A Declarative Approach to Wide-Area Network Programming with Service Level Agreement

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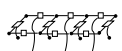




Plan of the talk

- What 'WAN programming' means (for us)
- Declarative programming model: Hypergraphs
  - Hint on its adequacy
    - Ambient calculus
    - Wireless communications
    - GRID
- Programming SLA: KAOS
  - SLA & Hypergraphs: reasoning on optimal routing
- SLAK 

- Final considerations

Global Computing

WAN programming for building *global systems*.
They are hard to be made roboust because:

- Absence of centralised control
- Client-Server not enough: P2P
- Administrative domains (Security)
- Interoperability
  - different platforms
  - different devices
    (e.g. PDA, laptop, mobile phones...)
- “Mobility” (resources and computation)
- ...

Global Computing

WAN programming for building *global systems*.
They are hard to be made roboust because:

- *Network Awareness*
  - Applications are location dependent
  - Locations have different features
  - and allow multiple access policies
- Independently programmed in a distributed environment
- Reasoning on space and time
- ...

Web Services: A programming metaphor

- Applications access *services* that must be
  - Published
  - Searched
  - Binded
- Services are
  - “Autonomous”
  - Independent (local choices, independently built)
  - Mobile/stationary
  - “Interconnected”

Motivations

WAN programming is not just **go**(P), $\bar{s}\langle x \rangle$ or $s(y)$

- Lifting SLA issues to application level...
- ...in a WAN scenario, where programming is composition of WS
- SLA as a coordination mechanism
- A Formal Basis for Reasoning on Programmable SLA [DFM+03]
- Resource availability and access as a parameter for the SLA
- Proof techniques and tools

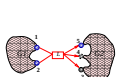
A Model for Declarative WAN Programming

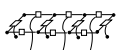
In collaboration with

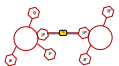
G. Ferrari (Pisa) and U. Montanari (Pisa)

Working Group:

Dan Hirsch (Pisa), Ivan Lanese (Pisa),








Process Algebraic Foundations of WAN

π-calculus [MPW92] Djoin [FG96, FGL+96] Dπ [HR98, HR00] Fusion [PV98]	Rich theory	basic wrt WAN (only link mobility)
Ambient [CG00] Seal [VC98] Boxed [BCC01] Safe [LS00]	Hierarchical	not very natural
Klaim [BBD+03] Hierarchical [BLP02] OKlaim [BBV03] MetaKlaim [FMPar]	Very natural	Lack of observational semantics
...	...	...

Hypergraphs Programming model[1]

- Edge replacement for graph rewritings [Fed71, Pav72]
- Graphs for distributed systems [CM83, DM87]
- Edge replacement/distributed constraint solving problem [MR96]
- Graphs grammars for software architecture styles [HIM00]
- Synchronised Hyperedge Replacement (SHR) with mobility for name passing calculi [HM01]
- Extension to node fusions [FMT01]
- ...

Hypergraphs Programming model^2

We aim at tackling new *non-functional* computational phenomena of systems using SHR.
The metaphor is

- "WAN systems *as* Hypergraphs"
- "WAN computations *as* SHR"

In other words:

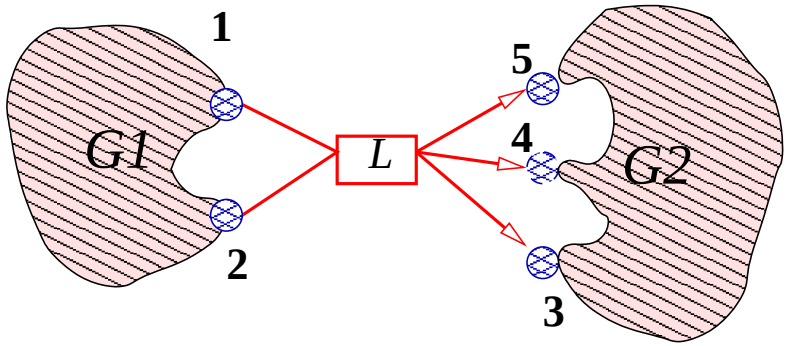
- Components are represented by hyperedges
- Systems are *bunches* of (connected) hyperedges
- Computing means to synchronously rewrite hyperedges...
- ...according to a synchronisation policy

Replacement of Hyperedges

$L \rightarrow G$

Replacement of Hyperedges

$L \rightarrow G$



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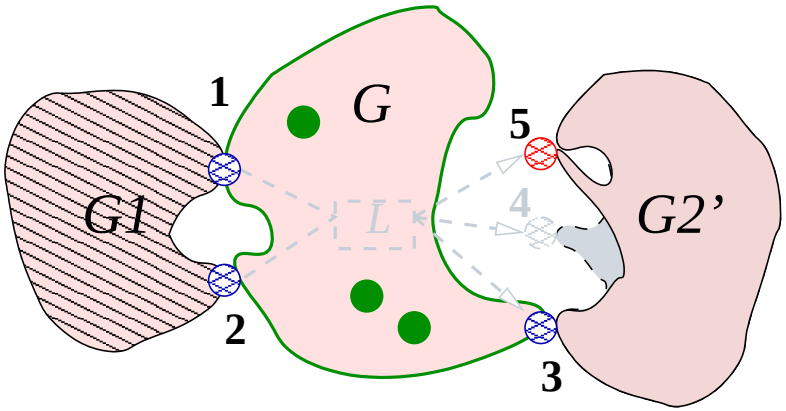

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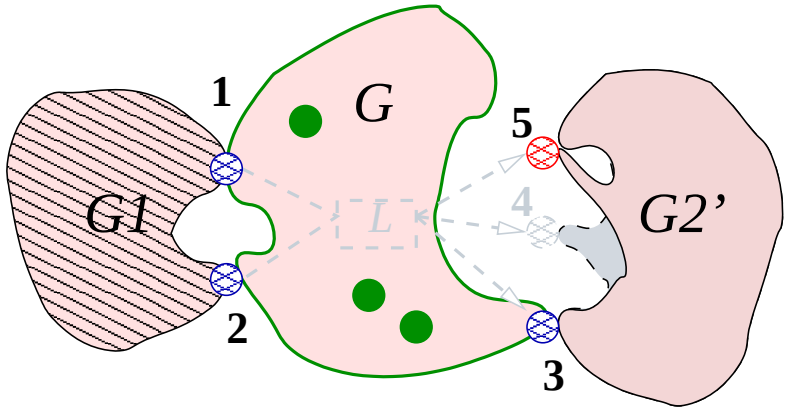

- Edge replacement: local
- Synchronisation as distributed constraint solving
- Multiple synchronisation
- New node creation
- Node fusion: model of mobility and communication

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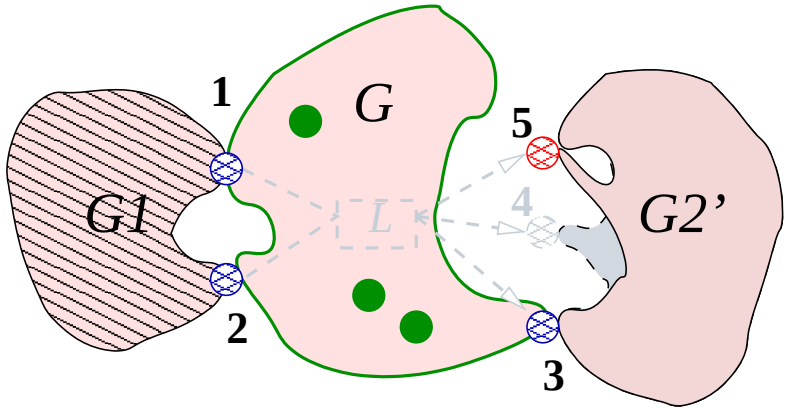

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Benefits:

- Uniform framework for π, π-I, fusion
- LTS for Ambient ...
- ... for Klaim ...

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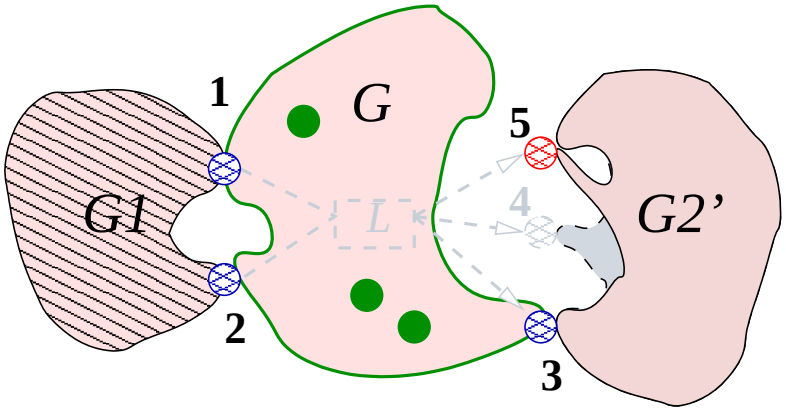

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Benefits:

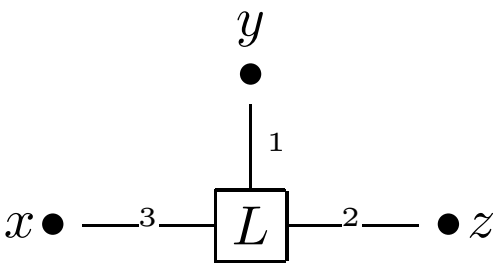
- Uniform framework for π, π-I, fusion
- LTS for Ambient ...
- ... for Klaim ...
- ... and *path reservation* for KAOS
- expressive for distributed coordination
- wireless networks

new

Hyperedges and Hypergraphs Syntax

A hyperedge generalises edges: It connects more than two nodes

$$L : 3, \quad L(y, z, x),$$



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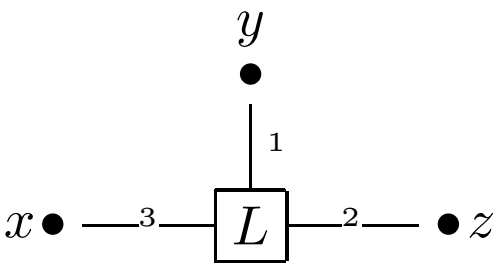

$$\begin{array}{rcl} G & ::= & nil \mid \nu\, y.G \\ & \mid & L(\vec{x}) \mid G|G \end{array}$$

