Towards the Support of Design Patterns in the Fast Healthcare Interoperability Resources (FHIR) Standard

Timoteus Ziminski
Department of Computer Science and Engineering
University of Connecticut
Storrs, USA
e-mail: timoteus.ziminski@uconn.edu

Steven Demurjian
Department of Computer Science and Engineering
University of Connecticut
Storrs, USA
e-mail: steven.demurjian@uconn.edu

Thomas Agresta
Department of Family Medicine
University of Connecticut Health Center
Farmington, USA
e-mail: thomas.agresta@uconn.edu

Edward VanBaak
University College
University of Denver
Denver, USA
e-mail: edward.vanbaak@du.edu

***Abstract*— The Fast Healthcare Interoperability Resources (FHIR) advanced the Health Level 7 v2 (HL7), Extensible Markup Language v3 (XML), and Clinical Document Architecture (CDA) standards by defining over 135 resources that conceptualize the different aspects of healthcare data to facilitate the secure exchange of data for patients using cloud-based Application Programming Interfaces (APIs). As part of the design and development process of FHIR applications, a subset of the resources would be chosen to satisfy application requirements. While the FHIR standard is excellent at conceptualizing resources, this process is very targeted at the implementation level. FHIR provides no higher-level constructs to organize resources in a predevelopment process similar to what is available in software design patterns, which arose when developers noticed that they were constantly reimplementing the same types of functionalities in the same way for different applications. Our prior work extended the FHIR standard with meta resources, a conceptual construct that defines the involved resources and their interactions into one unified artifact akin to a design pattern, with the ability to generate a FHIR XML schema bundle that could serve as the foundation in a development workflow. This paper examines the way that our previously defined meta resource extension to FHIR can be positioned within the FHIR standard by: considering the relation between meta resources and resources that extends the FHIR Unified Modeling Language (UML) model; assessing the ability of the abstract DomainResource to implement containment in meta resources; exploring FHIR modules that provide organizational and contextual information different resources; examining the way that meta resources fit into the FHIR information architecture; and, determining if it is possible to employ a composition of Library resources and ActivityDefiniton resources in support of realizing meta resources.**

Keywords—design patterns; FHIR standard; interoperability; data design

I. INTRODUCTION

The Fast Healthcare Interoperability Resources (FHIR) [1] was introduced in 2014 to support and continue to advance interoperability and Health Information Exchange (HIE) and promote the secure sharing of healthcare data. The standard has passed through an initial maturity level and is currently widely endorsed and accepted by stakeholders, policymakers, and healthcare application developers. As a prominent example, The Office of the National Coordinator mandates FHIR [2] for making data available via APIs to patients and for data sharing. The FHIR standard defines over 135 resources, which are data elements to capture all types of healthcare data organized into different layers; the *base resource* layer contains patients, practitioners, family relationships, organizations, services, appointments, and encounters; and, the *clinical* layer has resources for a patient's health history, diagnostic data, medications, care provision, and request/response communication. Resources are also organized in the *foundation*, *financial*, and *specialized* layers.

In support of HIE and interoperability, we have prior work [3] on software architectural alternatives (e.g., service-oriented, grid computing, publish & subscribe paradigm, and data warehousing) with follow-up work [4] using FHIR to integrate health information technology (HIT) systems to facilitate collaboration among medical providers. Our most recent work [5] explored the inclusion of a design pattern-like concept of a *meta resource* in the FHIR standard. Meta resources can logically organize FHIR resources into a conceptual unit that, like a design pattern, can be customized and reused across multiple applications. With a collection of meta resources, it becomes possible to take design decisions in application development on a higher conceptual level, lower the overall development effort through the reuse of knowledge and introduce tool support and automated requirement validation of implemented solutions. Our focus in this paper is to explore integrating the meta resource concepts directly into the FHIR standard.

Design patterns are a classic and widespread approach in software engineering and development pioneered in [6]. The idea originated in an investigatory process when software engineers and developers realized that they constantly copied and reimplemented similar code in different projects. A well-known example is the Observer pattern for defining a one-to-many relationship between a *subject* (active object) and *observers* (passive objects), in which observers are notified about changes to the subject. The Observer pattern is instantiated to solve the problem of having one object change multiple other objects (e.g., reacting on an incoming HTTP request). Another widely used example is the Model View Controller pattern, which consists of: a *model* that captures the Enterprise data and the business rules associated with accessing and updating the data; a *view* that renders the contents or subset of the model for the presentation of the stored data; and, the *controller* that translates interactions with the view (button clicks, user interface (UI) actions, Hypertext Transfer Protocol (HTTP) calls, etc.) into actions on the model. This initial work subsequently led to the definition of higher-level architectural design patterns [7] that are more conducive to use application development using FHIR to facilitate HIE.

 ISBN: 978-1-61208-916-4

Design patterns can fit into the Enterprise architecture [8] of FHIR [9] as part of its overall information architecture. In addition to resources organized in the aforementioned five layers, the broader FHIR architecture model also includes a sixth *resource contextualization* layer containing FHIR profiles and graphs. Meta resources can fit into the FHIR's resource contextualization layer, thereby extending its architecture with additional relationship types, attributes, and constraints. Our recent work [5] leverages the extension concepts of FHIR profiles along with the grouping operation of Bundle resources to integrate meta resources seamlessly into the FHIR standard. This approach provides a design pattern-like capability that can augment and extend the existing functionality of FHIR by higher-level conceptual named constructs that, for particular workflows, clearly define the involved resources and their interactions into one unified artifact.

