Event Structure Semantics for Nominal Calculi

Roberto Bruni

Dipartimento di Informatica
Università di Pisa

CONCUR 2006
Bonn, August 27–30, 2006

A joint work with:

H. Melgratti and U. Montanari

Disclaim: Lightweight presentation of technical details, where intuition is deliberately advantaged over precision

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Outline

True Concurrent Semantics

Models of concurrency

- *interleaving*: concurrency reduces to nondeterministic choices
- *conflict*: focus on choice points
- *causal*: causal dependencies are explicit
- *concurrent*: multiple actions are allowed

(Prime) Event Structures

Suitable domain of events where conflicts, causality and concurrency are accounted for and related altogether.

A Curious Fact of Life

In concurrency theory, interleaving semantics are far more frequently studied than true concurrent ones (even at CONCUR).

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Event Structures and Nominal Calculi

Event Structures and π

Daniele Varacca and Nobuko Yoshida recently defined the (**direct**, typed, sound) event structure semantics of (a **linearly typed version** of) Sangiorgi's π**I-calculus** [MFPS'06]

- Glynn Winskel's original event structure semantics of CCS is extended to π-calculi for the *first* time
- the considered fragment is expressive enough to encode the typed λ-calculus (fully abstractly)
- compile-time α-conversion is allowed
- typed event structures guarantees confusion freeness (closed under parallel composition)

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Indirect Event Structures Semantics?

Via Petri Nets Encoding

- Engelfriet [CONCUR'93]
- Busi and Gorrieri [CONCUR'95]
- Buscemi and Sassone (for join) [FOSSACS'01]
- Devillers, Klaudel, Koutny [FORTE'04]

Via Graph Rewriting Encoding

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- Gadducci and Montanari (for ambients) [MFPS'01]
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Devil is in the Detail!

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A Nice Event Structures Semantics

Winskel's Construction

$$\textbf{Safe Nets} \underset{\mathcal{U}}{\overset{\perp}{\rightleftarrows}} \textbf{Occurrence Nets} \underset{\mathcal{E}}{\overset{\mathcal{N}}{\underset{\perp}{\leftrightarrows}}} \textbf{Prime Event Structures} \underset{\mathcal{L}}{\overset{\mathcal{P}}{\underset{\sim}{\leftrightarrows}}} \textbf{Domains}$$

- **Categories** instead of sets (objects related via morphisms)
- **Functorial** semantics (morphisms are preserved)
- **Backward** constructions (and they are still functors)
- Forward and backward constructions form **adjunctions** (universal property witnesses optimality, preservation of (co)limits)...
- ... more precisely, **coreflections** (particularly nice adjunctions, where a natural iso establishes an equivalence between the denotational domain and a full subcategory of computational models)
- Later generalized to (semi-weighted) P/T nets (Sassone's PhD Thesis)

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More Sophisticated Event Structures

Goguen's Categorical Manifesto [MSCS 1(1):49–67, 1991]

- To each species of mathematical structure, there corresponds a category whose objects have that structure, and whose morpshisms preserve it.
- To any construction from one species of structure to another, there corresponds a functor between the corresponding categories
- To any **canonical** construction from one species of structure to another corresponds an adjunction between the corresponding categories

What about read / inhibitor arcs, high-level / dynamic nets, graph grammars?

Additional Efforts

- Asymmetric Event Structures (AES) and Inhibitor Event Structures (IES) are needed (Baldan's PhD Thesis)
- Theory not available when encodings were first defined
- Constructions become much more complex, less elegant (categorically speaking)... and still not always applicable

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Our Contribution

Computational Model Requirements

- Based on Graph Grammars (convenient for modeling many features)
- As simple as possible, but general enough to be widely applicable for encoding nominal calculi (finite representation of each process, avoid dealing with those GG features not really needed in encodings)
- PES semantics via chain of coreflections (like Winskel's approach)...
- ... possibly stable under SPO and DPO approaches

