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# Can Actors and $\pi$-Agents Live Together?

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**Abstract**

The syntax and semantics of actors and $\pi$-agents is first defined separately, using a uniform, "unbiased" approach. New coordination primitives are the added to the union of the two calculi which allow actors and $\pi$-agents to cooperate.

## 1 Modeling Actors and Agents

The syntax and semantics of actors and $\pi$-agents are first defined separately, using a uniform, "unbiased" approach. Since we aim at modeling concurrent distributed systems, and thus we are interested in asynchronous behavior, we choose for comparison with actors an asynchronous version of the $\pi$-calculus.

In the paper, the behavior of both actors and $\pi$-agents is defined by certain logic sequents called *tiles*. A tile is a rewrite rule which describes a possible evolution of a part $s$ of the system which is matched by it. In addition, a tile also describes the evolution of the *interfaces* of $s$ with the rest of the system. Thus two parts $s$ and $s'$ sharing an interface can be rewritten only by tiles which agree on the evolution of the common interface. This restriction

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introduces a powerful notion of synchronization [3] among tiles, and also makes possible to see the synchronization of two tiles as a (larger) tile. Eventually, all the possible evolutions are obtained by the repeated composition (synchronized, or in sequence, or in parallel) of certain small *basic* tiles called *rewrite rules*.

In the case of actors and $\pi$-agents, it is convenient to take a coordination [19] point of view and to distinguish between the behavior of agents in isolation and the behavior of *coordinators*, i.e. of system components whose role is to connect agents and to control their behavior. This approach allows us to abstract from the behavior *in the small* of agents, which is presented in a state transition, syntax-independent form, and to focus on the behavior of coordinators, which are the most characteristic feature of distributed systems. Correspondingly, we distinguish between two kinds of rewrite rules: *activity* rules and *coordination* rules. An activity rule describes an evolution of a single sequential agent, and may produce some action at its interface with the rest of the system. A coordination rule describes an evolution of a coordinator, and may both require certain actions from the agents it controls, and produce actions for a coordinator operating at a higher level.

For actors and $\pi$-agents, the interfaces with the rest of the system contain the free names of the agent, or, equivalently, the acquaintances (including self) of the actor. We call both of them names. An important difference with the ordinary semantics of both calculi is that in our approach names have only a local scope. Thus if in a particular subsystem there are $n$ names, we can just denote them with $x_1, x_2, \ldots, x_n$. This choice makes the handling of names much easier, especially in the presence of bound (restricted) names and of name extrusion steps: it avoids $\alpha$-conversion, infinite branching and in general the need of making provisions for an infinite number of possible names when connecting with the external world.

In addition to names, the interfaces contain also *events*. Events are the mechanism we use for establishing concurrency control in a distributed system. Agents and messages include references to the events which generated them, and to the previous events which caused these events. For instance in the *event diagram* semantics [11,33], when a message is received, a new event is created, and pointers to it and its causes are made available to all the components spawned by the step. The *causes* of this new event are the events both the message and the receiving agent pointed to. The causal relation determines the orderings in which the events can happen: all the sequential orderings compatible with the causal relation are possible, and they correspond to the same *concurrent* computation.

In the representation of agents, actions and events, the key notion is *sharing*. In fact, the only role of a name is to specify which agents share it, and

[3] Even in an asynchronous system, synchronization is required to model the reception of messages and the extrusion of names.

similarly several events may share the same cause. Sharing is a well-studied notion from a formal point of view, in particular for the subterms shared by a term. For instance, terms can be broken into the parallel and sequential composition of term constructors and basic substitutions, modulo certain axioms. Sharing in its purest form is then represented by the basic substitution $\nabla$ from one variable to two values:

$$\nabla\colon 1 \to 2 = \{y_1 := x_1, y_2 := x_1\}.$$

However, in the algebra of terms and substitutions, sharing is not a first class component, in the sense that it can be freely removed by copying the shared subterm. In the paper, instead of terms we use *term graphs*. They are more expressive than terms, since terms graphs with a different amount of sharing among subterms are actually different. As a consequence, in term graphs, the $\nabla$ operator becomes a basic constructor.

## 2 Interoperability of Actors and Agents

In the ordinary syntax of actors and $\pi$-agents, we have three configuration operators: parallel composition, restriction and renaming. Parallel composition is very powerful, since references to the same name on both operands are automatically identified. In our approach, since names are only local, parallel composition considers all names as different and yields the union of the two subsystems without establishing any connection between them. Names are actually identified by the $\Delta$ *matching* operator, which is thus our second coordinator. The $\Delta$ operator is analogous but opposite to $\nabla$, since it merges two names, or two events, into one, rather that creating two instances of the same variable. It replaces both variable substitution $\_\ [\_\ /\ \_]$ and parallel composition $\_ \mid \_$ , which turn out, somewhat surprisingly, to have analogous meanings.

Renaming, which is of difficult interpretation in a distributed setting, becomes useless and is discarded[4]. Restriction is mantained, essentially with the same meaning.