The main objective of this paper is to provide a detailed examination of the way that our meta resource extension to FHIR [5] can be positioned within five facets of the FHIR standard. The first facet is the inclusion of meta resources that would extend the FHIR UML model of resources [10]. The second facet will assess whether the abstract DomainResource [11] can be leveraged to implement containment in meta resources. The third facet explores FHIR modules [12] to see if they can provide the organizational and contextual information required for meta resources. The fourth facet examines the way that meta resources could fit into the FHIR information architecture [9]. The final facet explores the extent to which meta resources can be realized as a composition of Library resources [13] and ActivityDefiniton resources [14].

To illustrate the potential of the concepts of this paper, we will focus our work on the development of a mobile health application and framework [15] for medication reconciliation that integrates information from multiple EHRs. Please note that FHIR is an evolving standard (normative version v.4.0.1 at the time of writing). Therefore, the concepts in this paper and a discussion of the facets may be subject to change in future releases. As a result, the paper explores these facets as alternative approaches for incorporating meta resources into the FHIR standard instead of suggesting one fixed approach.

The remainder of this paper has four sections. Section 2 provides background information on medication reconciliation concepts and the FHIR concepts, both of which are used for examples throughout the paper. Section 3 summarizes our prior work [5] to present an outline of our model that extends FHIR with meta resources from which FHIR bundles can be automatically generated. Section 4 explores the aforementioned five facets to fully understand the way that meta resources can be included in the FHIR standard, thereby supporting a design pattern-like capability. Section 5 contains concluding remarks and outlines ongoing work.

II. BACKGROUND

This section provides background material in two areas. Section II.A explores medication reconciliation and its importance for healthcare. Section II.B presents FHIR concepts relevant to the paper.

A. Medication Reconciliation

Since a patient's medication regimen is the basis for treatment decisions, medication lists must be accurate to maximize therapeutic impact and prevent potentially life-threatening events. Discrepancies between the medication lists in HITs where patients receive care can potentially harm patients. This challenge is significant enough that in Connecticut (CT), the CT General Assembly passed Special Act 18-6: An Act Requiring the HIT Officer to Establish a Work Group to Evaluate Issues Concerning Polypharmacy and Medication Reconciliation [16] which produced several recommendations to the legislature which includes the development of technology to support the ability to generate the Best Possible Medication History via an automated electronic means [17]. To substantiate the discussion in this paper, we provide examples from our work [15], which presents a medication reconciliation solution that integrates information from multiple EHRs. We can combine the FHIR resources used by this solution (Patient, Medication, MedicationStatement, etc.) into a MedicationReconciliation meta resource which supports the actions of the application, including: retrieving medications from multiple EHRs, personal health records, and other HITs; combining and reconciling medications into a best medication list that identifies potential conflicts between the same or different medications; and, supporting an adaptive multi-use algorithm for medication reconciliation.

B. The Fast Healthcare Interoperability Resource, FHIR

FHIR is structured around the concept of resources, which are comprehensive data elements that hold the information expressed in FHIR. Formally, a FHIR resource R is defined as an entity with the properties set P = (Identity, Type, (Data Item*), Version). The *identity* property is used to address a given resource entity within a FHIR system consisting of one or more FHIR servers. The *type* property specifies one of the resource types that are provided by the FHIR specification. The *data items* property is a set of structured data elements, which holds the resource's actual data content as specified by its definition. The *version* property implements a version counter which tracks changes that occur to the contents of a resource through its lifetime. The record version automatically changes each time the resource changes, allowing a complete audit trail that tracks the evolution and the provenance of a resource. The FHIR standard defines representation formats in XML, JavaScript Object Notation (JSON), and Terse RDF Triple Language (Turtle).

```
<Medication xmlns="http://hl7.org/fhir">
 <identifier><!-- 0..* Identifier -->
 </identifier>
 <code><!-- 0..1 CodeableConcept --></code>
 <status value="[code]"/><!-- 0..1 -->
 <manufacturer>
  <!-- 0..1 Reference(Organization) -->
 </manufacturer>
 <form><!-- 0..1 CodeableConcept --></form>
 <amount><!-- 0..1 Ratio --></amount>
 <ingredient>
  <!-- 0..* Active/inactive ingredient -->
  <item[x]>
  <!-- 1..1 CodeableConcept|
   Reference(Substance|Medication) -->
  </item[x]>
  <isActive value="[boolean]"/><!-- 0..1 -->
```

```
  <strength><!-- 0..1 Ratio --></strength>
 </ingredient>
 <batch>
  <!-- 0..1 Packaged medications details -->
  <lotNumber value="[string]"/><!-- 0..1 -->
  <expirationDate value of="[dateTime]"/>
   <!-- 0..1 -->
 </batch>
</Medication>
```

Figure 1: Medication XML Schema.

Figure 1 contains an abbreviated portion of the Medication resource. Note that for these two examples and all other examples, we have omitted some of the details as it impacts the single column display; see [18] for complete versions.

III. Summarizing Meta Resource Concepts

This section reviews the meta resource model of our prior work [5], highlighting the key concepts necessary for the remainder of the paper. Section III.A reviews the model for describing a meta resource and provides examples. Section III.B explores the generation of a FHIR bundle that, combined with the meta resource definition, represents a design pattern-like for a particular problem.

A. *Meta Resource Capabilities and Example*

To begin, a *FHIR resource* is a four-tuple of identifier, type, date, and version $R = < R_{ID}, R_{Type}, R_{Data}, R_{Version} >$. Example 1 illustrates a Patient [18] instance according to this definition.

