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Measures of Similarity for Command and Control Situation Analysis

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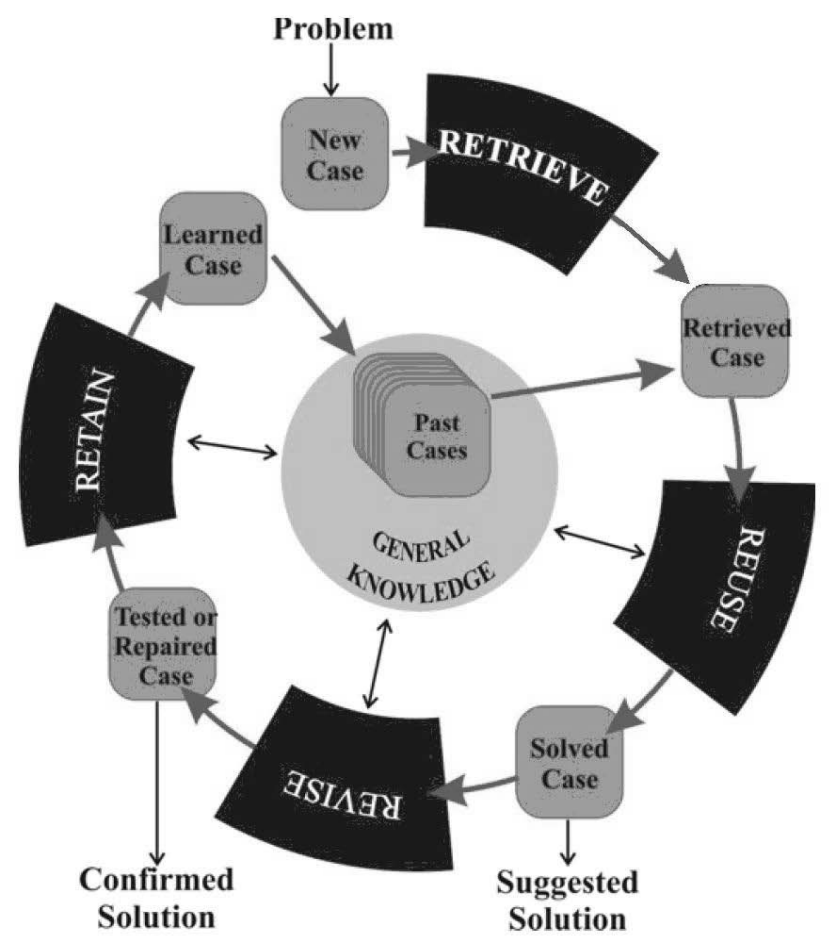
Introduction

- Command and Control (C2) in Multinational Civil-Military Operations is a demanding environment
- Information Systems supporting this environment need adaptable automated reasoning capabilities
- Case-Based Reasoning offers a flexible approach to automated reasoning compared to formal logic approaches.
- CBR relies on the ability to establish *similarity* between unfolding situations (current cases) and known cases (from a case base)
- Measuring similarity is CBR's Achile's heel.
- Understanding measures of similarity is of prime importance to successfully apply CBR.

Case-Based Reasoning Basic Concepts

- The Case-Based Reasoning Cycle
  - Retrieve *similar* cases to the problem description
  - Reuse a solution suggested by a *similar* case
  - Revise or adapt that solution to better fit the new problem
  - Retain the new solution once it has been confirmed or validated



Case-Based Reasoning Basic Concepts

- The Case-Based Reasoning Challenges
  - A standard problem template must be produced in order to describe and organize problems in a way that will allow comparison
  - In order to retrieve a similar problem from the case base's problem space, there must be a way to *measure similarity* between problems

Measures of Similarity

- Geometry-based Measures
- Feature-based Measures
- Structure-based Measures
- Transformation-based Measures
- Information Content-Based Measures

