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Semantic Models of Pottery Making

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***Abstract* — We explore semantic models for workflows in digital humanities. Specifically, we consider modeling the production of Celadon pottery and focus on the description of processes and transitions for state changes in that context. Semantic models are based on ontologies and other structured information resources. The Getty Art and Architecture Thesaurus (AAT) is a valuable resource for humanities, but is purely hierarchical and does not include rich semantic relationships across its facets. We coordinate AAT with the Suggested Upper Merged Ontology (SUMO) and use the combination to model an executable workflow for pottery making. In addition, we present a prototype interactive interface for exploring those workflows.**

Keywords— Case Roles, Celadon, Constraints, Dynamic Knowledge Graphs, Explanations, Flows, Metaphysics, Process Models, Rules, Semantic Flow Explorer, Semantic Modeling Vocabulary, States, Transitional Propositions, Workflows

I. Introduction

Processes and change are fundamental to human activity, yet many ontologies focus on objects and not processes. We are developing a framework for modeling processes in the humanities. Part of the effort is to develop a vocabulary to support semantic modeling and simulation.

While there are extensive ontologies for biology, there are few comprehensive ontologies tailored for humanities. One contender is the Getty Art and Architecture Thesaurus (AAT)[1] which is an exceptionally rich resource. However, as a thesaurus rather than an ontology, AAT does not have relationship links across its facets [8]. SUMO [21][2], the Suggested Upper Merged Ontology, is a rule-based ontology that has exceptionally broad coverage and seems promising as an integrative framework. It is implemented in SUO-KIF (Standard Upper Ontology-KIF), a variant of KIF, the Knowledge Interchange Format.[3] We propose extending and coordinating AAT with our semantic modeling framework based on SUMO [4]. We apply this combination in the development of standardized, structured, and interoperating flows. Our approach is broader than traditional ontology and includes aspects of epistemology and metaphysics.

We use the general term "flows" to describe a range of causally related sequential transitions. In our usage, flows include sequences, mechanisms, plans, procedures, recipes, workflows, flowcharts, and histories. A workflow is a planned sequence of actions that are triggered by a human agent for accomplishing a specific goal. It has interacting complex objects with multiple dimensions.

We explore the coordination of AAT and SUMO for describing a workflow for making pottery [8]. Specifically, we consider semantics for modeling the production of celadon pottery as practiced in Gangjin, Korea during the Goryeo Dynasty. Pottery Making implies a transition from raw clay to a finished piece of pottery. It is composed of several steps. For sequences of transitions, we follow the workflow diagrams at the Gangjin Goryeo Celadon Museum website.[4]

II. Workflow for Celadon Pottery

A. *Coordinating AAT and SUMO for Modeling Pottery Making*

SUMO is a comprehensive ontology while AAT is a thesaurus focused on arts. In some areas, they overlap and are relatively consistent, while in other areas, the overlap is minimal. We believe that they would benefit from being coordinated. Rules are an important part of SUMO. Most of these rules describe the properties of objects while others describe state changes. Here, we focus on the latter because of our interest in workflows.

Several SUMO rules associated with pottery are shown in Table I. In SUMO, Pottery is an Artifact that is produced by an instance of Making.[5] Making is both a subclass of Creation and an Intentional Process. SUMO defines Relationships and Predicates, which include Case Roles and Parts. As shown in Table I, the rules for Making specifically include case roles for Agent and Result [21].

Fig. 1 graphically extends SUMO's generic Making rule to Pottery Making. We apply terms from the AAT by adding rules with Case Roles such as Instrument and Resource. Specifically, we introduce AAT terms such as wheel and kiln

[1] Getty Vocabularies: LOD AAT Semantic Representation Version: 1.2 Last updated: March 18, 2014. https://www.getty.edu/research/tools/vocabularies/aat/

[2] https://www.ontologyportal.org/

[3] SUMO allows for search, validation, and inference about statements through theorem proving. Here we focus on using it for description with limited inferences.

[4] https://www.gangjin.go.kr/en/celadon/process and https://www.celadon.go.kr/contentsView.do?menuId=enCeladon0104020000

[5] SUMO Merge.kif, lines 11913-11918.

as instruments because the AAT has a much broader range of such terms than SUMO.

