# Generating None-Plans in Order to Find Plans

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*a joint work with Wojciech Penczek and Artur Niewiadomski

# Outline

## Main Contributions

- A (new?) method for improving efficiency of algorithms solving hard problems,
- A (new?) reduction method for planning,
- Application of the results in the tool PlanICS.

## Related Work

- Planning methods and tools: OWLS-Xplan, OWLS-MX, WSMO, PDDL3, PlanICS, . . .,
- Abstraction methods [Cousot, . . .],
- Partial order reductions [Valmari, Peled, Godefroid, . . .],
- Symmetry reductions [Clarke, Emerson, Jha, Sistla, . . .],
- CEGAR – Counterexample Guided Abstraction [Clarke],
- . . . and others.

# General idea – intuition

- **D** – a domain to find a **plan** (problem is NP-complete),
- **D'** – an abstract domain in which finding a **plan** is easy,
- a **plan** in **D'** does not need to correspond to a **plan** in **D** ,
- a **none-plan** in **D'** corresponds to a **none-plan** in **D** ,
- find (the) **none-plans** in **D'** ,
- prune **D** from (the) **none-plans** of **D'** ,
- search for (the) **plans** in **D** pruned.

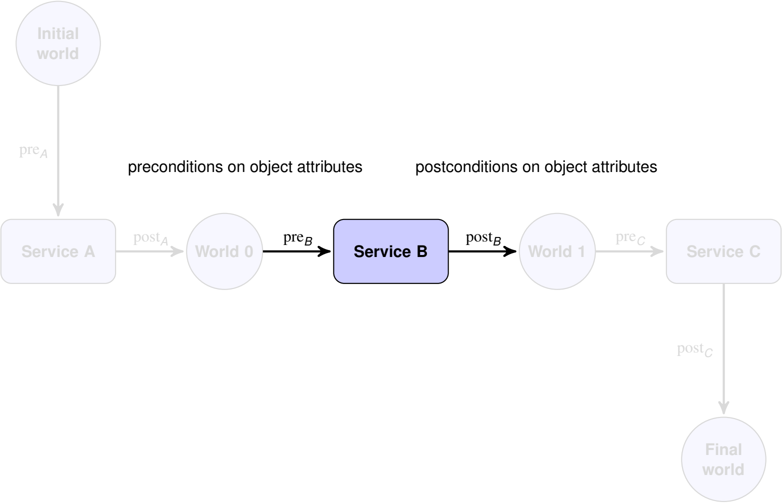
# Application to planning in PlanICS

- Given an ontology of object types and services,
- Given a user query: (initial worlds, final worlds),
- A **world** – a set of objects (object has a type and attributes),
- A **service**: **(in, inout, out, pre, post)**, where in, inout, out are sets of objects,
- **pre** – a bool. form. over object attributes of in and inout,
- **post** – a bool. form. over object attributes of inout and out.

**Task: Find all plans from some initial to some final world.**

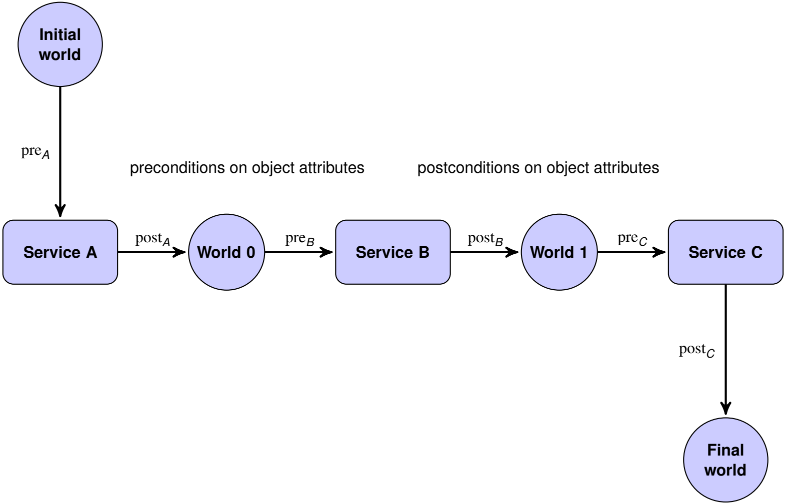
(*This problem is NP-complete.*)

