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Spatiotemporal and Thematic Semantic Analytics

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Spatiotemporal and Thematic Semantic Analytics

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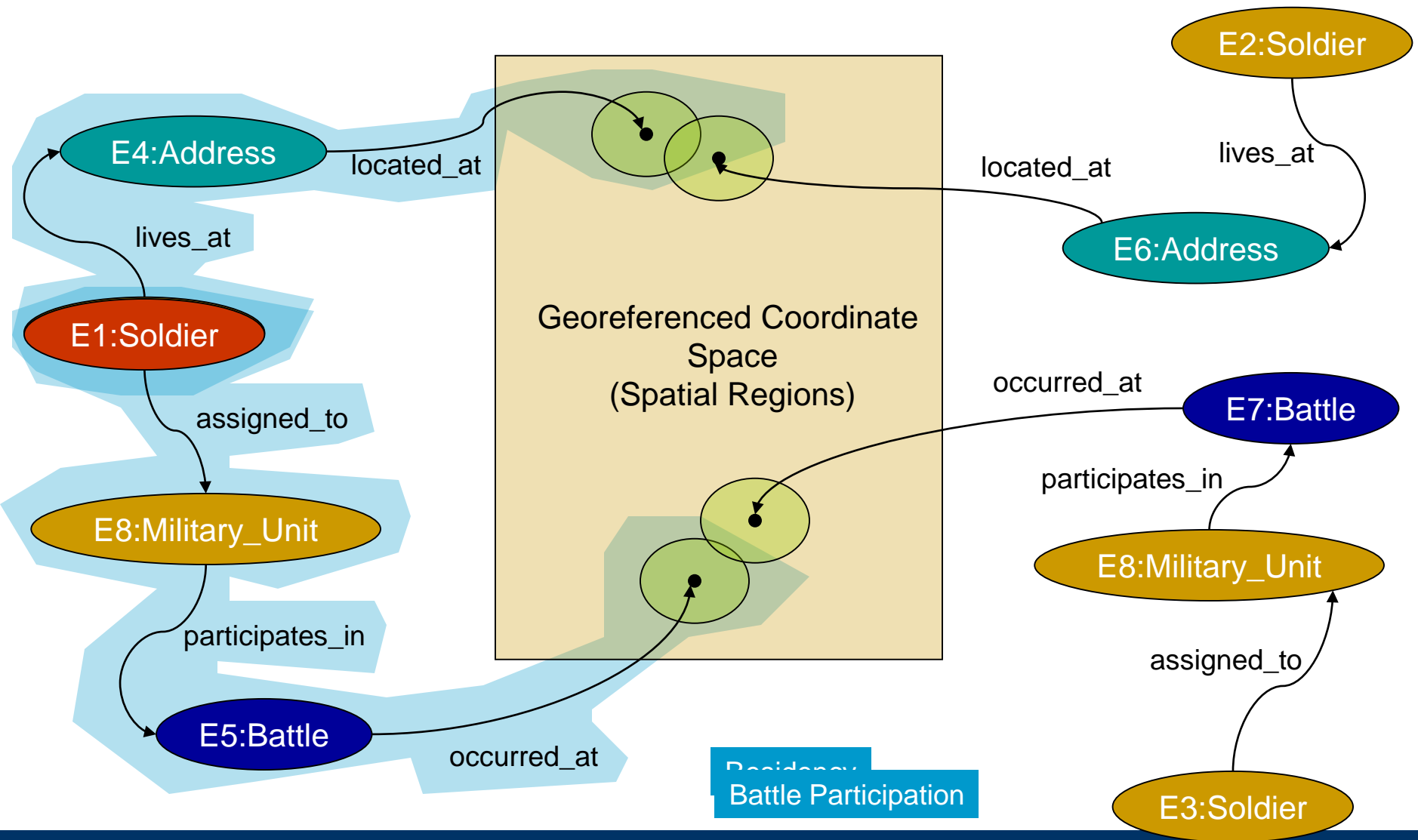
Thematic Dimension: What

