

Planning and Optimization

A6. Positive Normal Form and STRIPS

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Motivation

Example: Freecell



Example (Good and Bad Effects)

If we move $K♦$ to a free tableau position, the **good effect** is that $4♣$ is now accessible.

The **bad effect** is that we lose one free tableau position.

What is a Good or Bad Effect?

Question: Which operator effects are good, and which are bad?

Difficult to answer in general, because it depends on context:

- Locking our door is **good** if we want to keep burglars out.
- Locking our door is **bad** if we want to enter.

We will now consider a reformulation of planning tasks that makes the distinction between good and bad effects obvious.

Positive Normal Form

Positive Normal Form

Definition (Operator in Positive Normal Form)

An operator o is in **positive normal form** if it is in effect normal form, no negation symbols appear in $pre(o)$, and no negation symbols appear in any effect condition in $eff(o)$.

Definition (Planning Task in Positive Normal Form)

A planning task $\langle V, I, O, \gamma \rangle$ is in **positive normal form** if all operators in O are in positive normal form and no negation symbols occur in the goal γ .

Positive Normal Form: Existence

Theorem (Positive Normal Form)

For every planning task Π , there is an equivalent planning task Π' in positive normal form.

Moreover, Π' can be computed from Π in polynomial time.

Note: Equivalence here means that the transition systems induced by Π and Π' , restricted to the reachable states, are isomorphic.

We prove the theorem by describing a suitable algorithm.
(However, we do not prove its correctness or complexity.)

Positive Normal Form: Algorithm

Transformation of $\langle V, I, O, \gamma \rangle$ to Positive Normal Form

Convert all operators $o \in O$ to effect normal form.

Convert all conditions to negation normal form (NNF).

while any condition contains a negative literal $\neg v$:

Let v be a variable which occurs negatively in a condition.

$V := V \cup \{\hat{v}\}$ for some new state variable \hat{v}

$$I(\hat{v}) := \begin{cases} \mathbf{F} & \text{if } I(v) = \mathbf{T} \\ \mathbf{T} & \text{if } I(v) = \mathbf{F} \end{cases}$$

Replace the effect v by $(v \wedge \neg \hat{v})$ in all operators $o \in O$.

Replace the effect $\neg v$ by $(\neg v \wedge \hat{v})$ in all operators $o \in O$.

Replace $\neg v$ by \hat{v} in all conditions.

Convert all operators $o \in O$ to effect normal form (again).

Here, **all conditions** refers to all operator preconditions, operator effect conditions and the goal.

Example and Discussion

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

$$V = \{home, uni, lecture, bike, bike-locked\}$$

$$I = \{home \mapsto \mathbf{T}, bike \mapsto \mathbf{T}, bike-locked \mapsto \mathbf{T}, \\ uni \mapsto \mathbf{F}, lecture \mapsto \mathbf{F}\}$$

$$O = \{\langle home \wedge bike \wedge \neg bike-locked, \neg home \wedge uni \rangle, \\ \langle bike \wedge bike-locked, \neg bike-locked \rangle, \\ \langle bike \wedge \neg bike-locked, bike-locked \rangle, \\ \langle uni, lecture \wedge ((bike \wedge \neg bike-locked) \triangleright \neg bike) \rangle\}$$

$$\gamma = lecture \wedge bike$$

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

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$$O = \{\langle home \wedge bike \wedge \neg bike-locked, \neg home \wedge uni \rangle, \\ \langle bike \wedge bike-locked, \neg bike-locked \rangle, \\ \langle bike \wedge \neg bike-locked, bike-locked \rangle, \\ \langle uni, lecture \wedge ((bike \wedge \neg bike-locked) \triangleright \neg bike) \rangle\}$$

$$\gamma = lecture \wedge bike$$

Identify state variable v occurring negatively in conditions.

