CSCE 590-1: From Data to Decisions with Open Data: A Practical Introduction to AI

Lecture 5: Data Preparation, Knowledge Representation/ Graph, Ontology

PROF. BIPLAV SRIVASTAVA, AI INSTITUTE

26TH JAN 2021

Carolinian Creed: "I will practice personal and academic integrity."

Organization of Lecture 5

- Introduction Segment
  - Announcements
  - Recap of Lecture 4
  - Course Project
- Main Segment
  - Data preparation
  - Knowledge representation/ graph
  - Ontology
- Concluding Segment
  - About Next Lecture – Lecture 6
  - Ask me anything

Introduction Segment

Announcements

- Office hour on Monday and Wednesdays
  - 11:30 am – 12:30 pm
  - Please join using Blackboard Ultra
  - Send email if you do not see me/ or am inactive

- Quiz in next class
  - From material covered in Lectures 1-5
  - First class (~45 mins) and then Quiz

Course Project

- (**Undergraduate**) Project: 50% + 10%:
  - Do a significant project of your choice following the framework presented in Lecture 3
  - Deliverable: Project report and code (50%), 1-slide elevator presentation to class (10%)

- **Framework**: Value of decision: before and after, Data-needed, Method, Evaluation, Integrating with overall process

- **Illustration**:
  - Data analysis project
  - Dataset must be from given catalog – Lecture 1 - (US: https://www.data.gov/ or any US state; Text of legislations - LegiScan, https://legiscan.com/; Kaggle datasets: https://www.kaggle.com/datasets; Google datasets search: https://datasetsearch.research.google.com/) OR discussed with instructor
  - Use analytical methods to present new insights
  - Problem (method) to be discussed with instructor
  - Examples: SC traffic deaths, COVID responses of a US states, economic growth and tax rates

Course Project

- (**<u>Graduate</u>**) Project: 50% + 10%:
  - Do a significant project of your choice following the framework presented in Lecture 3
  - Deliverable: Project report and code (50%), 1-slide elevator presentation to class (10%)

- **Framework**: Value of decision: before and after, Data-needed, Method, Evaluation, Integrating with overall process

- **Illustrations**:
  - Project on data analysis (like for undergraduates) but bigger scope
  - Project on creating or exploring new methods (preferred)
  - Problem (method) to be discussed with instructor
  - **Examples**: Estimate crowd from sound, find mask adherence from photos, find algal bloom from images of water

Rubric for Evaluation of Course Project

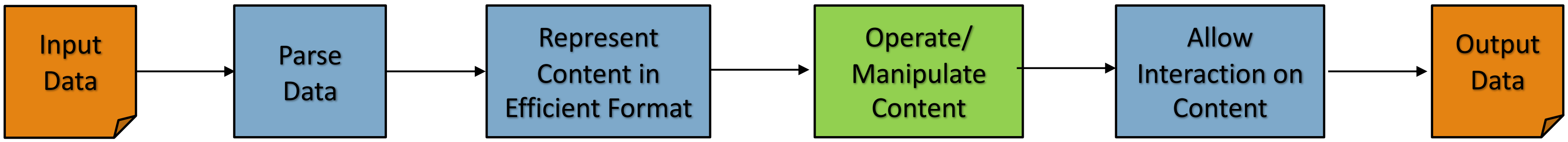
- Project
  - Project plan
  - Challenging nature of project
  - Actual achievement
  - Report
  - Sharing of code
- Presentation
  - Motivation
  - Coverage of related work
  - Results and significance
  - Handling of questions

Recap of Lecture 4

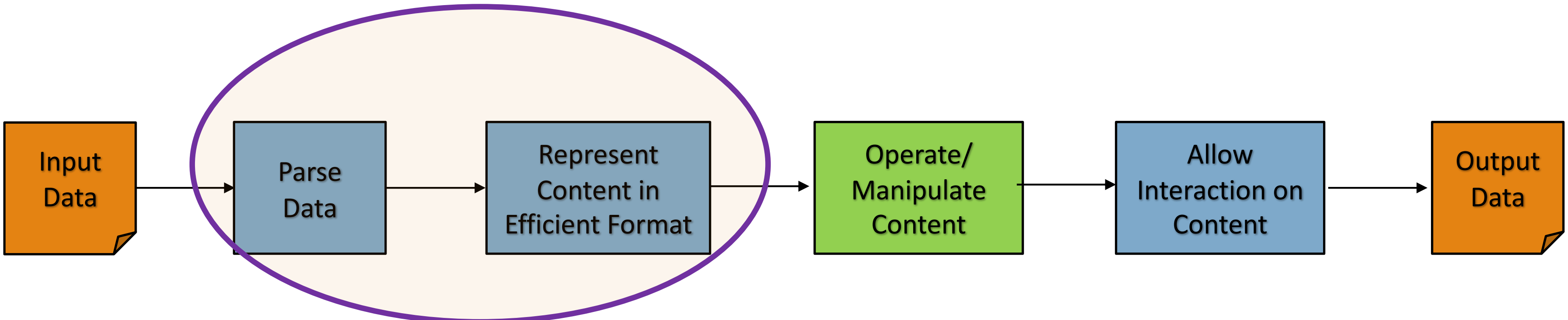
- We covered a background in water
  - Looked at common problems
- Looked at decision-support situations from US and a few solutions
- Looked at decision-support situations from India and a few solutions
- We explored the scope of AI

