Ontology Design Patterns for Modeling Events, Places, & Relationships

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1 Overview

We are presenting the ontology which drives the data gathering and integration done as part of the project *Enslaved: People of the Historic Slave Trade*,[1] funded by The Andrew W. Mellon Foundation through Michigan State University's Matrix: The Center for digital Humanities & Social Sciences.

Development of the ontology was a collaborative effort and was carried out using the principles laid out in, e.g., [**?**, **?**, **?**]. The modeling team included domain experts, data experts, software developers, and ontology engineers.

The ontology has, in particular, be developed as a *modular* ontology [**?**] based on ontology design patterns [**?**]. This means, in a nutshell, that we first identified key terms relating to the data content and expert perspectives on the domain to be modeled, and then developed ontology modules for these terms. The resulting modules, which were informed by corresponding ontology design patterns, are listed and discussed in Chapter 2. The Enslaved Ontology, assembled from these modules, is then presented in Chapter **??**.

For background regarding Semantic Web standards, in particular the Web Ontology Language OWL, including its relation to description logics, we refer the reader to [**?**, **?**].

Primer on Ontology Axioms

Logical axioms are presented (mostly) in description logic notation, which can be directly translated into the Web Ontology Language OWL [**?**]. We use description logic notation because it is, in the end, easier for humans to read than any of the other serializations.[2]

Logical axioms serve many purposes in ontology modeling and engineering [**?**]; in our context, the primary reason why we choose a strong axiomatization is to disambiguate the ontology.

Almost all axioms which are part of the Enslaved Ontology are of the straightforward and local types. We will now describe these types in more detail, as it will make it much easier to understand the axiomatization of the Enslaved Ontology.

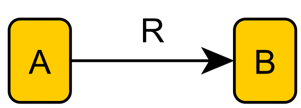

Figure 1.1: Generic node-edge-node schema diagram for explaining systematic axiomatization

There is a systematic way to look at each node-edge-node triple in a schema diagram in order to decide on some of the axioms which should be added: Given a node-edge-node triple with

[1] `http://enslaved.org/`

[2] Preliminary results supporting this claim can be found in [**?**].

1. $A \sqsubseteq B$
2. $A \sqcap B \sqsubseteq \bot$
3. $\exists R.\top \sqsubseteq A$
4. $\exists R.B \sqsubseteq A$
5. $\top \sqsubseteq \forall R.B$
6. $A \sqsubseteq \forall R.B$
7. $A \sqsubseteq R.B$
8. $B \sqsubseteq R^{-}.A$
9. $\top \sqsubseteq \leq 1R.\top$
10. $\top \sqsubseteq \leq 1R.B$
11. $A \sqsubseteq \leq 1R.\top$
12. $A \sqsubseteq \leq 1R.B$
13. $\top \sqsubseteq \leq 1R^{-}.\top$
14. $\top \sqsubseteq \leq 1R^{-}.A$
15. $B \sqsubseteq \leq 1R^{-}.\top$
16. $B \sqsubseteq \leq 1R^{-}.A$
17. $A \sqsubseteq \geq 0R.B$

Figure 1.2: Most common axioms which could be produced from a single edge R between nodes A and B in a schema diagram: description logic notation.

nodes A and B and edge R from A to B, as depicted in Figure 1.1, we check all of the following axioms whether they should be included.[3] We list them in natural language, see Figure 1.2 for the formal versions in description logic notation, and Figure 1.3 for the same in Manchester syntax, where we also list our names for these axioms.

1. A is a subClass of B.
2. A and B are disjoint.
3. The domain of R is A.
4. For every B which has an inverse R-filler, this inverse R-filler is in A. In other words, the domain of R, scoped by B, is A.
5. The range of R is B.
6. For every A which has an R-filler, this R-filler is in B. In other words, the range of R, scoped by A, is B.
7. For every A there has to be an R-filler in B.
8. For every B there has to be an inverse R-filler in A.
9. R is functional.
10. R has at most one filler in B.
11. For every A there is at most one R-filler.
12. For every A there is at most one R-filler in B.
13. R is inverse functional.
14. R has at most one inverse filler in A.
15. For every B there is at most one inverse R-filler.
16. For every B there is at most one inverse R-filler in A.
17. An A may have an R-filler in B.

