# A SPATIAL ONTOLOGY FOR ARCHAEOLOGY

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## 1. Data Models in Archaeology

Databases are a ubiquitous part of contemporary archaeological research. However, most of the scholarly discussion of GIS in archaeology focuses on analysis rather than the formal models we use to represent our data (Tennant 2007:12). Although they describe the mechanics of geodatabases in their GIS textbook, Conolly and Lake (2006:33) choose not to discuss the how and why behind the design of archaeological data models. This should not be seen as a fault in an otherwise sterling textbook, but as a reflection of the still disconnected state of archaeological data. Any archaeologist using GIS should be concerned at the lack of discussion about data models, since the choices made while building a database will affect all future analyses and how useful the data will be to future research (cf. Plog and Most 2006). One conceptual toolkit that is very useful in this regard is formal ontology, developed by information scientists for modeling representational systems. A brief introduction to formal ontology and an example of how it may be applied to archaeological data are given in the following pages.

## 2. What is an Ontology?

In *Metaphysics*, Aristotle identified a philosophy which studied "being *qua* being" and described various categories of being:

"Some things are said to 'be' because they are (a) substances; others because they are (b) modifications of substance; others because they are (c) a process towards substance, or (d) destructions of privations or qualities of substance, or (e) productive or generative of substance or of terms relating to substance, or (f) negations of some of these terms or of the substance itself." (Warrington 1970:116).

This is the origin of the ontological models presented in this paper, although the *ontologies* discussed here fundamentally differ from the *Ontology* of Aristotle. Aristotle was concerned with the nature of being itself, separate from human perception, while in the information sciences ontologies ("formal ontologies") are toolkits that represent our perceptions. Modern ontology can be traced to Woods' (1975) article *What's in a Link?*, in which he demonstrated the need for a notation system with the logical adequacy to represent natural language in formal systems. Formal ontology is about semantic interoperability, ensuring logical coherence between different information systems, and between information systems and natural language.

Therefore the term 'ontology' does not have the same meaning in this paper as it has in current anthropological theory (see Gosden 2008). It is not a philosophical discourse to encourage symmetry between people and material, or to investigate types of agency. It is a set of representational levels for data models in a specific domain, in this case archaeological information.

A formal ontology is "… a representational artifact whose representational units are intended to designate universals in reality and the relations between them" (Spear 2006:10). This definition has two parts: first, an ontology is a model of the universals represented within a domain (e.g. ceramic, lithic, a trench unit); and second, how these universals are meaningfully arranged *vis-à-vis* each other (e.g. ceramics and lithics are both classes of artifacts, and the class artifact is found in the context of a feature, or a 3D spatial entity). These ontologies are useful to archaeologists working with GIS because they are explicit and formal declarations of how archaeological phenomena are represented (Cripps et al 2004:3). Put succinctly, "An *ontology* is an explicit specification of a conceptualization" (Gruber 1993:199).

The anatomy of a formal ontology can be divided into two parts. The first is an upper level ontology, or meta-ontology. These are not domain specific, but define, at an axiomatic level, the categories used in lower level ontologies. In part, this ensures semantic interoperability, or communications across systems, by providing a basic conceptual structure for all domain ontologies. The structure of an upper level ontology plays an important role in how phenomena are related. For example, Basic Formal Ontology (BFO) is designed to represent scientific domains. BFO utilizes two ontologies, corresponding to a synchronic ontology of substances and their arrangements and a diachronic ontology of processes respectively referred to as SNAP and SPAN (Grenon and Smith 2004). On the other hand, the Descriptive Ontology for Lingustic and Cognitive Engineering (DOLCE) is built on the principle that no universal ontology can exist, and is designed to model the intuitive structures behind common sense concepts (Borgo and Masolo 2009:12).

The upper level ontology provides the basic structure for a domain ontology. The practice of creating an ontology can be seen as moving between representation levels (Figure 1). While the linguistic level of representation carries the most information about archaeological phenomena, it is also the most informal. Conversely, the epistemological level establishes a categorical structure suitable for formal representation (Guarino 2009:4-5). By tacking between these levels, a conceptual model of archaeological data can be created which maintains the information of the linguistic level in a form suitable for representation in an information system.

