

The Importance of Establishing Common Methods and Terminologies in Data Mappings

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ABSTRACT: *Data providers have methodologies for identifying and defining the content in their data products. Often these methodologies are based on formal dictionaries or catalogues of terms/concepts, which may or may not be unique to a particular data product or a specific data model. Most data users combine products from different data providers and data sources, requiring data to be aligned, corrected, and correlated. This requires a process that involves value adding to existing data by combining, adjudicating, conflating, merging, thinning, organizing, and adding detail to the final data from various sources. Such data integration demands the use of a single consistent methodology for identifying and defining the content. Interoperability between systems using different methodologies requires the development of consistent and logical exchange mechanisms that must take into account data syntax, semantics and organization. An important component of developing such data exchange mechanisms is the establishment and use of formal mappings between different dictionaries within the context of their respective data models. To establish these mappings it is critical to employ a common approach and terminology that addresses the variations and types in mapping of concepts. This paper discusses methods and terminologies that can facilitate the development of mappings between dictionaries and/or between data models used in the environmental domain. The paper highlights why the use of such methods and terminologies is critical in establishing reliable and practical mappings between systems, and, through specific examples, discusses the types of problems that can occur in mapping.*

1. Introduction

Successful data interoperability between systems or applications depends on several factors. These include a solid understanding of how the systems or applications use the data, which in turn requires an understanding of data semantics, data organization, and data constructs. To successfully interoperate between systems, the software components involved in data conversion or translation usually rely on a design that heavily depends on understanding these data constructs and requirements. Therefore, developing a robust mapping between the relevant data elements used in different systems becomes a critical step in fulfilling interoperability. In the modelling and simulation (M&S) domain this mapping task becomes even more complex and critical, since usually many diverse systems are involved in networked M&S applications. This means data communication requirements, which often involve data translation or conversion, demand a solid foundation for a common data mapping between many diverse systems or applications. In addition, for many models or simulations, data is often brought in from a variety of sources, then integrated and fused before being utilized in the system. Therefore, similar to the interoperation requirements between systems, a consistent and common approach to data mapping from different sources to the internal data requirements of a given system becomes a natural part of the data integration process. To incorporate a reliable data mapping approach, whether for interoperation of heterogeneous systems or integration of data from diverse sources, the establishment and use of common mapping terminologies becomes an inherent part of the mapping process.

This paper draws from lessons learned in practical application of mapping methodologies and terminologies and discusses why such steps are important. The paper focuses on mappings related to environmental data, and discusses the importance of establishing standard terminology and approach for use in the development of mappings between environmental concept dictionaries and/or between data models or products. However, despite this specific focus, the same issues and principles will easily find application in other (non-environmental) data mapping efforts.

2. Background

In dealing with environmental data (such as ocean, terrain, atmosphere, or space data) many systems, databases, or data products employ their own dictionaries of terms or concepts in their data models, formats, or schemas. These systems often do not interoperate well together in part due to their diverse concept dictionaries, data models, or their use. The creation of a mapping between the concept dictionaries, data models, or products is a necessary, but not sufficient, step in developing applications that convert or translate data between systems.

Categorization, the process of classifying objects into categories, is fundamental to human reasoning and communication. The formal study of this topic dates back centuries, and plays a central role in philosophy, language, logic, mathematics, and many other areas. Classifying objects into categories is usually dependent on how the uses, functions, characteristics, and/or applications of those objects are viewed. This context-specific nature of categorization makes it difficult, if not impossible, to apply a single categorization for all purposes. How objects are organized within a given context can be completely different from how those same objects are thought of within a different context. Categorization is also critical to communication and interoperability between information systems. It is commonly necessary to translate data from the format(s) used by a given information system, to the format(s) used by another. Categorization plays a critical role in the creation of the mappings that allow such automated data translation to be performed. The process of creating such mappings, establishing a set of terminology to describe such mappings, and why this is an important process is the subject of this paper.