Main Segment

Data Processing Pipeline

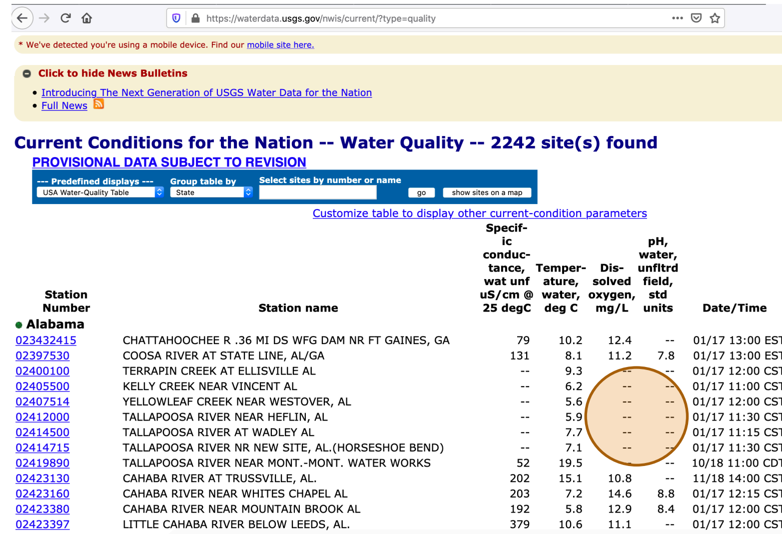


Data Preparation



Common Problem: Missing Value

- Occurrence
  - Missing completely at random
  - Missing at random (a group not wanting to participate)
  - Missing not at random (a group not able to participate)
- What does it mean?
  - The value was not provided
  - The value does not exist or has no practical interpretation
  - The value is being hidden (redaction)
  - Others: The value is not reliable, …
- How to detect it?
  - By checking for specific values: NA, Not applicable, out-of-range value, 0, -1, "".



https://waterdata.usgs.gov/nwis/current/?type=quality

* We've detected you're using a mobile device. Find our mobile site here.

Click to hide News Bulletins

- Introducing The Next Generation of USGS Water Data for the Nation
- Full News

Current Conditions for the Nation -- Water Quality -- 2242 site(s) found

PROVISIONAL DATA SUBJECT TO REVISION

--- Predefined displays --- USA Water-Quality Table | Group table by State | Select sites by number or name | go | show sites on a map

Customize table to display other current-condition parameters

Station Number	Station name	Specific conductance, wat unf uS/cm @ 25 degC	Temperature, water, deg C	Dissolved oxygen, mg/L	pH, water, unfltrd field, std units	Date/Time
Alabama						
023432415	CHATTAHOOCHEE R .36 MI DS WFG DAM NR FT GAINES, GA	79	10.2	12.4	--	01/17 13:00 EST
02397530	COOSA RIVER AT STATE LINE, AL/GA	131	8.1	11.2	7.8	01/17 13:00 EST
02400100	TERRAPIN CREEK AT ELLISVILLE AL	--	9.3	--	--	01/17 12:00 CST
02405500	KELLY CREEK NEAR VINCENT AL	--	6.2	--	--	01/17 11:00 CST
02407514	YELLOWLEAF CREEK NEAR WESTOVER, AL	--	5.6	--	--	01/17 12:00 CST
02412000	TALLAPOOSA RIVER NEAR HEFLIN, AL	--	5.9	--	--	01/17 11:30 CST
02414500	TALLAPOOSA RIVER AT WADLEY AL	--	7.7	--	--	01/17 11:15 CST
02414715	TALLAPOOSA RIVER NR NEW SITE, AL.(HORSESHOE BEND)	--	7.1	--	--	01/17 11:30 CST
02419890	TALLAPOOSA RIVER NEAR MONT.-MONT. WATER WORKS	52	19.5	--	--	10/18 11:00 CDT
02423130	CAHABA RIVER AT TRUSSVILLE, AL.	202	15.1	10.8	--	11/18 14:00 CST
02423160	CAHABA RIVER NEAR WHITES CHAPEL AL	203	7.2	14.6	8.8	01/17 12:15 CST
02423380	CAHABA RIVER NEAR MOUNTAIN BROOK AL	192	5.8	12.9	8.4	01/17 12:00 CST
02423397	LITTLE CAHABA RIVER BELOW LEEDS, AL.	379	10.6	11.1	--	01/17 12:00 CST

Missing Value – Handling

- Ignoring missing value (Omission)
  - Reduces available data
- Impute new value (Imputation)
  - Mean or median
  - Default value
- Analysis techniques which are robust against missing value
  - Expectation maximization

