



UC Berkeley EECS
Lecturer SOE
Dan Garcia

Form a learning community!

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!

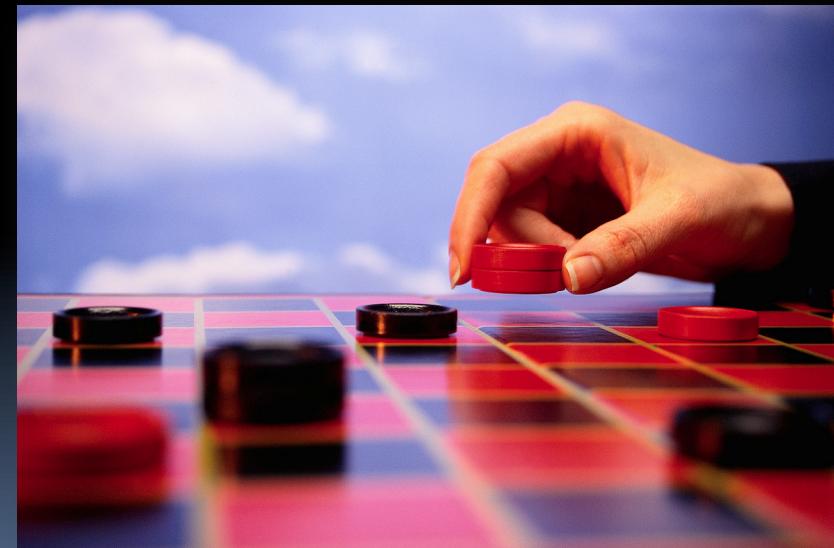
CS10 : The Beauty and Joy of Computing

Lecture #16 : Computational Game Theory

2012-03-12



Summer courses (CS61A, CS70) avail



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

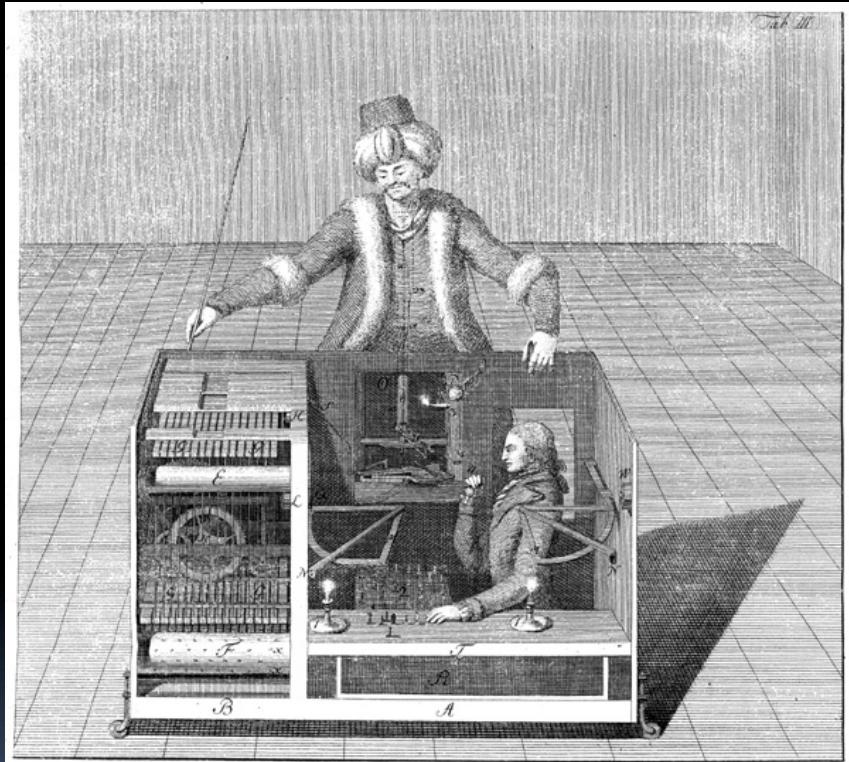
- CS research areas:

- 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)

- 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)



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



Garcia, Spring 2012



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?

