Automatic Composition of *e*-Services: The "Roman" way

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Overview

- Activity based model: the “Roman” approach
- Composition results in the “Roman” model
- Message based model
- Activity vs Message based model
- Embedding Activity based model into SitCalc
- Embedding Activity based model into PSL

e-Services and Community of *e*-Services: The Model used by "Roman" Results

- An *e*-Service is an interactive program that exports its behavior in terms of an abstract description
- A client selects and interacts with it according to the description exported

- A community of *e*-Services is:
  - a set of *e*-Services …
  - … that share implicitly a *common understanding* on a common set of actions and export their behavior using this common set of actions
- A client specifies needs as e-Service behavior using the common set of actions of the community

e-Service Exports its Behavior ...

Many possible ways. In this talk…

- Behavior modeled by finite state machines

  core of state chart, UML state-transition diagram, etc.

  – in our FSMs, each transaction corresponds to an action *(e.g., search-by author-and-select, search-by title-and-select, listen-the-selected-song, ...)*

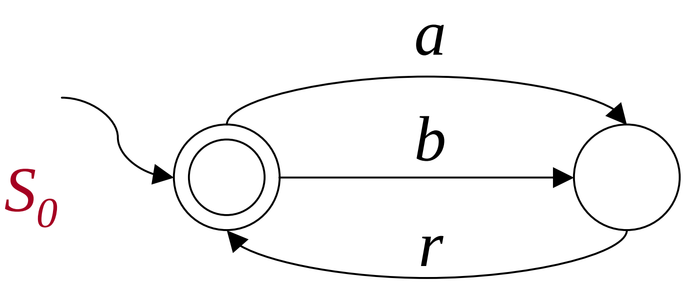
- In fact using a FSM we compactly describe all possible sequences of deterministic (atomic) actions: tree of all possible sequences of actions

- Data produced by actions not explicitly modeled

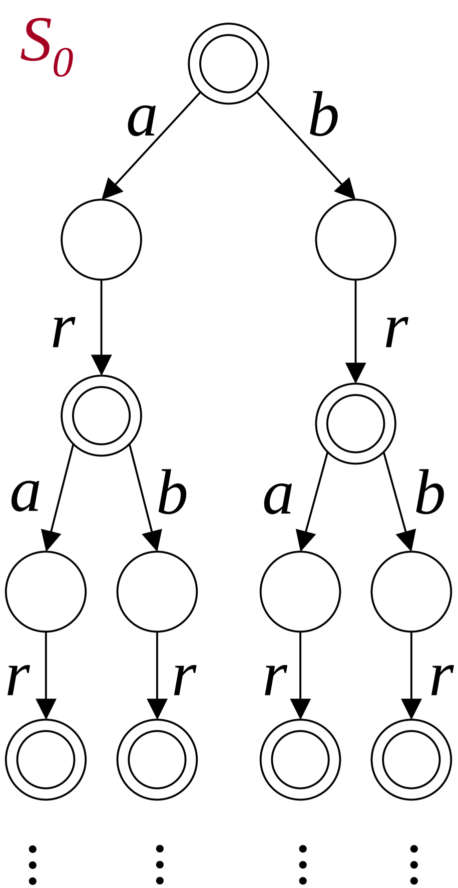
  data are used by the client to choose next action

e-Service as Execution Tree

Required behavior represented as a FSM



Execution tree (obtained by FSM unfolding)

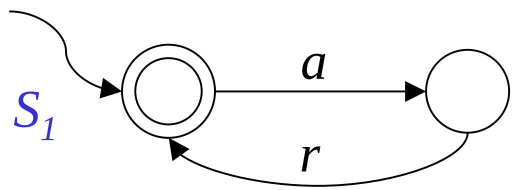


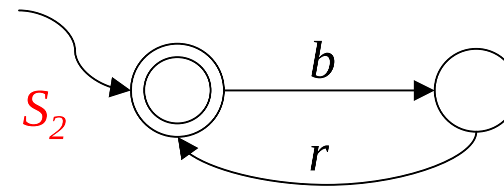
a: "search by author (and select)"
b: "search by title (and select)"
r: "listen (the selected song)"

e-Service Composition in the "Roman Framework"

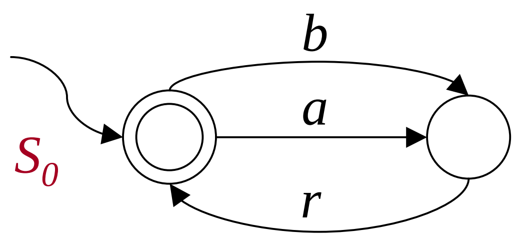
Given:

- Community C of *e*-Services
(expressed as FSMs)



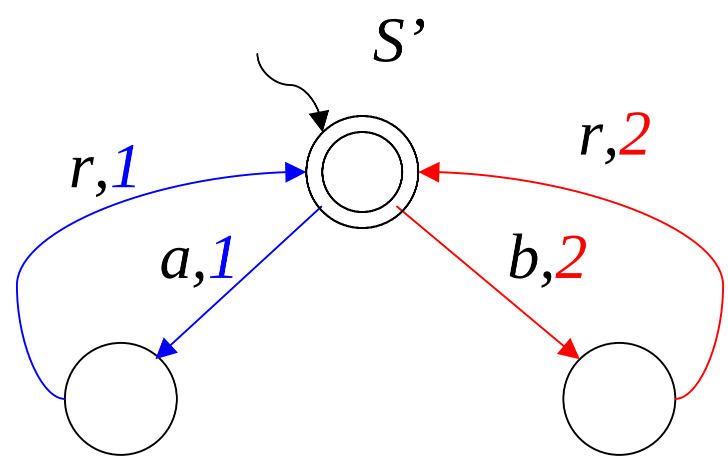


- Target *e*-Service S_0
(again expressed as FSM)



Find:

- new FSM *e*-Service S' (delegator):
  - new alphabet = actions x (sets of service identifiers)
  - "accepts" same language as S_0
  - For each accepting run of S' on word w, and for each S in C, "projection" of this run onto moves of S is an accepting computation for S



Key Idea for Finding Composition: Exploit Description Logics (DLs)

- Description Logics:
  - represent knowledge in terms of classes and relationships between classes
  - equipped with decidable reasoning

- Interesting properties:
  - Tree model property
  - Small model property
  - EXPTIME decidability

Results on Automatically Building e-Service Composition

DL encoding of target *e*-Service

DL encoding of *i*-th component *e*-Service

DL additional domain-independent conditions

Initially all *e*-Services are in their initial states

DL Knowledge Base:

Δ_0

Δ_i

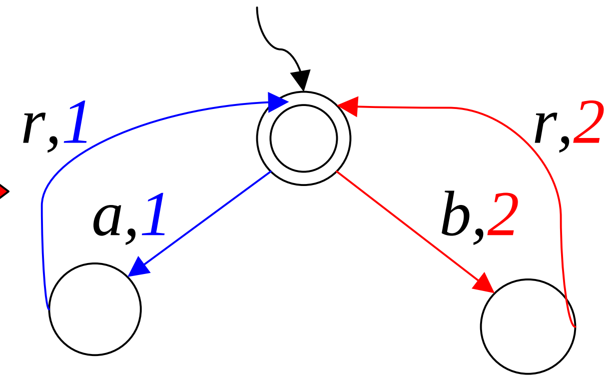
Δ_{aux}

Δ_{Init}

Check satisfiability (and build a model)

EXPTIME

e-Service composition



Results

Thm 1: Composition exists iff DL Knowledge Base satisfiable

From composition labeling of the target e-Service one can build a tree model for the Knowledge Base, and vice-versa

Cor 1: Composition existence of *e*-Services, expressible as FSMs, is decidable in EXPTIME

Thm 2: If composition exists then finite state composition exists.