Domain and range axoims are items 2–5 in this list. Items 6 and 7 are extistential axioms. Items 8–15 are about variants of functionality and inverse functionality. All axiom types except disjointness and those utilizing inverses also apply to datatype properties.

Structural tautologies are, indeed, tautologies, i.e., they do not carry any formal logical content. However as argued in [**?**] they can help humans to understand the ontology, by indicating *possible* relationships, i.e., relationships intended by the modeler which, however, cannot be cast into non-tautological axioms.

[3] The OWLAx Protégé plug-in [**?**] provides a convenient interface for adding these axioms.

1. A SubClassOf B (subClass)
2. A DisjointWith B (disjointness)
3. R some `owl:Thing` SubClassOf A (domain)
4. R some B SubClassOf A (scoped domain)
5. `owl:Thing` SubClassOf R only B (range)
6. A SubClassOf R only B (scoped range)
7. A SubClassOf R some B (existential)
8. B SubClassOf inverse R some A (inverse existential)
9. `owl:Thing` SubClassOf R max 1 `owl:Thing` (functionality)
10. `owl:Thing` SubClassOf R max 1 B (qualified functionality)
11. A SubClassOf R max 1 `owl:Thing` (scoped functionality)
12. A SubClassOf R max 1 B (qualified scoped functionality)
13. `owl:Thing` SubClassOf inverse R max 1 `owl:Thing` (inverse functionality)
14. `owl:Thing` SubClassOf inverse R max 1 A (inverse qualified functionality)
15. B SubClassOf inverse R max 1 `owl:Thing` (inverse scoped functionality)
16. B SubClassOf inverse R max 1 A (inverse qualified scoped functionality)
17. A SubClassOf R min 0 B (structural tautology)

Figure 1.3: Most common axioms which could be produced from a single edge R between nodes A and B in a schema diagram: Manchester syntax.

Explanations Regarding Schema Diagrams

We utilize schema diagrams to visualize the ontology. In our experience, simple diagrams work best for this purpose. The reader needs to bear in mind, though, that these diagrams are ambiguous and incomplete visualizations of the ontology (or module), as the actual ontology (or module) is constituted by the set of axioms provided.

We use the following visuals in our diagrams:

rectangular box with solid frame and orange fill: a class

rectangual box with dashed frame and blue fill: a module, which is described in more detail elsewhere in the document

rectangular box with dashed frame and purple fill: a set of URIs constituting a controlled vocabulary

oval with solid frame and yellow fill: a data type

arrow with white head and no label: a subClass relationship

arrow with solid tip and label: a relationship (or property) other than a subClass relationship

2 Patterns

We list the individual modules of the ontology, together with their axioms and explanations thereof. Each axiom is listed only once (for now), i.e. some axioms pertaining to a module may be found in the axiom set listed for an earlier listed module. Schema diagrams are provided throughout, but the reader should keep in mind that while schema diagrams are very useful for understanding an ontology [?], they are also inherently ambiguous.

2.1 Causal Event Pattern

2.1.1 Overview

I am the overview.

