

## Heuristic analysis

### Optimal plans for all Problems:

#### Problem 1:

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

#### Problem 2:

*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)*

#### 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)*

## Non-heuristic search result metrics:

### Breadth first search:

(aind) → AIND-Planning git:(master) ✗ python run\_search.py -p 1 -s 1

Solving Air Cargo Problem 1 using breadth\_first\_search...

Expansions	Goal Tests	New Nodes
43	56	180

Plan length: 6 Time elapsed in seconds: 0.02768918900983408

Load(C2, P2, JFK)

Load(C1, P1, SFO)

Fly(P2, JFK, SFO)

Unload(C2, P2, SFO)

Fly(P1, SFO, JFK)

Unload(C1, P1, JFK)

(aind) → AIND-Planning git:(master) ✗ python run\_search.py -p 2 -s 1

Solving Air Cargo Problem 2 using breadth\_first\_search...

Expansions	Goal Tests	New Nodes
3343	4609	30509

Plan length: 9 Time elapsed in seconds: 14.179230245994404

Load(C2, P2, JFK)

Load(C1, P1, SFO)

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)

(aind) → AIND-Planning git:(master) ✗ python run\_search.py -p 3 -s 1

Solving Air Cargo Problem 3 using breadth\_first\_search...

Expansions	Goal Tests	New Nodes
14663	18098	129631

Plan length: 12 Time elapsed in seconds: 103.99969666398829

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

### Depth first search:

(aind) → AIND-Planning git:(master) ✗ python run\_search.py -p1 -s3

Solving Air Cargo Problem 1 using depth\_first\_graph\_search...

Expansions	Goal Tests	New Nodes
12	13	48

Plan length: 12 Time elapsed in seconds: 0.007857046992285177

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

Fly(P1, JFK, SFO)  
Unload(C2, P1, SFO)

(aind) → AIND-Planning git:(master) ✗ python run\_search.py -p2 -s3

Solving Air Cargo Problem 2 using depth\_first\_graph\_search...

Expansions	Goal Tests	New Nodes
582	583	5211

Plan length: 575 Time elapsed in seconds: 3.075095659994986

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

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

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

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



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

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

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

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

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

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



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

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

(aind) → AIND-Planning git:(master) ✗ python run\_search.py -p3 -s3

Solving Air Cargo Problem 3 using depth\_first\_graph\_search...

Expansions	Goal Tests	New Nodes
627	628	5176

Plan length: 596 Time elapsed in seconds: 3.2433186949929222

Fly(P1, SFO, ORD)  
Fly(P2, JFK, ORD)  
Fly(P1, ORD, ATL)

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

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

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

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

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

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

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

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

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

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

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

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

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



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

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**Uniform cost search:**

(aind) → AIND-Planning git:(master) ✗ python run\_search.py -p1 -s5

Solving Air Cargo Problem 1 using uniform\_cost\_search...

Expansions	Goal Tests	New Nodes
55	57	224

Plan length: 6 Time elapsed in seconds: 0.03706168298958801

Load(C1, P1, SFO)

Load(C2, P2, JFK)

Fly(P1, SFO, JFK)

Fly(P2, JFK, SFO)

Unload(C1, P1, JFK)

Unload(C2, P2, SFO)

(aind) → AIND-Planning git:(master) ✗ python run\_search.py -p2 -s5

Solving Air Cargo Problem 2 using uniform\_cost\_search...

Expansions	Goal Tests	New Nodes
4853	4855	44041

Plan length: 9 Time elapsed in seconds: 46.5322795510001

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)

(aind) → AIND-Planning git:(master) ✗ python run\_search.py -p3 -s5

Solving Air Cargo Problem 3 using uniform\_cost\_search...

