General vs Symbolized Skirmish

General:

minimax depth 1	21 nodes in	77 msec
minimax depth 2	421 nodes in	1151 msec
minimax depth 3	9383 nodes in	23532 msec
depthcharge	35 nodes in	1560 msec

Symbolized:

minimax depth 1	21 nodes in	39 msec
minimax depth 2	421 nodes in	335 msec
minimax depth 3	9383 nodes in	5354 msec
depthcharge	35 nodes in	446 msec

Skirmish Grounding and Symbolizing

Before:

2174 base propositions

2048 actions

564194 rules computed in 258,565 msec

After:

2287 base propositions

2177 actions

53884 rules in 48,343 msec

General Game Playing

Game Reformulation

Michael Genesereth
Logic Group
Stanford University

Types of Optimization

Game Optimizations with standard interpreter:
  Logical Optimization, e.g. dropping subgoals
  Objective: compute game tree faster

Game Optimizations with different interpreters:
  Grounding
  Symbolizing
  Objective: compute game tree faster

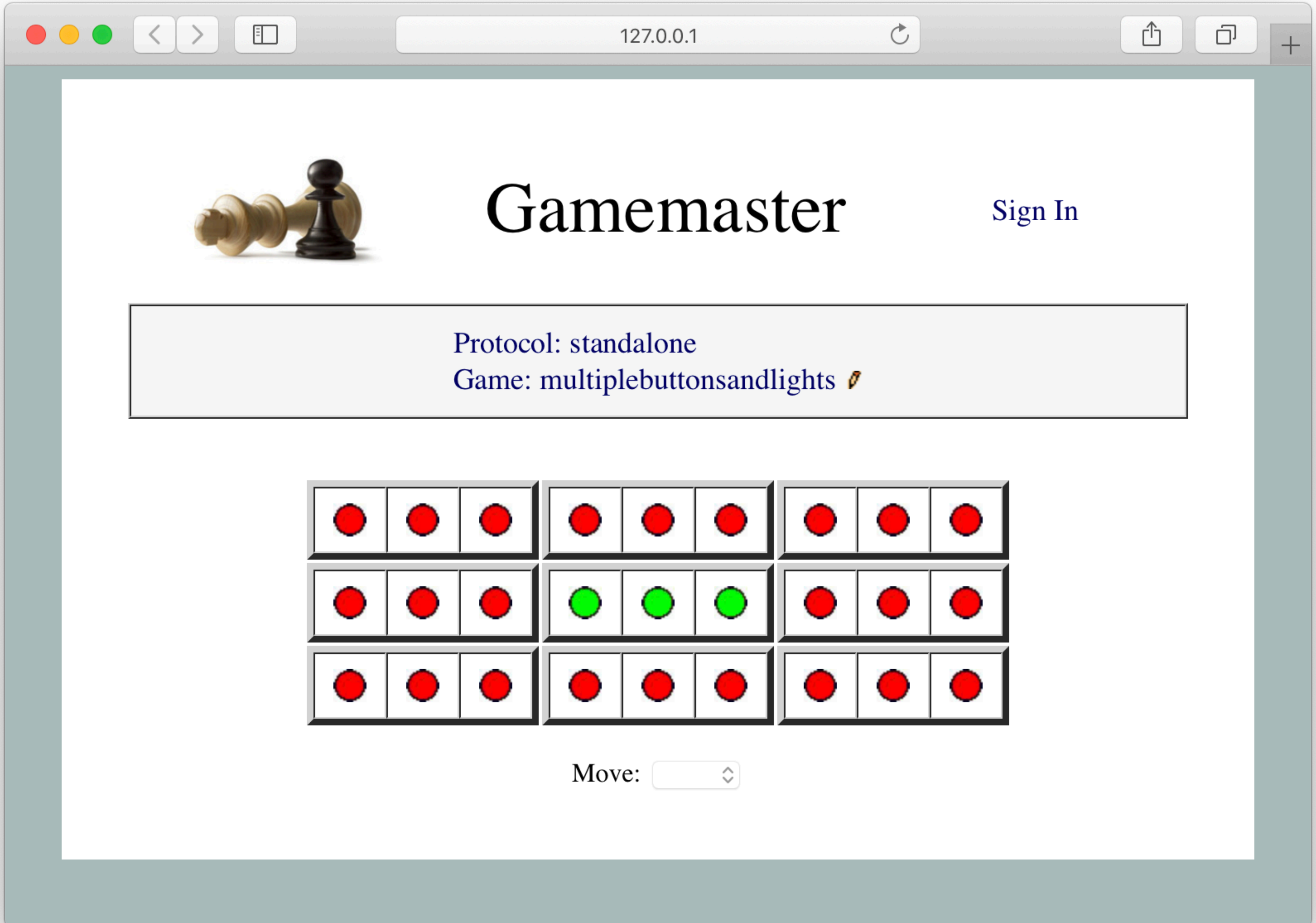
Game Reformulation:
  Pruning game trees
  Decomposing games into independent subgames
  Objective: decrease the size of the game tree