TABLE I. SUMO Rules associated with pottery and making (left) and our narrative interpretation of those Rules (right).

Rule definition	**Interpretation**
(subclass Pottery Artifact)	Pottery is a subclass of artifact
(=> (instance ?POTTERY Pottery) (exists (?CLAY) (and (instance ?CLAY Clay) (part ?CLAY ?POTTERY))))	**If** an object is an instance of pottery, **Then** there exists another object and that the other object is an instance of clay and the clay is a part of the pottery
(=> (attribute ?H Potter) (exists (?M ?P) (and (instance ?P Pottery) (instance ?M Making) (agent ?M ?H) (result ?M ?P))))	**If** someone has an attribute of being a Potter, **Then** there exists a making process and an entity such that the entity is an instance of pottery and the process is an instance of making and the agent is an agent of the making and the entity is a result of the making
(subclass Making Intentional Process)	Making is a subclass of Intentional Process
(subclass Making Creation)	Making is a subclass of Creation
(=> (instance ?MAKING Making) (exists (?ARTIFACT) (and (instance ?ARTIFACT Artifact) (result ?MAKING ?ARTIFACT))))	**If** a process is an instance of making, **Then** there exists an artifact and that artifact is the result of the making

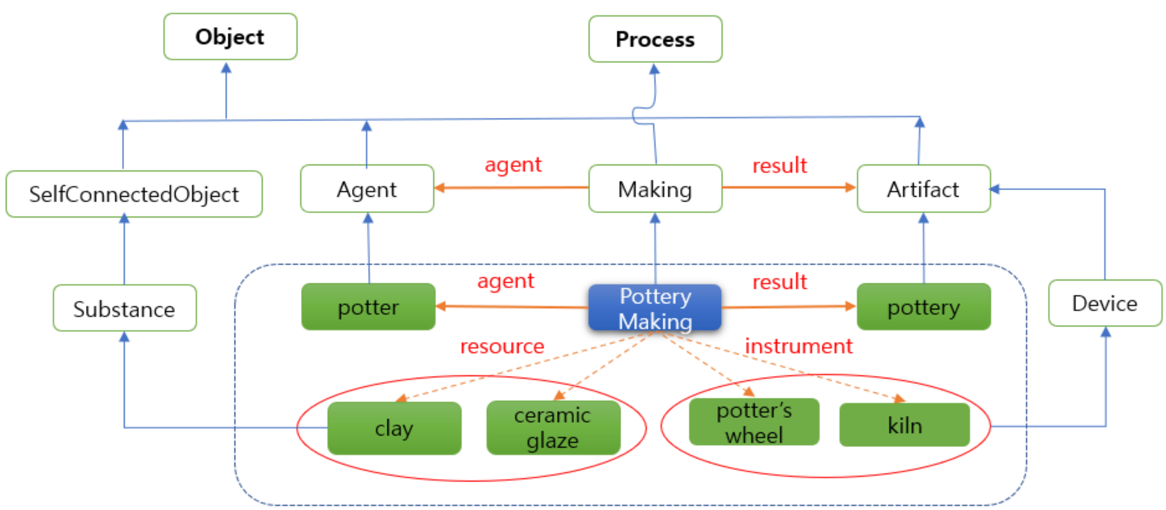

Fig. 1. Description of Pottery Making by combining SUMO terms (white boxes) with AAT terms (green boxes). The words in red are Case Roles as defined by SUMO for "making" (Table I); we have extended them to cover "PotteryMaking" by adding case roles for resources and instruments. (Some intermediate nodes are not shown.)

B. Objects and Transitions

A workflow is composed of a sequence of transitions. Some transitions are state changes while other transitions create new objects [4]. When a portion of clay is shaped (e.g., into a vase)[6] it becomes a new type of object, Greenware (see Fig. 3). In drying, a change of state occurs but the clay object is still Greenware; it becomes Pottery only after it is fired. That is, we may have a Greenware vase that becomes a Pottery vase. To some extent, the distinction between an object transition and a state transition is a matter of definition (see Section II.D). The distinctions need to be carefully specified. Greenware is shaped but not fired while Pottery is both shaped and fired. We included Greenware as a distinct object because it is part of the AAT; if it had not been part of the AAT, the shape change could be coded simply as a change of state. These issues are related to those encountered in describing developmental stages in domains such as biology.

