3-D Visualization Using an Open-Source Ontological Data Structure

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ABSTRACT

In recent years, feature classification systems have proven to be inadequate in their ability to assist in the detailed description of synthetic cultural and natural environments. Many existing feature classification systems were developed when limited display capabilities demanded economy in the database generation process. Others are so limited in scope that they do not provide the feature specificity necessary for current and future display capabilities. Based on current client requirements and the anticipated detail requirements of future synthetic environment databases, an alternate taxonomic structure must be available to database developers. In a presentation at I/ITSEC-2002, we described a conceptual feature classification system, designed for use in the development of synthetic environments. We described the potential uses and a conceptual design of a hierarchical data structure that could be used to store natural and cultural feature data.

The first version of this taxonomy is now available for public review and possible implementation in existing and future software systems. The development of this new system was based on creating a logical intersection of classes and concepts from many existing taxonomies, thesauri, ontologies and classification schema. This new data structure now allows unambiguous inventorying of natural and cultural landscapes. It can also assist in the unambiguous importing of disparate sources of feature data. A significant portion of this research/production effort also involved the creation of a public-domain library of generic 3D models – models closely aligned to the concepts in the feature taxonomy. These data structures and their availability are discussed in detail. The trials and tribulations encountered during development, potential uses of the data structure, and future developments to be performed under this research effort, are also discussed.

INTRODUCTION

Cartography is concerned with space and place. Because things occupy space and have a place, cartography is also about things. Cartography is concerned with mapping things in their own place. Over time, relationships between things change. Therefore, there is also a temporal characteristic to things, to space, and to place. Further, over time these changing relationships are indicative of processes that act on things. In reality then, cartography is not only concerned with things relative to space and place but is also concerned with relationships between things, temporal changes of things, and processes that interact upon things. How to precisely represent these things, their place and space, their relationships to other things, their temporal characteristics, and processes that act upon them – this is the very essence of cartography.

As technology becomes more powerful, the ability to map more types of things will become possible and it must be possible to address explicitly the uniqueness of things at varying levels of granularity. In the future, creating realistic synthetic landscapes will require the ability to inventory actual natural and cultural objects at the same level of detail as they exist within the real-world landscape. With the continued call for higher detail in real-time simulation displays, producers of real-time simulation databases have to search for non-traditional sources of feature, elevation, and image data to meet ever increasing detail requirements. Today's challenge is to develop advanced techniques to rapidly capture, manipulate, and display large volumes of non-standard geospatial data about a cultural or natural landscape. The automated assimilation of disparate sources of geospatial data is an attractive and potentially cost-effective future means of populating visual databases with high density feature detail. However, for this to be a viable technique, standardized means for resolving semantic, syntactic and multi-lingual differences in data must be addressed. To do this, a feature classification system that contains detailed categorizations of natural and cultural objects is essential. However, using current feature classification systems, it is impossible to store geospatial feature information on many of the more common cultural features encountered on the landscape. In the classification schemes commonly used in the Modeling and Simulation (M&S) environment, no categories are available to store feature information about the most common non-pavement highway features – regulatory and informational signs. Try and find a classification code for a stop sign, or any other standard traffic sign. Search in vain for a classification code for a covered bus stop, or a park bench.

At the 2002 Interservice/Industry Training, Simulation & Education (I/ITSEC) Conference, Bitters [2002] reported on a pilot project and conceptual design for the creation of a comprehensive feature classification schema of common objects within the visual domain. Since that time, these development efforts have resulted in the production of an initial version of a taxonomic structure, the Visual Object Taxonomy (VOT) that allows a detailed categorization of cultural and natural objects. In conjunction with the development of this taxonomy, an extensive collection of public-domain, generic 3-D models have also been developed. What is unique about this research is that a direct relationship has been maintained between the collection of 3-D models and the concepts within the taxonomic structure.

In this paper, we will briefly examine the philosophical basis of classification and the perception of reality and how it bears on this research effort. The design principles behind systematic taxonomy development will be discussed followed by a discussion of the methodology used to create this taxonomy. A brief overview of the taxonomic structure will then be presented and the potential uses of the data structure will be discussed.