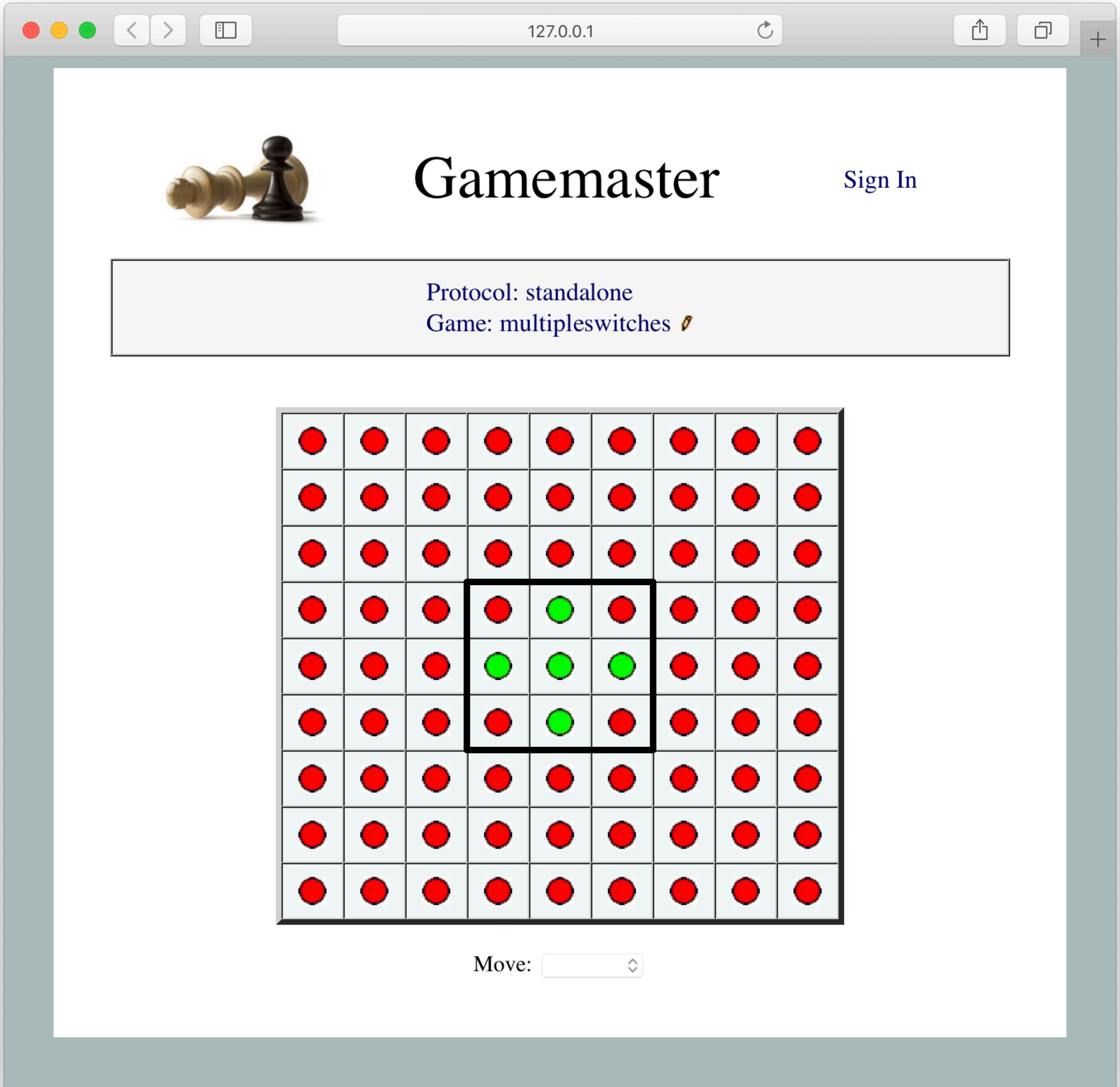
Jester versus Hangman

Multipletictactoe

Egghead versus Maverick

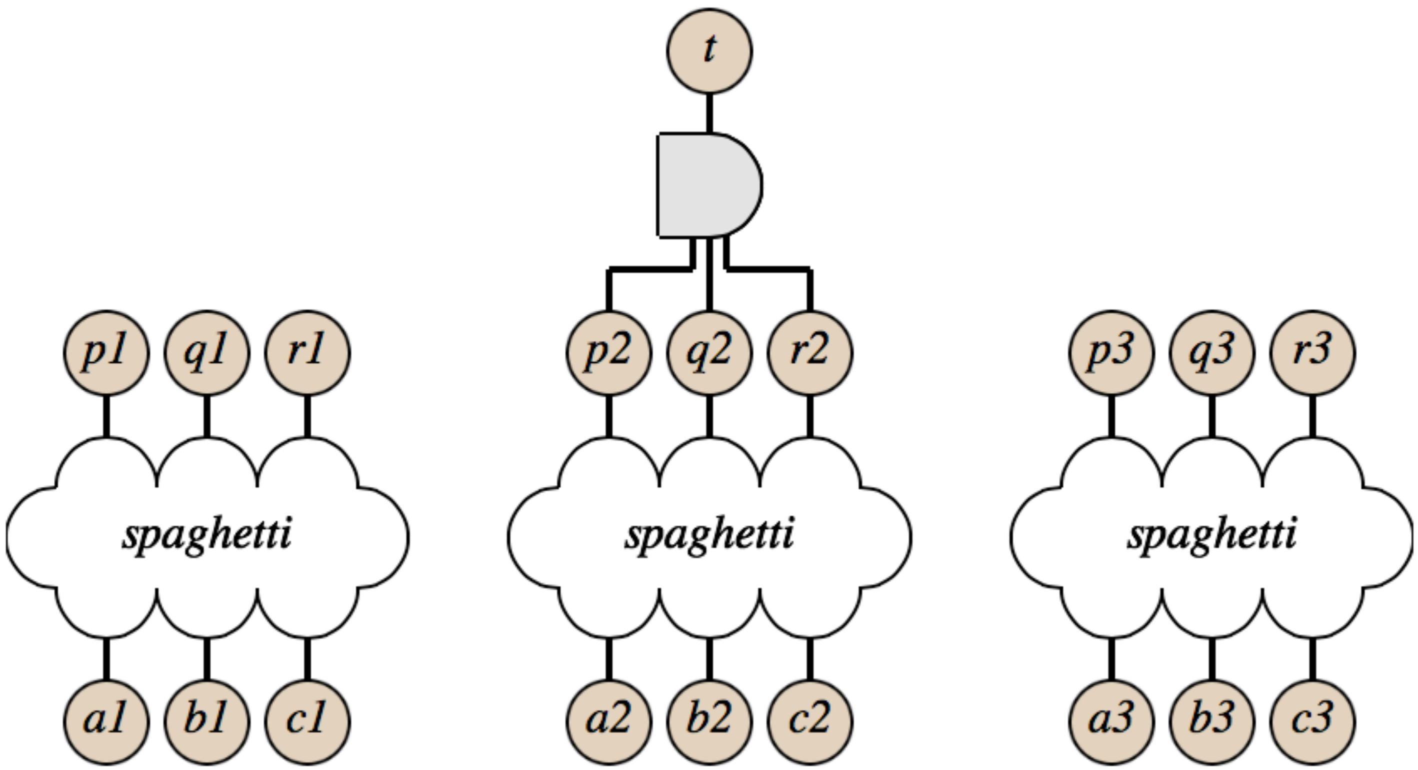
<u>Multipletictactoe</u>


127.0.0.1
Gamemaster
Sign In
Protocol: standalone
Game: multiplebuttonsandlights
Move:

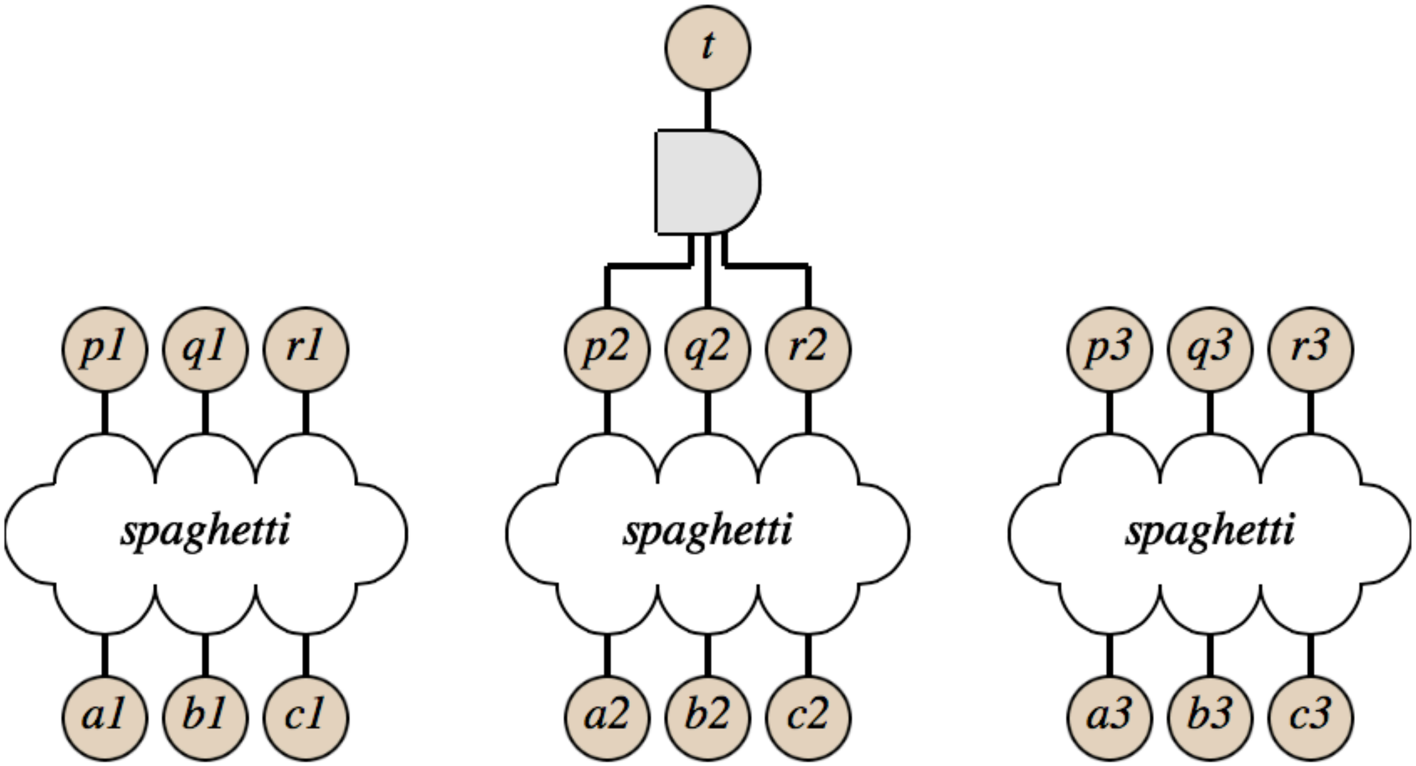

127.0.0.1
Gamemaster
Sign In
Protocol: standalone
Game: multipleswitches
Move:

"Multiple" Games

Propnet for "Multiple" Game

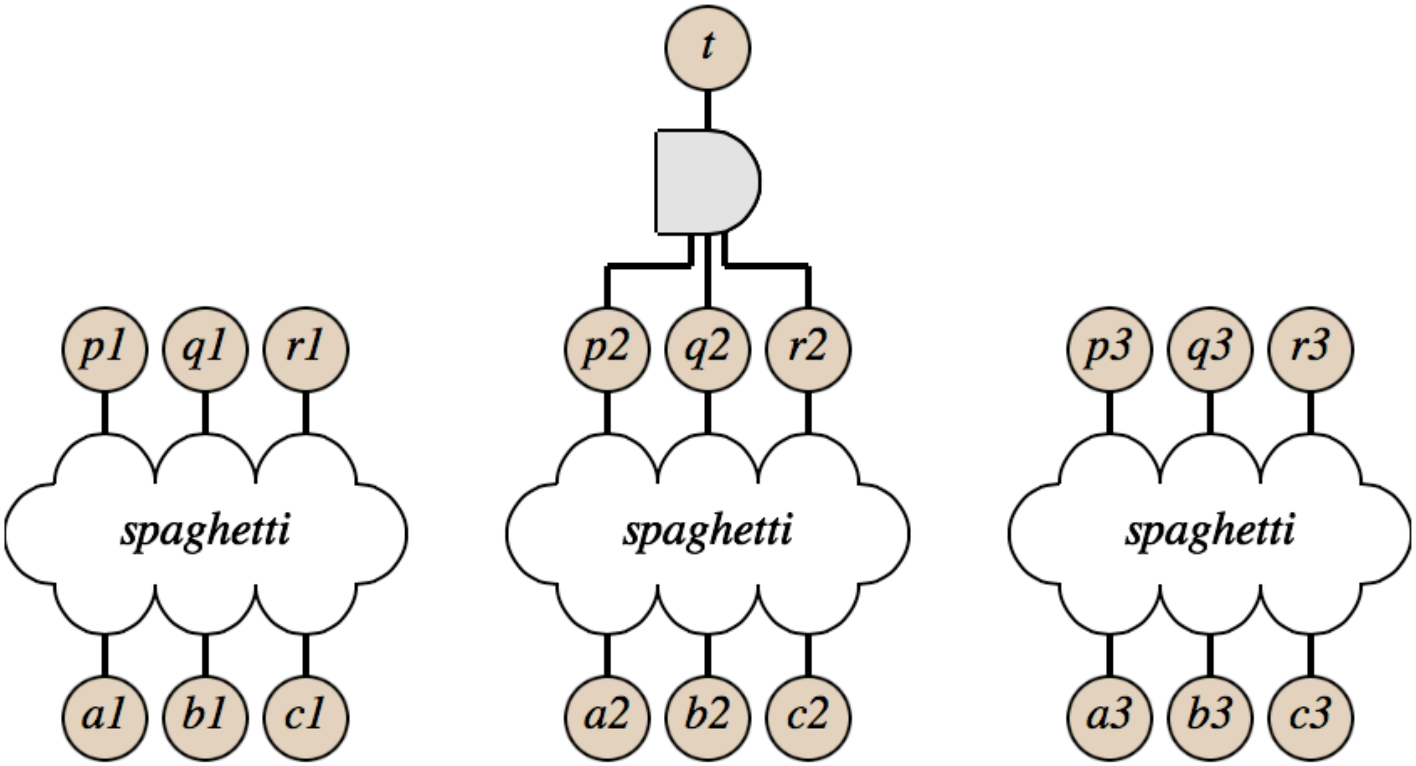


Inertia



t
p1
q1
r1
p2
q2
r2
p3
q3
r3
spaghetti
spaghetti
spaghetti
a1
b1
c1
a2
b2
c2
a3
b3
c3

Ultimate Return



Procedure

(1) Ground the Game.

(2) Compute actions affecting goals, termination, legality.

(3) Adjust legalities to eliminate useless actions.

Grounding

```
legal(a(X)) :- index(X) & ~step(X,7)
```

↓

```
legal(a(1)) :- index(1) & ~step(1,7)
legal(a(2)) :- index(2) & ~step(2,7)
legal(a(3)) :- index(3) & ~step(3,7)
legal(a(4)) :- index(4) & ~step(4,7)
legal(a(5)) :- index(5) & ~step(5,7)
legal(a(6)) :- index(6) & ~step(6,7)
legal(a(7)) :- index(7) & ~step(7,7)
legal(a(8)) :- index(8) & ~step(8,7)
legal(a(9)) :- index(9) & ~step(9,7)
```

Actions That Affect Goals

```
goal(robot,100):- p(5)&q(5)&r(5)
goal(robot,50) :- p(5)&q(5)&~r(5)
goal(robot,50) :- p(5)&~q(5)&r(5)
goal(robot,50) :- ~p(5)& q(5)&r(5)
goal(robot,25) :- p(5)&~q(5)&~r(5)
goal(robot,25) :- ~p(5)&q(5)&~r(5)