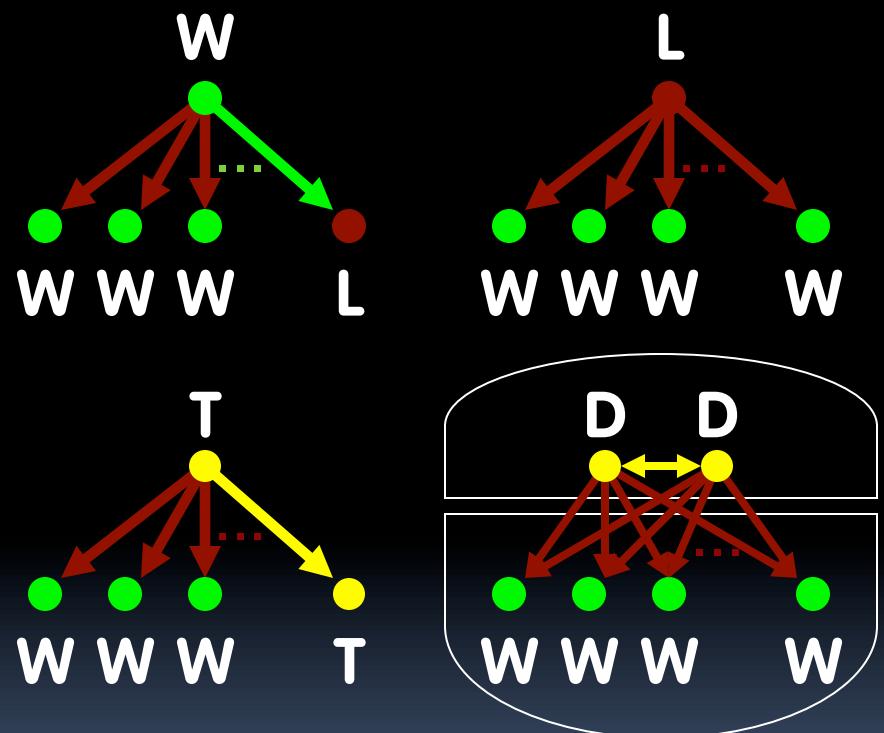
- No chance, such as dice or shuffled cards
- Both players have **complete information**
 - No hidden information, as in Stratego & Magic
- Two players (Left & Right) usually alternate moves
 - Repeat & skip moves ok
 - Simultaneous moves not ok
- The game can end in a pattern, capture, by the absence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



What's in a Strong Solution

- **For every position**

- Assuming alternating play
- Value ...
(for player whose turn it is)
 - Winning (\exists losing child)
 - Losing (All children winning)
 - Tieing (\nexists losing child, but \exists 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

The screenshot shows the GamesCrafters software interface. On the left, a vertical sidebar lists various games: Abalone, Achi, Asalto, Changel, Chung-Toi, Connect-4, Connections!, Dao, Dino Dodgem, Dodgem, Dots and Boxes, and Foxes and Geese. The main area is titled "Achi" and displays a 6x6 board with red and blue pieces. A "Play GUI" button is visible. To the right, there is a "History" section with a detailed description of Achi, a "Game Play" section with instructions for the board, pieces, and rules, and a "Rules" section with specific moves for Achi.

Achi

History

Achi

History

Game Play:

The Board:
Draw six dots and connect all of the dots to each other with a line. The shape of the board after connecting the outer dots will be a hexagon.

The Pieces:
Two different color pens to mark the lines.