From a small model of a DL Knowledge Base, one can build a finite state composition

Cor 2: Finite state composition existence of *e*-Services, expressible as FSMs, is decidable in EXPTIME

$\Rightarrow$ **Building finite state composition can be done in EXPTIME**

Message Based Model

ec-Schema:

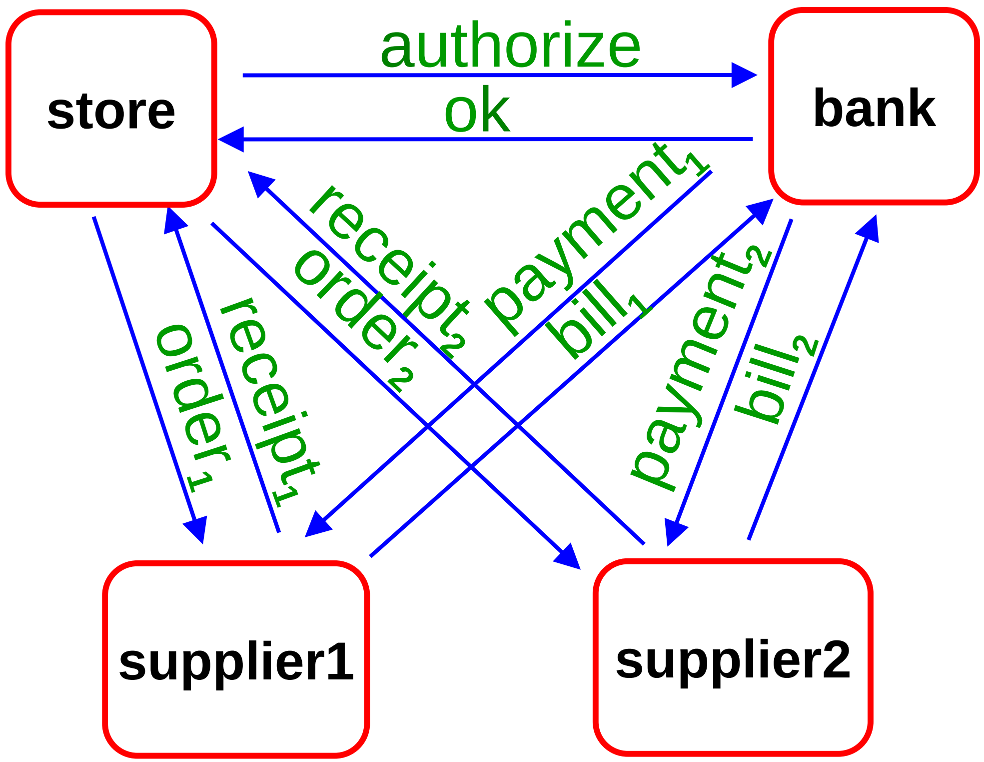
- finite set of abstract peers (*e*-Services)
  - peers can be implemented as FSM with input/output
  - each peer has a (bounded) queue

  ⇒ asynchronous communication between peers
- finite set of channels
  - i.e., {<sender, receiver, message_type>}
- finite set of incoming and outgoing messages over some alphabet Σ
  - input messages: ?a, $a \in \Sigma$
  - output messages !a, $a \in \Sigma$
  - As technical simplification in theoretical model, each symbol "a" encodes a triple <sender,receiver,message-type>
- Conversation language: sequence of messages exchanged between peers

Model is peer-to-peer, but can restrict to mediated by assuming "hub-and-spoke" connection graph. (I.e., one peer acts as the mediator)

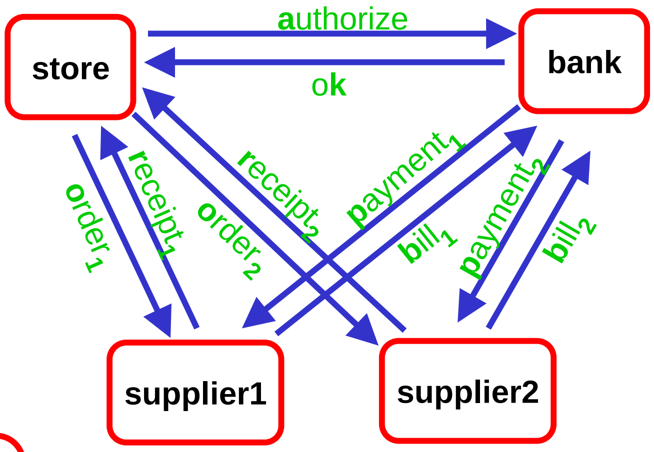
E-Composition Schema

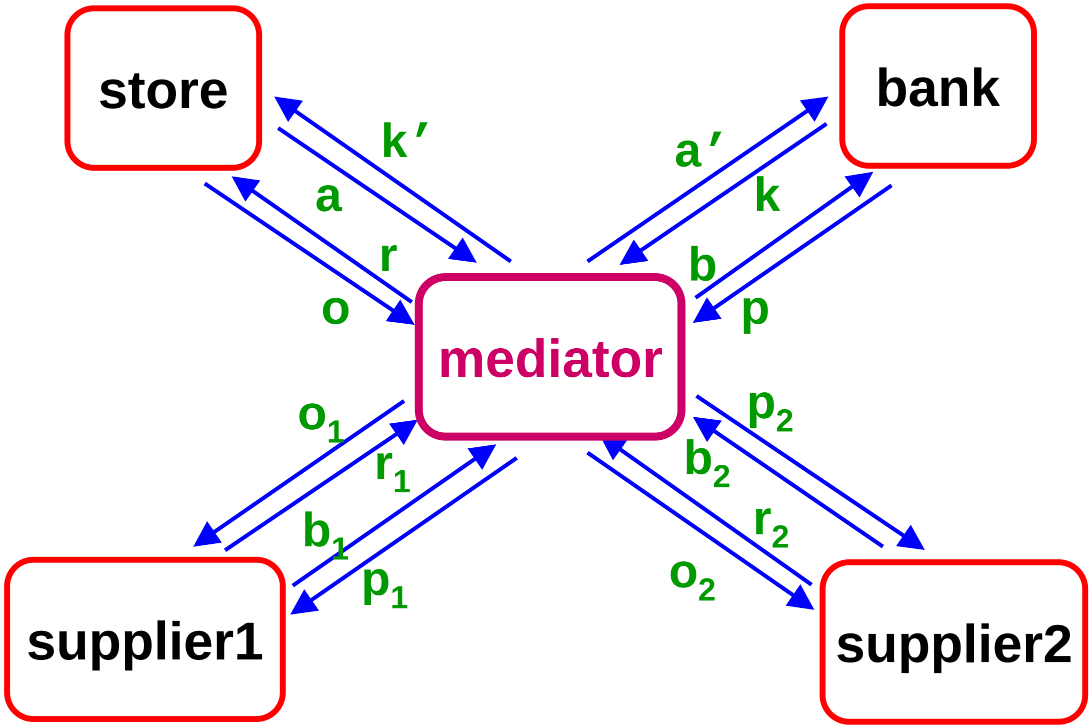
- An <u>E-C schema</u> specifies the infrastructure of composition
- Assume finite domains $\Rightarrow$ can model parameters



Composition Infrastructure

- Peer-to-peer (distributed control)





- Hub-and-spoke (centralized control)

Peer Synthesis Statement and Results

- Problem statement
  - Given: ec-schema and LTL formula φ
  - Create: a FSM for each peer so that φ is satisfied
  - Note: not a composition problem, because this result is creating peers, not selecting them from a pre-existing "UDDI"
- Synthesis results for Mealy implementations with bounded queues
  - Mealy peer synthesis: decidable
    - Propositional LTL description ⇒ PSPACE
- (Also, results contrasting bounded vs. unbounded message queues)

“Roman” Activity Based Composition Result vs Message Based Synthesis Result

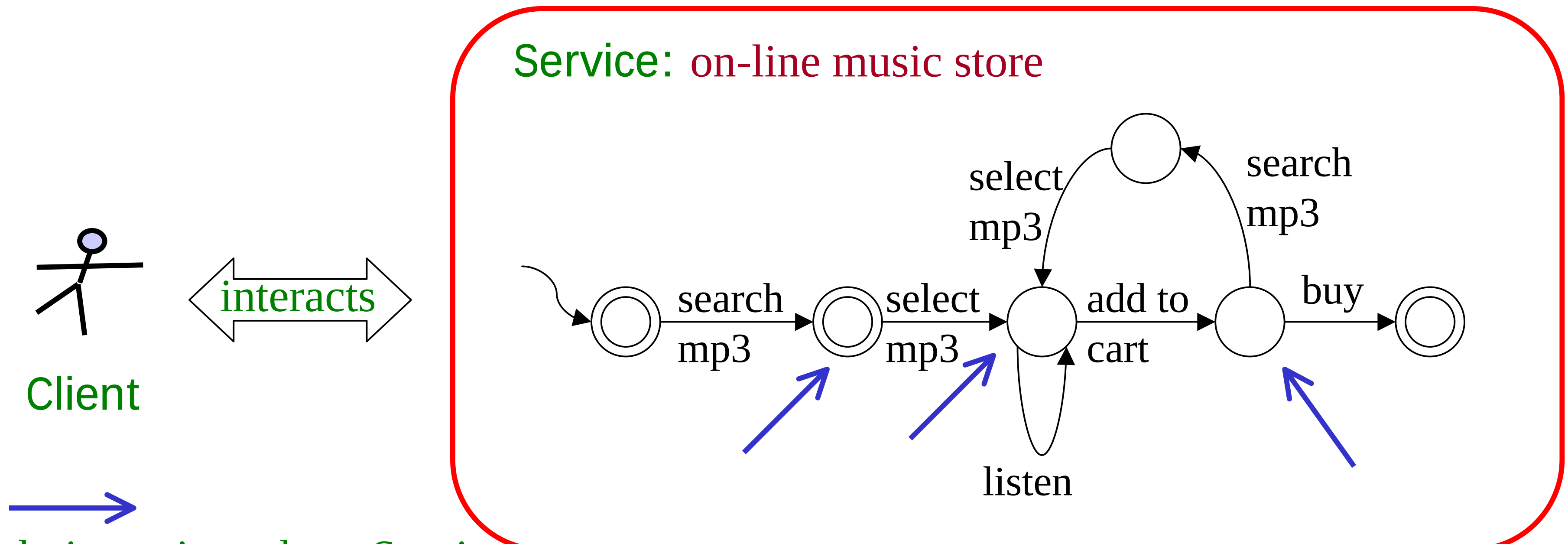
- Activity based Model:
  - behavior modeled as FSM, with transitions labeled by actions
  - client/server model: “active” client: s/he selects from a set of choices presented by e-service
- Result
  - Start with community of activity-based FSMs (e-services)
  - FMSs define constraint on legal sequence of actions executed by each peer
  - given a branching time spec. Ψ of global behavior and “constrained” peers, synthesize a delegator
  - peers communicate only with delegator
  - determinism only (for the moment)

