FML2Mirth: Generic Transformation of complex laboratory data based on FML-mapping rules and automatically generated Mirth channels

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Submitted to: JMIR Medical Informatics
on: February 20, 2024

Table of Contents

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Abstract

Background: Reaching a significant amount of interoperability between proprietary healthcare systems is an ubiquitous task in medical informatics, where communication servers are traditionally used for referring and transforming data from source to target systems. The Mirth Connect Server, which is an open-source communication server, offers in addition to the exchange functionality, also functions for the simultaneous manipulation of data. In recent times, the standard Fast Healthcare Interoperability Resources (FHIR) is becoming more and more prevalent in the German healthcare system. This standard specifies its own standardized mechanisms for transforming data structures in the form of StructureMaps and the FHIR Mapping Language.

Objective: In this study, a generic approach will be developed, which allows to apply these formalized mapping rules defined by the FHIR Mapping Language in an exchangeable manner. A transformation engine is required to execute the mapping rules.

Methods: FHIR natively defines resources to support conversion of instance data, the FHIR resource StructureMap. This resource encodes all information required to transform data from a source system into a target system. In our approach, this information is defined in an implementation-independent manner using the FHIR Mapping Language. Once the mapping has been defined, executable Mirth channels are automatically generated from the resources containing the mapping in form of JavaScript. These channels can be deployed to the Mirth Connect Server.

Results: The resulting tool is called FML2Mirth, a Java-based transformer that derives Mirth channels from a given mapping based on the underlying StructureMaps that contain the detailed rules. The implementation of the translate functionality is guaranteed by the integration of a terminology server and to achieve conformity with existing profiles, validation via the FHIR validator is built in. The system is evaluated for its practical use by transforming LDTv.2 laboratory results into MIO lab reports according to NASHIP specifications and into to the HL7 Europe Laboratory Report. It is shown that the system can generate complex structures, but LDTv.2 lacks some information to fully comply with the specification.

Conclusions: The tool for the auto-generation of Mirth channels was successfully presented. Initial tests have shown that it is feasible to use the complex structures of the mapping language in combination with a terminology server to transform instance data. Although the Mirth Server and FHIR are well established in the field of medical informatics, the combination offers space for more research, especially with regard to the FHIR Mapping Language. At the same time, it can be stated that the Mapping Language still has implementation short comings that can be compensated by Mirth Connect as a base technology. Clinical Trial: N/A

(JMIR Preprints 20/02/2024:57569)
DOI: https://doi.org/10.2196/preprints.57569

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Connect as a base technology.
Trial Registration: N/A

Keywords: FHIR; StructureMaps; FHIR Mapping Language; Mirth; Laboratory Data

Introduction

The digital change is progressively transforming healthcare systems, and the rapid pace of digitalization is creating new clinical data sources that need to be integrated. This is of enormous importance for patient care, as data integration and fusion of all sources allow a comprehensive, holistic overview and ensure the best treatment possible. However, the lack of interoperability of healthcare systems is a significant and long-lasting problem [1]. However, this interoperability is required to ensure seamless and effortless access to essential healthcare information. Existing data is presented in a multitude of proprietary formats or different standards [2]. Therefore, it is inevitable to transform data into a harmonized structure to enable a collective use. Current (inter)national initiatives are integrating large volumes of data in clinical environments to enable their use [3–5]. The established data integration is close to the data origin which is highly desirable since a late mapping harbors disadvantages and issues can be addressed accordingly [6].

Aligning the multitude of standards and thus making the data usable is a major task. The mapping is mainly done by data stewards and following a qualitive evaluation involving medical professionals. This process is time-consuming and demands a significant number of resources. This process occurs at every site involved, which commits a substantial additional number of stewards and health care professionals across the entire healthcare system [6,7]. Thus, sharing and reusing of these mappings is highly desirable and can release the needed resource and speed up the data enabling. For this reason, the presented study aims to provide a generic approach to share formalized mapping rules in a standardized and adaptable manner.

Methods

The transformation of healthcare-related information needs two major components to enable generalization: a highly adaptable exchange format and a modular transformation engine. Our approach is based on the HL7 standard Fast Healthcare Interoperability Resources (FHIR) and the Mirth communication server.

