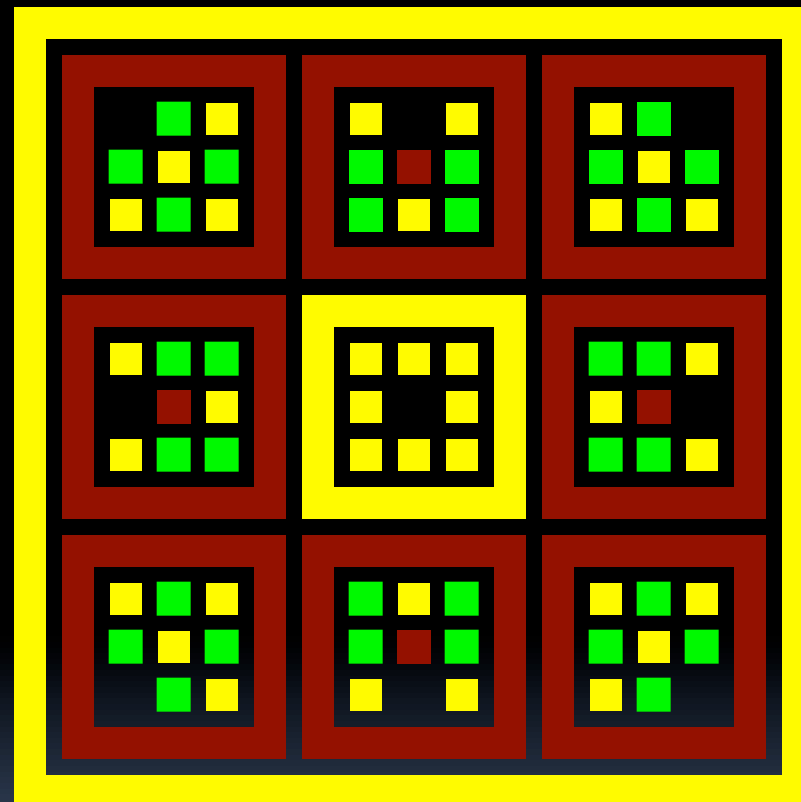
Values Visualization for Tic-Tac-Toe

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 (revisited)

- **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!

- **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 <u>prove</u> game's value by only visiting SOME positions, so we only know value of SOME positions
  - E.g., Checkers

17408965065903192790718
82380705643679466027249
50263541194828118706801
05167618464984116279288
98871493861209698881632
07806137549871813550931
29514803369660572893075
468180597603

Go's search space ~ 3^{361}