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FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

FreeCell Solitaire Search Problem

João Soares up202105364
João Vieira up202107689
Martim Lousado up202104630

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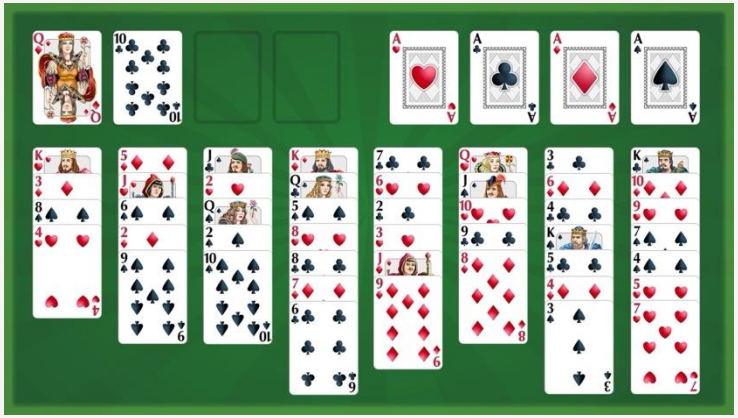
01 The Game

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**

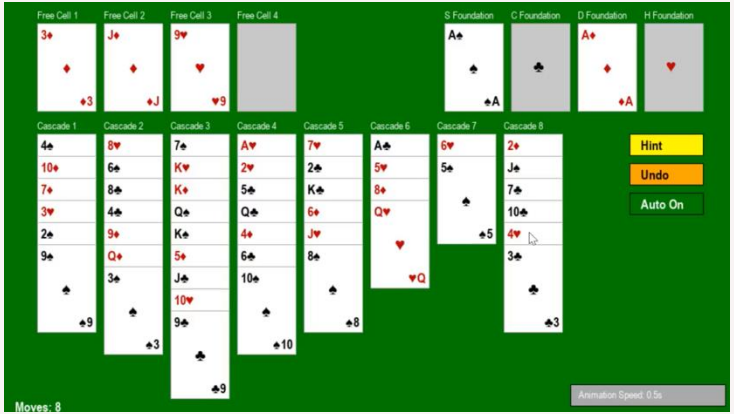


- Out of 8.6 billion deals, 102075 were impossible to solve **(99.999% of possible deals are solvable)**.
- There are **1.75×10^64** distinct games.
- Branching factor can vary between **8 to 10** and normal solutions have a depth of **20 to 50** moves

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)
- Cascadeto another cascade (8 x 7)
- Free cell to cascade (4 x 8)

SOLUTION TEST:

- No cards in cascades and free cells

The Interface

Chosing Algorithm

Solving the Algorithm

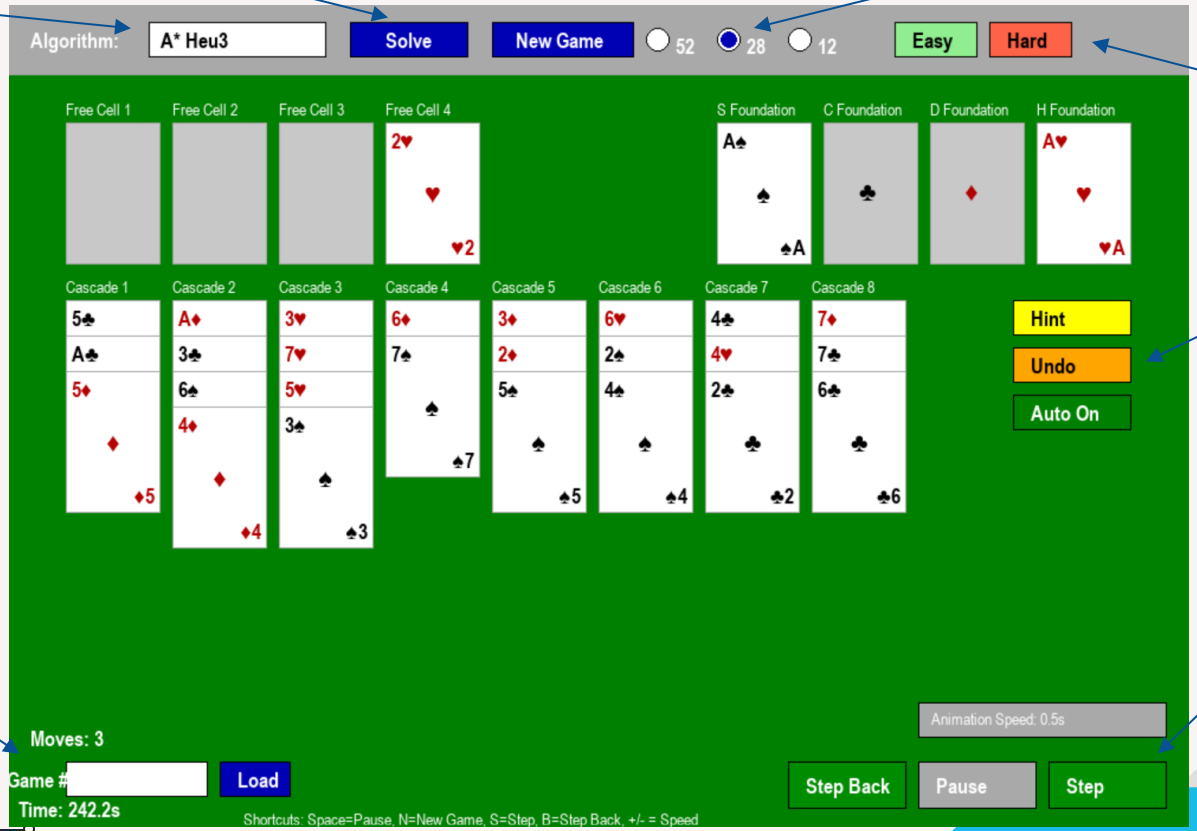
Nº of Cards

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. **Uniformed Search is not feasible for freecell solitaire** (unless with higher processing capabilities)

“Empty to Empty” Optimization (E2E)

200 000 Max States

When enabled, eliminates unnecessary moves between empty cascades:

- Disables **unnecessary** moves between **empty cascades**
- Significantly **improves** performance of uninformed search algorithms (DFS and IDS)
- For **game2.txt**, it found an optimal solution in **47 moves** instead of **92**, and for **DFS**, it found a solution in **35 moves** instead of **78 moves**.