Our Proposal: Persistent Graph Grammars

$$\begin{tikzcd}
\textbf{Persistent GG} \arrow[r, shift right=1.5ex, "\mathcal{U}_p"'] \arrow[r, phantom, "\perp"] & \textbf{Persistent Occurrence GG} \arrow[l, hook', shift right=1.5ex] \arrow[r, shift right=1.5ex, "\mathcal{E}_p"'] \arrow[r, phantom, "\perp"] & \textbf{PES} \arrow[l, shift right=1.5ex, "\mathcal{N}_p"'] \arrow[r, shift right=1.5ex, "\mathcal{L}"'] \arrow[r, phantom, "\sim"] & \textbf{Domains} \arrow[l, shift right=1.5ex, "\mathcal{P}"']
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Sample encodings: π-calculus and join calculus

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Outline

DPO Graph Grammars at a Glance

Configurations are (Directed) Typed Graphs

$\tau_G : G \rightarrow T$ (ex: G bipartite if $T =$ $\begin{tikzcd} n_1 \arrow[r, bend right, "a_1"'] & n_2 \arrow[l, bend right, "a_2"'] \end{tikzcd}$, G any if $T =$ $\begin{tikzcd} n \arrow[loop right, "a"] \end{tikzcd}$)

Rewrite Rules are Spans

$p : (L \stackrel{l}{\leftarrow} K \stackrel{r}{\rightarrow} R)$ (T-typed:

$$\begin{tikzcd} L \arrow[dr, "\tau_L"'] & K \arrow[l, "l"'] \arrow[r, "r"] \arrow[d, "\tau_K"] & R \arrow[dl, "\tau_R"] \\ & T & \end{tikzcd}$$

)

Double Pushout Rewriting (from G to H via p)

$$p : \begin{tikzcd} L \arrow[d, "m"'] \arrow[dr, phantom, "(2)"] & K \arrow[l, "l"'] \arrow[r, "r"] \arrow[d, "k"] \arrow[dr, phantom, "(3)"] & R \arrow[d, "f"] \\ G & D \arrow[l] \arrow[r] & H \end{tikzcd}$$

(1) find a (valid) match m
(2) $D =$ remove $m(L - l(K))$ from G
(3) $H =$ paste a fresh copy of $R - r(K)$
T is preserved everywhere

DPO Graph Grammars at a Glance

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Example: Place/Transition Petri Nets as Graph Grammars

From N to GG_N

- Consider just discrete graphs (no arcs)
- Type graph T = set of places of N
- Typed graphs = markings
- Nodes of a typed graph = (named) tokens
- Productions = transitions of N
  - L_t is the preset of t
  - K_t is empty
  - R_t is the postset of t

A Tiny Example

preset of $t = a \oplus b$

postset of $t = b \oplus c$

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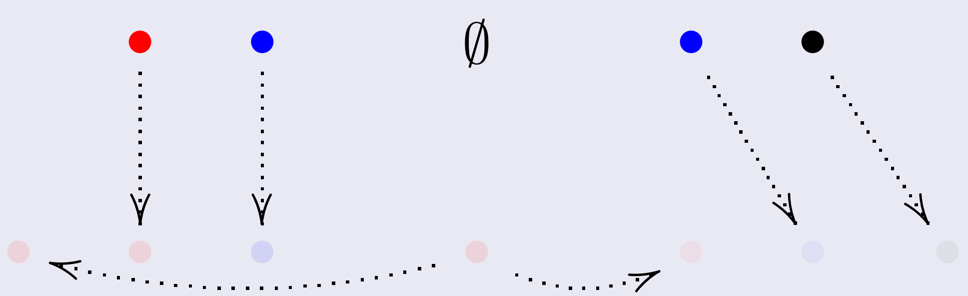

preset of $t = a \oplus b$

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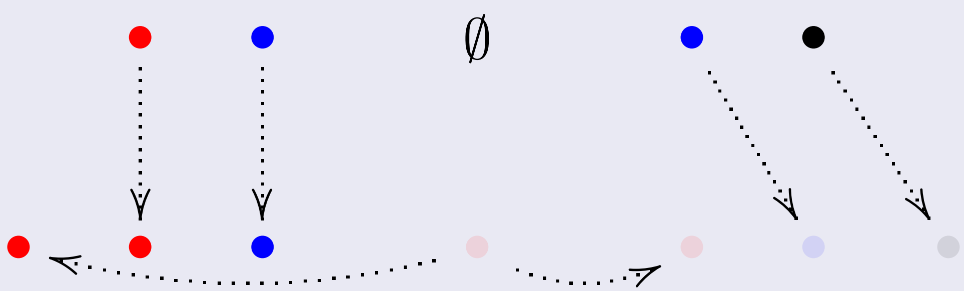

