GLAIVE: A STATE-SPACE NARRATIVE PLANNER SUPPORTING INTENTIONALITY AND CONFLICT

Paper by:

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Narrative Planning Review

- An Intentional Planning domain defines parameterized actions that can occur as events in a story
- An intentional planning problem defines the initial state of the story world and a set of author goals which must be true by the time the story has finished
- In addition to the author's goals, Glaive tracks individual goals for each character which may be adopted and abandoned at various times during the story

Important Definitions

INTENTIONAL PATH

An intentional path for some character ‘c’ and some goal ‘g’ is an alternating sequence of n steps and n propositions<s_1 ,p_1,s_2,p_2 ,.., s_n ,g> such that:

1. Character ‘c’ consents to all steps
2. ‘c’ intends ‘g’ is true before s_1 and true until step s_n
3. Step s_n has effect ‘g’
4. Each step is causally linked to the next
5. No proposition appears twice
6. The path never contains a proposition and its negation

EXPLANATION

A step ‘s’ is explained if and only if:

1. For all consenting characters, ‘s’ is on an intentional path for ‘c’
2. All other steps on that intentional path are explained.

In other words, every character who takes s has a reason to take s, and the other steps used to explain s are also reasonable steps with explanations of their own

Valid Intentional Plan

A valid intentional plan is a sequence of steps such that:

1. Each step's preconditions are satisfied immediately before the step is taken
2. After all steps are taken, the authors goals are satisfied
3. Every step is explained in *some possible world* (This will be explained later)

The Glaive Algorithm

- Glaive is a state-space planner, meaning that it begins at the initial state of the problem and takes steps which change that state until it finds a state in which the author's goals are true
- Along with current plan and state, Glaive tracks a set of character goals 'G' and a set of unexplained steps 'X'
- A character goal is a 2-tuple<c,g> which represents that character 'c' intends goal 'g'
- Character goals can be added to the list during the story (character goals can change)
- Once an intentional path is found for 'c' that ends in 'g', that goal is removed
- When a step 's' with one or more consenting characters is taken, it gets added to 'X', which implies a commitment to explain this action
- When a step is taken that directly satisfies a goal, all steps that are in that goal graph (explained later) are explained because the goal was satisfied in this "world"
- Glaive returns a solution if it finds a node where the author's goals are satisfied and no steps remain unexplained

Running Example: Indiana Jones and the Raiders of the Lost Ark

Problem

Initial State: R buried. J alive.
J knows R. J intends U has R.
U alive. U intends U has R.
N alive. N armed.
N intends R opened.
Goal: U has R. ¬ N alive.

Key

J = Indiana Jones
R = Ark of the Covenant
N = Nazi Soldiers
U = US Army

Domain

dig(?char,?item)

Precons: ?char alive.
?item buried.
?char knows ?item.

Effects: ?char has ?item.
¬ ?item buried.

Consent: ?char

give(?gvr,?item,?rcvr)

Precons: ?gvr alive.
?gvr has ?item.
?rcvr alive.

Effects: ?rcvr has ?item.
¬ ?gvr has ?item.

Consent: ?gvr ?rcvr

open(?char)

Precons: ?char alive.
?char has ?item.

Effects: R opened.
¬ ?char alive.

Consent: ?char

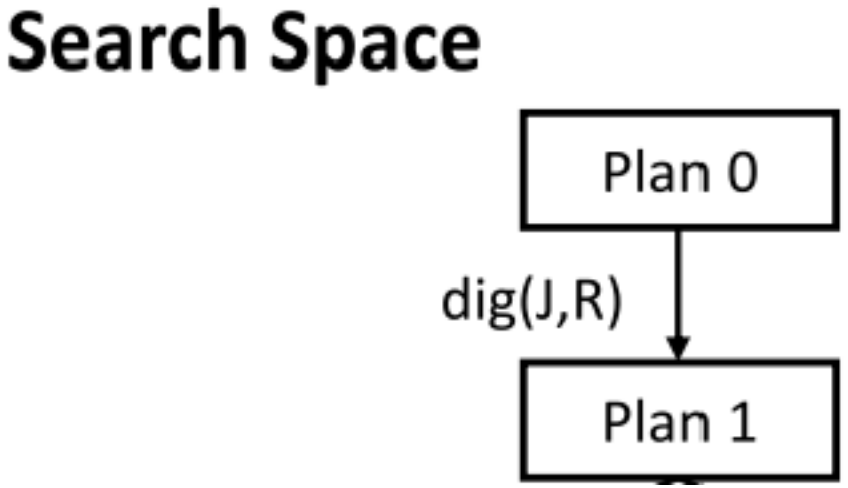
take(?thief,?item,?char)

Precons: ?thief alive.
?char has ?item.
¬ ?char alive OR
?thief armed.

Effects: ?thief has ?item.
¬ ?char has ?item.

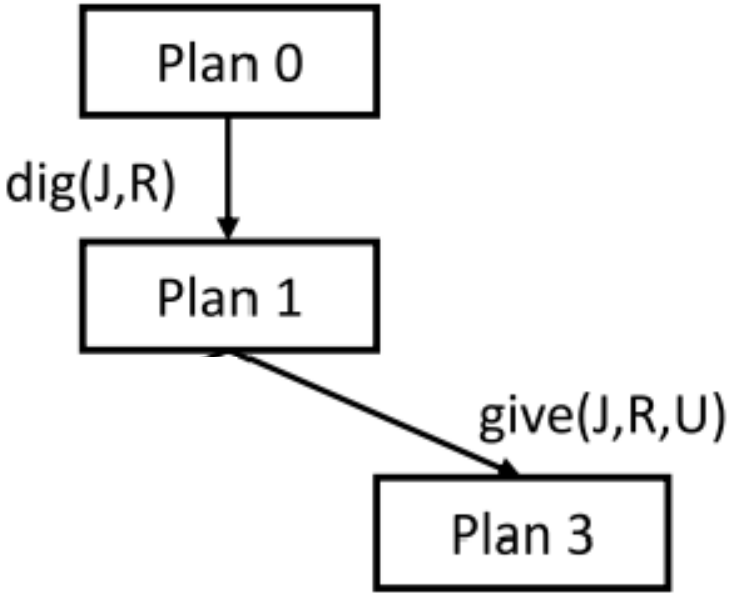
Consent: ?thief

Example of Explaining Actions:



- The First step selected is Dig(J,R)
- In Plan 1, Dig(J,R) is not explained, since it does not solve any character goals.
- It is put into ‘X’, the set of unexplained steps

Search Space



- The next step selected is Give(J,R,U)
- This step solves Indiana's character goal of the Army having the Ark, so this step is explained
- For the intentional plan corresponding to this tuple, all steps that exist in the plan relating to this goal are now explained, meaning Dig(J,R) is explained

Possible Worlds and Conflict

- A character's plan may fail, which is a key element of conflict
- Glaive reasons about failed plans by treating a state space as a representation of many possible worlds, as well as for performing the search
- This is achieved by considering a step explained in every node in the search, once a single node has explained it
- Simply put, a step is explained when there exists a world where it makes sense for that action to occur
- Glaive can combine multiple nodes into a single solution to explain each character's actions

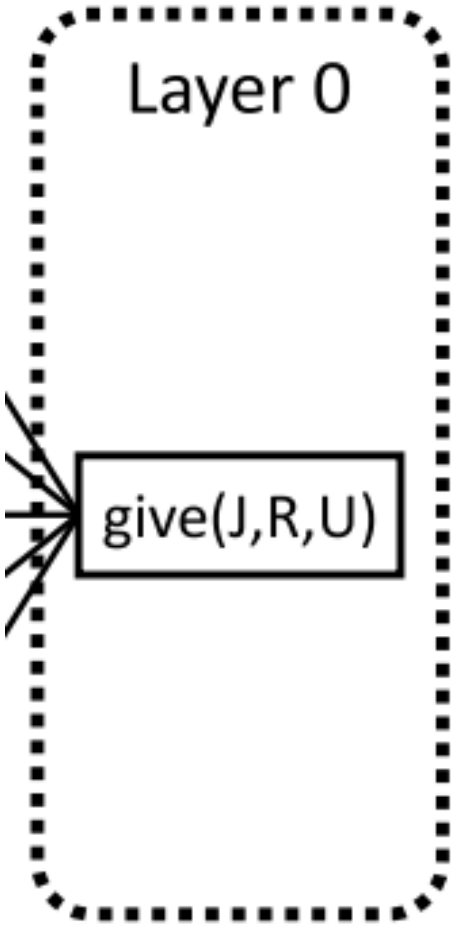
The Glaive Heuristic

The Glaive Heuristic is calculated as the maximum of two numbers

- An estimate derived by reasoning backward from each character goal
- An estimate derived by reasoning forward from the current state to the author's goals

Glaive uses Goal Graphs and Plan Graphs for these estimates respectively

Goal Graphs: "Indiana Jones *intends* Army has the Ark"

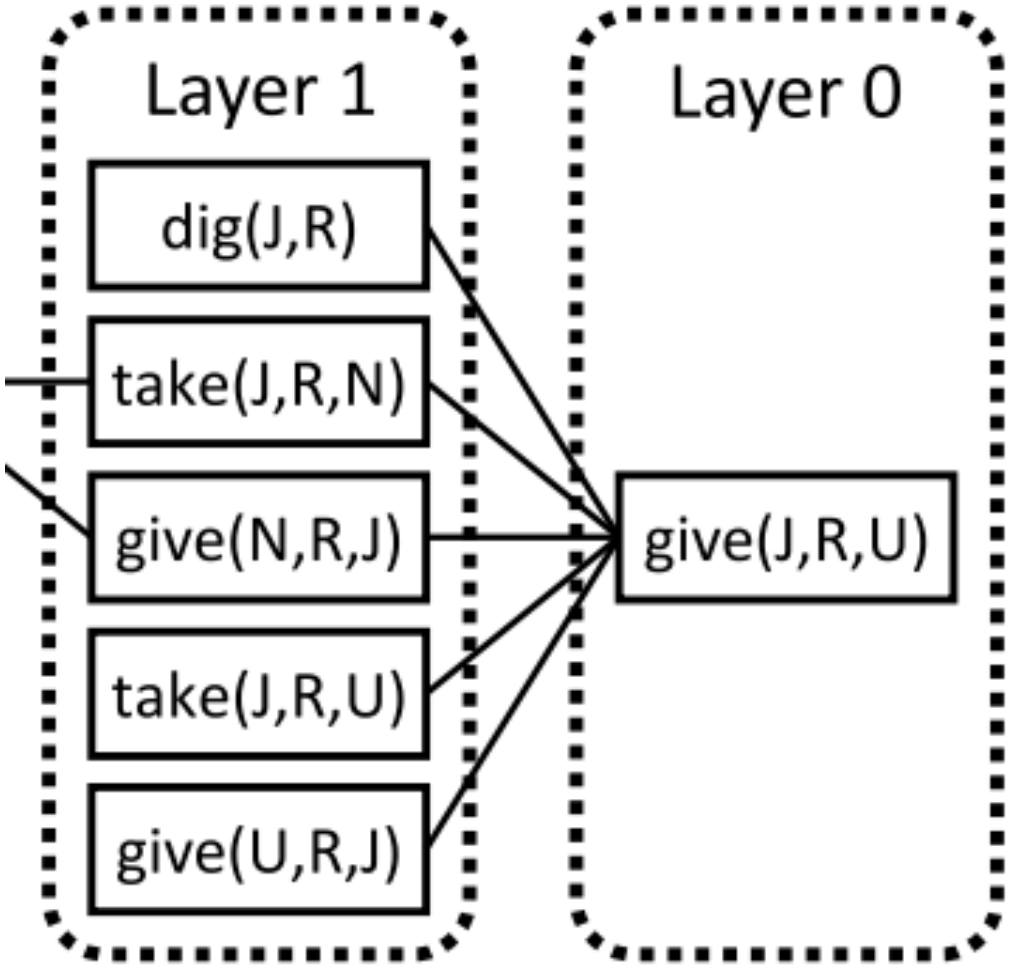


A step exists at layer 0 if and only if:

- 'c' consents to 's'
- 's' has 'g' as an effect

For this Goal Graph, there is only 1 action that has "U has R" as an effect and Indiana must consent to, so it is the only action at Layer 0

Goal Graphs: "Indiana Jones *intends* Army has the Ark"

