Extension of Behaviours with Formal Data Types: Integration and Coordination

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Invited Lecture, Universities of Málaga and Extremadura

1. Introduction
2. Integration
3. Coordination
4. Conclusions

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- expressive structuring needed
  (modules $\leadsto$ objects $\leadsto$ components $\leadsto$ aspects)
- encapsulated datatypes
- behaviours, communication, value-passing
- verification

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- formality

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Our framework

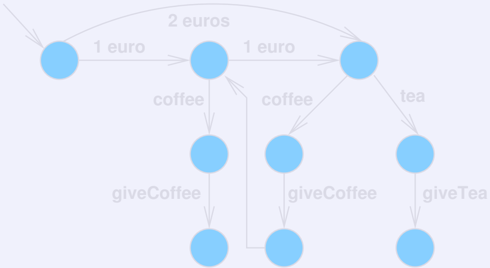
- formal components with BIDL
- expressive gluing mechanisms
- mixity: behaviours + abstract datatypes = STS
- analysis techniques for STS

LTS in everyday life

Labelled Transition Systems

Usual models for behaviours are LTS $< S, s_0, A, T >$
with $s_0 \in S$ and $T \subseteq S \times A \times S$, often, $A = A^{\mathrm{in}} \uplus A^{\mathrm{out}}$ (IOLTS)

Example (Coffee Machine)



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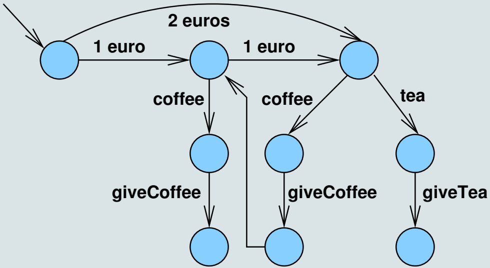

State explosion

In presence of data ...

The computation of an LTS from a specification may explode !

Example (Buffer)

