

# BUILDING BLOCKS FOR DISTRIBUTED KNOWLEDGE GRAPHS

GEOVoCAMP DC 2016

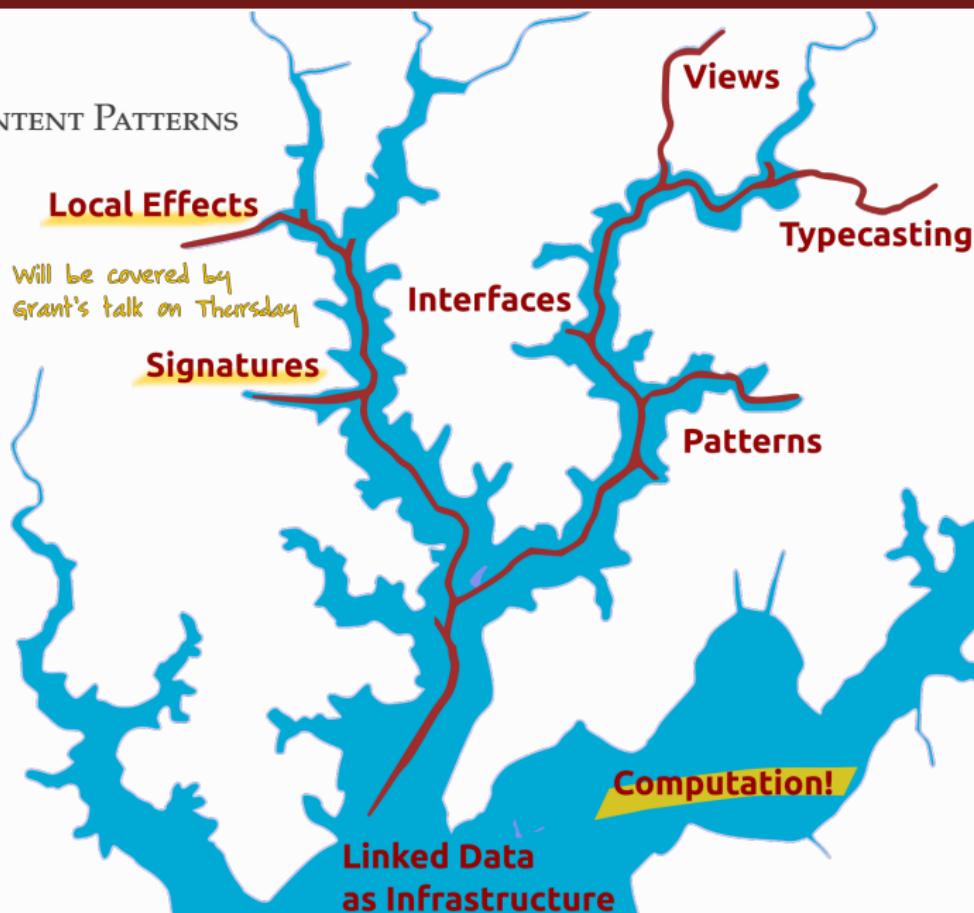
Krzysztof Janowicz

**STKO Lab**, University of California, Santa Barbara, USA



# THE BIG PICTURE

MORE THAN JUST CONTENT PATTERNS



# WHAT IS INTEROPERABILITY ANYWAY?

(Technical) Interoperability **measures the degree** to which different **systems** (e.g., Web Services/APIs) are able to work in concert to reach a common task.

Some (subtle) consequences

- Data do **not** inter-operate.
- Operating requires an **intension**, e.g., a goal.
- Interoperability is about a **degree** of meaningful exchange.

**Syntactic interoperability** relies on **common protocols and data formats** to ensure the proper exchange of data. We can ensure a **perfect** syntactic interoperability, e.g., via rigid standardization.

**Semantic interoperability** relies on a **common understanding** of the exchanged data, i.e., **meaning** remains invariant during the exchange between multiple systems. This requires common **reference systems**.

# WHAT IS MEANING ANYWAY?

Semantics is the study of meaning, i.e., the study of how and what **signifiers denote**. Meaning is an **emergent** property of interaction.

Humans use complex processes such as **situated simulation** to negotiate the **approximate**, common meaning of terms during interaction.

**Unfortunately, we cannot do so with data.**

The driving, often implied assumption behind the call for **raw** data is the idea that once collected data can be reused outside its original creation context and is free of interpretation.

However, there are no raw data. Data are always created following particular workflows, **procedures**, sampling strategies, are derived using specific instrumentation, are pre-processes in specific ways, and so forth.

One way to approach this problem are **ontologies**. However, they cannot fix meaning. Rather, they formally restrict the **possible interpretations** of domain terminology towards their intended meaning.

# CONSEQUENCES?

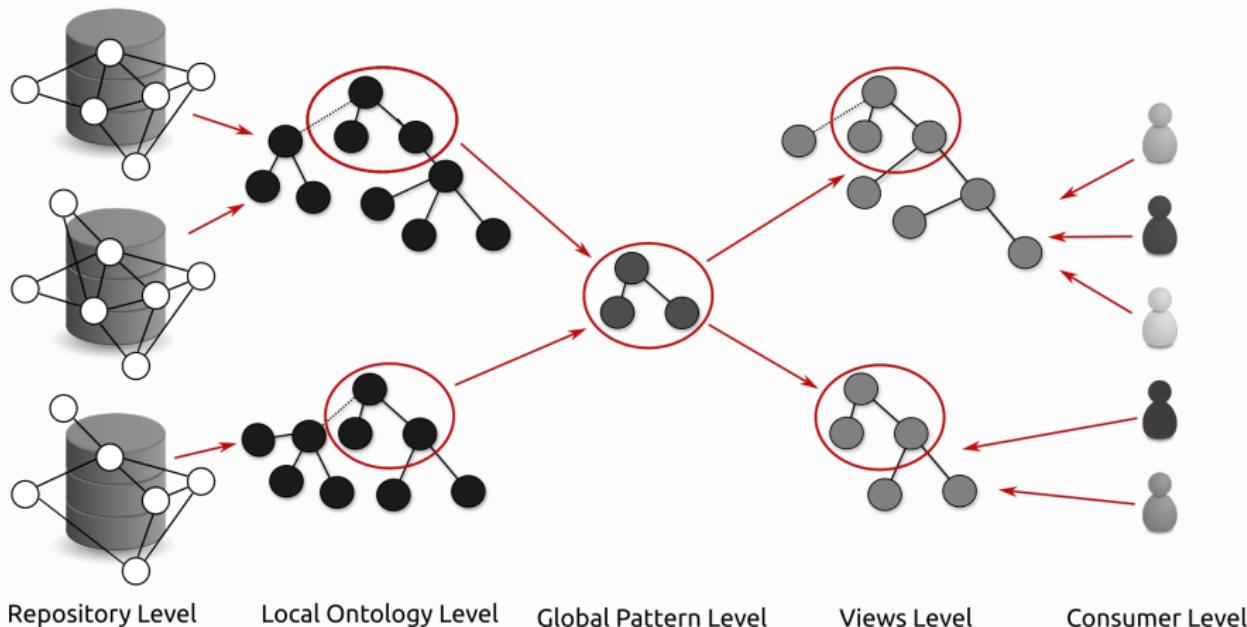
**We can only measure semantic interoperability after the fact.**