BACKGROUND

Ontology refers to the theory of existence. This philosophical discipline asks the fundamental question: What exists? The answer to this question will determine what is accepted as "fact" and what can be known of the realities around us. Long-standing philosophical debates concern the nature of human perception of reality. Traditionally, the two opposing extremes of this debate have been the realist view and the nominalist view. To the realist, reality is external to the individual and imposes itself on individual consciousness. In this philosophical position it is a given that objects exist and that they occupy space. To the nominalist, however, reality is considered to be a product of individual consciousness, a product of one's own mind or of ones individual cognition. Nominalism questions whether humans can effectively and objectively view, define, and recognize the realities around them because all stimulations of the senses are filtered and interpreted based on an individuals past experiences. For example: If an English-speaking man, a French-speaking woman, a dog, and a robot were all standing around looking at a luscious piece of cheese; the man might think of cheese and its taste. The French woman might think of *fromage* and its taste. The dog also might think about the taste and might have mentally verbalized a concept name in "dog-speak". The robot would just recognize the existence of an object with a certain chemical or physical makeup and as a result equate that to the concept of cheese. They each would recognize that an object exists and possesses certain qualities. They each would generalize the objects existence and recognize the object relative to all other things in their individual universe. In this illustration, what is important is that each individual perceives the same object and they conceptualize the object in a similar fashion. It is not important that they categorized the object differently; i.e. cheese or *fromage*. This is a differentiation based on linguistics not based on concept definition. In the broadest sense, the language difference is not significant since each individual arrived at the same concept.

Perception and Classification. Aristotle investigated the theory of taxonomies by studying marine life intensively and grouped different living things together by their nature, not by their resemblance. This form of classification was used until the 19th century. Aristotle's teacher, Plato had defined reality based on ideas or eternal forms, knowable only through reflection and reasoning. However, Aristotle saw ultimate reality in physical objects, knowable through experience. Objects, including organisms, were composed of a potential, their **matter**, and of a reality, their **form**; thus, a log -- matter -- has the potential to assume whatever form a carpenter gives it.

In the 18th Century, Carolus Linnaeus described a hierarchical classification system using seven taxonomic categories, or *taxa* (Kingdom, Phylum, Class, Order, Family, Genus, and Species) to describe the plant and animal kingdom. The Linnaean taxonomic structure, although constantly evolving, is still used to this day to describe the evolutionary, genetic, and physical characteristics of all living things. In the Linnaean taxonomic system, physical objecthood was initially delineated based on identifiable characteristics, initially visual characteristics, and evolved to its modern form of using a combination of genetic, evolutionary, and visual characteristics to identify unique objects. To circumvent the problem of "universally" understandable verbal descriptions of objects, the Linnaean system augmented verbal definitions by using prototypes to identify the epitomized form of each described object. Natural history museums the world over store preserved prototype specimens -examples of originally described instances of all known plant and animal species. This use of prototypes improves understanding by extending the communication process beyond verbiage to include visual communication of ideas. This descriptive technique overcomes the inadequacies and ambiguities inherent in verbal description using natural language.

However, in some sectors, there has been a distinct mistrust of the generalization process used in the development of ontological structures such as thesauri and taxonomies. This is because these ontological structures are so heavily dependent on the written word, and understanding of the written word is not always universal. This line of though might be difficult for some to fathom since every time a proper noun is used in speech or writing, the same generalization process takes place. Ontologies, lexicons, taxonomies, thesauri, classification systems, synonym rings - whatever name is used, are all data structures by which we can generalize our environment into a more easily understood form. Each of these is a controlled vocabulary - an organized list of words, phrases, concepts and/or notation systems for a specific subject domain.

Classification is the act of removing certain distinctions between concepts so that we may see their commonalities [Taylor, 1999]. A concept is an idea or notion that we apply to classify those objects around us. However, what I perceive as a distinctive concept may not be the same as your perceptions. Take the word "chair." The mental picture that comes to mind at the mention of this word will not be the same from one individual to another. However, the concept of the chair, as with the concepts of individual plants and animals, is unique and is describable in that uniqueness. Capturing this uniqueness of form is the basis for the act of classification. Therefore, a systematic means must be devised to incorporate detailed and accurate descriptions of this uniqueness into each object definition. When properly documented, a formal classification system provides the basis for a relatively uniform and standardized nomenclature, thereby simplifying and standardizing the exchange of data and ideas. The key to the effective use of knowledge in any classification system is the concise, unambiguous, and detailed definition of each object in the system.

Why Is Classification Essential? In essence, this entire discussion has, so far been an analysis of subjective views of reality versus objective views of reality, and this debate has persisted since ancient times. A classic example of subjectivity in language can be seen in the phrase "There is a pink lizard." This sentence is subjective in that it does not use succinct and unambiguous terms. What shade of pink - hot pink or crimson? What exactly is a lizard? Some might call the creature a toad! A more objective means of phrasing the same sentence would be, "There is an animate object of the form *Prynosoma cornutum* with a visible wavelength of 124,94,94 on an RGB scale of 255,255,255." Although this would be considered an absurd way of conveying an observation in casual conversation, in the modern digital environment this type of detailed and explicit definition of fact is essential to ensure total and explicit understanding between two parties. Without total and explicit understanding, communication fails.

