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Center

Translating PDDL into NDDL

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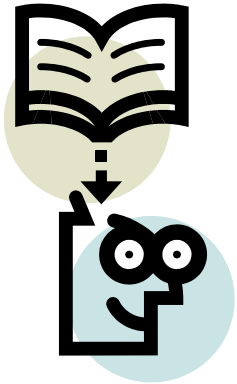
More than you ever wanted to know



PDDL 1.1

Drive (?trk-truck, ?loc1-location, ?loc2-location)

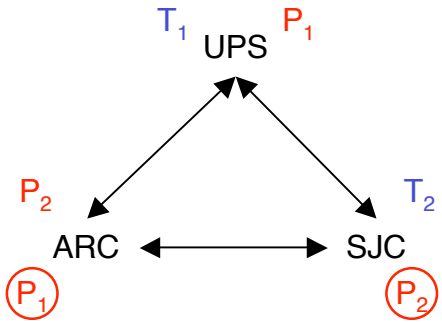
pre: at(?trk, ?loc1)
eff: ¬at(?trk, ?loc1)
at(?trk,?loc2)

Load (?pkg-package,?trk-truck)

pre: at(?trk, ?loc)
at(?pkg, ?loc)
eff: ¬at(?pkg, ?loc)
in(?pkg,?trk)

Unload (?pkg-package,?trk-truck)

pre: at(?trk, ?loc)
in(?pkg, ?trk)
eff: ¬in(?pkg, ?trk)
at(?pkg,?loc)



T_1, T_2 – truck
P_1, P_2 – package
ARC, UPS, SJC – location

Init: at(T_1, UPS)
at(T_2, SJC)
at(P_1, UPS)
at(P_2, ARC)

Goal: at(P_1, ARC)
at(P_2, SJC)

PDDL 2.1

Drive (?trk, ?loc1, ?loc2)

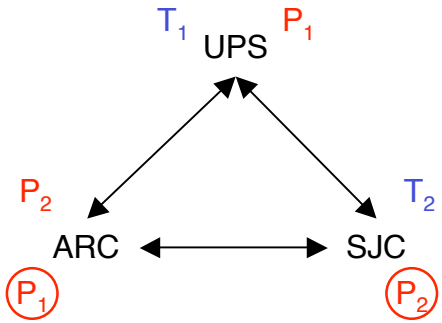
pre: at-start at(?trk, ?loc1)
eff: at-start ¬at(?trk, ?loc1)
et-end at(?trk,?loc2)

Load (?pkg,?trk)

pre: at-start &
over-all at(?trk, ?loc)
at-start at(?pkg, ?loc)
eff: at-start ¬at(?pkg, ?loc)
at-end in(?pkg,?trk)

Unload (?pkg,?trk)

pre: at-start &
over-all at(?trk, ?loc)
at-start in(?pkg, ?trk)
eff: at-start ¬in(?pkg, ?trk)
at-end at(?pkg,?loc)



T_1, T_2 – truck
P_1, P_2 – package
ARC, UPS, SJC – location

Init: at(T_1, UPS)
at(T_2, SJC)
at(P_1, UPS)
at(P_2, ARC)

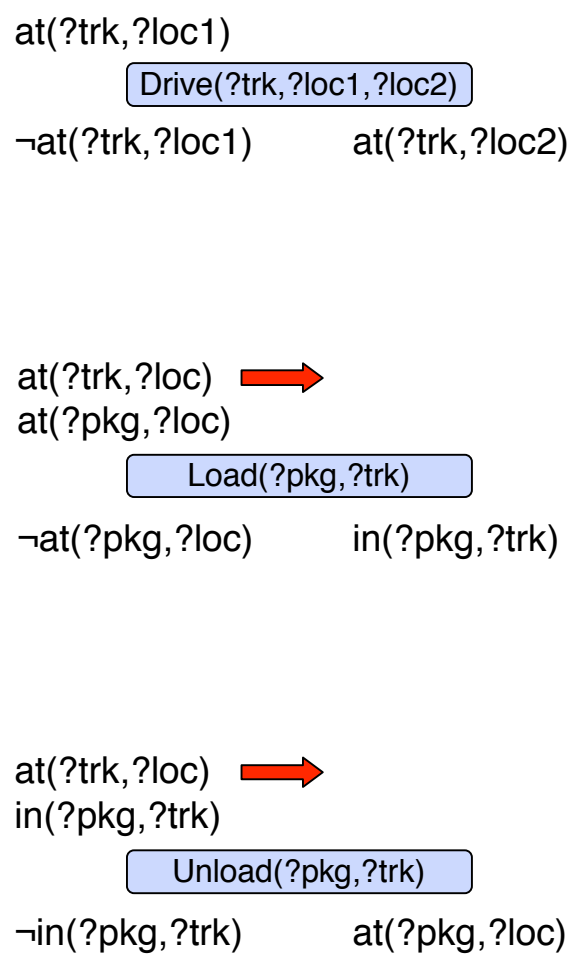
Goal: at(P_1, ARC)
at(P_2, SJC)

PDDL 2.1

```
Drive (?trk, ?loc1, ?loc2)
    pre:    at-start  at(?trk, ?loc1)
    eff:    at-start  ¬at(?trk, ?loc1)
            et-end    at(?trk,?loc2)

Load (?pkg,?trk)
    pre:    at-start
            over-all  at(?trk, ?loc)
            at-start  at(?pkg, ?loc)
    eff:    at-start  ¬at(?pkg, ?loc)
            at-end    in(?pkg,?trk)

Unload (?pkg,?trk)
    pre:    at-start
            over-all  at(?trk, ?loc)
            at-start  in(?pkg, ?trk)
    eff:    at-start  ¬in(?pkg, ?trk)
            at-end    at(?pkg,?loc)
```



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NDDL

Timelines

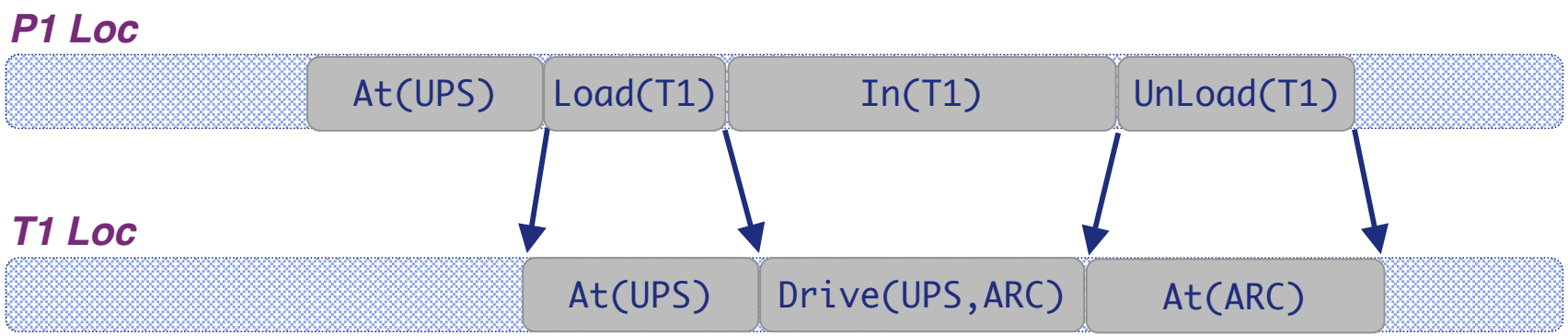
PkgLoc(p):
- Predicates: At(loc l) [0,∞]
  In(truck t) [0,∞]
  Load(truck t) [10,10]
  Unload(truck t) [10,10]

TrkLoc(t):
- Predicates: At(loc l) [0,∞]
  Drive(loc l1, loc l2) [20,20]

Compatabilities

PkgLoc(p)

In(truck t)	met-by Load(truck t) meets Unload(truck t)
Load(truck t)	met-by At(loc l) meets In(truck t) contained-by TrkLoc(truck t).At(loc l)
UnLoad(truck t)	met-by In(truck t) meets At(loc l) contained-by TrkLoc(truck t).At(loc l)



Naive Translation

Drive (?trk, ?loc1, ?loc2)

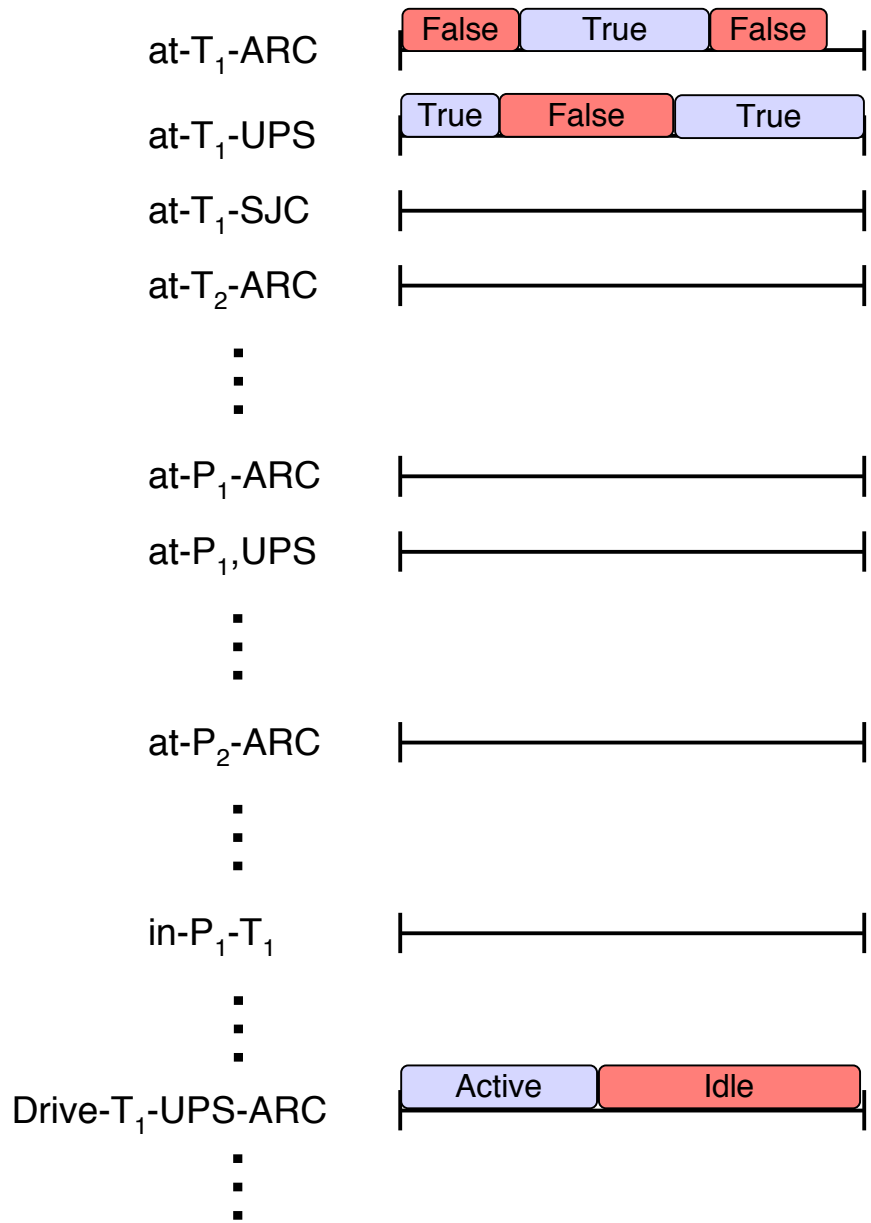
pre:	at-start	at(?trk, ?loc1)
eff:	at-start	¬at(?trk, ?loc1)
	et-end	at(?trk,?loc2)

Load (?pkg,?trk)

pre:	at-start	
	over-all	at(?trk, ?loc)
	at-start	at(?pkg, ?loc)
eff:	at-start	¬at(?pkg, ?loc)
	at-end	in(?pkg,?trk)

Unload (?pkg,?trk)

pre:	at-start	
	over-all	at(?trk, ?loc)
	at-start	in(?pkg, ?trk)
eff:	at-start	¬in(?pkg, ?trk)
	at-end	at(?pkg,?loc)



What We Want

Drive (?trk, ?loc1, ?loc2)

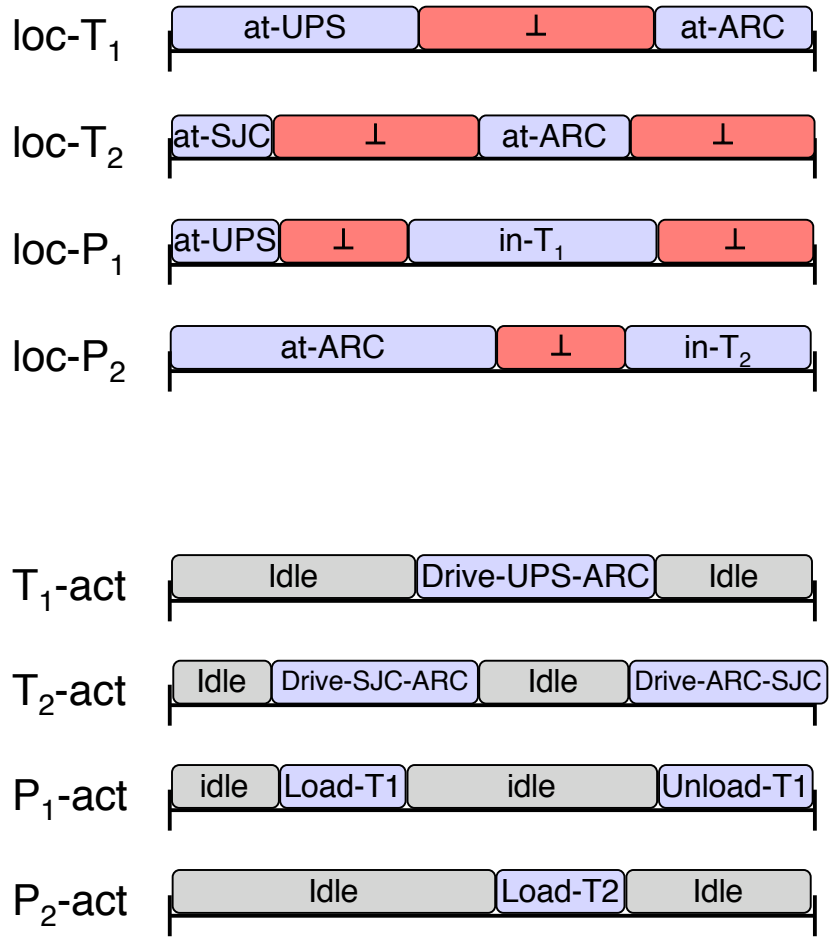
pre: at-start at(?trk, ?loc1)
eff: at-start ¬at(?trk, ?loc1)
et-end at(?trk,?loc2)

Load (?pkg,?trk)

pre: at-start
over-all at(?trk, ?loc)
at-start at(?pkg, ?loc)
eff: at-start ¬at(?pkg, ?loc)
at-end in(?pkg,?trk)

Unload (?pkg,?trk)

pre: at-start
over-all at(?trk, ?loc)
at-start in(?pkg, ?trk)
eff: at-start ¬in(?pkg, ?trk)
at-end at(?pkg,?loc)



History

- Helmert 2006:thesis, 2009:AIJ

  non-numerical & ***non-temporal*** PDDL
  to Multi-valued Planning Task (MPT).

