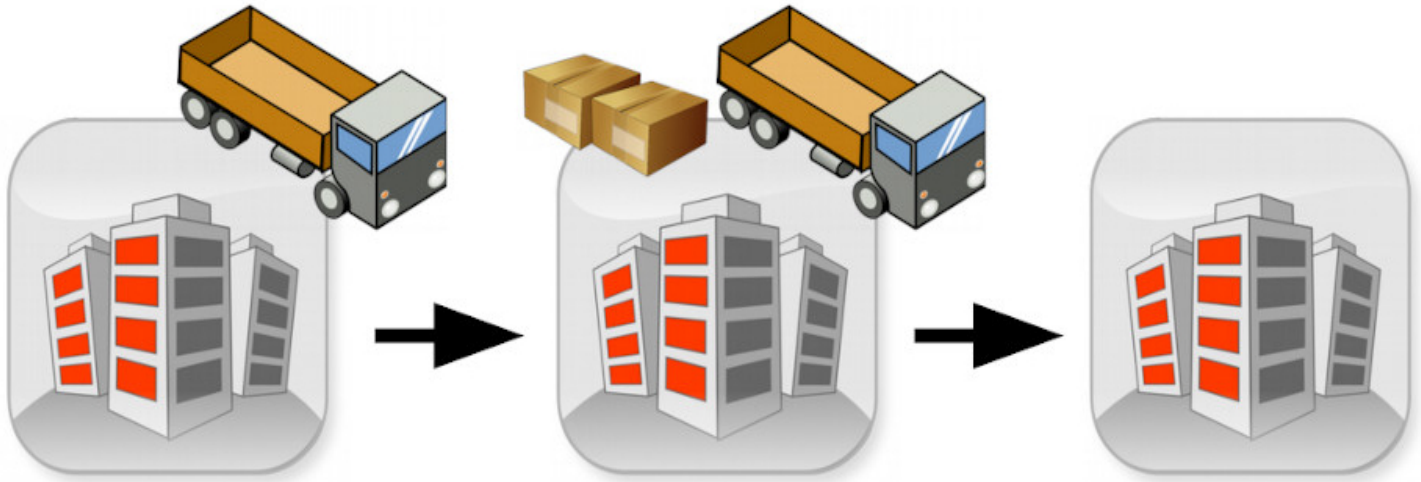
Karlsruhe Institute of Technology

PASAR - Planning as Satisfiability with Abstraction Refinement

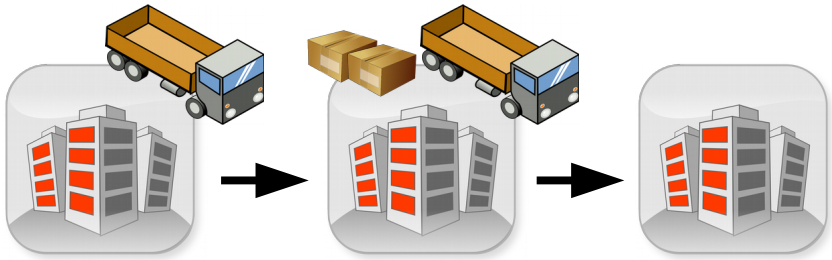
12th Annual Symposium on Combinatorial Search

Nils Froleyks (Speaker), Tomáš Balyo, Dominik Schreiber | July 17, 2019

INSTITUT FÜR THEORETISCHE INFORMATIK

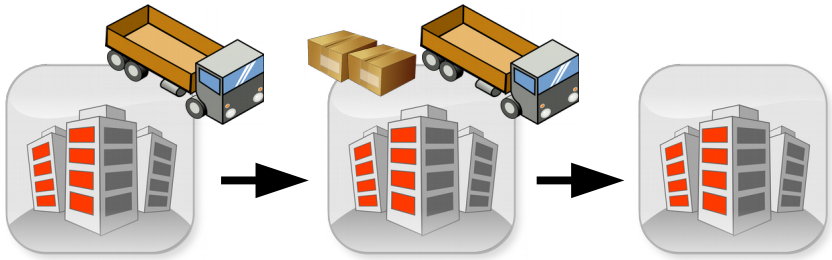


Planning as Satisfiability with Abstraction Refinement



Find a valid sequence of actions from some initial world state to a desired goal state.

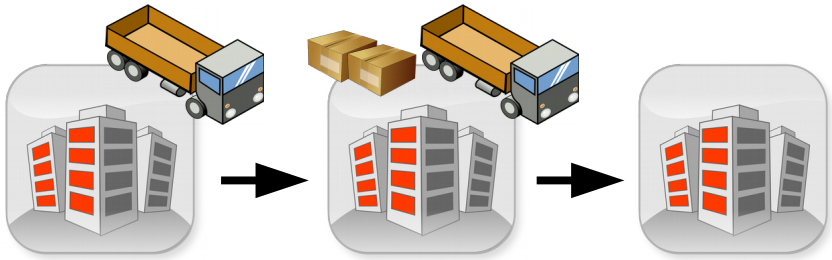
Planning as Satisfiability with Abstraction Refinement



Find a valid sequence of actions from some initial world state to a desired goal state.

- (World) State: Consistent set of boolean atoms:
  $\texttt{at}(T_1, A)$, $\texttt{at}(T_2, B)$, $\texttt{at}(P_1, B)$, $\texttt{at}(P_2, B)$,
  $\texttt{empty}(T_1)$, $\texttt{empty}(T_2)$, $\texttt{road}(A, B)$, $\texttt{road}(B, C)$

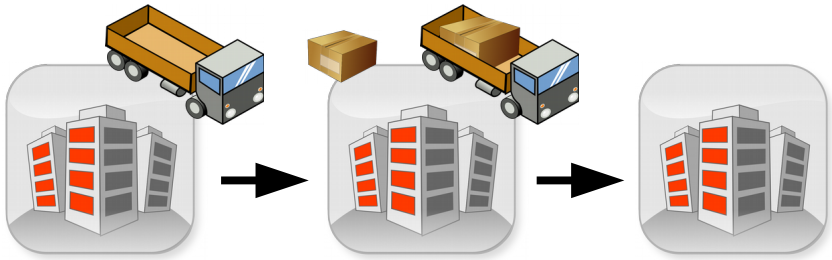
Planning as Satisfiability with Abstraction Refinement



Find a valid sequence of actions from some initial world state to a desired goal state.

- $\texttt{pickup}(T_2, P_1, B)$
  requires $\texttt{empty}(T_2), \texttt{at}(T_2, B), \texttt{at}(P_1, B)$
  deletes $\texttt{at}(P_1, B), \texttt{empty}(T_2)$ adds $\texttt{in}(P_1, T_2)$

Planning as Satisfiability with Abstraction Refinement



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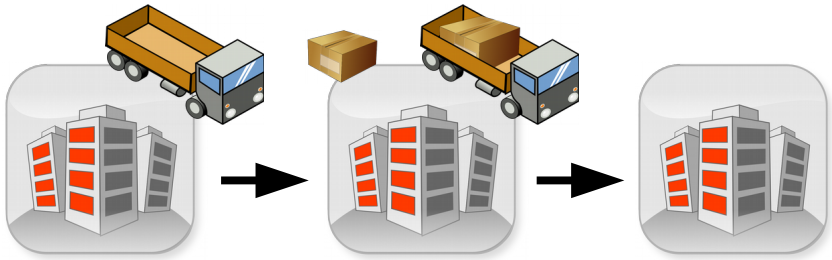
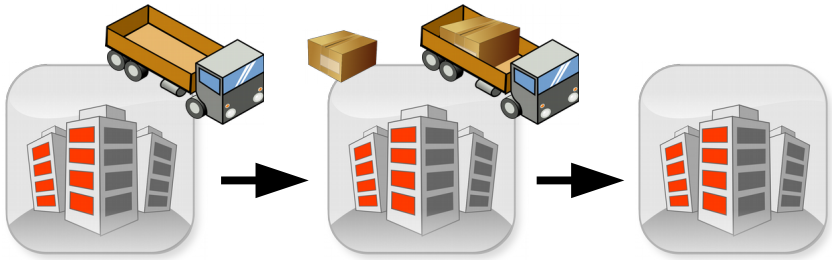


Find a valid sequence of actions from some initial world state to a desired goal state.

- Goal g: Set of Atoms that must hold,
  e.g. $\texttt{at}(P_1, C)$ and $\texttt{at}(P_2, C)$

Planning as Satisfiability with Abstraction Refinement



Find a valid sequence of actions from some initial world state to a desired goal state.

- Plan $\pi = \langle \texttt{pickup}(T_2, P_1, B)$

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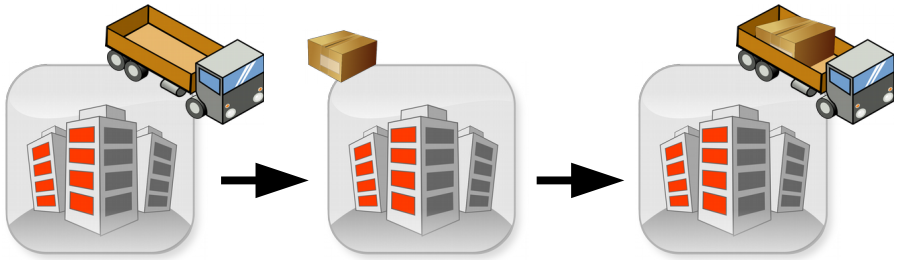
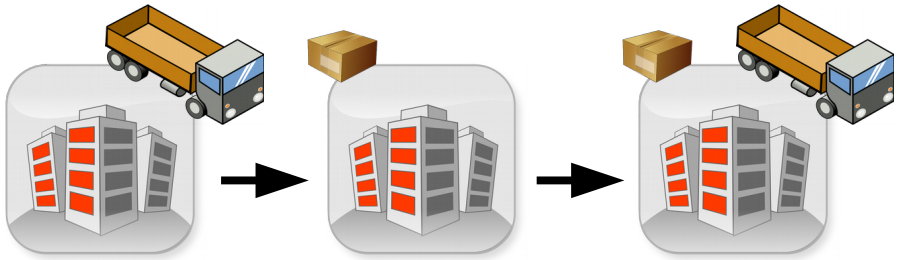


Find a valid sequence of actions from some initial world state to a desired goal state.

- Plan $\pi = \langle \texttt{pickup}(T_2, P_1, B), \texttt{move}(T_2, B, C) \rangle$

Planning as Satisfiability with Abstraction Refinement



Find a valid sequence of actions from some initial world state to a desired goal state.

- Plan $\pi = \langle \texttt{pickup}(T_2, P_1, B), \texttt{move}(T_2, B, C), \texttt{drop}(T_2, P_1, C)$

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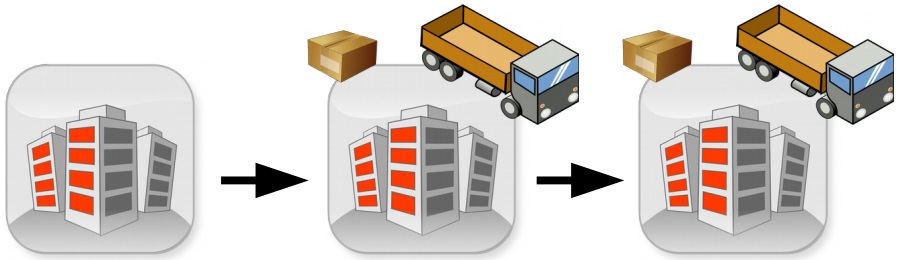

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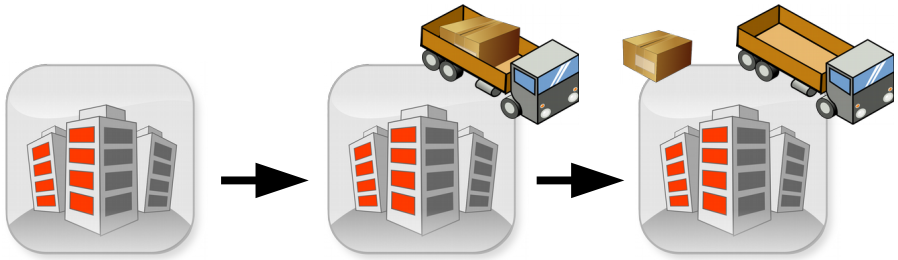
- Plan $\pi = \langle \texttt{pickup}(T_2, P_1, B), \texttt{move}(T_2, B, C), \texttt{drop}(T_2, P_1, C), \texttt{move}(T_1, A, B)$

Planning as Satisfiability with Abstraction Refinement



Find a valid sequence of actions from some initial world state to a desired goal state.