Development and use of such mappings may apply to a broad range of data encapsulations and at various levels of data abstraction. These range from dictionaries, to data/information models, to physical data products, and any number of derivatives in-between these. The process of how such mappings are developed can be generalized to apply at any of these levels of abstraction. However, there are enough variations in creating the mappings that the details of an approach often become critical to understanding the mapping. As a result, it is important to first establish a baseline for what is

meant by each of these data abstraction levels, and only then define the mapping approach and the corresponding terminology in accordance with that baseline.

3. Data abstraction

Defining data semantics and data specifications can be organized into several broad categories. Each of these can also be thought of as a model of the data at some level of abstraction. Some of the relevant and key categories are noted in this section. The DoD Architecture Framework (DoDAF) version 2.0 also defines similar required artifacts for system architectures.

Dictionaries – A dictionary simply consists of a collection of terms and their definitions that are used within a particular domain and context. There are variations in the scope of how a dictionary may be applied. These will be further highlighted. DoDAF requires that every system architecture description include an Integrated Dictionary (AV-2) that defines the terms used in the architecture to ensure semantic understanding across the enterprise.

Logical Data Models – A logical data model defines the various kinds of classes (also referred to as concepts, items, objects, or entities) that are of interest within a domain, the attributes that describe those classes, and the relationships among those classes. A logical data model is not particularly concerned with how information may be implemented or manifested in specific form or media. DoDAF requires a Logical Data Model (DIV-2) to document system data requirements and structural business process rules.

Physical Data Models – A physical data model adds the details of how information about each kind of object is to be stored, transmitted, and manipulated by hardware and software. This includes the specific data types to be used to represent each attribute, and the details of how each relationship and operation is to be implemented. DoDAF requires a Physical Data Model (DIV-3) to specify how a Logical Data Model is to be implemented in terms of message formats, file structures, and physical database schemas.

Based on the amount of detail that they may contain, data models cover a very broad range,

from highly abstract or conceptual data models to detailed physical data models. Since a dictionary can be assumed to reflect a model of the data at some abstract level, it can be considered to form one extreme of the overall range of data models, providing the minimum amount of information necessary to start developing a mapping between different domains. At the other extreme, physical data models provide the necessary detailed information that allows automated data translation to be performed.

Whether formally identified or not, dictionaries play a fundamental role in the development of specifications and in the production of content for information systems. For example, for the standards developed by the International Organization for Standardization (ISO), the Shorter Oxford English Dictionary (SOED)³ is the default dictionary for all terms that are used, but not explicitly defined.

In the context of expressing semantics of environmental data, and in particular in this paper, the terms defined in a dictionary denote concepts, which can include:

Objects – Also known as classes, entities, things, and, in the geospatial community, features. These terms refer to objects of interest within the domain addressed by the dictionary. They are generally nouns, or noun phrases, that are used as the subjects and/or direct or indirect objects in declarative statements.

Attributes – Also known as properties, characteristics, etc. These terms are used in describing objects, either qualitatively or quantitatively. They, or their associated values, are used as adjectives, or in other forms of descriptive phrases.

In practice, a dictionary is not a data model. However, its definitions may implicitly specify the basic relationship information from which a data model can be developed, for a given context.

General-purpose dictionaries, sometimes referred to as concept dictionaries, can be used, in part or whole, as building blocks in the development of specific data models for specific applications or products. Once a data model has been developed, the collection of specific terms (classes or entities, and associated attributes)

used in that data model form an associated dictionary specific to that data model. Such a dictionary is called a *data dictionary*. However, the term data dictionary is often incorrectly used to refer to concept dictionaries, catalogs, feature/attribute lists, and dictionaries of terms.

In concept dictionaries, attributes are defined generically, independent of how they may be used to describe specific objects. Concepts such as length or color can be used to describe many different types of objects. Defining these terms in a generic manner facilitates their consistent use when applied to different objects. By contrast, data models usually require, and define, specific pairings between objects and attributes. Additional constraints are provided in data models to meet specific application or product needs. As a result data dictionaries (dictionaries associated with a given data model) contain only those terms required for that data model.

