**Non-Heuristic Search Analyses**

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

Expansions Goal Tests New Nodes

43 56 180

Optimality of solution: 6

Time elapsed in seconds: 0.030091724009253085

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**...

Expansions Goal Tests New Nodes

21 22 84

Optimality of solution: 20

Time elapsed in seconds: 0.012733761017443612

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)

Solving Air Cargo **Problem 1 using depth\_limited\_search**...

Expansions Goal Tests New Nodes

101 271 414

Optimality of solution: 50

Time elapsed in seconds: 0.08026853401679546

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)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Unload(C1, P1, SFO)

Load(C1, P1, SFO)

Fly(P2, JFK, SFO)

Unload(C2, P2, SFO)

Fly(P1, SFO, JFK)

Unload(C1, P1, JFK)

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

Expansions Goal Tests New Nodes

1765 2376 14713

Optimality of solution: 9

Time elapsed in seconds: 3.2836126890033484

Load(C1, P1, SFO)

Fly(P1, SFO, JFK)

Load(C2, P1, JFK)

Unload(C1, P1, JFK)

Fly(P1, JFK, ATL)

Load(C3, P1, ATL)

Fly(P1, ATL, SFO)

Unload(C2, P1, SFO)

Unload(C3, P1, SFO)

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

Expansions Goal Tests New Nodes

1999 2000 15982

Optimality of solution: 327

Time elapsed in seconds: 3.991107910987921

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)

Load(C2, P1, JFK)

Fly(P1, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, JFK)

Unload(C2, P1, ATL)

Fly(P1, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P1, JFK, SFO)

Fly(P2, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, JFK)

Fly(P3, ATL, JFK)

Load(C1, P1, SFO)

Fly(P2, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Unload(C1, P1, JFK)

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)

Fly(P2, ATL, JFK)

Load(C3, P1, ATL)

Fly(P1, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P1, JFK, SFO)

Fly(P3, SFO, ATL)

Unload(C3, P1, SFO)

Fly(P3, ATL, JFK)

Fly(P2, SFO, ATL)

Fly(P3, JFK, SFO)

Fly(P2, ATL, JFK)

Fly(P1, SFO, ATL)

Fly(P2, JFK, SFO)

Fly(P1, ATL, JFK)

Load(C1, P1, JFK)

Fly(P1, JFK, ATL)

Fly(P3, SFO, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, JFK)

Fly(P2, SFO, ATL)

Fly(P3, JFK, SFO)

Fly(P2, ATL, JFK)

Unload(C1, P1, SFO)

Fly(P2, JFK, 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)

Load(C2, P1, ATL)

Fly(P1, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P1, JFK, SFO)

Fly(P3, SFO, ATL)

Unload(C2, P1, SFO)

Fly(P3, ATL, JFK)

Fly(P2, SFO, ATL)

Fly(P3, JFK, SFO)

Fly(P2, ATL, JFK)

Load(C3, P1, SFO)

Fly(P2, JFK, 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)

Unload(C3, P1, ATL)

Fly(P1, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P1, JFK, SFO)

Fly(P3, ATL, JFK)

Fly(P2, ATL, SFO)

Load(C1, P1, SFO)

Fly(P3, JFK, ATL)

Fly(P1, SFO, ATL)

Fly(P3, ATL, SFO)

Fly(P1, ATL, JFK)

Fly(P2, SFO, ATL)

Fly(P1, JFK, SFO)

Fly(P2, ATL, JFK)

Load(C2, P1, SFO)

Fly(P3, SFO, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, JFK)

Fly(P1, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P2, JFK, SFO)

Fly(P3, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P3, ATL, SFO)

Unload(C2, P1, ATL)

Fly(P3, SFO, JFK)

Unload(C1, P1, ATL)

Fly(P1, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P1, JFK, SFO)

Fly(P3, ATL, SFO)

Fly(P2, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, JFK)

Load(C3, P1, ATL)

Fly(P1, ATL, JFK)

Fly(P2, JFK, ATL)

Fly(P1, JFK, SFO)

Fly(P2, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P1, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Load(C2, P1, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P1, JFK, SFO)

Fly(P3, SFO, ATL)

Unload(C3, P1, SFO)

Fly(P3, ATL, JFK)

Fly(P2, SFO, ATL)

Fly(P3, JFK, SFO)

Fly(P2, ATL, JFK)

Fly(P1, SFO, ATL)

Fly(P2, JFK, SFO)

Fly(P1, ATL, JFK)

Unload(C2, P1, JFK)

Fly(P1, JFK, ATL)

