Extending the Fast Healthcare Interoperability Resources (FHIR) with Meta Resources

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Abstract: The Fast Healthcare Interoperability Resources (FHIR) from the international Health Language Seven (HL7) organization has been mandated by the United States Office of National Coordinator to promote the secure exchange of healthcare data for patients through the use of cloud-based APIs. FHIR reformulated the HL7 XML standard by defining 135+ resources that conceptualize the different aspects of healthcare data such as patients, practitioners, organizations, services, appointments, encounters, diagnostic data, and medications. Developers of healthcare applications select a subset of the resources that are required to solve their problems. However, the standard provides no way to effectively organize a subset of resources into a higher-level construct similar to software design patterns. This paper leverages the design pattern concept to extend the FHIR standard by defining *meta resources* that are a conceptual construct that clearly defines the involved resources and their interactions into one unified artifact. To illustrate the concepts of this paper, we use a mobile health application for medication reconciliation that integrates information from multiple electronic health records. We leverage FHIR extension mechanisms such as profiles and Bundle resources to integrate the meta resource into the resource contextualization layer of the FHIR standard.

1 INTRODUCTION

Electronic health records (EHRs) have reached a market saturation nearing 92% (Heath, 2016) but cross-institutional data-sharing is still challenging for stakeholders (e.g., medical providers such as physicians, hospitals, clinics, labs, etc.) and fails to be fully supported by health information exchange (HIE). Particularly when clinical providers use different health information technology (HITs) systems in geographically separate locations. The demand for interoperable HIE that allows multiple HITs (e.g., EHRs, e-prescribing systems, pharmacy information systems, patient portals, etc.) to interact with one another for healthcare data sharing between providers is growing rapidly (De Pietro & Francetic, 2018). Increasingly, this exchange is being facilitated utilizing Fast Healthcare Interoperability Resources (FHIR) (FHIR, 2021), an HIE standard introduced in 2014 to promote secure sharing of healthcare data. The standard has passed through an initial maturity level and is currently widely endorsed and accepted by HIE stakeholders, policymakers, and developers of healthcare application systems. FHIR is mandated by the Office of National Coordinator for Health Information (ONC, 2021) for making data available via APIs to patients and for data sharing.

In support of HIE, we have done prior work (Ziminski et al., 2015) on different software architectural alternatives and proposed a hybrid HIE architecture that leverages paradigms that include service-oriented architecture, grid computing, publish/subscribe paradigm, and data warehousing to allow the HITs of stakeholders to be integrated to ease collaboration among medical providers. Our follow-up work (Ziminski et al., 2020) extended that effort to detail an architectural solution for HIE using FHIR to integrate HITs to facilitate collaboration among medical providers. Our focus in this paper is to explore the interoperability at a coarser granularity

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level that considers the way that the architectures in our prior work use FHIR for HIE more effectively.

The FHIR standard has 135+ *resources*, which are data elements to capture all types of healthcare data organized into different layers. For example, the *base* resource layer contains patients, practitioners, and family relationships, organizations, services, appointments, and encounters. The *clinical* resources are for a patient's health history, diagnostic data, medications, care provision, and request/response communication. Further resources are organized in the *foundation*, *financial*, and *specialized* layers.

One of the limitations of the FHIR standard is that it is left up to the discretion of each designer and developer to individually choose a set of resources that is used to solve a particular problem. However, at a design level, there is no way to effectively organize the subset of FHIR resources required for a particular problem in any way that would promote reuse. One of the classic software engineering design and development approaches is design patterns which were pioneered in (Gamma, 1995) and came into widespread use. Design patterns originated in an investigatory process when software engineers and developers realized that they were constantly copying and reimplementing similar code in different projects. For example, the Observer pattern is utilized to define a one-to-many relationship between objects. The Model View Controller pattern has: a model to capture business rules for accessing and updating data, a view that renders the contents of the model for the presentation of the stored data, and the controller that translates the view into actions such as button clicks, UI actions, or HTTP calls.