Measures of Similarity

- **Geometry-based Measures**
- Feature-based Measures
- Structure-based Measures
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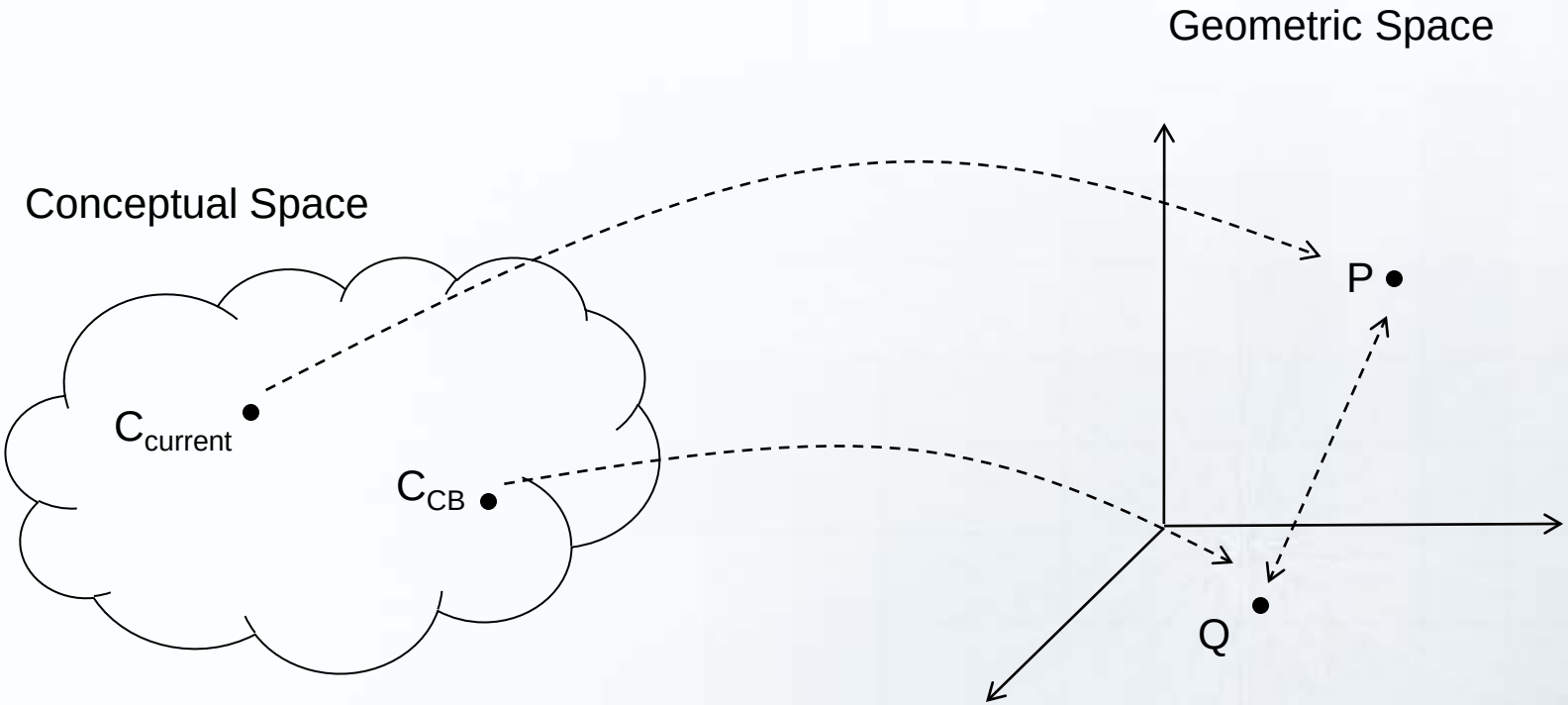
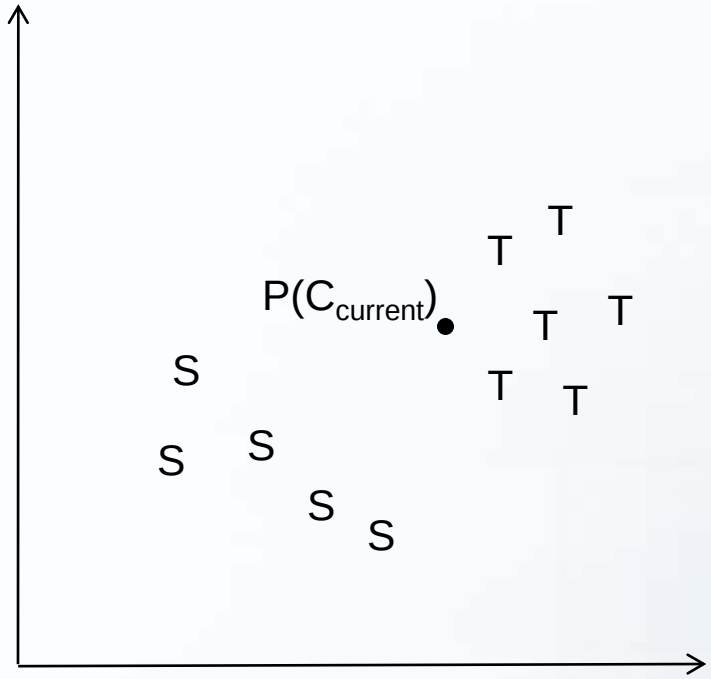
Measures of Similarity

