Ontologies

Hideaki Takeda

Ontologies

- Introduction of Ontology
  - What is Ontology?
  - Typology of Ontologies
- Top-level Ontologies
  - Formal Ontology
    - **DOLCE**
    - **BFO(Basic Formal Ontology**)
    - Sowa's top-level ontology
  - Pragmatic top-level ontology
    - SUMO
    - OpenCyc
  - Linguistic top-level ontology
    - **WordNet**
   - Penman Upper Model/The Generalized Upper Model

Ontologies

- Introduction of Ontology
  - What is Ontology?
  - Typology of Ontologies
- Top-level Ontologies
  - Formal Ontology
    - **DOLCE**
    - **BFO(Basic Formal Ontology**)
    - Sowa's top-level ontology
  - Pragmatic top-level ontology
    - SUMO
    - OpenCyc
  - Linguistic top-level ontology
    - **WordNet**
    - Penman Upper Model/The Generalized Upper Model

Ontology in information system
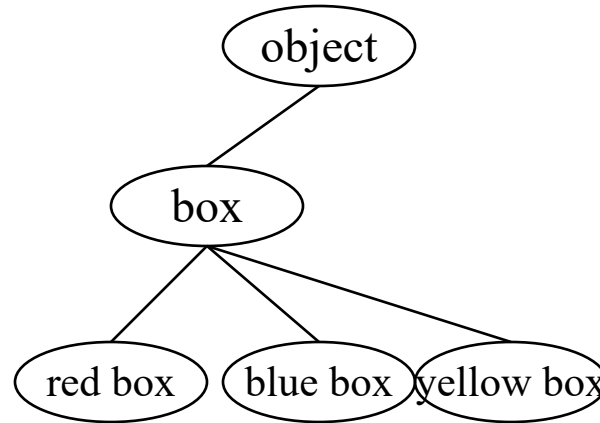
- *An ontology is an explicit specification of a conceptualization [Gruber]*

Conceptualization
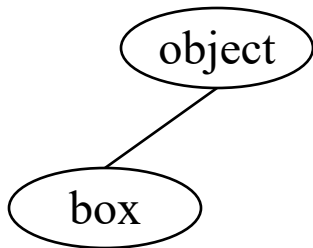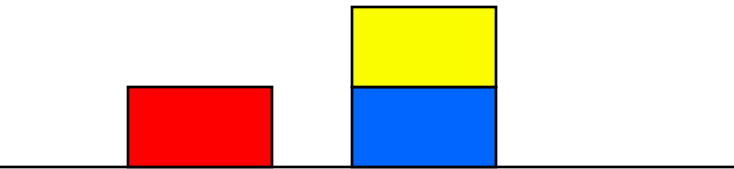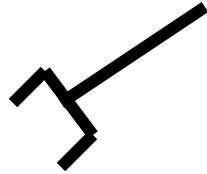
on_desk(A)
on(A, B)
put(A,B)

on_desk(A)
on(A, B)
put(A,B)

on(A/box, B/object)
put(A/box,B/object)

box
color:{red, blue, yellow}

box
color:{red, blue, yellow}

There are many possible ways to conceptualize the target world

Trade off between generality and efficiency

Ontology vs. Knowledge

- Knowledge in expert systems
  - Descriptions of knowledge in expert systems
  - The problems
    - Updating
    - Re-using
- The need of solid ground of knowledge for these knowledge
  - Common Sense Knowledge
  - Ontology

Ontology in Information System

An ontology is an explicit specification of a conceptualization [Gruber]

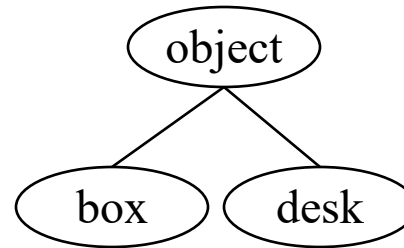- An **ontology** is an explicit specification of a conceptualization. The term is borrowed from philosophy, where an Ontology is a systematic account of Existence. For AI systems, what "exists" is that which can be represented. When the knowledge of a domain is represented in a declarative formalism, the set of objects that can be represented is called the universe of discourse. This set of objects, and the describable relationships among them, are reflected in the representational vocabulary with which a knowledge-based program represents knowledge. Thus, in the context of AI, we can describe the ontology of a program by defining a set of representational terms. In such an ontology, definitions associate the names of entities in the universe of discourse (e.g., classes, relations, functions, or other objects) with human-readable text describing what the names mean, and formal axioms that constrain the interpretation and well-formed use of these terms. Formally, an ontology is the statement of a logical theory.

Ontology and Agent Communication

Real World

Ontology

? ?

Knowledge

Knowledge

コミュニケーション
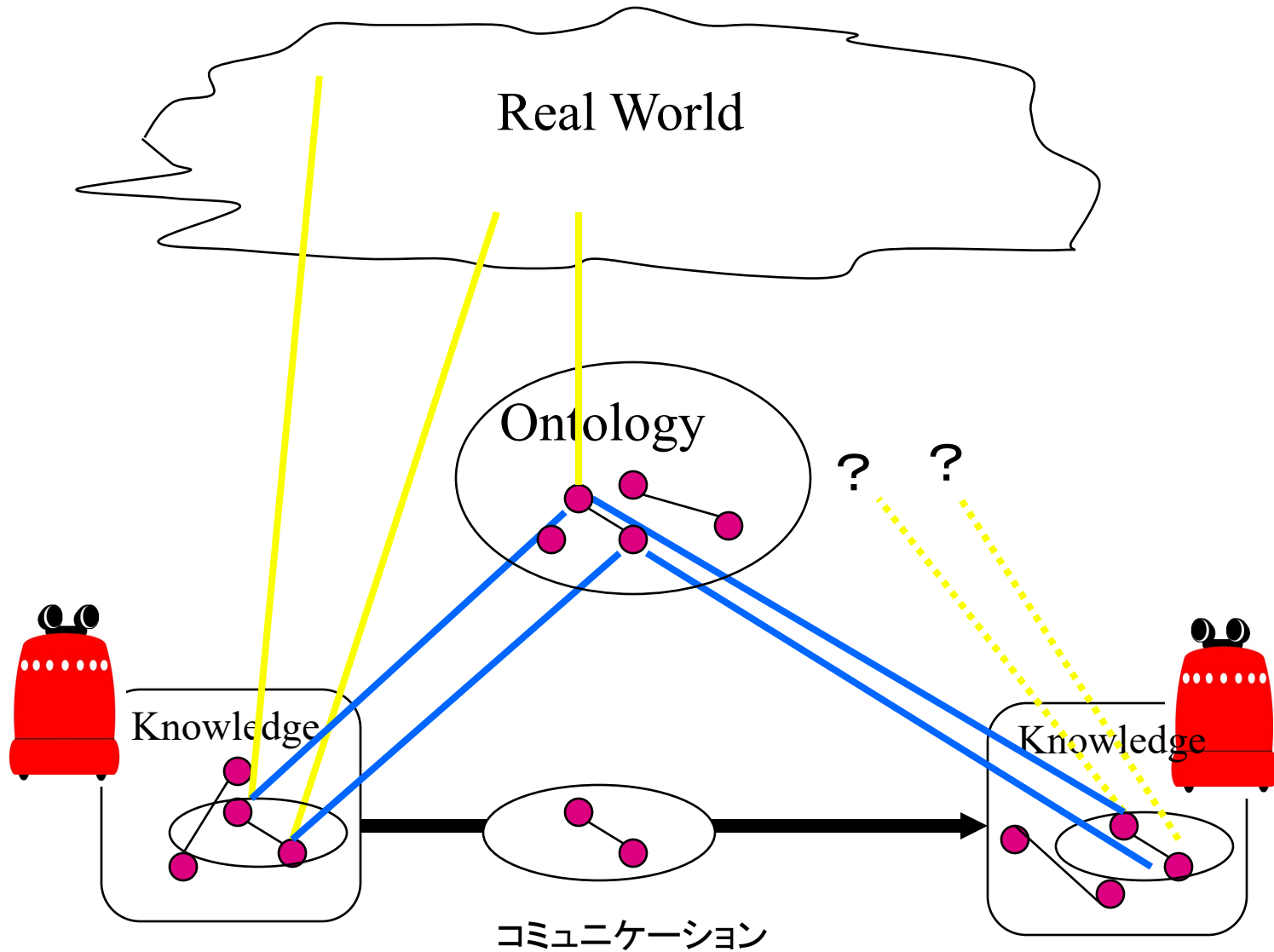
Types of Ontologies

- Upper (top-level) ontology vs. Domain ontology
  - Upper Ontology: A common ontology throughout all domains
  - Domain Ontology: An ontology which is meaningful in a specific domain
- Object ontology vs. Task ontology
  - Object Ontology: An ontology on "things" and "events"
  - Task Ontology: An ontology on "doing"

Types of Ontologies

- Heavy-weight ontology vs. light-weight ontology
  - Heavy-weight ontology: fully described ontology including concept definitions and relations, in particular in a logical way
    - Definition of concepts with axioms
  - Light-weight ontology: partially described ontology including typically only is-a relations
    - Taxonomy
    - Thesaurus

Domain ontologies

- Ontologies for individual domains
  - UMLS (Unified Medical Language System):
  - Open Biomedical Ontologies (OBO)
  - Gene Ontology: for genomics
  - Plant Ontology: for plant structures and growth/development stages, etc
  - CIDOC CRM (Conceptual Reference Model) - an ontology for "cultural heritage information".
  - …

Top-level ontology

- Ontology which covers all of the world!
- Very…. Difficult
  - e.g., how does a thing exist?
    - A thing is four dimensional existence?
    - A thing exists three-dimensionally over time?
- Common requirements
  - A small number of concepts can cover the world
  - Concepts can be used in lower ontologies

  - Concept should be general and abstract

Top-level ontology

- Three approaches
  - Formal approach
    - Logical formalization
    - Fully Abstract
    - Pros: clean
    - Cons: hardly understandable
    - e.g., Sowa's top-level ontology, DOLCE, Basic Formal Ontology (BFO)
  - Pragmatic Approach
    - Use and extension of everyday concepts
    - Mostly general
    - Pros: understandable and applicable to all the world
    - Cons: lack of solid foundation
    - e.g. SUMO, OpenCyc, EDR
  - Linguistic approach
    - Use and extension of linguistic concepts
    - Partially abstract and partially general
    - Pros: understandable
    - Cons: limitation to the linguistic world
    - e.g., Penman Upper Model, WordNet

Formal Ontology

- Formally (often logically) defined ontology
- Top-level ontology guiding or constraining domain ontologies.

- Most of top-level ontologies tend to be "formal"
  - Formal ontology = top-level ontology

Ontological Factors

- Factors are ontological grounds of the basic differences
- Categories or concepts are determined by combinations of factors

- Factors
  - Sort, type (*is-a*, taxonomy)
  - Part/whole (*part-of*, mereology)
  - Dependence
  - Number
  - Quantity
  - Spatio-temporality
  - Determination, causality
  - Predicablility (*instance-of*)

Ontologies

- Introduction of Ontology
  - What is Ontology?
  - Typology of Ontologies
- Top-level Ontologies
  - Formal Ontology
    - **DOLCE**
    - **BFO(Basic Formal Ontology**)
    - Sowa's top-level ontology
  - Pragmatic top-level ontology
    - SUMO
    - OpenCyc
  - Linguistic top-level ontology
    - **WordNet**
    - Penman Upper Model/The Generalized Upper Model

Formal Ontology: DOLCE

- DOLCE(a Descriptive Ontology for Linguistic and Cognitive Engineering)
  - Developed by Nicola Guarino and his associates at the Laboratory for Applied Ontology (LOA)
  - Intended to a reference system for top-level ontology
  - Approach:
    - ◆ Logical definition
    - ◆ Multiplicative approach
  - Ontology for Particulars

Particulars and Universals

- Particulars and Universals
  - Particulars: cognitions of the worlds, ex., objects, qualities …
    - No instances
  - Universals: how concepts exist
    - Instances
    - Meta-ontology

DOLCE

- Multiplicative approach
    - Different entities can be co-located in the same space-time
    - Combination of incompatibility of essential properties
    - Aspect/role
- Ex, a vase and a mount of clay

Formal Ontology: DOLCE

- Concepts
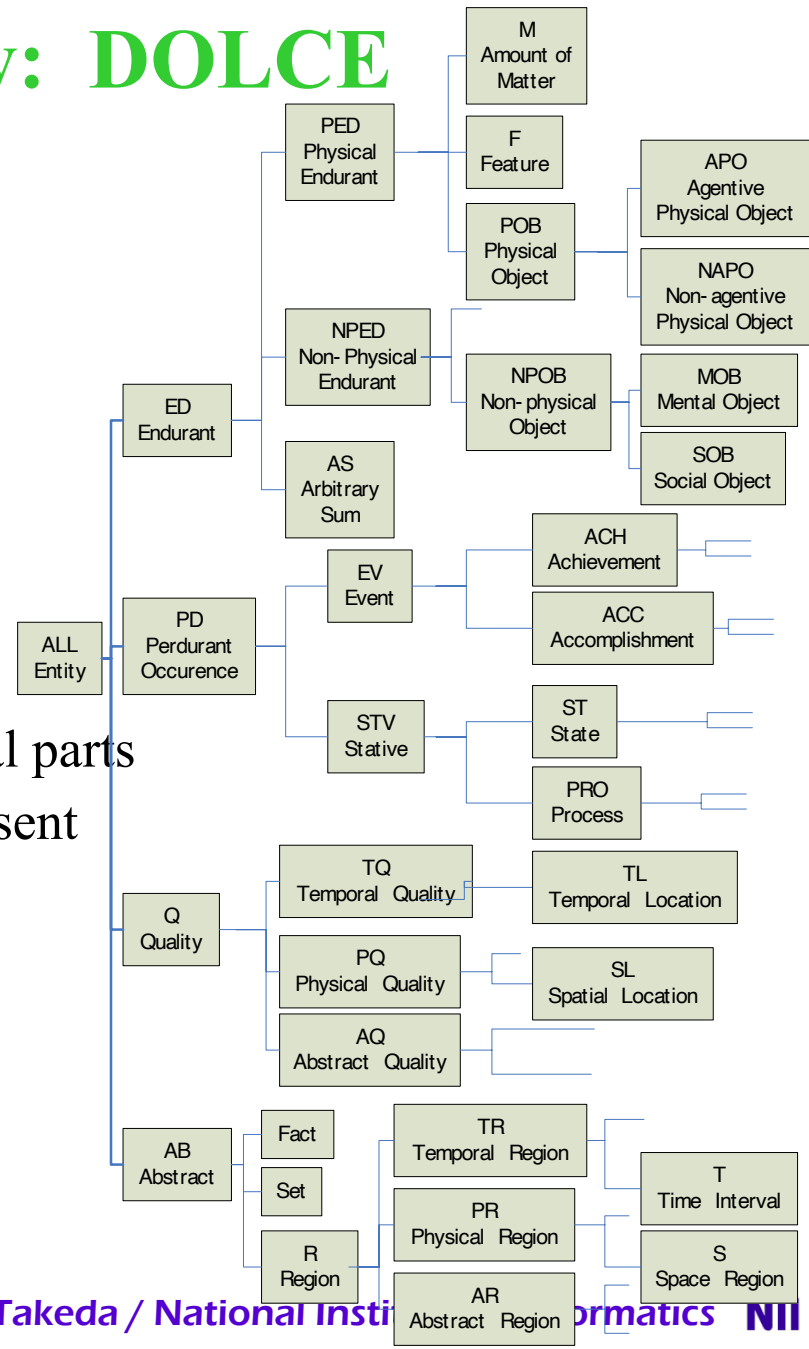 - Endurant / Perdurant
    - Endurant (continuant)
      - "Things"
      - An existence over time
      - May change its attribute
    - Perdurant (occurent)
      - "process"
      - Accumulating different temporal parts
      - At anytime, it only partially present
      - No change over time
      - May switch a part to the other