Design patterns can fit into an Enterprise architecture (Zachman, 2019) as well as with the architecture of FHIR (FHIR Arch, 2021) as part of an overall information architecture. In addition to resources organized in the mentioned layers, FHIR also includes a Resource Contextualization component containing FHIR profiles and graphs. Within this context, this paper will propose a *meta resource,* which is a set of resources created using containment and relationships and which is geared towards solving specific problems in the design of healthcare applications. We believe that meta resources can fit into the FHIR's resource contextualization layer, thereby extending its architecture with additional relationship types, attributes, and constraints.

The intent is to have an identifiable construct that can meaningfully relate multiple FHIR resources in an ordered manner and that allows sharing and exchange to happen at a higher granularity level akin to a design pattern. To facilitate this process, we define the *meta resource* as a named construct that associates multiple resources so that they can then be utilized in multiple contexts.

For this purpose, we leverage the extension concepts of FHIR profiles along with the grouping operation of Bundle resources to integrate seamlessly into the FHIR standard. This 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.

To illustrate the potential of the concepts of this paper, we will leverage our work on the development of a mobile health application and framework (Agresta et al., 2020) for medication reconciliation that integrates information from multiple EHRs. We show how the FHIR resources used in our solution can be better conceptualized into a meta resource, which also could be effectively utilized and deployed in different settings for purposes related to medication reconciliation. For this, we combine the resources (Patient, Medication, MedicationStatement, Detected Issues, 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.

The remainder of this paper has four sections. Section 2 provides background information on the critical FHIR concepts and our medication reconciliation work which will be used for examples throughout the paper. Section 3 presents a model that extends FHIR with meta resources. Section 4 explores the algorithmic process for integrating meta resources based on FHIR bundles. Section 5 contains concluding remarks and outlines ongoing work.

2 BACKGROUND

This section provides background material in three areas. Section 2.1 explores medication reconciliation and its importance for healthcare. Section 2.2 presents the concepts of the FHIR relevant for the paper. Section 2.3 discusses our medication reconciliation architecture and app.

2.1 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 (CTACT, 2018) which produced a number of 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 (OHS, 2019).

Medication Reconciliation is defined as: "the process of comparing a patient's medication orders to all of the medications that the patient has been taking. This reconciliation is done to avoid medication errors such as omissions, duplications, dosing errors, or drug interactions." (JC, 2006) Transitions of care (hospital to ambulatory care, nursing facility to home) can be particularly dangerous without an accurate medication list. Different EHRs at these locations can lead to medication errors that contribute to this harm. Medication errors account for over 1M ED visits, 3.5M office visits, and 125k hospital admissions annually (ADE, 2020). Medication reconciliation can address these issues by compiling a list of medications from various EHRs into a single source-of-truth resource for seamless access by users for medication management.

In regards to prior work, we highlight a number of related efforts, the first (Coons, et al., 2019) is the development of a mobile application for a medication list leveraging FHIR. The next related effort (Pandolfe, et al. 2016) provides a framework that improves accuracy of the medication reconciliation process focusing on an outpatient medication list through a centralized architecture. Another study (Schnipper, et al., 2012) concluded that concordance between documented and patient-reported medication regimens and reduction in potentially harmful medication discrepancies can be improved with a PHR medication review tool linked to the provider's medical record. Finally, (Yang et al., 2018) discussed the importance of improving standardization of the process and technology used for Medication Reconciliation by exposing some of the challenges and potential harms when a clinician attempts to discontinue a medication electronically using an approved HL7 messaging standard called CancelRx that their system has only partially implemented. It left medications that should no longer be taken on different EHR and Pharmacy HIT system lists.

2.2 The FHIR Standard

FHIR is structured around the concept of resources, which are comprehensive data elements that hold the information that can be 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 *identified 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 full audit trail. The *business version* changes each time the content in the resource changes. The FHIR standard defines representation formats in XML, JSON and Turtle. Figure 1 contains an abbreviated portion of the patient resource XML schema and Figure 2 for 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 (FHIR Res, 2021) for complete versions.

```
<Patient xmlns="http://hl7.org/fhir">
 <identifier><!-- 0..* Identifier -->
 </identifier>
 <active value="[boolean]"/><!-- 0..1 -->
 <name><!-- 0..* HumanName --></name>
 <telecom><!-- 0..* ContactPoint -->
 </telecom>
 <gender value="[code]"/><!-- 0..1 -->
 <birthDate value="[date]"/><!-- 0..1 -->
 <deceased[x]><!-- 0..1 boolean|dateTime -->
</deceased[x]>
 <address><!-- 0..* Address --></address>
 <maritalStatus>
  <!-- 0..1 CodeableConcept -->
 </maritalStatus>
 <!--omitted material due to length -->
 <other>
  <!-- 1..1 Reference(
  Patient|RelatedPerson) -->
 </other>
  <type value="[code]"/><!-- 1..1 -->
 </link>
</Patient>
```

