

General Game Learning

Matthew Fisher

What is general game learning?

Learning to play games you have never seen

- Reading or listening to the rules
- Asking questions about the rules
- Learning the rules by playing (ex. Tetris)
- Figuring out the objective
- Being reprimanded for making illegal moves
- Learning from mistakes
- Deciding on good strategies
 - The focus of 99% of game AI research

Goal of this talk

Convince you that general game learning is:

- Important
- Interesting
- Possible

Why is GGL specifically interesting?

Task Automation

- Automating real tasks is a big AI goal (folding clothes, driving cars, SQL-injection attacks)
 - manually code specialized controllers for each task
 - have controllers that can learn a task from examples
- Real tasks are hard to setup and evaluate
- Digital games are plentiful, complex, accessible to a computer, and easily evaluated
- To a computer there is no difference between the real world and a good simulation

Games

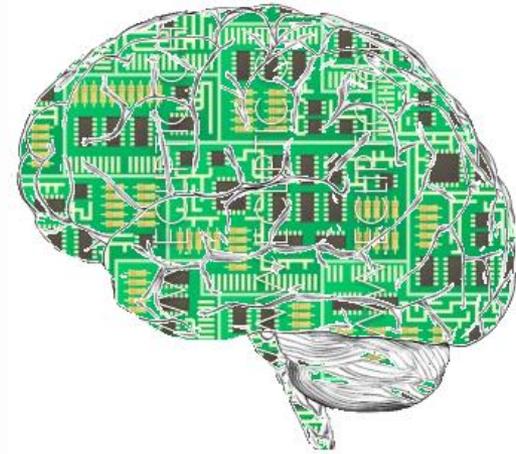
Why are games a great task?

- Games have a clear goal that can be quantified
- Games are challenging to understand
 - Games require complex reasoning
 - Games require often incomplete rule-learning
- **Digital games are fully accessible to computers**
- Games are one way humans and computers interact
- Games are fun and popular
 - Deep Blue, Watson
- **The dataset of available games is huge and untapped**

We will use digital games to study...

- **Unsupervised** object segmentation and categorization
- Rule learning
- Knowledge transfer between categories
 - Between Mario & Luigi
- Goal inference
- Game state value estimation
- Action planning
- Knowledge transfer between games
 - Between Super Mario 1 and Super Mario 3
 - Between Shogi and Chess

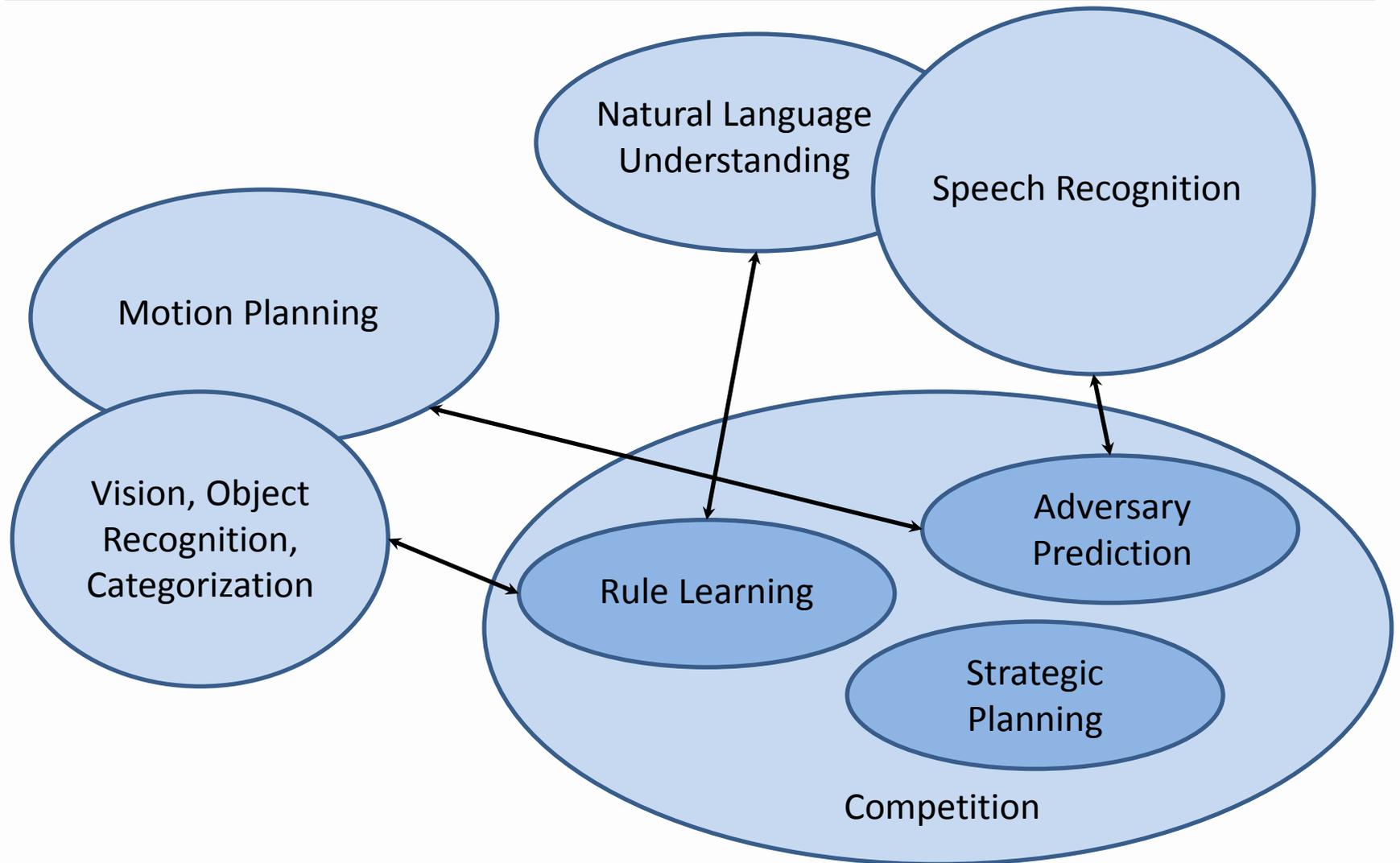
Artificial intelligence



Goal is to solve problems



Problem Space (Humans)



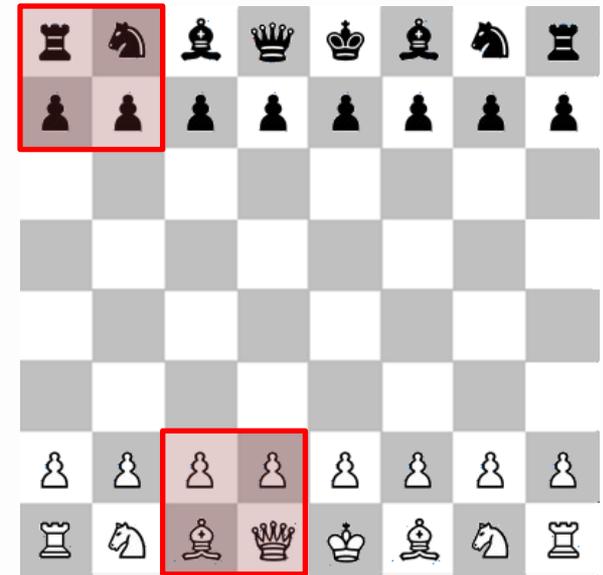
(Some) Tasks in General Learning

- Define meaningful internal representation
 - Categorize, classify, and learn from raw data
- Process raw signal
- Map raw signal onto internal representation
- Solve problem using the internal representation
- Map solution to an action and execute it

