SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN

Planning IV

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50.021 Artificial Intelligence

The following notes are compiled from various sources such as textbooks, lecture materials, Web resources and are shared for academic purposes only, intended for use by students registered for a specific course. In the interest of brevity, every source is not cited. The compiler of these notes gratefully acknowledges all such sources.

Faster Heuristics: Overall Idea

- Concise representation using facts (F) and actions (A)
  - $F_0 = x_1, x_2$
  - $A_0 = o_1, o_2$
  - $F_1 = x_1, x_2, x_3, x_4, x_5$
  - $A_1 = o_3, o_4$
  - $F_2 = x_1, x_2, x_3, x_4, x_5, x_6, x_7$
  - $A_2 = o_5$
  - $F_3 = x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8$

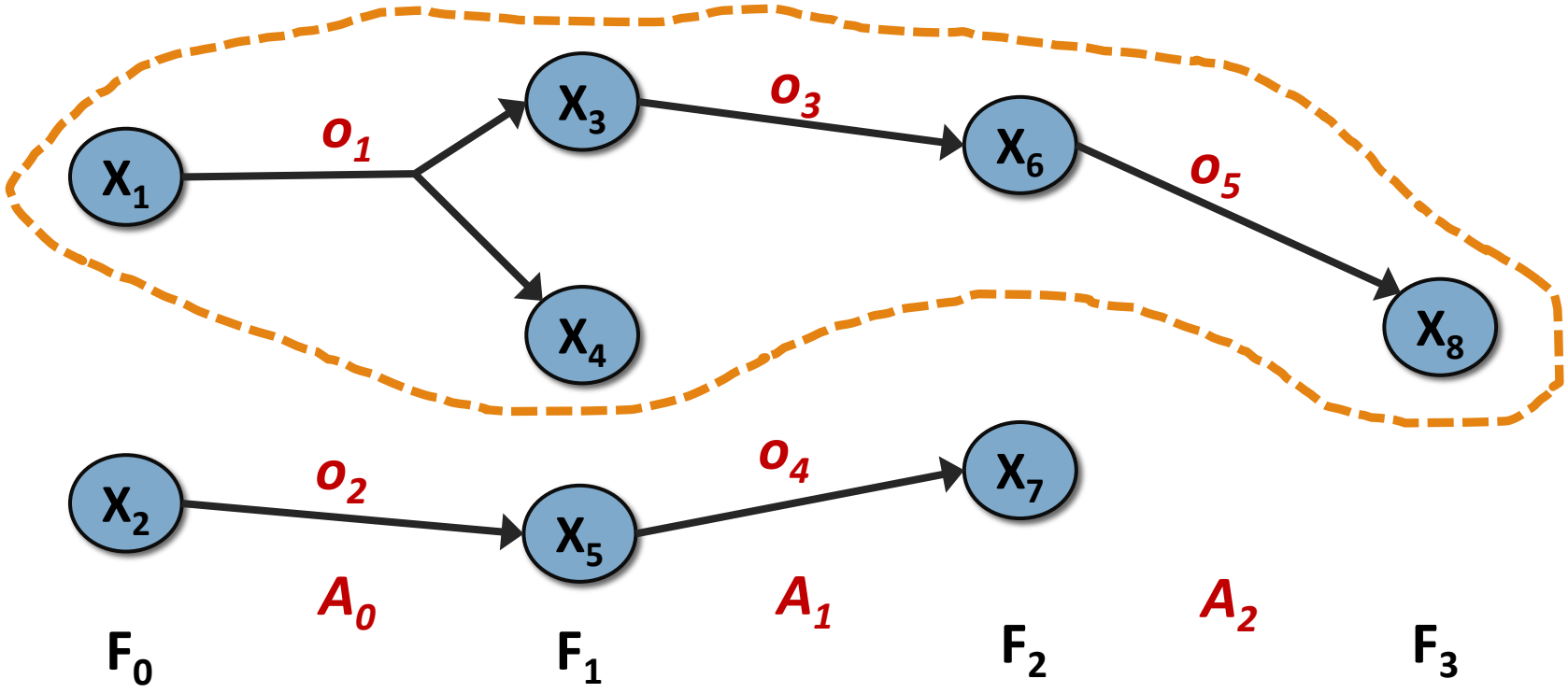
- Why do we care about the level/index of a fact?
  - It tells us the ***number of actions (i.e., cost) required*** to achieve that fact
  - This is useful as we examine the h_{max}, h_{add} heuristics

h_{max} Heuristic

- h_{max} is the cost of the single most costly goal fact (out of all goal facts)
  - i.e., the max number of actions needed for achieving one of the goal facts.

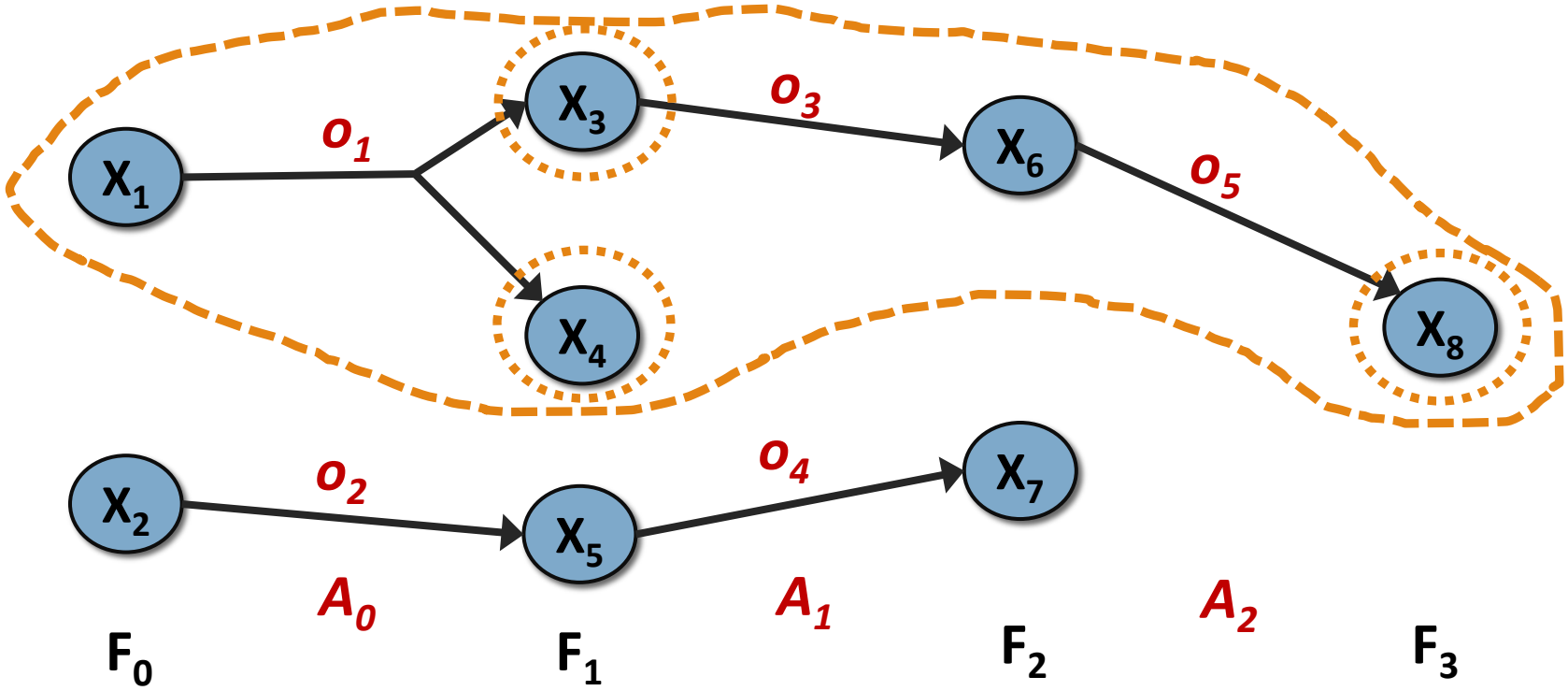
h_{max} Heuristic

- h_{max} is the cost of the single most costly goal fact (out of all goal facts)
  - Given goals x_3, x_4, x_8, $h_{max} = 3$