Fly(P3, SFO, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, JFK)

Fly(P2, SFO, ATL)

Fly(P3, JFK, SFO)

Fly(P2, ATL, JFK)

Load(C3, P1, SFO)

Fly(P2, JFK, 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)

Unload(C3, P1, ATL)

Fly(P1, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Load(C2, P1, JFK)

Fly(P1, JFK, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Unload(C2, P1, SFO)

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)

Fly(P3, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P2, SFO, ATL)

Load(C3, P1, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P3, ATL, SFO)

Fly(P2, ATL, SFO)

Unload(C3, P1, JFK)

Fly(P1, JFK, ATL)

Fly(P3, SFO, ATL)

Fly(P1, ATL, SFO)

Fly(P3, ATL, JFK)

Fly(P2, SFO, ATL)

Fly(P3, JFK, SFO)

Fly(P2, ATL, JFK)

Load(C2, P1, SFO)

Fly(P2, JFK, 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)

Unload(C2, P1, ATL)

Fly(P1, ATL, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P3, ATL, SFO)

Load(C1, P1, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P2, JFK, SFO)

Fly(P1, JFK, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Unload(C1, P1, SFO)

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)

Fly(P3, ATL, JFK)

Fly(P1, JFK, ATL)

Fly(P2, SFO, ATL)

Load(C2, P1, ATL)

Fly(P2, ATL, 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)

Fly(P3, ATL, JFK)

Unload(C2, P1, SFO)

Fly(P3, JFK, SFO)

Fly(P2, SFO, ATL)

Fly(P3, SFO, ATL)

Fly(P2, ATL, JFK)

Load(C1, P1, SFO)

Fly(P3, ATL, JFK)

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)

Unload(C1, P1, JFK)

Fly(P1, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P1, ATL, SFO)

Fly(P2, ATL, SFO)

Fly(P3, SFO, ATL)

Fly(P2, SFO, JFK)

Fly(P3, ATL, JFK)

Load(C2, P1, SFO)

Fly(P2, JFK, ATL)

Fly(P3, JFK, ATL)

Fly(P1, SFO, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P3, ATL, SFO)

Fly(P2, JFK, ATL)

Unload(C2, P1, JFK)

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)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Load(C3, P1, JFK)

Fly(P3, JFK, ATL)

Fly(P2, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, SFO)

Fly(P1, ATL, SFO)

Fly(P3, JFK, ATL)

Unload(C3, 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)

Load(C2, P1, JFK)

Fly(P3, JFK, ATL)

Fly(P1, JFK, ATL)

Fly(P2, SFO, ATL)

Fly(P3, ATL, JFK)

Fly(P2, ATL, JFK)

Fly(P1, ATL, SFO)

Fly(P3, JFK, ATL)

Unload(C2, P1, SFO)

Solving Air Cargo **Problem 2 using depth\_limited\_search**...

Took more than 10 minutes to solve

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

Expansions Goal Tests New Nodes

14120 17673 124926

Optimality of solution: 12

Time elapsed in seconds: 59.51860062999185

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(P1, ATL, JFK)

Unload(C1, P1, JFK)

Unload(C3, P1, JFK)

Fly(P2, ORD, SFO)

Unload(C2, P2, SFO)

Unload(C4, P2, SFO)

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

Expansions Goal Tests New Nodes

292 293 2388

Optimality of solution: 288

Time elapsed in seconds: 1.746686728001805

Fly(P2, JFK, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, JFK)

Load(C2, P1, JFK)

Fly(P1, JFK, ORD)

Fly(P2, SFO, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, SFO)

Fly(P2, ATL, JFK)

Unload(C2, P1, SFO)

Fly(P2, JFK, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, JFK)

Load(C2, P2, SFO)

Fly(P1, JFK, ORD)

Fly(P2, SFO, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, SFO)

Unload(C2, P2, ATL)

Fly(P2, ATL, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, JFK)

Fly(P1, ORD, ATL)

Fly(P2, JFK, SFO)

Fly(P1, ATL, JFK)

Load(C1, P2, SFO)

Fly(P1, JFK, ORD)

Fly(P2, SFO, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, SFO)

Fly(P2, ATL, JFK)

Unload(C1, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, JFK)

Load(C1, P1, JFK)

Fly(P1, JFK, ORD)

Fly(P2, SFO, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Load(C3, P2, ATL)

Fly(P2, ATL, ORD)

Fly(P1, ATL, ORD)

Fly(P2, ORD, JFK)

Fly(P1, ORD, JFK)