Representation is everything

Trying to learn rules without a good representation is impossible

- Imagine trying to learn the rules of Chess at the level of pixels or 2x2 blocks
- We can guess that one representation is better than another if it is easier to learn rules about how the environment behaves using the representation

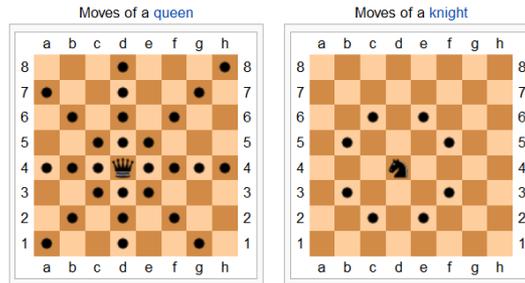


Real-world General Game Learning

Human Game Learning Process



The image shows a screenshot of the Wikipedia article for "Chess". At the top, there is a banner with the Wikipedia logo and the text "Please note: In less than 10 hours, the English Wikipedia will be... Learn more". Below this, the article title "Chess" is displayed, followed by a sub-header "From Wikipedia, the free encyclopedia". A note states: "This article is about the Western board game. For other chess games or other uses, see Chess (disambiguation)." The main text begins with "Chess is a two-player board game played on a chessboard, a square-checkered board with 64 squares arranged in an eight-by-eight grid. It is one of the world's most popular games, played by millions of people worldwide at home, in clubs, online, by correspondence, and in tournaments." To the right of the text is an image of chess pieces. On the left side of the screenshot, there is a navigation menu with links like "Main page", "Contents", "Featured content", "Current events", "Random article", "Donate to Wikipedia", "Interaction", "Help", "About Wikipedia", "Community portal", "Recent changes", "Contact Wikipedia", "Toolbox", "Print/export", and "Languages".



Rule Learning



Strategic Planning

Natural Language Understanding



Learning from Mistakes



Object Categorization and Recognition (Vision)



Conversation

Real-world Game Learning

Research is bottlenecked by

- 3D object segmentation and categorization
- 3D environment reconstruction
- Natural language processing

Human game learning in the physical world still provides us with useful insights

- Constructing a good representation for rule learning and action planning is rarely challenging to humans

Existing Game Research

Game AI Research

An AI that plays Chess well is only the summit of Mount Everest

- It assumes that you already have a perfect game representation and understanding of the rules that define this representation

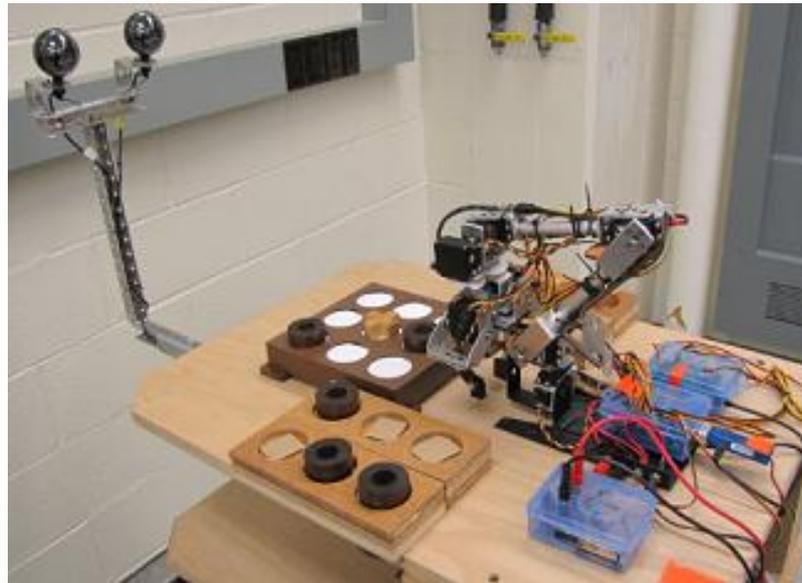
General Game Playing (Michael Genesereth) generalizes learning strategy across games but ignores learning the game representation

Forcing General Game Learning

A few people have tried general game learning

- Dramatically reduce space of games under consideration (ex. RPS, TTT variants)
- Manually teach system all relevant categories and train classifiers for them
 - the largest number of categories that has been successfully used is 3
- Focus is on robots interacting with humans, not so much on game learning

State of the art (2011)



- People have taught robots to observe two entities playing tic-tac-toe or rock-papers-scissors in contrived settings and then attempt to play these games

Digital-world General Game Learning

What games

Many different types of games

- Real-time (Mario) vs. turn-based (Reversi)
- Discrete (Tetris) vs. continuous (Space Invaders)
- Complete information (FreeCell) vs. incomplete information (Poker)
- Single player (Zelda) vs. competitive (Chess)

For now, focus is on 2D, sprite-based games



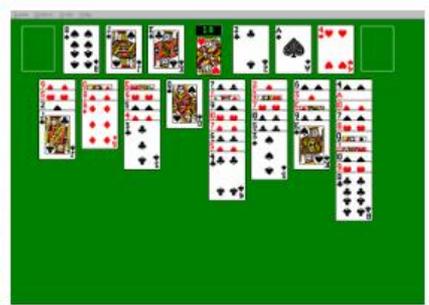
Bejeweled



Mahjong Solitaire



Peg Solitaire



FreeCell



Settlers of Catan



Pandemic



Braid



VVVVVV



Poker



Warcraft II: Tides of Darkness



SimCity 2000



The Sims



Eternal Champions



Final Fantasy 3



Megaman X



Metal Slug 3

(One Possible) General Game Learning Pipeline

Inputs

AI gets a video feed of the game

AI can take actions as if it were a human (ex. with the keyboard, mouse, or game controller)

AI may have access to: (semi-supervised)

- Human playthroughs of the game
- Partial annotations of playthroughs denoting specific objectives (ex. “reach the final boss”, “don’t die”)

Pipeline Strategy

Construct many possible representations

- Each segmentation of the input video feed leads to different symbolic representations
- Attempt to learn rules on each symbolic representation independently
- The representation which leads to the simplest rules and best predicts future states of the game is the best representation

Game Learning Pipeline

- Map video feed of the game onto a candidate symbolic representation
- Decide what kind of actions are possible
- Learn a model for how symbolic representation evolves as a function of the action taken
- Determine the goal of the game
- Plan actions that accomplish the goal

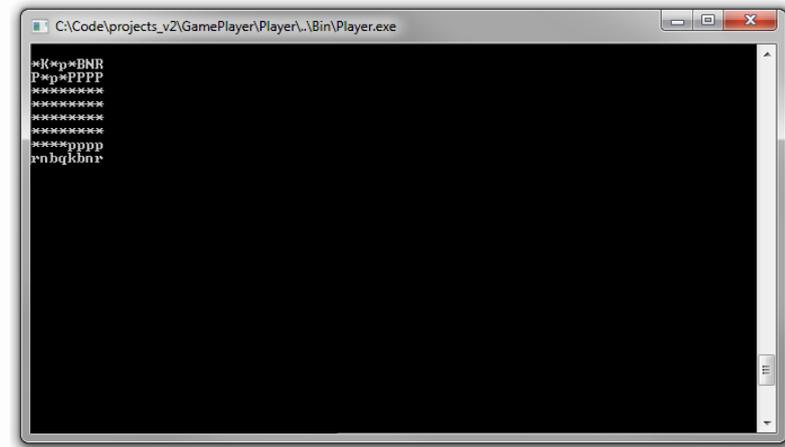
Specializing for a given game is “easy” – our focus is on generalizing learning across games

Pipeline Example: Chess Titans



1. Map to symbolic representation

Observable State



+

Hidden Variables

WhitePlayer has control

The black rooks and black king have not moved

No En passant is possible

...