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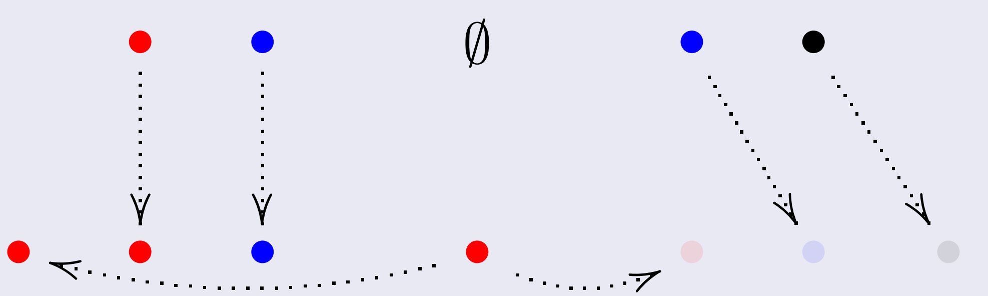

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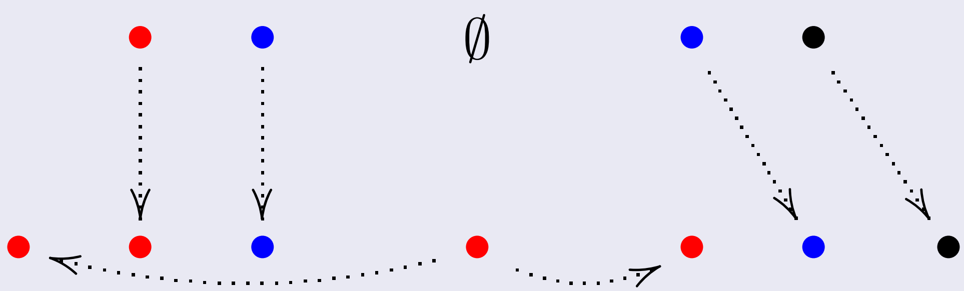

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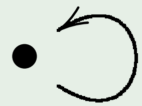
DPO vs SPO (Informally)

- type graph: 
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Final configuration?

- DPO not applicable: dangling arc in
- SPO is applicable: dangling arcs are removed

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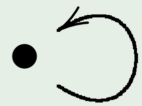
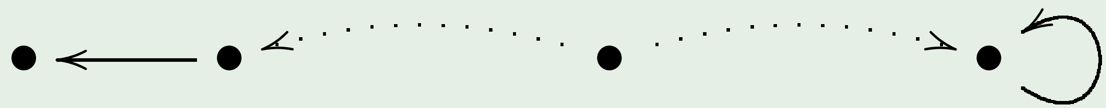
- type graph: 
- production: 
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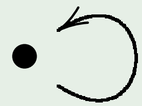
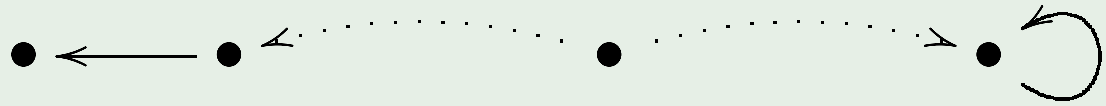
- type graph: 
- production: 
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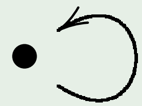
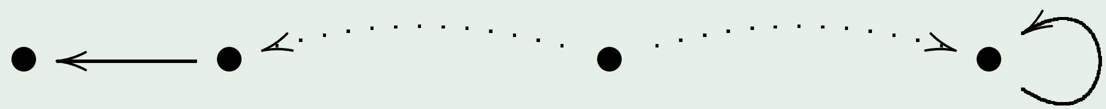
- type graph: 
- production: 
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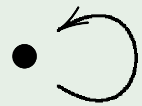
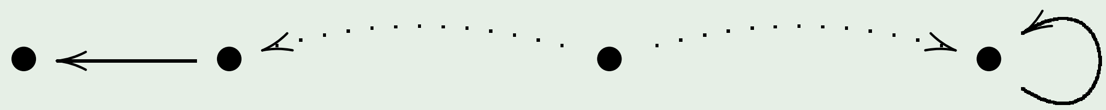
- type graph: 
- production: 
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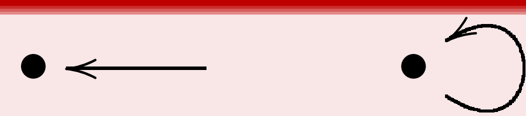
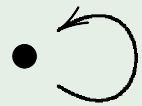
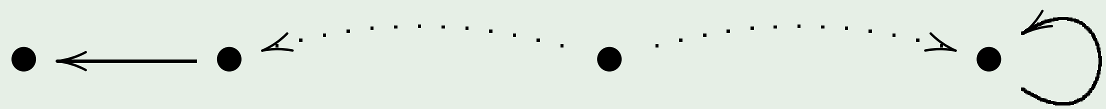
- DPO not applicable: dangling arc in 
- SPO is applicable: dangling arcs are removed