**3. SNAP/SPAN Upper Level Ontology**

BFO is used for the example in this paper because the SNAP/SPAN ontologies are well suited to the spatiotemporal characteristics of archaeological data. Both ontologies are hierarchical classification schemes. SNAP continuants and SPAN occurents are the highest level, and subclasses inherit all characteristics (Figures 2 and 3).

The three subclasses of the SNAP ontology represent location, substances (or 'things') and their qualities. The primary class within this domain is the object: artifacts, tools, radiocarbon samples, brick walls, and archaeologists are all objects. Objects may be broken down into internal parts, or grouped into an aggregate, such as a lithic scatter. Parts are governed by some special rules. First, a part of an object is distinct from the subclass of an object because a subclass inherits traits while a part does not (Guarino and Welty 2002:64). Parts are also divided into *fiat* and *bona fide* parts: the former is an arbitrary part, e.g. the left half of a projectile point, while the latter is distinct, e.g. the distal end of a projectile point. It is possible to find and record a *bona fide* part of an artifact as a fragment, but never a *fiat* part.

Objects have characteristics, which are referred to in BFO as dependent continuants because they depend on an object for their existence (Spear 2006:45). Qualities are the characteristics of objects, such as their dimensions, or the quantity of radioactive isotopes. Material should not be considered as a quality, since a Knife River Flint projectile point can be classified as both an instance of an artifact and an instance of a chert. Realizable qualities are characteristics which may only be realized in specific instances, and within an archaeological domain they adequately represent characteristics of material which may be realized by analysis, such as radiocarbon or calibrated years BP derived from a sample.

The spatial regions correspond to their geometric primitives. While they are entities in their own right, they are better imagined as entities in an absolute space rather than as material entities (Spear 2006:43-4). A spatial region is distinct from a site, which is an independent constituent with a spatial footprint. Therefore, we may consider a pit fill to be a site consisting of certain matter with parts, boundaries and qualities, and contained objects. The pit fill corresponds to a volume, but in the course of an excavation it is removed, samples are retained and the rest is disposed of. At that point the fill is better conceived of as a set of objects (soil samples) but the spatial region occupied by the pit is still intact in the trench.

This demonstrates one crucial, if sometimes frustrating, element of ontological modeling. The relations and constraints necessitated by the BFO environment may seem unnecessarily complicated at first, but this complexity is necessary. The primitive relations in an upper level ontology maintain semantic interoperability, or the data model's flexibility with regards to new conceptual models. It is possible, even likely, that the ontological model of domain is more complex than the databases it informs. However, this reduces the risk that a database will be incapable of representing relevant data. For example, differentiating between the material within a three dimensional space and the three dimensional space itself leaves open the possibility for representing other entities in, or overlapping with, that space at other points in time. This may be useful if an archaeological database is integrated into ecological or geological research, or if temporal changes are also represented using the SPAN ontology.

The counterpart to the SNAP object is the SPAN process. Whereas an object is an entity which can be completely represented at a single moment in time, the process is an entity which cannot be described without reference to a temporal dimension (Grenon and Smith 2004:152). Neither an object nor a process should be seen as the more fundamental or more 'real' representation of any given phenomena. A space-time vector biography of the material in a pot is no more an incorrect description than the total physical characteristics of that same pot at a single moment in time. There may be, however, more useful modes of representation within a domain.

A process is “a maximally connected spatio-temporal whole” that is always dependent on a SNAP occurent (Spear 2006:61, 63). For example, Lucas (2005: Chapter 4) presents a vector approach to thinking about a Roman jar. The jar’s life begin with its manufacture in 140 A.D., it is then used, deposited in the record, buried, excavated, and now exists in a museum in Britain (Lucas 2005:106-8). This is a process (SPAN entity) which corresponds to multiple instances of the same objects (SNAP entities at different moments in time). Like objects, processes can be lumped as aggregates, serve as the context for other processes, be divided into parts (e.g. the firing or use-life of the roman jar are part of the jar’s life), or have subclasses.

The relation between a processual entity and a spatiotemporal or temporal region is akin to the relation between an independent continuant and a spatial region. SPAN regions refer to the tracts, in an absolute sense, of time or space-time which are occupied by processual entities. The Cucuteni A phase is an aggregate of processual entities which occupies temporal (4600 B.C. – 4050 B.C.) and spatiotemporal (4600 B.C. – 4050 B.C. in Romania and Moldova) regions. Temporal and spatiotemporal regions may be defined as scattered rather than connected based on the granularity of a model, e.g., depicted across multiple years at a month-scale, an excavation may be a set of temporal distinct regions. Temporal and S-T instants are the period of events – moments of change which bound processes but do not have duration recognizable at the granularity of the model (Spear 2006:64, 66).