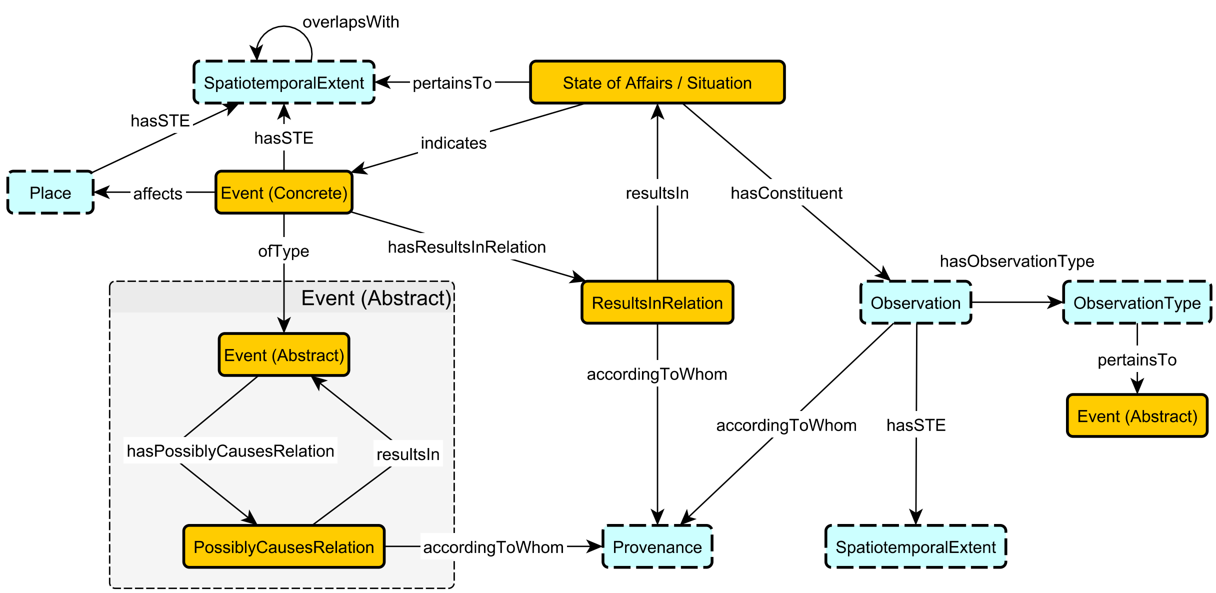

Figure 2.1: Empty Caption

2.1.2 Competency Questions

CQ 1. Are there areas in other states than California that are frequently affected by wildfires?
CQ 2. Given fire x, which regions will be effected by smoke exposure, given current wind direction projections?
CQ 3. How were the 2019 Southern California fires affecting the tourism industry?
CQ 4. If I am an agent of an insurance company, what information I can gain from your KWG? (not a competency question, but may help us to think)

CQ 5. Was the Cholera outbreak in Mozambique contributing to the food shortage in year x?
CQ 6. What are the causalities of the wildfire? To answer it, we need spatiotemporal information of temperature, precipitation, soil moisture and etc. in the KG.
CQ 7. What factors can you find in a specific region that would help explain e.g. the stroke belt. Which contaminants of farms may be related from the health literature to strokes?
CQ 8. What farmlands or vegetation covers have been mostly affected in the fire?
CQ 9. What were the reasons for the landslide east of Santa Barbara in April 2017?
CQ 10. What were wildfires affecting the Ventura area in the 2010s?
CQ 11. Where are areas of increased heat exceedance and pollution, where migration is not driven by urbanization?
CQ 12. Where are the places where heat is rising and migration is occurring that cannot be explained by urbanization?
CQ 13. Which farm has High productivity and low connectivity?
CQ 14. Which farm has adopted health soil practice after other nearby farms did so?
CQ 15. Which farm has experienced disease?
CQ 16. Which region affected by a transmissive disease is affected by a hurricane?
CQ 17. Which region affected by the current hurricane just suffers from another natural disaster?
CQ 18. Which regions affected by wildfires are expected to experience heavy rain (flood risk)
CQ 19. Which residents are still evacuated from the same region where the second hurricane hit?
CQ 20. where to deliver Covid-19 supplies?

2.1.3 Use Cases

These are the usecases!

2.1.3.1 Direct Relief

Hurricanes happen in Mozambique; Hurricanes disrupt sewer systems; Cholera is endemic to sub-Saharan region; Mozambique is in Sub-Saharan region; disrupted sewer systems lead to Cholera outbreaks; "this" Hurricane disrupted sewer systems in Mozambique; there were recent outbreaks of Cholera in Mozambique; Mozambique is experiencing a Cholera outbreak due to "this" Hurricane; Cholera outbreaks lead to Vaccination programs

2.1.3.2 Thomas Fire

Thunderstorm in Ventura County results in Wildfire in Ventura County Wildfire in Ventura County results in low air quality in Santa Barbara Low air quality in Santa Barbara results in evacuations in Santa Barbara

