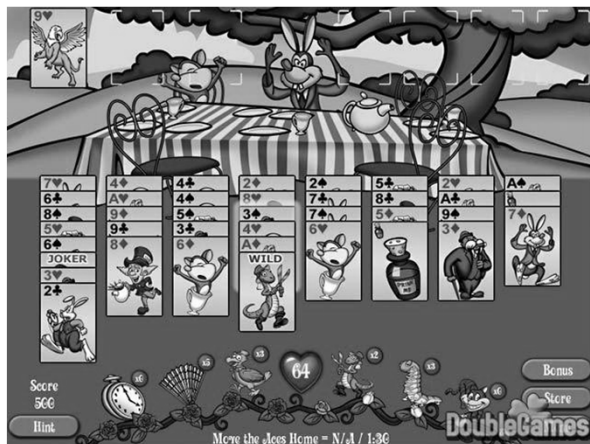# GA-FreeCell:

Evolving Solvers for the Game of FreeCell

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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 AIer

Previous Work

- **n x 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: <u>NumberWellPlaced</u> — 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)**

- **<u>NumCardsNotAtFoundations</u>, <u>HighestHomeCard</u>, <u>DifferenceHome</u>, …**

- **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:

$$w_1h_1+w_2h_2+...+w_nh_n$$

- Weights found by a coevolutionary GA

Results: 1. GA soluion vs. Best Solver

	Nodes	Time (in seconds)	Solution Length	Solved
HSDH	1,780,216	44.45	255	96.43%
GA-FreeCell	**230,345**	**2.95**	**151**	**98.36%**

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)

Name	Deals played	Time	Solved
sugar357	147,219	241	97.61 %
volwin	146,380	190	96.00 %
caralina	146,224	68	66.40 %
HSDH	32,000	44	96.43 %
GA-FreeCell	32,000	3	98.36 %

- **Humans:**
  - best of <u>thousands</u> at www.freecell.net
  - probably human players play most deals more than once, so gap <u>much</u> 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., <u>planning</u>) 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 <u>designed by humans</u>**

- **Our evolved solver's performance far surpasses that of <u>human players</u>, 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