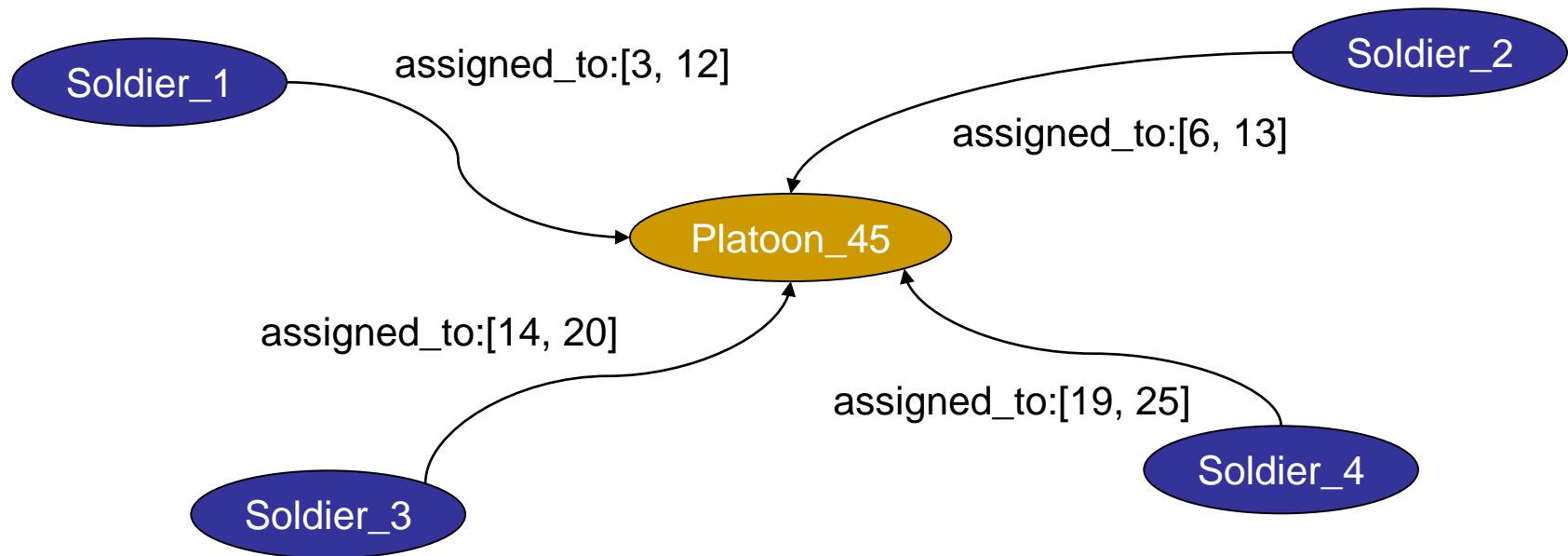
Temporal Dimension: When

North Korea detonates nuclear device on October 9, 2006
near Kilchu, North Korea

Spatial Dimension: Where

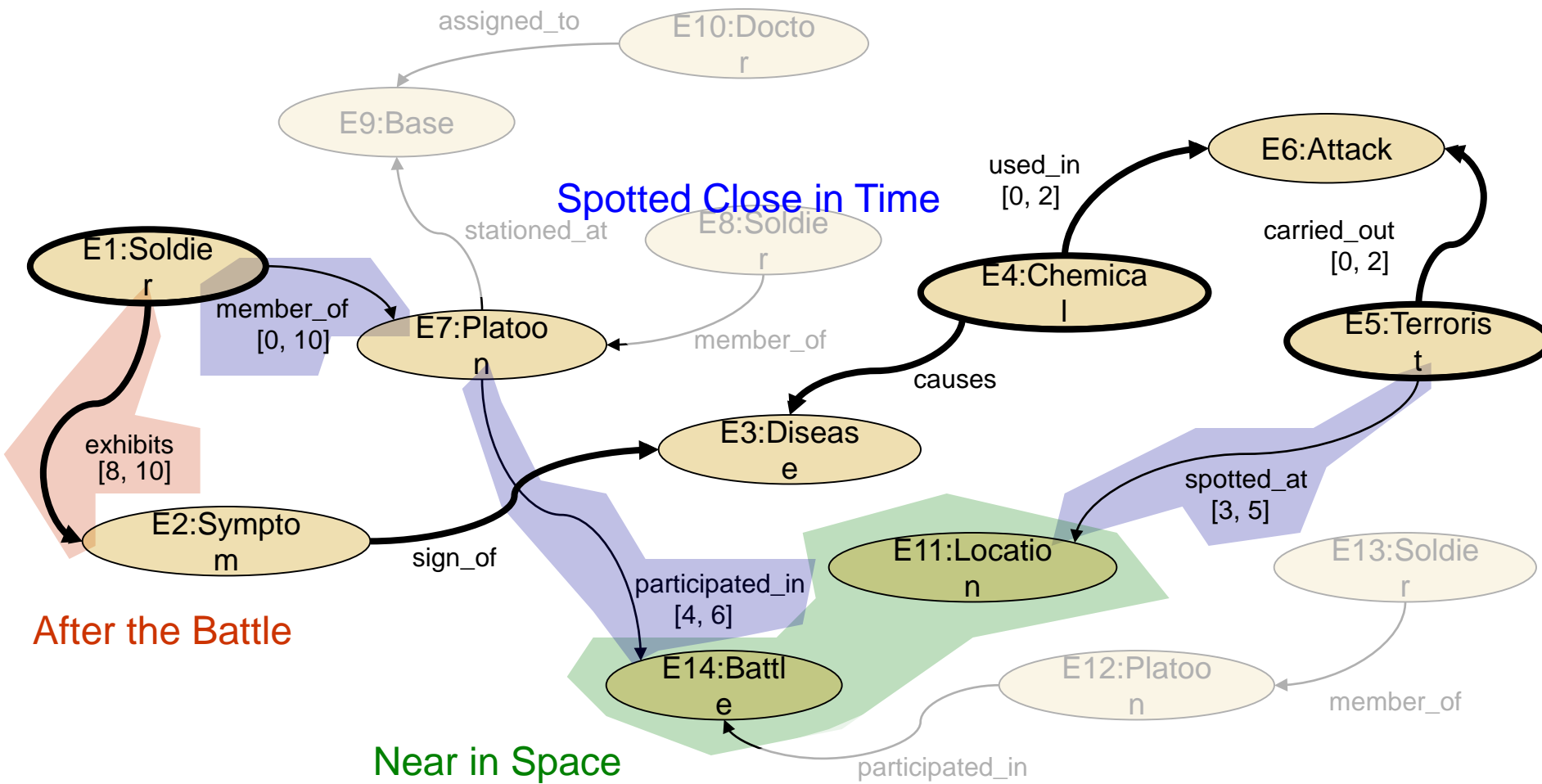
Using named relationships to connect thematic entities with spatial locations in a variety of meaningful ways (different contexts)





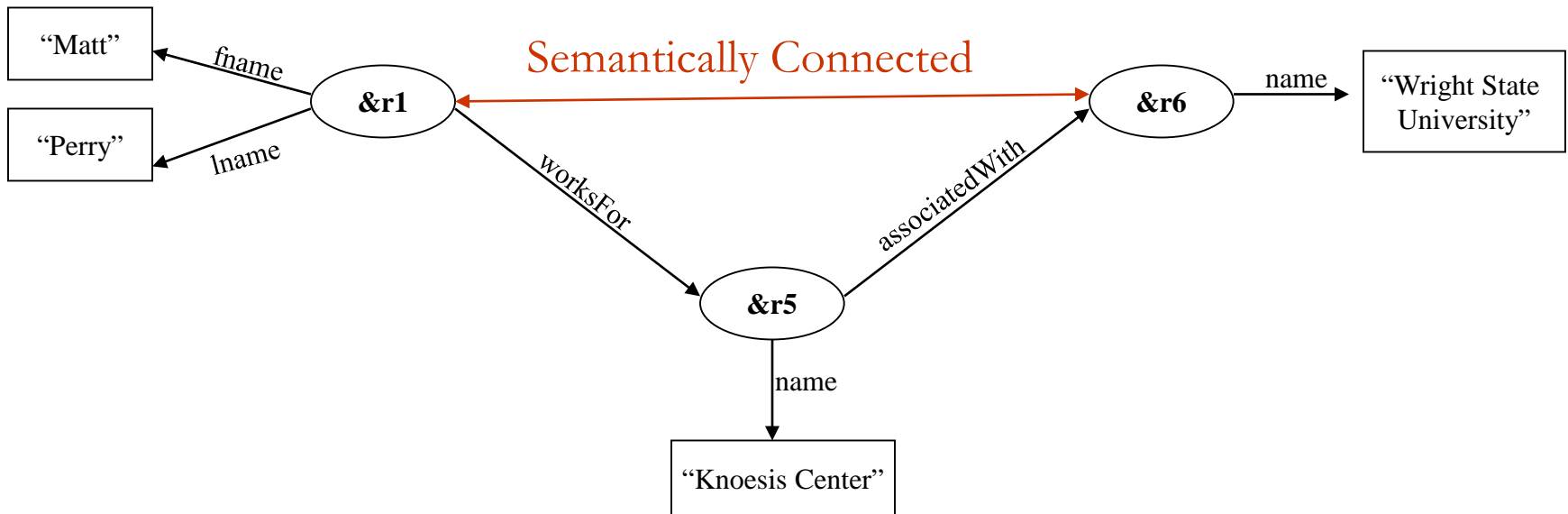
Which soldiers were members of Platoon_45 during the interval [5, 15] ?