DOLCE

- Relations
    - **Parthood** (abstract or perdurant)
        - "x is part of y"
        - $P(x, y)$
          $\rightarrow (AB(x) \lor PD(x)) \land (AB(y) \lor PD(y))$
    - **Temporary Parthood** (endurant)
        - "x is part of y during t"
        - $P(x,y,t) \rightarrow (ED(x) \land ED(y) \land T(t))$
    - **Constitution** (endurant or perdurant)
        - "x constitutes y during t"
        - $K(x, y, t)$
          $\rightarrow (AB(x) \lor PD(x)) \land (AB(y) \lor PD(y)) \land T(t))$
    - **Participation** (between perdurant and endurant)
        - "x participates in y during t"
        - "$PC(x,y,t) \rightarrow (ED(x) \land PD(y) \land T(t))$
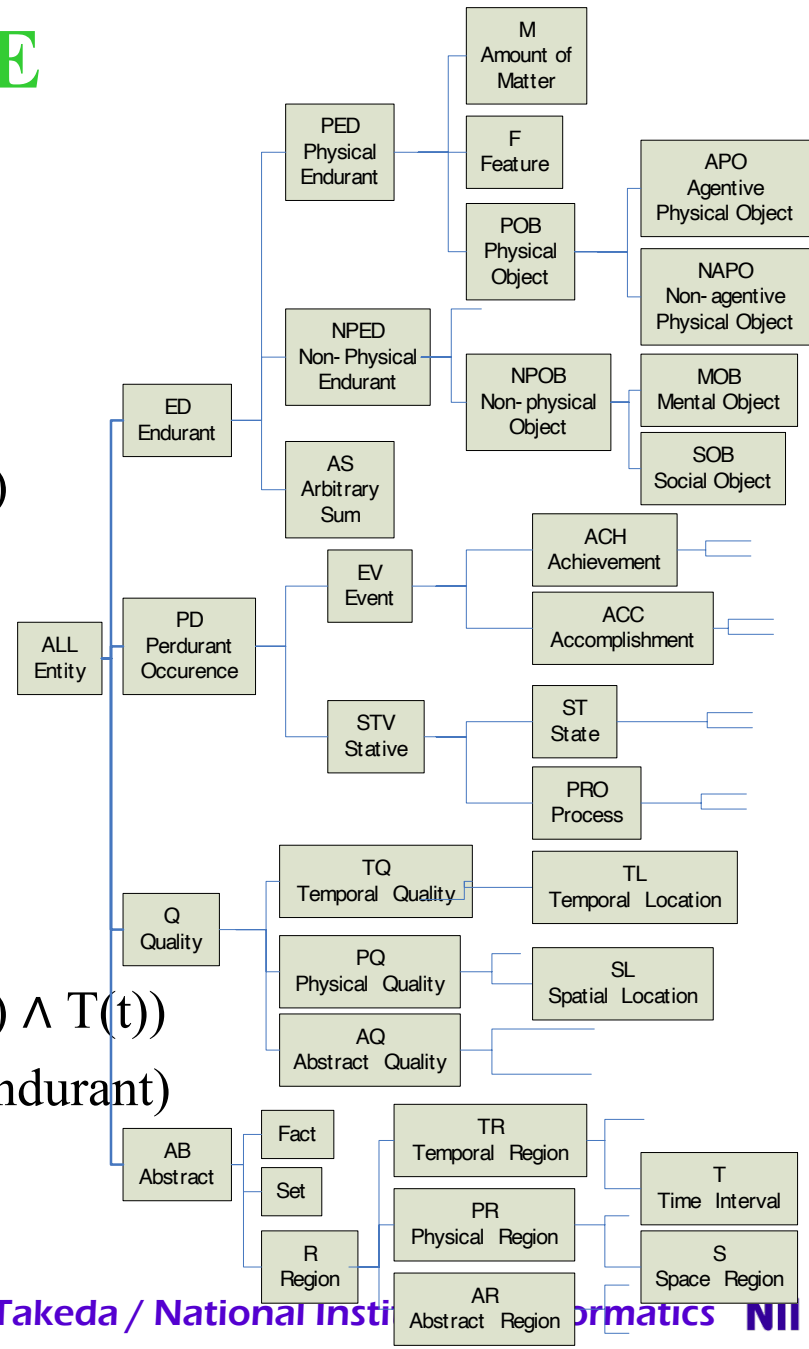
DOLCE

- Quality and Quale
  - quality: the basic entity we can perceive or measure
    - eg., Shapes, colors, sized, sounds, smells, weight, lengths…
    - Qualities inhere to entities
      - No two particulars can have the same quality
      - Each quality is specifically constantly dependent on the entity it inheres in
  - Quales: values of qualities
    - The position of an individual quality within a certain conceptual space (quality space)
    - eg,. "two roses have the same color"
      - Their color qualities have the same position in the color space, ie., the same color quale

DOLCE

- Relations
  - Quality
    - "x is a quality of y"
    - $Qt(x,y)$
      $-> Q(x) \wedge (ED(y) \vee PD(y))$
  - Quale
    - "x is the quale of y during t"
    - $ql(x,y) -> (TR(x) \wedge TQ(y))$
    - $ql(x,y,t) -> (PR(x) \vee AR(x))$
      $\wedge (PQ(y) \vee AQ(y)) \wedge T(t))$
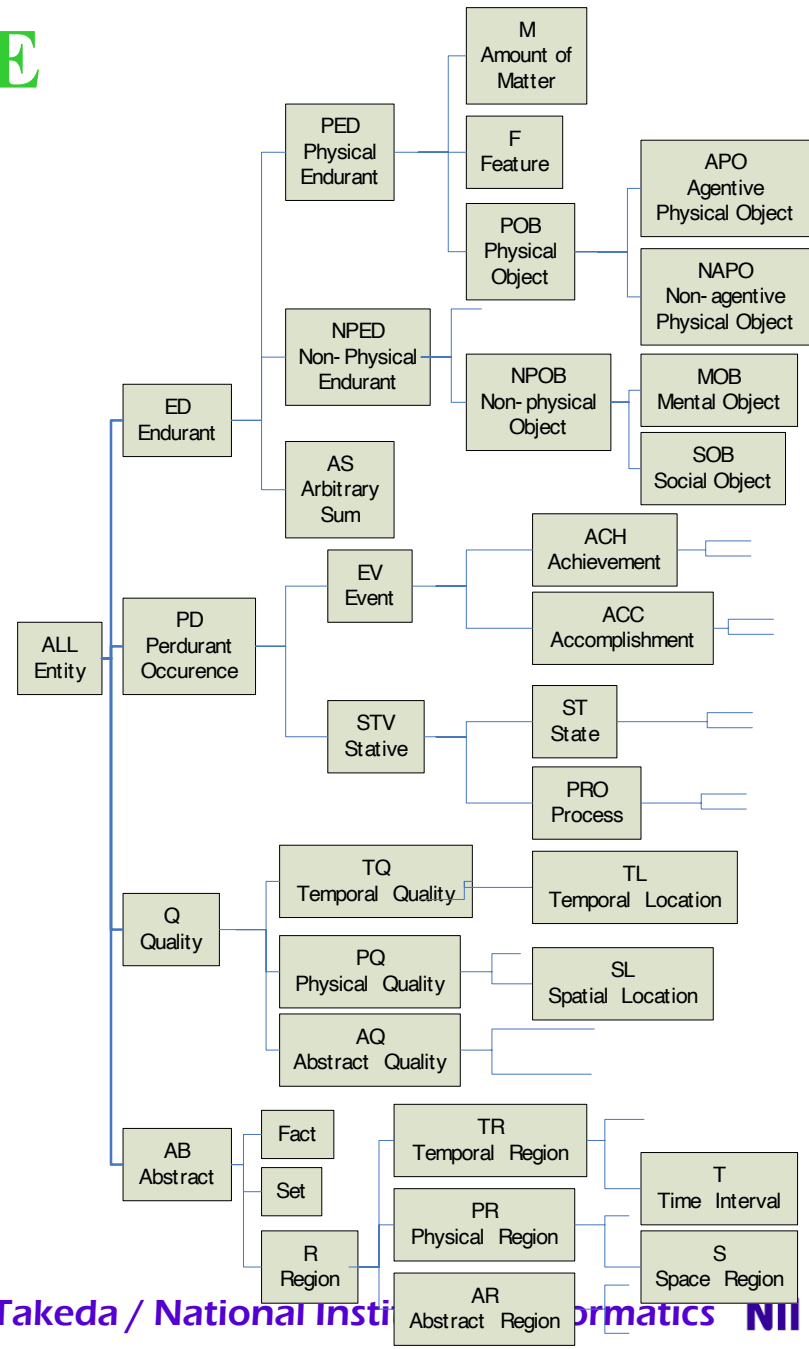
DOLCE: Formal Characterization

- Mereological Definitions:
    - (Proper Part) $PP(x,y) \equiv P(x,y) \wedge \neg P(y,x)$
    - (overlap) $O(x,y) \equiv \exists z(P(z,x) \wedge P(z,y))$
    - (Atom) $At(x) \equiv \neg \exists y(PP(y,x))$
    - (Atomic Part) $AtP(x,y) \equiv P(x,y) \wedge At(x)$
    - (Proper Part) $PP(x,y,t) \equiv P(x,y,t) \wedge \neg P(y,x,t)$
    - (overlap) $O(x,y,t) \equiv \exists z(P(x,y,t) \wedge P(z,y,t))$
    - (Atom) $At(x,t) \equiv \neg \exists y(PP(y,x,t))$
    - (Atomic Part) $AtP(x,y,t) \equiv P(x,y,t) \wedge At(x,t)$
    - (Coincidenc) $x \equiv_t y \equiv P(x,y,t) \wedge P(y,x,t)$

DOLCE: Formal Characterization

- Being present
  - (Being present at t)
    $PRE(x,t) \equiv \exists t'(ql_T(t', x) \wedge P(t,t'))$
  - (Being present in s at t)
    $PRE(x,s,t) \equiv PRE(x,t) \wedge \exists s'(ql_S(s', x,t) \wedge P(s,s'))$
- Perdurant
  - (Temporal part)
    $P_T(x,y) \equiv PD(x) \wedge P(x,y) \wedge \forall z((P(z,y) \wedge z \subseteq_T x) \rightarrow P(z,x))$
  - (Spatial part)
    $P_S(x,y) \equiv PD(x) \wedge P(x,y) \wedge x \approx_T y$

DOLCE: Formal Characterization

- Participation

  - (Constant Participation)
    $PC_C(x,y) \equiv \exists t(PRE(y,t)) \wedge \forall t(PRE(y,t) \rightarrow PC(x,y,t))$

  - (Temporary Total Participation)
    $PC_T(x,y,t) \equiv PD(y) \wedge \forall z((P(z,y) \wedge PRE(z,t)) \rightarrow PC(x,z,t))$

  - (Total Participation)
    $PC_T(x,y) \equiv \exists t(ql_T(t,y) \wedge PC_T(x,y,t))$

Particulars and Universals

- Particulars and Universals
  - Particulars: cognitions of the worlds, ex., objects, qualities …
    - No instances
  - Universals: how concepts exist
    - Instances
    - Meta-ontology

Meta ontology

- Ontology for ontology
  - Only abstract aspect
    - Ontology for Universals
      - Attribute of attribute

Some properties on predicates

- Difference between rigid and non-rigid predicates (rigidity)
  - Human-being vs. teacher
- Difference between divisive and non-divisive predicates (divisivity)
  - Apple vs. water
- Difference between identical and non-identical predicates
- …

Rigidity

- Rigidity (+R): an essential property for being
  - If the entity looses it, it cannot exist anymore
  - Ex., "being a human"
- Non-rigid (-R): an property which is essential to some entities and not to others
  - Ex. "having a brain" in Wizard of Oz
    - Scarecrow does not have a brain
  - Anti-rigid (~R): it cannot be essential to any entities
    - Ex. "being a student"
- Subsumption constraint
  - Anti-rigid properties cannot subsume rigid properties

Identity

- Identity: properties to recognize individual entities as being the same
- Identity criteria: conditions to determine equality (sufficient conditions) and that entailed by equality (necessary conditions)
  - Identity over time?
  - Two entities are the same?
- E.g.,
  - Time duration (e.g., "one hour") and Time interval (e.g., "9:00-10:00 May 10, 2009")
    - ◆ Time duration subsumes Time interval?
    - ◆ Time interval *have* Time duration?
  - A clay statue can be identical if the shape is not changed
- Identity is sometimes inherited to subsumed entities and some not
  - Identity (+I)
  - Own (+O): Can not be inherited

Unity

- Unity: being able to recognize all the parts that form an individual entity
  - E.g.,
    - "being water"
    - "being an ocean"
- Unity criteria: conditions that must hold among the parts of a certain entity in order to consider it a whole
  - Topological wholes (a piece of coal)
  - Morphological whole (a constellation)
  - Functional whole (a hammer)
- Unity (+U), non-unity (-U), anti-unity (~U)

Formalization

- $PP(x,y,t) =_{def} f(x,y,t) \land \neg x{=}y$ (proper part)

- $O(x,y,t) =_{def} \exists z(P(z,x,t) \land P(z,y,t))$ (overlap)

- $P(x,y,t) \rightarrow E(x,t) \land E(y,t)$ (actual existence of parts)

- $P(x,y,t) \land P(y,x,t) \rightarrow x{=}y$ (antisymmetry)

- $P(x,y,t) \land P(y,z,t) \rightarrow P(x,z,t)$ (transitivity)

- $PP(x,y,t) \rightarrow \exists z(PP(z,y,t) \land \neg O(z,x,t))$ (weak supplementation)

Formalization

- Rigidity
  - Rigid Φ^{+R}: Φ is a necessary property for all its instances
  - Non-Rigid Φ^{-R}: Φ is not a necessary property for all its instances
  - Anti-Rigid $\Phi^{\sim R}$: Φ is an optional property for all its instances

Identity

- $\Phi(x) \wedge \Phi(y) \rightarrow (\rho(x, y) \Leftrightarrow x=y)$

- Def. 1: Let Φ be a rigid property, and $\Gamma(x,y,t,t')$ a formula containing x,y,t,t' as the only free variable such that
  $\neg \forall xytt'(\Gamma(x,y,t,t') \Leftrightarrow x=y)$
  We say that Φ carries the IC Γ iff one of the following conditions is verified

  - Def. 2 Γ is a necessary IC carried by Φ when:
    $E(x,t) \wedge \Phi(x,t) \wedge E(y,t') \wedge \Phi(y,t') \wedge x=y \rightarrow \Gamma(x,y,t,t')$
    $\neg \forall xy(E(x,t) \wedge \Phi(x,t) \wedge E(y,t') \wedge \Phi(y,t') \wedge xy \rightarrow \Gamma(x,y,t,t'))$

  - Def. 3 Γ is a sufficient IC carried byΦ when:
    $E(x,t) \wedge \Phi(x,t) \wedge E(y,t') \wedge \Phi(y,t') \wedge \Gamma(x,y,t,t') \rightarrow x=y$
    $\exists xytt' \Gamma(x,y,t,t')$

- Ics are "inherited" along a hierarchy of properties
  if $\Phi(x) \to \varphi(x)$ and Γ is a necessary IC for φ then Γ is a necessary IC for Φ

- Def. 4: A non-rigid property carries an IC Γ iif it is subsumed by a rigid property carrying Γ

- Def. 5: Any property carrying an IC is marked with the meta property +I (-I otherwise)

- Def. 6: A property Φ supplies an IC Γ iff i) it is rigid; ii) it carries Γ; and iii) Γ is not caries by all the properties subsuming Φ

- Def. 7: Any property supplying an IC is marked with the meta property +O(-O otherwise).
  - +O implies +I and +R
  - E.g., Person and student

- Def. 8: Any property carrying an IC (+I) is called a sortal

Unity

- Def. 9: Let ω be an equivalence relation. At a given time t, An object x is contingent whole under ω if:
  $\neg(P(y,x,t) \land P(z,x,t) \Leftrightarrow \omega(z,y,t))$
  $\forall y(P(y,x,t) \rightarrow \forall z(P(z,x,t) \Leftrightarrow \omega(z,y,t)))$
  "at time t, each part of x must be bound by ω to all other parts and to nothing else"

- Variety of Unity Condition

  - Topological unity: based on some kind of topological conncetions (a piece of coal, a lump of coal)

  - Morphological unity: based on shape (a ball, a constellation)

  - Functional unity: (a hammer, a bikini)

- Def. 10: Let ω be an equivalence relation. An object x is an intrinsic whole under ω if, at any time where x exists, it is a contingent whole under ω

- Def. 11: A property Φ carries a unity condition (+U) iff there exists an equivalence relation ω such that all its instances are intrinsic wholes under ω

Dependence (+D)

- Property Φ is externally dependent on a property Ψ if, for all its instances x, necessarily some instance of Ψ must exist, which is not a part nor a constituent of x.

