BIOMICS – Biological and Mathematical Basis of Interaction Computing: Project Status at Half-Term

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Abstract

The concept of Interaction Computing (IC) was inspired by the observation that cell metabolic/regulatory systems are able to self-organize and/or construct order dynamically, through random interactions between their components and based on a wide range of possible inputs. Thus, BIOMICS is investigating how the dynamical characteristics of the cellular pathways studied in systems biology relate, mathematically, to the computational characteristics of automata derived from them. The fundamental hypothesis of BIOMICS is that the former are best understood through the symmetry properties of their differential models, that the algebraic structure of the automata can help us understand and optimize the latter, and that therefore the relationship between the two is fundamentally algebraic. The mathematical structure thus uncovered feeds into two different and complementary directions. On the one hand, it informs the automata theory formalisms for IC; on the other hand, it will be mapped through category theory to the coalgebraic logic foundations of a specification language. Whereas the automata theory research focuses on the structural properties of self-organizing systems, the BIOMICS specification language will focus instead on the specification of self-organizing behaviour. In this paper we report on progress towards the development of the formal tools and frameworks from both points of view of the behaviour-realization dichotomy. We discuss the architectural requirements of an environment which, through interactions, is capable of generating useful software systems that match the biological structure template – and are therefore themselves based on interactions. Progress towards a mathematical model of such a computing environment based on interactions is discussed in terms of several specific activities.

The first thread concerns the symmetry properties or Lie group structure of systems of ordinary differential equations derived from biochemical reactions. We are investigating the possibility to formalize the dynamical stability exhibited by some non-linear systems in terms of corresponding properties of their Lie group structure. In a parallel effort, we are investigating whether the Lie algebras of any such dynamical systems are finite-dimensional and semisimple, and could serve as the starting point in the Chevalley construction of the finite simple non-abelian groups that are found in the automorphism groups or in the Krohn-Rhodes decomposition of the corresponding finite-state automata. The implication of structure-preserving mappings between different mathematical realms is being rigorously studied in a third thread which is concerned with developing a category theory framework to relate biological, automata, and coalgebraic logic representations of analogous structures. We will report in particular on progress made in the characterization and study of adjunctions between structure and behaviour in the context of interaction. From a more applied point of view, in a fourth thread we are also analysing a range of computer science systems (e.g. Petri nets) and their corresponding finite-state automata. The objective here is to relate the algebraic structure of the automata as determined by the Krohn-Rhodes or holonomy decomposition to their algorithmic properties. This is a central part of the effort to develop a mathematical model for IC itself.