Expansions	Goal Tests	New Nodes
18223	18225	159618

Plan length: 12 Time elapsed in seconds: 383.1202584679995

Load(C1, P1, SFO)

Load(C2, P2, JFK)

Fly(P1, SFO, ATL)

Load(C3, P1, ATL)

Fly(P2, JFK, ORD)

Load(C4, P2, ORD)

Fly(P2, ORD, SFO)

Fly(P1, ATL, JFK)

Unload(C4, P2, SFO)

Unload(C3, P1, JFK)

Unload(C2, P2, SFO)

Unload(C1, P1, JFK)

(aind) → AIND-Planning git:(master) ✕

### Non-heuristic search results comparison:

	<i>Expansions</i>	<i>Goal Tests</i>	<i>New Nodes</i>	<i>Plan length</i>	<i>Time elapsed</i>
<b><i>Air Cargo Problem 1</i></b>					
Breadth first search	43	56	180	6	0.027689189
Depth first graph search	12	13	48	12	0.007857047
Uniform cost search	55	57	224	6	0.037061683
<b><i>Air Cargo Problem 2</i></b>					
Breadth first search	3343	4609	30509	9	14.17923025
Depth first graph search	582	583	5211	575	3.07509566
Uniform cost search	4853	4855	44041	9	46.53227955
<b><i>Air Cargo Problem 3</i></b>					
Breadth first search	14663	18098	129631	12	103.9996967
Depth first graph search	627	628	5176	596	3.243318695
Uniform cost search	18223	18225	159618	12	383.1202585

### Results explanation:

Based on table results we can see what depth first graph search algorithm takes much less time in all three problems, but depth first graph search does not provide plan with optimal length. These results are expected since depth first is not optimal and explore depth of the three first and not trying to find optimal solution. If non optimal solution will exist in left part of the three, depth first will find and return it, despite the fact that the solution is not optimal. This is confirmed by the numbers from the table where it is seen that relatively small number of nodes are expanded. In addition, depth first search algorithm is space efficient, and on every level  $n$  has in frontier only  $n$  nodes, where breadth first and uniform cost search has two to the  $n$  nodes in frontier for level  $n$ .

Breadth first graph search and uniform cost search are optimal algorithms, and they both provide optimal plan with optimal length. But we see the difference in elapsed time. Uniform cost search takes more time than breadth first graph search. This happens because breadth first search just consistently looking for a solution through the breadth of the three, where uniform cost search takes nodes in accordance with path cost, what is required addition computation and as results more nodes have to be expanded.

So, based on table results breadth first graph search is best choice for non-heuristic search for Air Cargo Problem, since it provides optimal solution with less elapse time.

## Heuristic search result metrics:

### A\* search with h\_ignore\_preconditions:

(aind) → AIND-Planning git:(master) ✗ python run\_search.py -p 1 -s 9

Solving Air Cargo Problem 1 using astar\_search with h\_ignore\_preconditions...

Expansions	Goal Tests	New Nodes
41	43	170

Plan length: 6 Time elapsed in seconds: 0.047705964010674506

Load(C1, P1, SFO)

Fly(P1, SFO, JFK)

Unload(C1, P1, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, SFO)

Unload(C2, P2, SFO)

(aind) → AIND-Planning git:(master) ✗ python run\_search.py -p 2 -s 9

Solving Air Cargo Problem 2 using astar\_search with h\_ignore\_preconditions...

Expansions	Goal Tests	New Nodes
1506	1508	13820

Plan length: 9 Time elapsed in seconds: 14.823811309004668

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)

(aind) → AIND-Planning git:(master) ✗ python run\_search.py -p 3 -s 9

Solving Air Cargo Problem 3 using astar\_search with h\_ignore\_preconditions...

Expansions	Goal Tests	New Nodes
5118	5120	45650

Plan length: 12 Time elapsed in seconds: 89.40691262099426

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)

### **A\* search with h\_pg\_levelsum:**

Solving Air Cargo Problem 1 using astar\_search with h\_pg\_levelsum...

Expansions	Goal Tests	New Nodes
11	13	50

Plan length: 6 Time elapsed in seconds: 1.5125191989936866

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

(aind) ➔ AIND-Planning git:(master) ✗ python run\_search.py -p2 -s10

Solving Air Cargo Problem 2 using astar\_search with h\_pg\_levelsum...