2. What actions are possible



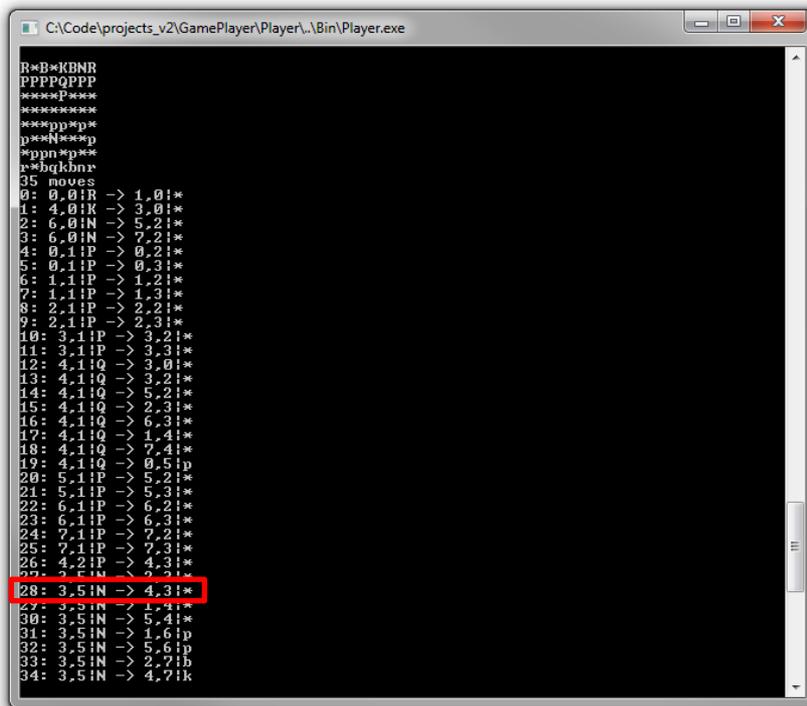
Physical Actions



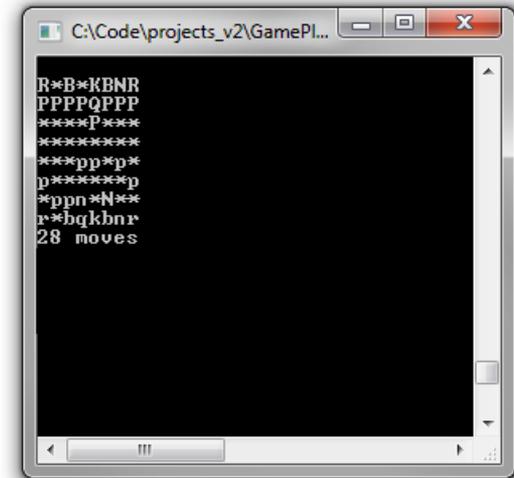
Symbolic Actions

3. What rules govern the game

How does the game state evolve in response to actions and time?

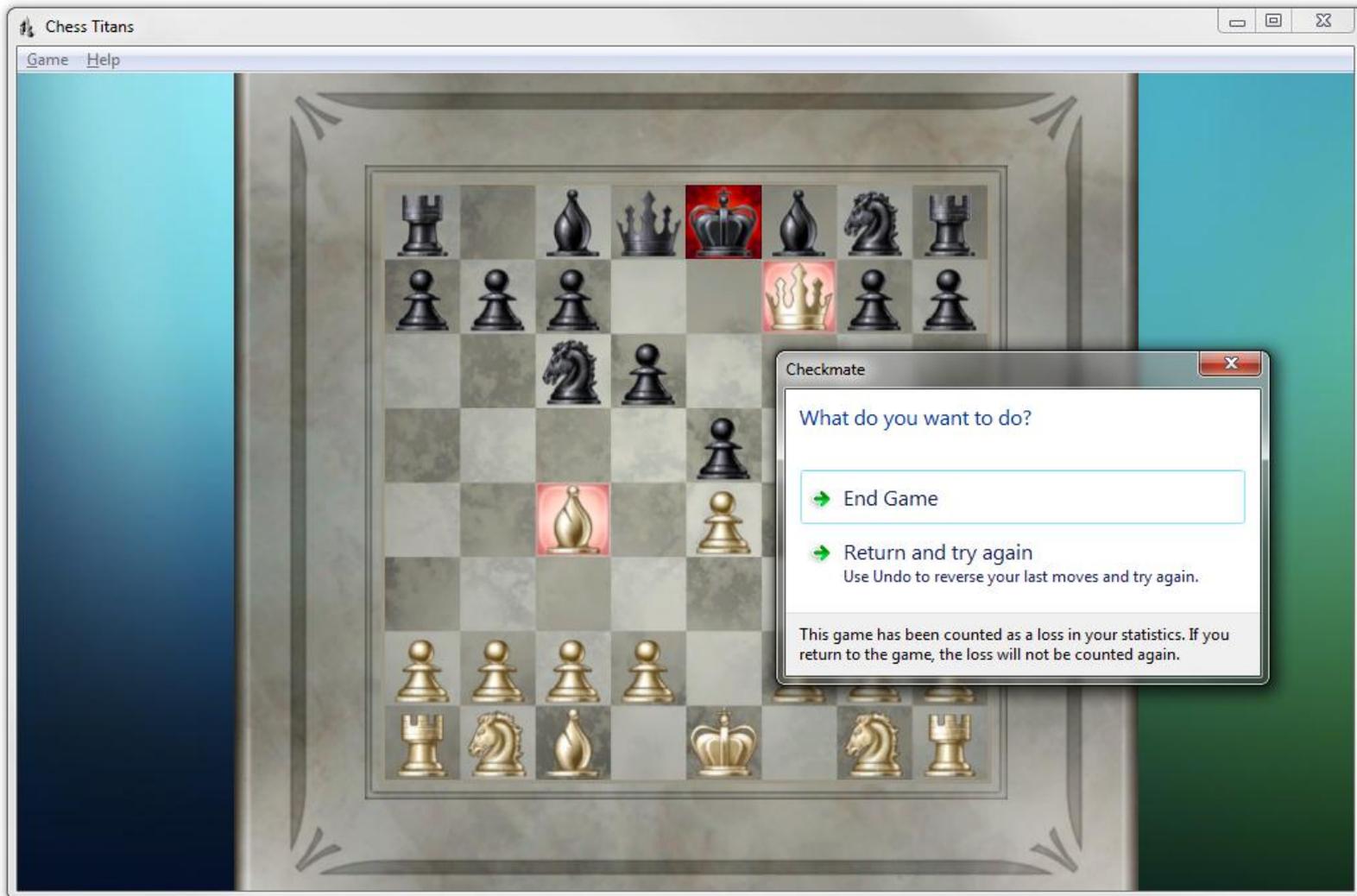


```
C:\Code\projects_v2\GamePlayer\Player\..Bin\Player.exe
R*B*KBNR
PPPPQPPP
*****
***pp*pp*
p*****p
*ppn**
r*bqkbnr
35 moves
0: 0,0:R -> 1,0:R
1: 4,0:R -> 3,0:R
2: 6,0:N -> 5,2:R
3: 6,0:N -> 7,2:R
4: 0,1:P -> 0,2:R
5: 0,1:P -> 0,3:R
6: 1,1:P -> 1,2:R
7: 1,1:P -> 1,3:R
8: 2,1:P -> 2,2:R
9: 2,1:P -> 2,3:R
10: 3,1:P -> 3,2:R
11: 3,1:P -> 3,3:R
12: 4,1:Q -> 3,2:R
13: 4,1:Q -> 3,2:R
14: 4,1:Q -> 5,2:R
15: 4,1:Q -> 2,3:R
16: 4,1:Q -> 6,3:R
17: 4,1:Q -> 1,4:R
18: 4,1:Q -> 7,4:R
19: 4,1:Q -> 0,5:P
20: 5,1:P -> 5,2:R
21: 5,1:P -> 5,2:R
22: 6,1:P -> 6,2:R
23: 6,1:P -> 6,3:R
24: 7,1:P -> 7,2:R
25: 7,1:P -> 7,3:R
26: 4,2:P -> 4,3:R
27: 3,2:R -> 3,3:R
28: 3,5:R -> 4,3:R
29: 3,5:R -> 5,4:R
30: 3,5:R -> 5,4:R
31: 3,5:R -> 1,6:P
32: 3,5:R -> 5,6:P
33: 3,5:R -> 2,7:b
34: 3,5:R -> 4,7:k
```



```
C:\Code\projects_v2\GamePl...
R*B*KBNR
PPPPQPPP
*****
***pp*pp*
p*****p
*ppn**N**
r*bqkbnr
28 moves
```

