Composition: the "Roman" Approach
Reduction to SAT in PDL

Encoding in PDL

Basic idea:

- A orchestrator program *P* realizes the target service *T* iff at each point:
  - ∀ transition labeled *a* of the target service *T* …
  - … ∃ an available service B_i (the one chosen by *P*) that can make an *a*-transition, realizing the *a*-transition of *T*
- Encoding in PDL:
  - ∀ transition labeled *a* …
    use **branching**
  - ∃ an available service B_i that can make an *a*-transition …
    use underspecified predicates **assigned through SAT**

Structure of the PDL Encoding

$$\Phi = \mathit{Init} \wedge [u](\Phi_0 \wedge \bigwedge_{i=1,\dots,n} \Phi_i \wedge \Phi_{aux})$$

Initial states of all services

PDL encoding of target service

PDL encoding of *i*-th component service

PDL additional domain-independent conditions

PDL encoding is polynomial in the size of the service TSs

PDL Encoding

- Target service $S_0 = (\Sigma, S_0, s^0_0, \delta_0, F_0)$ in PDL we define Φ_0 as the conjunction of:
  - $s \rightarrow \neg s'$ for all pairs of distinct states in S_0
    service states are pair-wise disjoint
  - $s \rightarrow \langle a \rangle T \wedge [a]s'$ for each $s'=\delta_0(s,a)$
    target service can do an a-transition going to state s'
  - $s \rightarrow [a] \perp$ for each $\delta_0(s,a)$ undef.
    target service cannot do an a-transition
  - $F_0 \equiv \vee_{s \in F0}\ s$
    denotes target service final states
- …

PDL Encoding (cont.d)

Dipartimento di Informatica e Sistemistica "Antonio Ruberti" SAPIENZA Università di Roma

- available services $\mathcal{S}_i = (\Sigma, S_i, s^0_i, \delta_i, F_i)$ in PDL we define Φ_i as the conjunction of:
  - $s \rightarrow \neg s'$ for all pairs of distinct states in S_i
    Service states are pair-wise disjoint
  - $s \rightarrow [a](moved_i \wedge s' \vee \neg moved_i \wedge s)$ for each $s'=\delta_i(s,a)$
    if service moved then new state, otherwise old state
  - $s \rightarrow [a](\neg moved_i \wedge s)$ for each $\delta_i(s,a)$ undef.
    if service cannot do a, and a is performed then it did not move
  - $F_i \equiv \vee_{s \in Fi}\ s$
    denotes available service final states
- …

PDL Encoding (cont.d)

Dipartimento di Informatica e Sistemistica "Antonio Ruberti" SAPIENZA Università di Roma

- Additional assertions Φ_{aux}
  - $<a>T \rightarrow [a] \vee_{i=1,\ldots,n} moved_i$ for each action a
    at least one of the available services must move at each step
  - $F_0 \rightarrow \wedge_{i=1,\ldots,n} F_i$
    when target service is final all comm. services are final
  - $Init \equiv s^0_0 \wedge_{i=1\ldots n} s^0_i$
    Initially all services are in their initial state

PDL encoding: $\Phi = Init \wedge [u](\Phi_0 \wedge_{i=1,\ldots,n} \Phi_i \wedge \Phi_{aux})$

Results

Thm[ICSOC' 03,IJCIS' 05]:

Composition exists iff PDL formula Φ SAT

From composition labeling of the target service one can build a tree model of the PDL formula and viceversa

Information on the labeling is encoded in predicates $moved_i$

Corollary [ICSOC' 03,IJCIS' 05]:

Checking composition existence is decidable in **EXPTIME**

Thm[Muscholl&Walukiewicz FoSSaCS'07]:

Checking composition existence is **EXPTIME-hard**

Results on TS Composition

Thm[ICSOC' 03,IJCIS' 05]:

If composition exists then finite TS composition exists.