Further, to enable systematic research in any research discipline, there is a need for a common language to succinctly express concepts and ideas. The development of a taxonomic structure is an integral part of the formulation of any such language. For this research effort, we have assumed the existence of a real world, populated by real entities that occupy regions of space. Language, when properly employed, allows sentient beings to explicitly and understandably express ideas, concepts, and thoughts. However, spoken, written, even non-verbal languages are all in a constant evolving form. The exact meaning of words and phases changes over time and regional variations in word meaning also vary. To counteract the evolving nature of linguistics, it is essential to document any formal ontological structure with concise and explicit definitions.

Further, we take the perspective that the real world is structured and that there is a certain geometry into which all the worldly objects are hierarchically expressible. This hierarchy of objects developed into an ontological data structure, reveals the relationships between these objects in a way that makes their existence explicit and more easily understood.

ONTOLOGICAL DESIGN PRINCIPLES

In the information technology sector, to reduce the cost of data capture, the natural tendency has been to find ways to share data. To share data effectively and economically, GIS systems must be interoperable – they must have the ability to provide portable information and maintain inter-application cooperative process control [Bishr, 1998]. Within the GIS community, semantic heterogeneity is usually the root evil of the data sharing problem. Bishr mentions two forms of semantic heterogeneity: cognitive and naming heterogeneity. Cognitive heterogeneity is characterized by inconsistencies in the definition of concepts between disciplines or locations. An object in one system is defined differently than the same object in another system. In this situation, a mediation interface is required to allow understanding between the two systems – an interpreter that takes into consideration the subtle often times blatant difference in concept definitions [Bishr, 1998].

Naming heterogeneity is a far less complex situation, in that common concept definitions are the same but concepts are labeled with different names. This situation can be resolved through the development of a synonym ring or thesaurus that serves as a translation mechanism between data sets at two disparate systems or locations. Development of this type of translation mechanism has been demonstrated for small data sets using semantic factoring and concept latticing techniques [Kokla, 2001]. However, these techniques are only satisfactory for small sets of concepts, and are not feasible for rectifying naming heterogeneity within large, multi-domain situations.

Since in the context of geospatial information, an ontology is a model of geographical knowledge within a specific subject domain, there must be some means to resolve semantic heterogeneity during the categorization process. Smith and Mark [2001] address the categorization of geospatial information based on the concept of extended entities. Two types of entities - objects and processes have a distinct dimensionality – either spatial and/or temporal (Figure 1). This conforms closely to the general trend in ontological development within the information technology realm where ontological data structures normally start with a top-level primitive object called “thing” and all entities, objects and processes are derived from this basic primitive object.

Egenhofer [1995] viewed ontology as a mix of not only formal geographical concepts but also informal naïve geographical concepts. The natural extension of this line of thought has been presented in an interesting study of layperson, non-expert, and professional perceptions of geographic features, objects, and concepts. Smith and Mark [2001] provide an insight into the depth of knowledge that would be involved in a geospatial ontological data structure – both the formal and the naïve. Their research provides “a first approximation to the basic noun lexicon for geographical ontologies, even while pointing out unexpected difficulties in the way of completing an ontology of the geographical (folk) domain” [Smith & Mark, 2001].

From a more philosophical perspective, Barry Smith and David Mark [2003] challenge the basic notions of the types of entities that must be included in a comprehensive ontological data structure of geospatial information. In the end, they accept that although it is a monumental task, the development of a broad-based geospatial ontological structure is essential, but that: “A complete ontology of the geospatial world would need to comprehend not only the common-sense world of primary theory but also the field-based ontologies that are used to model runoff and erosion…” [Smith & Mark, 2003]. This indicates that both technical and non-technical geographic terms are an integral part of the day-to-day vocabulary of geospatial information users and producers. Therefore, any standard nomenclature would have to include not only the full spectrum of standard technical but also include commonly used colloquial terminologies.

Tolk [2004] raises four challenges that must be dealt with when mediating heterogeneous data sources and these all must be resolved when developing a systematic ontological data structure:

- *Semantic Conflicts:* the concepts of the different schemata do not match exactly, but have to be aggregated or disaggregated.