03 Informed Search

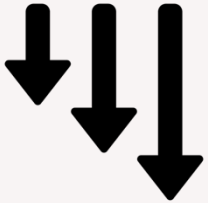
Heuristics

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

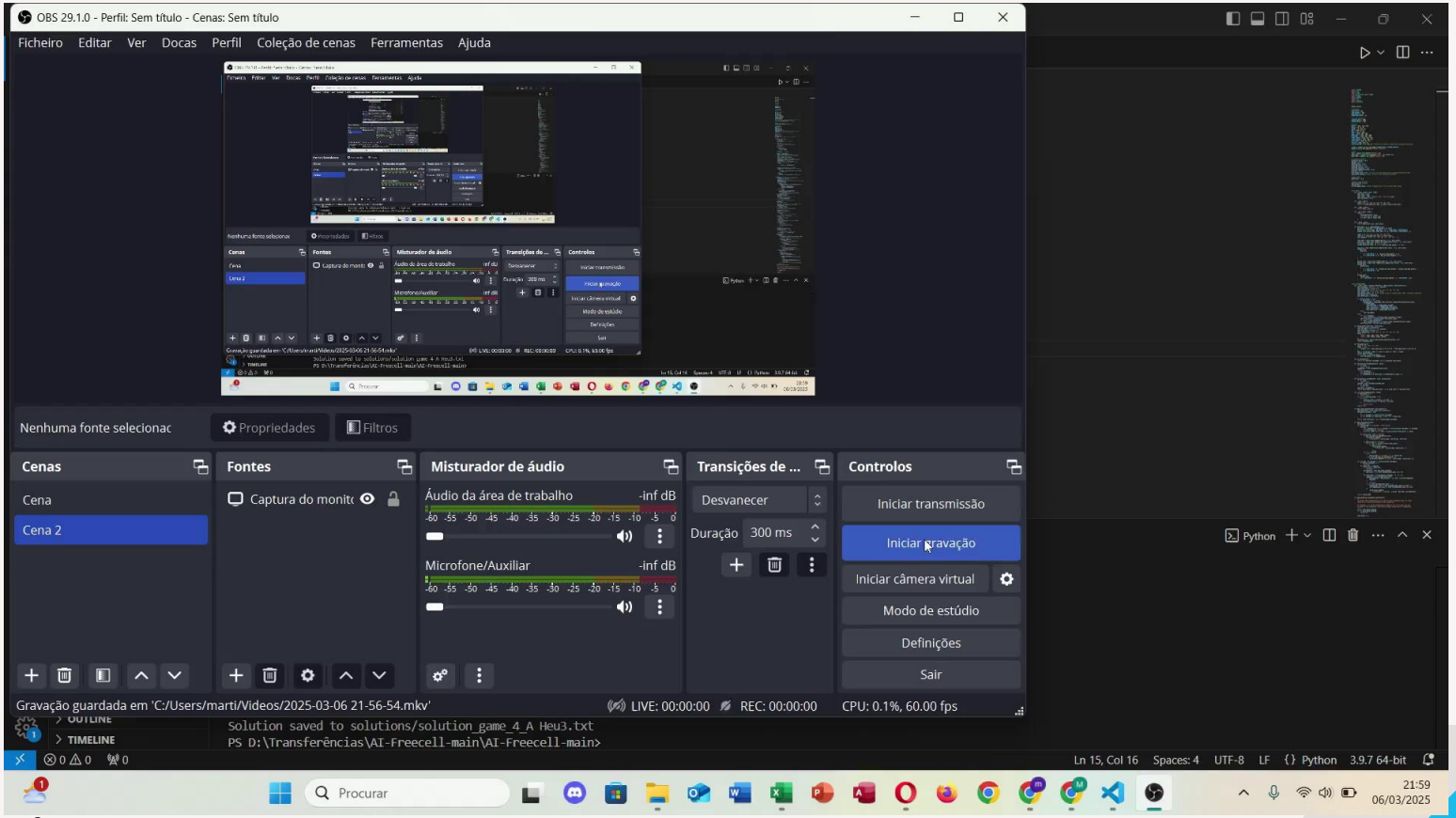
- Estimates the minimum number of moves required to place all cards in the foundations, considering gaps in sequences.



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


OBS 29.1.0 - Perfil: Sem título - Cenas: Sem título
Ficheiro Editar Ver Docas Perfil Coleção de cenas Ferramentas Ajuda
Nenhuma fonte selecionac
Propriedades
Filtros
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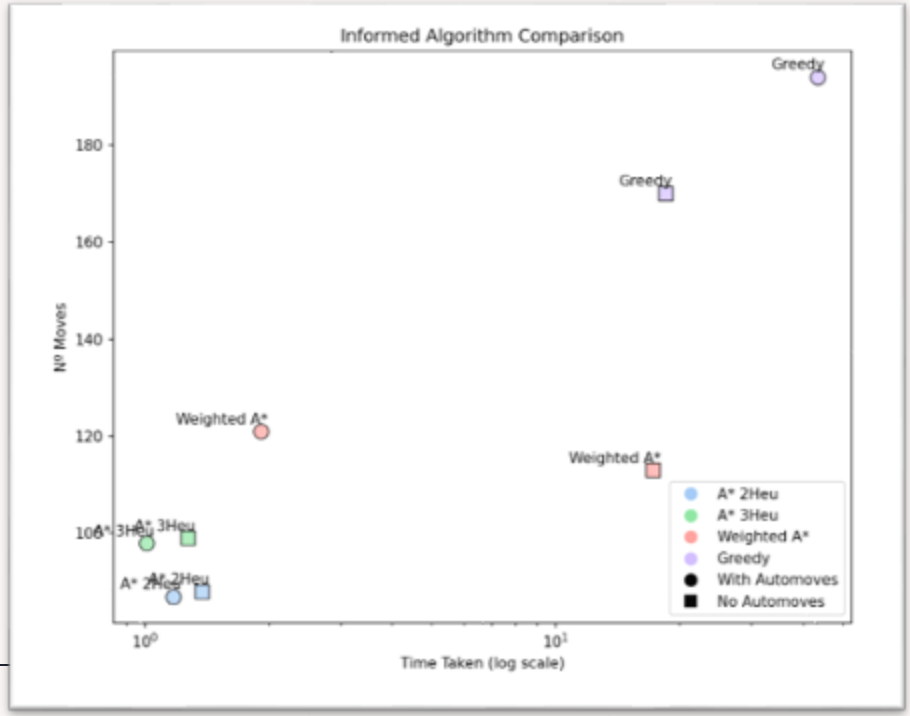
Cena
Cena 2
Fontes
Captura do monit
Misturador de áudio
Áudio da área de trabalho -inf dB
Microfone/Auxiliar -inf dB
Transições de ...
Desvanecer
Duração 300 ms
Controlos
Iniciar transmissão
Iniciar gravação
Iniciar câmera virtual
Modo de estúdio
Definições
Sair
Gravação guardada em 'C:/Users/marti/Videos/2025-03-06 21-56-54.mkv'
LIVE: 00:00:00
REC: 00:00:00
CPU: 0.1%, 60.00 fps
OUTLINE
TIMELINE
Solution saved to solutions/solution_game_4_A Heu3.txt
PS D:\Transferências\AI-Freecell-main\AI-Freecell-main>
Ln 15, Col 16 Spaces: 4 UTF-8 LF Python 3.9.7 64-bit
Python
Procurar
21:59
06/03/2025