- Message based Model:
  - behavior modeled as FSM, with transitions labeled by input/output messages
  - peer-to-peer model; no notion corresponding to client in activity model
- Result
  - Start with “ec-schema” which establishes topology for message-passing
  - no constraint on legal sequences of actions executed by each abstract peer
  - given a LTL spec. Φ of global behavior and “ec-schema”, synthesize peers such that Φ is realized
  - peer-to-peer communication
  - non determinism over messages (i.e., same message labeling different transition from same state)

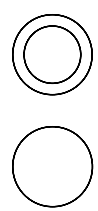
“Roman” Activity Based vs Message Based

- “Roman” Activity based and Message based are complementary approaches:
  - Can merge them?
  - How?
- (other) “Roman” Activity based future work:
  - is our algorithm EXPTIME-hard?
  - currently we are working on a DL based prototype system that implements our composition algorithm
  - also working on notion of “k-look-ahead” compositions - gives more flexibility than first Roman results
  - add non determinism
  - data (i.e., parameters of actions)

Summary: The “Roman” Activity Based Model for *e*-Services



choice points: the *e*-Service makes **always** the **client decide** what to do next (in principle, all states can be choice points).



states at which client can stop

states at which client cannot stop

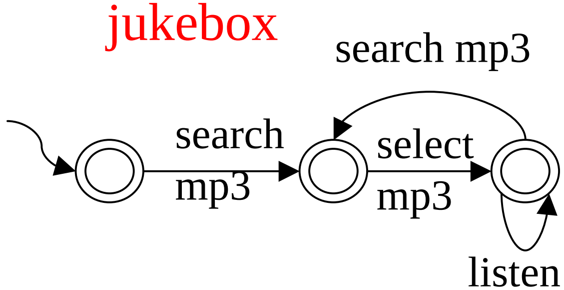
Summary: Automatic *e*-Service composition in the "Roman" Framework

But: what if

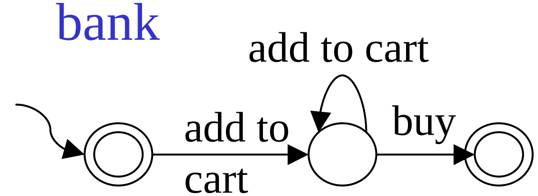
- there does not exist an *e*-Service on-line music store ?
- the only available *e*-Services are jukebox and bank?

Community of *e*-Services:

jukebox



bank



Summary: Automatic *e*-Service composition in the “Roman” Framework (cont.d)

<u>Target *e*-Service</u> (client request):
on-line music store

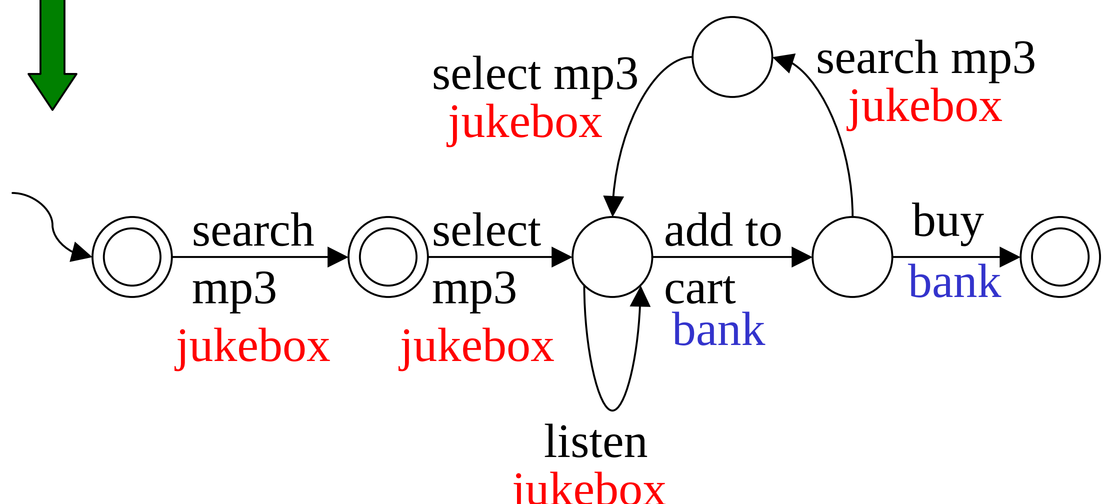
<u>Community of *e*-Services</u>
(available *e*-Services):
jukebox, bank

based on tableau techniques for DLs

e-Service Automatic Composition Engine

Domain indep. constraints

<u>Delegator</u> (delegates each action of target *e*-Service to *e*-Service(s) in the community):



Situation Calculus Encoding of Roman Model -- Idea

- Each *e*-Service *i* as Reiter's Basic Action Theory Γ_i:
  - each action as a Situation Calculus action
  - each state of FSM is a fluent
  - special fluent *Final* to indicate situation when e-Service execution can stop.

    ⇒ In Γ_i we have complete information on the initial situation and hence on the whole theory.
- *e*-Service composition:
  - represent which *e*-Services (in the community) are executed, when an action of the target *e*-Service is performed, by predicates $Step_i(a, s)$, denoting that *e*-Service *i* executes action *a* in situation *s*.

    ⇒ Situation Calculus Theory (but not basic)

    ⇒ Incomplete information over $Step_i(a, s)$
  - rename *Poss* to $Poss_i$, rename *Final* to $Final_i$
  - suitably modify the successor axioms to cope with $Step_i(a, s)$

Sit Calc Encoding -- Details

- Target *e*-Service $E_0 = (\Sigma, Q_0, q^0{}_0, \delta_0, \mathcal{F}_0)$

(Reiter Basic Action Theory)

  - $F_{q00}(S_0)$ *initial situation*
  - $\forall s.\ F_q(s) \supset \neg F_{q'}(s)$ *for all pairs of distinct states q, q' in E_0*

    e-Service states are pair-wise disjoint

  - $\forall s.\ Poss(a, s) \equiv \bigvee_{q\ st\ \delta 0(q, a)\ is\ defined} F_q(s)$

    $\forall s\ \forall \alpha.\ F_{q'}(do(\alpha,s)) \equiv \bigvee_{a,\ q,\ st\ q' = \delta 0(q,\ a)} (\alpha = a \wedge F_q(s)) \vee$

    $(F_{q'}(s) \wedge \bigwedge_{b\ st\ \delta 0(q',b)\ is\ defined} \alpha \neq b)$

    for each $q' = \delta_0(q,a)$

    target e-Service can do an a-transition going to state q'

  - $\forall s.\ Final(s) \equiv \bigvee_{q \in \mathcal{F}0} F_q(s)$

    denotes target e-Service final states

Sit Calc Encoding -- Details (cont.d)

- Community *e*-Services $E_i = (\Sigma, Q_i, q^0_i, \delta_i, \mathcal{F}_i)$
  - $F_{qi0}(S_0^i)$ *initial situation*
  - $\forall s.\ F_q(s) \supset \neg F_{q'}(s)$ *for all pairs of distinct states q, q' in* E_i
    e-Service states are pair-wise disjoint
  - $\forall s.\ Poss_i(a, s) \equiv \bigvee_{q \text{ st } \delta i(q, a) \text{ is defined}} F_q(s)$

    $\forall s\ \forall \alpha.\ F_{q'}(do(\alpha,s)) \equiv$

    $(\bigvee_{a,\, q,\, st\ q' = \delta i(q,\, a)} (\alpha = a \wedge F_q(s) \wedge Step_i(\alpha, s))) \vee$

