Adaptation and Implementation of the ISO42010 Standard to Software Design and Modeling Tools

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Abstract: Model cantered software development practices adoption remains limited to small niche domains. The broad development practices remain code centric. Modeling tool complexity is often cited as a significant factor limiting the adoption and negatively affecting user experience. Modeling and design tools complexity are due to multiple factors including complexity of the underlying language, weak support for methodologies, and insensitivity to users' concerns. This results in modeling and design tools that expose all or most of their capabilities and elements at once, often overwhelming users and negatively affecting user experience. The problem is further exacerbated when a tool supports multiple domain-specific modeling languages that are defined on top of a base language such as UML. In this case, the tool customizations and visual elements necessary to support each language often interfere with each other and further exacerbate the modeling tool complexity. In this paper, we present a novel and systematic approach to reduce the complexity of design and modeling tools by introducing an interpretation and adaptation of the ISO42010 standard on architecture description specific to the software domain. We demonstrate this approach by providing a working implementation as part of the Papyrus opensource modeling framework. In this approach, we leverage the notions of Architecture Contexts and Architecture Viewpoints to enable heterogeneous UML-based languages to be independently supported and help contextualize the exposed tool capabilities. This paper presents the ISO42010 interpretation and adaptation to software design and architecture and a case study with several definitions of architecture contexts. The implementation of this novel approach demonstrates the ability for multiple modeling languages and notations to coexist without interference and provides significant reduction in the exposed capabilities in the UI. Reducing design and modeling tool complexity has a potential to significantly broaden the adoption of modeling and design practices in the software engineering sphere.

Keywords: ISO 42010, Architecture Description Language, Architecture Framework, UML, SysML, Software Design, Model Driven Architecture, Model Driven Development, Software modeling.

1. Introduction

The Unified Modeling Language (UML) is a general-purpose modeling language in the field of software engineering. The language was first adopted by the Object Management Group as a standard in 1997, and since then has become widely adopted. UML has an abstract syntax (defining its concepts) and a concrete syntax (graphical notation) to model different concerns ranging from system structure (e.g., Class Diagram and Composite Structure Diagram) to system behavioral (State Machine Diagram and Activity Diagram). The language is large and complex; it contains over 250 concepts and directly supports 14 diagram kinds.

As such, a methodology is often required to guide designers on creating meaningful and consistent models. Meanwhile, the language itself is kept agnostic so it can support several methodologies.

Furthermore, despite being a general-purpose language, UML is often used as a base to define domain-specific modeling languages (DSMLs). This is made possible by leveraging UML's profile extension mechanisms. A UML profile allows extending the language's abstract syntax (with stereotypes) and/or concrete syntax (with graphical annotations). Many DSMLs have been defined on top of UML including: for systems design [9], MARTE for real-time and embedded design [25], SoaML for service-oriented architecture [26], and for BPMN for business process modeling [14]. Multiple profiles can be applied to a UML model at the same time to address different concerns. This capability is often leveraged by domain-specific frameworks (e.g., DoDAF [15]) that integrate multiple DSMLs together. These extension mechanisms add to the complexity, and is a significant overhead that designers have to manage.

UML enjoys a wide range of tool support, including open-source, commercial, educational, and research tools [27]. These tools cater to designers with different levels of expertise (ranging from novices to experts) and needs (e.g., creating models to document a design, generating code from models, performing model-based testing, and creating executable models to simulate and analyze designs). Unfortunately, most of these tools cannot hide complexity without compromising functionality. For example, tools typically expose all possible diagram types, along with their relevant concepts, relationships and properties in the user interface. Tools often do not allow filtering of these UI items according to a specific methodology, and if they did, such filtering is globally applied and is not contextual to the model and the underlying methodology. This filtering approach often leads to further user frustration as required elements may become inaccessible (when filters are applied) or the user interface becomes too complex when such filters are absent. Moreover, when tools support DSMLs defined with UML profiles, they typically add to the UI additional elements that facilitate the creation of DSML models. Since there are no formalisms to identify relevant and/or dependent elements, the UI becomes quickly cluttered with elements from the base modeling notation (i.e. UML) and elements from DSML extensions. More importantly, many DSMLs require tooling customizations. When multiple DSMLs are applied to a model, their customizations may sometimes interfere with each other in unexpected ways. For example, one DSML may expect a newly created Class to have public visibility, while another may expect it to be private. Furthermore, tools that attempt to address these issues do not achieve this in a systematic scalable manner, making extensions to other DSMLs unpredictable and unreliable, and further complicates modeling tool development, testing, and maintenance.

The aforementioned issues are caused by two main underlying fundamental limitations. The first one is that a UML model is not characterized by a unique context, for which customizations can be formally specified. Such context cannot simply be a UML profile, since a) multiple profiles can be applied at once, possibly leading to customization interference, and b) many customizations do not depend on profiles at all, like ones intended to implement a framework (e.g., DoDAF) or methodology. The second limitation is the lack of methods to control UML tool UI item visibility based on a methodology, user role, or user concerns.

In this paper, we describe an approach to address the aforementioned limitations that can be applied to any UML modeling tool. Our approach is inspired by the ISO42010 Standard which specifies how architecture is described [1][3]. In this standard, architecture description must always be associated with a context that can either be an architecture description language (ADL) or an architecture framework (AF). A context specifies a set of architecture viewpoints that define a set of permissible Model Kinds.

We make four contributions in this paper. Our first contribution is adapting and implementing the ISO 42010 standard for the Model Driven Engineering context, and in particular for the UML modeling domain. This entails an Architecture metamodel, whose instances, i.e., architecture models, can be referenced by UML models to specify their context and viewpoints. Our second contribution is a demonstration of how architecture models can be used to mitigate common concerns in UML modeling tools. One concern is the complexity of the UML tool's UI. Another concern is the ability to extend UML architecture contexts or define new contexts by extending existing ones. A third concern is migrating UML models from one architecture context to another. A fourth concern is supporting modeling methodologies. Our third contribution is an implementation of the proposed approach in the Papyrus open source modeling tool [28]. This implementation includes defining a Papyrus Architecture metamodel that extends the base Architecture metamodel. It also includes an implementation of solutions to the aforementioned concerns in Papyrus. Our fourth contribution is a case study that involves defining three architecture contexts (UML, Profile, SysML) in Papyrus. The case study demonstrated that several UML-based architecture contexts can coexist in the same modeling tool without interfering with each other. The case study also demonstrates that the approach can reduce the complexity of the UML modeling tool's UI.

This paper extends previous published work as follows [24]. First, we formally define the ISO42010 interpretation and adaptation to the Model Driven Software Engineering domain. We introduce the concept of extensibility points that enables users to contribute and extend architecture domain models. We also specify assumptions and a rule-based approach for materializing these extensibility points. Moreover, we improved the case study and included additional modeling domains.

