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Topic: Interoperability

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Abstract (for dissemination)	This document provides guidance on the attributes required of VPH NoE ToolKit content.
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EXECUTIVE SUMMARY

This guideline is intended to assist potential contributors to the VPH NoE ToolKit in preparing their content for submission.

There are several such guideline documents in this series, covering the full range of issues affecting content providers. They are being developed over a period of time and, once finalised, these guideline may be bound together into a single VPH NoE resource.

This guideline will focus on Interoperability, which has been identified as one of the three principal strands of activity (with engagement and standards) in “The Virtual Physiological Human ToolKit – Evolution and Sustainability”¹. The focus is put on interoperable content: *“High-quality content for the ToolKit needs to be collected. Wherever possible, this is sought from existing developments external to the VPH-NoE, in order both to maximise engagement and to make best use of VPH-NoE resources. The focus is on making existing tools interoperable with other ToolKit content.”*. This documents' intent is to guide researchers and developers in their choices so that to maximise interoperability with other developments.

¹ The Virtual Physiological Human ToolKit – Evolution and Sustainability by Jonathan Cooper ([link](#))

Introduction

This document is one of a series that together build to form a complete guide to the ideal content and presentation of materials offered for distribution via the Virtual Physiological Human Network of Excellence ToolKit Portal. The full set of Guideline Documents is summarised below.

Guidance Area	Description
Tool characterisation	The attributes important for inclusion in the documentation of Tools, including performance validation
Model characterisation	The attributes important for inclusion in the documentation of Models, including performance validation
Data Characterisation	The attributes important for inclusion in the documentation of Data
Ontological Annotation	The significance, benefits and methods of ontological annotation of ToolKit content
Interoperability	Key attributes concerning the additional specification of predominantly tools and models that will allow operation in a multistage workflow alongside other items of ToolKit content
Ethico-legal issues, provenance	The inherited responsibilities that are attached to any item of ToolKit content – perhaps particularly data – including legal, ethical and territorial restrictions
Licensing	The conditions that apply to the legitimate use of the content from a commercial and intellectual property standpoint
Usability & Training	The factors that are important for the easy use and ready acceptance of ToolKit content, taking into account the environment, the likely users and the need for interoperability. Additionally, the nature of training facilities of all types appropriate to particular content categories.

Guideline Topic: Interoperability

In its effort to integrate tools, data and models to support the development of patient-specific computer models and their application in personalized and predictive healthcare, the VPH Toolkit also aims at improving their interoperability, a condition for a greater sustainability. First let us define interoperability.

The International Standards Organization suggests in its draft technical report (ISO/IEC 2382-01, Information Technology Vocabulary, Fundamental Terms) that interoperability be defined as "*the capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units*".

The Institute of Electrical and Electronic Engineers (IEEE) provides the generally accepted definition of interoperability, at least from a technical perspective. It defines the term as "*the ability of two or more systems or components to exchange information and to use the information that has been exchanged.*" (See IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries (New York, NY: 1990)).

After defining the underlying concepts and the interactions with the other VPH guidelines, we will look at the impacts of legislation and standards on interoperability. We will then try to practically define the guidelines for specific domains. The verification of interoperability statements is a difficult task, a section is dedicated to possible solutions. Next, we will discuss possible training for learning about interoperability and standards. Demand and standards do evolve, this raises the topic of the maintenance of interoperability. Ranking tools according to a 'level' of interoperability will then be proposed. Other sources of information and references will conclude this document.

Underlying Concepts

As we have seen in its definition, interoperability is a broad term, encompassing many of the issues impinging upon the effectiveness with which diverse information resources might fruitfully co-exist. This working group will only concentrate in technical and informational interoperability, in the scope of data, models, software programs and infrastructure in the domains of the VPH. We will not address the topic of organizational interoperability which covers the relationships between organizations and individuals and their parts of the system, including business relationships and legal relationships.

