analysis

June 21, 2018

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In [2]: import pandas as pd
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1 Problem #1

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In [1]: !python run_search.py -p 1 -s 1 2 3 4 5 6 7 8 9 10 11
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Solving Air Cargo Problem 1 using breadth_first_search...

# Actions   Expansions   Goal Tests   New Nodes
    20          43          56         178

Plan length: 6  Time elapsed in seconds: 0.007080069990479387
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)


Solving Air Cargo Problem 1 using depth_first_graph_search...

# Actions   Expansions   Goal Tests   New Nodes
    20          21          22          84

Plan length: 20  Time elapsed in seconds: 0.004421083009219728
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)
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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)


Solving Air Cargo Problem 1 using uniform_cost_search...

# Actions   Expansions   Goal Tests   New Nodes
    20          60          62         240

Plan length: 6  Time elapsed in seconds: 0.011631151995970868
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Load(C1, P2, SFO)
Unload(C2, P2, SFO)
Fly(P2, SFO, JFK)
Unload(C1, P2, JFK)


Solving Air Cargo Problem 1 using greedy_best_first_graph_search with h_unmet_goals...

# Actions   Expansions   Goal Tests   New Nodes
    20          7           9           29

Plan length: 6  Time elapsed in seconds: 0.001940809001098387
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)


Solving Air Cargo Problem 1 using greedy_best_first_graph_search with h_pg_levelsum...

# Actions   Expansions   Goal Tests   New Nodes
    20          6           8           28

Plan length: 6  Time elapsed in seconds: 0.4006290220131632
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
```

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


Solving Air Cargo Problem 1 using greedy_best_first_graph_search with h_pg_maxlevel...

# Actions   Expansions   Goal Tests   New Nodes
    20          6           8           24

Plan length: 6  Time elapsed in seconds: 0.2679013169981772
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Fly(P1, SFO, JFK)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)


Solving Air Cargo Problem 1 using greedy_best_first_graph_search with h_pg_setlevel...

# Actions   Expansions   Goal Tests   New Nodes
    20          6           8           28

Plan length: 6  Time elapsed in seconds: 0.8791906779952114
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)


Solving Air Cargo Problem 1 using astar_search with h_unmet_goals...

# Actions   Expansions   Goal Tests   New Nodes
    20          50          52         206

Plan length: 6  Time elapsed in seconds: 0.010402537998743355
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Load(C1, P2, SFO)
Fly(P2, SFO, JFK)
Unload(C1, P2, JFK)
```

```
Solving Air Cargo Problem 1 using astar_search with h_pg_levelsum...

# Actions   Expansions   Goal Tests   New Nodes
    20          28          30          122

Plan length: 6  Time elapsed in seconds: 0.9959241950127762
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Load(C1, P2, SFO)
Fly(P2, SFO, JFK)
Unload(C1, P2, JFK)


Solving Air Cargo Problem 1 using astar_search with h_pg_maxlevel...

# Actions   Expansions   Goal Tests   New Nodes
    20          43          45          180

Plan length: 6  Time elapsed in seconds: 1.0290616809943458
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Load(C1, P2, SFO)
Unload(C2, P2, SFO)
Fly(P2, SFO, JFK)
Unload(C1, P2, JFK)


Solving Air Cargo Problem 1 using astar_search with h_pg_setlevel...

# Actions   Expansions   Goal Tests   New Nodes
    20          33          35          138

Plan length: 6  Time elapsed in seconds: 2.0407893910014536
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Load(C1, P2, SFO)
Fly(P2, SFO, JFK)
Unload(C1, P2, JFK)
```

```
In [10]: pd.DataFrame()
```

```
         import pandas as pd

         df = pd.DataFrame([
```

```
                        ["breadth_first_graph_search",43,56,178,6,0.007080069990479387],
                        ["depth_first_graph_search",21,22,84,20,0.004421083009219728],
                        ["uniform_cost_search",60,62,240,6,0.011631151995970868],
                        ["greedy_best_first_graph_search + h_unmet_goals",7,9,29,6,0.00194
                        ["greedy_best_first_graph_search + h_pg_levelsum",6,8,28,6,0.40062
                        ["greedy_best_first_graph_search + h_pg_maxlevel",6,8,24,6,0.26790
                        ["greedy_best_first_graph_search + h_pg_setlevel",6,8,28,6,0.87919
                        ["astar_search + h_unmet_goals",50,52,206,6,0.010402537998743355],
                        ["astar_search + h_pg_levelsum",28,30,122,6,0.9959241950127762],
                        ["astar_search + h_pg_maxlevel",43,45,180,6,1.0290616809943458],
                        ["astar_search + h_pg_setlevel",33,35,138,6,2.0407893910014536]

                        ],
                       columns = ["Algorithm","Expansions","Goal Tests","New Nodes","Plan
```

```
df
```

