Truth or Consequences: The case for evidence-based ontologies in an Ecology of Knowledge Representation

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“Ontologies”: What are they for?

- To use in information systems
  - The claim is that “ontologies” are key components of modern biomedical information system

- If so, it follows that...
  - The criteria for “ontologies” should be
    - The consequences for Information Systems
      - Their fitness for the purposes of their roles in information systems
      - Whether or not they lead to errors
      - Their faithfullness to the information to be represented
      - The repeatability of their use in information systems
      - Their role in the broader ecology of knowledge in info systems
About this talk

► What have been doing recently – my motivations

► What is an ontology – narrow sense & broad sense
  ► The word has drifted until it can mean anything or nothing:
  ► I will try to define Ontology_{NarrowSense}

► Some example conundrums to illustrate methods of argument
  ► How we should make decisions “ontologies”
    ‣ What counts as arguments?
    ‣ What counts as evidence?

► Some areas where ontologies need to interwork with other knowledge representation in an “ecosystem”

► Conclusion
Problems I am trying to solve

► How to generate complex forms for patient situations with multiple diseases and considerations

► “An elderly man with confusion, rapid breathing, and extensive bruising as seen by the Emergency room Medic”
  • Pneumonia v alcohol v liver disease v head injury v diabetic coma…
    ‣ Probably more than one

► Without combinatorial explosion & assuring correctness
  • A typical hospital has several thousand forms many of which take over a person-year to develop; A typical patient may need several.
    ‣ … and they don’t begin to cover what’s needed – THE bottleneck

Too many

Too big

Too complicated & repetitive
Problems I am trying to solve (II)
How to tell if SNOMED is safe to use
(or any other big terminology – 50K..500K classes)

► Is it correct clinically? Formally?

► Will “users” understand it sufficiently to use it correctly?
  End users? Knowledge & software engineer users?
  • (See JAMIA, J Biomed Informatics, & KCAP papers on my website http://cs.man.ac.uk/~rector)

► Why isn’t Myocardial Infarction a kind of Ischemic Heart Disease?

► Why isn’t Subdural hematoma a kind of Intracranial bleed?

► Why isn’t Chronic duodenal ulcer a kind of Chronic disease?

► Why is Thrombophlebitis of breast a kind of Disorder of leg?
  Why is Thrombosis of ankle vein a Disorder of pelvis?
Problems I am trying to solve (III)

► How to reconcile ICD’s traditional classification and legacy with new requirements
  ► Retain stability with previous versions
    • A classification – not an ontology
    • Fixed depth; mutually exclusive and exhaustive at every level
      ‣ Every patient event counted exactly once at every granularity
  ► Overcome major problems
    • Shorten 20-year revision cycle & support Social Computing approaches
    • Support multiple views & new requirements

► Multi-layered structure
  ► Ontology layer – hopefully reconciled with SNOMED
  ► Foundation layer – lots more around the “skeleton” of the ontology
  ► “Linearizations” – traditional classifications linked to Foundation layer
Problems I am trying to solve (IV)

► How to create an “Ontology of Clinical Research” that fits into standards

► Must ultimately integrate with UML to specify a “system”

► System of which it is part must carry many arbitrary “rules” and “calculations”
  • Mix of formal and text
  • Eg
    ‣ Criteria for inclusion and exclusion of patients
    ‣ Algorithms for calculation of statistics

► System must provide a way of
  • Indexing and discovering trials as a whole based on its characteristics
  • Represent or link to detailed trial protocols
    ‣ Complex contingent transition networks / plans
  • Recording “journeys” of individual patients through those protocol
    ‣ Which may or may not conform to the protocols
      - And can describe the reasons for deviations from protocol
What is an ontology?

Historical definitions...