To move forward, we should measure our **progress in preventing** interoperability problems, not by trying to ensure semantic interoperability.

Our work should notify users that two datasets cannot be meaningfully combined or two systems will not meaningfully interact, instead of dreaming the **dream** of **fully-automated service orchestration** in heterogeneous environments.

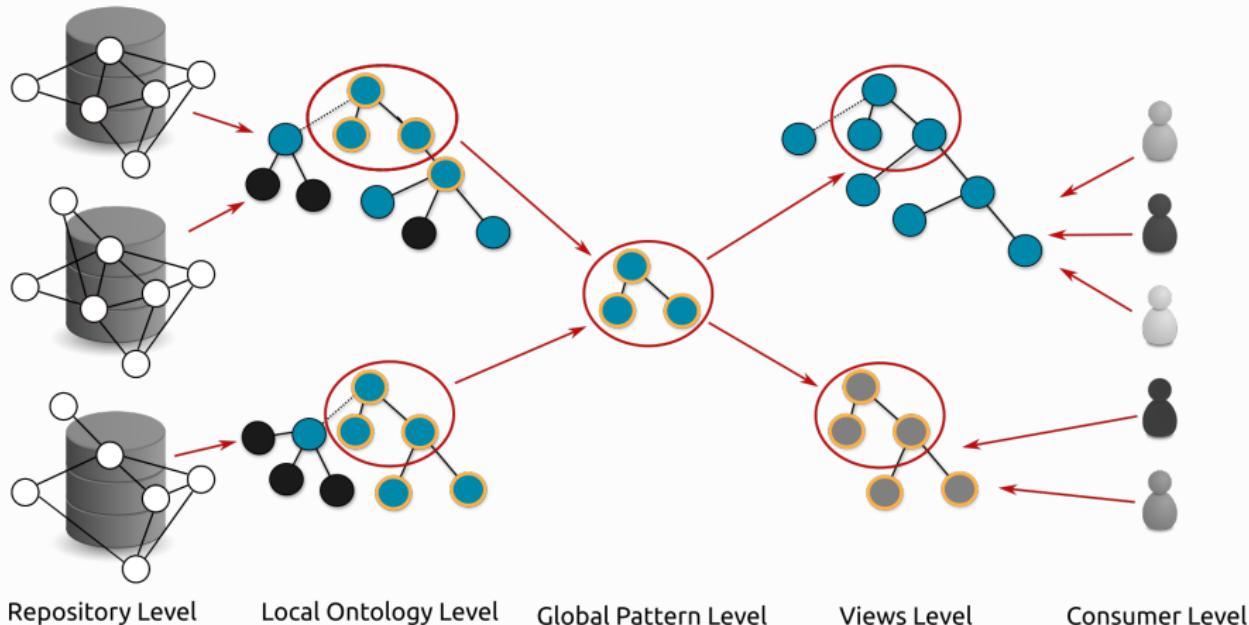
**Example:** If one application ontology models cars exclusively by fuel consumption and another ontology models cars exclusively by color, can data about cars be integrated across them?

## ENVISIONED, PATTERN-BASED ARCHITECTURE (HORIZONTAL)



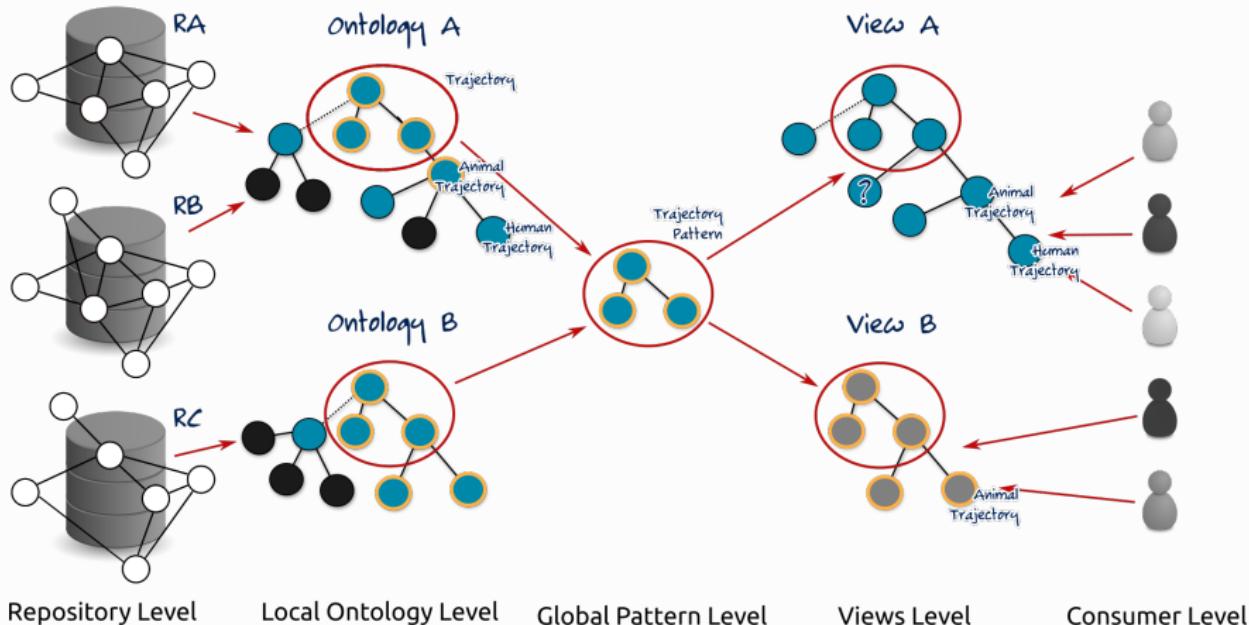
Patterns act as **fallback** level that ensures **minimal interoperability** while preserving **heterogeneity** (i.e., local, repository-specific ontologies can differ).