Which soldiers were members of Platoon_45 at the same time ?

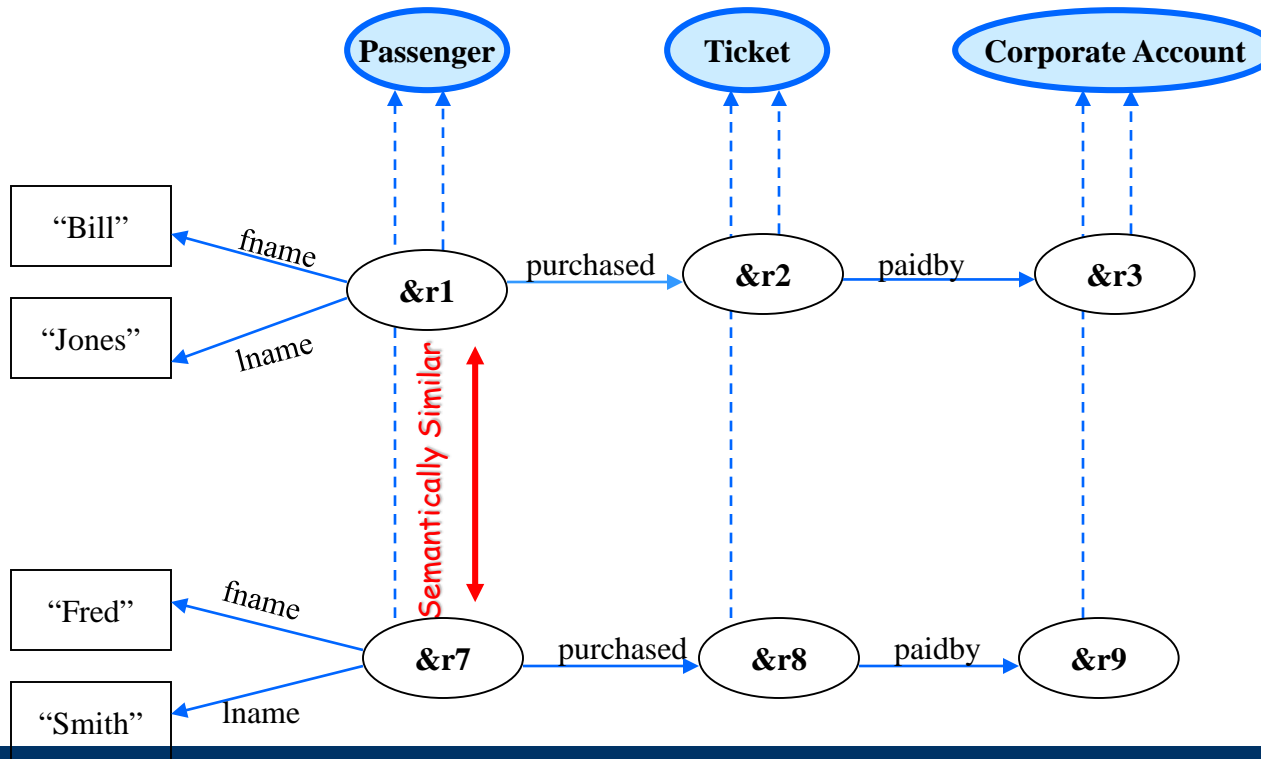


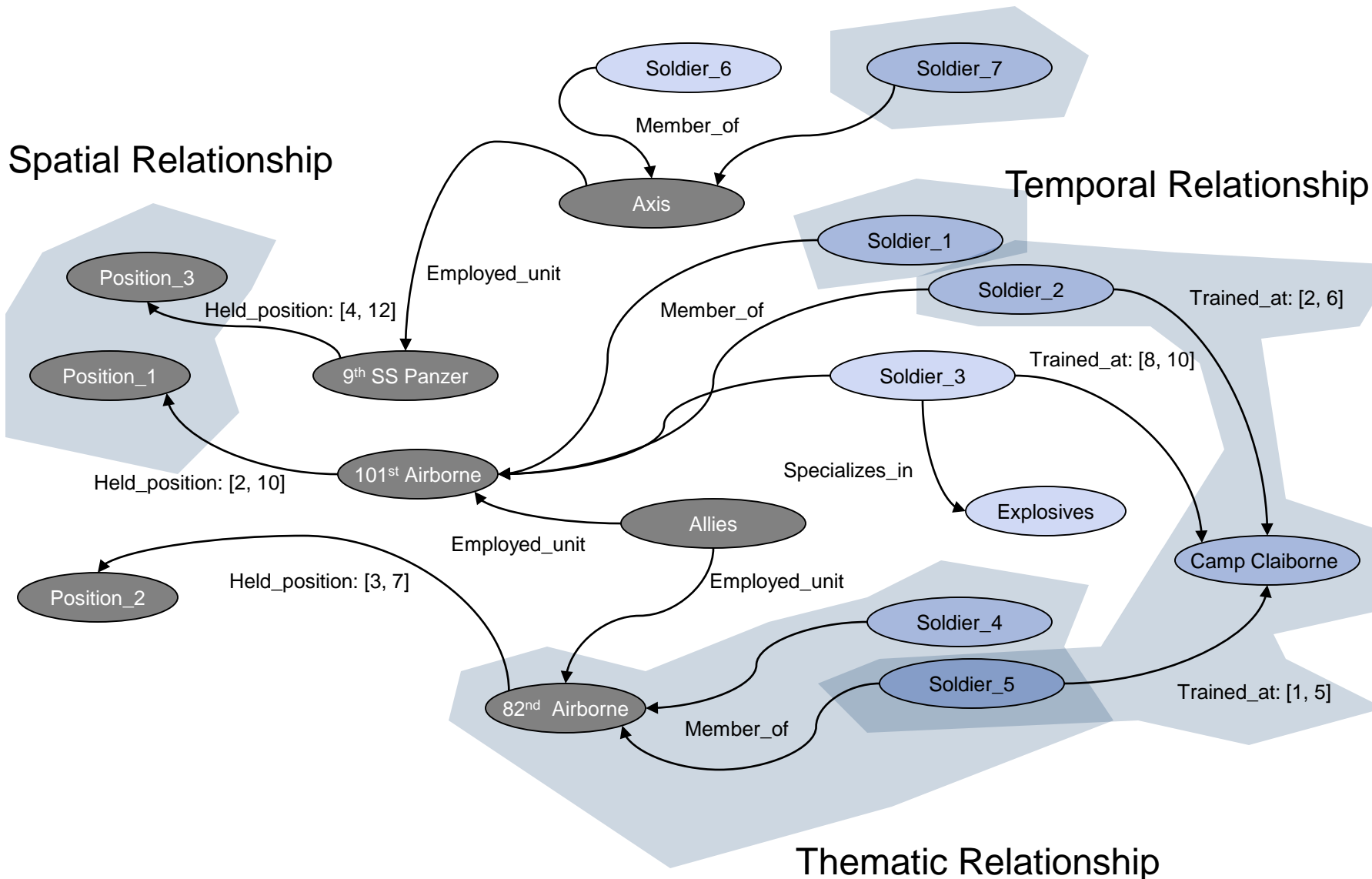
- **New types of applications exploiting named relationships between entities (semantic graphs)**
 - Data Mining – Link Mining, Graph Mining
 - Semantic Web – Semantic Analytics
 - Analysis of relationships in Large RDF graphs
 - Detecting Conflict of Interest, Collaboration, Insider Threat Problem

- Two entities e_1 and e_n are semantically connected if there exists a sequence $e_1, P_1, e_2, P_2, e_3, \dots, e_{n-1}, P_{n-1}, e_n$ in an RDF graph where $e_i, 1 \leq i \leq n$, are entities and $P_j, 1 \leq j < n$, are properties



