Automatic Verification of Dynamic Constraints in LTI Control Systems Through Model Transformations

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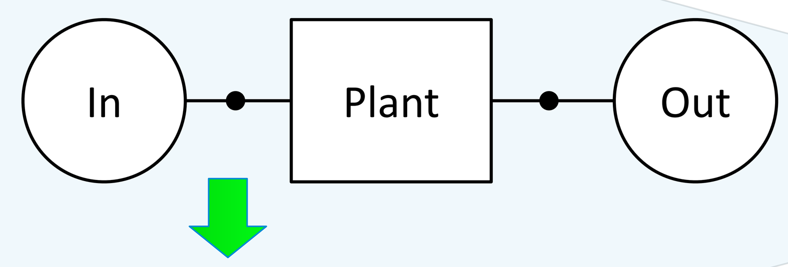
Supported Under NSF CNS-1253334

Abstract: Using modeling tools it is possible to construct Domain Specific Modeling Languages (DSMLs) for cyber-physical systems. In developing these languages a metamodeler can specify structural constraints that prevent modelers from constructing invalid systems. However, these structural constraints do not prevent modelers from constructing systems that do not meet design requirements such as preventing roll-overs in autonomous ground vehicles or collisions between unmanned aerial vehicles. These requirements are referred to as dynamic constraints. In control systems dynamic constraints can be considered any requirement on the system that necessitates mathematical analysis (in second order systems: percent overshoot, rise time, settling time, etc.). The research proposed herein will lay the foundation for the process of incorporating dynamic constraints into the construction of DSMLs by exploring the process as applied to dynamic constraints in linear time-invariant (LTI) control systems.

Motivation

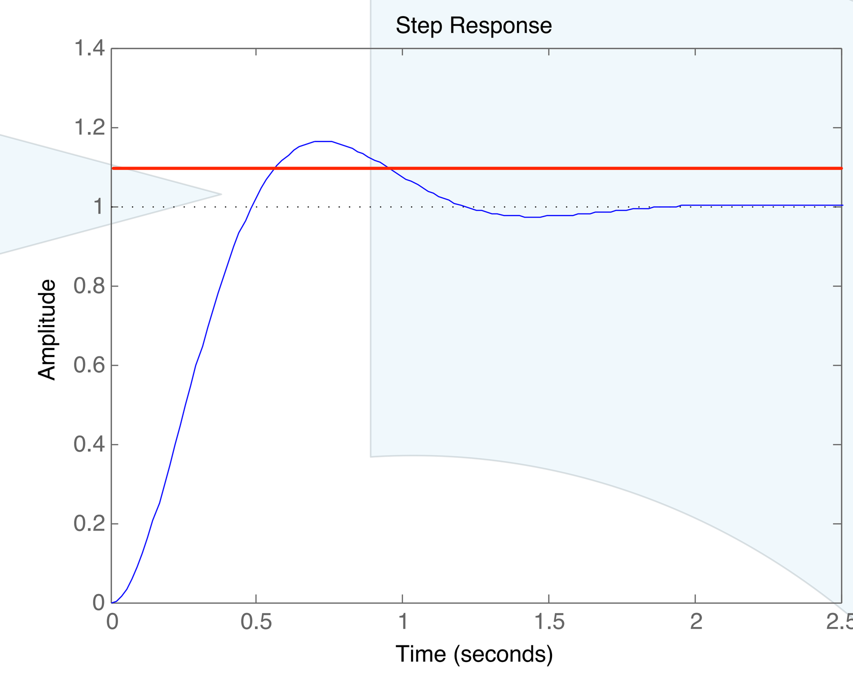
No one person is an expert in every little detail of CPSs. For this reason, CPS development does not scale well. For every additional subsection of CPSs that a project must cover, more experts have to be brought in or the quality of the project will suffer. This project proposes a solution where some portions of CPS projects that are currently handled by humans can be delegated to system design and automated. **Specifically, this research proposes to lay the groundwork for this concept by automatically verifying the dynamic constraints of LTI systems through model transformations.**