- Plan $\pi = \langle \texttt{pickup}(T_2, P_1, B), \texttt{move}(T_2, B, C), \texttt{drop}(T_2, P_1, C), \texttt{move}(T_1, A, B), \texttt{pickup}(T_1, P_2, B)$

Planning as Satisfiability with Abstraction Refinement

Find a valid sequence of actions from some initial world state to a desired goal state.

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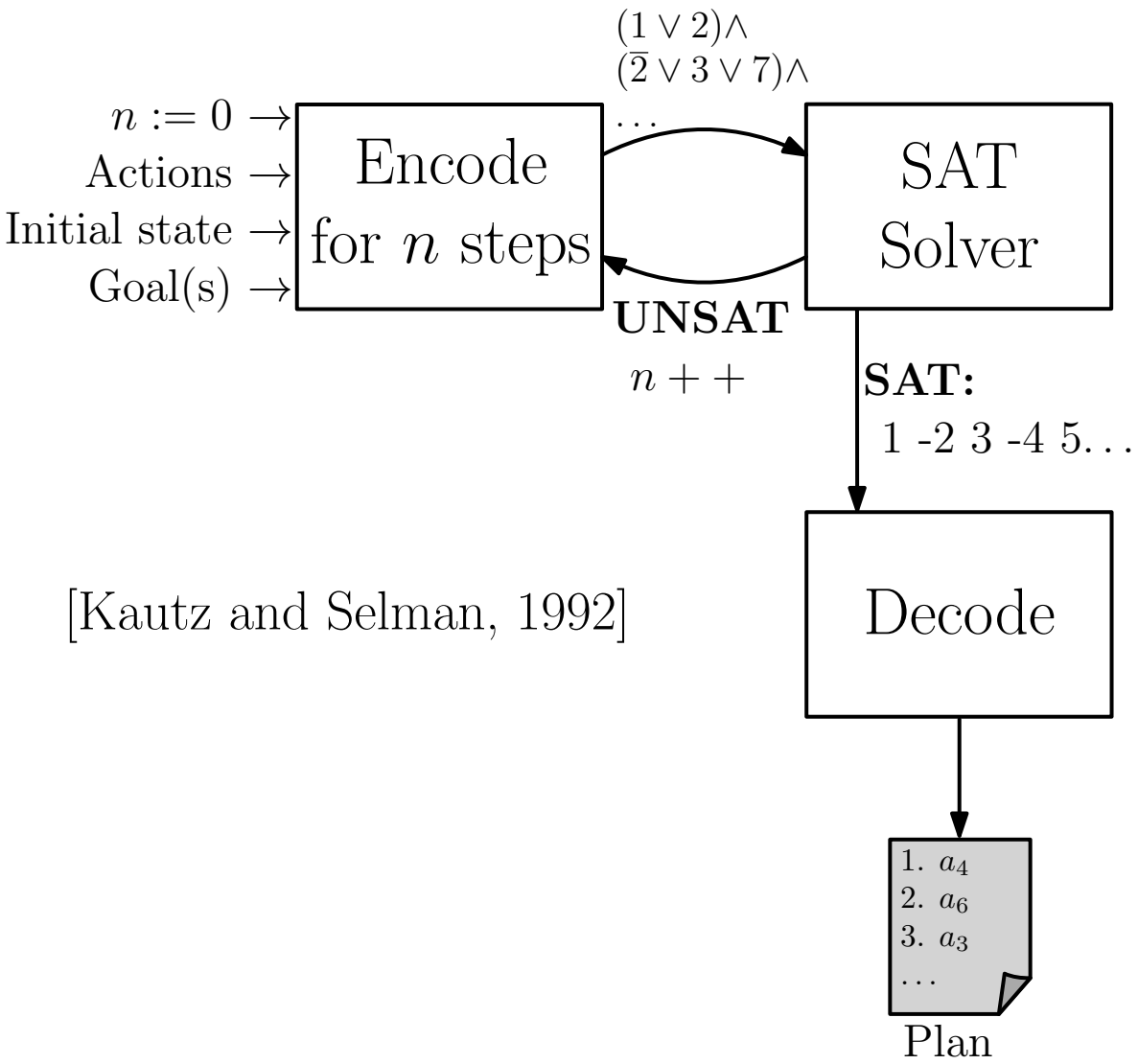
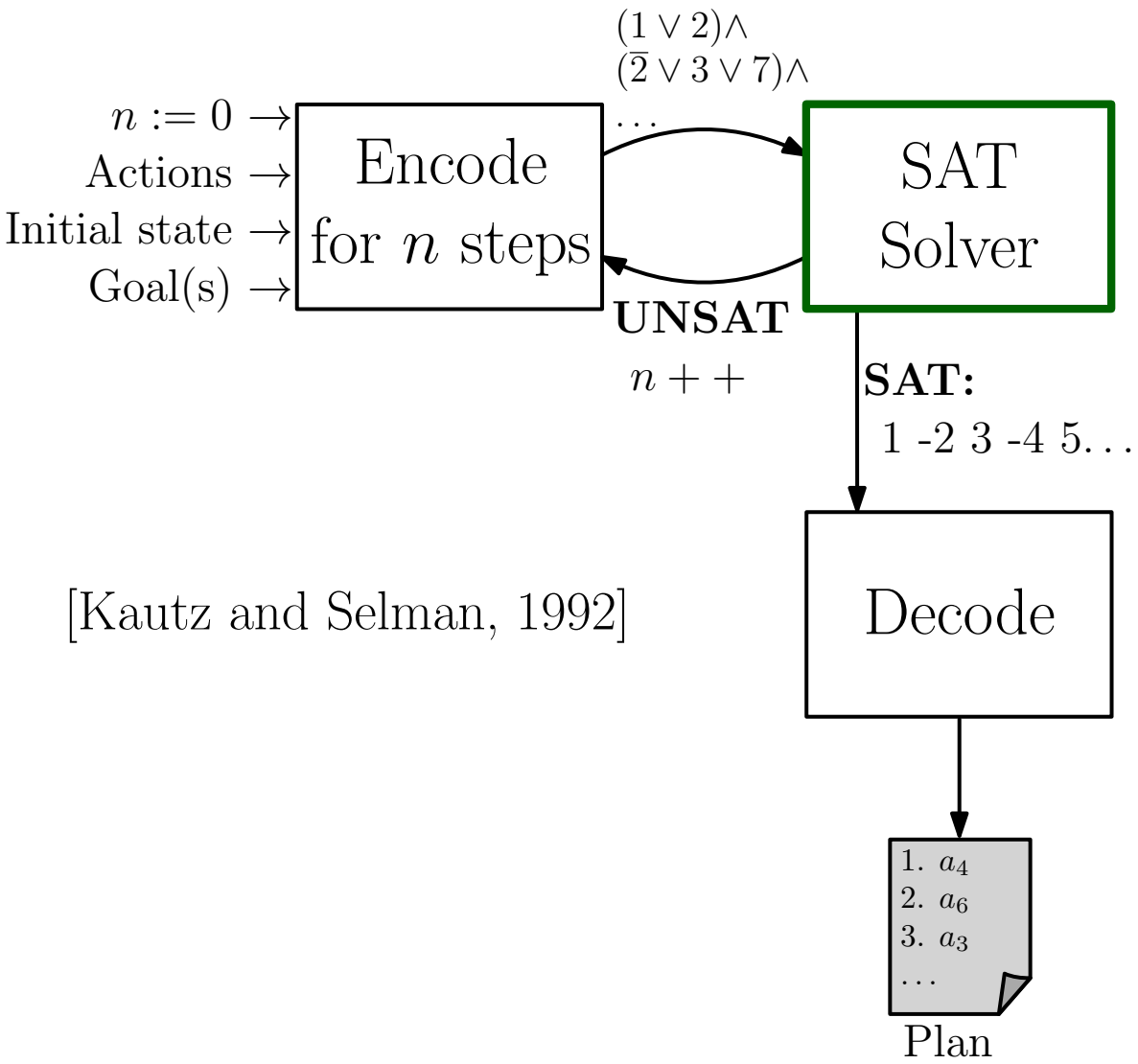
Planning as Satisfiability with Abstraction Refinement



[Kautz and Selman, 1992]

Planning as Satisfiability with Abstraction Refinement



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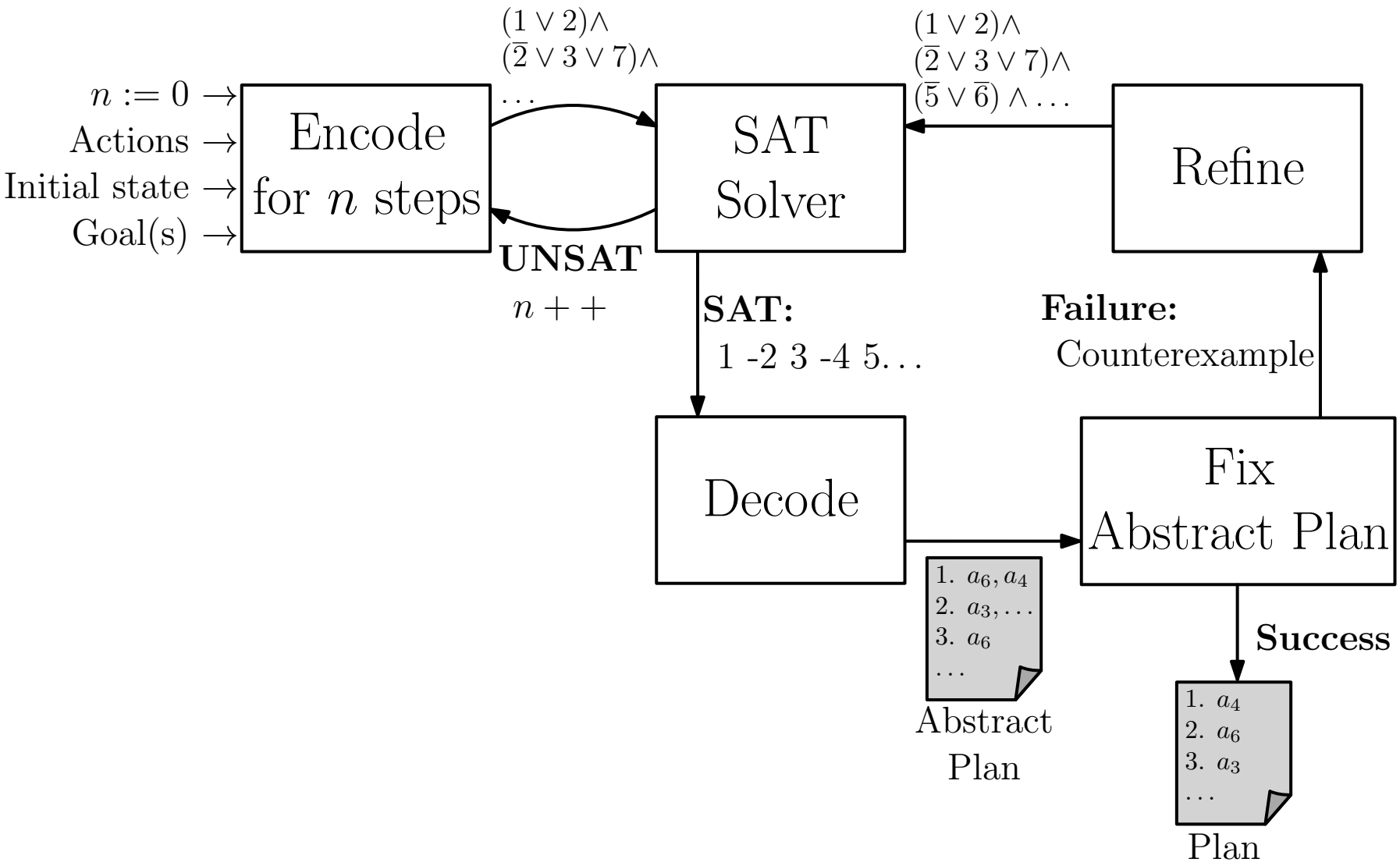

