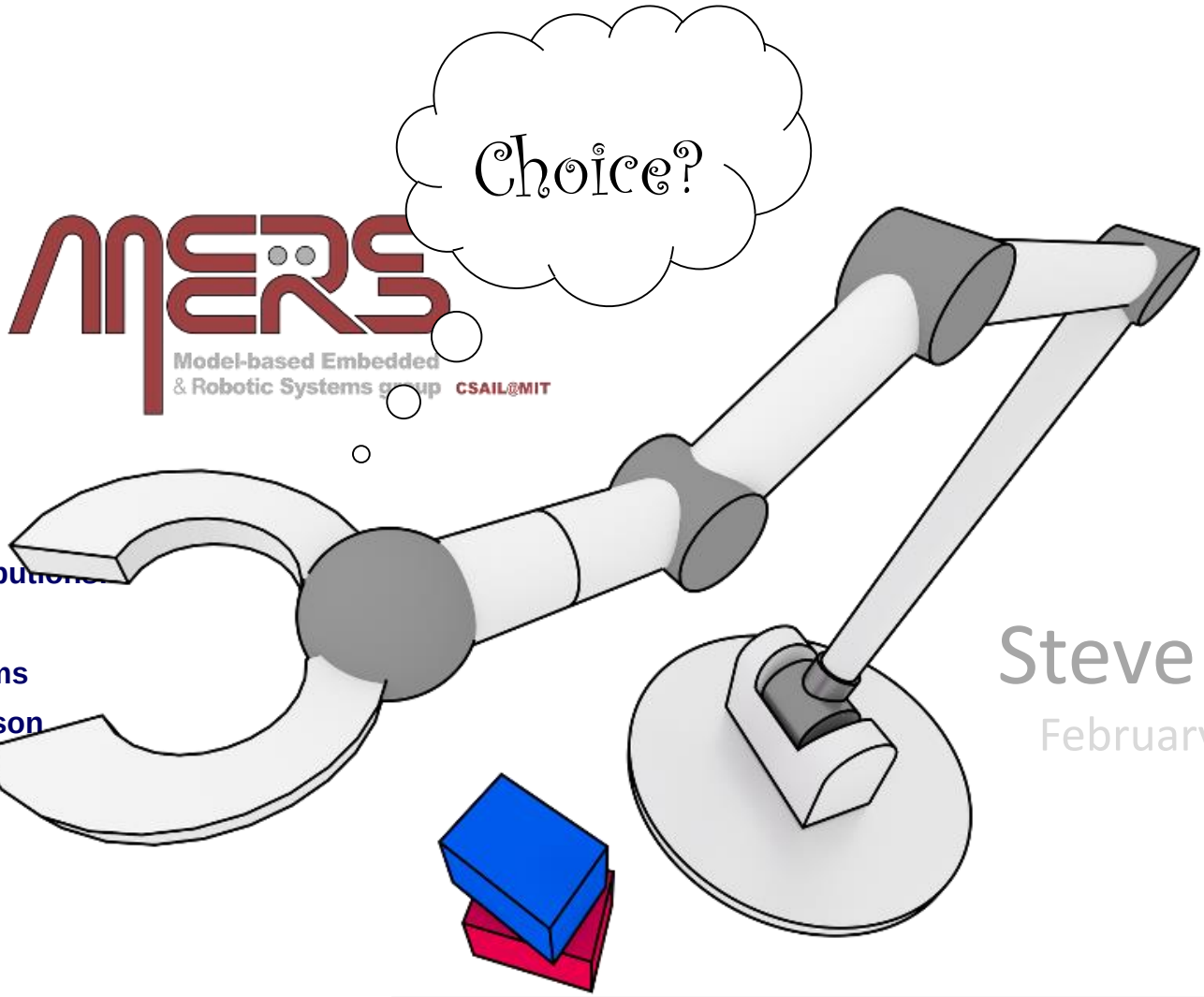
Programs with Flexible Time, Choice, and State



Slide Contributions:
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Brian Williams
Paul Robertson

Steve Levine

February 17th, 2016

Assignments

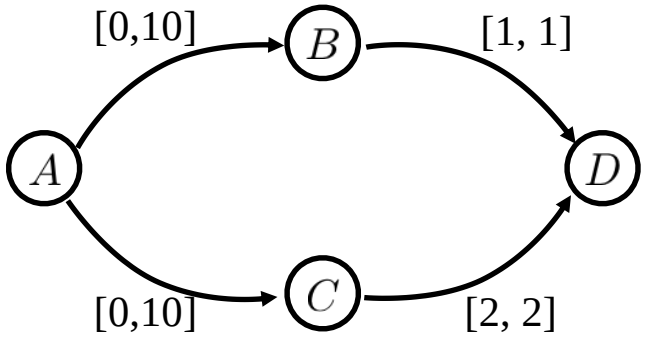
Problems Sets:

- Pset 1 due tonight at 11:59pm
- Pset 2 released tonight (Scheduling)
- **Backup your work before updating!**

Interesting references:

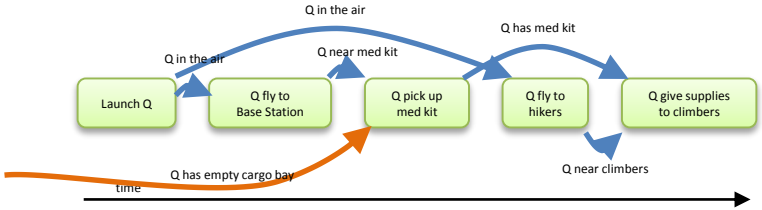
- ITC: I-hsiang Shu, Robert Effinger, Brian Williams, Enabling Fast Flexible Planning through Incremental Temporal Reasoning with Conflict Extraction.

Today: Combining what we've learned



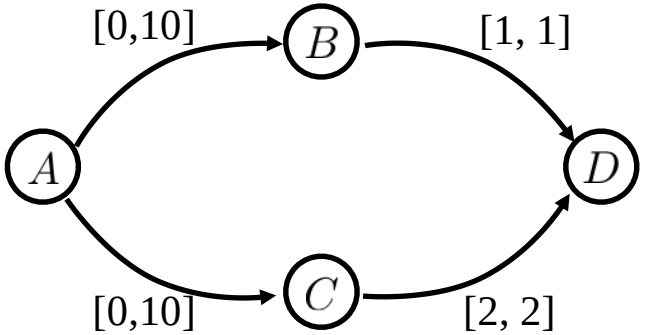
Flexible Time

+



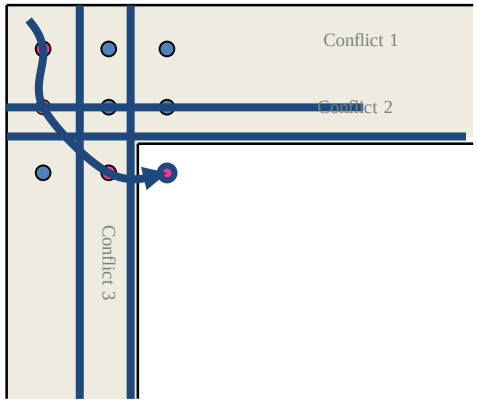
Execution monitoring

and



Flexible Time

+



Conflict-directed A*

Outline

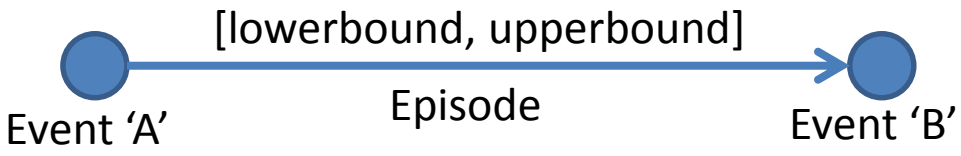
- Flexible time + execution monitoring
  - Extracting causal links
  - Dispatching & monitoring
- Flexible time + conflict-directed A*
  - Plans with choice
  - Making optimal choices

Adding more flexibility

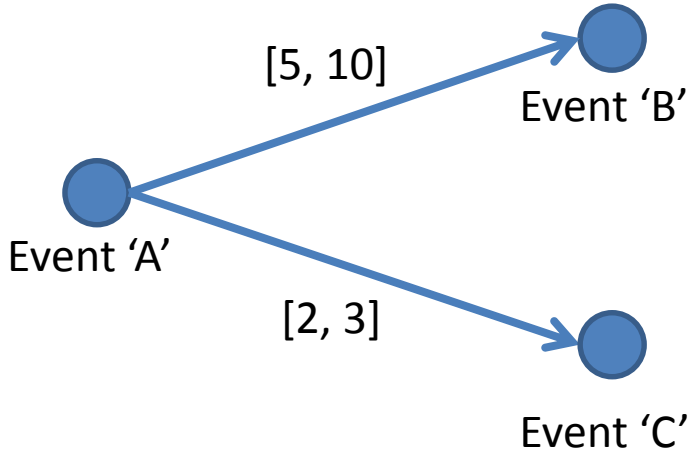
PLANS WITH CHOICE & TIME

Simple Temporal Network (STN)

Simple Temporal Network (STN):



Read: "Event B must occur between lowerbound and upperbound time after A"

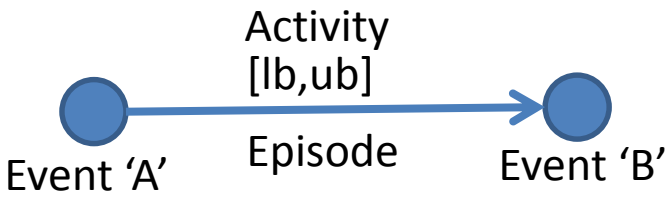


Read: "Event B must occur between 5 and 10 [seconds] after A.
AND Event C must occur between 2 and 3 [seconds] after C."

Temporal Plan Network (TPN)

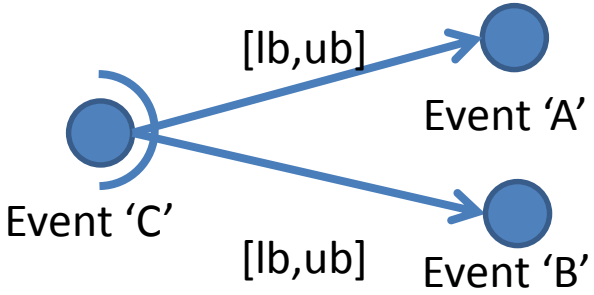
Temporal Plan Network (TPN) :

Idea 1: Durative Activities



Read: “Start Activity at Event A and end it at Event B.”
Alt: “Activity will take between lb and ub time to execute.”

Idea 2: Decision Events: execute only one outgoing episode

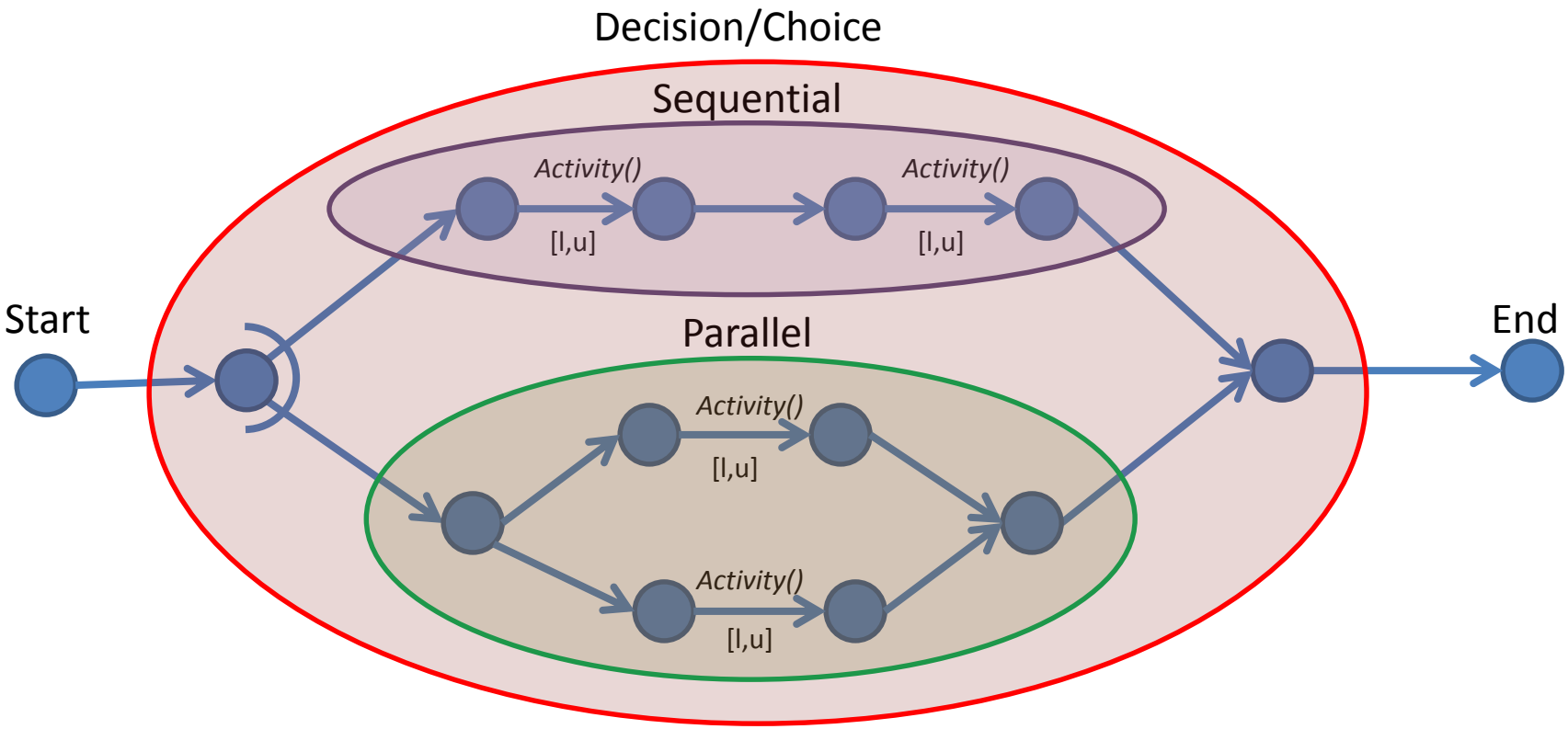


Read: “After Event C, execute either Event A or Event B, depending on which episode has the lowest cost.”

Temporal Plan Network

Temporal Plan Network (TPN) :

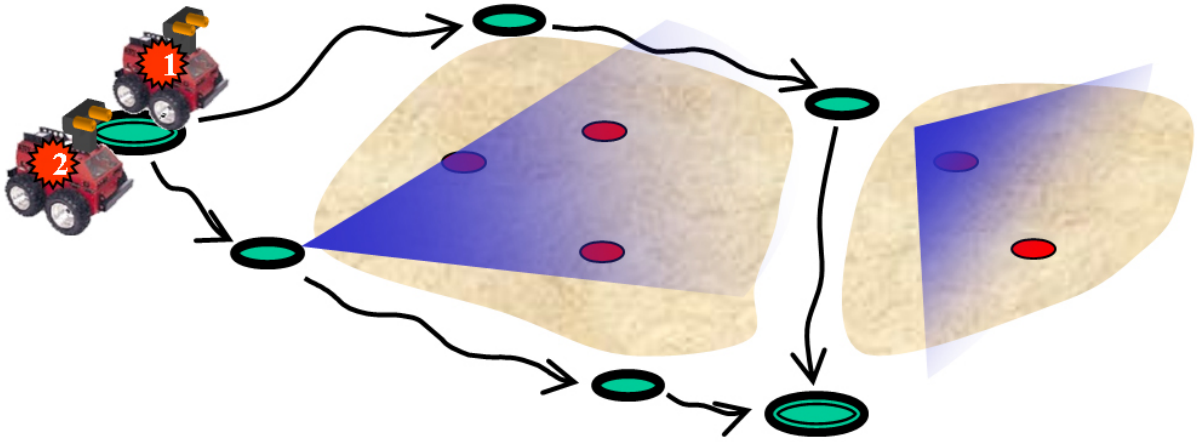
Idea 3: Hierarchical Composition

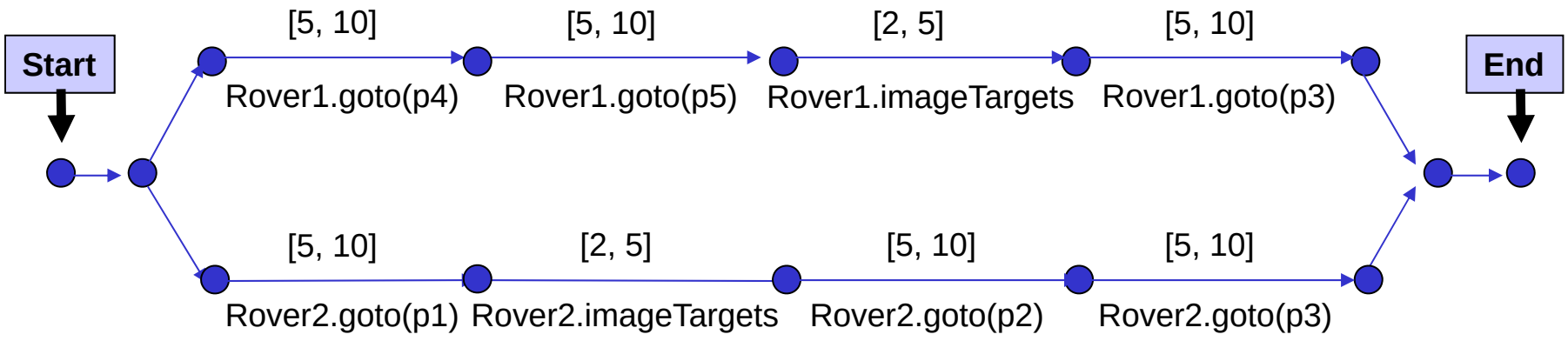


Robust Program and Plan Execution

RMPL

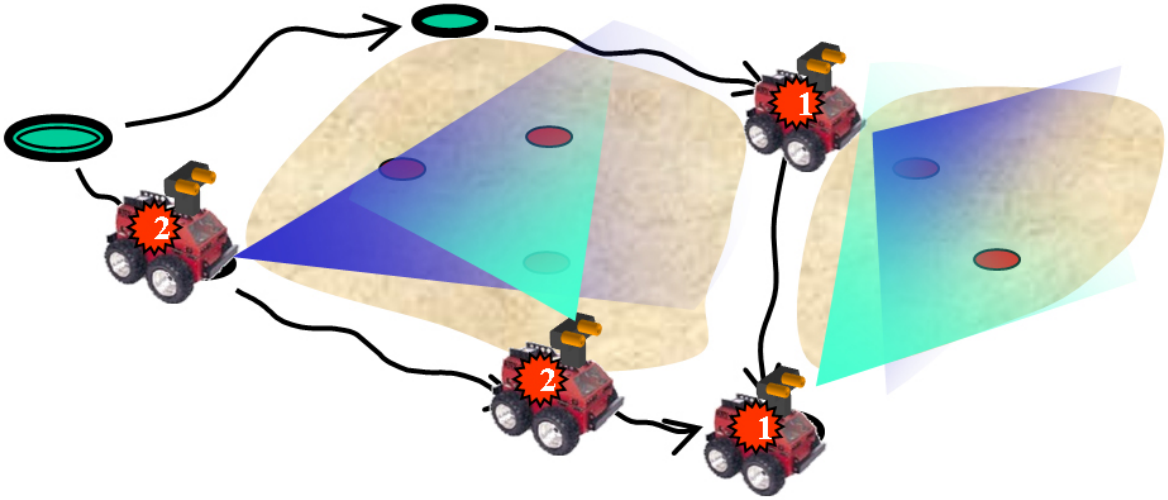
```
imageScienceTargets(Rover1, Rover2)
Parallel{
  Sequence{
      [5,10] Rover1.goto(p4);
      [5,10] Rover1.goto(p5);
      [2,5] Rover1.imageTargets1();
      [5,10] Rover1.goto(p3);
   }
   Sequence{
       [5,10] Rover2.goto(p1);
       [5,10]Rover2.imageTargets2();
       [2,5] Rover2.goto(p2);
       [5,10] Rover2.goto(p3);
   }
}
```