Example 1. A FHIR *Patient* resource instance for patient John Doe after five changes is represented by

$$R_1 = < R_{ID_1}, t_1, R_{Data_1}, x >$$

where

$$R_{ID_1} = \ http://test.fhir.org/rest/Patient/123$$

and

$$t_1 = Patient$$

and

$$R_{Data_1} = \{\{"identifier": \text{"ea44426f"}, \text{"active": "true"}, \text{"name": "John Doe"}, \text{"telecom": "555-370-8047"}, \text{"gender": "male"}, "birthDate": \text{"1970} - 12 - 12\text{"}, \ldots\}$$

and

$$x = 5$$

Next, we review the concept of *meta resources* to leverage the design pattern idea and define higher-level design constructs that can represent multiple resources needed to implement a particular application. This transcends the resource-centric view of FHIR on clinical data. Meta resources provide reusable workflow-centric patterns that allow a conceptual view for implementing functionalities in an already FHIR enabled system. Sample workflows include medication reconciliation, patient admission, or vaccination support.

The definition of a specific meta resource determines the properties, components, relationships, and requirements that the given meta resource has to an implementing system. To implement a particular workflow, a meta resource from a library of previously implemented solutions can be used as a pattern for the high-level design of applications and as a schema against which actual implementations are checked for full functionality. The overall objective of a meta resource is the larger granular organization of resources for a specific health-related workflow, described via human-readable description.

Example 2 has an instance of a *MedicationReconciliation* meta resource for the medication reconciliation as introduced in Section II.A and implementing the meta resource structure shown in Figure 2: the Patient resource holds demographic information of the affected patient. It references one or more MedicationStatement resources. The MedicationStatement identifies that a patient is or was taking a medication. It contains a Medication resource identifying the actual medication. It also references one Endpoint resource to indicate from where the statement was retrieved. Finally, it also references one Practitioner resource that identifies the individual who should be notified if issues regarding this statement are detected. A DetectedIssue resource references two or more medication statements, indicating a potential problem between those statements, which must be resolved during reconciliation. An Endpoint records information on which system needs to be notified regarding a discovered issue. It represents a health information technology system such as an electronic health record at a hospital, a rehab facility, a clinician’s office, etc., that must be notified whenever a change is made. The Endpoint references a Practitioner resource to identify a practitioner who needs to be contacted regarding issues detected during reconciliation for a given medication statement. In summary, the MedicationReconciliation meta resource comprises six different FHIR resource types and models their relationships in the scope of a medication reconciliation workflow.

Example 2. In the formal model introduced in [5], the meta resource *MedicationReconciliation* is represented by

$$MR_1 = < MR_{ID_1}, MR_{Name}, MR_{Desc_1}, MR_{PR_1}, MR_{API}, MR_{REF_1}, MR_{COM_1} >$$

where

$$MR_{ID_1} = http://test.fhir.org/rest/meta/MedicationReconconciliation/123$$

and

$$MR_{Name_1} = MedicationReconciliation$$

and

$MR_{Desc_1} =$ *”Medication reconciliation is the process of comparing a patient’s medication orders to all the medications that the patient has been taking and eliminating potential errors, resulting in a new up to date list of medications.”*

and

$$\begin{aligned} MR_{PR_1} = \{ &\mathrm{pr_{patient}} = < Patient, \mathrm{entity} >), \\ &\mathrm{pr_{medStatement}} = < MedicationStatement, \mathrm{producer} >, \\ &\mathrm{pr_{med}} = < Medication, \mathrm{dataSource} >, \\ &\mathrm{pr_{endPoint}} = < EndPoint, \mathrm{address} >, \\ &\mathrm{pr_{practiotioner}} =< Practitioner, \mathrm{entity} >, \\ &\mathrm{pr_{issue}} = < DetectedIssue, entity >\} \end{aligned}$$

and

$$MR_{API} = < profile >$$

and

$$\begin{aligned} MR_{REF_1} = \{ &< pr_{patient}, pr_{medStatement} >, < pr_{medStatement}, pr_{endPoint} >, \\ &< pr_{medStatement}, pr_{practitioner} >, \\ &< pr_{issue}, pr_{medStatement} >\} \end{aligned}$$

 ISBN: 978-1-61208-916-4

and

$$MR_{COM_1} = < pr_{medStatement}, pr_{med} >$$

Each resource in a meta resource is classified according to the service it provides, such as *consumer*, *producer*, *data source*, or *data generator*. For example, in Figure 2, the Medication resource will serve as a *data source* for performing the reconciliation. In contrast, the FHIR *MedicationStatement* can serve as a *producer* of further medication resources. Fundamentally, a meta-resource is a composition of standard FHIR resources enriched with meta-information to define the structure and interactions of FHIR resources on the design level. A meta-resource definition contains a specification of FHIR resources that must be available to instantiate the meta resource, known as the participating resources.

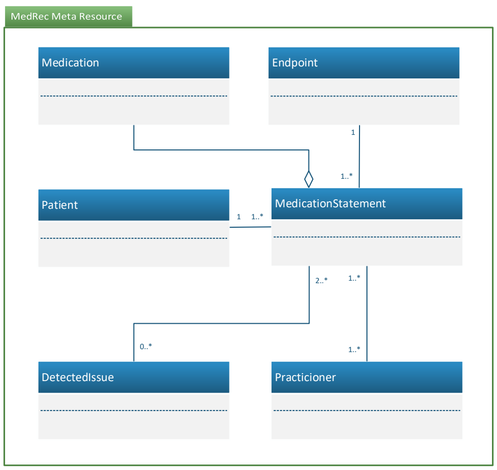

Figure 2. Medication Reconciliation Meta Resource.

