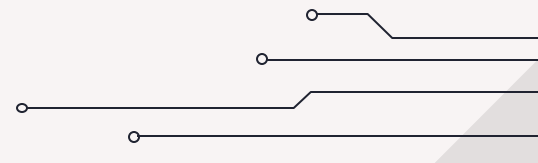


# FreeCell Solitaire Search Problem

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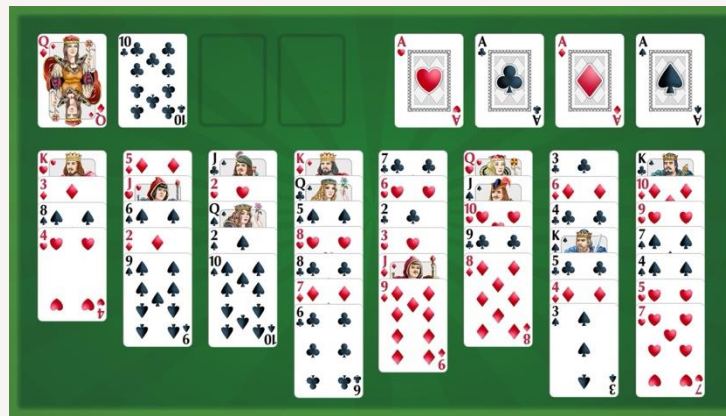
# 01 **The Game**



# FreeCell Card Solitaire

## Rules

- **8 face up** cascades
- **4 free cells** for 1 card
- Cards can be moved to other cascades if they are 1 rank lower and of an alternate color
- The objective is **to fully fill the foundations**

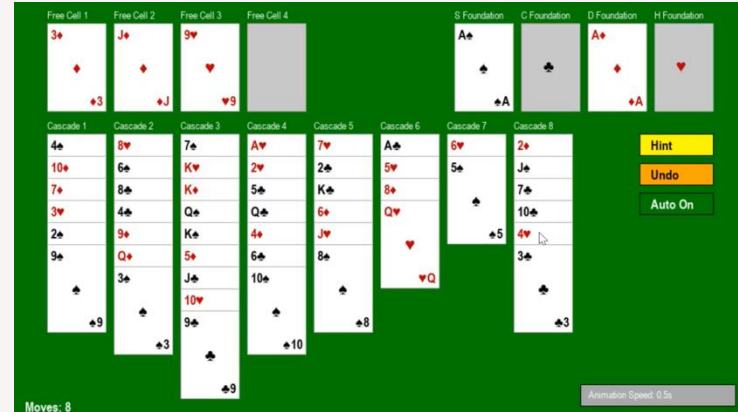


- Out of 8.6 billion deals, 102075 were impossible to solve (**99.999% of possible deals are solvable**).
- There are  **$1.75 \times 10^{64}$**  distinct games.
- Branching factor can vary between **8 to 10** and normal solutions have a depth of **20 to 50** moves

# Extra Rules / Functionalities

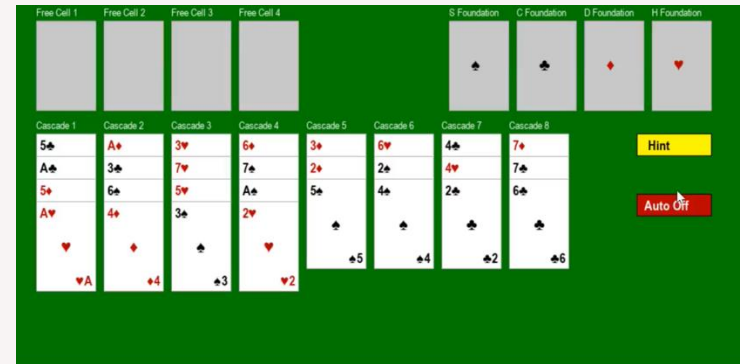
## Supermoves

With enough free spaces, **multiple cards can be moved with only 1 move.**



## Automatic moves

**Cards are automatically moved to foundation** when this move would harm the solution



# Problem Formulation

## STATES:

- 8 cascades (columns) of cards. `self.cascades = [[] for _ in range(8)]`
- 4 free cells that can each hold one card `self.free_cells = [None] * 4`
- 4 foundation piles (one per suit)

```
self.foundations = {"H": [], "D": [], "C": [], "S": []}
```

## INITIAL STATE:

- Complete deck of 52 playing cards (Cards distributed across 8 cascades)
- Empty free cells
- Empty foundation piles

## SOLUTION COST:

- Number of card moves from initial state to goal state. Each move has a uniform cost of 1.

