Reasoning Over 2D and 3D Directional Relations in OWL: A Rule Based Approach

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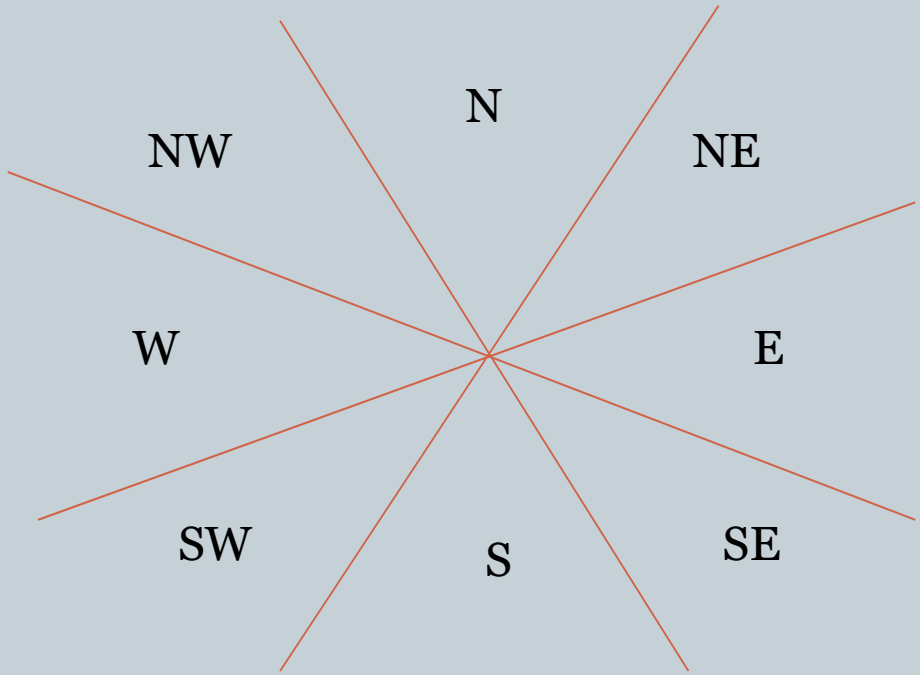
Problem Description

- Representing directional relations (e.g. “North”) in OWL poses several challenges
  - Relations have specific semantics that must be represented
    - Use dedicated spatial reasoners
      - Need for additional software besides standard tools
      - Reduces reusability, modifications both on representation and software are required
    - Embedding reasoning into ontology [Batsakis & Petrakis, RuleML11]
      - Representing Cone shaped directional relations (CSD-9)
        - Complicated representation
        - No 3D representation

Proposed solution

- Decompose CSD-9 relations to sets of independent relations
  - Represent each CSD-9 relation as pair of new relations
    - NW becomes N and W
  - Reasoning for each set of relations separately
  - Obtain resulting CSD-9 relation from pairs of inferred new relations
  - Straightforward extension to 3D

