### ADAPTIVE KNOWLEDGE INJECTION FOR MONTE CARLO TREE SEARCH FOR MPERFECT INFORMATION G

Jeremy Lai Hong

Supervised by: Dr. Benjamin Rosman & Mr. Richard Klein

## Introduction

- Why Study Games?
- Magic The Gathering:
  - Large Amount of Uncertainty
  - Large Branching Factor
  - Tactical Play
  - Disambiguation

## Magic: The Gathering

- 20 Starting Life
- 60 Card Decks From Set of 10,000
- 5 Different Colours: Red, Blue, Green, White, Black
- Different Types Of Cards:
  - Land
  - Creature
  - Instant



- Produce Mana
- No Cost
- Can Only Play 1 A Turn





Land Card

Tapped Land Card



### Creature

- Used for Combat
- Has Power and Toughness
- Summoning Sickness





#### Tapped





- 1 Combat Phase Per Turn
- Turn Player Chooses attackers
- Opponent which creatures to block
- Unblocked creatures deal damage to opponents





 Creatures deal damage equal to their power to enemy creatures tough simultaneously.
 Receives 2 damage

> Deals 2 damage. Receives 1 damage







• Another Example...





• Another Example...

> Deals 2 damage. Receives 2 damage



Deals 2 damage. Receives 1 damage

10

Deals 2 damage to creature 1 and 1 damage to creature 2.

> Receives 4 damage

• Another Example...









- Once Off
- Play During any Phase of the game
- Make the game highly interactive







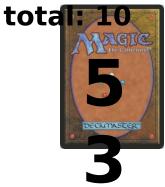
## Magic: The Gathering

- Turn Based
- Different Phases
  - Upkeep
  - Draw
  - Main
  - Combat (Attack, Block)
  - Second Main
  - End



- Jeremy has rolled 14
- Bob has rolled 11
- Jeremy Chooses to play first

### **Opponent life**





### My life total: 10





## Cards In Hand





### Cards In Hand

Option 1:

- Turn 1: Foundry Street Denizen
- Turn 2: 2 x Satyr Hoplite, Attack for 3
- Turn 3: Coordinated Assault, Attack for 7





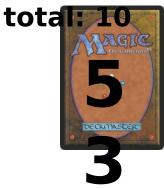
### Cards In Hand

Option 2:

- Turn 1: Satyr Hoplite
- Turn 2: Foundry Street Denizen, Satyr Hoplite, Attack for 1?



### **Opponent life**



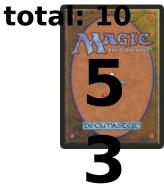


### My life total: 10





### **Opponent life**





### My life total: 10

















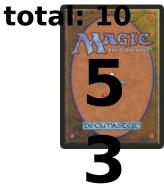








### **Opponent life**





### My life total: 10



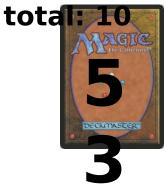








### **Opponent life**





### My life total: 10

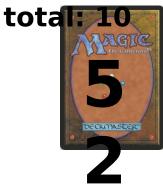




oundry Street Denizer



### **Opponent life**





### My life total: 10



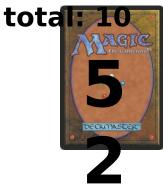


oundry Street Denizer





### **Opponent life**







Heroic — Whenever you cast a spell hat targets Satyr Hoplite, put a +1/+1 counter on Satyr Hoplite. "Xenagos has become what he once lespised: a tyrant and an oppressor."

#### My life total: 10







undry Street Denizer





hout "Shields up!" with a ir chest.

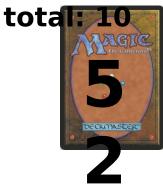






### Sample Game 🔅 💮 🤭 🚯

### **Opponent life**









### My life total: 10



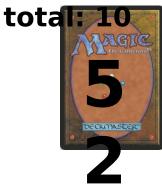








### **Opponent life**





### My life total: 10





undry Street Denize



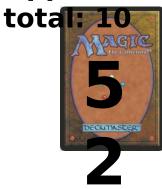




Heroic — Whenever you cast a spell hat targets Satyr Hoplite, put a +1/+1 counter on Satyr Hoplite.

Kenagos has become what he once spised: a tyrant and an oppressor.

### **Opponent life**



#### My life total: 10









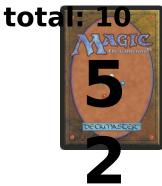
Up to two target creatures each get +1/+0 and gain first strike until en-







### **Opponent life**







undry Street Denize

### My life total: 10





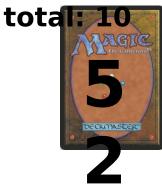






### Sample Game 🔅 💮 🤭 🚯

### **Opponent life**







#### My life total: 10



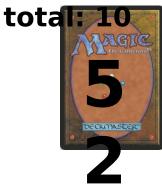








### **Opponent life**







#### My life total: 10





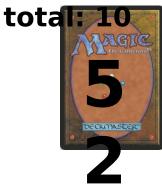




Heroic – Whenever you cast a spe final function of the state of the spectral spectral spectral block this turn. The Irean Games atcard no medals, Abitest evic for a sist from Ireas, see of victory. 21



### **Opponent life**



#### My life total: 10















Arena Athlete

lason Chan



31

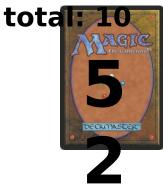
Heroic --- Whenever you cast a spell that targets Arena Athlete, target creature an opponent controls can't block this turn.

The Iroan Games award no medals. Athletes vie for a visit from Iroas, god of victory.

2/1

### Sample Game 🔅 💮 🤭 🚯

### **Opponent life**







#### My life total: 10







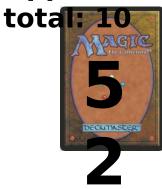


21

an opponent con ck this turn.



### **Opponent life**





Ę

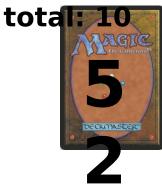


#### My life total: 10





### **Opponent life**





Ę



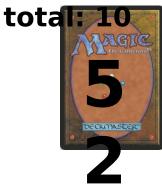
#### My life total: 10







### **Opponent life**







undry Street Denize

### My life total: 10

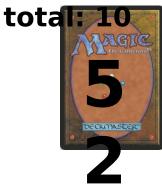






### Sample Game 🔅 💮 🤭 🚯

### **Opponent life**





4



undry Street Denize

### My life total: 10



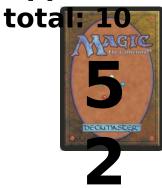




3

2/1

#### **Opponent life**









#### My life total: 10











Heroic — Whenever you cast a spell that targets Satyr Hoplite, put a +1/41 counter on Satyr Hoplite. "Xenagos has become twhat he once despised: a tyrant and an oppressor."



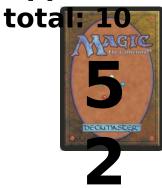




Heroic — Human Heroic — Whenever you cast a spell that targets Arena Athlete, target creature an opponent controls can't block this turn. The Iroan Games award no medals. Athletes vie for a visit from Iroas, god of victory. 201



#### **Opponent life**







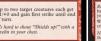
#### My life total: 10











you atfacked with a creature this War-Name Aspirant can't be blo creatures with power 1 or less. No battle means now, to a Mardus than the one that carris her toar nam



vic — Whenever you cast a spel t targets Satyr Hoplite, put a +1 counter on Satyr Hoplite.

agos has become what he once

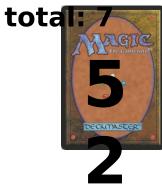




38

Heroic — Whenever you cast a spen that targets Satyt Hoplite, but a +1/+1 counter on Satyr Hoplite. "Xenagos has become tohat he once despised: a tyrant and an oppressor."

#### **Opponent life**





Ę



#### My life total: 10















vic — Whenever you cast a spel t targets Satyr Hoplite, put a +1 counter on Satyr Hoplite.

agos has become what he once



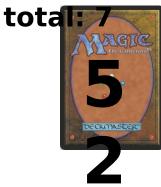




39

hat targets Satyr Hoplite, put a +1/+1 counter on Satyr Hoplite. Xenagos has become what he once espised: a tyrant and an oppressor.

#### **Opponent life**





4



#### My life total: 10











You and the work of the relative of War-Name Aspirant Can't be to creatures with power 1 or less. No battle means nom to a Mard than the one that earn's her tear of Waster



nic — Whenever you cast a spel targets Satyr Hoplite, put a +1 counter on Satyr Hoplite.

agos has become what he once



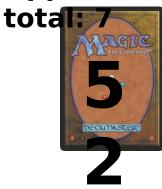


40



"Xenagos has become what he once lespised: a tyrant and an oppressor."