Basic Example

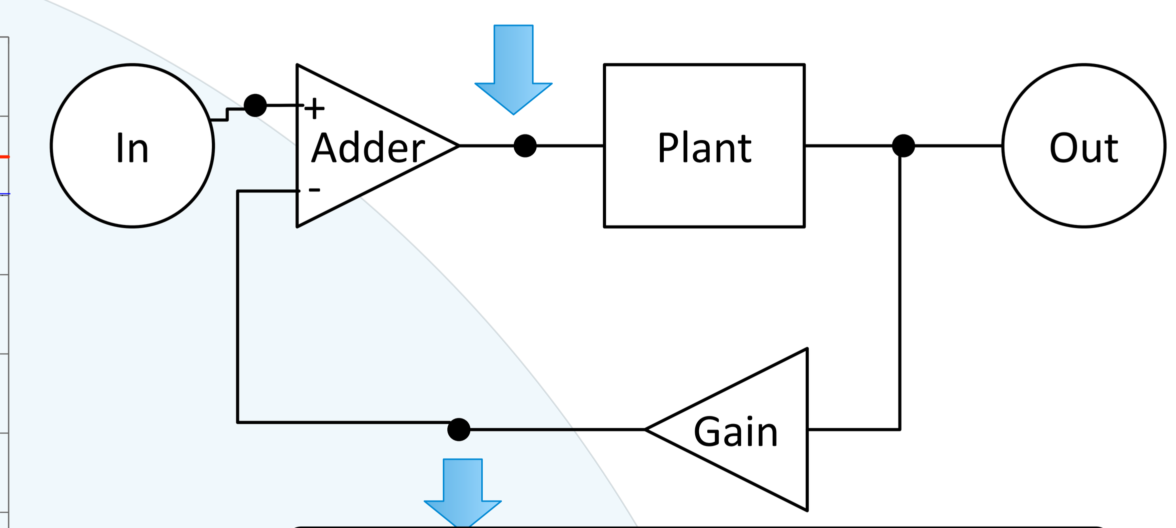


This example illustrates how a simple LTI system might be constructed.

Structurally the example is sound, but when it is analyzed a problem is found with the overshoot.



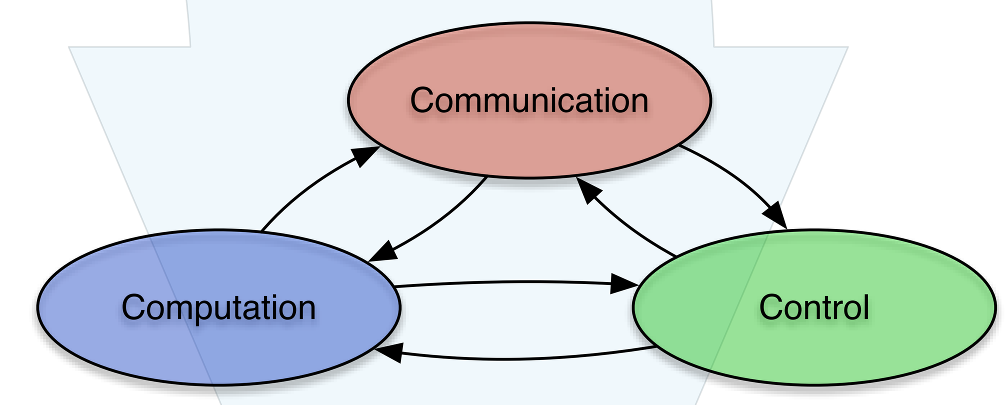
A control engineer understands how to fix this simple issue.