4. Determine the goal



Imperfect game models

Learning at each stage in this pipeline is going to be hard, but it doesn't need to be perfect

- You can play a fine game of Chess if you don't know the en passant or castling rules
- The rules that occur often are typically the ones that are most important

Pipeline Stages

Stage 1: Extract Symbolic Representation

Extract Symbolic Representation

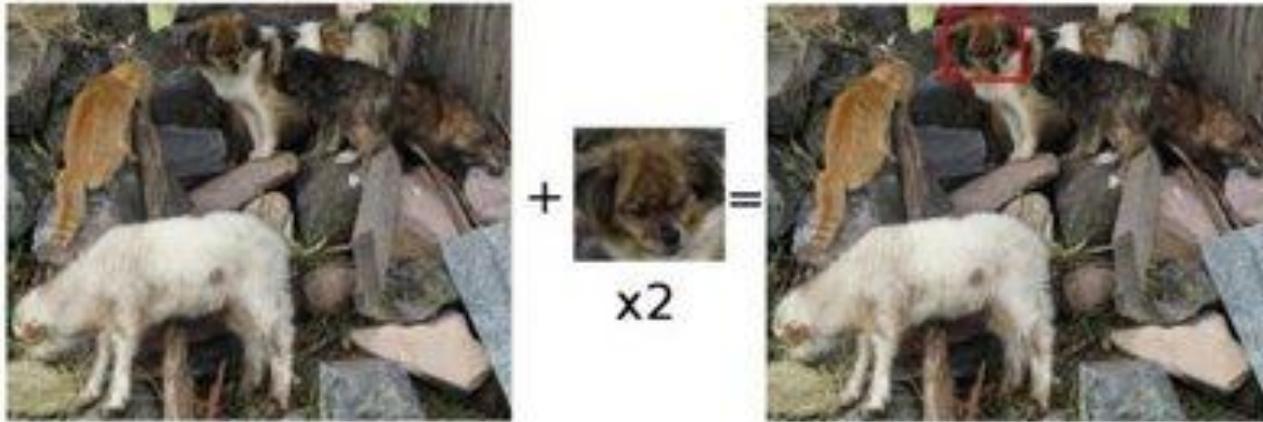
Co-segmentation

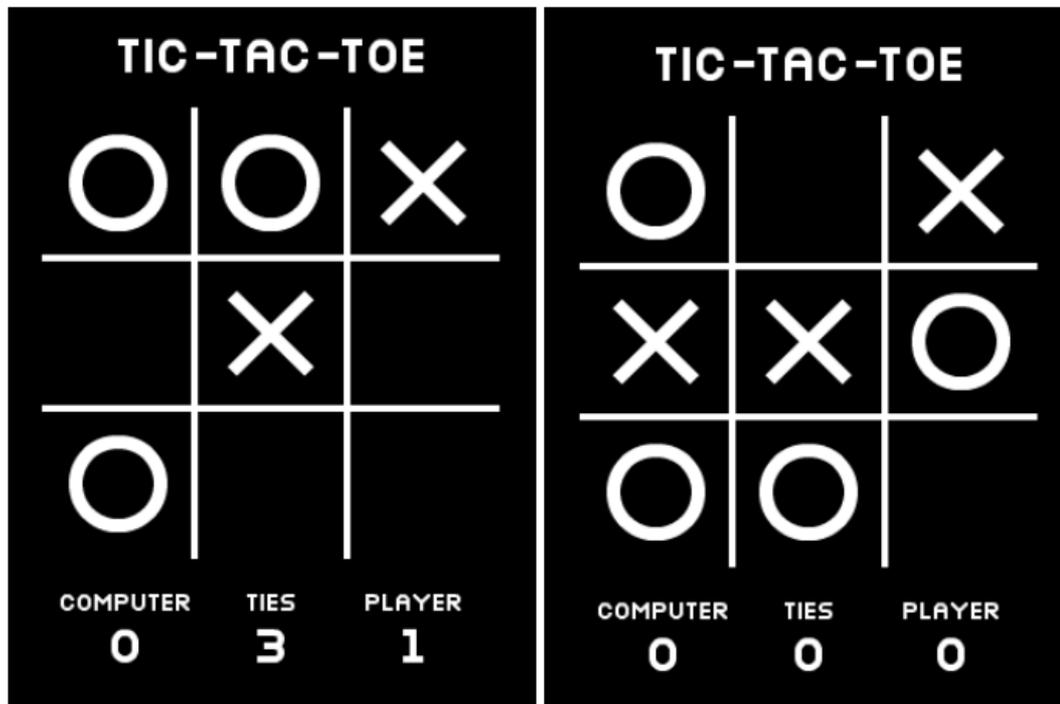
- Assume the set of input images contain many instances of similar objects
- Simultaneously segment the images and extract a set of commonly-occurring templates

Template matching

- Use template matching to isolate the instances and extract a set of representations

Template Matching





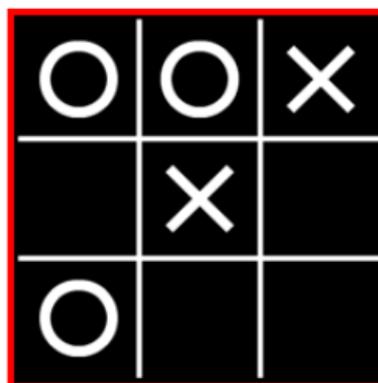
Pixels



X and O



Rows (or
Columns)



Boards



Digits

Human Knowledge

The AI cannot be expected to re-derive the meaning of human language and numerals

- Search for dominant patterns among the symbol sets (grids, graphs, text)
- When certain patterns are detected (ex. a string of glyphs) use character recognition to replace them with a related symbolic form (ex. “Score” or “9000”)
- One goal of GGL is to discover what patterns are necessary and which can be learned

Stage 2: Determine Valid Actions

Discrete input



Near-continuous input



Use symbolic representation



Physical Actions



Symbolic Actions

Use symbolic representation



Stage 3: Learn a Game Model

Game Model

A game model encodes all the relevant rules of the game

- Defines which actions are legal (Chess, Reversi)
- Takes the current state and a user action and returns the next state
- Need to learn from observations and experiments
- Markov decision process