## ENVISIONED, PATTERN-BASED ARCHITECTURE (HORIZONTAL)



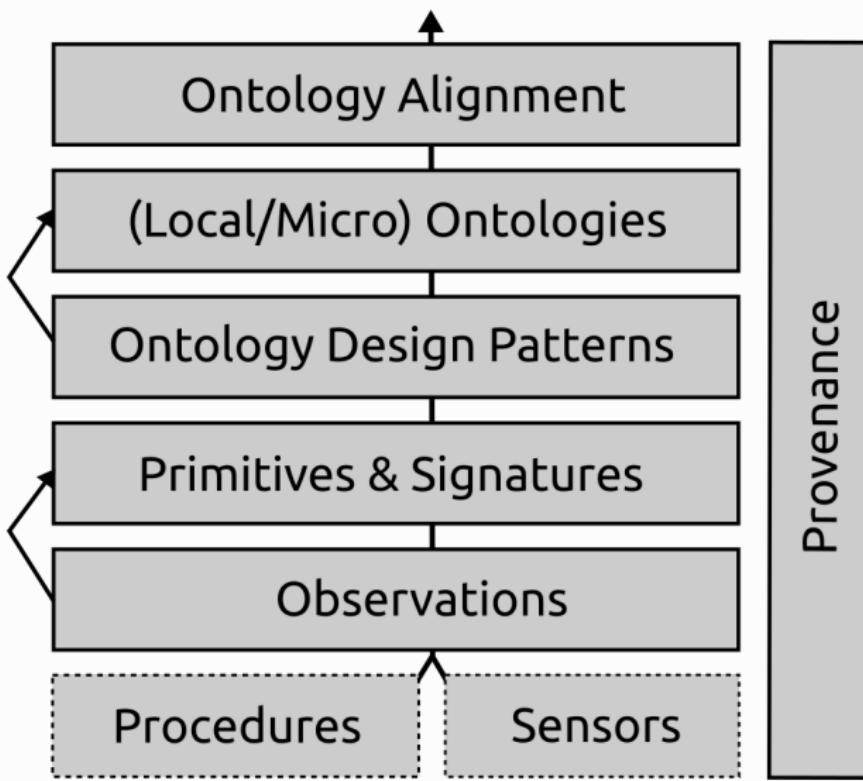
Views as virtual ontologies. 'All' provider- and user-perspectives agree on a common core; more specific results can differ.

## ENVISIONED, PATTERN-BASED ARCHITECTURE (HORIZONTAL)

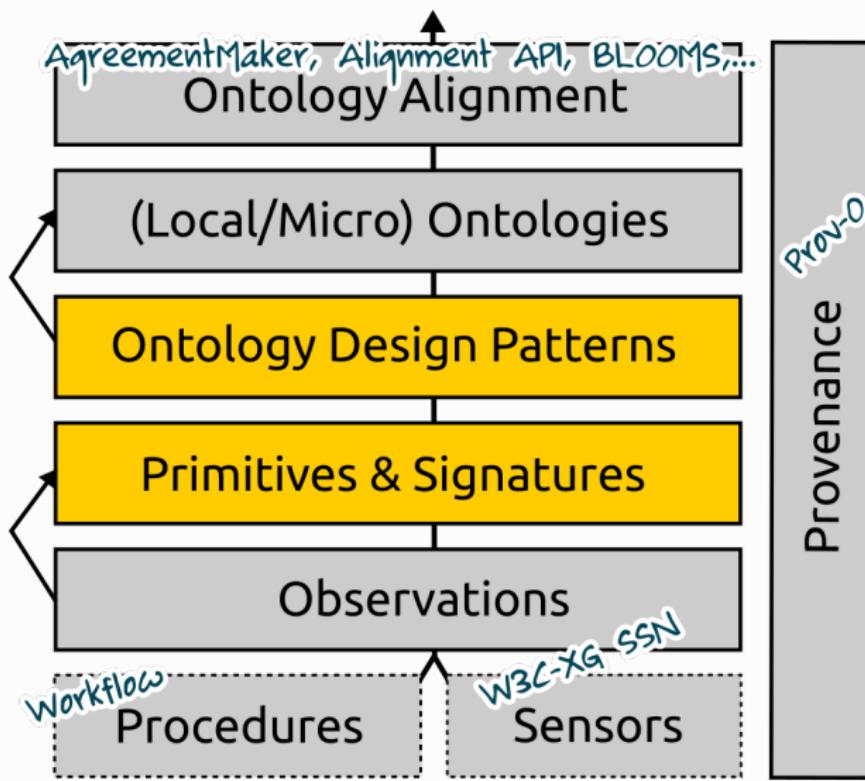


All users can query for data that correspond to the pattern, using view A one can retrieve data on human trajectories but these data will only come from RA and RB.