Out[10]:

	Algorithm	Expansions	Goal Tests	New Nodes	Plan Length	Time
0	breadth_first_graph_search	43	56	178	6	0.007080
1	depth_first_graph_search	21	22	84	20	0.004421
2	uniform_cost_search	60	62	240	6	0.011631
3	greedy_best_first_graph_search + h_unmet_goals	7	9	29	6	0.001941
4	greedy_best_first_graph_search + h_pg_levelsum	6	8	28	6	0.400629
5	greedy_best_first_graph_search + h_pg_maxlevel	6	8	24	6	0.267901
6	greedy_best_first_graph_search + h_pg_setlevel	6	8	28	6	0.879191
7	astar_search + h_unmet_goals	50	52	206	6	0.010403
8	astar_search + h_pg_levelsum	28	30	122	6	0.995924
9	astar_search + h_pg_maxlevel	43	45	180	6	1.029062
10	astar_search + h_pg_setlevel	33	35	138	6	2.040789

P1 --> Actions: 20

2 Problem #2

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In [11]: !python run_search.py -p 2 -s 1 2 3 4 5 6 7 8 9 10 11
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Solving Air Cargo Problem 2 using breadth_first_search...

# Actions   Expansions   Goal Tests   New Nodes
    72         3343         4609       30503

Plan length: 9  Time elapsed in seconds: 2.280459322995739
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)


Solving Air Cargo Problem 2 using depth_first_graph_search...