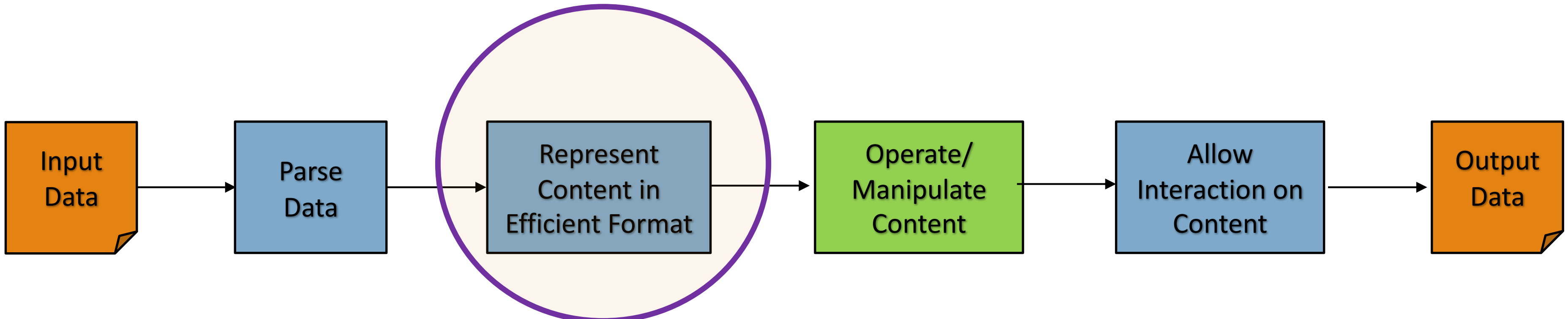
Code Examples

https://github.com/biplav-s/course-d2d-ai/tree/main/sample-code/l4-dataprep

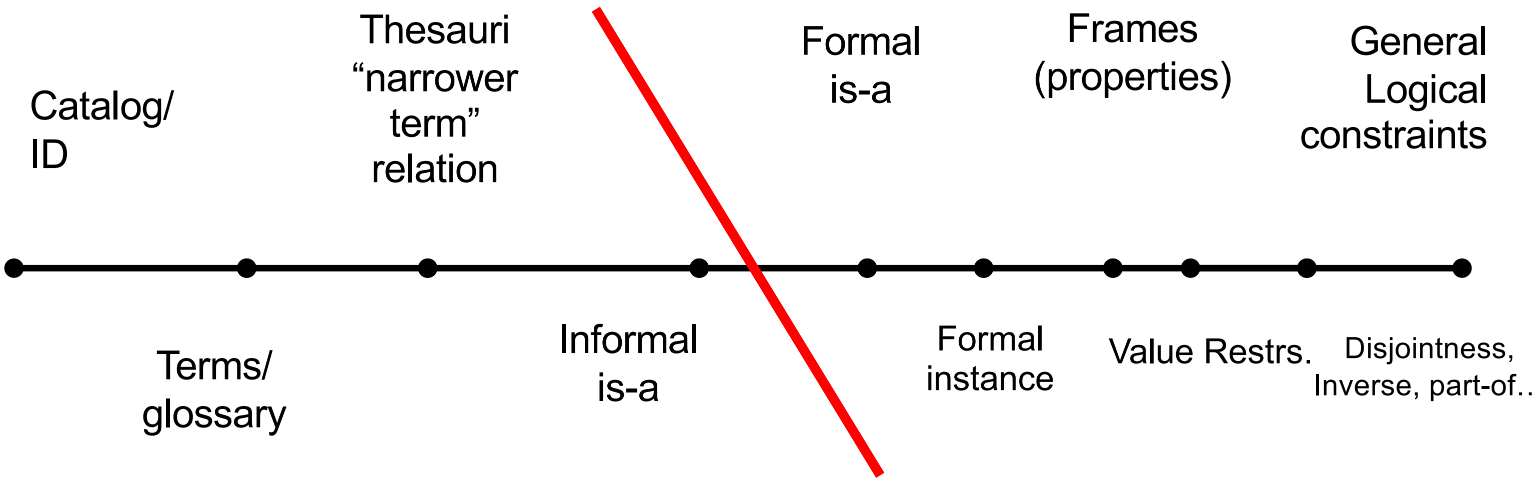
- Basic concepts: **DataPreparation-Numeric.ipynb**

- An illustration: **Clean-RealSample.ipynb**

Annotation: Knowledge Graphs and Ontology



The Spectrum of Annotation Methods



Ontologies Come of Age McGuinness, 2001, and From AAAI Panel 99 – McGuinness, Welty, Uschold, Gruninger, Lehmann
Plus basis of Ontologies Come of Age – McGuinness, 2003

Thesaurus – Authoritative Entities and Relationships

Countries: https://en.wikipedia.org/wiki/List_of_ISO_3166_country_codes

ISO 3166[1]			ISO 3166-1[2]			ISO 3166-2[3]	
Country name[5]	Official state name[6]	Sovereignty[6][7][8]	Alpha-2 code[5]	Alpha-3 code[5]	Numeric code[5]	Subdivision code links[3]	Internet ccTLD[9]
Afghanistan	The Islamic Republic of Afghanistan	UN member state	AF	AFG	004	ISO 3166-2:AF	.af
Akrotiri and Dhekelia – See United Kingdom, The							
Åland Islands	Åland	Finland	AX	ALA	248	ISO 3166-2:AX	.ax
Albania	The Republic of Albania	UN member state	AL	ALB	008	ISO 3166-2:AL	.al
Algeria	The People's Democratic Republic of Algeria	UN member state	DZ	DZA	012	ISO 3166-2:DZ	.dz
American Samoa	The Territory of American Samoa	United States	AS	ASM	016	ISO 3166-2:AS	.as
Andorra	The Principality of Andorra	UN member state	AD	AND	020	ISO 3166-2:AD	.ad
Angola	The Republic of Angola	UN member state	AO	AGO	024	ISO 3166-2:AO	.ao
Anguilla	Anguilla	United Kingdom	AI	AIA	660	ISO 3166-2:AI	.ai
Antarctica[a]	All land and ice shelves south of the 60th parallel south	Antarctic Treaty	AQ	ATA	010	ISO 3166-2:AQ	.aq
Antigua and Barbuda	Antigua and Barbuda	UN member state	AG	ATG	028	ISO 3166-2:AG	.ag
Argentina	The Argentine Republic	UN member state	AR	ARG	032	ISO 3166-2:AR	.ar

(Unique) US Counties Information

In COVID sample code: https://github.com/biplav-s/course-d2d-ai/blob/main/sample-code/l3-health/CovidExploration.ipynb,

reference made to **FIPS** code

References:

- https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/home/?cid=nrcs143_013697
- https://github.com/kjhealy/fips-codes/blob/master/county_fips_master.csv

Question: how many Richland counties are there in US ?

