Planning and Optimization
A6. Positive Normal Form and STRIPS

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October 6, 2016

A6.1 Motivation

Example: Freecell
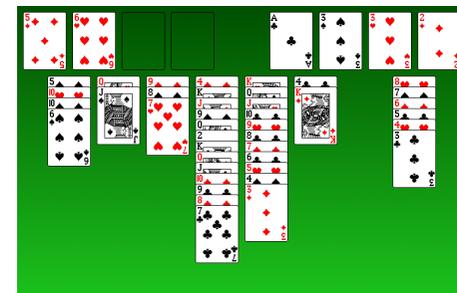
Example (Good and Bad Effects)

If we move K$\diamond$ to a free tableau position,
the good effect is that 4$\clubsuit$ 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.

A6.2 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.

A6.3 Example and Discussion

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

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

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

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

Identify state variable v occurring negatively in conditions.

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

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

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

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

$\gamma = lecture \wedge bike$

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

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

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

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

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

$\gamma = lecture \wedge bike$

Identify effects on variable v.

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

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

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

$O = \{\langle home \wedge bike \wedge \neg bike\text{-}locked, \neg home \wedge uni\rangle,$
$\quad \langle bike \wedge bike\text{-}locked, \neg bike\text{-}locked \wedge bike\text{-}unlocked\rangle,$
$\quad \langle bike \wedge \neg bike\text{-}locked, bike\text{-}locked \wedge \neg bike\text{-}unlocked\rangle,$
$\quad \langle uni, lecture \wedge ((bike \wedge \neg bike\text{-}locked) \rhd \neg bike)\rangle\}$

$\gamma = lecture \wedge bike$

Introduce complementary effects for $\hat{v}$.

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

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

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

$O = \{\langle home \wedge bike \wedge \neg bike\text{-}locked, \neg home \wedge uni\rangle,$
$\quad \langle bike \wedge bike\text{-}locked, \neg bike\text{-}locked \wedge bike\text{-}unlocked\rangle,$
$\quad \langle bike \wedge \neg bike\text{-}locked, bike\text{-}locked \wedge \neg bike\text{-}unlocked\rangle,$
$\quad \langle uni, lecture \wedge ((bike \wedge \neg bike\text{-}locked) \rhd \neg bike)\rangle\}$

$\gamma = lecture \wedge bike$

Identify negative conditions for v.

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

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

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

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

$\gamma = lecture \wedge bike$

Replace by positive condition $\hat{v}$.

Positive Normal Form: Example

Example (Transformation to Positive Normal Form)

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

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

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

$\gamma = lecture \wedge bike$

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.

A6.4 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.)

A6.5 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.