  MPT: *- Multi-valued State Variables*
  - Operators: preconditions--effects

  Similar steps, but:

  - Temporal Extension of the MPT formalism
  - New Invariant Synthesis Algorithm
  - Identification of Mutex Operators
  - Complex compatibilities synthesis

- Gerevini and Schubert 2000: Discoplan

- Fox and Long 1998: TIM

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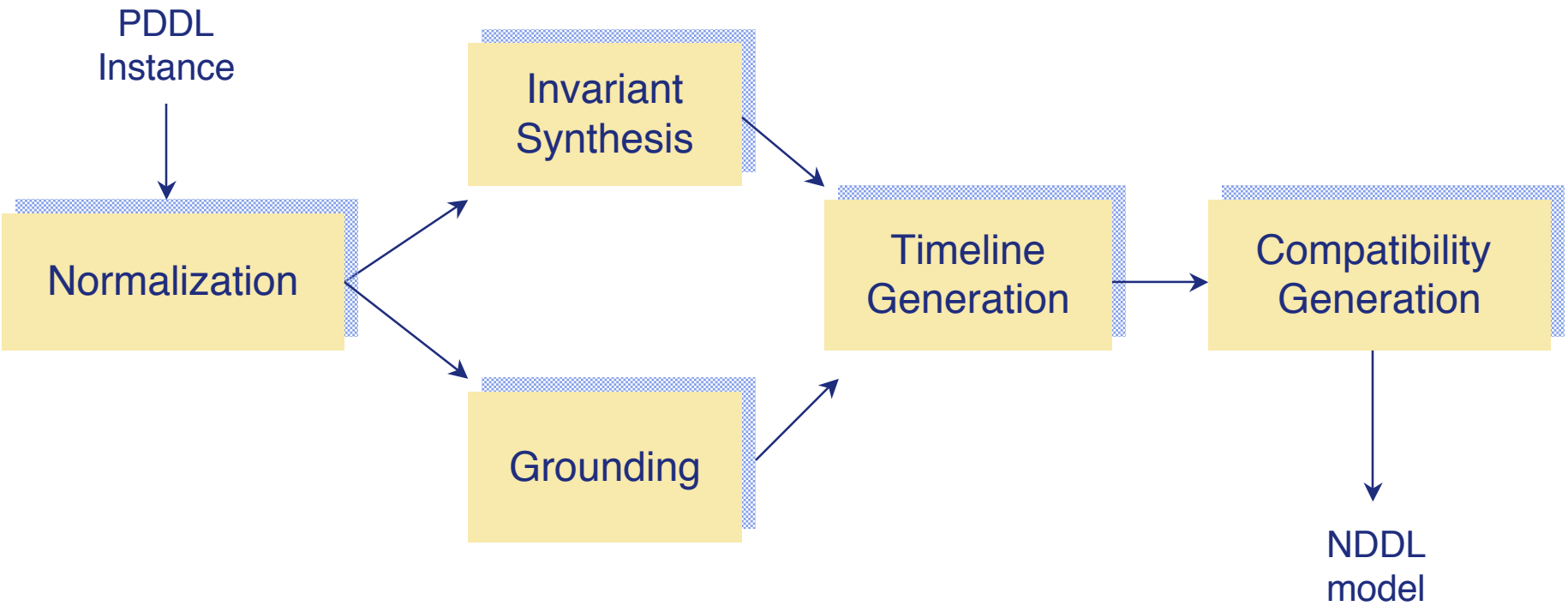
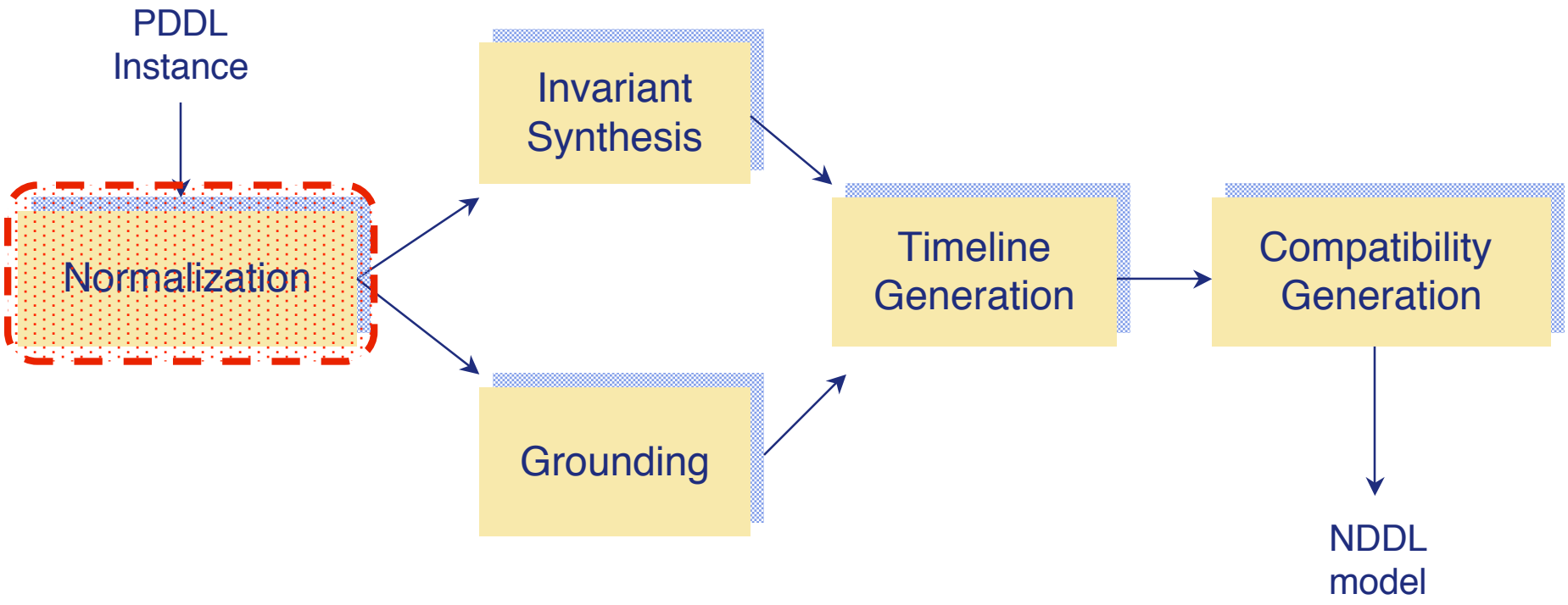
Translation Steps



Translation Steps



Normalization

[Helmert-2009]

Normalization: 3 tasks

1. Compiles away ***types***
2. Simplify ***conditions***
   - -goal formula
   - -axiom bodies
   - -operator conditions
   - -conditions of conditional effects
3. Simplify ***effects***

Eliminating Types

[Helmert-2009]

Drive (?trk-truck, ?loc1-location, ?loc2-location)
pre: at(?trk, ?loc1)
eff: ¬at(?trk, ?loc1)
at(?trk,?loc2)

↓

Drive (?trk, ?loc1, ?loc2)
pre: truck(?trk)
location(?loc1), location(?loc2)
at(?trk, ?loc1)
eff: ¬at(?trk, ?loc1)
at(?trk,?loc2)

Simplifying Conditions

(goals, preconds, premises,ce-conds)

[Helmert-2009]

1. Implications

Actions:	A pre: $\Phi \Rightarrow \Psi$	→	A pre: $\neg\Phi \vee \Psi$
Axioms:	$(\Phi \Rightarrow \Psi) \Rightarrow e$	→	$(\neg\Phi \vee \Psi) \Rightarrow e$

2. Universally quantified conditions
3. Disjunctive goals
4. Disjunctive conditions
5. Existential quantifiers

Simplifying Conditions

(goals, preconds, premises,ce-conds)

[Helmert-2009]

1. Implications
2. Universally quantified conditions

$\forall x \Phi$ → $\neg \exists x \neg \Phi$ → $\neg \Psi$ + axiom: $\exists x \neg \Phi \Rightarrow \Psi$

3. Disjunctive goals
4. Disjunctive conditions
5. Existential quantifiers

Simplifying Conditions

(goals, preconds, premises,ce-conds)

[Helmert-2009]

1. Implications
2. Universally quantified conditions
3. Disjunctive goals

$$G_1 \vee G_2 \;\Rightarrow\; \Psi \;+\; \text{axiom: } G_1 \vee G_2 \Rightarrow \Psi$$

4. Disjunctive conditions
5. Existential quantifiers

Simplifying Conditions

(goals, preconds, premises,ce-conds)

[Helmert-2009]

1. Implications
2. Universally quantified conditions
3. Disjunctive goals
4. Disjunctive conditions

Actions:

A pre: $C_1 \vee C_2$ eff: Ψ	→	A_1 pre: C_1 eff: Ψ	+	A_2 pre: C_2 eff: Ψ

Axioms:

$C_1 \vee C_2 \Rightarrow \Psi$	→	$C_1 \Rightarrow \Psi$	+	$C_2 \Rightarrow \Psi$

5. Existential quantifiers

Simplifying Conditions

(goals, preconds, premises,ce-conds)

[Helmert-2009]

1. Implications
2. Universally quantified conditions
3. Disjunctive goals
4. Disjunctive conditions
5. Existential quantifiers

$$\exists x\ \Phi \Rightarrow \Psi \quad \Rightarrow \quad \forall x\ (\Phi \Rightarrow \Psi)$$

Simplifying Effects

[Helmert-2009]

1. Universal quantifiers

$\forall x\ (e_1 \wedge e_2)$ → $\forall x\ e_1 \wedge \forall x\ e_2$

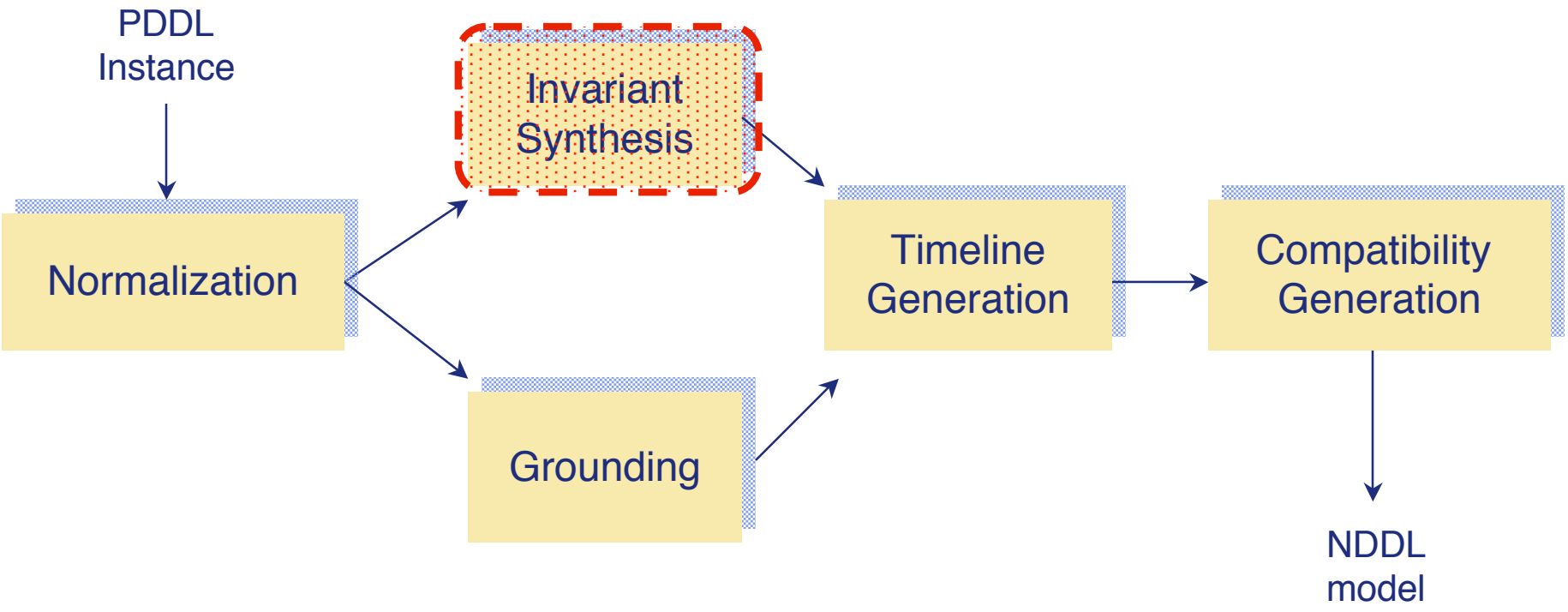
$\Phi \Rightarrow \forall x\ e$ → $\forall x\ (\Phi \Rightarrow e)$

2. Conditional effects

$\Phi \Rightarrow (e_1 \wedge e_2)$ → $\Phi \Rightarrow e_1 \ \wedge\ \Phi \Rightarrow e_2$

$\Phi \Rightarrow (\Psi \Rightarrow e)$ → $(\Phi \wedge \Psi) \Rightarrow e)$

Translation Steps



Invariant Synthesis

- ***Invariant***: property satisfied by all states reachable from initial state

  Interested in ***Mutual Exclusion Invariants***

$$at(T_1,ARC) \otimes at(T_1,UPS) \otimes at(T_1, SJC)$$

$$at(P_1,ARC) \otimes at(P_1,UPS) \otimes at(P_1,SJC) \otimes in(P_1,T_1) \otimes in(P_1,T_2)$$

- We synthesize ***timelines*** by grouping together mutually exclusive atoms identified by ***invariants***

$$loc\text{-}T_1 \in \{at\text{-}ARC,\ at\text{-}UPS,\ at\text{-}SJC\}$$

$$loc\text{-}P_1 \in \{at\text{-}ARC,\ at\text{-}UPS,\ at\text{-}SJC,\ in\text{-}T_1,\ in\text{-}T_2\}$$

- How do we find invariants?

  Guess, check and repair approach

  -Start with invariant candidates

  -Check if candidates are actual invariants

  -If not, refine the candidate and check again

Invariant Candidate

- ***Invariant Candidate***: $C = \langle u, \Phi(u,v) \rangle$

Fixed variables

Subset of propositions in D

$C_1 = \langle \langle ?obj \rangle, \{at(?obj,?loc)\} \rangle$

$C_2 = \langle \langle ?loc \rangle, \{at(?obj,?loc)\} \rangle$

$C_3 = \langle \langle ?obj \rangle, \{at(?obj,?loc), in(?obj,?trk)\} \rangle$

Instance of Candidate

- ***Invariant Candidate***: $C = \langle u, \Phi(u,v) \rangle$

Fixed variables

Subset of propositions in D

$C_1 = \langle \langle ?obj \rangle, \{at(?obj,?loc)\} \rangle$
$C_2 = \langle \langle ?loc \rangle, \{at(?obj,?loc)\} \rangle$
$C_3 = \langle \langle ?obj \rangle, \{at(?obj,?loc), in(?obj,?trk)\} \rangle$

- ***Instance I of candidate C:***

$I_{1\text{-}T1} = \{at(T_1,?loc)\}$
$I_{2\text{-}ARC} = \{at(?obj,ARC)\}$
$I_{3\text{-}T2} = \{at(T_2,?loc), in(T_2,?trk)\}$

Instance of Candidate

- ***Invariant Candidate***: $C = \langle u, \Phi(u,v) \rangle$

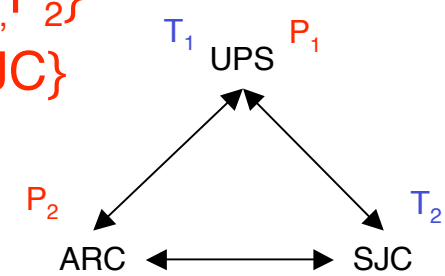
Fixed variables

Subset of propositions in D

$C_1 = \langle \langle ?obj \rangle, \{at(?obj,?loc)\} \rangle$
$C_2 = \langle \langle ?loc \rangle, \{at(?obj,?loc)\} \rangle$
$C_3 = \langle \langle ?obj \rangle, \{at(?obj,?loc), in(?obj,?trk)\} \rangle$

- ***Weight of Instance I in s :*** $W(I,s) \equiv |\{v : \Phi(I,v)\}|$

$I_{1\text{-}T1} = \{at(T_1,?loc)\}$ w=1 {UPS}
$I_{2\text{-}ARC} = \{at(?obj,ARC)\}$ w=2 $\{T_1, P_2\}$
$I_{3\text{-}T2} = \{at(T_2,?loc), in(T_2,?trk)\}$ w=1 {SJC}



Weight of Instance

- ***Invariant Candidate***: $C = \langle u, \Phi(u,v) \rangle$

  Fixed variables — Subset of propositions in D

- ***Weight of instance I in s***: $W(I,s) \equiv |\{v : \Phi(I,v)\}|$

- ***Want to show***: $\forall i \in Inst(C), s \;\; W(i,s) \leq 1$

$$\Phi(I,V_1) \otimes \Phi(I,V_2) \otimes \Phi(I,V_3) \otimes \ldots$$

Checking Candidates

When is a candidate C an actual invariant?