Answer: 14

County FIPS Codes

FIPS	Name	Stat
01001	Autauga	AL
01003	Baldwin	AL
01005	Barbour	AL
01007	Bibb	AL
01009	Blount	AL
01011	Bullock	AL
01013	Butler	AL
01015	Calhoun	AL
01017	Chambers	AL
01019	Cherokee	AL
01021	Chilton	AL
01023	Choctaw	AL
01025	Clarke	AL
01027	Clay	AL
01029	Cleburne	AL
01031	Coffee	AL
01033	Colbert	AL
01035	Conecuh	AL

Is-a Relationship

List of Countries, States, … (County), City

- United Nations: https://unece.org/trade/cefact/unlocode-code-list-country-and-territory
- US Source: https://github.com/grammakov/USA-cities-and-states

Schema.org

- Website: https://schema.org/docs/about.html
- GitHub: https://github.com/schemaorg/schemaorg

- An organization of metadata information for entities found on the web. Mostly backed by web search companies.
- Explore
  - Thing: https://schema.org/Thing
  - Product:

Schema.org - 2

Example 2

No Markup | Microdata | RDFa | JSON-LD | Structure

Example notes or example HTML without markup.

```
<img src="dell-30in-lcd.jpg" alt="A Dell UltraSharp monitor" />
Dell UltraSharp 30" LCD Monitor

87 out of 100 based on 24 user ratings

$1250 to $1495 from 8 sellers

Sellers:
<a href="save-a-lot-monitors.com/dell-30.html">
  Save A Lot Monitors - $1250</a>
<a href="jondoe-gadgets.com/dell-30.html">
  Jon Doe's Gadgets - $1350</a>
...
```

No structure

Example 2

No Markup | Microdata | RDFa | JSON-LD | Structure

Example encoded as JSON-LD in a HTML script tag.

```
<script type="application/ld+json">
{
  "@context": "https://schema.org",
  "@type": "Product",
  "aggregateRating": {
    "@type": "AggregateRating",
    "bestRating": "100",
    "ratingCount": "24",
    "ratingValue": "87"
  },
  "image": "dell-30in-lcd.jpg",
  "name": "Dell UltraSharp 30\" LCD Monitor",
  "offers": {
    "@type": "AggregateOffer",
    "highPrice": "$1495",
    "lowPrice": "$1250",
    "offerCount": "8",
    "offers": [
      {
        "@type": "Offer",
        "url": "save-a-lot-monitors.com/dell-30.html"
      },
      {
        "@type": "Offer",
        "url": "jondoe-gadgets.com/dell-30.html"
      }
    ]
  }
}
</script>
```

Structure in JSON-LD format

Example 2

No Markup | Microdata | RDFa | JSON-LD | Structure

Structured representation of the JSON-LD example.

@type	Product
name	Dell UltraSharp 30" LCD Monitor
offers	
@type	AggregateOffer
offerCount	8
lowPrice	$1250
highPrice	$1495
offers	
@type	Offer
url	http://example.org/jondoe-gadgets.com/dell-30.html
offers	
@type	Offer
url	http://example.org/save-a-lot-monitors.com/dell-30.html
image	http://example.org/dell-30in-lcd.jpg
aggregateRating	
@type	AggregateRating
ratingValue	87
ratingCount	24
bestRating	100

Induced Structure

Schema.org - continued

- **Exploration Exercise**
  - Services: https://schema.org/Service
  - Event: https://schema.org/Event

- Benefit:
  - Easy to incorporate annotations
  - Uses popular development tools and technologies (JSON, Microformat)
- Disadvantage
  - Cannot perform deep inferencing
  - Popular in certain communities

Formalizing Knowledge in an Ontology

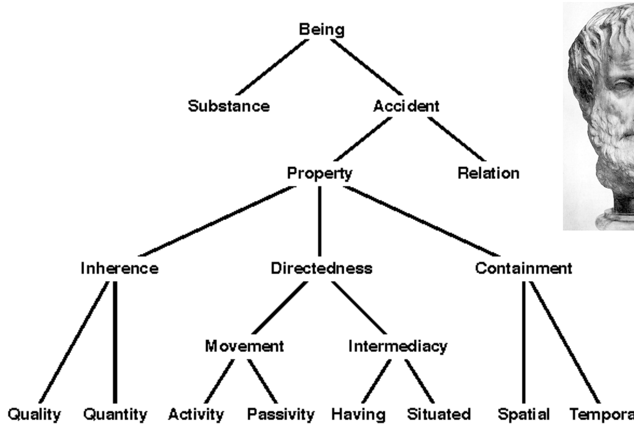
Sources:
Achille Fokoue, Anastasios Kementsietsidis Tutorial
SCRIBE presentation by Rosario Usceda Sosa, Biplav Srivastava, Bob Schloss

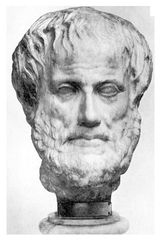
- https://github.com/rschloss/ismp ,
- https://researcher.watson.ibm.com/researcher/view_group.php?id=2505

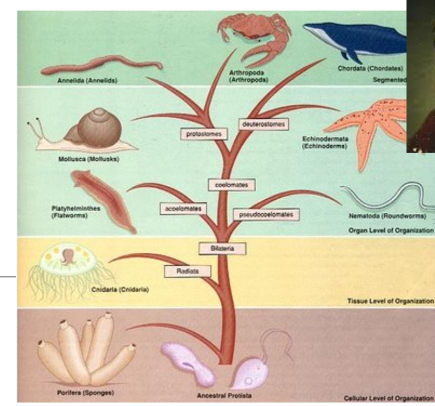
What is an ontology, anyway?