There is one final component of upper level ontologies that are not represented here graphically – relations. Relations are dependent on the upper level ontological primitives, and there are several universal characteristics of relations that must be understood in order to construct a domain ontology (Smith and Grenon 2004). Two primitive relations are *is_a* and *instance_of* (Spear 2006:77). *Is_a* denotes a subclass and inheritance – Process *is_a* Processual

Entity, and inherits all characteristics of processual entities. *Instance_of* defines the relation between an entity and the ontological universal – a projectile point is an *instance_of* a man-made object and an *instance_of* a chert. The latter relation is crucial to archaeology. While we do not want to mix classification schemes at the ontological level (to avoid unnecessary complexity), we acknowledge that any given object can be classified according to multiple schemes. In addition to these primitive relations, there are characteristics which apply to all relations – reflexivity, symmetry, and transitivity (Figure 4). These characteristics establish the formal meaning of a relationship, and are useful for conceptualizing entities in a query-friendly manner.

**4. Example: Archaeological Site and Archaeological Feature**

This paper is not the first to present an ontological model for archaeology. The most comprehensive is the CIDOC CRM ontology developed by the Centre for Archaeology for museum and CRM applications (Cripps et al 2004; Crofts et al 2003; see Katsianis et al 2008 for an example of its implementation). The ontology contains 90 classes and 148 properties for the description of cultural resource inventories. While the ontology is an excellent reference, it is built on a relatively simple upper level ontology, with only two types of primitives – classes and properties. Therefore, the authors acknowledge some difficulty in certain place/time relationships between a context (e.g. an archaeological feature) and the context's formation process (Cripps et al 2004:21), which could be accommodated by a more detailed upper level ontology. A less comprehensive ontology structured on early principles of BFO was also developed by Zhang et al (2002).

The domain ontology presented here (Figures 5 and 6) is under development for the author's doctoral research of Eneolithic settlements in Transylvania and Moldova, Romania and is based on the BFO ontology. It is still a work in progress since it lacks "field-testing" in archaeological database. Therefore some aspects are underdeveloped, especially the representation of survey or remote-sensing data, techniques not frequently used in the area. As an example of how ontology can inform archaeology, components of a domain ontology which support archaeological sites and 'siteless' archaeological principles (Dunnell 1992) are examined here. The guiding principles used to construct this ontology can be found in Guarino and Welty (2002), and Spear (2006).

Whether it is conducted by survey, excavation, or non-intrusive methods, archaeological investigation involves two kinds of sites. The first kind of site is a modern construct, establish by the archaeologist in conjunction with acceptable techniques and according to legal or disciplinary traditions. This is referred to as an "Archaeological Site" in the ontology. An archaeological site has parts- "study areas"- which may consist of trenches, survey transects, or the location of individual survey finds or soil cores. The location of the archaeological site may be defined either by a datum point for the site, or by a boundary based on legal guidelines for cultural resources. Additionally, the parts of the archaeological site are all located in 0-, 1-, 2-, or 3-dimensional regions. As it is formulated here, the archaeological site is a contemporary entity that represents the site where archaeological research takes place. It has relations to other contemporary entities – it is investigated by archaeologists who are affiliated with institutions, and data found at the site is stored by an institution and published in a publication.

The archaeological site does not refer to prehistoric activity at these locations, however. This is represented by a different kind of site, called a "Feature" in the ontology. A feature is a 2- or 3- dimensional region which bears the mark of human activity. Intrinsic to the SNAP object "Feature" is the SPAN process "Feature Formation" which defines how the feature formed in relation to human activity. These two entities are dependent on each other, and reflect the principles behind context excavation. A feature is defined by a set of relations to other objects: it can contain artifacts, and it has a stratigraphic relations (“StratRel”) to other features. The stratigraphic relations may be represented by Harris Matrix relations (Harris 1989) or if it represented in a geodatabase, this may be represented by topological relations.

A feature is related to an archaeological site when there is spatial overlap – full or partial – between the study area space and the feature space. Since the sites “Study Area” and “Feature” are each located in spatial regions, overlap is calculated using topological relations.