Figure 1: Patient XML schema.

```xml
<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 2: Medication XML schema.

The FHIR standard provides an explicit extension mechanisms called *profile* to satisfy the need for adjustments to specific organizational needs. This is integrated already at the core specification level and allows to define extensions, constraints, and additional APIs for FHIR implementations that need to provide functionality in addition to the built-in capabilities.

2.3 MedRec Architecture and App

Following a hackathon in spring 2019 (OHS, 2019), we developed an architecture for our MedRec application, as shown in Figure 3. To establish our test environment, we set up four separate HITs: one as a gold standard to have the exact correct medications for every patient without any duplications or problems and three HITs with perturbed versions of that gold standard with missing medications, different medications, errors in dosage, old medications etc. This scenario models what happens in practice.

A HAPI FHIR client iterates over a list of other FHIR sources, parses the response, and merges them into a single Bundle. Reconciliation is then performed on the Bundle by making requests to the RxNorm API (RxNorm, 2021) for similar medications on a per-medication basis, then attempting to find duplicates within the Bundle. Duplicates are removed from the queue for RxNorm requests for efficiency, since they have already been matched. When a duplicate is found, a DetectedIssue resource (FHIR, 2021) is created and added to the bundle. The returned medication list is intact as returned from the multiple FHIR sources, and the duplicates must be displayed in the app through processing the DetectedIssue resources, so that final authority as to which medications are duplicates rests with the user.

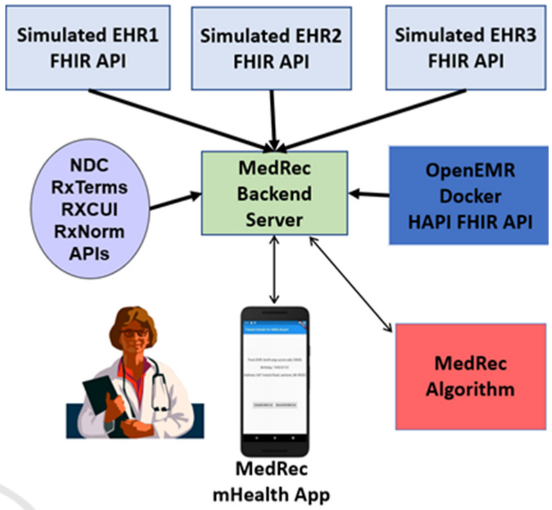

Figure 3: MedRec Architecture.

To explain medication reconciliation, Figure 4 presents a simplified process: a User selects a patient; App initiates the reconciliation and triggers the backend; Backend requests medications for the patient from both EHRs; MedRec algorithm processes medication lists and detects issues; App displays medication list with highlighted issues; User reconciles conflicts; Reconciled list is returned to the backend; Backend identifies which sources were contributing the data causing identified issues; Affected sources are notified (in this example a warning is sent to EHR2); and, Sources may issue a warning to their users.

3 META RESOURCE MODEL

This section introduces a formal model for the meta resource extension of FHIR. Section 3.1 presents a set of core definitions for resources from the FHIR standard used as the foundation for the meta resource definitions in Section 3.2.

3.1 Core Definitions

The Fast Healthcare Interoperability Resources (FHIR) standard is built around data elements called resources and application programming interfaces for exchanging them. Definitions Defn. 1 to 5 describe the core capabilities of FHIR resources from a general perspective in order to support the rest of the meta resource model to be presented in Section 3.2.

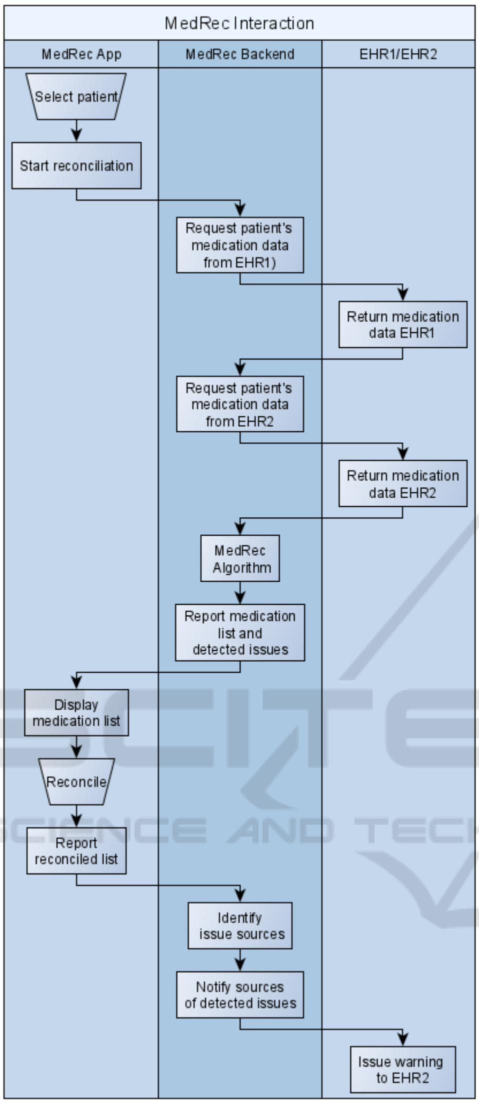

Figure 4: Medication Reconciliation Process.

Defn. 1. The *resource identity* (R_{ID}) is given by an URL that allows to identify and address a resource uniformly.

Defn. 2. Let $\mathcal{RT}_{FHIR} =< t_1, t_2, \ldots, t_n >$ be the list of different resources that are defined in the resource list of the FHIR specification (FHIR Res, 2021). Then the *resource type* is defined as $R_{Type} = t_i \in \mathcal{RT}_{FHIR}$.

Defn. 3. The resource data (R_{Data}) is the specific collection of data fields that a resource of type R_{Type} receives in the FHIR specification.

