Axioms & Templates: Distinctions & Transformations amongst Ontologies, Frames, & Information Models

or

OWL, UML, and Frames

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Common Questions:

- ► How do I convert between UML and OWL? Frames & OWL?
  - ►How do I determine which properties go with which classes?
    - The "Sanctioning" problem
  - ►"Can I use OWL as a richer schema for databases?"
    - Or to enhance / check database schemas
- ► How do I say "may" or "typically" in OWL?
  - ►How do I manage defaults and exceptions in OWL?
- ► Why is it so hard for people to switch from frames to OWL
  - ►Why do people still use frames? Why switch to OWL?
- ► How do I get back to what was easy in 1985?

Why I use OWL (for the record)

- ► Composite concepts and definitions
  - ► Left_leg ≡ Leg & has_laterality value left
    - Avoid combinatorial explosions – the "exploding bicycle" or…
      - *It's even made the NY Times:*
        - *"Roughed up by an Orca? There's a code for that" http://www.nytimes.com/2013/12/30/technology/medical-billing-nears-a-new-era-of-ultra-specific-codes.html?_r=0Inferred subsumption hierarchy*
          - *>500 codes for kinds of bicycle injuries*
          - *>200 codes for accidents to space craft crew*
  - ► Maintain parallel hierarchies
  - ► Propagate definitions consistently
- ► Validation & error detection
  - ► Difficult, but less difficult than with totally asserted hierarchy
- ► Basis for Natural Language Generation of Labels
  - ► From definitions
- ► Because it is a standard – and I live in that community

The role of ontologies

- ► Ontology ?=? Knowledge Representation

- ► Is OWL/DLs a general KR language?

- ► Need KR languages be based on logic and axioms?
  - ►Should they be?
  - ►Can they be?

- ► How to select a technology for an application?

One approach: Refactor the problem
Key Distinctions

- ► Ontology **vs** background knowledge **vs** information model

- ► Axiom-based **vs** Template-based representations

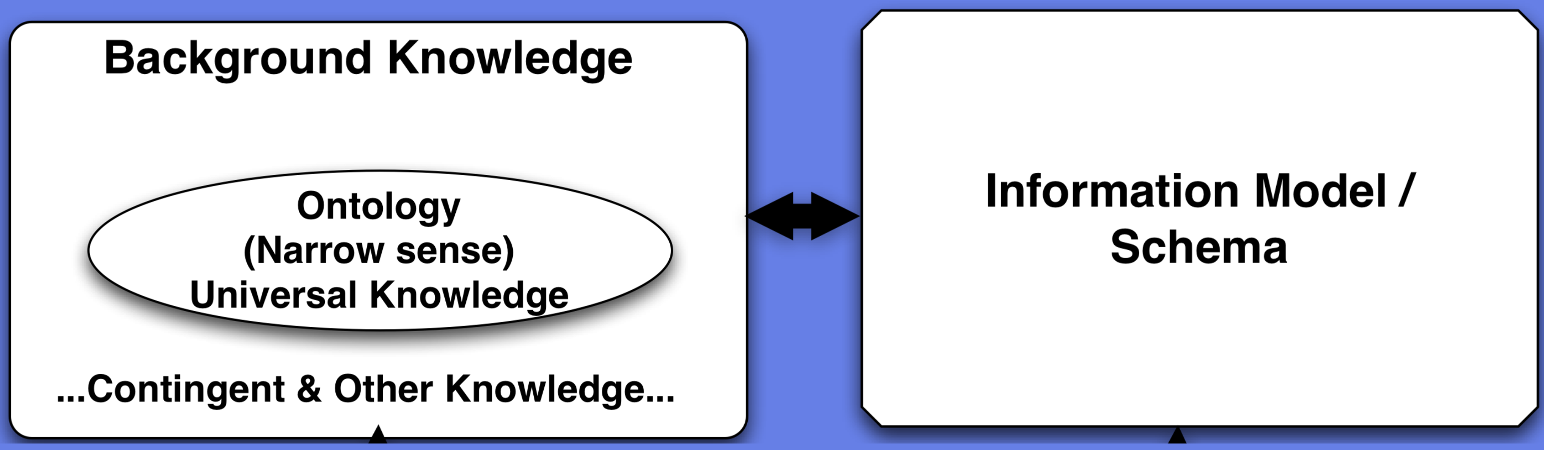
- ► Class expressions **vs** Queries in OWL/DLs

- ► Models of the domain **vs** Models of Information about that domain

Illustrate starting with UML and OWL;
Then discuss frames

Ontology vs background knowledge base vs Information model

New look at an old architecture:



What is an ontology?