The rest of this paper is organized as follows. Section 2 introduces the motivation and significance of this work. In section 3 we present a background on the ISO 42010 standard; a description of our Architecture metamodel is given in Section 3; Section 4 discusses how architecture models can address UML tools' concerns; an implementation of the approach in Papyrus is described in Section 5; Section 6 presents a case study where several architecture contexts are defined in Papyrus; related works are presented in Section 7; and finally, Section 8 provides conclusions and outlines future research directions.

2. Motivation and Significance

Despite the near consensus on the value-added of software design and modeling using languages such as UML, adoption of model-centric methodologies remains dismal. A study that included 113 professionals reveals that modeling tools complexity is a major factor limiting adoption [12]. In the open source sphere, the majority of software development practices remains code-centric [31][32], but recent studies show significant uptake of modeling using UML [29]. Modeling tools complexities has also been cited as a significant concern. As the adoption of Domain Specific Modeling Languages continue to increase, modeling tools complexity will continue to grow as these DSML often introduce new modeling concepts and elements. Models play a key role in communication and collaboration due to their level of abstraction and support for visual elements. Nevertheless, modeling tools are often perceived to have weak support for collaboration and communication [34]. Modeling tools that attempt to add such support often introduces additional complexities and further exacerbate the learning curve. Abrahão et. al report that extensive usability studies of modeling notations and tools is uncommon as evident by the scarcity of user experience studies in model driven engineering domain [33]. They also report that based on feedback from industry practitioners, user interface and user experience is an important factor for the dissemination and adoption.

In education, multiple researchers have identified the need for educational-specific modeling tools in order to achieve their educational goals [30]. In this study, Liebel e.t al have conducted a case study and found that using industrial-level modeling tools require dedicated tool support and instructions. As such, they reiterate the need for simplified tooling for educational purposes.

Solving the challenge of modeling tools complexity is likely to impact the education and practices of broad community of practitioners and educators. Ultimately, this could significantly increase the adoption of model-centric software development.

3. Background on the ISO 42010 Standard

In our attempt to search for methods to reduce the complexity of UML and DSML tools, we broadened our search to include architectural tools at large. This lead us to the ISO42010 standard which specifies the requirements for creating an Architecture Description (AD), shown in Figure 1, as a product of systems / software architecting. The standard provides a uniform vocabulary to specify architectures and aims at systematizing the architecting processes.

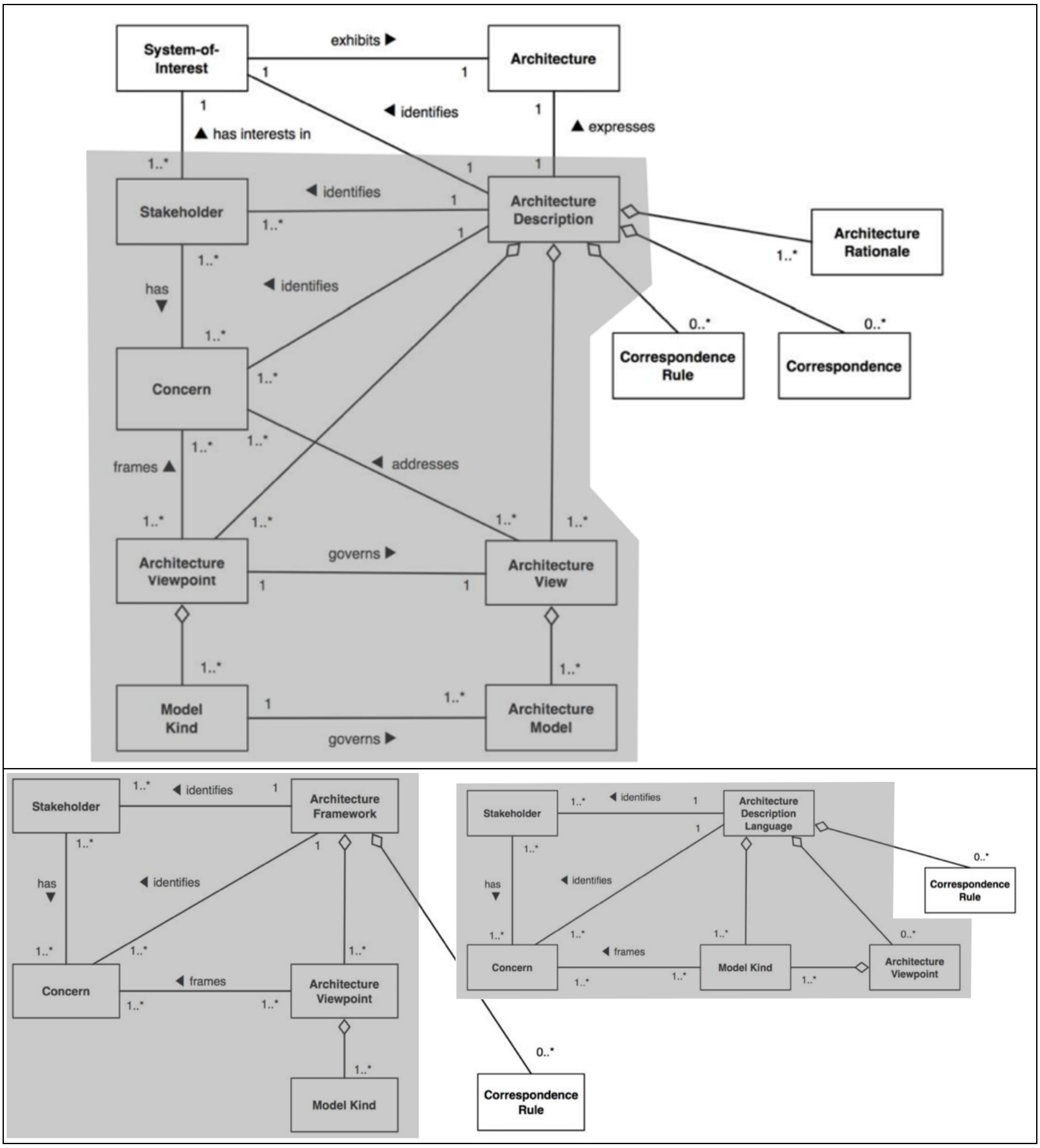

Figure 1: Highlighted Fragments of the ISO 42010 Standard Vocabulary on Architecture Description (AD) [24]

In a nutshell, the standard adheres to the concept that every system has an architecture and that AD is a specification of that architecture. It defines architecting as the "process of conceiving, defining, expressing, documenting, communicating, certifying proper implementation of, maintaining and improving an architecture throughout a system's life cycle [1], which takes place in the context of a specific organization or project. The architecture of a system, within the context of this standard, intends to convey the essence of a system. The rationale for this rather broad definition is to capture the underlying common theme of various existing definitions of architectures. This also ensures that the standard is not domain or discipline specific, but rather, a generic standard that targets complex systems architecture in general.

