Search methods analysis by Yevgen Nerush

This analysis contains brief overview of the different search methods including non-heuristic and heuristic ones, their performance metrics along with benefits and limitations. Each search method is researched on the Air Cargo Problem of small (1), medium (2) and large sizes (3).

There are five performance metrics in each search method evaluation:

- Expansions: the number of times the frontier is expanded by calling `PlanningProblem`'s `actions` function
- Goal Tests: the number of nodes verified for the goal match by calling `PlanningProblem`'s `goal_test` function
- New Nodes: the number of nodes added to the graph during the search by calling `PlanningProblem`'s `result` function
- Plan length: size of a list of the actions consecutive execution of which leads to an optimal solution (a solution with all sub-goals being satisfied)
- Execution time: the number of seconds a search algorithm takes to search for an optimal solution

After analysing all 10 search methods listed in this paper, the following optimal plans have been found for Problems 1, 2 and 3.

Air Cargo Problem 1

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

Air Cargo Problem 2

```
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Load(C3, P3, ATL)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)
```

Air Cargo Problem 3

```
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P2, ORD, SFO)
Unload(C4, P2, SFO)
Load(C1, P1, SFO)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C3, P1, JFK)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)
```

1. Breadth first search

Air Cargo Problem 1

- Expansions: 43
- Goal Tests: 56
- New Nodes: 180
- Plan length: 6
- Execution time: 0.03547631500987336 seconds

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
```

Air Cargo Problem 2

- Expansions: 3346
- Goal Tests: 4612
- New Nodes: 30534
- Plan length: 9
- Execution time: 81.65928123100002 seconds

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
```

Air Cargo Problem 3

- Expansions: 14663
- Goal Tests: 18098
- New Nodes: 129631
- Plan length: 12
- Execution time: 457.6173511959996 seconds

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C1, P1, JFK)
Unload(C3, P1, JFK)
Fly(P2, ORD, SFO)
Unload(C2, P2, SFO)
Unload(C4, P2, SFO)
```

2. Breadth first tree search

Air Cargo Problem 1

- Expansions: 1458
- Goal Tests: 1459
- New Nodes: 5960
- Plan length: 6
- Execution time: 6.019270433000202 seconds

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
```

Air Cargo Problem 2

Does not terminate in 10 minutes.

Air Cargo Problem 3

Does not terminate in 10 minutes.

3. Depth first graph search

Air Cargo Problem 1

- Expansions: 21
- Goal Tests: 22
- New Nodes: 84
- Plan length: 20
- Execution time: 0.09816352300003928 seconds

```
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Load(C2, P1, JFK)
Fly(P1, JFK, SFO)
Fly(P2, SFO, JFK)
Unload(C2, P1, SFO)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Load(C2, P2, SFO)
Fly(P1, JFK, SFO)
Load(C1, P2, SFO)
Fly(P2, SFO, JFK)
Fly(P1, SFO, JFK)
Unload(C2, P2, JFK)
Unload(C1, P2, JFK)
Fly(P2, JFK, SFO)
Load(C2, P1, JFK)
Fly(P1, JFK, SFO)
Fly(P2, SFO, JFK)
Unload(C2, P1, SFO)
```

Air Cargo Problem 2

- Expansions: 107
- Goal Tests: 108
- New Nodes: 959
- Plan length: 105
- Execution time: 2.255084823999823 seconds

```
Fly(P3, ATL, JFK)
Fly(P2, JFK, ATL)
Fly(P3, JFK, SFO)
Fly(P2, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P3, SFO, ATL)
Fly(P1, ATL, JFK)
Fly(P3, ATL, JFK)
```

```
...
Unload(C2, P3, SFO)
```

Air Cargo Problem 3

- Expansions: 408
- Goal Tests: 409
- New Nodes: 3364
- Plan length: 392
- Execution time: 11.076630202999695 seconds

```
Fly(P1, SFO, ORD)
Fly(P2, JFK, ORD)
Fly(P1, ORD, ATL)
Fly(P2, ORD, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
...
Unload(C3, P1, JFK)
```

4. Depth limited search

Air Cargo Problem 1

- Expansions: 101
- Goal Tests: 271
- New Nodes: 414
- Plan length: 50
- Execution time: 0.48083225499794935 seconds

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Unload(C1, P1, SFO)
Load(C1, P1, SFO)
Unload(C1, P1, SFO)
Load(C1, P1, SFO)
Unload(C1, P1, SFO)
...
Unload(C1, P1, JFK)
```

Air Cargo Problem 2

Does not terminate in 10 minutes.

Air Cargo Problem 3

Does not terminate in 10 minutes.

5. Uniform cost search

Air Cargo Problem 1

- Expansions: 55
- Goal Tests: 57
- New Nodes: 224
- Plan length: 6
- Execution time: 0.2418411139951786 seconds

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

Air Cargo Problem 2

- Expansions: 4853
- Goal Tests: 4855
- New Nodes: 44041
- Plan length: 9
- Execution time: 140.8912663539959 seconds

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)
```

Air Cargo Problem 3

Does not terminate in 10 minutes.