# Actions   Expansions   Goal Tests   New Nodes
    72         624          625          5602

Plan length: 619  Time elapsed in seconds: 2.899390610997216
Fly(P3, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P3, SFO, JFK)
Fly(P1, ATL, JFK)
Fly(P2, JFK, ATL)
Fly(P3, JFK, ATL)
Fly(P2, ATL, SFO)
Fly(P3, ATL, SFO)
Load(C2, P1, JFK)
Fly(P2, SFO, ATL)
Fly(P1, JFK, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, SFO)
Fly(P3, SFO, ATL)
Fly(P1, SFO, JFK)
Load(C3, P3, ATL)
Fly(P3, ATL, SFO)
Fly(P2, JFK, ATL)
Fly(P3, SFO, JFK)
Fly(P2, ATL, SFO)
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Fly(P1, JFK, ATL)
Fly(P2, SFO, JFK)
Fly(P1, ATL, SFO)
Unload(C3, P3, JFK)
Fly(P1, SFO, JFK)
Fly(P3, JFK, ATL)
Fly(P2, JFK, ATL)
Fly(P3, ATL, SFO)
Fly(P2, ATL, SFO)
Fly(P1, JFK, ATL)
Fly(P3, SFO, ATL)
Fly(P1, ATL, SFO)
Unload(C2, P1, SFO)
Fly(P3, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P1, SFO, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, JFK)
Fly(P3, SFO, ATL)
Fly(P2, JFK, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, SFO)
Fly(P1, JFK, ATL)
Load(C3, P3, JFK)
Fly(P1, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P3, JFK, ATL)
Fly(P2, ATL, JFK)
Fly(P3, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P2, JFK, ATL)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Fly(P3, SFO, ATL)
Unload(C3, P3, ATL)
Fly(P3, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P3, SFO, JFK)
Fly(P2, ATL, JFK)
Fly(P1, JFK, ATL)
Fly(P3, JFK, ATL)
Fly(P2, JFK, ATL)
Load(C3, P2, ATL)
Fly(P3, ATL, SFO)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Fly(P3, SFO, ATL)
Fly(P2, SFO, JFK)
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Fly(P3, ATL, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C3, P2, SFO)
Fly(P2, SFO, ATL)
Fly(P3, JFK, ATL)
Fly(P2, ATL, JFK)
Fly(P3, ATL, SFO)
Load(C2, P3, SFO)
Fly(P3, SFO, ATL)
Fly(P2, JFK, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, SFO)
Fly(P1, JFK, ATL)
Fly(P2, SFO, JFK)
Fly(P1, ATL, SFO)
Unload(C2, P3, JFK)
Fly(P1, SFO, JFK)
Fly(P3, JFK, ATL)
Fly(P2, JFK, ATL)
Fly(P3, ATL, SFO)
Fly(P2, ATL, SFO)
Fly(P1, JFK, ATL)
Fly(P3, SFO, ATL)
Fly(P1, ATL, SFO)
Load(C3, P2, SFO)
Fly(P3, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P1, SFO, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, JFK)
Fly(P3, SFO, ATL)
Load(C2, P2, JFK)
Fly(P3, ATL, JFK)
Fly(P2, JFK, ATL)
Fly(P1, JFK, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Unload(C3, P2, SFO)
Fly(P2, SFO, ATL)
Fly(P1, SFO, ATL)
Fly(P2, ATL, JFK)
Fly(P3, JFK, ATL)
Fly(P1, ATL, SFO)
Fly(P3, ATL, SFO)
Fly(P1, SFO, JFK)
Fly(P2, JFK, ATL)
Fly(P3, SFO, ATL)
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Fly(P2, ATL, SFO)
Load(C1, P2, SFO)
Fly(P3, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P3, SFO, JFK)
Fly(P2, ATL, JFK)
Fly(P1, JFK, ATL)
Fly(P3, JFK, ATL)
Fly(P1, ATL, SFO)
Fly(P3, ATL, SFO)
Unload(C2, P2, JFK)
Fly(P1, SFO, ATL)
Fly(P2, JFK, ATL)
Fly(P1, ATL, JFK)
Fly(P3, SFO, ATL)
Fly(P2, ATL, SFO)
Fly(P3, ATL, JFK)
Fly(P1, JFK, ATL)
Load(C3, P2, SFO)
Fly(P1, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P1, SFO, JFK)
Fly(P2, ATL, JFK)
Fly(P3, JFK, ATL)
Fly(P1, JFK, ATL)
Fly(P3, ATL, SFO)
Fly(P1, ATL, SFO)
Unload(C3, P2, JFK)
Fly(P3, SFO, ATL)
Fly(P2, JFK, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P2, SFO, JFK)
Unload(C1, P2, JFK)
Fly(P1, ATL, SFO)
Fly(P2, JFK, ATL)
Fly(P1, SFO, JFK)
Fly(P2, ATL, SFO)
Fly(P3, JFK, ATL)
Fly(P2, SFO, JFK)
Fly(P3, ATL, SFO)
Load(C3, P2, JFK)
Fly(P2, JFK, ATL)
Fly(P3, SFO, ATL)
Fly(P2, ATL, SFO)
Fly(P3, ATL, JFK)
Fly(P1, JFK, ATL)
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Fly(P2, SFO, ATL)
Fly(P1, ATL, SFO)
Unload(C3, P2, ATL)
Fly(P2, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P2, SFO, JFK)