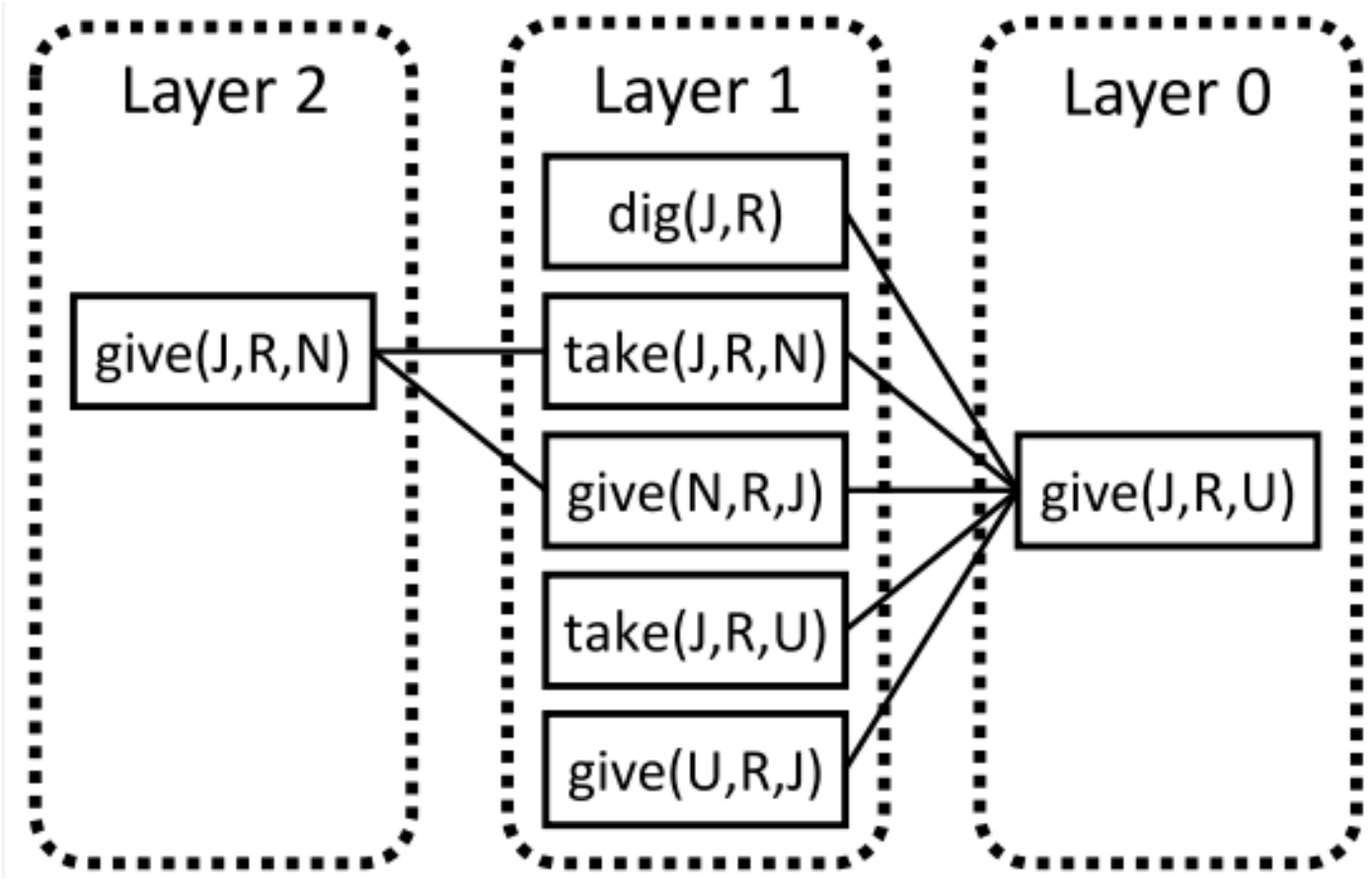


A step exists at layer i >= 0 if and only if:

- 'c' consents to 's'
- 's' does not exist at any earlier level
- The effects of 's' are a precondition to a step at layer 'i-1'

Each step shown here at layer 1 are consenting actions of J, have the effect of 'J has R' which is the precondition to give(J,R,U), and don't exist at an earlier level

Goal Graphs: "Indiana Jones *intends* Army has the Ark"



This is then continued as far back as possible within the Criteria for levels i>=0

This is the full goal graph for "J intends U has R"

Goal Graphs

- Only steps that are in goal graphs are considered during the search
- This is because, if a step cannot be explained, then there is no reason to consider it as a next step during a search
- A goal graph represents all possible intentional paths that might exist for character ‘c’ to achieve goal ‘g’
- When a step is unexplained, Glaive uses the layer at which that step appears in a goal graph to estimate how difficult it will be to explain it

Goal Graph Cost Calculation

- It is possible that multiple unexplained steps will eventually be explained by a single step
- To avoid overestimating, Glaive considers this
- A step ‘s’ in a goal graph is dominated by a step ‘t’ if and only if there exists a goal graph for some current character goal containing ‘s’ and ‘t’ which has an edge ‘s’->’t’
- In simple terms, if a step exists in the plan that comes later in your intention graph, consider your intention graph at that point (If U takes R, consider J’s intention graph at the point, in this case finished)

$$\text{cost}(x) = \sum_{c \in C} \left(\min_{\gamma \in \Gamma(x,c)} \begin{cases} 0 & \text{if } x \text{ is dominated in } \gamma \\ layer(x, \gamma) & \text{otherwise} \end{cases} \right)$$