DPO vs SPO (Informally)

- type graph: 
- production: 
- initial configuration: 
- matching: 

Final configuration?

- DPO not applicable: dangling arc in 
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DPO vs SPO (Semantically)

DPO: Baldan's PhD Thesis

$$\begin{tikzcd} \textbf{S-W DPO GG} \arrow[r, shift right, "\mathcal{U}_g"'] \arrow[r, phantom, "\perp"] & \textbf{S-W Occurrence DPO GG} \arrow[l, hook, shift right] \arrow[r, "\mathcal{E}_g"'] & \textbf{IES} \arrow[r, shift right, "\mathcal{L}_i"'] \arrow[r, phantom, "\perp"] & \textbf{Domains} \arrow[l, shift right, "\mathcal{P}_i"'] \end{tikzcd}$$

SPO: A Recent Result (Baldan, Corradini, Montanari, Ribeiro)

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Graph Grammars Instead of Petri Nets

Graph Grammars Benefits

- Computational power
- Multiple accesses in reading is built-in (via K)
- More sophisticated typing mechanism
- Structural congruence as graph isomorphism
- Name sharing as node sharing
- Creation of fresh items is built-in (right-hand square of DPO)
- Can encode dynamic productions (Bruni and Melgratti [ICGT'06])

Applicability vs Categorical Adequacy of the Semantics

- Which constructions?
- Which approach (DPO /SPO)?
- Too much general for the purpose of encoding nominal calculi?

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Outline

PGG

Some Restrictions

- *Consuming Productions*: to avoid infinite auto-concurrency
- *Node Persistence*: to reconcile SPO and DPO
- **Typeable Persistent Arcs**: to construct PES instead of AES
- *Semi-Weightedness*: to avoid ambiguity and redundancy in the unfolding and get a chain of coreflections

Main Result

$$
\begin{tikzcd}
\textbf{Persistent GG} \arrow[r, bend right, "\mathcal{U}_p"'] \arrow[r, phantom, "\perp"] & \textbf{Persistent Occurrence GG} \arrow[l, hook', bend right] \arrow[r, bend right, "\mathcal{E}_p"'] \arrow[r, phantom, "\perp"] & \textbf{PES} \arrow[l, bend right, "\mathcal{N}_p"'] \arrow[r, bend right, "\mathcal{L}"'] \arrow[r, phantom, "\sim"] & \textbf{Domains} \arrow[l, bend right, "\mathcal{P}"']
\end{tikzcd}
$$

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Main Result

$$\textbf{Persistent GG} \;\underset{\mathcal{U}_p}{\overset{\perp}{\rightleftarrows}}\; \begin{array}{c}\textbf{Persistent}\\ \textbf{Occurrence GG}\end{array} \;\underset{\mathcal{E}_p}{\overset{\mathcal{N}_p}{\rightleftarrows}}\; \textbf{PES} \;\underset{\mathcal{L}}{\overset{\mathcal{P}}{\rightleftarrows}}\; \textbf{Domains}$$

Discussion

Some Restrictions

- **Consuming Productions**: corresponds to the common constraint on Petri nets about *non-emptiness of presets*. This constraint has e.g. some consequences in the design of productions for modeling replication and join definitions.
- **Node Persistence**: solves the matter of *dangling arcs*. No relevant consequences for the event structure semantics, because in our modeling all computational entities are represented as arcs, not as nodes.
- **Typeable Persistent Arcs**: solves the matter of *asymmetric conflicts* (it is not possible to fetch resources that others can access in reading). It has no particular consequences in the encodings that we have considered.
- **Semi-Weightedness**: bans the presence of *multiple, indistinguishable resources*. It has some (non-dramatic) consequences on the encodable agents and it is likely the most restrictive requirement on PGG.