B. *FHIR Bundle Generation*

This section briefly reviews our approach for automatically transitioning a meta resource definition into a destination FHIR bundle at the schema level. Details of the process and the associated algorithm were documented in our previous work [5]. FHIR Bundle resources [19] are container resources built explicitly into the standard to group other references, for example, in the context of search results or for the exchange of messages. Conceptually, a bundle consists of meta-information about the bundle itself (such as an identifier), entries encapsulating FHIR resources, and links between those entries and potentially other outside resources. FHIR bundles allow references and containment and are capable of reflecting the relationships shown in the meta resource in Figure 2.

As one transitions from design to the development of the healthcare application, the FHIR bundle can facilitate the exchange with another system. This approach aims to ensure baseline compatibility with systems that are not aware of meta resources while simultaneously leveraging existing communication APIs for interacting with other meta resource-enabled systems. To illustrate the process, a meta resource needs to be transitioned to a suitable FHIR artifact to construct a representation that is amenable to realization within a particular healthcare application.

```xml
<Bundle xmlns="http://hl7.org/fhir">
 <!-- for readability expand $url = http://hie.org/fhir -->
 <id value="bundle-metaressource-collection"/>
 <type value="collection"/>
 <entry>
  <fullUrl value="$url/Patient/123"/>
  <resource><Patient><!-- John Doe --></Patient></resource>
 </entry>
 <entry>
  <fullUrl value="$url/Practioner/123"/>
  <resource><Practitioner><!-- Dr. Max Mustermann --></Practitioner></resource>
 </entry>
 <!-- Further practioner entries -->
 <entry>
  <fullUrl value="$url/Endpoint/123"/>
  <resource><Endpoint><!-- hl7-fhir-rest endpoint --></Endpoint></resource>
 </entry>
 <!-- Further endpoint entries -->
 <entry>
  <fullUrl value="$url/MedicationStatement/123"/>
  <link><relation value="related"/><url value="$url/Patient/123"/></link>
  <link><relation value="related"/><url value="$url/Practioner/123"/></link>
  <link><relation value="related"/><url value="$url/Endpoint/123"/></link>
  <resource>
   <MedicationStatement>
    <id value="medstatement001"/>
    <contained><Medication> <!-- id="med309" --></Medication></contained>
    <medicationReference><reference value="#med0309"/></medicationReference>
    <subject><reference value="Patient/123"/></subject>
   </MedicationStatement>
  </resource>
 </entry>
 <!-- Further MedicationStatement entries, including
 medstatement002 at $url/MedicationStatement/124 -->
 <entry>
  <fullUrl value="$url/DetectedIssue/123"/>
  <link><relation value="related"/><url value="$url/MedicationStatement/123"/></link>
  <link><relation value="related"/><url value="$url/MedicationStatement/124"/></link>
  <resource>
   <DetectedIssue>
    <code><!-- Drug Interaction Alert --></code>
    <implicated><reference value="MedicationStatement/medstatement001"/></implicated>
    <implicated><reference value="MedicationStatement/medstatement002"/></implicated>
   </DetectedIssue>
  </resource>
 </entry>
 <!-- Further DetectedIssue statements -->
</Bundle>
```

Figure 3. Generated Bundle.

Our algorithmic process documented in [5] takes the meta resource of Figure 2 and creates a meta resource bundle that captures all of the components and relationships conforms to the FHIR bundle XML schema and generates a bundle resource as given in Figure 3. Specifically, for every medication reconciliation meta resource, the initial generation is the top-level bundle element and a single patient element. Then the participating resources, as given in Figure 2, are processed into matching bundle entries and explicitly connected by bundle links to express their interactions and relationships.

IV. INTEGRATING DESIGN PATTERNS INTO FHIR

This section reviews five facets of the FHIR standard that give anchor points for extending the standard and explores multiple approaches for conceptually including the meta resource model concepts of Section III.A into the standard. The first facet in Section IV.A investigates the relation between meta resources and FHIR resources, which is explored by extending the relevant UML model. Section IV.B, the second facet, inspects the functionality provided by the abstract DomainResource resource as a potential candidate to implement the containment of resources in meta resources. Section IV.C, the third facet, explores the organization of FHIR resources in FHIR modules and identifies modules that would be affected by the meta resource extension. Section IV.D, the fourth facet, details the way that meta recourses fit into the FHIR information architecture. The fifth facet in Section VI.E explores the composition of the Library and ActivityDefiniton resources. The concepts discussed in this section are partially at the initial stages of development (e.g., the FHIR module definitions) and may be subject to change in future releases. Therefore, we explore several alternative approaches for incorporating meta resources instead of suggesting a fixed direction.

 ISBN: 978-1-61208-916-4

A. Meta Resource Capabilities and Example

To begin, in the first facet we consider, meta resources are directly related to the published resources [10] defined in the FHIR standard. They assemble a set of participating resources enriched with additional context information into higher-level artifacts. On a schema level, this enhances reusability by tailoring extensive resources that can be used to solve specific workflows in different parts of the health care domain. This is similar to the way that design patterns are used to tackle reoccurring problems across the software engineering domain. Then on an instance level, meta resource instances directly group instances of FHIR resources containing medical data and share them across systems that use FHIR seamlessly. This direct relationship between meta resources and participating FHIR resources allows for incorporating meta resources into FHIR by regarding them as entities related to FHIR resources. Figure 4 shows the UML structure of meta resources in the context of the FHIR resource UML structure, with new UML classes added for MetaResource and ResourceTuple at the top of the figure (top two boxes).