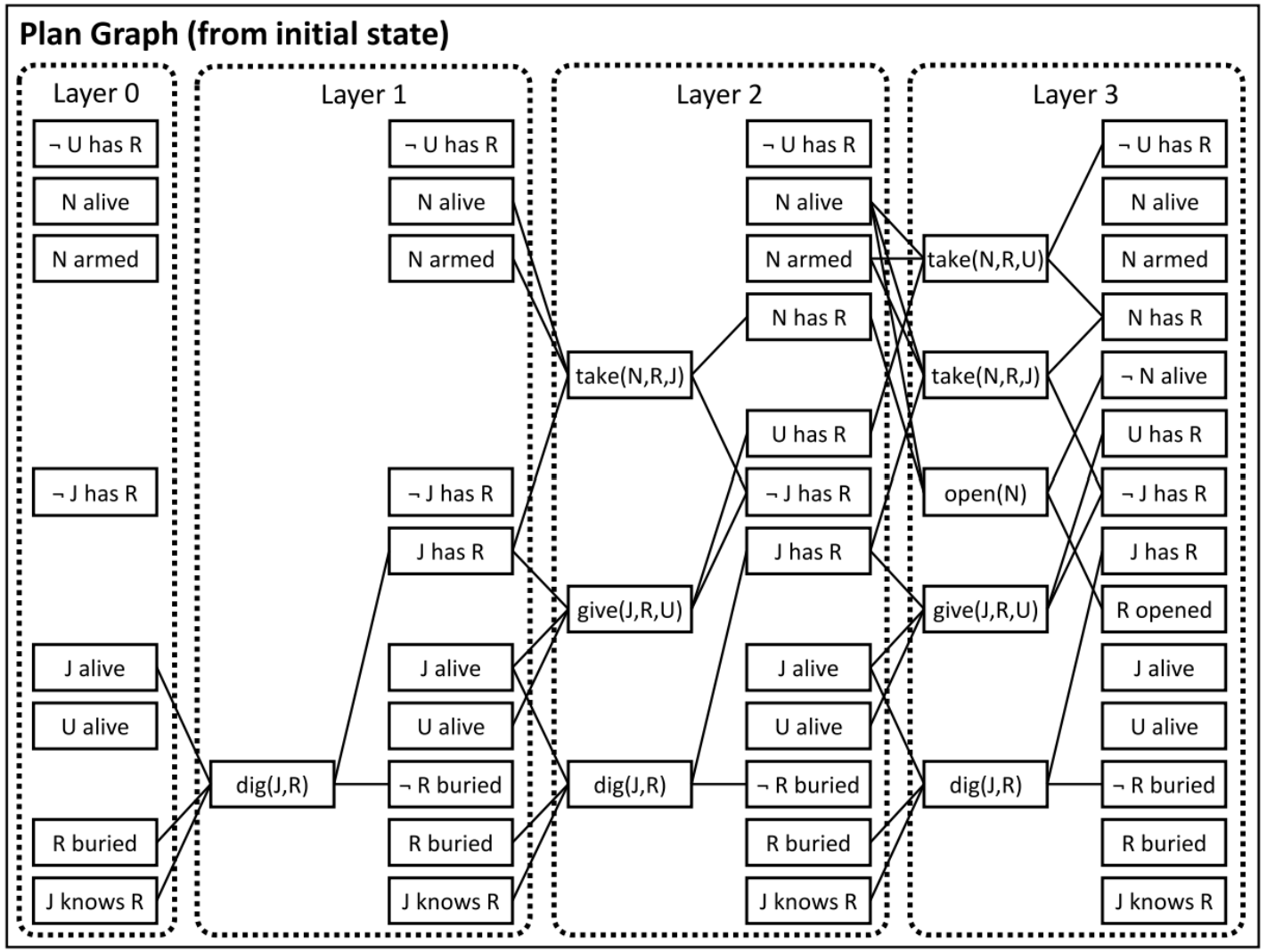
γ A goal Graph

$\Gamma(x, c)$ A List of all Goal Graphs

Plan Graph

This is the same plan graph formula from fast-forward plan graph with a couple changes:

- a step may not appear at a layer until it is potentially motivated in the previous layer
- When a step gets included in a relaxed solution, one of its motivations must also be included

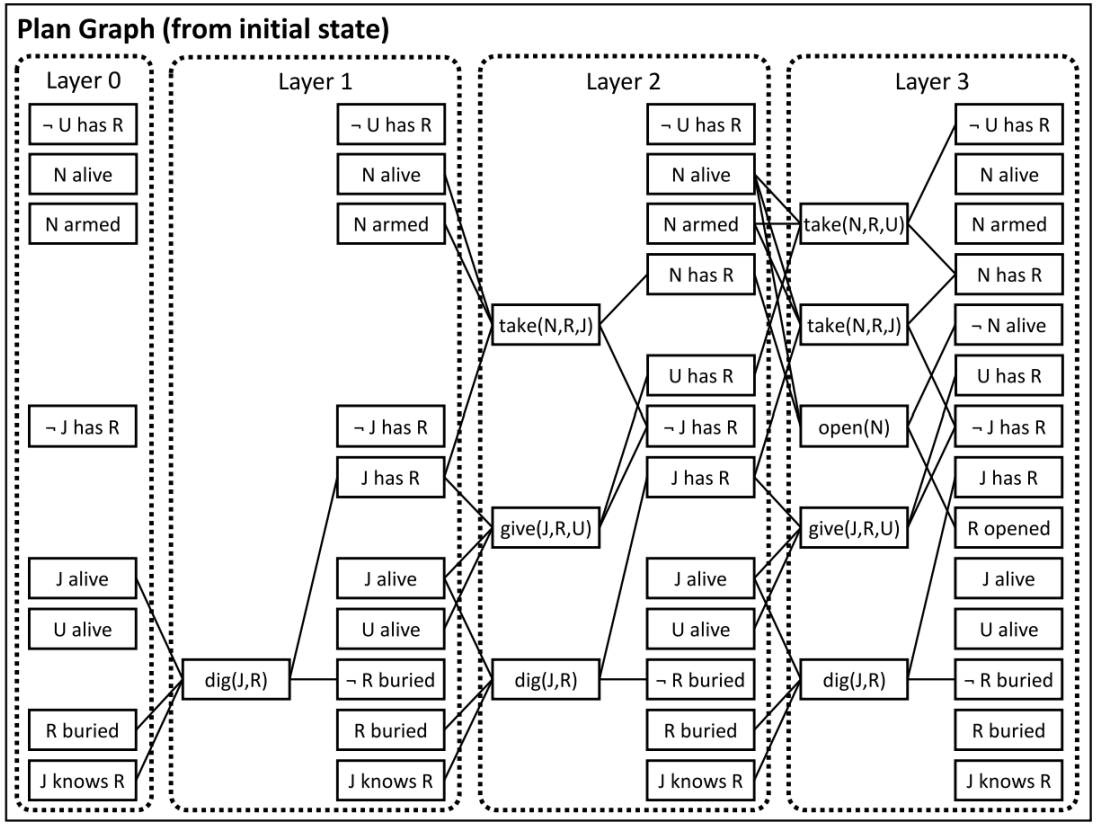


Heuristic Calculation

$$h(n) = \max(\mathrm{FF}(n), \mathrm{cost}(n))$$

The maximum of these two estimates is used (rather than the sum) because they are likely to consider some of the same steps and Glaive attempts to avoid overestimating. Glaive's heuristic could be improved if double counting could be efficiently avoided

Full Example: Indiana Jones and the Raiders of the Lost Ark



Search Space

Plan 0

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N alive. N armed.
N intends R opened.
Goal: U has R. ¬ N alive.