    $(\neg Step_i(\alpha, s) \wedge F_{q'}(s))$

    for each $q' = \delta_i(q, a)$

    if e-Service moved then new state, otherwise old state
  - $\forall s.\ Final_i(s) \equiv \bigvee_{q \in \mathcal{F}i} F_q(s)$
    denotes community e-Service final states

SitCalc Encoding -- Details (cont.d)

- Foundational, domain independent axioms:
  - $\forall s,a.\ Poss(a,s) \wedge \neg\ Final(s) \rightarrow \bigvee_{i=1..n}\ Step_i\ (a,s) \wedge Poss_i(a,s)$

    for each action a

    at least one of the community e-Services must move at each step
  - $\forall s.\ Final(s) \rightarrow \bigwedge_{i=1..n} Final_i\ (s)$

    when target e-Service is final all comm. e-Services are final
  - $\bigwedge_{i=0..n} F_{qi0}\ (S_0^{\ i})$

    in the initial situation all e-Services are in their initial state

PSL Encoding of Roman Model -- Idea

- Based on Rick Hull and Michael Gruninger encoding of message based model in PSL
- Basic idea to model an *e-Service*:
  - fluents to denote:
    - initial situation (*Init*)
    - states of FSM (F_q),
    - final states (*Final*),
  - one activity for each action

  .
- Component *e*-Services:
  - rename *poss* to $poss_i$, rename *Final* to $Final_i$
  - fluent $Step_{ai}$ to denote which component *e*-Service “moves”

PSL Encoding of Roman Model -- Idea

- Based on Rick Hull and Michael Gruninger encoding of message based model in PSL
- Basic idea to model an *e-Service*:
  - fluents to denote:
    - initial situation (*Init*)
    - states of FSM (F_q),
    - final states (*Final*),
  - one activity for each action

very similar to Sit Calc !

- Component *e*-Services:
  - rename *poss* to $poss_i$, rename *Final* to $Final_i$
  - fluent $Step_{ai}$ to denote which component *e*-Service “moves”

PSL Encoding -- Details

- Target *e*-Service $E_0 = (\Sigma, Q_0, q^0_0, \delta_0, \mathcal{F}_0)$
  - $\forall o.prior\ (F_q \supset \neg F_{q'}\ , o)$

    for all pairs of distinct states q, q' in E_0

    e-Service states are pair-wise disjoint
  - $\forall o.\ holds(F_q\ ,o) \supset poss(a, o)$ *(prec)*

    $\forall o.\ occurrence\_of(o\ ,a) \wedge prior(F_q\ , o) \supset holds(F_{q'}, o)$ *(eff)*

    for each $q'=\delta_0(q,a)$

    target e-Service can do an a-transition going to state q'
  - $\forall o.\ holds(F_q\ ,o) \wedge poss(a, o) \supset false$ *for each $\delta_0(q,a)$ undef.*

    target e-Service cannot do an a-transition
  - $Final \equiv \vee_{q \in \mathcal{F}0} F_q$

    denotes target e-Service final states

PSL Encoding -- Details

- Target *e*-Service $E_0 = (\Sigma, Q_0, q^0_0, \delta_0, \mathcal{F}_0)$
  - $\forall o.prior\ (F_q \supset \neg F_{q'}, o)$
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    $\forall o.\ occurrence\_of(o, a) \wedge prior(F_q, o) \supset holds(F_{q'}, o)$ *(eff)*
  - $\forall o.\ holds(F_q, o) \wedge poss(a, o) \supset false$
  - $Final \equiv \vee_{q \in \mathcal{F}0} F_q$

similar to Sit Calc !

PSL Encoding -- Details (cont.d)

- Community *e*-Services $E_i = (\Sigma, Q_i, q^0_i, \delta_i, \mathcal{F}_i)$
  - $\forall o.prior\ (F_q \supset \neg F_{q'}, o)$ *for all pairs of distinct states q, q' in E_i*
    e-Service states are pair-wise disjoint
  - $\forall o.\ holds(F_q, o) \supset poss_i(a, o)$ *(prec)*
    $\forall o.\ occurrence\_of(o, a) \wedge prior(F_q, o) \supset$ *(eff)*
    $(holds(F_{q'}, o) \wedge holds(Step_{ia}, o)) \vee (holds(F_q, o) \wedge \neg holds(Step_{ia}, o))$
    for each $q' = \delta_i(q, a)$
    if e-Service moved then new state, otherwise old state
  - $\forall o.\ holds(F_q, o) \wedge poss_i(a, o) \supset false$
    $\forall o.\ occurrence\_of(o, a) \wedge prior(F_q, o) \supset$
    $holds(F_q, o) \wedge \neg holds(Step_{ia}, o)$ *for each $\delta_i(q,a)$ undef.*
    if e-Service cannot do a, and a is performed then it did not move
  - $Final_i \equiv \vee_{q \in \mathcal{F}i} F_q$ *denotes community e-Service final states*

PSL Encoding -- Details (cont.d)

- Community *e*-Services $E_i = (\Sigma, Q_i, q^0_i, \delta_i, \mathcal{F}_i)$
  - $\forall o.\mathrm{prior}(F_q \supset \neg F_{q'}, o)$
  - $\forall o.\ \mathrm{holds}(F_q, o) \supset \mathrm{poss}_i(a, o)$ *(prec)*

    $\forall o.\ \mathrm{occurrence\_of}(o, a) \wedge \mathrm{prior}(F_q, o) \supset$ *(eff)*

    $(\mathrm{holds}(F_{q'}, o) \wedge \mathrm{holds}(Step_{ia}, o)) \vee (\mathrm{holds}(F_q, o) \wedge \neg \mathrm{holds}(Step_{ia}, o))$
  - $\forall o.\ \mathrm{holds}(F_q, o) \wedge \mathrm{poss}_i(a, o) \supset \mathrm{false}$

    $\forall o.\ \mathrm{occurrence\_of}(o, a) \wedge \mathrm{prior}(F_q, o) \supset$

    $\mathrm{holds}(F_q, o) \wedge \neg \mathrm{holds}(Step_{ia}, o)$
  - $Final_i \equiv \vee_{q \in \mathcal{F}i} F_q$

similar to Sit Calc !

PSL Encoding -- Details (cont.d)

- Additional assertions:
  - $\forall o.\ poss(a, o) \wedge occurrence\_of(o, a) \supset \bigvee_{i=1..n} step_{ia}(o) \wedge poss_i(a,o)$

    for each action a

    at least one of the community e-Services must move at each step

  - $\forall o.\ prior(Final \supset \bigwedge_{i=1..n} Final_i, o)$

    when target e-Service is final all comm. e-Services are final

  - $Init \equiv \bigwedge_{i=0..n} F_{qi0}$

    Initially all e-Services are in their initial state

PSL Encoding -- Details (cont.d)

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  - $\forall o.\ poss(a, o) \wedge occurrence\_of(o, a) \supset \bigvee_{i=1..n} step_{ia}(o) \wedge poss_i(a, o)$
  - $\forall o.\ prior(Final \supset \bigwedge_{i=1..n} Final_i, o)$
  - $Init \equiv \bigwedge_{i=0..n} F_{qi0}$

similar to SIt Calc!

Info & Contacts

- Thesis dissertation scheduled for January 2005

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Further Discussion about PSL and Sit Calc

(brief discussion with Michael Gruninger)

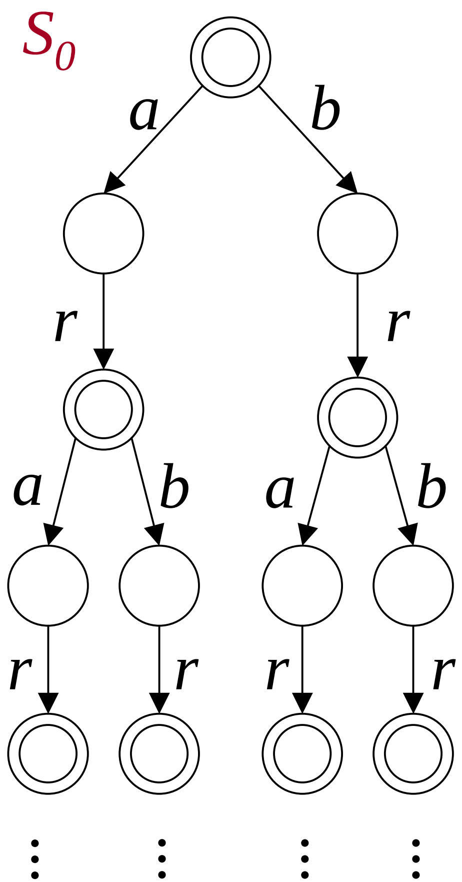
- PSL core theory occtree equivalent to Reiter's axiomatization of the situation trees
- PSL defines several classes of activities (e.g., markov_precond act., etc.)
  - markov_precond activities have precondition axioms of the form equivalent to situation calculus.

