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HANDLING SPATIO-TEMPORAL INFORMATION IN OWL

Semantic Web

- WWW: collection of distributed interlinked documents encoded in html
  - Content written in natural language
  - Computers don't understand their meaning
- Machine readable annotations are added and web-pages are linked by virtue of similar content
  - Content of Web-pages is encoded by special vocabularies called "ontologies"

Ontologies

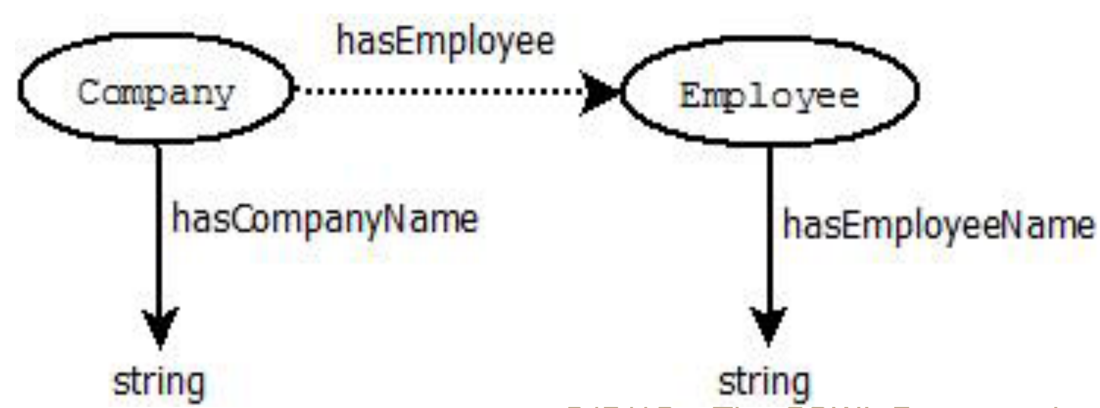
- A method for representing items of knowledge (e.g., ideas, facts, thinks) in a way that defines the relationships (e.g., part-of, functional) and classifications of concepts within a specified domain of knowledge

Typical Components of Ontologies

- Terms denote important concepts (classes of objects) of the domain
  - e.g., professors, staff, students, courses, departments
- Relationships between these terms: typically class hierarchies
  - a class C to be a subclass of another class C' if every object in C is also included in C'
  - e.g., all professors are staff members
- Properties of relations, value restrictions

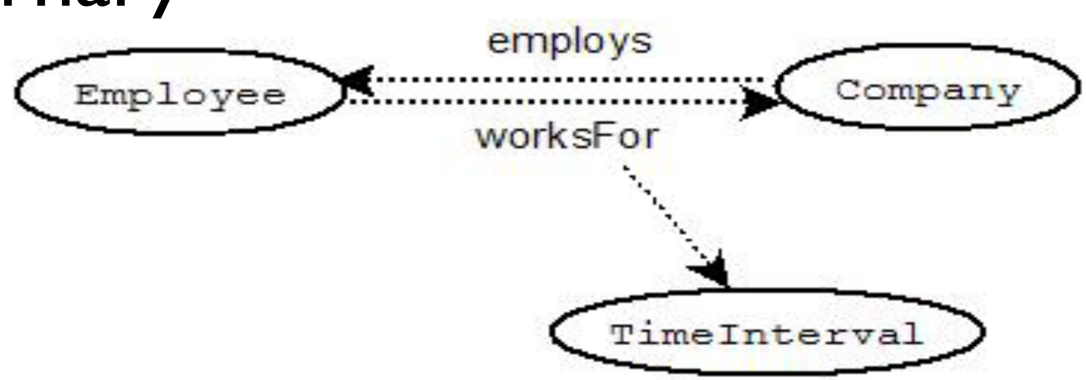
OWL

- OWL (Web Ontology Language) is a language that can be used to describe the classes, relations and their properties
  - more expressive than XML, RDF and RDF-S
- Allows to reason about the entities and check whether or not all statements and definitions are mutually consistent



Dynamic Ontologies

- Represent concepts that occur and evolve in time
  - a company will be established, hire personnel and develop products
  - relation “employs" and its inverse are ternary



OWL-Time Ontology

- OWL-Time is an OWL ontology of temporal concepts. It provides a vocabulary for describing:
  - relations between temporal entities (instants, intervals)
  - information about durations
  - provides no means of representing information that changes in time

