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Robustness diagram with loop and time controls for system modelling and scenario extraction with energy system applications

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Abstract

In this research, we introduce an extension of Robustness Diagrams for modelling complex systems such as energy systems. We provide a construction scheme of this extension for the inclusion of looped and time-dependent substructures for an effective modelling framework. The latter set of substructures is introduced in this work as "reset-bound subsystems". We introduce a scenario extraction algorithm to obtain behavioral profiles from the models. Lastly, we apply our scheme to create a model of a real-world energy system and use the proposed algorithm to extract a scenario describing one process done by the system being modelled.

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1. Introduction

Workflow models, as formulated by van der Aalst[1], are case-driven representations of processes that are formulated under three dimensions namely, i) process, ii) resource, and iii) case. Some of the models where the process dimension is used are Petri nets by Murata[2], workflow nets by van der Aalst[1, 3], Spiking Neural networks by Cabarle et al[4], among others. Meanwhile, Class and Use Case Diagrams of the Unified Modelling Language(UML) from Rosenberg[5] are examples of models using the resource

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and case dimensions, respectively. However, these models (and including others in literature) are only specifically constructed using one or two dimensions. Therefore, users are not provided a holistic view of the various components and processes composing the activities that a system undertakes in its operation. It would become more difficult and cumbersome for users to perform repeated cross-referencing of multiple, multi-type sub-models as the complexity of the system grows. Nevertheless, the Robustness Diagram(RD) of the UML as proposed by Rosenberg et al.[6] provides partial support for modelling using all three dimensions. Moreover, the algorithm based in RDs which was introduced by Malinao et al. [7] which extracts a scenario, i.e. a description of system functionality with temporal information, from RDs has the following weaknesses: a) there is no distinction between sequential tasks which occur with prerequisites and those which do not have. The execution of the second task in the sequence is needlessly suspended where the suspension may trigger faults and failure in a complex system; and b) the absence of the mechanism to redo a task or a group of task wherein the repetition may be time-dependent in real-world systems.

In this work, we propose the **RD with loops and time controls**(RDLT) to address the aforementioned problems. RDLTs provide users to create a model with all three workflow dimensions in use. We provide a construction scheme for RDLTs to enable this integration of the dimensions in a workflow. We also propose "reset-bound subsystems" in RDLTs to include volatile components in modelling. With these, we revise the scenario extraction algorithm in [7] to effectively extract scenarios since RDLTs are now multi-input, multi-output, and multi-case representations of real-world complex systems. Finally, we use RDLTs to represent an instance of a complex system, i.e. an energy system[8], and extract a scenario from this model.

2. RD with loop and time controls

DEFINITION 1. A *Robustness diagram with loop and time controls(RDLT) is an 8-tuple* $R' = (V1, V2, V3, E, C, T, L, M)$ *where:*

1. $V1$ *are boundary objects,* $V2$ *are entity objects,* $V3$ *are controllers, where* $V1 \cap V2 \cap V3 =$ null*,*
2. $E \subset ((V1 \cup V2)\times V3) \cup (V3 \times(V1 \cup V2 \cup V3))$ *is a set of arcs,*
3. $C : E \rightarrow\{\Sigma \cup \{\lambda\}\}$ *is a multiset of labels, where* Σ *is a finite non-empty set of symbols, and* λ *is the empty string. For any* $(x,x)\in E$*,* $x\in V3$*,* $C((x,x)) = \lambda$*.*
4. *L assigns the maximum number of traversals allowed for each arc in* R'*, where* $L(.) \geq 1$.
5. $T : E \rightarrow [ti]^n$ *assigns a nonnegative value ti to* (x,y) *marking the time at the ith traversal on (x,y) using an algorithm's walk in* R'*,* $i = 1, 2,\ldots,n$*,* $n = L((x,y))$*. All values of T are initially set to* $[0]^n$.
6. $M : V1 \cup V2 \rightarrow \{0, 1\}$ *is a (user-defined) value of an object* $u \in V1 \cup V2$ *to indicate whether a subgraph of* R' **with center** *u, denoted as* $Gu \subseteq R'$*, resets its values of T under some reset process (to be discussed later). The vertex set VGu(which includes u) of Gu's, and edge set EGu includes* $v \in V3$ *if* $(u,v) \in E$ *and* $C((u,v)) = \lambda$*, and* $(a,b) \in EGu$ *if* $a,b \in VGu$*, and* $(a,b) \in E$*. If* $M(u) = 1$*, we call Gu a* **reset-bound subsystem** *of* R'*.*