# On Weak Stubborn Sets in Classical Planning

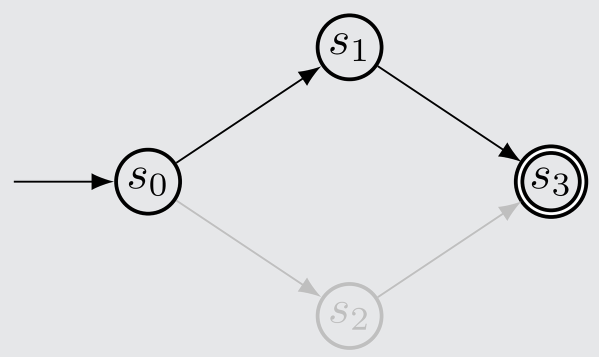
Silvan Sievers[1] Martin Wehrle

[1]University of Basel, Switzerland

## TL;DR

### Setting

- optimal classical planning
- A* search with safe pruning:
  - consider subset of applicable operators at expansion
  - guarantee optimality




### Contributions

- previously called "weak stubborn sets" (now: compliant stubborn sets) are not stubborn sets in Valmari's sense
- generalized weak stubborn sets (GWSS) reflect original definition and satisfy "operator shifting property"
- GWSS higher pruning power than GSSS and incomparable pruning power with CSS

## SAS⁺ Planning Tasks

planning tasks $\Pi = \langle \mathcal{V}, \mathcal{O}, s_0, s_\star \rangle$

- $\mathcal{V}$: finite-domain state variables $v$ with domain $\mathcal{D}(v)$
  - atom: $\{v \mapsto p\}$, $p \in \mathcal{D}(v)$
  - (partial) state: set of atoms
- $\mathcal{O}$: operators $o$ with partial states precondition $pre(o)$ and effect $eff(o)$, and $cost(o) \in \mathbb{R}_0^+$
  - $o$ applicable if $pre(o) \subseteq s$
  - $o(s)$: successor state updated according to $eff(o)$
- $s_0$: initial state
- $s_\star$: partial goal state

## State-based Interference

$o_1$ weakly interferes with $o_2$ in state $s$ if

- $o_1$ disables $o_2$ in $s$: $o_2$ not applicable in $o_1(s)$, or
- $o_1$ and $o_2$ conflict in $s$: $o_2(o_1(s)) \neq o_1(o_2(s))$

$o_1$ interferes with $o_2$ in state $s$ if

- $o_1$ weakly interferes with $o_2$ in $s$, or
- $o_2$ disables $o_1$

## Syntax-Based Interference

$o_1$ syntactically weakly interferes with $o_2$ if

- $\{v \mapsto p\} \in eff(o_1)$ and $\{v \mapsto p'\} \in pre(o_2)$ ("disables"), or
- $\{v \mapsto p\} \in eff(o_1)$ and $\{v \mapsto p'\} \in eff(o_2)$ ("conflicts")

$o_1$ syntactically interferes with $o_2$ if

- $o_1$ syntactically wekly interferes with $o_2$, or
- $\{v \mapsto p\} \in eff(o_2)$ and $\{v \mapsto p'\} \in pre(o_1)$ ("disables")

## Stubborn Sets

### Generalized Strong Stubborn Sets (GSSS)

$Opt$: all strongly optimal plans for state $s$; $S_{Opt}$: all states visited by plans in $Opt$

Operator subset $T \subseteq \mathcal{O}$ GSSS in $s$ if:

C1 $T$ contains at least one operator from at least one plan from $Opt$ (approximation: include disjunctive action landmark for $s$)

C2 for all $o \in T$ not applicable in $s$, $T$ contains necessary enabling set for $o$ and $Opt$ (approximation: include achievers of $o$)

C3 for all $o \in T$ applicable in $s$, $T$ contains all $o'$ which interfere with $o$ in any state from $S_{Opt}$ (approximation: syntax-based interference)

### Generalized Weak Stubborn Sets (GWSS)

Like GSSS, but with C3' instead of C3

C3' for all $o \in T$ applicable in $s$, $T$ contains all $o'$ s.t. $o$ weakly interferes with $o'$ in any state from $S_{Opt}$, and additionally: for all $\{v \mapsto p\} \in pre(o)$, $T$ either contains all disablers or enablers on $\{v \mapsto p\}$ of $o$ in any state from $S_{Opt}$