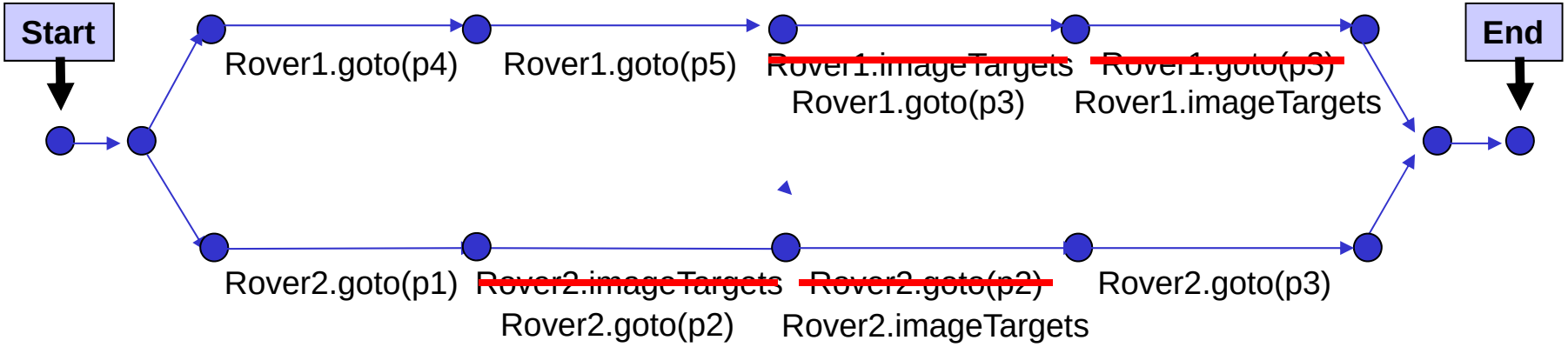




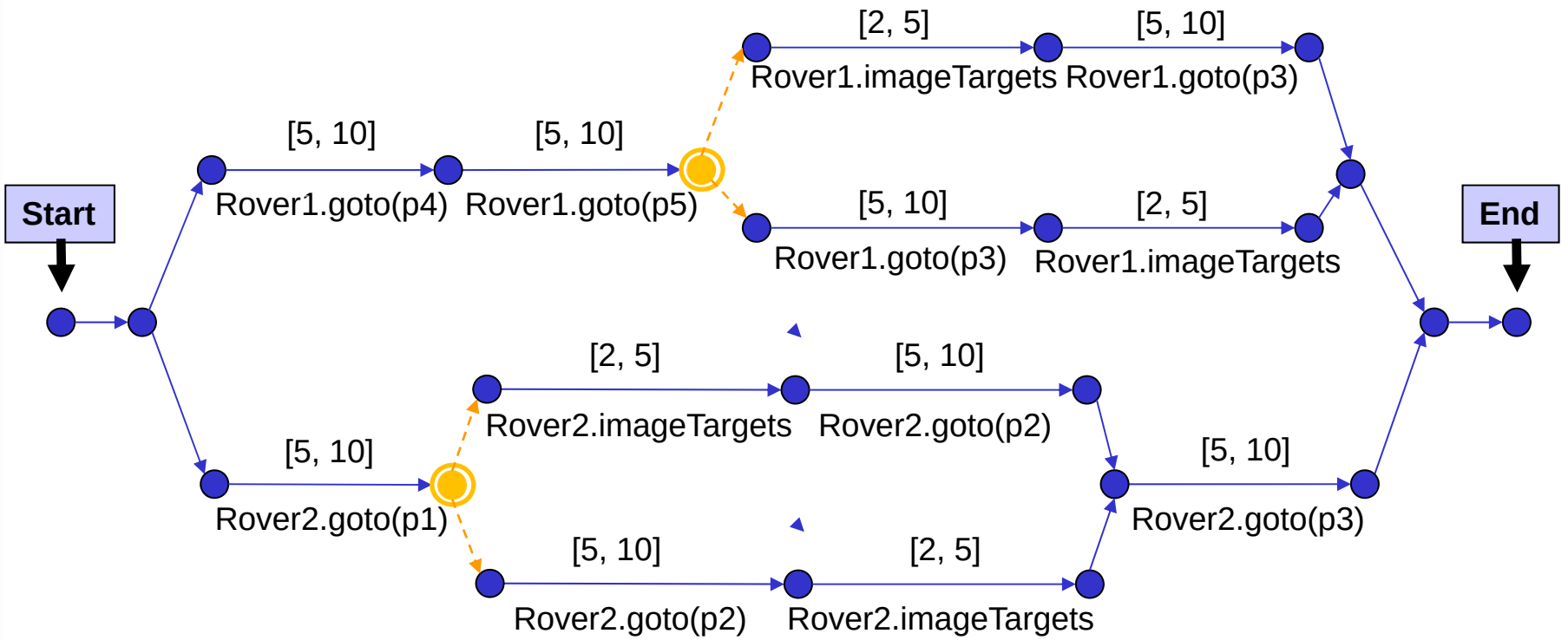
What if we want more flexibility in our plan?

A Different Choice



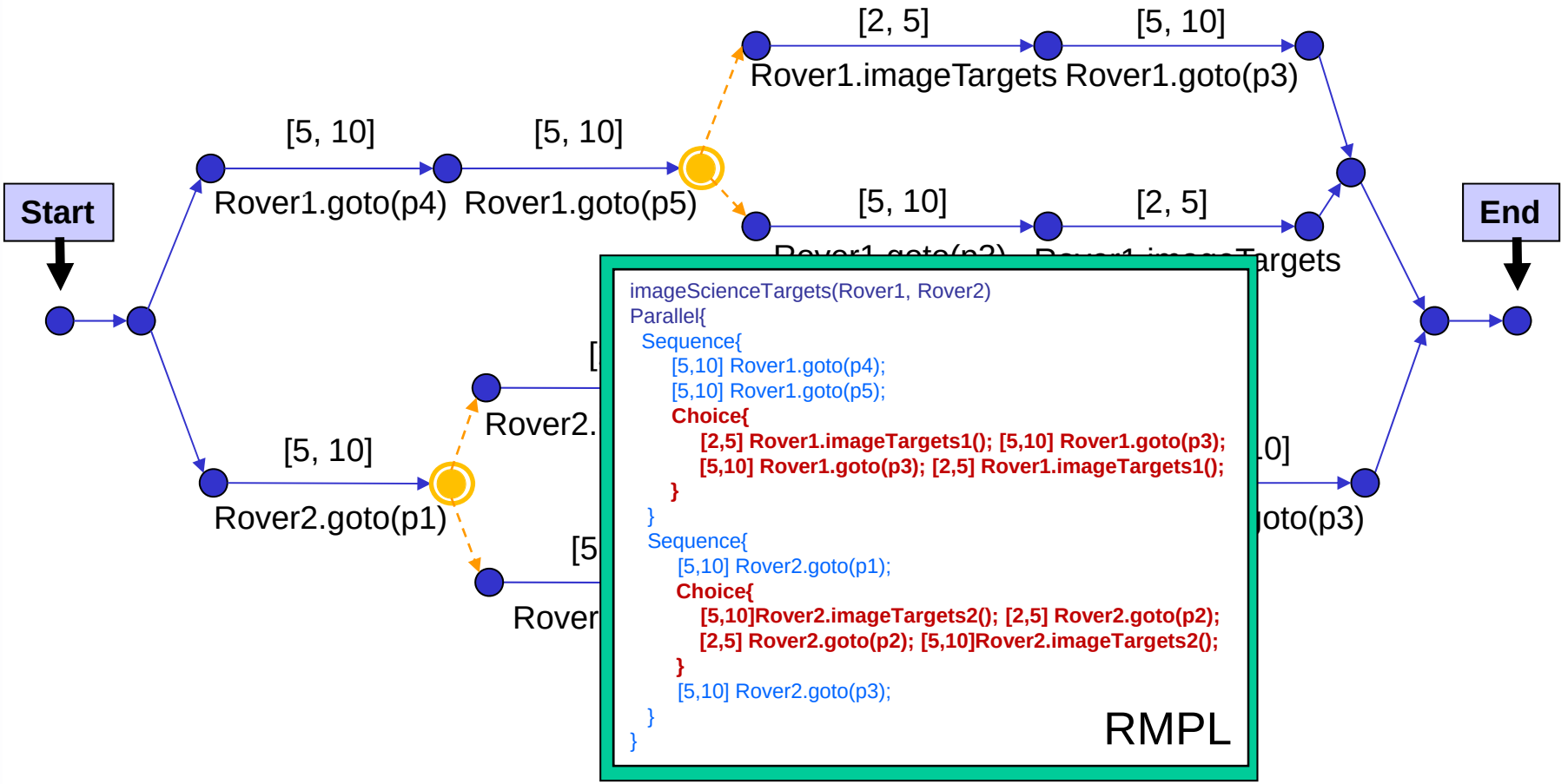


A Plan with **Choice**

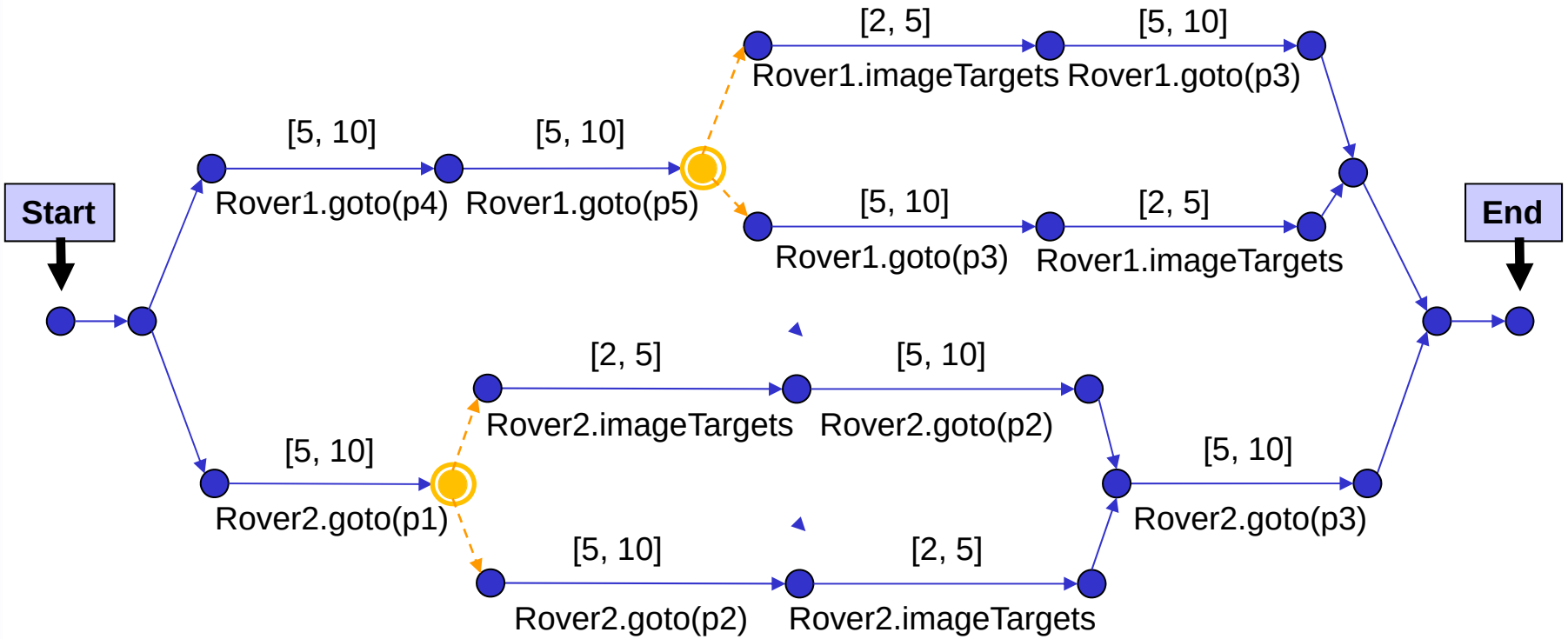


Assume for this plan, that edges without explicit temporal constrains are [0,0].

A Plan with **Choice**

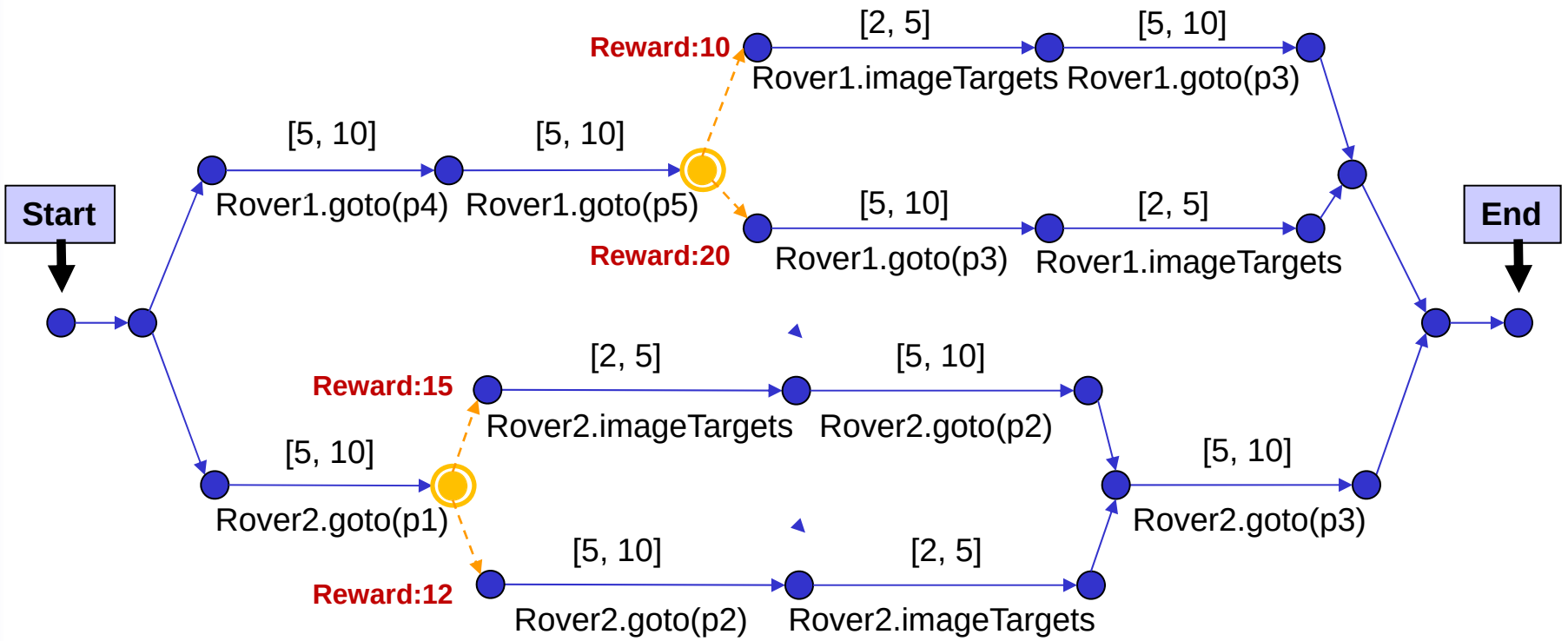


What can Influence the Choice?