Fly(P2, JFK, SFO)

Fly(P1, JFK, 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)

Unload(C1, P1, 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(C3, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, JFK)

Fly(P1, ORD, ATL)

Unload(C3, P2, JFK)

Fly(P1, ATL, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, SFO)

Load(C2, P2, ATL)

Fly(P2, ATL, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, JFK)

Fly(P1, ORD, ATL)

Fly(P2, JFK, SFO)

Fly(P1, ATL, JFK)

Unload(C2, P2, SFO)

Fly(P1, JFK, ORD)

Fly(P2, SFO, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, SFO)

Fly(P2, ATL, JFK)

Load(C3, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, JFK)

Unload(C3, P2, SFO)

Fly(P1, JFK, ORD)

Fly(P2, SFO, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, SFO)

Fly(P2, ATL, JFK)

Load(C3, P1, SFO)

Fly(P2, JFK, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Unload(C3, P1, ATL)

Fly(P1, ATL, ORD)

Fly(P2, SFO, ORD)

Fly(P1, ORD, JFK)

Fly(P2, ORD, ATL)

Fly(P1, JFK, SFO)

Fly(P2, ATL, JFK)

Load(C2, P1, SFO)

Fly(P2, JFK, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, JFK)

Fly(P2, ATL, SFO)

Unload(C2, P1, JFK)

Fly(P1, JFK, ORD)

Fly(P2, SFO, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, SFO)

Fly(P2, ATL, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, SFO, ORD)

Load(C4, P2, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, JFK)

Fly(P1, ATL, JFK)

Fly(P2, JFK, SFO)

Fly(P1, JFK, 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(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(C4, P2, SFO)

Fly(P2, SFO, ORD)

Fly(P1, SFO, JFK)

Fly(P2, ORD, ATL)

Fly(P1, JFK, ORD)

Fly(P2, ATL, JFK)

Unload(C4, P2, JFK)

Fly(P1, ORD, ATL)

Fly(P2, JFK, ORD)

Fly(P1, ATL, JFK)

Fly(P2, ORD, ATL)

Fly(P1, JFK, SFO)

Load(C3, P2, ATL)

Fly(P2, ATL, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, JFK)

Fly(P1, ORD, ATL)

Fly(P2, JFK, SFO)

Fly(P1, ATL, JFK)

Unload(C3, P2, SFO)

Fly(P1, JFK, ORD)

Fly(P2, SFO, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, SFO)

Fly(P2, ATL, JFK)

Load(C4, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, JFK)

Unload(C4, P2, SFO)

Fly(P1, JFK, ORD)

Fly(P2, SFO, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, SFO)

Fly(P2, ATL, JFK)

Load(C4, P1, SFO)

Fly(P2, JFK, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Unload(C4, P1, ATL)

Fly(P1, ATL, ORD)

Fly(P2, SFO, ORD)

Fly(P1, ORD, JFK)

Fly(P2, ORD, ATL)

Fly(P1, JFK, SFO)

Fly(P2, ATL, JFK)

Load(C3, P1, SFO)

Fly(P2, JFK, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, JFK)

Unload(C3, P1, JFK)

Fly(P1, JFK, ORD)

Fly(P2, SFO, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, SFO)

Fly(P2, ATL, JFK)

Load(C3, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Load(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)

Unload(C3, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, SFO)

Fly(P1, ORD, ATL)

Unload(C4, P2, SFO)

Fly(P1, ATL, JFK)

Fly(P2, SFO, ORD)

Fly(P1, JFK, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, SFO)

Fly(P2, ATL, JFK)

Load(C4, P1, SFO)

Fly(P2, JFK, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, JFK)

Fly(P2, ATL, SFO)

Unload(C4, P1, JFK)

Fly(P1, JFK, ORD)

Fly(P2, SFO, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, SFO)

Fly(P2, ATL, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, SFO, ORD)

Fly(P2, ORD, ATL)

Fly(P1, ORD, ATL)

Fly(P2, ATL, SFO)

Fly(P1, ATL, JFK)

Unload(C2, P2, SFO)

Fly(P1, JFK, ORD)

Fly(P2, SFO, ORD)

Fly(P1, ORD, ATL)

Fly(P2, ORD, ATL)

Fly(P1, ATL, SFO)

Fly(P2, ATL, JFK)

Load(C4, P2, JFK)

Fly(P2, JFK, ORD)

Fly(P1, SFO, JFK)

Fly(P2, ORD, ATL)

Fly(P1, JFK, ORD)

Fly(P2, ATL, SFO)

Fly(P1, ORD, ATL)

Unload(C4, P2, SFO)

Solving Air Cargo **Problem 3 using depth\_limited\_search**...

