Ontology-based Standards for Smart Cities

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Motivation

• **Data Interoperability**: A common data model enables city software applications to share information, plan, coordinate, and execute city tasks, and support decision making within and across city services,

• An **Ontology** can provide a **precise, unambiguous representation and interpretation (semantics)** of information and knowledge commonly shared across city services.
What is an Ontology?

• Answers the questions:
  • What are the core concepts and properties that span the domain’s data?
  • To what extent can we generalize them in a useful way?
  • What are the key distinctions?
    • Can we formally define necessary and/or sufficient conditions (using properties) for something to be an example (member) of a concept?

• More than a reference model (vocabulary) for a domain:
  A precise, formal (logical language) representation of the meaning of concepts and properties
Ontology Components

**Micro-Theory**
- Axioms/Rules
- Deduction – answering questions

**Definitions and Constraints**
- Class Definitions (in Logic)
- Automated classification

**Knowledge Graph**
- Classes, Properties, Instances
- (boosted with) Taxonomy and Inheritance

**Transportation Planning**
- Transportation Planning predicts transportation demand over a multi-decade horizon.
- In order to predict demand, it has to simulate how the city will change over those decades.
- For example, how households and their members will change over time, and their changing transportation requirements as they age.

- Residents, Households, members
- Transportation Network
- Vehicles
City Resident

• Cities provide many services to their residents, but in order to receive those services, the validity of their residency must be determined.
  • For example, free transportation for senior residents
• Possible uses of an ontological description of a city resident include:
  • Verifying that a person who requests a service is a resident
  • Determining in a database of people what subset are residents of the city
  • Validating manually provided classifications of residency
• How would an ontology help?
Definition Example: City Resident

- **Toronto**: “you are identified as a resident if you reside in, own property, or own or operate a business in Toronto” (311 Toronto).

- **Beijing**: “all individuals holding the nationality of the People’s Republic of China who [have] a domicile in Beijing and nowhere else. If the individual maintains a regular dwelling somewhere else, the more regular dwelling is considered their place of residence” (Li, 1991).

- **New York**: “the place which an individual intends to be his permanent home – the place to which he intends to return. It is the home with range of sentiment, feeling and permanent association. One must be domiciled in New York and maintain a home in New York, the time spent in the State is irrelevant” (McGladrey, 2009).

- **Germany**: “a resident of Germany generally refers to an individual who has a domicile in Germany or spends more than six consecutive months in Germany (habitual place of abode)” (Seidel, 2011).
“you are identified as a resident if you reside in, own property, or own or operate a business in Toronto”
Definitions and Constraints
Semantics of Toronto Resident

“you are identified as a resident if you reside in, own property, or own or operate a business in Toronto”

TorontoResident subClassOf Resident
and (residesIn.Toronto
or ownsPropertyIn.Toronto
or operates.(Business
and hasAddress.(Address and inCity.Toronto)))
Different Definitions of City Resident

- Toronto Resident
  - residesIn
  - ownsProperty
  - operates

- Beijing Resident
  - hasAddress
  - inCity
  - citizenOf

- Mumbai Resident
  - Resident
  - Address
  - Business

Defined in terms of more fundamental properties and concepts
Micro-Theory

• For each year above the age of 14, a member of a household will leave with a probability $p(Age)$

Person(?x) and Household(?y) and memberOf(?x, ?y) and age(?x, ?z) and greaterThan(?z, 14) and probleave(?z, ?pl) ----> leave (?x, ?y, ?pl)
How are Ontologies Used?

• Data Integration:
  • Ontology to serve as an *interlingua*
  • Data and systems may be mapped into the ontology to support exchange of information

• Automated Classification
  • Definition-based classification of data

• Automated Deduction
  • New information may be inferred based on the data and knowledge of the domain formalized with the ontology.

