PhD Project Proposal
Categorical Semantics and Verification of Reactive Programs

Elena Di Lavore

April 17, 2026

This PhD project will aim for a categorical semantics and program logics of reactive programs. Categorical structures are well-suited as semantics of programs with generic effects: they allow precise tailoring of the axioms to specific classes of programs, and provide the necessary abstraction and compositionality that ease human understanding.

Reactive programs take infinite streams of inputs and produce infinite streams of outputs [1]. Such programs express models or specifications of machines that run indefinitely: machines that receive inputs from the environment and produce outputs accordingly. The outputs of these machines are not assumed to depend functionally on the inputs, so that programs may express probabilistic models, like partially observable Markov decision processes [6], or allow other kinds of program effects, like nondeterminism and access to a global state.

The projects below address some concrete questions.

Categorical structure of reactive programs. Effectful streams give categorical semantics to effectful reactive programs, but only consider their data flow [3, 5]. This project would aim at increasing the expressivity of the reactive programs that we can give semantics to. The categorical structure should be able to express the control flow of programs to give semantics to program statements like if-else choices and while loops. Semantics of higher-order computations would also require additional categorical structure.

Program logics for reactive programs. Categorical semantics informs the development of appropriate program logics: for imperative programs, the rules of Hoare-like logics derive from the categorical structure of their denotational semantics [2]. This project would aim at finding an appropriate categorical structure, building on the previous project, that derives rules for verification of reactive programs. In particular, the internal logic of predicates that is determined by the categorical structure should be able to express temporal properties of programs.

Quantitative program logics and approximate traces via metric enrichment. Quantitative reasoning is more appropriate when dealing with probabilistic programs: their behaviour may not be exactly the same, but it may be the same with very high probability [4]. This project would aim at adding quantitative aspects to both the semantics and the program logic of reactive programs. A technique that may help achieving this is metric enrichment.

References

[1] Engineer Bainomugisha, Andoni Lombide Carreton, Tom van Cutsem, Stijn Mostinckx, and Wolfgang de Meuter. A survey on reactive programming. *ACM Computing Surveys*, 45(4), August 2013. doi:10.1145/2501654.2501666.

[2] Filippo Bonchi, Alessandro Di Giorgio, and Elena Di Lavore. A diagrammatic algebra for program logics. In Parosh Aziz Abdulla and Delia Kesner, editors, *Foundations of Software Science and Computation Structures*, pages 308–330. Springer Nature Switzerland, 2025. doi:10.1007/978-3-031-90897-2_15.

[3] Filippo Bonchi, Elena Di Lavore, and Mario Román. Effectful mealy machines: Bisimulation and trace. In *Proceedings of the 40th Annual ACM/IEEE Symposium on Logic in Computer Science (LICS 2025)*, pages 541–554, 2025. arXiv:2410.10627v2, doi:10.1109/LICS65433.2025.00047.

[4] Josée Desharnais and Ana Sokolova. ϵ-Distance via Lévy-Prokhorov Lifting. In Stefano Guerrini and Barbara König, editors, *34th EACSL Annual Conference on Computer Science Logic (CSL 2026)*, volume 363 of *Leibniz International Proceedings in Informatics (LIPIcs)*, pages 26:1–26:24, Dagstuhl, Germany, 2026. Schloss Dagstuhl – Leibniz-Zentrum für Informatik. URL: https://drops.dagstuhl.de/entities/document/10.4230/LIPIcs.CSL.2026.26, doi:10.4230/LIPIcs.CSL.2026.26.

[5] Elena Di Lavore, Giovanni de Felice, and Mario Román. Monoidal Streams for Dataflow Programming. In *Proceedings of the 37th Annual ACM/IEEE Symposium on Logic in Computer Science (LICS 2022)*, pages 1–14, 2022. arXiv:2202.02061, doi:10.1145/3531130.3533365.

[6] Joost-Pieter Katoen. The probabilistic model checking landscape. In *Proceedings of the 31st Annual ACM/IEEE Symposium on Logic in Computer Science (LICS 2016)*, page 31–45, New York, NY, USA, 2016. Association for Computing Machinery. doi:10.1145/2933575.2934574.