'X' = {}

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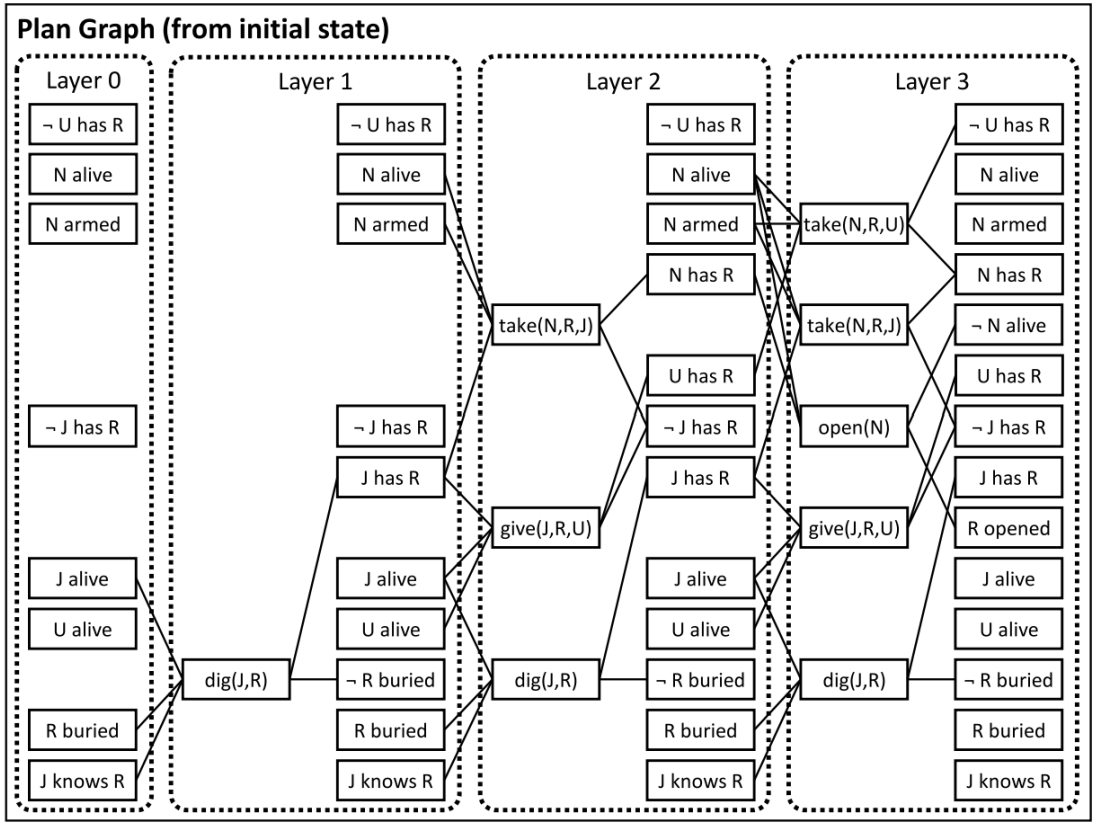

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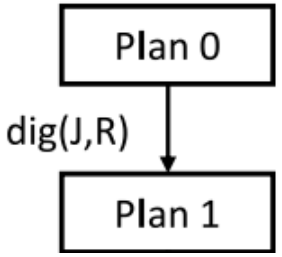

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'X' = {Dig(J,R)}

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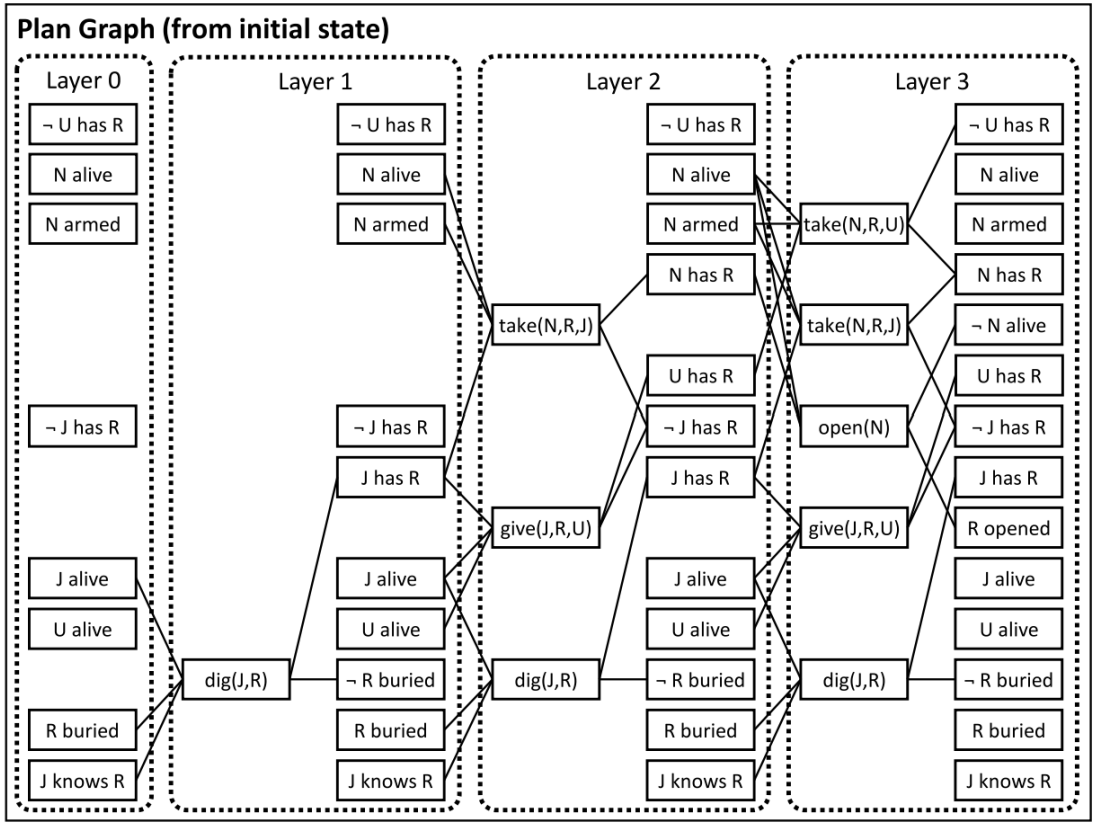