- Geometry-based Measures



Measures of Similarity

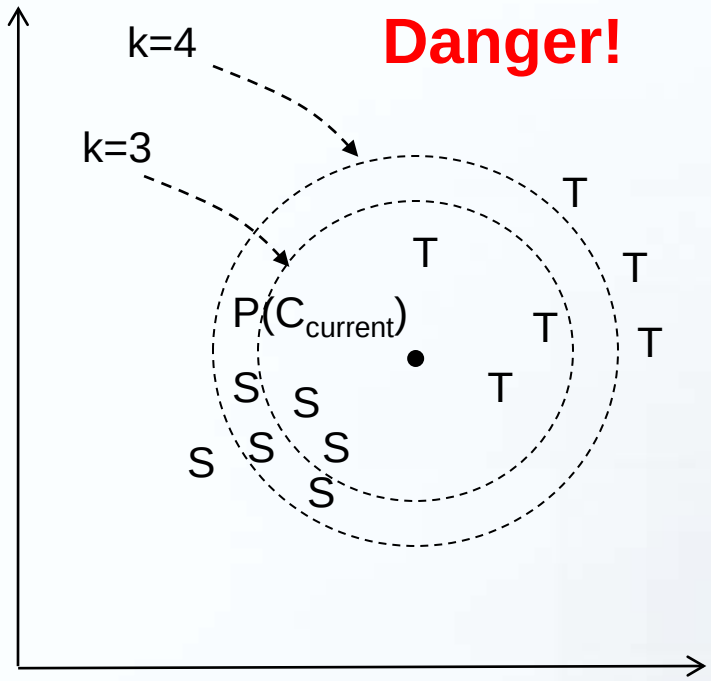
- Geometry-based Measure: K Nearest Neighbor Rule



$P(C_{current})$ is associated with Case T

Measures of Similarity

- Geometry-based Measure: K Nearest Neighbor Rule

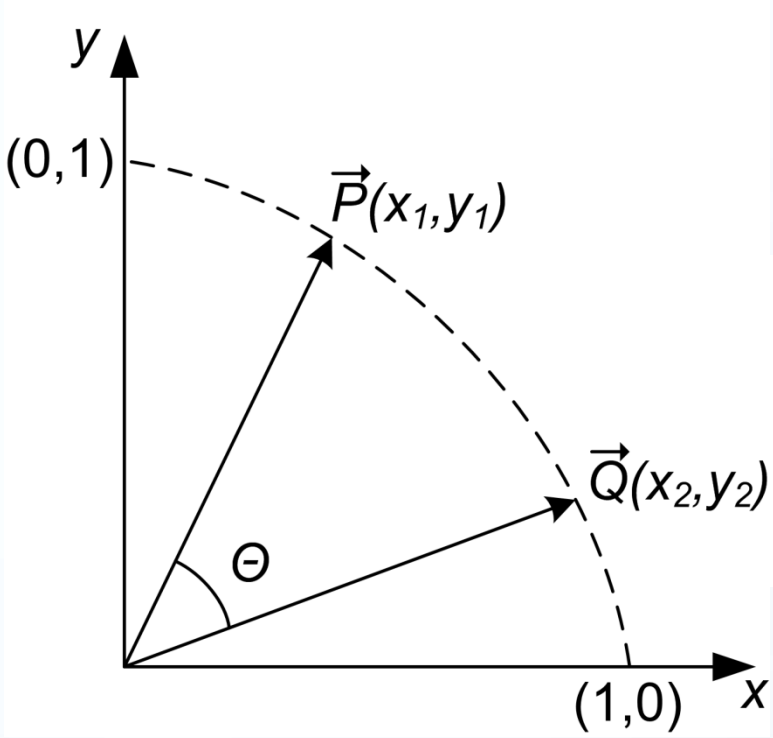


If k=3, then $P(C_{current})$ is associated with Case T.