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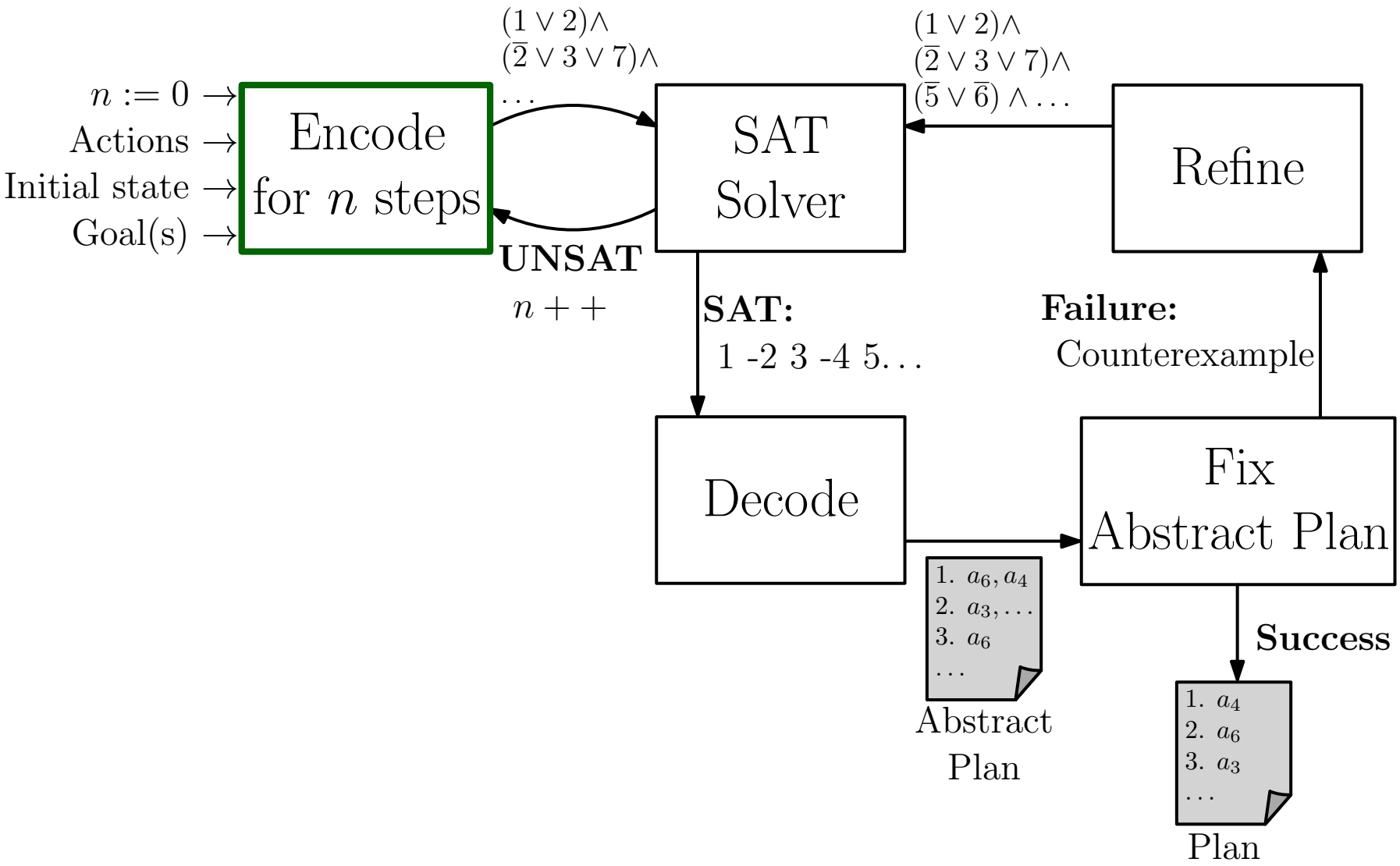
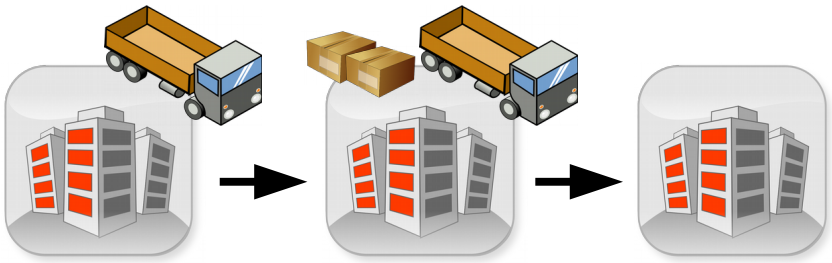


Encoding

State variable is_p^t and action variable do_a^t for each step $t = 0 \ldots n$

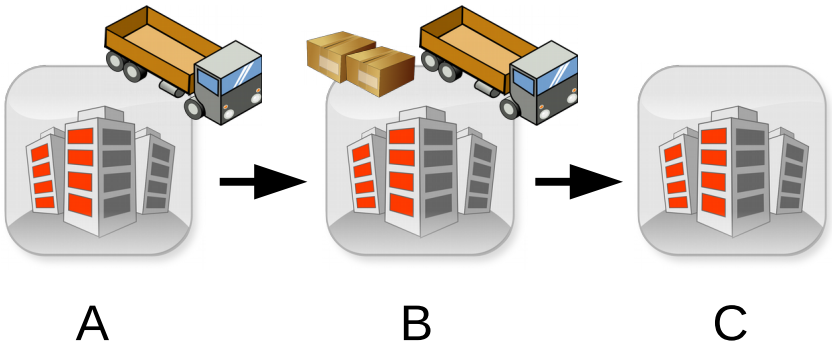
1. Initial state
2. Goal conditions
3. Preconditions are satisfied at step t
4. Effects hold at step $t + 1$
5. Frame axioms (state doesn't change arbitrarily)
6.

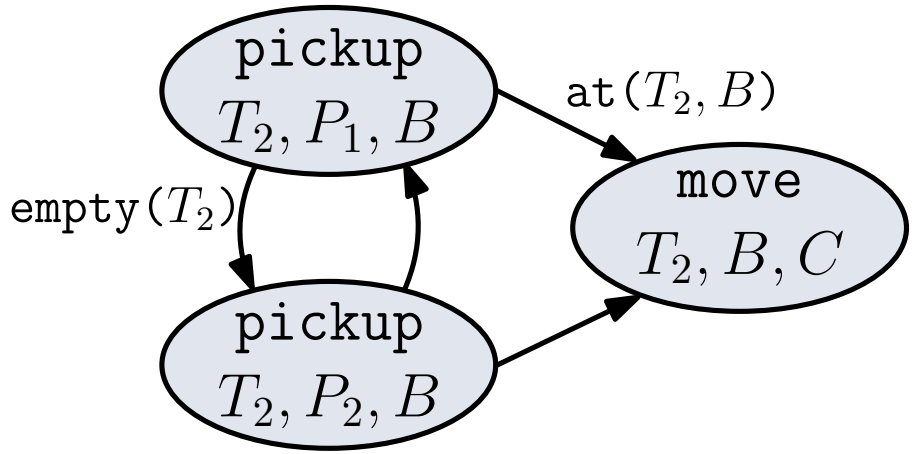
Interference



1. $\{\texttt{pickup}(T_2, P_1, B), \texttt{pickup}(T_2, P_2, B), \texttt{move}(T_2, B, C)\}$
2. $\{\texttt{drop}(T_2, P_1, C), \texttt{drop}(T_2, P_2, C)\}$

Interference





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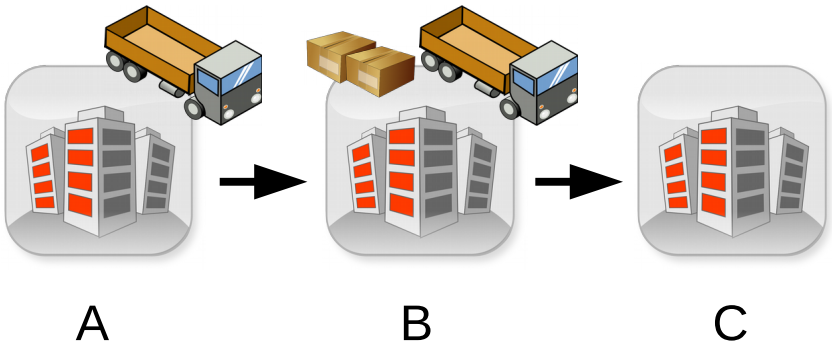
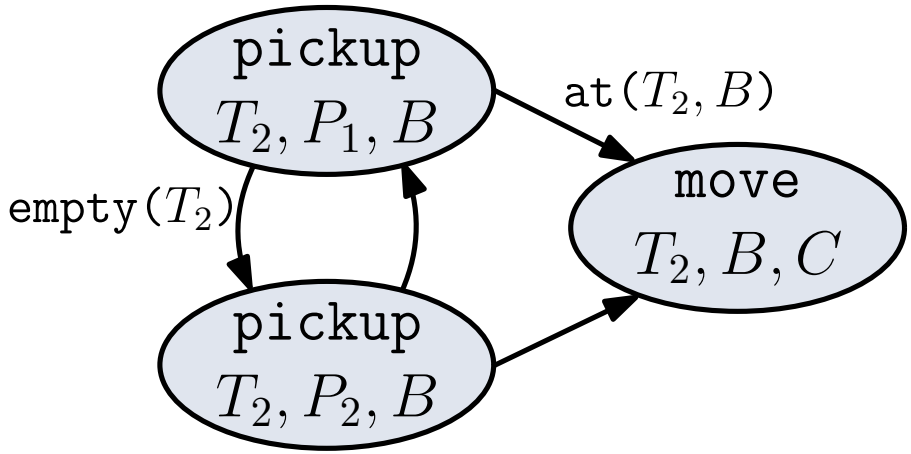
Disabling graphs

- $V =$ Actions
- $(A, B) \in E \Leftrightarrow A$ requires a precondition that is deleted by B

Interference





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- $\forall$-step [Rintanen et al., 2006]
- Interference $(A, B) \Rightarrow \overline{A} \vee \overline{B}$