# Service composition in PlanICS




Planning – composition of services (a huge number of plans)

# Service composition in PlanICS




Planning – composition of services (a huge number of plans)

# Simplifying the planning domain

**Idea** – simplify services and worlds:

- the simplified **objects** do not have attributes,
- a simplified **world** – a multiset of objects,
- a simplified **service** – **(precondition, effect)**,
- **precondition** – a multiset of objects (objects required),
- **effect** – a multiset of objects (new objects added).

- **B** – a set of services, **B'** – the set of simplified services,
- Fact: If **B'** cannot be composed into a plan, then **B** cannot be composed into a plan,
- **Goal:** synthesize constraints of non-composability.

# (Simplified) Planning Domain

**(Simplified) Planning Domain** $\mathcal{P} = (\mathcal{W}_{\mathcal{H}}, F_I, F_G, Act)$:

- $\mathcal{W}_{\mathcal{H}} \subseteq \mathbb{N}^n$ – a set of abstract worlds (multisets),
- $F_I, F_G \subseteq \mathcal{W}_{\mathcal{H}}$ – initial, final worlds,
- $Act$ – a set of actions (simplified services).

where $n$ is the number of all types of the objects.

For each $\mathrm{act} \in Act$:

- $\mathrm{pre}(\mathrm{act})$ – **precondition** of $\mathrm{act}$,
- $\mathrm{eff}(\mathrm{act})$ – **effect** of $\mathrm{act}$.

$\mathrm{pre}(\mathrm{act}), \mathrm{eff}(\mathrm{act}) \in \mathbb{N}^n$.

Action $\mathrm{act} \in Act$ is **enabled** in $\omega \in \mathcal{W}_{\mathcal{H}}$ iff $\mathrm{pre}(\mathrm{act}) \leq \omega$ and the results of firing $\mathrm{act}$: $\omega \stackrel{\mathrm{act}}{\rightarrow} \omega + \mathrm{eff}(\mathrm{act})$

# Plans

Given $\mathcal{P} = (\mathcal{W}_{\mathcal{H}}, F_I, F_G, Act)$, $\mathbf{B} \subseteq Act$

- $\pi \in \Pi(\omega, \mathbf{B}, \omega')$ iff

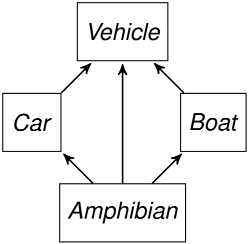
$$\pi = \omega_0 \overset{\mathrm{act}_1}{\rightarrow} \omega_1 \overset{\mathrm{act}_2}{\rightarrow} \ldots \overset{\mathrm{act}_{n-1}}{\rightarrow} \omega_{n-1} \overset{\mathrm{act}_n}{\rightarrow} \omega_n$$

  where $\omega_0 = \omega$, $\omega_n \geq \omega'$, and $\{\mathrm{act}_1, \ldots, \mathrm{act}_n\} \subseteq \mathbf{B}$

- $\bigcup_{\omega_I \in F_I} \bigcup_{\omega_F \in F_G} \Pi(\omega_I, \mathbf{B}, \omega_F)$ – the **plans** over **B**

Each plan starts from an initial world and its last world covers a final world.