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```
Buffer<>     = in  ?a:Nat .  Buffer<a>
Buffer<b.X> = in  ?a:Nat .  Buffer<b.X.a>
             + out !b     .  Buffer<X>
```

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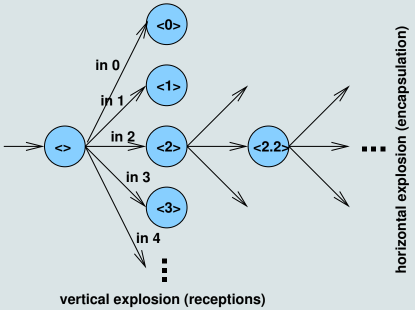

The STS Solution

Symbolic Transition Systems

STS abstract the data on states and transitions

[HL-HandbookPA,STS4LOTOS], [CPR00]

e.g., $< D, (\Sigma, Ax), S, s_0, v_0, T >$ [MPR04]

with elements of T of the form:

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$$s \xrightarrow{[\text{guard}(\text{self}, x_1, \ldots, x_n)]\ \text{event}?x_1 \ldots ?x_n\ !t_1 \ldots !t_m\ /\text{action}(\text{self}, x_1, \ldots, x_n)} s'$$

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Question

Are BIDL needed anyway ?

Yes

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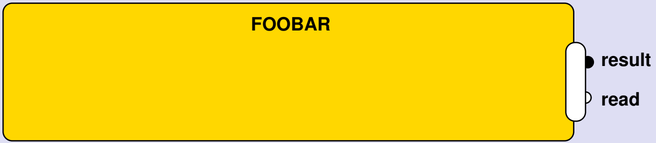
Yes
what does this component ?



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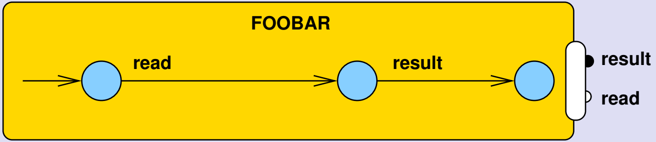
Are BIDL needed anyway ?

Yes

it reads (something) and then outputs a result



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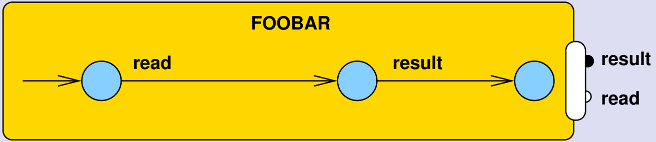
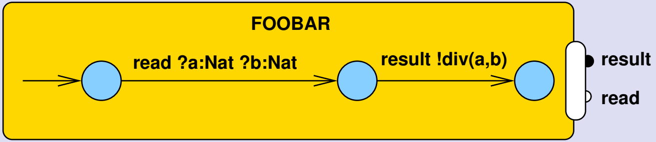


Question

Are data needed anyway ?

Yes
it reads (at a time) two integers and then outputs the result of the `div` operation applied to the integers



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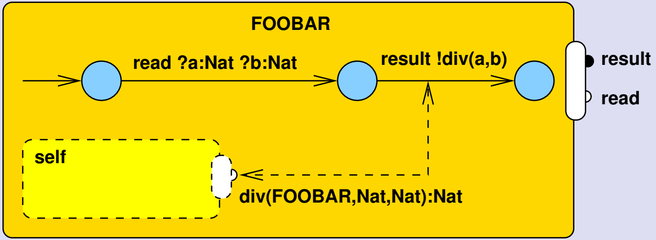
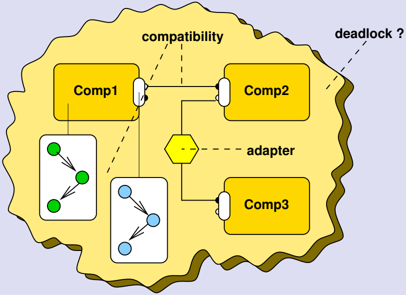
hidden underlying static type (with usual static signatures)



What does formality bring in ?

Some information in [PRS04]:

- abstract, expressive descriptions for BIDL
- animation
- equivalence checking, deadlock freedom, adaptors



Lots of mixed specification languages

kind	dynamic	static	examples
Heterogeneous	P. Alg.	model	ObjectZ-CSP, CSP-OZ, ZCCS, ZCSP, TCOZ
	P. Alg.	alg.	LOTOS, PSF
	T/S	model	$\mu\mathcal{SZ}$, MaC, Event Calculus
	T/S	alg.	Korrigan, SDL, CASLChart, TAG