Fly(P1, ATL, JFK)
Fly(P3, JFK, ATL)
Fly(P2, JFK, SFO)
Fly(P3, ATL, SFO)
Load(C2, P1, JFK)
Fly(P2, SFO, ATL)
Fly(P3, SFO, ATL)
Fly(P1, JFK, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Fly(P3, ATL, JFK)
Fly(P2, SFO, ATL)
Unload(C2, P1, SFO)
Fly(P2, ATL, JFK)
Fly(P1, SFO, ATL)
Fly(P3, JFK, ATL)
Fly(P1, ATL, JFK)
Fly(P3, ATL, SFO)
Fly(P2, JFK, ATL)
Fly(P1, JFK, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Load(C2, P3, SFO)
Fly(P3, SFO, ATL)
Fly(P2, SFO, ATL)
Fly(P1, SFO, ATL)
Fly(P3, ATL, JFK)
Fly(P1, ATL, JFK)
Fly(P2, ATL, SFO)
Load(C1, P3, JFK)
Fly(P2, SFO, JFK)
Fly(P3, JFK, ATL)
Fly(P2, JFK, ATL)
Fly(P3, ATL, SFO)
Fly(P1, JFK, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Fly(P3, SFO, ATL)
Unload(C2, P3, ATL)
Fly(P3, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P1, SFO, ATL)
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```
Fly(P2, ATL, JFK)
Fly(P1, ATL, JFK)
Fly(P3, SFO, JFK)
Fly(P2, JFK, ATL)
Unload(C1, P3, JFK)
Fly(P2, ATL, SFO)
Fly(P3, JFK, ATL)
Fly(P2, SFO, JFK)
Fly(P3, ATL, SFO)
Fly(P1, JFK, ATL)
Fly(P3, SFO, JFK)
Fly(P1, ATL, SFO)
Load(C1, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, ATL)
Fly(P3, JFK, ATL)
Fly(P2, ATL, SFO)
Fly(P3, ATL, SFO)
Fly(P1, JFK, ATL)
Fly(P2, SFO, ATL)
Fly(P1, ATL, SFO)
Unload(C1, P2, ATL)
Fly(P2, ATL, SFO)
Fly(P1, SFO, ATL)
Fly(P3, SFO, ATL)
Fly(P1, ATL, JFK)
Fly(P3, ATL, JFK)
Fly(P2, SFO, JFK)
Fly(P1, JFK, ATL)
Fly(P2, JFK, ATL)
Load(C3, P2, ATL)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Fly(P2, SFO, JFK)
Fly(P1, SFO, JFK)
Fly(P3, JFK, ATL)
Fly(P2, JFK, ATL)
Fly(P3, ATL, SFO)
Fly(P2, ATL, SFO)
Unload(C3, P2, SFO)
Fly(P3, SFO, ATL)
Fly(P2, SFO, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, JFK)
Fly(P1, JFK, ATL)
Fly(P3, JFK, ATL)
Fly(P1, ATL, SFO)
Fly(P3, ATL, SFO)
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Fly(P2, JFK, ATL)
Fly(P1, SFO, ATL)
Load(C3, P3, SFO)
Fly(P2, ATL, SFO)
Fly(P1, ATL, SFO)
Fly(P3, SFO, ATL)
Fly(P2, SFO, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, JFK)
Fly(P1, SFO, ATL)
Fly(P3, JFK, ATL)
Fly(P1, ATL, JFK)
Load(C2, P3, ATL)
Fly(P3, ATL, SFO)
Fly(P2, JFK, ATL)
Fly(P3, SFO, JFK)
Fly(P2, ATL, SFO)
Fly(P1, JFK, ATL)
Fly(P2, SFO, JFK)
Fly(P1, ATL, SFO)
Unload(C3, P3, JFK)
Fly(P1, SFO, JFK)
Fly(P3, JFK, ATL)
Fly(P2, JFK, ATL)
Fly(P3, ATL, SFO)
Fly(P2, ATL, SFO)
Fly(P1, JFK, ATL)
Fly(P3, SFO, ATL)
Fly(P1, ATL, SFO)
Unload(C2, P3, ATL)
Fly(P3, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P1, SFO, ATL)
Fly(P2, ATL, JFK)
Fly(P1, ATL, JFK)
Load(C3, P1, JFK)
Fly(P3, SFO, ATL)
Fly(P2, JFK, ATL)
Fly(P3, ATL, JFK)
Fly(P2, ATL, SFO)
Fly(P1, JFK, ATL)
Load(C2, P1, ATL)
Fly(P1, ATL, SFO)
Fly(P2, SFO, ATL)
Fly(P1, SFO, JFK)
Fly(P2, ATL, JFK)
Fly(P3, JFK, ATL)
Fly(P1, JFK, ATL)
```

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

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

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

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

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

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

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


Solving Air Cargo Problem 2 using uniform_cost_search...

# Actions   Expansions   Goal Tests   New Nodes
    72         5154        5156       46618

Plan length: 9  Time elapsed in seconds: 3.6765052149858093
Load(C3, P3, ATL)
Fly(P3, ATL, SFO)
Load(C1, P3, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C3, P3, SFO)
Fly(P3, SFO, JFK)
Unload(C2, P2, SFO)
Unload(C1, P3, JFK)


Solving Air Cargo Problem 2 using greedy_best_first_graph_search with h_unmet_goals...

# Actions   Expansions   Goal Tests   New Nodes
    72          17          19         170

Plan length: 9  Time elapsed in seconds: 0.022101587994256988
```

