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DIPARTIMENTO DI INFORMATICA

Temporal Multiagent Plan Execution: Explaining what Happened

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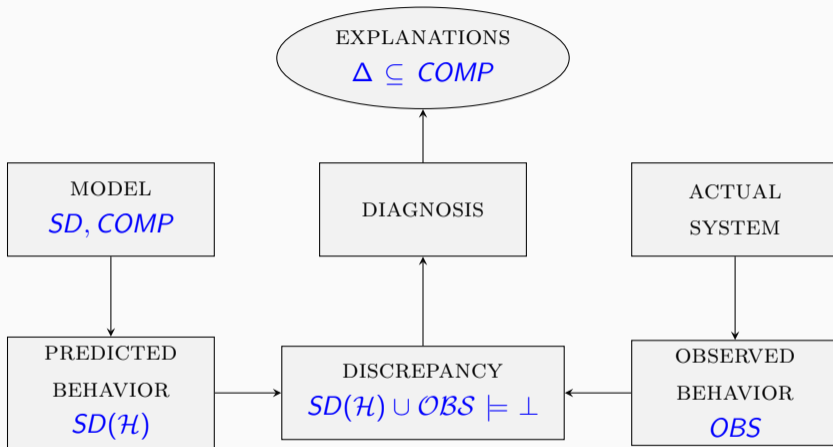
- Many real-world problems can be thought of as **distributed systems** with parallel threads of executions **where activities are planned in advance**
 - Business processes
 - Service robots
 - Guidelines
- However, **the actual execution of activities can deviate** from the normal expected one
- **Understanding what went wrong and why is fundamental to attempt recovery**, but:
 - partial observability
 - concurrency
 - non-determinism
 - fault propagation (primary faults causing secondary ones)makes this understanding a challenging task

- Adopt **Model-Based Diagnosis** to explain faults such as:
 - unexpected duration of actions (lasting longer than normally required) [**temporal dimension**]
 - unexpected (missing) effects [**propositional dimension**]

Contributions

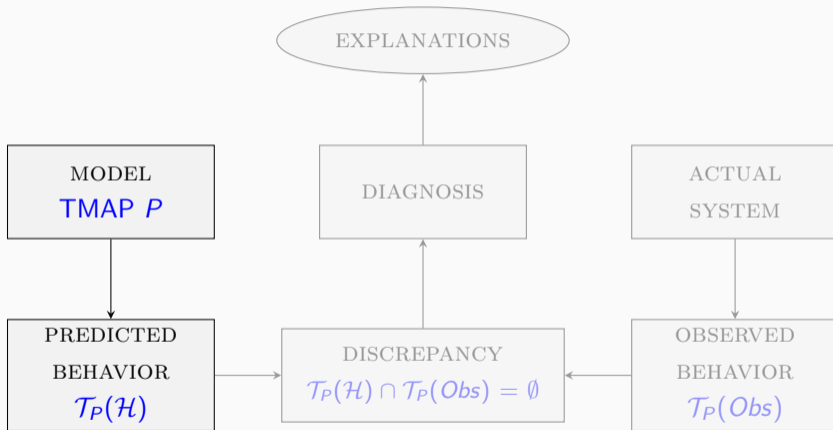
- Modeling the system such as a **Multiagent Plan** capturing *normal* and *abnormal* models (considering both temporal and propositional aspects)
- Mapping **Plan Execution Failure (PEF)** problem into a *Consistency-Based Diagnosis* problem
- Complementing the inferred diagnosis with **temporal explanations**
- Encoding the above model into an SMT program for solution

Consistency-based Diagnosis



$$SD \cup OBS \cup \{ab(c) \mid c \in \Delta\} \cup \{\neg ab(c) \mid c \in COMP \setminus \Delta\} \not\models \perp$$

Temporal Multiagent Plans: Modeling for Diagnosis



- A TMAP P is a tuple $\langle T, A, O, CL, M \rangle$

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T is the team of agents ag1:

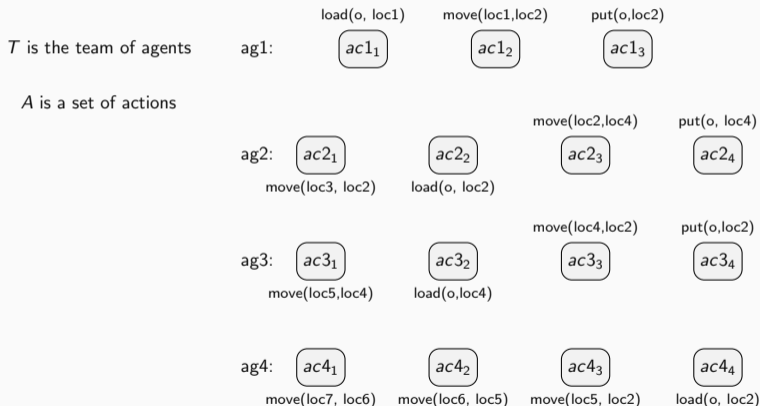
ag2:

ag3:

ag4:

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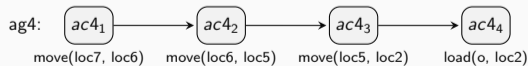
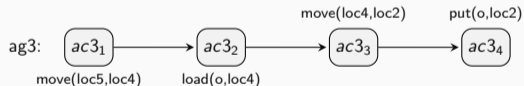
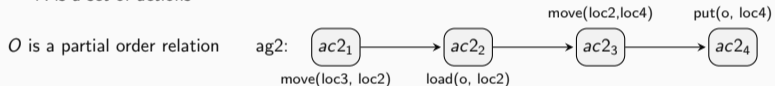


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A is a set of actions



Temporal Multiagent Plans: Modeling for Diagnosis

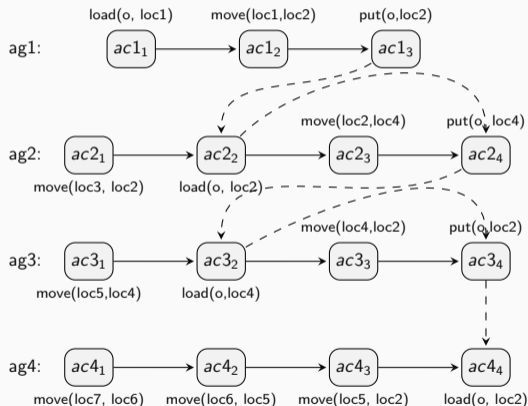
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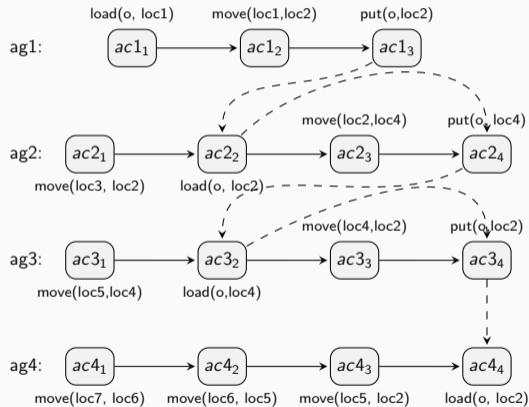
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M is an assignment of modes to each action



Action Modes

act	pre	mode	post	range	rank
move(ag,p1,p2)	at(ag,p1)	N	at(ag,p2)	[1,3)	0
		F1	at(ag,p2)	[3,10)	1
		F2	at(ag,p2)	[10,25]	2
		F3	\emptyset	[10,25]	3
load(ag,p,o)	at(ag,p), at(o,p), holds(ag, \emptyset)	N	\neg at(o,p), holds(ag,o)	[1,2)	0
		F1	\neg at(o,p), holds(ag,o)	[2,10)	1
		F2	\emptyset	[10,25]	2
put(ag,p,o)	at(ag,p), holds(ag,o)	N	at(o,p), \neg holds(ag,o)	[1,2)	0
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load(ag,p,o)	at(ag,p), at(o,p), holds(ag,o)	N	\neg at(o,p), holds(ag,o)	[1,2)	0
		Nominal Mode	\neg at(o,p), holds(ag,o)	[2,10)	1
		F2	\emptyset	[10,25]	2
put(ag,p,o)	at(ag,p), holds(ag,o)	N	at(o,p), \neg holds(ag,o)	[1,2)	0
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		F1	Effects and duration under nominal mode	[2,10]	1
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Rank:

- non-negative integer value representing the order-of-magnitude probability of the mode
- lower ranks correspond to higher probabilities

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Faulty modes with possibly missing effects and increasing duration.
The higher the rank the least probable the fault.