- Is it the same as a knowledge base?
  - "Conceptualisation of a domain" imprecise
    - If it means everything it means nothing
- Original philosophical meaning: the study of what there is
  - Useful KR interpretation: Ontology (narrow sense)
    The definitions and essential properties of the entities that can be represented
    - What is necessarily true
      - *"by definition"*
      - *As universal/essential characteristics*
        - *Representable in logic statements beginning $\forall x$. …*
    - Corresponds to subset of OWL/DL T-Box

Examples

Universal Knowledge

- Pneumonia is a lung disease
- Rashs are located on the skin (epithelium)
- Penicillin is an antibiotic

Contingent/Particular Knowledge

- Pneumonia may be caused by bacteria.
- Meningitis *may* cause a rash
  (Rash is a symptom of Meningitis)
- Penicillins may be used to treat Bacterial Meningitis

Ontology (Narrow Sense)

- ► Universally qualified statements about the domain: true in all possible models/worlds
  - ► OWL/DL statements are a subset of such statements in F2
    - B subClassOf A — $\forall x . B(x) \rightarrow A(x)$
      B subClassOf p some C — $\forall x . B(x) \rightarrow \exists y . C(y) \wedge p(x,y)$
      B EquivalentTo A & p some C — $\forall x. B(x) \leftrightarrow A \wedge \exists y . C(y) \wedge p(x,y)$
      B EquivalentTo A & p value c — $\forall x. B(x) \leftrightarrow A \wedge) \wedge p(x,c)$
  - ► Examples
    - All pneumonias are lung disease;
      Pneumonia is defined as an Inflammation localised to the lung
      …
- ► Excludes "contingent" knowledge: True of given world
    - "may", "typically", "probably", "with probability X", …
  - ► FOL approximations beginning ∃
  - ► FOL approximations that are ground clauses p(a,b)
    - Almost all of a DL A-Box

Axioms vs Templates

Axioms

- *Axioms* from which to *draw inferences*
- *Definitions and necessary truths* (Universal knowledge)
  - Monotonic, open world, negation as unsatisfiability
  - Composite concepts
- Strictly first order
  - Metaclasses impossible (or kluged)
- *Restrict* what may be said
  - What *may not* be said
- *Global*
- *Inferred existence, underspecificaton*
  - "John has a sister"
- *Classification* inferred & asserted
- Built in two steps
  - assertion + reasoning ("compiled")
  - Validation delayed to reasoning-time

Templates

- *Data structures* to be *queried*.
- *Statements*, universal & contingent (undistinguished)
  - Non-monotonic (usually), closed world, negation as failure
  - Primitve concepts only
- Higher order
  - Metaclasses essential to representation
- *Permit new* things to be said
  - What *may* be said ("sanctioning")
- *Local* (to class & descendants)
- *Explicit existence* (+ skolemization)
  - "John's sister is Mary"
- *Classification* asserted only
- Built in one step ("interpreted")
  - Validation immediate

Domain Knowledge vs Information

Domain Knowledge Model	Information Model
► About the domain	► About the informaiton structures
► True or false or uncertain	► Entered or missing
► Open, at least in parts	► Closed
► Inferred existence "Has no body temperature" *makes no sense*	► Expliicit existence "Missing entry for body temperature" *makes sense*
► Repesesnts our understanding of a domain	► Specifies structures to hold information motivated by that understanding
► Variables range over domain entities	► Variables range over data structures & symbols