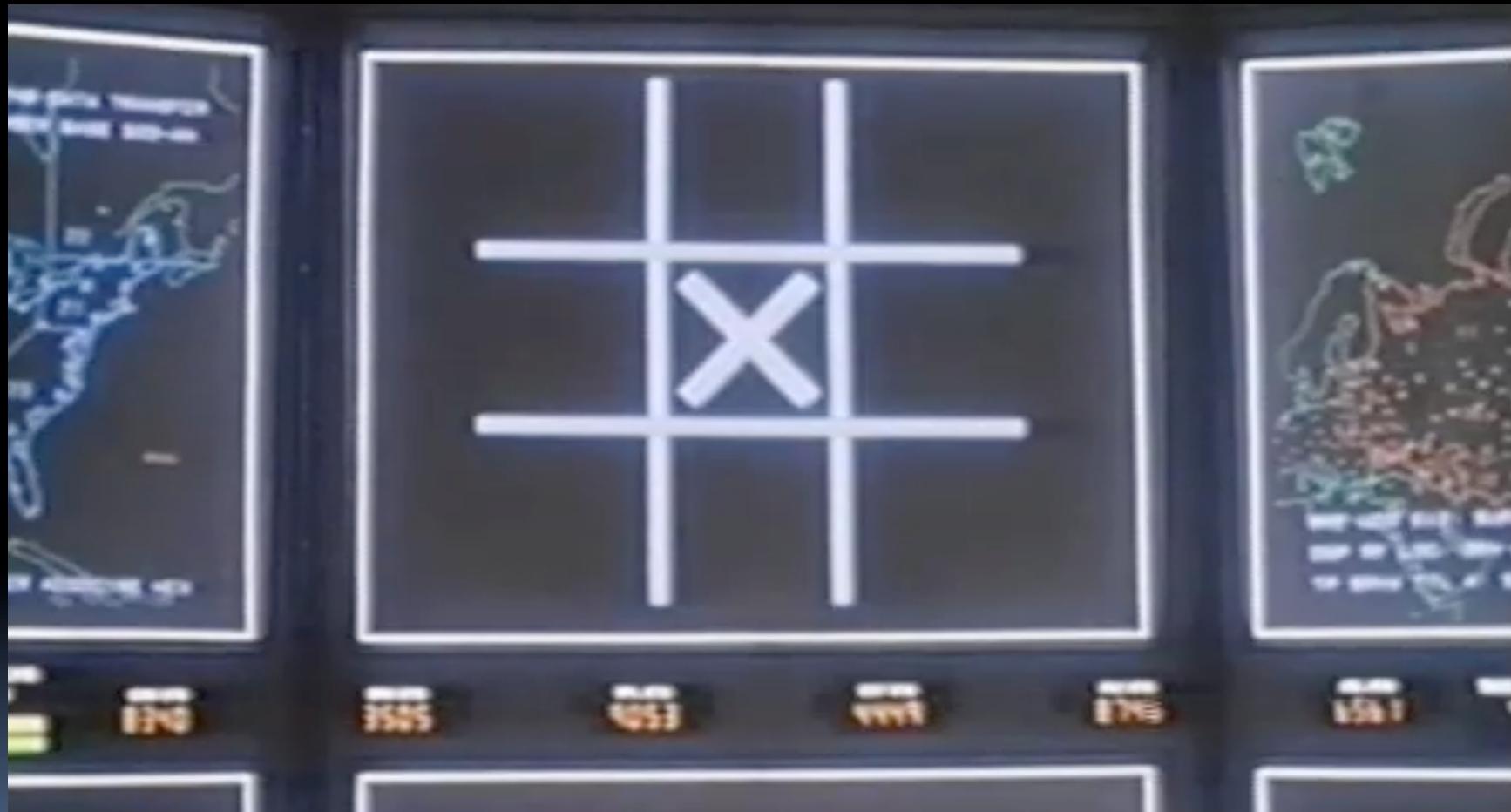
Rules:
To move: There are two types of moves in Achi: place