The feature formation process is the action or activity that created the feature. The process exists in a connected temporal region and has a duration (sudden or gradual). If the feature site contains artifacts, then the feature formation process must have a temporal overlap with the deposition process of the contained artifacts. A feature formation process often occurs in sequence with other formation processes: digging a pit is followed by filling a pit. When these processes occur in a sequence such that no gaps- temporal regions in which no processes occur- they are grouped as a process aggregate, “Level Formation.” The level formation process depends on the object aggregate “Strat Level.” Artifacts contained by a feature are contained by a stratigraphic level, and the stratigraphic level possesses the same external stratigraphic relations as its member features. Currently, the stratigraphic level is considered a *bona fide* set of features resulting from formation processes; however this aggregate could be equally represented as a *fiat* grouping of features established by the archaeologist, in which case the corresponding process aggregate would be eliminated.

This formulation accommodates the distinction between the continuous activity areas which form the archaeological record and the arbitrary boundaries of archaeological sites. However, it does not abandon the notion of an archaeological site, which plays a crucial role in how archaeological data is organized and presented. Working from this structure it is possible to dispense with the notion of site and model each object or feature with attribute data pertaining to their discovery, or to model an archaeological site with attribute data corresponding to the objects and features within it. While either choices requires a commitment to certain geographic representations, this commitment can be made while maintaining the flexibility of sharing attribute data between systems.

## 5. Discussion

The above example should not be seen as finalized. A sound ontology can only be developed by incorporating the perspectives of multiple specialists, each with their own conceptual models. Grenon and Smith (2004:138-9) detail four principles of their ontological approach, three of which may be used to evaluate an archaeological ontologies[1] - perspective, fallibility, and adequacy. Perspective is the perception of phenomena as continuants or occurents and at what granularity, fallibility is the understanding that any model is inherently incorrect and will need to incorporate new concepts, and adequacy is the degree to which the phenomena are represented as objectively as possible.

It may seem that ontological modeling is primarily an exercise in constraining the meaning of certain key concepts. This is not the case. Ontological primitives are inherently constrained because they are axioms expressed through first order logic. As such, ontological primitives are inherently meaningful, even within a digital environment. Developing an archaeological ontology, then, is an exercise in expanding the capacity of a digital system to represent a range of archaeological concepts. For example, some archaeologists have made use of Pred's (1984) space-time geography (Thurston 1999), and recently space-time prisms have

[1] Grenon and Smith use a fourth postulate, realism, which purports that the world is real and some systems portray the world better than others. However, this is a difficult postulate to incorporate in the archaeological and culture resource domain. It is the author's view that omitting the postulate does not hamper BFO's utility to archaeologists.

been adapted to represent connections between archaeological sites (Huisman et al 2009). The SNAP/SPAN ontologies emphasize the relations between an object, time, and space, providing a conceptual model through which stages of any continuant's space-time path may be grounded in instances of actual data.

Basic Formal Ontology was used here because the ontological primitives suited the spatiotemporal data being modeled. However, the DOLCE upper level ontology has a robust formulation of perspective, allowing users to model entities that have different roles and functions depending on the agents that interact with them (Borgo and Masolo 2009). A DOLCE-inspired domain ontology may be useful for archaeologists who engage in agent-based modeling, or who design and maintain databases with a community-involvement dimension.

As archaeologists specializing in GIS we must recognize the consequences of how we model data in a precise and formalized information system. Whether or not ontology becomes more than a buzzword for formal models depends on the extent to which domain practitioners use it to ground or clarify their models (Winter 2001). In their current state, upper level ontologies are rigorously developed models of representational primitives which can span the divide between linguistic and formal concepts. An ontology is not an end in itself, but it is a means to begin a critical discussion of how we perceive, model, and obtain information from archaeological data.

## 6. Figures

| Level | Construction | Form of Expression | Use |
|---|---|---|---|
| Epistemological | Structuring Concepts and Roles | Structure: Hierarchical Categories, Relationships | Upper Level Ontology |
| Ontological | Meaningful Structures and Relations | Classes and categories with meanings constrained by domain | Domain Ontology |
| Conceptual | Conceptual Primitives | Conceptual Model of Data | Data Model |
| Linguistic | Language/Words | Language with specialized/ contextual meaning | Specialist Discourse |

Figure 1. Levels of representation, adopted with modifications from Guarino 2009: Figure 3.