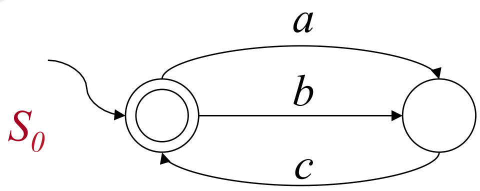
From a small model of the PDL formula Φ, one can build a finite TS machine

Information on the output function of the machine is encoded in predicates $moved_i$

$\Rightarrow$ finite TS composition existence of services expressible as finite TS is EXPTIME-complete

Example (1)

Target service



PDL

...

...

...

$s_0^0 \wedge s_1^0 \wedge s_2^0$

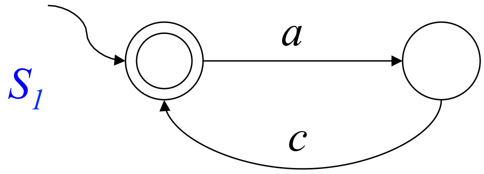
$\langle a\rangle T \rightarrow [a]\ (moved_1 \vee moved_2)$

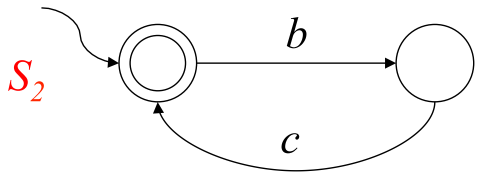
$\langle b\rangle T \rightarrow [b]\ (moved_1 \vee moved_2)$

$\langle c\rangle T \rightarrow [c]\ (moved_1 \vee moved_2)$

$F_0 \rightarrow F_1 \wedge F_2$

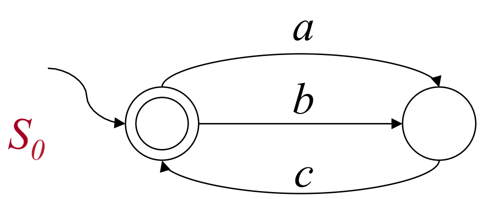
Available services





Example (2)

Target service



$s_0^0 \rightarrow \neg\, s_0^1$

$s_0^0 \rightarrow \langle a\rangle T \wedge [a]\ s_0^1$

$s_0^0 \rightarrow \langle b\rangle T \wedge [b]\ s_0^1$

$s_0^1 \rightarrow \langle c\rangle T \wedge [c]\ s_0^0$

$s_0^0 \rightarrow [c] \perp$

$s_0^1 \rightarrow [a] \perp$

$s_0^1 \rightarrow [b] \perp$

$F_0 \equiv s_0^0$

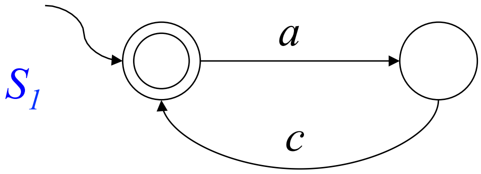
...

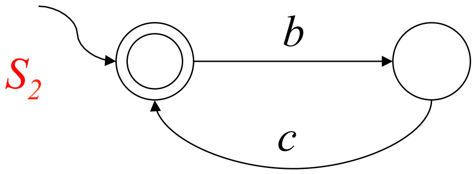
...

...

Example (3)

Available services





...