## ENVISIONED, PATTERN-BASED ARCHITECTURE (VERTICAL)

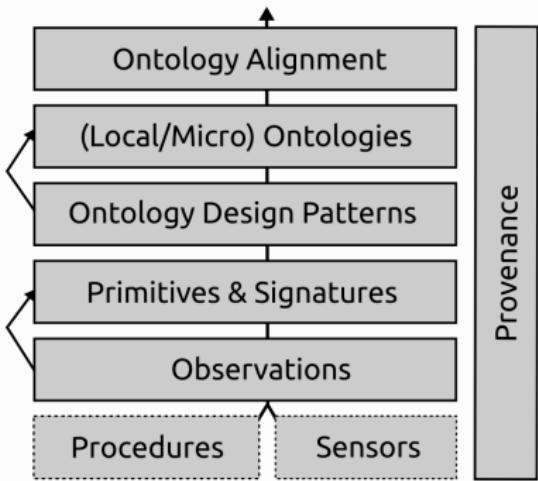


## ENVISIONED, PATTERN-BASED ARCHITECTURE (VERTICAL)



# ENVISIONED, PATTERN-BASED ARCHITECTURE (**VERTICAL**)

## Pros

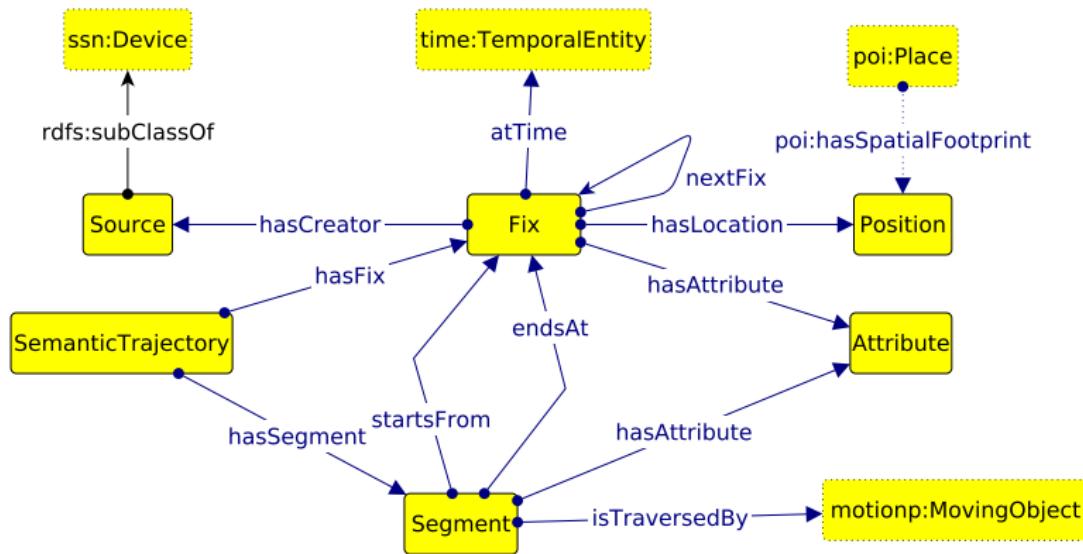


## Cons

- ... speak now or forever hold your peace

- **Defers** the introduction of classes that are heavy on ontological **commitments** (e.g., ‘vulnerability’)
- No need for (community-wide) **agreement** which is a key (social) challenge for other approaches. Preserves heterogeneity
- Mines ontological primitives out of real **observation data**
- Assists domain experts in becoming knowledge engineers by developing reusable **patterns**
- Moves ontology **reuse** to the layer where it belongs (and avoid *Frankenontologies*)
- Is driven by publishing, **discovery, reuse**, and integration needs.

# A SEMANTIC TRAJECTORY PATTERN

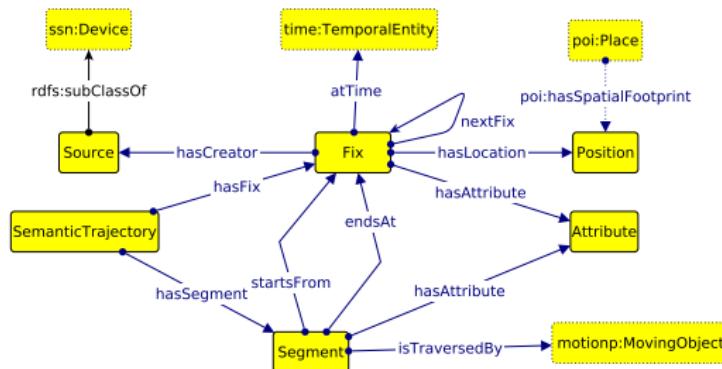


A pattern for **discrete** trajectories of people, wildlife, vessels, and so forth.

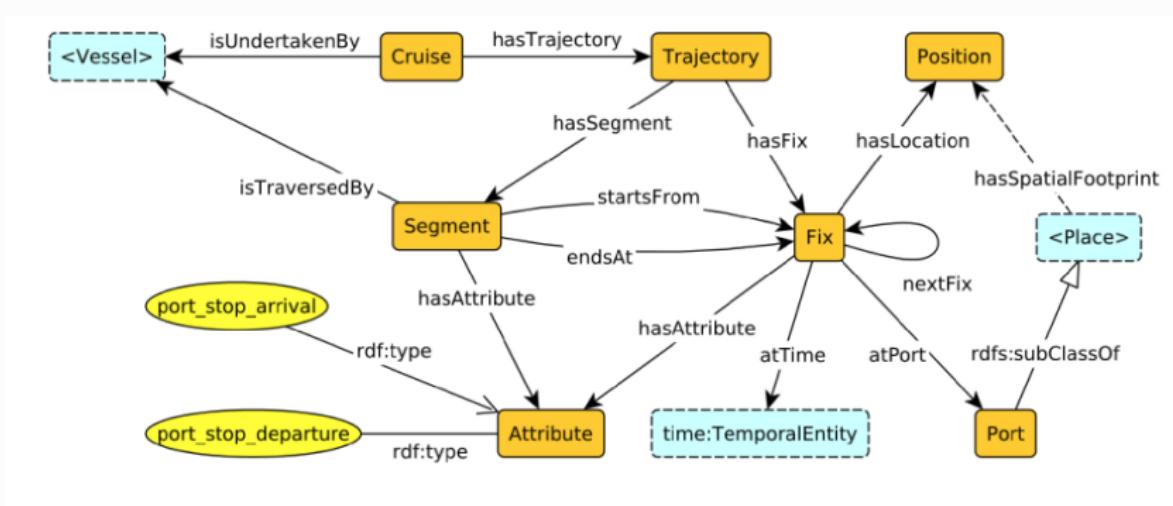
# A SEMANTIC TRAJECTORY PATTERN

$\text{Fix} \sqsubseteq \exists \text{hasLocation}.\text{Position} \sqcap \exists \text{atTime}.\text{time:TemporalEntity} \sqcap (=1 \text{ hasFix}^-.\text{Trajectory})$   
 $\sqcap (\leqslant 1 \text{ nextFix}.\text{Fix}) \sqcap \neg \exists \text{nextFix}.\text{Self}$

