Logic Programming
General Game Playing

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Game Playing

Human Game Playing
• Intellectual Activity
• Skill Comparison

Computer Game Playing
• Testbed for AI
• Limitations
Narrowness
  Good at one game, not so good at others
  Cannot do anything else

Not really testing intelligence of machine
  Programmer does all the interesting analysis / design
  Machine simply follows the recipe
General Game Players are systems able to play arbitrary games effectively based solely on formal descriptions supplied at “runtime”.

Translation: They don’t know the rules until the game starts.

Must figure out for themselves:
legal moves, winning strategy
in the face of incomplete info and resource bounds
Variety of Games
Novelty
International GGP Competition
Annual GGP Competition
Held at AAAI or IJCAI conference
Administered by Stanford University
(Stanford folks not eligible to participate)
Winners

2005 - ClunePlayer - Jim Clune (USA)
2006 - FluxPlayer - Schiffel, Thielscher (Germany)
2007 - CadiaPlayer - Bjornsson, Finsson (Iceland)
2008 - CadiaPlayer - Bjornsson, Finsson (Iceland)
2010 - Ary - Mehat (France)
2011 - TurboTurtle - Schreiber (USA)
2012 - CadiaPlayer - Bjornsson, Finsson (Iceland)
2013 - TurboTurtle - Schreiber (USA)
Carbon versus Silicon
Human Race Being Defeated
Game Description
Finite Synchronous Games

Environment
- Environment with finitely many states
- One initial state and one or more terminal states
- Each state has a unique goal value for each player

Players
- Fixed, finite number of players
- Each with finitely many moves

Dynamics
- Finitely many steps
- All players move on all steps (some no ops)
- Environment changes only in response to moves
Single Player Game
Multiple Player Game
Good News: Since all of the games that we are considering are finite, it is possible in principle to communicate game information in the form of state graphs.
Problem: Size of description. Even though everything is finite, these sets can be large.

Solution:
Exploit regularities / structure in state graphs to produce compact encoding
Game Description Language (or GDL) is a formal language for encoding the rules of games.

Game rules written as sentences in Symbolic Logic.

GDL is widely used in the research literature and is used in virtually all General Game Playing competitions.

GDL extensions are applicable in real-world applications such as Enterprise Management and Computational Law.
Symbols:

white, black - roles
1, 2, 3 - indices of rows and columns
x, o, b - marks
noop - no-op action

Constructors:

cell(index,index,mark) --> proposition
control(role) --> proposition
mark(index,index) --> action

Predicates:

row(index,mark)
column(index,mark)
diagonal(mark)
line(mark)
open
State Representation

X

O

X

cell(1,1,x)
cell(1,2,b)
cell(1,3,b)
cell(2,1,b)
cell(2,2,o)
cell(2,3,b)
cell(3,1,b)
cell(3,2,b)
cell(3,3,x)
control(black)
Rules of Tic-Tac-Toe