Sufficient condition:

1. Weight of C in initial state ≤ 1
2. C is not ***threatened*** by any operator op in D

op does not ***threaten*** C if:

op does not increase the weight of any instance of C beyond 1

Type 1 Ops – Inert

$C_1 = \langle \langle ?obj \rangle, \{at(?obj,?loc)\} \rangle$

op does not ***threaten*** C if:

1. op does not affect the weight of C

at(?t,?l)
washrack(?l)

weight=k

wash-truck (?t)

weight=k

Type 2 Ops – Decreasing

$C_1 = \langle \langle ?obj \rangle, \{at(?obj,?loc)\} \rangle$

op does not ***threaten*** C if:

2. op decreases the weight of C by 1

at(?t,?l) weight=k

vaporize-truck(?t,?l)

¬at(?t,?l) weight=k-1

Type 2 Ops – Decreasing

$C_1 = \langle \langle ?obj \rangle, \{at(?obj,?loc)\} \rangle$

op does not ***threaten*** C if:

2. op decreases the weight of C by 1

	at(?t,?l)		weight=k
2s		vaporize-truck(?t,?l)	
	¬at(?t,?l)		weight=k-1
		at(?t,?l)	weight=k
2e		vaporize-truck(?t,?l)	
		¬at(?t,?l)	weight=k-1
	at(?t,?l)		weight=k
2x		vaporize-truck(?t,?l)	
		¬at(?t,?l)	weight=k-1

Type 3 Ops – Increasing

op does not ***threaten*** C if:

3. op increases the weight by 1 at a timepoint
   but its conditions require that the weight be 0 at that timepoint

$\forall ?l : \neg at(?t,?l)$ weight=0

build-truck(?t,?n)

at(?t,?n) weight=1

Type 3 Ops – Increasing

op does not ***threaten*** C if:

3. op increases the weight by 1 at a timepoint
   but its conditions require that the weight be 0 at that timepoint

3s

$\forall ?l : \neg at(?t,?l)$ weight=0

build-truck(?t,?n)

at(?t,?n) weight=1

3e

$\forall ?l : \neg at(?t,?l)$ weight=0

build-truck(?t,?n)

at(?t,?n) weight=1

3x

$\forall ?l : \neg at(?t,?l)$ weight=0

build-truck(?t,?n)

at(?t,?n) weight=1

Type 4 Ops – Balanced

op does not ***threaten*** C if:

4. op is ***balanced*** at all timepoints

	at(?t,?l1)	weight=k
4s	Insta-Drive (?t,?l1,?l2)	
	¬ at(?t,?l1)	weight=k-1
	at(?t,?l2)	weight=k

	at(?t,?l1)	weight=k
4e	Insta-Drive (?t,?l1,?l2)	
	¬ at(?t,?l1)	weight=k-1
	at(?t,?l2)	weight=k

Type 5 Ops – Unbalanced

op does not ***threaten*** C if:

5. op is ***temporarily unbalanced*** and certain ***mutex*** conditions apply

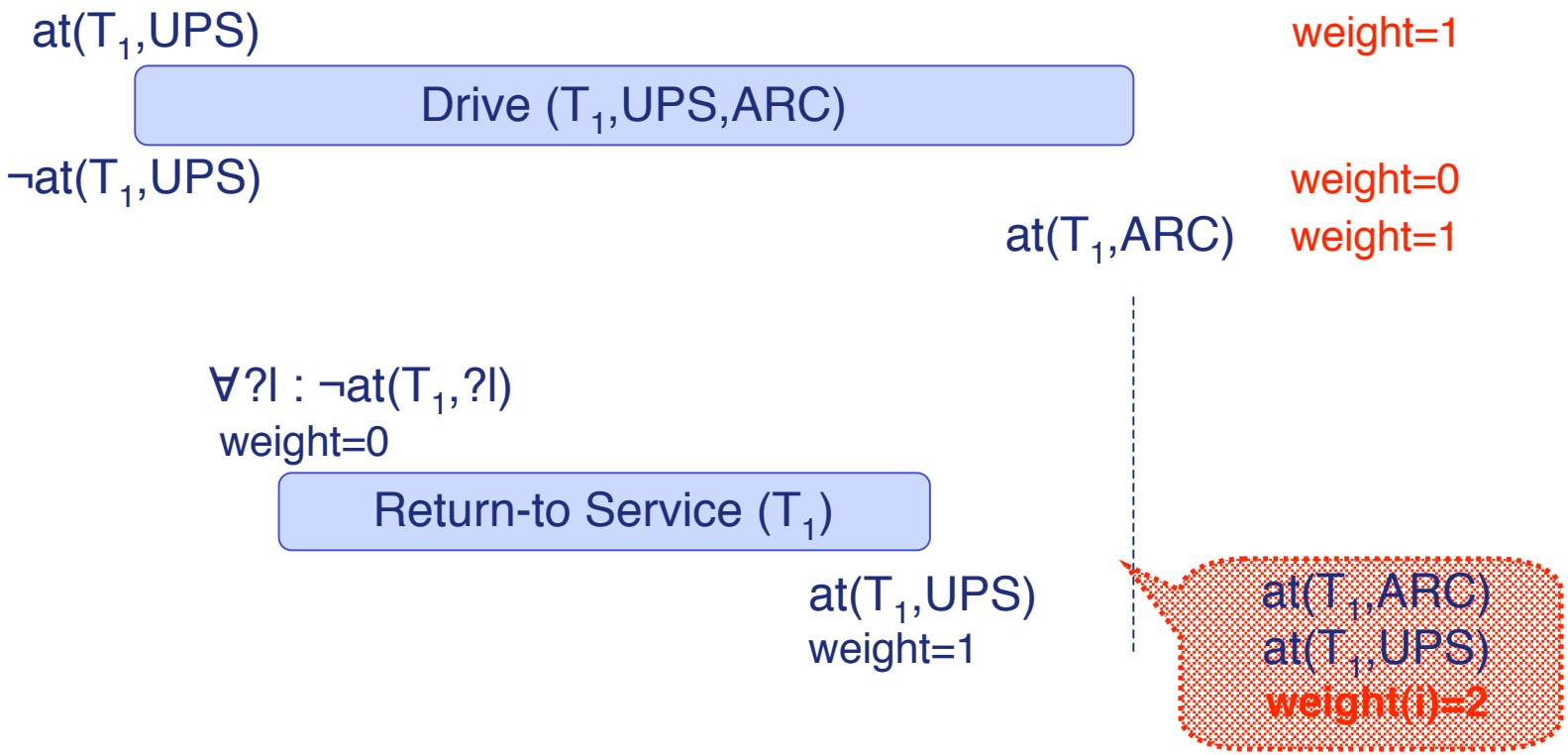
	at(?t,?l1)		weight=1
5s	Drive (?t,?l1,?l2)		
	¬at(?t,?l1)		weight=0
		at(?t,?l1)	weight=1

	at(?t,?l1)		weight=1
5e	Drive (?t,?l1,?l2)		
		¬at(?t,?l1)	weight=0
		at(?t,?l1)	weight=1

Type 5s Ops – Unbalanced

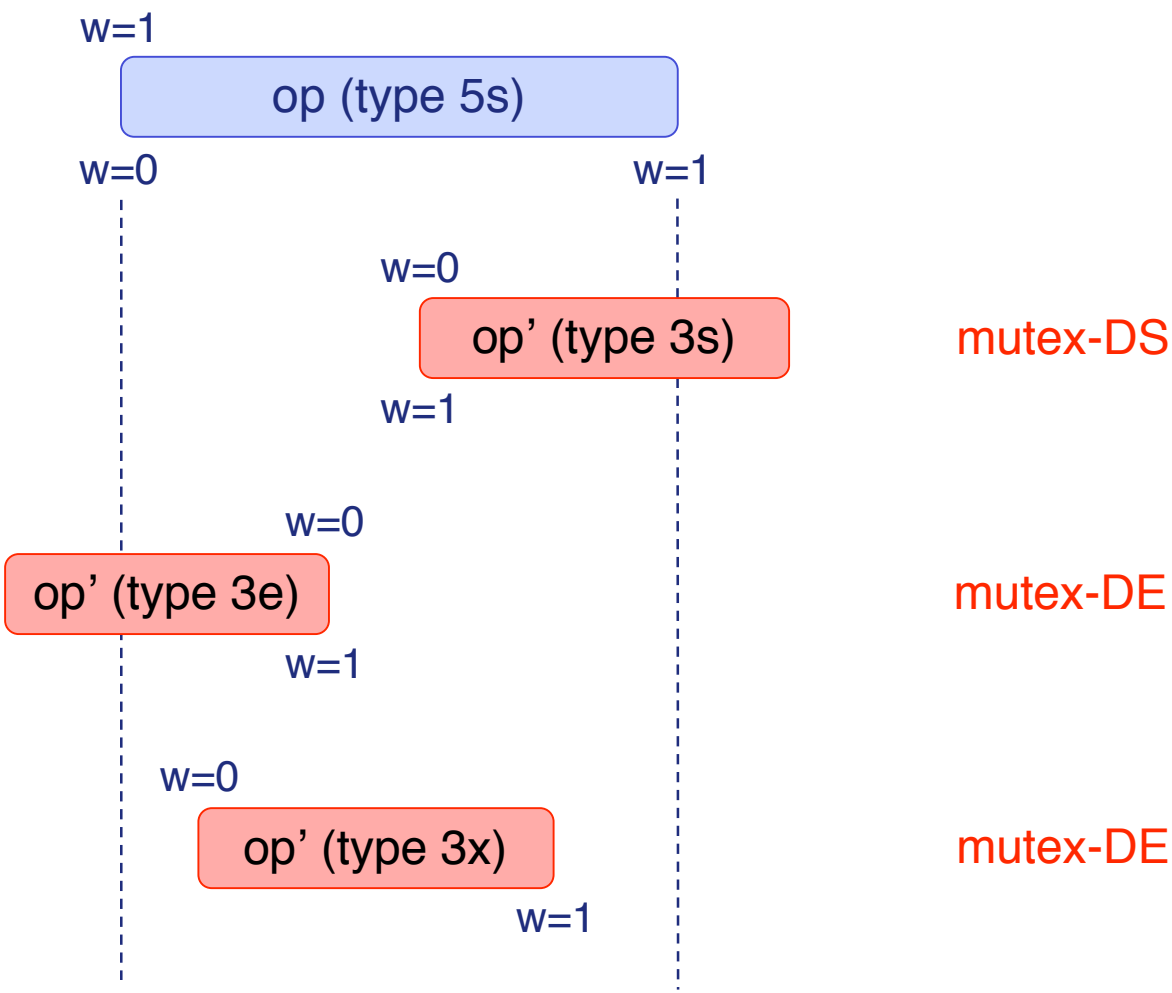
When op is ***temporarily unbalanced,*** we require that all operators that could intervene and increase the weight are ***mutex*** with op

Those operators may disrupt the balance of the candidate



Type 5s – Mutex Requirements

op is a ***non-threatening temporarily unbalanced operator*** if for each op':



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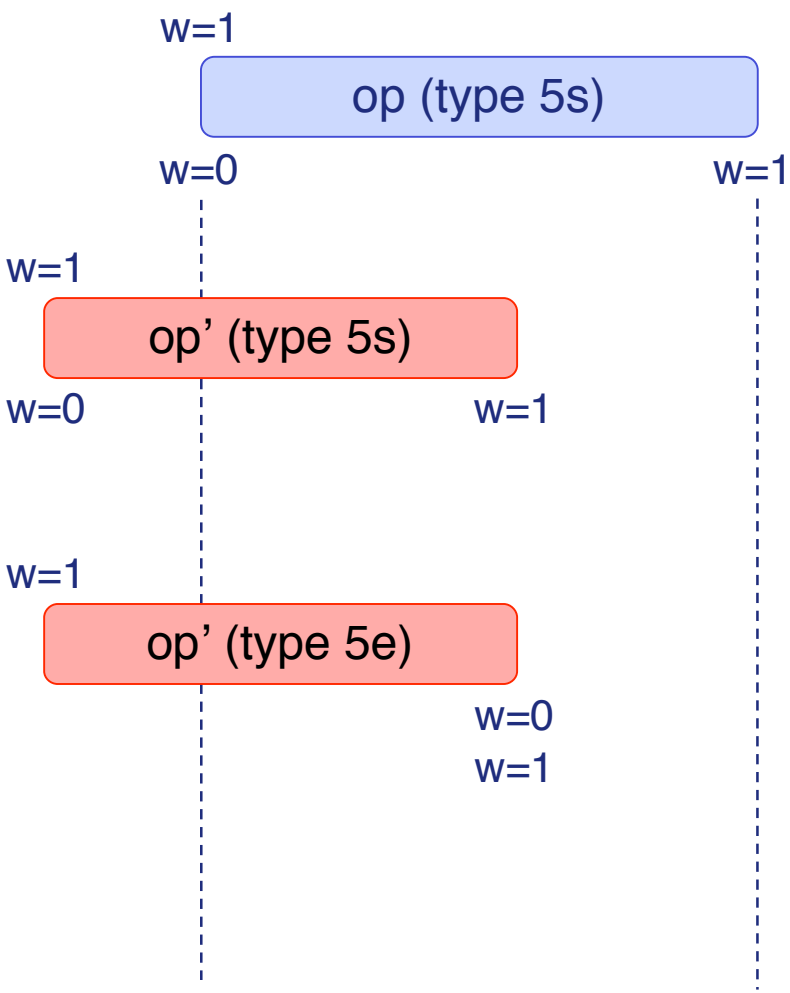


not possible

mutex-DE

Type 5 Ops – Unbalanced

op does not ***threaten*** C if:

5. op is ***temporarily unbalanced*** and certain ***mutex*** conditions apply

5s

at(?t,?l1)

Drive (?t,?l1,?l2)

¬at(?t,?l1)

at(?t,?l1)

mutex w/type 3, 5e

5e

at(?t,?l1)

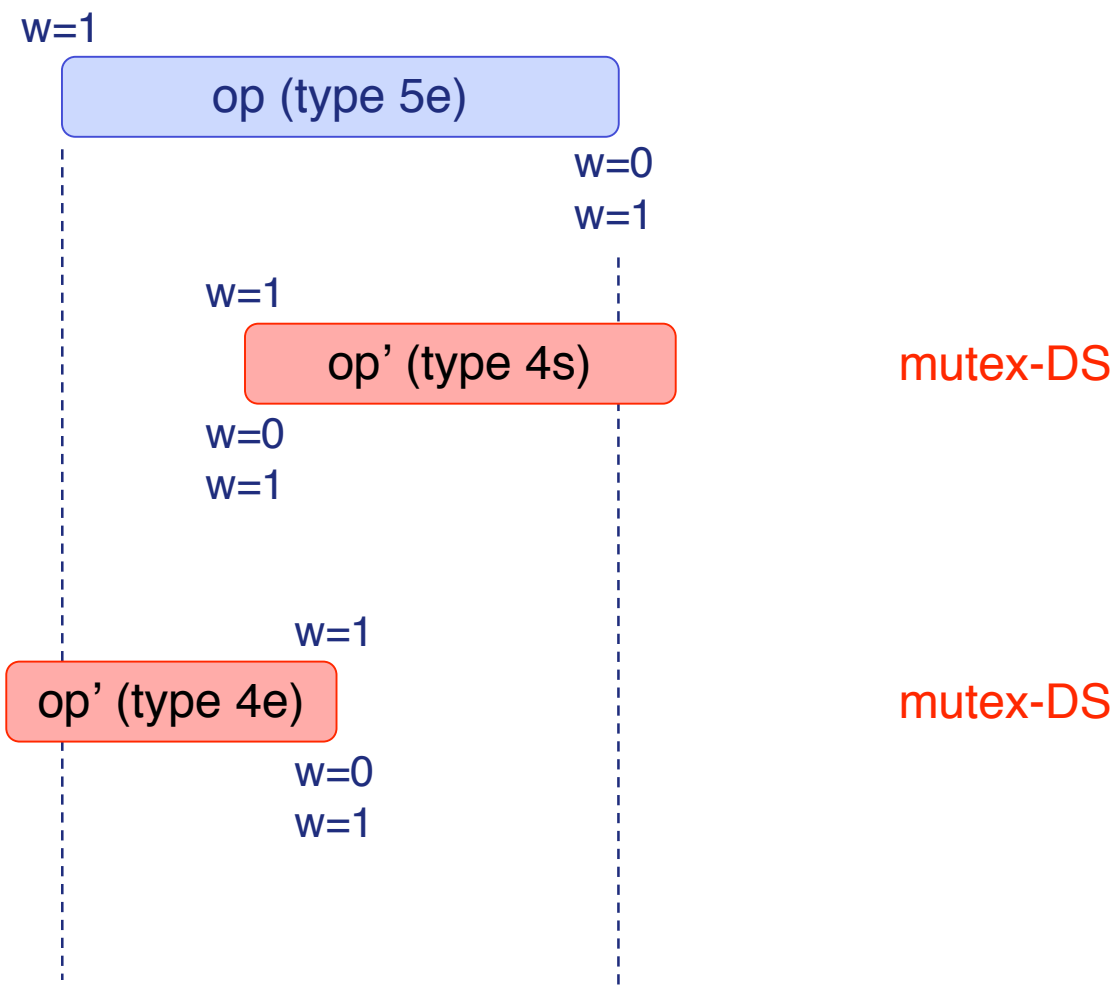
Drive (?t,?l1,?l2)