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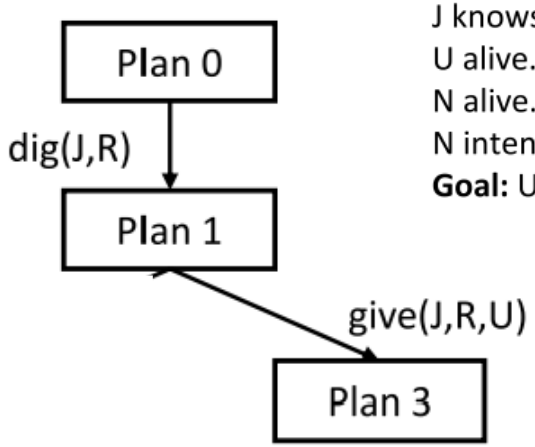

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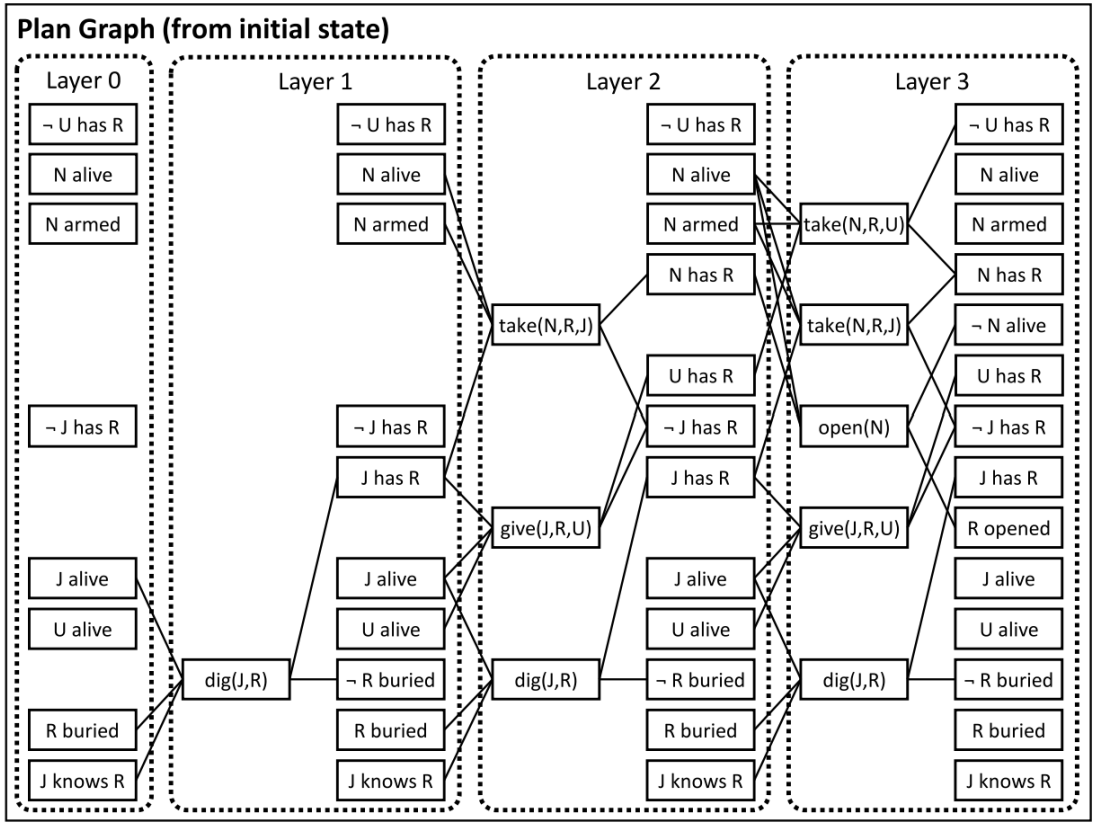

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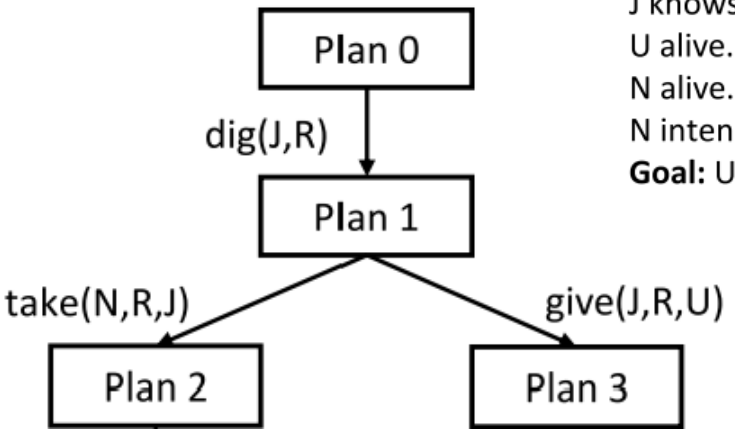