#### **Opponent life**









#### My life total: 10















roic — Whenever you cast a spell t targets Satyr Hoplite, put a (+1 counter on Satyr Hoplite.

agos has become what he once



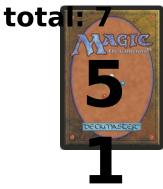




hat targets Satyr Hoplite, put a +1/+1 counter on Satyr Hoplite. Xenagos has become what he once lespised: a tyrant and an oppressor.

1/1

#### **Opponent life**









#### My life total: 10











you affacted with a creature this War-Name Aspirant can't be blo creatures with power 1 or less. No battle means now to a Mardiu than the one that carris her twar non than the one that carris her twar non



roic — Whenever you cast a spell t targets Satyr Hoplite, put a (+1 counter on Satyr Hoplite.

agos has become what he once





tyr Hopli

42

+1/+1 counter on Satyr Hoplite. "Xenagos has become tohat he once despised: a tyrant and an oppressor."

#### **Opponent life**





#### My life total: 10











War-Name Aspirant can't be blo creatures with power 1 or less. No bastle means none to a Mardu a than the one that carris her war non BETHY and the sense faunt of the sense that the sense faunt of the sense faunt of the sense factors of the sense faunt of the sense factors of the sense faunt factors



roic — Whenever you cast a spell t targets Satyr Hoplite, put a (+1 counter on Satyr Hoplite.

agos has become what he once





43

Heroic — Whenever you cast a spell that targets Satyr Hoplite, put a +1/+1 counter on Satyr Hoplite. "Xenagos has become what he once despised: a tyrant and an oppressor."

despised: a tyrant and an oppressor."







#### My life total: 10















hat targets Satyr Hoplite, put a +1/+1 counter on Satyr Hoplite. Xenagos has become what he once espised: a tyrant and an oppressor.







## Block Analysis

### Single Block







45

Heroic — Whenever you cast a spell that targets Satyr Hoplite, put a +1/+1 counter on Satyr Hoplite. "Xenago has become that he once despised: a tyrant and an oppressor."

## Block Analysis

### Single Block







**46** 

Heroic — Whenever you cast a spell that targets Satyr Hoplite, put a +1/+1 counter on Satyr Hoplite. "Xenagos has become that he once despised: a tyrant and an oppressor."

### Block Analysis 🕸 🚱 🤣 🎲 🚺

### **Double Block**







47

Heroic — Whenever you cast a spell that targets Satyr Hoplite, put a +1/+1 counter on Satyr Hoplite. Xenagos has become what he once espised: a tyrant and an oppresson 1/1

### **Block Analysis** 🕸 🚱 🤣 🚱 🚺

### **Double Block**













#### My life total: 10











you attacked with a creature thi War-Name Aspirant can't be blo creatures with power 1 or less. No battle means more to a Marthu than the one that carris her war na



vic — Whenever you cast a spel t targets Satyr Hoplite, put a +1 counter on Satyr Hoplite.

agos has become what he once





49

Heroic — Whenever you cast a spell that targets Satyr Hoplite, put a +1/+1 counter on Satyr Hoplite. "Xenagos has become what he once despised: a tyrant and an oppressor."

"Xenagos has become tehat he once despised: a tyrant and an oppressor."







#### My life total: 8















vic — Whenever you cast a spel t targets Satyr Hoplite, put a +1 counter on Satyr Hoplite.

agos has become what he once



hat targets Satyr Hoplite, put a +1/+1 counter on Satyr Hoplite. "Xenagos has become what he once despised: a tyrant and an oppressor.









#### My life total: 8













Heroic — Whenever you cast a spell that targets Satyr Hoplite, put a +1/+1 counter on Satyr Hoplite. "Xenagoh as become thehat he once despised: a tyrant and an oppressor."















My life total: 8











#### My life total: 8













Heroic — Whenever you cast a spell that targets Satyr Hoplite, put a +1/+1 counter on Satyr Hoplite. "Xenagoh as become thehat he once despised: a tyrant and an oppressor."





Creature – Human Heroic – Whenever you cast a spell that targets Arena Athlete, target creature an opponent controls can't block this turn. The Iroan Games attand no medali. Athletes sie for a visit from Iroas, god of victory. 201



#### **Opponent life**





#### My life total: 8











atyr Hoplit



Ip to two target creatures each get 1/+0 and gain first strike until end t's hard to shout "Shields up!" with



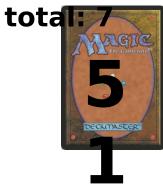




54

2/1

#### **Opponent life**





#### My life total: 8











Ip to two target creatures each get 1/+0 and gain first strike until end t's hard to shout "Shields up!" with







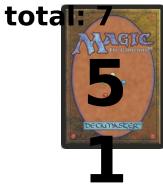








#### **Opponent life**



















p to two target creatures each get 1/+0 and gain first strike until end 's hard to shout "Shields up!



















#### My life total: 8













Creature – Johann Harrior Raid – War-Name Asyriant er battlefield with a +1141 count you attacked with a creature th War-Name Aspartant can't be creatures with power 1 or less. No battle means mon to a Marth than the one that carrie her earn these the











58

My life total: 8





3 (6) (2









## Sample Game 🕸 🚱 🤣 🚱 🚺



total: 8 AGIC

DECKMASCER







#### My life total: 8















## Sample Game 🕸 🚱 🤭 🚯







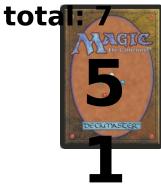






## Sample Game 🕸 🚱 🤭 🚯









#### My life total: 8











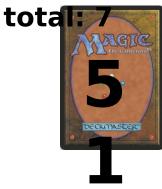








#### **Opponent life**









#### My life total: 8











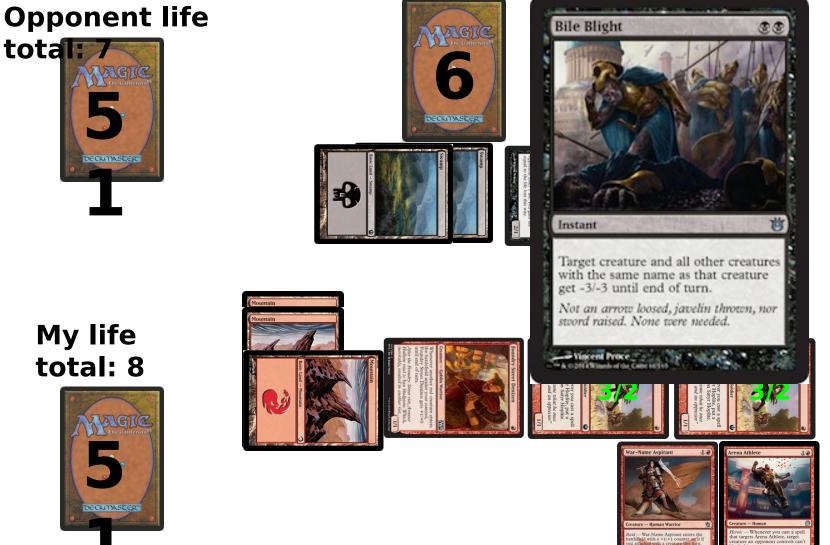






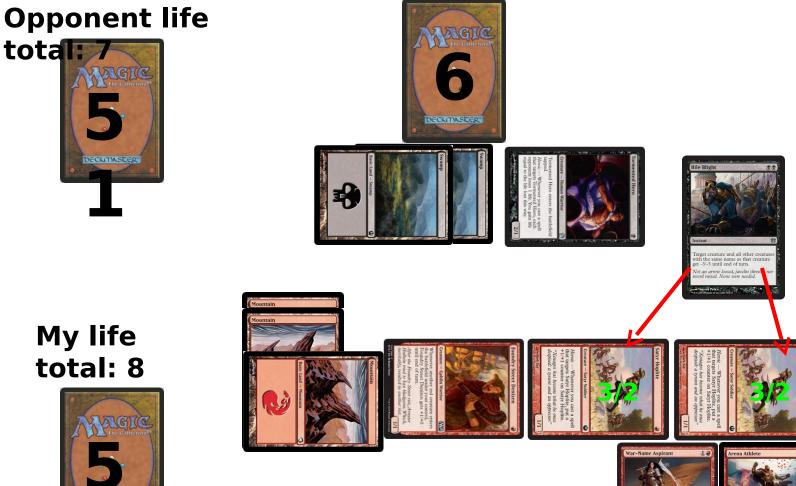






## Sample Game 🔅 🚱 🤭 🚺

DECKMASCER















#### My life total: 8

















#### My life total: 8







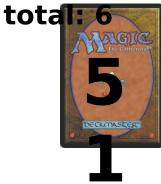






## Sample Game 🕸 🚱 🤭 🚯







#### My life total: 8















## Sample Game 🕸 🚱 🤭 🚯



AGIC



#### My life total: 8









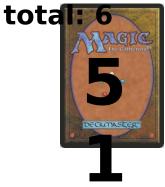














#### My life total: 8







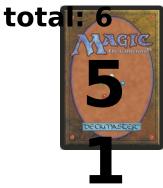




Ireature – Human Herois, – Whenever you cast a spell that targets Arena Athlete, target recature an opponent controls can't block this turn. The Irean Games attard no medals. Athletas vie for a visit from Ireas, god of victory. 2/1









