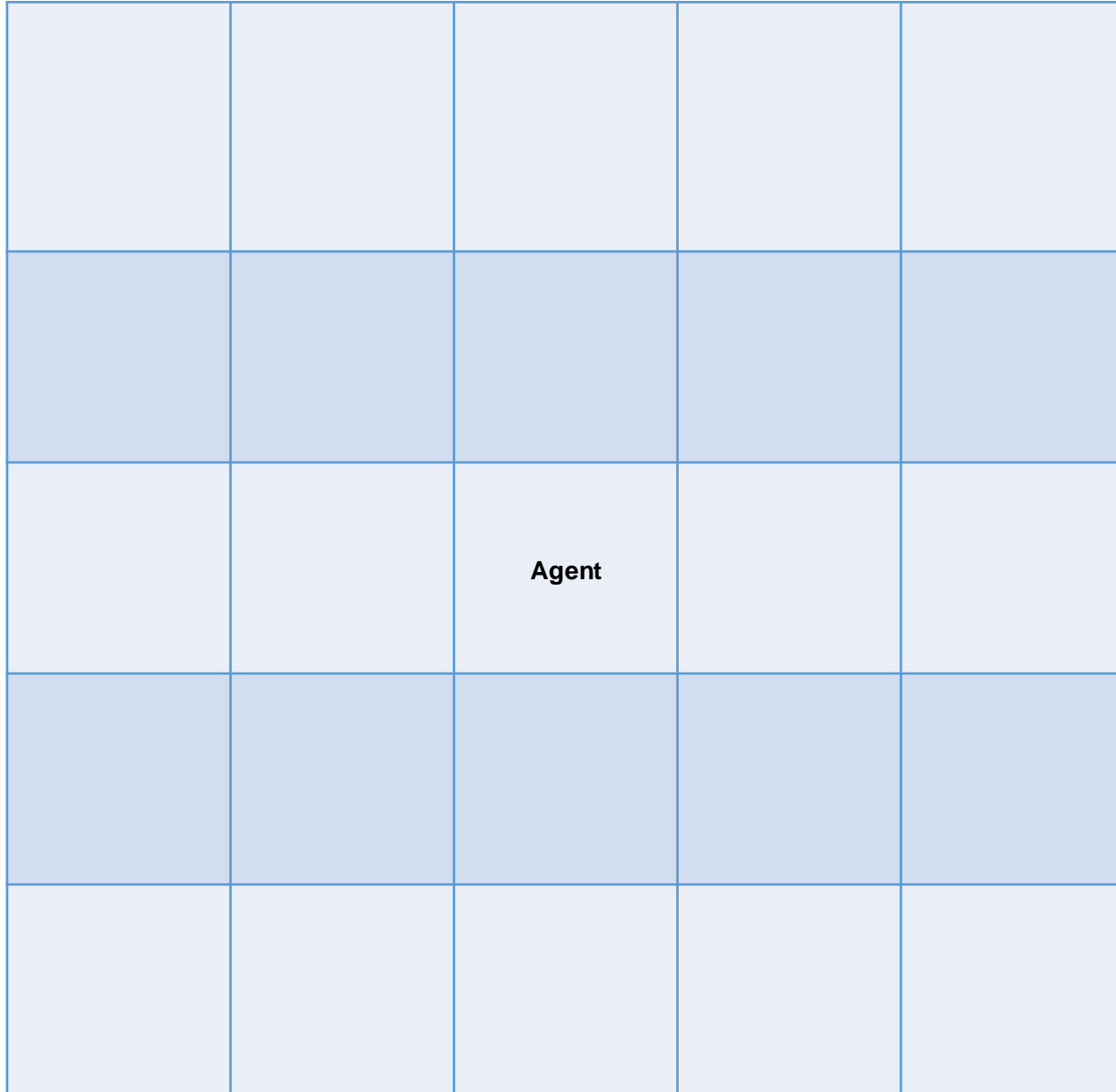


Recap: Manhattan Problem

- Consider an $m \times m$ **Manhattan Grid**, and a set of coordinates G to visit in any order.
- **Hint:** Consider a set of coordinates V' remaining to be visited, or a set of coordinates V already visited. What's the difference between them
- Formulate a state-based search problem to find a tour of all the desired points (i.e. define a state space, applicable actions, transition and cost functions).

m x m Grid



$P = \{S, s0, SG, A, T, C\}$

- a set of coordinates G to visit in any order
- Using a set of coordinates V' remaining to be visited,

Recap: Manhattan Problem

- a set of coordinates G to visit in any order
- Using a set of coordinates V' remaining to be visited