## OPERATORS:

- Cascade to foundation (8)
- Free cell to foundation (4)
- Cascade to free cell (8)
- Cascade to another cascade (8 x 7)
- Free cell to cascade (4 x 8)

## SOLUTION TEST:

- No cards in cascades and free cells

# The Interface

Solving the Algorithm

Nº of Cards

Chosing Algorithm

The interface is a Solitaire game window with a green background. At the top, there is a header bar with the following elements: 'Algorithm:' followed by a text box containing 'A\* Heu3', a blue 'Solve' button, a blue 'New Game' button, three radio buttons for card counts (52, 28, 12) with the 28 button selected, and two buttons for 'Easy' (green) and 'Hard' (red). Below the header, the game board is divided into several sections: 'Free Cell' (4 empty slots), 'S Foundation' (1 card: A♠), 'C Foundation' (1 card: ♣A), 'D Foundation' (1 card: ♦), 'H Foundation' (1 card: A♥), 'Cascade' (8 columns of cards), and 'Single Player Buttons' (Hint, Undo, Auto On). The Cascade section contains the following cards from left to right: Cascade 1 (5♣, A♣, 5♦), Cascade 2 (A♦, 3♣, 6♣, 4♦), Cascade 3 (3♥, 7♥, 5♥, 3♣), Cascade 4 (6♦, 7♠, ♠7), Cascade 5 (3♦, 2♦, 5♣), Cascade 6 (6♥, 2♠, 4♣), Cascade 7 (4♣, 4♥, 2♣), and Cascade 8 (7♦, 7♣, 6♣). At the bottom, there is a status bar with 'Moves: 3', 'Game #' followed by a text box, a blue 'Load' button, 'Time: 242.2s', 'Animation Speed: 0.5s', and three buttons: 'Step Back', 'Pause', and 'Step'. A small text at the bottom center reads 'Shortcuts: Space=Pause, N=New Game, S=Step, B=Step Back, +/- = Speed'.

Algorithm: A\* Heu3

Solve New Game

52 28 12

Easy Hard

Free Cell 1 Free Cell 2 Free Cell 3 Free Cell 4

S Foundation C Foundation D Foundation H Foundation

Cascade 1 Cascade 2 Cascade 3 Cascade 4 Cascade 5 Cascade 6 Cascade 7 Cascade 8

Hint Undo Auto On

Moves: 3

Game # Load

Time: 242.2s

Animation Speed: 0.5s

Step Back Pause Step

Shortcuts: Space=Pause, N=New Game, S=Step, B=Step Back, +/- = Speed

Difficulty Settings

Single Player Buttons

AI Solving Functionalities

Choose Game Number



# 02 **Uninformed Search**





# Uninformed Search Algorithms

Type of Player

BFS

- Breadth First Search
- Explores all possible moves level by level
- **Advantage:** Guarantees the shortest solution in moves
- **Challenge:** Uses a lot of memory, storing every card position (up to 200,000 states in your limit)

**Perfectionist**

DFS

- Depth First Search
- Dives deep into one move sequence
- **Advantage:** Low memory use
- **Challenge:** Can get stuck in long, fruitless paths (depth limit of 150)

**Bold**

IDS

- Iterative Deepening Search
- Has the best results out of the three.
- **Advantage:** Uses less memory
- **Challenge:** Takes more time to find a solution

**Balanced**

# Uninformed Search Algorithms

200 000 Max States



1. The algorithms were **not able to find a solution** with more than 12 cards and Breadth First Search did not achieve a solution for 12 cards either
2. The solutions were **far from optimal**
3. **Uninformed Search is not feasible for freecell solitaire** (unless with higher processing capabilities)



## 03 **Informed Search**

# Heuristics

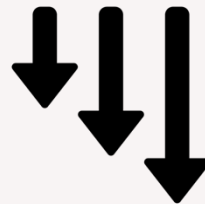
## 1. Missing Cards in Foundations

- Measures how far the game is from completion by counting the number of cards still missing in the foundations



## 2. Minimum Moves to Foundation

- Estimates the minimum number of moves required to place all cards in the foundations, considering gaps in sequences.

