Modeling Interoperable Information Systems with 3LGM² and IHE*

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Summary
Background: Strategic planning of information systems (IS) in healthcare requires descriptions of the current and the future IS state. Enterprise architecture planning (EAP) tools like the 3LGM² tool help to build up and to analyze IS models. A model of the planned architecture can be derived from an analysis of current state IS models. Building an interoperable IS, i.e. an IS consisting of interoperable components, can be considered a relevant strategic information management goal for many IS in healthcare. Integrating the healthcare enterprise (IHE) is an initiative which targets interoperability by using established standards.

Objectives: To link IHE concepts to 3LGM² concepts within the 3LGM² tool. To describe how an information manager can be supported in handling the complex IHE world and planning interoperable IS using 3LGM² models. To describe how developers or maintainers of IHE profiles can be supported by the representation of IHE concepts in 3LGM².

Methods: Conceptualization and concept mapping methods are used to assign IHE concepts such as domains, integration profiles actors and transactions to the concepts of the three-layer graph-based meta-model (3LGM²).

Results: IHE concepts were successfully linked to 3LGM² concepts. An IHE-master-model, i.e. an abstract model for IHE concepts, was modeled with the help of 3LGM² tool. Two IHE domains were modeled in detail (TI, QRPH). We describe two use cases for the representation of IHE concepts and IHE domains as 3LGM² models. Information managers can use the IHE-master-model as reference model for modeling interoperable IS based on IHE profiles during EAP activities. IHE developers are supported in analyzing consistency of IHE concepts with the help of the IHE-master-model and functionalities of the 3LGM² tool

Conclusion: The complex relations between IHE concepts can be modeled by using the EAP method 3LGM². 3LGM² tool offers visualization and analysis features which are now available for the IHE-master-model. Thus information managers and IHE developers can use or develop IHE profiles systematically. In order to improve the usability and handling of the IHE-master-model and its usage as a reference model, some further refinements have to be done. Evaluating the use of the IHE-master-model by information managers and IHE developers is subject to further research.

1. Introduction

Information systems (IS) in healthcare are complex systems. E.g., in hospitals complexity derives from the variety of specialized hospital functions [1] to be supported. In addition, there are numerous regulatory, professional and technical constraints [2]. These requirements are typically implemented by specialized application systems from different vendors. The resulting heterogeneous IT landscape implies challenges in information management. Establishing information exchange between application systems and therefore solving problems of interoperability [3–5] are challenging topics, especially in shared care scenarios [6] or when using patient data for clinical research [7–11]. It might be a part of the information management strategy [12] of a hospital to work for an IS with interoperable (computer-based) application systems, creating an interoperable IS. Enterprise architecture planning (EAP) is a method helping to design or to change an IS according to the strategic goals of an enterprise [13–17]. The three-layer graph-based meta-model [18–21] and the corresponding 3LGM² tool [22] support EAP of health information systems [18]. The enterprise architecture (EA) is defined as a high-level description and “the blueprint that focuses on the essential features and characteristics of the system” [23]. Specific suggestions for the information manager of a hospital to align the IS to an interoperable strategy are offered by integrating the healthcare enterprise (IHE) [24].

IHE provides integration profiles describing requirements as use cases and facilitating interoperability by using existing standards. IHE groups integration profiles by domains (e.g. Radiology, Cardiology, IT Infrastructure). Integration profiles are available for many use cases [25]. The spec-
trum of profiles is very broad and ranges from describing the exchange of electronic documents between healthcare enterprises (XDS – Cross-Enterprise Document Sharing [26]) to the definition of content for a cardiac imaging report (CIRC – Cardiac Imaging Report Content [27]). There are two kinds of profiles – integration and content profiles. Integration profiles consist of actors and transactions. Actors describe functionalities of application system transactions. Transactions describe communication between actors using existing standards. Content profiles describe the data elements and the structure of the payload used in a transaction. Profiles are the result of the IHE development process and describe actions, transactions and content originating from a use case. Domain, profile, actor and transaction are key components in IHE because of their structuring role.

IHE currently supports 13 domains with several use cases, 141 integration and 17 content profiles (66 resp. 4 in status final) [28, 29]. For each domain, specific profiles and transactions are summarized in a single document, called technical framework. In addition to medical domains (e.g. Cardiology, Dental, Eye Care and so on), the IT Infrastructure domain (ITI [30, 31]) provides basic profiles for all domains.

The great number of IHE concepts and the complex dependencies are difficult to understand from a beginner’s point of view. The IHE Wiki [28] and cookbooks [32, 33] are quite helpful and amend the technical frameworks [29]. However, using these references in combination tends to be confusing both for IHE developers and information managers.