Games are complicated but the behaviors of subcomponents is often simple

Simple Entity Behavior

t

t+200ms

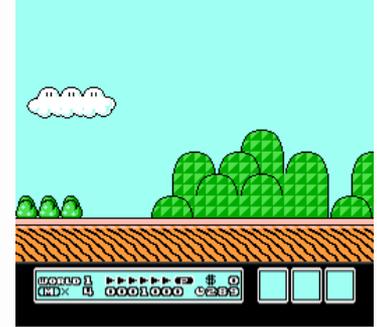
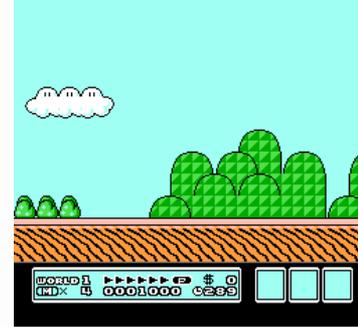
t+400ms

Composite

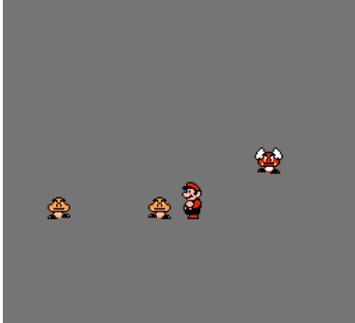
Whole Frame



Background Estimation



Sprite Extraction



Natural Language Rules

Chess

- A player can move a rook or queen along any horizontal or vertical straight line so long as the intervening pieces are all empty
- Players can only move pieces of their color
- It is legal for white player to move a white pawn forward two squares if it is in its home row and the two squares in front of the pawn are empty

Natural Language Rules

Super Mario Bros.

- Pressing right moves Mario to the right
- If Mario falls into a pit or fire he will die
- Goombas move slowly in one direction and can fall off ledges
- If Goombas hit an obstacle they will flip directions
- Jumping on Goombas kills them but colliding with them from the side will hurt Mario
- When Mario reaches a flag at the end of a stage he advances to the next stage in that world

Models encode rules

Need to specify a language that can encode game rules

- Complex enough to model important game behavior
- Simple enough to be learned from observations

Genre-specific vocabulary

- Piece, grid, board location, move
- Collision, velocity, parabola, atlas/map, portal

Reversi

The screenshot shows a Reversi game window with a blue title bar and standard window controls. The menu bar includes 'Game', 'Move', and 'Help'. Below the menu is a toolbar with icons for game actions. The main area features an 8x8 green board with columns labeled A-H and rows labeled 1-8. A black piece is highlighted at G4. To the right, the game status shows Black with 8 pieces, White with 3 pieces, and Black as the current player. A table at the bottom right lists the game history.

Game Move Help

Black: 8
White: 3
Current: ■

#	Player	Position
1	Black	F5
2	White	D6
3	Black	C3
4	White	F4
5	Black	C6
6	White	E3
7	Black	G4

Game Model Languages

Legal(whitePlayer, place(x),
line(x, n, m) \in blackPiece &&
lineEndPt(x, n, m) \in whitePiece)

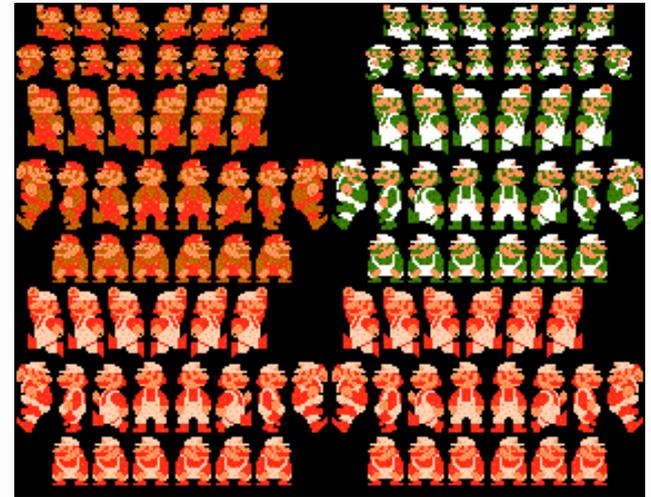
“It is legal for white to place at a coordinate x if the line starting at x parameterized by n and m contains only black pieces and the end point of this line is a white piece for all board locations x and certain values of n and m ”

Terminal(countPieces(whitePiece) +
countPieces(blackPiece) == 64)

Learning Rules and Representation

Rules that apply generally are more likely than a bunch of special cases

- Information gain criteria
- Occam's razor



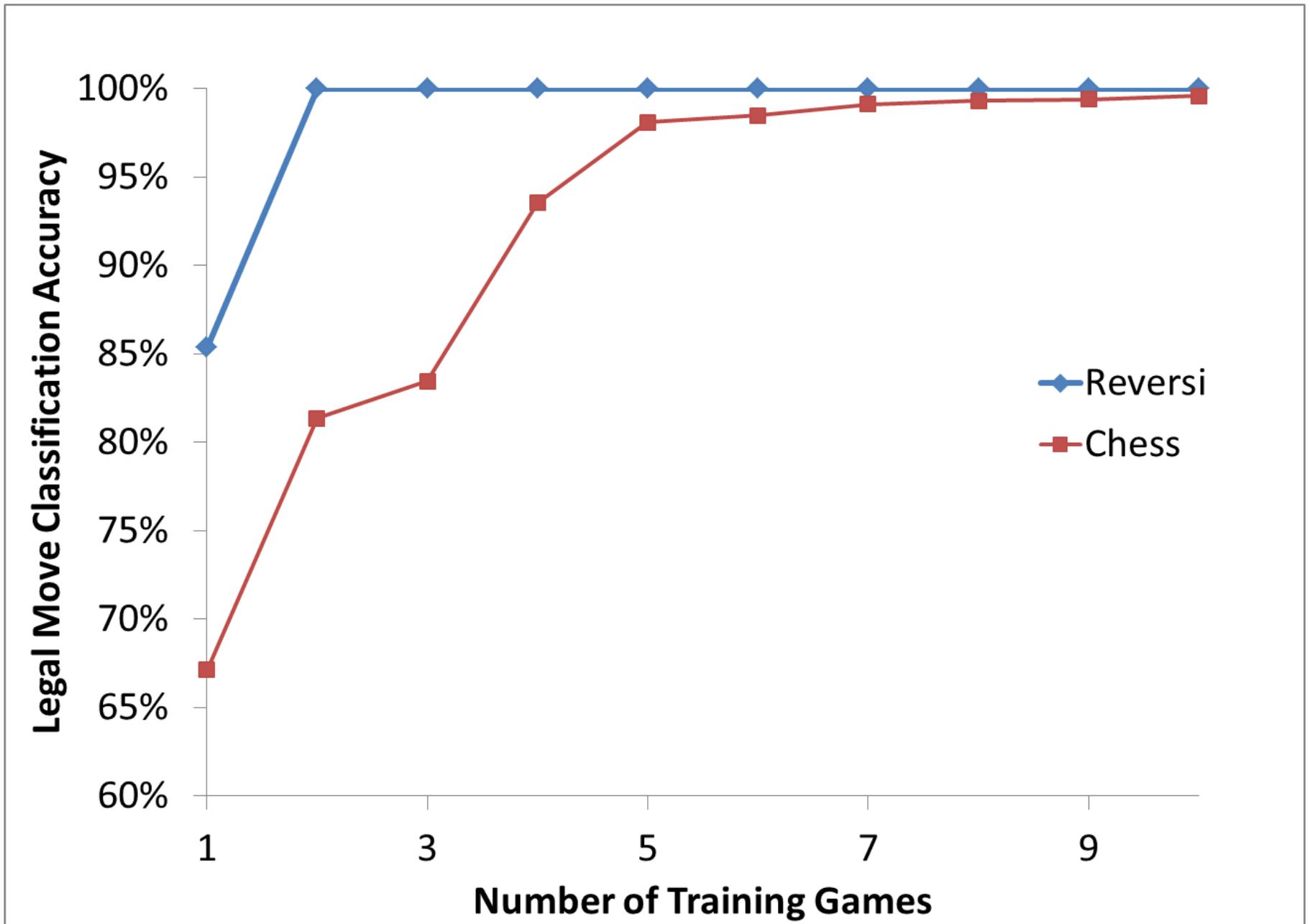
Categories are important

- Two entities probably belong to the same category if most of the rules that apply to entity A apply to entity B

Learning Rules and Representation

A representation is good if it is easy to build rules that describe it

- We can use this to decide between many possible candidate representations



Stage 4: Determine the Goal

Giveaway Checkers



Giveaway Checkers

How can we tell if we are playing regular Checkers or Giveaway Checkers?