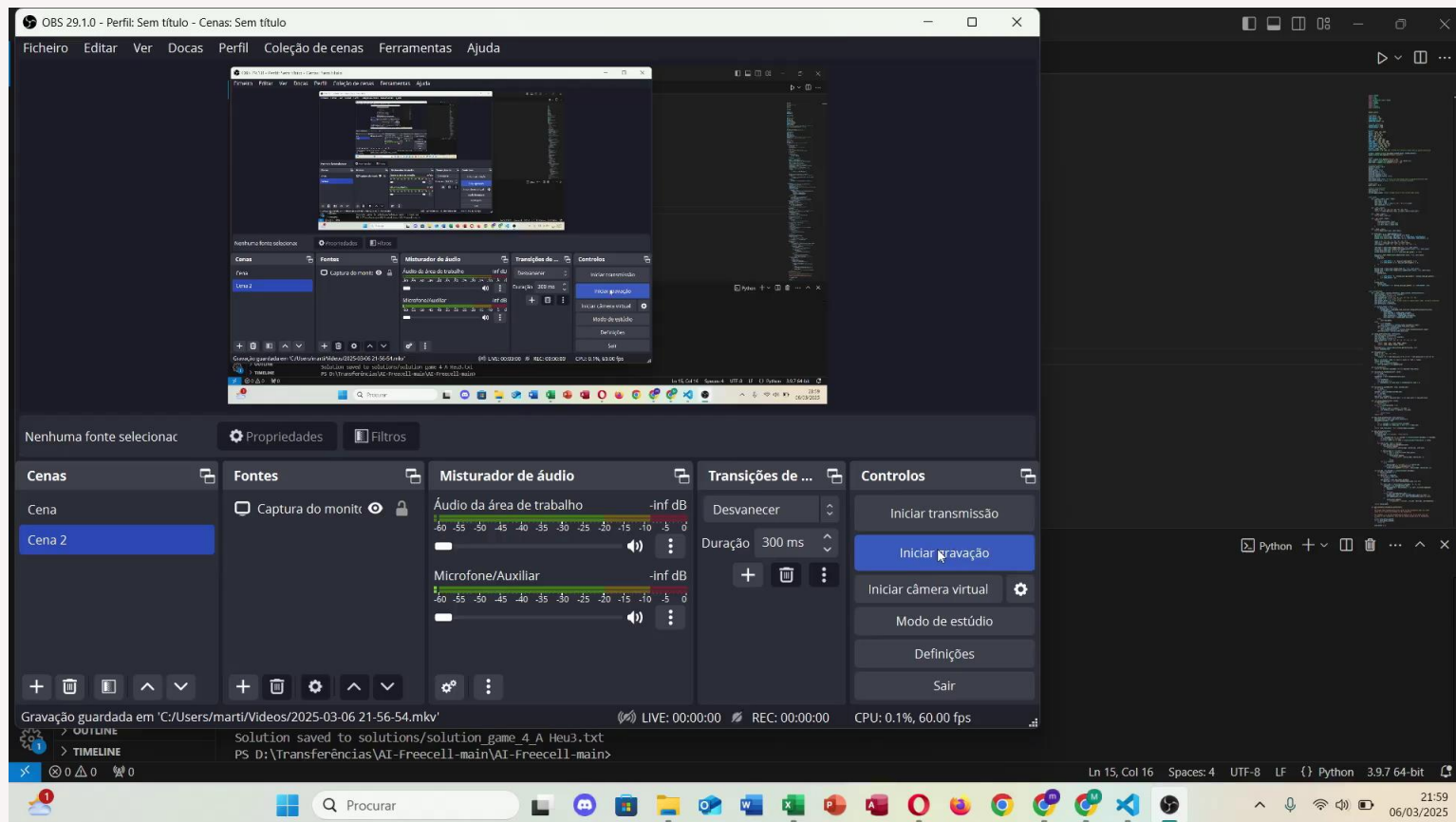


## 3. Context-Aware Move Estimation

- Refines Heuristic 2 by considering card positioning, blockers, and required sequences to estimate a more realistic number of moves.