► Ontology Philosophy
  ► The study of “being” – of “What there is”
  ► The study of “universals” – “What is necessarily true”
    • As opposed to:
      “Particulars” – What happens to be true in this world/time-place
    • ... but not all of the study of knowledge

► Ontology Information systems
  ► Gruber’s fancy word to describe “static knowledge base”
    • Gave it a fancy definition: “A conceptualisation of a domain”
  ► A fancy word for a common terminology used in a set of data structures and/or applications
  ► What we can implement in OWL
... What do we mean by “ontology\textsubscript{NarrowSense}”? 
* One part of study of knowledge 
* One part of knowledge representation 
* The source of the entities/terminology
Two Hypotheses / Doctrines

1. Weak version
   - Ontology\textsubscript{Philosophy} has useful insights for Ontology\textsubscript{InformationSystems}
     - It would be surprising if 2500 years of thinking had nothing to offer

2. Strong version
   - Ontology\textsubscript{Philosophy} should set the criteria for Ontology\textsubscript{InformationSystems}
     - It would be surprising if thinking from before information systems could be accepted uncritically for information systems

- Can we find empirical evidence?`
- Can we find a rational basis of argument?
  - What would count as evidence? Arguments?
  - Can we refine the hypotheses?
That part of knowledge representation that can be expressed as positive universal statements in logic:

\[ \forall x \ . \ C(x) \ ... \ \rightarrow \ ... \]

Often in the form hierarchies of statements:

“Cs are kinds of Ds” == “All Cs are Ds”

One important subset: what can be expressed in OWL

- Other important subsets: Less expressive but easier computationally (EL++, CQs, ...)

Linked to language for communication with human users

Forms part of a system of “Knowledge Representation”:

Physical symbol systems that model our knowledge of some topic (after Newell & Simon)

- As models, always have limitations
Exclude artefacts that are not “ontologies” …but have hierarchies & look a bit like them

► Classifications & Groupings – ICD, DRGs, etc.
  ► Designed for counting / remuneration

► Thesauri, Library catalogues, SKOS networks (also MindMaps, etc.)
  ► Designed for navigation by human users

► Lexicons & other Linguistic resources
  ► Designed for language processing (WordNet, UMLS SN, etc.)
    • Although may be linked to “ontologies” to form “terminologies”

► Data schemas, structures & databases (UML, etc.)
  ► Information on particulars and how to store it

► Other logico/mathematical modelling techniques
  ► Bayesian networks, neural networks, equation systems,…
Most common use case:

Ontology

Data structure
Most common use case:

```
Entity
  - Disorder
    - Malignancy
      - Person
      - Situation
    - Melanoma
  - Procedure
    - Infection
    - Excision
```

```
Subject
  - Alan now according to Dr. Smith
```

```
Diagnosis
```

```
Treatment
```

```
Complication
```
Why I use DLs/OWL for Ontologies in Information Systems

► **Composition**
   “Burn *that* has_site *some* (Foot *that* has_laterality *some* Left) & has_penetration *some* Full_thickness & has_extent …& … & … & …”

► **Avoid combinatorial explosion** –
  - Smaller terminologies that say more
  - Support for expressions as well as names (“post-coordination”)  

► **Express context**
  - The “size of elephants” vs the “size of mice”

► **Coordinate hierarchies and index information, e.g. hierarchies for:**

► **How else to get it correct?**

► **Quality assurance**

► **Computational tractability**

► **A standard**
Composition: Building with “Conceptual Lego” Parallel families of hierarchies

Species → Genes

Protein

Function

Disease

CFTRGene in humans

Protein coded by (CFTRgene & in humans)

Membrane transport mediated by (Protein coded by (CFTRgene in humans))

Disease caused by (abnormality in (Membrane transport mediated by (Protein coded by (CFTRgene & in humans)))).
I use OWL/DLs for many things, but...

► Not everything written in OWL is an ontology
► Not every ontology need be, or can be, written in OWL.

► OWL is a logic language – a subset of First order Logic
  ► Designed to make it easy to represent (aspects of) ontologies
    • But can be used for other things.
    • Has many limitations
      ‣ First order, binary-relational, tree-model property, ...
    • And many serious flaws
      ‣ Handling of meta-data, relation to RDF, ...

