Automatic Metadata Creation for Supporting Interoperability Levels of Spatial Data Infrastructures

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Abstract:

Interoperability in Spatial Data Infrastructures (*SDI*) is a full-grown subject and an objective with many shortcomings as far as definition of standards for geographic data transfer and exchange, different data types' integration, and comprehensive semantic models is concerned. There is a vast literature available on interoperability models containing different interoperability levels, including technological, syntactic and semantic levels. However, very limited research has been carried out on the development of interoperability models for the implementation of Spatial Data Infrastructures (*SDI*). This paper provides a short review of the main advances in interoperability related to *SDI*. It also discusses the important role of metadata elements in the formalization of interoperability models for the implementation of *SDI*. We propose an integrated interoperability model based on the definition of a common template that integrates seven interoperability levels: technical, syntactic, semantic, pragmatic, dynamic, conceptual and organizational. The implementation is carried out by automatic production of ISO19115 metadata. Finally, the results outline the strength and deficiencies in terms of the dynamic interoperability level of *SDI* based on the elements of ISO19115 metadata.

Keywords: SDI, Interoperability Model, Metadata.

1 INTRODUCTION

Two usual definitions of SDI have been provided: 1) the SDI cookbook version 2.0 "Spatial Data Infrastructure" (*SDI*), which is often used to denote the relevant base collection of technologies, policies and institutional arrangements that facilitate the availability of and access to spatial data' (GSDI 2004 p. 8), and 2) *SDI* subsumes technology, systems, standards, networks, people, policies, organizational aspects, geo-referenced data, and delivery mechanisms to end-users (Georgiadou, Puri, and Sahay 2005, Williamson 2004).

SDI provides a basis for spatial data discovery, evaluation, and application for users, promoting a reliable environment to facilitate the access to geographic information and the agreements, organizations and programs needed to coordinate *SDIs* at different scales (Béjar *et al.* 2008; GSDI 2004).

Georgiadou, Puri, and Sahay (2005) consider that *SDI* must be dealt with from both a technical and a social point of view. They state that *SDIs* are a special case of Information Infrastructures (*IIs*), specifically geared towards geographic information, according to Bernard *et al.* (2005). Béjar *et al.* (2008) propose other frameworks to support *SDI* research such as System of Systems (*SoS*) compositions, in the sense suggested by Maier (1996). Before reviewing the relationship between *II* and *SoS*, the main conclusion of this proposal is that these terms are used to refer to similar concepts from different perspectives, *SoS* being a broader term. This relationship provides a new conceptual framework to study *SDIs*.

As a result of the review carried out to define the state of the art of interoperability within the *GIS* context (Manso and Wachowicz 2009), we planned to research interoperability in the SoS, the use of non-hierarchical levels and the definition of a model allowing measurement of interoperability between systems. As an outcome of the research carried out on system interoperability, where we have dealt with *SD*I as an *SoS*, we have put forward an Interoperability Model Based on Metadata for *SDI* (*IMBM-SDI*) (Manso, Wachowicz and Bernabé, 2009). This model is made up of the technical, syntactic, semantic, pragmatic, dynamic and conceptual levels – as defined by the "Levels of Conceptual Interoperability Model", *LCIM*) – to which an organizational level has been added, gathering the legal aspects, the data policies and responsibilities among other aspects. In addition to defining the levels the integrated model is made up of from the *SDI* perspective, the metadata items of ISO 19115 (2003) are analyzed as regards the interoperability they provide. This same idea has also been used by Tolk, Diallo and Turnitsa (2007) by applying the *LCIM* model in the design of *SoS* supporting integration, interoperability and orchestration or chaining of systems.

Metadata are key elements for Information Infrastructures (*II*), especially for *SDIs*. In addition to carrying out discovery, evaluation, access and use functions (Gayatri & Ramachandran 2007, Johnston 2005, GSDI 2004, Gilliland-Swetland 2000, Beard, 1996), they may support interoperability. In this sense Tolk, Diallo y Turnitsa (2007) state that 'we are moving towards a "Dynamic Web", supporting the orchestration and alignment of agile components at least up to the dynamic layer with standardized metadata'. In our *IMBM-SDI* model we have also verified that the main interoperability levels supported by ISO 19115 metadata are the semantic, dynamic and organizational levels.

West and Hess (2002) and Guptill (1999) state that the manual creation of contents adequately describing a geodata set is a boring, tedious work consuming a great deal of resources, besides being prone to errors. Anderson and Pérez-Carballo (2001) maintain that the metadata created by automatic procedures tend to be more efficient, more consistent and cost-effective than the manually created metadata.

The purpose of this paper is to show that ISO19115-conformant metadata automatically produced for a dataset, support the interoperability of systems in an *SDI*. Given the importance of the dynamic interoperability and the complexity of the metadata standard in the composition of services, the scope of this demonstration is limited to metadata items capable of being automatically produced and supporting such interoperability level.