HL7 FHIR and the FHIR Mapping Language

HL7 FHIR is the emerging standard for healthcare-specific data exchange and finds broad adaption around the globe [8]. FHIR provides state-of-the-art technologies to modernize the current healthcare landscape using extensible resources as harmonized and semantically annotatable information units [9]. But FHIR also provides mechanisms to define transformations natively on its structures. The essential FHIR resource for automated conversion of instance data is the *StructureMap*, which defines a mapping from a source structure to a target structure [10] and provides all necessary information for automatic transformation. To aid the definition of StructureMap resources, FHIR has specified a domain-specific language, the FHIR Mapping Language (FML) [11]. By specifying the mappings in an implementation-independent manner, the mapping between structures can be easily shared within the medical informatics community.

The domain specific FML is part of the FHIR-specification and was introduced in FHIR Release 3. A major benefit is the usage of generic data structures as input formats, since FML can define mappings on non-FHIR structures. Consequently, the FML can also be used to map older healthcare-related formats such as HL7 v.2 or LDT to FHIR.

The syntax of the FML is very declarative and enables users to define mappings concisely. The mapping itself is structured in so called *groups* within the mapping being formalized by mapping rules. These rules consist of two parts separated by an arrow. On the left-hand side of the arrow is the source part. Here, fields of source structures can be accessed, and the values can be written in variables. On the right-hand side fields of a target structure can be accessed and built-in transformation functions can be invoked (see Figure 1). Those provided functions cover a broad functionality, ranging from simple *copy* till a *translate* function to resolve given concepts codes using an external FHIR *ConceptMap*.

```
group populateObservation(source test : LDT_Test, target observation : Observation) {          Group
// snip..

    test.LDT_8410 as s_code -> observation.code as code,                                        Rule 1
                               code.coding = translate(s_code, "<URL>", "coding") "set Observation code";

    test.LDT_8420 as s_result -> observation.valueQuantity as quantity,                         Rule 2
                                 quantity.value = s_result then {

    test.LDT_8421 as s_unit -> quantity.unit = translate(s_unit, "<URL>", "code") as t_unit,    Rule 3
                               quantity.system = "http://unitsofmeasure.org",
                               quantity.code = t_unit
                                      "set unit";
                        } "set result";

// snip..
}
```

Figure 1The code illustrates an FML snippet showing how a conventional laboratory test in LDT format can be mapped to an FHIR observation resource. The mapping is structured in groups, containing the specific rules.

Mirth Connect Communication Server

Mirth Connect is an open-source communication server designed specifically for the healthcare sector. It features support for domain-specific formats, such as HL7v.2, as well as more general formats such as XML and JSON. Mirth is widely used as a communication server and is applied in various areas for data integration [12,13]. As a communication server, Mirth receives messages from one system and forwards them to downstream systems. Mirth introduces the concept of Channels to establish a connection from a source system to various target systems. Within the channels rule-based transformers can be defined to enable message manipulation. The received message can be automatically modified in terms of content or structure. The transformer rules are implemented as JavaScript code snippets which Mirth applies to the messages. The channels including its transformers are serialized as XML files and can easily be shared and redeployed at other sites.

Architecture for Generic Data Transformation

The envisioned process, shown in Figure 2, shall provide a light and adaptable data transformation is two-folded: transformation design (1) and staging (2).
In the transformation design phase, the source and target systems are selected, and the mapping is formalized in FML. The mapping needs to be created manually by a data-steward. This process can be supported by prior proposed algorithms and tools [14]. In addition, semantic concepts and codes are mapped from source to target based on prepared mapping relationships provided using the FHIR ConceptMap resource, if necessary. It is recommended that this process is done by a healthcare professional to ensure data validity and integrity.
In the staging phase, the Mirth channel, built based on the prior mapping efforts, is injected in the productive communication server at runtime. The mapping within the transformer uses the rules derived from FML for the format manipulation and dynamically translates the semantic codes using

the ConceptMap dynamically.