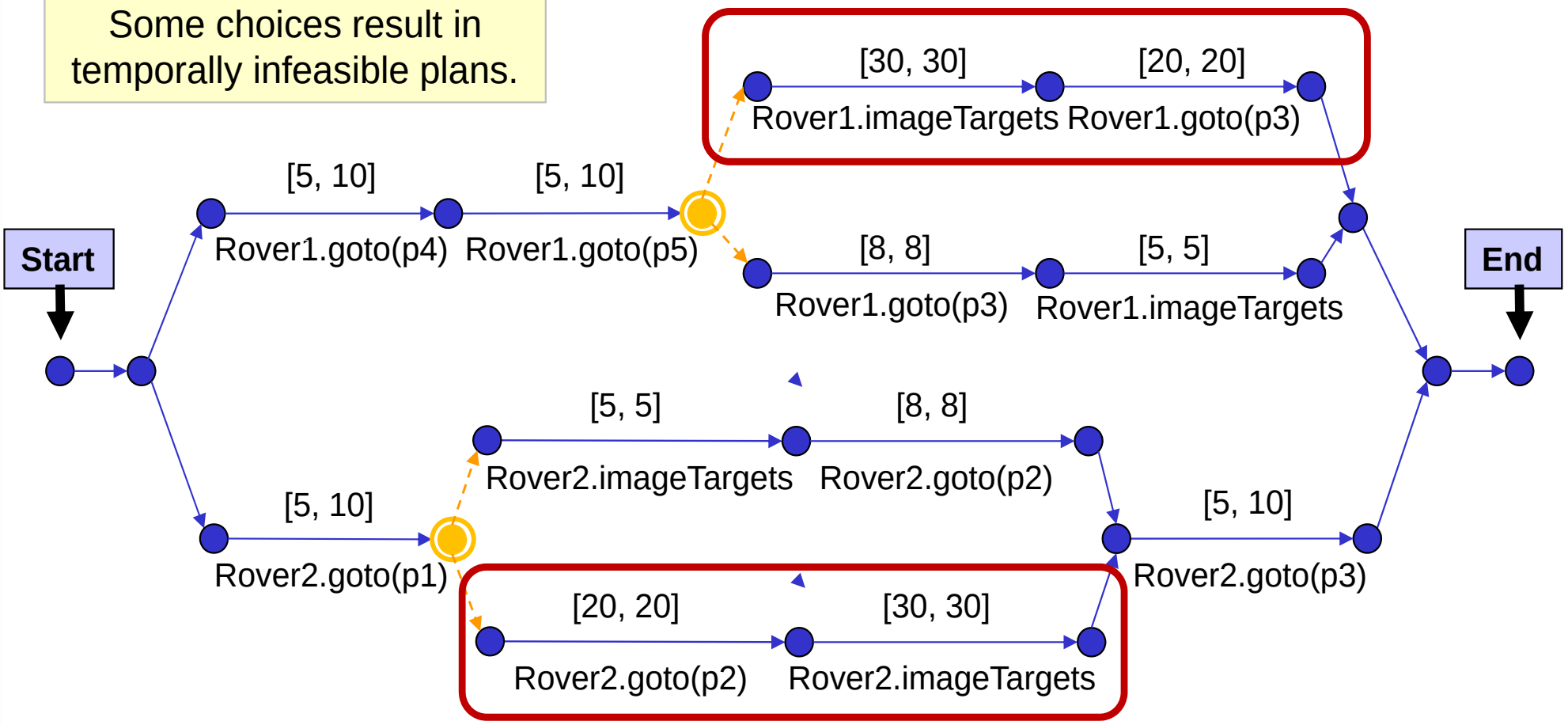
What can Influence the Choice?

A ***utility*** associated with the choice.



What can Influence the Choice?

Temporal Consistency:
Some choices result in temporally infeasible plans.

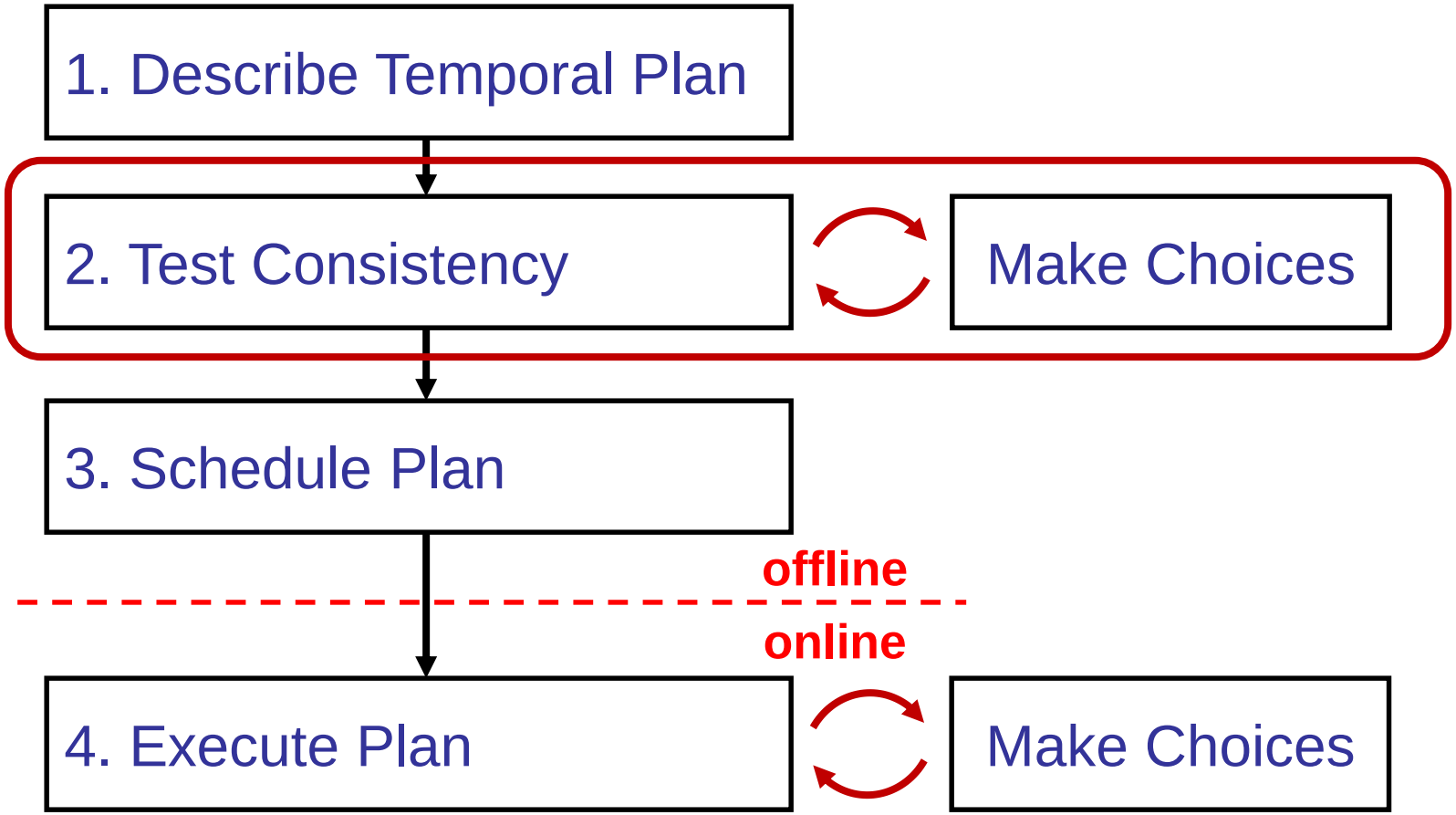


(In order for the rovers to rendezvous)
One choice influences the other choice.

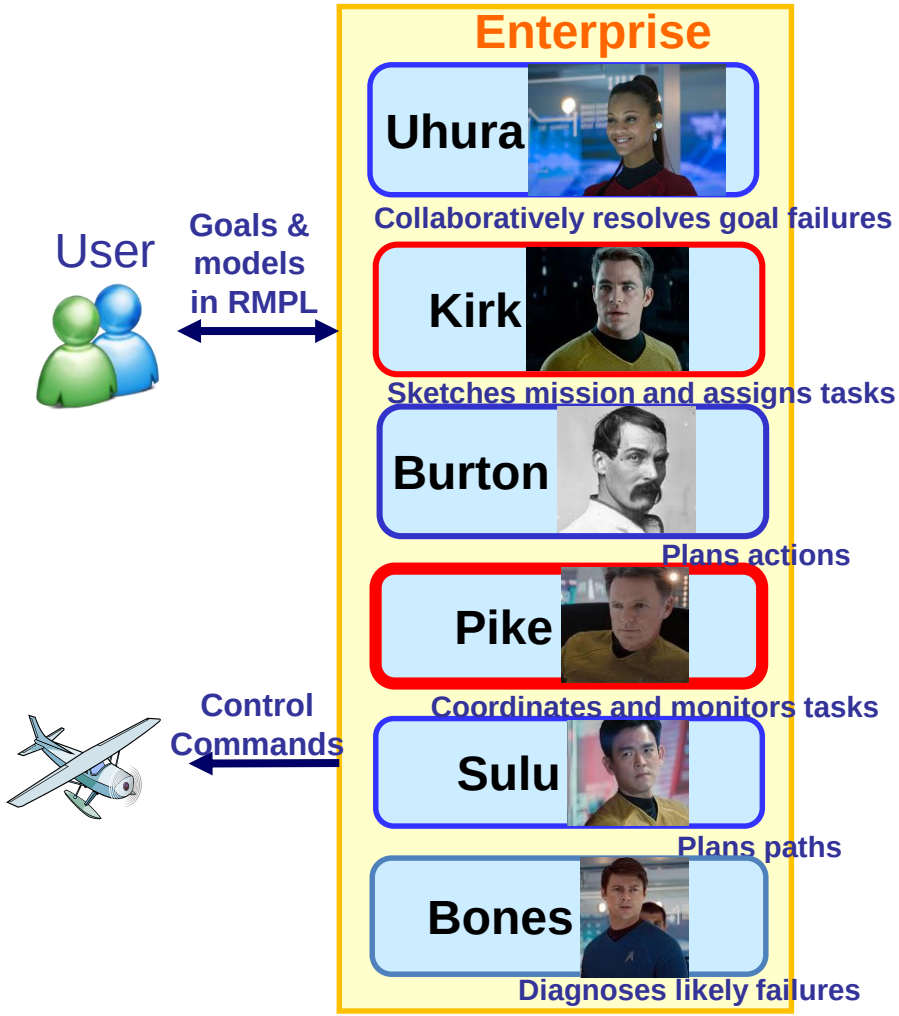
With choices we can represent…

- Alternative ordering of actions
- Alternative methods for competing a task
- Alternative resource assignments
- Alternative task assignments (who does what)

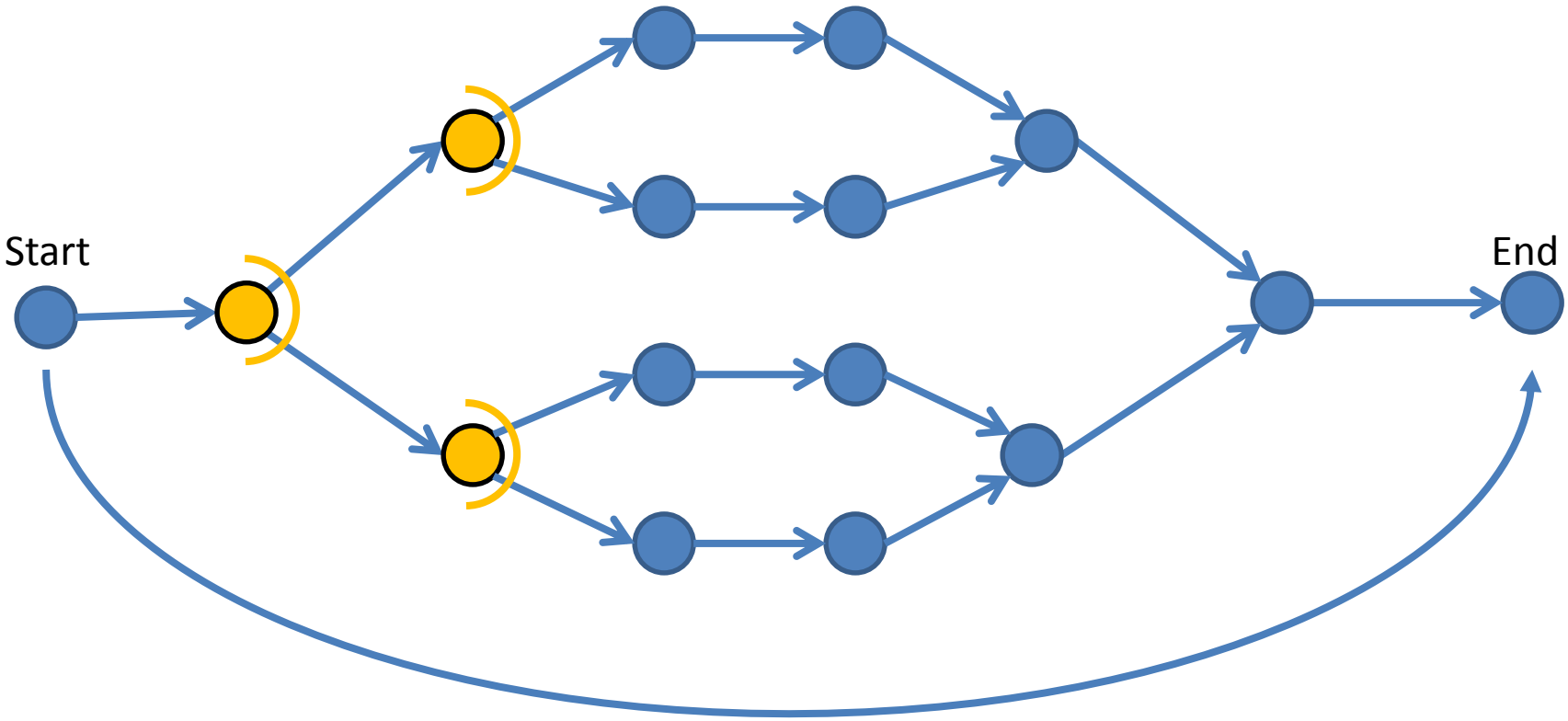
When can the Choice be made?



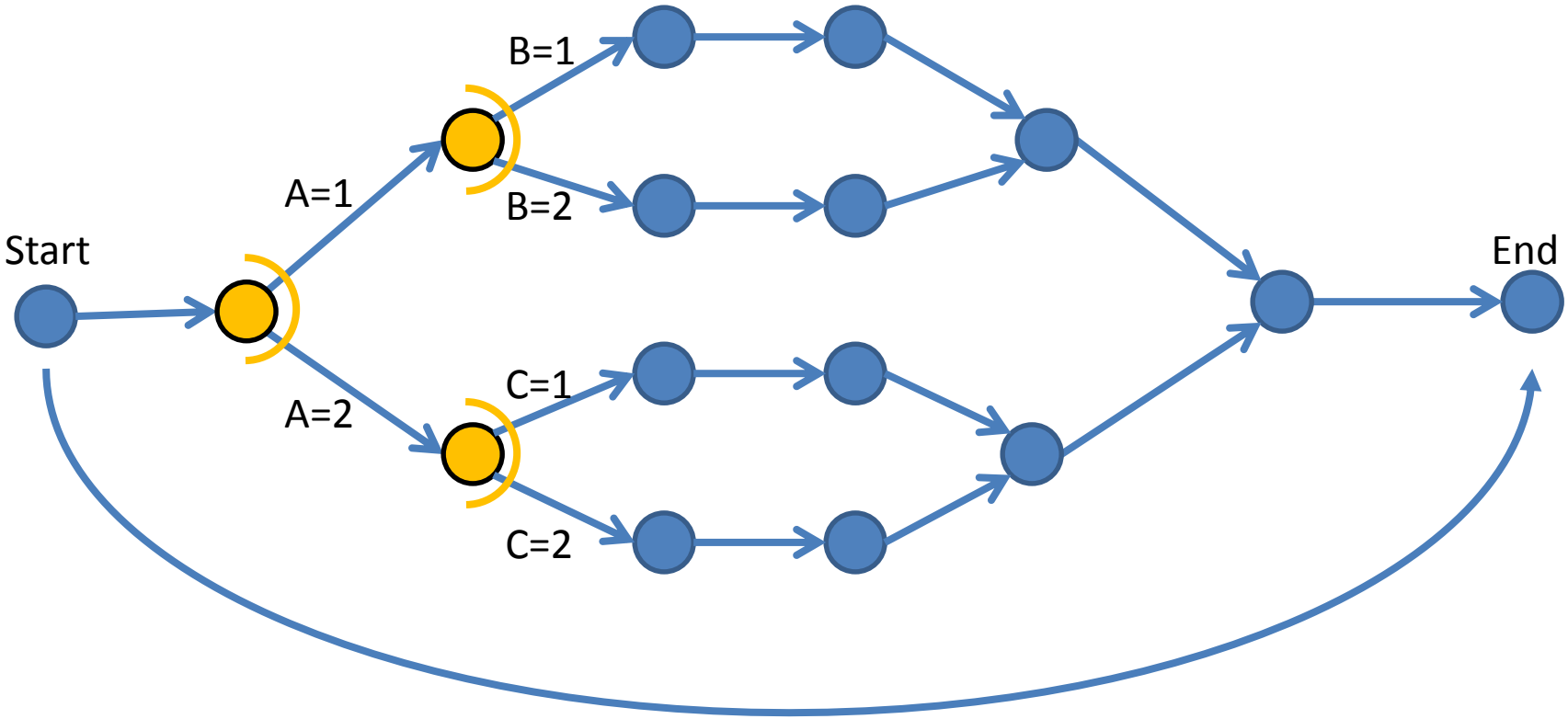
A single "cognitive system" language and executive.