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put(ag,p,o)	at(ag,p), holds(ag,o)	F1	\neg holds(ag,o) at(o,p), \neg holds(ag,o)	[2,10)	1
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A special mode *SKIPPED* is used to denote that the action preconditions do not hold and the action is therefore skipped. Under *SKIPPED* mode:

- no effects are produced by the action
- duration is 0
- rank is 0 because this is a **secondary fault**

- Given a TMAP P , a **hypothesis \mathcal{H} over P** is an assignment of modes to each action in P
- Given a TMAP P , and a hypothesis \mathcal{H} over P a **temporal profile θ** is an ordered sequence of pairs

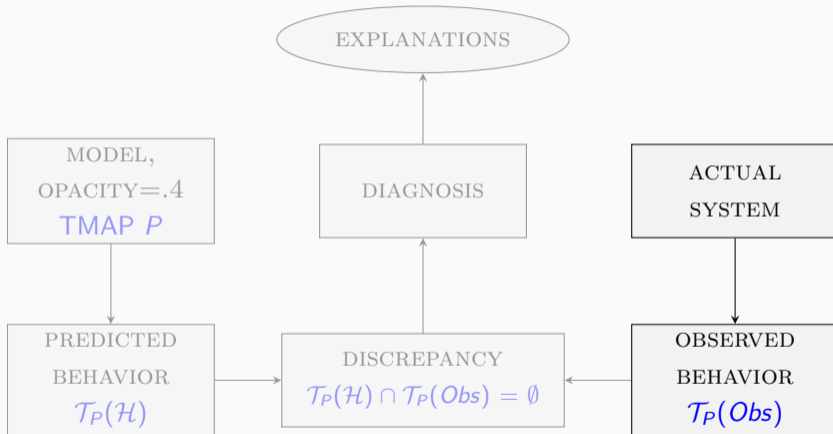
$$\langle s_0, t_0 \rangle, \dots, \langle s_n, t_n \rangle$$

s_i ($i : 0..n$) is a state of the whole system consisting of all the atoms holding at time t_i .

Space of Temporal Profiles $\mathcal{T}_P(\mathcal{H})$

Given a TMAP P and a hypothesis \mathcal{H} many temporal profiles are possible, $\mathcal{T}_P(\mathcal{H})$ denotes the space of all temporal profiles consistent with \mathcal{H}

Observations



- **Timed Observations:**

$Obs = \{\langle e, t \rangle\}$ where:

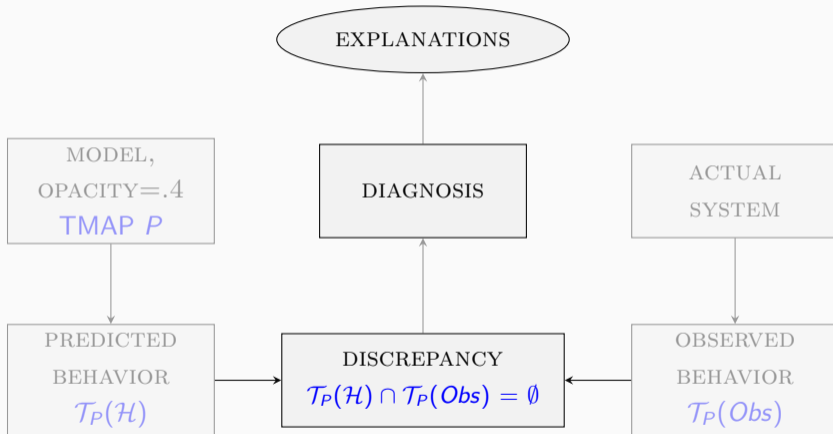
- e is the observed event, it is a propositional literal such as $at(ag_1, p_1)$ or $\neg at(ag_1, p_1)$
- t timestamp

- **Partial observability:**

observations are not available at each time instant, and are about just some events (not all events occurring at a given time t are observed and reported)

- Given a TMAP P and a set of observations Obs , $\mathcal{T}_P(Obs)$ is the **space of all temporal profiles that are consistent with Obs**