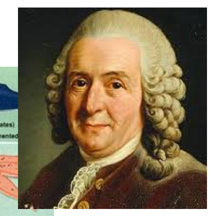
In Computer Science, “An ontology is a formal explicit description of concepts in a domain of discourse (**classes** (sometimes called concepts)), **properties** of each concept describing various features and **attributes** of the concept (slots (sometimes called roles or properties)), and **restrictions** on slots (facets (sometimes called role restrictions)). An ontology together with a set of individual instances of classes constitutes a knowledge base. In reality, there is a fine line where the ontology ends and the knowledge base begins.” [Noy, 2000]

Not to be confused with ontologies (and/or taxonomies) in Philosophy or Life Sciences







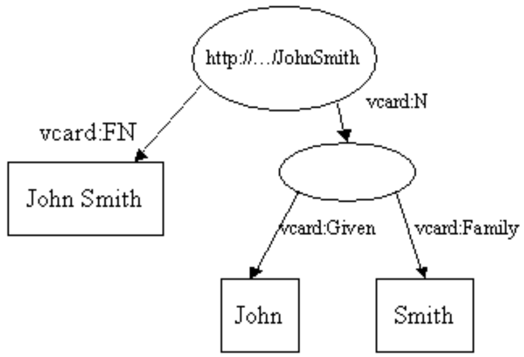


In a Smart City domain, we’re concerned with modeling the *city data* (city activity data, city departments, assets, KPIs), not the city itself (the full set of spatial and temporal relations between people and objects in the city) Ontologies help us to structure and reason about city *events*, *entities* and *services*.

Ontology = Class + Relations + Constraints

Knowledge Base = Ontology + instances + (Standard) Inference and rules

RDF / Turtle Example




```
---- Turtle ----
<http://somewhere/JohnSmith>
    <http://www.w3.org/2001/vcard-rdf/3.0#FN>
         "John Smith" ;
    <http://www.w3.org/2001/vcard-rdf/3.0#N>
         [ <http://www.w3.org/2001/vcard-
    rdf/3.0#Family>
               "Smith" ;
          <http://www.w3.org/2001/vcard-
    rdf/3.0#Given>
               "John"
         ] .
```

```
<rdf:RDF
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-
 syntax-ns#"
  xmlns:vcard="http://www.w3.org/2001/vcard-
 rdf/3.0#" >
 <rdf:Description rdf:nodeID="A0">
  <vcard:Given>John</vcard:Given>
  <vcard:Family>Smith</vcard:Family>
 </rdf:Description>
 <rdf:Description
 rdf:about="http://somewhere/JohnSmith">
  <vcard:FN>John Smith</vcard:FN>
  <vcard:N rdf:nodeID="A0"/>
 </rdf:Description>
</rdf:RDF>
```

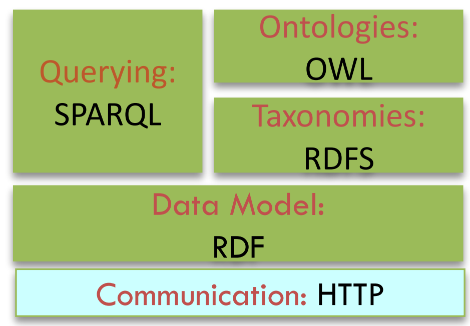
OWL extends RDF…

RDF-schema
- Class, subclass
- Property, subproperty

+ Restrictions
- Range, domain
- Local, global
- Existential
- Cardinality

+ Combinators
- Union, Intersection
- Complement
- Symmetric, transitive

+ Mapping
- Equivalence
- Inverse



Source: Achille Fokoue, Anastasios Kementsietsidis Tutorial

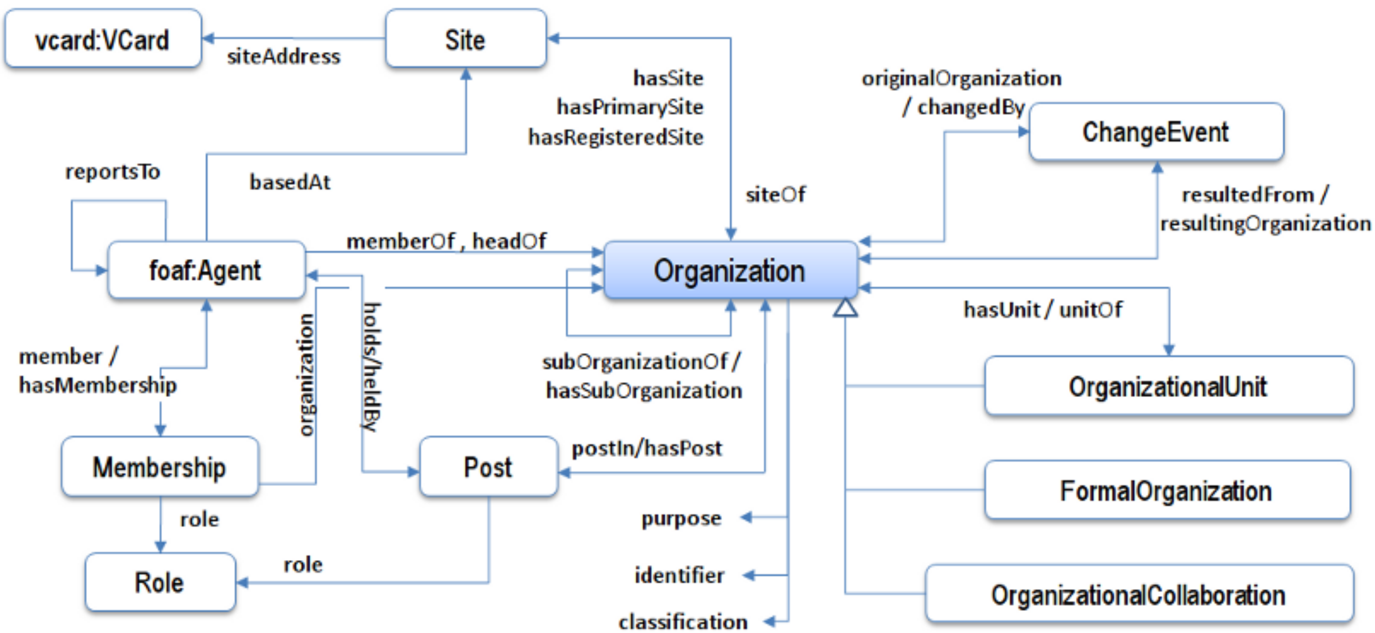
Not all ontologies are created equal

In practice, ontologies are used -together with inferencing engines and rules-, for a variety of purposes. If we think of them as schemas, there are different ways