# Exemplary planning domain

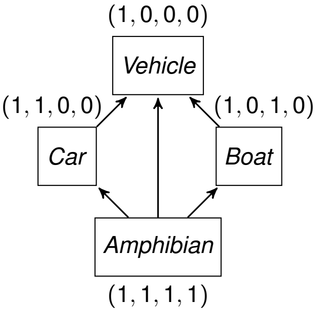


Vehicles' inheritance

Actions:

- *makeVehicle*:
  *needs nothing, builds vehicle*
- *makeCar*:
  *needs vehicle, builds car*
- *makeBoat*:
  *needs vehicle, builds boat*
- *makeAmphibian*:
  *needs boat and car, builds amphibian*
- *tinker*:
  *needs amphibian and car, builds two amphibians*

# Exemplary planning domain, ct'd




Vehicles' inheritance

Order of the objects:
(*Vehicle*, *Car*, *Boat*, *Amphibian*)

- *makeAmphibian*:
  *needs boat and car, builds amphibian*

  $\mathrm{pre}(\textit{makeAmphibian}) = (\mathbf{1}, \mathbf{0}, \mathbf{1}, \mathbf{0}) + (\mathbf{1}, \mathbf{1}, \mathbf{0}, \mathbf{0}) = (\mathbf{2}, \mathbf{1}, \mathbf{1}, \mathbf{0})$

  $\mathrm{eff}(\textit{makeAmphibian}) = (\mathbf{1}, \mathbf{1}, \mathbf{1}, \mathbf{1})$

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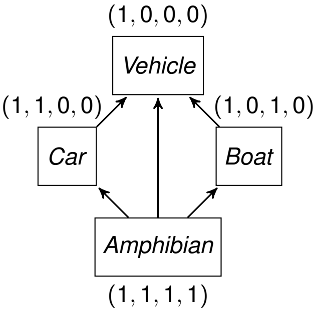


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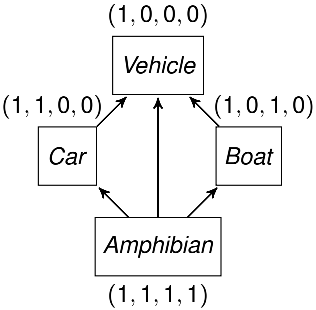


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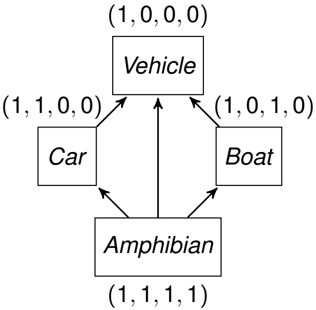


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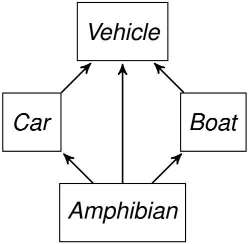



Vehicles' inheritance

Actions:

- $\mathrm{pre}(\mathit{makeVehicle}) = (0, 0, 0, 0)$
  $\mathrm{eff}(\mathit{makeVehicle}) = (1, 0, 0, 0)$
- $\mathrm{pre}(\mathit{makeCar}) = (1, 0, 0, 0)$
  $\mathrm{eff}(\mathit{makeCar}) = (1, 1, 0, 0)$
- $\mathrm{pre}(\mathit{makeBoat}) = (1, 0, 0, 0)$
  $\mathrm{eff}(\mathit{makeBoat}) = (1, 0, 1, 0)$
- $\mathrm{pre}(\mathit{makeAmphibian}) = (2, 1, 1, 0)$
  $\mathrm{eff}(\mathit{makeAmphibian}) = (1, 1, 1, 1)$
- $\mathrm{pre}(\mathit{tinker}) = (2, 2, 1, 1)$
  $\mathrm{eff}(\mathit{tinker}) = (2, 2, 2, 2)$

$\omega_I = (0, 0, 0, 0)$ (one initial world)
$\omega_F = (0, 0, 0, 1)$ (one final world)

# Classifying actions

$V_{\max}$ - the largest number occurring in pre(act) for $act \in Act$.