	T/S	– spec. –	Estelle, UML, Argos, BDL
	Petri	alg.	OBJSA, Clown, CO-OPN/2
	Petri	– spec. –	CO, OPN
Homogeneous	Algebraic		LTL, Rewriting Logic, ASM
	Logical		TLA, Unity, TRIO, OSL
	Proc. Alg.		CCS+value, CSP, π-calcul

Formal + Semi-Formal

semi-formal

+ graph. notations, readability, expressiveness, structuring
    - UML (formal ?)
- tools, consistency ?
    - ArgoUML, SMW, UMLAut, ...

formal

+ abstraction
    - what not how
+ semantics
    - tools, verification
- not easy to learn and use

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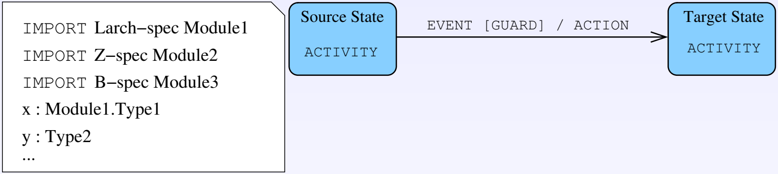
Syntactic Extensions



transition part	interaction kind	example
EVENT	reception	$evt\text{-}name(x_1{:}T_1,\ldots,x_n{:}T_n)$
GUARD	guard	*predicate*
ACTION	emission	$receiver\,\hat{}\,evt\text{-}name(t_1,\ldots,t_n)$
ACTION	assignment	$x{:=}t$

Typical Use: Case Study

The Gas Station

- furnishes different gas
- three pumps, three tanks
- credit card payment

Typical Use: Analysis

Static part

- booleans (Z)
- integers, real numbers (Larch)
- gases, pumps, tanks (Z)

Dynamic part

- card manager
- pump manager 3 Extended State Diagrams
- tank manager

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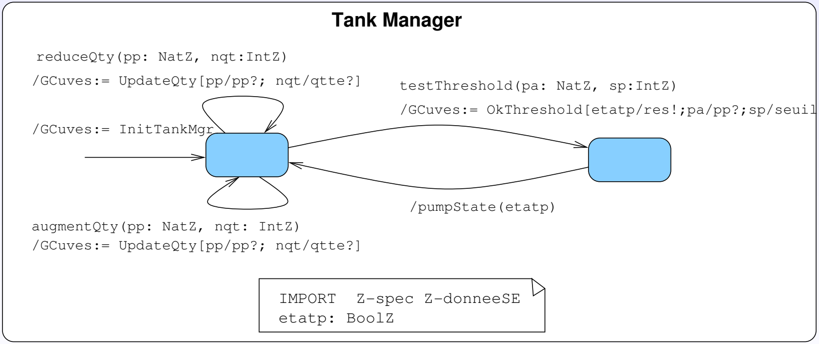
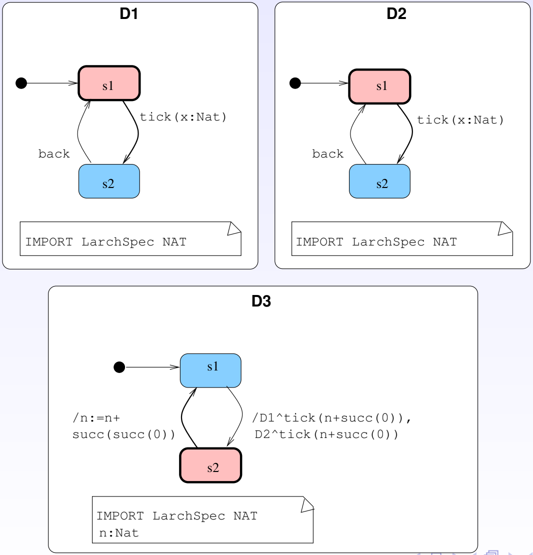

Tank Manager
reduceQty(pp: NatZ, nqt:IntZ)
/GCuves:= UpdateQty[pp/pp?; nqt/qtte?]
testThreshold(pa: NatZ, sp:IntZ)
/GCuves:= OkThreshold[etatp/res!;pa/pp?;sp/seuil
/GCuves:= InitTankMgr
/pumpState(etatp)
augmentQty(pp: NatZ, nqt: IntZ)
/GCuves:= UpdateQty[pp/pp?; nqt/qtte?]
IMPORT Z-spec Z-donneeSE
etatp: BoolZ


D1
s1
tick(x:Nat)
back
s2
IMPORT LarchSpec NAT
D2
s1
tick(x:Nat)
back
s2
IMPORT LarchSpec NAT
D3
s1
/n:=n+
succ(succ(0))
/D1^tick(n+succ(0)),
D2^tick(n+succ(0))
s2
IMPORT LarchSpec NAT
n:Nat

Operational Semantics – $||.||_{sos}$

On operational semantics ...

- can be used for Transition Systems and Process Algebras
- well suited for animation and equivalence checking