Example TPN

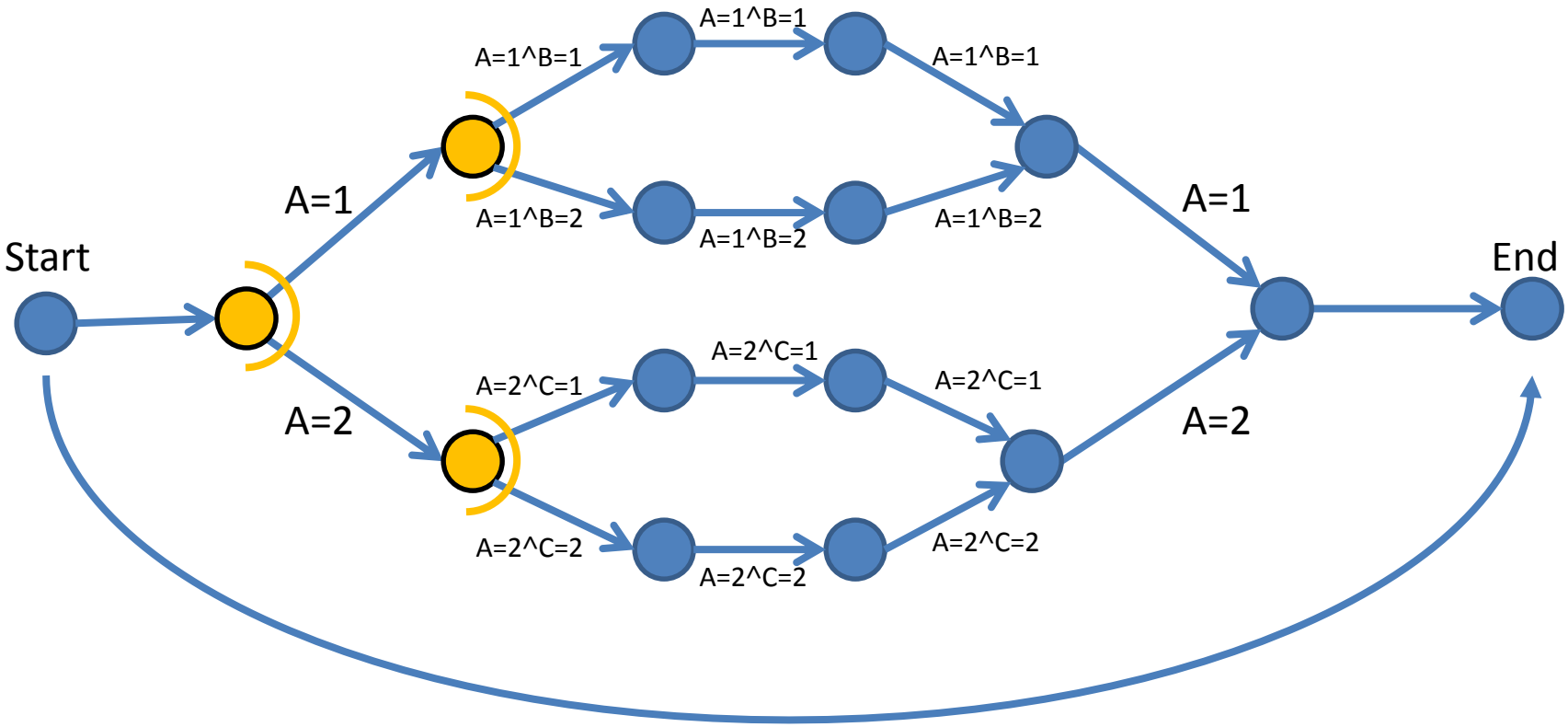


Choosing as a Constraint Satisfaction Problem



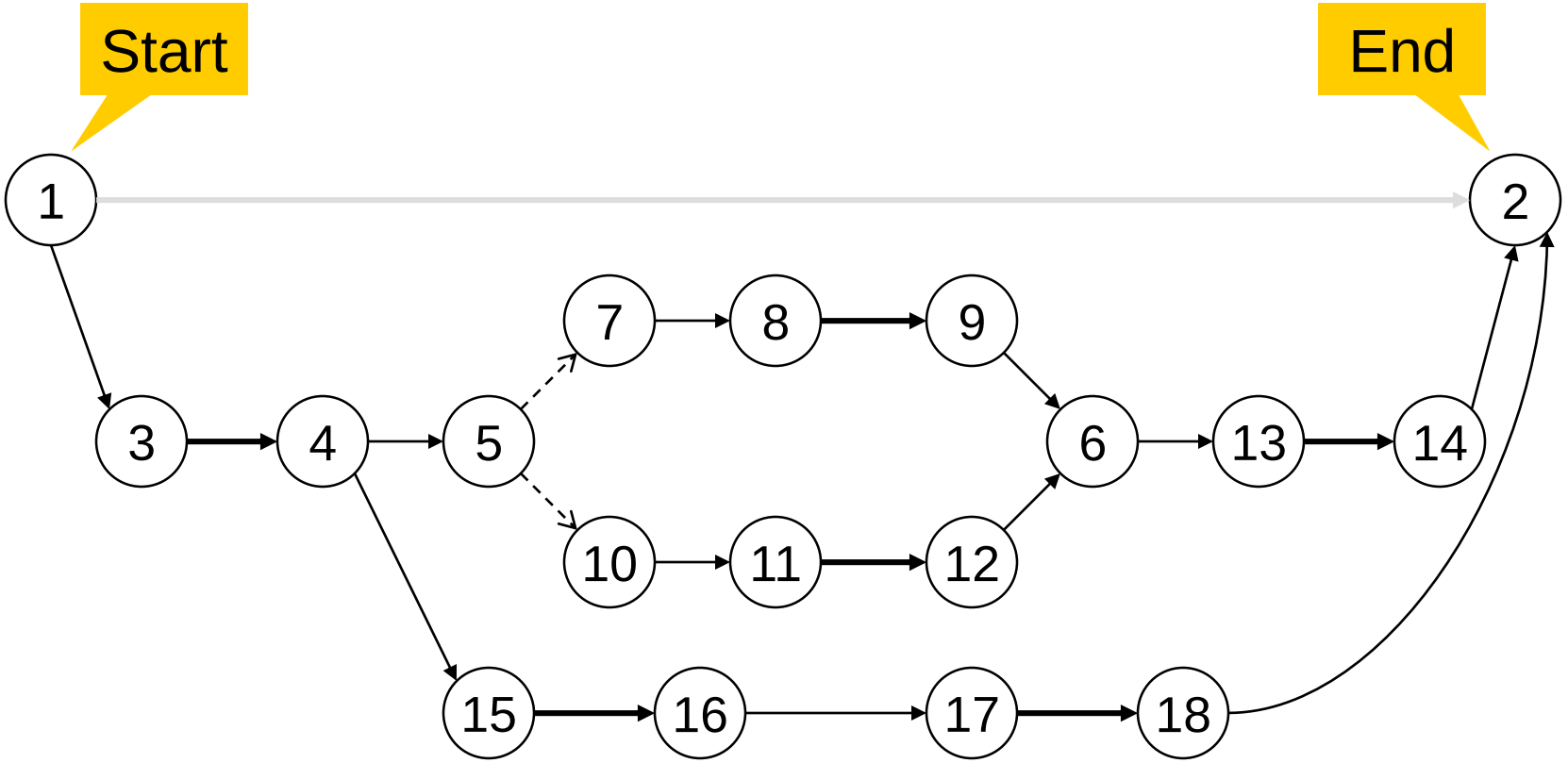
Choosing as a Constraint Satisfaction Problem

Assign variables A, B, & C such that
all of the temporal constraints
with true ***guards*** are temporally consistent.

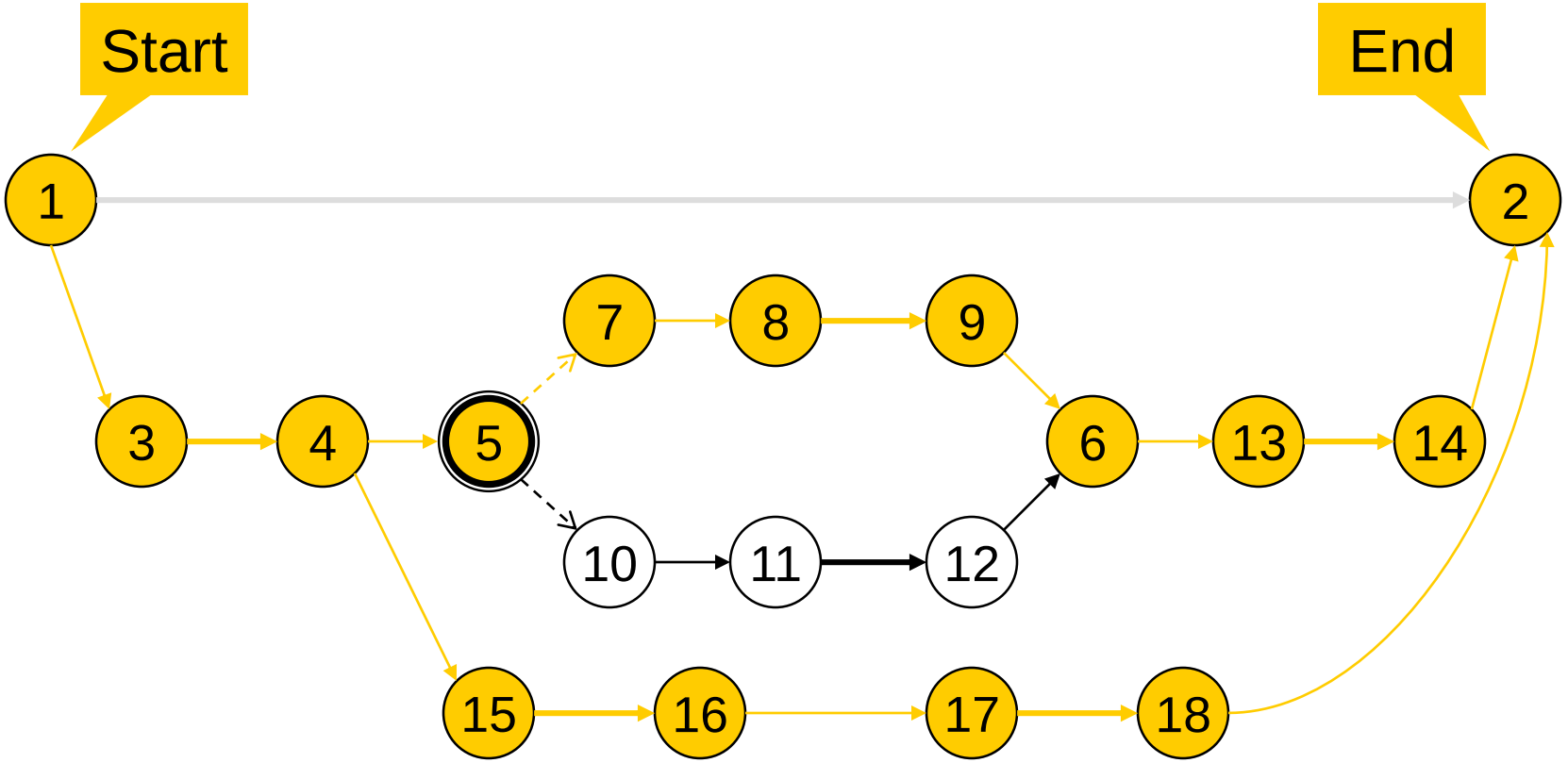


Different candidate subplans of TPN

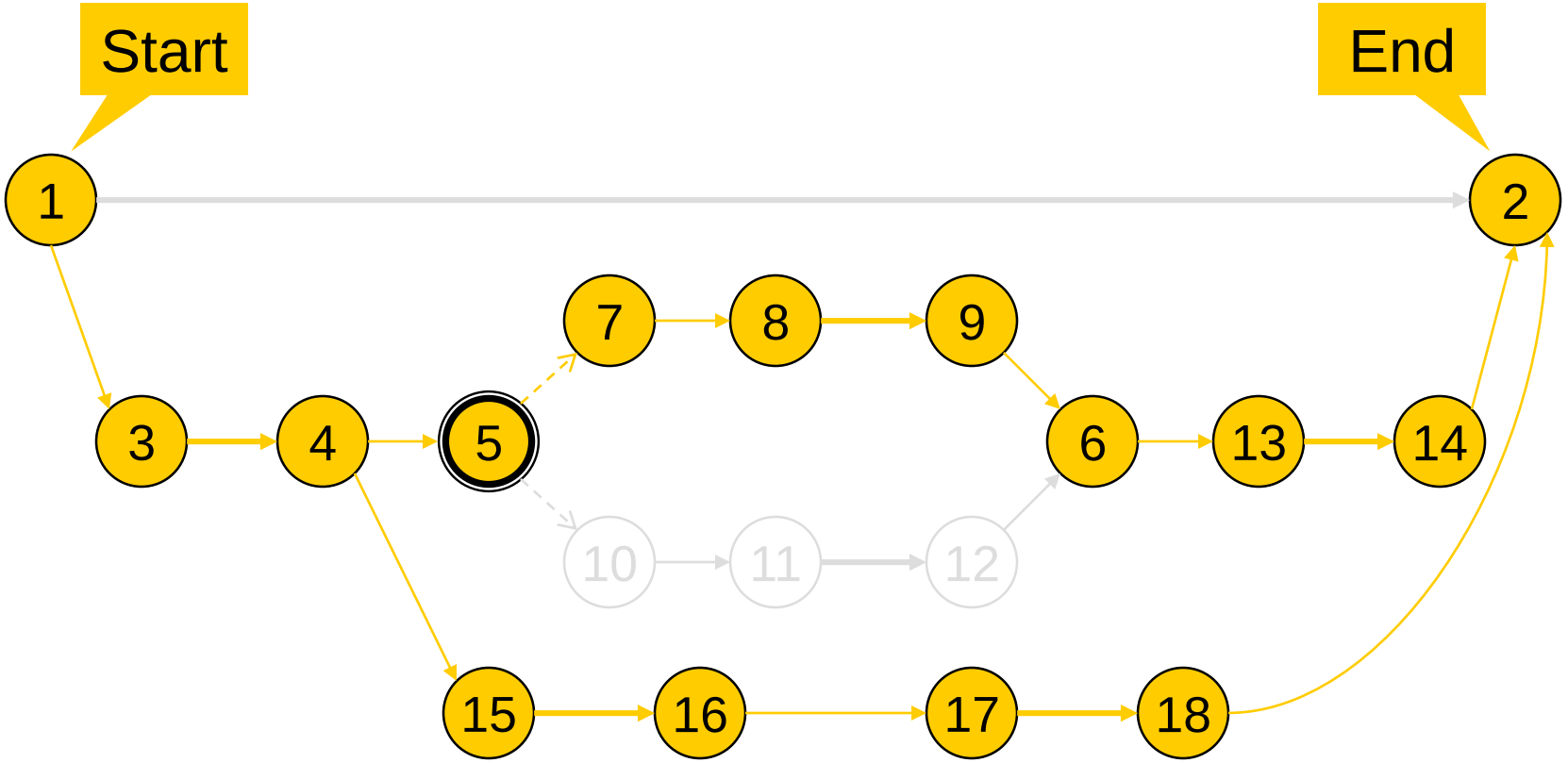
- Find which edges have activated guards



Different candidate subplans of TPN



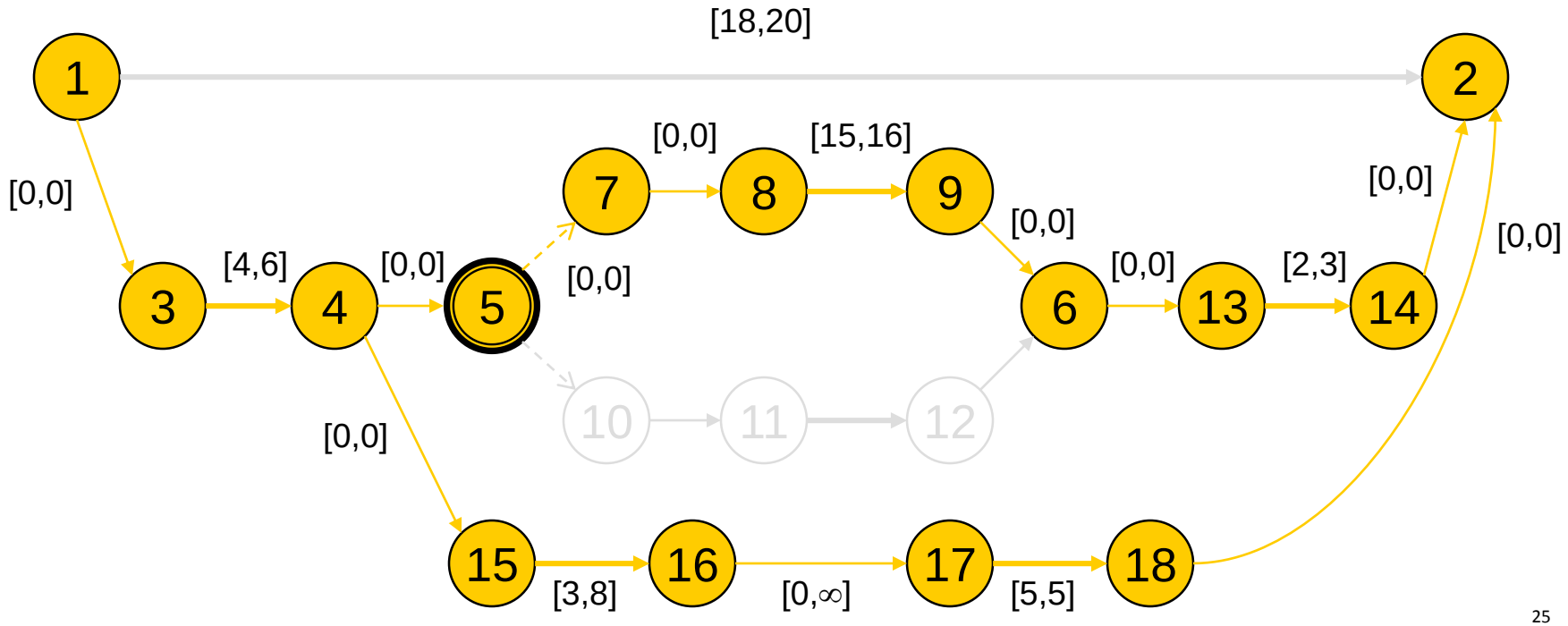
Trace Trajectories



Check Schedulability

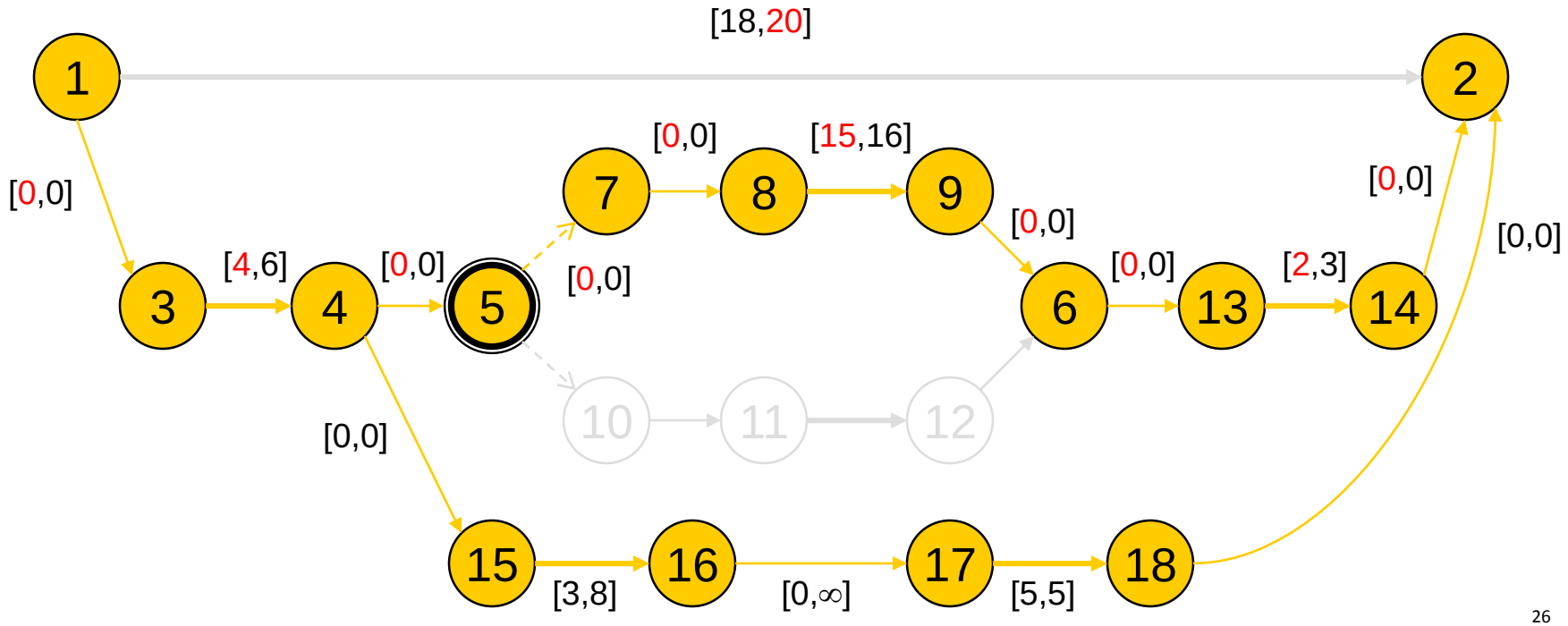
- Don’t test consistency at each step.