$$\mathrm{enact}(\mathbf{A}) = \{\mathrm{act} \in Act \mid \sum_{\mathrm{act}' \in \mathbf{A}} V_{\max} \cdot \mathrm{eff}(\mathrm{act}') \geq \mathrm{pre}(\mathrm{act})\}.$$

all actions that can be enabled by firing actions from $\mathbf{A} \subseteq Act$,

$\omega \in \mathcal{W}_{\mathcal{H}}$, $i > 0$

- $G_0^\omega = \{\mathrm{act} \in Act \mid pre(\mathrm{act}) \leq \omega\}$ – the actions enabled in $\omega$,
- $G_{i+1}^\omega = \mathrm{enact}(G_i^\omega)$ – the actions enabled in $i$–th step
- $H_0^\omega = G_0^\omega$,
- $H_{i+1}^\omega = G_{i+1}^\omega \setminus G_i^\omega$ – the actions **newly** enabled in $i$–th step.

# Classifying actions, ct'd

$\omega, \omega' \in \mathcal{W}_{\mathcal{H}}$

$$\mathrm{kgoal}(\omega, \omega') = \mathit{min}(\{k \in \mathbb{N} \mid \sum_{\mathrm{act} \in G_k^{\omega}} V_{\max} \cdot \mathrm{eff}(\mathrm{act}) \geq \omega'\})$$

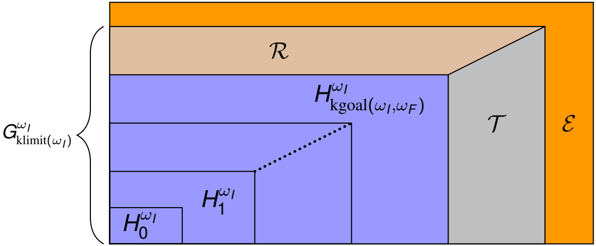
the minimal step at which greedily fired actions cover $\omega'$.

**Lemma A**

- $\mathrm{kgoal}(\omega, \omega') < \infty$ iff $\Pi(\omega, \mathit{Act}, \omega') \neq \emptyset$,
- $\mathrm{kgoal}(\omega, \omega')$ can be computed in time $O(|\mathit{Act}|^2 \cdot n)$.

Planning in $\mathcal{P}$ is easy.

# Classifying actions, cont'd




$\omega_I \in F_I$, $\omega_F \in F_G$, $\mathrm{klimit}(\omega_I) = min(\{k \in \mathbb{N} \mid H^{\omega_I}_k = \emptyset\})$

- $\mathcal{E} = Act \setminus G^{\omega_I}_{\mathrm{klimit}(\omega_I)}$ – **useless** actions can't be enabled
- $\mathcal{G} = G^{\omega_I}_{\mathrm{kgoal}(\omega_I,\omega_F)}$ – **sufficient** actions can cover goal
- $\mathcal{R} = \{\mathrm{act} \in G^{\omega_I}_{\mathrm{klimit}(\omega_I)} \mid \mathrm{pre}(\mathrm{act}) \geq \omega_F\}$ – **redundant** actions
- $\mathcal{T} = G^{\omega_I}_{\mathrm{klimit}(\omega_I)} \setminus (G^{\omega_I}_{\mathrm{kgoal}(\omega_I,\omega_F)} \cup \mathcal{R})$ – **potentially** useful acts

# Classifying actions, cont'd

**Lemma B**
Let $A \subseteq Act$. If there is a plan over $A$, then $A$ contains at least one element from $H_i^{\omega_I}$ for all $0 \leq i \leq \mathrm{kgoal}(\omega_I, \omega_F)$

First easy reductions:

- throw away **redundant** (e.g., *tinker*) and **useless** actions,
- block all sets of actions that do not satisfy Lemma B.

More reductions: consider none-plans.

# None-plans

$\mathbf{A} \subseteq \mathit{Act}$, $\omega, \omega' \in \mathcal{W}_{\mathcal{H}}$

$$\mathcal{Z}(\omega, \mathbf{A}, \omega') := \{B \subseteq \mathbf{A} \mid \Pi(\omega, B, \omega') = \emptyset\}$$

None-plan: a set of actions $B$, which is not a support of a plan starting at $\omega$ and covering $\omega'$.