  are the interfaces of C(lient) and S(erver) compatible ?
- refinement

  does the C implementation do what is required in its interface ?
- compositionality

  if I prove that C and C' are compatible, may I replace C with C' in any system ?
- adequacy wrt temporal logic

  if C and C' are equal, may I prove properties on the simplest one ?

Operational Semantics – $||.||_{SOS}$

On operational semantics ...

- can be used for Transition Systems and Process Algebras
- *are the interfaces of C(lient) and S(erver) compatible ?*
  $\mathrm{Interf}(C) = \mathrm{Interf}(S)$, with $= \in \{=_T, \sim, \approx, ...\}$
- *does the C implementation do what is required in its interface ?*
  $\mathrm{Interf}(C) \subseteq \mathrm{Interf}(\mathrm{Impl}(C))$, with $\subseteq \in \{\sqsubseteq_T, \sqsubseteq_F, ...\}$
- *if I prove that C and C' are compatible, may I replace C with C' in any system ?*
  $C \sim C' \Rightarrow (\forall \mathcal{S}[.].\mathcal{S}[C] \sim \mathcal{S}[C'])$
- *if C and C' are equal, may I prove properties on the simplest one ?*
  $C \sim C' \Leftrightarrow (\forall \phi \in \Phi_{HML}.C \models \phi \Leftrightarrow C' \models \phi)$

The [APS03] Semantics

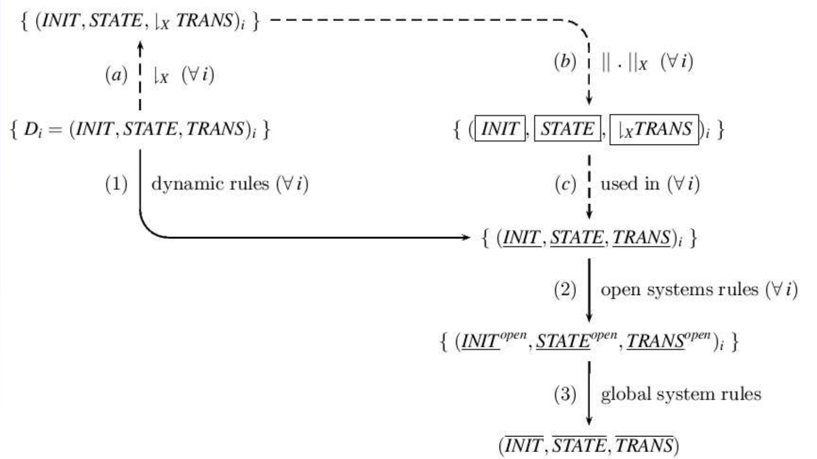
- based on experience with several mixed languages (Korrigan, CCS+ADT, TAG, MaC, ...)
- representative for the definition of a generic approach to integrate static formal specifications (SFS) into dynamic formal specification (DFS)
  - builds on a first proposal for UML state diagrams + SFS + synchronous communication
  - generalizing and asynchronous communication

Principle

Formal rules in 4 layers

- meta-typing
- static evolution
- dynamic evolution and open-systems
- composition

Principle


{ (INIT, STATE, ⌊X TRANS)i }
(a) ⌊X (∀ i)
(b) || . ||X (∀ i)
{ Di = (INIT, STATE, TRANS)i }
{ (INIT, STATE, ⌊XTRANS)i }
(1) dynamic rules (∀ i)
(c) used in (∀ i)
{ (INIT, STATE, TRANS)i }
(2) open systems rules (∀ i)
{ (INIT^open, STATE^open, TRANS^open)i }
(3) global system rules