Many transitions can be triggered only when an object is in a specific state. That state may be defined qualitatively (e.g., that Greenware should not be fired until it has been dried) or quantitatively (e.g., the glaze must reach 1200 degrees before it melts). These conditions can be set by rules and are related to gating by Petri Nets and guard conditions for software functions (see [3, 4] and Table II).

Some transitions have multiple effects. For instance, one of the steps in the Celadon workflow (Fig. 3) is preparing the clay. The preparation may include cleaning the clay, moistening it, and wedging it. Limitations to the application of the transitions can be specified by rules. For instance, how the clay is prepared. Or, when an object is glazed and fired, how much glaze should be applied and how long should it be fired?

C. Roles and Rules

In linguistics, verbs are associated with case roles. Case roles are essential for supporting meaning and are fundamentally different from parts of speech. SUMO includes some case roles.[7] In other work, we have proposed using case roles for semantic modeling [2, 4][8]. Case roles are the bridge between objects and transitionals. Case roles imply certain types of behavior. For instance, instruments are generally necessary for a transition but do not, themselves, change. In that sense, they are analogous to functions in computer programs or catalysts in chemical reactions. A kiln is such an instrument; it requires loading and unloading and, in the Goryeo era, would require stoking with firewood.

Another common case role is "agent". Note that the use of agent as a case role is somewhat different from its use in sociology[9] so we need to carefully define what type of agent we are considering. There must be at least one agent for a workflow; that agent will have a goal or plan for the entire workflow. However, there will often be more than one agent. For pottery, there might have been a team of workers with specialists implementing each of the transitions.

One interpretation of case roles suggests their exact meaning and use depends on "compositionality" [22]. Such interactions are highly nuanced but relatively stable. While specifying such compositions may be laborious, it should be feasible for documentary applications such as workflows and scientific research reports.

TABLE II: SUMO-style Rule for High Firing.

```
(=>
   (and
      (instance ?Firing Firing)
      (patient ?Firing ?OBJ))
   (exists (?UNIT ?QUANT1 ?QUANT2)
      (and
         (instance ?UNIT TemperatureMeasure)
         (holdsDuring
            (EndFn
               (WhenFn ?Firing))
            (equal
              (MeasureFn ?OBJ ?UNIT) ?QUANT1))
         (holdsDuring
            (EndFn
               (WhenFn ?Firing))
            (equal
              (MeasureFn ?OBJ ?UNIT) ?QUANT2))
            (greaterThan ?QUANT1 1200)
            (greaterThan ?QUANT2 1200)
          ))))
```

[6] When describing objects, we should have the option of using modifiers. We might decide that a pitcher without a spout is still a pitcher, but, for clarity, rather than just saying it is a pitcher, we could specify that it is a "pitcher without a spout".

[7] While these basic case roles in Fig.1 are uncontroversial, some of the other roles in SUMO should be revisited. A commonly accepted set of semantic role labels includes Agent, Experiences, Force, Theme, Result, Content, Instrument, Beneficiary, Source, Goal. In addition, there are several other possible systems of case roles such as those described in [2, 23] which could be considered. Case Roles can be quite rich; they may even be considered as forming an ontology of relationships.

[8] Case roles may be distinguished from social roles as in [12].