► But it is a standard and computationally tractable
  ► Usually worth using a standard for that part of a task that it covers
    • But using it where it doesn’t work, doesn’t work.
Before going further:

Some history & evolution of meaning of the word “ontology”
Early Knowledge representation

- Mid 1980s, AI toolkits (KEE, ART, KnowledgeCraft...)
  - Tripartite “Knowledge based systems”
    - Static knowledge base – Semantic Networks & frames
      - Included both “universal” and “particular” knowledge
    - Rules
    - Dynamic knowledge base
    - Plus Metadata, attached procedures, event driven Uis, ...

- Addressed good questions in knowledge representation, and gave some good answers, even if sometimes limited
  - Heuristic
    - Programming languages rather than logics
... some systems resembled Rube Goldberg machines

Neither complete, decidable nor provably sound

But good enough that still asked: “Why can’t we get back to 1985?”

Serious question from Zak Kohane, top HI researcher, PhD in AI from MIT.
Knowledge Based Systems co-evolved with semantic networks & frames

► “Frame” coined by Minsky for computer vision but rapidly adopted by knowledge representation

► Convenient way to represent Object-Attribute-Value triples & semantic networks

► Protégé-frames / OKBS is modern descendant
Key event 1: Logicians asked ‘What’s it mean?’

- Questions about Semantic Networks and Frames
  - Wood: *What’s in a Link*; Brachman *What IS-A is and IS-A isn’t*.

- First Formalisation (1980)
  - Bobrow *KRL*,
    - *Cognitive Science Vol 1 Issue 1 Page 1*
  - Brachman: *KL-ONE*
    - *Went on to be the ancestor of DLs*
    - *…of rather its failure stimulated the development of DLs*

- All useful systems are intractable (1983)

- Hybrid systems: T-Box and A-Box
  - *Focus on Terminology (T-Box) – Universal knowledge*
    - *Became what I now call Ontology Information Systems*

- All tractable systems are useless (1987-1990)
Emergence of DLs and “Tbox” reasoning

► ‘Maverick’ incomplete tractable in practice Tbox/logic systems (1985-90)
  ► GRAIL, Krep (SNOMED), LOOM, Cyc, …,

► The German School: Description Logics (1988-98)
  ► Detailed catalogue of complexity of family – “alphabet soup” of logics
  ► Horrocks (& Nowlan): practically tractable even if worst case intractable

► Emergence of the Semantic Web & OWL
  ► Development of DAML (frames), OIL (DLs) → DAML+OIL → OWL → OWL2

► Emergence of Tractable Subsets of DLs/OWL – EL++, Conjunctive queries, … (2005..current)
  ► Roughly what GRAIL and SNOMED had been doing but logically proven
    • Missed completely by early DL developers
...but Description logics are very different from frames (even though intended to formalise them)

▶ Frames are systems of **Templates**
Description logics/OWL are sets of **Axioms**

▶ Failures to realise the difference led to confusion

  • Most SW Engineering paradigms use templates
    ‣ **OO Programming** (e.g. Java objects)
    ‣ **UML Class diagrams, Model Driven Architectures (MDA/OMG)**

  • Many general knowledge representations use templates
    ‣ **Frames** (Protégé frames)
    ‣ **Canonical Graphs in Sowa’s Conceptual Graphs**
    ‣ **RDF(S) (as usually used)**
    ‣ **F-Logic, ...**
    ‣ **Protocols, guidelines, ...**
Axioms & Templates: *Fundamentally different*

► **Axioms restrict**

► The more you know the less you can say
  • If there are no axioms, you can say anything
  • “Sanctioning” hard - Hard to ask “what can be said here?”

► Global – any change can affect anything anywhere

► Violations of axioms $\rightarrow$ unintended inferences (often of unsatisfiability)

► Over-riding impossible - monotonic

► Open world - Must be closed for instance validation of missing values

► Inferentially rich; most semantics internal & standard, composition natural

► **Templates permit**

► The more you know the more you can say
  • If there is no field/slot in the template you just can’t say it
  • “Sanctioing easy” – Easy to ask “what can be said here?”