Nevertheless, using IHE offers many advantages for IS in healthcare. IHE in particular can be used in bids for single new application systems in order to ensure their conformancy with certain integration or content profiles. If complex changes of multiple application systems are necessary, for instance, to implement the mentioned shared care scenarios or secondary use of patient data for clinical research, information managers may need support in designing a target state model of the IS.

2. Objectives

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3. Methods

3.1 Conceptualization and Linkage

The IHE technical frameworks and the IHE Wiki were reviewed to extract IHE concepts like domain, integration profile, actor and transaction. If an IHE concept has a structuring role in IHE, we call it IHE key concept. The IHE key concepts are modeled by the authors in UML class diagrams [34].

IHE describes an IS on three layers [18]. The first layer is called domain layer and describes the enterprise functions and the information processed. The information is represented by entity types (e.g. “laboratory result”), which can be updated or used by enterprise functions (e.g. “create laboratory results” or “surgery planning”). The logical tool layer contains applications and communication links, which are needed to perform the enterprise functions. Application systems in hospitals are, for example, “medical documentation system” and “laboratory information system” which are connected to each other. In 3LGM², this connection is described by communication interfaces and communication links. Hardware components which are necessary for running the application systems are described on the physical tool layer. Since IHE primarily focuses on describing data exchange on a logical level, the physical tool layer is not relevant to us. Inter-layer relationships represent the connections between classes on adjacent layers.

IHE concepts have been linked to classes of the 3LGM² meta-model, which is described by UML class diagrams, too. Table 1 lists IHE key concepts and the associated 3LGM² classes and Figure 1 exemplarily shows the linkage for the IHE key concept “transaction” in form of a UML class diagram.

3.2 Modeling IHE with 3LGM²

3LGM² tool is a software written in Java [36] that implements 3LGM². 3LGM² tool can be used to model the IHE concepts based on the linkage created previously. Additionally, modeling conventions (rules) are developed to use the linkage in a consistent way (Figure 2). To explain these

<table>
<thead>
<tr>
<th>IHE key concept</th>
<th>3LGM² class</th>
</tr>
</thead>
<tbody>
<tr>
<td>domain</td>
<td>submodel, application system</td>
</tr>
<tr>
<td>integration profile</td>
<td>application system as part of the application system representing the respective domain</td>
</tr>
<tr>
<td>content profile</td>
<td>entity type</td>
</tr>
<tr>
<td>actor</td>
<td>application system as part of the superordinate application system representing the respective integration profile</td>
</tr>
<tr>
<td>transaction</td>
<td>communication link between application systems representing the respective actors (including the participating communication interfaces)</td>
</tr>
</tbody>
</table>
conventions, we exemplarily refer to the IHE domain IT Infrastructure (ITI) and the IHE integration profile Patient Identifier Cross Referencing (PIX) which is part of ITI. The PIX integration profile describes how to link different patient identifiers from different IS [37].

One of the modeling rules stipulates that the IHE concepts domain, integration profile and actor are connected to each other via a part-of relationship according to their occurrence in the respective technical framework (see example in Figure 2: IHE actor Patient Identifier Cross-reference Manager is part of IHE integration profile Patient Identifier Cross Referencing which is part of IHE domain IT Infrastructure). This is necessary because both are linked to the class application system in 3LGM². A generalized formalization leads to the following rules:

- IHE domain \(\rightarrow\) AC with name = IHE domain name
- IHE integration profile \(\rightarrow\) AC being part of AC of type IHE integration profile

In addition, grey tones are used in the graphical representation of the model to differentiate between domain, integration profiles and actors in Figure 2. In the model file available in supplementary material [38], the grey tones are replaced with colors (IHE domain = red, IHE actor = orange). The colours also indicate the status of a profile [25, 39], which can be final (green), trial implementation (yellow) or retired (white). In the model file the colors are explained in a legend.

IHE profiles have a prefix in the model. This prefix consists of the abbreviation for the IHE technical framework (“ITI”) followed by a dot and the abbreviation of the IHE profile (“[PIX]”). The prefix is added because in IHE it is allowed to reuse profiles in multiple domains and therefore it is useful to know where the profile is originally defined. Formal description of IHE profile names:

\[ \text{[domain abbreviation].[profile abbreviation]} \] <Profile Name>

Other rules concern IHE transactions. Modeling IHE transactions is tricky because several 3LGM²-classes have to be used in combination. IHE transactions are modeled in 3LGM² as communication links between application systems representing the respective IHE actors. See example in Figure 2: Each IHE actor (Patient Identity Source, Patient Identifier Cross-reference Manager and Patient Identifier Cross-reference Consumer) has communication interfaces (circles) which are connected via communication links (solid arrows). Modeling details of a transaction like communication standards and triggering events is also possible (Figure 3). Formalization:

- IHE transaction \(\rightarrow\)
  - each of the two AC involved in IHE transaction (T) gets a component interface (CI) with name = [IHE transaction abbreviation] IHE transaction name and communication standard = communication standard of T