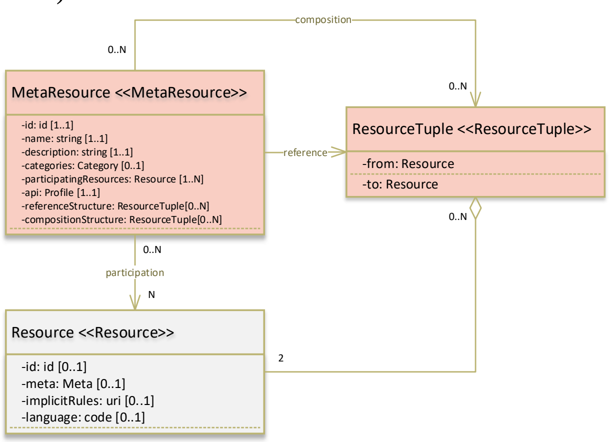

Figure 4. Meta Resource UML Structure.

Figure 4 demonstrates the UML artifact of a FHIR resource class defined by the FHIR specification [10] and the UML artifact of a meta resource class with its attributes as defined in Section III. The meta resource relates directly to FHIR resources by the participation relation, which models the collection of participating resources. Furthermore, the reference relation which models the *referenceStructure* property relates the meta resource to a ResourceTuple class, which combines two FHIR resources into a directed pair. For this use case, the *from* resource in the tuple references the *to* resource. A similar application is modeled for the composition relation, which models the *compositionStructure* property of a meta resource. Here the from resource contains the to resource of the tuple.

B. Domain Resources

The abstract resource DomainResource is the second facet we explore and is a foundation resource that provides common functionality to resources from which they were derived [11]. As an abstract resource, it is not directly instantiated, but because all of the standardized resources (except for Bundle, Parameter, and Binary) extend the DomainResource, its functionality is broadly available in the resource model. There is a property to a DomainResource that initially appears highly useful for including meta resources in the FHIR framework: the option to specify additional *contained* resources within a resource that closely relates to the grouping nature of meta resources. Since the *contained* property allows a designer to assemble other resources within a given resource (which then becomes a container), it provides functionality that fundamentally could express participating resources. Based on this, a possible approach would be to define a meta resource as a resource derived from DomainResource as illustrated in Figure 5. In the figure, the inheritance relation of DomainResource and Resource, the contained property, and a suggested extension relation of the MetaResource in the upper left would make the *contained* property available to all of the meta resources.

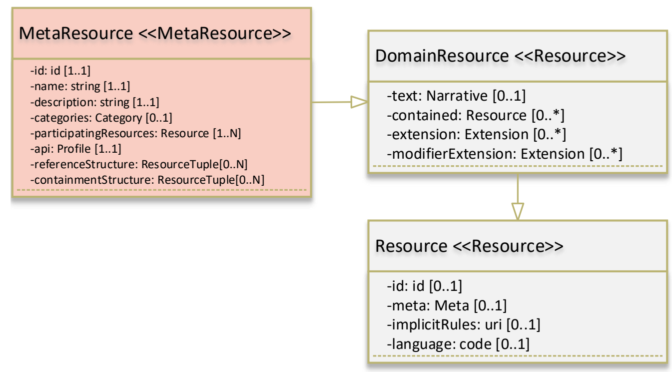

Figure 5. DomainResource Inheritance Structure.

However, closer inspection shows some significant limitations to this property and its application within the current version of the framework, limiting its value for incorporating meta resources into the standard. The resources referenced by the contained property are conceptually only existent in the scope of the container resource [11] and can neither be referred to without the container nor be passed around in their own transactions. This prohibits the idea of disassembling and partially using meta resources where they cannot be understood by plain FHIR systems and poses a problem to implement the reference and containment structures since they cannot reliably reference the contained elements without them having an own identity. Finally, contained resources may not contain further nested resources; therefore, a meta resource based on this property could not assemble arbitrary participating FHIR resources but would need to explicitly prevent them from nesting any data, which would harm the expressiveness of the model. As a result, the DomainResource functionality alone is not suitable to model meta resources within the FHIR standard.

C. FHIR Modules

The FHIR specification is organized in different functional areas to provide high-level guidance to implementers of the standard to make appropriate decisions on which parts of FHIR are required to model a particular healthcare process for solving a specific problem. These areas are reflected by *FHIR modules* [12] which is the third facet that we examine and aims to provide organizational and contextual information about the parts of the standard they cover. Towards this goal, modules are utilized to define: a *scope and index*, *use cases*, *security and privacy information*, and a *roadmap* for their content. The *scope and*

 ISBN: 978-1-61208-916-4

index provide developers with an introduction to the module, which consists of a textual description of the conceptual goals of the module and the envisioned functional range of the module. Furthermore, scope and index also summarize the technical content (i.e., the resources) of the module. The included *use cases* provide guidance and examples on using the contents of the module for implementing solutions. The *security and privacy information* component of the modules highlights areas of special caution and overall consideration for securing data expressed by the module. With FHIR still evolving as a standard, the roadmap provides information on the state of the evolution in maturity of the module's contents with respect to the overall standard.