► Local – changes affect only a class & its descendants

► Violations of templates $\rightarrow$ validation errors

► Over-riding natural – usually non-monotonic

► Closed world - Instance validation natural & local

► Inferentially weak; most semantics external in queries, no composition
Key event 2: Borrowing of the word “ontology” for InformationSystems

► Most notably by Tom Gruber
  ► But “in the air”. UML and Model Based Architectures on the rise.

► Victim of our own success
  ► “Ontology” ~ “Good”

► But did not initially differentiate “ontologies” from “Knowledge Representation” or “information modelling”
  ► Confused the universal & particular
    any world & this world
    things in the world & information about them

► …and invited philosophers to both clarify and confuse

► … and then became identified with T-Boxes, DLs/OWL
  ► At least by some communities
    • … and distorted to do many things for which never intended
...but there is much more to knowledge representation than ontologies / DLs

► DLs / OWL / T-Boxes represents “universal knowledge”
  ► Universal, two valued, monotonic, first-order…

► Most knowledge is not “universal” (“particular”)
  ► About this “world”, rather than all “worlds”

► Much knowledge is not first order, monotonic or even logical
  ► Probabalistic, possibilistic, fuzzy, associationist, navigational, linguistic, procedural, heuristic, defeasible, higher order, epistemic, …

► So the question is:
  ► How do “ontologies” fit into the rest of knowledge representation?
How do ontologies relate to the rest of Knowledge Representation (& Information systems)

Deeply intertwined with thinking about how “Ontologies InformationSystems” should be built

Examples from use for Terminology

conundrums & approaches to evidence
What matters & what doesn’t: How do we know if it is correct?

► If I ask questions, do I get the correct answers?
  ► Inferences and responses to queries
    • As judged by domain experts
    • As tested by empirical studies
    • As tested by results when used in applications

► Some errors are obvious in applications
  ► Omissions:
    • Myocardial infarction should be kind of Ischemic heart disease
      ‣ Queries for Ischemic Heart disease are expected to return Myocardial Infarctions
      ‣ Rules for Ischemic Heart Disease should apply to Myocardial infarctions
    • Definition: “Infarction” == “Cell death due to ischemia”
      ‣ Omitted in prior versions of SNOMED

► Commissions
  • Injuries to arteries of the ankle are not disorders of the pelvis
    ‣ Schema error in SNOMED
  • Thrombophlebitis of breast is not a disorder of the lower extremity
    ‣ Simple accident in anatomy compounded by same schema error in SNOMED
Some seem natural from the language but Can lead to dangerous mis-interpretations in applications

► In SNOMED, “Subdural Hematoma” is not a kind of intracranial bleed.
  ► One of 1000 most common entries in hospital systems
    • Life threatening & requires immediate action

► Literally, there are “spinal subdural hematomas”
  • The dura covers both brain and spinal cord
  ► Roughly .5% of all Subdural hematomas
    • Always specified as “Spinal subdural hematoma”
  ► Strong evidence that when doctors write/code “Subdural hematoma” they mean “intracranial”
    • Failing to represent this is life-threatening
Labelling needs to be at multiple levels to avoid confusion

► Fully specified names
  ► Need an entities for
    • “Subdural hematoma, spinal AND/OR intracranial”
    • “Intracranial subdural hematoma”
    • “Spinal subdural hematoma”

► Preferred named
  ► “Subdural hematoma” → “Intracranial subdural hematoma”

► Text definitions
  ► To be completely unambiguous – but don’t count on their being read

► Synonyms

► Search terms (hidden labels)
Other labels make little difference

► Most ontology formalisms require a single root node
  ► Labelled in different systems:
      • Main consideration is that it not conflict with the name for something else
        ‣ *But content of root note is almost always nil*
        ‣ *Label rarely affects consequences*

