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Digital-twin Co-evolution using Continuous Validation

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Abstract

In a continuous improvement design-operation continuum, model-based digital twins are used throughout. However, to make correct decisions, the model must remain a valid representation of the real-world system it twins. If a system only performs its cyclic operation, it may fail to collect the right data to detect when the model invalidation occurs. To tackle this challenge, we propose a workflow that works with continuous validation, in which a system's digital twin continuously performs validation experiments, such that trust can be placed on the validity of the model.

CCS Concepts: • **General and reference** → *Estimation*; **Validation**; • **Applied computing** → *Engineering*.

Keywords: Digital Twin, Continuous Validation

ACM Reference Format:
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1 Introduction

In the domain of Cyber-Physical Systems (CPS) we see a push for agile development techniques such as continuous integration, delivery, deployment and improvement [4]. We also see the adoption of digital twins, a digital representation of a CPS. This digital twin can be both data-based or physics-based, and depending on the type of data exchange between the physical system and digital copy, we discern digital models, digital shadows and digital twins [2]. Often the terms do get lumped together as digital twin.

An attractive proposition for the digital twin in an environment of continuous improvement is its application in discovering system evolution. For example, in [1], the digital twin is used to detect a state of the physical system not covered by the model, and to develop an improved control policy. [1] notes one crucial challenge, which they call the "Not-Enough-Data Failure": ensuring that the correct data is collected to detect changes in the physical system.

We use a digital twin to detect system evolution and to co-evolve our twin together with the system. However, certain systems in operation repeat the same operating cycle. Models of systems have a specific range in which they are valid, but the entire validity range is not always covered by the cyclic operation. In an environment without continuous improvement, this is not a problem, and routine data suffices, as we only care if the system operates as expected. With continuous improvement, where changes are continuously made to the system, routine data is insufficient to make a confident statement about the model validity. In this paper, we propose a workflow that can be used in the design-operation continuum for continuous validation. To aid the explanation, we also elaborate on model and instance validity. This is an extension on a workflow we presented in [3]

2 Background: Model and Instance validity

The concepts of model and instance validity are easily explained with an approximation of a mathematical function. We model $y = a * \sin x$ by its approximation $y = a * x$, shown in Fig. 1.a. Intuitively, the approximation is only valid for certain values of the input x and the parameter a. A specific range of validity can only be specified if the acceptable error $e = y - y_{model}$, the difference between ground truth and approximation, is quantified. If we assume that for our use an error of $-0.1 \leq e \leq 0.1$ is acceptable, then Fig. 1.b. shows the (in)valid range for x. By performing this check for a range of values of a and x we can visualize the model validity in Fig. 1.c. It shows the combination of inputs, x, and parameters, a, for which the error is acceptable. For a specific instantiated model, say for $a = 2.5$, we can perform a similar check with $e = y - y_{instance}$. Logically speaking, the approximation with $a = 2.5$ is the most valid approximation for the system $y = 2.5 * \sin x$, but for other systems it is still valid albeit for a smaller range of x. This is shown in Fig. 1.d., we call this instance validity, it tells us where the instantiated model is valid. Lastly, note that since this example does not

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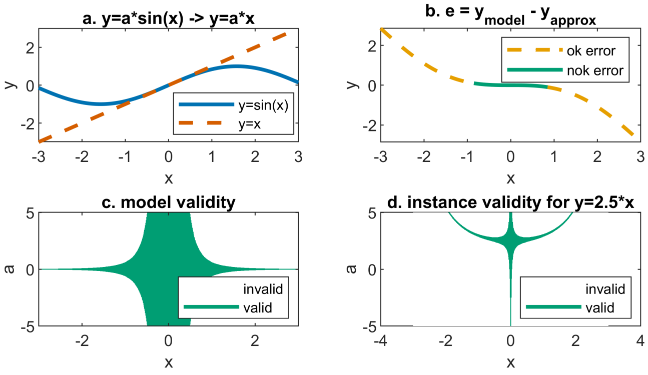

Figure 1. Illustration of model and instance validity.

use any uncertainty, the edge between the valid and invalid regions is straight rather than a gradient of confidence.

3 Continuous Validation Workflow

The proposed workflow is shown in Fig. 2. To perform validation, two datasets must be compared: simulated data and measured data. To gather this data, we have two alternatives, depending on if a digital shadow (upper part of the alternatives box) or digital twin (lower part of the alternatives box) is used. When a digital shadow is used, the physical system operates its routine as usual, this yields real-world data. From this data we must infer the conditions of a digital experiment to compare with, e.g. by finding the start of the routine and noting the initial conditions for that routine. In the case of a digital twin, we have more flexibility. The digital twin can be used to define the control for the system. In doing so, it automatically knows the control of the system, and can generate simulation results for it. The physical system must only enact this control to yield data. Note that a digital twin is a necessity to tackle the proposed challenge, a digital shadow only operates in its routine and does not truly solve the not-the-right-data problem. The model can then be validated by comparing the data. If deemed invalid, we should perform a model calibration to fit another instance of the model to the system, within the range of the model validity. If this is possible, the new recalibration becomes the system instance. If this is not feasible, our model no longer suffices and an alternative model must be searched/created.

Within this workflow, we do not check for the lack of data because of the cyclic operation of the system. However, the infrastructure shown here can be used to enforce certain remote experiments on the system to gather this needed data for validation. To do so does require a digital twin to provide those experiments to the system that executes them. However, this solution comes with its own inherent challenges as remote experiments need to be modelled, and executed safely on the target.

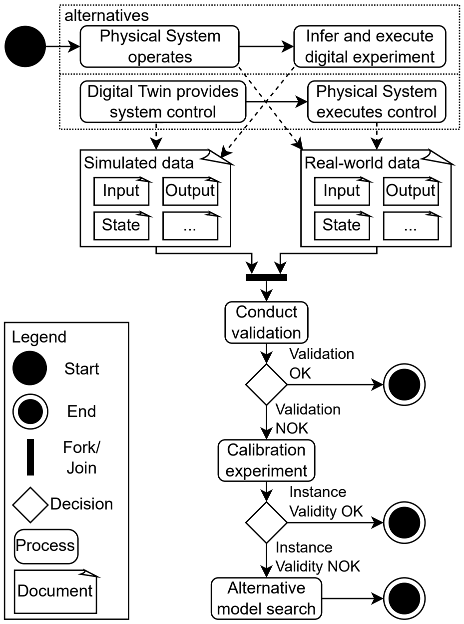

Figure 2. Workflow activity diagram.

4 Conclusion and Future Work

The idea of continuous validation is presented using the concepts of model and instance validity. An open question is how to apply these techniques to systems that are in 24/7 operation, i.e. there is no time to run these validation checks. Nonetheless, we believe that, at least for physics-based digital twins, the concept of continuous validation must be incorporated in each twin's continuous improvement cycle. If not, we risk wrongly trusting the twin.

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