	Purpose	Instances	Inferencing	Examples
As a deductive system	Deductive System (axioms + deductive rules)	Part of the knowledge base	Defined by rules.	Expert systems, Planning, Optimization.
As a data blueprint	Constrain a domain	Must conform to the normative schema determined by the ontology	Subsumption, class inferencing	Biomedical and life sciences (FMA, Radlex)
As a data classifier	Classify open data	Unknown formats	Subsumption, class inferencing	Tag ontologies (MOAT, Echarte, SCOT, NAO, etc.)
As a data integrator	Integrating pre-defined model to existing data sources	Instances are mapped, no constraint enforcement.	Subsumption, class, entity inferencing	**SCRIBE**
As data mapping vocabulary	Mapping to/from existing data sources	Mined instances determine the ontology/schema.	Subsumption, class inferencing	D2RQ (a tool)

SCRIBE belongs to the **fourth** category: It has no constraints and was designed to support the programming of tools that allow domain experts to deal with entities natural to them (even if the recorded data is actually distributed).

Larger Example: Organization Ontology



Ontology description: http://www.w3.org/TR/vocab-org/

Ontology: http://www.w3.org/ns/org.ttl

Larger Ontology

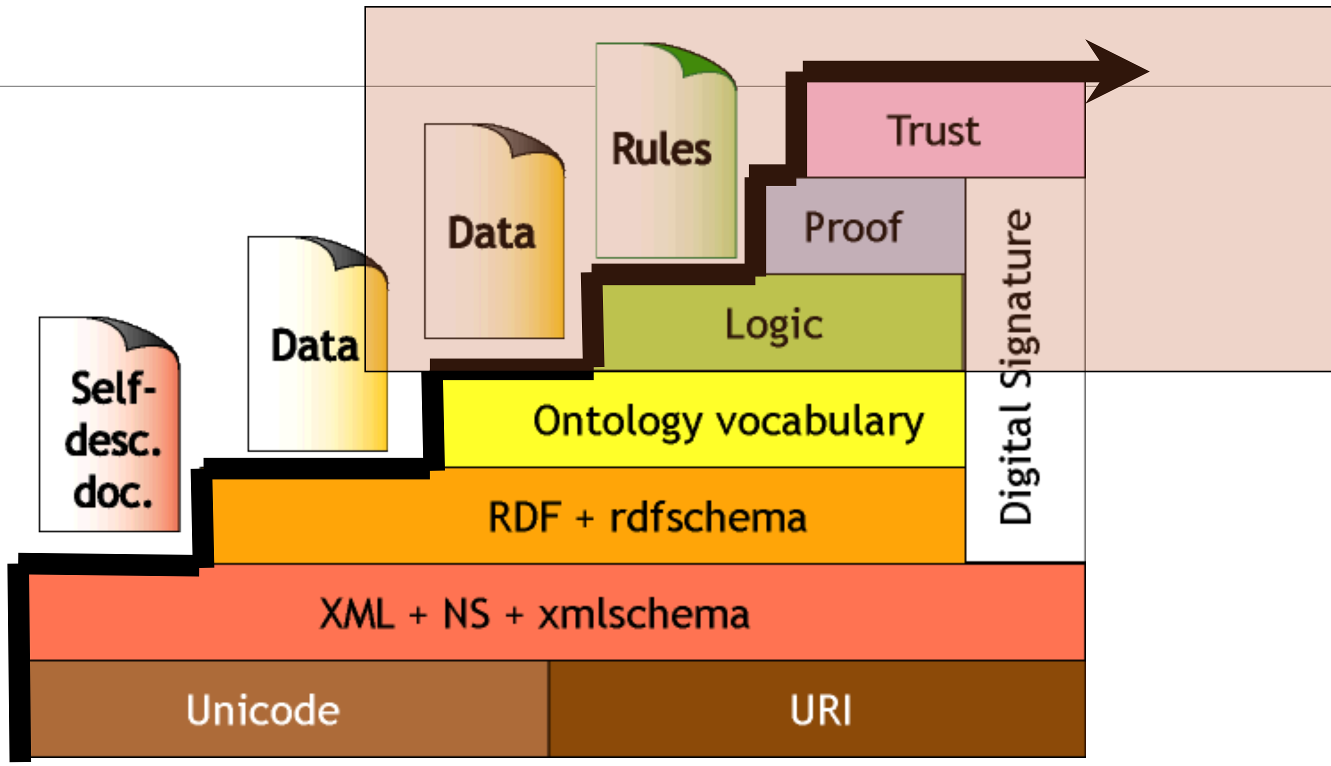
http://www.w3.org/ns/org.ttl

```
@prefix rdf:        <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs:       <http://www.w3.org/2000/01/rdf-schema#> .
@prefix owl:        <http://www.w3.org/2002/07/owl#> .
@prefix xsd:        <http://www.w3.org/2001/XMLSchema#> .
@prefix skos:       <http://www.w3.org/2004/02/skos/core#> .
@prefix foaf:       <http://xmlns.com/foaf/0.1/> .
…
@prefix :           <http://www.w3.org/ns/org#> .

# -- Meta data -----------------------------------------------------------

<http://www.w3.org/ns/org#>
    a owl:Ontology;
    owl:versionInfo "0.7";
    rdfs:label "Core organization ontology"@en;
    rdfs:comment "Vocabulary for describing organizational structures, specializable to a
broad variety of types of organization."@en;
    dct:created "2010-05-28"^^xsd:date;
    dct:modified "2010-06-09"^^xsd:date;
    dct:modified "2010-10-08"^^xsd:date;
…
    rdfs:seeAlso <http://www.w3.org/TR/vocab-org/> ;
    .

# -- Organizational structure -----------------------------------------------------------

org:Organization a owl:Class, rdfs:Class;
    rdfs:subClassOf  foaf:Agent;
    owl:equivalentClass foaf:Organization;
    rdfs:label "Organization"@en;
    rdfs:label "Organisation"@fr;
    owl:hasKey (org:identifier) ;
    rdfs:comment """Represents a collection of people organized together into a community
or other social, commercial or political structure. … Alternative names: _Collective_
_Body_ _Org_ _Group_"""@en;