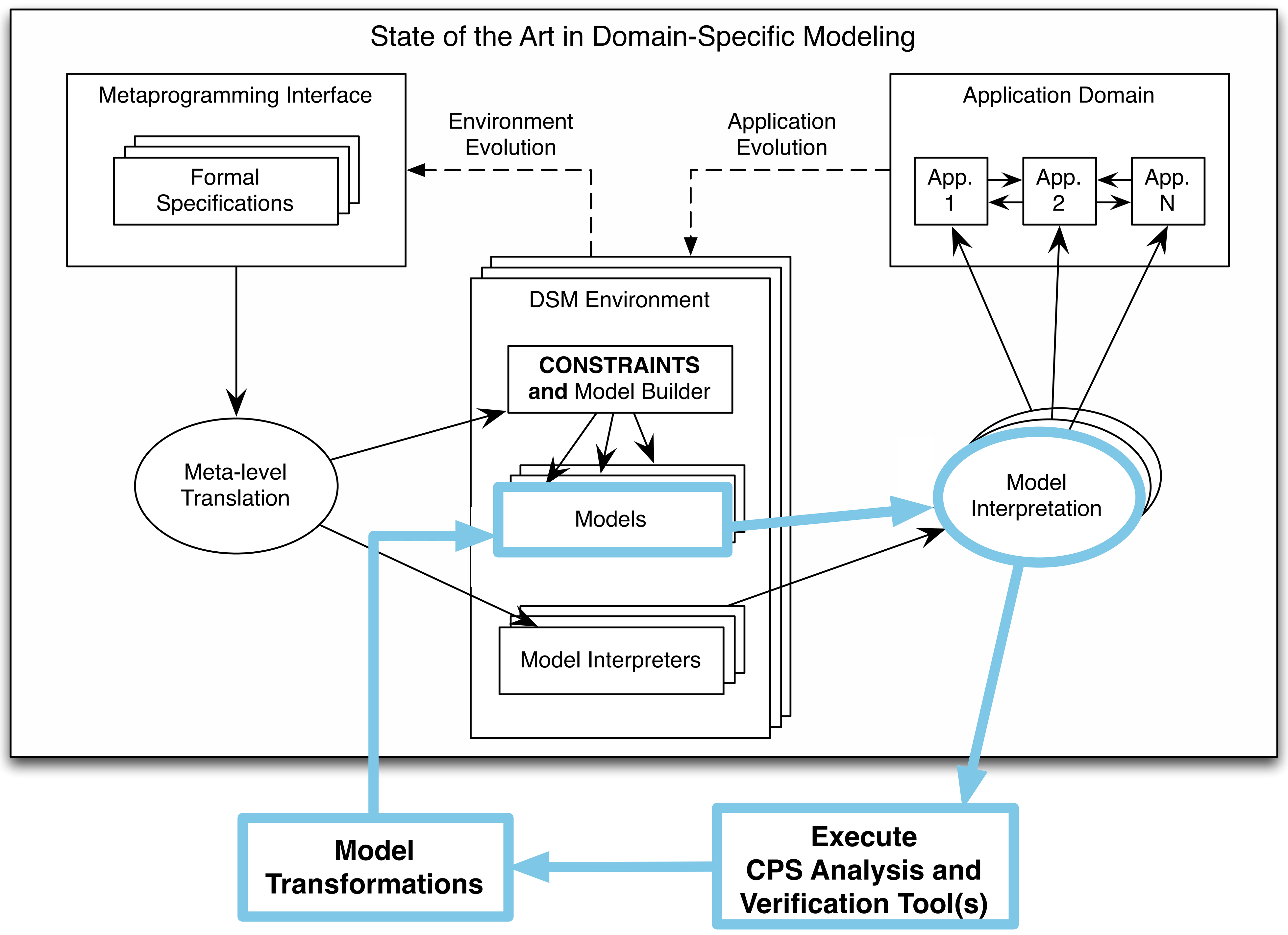


But what about non-control engineers?

Delegating Verification

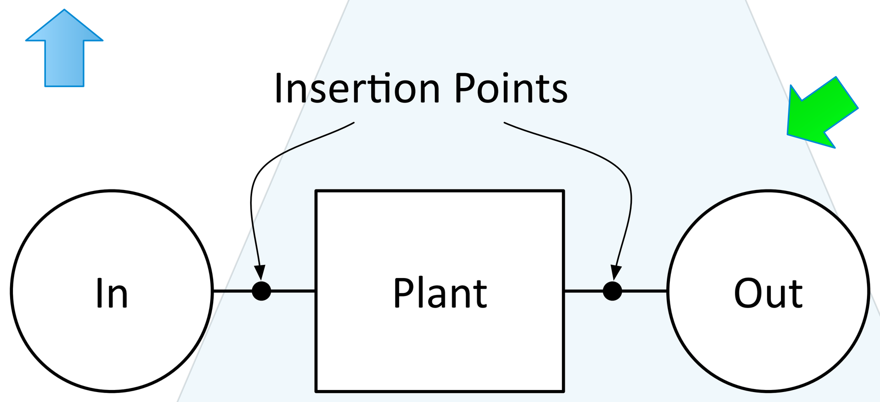
We can build a system that can verify dynamic constraints in other systems and modify them to fix any violations. This would alleviate the need to hire experts in all three major areas of CPS.