- If we have observations of humans playing the game, what value are they placing on their pieces?
- If we have an AI (or human) opponent, are they trying to capture our pieces or not?

State Value Inference

True Goal of Chess

- Construct a situation in which your opponent is unable to prevent you from capturing their king

Inferred Value Function

- Capture enemy pieces, keep your own pieces from being captured
- King=20, Queen=10, Rook=6, Bishop=4, Knight=3, Pawn=1
- We can play the game just fine using this value function, in fact, it is ultimately more useful

State Value Inference



GAME OVER
DEAD
DIED

THANK YOU
CONGLATURATION !!!
WINNER IS
HAPPY END!

General Values

Novelty

- Seeing the death screen 10,000 times is not as interesting as exploring the world. If you explore a game and manage to see the ending, you've won.

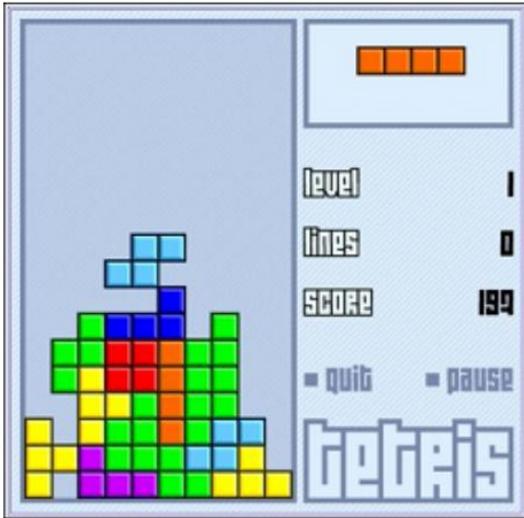
Canonical directions

- In many platformer games “proceed to the right, and don't die” is a good approximation of the goal

Number of actions

- Maximizing the number of actions available is a good idea in many piece-type games

State Value Inference



Tetris



The Legend of Zelda



Desktop Tower Defense

Level, lines, score, life

- See what humans appear to be optimizing
- Try to optimize each possible number on many different passes, see which results in the best behavior (ex. exploration criteria)

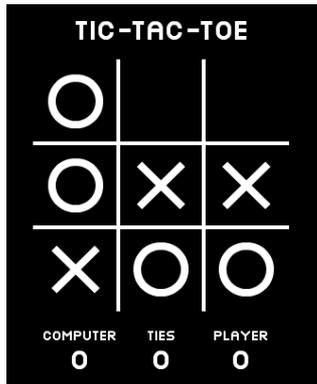
Prior work

Value function inference for specific games is often used to derive information from experts

- Value function for Chess was parameterized with approximately 8,000 parameters
- Parameter values were learned by analyzing thousands of grandmaster Chess games

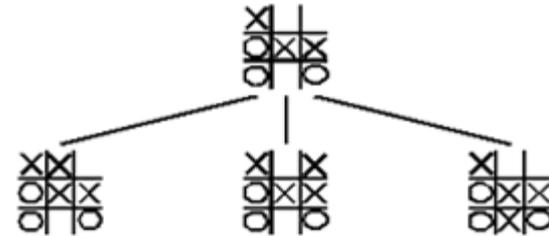
Goal is to use this idea on learned game models and construct “general parameterizations” of the value function

Stage 1 – 4 Summary



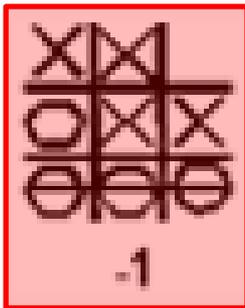
Pixels

Symbolic
Game State

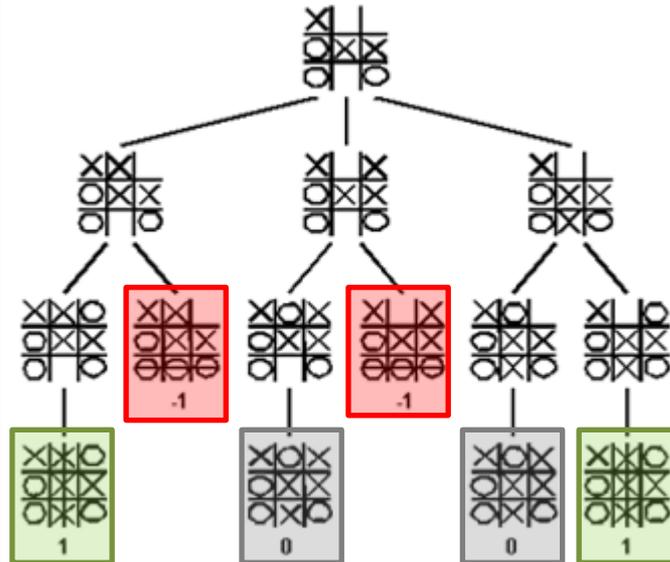


Symbolic
Game State

List of Actions and Resulting
Game States



Goal Evaluator



Complete
Game
Description

Stage 5: Plan Actions

Execute actions leading to goal

Different games are solved in different ways

- Minimax tree search (Chess, Chinese Checkers)
 - Requires value function:
 - Use one modeled from examples in Stage 4
 - Use one derived from General Game Playing
- Motion planning (Mario, Tetris)
 - Try many different state value functions
 - Reinforcement learning techniques
 - Markov decision process formulation

Execute actions leading to goal

This is what General Game Playing is for

- Active area of research
- CS227B, Michael Genesereth
- Not designed for incomplete game models

Uses Game Description Language

- Mapping from a symbolic representation of the game state to a list of actions and the resulting states
- Many general game players have been developed
 - Bandit-based Monte Carlo
- Can easily convert game model to GGP

Execute actions leading to goal

```
legal(Y,mark(M,N)) <=
  true(cell(M,N,b)) &
  true(control(Y))
```

```
legal(white,noop) <=
  true(cell(M,N,b)) &
  true(control(black))
```

```
legal(black,noop) <=
  true(cell(X,Y,b)) &
  true(control(white))
```

```
next(cell(M,N,x)) <=
  does(white,mark(M,N)) &
  true(cell(M,N,b))
```

```
next(cell(M,N,o)) <=
  does(black,mark(M,N)) &
  true(cell(M,N,b))
```

```
next(cell(M,N,W)) <=
  true(cell(M,N,W)) &
  distinct(W,b)
```

```
init(cell(1,1,b))
init(cell(1,2,b))
init(cell(1,3,b))
init(cell(2,1,b))
init(cell(2,2,b))
init(cell(2,3,b))
init(cell(3,1,b))
init(cell(3,2,b))
init(cell(3,3,b))
init(control(white))
```