As noted earlier, a concept dictionary is not a logical data model, let alone a physical data model. However, the definitions in a concept dictionary play a key role in identifying the attributes and relationships that are (or can be) associated with the concepts in the data models. Many definitions follow a pattern: they typically relate a concept to a more general concept, and then use descriptive phrases to further specify what differentiates this concept from all others within that more general concept. For example, in the definition: “A barn is an agricultural building that is designed to house animals and related equipment,” “building” is the more general concept, while the phrases “agricultural” and “designed to house animals and related equipment” specify how a “barn” is distinguished, from other kinds of buildings, with respect to its form, function, and/or use.

4. Why mapping between dictionaries is important

To illustrate why mapping between dictionaries becomes an important step in the data conversion or translation process, it is useful to examine a few simple examples of how concepts are defined and provided in different dictionaries. We will use three dictionaries to illustrate this. These dictionaries have evolved over time and generally share similar lineage, but differ in approach, style, and content.

Within the geographic information community, the objects of interest are referred to as “features”. The ISO Technical Committee 211 family of International Standards defines concepts and conceptual models for geographic information. ISO 19126:2009, Geographic Information – Feature concept dictionaries and registers, defines a “feature concept dictionary” to be a “dictionary that contains definitions of and related descriptive information about concepts that may be specified in detail in a feature catalogue”. ISO 19110:2005/DAmD 1, Geographic Information – Methodology for feature cataloguing, Amendment 1, defines a “feature catalogue” as a “catalogue containing definitions and descriptions of the feature types, feature attributes, and feature relationships occurring in one or more sets of geographic data, together with any feature operations that may be applied. Thus, a feature catalogue, in general, should be expected to provide more of a data model than a feature concept dictionary.

These concepts have evolved over time, and are continuing to evolve. For example, most traditional NGA products were based on definitions of features and attributes contained in the Defence Geospatial Information Working Group (DGIWG) Feature and Attribute Coding Catalogue (FACC)¹. Note the use of the term “catalogue” in its title. Earlier versions of FACC related attributes to features, but in the final version (Edition 2.1, Sep 2000, and the subsequent baseline maintenance releases, ending with BL 2003-4) these relationships were dropped.

The Environmental Data Coding Specification (EDCS)⁶, ISO/IEC 18025:2005, is composed of nine related concept dictionaries, and is one of the SEDRIS technology components. Lessons learned from use of FACC were instrumental in the development of EDCS; however, because of requirements in SEDRIS the scope and level of detail in EDCS was broader than FACC. In addition, EDCS introduced a set of refinements in the logical decomposition of concept definitions. These included separating units of measure and scale from attributes; placing units and scale definitions in their own dictionaries; explicitly relating a given concept to other concepts in EDCS; and providing citations and references for concept definitions. The standard also allows the extension of its content through an online registration process.

The DGIWG Feature Data Dictionary (DFDD)² is the successor to FACC, and is derived from both FACC and EDCS, incorporating concepts such as separating units of measure from definitions, as well as utilizing an online registry. However, DFDD does not explicitly relate definitions.

To illustrate why consistent mapping methodologies are important, we briefly examine several related concepts in these three dictionaries.

FACC 2.1 defined the feature concept “Building” (AL015) as: “A relatively permanent structure, roofed and usually walled and designed for some particular use.” FACC did not define specific kinds of buildings. Instead, it provided an attribute called “Building Function Category” (BFC), defined as: “Type or purpose of the building”, with a list of coded values. One of these values was BFC 125, “Barn/Machinery Shed”.

EDCS defines a “Building” as: “A fixed, relatively permanent <STRUCTURE> with a <ROOF> and usually with <WALL>(s) that is designed for use and occupancy by <HUMAN>s; a building.” Note the links and reuse of other related concepts, denoted by brackets and all-cap identifiers. The linked items explicitly refer to other existing concepts in the EDCS. EDCS also defines a “Barn” as: “A <FARM_BUILDING> that is used to store hay, grain, and implements and/or to house <NON_HUMAN_ANIMAL>s; a barn [SOED, "barn", A.1] [SOED, "barn", A.2].” And the concept of “Farm Building”, used in the definition of “Barn”, is defined as: “A <BUILDING> located on a <FARM>.” Similar to FACC, EDCS also includes a “Building Function” attribute, defined as “The function of a <BUILDING>”, which includes a value “Barn”. EDCS also defines many components of buildings, including roof, wall, door, window, etc.