Informed Algorithms Comparison

200 000 Max States

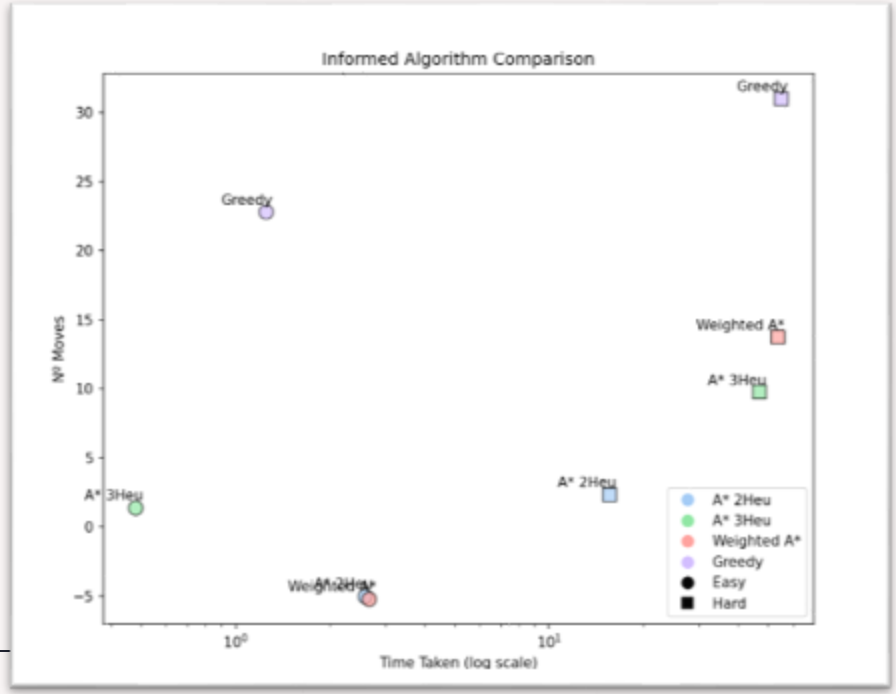


- Apart from heurist 1, every **heuristic found a solution for 52 cards deals.**
- A* with the second Heuristic was the **best overall method**, regarding best solution .
- Greedy was the **worst algorithm**

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

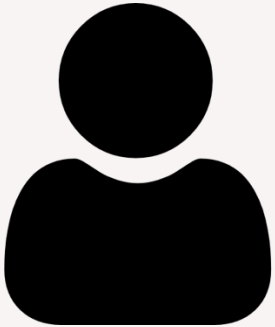
Informed Algorithms Comparison

500 000 Max States



- For easy problems **A* with heuristic 2 weighted A* were the best algorithms**
- For hard problems, altough A* with heurist 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

Meta Heuristic 2

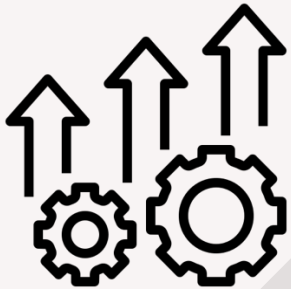
The second meta heuristic **resembled the first one in many aspects** altough simpler and with changed score values. These were the criteria:

- A **rewards for each card in the foundations**, with a reward of 10 points per card.
- A **penalizes free cells occupied** by a card, with 5 points for each card.
- A **penalizes for each pair of consecutive cards** in the cascades that are not in the correct sequence (i.e., rank and color mismatched).