If k=4, then $P(C_{current})$ is associated with Case S.

Measures of Similarity

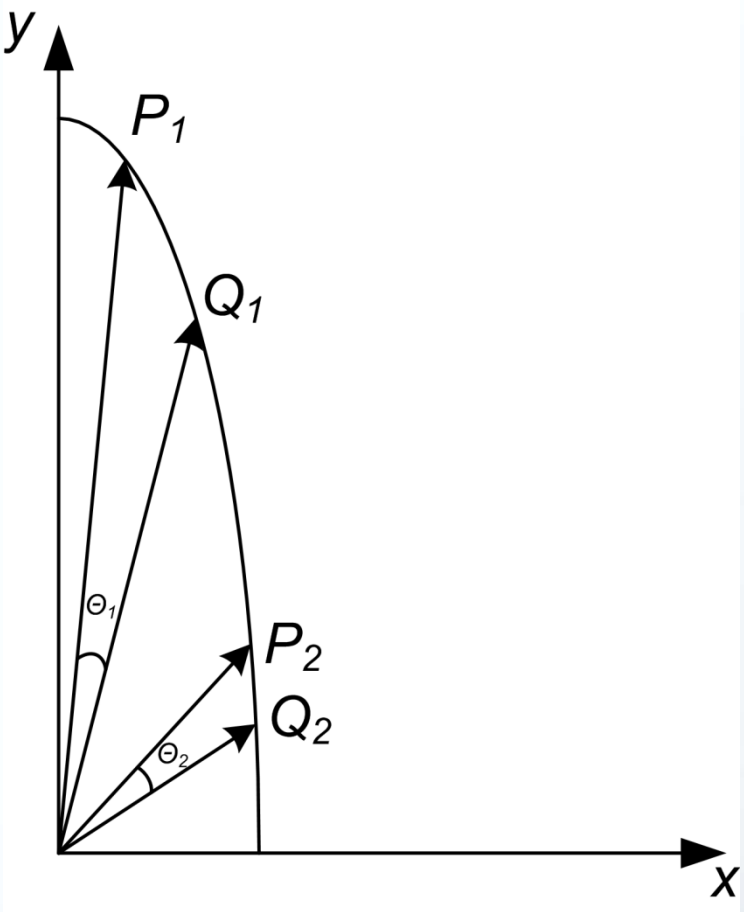
- Geometry-based Measure: Cosine Similarity



$$sim(C_{cur.}, C_{CB}) = \begin{cases} Identical, & \text{if } \cos(\vec{P}, \vec{Q}) = 1; \\ Independent, & \text{if } \cos(\vec{P}, \vec{Q}) = 0; \\ Opposite, & \text{if } \cos(\vec{P}, \vec{Q}) = -1; \\ (dis)similar, & \text{otherwise.} \end{cases}$$

Measures of Similarity

- Geometry-based Measure: Cosine Similarity (Limit?)