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


Solving Air Cargo Problem 2 using greedy_best_first_graph_search with h_pg_levelsum...

# Actions   Expansions   Goal Tests   New Nodes
    72          9           11          86

Plan length: 9  Time elapsed in seconds: 9.359082244001911
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Load(C3, P3, ATL)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)


Solving Air Cargo Problem 2 using greedy_best_first_graph_search with h_pg_maxlevel...

# Actions   Expansions   Goal Tests   New Nodes
    72          27          29         249

Plan length: 9  Time elapsed in seconds: 17.23754288199416
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P2, JFK, SFO)
Fly(P3, ATL, SFO)
Fly(P1, SFO, JFK)
Unload(C3, P3, SFO)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)


Solving Air Cargo Problem 2 using greedy_best_first_graph_search with h_pg_setlevel...

# Actions   Expansions   Goal Tests   New Nodes
```

```
    72          9           11          84

Plan length: 9  Time elapsed in seconds: 31.942059952009004
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P2, JFK, SFO)
Fly(P3, ATL, SFO)
Fly(P1, SFO, JFK)
Unload(C3, P3, SFO)
Unload(C2, P2, SFO)
Unload(C1, P1, JFK)


Solving Air Cargo Problem 2 using astar_search with h_unmet_goals...

# Actions   Expansions   Goal Tests   New Nodes
    72         2467        2469       22522

Plan length: 9  Time elapsed in seconds: 2.465348088007886
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, P3, SFO)
Fly(P3, SFO, JFK)
Unload(C1, P3, JFK)


Solving Air Cargo Problem 2 using astar_search with h_pg_levelsum...

# Actions   Expansions   Goal Tests   New Nodes
    72         357         359         3426

Plan length: 9  Time elapsed in seconds: 258.14404204800667
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Load(C3, P3, ATL)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
Load(C1, P3, SFO)
Fly(P3, SFO, JFK)
Unload(C2, P2, SFO)
Unload(C1, P3, JFK)
```

```
Solving Air Cargo Problem 2 using astar_search with h_pg_maxlevel...

# Actions   Expansions   Goal Tests   New Nodes
    72         2887         2889       26594

Plan length: 9  Time elapsed in seconds: 1545.093450130007
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Load(C2, P1, JFK)
Load(C3, P3, ATL)
Unload(C1, P1, JFK)
Fly(P1, JFK, SFO)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
Unload(C2, P1, SFO)


Solving Air Cargo Problem 2 using astar_search with h_pg_setlevel...

# Actions   Expansions   Goal Tests   New Nodes
    72         1037         1039        9605

Plan length: 9  Time elapsed in seconds: 3052.5694550300104
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P2, JFK, SFO)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)
Unload(C2, P2, SFO)
Load(C1, P3, SFO)
Fly(P3, SFO, JFK)
Unload(C1, P3, JFK)
```

```
In [16]: df2 = pd.DataFrame([
                              ["breadth_first_graph_search",3343,4609,30503,9,2.280459322995739]
                              ["depth_first_graph_search",624,625,5602,619,2.899390610997216],
                              ["uniform_cost_search",5154,5156,46618,9,3.6765052149858093],
                              ["greedy_best_first_graph_search + h_unmet_goals",17,19,170,9,0.02
                              ["greedy_best_first_graph_search + h_pg_levelsum",9,11,86,9,9.3590
                              ["greedy_best_first_graph_search + h_pg_maxlevel",27,29,249,9,17.2
                              ["greedy_best_first_graph_search + h_pg_setlevel",9,11,84,9,31.942
                              ["astar_search + h_unmet_goals",2467,2469,22522,9,2.46534808800788
                              ["astar_search + h_pg_levelsum",357,359,3426,9,258.14404204800667]
                              ["astar_search + h_pg_maxlevel",2887,2889,26594,9,1545.0934501300
                              ["astar_search + h_pg_setlevel",1037,1039,9605,9,3052.569455030010
```

```
                          ],
                         columns = ["Algorithm","Expansions","Goal Tests","New Nodes","Plan L
```

```
df2
```

Out[16]:

	Algorithm	Expansions	Goal Tests	New Nodes	Plan Length	Time
0	breadth_first_graph_search	3343	4609	30503	9	2.280459
1	depth_first_graph_search	624	625	5602	619	2.899391
2	uniform_cost_search	5154	5156	46618	9	3.676505
3	greedy_best_first_graph_search + h_unmet_goals	17	19	170	9	0.022102
4	greedy_best_first_graph_search + h_pg_levelsum	9	11	86	9	9.359082
5	greedy_best_first_graph_search + h_pg_maxlevel	27	29	249	9	17.237543
6	greedy_best_first_graph_search + h_pg_setlevel	9	11	84	9	31.942060
7	astar_search + h_unmet_goals	2467	2469	22522	9	2.465348
8	astar_search + h_pg_levelsum	357	359	3426	9	258.144042
9	astar_search + h_pg_maxlevel	2887	2889	26594	9	1545.093450
10	astar_search + h_pg_setlevel	1037	1039	9605	9	3052.569455

P2 --> Actions: 72