► Other cases where arguments are about words rather than the entities themselves
  ► “Neoplasm”
    • We need a nodes for
      “Proliferation or tumour, benign or malignant”
      “Malignant proliferation or tumour”
      ‣ *But which should be “neoplasm”?*
And some really are about conventions:
2 hands & 2 Feet? 4 hands? 4 feet?
Some artefacts present special problems: Recent example: What do SNOMED &/or ICD disease codes represent? (Thanks to Stefan Schulz)

► A “disorder”? (or “dispositiion”)
  ► “Condition” interpretation

► “having a disorder”?  
  ► “Situation” interpretation
    • “Situation of having a disorder” / “Patient having the disorder at a given place and time as observed by a given clinician”

► It does make a difference
  ► For codes representing compound diagnosis, e.g. “Fracture of Radius and Ulna”
  ► For complications: “Diabetic retinitis”

► How to decide?
Consider: Fracture of Radius & Ulna (Forearm) – a single code in ICD and SNOMED

► “Condition interpretation”
  ► Nothing can be both a “fracture of radius” and “fracture of ulna”

► “Situation interpretation”
  ► A patient can simultaneously have both a “fracture of radius” and “fracture of ulna”
What might count as evidence? What is the question?

Should responses to queries for patients with “Fracture of Radius” include patients with “Fracture of the radius & ulna”?

- Most doctors say “yes”
- Both SNOMED and ICD are hierarchies classify:
  - “Fracture of Radius” and Ulna as a kind of “Fracture of Radius”
What do we ask the questions for?
What is the right answer for these purposes?

► Deciding patients’ treatment
  ► As antecedents of rules

► Counting patients’ by causes of illness & death (morbity & mortality)
  ► To contribute to vital statistics

► Counting patient episodes for remuneration & Health Care Planning
  ► To manage the healthcare system

► Counting patient events for research into cause and effect
  ► As nodes in a causal network
  ► As part of the inclusion/exclusion/outcome criteria for clinical studies
A further example

► Should “Diabetic kidney disease” be classified under Diabetes? Kidney disease? Both? Neither?

► Should queries for patients with “Diabetes” include those coded only for “Diabetic kidney disease”
  • Can anyone have “Diabetic kidney disease” without having “Diabetes”?

► Many similar cases examined and experiments performed

► Conclusion:
  “having a condition” (“Situation interpretation”)
  • Best fit for both:
    ‣ Current practice
    ‣ Intended consequences
    ‣ The reality of clinical practice
    ‣ Safety in clinical decision support

► Can fit into an ontological framework, but not in the obvious way
Conundrum 2: What do biomedical experts mean by is_part_of?

► In medicine, function is often more important than structure (except for surgeons & anatomists)
  ► “A fault in the part is a fault in the whole”
    Conclusion or Criterion?
    • Is the radio part of the electrical system of my car?
    • Are T cells part of the immune system?
    • Is there any structure that can be called the “endocrine system”
  ► Is the brain part of the skull? The pericardium part of the Heart?

► Accidents & abnormalities often ignored
  ► e.g. “Finger” defined as part of hand
    • Even if amputated, crushed, or congenitally missing
    • Even though rarely arises congenitally someplace else
What answers do we want to our questions

► What are the parts of the hand?
  ► What is in that path bottle that is/was “John’s finger”

► What are the disorders of the hand
  ► Fracture of finger? Amputation of Finger? Missing finger?
  ► Mitochondrial disease (that includes mitochondria in cells of the hand)?

► Is pericarditis a heart disease?
  ► Clinically yes, contrary to FMA

► Is a brain disease a disease of the skull?
  ► Clinically no, consistent with FMA

► A real problem for Foundational Model of Anatomy
  ► If used “as is” gives some answers inappropriate clinically
    • Even when ontologically and anatomically correct
Conundrum III: When to argue
Some choices make little difference
(as long as we adhere to standards)

► Logical / mathematical equivalence, e.g.
  ► Should location be specified using Rectangular or Polar coordinates?
    • Choose according to ease of use & calculation
      ‣ Not something to argue about in principle
  ► Should we use metric or imperial units?