2.1.4 Formalization

2.1.4.1 Axioms

$$\mathsf{Place} \sqsubseteq \forall \mathsf{hasSTE.STE} \tag{1}$$
$$\exists \mathsf{hasSTE.Place} \sqsubseteq \mathsf{STE} \tag{2}$$
$$\mathsf{Event(Concrete)} \sqsubseteq \forall \mathsf{hasSTE.STE} \tag{3}$$
$$\exists \mathsf{hasSTE.Event(Concrete)} \sqsubseteq \mathsf{STE} \tag{4}$$
$$\mathsf{Event(Concrete)} \sqsubseteq \forall \mathsf{affects.Place} \tag{5}$$
$$\exists \mathsf{affects.Event(Concrete)} \sqsubseteq \mathsf{Place} \tag{6}$$
$$\mathsf{Event(Concrete)} \sqsubseteq \forall \mathsf{ofType.Event(Abstract)} \tag{7}$$
$$\exists \mathsf{ofType.Event(Concrete)} \sqsubseteq \mathsf{Event(Abstract)} \tag{8}$$
$$\mathsf{Event(Concrete)} \sqsubseteq \forall \mathsf{hasResultsInRelation.ResultsInRelation} \tag{9}$$
$$\exists \mathsf{hasResultsInRelation.Event(Concrete)} \sqsubseteq \mathsf{ResultsInRelation} \tag{10}$$
$$\mathsf{STE} \sqsubseteq \forall \mathsf{overlapsWith.STE} \tag{11}$$
$$\exists \mathsf{overlapsWith.STE} \sqsubseteq \mathsf{STE} \tag{12}$$
$$\mathsf{StateOfAffairs} \sqsubseteq \forall \mathsf{pertainsTo.STE} \tag{13}$$
$$\exists \mathsf{pertainsTo.StateOfAffairs} \sqsubseteq \mathsf{STE} \tag{14}$$
$$\mathsf{StateOfAffairs} \sqsubseteq \forall \mathsf{indicates.Event(Concrete)} \tag{15}$$
$$\exists \mathsf{indicates.StateOfAffairs} \sqsubseteq \mathsf{Event(Concrete)} \tag{16}$$
$$\mathsf{StateOfAffairs} \sqsubseteq \forall \mathsf{hasConstituent.Observation} \tag{17}$$
$$\exists \mathsf{hasConstituent.StateOfAffairs} \sqsubseteq \mathsf{Observation} \tag{18}$$
$$\mathsf{ResultsInRelation} \sqsubseteq \forall \mathsf{resultsIn.StateOfAffairs} \tag{19}$$
$$\exists \mathsf{resultsIn.ResultsInRelation} \sqsubseteq \mathsf{StateOfAffairs} \tag{20}$$
$$\mathsf{ResultsInRelation} \sqsubseteq \forall \mathsf{accordingToWhom.Provenance} \tag{21}$$
$$\exists \mathsf{accordingToWhom.ResultsInRelation} \sqsubseteq \mathsf{Provenance} \tag{22}$$
$$\mathsf{Observation} \sqsubseteq \forall \mathsf{accordingToWhom.Provenance} \tag{23}$$
$$\exists \mathsf{accordingToWhom.Observation} \sqsubseteq \mathsf{Provenance} \tag{24}$$
$$\mathsf{Observation} \sqsubseteq \forall \mathsf{hasSTE.STE} \tag{25}$$
$$\exists \mathsf{hasSTE.Observation} \sqsubseteq \mathsf{STE} \tag{26}$$
$$\mathsf{Observation} \sqsubseteq \forall \mathsf{hasObservationType.ObservationType} \tag{27}$$
$$\exists \mathsf{hasObservationType.Observation} \sqsubseteq \mathsf{ObservationType} \tag{28}$$
$$\mathsf{ObservationType} \sqsubseteq \forall \mathsf{pertainsTo.Event(Abstract)} \tag{29}$$
$$\exists \mathsf{pertainsTo.ObservationType} \sqsubseteq \mathsf{Event(Abstract)} \tag{30}$$
$$\mathsf{Event(Abstract)} \sqsubseteq \forall \mathsf{hasPCR.PCR} \tag{31}$$
$$\exists \mathsf{hasPCR.Event(Abstract)} \sqsubseteq \mathsf{PCR} \tag{32}$$
$$\mathsf{PCR} \sqsubseteq \forall \mathsf{resultsIn.Event(Abstract)} \tag{33}$$
$$\exists \mathsf{resultsIn.PCR} \sqsubseteq \mathsf{Event(Abstract)} \tag{34}$$
$$\mathsf{PCR} \sqsubseteq \forall \mathsf{accordingToWhom.Provenance} \tag{35}$$

$$\exists \text{accordingToWhom.PCR} \sqsubseteq \text{Provenance} \tag{36}$$

(37)

2.1.4.2 Explanations

(38)

2.1.5 Submodules

2.1.6 Views

2.1.7 Entanglements

2.1.8 Examples

Example Triples

2.2 Cell Relations

2.2.1 Overview

I am the overview.