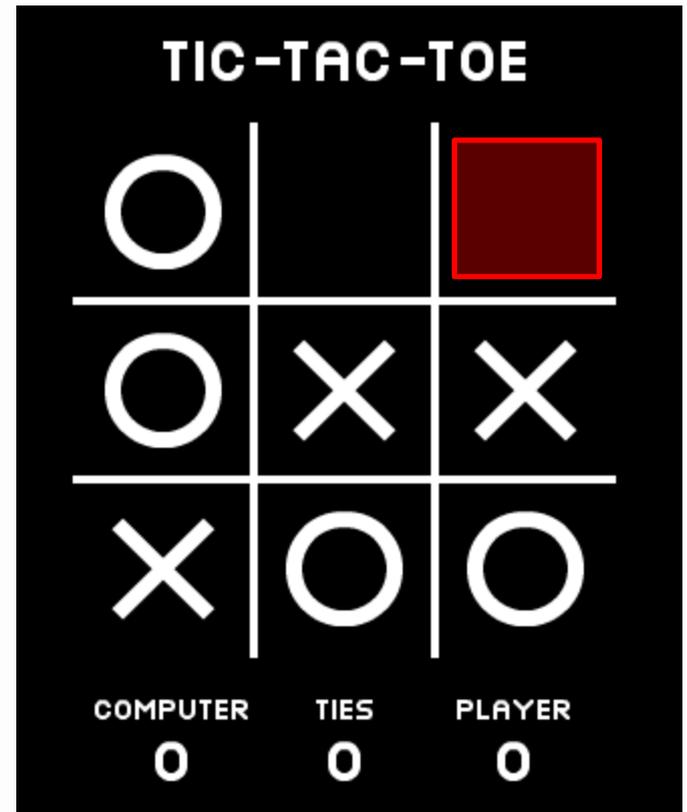
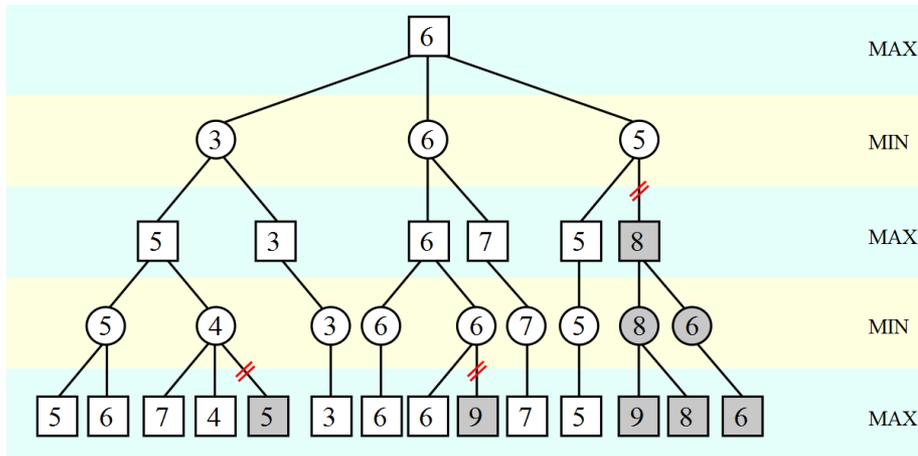
```
goal(white,100) <= line(x)
goal(white,50) <=
  ~line(x) &
  ~line(o) &
  ~open
goal(white,0) <= line(o)
goal(black,100) <= line(o)
goal(black,50) <=
  ~line(x) &
  ~line(o) &
  ~open
goal(black,0) <= line(x)
```

```
terminal <= line(x)
terminal <= line(o)
terminal <= ~open
```

Typical general game player

“Game state value estimator” trained from many game simulations

+



5. Execute actions leading to goal

General Game Playing is not going to help much for Mario or Zelda

Can use basic search and control algorithms

- Relies on a reasonably good model of the state space transitions for the game

Try and try again

- Millions of deaths are fine as long as it eventually learns; once it does we can look at how to make it learn faster or better

Mario AI Competition



Conclusions

Results: Deliverables are easy

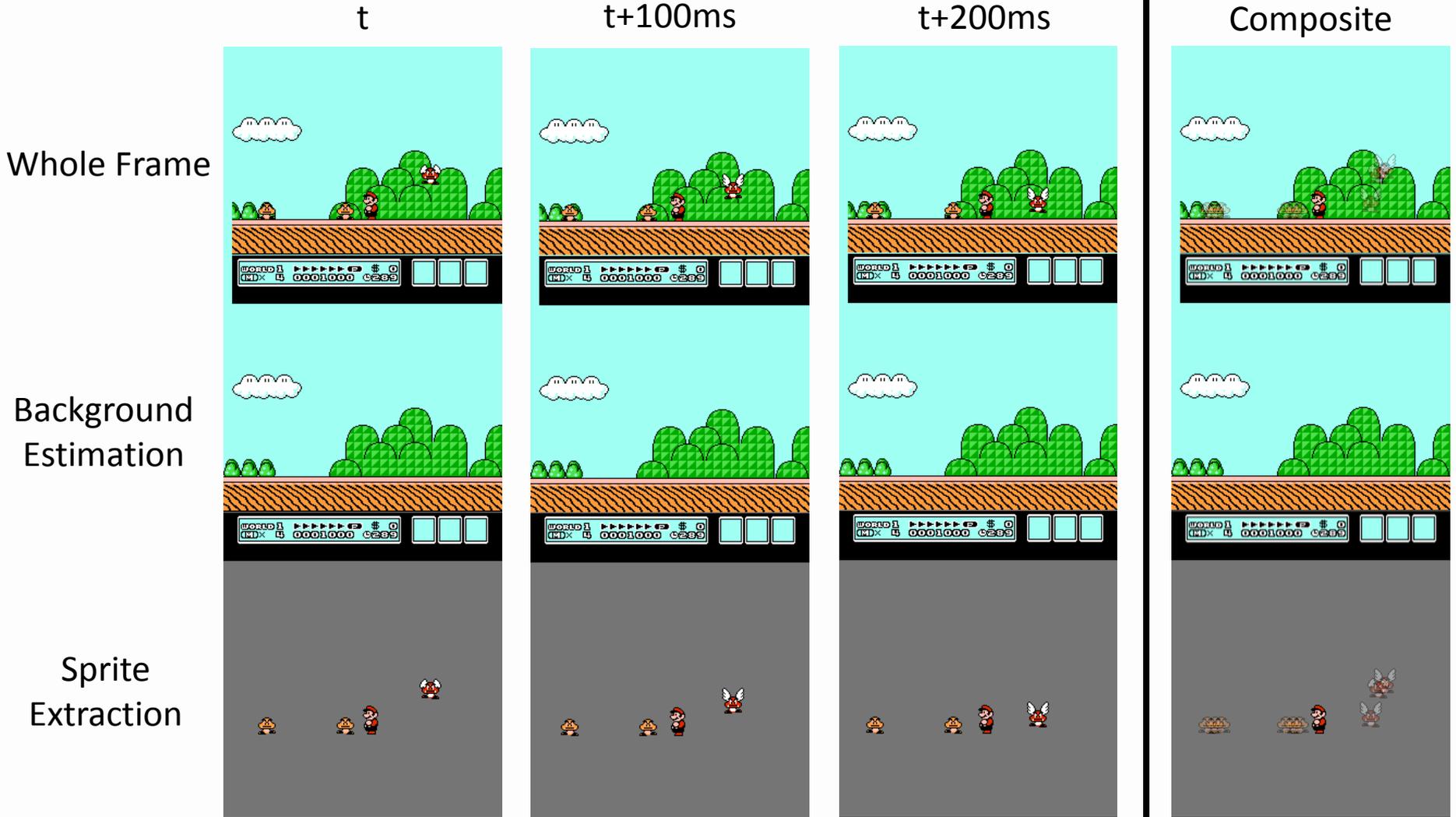
Viable game learners answer a lot of questions

- Can we determine what components are meaningful?
- What games are hard to learn?
- How many games do you need to learn rules?
- Can we construct a useful set of rules that generalize across many games?
- How well can we play even if we only know some of the rules?
- Can we compute a useful reward function from watching human players?