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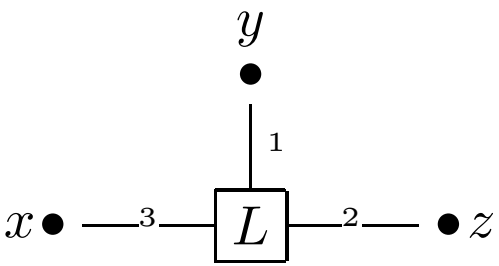

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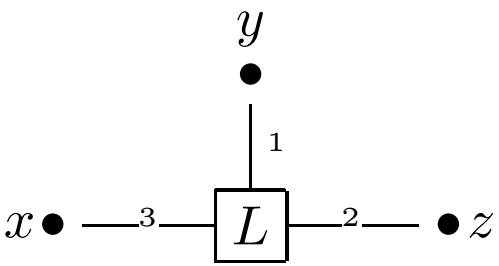

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An example:

$$L : 3, \quad M : 2$$
$$x, y \vdash \nu\, z.(L(y, z, x)|M(y, z))$$

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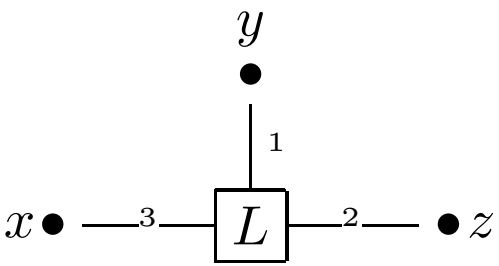

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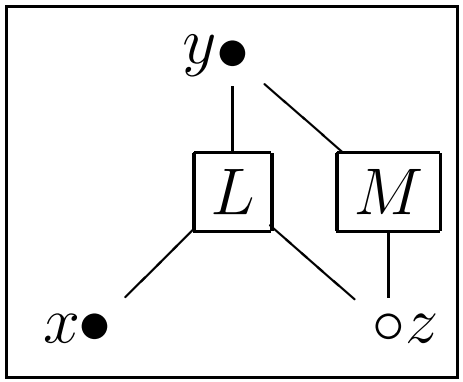

Hypergraph Semantics: Productions

$$\underbrace{x_1, \ldots, x_n}_{X} \vdash L(x_1, \ldots, x_n) \xrightarrow[\pi]{\Lambda} \Gamma \vdash G,$$

- $\Lambda \subseteq X \times Act \times \mathcal{N}^*$ set of constraints
- $\pi : X \to X$ fusion substitution, i.e.

$$\forall x_i, x_j \in X . \pi(x_i) = x_j \Rightarrow \pi(x_j) = x_j$$

- $\Gamma = \pi(X) \cup (\mathrm{n}(\Lambda) \setminus X)$
- $\mathrm{fn}(G) \subseteq \Gamma$

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Graph Rewritings

$$\Gamma_1 \vdash G_1 \xrightarrow[\pi]{\Lambda} \Gamma_2 \vdash G_2$$

Hypergraph Semantics: Transitions

$$\Gamma, y \vdash G \xrightarrow[\pi]{\Lambda} \Gamma' \vdash G'$$

$$\Lambda(y) \uparrow \qquad x \simeq_\pi y \Rightarrow y \neq \pi(y)$$

$$\rho = [{}^{\pi(x)}/_{\pi(y)}]$$

$$\Gamma \vdash [{}^{x}/_{y}]G \xrightarrow[(\pi;\rho)_{-y}]{\rho\Lambda} \mathrm{n}(\rho\Lambda) \cup (\pi;\rho)_{-y}(\Gamma) \vdash \rho G'$$

$$\Gamma, y \vdash G \xrightarrow[\pi]{\Lambda \cup \{(x,a,\vec{v}),(y,\overline{a},\vec{w})\}} \Gamma' \vdash G'$$

$$x \simeq_\pi y \Rightarrow y \neq \pi(y) \qquad \rho = mgu\{[{}^{[x/_y]\vec{w}}/_{[x/_y]\vec{v}}], [{}^{\pi(x)}/_{\pi(y)}]\}$$

$$\Gamma'' = \mathrm{n}(\rho\Lambda) \cup (\pi;\rho)_{-y}(\Gamma) \qquad U = \rho(\Gamma') \setminus \Gamma''$$

$$\Gamma \vdash [{}^{x}/_{y}]G \xrightarrow[(\pi;\rho)_{-y}]{(\rho\Lambda \cup (x,\tau,\langle\rangle))} \Gamma'' \vdash \nu\, U.\rho G'$$

Hypergraph Semantics: Transitions

$$\Gamma, y \vdash G \xrightarrow[\pi]{\Lambda} \Gamma' \vdash G'$$

$$\Lambda(y) \uparrow \vee \Lambda(y) = (\tau, \langle\rangle) \qquad x \simeq_\pi y \Rightarrow y \neq \pi(y)$$

$$U = \Gamma' \setminus (\mathrm{n}(\Lambda) \cup \pi_{-y}(\Gamma))$$

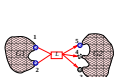
$$\Gamma \vdash \nu\, y.G \xrightarrow[\pi_{-y}]{\Lambda\setminus(y,\tau,\langle\rangle)} \mathrm{n}(\Lambda) \cup \pi_{-y}(\Gamma) \vdash \nu\, U.G'$$

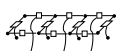
$$\Gamma_1 \vdash G_1 \xrightarrow[\pi]{\Lambda} \Gamma_2 \vdash G_2 \qquad \Gamma_1' \vdash G_1' \xrightarrow[\pi']{\Lambda'} \Gamma_2' \vdash G_2' \qquad \Gamma_1 \cap \Gamma_1' = \emptyset$$

$$\Gamma_1 \cup \Gamma_1' \vdash G_1 \mid G_1' \xrightarrow[\pi \cup \pi']{\Lambda \cup \Lambda'} \Gamma_2 \cup \Gamma_2' \vdash G_2 \mid G_2'$$

Hypergraph Adequacy: Ambient

In collaboration with
G. Ferrari (Pisa) and U. Montanari (Pisa)






From SHR to Ambient

Ambient $a[...]|open\ a \longrightarrow ...$

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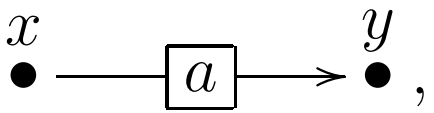
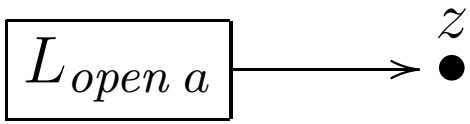
Ambient $a[...]|open\ a \longrightarrow ...$

$a[\cdots]$:



Components

$open\ a$:



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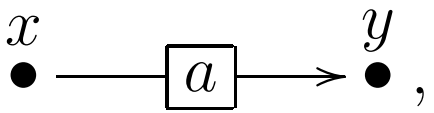

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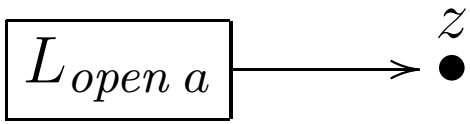
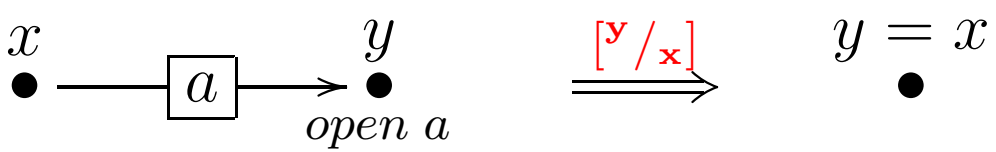
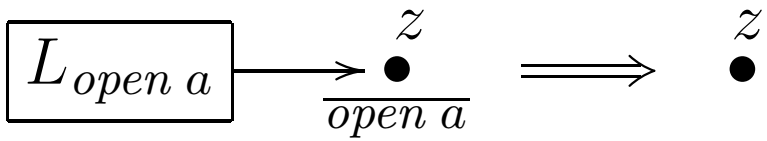
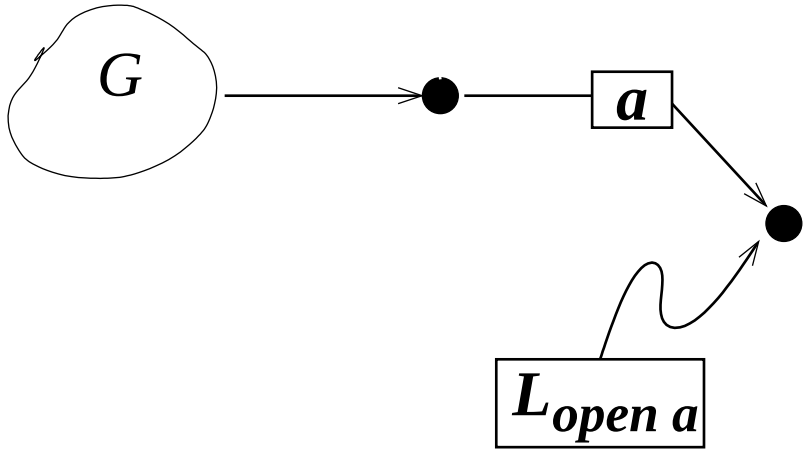