Encoding

State variable is_p^t and action variable do_a^t for each step $t = 0 \ldots n$

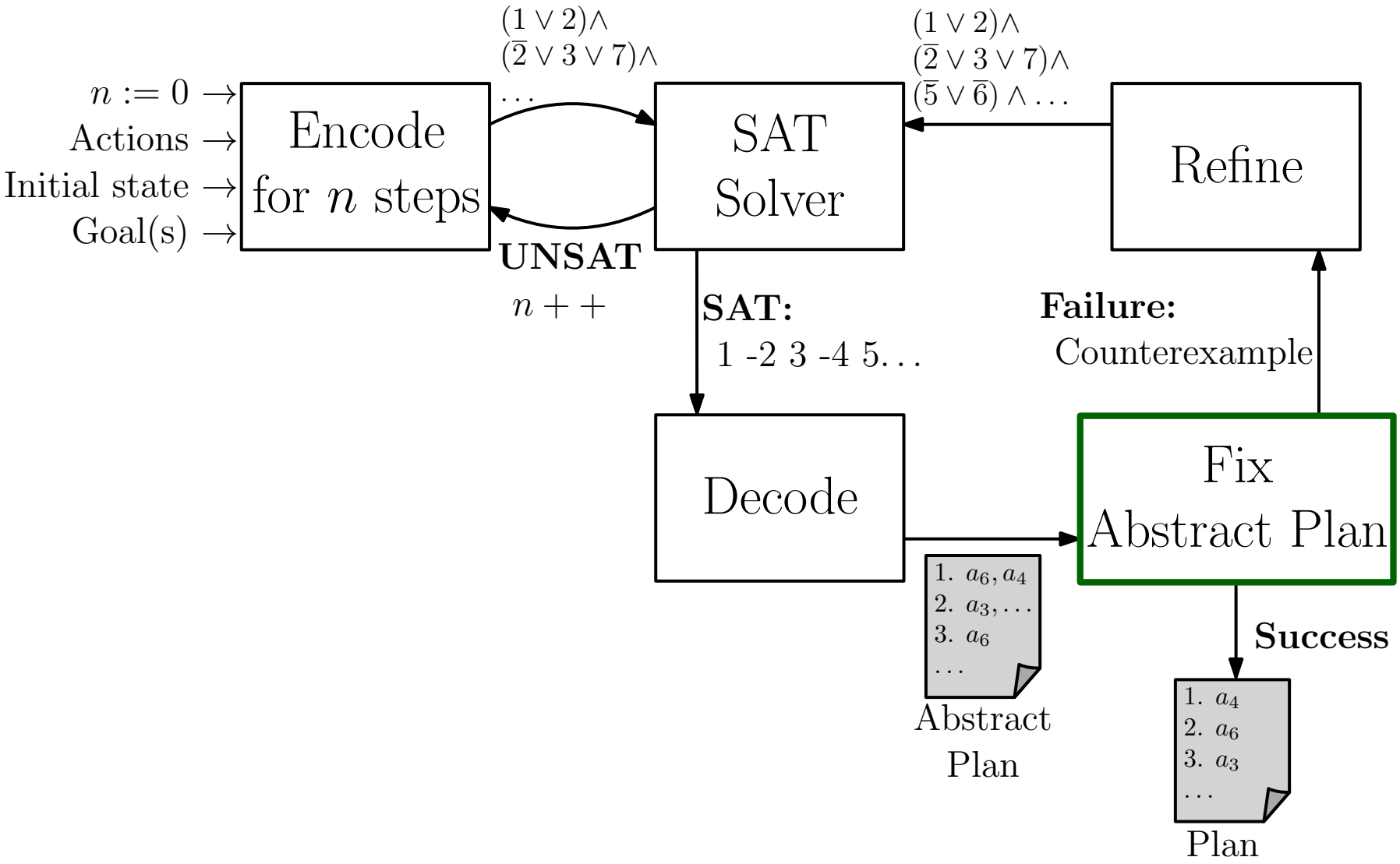
1. Initial state $\mathcal{O}(|P|)$
2. Goal conditions $\mathcal{O}(|P|)$
3. Preconditions are satisfied at step t $\mathcal{O}(n \cdot |A| \cdot |E|)$
4. Effects hold at step $t + 1$ $\mathcal{O}(n \cdot |A| \cdot |E|)$
5. Frame axioms (state doesn't change arbitrarily) $\mathcal{O}(n \cdot |P|)$
6. Interference $\mathcal{O}(n \cdot |A|^2)$
   - Sequential action execution or $\forall$-step encoding

Encoding

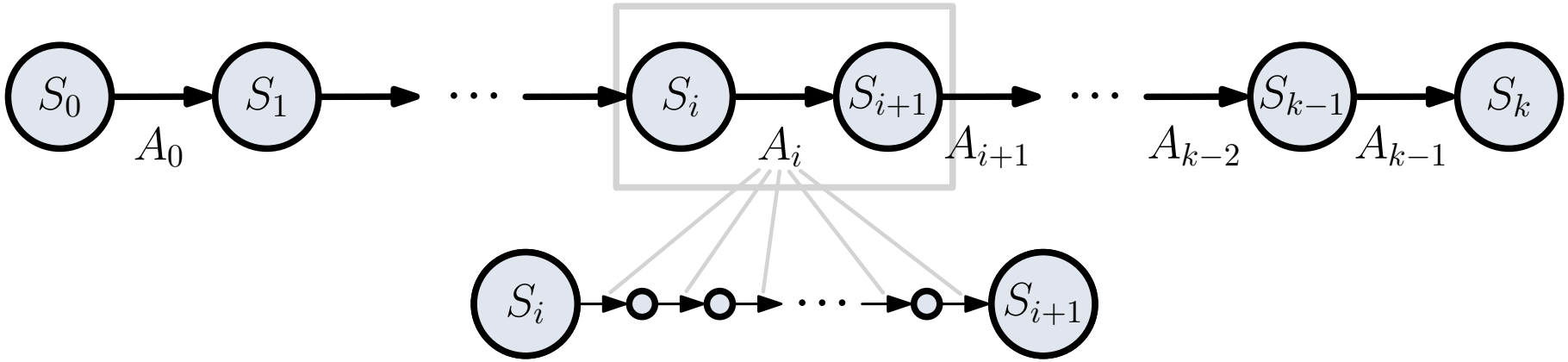
State variable is_p^t and action variable do_a^t for each step $t = 0 \ldots n$

1. Initial state $\mathcal{O}(|P|)$
2. Goal conditions $\mathcal{O}(|P|)$
3. Preconditions are satisfied at step t $\mathcal{O}(n \cdot |A| \cdot |E|)$
4. Effects hold at step $t + 1$ $\mathcal{O}(n \cdot |A| \cdot |E|)$
5. Frame axioms (state doesn't change arbitrarily) $\mathcal{O}(n \cdot |P|)$
6. Interference $\mathcal{O}(n \cdot |A|^2)$
   - Sequential action execution or $\forall$-step encoding
   - Abstraction: Nothing ($\exists$-step)

Fix Abstract Plan

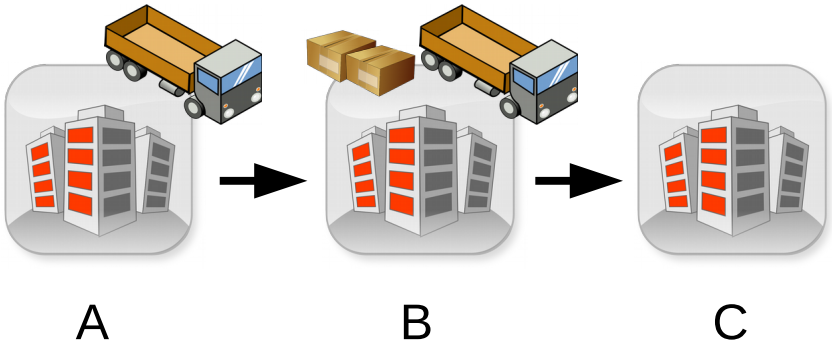


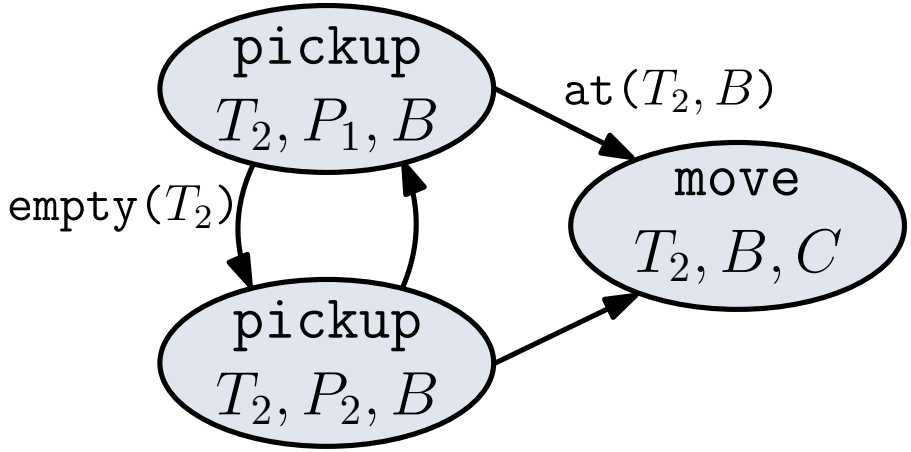
Fix Abstract Plan



1. Order actions
   - Topological ordering of disabling graph
2. Replan
   - GBFS from s_i to s_{i+1}
   - Small timeout
3. Refine
   - Action set is a counter example
   - Refine Abstraction

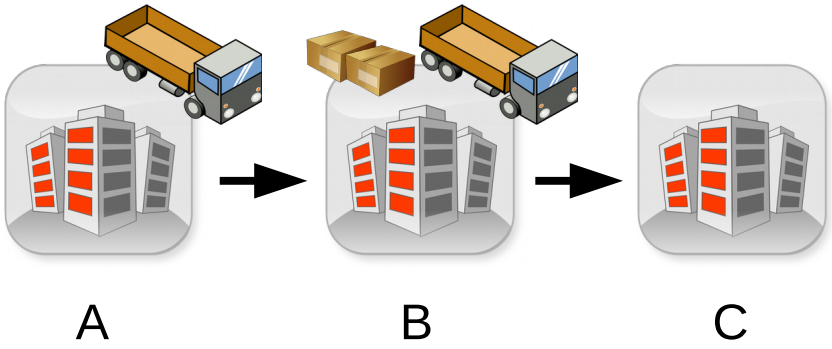
Trucking – Order

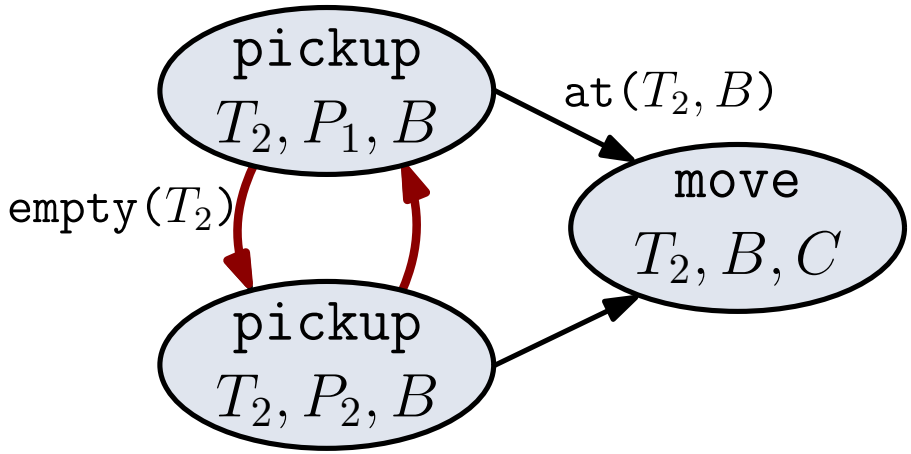




1. $\{\texttt{pickup}(T_2, P_1, B), \texttt{pickup}(T_2, P_2, B), \texttt{move}(T_2, B, C)\}$
2. $\{\texttt{drop}(T_2, P_1, C), \texttt{drop}(T_2, P_2, C)\}$