#### My life total: 8







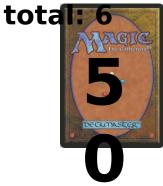




Heroic — Whenever you cast a spell that targets Arena Athlete, target rectature an opponent controls can't block this turn. The Ireon Games atteard no medali. Athletes vie for a visit from Ireas, god of victory. 2/1









#### My life total: 8







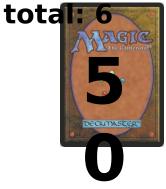




Creature – Human Heroic – Whenever you cast a spell that targets Arena Athlete, target creature an opponent controls can't block this turn. The Irean Games atural no medal. Athletes vie for a visit from Ireas, god of victory. 2019



#### **Opponent life**





#### My life total: 8







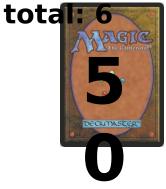




Creature – Human Hernic – Whenever you cast a spell that targets Arena Athlete, target recature an opponent controls can't block this turn. The Irean Games strand no medal. Athlets cie for a visit from Ireas, god of victory. Zersances 22/1



#### **Opponent life**







#### My life total: 8











Herainer – numan Horoie – Whenever you cast a spell that targets Arena Athlete, target reature an opponent controls can't block this turn. The Iroan Games assund no medali. Athlease sie for a visit from Iroas, god of citory. 2/1



#### **Opponent life**





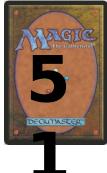








#### My life total: 8











Levature – Human Hencis – Whenever you cast a spell that targets Arena Athlete, target retature an opponent controls can't block this turn. The Ireon Games attard no medals. Athletes vie for a visit from Ireas, god of victory. 2/1



#### **Opponent life**

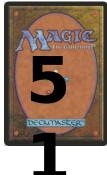








#### My life total: 8











Creature – Human Heroic, – Whenever you cast a spell that targets Arena Athlete, target creature an opponent controls can't block this turn. The Irean Games stread no medals. Athletes vie for a visit from Ireas, god of victory. 2/1



#### **Opponent life**





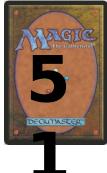








#### My life total: 8







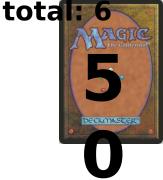




 Creature -- Human
 Continue -- Continue

















Kolaghan blades rarely stay clean for long.

more creatures.

009/264 U 075 - EN Noline Services



79



2/2

The B 40 2015 Waterula of the Cases



#### **Opponent life**











#### My life total: 8











Heric – Mhenever you cast a spell that targets Arena Athlete, target rectature an opponent controls car't block this turn. The Iroom Games attard no medali. Athletes vie for a visit from Iroas, god of victory. 2/1





#### **Opponent life**











od-Chin Rager

1.5



Whenever Mardu Shadowspear attacks, each opponent loses 4 life. Dash 1 e (Verway eau in thi pell (or it dash cou, I) your do a pair haire, and it's returned from the battlefield to it ormer's hand at the beginning of the mext end step.)

My life total: 8











Heroic — Whenever you cast a spell that targets Arena Athlete, target revature an opponent controls can't block this turn. The Irean Games attard no medals. Athletes vie for a visit from Ireas, god of victory. 2/11





(3)(2







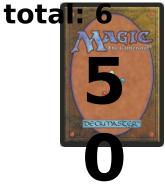


VAGIC

DECKMASCER



#### **Opponent life**











#### Whenever Blood-Chin Bager attacks, each Warrie evolutier you control can't be blocked this turn except by two or more creatures. Kolaghan blades randy stay clean for long. 2/2





#### My life total: 8







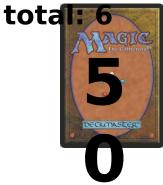




Heroic – Whenever you cast a spell that targets Arena Athlete, target creature an opponent controls can't block this turn. The Iroan Games atural no medals. Athletas cie for a visit from Iroas, god of victory. Zamotas









#### My life total: 8











Heroic — Whenever you cast a spell that targets Arena Athlete, target reature an opponent controls can't block this turn. The Irean Games attend no medals. Athletes eie for a visit from Ireas, god of victory. 2/1



### Block Analysis

#### Deals 2 damage. Receives 3 damage



Deals 3 damage. Receives 2 damage





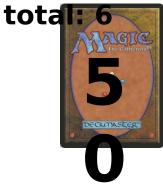
### Block Analysis













#### My life total: 8







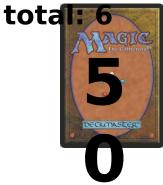




Heroic — Whenever you cast a spell that targets Arena Athlete, target reature an opponent controls can't block this turn. The Iroan Games attend no medali. Athletes vie for a visit from Iroas, god of victory. Athletes data









#### My life total: 6









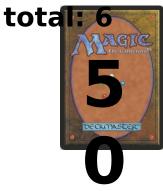


Heroic — Whenever you cast a spell that targets Arena Athlete, target reature an opponent controls can't block this turn. The Iroan Games attord no medals. Athletes eie for a visit from Iroas, god o teicory.



### Sample Game 🕸 🚱 🤣 🚱 🚺

#### **Opponent life**





My life total: 6





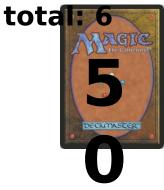








#### **Opponent life**





#### My life total: 6











Raid — War-Name Aspirant enters the availability with a +11/+1 counter on it i vou attacked with a creature this turn. War-Name Aspirant can't be blocked b treatures with power 1 or less. No bottle means mong to a Marda surrivol bottle means the surrivol bottle means the surrivol with the surge fails





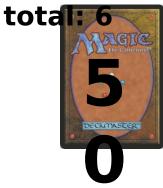




90

Whenever Mardu Shadowspear attacks, each opponent lose 4 life. Dash 1 @ 'Yen may cait this spill for its dash cont. If you do a game haile, and it's returned from the buttlefield to its orener's hand in the beginning of the next end step.) Th

#### **Opponent life**



My life total: 6



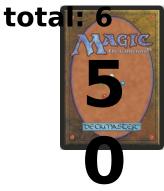


 Image: A standard stan



Heroic – Whenever you cast a spell that targets Arena Athlete, target block this turn. The Irean Games award no medals. Athletes vie for a visit from Ireas, god of victory. 2/11

#### **Opponent life**





#### My life total: 6







he battlefield under your control, Foundry Street Denizen gets +1/+0 mill end of turn. After the Foundry Street riot, Arrester Hubbeit tried to ban bladgeon; Which, newitably, resulted in another riot.



reature enters ir control, gets +1/-0 lot, Arreater const. Which, her rior. 1/1 vora verse

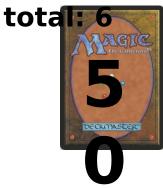




Heroic — Whenever you cast a spell that targets Arena Athlete, target creature an opponent controls can't block this turn. The Ircan Games carard no medals. Athletes vie for a visit from Iroas, god of victory. 2019









My life total: 6









Raid — War-Name Aspirant enters battleffield with a \*11\*1 countre of you attacked with a ercanare tills in War-Name Aspirant can't be block creatures with power 1 or less. No battle means mon, to g March to than the one that earth fer two manne







Heroic – Whenever you cast a spell that targets Arena Athlete, target creature an opponent controls can't block this turn. The Iroan Games aturn aro medula. Athletes the for a wish from Iroas, god of victory. 211



### Sample Game 🔅 🚱 🤣 🚱 🚺

#### **Opponent life**





My life total: 6















### Attack Analysis

💱 🎲 🤣 🚱 🚺

Opponent life tetal: 6 Option 1:

- Attack With Both our creatures, hope Bob doesn't block.
- Lightning bolt to kill Bob





### Attack Analysis

#### 🎲 🎲 🤣 🚱 🚺

**Opponent life** tetal: 6 Option 1:

- Attack With Both our creatures, hope Bob doesn't block.
- Lightning bolt to kill Bob





Bob Blocks = Trade 2/1 for 1/1 and 3/2 for 2/2

### Attack Analysis

🞲 🚱 🤣 🚱 🚺

Opponent life total: 6 Option 2:

- Lightning Bolt Creature 1.
- Attack with War-Name Aspirant
- Leave Bob at 3





#### **Opponent life**





My life total: 6







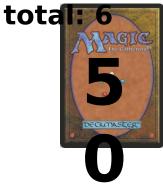


Reid — War-Name Aspirant enters th battlefield with a 414 counter out's you attacked with a creature this turn. War-Name Aspirant can't be blocked creatures with power 1 or less. No battle means nown, to a Mardu surriv from the one that carris her war name.





