Mobility in Computer Science and in Membrane Systems

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Mathematical models are useful in different fields to provide a deeper and more insightful understanding of systems. We refer here to the formal description of mobility in computer science, and in particular in membrane computing.

The first formalism in computer science able to describe mobility is the *pi*-calculus [9]. It was followed by ambient calculus [5]. A biologically-inspired version of ambient calculus is given by bioambients [11]. Several brane calculi [4] and mobile membranes [8] are other formalisms with strong connections to biology.

The process calculi (or process algebras) represent a family of related approaches for modelling concurrent systems. Process calculi provide a tool for the high-level description of interactions, communications, and synchronizations between a collection of independent agents or processes. They also provide algebraic laws that allow process descriptions to be manipulated and analyzed, and permit formal reasoning about equivalences between processes using various bisimulations. Some examples include the π-calculus and ambient calculus.

The π-calculus, a member of the process calculi family, was developed as a calculus of communicating systems that allows the representation of concurrent computations whose configuration may change during the computation [9]. In contrast to λ-calculus which represents computations through functions, the π-calculus uses the process as an abstraction of an independent thread of control. A channel or link is an abstraction of the communication link between processes; processes interact by sending information through these channels. When expressing mobility, we should mention what entities move and in what space they move. There are several possibilities: processes moving in a physical space of computing locations, processes moving in a virtual space of linked processes, links moving in a virtual space of linked processes, etc. The π-calculus is a formalism where links are the moving entities, and they move in a virtual space of linked processes. The network of web pages is a good example for this approach. However this option is able to express moving processes both in a physical space of computing locations and in a virtual space of linked processes [9].

The evolution of a process is described in π-calculus by a relation over processes; this relation contains those transitions which can be inferred from a set of rules. The π-calculus mobility is coming from its scoping of names and extrusion of names from their scopes. Explicit locations and a new primitive $goto\ l.P$ enabling migration between domains is introduced in distributed π-calculus [7]. A timed distributed π-calculus is introduced in [6].

Regev and Shapiro use π-calculus in describing the biochemical systems by abstracting "cell as computation" and using processes as abstractions of molecules in biomolecular systems [12]. The authors use such an abstraction for representation, simulation, and analysis of metabolic pathways.

Another formalism able to express mobility is ambient calculus, where ambients change their location by consuming certain capabilities. This formalism is well suited for expressing such issues. A description of mobile ambients can be found in [5]. Bioambients are introduced as abstraction for biological compartments [11]. Membrane systems are also inspired by the living cells compartments. Membrane systems contain multisets of *objects*, *evolution rules* and possibly other membranes [10]. Brane calculus [4] deals with membranes representing the sites of activity, and the computation happens on the membrane surface. The operations of the two basic brane calculi, namely *pino, exo, phago* for the PEP fragment and *mate, drip, bud* for the MBD fragment of brane calculus, are directly inspired by the biologic processes as endocytosis, exocytosis and mitosis. Mobile membranes represents a formalism which describes the movement of membranes inside a spatial structure by applying specific endocytosis and exocytosis rules [8]. Several systems of mobile membranes are studied in [2], and their computational universality are proved by using a small number of membranes [3]. We also prove that mobile membranes has at least the same expressive power as ambient calculus [1], and encode the PEP fragment of brane calculus by systems of mutual mobile membranes with objects on surface.

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