A runtime adaptation tool for cyber-physical systems

Guillaume Roumage, Selma Azaiez, Stephane Louise

A Runtime Adaptation Tool for Cyber-Physical Systems modeled by a dataflow MoCC

Guillaume Roumage[1], Selma Azaiez[1], Stéphane Louise[1]

[1] *Université Paris-Saclay, CEA, List* F-91120, Palaiseau, France

{guillaume.roumage, selma.azaiez, stephane.louise}@cea.fr

In this PhD work, we want to provide a fault mitigation capability at run-time to a Cyber-Physical System (CPS) whose design and implementation are based on a Dataflow Model of Computation and Communication (MoCC).

Context, Motivations & Objectives

Deterministic Dataflow MoCC-based CPS design

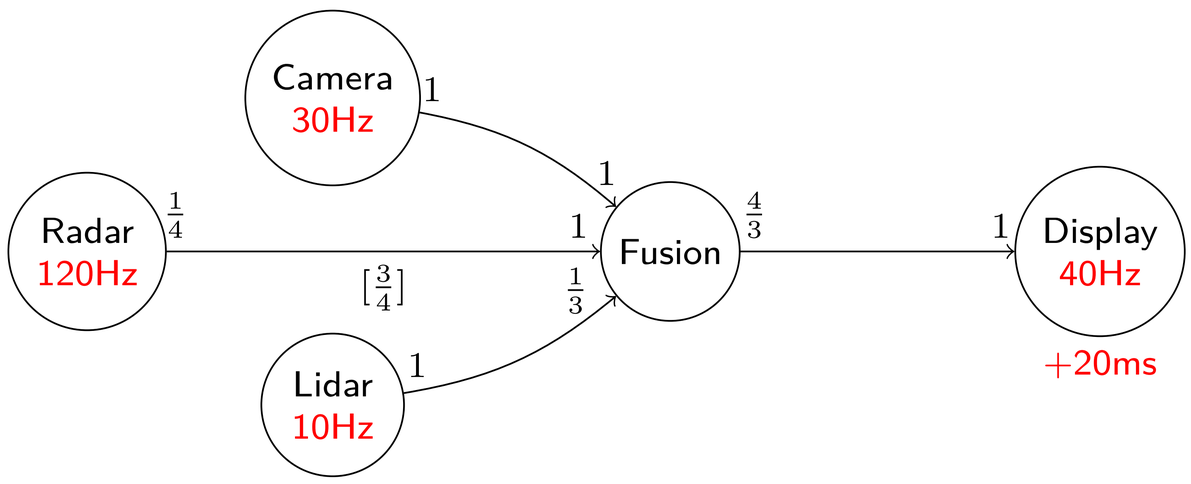
- Deterministic Dataflow Models of Computation and Communication (MoCC) are well fitted to model and form the base of design and implementations of distributed Cyber-Physical Systems (CPS).
- The most popular ones are the Synchronous DataFlow (SDF, [1]) and the Cyclo-Static DataFlow (CSDF, [2]).
- The Dataflow MoCC PolyGraph ([3]) is one of the most expressive of the deterministic dataflow:
  - Additional frequency and phase constraints on **actors** (i.e. distributed tasks).
  - Rational production and consumption rate instead of integers (for clock domain synchronizations).

Runtime Verification

- Runtime verification tools evaluate the system's behavior at run-time.
- The monitoring of global properties has serious drawbacks.
- The system in [4] re-constructs the global trace from local ones.
- Decentralized monitoring of Linear Temporal Logic (LTL) properties is explored [6].

PolyGraph

- Below is the PolyGraph modeling of a data fusion system for ADAS.



The actors with a frequency must fire at that frequency. The first fire can be delayed with a phase, like the Display actor. The rates on the channels represent token production/consumption between the actors at both endpoints. The values between brackets are the initials tokens.