  In Sitcalc all activities have markov preconditions. (Same comment for effects).
- Complex activities can be axiomatized both in PSL (core theory) and in Sit Calc.
- Both PSL and Sit Calc can represent concurrency of activities.
- As for encoding of activity prec (and effect), PSL uses the $\supset$ symbol (for markov_precond act.), whereas Sit Calc uses more often the $\equiv$ symbol: is this based on some deeper difference?
- ...

Back up

Execution tree

An execution tree



a: "search by author (and select)"
b: "search by title (and select)"
r: "listen (the selected song)"

- *Nodes: history (sequence) of actions executed so far*
- *Root: no action yet performed*
- *Successor node x·a of x: action a can be executed after the sequence of action x*
- *Final nodes: the e-Service can terminate*

e-Service composition

- Added value of the community:

  when a client request cannot be satisfied by any available e-Service, it may still be possible to satisfy it by combining "pieces" of e-Services in the community

- Two issues arise:
  - support for synthesizing composition:
    - automatic synthesis of a coordinating program (composition) …
    - … that realizes the target e-Service (client request) …
    - … by suitably coordinating available e-Services

    addressed here

  - support for orchestration: execution of the coordinating program

    not addressed here

Formalizing *e*-Service composition

Composition:

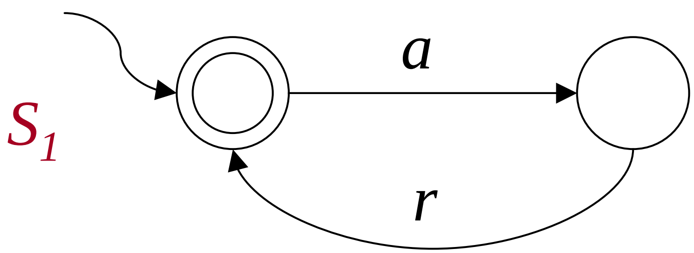
- coordinating program …
- … that realizes the target e-Service …
- … by suitably coordinating available e-Services

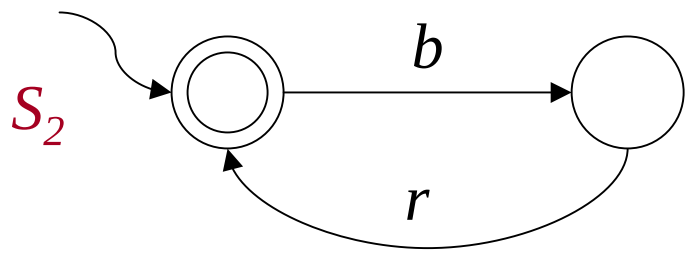
⇒ Composition can be formalized as:

- a labeling of the execution tree of the target *e*-Service such that …
- … each action in the execution tree is labeled by the community *e*-Service that executes it …
- … and each possible sequence of actions on the target *e*-Service execution tree corresponds to possible sequences of actions on the community *e*-Service execution trees, suitably interleaved.