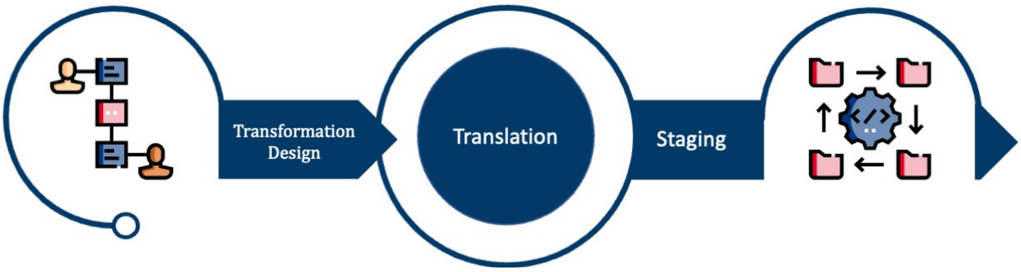

Figure 2 Conceptual Overview of the two-step process. In the first phase, the mapping is formalized as a FML script and corresponding semantic CodeSystems are aligned in a ConceptMap to each other. In the second phase, the priorly defined rules are used to deploy the mapping to Mirth. If semantic translation is needed the ConceptMaps can be queried during runtime.

Results

The proposed system implements the transition between the two process phases transformation design (1) and staging (2). For this transition, a generator called *FML2Mirth [15]* is implemented in Java which derives Mirth channels based on the given mapping. As input FML2Mirth needs the formalized mapping rules as a FML script and administrative information such as the IP address of the targeted Mirth communication server. The FML2Mirth generator uses the official FHIR validator to create a StructureMap from the FML script and transforms it into a deployable Mirth channel. Once the channel creation is completed, the staging phase commences. The generator deploys the channel to the given Mirth server and incoming messages are automatically transformed into the desired structure. On encounter of the FML *translate* function, Mirth queries a given terminology server to perform translation between the different code systems of the source and the target structure based on the previously created ConceptMaps. In our setting seen in Figure 3, a HAPI FHIR JPA server instance is used as an external terminology server. The transformed message is then forwarded to the defined target system, e.g., a FHIR repository.
The evaluation of the transformation within Mirth is implemented using the JUnit testing framework. The JUnit runner loads LDT lab messages from files and sends them to the Mirth server via the REST API. The destination connector of the test channel is a Java Script connector. This ensures that Mirth returns the transformed message as a response to the requesting system. The JUnit runner receives the transformed message as a response and uses HAPI FHIR as the incoming bundles parser and the HAPI instance validator. The incoming resources are automatically tested for their conformity to the specification and validated against the corresponding profiles.

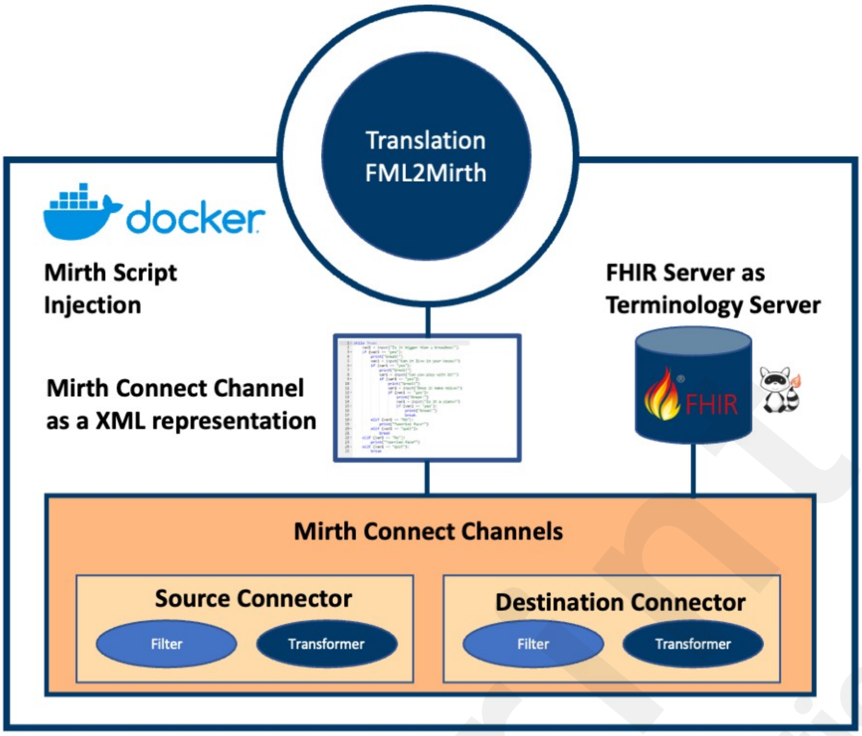

Figure 3 Conceptual overview of the proposed architecture for a generic data transformation process.