Productions





Node Fusion



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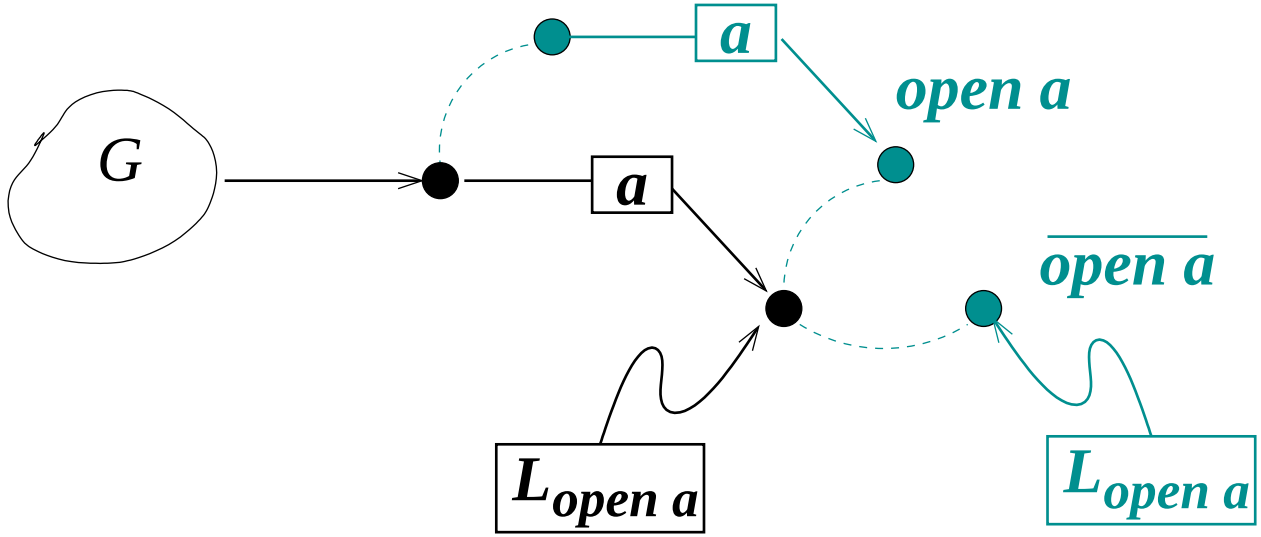

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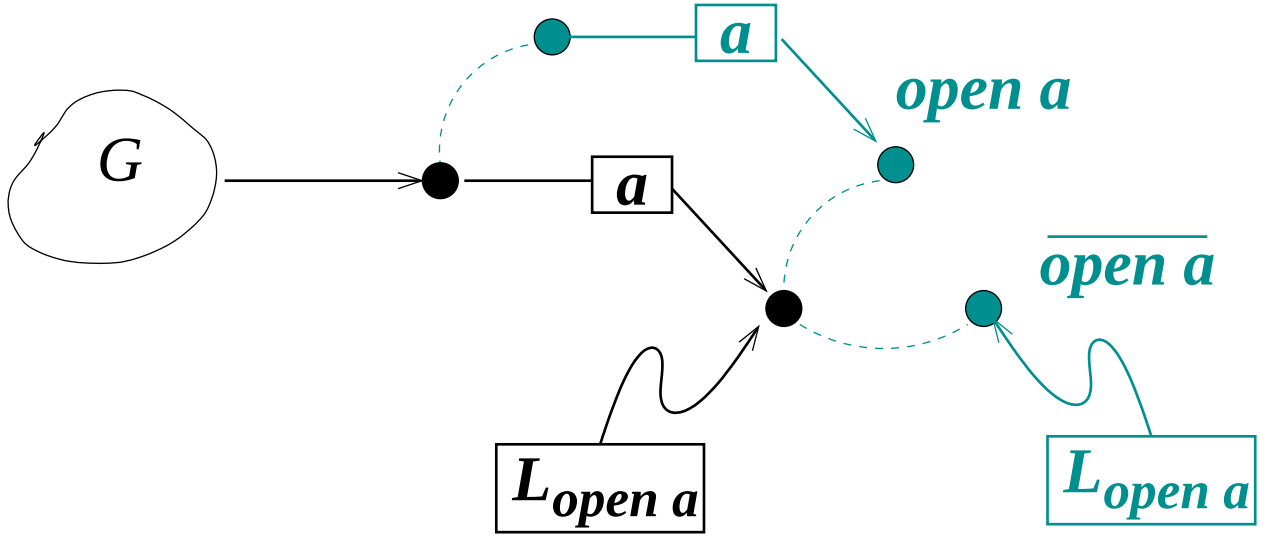
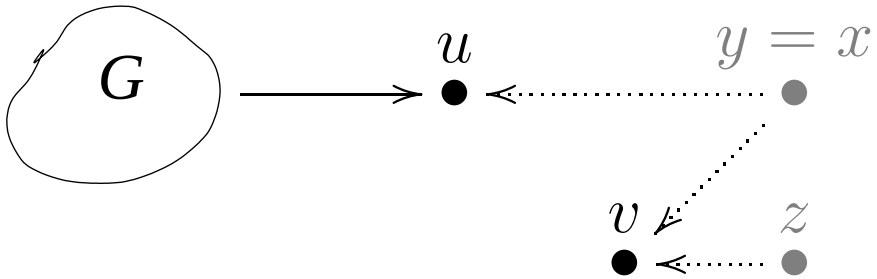
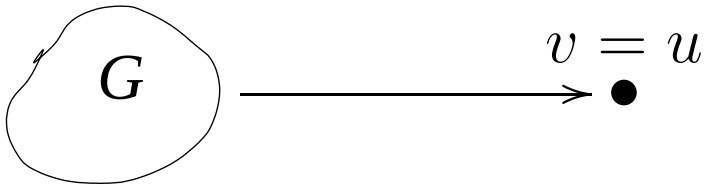


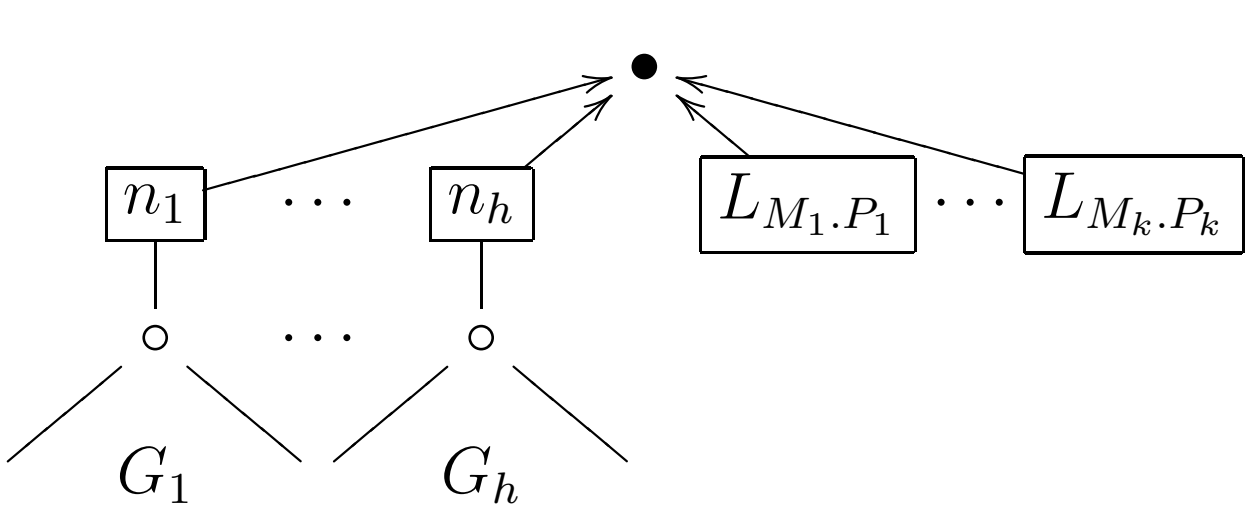




Graphs and Ambient

$$
\begin{aligned}
[\![\ \mathbf{nil}\ ]\!]_x &= x \vdash nil \\
[\![\ n[P]\ ]\!]_x &= x \vdash \nu\, y.(G \mid n(y,x)), \quad \text{if } y \neq x \wedge [\![\ P\ ]\!]_y = y \vdash G \\
[\![\ M.P\ ]\!]_x &= x \vdash L_{M.P}(x) \\
[\![\ P_1|P_2\ ]\!]_x &= x \vdash G_1 \mid G_2, \qquad \text{if } [\![\ P_i\ ]\!]_x = x \vdash G_i \ \wedge\ i = 1,2 \\
[\![\ rec\, X.\, P\ ]\!]_x &= [\![\ P[^{rec\, X.\, P}/_X]\ ]\!]_x
\end{aligned}
$$

Ambient Graphs

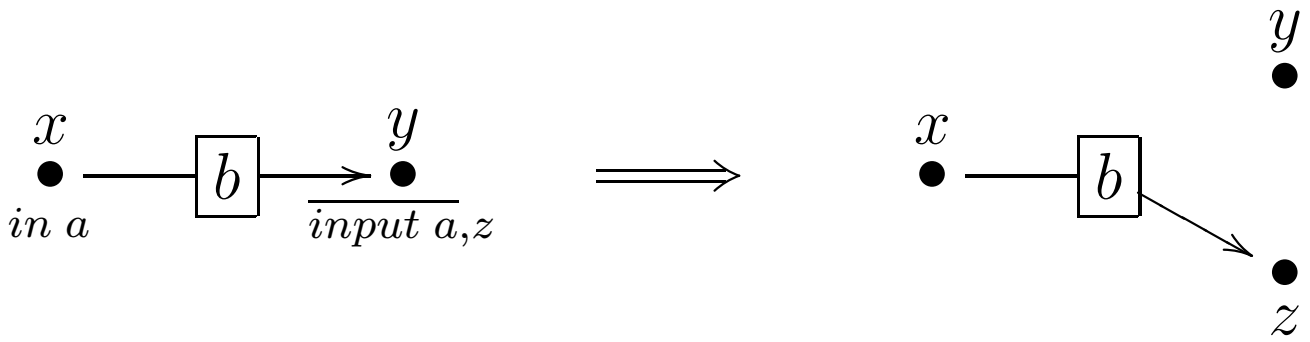


Theorem $[\![\ \_\ ]\!]_\_$ is a bijection on ambient graphs

Coordination Productions for Ambient

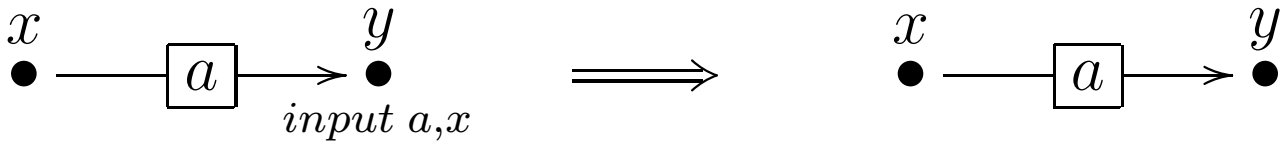
$$x, y \vdash b(x, y) \xrightarrow{\{(x,in\ a,\langle\rangle),(y,\overline{input\ a},\langle z\rangle)\}} x, y, z \vdash b(x, z)$$