As shown in Figure 6 [12], modules are classified into multiple levels, which offer a comprehensive and goal-focused view of FHIR information architecture. Levels 1 and 2 provide the technological foundation starting at low-level data types and exchange formats and extending to implementation basics and external specifications. Levels 3 and 4 contain parts of the standard used to model the healthcare domain's content and processes. Finally, Level 5 provides the means for reasoning over the information recorded and exchanged in the lower levels. Again, concepts from higher levels logically depend on the concepts introduced in the lower levels.

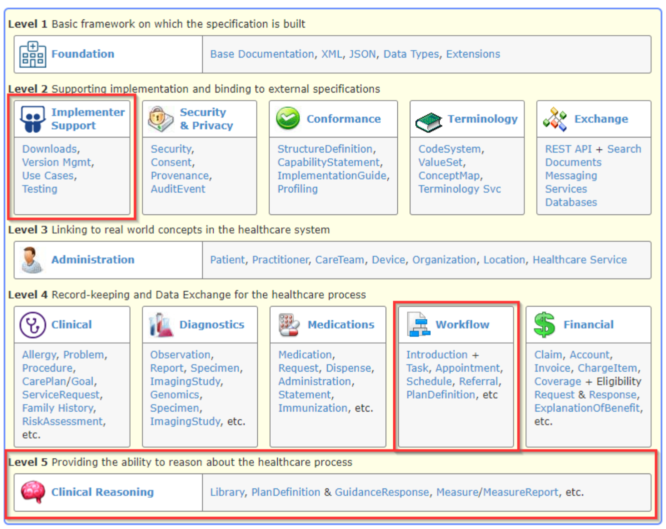

Figure 6. Organization of FHIR in Modules.

Note that modules are not necessarily mutually exclusive in their content. To illustrate this, consider that the PlanDefinition resource is used to define executable plans such as a chemotherapy regimen which means that it is both conceptually part of the workflow module in Level 4 as well as of the clinical reasoning module in Level 5. Similarly, the meta resources introduced by this proposal crosscut the module classification and can be primarily assigned to multiple levels specifically: the implementer support module in Level 2; the workflows module in Level 4; and, to some extent, to the clinical reasoning module in Level 5. Fundamentally, a meta resource (as with a design pattern) intends to simplify the development process of FHIR applications and eliminate repetitive decision processes by providing a specific framework for resource assembly. At the schema level, this is initially unrelated to the actual content of the resources and therefore fits into the implementer support module (at the technological foundation provided by Level 1 and Level 2). However, the composition of resources as part of the meta resource naturally allows for simplified and reusable modeling of generic workflows; therefore, actual instances of meta resource would be used to improve the workflow module in Level 4. Finally, the management of meta resources as artifacts that bundle lower-level resources, enrich them with additional knowledge about their relationships, and are provided as an advanced toolset in the standard would be classified into the clinical reasoning module in Level 5. Figure 7 illustrates the selected FHIR modules of the module architecture extended by meta resources (reduced to just the affected modules).

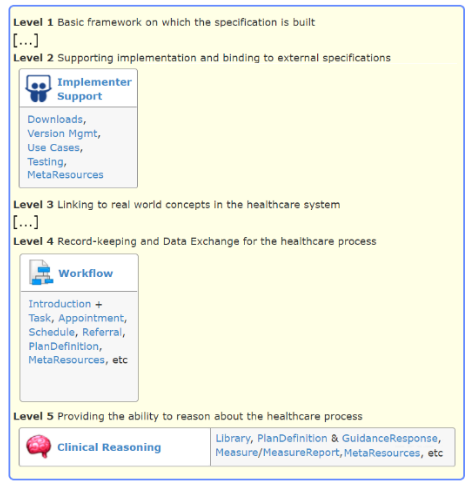

Figure 7. FHIR Modules extended by Meta Resources.

D. *Information Architecture*

Meta resources can be introduced into the FHIR standard as part of the information architecture, the fourth facet we explore, depicted as the composition framework in Figure 8 [9]. The resource contextualization Layer 6 of the architecture is designated to adapt FHIR resources to a specific environment. In contrast to the other layers, the information architecture serves a special purpose, as it does not contain resources but represents concepts that extend, constrain, add additional attributes, or provide meta information to the resources that are assigned to Layer 1 (Foundation Resources) through Layer 5 (Specialized Resources). Figure 8 illustrates a suggested extension of Layer 6 (hosting FHIR profiles and graphs) by the meta resource concept.

Profiles are used to tailor the FHIR specification to a specific environment. They achieve this by providing rules that allow a designer to restrict or extend the specification. In terms of resource attributes, profiles offer the ability to either disallow the use of specific attributes or add additional attributes to resources. An example use-case for this functionality is to facilitate the enforcement of adequate terminologies for a given domain. Profiles also allow the extension/restriction of the API that a FHIR server supports, therefore enabling an implementer to add custom services to the rest interface. In summary, profiles allow the modification of the data model of the specification and extend the supported means of communication, which is fundamental for supporting our meta resource extension.

 ISBN: 978-1-61208-916-4

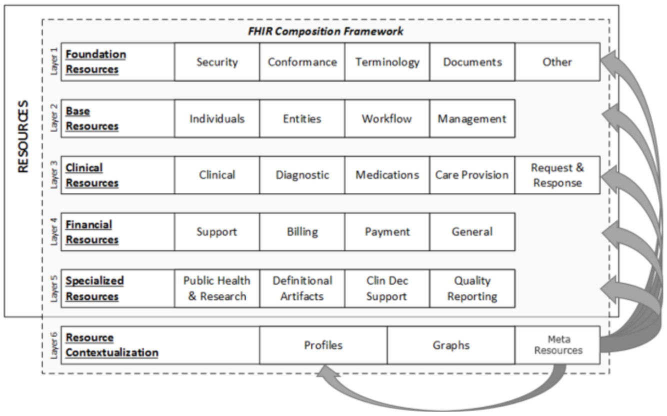

Figure 8. Information Architecture in FHIR.