goal(robot,25) :- p(5)&~q(5)&~r(5)
goal(robot,0)  :- ~p(5)&~q(5)&~r(5)
```

```
a(5) :: ~p(5) ==> p(5)
a(5) :: p(5) ==> ~p(5)
b(5) :: q(5) ==> p(5)
b(5) :: ~q(5) ==> ~p(5)
b(5) :: p(5) ==> q(5)
b(5) :: ~p(5) ==> ~q(5)
c(5) :: q(5) ==> r(5)
c(5) :: ~q(5) ==> ~r(5)
c(5) :: r(5) ==> q(5)
c(5) :: ~r(5) ==> ~q(5)
```

↓

```
{a(5), b(5), c(5)}
```

Termination

```
terminal :- p(5) & q(5) & r(5)
terminal :- step(5,7)

a(5)::step(5,1)==>~step(5,1)&step(5,2)
a(5)::step(5,2)==>~step(5,2)&step(5,3)
              ...
b(5)::step(5,1)==>~step(5,1)&step(5,2)
b(5)::step(5,2)==>~step(5,2)&step(5,3)
              ...
c(5)::step(5,5)==>~step(5,5)&step(5,6)
c(5)::step(5,6)==>~step(5,6)&step(5,7)
```

```
a(5) :: ~p(5) ==> p(5)
a(5) :: p(5) ==> ~p(5)
b(5) :: q(5) ==> p(5)
b(5) :: ~q(5) ==> ~p(5)
b(5) :: p(5) ==> q(5)
b(5) :: ~p(5) ==> ~q(5)
c(5) :: q(5) ==> r(5)
c(5) :: ~q(5) ==> ~r(5)
c(5) :: r(5) ==> q(5)
c(5) :: ~r(5) ==> ~q(5)
```

```
{a(5), b(5), c(5)}
```

Legality of Relevant Actions

```
legal(a(5)) :- index(5) & ~step(5,7)
legal(b(5)) :- index(5) & ~step(5,7)
legal(c(5)) :- index(5) & ~step(5,7)

a(5)::step(5,1)==>~step(5,1)&step(5,2)
a(5)::step(5,2)==>~step(5,2)&step(5,3)
                ...
b(5)::step(5,1)==>~step(5,1)&step(5,2)
b(5)::step(5,2)==>~step(5,2)&step(5,3)
                ...
c(5)::step(5,5)==>~step(5,5)&step(5,6)
c(5)::step(5,6)==>~step(5,6)&step(5,7)
```

