Patterns of Ontology

John F. Sowa

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Prospects for a Universal Ontology

Many projects, many useful theories, but no consensus.

- 4th century BC: Aristotle's categories and syllogisms.
- 12th to 16th century AD: Scholastic logic, ontology, and semiotics.
- 17th c: Universal language schemes by Descartes, Mersenne, Pascal, Leibniz, Newton, Wilkins. L'Académie française.
- 18th c: More schemes. Satire of the Grand Academy of Lagado by Jonathan Swift. Kant's categories.
- 19th c: Ontology by Hegel, Bolzano. Roget's Thesaurus. Boolean algebra. Modern science, philosophy of science, early computers.
- Late 19th and early 20th c: FOL. Set theory. Ontology by Peirce, Brentano, Meinong, Husserl, Leśniewski, Russell, Whitehead.
- 1970s: Databases, knowledge bases, and terminologies.
- 1980s: Cyc, WordNet, Japanese Electronic Dictionary Research.
- 1990s: Many research projects. Shared Reusable Knowledge Base (SRKB), ISO Conceptual Schema, Semantic Web.
- 21st c: Many useful terminologies, but no universal ontology.

Relating Multiple Ontologies

The lack of consensus is inevitable:

- Different applications, different domains, different requirements.
- General-purpose systems require multiple paradigms.
- Trillions of dollars of legacy systems have no explicit ontology.

A descriptive ontology is always fallible:

- Describes the concepts of empirical sciences and everyday life.
- Must accommodate anything anyone observes or does.
- But it may change with every new discovery or theory.

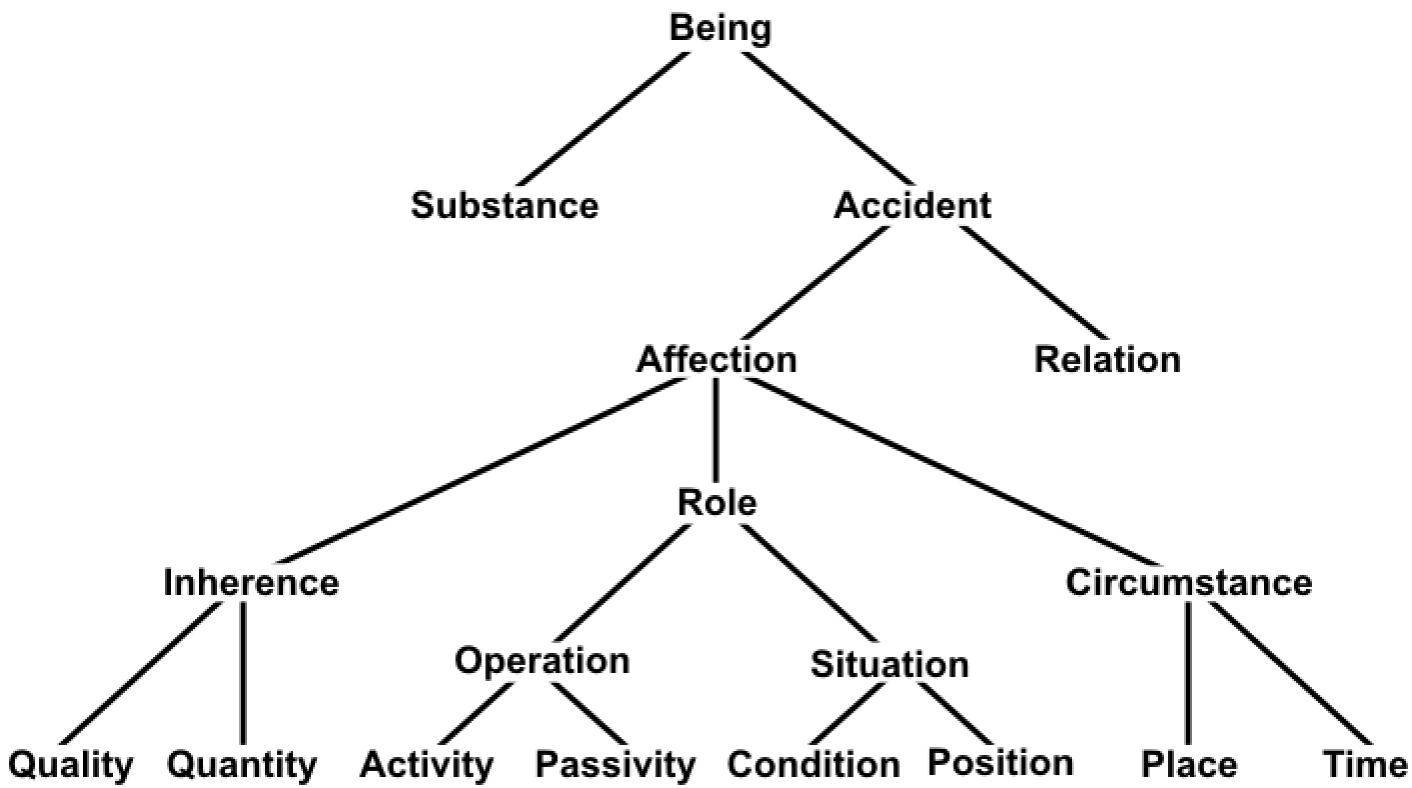
A normative ontology depends on agreement to a standard:

- Specifies the conventions for certain domains or applications.
- But standards may change to support new developments.

Requirements for interoperability among independent systems:

- An underspecified, descriptive upper level ontology.
- Open-ended variety of descriptive or normative microtheories.