⇨ Only when a path induces a cycle,
check for negative cycle in the STN distance graph



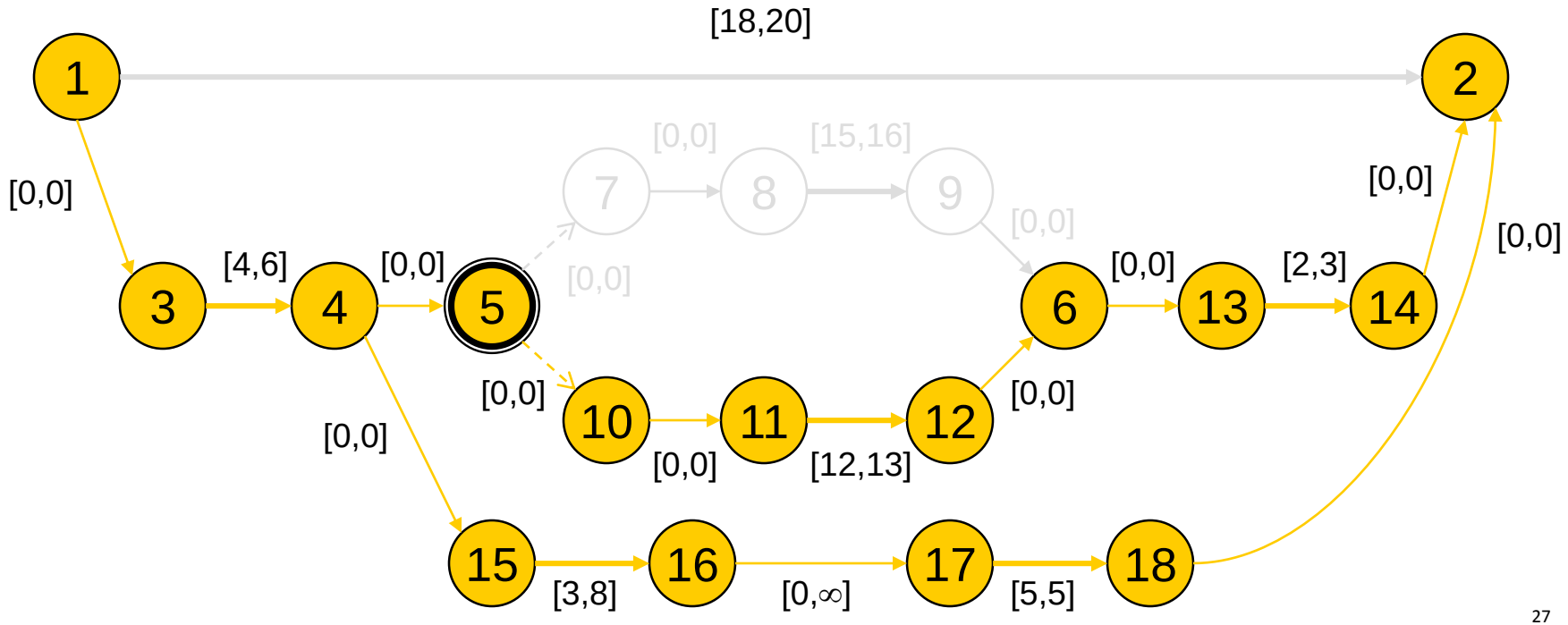
Check Schedulability

- Example: Inconsistent → Conflict!



Trace Alternative Trajectories

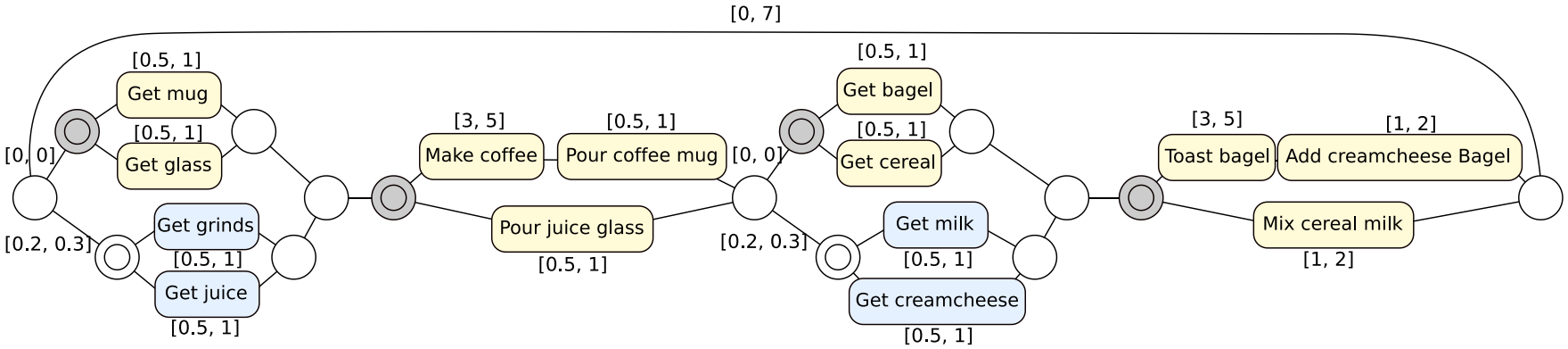
- Complete paths



Are all choices consistent?

- (Board)

Another example: Breakfast



How to get conflicts

- In problem set / polycell:
  - Conflicts came from DPLL + unit propagation
- Here:
  - Conflicts come from negative cycle detection (through ITC – Incremental Temporal Consistency)

ITC Problem

- Objective: Need to check the Simple Temporal Network (STN) for temporal consistency and return a conflict – under adding / removing / changing constraints

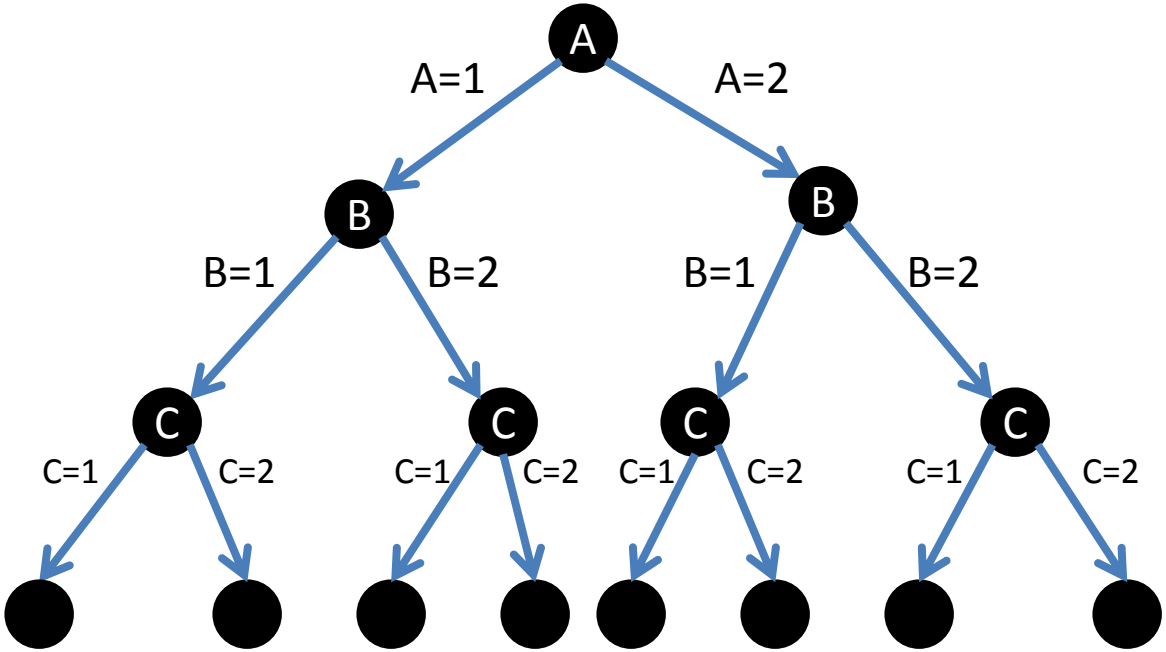
- Observation: The [partial] plan doesn't change that much between checks for temporal consistency.

- Approach: Incrementally check for temporal consistency by maintaining data between calls.

I-hsiang Shu, Robert Effinger, Brian Williams, Enabling Fast Flexible Planning through Incremental Temporal Reasoning with Conflict Extraction.

Choosing as a Constraint Satisfaction Problem

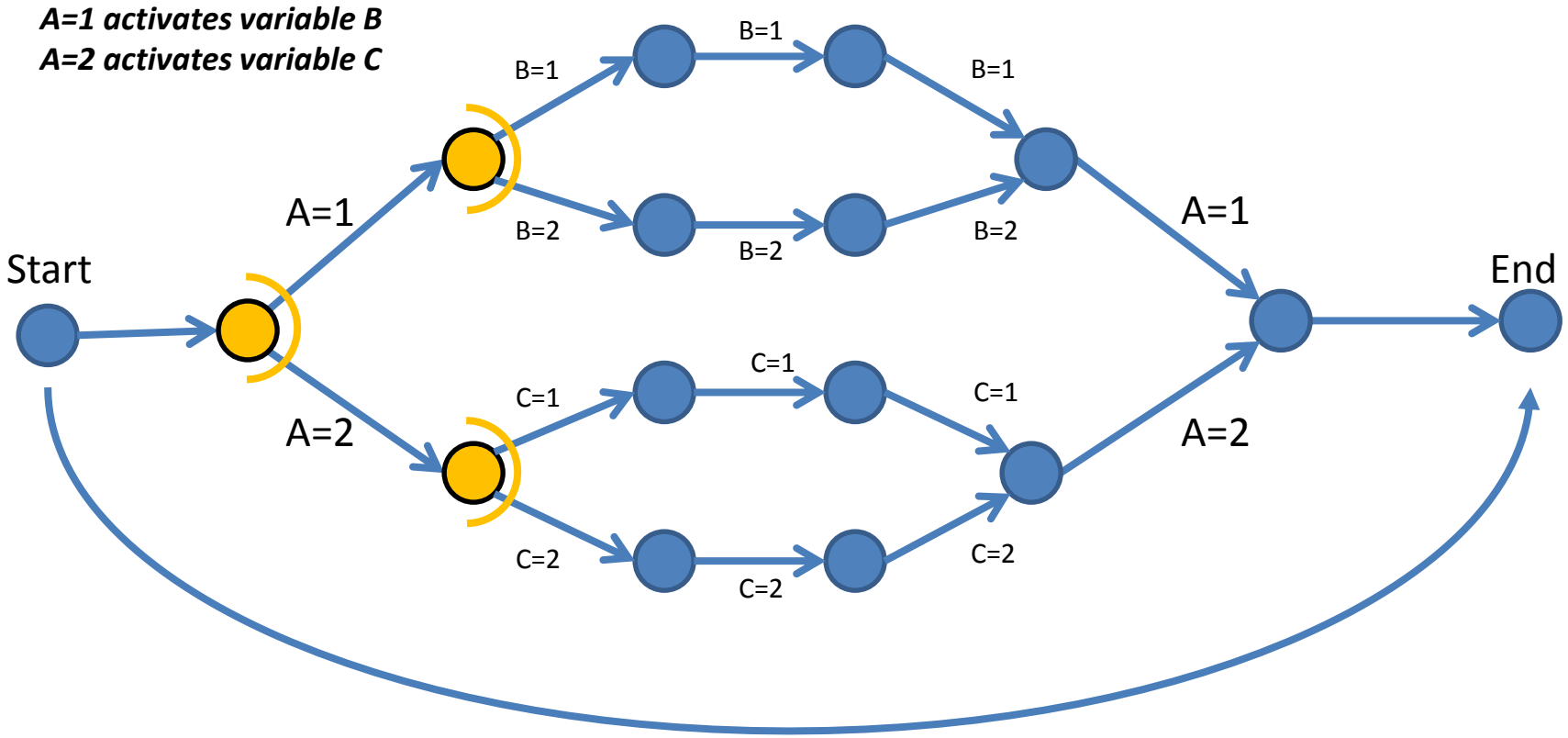
The Corresponding Search Tree:



Choosing as a

Conditional Constraint Satisfaction Problem

Assign ***active*** variables A, B, & C such that
all of the temporal constraints
with true guards are temporally consistent.



TPN Planning as conflict-directed search

- Decision variables: choices in TPN
- Utility: choice reward (not probability here)
- Consistency check: temporal consistency

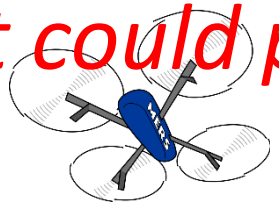
Monitoring plans with time

MONITORING TEMPORAL PLANS

Volcano eruption!

Base Station

What could possibly go wrong??