Axioms vs templates, Knowledge vs Data schemas

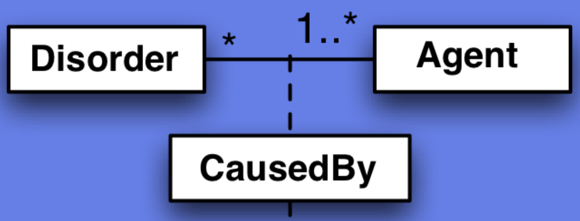
	Axioms	Templates
Knowledge	OWL, Logics, Conceptual Graphs (existential logic) GRAIL axioms	Frames, Conceptual Graphs (cannonical graphs) GRAIL sanctions
Data schemas	OCL constraints on UML	UML, Archetypes, XML, …

Three possible reconciliations

- ► Hybrid models
  - ► Represent ontology(narrow sense) in OWL and use for values in UML/Frames
- ► Represent Templates in OWL or
  OWL in Templates
  - ► Tried representing OWL in templates in Protégé 3
    - problematic
  - ► Explore representing templates in OWL
    - Illustrates issues clearly
    - Practical set of transformations and limitations
    - So far explored only with toy examples – needs tooling for larger scale work
- ► Treat OWL as having dual semantics
  - ► Axioms + queries & annotations for templates
  - ► Works in HOBO ontology programming environment

Example: What cause pneumonia?

- **UML:**

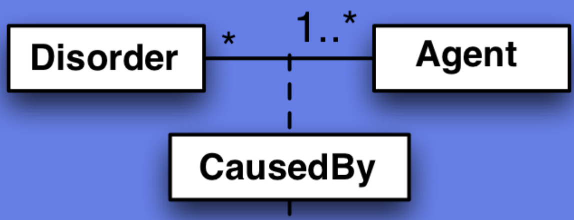


  - Disorder entries must be linked to one or more agent entries by the CausedBy association
    - *NB: All UML associations are linked implicitly to a class*
  - Also, any agent can be linked to any number of disorders
  - Reciprocal: associations can be traced in both directions
  - The agent is *mandatory* for Disorder; Disorder is *optional* for agent
    An exception will be raised for missing agents

- **Obvious OWL:** *Property*: CausedBy *domain* Disorder; *range* Agent
  Class: Disorder *subClassOf* causedBy *some* Agent
  - All disorders are caused by some agent (even if we don't know which)
  - Unidirectional – & does not generalise easily to other multiplicities
  - An agent will be inferred to exist whenever a disorder exists
  - Domain/range constraints axioms for inference rather than constraints
    - What properties apply to Disorder hard to determine

Alternative OWL: Model the template
Make Associations classes

- ▶ UML:



- ▶ Alt OWL: *Property* to *functional*
  Property from *functional*
  Class DomainEntity
  Class Association → to *some* DomainEntity &
  from *some* DomainEntity
  key(to, from)

  Class CausedBy → Association
  Class Disorder → DomainEntity &
  inv(from) *some* (CausedBy &
  to *some* Agent)

- ▶ Similar meaning but:
  - Schema symmetrical – generalises naturally to all multiplicities
  - Easy to retrieve the associatons relevant to any DomainEntity
  - Has direct transformation to/from original for cases where possible

Issues:

Alt OWL: *Property* to *functional*
Property from *functional*
Class DomainEntity
Class Association → to *some* DomainEntity &
from *some* Domain
key(to, from)

Class CausedBy → Association
Class Disorder → DomainEntity &
inv(from) *some* (CausedBy &
to *some* Agent)