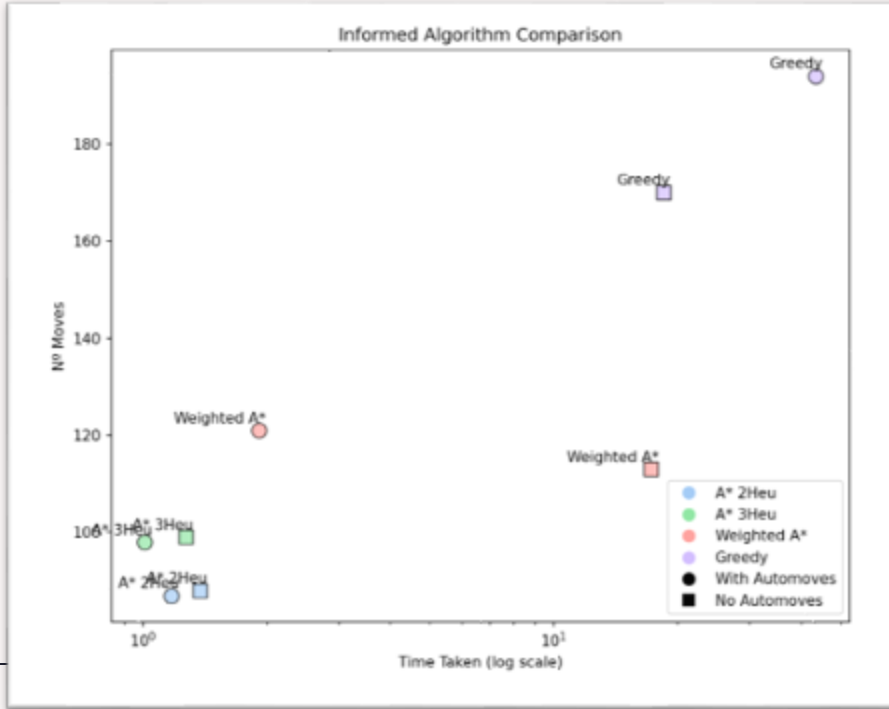


# Demo



# Informed Algorithms Comparison

200 000 Max States

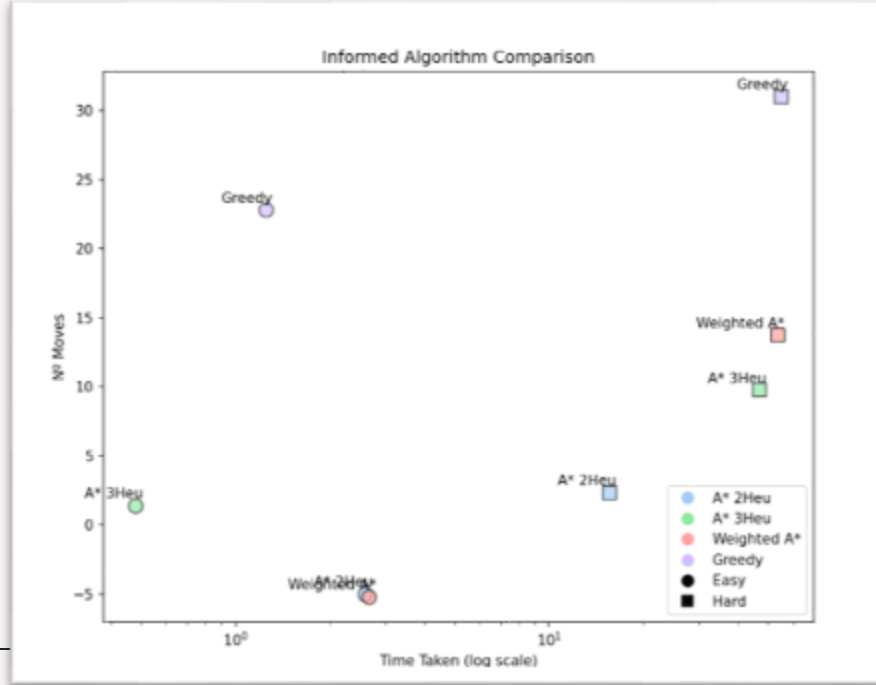


- ❖ Apart from heuristic 1, every **heuristic found a solution for 52 cards deals.**
- ❖ A\* with the second Heuristic was the **best overall method**, regarding best solution .
- ❖ Greedy was the **worst algorithm**