Evaluation

The assessment of our proposed transformation process is carried out in cooperation with the LADR laboratory network (LADR)[16], an association of 19 specialist laboratories throughout Germany serving more than 400 clinics. As an evaluation scenario, laboratory findings standardized in the German *Labordatenträger* (LDT)[17] format are transformed into FHIR resources. The LDT format is a perennial standard developed and published by the National Association of Statutory Health Insurance Physicians (NASHIP) and is applied daily to up to one million messages in Germany. In our evaluation scenario, LADR provided 20 anonymized LDT laboratory messages representing complete blood counts in LDT version 2 according to the data format description in the FHIR version 5.12 for the evaluation. Two different FHIR Implementation Guides were used as target formats: the German Laboratory finding of the NASHIP and the HL7 Europe Laboratory Report [18].

The LDT format is mapped to both target formats using FML. Using the FML2Mirth generator, the FML scripts are translated into StructureMaps, and two separate channels are generated and deployed on a Mirth instance. Each format has a distinct set of semantic codes, which are permissible values for certain elements (binding). The sending system in our evaluation scenario uses proprietary codes that must be mapped to the specified CodeSystem in the target profiles. A terminology server is used to provide a translate service based on ConceptMaps which is accessed by the Mirth channel via a REST API. The initial FML script for the transformation to the target format *MIO Laborbefund* [19] of the NASHIP consists of over 400 lines of formalized mapping rules, resulting in StructureMaps with over 3500 lines and more than 2300 elements. The 20 transformed LDT laboratory findings resulted in 62 unique FHIR resources each. Only one report failed the closing instance validation due to the missing first name within the corresponding patient resource.

The second Mirth channel transforming LDT to the profiles of the Europe Laboratory Report is based on the initial FML script. The same 20 LDT laboratory results sum up a total of over 694 FHIR resources. The subsequent validation process revealed for all test cases a structural issue that occurred due to a required extension of the DiagnosticReport profile. The extension should be a Composition reference to the report, but the extension itself is not included in the FHIR package, and the referral link is broken. Yet, a manual check and a comparison with the NASHIP MIO resources proved their validity.

Discussion

This study presented a concept and implementation of an adaptable transformation process for various data structures into a standardized format. Our approach is based on FHIR resources as a standardized data exchange format, FML as the formalized transformation rules and Mirth Connect as the transformation executor.

Principal Results

The approach focusses on separating the transformation rules from the actual transformation to extract the rules out of the process. Due to the detachment, the rules which are created in a labor-intensive process, can be shared in a formalized and standardized manner. In addition, the separation allows a degree of modularization and thus the reuse of the created rules. For example, it was possible to modify the mapping for the MIO reports to generate laboratory reports, that conform to the profiles of the EU laboratory report within a few hours. This emphasizes the flexibility of the proposed method. A significant advantage of this approach is that it allows mappings of concepts to be exchanged at runtime of the Mirth channel and developed and updated independently of the structural mapping. Compared to common ETL jobs, this approach needs much less manual intervention.

The mapping is formalized using FML to render the StructureMap using the official FHIR Validator. The formalized mapping is enclosed in the generated StructureMap instances as a parse tree. Referring and combining various FML scripts is possible per the specification but is not yet implemented. Therefore, the mapping shall be edited incrementally during the transformation design in the FML scripts rather than in the StructureMaps directly. Nevertheless, the initial creation of the FML scripts is less time-consuming but still a labor-intensive task and currently there is a lack of suitable tool support. In addition, a FML script is always a one-way-mapping, and the reverse transformation is not implied automatically.