Expansions	Goal Tests	New Nodes
86	88	841

Plan length: 9 Time elapsed in seconds: 167.72710996100795

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)

(aind) → AIND-Planning git:(master) ✗ python run\_search.py -p3 -s10

Solving Air Cargo Problem 3 using astar\_search with h\_pg\_levelsum...

Expansions	Goal Tests	New Nodes
414	416	3818

Plan length: 12 Time elapsed in seconds: 1229.0756016929809

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

(aind) → AIND-Planning git:(master) ✗

### Heuristic search results comparison:

	<i>Expansions</i>	<i>Goal Tests</i>	<i>New Nodes</i>	<i>Plan length</i>	<i>Time elapsed</i>
<b><i>Air Cargo Problem 1</i></b>					
A*, h_ignore_preconditions	41	43	170	6	0.047705964
A*, h_pg_levelsum	11	13	50	6	1.512519199
<b><i>Air Cargo Problem 2</i></b>					
A*, h_ignore_preconditions	1506	1508	13820	9	14.82381131
A*, h_pg_levelsum	86	88	841	9	167.72711
<b><i>Air Cargo Problem 3</i></b>					
A*, h_ignore_preconditions	5118	5120	45650	12	89.40691262
A*, h_pg_levelsum	414	416	3818	12	1229.075602

### Results explanation:

Based on table results we can see what if we have good admissible heuristic that does not overestimate we can successfully use A\* search to find optimal solution. With both heuristics ignore preconditions heuristic and levelsum heuristic we find optimal path for all problems. In elapsed time comparison A\* search with ignore preconditions heuristic takes much less time than with levelsum heuristic. This can be explained by complexity of the heuristics. In ignore preconditions heuristic, we relax the problem by ignore all precondition and consider what every action is possible in every state. The sum of action in relax problem which achieve the goal will be ignore preconditions heuristic. In levelsum heuristic we need to build complex data structure called planning graph, which will include all possible states and actions in a problem, and relation between states and actions. After planning graph build we can find levelsum heuristic by calculating the level cost of individual sub goals.

It should be noted, what levelsum heuristic expand much less notes in comparison to ignore all precondition heuristic. Likely most of the elapsed time in levelsum heuristic spends on building planning graph, which later can use to receive very precise heuristic and also give a lot of useful information about the problem.

So, based on table results A\* search with ignore preconditions heuristic is best choice for heuristic search for Air Cargo Problem, since it takes less elapse time.



### All search results comparison:

	<i>Expansions</i>	<i>Goal Tests</i>	<i>New Nodes</i>	<i>Plan length</i>	<i>Time elapsed</i>
<b><i>Air Cargo Problem 1</i></b>					
breadth_first_search	43	56	180	6	0.027689189
depth_first_graph_search	12	13	48	12	0.007857047
uniform_cost_search	55	57	224	6	0.037061683
A*, h_ignore_preconditions	41	43	170	6	0.047705964
A*, h_pg_levelsum	11	13	50	6	1.512519199
<b><i>Air Cargo Problem 2</i></b>					
breadth_first_search	3343	4609	30509	9	14.17923025
depth_first_graph_search	582	583	5211	575	3.07509566
uniform_cost_search	4853	4855	44041	9	46.53227955
A*, h_ignore_preconditions	1506	1508	13820	9	14.82381131
A*, h_pg_levelsum	86	88	841	9	167.72711
<b><i>Air Cargo Problem 3</i></b>					
breadth_first_search	14663	18098	129631	12	103.9996967
depth_first_graph_search	627	628	5176	596	3.243318695
uniform_cost_search	18223	18225	159618	12	383.1202585
A*, h_ignore_preconditions	5118	5120	45650	12	89.40691262
A*, h_pg_levelsum	414	416	3818	12	1229.075602

### Results:

Per table results, we can make a conclusion what non-heuristic search algorithms works well for small problem, when complexity of the problem growing it is better to A\* algorithm with admissible heuristic. From considered algorithms best choice for small problems will be breadth first search algorithm. For complex problem, we should consider A\* algorithm with ignore preconditions heuristic or levelsum heuristic.