2.2.2 Competency Questions

There are no competency questions listed.

2.2.3 Use Cases

There are no usecases listed.

2.2.4 Formalization

There is currently no formalization.

2.2.5 Submodules

2.2.6 Views

2.2.7 Entanglements

2.2.8 Examples

Example Triples

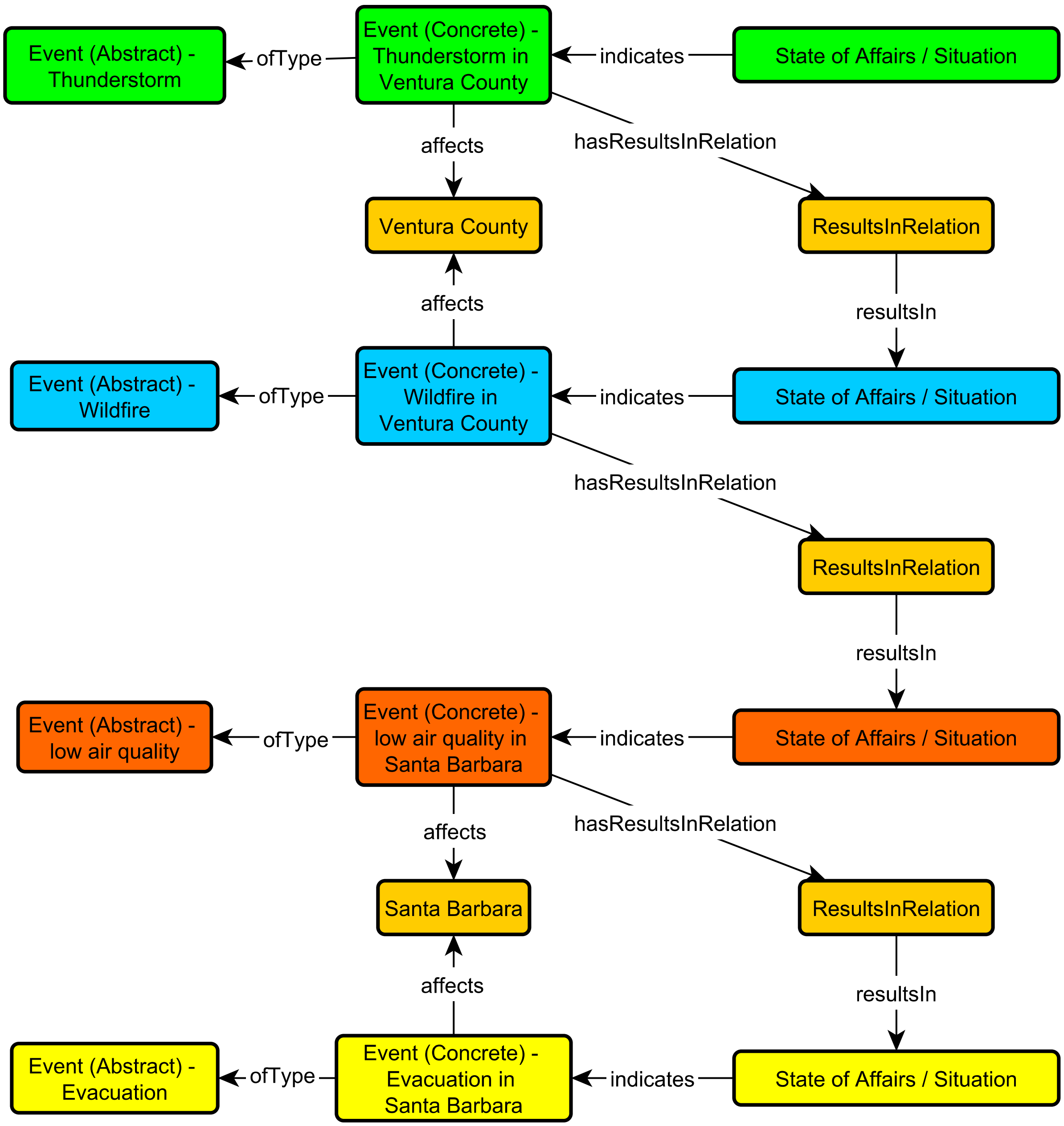

Figure 2.2: Empty Caption