    - E.g., parent depends child

Constraints

- Rigidity constraints
  - $\Phi^{\sim R}$ can't subsume Ψ^{+R}
- Identity constraints
  - Φ^{+I} can't subsume Ψ^{-I}
- Unity constraints
  - Φ^{+U} can't subsume Ψ^{-U}
  - Φ^{-U} can't subsume Ψ^{+U}
- Dependence constraints
  - Φ^{+D} can't subsume Ψ^{-D}
- (Identity and Own Identity)
  - $+O \rightarrow +I$
  - $+O \rightarrow +R$

Constraints

- q subsumes p, then the following constraints hold
    - If q is anti-rigid (~R), then p must be anti-rigid (~R)
    - If q carries an identity criterion (+I), then p must carry the same criterion (+I)
    - If q caries a unity criterion (+U), then p must carry the same criterion (+U)
    - If q has anti-unity (~U), then p must also have anti-unity (~U)

Meta ontology

- Attribute of attribute

  - Rigidity (R)
  - Identity (I)
  - Own Identity (O)
  - Dependency (D)

```
                                              Category (+R)
                    Non-sortal (-I)           Attribution (-R-D)
                                              Formal Role
   Property           Role (~R+D)             Material Role
                                    Anti-Rigid (~R)
                      Non-rigid (-R)          Phased Sortal (-D)
                                              Mixin (-D)
   Sortal (+I)                               Type (+O)
                      Rigid (+R)             Quasi-Type (-O)
```
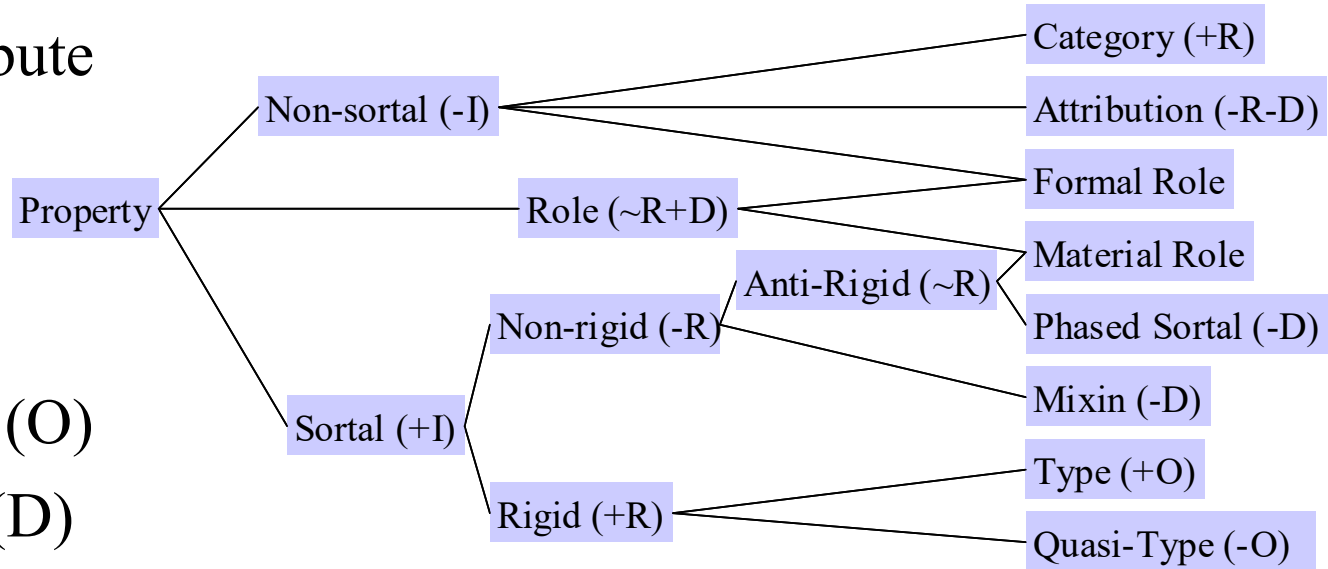
  - +: should be satisfied

  - -: is not satisfied

  - ~: each attribute is not satisfied

An example
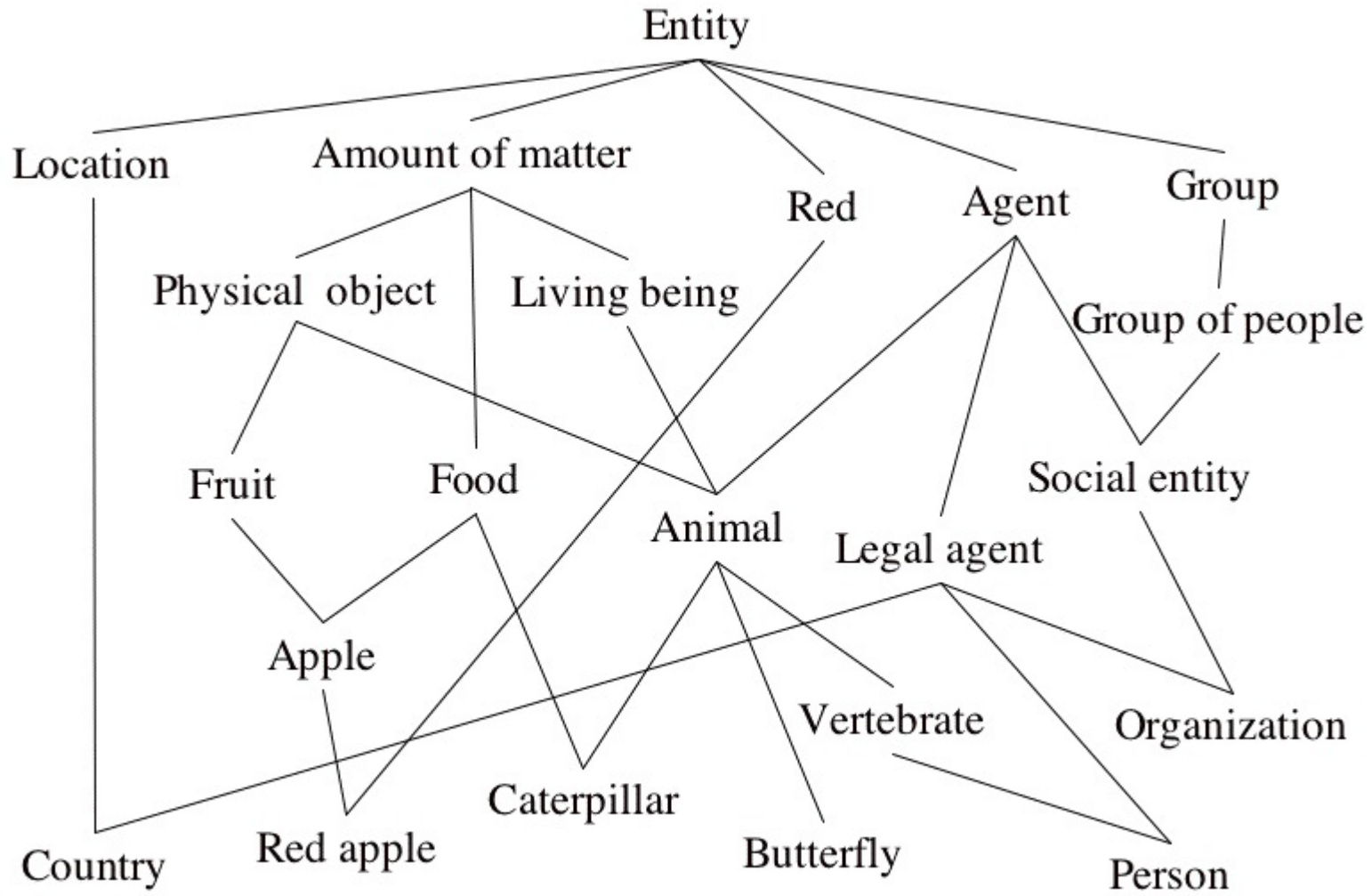
Ontological checking

- Entity: -I-U+R
- Location: +O~U+R
- Amount of matter: +O~U+R
- Red: -I-U-R
- Agent: -I-U~R
- Group; +O~U+R
- Physical object: +O+U+R
- Living Being: +O+U+R
- Food: +I~U~R
- Animal: +O+U+R

- Legal Agent: +O-U~R
- Group of People: +I~U+R
- Social Entity: -I+U+R
- Organization; +O+U+R
- Fruit: +O+U+R
- Apple: +O+U+R
- Red Apple: +O+U~R
- Vertebrate: +I+U+R
- Person: +O+U+R
- Butterfly and Caterpillar: +I+U~R
- Country: +O+U~R

Entity $^{-I-U+R}$

Location +O-U+R

Amount of matter +O~U+R

Physical object +O+U+R

Living being +O+U+R

Group +O~U+R

Group of people +I~U+R

Fruit +O+U+R

Animal +O+U+R

Social entity -I+U+R

Apple +O+U+R

Vertebrate +I+U+R

Organization +O+U+R

Person +O+U+R
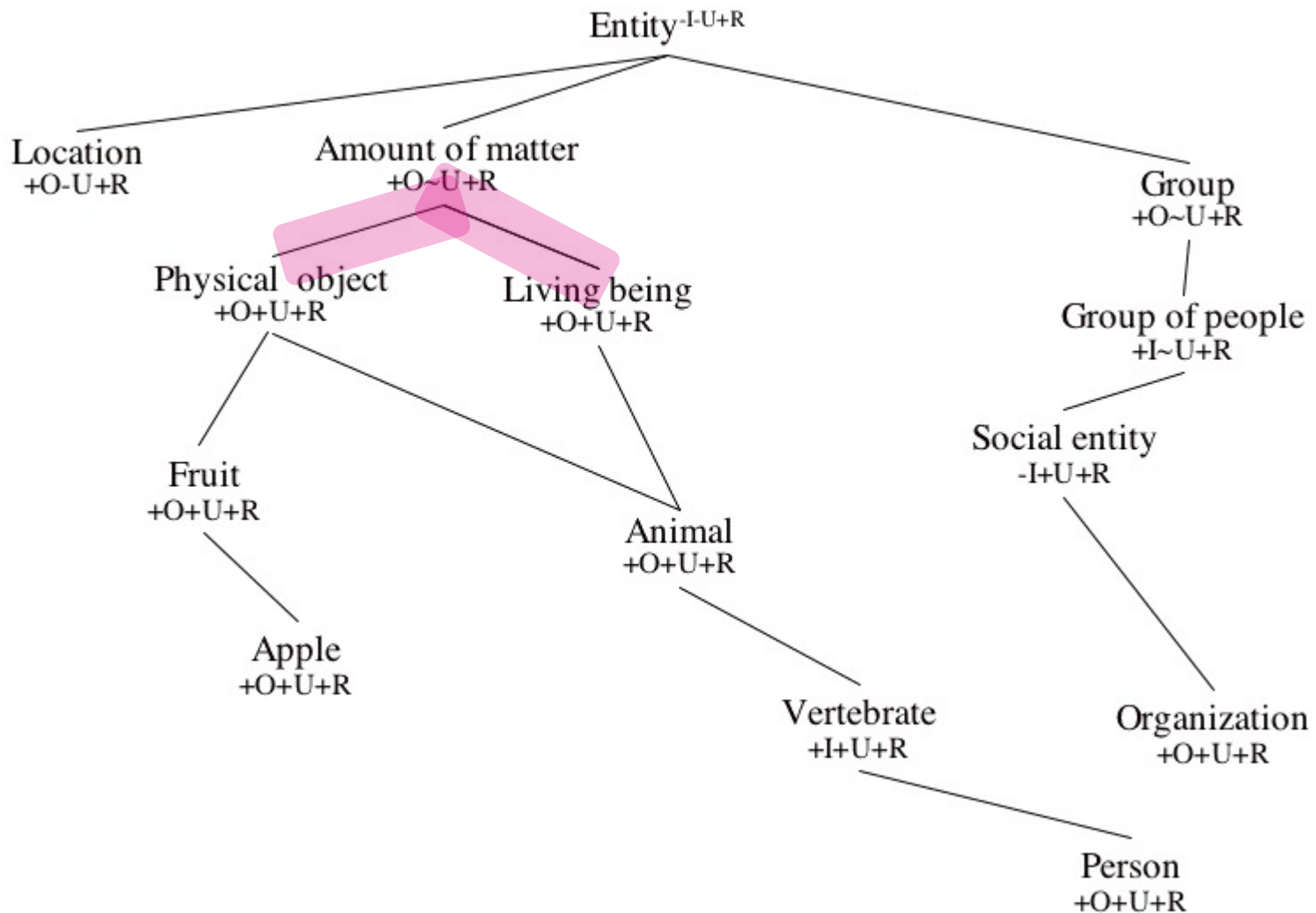
~U(AMOUNT-OF-MATTER) .cannot subsume +U(PHYSICAL-OBJECT)