¬at(?t,?l1)

at(?t,?l1)

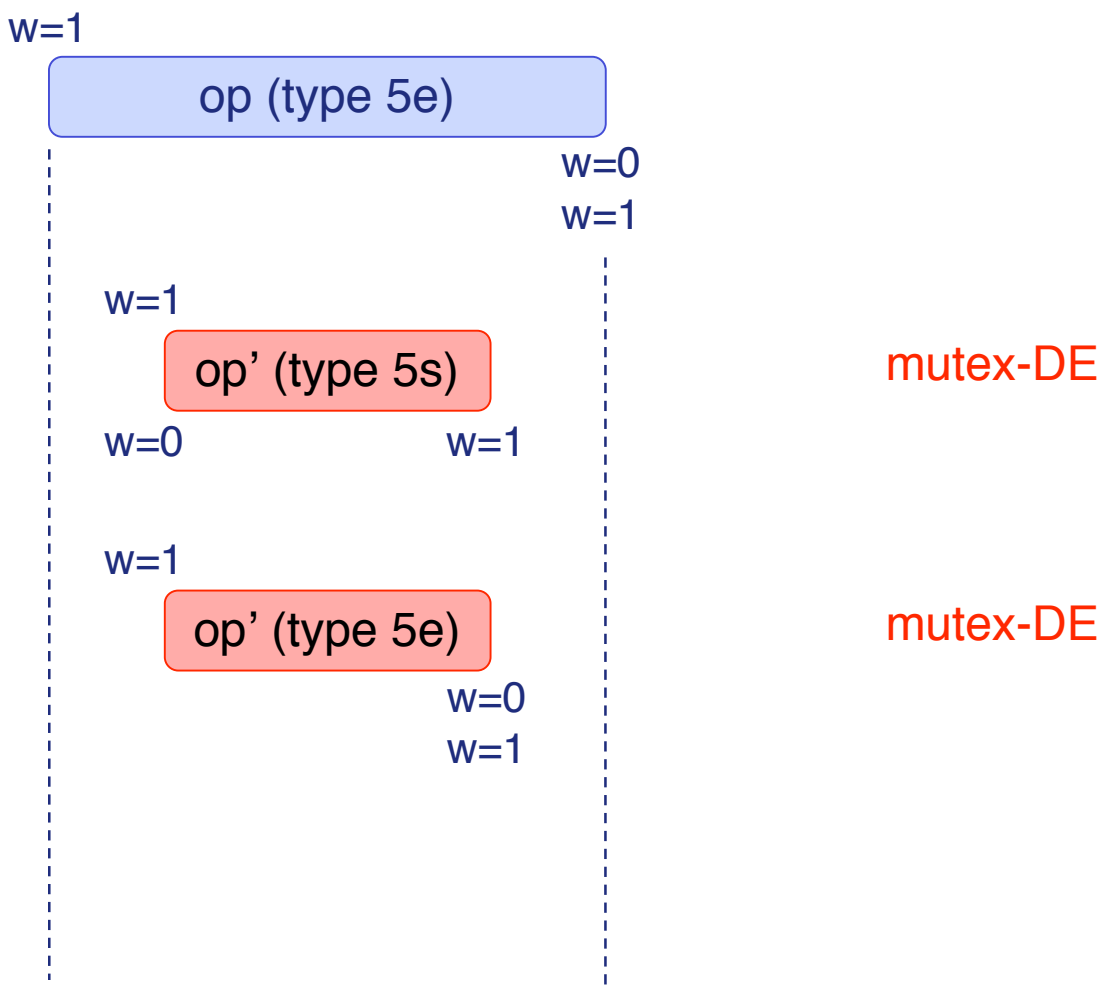
Type 5e – Mutex Requirements

op is a ***non-threatening temporarily unbalanced operator*** if for each op':



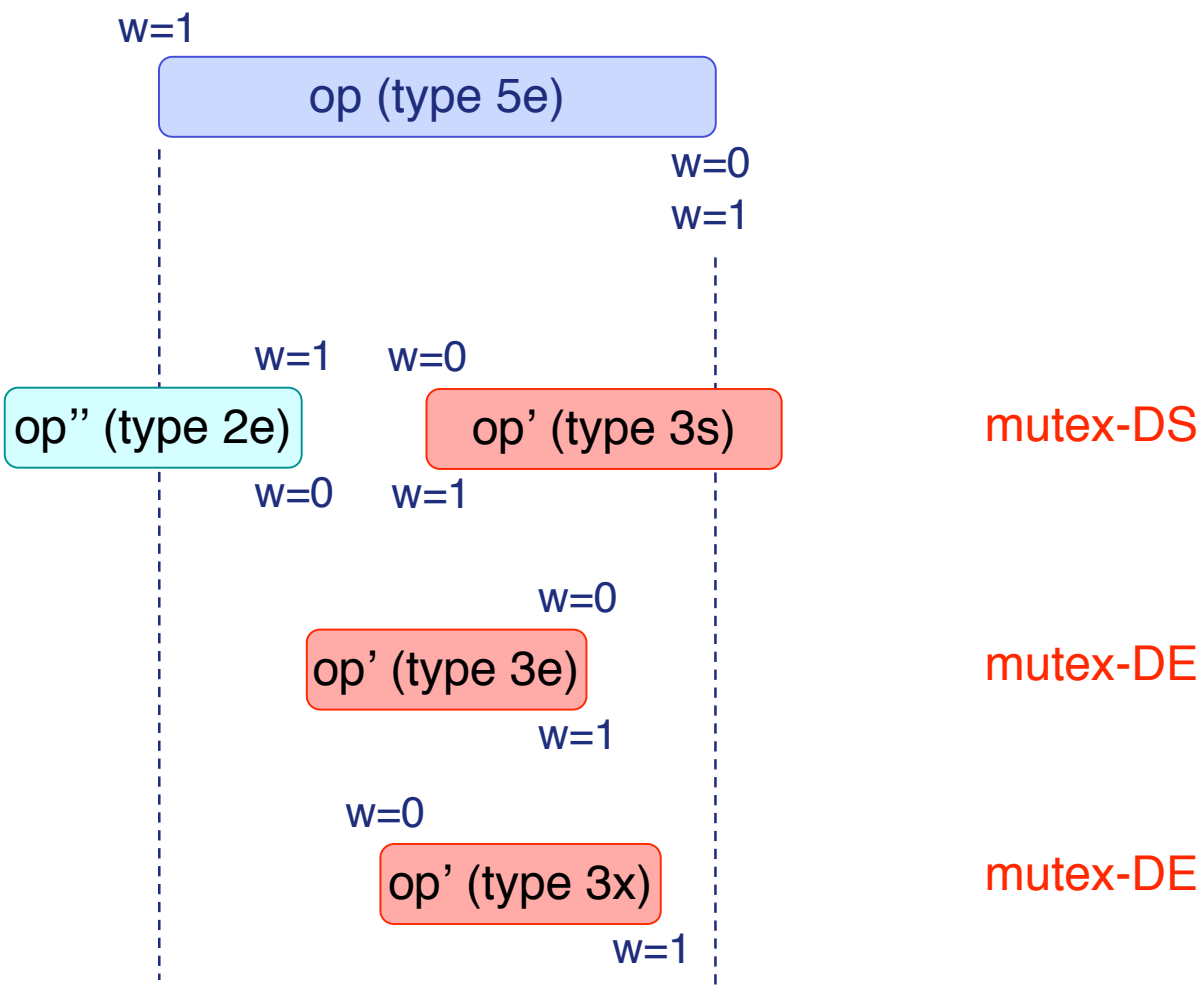
Type 5e – Mutex Requirements

op is a ***non-threatening temporarily unbalanced operator*** if for each op':



Type 5e – Mutex Requirements

op is a ***non-threatening temporarily unbalanced operator*** if for each op':



Type 5 Ops – Unbalanced

op does not ***threaten*** C if:

5. op is ***temporarily unbalanced*** and certain ***mutex*** conditions apply

5s

at(?t,?l1)

Drive (?t,?l1,?l2)

¬at(?t,?l1) at(?t,?l1)

mutex w/type 3, 5e

5e

at(?t,?l1)

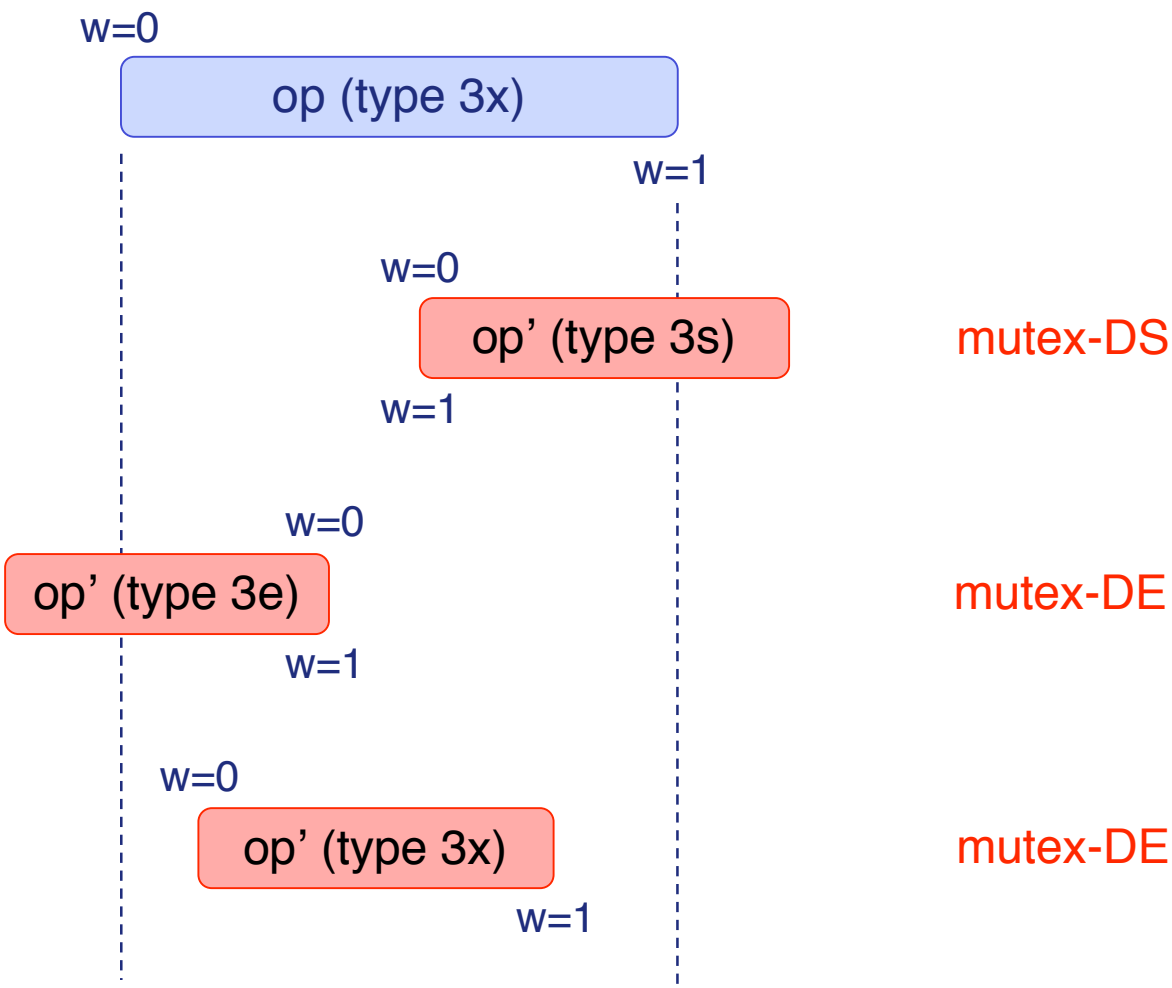
Drive (?t,?l1,?l2)

¬at(?t,?l1)
at(?t,?l1)

mutex w/type 3, 4, 5

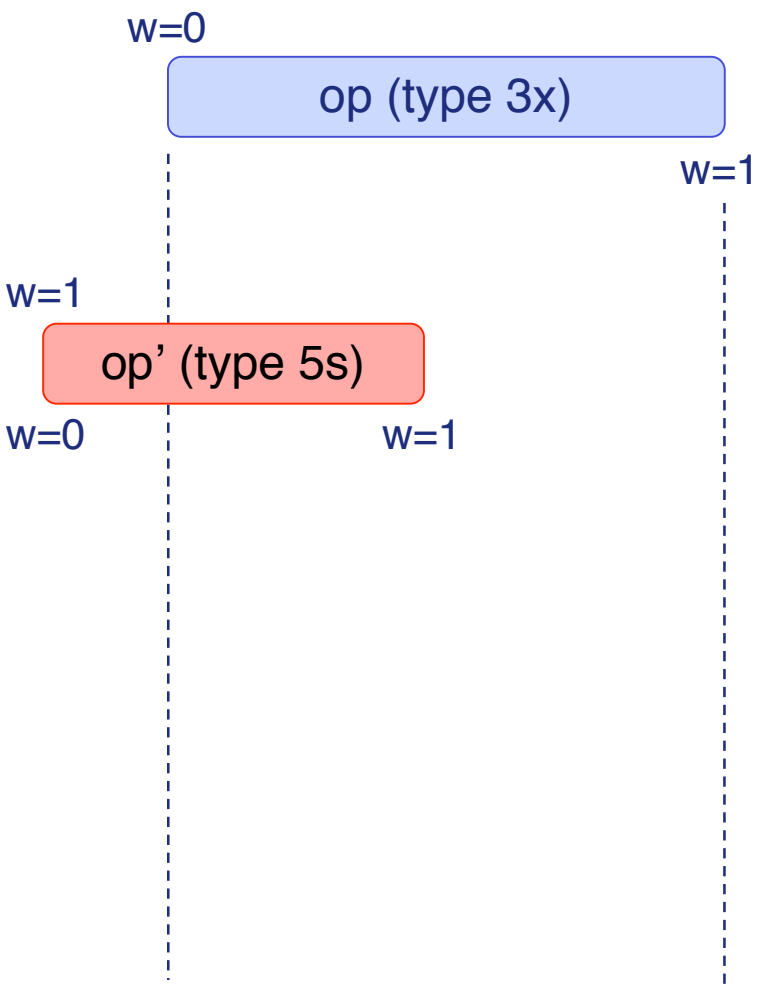
Type 3x – Mutex Requirements

op is a ***non-threatening temporarily unbalanced operator*** if for each op':



Type 3x – Mutex Requirements

op is a ***non-threatening temporarily unbalanced operator*** if for each op':



mutex-DE

Type 3 Ops – Increasing

op does not ***threaten*** C if:

3. op increases the weight by 1 at a timepoint
   but its conditions require that the weight be 0 at that timepoint

3s

$\forall ?l : \neg at(?t,?l)$ weight=0

build-truck(?t,?n)

at(?t,?n) weight=1

3e

$\forall ?l : \neg at(?t,?l)$ weight=0

build-truck(?t,?n)

at(?t,?n) weight=1

3x

$\forall ?l : \neg at(?t,?l)$ weight=0

build-truck(?t,?n)

at(?t,?n) weight=1

Checking Candidates recap

op does not ***threaten*** C if:

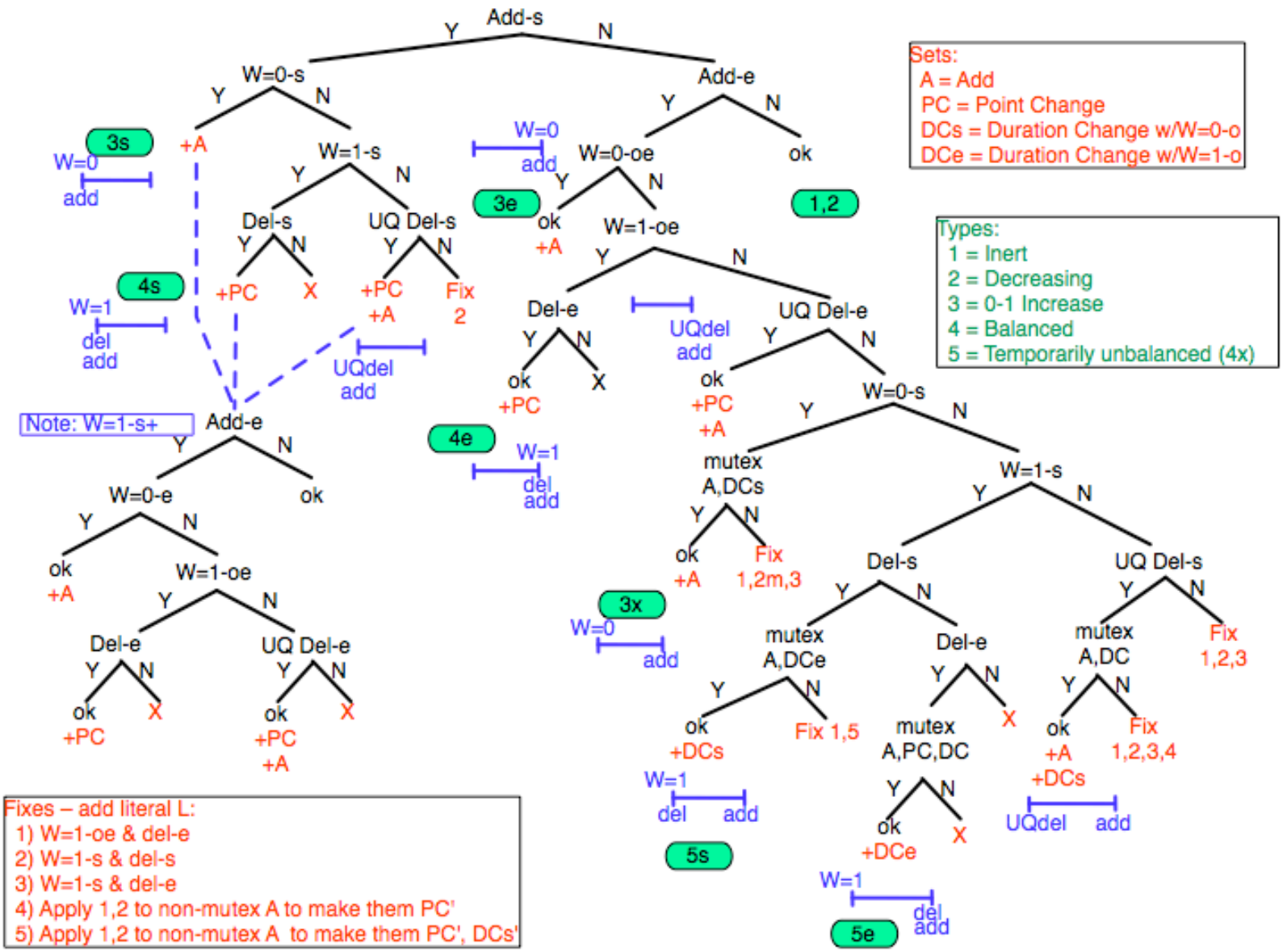
1. Inert – op does not affect the weight
2. Decreasing – op decreases the weight by 1
3. Increasing – op increases the weight by 1
   but conditions require that the weight is 0 prior

   3x – mutex with all type 3, type 5s
4. Balanced – op decreases then increases weight by 1
5. Temporarily unbalanced – spread out over time (4x)

   5s – mutex with all type 3, type 5e

   5e – mutex with all type 3, type 4, type 5

More Difficult Cases



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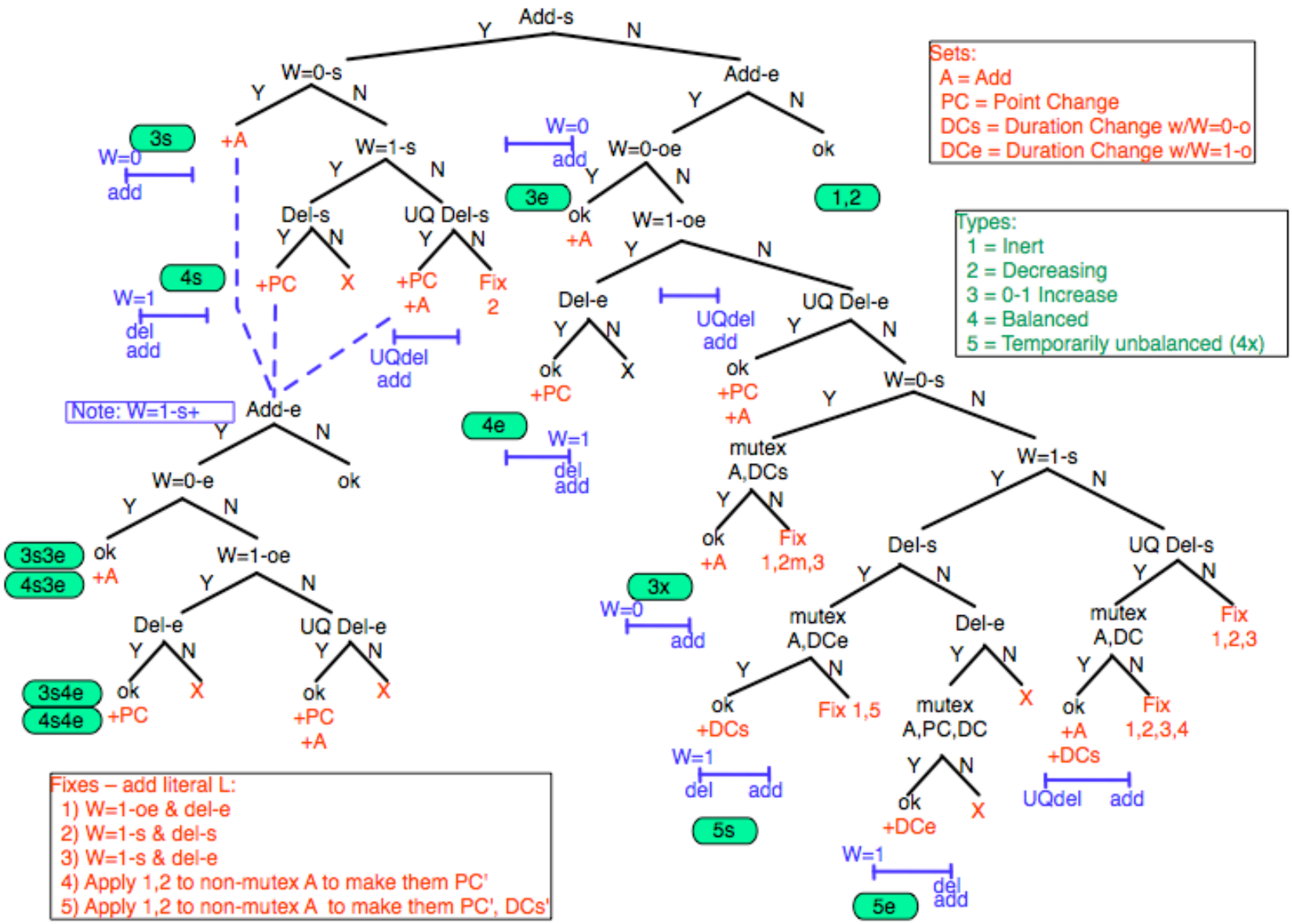
More Difficult Cases



Finding Invariants

Guess, check and repair approach

-Start with invariant candidates

$C_{at1} = \langle \langle ?obj \rangle, \{at(?obj,?loc)\} \rangle$ w=1

$C_{at2} = \langle \langle ?loc \rangle, \{at(?obj,?loc)\} \rangle$ w=2 X

$C_{in1} = \langle \langle ?obj \rangle, \{in(?obj,?trk)\} \rangle$ w=0

$C_{in2} = \langle \langle ?trk \rangle, \{in(?obj,?trk)\} \rangle$ w=0

-Check if candidates are actual invariants

initial conditions

Drive, Load, Unload

-If not, refine the candidate and check again

add additional predicates

Example

Candidate: $C_{at1} = \langle \langle ?obj \rangle, \{at(?obj,?loc)\} \rangle$

initially: w=1

Drive op: type 5s

mutex w/type 3?

at(?trk,?loc1)

Drive(?trk,?loc1,?loc2)

¬at(?trk,?loc1) at(?trk,?loc2)

Load op: type 2s

at(?trk,?loc) →
at(?pkg,?loc)

Load(?pkg,?trk)

¬at(?pkg,?loc) in(?pkg,?trk)

UnLoad op: unprotected add!

at(?trk,?loc) →
in(?pkg,?trk)

Unload(?pkg,?trk)

¬in(?pkg,?trk) at(?pkg,?loc)

Example

Candidate: $C_{at1} = \langle \langle ?obj \rangle, \{at(?obj,?loc)\} \rangle$

initially: w=1

Drive op: type 5s

mutex w/type 3?

at(?trk,?loc1)

Drive(?trk,?loc1,?loc2)

¬at(?trk,?loc1) at(?trk,?loc2)

Load op: type 2s

at(?trk,?loc) →
at(?pkg,?loc)

Load(?pkg,?trk)

¬at(?pkg,?loc) in(?pkg,?trk)

UnLoad op: unprotected add!

at(?trk,?loc) →
in(?pkg,?trk)

Unload(?pkg,?trk)

¬in(?pkg,?trk) at(?pkg,?loc)

Refine candidate: add in(?pkg,?trk)

Example

Candidate: $C_{at\text{-}in1} = \langle \langle ?obj \rangle, \{at(?obj,?loc), in(?obj, ?trk)\} \rangle$

initially: w=1

Drive op: type 5s

mutex w/type 3?

at(?trk,?loc1)

Drive(?trk,?loc1,?loc2)

¬at(?trk,?loc1) at(?trk,?loc2)

Load op: type 5s

at(?trk,?loc) →
at(?pkg,?loc)

Load(?pkg,?trk)

¬at(?pkg,?loc) in(?pkg,?trk)

UnLoad op: type 5s

at(?trk,?loc) →
in(?pkg,?trk)

Unload(?pkg,?trk)

¬in(?pkg,?trk) at(?pkg,?loc)

Finding Invariants

$C_{at1} = \langle \langle ?obj \rangle, \{at(?obj,?loc)\} \rangle$ UnLoad $\Rightarrow$ in(?obj,?trk)

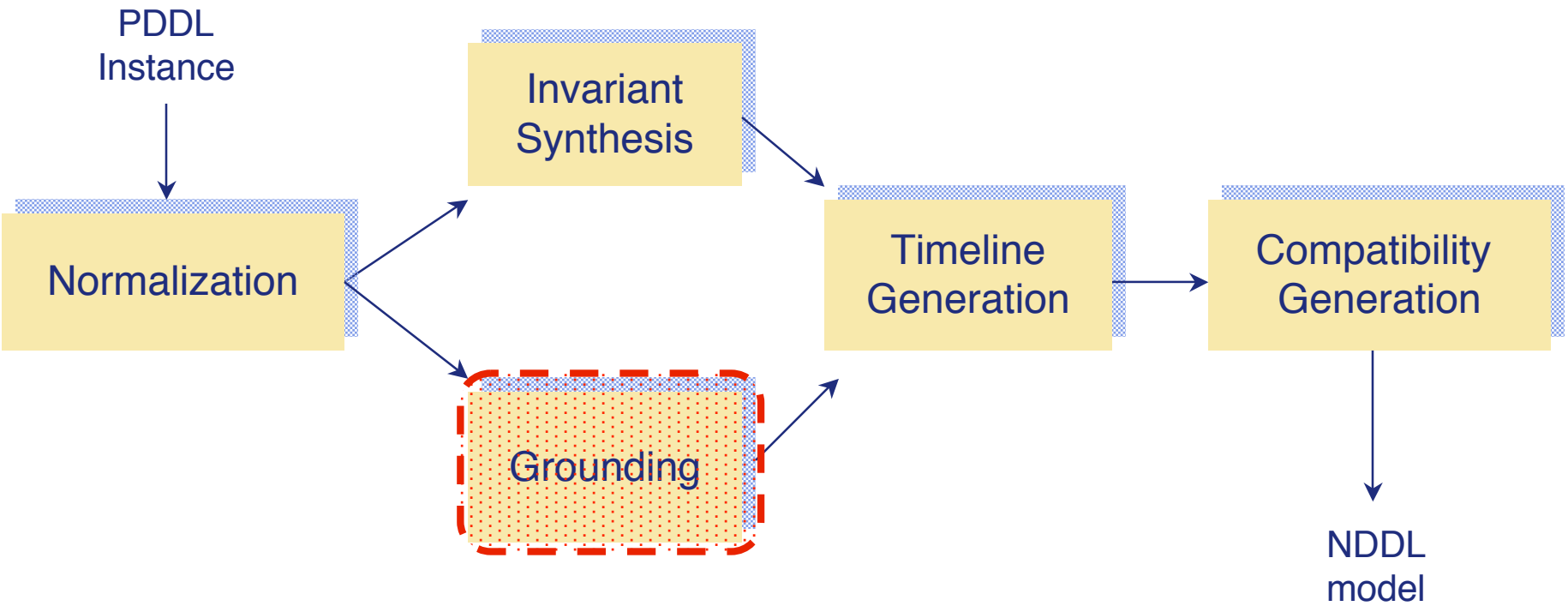
$C_{at2} = \langle \langle ?loc \rangle, \{at(?obj,?loc)\} \rangle$ X (init)

$C_{in1} = \langle \langle ?obj \rangle, \{in(?obj,?trk)\} \rangle$ Load $\Rightarrow$ at(?obj,?trk)

$C_{in2} = \langle \langle ?trk \rangle, \{in(?obj,?trk)\} \rangle$ X (Load)

$C_{at1\text{-}in1} = \langle \langle ?obj \rangle, \{at(?obj,?loc), in(?obj, ?trk)\} \rangle$

Translation Steps



Grounding

[Helmert-2009]

- ***Grounded*** PDDL domain:

  all the literals occurring in the goal formula and operators are ground literals

- How to calculate a grounded PDDL domain?