Tree of Aristotle's Categories



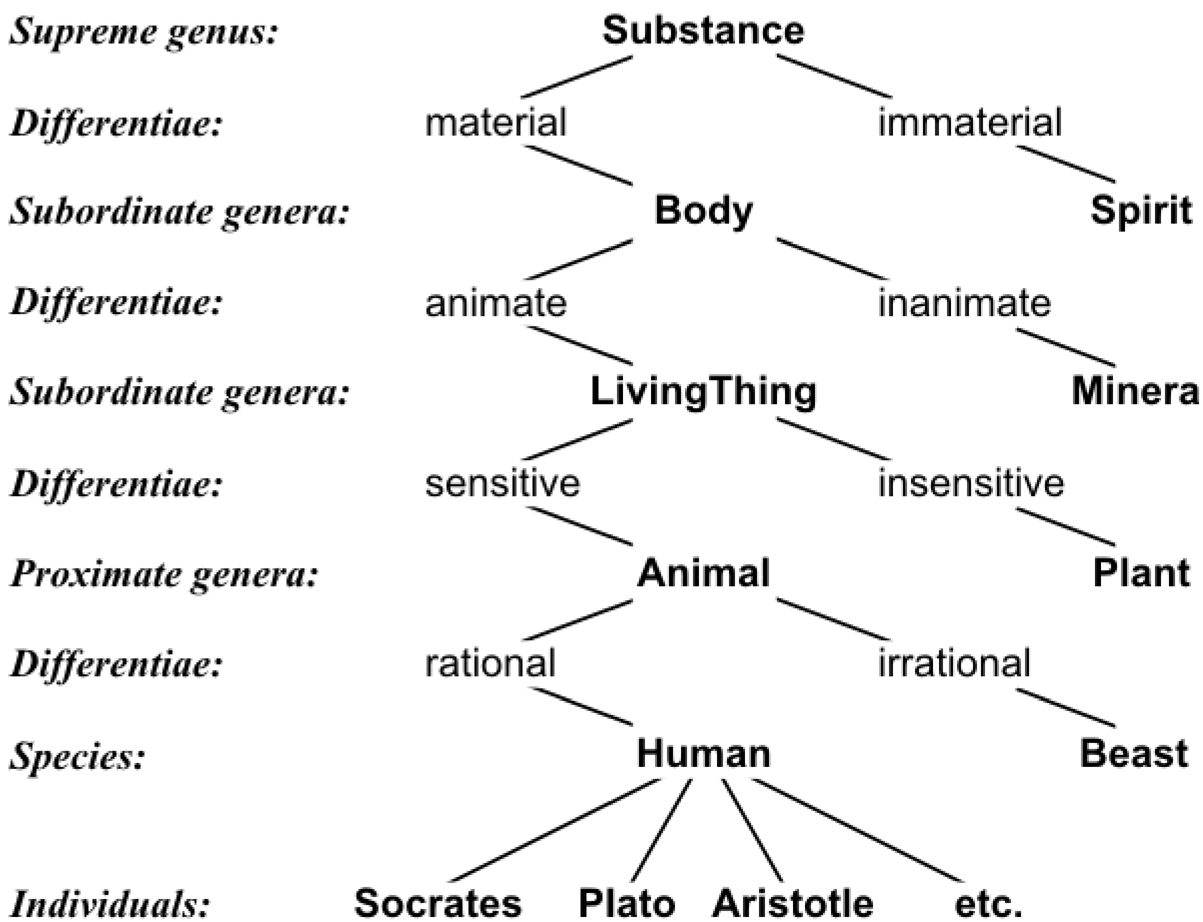
Aristotle's categories, as arranged by Franz Brentano (1862). *

The ten categories are the endpoints (leaves) of the tree.

The branch points are based on writings by Aristotle.

*** The English labels are based on Aristotle's Greek, Brentano's German, and a selection among several English translations of Aristotle.**

Tree of Porphyry



A tree of categories and differentiae was found in a commentary on Aristotle by the philosopher Porphyry (3rd century AD).

This tree is based on a version by Peter of Spain (1239).

Medieval Scholastics

The Scholastic logicians organized and systematized the contributions by Greek, Roman, and Arabic philosophers:

- **Aristotle's syllogisms, categories, and definitions.**
- **Propositional logic developed by the Stoic philosophers.**
- **Diagrams for showing relationships.**
- **Controlled Latin for the notation.**

They also made many innovations and extensions:

- **Ontology of suppositions for reasoning about fictional, hypothetical, and metalevel language and logic.**
- **Modal and temporal operators and rules of inference.**
- **Model-theoretic semantics for Latin by William of Ockham.**
- **Methodology of conceptual analysis.**

Unfortunately, Renaissance scholars ridiculed the "logic chopping." In logic, the 17th century was less advanced than the 14th.

Combining Logic and Ontology

Aristotle's syllogisms use logic to analyze the ontology.

Professionals in every field develop notations that mix logic with an ontology specialized for their subject matter.

Areas of active research:

- Parts, shapes, spaces, systems, and life.
- Time, events, situations, agents, processes, and causality.
- Patterns of signs: Syntax, semantics, and pragmatics.
- Intentionality: Attention and goals in every aspect of life.

Ways of combining logic and ontology:

- Simplest method: Use some notation for logic to represent the ontology with some choice of functions and relations.
- More complex method: Design special syntax to represent the most important functions and relations in the ontology.

Patterns of Ontology

Everything that anybody knows, does, feels, or thinks:

- Parts: Physical, abstract, discrete, continuous.
- Shapes: Natural, artificial, regular, irregular, static, dynamic.
- Spaces: 3-D space, 4-D space-time, any theory of physics.
- Systems: Dynamic structures of interoperating parts.
- Life: Every kind of organism, behavior, society, ecology.

Notations that mix ontology with some version of logic:

- Temporal logic includes an ontology of time.
- Higher-order logic assumes a hierarchy of infinite sets.
- Procedural languages represent temporal sequences.
- Many kinds of diagrams highlight different aspects.

Temporal Patterns

Ways of analyzing patterns that occur in space and time:

- **Time: Discrete, continuous, branching, 4-D space-time.**
- **Events: Meaningful occurrences in space and time.**
- **Situations: Chunks of space-time that contain events.**
- **Processes: Causally connected chains of events.**

The word *meaningful* raises a philosophical puzzle.

- **What is a meaningful event or situation?**
- **Scientists observe patterns in nature, and they form theories about the laws that generate the patterns.**
- **But the laws say nothing about meaning or value.**
- **Why should one pattern be more meaningful than another?**

Intentionality

Without life, there is no meaning in the universe.

- **Philosopher Franz Brentano: Intentionality is "*the directedness of thought toward some object, real or imagined*."**
- **Biologist Lynn Margulis: "*The growth, reproduction, and communication of these moving, alliance-forming bacteria become isomorphic with our thought, with our happiness, our sensitivities and stimulations*." ***
- **A bacterium swimming upstream in a glucose gradient marks the beginning of goal-directed intentionality.**

Physicists study the universe independent of the life in it.

- **Meaning, intention, purpose, and value originate with life.**
- **Aristotle the biologist used the term *telos* or *final aitia*.**
- **Both Peirce and Brentano adopted the word *intentional* from the Scholastic tradition based on Aristotle.**