Defn. 4. The resource version ($R_{Version}$) is a sequence number that increases each time the resource changes.

Definitions Defn. 1 to 4 support the following two definitions.

Defn. 5. An *FHIR resource* is described by the four-tuple $R = < R_{ID}, R_{Type}, R_{Data}, R_{Version} >$

Defn. 6. Let $\mathcal{R} = \{R_1, R_2, \ldots R_n\}$ be the set of all FHIR resources.

Example 1 illustrates a Patient (FHIR Res, 2021) instance according to the schema in Figure 1 using the model concepts introduced in Defn.1 to 6.

Example 1. An 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*" : "ea44426f",
"active": "true",
"name": "John Doe",
"telecom": "555-370-8047",
"gender": "male",
"*birthDate*" : "1970 – 12 – 12",…}

and

$$x = 5$$

3.2 Meta-Resource Definitions

We are introducing 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. When facing implementing 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.

In detail, a meta resource is described by a selection of descriptive properties, a set of resources organized using composition and relationships, and API extensions for interaction. The related model is given in Defn. 7 to Defn. 12. First, to support the classification and management of meta resources, they require identifying properties.

Defn 7. The *meta resource identifier* (MR_{ID}) is a unique identifier for the meta resource.

Defn 8. The *meta resource name* (MR_{Name}) is a human-readable name for identifying the meta resource.

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.

Defn 9. The *meta resource description* (MR_{Desc}) is a textual description of the medical workflow that a meta resource enables.

Combining definitions Defn 7 through Defn 9, we define a *meta resource*.

Defn. 10 (v1). A *meta resource* (*intermediate*) is described by the three-tuple $MR = < MR_{ID}, MR_{Name}, MR_{Desc} >$.

Defn 11. Let $\boldsymbol{\mathcal{MR}} = \{MR_1, MR_2, \dots, MR_n\}$ be the set of all meta resources.

Example 2 shows an instance of a *MedicationReconciliation* meta resource for the medication reconciliation app in Section 2.1 and implementing the structure shown in Figure 5, which gives an overview of the meta resource: 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 that individual that should be notified about issues regarding this statement. 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 references a practitioner as designated contact in the scope of this endpoint. An endpoint represents a health information technology system such as an electronic health record that could be at a hospital, a rehab facility, a clinician's office, etc., that must be notified whenever a change is made. A Practitioner resource identifies the practitioner that needs to be contacted regarding issues detected for a given medication statement during reconciliation.

Example 2. The *MedicationReconciliation* meta resource is represented by

$$MR_1 = < MR_{ID_1}, \mathrm{MR}_{\mathrm{Name}_1}, MR_{Desc_1} >$$

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."*

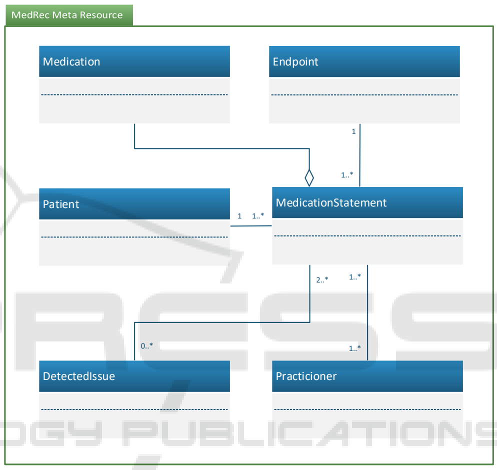

Figure 5: Medication Reconciliation Meta Resource.

Each of the resources 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 5, the Medication resource will serve as *data sources* for performing the reconciliation. In contrast, the FHIR *MedicationStatement* can serve as a *producer* of further medication resources.

Defn 12. Let $\boldsymbol{\mathcal{RC}}_{Category} = \{c_1, c_2 \dots, c_n\}$ be the set of all recognized classification categories for a resource within the scope of a meta resource.

Example 3 shows the definition of a category.