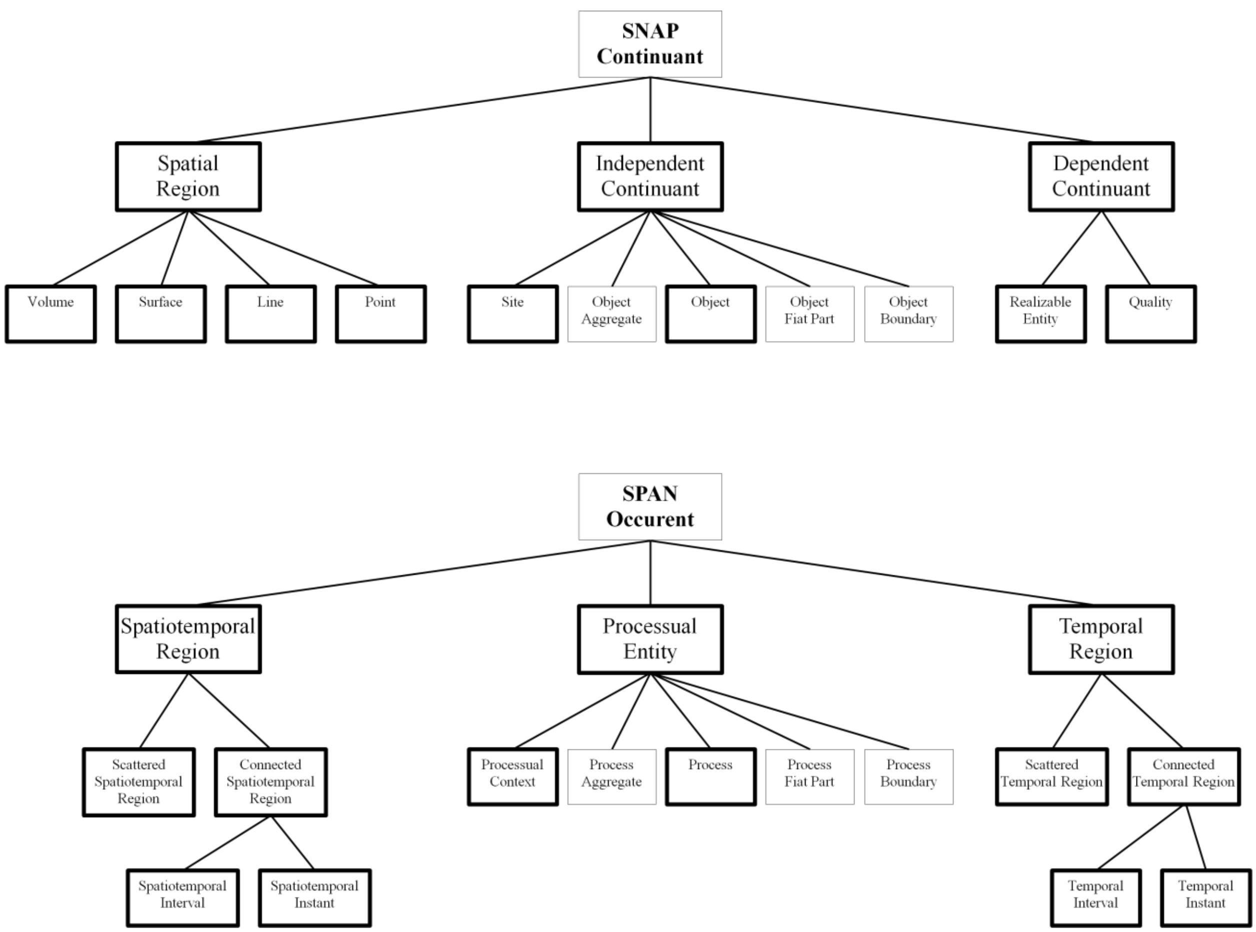


Figure 2. Universal SNAP/SPAN classes in Basic Formal Ontology (Spear 2006). Descriptions for the highlighted boxes can be found in figure 2.