### Compliant Stubborn Sets (CSS)

previously called "weak stubborn sets" in the planning literature

operator subset $T \subseteq \mathcal{O}$ CSS in state $s$ if:

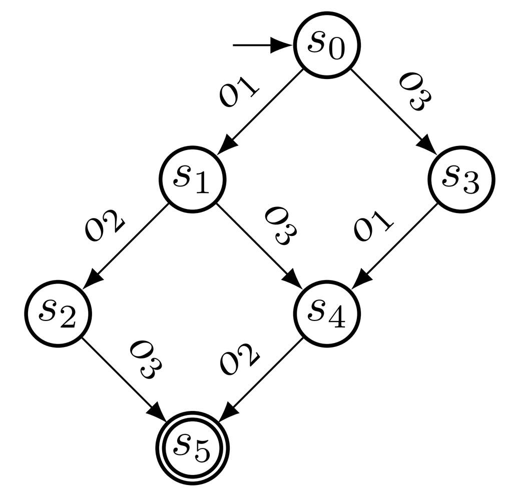
- $T$ contains disjunctive action landmark for $s$
- for all $o \in T$ not applicable in $s$, $T$ contains necessary enabling set for $o$ and all applicable operator sequences in $s$
- for all $o \in T$ applicable in $s$, $T$ contains all $o'$ s.t. $o$ syntactically weakly interferes with $o'$

### Operator Shifting Property

Operator subset $T \subseteq \mathcal{O}$ has the operator shifting property in state $s$ if for all plans $\pi$ for $s$,

- shifting the first operator $o$ from $\pi$ which is also in $T$ to the front results in a plan $\pi'$ for $s$, and
- $o$ is applicable in all intermediate states before its application when executing $\pi$.

## Examples




$T = \{o_3\}$:

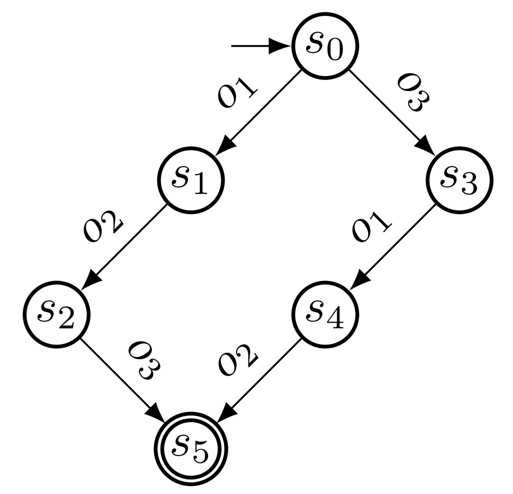
- GSSS in $s_0$
- satisfies the operator shifiting property in $s_0$

planning task with:

- $s_0 = \{v \mapsto 0, X \mapsto 0, Y \mapsto 0, Z \mapsto 0\}$
- $s_\star = \{X \mapsto 1, Y \mapsto 1, Z \mapsto 1\}$
- $pre(o_1) = \{v \mapsto 0\}$, $eff(o_1) = \{v \mapsto 1, X \mapsto 1\}$
- $pre(o_2) = \{v \mapsto 1\}$, $eff(o_2) = \{v \mapsto 0, Y \mapsto 1\}$
- $pre(o_3) = \{v \mapsto 0\}$, $eff(o_3) = \{Z \mapsto 1\}$

$T = \{o_3\}$:

- not a GSSS in $s_0$ ($T = \{o_1, o_3\}$ GSSS because $o_1$ disables $o_3$ in $s_0$)
- no longer satisfies operator shifting property in $s_0$
- CSS in $s_0$ ($o_3$ does not syntactically weakly interfere with $o_1$)
- not a GWSS in $s_0$: C3' requires including all disablers or all enablers of $\{v \mapsto 0\}$: disablers $\rightsquigarrow T = \{o_1, o_3\}$ (= GSSS); enablers $\rightsquigarrow T = \{o_2, o_3\}$




## Properties of GWSS

- safe pruning
- satisfy operator shifting property
- exponentially higher pruning power than GSSS: choosing all disablers in condition C3' leads to GSSS
- comparison with CSS:
  - CSS stricter due to restriction to syntactic interference
  - CSS less restrictive due to not requiring operator shifting property
  - incomparable pruning power

## Experimental Results