The remainder of this paper is organized as follows. Section 2 reviews the interoperability levels described in the literature and related to *SDI*; the most prominent authors are indicated. Section 3 describes the meaning and objective of the levels in the "Integrated Model of Interoperability for *SDI*". Section 4 describes the role of metadata at the interoperability levels of the integrated model. Section 5 enumerates the metadata items supporting dynamic interoperability and able to be automatically generated by extraction, computing or inference; a description about how to generate the metadata is included. In Section 6 the conclusions and future research lines are presented.

2 UNDERLYING INTEROPERABILITY LEVELS

In *SDI* different hardware and software components, supplies, policies, procedures and people must interoperate, for storage, processing and enabling access to spatial data. Interoperability has many meanings, including the facets of communication, exchange, cooperation, and sharing of information between systems. In fact, the essence of interoperability is being relationships between systems, where each relationship is a form of communication, exchange, cooperation and sharing (Carney *et al.* 2005). Usually different definitions of interoperability differ in terms of the relationship description and the system components. Some focus on system and hardware components, others on services in order to provide information and components sharing information, and still others on how to use the exchanged information in a meaningful manner without any special manipulation (Ford *et al.* 2007, Flater 2002, Buehler and McKee 1998). In contrast, interoperability definitions proposed by policy organizations have stressed the engagement process necessary to exchange and re-use information. Some authors point out that such a process should ensure that systems, procedures and the culture of an organization are managed in such a way as to maximize opportunities for exchange and re-use of information, whether internally or externally (Dekkers 2007, Nedovic-Budic and Pinto 2001, Miller 2000).

The levels of interoperability are a set of criteria and associated processes for assessing system capabilities in the context of the degree of interoperability required. Several levels have been proposed in the literature according to the interoperability required: semantic, syntactic, technical, organizational, schematic or structural, pragmatic, dynamic, social, legal, and others.

Semantic Interoperability is related to the meaning of the information. Some authors have emphasized the need for a common reference model for information exchange and interpretation of concepts (Turnitsa and Tolk 2006, Kalantari *et al.* 2006, Antonovic and Novak 2006). The fact that the geographic space may have more than one description is handled as semantic heterogeneity (Kuhn and Raubal 2003). Standardized taxonomies in domains related to geography as well as new approaches for the description of semantic proximity between objects are objectives of this level (Probst 2006, Rodríguez and Egenhofer 2003).

The *Syntactic* Interoperability level provides a common structure to exchange information (Turnitsa and Tolk 2006) or a common message format (Shekhar 2004).

Communication, transport, storage and representation standards are understood as *Technical* Interoperability aspects (Miller 2000), and system linking is the basic objective (Schekkerman 2004).

The *Pragmatic* Interoperability deals with the exchange of services and processing (Shanzhen *et al.* 1999). This level is reached when the interoperating systems are aware of the methods and procedures every one of them is employing (Turnitsa and Tolk, 2006).

The *Organizational* Interoperability deals with enabling a cooperation process by encouraging partnership among organizations to assist best practices in data sharing (Lance *et al.* 2008, Georgiadou and Harvey 2007).

Abstract model interpretation by third party is the main objective of the *Conceptual* Interoperability level (Turnitsa and Tolk 2006), in such a manner that the model might be documented by engineering methods. Some authors have studied different data types, label inconsistencies, aggregation discrepancies and generalization conflicts (Shekhar 2004, Bishr 1998, Goh 1997).

When systems are able to detect state changes and to take advantage of those changes (Turnitsa and Tolk 2006) or when systems are able to locate resources for their use based on the existence of standardized metadata (Shanzhen *et al.* 1999), *Dynamic* Interoperability is achieved.

Intellectual Property (*IP*) rights (Miller 2000) and directives, rules, parameters and instructions for the management of business workflow, and considering incorporation of information and communication in the business of land administration (Kalantari *et al.* 2006) are all aspects dealt with by Legal Interoperability.

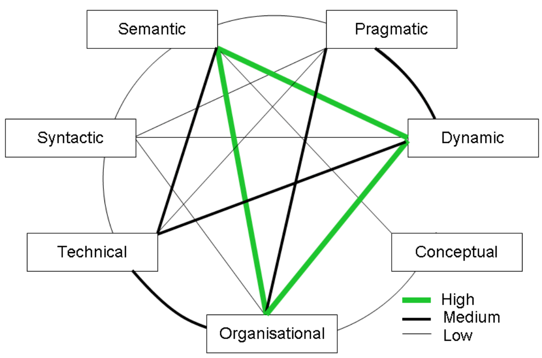
The Social Interoperability identifies aspects such as interests, beliefs, expectations and commitments (Assche 2006, Mohammadi *et al.* 2006).

Assuming that a large set of systems and *SDIs* must interoperate in the near future, we claim that there will be a need to study the complexity of the relationships between interoperability levels of *SoS*, and to develop new interoperability models. One example is given by the design of the Global Earth Observation System of Systems that aims to provide decision-support tools to a wide variety of users (GEOSS 2008).