For example, consider the mapping of the components of a meta resource serving for a medication reconciliation workflow to the relevant framework layers as displayed in Figure 9, where the box in the lower-left labeled MedRec Meta Resource indicates the system borders of the meta resources. The implementation of such a medication reconciliation meta resource (see Section III.A again) requires at least six FHIR resources: Medication, MedicationStatement, and DetectedIssue resources (*Clinical* resources in Layer 3) for modeling the medication information; the Patient and Practitioner resources (*Individuals* resources in Layer 2) for representing the involved individuals; and the Endpoint resource (*Entities* resources in Layer 2) to identify and address participating HER systems. Finally, the functionality of a specific MedRec FHIR profile is required to describe the APIs functionality for interacting with the meta resource (Layer 6).

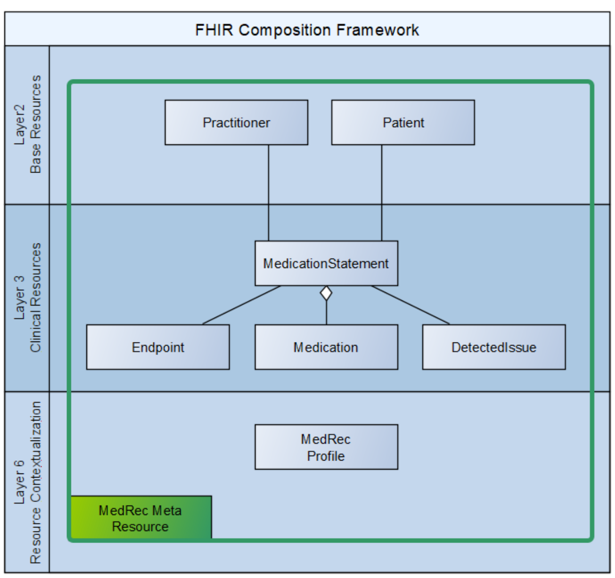

Figure 9. MedRec Meta Resource with Layer Associations.

E. Composition of Library and ActivityDefiniton Resources

In addition to Bundle resources, the FHIR standard offers further resources that can define collections of other resources, such as the Library resource and the ActivityDefinition resource, the fifth facet we explore, that can be combined to model an advanced level of resource composition. The FHIR Library resources are general purpose containers for expressing and sharing clinical knowledge assets independently of a particular patient [13]. The content of a Library resource (i.e., the *knowledge asset*) may consist of arbitrary non-FHIR data (e.g., the XML schema for an information model) but can equally consist of nested FHIR resources. Furthermore, Library resources also allow the definition of *parameter* properties for enforcing prerequisites to using the library's functionality. In this function, Library resources can provide some degree of composition of FHIR resources as required for the proposed meta resource.

The FHIR ActivityDefinition resource describes an activity in a sharable and potentially machine-consumable form [14], which can then be utilized to define parts of a workflow, to describe a protocol, or to create a catalog of activities. This functionality is consistent with our objective of realizing meta resource as a reusable, shareable, design pattern-like component. An ActivityDefinition is intended to be interpreted by humans but can also be filled with enough structured data to instantiate resources that reflect the modeled information. The combined use of Library resources and ActivityDefinition resources has the potential for utilization to represent a significant portion of the meta resource concept. The structure of this approach is illustrated in Figure 10, which shows the realization of meta resources together with a supporting ParticipantTuple structure (both extensions are at the bottom of the figure) through the extension of a Library resource that references an Activity resource definition (Library and ActivityDefinition are reduced in the diagram to the attributes relevant for the discussion).

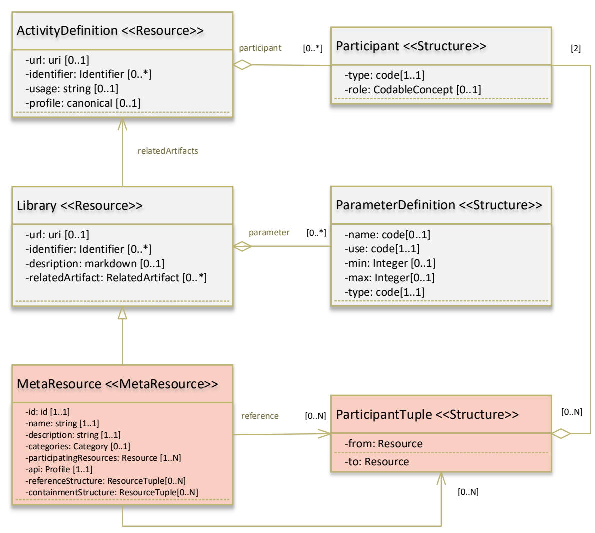

Figure 10. Composition of Library and ActivityDefinition.