$\text{Segment} \sqsubseteq (=1 \text{ startsFrom}.\text{Fix}) \sqcap (=1 \text{ endsAt}.\text{Fix}) \sqcap (=1 \text{ hasSegment}^-.\text{Trajectory})$   
 $\exists \text{nextFix}.\text{Fix} \sqsubseteq (=1 \text{ startsFrom}^-.\text{Segment})$   
 $\exists \text{nextFix}^-.\text{Fix} \sqsubseteq (=1 \text{ endsAt}^-.\text{Segment})$   
 $\text{startsWith} \circ \text{nextFix} \sqsubseteq \text{endsAt}$   
 $\text{hasFix} \circ \text{startsWith}^- \sqsubseteq \text{hasSegment}$

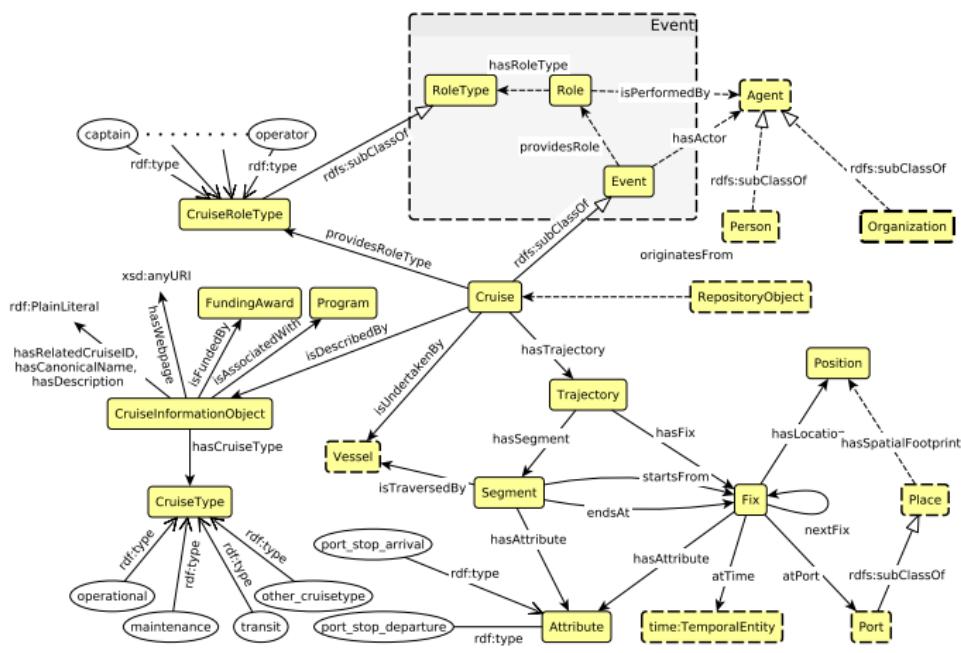


# ONTOLOGY DESIGN PATTERNS CAN BE SPECIALIZED



- Trajectories that model the research **cruises** of scientific vessels
- Is this still an ontology design pattern?

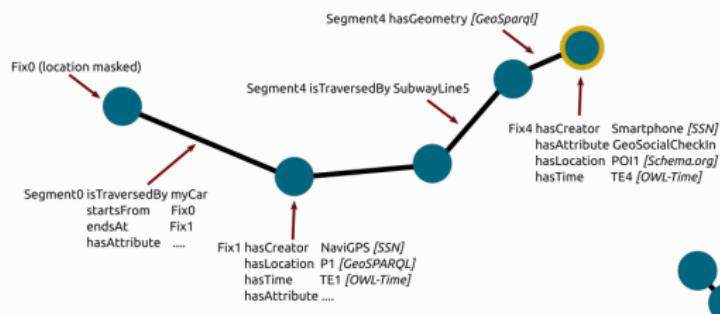
# A MICRO-ONTOLOGY FOR CRUISES



**Combining** the InformationObject, Agent, Event, Vessel, and Trajectory patterns

# IDEA BEHIND SEMANTIC TRAJECTORY PATTERN

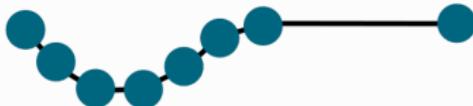
## Human travel trajectory



## Abstraction



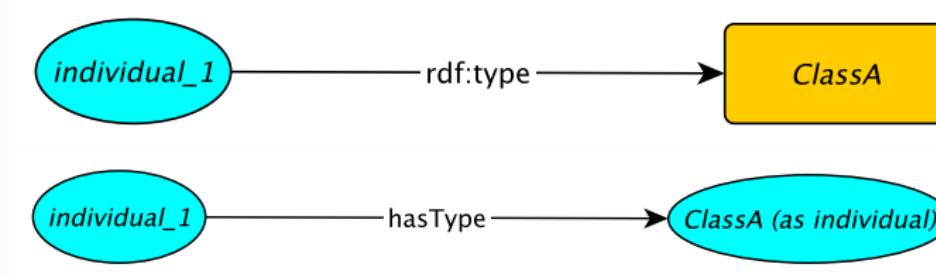
## Discretization



- Can cover a wide range of **domains**
- Can be easily **extended**
- Supports multiple **granularities**
- **Axiomatization** beyond mere surface semantics
- Has various **hooks** to well-known ontologies / patterns.
- Only partially self-contained ☹

# TYPECASTING – DEALING WITH STYLES

## Typecasting Individual to Class and Back



$$\text{ClassName} \sqsubseteq \exists \text{hasType}.\{\text{classname}\} \quad (1)$$

$$\exists \text{hasType}.\{\text{classname}\} \sqsubseteq \text{ClassName} \quad (2)$$

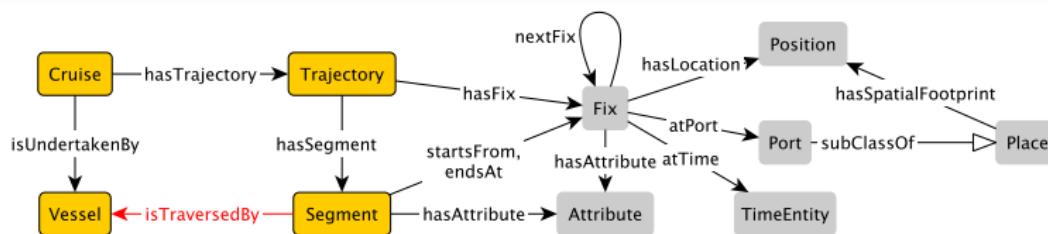
## Rolification: Typecasting from Classes to Properties

...