- Two entities e_1 and f_1 are semantically similar if there exist two semantic paths $e_1, P_1, e_2, P_2, e_3, \dots, e_{n-1}, P_{n-1}, e_n$ and $f_1, Q_1, f_2, Q_2, f_3, \dots, f_{n-1}, Q_{n-1}, f_n$ 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





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

Examples:

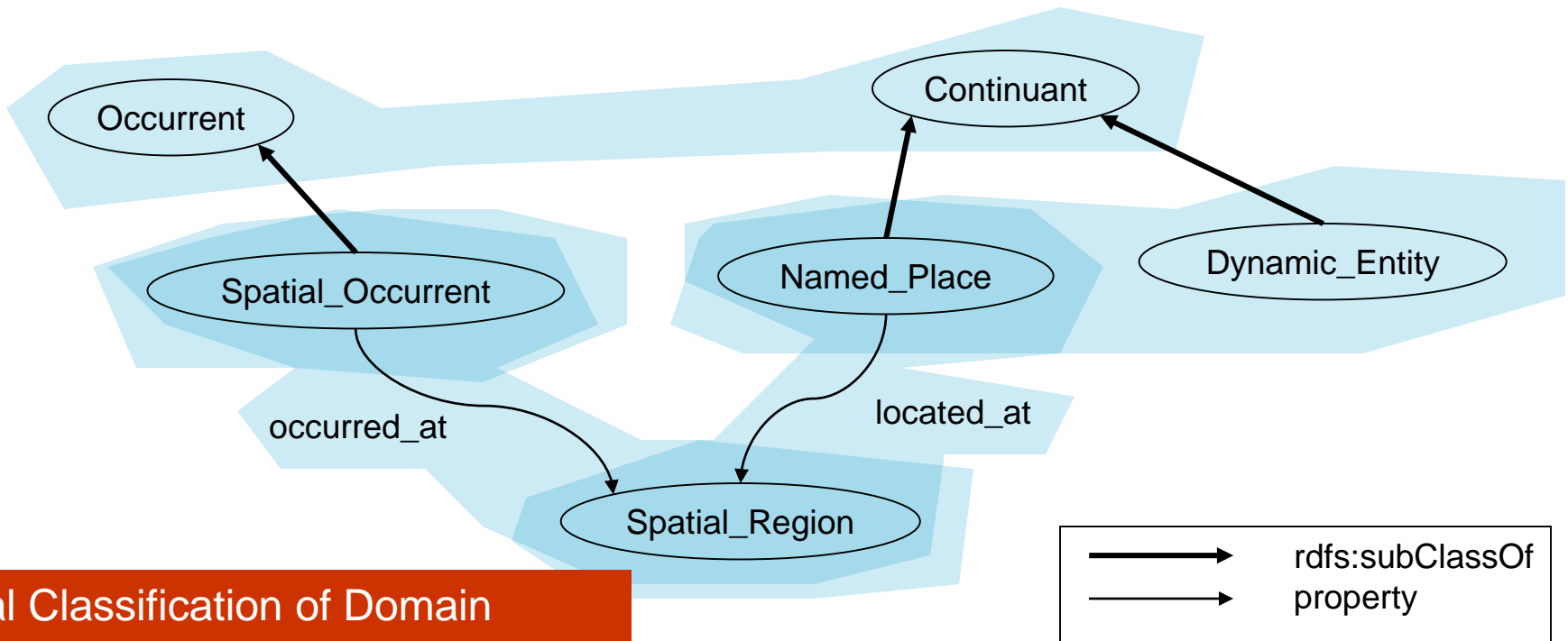
- Which Speeches by President Roosevelt were given within one day of a major battle?
- Who were members of the 101st Airborne during November 1944?