The functionality provided by Mirth highly constrains the design of our approach, as external dependencies should be kept to a minimum to ensure ease of use. With this in mind, the implemented single command line tool in Java injects the transformations into a specified Mirth channel. In addition, only the Mirth server and a FHIR server, which provides terminology services, are required. At the same time, the system should be as flexible as possible and support arbitrary StructureMaps. To fulfill these requirements, it was necessary to work with the circumstances given by Mirth. Since Mirth itself works on XML objects, it makes sense to use this approach as well. So, the transformations defined in the StructureMap are translated into transformations on XML objects. This allows any structures in XML to be used and enables the transformation of any desired source format.

Limitations

During the evaluation, a problem was discovered with the FHIR implementation within the different FHIR servers. In particular, the issue concerned the FHIRPath implementation, which is used by the FHIR Validator to evaluate the validation rules. In our test setting, one rule is interpreted differently depending on the implementation used. On the tested laboratory reports, the .NET and the JavaScript implementations returned true, which is correct in our understanding. In contrast, both Java implementations tested (HAPI and IBM) returned false.

Alongside to the complex structural mapping, semantic integrity must also be ensured. In our approach, the semantic mappings are created and validated by healthcare professionals and stored in a FHIR server as an external service – which is standard procedure. While existing terminology systems generally provide transition rules to newer versions, the maintenance of FHIR resources is not standardized and is an ongoing topic in the medical informatics research [20].

Furthermore, a mechanism is missing to process further StructureMaps, which are referenced from a given StructureMap. FML uses FHIRPath as an embedded language in several places. The associated specification is extensive and was implemented in this project only in parts.

Comparison with Prior Work

The use of formalized mapping rules in data integration is a well studied topic, and Mirth as a transformation engine for clinical data integration is also a well known tool. However, to our knowledge, the combination of both topics with the goal of a generic and easily adaptive mapper is, to our knowledge, missing in the literature. On the side of formalized rules, the work of Ong et al. [21] must be mentioned. The authors present an extensive study of a dynamic ETL approach that uses a custom mapping language to transform healthcare-related data into the OMOP common data model. The formalized rules are rich in details, but proprietary and rather database-oriented due to their use-case. An innovative feasibility study for FML has been presented by Dimitrov et al. [22]. The authors use FML for the transformation of the HL7 CDA based national Austrian electronic patient record. Using FML, a transformation from the CDA documents to the International Patient Summaries (IPS) based on FHIR could be accomplished. The usage of Mirth as a transformation engine is an intuitive choice due to its functionality and product scope. So various studies are found dealing with the transformation from HL7 v2 message into further target formats, including structural reformation into JSON [23] or standardization into HL7 FHIR [24].

Our approach is based on a prior study that evaluated the transformation of StructureMaps into Mirth channels [25]. The results were promising, but it also emerged that the manual definition of StructureMaps became to be cumbersome and quickly very complex. The presented approach overcomes this shortage using FML and its intuitive nature.

Conclusions

We succeeded in implementing a functional system based on Mirth, which automatically generates transformations from StructureMaps and integrates them into a Mirth channel. The presented system supports large parts of the FML specification. First tests have shown that complex structures based on FML maps, generated in a channel in conjunction with a terminology server and ConceptMaps are feasible. The topic of FML is still an ongoing discussion and has not been extensively researched in the FHIR community so far. Accordingly, the tooling in this area is at this point, rather rudimentary.

If a new format is to be supported, it may only be necessary to insert another Mirth transformation step before the transformation from the StructureMap, to transform the input structure into XML. One advantage of the current solution is its flexibility and robustness in that only one resource is used for translation.

Acknowledgements

This research was funded by German Federal Ministry of Education and Research, grant number 01ZZ2312A and 01ZZ2011.

Conflicts of Interest

N/A

Abbreviations

FHIR: Fast Healthcare Interoperability Resources

FML: FHIR Mapping Language
NASHIP: National Association of Statutory Health Insurance Physicians
IPS: International Patient Summaries
LDT: Labordatenträger
MIO: Medical Information Object (*Medizinisches Informationsobjekt*)
ETL: Extract, Transform, Load Process
OMOP: Observational Medical Outcomes Partnership
CDA: Clinical Document Architecture

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Supplementary Files

Figures

The code illustrates an FML snippet showing how a conventional laboratory test in LDT format can be mapped to an FHIR observation resource. The mapping is structured in groups, containing the specific rules.