$s_1^0 \rightarrow \neg\, s_1^1$

$s_1^0 \rightarrow [a]\ (moved_1 \wedge s_1^1 \vee \neg moved_1 \wedge s_1^0)$

$s_1^0 \rightarrow [c]\ \neg moved_1 \wedge s_1^0$

$s_1^0 \rightarrow [b]\ \neg moved_1 \wedge s_1^0$

$s_1^1 \rightarrow [a]\ \neg moved_1 \wedge s_1^1$

$s_1^1 \rightarrow [b]\ \neg moved_1 \wedge s_1^1$

$s_1^1 \rightarrow [c]\ (moved_1 \wedge s_1^0 \vee \neg moved_1 \wedge s_1^1)$

$F_1 \equiv s_1^0$

$s_2^0 \rightarrow \neg\, s_2^1$

$s_2^0 \rightarrow [b]\ (moved_2 \wedge s_2^1 \vee \neg moved_2 \wedge s_2^0)$

$s_2^0 \rightarrow [c]\ \neg moved_2 \wedge s_2^0$

$s_2^0 \rightarrow [a]\ \neg moved_2 \wedge s_2^0$

$s_2^1 \rightarrow [b]\ \neg moved_2 \wedge s_2^1$

$s_2^1 \rightarrow [a]\ \neg moved_2 \wedge s_2^1$

$s_2^1 \rightarrow [c]\ (moved_2 \wedge s_2^0 \vee \neg moved_2 \wedge s_2^1)$

$F_2 \equiv s_2^0$

...

Example (4)

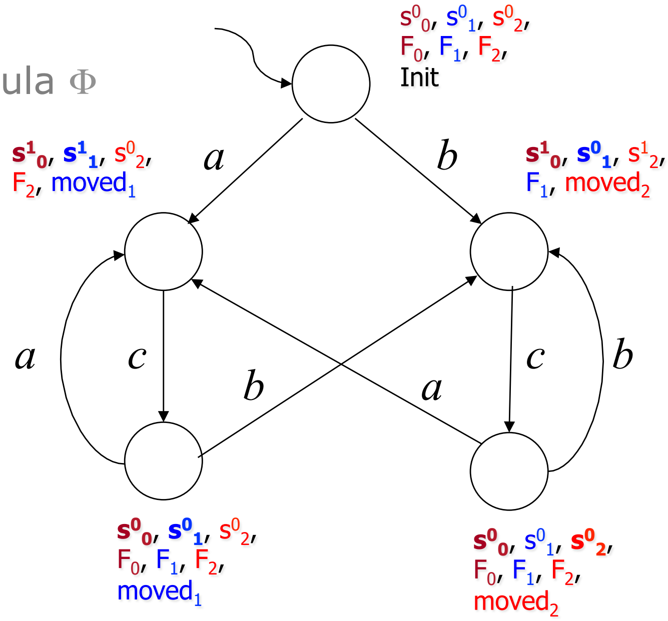
Check: run SAT on PDL formula Φ

Example

Dipartimento di Informatica e Sistemistica "Antonio Ruberti"
SAPIENZA Università di Roma

Check: run SAT on PDL formula Φ

Yes $\Rightarrow$ (small) model



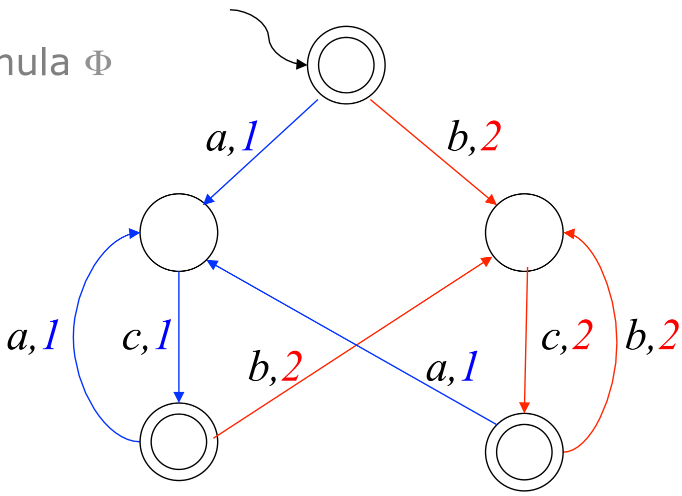
Example

Dipartimento di Informatica e Sistemistica "Antonio Ruberti"
SAPIENZA Università di Roma