- $S = \{\langle x, y, V' \rangle \mid x, y \in \{0, \dots, m-1\} \wedge V' \subseteq G\}$
- $s_0 = \langle (0, 0), G \setminus \{(0, 0)\} \rangle$
- $S_G = \{\langle (x, y), \{\} \rangle \mid x, y \in \{0, \dots, m-1\}\}$
- $A(\langle x, y, V' \rangle) = \{(dx, dy) \mid$
 - $dx, dy \in \{-1, 0, 1\}$
 - $\wedge |dx| + |dy| = 1$
 - $\wedge x + dx, y + dy \in \{0, \dots, m-1\}$
 - $(x + dx, y + dy) \notin W \}$
- $T(\langle x, y, V' \rangle, (dx, dy)) = \langle x + dx, y + dy, V' \setminus \{(x + dx, y + dy)\} \rangle$
- $c(a, s) = 1$

Problem 1

Reformulate the state-space model from *Review and Recap* as a STRIPS problem $P = \langle F, O, I, G \rangle$

STRIPS Model

- A **problem** in **STRIPS** is a tuple $P = \langle F, O, I, G \rangle$:
 - F stands for set of all **atoms** (boolean vars)
 - O stands for set of all **operators** (actions)
 - $I \subseteq F$ stands for **initial situation**
 - $G \subseteq F$ stands for **goal situation**

STRIPS Model

- Operators $o \in O$ **represented** by
 - the **Add** list $Add(o) \subseteq F$
 - the **Delete** list $Del(o) \subseteq F$
 - the **Precondition** list $Pre(o) \subseteq F$

Recap: Manhattan Problem

- a set of coordinates G to visit in any order
- Using a set of coordinates V' remaining to be visited,
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 - $(x + dx, y + dy) \notin W \}$
 - $T(\langle x, y, V' \rangle, (dx, dy)) = \langle x + dx, y + dy, V' \setminus \{(x + dx, y + dy)\} \rangle$
 - $c(a, s) = 1$

Problem 1

- $F = \{at(x, y), visited(x, y) \mid x, y \in \{0, \dots, m - 1\}\}$
- $O = \{move(x, y, x', y'):$
 - Prec:
 - Add:
 - Del:
- $I = \{at(0, 0), visited(0, 0)\}$
- $G = \{visited(x, y) \mid (x, y) \in G'\}$

Problem 1

- $F = \{at(x, y), visited(x, y) \mid x, y \in \{0, \dots, m - 1\}\}$
- $O = \{move(x, y, x', y'):$
 - Prec: $at(x, y)$
 - Add: $at(x', y'), visited(x', y')$
 - Del: $at(x, y)$ $\mid \text{for each adjacent } (x, y), (x', y'), \text{ and } (x', y') \notin W \}$
- $I = \{at(0, 0), visited(0, 0)\}$
- $G = \{visited(x, y) \mid (x, y) \in G'\}$

Problem 1

notWall(x,y)

- $F = \{at(x, y), visited(x, y) \mid x, y \in \{0, \dots, m - 1\}\}$
- $O = \{move(x, y, x', y'):$
 - Prec: $at(x, y)$ **notWall(x', y')**
 - Add: $at(x', y'), visited(x', y')$
 - Del: $at(x, y)$

| for each adjacent $(x, y), (x', y')$
- $I = \{at(0, 0), visited(0, 0)\}$ —
- $G = \{visited(x, y) \mid (x, y) \in G'\}$

Problem 2

G1						G2
	Wall	Wall	Startin g point			

Problem 2

- Goal-counting
- Manhattan distance to the closest goal(position) heuristic
- Manhattan distance to the furthest goal(position) heuristic
- Your own heuristic...

Recap: Dominant Relation

- If heuristic h_1 dominates heuristic h_2 :
- Then we will have $h_1(s) \geq h_2(s)$, for all s belongs to state space S
- And both h_1 and h_2 need to be admissible

Recap: Dominant Relation

- If heuristic h_1 dominates heuristic h_2 :
- Then we will have $h_1(s) \geq h_2(s)$, for all s belongs to state space S
- And both h_1 and h_2 need to be admissible

Common Heuristic for Manhattan Problems

- Null Heuristic: $h = 0$ for all state
- Goal counting: $h = |V'|$
- Manhattan to the closest: $h = \min(\text{Manhattan}(\text{all food}))$
- Manhattan to the furthest: $h = \max(\text{Manhattan}(\text{all food}))$
- Average of these two: $h = \text{average}(\min, \max)$
- Sum Manhattan: $h = \text{sum}(\text{Manhattan}(\text{all food}))$
- Minimum Spanning Tree: $h = \text{len}(\text{minimum spanning tree}(\text{all food}))$

Properties of Heuristic functions

Definition (Safe/Goal-Aware/Admissible/Consistent). Let Π be a planning task with state space $\Theta_{\Pi} = (S, L, c, T, I, S^G)$, and let h be a heuristic for Π . The heuristic is called:

- **safe** if $h^*(s) = \infty$ for all $s \in S$ with $h(s) = \infty$;
- **goal-aware** if $h(s) = 0$ for all goal states $s \in S^G$;
- **admissible** if $h(s) \leq h^*(s)$ for all $s \in S$;
- **consistent** if $h(s) \leq h(s') + c(a)$ for all transitions $s \xrightarrow{a} s'$.