[9] https://plato.stanford.edu/entries/agency/

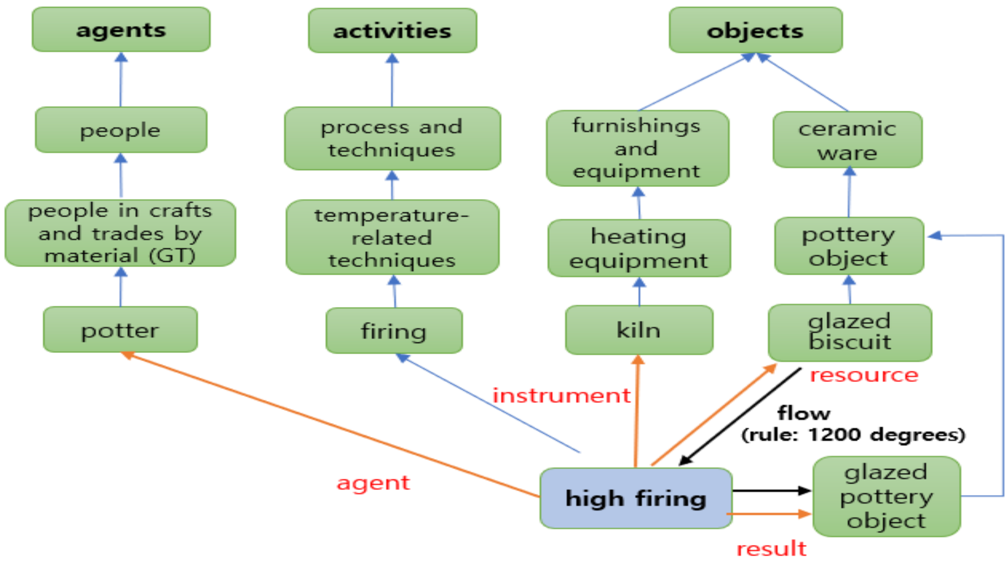

Fig. 2. One of the steps in making celadon is HighFiring. In previous steps, Biscuit-fired pottery is covered with raw glaze and fired in a high-temperature kiln. The figure shows the ontological parents for the objects associated with HighFiring. Because the objects deal with pottery, they are drawn from the AAT. The case roles associated with HighFiring are taken from the HighFiring Rule adapted from SUMO (Table II). Note, AAT includes some "guide terms" (GT) such as "people in crafts and trades by materials". These are not first-class entities but we include them here because they provide clarity.

Fig. 2 illustrates the objects associated with a HighFiring transition rule. HighFiring converts a raw-glazed, biscuit-fired piece of pottery into finished pottery. The figure shows the objects filling the active case roles and their AAT parents.

D. Flows as a Unit

Flows such as mechanisms or workflows bind together and show the relationships among several different objects and their states. Flows such as we describe here form a family of related structures. The flow at the top level is abstract. Even a few details provide constraints. For instance, if we know the workflow describes Terra Cotta then we know that it has only one firing.

A flow-control language could be developed to structure and describe flows. This would include (a) INIT and END states as is typical for state machines; (b) Conditionals such as engraving which was indicated as optional in Fig. 3[10]; (c) Loops, such as wedging clay until it is free of air bubbles; (d) Timing and threads; and, (e) if multiple flows are considered, synchronization among them.

The microworld is a space in which objects interact. It may be composed of several regions and those regions can be at different resolutions. In the current implementation, we assume standard conditions (e.g., standard temperature, humidity, daylight, etc.) and the presence of common objects such as water and a table. Because the pottery workflow needs a pottery wheel and kiln, the microworld must include them.

Some attributes are carried across object and state transitions while others are not. As one example, Firing changes the material of Greenware from clay to ceramic, but it does not significantly change the shape. As a second example, when a raw glazed Pottery Object is fired, the glaze melts; the Pottery Object remains the same type but the fused glaze becomes a part of it. Similarly, parts may be added such as handles or spouts. These enhance functionality and may confirm that an object is of a certain sub-type (e.g., vase or pitcher). But, they do not change the primary object type.

We envision developing a library of flows on which large-scale applied knowledgebases can be built. These flows would be based on a coordinated vocabulary and semantic structures. Such a collection of flows will need to be organized and managed. In the following section, we describe an end-user interface. That interface could be extended to provide support for managing the collection of workflows and the broader knowledgebase.

[10] Engraving is used for decorating but is not essential. In Korean celadon, it is often used for inlays.

Fig. 3. Screenshot from the prototype implementation of the Semantic Workflow Explorer. This shows a high-level workflow for the production of a celadon pottery object which has been coded with AAT terms that have rules to describe transitions. Objects are shown in black and Transitions in green. In the figure, Greenware has been selected and the right panel shows details about that object. Note that the term Greenware is not related to the green color of celadon but comes from the fact that it is an unfired clay object.

III. Prototype Interactive Model and Interface

A. *Semantic Workflow Explorer*

Fig. 3 shows a screenshot of the prototype Semantic Workflow Explorer with the flow of transitions for the production of celadon pottery. The model coding and browser allow users to step through its execution and to bring up views of individual objects. The underlying model and interface are programmed in Python using the Tk graphics library.