$(input1)$



$$x, y \vdash a(x, y) \xrightarrow{\{(y,input\ a,\langle x\rangle)\}} x, y \vdash a(x, y)$$

$(input2)$



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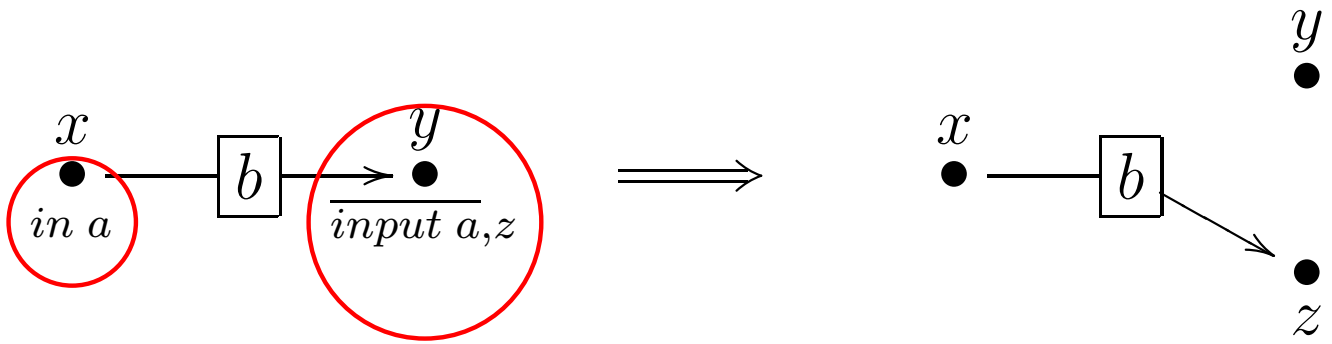

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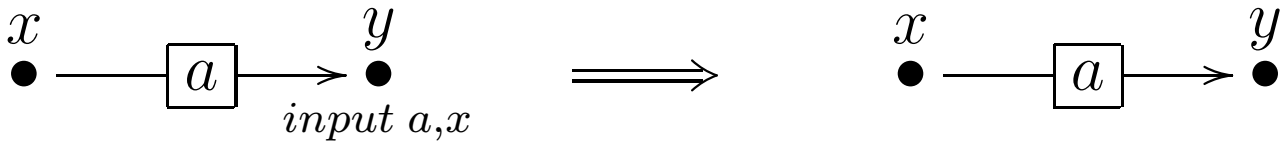
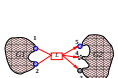
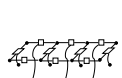


Semantic Correspondence

Theorem If $P \rightarrow Q$ then $[\![P]\!]_x \xrightarrow[id]{\Lambda} [\![Q]\!]_x$ and

- either $\Lambda = \emptyset$
- or $\Lambda = \{(x, \tau, \langle\rangle)\}$




Semantic Correspondence

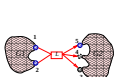
Theorem If $P \rightarrow Q$ then $[\![P]\!]_x \xrightarrow[id]{\Lambda} [\![Q]\!]_x$ and

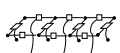
- either $\Lambda = \emptyset$
- or $\Lambda = \{(x, \tau, \langle\rangle)\}$

Theorem If $[\![P]\!]_x \xrightarrow[\pi]{\Lambda} \Gamma \vdash G$ is a basic transition, then

- either $[\![P]\!]_x = \Gamma \vdash G$
- or $\exists Q \in Proc : \quad P \rightarrow Q \ \wedge \ \Gamma \vdash G = [\![Q]\!]_x$

Hypergraph Adequacy: Wireless communications






Wireless Phenomena

- Wireless networks devices present peculiarities wrt wired ones
  - Dynamism of network topology
  - Energy constraints
  - Transmitting capacity
- Hence, nodes can asynchronously disappear
- Wireless networks typically are *peer-to-peer*
- the physical environment might cause interferences or interdict communications

For ad-hoc networks that share the same spectrum, new methods of cooperation are required to permit coexistence. Such methods are difficult to research without real-world channel models and simulation methodologies; there is still fundamental work to be done in this area [Mob98]

Traditional Models not Satisfactory

The communication infrastructure does not permit to individuate the position of components by their name

- Ambient: “vicinity” condition does not encompass any distance concept ($|$ is commutative, therefore $a[P|Q|R] = a[P|R|Q]$)
- KAOS can deal with distance between but...

... neither Ambient nor KAOS can easily model interference on wireless communications caused by *third party* movements.

This is diffi cult to capture in traditional frameworks because even if a link encompass the distance between nodes, it is under the control of the connected nodes and a third entity cannot “break” or modify it.

Tarzan

Tarzan is a SHR-based framework that captures

- Radio/Infrared Signal propagation
- Devices nomadism
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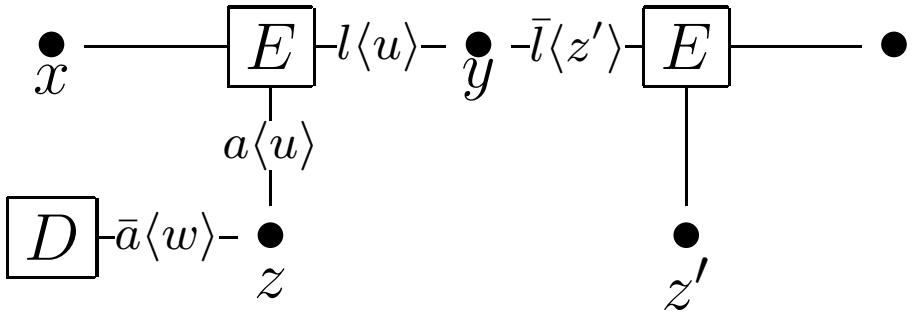

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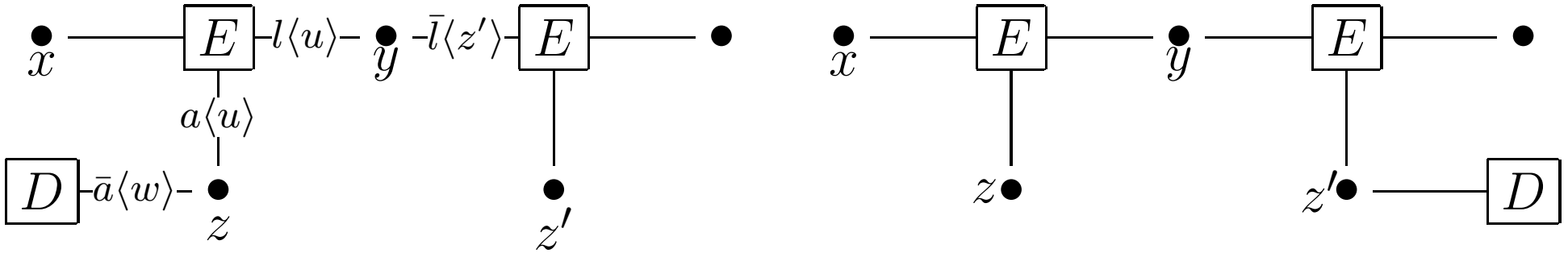
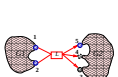
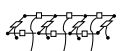
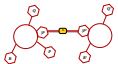


Hypergraph Adequacy: GRID

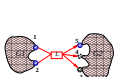
In collaboration with
Marco Aldinucci (Pisa)

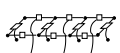







Semantics for GRID





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- Grid-aware applications are usually made of cooperating components with a graph topology
- Successively behaviors to adhere performance and fault-tolerance constraints are defi ned
- These behaviors regard parallelism degree adaptivity matching both performance and fault-tolerance requirements
- Point out patterns of behaviors for abstracting suitable primitives

SHR vs GRID Programming

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- Developing algorithms able to exploit GRID is diffi cult
- Programmers must design highly concurrent WAN algorithms with few homogeneity hypothesis
- Hence programmers have to face up classical problems of parallel computing as well as Grid-specifi c ones