- *Descriptive Conflicts:* there are homonyms, synonyms, different names for the same concept, different attributes or slot values for the same concept.
- *Heterogeneous Conflicts:* the methodologies being used to describe the concepts differ substantially, e.g., one concept is described in the Unified Modeling Language (UML), the other in a relational data model.
- *Structural Conflicts:* different structures are used to describe the same concept, e.g., in one local schema an attribute is used, in the other schema a reference to another concept is used to describe the same part of the view of "reality".

The effective use of a standard reference model can resolve most descriptive, heterogeneous and structural conflicts and eliminate many of the problems inherent in the handling of disparate data sources. However, semantic conflicts and some descriptive conflicts will remain, even with the most robust model-based data management. The purpose of ontologies in the form of classification systems is to resolve many of the semantic and descriptive conflicts that arise when working with disparate sources of feature data. Removing, or reducing these conflicts, allows a smooth and systematic categorization of feature objects using a generalized set of class concepts. By creating a logical and orderly grouping of classes and subclasses, it is possible to identify relationships about objects contained in the categories. A taxonomic structure is an accepted means of generalizing domain knowledge into an ordered set of class objects.

The approach taken in this production effort has been that a properly developed taxonomy must have the following qualities:

- An explicitly defined domain that limits the set of items to be categorized.
- Distinct categories based on visually recognizable properties.
- Mutually exclusive categories.
- Exhaustive and unambiguous categories.
- Explicitly defined categories.
- Formulated in a single language.

If the concepts within a taxonomy lack any of these properties, then a classification performed by one individual may not be repeatable by another individual, or even by the same person at different time. Without repeatability, the taxonomic structure becomes useless.

An Explicitly Defined Knowledge Domain. A taxonomy must have a knowledge domain with defined limits. This in effect identifies the extent of the allowable categories that can be included in the final data structure. For this research project, the limits of the knowledge domain have been defined as "all objects within the visual domain." To say the least, this encompasses a very broad set of objects. For this reason, we have limited the domain extent based on the current state of the art of military modeling and simulation and other cartographic endeavors. For the purposes of the object model being developed, those objects that are typically inside buildings and other structures, are generally excluded from the domain of knowledge included in the VOT. This effectively eliminates household furnishings and fixtures, commercial and industrial furnishings, and equipment that would be found inside structures.

Distinct Categories - What Constitutes a Valid Concept? In the context of this research effort, the declaration of a valid concept is based on the distinct and unprecedented visual appearance of an object, its functional characteristics, and on the assertion of its uniqueness within another ontological data structure. It is intuitively obvious that the visual appearance of a chair is markedly different from that of an automobile. However, many of the concepts developed from and transferred into the VOT from heritage ontological structures, may not possess apparent and distinct differences in visual appearance. For instance, what is the difference between a **pinnacle**, a, **butte,** a **mesa**, or a **plateau**. By definition, a plateau is larger than a mesa, which is larger than a butte, which is larger than a pinnacle. Except for their size, each of these objects can be visually similar. However, each term/concept is considered to be a definitive geographic feature based on their existence in several heritage ontological systems. For the purposes of this project, if a term is defined in any heritage taxonomic structure, and the functionality and the visual appearance described in its definition makes it a unique concept, then it will appear as a unique concept in the VOT.

Mutually Exclusive Categories. The existence of concepts in the VOT indicates that there is enough differentiation in meaning to constitute a unique category. Mutual exclusivity of categories means that at the same level within the hierarchy there will be no duplicate categories. In other words, at the same level within the hierarchy each concept definition will define a set of qualities that are not duplicated in any other concept at that same level.

Unambiguous Categories. Ambiguity in a concept definition within a taxonomic structure is a direct violation of one of the basics tenants of taxonomy development. In the past, taxonomies were often developed based purely on a concept idea as expressed by the concept name. Even when a definition was included in heritage taxonomies, assumptions were often made that everyone would know what was meant! This is a faulty assumption since words generate mental images that may not be the same for different individuals. As an example, an individual in the desert may conjure up a different mental image of a "tree" than an individual living in a temperate region. For this reason, to insure unambiguity, in addition to a precise definitions, we will ultimately include graphic, photographic, or 3-D model representations of all concepts. In this way, there is no mistaking the meaning of definitions.

