

Answer all questions. Test is open book and open notes. No talking or sharing of notes/books.

Please read all questions carefully. Several have detailed descriptions but require fairly brief answers.

1. (10 points) Consider an environment where there are n objects and the objects are so tightly inter-connected that any change in one object causes changes in all the other objects. For this domain, what is the maximum number of frame axioms needed to describe the changing state of the world as actions are performed?

2. (15 points) Unify the following expressions, or explain why they do not unify:

- (a) $F(?a, G(?a, ?b, c), c)$ and $F(G(?x), G(G(k), c, ?y), ?y)$
- (b) $\{P(f(A), x), P(x, A)\}$

3. (20 points) Perform Alpha-Beta pruning on the below graph, proceeding with a RIGHT to LEFT expansion of the nodes.

4. (25 points) An intelligent computerized paging system wishes to locate Dr. Spivey. Checking its knowledge-base, it discovers that:

- (a) Dr. Spivey is visiting Mr. Randle Patrick “RP” McMurphy
- (b) Mr. “RP” McMurphy is a patient at the Byberry Medical Center.

Write the situation calculus sentences and axioms to help the computer discover how to page Dr. Spivey. As well as the ground facts, you will need axioms to represent:

- (a) The relationship between VISITing and being AT some place;
- (b) The relationship between being AT some locaitons and being reachable by phone at the place;
- (c) The fact that a phone number for a place can be found by via a function for looking it up (the function takes the name of the place and the presons to be looked up there, i.e., LOOKUP(Korman,Regli)).
- (d) Dr. Spivey in visiting RP McMurphy: VISIT(Spivey,McMurphy)
- (e) RP McMurphy is a patient at Byberry Medical Center: AT(Byberry,McMurphy)
- (f) Relationship between VISITING and being AT:

$$\forall x, y, z \text{ VISIT}(x, y) \wedge \text{AT}(z, x) \implies \text{AT}(z, y)$$
- (g) The relationship between being AT and being REACHABLE-BY-PHONE:

$$\forall x, y \text{ AT}(x, y) \implies \text{REACHABLE-BY-PHONE}(x, y)$$

- (e) The fact that the phone number for a place can be found via an automated function for looking it up (*Lookup*(KORMAN,REGLI)):
 $\forall x, y \text{ REACHABLE-BY-PHONE}(x, y) \implies \text{CURRENT-PHONE}(y, \text{Lookup}(x, y))$
- (f) Query to determine Dr. Spivey's phone number (not part of the assignment):
 $\exists x \text{ CURRENT-PHONE}(\text{Dr.Spivey}, x)$
5. (30 points) Consider the problem of a planning system for travel planning. The agent wants to get from Drexel University in Philadelphia to the Robotics Institute at Carnegie Mellon University. To get there the agent must WALK to 30th STREET STATION; take a TRAIN to PHILADELPHIA INTERNATIONAL AIRPORT (PHL); FLY to PITTSBURGH INTERNATIONAL AIRPORT (PIT); and take a BUS to CMU.
- (a) (9 points) Write the four STRIPS-style operators (WALK, TRAIN, FLY, BUS) that would allow a STRIPS-like planner to plan this trip. To make matters briefer, you may assume the operators are uni-directional (i.e. FLY(X) is only for flights from PHL, its not a general flight operator for arbitrary cities).
- (b) (7 points) State the initial state and the goal state for the STRIPS-like planner and explain, in a couple brief sentences, how a STRIPS-like planner would use these operators to plan this trip.
- (c) (7 points) Suppose we employed a hierarchical planner (such as HD-POP) to create a skeletal plan and then flesh out the details. Create three more operators: BUY-PLANE-TICKET, BOARD-PLANE, PAY-BUS-DRIVER.
- (d) (7 points) State the initial state and the goal state for the HD-POP-like planner and, assuming that these three steps are part of the decomposition of the skeletal plan (generated above), explain (briefly) how a HD-POP-like planner would use these new operators, plus WALK, TRAIN, FLY, BUS, to plan the trip.
6. (Extra Credit) In Stanley Kubrick's screen adaptation of Arthur C. Clarke's *2001:A Space Odyssey* one of the central characters is a large black monolith. Explain (succinctly) the symbolism behind the monolith and how it relates to the two transformations that occur to David Bowman and to HAL at the end of the film. What ramifications are there, if any, for the future of machine and human intelligence? You may refer to any religious, philosophical, or scientific thought you require to phrase your answer.