Note that "red items" apply to general GG, not just PGG

Outline

Why π-calculus and join calculus

Why π-calculus

- Popularity
- Refine Montanari and Pistore's [MFPS'95] encoding
- Not just the finite fragment, still finite representation of each process
- Asynchronous case shown in the paper (see Uwe Nestmann's tutorial), but straightforward extension to the synchronous case

Why join calculus

- Carefully designed with an eye to implementation issues
- Interesting as reflexive extension of Petri nets
- Join definitions introduce challenging synchronization patterns for the reuse of other techniques (like direct encoding)
- First event structure semantics for the join calculus (that we are aware of)

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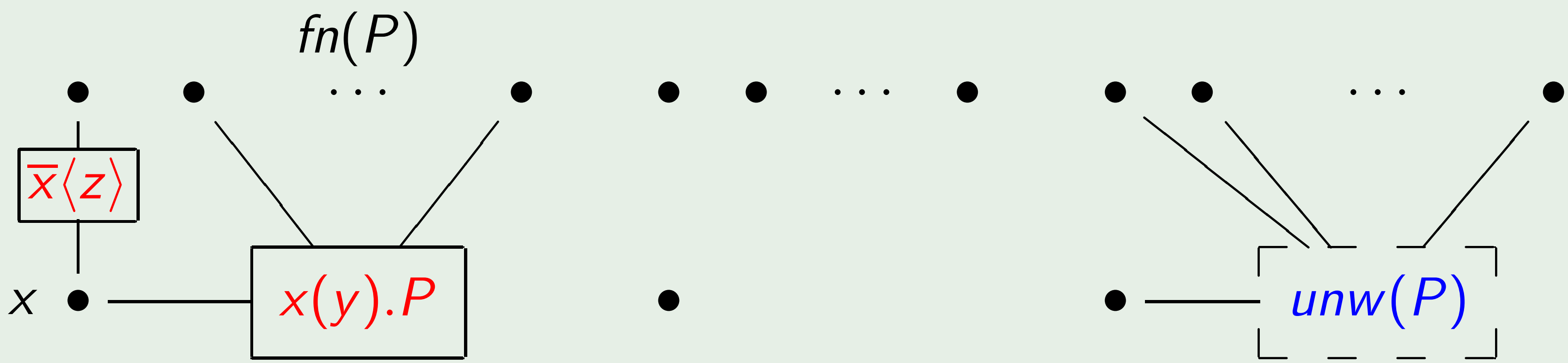
The General Idea

Common Guidelines

- Canonical representation of processes
- Names are represented as nodes in configurations
- Sequential computational entities are represented as (hyper)arcs in configurations
- Distinct agents can execute concurrently
- Node sharing is the key to establish connectivity and communication
- Finitely many types, statically determined by subterms of canonical processes
- Types determine the applicable productions and hence the behaviour of computational entities
- Within productions, π-replication and join-definitions are modeled as persistent resources, so they can produce multiple concurrent events without introducing unnecessary serialization