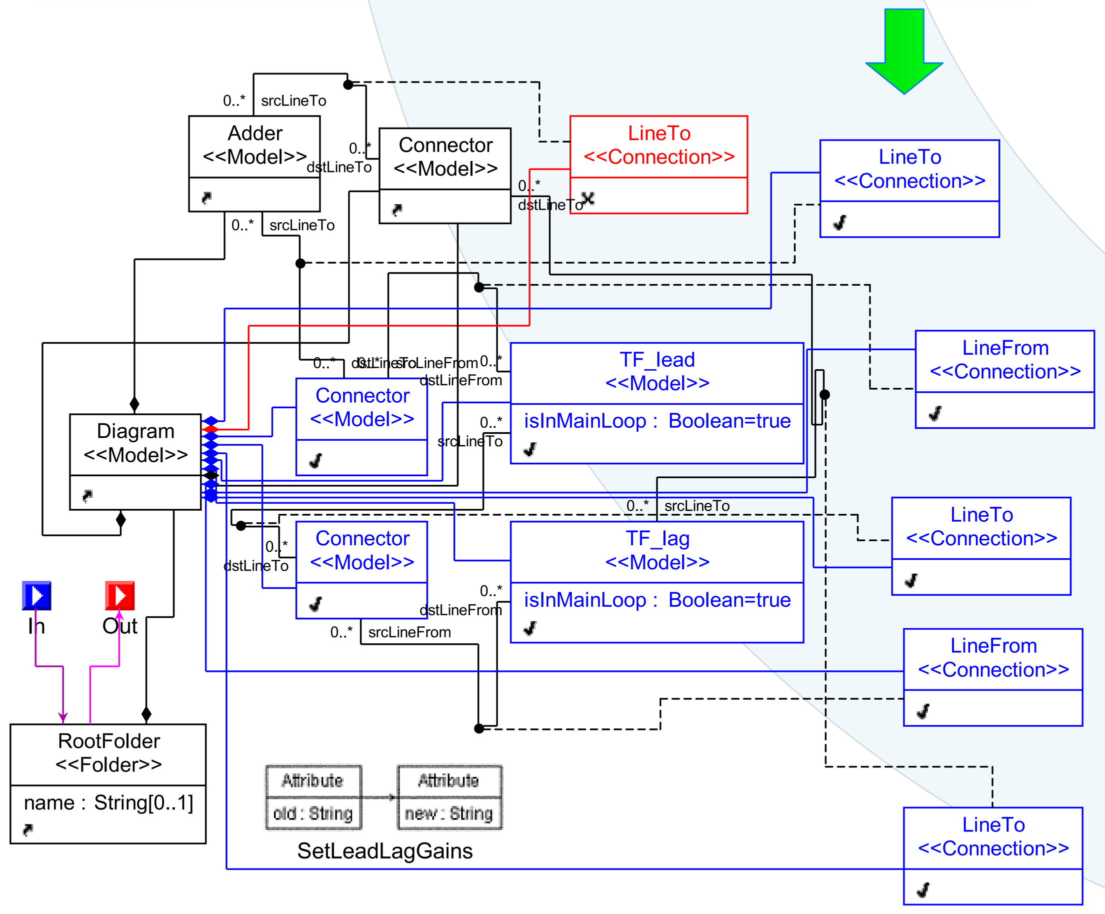
Closing the Loop

The final milestone is to close the loop. This means integrating the dynamic constraints and model transformation into a language for building LTI systems. More importantly, this means laying the ground work for expanding the state of the art in model based development to include transforming original models into verifiable models automatically.