    rdfs:comment """Représente un groupe de personnes organisées en communauté où tout
autre forme de structure sociale, commerciale ou politique. … code provenant d'une liste
de code."""@fr;
    rdfs:isDefinedBy <http://www.w3.org/ns/org> ;
    .
```

```
- <rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:skos="http://www.w3.org/2004/02/skos/core#" xmlns:foaf="http://xmlns.com/foaf/0.1/"
    xmlns:org="http://www.w3.org/ns/org#" xmlns:gr="http://purl.org/goodrelations/v1#"
    xmlns:owl="http://www.w3.org/2002/07/owl#" xmlns:dct="http://purl.org/dc/terms/"
    xmlns:prov="http://www.w3.org/ns/prov#" xmlns:owlTime="http://www.w3.org/2006/time#"
    xmlns:xsd="http://www.w3.org/2001/XMLSchema#" xmlns:vcard="http://www.w3.org/2006/vcard/ns#"
    xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#">
  + <owl:Ontology rdf:about="http://www.w3.org/ns/org#">
  + <rdfs:Class rdf:about="http://www.w3.org/ns/org#Organization">
  - <rdfs:Class rdf:about="http://www.w3.org/ns/org#Role">
      <rdfs:label xml:lang="fr">Rôle</rdfs:label>
    - <owl:disjointWith>
        <owl:Class rdf:about="http://www.w3.org/ns/org#ChangeEvent" />
      </owl:disjointWith>
      <rdfs:subClassOf rdf:resource="http://www.w3.org/2004/02/skos/core#Concept" />
    - <owl:disjointWith>
        <owl:Class rdf:about="http://www.w3.org/ns/org#Site" />
      </owl:disjointWith>
      <rdfs:comment xml:lang="fr">Indique le rôle qu'une Personne ou un autre Agent peut avoir dans une
        Organisation. Les instances de cette classe décrivent le rôle dans l'absolu; pour indiquer une personne
        ayant ce rôle spécifique dans une Organisation, utilisez une instance de `org:Membership`. Il est
        courant que les rôles soient organisés dans une sorte de taxonomie, ce qui peut être représenté avec
        SKOS. Les propriétés de libellés standards de SKOS devraient être utilisées pour libeller le Rôle.
        D'autres propriétés additionnelles pour ce rôle, comme une fourchette de Salaire peuvent être ajoutées
        par une extension de ce vocabulaire.</rdfs:comment>
    - <owl:disjointWith>
        <owl:Class rdf:about="http://www.w3.org/ns/org#Membership" />
      </owl:disjointWith>
      <rdfs:label xml:lang="en">Role</rdfs:label>
      <rdfs:isDefinedBy rdf:resource="http://www.w3.org/ns/org" />
      <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#Class" />
      <rdfs:comment xml:lang="en">Denotes a role that a Person or other Agent can take in an organization.
        Instances of this class describe the abstract role; to denote a specific instance of a person playing that
        role in a specific organization use an instance of `org:Membership`. It is common for roles to be
```