SHR as a Semantics for GRID

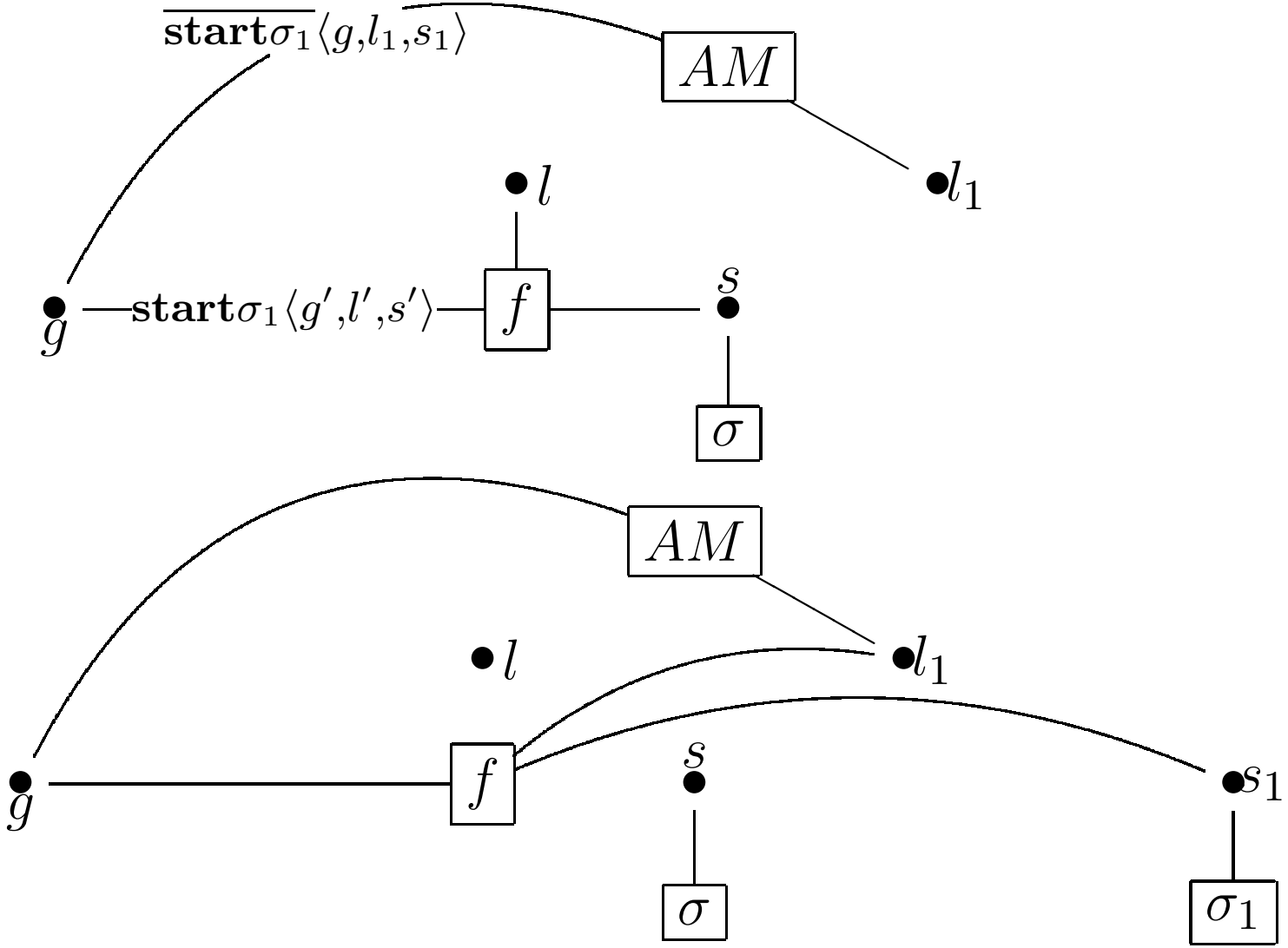
- We provide a high-level programming model for GRID programming
- We describe a SHR semantics of the framework

For instance

- Migration
- Replication
- Kill

- Components as hyperedges
- Coordination interface separated by its computational activity
- SHR rewriting mechanism for coordinating components

SHR as a Semantics for GRID



KAOS: Expressing and reasoning on Connection Properties

In collaboration with

R. De Nicola (Firenze) , G. Ferrari, U. Montanari, R. Pugliese (Firenze)

Klaim

Klaim

- Multiple tuple spaces

[DFP98]

Klaim

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- Localities: fi rst class citizens

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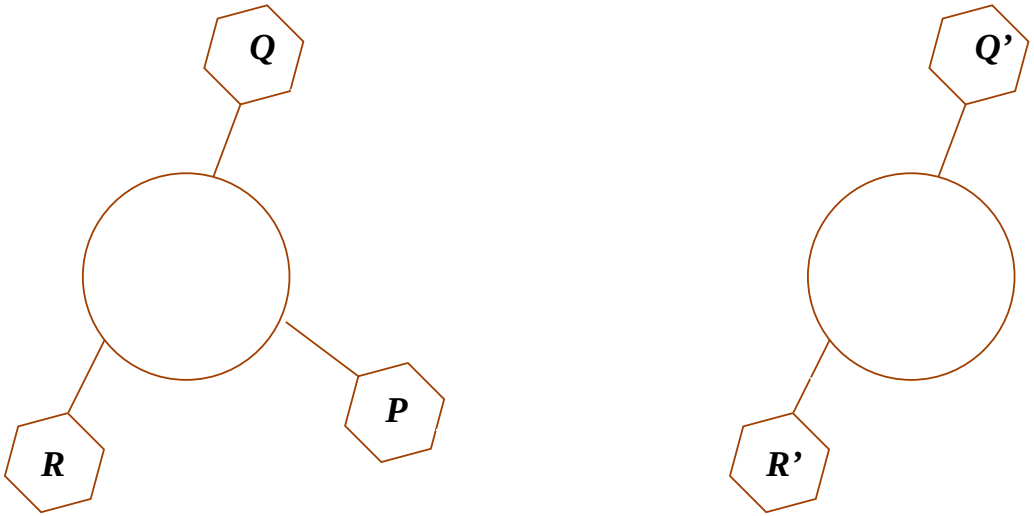

site s site s'

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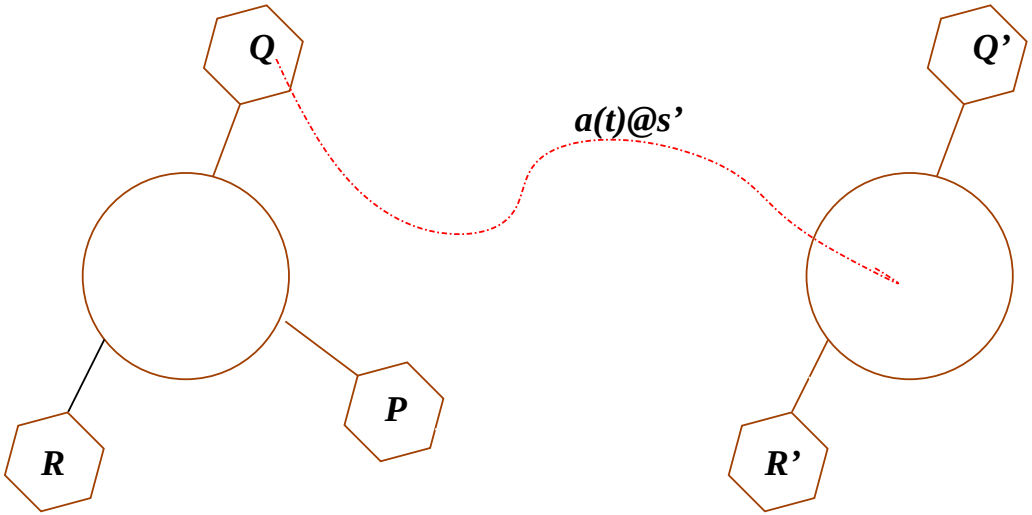

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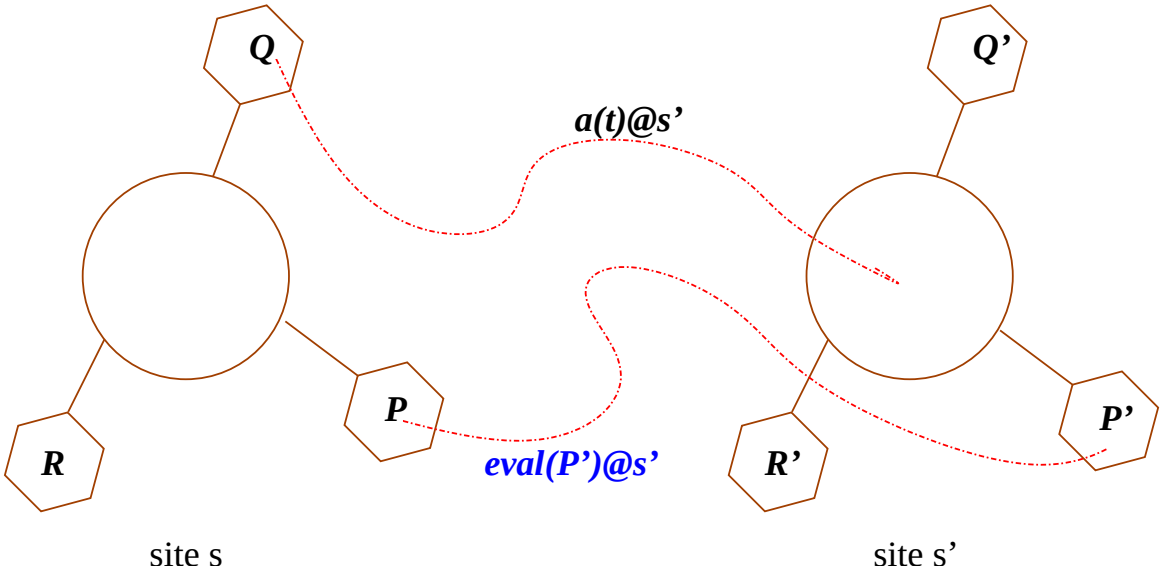

$$
\begin{array}{lcl}
P & ::= & \mathbf{nil} \\
 & | & \alpha.P \\
 & | & P_1 \mid P_2 \\
\alpha & ::= & a@s \\
a & ::= & \ldots \text{ // Klaim actions} \\
 & | & \varepsilon(P)
\end{array}
$$

KAOS: Gateways

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- Coordinators (super processes)

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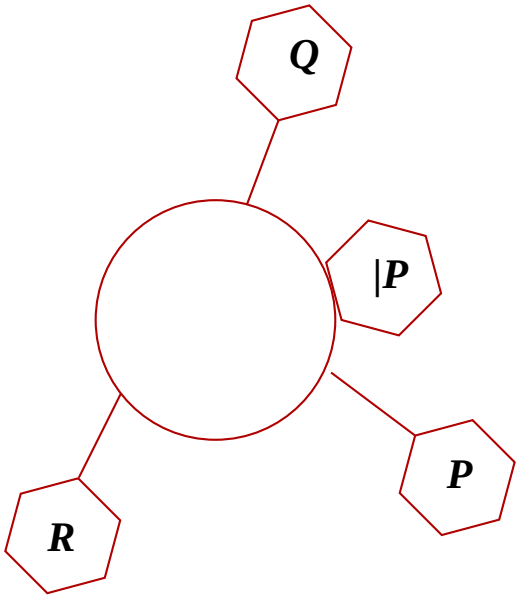

