Artefact: A UML-Based Framework for Model-Driven Development of Interactive Surface Prototypes

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Artefact: A UML-based framework for model-driven development of interactive surface prototypes

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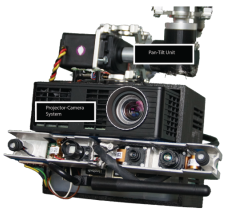
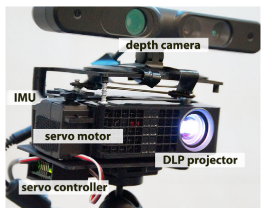
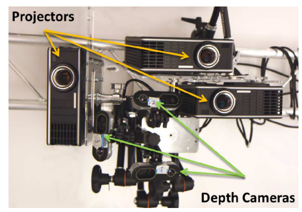


(a) Ubeam [12].



(b) AMP-D [35].



(c) LightSpace [32].

(d) Beamatron [33].

Figure 1: Interactive surface prototypes.

ABSTRACT

While interactive surface prototypes may be highly application-specific, existing prototypes hint at common, recurring design considerations. Given the rapid accumulation of near-identical prototypes, there is a need to promote design reuse. In this context, existing research prototypes motivate abstracting generic structures, architectural views, and descriptions to inform future designs. This paper proposes Artefact: a UML-based framework for model-driven development of interactive surface prototypes. We define flexible base models using existing research prototypes: initial hardware and middleware abstractions to support developers in the early design stages. For validation, we use the proposed framework to capture existing research prototypes. We then conduct an interview study to learn expert perceptions towards the captured model representations. Our initial findings highlight three significant benefits: (1) an accessible graphical syntax with unambiguous model representation, (2) a system for capturing arbitrary technical specifications, and (3) flexible model representation with consistent notation. While we can not draw any absolute conclusions, initial results suggest benefits in the model-driven approach.

CCS CONCEPTS

• **Hardware → Design reuse and communication-based design**.

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KEYWORDS

Interactive surface environments, interactive surface prototypes, UML-based framework

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1 INTRODUCTION

In the research space of interactive surface environments, prototypes are a fundamental contribution. They enable exploring new technologies and are quintessential representations of emerging designs. While interactive surface prototypes are application-specific, there is evidence of recurring design considerations [12, 32, 33, 35]. Given the near-identical implementations and their rapid accumulation, there is a need to promote design reuse. In this context, existing research prototypes enable abstracting generic structures, architectural views, and descriptions to inform future artifact designs. Da Silva and Oliveira suggested adopting UML stereotype-based approaches to promote the reuse of artifact designs. The authors focused on formulating generic abstractions from existing implementations [3]. In [10], Genero et al. emphasized the role of conceptual models in improving domain-specific applications. The authors put forward a literature review (1999—2009), highlighting a need to *"get the model right"* towards improving artifact designs. To learn the general perception of developers toward using UML, Torre et al. conducted a case study. Their findings highlighted widespread adoption of UML-based object-oriented models [28], pointing to rapidly expanding open-source repositories of UML models [7, 14]. Ho-Quang et al. suggested that the rapid adoption of UML-based model-driven approaches to be driven by a need to promote communicating implementations unambiguously. In the same context, Becker and Schäfer underlined lack of modeling support [2].

In this paper, we propose Artefact: a UML-based framework for model-driven development of interactive surface prototypes. We define flexible models based on existing research prototypes: initial hardware and middleware abstractions to support developers in the early design stages. For validation, we express existing research prototypes using the proposed framework. We then conduct an interview study to learn expert perceptions towards the captured model representations proposed model-driven approach.

2 THE ARTEFACT FRAMEWORK

The proposed framework employs UML to establish a flexible, reusable, and expressive syntax for modeling interactive surface prototypes. For flexibility, UML notation enables technology-agnostic representation of abstract components regardless of domain. UML also defines a formal notation for modeling constructs, promoting consistent logical analysis as well as unambiguous model representation. For expressiveness, UML builds on generalization hierarchies [24], and is inherently expressive. A significant benefit to adopting UML is its extensive documentation.

Artefact leverages metaclasses, stereotypes, profiles, and tag values; extension mechanisms that enable extending the normative UML to describe a specific domain [24]. In a broad sense, a Model is an abstract description of a system's environment, i.e., the organization of its members and member associations. As such, for a multi-layered interactive surface prototype, the hardware and middleware systems can be described as complementary models. Metaclasses are abstract Class representations that extend the notion of a conventional UML Class. Profiles are necessary to realize concrete instances of metaclasses using stereotypes. Profiles can also be described as package modules containing stereotypes (i.e., concrete Metaclass extensions). Profiles are reusable, can extend to other profiles, and can be factored for reuse. Within a profile, a Stereotype can extend one or multiple metaclasses, enabling notation in place of and in addition to an extended Metaclass. Note that stereotypes can only be used by extending a pre-defined Metaclass, where extensions indicate that properties of a Metaclass extend to a Stereotype. Akin to a conventional Class, a Stereotype has structural compartments for describing attributes, members, and tag values [24].