Example 3. The MedicationReconciliation meta resource utilizes categories $\boldsymbol{\mathcal{RC}}_{MedRec} = \{c_{producer}, c_{dataSource}, c_{adress}, c_{entity}\} \subset \boldsymbol{\mathcal{RC}}_{Category}$.

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.

Defn. 13. The *participating resources* of a meta resource are defined as the set $MR_{PR} = \{pr_1, pr_2, \ldots pr_n\}$, where a *participating resource* $pr_m = < r_i, c_j >$ is a tuple in which r_i is identifying either an FHIR standard resource or recursively a meta resource, therefore $r_i \in (\boldsymbol{\mathcal{R}} \cup \boldsymbol{\mathcal{MR}})$. The category of the participating resource is given by $c_j \in \boldsymbol{\mathcal{RC}}$.

For supporting a meta-resource, the application being developed needs to provide a matching API:

Defn. 14. The meta resource API extension (MR_{API}) is defined as an FHIR profile (FHIR Pro, 2021) providing the API extensions needed for interacting with the meta resource.

Participating resources relate to one another by reference or composition, leading to:

Defn 15. The *meta resource reference* structure is defined as the set $MR_{REF} = \{ref_1, ref_2, \ldots ref_n\}$, where $ref_m =< pr_i, pr_j >$ with $pr_i, pr_j \in MR_{PR}$ and $i \neq j$ is a tuple of distinct participating resources and pr_i references pr_j.

Defn 16. The *meta resource composition* structure is defined as the set $MR_{COM} = \{com_1, com_2, \ldots com_n\}$, where $com_m =< pr_i, pr_j >$ with $pr_i, pr_j \in MR_{PR}$ and $i \neq j$ is a tuple of distinct participating resources and pr_j is contained in pr_i.

Definitions Defn. 11 to 16 require a revision of Defn.10:

Defn. 10 (v2). A *meta resource* is described by the seven-tuple

$$MR =< MR_{ID}, MR_{Name}, MR_{Desc}, MR_{PR}, MR_{API}, MR_{REF}, MR_{COM} >.$$

Example 4 illustrates the revised Defn.10.

Example 4. An instance of the meta resource *MedicationReconciliation* can be represented by

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

where

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

and

$$MR_{Name} = MedicationReconciliation$$

and

$$MR_{Desc_1} =< string > (see\ Example\ 2)$$

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

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

and

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

4 FROM META RESOURCES TO FHIR BUNDLES

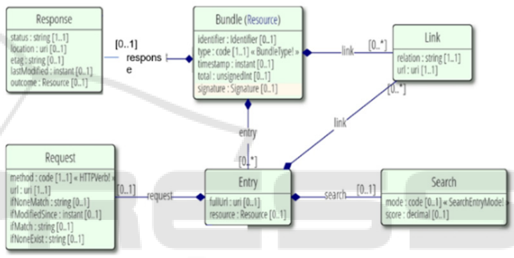

Figure 6: FHIR Bundle in UML Representation.

This section presents the process and an associated algorithm that can automatically transition a meta resource definition into a destination FHIR bundle at the schema level. FHIR bundles 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. FHIR bundles allow both references and containment and are therefore capable of reflecting the relationships shown in the meta resource in Figure 5. In Figure 6, the UML representation of the FHIR Bundle (FHIR Res, 2021) is shown, where we focus on the Bundle, Link, and Entry. The corresponding XML schema for the FHIR bundle is found in Figure 7. 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 as presented in Defn. 10v2 in Section 3.2 needs to be transitioned to a suitable FHIR artifact to construct a representation that is amenable to realization within a particular healthcare application. Figure 6 has the UML representation of an FHIR bundle that gives an overview of its components and interdependencies. 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 further outside resources). Additionally, the *request*, *response,* and *search* components can be used to make the bundle suitable for workflows such as search queries to a system. To transition from a meta resource to a bundle, we utilize only the Bundle, Link, and Entry components shown in Figure 6.