↓

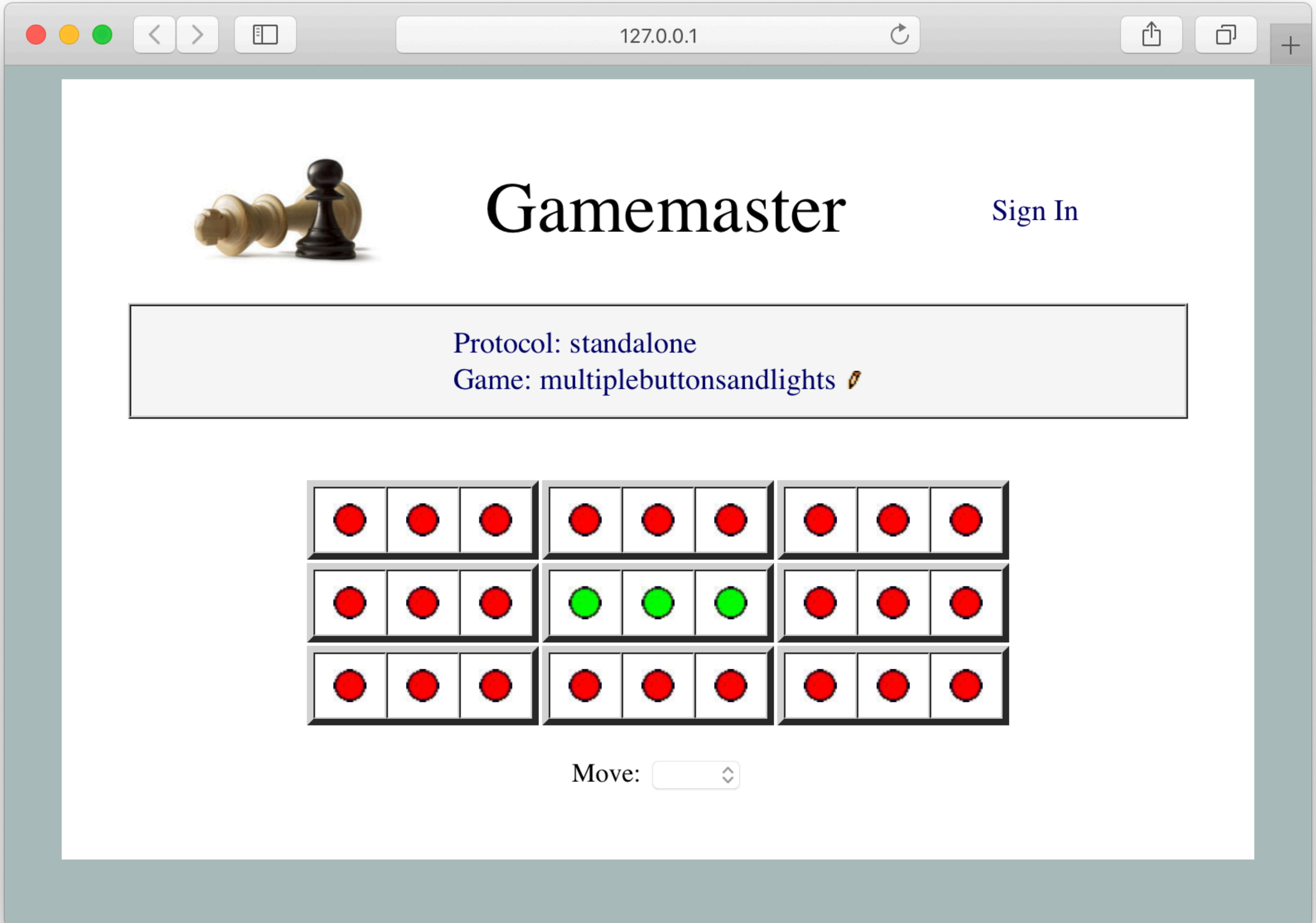
```
{a(5), b(5), c(5)}
```

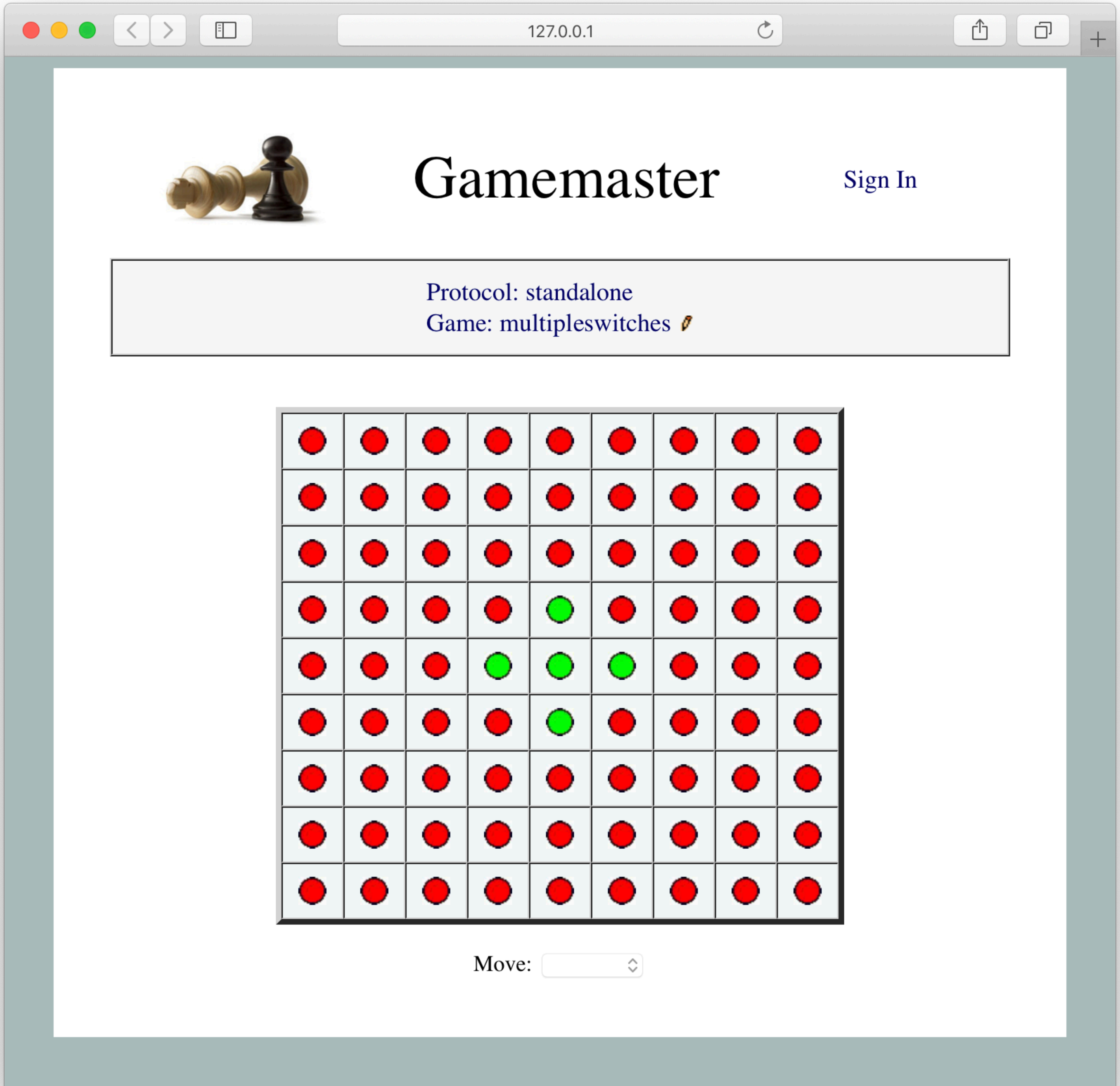
Adjusting Legality

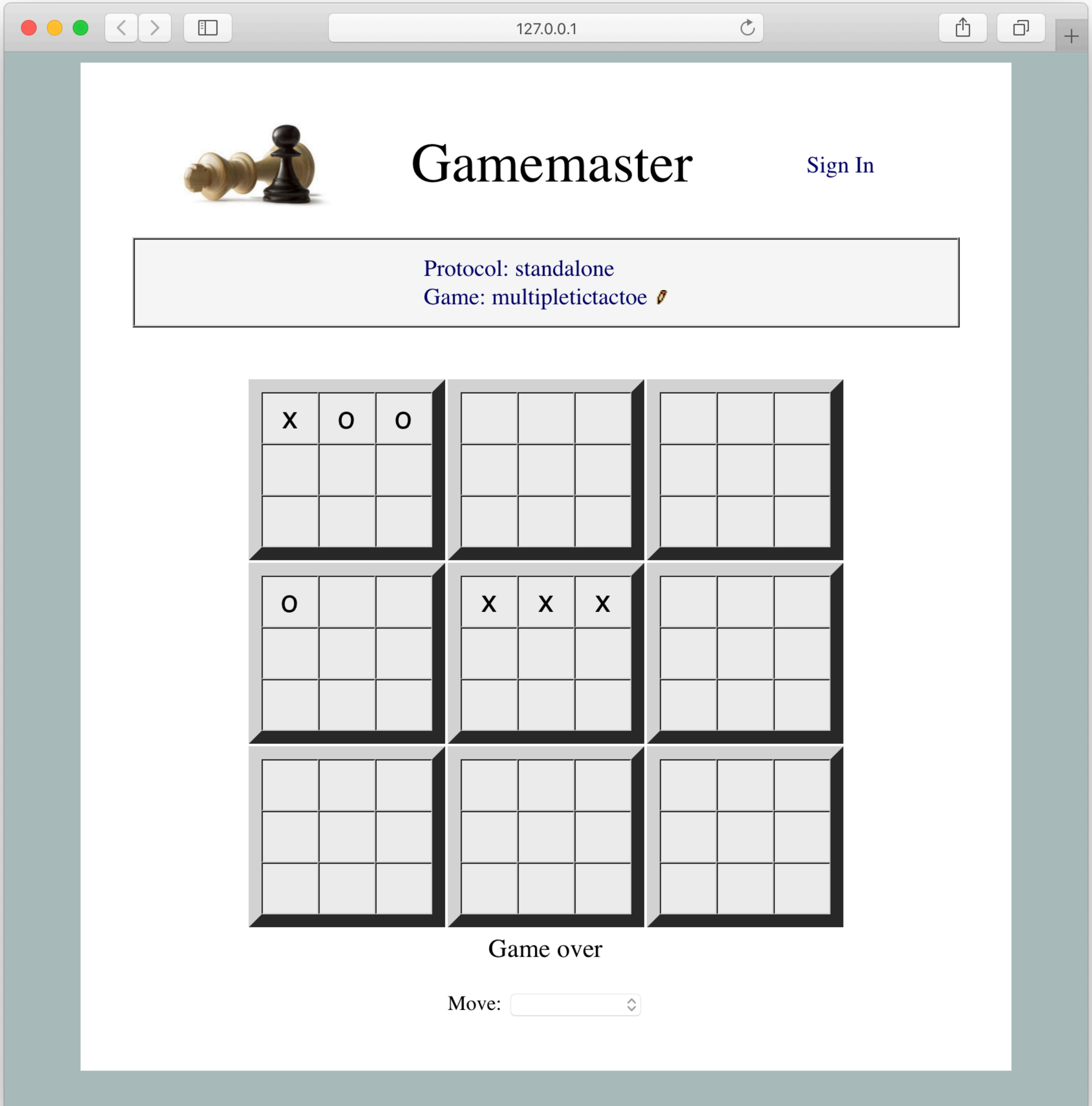
```
legal(a(X)) :- index(X) & ~step(X,7)
legal(b(X)) :- index(X) & ~step(X,7)
legal(c(X)) :- index(X) & ~step(X,7)
```

$\Big\downarrow$ {a(5), b(5), c(5)}

```
legal(a(5)) :- index(5) & ~step(5,7)
legal(b(5)) :- index(5) & ~step(5,7)
legal(c(5)) :- index(5) & ~step(5,7)
```


127.0.0.1
Gamemaster
Sign In
Protocol: standalone
Game: multiplebuttonsandlights
Move:


127.0.0.1
Gamemaster
Sign In
Protocol: standalone
Game: multipleswitches
Move:


127.0.0.1
Gamemaster
Sign In
Protocol: standalone
Game: multipletictactoe
X O O
O
X X X
Game over
Move:

Experimental Results

127.0.0.1

Gamemaster

General Game Playing

Game	Depth	Result	Normal Terms	Normal Nodes	Normal Runtime	Simple Terms	Simple Nodes	Simple Runtime
multiplebuttonsandlights	4	50	531441	551881	16700	81	121	6
multipleswitches	5	100	3074591520	~4B	~22M	15120	18730	210
multipletictactoe	3	0	511920	518482	88000	504	586	150

Egghead versus Maverick

Parallelknightthrough

Egghead versus Maverick

<u>Parallelknightthrough</u>

Standard Players

Legal - Legal player

Random - Random player

Onestep - One Step player using intermediate values

Twostep - Two Step player using intermediate values

Minimax - Full Minimax player using intermediate values

Minimaxdepth - Minimax player to fixed depth using intermediate values

Minimaxid - Minimax player with iterative deepening using intermediate values

MCS - Monte Carlo Search - one step player using depth charges

PTS - Minimax player with persistent breadth-first search using intermediate values

Greedy - PTS player with search based on exploration and exploitation

---

Standard Metagamers

Optimizer - performs optimizations on game descriptions.

Materializer - materializes relations used in game descriptions.

Simplifier - simplifies games by eliminating subgoals or rules based on ground facts in the game description.

Grounder - converts game descriptions with variables to fully grounded versions.

Symbolizer - converts game descriptions with variables to fully grounded and symbolized versions (i.e. with all ground atoms converted to propositions).

Pruner - prunes games to include only potentially relevant actions based on dependency analysis of fully grounded game descriptions.

Older General Game Playing Websites

Tiltyard (web site) - allows users to register players for automatic round robin competition against other general game playing programs. Warning: Games on this website do not necessarily comply with the current General Game Playing standard.

