General Game Playing
Game Reformulation

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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

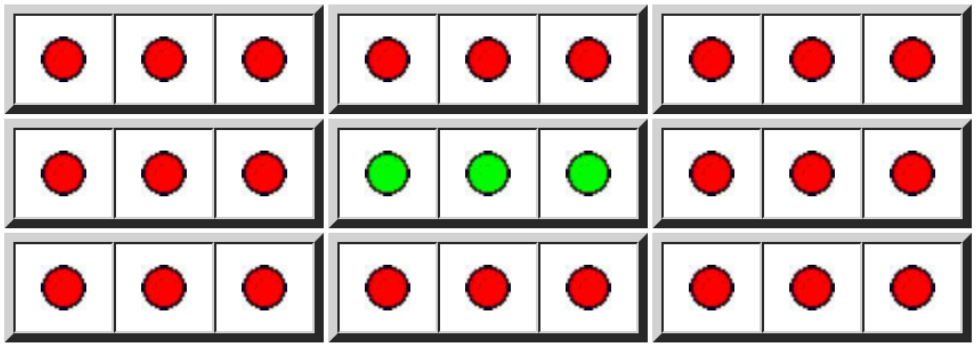
Egghead versus Maverick

Multipletictactoe

Gamemaster

Sign In

Protocol: standalone
Game: multiplebuttonsandlights

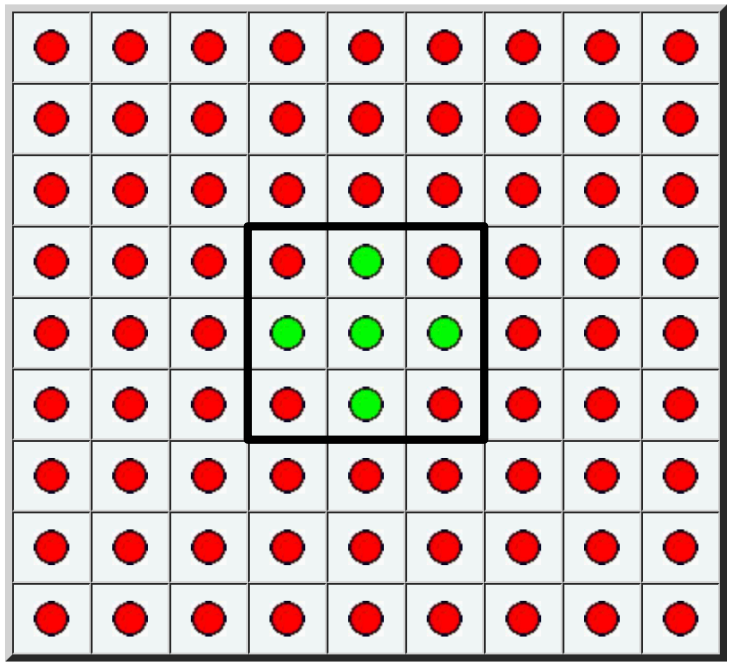


Move:

Gamemaster

Sign In

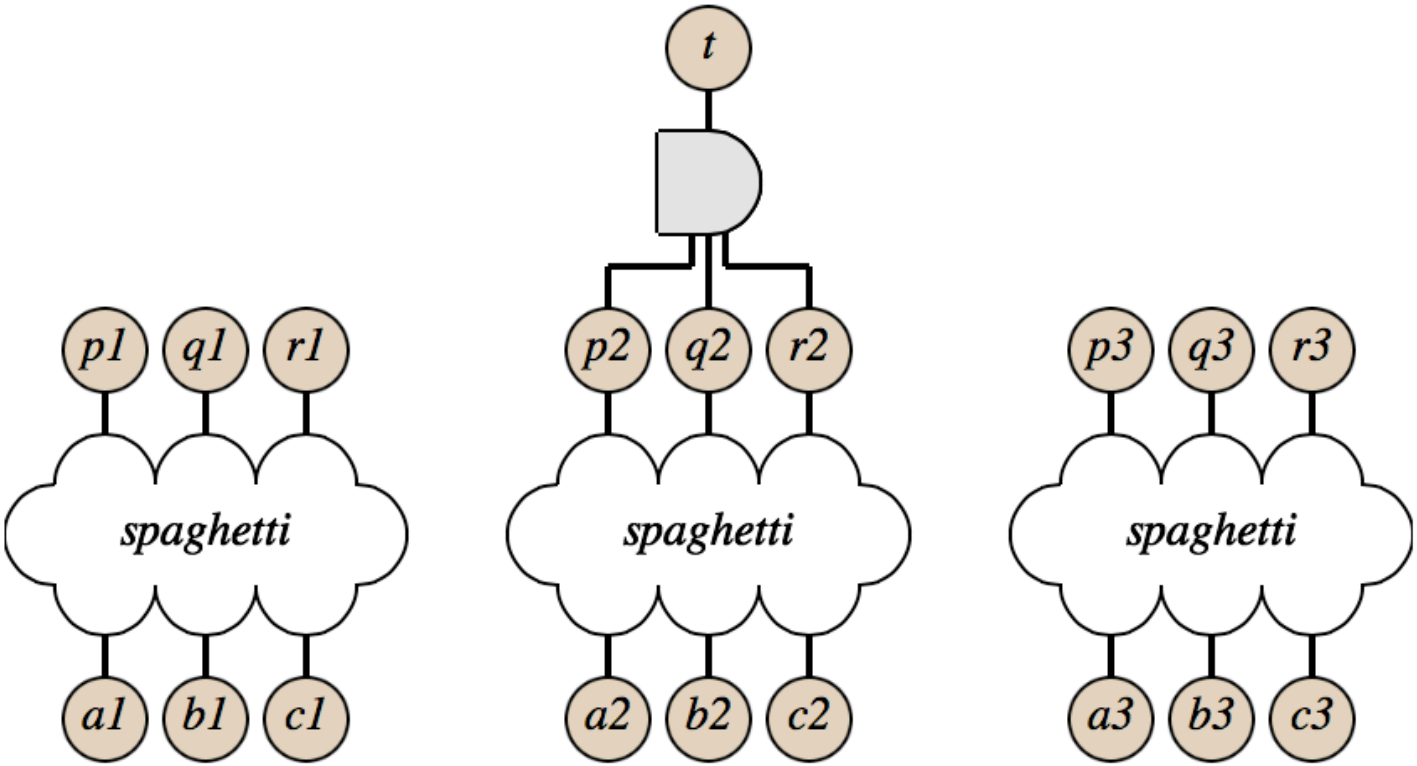
Protocol: standalone
Game: multipleswitches