## Reification: Typecasting Properties into Classes

...

# VIEWS – DEALING WITH GRANULARITY AND PERSPECTIVES



$Vessel \equiv \exists R_{Vessel}.Self$

$Cruise \equiv \exists R_{Cruise}.Self$

$Trajectory \equiv \exists R_{Trajectory}.Self$

$Segment \equiv \exists R_{Segment}.Self$

$R_{Segment} \circ hasSegment^- \circ R_{Trajectory} \circ$

$\circ hasTrajectory^- \circ R_{Cruise} \circ isUndertakenBy \sqsubseteq isTraversedBy$

# ONTOLOGIES AS INTERFACES

Our completely **client-based** JS explorer can be connected to any triple store

# ONTOLOGIES AS INTERFACES

The screenshot displays the Alexandria Digital Library interface. On the left is a map of Southern California, including the San Joaquin Valley, the Los Angeles basin, and the San Diego region. The map shows various cities, national forests, and state parks. On the right is a query builder window titled "UC LIBRARY". The query bar contains "ns10:elevation > 500". The results pane shows a list of properties: ns2:hasDescription, ns3:hasEntryDate, ns3:hasModificationDate, ns5:hasSchema, ns6:onPlanet, ns7:centerLongitude, ns8:centerLatitude, ns9:geomType, geosparql:hasGeometry, ns10:elevation (selected), ns11:supplementalNote, and ns12:hasRelatedFeature. Below this is a button "Add to Bucket". The number of matching entities is 11. At the bottom, there's an "ADD TO LAYERS" button and a note that results are bounded by Map Extent. The footer of the interface includes the text "Design & development by STKO Lab | UCSB Libraries" and "Map data © OpenStreetMap contributors, CC-BY-SA".

Allows users to explore Linked Data; constructs filters (e.g.,  $>$ ) based on **probing**

# ONTOLOGIES AS INTERFACES

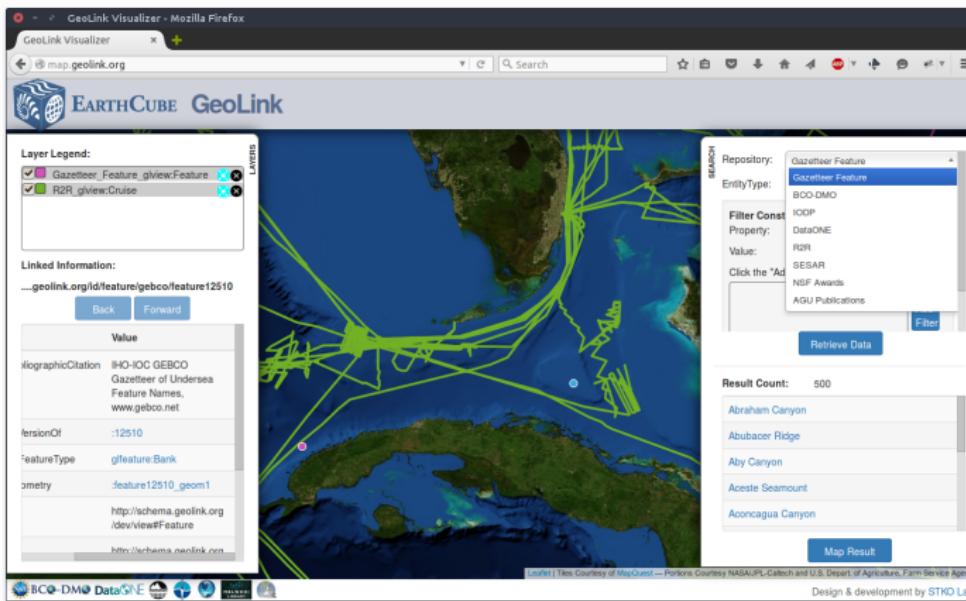
The screenshot shows the Alexandria Digital Library interface. On the left, there is a map of Southern California with several pink location pins placed on various cities and towns. The map includes labels for major cities like Los Angeles, San Diego, and San Bernardino, as well as smaller towns like Ridgecrest, Barstow, and Indio. A legend on the left side indicates that the pink markers represent "populated\_places". To the right of the map, there is a sidebar with the UC Santa Barbara logo. The sidebar contains the following information:

- SPARQL Endpoint:** <http://adl-gazetteer.geog.ucsb.edu:8080/repositories>
- Default Graph:** <http://adl-gazetteer.geog.ucsb.edu>
- Base Type:** <http://adl-gazetteer.geog.ucsb.edu/ONT/ADL#place>

At the bottom of the sidebar is a large green button labeled "QUERY". At the very bottom of the interface, there is a footer note: "Design & development by STKO Lab | UCSB Libraries".

How does the interface know **which data can be mapped** and how to do this?

# ONTOLOGIES AS INTERFACES



Our explorer can even combine data from multiple sources as **layers** (here cruises from R2R in green and gazetteer features in pink)

# WHAT ABOUT TIME AND AGE?

Eratosthenes age

About 796,000 results (0.31 seconds)

**about 2288 years (BC 276)**

Eratosthenes, age  
Hide details

[Eratosthenes - Biography of ...](#) - about.com  
 Eratosthenes was born around **276 B.C.E.** at a Greek ...

[Eratosthenes](#) - windows2universe.org  
 Eratosthenes was born in **276 B.C.** ...

Is this accurate? Yes - No

**Eratosthenes - Wikipedia, the free encyclopedia**  
[en.wikipedia.org/wiki/Eratosthenes](#)  
 For the ancient Athenian statesman of the fifth century BC, see **Eratosthenes** .... 285 BC) since he is unlikely to have studied under him at the young **age** of 14.  
 ↪ Sieve of Eratosthenes - Eratosthenes (crater) - Eratosthenes Seamount

**Eratosthenes - Biography of Eratosthenes**  
[geography.about.com/od/historyofgeography/a/eratosthenes.htm](#)  
 Eratosthenes was born around **276 B.C.E.** at a Greek colony in Cyrene, Libya. ... In old age, **Eratosthenes** became blind and died of self-induced starvation in ...