```
In [ ]: run_search.py -p 3 -s 1 4 5 8 9
```

```
In [18]: df3 = pd.DataFrame([
                          ["breadth_first_graph_search",14663,18098,129625,12,19.23771613100
                          ["greedy_best_first_graph_search + h_unmet_goals",25,27,230,15,0.0
                          ["greedy_best_first_graph_search + h_pg_levelsum",14,16,126,14,34.
                          ["astar_search + h_unmet_goals",7388,7390,65711,12,15.695320989000
                          ["astar_search + h_pg_levelsum",369,371,3403,12,738.318932228]
                           ],
                         columns = ["Algorithm","Expansions","Goal Tests","New Nodes","Plan L
```

```
df3
```

```
Out[18]:                                          Algorithm  Expansions  Goal Tests  \
         0                       breadth_first_graph_search       14663       18098
         1  greedy_best_first_graph_search + h_unmet_goals          25          27
         2  greedy_best_first_graph_search + h_pg_levelsum          14          16
         3                    astar_search + h_unmet_goals        7388        7390
         4                    astar_search + h_pg_levelsum         369         371

            New Nodes  Plan Length        Time
         0     129625           12   19.237716
         1        230           15    0.061653
         2        126           14   34.746687
         3      65711           12   15.695321
         4       3403           12  738.318932
```

P3 --> Actions: 88

3 Problem #4

```
In [23]: !python run_search.py -p 4 -s 1 4 5 8 9


Solving Air Cargo Problem 4 using breadth_first_search...

# Actions   Expansions   Goal Tests   New Nodes
   104        99736       114953      944130

Plan length: 14  Time elapsed in seconds: 102.80974665802205
Load(C1, P1, SFO)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, ORD)
Load(C4, P1, ORD)
Load(C5, P1, ORD)
Fly(P1, ORD, JFK)
Load(C2, P1, JFK)
Unload(C1, P1, JFK)
Unload(C3, P1, JFK)
Unload(C5, P1, JFK)
Fly(P1, JFK, SFO)
Unload(C2, P1, SFO)
Unload(C4, P1, SFO)


Solving Air Cargo Problem 4 using greedy_best_first_graph_search with h_unmet_goals...

# Actions   Expansions   Goal Tests   New Nodes
   104          29          31         280
```

```
Plan length: 18  Time elapsed in seconds: 0.06987414401373826
Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P2, SFO, ORD)
Load(C4, P2, ORD)
Load(C5, P2, ORD)
Fly(P2, ORD, SFO)
Unload(C4, P2, SFO)
Fly(P2, SFO, JFK)
Unload(C5, P2, JFK)
Fly(P2, JFK, ATL)
Load(C3, P2, ATL)
Fly(P2, ATL, JFK)
Unload(C3, P2, JFK)
Fly(P2, JFK, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)


Solving Air Cargo Problem 4 using greedy_best_first_graph_search with h_pg_levelsum...

# Actions   Expansions   Goal Tests   New Nodes
   104          17           19         165

Plan length: 17  Time elapsed in seconds: 38.38155503201415
Fly(P2, JFK, ORD)
Load(C1, P1, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Load(C2, P1, JFK)
Fly(P1, JFK, SFO)
Unload(C2, P1, SFO)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C3, P1, JFK)
Load(C4, P2, ORD)
Load(C5, P2, ORD)
Fly(P2, ORD, SFO)
Unload(C4, P2, SFO)
Fly(P2, SFO, JFK)
Unload(C5, P2, JFK)


Solving Air Cargo Problem 4 using astar_search with h_unmet_goals...
```

```
# Actions   Expansions   Goal Tests   New Nodes
   104        34330       34332       328509

Plan length: 14  Time elapsed in seconds: 62.31459730499773
Load(C2, P2, JFK)
Fly(P2, JFK, ATL)
Load(C3, P2, ATL)
Fly(P2, ATL, ORD)
Load(C4, P2, ORD)
Load(C5, P2, ORD)
Fly(P2, ORD, SFO)
Unload(C4, P2, SFO)
Unload(C2, P2, SFO)
Load(C1, P2, SFO)
Fly(P2, SFO, JFK)
Unload(C5, P2, JFK)
Unload(C3, P2, JFK)
Unload(C1, P2, JFK)


Solving Air Cargo Problem 4 using astar_search with h_pg_levelsum...