Trucking – Order





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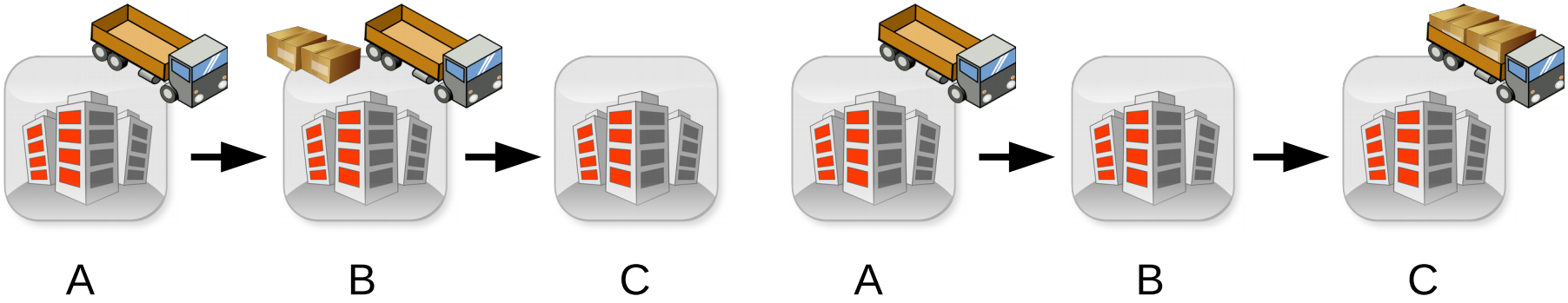
Trucking – Replan



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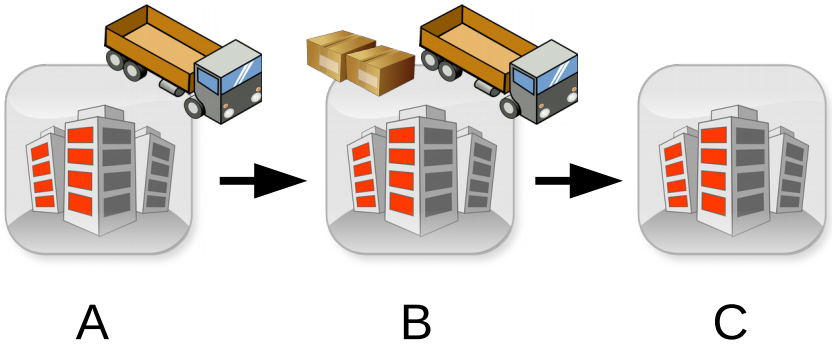
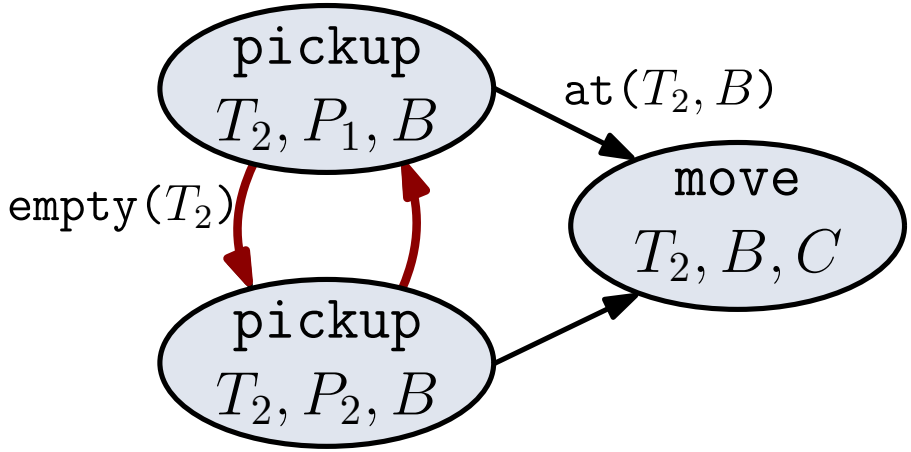
Trucking – Refine





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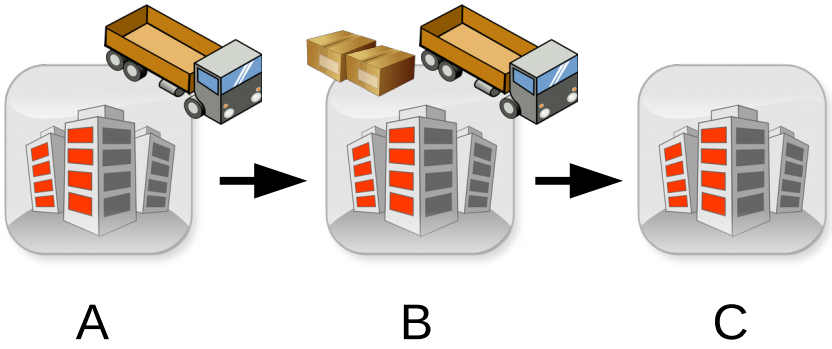
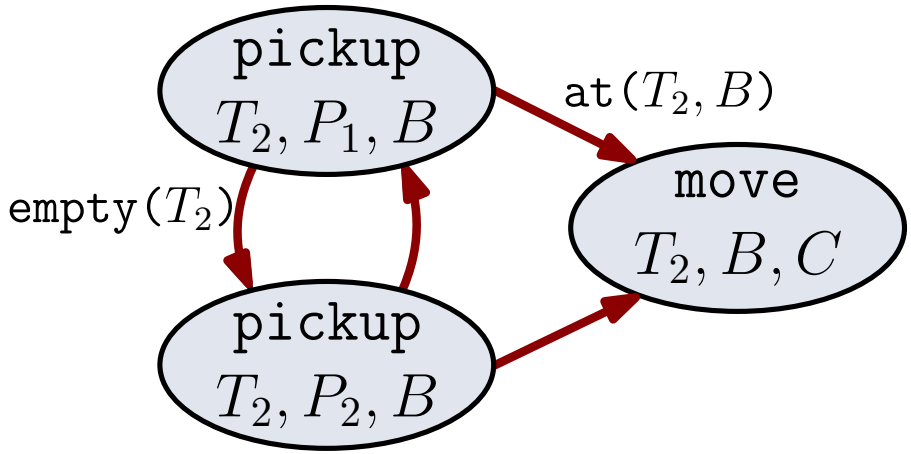
Trucking – Refine





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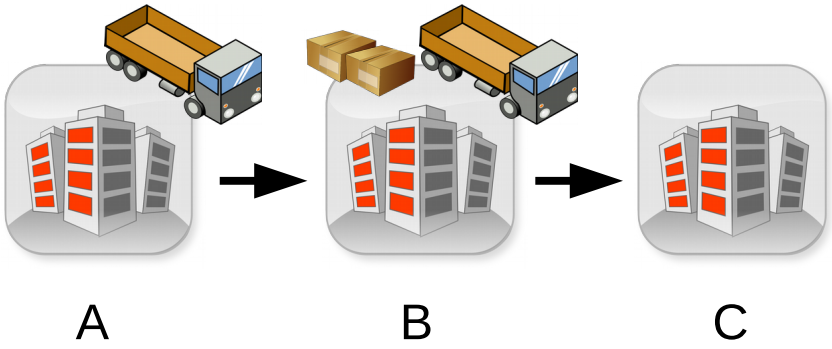
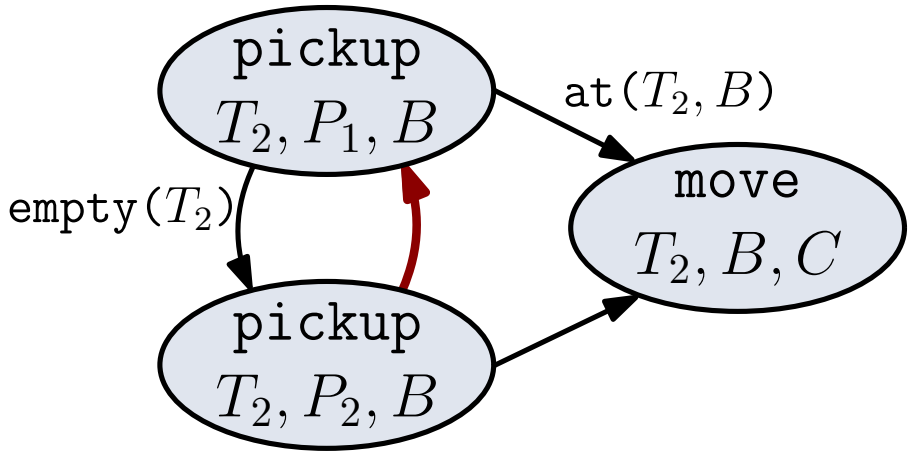
2. $\{\texttt{drop}(T_2, P_1, C), \texttt{drop}(T_2, P_2, C)\}$

- Add all edges $\rightarrow$ $\forall$-step semantics

Trucking – Refine





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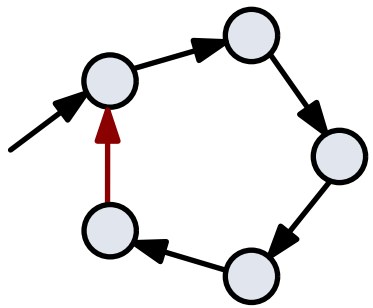
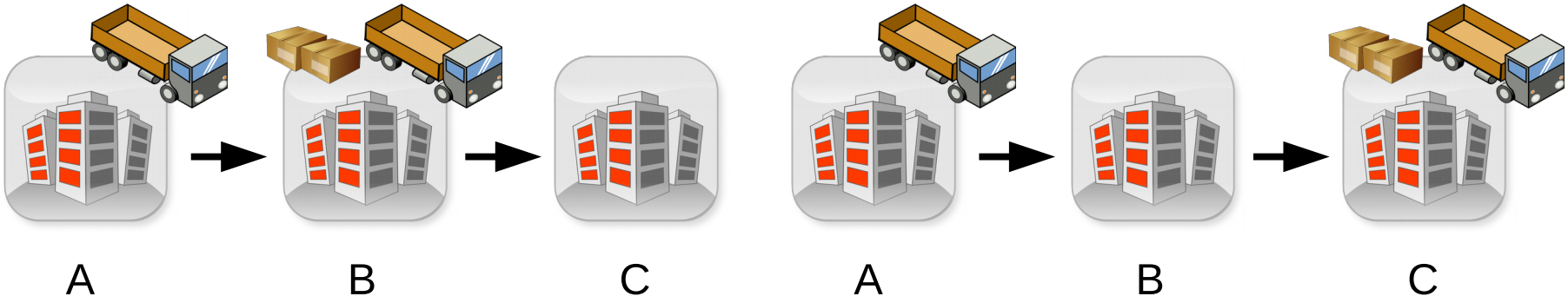
- Add all edges $\rightarrow$ $\forall$-step semantics
- Mutex reduction: DFS back edges



Sparsification

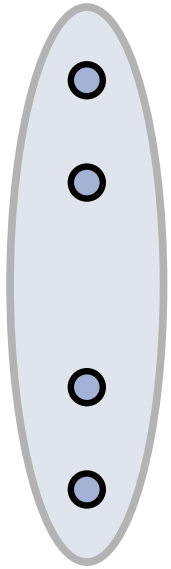


1. $\{\texttt{deliver}(T_2, P_1, B, C), \texttt{deliver}(T_2, P_2, B, C)\}$

Planning problem is overdefined

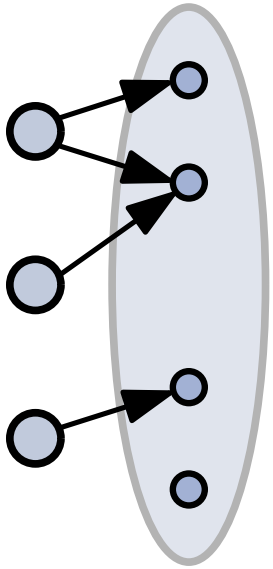
$\Rightarrow$ Plan sparsification

Sparsification



- Plan sparsification
- Greedy Action elimination algorithm [Nakhost and Müller, 2010]