Quantitative Relationships

Qualitative Relationships

- **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**

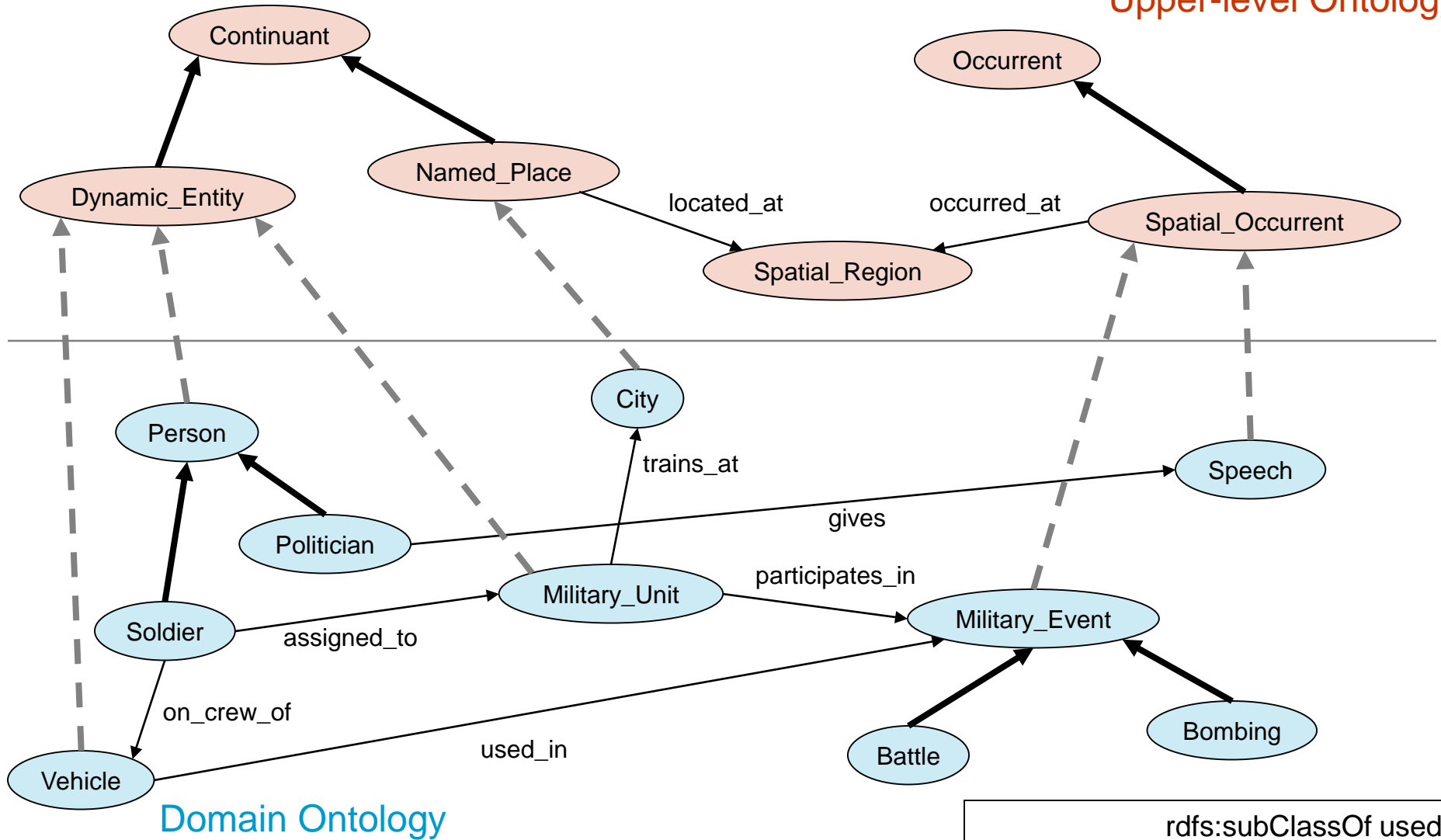
Matthew Perry, Farshad Hakimpour, Amit Sheth. "[Analyzing Theme, Space and Time: An Ontology-based Approach](#)", Fourteenth International Symposium on Advances in Geographic Information Systems (ACM-GIS '06), Arlington, VA, November 10 - 11, 2006



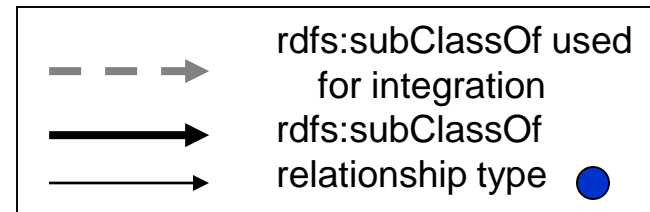
Final Classification of Domain Classes depends upon the intended application

Occurrent: Events – happen and then don't exist
occurred_at: Links Spatial Occurrents to their geographic locations
Spatial_Occurrent: Events which have a spatial location (e.g. a speech)
located_at: Links Named Places to their geographic locations
Dynamic_Entity: Those entities with dynamic spatial location (e.g. person)