The main difference between actor calculus and $\pi$-calculus resides, in our setting, in the different typing of names and in the different versions of $\Delta$'s and their coordination rules. The free names of a $\pi$-agent are all typed $c$ (for *channel*) and thus there is only one $\Delta$, which we call $\Delta^c$. Given an actor, its name is typed $a$, while its acquaintances are typed $r$ (for *reference*). Also, all the acquaintances of a message, including its addressee, are typed $r$. There are only two $\Delta$'s: $\Delta^r$ accepting two references and yielding a reference, and $\Delta^a$ accepting an actor and a reference and yielding an actor. There is no $\Delta$ accepting two actors: this restriction fully enforces the uniqueness of actor

[4] A weak notion of renaming, *permutations*, is used. They correspond exactly to substitutions of the form $\rho : 2 \to 2 = \{y_1 := x_2, y_2 := x_1\}$. However, they just describe a “wire twisting”, they have no coordinating role, and no rewrite rule matches a substitution.

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|---|---|---|---|---|---|
| *Coordinator* | $\Delta^a$ | $\Delta^r$ | $\Delta^c$ | $\nu^{ac}$ | $\nu^{cr}$ |
| *Type* | $ar \to a$ | $rr \to r$ | $cc \to c$ | $ar \to \epsilon$ | $rc \to \epsilon$ |
| *Permeability to* : | | | | | |
| *output* | $n$ | $y$ | $y$ | $n$ | $n$ |
| *input* | $y$ | $-$ | $y$ | $n$ | $n$ |
| *synchronization* | $y$ | $-$ | $y$ | $y$ | $y$ |

Table 1
Permeability of coordinators for name sharing.

names.

The behaviour of a $\Delta$ is determined by its permeability to input/output actions and to synchronization. It is easy to see that $\Delta^c$ must be permeable to everything, while $\Delta^r$ cannot be presented with any input action, and thus cannot synchronize either. The most interesting case is $\Delta^a$, which is permeable to input and synchronization, but impermeable to output. The rationale under this restriction is that a message cannot exit a system if its addressee is inside the system. The permeability of the various $\Delta$ coordinators is summarized in Table 1.

Actors and $\pi$-agents are connected by coordinators that match channels and actor names or references and restrict visibility of the matched pair. $\nu^{ac}$ accepts an actor name and a channel and yields nothing. $\nu^{ac}$ allows a message to be sent from a $\pi$-agent to the named actor, by sending the message on the matching channel. Symmetrically, $\nu^{cr}$ accepts a channel and an actor reference and yields nothing. $\nu^{cr}$ allows a message to be sent from an actor to a $\pi$-agent receiving on the named channel, by sending the message to the matching actor reference. The hiding aspect of the actor-$\pi$ coordinators enforces a clean separation between the two worlds, preserving the local behavior of individual agents and making the interaction invisible to the outside world. To enforce this separation, names communicated in messages are required to be newly created and the coordination rule matches and hides them appropriately. The permeability of the actor-$\pi$ coordinators is also summarized in Table 1.

Both calculi are equipped with mobility, thus the amount of name sharing established at configuration time can be modified, actually only increased, at run time. In our setting, new $\Delta$'s are created only by input instantiation, by a synchronization where the output action is extruding (similar to a *Close* step for $\pi$-calculus) , or by an activity tile describing the forking of some actor or some $\pi$-agent. In these cases only homogeneous subsystems, either both actors or both $\pi$-agents, are connected. Synchronization via an actor-$\pi$ coordination rule creates a new coordinator to match (and hide) the actor and $\pi$ versions of the communicated name.

For full composability we have required that agent behavior can not test for equality of names (no matching construct in process algebra terms). This restriction is also made for the actor language studied in [4]. The restriction was removed in the langauge studied in [23] in order to implement synchronous message passing (remote procedure call) in terms of asynchronous communication. An alternative might be to allow actors to receive on more than one port.

We conjecture that the partial order on events that is the observation of a tile-based computation for actors gives the same semantics to actor components as the interaction diagram semantics of [33] for the case of actor behaviors without matching. The event-based semantics for the $\pi$-calculus is new, and seems like a natural framework both for comparing calculi for concurrent/distributed computation and for semantic interoperation of heterogeneous systems.

## 3 Related Work

The actor model [20,6,1,2] is one of the first and best known models for concurrent distributed systems and consists of independent computational agents which interact solely via asynchronous message passing. Semantic foundations for actor computation have been given in [4,31–33]. An approach to specifying and implementing mechanisms for coordination of actors based on reflection is described in [3].

The $\pi$-calculus [28] is one of the best studied examples of *mobile* process calculi, namely calculi in which the communication topology among processes can dynamically evolve when computation progresses. The asynchronous version of the $\pi$-calculus has been introduced in [8,21] and studied in [5].

The tile model, introduced in [16], is described in general terms in [17,18]. Tiles are much like SOS inference rules [30], but they can be composed horizontally, vertically and in parallel to build larger proof steps. Tile systems generalize Kim Larsen and Liu Xinxin *context systems* [22] since they allow for more general rule formats. The tile model also extends rewriting logic [24–26] (in the nonconditional case), since it takes into account rewritings with side effects and rewriting synchronization. Tile systems can be seen as double categories [13] and tiles themselves as double cells. They can be equipped with observational equivalences and congruences.

The combined used of tiles and term graphs [7,12] for modeling asynchronous $\pi$-calculus and CCS with locations [9] has been described in [14,15]. Also coordination models equipped with flexible synchronization primitives are presented in [29,10]. Ongoing work [27] aims at translating the tile model into rewriting logic, in order to take advantage of important features of rewriting logic, like execution strategies and reflective logics, and to employ its existing implementations.

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