Although the changes were not that significant, it led to huge increases in performance regarding better solutions and less time taken, revealing once more the impact that heuristics have in the performance of informed solvers

Results

- For easy games, both the solutions and time spent were **better than A* with heuristic 3.**
- For hard games, was able to **solve one more problem** than the other Meta Heuristic



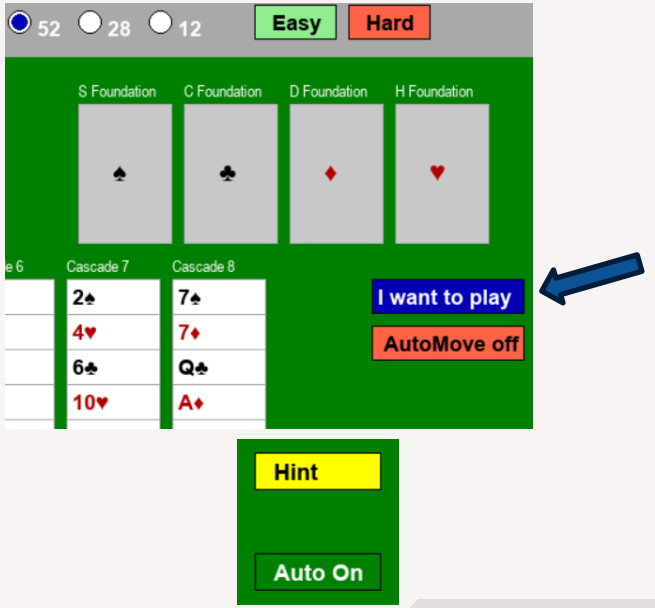
04 Single Player

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.

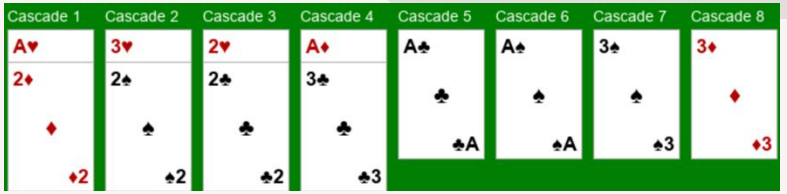
Besides that you can also activate "**Automatic Moves**" and "**Undo**" your latest move.



"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 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)

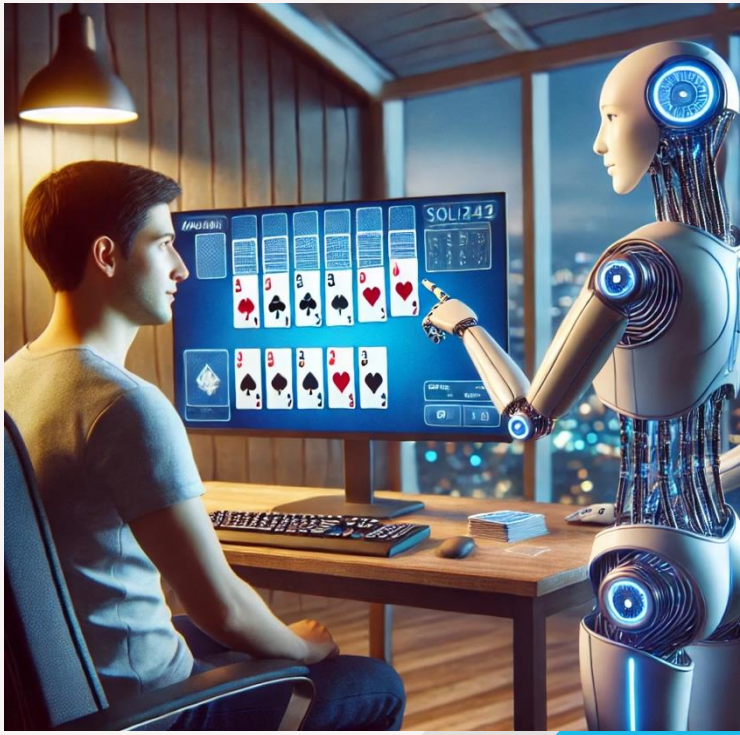
Zero shot attempt

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

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?