Upper-level Ontology

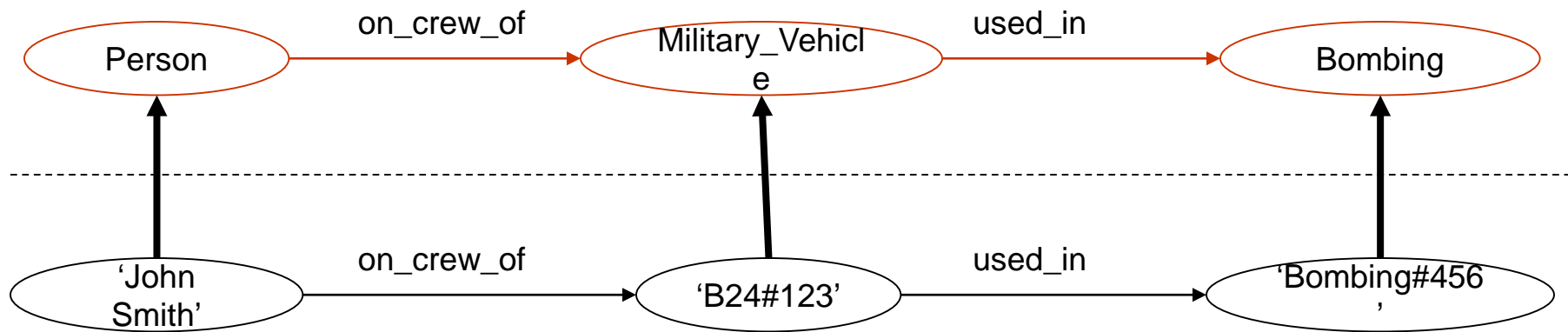


Domain Ontology



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

Schema



Path Template

Person.on_crew_of.Military_Vehicle.used_in.Bombing

'John Smith'.on_crew_of.Military_Vehicle.used_in.Bombing

$$\rho\text{-theme}(G, t_c) \rightarrow \{p_t\}$$

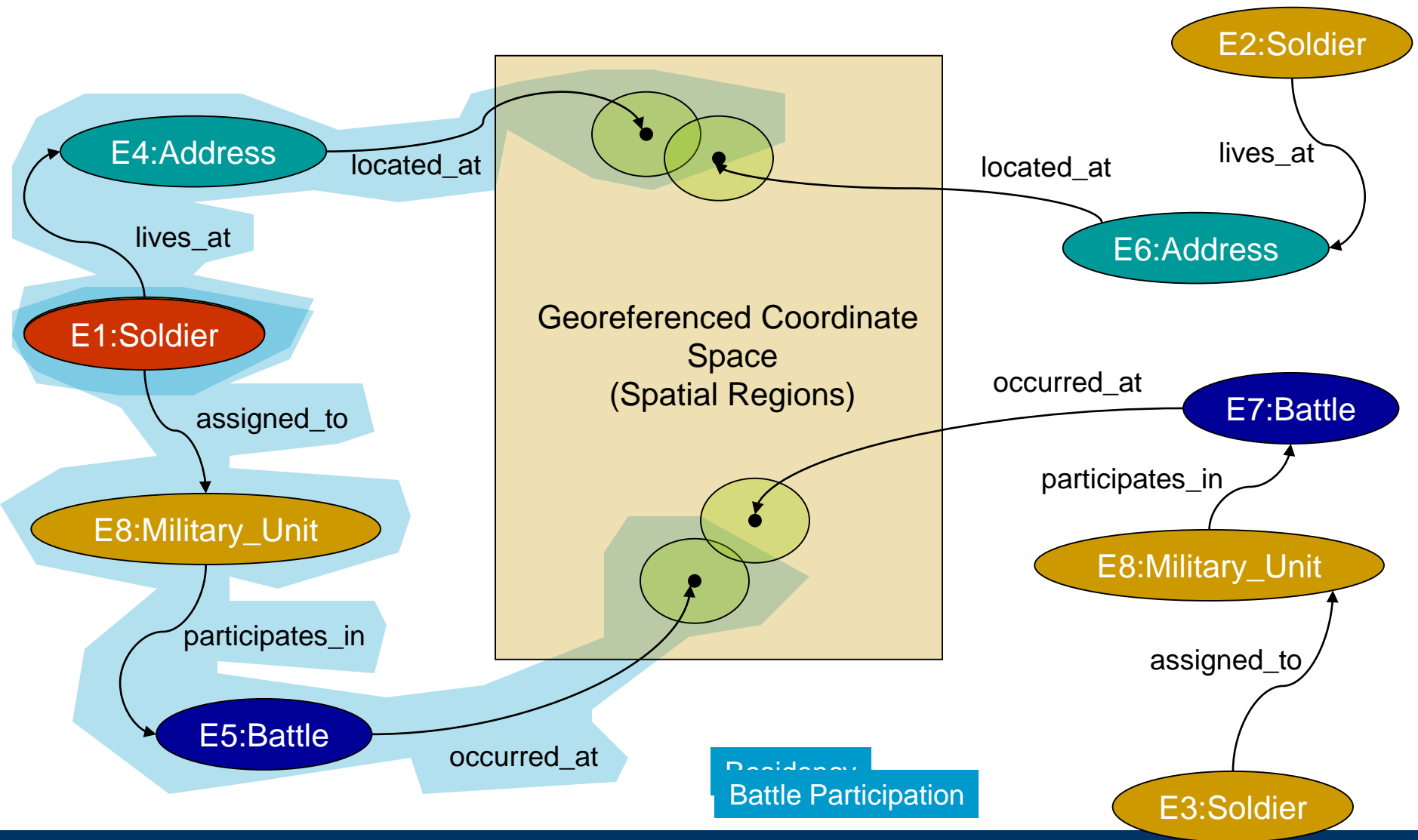
Example: find all *Bombing* events connected to *'John Smith'* through a *vehicle participation* context

$\rho\text{-theme}(G, \text{'John Smith'.on_crew_of.Military_Vehicle.used_in.Bombing})$

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'