Existing Approaches

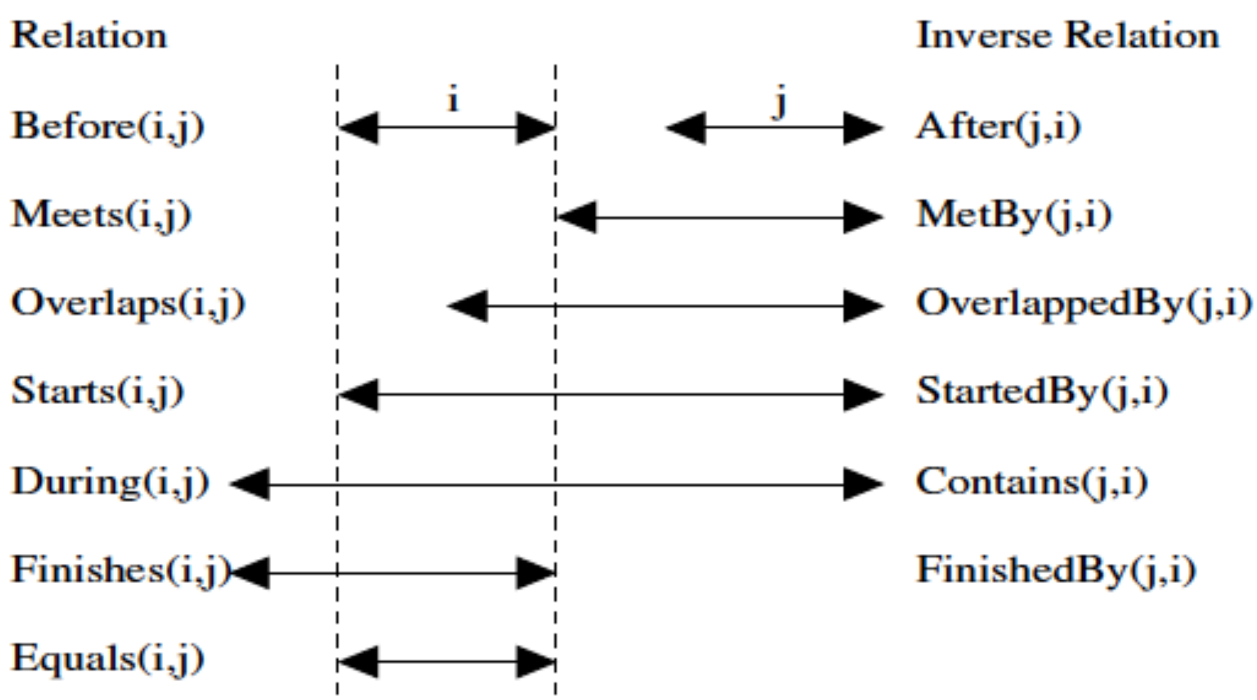
- Temporal Description Logics, Temporal RDF, Named Graphs, Reification, Versioning, N-ary, 4D-fluents approach
- Limitations:
  - Require extending OWL with new constructs
  - Qualitative information (using natural language) cant be represented
  - No Integration with spatial information
  - Limited OWL reasoning support
  - Querying of spatio-temporal information is also a problem (queries become complicated)

Proposed Solution [Batsakis 2011]

- SOWL: A framework for handling spatio-temporal information in OWL
  - Representation of quantitative and qualitative spatial and temporal information
    - ✓Using a point or an equivalent, interval-based representation
  - Consistent with existing Semantic Web standards (OWL, Pellet, Protégé, etc.)
  - Sound, Complete and Tractable reasoning embedded within the ontology
  - Querying using SOWL and TOQL query languages

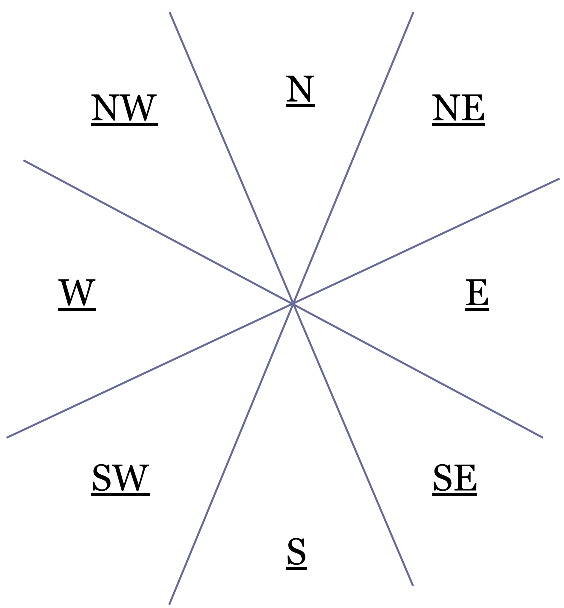
Time

- Temporal concepts by OWL-Time
- Time instants: “before”, “after”, “equals”
- Intervals: one of the 13 Allen relation