  - compute an ***over-approximation*** of the atoms that can ever be true
  - instantiate the goal formula and the operators on those atoms

- Over-approximation of reachable atoms:

  by using a ***relaxed version*** of the domain

  - delete effects of operators are ignored
  - negative literals in conditions assumed true

Relaxed PlanGraph

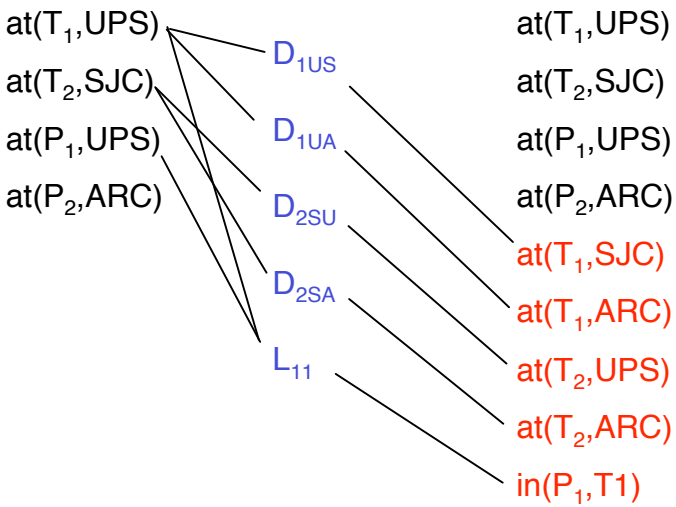
at(T_1,UPS)

at(T_2,SJC)

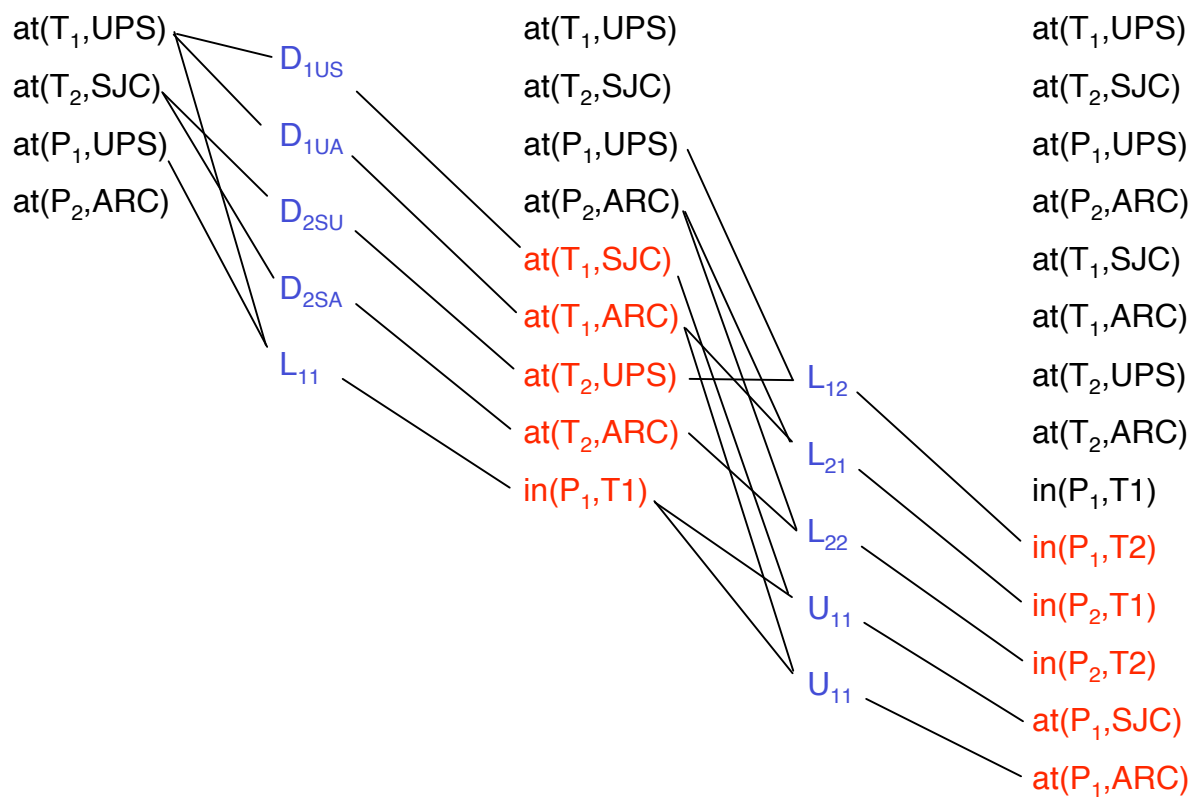
at(P_1,UPS)

at(P_2,ARC)

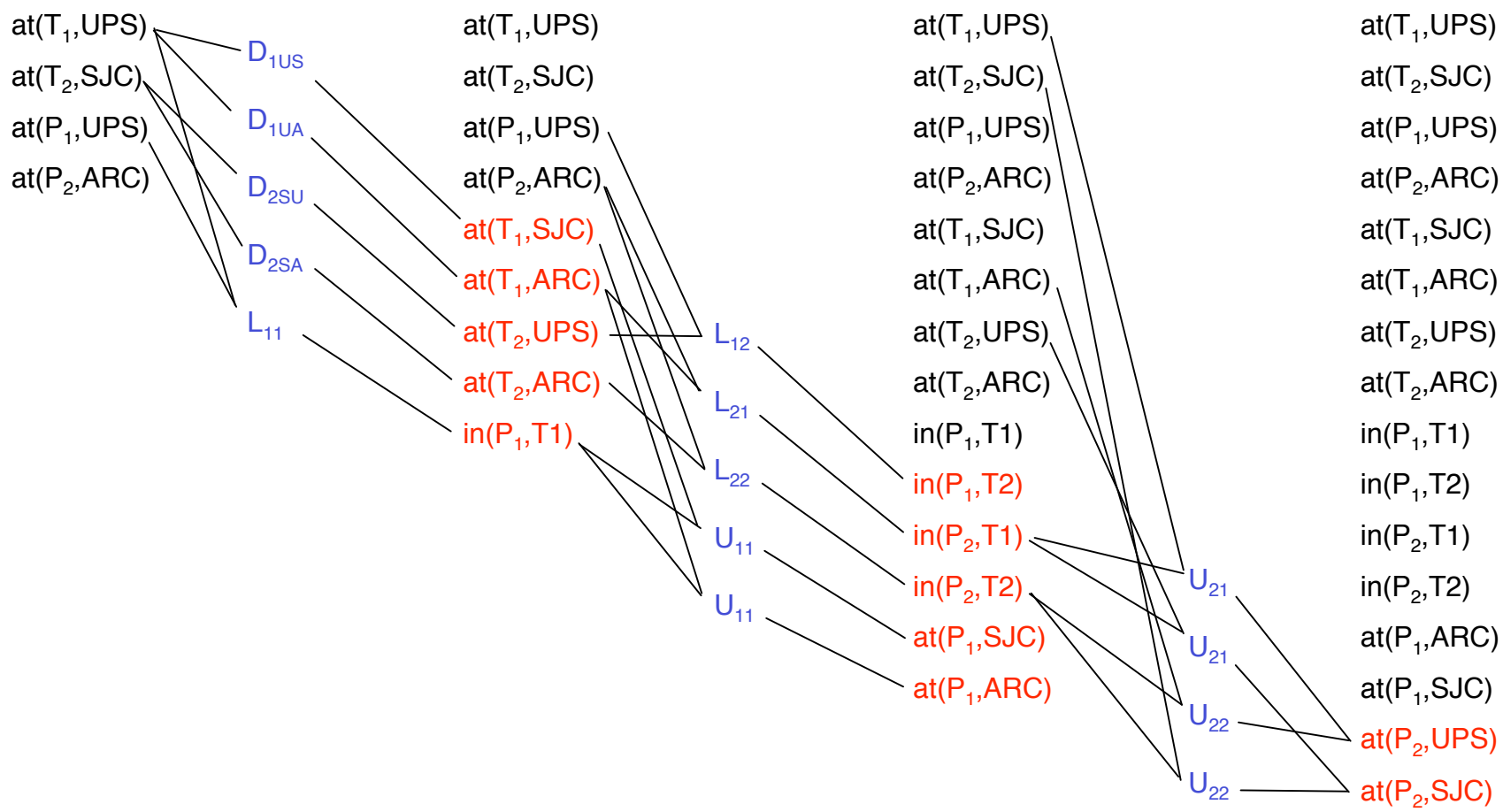
Relaxed PlanGraph



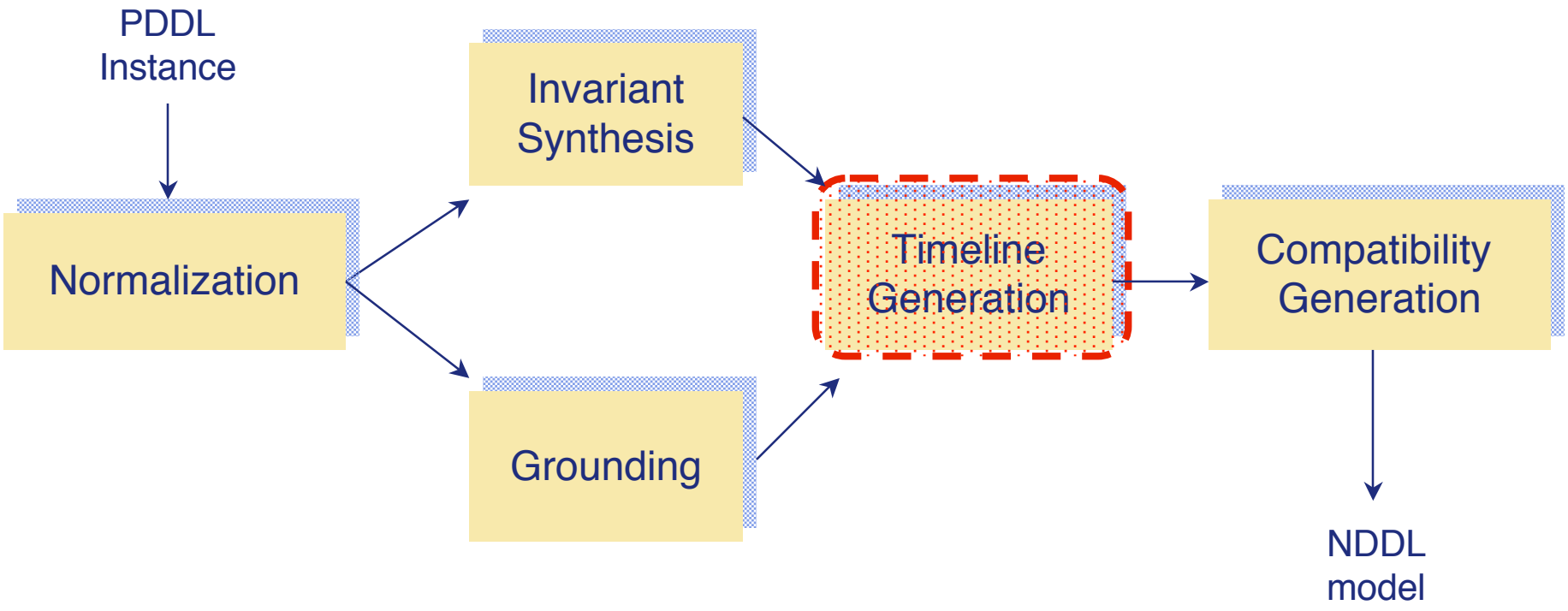
Relaxed PlanGraph



Relaxed PlanGraph



Translation Steps



Timeline Generation

- We synthesize a set of timelines from each invariant:

Invariant: $C_{at\text{-}in1} = \langle \langle ?obj \rangle, \{at(?obj,?loc), in(?obj, ?trk)\} \rangle$

Instances: i_1:?obj $\rightarrow T_1$
i_2:?obj $\rightarrow T_2$
i_3:?obj $\rightarrow P_1$
i_4:?obj $\rightarrow P_2$

$\Downarrow$

Four ***timelines***: $\Gamma_{at\text{-}in\text{-}T1}$, $\Gamma_{at\text{-}in\text{-}T2}$, $\Gamma_{at\text{-}in\text{-}P1}$, $\Gamma_{at\text{-}in\text{-}P2}$

- ***Activities*** for $\Gamma_{at\text{-}in\text{-}P1}$?

Reachable ground atoms with ?obj = P_1:

Activities[$\Gamma_{at\text{-}in\text{-}P1}$] = $\{at(P_1,ARC), at(P_1,UPS), at(P_1,SJC), in(P_1,T_1), in(P_1,T_2), \perp\}$

Proposition Timelines

$\Gamma_{\text{at-in-T1}}$: at(T_1,ARC), at(T_1,UPS), at(T_1,SJC), $\perp$

$\Gamma_{\text{at-in-T2}}$: at(T_2,ARC), at(T_2,UPS), at(T_2,SJC), $\perp$

$\Gamma_{\text{at-in-P1}}$: at(P_1,ARC), at(P_1,UPS), at(P_1,SJC), in(P_1,T_1), in(P_1,T_2), $\perp$

$\Gamma_{\text{at-in-P2}}$: at(P_2,ARC), at(P_2,UPS), at(P_2,SJC), in(P_2,T_1), in(P_2,T_2), $\perp$

Op Timelines

For each ground operator op in D $\Rightarrow$ one timeline T_{op}

Activities for T_{op}?

Two activities: Exe (executing)
Idle (not executing)

$\Gamma_{Drive(T1,UPS,ARC)}$: Exe, Idle

$\Gamma_{Drive(T1,UPS,SJC)}$: Exe, Idle

…

$\Gamma_{Drive(T2,UPS,SJC)}$: Exe, Idle

…

$\Gamma_{Load(P1,T1)}$: Exe, Idle

$\Gamma_{Load(P1,T2)}$: Exe, Idle

…

$\Gamma_{UnLoad(P1,T1)}$: Exe, Idle

…

Better Op Timelines

Cliques of mutex ops can go on the same timeline

Drive(T_1,UPS, ARC) ⊗ Drive(T_1,UPS, SJC) ⊗ …

Drive(T_2,UPS, ARC) ⊗ Drive(T_2,UPS, SJC) ⊗ …

$\Gamma_{Drive(T1)}$: Drive(T_1,UPS, ARC), Drive(T_1,UPS, SJC), …, Idle

$\Gamma_{Drive(T2)}$: Drive(T_2,UPS, ARC), Drive(T_2,UPS, SJC), …, Idle

Load(P_1,T_1) ⊗ UnLoad(P_1,T_1) ⊗ Load(P_1,T_2) ⊗ Load(P_1,T_2)

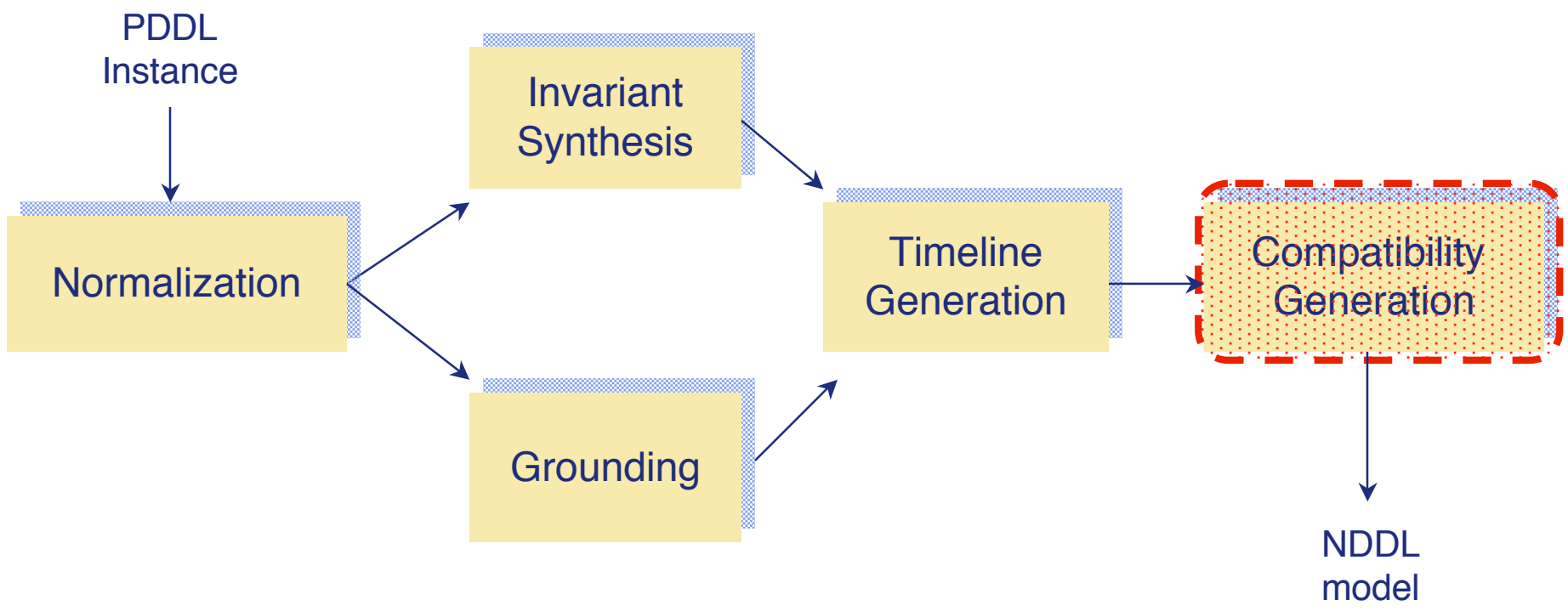
Load(P_2,T_1) ⊗ UnLoad(P_2,T_1) ⊗ Load(P_2,T_2) ⊗ UnLoad(P_2,T_2)

$\Gamma_{Load\text{-}UnLoad(P1)}$: Load($P_1$,$T_1$), UnLoad($P_1$,$T_1$), Load($P_1$,$T_2$), Load($P_1$,$T_2$), Idle

$\Gamma_{Load\text{-}UnLoad(P2)}$: Load($P_2$,$T_1$), UnLoad($P_2$,$T_1$), Load($P_2$,$T_2$), Load($P_2$,$T_2$), Idle

but Load(P_1,T_1) can occur in parallel with Load(P_2,T_1)

Translation Steps



Op Compatibility Synthesis

PDDL: op $\Rightarrow$ NDDL: T_{op}

How to generate the compatibilities for the activities exe and not_exe of the timeline T_{op}?