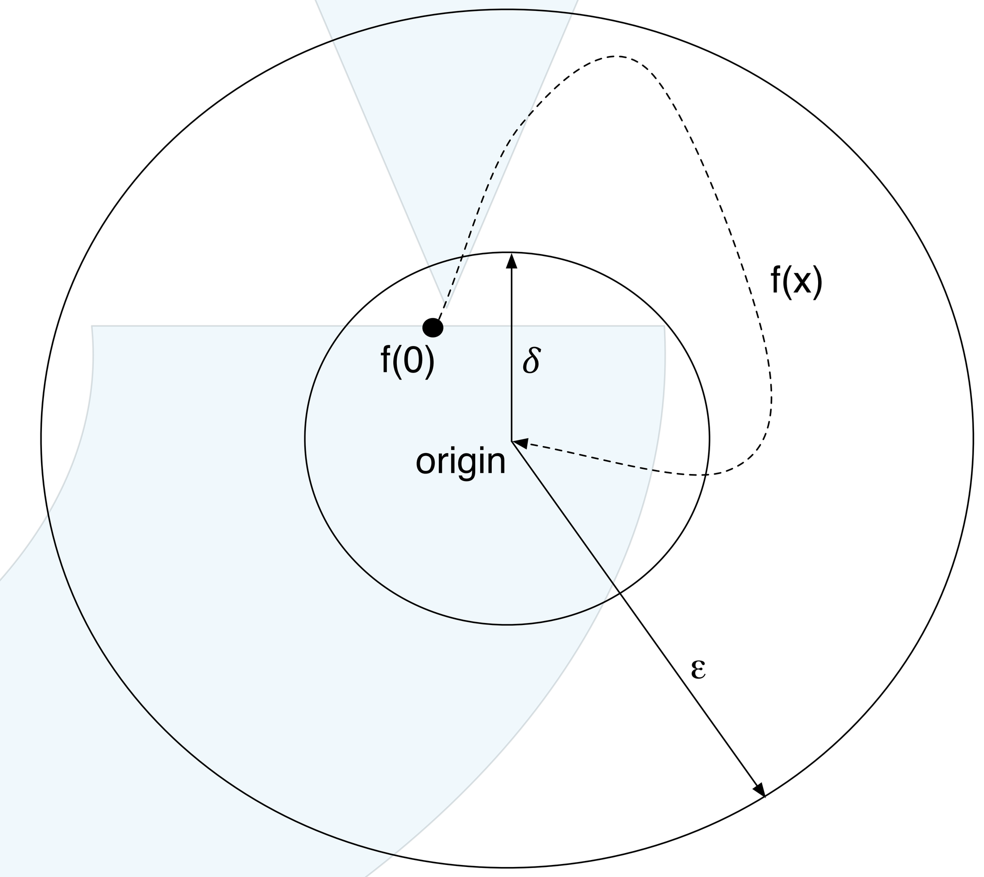


The common theme in all model transforms is that they look for special places indicated by design to make changes.

For issues that cannot be solved with simple solutions such as gain tweaking, a more complicated model transformation might be necessary.



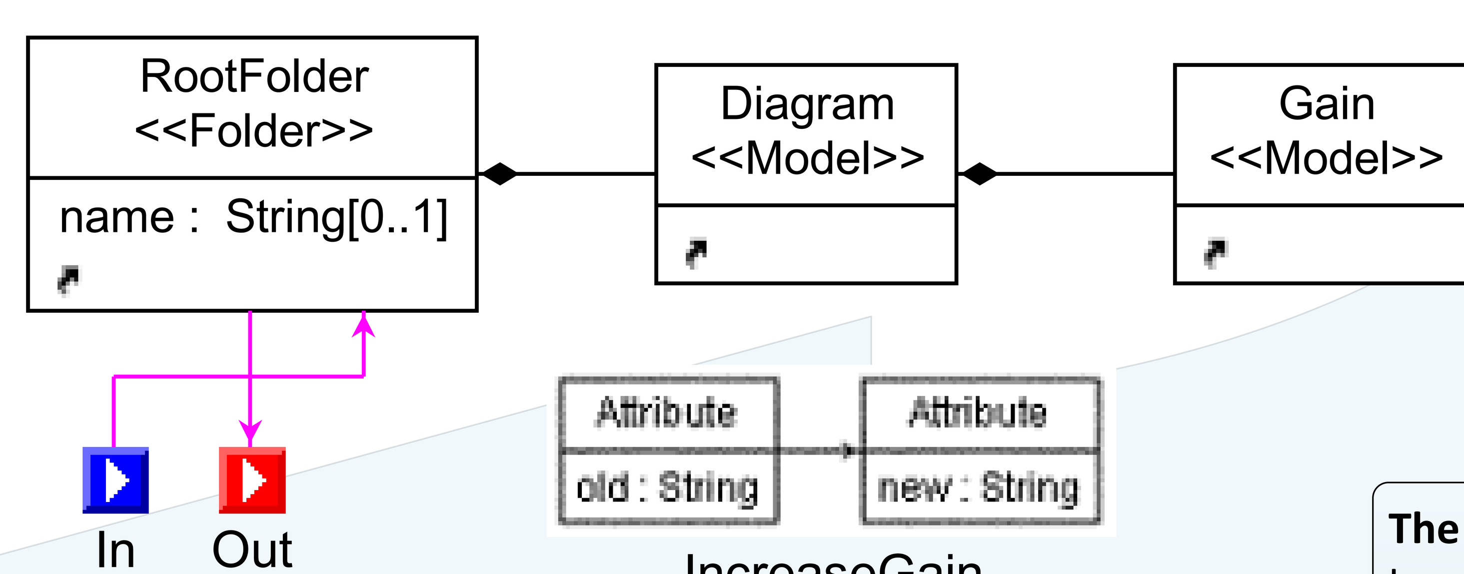
Dynamic Constraints



The first milestone is to identify what dynamic constraints are and how to integrate them into a language for LTI systems. As a general definition dynamic constraints are constraints that are not verifiable in the structure of a model. For example, stability in a system cannot be shown without some mathematical proof. Even though this research focuses on LTI systems, the research can be applied to broader concepts, as in the view of stability shown above.

Identifying Transformations

The second milestone is to identify how to transform system models. Control engineers know how to transform systems such that they meet their intended dynamic constraints. From their knowledge base, a set of possible transformations can be developed and drawn upon to automatically transform models based on analysis results.



Some of these transformations might be as simple as tweaking gains, as shown in here.

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