Generating None-Plans in Order to Find Plans[1]

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[1] Best Paper Reward at SEFM'15

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, Cousot, ...],
- Partial order reductions [Valmari, Peled, Godefroid, ...],
- Symmetry reductions [Clarke, Emerson, Jha, Sistla, ...],
- CEGAR – Counterexample Guided Abstraction [Clarke et al.],
- and others.

General idea – intuition

- D – a domain to search for a **plan** (difficult task!),

- D' – an abstract domain in which finding a **plan** is easier,
- 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',

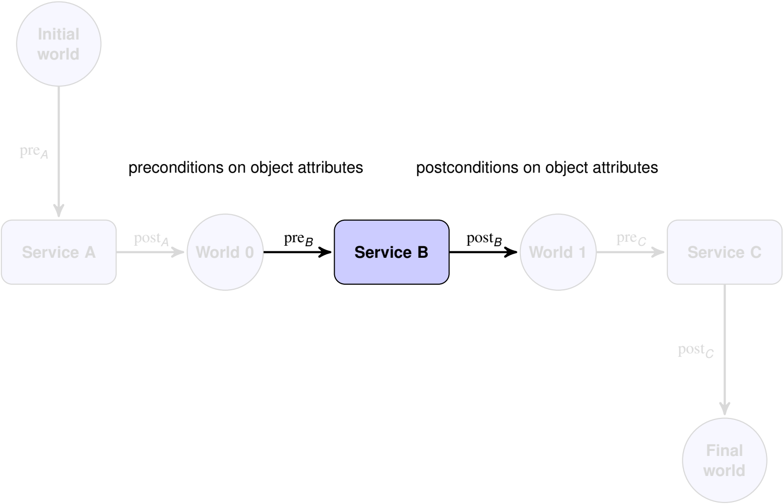
- prune D from (the) **none-plans** of D',
- search for (the) **plans** in D pruned.

Application to planning in PlanICS

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

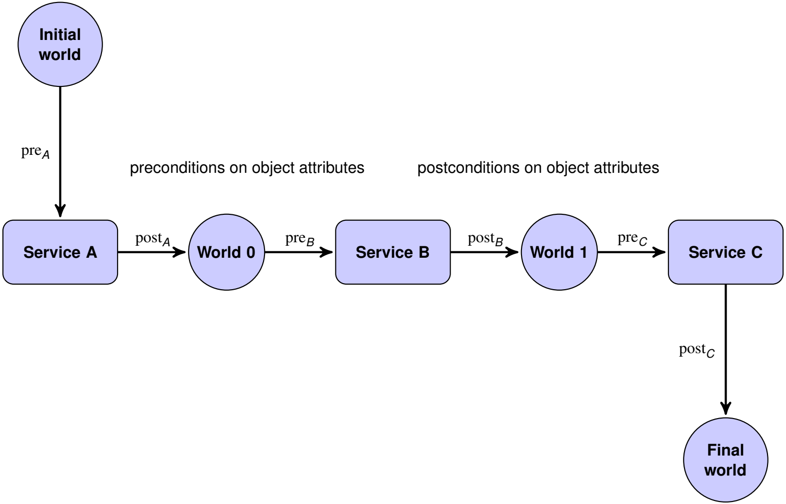
Task: Find all plans from some initial to some final world.
This problem is NP-complete.

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).

- Let B be a set of **services**,
- B' – the set of **simplified services** of B,
- **The main Property of Abstraction:** If B' **cannot** be composed into a **plan**, then B **cannot either.**
- **Goal:** synthesize constraints of non-composability.

(Abstract) Planning Domain

(Abstract) 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 act,
- $\mathrm{eff}(\mathrm{act})$ – **effect** of 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 act: $\omega \xrightarrow{\mathrm{act}} \omega + \mathrm{eff}(\mathrm{act})$

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

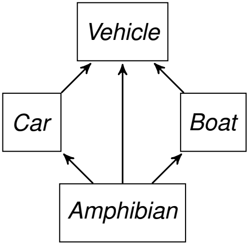
$$\pi = \omega_0 \stackrel{\text{act}_1}{\rightarrow} \omega_1 \stackrel{\text{act}_2}{\rightarrow} \dots \stackrel{\text{act}_{n-1}}{\rightarrow} \omega_{n-1} \stackrel{\text{act}_n}{\rightarrow} \omega_n$$