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'X' = {Take(N,R,J)}

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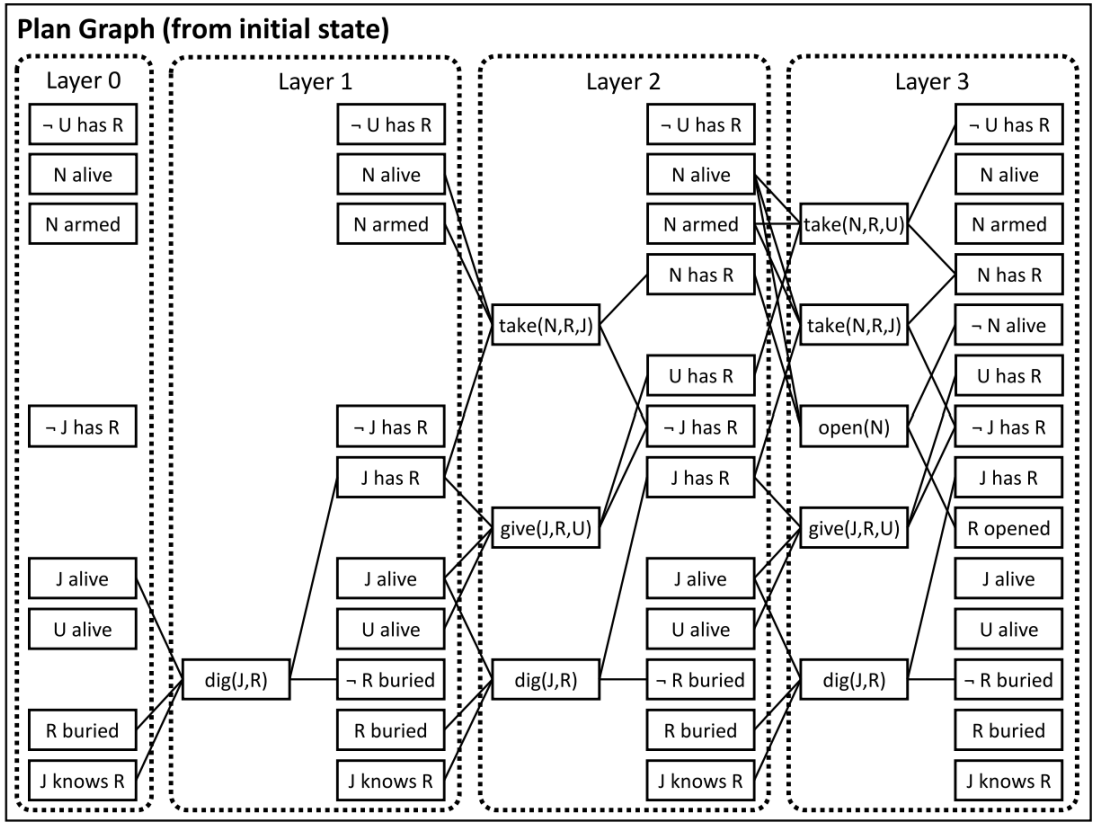

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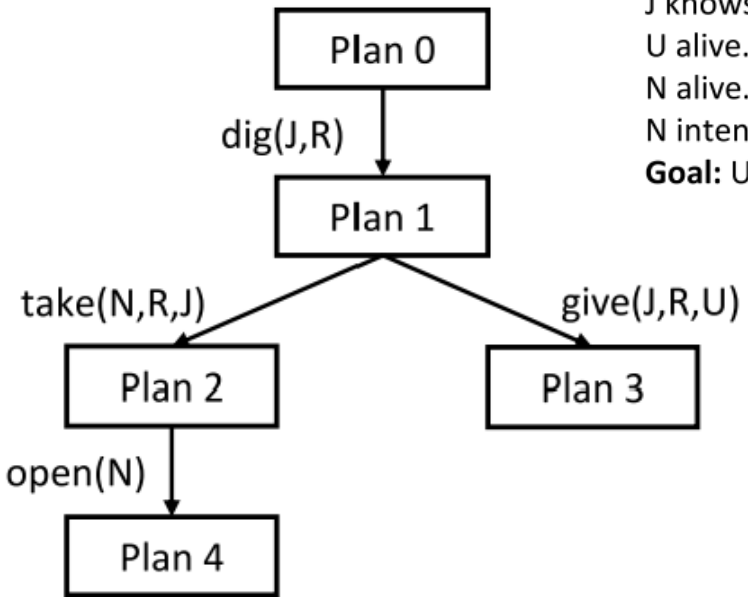

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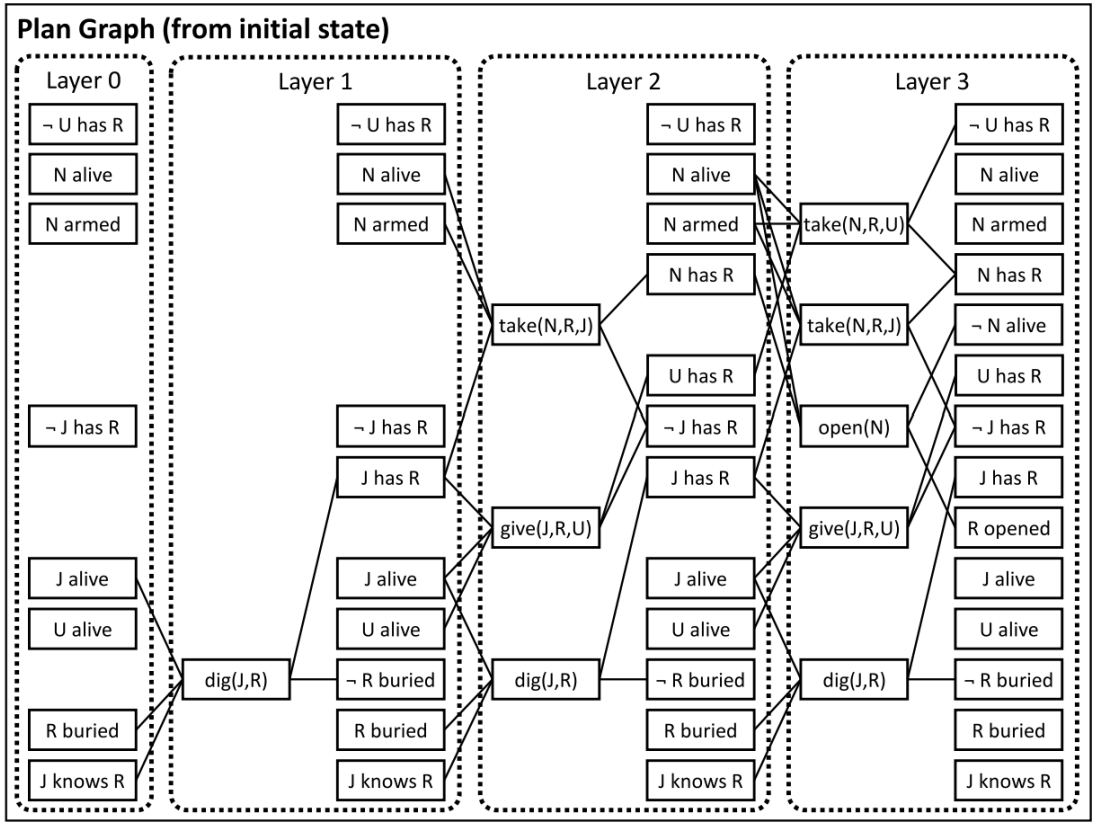