SOLUTIONS

1. Zero (0) Frame Axioms are required. Because everything is inter-linked, everything changes from state to state. Hence, nothing remains constant—no need for any Frame Axioms.
2. (a) {BILL/? x , Father(BILL)/? y }
(b) Does not unify: x has to be both y and $f(y, A)$, where y is $f(x, x)$. They are inter-dependent.
3. (a) $\forall x, \text{BASKETBALL-PLAYER}(x) \implies \text{TALL}(x)$
(b) $\forall x \text{ ANCESTOR}(\text{JOE}, x) \implies \exists y ((\text{FATHER}(\text{JOE}, y) \vee \text{MOTHER}(\text{JOE}, y)) \wedge (\text{EQUAL}(x, y) \vee \text{ANCESTOR}(y, x)))$
4. States in the game graph are represented by the size of the pile of sticks that remains. The observation is that, for any starting pile size n , no matter what the first player (MAX) does on their first move, the second player (MIN) can always move the first player back to a state that contains $4*k+1$ sticks (where k is a positive integer) within 2 moves and keep them there. Hence, eventually, the first player will be stuck having to play a pile of size 1.
5. Planning:
 - (a) The operators are set up with PRECONDITION, ADD, and DELETE lists which are chained together by a STRIPS-style planner to reach a solution.
 - i. WALK(X):
P&D: AT(ME,DREXEL-UNIVERSITY)
A: AT(ME, X)
 - ii. TRAIN(X):
P&D: AT(ME,30TH-STREET-STATION)
A: AT(ME, X)
 - iii. FLY(X)
P: AT(ME,PHL) \wedge PLANE-ROUTE(PHL, X)
D: AT(ME,PHL)
A: AT(ME, X)

iv. BUS(X)

P&D: AT(ME,PIT)

A: AT(ME,X)

- (b) STRIPS would solve the goal by performing a regressive (backward) search through the space of possible situations achievable from the goal situation. STRIPS would solve the goal, AT(ME,CMU), with the initial conditions AT(ME,DREXEL-UNIVERSITY) \wedge PLANE-ROUTE(PHL,PIT). The resulting plan would be: WALK(30TH-STREET-STATION), TRAIN(PHL), FLY(PHL,PIT), BUS(PIT,CMU).

Note, we could also add pre-conditions to TRAIN, WALK, and BUS to ensure we do not (for example) attempt to WALK to CMU.

- (c) For this hierarchical planner, FLY and BUS become decomposition and the new operators (along with the unchanged earlier ones) are primitive operators: operators:

i. FLY(X)

P: AT(ME,PHL) \wedge PLANE-ROUTE(PHL,X)

SUB-PLAN: BUY-PLANE-TICKET(FEE) \rightarrow BOARD-PLANE

D: AT(ME,PHL)

A: AT(ME,X)

ii. BUS(X)

P&D: AT(ME,PIT)

SUB-PLAN: PAY-BUS-DRIVER(FEE) A: IN(ME,BUS) \wedge AT(ME,X)

iii. BUY-PLANE-TICKET(FEE)

P&D: AT(ME,PHL) \wedge HAS(ME,FEE)

A: HAS(ME,PLANE-TICKET)

iv. BOARD-PLANE

P&D: HAS(ME,PLANE-TICKET) \wedge AT(ME,PHL)

A: ON(ME,PLANE)

v. PAY-BUS-DRIVER(FEE)

P&D: HAS(ME,FEE)

A: IN(ME,BUS)

- (d) A hierarchical planner like HD-POP will perform a search of the space of possible partial-order (non-linear) plans in an attempt to build a plan that can transform the start state into the goal state. The initial state for this planner is the empty plan: AT(ME,DREXEL-UNIVERSITY) \wedge PLANE-ROUTE(PHL,PIT) \rightarrow AT(ME,CMU); the goal is to find a plan that achieves the goal condition (AT(ME,CMU)) from the start condition.

The planning algorithm would work by determining the unachieved goal conditions (AT(ME,CMU)) and inserting operators into the plan that can achieve these conditions (BUS(CMU)). The preconditions of the operators added to the plan would be inserted as goals that need to be achieved, and SUB-PLANS would also be added to the plan to be fleshed out.

6. While an exact interpretation is a matter for debate, one possible interpretation of the Large Black Monolith (LBM) is as an agent (possibly of a greater extra-terrestrial intelligence, possibly divine, possibly of natural origins) for creation, evolution and change. The transformations that occur at the end of the film parallel, and are as transforming as, divine creation (n.b. Bowman's hand extended from his "death" bed toward the LBM in the same manner as Michaelangelo's Adam on the Sistine Chapel ceiling, reaches from the dust toward God as life is breathed into him). For Bowman, it is re-birth as a "Star Child"—somehow the offspring of humanity as a whole. For HAL, it is the transformation from a mere machine to a sentient being that is fallible and that has emotions. One gets the impression that the LBM "influenced" HAL, causing him to panic about the goal conflicts in his mission planner, initiating the sequence of events that finally cause Dave Bowman to leave the ship and get pulled into the monolith, becoming transformed—implying, perhaps, that the future evolution of human and machine intelligence will be forever linked.