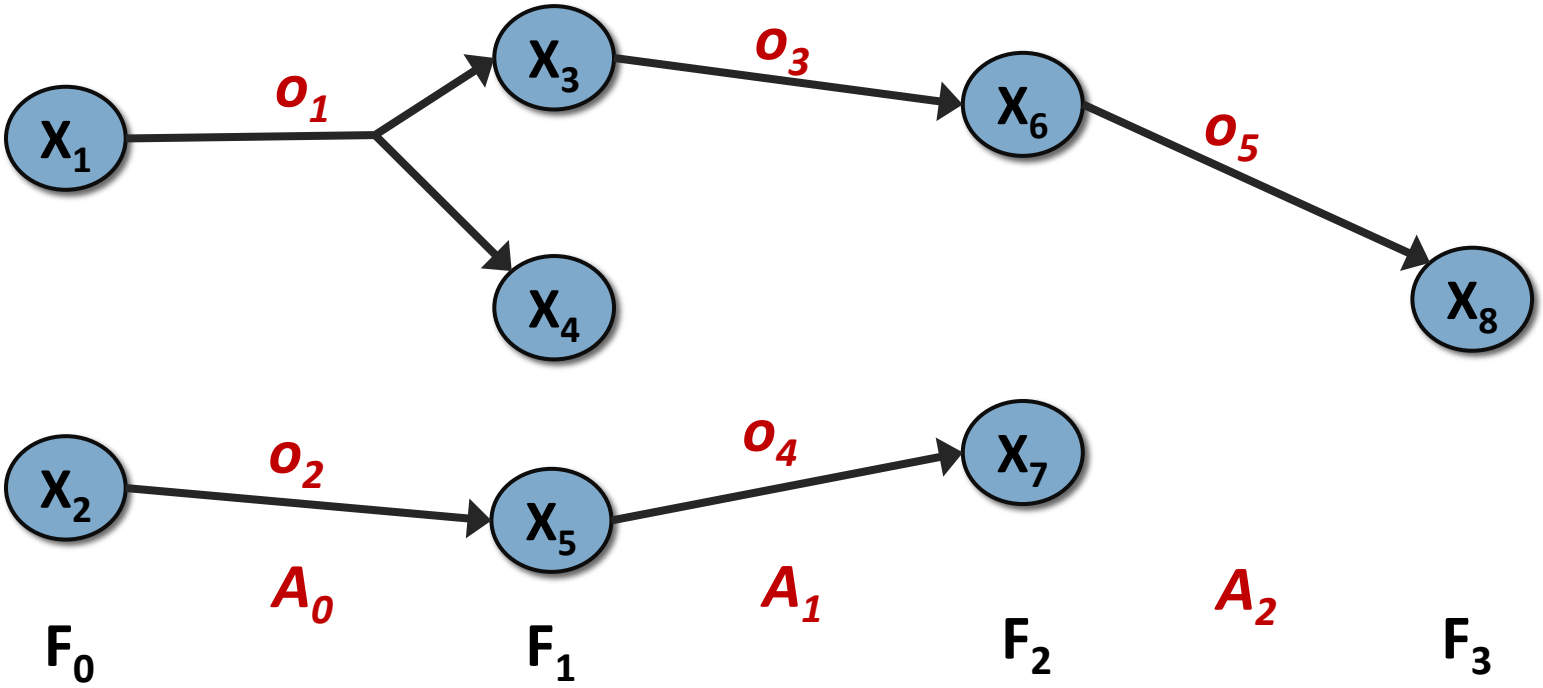
h_{max} Heuristic

- An optimistic heuristic
  - Implicit assumption is that an action can set multiple facts to true



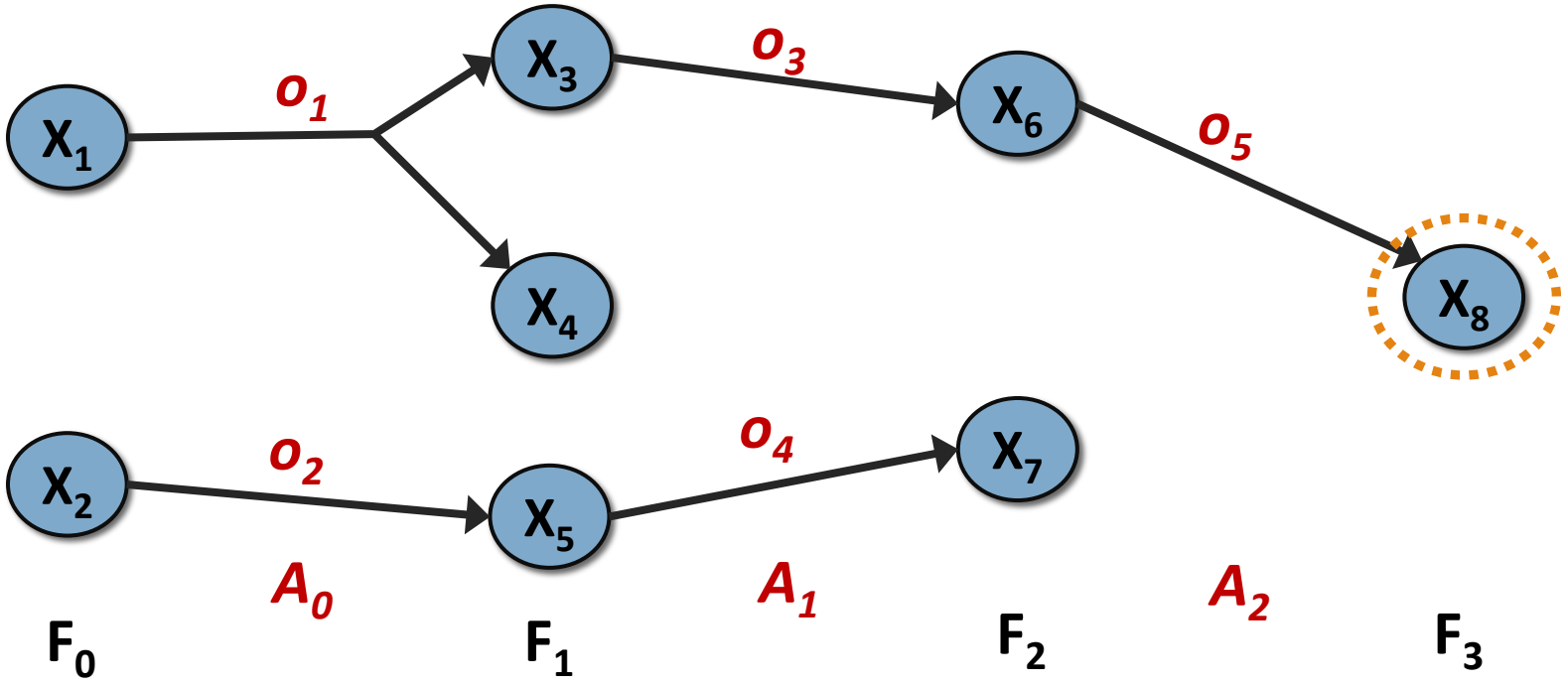
h_{max} Heuristic

- Is h_{max} admissible?