Explicitly Defined Categories. The notion of the explicitly defined category has never been expressed so well than when HG Wells [1908] said:

> *"Think of the arm chairs and reading chairs and dining-room chairs, and kitchen chairs; chairs that pass as benches, chairs that cross the boundary and become settees, dentist's chairs, thrones, opera stalls, seats of all sorts, those miraculous fungoid growths that encumber the floor of arts and crafts exhibitions, and you will perceive what a lax bundle in fact is this simple straightforward term."*

This quotation would lead one to believe that there is no such thing as a "chair" – but that there are all sorts of things that approximate the concept of a "chair". If the exact meaning of an object is not explicitly defined, then the philosophical concepts of Heidegger and Foucault take over. Each individual would conceptualize the "chair" based on there own life experiences. In this situation, precise communication has broken down. Differences in size, shape, and material should not contribute to the functionality of a class. We can all conceptualize the concept of a "chair". However, as Wells has illustrated, the exact material idea of that 'chair" can and will vary from one individual to another. To remedy this situation, if the "epitome of a chair" is defined and described in detail - both literally and graphically - then there can be no mistaking what the precise definition of the object is. In the past, many taxonomy developers have ignored the requirement to precisely define concepts. Many existing heritage taxonomies rely solely on the understanding of a stand-alone concept name – a concept name without an explicit and precise definition. The trick to defining an explicit class concept is to both graphically and literally identify a particular instance of an object as the prototypical example of that class.

Our intent in this research effort is ultimately to develop explicit and definitive class concepts for all categories. The definitions have been developed based on an ordered vocabulary to reduce the potential for future linguistic confusion. Further to insure full understanding and recognition of concepts, whenever possible, class definitions should be accompanied by an illustration or photographic image of a prototypical example of the category. Later in this project, we will expand the definition understandability to include definitions developed based on a first-order predicate calculus – a recently developed set of languages for knowledge representation. In this way, definitions will then be readily understandable in the computer environment - not just parsable in the computer environment.

Several knowledge representation languages are currently available; i.e. DARPA's Knowledge Representation Specification Language (KRSL), University of Maryland's Knowledge [Finnin, 1994] Query and Manipulation Language (KQML), and Stanford University's [Genesereth, 1998] Knowledge Interchange Format (KIF). An International Organization for Standardization (ISO) initiative is being drafted to describe and implement a new form of first-order logic (FOL) [Menzel 2005]. This initiative is not being performed isolated from the existing FOL community but is being performed in close coordination with the proponents of KIF, RDF, and OWL. It is hoped that the introduction of this new form of FOL will remedy many of the semantic problems inherent in existing FOL languages and will "pave the way" for true machine understanding of translated natural language text. The draft specification for SCL/CL was published and submitted to ISO/EOC in February 2005. However, none of these machine understandable languages/interchange formats are in exclusive wide-spread use. Because we do not want to be guilty of making a choice similar to the BetaMAX versus VHS dilemma in the video recording industry, we have delayed the decision on which language to use. Hopefully, in the near future one of the currently available knowledge representation languages will become a wide-spread and accepted standard.

Formulated in a Single Language. Multi-linguistics adds a major complication to taxonomy development. Direct translation of concept names from one language to another introduces a significant difficulty into the development process. First, to be successful at translating explicit concepts into another language, an intimate knowledge of both languages is required. Even with an intimate knowledge of both languages it is often difficult to arrive at an exact translation of terms. The subtle differences in meaning and fine distinctions that must be determined during the translation process make this process difficult. To make matters worse, the same problems arise when attempting to develop an ontological structure that spans dialects of a single language. After a detailed analysis of both non-technical and technical terminology in the Oxford and Webster's dictionaries, significant differences have been found in word meaning. If it is difficult to agree on word definitions between dialects, then the situation will be exacerbated when attempting the same processes between different languages. For this reason, we have restricted our taxonomy development efforts to the Webster's version of the English language. And, this will not totally eliminated the problem of precise word definition since, in the United States there are major regional differences in word meaning.

METHODOLOGY

Taxonomy Development. Over the last 10 years, numerous academic and governmental scientific organizations have advocated the development of broad-based ontological structures to describe major knowledge domains. However, because of the daunting size of such a task, outside the information technology discipline, there have been only limited attempts at the development of such knowledge bases. Under the auspices of the University Consortium for Geographic Information Systems (UCGIS), Mark, *et al* [Mark, 2002] have proposed as a research priority the development of an exhaustive ontology of the geospatial domain. This ontological structure would precisely "define geographic objects, fields, spatial relations, processes, and their categories. It would be accompanied by translation algorithms, mapping the ontology into the basic data models and representations necessary for scientific computing about geographic phenomena."

At first glance, a project of this magnitude might seem to be not only an overly ambitious venture, but also an insurmountable task. However, as Mark goes on to say, a task of this sort must be performed incrementally and by a number of different research teams all working in concert toward a common goal. In our research effort, we have taken on only a portion of the overall task identified as a UCGIS research priority. Before a complete ontology of the entire geospatial domain can be created, a detailed ontological knowledge base must be developed that systematically identifies all the physical (and non-physical) objects that comprise the geospatial domain. The taxonomic structure developed in this research effort is a first attempt at this task.