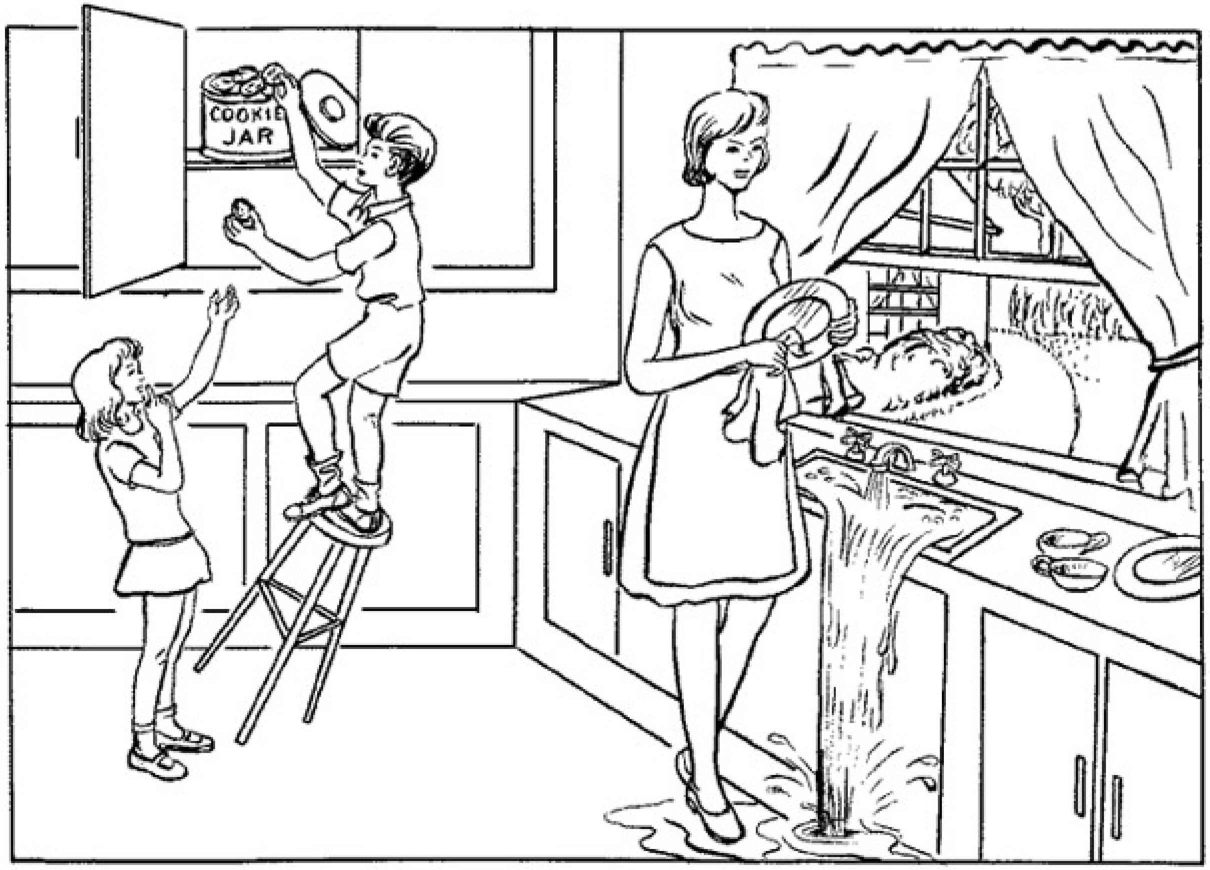
*** Margulis (1995) Gaia is a tough bitch, http://edge.org/documents/ThirdCulture/n-Ch.7.html**

What is a Situation?

Definition: A situation is a region of space-time that bounds the range of perception, action, interaction, and communication of one or more agents.

- **The boundary of a situation is determined by the range of perception, action, and communication by the agents in it.**
- **A situation without agents is possible, but meaningless.**
- **Microscopes, telescopes, and TV use enhanced methods of perception and action to change the boundary of a situation.**
- **Psychologists and sociologists study human situations.**
- **Logicians and philosophers formulate theoretical models of agents interacting and communicating in situations.**
- **Computer scientists develop methods for simulating and reasoning about the models.**

Example of a Situation



This is a test picture used to diagnose patients with aphasia.

A patient's description of the situation can show the effects of lesions caused by wound, stroke, tumor, or infection.

Diagram adapted from Goodglass & Kaplan (1972).

Meaningful Aspects of the Situation

Space-time region shown in the diagram:

- The kitchen of a private home.

Agents:

- Girl, boy, woman.

Goals of the agents:

- Girl, boy: get cookies.
- Woman: wash dishes; maintain discipline.

Actions:

- Wiping, spilling, reaching, holding, grasping, tipping, falling.

Question:

- How can we represent this situation in logic?

Patterns of Situations

Philosophers, linguists, logicians, and computer scientists emphasize different aspects of situations.

But there are important commonalities:

- A situation is an actual, hypothetical, or fictional region.
- Somebody decided that the region is significant.
- Some version of logic and ontology can be used to describe it.
- Linguistic theories relate sentences to situations and speakers.

Questions:

- How do we decide what situations are important?
- How can we describe them effectively?
- How can we reason about them?

Representing Situations

Common Logic in any dialect can represent a situation and the things and events in it.

But the IKL extension to Common Logic is necessary to express theories about propositions and situations. *

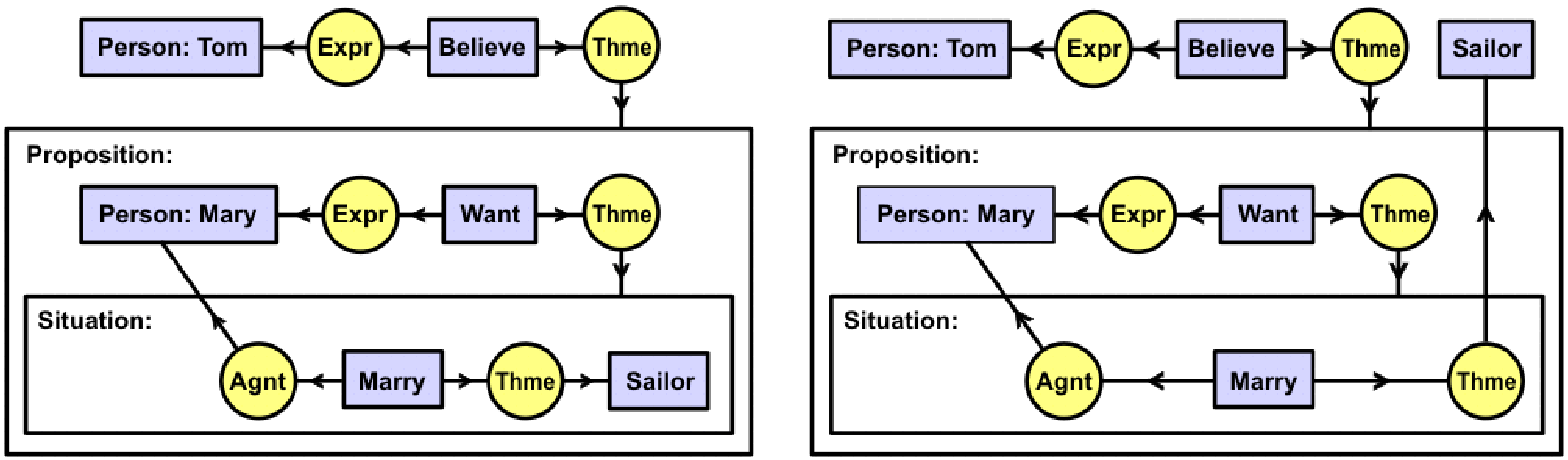
That extension enables the logic to make metalevel statements that relate propositions and situations.

It introduces an ontology about propositions, situations, and the language for relating them.

It enables a logic to reason about the propositions expressed in that logic or some other logic.