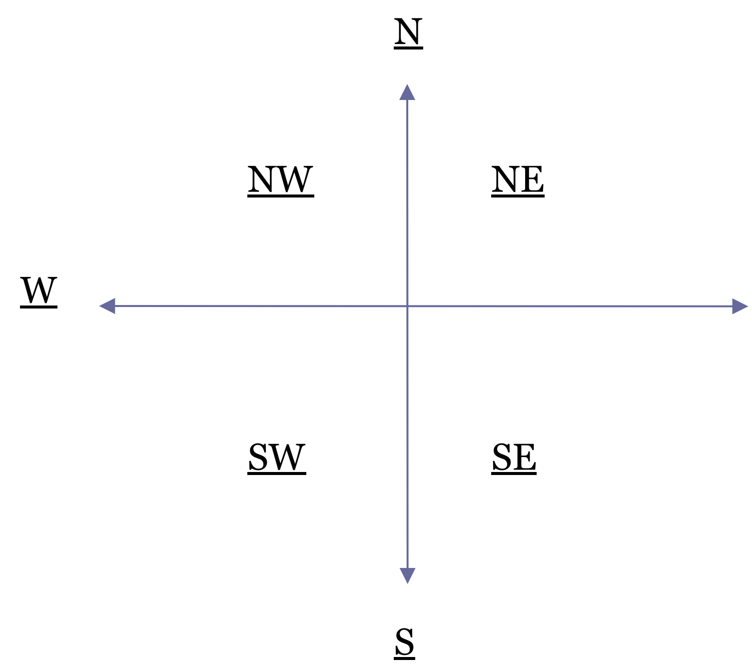


Spatial Directional Relations

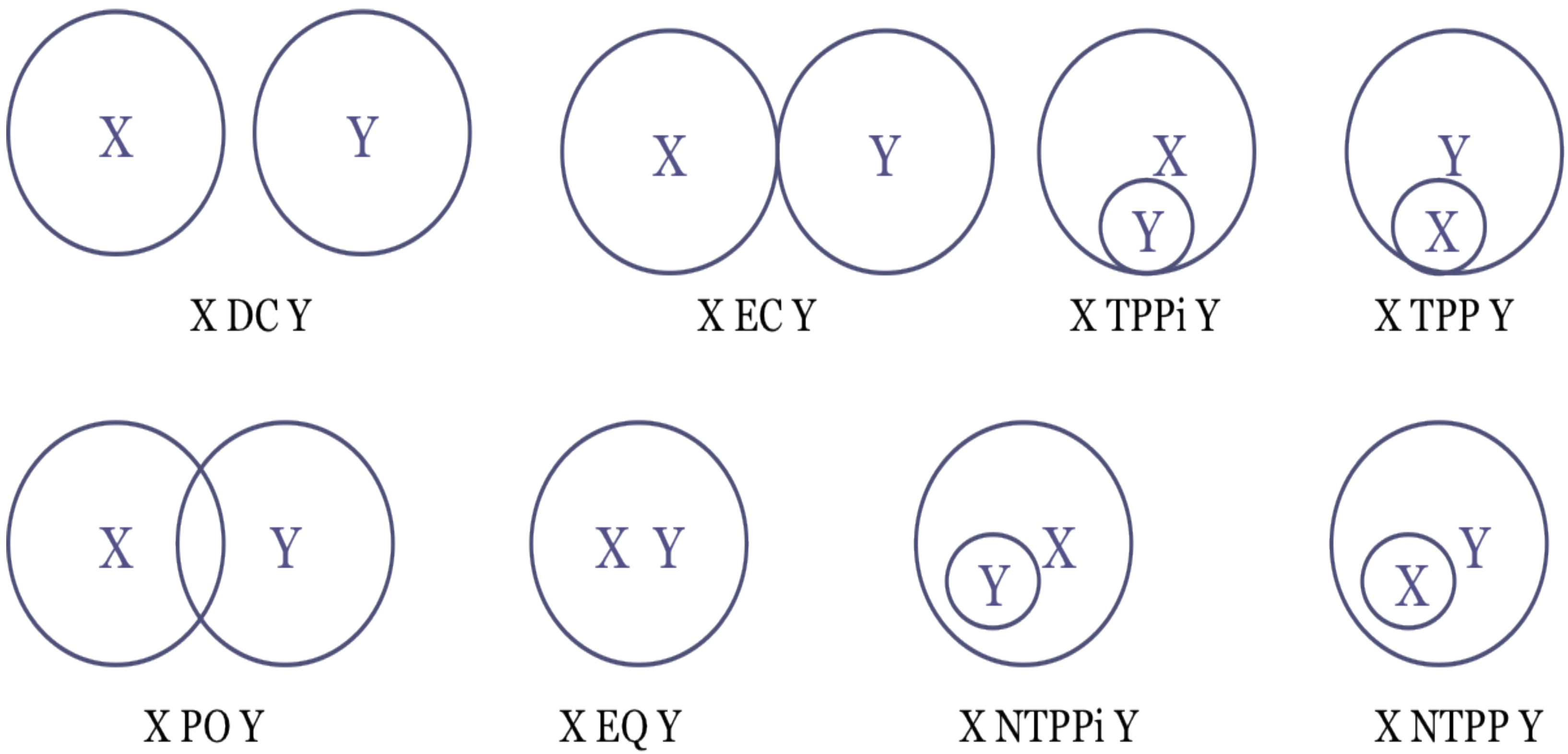
Cone-shaped



Projection-based



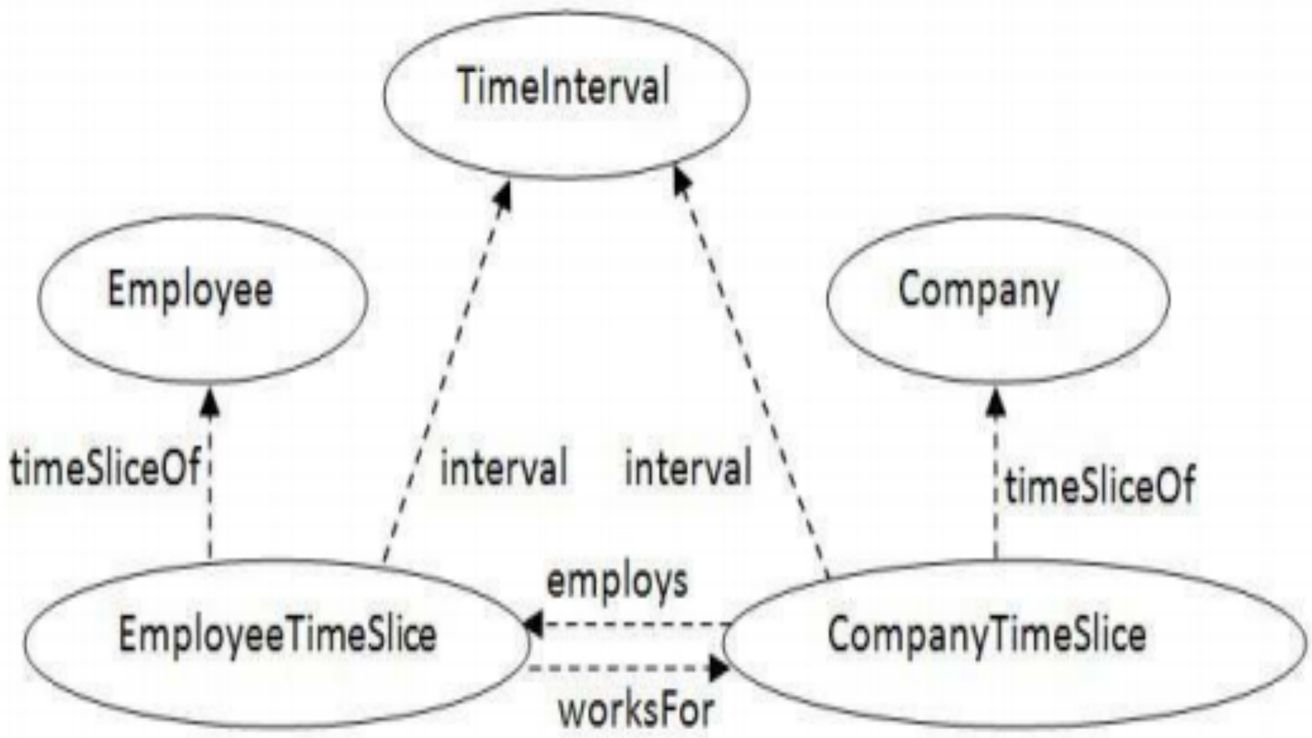
Spatial Topologic RCC-8 Relations



4D Fluents [Welty & Fikes 2006]

- Classes *TimeSlice*, *TimeInterval* are introduced