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

$$V = \{home, uni, lecture, bike, bike-locked, \textit{bike-unlocked}\}$$

$$I = \{home \mapsto \mathbf{T}, bike \mapsto \mathbf{T}, bike-locked \mapsto \mathbf{T}, \\ uni \mapsto \mathbf{F}, lecture \mapsto \mathbf{F}, \textit{bike-unlocked} \mapsto \mathbf{F}\}$$

$$O = \{\langle home \wedge bike \wedge \neg bike-locked, \neg home \wedge uni \rangle, \\ \langle bike \wedge bike-locked, \neg bike-locked \rangle, \\ \langle bike \wedge \neg bike-locked, bike-locked \rangle, \\ \langle uni, lecture \wedge ((bike \wedge \neg bike-locked) \triangleright \neg bike) \rangle\}$$

$$\gamma = lecture \wedge bike$$

Introduce new variable \hat{v} with complementary initial value.

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

$$V = \{home, uni, lecture, bike, bike-locked, bike-unlocked\}$$
$$I = \{home \mapsto \mathbf{T}, bike \mapsto \mathbf{T}, bike-locked \mapsto \mathbf{T}, \\ uni \mapsto \mathbf{F}, lecture \mapsto \mathbf{F}, bike-unlocked \mapsto \mathbf{F}\}$$
$$O = \{\langle home \wedge bike \wedge \neg bike-locked, \neg home \wedge uni \rangle, \\ \langle bike \wedge bike-locked, \neg bike-locked \rangle, \\ \langle bike \wedge \neg bike-locked, bike-locked \rangle, \\ \langle uni, lecture \wedge ((bike \wedge \neg bike-locked) \triangleright \neg bike) \rangle\}$$
$$\gamma = lecture \wedge bike$$

Identify effects on variable v .

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

$$V = \{home, uni, lecture, bike, bike-locked, bike-unlocked\}$$
$$I = \{home \mapsto \mathbf{T}, bike \mapsto \mathbf{T}, bike-locked \mapsto \mathbf{T}, \\ uni \mapsto \mathbf{F}, lecture \mapsto \mathbf{F}, bike-unlocked \mapsto \mathbf{F}\}$$
$$O = \{\langle home \wedge bike \wedge \neg bike-locked, \neg home \wedge uni \rangle, \\ \langle bike \wedge bike-locked, \neg bike-locked \wedge bike-unlocked \rangle, \\ \langle bike \wedge \neg bike-locked, bike-locked \wedge \neg bike-unlocked \rangle, \\ \langle uni, lecture \wedge ((bike \wedge \neg bike-locked) \triangleright \neg bike) \rangle\}$$
$$\gamma = lecture \wedge bike$$

Introduce complementary effects for \hat{v} .

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

$$V = \{home, uni, lecture, bike, bike-locked, bike-unlocked\}$$
$$I = \{home \mapsto \mathbf{T}, bike \mapsto \mathbf{T}, bike-locked \mapsto \mathbf{T}, \\ uni \mapsto \mathbf{F}, lecture \mapsto \mathbf{F}, bike-unlocked \mapsto \mathbf{F}\}$$
$$O = \{\langle home \wedge bike \wedge \neg bike-locked, \neg home \wedge uni \rangle, \\ \langle bike \wedge bike-locked, \neg bike-locked \wedge bike-unlocked \rangle, \\ \langle bike \wedge \neg bike-locked, bike-locked \wedge \neg bike-unlocked \rangle, \\ \langle uni, lecture \wedge ((bike \wedge \neg bike-locked) \triangleright \neg bike) \rangle\}$$
$$\gamma = lecture \wedge bike$$

Identify negative conditions for v .

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

$$V = \{home, uni, lecture, bike, bike-locked, bike-unlocked\}$$
$$I = \{home \mapsto \mathbf{T}, bike \mapsto \mathbf{T}, bike-locked \mapsto \mathbf{T}, \\ uni \mapsto \mathbf{F}, lecture \mapsto \mathbf{F}, bike-unlocked \mapsto \mathbf{F}\}$$
$$O = \{\langle home \wedge bike \wedge \mathit{bike-unlocked}, \neg home \wedge uni \rangle, \\ \langle bike \wedge bike-locked, \neg bike-locked \wedge bike-unlocked \rangle, \\ \langle bike \wedge \mathit{bike-unlocked}, bike-locked \wedge \neg bike-unlocked \rangle, \\ \langle uni, lecture \wedge ((bike \wedge \mathit{bike-unlocked}) \triangleright \neg bike) \rangle\}$$
$$\gamma = lecture \wedge bike$$

Replace by positive condition \hat{v} .