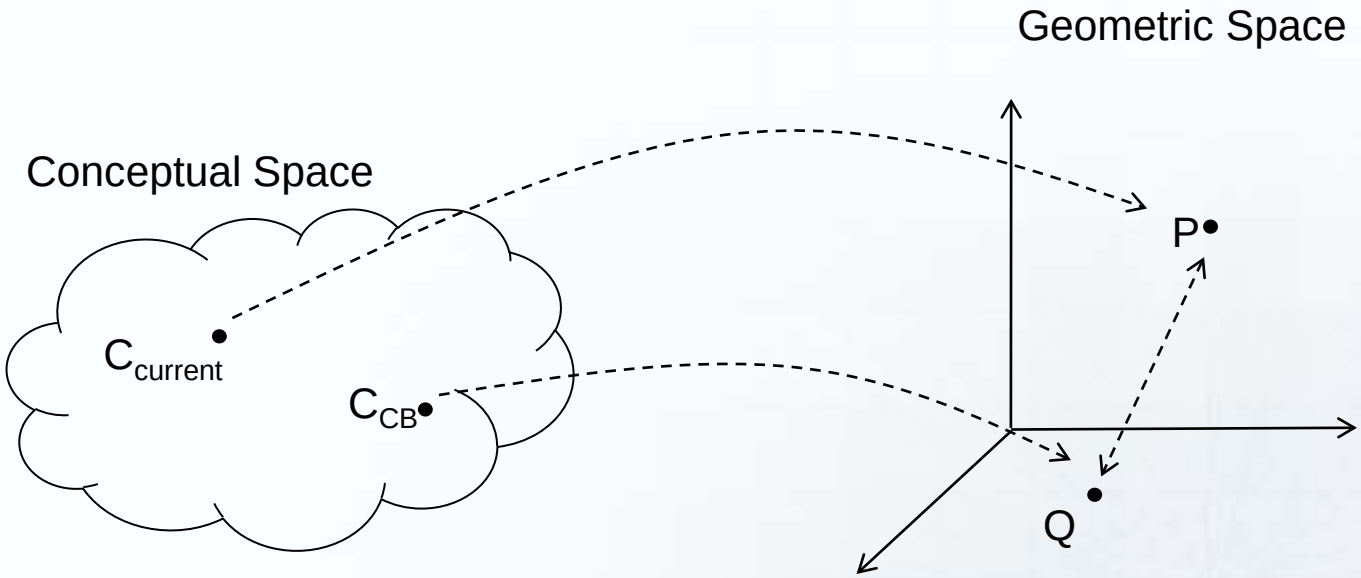
Feature *y* is more important then *x.*

$\theta_1 = \theta_2$ implies that $\cos(\theta_1) = \cos(\theta_2)$, but $dist(P_1,Q_1) > dist(P_2,Q_2)$.

What does that mean in the conceptual space?

Measures of Similarity

- Geometry-based Measure: Limits



Geometry Axioms

Amos Tversky 1977 showed examples where these axioms were violated.

$$d(x,y) \geq 0; \text{ non-negativity},$$

$$d(x,y) = 0 \text{ iff } x = y; \text{ identity},$$

$$d(x,y) = d(y,x); \text{ symmetry},$$

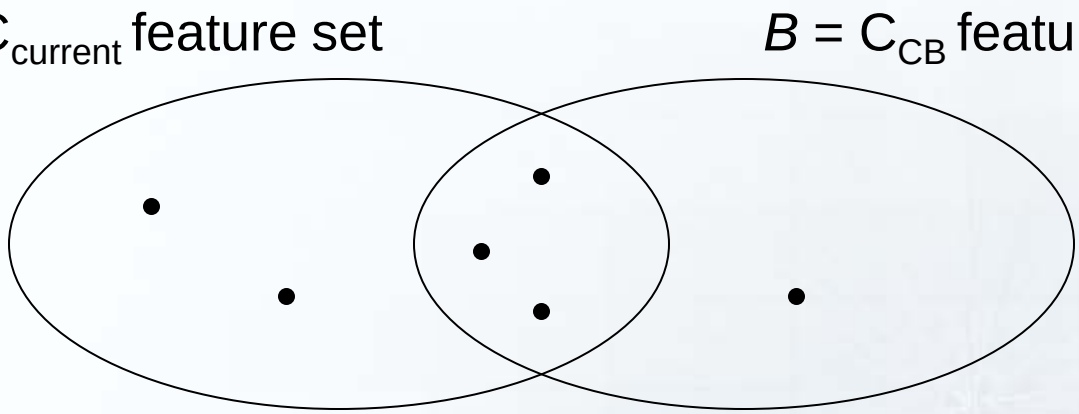
$$d(x,z) \leq d(x,y) + d(y,z); \text{ triangle inequality}$$

Measures of Similarity

- Geometry-based Measures
- **Feature-based Measures**
- Structure-based Measures
- Transformation-based Measures
- Information Content-Based Measures