3 INTEGRATED MODEL OF INTEROPERABILITY FOR SDI

As we have described in 'Towards an Integrated Model of Interoperability for Spatial Data Infrastructures' (Manso et al. 2009), before reviewing interoperability levels and models, some levels are not pertinent to this context and some are included within other levels. This integrated model of interoperability for SDI is made up of levels: Technical, Syntactical, Semantic, Dynamic, Pragmatic, Conceptual and Organizational. Our integrated model assumes the associations across all interoperability levels with different intensity. Figure 1 present an overview of the resulting pair-wise relations of our interoperability model.

Figure 1: Integrated Model of Interoperability for SDI.



The meaning and objectives for these levels is summarized below.

Technical interoperability is the level enabling the interconnection of systems through common communication protocols allowing information exchange at its most basic level: bits and bytes. Regarding *SDIs*, technical interoperability is a series of technical aspects: character sets, character encoding, file identifiers, description of processing environment, file names, service types and versions, transfer size, file formats and versions, storage means, links and protocols.

Syntactic interoperability is about the information exchange between systems by using a common data format or structure, language, logic, registers and files. Key aspects are the standards or format specifications which structure information, so that the information could be interpreted and processed. XML Schemas (*XSD*) defined by Open Geospatial Consortium (*OGC*) is a good practice enabling syntactic interoperability.

Semantic interoperability is about information exchange using a shared, common vocabulary that avoids inaccuracies or mix-ups when interpreting the meaning of terms. *Web Service Description Language* (*WSDL*), the *Simple Object Access Protocol* (*SOAP*) at the level of service interconnection or the *Geographic Mark-Up Language* (*GML*) for the transfer of vector GI, and the *Style Layer Description* (*SLD*) for definition of a visualization style are good practices enabling semantic interoperability.

The dynamic interoperability allows systems to supervise other systems and to respond to detected changes in information transfer or time delay, taking advantage thereof. In order to enable switching from the use of one service to another by supervising the functioning of the network and other services, systems need dynamic discovery capabilities of services complying with the requirements called for. Initiatives such as the spatial data themes of Directive 2007/2/EC, classified into a topic category metadata help to keep the reliability of dynamic service interchange.

Conceptual interoperability is about knowing and reproducing the functions of a system based on documentation usually stored in formats used in Engineering. Aspects of conceptual interoperability are those describing data and system model in standardized documentation format from an engineering viewpoint. *OGC WFS describeFeatureType* response containing a GML application schema is a good practice of conceptual interoperability.

The organizational interoperability allows knowledge of business targets, process models, regulations and policies of access and use of data and services. It has to do with aspects related to expectations, contracts and culture. Knowledge about goals, responsibilities, access and use policies are considered as a constraint or as identification information helpful to evaluate the use of metadata elements.

We advance an interoperability model which, in addition to the models proposed by the *LCIM*, includes the organizational interoperability level, in which the legal aspects and the relationships between data providers and users are framed, as mentioned above in the Introduction, along with the definition of *SDI*.

Although the scope of the integrated model of interoperability has been defined for *SDIs*, we believe that it may also be used within wider contexts, such as *SoS*.

4 METADATA ROLES IN THE INTEGRATED METADATA MODEL

As mentioned above, metadata in *II*, and especially in *SDIs*, allow the discovery, evaluation, access and use functions. The wider, boosted utilization of metadata allows discovery and access to data, as we are observing in INSPIRE Implementation Rules (*IR*) Metadata. However, from the perspective of system interoperability, some authors highlight the usefulness of metadata to enable different interoperability levels in the *LCIM* model (Tolk, Diallo and Turnitsa 2007). These authors emphasize the usefulness of metadata for the communication among intelligent software agents, ‘to communicate about situations’, ‘to enable software agents to select different components and compose them to evaluate alternative hypotheses’, ‘to support decision makers’ and finally ‘to support the orchestration and alignment of agile components at least up to the dynamic layer’.

Under SDI context, metadata has been consider an element that support discovery, evaluation, access and use functions mainly oriented to human users. Since *SoS* perspective, metadata enable communication among intelligent agents, hypotheses evaluation, support decision makers and orchestration of components in dynamic contexts. In the near future intelligent software agents can run SDI components using geospatial metadata. In this scenario interoperability levels provided by metadata are important. The lack of studies regarding the analysis of interoperability levels provided by the ISO19115 metadata items bears out our consideration.

In this Section the results of such analysis are presented. Table 1 shows the count of the metadata items which support the different interoperability levels of the integrated model individually. These values can be appreciated in the main diagonal of Table 1. The remainder of the values indicates the amount of items supporting two interoperability levels simultaneously.

Table 1: Metadata elements count for each interoperability level and simultaneous relations.