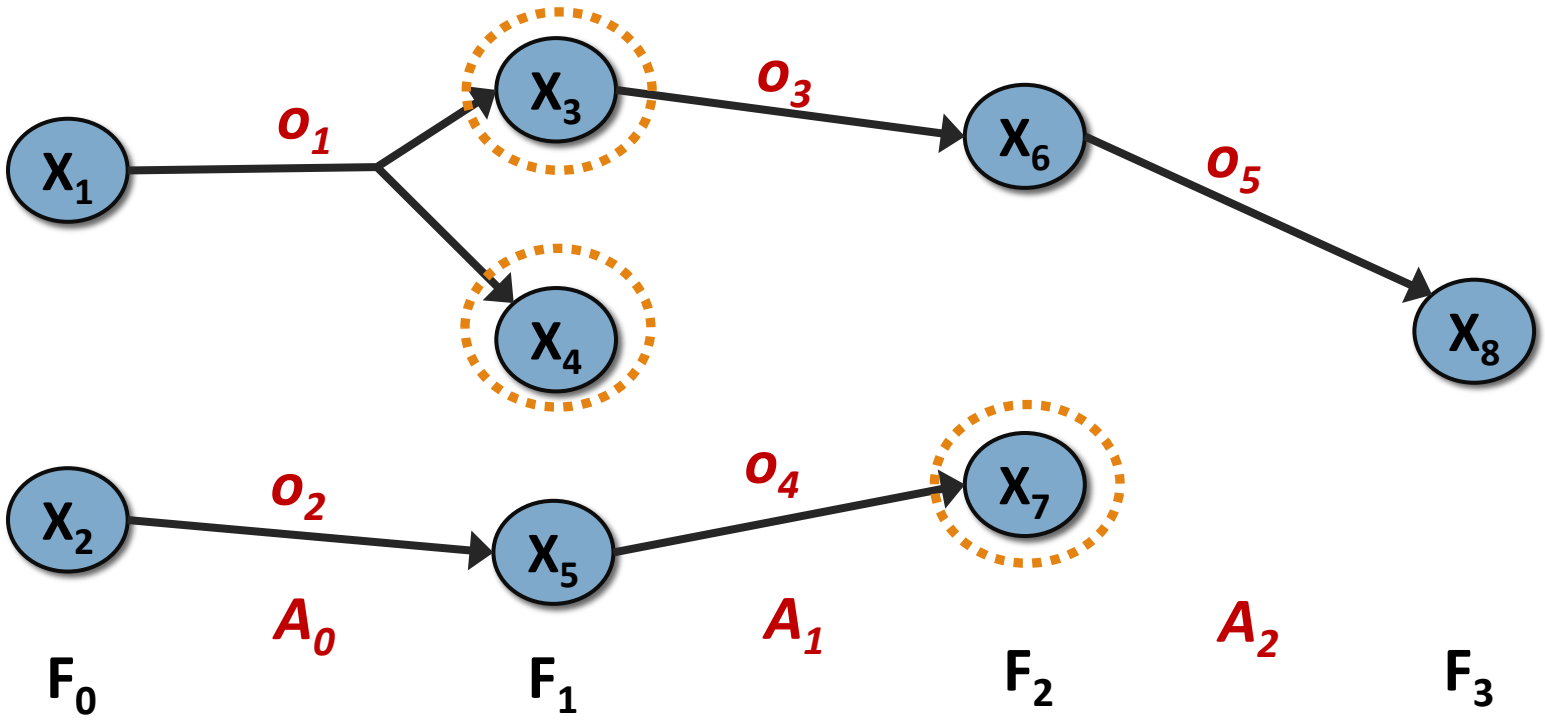
h_{max} Heuristic

- Is h_{max} admissible? Yes
  - Given goals x_8, $h_{max} = h^*$



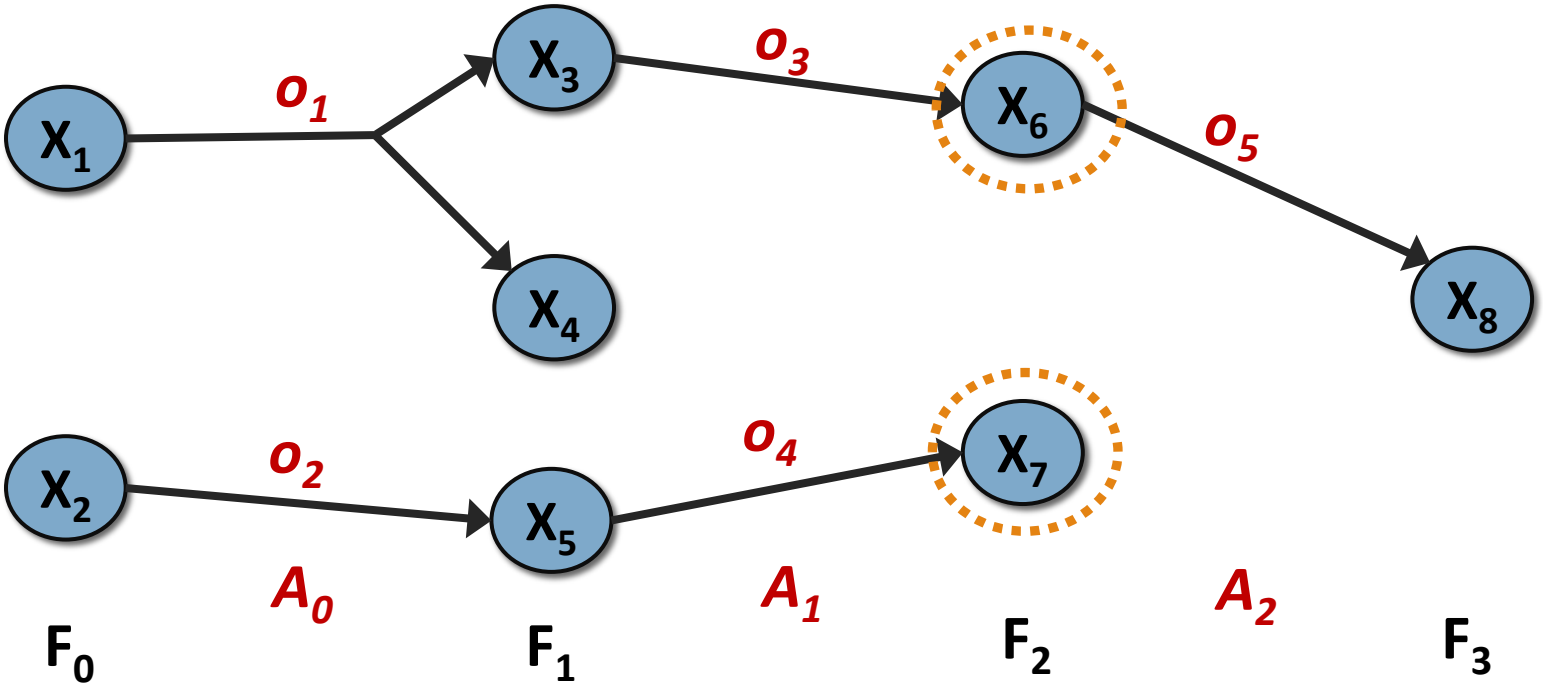
h_{max} Heuristic

- Is h_{max} admissible? Yes
  - Given goals x_3, x_4, x_7, $h_{max} < h^*$



h_{max} Heuristic

- However, h_{max} could under-estimate the true cost (by a lot)
  - What if the goals were x_6, x_7?