```
<Bundle xmlns="http://hl7.org/fhir">
<identifier><!-- 0..1 --></identifier>
 <type value="[code]"/><!-- 1..1 -->
 <timestamp value="[instant]"/><!-- 0..1 -->
 <total value="[unsignedInt]"/><!-- 0..1 -->
 <link>  <!-- 0..* -->
  <relation value="[string]"/>
    <!-- 1..1  -->
  <url value="[uri]"/><!-- 1..1 -->
 </link>
 <entry>  <!-- 0..* -->
  <link><!-- 0..* --></link>
  <fullUrl value="[uri]"/>
    <!-- 0..1 -->
  <resource><!-- 0.. --></resource>
  <search>  <!-- 0..1 ... --> </search>
  <request> <!-- 0..1 ... -->
  <response>  <!--  0..1 ... --></outcome>
  </response>
 </entry>
 <signature><!-- 0..1 digital -->
</signature>
</Bundle>
```

Figure 7: FHIR Bundle XML Schema.

Our algorithmic process takes the meta resource as defined in Defn. 10v2 in Section 3.2 and, using the XML schema of Figure 7, creates a meta resource bundle that captures all components and relationships. For the meta resource presented in Figure 5, this would use all the defined resources in the figure and the indicated relationships and components to generate the medication reconciliation bundle XML as shown in Figure 10. Note that adding any Search, Request, or Response components of Figure 6 is left to the responsibility of the developer of the healthcare application where required.

Figure 8 gives an overview of the processing steps that our approach takes to generate the bundle. Specifically, for every medication reconciliation meta resource, the initial generation is of the top-level bundle element and a single patient element. Then the participating resources, as given in Figure 5, are processed into matching bundle entries. The comments in the pseudo code relate which parts of the example in Figure 10 are generated by a given step.

