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Spatiotemporal and Thematic Semantic Analytics

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North Korea detonates nuclear device on October 9, 2006 near Kilchu, North Korea
Using named relationships to connect thematic entities with spatial locations in a variety of meaningful ways (different contexts)
Temporal Properties of Paths

Which soldiers were members of Platoon_45 during the interval [5, 15]?

Which soldiers were members of Platoon_45 at the same time?
Example: Bioterrorism

After the Battle

Near in Space
• New types of applications exploiting named relationships between entities (semantic graphs)
  – Data Mining – Link Mining, Graph Mining
  – Semantic Web – Semantic Analytics
    • Analysis of relationships in Large RDF graphs
    • Detecting Conflict of Interest, Collaboration, Insider Threat Problem
Two entities $e_1$ and $e_n$ are semantically connected if there exists a sequence $e_1, P_1, e_2, P_2, e_3, \ldots, e_{n-1}, P_{n-1}, e_n$ in an RDF graph where $e_i, 1 \leq i \leq n$, are entities and $P_j, 1 \leq j < n$, are properties.

[Diagram showing semantic connectivity between entities.]
Semantic Similarity

- Two entities $e_1$ and $f_1$ are semantically similar if there exist two semantic paths $e_1, P_1, e_2, P_2, e_3, \ldots, e_{n-1}, P_{n-1}, e_n$ and $f_1, Q_1, f_2, Q_2, f_3, \ldots, f_{n-1}, Q_{n-1}, f_n$ semantically connecting $e_1$ with $e_n$ and $f_1$ with $f_n$, respectively, and that for every pair of properties $P_i$ and $Q_i$, $1 \leq i < n$, either of the following conditions holds: $P_i = Q_i$ or $P_i \subseteq Q_i$ or $Q_i \subseteq P_i$ ($\subseteq$ means rdf:subPropertyOf).

- We say that the two paths originating at $e_1$ and $f_1$, respectively, are semantically similar and thus so are the entities $e_1$ and $f_1$.

![Diagram showing relationships between entities and properties]

- The diagram illustrates the relationships between entities and properties, with arrows indicating the direction of properties such as `purchased` and `paidby`. The entity `Passenger` is connected to `Ticket` and `Corporate Account`, and the names `Bill`, `Fred`, and `Smith` are associated with these entities. The property `lname` connects these names to the respective entities.
Spatial Relationship

- Position_1
  - Held_position: [2, 10]
  - Employed_unit: 101st Airborne
    - Held_position: [3, 7]
    - Member_of: Position_2

- Position_3
  - Held_position: [4, 12]
  - Employed_unit: 9th SS Panzer
    - Member_of: Axis

Temporally...

- Soldier_1
  - Trained_at: [2, 6]
  - Member_of: 101st Airborne
  - Specializes_in: Explosives

- Soldier_2
  - Trained_at: [8, 10]
  - Employed_unit: Camp Claiborne

- Soldier_3
  - Trained_at: [1, 5]
  - Member_of: 82nd Airborne

- Soldier_4
  - Member_of: Camp Claiborne

- Soldier_5
  - Employment details not explicitly shown

- Soldier_6
  - Member_of: 82nd Airborne

- Soldier_7
  - Member_of: Camp Claiborne

Thematic Relationship

- Employment and Training of Soldiers
- Position and Unit Assignment
- Specialization in Explosives
- Training Locations

Knowledge Enabled Information and Services Science
Spatial Relationships Between Entities

Examples:

– Which Military Units have spatial extents which are within 20 miles of (48.45° N, 44.30° E) in the context of Battle participation?

– Which infantry unit’s operational area overlaps the operational area of the 3rd Armored Division?

Quantitative Relationships

Qualitative Relationships
Temporal Relationships Between Entities

Examples:

- Which Speeches by President Roosevelt were given within one day of a major battle?

- Who were members of the 101st Airborne during November 1944?

Quantitative Relationships

Qualitative Relationships
Current Work

- Define a Domain-independent Ontology which integrates Spatial and Thematic Knowledge
  - Allows exploiting the flexibility and extensibility of Semantic Web data models
  - Can deal with incompleteness of information on the web
- Incorporate temporal metadata into this model
- Identify and formalize basic spatial and temporal relationship-based query operators which complement current thematic operators of SemDis

Upper-level Ontology modeling Theme and Space

Final Classification of Domain Classes depends upon the intended application

Occurrent: Events – happen and then don’t exist
Continuant: Concrete and Abstract Entities – persist over time
Named_Place: Those entities with static spatial behavior (e.g. building)
Dynamic_Entity: Those entities with dynamic spatial behavior (e.g. person)
Spatial_Occurrent: Events with concrete spatial locations (e.g. a speech)
Spatial_Region: Records exact spatial location (geometry objects, coordinate system info)

occurred_at located_at

rdfs:subClassOf property
Knowledge Enabled Information and Services Science

Occurrent

Continuant

Named Place

Dynamic Entity

Spatial Region

Spatial Occurrent

Person

City

Politician

Soldier

Military Unit

Military Event

Battle

Bombing

Vehicle

assigned_to

on_crew_of

used_in

gives

participates_in

located_at

occurred_at

Domain Ontology

Upper-level Ontology

rdfs:subClassOf used for integration

rdfs:subClassOf relationship type

Knowledge Enable
Specifies a *type* of connection between resources in the thematic dimension of our ontology.