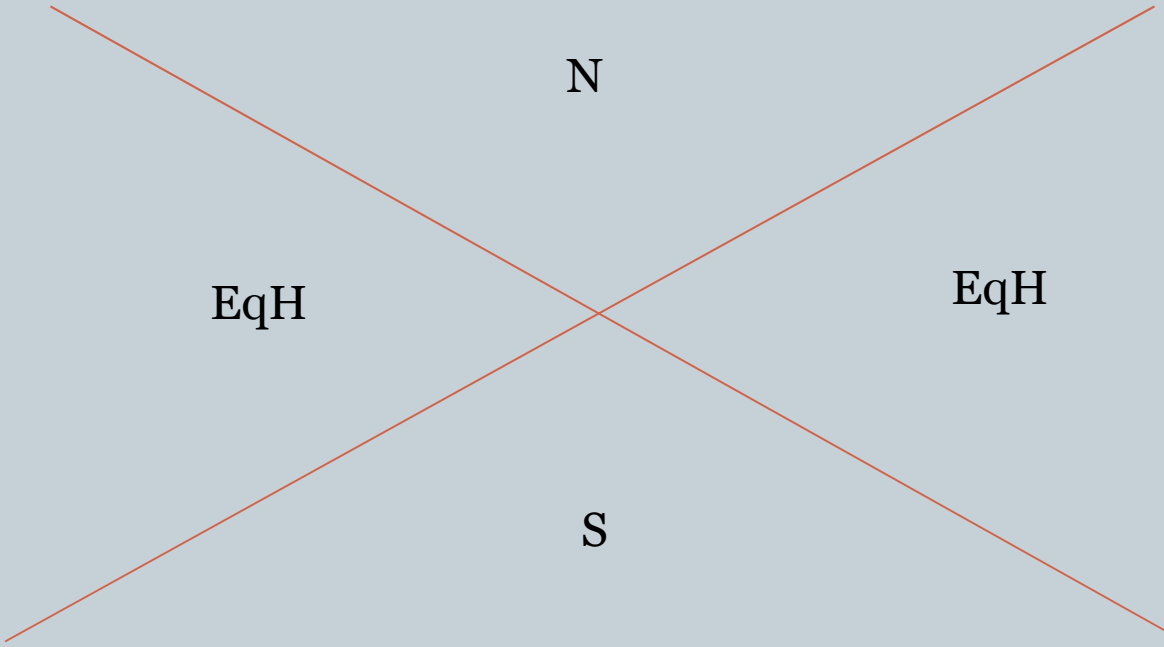
CSD-9 relations



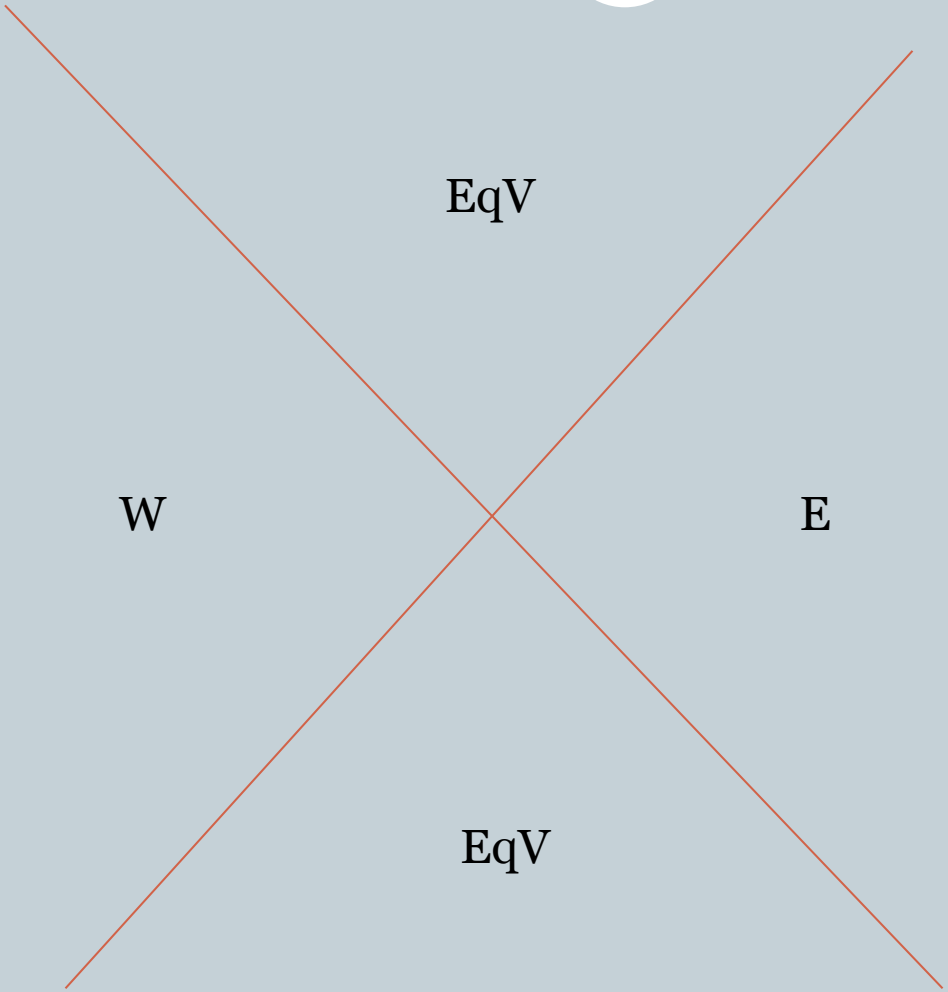
Reasoning over CSD-9 relations

- Based on Path Consistency
  - Compose and intersect existing relations until
    - Fixed point is reached
    - Inconsistency is detected
  - Implemented using SWRL
    - Compositions of relations
      - $N(x,y) \wedge NW(y,z) \rightarrow (N \cup NW)(x,z)$
    - Intersections of relations
      - $(N \cup NE)(x,y) \wedge (NE \cup E)(x,y) \rightarrow NE(x,y)$
    - Additional relations required besides basic CSD-9
    - Complicated representation and reasoning
      - 33 relations and 964 rules

