GA-FreeCell:
Evolving Solvers for the Game of FreeCell

Achiya Elyasaf, Ami Hauptman, Moshe Sipper
Ben-Gurion University

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The Game of FreeCell

• Card game played with standard deck

• Simple rules:
  • Only exposed cards can be moved, either from FreeCells or foundations
  • Legal move destinations include
    • a home cell, if all previous cards are already there
    • empty FreeCells
    • on top of a next-highest card of opposite color in a cascade

• Purpose: move all cards onto 4 different piles, one per suit
FreeCell

• FreeCell remained relatively obscure until it was included in the Windows 95 OS, along with 32,000 problems — known as Microsoft 32K — all solvable but one (#11982)

• Due to Microsoft's move FreeCell has been claimed to be one of the world's most popular games
EASY TO LEARN

HARD TO PLAY

HARD FOR Aler
Previous Work

- $n \times n$ FreeCell is NP-complete
- Computational complexity aside, many (oft-frustrated) human players (including the authors) will readily attest to the game's hardness
- FreeCell requires an enormous amount of search, due both to long solutions and to large branching factors
- Thus it remains out of reach for popular, optimal heuristic search algorithms, such as $A^*$ and iterative deepening $A^*$
Top Solver to Date

• Few solvers have been written up in the scientific literature

• Best published solver before us was that of Heineman’s, able to solve 96% of Microsoft 32K
Our Solution: 1. Heuristics

• We designed “human-like” heuristics for use with Heineman’s algorithm

• Example: NumberWellPlaced — Count the number of well-placed cards in cascade piles (a pile of cards is well placed if all its cards are in descending order and alternating colors)

• NumCardsNotAtFoundations, HighestHomeCard, DifferenceHome, ...

• All proved to be of limited utility by themselves
Our Solution: 2. Evolution

• Basic heuristics serve as building blocks

• Evolution is used to build new heuristics, which are combinations of the basic ones:

\[ w_1h_1 + w_2h_2 + \ldots + w_nh_n \]

• Weights found by a coevolutionary GA
## Results: 1. GA solution vs. Best Solver

<table>
<thead>
<tr>
<th></th>
<th>Nodes</th>
<th>Time (in seconds)</th>
<th>Solution Length</th>
<th>Solved</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSDH</td>
<td>1,780,216</td>
<td>44.45</td>
<td>255</td>
<td>96.43%</td>
</tr>
<tr>
<td>GA-FreeCell</td>
<td>230,345</td>
<td>2.95</td>
<td>151</td>
<td>98.36%</td>
</tr>
</tbody>
</table>

**HSDH - Heineman’s heuristic**

- Evolution drastically cuts all search measures
- Evolution solves more than half of the problems the best solver to date did not solve
Results: 2. GA vs. Human Player

Time to solve (seconds)

<table>
<thead>
<tr>
<th>Name</th>
<th>Deals played</th>
<th>Time</th>
<th>Solved</th>
</tr>
</thead>
<tbody>
<tr>
<td>sugar357</td>
<td>147,219</td>
<td>241</td>
<td>97.61 %</td>
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<tr>
<td>volwin</td>
<td>146,380</td>
<td>190</td>
<td>96.00 %</td>
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<tr>
<td>caralina</td>
<td>146,224</td>
<td>68</td>
<td>66.40 %</td>
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<tr>
<td>HSDH</td>
<td>32,000</td>
<td>44</td>
<td>96.43 %</td>
</tr>
<tr>
<td>GA-FreeCell</td>
<td>32,000</td>
<td>3</td>
<td>98.36 %</td>
</tr>
</tbody>
</table>

• **Humans:**
  • best of **thousands** at www.freecell.net
  • probably human players play most deals more than once, so gap **much** wider

• **More than mere raw computing power**
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
Why is Result Best? (1)

SOLVE DIFFICULT PROBLEM WITH LONG HISTORY

• Difficult puzzles (involving search and planning problems) have a longstanding tradition in the AI community

• FreeCell tackled in several International Planning Competitions and in numerous attempts to construct state-of-the-art planners

• Yet, in all competitions, all of the general-purpose planners performed poorly on this domain

• In 2009, Heineman published the best FreeCell solver to date

• Our evolutionary algorithm beats Heineman's algorithm in all measures by a wide margin
Why is Result Best? (2)

PUSHING EVOLUTION FURTHER

- Most difficult single-player search (i.e., planning) problem solved (so successfully) with evolution so far, as FreeCell requires an enormous amount of search, due both to long solutions and to large branching factors
Why is Result Best? (3)

SEVERAL DEGREES (AND MODALITIES) OF IMPROVEMENT:

• The popular Enhanced Iterative Deepening algorithm was outperformed by the HSD algorithm, all of which were beaten by our evolved solvers

• Evolution managed to take our best designed ingredients of limited performance and transform them into HIGHLY successful strategies

• Our EA not only beat human AI researchers but also all human players of FreeCell on record
Why is Result Best? (4)

VICTORY OVER HUMANS IS TWO-FOLD:

• We have developed the best algorithm for the hard FreeCell game, better than any algorithm designed by humans.

• Our evolved solver's performance far surpasses that of human players, in terms of game time: Over 70 times faster.

• In addition, our evolved solver solves 98.36% of the problem instances, compared to 97.61% solved by the top human player.
KILLER APPLICATION