	Organizational	Semantic	Dynamic	Technical	Pragmatic	Conceptual	Syntactic
Organizational	229	181	143	22	19	7	3
Semantic	181	196	127	11	4	6	3
Dynamic	143	127	151	10	21	0	4
Technical	22	11	10	32	8	0	3
Pragmatic	19	4	21	8	24	0	3
Conceptual	7	6	0	0	0	7	0
Syntactic	3	3	4	3	3	0	6

The results of the classification study have shown that the metadata elements supporting semantic interoperability (196) also provide dynamic (127/196 – high intensity) and organizational (181/196 – high intensity) interoperability levels as well. The same results may be observed for the dynamic and organizational interoperability. The interoperability levels least favored by metadata items of the ISO19115 Standard are the syntactic, conceptual, pragmatic and technical levels.

We can say that the proposed Interoperability Model Based on Metadata for SDI (*IMBM-SDI*) is not a hierarchical model in which the higher levels need all the lower levels; instead each level may require the functionality of other non-subordinate interoperability levels. The proposed integrated model of interoperability might be metaphorically compared with the TCP/IP communication protocol and other models proposed in the literature such as *LCIM*, suggesting hierarchical structures in the style of ISO communication protocols.

The study has also allowed determining the set of metadata items providing a definite interoperability level, as well as those providing several levels simultaneously (e.g. semantic and dynamic levels).

In-depth analysis of this information may be useful to define a core set of metadata items that should maximize interoperability with a minimum of metadata or else ensure a minimum of interoperability based on the metadata. This analysis might be carried out while thinking of the future, so that expert and automatic systems will be able to exploit *SDI's* functionalities and capabilities.

Such as has been comment, manual creation of geospatial metadata is tedious works that consume resources and is error-prone. This has motivated us to study automatic metadata productions to support dynamic interoperability level.

5 AUTOMATIC METADATA PRODUCTIONS TO SUPPORT INTEROPERABILITY: DYNAMIC INTEROPERABILITY CASE USE

In this section the metadata items supporting dynamic interoperability and being automatically produced by extraction, computation and inference are enumerated, as proposed by Beard (1996).

In the first stage, in order to reach this objective, the metadata items have been adopted, providing dynamic interoperability resulting from the analysis carried out to define the integrated model of interoperability. In the second stage, use has been made of the knowledge acquired by investigating the data that may be automatically extracted from the different types of Geographic Information (*GI)* (raster, vector and Digital Terrain Model - *DTM*), in order to select the metadata items that may both provide dynamic interoperability and be automatically obtained. In the third stage, the remainder of the items has been analyzed with the purpose of considering if it is possible to assign them value, by carrying out some kind of calculation or deriving information on the basis of other pieces of available information.

Table 2 shows the outcome of these three stages. After its presentation, we will reflect on the techniques used in order to be able to automatically produce these metadata items.

Table 2 contains 5 columns.
The class to which the item belongs is shown in the first column.
The item is identified in the second column.
Items classified as "P" (produced: extracted, calculated or derived) or as "M" (may appear many times according to the data type) are identified in the third column.
Items that are only applied to a certain type of *GI* ("R" = raster data; "D" = DTM and "V" = vector data) are identified in the fourth column.
A description of the content and an explanation appears in the fifth column.

Table 2: Automatic metadata element production enabling dynamic interoperability.

MD_Metadata: Packed	Metadata element	(P) Produced; (M) Multiple values)	(R:Raster, V:Vector, D:DTM)	Explanation
	dateStamp	P		Date, time of metadata generation
distributionInfo:distributionFormat	name	P		Implicit to GI store.
distributionInfo:distributionFormat	version	P		Some stores have versions
distributionInfo:distributionFormat	fileDecompressionTechnique	P		Some stores (mainly imagery) use compression techniques
contentInfo:MD_CoverageDescription	contentType	P	R	Raster and grid data must be distinguished