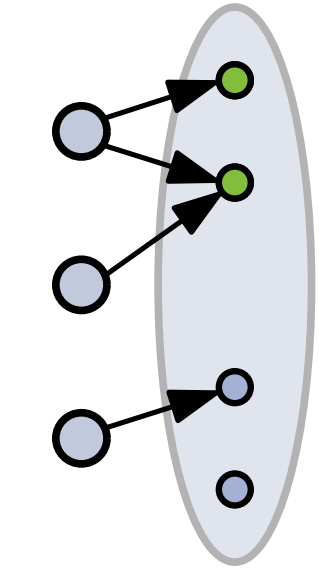
Sparsification



A_{k-1}

- Plan sparsification
- Greedy Action elimination algorithm [Nakhost and Müller, 2010]

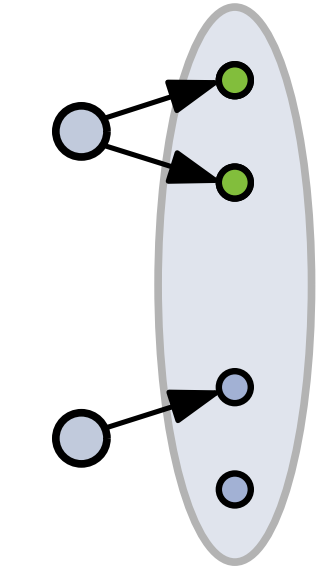
Sparsification



A_{k-1}

- Plan sparsification
- Greedy Action elimination algorithm [Nakhost and Müller, 2010]

Sparsification



- Plan sparsification
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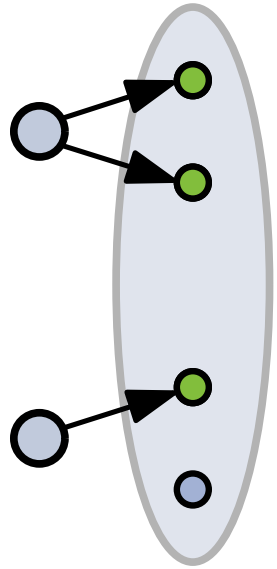
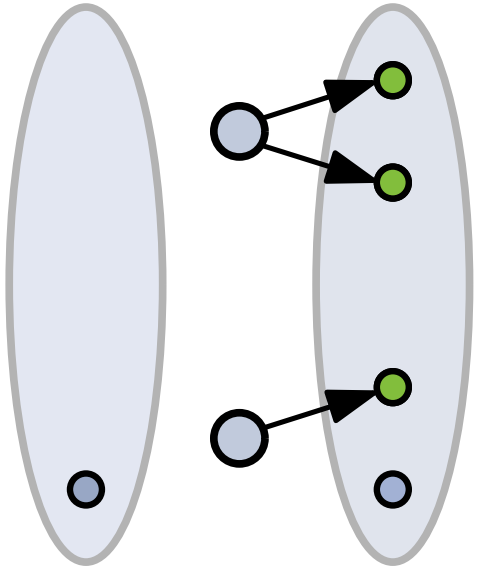
Sparsification



A_{k-1}

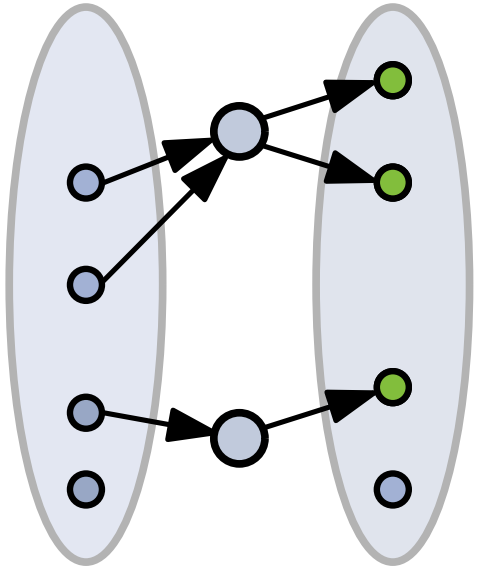
- Plan sparsification
- Greedy Action elimination algorithm [Nakhost and Müller, 2010]

Sparsification



- Plan sparsification
- Greedy Action elimination algorithm [Nakhost and Müller, 2010]

Sparsification



A_{k-1}

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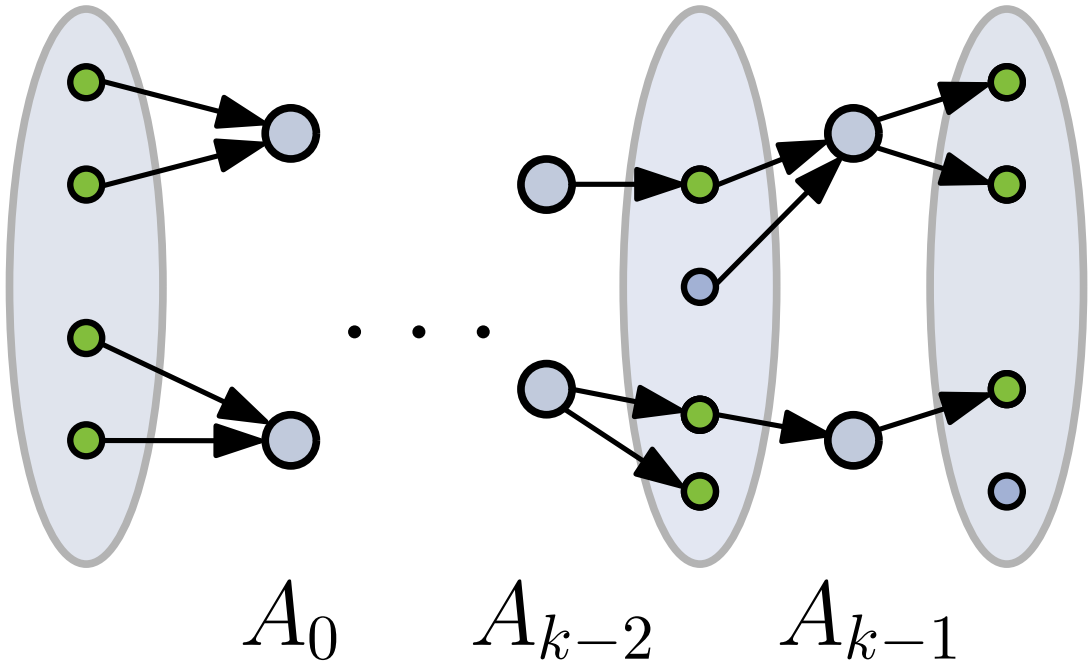
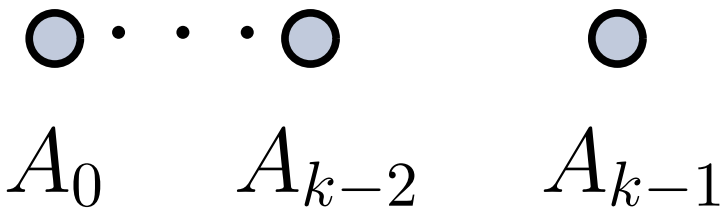
Sparsification



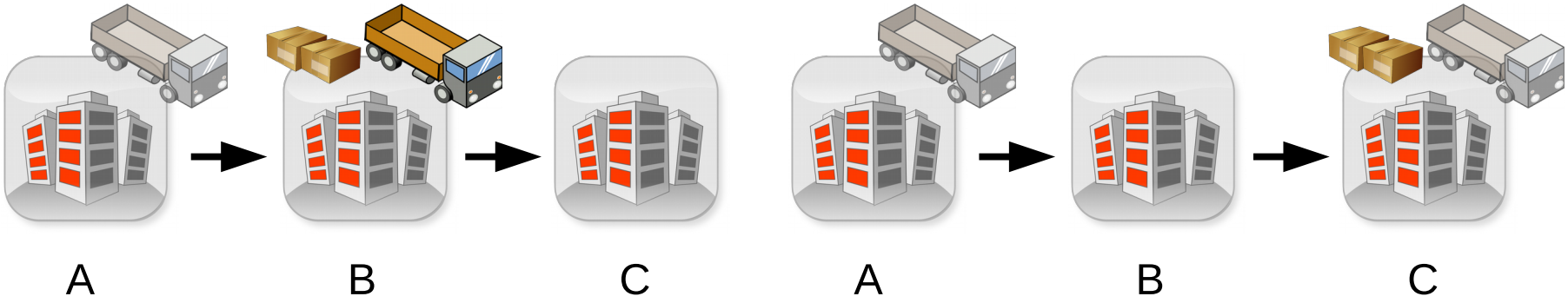
- Plan sparsification
- Greedy Action elimination algorithm [Nakhost and Müller, 2010]

Sparsification



- Plan sparsification
- Greedy Action elimination algorithm [Nakhost and Müller, 2010]

Sparsification



1. $\{\texttt{deliver}(T_2, P_1, B, C), \texttt{deliver}(T_2, P_2, B, C)\}$

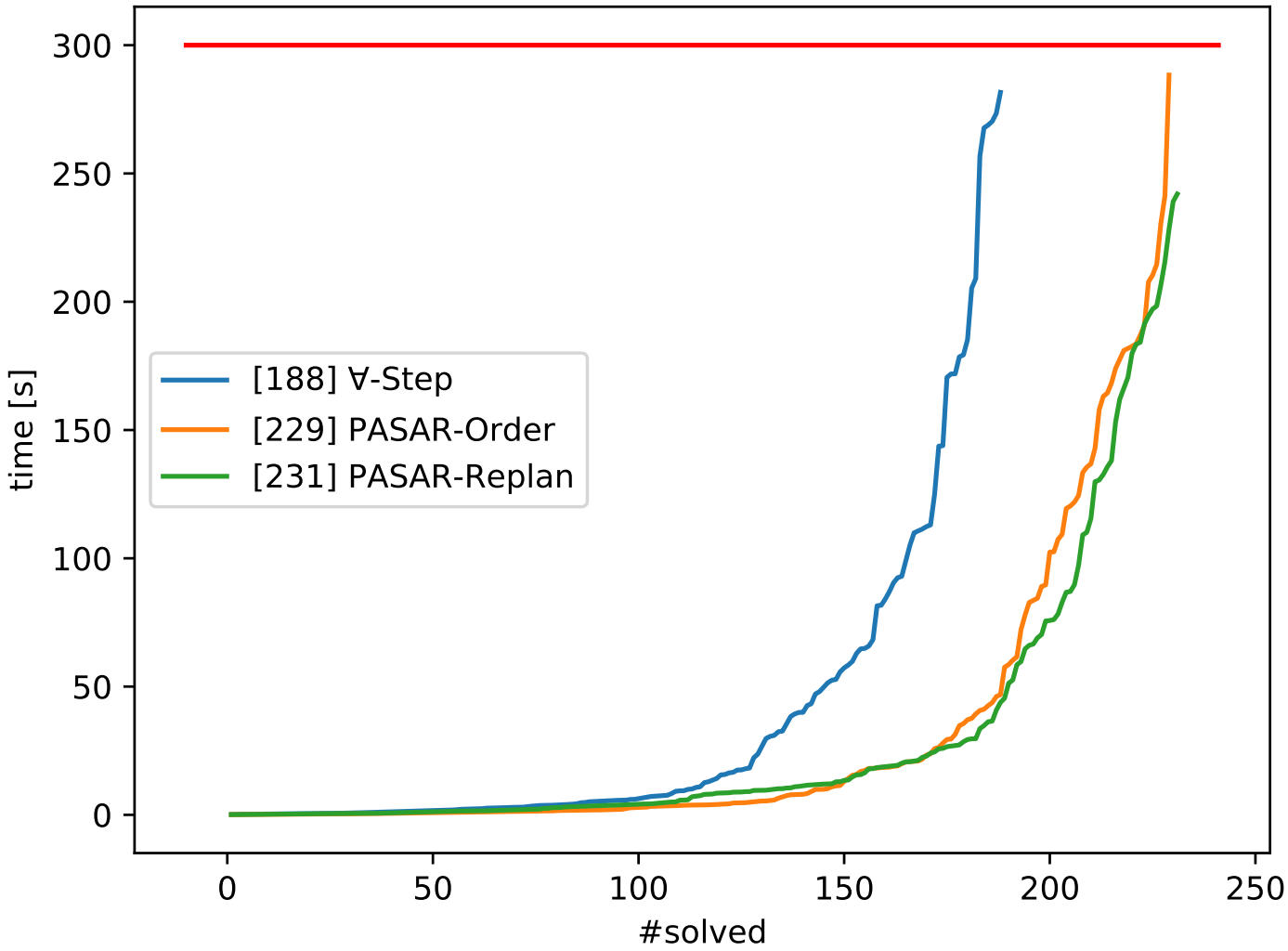
Implementation Details

- Fast Downward to ground to *SAS+* [Helmert, 2006]
- *IPASIR* generic interface for incremental SAT solving [Balyo et al., 2016]
- We chose Glucose [Audemard and Simon, 2009]