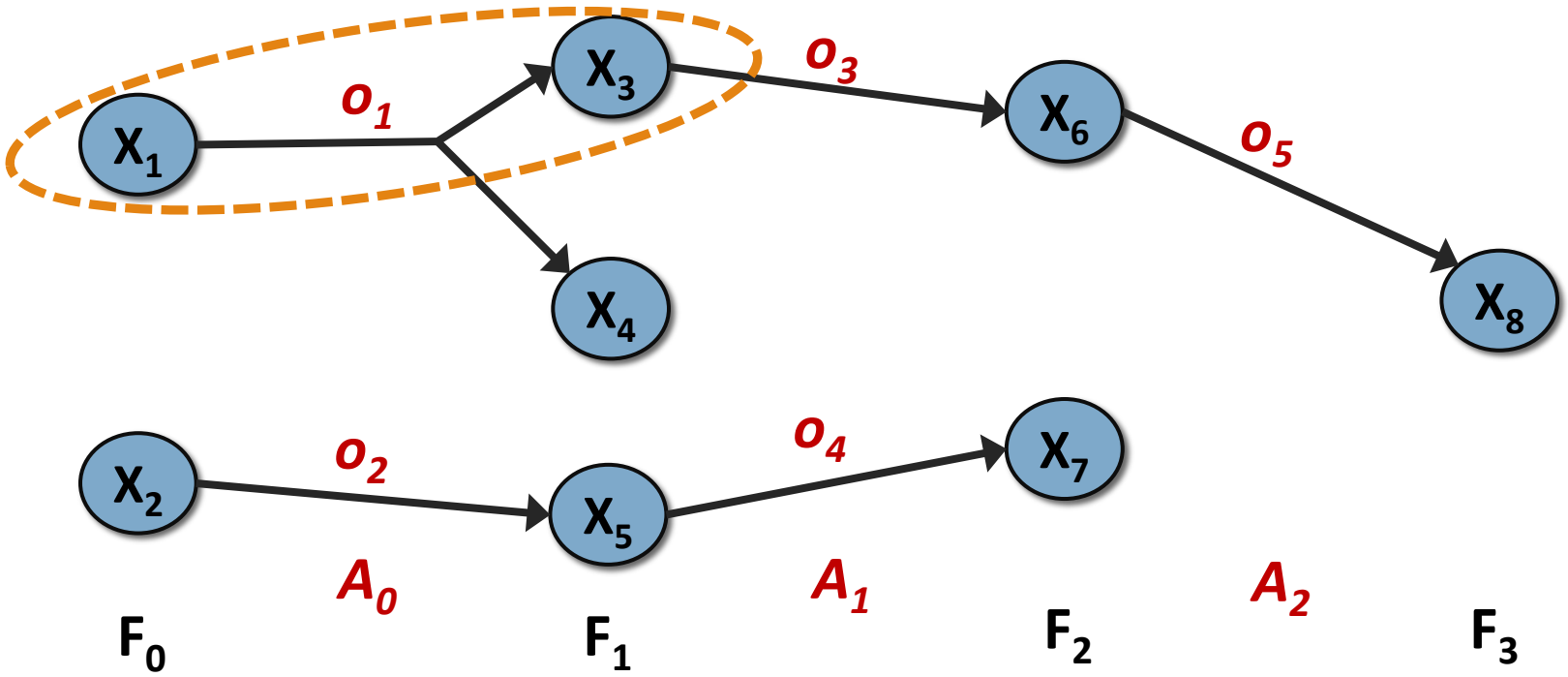


h_{add} Heuristic

- h_{add} is the summed cost of all goal facts
  - Adds up the number of actions needed to set a fact to true

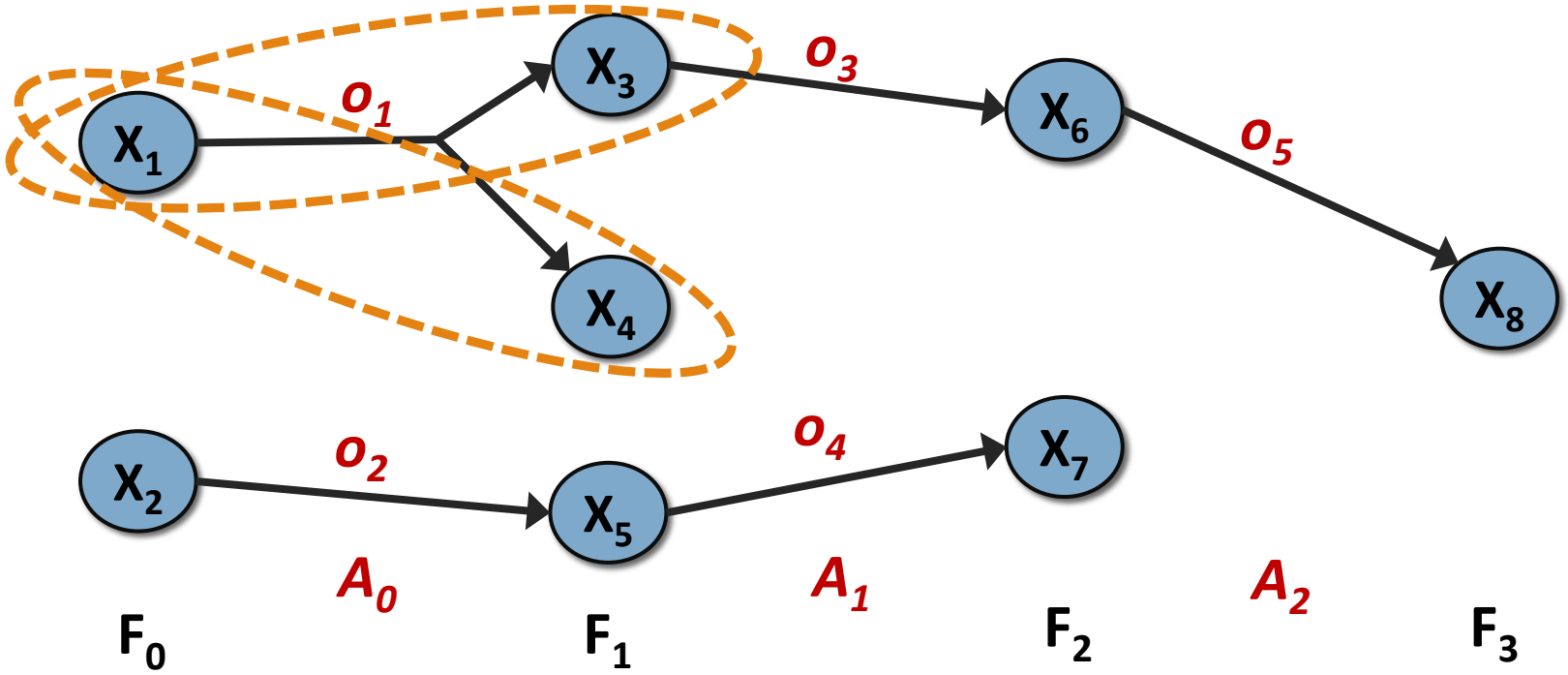
h_{add} Heuristic

- h_{add} is the summed cost of all goal facts
  - Given goals x_3, x_4, x_8, $h_{add} = 1$