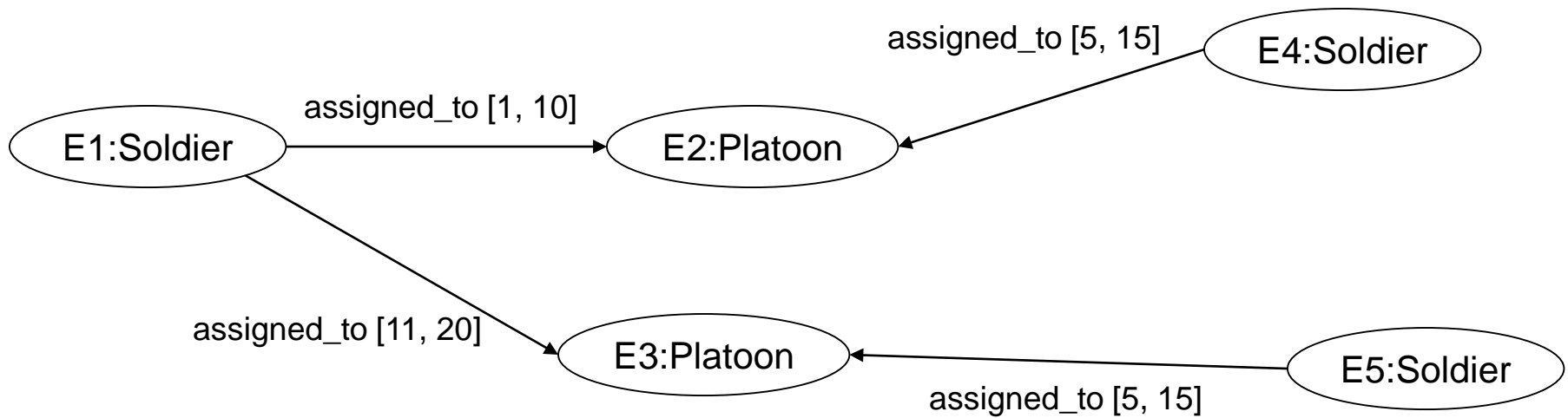
$G = \text{temporal RDF Graph}$, $t_c = \text{thematic context}$, $p_t = \text{thematic context instance}$



- Use Temporal RDF Graphs defined by Gutiérrez, et al¹
- 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

1. Claudio Gutiérrez, Carlos A. Hurtado, Alejandro A. Vaisman: *Temporal RDF*. ESWC 2005: 93-107

Example Temporal Graph: Platoon Membership



- 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

$$\rho\text{-spatial_extent} (G, \{p_t\}) \rightarrow \{p_t, sr\}$$

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

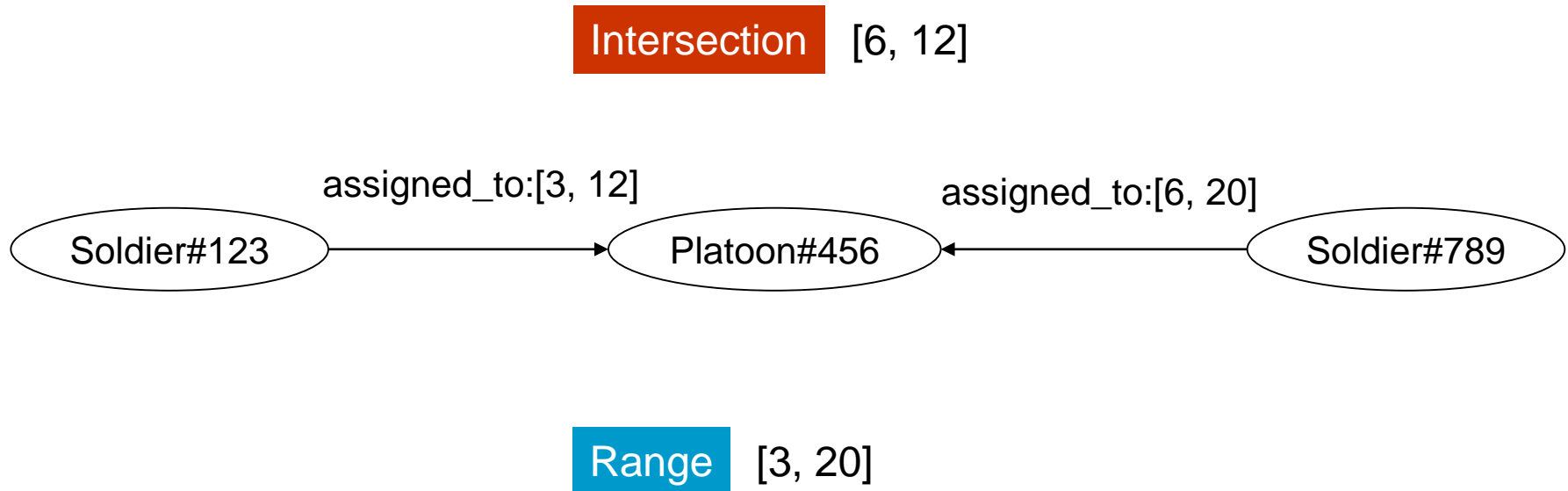
Example: Where were the battles in which the '101st Airborne Division' fought?

$$\rho\text{-spatial_extent} (G, \rho\text{-theme} (G, \text{'101st Airborne Division'}. \text{participates_in. Battle}))$$

Result

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

G = temporal RDF Graph, p_t = thematic context instance, sr = spatial region



$$\rho\text{-temporal_intersect} (\{p_t\}) \rightarrow \{p_t, [t_1, t_2]\}$$

Retrieves the interval during which the entire path is valid

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

$$\rho\text{-temporal_intersect} (\rho\text{-theme} (G, \text{Soldier.assigned_to.}'1^{\text{st}} \text{ Armored Division}'.\text{assigned_to.Soldier}))$$

Result

*'Fred Smith'.assigned_to.'1st Armored Division'.assigned_to.
'Bill Jones', [1941:04:15, 1943:02:30]*

p_t = thematic context instance, $[t_1, t_2]$ = temporal interval

(Thematic Context Instance t_p , Temporal Interval $[t_i, t_j]$, Spatial Region sr)