DFDD defines the feature concept “General Building” (AL015) as: “A relatively permanent structure, roofed and usually walled and designed for some particular use.” DFDD also defines the feature concept “Building” (AL013) as: “A free-standing self-supporting construction that is roofed, usually walled, and is intended for human occupancy (for example: a place of work or recreation) and/or habitation.” As in EDCS,

since the DFDD definition of building is more specifically oriented toward human occupancy, DFDD also defines the feature concept “Barn” (AJ085) as: “A roofed farm building designed for sheltering harvested crops (for example: hay), livestock (for example: cattle), and/or farm machinery (for example: tractors and plows).” DFDD does not include a general building function attribute. Instead, it provides a collection of more specific “Facility Type” attributes, including “Agricultural Facility Type”, which has values that include “Barn” and “Farm Building”.

It is clear that different dictionaries, even those that share a common heritage, vary significantly in how they deal with hierarchical concepts. In some cases, feature concepts are defined at multiple levels of specialization; in other cases, attributes are used to further specialize a feature concept. It is not uncommon for these two approaches to be combined within a single dictionary.

In M&S applications, data is received from legacy sources (such as those products based on FACC) or new sources (such as those based on DFDD). It becomes important to provide a consistent and common mapping approach and terminology to capture which concept (or concept combination) in a given source dictionary can or should map to which concept (or concept combination) in a target dictionary. The mapping product must be clear in its terms and semantics of the mapping, and be provided as a software library that can be easily incorporated into a converter or translation application.

To facilitate data interoperability between systems that use different data products based on different dictionaries, it is clear that establishing a mapping between corresponding concept dictionaries, data dictionaries, and data models is critical and necessary, however, it may still be insufficient. Because many data products can use the same dictionary, once such mappings between dictionaries are established the designer of data conversion applications can start with those established mappings, take into account the specific data model of the format or product, and further design a mapping that completes the full mapping of data, including not only the dictionary mappings but also the data structure and data organization mappings.

During data model mapping a specialized mapping of the concepts may be needed that is a refinement of the original concept dictionary. Mappings of data dictionaries often use concept dictionary mappings in whole or part. Therefore, a data model or product mapping will rely not only on the mappings between data dictionaries, but also the mappings of data structures and organizational constructs between data models or products.

Therefore, a concept dictionary mapping is a mapping independent of any data model or product. A data model, catalogue, or other non-concept dictionary mapping is a mapping between corresponding constructs. Such mappings may use concept dictionary mappings modified by the associated data structures and rules.

5. Mapping approach

A mapping between concepts begins by analyzing a single concept entry in the source dictionary and determining whether an equivalent concept exists in the destination dictionary, either as another single entry or as a combination of several entries. If such a semantic equal can be identified in the destination, then there is a mapping between those concepts, from source to destination. Otherwise, the single entry in the source dictionary has no equivalent concept in the destination dictionary. This same approach is often used in mapping data models or other similar products. However, in addition to starting with a single concept in the source, it may be necessary to combine multiple concepts to meet specific data model requirements.

Since in practice at any given point in time data translation or data movement is in one direction, we consider mapping from a concept in the source to a concept in the destination as a single one-directional mapping. The mapping from the destination concept back to the source concept is considered to be another, separate, one-way mapping. A complete two-way mapping is therefore composed of two one-way mappings. Often the two one-way mappings between concepts are inverses of each other, but for a variety of practical reasons this is not guaranteed for all concepts or instances.

Independent of whether mapping is being done between concept dictionaries, data dictionaries or data models, when developing mappings for use in data conversion applications, the end result for a given concept is either that a mapping exists for that concept or there is no mapping. This principle is particularly important to application designers when using a given mapping product for two concept dictionaries, since declaring a partial or potential mapping is not useful to the designer, unless explicit conditions can be established clearly so there is no ambiguity in how a mapping is to be applied. However, during the development of a mapping, some instances may be marked as “unresolved” (along with appropriate explanation) until these are further reviewed and then resolved (in the final product) to either having a specific mapping or marked as having no mapping.