Launch Q

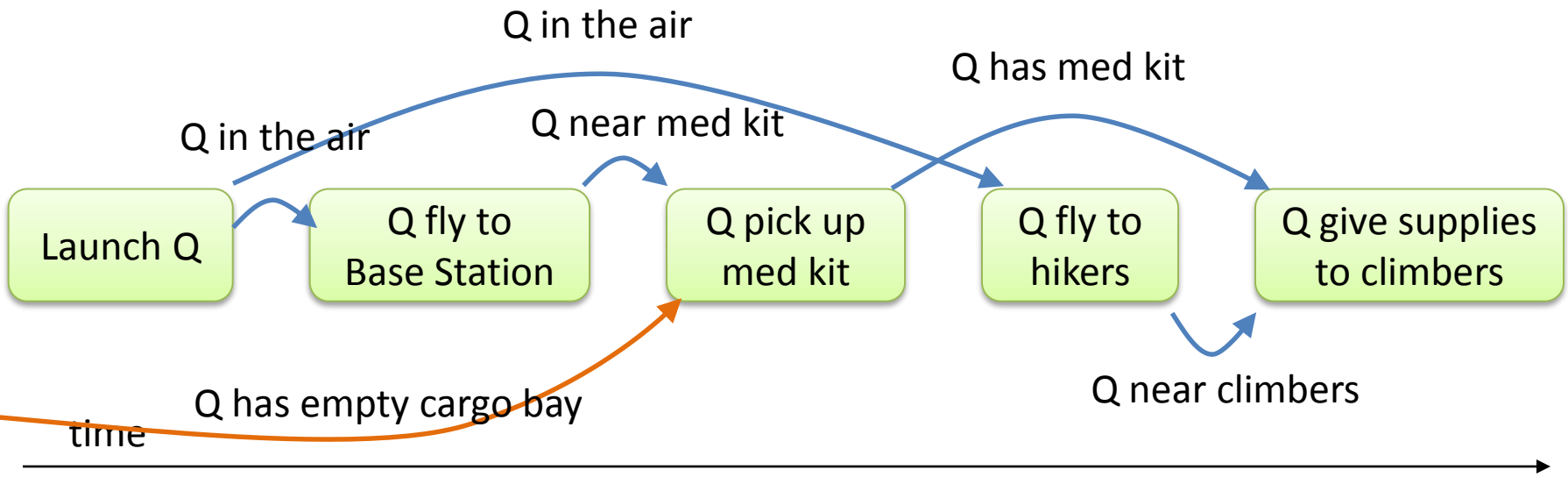
Q fly to Base Station

Q pick up med kit

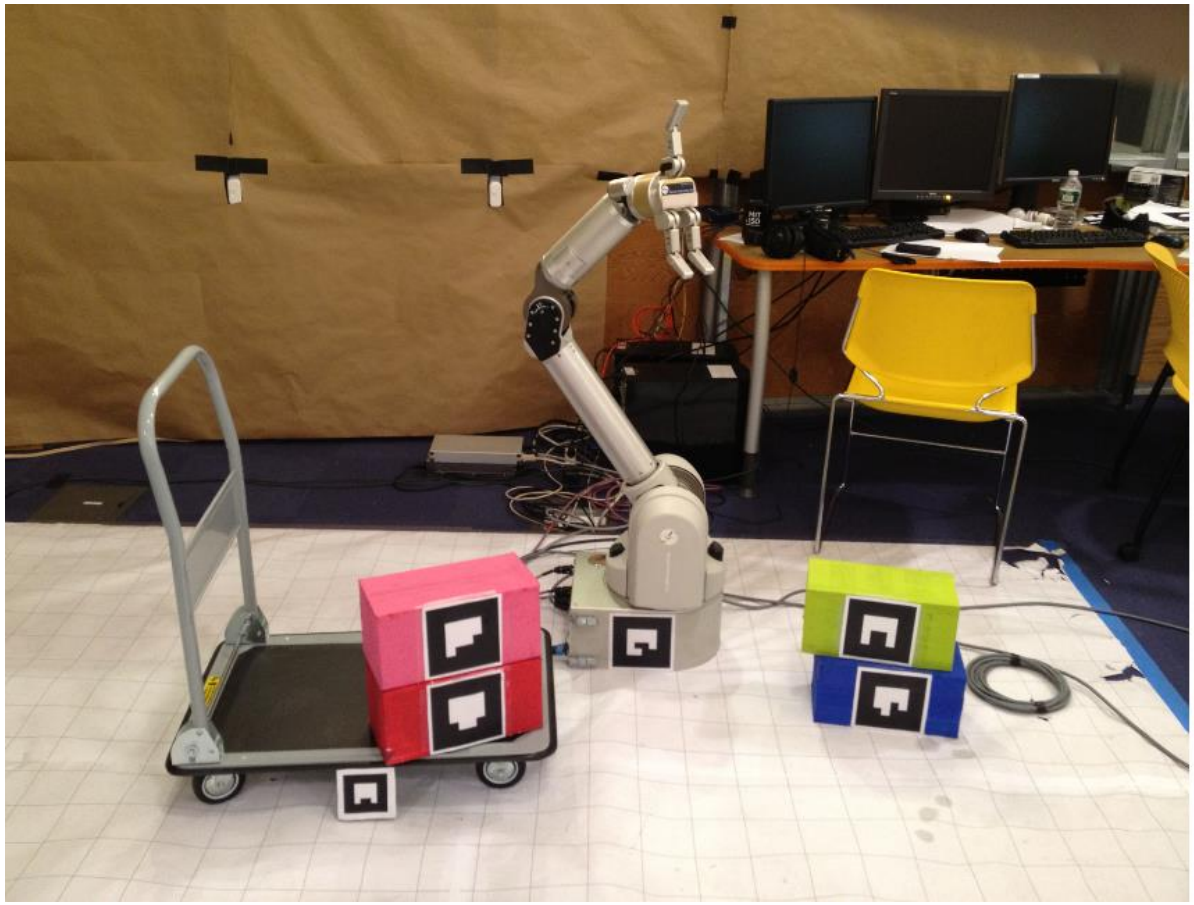
Q fly to hikers

Q give med kit to climbers

Where do preconditions come from?



Suppose we have a block-stacking cognitive robot



What sorts of actions might it do?

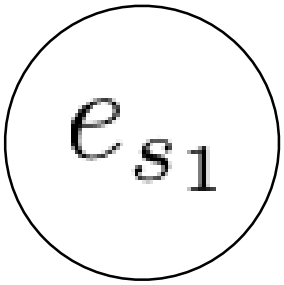
- Conditions? Effects?

Example PDDL temporal action

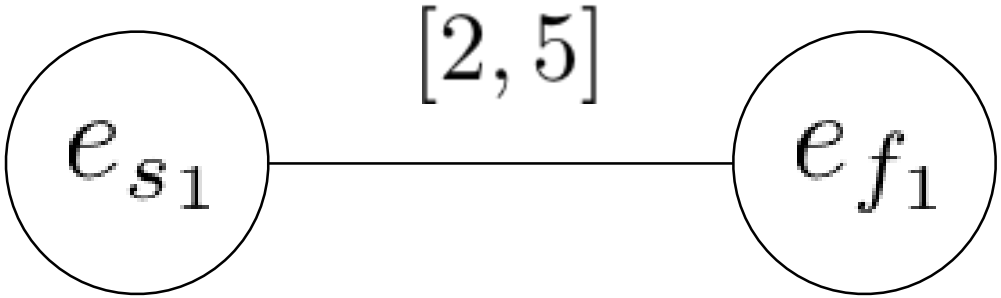
```
(:durative-action pick-up-block

   :parameters (?r - robot ?t ?b - block)

   :duration  (and (>= ?duration 10) (<= ?duration 30))

   :condition (and (at start (clear-above ?t))
                   (at start (empty-gripper ?r))
                   (over all (can-reach ?r ?t))
                   (at start (on ?t ?b)))

   :effect    (and (at end (not (empty-gripper ?r)))
                   (at end (not (on ?t ?b)))
                   (at end (holding ?r ?t))
                   (at end (clear-above ?b))
                   (at end (not (clear-above ?t))))
)
```

Temporal plan representation

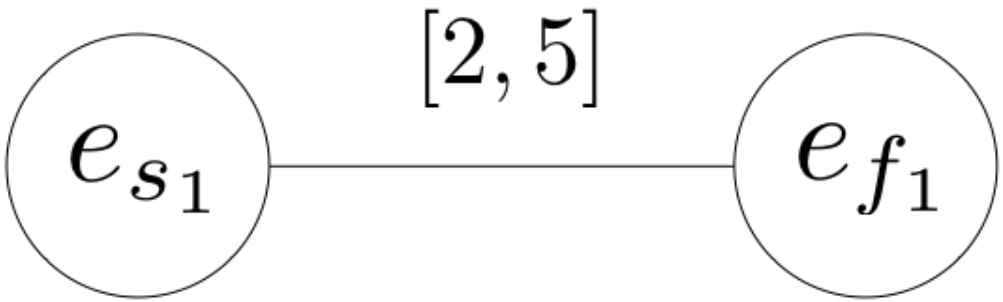
Events represent points in time



Events may be constrained with simple temporal constraints

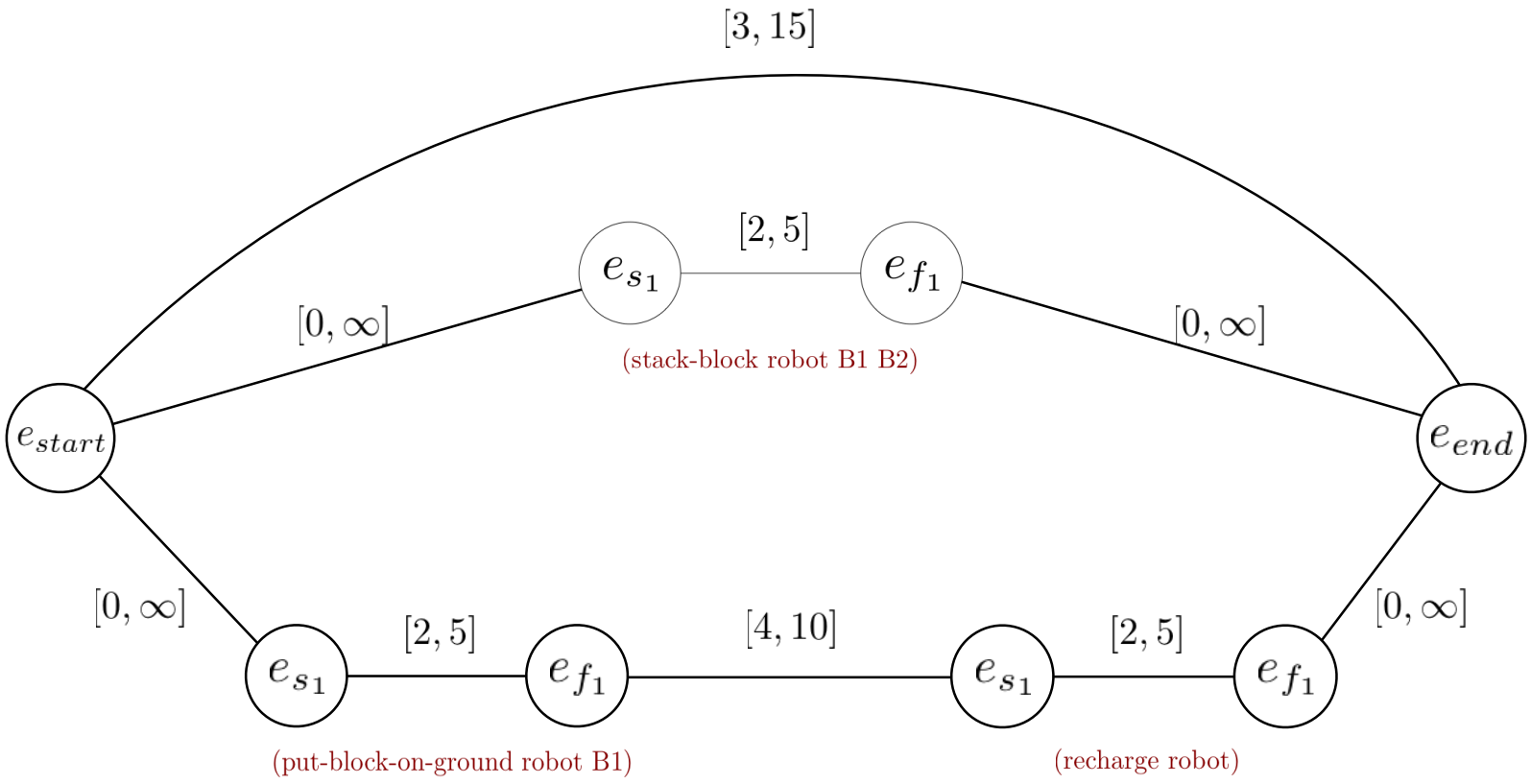


Actions consist of a start event, end event, and PDDL action

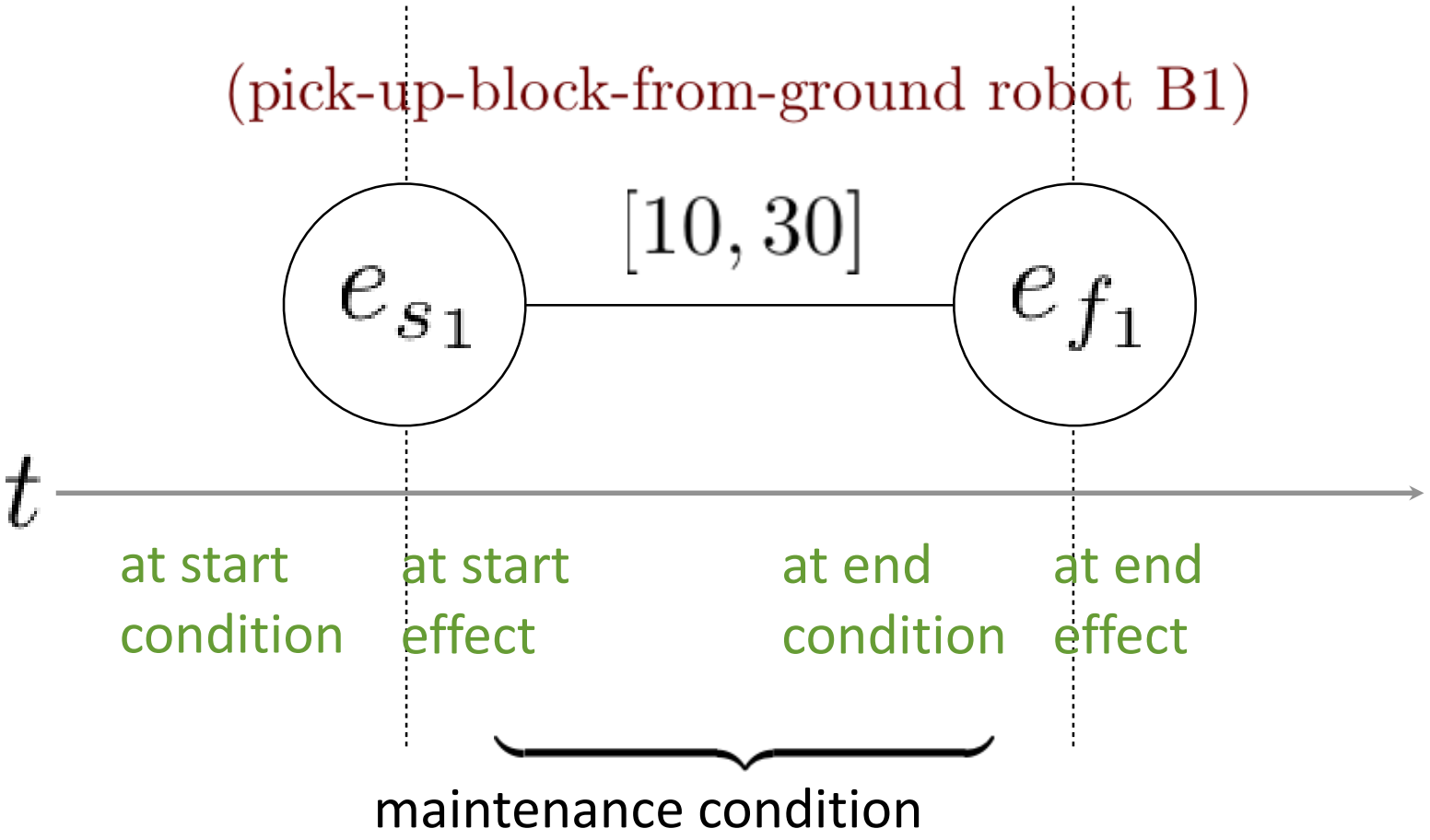


(stack-block robot B1 B2)

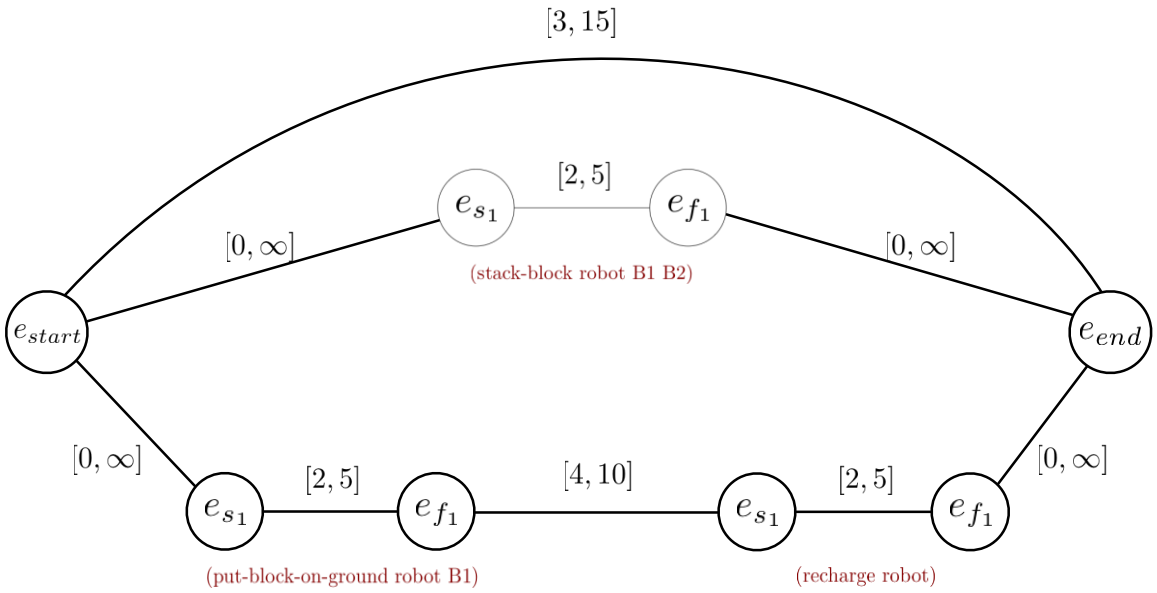
Temporal plans consist of actions



PDDL temporal actions have conditions & effects, at start & end



Conditions of actions: effects of prior actions, or come from initial conditions



Pike is a *plan executive:* it executes and monitors temporal plans.

- Events must be scheduled + dispatched to robot hardware
- Temporal disturbances handled
- Conditions for success must be monitored
- Signals a problem immediately if detected

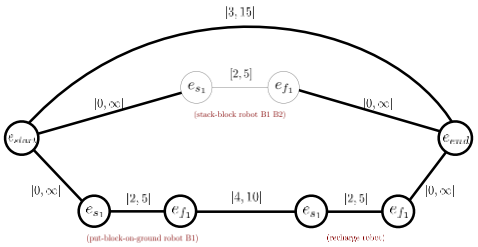
Pike problem statement

- **Input**:
  - Temporal plan
  - PDDL operators used in plan
  - Initial state, goal state
  - Stream of state estimates (observations)

- **Output**
  - Dispatch of plan activities at appropriate times
  - Signal if a failure is detected

Pike problem statement

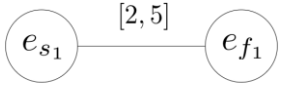
Initial state,
goal state




```
:durative-action pick-up-block
 :parameters  ?r                ?t ?b
 :duration
 :condition
            at start (clear-above ?t)
            at start (empty-gripper ?r)
            over all (can-reach ?r ?t)
            at start (on ?t ?b))
:effect     (and (at end  not (empty-gripper ?r))
            (at end  not (on ?t ?b))
            (at end  (holding ?r ?t)
            (at end  (clear-above ?b)
            (at end  not (clear-above ?t))))
```

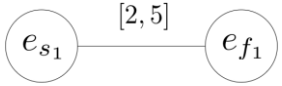
Pike

$t = 0$:



(stack-block robot B1 B2)

$t = 3$:



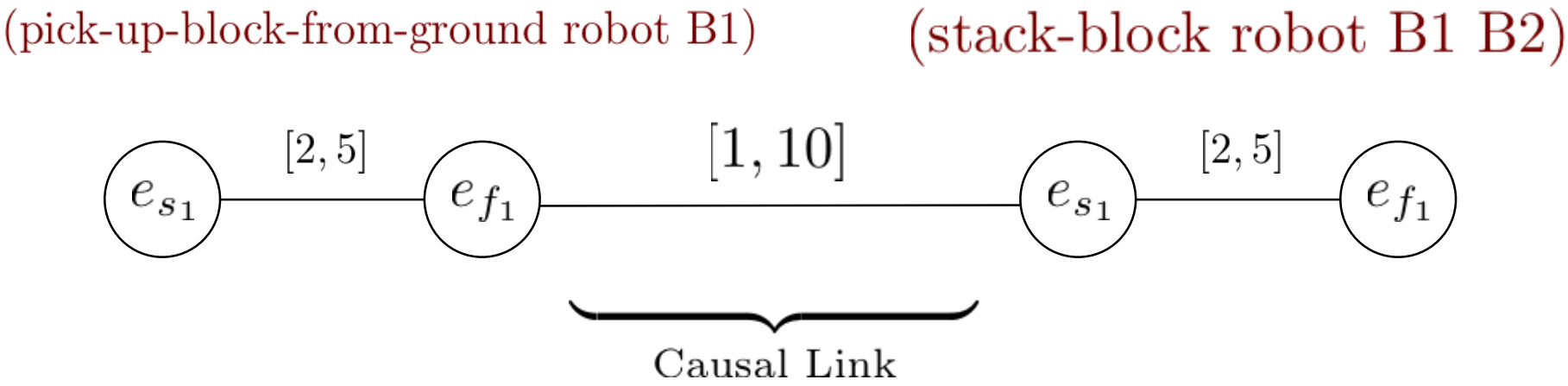
(stack-block robot B1 B2)

FAIL?