# Actions   Expansions   Goal Tests   New Nodes
   104         1208        1210       12210

Plan length: 15  Time elapsed in seconds: 2419.6033478610043
Load(C1, P1, SFO)
Fly(P1, SFO, ORD)
Load(C4, P1, ORD)
Load(C5, P1, ORD)
Fly(P1, ORD, JFK)
Unload(C5, P1, JFK)
Unload(C1, P1, JFK)
Load(C2, P1, JFK)
Fly(P1, JFK, SFO)
Fly(P2, JFK, ATL)
Load(C3, P2, ATL)
Fly(P2, ATL, JFK)
Unload(C4, P1, SFO)
Unload(C3, P2, JFK)
Unload(C2, P1, SFO)
```

```
In [25]: df4 = pd.DataFrame([
                              ["breadth_first_graph_search",99736,114953,944130,14,190.578755048
                              ["greedy_best_first_graph_search + h_unmet_goals",29,31,280,18,0.1
```

```
                            ["greedy_best_first_graph_search + h_pg_levelsum",17,19,165,17,61.5
                            ["astar_search + h_unmet_goals",34330,34332,328509,14,106.94871843
                            ["astar_search + h_pg_levelsum",1208,1210,122210,15,2419.603347861
                             ],
                           columns = ["Algorithm","Expansions","Goal Tests","New Nodes","Plan L
```

```
In [25]: df4
```

Out[25]:

	Algorithm	Expansions	Goal Tests	New Nodes	Plan Length	Time
0	breadth_first_graph_search	99736	114953	944130	14	190.578755
1	greedy_best_first_graph_search + h_unmet_goals	29	31	280	18	0.110992
2	greedy_best_first_graph_search + h_pg_levelsum	17	19	165	17	61.544927
3	astar_search + h_unmet_goals	34330	34332	328509	14	106.948718
4	astar_search + h_pg_levelsum	1208	1210	122210	15	2419.603348

P4 --> Actions: 104

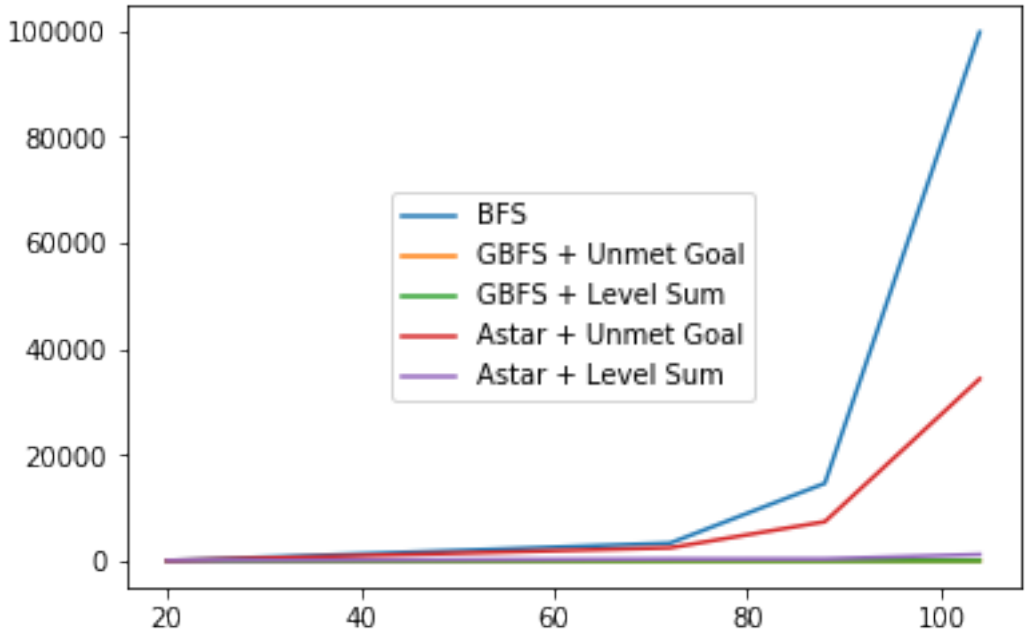
4 Visuals