<http://youtu.be/NHWj1CaIrQo>

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

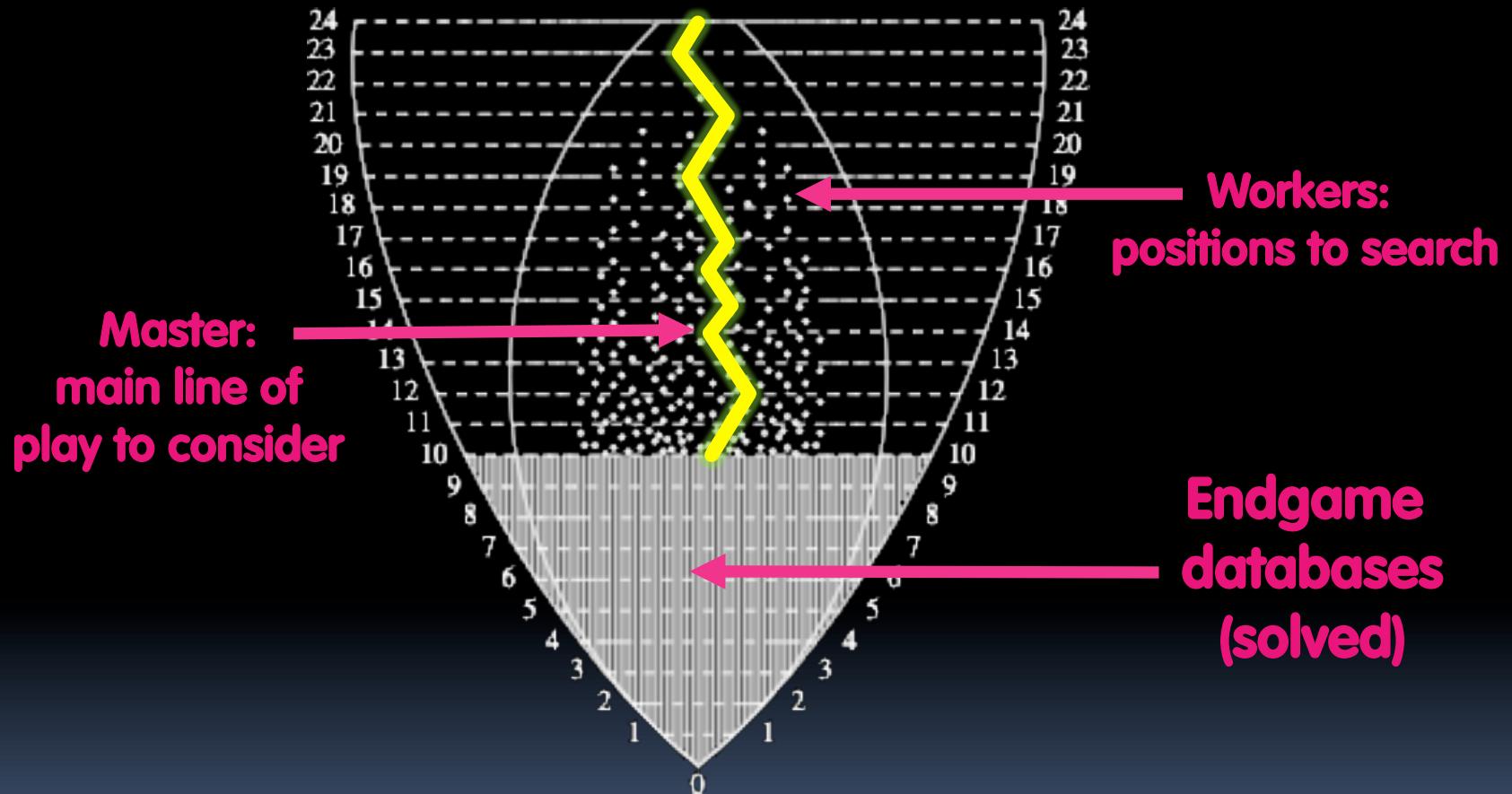
c) TF

d) TT

The English grandmaster Nigel Short says that chess computers, which now regularly beat the top human players, are taking away some of the mystery of the game. He likens them to “chainsaws chopping down the Amazon.”



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!