Measures of Similarity

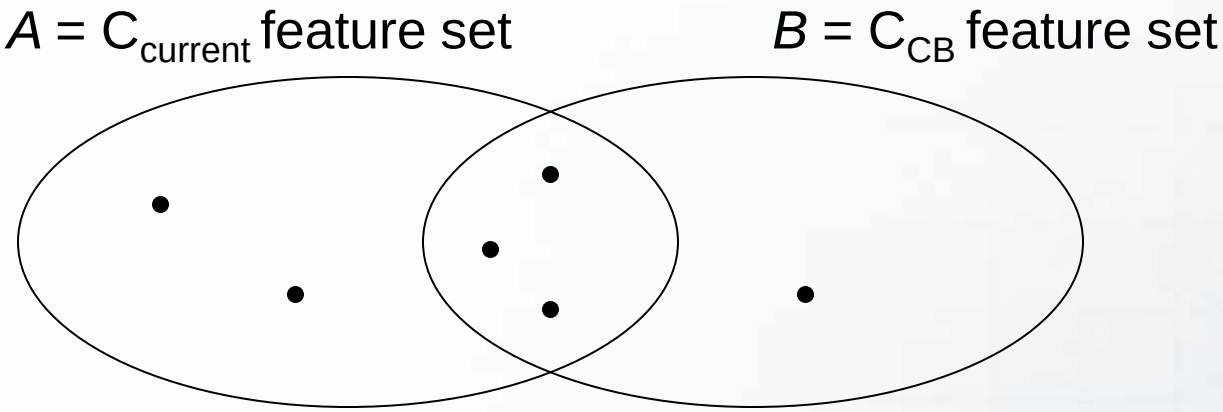
- Feature-based Measures



Tversky's index = $$S(A,B) = \frac{|A \cap B|}{|A \cap B| + \alpha \cdot |A - B| + \beta \cdot |B - A|}$$

Measures of Similarity

- Feature-based Measures: Limits



This similarity measure only depends on the feature *count*.

Does not take into account feature weighting.

Measures of Similarity

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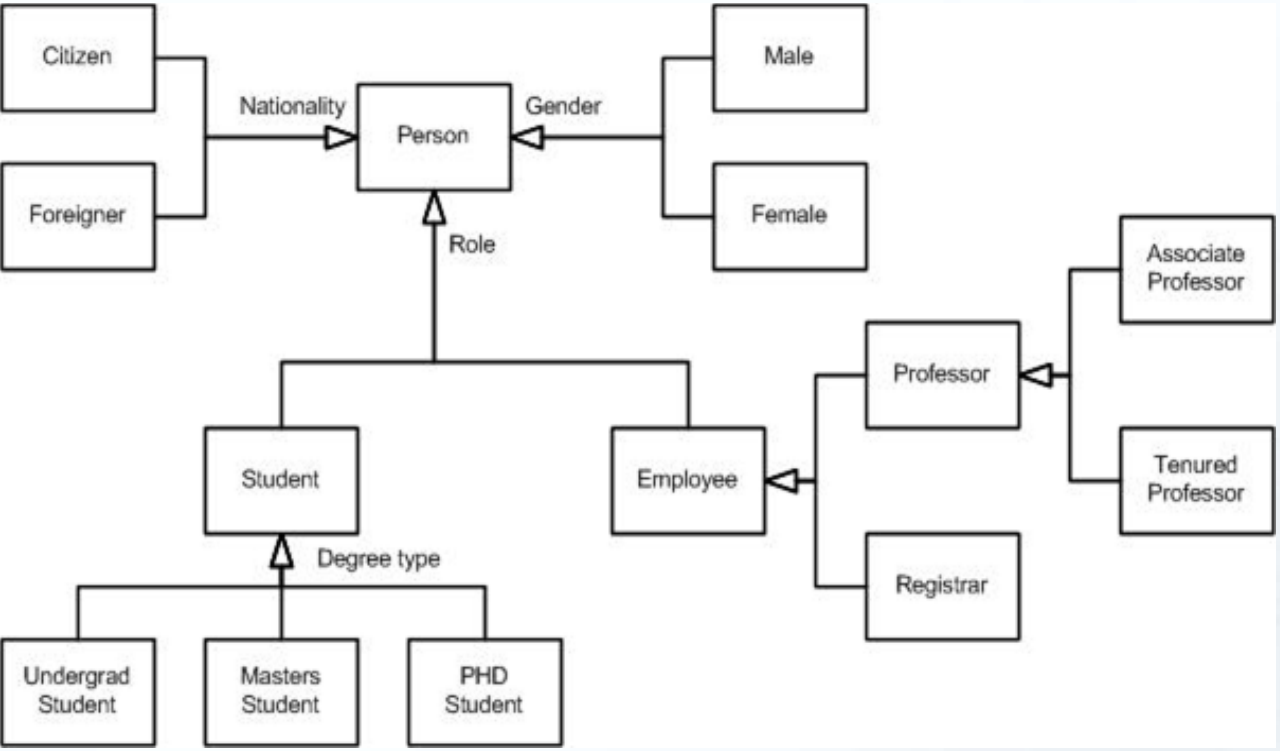
Measures of Similarity