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

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

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

Exemplary planning domain

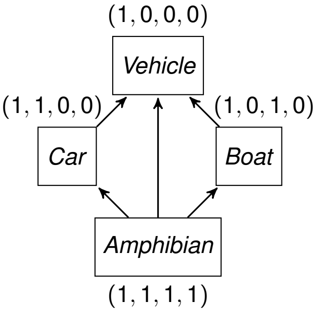


Vehicles' inheritance

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

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

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

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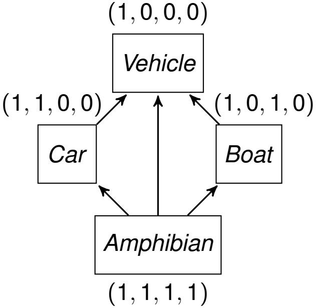

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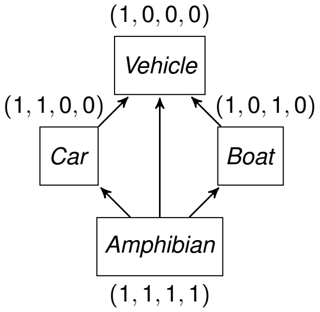

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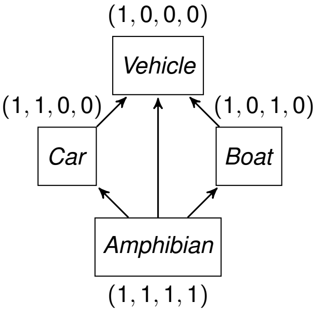

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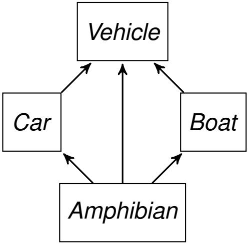

Vehicles' inheritance

Actions:

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

$\omega_I = (0, 0, 0, 0)$ (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 ω,
- $G_{i+1}^\omega = \mathrm{enact}(G_i^\omega)$ – 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 ω'.

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

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:

- 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 any plan starting at ω and covering ω'.

$\mathbb{I}(\omega) := \{\omega' \mid \|\omega'\| = 1 \wedge \omega \geq \omega'\}$ – unitary coordination vectors of ω

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

Characterisation of none-plans, ct'd

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

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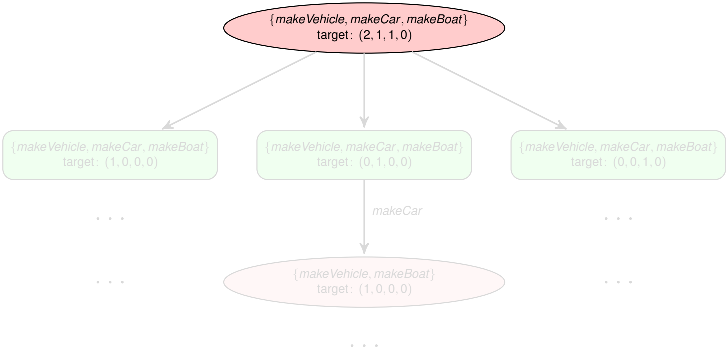
None-plans: tree encoding



$$\mathcal{Z}((0,0,0,0), \{\mathit{makeVehicle}, \mathit{makeCar}, \mathit{makeBoat}\}, (2,1,1,0)) =$$

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

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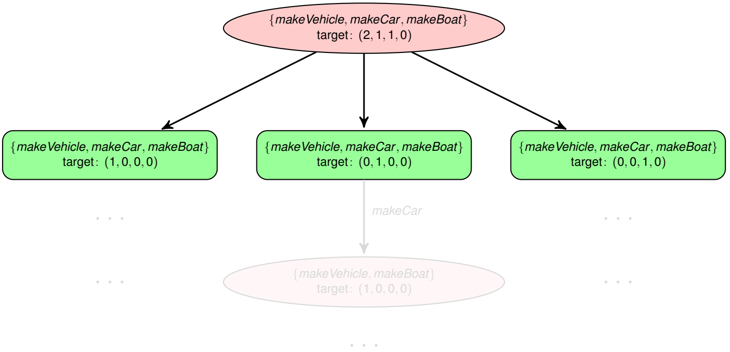

