iCity: Urban Informatics for Sustainable Metropolitan Growth

• A collaboration among researchers at UofT, OCAD-U and U of Waterloo, partnered with City of Toronto and Waterfront Toronto Esri Canada, IBM Canada, Cellint, and Maximum City

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The iCity Ontology: Transportation Data to Transportation Knowledge

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iCity: Three themes and 10 projects

1: URBAN INFORMATICS FOR TRANSPORTATION OPERATIONS, PLANNING & DECISION-MAKING

- Complete Streets Design
- Parking Management
- Transit Management
- Integrated Urban Modelling & Economic Analysis

2: URBAN MOBILITY & INTEGRATED URBAN SYSTEMS DESIGN

3. Visualization & Decision-Support

http://uttri.utoronto.ca/research/projects/icity/

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A Morass of Data

• Sensors, studies, simulations,…
Challenge: Semantic Interoperability

- Ability of computer systems to exchange data with unambiguous, shared meaning.

- A requirement for machine reasoning, knowledge discovery, and data federation across information systems.
The Source Of Problem

Data

Semantics

Code
Solution: an Ontology for Urban Informatics

- The iCity project addresses this challenge by designing a formal representation of the transportation domain: an ontology.
The Ontology Approach

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

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

Knowledge Graph
- Classes and Properties
- Taxonomy and Inheritance
Example Knowledge Graph

```reasoning
veh1234 rdfs:type Vehicle.
veh2536 rdfs:type Vehicle.
veh1402 rdfs:type Vehicle.
network1 rdfs:type RoadSystem.
network2 rdfs:type TransitSystem.
...
veh1234 accessTo network1.
veh1234 accessTo network2.
veh1234 accessTo network1.
...
veh1234 ownedBy ttc.
veh1234 ownedBy ctc.
veh1234 ownedBy johnsmith.
```

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An Example: Definitions and Constraints

Vehicle

\exists \text{accessTo.RoadSystem}

TransitVehicle:

TransitVehicle ≡ Vehicle \land \exists \text{accessTo.TransitSystem}

TransitVehicle ⊑ ¬(HouseholdVehicle)

HouseholdVehicle:

HouseholdVehicle ≡ Vehicle \land \exists \text{ownedBy.Person}

HouseholdVehicle ⊑ ¬(TransitVehicle)

CommercialVehicle ≡ Vehicle \land \exists \text{accessTo.RoadSystem} \land ¬(TransitVehicle) \land ¬(HouseholdVehicle)

Bus ≡ TransitVehicle \land \exists \text{accessTo.RoadSystem}
Inference

**Ontology:**
Understands the domain, e.g. transportation networks, knows what an arc and a node are, and the kinds of properties they can have.

**Knowledge Graph:**
Extracted from some source/service. Arcs begin and end at nodes. Arcs may have allowable modes of access, posted speeds, current speeds, traffic incidents, …

**Microtheory:**
A focused, in-depth formalization of part of the domain, e.g. what defines a path in a transportation network.

**Question**

**Reasoning**

**Answer**
Example Road Network
Example Road Network

Is it possible to get from $n_1$ to $n_{12}$? How?
Formalization

Knowledge Graph Translation

\(<a_1> \text{rdfs:type Arc;}\)
\<\text{startNode } <n_1>;\>
\<\text{endNode } <n_2>.\>
\(<a_2> \text{rdfs:type Arc;}\)
\<\text{startNode } <n_2>;\>
\<\text{endNode } <n_1>.\>
\(<a_3> \text{rdfs:type Arc;}\)
\<\text{startNode } <n_6>;\>
\<\text{endNode } <n_2>.\>

...
Automated Reasoning

Question:
Is it possible to travel from n1 to n12?

?- path(X, point-a, point-b).

Reasoning

Arcs are paths.
(∀x, n₁, n₂) arc(x, n₁, n₂) ⊃ path(x, n₁, n₂)

Connected paths that don’t form a loop form new paths.

(∃p) path(p, n₁, n₃) ∧ partof(x, p) ∧ partof(y, p)

Answer:
Yes, there are 3 possible paths.

path(_,x01,n1,n12).
path(_,x02,n1,n12).
path(_,x02,n1,n12).
New Knowledge

• Infer the existence of paths
• Infer additional knowledge about the paths based on properties of the arcs
Final Thoughts

• Explicit specification of semantics supports:
  • Integration
  • Deduction of new knowledge
• Applications beyond the iCity project

• Ongoing Work
  • Implementation with IT-SoS
  • Development of microtheories: focused, detailed extensions to enable specialized reasoning
    • Deployment as web application(s)
  • Explore visualization solutions to support communication of the ontology and its instances.
Thank you

• Questions?
• Contact me:
  • katsumi@mie.utoronto.ca
• More on the iCity Ontology and related work:
  • http://uttri.utoronto.ca/research/projects/icity/papers/theme-one/