Decomposition: North-South Relations



Decomposition: East-West Relations



Reasoning

- Convert CSD-9 relations to new sets
  - E.g. SW(x,y) → S (x,y) ∧ W(x,y)
- Apply Path Consistency on each set
  - Compositions
    - Composition Tables defined
      - Similar to adding vectors
    - New relations representing disjunctions are required
    - Detected using closure method
      - Intersect and compose relations until fix point is reached (i.e., all compositions and intersections yield relations into existing set)
  - Intersections

CSD-9 Decomposition

- Each CSD-9 relation is decomposed to new relations
  - $N_{CSD\text{-}9}(x,y) \leftrightarrow N(x,y) \wedge EqV(x,y)$
  - $NE_{CSD\text{-}9}(x,y) \leftrightarrow N(x,y) \wedge E(x,y)$
  - $E_{CSD\text{-}9}(x,y) \leftrightarrow EqH(x,y) \wedge E(x,y)$
  - $SE_{CSD\text{-}9}(x,y) \leftrightarrow S(x,y) \wedge E(x,y)$
  - $S_{CSD\text{-}9}(x,y) \leftrightarrow S(x,y) \wedge EqV(x,y)$
  - $SW_{CSD\text{-}9}(x,y) \leftrightarrow S(x,y) \wedge W(x,y)$
  - $W_{CSD\text{-}9}(x,y) \leftrightarrow EqH(x,y) \wedge W(x,y)$
  - $NW_{CSD\text{-}9}(x,y) \leftrightarrow N(x,y) \wedge W(x,y)$
  - $Id_{CSD\text{-}9}(x,y) \leftrightarrow IdH(x,y) \wedge IdV(x,y)$

Composition table (North-South)

Relations	N	S	EqH	IdH
N	N	N,S,EqH,IdH	N,EqH	N
S	N,S,EqH,IdH	S	S,EqH	S
EqH	N,EqH	S,EqH	N,S,EqH,IdH	EqH
IdH	N	S	EqH	IdH

Composition table (East-West)

Relations	E	W	EqV	IdV
E	E	E,W,EqV,IdV	E,EqV	E
W	E,W,EqV,IdV	W	W,EqV	W
EqV	E,EqV	W,EqV	E,W,EqV,IdV	EqV
IdV	E	W	EqV	IdV