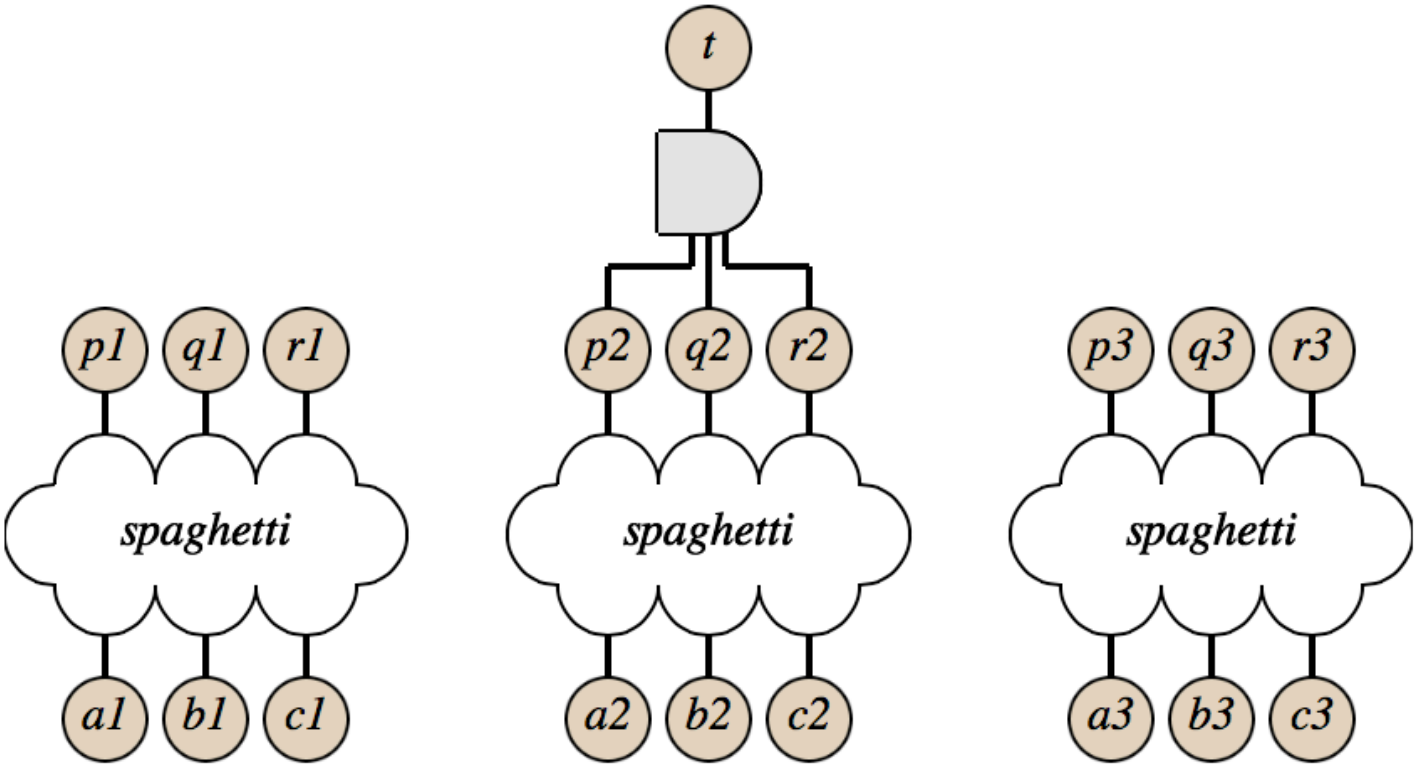
Move:

"Multiple" Games

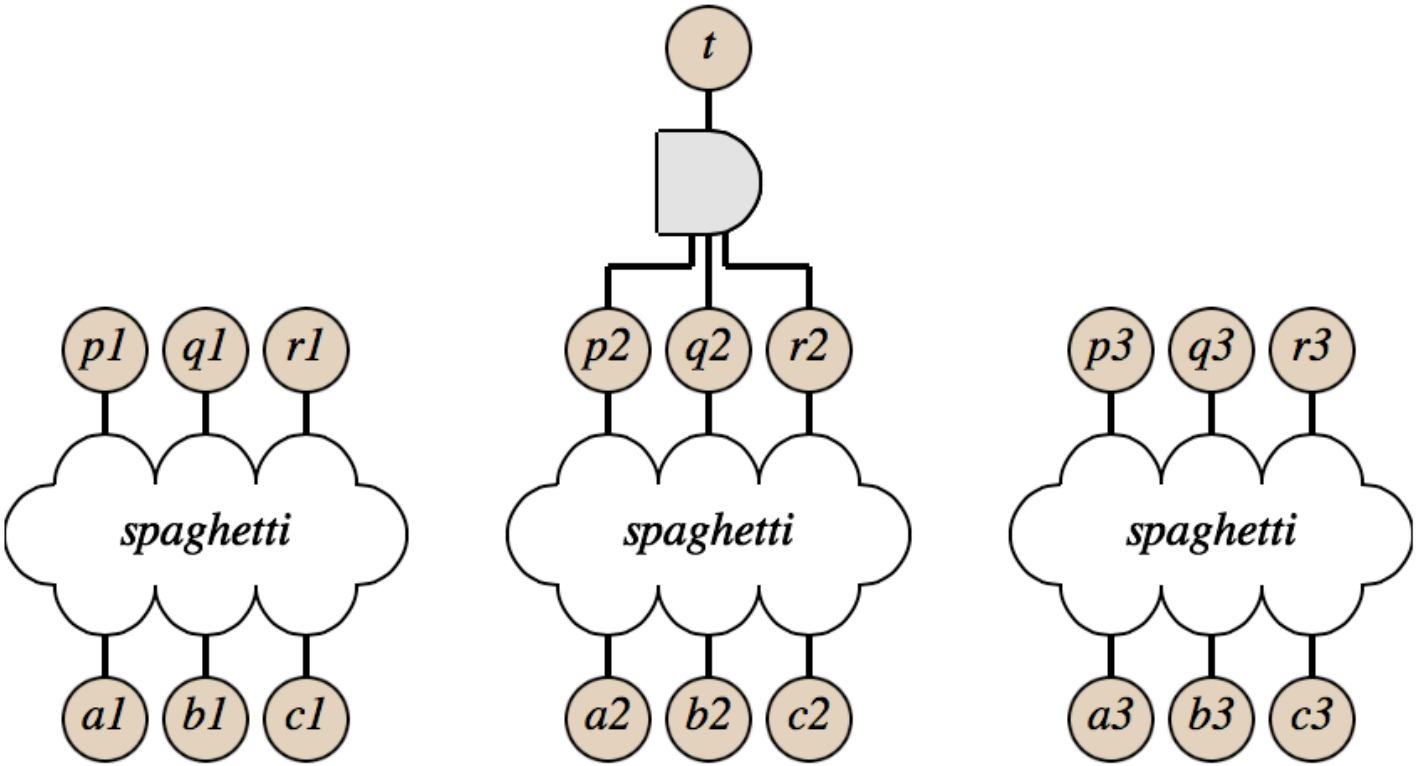
Propnet for "Multiple" Game



Inertia


t
p1
q1
r1
spaghetti
a1
b1
c1
p2
q2
r2
spaghetti
a2
b2
c2
p3
q3
r3
spaghetti
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)}
```

Actions that Affect 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)
```

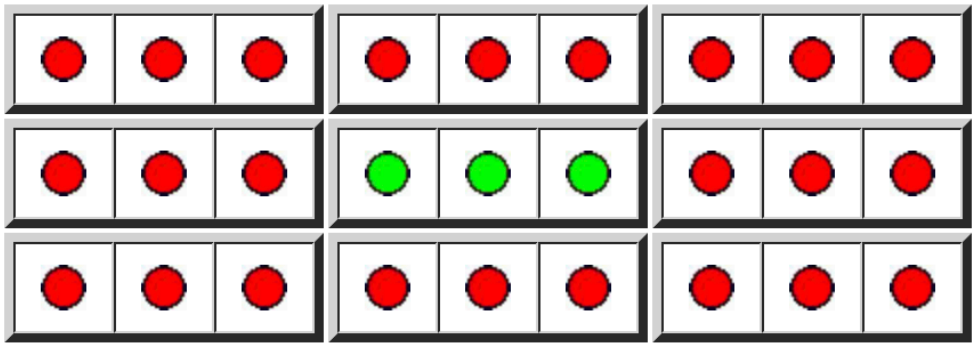
{a(5), b(5), c(5)}

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

Gamemaster

Sign In

Protocol: standalone
Game: multiplebuttonsandlights



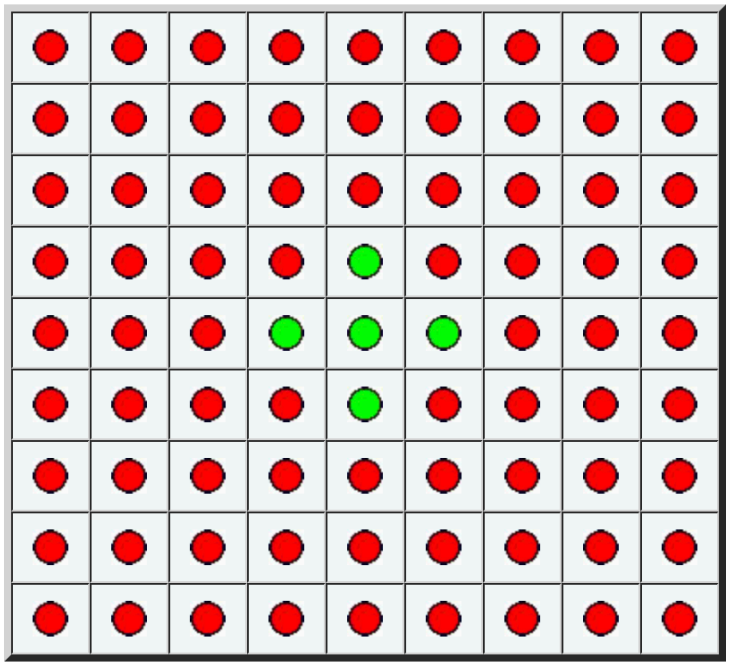
Move:

127.0.0.1

Gamemaster

Sign In

Protocol: standalone
Game: multipleswitches



Move:

Gamemaster

Sign In

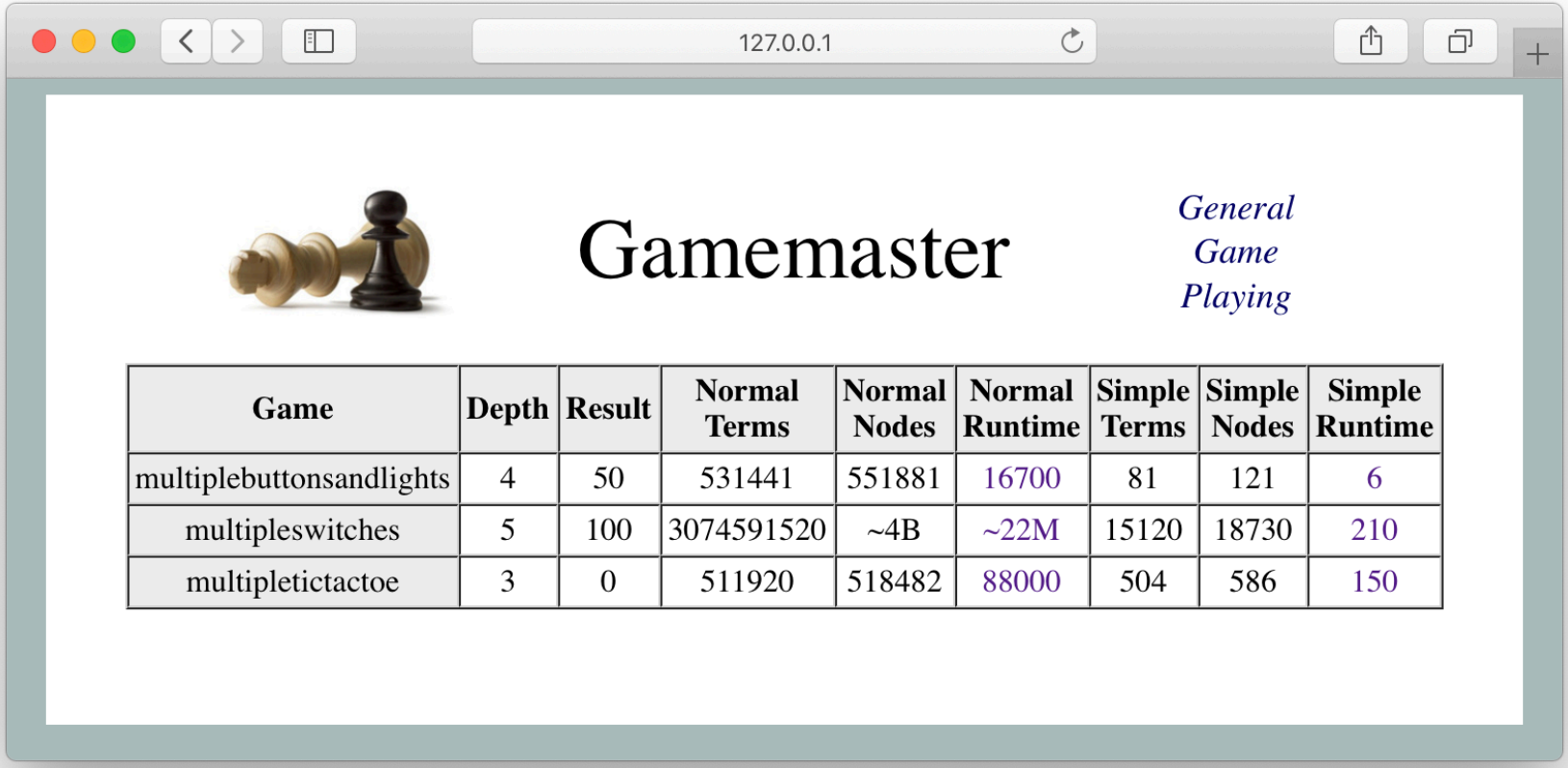
Protocol: standalone
Game: multipletictactoe