There have been numerous attempts to define levels or layers of interoperability in the technical domain. One of them is called the Levels of Conceptual Interoperability Model (LCIM). It defines seven levels of interoperability that can be described as follow²:

- **Level 0:** Stand-alone systems have no interoperability.
- **Level 1:** On the level of Technical Interoperability, a communication protocol exists for exchanging data between participating systems. On this level, a communication infrastructure is established allowing systems to exchange bits and bytes, the underlying networks and protocols are unambiguously defined.
- **Level 2:** The Syntactic Interoperability level introduces a common structure to exchange information; i.e., a common data format is applied. On this level, a common protocol to structure the data is used; the format of the information exchange is unambiguously defined. This layer defines structure. It is, for example, facilitated by using the XML standard.
- **Level 3:** If a common information exchange reference model is used, the level of Semantic Interoperability is reached. On this level, the meaning of the data is shared; the content of the information exchange requests are unambiguously defined. This layer defines (word) meaning. Ontologies can be used to define meaning.
- **Level 4:** Pragmatic Interoperability is reached when the interoperating systems are aware of the methods and procedures that each system is employing. In other words, the use of the data – or the context of its application – is understood by the participating systems; the context in which the information is exchanged is unambiguously defined. This layer puts the (word) meaning into context.
- **Level 5:** As a system operates on data over time, the state of that system will change, and this includes the assumptions and constraints that affect its data interchange. If systems have attained Dynamic Interoperability, they are able to comprehend the state changes that occur in the assumptions and constraints that each is making over time, and they are able to take advantage of those changes. When interested specifically in the effects of operations, this becomes increasingly important; the effect of the information exchange within the participating systems is unambiguously defined.
- **Level 6:** Finally, if the conceptual model – i.e. the assumptions and constraints of the meaningful abstraction of reality – are aligned, the highest level of interoperability is reached: Conceptual Interoperability. This requires that

² Applying the Levels of Conceptual Interoperability Model in Support of Integrability, Interoperability, and Composability for System-of-Systems Engineering by Andreas Tolk, ([link](#))

conceptual models are documented based on engineering methods enabling their interpretation and evaluation by other engineers. In essence, this requires a fully specified, but implementation independent model.