During the development of a mapping and in particular during the analysis phase, there are often cases when it is possible to map a given concept in the source to more than one semantically equal concept in the destination. In such cases, the final mapping product should identify only the best, most logical, and most practical of those mappings.

There are a number of mapping types and sub-types. These usually involve additional information, special conditions, or a collection of concepts in order to provide the same semantics in the destination. For all mapping types and sub-types, additional explanation, rationale, or analysis may be provided to help the end user (as well as the reviewers, during the development of mappings) to better understand why a certain type of mapping has been designated for a given concept. These supplemental data often can be binned into one of several specific categories of rationale or analysis, and can be used with a number of mapping types. This supplemental information is captured in a separate field, adjacent to the mapping type.

6. Terminology for mappings

Different terminologies are needed for different stages or categories of mappings. To establish a mapping for environmental data, a developer may produce mapping products between concept dictionaries or between data models (or specific data products). During the development of such mapping products there is considerable analysis

that will take place to search and analyze the concepts in both the source and destination material. Therefore, it is important to be able to identify, through a shorthand notation, the type of analysis as well as the type of mapping associated with a given mapping.

Specific notation, definition of types, and examples of how different categories and types of terminology can be applied have been developed by the authors, but inclusion of that detail will make this paper unnecessarily lengthy. Therefore, detailed listing of types of terminology for each category, and examples for each case, are not included in this paper, however, a brief description of the various mapping categories and terminology types is provided in the following sections.

7. Analysis terminology

During the analysis phase appropriate terminology, and associated shorthand identifiers, are needed to concisely express the reasoning for a specified mapping. This analysis terminology is distinct from the formal mapping terminology and should be captured in a separate field associated with a given mapping. This allows formal mapping cases to be clearly delineated, and after the mapping is completed, the retained analysis information in conjunction with other comments can be helpful in understanding why the specified mapping was chosen. Such information is not necessary for the end use of the mapping product and need not become part of the mapping library that will be used to look up the mapping for a given concept, but is useful both during the analysis and review phase as well as in retaining a trace of the rationale for a given mapping for future revisions or reviews.

Analysis terminology is used to describe the relationship between the source and destination concepts. Examples of these terminologies include such relationships as aggregate-component relationship, specific concept to general concept, inverse of these, concept does not have an equal, concept cannot be mapped, concept has an equal, concept is identical to destination concept, etc.






Given a definition in a dictionary, a set of real object instances should exist that conform to that definition. Furthermore, given a pair of

definitions in two different dictionaries, two sets of real object instances should exist, conforming to each of those two definitions. For example, given the respective EDCS and DFDD definitions of “Barn”, a set of real (farm/agricultural) buildings exist that conform to each of those definitions.

One way of determining the relationship between the two concepts is to consider the relationship between those two sets of object instances. There are only five possible relationships between those two sets. Which relationship applies in a given case can be determined by asking three yes-or-no questions:

- Q1) Are there instances that conform to both definitions?
- Q2) Are there instances that conform to the first definition, but not to the second definition?
- Q3) Are there instances that conform to the second definition, but not to the first definition?

The relationship between the two sets, and therefore between the two concepts, is then given by the following table:

Q1	Q2	Q3	Result	Graphic
Y	N	N	Concepts are identical	
Y	Y	N	First concept includes second concept	
Y	N	Y	Second concept includes first concept	
Y	Y	Y	Concepts overlap	
N	-	-	Concepts are disjoint	

In addition, there are other kinds of relationships, such as component and functional relationships, which also may need to be identified and documented as part of the analysis process.

8. Mapping terminology for concept dictionaries

The key to creating mappings between different concept dictionaries is to determine that a given concept definition in the source corresponds to a particular concept in the destination. Furthermore within a dictionary of concepts it is only necessary that definitions be unique and unambiguous, not that they be "normalized" such that no two concepts overlap within a dictionary. As a result, terminologies used in the development of mapping products between concept dictionaries may also be used in the development of mapping products between data models.