The standard also acknowledges that architecting a system, especially when it is a complex system, involves multiple Stakeholders that have various Concerns that are framed by Architecture Viewpoints and their referenced Model Kinds. An AD contains instances of those Architecture Viewpoints, called Architecture Views, which in turn contain instances of Model Kinds, called Architecture Models.

Furthermore, the ISO42010 standard specifies that an AD conforms to a meta (higher level) description. This meta description can be an Architecture Description Language (ADL), shown in Figure 1 (top-right) or an Architecture Framework (AF), shown in Figure 1 (bottom-right), which are two widely used mechanisms to describe architectures. Each mechanism establishes common practices for creating, interpreting, analyzing and using ADs within a particular domain of application or stakeholder community. ADL and AF can both contain Architectural Viewpoints. However, only ADL can contain Model Kinds, which can be referenced by any viewpoints.

4. ISO42010 Interpretation for the Software Architecture Domain

This international standard defines architectures and the architecting processes broadly and abstractly to ensure domain and discipline independence. In this Section, we present an interpretation specific for the software architecting domain. Namely, we present formal interpretation for the Conceptual Model, Architecture Description, Architecture Concerns, and Architecture Views and Viewpoints.

4.1 Conceptual Model

The presented conceptual model in Figure 2 should serve as a context for understanding the process of architecting at a high level. An architecture is an emergence property of the system (i.e. the system-of-interest exhibits an architecture). The system-of-interest is situated in exactly one environment which may contain multiple systems.

System stakeholders, in this context, refers to those who have fundamental concerns pertaining to the architecture of the system-of-interest. This includes users, operators, acquirers, owners, suppliers, developers, builders, and maintainers of the system. Stakeholders have a set of ‘concerns’ that are fundamental to the system architecture. As shown in Figure 2, the ‘Purpose’ of the system is one type of such concerns. Other concerns include suitability of the system for achieving its purpose, feasibility of construction and deployment, risks and hazards, and maintainability and evolvability of the system. An important aspect of this conceptual model is that the system-of-interest may exhibit zero or more Architectures. Similarly, a specific architecture may specify zero or more systems.

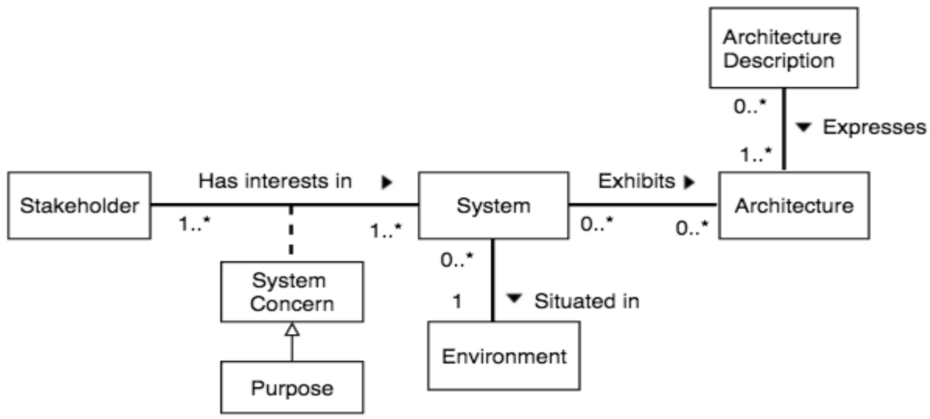

Figure 2: Architecture Conceptual Model

4.2 Architecture Description

The Architecture Description (AD) contains a set of Correspondences and Correspondence Rules (Figure 3). A correspondence is a relationship between AD elements which are governed by correspondence rules. An element in this context is the most primitive construct, such as stakeholder, concern, architecture viewpoint, architecture view, model kind, architecture model, architecture decision and rationale. AD also contains Architecture Rationale, which records reasoning for architecture decisions, alternatives, and trade-offs, and may cite external sources for additional information on potential consequences of decisions.

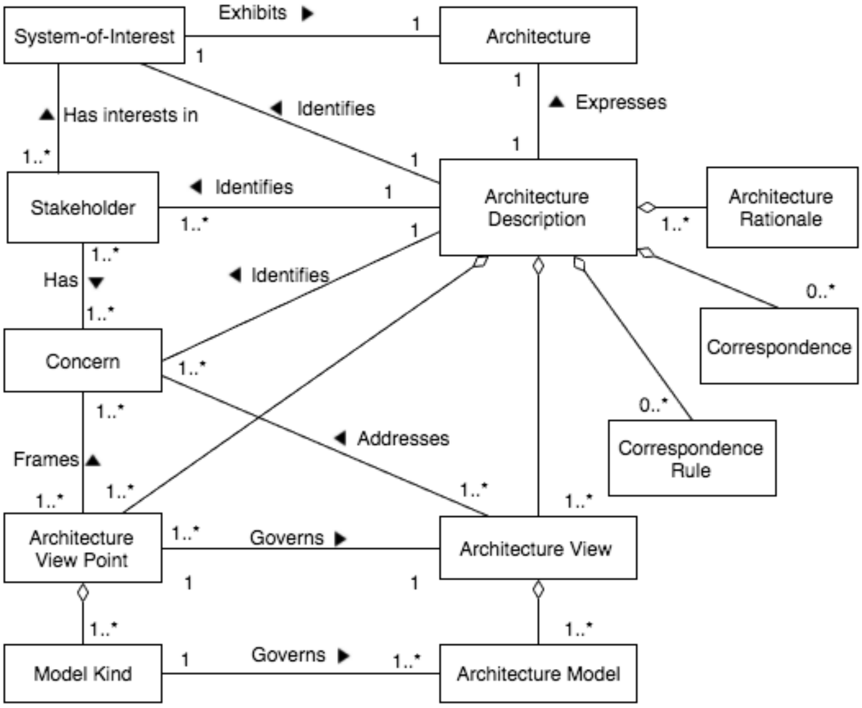

Figure 3: Architecture Decision, Rationale, and Concerns

4.3 Architecture Concerns

A concern is any topic of interest pertaining to the system, which are held by the system's stakeholders. This definition is aligned with "separation of concerns" concept in software and systems engineering, first coined by Edsger W. Dijkstra [35]. Each architecture viewpoint frames one or more of the known concerns of the system, as shown in Figure 4. Since the fundamental premise of separation of concerns is to enable stakeholders to reason on an individual concern independently of the others (to the extent possible), architecture viewpoints enable stakeholders to manage the underlying system complexity. In the context of this definition, concerns include, but are not limited to, risks and hazards. Concerns are framed by architecture viewpoints and are addressed by one of more Architecture views. Architecture views are governed by Architecture viewpoints, which formalizes how views are constructed. Distinction and elaboration on views and viewpoints are discussed in the next section.

