# Q1. Search

**For this problem, assume that all of our search algorithms use tree search, unless specified otherwise.**

**(a)** For each algorithm below, indicate whether the path returned after the modification to the search tree is guaranteed to be identical to the unmodified algorithm. Assume all edge weights are non-negative before modifications.

**(i)** Adding additional cost $c > 0$ to every edge weight.

| | Yes | No |
|---|---|---|
| BFS | ○ | ○ |
| DFS | ○ | ○ |
| UCS | ○ | ○ |

**(ii)** Multiplying a constant $w > 0$ to every edge weight.

| | Yes | No |
|---|---|---|
| BFS | ○ | ○ |
| DFS | ○ | ○ |
| UCS | ○ | ○ |

**(b)** **For part (b)**, two search algorithms are defined to be **equivalent** if and only if they expand the same states in the same order and return the same path. **Assume all graphs are directed and acyclic.**

**(i)** Assume we have access to costs $c_{ij}$ that make running UCS algorithm with these costs $c_{ij}$ equivalent to running BFS. How can we construct new costs $c'_{ij}$ such that running UCS with these costs is equivalent to running DFS?

○ $c'_{ij} = 0$ ○ $c'_{ij} = 1$ ○ $c'_{ij} = c_{ij}$

○ $c'_{ij} = -c_{ij}$ ○ $c'_{ij} = c_{ij} + \alpha$ ○ Not possible

# Q2. Search Party

Annie is throwing a party tonight, but she only has a couple hours to get ready. Luckily, she was recently gifted 4 one-armed robots! She will use them to rearrange her room for the guests . Here are the specifications:

- Her room is modeled as a $W$-by-$L$-by-$H$ 3D grid in which there are $N$ objects (which could be anywhere in the grid to start with) that need rearrangement.
- Each object occupies one grid cell, and no two objects can be in the same grid cell. Do not consider any part of the robot an "object."
- At each time-step, one robot may take an action $\in$ {move gripper to legal grid cell, close gripper, open gripper}. Moving the gripper does not change whether the gripper was closed/open.
- A robot can move an object by
  1. Moving an open gripper into the object's grid cell
  2. Closing the gripper to grasp the object
  3. Moving to desired location
  4. Opening the gripper to release the object in-hand.
- The robots do not have unlimited range. The arm can move to any point *within* the room that is strictly less than $R$ grid cells from its base per direction along each axis. Explicitly, if $R = 2$ and a robot's base is at (0,0,0), the robot cannot reach (0,0,2) but can reach (1,1,1). Assume $R < W, L, H$.

**(a)** Annie stations one robot's stationary base at each of the 4 *corners* of the room. Thankfully, she knows where each of the $N$ objects in the room should be and uses that to define the robots' goal. Complete the following expression such that it evaluates to the size of the minimal state space. Please approximate permutations as follows: $X$ permute $Y \approx X^Y$. You may use scalars and the variables: $W$, $L$, $H$, $R$, and $N$ in your answers.

$$2^{(a)} \cdot N^{(b)} \cdot R^{(c)} \cdot W^{(d)} \cdot L^{(e)} \cdot H^{(f)}$$

(a): ☐ (b): ☐ (c): ☐

(d): ☐ (e): ☐ (f): ☐

**(b)** Each of the following describes a modification to the scenario previously described and depicted in the figure. **Consider each modification independently (that is, the modifications introduced in (i) are *not* present in (ii)).** For each scenario, give the size of the new minimal state space.

**(i)** The robots are given wheels, so each base is able to slide along the floor (they still can't jump) from their original corners. That is, at each time-step, a robot has a new action that allows them to move its (once stationary) base arbitrarily far across the floor. When the robot slides its base, the relative arm position and status of the gripper remain the same.

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**(ii)** *One* robot is defective and can move for a maximum of $T$ timesteps before it must rest for at least $S$ timesteps. You may use $S$ or $T$ in your expression.

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