• Model Checking:
  • Data may be automatically validated against the ontology to check whether it conforms to the definitions.
ISO/IEC 5087 Framework

**Service Level (5087-n)** spans concepts commonly associated with a particular service but still shared with other services, such as Vehicles and Transportation network. *Can be read by multiple services, but updated only by one service.*

**City Level (5087-2)** covers concepts that are general to cities and span all services such as Households, Services, Residents. *Can be read and updated by multiple services.*

**Foundation Level (5087-1)** covers very general concepts such as Time, Location, and Activity, upon which other levels are based.

*The process of development of this standard is to iteratively select a city service and apply the ontology engineering development process to create, extend and/or modify each level of the standard.*
ISO JTC1/WG 11 Smart Cities: 5087

**Example Classes/Concepts**

**Part 1**
- Recurring Events
- Location
- Time
- Units of Measure
- Change
- Activity
- Part-of

**Part 2**
- Land Use
- Building
- Household
- Person
- Organization
- Parking
- Sensors

**Part 3**
- Transportation Network
- Transit
- Vehicle
- Travel Cost
- Trip Cost
- Trip

- Bylaws
- Contract
- Program Service
- Resident
- Contact
- Resource
- Observations
- Organization
- Agent
- Agreement
5087-1: Agreement Pattern
21972/5087-2: Indicator Pattern

<table>
<thead>
<tr>
<th>Class</th>
<th>Property</th>
<th>Value Restriction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicator</td>
<td>sch:identifier</td>
<td>exactly 1 xsd:string (begins with IND)</td>
</tr>
<tr>
<td></td>
<td>sch:name</td>
<td>exactly 1 xsd:string</td>
</tr>
<tr>
<td></td>
<td>sch:description</td>
<td>&quot;Average Number of Skills each Job Seeker gained&quot;</td>
</tr>
<tr>
<td></td>
<td>definedBy</td>
<td>exactly 1 xsd:string (begins with ORG)</td>
</tr>
<tr>
<td></td>
<td>forOutcome</td>
<td>only xsd:string (begins with OUT)</td>
</tr>
<tr>
<td></td>
<td>hasSimilarIndicator</td>
<td>only xsd:string (begins with SI)</td>
</tr>
<tr>
<td></td>
<td>hasThreshold</td>
<td>exactly 1 xsd:string</td>
</tr>
<tr>
<td></td>
<td>sch:dateCreated</td>
<td>exactly 1 &quot;yyyy-mm-dd&quot;</td>
</tr>
<tr>
<td></td>
<td>sch:provider</td>
<td>max 1 xsd:string</td>
</tr>
</tbody>
</table>

**Vocabulary**

**ISO/IEC 21972:2020:**
Representing textual descriptions of Indicators using a semantically precise representation.

Enables automated comparison/analysis of Indicators.
5087-2: Program/Service Pattern
5087-3: Trip Pattern

Transit Trip
A Transit Trip is a specialized type of trip that (typically) occurs on a predefined route. The start and end location of a Transit Trip must be designated Stop Points and the trip must be performed with a Transit Vehicle.
Methodology

Our goal is to identify, define, formalize and validate urban data concepts. In particular, our objectives are to:

1. Identify candidate concepts (and their properties) and their use cases through a detail analysis of existing urban vocabularies, ontologies and city enterprise software.
2. Reduce the candidate concepts from the different sources into a minimal set of core concepts.
3. Manage and curate an open process where Standards Development Organizations (SDOs) and other experts can comment on the core concepts (defined in step 2) and post modifications, use cases and new concepts.
4. Formalize and evaluate the resulting concepts from step 3.
5. Promulgate the results through the International Standards Organization.
City Data Model Project: A Global Collaboratory
citydata.utoronto.ca
Status

- Three virtual workshops on city data models held in the fall of 2019 with over 100 people registered
- 5087-1,2,3 under development by ISO/IEC JTC1
- Collaboratory in beta test, to be launched beginning of 2021
- Participation by other SDOs in the development of the city data model via the collaboratory
  - JTC1 WG11
  - W3C
  - OGC
  - TC204 WG1