- Dynamic objects become instances of *TimeSlice*
- Temporal properties of dynamic classes become instances of *TimeInterval*
- A time slice object is created each time a (fluent) property changes

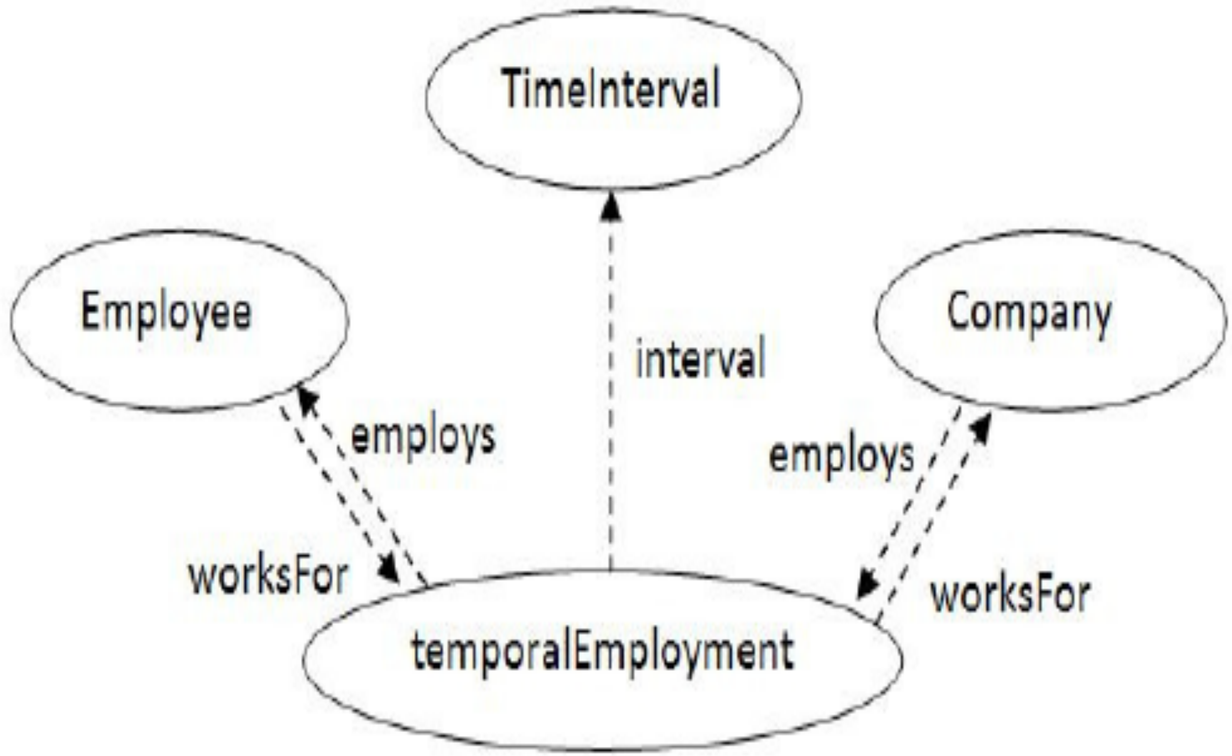
4-D fluents example



N-ary approach [Noy & Rector 2006]