João Soares up202105364
João Vieira up202107689
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06 Results

Results regarding number of cards

		Time (seconds)			Nº of Moves			Peak memory (Mbs)			Nº of states explored		
	With Automoves ?	12	28	52	12	28	52	12	28	52	12	28	
Depth First Search	Yes	0.0093	3.9092	29.6813	14	No Solution (depth 101)	lo Solutions (depth of 150	56.27	79.84	78.10	16	200000	20
	No	0.0431	4.2436	8.1031	92	No solution (depth 150)	No Solution (depth 101)	61.79	81.46	78.54	94	200000	20
Breath First Search	Yes	37.6076	35.3730	41.5009	No solution (depth of 8)	Vo solutions (depth of 7	No Solution (depth of 12)	1910.08	1270.54	216.57	200000	200000	20
	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	200000	200000	20
Iterative Deepening Search	Yes	20.1249	640.5002	2070.6229	14	No Solution	No Solution	76.69	80.20	80.34	1332149	28892538	28
	No	229.4987	688.6425	1412.8835	78	No solution	No solution	80.90	82.25	581.62	14890390	28952445	28
A* - heu1	Yes	0.0062	55.2818	43.1403	12	Vo Solution (depth of 16	No Solution (depth of 14)	56.32	2344.22	642.63	16	200000	20
	No	0.0159	58.4548	43.5926	12	Vo Solution (depth of 16	No Solution (depth of 13)	57.18	2260.82	665.41	31	200000	20
A* - heu2	Yes	0.0065	0.6551	1.1752	12	39	87	55.92	93.22	109.08	14	1023	
	No	0.0188	0.2145	1.3807	12	41	88	57.27	83.18	112.05	19	391	
A* - heu3	Yes	0.0078	0.0459	1.0105	12	42	98	56.26	57.75	73.14	16	128	
	No	0.0196	0.1701	1.2731	12	42	99	3527.15	70.17	105.18	22	285	
Weight A* - heu3	Yes	0.0075	0.0514	1.9166	12	47	121	56.22	57.97	74.32	13	124	
	No	0.0102	0.0631	17.3260	13	47	113	56.22	58.89	272.68	14	124	5
Greedy - heu3	Yes	0.0075	0.0273	43.5625	12	50	194	56.11	56.84	107.82	14	68	18
	No	0.0124	0.0444	18.5396	13	45	170	56.45	57.90	238.92	15	73	6
Meta heurístic	Yes	0.0072	0.0451	0.3377	12	51	97	56.10	59.32	74.93	14	88	
	No	0.0206	0.0639	0.4140	12	50	98	56.43	61.56	81.34	14	89	

12 cards	game2.txt
28 cards	game3.txt
52 cards	game4.txt

Results regarding difficulty setting

		Time (seconds)		Differece of Nº moves to optimal solution		Peak memory (Mbs)		Nº of states explored	
	With Automoves ?	Easy	Hard	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	6986.00	62866.3
	No								
A* - heu3	Yes	0.48	46.88	1.40	9.75	69.37	292.69	1278.00	198027.5
	No								
Weight A* - heu3	Yes	2.67	53.56	-5.20	13.75	126.06	523.69	6082.80	199801.5
	No								
Greedy - heu3	Yes	1.25	55.07	22.80	31.00	98.31	650.78	3110.60	170536.5
	No								
Meta heurístic	Yes	3.42	130.08	5.20	23.00	242.28	6540.69	3911.00	188700.0
	No								

Results for Meta Heurist 2

		Time (seconds)		Differece of Nº moves to optimal solution		Peak memory (Mbs)		Nº of states explored	
	With Automoves ?	Easy	Hard	Easy	Hard	Easy	Hard	Easy	Hard
Meta heurístic 2	Yes	0.40	3.33	1.20	19.50	74.09	147.19	694.20	10501.50
	No								

Results for removing E2E moves

Removing Empty to empty moves (eliminates unnecessary moves)							
		Time (seconds)			Nº of Moves		
	With Automoves ?	12 cards (2)	28 cards (3)	52 cards (4)	12 cards (2)	28 cards (3)	52 cards (4)
Depth First Search	Yes						
	No	0.0469			47		
Iterative Deepening Search	Yes						
	No	157.4466			35		

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