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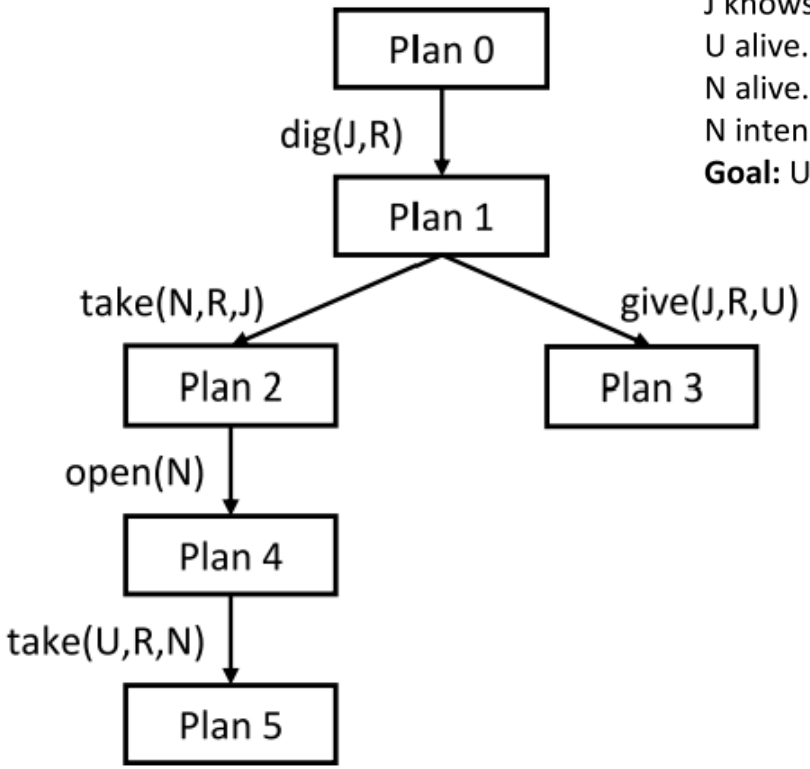

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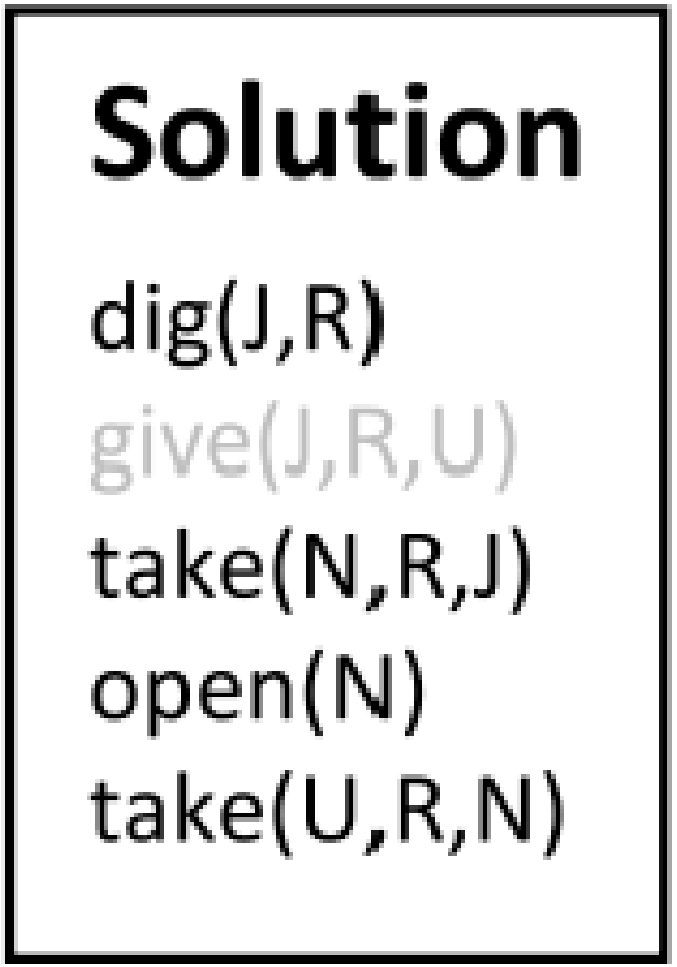
'X' = {}

Example Solution

This is the full solution to the authors goals. The step greyed is a step that isn't executed. These steps are included for explanation of characters actions. In larger problems, there can be multiple "branches" that can explain other characters actions because of their intentions



Evaluation

The Graph compares the Fast-Forward Heuristic to the Glaive heuristic

Problem	Planner	Sol?	Time	Visited	Expanded
Space	FF	Yes	0.00	3	15
	Glaive	Yes	0.00	3	9
Fantasy	FF	Yes	2.76	35,407	212,046
	Glaive	Yes	0.03	14	107
Raiders	FF	Yes	0.23	1,334	4,073
	Glaive	Yes	0.03	35	142
Aladdin	FF	No	288.49	67,758	2,063,927
	Glaive	Yes	0.06	12	189
BLP-Win	FF	Yes	27.38	32,262	196,576
	Glaive	Yes	0.31	109	586
Western	FF	No	440.55	166,110	3,079,097
	Glaive	Yes	28.41	18,855	296,150
BLP-Die	FF	No	195.93	106,750	731,948
	Glaive	No	236.97	91,887	720,024
Heist	FF	No	367.92	84,854	1,654,916
	Glaive	No	351.38	115,782	1,544,048