| Class | Description | Example |
|---|---|---|
| Spatial Region | A region of space that does not contain qualities of its own but is the location for Independent continuants | Space occupied by a feature; location of a vessel |
| Volume/Surface/ Line/Point | 3D, 2D, 1D, and 0D subclasses of Spatial Region. | Vector geometric primitives |
| Independent Continuant | Entities with parts, qualities, that are fully present within a single moment of time. | Artifacts; features; trenches; |
| Site | A spatial region with parts and qualities, medium/context for other entities | Pit fill; pit cut; house; activity area; hearth; |
| Object | A maximally self-connected and self-contained entity. May have parts, dependent continuants, and boundaries | Diagnostic sherd; soil sample; mudbricks; metate; archaeologist; |
| Dependent Continuant | Entities which are dependent on other entities for their existence; characteristics of objects | Artifact dimensions; lithic flaking pattern; tree rings |
| Realizable Entity | Dependent entities which may only be present in certain conditions; roles, dispositions | 14C date; dendrochronology date |
| Spatiotemporal Region | A region of space-time that does not contain qualities of its own but is the S-T location for other processes | Space-Time cube occupied by phase; S-T path of artifact lifespan |
| Scattered & Connected S-T Region | Subclasses of S-T regions, representing either connected and disparate S-T regions | |
| S-T Interval & S-T Instant | Temporal dimension of S-T regions; intervals have a duration, instants represent events with no duration | |
| Processual Entity | An entity that happens or occurs, has parts and depends on an Independent Continuant | Artifact lifespan; Site Formation Process |
| Processual Context | Processes which serve as the context (setting, period) for other processes | Late Woodland; Bronze Age |
| Process | A maximally connected temporal entity with *bona fide* beginning and ending | Deposition; Cut; Use-life of artifact |
| Temporal Region | A period of time that does not contain qualities of its own but is the period in which processual entities occur | Duration of artifact use life; duration of deposition process |
| Scattered & Connected Temporal Region | Similar to Scattered and Connected S-T Regions w/out spatial components. Connected or disparate period of time. | Connected: 100-44 B.C. Scattered: Repeated seasonal activity |
| Temporal Interval &Temporal Instant | Similar to S-T interval & instant w/out spatial component. Instant is event/process boundary | Interval: 100-44 B.C. Instant: March 15, 44 B.C. |

Figure 3. Definitions and examples of BFO SNAP/SPAN universals (Spear 2006:43-66).

| Relation | Definition | Explanation |
|---|---|---|
| Reflexive | The relation between entities A and B also holds for entity A | If object A is the same age as object B, then A is the same age as A. This formalizes the distinction between comparative and equivalent relations. |
| Symmetrical | The relation between entities A and B also holds between entities B and A. | Indicates relations which work in both directions. For example, the *same as* stratigraphic relation is symmetrical, *overlies* is not. |
| Transitive | If the relation holds between A and B *and* B and C, it also holds between A and C | Indicates a sequence of relations in which the same relation holds between any two objects in the sequence. |

Figure 4. Characteristics of relations.