contentInfo:MD_CoverageDescription: dimension:MD_RangeDimension	sequenceIdentifier	M	R	Band number
contentInfo:MD_CoverageDescription: dimension: MD_Band	maxValue	M	R	Pixel or cell maximum value
contentInfo:MD_CoverageDescription: dimension: MD_Band	minValue	M	R	Pixel or cell minimum value
contentInfo:MD_CoverageDescription: dimension: MD_Band	units	M	R	When grid data have associated units as DTM
contentInfo:MD_CoverageDescription: dimension: MD_Band	bitsPerValue	M	R	Number of bits used to encode band
contenInfo:MD_ContentInformation: MD_FeatureCatalogueDescription	includedWithDataset	P		When grid data have associated categories like classified image
contenInfo:MD_ContentInformation	featuresTypes	P		Name for every feature type
spatialRepresentationInfo: MD_GridSpatialRepresentation	numberOfDimensions	M	R	Usually 2
spatialRepresentationInfo: MD_GridSpatialRepresentation	cellGeometry	M	R	Depend on whether grid or image is rectified; can be point or area
spatialRepresentationInfo: MD_GridSpatialRepresentation	transformationParameterAvailability	M	R	If GI store information is about control points.
spatialRepresentationInfo: MD_GridSpatialRepresentation: axisDimensionProperties:MD_Dimension	dimensioName	M	R	Grid and image, row or column
axisDimensionProperties:MD_Dimension	dimesionSize	M	R	Count of rows or columns
spatialRepresentationInfo: MD_GridSpatialRepresentation: axisDimensionProperties:MD_Dimension: resolution	value	M	R	Pixel size on grid and raster rectified
axisDimensionProperties:MD_Dimension: resolution	units	M	R	Units of measure of resolution if known
spatialRepresentationInfo: MD_VectorSpatialRepresentation	topologyLevel	M	V	For vector data, topology information about data.
spatialRepresentationInfo: MD_VectorSpatialRepresentation: geometricObjects: MD_GeometricObjects	geometricObjectType	M	V	Type of geometry elements. One per type informing about type.
spatialRepresentationInfo: MD_VectorSpatialRepresentation: geometricObjects: MD_GeometricObjects	geometricObjectCount	M	V	Count of object elements per type
identification:MD_Identificacion: MD_DataIdentification: citation: CI_Citation	title	P		Title inferred for dataset, based on BBOX, time information and other information that can be extracted, computed or inferred.
identification:MD_Identificacion: MD_DataIdentification:citation: CI_Citation: date: CI_Date	date	P		Date, time of metadata generation
identification:MD_Identificacion: MD_DataIdentification:citation: CI_Citation: date: CI_Date	dateType	P		Creation
identification:MD_Identificacion: MD_DataIdentification: resourceFormat: MD_Format	name	P		Same as distribution Format
identification:MD_Identificacion: MD_DataIdentification: resourceFormat: MD_Format	version	P		Same as distribution Format
identification:MD_Identificacion: MD_DataIdentification: resourceFormat: MD_Format	fileDecompressionTechnique	P		Same as distribution Format
identification:MD_Identificacion: MD_DataIdentification: resourceSpecificUsage: MD_Usage	userDeterminedLimitations	P		Some datasets stores use limitations. In this case, extract and include
identification:MD_Identificacion: MD_DataIdentification: resourceConstraints: MD_LegalConstraints	useConstraints	P		Some datasets stores use constraints. In this case, extract and include
identification:MD_Identificacion: descriptiveKeywords: MD_Keywords	keyword	P		Based on raster datasets analysis, content type can be inferred. Then some keywords included in thesaurus can be inferred.
identification:MD_Identificacion: descriptiveKeywords: MD_Keywords	type	P		Keyword type
identification:MD_Identificacion: descriptiveKeywords: MD_Keywords: thesaurusName:CI_Citation	title	P		Thesaurus Name
identification:MD_Identificacion: descriptiveKeywords: MD_Keywords: thesaurusName:CI_Citation	date	P		Thesaurus keywords date
identification:MD_Identificacion: descriptiveKeywords: MD_Keywords: thesaurusName:CI_Citation	dateType	P		Thesaurus date type
identification: MD_Identificacion	spatialRepresentationType	P		From dataset representation type can be extracted.
identification: MD_Identificacion: spatialResolution: MD_Resolution	distance	M	R	For raster and rectified grid, pixel size can be used to define resolution distance
identification: MD_Identificacion: spatialResolution: MD_Resolution: equivalentScale: MD_RepresentativeFraction	denominator	M	R	From resolution distance denominator can be computed, but only one is needed.
identification: MD_Identification: extent: EX_Extent: geographicElement: EX_GeographicExtent: EX_GeographicBoundingBox	extentTypeCode	P		1 (true: inclusion)
identification: MD_Identification: extent: EX_Extent: geographicElement: EX_GeographicExtent: EX_GeographicBoundingBox	westBoundLongitude	P		West Longitude computed from dataset identifying source CRS.
identification: MD_Identification: extent: EX_Extent: geographicElement: EX_GeographicExtent: EX_GeographicBoundingBox	eastBoundLongitude	P		East Longitude computed from dataset identifying source CRS.
identification: MD_Identification: extent: EX_Extent: geographicElement: EX_GeographicExtent: EX_GeographicBoundingBox	southBoundLatitude	P		South Latitude computed from dataset identifying source CRS.
identification: MD_Identification: extent: EX_Extent: geographicElement: EX_GeographicExtent: EX_GeographicBoundingBox	northBoundLatitude	P		North Latitude computed from dataset identifying source CRS.
identification: MD_Identification: extent: EX_Extent: geographicElement: EX_GeographicExtent: EX_GeographicDescription: geographicIdentifier: RS_Identifier: authority: CI_Citation	title	P		Geographic identifier (toponym) computed by gazetteer reverse query
identification: MD_Identification: extent: EX_Extent: geographicElement: EX_GeographicExtent: EX_GeographicDescription: geographicIdentifier: RS_Identifier: authority: CI_Citation : date : CI_Date	date	P		Date time extracted from gazetteer metadata or database used to compute toponym
identification: MD_Identification: extent: EX_Extent: geographicElement: EX_GeographicExtent: EX_GeographicDescription: geographicIdentifier: RS_Identifier: authority: CI_Citation : date : CI_Date	dateType	P		publication
identification: MD_Identification: extent: EX_Extent: verticalElement:Ex_VerticalExtent	minimumValue	M	D	For grid dataset containing DTM, lower value.