X	O	O						
O			X	X	X			

Game over

Move:

Experimental Results



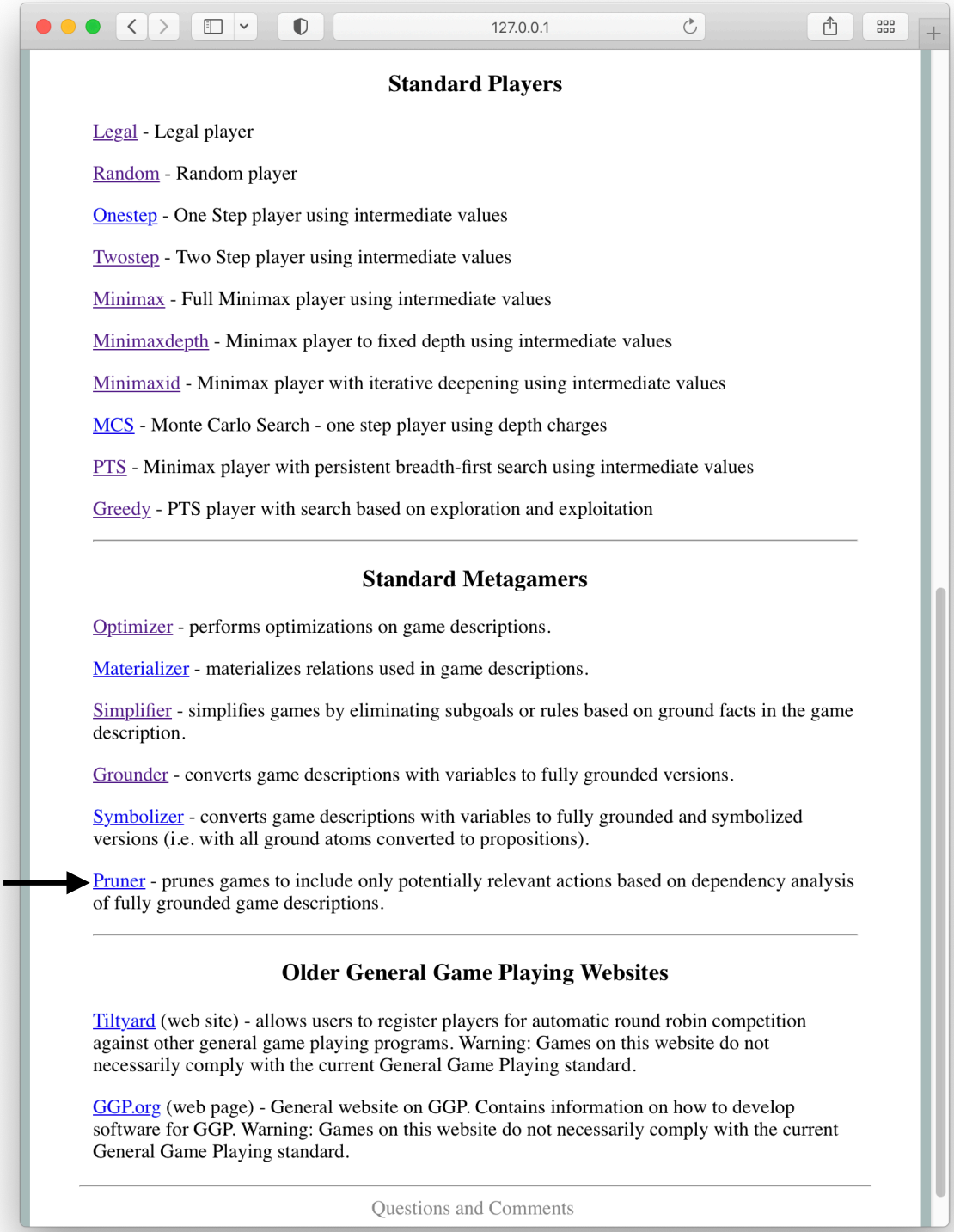
Game	Depth	Result	Normal Terms	Normal Nodes	Normal Runtime	Simple Terms	Simple Nodes	Simple Runtime
multiplebuttonsandlights	4	50	531441	551881	16700	81	121	6
multipleswitches	5	100	3074591520	~4B	~22M	15120	18730	210
multipletictactoe	3	0	511920	518482	88000	504	586	150

Egghead versus Maverick

Parallelknightthrough

Egghead versus Maverick

Parallelknightthrough


127.0.0.1
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.
Questions and Comments