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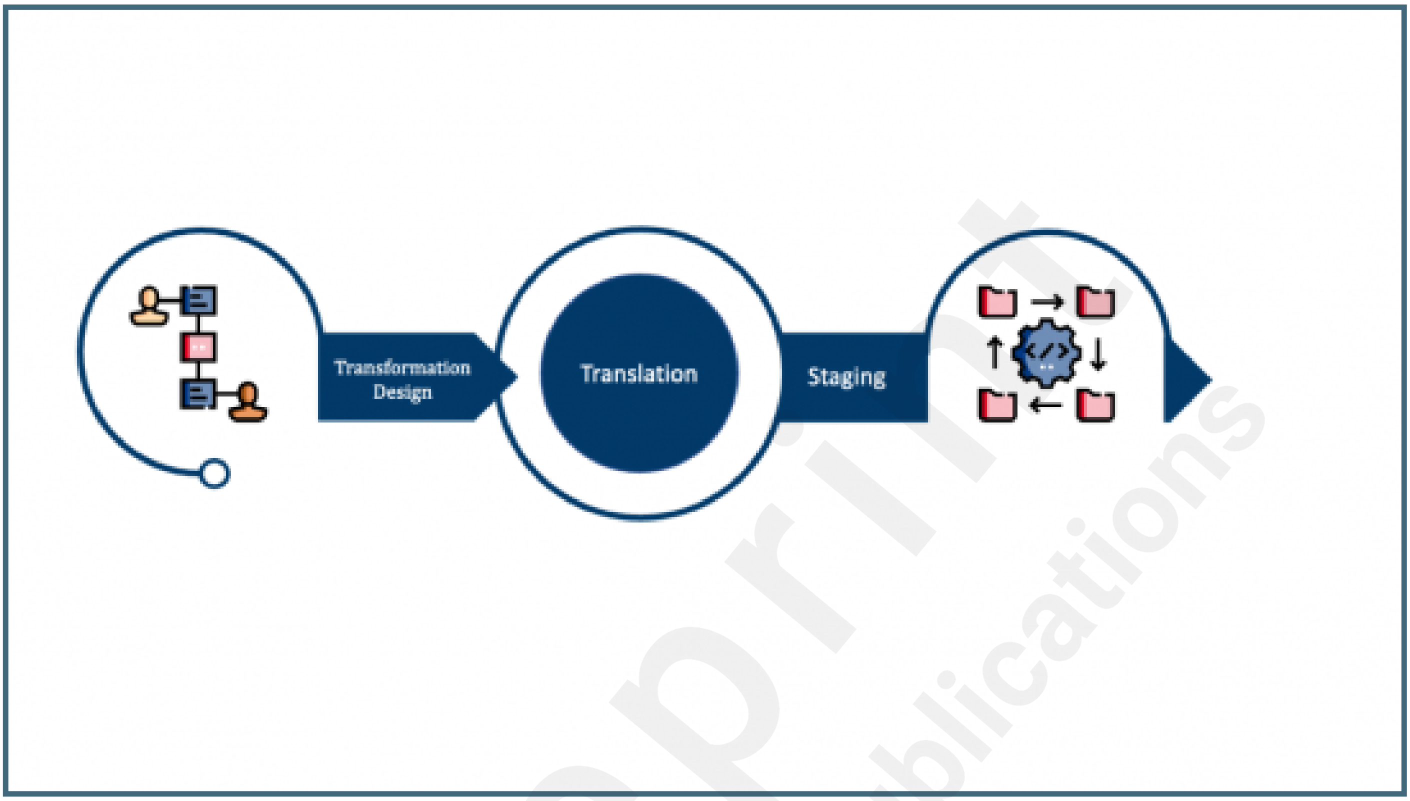
                               code.coding = translate(s_code, "<URL>", "coding") "set Observation code";

    test.LDT_8420 as s_result -> observation.valueQuantity as quantity,                         Rule 2
                                          quantity.value = s_result then {