Ontology checking

Entity$^{-I-U-D+R}$

Location
+O-U-D+R

Amount of matter
+O~U-D+R

Group
+O~U-D+R

Physical object
+O+U-D+R

Living being
+O+U-D+R

Group of people
+I-O~U-D+R

Fruit
+O+U-D+R

Social entity
-I+U-D+R

Animal
+O+U-D+R

Apple
+O+U-D+R

Country
+O+U+D+R

Geographical
Region
+I-U-D+R

Lepidopteran
+O+U-D+R

Vertebrate
+I-O+U-D+R

Caterpillar
+I+U-D~R

Butterfly
+I+U-D~R

Organization
+O+U-D+R

Person
+O+U-D+R
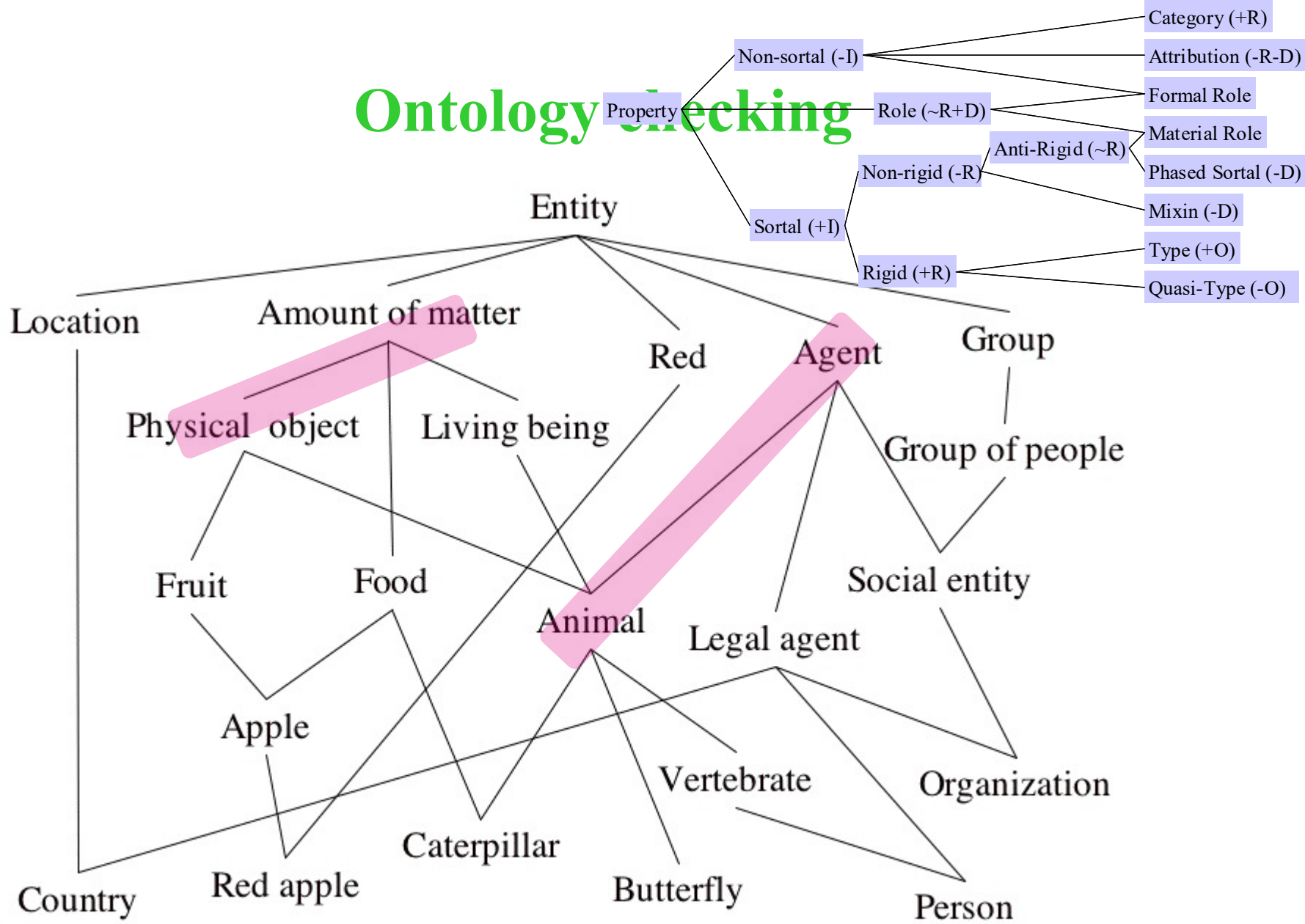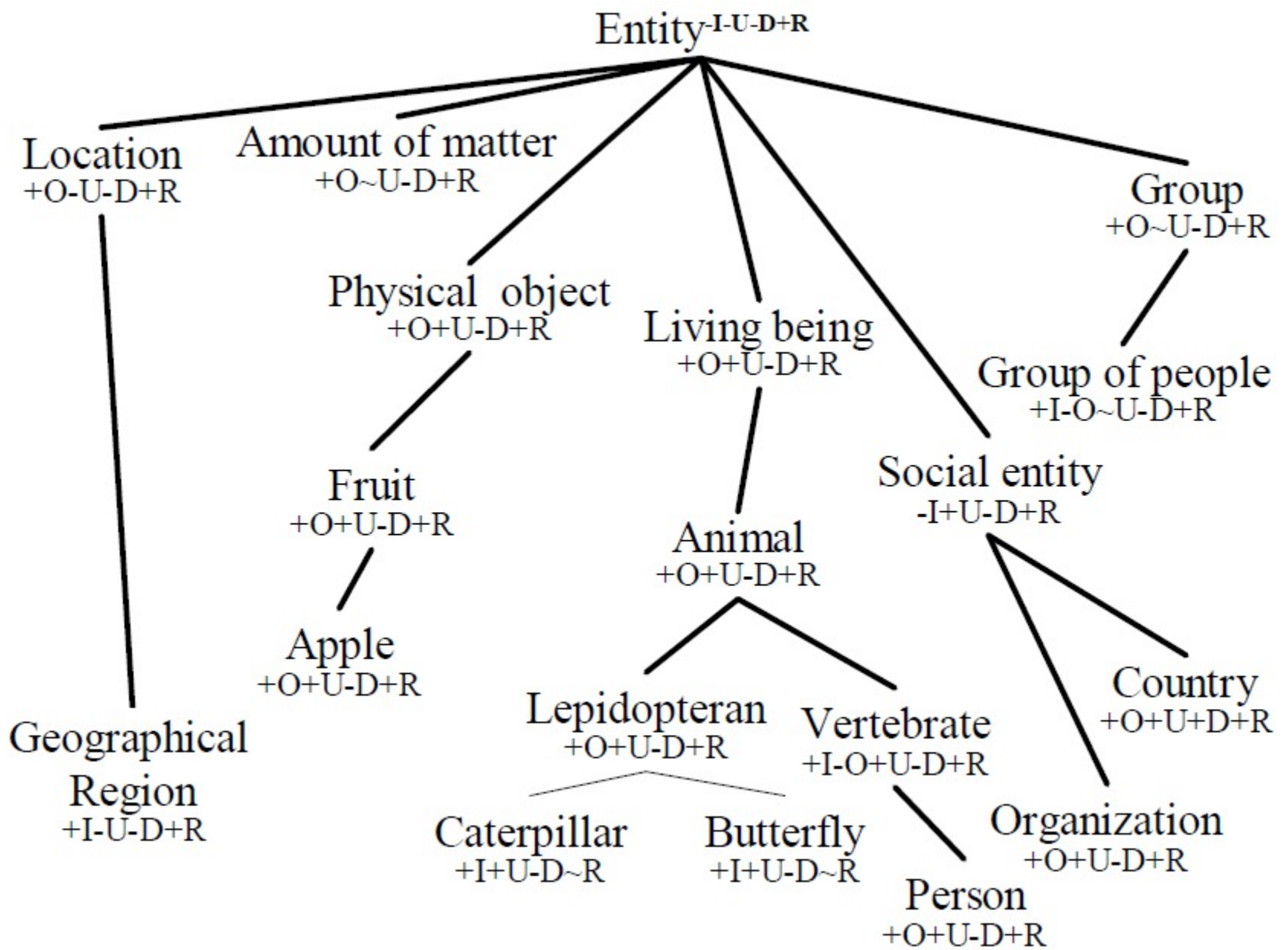
Agent and legal agent
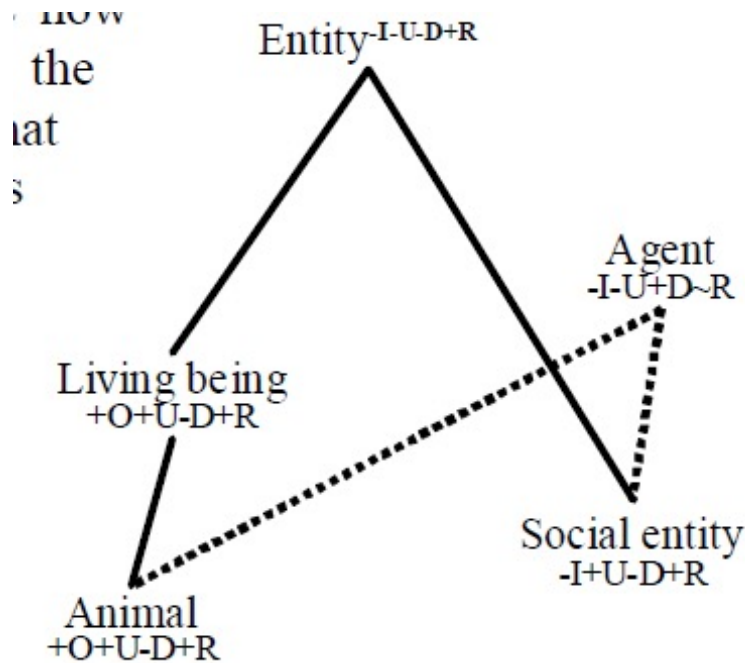
+D(AGENT) cannot subsume –D(ANIMAL)
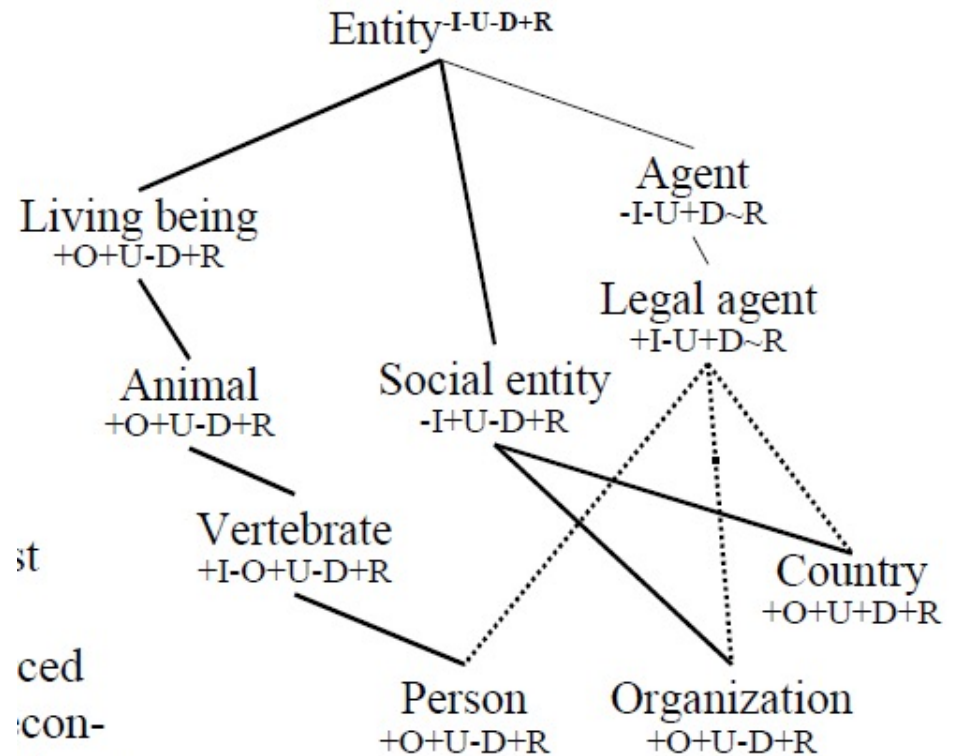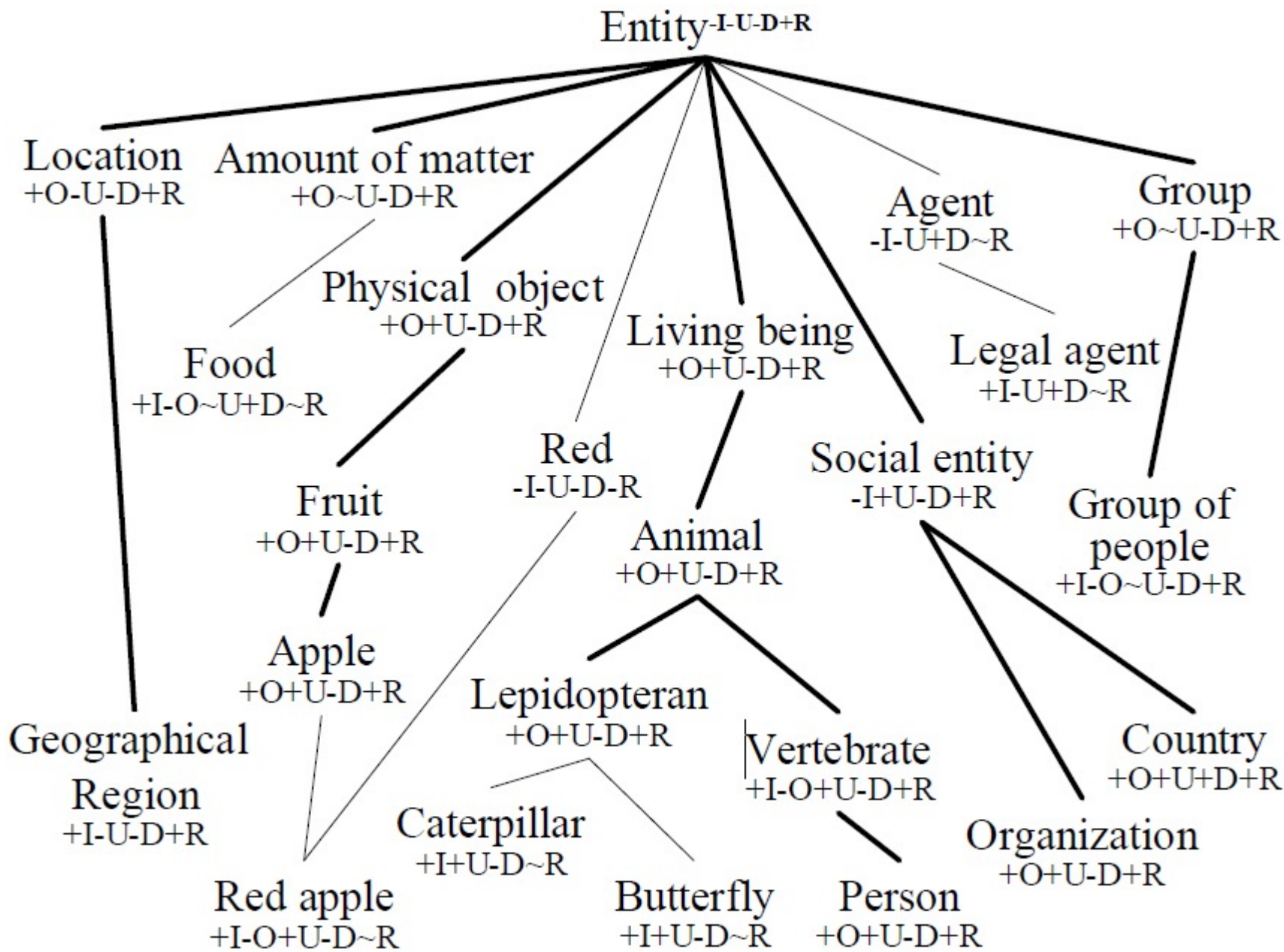
Ontology checking
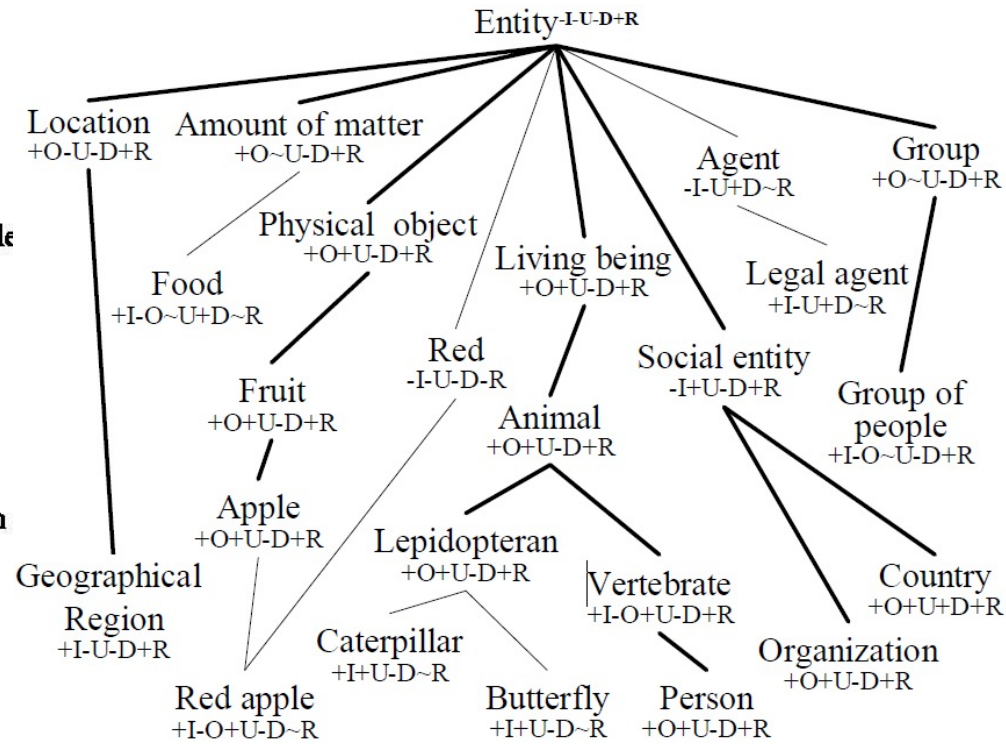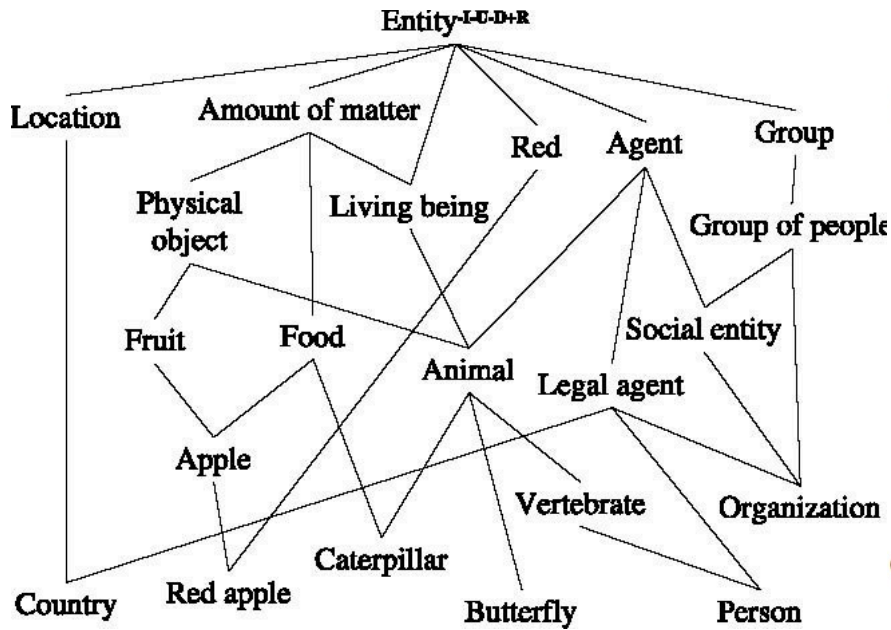
Ontologies