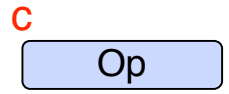
Compatibilities synthesized from the conditions Cond(op) and effects Eff(op)

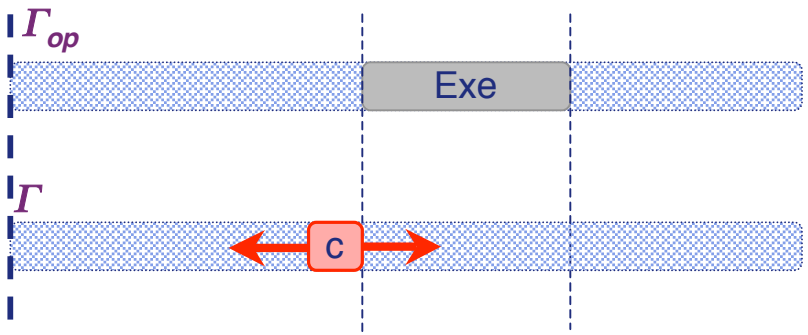
- ***Conditions***:
  - Positive at_start/over_all/at_end
  - Protected Negative at start/over_all/at_end
  - Unprotected Negative at start/over_all/at_end

- ***Effects***:
  - Add Effect at_start/at_end
  - Protected Delete Effect at_start/at_end
  - Unprotected Delete Effect at_start/at_end

Op Compatibility Synthesis

Positive Condition at_start:

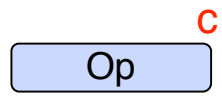


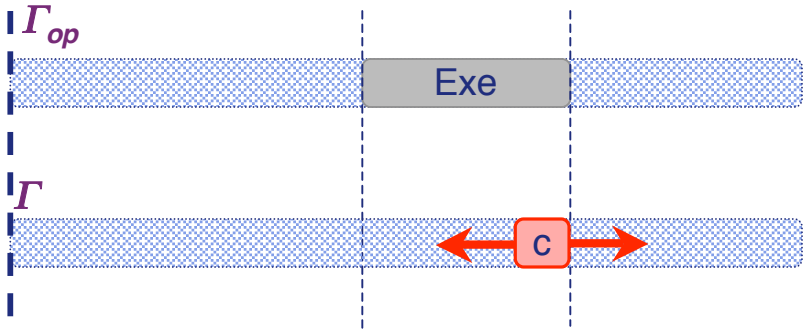


Γ.c.start < exe.start ≤ Γ.c.end

Γ_{op}:: exe{
starts_before_end Γ.c;
precedes (Γ.c.start,start);}

Positive Condition at_end:



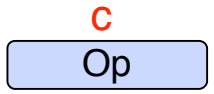


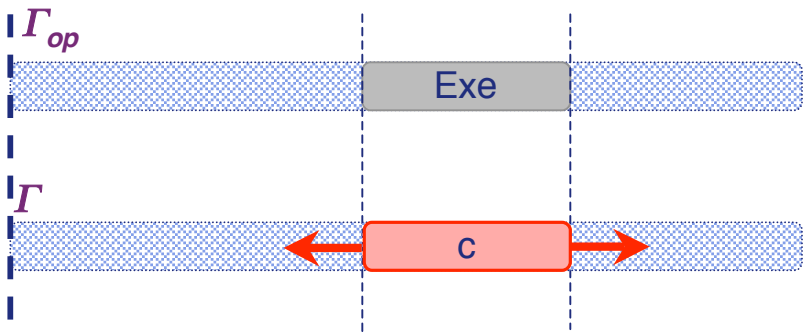
Γ.c.start < exe.end ≤ Γ.c.end

Γ_{op}:: exe{
ends_before_end Γ.c;
precedes (Γ.c.start,end);}

Op Compatibility Synthesis

Positive Condition over_all:





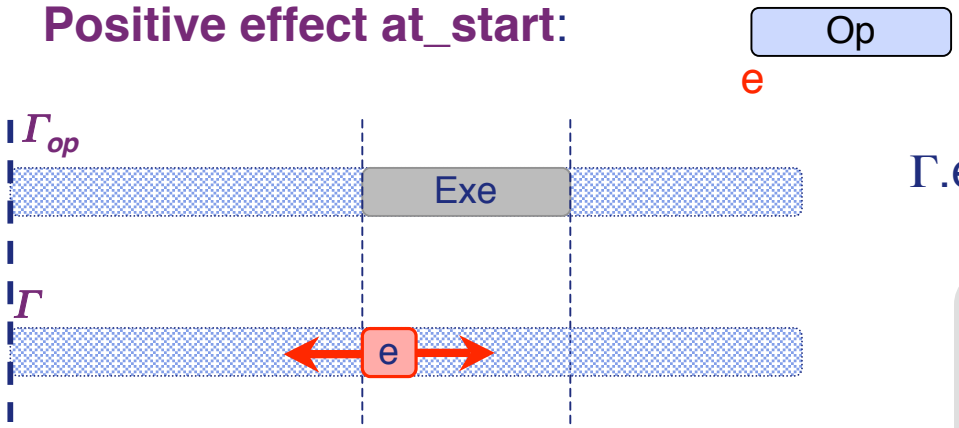
Γ.c.start ≤ exe.start
& exec.end ≤ Γ.c.end

Í

Γ_{op}:: exe{
starts_before_end Γ.c;
ends_before_end Γ.c;}

Op Compatibility Synthesis

Positive effect at_start:

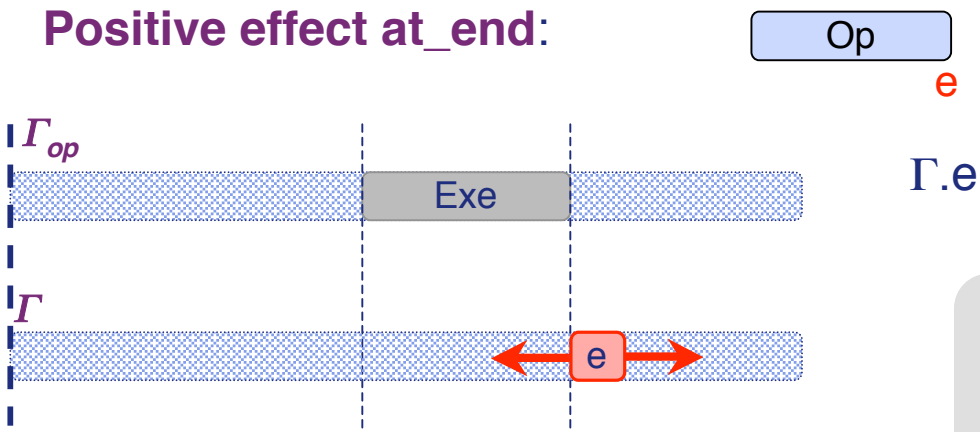


Γ.e.start ≤ exe.start < Γ.e.end

Í

Γ_{op}:: exe{
starts_after Γ.e;
precedes (start, Γ.e.end);}

Positive effect at_end:



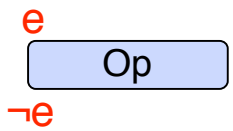
Γ.e.start ≤ exe.start < Γ.e.end

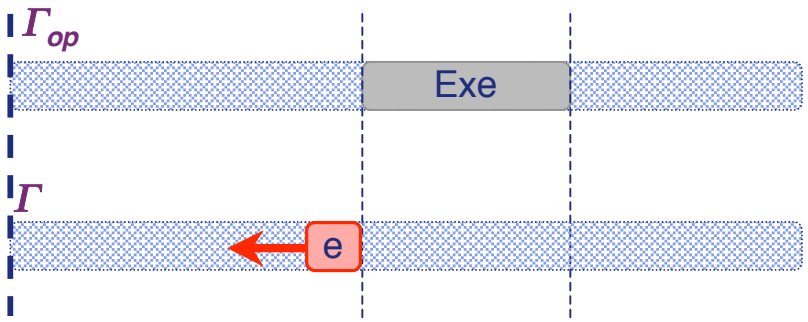
Í

Γ_{op}:: exe{
ends_before Γ.e;
precedes (end, Γ.e.end);}

Op Compatibility Synthesis

Condition and Negative effect at_start:





Γ.e.start < exe.start = Γ.e.end = Γ.$\perp$.start

Í

Γ_{op}:: exe{ met_by(Γ.e);
starts(Γ.$\perp$);}

Op Compatibility Synthesis

at(T_1,UPS)

Drive(T_1,UPS,ARC)

¬at(T_1,UPS) at(T_1,ARC)

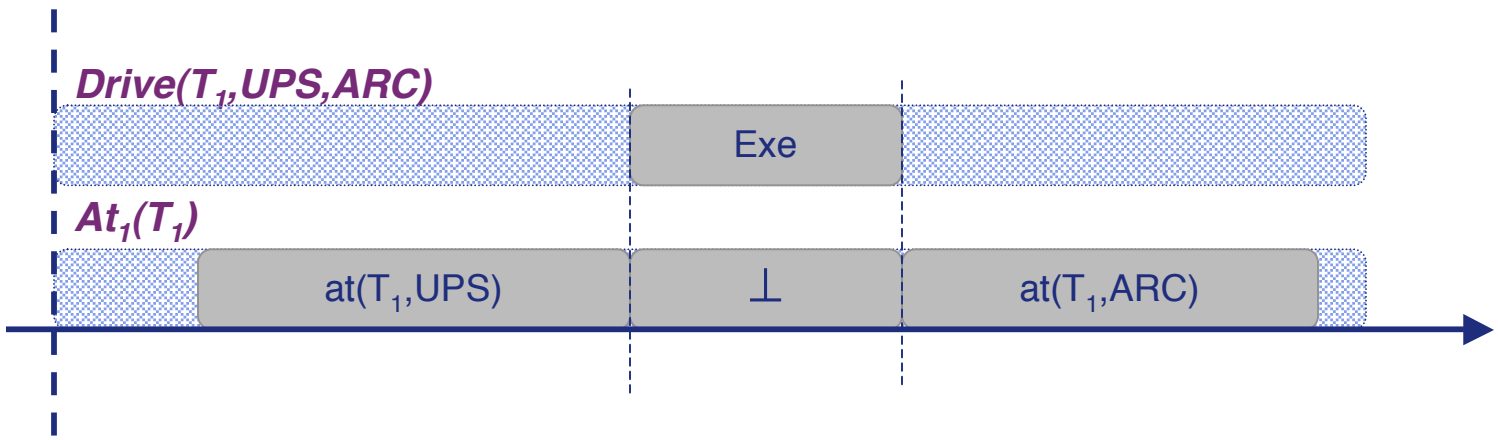
PDDL

```
:durative-action Drive(T1,UPS,ARC)
  :condition   at_start  at(T1,UPS)
  :effect (and
            at_start  ¬at(T1,UPS)
            at_end    at(T1,ARC)
```

Ë

NDDL

```
Drive(T1,UPS,ARC):: Exe{
        met_by(At1(T1).at(T1,UPS));
        equals(At1(T1).⊥);
        meets(At1(T1).at(T1,ARC));}
```



Explanatory Frame Axioms

Positive PDDL proposition p => NDDL activity p

- How to generate the compatibilities for the activity p?

They are synthesized on the basis of ***frame axioms*** of p

- Two disjunctions:

1. activities that cause the ***start*** of p
2. activities that cause the ***end*** of p

- We look for PDDL operators that contain p or its negation in their effects.

Compatibilities for Propositions

Γ

at(P1,UPS)

What activities:

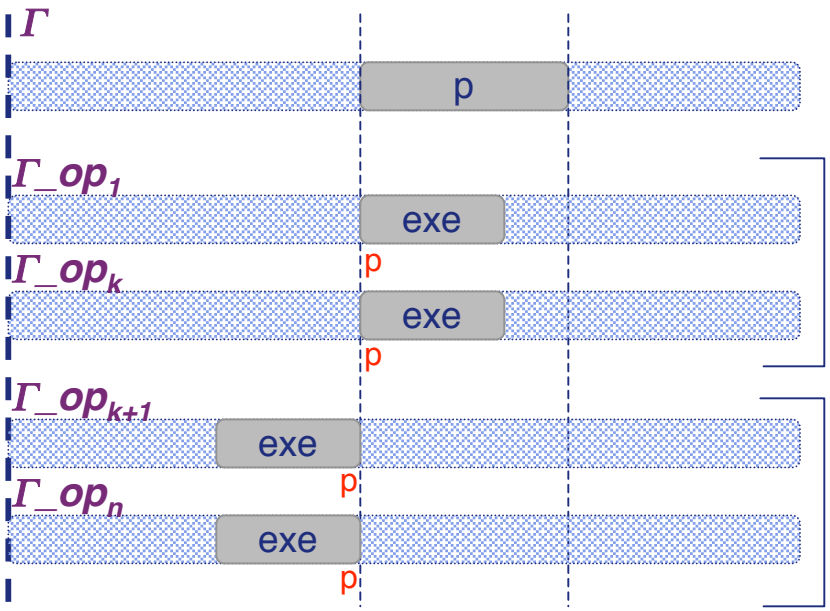
1. cause the ***start*** of p ?
2. cause the ***end*** of p ?

Explanatory frame axioms

1. Find all ops with effects p or ¬p
2. Form disjunction

Frame Axioms

Which operators cause the activity ***p*** to **start**?



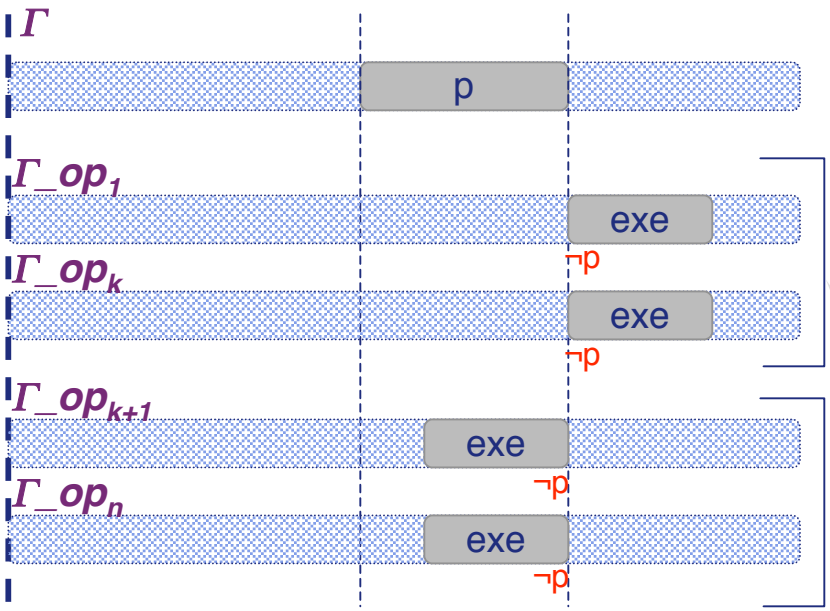

```
T:: p{
  if (guard=c1)
            starts(op1.exe);
  ...
  if (guard=ck)
            starts(opk.exe);
  if (guard=ck+1)
            met_by(opk+1.exe);
  ...
  if (guard=cn)
            met_by(opn.exe);}
```

operators whose effects **at_end** contain p

operators whose effects ***at_start*** contain p

Frame Axioms

Which operators cause the activity ***p*** to **end**?