The *name* and *description* elements of the meta resource can be realized by the respective *description* and *usage* attributes in Library and ActivityDefinition resources. The participating resources are defined by the parameter relation of the Library to a set of ParameterDefinition structures. Among a series of other types, ParameterDefinitions can be of type Resource, and therefore can encode the knowledge about required resource types for a meta resource. The Library resource then references an ActivityDefinition, which in turn groups the instances of the participating resources as Participant structures and provides the necessary FHIR profile for interacting with the resource. As a result, the meta resource extension is only left with defining the *referenceStructure* and the *compositionStructure*, which can be achieved by introducing a directed ParticipantTuple relation between Participant instances (in the same fashion as suggested for ResourceTuples in Section IV.A)

V. CONCLUSION

This paper has presented the extension of the FHIR standard with the concept of a meta resource for design pattern-like capabilities and provided an examination of the alternative ways that meta resources can be positioned within five different facets of the FHIR standard. To present our work, we reviewed the background on medication reconciliation concepts and FHIR that we use for examples in Sections III & IV. We briefly reviewed the formal model for meta resources and the algorithmic translation of meta resources to FHIR bundles in Section III. In Section IV, we examined five facets of FHIR as alternative approaches for integrating meta resources into the FHIR standard. Specifically, we: explored meta resources as an extension to the FHIR UML model; assessed the relationship of the abstract DomainResource to meta resources; examined FHIR modules and the organizational and contextual information they could provide for meta resource integration; included meta resources into the FHIR information architecture; and considered meta resources as a composition of Library resources and ActivityDefiniton resources. Overall, we believe that meta resources offer an important design pattern-like capability to expand the FHIR standard and promote a much higher level of abstraction.

Ongoing work focuses on several different areas. To fully determine the benefits from using the meta resource concept, we intend to work with the team of the medication reconciliation application to assist in reformulating their usage of FHIR resources into a MedicationReconciliation meta resource as given in Section III. Another area is to fully formalize the appropriate notation so that the meta resource can fully fit into the defined FHIR standard by using only predefined FHIR conventions. Finally, we will explore generation options for FHIR facets introduced in Section IV in addition to the discussed bundle generation.

REFERENCES

[1] HL7 International. *FHIR Overview*. [Online]. Available from: https://www.hl7.org/fhir/overview.html 2021.09.08

[2] Office of the National Coordinator for Health Information Technology. *ONC's Cures Act Final Rule*. [Online]. Available from https://www.healthit.gov/curesrule/ 2021.09.08

[3] T. B. Ziminski, S. A. Demurjian, E. Sanzi, and T. Agresta, "Toward Integrating Healthcare Data and Systems: A Study of Architectural Alternatives," in Maximizing Healthcare Delivery and Management through Technology Integration, Iyamu, T., Tatnall, D., Eds. IGI Global, pp. 270-304, 2015

[4] T. B. Ziminski, S. A. Demurjian, E. Sanzi, M. Baihan, and T. Agresta, "Chapter 14: An Architectural Solution for Health Information Exchange," in Virtual and Mobile Healthcare: Breakthroughs in Research and Practice, IGI Global, pp. 283-327, 2020.

[5] T. B. Ziminski, S. A. Demurjian, and T. Agresta, "Extending the Fast Healthcare Interoperability Resources (FHIR) with Meta Resources," Proceedings of the 16th International Conference on Software Technologies, ICSOFT 2021, July 2021, in press.

[6] E. Gamma, *Design patterns: elements of reusable object-oriented software*, Addison-Wesley Professional, 1995.

[7] P. Kuchana, *Software architecture design patterns in Java,* CRC Press, 2004.

[8] J. A. Zachman. *Enterprise Architecture Defined: Architecture Abstractions*. [Online]. Available from https://www.zachman.com/resources/zblog/item/enterprise-architecture-defined-architecture-abstractions 2021.09.08

[9] HL7 International. *FHIR Architecture*. [Online]. Available from: https://www.hl7.org/fhir/overview-arch.html 2021.09.08

[10] HL7 International. *FHIR Specification: Base Resource Definitions*. [Online]. Available from: http://hl7.org/fhir/resource.html 2021.09.08

[11] HL7 International. *FHIR Specification: DomainResource Resource*. [Online]. Available from: http://hl7.org/fhir/domainresource.html 2021.09.08

[12] HL7 International. *FHIR Modules*. [Online]. Available from: https://www.hl7.org/FHIR/modules.html 2021.09.08

[13] HL7 International. *FHIR Specification: Library Resource*. [Online]. Available from: http://hl7.org/fhir/library.html 2021.09.08

[14] HL7 International. *FHIR Specification:ActivityDefinition Resource*. [Online]. Available from: http://hl7.org/fhir/activitydefinition.html 2021.09.08

[15] T. Agresta et al., "A Mobile Health Application for Medication Reconciliation Using RxNorm and FHIR". Proc. of the Fifth Intl. Conf. on Informatics and Assistive Technologies for Health-Care, Medical Support and Wellbeing (HEALTHINFO 2020), pp. 1-10, Oct 2020.

[16] CT State Legislature. *Connecticut SB00217 | 2018 | General Assembly*, *LegiScan*. [Online] Available from: https://legiscan.com/CT/bill/SB00217/2018 2021.09.08

[17] OHS Connecticut. *Work Group – Final Report*, pp 25-76 [Online]. Available from: https://portal.ct.gov/-/media/OHS/Health-IT-Advisory-Council/MRP/MRP_WG_FINAL_Recommendations.pdf 2021.09.08

[18] HL7 International. *FHIR Architecture*. [Online]. Available from: https://www.hl7.org/fhir/resourcelist.html 2021.09.08

[19] HL7 International. *FHIR Architecture*. [Online]. Available from: https://www.hl7.org/fhir/bundle.html 2021.09.08

 ISBN: 978-1-61208-916-4