(INIT, STATE, TRANS)

Remarks

- lots of dynamic semantics
  - use of generic elements, *e.g.*, *event* $\boxed{\in}$ $\mathcal{Q}_{in}$

Constraints

- $||D||_{SOS}$ = LTS ($\boxed{INIT}$, $\boxed{STATE}$, $\boxed{TRANS}$) $\Rightarrow$OK !

Notation

- $\mathcal{D}$, $D = (INIT, STATE, TRANS, DeclImp, DeclVar) \in \mathcal{D}$
- $EVENT = EVENT^{?} \cup EVENT^{!}$, $DeclVar = DeclVar^{?} \cup DeclVar^{!}$
- $\mathcal{S} \subseteq \boxed{STATE} \times \mathcal{E} \times \boxed{\mathcal{Q}} [EVENT^{?}] \times \boxed{\mathcal{Q}} [EVENT^{!}]$

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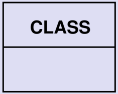
Static Evolution

$$\frac{\forall i \in 1..n \;.\; \exists X_i \;.\; t_i ::_D X_i \quad \exists v_i \;.\; E \vdash t_i \rhd_{X_i} v_i}{act-eval(rec\hat{\ }e(t_1,\ldots,t_n), <\Gamma, E, Q_{in}, Q_{out}>, D) = <\Gamma, E, Q_{in}, Q_{out} \boxed{\uplus} \{rec\hat{\ }e(v_1,\ldots,v_n)\}>}$$

$$\frac{\exists X \;.\; t ::_D X \quad \exists v \;.\; E \vdash t \rhd_X v}{act-eval(x := t, <\Gamma, E, Q_{in}, Q_{out}>, D) = <\Gamma, E\{x \mapsto v\}, Q_{in}, Q_{out}>}$$

Static Evolution

Term evaluation, $\triangleright_X$

- $\triangleright_{Alg}$: rewriting (+ tools : Larch Prover, ELAN)
- $\triangleright_Z$, $\triangleright_B$: LTS construction (+ tools : Z-Eves)
- $\triangleright$ 

: classes formelles, Z

Dynamic Evolution

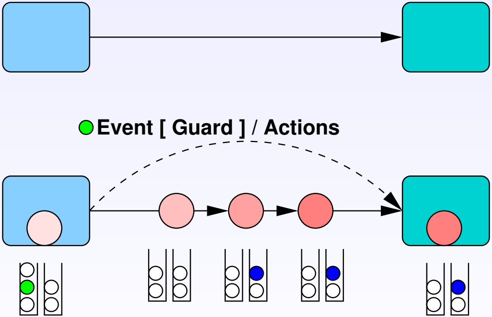
Notation

$EVENT^{?+} = EVENT^{?} \cup \{\varepsilon\}$

$||D||_{SOS} = LTS(\underline{INIT}, \underline{STATE}, \underline{TRANS})$ with:

- $\underline{STATE} \subseteq \mathcal{S}$
- $\underline{INIT} \subseteq \underline{STATE}$
- $\underline{TRANS} \subseteq \underline{STATE} \times EVENT^{?+} \times \underline{STATE}$

Dynamic Evolution



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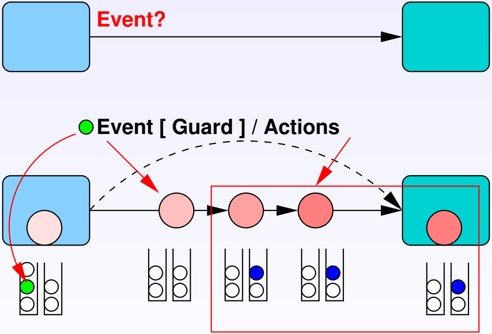


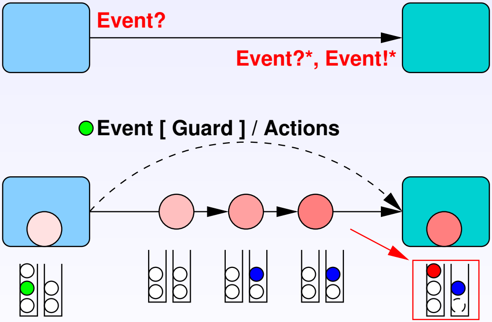
Open Systems

Notation

$||D||^{open}_{SOS} = LTS(\underline{INIT}^{open}, \underline{STATE}^{open}, \underline{TRANS}^{open})$ with:

- $\underline{INIT}^{open} \subseteq \underline{INIT}$
- $\underline{TRANS}^{open} \subseteq \underline{TRANS} \times \boxed{\mathcal{Q}}[EVENT^{?}] \times \boxed{\mathcal{Q}}[EVENT^{!}]$
- $\underline{STATE}^{open} \subseteq SOURCE(\underline{TRANS}^{open}) \cup TARGET(\underline{TRANS}^{open})$

Open Systems



Compositions

Notation

$|| \cup_{i \in 1..n} D_i ||^{open}_{oper} =$
$LTS(\overline{INIT}^{open}(\cup_{i \in 1..n} D_i), \overline{STATE}^{open}(\cup_{i \in 1..n} D_i), \overline{TRANS}^{open}(\cup_{i \in 1..n} D_i))$
with:

- $\overline{INIT}(\cup_{i \in 1..n} D_i) \subseteq \Pi_i \underline{INIT}^{open}(D_i)$
- $\overline{TRANS}(\cup_{i \in 1..n} D_i) \subseteq \{t \in \Pi_i \underline{TRANS}^{open}(D_i) | CC(t)\}$
- $\overline{STATE}(\cup_{i \in 1..n} D_i) \subseteq$ $\overline{INIT}(\cup_{i \in 1..n} D_i) \cup TARGET(\overline{TRANS}(\cup_{i \in 1..n} D_i))$

Compositions

Idea

whenever

something addressed to D_j

is taken out of a given D_k output queue

then

it is put, at the same time, within the D_j input queue

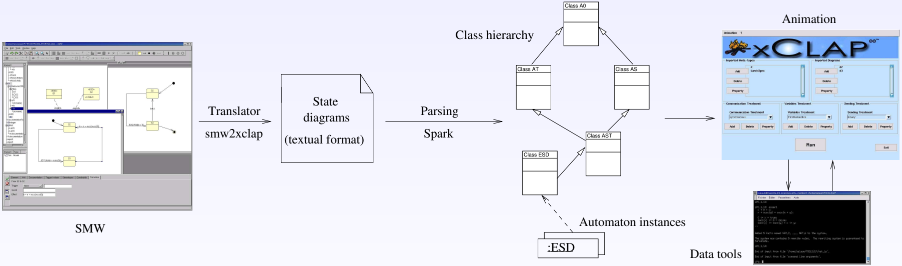
Compositions

Formally ...

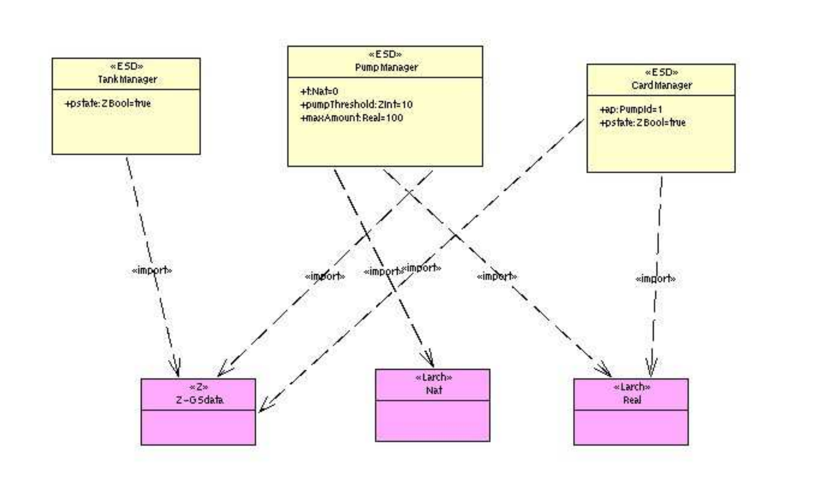
$$CC(S_1 \xrightarrow{l_1}_{E_{in_1},E_{out_1}} S'_1, \ldots, S_n \xrightarrow{l_n}_{E_{in_n},E_{out_n}} S'_n) \Leftrightarrow$$

$$\forall k \in 1 \ldots n \;.\; \forall D_j\hat{\ }e \boxed{\in} E_{out_k} \;.\; D_j \in \cup_{i \in 1..n} D_i \Longrightarrow e \boxed{\in} E_{in_j}$$

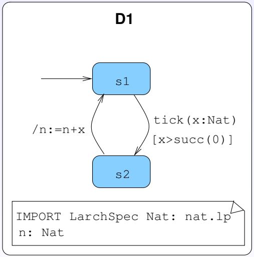
xCLAP - Architecture



xCLAP - Designing



xCLAP - Translation



(a) state diagram (graphical format)

Translator

→

smw2xclap

declare D1

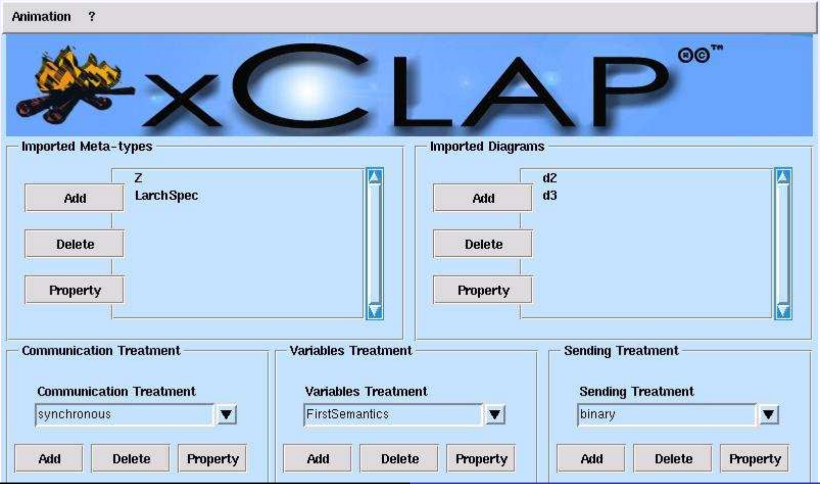
import LarchSpec Nat: nat.lp
n: Nat

esdstate
EsdState s1 {'initial':1, 'final':0}.
EsdState s2 {'initial':0, 'final':0}.
−−
END_STATES

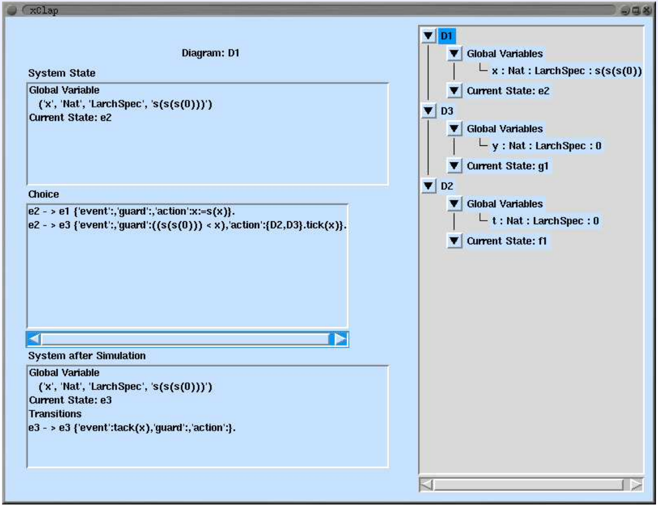
esdtrans
EsdTrans s1 − > s2 {'event':"tick(x:nat)", 'guard':"x>succ(0)", 'action':""}.
EsdTrans s2 − > s1 {'event':"", 'guard':"", 'action':"n:=n+x"}.