![Figure 1](link)

**Figure 1** Linkage example: The IHE key concept transaction and its neighborhood relations. DICOM transaction and HL7 transaction have further relations to dedicated 3LGM² classes. Other communication standards which are used in IHE are linked to the 3LGM² class communication standard. (The UML diagrams in this paper are created with yEd [35].)
4. Results

Applying the methods described above, we constructed a model of IHE concepts in the 3LGM² tool. First, the knowledge contained in IHE documents was conceptualized. Then the IHE concepts were linked to 3LGM² classes (the model files as well as exported pictures are available as supplementary material [38]). Using these links together with modeling rules we found a way to combine IHE with 3LGM² and therefore we could achieve objective a). The resulting model is designated as the IHE-master-model [38].

Having the IHE-master-model, there are several new functions available through 3LGM² tool. The most impressive one might be the graphical representation of the model. It gives an overview of all the IHE domains, integration profiles, actors and how they are linked together [38]. To locate a desired IHE concept in the model, there is a search function available. Choosing the appropriate 3LGM² element types or using wildcards in the name or description fields, enables the user to find IHE concepts. Each IHE concept in the model has a property-dialog with corresponding attributes according to the element type. The attributes can be used to fill in a description (e.g. from the description in the technical framework), the used communication standard (e.g. if the component is a communication interface) or to add combinations of events and messages (e.g. if the component is a communication link and uses the HL7 protocol). We added hyperlinks to the corresponding text passage of the respective technical framework and a second link to the corresponding URL in the IHE wiki. These standard 3LGM² features support effective navigation through the IHE world without losing the overview.

There are some more functions available in 3LGM² tool [18, 19, 22, 42, 43]. To identify helpful functions for the use of the IHE-master-model by target user groups (e.g. information managers, IHE devel-
opers), we defined use cases and analyzed them with respect to the features available in 3LGM² tool. The analysis was done by the authors in focus group sessions. The results of this analysis were presented and discussed in an IHE workshop [44] organized by TMF a together with IHE-Deutschland b and on the annual conference [47] of the GMDS c. The two most important use cases are:

- Use case 1: To derive IS models (build instances) from the IHE-master-model (corresponds to objective b)).
- Use case 2: Analyzing the IHE-master-model to find conflicts in IHE (corresponds to objective c)).

4.1 Using the IHE-master-model as a Template (Use Case 1)

To support a hospital’s information manager, the IHE-master-model can be used as a template. Therefore the information manager chooses the needed IHE concepts from the IHE-master-model for constructing the current or the planned state of an IS. This might be necessary, e.g. to transform an existing IS into an interoperable one, according to the information management strategy. Therefore she or he uses the IHE-master-model as a reference model d and executes the following steps (Figure 4):

1. Open the IHE-master-model in 3LGM² tool.
2. Create a new model of the current state of an IS or open an existing one.
3. Switch to the IHE-master-model and select the needed IHE concepts. For example, if you want to add the PIX integration profile (PIX – Patient Identifier Cross Referencing [49]) to your current state model, you have to select the three PIX actors (Patient Identity Source, Patient Identifier Cross-reference Manager, Patient Identifier Cross-reference Consumer) including their component interfaces and communication links.
4. Take over the selected IHE concepts to the target model. There are two options doing that: copy & paste or by using the “add to model/submodel” function. Copy & paste duplicates the selected components. The pasted components get new internal IDs. Using the second option creates the selected components in the target model/submodel with the original internal IDs. Then 3LGM² tool is able to handle these IDs and to synchronize the components.
5. Assign the actors imported in step 4 to the target model application systems. To do that, you have to decide which application system takes on which role in the interoperable target scenario. In the above mentioned PIX example the “patient administration system” could take on the role of the actor Patient Identity Source. To model this, we assign the former imported actor from the IHE PIX integration profile Patient Identity Source to the application system “patient administration system” by using the part_of relation. The same procedure can be applied to the other application systems in the target model. So, the application system, which implements the master patient index, can act as Patient Identifier Cross-reference Manager and the “laboratory information system” takes on the role of a Patient Identifier Cross-reference Consumer.

Figure 4
Modeling workflow to create IS models using the IHE-master-model

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a TMF e.V. – Technology, Methods, and Infrastructure for Networked Medical Research [45]
b IHE-Deutschland e.V. – German regional grouping of IHE International [46]
c GMDS e.V. – German Society for Medical Informatics, Biometry and Epidemiology [48]
d in the sense of a model which provides model patterns [15]
The result of this approach is a model of an IS annotated with IHE concepts. All information needed for an interoperable information exchange is now available in the model. The information manager can now access the needed information via the search function, different graphical representations or analyses available in 3LGM² tool. Answers to questions like: “How does application system X communicate with application system Y and what communication standards are used?” can be found easily, because the information from the respective IHE concepts is linked to the model and additional details are accessible through the linked context-sensitive IHE documentation. The model may also help to prepare a bid requesting the acquisition, customization or implementation of the planned target state.

