A hybrid-logic approach to dynamic networks of interactions

Ionuţ Ţuţu and José Luiz Fiadeiro

Department of Computer Science, Royal Holloway University of London
ittutu@gmail.com, jose.fiadeiro@rhul.ac.uk

The advent of the Web and of new distributed frameworks such as service-oriented and cloud-computing architectures has led to a paradigm shift from human-based engineering of software systems to reconfigurable systems that are endowed – by middleware and network infrastructures – with the capability of organising themselves [5]. As distributed applications execute, they can trigger changes in the topology of the networks that support them: new links, nodes, or even entire subnetworks can be created at run time, often without human intervention, in response to the need for external resources or services [9,6].

Over the past few years, several research initiatives have proposed formal-methods approaches that address different aspects of the new generation of dynamic systems that are now operating in cyberspace. One of the most prominent is the mathematical model for the specification and verification of reconfigurable systems based on hybrid(ized) logics [1,2,11]. In their most basic form, these are logics obtained by enriching ordinary modal logics with nominals – symbols that name individual states (possible worlds) in Kripke models – and a dedicated satisfaction operator @ that enables a change of perspective from the current state to one that is named. The development of hybrid logics originated in Arthur Prior's work in the 1960s [14], and recently has been the subject of a renewed interest from the formal specification and verification community [13,3,8,7], part of which is by virtue of the use of hybrid logics in reasoning about reconfigurations.

In a nutshell, the hybrid-logic approach builds on the intuitive idea that system configurations (and the functionalities associated with them) can be regarded as local models of a Kripke structure; moreover, they can change simply by switching from one mode of operation to another via an accessibility relation. The key advancement here lies in understanding that the features characteristic to basic hybrid logic can be developed, through a process known as hybridization [12], on top of an arbitrary logical system, which is used for expressing configuration-specific requirements. This means that, depending on the base logical system, configurations can be captured, for example, as algebras, relational structures or, when the hybridization process is iterated, even as Kripke models.

In this work, we focus on the use of hybrid logics for specifying and reasoning about those reconfigurable systems whose configurations, or local models, are given by networks of interacting actors. These should be understood in the wider sense of Latour's actor-network theory [10]: actors are cyberphisical entities that have shared agency, from people, to objects, to locations; they interact through so-called channels, which account, for instance, of observations that an actor may make of another, of control that an actor may exert on another, or of movement of an actor (e.g. a person) inside another (e.g. a location).

The ordinary hybridization process outlined above yields logical systems that are suitable for dealing with the structural aspects of actor networks. They can be naturally used, for example, to give faithful descriptions of the shapes of networks, of the (states of the) actors involved, or of the channels through which interactions can take place. Yet, in contrast to the general adequacy of hybrid logics to cope with reconfigurations, the challenge lies precisely in capturing the way networks evolve over time. This is because, for such dynamic networks of interactions, the higher-level reconfigurations of networks and the lower-level interactions between actors are closely intertwined: for instance, reconfigurations are always triggered by interactions, and they may result in new opportunities for interaction. In other words, dynamic networks of interactions do not exhibit the full orthogonality that the hybridization process requires between the details of the underlying logical system and the hybrid features to be developed. We therefore propose a new kind of hybridization that takes as input a hybrid logic, which can be used in specifying network states, and produces another logic with hybrid features, which can be used in specifying network reconfigurations. But the resulting logic is not hybrid: even though the accessibility relations model reconfigurations, they do not link networks directly; instead, they define inter-network connections between different actor states. We discuss what are the implications from a specification-theoretic perspective of this important distinction, and show that, much like ordinary hybrid logics [4], the ones that we propose here can also be encoded into first-order logic, assuming that the base logical system admits such an encoding. This provides preliminary proof-theoretic support for the hybrid specifications of dynamic networks of interactions.

References

1. Blackburn, P.: Representation, reasoning, and relational structures: a hybrid logic manifesto. Logic Journal of the IGPL 8(3), 339–365 (2000)
2. Braüner, T.: Hybrid logic and its Proof-Theory, Applied Logic Series, vol. 37. Springer (2011)
3. Diaconescu, R.: Quasi-varieties and initial semantics for hybridized institutions. Journal of Logic and Computation 26(3), 855–891 (2016)
4. Diaconescu, R., Madeira, A.: Encoding hybridized institutions into first-order logic. Mathematical Structures in Computer Science 26(5), 745–788 (2016)
5. Fiadeiro, J.L.: The many faces of complexity in software design. In: Hinchey, M., Coyle, L. (eds.) Conquering Complexity, pp. 3–47. Springer (2012)
6. Fiadeiro, J.L., Lopes, A., Bocchi, L.: An abstract model of service discovery and binding. Formal Aspects of Computing 23(4), 433–463 (2011)
7. Găină, D.: Birkhoff style calculi for hybrid logics. Formal Aspects of Computing pp. 1–28 (in press)
8. Găină, D.: Foundations of logic programming in hybrid logics with user-defined sharing. Theoretical Computer Science (in press)
9. Kon, F., Costa, F., Blair, G., Campbell, R.H.: The case for reflective middleware. Communications of the ACM 45(6), 33–38 (2002)

10. Latour, B.: Reassembling the Social: An Introduction to Actor-Network Theory. Oxford University Press (2005)
11. Madeira, A.: Foundations and techniques for software reconfigurability. PhD thesis, MAP-i (Minho, Aveiro, Porto) (2013)
12. Martins, M.A., Madeira, A., Diaconescu, R., Barbosa, L.S.: Hybridization of institutions. In: Corradini, A., Klin, B., Cîrstea, C. (eds.) Algebra and Coalgebra in Computer Science. Lecture Notes in Computer Science, vol. 6859, pp. 283–297. Springer (2011)
13. Neves, R., Madeira, A., Martins, M.A., Barbosa, L.S.: Proof theory for hybrid(ised) logics. Science of Computer Programming 126, 73–93 (2016)
14. Prior, A.: Past, Present and Future. Oxford University Press (1967)