Plan Execution Failure (PEF) Problem



Plan Execution Failure (PEF) Problem

- A solution to a PEF problem is a new hypothesis \mathcal{H}' such that

$$\mathcal{T}_P(\mathcal{H}') \cap \mathcal{T}_P(Obs) \neq \emptyset$$

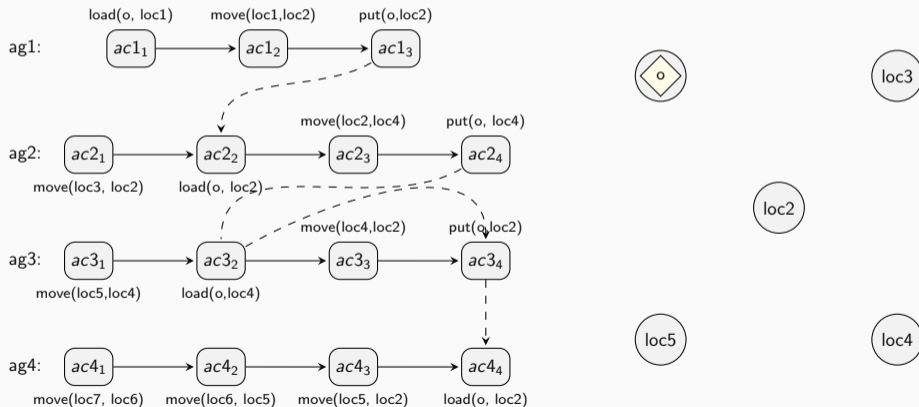
- Among all the possible solutions we look for the minimal rank ones:

$$rank(\mathcal{H}') = \sum_{ac \in A} \mathcal{H}'(ac).rank$$

Intuitively, these are the preferred ones since assume the least anomalous conditions to explain the observations

Temporal Explanations

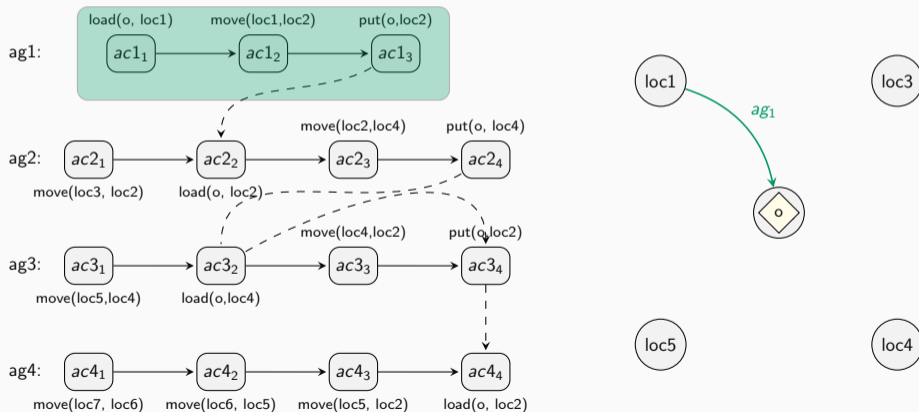
- A labeling of modes to actions may not be sufficiently informative due to the non-determinism of action duration
- Temporal explanations enrich diagnoses with a set of possible scenarios of execution



Temporal Explanations

- For example, let us consider diagnosis $\delta: \{mode(ac2_1)=F1\}$
- two very different scenarios are possible

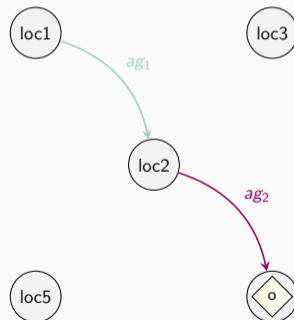
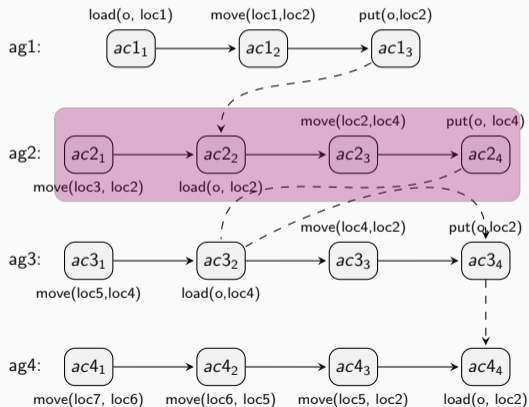
First: although delayed, *ag2* reaches the object correctly