The basic tenet in this research has been that there exists an abundance of domain-specific English language taxonomic structures that describe some portion of the objects in the geospatial domain. An assumption has also been made that these heritage taxonomies were designed and developed by subject matter experts. Based on this assumption, each heritage taxonomic structure would constitute an authoritative assemblage of defined objects within that domain. Therefore, if enough heritage taxonomic structures could be located, taxonomic structures that would provide "coverage" of concepts across the entire gamut of the visual domain, then the union of these heritage taxonomies would serve as the basis for a broad-based taxonomy of the visual domain. After significant research, over 200 different English language heritage taxonomic structures have been identified. These range from formal ontological domain studies to taxonomic structures developed for purely information technology purposes.

The initial attempt to combine these heritage structures into a single unified and logical taxonomy failed. In this initial attempt, all concepts for 151 heritage taxonomies were merged into a single data file without any preprocessing. The result was a data file containing 30,000 concepts in no logical order. The second attempt at combining these 200 heritage taxonomies involved a five phase process that limited the total number of newly introduced concepts that would be incrementally added to the finished structure. As each new increment of features was added, these new concepts were logically merged into the new data structure and the entire data structure was logically re-sorted to accommodate the additional concepts.

To perform these incremental additions of new concepts, the following five-phase process was performed:

1. Top-level Assignment of Heritage Feature Classes
2. Hierarchical Sorting
3. Synonym Control
4. Definition Development
5. Relationship Definition

<u>Phase 1, Top-level Assignment of Heritage Feature Classes</u> involved the assignment of approximate hierarchical classification designations to each concept within all heritage taxonomies. After all concepts of each heritage taxonomic structure were assigned an approximate hierarchical classification designation, then each heritage taxonomy was merged into the VOT. At the point where approximately 1000 new heritage classes had been added to the VOT taxonomy, then Phase 2 processing was performed.

<u>Phase 2 - Hierarchical Sorting</u> involved individually within each top-level class arranging all subordinate categories into a preliminary logical sequence. This process of rearranging each individual top-level class hierarchy was performed iteratively after the introduction of each set of 1000 new heritage classes. When building a hierarchical structure, all terms must be arranged based on a BT-NT, or "broader term/narrower term", relationship. The advantage of this approach is that users can better understand this arrangement, and as a consequence, are able to more efficiently navigate through the structure. By performing this BT-NT sort incrementally, there was less confusion then what was encountered in the failed first attempt.

<u>Phase 3 - Synonym Control</u>. Because multiple, often overlapping ontological structures were used in the development of the VOT, it is only natural that duplicate concepts would be present. For the same reason synonymous concepts – same meaning with different names – would be present Also, for the same reason partial synonyms are also present. Partial synonyms are ambiguous concepts that have an overlapping meaning; i.e. the term "river/stream" and the term "river". For each of these situations, a decision must be made as to whether two distinct concepts exist or if the two terms are in fact completely synonymous.

<u>Phase 4 - Definition Development</u> involved the formal adoption of a definitive definition for each final concept. This process is ongoing. Most of the definition protocols used in the SEDRIS^{TM} Environmental Data Coding Specification (EDCS) [SEDRIS 2004] have been adopted for use in the VOT. In fact, the basic starting definition set was and remains the most recent version of the EDCS concept definitions. After all concepts have been assigned a final English language definition, as was mentioned earlier, each English language definitions will be translated into a machine-understandable form. This last step will involve the use of a knowledge representation language based on first-order predicate calculus.

<u>Phase 5 - Relationship Definition</u>. The last phase in the formal taxonomy development process is to define the taxonomic relationships between each concept and other concepts within the taxonomy. Besides the identification of synonyms, homonyms and derivatives,

THE DATA STRUCTURE

Hierarchies are the most ubiquitous organization structure used for taxonomies and thesauri. The hierarchical structure is also intuitive to users, and provides a means to show the relationships among content items according to their specificity or generality. The hierarchical structure allows the implicit definition of a set of scaled concept categories based on observation distance from the object. For instance, while flying in a high altitude aircraft it is often possible to see an area of distinctly industrial use. It may not be possible to identify particular characteristics about that industrial operation. However, as one moves closer more characteristics become discernable. Based on the configuration of buildings and some knowledge of the terrain, a more detailed definition of the primary function of the industrial operation reveals that it is a mining operation. As one moves even closer, building configuration will reveal the exact nature of the mining operation as, for instance a copper mine. Imbedding this scaled specificity/generality relationship implicitly within the hierarchical structure, duplicates the same principle that is currently used in image generators to instance features – the closer the observer is to an object, the higher the level of detail and the more knowledge about the exact nature of the object is revealed. The hierarchal structure of the VOT attempts to preserve this scaled specificity/generality relationship.