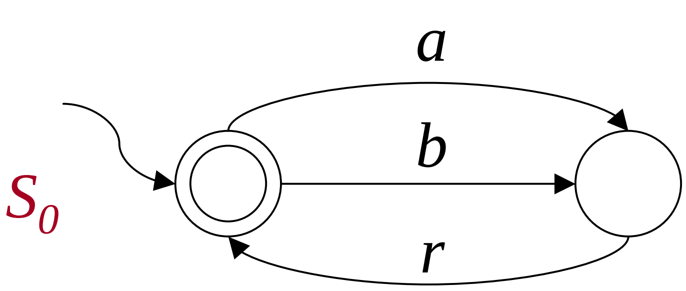
Example of composition

- Community *e*-Services *(expressed as FSMs)*

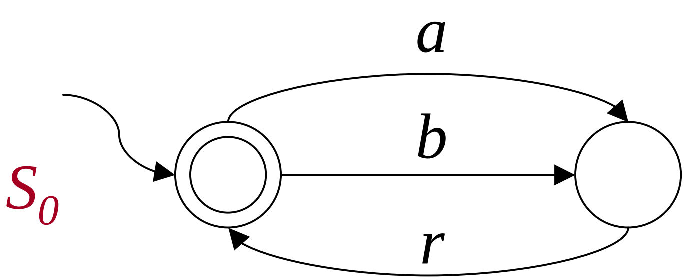


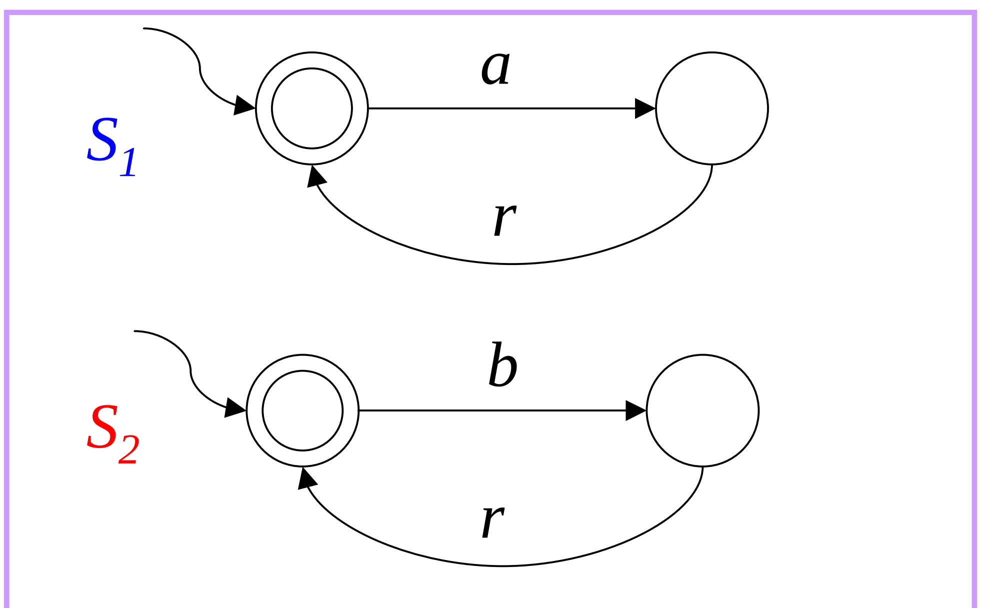


- Target *e*-Service *(again expressed as FSM)*

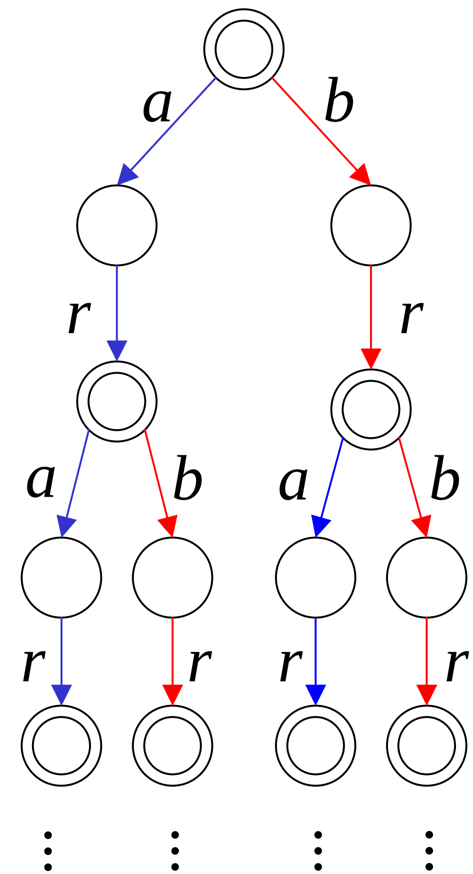


Example of composition

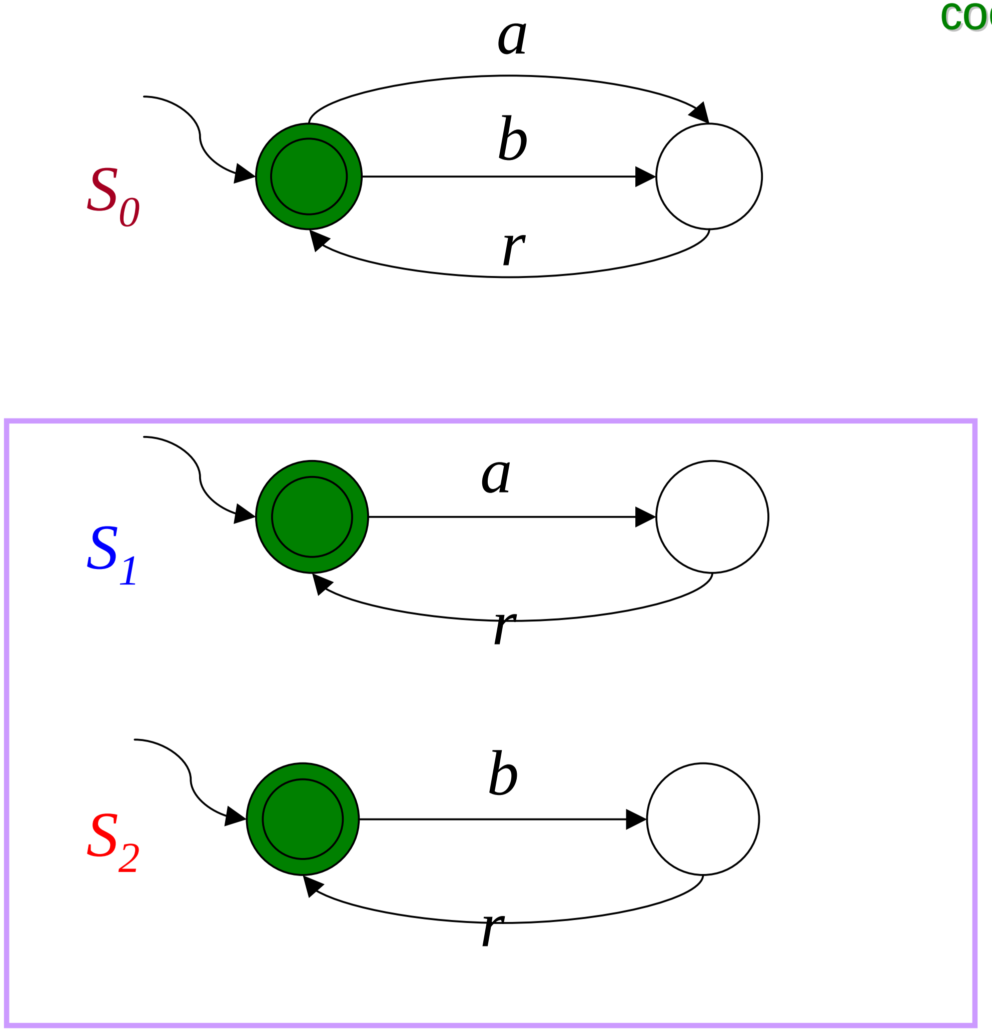




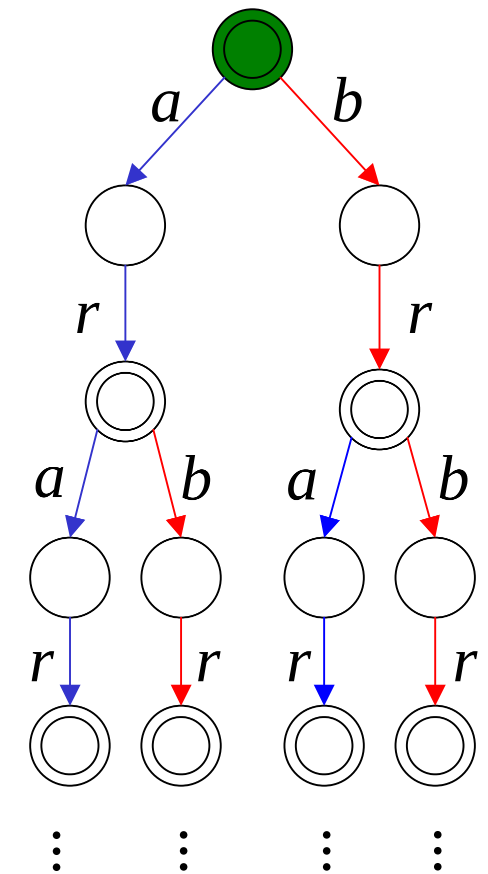
coordinating program (composition)



Example of composition

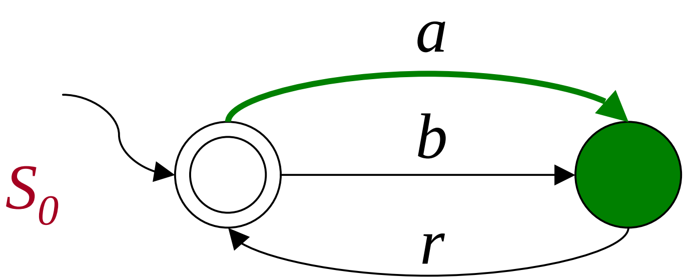


coordinating program (composition)

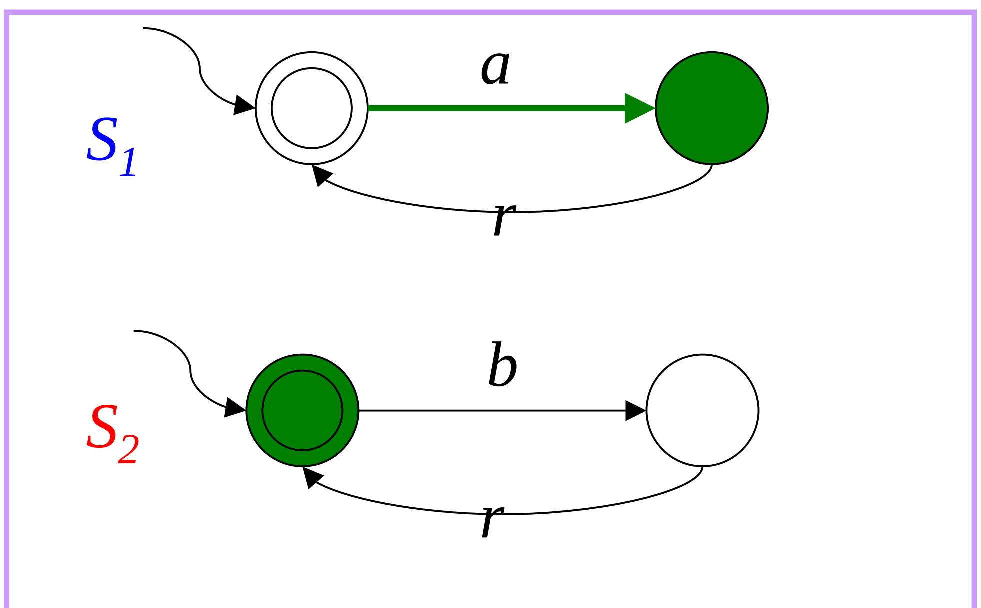


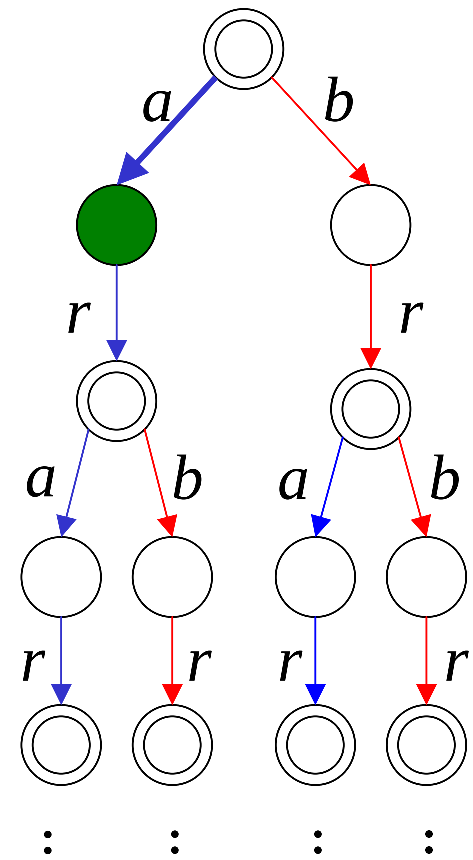
All e-Services start from their starting state