−−
END_TRANS

(b) state diagram (textual format)

xCLAP - Configuration



xCLAP - Animation



What do we model ?

Distributed Entities

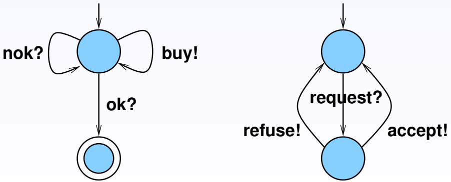
- viewed through interfaces (black-box foundation)
- interfaces have to take into account behavioural information (BIDL)
- goal: quick survey and comparison of formal material to describe coordination/interaction among entities
- remember ?
  formal means enable one to use existing verification tools to ensure correctness of interactions
- applications: web services, genetic regulatory networks

How ?

A Simple Formal Model: LTS

- here: simple yet general formal model of entities: a nondeterministic LTS $< L, S, I, F, T >$
- labels may be emissions `e!` or receptions `r?`
- data information is discarded for simplicity
- running example: one store and several suppliers

Store **Supplier**

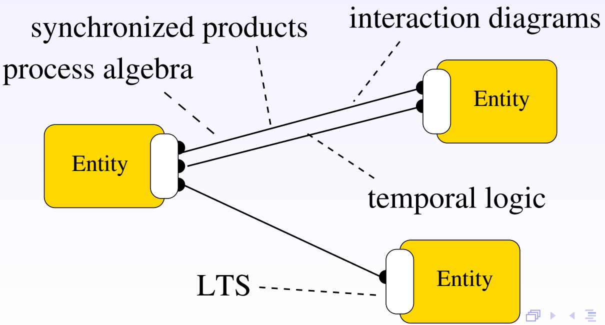


[YellinEtAl-TOPLAS'97]
[deAlfaroHenzinger-ESEC'01]

[ArbabEtAl-FOCLASA'02]

Communication Model

- depends on the means used to compose entities
- implicit means: semantic rules (first part)
- explicit means



Semantics

- basic idea: redefine the *CC* constraint of part I

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$$CC(S_1 \xrightarrow{l_1}_{E_{in_1}, E_{out_1}} S'_1, \ldots, S_n \xrightarrow{l_n}_{E_{in_n}, E_{out_n}} S'_n) \Leftrightarrow$$

$$\forall k \in 1 \ldots n \,.\, \forall D_j\hat{\ }e \boxed{\in} E_{out_k} \,.\, D_j \in \cup_{i \in 1..n} D_i \Longrightarrow e \boxed{\in} E_{in_j}$$

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$$CC(S_1 \xrightarrow{l_1}_{E_{in_1}, E_{out_1}} S'_1, \ldots, S_n \xrightarrow{l_n}_{E_{in_n}, E_{out_n}} S'_n, \text{Coord}) \Leftrightarrow$$

$$???$$

- see [SP04], [JUCS, 2005, submitted]
- here: examples

Process Algebra

- parallel composition operators are way to match inputs and outputs
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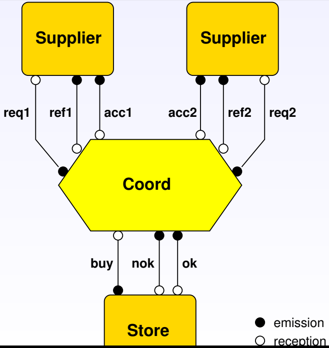

Example (with processes)