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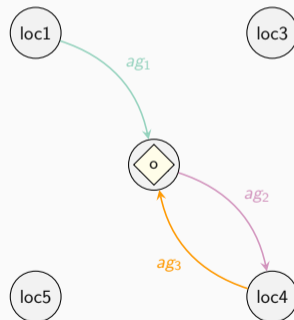
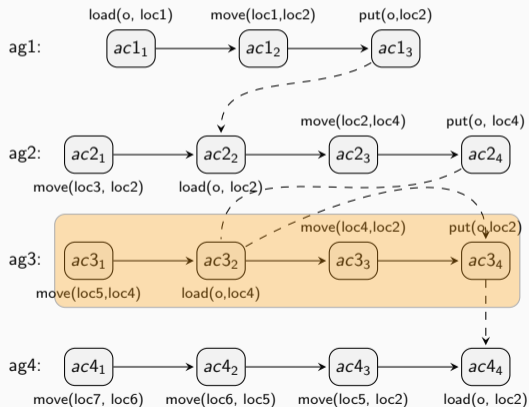
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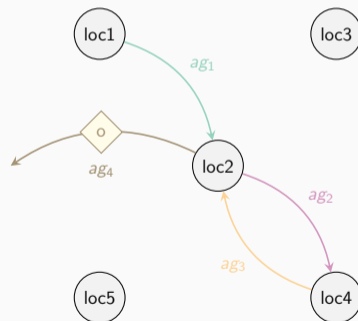
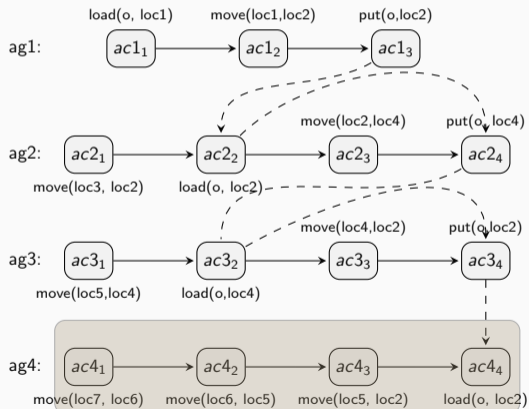
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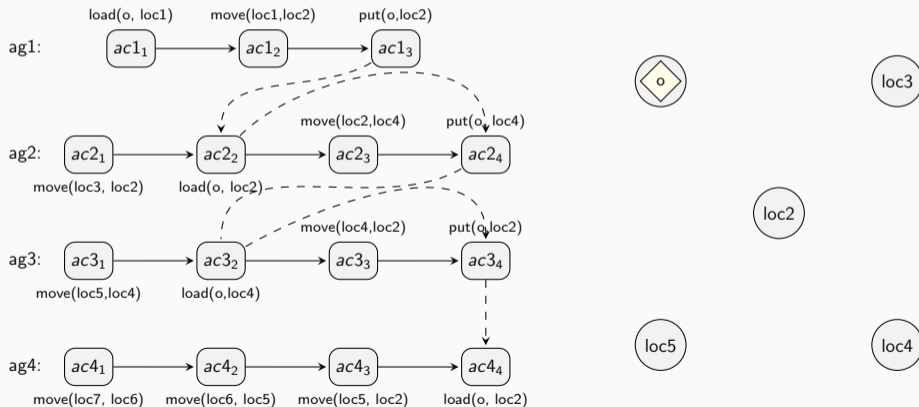
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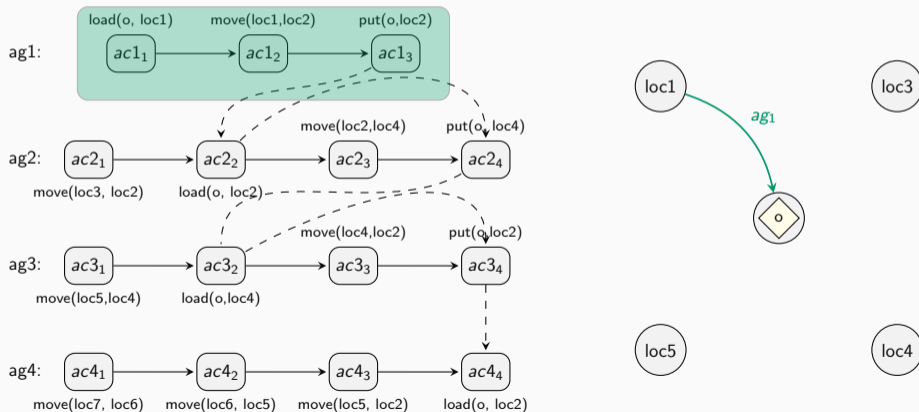