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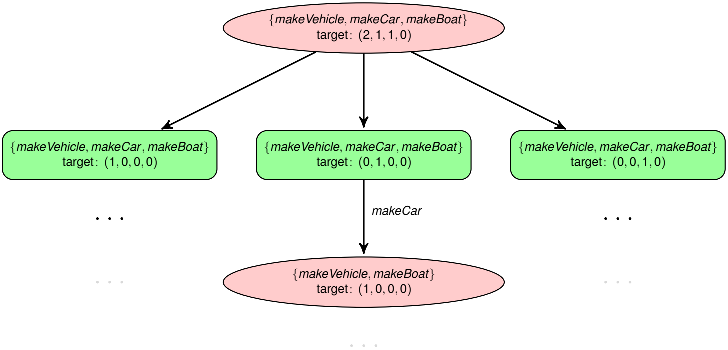

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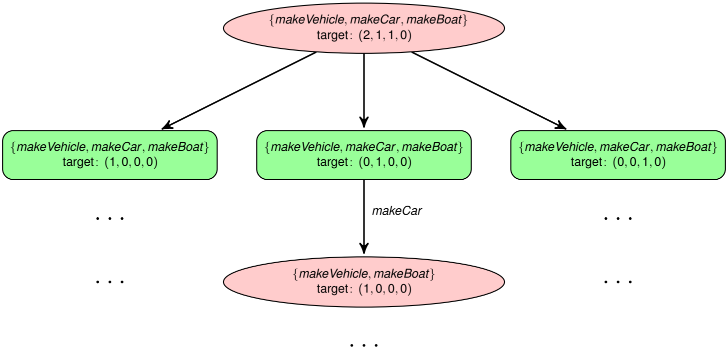

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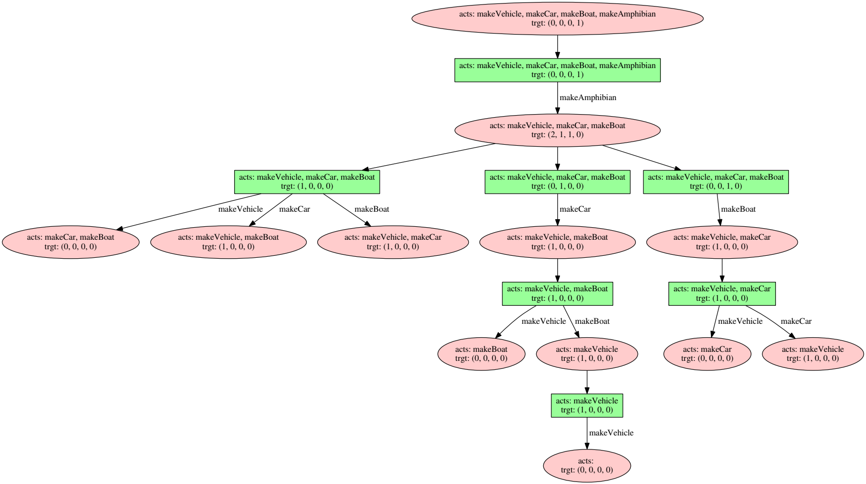
None-plans: the full tree unfolding



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

Back to the original domain

The SMT-formulae:

- $\mathcal{AP}$ – encoding of the **original domain** plan space (courtesy of PlanICS),
- $\mathcal{CL}$ – 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:

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

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

Experimental results

Setup:

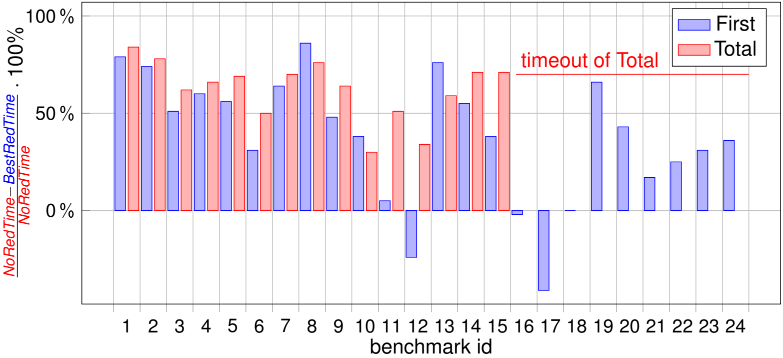
- random ontologies produced by Ontology Generator
- two experiments/ontology:

  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.

Thank you!