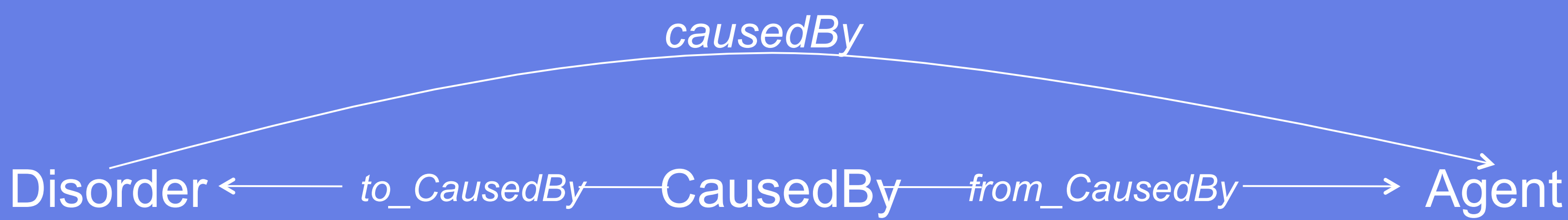
- key declaration:
  - OWL 2 construct so that each Association instance links exactly one pair of DomainEntities – analogous to prohibiting duplicate rows in a database.
  - Multiplicities always associated with DomainEntities, never the association itelf
- Gain
  - Agents *may* cause Disorders
    - Natural extension to other uses of "may"
    - Natural representation of contingent knowledge
    - Naturally reciprocal
  - Ability to say other things about association – e.g. strength, time, etc.
  - DL expressions for Association to or from any DomainEntity
- Lose
  - Transitive relations and property paths (& other property characteristics except *functional* and *inverseFunctional*
- Still must content with
  - Domain and range declarations are *axioms* rather than *constraints*

Comparison to frames

- For “association” substitute “slot”
  - Almost identical structure
- Gain for frames…
  - Composition and inferred classification
  - Clear criteria to distinguish “ontology (narrow sense)”
    - Axioms with DomainEntities on left-hand side
- But still …
  - No metadata or meta classes
    - except by punning or annotation
  - Domain & range constraints behave as axioms
    - Inference when reasoning rather than constraints when entering
- Loss to OWL
  - Transitivity and property paths, etc.
    - Powerful additions to inferences

Restoring transitivity and property paths
Extensions via preprocessing

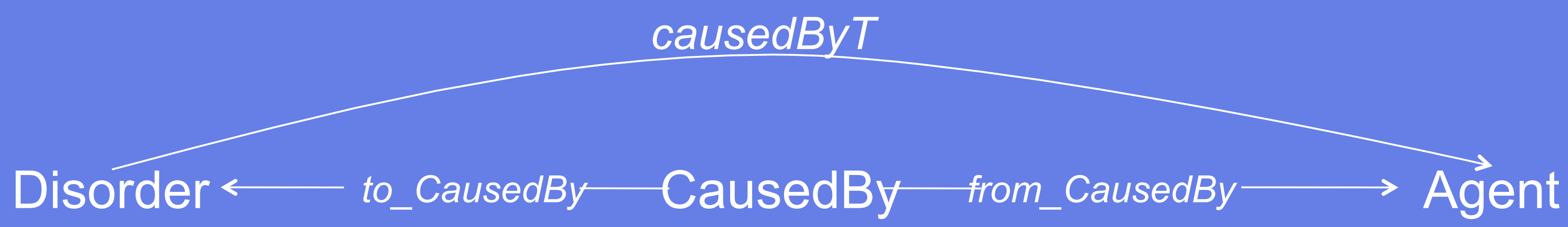
- ► **Domain and range**
  - ► **Replace with Motik style constraints**
    - **Limited support in current classifiers but easy in preprocessing**
- ► **Transitivity and property paths**
  - ► **Specialise to, from & Association for each property**
  - ► **Define a bridging property**
  - ► **Filter out Associations from query results**



► **Property paths almost work, but queries would include CausedBy class**

- ► **Restrict by transformations, e.g.**
  - ► **(causedBy *some* X) ➻ (DomainEntity & causedBy *some* X)**