**Schema**

```
Person: 'John Smith' on_crew_of Military_Vehicle 'B24#123' used_in Bombing

Path Template
Person.on_crew_of.Military_Vehicle.used_in.Bombing

'John Smith'.on_crew_of.Military_Vehicle.used_in.Bombing
```
\[ \rho\text{-theme} (G, t_c) \rightarrow \{ p_t \} \]

Example: find all Bombing events connected to ‘John Smith’ through a vehicle participation context

\[ \rho\text{-theme} (G, \text{‘John Smith’}.on\_crew\_of.Military\_Vehicle.\ used\_in.Bombing) \]

Result

‘John Smith’.on\_crew\_of.‘B-24#123’.used\_in.‘Bombing#456’
‘John Smith’.on\_crew\_of.‘B-24#123’.used\_in.‘Bombing#789’

G = temporal RDF Graph, tc = thematic context, \( p_t \) = thematic context instance
Thematic Contexts Linking Non-Spatial Entities to Spatial Entities

- E1: Soldier
  - assigned_to: E8: Military_Unit
  - occurred_at: E5: Battle
  - located_at: E4: Address
- E2: Soldier
  - lives_at: E6: Address
  - located_at: E4: Address
- E3: Soldier
  - lives_at: E6: Address
  - located_at: E4: Address
- E4: Address
- E5: Battle
- E6: Address
- E7: Battle
- E8: Military_Unit
  - participates_in: E5: Battle
  - assigned_to: E2: Soldier

Named Places | Spatial Occurrents | Dynamic Entities
• Use Temporal RDF Graphs defined by Gutiérrez, et al\textsuperscript{1}
• Models Absolute Time
• Considers time as a discrete, linearly-ordered domain
• Associate time intervals with statements which represent the valid-time of the statement
  – Essentially a quad instead of a triple

\textsuperscript{1} Claudio Gutiérrez, Carlos A. Hurtado, Alejandro A. Vaisman: \textit{Temporal RDF}. ESWC 2005: 93-107
Example Temporal Graph: Platoon Membership

- E1: Soldier assigned to [1, 10]
- E2: Platoon
- E3: Platoon assigned to [11, 20]
- E4: Soldier assigned to [5, 15]
- E5: Soldier assigned to [5, 15]
• Provide a means to query about spatial, thematic, and temporal properties/relationships of all entities

• Path Query in the thematic dimension
  – Thematic Context

• Associate spatial region with a path

• Associate temporal interval with a path

• Query operators based on properties of and relationships between associated spatial regions and temporal intervals
ρ-spatial_extent (G, {p_t}) → {p_t, sr}

Retrieves the Spatial Region connected (through occurred_at or located_at) to the terminating Spatial Entity of the context instances

Example: Where were the battles in which the ‘101st Airborne Division’ fought?

ρ-spatial_extent (G, ρ-theme (G, ‘101st Airborne Division’.participates_in.Battle))

Result

‘101st Airborne Division’.participates_in.
‘Operation Market Garden’, ‘Geom#123’

G = temporal RDF Graph, p_t = thematic context instance, sr = spatial region
Temporal Properties of Context Instances

Soldier#123

assigned_to:[3, 12]

Platoon#456

assigned_to:[6, 20]

Soldier#789

Intersection [6, 12]

Range [3, 20]
\[ \rho\text{-temporal}\_intersect \left( \{p_t\} \right) \rightarrow \{p_t, [t_1, t_2]\} \]

Retrieves the interval during which the entire path is valid

Example: Which Soldiers were members of the ‘1st Armored Division’ at the same time?

\[ \rho\text{-temporal}\_intersect \left( \rho\text{-theme} \left( G, \text{Soldier.assigned\_to.} \text{‘1st Armored Division’}.\text{assigned\_to.} \text{Soldier} \right) \right) \]

\text{Result}

‘Fred Smith’.\text{assigned\_to.}’1\text{st Armored Division’}.\text{assigned\_to.} ‘Bill Jones’, [1941:04:15, 1943:02:30]

\[ p_t = \text{thematic context instance, } [t_1, t_2] = \text{temporal interval} \]
(Thematic Context Instance $t_p$, Temporal Interval $[t_i, t_j]$, Spatial Region $sr$)

Identify 6 major Spatiotemporal Relationship Queries which can be answered by combining previously defined operators
Example: When did the 101st Airborne Division come within 10 miles of the 1st Armored Division in the context of Battle participation?

\[ S_1 \leftarrow \rho\text{-spatial}_\text{extent} (G, \rho\text{-theme} (G, '101st Airborne Division', participates\_in.Battle)) \]

\[ S_2 \leftarrow \rho\text{-spatial}_\text{extent} (G, \rho\text{-theme} (G, '1st Armored Division', participates\_in.Battle)) \]

\[ \text{ANS} \leftarrow \rho\text{-temporal}_\text{intersect} (\rho\text{-spatial}_\text{eval} (S_1, S_2, \text{distance} (S_1, S_2) \leq 10 \text{ miles})) \]
Spatiotemporal Semantic Associations

- Define setting as a **region of space** in combination with an **interval of time**
- How is entity X related to Spatial setting S? \( \rho (\text{entity}, \text{setting}) \)

How is Group 1 connected to the setting of the expected attack?
How are entity X and entity Y related w.r.t Spatial setting S? 
\[ \rho \text{ (entity, entity, setting)} \]

How are Group 1 and Group 2 connected with respect to the location of the crime?
• Idea of **Virtual Links** between entities based on Spatiotemporal information

• Possible definition of **rules** to define a virtual link type
  – **Collaboration**: entity X and Y are in close ST proximity more often than a given threshold
  – **Knows**: entity X and Y are in close ST proximity regularly
• How do temporal relationships affect association semantics
  – 2 works_for relationships (overlapping times, disjoint times, etc)

• Complex queries based on all 3 dimensions
  – Which location is the most likely storage facility for exfiltrated weapon material
    • Thematic (correct capabilities, linked to correct people)
    • Spatial (where was the material last seen)
    • Temporal (how long can the material stay out of storage)