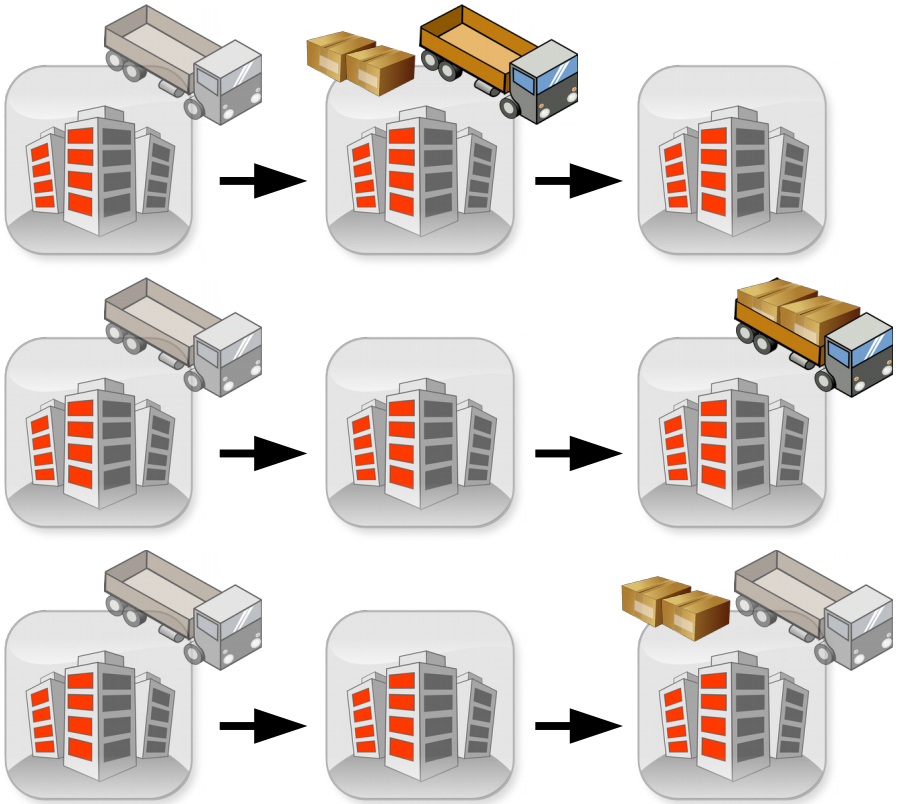
Evaluation I

- Benchmarks from the satisficing and optimal tracks of *IPC* 2014 and 2018
- Up to 5 minutes of total run time
- State space search limited to 0.2 seconds
- Competitors:
  - $\forall$-Step encoding using our translation
  - PASAR-Order only ordering
  - PASAR-Replan ordering and replan

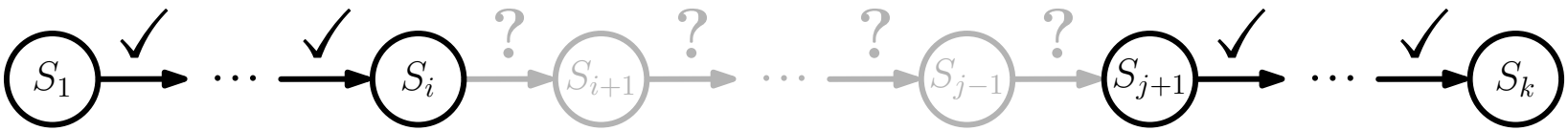
Evaluation I



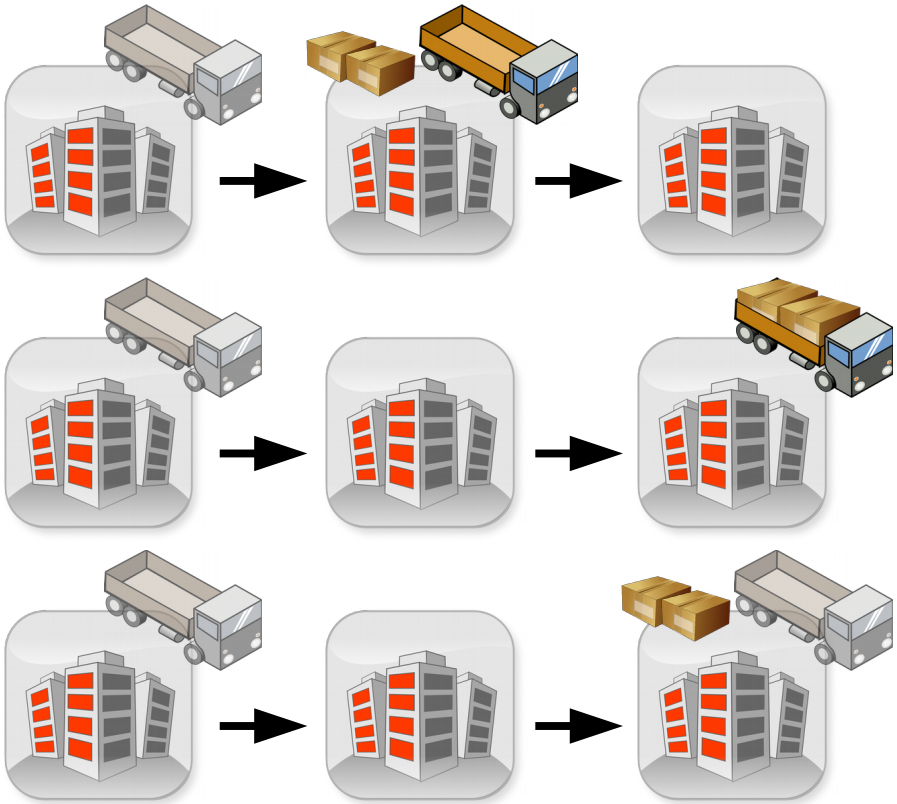
Step Skipping



1. $\{\texttt{pickup}(T_2, P_1, B),$
   $\texttt{pickup}(T_2, P_2, B),$
   $\texttt{move}(T_2, B, C)\}$
2. $\{\texttt{drop}(T_2, P_1, C),$
   $\texttt{drop}(T_2, P_2, C)\}$

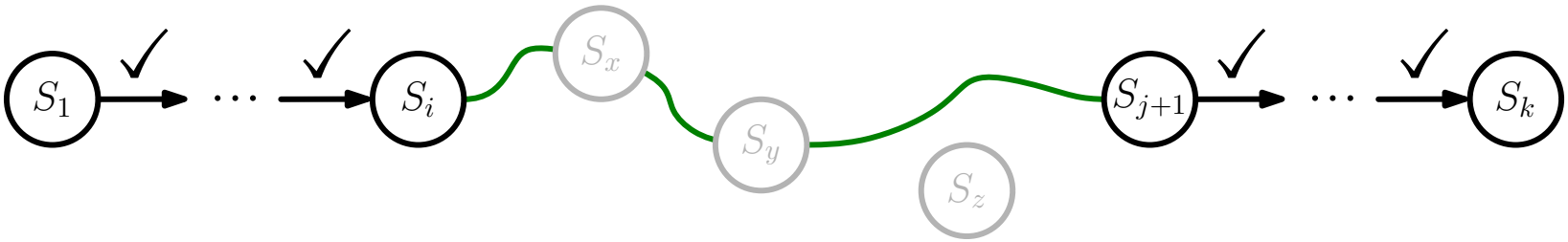


Step Skipping – local

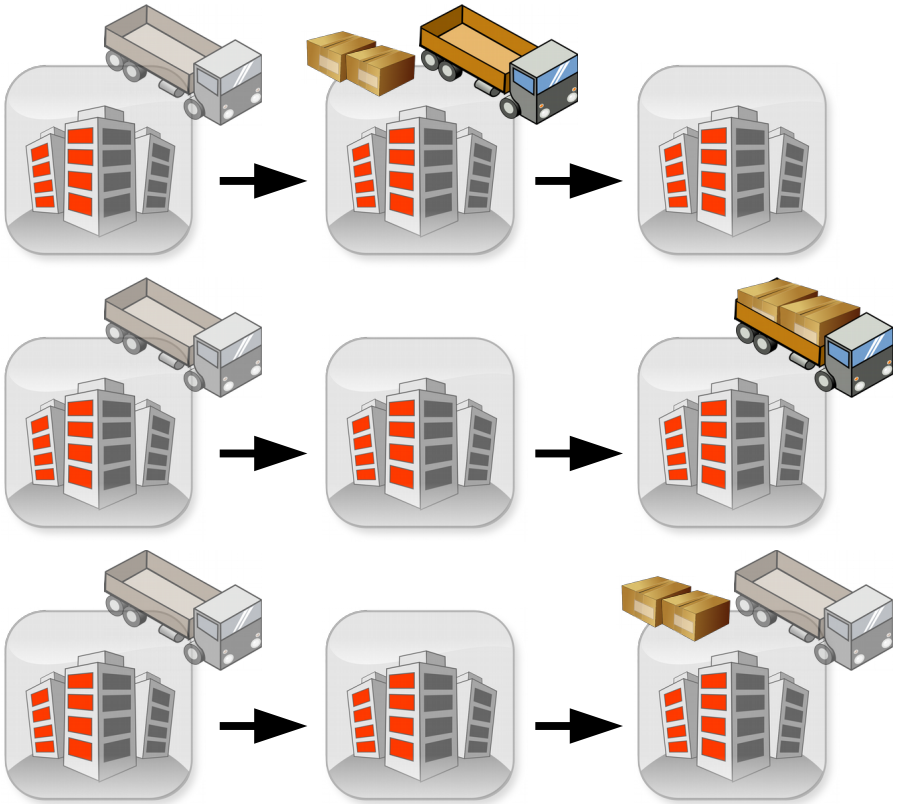


1. $\{\texttt{pickup}(T_2, P_1, B),$
   $\texttt{pickup}(T_2, P_2, B),$
   $\texttt{move}(T_2, B, C)\}$
2. $\{\texttt{drop}(T_2, P_1, C),$
   $\texttt{drop}(T_2, P_2, C)\}$

$$h(s) = \sum_{x=i+1}^{j+1} d_M(s, s_x) \cdot 1.2^x$$

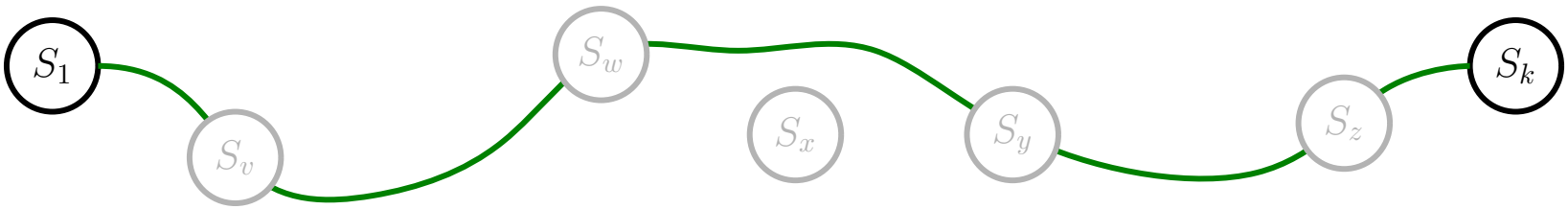


Step Skipping – global



1. $\{\texttt{pickup}(T_2, P_1, B),$
   $\texttt{pickup}(T_2, P_2, B),$
   $\texttt{move}(T_2, B, C)\}$
2. $\{\texttt{drop}(T_2, P_1, C),$
   $\texttt{drop}(T_2, P_2, C)\}$