- Introduction of Ontology
  - What is Ontology?
  - Typology of Ontologies
- Top-level Ontologies
  - Formal Ontology
    - **DOLCE**
    - **BFO(Basic Formal Ontology)**
    - Sowa's top-level ontology
  - Pragmatic top-level ontology
    - SUMO
    - OpenCyc
  - Linguistic top-level ontology
    - **WordNet**
    - Penman Upper Model/The Generalized Upper Model

Basic Formal Ontology

- Barry Smith and his colleagues at the Institute for Formal Ontology and Medical Information Science (IFOMIS) at the University of Leipzig and in University of Buffalo

- Basically developed for biomedicine applications

  - To represent the biological reality

    - The static or the dynamic aspect of the biological reality

Methodology

- ***Realism*** (実在論) holds that
  - Reality and its constituents exist independently of our (linguistic, conceptual, theoretical, cultural) representations thereof
- ***Fallibilism*** (可謬主義) accepts that
  - Our theories and classifications can be subject to revision
- ***Perspectivalism*** (観点主義) maintains that
  - There exists a plurality of alternative, equally legitimate perspectives on reality
- ***Adequatism*** (十全主義) maintains that
  - These alternative views are not reducible to any single basic views. Thus adequatism is opposed to reductionism, i.e., to the thesis that there is some one privileged perspective to which all other representaions of reality can be reduced

Basic Formal Ontology

- Two dimensions
  - Opposition between different levels of granularity
  - Opposition between objects and processes
- Continuants and Occurrents
  - Continuants
    - bound with respect to space
  - Occurents
    - bound with respect to time
    - Can have temporal parts or phases

Basic Formal Ontology

- SNAP ontology and SPAN ontology
  - SNAP Ontology for continuants
  - SPAN Ontology for Occurents
  - Relations between continuants and occurrents are inter-ontologial
- Opposed to three-dimensionalists and four-dimensionalists
  - Three-dimensionalists
    - Process of change and motion are not entities but terms of sequences of attributes of continuant entities
  - Four-dimensionalists
    - Entities are like "spatio-temporal worms" or "process-thing"
  - Both do not accept the other entities

SNAP Ontology

- Substances
  - Maximal connected substantial entities
  - Do not depend for other being
  - Bearers of qualities
  - Preserve identity over time and through changes of various sorts
  - Have a location in space
  - Self-connected wholes which physical bourndaries

SNAP entities
- Substantial entities
  - Substances
  - Fiat Parts
  - Boundaries
  - Aggregates of substances
  - Sites — Niches etc.
- SNAP dependent entities
  - Qualities
  - Roles
  - Functions
  - …
- Spatial regions
  - Points
  - Lines
  - Surfaces
  - Volumes
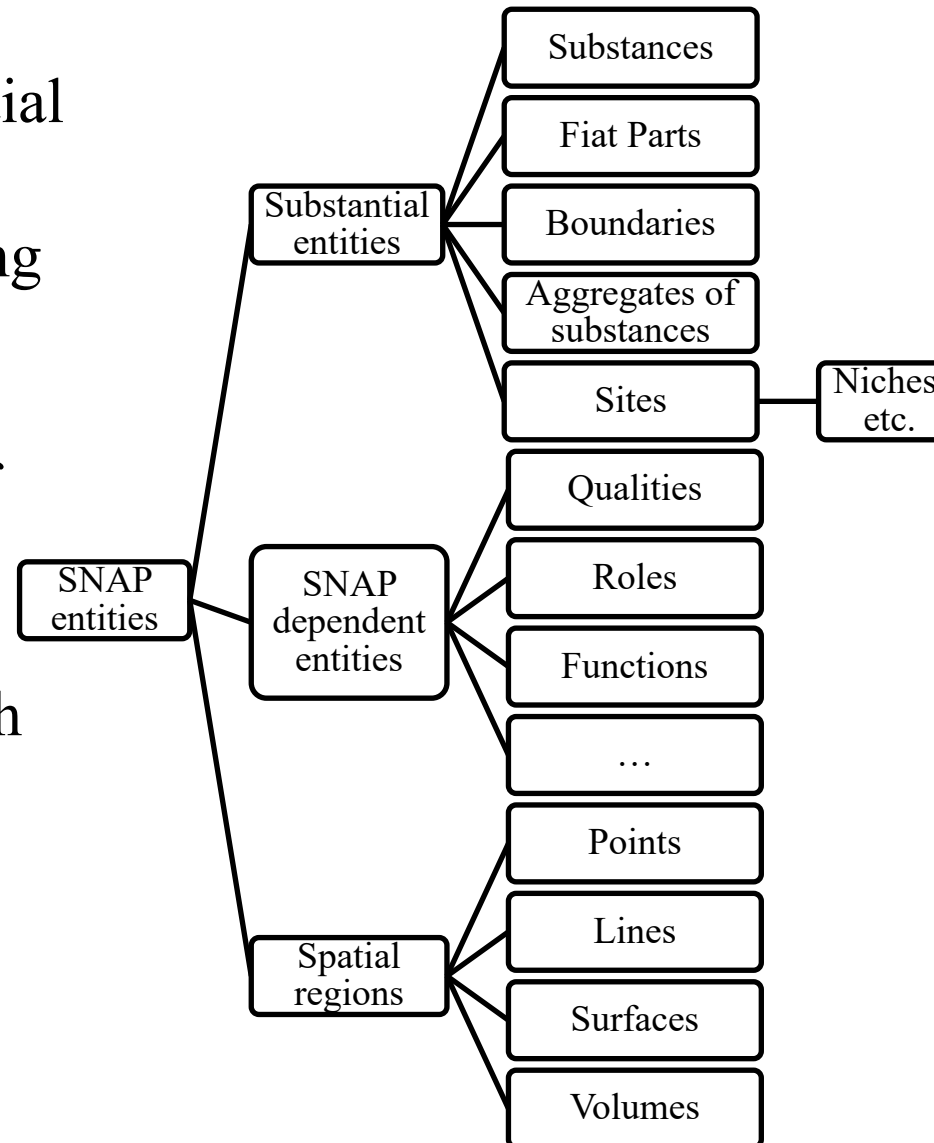
SNAP Ontology

- Fiat Parts (規約的部分)
  - E.g., *lower* lobes of the left lung (左肺下葉）
  - Not demarcated by physical discontinuities
- Boundaries
  - Lower dimensional parts of spatial entities
  - E.g., the inner surface of the stomach
  - fiat vs. bona fide (真性)

```
SNAP entities
├── Substantial entities
│   ├── Substances
│   ├── Fiat Parts
│   ├── Boundaries
│   ├── Aggregates of substances
│   └── Sites ── Niches etc.
├── SNAP dependent entities
│   ├── Qualities
│   ├── Roles
│   ├── Functions
│   └── …
└── Spatial regions
    ├── Points
    ├── Lines
    ├── Surfaces
    └── Volumes
```
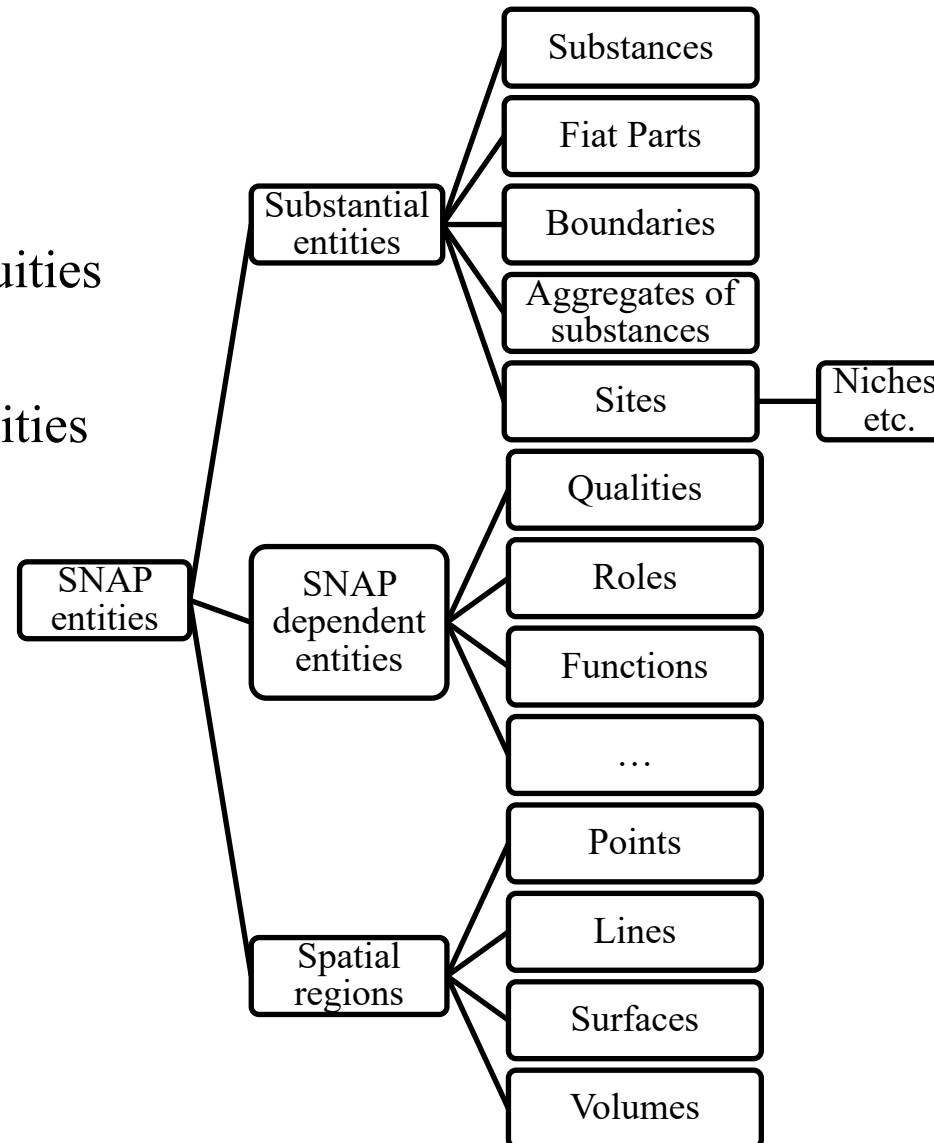
- Aggregates
  - Mereological sums comprehending separate substances as parts
  - Non connected boundaries
- Sites
  - Holes, cavities and so on
  - E.g., spinal canal (脊髄管), cranial cavity (頭蓋腔), the lumen of the gastrointestinal tract (胃腸内管)
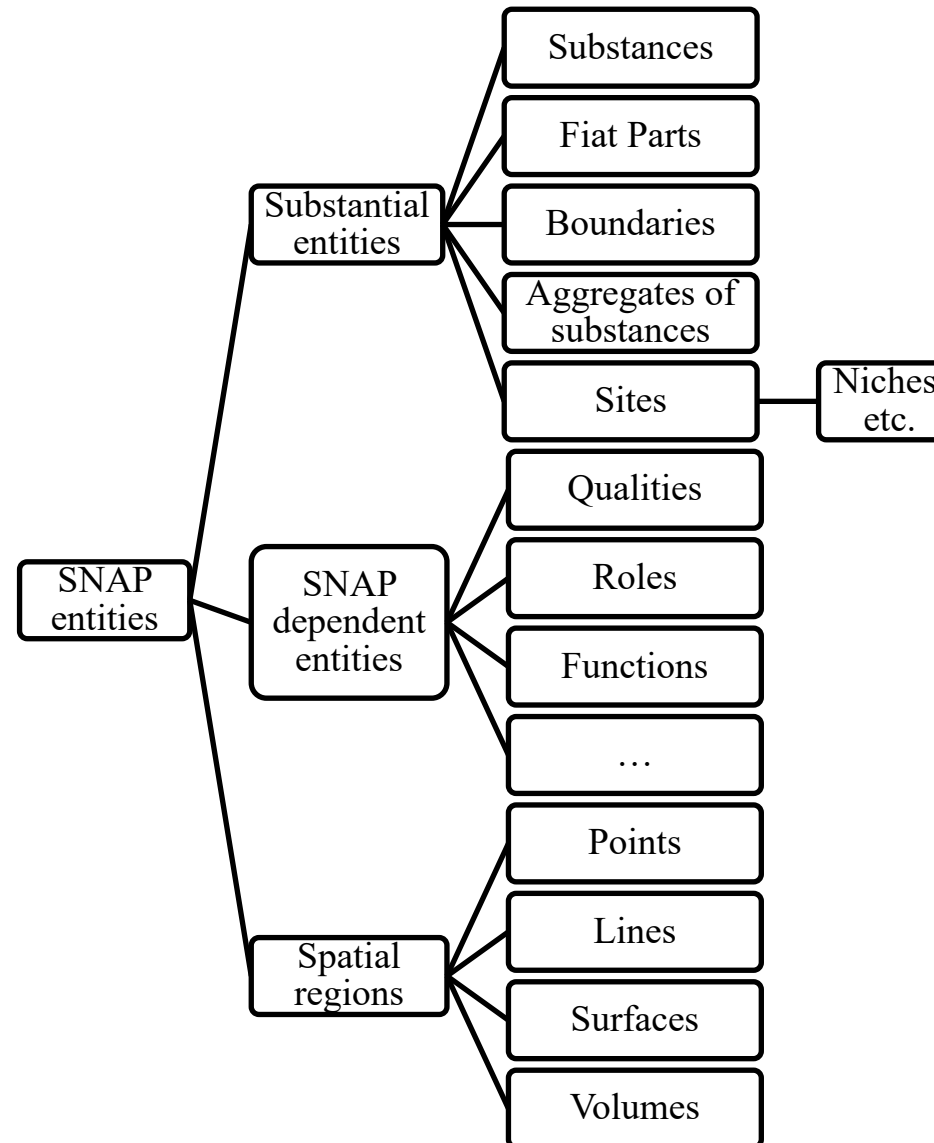
SNAP Ontology

