

₁ A Unified Modeling Framework to Abstract
₂ Knowledge of Dynamically Adaptive Systems

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1 Abstract

2 **Vision:** As state-of-the-art techniques fail to model efficiently the evolution and the
3 uncertainty existing in dynamically adaptive systems, the adaptation process makes
suboptimal decisions. To tackle this challenge, modern modeling frameworks should
efficiently encapsulate time and uncertainty as first-class concepts.

4 *Context* Smart grid approach introduces information and communication technolo-
5 gies into traditional power grid to cope with new challenges of electricity distribution.
6 Among them, one challenge is the resiliency of the grid: how to automatically re-
7 cover from any incident such as overload? These systems therefore need a deep under-
8 standing of the ongoing situation which enables reasoning tasks for healing operations.
9 **Abstraction** is a key technique that provided an illuminating description of systems,
10 their behaviors, and/or their environments alleviating their complexity. **Adaptation**
11 is a cornerstone feature that enables reconfiguration at runtime for optimizing software
12 to the current and/or future situation.

13 Abstraction technique is pushed to its paramountcy by the model-driven engineering
14 (MDE) methodology. However, information concerning the grid, such as loads, is not
15 always known with absolute confidence. Through the thesis, this lack of confidence
16 about data is referred to as **data uncertainty**. They are approximated from the
17 measured consumption and the grid topology. This topology is inferred from fuse
18 states, which are set by technicians after their services on the grid. As humans are
19 not error-free, the topology is therefore not known with absolute confidence. This data
20 uncertainty is propagated to the load through the computation made. If it is neither
21 present in the model nor not considered by the adaptation process, then the adaptation

1 process may make suboptimal reconfiguration decision.

2 The literature refers to systems which provide adaptation capabilities as dynamically
3 adaptive systems (DAS). One challenge in the grid is the phase difference between the
4 monitoring frequency and the time for actions to have measurable effects. Action with
5 no immediate measurable effects are named **delayed action**. On the one hand, an
6 incident should be detected in the next minutes. On the other hand, a reconfiguration
7 action can take up to several hours. For example, when a tree falls on a cable and cuts
8 it during a storm, the grid manager should be noticed in real time. The reconfiguration
9 of the grid, to reconnect as many people as possible before replacing the cable, is done
10 by technicians who need to use their cars to go on the reconfiguration places. In a fully
11 autonomous adaptive system, the reasoning process should be considered the ongoing
12 actions to avoid repeating decisions.

13 *Problematic* **Data uncertainty and delayed actions are not specific to smart**
14 **grids.**

15 First, data are, almost by definition, uncertain and developers always work with
16 estimates. Hardware sensors have by construction a precision that can vary accord-
17 ing to the current environment in which they are deployed. A simple example is the
18 temperature sensor that provides a temperature with precision to the nearest degree.
19 Software sensors approximate also values from these physical sensors, which increases
20 the uncertainty. For example, CPU usage is computed counting the cycle used by a
21 program. As stated by Intel, this counter is not error-prone¹.

22 Second, it always exists a delay between the moment where a suboptimal state is
23 detected by the adaptation process and the moment where the effects of decisions taken
24 are measured. This delayed is due to the time needed by a computer to process data
25 and, eventually, to send orders or data through networks. For example, migrating a
26 virtual machine from a server to another one can take several minutes.

27 **Through this thesis, I argue that this data uncertainty and this delay**
28 **cannot be ignored for all dynamic adaptive systems.** To know if the data un-
29 certainty should be considered, stakeholders should wonder **if this data uncertainty**

¹<https://software.intel.com/en-us/itc-user-and-reference-guide-cpu-cycle-counter>

1 **affects the result of their reasoning process, like adaptation.** Regarding delayed
2 action, they should verify **if the frequency of the monitoring stage is lower than**
3 **the time of action effects to be measurable.** These characteristics are common
4 to smart grids, cloud infrastructure or cyber-physical systems in general.

5 *Challenge* These problematics come with different challenges concerning the represen-
6 tation of the knowledge for DAS. The global challenge address by this thesis is: **how**
7 **to represent the uncertain knowledge allowing to efficiently query it and to**
8 **represent ongoing actions in order to improve adaptation processes?**

9 *Vision* **This thesis defends the need for a unified modeling framework which**
10 **includes, despite all traditional elements, temporal and uncertainty as first-**
11 **class concepts.** Therefore, a developer will be able to abstract information related to
12 the adaptation process, the environment as well as the system itself.

13 Concerning the adaptation process, the framework should enable abstraction of the
14 actions, their context, their impact, and the specification of this process (requirements
15 and constraints). It should also enable the abstraction of the system environment and its
16 behavior. Finally, the framework should represent the structure, behavior and specifi-
17 cation of the system itself as well as the actuators and sensors. All these representations
18 should integrate the data uncertainty existing.

19 *Contributions* Towards this vision, this document presents two approaches: a temporal
20 context model and a language for uncertain data.

21 The temporal context model allows abstracting past, ongoing and future actions
22 with their impacts and context. First, a developer can use this model to know what the
23 ongoing actions, with their expect future impacts on the system, are. Second, she/he
24 can navigate through past decisions to understand why they have been made when they
25 have led to a sub-optimal state.

26 The language, named Ain'tea, integrates data uncertainty as a first-class concept. It
27 allows developers to attach data with a probability distribution which represents their
28 uncertainty. Plus, it mapped all arithmetic and boolean operators to uncertainty prop-
29 agation operations. And so, developers will automatically propagate the uncertainty

1 of data without additional effort, compared to an algorithm which manipulates certain
2 data.

3 *Validation* Each contribution has been evaluated separately. The language has been
4 evaluated through two axes: its ability to detect errors at development time and its
5 expressiveness. Ain'tea can detect errors in the combination of uncertain data earlier
6 than state-of-the-art approaches. The language is also as expressive as current ap-
7 proaches found in the literature. Moreover, we use this language to implement the load
8 approximation of a smart grid furnished by an industrial partner, Creos S.A.².

9 The context model has been evaluated through the performance axis. The disser-
10 tation shows that it can be used to represent the Luxembourg smart grid. The model
11 also provides an API which enables the execution of query for diagnosis purpose. In
12 order to show the feasibility of the solution, it has also been applied to the use case
13 provided by the industrial partner.

14 **Keywords:** dynamically adaptive systems, knowledge representation, model-driven
15 engineering, uncertainty modeling, time modeling

²Creos S.A. is the power grid manager of Luxembourg. <https://www.creos-net.lu>