GGP.org (web page) - General website on GGP. Contains information on how to develop software for GGP. Warning: Games on this website do not necessarily comply with the current General Game Playing standard.


127.0.0.1
Gamemaster
General Game Playing
Pruner
Game Description:
%%
%%% legal
%%
legal(a(X)) :- index(X) & ~step(X,7)
legal(b(X)) :- index(X) & ~step(X,7)
legal(c(X)) :- index(X) & ~step(X,7)
%%
%%% operations
%%
a(X) :: ~p(X) ==> p(X)
a(X) :: p(X) ==> ~p(X)
a(X) :: step(X,M) & successor(M,N) ==> ~step(X,M) & step(X,N)
b(X) :: q(X) ==> p(X)
b(X) :: ~q(X) ==> ~p(X)
Actions
Rules
Result:
goal(robot,50) :- p(5) & ~q(5) & r(5)
goal(robot,50) :- ~p(5) & q(5) & r(5)
goal(robot,25) :- p(5) & ~q(5) & ~r(5)
goal(robot,25) :- ~p(5) & q(5) & ~r(5)
goal(robot,25) :- p(5) & ~q(5) & ~r(5)
goal(robot,0) :- ~p(5) & ~q(5) & ~r(5)
terminal :- p(5) & q(5) & r(5)
terminal :- step(5,7)
successor(1,2)
successor(2,3)
successor(3,4)
successor(4,5)
successor(5,6)
successor(6,7)
legal(a(5)) :- index(5) & ~step(5,7)
legal(b(5)) :- index(5) & ~step(5,7)
legal(c(5)) :- index(5) & ~step(5,7)

127.0.0.1

Gamemaster

Sign In

Software

Standard Players

legal.js - Legal player

random.js - Random player

onestep.js - One Step player

twostep.js - Two Step player

minimax.js - Full Minimax player

minimaxdepth.js - Minimax player with fixed depth

minimaxid.js - Minimax player with iterative deepening

greedy.js - Greedy player

mcs.js - Monte Carlo Search player

Metagamers

grounder.js - Grounding subroutines

symbolizer.js - Symbolizing subroutines

pruner.js - Simplification subroutines

Reasoners

general.js - Subroutines for computing properties of games in general representation

ground.js - Subroutines for for computing properties of grounded games

symbol.js - Basic subroutines for computing properties of symbolized games

---

Including Metagaming Code in Players

```
<script src='http://epilog.stanford.edu/javascript/
epilog.js'></script>
<script src='http://gamemaster.stanford.edu/javascript/
localstorage.js'></script>

<script src='http://gamemaster.stanford.edu/metagaming/
grounder.js'></script>
<script src='http://gamemaster.stanford.edu/metagaming/
symbolizer.js'></script>
<script src='http://gamemaster.stanford.edu/metagaming/
simplifier.js'></script>

<script src='http://gamemaster.stanford.edu/metagaming/
pruner.js'></script>

<script src='http://gamemaster.stanford.edu/gameplaying/
pts.js'></script>
<script src='http://gamemaster.stanford.edu/reasoning/
general.js'></script>
```