Gamemaster

General Game Playing

Pruner

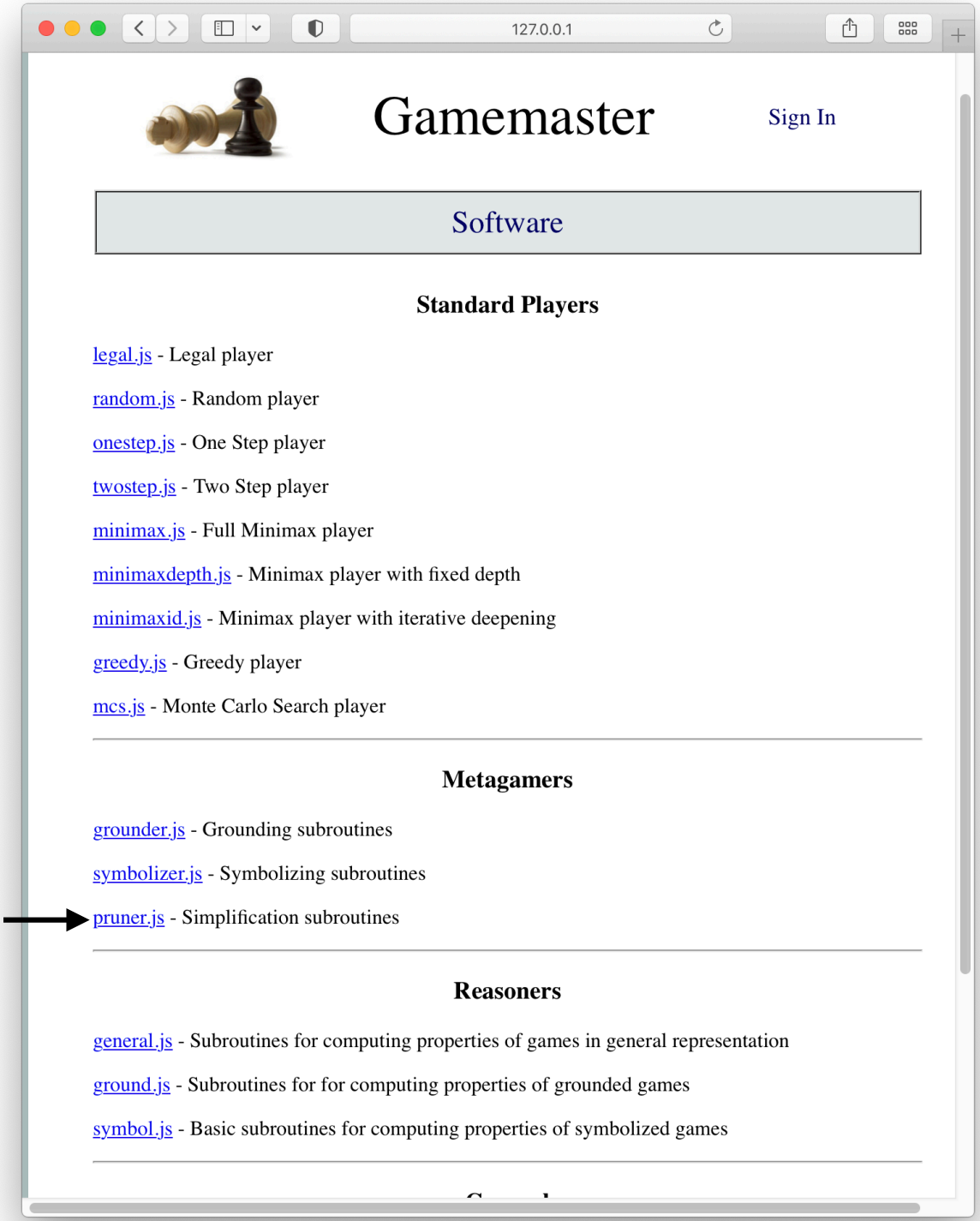
Game Description:

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%% 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