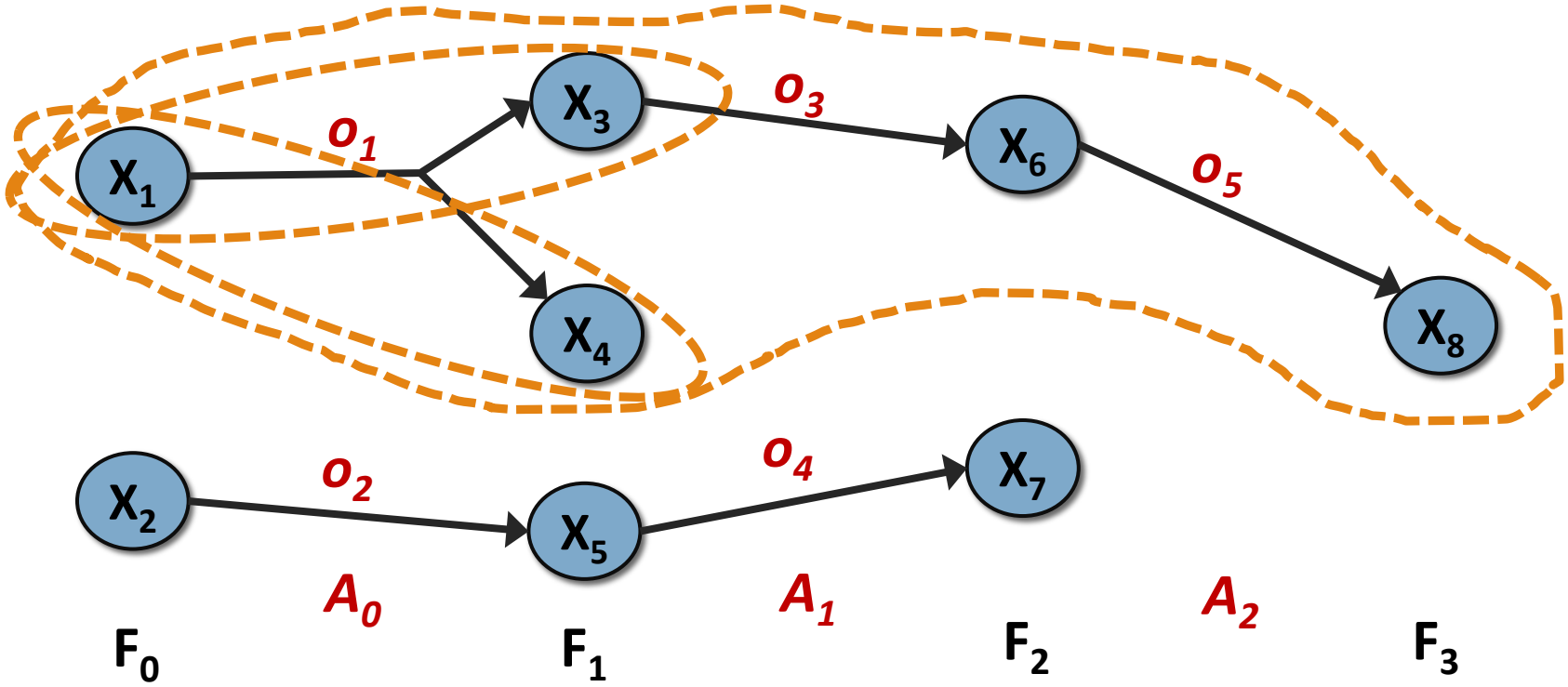
h_{add} Heuristic

- h_{add} is the summed cost of all goal facts
  - Given goals x_3, x_4, x_8, $h_{add} = 1 + 1$



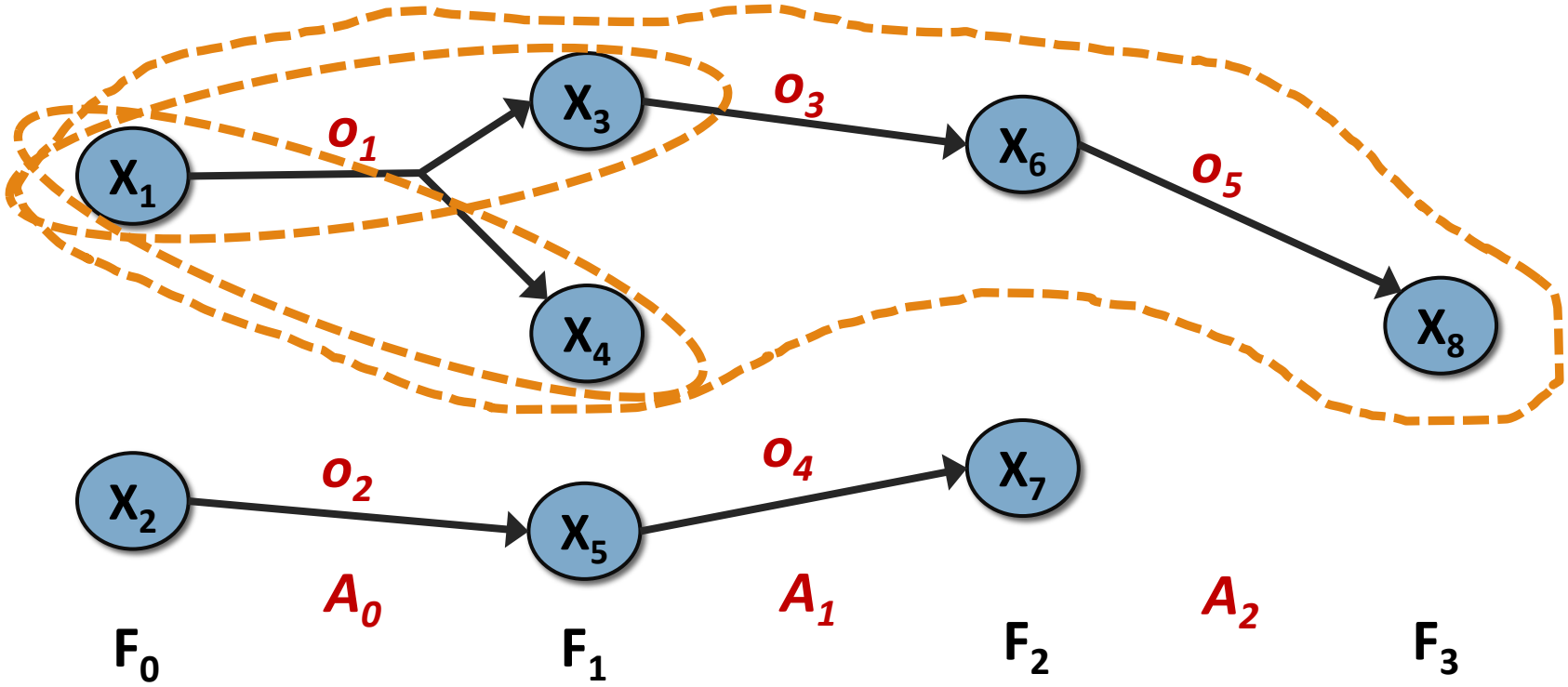
h_{add} Heuristic

- h_{add} is the summed cost of all goal facts
  - Given goals x_3, x_4, x_8, $h_{add} = 1 + 1 + 3 = 5$