Old Code

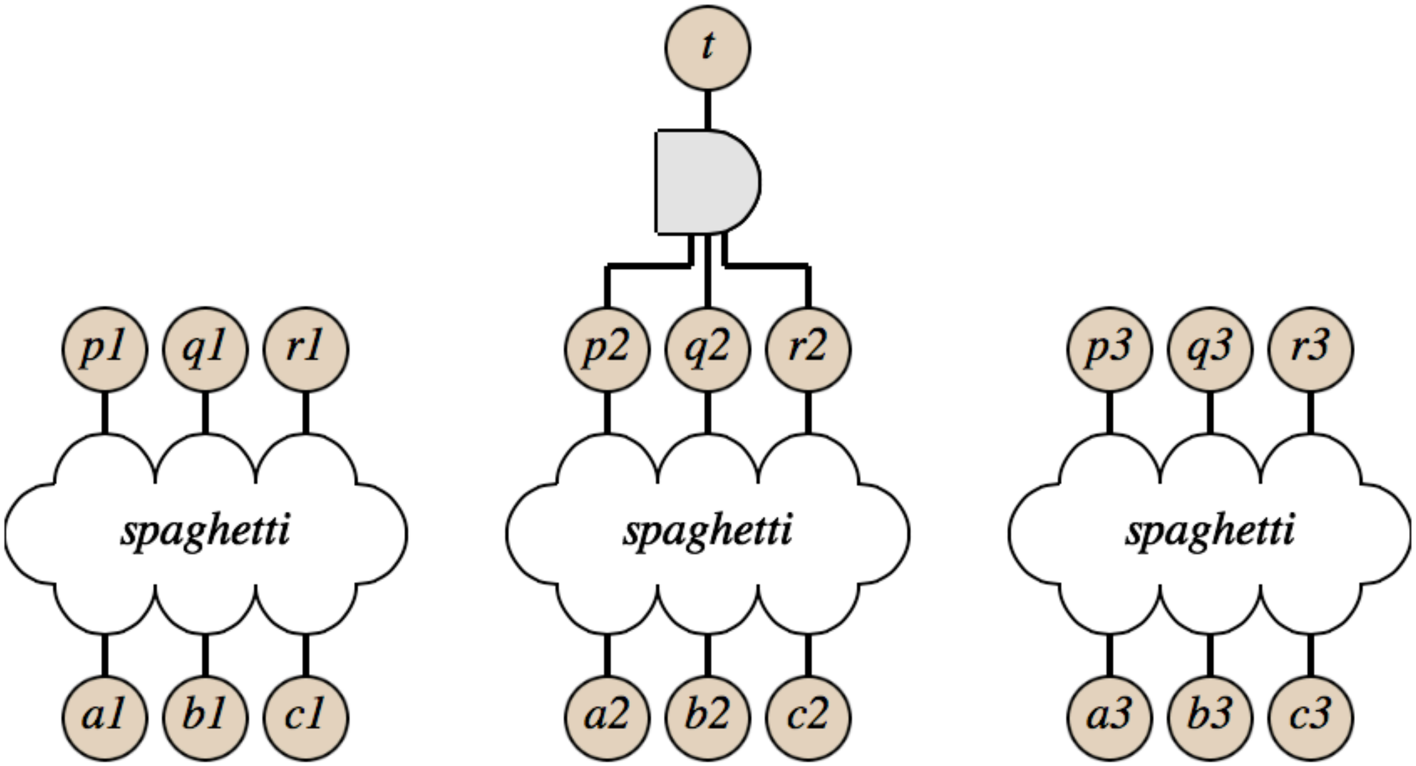
```
function start (r,rs,sc,pc)
 {role = r;
  rules = rs.slice(1)
  startclock = parseInt(sc);
  playclock = parseInt(pc);

  library = definemorerules([],rules);
  roles = findroles(library);
  state = findinits(library);
  return 'ready'}
```

New Code

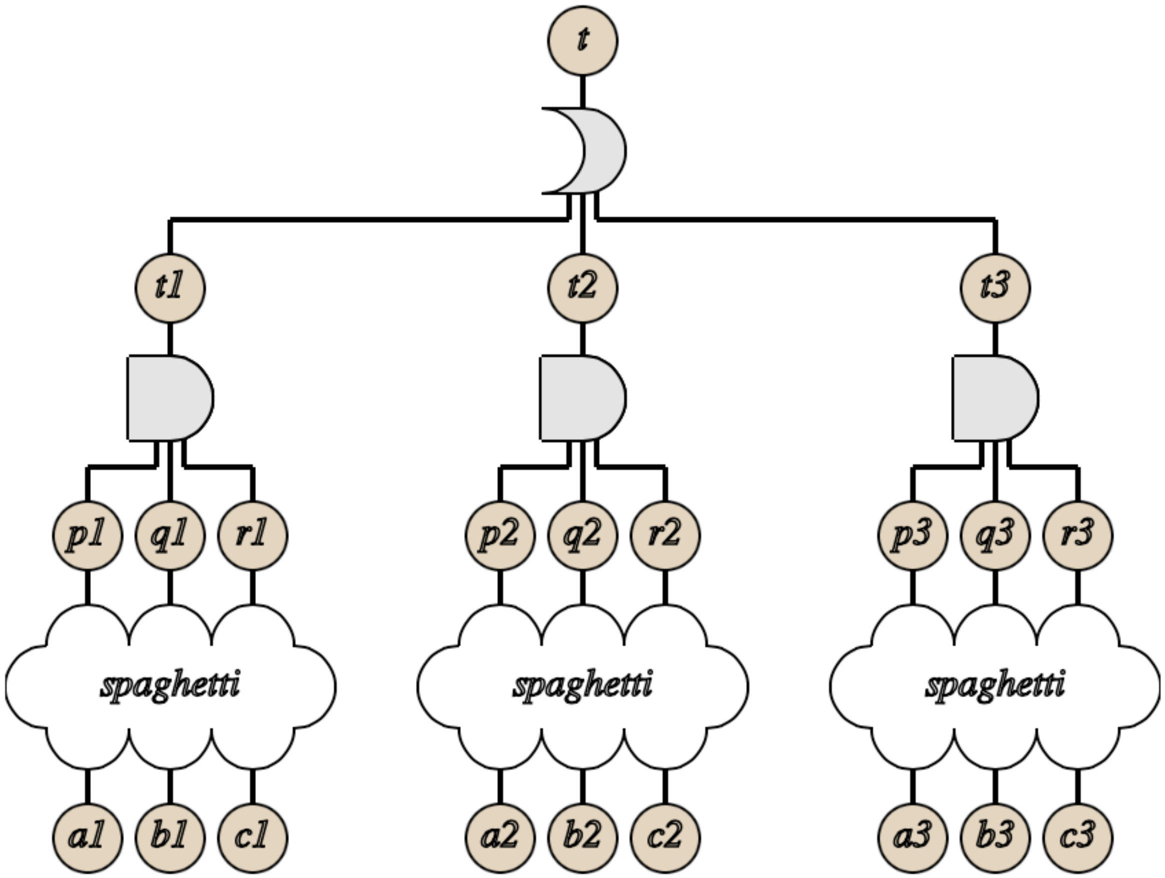
```
function start (r,rs,sc,pc)
 {role = r;
  rules = rs.slice(1)
  startclock = parseInt(sc);
  playclock = parseInt(pc);

  rules = definemorerules([],rules);
  rules = groundrules(rules);
  rules = symbolizerules(rules);
  rules = simplifyrules(rules);

  rules = definemorerules([],rules);
  rules = pruneprogram(rules);

  library = definemorerules([],rules);
  roles = findroles(library);
  state = findinits(library);
  return 'ready'}
```