\[
\begin{align*}
\text{role}(white) & \quad \text{next}(\text{cell}(M,N,x)) : - \\
\text{role}(black) & \quad \text{does}(white,\text{mark}(M,N)) \\
\text{base}(\text{cell}(M,N,Z)) : - & \quad \text{next}(\text{cell}(M,N,0)) : - \\
& \quad \text{does}(black,\text{mark}(M,N)) \\
& \quad \text{next}(\text{cell}(M,N,Z)) : - \\
& \quad \text{does}(P,\text{mark}(M,N)) & \text{true}(\text{cell}(M,N,Z)) & Z!=b \\
\text{base}(\text{control}(W)) : - & \quad \text{role}(W) \\
& \quad \text{true}(\text{cell}(M,N,Z)) & Z!=b \\
\text{input}(W,\text{mark}(X,Y)) : - & \quad \text{next}(\text{cell}(M,N,b)) : - \\
& \quad \text{does}(P,\text{mark}(J,K)) & \text{true}(\text{cell}(M,N,b)) & \text{distinct}(M,J) \\
& \quad \text{true}(\text{cell}(M,N,b)) & \text{distinct}(N,K) \\
\text{input}(W,\text{noop}) : - & \quad \text{role}(W) \\
\text{init}(\text{cell}(X,Y,b)) : - & \quad \text{next}(\text{cell}(M,N,b)) : - \\
& \quad \text{true}(\text{cell}(M,N,b)) & \text{distinct}(M,J) \\
& \quad \text{distinct}(N,K) \\
\text{init}(\text{control}(white)) & \quad \text{true}(\text{control}(black)) \\
\text{legal}(P,\text{mark}(X,Y)) : - & \quad \text{next}(\text{control}(black)) : - \\
& \quad \text{true}(\text{control}(white)) \\
& \quad \text{true}(\text{control}(P)) \\
\text{goal}(white,100) : - & \quad \text{line}(x) & \sim\text{line}(o) \\
& \quad \text{line}(P) : - \text{row}(M,P) \\
& \quad \text{line}(P) : - \sim\text{open} \\
& \quad \text{line}(P) : - \text{column}(N,P) \\
& \quad \text{line}(P) : - \text{diagonal}(P) \\
\text{goal}(white,50) : - & \quad \sim\text{line}(x) & \sim\text{line}(o) \\
& \quad \text{open} : \sim\text{true}(\text{cell}(M,N,b)) \\
\text{goal}(white,0) : - & \quad \sim\text{line}(x) & \text{line}(o) \\
\text{goal}(black,100) : - & \sim\text{line}(x) & \text{line}(o) \\
\text{goal}(black,50) : - & \sim\text{line}(x) & \sim\text{line}(o) \\
\text{goal}(black,0) : - & \text{line}(x) & \sim\text{line}(o) \\
\text{legal}(x,\text{noop}) : - & \text{true}(\text{control}(black)) \\
\text{legal}(o,\text{noop}) : - & \text{true}(\text{control}(white)) \\
\end{align*}
\]
Roles

role(white)
role(black)
\textbf{base}(\texttt{cell}(X,Y,W)) :-
\begin{align*}
\text{index}(X) & \, \& \, \\
\text{index}(Y) & \, \& \, \\
\text{filler}(W)
\end{align*}

\textbf{base}(\texttt{control}(W)) :-
\begin{align*}
\text{role}(W)
\end{align*}

\begin{align*}
\text{index}(1) & \, \\
\text{index}(2) & \\
\text{index}(3) & \\
\text{filler}(x) & \\
\text{filler}(o) & \\
\text{filler}(b)
\end{align*}
\textbf{Actions}

\begin{verbatim}
input(W, mark(X,Y)) :-
    role(W) &
    index(X) &
    index(Y)

input(W,noop) :-
    role(W)
\end{verbatim}
\textbf{Initial State}

\begin{verbatim}
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))
\end{verbatim}
 legality(W,mark(X,Y)) :-
    true(cell(X,Y,b)) &
    true(control(W))

 legality(white,noop) :-
    true(control(black))

 legality(black,noop) :-
    true(control(white))
next(cell(M,N,x)) :-
    does(white,mark(M,N))

next(cell(M,N,o)) :-
    does(black,mark(M,N))

next(cell(M,N,b)) :-
    does(W,mark(J,K)) &
    true(cell(M,N,b)) & M!=J

next(cell(M,N,b)) :-
    does(W,mark(J,K)) &
    true(cell(M,N,b)) & N!=K

next(cell(M,N,Z)) :-
    does(W,mark(M,N)) &
    true(cell(M,N,Z)) & Z!=b

next(control(white)) :-
    true(control(black))

next(control(black)) :-
    true(control(white))
row(M, W) :-
    true(cell(M, 1, W)) &
    true(cell(M, 2, W)) &
    true(cell(M, 3, W))

diagonal(W) :-
    true(cell(1, 1, W)) &
    true(cell(2, 2, W)) &
    true(cell(3, 3, W))

column(N, W) :-
    true(cell(1, N, W)) &
    true(cell(2, N, W)) &
    true(cell(3, N, W))

diagonal(W) :-
    true(cell(1, 3, W)) &
    true(cell(2, 2, W)) &
    true(cell(3, 1, W))

line(W) :- row(M, W)
line(W) :- column(N, W)
line(W) :- diagonal(W)

open :- true(cell(M, N, b))
goals and termination

\[
\text{goal}(\text{white}, 100) :- \text{line}(x) \\
\text{goal}(\text{white}, 50) :- \neg\text{line}(x) \land \neg\text{line}(o) \\
\text{goal}(\text{white}, 0) :- \text{line}(o) \\
\text{goal}(\text{black}, 100) :- \text{line}(o) \\
\text{goal}(\text{black}, 50) :- \neg\text{line}(x) \land \neg\text{line}(o) \\
\text{goal}(\text{black}, 0) :- \text{line}(x) \\
\]

\[
\text{terminal} :- \text{line}(W) \\
\text{terminal} :- \neg\text{open} \\
\]
Game Management
Game Management is the process of administering a game in General Game Playing.