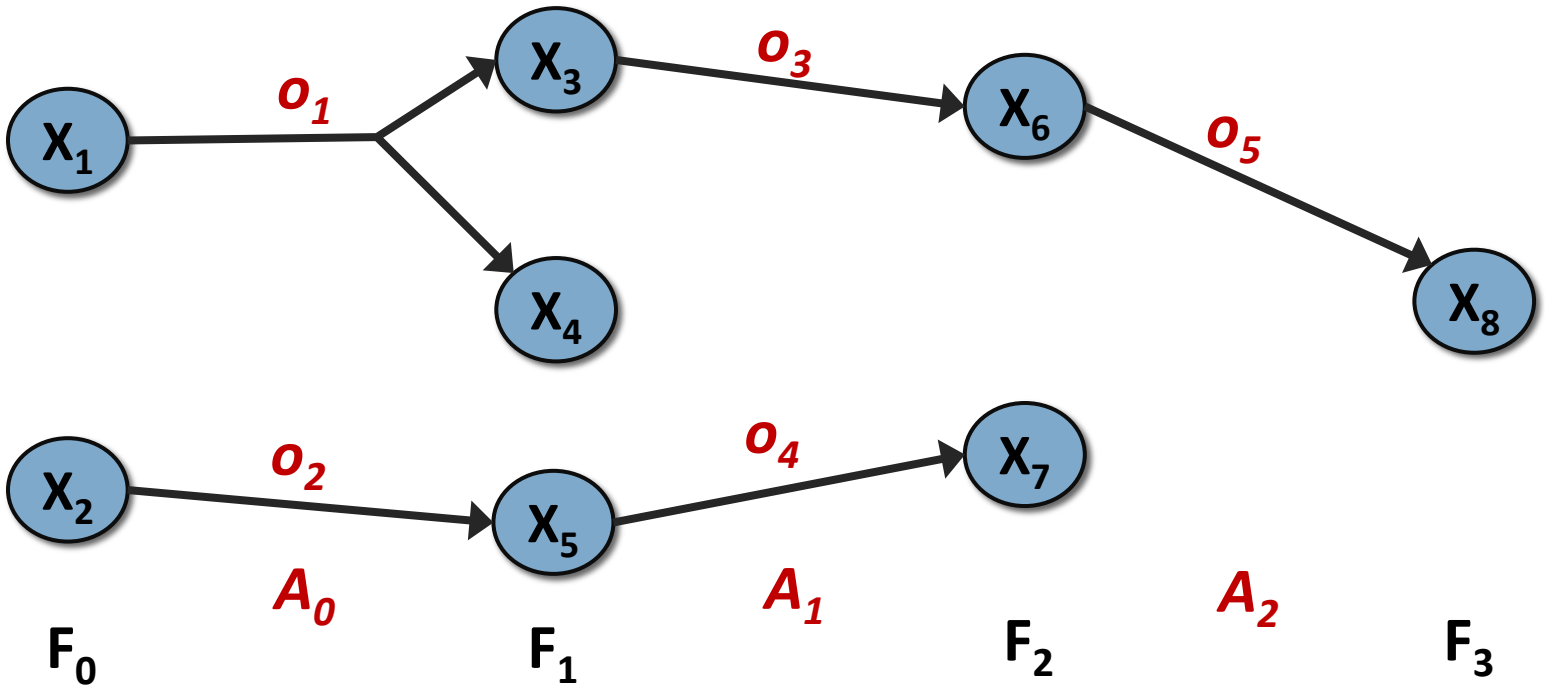
h_{add} Heuristic

- A pessimistic heuristic
  - Implicit assumption is that an action can only set one fact to true, and vice versa



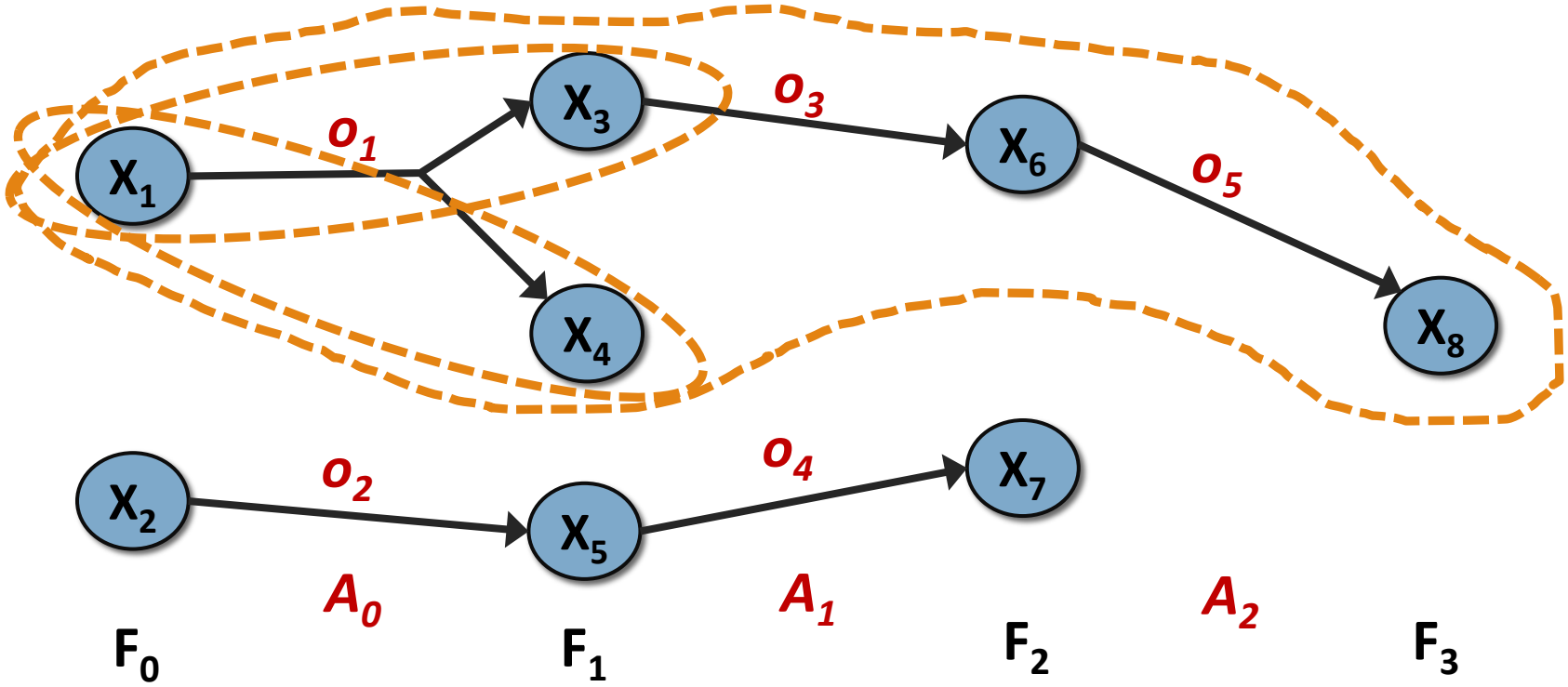
h_{add} Heuristic

- Is h_{add} admissible?