*** For documents about Common Logic and IKL, see http://www.jfsowa.com/ikl**

Propositions and Situations



The two CGs above show two different interpretations of the English sentence *Tom believes that Mary wants to marry a sailor*:

- ***There exists a sailor, and Tom believes a proposition that Mary wants a situation in which she marries the sailor.***
- ***Tom believes a proposition that Mary wants a situation in which there exists a sailor whom she marries.***

A situation is a meaningful region of space-time described by the proposition stated by the nested CG.

For further discussion, see http://www.jfsowa.com/pubs/eg2cg.pdf

Situation Semantics

In situation theory, the unit of information is called an *infon* σ, which is entailed by some *situation s*: $s \models \sigma$

The meaning of a language expression φ is a relation between a *discourse situation d*, a *speaker connection function c*, and a *described situation e*: $d, c \, \| \varphi \| \, e$

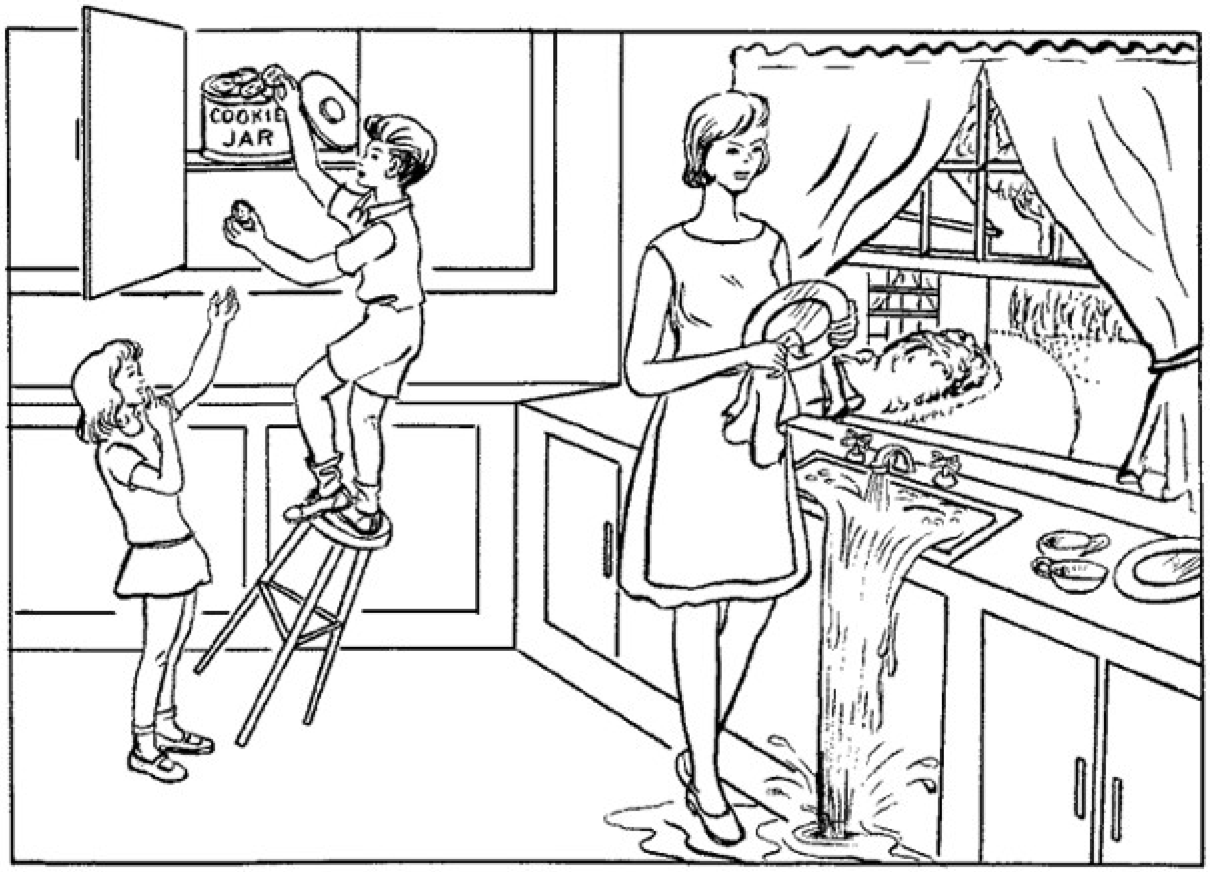
All those relations can be expressed in Common Logic:

- **A single relation with all its arguments corresponds to an infon.**
- **A compound infon is a CL expression that combines the relations.**
- **The theory, notation, and terminology by Devlin (1991) can be directly mapped to any dialect of CL.**

The IKL extension to CL provides a rich formalism for talking about situations, agents, and the intentions of the agents.

Controlled NLs can serve as a notation for CL and IKL.

A Description in Controlled English



{Situation: ***A woman, a girl, and a boy are in a kitchen of a house. The woman wipes a plate with a cloth. Water spills on the floor of the kitchen. The girl reaches for a cookie. The boy holds a cookie in his left hand. The boy grasps a cookie with his right hand. The boy stands on a stool. The stool tips over. The boy falls down.*****}**

Patterns of Patterns of Patterns

An ontology is a pattern of signs for describing and classifying whatever exists or can exist in some domain of interest.

A logic is a system of signs for relating and reasoning about the patterns of signs in an ontology.

Semantics evaluates truth by relating the patterns of signs of logic and ontology to the patterns of signs in the world.

Semiotics, the study of signs, is the foundation for language:

- **Every living cell responds to signs and communicates by generating signs.**
- **Larger organisms are colonies of cells that communicate by signs.**
- **Neurons are cells that facilitate communication in an organism.**
- **A social system is a community of organisms of some species.**
- **Every language, natural or artificial, is a system of signs that facilitates communication in one or more social systems.**

Is Logic the Foundation for Language?

Richard Montague (1970) treated NLs as a version of logic:

"I reject the contention that an important theoretical difference exists between formal and natural languages."

Hans Kamp (2001) followed Montague with qualifications:

"The basic concepts of linguistics — and especially those of semantics — have to be thought through anew... Many more distinctions have to be drawn than are dreamt of in current semantic theory."

Barbara Partee (2005) added further qualifications:

"The present formalizations of model-theoretic semantics are undoubtedly still rather primitive compared to what is needed to capture many important semantic properties of natural languages... There are other approaches to semantics that are concerned with other aspects of natural language, perhaps even cognitively deeper in some sense, but which we presently lack the tools to adequately formalize."