```
S = Supplier[req1/request, ref1/refuse, ..]
  | Supplier[req2/request, ref2/refuse, ..]
  | Store
  | Coord
Coord = buy.('req1.Wait1 + 'req2.Wait2)
Wait1 = acc1.'ok .0 + ref1.'nok.Coord
Wait2 = acc2.'ok.0 + ref2.'nok.Coord
```

[SalaünEtAl-IJBPIM]

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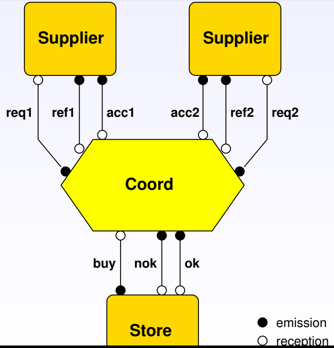

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Synchronized Products

- simple and readable means to define interactions among entities [Arnold94,ArnoldEtAl-FI04]
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synchronous, one to many: $<a!,\varepsilon,b?,\varepsilon,c?>$

synchronous, matching: $<a!,\varepsilon,b!,\varepsilon,c!>$

synchronous, generation: $<a?,\varepsilon,b?,\varepsilon,c?>$

asynchronous, one to many: $[a!,\varepsilon,b?,\varepsilon,c?]$

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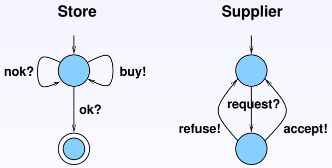

Example (with vectors)

$<$ buy!, request?, request? $>$
$<$ nok?, ε, refuse! $>$
$<$ nok?, refuse!, ε $>$
$<$ ok?, ε, accept! $>$
$<$ ok?, accept!, ε $>$

Interaction Diagrams

- coordination may be described using interaction diagrams: MSC, or UML sequence and collaboration diagrams
- many formalisations proposed so far

  [ITU-MSC'96,MauwReniers-MSC'96,KrügerEtAl-SFEDL'02]

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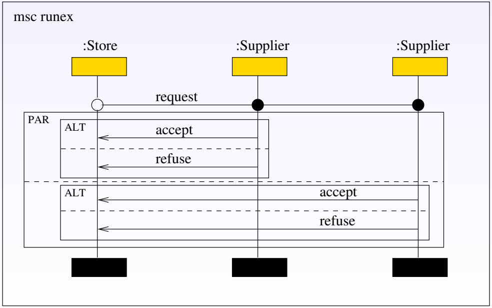

Temporal Logic

- numerous: LTL,CTL/CTL*,ACTL,TLA, μ-calculus,...
- expressive means to coordinate entities, *e.g.* in formal ADLs [JUCS, 2005, submitted]
  - first, being able to describe the properties of objects that are to be glued (states and transitions)
  - indexed formulas, then lift the properties of the subcomponents of a composition up to the composition
  - the logic also takes into account coordination using logical conjunction

Example (with logic)

$$\begin{aligned} & \texttt{Store.buy!} \Leftrightarrow \textbf{ALL}(\{i : [1..N]\texttt{Supplier}_i\}).\texttt{request?} \\ \vee\ & \texttt{Store.ok?} \Leftrightarrow \textbf{ONE}(\{i : [1..N]\texttt{Supplier}_i\}).\texttt{accept!} \\ \vee\ & \texttt{Store.nok?} \Leftrightarrow \textbf{ONE}(\{i : [1..N]\texttt{Supplier}_i\}).\texttt{refuse!} \end{aligned}$$

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A First Comparison

		Process Algebras	Vectors	Interaction Diagrams	Logics
Communication Expressiveness	1 to 1 1 to N 1 to M in N	+ yes yes extension	++ yes yes yes	++ yes yes yes	++ yes yes yes
	Name matching Data Order	+ no yes yes	+ yes extension no	− no no yes	+ yes yes no
User Friendliness	Tools Executability	++ animation equivalence checking model–checking yes	+ animation equivalence checking model–checking no	+ animation model–checking yes	− embeddings no
	Graphical notations	− no	− no	++ yes	−− no

Conclusions

Overview

- semantics for STS: operational (here), denotational
- partially tool-equipped: animating (xCLAP), PVS embedding
- semantics for different coordination means

Perspectives

- framework for STS (Eclipse)
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Any questions ?

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