```
In [30]: import numpy as np
         import matplotlib.pyplot as plt
```

```
In [26]: actions=[20, 72, 88, 104]
         legend = ['BFS','GBFS + Unmet Goal','GBFS + Level Sum','Astar + Unmet Goal','Astar + L
```

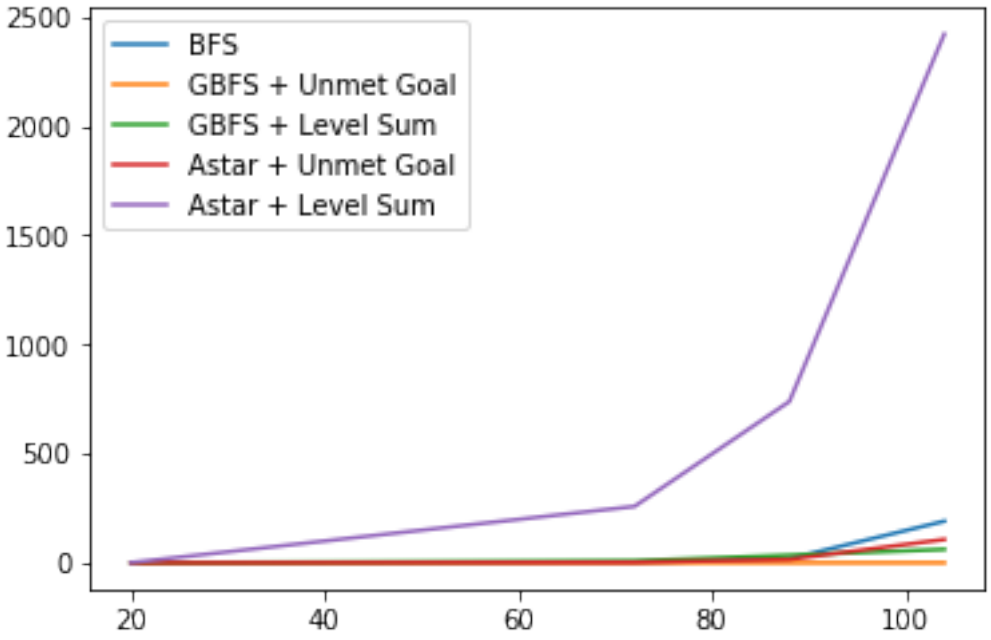
```
In [28]: #Plotting from expansions dict
         expansions = {}
         expansions['bfs'] = [43, 3343, 14633, 99736]
         expansions['gbfs_unmet'] = [7, 17, 25, 29]
         expansions['gbfs_levelsum'] = [6, 9, 14, 17]
         expansions['astar_unmet'] = [50, 2467, 7388, 34330]
         expansions['astar_levelsum'] = [28, 357, 369, 1208]
```

```
In [33]: # Action vs. Expansion Nodes
         for key,value in expansions.items():
             plt.plot(actions, value)
         plt.legend(legend, loc='center')
         plt.show()
```




```
In [35]: # Plotting from time dict
         time = {}
         time['bfs'] = [0.007080,2.280459,19.237716,190.578755]
         time['gbfs_unmet'] = [0.001941,0.02210,0.061653,0.110992]
         time['gbfs_levelsum'] = [0.400629,9.359082,34.746687,61.544927]
         time['astar_unmet'] = [0.010403,2.465348,15.695321,106.948718]
         time['astar_levelsum'] = [0.995924,258.144042,738.318932,2419.603348]

In [36]: # Actions vs. time
         for key, value in time.items():
             plt.plot(actions, value)
         plt.legend(legend, loc='upper left')
         plt.show()
```



Use your results to answer the following questions:

Which algorithm or algorithms would be most appropriate for planning in a very restricted domain (i.e., one that has only a few actions) and needs to operate in real time?

Ans: We need less complex heuristics for real-time operations and restricetd domains. Problem #1 is a good example of the same. I would consider greedy breadth first search and astar search with unmet goals as top options.

Which algorithm or algorithms would be most appropriate for planning in very large domains (e.g., planning delivery routes for all UPS drivers in the U.S. on a given day)

Ans: Uniform cost search(UCS), Breadth First Search(BFS), Astar search(A*) and Depth First Search(DFS) --> all of these have drastically increased number of nodes that for increased number of actions or large domains. GBFS(irrespective of heuristics), though not guranteed to find optimal solution might find good plans in general.

Which algorithm or algorithms would be most appropriate for planning problems where it is important to find only optimal plans?

Ans: UCS and BFS and A* with appropriate heuristics are guaranteed to find optimal plans. A* with max level and set level might be the most appropriate. DFS and GBFS cannot guarantee optimal plans.