## Why classical constraints are not enough? Lin's suitcase example

- Domain description

  **always** $up_1 \wedge up_2 \Rightarrow open$

  $flip_1$ **causes** $up_1$

  $flip_2$ **causes** $up_2$

  **initially** $up_1, \neg up_2, \neg open$

- What happens if we do $flip_2$? I.e., what is $\Phi(flip_2, \{up_1\}$?
  - $\{up_1, up_2\}$ is not a valid state.
  - Intuitively: $\Phi(flip_2, \{up_1\})$ contains $\{up_1, up_2, open\}$.
  - But what about $\{up_2\}$?

    Note: $up_1 \wedge up_2 \Rightarrow open$ is logically equivalent to $\neg open \wedge up_2 \Rightarrow \neg up_1$.

# Adding static causality to $\mathcal{A}_0$

- Static Causal rules: $p_1, \ldots, p_n$ **s_causes** $f$, where $p_1, \ldots, p_n$ are fluent literals and $f$ is either a fluent literal or the symbol $\perp$ (which is a special symbol and not a fleunt literal).
- Interpretation: A consistent set of fluent literals involving all the fluents.
- A set of fluent literals $S$ is said to be closed with respect to a set of static causal rules $R$, if for each static causal rule of the form $p_1, \ldots, p_n$ **s_causes** $f$ in $R$, $\{p_1, \ldots, p_n\} \subseteq S$ implies that $f \in S$.
- Given a set of fluent literals $S$, and a set of static causal rules $R$, $Cn_R(S)$, the closure of $S$ with respect to $R$ is the smallest (w.r.t. $\subseteq$) set that contains $S$ and that is closed w.r.t. $R$.
- $E_a(s) = \{f \ : \ a$ **causes** $f$ **if** $p_1, \ldots, p_k \in D$ and $\{p_1, \ldots, p_n\} \subseteq s\}$.
- $\Phi(a, s) = \{s' \ : \ s' = Cn_R((s \cap s') \cup E_a(s))$ and $s'$ is an interpretation $\}$.

# Lin's suitcase example revisited

- Domain description

  $up_1, up_2$ **s_causes** $open$

  $flip_1$ **causes** $up_1$

  $flip_2$ **causes** $up_2$

  **initially** $up_1, \neg up_2, \neg open$

- $s = \{up_1, \neg up_2, \neg open\}$.

- Let $s' = \{up_1, up_2, open\}$.
  - $s \cap s' = \{up_1\}$; $E_{flip_2}(s) = \{up_2\}$.
  - $Cn((s \cap s') \cup E_{flip_2}(s)) = Cn(\{up_1, up_2\}) = \{up_1, up_2, open\} = s'$.
  - Hence, $s' \in \Phi(flip_2, s)$.

- Let $s'' = \{\neg up_1, up_2, \neg open\}$.
  - $s \cap s'' = \{\neg open\}$; $E_{flip_2}(s) = \{up_2\}$.
  - $Cn((s \cap s'') \cup E_{flip_2}(s)) = Cn(\{\neg open, up_2\}) = \{up_2, \neg open\} \neq s''$.
  - Hence, $s'' \notin \Phi(flip_2, s)$.

## An example with a non-deterministic transition function

- Domain description
  - $f, g$ **s_causes** $\neg h$
  - $f, h$ **s_causes** $\neg g$.
  - **initially** $\neg f, g, h$
  - $make_f$ **causes** $f$.
- Computing $\Phi(make_f, \{\neg f, g, h\})$
  - $s = \{\neg f, g, h\}$. $E_{make_f}(s) = \{f\}$.
  - $s' = \{f, g, \neg h\}$. $s \cap s' = \{g\}$.
    $Cn((s \cap s') \cup E_{make_f}(s)) = Cn(\{f, g\}) = \{f, g, \neg h\} = s'$.
  - $s'' = \{f, \neg g, h\}$. $s \cap s'' = \{h\}$.
    $Cn((s \cap s'') \cup E_{make_f}(s)) = Cn(\{f, h\}) = \{f, \neg g, h\} = s''$.
  - $s''' = \{f, g, h\}$. $s \cap s''' = \{g, h\}$.
    $Cn((s \cap s'') \cup E_{make_f}(s)) = Cn(\{f, g, h\}) = \{f, g, \neg g, h, \neg h\} \neq s'''$.
  - $\Phi(make_f, \{\neg f, g, h\}) = \{s', s''\}$

# Ramification and qualification

- Domain description
  - $kill$ **causes** $\neg alive$
  - $make\_walk$ **causes** $walking$
  - $\neg alive$ **s_causes** $\neg walking$
- $s_1 = \{walking, alive\}$; $s_2 = \{\neg alive, \neg walking\}$.
- $\Phi(kill, s_1) = \{s_2\}$.
  $s_2 \cap s_1 = \emptyset$; $E_{kill}(s_1) = \{\neg alive\}$. $Cn(\{\neg alive\}) = \{\neg alive, \neg walking\} = s_2$.
- $\Phi(make\_walk, s_2) = \{\}$. **i.e.,** $make\_walk$ **can not be executed in** $s_2$
  - $E_{make\_walk}(s_2) = \{walking\}$.
  - $s' = \{walking, \neg alive\}$. $s' \cap s_2 = \{\neg alive\}$.
    $Cn(\{walking, \neg alive\}) = \{walking, \neg alive, \neg walking\} \neq s'$. Hence, $s' \notin E_{make\_walk}(s_2)$.
  - $s'' = \{walking, alive\}$. $s'' \cap s_2 = \{\}$. $Cn(\{walking\}) = \{walking\} \neq s''$.
    Hence, $s'' \notin E_{make\_walk}(s_2)$.

# Using $\perp$

- Ramification
  - $f$ **s_causes** $\neg g$
  - $make\_f$ **causes** $f$
  - $\Phi(make\_f, \{\neg f, g\}) = \{\{f, \neg g\}\}$.
- Qualification
  - $f, g$ **s_causes** $\perp$
  - $make\_f$ **causes** $f$
  - $\Phi(make\_f, \{\neg f, g\}) = \{\}$.