\*Weighted A\* and Greedy algorithms were tested using the Heuristic 3

# Informed Algorithms Comparison

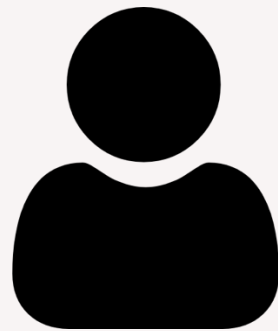
500 000 Max States



- ❖ For easy problems **A\*** with **heuristic 2** **weighted A\*** were the **best algorithms**
- ❖ For hard problems, although A\* with heuristic 2 got the solutions with best moves, it **was not able to solve every setup predefined**.
- ❖ **Different heuristics have different use cases**

# Meta Heuristic

- A. Evaluates the game state **like a Human would**.
- B. Scores based on strategys
  - I. **More cards in foundation** the better
  - II. Penalizes **usage of freecells**
  - III. Penalizes cascades **without sequences**
  - IV. Penalizes lack of **card mobility**
- c. Applies A\*. The **lower the score the better**



## Results

- ❖ Did not reveal to be a good model
- ❖ The solutions were not optimal and cost a lot of memory
- ❖ Found only 1 solution for the hard problems







# 04 **Single Player**

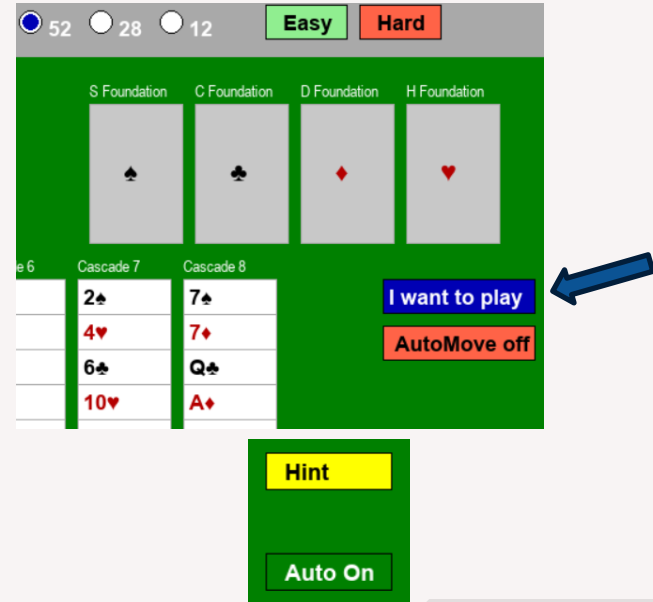
# Single player

When you load a new game, you can also play it yourself by clicking "**I want to play !**"

If you are not sure about which move you should do next you can ask for a "**Hint**" that will be calculated using the current state and the algorithm that is selected in the **Algorithm Box**. It is important to **choose an algorithm that is able to solve games with those characteristics** (for example it would be most efficient to not use "Depth First Search" if the game has 28 or 52 cards). This information can be seen in a table in the last slides.

Besides that you can also activate "**Automatic Moves**" and "**Undo**" your latest move.