http://www.w3.org/ns/org

Moving to the futureof the web



Semantic Web LayerCake **(Berners-Lee, 99;Swartz-Hendler, 2001)**

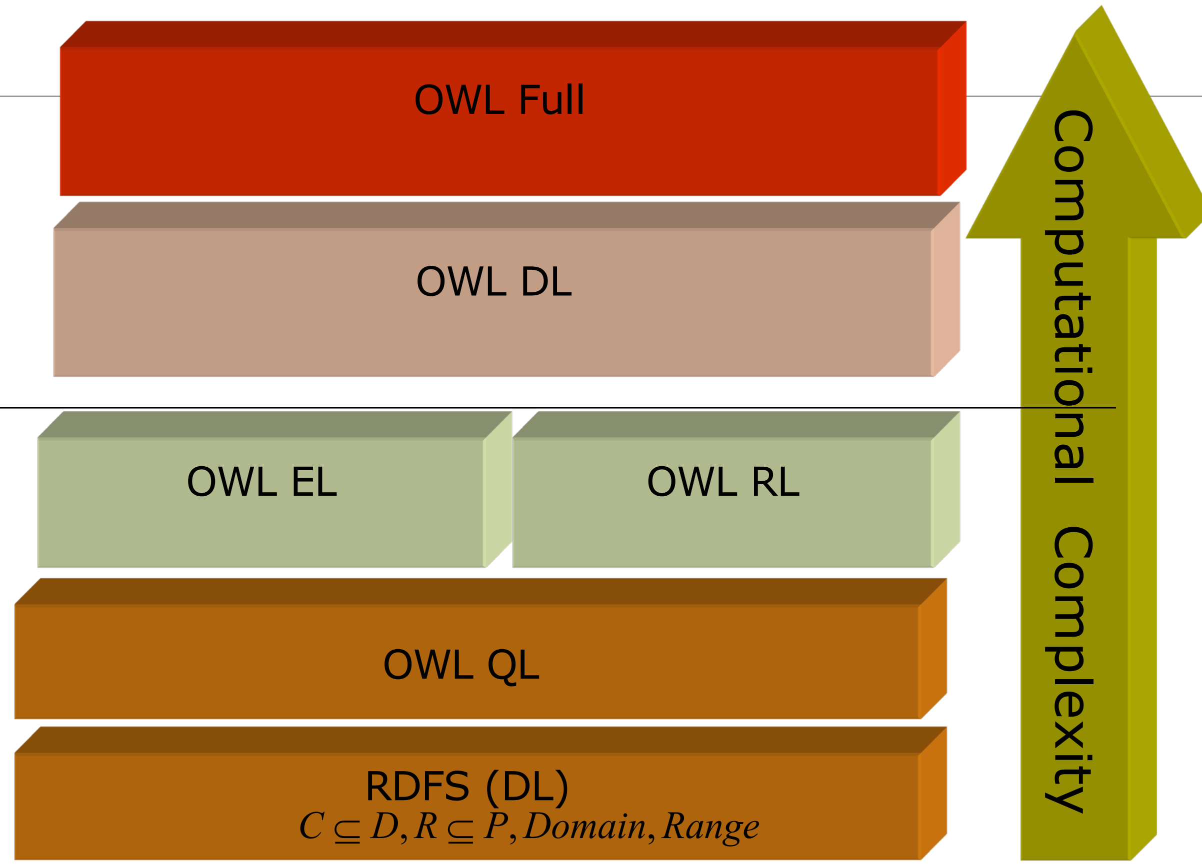
Challenge of Reasoning on Ontologies

•Undecidable

•Data Complexity open (NP-hard)
• Optimized tableau-based reasoners

• PTime-complete Data Complexity
• Efficient implementation on top of rule engine

• LogSpace Data Complexity
• Efficient evaluation on top of RDBMS



What makes a good ontology for data integration?

A *good* ontology is a *useful* ontology, an ontology that *both* humans and systems can process.

Human Usability

- **Communicable**. Naming, natural language support, etc.
- **Concise**. A simple way to describe the key entities of the model and yet able to infer many facts
- **Consistent**. Naming conventions and modeling patterns
- **Authoritative** to domain experts
- **Documented**, not just descriptions, but also provenance
- **Managed and maintained** by people throughout the model lifecycle.
- **Reusable** in similar domains, for similar instances.

System Usability

- **Scalable** so large amounts of data can be parsed, stored and retrieved.
- **Efficient** query and inferencing
- **Programmable** solutions, both in open and closed data paradigms.
- **Open** infrastructure and tools

- ***Formal*** *representation of* ***knowledge*** *in a particular domain*
- *Formally defines key* ***concepts*** *and* ***relations*** *in the domain*
- *Specifies relationships between those key concepts and relations*
- *Supports* ***automated reasoning*** *about entities in the domain*

Using Ontology

- Visually via tools like Protégé - https://protege.stanford.edu/
- Programmatically with APIs like
  - Jena (Java) - https://jena.apache.org/documentation/ontology/
  - OwlReady2 (Python) - https://bitbucket.org/jibalamy/owlready2/src/master/
  - Rdflib (Python) - https://github.com/RDFLib/OWL-RL
- A compendium of resources - https://github.com/totogo/awesome-knowledge-graph

Code Illustration

On Github:
https://github.com/biplav-s/course-nl/blob/master/l11-ontology/Exploring%20ontologies.ipynb

Knowledge Graph

- No clear definition
  - "Towards a Definition of Knowledge Graphs," by Lisa Eherlinger and Wolfram Wöß, CEURWorkshop Proceedings. 2016, http://ceur-ws.org/Vol-1695/paper4.pdf
  - For practical purposes, concepts and their relationships; not constraints
  - Driven by applications in search and information integration
  - See discussion at: http://accidental-taxonomist.blogspot.com/2019/05/knowledge-graphs-and-ontologies.html
- But ontology as knowledge graph widely used in industries
  - Industry-Scale Knowledge Graphs: Lessons and Challenges, CACM 2019, https://cacm.acm.org/magazines/2019/8/238342-industry-scale-knowledge-graphs/fulltext

KG Usage

	Data model	Size of the graph	Development stage
Microsoft	The types of entities, relations, and attributes in the graph are defined in an ontology.	~2 billion primary entities, ~55 billion facts	Actively used in products
Google	Strongly typed entities, relations with domain and range inference	1 billion entities, 70 billion assertions	Actively used in products
Facebook	All of the attributes and relations are structured and strongly typed, and optionally indexed to enable efficient retrieval, search, and traversal.	~50 million primary entities, ~500 million assertions	Actively used in products
eBay	Entities and relation, well-structured and strongly typed	Expect around 100 million products, >1 billion triples	Early stages of development and deployment
IBM	Entities and relations with evidence information associated with them.	Various sizes. Proven on scales documents >100 million, relationships >5 billion, entities >100 million	Actively used in products and by clients

Figure courtesy: Industry-Scale Knowledge Graphs: Lessons and Challenges, CACM 2019

Lecture 5: Concluding Comments

- We looked at how to improve the quality of data
- Data preparation: handling missing values
- Importance of annotation and methods
  - Glossary
  - Taxonomy, Is-a relationship
  - Ontology

Concluding Segment

About Next Lecture – Lecture 6

Lecture 6: Analysis

- Machine Learning
- Structured Data: Supervised Methods
- Quiz 1