Check: run SAT on PDL formula Φ

Yes $\Rightarrow$ (small) model

$\Rightarrow$ extract finite TS



Example

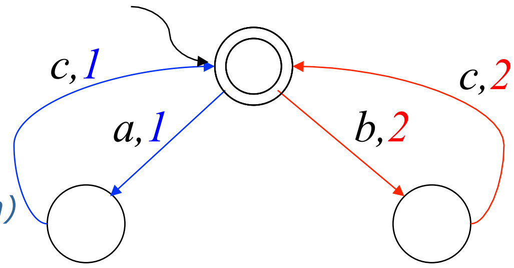
Check: run SAT on PDL formula Φ

Yes $\Rightarrow$ (small) model

$\Rightarrow$ extract finite TS

$\Rightarrow$ minimize finite TS

(similar to Mealy machine minimization)



Results on Synthesizing Composition

- Using PDL reasoning algorithms based on model construction (cf. tableaux), build a (small) model

  Exponential in the size of the PDL encoding/services finite TS

  Note: SitCalc, etc. can compactly represent finite TS, PDL encoding can preserve compactness of representation

- From this model extract a corresponding finite TS

  Polynomial in the size of the model

- Minimize such a finite TS using standard techniques (opt.)

  Polynomial in the size of the TS

  Note: finite TS extracted from the model is not minimal because encodes output in properties of individuals/states

Tools for Synthesizing Composition

Dipartimento di Informatica e Sistemistica "Antonio Ruberti"
SAPIENZA Università di Roma

- In fact we use only a fragment of PDL in particular we use fixpoint (transitive closure) only to get the universal modality …

- … thanks to a tight correspondence between PDLs and Description Logics (DLs), lately highly optimized tableaux based reasoning systems are available to:
  - check for composition existence
  - do composition synthesis *(if the ability or returning models is present)*

- Among them we recall:
  - Racer (http://www.racer-systems.com/) based on DLs
  - Pellet (http://clarkparsia.com/pellet) based on DLs
  - Fact++ (http://owl.man.ac.uk/factplusplus/) based on DLs
  - PDL Tableaux (http://www.cs.manchester.ac.uk/~schmidt/pdl-tableau/) based on PDL
  - Tableaux Workbench (http://twb.rsise.anu.edu.au/) based on PDL
  - Lotrec (http://www.irit.fr/Lotrec/) based on PDL

Dipartimento di Informatica e Sistemistica "Antonio Ruberti"
SAPIENZA Università di Roma

Reduction to PDL SAT works also for nondeteminisitic available services

Technique1: Reduction to PDL

Dipartimento di Informatica e Sistemistica "Antonio Ruberti"
SAPIENZA Università di Roma

Basic idea:

- A orchestrator program *P* realizes the target service *T* iff at each point:
  - ∀ transition labeled *a* of the target service *T* …
  - … ∃ an available service B_i (the one chosen by *P*) which can make an *a*-transition …
  - … and ∀ *a*-transition of B_i realize the *a*-transition of *T*
- Encoding in PDL:
  - ∀ transition labeled *a* …
    use **branching**
  - ∃ an available service B_i …
    use underspecified predicates **assigned through SAT**
  - ∀ *a*-transition of B_i … :
    use **branching** again

Technical Results: Practical

Dipartimento di Informatica e Sistemistica "Antonio Ruberti"
SAPIENZA Università di Roma

Reduction to PDL provides also a practical sound and complete technique to compute the orchestrator program also in this case

eg, PELLET @ Univ. Maryland

- Use state-of-the-art tableaux systems for OWL-DL for checking SAT of PDL formula Φ coding the composition existence
- *If SAT, the tableau returns a finite model of* Φ

  exponential in the size of the behaviors
- Project away irrelevant predicates from such model, and possibly minimize
- *The resulting structure is a finite orchestrator program that realizes the target behavior*

  polynomial in the size of the model