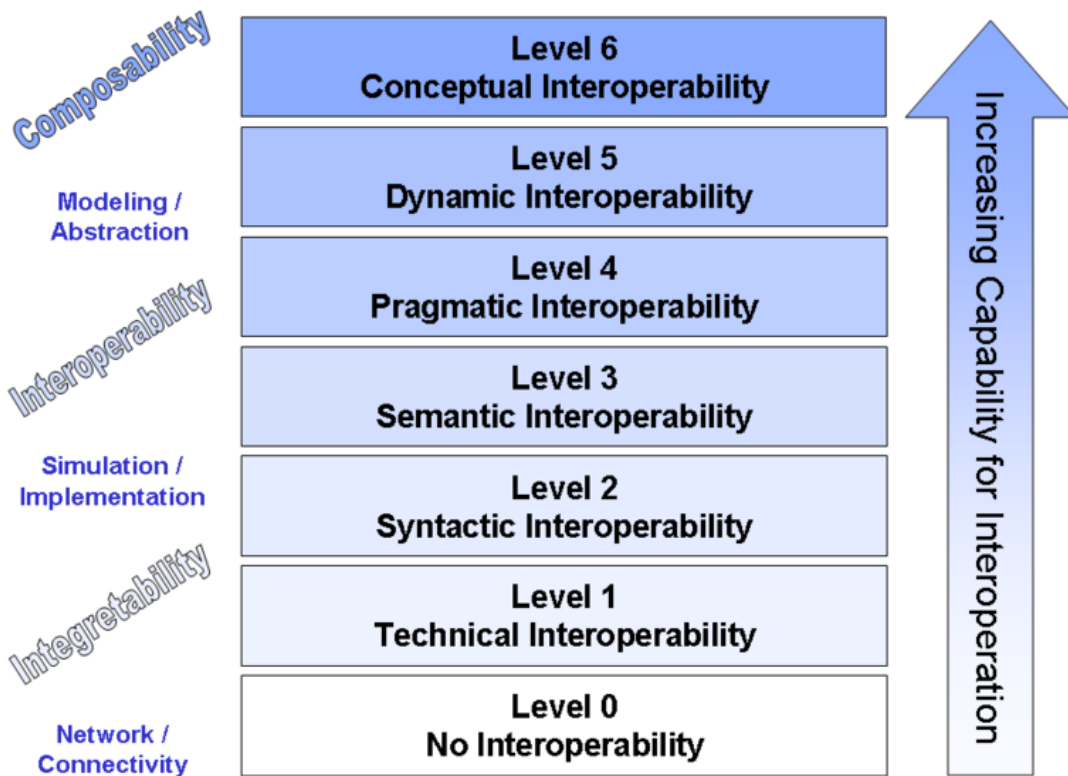


Illustration 1: Levels of Conceptual Interoperability Model (LCIM)

This illustration is from Andreas Tolk, first used in “Tolk A, Diallo SY, Turnitsa CD, Winters LS (2006) "Composable M&S Web Services for Net-centric Applications," Journal for Defense Modeling & Simulation (JDMS), Volume 3 Number 1, pp. 27-44, January 2006”.

Level 5 and 6 are hypothetical levels that are topic of ongoing research. Tolk² mentions that “Ontologies have been shown to be a potential contributor on the semantic and pragmatic level”.

A more pragmatic view of the topic has been studied by the cancer Biomedical Informatics Grid (caBIG)³ project. This project has defined Compatibility Guidelines⁴ for achieving caBIG compatibility. The degrees of interoperability between systems are qualified in terms of four maturity levels:

- **Legacy:** Implies no interoperability with an external system or resource. A legacy system is a system that was designed prior to or without awareness of the availability of these compatibility guidelines, and which may not meet any of the requirements for interoperability.

³ caBIG: <https://cabig.nci.nih.gov/>

⁴ caBIG Guidelines: https://cabig.nci.nih.gov/guidelines_documentation

- **Bronze:** Classifies the minimum requirements that must be met to achieve a basic degree of interoperability.
- **Silver:** A rigorous set of requirements that, when met, significantly reduce the barrier for using a resource by a remote party who was not involved in the development of that resource.
- **Gold:** Extensions to the silver requirements aimed at standardization and harmonization, which when met, enable full syntactic and semantic interoperability of disparate systems.

The document “caBIG® Compatibility Guidelines” (version 3.0) is a very good reference for an in depth study of interoperability in the context of a biomedical project.

Interactions and Dependencies

This guideline has relationships with the following guideline documents created by the VPH NoE:

- Tool, Model and Data characterisation: interoperability is considered as an important feature of VPH tools, models and data, its description and validation need to be clearly defined in a standard way so that characterisations refer to it accordingly; for example data formats need to be unambiguously named (using a version number) when supported by a tool.
- Ontological Annotation: these standards are an integrated part to interoperability, they allow Semantic Interoperability.
- Licensing and Ethico-Legal/Provenance: in a non-technical way, licensing and legal issues can limit or break interoperability (see the section “Applicable Legislation”).
- Usability & Training: what interoperability is, its repercussion on implementations and how it helps combining tools, models and data needs to be taught (see the section “Training”).

Applicable Legislation

It is possible that legislation dictates that certain interface or data format standards are followed in certain cases (especially in a clinical setting) which can impact interoperability. The following paragraphs describe possible regulations that can limit interoperability.

Licenses and Patents may force you to pay upfront for the right to write in a format, such as MP3 for instance. However it's a popular format and you need it to interoperate with other tools. The VPH encourages the use of open standards that are published in the public domain and do not require any licence fee. The standards listed in the following section are all open. It is to be noted that incompatibility between licences, commercial and open-source, but also between open-source licences can have an effect on integration of content. The most famous example being the copyleft licences (as the GNU General Public Licences (GPL)) that require that any resulting copies or adaptations are bound by the same licensing agreement. This makes it incompatible with more permissive licences. This has to be taken in consideration when, for example, integrating a plug-in in a framework.

Ethico-legal concerns can also impact interoperability. Access permission to certain data or networks can limit how someone can use data. Medical data is also bound to specific legislation that could prevent its use by any tool, one example being its level of anonymisation.