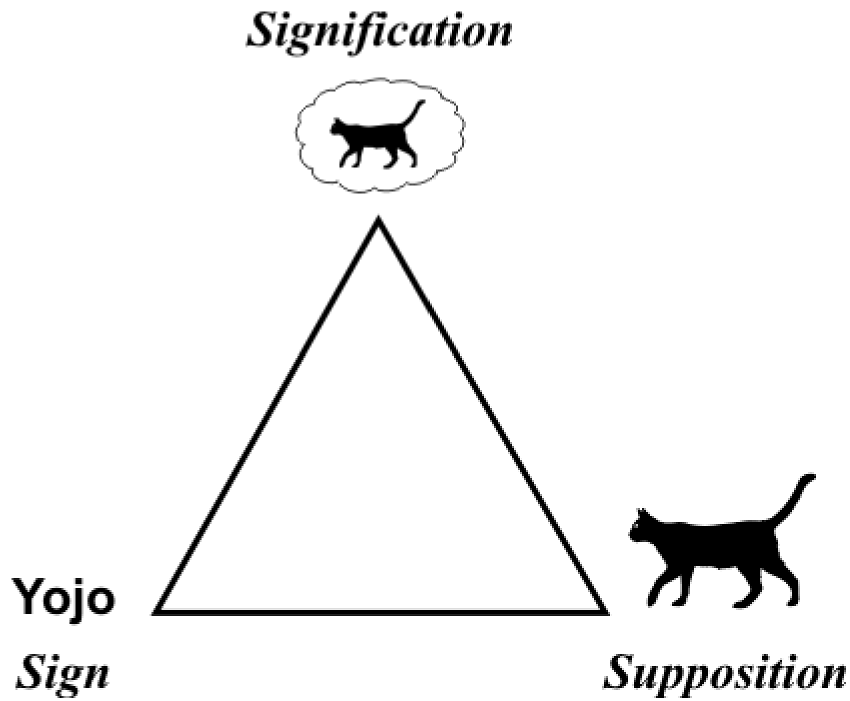
Aristotle's Foundation

The most influential and most widely debated paragraph about signs and language ever written:

> **First we must determine what are noun (*onoma*) and verb (*rhêma*); and after that, what are negation (*apophasis*), assertion (*kataphasis*), proposition (*apophansis*), and sentence (*logos*). Those in speech (*phonê*) are symbols (*symbola*) of affections (*pathêmata*) in the psyche, and those written (*graphomena*) are symbols of those in speech. As letters (*grammata*), so are speech sounds not the same for everyone. But they are signs (*sêmeia*) primarily of the affections in the psyche, which are the same for everyone, and so are the objects (*pragmata*) of which they are likenesses (*homoiômata*). On these matters we speak in the treatise on the psyche, for it is a different subject. ***

*** Aristotle, *On Interpretation*, 16a1.**

Scholastic Meaning Triangle



Ogden and Richards (1923) drew meaning triangles, but Aristotle and the Scholastics developed the theory.

The Scholastics used the Latin *signum* for the sign, *significatio* for the affection in the psyche, and *suppositio* for the object.

For the signification, this diagram follows Aristotle by showing a cloud that contains a likeness (*homoiôma*) of the object.

Different Labels for the Triangle

A Scholastic alternative:

- ***Signum, conceptus, objectus*** **(sign, concept, object).**

Charles Sanders Peirce:

- **Sign, interpretant, object.**

Gottlob Frege:

- ***Zeichen, Sinn, Bedeutung*** **(sign, sense, reference).**

Edmund Husserl:

- ***Zeichen, Bedeutung, Gegenstand*** **(sign, meaning, object).**

Ferdinand de Saussure:

- **Signifier, signified. (He ignored the vertex on the lower right.)**

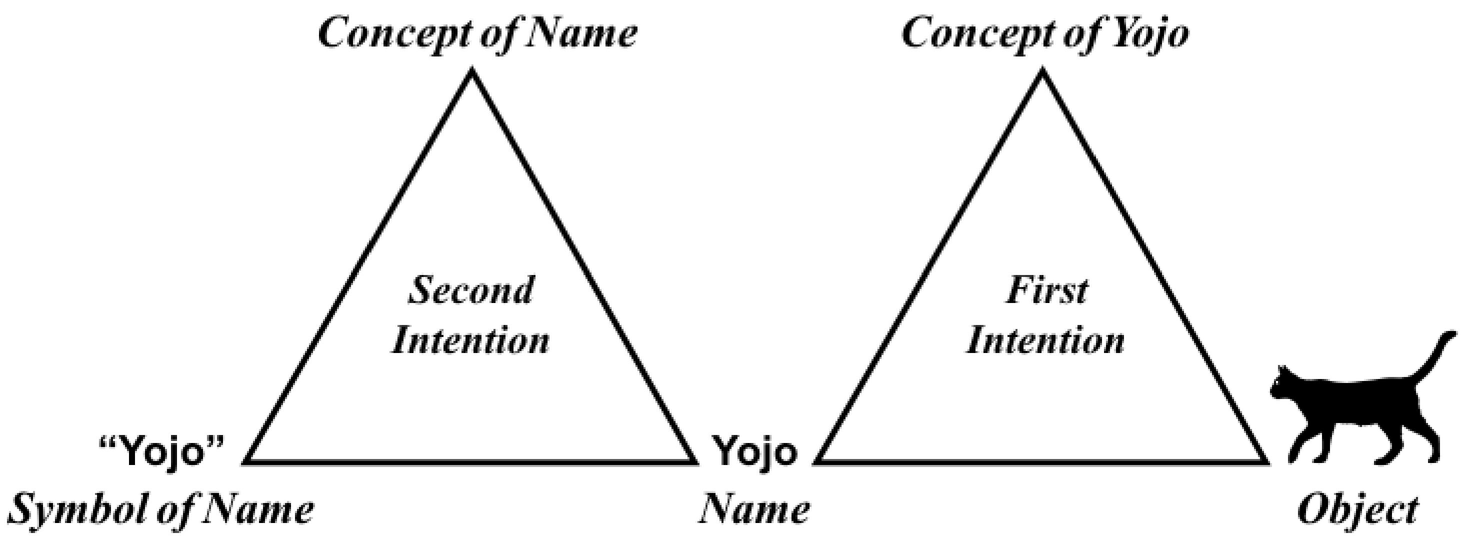
Alfred Tarski:

- **Sign, object. (He ignored the top of the triangle.)**

The dyads by Saussure and Tarski omit important distinctions:

- **Saussure did not distinguish the meaning from the object.**
- **Tarski did not distinguish different meanings with the same object.**

Metalanguage



Aristotle: "Written words are symbols of those in speech."

The Scholastics generalized that principle:

- **First intentions: Signs that refer to things in the world.**
- **Second intentions: Signs that refer to other signs.**

In the 1930s, Alfred Tarski introduced the terms *object language* for first intentions and *metalanguage* for second intentions.

Universal Language Schemes

With the printing press and the new nation states, a flood of books in modern languages was rapidly displacing Latin.

In the 17th century, scientists, philosophers, merchants, bankers, and diplomats felt the need for a new universal language.

Francis Bacon claimed that "real characters" similar to Chinese characters could be used for mutually unintelligible languages.