site s

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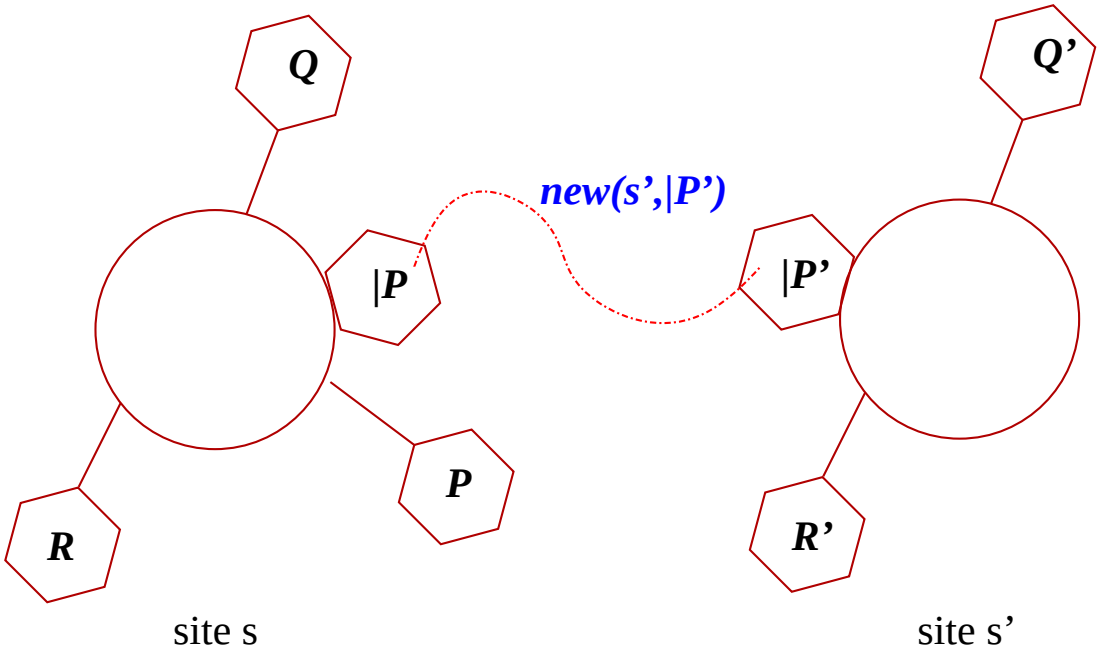

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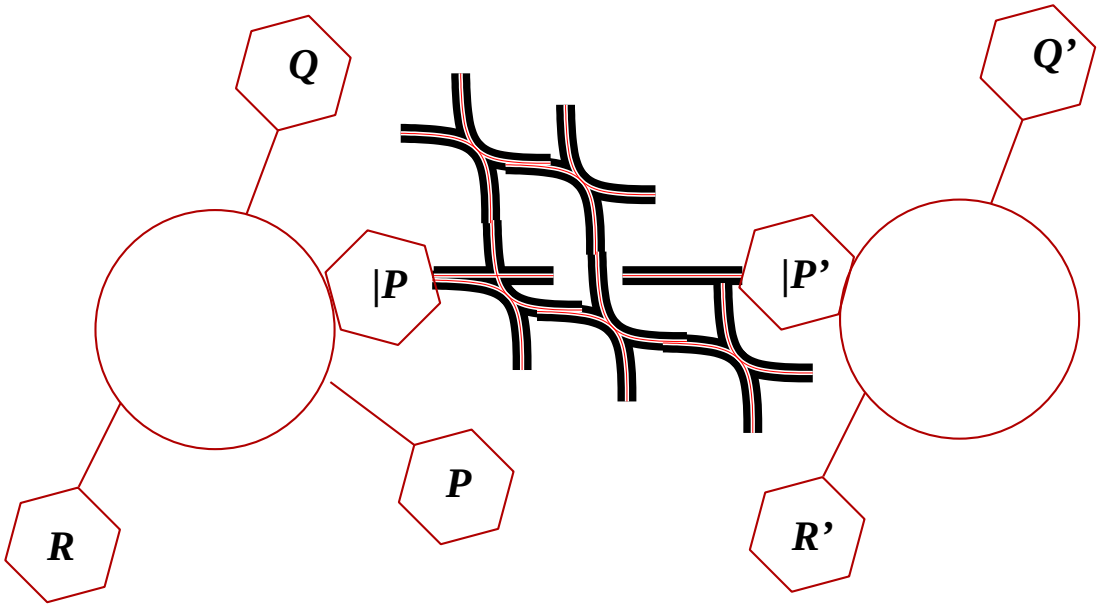

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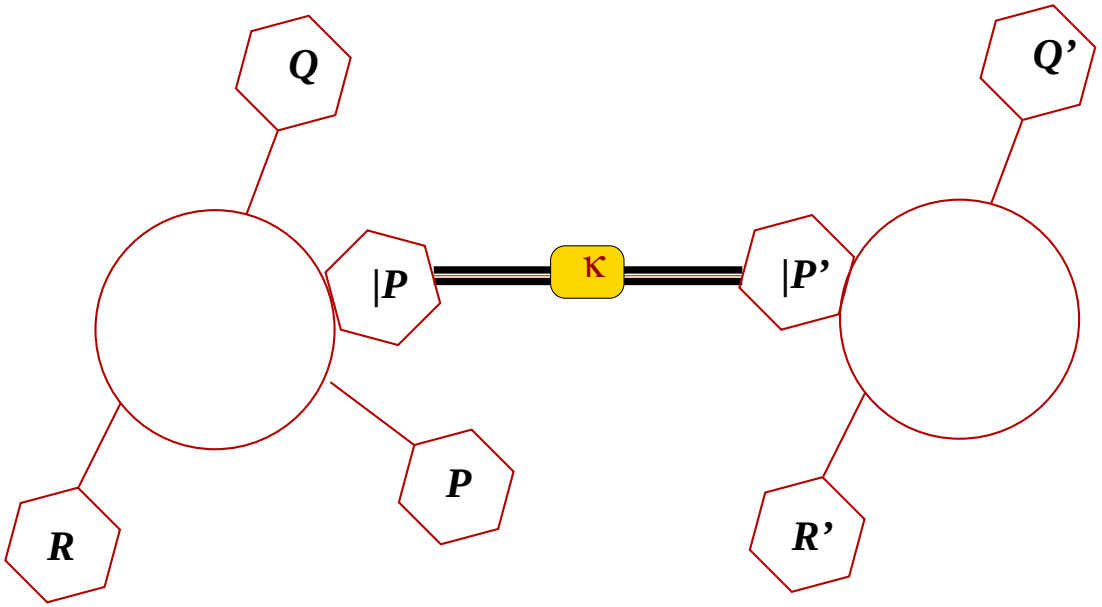

$$
\begin{array}{lcl}
\mathbb{P} & ::= & \gamma.\mathbb{P} \mid \mathbb{P}_1 \mid \mathbb{P}_2 \\
\gamma & ::= & \alpha \\
 & \mid & \mathbf{new}(s, \mathbb{P}) \\
 & \mid & \mathbf{link}(s_\kappa) \\
 & \mid & \mathbf{accept}(s_\kappa) \\
 & \mid & \mathbf{logout}(s) \\
 & \mid & \mathbf{disc}(s)
\end{array}
$$

Connection costs

κ abstracts characteristics of connections (distance, access rights, price ...)

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Algebra on costs: c-semiring [BMR95, BMR97]
$\langle A, +, \star, \mathbf{0}, \mathbf{1} \rangle$ where

- A is a set
- $\mathbf{0},\ \mathbf{1} \in A$
- $+ : A \times A \to A$
- $\star : A \times A \to A$

$$x + y = y + x \qquad (x + y) + z = x + (y + z)$$
$$x + x = x \qquad x + \mathbf{0} = x \qquad x + \mathbf{1} = \mathbf{1}$$
$$x \star y = y \star x \qquad (x \star y) \star z = x \star (y \star z)$$
$$x \star \mathbf{1} = x \qquad x \star \mathbf{0} = \mathbf{0}$$
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$$(x + y) \star z = (x \star z) + (y \star z)$$

$$a \leq b \iff \exists c : a + c = b$$

$a \leq b$ means that a is more constrained than b.

Connection costs: examples

- $(\{T, F\}, \vee, \wedge, F, T)$ truth values
- $\langle N, min, +, +\infty, 0\rangle$, the c-semiring of natural numbers N
- $\langle \wp(\{A\}), \cup, \cap, A, A\}\rangle$, the powerset semiring

Cartesian product of c-semirings is a c-semiring. For instance

$$\langle c_1, \pi_1\rangle \oplus \langle c_2, \pi_2\rangle = \langle c_1 \; min \; c_2, \pi_1 \cup \pi_2\rangle$$

$$\langle c_1, \pi_1\rangle \otimes \langle c_2, \pi_2\rangle = \langle c_1 + c_2, \pi_1 \cap \pi_2\rangle$$

Syntax of KAOS

N	$::=$		Nets
		$s ::^{L} P$	Single node
	$\mid$	$(\nu\, s)N$	Node restriction
	$\mid$	$N_1 \parallel N_2$	Net composition

γ	$::=$		Actions
		(s)	Input
	$\mid$	$\mathbf{new}(s_\kappa)$	Node creation
	$\mid$	$\mathbf{link}(s_\kappa)$	Login
	$\mid$	$\mathbf{accept}(s_\kappa)$	Accept
	$\mid$	$\delta\, l$	Disconnect

l	$::=$		Links
		$\langle s, \kappa \rangle$	Incoming link
	$\mid$	$\langle \kappa, s \rangle$	Outgoing link

P	$::=$		Processes
		$\mathbf{nil}$	Null process
	$\mid$	$\gamma.P$	Action prefi xing
	$\mid$	$\mathbf{out}(t)$	Output
	$\mid$	$\varepsilon(P)@s$	Remote spawning
	$\mid$	$P_1 \mid P_2$	Parallel
	$\mid$	X	Process vars

Semantics of KAOS

(OUT) $$s ::^{L} \mathbf{out}(t) \xrightarrow{s \triangleright t} s ::^{L} \mathbf{nil}$$

(IN) $$s ::^{L} (x).P \xrightarrow{s \triangleleft t} s ::^{L} P[{}^{t}/_{x}]$$

(LEVAL) $$s ::^{L \cup \langle s,\kappa \rangle} \varepsilon(P)@s \xrightarrow{\tau} s ::^{L \cup \langle s,\kappa \rangle} P, \qquad \text{if } \kappa \models T(P)$$