Sketched Rules

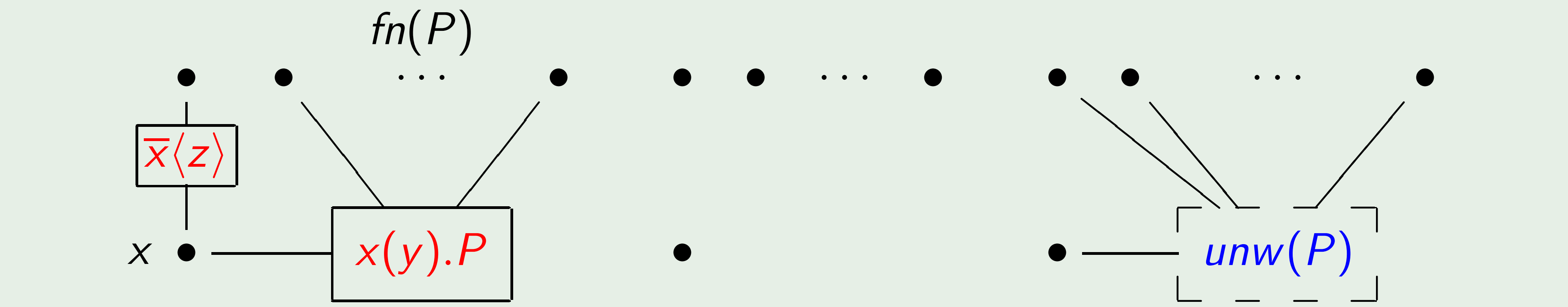
Input in π



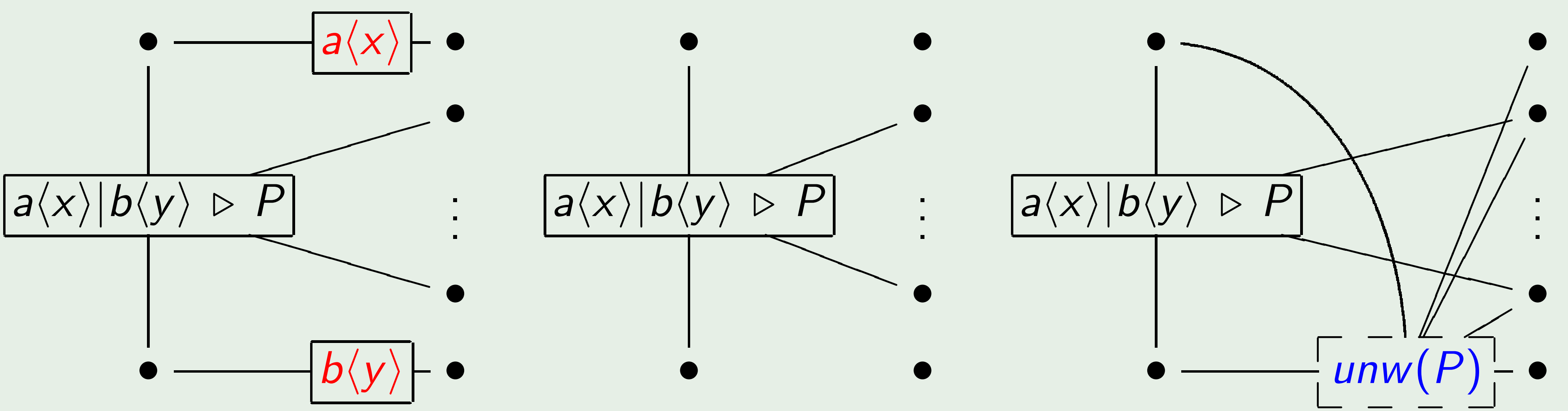
Reaction in Core Join

Sketched Rules

Input in π



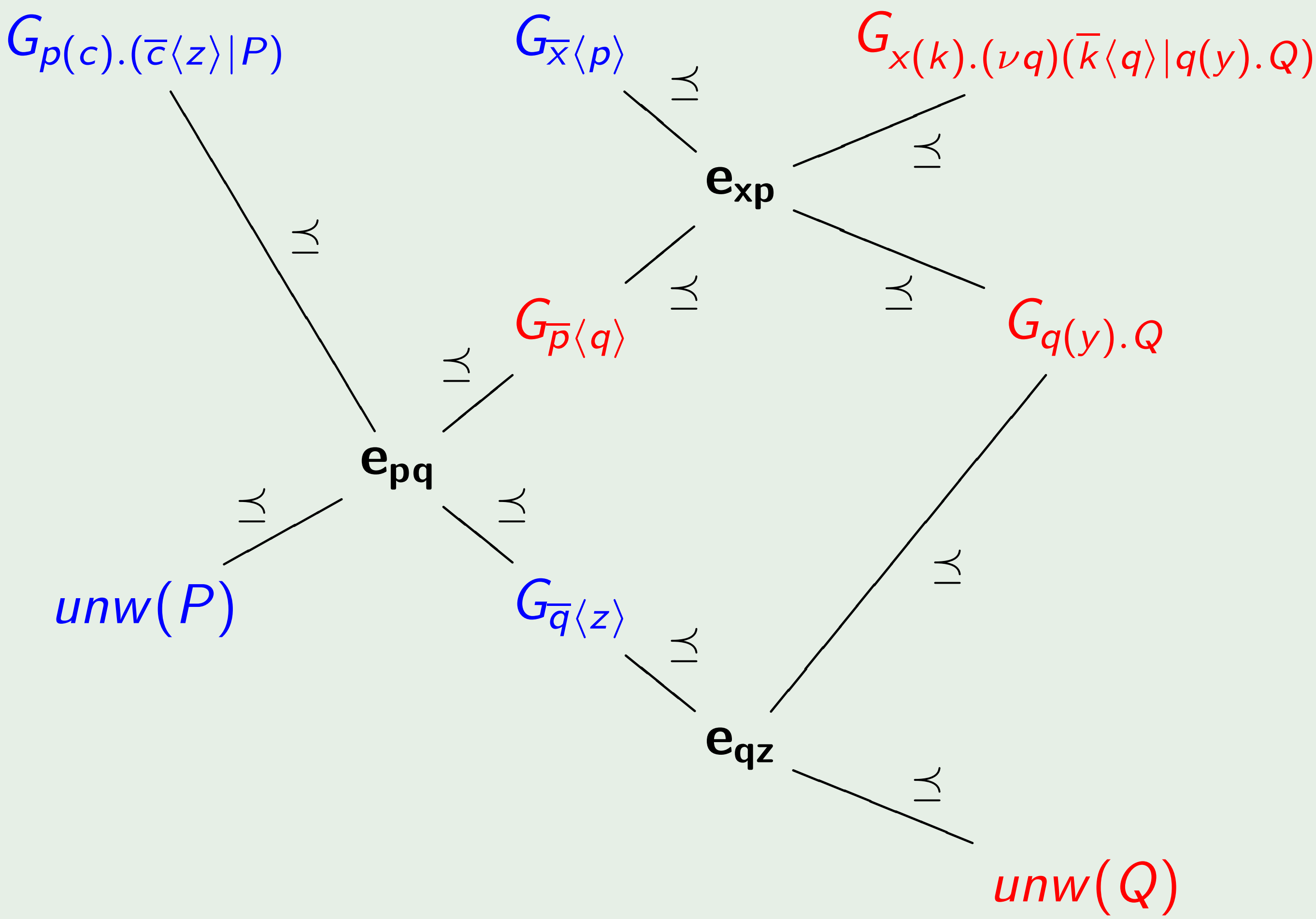
Reaction in Core Join



Short Example

From Synchronous to Asynchronous

$$S = \quad \ldots \quad \overline{x}\langle z\rangle.P \quad \ldots \quad x(y).Q \quad \ldots$$
$$A = \quad \ldots \quad (\nu p)(\overline{x}\langle p\rangle | p(c).(\overline{c}\langle z\rangle | P)) \quad \ldots \quad x(k).(\nu q)(\overline{k}\langle q\rangle | q(y).Q) \quad \ldots$$



Outline

Conclusions

Recap

- Persistent Graph Grammars (PGGs) offer a suitable setting for equipping nominal calculi with (indirect) truly concurrent semantics collecting the best of the two worlds:
  - PES via a chain of coreflections
  - disciplined encoding of nominal calculi
- Constructions are stable under DPO and SPO
- First PES semantics for join
  - applicable to coloured and reconfigurable nets by exploiting the result in Buscemi and Sassone [FOSSACS'01]
- We exploit finite type graph (and configuration) for each process

Related Issues

Shifting the Ground

- Reduction semantics vs open semantics: problems of non-consuming productions
- Parallel extrusion: it can be allowed or disallowed as already shown by Montanari and Pistore [MFPS'01]
- Structure vs link dependencies: not clear how to distinguish between the two
- Isolated (persistent) nodes: always garbage collectable
- Hierarchical encoding of sequential processes vs flat encoding: the latter may require node fusion (see Baldan, Gadducci and Montanari's paper)
- Non semi-weighted processes: serialize the release of resources with the same type

Future Work

Open issues

- Relax semi-weightedness? (adjunctions instead of coreflections?)
- Similarities between Varacca and Yoshida's linearity constraint and semi-weightedness criterion? (can their type systems be transferred to graph grammar productions?)
- Application of the technique to other mobile calculi, like ambients?
- Comparison with previous non-interleaving semantics of the π-calculus?

The End

T H A N K S !