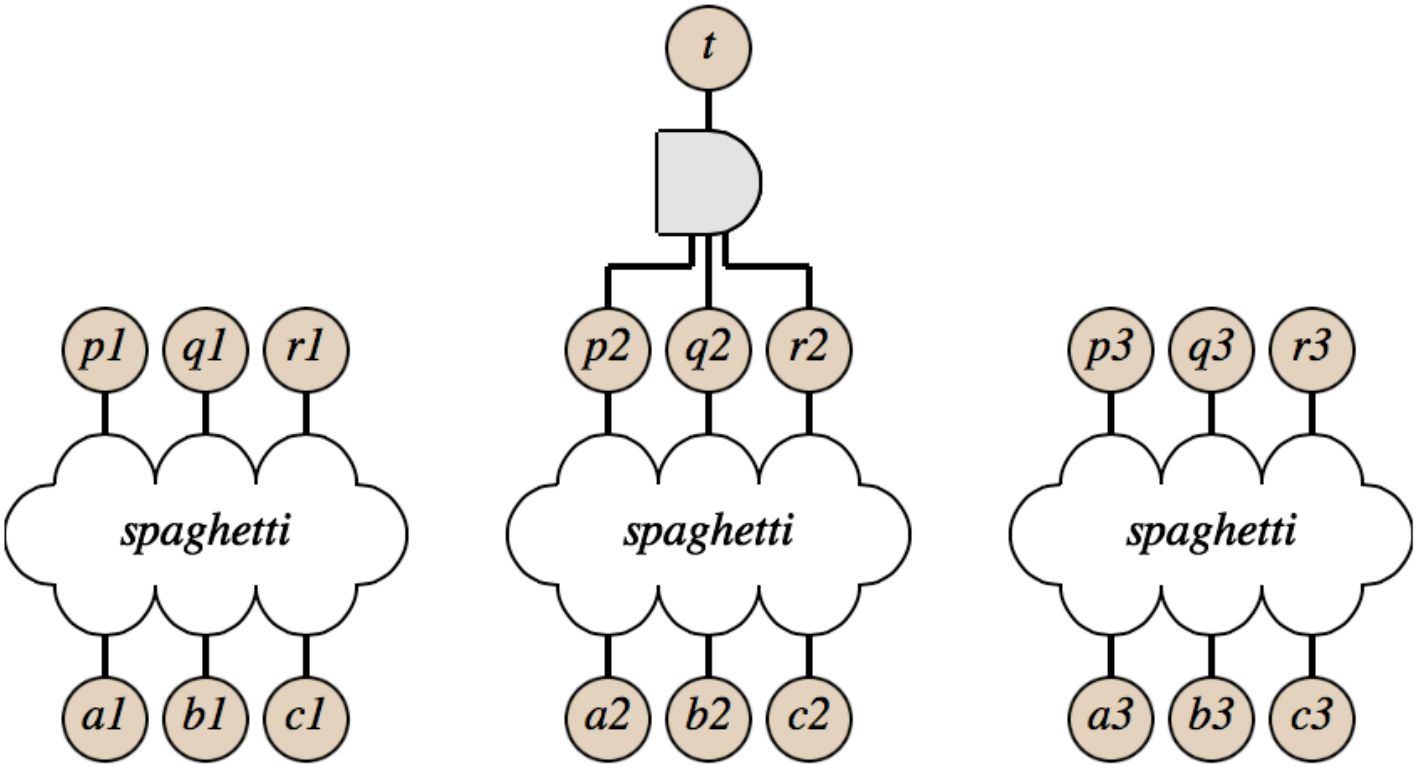
```
function start (r,rs,sc,pc)
 {role = r;
  rules = rs.slice(1)
  startclock = parseInt(sc);
  playclock = parseInt(pc);

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

New Code

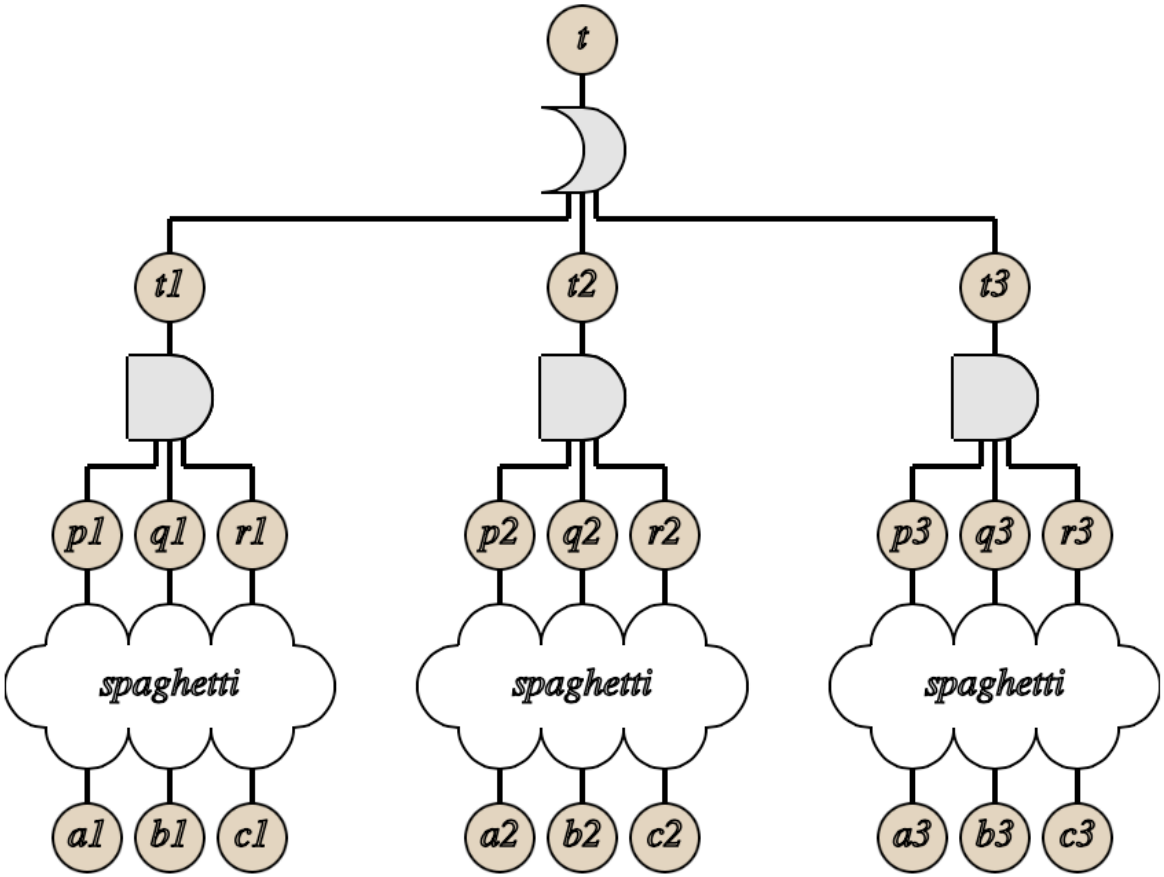
```
function start (r,rs,sc,pc)
 {role = r;
  rules = rs.slice(1)
  startclock = parseInt(sc);
  playclock = parseInt(pc);

  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

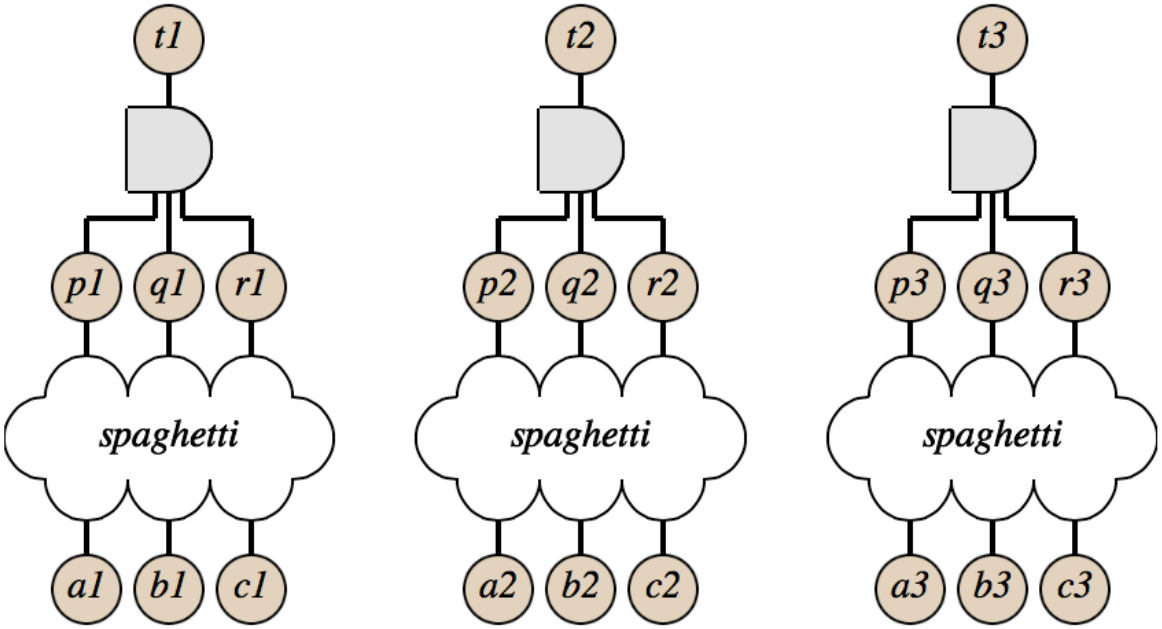
Propnet for a "Multiple" Game



Propnet for a "Best" Game



Modified Propnet



Strategy for Single Player "Best" Games

Strategy: Play all games and choose the one that yields highest value.