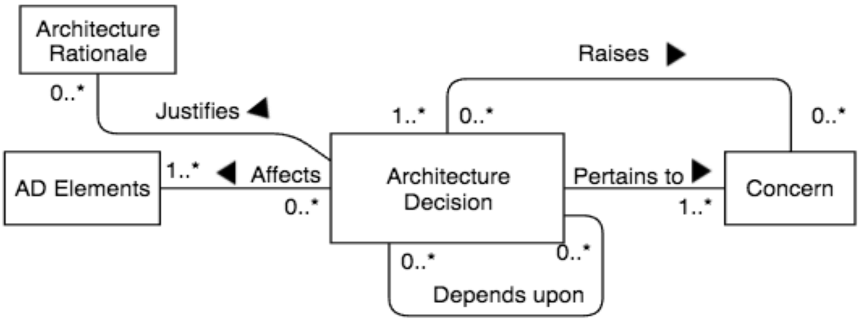

Figure 4: Architecture Concerns

4.4 Architecture View and Viewpoint

The terms architecture view and architecture viewpoint, despite being apparently similar and are sometimes used synonymously, refer to distinctly different concepts. System architectures typically contain a wide variety of collections of models. In current practices, when a set of these models are organized together to form a cohesive group, the group is referred to as a 'view'. In practice, the view addresses a specific concern(s), and hides away unrelated models and elements. This serves the objective of separation of concerns.

However, there is no formal mechanism for constructing these views. As a result, the formation of the grouping remains implicit, resulting in weakened validation and analysis by the users of the framework. This standard, therefore, defines viewpoint as the set of conventions or formalisms for expressing an architecture with respect to a set of concerns. In a nutshell, A "viewpoint is a way of looking at systems; a view is the result of applying a viewpoint to a particular system-of-interest".

Viewpoints are treated as first class architectural elements, and the standard does not provide a pre-defined set of viewpoints. Because the standard does not target a specific domain or type of systems, it provides users of the standard with the ability to define their own viewpoints. In effect, this perspective improves the portability of the standard across different domains. This perspective of viewpoints is not novel, however. As early as in 1977, Ross has proposed treating Viewpoints as first-class entity in the Structured Analysis approach (SADT) [36].

The distinction between view and viewpoint is a source of confusion. The reported definitions of such concepts are far from being uniform. This concept of a viewpoint is not popular in practice but has been proposed in some architecture frameworks. To clarify this concept, one can think of the relationship between a view to a viewpoint similar to the relationship between a map and a legend. The legend defines the reasoning and semantics of constructing the map, and aids in the understanding of it. Similarly, the viewpoints define the rational and conventions of the contents and elements of the view. This formal distinction has the goal of promoting reuse of tools and techniques within a community, and across-communities, of the architecture frameworks that conforms to this standard. There are two common approaches to the construction of views: the synthetic approach and the projective approach. The synthetic approach is based on model correspondences, while the projection approach is based on routine procedure of extraction from the underlying model repository.

5. Architecture Metamodel

Our first contribution is adapting the ISO42010 standard to the context of Model Driven Engineering. We achieved this by implementing the vocabulary of the standard in the form of a metamodel (Fig. 5). Our approach employs the metamodel to create architecture models that govern how UML and other DSML models represent architecture descriptions.

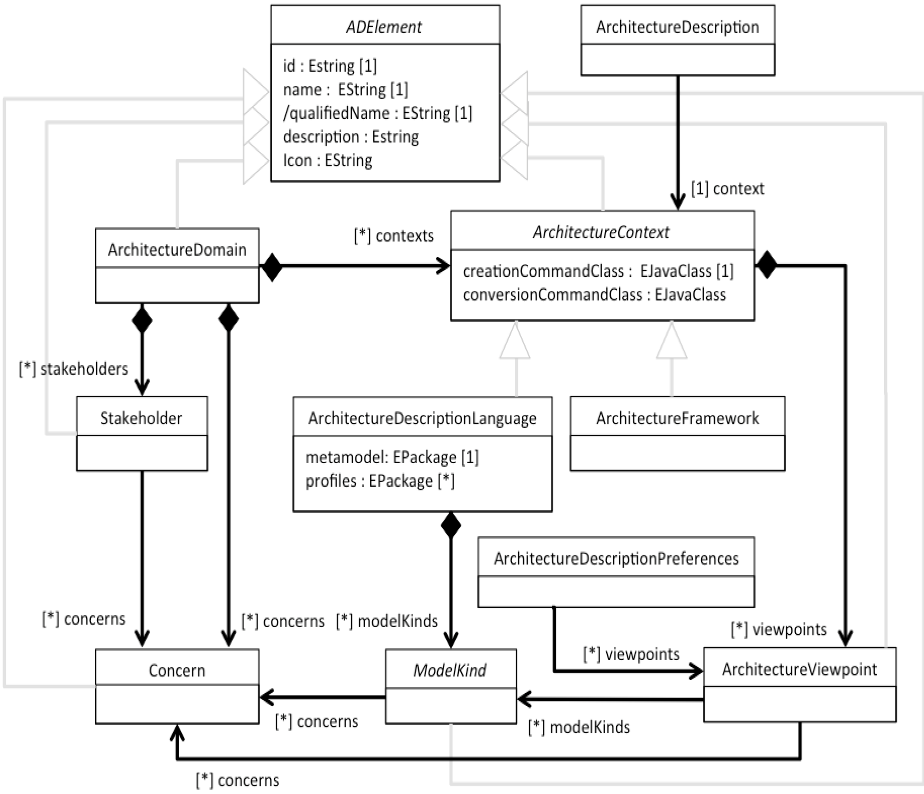

Fig. 5. Architecture Metamodel [24]

All elements in an architecture model have types that extend *ADElement* in the architecture metamodel. This type characterizes elements by their unique id, name, qualified name, optional description and optional icon. The *Architecture Domain* type represents the root of the architecture model. This type, which is not explicitly defined in the standard, represents an application domain or a stakeholder community (e.g., Software Engineering, Systems Engineering, Automotive, Aerospace). It contains a set of Stakeholders (e.g., Software Engineers, Systems Analysts) and Concerns (e.g., Structure, Behavior, Parametrics). A stakeholder may have concerns from any domain. A domain may contain a set of Architecture Contexts. This new type (also not in the standard) is an abstract supertype of both ADL and AF and represents the context of an Architecture Description (represented by a UML or a DSML model). A context specifies a *creationCommandClass* and (optionally) a *conversionCommandClass* that can be used by a modeling tool to create a new user model in, or convert an existing user model to, that context respectively. A context also captures the capability of both ADLs and AFs to contain *Architecture Viewpoints*, which reference a set of *Model Kinds*. An ADL specifies a modeling language (e.g., UML, SysML) by defining its abstract syntax with a metamodel and an optional set of UML profiles (when the metamodel is that of UML), and its concrete syntax, or notation, by a set of Model Kinds (e.g., diagrams and tables). An AF, on the other hand, specifies a modeling methodology that involves Model Kinds from one or more ADLs.