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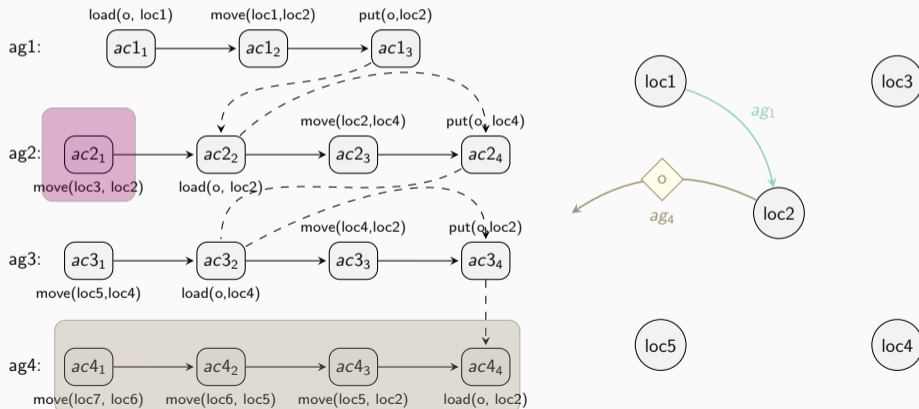
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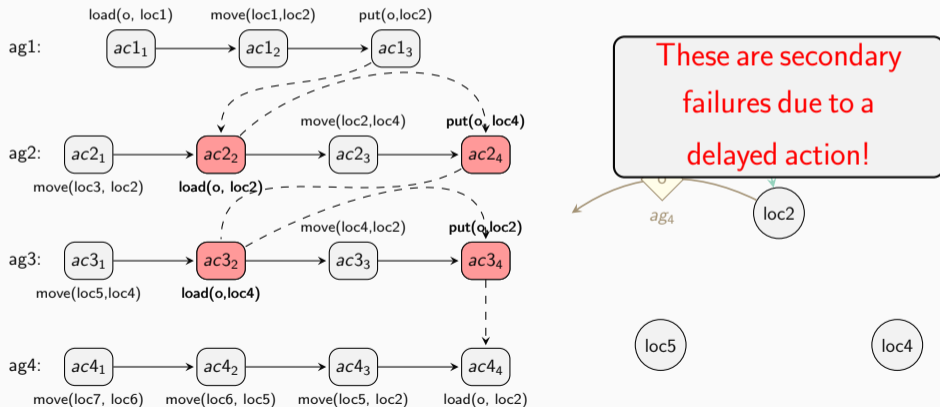
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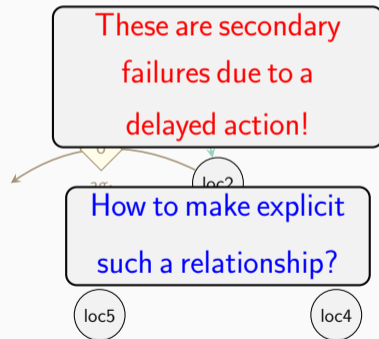
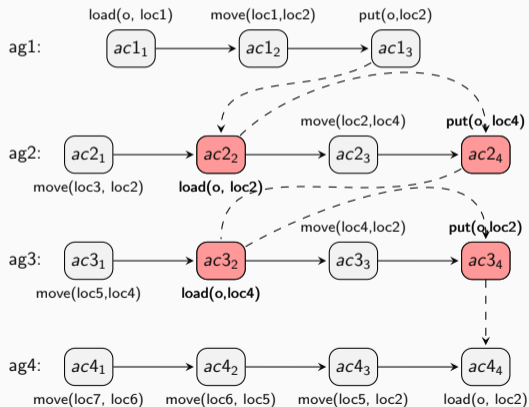
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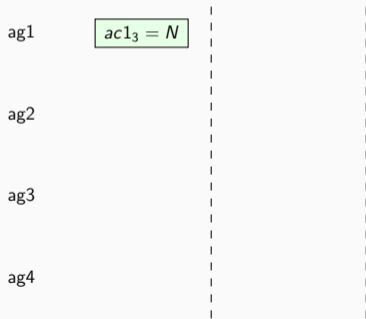
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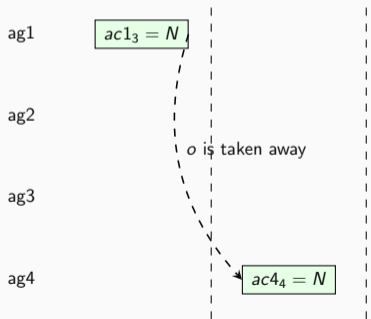
Temporal Explanations: Example