The current version of the VOT is stored as a relational database using Microsoft Access. Figure 1 shows the ultimate structure of the VOT data set. Individual databases have been developed for each heritage taxonomic structure used in the project. The relationship of each record in these heritage taxonomic structures has been preserved for later use in developing "lossless" import routines. For those heritage taxonomic structures that contain definitions, theses definitions are used as a starting point in developing VOT compliant definitions.

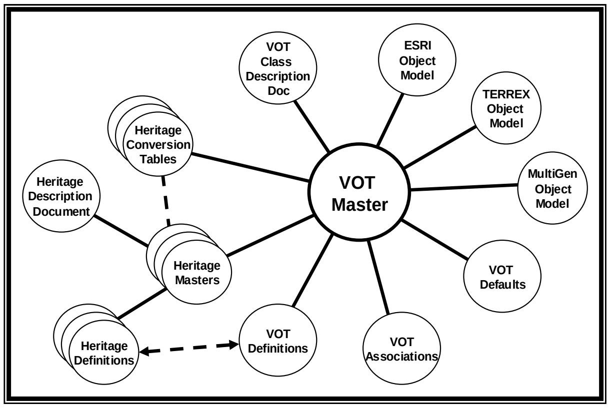

Figure 1. A Schematic of the Visual Object Taxonomy (VOT) MS Access^{TM} Database

Because the master VOT database was developed from multiple and disparate data structures, the master database initially contained extensive duplicate concept records. To remedy this situation, Access query capabilities are used to automatically extract and reformat data into several different final formats. A VOT Class description document is a formal database description document that identifies and defines each class in the taxonomy. Three formal object models will also be extracted and reformatted to be used in ArcGIS© produced by Environmental Systems Research Institute (ESRI), in TerraVista© software developed by Terrex Inc., and in the Creator Terrain Studio (CTS) software developed by MultiGen Paradigm, Inc.

Table 1. Top-Level Groups, Number of Concepts and 3-D Models in the Current VOT Structure.

ID	*Top-Level Groups*	*Number of Concepts*	*Number of 3-D Models*
1	Industry	1867	58
2	Transportation	1289	354
3	Commercial	851	132
4	Recreational	460	28
5	Residential	368	117
6	Agricultural	330	26
7	Communications	128	16
8	Governmental	234	30
9	Institutional	419	51
10	Military	571	70
11	Storage	229	26
12	Hydrography	912	16
13	Physiography	576	3
14	Vegetation	224	37
15	Miscellaneous	63	5
16	Vehicles	1495	33
17	Human Forms	34	0
18	Animal Forms	124	1
19	Demarcation	96	0
20	Map Symbology	12	0
21	Law Enforcement	241	0
22	Parks and Recreation	374	160
23	Animal Studies	10	0
24	Urban Studies	96	0
25	Forestry	20	0
26	Geology	60	0
27	Atmosphere & Climate	140	0
28	Real Estate	10	0

29	Hazards and Hazmat	24	20
30	Utilities	25	0
31	Wetlands	299	0
32	Health and Disease	15	0
33	Pollution	31	0
34	FGDC Vegetation 1	704	0
35	Hydrology	18	0
36	Landmarks	7	0
37	Landscaping	5	0
38	Survey	70	0
39	Conservation	48	0
40	Survey Control	140	0
41	Archeology	48	0
42	Parcels	78	0
43	Land Use/Land Cover	131	0
44	Soil Science	71	0
45	Census	67	0
46	Space	52	0
50	Units of Measure	210	N/A
70	NonObject Definitions	906	N/A

Table 1 identifies the 48 top-level groups used in this version of the VOT. Of these 48 top-level groups the first 15 represent those broad top-level categories of cultural and natural features that have been traditionally used in mapping and charting classification schema – in particular in the Digital Feature Analysis Data (DFAD), Feature and Attribute Coding Catalogue (FACC), and most recently in the SEDRIS^{TM} EDCS classification schema. Groups 16 through 18 are an extension to these traditional groups and address the categorization of all forms of vehicles, human forms, and animal forms. The objects within these first 18 broad top-level groups represent the preponderance of feature classes for those tangible objects that would be encountered on the Earth's surface. Groups 19 through 47 contain a set of classes for various forms of tangible and intangible feature data that can be encountered in the GIS community. Group 50 contains a set of standard units of measure and group 70 contains a set of non-feature concepts and their related definitions.