Standards and Standards Bodies

The “integration” and development of standards is central to the VPH NoE objectives. They are crucial to ensure interoperability. The main standards developed by the VPH NoE concern ontology, data, modelling and infrastructure (see ⁵).

Interoperability and standards need to be differentiated. Each of them aims at enabling effective sharing between computer systems. If two tools use the same standard, they will be able to interoperate but using standards is not the only way. Interoperability can be the results of an agreement between two or more vendors made to exclude competitors. The spirit is then the opposite to the one of standards. This is not the purpose of the VPH and we will only treat the case of interoperability via standards or commonly used open formats/protocols.

Here are common standards and standards bodies grouped in categories that we will refer to in the specific guidelines of the Characteristics chapter. All these standards do not cover the full extent of the VPH topics. In these cases, the VPH participates actively in the elaboration and promotion of new standards.

Modelling

The following standards are markup languages used in the context of modelling. Most of them do not include meta information, their usage only allowing syntactic interoperability.

- CellML: The purpose of CellML is to store and exchange computer-based mathematical models, based on the XML markup language (<http://www.cellml.org/>).
- FieldML: Field Modelling/Markup Language (http://www.physiome.org.nz/xml_languages/fieldml). Its goal is to be a declarative language for building hierarchical models represented by generalized mathematical fields. Its primary use will be to represent the dynamic geometry and solution fields from computational models of cells, tissues and organs.
- SBML: Systems Biology Markup Language (<http://sbml.org>). Oriented towards describing systems where biological entities are involved in, and modified by, processes that occur over time.
- NeuroML: computational neurosciences mark-up language to facilitate the exchange of complex neural models, allow for greater transparency and accessibility of models, enhance interoperability between simulators and other tools, and support the development of new software and databases (<http://www.neuroml.org/>)

Data

The following standards are medical data standards used to store images and signals from medical acquisition devices but also health information. As for modelling standards, these formats do not include meta information and therefore only allow syntactic interoperability.

⁵ The Virtual Physiological Human ToolKit, AHM 2009 by Jonathan Cooper ([link](#))

- DICOM: Digital Imaging and Communications in Medicine (<http://medical.nema.org/>), maintained by the National Electrical Manufacturers Association (NEMA). It is designed to ensure the interoperability of systems used to produce, store, display, process, send, retrieve, query or print medical images and derived structured documents as well as to manage related workflow. Not related to data, the DICOM standard also defines an application hosting standard for launching and communicating with plug-in applications. First implemented in 1993, its official version number is 3.0 but specifications are updated every year and named using the year number.
- HL7: Health Level Seven (<http://www.hl7.org/>). HL7 is the name of an electronic health information transaction protocol and also the name of the group that maintains it. It concentrates in exchange, integration, sharing, and retrieval of records. First implemented in 1987, its current version number is 3.
- JPEG: Joint Photographic Experts Group. JPEG is a lossy compression for 2D image. JPEG (and JPG) is also commonly used to specify the file format for this compressed data, its official name being JPEG/Exif.
- TIFF: Tagged Image File Format. TIFF is a generic image file format that allows tagging.

The following data formats are not standards but are commonly used in the community or a tentatives to standardise a specific data.

- VTK file format. The VTK (Visualisation ToolKit) defines files formats for generic data representation. The legacy file format is a serial format either encoded in ASCII or binary form. A new XML based format is also available from the toolkit.
- BioSignalML: Biological Signal Markup Language (<http://www.embs.org/techcomm/tc-cbap/biosignal.html>). Standard under development for annotating physiological time-dependent signals.
- GDF: General Data Format for biomedical signals (<http://arxiv.org/abs/cs.DB/0608052>). GDF is a tentative to standardise biomedical signals (mainly ECG (Electrocardiography), EEG (Electroencephalography)) comparable to the BioSignalML. First implemented in 2006, its current version number is 2.
- Analyse 7.5. This format is the one used in the Analyze, a software package developed by the Biomedical Imaging Resource (BIR) at the Mayo Clinic for the display and processing of multi-modality biomedical images.
- Nifti: Neuroimaging Informatics Technology Initiative (<http://nifti.nimh.nih.gov/>). The Nifti format is an extension of the Analyze 7.5 file format that stores extra information as the medical image orientation.