- Situation: $\delta = \{mode(ac2_1) = F1\}$ and $mode(ac2_2) = SKIPPED$
- Why was $ac2_2$ skipped?
 - It required the shared literal $at(o, loc2)$
 - Look for **Allen algebra relations between start/end events of actions manipulating that literal**



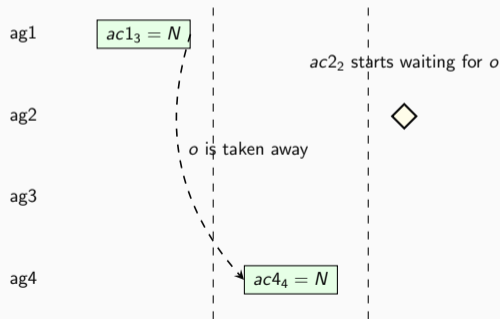
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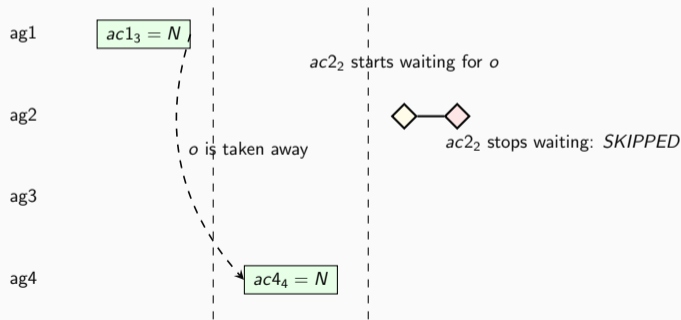
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Solving a PEF problem

- An SMT solver (i.e., Z3) is used to solve a PEF problem by taking into account both the propositional effects of actions and their non-deterministic duration
- The TMAP model is therefore encoded as a proper set of constraints for the Z3 solver
- The solver is used to check the consistency of an hypothesis (a labeling of modes to actions) w.r.t. observations
- **Conflict-based Best First Search** (CBFS) algorithm explores the space of possible solutions so as to guarantee the rank minimality, and checking the consistency of an hypothesis by invoking Z3 solver

	CBFS			
	time	#sol	time/sol	#expl
ag 2 ac 8 (R2)	0.48	2.0	0.24	2.0
ag 4 ac 10 (R2)	1.32	2.5	0.53	3.0
ac 20 (R2)	6.83	4.0	1.71	6.1
ac 20 (R4)	25.53	15.6	1.64	23.2

Table 1: avg time (sec), sols, time/sol, and explanations of experiments.

- Diagnosing TMAPs can be mapped into Consistency-based diagnosis:
 - a proof of concept based on a SMT solver demonstrate the feasibility of the approach
 - however, the non-determinism in action duration creates alternative consistent scenarios with different secondary failures
- Temporal explanations represent a first attempt to cope with this problem:
 - so far, temporal explanations relate a single secondary failure to a subset of relevant events
 - How to build a consistent temporal explanation for the all the secondary failures?
 - How to establish preference criteria among alternative explanations?

Questions?