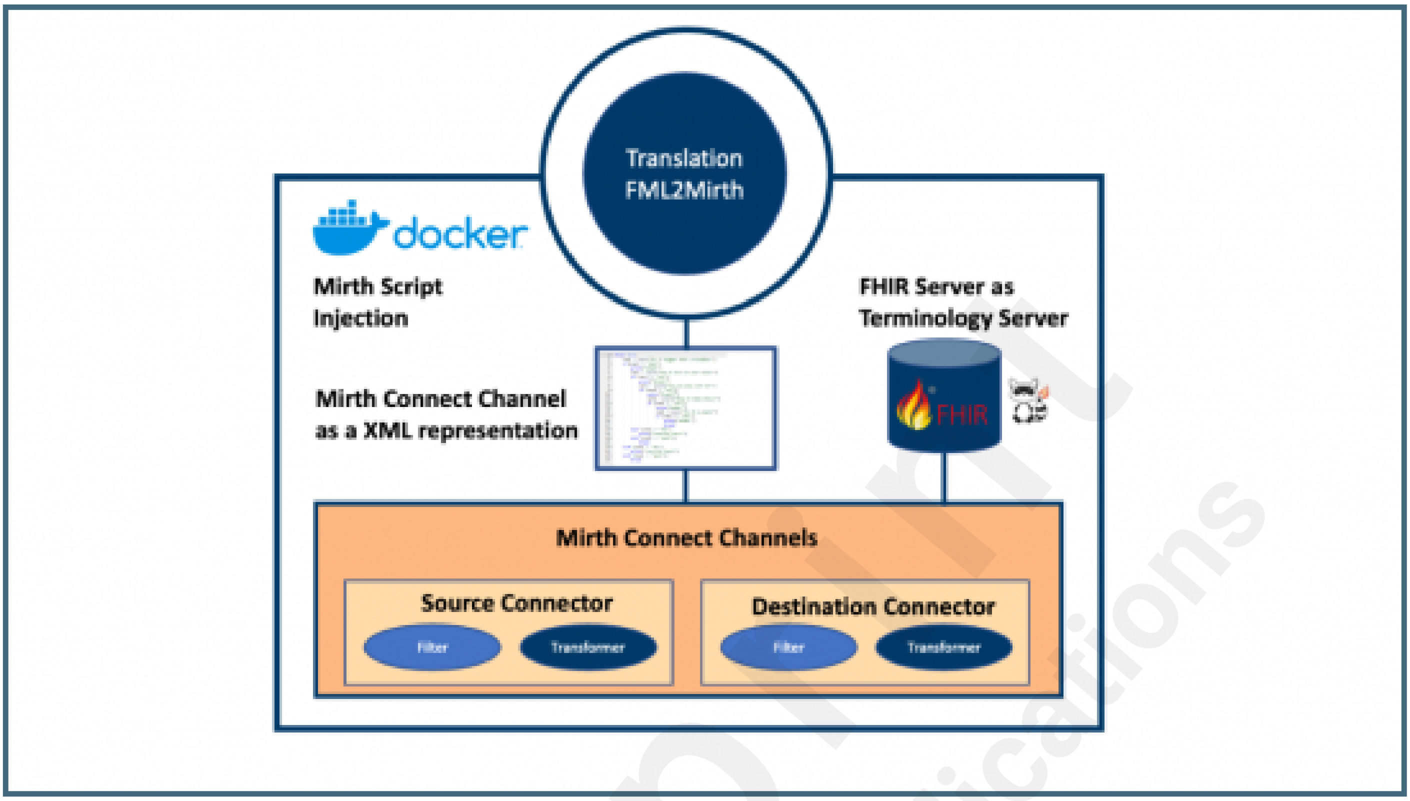
    test.LDT_8421 as s_unit -> quantity.unit = translate(s_unit, "<URL>", "code") as t_unit,    Rule 3
                                   quantity.system = "http://unitsofmeasure.org",
                                   quantity.code = t_unit
                                          "set unit";
                         } "set result";

// snip..
}
```

Conceptual Overview of the two-step process. In the first phase, the mapping is formalized as a FML script and corresponding semantic CodeSystems are aligned in a ConceptMap to each other. In the second phase, the priorly defined rules are used to deploy the mapping to Mirth. If semantic translation is needed the ConceptMaps can be queried during runtime.



Conceptual overview of the proposed architecture for a generic data transformation process.



Multimedia Appendixes

This example shows the different transformation steps, including the FHIR StructureMap and JavaScript result.
URL: http://asset.jmir.pub/assets/56496f4b01f2f5c24b0f0b667461909c.png