Is Manhattan furthest heuristic consistent?

- Being consistent: reduced value $h(s) - h(s') \leq 1$
- Every time perform an action using this heuristic,
- There are 3 possible outcome:
 1. one step closer: $h(s) - h(s') = 1$, also consistent
 2. one step further: $h(s) - h(s') = -1$, also consistent
 3. furthest food change

Furthest Manhattan heuristic



Furthest Manhattan heuristic

- For state s , agent position: $P1$, furthest coordinate: $G1$
- For state s' , agent position: $P2$, furthest coordinate: $G2$
- $h(s) = \text{Distance}(P1, G1)$, $h(s') = \text{Distance}(P2, G2)$

And for being consistent, we need to prove $h(s) \leq h(s') + 1$

If $h(s) > h(s') + 1$, then it is not consistent

However, is it even possible that $h(s) > h(s')$?

Furthest Manhattan heuristic

For state s , agent position: $P1$, furthest coordinate: $G1$

For state s' , agent position: $P2$, furthest coordinate: $G2$

- $h(s) = \text{Distance}(P1, G1)$, $h(s') = \text{Distance}(P2, G2)$

Is it possible that $h(s) > h(s')$?

- Which means $h(s) \geq h(s') + 1$, i.e, $h(s') \leq h(s) - 1$

And we also have

- $h(s) - 1 \leq \text{Distance}(P2, G1) \leq h(s) + 1$
- as $\text{Distance}(P1, P2) == 1$

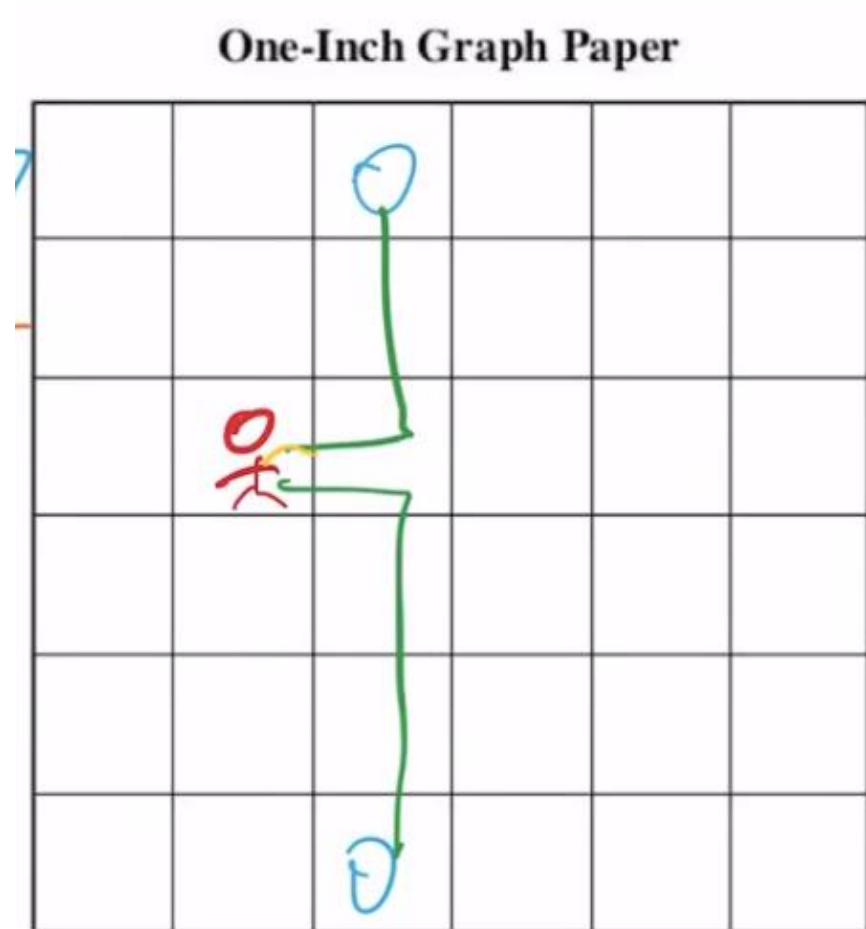
In conclusion,

- $h(s') = \text{Distance}(P2, G2) \leq \text{Distance}(P2, G1)$
- **Furthest food should not change (which conflict with our assumption)**

Sum Manhattan heuristic

			Agent	G1	G2	
	Wall	Wall				

Minimum Spanning Tree Heuristic



Minimum Spanning Tree Heuristic

- Admissible
- Not consistent