As a demonstration of the increased granularity and specificity of the VOT compared to other heritage classification systems, Table 2 compares the number of feature concepts for the Physiography group in the VOT with the number of Physiography concepts in SEDRIS, FACC, DFAD, and SDTS. Notice that there is a 10 to 30-fold increase of unique Physiography concepts in the VOT compared to any of the heritage systems; more precisely, an 831% increase over SEDRIS, a 1364% increase over FACC, a 2800% increase over DFAD and a 1716% increase over SDTS. In the VOT data set, this increase in the clarity can be seen across the entire spectrum of traditional top-level groups. This increase is primarily because the VOT was created by performing an intersection of all heritage categories and contains a superset of all physiographic categories used within all the different heritage classification schemes.

Table 2. A Comparison of VOT Categories Versus Other Heritage Classification Schemes.

Taxonomic Structure	*Total No. of Categories*	*No. of Surface Categories*
VOT	**16,000**	**532**
SEDRIS	**1225**	**64**
FACC	**550**	**39**
DFAD	**309**	**19**
SDTS	**201**	**31**

The 3-D model library contains individual 3-D model files for over 1500 different objects/concept, all in standard OpenFlight^{TM} format. There is also a separate directory that contains several thousand different texture maps, all in Silicon Graphics (SGI) image format (in either .rgb, .rgba, .int, or .inta format.)

FUTURE DEVELOPMENT

Based on future user feedback and through review by subject matter experts, we will be refining the current data structure over the next two years. We hope to expand the current taxonomy to include more concepts from other heritage ontological and taxonomic structures – heritage data structures that were not included in this initial version of the taxonomy.

At the same time, we will continue the expansion of the model library, eventually to provide representative 3-D models for a significant number of the VOT feature categories. In the real-time simulation environment the more 3-D models that are available, the more variety, detail, and specificity will become possible in future simulation display systems.

Another major undertaking that will take place over the next two years is the transfer of the VOT concept base and their associated definitions into the SEDRIS™ EDCS system [ISO/IEC, 2002]. An initial submission to SEDRIS was performed to validate the feasibility of exporting non-duplicated VOT concepts into a form suitable for submission into future revisions of the EDCS. This is a feasible option and will be exercised over the next two years.

One of the by-products that have resulted from the development of the VOT data structure is a set of cross-reference tables of heritage feature classes to VOT feature classes. Using these cross-reference tables, it will be relatively simple to produce a software suite that will allow lossless import of various supported source data formats. In a cooperative development effort with several software vendors, this lossless data import software will be developed.

We are currently exploring the feasibility of adding additional levels of detail into the VOT by adding two or even four decimal places to the hierarchy. This would allow the expansion of the system to include many common additional objects that would be encountered – objects currently outside the scope of this research. This could allow the future expansion of the VOT to encompass common object at a much higher level of granularity than it currently provides

CONCLUSIONS

There currently exists on the Internet (http://vizsim.uwf.edu/) the initial version of the Visual Object Model (VOT) and its accompanying 3-D model library. Currently, the VOT contains over 12,000 feature classes that provide unambiguous feature categories of objects below the Earth's surface, on the Earth's surface, in the atmosphere, and in outer space. Additionally, at the same URL, the current version of the public-domain, VOT 3-D generic model library is also available for download. Currently this model library contains an assortment of over 1,500 3-D models that are associated with categories in the current taxonomy.

The VOT is intended as a data structure that will be the basis for unprecedented interoperability within geographic information science discipline, the cartographic production environment, and future modeling and simulation efforts. Because the VOT significantly expands the potential for detailed inventorying and storing of geographic objects on, above, and below natural and cultural landscapes, any discipline that is involved in the mapping of any form of geographic phenomenon could profit from its existence. Automated mapping capabilities of the future, will have the ability to discern, capture and store positional and attribute information of a much wider variety of features than is currently available. The VOT data structure is intended to serve as the data structure to make the storage of this expanded data possible.

In the M&S discipline, as in the past, we can expect that customer demands for higher detail will continue to direct the future development of processing and display capabilities. The VOT data structure in consort with future expanded versions of the 3-D model library will encourage the improvement of image generation (IG) capabilities by allowing the storage and display of more detailed feature information. Every simulation site will have access to the same model library- therefore correlated visual displays in High-Level Architecture (HLA) and Distributed Interactive Simulations (DIS) environments will be enhanced.

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