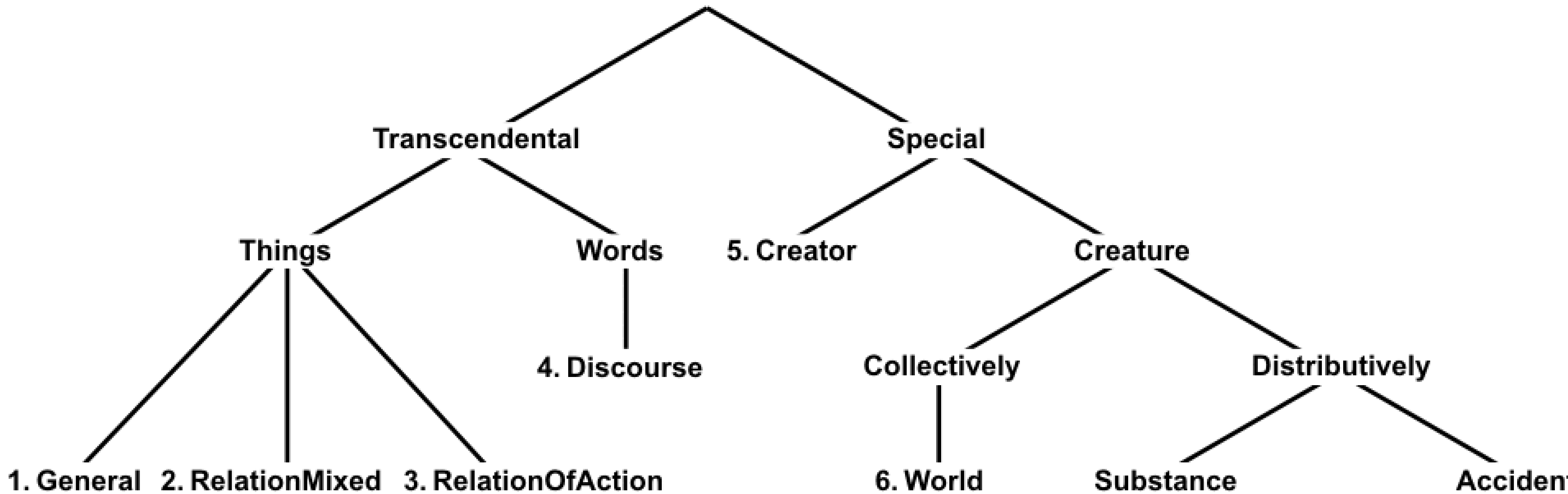
Descartes, Mersenne, Pascal, Newton, and Leibniz proposed mathematical principles as the basis for a universal language.

The largest and most impressive system was the *Real Character and Philosophical Language* by John Wilkins.

Wilkins was secretary of the British Royal Society. Several other members collaborated on the project.

For further discussion, see Knowlson (1975), Eco (1995), and Okrent (2009).

Wilkins' Upper-Level Ontology



In a 600-page book, Wilkins (1668) devoted 270 pages to tables that define 40 genera subdivided in 2,030 species.

The categories labeled 1 through 6 are the first of his 40 genera. The other 34 genera are subtypes of Substance or Accident.

Inheritance: Each species is defined by the conjunction of all the differentiae along the path from one of the 40 genera.

Summary of Wilkins' System

An impressive combination of upper-level ontology, metalevel ontology, mid-level ontology, thesaurus, and notation.

A failure as a replacement for Latin, but an inspiration for Leibniz, Kant, Roget, and many others.

The division of Transcendental vs. Special corresponds roughly to the distinction between signs and their referents.

The division of Collectively vs. Distributively is an important distinction that many ontologies ignore.

But 2,030 categories at the endpoints of the tree are inadequate for a general-purpose language.

Other members of the Royal Society added about 15,000 English words as approximate synonyms of those 2,030 categories.

Unfortunately, the system contained many ad hoc features that were ridiculed by Jonathan Swift and Jorge Luis Borges.

Immanuel Kant

Quantity	Quality	Relation	Modality
Unity	Reality	Inherence	Possibility
Plurality	Negation	Causality	Existence
Totality	Limitation	Community	Necessity

Kant defined 12 categories, organized in four groups of three.

He also claimed that his categories could replace the top level in an ontology such as Aristotle's or Wilkins':

> *"If one has the original and primitive concepts, it is easy to add the derivative and subsidiary, and thus give a complete picture of the family tree of the pure understanding.... It can easily be carried out with the aid of the ontological manuals."* *

But nobody ever carried out that "easy" task.

* **Kant (1787)** *Critique of Pure Reason,* **(A:82, B:108).**

Charles Sanders Peirce

Peirce was a pioneer in modern logic, and he was familiar with logic, ontology, and semiotics from Aristotle to the 19th century.

He also studied Kant and analyzed the patterns of triads in Kant's table of categories.

He discovered metalevel patterns underlying various triads:

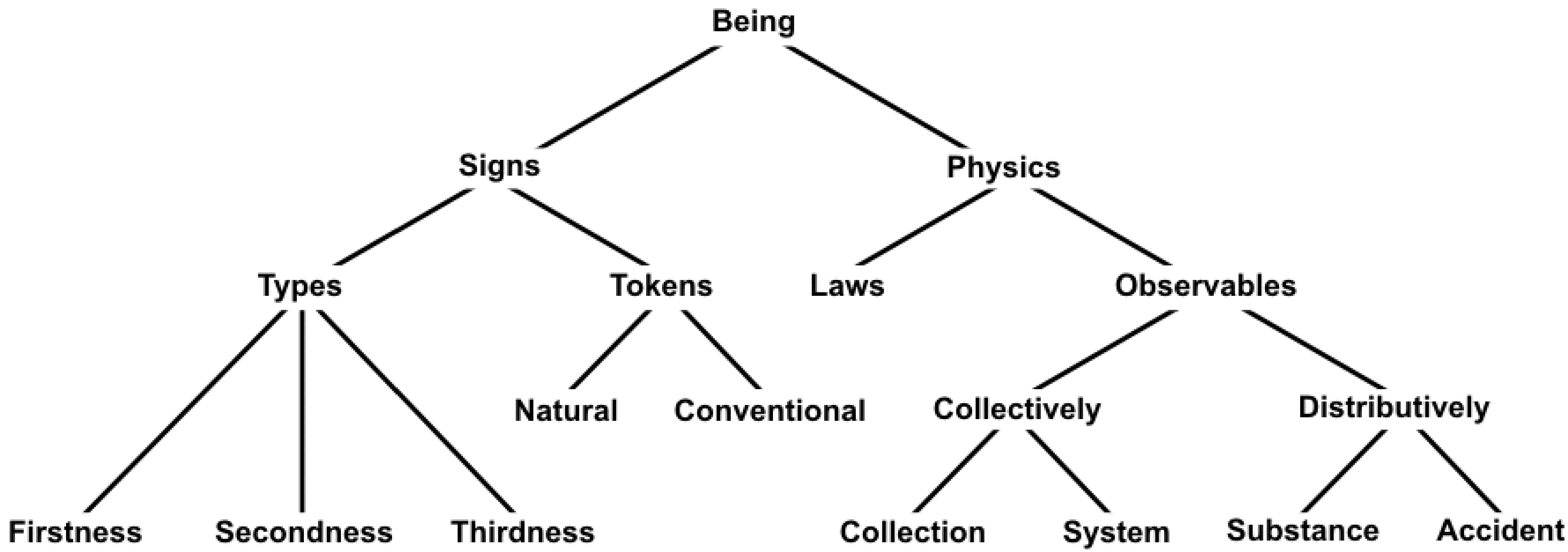
- **Firstness: Quality expressible by a monadic predicate.**
- **Secondness: Reaction expressible by a dyadic relation.**
- **Thirdness: Mediation that requires a triadic relation to bring a First and a Second into a dyadic relationship.**

The basic triad: Some observable Mark (1) that can be interpreted as a Token (2) of some Type (3).