► Approximations fit for purpose
  ► Euclidean geometry to survey my property
    • Spherical geometry to navigate around the world
  ► Newtonian laws of motion to calculate planetary motions
    • Relativity to calculate motion at cosmic distances at LHC

► But standards do matter
  ► A Mars probe was lost because of confusion between metric and imperial units!
Example of logical approximations: 
*Entity-Quality vs Entity-Quality-Value*

1. Red_Ball == Ball & bears some Red_quality

2. Red_Ball == Ball & has_quality some 
   (Colour & has_value some Red_value)

► What difference does it make?

► Assume
   Red_quality == (Colour & has_value some Red_value)

► For inference, usually very little

► For asking what can say be said, a lot
   ► Easy to ask what qualities and values apply where in 2.
     ► Does this matter to systems? Which systems? For what tasks?

► 1) can be seen as an approximation of 2) but not vice versa.
Conundrum IV: How strong can ontological commitments before they become problems?

► Mutually exhaustive & pairwise disjoint
  ► Few biological classifications are exhaustive – diseases, organisms, etc.
    • without = “residual categories”: “other”, “not elsewhere classified”, etc.
  ► Even some disjoints can be awkward
    • Hybrids, chimeras, …
  ► Need even Continuant and Occurrent be exhaustive?
    • E.g. Are time and space best represented as neither?

► Many biomedical ontologies do not implement disjointness, e.g. SNOMED, GO
  ► Requires a surprising amount of extra work; easy to make errors
  ► But not doing so sacrifices much consistency checking
    • No class can be inferred to be inconsistent in FoL, OWL, or related formalisms without negation and/or disjointness
Conundrum V: Hypotheticals, counterfactuals & imaginary constructs

- **Unicorn** == Horse that has_part exactly 1 Horn

- Unicorn \(\rightarrow\) Bottom (or has_status mythological)
  - To say/infer something does not exist, I must first define it
    - To say nothing, leaves the question formally open
      - But we don’t want to clutter our ontologies
      - Or close them impractically

- Higgs Boson, Gene for obesity, for high cholesterol?
  - Lots of information to be recorded before confirmed to exist

- Art and Architecture ontology (includes Archeology)
  - Full of mythological creatures as topics of art

**If there is information about it, I need to represent it in my ontology**
Ontologies & the Ecology of Knowledge Representation

We need both dictionaries & encyclopedias
Ontologies as “Conceptual coat-racks”

► The framework on which to hang other knowledge
  ► The source definitions, values and value-sets

► To use in other formalisms about
  ► “may” – diabetes may cause renal disease
  ► “probably”/”usually” – Appendicitis usually causes pain in the right lower quadrant
  ► “facts” – Metformin is licensed for treatment Diabetes type 2
  ► Mathematical formulations – sets of partial differential equations, etc.

► There are many other knowledge representation formalisms
To integrate or interoperate?

► Four choices

► Integrate other methods into ontologies
  - Risks “mission creep” & loosing ontologies’ unique value
  - Risks ignoring well developed work in other disciplines

► Make ontology implementations “friendly” to hybrid systems
  - Define interfaces & formulations for convenient interworking
    ‣ Leverages other work, but requires compromise and new understanding

► Force knowledge representation onto an ontological procrustean bed?

► Keep each form of knowledge in its own silo?
What do we need to interoperate with? Where is the added value?