(EVAL) $$s ::^{L} \varepsilon(P)@t \xrightarrow[s,\mathbf{1}]{s(\emptyset,\, P)@t} s ::^{L} \mathbf{nil}, \qquad \text{if } s \neq t$$

(NEW) $$s ::^{L} (\mathbf{new}(x_\kappa).P) \mid Q \xrightarrow{\tau} (\nu\, x)(s ::^{L \cup \langle \kappa, x \rangle} P \mid Q \parallel x ::^{\langle s,\kappa \rangle} \mathbf{nil}),$$
$$\text{if } x \notin \mathrm{n}(L) \cup \{s\} \cup \mathrm{fn}(Q)$$

(LLOGIN) $$s ::^{L} \mathbf{link}(s_\kappa).P \xrightarrow{\tau} s ::^{L \cup \{\langle s,\kappa \rangle, \langle \kappa, s \rangle\}} P$$

(LOGIN) $$s ::^{L} \mathbf{link}(t_\kappa).P \xrightarrow{s \overset{\kappa}{\frown} t} s ::^{L \cup \langle \kappa, t \rangle} P, \qquad \text{if } s \neq t$$

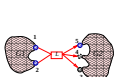
(ACCEPT) $$s ::^{L} \mathbf{accept}(t_{\kappa'}).P \xrightarrow{t \overset{\kappa}{\smile} s} s ::^{L \cup \langle t,\kappa \rangle} P, \qquad \text{if } \kappa \leq \kappa'$$

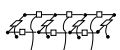
(LDISC) $$s ::^{L} \delta\langle s, \kappa \rangle.P \xrightarrow{\tau} s ::^{L \setminus \langle s,\kappa \rangle \setminus \langle \kappa . s \rangle} P$$

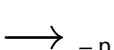
(IDISC) $$s ::^{L} \delta\, \langle t, \kappa \rangle.P \xrightarrow{\delta(s, \langle t,\kappa \rangle)} s ::^{L \setminus \langle t,\kappa \rangle} P, \qquad \text{if } t \neq s$$

(ODISC) $$s ::^{L} \delta\, \langle \kappa, t \rangle.P \xrightarrow{\delta(s, \langle \kappa,t \rangle)} s ::^{L \setminus \langle \kappa,t \rangle} P, \qquad \text{if } t \neq s$$

(NODE) $$s ::^{L \cup \langle r,\kappa \rangle} P \xrightarrow[r,\kappa]{X@s} s ::^{L \cup \langle r,\kappa \rangle} P \mid X, \qquad \text{if } X \text{ fresh}$$

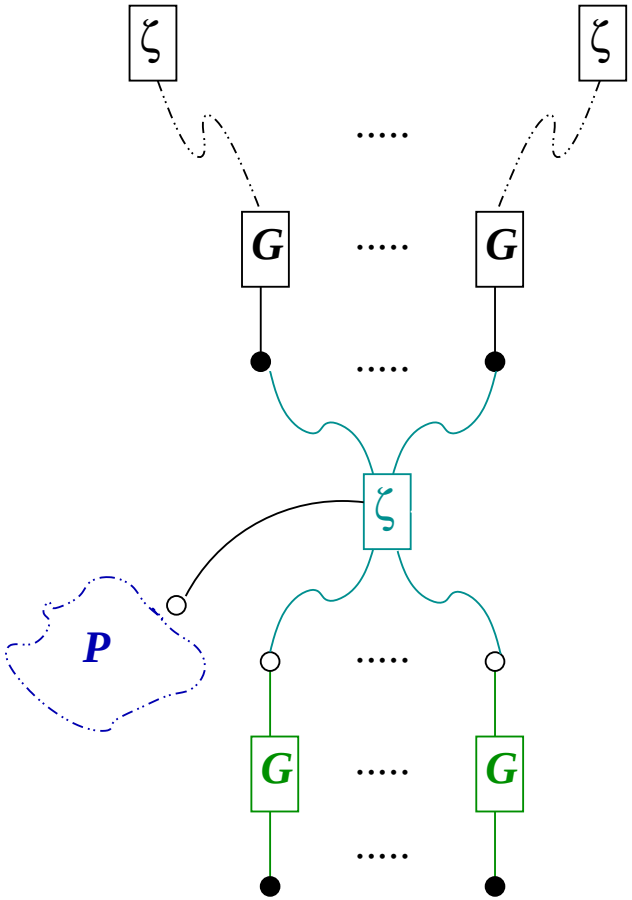




KAOS & Hypergraphs

$$[\![\ s ::^{L}\ P\ ]\!] \ = \ \Gamma \vdash (\nu\ \vec{x}, p)([\![\ P\ ]\!]_p \mid \mathfrak{S}^{s}_{m,n}(\vec{u}, \vec{x}, p) \mid \prod_{j=1}^{n} G^{\kappa_j}_{t_j}(x_j, v_j))$$



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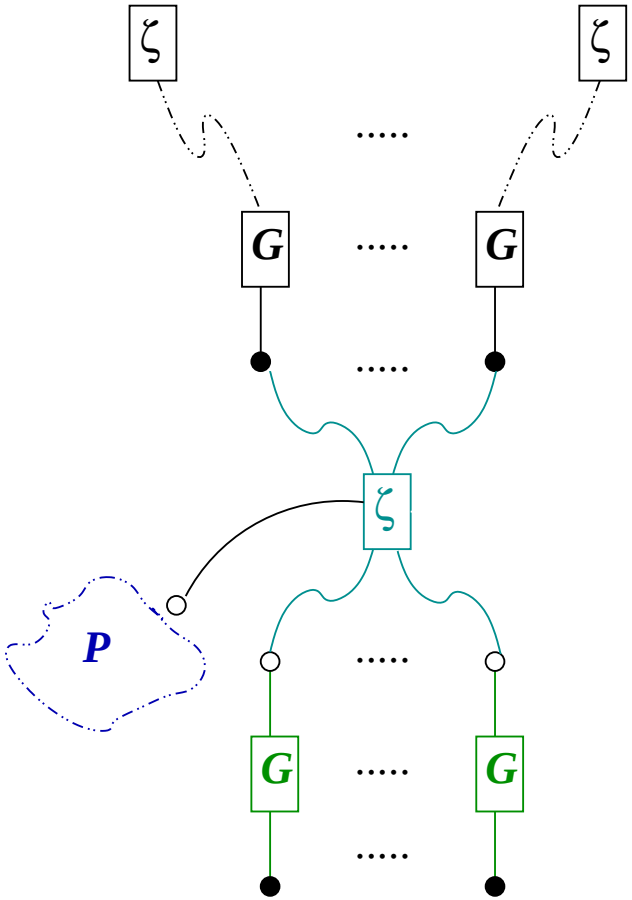

$$
\begin{aligned}
[\![\ \mathbf{nil}\ ]\!]_p &= nil \\
[\![\ \mathbf{out}(t)\ ]\!]_p &= L_{\mathbf{out}(t)}(p) \\
[\![\ \gamma.P\ ]\!]_p &= L_{\gamma.P}(p) \\
[\![\ \varepsilon(P)@s\ ]\!]_p &= (\nu\, u)(\varepsilon^{T(P)}_{s}(u, p) \mid S_P(u)) \\
[\![\ P_1 \mid P_2\ ]\!]_p &= [\![\ P_1\ ]\!]_p \mid [\![\ P_2\ ]\!]_p \\
[\![\ rec\ X.\, P\ ]\!]_p &= [\![\ P[^{rec\ X.\, P}/_{X}]\ ]\!]_p.
\end{aligned}
$$

KAOS's Graph semantics: pros & cons

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– Many productions (recently reduced :-)

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= Determines the "optimal" path (also KAOS)

Theorem If $\Gamma \vdash G \xrightarrow{\Lambda \cup \{(u,\, v\ \kappa,\, \langle u \rangle)\}} \Gamma' \vdash G'$ then

1. u and v are link-connected by a path of cost κ;
2. for any

there is a $\Gamma \vdash G \xrightarrow{\Lambda \cup \{(u,\, v\ \kappa,\, \langle u \rangle)\}} \Gamma' \vdash G'$ s.t. $\kappa \leq \prod_{i=1}^{h} \kappa_i$.

($\prod$ is the c-semiring multiplication)

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\+ Path reservation

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($\prod$ is the c-semiring multiplication)

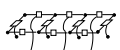
\+ Path reservation

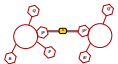
\+ Optimal path routing (e.g., Floyd-Warshall)

SLAK: Service Level Agreement in Klaim

In collaboration with
R. De Nicola








Focussing on SLA

- Modern WAN applications quest for SLA specifi cation and programming
- Consider WS:
  - programmers could drive the search phase of the required services by declaring their SLA constraint, and
  - language support guarantees satisfaction of requirements
  - Synchronizing = signing a “contract”
- KAOS is an attempt in this direction, but it has many concepts (e.g., links, costs, coordinators,...)
- We aim at refi ning KAOS in a calculus that abstracts
  - mechanisms for WAN programming...
  - ...together with SLA constraints
  - in a “flexible” framework

SLAK vs KAOS

Similarities wrt KAOS

- costs are c-semiring [BMR97]
- local (anonymous) communications
- remote spawning of processes

Simplifi cations wrt KAOS

- Bidirectional Links
- Incremental defi nition
- A different (syntactic) concept of “site”
- $\Rightarrow$ *self-links* are dealt with uniformly

SLAK Syntax

N	$::=$		Nets
		$s ::^{L} P$	Located Process
	$\mid$	$N_1 \parallel N_2$	Net composition
γ	$::=$		Prefi xes
		(x)	Input
	$\mid$	$\mathbf{new}(s_\kappa)$	Node creation
	$\mid$	$\varepsilon(P)@s$	Process spawning
P	$::=$		Processes
		$\mathbf{nil}$	Null process
	$\mid$	$\gamma.P$	Action prefi xing
	$\mid$	$\mathbf{out}(t)$	Output