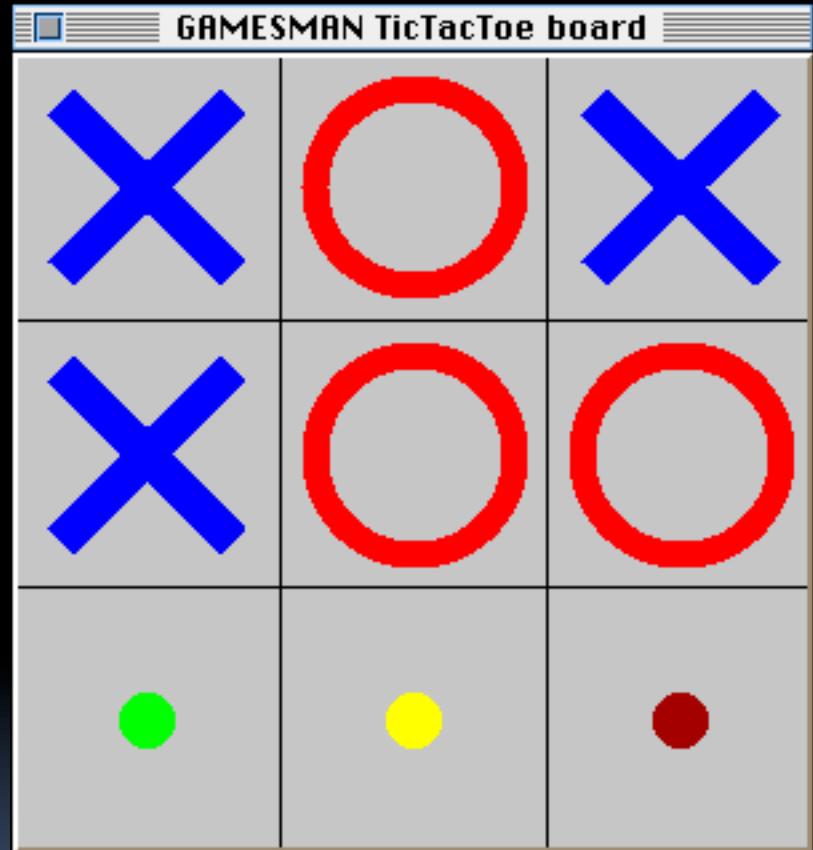


7 ducks (out of 10)



Example: Tic-Tac-Toe

- **Rules (on your turn):**
 - Place your X or O in an empty slot on 3x3 board
- **Goal**
 - If you 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



Values Visualization for Tic-Tac-Toe



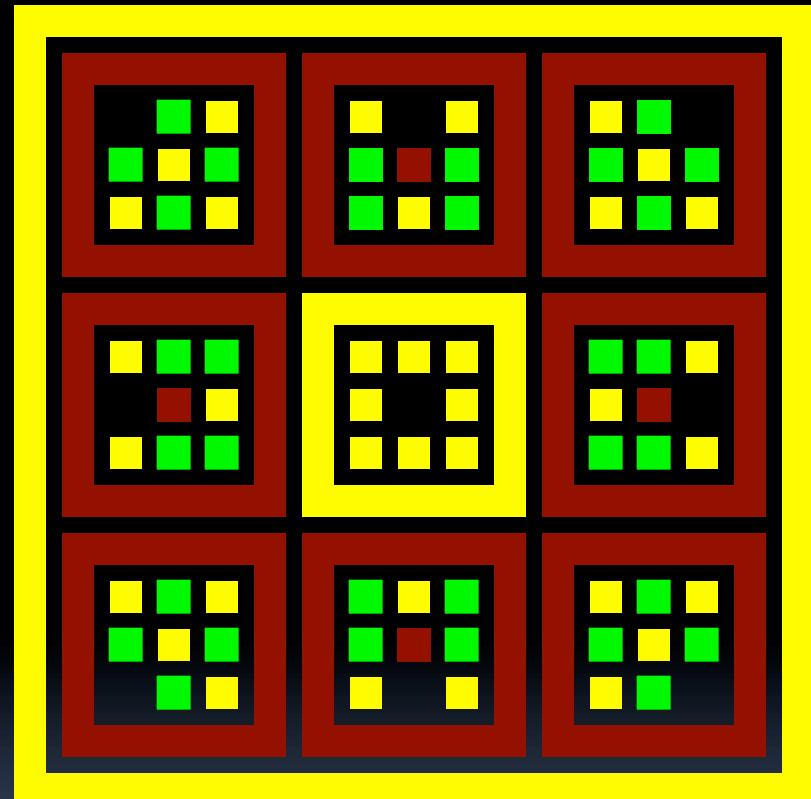


Tic-Tac-Toe Answer Visualized!

- Recursive Values Visualization Image

- Misérable Tic-tac-toe

- Outer rim is position
- Inner levels moves
- Legend
 - Lose
 - Tie
 - Win



Misérable 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!

- 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

17408965065903192790718
 8238070564367946602724
 950263541194828118706801
 05167618464984116279288
 98871493861209698881632
 07806137549871813550931
 2951480336966057289307
 5468180597603

Go’s search space $\sim 3^{361}$