#### **Opponent life**













Whenever Mardu Shadowspear attacks, each opponent loss: Jelle. Dash 1 & Warnay each thin spill forand it's rearrent from the bottlefeld to its orsner's hand at the boginning of the next end step.

My life total: 6







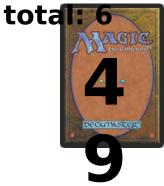


Raid — Wer-Name Asymptote to the sounder on it is you arise as the sound of the sou





#### **Opponent life**













Creature – Human Warrior

10

Whenever Mardu Shadowspear attacks, each opponent loses 4 life. Dash 1 & Chen way can thin spill for its dash cent, IJ you do it same hant, and it's returned from the battlefield to its owner's hand at the beginning of the next end step.)

My life total: 6









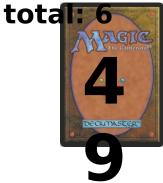
r-Name Aspiran

Reid — War-Name Aspirant enters i battefield with a +1+4 - counter on you attacked with a creature this fur War-Name Aspirant can't be blocke creatures with power 1 or less. No battle means mong to a Maraha start than the one that eartis her trar name.





#### **Opponent life**

















10

My life total: 6







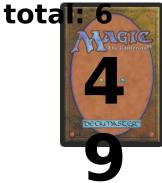


Raid — War-Name Aspirant enters battlefield with a +1/+1 counter or you attacked with a creature thin to War-Name Aspirant can't be block creatures with power 1 or best. No battle means now to a Maraha su than the one that carris her war name that the one that carris her war name there.





#### **Opponent life**











Whenever Blood-Chin Roger attacks, each Warrior constancy our control can't be blocked this turn except by two or more creatures. Kolaghan blades rarely stay clean for long. 212





10

When Mogis's Marauder enters the battlefield, up to X target creatures and of turn, where X is your devotion to black. (Cach 0 in the mana cont of permanents you control counts torcard your devotion to black.) 2/2

#### My life total: 6









r-Namo Achiran

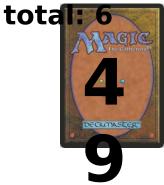
Raid — War-Name Aspirant enters th battlefield with a +1+1 counter on it you attacked with a creature this turn. War-Name Aspirant can't be blocked creatures with power 1 or less. No battle means more to a March starris than the one that carris for taran tane.





### Sample Game 🕸 🚱 🤣 🚱 🚺

### **Opponent life**









**My life** total: 6









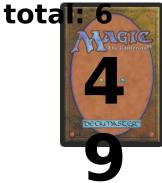
Chase Stone A OOFD Witteds of the CADY



2/2

### Sample Game 🔅 🚱 🤣 🚱 🚺

#### **Opponent life**















10

My life total: 6







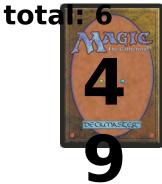








#### **Opponent life**







10

6

#### My life total: -2









Raid — Ware-Name Aspirant enters by a stacked with a creature this to war-Name Aspirant can't be blocks creatures with power 1 oc less. No battle means mon, to a Marah war how the one that carefore for war more





### Why did we lose?



 Playing against black, we should have been suspicious of bile blight





### Why did we lose?

10

 People playing these 3 cards are usually playing the fourth







- Modelling our opponent's hand is important
- Guessing randomly doesn't help
- Can guess based on opponent plays

# Imperfect Info Games

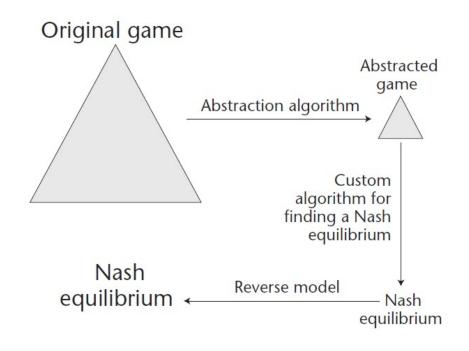


- What are they?
- General Methods for creating
  - Abstraction
  - Sampling

### Abstraction



- Information Abstraction
- Action Abstraction
- Phase Abstraction



# Information Abstraction



- Merge Similar States of the Game
- Agents can't distinguish between merged states
- Eg: Merge hands of similar strength into buckets
- Works with Poker, not so well with Bridge, Skat and MTG

# Action Abstraction

11 2

- Group Distinct Actions Together
- Works in Texas Hold'em
- Eg: Grouping betting actions

# Phase Abstraction



- Some games are played in different phases
- Solve for the phases separately
- MTG seems like a good candidate

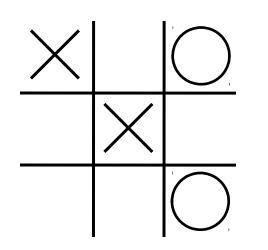
# Sampling Algorithms



- Traverse Selected Nodes In a Game Tree
- Monte Carlo Tree Search (MCTS)
  - Selection
  - Expansion
  - Simulation
  - Back Propagation