- Dynamic Properties are attached to reified objects representing events
- Dynamic properties are represented as properties
- Event objects
  - Attached to specific static objects
  - Connect to Time Intervals

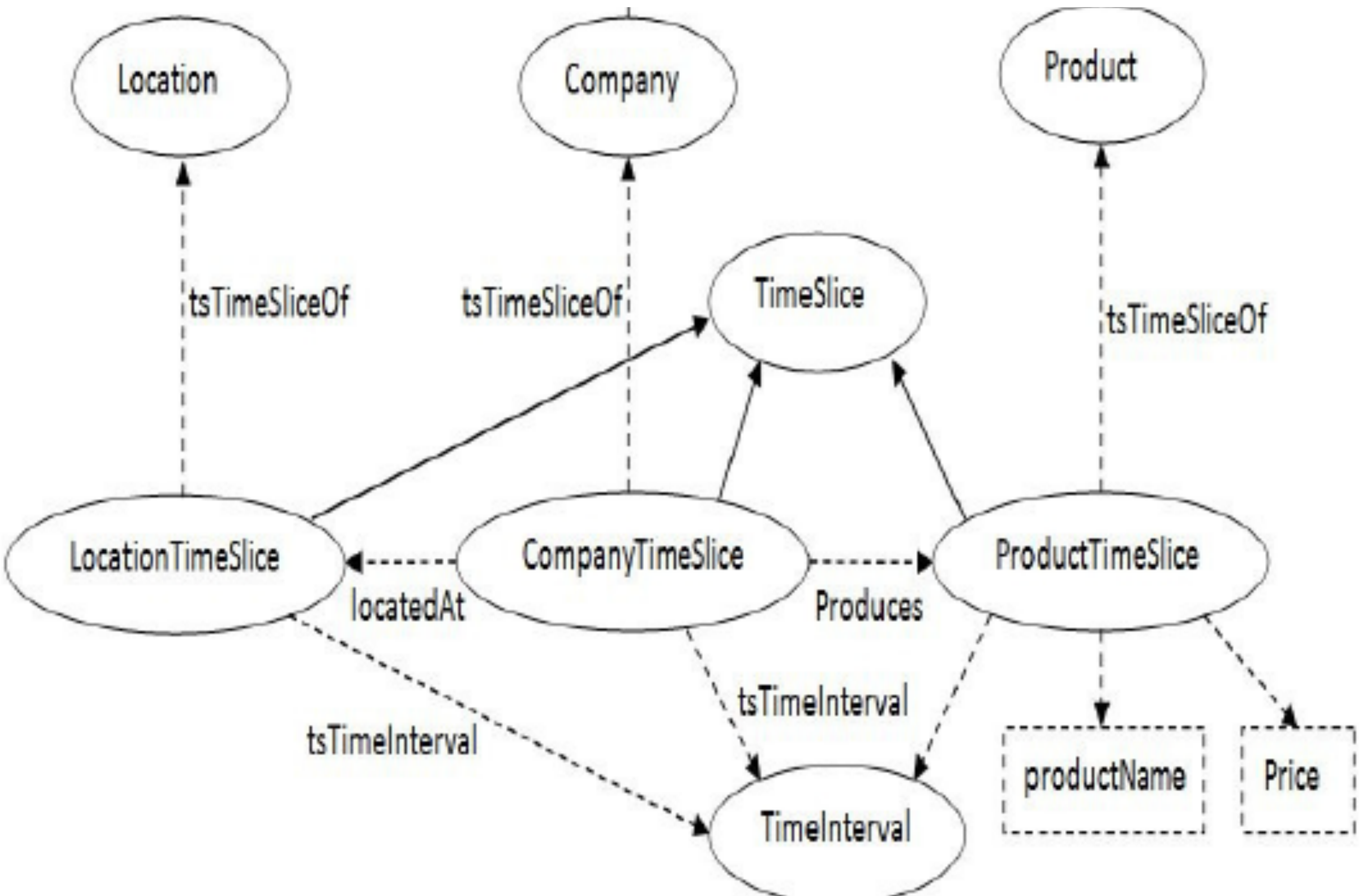
N-ary Relations example



SOWL Spatial Representation

- Static objects: Locations are properties of objects
- Dynamic (Moving) Objects: Locations are properties of TimeSlices (4D-fluents) or of the reified relation object (N-ary approach)

Example with Spatial Relation



SOWL Reasoning

- Checks consistency, infers implied relations
- Reasoning over a mix of qualitative and quantitative information:
  - Extract qualitative relations from quantitative ones
  - Reasoning over qualitative information
- Assertions may be inconsistent or new assertions may take exponential time to compute
  - Restrict to tractable sets decided by polynomial algorithms such as "Path Consistency"