- SNAP Dependent Entities
  - Entities which endure in time and which inhere in substantial entities
  - "Inherence" is an intra-ontological relation
    between a SNAP dependent entity and its substantial bearer
  - E.g., the *redness* of the red blood, the *shape* of a nose
  - Monadic: qualities
  - Polyadic or relational: connection
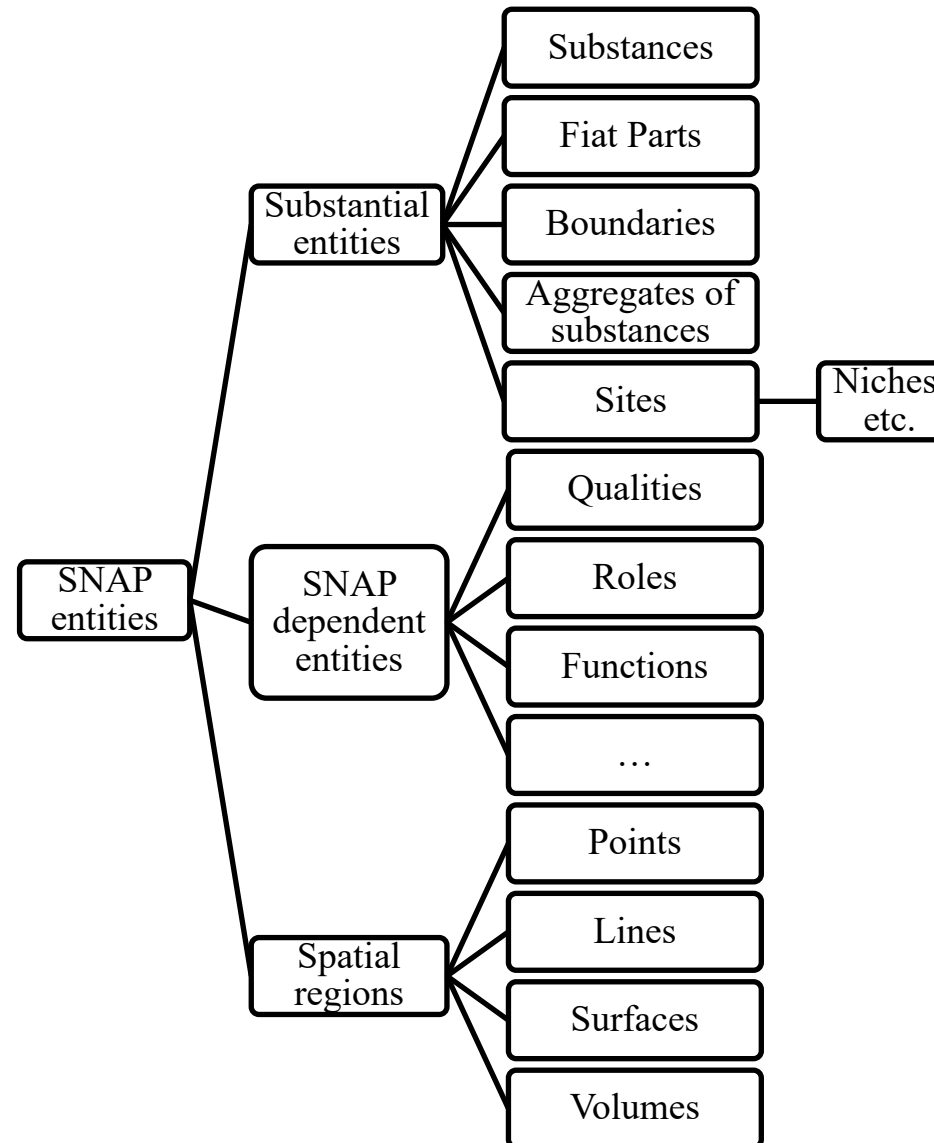
SNAP Ontology

- SNAP Universals
  - Universals form taxonomies of various sorts
  - Each taxonomy is a tree
    - Greater and lesser generality
  - Substantial universals and universals instantiated by SNAP dependent entities
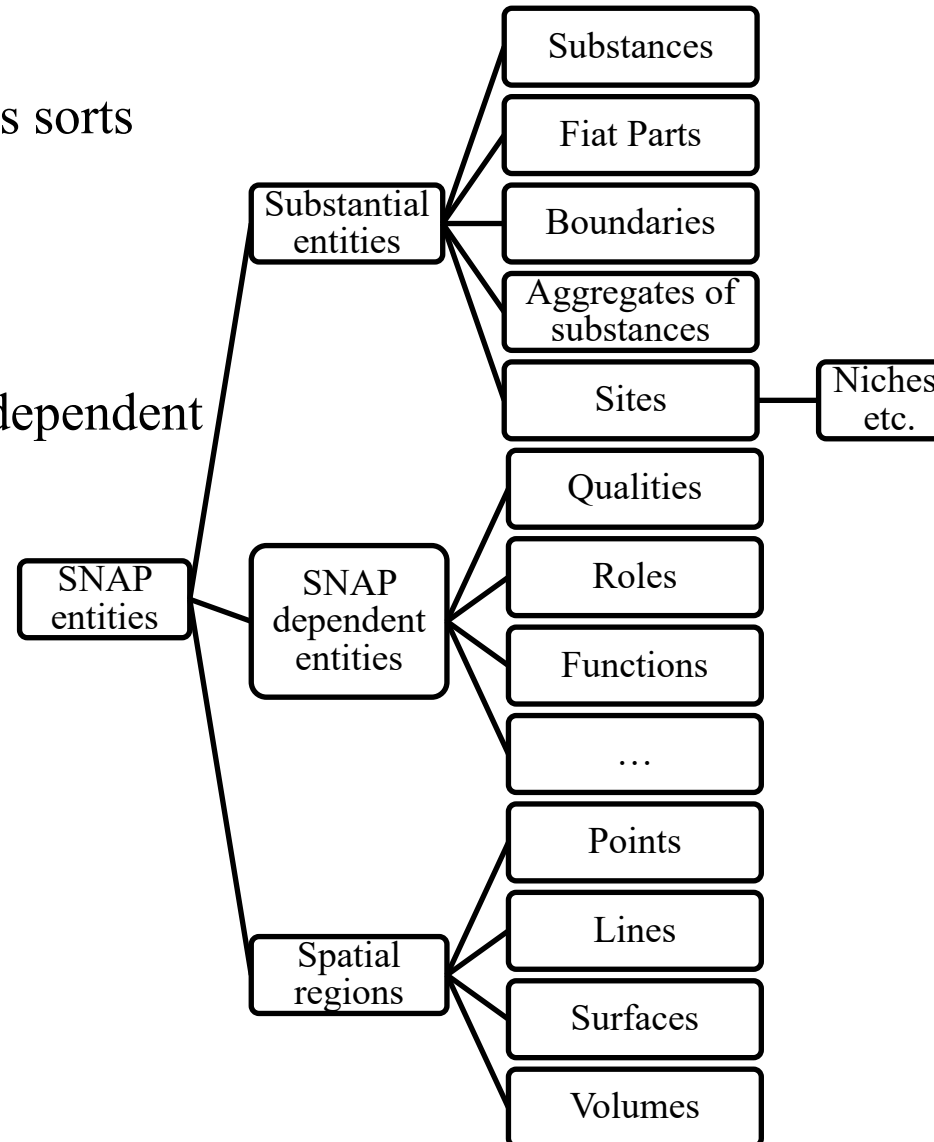
SPAN Ontology

- Process
  - the natural units in the processual realm
  - Have bona fide beginnings and endings corresponding to real discontinuities in the processual order.
  - E.g., the life of an organsim, the process of sleeping (the boundary of falling asleep and waking up)
  - Be maximal spatiotemprally connected wholes

```
SPAN entities ── Processual entities ── Processes
                                      ── Fiat Parts
                                      ── Aggregates
                                      ── Instantaneous temporal boundaries ── Event
              ── Temporal Regions ── Connected ── Interval
                                   ── Scattered ── Instant
              ── Spatiotemporal regions ── Connected
                                         ── Scattered
```
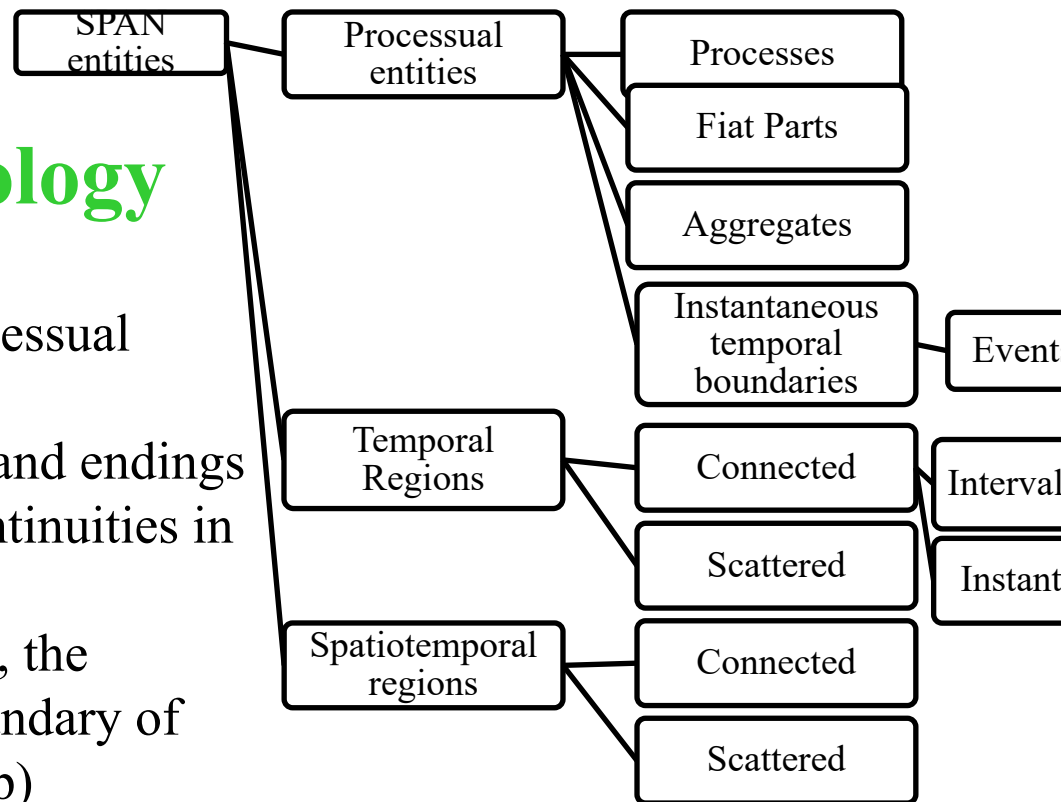
SNAN Ontology

- Fiat parts
  - The parts of processes on a given level of granularity are by definition fiat parts
  - E.g., an individual chewing process in the course of a meal

```
SPAN entities
├── Processual entities
│   ├── Processes
│   ├── Fiat Parts
│   ├── Aggregates
│   └── Instantaneous temporal boundaries ── Event
├── Temporal Regions
│   ├── Connected ── Interval
│   └── Scattered ── Instant
└── Spatiotemporal regions
    ├── Connected
    └── Scattered
```
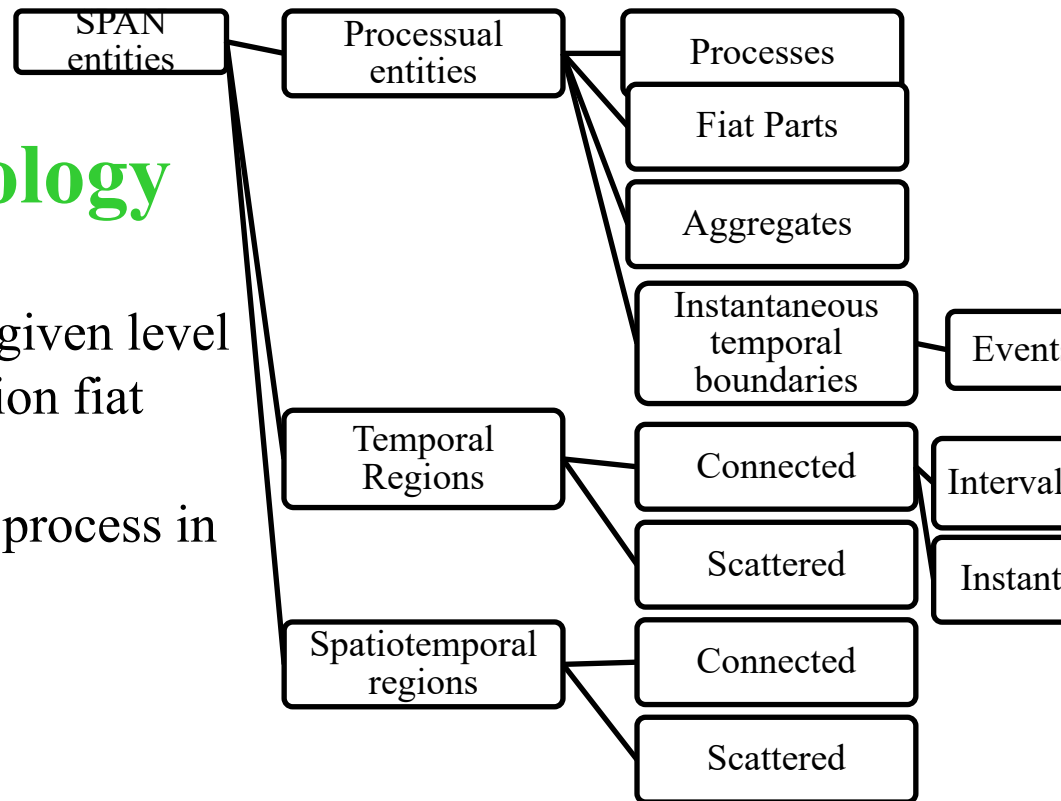
SNAN Ontology