$\mathbb{I}(\omega) := \{\omega' \mid \|\omega'\| = 1 \wedge \omega \geq \omega'\}$ – unitary coord. vects. of $\omega$

e.g., $\mathbb{I}((2, 1, 1, 0)) = \{(1, 0, 0, 0), (0, 1, 0, 0), (0, 0, 1, 0)\}$

# Characterisation of none-plans

**Theorem**

$$\mathcal{Z}(\omega, A, \omega') = \bigcup_{\substack{\omega'' \in \mathbb{I}(\omega') \\ \omega \not\geq \omega''}} \bigcap_{\substack{\mathrm{act} \in A \\ \mathrm{eff}(\mathrm{act}) \geq \omega''}} \left(\mathcal{D}(\omega, A, \mathrm{act}) \cup 2^{A \setminus \{\mathrm{act}\}}\right)$$

where $\mathcal{D}(\omega, A, \mathrm{act}) = \{B \cup \{\mathrm{act}\} \mid B \in \mathcal{Z}(\omega, A \setminus \{\mathrm{act}\}, \mathrm{pre}(\mathrm{act}))\}$

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To find all $B \subseteq A$ that do not make a plan from $\omega$ to cover $\omega'$
take a coordinate $\omega''$ of $\omega'$ that needs to be covered
for each action $\mathrm{act}$ that could cover $\omega''$ when fired
ensure that $\mathrm{act}$ cannot be enabled and take it
or throw $\mathrm{act}$ away.

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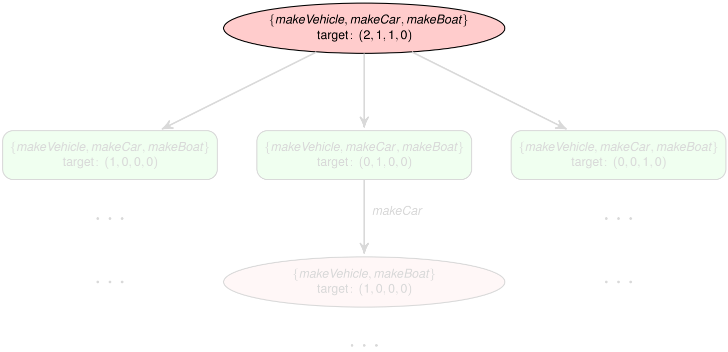
# None-plans: tree encoding




$$\mathcal{Z}((0,0,0,0), \{\mathit{makeVehicle}, \mathit{makeCar}, \mathit{makeBoat}\}, (2,1,1,0)) = \bigcup_{\omega \in \mathbb{I}((2,1,1,0))} \mathcal{Z}((0,0,0,0), \{\mathit{makeVehicle}, \mathit{makeCar}, \mathit{makeBoat}\}, \omega) =$$

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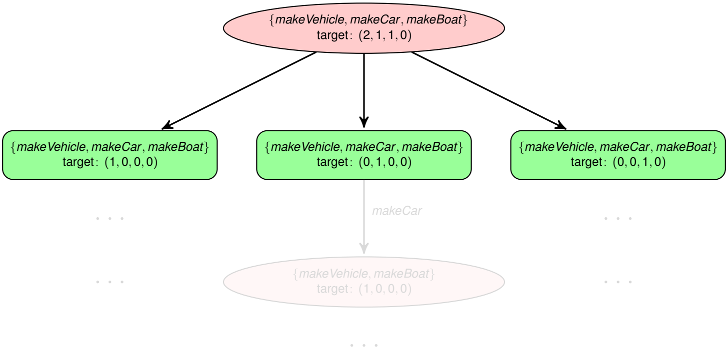