```
MED_REC_BUNDLE_GENERATION(med_rec_meta_resources){
 foreach(meta_res from med_rec_meta_resources){
  bundle = createBundle(meta_res);                   // lines 1-4,48
  patient = createPatient(meta_res);                 // lines 5-8
  part_res = getPertRes(meta_res);

  practioners = findPractioners(part_res);
  foreach(practioner from practioners){
   addPractitionerEntry(practioner, bundle);         // lines 9-13
  }

  endpoints = findEndpoints(part_res)
  foreach(endpoint from endpoints){
   addEnpointEntry(endpoint, bundle);
  }                                                  // lines 14-18

  medStatements = findMedStatements(part_res);
  foreach(medStatement from medStatements){
   addmedStatementEntry(patient, practioners,        // lines 19 - 34
                        endpoints, bundle);
  }

  detectedIssues = findDetectedIssues(part_res);
  foreach(detectedIssue from detectedIssues){
   addDetectedIssueEntry(bundle, medStatements); // lines 35-46
  }
 }
```

Figure 8: Pseudo-code Algorithm for Bundle Generation (comments indicate lines generated in Figure 10.)

In summary, Figure 10 contains an excerpt of the bundle schema (shortened for readability) that was generated for a MedicationReconciliation meta resource (see Figure 5) for a patient John Doe. The resource recorded a drug interaction between two drugs while reconciling the patient's medication statements from an openEHR instance and another HIE system. Lines 1-4 define the bundle, assign an id and a collection type, which defines a simple collection without further constraints. Lines 5-8 contain an entry for the participating Patient resource. Note that for every entry, a *fullUrl* property defines the referenceable identity for the serialized resource of the entry. We use this URL to reference participating resources within the bundle itself.

Entries for the participating Practitioner (lines 9-13) and Endpoint resources (lines 14-18) provide the location and the person necessary for issuing an alert about the drug interaction. Lines 19-32 contain the participating MedicationStatement resource for a medication which the patient is taking. The structural references to the related Patient, Practitioner, and Endpoint resources (as introduced in Figure 5) are explicitly serialized to the link elements in lines 21-23. While links handle the references introduced by the meta resource concept, aggregations are serialized to FHIR built-ins, i.e., the *contained* element of MedicationStatement, as shown in line 27. Note that a reference is always serialized to a link for consistency within the meta resource model representation. This is the case even if a potential built-in exists (e.g., the Patient resource in the *subject* entry in line 29).

Further medication resources are omitted in this example (lines 33-34). The drug interaction risk is recorded in lines 35-46, where a participating DetectedIssue resource flags two medication statements. References from the meta resource are expressed as links for a possible meta resource deserialization (lines 37-38). Additionally, the built-in FHIR relation in the *implicated* elements (lines 42-43) is preserved for usage as regular FHIR resources.

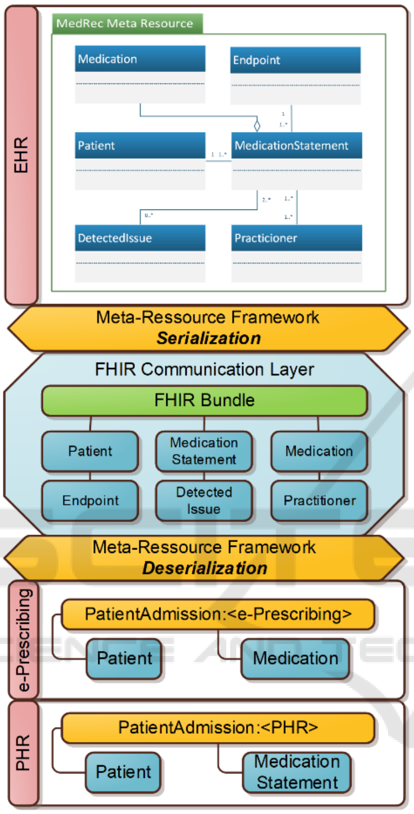

Figure 9: Meta Resource Serialization to Bundle.

The generic high-level concept of our transformation approach and its related information flow between systems is illustrated in Figure 9. The EHR at the top of the figure uses the previously introduced medication reconciliation meta resource for enabling a reconciliation workflow. However, the information encapsulated within the meta resource's participating resources can be read by different involved HITs. For this, the meta resources are serialized to an FHIR bundle by iterating over the meta resource's participating resource and adding them to the generated bundle one by one. The resulting bundle conforms to the FHIR standard and reflects the contents of the meta resource in a flat structure (depicted in the middle of Figure 9). In the serialization process, the relationships introduced in