h_{add} Heuristic

- Is h_{add} admissible? No
  - Given goals x_3, x_4, x_8, $h_{add} > h^*$



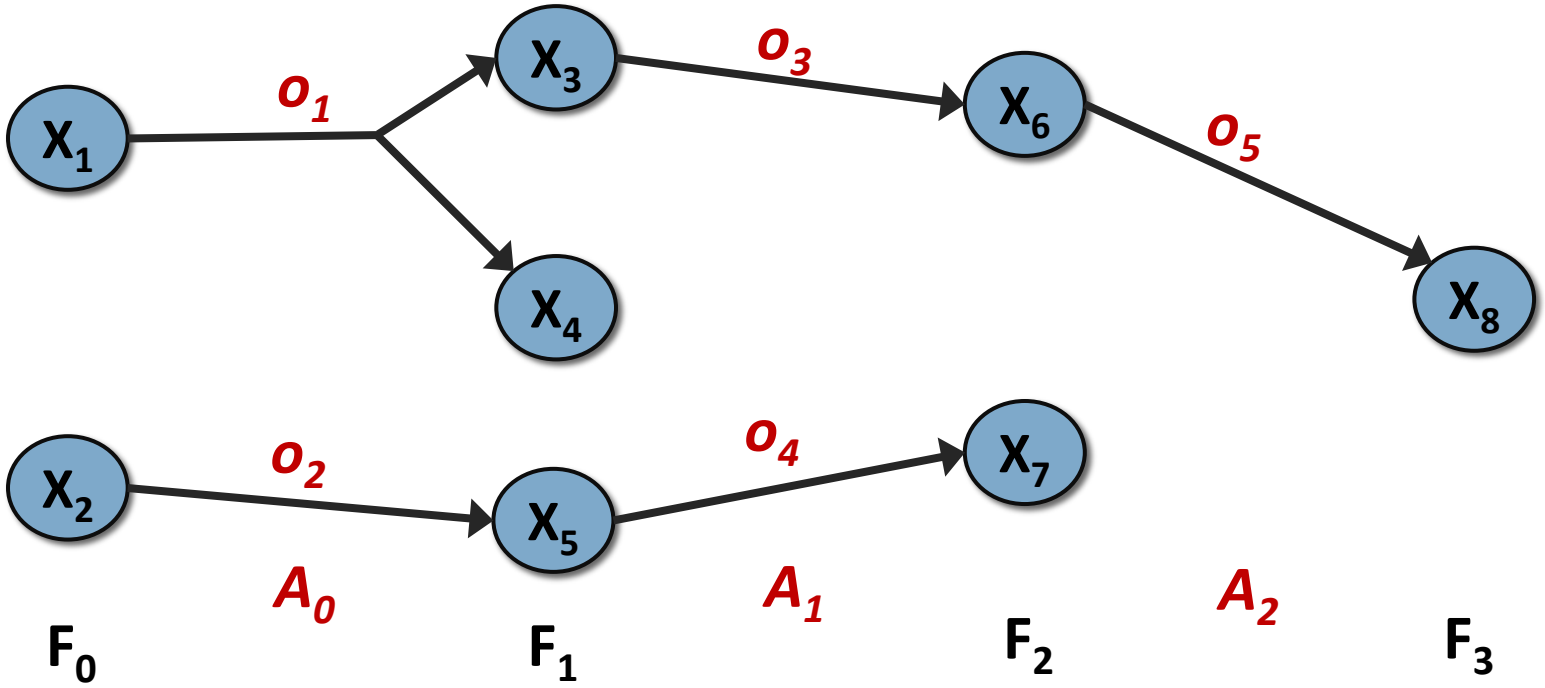
Exercise: h_{max} and h_{add}

- Given goals x_3, x_4, x_7, x_8, calculate h_{max} and h_{add}?

h max = 3
h add = 1+1+3+2 = 7

- Given goals x_6, x_7, calculate h_{max} and h_{add}?

h max = 2
h add = 2+2 = 4

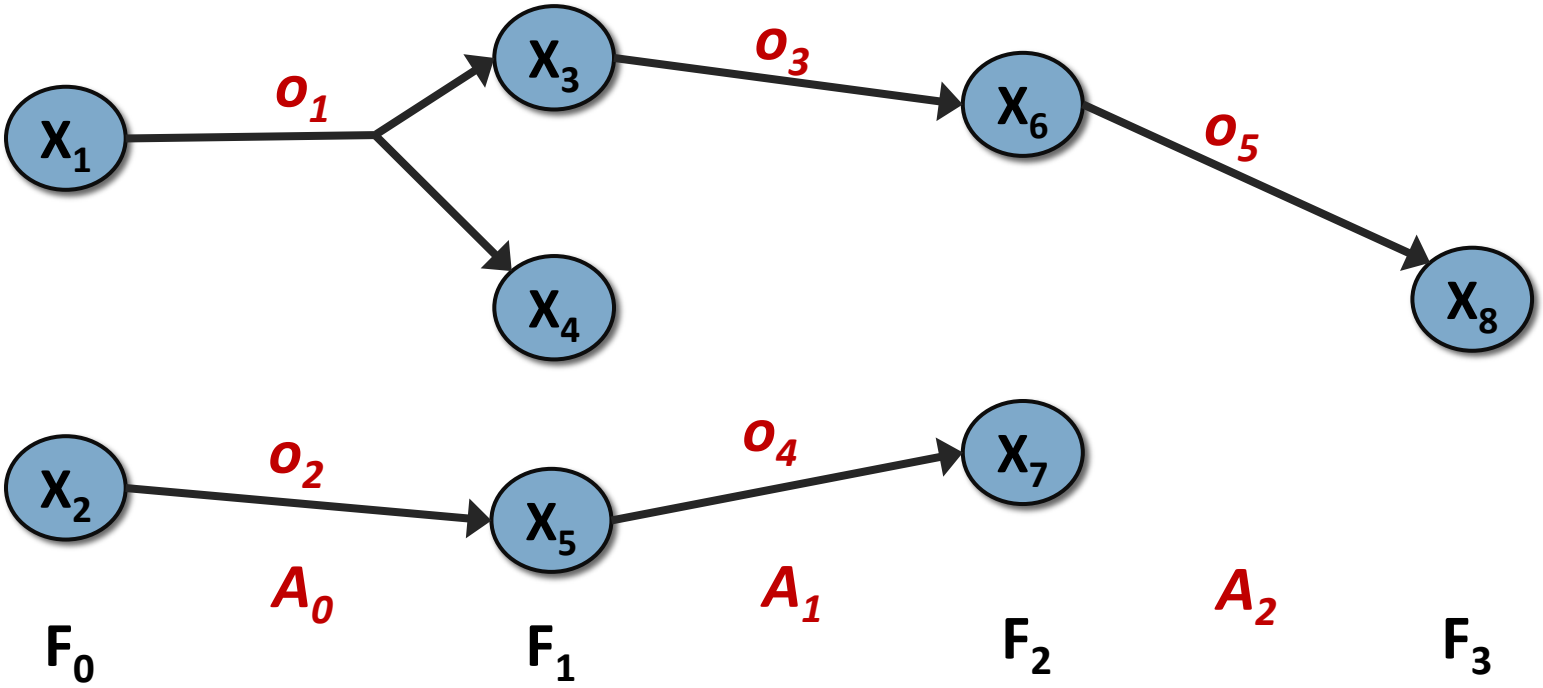


Exercise: h_{max} and h_{add}

- Given goals x_3, x_4, x_7, x_8, calculate h_{max} and h_{add}? $h_{max}=3$, $h_{add}=7$
- Given goals x_6, x_7, calculate h_{max} and h_{add}?
- Concise representation using facts (F) and actions (A)
  - F_0 = x_1, x_2
  - A_0 = o_1, o_2
  - F_1 = x_1, x_2, x_3, x_4, x_5
  - A_1 = o_3, o_4
  - F_2 = x_1, x_2, x_3, x_4, x_5, x_6, x_7
  - A_2 = o_5
  - F_3 = x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8

Exercise: h_{max} and h_{add}

- Given goals x_3, x_4, x_7, x_8, calculate h_{max} and h_{add}? $h_{max}=3$, $h_{add}=7$
- Given goals x_6, x_7, calculate h_{max} and h_{add}?