3 EMPIRICAL VALIDATION

Given that there is no standard method for determining the absolute correctness of a model [24], for validation, we adopted a two-fold approach. First, the hardware and middleware models were used to capture prototypes presented in [8, 9, 11, 16] and [36]. The criteria for the selected prototypes considered peer-reviewed studies published from 2019 onwards, focusing on current prototypes. Services, formats, transmission rate, vendors, models, modes, quantities, process speeds, sampling rares, and communication interfaces we captured and expressed using tag values, directed relations, cardinalities, stereotype compartments. Once captured, we used the resulting model descriptions for validation. In [27], Sargent suggested evaluating the correctness of a model using *"face validation"*, i.e., subjecting a model to scrutiny of experts. Following this guideline, we conducted an interview study to determine whether experts considered the proposed modeling framework reasonable and acceptable. The study was also used to gain insights about perceptions towards adopting a model-driven approach to support developing interactive surface research prototypes. A call for participation was sent out to research centers at KTH Royal Institute of Technology, the University of Regensburg, and Bauhaus-Universität Weimar. We also invited industry experts from Extend3D GmbH, Munich. Of twelve experts, five met the requirement of at least two years working with interactive surface environments or components associated with interactive surface environments (e.g., projector-camera systems). The interviews were conducted over Skype, and an online form was used to collect expert perceptions. Each interview was structured as follows: First, the research aim was discussed. Then, we asked the experts to confirm the suitability of their experience given the context of the research. Afterward, experts were introduced to the proposed modeling framework. Thereafter, we introduced the formulated hardware and middleware models. After discussing the rationale and objectives of each model, we presented captured model representations of prototypes from [8, 9, 11, 16] and [36]. We asked the experts to scrutinize and remark on the efficacy of using the framework to model prototypes. Lastly, we discussed whether a model-driven approach would benefit the research community for developing prototypes in the early design stages. Discussion with all experts was structured using questionnaires. All questions were open-ended towards deeper discussions, as led by the experts. This approach promoted collecting experts' perceptions and learning their opinions on setbacks, benefits, and implications of a model-driven approach using the proposed framework.

Expert #1 remarked on the rationality of the models, "The models are rational and clear.". **Expert #2** gave merit to unambiguous technical outlines, "…specifications simplify prototyping.". **Expert #3** pointed to capitalizing existing prototypes, "…developers can obtain structured information about existing prototypes…". **Expert #4** remarked on learnability, "…it took me ~5 minutes to grasp the framework.". **Expert #5** underlined inherent fostering of artifact replication, "…full specifications simplify replicating prototypes.".

Data collected during the interviews was coded and analyzed by the first author. Our findings suggest that experts found the proposed framework to be beneficial with perceptions converging toward three main benefits: (1) a generic and simple syntax for prototyping, (2) an approach to systematically compare different prototypes, and (3) a convenient starting point for developing interactive surface prototypes.

4 DISCUSSION

Our validation approach suffers from the absence of a standard methodology for evaluating the *"absolute"* validity of models [24, 27]. Although an argument can be made for the simple representation of structurally complex systems, the modeling framework we propose is not comprehensive by design. Absent an extensive set of all possible abstractions, the minimal set presented in this paper is insufficient for non-experts who may also seek to employ the modeling framework as a knowledge base. Face validation has demonstrated the role of experts in the iterative development of