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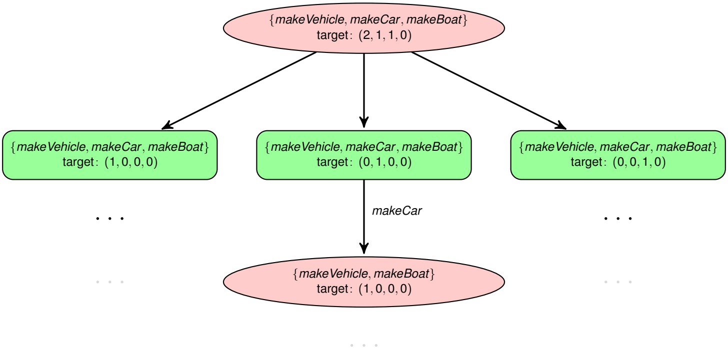


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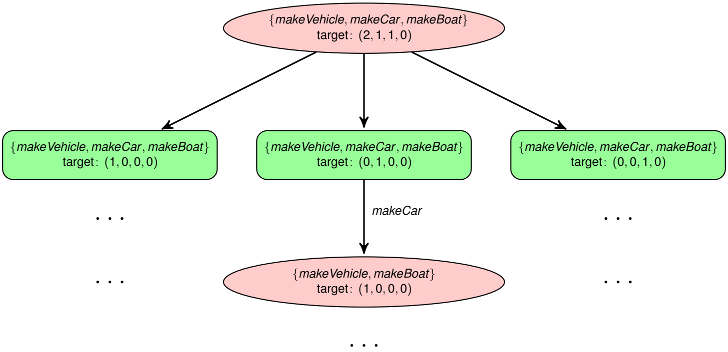


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# None-plans: the full tree unfolding

One can stop unfolding at depth $k$ to underapproximate the none-plan space.

# Back to the original domain

SMT-formulae encoding:

- $\mathcal{AP}$ – encoding of the **original domain** plan space (courtesy of PlanICS),
- $\mathcal{C_L}$ – blocking sets following from **Lemma B**,
- $\mathcal{NOP}^k$ – encoding of the **none-plan** space unfolding up to $k \in \mathbb{N} \cup \{\omega\}$

A new encoding in the **original domain** plan space:

$$\widetilde{\mathcal{AP}}^k = \mathcal{AP} \wedge \mathcal{C_L} \wedge \neg \mathcal{NOP}^k$$

A longer formula: easier or more difficult for an SMT-solver?

# Experimental results

Setup:

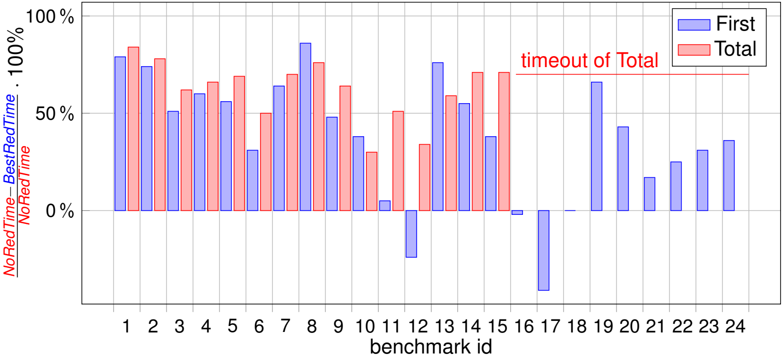
- random ontologies produced by Ontology Generator
- two experiments/ontology:

  **First** – single plan synthesis
  **Total** – all plan synthesis

Results for reduction:

- **First** – **usually** substantial speedup at **some** depth
- **Total** – **always** substantial speedup at **some** depth

# Experimental results, ct'd




*NoRedTime* – time without reduction
*BestRedTime* – best time with reduction

# Conclusions

- A new method for improving efficiency of algorithms solving hard problems,
- A new reduction method for planning,
- Application of the results in the tool PlanICS: quite impressive improvement in some cases,
- *SEFM 2015 Best Paper Award*.

Thank you!