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by

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Towards a Modeling Framework with Temporal and Uncertain Data for Adaptive Systems

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Abstract

Vision: As state-of-the-art techniques fail to model efficiently the evolution and the 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.

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

Abstraction technique is pushed to its paramountcy by the model-driven engineering (MDE) methodology. However, information concerning the grid, such as loads, is not always known with absolute confidence. Through the thesis, this lack of confidence about data is referred to as **data uncertainty**. They are approximated from the measured consumption and the grid topology. This topology is inferred from fuse states, which are set by technicians after their services on the grid. As humans are not error-free, the topology is therefore not known with absolute confidence. This data uncertainty is propagated to the load through the computation made. If it is

neither present in the model nor not considered by the adaptation process, then the adaptation process may make suboptimal reconfiguration decision.

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

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

First, data are, almost by definition, uncertain and developers always work with estimates. Hardware sensors have by construction a precision that can vary according to the current environment in which they are deployed. A simple example is the temperature sensor that provides a temperature with precision to the nearest degree. Software sensors approximate also values from these physical sensors, which increases the uncertainty. For example, CPU usage is computed counting the cycle used by a program. As stated by Intel, this counter is not error-prone[1].

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

Through this thesis, I argue that this data uncertainty and this delay

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

cannot be ignored for all dynamic adaptive systems. To know if the data uncertainty should be considered, stakeholders should wonder **if this data uncertainty affects the result of their reasoning process, like adaptation**. Regarding delayed action, they should verify **if the frequency of the monitoring stage is lower than the time of action effects to be measurable**. These characteristics are common to smart grids, cloud infrastructure or cyber-physical systems in general.

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

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

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

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

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

The language, named Ain'tea, integrates data uncertainty as a first-class concept. It allows developers to attach data with a probability distribution which represents their uncertainty. Plus, it mapped all arithmetic and boolean operators to uncertainty propagation operations. And so, developers will automatically propagate the uncertainty of data without additional effort, compared to an algorithm which manipulates certain data.

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

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

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

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

List of publications and tools

Papers included in the dissertation

- 2018
  - Ludovic Mouline, Amine Benelallam, François Fouquet, Johann Bourcier, and Olivier Barais. A temporal model for interactive diagnosis of adaptive systems. In *2018 IEEE International Conference on Autonomic Computing, ICAC 2018, Trento, Italy, September 3-7, 2018*, pages 175–180. IEEE Computer Society, 2018. DOI: 10.1109/ICAC.2018.00029. URL: https://doi.org/10.1109/ICAC.2018.00029
  - Ludovic Mouline, Amine Benelallam, Thomas Hartmann, François Fouquet, Johann Bourcier, Brice Morin, and Olivier Barais. Enabling temporal-aware contexts for adaptative distributed systems. In Hisham M. Haddad, Roger L. Wainwright, and Richard Chbeir, editors, *Proceedings of the 33rd Annual ACM Symposium on Applied Computing, SAC 2018, Pau, France, April 09-13, 2018*, pages 1433–1440. ACM, 2018. DOI: 10.1145/3167132.3167286. URL: https://doi.org/10.1145/3167132.3167286
- in the process of submission
  - Ludovic Mouline, Amine Benelallam, Thomas Hartmann, Johann Bourcier, Olivier Barais, and Maxime Cordy. Ain'tea: managing data uncertainty at the language level. *Forthcoming*, forthcoming

Papers not included in the dissertation

- 2017
  - Amine Benelallam, Thomas Hartmann, Ludovic Mouline, François Fou-

quet, Johann Bourcier, Olivier Barais, and Yves Le Traon. Raising time awareness in model-driven engineering: vision paper. In *20th ACM/IEEE International Conference on Model Driven Engineering Languages and Systems, MODELS 2017, Austin, TX, USA, September 17-22, 2017*, pages 181–188. IEEE Computer Society, 2017. DOI: 10.1109/MODELS.2017.11. URL: https://doi.org/10.1109/MODELS.2017.11
  - Ludovic Mouline, Thomas Hartmann, François Fouquet, Yves Le Traon, Johann Bourcier, and Olivier Barais. Weaving rules into models@run.time for embedded smart systems. In Jennifer B. Sartor, Theo D'Hondt, and Wolfgang De Meuter, editors, *Companion to the first International Conference on the Art, Science and Engineering of Programming, Programming 2017, Brussels, Belgium, April 3-6, 2017*, 17:1–17:6. ACM, 2017. DOI: 10.1145/3079368.3079394. URL: https://doi.org/10.1145/3079368.3079394
- 2018
  - Alejandro Sánchez Guinea, Andrey Boytsov, Ludovic Mouline, and Yves Le Traon. Continuous identification in smart environments using wrist-worn inertial sensors. In Henning Schulzrinne and Pan Li, editors, *Proceedings of the 15th EAI International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services, MobiQuitous 2018, 5-7 November 2018, New York City, NY, USA*, pages 87–96. ACM, 2018. DOI: 10.1145/3286978.3287001. URL: https://doi.org/10.1145/3286978.3287001

Tools

- Ain'tea: a language which integrated data uncertainty as a first-class citizen
  - https://github.com/lmouline/aintea
- LDAS: a meta-model of knowledge for adaptive systems
  - https://github.com/lmouline/LDAS