Model Kind is defined as an abstract *metaclass* in this metamodel. Instead of predefining possible representations, we assume that the Model Kind concept can be specialized to define any kind of representation and, as discussed later, our implementation allows toolsmiths to define their own.

There are two remaining types in the architecture metamodel, which are *Architecture Description* and *Architecture Description Preferences*, are not meant to be instantiated within an architecture model, but rather within a UML or other DSML model that represent an architecture description. The former references an Architecture Context that the description conforms to and is considered a characteristic of the model. The latter specifies which Architecture Viewpoints are currently enabled in the description and is considered a preference that may be stored in the description model, to share with all users of the model, or in a tool's preference store that belongs to one user or is shared with a group of users.

6. Using Architecture Models to Address UML Tooling Concerns

The architecture models that are discussed in the previous section allow UML models to specify their architecture contexts and viewpoints. This can in turn be leveraged by UML tools to address several concerns, which is another contribution of this work.

5.1 Modeling Tool Complexity

One concern is the complexity of the UML tool's UI. Typically, UML tools support all or most of the Model Kinds of UML, which include 14 diagram kinds. More Model Kinds can be supported for other UML-based DSMLs. For example, SysML supports 4 more diagram kinds and two table kinds. Each one of those Model Kinds supports many types of abstract syntax (AS) elements. The result is a cluttered UI to account for this wide range of concepts and modeling elements. Moreover, if the tool supports additional DSMLs, each may introduce more elements, further complicating the UI.

One strategy that UML tools typically follow to reduce this clutter is a global setting in the workspace that controls which subset(s) of those supported Model Kinds and AS elements are visible. This approach is not effective since users may be dealing with multiple kinds of models at the same time, each may require different subset(s) of UI elements enabled. However, when UML models specify their architecture contexts and enabled viewpoints, a tool can change its UI dynamically for each model by limiting its options to those suitable for its context and viewpoints. For example, showing only SysML diagrams and tables that are supported by the enabled viewpoints of the SysML context.

5.2 Tool Extensibility Concern

Another tooling concern is the ability to extend UML architecture contexts or define new contexts by extending existing ones. For example, some of SysML's Model Kinds (e.g., Block Definition Diagram and Internal Block Diagram) extend corresponding ones in UML (e.g., Class Diagram and Composite Structure Diagram), while including others as is (e.g., State Machine and Activity Diagram). Without formalisms to specify that, most UML tools today expose all of their supported Model Kinds. However, with architecture models, it is straightforward for an ADL or AF to define viewpoints that reference Model Kinds from other ADLs. This allows a tool to only show those Model Kinds that are supported by the visible viewpoints, while making them follow the rules of the ADL or AF in context. For example, the Profile AF has a viewpoint that includes the UML class diagram but restrict its elements to only classes, data types, associations and generalizations.

Our approach supports two types of extension mechanisms. These extension mechanisms are generic and not specific to the implementation we provide in the Papyrus modeling tool. They are discussed in this section since they are not defined as part of the ISO42010 standard. It is however important to note that one of the standard's goal is to establish coherent architecting practices, facilitate portability across different architecture frameworks, and remain domain neutral. For example, users of the standard are expected to contribute their own domain specific viewpoints. As such, providing extensibility mechanism is in strong alignment with the ISO41010 essence.

5.2.1 Extension Points for contribution of architecture domain models

The Papyrus implementation provides an eclipse extension point allowing contribution of architecture domain models. Each contribution is required to specify a path to a valid *.domain model. A second extension point is provided to allow the contribution of an implementation of an interface, which enables the application of a specific Architecture Context to and from models. This is automatically invoked when an architecture context is applied or unapplied to a model. Each architecture context with a unique ID corresponds to a GMF client context with the same ID. Therefore, contributions to the element type set configurations for a given architecture framework can also be made by extending the element type configuration extension point with the same ID.

5.3 Architecture Domain Extensibility

An architecture domain can be defined by several independent architecture models that are merged dynamically at runtime. This is demonstrated in the example shown in Table 1 where the domain systems engineering is defined more than once. These multiple definitions of the same architecture domain requires that the domain elements be merged together. This merge procedure is subject to the following two assumptions.

A1: It is expected that only one of the merge increments for each element to have a value for the description attribute. In the event that more than one increment has a description value, one of them will be randomly picked.

A2: It is expected that all merge increments of an architecture context to have the same value for the ID attribute. In the event that more than one increment has a unique ID, an error will be logged.

The semantics of the implemented merge is achieved by applying the following rules.

R1: Architecture domains with the same name will be merged.
Stakeholders with the same name will be merged
Concern references will be merged

R2: Concerns with the same name will be merged

R3: Architecture framework with the same name will be merged
Architecture viewpoint with the same name will be merged
Representation kind references will be merged
Concern references will be merged

R4: Architecture description language with the same name will be merged
Architecture viewpoint with the same name will be merged
Representation kind references will be merged
Concern references will be merged
Element type set configurations references will be merged
Representation kind references will be merged

5.4 Model Migration Across Different Contexts

A third tooling concern is the need to migrate UML models from one architecture context to another, which is usually considered as a refactoring operation. Without knowing which architecture context a model belongs to or is migrating to, performing this refactoring becomes very tricky and error prone. However, when a model references an architecture context "A" and is migrating to architecture context "B", the latter's *conversionCommandClass* can be instantiated and run to perform the conversion to "B", while taking "A" into account. For example, converting a UML model to a SysML model involves applying the SysML profile, applying the relevant SysML stereotypes to various UML elements (e.g., stereotyping all classes with SysML::Block), and deleting all non-supported elements (e.g., UML::Component).

5.5 Support for Modeling Methodologies

A fourth tooling concern is supporting modeling methodologies. As mentioned earlier, by default, UML tools either show all their supported capabilities or allow them to be filtered globally. Unfortunately, both approaches do not allow a tool to support a modeling methodology that most often revolves around defining Model Kinds and grouping them into viewpoints that address specific stakeholders' concerns. With architecture models, a UML model can specify which architecture viewpoints, from the selected architecture context, should be enabled. These could be ones that frame the concerns of the current stakeholder's role. For example, if the stakeholder is a systems analyst that has a Specifying Requirements concern, then the Systems Analysis viewpoint, which includes the Use Case Diagram and the Requirements Diagram, would be visible. By switching roles or concerns, different viewpoints will be available and thereby, depending on the activated viewpoints, different Model Kinds can be made available. A user may also want to change the activation of the viewpoints manually to follow the steps of a methodology.