11

5



Play for X

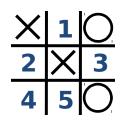


#### Selection





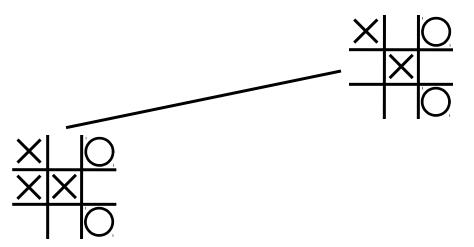
#### Expansion



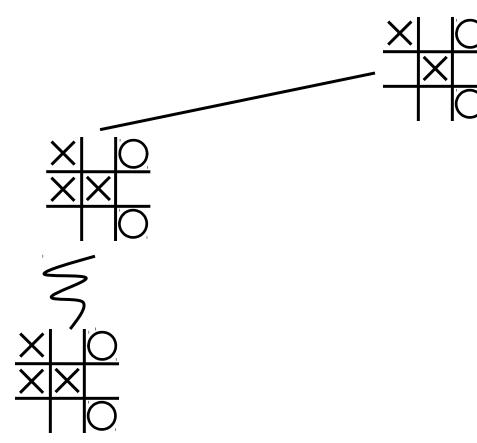
5 Unexplored Children



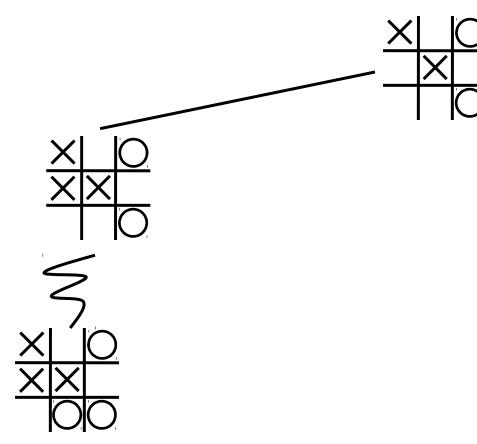




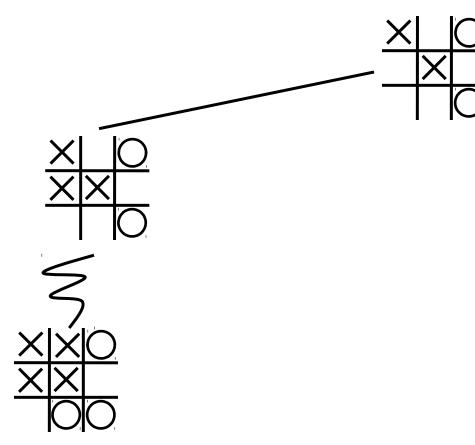




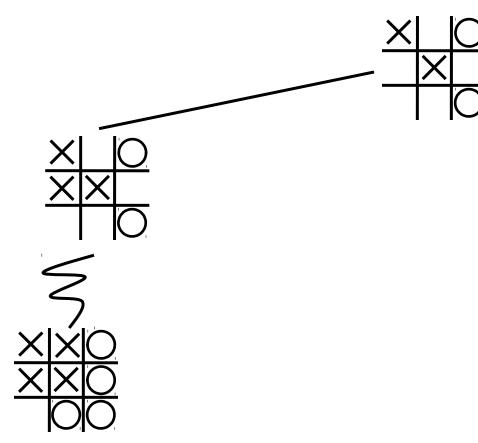






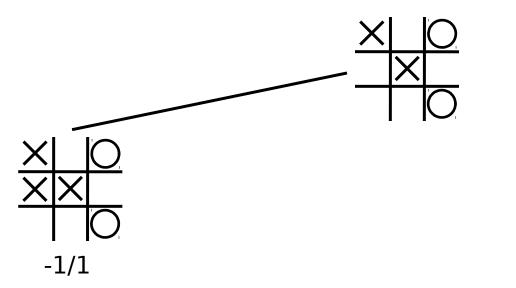






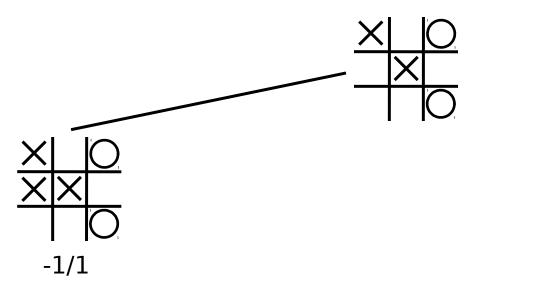


#### Backpropagation





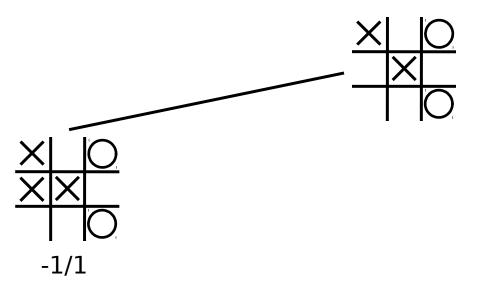
#### Backpropagation



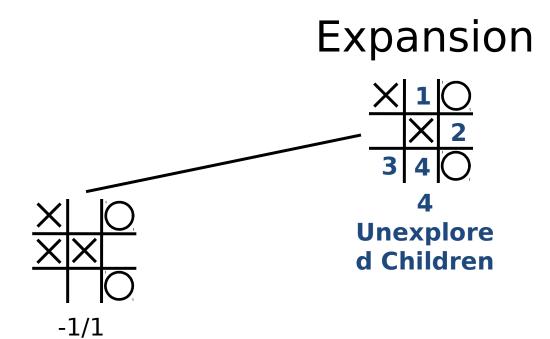
#### **Iteration 1 Complete**



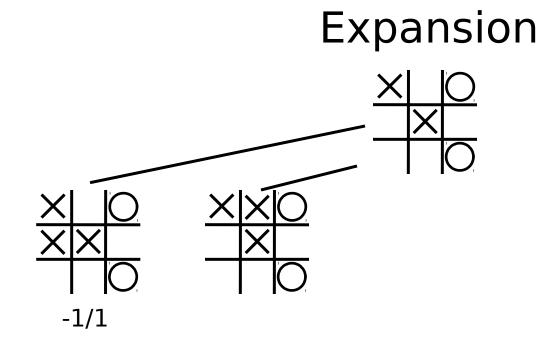
#### Selection



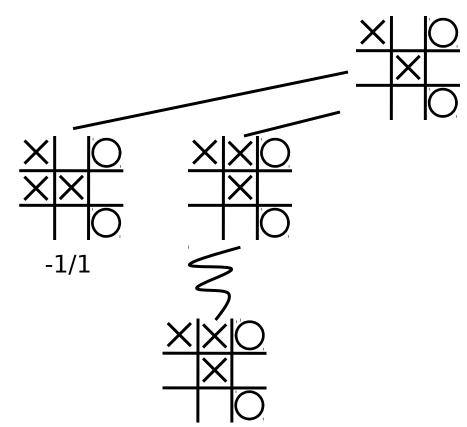




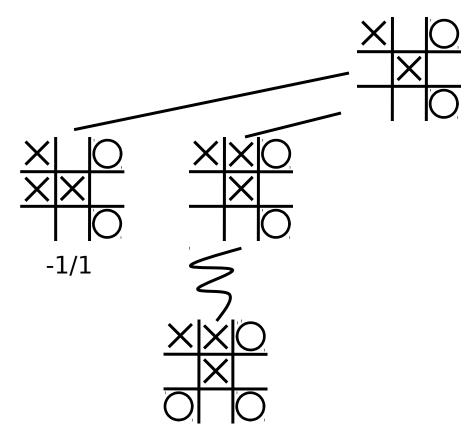




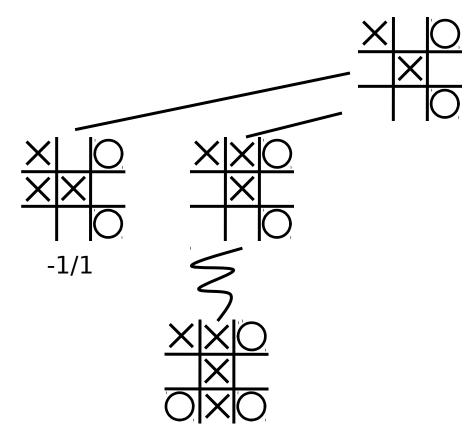






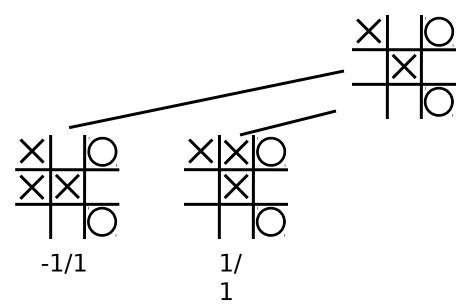






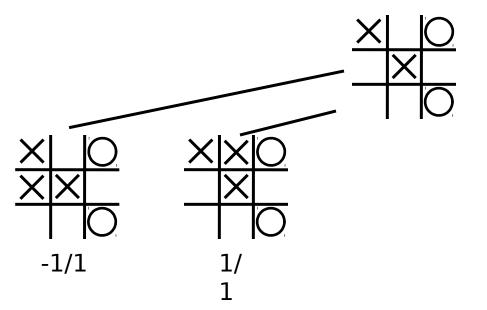