Planner-independence: infer relevant monitor conditions from the plan

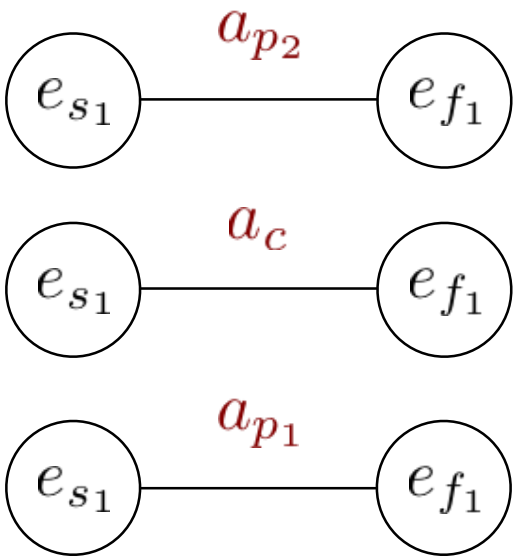
- Don't assume monitor conditions are provided by planner
- Approach: infer relevant monitor conditions form plan
  - –Reason over temporal constraints + conditions
  - –Extract *candidate* sets of causal links offline
  - –At runtime, monitor relevant causal links during appropriate time interval.

Example of a causal link in temporal plan



Causal links can be threatened.

- Suppose that a_{p_1} produces p, a_{p_2} produces $\neg p$, and a_c requires p as a condition.



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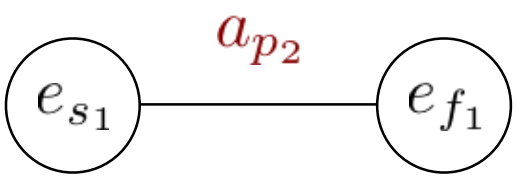
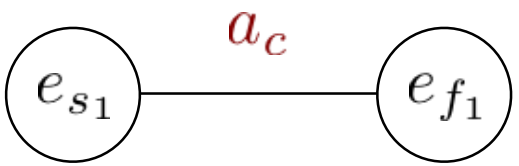
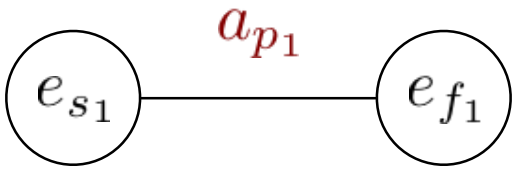


Is this OK??

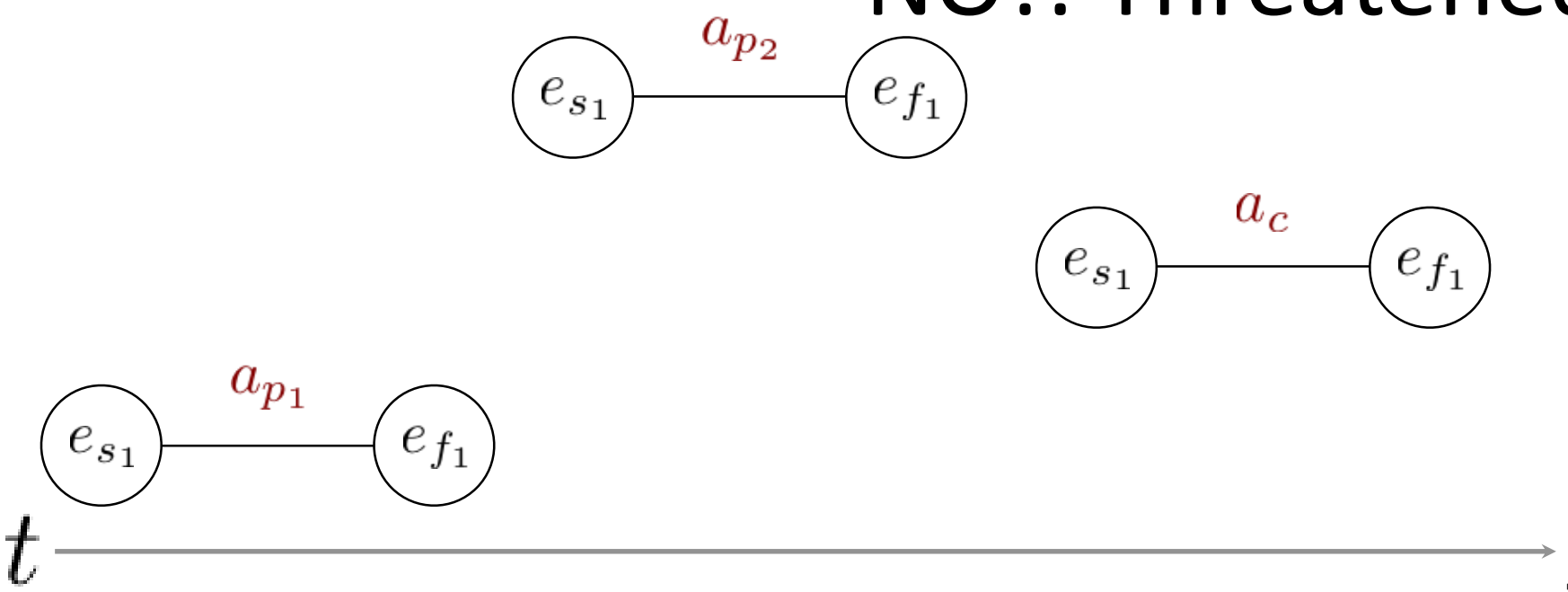




What about this?

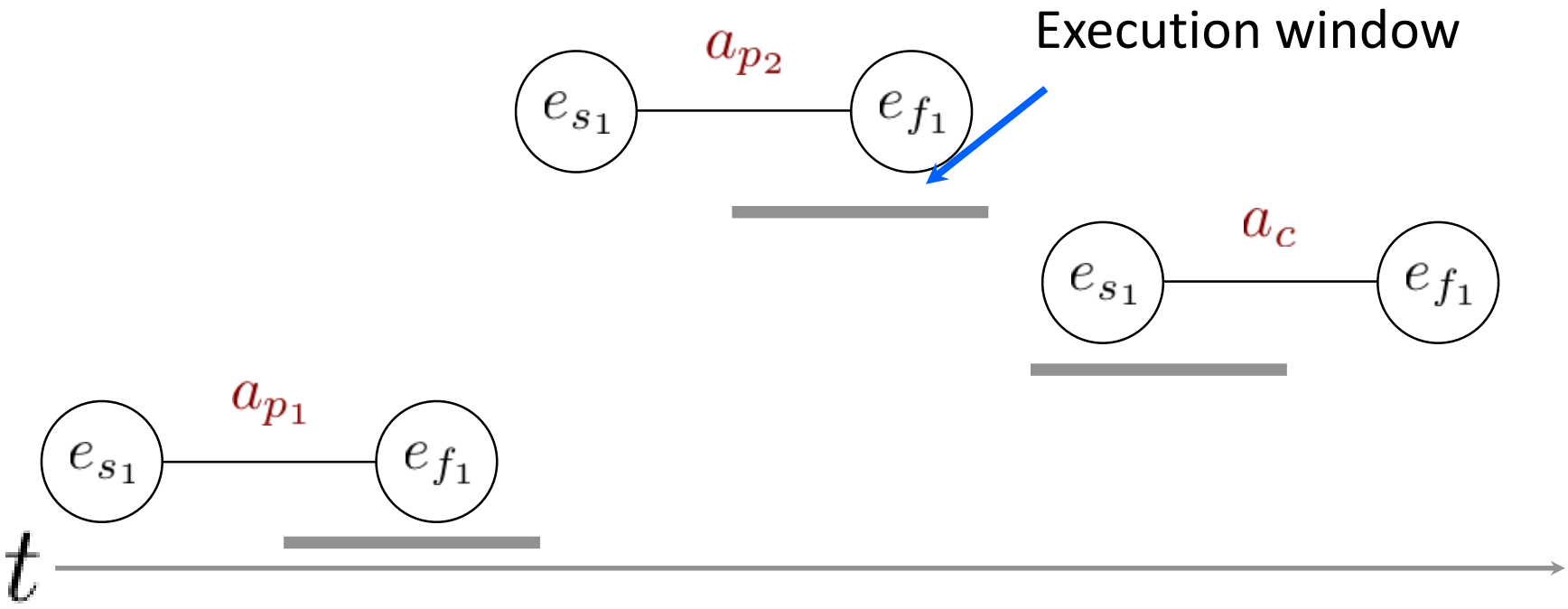
- Suppose that a_{p_1} produces p , a_{p_2} produces $\neg p$, and a_c requires p as a condition.

NO!! Threatened!



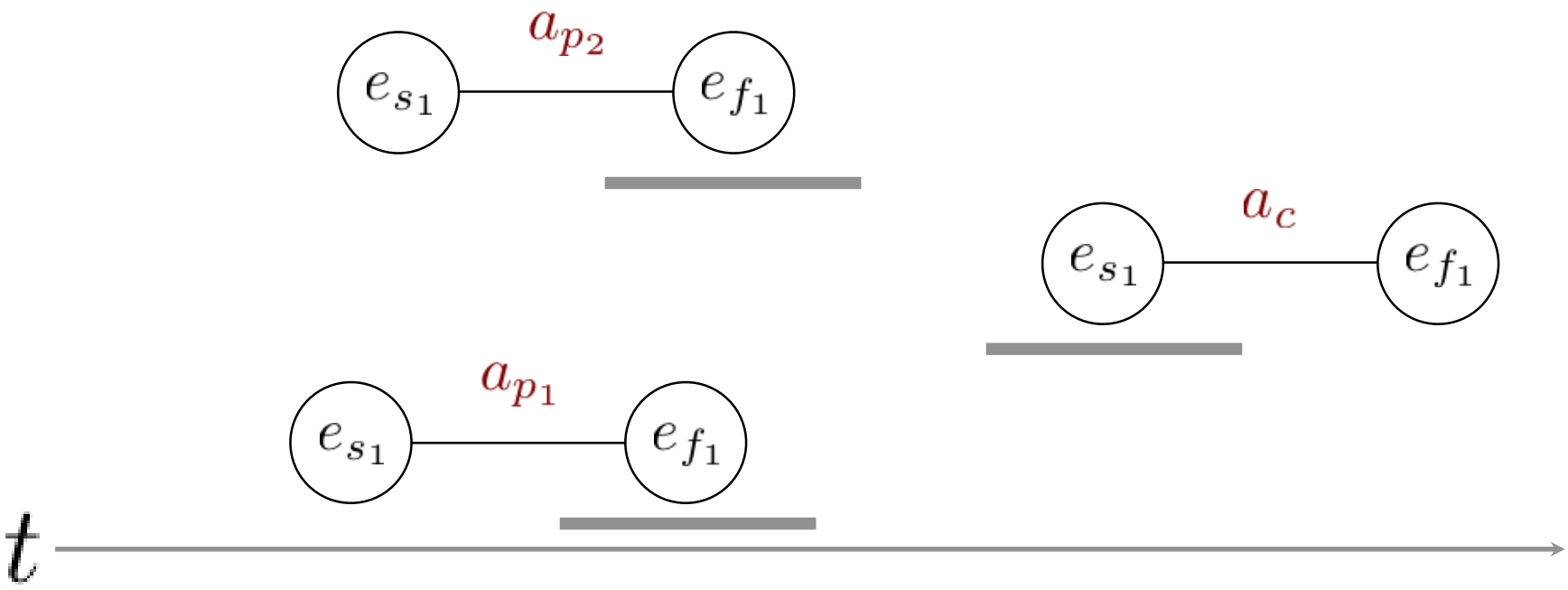
Causal links can dominate each other.

- Now, suppose that a_{p_1} and a_{p_2} both produce p, and that a_c requires p as a condition.



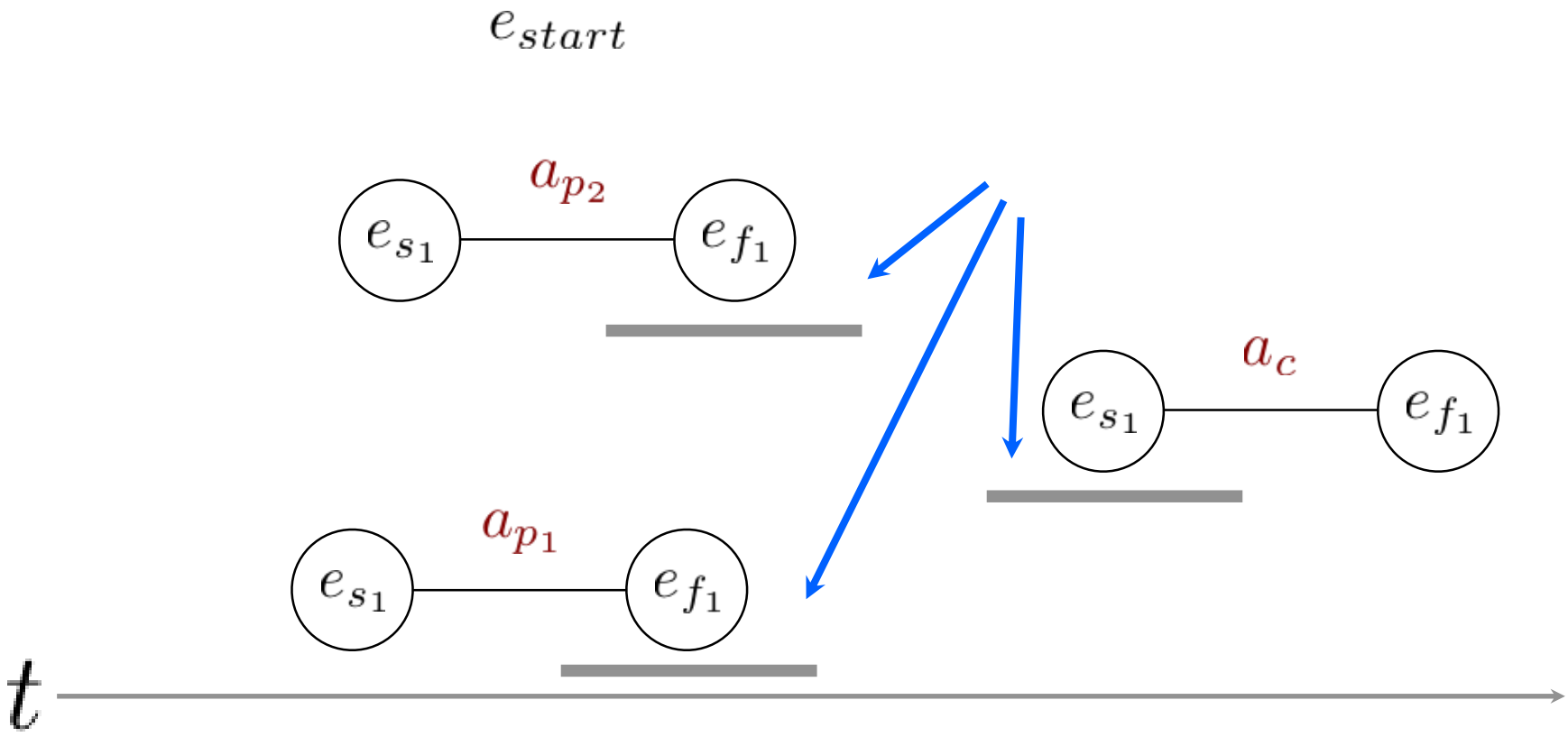
However, this domination cannot always be determined before execution.

- Now, suppose that a_{p_1} and a_{p_2} both produce p, and that a_c requires p as a condition.



But how can we determine these possible execution windows?