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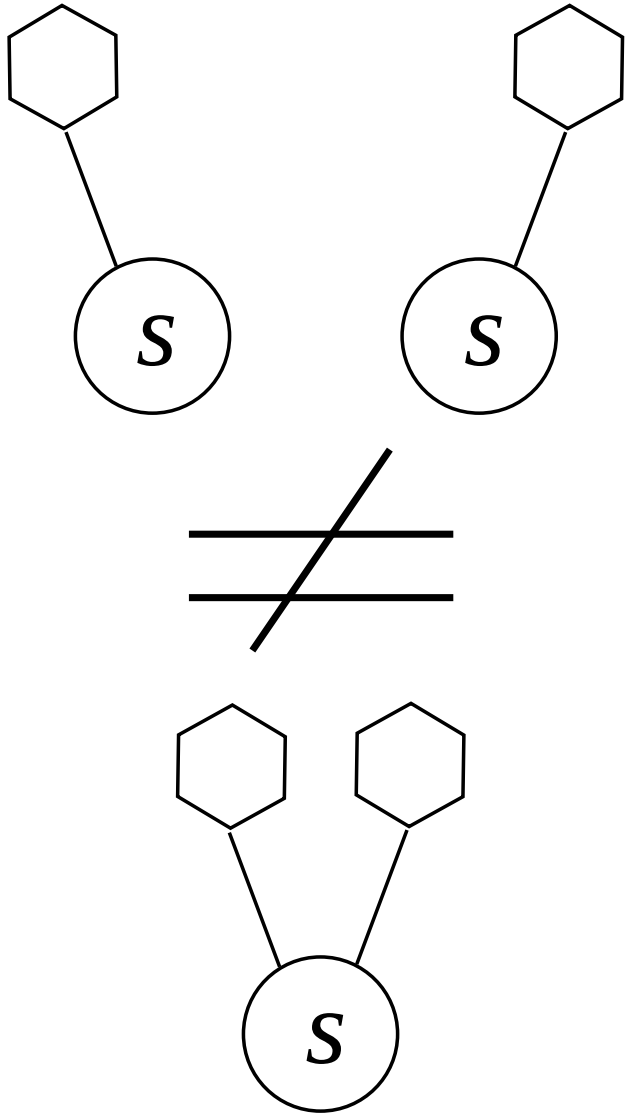


Local Transitions

(OUT) $$s ::^{L} \mathbf{out}(r) \xrightarrow[s,\mathbf{1}]{\langle r \rangle} s ::^{L} \mathbf{nil}$$

(IN) $$s ::^{L} (x).P \xrightarrow[s,\mathbf{1}]{(r)} s ::^{L} P[{}^{r}/_{x}], \qquad r \in \mathcal{S}$$

(NEW) $$s ::^{L} \mathbf{new}(u_\kappa).P \xrightarrow[s,\mathbf{1}]{\mathbf{new}(r)} s ::^{L \uplus r_\kappa} P \parallel r ::^{\{u_1, s_\kappa\}} \mathbf{nil}, \qquad r \notin \mathrm{dom}(L)$$

(EVAL) $$s ::^{L} \varepsilon(P)@t.Q \xrightarrow[s,\mathbf{1}]{s[P]@t} s ::^{L} Q$$

(SITE) $$s ::^{L \uplus r_\kappa} P \xrightarrow[s,\kappa]{\mathbf{from}(r)} s ::^{L \uplus r_\kappa} P$$

Global Transitions[1]

$$\text{(PAR)}\quad \frac{N_1 \xrightarrow[s,\kappa]{\alpha} N_1'}{N_1 \parallel N_2 \xrightarrow[s,\kappa]{\alpha} N_1' \parallel N_2} \qquad \mathrm{bn}(\alpha) \cap \mathrm{fn}(N_2) = \emptyset$$

$$\text{(COM)}\quad \frac{N_1 \xrightarrow[s,\mathbf{1}]{\langle r \rangle} N_1' \qquad N_2 \xrightarrow[s,\mathbf{1}]{(r)} N_2'}{N_1 \parallel N_2 \xrightarrow[s,\mathbf{1}]{\tau} N_1' \parallel N_2'}$$

Global Transitions[2]

$$\text{(ROUTE)}\quad \frac{N_1 \xrightarrow[r,\kappa_1]{s[P]@t} N_1' \qquad N_2 \xrightarrow[r',\kappa_2]{\mathbf{from}(r)} N_2' \qquad \kappa_2 \models T(P)}{N_1 \parallel N_2 \xrightarrow[r',\kappa_1 \star \kappa_2]{s[P]@t} N_1' \parallel N_2'} \quad t \neq r'$$

$$\text{(LANDING)}\quad \frac{N_1 \xrightarrow[r,\kappa_1]{s[P]@t} N_1' \qquad N_2 \xrightarrow[t,\kappa_2]{\mathbf{from}(r)} N_2' \qquad \kappa_2 \models T(P)}{N_1 \parallel N_2 \xrightarrow[t,\kappa_1 \star \kappa_2]{s[P]@} N_1' \parallel N_2' \parallel t ::^{\{t_{\kappa_1 \star \kappa_2}\}} P}$$

Correctness & Completeness

Definition Let N be a net and let s and t be two sites in N. We denote with $\mathcal{P}_N(s,t)$ the set of costs of the paths from s to t in N.

Theorem Let N be a net, then

$$N \xrightarrow[t,\kappa]{s[P]@} \Longrightarrow \quad \kappa \in \mathcal{P}_N(s,t)$$

Theorem Given a net N and a process P

$$N \xrightarrow[t,\mathbf{1}]{s[P]@} \Longrightarrow \quad N \xrightarrow[t,\kappa]{s[P]@}$$

for all $\kappa \in \mathcal{P}_N(s,t)$ s.t. $\kappa \models T(P)$

Ranges

A slight variation: $P ::= \ldots \mid \varepsilon_\kappa(P)@s$

(EVAL') $$s ::^L \varepsilon(P)@t \xrightarrow[s,\,\mathbf{1}]{s[P_\kappa]@t} s ::^L \mathbf{nil}$$

(ROUTE') $$\frac{N_1 \xrightarrow[r,\,\kappa_1]{s[P_\kappa]@t} N_1' \qquad N_2 \xrightarrow[r',\,\kappa_2]{\mathbf{from}(r)} N_2' \qquad \kappa_2 \models T(P) \quad \wedge \quad \boxed{\kappa \geq \kappa_1 \star \kappa_2}}{N_1 \parallel N_2 \xrightarrow[r',\,\kappa_1 \star \kappa_2]{s[P_\kappa]@t} N_1' \parallel N_2'} \quad t \neq r'$$

(LANDING') $$\frac{N_1 \xrightarrow[r,\,\kappa_1]{s[P]@t} N_1' \qquad N_2 \xrightarrow[t,\,\kappa_2]{\mathbf{from}(r)} N_2' \qquad \kappa_2 \models T(P) \quad \wedge \quad \boxed{\kappa \geq \kappa_1 \star \kappa_2}}{N_1 \parallel N_2 \xrightarrow[t,\,\kappa_1 \star \kappa_2]{s[P]@} N_1' \parallel N_2' \parallel t ::^{\{t_{\kappa_1 \star \kappa_2}\}} P}$$

Correspondence

Theorem If $N \xrightarrow[t,\kappa']{s[P_\kappa]@} N'$ then $\hat{N} \xrightarrow[t,\kappa']{s[P]@} \hat{N}'$ where $\hat{N}$ and $\hat{N}'$ are obtained by removing costs from ε prefixes in N and N', respectively.

Dynamic Links

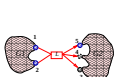
$$
\begin{array}{lll}
\gamma & ::= & \text{Prefixes} \\
 & \ldots & \\
 & \mid \quad \mathbf{link}(s_\kappa) & \text{Link} \\
 & \mid \quad \mathbf{accept}(s_\kappa) & \text{Accept} \\
 & \mid \quad \mathbf{disc}(s) & \text{Disconnect}
\end{array}
$$

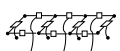
(LINK) $$s ::^{L} \mathbf{link}(r_\kappa).P \xrightarrow[s,\kappa']{\mathbf{link}(r_\kappa)} s ::^{L \uplus r_{\kappa\star\kappa'}} P$$

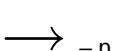
(ACCEPT) $$s ::^{L} \mathbf{accept}(r_\kappa).P \xrightarrow[s,\kappa']{\mathbf{accept}(r_\kappa)} s ::^{L \uplus r_{\kappa\star\kappa'}} P$$

(ACCEPT') $$s ::^{L \uplus r_\kappa} P \xrightarrow[s,\kappa]{\mathbf{accept}(r_\kappa)} s ::^{L \uplus r_\kappa} P$$

(DISC) $$s ::^{L} \mathbf{disc}(r).P \xrightarrow[s,\mathbf{1}]{\tau} s ::^{L \setminus r} P$$





Dynamic Links

$$\text{(ADDLINK)}\quad \frac{N_1 \xrightarrow[s,\,\kappa']{\mathbf{link}(r_\kappa)} N_1' \qquad N_2 \xrightarrow[r,\,\kappa']{\mathbf{accept}(s_\kappa)} N_2'}{N_1 \parallel N_2 \xrightarrow[s,\,\kappa \star \kappa']{\tau} N_1' \parallel N_2'}$$

Summing up...

Conclusions

Declarative Model of WAN programming

- Captures aspects of Web Services metaphor
- Suitable for representing several WAN network issues e.g.,
  - different models (Ambient, Klaim,...)
  - wireless communications
  - routing
- SLA as a Coordination Mechanism
- Toward formal techniques for SLA programming

On-going activity

- Simplifying the hypergraph framework
  Recently a very simple semantics has been found:
  - neither Γ nor π,
  - just one inference rule.

  Decreased expressive power but still an interesting model of WAN

- Modelling GRID via SHR [AT03]
- Modelling wireless phenomena [Tuo04]
- Tools
  - SHE (Synchronized Hyperedge Environment [CTT04])
  - Gredi (GRammar EDItor)

Future work

- Extending synchronizing policies
  - Synchronization algebra = c-semiring?
  - Is it possible to use c-semirings for semantic web?
  - Rule matching problem = semantic serch/bind of services
- Applying SLA to wireless routing problem
- Extending SHR futures to match GRID's data-oriented issues
- Analyzing SLAK expressivity (wrt KAOS)
- Extending SLAK
- Model Checking SLAK by exploiting [Lor02, DL02]
- and Gredi + SHE for verifying wireless networks
- SLAK's observational semantics

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