- Events
  - Instantaneous temporal boundaries of processes
  - Fiat and bona fide
  - E.g., forming of a synapse, the onset of REM sleep
- Aggregates of processes
  - E.g., the aggregate of all neuronal firing involved in the generation of a thought
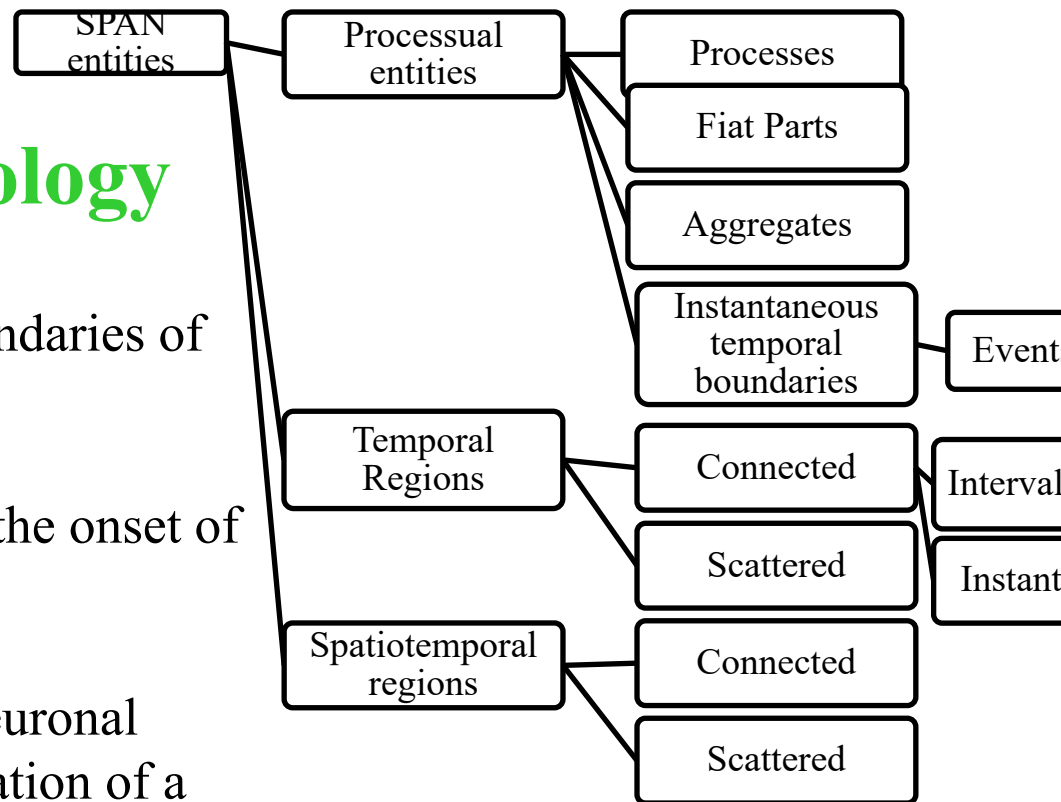
SPAN entities

Processual entities
- Processes
- Fiat Parts
- Aggregates
- Instantaneous temporal boundaries — Event

Temporal Regions
- Connected — Interval
- Scattered — Instant

Spatiotemporal regions
- Connected
- Scattered

Ontologies

- Introduction of Ontology
  - What is Ontology?
  - Typology of Ontologies
- Top-level Ontologies
  - Formal Ontology
    - **DOLCE**
    - **BFO(Basic Formal Ontology**)
    - Sowa's top-level ontology
  - Pragmatic top-level ontology
    - SUMO
    - OpenCyc
  - Linguistic top-level ontology
    - **WordNet**
    - Penman Upper Model/The Generalized Upper Model

Formal Ontology

- Sowa's top-level ontology
  - Physical / Abstract
  - Independent / Relative / Mediating
  - Continuant / Occurrent

Ontologies

- Introduction of Ontology
  - What is Ontology?
  - Typology of Ontologies
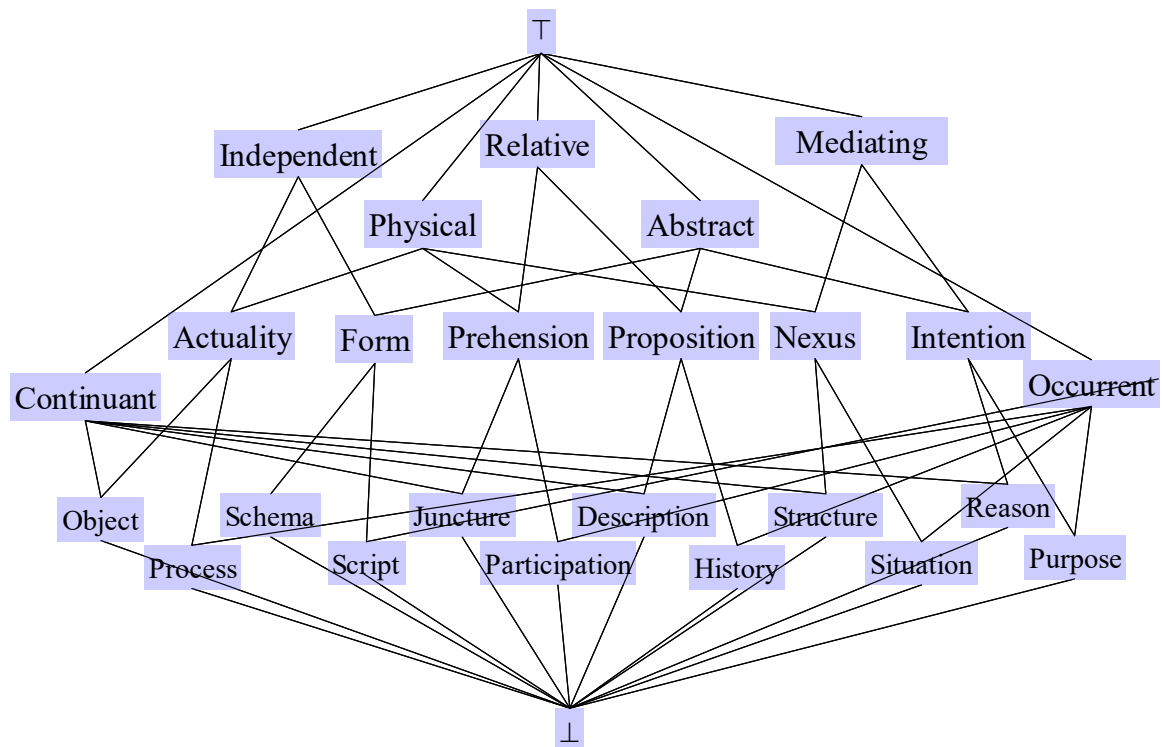- Top-level Ontologies
  - Formal Ontology
    - **DOLCE**
    - **BFO(Basic Formal Ontology**)
    - Sowa's top-level ontology
  - Pragmatic top-level ontology
    - SUMO
    - OpenCyc
  - Linguistic top-level ontology
    - **WordNet**
    - Penman Upper Model/The Generalized Upper Model

Pragmatic top-level ontology

- SUMO(Suggested Upper Merged Ontology)
  - Collection and organization of concepts used frequently
  - Simple relationship between concepts

Entity
- Phsical
  - Object
    - SelfConnectedObject
      - Substance
      - Organic
      - Inorganic
    - CorpuscularObject
    - Collection
  - Process
    - NaturalProcess
      - Biological Process
        - Phisiologic Process
        - Pathojogic Process
    - Intentionally Caused Process
      - ChangeOfProssession
      - Searching
      - Social Interaction
        - Communication
        - Cooperation
        - Contest
        - Meeting
    - Motion
      - Transfer
        - Impelling
        - Putting
        - Removing
        - Transportation
      - Impacting
      - BringingTogether
    - ChangeOf State
      - Separating
- Abstract

Pragmatic top-level ontology

- OpenCyc
  - Cyc: A project to construct very-large common knowledge base
  - OpenCyc: top-level concepts in Cyc knowledge base
    - Cyc: 120, 000 concepts and their relations
    - OpenCyc: 6,000 concepts and their relations
  - Concepts are defined logically

#$Thing
#$Individual   · #$Intangible
#$TemporalThing .... #$SetOrCollection
#$SpatialThing-Localized   #$Event
#$Collection
#$PartiallyTangible
#$ExistingStuffType
#$ExistingObjectType

#$genls
#$typeGenls
#$disjointWith
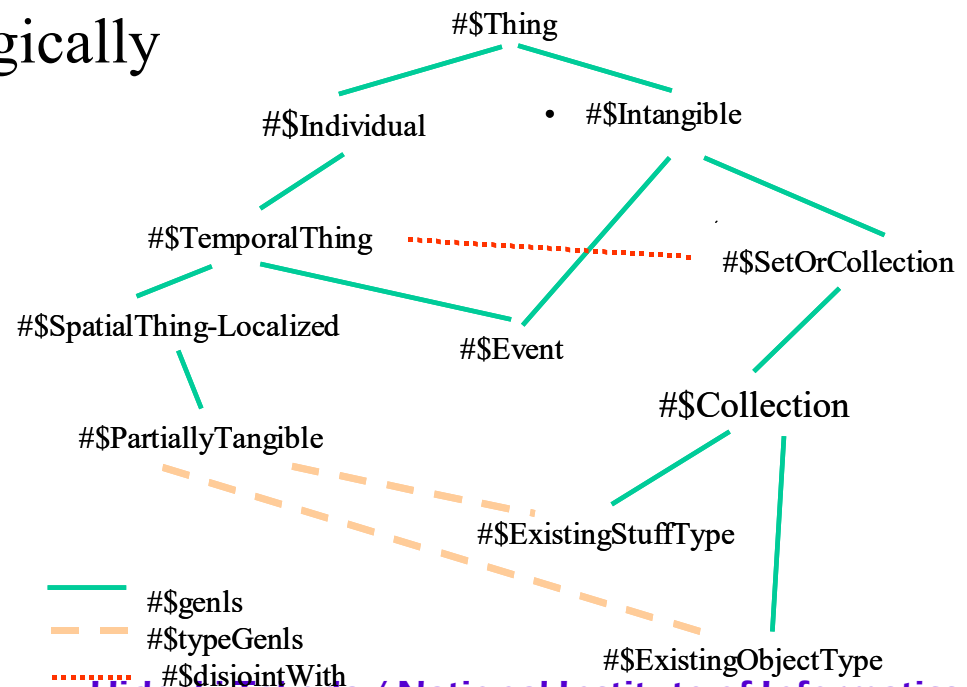
Pragmatic top-level ontology

- OpenCyc
  - Basic relations
    - #$genls: set inclusion
      - Hierarchy of categories is set inclusion
    - #$isa: relationship between a class and its instance
      - E.g,
        - (#$isa #$Dog #$BiologicalSpecies)
        - (#$genls #$Dog #$Carnivore)
        - An instance of #$Dog is also an instance of #$Carnivore but not an instance of #$BiologicalSpeicies
    - Logical operators like #$and and #$disjointWith
    - Specific operators like #$biologicalRelatives

Ontologies

- Introduction of Ontology
  - What is Ontology?
  - Typology of Ontologies
- Top-level Ontologies
  - Formal Ontology
    - **DOLCE**
    - **BFO(Basic Formal Ontology**)
    - Sowa's top-level ontology
  - Pragmatic top-level ontology
    - SUMO
    - OpenCyc
  - Linguistic top-level ontology
    - **WordNet**
    - Penman Upper Model/The Generalized Upper Model

Linguistic top-level ontology

- Lexicon, thesaurus and dictionaries are close to ontology
    - Plenty of concepts and their relations
    - Lack of formal system
- Difference between linguistic knowledge and object knowedge
    - Linguistic knowledge: grammar, categories …
    - Object knowledge: knowledge about target (ontology)
    - Two knowledge are dependent to each other
- WordNet
- Penman Upper Model/The Generalized Upper Model

Ontologies

- Introduction of Ontology
  - What is Ontology?
  - Typology of Ontologies
- Top-level Ontologies
  - Formal Ontology
    - **DOLCE**
    - **BFO(Basic Formal Ontology**)
    - Sowa's top-level ontology
  - Pragmatic top-level ontology
    - SUMO
    - OpenCyc
  - Linguistic top-level ontology
    - **WordNet**
    - Penman Upper Model/The Generalized Upper Model

WordNet

- A lexical reference system
  - "Link-based electronic dictionary"
    http://www.cogsci.princeton.edu/cgi-bin/webwn

Pos	Unique Strings	Synsets	Word-Sense Pairs
Noun	117,798	83,115	146,312
Verb	11,529	12,767	25,047
Adjective	21,479	18,156	30,002
Adverb	4,481	3,621	5,580
Total	155,287	117,659	206,941

- Synset Relations
  - synonym
  - hypernym/hyponym (is-a)
  - holonym/meronym (part-of)

WordNet Synset
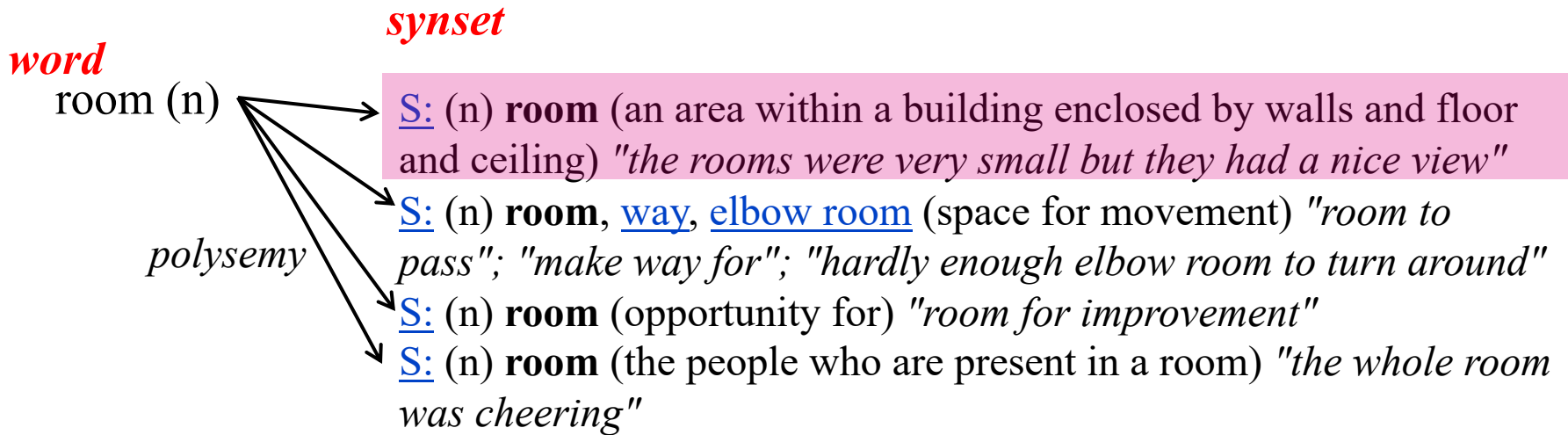
synset

word

room (n)

polysemy

S: (n) **room** (an area within a building enclosed by walls and floor and ceiling) *"the rooms were very small but they had a nice view"*

S: (n) **room**, way, elbow room (space for movement) *"room to pass"; "make way for"; "hardly enough elbow room to turn around"*

S: (n) **room** (opportunity for) *"room for improvement"*

S: (n) **room** (the people who are present in a room) *"the whole room was cheering"*

S: (n) **entity** (that which is perceived or known or inferred to have its own distinct existence (living or nonliving))

S: (n) **physical entity** (an entity that has physical existence)

S: (n) **object, physical object** (a tangible and visible entity; an entity that can cast a shadow)

S: (n) **whole, unit** (an assemblage of parts that is regarded as a single entity)

hypersym(is-a)

S: (n) **artifact, artefact** (a man-made object taken as a whole)

hypersym(is-a)

S: (n) **structure, construction** (a thing constructed; a complex entity constructed of many parts)

hypersym(is-a)

S: (n) **area** (a part of a structure having some specific characteristic or function)

S: (n) **room** (an area within a building enclosed by walls and floor and ceiling)

hyposym(is-a)

hyposym(is-a)