"Auto On" visible  Click if you want to activate Automoves  
"Auto Off" visible  Click if you want to deactivate Automoves

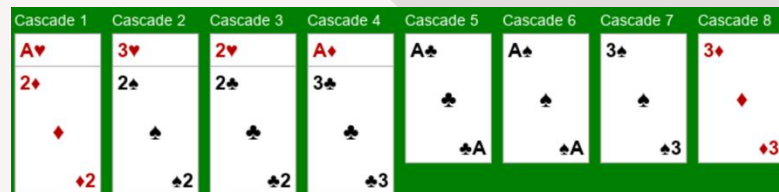




# 05 LLMs



# Experience with LLMs



Zero shot attempt

- Zero shot attempt with FreeCell solitaire puzzle with 12 cards
- Only reasoning models successfully solved the puzzle (6/14 models)
- O3-Mini (smaller model) found most efficient solution (12 moves) in shortest time (20s)
- LLMs are not reliable today for these tests (they struggle with more cards/complexity and cost more than traditional algorithms).
- Prompt follows the good practices (goal, input format, return format, context)

Model	Time	Moves	Status
<b>Grok3</b>	70s	14	✓
<b>O3-Mini-High</b>	1m 12s	13	✓
<b>O3-Mini</b>	20s	12	✓
<b>O1</b>	41s	12	✓
<b>DeepSeek-R1</b>	2m 58s	15	✓
<b>Claude 3.7 Sonnet (Extended Thinking)</b>	1m 36s	13	✓
<b>ChatGPT-4o (2025-01-29)</b>	-	-	✗
<b>ChatGPT-4.5-Preview</b>	-	-	✗
<b>Gemini 2.0 Flash Thinking (Experimental 01-21)</b>	-	-	✗
<b>Gemini 2.0 Pro (Experimental 02-05)</b>	-	-	✗
<b>Claude 3.7 (without Extended Thinking)</b>	-	-	✗
<b>Qwen-Max, Llama-3.3-70B, Mistral-Large</b>	-	-	✗

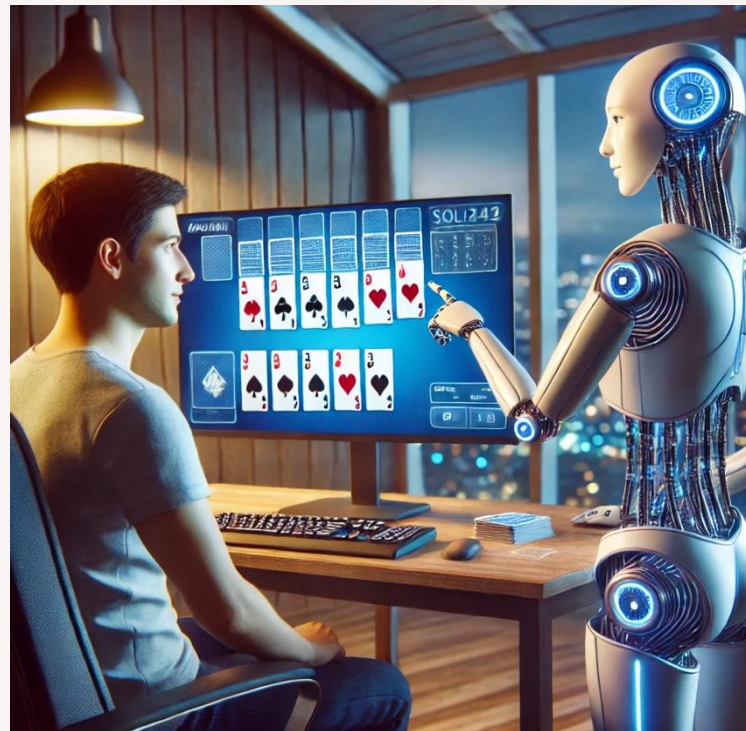
# Designing a Freecell LLM Agent

A **customized prompt** for the LLM to be friendly, funny, and educational if necessary.

The LLM will have access to **various functions** that it can call to have full knowledge of the board's state and make informed and legal choices.

## Function-Based Game Understanding

- Getting valid moves and board state (`Get_Valid_Move()`, `Make_move()`)
- Executing moves and suggesting hints (`Get_Hints()`)
- Finding complete solution paths (`Solve_Game()`)
- Supporting voice interaction



# Looking Back and Ahead

Uniformed search methods can **be very limiting**

The Heuristic choice has a **great impact** in both the solution and capabilities of the algorithm