**Eratosthenes**



en.wikipedia.org

**Born:** BC 276, Cyrene  
**Died:** BC 194, Alexandria  
**Parents:** Aglaus

**People also search for**







Ptolemy Anstarc... Archimedes Euclid Hipparchus

*Report a problem*

## Google's Knowledge Graph in 2012

# WHAT ABOUT TIME AND AGE?

Eratosthenes age

Web Images Maps Shopping More Search tools

About 2,160,000 results (0.19 seconds)

**82 (276 BC–194 BC)**

Eratosthenes, Age at death

[Feedback / More info](#)

**Eratosthenes - Biography of Eratosthenes - Geography - About.com**  
[geography.about.com](http://geography.about.com/od/education/a/geography-history-of-geography.htm) › Education › Geography › History of Geography ▾  
 In old age, **Eratosthenes** became blind and died of self-induced starvation in either 192 or 196 B.C.E. He had thus lived to be about 80 to 84 years old.

**Eratosthenes - Wikipedia, the free encyclopedia**  
[en.wikipedia.org/wiki/Eratosthenes](http://en.wikipedia.org/w/index.php?title=Eratosthenes&oldid=5000000) ▾  
 For the ancient Athenian statesman of the fifth century BC, see **Eratosthenes** .... 285 BC since he is unlikely to have studied under him at the young age of 14.  
 Sieve of Eratosthenes - Eratosthenes (crater) - History of geodesy

**Eratosthenes - Simple English Wikipedia, the free encyclopedia**  
[simple.wikipedia.org/wiki/Eratosthenes](http://simple.wikipedia.org/w/index.php?title=Eratosthenes&oldid=1000000) ▾  
**Eratosthenes** was a friend of Archimedes, who also lived and worked in Alexandria. Archimedes was the greatest mathematician and inventor of the age, ...

**Eratosthenes of Cyrene (Greek scientist) -- Encyclopedia Britannica**

**Eratosthenes**



Mathematician  
 Eratosthenes of Cyrene was a Greek mathematician, geographer, poet, astronomer, and music theorist. He was the first person to use the word "geography" in Greek and he invented the discipline of geography as we understand it. [Wikipedia](#)

**Born:** 276 BC, Cyrene, Shahhat, Libya  
**Died:** 194 BC, Alexandria, Egypt  
**Education:** Platonic Academy  
**Parents:** Aglaus

**People also search for**







[Feedback / More info](#)

Google's Knowledge Graph in 2013

# WHAT ABOUT TIME AND AGE?

**Google** Eiffel Tower

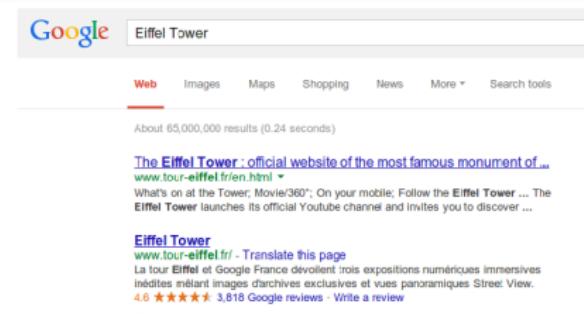
Web Images Maps Shopping News More Search tools

About 65,000,000 results (0.24 seconds)

[The Eiffel Tower : official website of the most famous monument of...](#)  
[www.tour-eiffel.fr/en.html](#) What's on at the Tower; Movie/360°; On your mobile; Follow the Eiffel Tower ... The Eiffel Tower launches its official YouTube channel and invites you to discover ...

**Eiffel Tower**  
[www.tour-eiffel.fr/ - Translate this page](#)  
 La tour Eiffel et Google France dévoilent trois expositions numériques immersives inédites : instant images d'archives exclusives et vues panoramiques Street View.  
 4.6 ★★★★★ 3,818 Google reviews · Write a review

Champ de Mars, 5 Avenue Anatole France, 75007 Paris, France  
 +33 892 70 39



**Google** Eiffel Tower age

Web Images Maps Shopping More Search tools

About 4,620,000 results (0.23 seconds)

[Gustave Eiffel - Wikipedia, the free encyclopedia](#)  
[en.wikipedia.org/w/Gustave\\_Eiffel](#) He is best known for the world-famous Eiffel Tower, built for the 1889 Universal Exposition in Paris, France. After his retirement from engineering, Eiffel ... early life · engineering career · influence · works

[What is the age of the Eiffel tower? - WikiAnswers](#)  
[www.wiki.answers.com/WikiAnswers/Categories/Entertainment%20&%20Arts](#) The Eiffel Tower once held the record for world's tallest structure but lost the title to the Burj Khalifa in 2009. The Eiffel Tower is an iron lattice tower located in Paris, France, and is one of ...

[How old is the Eiffel Tower? - Eva](#)  
[www.evi.com/how\\_old\\_is\\_the\\_eiffel\\_tower](#) The Eiffel Tower was constructed on March 31st 1889. That makes its current age 124 years, 7 months and 4 days old. website wikipedia. Report Abuse



## Google's Knowledge Graph in 2014

# WHAT ABOUT TIME AND AGE?

**Google** eiffel tower age

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About 4,040,000 results (0.64 seconds)

Eiffel Tower / Age

**128 years**  
c. 1887-1889



Feedback



Map data ©2015 Google

**Eiffel Tower**  
Tower in Paris, France

The Eiffel Tower is an iron lattice tower located on the Champ de Mars in Paris, France. It was named after the engineer Alexandre Gustave Eiffel, whose company designed and built the tower. [Wikipedia](#)

**Address:** Champ de Mars, 5 Avenue Anatole France, 75007 Paris, France  
**Opened:** March 31, 1889  
**Construction started:** January 28, 1887  
**Floors:** 3  
**Architects:** Gustave Eiffel, Stephen Sauvestre  
**Architecture firms:** Barbier, Benard and Turenne, Eiffel & Cie