identification: MD_Identification: extent: EX_Extent: verticalElement:Ex_VerticalExtent	maximumValue	M	D	For grid dataset containing DTM, upper value.
referenceSystemInfo: MD_ReferenceSystem: referenceSystemIdentifier: identifier: RS_Identifier	codeSpace	P		EPSG
referenceSystemInfo: MD_ReferenceSystem: referenceSystemIdentifier: identifier: RS_Identifier	version	P		EPSG database version
referenceSystemInfo: MD_ReferenceSystem: referenceSystemIdentifier: identifier: RS_Identifier	code	P		EPSG code computed by CRS extracted from dataset and translated to this codeSpace
referenceSystemInfo: MD_ReferenceSystem: referenceSystemIdentifier: identifier: RS_Identifier: authority: CI_Citation	title	P		EPSG Coordinate Reference Systems database
referenceSystemInfo: MD_ReferenceSystem: referenceSystemIdentifier: identifier: RS_Identifier: authority: CI_Citation: date: CI_Date	date	P		EPSG Database date
referenceSystemInfo: MD_ReferenceSystem: referenceSystemIdentifier: identifier: RS_Identifier: authority: CI_Citation: date: CI_Date	dateType	P		revision

Most of the 54 items enumerated in Table 2 are produced by extraction of information from data stores, whether files, directories or databases. That is the case for the items: version of format, data decompression technique, number of bands, number and types of geometry, geometric resolution of pixels, maximum and minimum coordinates in the reference system used, information about constraints and restrictions of use and access.

Some of them, e.g. *dateStamp* or the name of the format may be obtained from the context (date on the clock of the computer system).

There are also a sufficient number of items (12) that may be computed when they do not appear in the spatial information store. That is the case of the maximum and minimum radiometric values of the bands in the raster data, the denominator of the scale in raster data, the maximum and minimum non-geographic coordinates or the geographic identifier from the previous coordinates.

Another set of items (>12) may be produced by inferring their values. If the type of content stored in the spatial data (data mining, image classification) is somehow determined, a set of keywords belonging to thesauri may be contributed describing that content, and a title for the dataset may also be inferred. An important item for data is also the identification of the spatial reference system for data representation. On the basis of the information stored, it is sometimes possible to deduce the identifying code.

As a first conclusion, we may state that of the 151 metadata items providing dynamic interoperability, 54 of them may be automatically produced (35%). Although this value is quite high, it should be cautiously interpreted since it is a “hopeful” value representing the ceiling of the automatic production.

Depending on the type of spatial data storage, its nature and the possibility of determining the content type, these values may diminish or increase markedly since a fair amount of items have been identified as elements susceptible of being multi-assessed (cardinality >1).

6 CONCLUSIONS AND FUTURE RESEARCH WORK

Spatial Data Infrastructures (*SDIs*) subsume technology, standards, networks, people, policies, organizational aspects and systems as has been suggest by different authors. *SDIs* are a special case of Information Infrastructures (*IIs*). System of Systems (*SoS*) is a broad term that includes *IIs*. From this perspective *SDI* can be dealt with and modeled as an *SoS*.

The definitions of the interoperability levels have been reviewed and synthesized in the *SoS* context and an Interoperability Model Based on Metadata for Spatial Data

Infrastructures (*IMBM-SDI*) has been proposed. It is based on the *LCIM* model which has been extended with the organizational interoperability.

The authors of the *LCIM* model have studied how to achieve dynamic interoperability to orchestrate and chain services in the *SoS* and they have committed themselves to the use of metadata to enable communication between agents. We have followed that suggestion and analyzed metadata items of the International Standard ISO19115. The interoperability levels supported by every item have been identified. Table 1 shows the aggregate results of the analysis. It has been argued that it is a non-hierarchical integrated model.

As anticipated in the conclusions for the sections, we have bet on a new interoperability model in line with the existing models in the *SoS* context. We have also analyzed the interoperability that may support the metadata items of the ISO19115 Standard.

It has been argued that the manual creation of metadata is a slow, costly process, prone to the introduction of errors in metadata; nevertheless we bet on metadata as an element supporting system interoperability. This study shows at the theoretical level how to automatically produce metadata items supporting dynamic interoperability, by extracting the information stored in files and databases through computations or by inference.

The results shown indicate that a high percentage of the metadata items providing dynamic interoperability – limited objective of the study – may be automatically produced. This fact strengthens the hypothesis of automatic creation of metadata useful from the point of view of interoperability.

The following lines of research are suggested: 1) Study of metadata items from the point of view of interoperability in the framework of the proposed integrated model in order to define a metadata core with this aim, just like the ISO19115 Standard proposes a core from the perspective of discovery and use of resources. 2) Study of automatic methods to produce metadata inducing interoperability at the different levels proposed in the integrated model. 3) Implementation and testing of the automatic methods of metadata production with the end of encouraging interoperability in the domain of virtual map libraries made up of geo-referenced, digitized historical cartography, accessible through standardized services.