We will use digital games to study...

- **Unsupervised** object segmentation and categorization
- Rule learning
- Knowledge transfer between categories
 - Between Mario & Luigi
- Goal inference
- Game state value estimation
- Action planning
- Knowledge transfer between games
 - Between Super Mario 1 and Super Mario 3
 - Between Shogi and Chess

First steps: NES games



Lots and lots of 2D games (>100,000)

44,962 ONLINE PLAYING 47,881 FREE GAMES! PART OF THE **GameSpot** NETWORK

KONGREGATE

Sign In or Register Username Sign In Remember me Forgot password?

HOME GAMES ACHIEVEMENTS COMMUNITY DEVELOPERS HELP Search for games & more

New Top Rated My Favorites MMO Strategy/Defense Adventure/RPG Shooter Puzzle Action Multiplayer More

Browse Games

CATEGORIES

- All games
- Action
- Multiplayer
- Shooter
- Adventure & RPG
- Sports & Racing
- Strategy & Defense
- Puzzle
- Music & More
- Tutorials
- Zombie
- Tags & More:
- Top Rated
- Zombie
- Unity
- Fantasy
- Tower Defense
- MMO
- Alex's Picks

SORT: Highest rating

 <p>Learn to Fly 2 by light_briar222 ★★★★★ Jun. 16, 2011 You were able to learn how to fly, but Icebergs stopped you and crushed your dreams. Now... play now</p> <p>6,038,924 plays</p>	 <p>UPGRADE COMPLETE! by ArmorGames ★★★★★ Jun. 30, 2009 This game has crummy graphics... UNTIL YOU UPGRADE THE GRAPHICS ENGINE! And no sound? UNTIL... play now</p> <p>3,869,916 plays</p>
 <p>Cursed Treasure: Don't... by IvSaft ★★★★★ May. 06, 2011 Protect your gems from being stolen by "good" heroes in this tower defense game.... play now</p> <p>10,939,906 plays</p>	 <p>Bloons Tower Defense 4 by MistWolf ★★★★★ Jan. 26, 2010 BTD4 features improved graphics, loads of new and original tower types and tons of upgrades for... play now</p> <p>7,348,044 plays</p>
 <p>Cursed Treasure: Level... by IvSaft ★★★★★ May. 06, 2011 Level pack for the popular tower defense game Cursed Treasure. Take on the role as the evil... play now</p> <p>2,092,340 plays</p>	 <p>Mastermind: World Conq... by theswain ★★★★★ Feb. 01, 2009 Manage your minions, defend your base, and conquer this puny planet ONCE AND FOR ALL! play now</p> <p>2,392,376 plays</p>
 <p>Elephant Quest by ArmorGames ★★★★★ Apr. 13, 2011 The fight is on! Wooly has taken your precious bowler cap and now you are on a romp to get it... play now</p> <p>1,064,124 plays</p>	 <p>Villainous by Rite ★★★★★ Jun. 29, 2011 From the makers of "I Have 1 Day" and "Don't Sht Your Pants" comes... play now</p> <p>1,745,249 plays</p>
 <p>Rebuild by sarahnorthway ★★★★★ Feb. 12, 2011 Gather survivors of the zombie apocalypse and manage food supplies, housing and morale while... play now</p> <p>3,334,559 plays</p>	 <p>GemCraft by gameinabottle ★★★★★ Jun. 26, 2008 Havoc and corruption swarms through the land, and you are one of those few wizards who can put en... play now</p> <p>7,839,268 plays</p>
 <p>WORLD DOMINATOR by IvsaProductions ★★★★★ Feb. 14, 2010 To fix the freezing when the loading screen comes up, just hit tab until there is a yellow square... play now</p> <p>5,328,218 plays</p>	 <p>Sonny 2 by ArmorGames ★★★★★ Apr. 27, 2009 Sonny 2 is a combat based RPG where you play as a Zombie, level up and gain items to advance to... play now</p> <p>3,028,695 plays</p>
 <p>Epic Battle Fantasy 3 by kuza202 ★★★★★ Sep. 01, 2010 Battle over 70 types of monsters, collect over 80 types of equipment and use over 80 different... play now</p> <p>6,148,038 plays</p>	 <p>Learn to Fly by light_briar222 ★★★★★ May. 16, 2009 Grab your rockets and glider to show the world a penguin can fly! play now</p> <p>6,079,024 plays</p>
 <p>GemCraft Labyrinth by gameinabottle ★★★★★ Apr. 20, 2011 After decades of preparation, the test you've been waiting for, the Labyrinth, has finally... play now</p> <p>3,261,207 plays</p>	

< first < prev 1 - 15 [next](#) > last >

Armor Games

Enter Username Register
Enter Password Login

Action Adventure Arcade Shooting Puzzle & Skill Strategy Sports Misc

Search Armor Games FEATURED GAMES Endless Migration Submit Games News Community Store Blog Help

Get Free Games by Email
Subscribe to our newsletter

Random Game

New Games

Space Punk Racer
3,589 plays
Rating: 5.7/10

Monster Island
106,333 plays
Rating: 6.6/10

Genestealer Revenge
113,857 plays
Rating: 5.4/10

Dead Metal
257,142 plays
Rating: 6.6/10

The Kings League
573,851 plays
Rating: 8.5/10

Faultline
251,535 plays
Rating: 7.9/10

Raze 2
375,645 plays
Rating: 9.4/10

Roly-Poly Eliminator 2
111,353 plays
Rating: 7.4/10

Siege Hero - Viking Vengeance
176,490 plays
Rating: 7.5/10

Wonderputt
481,426 plays
Rating: 6.7/10

Zombocalypse
867,733 plays
Rating: 8.2/10

Coinbox Hero
867,485 plays
Rating: 6.6/10

Popular Games

The Last Stand - Union City
4,590,419 plays
Rating: 9.4/10

Kingdom Rush
9,125,922 plays
Rating: 9.6/10

Learn to Fly 2
2,670,850 plays
Rating: 9.5/10

Crush the Castle 2
3,203,622 plays
Rating: 9.3/10

GemCraft Labyrinth
11,051,406 plays
Rating: 9.3/10

Flight
13,361,512 plays
Rating: 9.3/10

Game Tags

action adventure ball battle click
defense fun mouse physics
platform platformer point puzzle
quick retro rpg shoot shooter shooting
space strategy tower war zombie

Action Adventure Arcade Shooting Puzzle & Skill Strategy Sports Misc

Siege Hero - Viking Vengeance
376,495 plays
Rating: 7.5/10

City Siege 2: Resort Siege
3,905,674 plays
Rating: 8.9/10

Echoes - Operation Stranglehold
4,012,866 plays
Rating: 8.5/10

Exit Path 2
1,325,569 plays
Rating: 9/10

Crush the Castle 2
3,203,622 plays
Rating: 9.3/10

Elona Shooter
5,405,427 plays
Rating: 8.7/10

The Last Stand - Union City
4,590,419 plays
Rating: 9.4/10

Armor Mayhem
5,581,645 plays
Rating: 9.2/10

Toss the Turtle
7,380,507 plays
Rating: 9.2/10

Zombotron
1,357,632 plays
Rating: 8.9/10

Achievement Unlocked 2
3,557,004 plays
Rating: 9.1/10

The Last Stand 2
21,714,907 plays
Rating: 9.4/10

All Action Games >

2D vs. 3D games