Path Consistency [VanBeek & Cohen 1990]

- Path Consistency suggests composing and intersecting relations until:
  - A fixed point is reached (no additional inferences can be made)
  - An empty relation is yielded implying inconsistent assertions
- Path Consistency is tractable, sound and complete for specific (tractable) sets of temporal relations

Implementation of the Reasoner

- Compositions and intersections of relations in SWRL:
  - Before(x,y) AND Equals(y,z)→ Before(x,z)
  - (Before(x,y) OR Equals(x,y)) AND (After(x,y) OR Equals(x,y))→Equals(x,y)
- They are defined based on the composition of pairs of the basic (Allen or spatial) relations
- Composition tables for each type of representation are known to exist

Intervals: Composition Table

	B	A	D	Di	O	Oi	M	Mi	S	Si	F	Fi
B	B	B,A,D,Di,O,OiM,MiS,Si,F,Fi,Eq	B,O,M,D,S	B	B	B,O,M,D,S	B	B,O,M,D,S	B	B	B,O,M,D,S	B
A	B,A,D,Di,O,Oi,M,Mi,S,Si,F,Fi,Eq	A	A,Oi,MiD,F	A	A,Oi,Mi,D,F	A	A,Oi,Mi,D,F	A	A,Oi,MiD,F	A	A	A
D	B	A	D	B,A,D,Di,O,OiM,MiS,Si,F,Fi,Eq	B,O,M,D,S	A,Oi,Mi,D,F	B	A	D	A,Oi,MiD,F	D	B,O,M,D,S
Di	B,O,M,Di,Fi	A,Oi,Di,Mi,Si	O,Oi,D,Di,S,Si,F,Fi,Eq	Di	O,Di,Fi	Oi,Di,Si	O,Di,Fi	Oi,Di,Si	O,Di,Fi	Di	Oi,Di,Si	Di
O	B	A,Oi,Di,Mi,Si	O,D,S	B,O,M,Di,Fi	B,O,M	O,Oi,D,Di,S,Si,F,Fi,Eq	B	Oi,Di,Si	O	O,Di,Fi	O,D,S	B,O,M
Oi	B,O,M,Di,Fi	A	Oi,D,F	A,Oi,Di,Mi,Si	O,Oi,D,Di,S,Si,F,Fi,Eq	A,Oi,Mi	O,Di,Fi	A	Oi,D,F	Oi,A,Mi	Oi	Oi,Di,Si
M	B	A,Oi,Di,Mi,Si	O,D,S	B	B	O,D,S	B	F,Fi,Eq	M	M	O,D,S	B
Mi	B,O,M,Di,Fi	A	Oi,D,F	A	Oi,D,F	A	S,Si,Eq	A	Oi,D,F	A	Mi	Mi
S	B	A	D	B,O,M,Di,Fi	B,O,M	Oi,D,F	B	Mi	S	S,Si,Eq	D	B,O,M
Si	B,O,M,Di,Fi	A	Oi,D,F	Di	O,Di,Fi	Oi	O,Di,Fi	Mi	S,Si,Eq	Si	Oi	Di
F	B	A	D	A,Oi,Di,Mi,Si	O,D,S	A,Oi,Mi	M	A	D	A,Oi,Mi	F	F,Fi,Eq
Fi	B	A,Oi,Di,Mi,Si	O,D,S	Di	O	Oi,Di,Si	M	Oi,Di,Si	O	Di	F,Fi,Eq	Fi

Point Relations: Composition Table

Relations	<	=	>
<	<	<	<,=,>
=	<	=	>
>	<,=,>	>	>

Topologic : Composition Table

	DC	EC	PO	TPP	NTPP	TPPi	NTPPi	EQ
DC	DC,EC,PO, TPP,NTPP, TPPi,NTPPi, EQ	DC,EC,PO, TPP,NTPP	DC,EC,PO, TPP,NTPP	DC,EC,PO, TPP,NTPP	DC,EC,PO, TPP,NTPP	DC	DC	DC
EC	DC,EC,PO, TPPi,NTPPi	DC,EC,PO,TPP TPPi,EQ	DC,EC,PO, TPP,NTPP	EC,PO, TPP,NTPP	PO,TPP,NTPP	DC,EC	DC	EC
PO	DC,EC,PO, TPPi,NTPPi	DC,EC,PO, TPPi,NTPPi	DC,EC,PO,TPP, NTPP,TPPi, NTPPi,EQ	PO,TPP,NTPP	PO,TPP,NTPP	DC,EC,PO, TPPi,NTPPi	DC,EC,PO, TPPi,NTPPi	PO
TPP	DC	DC,EC	DC,EC,PO, TPP,NTPP	TPP,NTPP	NTPP	DC,EC,PO, TPP,NTPP	DC,EC,PO, TPPi,NTPPi	TPP
NTPP	DC	DC	DC,EC,PO, TPP,NTPP	NTPP	NTPP	DC,EC,PO, TPP,NTPP	DC,EC,PO TPP,NTPP, TPPi,NTPPi EQ	NTPP
TPPi	DC,EC,PO, TPPi,NTPPi	EC,PO, TPPi,NTPPi	PO,TPPi, NTPPi	EQ,PO,TPPi, TPP	PO,TPP,NTPP	TPPi,NTPPi	NTPPi	TPPi
NTPPi	DC,EC,PO, TPPi,NTPPi	PO,TPPi, NTPPi	PO,TPPi, NTPPi	PO,TPPi, NTPPi	PO,TPP,NTPP EQ,TPPi,NTPPi	NTPPi	NTPPi	NTPPi
EQ	DC	EC	PO	TPP	NTPP	TPPi	NTPPi	EQ