- Structure-based Measures



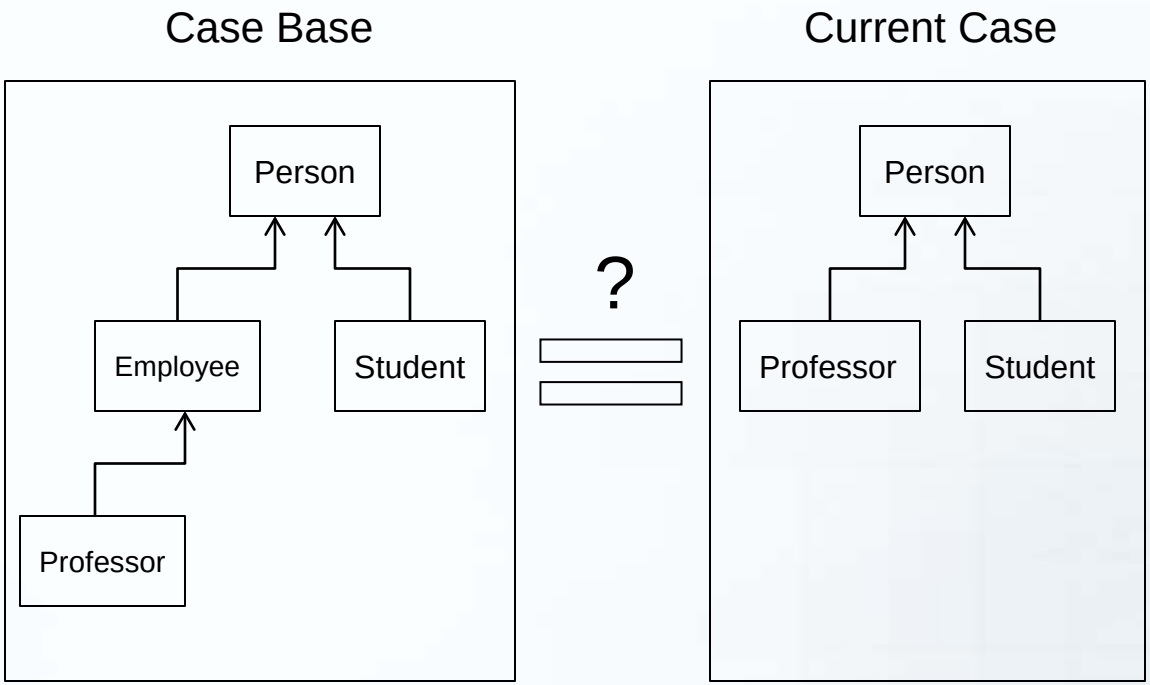
Sim(Male,Female)=1

Sim(PhD Student,Male)=2

Sim(Tenured Prof,Registrar)=2

Measures of Similarity

- Structure-based Measures: Limits



- Similarity value highly dependent on structure and semantic content
- Difficult to compare concepts of distinct structures

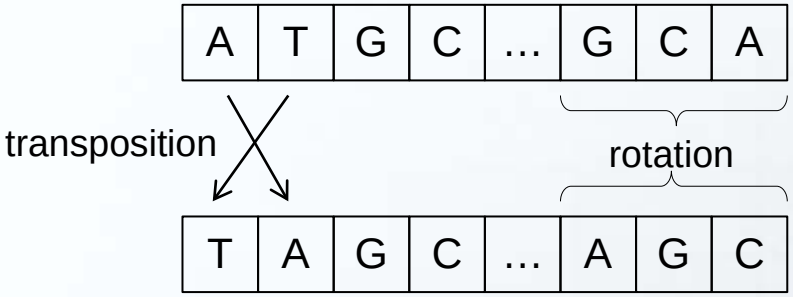
Measures of Similarity

- Geometry-based Measures
- Feature-based Measures
- Structure-based Measures
- **Transformation-based Measures**
- Information Content-Based Measures

Measures of Similarity

- Transformation-based Measures

  TBMs count how many allowable transforms are necessary to shape one pattern into the other.