6. Recursive best first search with h1 heuristic function

Air Cargo Problem 1

- Expansions: 4229

- Goal Tests: 4230
- New Nodes: 17023
- Plan length: 6
- Execution time: 17.971775871999853 seconds

```
Load(C2, P2, JFK)
Load(C1, P1, SFO)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
```

Air Cargo Problem 2

Does not terminate in 10 minutes.

Air Cargo Problem 3

Does not terminate in 10 minutes.

7. Greedy best first graph search with h_1

Air Cargo Problem 1

- Expansions: 7
- Goal Tests: 9
- New Nodes: 28
- Plan length: 6
- Execution time: 0.02786448599999858 seconds

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

Air Cargo Problem 2

- Expansions: 998
- Goal Tests: 1000
- New Nodes: 8982
- Plan length: 21
- Execution time: 26.12001982899983 seconds

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
```

```
Load(C3, P3, ATL)
Fly(P1, SFO, ATL)
Fly(P2, JFK, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, SFO)
Unload(C2, P2, SFO)
Fly(P2, SFO, ATL)
Fly(P3, JFK, SFO)
Load(C2, P3, SFO)
Fly(P3, SFO, JFK)
Fly(P1, ATL, JFK)
Unload(C1, P1, JFK)
Load(C1, P3, JFK)
Fly(P1, JFK, ATL)
Fly(P3, JFK, SFO)
Unload(C3, P3, SFO)
Unload(C2, P3, SFO)
Fly(P3, SFO, JFK)
Unload(C1, P3, JFK)
```

Air Cargo Problem 3

- Expansions: 5614
- Goal Tests: 5616
- New Nodes: 49429
- Plan length: 22
- Execution time: 259.74592149100044 seconds

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, ORD)
Load(C4, P1, ORD)
Fly(P2, JFK, ATL)
Load(C3, P2, ATL)
Fly(P2, ATL, ORD)
Fly(P1, ORD, ATL)
Unload(C4, P1, ATL)
Fly(P1, ATL, ORD)
Fly(P2, ORD, ATL)
Load(C4, P2, ATL)
Fly(P2, ATL, ORD)
Unload(C3, P2, ORD)
Load(C3, P1, ORD)
Fly(P1, ORD, JFK)
Unload(C3, P1, JFK)
Unload(C1, P1, JFK)
Fly(P1, JFK, ORD)
Fly(P2, ORD, SFO)
```

```
Unload(C4, P2, SFO)
Unload(C2, P2, SFO)
```

8. A* search with h1 heuristic function

Air Cargo Problem 1

- Expansions: 55
- Goal Tests: 57
- New Nodes: 224
- Plan length: 6
- Execution time: 0.25108054200245533 seconds

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

Air Cargo Problem 2

- Expansions: 4853
- Goal Tests: 4855
- New Nodes: 44041
- Plan length: 9
- Execution time: 162.15786768100224 seconds

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)
```

Air Cargo Problem 3

Does not terminate in 10 minutes.

9. A* search with h_ignore_preconditions

Air Cargo Problem 1

- Expansions: 41
- Goal Tests: 43
- New Nodes: 170
- Plan length: 6
- Execution time: 0.042065354995429516 seconds

```
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
```

Air Cargo Problem 2

- Expansions: 1506
- Goal Tests: 1508
- New Nodes: 13820
- Plan length: 9
- Execution time: 13.943244863010477 seconds

```
Load(C3, P3, ATL)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
```

Air Cargo Problem 3

- Expansions: 5118
- Goal Tests: 5120
- New Nodes: 45650
- Plan length: 12
- Execution time: 93.62522890602122 seconds

```
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P2, ORD, SFO)
Unload(C4, P2, SFO)
Load(C1, P1, SFO)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
```

```
Unload(C3, P1, JFK)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)
```

10. A* search with levelsum heuristic function

Air Cargo Problem 1

- Expansions: 7
- Goal Tests: 9
- New Nodes: 28
- Plan length: 6
- Execution time: 0.9002755659894319 seconds

```
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)
```

Air Cargo Problem 2

- Expansions: 77
- Goal Tests: 79
- New Nodes: 760
- Plan length: 9
- Execution time: 129.23260724698775 seconds

```
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Load(C3, P3, ATL)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)
```

Air Cargo Problem 3

Does not terminate in 10 minutes.