Game Factoring

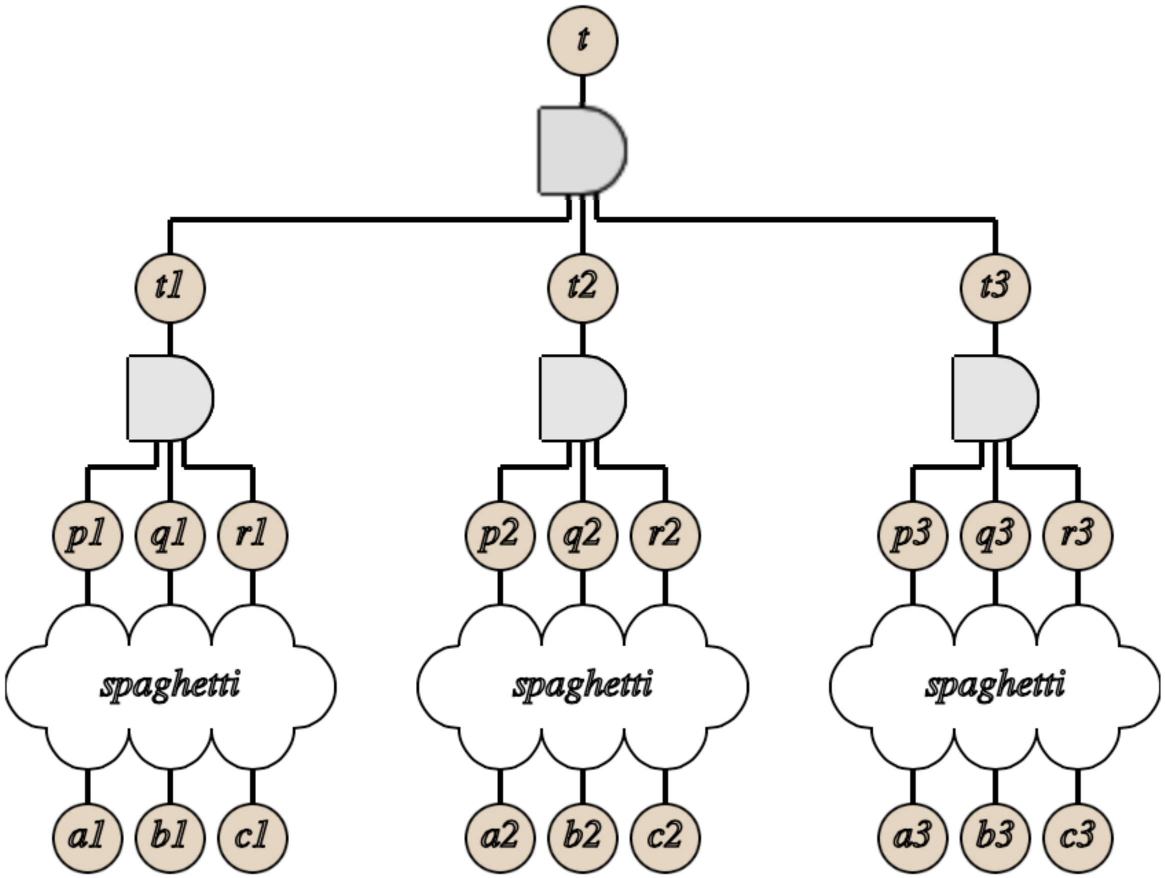
Propnet for a "Multiple" Game



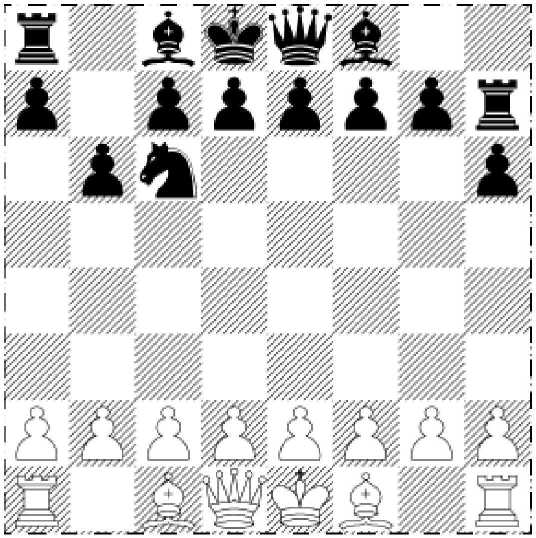
Propnet for a "Best" Game



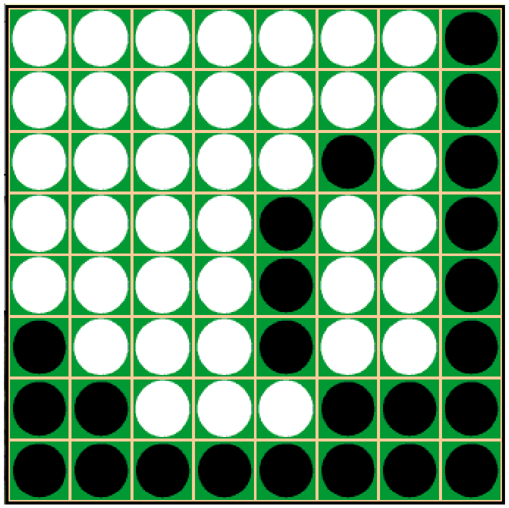
Propnet for a "Joint" Game



Hodgepodge



Branching factor: *a*

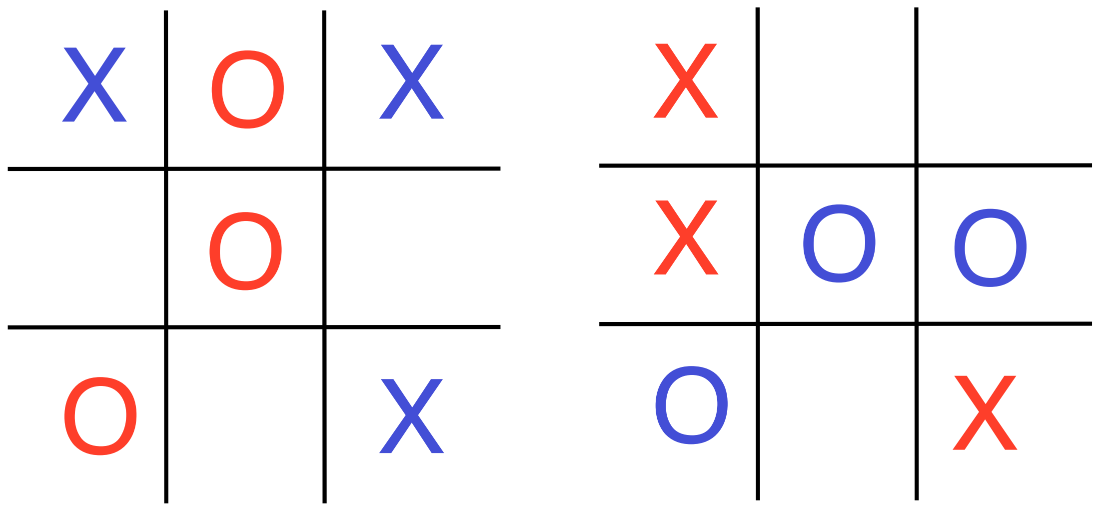


Branching factor: *b*

Analysis of joint game:

- Branching factor as given to players: $a*b$
- Fringe of tree at depth n as given: $(a*b)^n$
- Fringe of tree at depth n factored: a^n+b^n