Ontology

As mentioned in the Underlying Concepts section, ontologies allow semantic interoperability. The scope of specific ontologies and the needs of some VPH project can sometime not overlap, leading to the creation of new ontologies. This is not a recommended behaviour and the VPH should help developers find appropriate ontologies or start discussions with the ontology owner to append missing concepts.

- FMA: Foundational Model of Anatomy ontology (<http://sig.biostr.washington.edu/projects/fm/index.html>). Open source ontology for the representation of classes or types and relationships necessary for the symbolic representation of the phenotypic structure of the human body.
- SNOMED CT: Systematized Nomenclature of Medicine-Clinical Terms (<http://www.ihtsdo.org/>). Multilingual clinical healthcare terminology.
- GO: Gene Ontology (<http://www.geneontology.org/>). Aims at standardizing the representation of gene and gene product attributes across species and databases.
- LOINC: Logical Observation Identifiers Names and Codes (<http://loinc.org/>)
- MIASE: Minimal Information About a Simulation Experiment (<http://www.biomodels.net/miase/>).

This not an exhaustive list, you can find more information on community portals like the OBO Foundry (<http://www.obofoundry.org/>) or the National Centre for Biomedical Ontology's BioPortal (<http://bioportal.bioontology.org/>).

Infrastructure

Different efforts for federating computing grid infrastructures exist around the world: the cancer Biomedical Informatics Grid (caBIG, USA, <https://cabig.nci.nih.gov/>), the European Grid Initiative (EGI, <http://www.egi.eu/>) and the Distributed European Infrastructure for Supercomputing Applications (DEISA, <http://www.deisa.eu/>). Their usage is done via middle-ware that need to support certain standards as the ones listed below.

- JSDL: Job Submission Description Language. Language for describing the requirements of computational jobs for submission to resources, particularly in Grid environments.
- OGSA-BES: Open Grid Services Architecture - Basic Execution Service. Web services interfaces for creating, monitoring, and controlling computational entities such as UNIX or Windows processes, Web Services, or parallel programs within a defined environment.
- OGSA-DAI: Open Grid Services Architecture - Data Access and Integration (<http://www.ogsadai.org.uk>). Allows data resources (e.g. relational or XML databases, files or web services) to be federated and accessed via web services on the web or within grids or clouds.
- GridFTP: extension of the standard File Transfer Protocol (FTP) for use with Grid computing.
- SSH (Secure Shell), SSL (Security Socket Layer) and TLS (Transport Layer Security). Network protocols used to encrypt and secure communication over a network.
- MTOM: Message Transmission Optimization Mechanism (<http://www.w3.org/TR/soap12-mtom/>). MTOM is a optimised method for sending and receiving binary data using web services mostly using XML-binary Optimized Packaging (XOP).

More information about the grid computing standards can be found on the Open Grid

Forum (OGF, <http://www.ogf.org/>). The Globus Toolkit (<http://www.globus.org/toolkit/>) contains example implementations of the standards defined by the OGF.

Characteristics

The following sections go more into details about what interoperability means in the context of the main topics of the VPH. They will refer to standards listed in the “Standards and Standards Bodies” section.

Model Interoperability

Model should ideally be implemented in a standard markup language, as described in the Models Guidelines, and annotated according to the Ontologies Guidelines. Second best is for it to be available in an open format and suitable annotated and documented. Models may also be available as software. Preferably open, these APIs provide example usage of the model and basic functionality such reading/writing. In this case the considerations for tools apply.

Data Interoperability

Concerning file based interoperability, as far as images are concerned, protocols to exchange these files across network from within running tools include DICOM PACS. Insuring compliance with the DICOM TCP-IP protocols helps bringing transparent collaboration between tools. HL7 messaging standards also represent a common effort towards flawless connectivity between tools.

As for models, the availability of APIs helps the adoption of data standard in the community.

Interoperability of data becomes important when bridging domains that did not use to cooperate in the past. This is the case for example for multi-scale data (and also models). The need for visualising and integrating data at different scales is a recent topic of research that first needs to define a common data format before being able to process the data.