In more detail



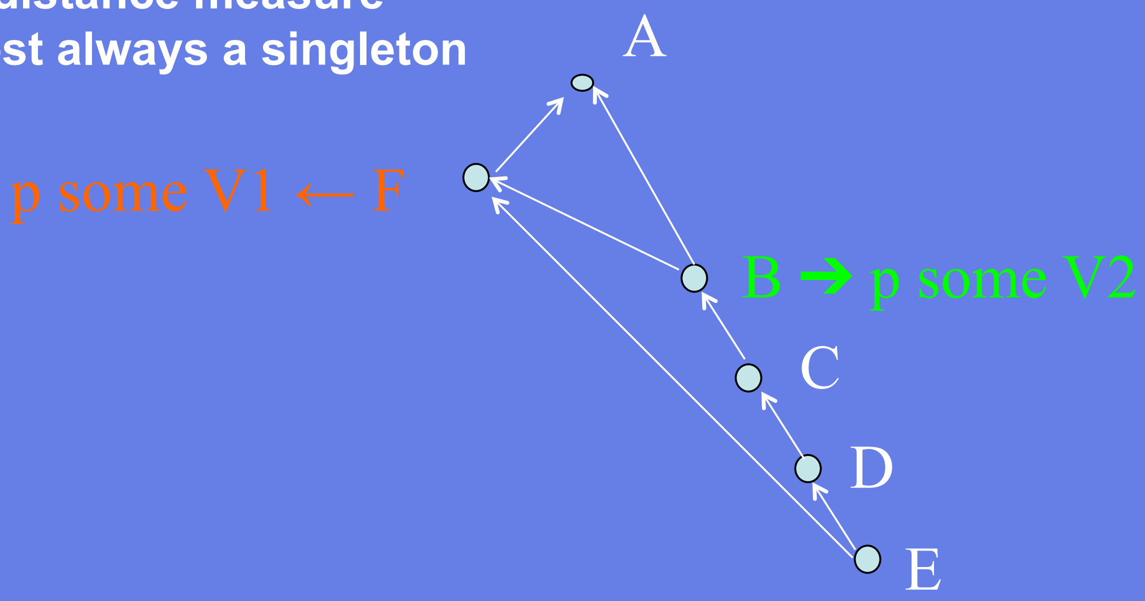
- *Properties* to_causedBy→ to; from_caused_by→ from;
  causedByT → bridgingProp, causedByT *transitive*
- *property_path:* inv(to_caused_by) o from_caused_by → causedBy
- *Enforce:* CausedBy → to *some* C ➽ CausedBy → to_causedBy *some* C
  → from *some* C ➽ CausedBy → from_causedBy *some* C
- *Enforce*: causedByT *some* C ➽ DomainEntity & causedByT *some* C

Metaknowledge & Metaclasses

- ► Use in frames
  - ► Define templates
    - OWL: Dealt with by Axiomization
  - ► Annotations
    - OWL: Annotation properties suffice
  - ► Higher order statements
    - *Classes as values – "books about lions"*
    - *Statements about classes – "Lion is an endangered species"*
    - OWL: No fully satisfactory solution
      - *Work arounds using Puns &additional post processing*
      - *Work arounds using annotation properties & additional post-processing*
      - Proposed "rich annotations" & layered OWL
        - Neither made it into OWL 2 recommendation

Defaults & Exceptions

- ► **Set of "nearest" existential restrictions or annotations**
  - ► **"Touretzky distance"**
  - ► **Set usually a singleton in a well consructed ontology**
    - **Example Tourezky distance measure t_nearest(p,E) almost always a singleton**



t_nearest(p,E) = { V2}

Other possible extensions

- ► Knowledge about associations
  - ► Strength, uncertainties
    - Extension to link to Bayesian probabilities a challenge for research
  - ► Evidence / provenance
  - ► Typicality
    - Links to exceptions

Summary: *Beware of Differences*

- ► Fundamental distinctions
  - ► Axioms & templates
  - ► Ontology (narrow sense) & Contingent/Particular knowledge
- ► Trade-offs of axioms vs templates
  - ► *Axioms* – Composition and Classification - ontologies
  - ► *Templates* – Contingent knowledge and data structures,
    Higher order (meta) knowledge
- ► One possible reconciliation & compromise
  - ► Alternative OWL with reified properties & enforced transformations
    - Gains but expressivity looses other
    - Basis for further extensions and expressivity
    - May sacrifice completeness
- ► Practical experiments & more theoretocal studies needed
  - ► Specialised environments & tools