Took more than 10 minutes to solve

**Heuristic Search Analyses**

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

Expansions Goal Tests New Nodes

41 43 170

Optimality of solution: 6

Time elapsed in seconds: 0.03411777998553589

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 2 using astar\_search with h\_ignore\_preconditions**...

Expansions Goal Tests New Nodes

1598 1600 13299

Optimality of solution: 10

Time elapsed in seconds: 3.3241536959831137

Fly(P1, SFO, ATL)

Load(C3, P1, ATL)

Fly(P1, ATL, SFO)

Unload(C3, P1, SFO)

Load(C1, P1, SFO)

Fly(P1, SFO, JFK)

Unload(C1, P1, JFK)

Load(C2, P1, JFK)

Fly(P1, JFK, SFO)

Unload(C2, P1, SFO)

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

Expansions Goal Tests New Nodes

5040 5042 44944

Optimality of solution: 12

Time elapsed in seconds: 14.272548448992893

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)

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

Expansions Goal Tests New Nodes

45 47 188

Optimality of solution: 6

Time elapsed in seconds: 0.8783456929959357

Load(C1, P1, SFO)

Fly(P1, SFO, JFK)

Load(C2, P2, JFK)

Fly(P2, JFK, SFO)

Unload(C1, P1, JFK)

Unload(C2, P2, SFO)

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

Expansions Goal Tests New Nodes

1509 1511 12343

Optimality of solution: 9

Time elapsed in seconds: 202.56986283801962

Load(C1, P1, SFO)

Fly(P1, SFO, JFK)

Load(C2, P1, JFK)

Unload(C1, P1, JFK)

Fly(P1, JFK, ATL)

Load(C3, P1, ATL)

Fly(P1, ATL, SFO)

Unload(C3, P1, SFO)

Unload(C2, P1, SFO)

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

Took more than 10 minutes to ended the execution

**Problem 1 Comparison Table:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Search** | **Plan length** | **Time Elapsed (sec)** | **Expansions** | **Goal Tests** | **New Nodes** |
| Breadth first search | 6 | 0.03 | 43 | 56 | 180 |
| Depth first search Graph Search | 20 | 0.01 | 21 | 22 | 84 |
| Depth Limited Search | 50 | 0.08 | 101 | 271 | 414 |
| astar search h ignore precond | 6 | 0.03 | 41 | 43 | 170 |
| astar search h pg\_levesum | 6 | 0.88 | 45 | 47 | 188 |

**Problem 2 Comparison Table:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Search** | **Plan length** | **Time Elapsed** | **Expansions** | **Goal Tests** | **New Nodes** |
| Breadth first search | 9 | 3.28 | 1765 | 2376 | 14713 |
| Depth first search Graph Search | 327 | 3.99 | 1999 | 2000 | 15982 |
| Depth Limited Search (> 10 Min) | NA | NA | NA | NA | NA |
| astar search h ignore precond | 10 | 3.32 | 1598 | 1600 | 13299 |
| astar search h pg\_levesum | 9 | 202.01 | 1509 | 1511 | 12343 |

**Problem 3 Comparison Table:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Search** | **Plan length** | **Time Elapsed** | **Expansions** | **Goal Tests** | **New Nodes** |
| Breadth first search | 12 | 59.12 | 14120 | 17673 | 124926 |
| Depth first search Graph Search | 288 | 1.74 | 292 | 293 | 2388 |
| Depth Limited Search | NA | NA | NA | NA | NA |
| astar search h ignore precond | 12 | 14.27 | 5040 | 5042 | 44944 |
| astar search h pg\_levesum (> 10 min) | NA | NA | NA | NA | NA |

Best heuristic user in this problem is h\_igore\_precondition; though, h\_levelsum performed better for problem 2 but it took a lot more time to compute. Level sum finds the least expansion node because it finds the optimal path to the goal but there cost of computation to find that optimal path and therefore not the best heuristic when it comes to finding the solution in optimal time.

H\_ignore\_precondition heuristic search was better than non-heuristic search as it relaxes the problem by removing all the preconditions so the search ignores what the state needs to be in order to achieve the goal and therefore quickly finds the path to the goal. Node expansion is lower when compared to non-heuristic search. This relaxed heuristic is explained in Lesson 15 (Planning) lecture 22 in the sliding puzzle example. Removing preconditions of block of a blank space to slide a block was removed to find a quicker solution to the goal.