Directional: Composition Table

	N	NE	E	SE	S	SW	W	NW	O
N	N	N,NE	N,NE,E	N,NE,E,SE	N,NE,E,SE S, SW,W NW,O	W,NW, SW,N	NW,N,W	NW,N	N
NE	NE,N	NE	NE,E	E,NE,SE	E,NE, SE,S	N,NE,E,SES, SW, W,NW,O	N,NE, NW,W	N,NE,NW	NE
E	NE,E,N	NE,E	E	SE,E	SE,E,S	S,SW,SE E,	N,NE,E, SE,S, SW W,NW,O	N,NW, NE,E	E
SE	E,SE, NE,N	E,SE,NE	SE,E	SE	SE,S	S,SE,SW	S,SE,SW	N,NE,E,SE,S, SW,W,NW,O	SE
S	N,NE,E,SE,S SW,W NW,O	E,S,NE,SE	SE,E,S	SE,S	S	S,SW	S,W,SW	W,S,NW, SW	S
SW	W,SW N,NW	N,NE,E,SE,S SW,W NW,O	S,SW SE,E	S,SW,SE	SW,S	SW	SW,W	W,NW,SW	SW
W	N,W,NW	N,NW,NE W	N,NE,E,SE,S ,SW,W NW,O	S,SE,SW W	W,S,SW	W,SW	W	W,NW	W
NW	N,NW	N,NW,NE	N,NW,NE,E	N,NE,E,SES,SW,W, NW,O	W,NW,SW,S	W,NW, SW	NW,W	NW	NW
O	N	NE	E	SE	S	SW	W	NW	O

Cardinality Restrictions

- Cardinality restrictions and preservation of property semantics (i.e., symmetric, transitive) need special attention
- Are applied on the reified object rather than on the objects on which they were meant to be defined originally
- Can no longer be handled by ordinary reasoners such as Pellet

Interpreting their Meaning

- 1st Interpretation: Restrictions are imposed over the whole lifetime of an object thus restricting related objects for their entire lifetime
  - A person cannot work for two companies during his lifetime
- 2nd Interpretation: Restrictions are imposed only on time intervals for which the property holds true
  - A person cannot work for two employers during summer

Querying in SOWL

- SPARQL queries become complicated
- The user must be familiar with the underlying spatio-temporal representation
- The SOWL Query Language extends SPARQL with spatial and temporal operators
- SOWL queries are translated to SPARQL

SOWL Query Language

- SPARQL like Syntax

SELECT <variable>
WHERE <conditions>

- Conditions may involve Spatial and Temporal Operators
  - AT operators
  - Allen operators
  - Topological and Directional

SOWL Temporal Queries

- SPARQL-like query language supporting temporal operators

SELECT ?x, ?y…
WHERE { ?x property ?y…
AT(date)…}

- Additional operators are introduced to SPARQL
  - AT, ALWAYS_AT, SOMETIMES_AT
  - Allen operators

Temporal Operators

- AT: search for time instants for which fluent properties hold true
- ALWAYS_AT, SOMETIMES_AT: search for overlapping temporal intervals
- Allen's operators: BEFORE, AFTER, MEETS, METBY, OVERLAPS, OVERLAPPEDBY, DURING, CONTAINS, STARTS, STARTEDBY, ENDS, ENDEDBY and EQUALS

AT Temporal Operator Example

```
SELECT ?x, ?y
WHERE
{?x employees ?y
AT "2-5-2007" }
```

- The reasoner is invoked when querying for specific temporal invervals

Allen Operator Example

SELECT ?x,?y

WHERE

{?x has-employee ?y

BEFORE

company1 has-employee ?y }

SPARQL Translation

```
SELECT ?x ?y WHERE { { ?_timeSlice_0 ex1:tsTimeSliceOf ?x.
?_timeSlice_0 ex1:tsTimeInterval ?_interval_0. ?_timeSlice_0 ex1:Employs ?_timeSlice_1 .
?_timeSlice_1 ex1:tsTimeSliceOf ?y.?_timeSlice_1 ex1:tsTimeInterval ?_interval_0.
?_atTimeInstant_0 time:inXSDDateTime "2007-02-05T00:00:00"^^xsd:dateTime.
?_interval_0 time:hasBeginning ?_instant_1.?_interval_0 time:hasEnd ?_instant_2.
{ ?_instant_1 time:before ?_atTimeInstant_0.  ?_instant_2 time:after ?_atTimeInstant_0.}
UNION
{ ?_instant_1 ex2:equals ?_atTimeInstant_0.}
UNION
{?_instant_2 ex2:equals ?_atTimeInstant_0.}
}
union {
?x ex1:Employs ?y.
optional { ?_temporalVar rdf:type ex1:TimeSlice. ?x rdf:type ex1:TimeSlice }
filter( !bound(?_temporalVar) )
} }
```