7 ACKNOWLEDGEMENTS

This work has been partially supported by the National Geographic Institute (IGN) of Spain through the project UPM-P086005573 and for the Plan Nacional de I+D through the Projects HUM2007-31128-E and CSO2008-03248/GEOG (Prototipo de Cartoteca Histórica Virtual Distribuida – Prototype of Distributed Virtual Historical Map Library)

REFERENCES

Anderson, J. and Pérez-Carballo, J. (2001). The nature of indexing: how humans and machines analyze messages and texts for retrieval: part I: research, and the nature of human indexing. Information Processing and Management: An International Journal 37 (2), 231–254.

Antonovic, V. and Novak, I. (2006). GISOSS - One-Stop-Shop GIS. Shaping the Change, XXIII FIG Congress, Munich, Germany, October 8-13, 2006. [Online]. Retrieved on 1 October 2008 from: http://www.fig.net/pub/fig2006/papers/ts37/ts37_02_antonovic_novak_0569.pdf

Assche, F. (2006). An Interoperability Framework. (Learning Interoperability Framework for Europe). [Online]. Retrieved on 1 October 2008 from: http://www.intermedia.uio.no/display/life/An+Interoperability+Framework

Beard, K. (1996). A Structure for Organizing Metadata Collection. Third International Conference/Workshop on Integrating GIS and Environmental Modeling, Santa Fe, New Mexico, USA, January 21-25, 1996.

Béjar, R., Nogueras-Iso, J., Muro-Medrano, P. and Zarazaga-Soria, F. (2008). Systems os Systems as a Conceptual Framework for Spatial Data Infrastructures. Article Under Review for the Internacional Journal of Spatial Data Infrastructure Research

Bernard, Lars et al. 2005. "Towards an SDI Research Agenda." *Proceedings of 11th EC-GIS*, Alghero, Sardinia, Italy

Bishr, Y. (1998). Overcoming the semantic and other barriers to GIS interoperability. Int. Journal for Geographical Information Science, 12(4):299–314, 1998

Buehler, K. and McKee, L. (1998). Open GIS Consortium Technical Committee, The OpenGIS Guide: Introduction to Interoperable Geoprocessing and the OpenGIS Specification, Third Edition, Draft, June 3, 1998.

Carney, D., Smith, J. and Place, P. (2005). Topics in Interoperability: Infrastructure Replacement in a System of Systems. Pittsburgh, Pa: Software Engineering Institute, Carnegie Mellon University (CMU/SEI-2005-TN-031), November 2005. [Online]. Retrieved on 1 October 2008 from: http://www.sei.cmu.edu/pub/documents/05.reports/pdf/05tn031.pdf

Dekkers, M. (2007). Metadata and modelling for Interoperability. [Online]. Retrieved on 1 October 2008 from: http://library2.nalis.gov.tt/Portals/0/cdl_Makx_Dekkers_20070712.pdf

Flater, D. (2002). Impact of Model-Driven Standards, Proceedings of the 35th Hawaii International Conference on System Sciences – 2002. [Online]. Retrieved on 1 October 2008 from: http://csdl2.computer.org/comp/proceedings/hicss/2002/1435/09/14350285.pdf

Ford, T., Colomb, J., Grahamr, S. and Jacques, D. (2007). A Survey on Interoperability Measurement. Proceedings of 12th International Command and Control Research and Technology Symposium, Newport, RI, June, 2007. [Online]. Retrieved on 1 October 2008 from: http://www.iceg.net/2007/books/2/2_398_2.pdf

Gayatri and Ramachandran, S. (2007). Understanding Metadata. The Icfai Journal of Information Technology • March 2007.

Georgiadou, P. and Harvey, F. (2007). A bigger picture: information systems and spatial data infrastructure research perspectives. Proceedings of the 10th AGILE international conference on geographic information science: the European Information Society: leading the way with geoinformation, Aalborg, Denmark, 8-11 May 2007. / ed. by M. Wachowicz and L. Bodum. AGILE, 2007. ISBN 978-87-819-3004-4. 6.

Georgiadou, Y., Puri S. and Sahay S. (2005). "Towards a potential research agenda to guide the implementation of Spatial Data Infrastructures - A case study from India." International Journal of Geographical Information Science 19(10): 1113—1130.

GEOSS (2008). The Global Earth Observation System of Systems. . [Online]. Retrieved on 1 October 2008 from: http://www.earthobservations.org/geoss.shtml

Gilliland-Swetland, A.J. (2000). Setting the Stage, in Introduction to Metadata: Pathways to Digital Information. Los Angeles: Getty Research Institute. http://www.getty.edu/research/conducting_research/standards/intrometadata/2_articles/index.html

Goh, C.H. (1997). Representing and Reasoning about Semantic Conflicts in Heterogeneous Information Sources, PhD Thesis. MIT Sloan School of Management, 1997.