7. Implementation in the Papyrus UML Tool

We demonstrate the proposed approach by providing an implementation in the Papyrus opensource UML modeling tool. As depicted in Figure 6, the Architecture metamodel has been extended to introduce Papyrus-specific concepts and Papyrus's Model Kinds.

The Papyrus-specific metamodel includes an extension to both the ADL and the AF that make them reference a set of Element Type Set Configurations. The latter is Papyrus's model-based mechanism (details of this mechanism is outside the scope of this paper) of configuring the editing behavior for abstract or concrete syntax model elements.

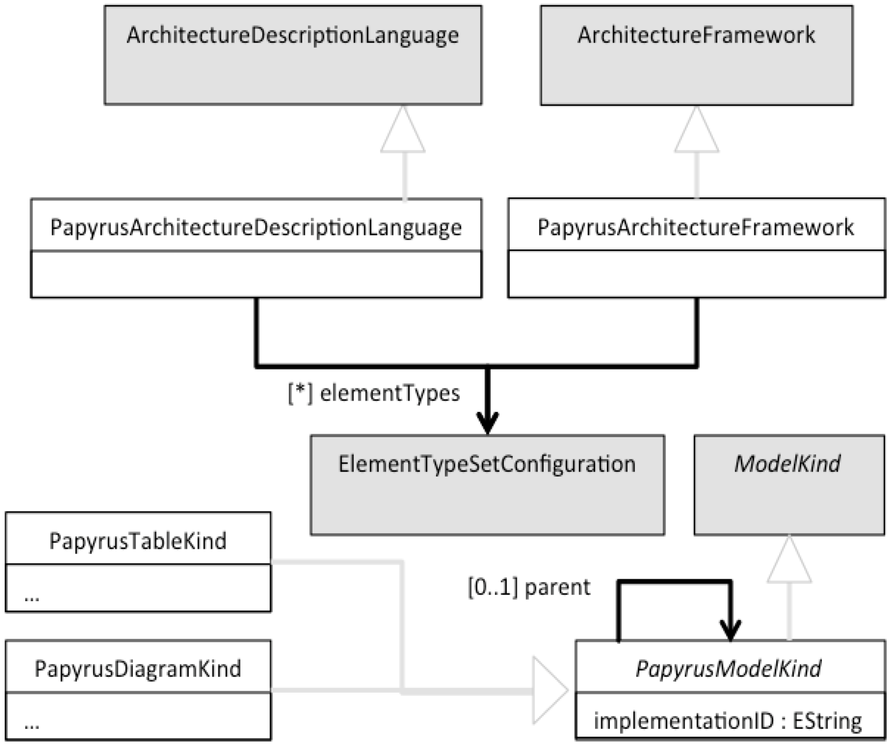

Figure 6. Papyrus Architecture Metamodel [24]

By referencing these configurations from an ADL or an AF, one can control how UML or DSML models can be edited in that context. The other extension in the Papyrus-specific metamodel is for Model Kind. The Papyrus Model Kind specifies an implementation id of an underlying model kind (diagram kind or table kind) that is supported by Papyrus. For example, the underlying Model Kinds include the 14 UML diagrams. This type has two subtypes, Papyrus Diagram Kind and Papyrus Table Kind that specify how an underlying model kind is customized (the customization details are beyond the scope of this paper) in the context of an ADL or AF. For example, a Package Diagram can be defined as a customization of the standard UML Class Diagram by limiting the elements on the diagram to UML Packages. Notice that a Papyrus Model Kind can also specify another model kind as its parent to inherit and add to its customization. For example, the UML Package Diagram can be a parent to a new version that restricts the content of the packages to Classes only.

Aside from the extended Architecture metamodel, we also implemented a mechanism, by which a single architecture domain can be defined across several architecture models that might be contributed by different extensions to Papyrus. To implement this, we used a composite design pattern. All the Papyrus tooling used the merged architecture elements from several architecture models. The merge required that single valued structural features (e.g., ADElement.id) have values in only one merge increment (the main architecture model), while multi-valued structural features (e.g., Architecture Domain. contexts) get their values aggregated across merge increments.

7.1 Examples

To demonstrate the impact of the approach implementation on Papyrus tool, we present two examples. The first to demonstrate the Architecture Context and the second to demonstrate the Architecture Viewpoints. At any point, users can modify their desired Context(s) and Viewpoint(s). If the UML Context is active, users will be able to create new UML relationship as shown in Figure 7. However, if SysML context is active, then only SysML relationships will be visible. In case both contexts are active, new relationships from both UML and SysML will be visible.

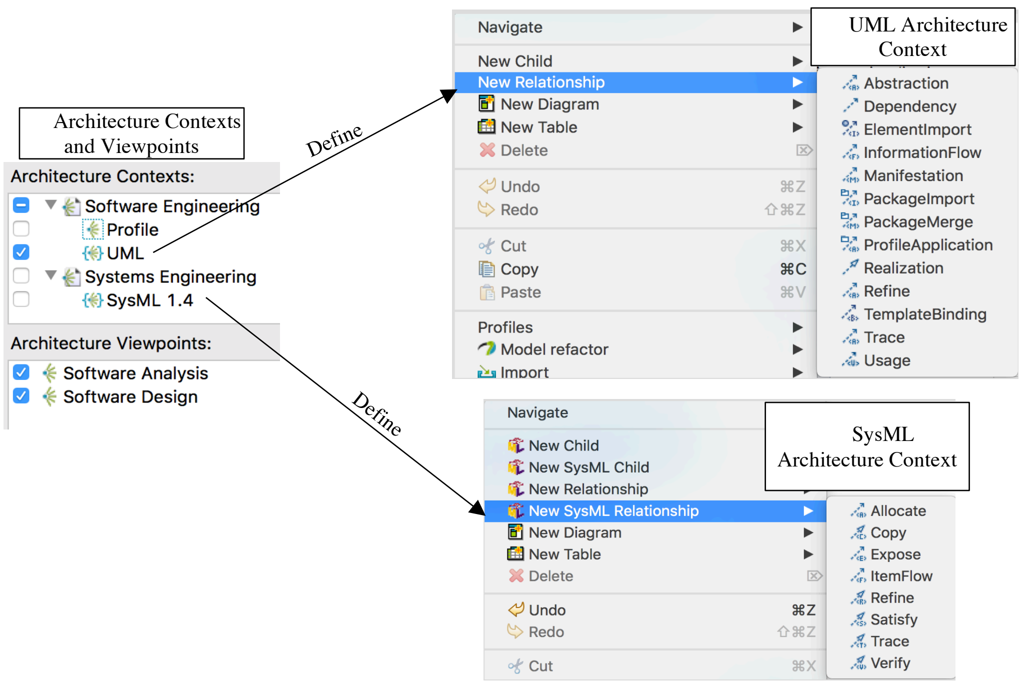

Figure 7: Architecture Context Implementation

Figure 8 demonstrates the implementation of Architecture Viewpoints. The example shows two Viewpoints; Analysis and design. Each viewpoint enables specific Model Types and addresses one or more user concerns.