Example of composition



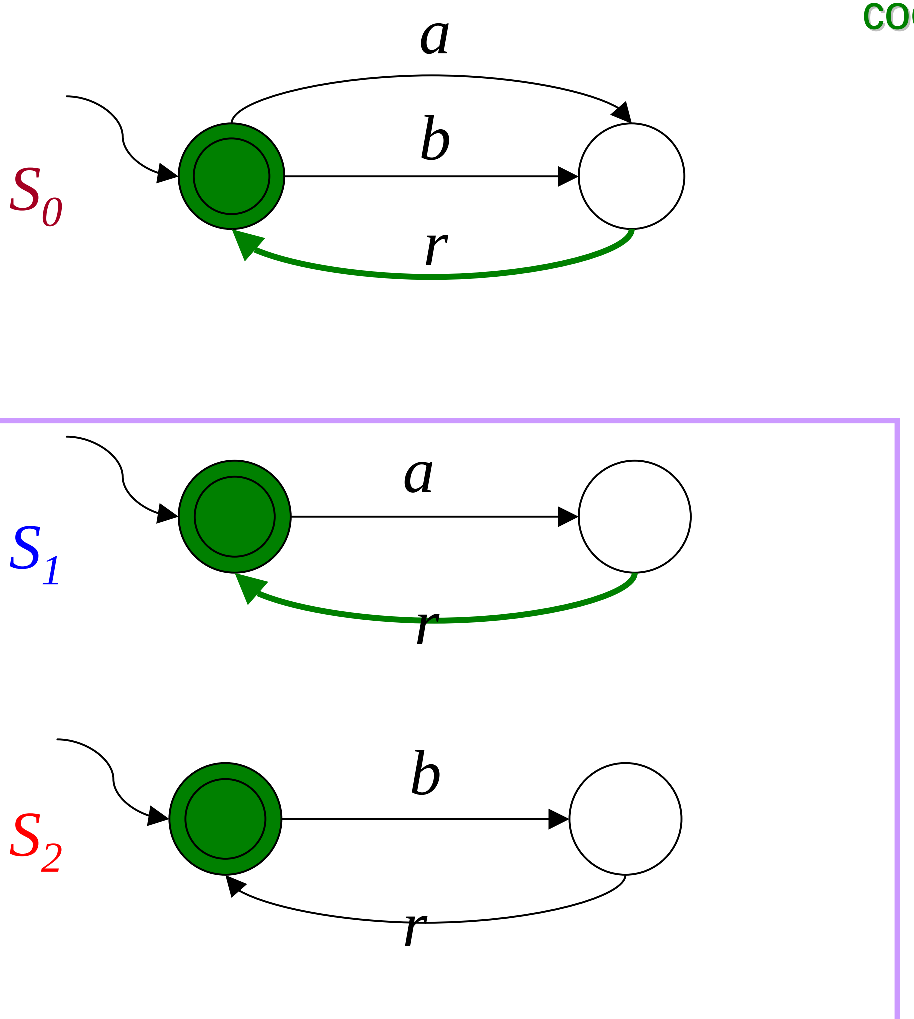
coordinating program (composition)



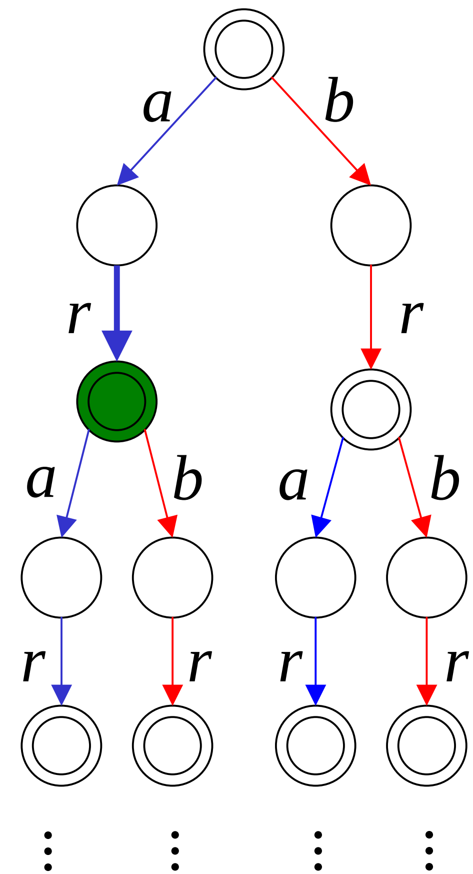


Each action of the target e-Service is executed by at least one of the component e-Services

Example of composition

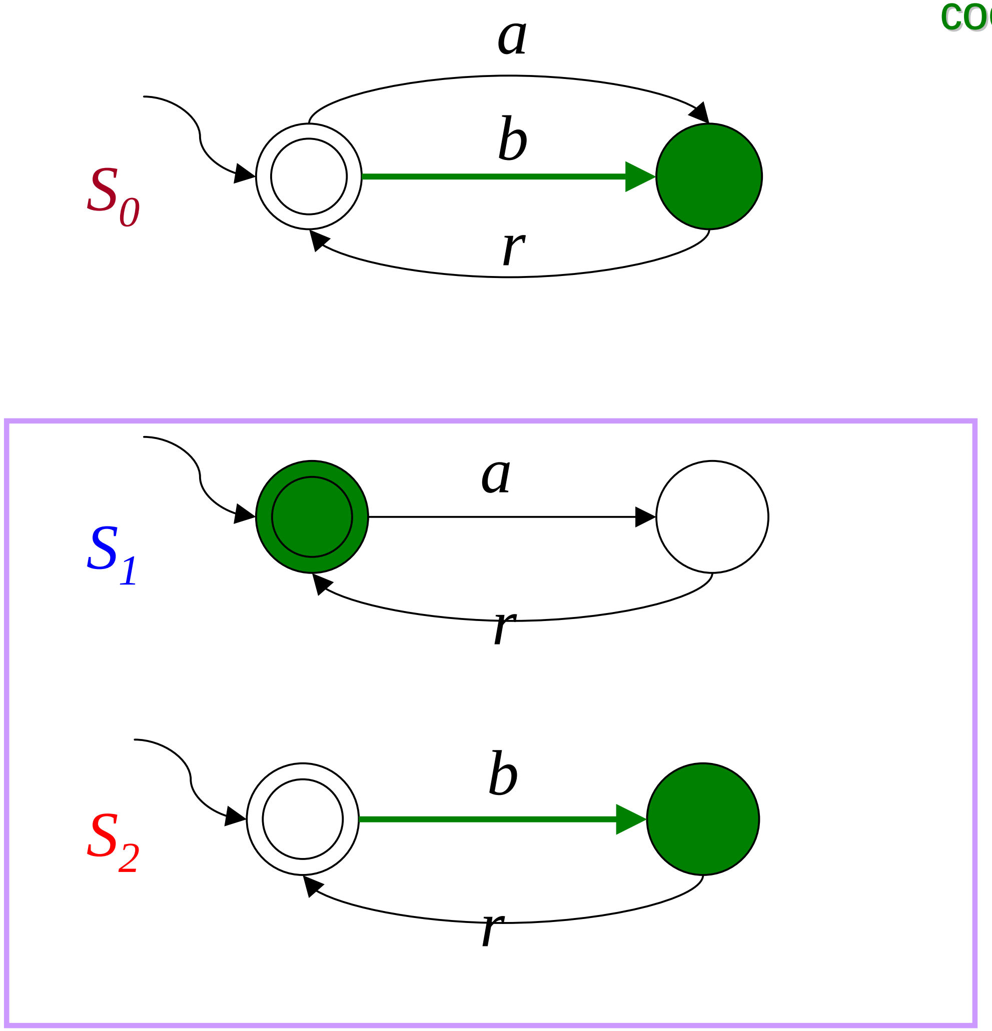


coordinating program (composition)

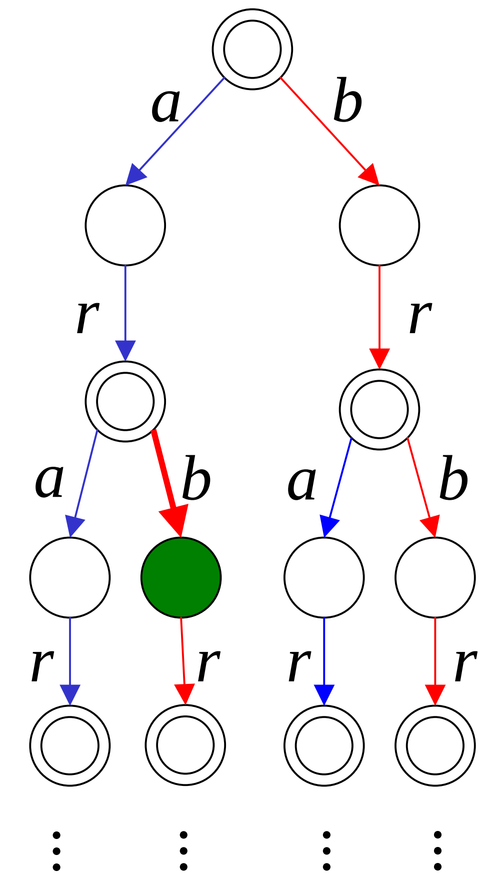


When the target e-Service can be left, then all component e-Services must be in a final state