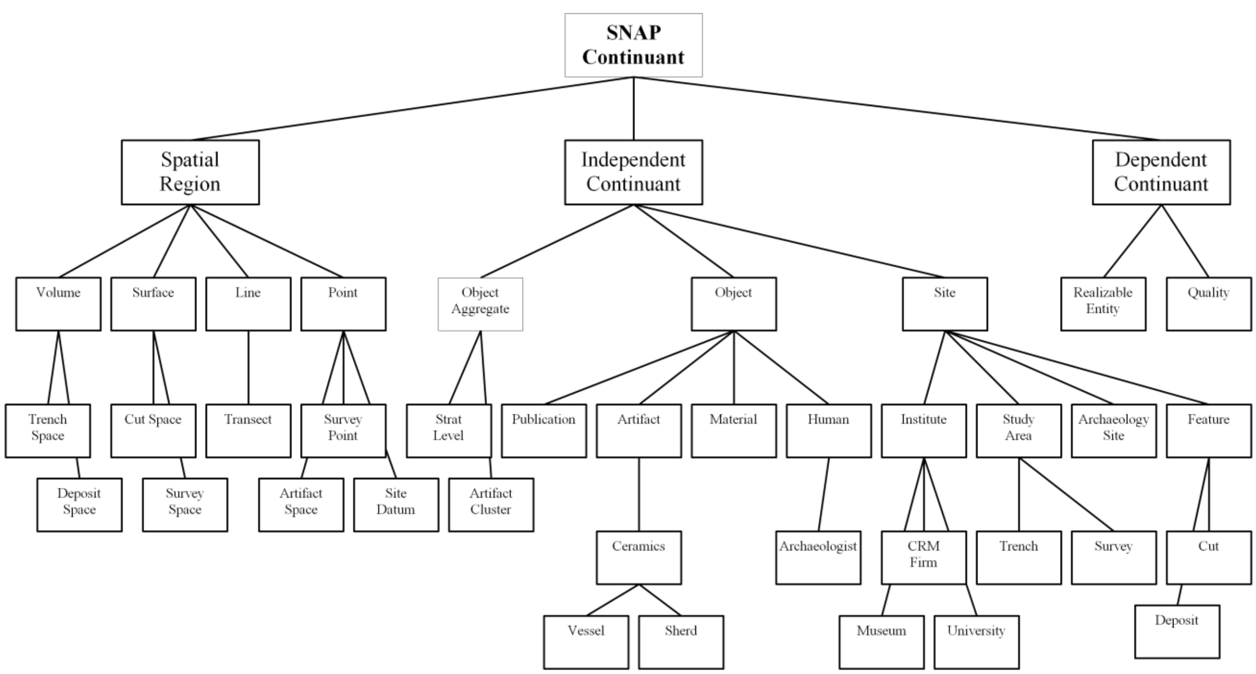


Figure 5. Archaeological SNAP entities.

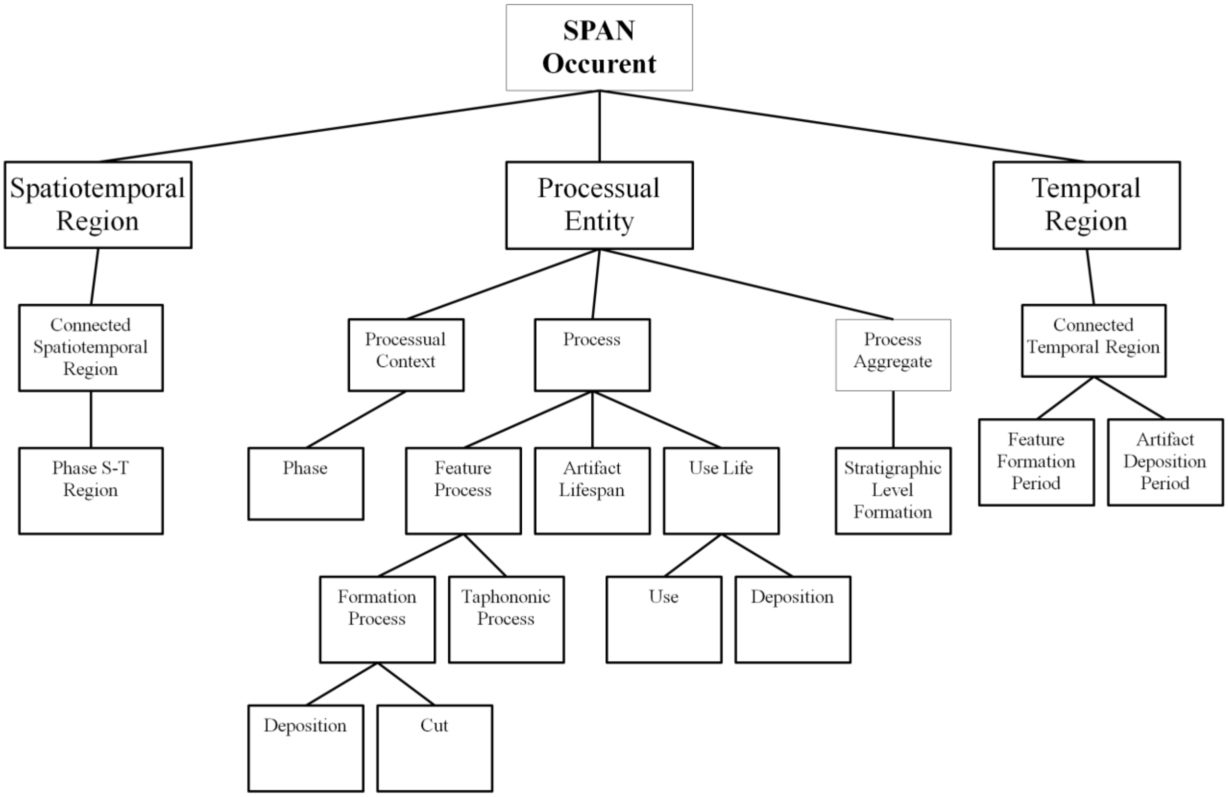


Figure 6. Archaeological SPAN entities.