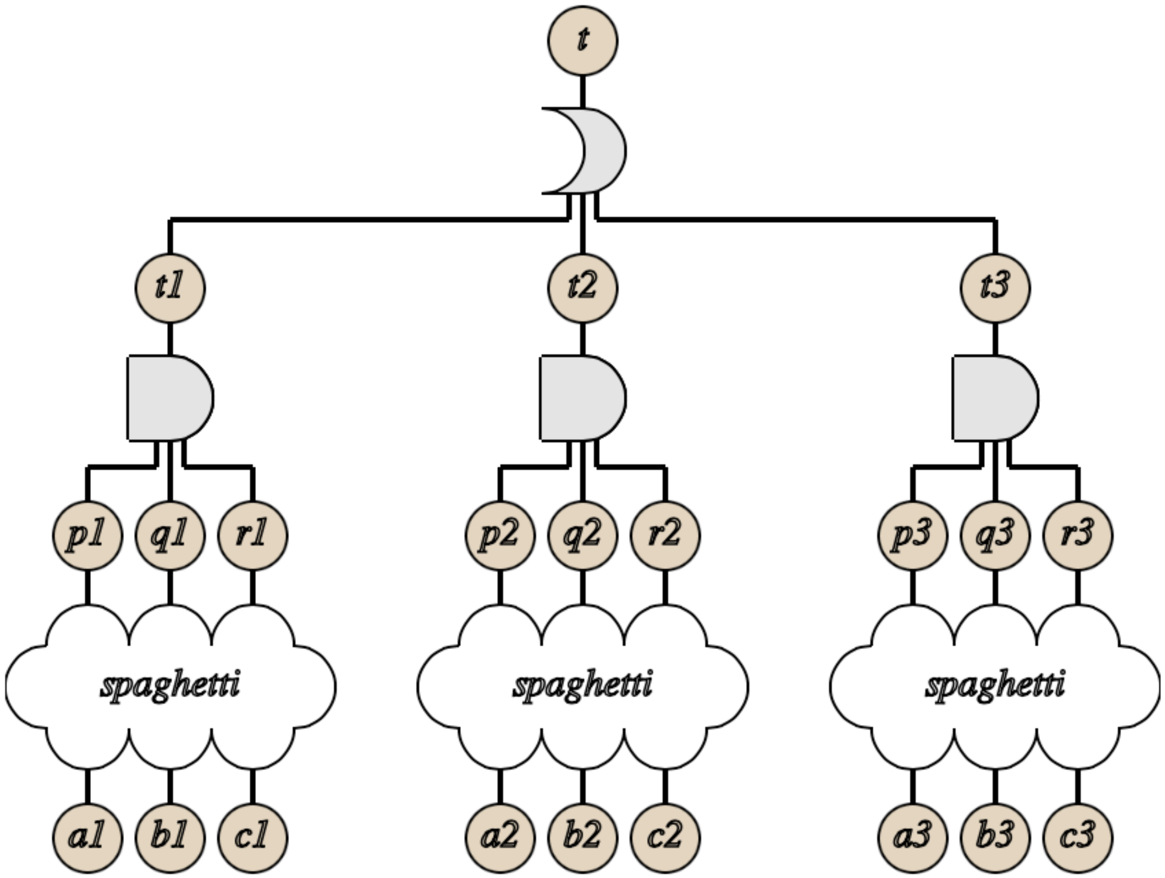
Best Tic Tac Toe



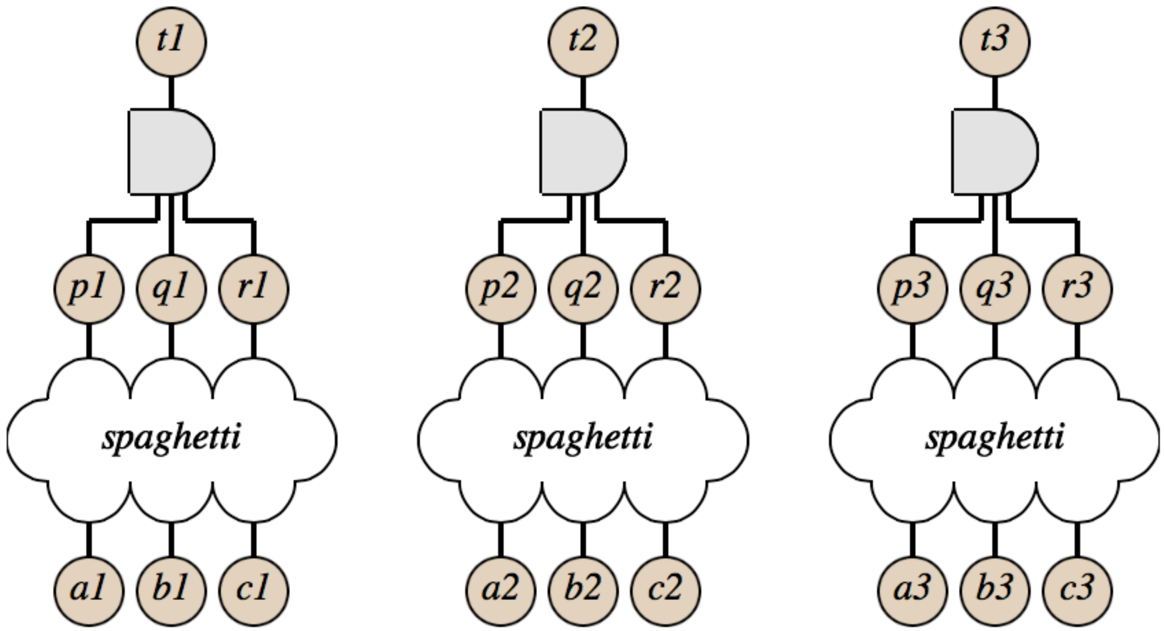
Joint branching factor: 81, 64, 49, 36, 25, 16, 9, 4, 1

Separate branching factor: 9, 8, 7, 6, 5, 4, 3, 2, 1

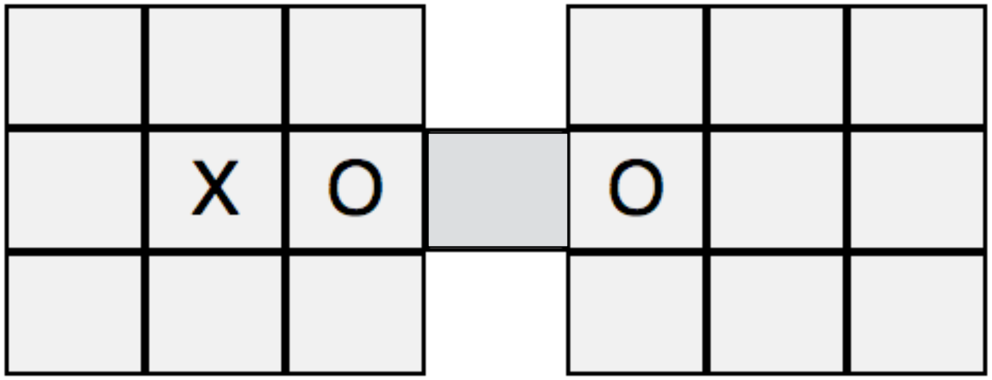
Propnet for a "Best" Game



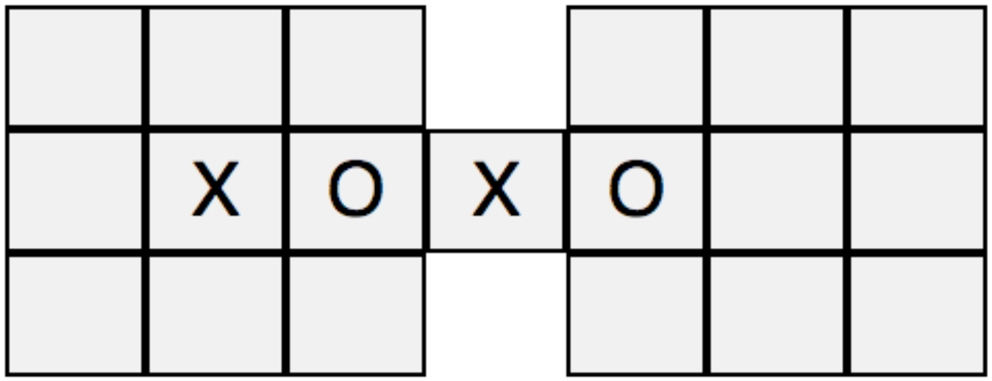
Modified Propnet



Conditional Factoring



Conditional Factoring



Other Techniques

Examples

Bottlenecks

Series of games

each of which must terminate before next begins

Invariant Detection (aka latch detection)

Find states that lead only to max terminal value

Find states that lead only to min terminal value

e.g. step off roof, 0 value from there on out

Goal Monotonicity

Detect monotonicity in states - use as values

e.g. goal values in non-terminal states never decrease


GENERAL
GAME
PLAYING