- We use an APSP, and examine values with respect to



Algorithmic approach for execution monitoring of temporally-flexible plans

- (Offline) Extract *candidate* sets of causal links for each consumer, consisting of sets of all mutually non-dominating possible causal links
- (Online) Monitor the order of event execution, and activate one causal link from each candidate set - the "latest" one
- (Online) Continuously check state estimates against all currently-activated causal links

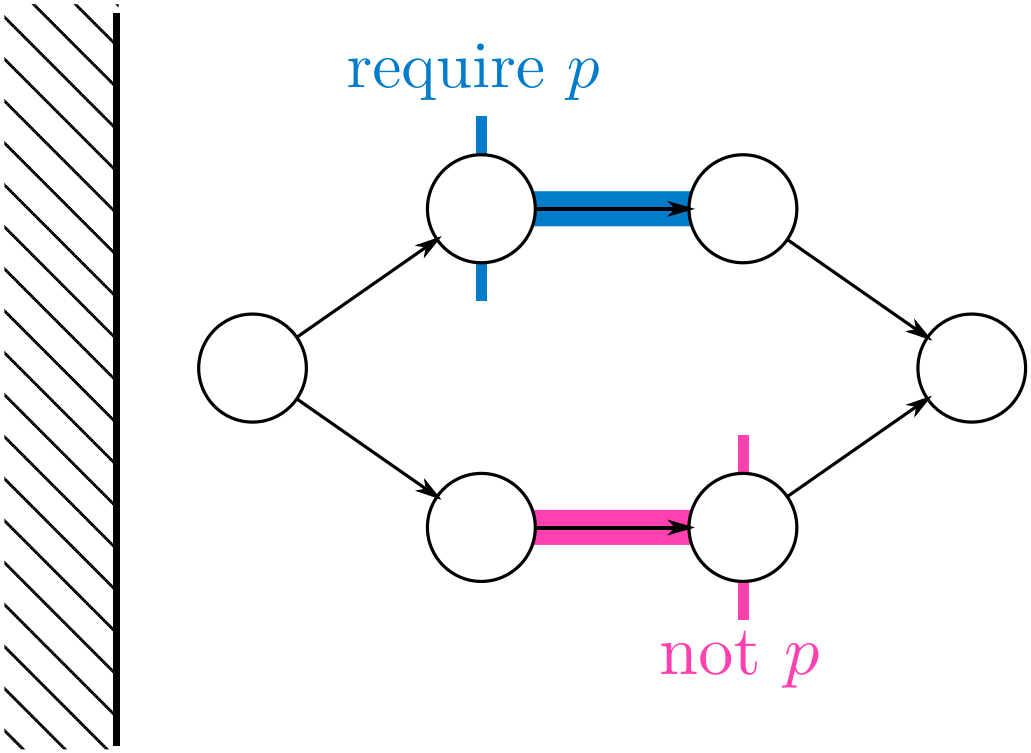
Causal link extraction rough pseudo code (certain details omitted)

- For each consuming event and precondition *p*:
  - Loop over all events and generate set of all mutually incomparable events affecting *p* that precede consuming event
  - If any events in this set produce ¬*p* then FAIL
  - Create a new monitor condition for each event in the set

Online causal link monitoring (rough pseudo code)

- While TRUE:
  - Receive current state estimates (from sensors)
  - Check if all activated monitor conditions contained current state, else SIGNAL FAIL
  - Upon dispatching an event, deactivate monitor conditions with event as consuming event. Activate monitor conditions for which no more possible candidates in set remain.

More food for thought…



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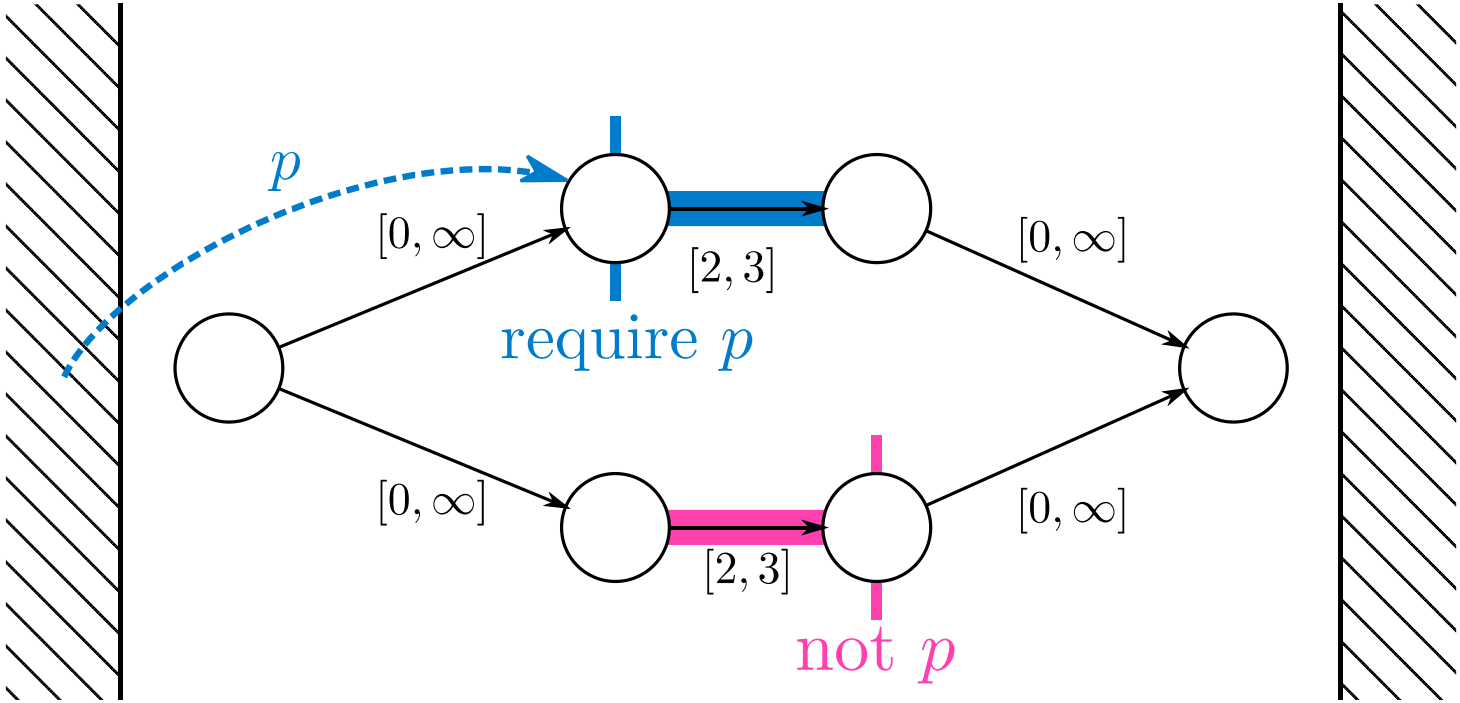

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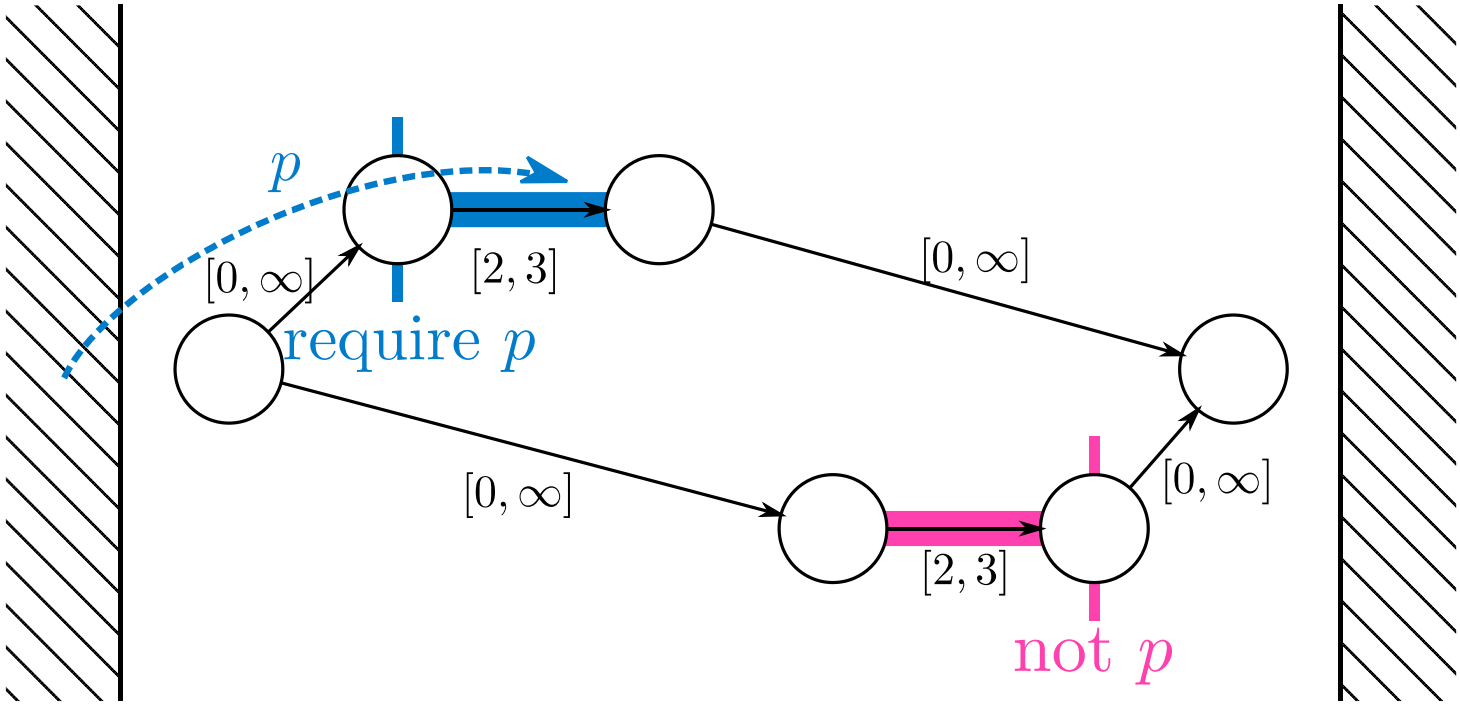

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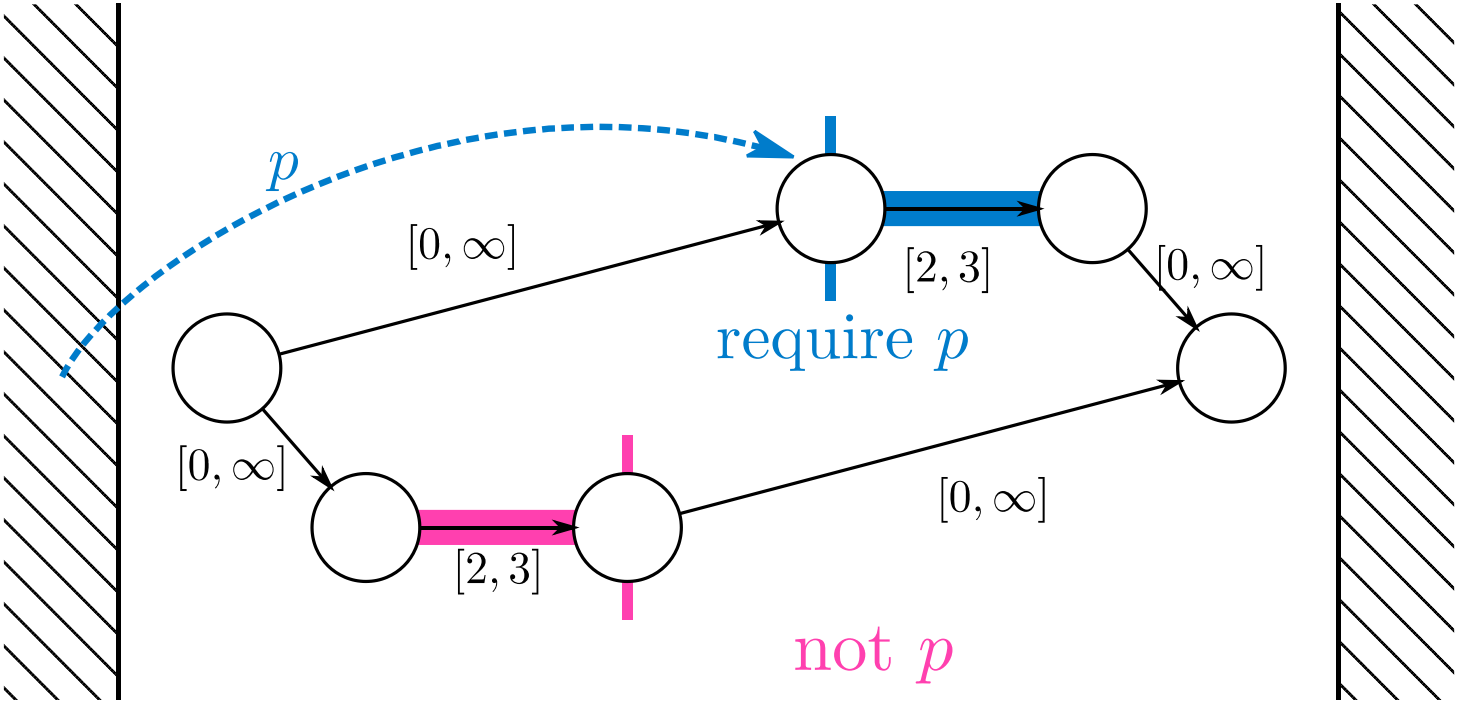

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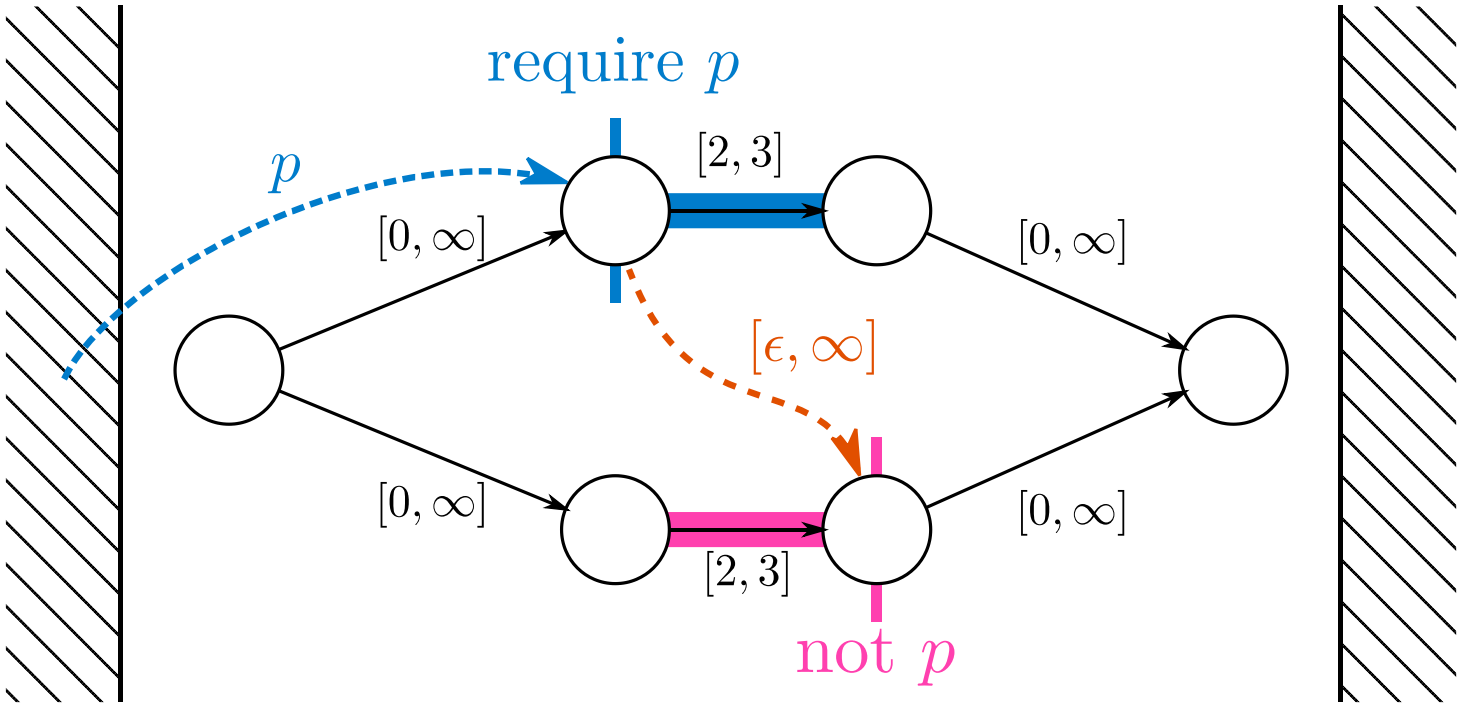

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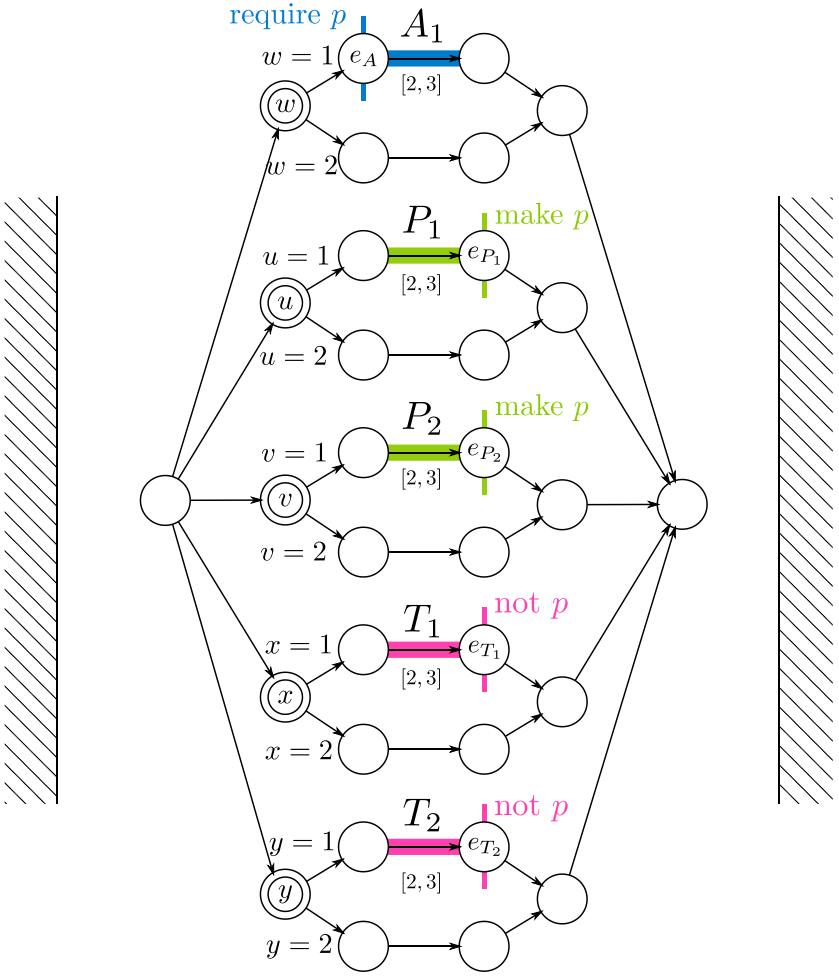

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