Infrastructure Interoperability

The Virtual Physiological Human ToolKit⁶ paper published for AHM in 2009 mentions infrastructure interoperability as an area of work:

“Appropriate accessibility of resources is key to the research and clinical uptake of simulations which use grid-based high performance computing (HPC) resources, networks, and data repositories. Various such resources are used for VPH research, as discussed in §4 c. Significant progress has already been made on the interoperability of these grids and work is continuing to promote standards-based interoperation at the protocol level—e.g. through Open Grid Forum (OGF) specifications such as JSDL and OGSA-BES—and the application level, where needed. The needs of coupled multi-scale physiological models impose particular requirements on computational resources, and so the VPH-SWG will work with the relevant OGF working groups to feedback our needs and use cases, to help in the evolution of standards in areas essential for the successful realization of VPH models in clinical workflows.”

A recent project proposal also reflects the need for a more federated infrastructure among VPH partners. Called VPH-Share, it aims at providing: “*a systematic framework for understanding physiological processes in the human*

⁶ The Virtual Physiological Human ToolKit by Jonathan Cooper ([link](#))

body in terms of anatomical structure and biophysical mechanisms across multiple length and time scales”.

Tool Interoperability

In terms of software, interoperability refers to the ability to read and write specific file formats but also the exchange of data using a common format and communication protocol. This independently of the underlying platform, being operating system compatible is not considered in the different levels of interoperability.

Interoperability can also refer to the relation between different implementation layers. To ease the connection between two algorithms, developers can bring them under the same software, blurring the border between tools to the point of non existence from the user's point of view. Plug-ins and linked libraries can reach that objective. A core / plug-in architecture enable the inclusion of different algorithms and function under the same executable, with the advantage of nullifying the transport overhead, and proposing a single interface. The work of porting algorithms under the same framework can be thought as the interoperability work. Usually done using the same programming language, 'foreign' code written in another language can also be used if the framework provides bindings between the two languages. A clear encapsulation Application Programming Interface (API) and a stable Application Binary Interface (ABI) are the conditions making it possible. Projects such as MedINRIA⁷, Gimias⁸, Slicer3D⁹, MITK¹⁰ or the Common Toolkit (CTK¹¹) offer such frameworks and aim at unifying the writing of plug-ins and widen their application by a wider community. A well formed platform must standardise the input and outputs of data, processes, visualisation objects, such that wrapping existing libraries becomes a simple library linking exercise. This is the purpose of the Application Hosting standard¹² developed by the DICOM community. Such software modules can then be run under all hosts implementing this standard. An example implementation has been developed by the OpenXIP¹³ project.

A greater level of abstraction is provided by Remote Procedure Call (RPC). RPC is a communication protocol that allow software running on disparate operating systems, running in different environments to make procedure calls. An example architecture using RPC coupled with an intermediate layer (the “Broker”) is CORBA, the Common Object Request Broker Architecture (<http://www.corba.org/>). Its specifications are from the Object Management Group (<http://www.omg.org/>). As described in the RTAE¹⁴: *“CORBA applications are composed of objects (individual units of running software that combine functionality and data) with strict interfaces defined using IDL. There are standard mappings from IDL to most common programming languages. Clients use the interfaces to invoke operations on objects.”*. Because of its complexity, other implementations are often preferred like the Microsoft .NET Remoting or the XML-RPC. For access over the internet, web services are commonly used. They provide a set of API accessible via the HTTP protocol. An example are

⁷ <http://www-sop.inria.fr/asclepios/software/MedINRIA/>

⁸ <http://www.gimias.org>

⁹ <http://www.slicer.org/>

¹⁰ <http://www.mitk.org/>

¹¹ <http://www.commonstk.org>

¹² ftp://medical.nema.org/medical/dicom/supps/sup118_lb.pdf

¹³ <http://www.openxip.org/>

¹⁴ http://www.vph-noe.eu/vph-repository/doc_download/51-vph-noe-requirements-and-technology-assessment-exercise

the webservices accessible for EBI databases
(<http://www.ebi.ac.uk/Tools/webservices>).