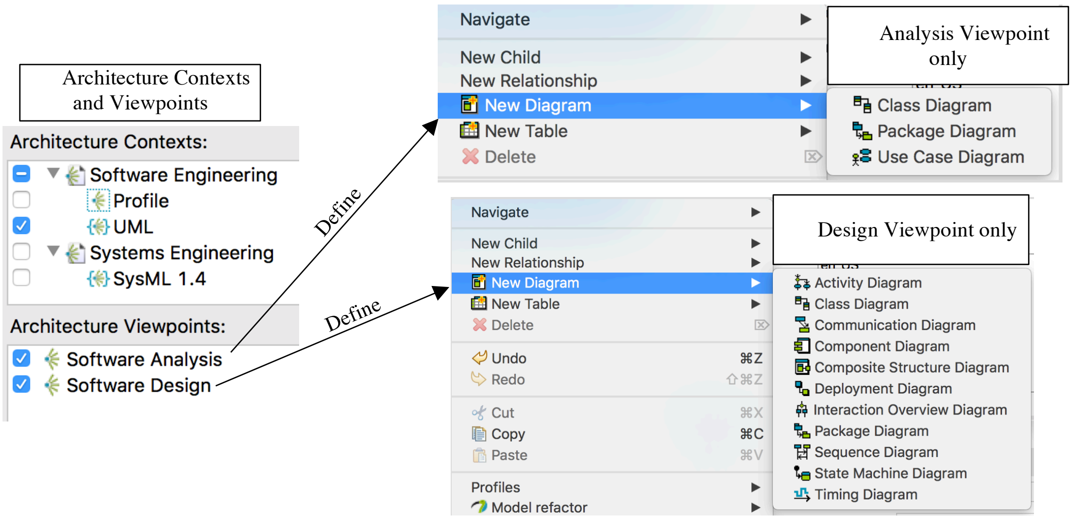

Figure 8: Architecture Viewpoints Implementation

Architecture Contexts and Viewpoints also defines other aspects of the UI, such as the available elements in the pallet, as well as other tool customization (i.e. default model element visibility).

8. Case Study

Our last contribution is a case study whose objectives are to a) show that several architecture contexts can be supported in the same tool (Papyrus in this case) without cross interference and b) that we can reduce the complexity of a modeling tool's UI by dynamically changing the UI based on a model's architecture context and enabled viewpoints. In particular, we defined two architecture models: a) one with one ADL (UML) and one AF (Profile), and b) one with another ADL (SysML). Table 1 summarizes the models' contents.

7.1 Architecture Context Independence

The first objective of the case study is to allow multiple architecture contexts (UML, SysML, Profile) to coexist in Papyrus without their contributions interfering with each other, which was a source of conflicts in the model editing behavior. Using the new approach, an architecture context is defined explicitly in architecture models. These contexts directly reference their supported model elements (using the Element Type Set Configurations), which makes it possible for Papyrus to allow exactly and only those elements to be used in each context, along with their supported editing behavior. This makes it easier to avoid interference, which increase the reliability of the tool but more importantly let tool smiths design their own domain specific tooling on top of Papyrus with no concern for potential conflicts with another architecture context. In fact, after the integration of this implementation with Papyrus code base, many other Papyrus ADLs and AFs were migrated to this new solution with reports of reduced development efforts.

Table 1. A Summary of the Case Study Architecture Models [24]

Context	UML	SysML	Profile
Context Kind	ADL	ADL	AF
Concerns	**C1**: Functions **C2**: Structure **C3**: Behavior **C4**: Interactions	**C5**: Requirements **C6**: Parametrics **C7**: Reliability	**C6**: UML Profiling
Stakeholders (Concerns)	**S1**: Software Engineer (C1, C2, C3)	**S2**: Systems Engineer (C1, C2, C3, C4, C5)	**S3**: Domain Architect (C6)

Model Kinds	**M1**: Class Diagram **M2**: Component Diagram **M3**: Deployment Diagram **M4**: Inner Class Diagram **M5**: Package Diagram **M6**: Profile Diagram **M7**: Composite Structure Diagram **M8**: State Machine Diagram **M9**: Sequence Diagram **M10**: Activity Diagram **M11**: Communication Diagram **M12**: Interaction Overview Diagram **M13**: Timing Diagram **M14**: Use Case Diagram	**M15**: Block Definition Diagram **M16**: Internal Block Diagram **M17**: Parametrics Diagram **M18**: Requirements Diagram **M19**: Requirements Table **M20**: Allocations Table	
Viewpoints (Model Kinds)	**V1**: Software Analysis (M1, M5, M10, M14) **V2**: Software Design (M1-M5, M7-M13)	**V3**: Systems Analysis (M15, M5, M14, M18, M19) **V4**: Systems Design (M15-M17, M20, M4, M5, M8-M13)	**V5**: Profile Definition (M1, M6)

7.2 Reducing UI Complexity

The second objective of the case study is to reduce the complexity (clutter) of the modeling tool's UI. Much of this complexity is due to displaying all existing model contents (abstract and concrete syntax elements) or potential new contents that can be created. For example, the model explorer view typically shows all existing elements in a model. Similarly, the explorer provides a context menu that allows creating all kinds of (abstract syntax and concrete syntax) elements in a model. Similarly, a diagram or table editor has a palette and/or a context menu that allows creating all possible model elements. The property sheet view also typically displays all properties of the current selection.

The way to reduce the UI complexity is to remove irrelevant existing elements (e.g., in the model explorer) or potential elements (e.g., menu actions to create new elements) from the UI. Traditionally, there is no reliable way to check for relevance, since there is neither explicit context nor any methodological preferences associated with the model. However, with our proposed approach, an explicit architecture context (ADL or AF), as well as a set of enabled/visible architecture viewpoints, are referenced by the model. As discussed in section 5, an architecture context in Papyrus specifies the set of (abstract syntax) element types that are supported. This can be used to automatically filter both the set of existing or potential elements in the model from the UI. Similarly, architecture viewpoints, and their Model Kinds, frame stakeholders' concerns. Therefore, by identifying the user as one of the supported stakeholders, the set of existing or potential Model Kinds that need to be visible can be derived automatically. Alternatively, a user can choose the set of enabled viewpoints, which also allows the calculation of the visible Model Kinds.