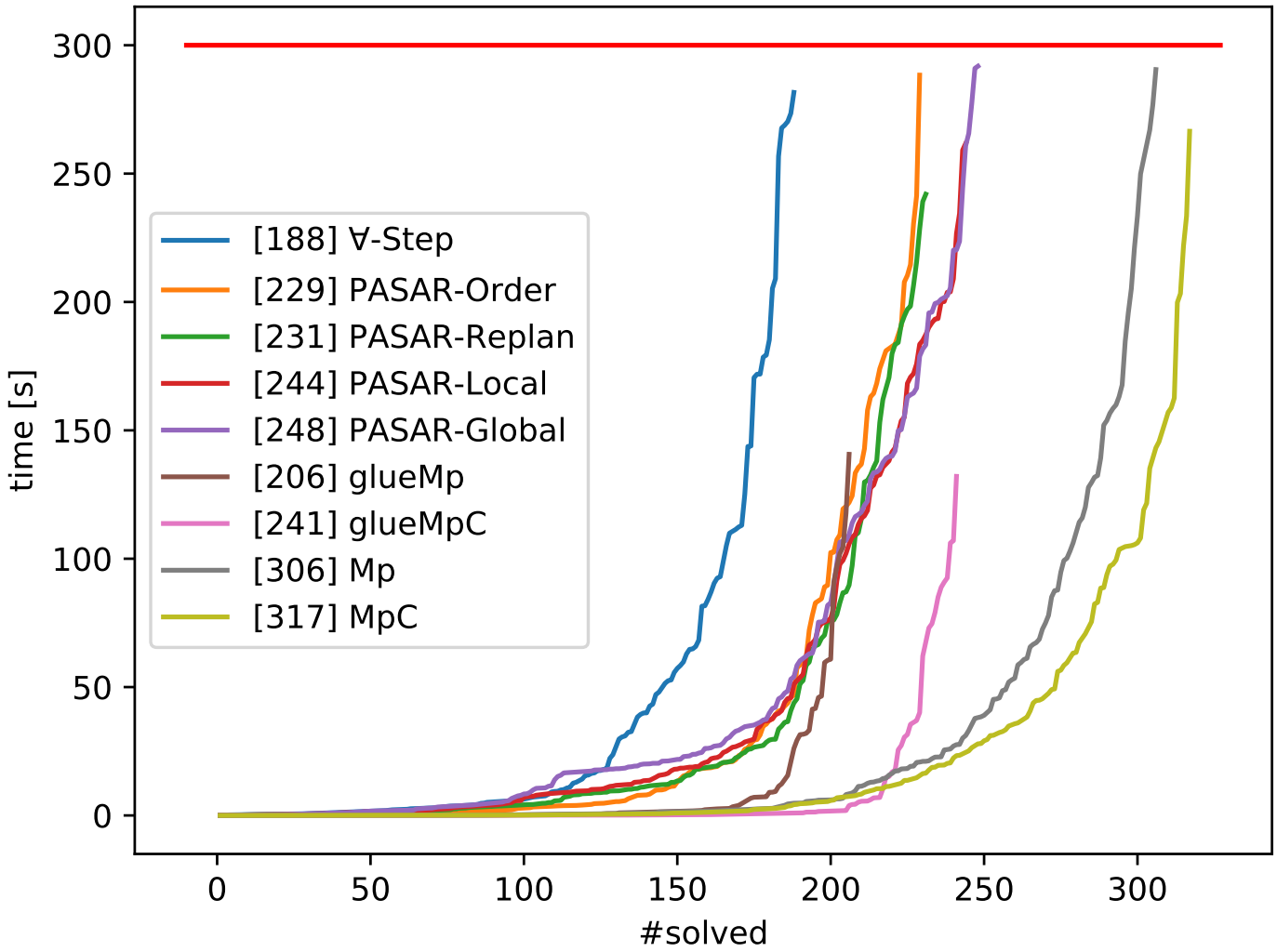
$$h(s) = \sum_{x=2}^{k} \quad d_M(s, s_x) \cdot 1.2^x$$



Evaluation II

- Competitors:
  - ∀-Step encoding using our translation
  - PASAR-Order only ordering
  - PASAR-Replan ordering and replan
  - PASAR-Local local step skipping
  - PASAR-Global additionally global step skipping fallback
  - Madagascar [Rintanen, 2013]
    - glueMp Madagascar (linear scheduling) with glucose
    - glueMpC Madagascar (exponential scheduling) with glucose
    - Mp Madagascar (linear scheduling)
    - MpC Madagascar (exponential scheduling)

Evaluation II



Conclusion

Sparkle Planning Challenge (ICAPS 19)

- Contributed 22% to the optimal portfolio
- 3rd most relevant planner

Future Work

- More coarse-grained Abstraction with increasing Refinement
- Relaxed encodings
- Action learning

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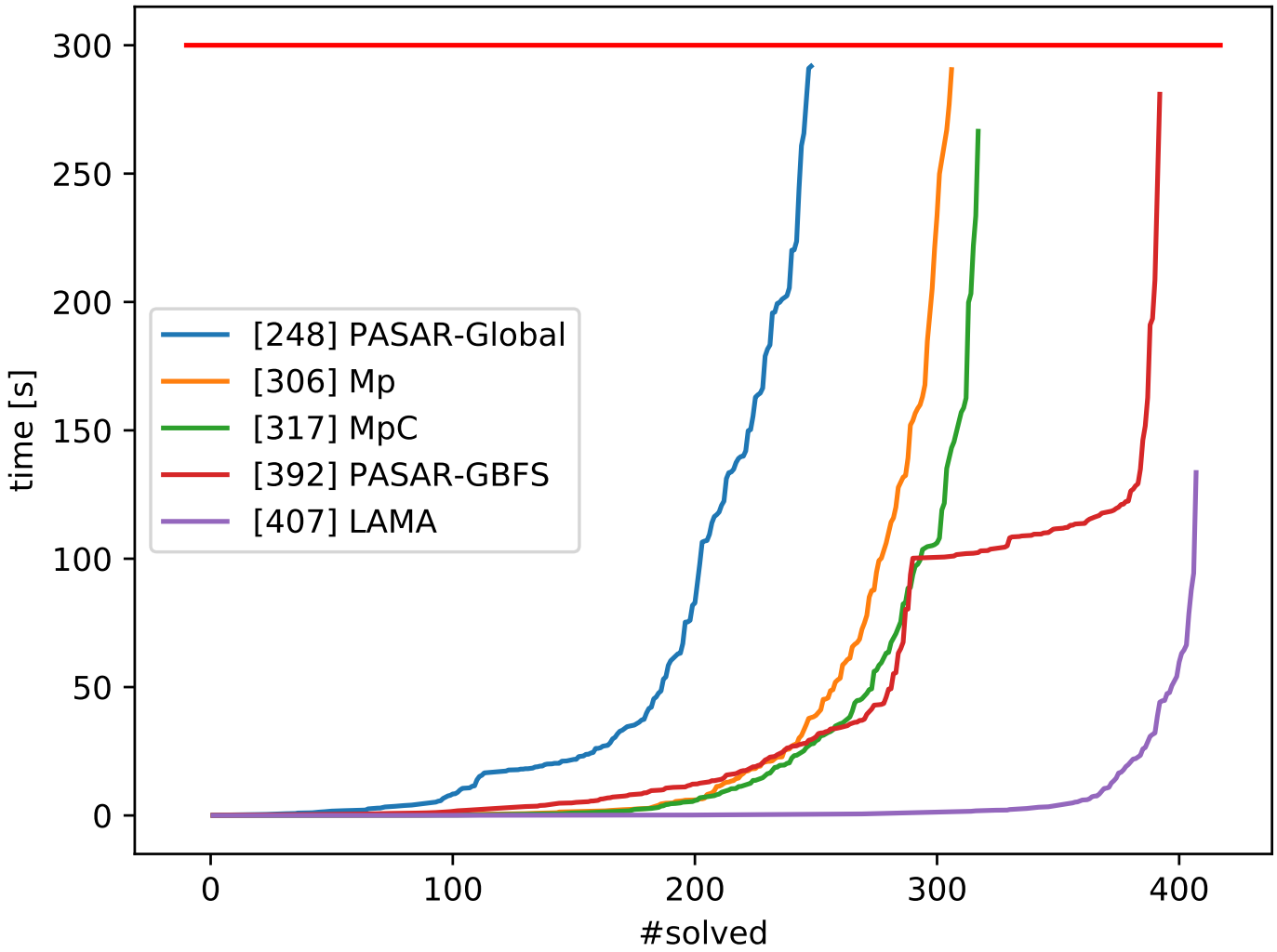
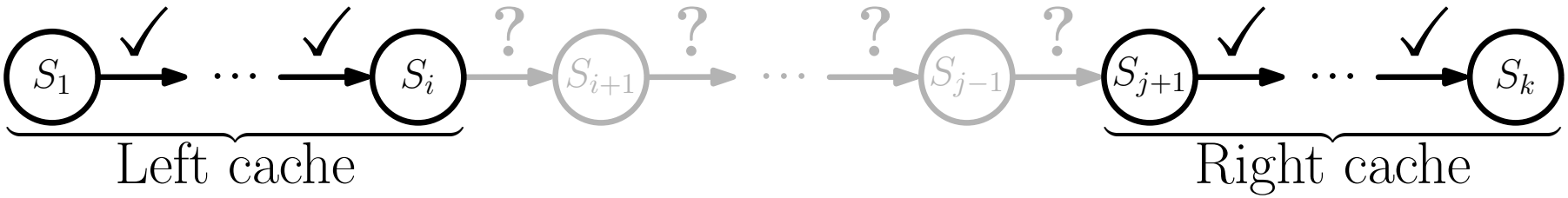
Evaluation III

- Competitors:
  - ∀-Step encoding using our translation
  - PASAR-Order only ordering
  - PASAR-Replan ordering and replan
  - PASAR-Local local step skipping
  - PASAR-Global additionally global step skipping fallback
  - Madagascar [Rintanen, 2013]
    - glueMp Madagascar (linear scheduling) with glucose
    - glueMpC Madagascar (exponential scheduling) with glucose
    - Mp Madagascar (linear scheduling)
    - MpC Madagascar (exponential scheduling)
  - PASAR-GBFS initial GBFS for 100 seconds
  - LAMA Fast Downward with the LAMA configuration [Helmert, 2006]

Evaluation III



Plan Caching



- Plan from initial state is known
- Order and replan
- Reached by state skipping search

- Plan to goal state is known
- Only order (no full state known)

Same Makespan Limit

- The abstraction doesn't represent enough of the problem
- When too many abstractions are solved in the same makespan
- Add all remaining interferences

  $\Rightarrow$ Fallback to $\forall$-step