Allen Operator Example

```
SELECT ?x, ?y
 WHERE
 {?x has-employee ?y
 BEFORE
 company1 has-employee ?y }
```

SOWL Spatial Queries

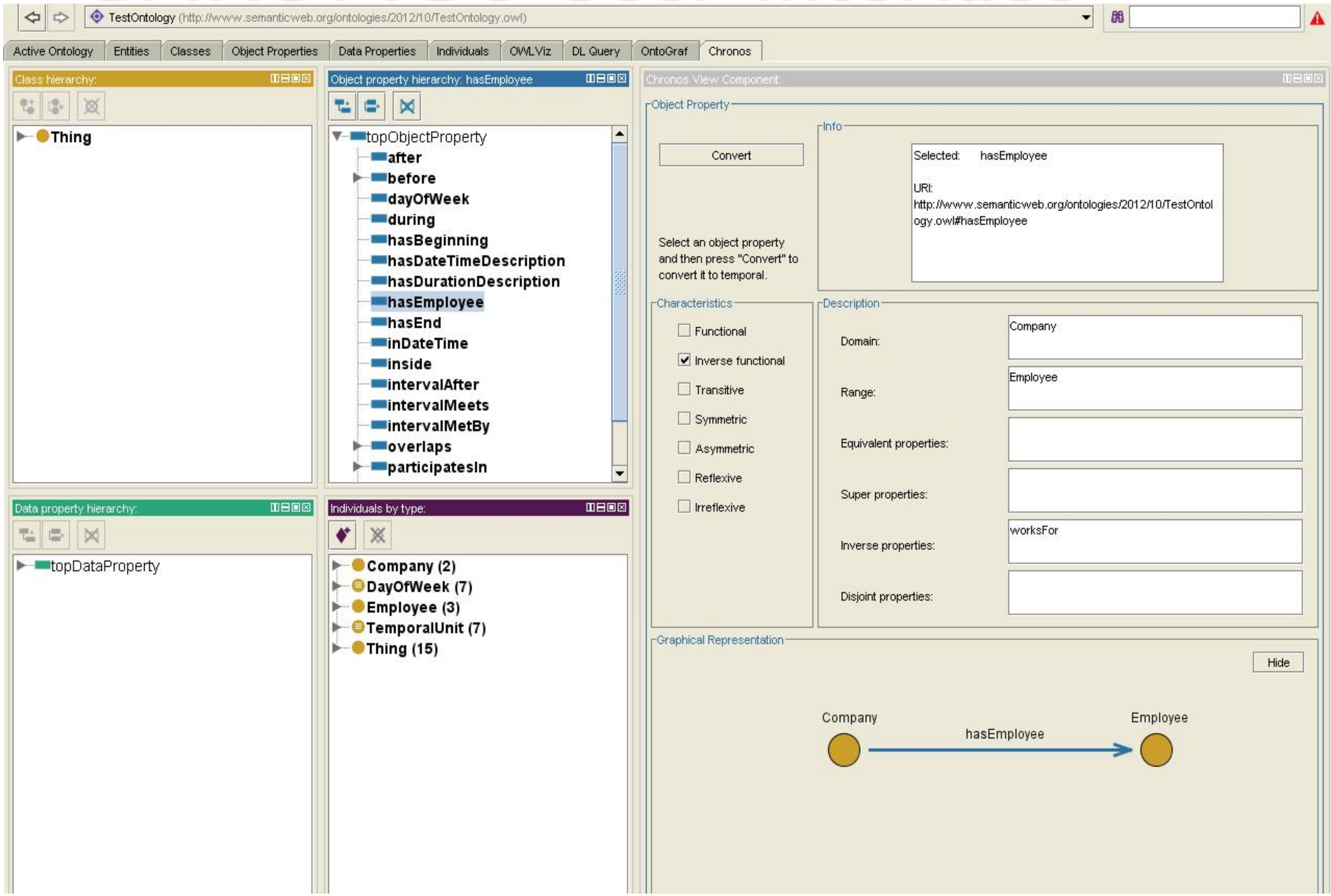
- All 8 topologic (RCC-8) and 9 Directional operators are supported
- Can be combined with temporal operators

```
select ?x, ?y
where {?y North-of ?x AT "date"}
```

CHRONOS Tab for Protégé [Preventis 2012]

- For crafting, editing temporal ontologies in Protégé
- Handles temporal ontologies as static ones
- Interface consistent with that of Protégé
- The user need not be familiar with the peculiarities of the representation
- Supports reasoning, restriction checking
- Available at http://www.intelligence.tuc.gr/prototypes.php

CHRONOS User Interface



Conclusion

- SOWL spatio-temporal information handling building-upon existing standards and tools
- Extends 4D-fluents and N-ary relations for representing evolution of qualitative (in addition to quantitative) temporal information in OWL ontologies
- Reasoning support over qualitative and quantitative relations
- Querying support by extending SPARQL with additional temporal and spatial operators

Future Work

- Addressing scalability issues, optimization of reasoning and querying
- Support for qualitative distance information ("further", "near")
- Optimizations for large scale applications
- Extension for 3Dimensions

Thank you

Questions ?