Match = instance of a game.

Components:
- Game Manager
- Game Playing Protocol
Game Manager

- Game Descriptions
- Match Records
- Graphics for Spectators
- Temporary State Data
- Player

Tcp/ip
Start
Manager sends Start message to players
Start(id, role, description, startclock, playclock)
General Game Playing Protocol

Start
   Manager sends Start message to players
   Start(id, role, description, startclock, playclock)

Play
   Manager sends Play messages to players
   Play(id, actions)
   Receives plays in response
General Game Playing Protocol

Start
Manager sends Start message to players
\[ \text{start}(id, \text{role}, \text{description}, \text{startclock}, \text{playclock}) \]

Play
Manager sends Play messages to players
\[ \text{play}(id, \text{actions}) \]
Receives plays in response

Stop
Manager sends Stop message to players
\[ \text{stop}(id, \text{actions}) \]
Game Playing
cell(1,1,b)
cell(1,2,b)
cell(1,3,b)
cell(2,1,b)
cell(2,2,b)
cell(2,3,b)
cell(3,1,b)
cell(3,2,b)
cell(3,3,b)
control(x)
<table>
<thead>
<tr>
<th>White’s moves:</th>
<th>Black’s moves:</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>mark(1,1)</code></td>
<td><code>noop</code></td>
</tr>
<tr>
<td><code>mark(1,2)</code></td>
<td></td>
</tr>
<tr>
<td><code>mark(1,3)</code></td>
<td></td>
</tr>
<tr>
<td><code>mark(2,1)</code></td>
<td></td>
</tr>
<tr>
<td><code>mark(2,2)</code></td>
<td></td>
</tr>
<tr>
<td><code>mark(2,3)</code></td>
<td></td>
</tr>
<tr>
<td><code>mark(3,1)</code></td>
<td></td>
</tr>
<tr>
<td><code>mark(3,2)</code></td>
<td></td>
</tr>
<tr>
<td><code>mark(3,3)</code></td>
<td></td>
</tr>
</tbody>
</table>
State Update

cell(1,1,b)  cell(1,1,b)
cell(1,2,b)  cell(1,2,b)
cell(1,3,b)  cell(1,3,x)
cell(2,1,b)  cell(2,1,b)
cell(2,2,b)  cell(2,2,b)
cell(2,3,b)  cell(2,3,b)
cell(3,1,b)  cell(3,1,b)
cell(3,2,b)  cell(3,2,b)
cell(3,3,b)  cell(3,3,b)
control(x)  control(o)
Complete Game Graph Search
How do we evaluate non-terminal states?
General Heuristics
Goal proximity (everyone)
Maximize mobility (Barney Pell)
Minimize opponent’s mobility (Jim Clune)
GGP-06 Final - Cylinder Checkers
Second Generation GGP (2007 on)

Monte Carlo Search

Monte Carlo Tree Search
  UCT - Uniform Confidence Bounds on Trees
Second Generation GGP

Monte Carlo Search
Offline Processing of Game Descriptions
Reformulate problem to decrease size of search space
Compile to do the search faster

What human programmers do in creating game players
Compilation

Conversion of logic to traditional programming language
Simple, widely published algorithms
several orders or magnitude speedup
no asymptotic change

Conversion to Field Programmable Gate Arrays (FPGAs)
several more orders of magnitude improvement
Hodgepodge = Chess + Othello

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: $a^n+b^n$
Examples

Factoring, e.g. Hodgepodge
Bottlenecks, e.g. Triathlon
Symmetry detection, e.g. Tic-Tac-Toe
Dead State Removal

Trade-off - cost of finding and using structure vs savings

*Sometimes* cost proportional to size of description
*Sometimes* savings proportional to size of game tree
Automatic Programming

\[
P(a, b) \quad q(b, c) \\
\neg p(b, d) \quad \forall x. \forall y. (p(x, y) \Rightarrow q(x, y)) \\
p(c, b) \lor p(c, d) \quad \exists x. p(x, d)
\]
Expertise in a Box
Opponent Modeling
Demoralizing the Opponent

X O
---
X X O
---
O O