GP-Rush: Using Genetic Programming to Evolve Solvers for the Rush Hour Puzzle

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2009 "HUMIES" AWARDS FOR HUMAN-COMPETITIVE RESULTS

Friday, July 10, 2009

The Rush Hour Puzzle

- Sliding-blocks game played on 6x6 board
- Simple rules:
  - Car can move horizontally OR vertically
  - No hopping, no turning
- Purpose:
  move cars such that red car can exit

EASY TO LEARN
HARD TO PLAY
HARD FOR AIer

Previous Work

- n x n Rush Hour is PSPACE-complete [Flake & Baum, 2002]
  (hard to play, hard for AIer...)
- Discovery of all 6x6 solvable boards [Servais, 2006]
  Approach not scalable to larger boards
No Work on Solvers

• One free simple program
• BUT: No heuristic function currently exists
• Very difficult to estimate distance to goal
• WHY?
  1. Relaxing constraints spoils the game
e.g., deleting cars, allowing cars to move freely
  2. Very difficult to find patterns / schemata
one cell or car can totally alter play

Our Solution: 1. Heuristics

• We designed “human-like” heuristics for use with standard methods (e.g., IDA*)
• Example: BlockersLowerBound
  Lower bound on number of steps to goal,
  by counting moves needed to free blocking cars
• Goal distance, Hybrid, IsMoveToSecluded,
  ...
• All proved limited (variable utility)

Our Solution: 2. Evolution

• Basic heuristics serve as building blocks
• Evolution may be used to:
  1) build new heuristics from existing building blocks
  2) Find weights for each heuristic
  3) Find conditions for applying each heuristic

Our Solution: 3. Policies

In the field of automated planning:
Policy = ordered set of deductive rules

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition 1</td>
<td>Result 1</td>
</tr>
<tr>
<td>Condition 2</td>
<td>Result 2</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Condition N</td>
<td>Result N</td>
</tr>
<tr>
<td></td>
<td>Default Result</td>
</tr>
</tbody>
</table>
Two Goals

1. Evolve Solvers (GP-Evolved Policies)

2. Finding hard problems is hard:
   Evolve difficult 8x8 boards

Second goal arose because GP proved so successful at solving hard boards (and beating humans) we had to evolve new hard cases...

Results: 1. GP vs. Human AIer

<table>
<thead>
<tr>
<th></th>
<th>Without Heuristics</th>
<th>Blockers Estimation</th>
<th>Goal Distance</th>
<th>Hybrid</th>
<th>Hand-Crafted Policy</th>
<th>GP Policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 x 6</td>
<td>100%</td>
<td>72%</td>
<td>94%</td>
<td>102%</td>
<td>70%</td>
<td>40%</td>
</tr>
<tr>
<td>8 x 8</td>
<td>100%</td>
<td>69%</td>
<td>75%</td>
<td>70%</td>
<td>50%</td>
<td>10%</td>
</tr>
</tbody>
</table>

% of boards used in search compared to Iterative Deepening A*

Evolution drastically cuts amount of search

Results: 2. GP vs. Human Player

<table>
<thead>
<tr>
<th></th>
<th>Time to solve (seconds)</th>
<th>GP</th>
<th>Humans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jam01…Jam08</td>
<td>0.03</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>Jam09…Jam16</td>
<td>0.6</td>
<td>8.15</td>
<td></td>
</tr>
<tr>
<td>Jam17…Jam24</td>
<td>0.83</td>
<td>10.32</td>
<td></td>
</tr>
<tr>
<td>Jam25…Jam32</td>
<td>1.17</td>
<td>14.1</td>
<td></td>
</tr>
<tr>
<td>Jam33…Jam40</td>
<td>2.65</td>
<td>20.00</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>1.04</td>
<td>11.03</td>
<td></td>
</tr>
</tbody>
</table>

Humans:
- best of thousands at www.trafficjamgame.com
- probably time to play (not solve), so gap much wider
- More than mere raw computing power

Why is Result Best? (1)

PUSHING EVOLUTION FURTHER

- Most difficult single-player search (i.e., planning) problem solved (so successfully) with evolution to date
- 6x6 Rush Hour more difficult than all other planning problems solved evolutionarily (difficult to design representation + huge, hard-to-navigate search space)
- Moreover, we evolved (& solved) yet harder 8x8 boards, never tackled before
Why is Result Best? (2)
SEVERAL DEGREES (& MODALITIES) OF IMPROVEMENT
- Popular Enhanced Iterative Deepening algorithm surpassed by our hand-crafted heuristics and policies, all of which were beaten by GP-evolved strategies
- Evolution managed to take our best designed ingredients of limited performance and transform them into highly successful strategies
- GP not only beat human AI researchers but also all human players of Rush Hour on record

Why is Result Best? (3)
SOLVE DIFFICULT PROBLEM WITH LONG HISTORY
- Difficult puzzles (involving search and planning) have a longstanding tradition in AI
- Rush Hour considered open problem until very recently [Kendall et al. 2008]
No efficient solvers designed, despite fertility of field of automated planning
(Note not only Rush Hour's open status but also its complexity, PSPACE-complete, superseding 23 other games described in 2008 Kendall survey paper, which are "only" NP-Complete)

Why is Result Best? (4)
- Our evolutionary algorithm "closed" Rush Hour's open status, in addition exhibiting the ability to scale up to new, more difficult problems — themselves discovered through evolution
- We used evolution to generate the most difficult Rush Hour problems known
- Thus, we evolved both the best known solvers and the most difficult existing boards

Result is Human-Competitive
(B) equal to / better than new scientific result
(D) publishable in its own right as new scientific result
(F) equal to / better than achievement in its field
(G) solves problem of indisputable difficulty in its field
(H) holds its own / wins competition vs. human