#### Backpropagation



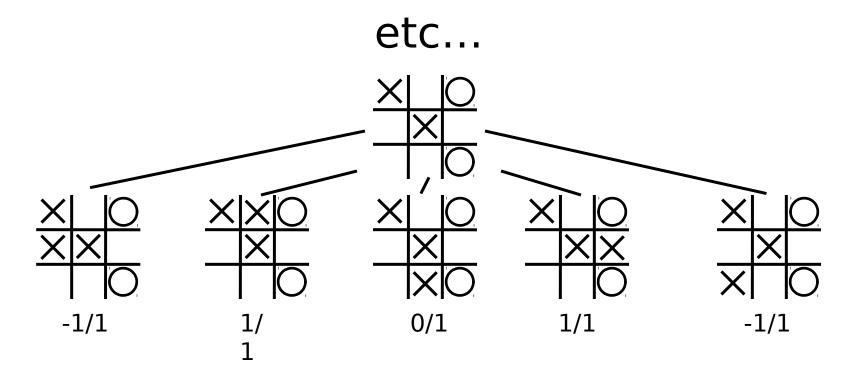


#### Backpropagation



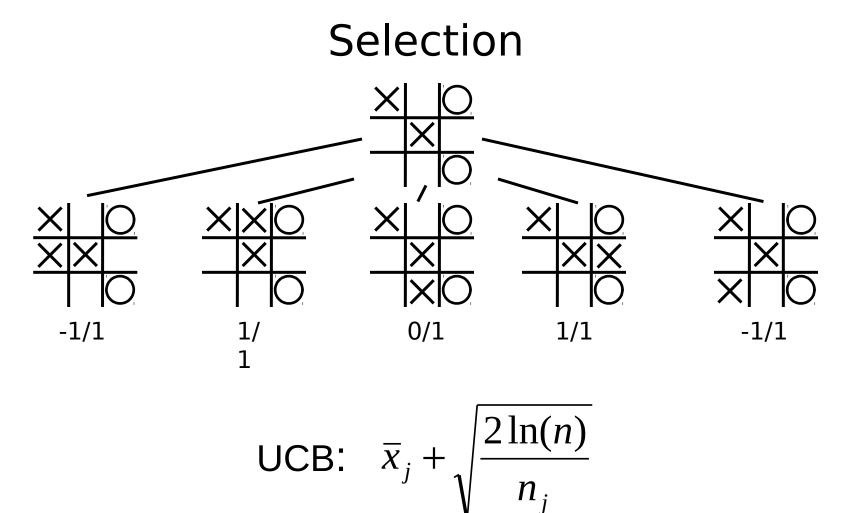
#### **Iteration 2 Complete**



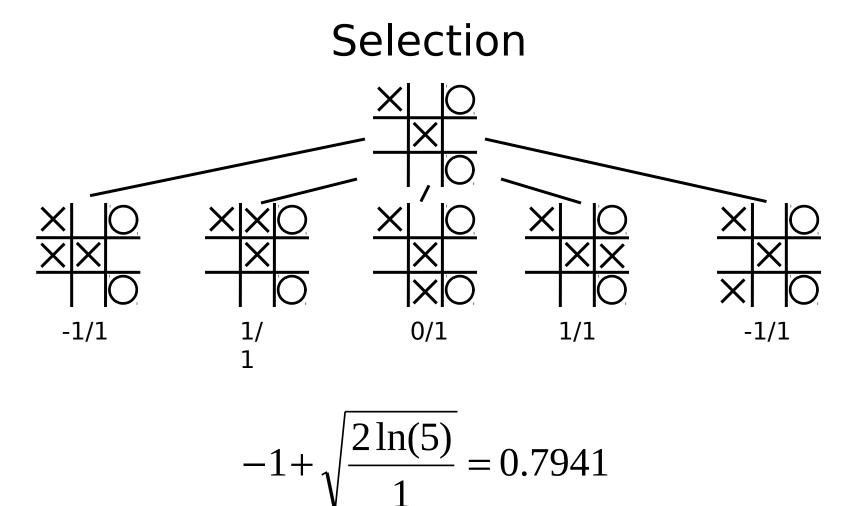


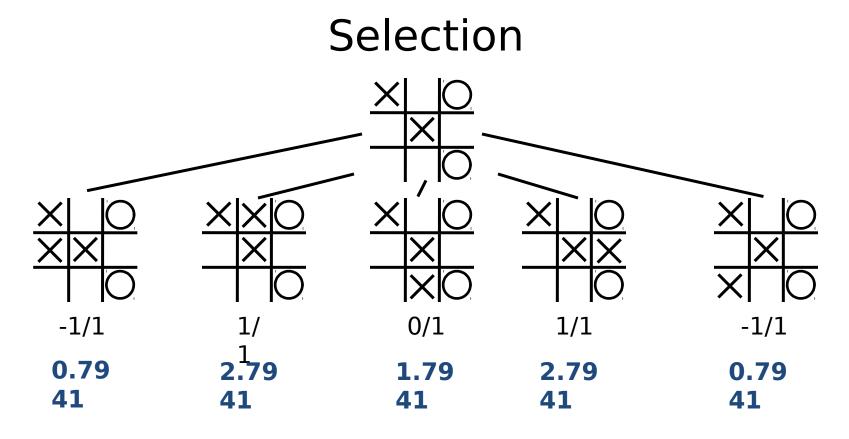
#### Iteration 5 complete



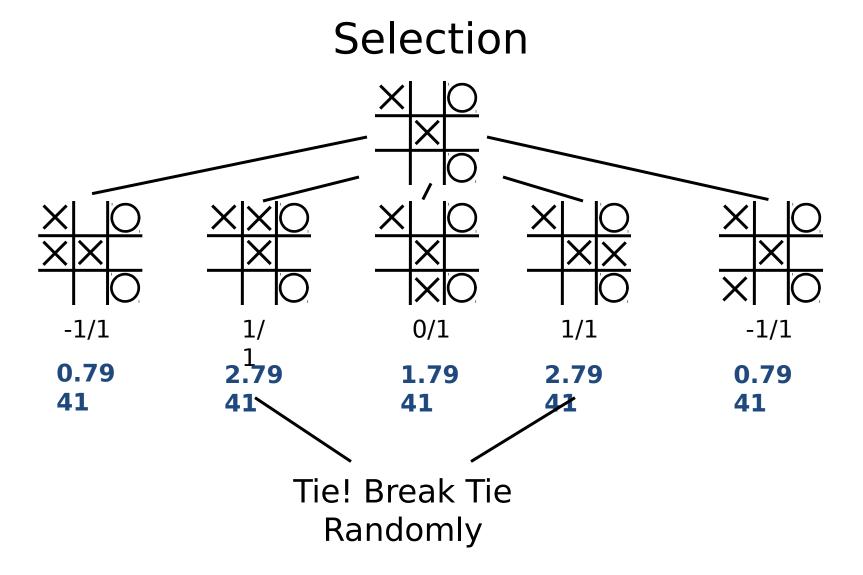




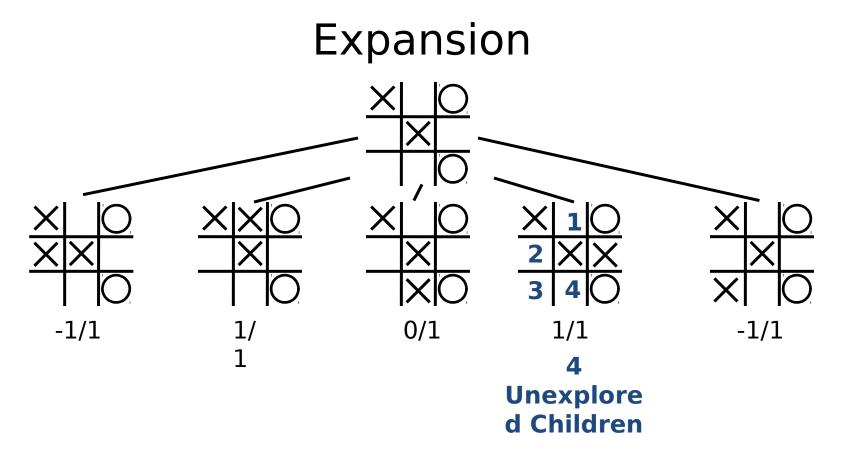




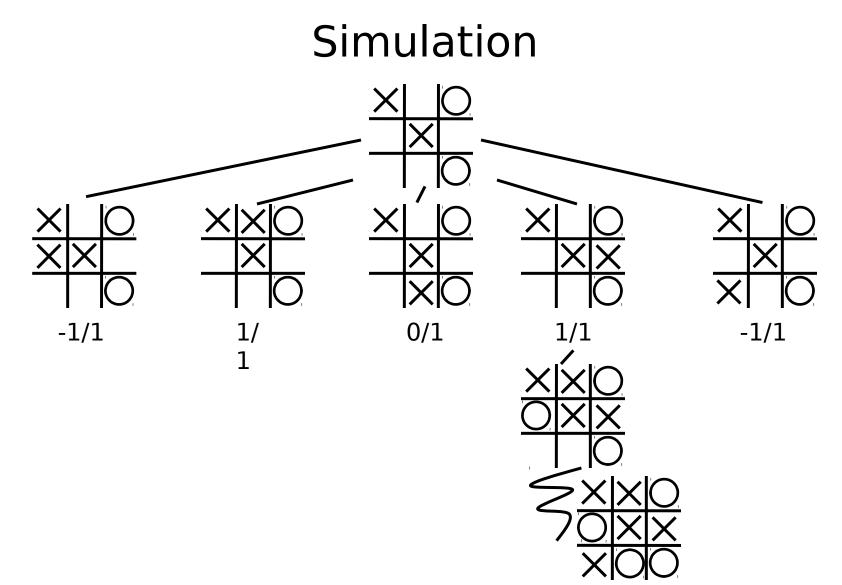




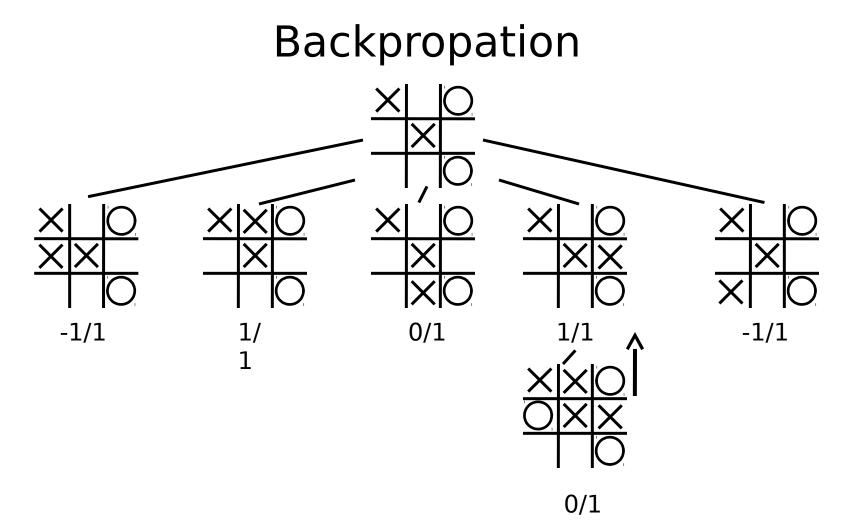
13



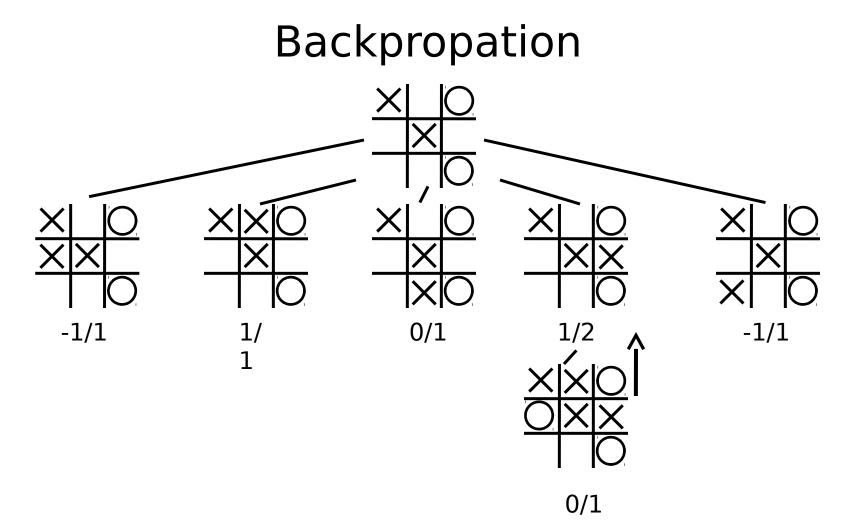




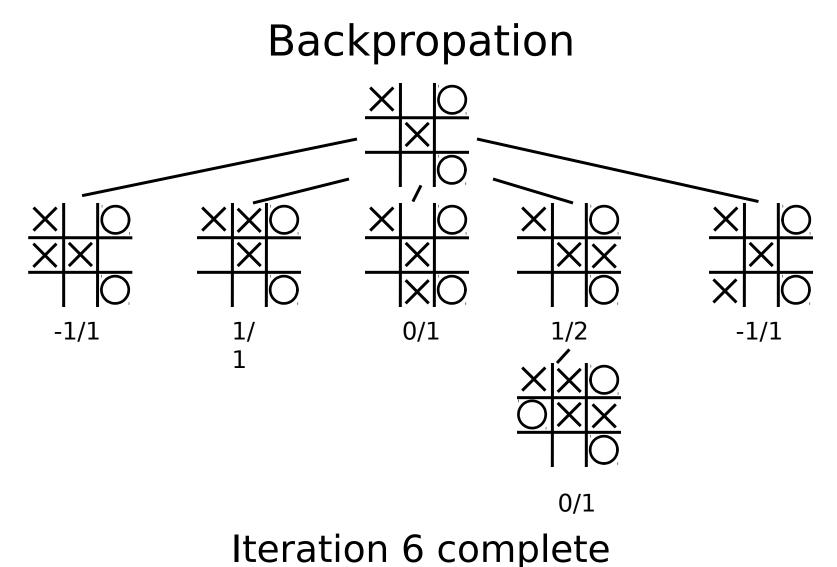






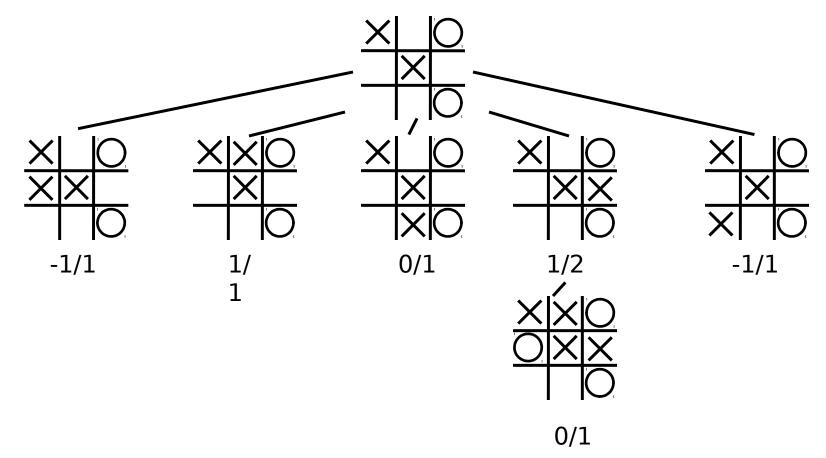






Continue until some predefined limit...

14



# MCTS For MTG



- Peter Cowling
- Perfect Information Mote Carlo Search (PIMC)
  - Sample Possible Worlds
  - Find Beset Move From Worlds
  - Play most chosen move

# PIMC For MTG



- Guess opponent's hand
- Guess exactly how our opponent will draw.
- Guess exactly how we will draw
- Collection of guesses makes a "World"
- Run MCTS on the "World"
- Repeat above

# Cowling et al MTG



- Used PIMC
- MCTS used Strong Heuristic Player + Random
- Downsides:
  - Need to update rules for the agent when card base changes
  - Provided opponent with exact composition of opponent's deck (Unrealistic)

# Our Approach



- Use a sampling algorithm
- Use Disambiguation to gain knowledge
- Use the knowledge to predict opponent's hand
- Random Predictions will lead to bad estimates/bad play
- Better estimate = Reduced # states => Better sampling

# Card Correlation



- What does this mean?
- Required Reasonable Decks

   Required Reasonable Agents
   Deck Building Procedure
- Play off against pre made deck
- Take top 1000 decks, create card correlation matrix