The tools characterisation guideline defines all the fields to fill in to specify to which standards a tool adheres to.

Standards become critical in the building of workflows that consists in a pipeline of algorithms. Consistent input/output formats and compatibility with the orchestration mechanism are compulsory. This combination of algorithms from different sources is a common task for VPH researchers, because of the multidisciplinary nature of their domains. Being able to easily create workflows helps saving time and is less error prone than implementing inter algorithm translators or using third party converters. No standard exist for the definition of a workflow so tools use their own. An example open source software is Taverna¹⁵.

¹⁵ <http://www.taverna.org.uk/>

Methods of Verification

The verification of interoperability statements can be done by checking that they are clearly defined in a way that allows their testing.

The IHE (Integrating the Healthcare Enterprise¹⁶) is an initiative by healthcare professionals and industry to improve the way computer systems in healthcare share information. The group defines common clinical use cases (profiles) and associated recommend standards. Medical software vendors can then test their interoperability statements during connectathons¹⁷. The IHE then publishes the validation of the participants' interoperability and compliance with IHE profiles. In this context, a set of tools called "IHE Gazelle Tools" have been developed to test interoperability¹⁸ according to the IHE standards.

Here are similar approaches:

- Connecting for Health (UK): <http://www.connectingforhealth.nhs.uk>
- ETSI PLUGTESTS: <http://www.etsi.org/plugtests>

¹⁶ IHE web site: <http://www.ihe.net/>

¹⁷ IHE connectathon: <http://www.ihe.net/Connectathon/index.cfm>

¹⁸ IHE gazelle tools: <http://gazelle.ihe-europe.net/>

Training

Interoperability is a top priority for the VPH NoE and tools will only be accepted in the toolkit according to their rank in terms of interoperability (among other rankings). So, what interoperability is, its repercussion on implementations and how it helps combining tools, models and data needs to be taught.

The IHE connectathon (mentioned above) or similar initiatives are perfect example of training days to promote generic interoperability. More specific training concerning topics of the VPH could be organized to support developers in reaching the acceptable level of interoperability for integration in the toolkit.

Maintenance

Because standards and best practices do evolve, interoperability statements need to refer to documentation of the used standard and clearly state its version or date of publication. In the case that no standard is used, reference to a data format specification or protocol definition needs to be made.

Ranking

The level of interoperability (see the Underlying Concepts chapter) can be used to rank tools, data and models that are proposed for integration in the VPH NoE Toolkit. The minimum level for acceptance should be the level 2: Syntactic Interoperability. Models, data and tools with no interoperability should not be accepted.

Documentation, Reporting Templates

Here are generic recommendations for the documentation of models, data and tools:

- For tools, libraries and services, API documentation must be provided. A minimum being an automated documentation produced directly from the code (e.g. as produced by the Doxygen tool¹⁹). Requirements, design and architecture documents can help better understand the implementation choices. A list of input/output formats should also be provided.
- For models, modelling assumptions must be available and comprehensively described, in a standard format if available, otherwise in English text.
- For data, the scope of its usage must be available.

These are basic recommendations, the Tool, Model and Data characterisation guidelines will provide you with a complete list of features to document.

¹⁹ <http://www.doxygen.org>

Further Information

Projects related to interoperability:

- RIDE project: A Roadmap for Interoperability of eHealth Systems (<http://www.srdc.metu.edu.tr/webpage/projects/ride/>). Ended 12-07.
- SEMANTICMINIMG: A Roadmap for Interoperability of eHealth Systems (<http://www.imt.liu.se/mi/semanticminimg/>). Ended 06-07.
- Semantic HEALTH: Semantic Interoperability (<http://www.semanticealth.org/>). Ended 12-07.
- CTK (<http://www.commonk.org>)
- ETSI (<http://www.etsi.org>)

References

Here are references to external content related to interoperability:

- Interoperability Focus (UKOLN): <http://www.ukoln.ac.uk/interop-focus/about/>
- Tech Topic 1: Interoperability (US Federal Communications Commission): <http://www.fcc.gov/pshs/techtopics/tech-interop.html>
- Wikipedia: <http://en.wikipedia.org/wiki/Interoperability>