The most commonly cited triad: Icon, Index, Symbol.

For further discussion, see http://www.jfsowa.com/pubs/signs.pdf

Updated Version of Wilkins' Ontology



This diagram preserves the pattern, but it relabels the nodes:

- **The top division distinguishes signs from their physical referents.**
- **The creator is replaced by the laws of physics. Theists can think of the laws as the *logos*, which John the Evangelist said is God.**
- **Sign types are defined by laws, and sign tokens refer to observables.**
- **The types can be organized in triads, as defined by C. S. Peirce**

Can Any Ontology be Complete?

The updated version of Wilkins' ontology is more complete than the great majority of published ontologies:

- **Signs would include all languages, natural or artificial, and any kind of data or metadata on the WWW.**
- **Laws would include theories about any natural, artificial, planned, hypothetical, or fictional phenomena in the universe.**
- **Collections and Systems include all structures and organizations.**

But science, technology, and the world are constantly changing.

- **A general framework can remain useful for centuries.**
- **But nobody can anticipate the innovations in the next 20 years.**

Observation by Alfred North Whitehead:

"Systems, scientific and philosophic, come and go. Each method of limited understanding is at length exhausted. In its prime, each system is a triumphant success: in its decay it is an obstructive nuisance."

Thesaurus vs. Ontology

Peter Roget was a secretary of the Royal Society who developed a thesaurus of words instead of an ontology of things.

- **A much simpler system of classification than Wilkins'.**
- **A top level with just six categories: Abstract relations, Space, Matter, Intellect, Volition, Affections.**
- **A bushy hierarchy with just three layers beneath the top level.**
- **No definitions, differentiae, inheritance, or logic.**

Roget's first edition (1852) was an instant success:

- **By 1869, he had produced 28 editions; his son continued the work.**
- **Computer versions are used in natural language processing (NLP).**

The modern WordNet is closer to a thesaurus than an ontology:

- **WordNet has a simple top level.**
- **It has no formal definitions, differentiae, inheritance, or logic.**
- **But it is a widely used resource for NLP in several languages.**

Lattice-Based Methods

Many classification schemes are organized as trees, which limit inheritance to just one parent for any node beneath the top.

To support multiple inheritance, S. R. Ranganathan developed a system of faceted classification for library catalogs:

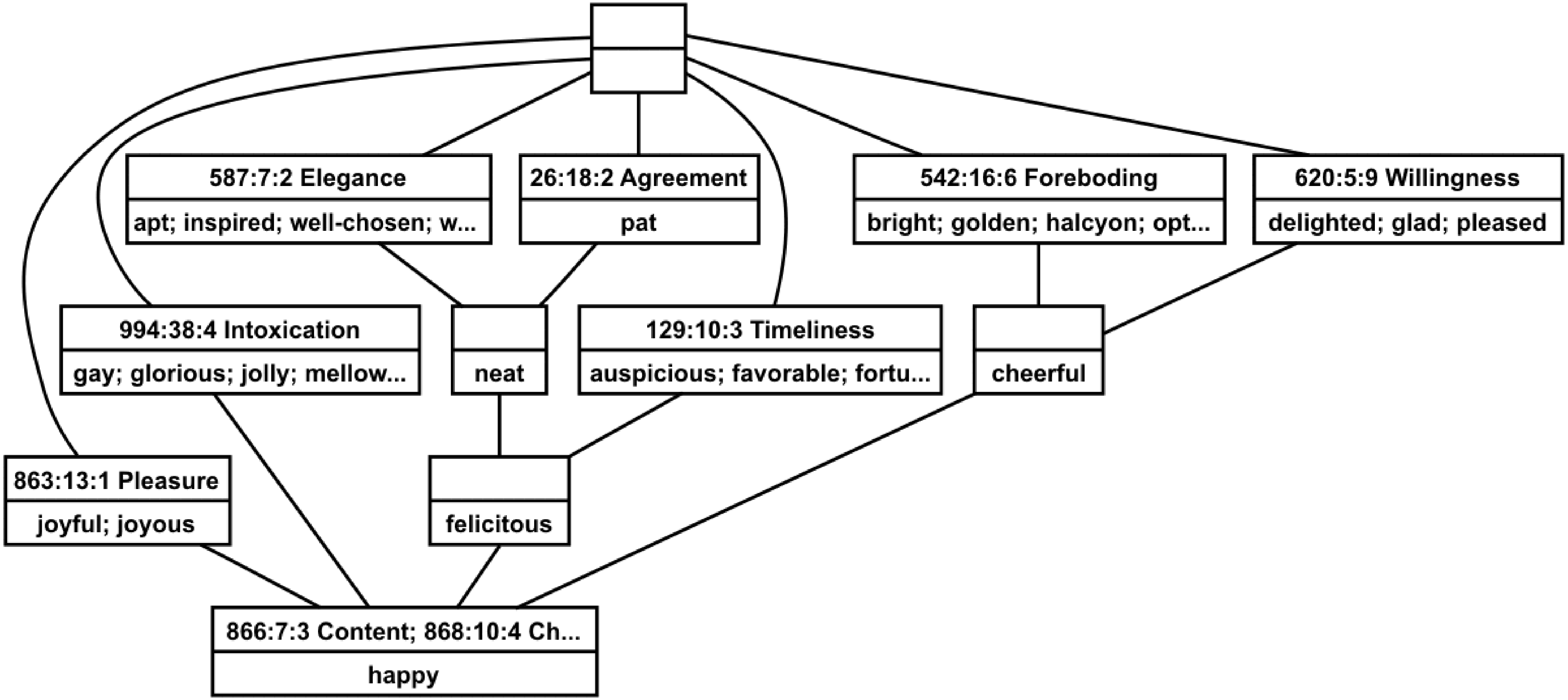
- Each facet represents a monadic relation.
- Each category is defined by a conjunction of facets.

Formal Concept Analysis (FCA) generates a minimal lattice for any concepts or categories defined by such a conjunction:

- Input to the FCA tools Is a list of concepts and definitions.
- Those definitions could be the list of facets for each concept.
- The output is a minimal lattice that shows all inheritance paths.
- FCA is often used to check OWL ontologies for consistency.