► The rest of the ontology & semantic web community
  ► IAOA, Ontolog, ontology summits, Linked Open Data, …

► Data structures, UML & Model Driven Architectures
  ► Key parts of today’s software engineering
  ► Made much easier by some choices than other
    • Reifying relations, E-Q-V rather than E-Q
      ‣ An urgent problem

► Clinical decision support, Trial Protocols, and Biological pathways
  ► Not primarily ontological but need ontologies
    • A mission critical challenge – if we are irrelevant here, then we are irrelevant to healthcare

► Probabilities and Bayesian Networks
  ► Highly developed theory and community
    • How best to leverage & interact
      ‣ A grand challenge

► Question answering
  ► Did Watson need an “ontology”? What kind?
One Example of making ontologies friendly to other formalisms: UML & frames:

Easier if we reify relations

► Simplified sketch:
  ► CLASS: MyAssociation → Association
    → hasTopic some Class1
    → hasObject some Class2
    → Key: (hasTopic, hasObject)

► Most of the benefits of UML models but retains composition
  ► At the cost of an extra level of nesting (to be hidden)
    • (close to “DRL-lite” Berardi et al 2005)
  ► Loss of some power of ontologies for property paths, transitivity etc
    • May need to filter out a few unwanted inferences
Side benefit
Take advantage of good diagramming tools

- Plus a bit of effort to sort out the multiplicities and cardinalities
- If we use subproperties & property paths & a bit of external checking, we can produce a bridging property, which can be transitive
  - \( \text{has}_\text{cause} \subseteq \text{inv}(\text{hasTopicC}) \circ \text{hasObjectC} \)
Other side benefits

► Natural representation for “sanctioning”
  ► Just ask for minimal set of associations with a given topic
► Natural approach to reconciling with frames
► Link provides attachment point for second order information on strengths of association/probabilities
► Natural representation for “some”/“may”
  ► “Pneumonia may be caused by Bacteria”
    • E.g. Pneumonia may be caused by Bacteria?
    • Causal_link_bacteria_pneumonia ==
      Causal_link &
      has_topic some Pneumonia &
      has_object some Bacteria
  ► It’s logic / OWL – but is it ontology

An interface between Ontology & KR?
Related issue - Value sets:  
*Mission critical for medical applications*

▶ Three cases

▶ Value types – often specialist – validated lexically
  - Strings numbers, date-time, quantities, …
  - Biological units per $f(\text{weight, height, lab test value})$
  - Fingers, ++..++++, grade i..iv, …

▶ Enumerated lists of entities from some domain
  - *Pain radiates to: Left/Right Shoulder, Left/Right Arm, Abdomen, Back, Left Axilla*
    ‣ *But NOT their subclasses*

▶ Systematic lists
  - *Regions of skin of the face excluding the eyelid*
    ‣ to a designated granularity

▶ NB Often non-monotonic
  ▶ More specific over-rides more general
    - Is this ontology? How can ontology add value?
The choice:

"Ontology" faces outwards in
Summary:

Ontologies in Information Systems & Ontologies in Philosophy in an Ecology of Knowledge Representation
Ontologies\textsubscript{BroadSense} vs Ontologies\textsubscript{NarrowSense}

“Ontologies” often used just to mean “Knowledge Representation”

- Can we recapture the narrow sense?
  - Do we need a new phrase? A campaign for the narrow sense?

The key to effective information systems is effective factoring of problems

- Over-broad usage of “ontology” obscures distinctions
  - Mission creep for ontologies leads to poor factoring & poor systems
Summary: Ontologies

- Ontologies are just a small part of knowledge representation
  - Most knowledge is not universal

- Ontologies should be judged on their consequences for Information Systems
  - Do they lead to the right answers? Wrong answers? Appropriate / Inappropriate decisions?
  - 2500 years of thinking should not be ignored, but…
    - Test each principle from Ontology empirically before acceptance in information systems

- All Ontologies are models (Physical symbol systems)
  - All are imperfect: There is no one way, although there are wrong ways
    - Tests are ultimately empirical: fitness for purpose, inferences, queries, inter-rater reliability,…

- Language matters if leads to misinterpretation
  - But can be a distraction

- Axioms and Templates are different
  - Reconciliation a “grand challenge”

- Time to look outwards
  - Become part of a larger ecology of knowledge representation – many challenges
OUTCUTS