4.2 Finding Conflicts (Use Case 2)

As we figured out, IHE consists of many components which are partly interconnected. They can be reused in different settings and have dependencies. Therefore developers or maintainers of IHE profiles may benefit from detecting possible conflicts to avoid inconsistencies. According to objective c) and the corresponding use case 2, developers or maintainers of IHE profiles can be supported by analyzing the IHE concepts in the IHE-master-model through the functions provided by the 3LGM² tool.

One of the sticking points concerns the usage of different versions of communication standards by different IHE integration profiles. 3LGM² tool provides built-in graphical analyses to evaluate the usage of a certain communication standard (see highlighted circles and arrows in Figure 3). A more detailed analysis concerning the usage of communication standards is provided by the 3LGM² matrix view. It shows, e.g., which communication standards are attached to actors. Analyzing the matrix view allows to reveal possible conflicts, e.g. that some actors are defined using multiple communication standards or multiple versions of a communication standard (Figure 5). 3LGM² tool highlights these conditions for further improvement of the respective IHE integration profiles. Further analyses are supported by additional customizable XSLT-scripts, which are able to query the model directly.

Of course, an information manager benefits from these analyses, too. He or she can use the same analyses to reveal conflicts if certain integration profiles are used in his derived IS model.

5. Discussion

The IHE-master-model, which was introduced in this paper, implements the developed linkage and integrates IHE concepts in an EAP tool.

5.1 Limitations

The linkage between IHE concepts and 3LGM² classes has some limitations. This relationship cannot be described by a mathematical function, because not all IHE concepts could be mapped to 3LGM² classes (and vice versa). Even the relationship between IHE key concepts, which are a subset of IHE concepts, and 3LGM² classes is no function. Nevertheless, there is an association for every IHE key concept. However, it is not necessarily unique (for example, domain is associated with submodel and with application system). Therefore the linkage is neither injective nor surjective or bijective.

Another limitation concerns completeness. Not all IHE concepts are modeled yet and the modeled IHE concepts vary in their degree of detail. The highest level of detail is used in the ITI and QRPH technical framework submodels.

IHE profiles are not machine readable. Therefore, achieving completeness is difficult and modeling or even adding or updating existing model elements is a manual task at the moment. Parts of IHE are still under development. New versions of IHE technical framework documents, new IHE profiles or even new IHE domains are published or frequently updated until they reach the final state. However, there is no automated synchronization between IHE and the IHE-master-model so far.

Due to our current research goal of conducting a proof-of-concept, an evaluation with real-world information managers is currently missing.

5.2 Outlook

Although not all IHE concepts are modeled yet, we could show that the intended users can benefit from this approach. Our effort was accompanied by an IHE expert, discussed in an IHE workshop and presented on the GMDS annual conference. We showed the application of the approach in two use cases and addressed further possibilities of application, e.g. in analyzing the model. The more IHE domains are available in the model, the more use cases are supported and therefore a wider audience will benefit from this work. The present paper deals with typical use cases for hospital IS. But other healthcare areas, e.g. primary care or radiology will also be supported when the respective IHE domains become available in the IHE-mastermodel.

Some work has to be done to refine and to complete the IHE-master-model towards a reference model and to improve its usability and handling. Especially, model-
ing transactions in detail requires a great effort. More experiences from IHE experts and information managers would help us to increase the quality and to ensure the correctness of the model. Once the model is complete, we have to find a way to keep the model consistent with the IHE development. Maybe the community can help to achieve this. Modeling interoperable IS in healthcare using the IHE-master-model seems to be a feasible approach from a theoretical point of view. However, we consider some modifications in 3LGM² and 3LGM² tool to directly support some of the IHE key concepts without using modeling workarounds.

We suggest using the IHE-master-model already during the development phase of an integration profile. This may help to avoid conflicts with existing integration profiles. By integrating IHE in 3LGM² the whole IHE development process could be supported in a positive way. Therefore it is also conceivable to integrate our model-based approach in the IHE development process.

Afterwards, we plan to evaluate the IHE-master-model and its handling by information managers as well as IHE developers. Therefore we currently collect practical experiences in using the IHE-master-model from the perspective of an information manager who is responsible for designing a transinstitutional IS. The project aims at establishing a regional healthcare network for oncology treatment. Several IHE profiles like XDS, PIX, XD-LAB and CRD are available for this setting and are considered in a first draft. In order to improve the support of IHE developers and to get more feedback by them, we are currently intensifying our contacts to IHE Germany, trying to disseminate our experiences to the IHE community with the goal of starting a dialog on modeling interoperable IS.

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