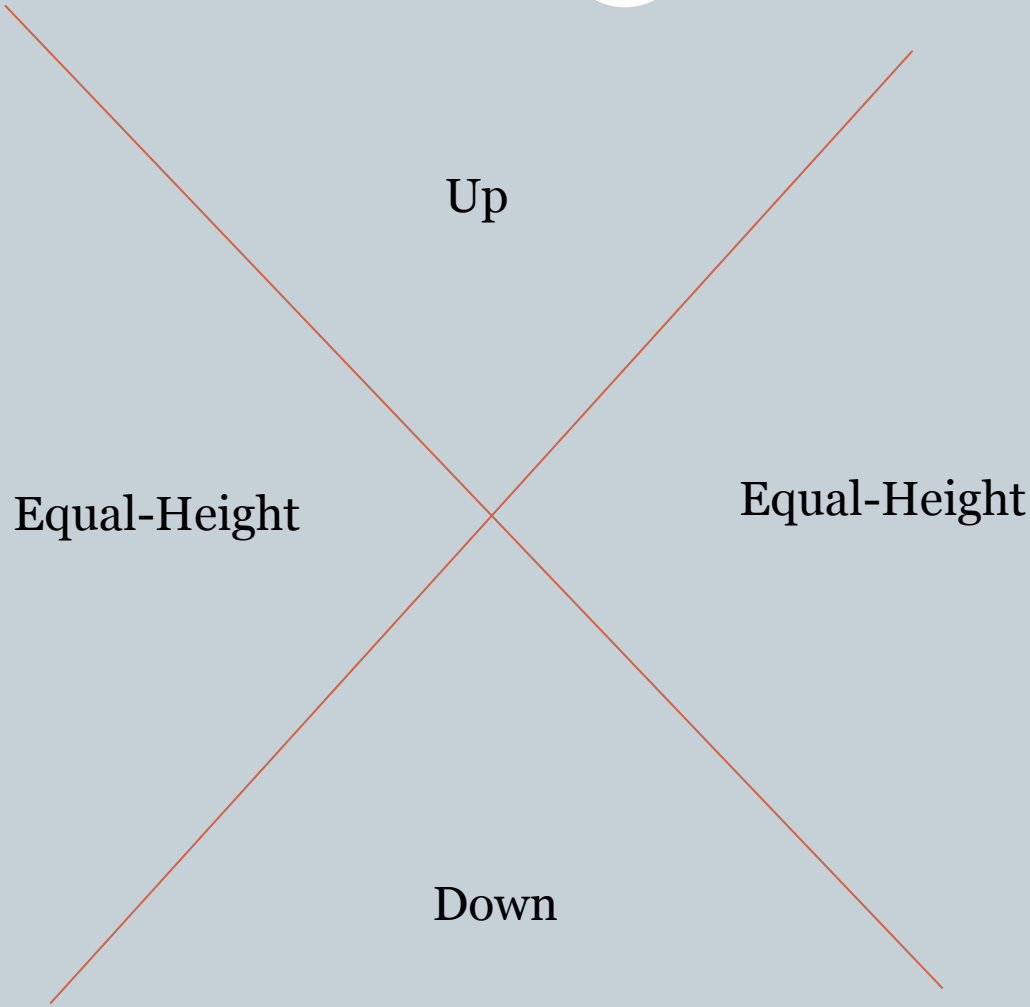
Reasoning Rules and Axioms

- Compositions derived from composition tables
  - $N(x,y) \wedge N(y,z) \rightarrow N(x,z)$
  - $E(x,y) \wedge EqV(y,z) \rightarrow (E \cup EqV)(x,z)$
- Additional axioms
  - Inverse
    - North-South
    - East-West
  - Symmetric
    - EqV
    - EqH
  - Disjoints basic 4 relations on each set

Reasoning implementation

- Applying closure method for detecting relations
  - 7 relations required for each set
    - Disjunction of all relations can be removed
    - 52 rules and axioms required
      - Compositions, Intersections,Inverse, Symmetric relations
  - Combine 2 sets
    - 14 Relations and 106 axioms
    - Important reduction compared to direct CSD-9 implementation

3D extension: Height relations



Composition table (Up-Down)

Relations	U	D	EqHe	IdHe
U	U	U,D,EqHe,IdHe	U,EqHe	U
D	U,D,EqHe,IdHe	D	D,EqHe	D
EqHe	U,EqHe	D,EqHe	U,D,EqHe,IdHe	EqHe
IdHe	U	D	EqHe	IdHe

3D reasoning

- Define composition table for additional relations
  - Similar to 2D sets
- Detect required relations
  - Apply closure method
    - Yields 7 relations
  - Define rules and axioms
    - Implement path consistency
      - Compositions
      - Intersections
      - 52 axioms

Combined 3D representation

- Between 2 points 3 relations are asserted
  - North-South
  - East-West
  - Up-down
- Reasoning using SWRL and OWL axioms for each set
  - Compositions & Intersections
  - 21 relations and 158 rules and axioms for all 3 sets
  - CSD-9 relations require 964 axioms only for 2D case

Quantitative evaluation

- Random points created
- Measuring average reasoning times

Points	Reasoning time		
	2D	3D	CSD-9
200	299.8	268.6	386.0
400	405.8	685.8	782.4
600	865.2	1099.0	1066.4
800	1053.6	1407.2	1396.4
1000	1526.2	2261.4	2380.2

Conclusions

- Integrated representation of relations and their semantics
  - Reasoning embedded into the ontology using SWRL
  - Compliance with standards
  - Use existing tools
    - No additional software
  - Reusability
  - Compact representation compared to CSD-9
    - Fewer relations
    - Much fewer rules
    - Faster reasoning (30% for 2D reasoning)
    - 3D representation

Thank You

Questions?