```
01 <Bundle xmlns="http://hl7.org/fhir">
02  <!-- for readability expand $url = http://hie.org/fhir -->
03  <id value="bundle-metaressource-collection"/>
04  <type value="collection"/>
05  <entry>
06   <fullUrl value="$url/Patient/123"/>
07   <resource><Patient><!-- John Doe --></Patient></resource>
08  </entry>
09  <entry>
10   <fullUrl value="$url/Practioner/123"/>
11   <resource><Practitioner><!-- Dr. Max Mustermann --></Practitioner></resource>
12  </entry>
13  <!-- Further practioner entries -->
14  <entry>
15   <fullUrl value="$url/Endpoint/123"/>
16   <resource><Endpoint><!-- hl7-fhir-rest endpoint --></Endpoint></resource>
17  </entry>
18  <!-- Further endpoint entries -->
19  <entry>
20   <fullUrl value="$url/MedicationStatement/123"/>
21   <link><relation value="related"/><url value="$url/Patient/123"/></link>
22   <link><relation value="related"/><url value="$url/Practioner/123"/></link>
23   <link><relation value="related"/><url value="$url/Endpoint/123"/></link>
24   <resource>
25    <MedicationStatement>
26     <id value="medstatement001"/>
27     <contained><Medication> <!-- id="med309" --></Medication></contained>
28     <medicationReference><reference value="#med0309"/></medicationReference>
29     <subject><reference value="Patient/123"/></subject>
30    </MedicationStatement>
31   </resource>
32  </entry>
33  <!-- Further MedicationStatement entries, including
34  medstatement002 at $url/MedicationStatement/124 -->
35  <entry>
36   <fullUrl value="$url/DetectedIssue/123"/>
37   <link><relation value="related"/><url value="$url/MedicationStatement/123"/></link>
38   <link><relation value="related"/><url value="$url/MedicationStatement/124"/></link>
39   <resource>
40    <DetectedIssue>
41     <code><!-- Drug Interaction Alert --></code>
42     <implicated><reference value="MedicationStatement/medstatement001"/></implicated>
43     <implicated><reference value="MedicationStatement/medstatement002"/></implicated>
44    </DetectedIssue>
45   </resource>
46  </entry>
47  <!-- Further DetectedIssue statements -->
48 </Bundle>
```

Figure 10: Generated Bundle.

the bundle by the meta resource are preserved in three cases: by using FHIR built-ins (for cases such as the relationship between a *MedicationStatement* and a *Medication* resource); by setting appropriate link elements in the bundle; or by adding them to extensions via the StructureDefinition mechanism (for cases such as the relation between a *Practitioner* and an *Endpoint* resource). The first case can be understood by systems without meta resource knowledge, while the two later cases must support the meta resource extension themselves for deserializing.

Other healthcare applications can use the generated bundles by processing the participating resources as direct information or reconstructing the bundle's meta resource. This operation is depicted at the bottom of Figure 9, where an e-Prescribing system extracts just the *Patient* and *Medication* resources from the bundle while a PHR system processes only on the *Patient* and *MedicationStatement* resources.

5 CONCLUSION AND ONGOING WORK

This paper has presented the extension of the FHIR standard with the concept of a meta resource which allows for a design pattern level capability to support reusable components that can be automatically generated and easily exchanged among healthcare applications that need to share the similar kind of data. The meta resource extension can be incorporated into the information architecture of FHIR in the resource contextualization layer as discussed in the introduction. To present our work, we reviewed background on FHIR and the medication reconciliation application that we use for examples in Section 2. Next we presented a formal model to represent meta resources in Section 3, which in turn was used as the basis to present an algorithm and associated process that automatically translates a meta resource to a FHIR XML bundle schema in Section 4. The generated bundle schema can be used as a basis for the developer to create an instance of the schema as the healthcare application is transitioned from a design level to an implementation.

The resulting healthcare application would have the bundled component that would be more easily exchanged and transferred among different HITs. Our work could improve healthcare interoperability by having meta resources for recurrent parts of clinical workflow such as for medication reconciliation.

Ongoing work is focusing on several different areas. We intend to work with the team of the medication reconciliation application to assist in reformulating their usage of resources into the medication reconciliation bundle as given in Section 4. This will allow us to fully understand the way to transition from the bundle schema to the actual exchangeable bundle instance. Another area is to formally define the appropriate notation so that the meta resource can fully fit into the defined FHIR standard by using only predefined FHIR conventions.

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