1. (25 points) A Mars rover has to leave the lander, collect rock samples from three places (in any order) and return to the lander.

Assume that it has a navigation module that can take it directly to places of interest. So it has primitive actions `go-to-lander`, `go-to-communications-location`, `go-to-rock-1`, `go-to-rock-2`, and `go-to-rock-3`.

We know the time it takes to traverse between each pair of special locations. Our goal is to find a sequence of actions that will perform this task in the shortest amount of time.

(a) (10 points) Formulate this problem as a problem-solving problem by specifying the search space, initial state, path-cost function, and goal test. Assume that the world dynamics are deterministic.

(b) (5 points) Say what search technique would be most appropriate, and why. If your search technique requires a heuristic, give an appropriate one.

(c) (5 points) Now assume that, in addition, on every day that it is not at the lander, the rover needs to be at a special communications location at 3PM. Any plan that misses a communications rendezvous is unsatisfactory.

How would you modify the search space, path-cost function, and/or goal-test to handle this additional requirement? Assume that there’s an additional action, called `communicate`, which can only be executed when the rover is at the communications location, and which waits until 3PM, and then executes a communications sequence that takes an hour.

(d) (5 points) Let’s go back to thinking about the original version of the problem (without the communications requirement). What, if any, would be the advantages of treating it as a STRIPS planning problem? What, if any, would be the disadvantages?

2. (25 points) Here are two sentences of first-order logic:

\[ \forall x. \exists y. x \geq y \]  
\[ \exists y. \forall x. x \geq y \]

(a) (2 points) Assume that the variables range over all the natural numbers 0, 1, 2, \ldots, \infty and that the “\(\geq\)” predicate means “is greater than or equal to.” Under this interpretation, translate (1) and (2) into English.

(b) (1 point) Is (1) true under this interpretation?
(c) (1 point) Is (2) true under this interpretation?
(d) (1 point) Does (1) logically entail (2)?
(e) (1 point) Does (2) logically entail (1)?
(f) (6 points) Using resolution, try to prove that (1) follows from (2). Do this even if you think (2) does not logically entail (1); continue until the proof breaks down and you cannot proceed (if in fact it does break down). Show the unifying substitution for each resolution step. If the proof fails, explain exactly where, how, and why it breaks down.
(g) (6 points) Now try to prove that (2) follows from (1), as in the previous question.
(h) (7 points) In our proofs so far, we have not been assuming anything about the semantics of “≥.” Let’s now see what happens if we know the following background axioms:

\[ \forall x, y. \ x \geq y \iff x > y \lor x = y \]  \hspace{1cm} (3)
\[ \forall x. \ x = x \]  \hspace{1cm} (4)

Is it possible to prove (1) from (3) and (4) (but not (2))? If so, do so, showing all resolution steps. If not, explain why not.

3. Dropping the negative effects from every operator description in a STRIPS problem yields a relaxed version of the problem.

(a) (5 points) Explain what it means to be a relaxed version of a problem, and why this is a relaxed version.
(b) (5 points) What use could we make of a relaxed version of the problem?