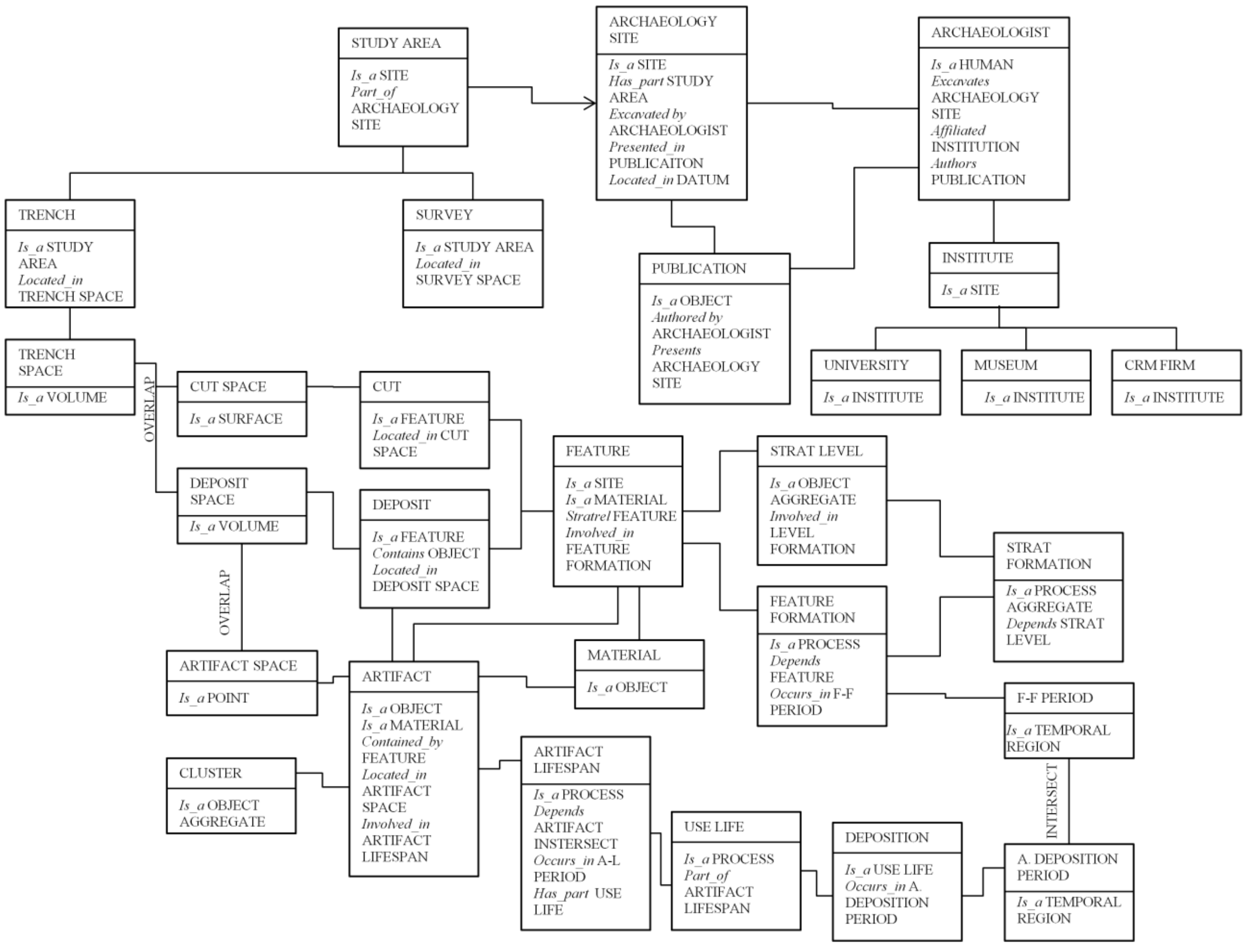


Figure 7. Partial Ontology for Archaeological Sites

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