  - Hamming: How many differences?
  - Levenshtein: How many *inserts, deletes* and *substitutes?*
  - Damerau–Levenshtein: Levenshtein + *transposition*
  - etc.

Measures of Similarity

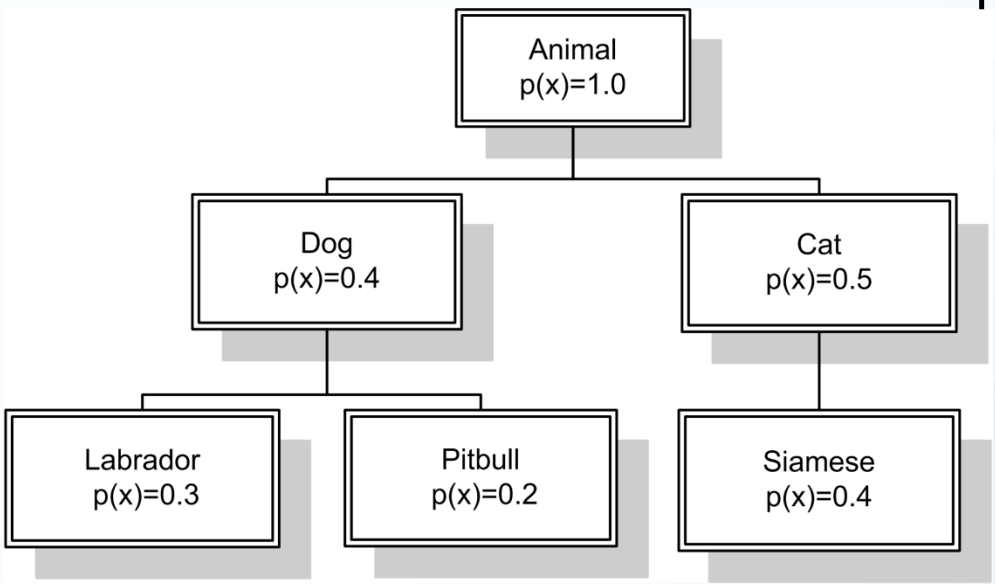
- Transformation-based Measures: Limits
  - Computes differences between *strings* (DNA, bitstreams, speech flow, etc.)
  - Cases representation complexity
  - Cases (between the Case base and the current case) may present too many differences (topological, semantics, context) for the measure to make sense
  - Difficult to establish what are the allowable and relevant transformations for between cases.

Measures of Similarity

- Geometry-based Measures
- Feature-based Measures
- Structure-based measures
- Transformation-based Measures
- **Information Content-Based Measures**

Measures of Similarity

- Information Content-Based Measures



Resnik 1999

- Based on Information Theory
- The similarity between 2 concepts within a taxonomy corresponds to the *information content* of the closest parent concept.
- A probability of *occurrence* is associated to every concept in the hierarchy.

*Sim(*Pitbull, Labrador) = Information content of *Dog* = - log(0.4) = 0.92

Sim(Siamese, Dog) = Information content of *Animal* = - log(1.0) = 0

Choosing a Similarity Measure for CBR

- Case representation and feature selection is a hard problem because the application domain is complex (C2 in Multinational Civil-Military Operations)
- A mix of Geometry-based and Feature-based measures have been used in DRDC Valcartier.
  - Lesson learned: Must take into account the military operation. (Scalability?)
- Structure-based measures' reliability depend on case representation, which varies a lot (many different standards).
- Transformation-based measures suffer from being too "local" (string-based). Difficult to see how it could apply to complex cases.
- Information content-based measures are under development. Resnik's approach too restrictive (what about Entropy?)

Conclusion

- The problem of characterizing Command and Control (C2) in Multinational Civil-Military Operations: What are the most relevant features?
- C2ISs using Case-Based Reasoning seems to be promising, but is the solution scalable and shareable to the Multinational Civil-Military Operational environment?
- CBR requires the ability to establish *similarity*, which is a cognitive process. Are we there yet? More research? Most certainly!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