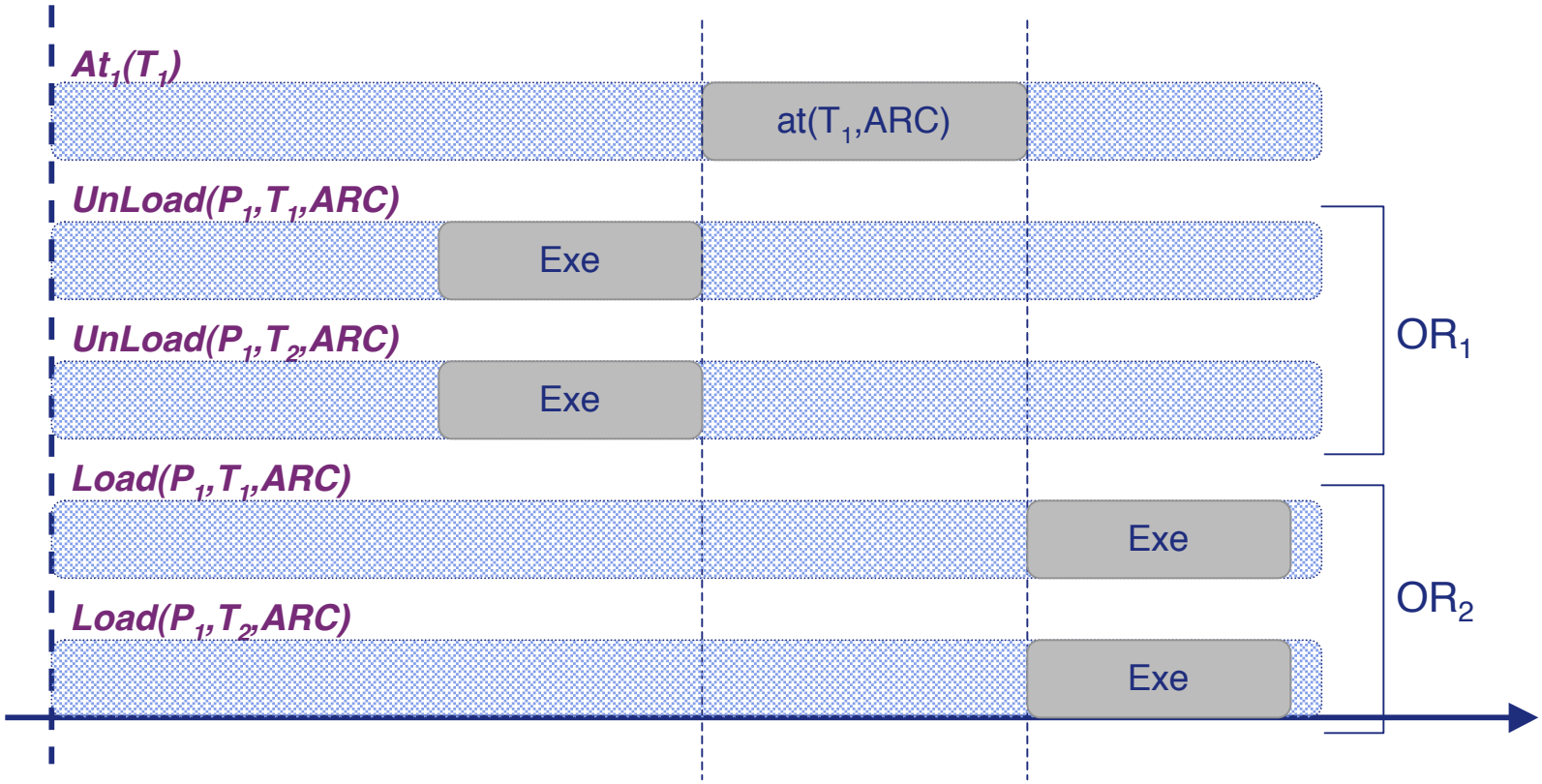



```
T:: p{
  if (guard=c1)
            meets(op1.exe);
  ...
  if (guard=ck)
            meets(opk.exe);
  if (guard=ck+1)
            ends(opk+1.exe);
  ...
  if (guard=cn)
            ends(opn.exe);}
```

operators whose effects **at_end** contain ¬p

operators whose effects ***at_start*** contain ¬p

Frame Axioms



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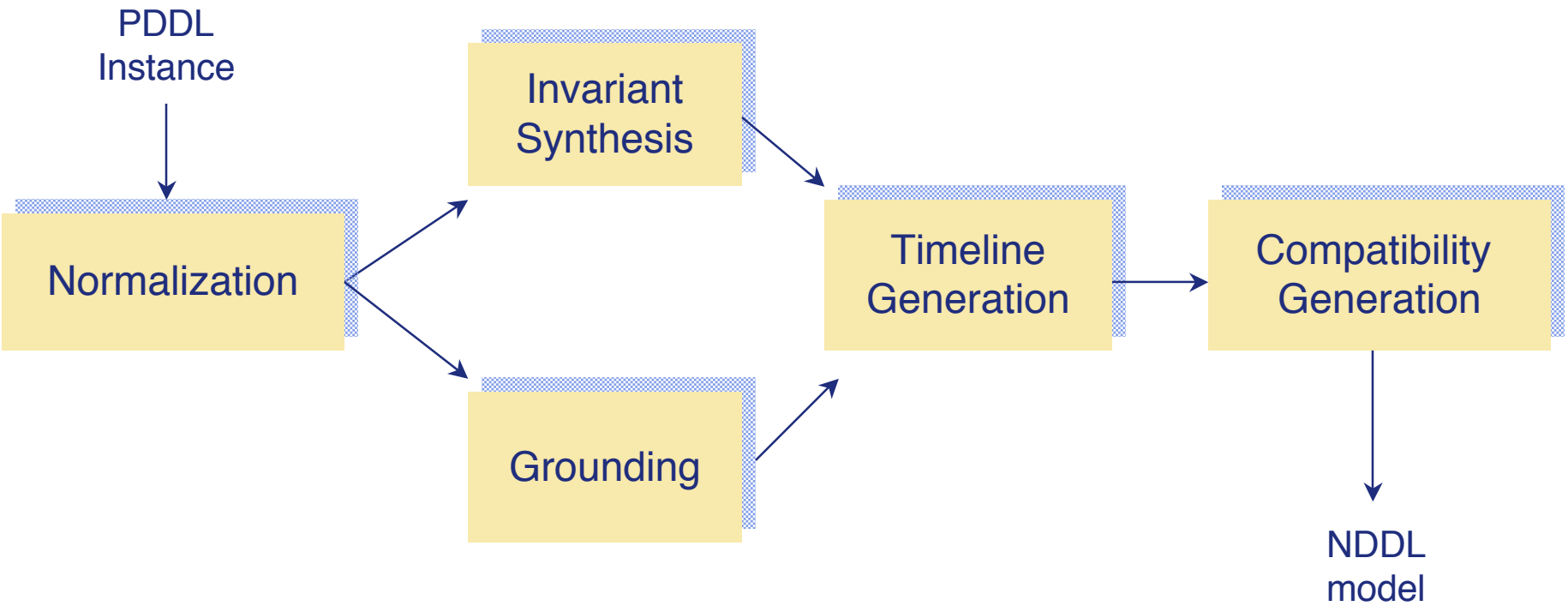
Translation Steps



Performance

[Helmert-2009]

Non-temporal problems from IPC 1-5: 1612

Runtime(s)	Problems
< 1	1054
1–10	452
10-30	67
30-60	10
60-120	14
> 120	15

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Performance

[Helmert-2009]

Non-temporal IPC 1-5 problems: 1612

Runtime(s)	Problems
< 1	1054
1–10	452
10-30	67
30-60	10
60-120	14
> 120	15

Domain	Problem	Runtime(s)
Satellite	35	130
PSR-Large	47	146
Satellite	31	148
PSR-Large	42	154
PSR-Large	43	182
PSR-Large	45	182
Satellite	36	189
PSR-Large	40	198
PSR-Large	49	306
Satellite	32	372
PSR-Large	44	377
PSR-Large	46	570
PSR-Large	48	715
Satellite	33	806
PSR-Large	50	1191

989,250 Ops

544,209 Vars

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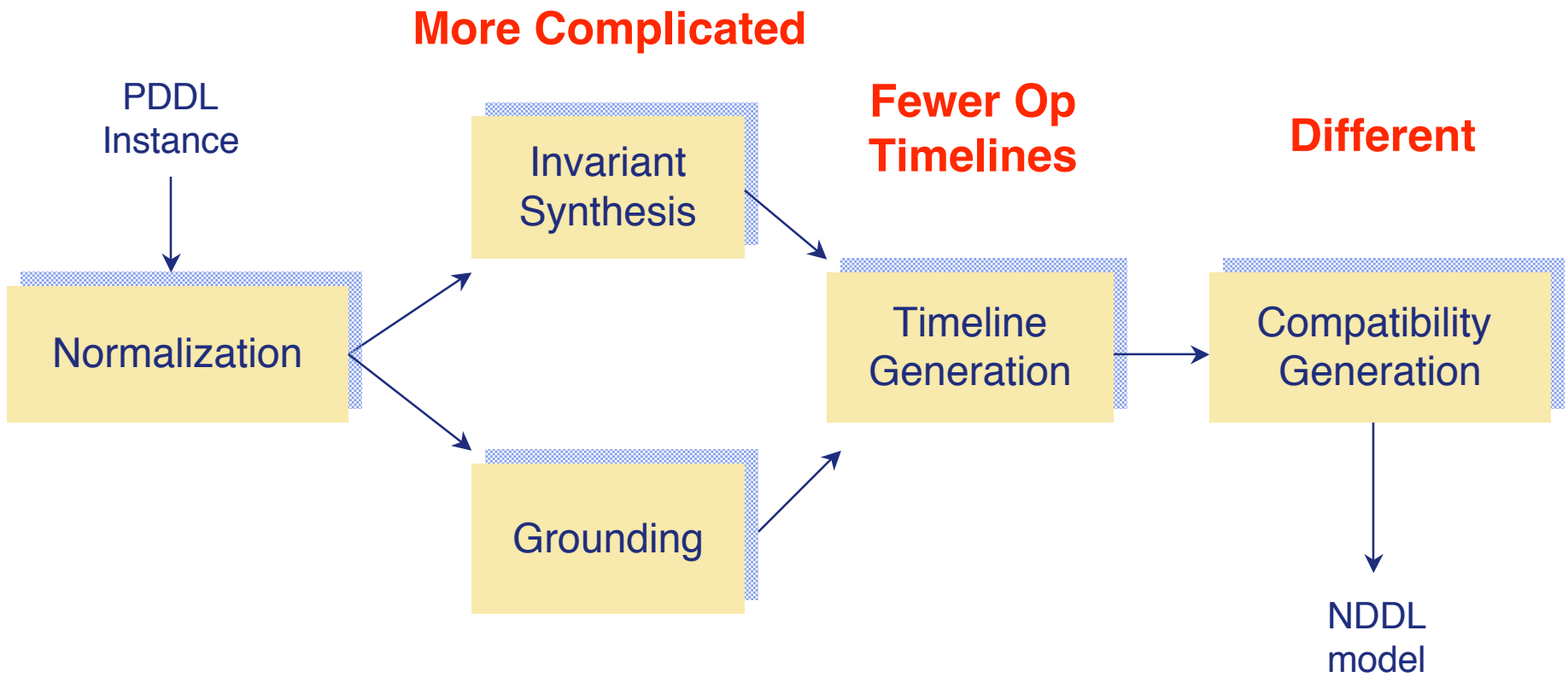
Breakdown (runtime > 1s)

[Helmert-2009]

Domain	Tasks	Parsing	Normalize	Invariants	Grounding	Generation
Airport	30/50	8-18%	1-4%	2-8%	48-64%	20-27%
Assembly	4/30	5-8%	< 1%	< 1%	80-84%	10-13%
Depot	7/22	4-6%	< 1%	< 1%	65-70%	26-30%
Driverlog	5/20	4-6%	< 1%	< 1%	69-73%	22-26%
Freecell	76/80	3-5%	< 1%	< 1%	67-71%	24-28%
Grid	4/5	4%	< 1%	< 1%	69-72%	24-27%
Logistics	21/63	3-6%	< 1%	< 1%	68-75%	21-30%
Miconic-full	95/150	1-5%	0-2%	< 1%	84-92%	7-10%
MPrime	23/35	3-6%	< 1%	< 1%	70-75%	22-27%
Mystery	14/30	3-6%	< 1%	< 1%	70-74%	22-27%
Openstacks	7/30	4-6%	< 1%	< 1%	63-65%	30-33%
OptTelegraph	41/48	4-7%	< 1%	< 1%	60-68%	25-35%
Pipes-NoTank	22/50	3-6%	< 1%	< 1%	71-75%	20-24%
Pipes-Tank	43/50	2-5%	< 1%	< 1%	71-76%	19-26%
PSR-Large	43/50	5-7%	< 1%	< 1%	80-87%	7-16%
PSR-Medium	27/50	5-8%	< 1%	< 1%	81-87%	8-14%
PSR-Small	2/50	29-34%	4%	1-11%	39-56%	11-13%
Rovers	22/40	2-7%	< 1%	< 1%	77-95%	4-17%
Satellite	18/36	1-6%	< 1%	< 1%	66-75%	20-34%
Storage	12/30	5-6%	< 1%	< 1%	64-67%	27-32%
TPP	15/30	3-5%	< 1%	< 1%	73-76%	20-24%
Trucks	20/30	5-9%	< 1%	< 1%	62-69%	25-33%
ZenoTravel	7/20	4%	< 1%	< 1%	73-76%	21-24%

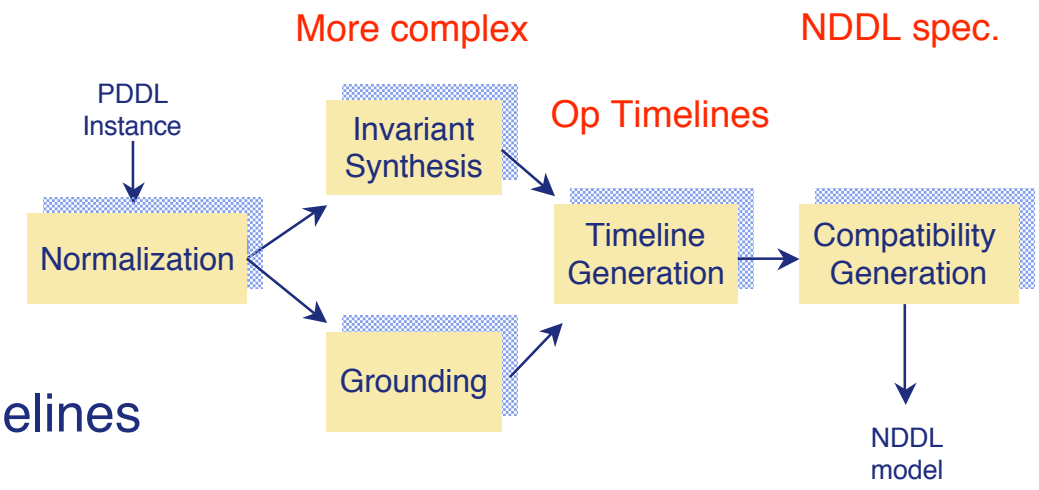
Differences for Temporal



Same Computational Complexity

Conclusions

1. Translation from PDDL2.1 into NDDL
   - ***Invariant Synthesis***
   - ***Timeline Generation***
   - ***Compatibility Generation***



2. Issues:
   - compacting operator timelines
   - numeric quantities
   - optimization criteria
   - timed initial literals (PDDL 2.2)
   - preferences (PDDL 3.0)

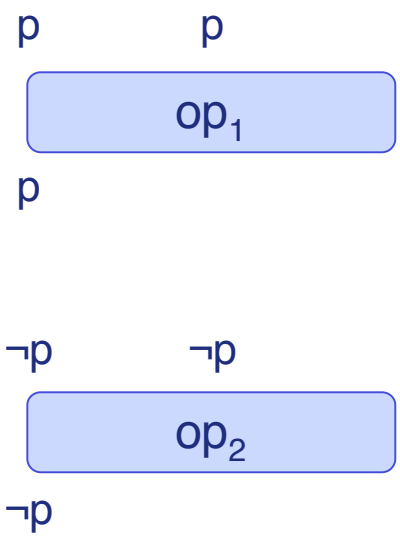
Extras

Mutex for Durative Actions

When are two durative PDDL operators ***mutex***?

Nine types of mutex:

1. **Start-Start**:
   op1 and op2 cannot start at the same time



Mutex for Durative Actions

Nine types of mutex:

1. **Start-Start**:
   op1 and op2 cannot start at the same time
2. **End-End:**
   op1 and op2 cannot end at the same time
3. **Start-End:**
   op1 cannot start at the same time that op2 ends
4. **Dur-Start:**
   op2 cannot start during op1
5. **Dur-End:**
   op2 cannot end during op1
6. **Dur-Dur:**
   op1 and op2 cannot overlap

Dual cases: End-Start (dual to 3), Start-Dur (dual to 4), and End-Dur (dual to 5)