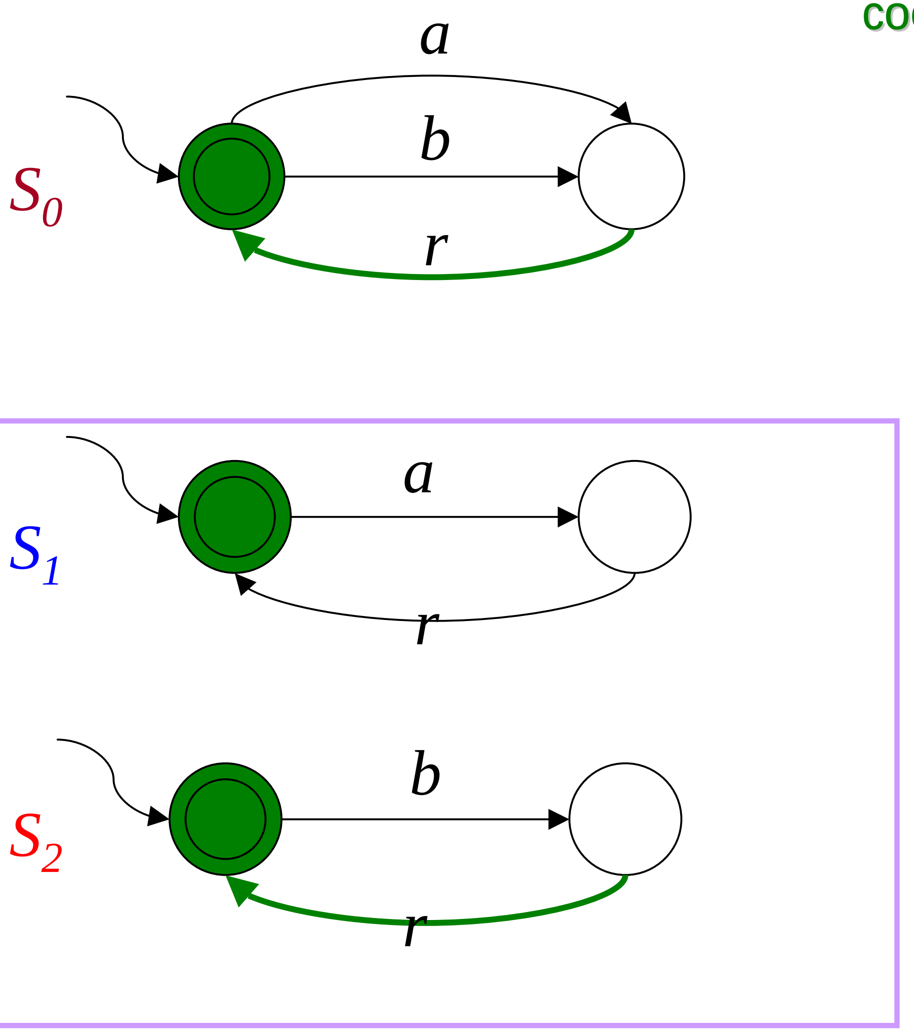
Example of composition



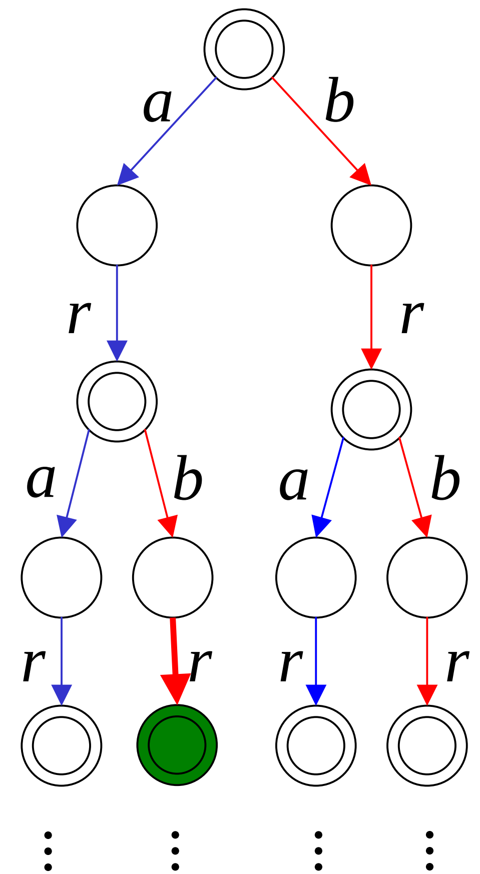
coordinating program (composition)



Example of composition



coordinating program (composition)



$\mathcal{ALC}$ encoding

- Target *e*-Service $S_0 = (\Sigma, S_0, s^0_0, \delta_0, F_0)$
  - $s \sqsubseteq \neg s'$ for all pairs of distinct states in S_0

    e-Service states are pair-wise disjoint

  - $s \sqsubseteq \exists a.\top \sqcap \forall a.s'$ for each $s'=\delta_0(s,a)$

    target e-Service can do an a-transition going to state s'

  - $s \sqsubseteq \forall a.\bot$ for each $\delta_0(s,a)$ undef.

    target e-Service cannot do an a-transition

  - $F_0 \equiv \sqcup_{s \in F0}\ s$

    denotes target e-Service final states

- …

$\mathcal{ALC}$ encoding (cont.d)

- Community *e*-Services $S_i = (\Sigma, S_i, s^0_i, \delta_i, F_i)$
  - $s \sqsubseteq \neg s'$ for all pairs of distinct states in S_i

    e-Service states are pair-wise disjoint
  - $s \sqsubseteq \forall a.(moved_i \sqcap s' \sqcup \neg moved_i \sqcap s)$ for each $s'=\delta_i(s,a)$

    if e-Service moved then new state, otherwise old state
  - $s \sqsubseteq \forall a. (\neg moved_i \sqcap s)$ for each $\delta_i(s,a)$ undef.

    if e-Service cannot do a, and a is performed then it did not move
  - $F_i \equiv \sqcup_{s \in Fi}\ s$

    denotes community e-Service final states
- …

$\mathcal{ALC}$ encoding (cont.d)

- Additional assertions
  - $\exists\, a.\top \sqsubseteq \forall\, a\,.\, \sqcup_{\mathbf{i=1,\ldots,n}}\ \mathrm{moved}_i$ for each action a

    at least one of the community e-Services must move at each step
  - $F_0 \sqsubseteq \sqcap_{\mathbf{i=1,\ldots,n}}\ F_i$

    when target e-Service is final all comm. e-Services are final
  - $\mathrm{Init} \equiv s^0_0 \sqcap \sqcap_{\mathbf{i=1\ldots}n}\ s^0_i$

    Initially all e-Services are in their initial state

DPDL encoding

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

Initial states of all *e*-Services

DPDL encoding of target *e*-Service

DPDL encoding of *i*-th component *e*-Service

DPDL additional domain-independent conditions

DPDL encoding is polinomial in the size of the e-Service FSMs

DPDL encoding

- Target *e*-Service $\mathcal{S}_0 = (\Sigma, S_0, s^0_0, \delta_0, F_0)$

  in DPDL we define Φ_0 as the conjuction of:

  – $s \rightarrow \neg s'$ for all pairs of distinct states in S_0

  e-Service states are pair-wise disjoint

  – $s \rightarrow \langle a \rangle \top \wedge [a]s'$ for each $s'=\delta_0(s,a)$

  target e-Service can do an a-transition going to state s'

  – $s \rightarrow [a]\bot$ for each $\delta_0(s,a)$ undef.

  target e-Service cannot do an a-transition

  – $F_0 \equiv \bigvee_{s \in F0} s$

  denotes target e-Service final states

- …

DPDL encoding (cont.d)

- Community *e*-Services $\mathcal{S}_i = (\Sigma, S_i, s^0_i, \delta_i, F_i)$

  in DPDL we define Φ_i as the conjuction of:

  - $s \rightarrow \neg s'$ for all pairs of distinct states in S_i

    e-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 e-Service moved then new state, otherwise old state

  - $s \rightarrow [a](\neg moved_i \wedge s)$ for each $\delta_i(s,a)$ undef.

    if e-Service cannot do a, and a is performed then it did not move

  - $F_i \equiv \bigvee_{s \in Fi} s$

    denotes community e-Service final states

- …

DPDL encoding (cont.d)

- Additional assertions $\Phi_{\mathbf{aux}}$
  - $\langle a \rangle \top \rightarrow [a] \vee_{\mathbf{i=1,\ldots,n}} \text{moved}_i$ for each action a

    at least one of the community e-Services must move at each step
  - $F_0 \rightarrow \wedge_{\mathbf{i=1,\ldots,n}} F_i$

    when target e-Service is final all comm. e-Services are final
  - $\text{Init} \equiv s^0{}_0 \wedge_{\mathbf{i=1....n}} s^0{}_i$

    Initially all e-Services are in their initial state

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

Results

Thm: Composition exists iff DPDL formula Φ SAT

From composition labeling of the target e-Service one can build a *<u>tree model</u> of the DPDL formula and viceversa*

Information on the labeling is encoded in predicates $moved_i$

$\Rightarrow$ Composition existence of *e*-Services expressible as FSMs is decidable in EXPTIME

Results on Finite State Composition

Thm: If composition exists then Mealy composition exists.

From a small model of the DPDL formula Φ, one can build a Mealy machine

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

⇒ Finite state composition existence of *e*-Services expressible as FSMs is decidable in EXPTIME