# Card Correlation



	LG	C1 G	C2 G	IG	LU	C1 U	C2 U	IU	LR	C1 R	C2 R	I R	LW	C1 W	C2 W	IW	LB	C1 B	C2 B	I B
LG	10.7839	2.4678	5.0594	4.6664	-2.7898	-0.6287	-1.4409	-1.2534	-2.5365	-0.6145	-1.1482	-1.1208	-2.7117	-0.5753	-1.269	-1.1018	-2.746	-0.6466	-1.3247	-1.0698
C1 G	2.4678	8.2908	1.2272	0.0372	-0.6627	-0.5786	-0.9977	-0.8906	-0.5494	-0.6699	-0.813	-0.7926	-0.6775	-0.6333	-0.9041	-1.0028	-0.5783	-0.6518	-0.8288	-0.7921
C2 G	5.0594	1.2272	12.1429	2.1016	-1.1936	-0.8562	-1.7037	-1.3069	-1.2032	-0.8707	-1.6765	-1.3733	-1.3441	-0.9978	-1.6685	-1.2199	-1.3185	-0.8101	-1.6924	-1.2958
IG	4.6664	0.0372	2.1016	12.6405	-1.1538	-0.864	-1.4779	-1.5416	-1.1087	-0.8669	-1.1813	-1.6215	-1.0933	-0.8831	-1.2192	-1.2959	-1.3106	-0.9426	-1.3507	-1.5348
LU	-2.7898	-0.6627	-1.1936	-1.1538	10.6839	2.4392	4.8019	4.7244	-2.7319	-0.5665	-1.1659	-1.2786	-2.5315	-0.6214	-1.1042	-1.2204	-2.6307	-0.5758	-1.1186	-1.304
C1 U	-0.6287	-0.5786	-0.8562	-0.864	2.4392	8.4824	1.1396	-0.0056	-0.6722	-0.6803	-0.9666	-0.8665	-0.4886	-0.611	-0.8216	-0.9035	-0.6497	-0.6342	-0.8631	-0.9709
C2 U	-1.4409	-0.9977	-1.7037	-1.4779	4.8019	1.1396	12.1412	2.1208	-1.1201	-0.8034	-1.479	-1.0741	-1.0917	-0.9473	-1.7921	-1.3093	-1.1492	-0.8435	-1.7366	-1.2372
IU	-1.2534	-0.8906	-1.3069	-1.5416	4.7244	-0.0056	2.1208	12.6595	-1.3088	-1.0117	-1.2254	-1.6586	-0.995	-0.8267	-1.0572	-1.4848	-1.1673	-0.8635	-1.2479	-1.6597
LR	-2.5365	-0.5494	-1.2032	-1.1087	-2.7319	-0.6722	-1.1201	-1.3088	10.4879	2.3942	4.8269	4.7135	-2.6492	-0.6047	-1.2422	-1.1756	-2.5703	-0.5596	-1.2608	-1.1294
C1 R	-0.6145	-0.6699	-0.8707	-0.8669	-0.5665	-0.6803	-0.8034	-1.0117	2.3942	8.3779	1.1666	0.2061	-0.6345	-0.6911	-0.9157	-0.9066	-0.5786	-0.6235	-0.8574	-0.8534
C2 R	-1.1482	-0.813	-1.6765	-1.1813	-1.1659	-0.9666	-1.479	-1.2254	4.8269	1.1666	12.248	2.1329	-1.1887	-0.9099	-1.749	-1.3778	-1.3242	-0.9665	-1.9248	-1.2779
I R	-1.1208	-0.7926	-1.3733	-1.6215	-1.2786	-0.8665	-1.0741	-1.6586	4.7135	0.2061	2.1329	12.5473	-1.2298	-0.9487	-1.2944	-1.6145	-1.0844	-0.8153	-1.2609	-1.5658
LW	-2.7117	-0.6775	-1.3441	-1.0933	-2.5315	-0.4886	-1.0917	-0.995	-2.6492	-0.6345	-1.1887	-1.2298	10.8988	2.542	4.9253	4.7042	-3.0064	-0.785	-1.2976	-1.3457
C1 W	-0.5753	-0.6333	-0.9978	-0.8831	-0.6214	-0.611	-0.9473	-0.8267	-0.6047	-0.6911	-0.9099	-0.9487	2.542	8.7958	1.0607	0.1636	-0.7406	-0.8177	-0.8409	-0.9126
C2 W	-1.269	-0.9041	-1.6685	-1.2192	-1.1042	-0.8216	-1.7921	-1.0572	-1.2422	-0.9157	-1.749	-1.2944	4.9253	1.0607	12.0402	2.182	-1.3099	-0.9378	-1.5696	-1.3537
IW	-1.1018	-1.0028	-1.2199	-1.2959	-1.2204	-0.9035	-1.3093	-1.4848	-1.1756	-0.9066	-1.3778	-1.6145	4.7042	0.1636	2.182	12.3901	-1.2063	-0.8879	-1.2378	-1.495
LB	-2.746	-0.5783	-1.3185	-1.3106	-2.6307	-0.6497	-1.1492	-1.1673	-2.5703	-0.5786	-1.3242	-1.0844	-3.0064	-0.7406	-1.3099	-1.2063	10.9535	2.567	5.0017	4.8489
C1 B	-0.6466	-0.6518	-0.8101	-0.9426	-0.5758	-0.6342	-0.8435	-0.8635	-0.5596	-0.6235	-0.9665	-0.8153	-0.785	-0.8177	-0.9378	-0.8879	2.567	8.4919	1.112	0.1903
C2 B	-1.3247	-0.8288	-1.6924	-1.3507	-1.1186	-0.8631	-1.7366	-1.2479	-1.2608	-0.8574	-1.9248	-1.2609	-1.2976	-0.8409	-1.5696	-1.2378	5.0017	1.112	12.1566	2.1423
IB	-1.0698	-0.7921	-1.2958	-1.5348	-1.304	-0.9709	-1.2372	-1.6597	-1.1294	-0.8534	-1.2779	-1.5658	-1.3457	-0.9126	-1.3537	-1.495	4.8489	0.1903	2.1423	12.6162

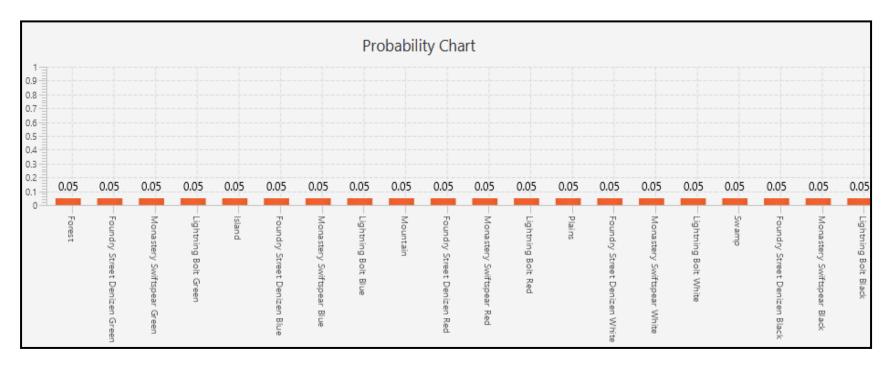
L	Land					
C1	Creature 1					
C2	Creature 2					
- I	Instant					

G	Green
U	Blue
R	Red
w	White
В	Black

#### Prior Knowledge Agent

15 0

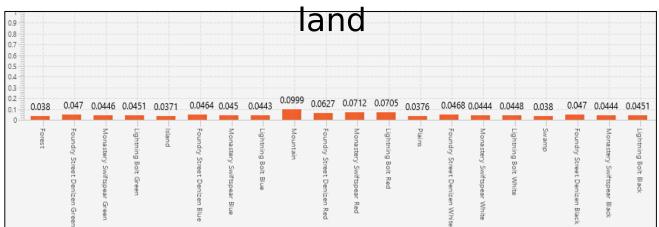
- Should do
  - Better than no knowledge
  - Worse than perfect knowledge



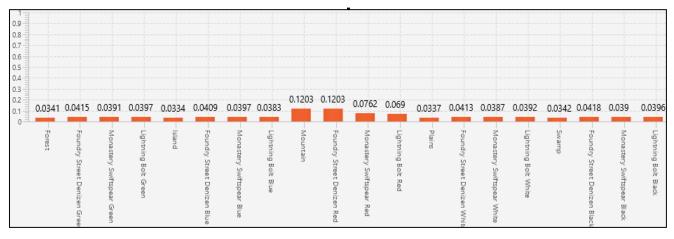
# Prior Knowledge Agent

#### Distribution After seeing a red

15



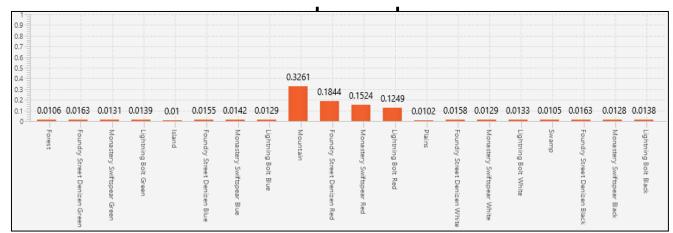
#### Distribution After seeing a red land, red



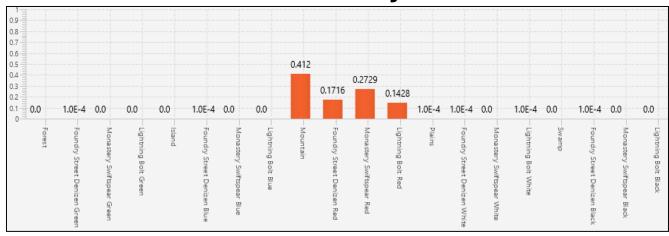
### Prior Knowledge Agent

#### Distribution After seeing a few more

15

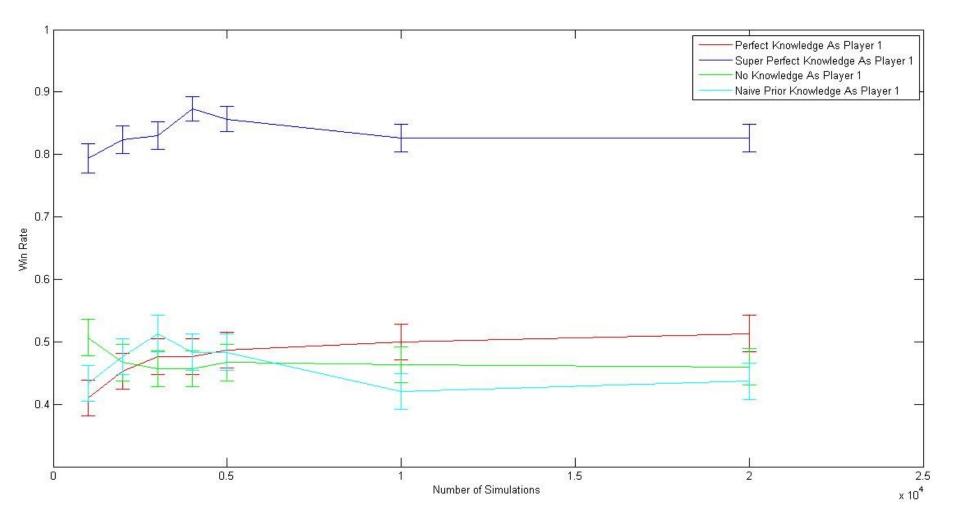


#### Eventually...



### Current Results









- Carry Knowledge Across Games
- Run Experiments With Different Decks
- Model Distributions Over Decks Instead of cards