**Eiffel Tower**  
[www.toureiffel.paris/](http://www.toureiffel.paris/)

 Champ de Mars, 5 Avenue Anatole France, 75007 Paris, France  
+33 892 70 12 39

**Eiffel Tower - Wikipedia, the free encyclopedia**  
[https://en.wikipedia.org/wiki/Eiffel\\_Tower](https://en.wikipedia.org/wiki/Eiffel_Tower) ▾ Wikipedia ▾  
The Eiffel Tower [i'efɛl 'taʊər] EYE-fel TOWR; French: tour Eiffel [tuʁ\_ɛfɛl] About this sound listen) is an ..... The Eiffel Tower:Symbol of an Age. London: ...  
Gustave Eiffel - Millau Viaduct - Exposition Universelle (1889) - Champ de Mars

[Eiffel Tower - Facts & Summary - HISTORY.com](#)

Upcoming events

Google's Knowledge Graph in 2015

# WHAT ABOUT TIME AND AGE?

**Google** Ham the Astrochimp 

Web Images Videos Shopping News More ▾ Search tools

About 11,300 results (0.25 seconds)

**Ham (chimpanzee) - Wikipedia, the free encyclopedia**  
[https://en.wikipedia.org/wiki/Ham\\_\(chimpanzee\)](https://en.wikipedia.org/wiki/Ham_(chimpanzee)) ▾ Wikipedia  
 Ham (July 1956 – January 19, 1983), also known as Ham the Chimp and Ham the Astrochimp, was a chimpanzee and the first hominid launched into space, on ...  
 Early life - Training and mission - Later life - Popular culture

**Ham the astrochimp: hero or victim? | Science | The Guardian**  
[www.theguardian.com/science/space/ham-the-chimp](http://www.theguardian.com/science/space/ham-the-chimp) ▾ The Guardian  
 Dec 16, 2013 - Spare a thought for Ham the Chimp, an object and victim in the human race for space.

**Grave of Ham the Astrochimp, Alamogordo, New Mexico**  
[www.roadsidearm.com/story/3321](http://www.roadsidearm.com/story/3321) ▾  
 The final resting place of Ham; in January 1961 he became the first chimp launched into space.

**LIFE With the Astrochimps: Early Stars of the Space Race ...**  
[time.com/life-with-the-astrochimps-early-stars-of-the-space-race/](http://time.com/life-with-the-astrochimps-early-stars-of-the-space-race/) ▾ Time  
 Nov 20, 2013 - Remembering America's famous "astrochimps" with photos of Ham and his ... Ham the astrochimp after his historic 1961 suborbital flight.

**Ham the Chimp Biography - Birthday, Photos - Who2.com**  
[www.who2.com/bio/ham-the-chimp](http://www.who2.com/bio/ham-the-chimp) ▾  
 Ham the Chimp was one of the chimpanzees specially trained by NASA rocket scientists to fly in tests of American space capsules. On January 31, 1961, Ham ...



[More images](#)

**Ham**  
 Chimpanzee

Ham, also known as Ham the Chimp and Ham the Astrochimp, was a chimpanzee and the first hominid launched into space, on 31 January 1961, as part of America's space program. [Wikipedia](#)

**Born:** July 1957, Cameroon  
**Died:** January 19, 1983, North Carolina Zoo, Asheboro, NC  
**Space missions:** Mercury-Redstone 2  
**Space time:** 0d 0h 16m  
**First space flight:** Mercury-Redstone 2  
**Space agency:** NASA

[Feedback](#)

## Google's Knowledge Graph in 2015

# WHAT ABOUT TIME AND AGE?

Google Ham the Astrochimp age

Web Images Videos Shopping News More Search tools

About 11,800 results (0.33 seconds)

**Ham (chimpanzee) - Wikipedia, the free encyclopedia**  
[https://en.wikipedia.org/wiki/Ham\\_\(chimpanzee\)](https://en.wikipedia.org/wiki/Ham_(chimpanzee)) ▾ Wikipedia ▾  
Ham (July 1956 – January 19, 1983), also known as Ham the Chimp and .... 258–259  
The last surviving astro-chimp, she died at age 41 on March 14, 1998.  
Early life - Training and mission - Later life - Popular culture

People also ask

When did Ham the chimp go into space? ▾

Grave of Ham the Astrochimp, Alamogordo, New Mexico  
[www.roadsideamerica.com/story/3321](http://www.roadsideamerica.com/story/3321) ▾  
The final resting place of Ham; in January 1961 he became the first chimp launched  
into .... He died, peacefully, of old age on January 19, 1983, at age 27.

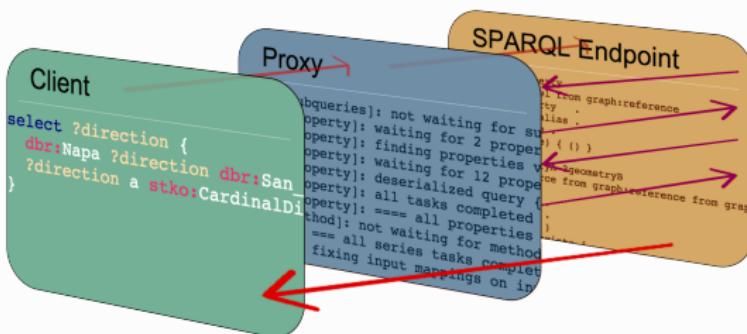
Images for Ham the Astrochimp age Report Images



Will you please define a rule how age is computed... (like a Time Interface 😊)

## STORING VERSUS COMPUTING

- We cannot possibly **materialize** (store) all interesting (geo-)properties such as *cardinal directions* between places ( $\approx 452$  billion), *nearby* triples, *elevations*, *topological* relations, population *density*, and so forth.
- However, we could try to **compute** properties on-demand (if we could figure out a way of doing so without changing the SW layer cake).
- The VOLT framework acts as a **transparent proxy** on top of any existing SPARQL 1.1 endpoint and can **compute results** and their **provenance** graphs **on-demand**.
- How to decide which properties to store and which to compute? → **patterns!**



Detailed slides at: <http://www.slideshare.net/BlakeRegalia/volt-eswc-2016>

# ONTOLOGY DESIGN PATTERNS BOOK

