PhD thesis proposal

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Invariant sets for control and monitoring of systems in dynamic environments

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Context:

Cyber-physical systems (CPSs) [1] consist of physical systems augmented with computation and communication infrastructure making it possible to design highly dynamic systems able to perform efficiently under high uncertainty. CPSs are often deployed at large scale, which makes the design of such system a real challenge in modern engineering. Examples of large-scale CPS are modern electrical or transportation networks that integrate many heterogeneous components.

Contract theory [2] is a promising framework for rigorous component-based design of highly dynamic distributed systems. Formally, a contract consists of pairs of assumptions and guarantees which are described in some mathematical language. The guarantee describes the task that the component must fulfill when its environment (made of other components and of the external environment) satisfies the associated assumption. Hence, assume-guarantee contracts make it possible to design components that can adapt under various working conditions, as well as to define desired interactions for agents even of different nature. Moreover, compositional reasoning makes it possible to prove properties of large scale systems based on the contracts satisfied by their components.

Some recent works have explored contract theory from a control theoretical perspective and allowed contract-based compositional reasoning in dynamical systems. In this framework, contract theory is versatile enough to consider various techniques to achieve classical control objectives. In [3], a new general class of assume-guarantee contract is introduced. In this framework, contract satisfaction can be characterized in terms of invariant sets of an auxiliary dynamical system evolving in an extended state space. This makes it possible to design efficient computational approaches for contract-based system design. The topic of this thesis aligns with this research line.

Research program:

In this doctoral work, we will build on the preliminary results of [3] to design new methodologies based on set invariance for contract-based system design. We aim at tackling the following problems:

- **Verification**: given a contract and a component model, verify that the contract is satisfied. We will develop tools based on invariant sets which will allow us to leverage existing techniques such as set theoretic methods [4], abstraction-based and data-driven approaches.
- **Controller synthesis**: given a contract and a component model, synthesize a controller that fulfills the contract. We are particularly interested in designing model predictive control approaches that provably enforce assume-guarantee contracts even beyond their prediction horizon.
- **Monitoring algorithms**: given a contract and a component model, design a monitor that raises an alarm when a contract is violated. We aim at designing predictive algorithms able to raise alarms even before the contract is violated.

The proposed methodologies will be evaluated on use cases of industrial interest from the electrical transmission grid, such as congestion management in the context of the inclusion of renewable energy. The PhD thesis will be attached to the activities of the RTE chair.

References:

[1] P. Derler, E. A. Lee, and A. Sangiovanni Vincentelli, “Modeling cyber–physical systems,” Proceedings of the IEEE, vol. 100, no. 1, pp. 13–28, 2012.

[2] A. Benveniste, B. Caillaud, D. Nickovic, R. Passerone, J.-B. Raclet, P. Reinkemeier, A. Sangiovanni-Vincentelli, W. Damm, T. Henzinger, and K. Larsen, “Contracts for system design,” Foundations and Trends in Electronic Design Automation, vol. 12, no. 2-3, pp. 124–400, 2018.

[3] A. Girard, A. Iovine and S. Benberkane, "Invariant Sets for Assume-Guarantee Contracts," *2022 IEEE 61st Conference on Decision and Control (CDC)*, Cancun, Mexico, 2022, pp. 2190-2195, https://hal.science/hal-03767014/document

[4] F. Blanchini and S. Miani, Set-Theoretic Methods in Control. Systems & Control: Foundations & Applications, Birkhauser Boston, 2007.