For FCA tools and techniques, see http://www.upriss.org.uk/fca/fca.html
For faceted classification, see http://www.iskouk.org/kokonov2007.htm

Concept Neighborhood for *happy*



A lattice of word senses derived from Roget's Thesaurus by FCA.

To see a similar lattice for any word, go to the FCA web site:

- **For Roget's Thesaurus, http://www.ketlab.org.uk/roget.html**
- **For WordNet, http://www.ketlab.org.uk/wordnet.html**
- **For concept neighborhoods, http://www.upriss.org.uk/papers/icfca10.pdf**

Lexical Collocations

Patterns of words that are typically combined for some purpose.

1. Creation or activation patterns: Verb Noun.

Make an impression, compose music, fly a kite, spin a top, launch a missile.

2. Eradication or nullification patterns: Verb Noun.

Reject an appeal, lift a blockade, raze a house, repeal a law, revoke a license.

3. Modifiers that intensify a noun: Adjective Noun.

Reckless abandon, pitched battle, crushing defeat, sweeping generalization.

4. Characteristic verbs with a given subject: Noun Verb.

Alarms go off, bees swarm, blizzards rage, blood circulates, bombs explode.

5. Units of things or units of stuff: Noun *of* Noun.

Herd of buffalo, bouquet of flowers, word of advice, act of violence.

6. Modifiers that intensify an adjective: Adverb Adjective.

Deeply absorbed, strictly accurate, intimately acquainted, keenly aware.

7. Modifiers that intensify a verb: Verb Adverb | Adverb Verb.

Affect deeply, anchor firmly, appreciate sincerely, argue heatedly.

Examples from M. Benson, E. Benson, & R. Ilson (1986) ***The BBI Combinatory Dictionary of English.***

Relating Language to Logic

Peirce wrote a succinct, but accurate summary of the issues:

> ***"It is easy to speak with precision upon a general theme. Only, one must commonly surrender all ambition to be certain. It is equally easy to be certain. One has only to be sufficiently vague. It is not so difficult to be pretty precise and fairly certain at once about a very narrow subject."*** **(CP 4.237)**

Implications:

- **A precise formal ontology of everything can be stated in logic, but it's almost certainly false in many important respects.**
- **A looser classification, such as WordNet or Roget's *Thesaurus*, can be more flexible for representing patterns of words.**
- **A specification in logic can be "pretty precise and fairly certain" only for a very narrow subject.**

Logic is an abstraction from language that emphasizes patterns of reasoning, but the patterns of words are also important.

“I don’t believe in word senses.”

The title is a quotation by the lexicographer Sue Atkins, who devoted her career to writing and analyzing word definitions.

In an article with that title,* Adam Kilgarriff observed that

- **“A task-independent set of word senses for a language is not a coherent concept.”**
- **The basic units of meaning are not the word senses, but the actual “occurrences of a word in context.”**
- **“There is no reason to expect the same set of word senses to be relevant for different tasks.”**
- **“The set of senses defined by a dictionary may or may not match the set that is relevant for an NLP application.”**
- **Professional lexicographers are well aware of these issues.**
- **The senses they select for a dictionary entry are based on editorial policy and assumptions about the readers’ expectations.**

*** See http://www.kilgarriff.co.uk/Publications/1997-K-CHum-believe.pdf**

Organizing a Large Ontology

No single ontology can ever be complete, consistent, and useful.

An underspecifed framework for everything with an open-ended collection of microtheories is more useful and practical:

- **An upper-level ontology, such as Aristotle's, Wilkins', or Kant's, can show the broad patterns of how everything fits together.**
- **But different problems for different purposes require different representations and algorithms for processing the details.**
- **For interoperability, upper level definitions must be underspecified with the barest minimum of axioms and differentiae.**
- **For precise reasoning and problem solving, the details must be pushed down to the highly specialized, low-level microtheories.**

To be humanly intelligible, ontology must be related to language.

Lexical resources that show the patterns of words are valuable, but they should never be confused with ontologies.

Controlled Natural Language

Aristotle invented the first controlled NL for his syllogisms.

CNLs are easy to read, but they require training to write.

Experts don't use CNLs when they talk or write to one another.

The restrictions on syntax and semantics required for a CNL are much easier for a computer to enforce.

Recommendation:

- Let people use any notation they prefer, including full NLs.
- Develop learning methods that enable computers to interpret more NL patterns as they acquire more knowledge.
- But the computers always generate CNLs in response.

Over time, communication becomes more efficient as people and computers learn each other's patterns.

Translation by Pattern Matching

Many machine-translation systems learn corresponding patterns in two NLs from a bilingual corpus:

- **For any language pair, find texts written in both languages.**
- **For each pair of texts, identify corresponding sentences.**
- **Analyze multiple sentence pairs to derive patterns of phrases.**

NLs have patterns at many different levels:

- **N-grams: unanalyzed strings of N words (or other units).**
- **Named entities:** ***Bob*** **=** ***Robert Smith*** **=** ***Mr. R. W. Smith*****.**
- **Parse trees: syntactic patterns of phrases in each sentence.**
- **Logic: quantifiers, Boolean operators, and anaphoric references.**
- **Ontology: categories of the referents of each word or phrase.**
- **Context: patterns in the text that surrounds each sentence.**

A translation can be improved by using multiple kinds of patterns to verify, extend, and correct one another.

Patterns of Patterns of Patterns

Knowledge in the brain consists of patterns of patterns.

All languages, natural and artificial, express patterns.

Structured representations in tables, diagrams, and networks are based on computable patterns.

Recommendations:

- **For teaching people, emphasize the patterns of the subject.**
- **For designing artifacts – hardware, software, or houses – start by analyzing the patterns and revising them as needed.**
- **For human-computer interfaces, build on the patterns that people use in talking, thinking, and working with the subject.**
- **For interoperability among computer systems, focus on the fundamental patterns, not the quirks of specific notations.**

Related Readings

Peirce's contributions to the 21st century,
http://www.jfsowa.com/pubs/csp21st.pdf

Signs and reality,
http://www.jfsowa.com/pubs/signs.pdf

Signs, processes, and language games,
http://www.jfsowa.com/pubs/signproc.pdf

Fads and fallacies about logic,
http://www.jfsowa.com/pubs/fflogic.pdf

The role of logic and language in ontology,
http://www.jfsowa.com/pubs/rolelog.pdf

From existential graphs to conceptual graphs,
http://www.jfsowa.com/pubs/eg2cg.pdf

Five questions on epistemic logic,
http://www.jfsowa.com/pubs/5qelogic.pdf

Worlds, models, and descriptions,
http://www.jfsowa.com/pubs/worlds.pdf

The virtual reality of the mind,
http://www.jfsowa.com/talks/vrmind.pdf

For other references, see the bibliography at http://www.jfsowa.com/bib.htm