Test with more **powerfull computers**, more states and depth

Look into aplying these algorithms to other **solitaire types**

Possibly transforming this game into an **optimization problem**



# THANKS!

**Do you have any questions?**

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# 06 **Results**





# Results regarding number of cards

		Time (seconds)			N° of Moves			Peak memory (Mbs)		
	With Automoves ?	12	28	52	12	28	52	12	28	52
Depth First Search	Yes	0.0093	3.9092	29.6813	14	No Solution (depth 101)	No Solutions (depth of 150)	56.27	79.84	78.10
	No	0.0431	4.2436	8.1031	92	No solution (depth 150)	No Solution (depth 101)	61.79	81.46	78.54
Breath First Search	Yes	37.6076	35.3730	41.5009	No solution (depth of 8)	No solutions (depth of 7)	No Solution (depth of 12)	1910.08	1270.54	216.57
	No	75.5775	49.8426	42.9091	No solution (depth of 5)	No solution (depth of 6)	No solutions (depth of 7)	3600.42	1544.89	581.62
Iterative Deepening Search	Yes	20.1249	640.5002	2070.6229	14	No Solution	No Solution	76.69	80.20	80.34
	No	229.4987	688.6425	1412.8835	78	No solution	No solution	80.90	82.25	581.62
A* - heu1	Yes	0.0062	55.2818	43.1403	12	No Solution (depth of 16)	No Solution (depth of 14)	56.32	2344.22	642.63
	No	0.0159	58.4548	43.5926	12	No Solution (depth of 16)	No Solution (depth of 13)	57.18	2260.82	665.41
A* - heu2	Yes	0.0065	0.6551	1.1752	12	39	87	55.92	93.22	109.08
	No	0.0188	0.2145	1.3807	12	41	88	57.27	83.18	112.05
A* - heu3	Yes	0.0078	0.0459	1.0105	12	42	98	56.26	57.75	73.14
	No	0.0196	0.1701	1.2731	12	42	99	3527.15	70.17	105.18
Weight A* - heuXXXX	Yes	0.0075	0.0514	1.9166	12	47	121	56.22	57.97	74.32
	No	0.0102	0.0631	17.3260	13	47	113	56.22	58.89	272.68
Greedy - heuXXXX	Yes	0.0075	0.0273	43.5625	12	50	194	56.11	56.84	107.82
	No	0.0124	0.0444	18.5396	13	45	170	56.45	57.90	238.92
Meta heuristic	Yes	0.0072	0.0451	0.3377	12	51	97	56.10	59.32	74.93
	No	0.0206	0.0639	0.4140	12	50	98	56.43	61.56	81.34

# Results regarding difficulty setting

		Time (seconds)		Differece of N° moves to optimal solution		Peak memory (Mbs)	
	With Automoves ?	Easy	Hard	Easy	Hard	Easy	Hard
A* - heu1	Yes						
	No						
A* - heu2	Yes	2.59	15.55	-5.00	2.33	118.20	185.19
	No						
A* - heu3	Yes	0.48	46.88	1.40	9.75	69.37	292.69
	No						
Weight A* - heuXXXX	Yes	2.67	53.56	-5.20	13.75	126.06	523.69
	No						
Greedy - heuXXXX	Yes	1.25	55.07	22.80	31.00	98.31	650.78
	No						
Meta heuristic	Yes	3.42	130.08	5.20	23.00	242.28	6540.69
	No						

# References

Artificial Intelligence: A Modern Approach code repository. (2019, July 20). GitHub. <https://github.com/aimacode>

Artificial Intelligence: A Modern Approach, 4th US ed. (n.d.). Aima.cs.berkeley.edu. <https://aima.cs.berkeley.edu>

Easy and difficult games | FreeCell Solutions. (2025). Freecellgamesolutions.com.  
<https://freecellgamesolutions.com/stats.html>

View of Optimal Solitaire Game Solutions Using A\* Search and Deadlock Analysis. (2025). Aaai.org.  
<https://ojs.aaai.org/index.php/SOCS/article/view/18405/18196>

Wikipedia Contributors. (2024, November 28). FreeCell. Wikipedia; Wikimedia Foundation.  
<https://en.wikipedia.org/wiki/FreeCell>

Yan, X., Diaconis, P., Rusmevichientong, P., & Roy, B. (n.d.). Solitaire: Man Versus Machine.  
<https://web.stanford.edu/~bvr/pubs/solitaire.pdf>