Search cost still much lower than on unfactored game.

Strategy for Multiple Player "Best" Games?

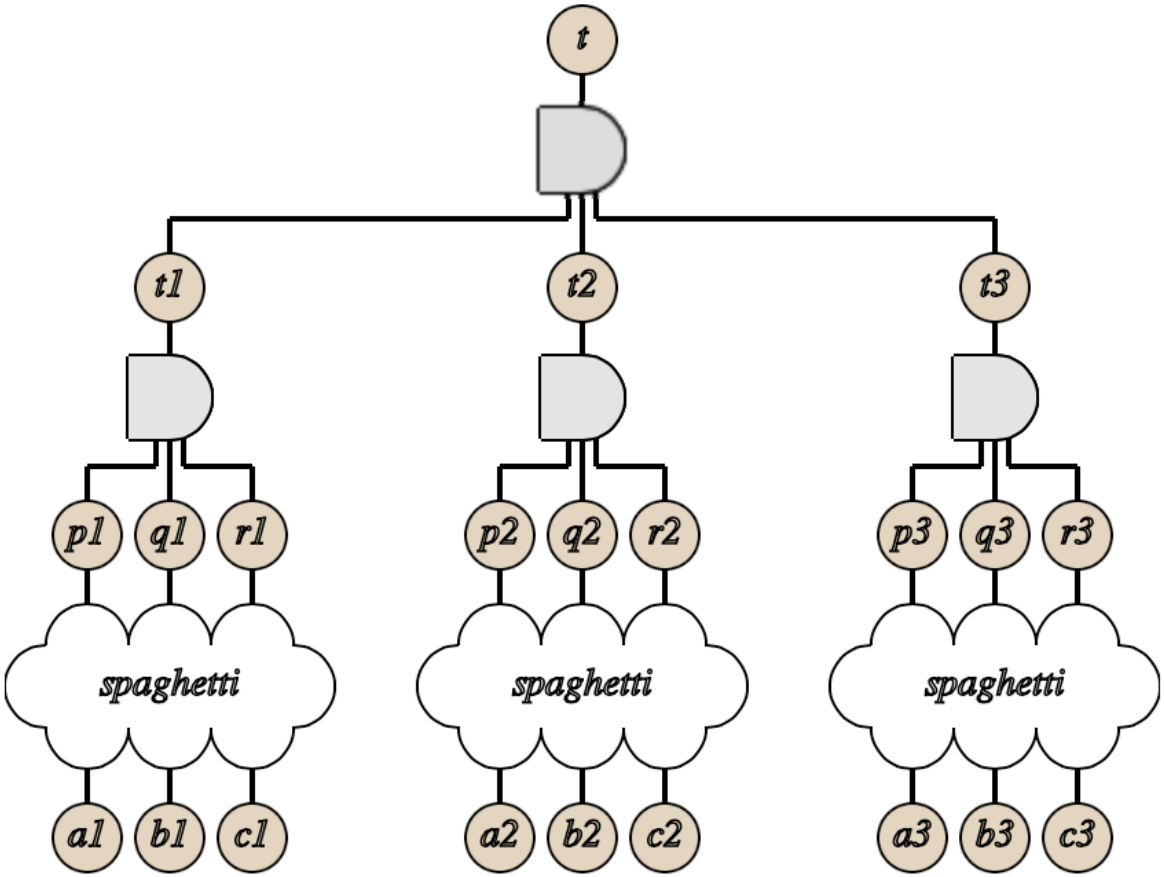
What moves does opponent have in selected game? Maybe none. Solution: create a "noop" action. (NB: This assumes inertia across subgames.)

What if there is a tempo issue (e.g. can only win on even steps)? Solution: create a "noop" action for self and play elsewhere on such steps.

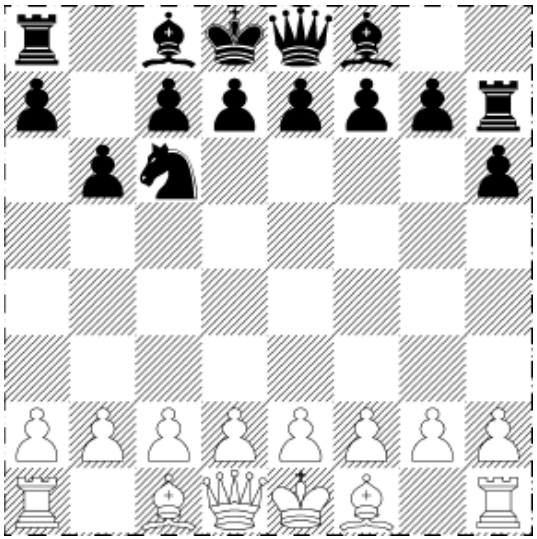
Need to ensure that other subgame does not terminate before chosen subgame terminates.

"noop" actions may not tick the clock and subgames may not terminate. Solution: add a clock that reflect how often players can move in other subgames. Very difficult.