3 Spatial Relationship Operators

ρ -spatial_locate
 ρ -spatial_eval
 ρ -spatial_find

3 Temporal Relationship Operators

ρ -temporal_restrict
 ρ -temporal_eval
 ρ -temporal_find

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

$$S_1 \leftarrow \rho\text{-spatial_extent} (G, \rho\text{-theme} (G, \text{'101st Airborne Division'}$$

$$\text{participates_in.Battle}))$$

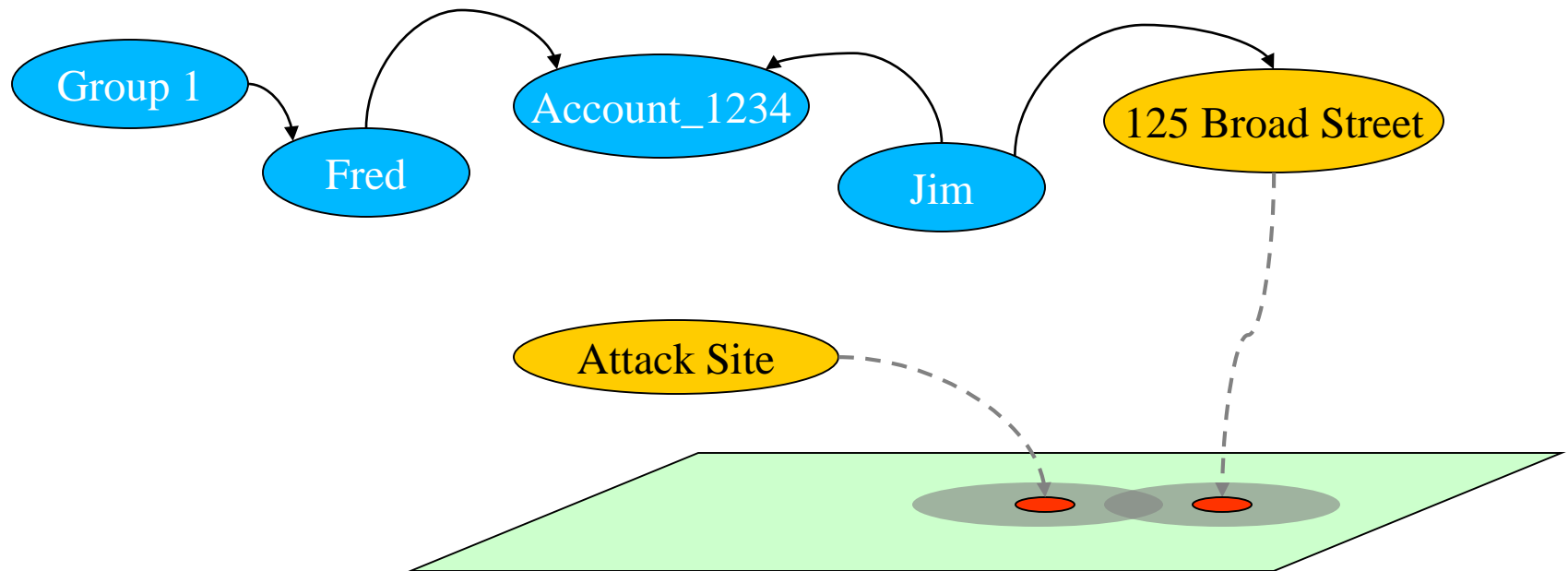
$$S_2 \leftarrow \rho\text{-spatial_extent} (G, \rho\text{-theme} (G, \text{'1st Armored Division'}$$

$$\text{participates_in.Battle}))$$

$$\text{ANS} \leftarrow \rho\text{-temporal_intersect} (\rho\text{-spatial_eval} (S_1, S_2,$$

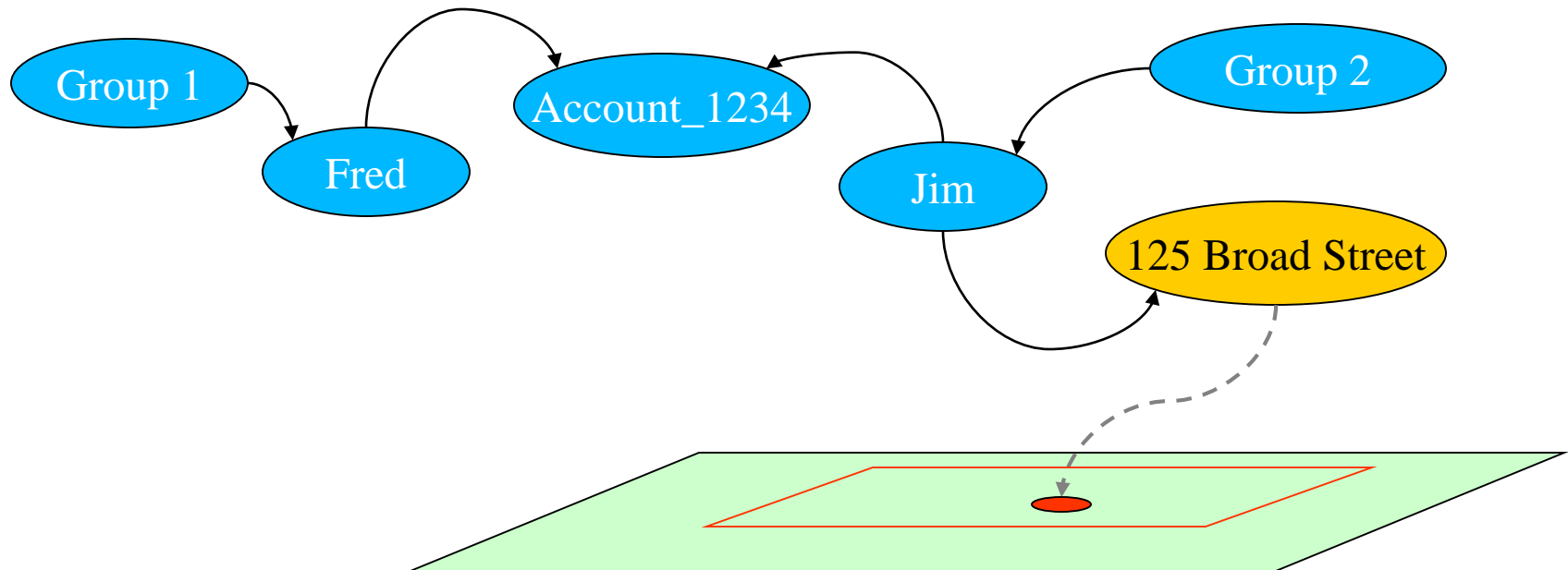
$$\text{distance} (S_1, S_2) \leq 10 \text{ miles}))$$

- 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?
 ρ (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)