Furthermore, when we defined the set of three architecture contexts in the case study, we achieved reductions in the number of visible UI items, both existing and potential. Since the reduction of existing elements can only have statistical significance when measured on a set of representative UML or DSML user models, which we do not have now (we leave it to future work), we choose to report only on the reduction of potential elements (i.e., menu actions for creating new elements). Table 2 shows the number of menu actions for creating new abstract syntax elements (e.g., UML elements) and concrete syntax elements (i.e., diagrams and tables), both before and after applying our approach, as counted in the context menu of Papyrus's model explorer by right clicking on the root package (different numbers will result when clicking elsewhere in the hierarchy). For all architecture contexts, we assume that all their viewpoints are enabled (further reduction is expected when some of those views are disabled).

The data in Table 2 suggests that before applying our approach, the number of abstract syntax element create actions, which spanned all Packageable Elements in UML and SysML equaled 88. After applying our approach, the number is reduced by ~23% for UML, ~14% for SysML (lost the subset of UML not used in SysML but gained SysML specific subset), and ~72% for Profile (this is not surprising given that only a few elements from UML are needed). The table also suggests that the total number of concrete syntax elements (Model Kinds) create actions before our approach was 20 (14 UML diagrams+4 SysML diagrams+2 SysML tables). After our approach, the number is reduced by 35% for UML, 40% for SysML, and 90% for Profile.

Table 2. Number of New Element Actions in Model Explorer Before and After the New Approach [24]

Syntax	UML	SysML	Profile
Abstract Syntax Before	88	88	88
Abstract Syntax After	68	76	25
Concrete Syntax Before	20	20	20
Concrete Syntax After	13	12	2

Table 1: Percentage reduction in abstract and concrete syntax

Complexity Reduction in	UML	SysML	Profile	Average
Abstract Syntax	23%	14%	72%	36%
Concrete Syntax	35%	40%	90%	55%

9. Related Works

Complexity of UML modeling tools is a recognized and persistent challenge. The emergence of domain specific modeling languages and architectural frameworks means that modern modeling tools must support broader set of functionalities and expose even more elements to users. Petre has conducted a large-scale study of professional software engineers in 50 companies and reported that modeling tools complexity is a key impediment [11]. Forward and Lethbridge surveyed 113 software engineers to uncover patterns in their modeling practices [12]. Among their findings, the tools' steep learning curve and complexity appear to limit the adoption of the modeling practice. Baker et al report on their experience with MDA for over 20 years at Motorola [20]. They state multiple positive findings, including improved software quality and reduced defects rates. However, they identify key deficiencies in tool support for different languages and model exchange issues between development groups using different tools. Surveying the MDE practices in the Embedded Systems domain, Liebel et al find that interoperability, high levels of required training, and usability to be the biggest shortcomings of all [21].

Education on modeling driven engineering in software engineering programs seems to also suffer from the complexity of UML tools. One study reports that industrial-level modeling tools can be used in education, only if a dedicated and expert tool support is available [23], a prerequisite not easily met at many academic institutions. In an investigation of MDA pedagogies at four higher-level institutions, students consistently reported that UML, and its supporting tools, are too complex, and their associated overhead does not justify the added value [22].

Lightweight modeling tools have been developed to minimize the learning curve and reduce tool complexity. Examples of such tools include Umple [16] and TxtUML [17] that enable users to create models quickly using textual editors. Other works proposed a light version of UML itself [18]. These approaches do achieve some level of complexity reduction, but typically at the cost of compromised functionality.

Existing modeling tools may provide global preferences or settings to allow users to enable and disable modeling notations and/or features. This is the case in Rational Software Architect [19]. These global sittings are not tuned to the specific model(s) being worked on. Other tools provide pre-set preferences per role. For example, for an analyst role, the tool may hide away specific modeling notations and UI elements.

Architecture description languages and frameworks have emerged around the same time as UML. Some of the early ADLs include Rapide [5], Wright [6], and [7]. These early ADLs focused on structural concerns: large-scale system organization expressed in terms of components, connectors and configurations and had varying support for framing behavioral concerns. More recently, "wide-spectrum" ADLs have been developed which support a wider range of concerns. These include Architecture Analysis & Description Language (AADL) [8], SysML [9] and ArchiMate [10].

In 2000, the Computer Society approved IEEE Standard 1471 [4] which established a consensus on desirable architectural description practices. Heescha and Hilliard have proposed a documentation for architecture decision that is based on ISO42010 standard [2]. This framework focuses on four viewpoint definitions; a Decision Detail viewpoint, a Decision Relationship viewpoint, a Decision Chronology viewpoint, and a Decision Stakeholder Involvement viewpoint. These viewpoints definitions satisfy several stakeholder concerns related to architecture decision management. Hilliard also published a template that can be used by architects and organizations to specify architecture viewpoints in accordance with the ISO42010 standard [3].

10. Conclusion

Software modeling tools are notorious for their high level of complexity which negatively affect the tool usability and user experience. This complexity often stems from the underlying modeling language as tools must support broad set of modeling notations and concepts. As an example, UML modeling language contains thirteen modeling notations. This challenge is exacerbated further when Domain Specific Modeling Languages DSML are introduced. These DSMLs often introduce additional concepts and elements, further cluttering the user interface with more elements. Current approaches rely on using filtering mechanisms to control what elements are made visible to the user. However, these approaches suffer from two fundamental limitations. First, such filtering is often applied globally and is not sensitive to the specific user concerns or the related context. Second, these filtering approaches are not sensitive to the underlying methodology. Moreover, these filters do not address the need for tool customization required for specific context and model types.

This paper introduces a novel and systematic approach for reducing the complexity of modeling tools by leveraging the concepts of architectural contexts and viewpoints. This approach is inspired by and based on the ISO42010 standard which establishes coherent practices for describing the architecture of large and complex systems.

This paper makes four contributions; 1) interpreting and implementing the ISO 42010 standard in the Model Driven Engineering domain through a new Architecture metamodel that reflects and refines the vocabulary of the standard; 2) a demonstration of how the approach addresses several modeling tools' concerns including UI complexity, extensibility to other architecture contexts, model migration between architecture contexts, and support of modeling methodologies; 3) a working implementation of the approach in the Papyrus modeling tool, and 4) a case study that includes two architecture models that define three architecture contexts (UML, SysML, Profile). The case study demonstrates a) the proposed approach's effectiveness in easing the implementation of domain specific tooling and improving the reliability when several architecture contexts are supported, and b) the proposed approach's ability to reduce UI complexity by filtering UI items that do not suit the model's context and enabled viewpoints.

The proposed approach has the potential to significantly improve the usability of modeling tools in general. However, several limitations have been identified throughout the paper that we plan to address in future work. One of them is the effort to standardize the Architecture metamodel at OMG. However, we will first need to define the Model Kinds in a tool-neutral way, which would open the door for better modeling tool interoperability and improve the users' experiences across different modeling tools. We also plan to investigate the limit to which we can automate model migration between architecture contexts with more declarative means. We also plan to study the impact of this approach on reducing the visible details in user models.

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