The full sequence is shown on the left side of the figure. Here we provide a quick summary: A portion of Raw Clay is obtained and prepared. After it is shaped it becomes Greenware. The Greenware then is dried and may be engraved for inlays. It is then biscuit fired and the resulting Biscuit object is a ceramic rather than clay. That Biscuit is then glazed (the presence of raw glaze is needed for this step) and fired a second time (High Firing). Finally, the finished object is cooled and removed from the kiln.

Near the top of the left panel are options for the user to control the display. The "Step from Top" option opens a second panel (right side of Fig. 3) that allows the user to view details about each of the objects in turn. The display includes a definition, the status of the various states associated with the object, other properties, and other objects in the microworld.[11]

The coding of states and properties needs to be refined. In the current version, state coding is binary (Yes/No) to indicate whether a given state is active. The coding for the properties currently allows "Yes" if there is a set value for the property even if that value is not known. Size and weight use qualitative coding when specific measurements are unavailable. "Moderate" refers to human-scale dimensions.

Although it is not yet implemented, it would be possible to bring up views of transitions comparable to the view of focus objects. The display of case roles and their ontological parents would resemble Fig. 2.

B. *Interface Extensions*

There are many ways the model and its associated interface could be expanded. Images and audio could be added (e.g., [7]) to make multimedia presentations. Images may be particularly helpful in orienting the user to the details of the workflow. We could also show coordination among multiple flows such as mixing a glaze to be applied to the Biscuit, provide details about the use of a pottery wheel, or describe the chemical reactions that occur during firing.

Properties are inherited as the workflow advances. If at some point additional information is provided and the object type (e.g., vase) confirmed, that could be carried forward and affect later states and transitions. For a given workflow, once we learn the object is a vase, we could go back and update earlier mentions of it.

As the implementation of the interface evolves, interviews could be conducted with potential users about additional features they would find useful. Once it is operational, direct usability testing could be done.

C. *Explanations and Rationale*

Beyond viewing the transitions, users may want to know more about what a specific transition does and how it contributes to the overall goal. For instance, wedging clay during preparation would be explained as being needed to remove air bubbles, and further, that the removal of bubbles prevents the object from cracking during firing, rendering it unusable. Such descriptions would link to a knowledgebase of empirically supported propositions and rules about physical processes [14, 19]. Ultimately they could also provide rationale and justification in terms of outcomes such as quality of life.

Other types of discourse links could also be included (cf., [1]). For instance, two procedures could be compared. Tutorials could be based on model-driven visualizations. Tutorials imply structured, systematic presentations adapted to the users. Multiple interlocking vocabularies could be developed so that beginners could be given a simplified version while advanced students and professionals could use a more richly detailed version.

D. *Integration into other Applications*

The flows could be integrated into other information services. For instance, they might support Wikipedia-style text presentations or tutorials. In other cases, structured workflows could provide detailed prescriptions such as recipes for cooking. In still other applications, the flows could document the actions of a person making a given object. This could be useful for documenting the details in the production of a work of art (e.g., Michelangelo's David). Beyond humanities, the techniques developed here should also be useful for describing scientific research reports [5] and for linking technological developments into a scientific knowledgebase.

IV. Relationship to Other Information Organization Systems

Combining SUMO with AAT and other humanities-related thesauri could produce a broad resource for describing human activities and infrastructures (cf., [9]). In addition, standard visualization interface tools could be developed that would extend Fig. 3. Such a tool could readily be adapted to describe the production of other types of pottery (e.g., Greek black-and-red vases or Korean onggi) and integrate diverse thesauri (e.g., [15, 25]). Beyond pottery workflows, we could develop structured flows for many different domains. In the arts and humanities, this might include bookbinding, making paints, and procedures for conservation. As a process ontology, it may be applied to activities that vary across time, including intangible cultural activities, especially when thesauri are already available for them. However, it remains challenging to define the cultural meaning of artifacts and their interconnectedness [11, 23].

The International Committee for Documentation Conceptual Reference Model (CIDOC CRM) standard [13] is a wrapper that facilitates and standardizes the application of thesauri to cultural objects. It is primarily used to organize metadata about museum holdings. While CIDOC-CRM may be considered an upper ontology, it is not as comprehensive as upper ontologies such as SUMO, DOLCE, or YAMATO.