Mapping terminology is used to identify how a concept maps to a destination concept. Examples of mapping terminologies include identifications such as: a concept maps directly to a specific destination concept; there is no mapping for a given concept; there is a mapping, however the main concept in the destination dictionary is qualified by one or more attributes from the destination dictionary; there is a mapping between attributes, but a data type change is required; there is a mapping, but a change in unit of measure is needed; there is an intermediate mapping that requires additional determination at data conversion; there is an attribute mapping, but the concept's enumerants are specifically split into multiple attribute-enumerant combination concepts in the destination dictionary; etc.

9. Mapping terminology for data models

When the mapping involves more than the isolated entries between two concept dictionaries, and includes the specific context of a data model or a product that uses a source dictionary, and is being mapped to another data model or product that uses a separate destination dictionary, additional terminology may be applied to better identify the mapping between such data models or products.

Typically, in such cases, the mapping process begins with the results of the formal concept dictionary mappings (if they exist), and uses those defined mappings (through the terminology specified in the earlier sections) to apply additional constraints imposed by the source and/or destination data models or product structures.

When mapping data models or products, some of the concept dictionary terminologies can be used, however, these will cover the complexities associated with data model mapping cases. Specific data model mapping terminology is required to express those types of mappings that occur when data models or products are involved. Examples of data model mapping terminology include: the source concept is qualified with other concepts and the combination has an equal (single) concept in the destination dictionary; the source concept may be mapped, if a given condition is met in the

source data; the source concept, qualified with other concepts in the source dictionary, has an equal in the destination which itself is qualified by other concepts in the destination dictionary.

10. Summary

Enabling interoperability between M&S systems, and allowing coherent data integration from multiple sources, requires a consistent and common approach to handling, converting, and adjudicating the data. Data providers and system developers have their internal and often unique methodologies for identifying and defining the content in their data. These are based on formal (and sometimes informal) dictionaries of terms/concepts, whether they are concept dictionaries that are used in a variety of data models, or specific data dictionaries associated with a particular data model or data product. Since most M&S systems, in particular networked M&S systems, combine data used by different systems or integrate data from various data sources, having a consistent methodology and terminology for providing mapping between these data becomes critical. Such mapping products are in turn used in data conversion or translation applications. While data exchange between applications must take into account data syntax, semantics and organization, establishment and use of a common mapping terminology and a consistent mapping methodology is a significant factor in increasing the interoperability of systems and applications, and reducing development cost of converters.

This paper has described an overview of the issues and principles that are involved in establishing such mapping methodology and terminology, and has highlighted various categories of terminology and mapping stages, and why utilizing a common and consistent mapping approach and terminology is important. Many of the concepts discussed in this paper are the results of past and on-going mapping experiences, including mapping work, dating back to late 90's, between FACC and EDCS, more recent experiences in establishing mappings between DFDD and EDCS, as well as the on-going mapping efforts between the National Geospatial and Intelligence Agency's NFDD, which is based on (but not identical to) the DGIWG DFDD, and EDCS. Although the concepts described in this paper are based on examples from use of environmental data, the

same principles are applicable to other data interoperability challenges in M&S applications.

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Author Biographies

Dr. Rob Cox has held many positions in industry and the U.S. military. Currently, he is a member of the US Army PEO STRI Engineering Directorate supporting PM Instrumentation Target and Threats Simulators (ITTS) and is responsible for the engineering design and testing of full motion and tracking simulators. Prior to joining PM ITTS, he was a member of the Future Combat System (FCS) Lead System Integrator (LSI) Training IPT. His primary responsibility was the development of the common environmental representation for FCS. He led the SAIC Synthetic Natural Environment (SNE) Research and Development team developing core SNE technologies to include the US Army OneSAF Environmental Runtime Component (ERC) and the SEDRIS project. Prior to joining SAIC, Dr. Cox was a member of the USAF where he held Program Manager Positions at the Defense Threat Reduction Agency (DTRA), the National Defense University (NDU), and with Air Force Weather (AFWA). Dr. Cox has an earned Doctorate from Texas A&M University.

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