Guptill, S.G. (1999). Metadata and data catalogues. In: Longley, P., Goodchild, M.F., Maguire, D.J., Rhind, D.W. (Eds.), Geographical Information Systems. Wiley, Chichester, pp. 677–692

GSDI (2004). Technical Working Group and contributors. 2004. Developing Spatial Data Infrastructures: The SDI Cookbook v.2.0. ed. Douglas D. Nebert. Global Spatial Data Infrastructure (http://www.gsdi.org).

ISO-19115 (2005). Geographic Information - Metadata. International Standard Organization

Johnston, P. (2005). Good Practice Guide for Developers of Cultural Heritage Web Services. Research Officer, UKOLN. Enlace: http://www.ukoln.ac.uk/interop-focus/gpg/Metadata/

Kalantari, M., Rajabifard, A., Wallace, J., and Williamson, I. (2006). An interoperability toolkit for e-Land administration, Williamson, Enemark and Wallace (eds), Sustainability and Land Administration Systems, Department of Geomatics, Melbourne , 213-222

Kuhn,W. and Raubal, M. (2003). Implementing semantic reference systems. The 6th AGILE Conference in GIScience, Lyon France, April 24-26 2003.

Lance, K. Georgiadou, Y. and Bregt, A. (2008). Cross-agency coordination in the shadow of hierarchy: 'joing up' government geospatial information systems. International Journal of Geographical Information Science.

Maier, M. (1996). "Architecting Principles for Systems-of-Systems." In 6th Annual International Symposium of INCOSE, Boston, MA, USA, p. 567-574.

Manso, M., Wachowicz, M. and Bernabé, M. (2009). Towards an Integrated Model of Interoperability for Spatial Data Infrastructures. *Transactions in GIS* 2009*,* 13 (1), p.43 – 67 doi:10.1111/j.1467-9671.2009.01143.x.

Manso, M. and Wachowicz, M. (2009). GIS Design: A review of current issues in interoperability. Geo*graphy Compass*.

Miller, P. (2000). Interoperability. What is it and Why should I want it? Ariadne Issue 24. 21-Jun-2000. [Online]. Retrieved on 1 October 2008 from: http://www.ariadne.ac.uk/issue24/interoperability/intro.html

Mohammadi, M., Binns, A., Rajabifard, A. and Williamson, I. (2006). Spatial Data Integration. 17th UNRCC-AP Conference and 12th Meeting of the PCGIAP, Bangkok, 18-22 September 2006. [Online]. Retrieved on 1 October 2008 from:

http://www.geom.unimelb.edu.au/research/SDI_research/publications/files/Spatial%20Data%20Integration.doc

Nedovic-Budic, Z. and Pinto, J. (2001). Organizational (soft) GIS interoperability: lesson from the U.S. International Journal of Applied Earth Observation and Geoinformation, Volume 3, Number 3, 2001, pp. 290-298(9). Elseivier.

Probst, F. (2006). Ontological Analysis of Observations and Measurements. International Conference on Geographic Information Science No4, Münster, ALLEMAGNE (2006) , vol. 4197, pp. 304-320. ISBN 3-540-44526-9 ; 978-3-540-44526-5

Rodriguez, M. and Egenhofer, M. (2003). Determining Semantic Similarity Among Entity Classes from Different Ontologies. IEEE Transactions on Knowledge and Data Engineering. vol.15, no.2, pp. 442-456, March-April 2003

Schekkerman, J. (2004). President of the Institute for Enterprise Architecture Development (IFEAD). Roadmap to implementation. [Online]. Retrieved on 1 October 2008 from: http://web-services.gov/region4soa10104.ppt

Shanzhen, Y., Qi, L. and Jicheng, C. (1999). An interoperability GIS model based on the spatial information infrastructure. Geoinformatics and Socioinformatics. The Proceedings of Geoinformatics'99 Conference. Ann Arbor, 12-21 June, pp, 1-5.

Shekhar, S. (2004). Spatial Data Mining and Geo-spatial Interoperability. Report of the NCGIA Specialist Meeting on Spatial Webs, Santa Barbara, December 2-4 2004, National Center for Geographic Information and Analysis, University of California

Tolk, A., Diallo, S. and Turnitsa, C. (2007) Applying the levels of Conceptual Interoperability Model in Support of Integratability, Interoperability, and Composability for System-of-Systems Engineering. International Journal Systemics, Cybernetics and Informatics. Volume 5 – Number 5

Turnitsa, C. and Tolk, A. (2006). Battle Management Language: A Triangle with Five Sides Proceedings of the Simulation Interoperability Standards Organization (SISO) Spring Simulation Interoperability Workshop (SIW), Huntsville, AL, April 2-7, 2006

West, L. and Hess, T. (2002). Metadata as a knowledge management tool: supporting intelligent agent and end user access to spatial data. Decision Support Systems 32, 247–264

Williamson, I. (2004), Building SDIs—the challenges ahead. In Proceedings of the 7th International Conference: Global Spatial Data Infrastructure, 2–6 February, Bangalore, India.