We propose that CIDOC-CRM would benefit from adopting a broad-based semantic modeling approach. While CIDOC-CRM is oriented to describing specific aspects of metadata, a semantic modeling approach would support a much

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[11] In the current version, we have included only active objects. Presumably, other objects are in the environment even if they are not used in a given transition; they could be listed as probably present but not required.

broader range of applications. It would also support the integration of thesauri directly into the museum model, and coordination across thesauri along the lines outlined in this paper for the AAT. CIDOC-CRM describes some actions associated with museum collections (e.g., accession)[12]. We believe it would be useful to model those actions as state transitions in the context of other ontologically related actions. Potentially, it could also be applied to other systematic documentation efforts related to CIDOC-CRM such as archeological documentation.

Indeed, the approach could also be applied to the coordination of flows associated with the management of documents in other settings such as libraries and archives [9]. The Europeana Data Model (EDM) [18] is a cousin of CIDOC-CRM that describes a system applied to digital library objects. It is object-centric in focusing on particulars (such as the Mona Lisa) and is event-centric in the sense of focusing on specific activities associated with documentation and occasionally with specific historical events. Our approach and goals are broader than EDM. Our approach is grounded in well-established upper ontologies, is coordinated with programming languages, and develops generic flows which apply to a broad range of real-world events.

Knowledge graphs [16] are an increasingly popular approach to the representation of knowledge about the world. Our approach extends current approaches and could be considered as implementing dynamic knowledge graphs.

V. Discussion

A. Knowledgebased Digital Libraries and Community Models

The semantic model in Section III describes a generic process for the production of celadon rather than any specific event. We could add much more detail and would still not describe any actual event. However, there are occasions, such as for histories or legal proceedings, when we need to document specific sequences of events. These descriptions may be based on considerable evidence [17] and from that evidence, additional inferences may be made. As suggested above, new evidence could percolate throughout the model. Nonetheless, there may still be unknowns, contradictory evidence, or even logical impossibilities. The structured flow descriptions should facilitate detecting and resolving conflicts and identifying the most likely alternatives.

We envision that collections of structured scenarios can be developed as a knowledge-based digital library. This could incorporate traditional library services such as collection management and indexing. For instance, structured flows could be applied to community models [2]. The description for how assistants support a master Potter (Section II) could be broadened to descriptions of social organization and life in the Gangjin area. The descriptions could support analysis of the role of pottery production for the Goryeo kingdom. After all, many of the Gangjin kilns were state-run and approached industrial scale. Thus, the structured flows could support analysis of how pottery production in Gangjin is related to the dynasty's overall economy and cultural traditions [6]. For modeling the social aspects of history, we can lean toward natural language ontology [20].

B. Implementation

The flow described in Section III can be considered as an object-oriented computer program (cf., [4]). Objects are part of an inheritance hierarchy and are associated with specific methods (i.e., rules or transitions). Our use of a microworld is analogous to its use in object-oriented programming.

While the transitions in the pottery model described above were triggered in sequence, the model includes a check to ensure the necessary conditions are met. Thus, it would also be possible to trigger the transitions whenever specific conditions were met. In other words, the transitions would be like productions in a production system model. That approach would also implement a type of constraint satisfaction. This could be useful for simulating relatively unstructured scenarios such as community models, although there are challenges to developing a stable model because there are many open parameters [24].

While the workflow discussed in Section III is linear, because flows could include branches, loops and even cycles, future versions of flow visualization tools may include richer techniques for program visualizations such as UML diagrams.

C. Envoi

AAT provides a rich vocabulary for humanities-related domains while SUMO provides features such as rules and case roles. In this paper, we have begun to explore how AAT could be incorporated into and extended with the comprehensive SUMO rule-based ontology. We also developed an example based on pottery making of how a coordinated ontology could be used for semantic modeling and visualization. From that, we generated many suggestions for implementing vocabularies associated with workflows, for developing libraries of structured workflows, and for a variety of information services.

In summary, this work is part of our broad interest in direct representation for history and humanities for which we propose a new generation of digital libraries based on highly structured rich semantic descriptions.

[12] The notions of state and methods are included in CIDOC-CRM but they are applied to attributes associated with metadata descriptions of an object (e.g., http://www.cidoc-crm.org/Issue/ID-329-states-and-situations).

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