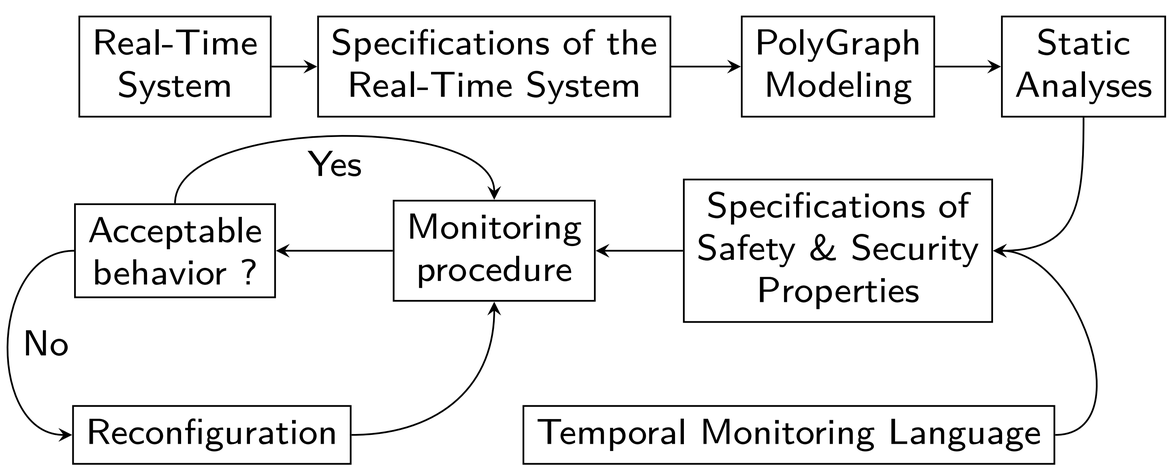
- Dynamic PolyGraph ([5]) enhances PolyGraph ([3]) with a runtime reconfiguration mechanism.

Targeted Contributions

- A Temporal Monitoring Language tailored for a dataflow CPS design.
- A runtime verification tool whose monitoring specifications are derived from PolyGraph's static analyses.
- The validation of global properties from local monitoring.
- The rise of an early alert and a reconfiguration process that mitigates run-time faults.

Runtime Adaptation Tool

Targeted Tool Overview



- The system provides a fault mitigation capability at run-time.

Use Cases

The Ingenuity Mars Helicopter: Position, velocity, and altitude are estimated using an Inertial Measurement Unit, and navigation adjustments are made using a camera.

An Advanced Driver Assistance System (ADAS): An odometer measures the current speed, a lidar perceives nearby obstacles, and a stereo camera films the road ahead.

Perspectives

Static analyses

- Formalize the Temporal Monitoring Language to specify the actors' (task) execution window, latency, and throughput.
- Define a PolyGraph's mode and the triggering mechanisms.

Implementation & Evaluation

- Implement run-time verification & reconfiguration procedures, and quantify the monitor's overhead.
- Evaluation with faults injection and ensure the system detects them.

[1] Lee, E., Messerschmitt, D. (1987). Synchronous data flow. Proceedings of the IEEE, 75(9), 1235–1245.
[2] Bilsen, G., Engels, M., Lauwereins, R., Peperstraete, J. (1996). Cyclo-static dataflow. IEEE Transactions on Signal Processing, 44(2), 397–408.
[3] Dubrulle, P., Gaston, C., Kosmatov, N., Lapitre, A., Louise, S. (2019). A Data Flow Model with Frequency Arithmetic. Fundamental Approaches to Software Engineering (Vol. 11424, pp. 369–385).
[4] Falcone, Y., Nazarpour, H., Bensalem, S., Bozga, M. (2021). Monitoring Distributed Component-Based Systems. International Conference on Formal Aspects of Component Software, 153–173.
[5] Dubrulle, P., Gaston, C., Kosmatov, N., Lapitre, A. (2019). Dynamic Reconfigurations in Frequency Constrained Data Flow. Integrated Formal Methods.
[6] Bauer, A., Falcone, Y. (2012). Decentralised LTL Monitoring. International Symposium on Formal Methods.