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

$$V = \{ \textit{home}, \textit{uni}, \textit{lecture}, \textit{bike}, \textit{bike-locked}, \textit{bike-unlocked} \}$$
$$I = \{ \textit{home} \mapsto \mathbf{T}, \textit{bike} \mapsto \mathbf{T}, \textit{bike-locked} \mapsto \mathbf{T}, \\ \textit{uni} \mapsto \mathbf{F}, \textit{lecture} \mapsto \mathbf{F}, \textit{bike-unlocked} \mapsto \mathbf{F} \}$$
$$O = \{ \langle \textit{home} \wedge \textit{bike} \wedge \textit{bike-unlocked}, \neg \textit{home} \wedge \textit{uni} \rangle, \\ \langle \textit{bike} \wedge \textit{bike-locked}, \neg \textit{bike-locked} \wedge \textit{bike-unlocked} \rangle, \\ \langle \textit{bike} \wedge \textit{bike-unlocked}, \textit{bike-locked} \wedge \neg \textit{bike-unlocked} \rangle, \\ \langle \textit{uni}, \textit{lecture} \wedge ((\textit{bike} \wedge \textit{bike-unlocked}) \triangleright \neg \textit{bike}) \rangle \}$$
$$\gamma = \textit{lecture} \wedge \textit{bike}$$

Why Positive Normal Form is Interesting

In positive normal form, good and bad effects are easy to distinguish:

- Effects that make state variables true (**add effects**) are good.
- Effects that make state variables false (**delete effects**) are bad.

This is particularly useful for planning algorithms based on **delete relaxation**, which we will study later in this course.

STRIPS

STRIPS Operators and Planning Tasks

Definition (STRIPS Operator)

An operator o is a **STRIPS operator** if

- $pre(o)$ is a conjunction of state variables, and
- $eff(o)$ is a conjunction of atomic effects.

Definition (STRIPS Planning Task)

A planning task $\langle V, O, I, \gamma \rangle$ is a **STRIPS planning task** if all operators $o \in O$ are STRIPS operators and γ is a conjunction of state variables.

STRIPS Operators: Remarks

- Every STRIPS operator is of the form

$$\langle v_1 \wedge \cdots \wedge v_n, \quad \ell_1 \wedge \cdots \wedge \ell_m \rangle$$

where v_i are state variables and ℓ_j are atomic effects.

- Often, STRIPS operators o are described via three **sets** of state variables:
 - the **preconditions** (state variables occurring in $pre(o)$)
 - the **add effects** (state variables occurring positively in $eff(o)$)
 - the **delete effects** (state variables occurring negatively in $eff(o)$)
- There exists a variant called **STRIPS with negation** where negative literals are also allowed in conditions.

Why STRIPS is Interesting

- STRIPS operators are **particularly simple**, yet expressive enough to capture general planning tasks.
- In particular, STRIPS planning is **no easier** than planning in general.
- Most algorithms in the planning literature are **only presented for STRIPS operators** (generalization is often, but not always, obvious).

STRIPS

STanford Research Institute Planning System
(Fikes & Nilsson, 1971)

Transformation to STRIPS

- Not every operator is equivalent to a STRIPS operator.
- However, each operator can be transformed into a **set** of STRIPS operators whose “combination” is equivalent to the original operator. (How?)
- However, this transformation may exponentially increase the number of operators. There are planning tasks for which such a blow-up is unavoidable.
- There are polynomial transformations of planning tasks to STRIPS, but these do not lead to isomorphic transition system (e.g., auxiliary transitions may be needed). (They are, however, equivalent in a weaker sense.)

Summary

Summary

- **Positive normal form** allows distinguishing good and bad effects.
- **STRIPS** is even more restrictive than positive normal form, forbidding complex preconditions and conditional effects.
- Both forms are expressive enough to capture general planning tasks.
- Transformation to positive normal form is possible with polynomial size increase.
- Isomorphic transformations of planning tasks to STRIPS can increase the number of operators exponentially; non-isomorphic polynomial transformations exist.