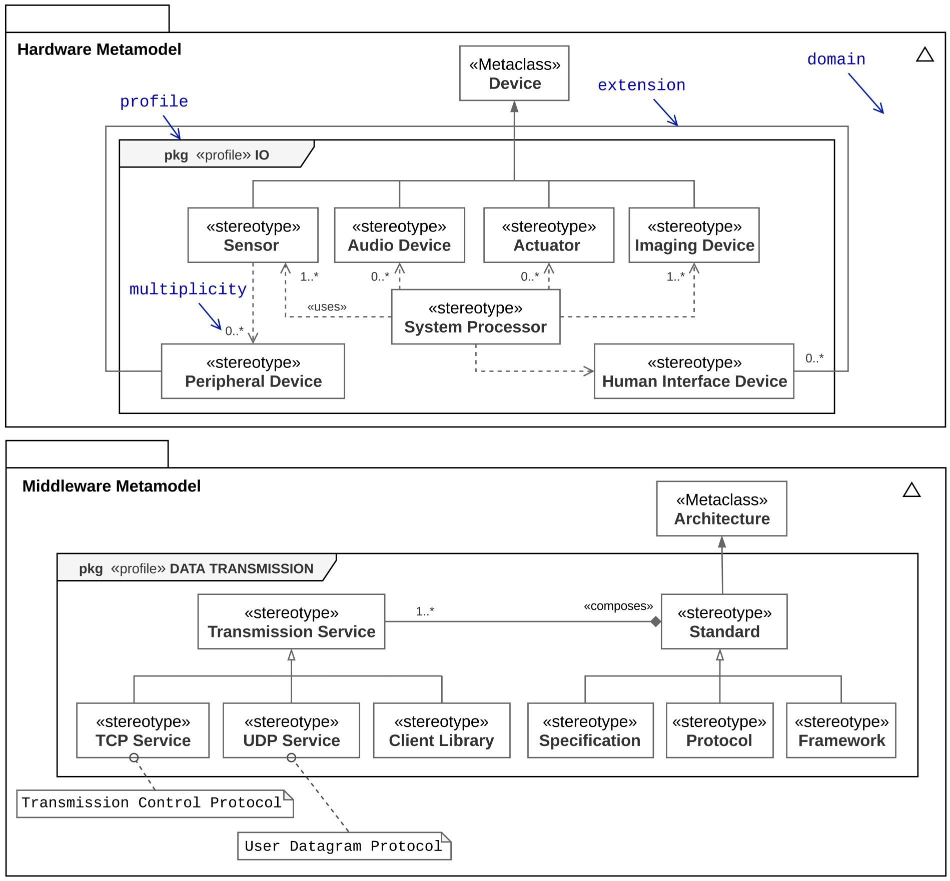

Figure 2: Flexible base models for the hardware and middleware layers (abstracted in Tab. 1). Profiles and metaclasses are used to describe a domain's environment. Properties and tagged values are utilized to convey arbitrary technical specifications. Last, directed relationships and cardinality are used to capture dependencies. Each model is suggestible and can be modified for variable application scenarios.

the modeling infrastructure. There is much promise in conducting face validation on a larger scale and learning expert perceptions towards *"models as end products"* [1], i.e., in the space of interactive surface environments. Suggestions from experts point to benefit in open discourse about design considerations for the modeling framework. Conducting workshops with experts and developers would be one possible approach to promote such a discussion.

5 CONCLUSION

This paper identifies the accelerated accumulation of comparable prototypes and proposes a model-driven approach to promote design reuse. Existing prototypes have been leveraged to define a generic UML-based framework for modeling hardware and middleware layers of interactive surface prototypes. The proposed framework has been applied to capture existing prototypes, and a face validation study has been conducted to learn experts' perceptions towards the captured model representations. Our initial findings highlight three significant benefits: (1) an accessible graphical syntax with unambiguous model representation, (2) a system for capturing arbitrary technical specifications, and (3) flexible model representation with consistent notation. While no absolute conclusions can be drawn, initial results suggest benefits in the proposed framework.

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Table 1: Abstraction of hardware and middleware modeling constructs. Components identified in reviewed body of literature are generalized to stereotypes. The stereotypes are then abstracted to high-level metaclasses.

Metaclass	Stereotype	Component	Body of literature
Device	System Processor	Workstation, Server	[4–6, 12, 13, 21–23, 25, 26, 29–35]
		Microprocessor	[13, 25]
Device	Sensor	Camera Sensor	[4, 5, 12, 13, 21, 23, 25, 26, 29, 30, 33–35, 37]
		Depth Sensor	[4, 5, 13, 23, 25, 31–33, 35, 37]
		Infrared Sensor	[22, 29]
Device	Imaging Device	Projector, Display	[4, 6, 12, 13, 22, 23, 25, 26, 29, 30, 32–35, 37]
Device	Actuator	Actuator	[12, 22, 26, 29, 33, 35]
Device	Human Interface Device	Mobile Device	[13, 21, 23, 25, 26, 30, 33, 35]
Device	Peripheral Device	Phicon	[29]
		Marker	[21, 22, 26]
		Mirror	[6, 22, 29]
Device	Audio Device	Transducer	[6]
Architecture	Transmission Service	Framework	[4, 19]
		Specification/Protocol	[17, 18, 20]

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