Exercise: h_{max} and h_{add}

- Given goals x_3, x_4, x_7, x_8, calculate h_{max} and h_{add}? $h_{max}=3$, $h_{add}=7$
- Given goals x_6, x_7, calculate h_{max} and h_{add}? $h_{max}=2$, $h_{add}=4$
- Concise representation using facts (F) and actions (A)
  - F_0 = x_1, x_2
  - A_0 = o_1, o_2
  - F_1 = x_1, x_2, x_3, x_4, x_5
  - A_1 = o_3, o_4
  - F_2 = x_1, x_2, x_3, x_4, x_5, x_6, x_7
  - A_2 = o_5
  - F_3 = x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8

h_{max} versus h_{add}

- h_{max} is too optimistic - tends to underestimate true cost
  - Only considers the longest path of actions (assumes that all goals are on that path)
  - Ignores that there can be partially non-overlapping or independent paths of actions leading to multiple goals.
- h_{add} is too pessimistic – tends to overestimate true cost
  - Assumes that there are only independent paths leading to each goal
  - However, multiple goals or facts can exist on a single path of action
- In reality, paths of actions can be partially independent, and partially overlapping/shared

Summary

- Discussed planning problem formulation using STRIPS
- Discussed a relaxation to the planning problem by removing negations
- Discussed various heuristics:
  - h+ is the optimal plan to a delete-relaxed problem
  - h_{max} is admissible, but often too loose, too low.
  - h_{add} is inadmissible, sometimes way too large compared to h+ which we want to approximate
  - h_{FF} is inadmissible, but in practice useful

Exercise: Faster Heuristics

- Given this problem definition:
  - Variables: $x_1, x_2, x_3, x_4, x_5, x_6$
  - Initial State: x_1
  - Goal: x_2, x_5, x_6
  - Actions:

o_1 :	precond: x_1,	postcond: x_2
o_2 :	precond: x_2,	postcond: ~~$\neg x_1$~~, x_3
o_3 :	precond: x_3,	postcond: ~~$\neg x_2$~~, x_1, x_4
o_4 :	precond: x_2, x_4,	postcond: x_5
o_5 :	precond: x_1, x_5,	postcond: ~~$\neg x_5$~~, x_6

  - ***Task: Make this a delete-relaxed problem***
  - ***Task: Determine the level where all goal facts are achieved***
  - ***Task: Calculate the h_{max} and h_{add} heuristics***

Exercise: Faster Heuristics

- Given this problem definition:
  - Variables: $x_1, x_2, x_3, x_4, x_5, x_6$
  - Initial State: x_1
  - Goal: x_2, x_5, x_6
  - Actions:

o_1 :	precond: x_1,	postcond: x_2
o_2 :	precond: x_2,	postcond: ~~$\neg x_1$~~, x_3
o_3 :	precond: x_3,	postcond: ~~$\neg x_2$~~, x_1, x_4
o_4 :	precond: x_2, x_4,	postcond: x_5
o_5 :	precond: x_1, x_5,	postcond: ~~$\neg x_5$~~, x_6

  - ***Task: Make this a delete-relaxed problem***

Exercise: Faster Heuristics

- Given this problem definition:
  - Variables: $x_1, x_2, x_3, x_4, x_5, x_6$
  - Initial State: x_1
  - Goal: x_2, x_5, x_6
  - Actions:

o_1 :	precond: x_1,	postcond: x_2
o_2 :	precond: x_2,	postcond: ~~$\neg x_1$~~, x_3
o_3 :	precond: x_3,	postcond: ~~$\neg x_2$~~, x_1, x_4
o_4 :	precond: x_2, x_4,	postcond: x_5
o_5 :	precond: x_1, x_5,	postcond: ~~$\neg x_5$~~, x_6

  - ***Task: Determine the level where all goal facts are achieved***

Exercise: Faster Heuristics

- Concise representation using facts (F) and actions (A)
  - $F_0 = x_1$
  - $A_0 = o_1,$
  - $F_1 = x_1, x_2$
  - $A_1 = o_2$
  - $F_2 = x_1, x_2, x_3$
  - $A_2 = o_3$
  - $F_3 = x_1, x_2, x_3, x_4$
  - $A_4 = o_4$
  - $F_4 = x_1, x_2, x_3, x_4, x_5$
  - $A_5 = o_5$
  - $F_5 = x_1, x_2, x_3, x_4, x_5, x_6$

Variables: $x_1, x_2, x_3, x_4, x_5, x_6$
Initial State: x_1
Goal: x_2, x_5, x_6
Actions:

o_1 :	pre: x_1,	post: x_2
o_2 :	pre: x_2,	post: $\neg\cancel{x_1}$, x_3
o_3 :	pre: x_3,	post: $\neg\cancel{x_2}$, x_1, x_4
o_4 :	pre: x_2, x_4,	post: x_5
o_5 :	pre: x_1, x_5,	post: $\neg\cancel{x_5}$, x_6

Exercise: Faster Heuristics

- Concise representation using facts (F) and actions (A)
  - $F_0 = x_1$
  - $A_0 = o_1$,
  - $F_1 = x_1, x_2$
  - $A_1 = o_2$
  - $F_2 = x_1, x_2, x_3$
  - $A_2 = o_3$
  - $F_3 = x_1, x_2, x_3, x_4$
  - A_4 3 $= o_4$
  - $F_4 = x_1, x_2, x_3, x_4, x_5$
  - A_5 4 $= o_5$
  - $F_5 = x_1, x_2, x_3, x_4, x_5, x_6$

Variables: $x_1, x_2, x_3, x_4, x_5, x_6$
Initial State: x_1
Goal: x_2, x_5, x_6
Actions:

o_1 :	pre: x_1,	post: x_2
o_2 :	pre: x_2,	post: ~~$\neg x_1$~~, x_3
o_3 :	pre: x_3,	post: ~~$\neg x_2$~~, x_1, x_4
o_4 :	pre: x_2, x_4,	post: x_5
o_5 :	pre: x_1, x_5,	post: ~~$\neg x_5$~~, x_6

Task: Calculate the h_{max} and h_{add} heuristics

Exercise: Faster Heuristics

- Concise representation using facts (F) and actions (A)
  - $F_0 = x_1$
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  - $A_2 = o_3$
  - $F_3 = x_1, x_2, x_3, x_4$
  - $A_4 = o_4$
  - $F_4 = x_1, x_2, x_3, x_4, x_5$
  - $A_5 = o_5$
  - $F_5 = x_1, x_2, x_3, x_4, x_5, x_6$

Variables: $x_1, x_2, x_3, x_4, x_5, x_6$
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Goal: x_2, x_5, x_6
Actions:

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o_3 :	pre: x_3,	post: ~~$\neg x_2$~~, x_1, x_4
o_4 :	pre: x_2, x_4,	post: x_5
o_5 :	pre: x_1, x_5,	post: ~~$\neg x_5$~~, x_6

Task: Calculate the h_{max} and h_{add} heuristics

- $h_{max} = \max(1, 4, 5) = 5$
- $h_{add} = 1 + 4 + 5 = 10$

Overall Summary

- Able to describe planning problems in a simple formalism - that is finding a sequence of actions.
- Able to formulate a planning problem as a STRIPS instance
- Understand the PDDL planning language
- Develop relaxed versions of planning problems and understand the various heuristics that can be used