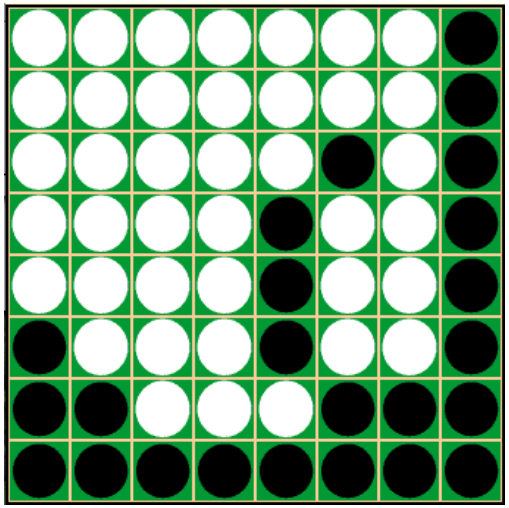
Propnet for a "Joint" Game



Hodgepodge



Branching factor: *a*

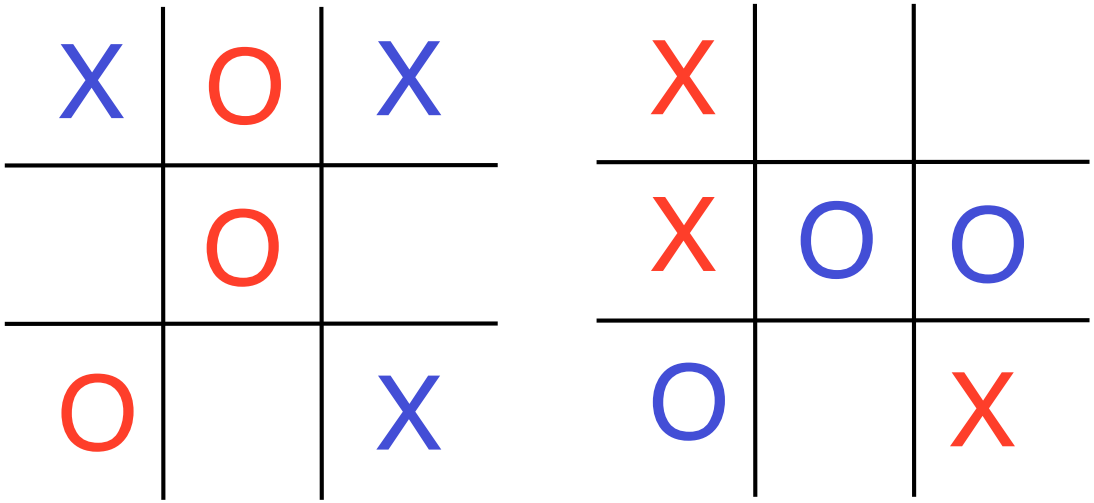


Branching factor: *b*

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

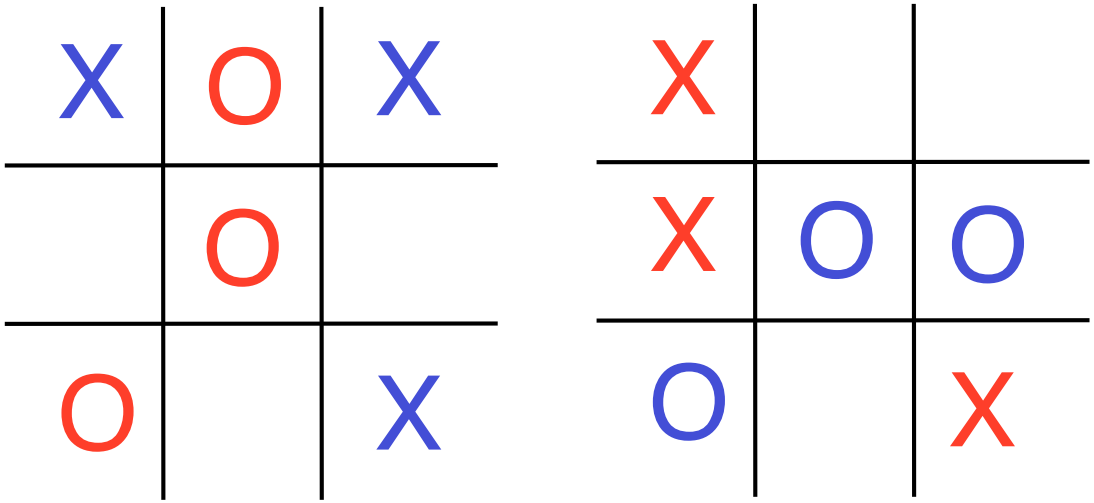
Best Tic Tac Toe



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

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

Joint Tic Tac Toe



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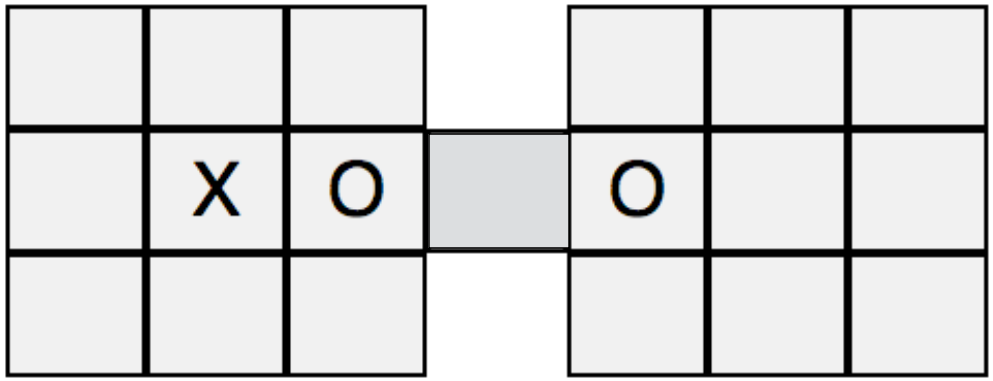
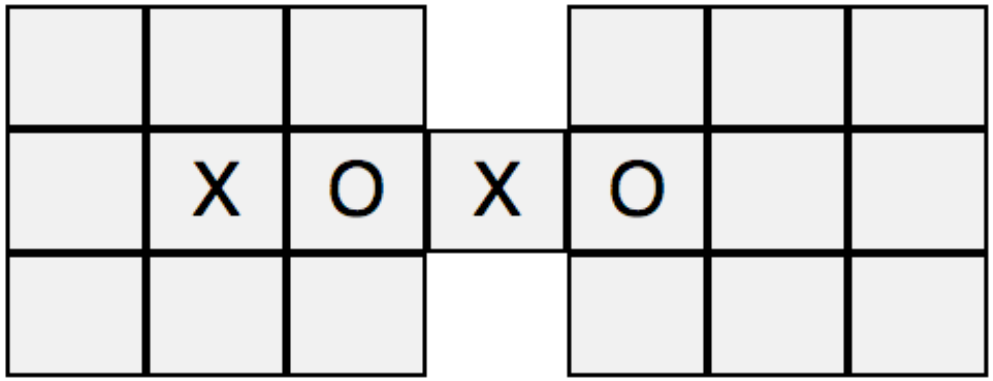
Separate branching factor: 9, 8, 7, 6, 5, 4, 3, 2, 1

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