S: (n) **anechoic chamber** (a chamber having very little reverberation)

S: (n) **anteroom, antechamber, entrance hall, hall, foyer, lobby, vestibule** (a large entrance or reception room or area)

S: (n) **back room** (a room located in the rear of an establishment; usually accessible only to privileged groups)

S: (n) **…**

S: (n) **building, edifice** (a structure that has a roof and walls and stands more or less permanently in one place)

holonym (part-of)

S: (n) **room** (an area within a building enclosed by walls and floor and ceiling)

meronym (part-of)

S: (n) **ceiling** (the overhead upper surface of a covered space)

S: (n) **floor, flooring** (the inside lower horizontal surface (as of a room, hallway, tent, or other structure))

S: (n) **room light** (light that provides general illumination for a room)

S: (n) **wall** (an architectural partition with a height and length greater than its thickness; used to divide or enclose an area or to support another structure)

S: (n) **building, edifice** (a structure that has a roof and walls and stands more or less permanently in one place)

meronym (part-of)

S: (n) **annex, annexe, extension, wing** (an addition that extends a main building)

S: (n) **anteroom, antechamber, entrance hall, hall, foyer, lobby, vestibule** (a large entrance or reception room or area)

S: (n) **corner, quoin** ((architecture) solid exterior angle of a building; especially one formed by a cornerstone)

S: (n) **room** (an area within a building enclosed by walls and floor and ceiling)
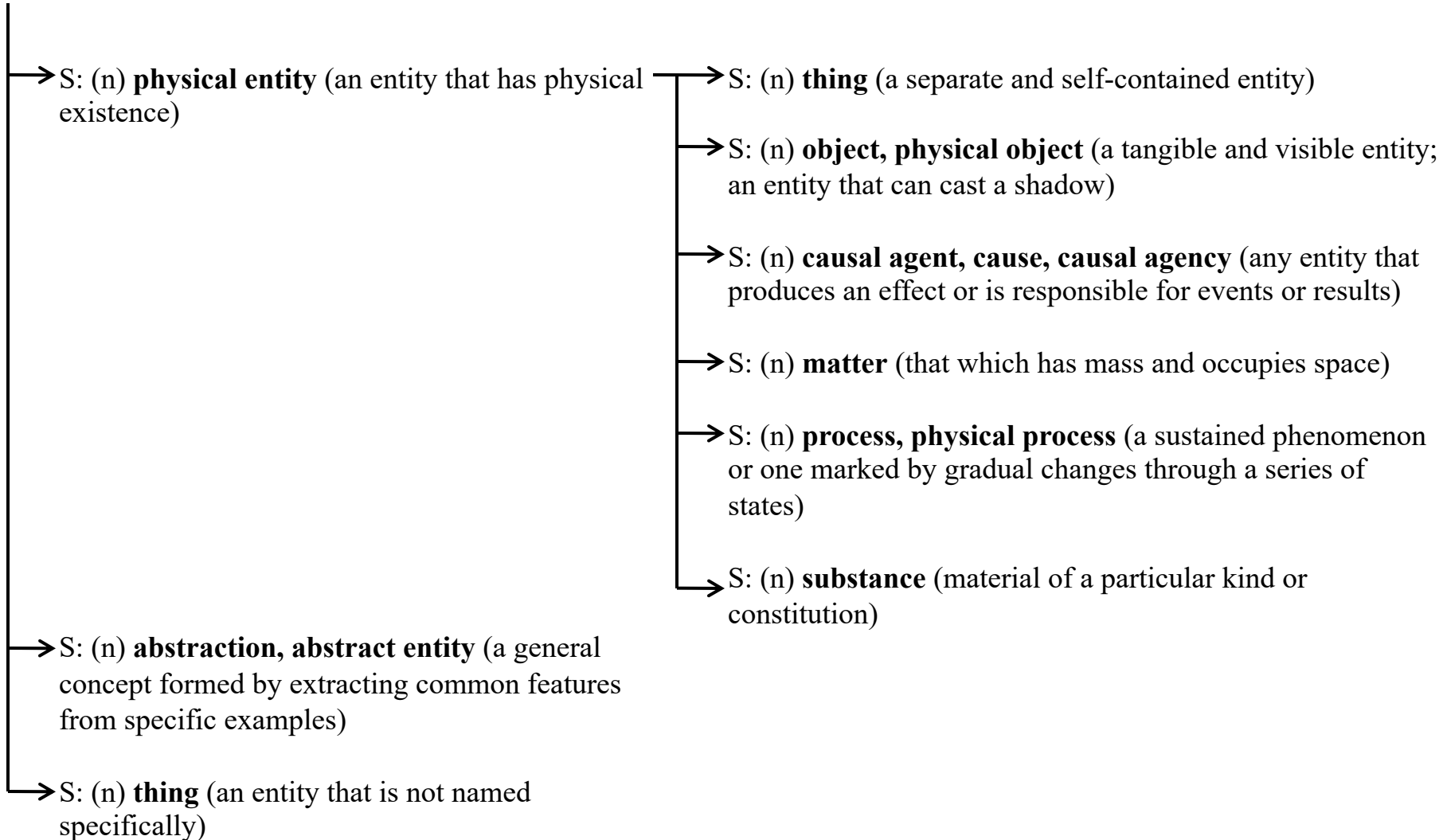
Instance-of

Independence Hall

Houses of Parliament

WordNet

- Top-level (note: WordNet 2.1)
  - { **entity, physical thing** (that which is perceived or known or inferred to have its own physical existence (living or nonliving)) }
  - { **psychological_feature**, (a feature of the mental life of a living organism) }
  - { **abstraction**, (a general concept formed by extracting common features from specific examples) }
  - { **state**, (the way something is with respect to its main attributes; "the current state of knowledge"; "his state of health"; "in a weak financial state") }
  - { **event**, (something that happens at a given place and time) }
  - { **act, human_action, human_activity**, (something that people do or cause to happen) }
  - { **group, grouping**, (any number of entities (members) considered as a unit) }
  - { **possession**, (anything owned or possessed) }
  - { **phenomenon**, (any state or process known through the senses rather than by intuition or reasoning) }

WordNet Synset

S: (n) **entity** (that which is perceived or known or inferred to have its own distinct existence (living or nonliving))

→ S: (n) **physical entity** (an entity that has physical existence)

→ S: (n) **thing** (a separate and self-contained entity)

→ S: (n) **object, physical object** (a tangible and visible entity; an entity that can cast a shadow)

→ S: (n) **causal agent, cause, causal agency** (any entity that produces an effect or is responsible for events or results)

→ S: (n) **matter** (that which has mass and occupies space)

→ S: (n) **process, physical process** (a sustained phenomenon or one marked by gradual changes through a series of states)

→ S: (n) **substance** (material of a particular kind or constitution)

→ S: (n) **abstraction, abstract entity** (a general concept formed by extracting common features from specific examples)

→ S: (n) **thing** (an entity that is not named specifically)

WordNet Synset

S: (n) thing (a separate and self-contained entity)

S: (n) subject, content, depicted object (something (a person or object or scene) selected by an artist or photographer for graphic representation) *"a moving picture of a train is more dramatic than a still picture of the same subject"*

S: (n) body of water, water (the part of the earth's surface covered with water (such as a river or lake or ocean)) *"they invaded our territorial waters"; "they were sitting by the water's edge"*

S: (n) inessential, nonessential (anything that is not essential) *"they discarded all their inessentials"*

S: (n) necessity, essential, requirement, requisite, necessary (anything indispensable) *"food and shelter are necessities of life"; "the essentials of the good life"; "allow farmers to buy their requirements under favorable conditions"; "a place where the requisites of water fuel and fodder can be obtained"*

S: (n) part, piece (a portion of a natural object) *"they analyzed the river into three parts"; "he needed a piece of granite"*

S: (n) reservoir, source (anything (a person or animal or plant or substance) in which an infectious agent normally lives and multiplies) *"an infectious agent depends on a reservoir for its survival"*

S: (n) unit, building block (a single undivided natural thing occurring in the composition of something else) *"units of nucleic acids"*

S: (n) variable (something that is likely to vary; something that is subject to variation) *"the weather is one variable to be considered"*

WordNet Synset

S: (n) **object, physical object** (a tangible and visible entity;
an entity that can cast a shadow)

S: (n) whole, unit (an assemblage of parts that is regarded as a single entity
S: (n) location (a point or extent in space)
S: (n) charm, good luck charm (something believed to bring good luck)
S: (n) curio, curiosity, oddity, oddment, peculiarity, rarity (something unusual -- perhaps worthy of collecting)
S: (n) draw, lot (anything (straws or pebbles etc.) taken or chosen at random)
S: (n) film (a thin coating or layer)
S: (n) hoodoo (something believed to bring bad luck)
S: (n) je ne sais quoi (something indescribable)
S: (n) keepsake, souvenir, token, relic (something of sentimental value)
S: (n) makeweight, filler (anything added to fill out a whole)
S: (n) part, portion (something less than the whole of a human artifact)
S: (n) property, prop (any movable articles or objects used on the set of a play or movie)
S: (n) snake (something long, thin, and flexible that resembles a snake)
S: (n) stuff (miscellaneous unspecified objects)
S: (n) triviality, trivia, trifle, small beer (something of small importance)
S: (n) paring ((usually plural) a part of a fruit or vegetable that is pared or cut off; especially the skin or peel)
S: (n) catch (anything that is caught (especially if it is worth catching))
S: (n) commemorative (an object (such as a coin or postage stamp) made to mark an event or honor a person)
S: (n) discard (anything that is cast aside or discarded)

WordNet Synset

S: (n) **object, physical object** (a tangible and visible entity;
an entity that can cast a shadow)

S: (n) finding (something that is found)
S: (n) floater (an object that floats or is capable of floating)
S: (n) fomite, vehicle (any inanimate object (as a towel or money or clothing or dishes or books or toys etc.) that can transmit infectious agents from one person to another)
S: (n) geological formation, formation ((geology) the geological features of the earth)
S: (n) growth (something grown or growing)
S: (n) hail (many objects thrown forcefully through the air)
S: (n) head (a rounded compact mass)
S: (n) ice (the frozen part of a body of water)
S: (n) land, dry land, earth, ground, solid ground, terra firma (the solid part of the earth's surface)
S: (n) land, ground, soil (material in the top layer of the surface of the earth in which plants can grow (especially with reference to its quality or use))
S: (n) moon (any object resembling a moon)
S: (n) neighbor, neighbour (a nearby object of the same kind)
S: (n) remains (any object that is left unused or still extant)
S: (n) ribbon, thread (any long object resembling a thin line)
S: (n) shiner (something that shines (with emitted or reflected light))
S: (n) vagabond (anything that resembles a vagabond in having no fixed place)
S: (n) wall (anything that suggests a wall in structure or function or effect)
S: (n) web (an intricate network suggesting something that was formed by weaving or interweaving

WordNet Synset

S: (n) **causal agent, cause, causal agency** (any entity that produces an effect or is responsible for events or results)

S: (n) person, individual, someone, somebody, mortal, soul (a human being)
S: (n) agent (an active and efficient cause; capable of producing a certain effect)
S: (n) nature (a causal agent creating and controlling things in the universe)
S: (n) supernatural, occult (supernatural forces and events and beings collectively)
S: (n) theurgy (the effect of supernatural or divine intervention in human affairs)
S: (n) first cause, prime mover, primum mobile (an agent that is the cause of all things but does not itself have a cause) *"God is the first cause"*
S: (n) destiny, fate (the ultimate agency regarded as predetermining the course of events (often personified as a woman)) *"we are helpless in the face of destiny"*
S: (n) catalyst (something that causes an important event to happen)
S: (n) deus ex machina (any active agent who appears unexpectedly to solve an insoluble difficulty)
S: (n) operator, manipulator (an agent that operates some apparatus or machine)
S: (n) power, force (one possessing or exercising power or influence or authority)
S: (n) vital principle, life principle (a hypothetical force to which the functions and qualities peculiar to living things are sometimes ascribed)
S: (n) engine (something used to achieve a purpose) *"an engine of change"*
S: (n) cause of death, killer (the causal agent resulting in death)
S: (n) danger (a cause of pain or injury or loss)
S: (n) agent (a substance that exerts some force or effect)

WordNet Synset

S: (n) matter (that which has mass and occupies space)

       S: (n) substance (the real physical matter of which a person or thing consists)

       S: (n) substance (a particular kind or species of matter with uniform properties)

       S: (n) sediment, deposit (matter that has been deposited by some natural process)

       S: (n) ylem ((cosmology) the original matter that (according to the big bang theory) existed before the formation of the chemical elements)

       S: (n) dark matter ((cosmology) a hypothetical form of matter that is believed to make up 90 percent of the universe; it is invisible (does not absorb or emit light) and does not collide with atomic particles but exerts gravitational force)

       S: (n) antimatter (matter consisting of elementary particles that are the antiparticles of those making up normal substances)

       S: (n) glop (any gummy shapeless matter; usually unpleasant)

       S: (n) fluid (continuous amorphous matter that tends to flow and to conform to the outline of its container: a liquid or a gas)

       S: (n) sludge, slime, goo, goop, gook, guck, gunk, muck, ooze (any thick, viscous matter)

       S: (n) system ((physical chemistry) a sample of matter in which substances in different phases are in equilibrium)

       S: (n) residue (matter that remains after something has been removed)

       S: (n) solid (matter that is solid at room temperature and pressure)

       S: (n) solute (the dissolved matter in a solution; the component of a solution that changes its state)

       S: (n) emanation (something that is emitted or radiated (as a gas or an odor or a light, etc.))

       S: (n) vegetable matter (matter produced by plants or growing in the manner of a plant)

WordNet Synset

S: (n) process, physical process (a sustained phenomenon or one marked by gradual changes through a series of states)

S: (n) phenomenon (any state or process known through the senses rather than by intuition or reasoning)

S: (n) chelation ((medicine) the process of removing a heavy metal from the bloodstream by means of a chelate as in treating lead or mercury poisoning)

S: (n) dealignment (a process whereby voters are moved toward nonpartisanship thus weakening the structure of political parties)

S: (n) decrease, decrement (a process of becoming smaller or shorter)

S: (n) degeneration, devolution (the process of declining from a higher to a lower level of effective power or vitality or essential quality)

S: (n) development, evolution (a process in which something passes by degrees to a different stage (especially a more advanced or mature stage)) "

S: (n) economic process (any process affecting the production and development and management of material wealth)

S: (n) encapsulation (the process of enclosing (as in a capsule))

S: (n) execution, instruction execution ((computer science) the process of carrying out an instruction by a computer)

S: (n) human process (a process in which human beings are involved)

S: (n) increase, increment, growth (a process of becoming larger or longer or more numerous or more important)

S: (n) industrial process (a systematic series of mechanical or chemical operations that produce or manufacture something)

S: (n) irreversible process (any process that is not reversible)

S: (n) iteration, looping ((computer science) executing the same set of instructions a given number of times or until a specified result is obtained)

S: (n) iteration, loop ((computer science) a single execution of a set of instructions that are to be repeated)

S: (n) natural process, natural action, action, activity (a process existing in or produced by nature (rather than by the intent of human beings))

S: (n) operation, functioning, performance (process or manner of functioning or operating)

S: (n) organic process, biological process (a process occurring in living organisms)

S: (n) photography (the process of producing images of objects on photosensitive surfaces)

S: (n) processing (preparing or putting through a prescribed procedure)

S: (n) reversible process (any process in which a system can be made to pass through the same states in the reverse order when the process is reversed)

S: (n) sensitization, sensitisation ((psychology) the process of becoming highly sensitive to specific events or situations (especially emotional events or situations))

S: (n) shaping, defining (any process serving to define the shape of something)

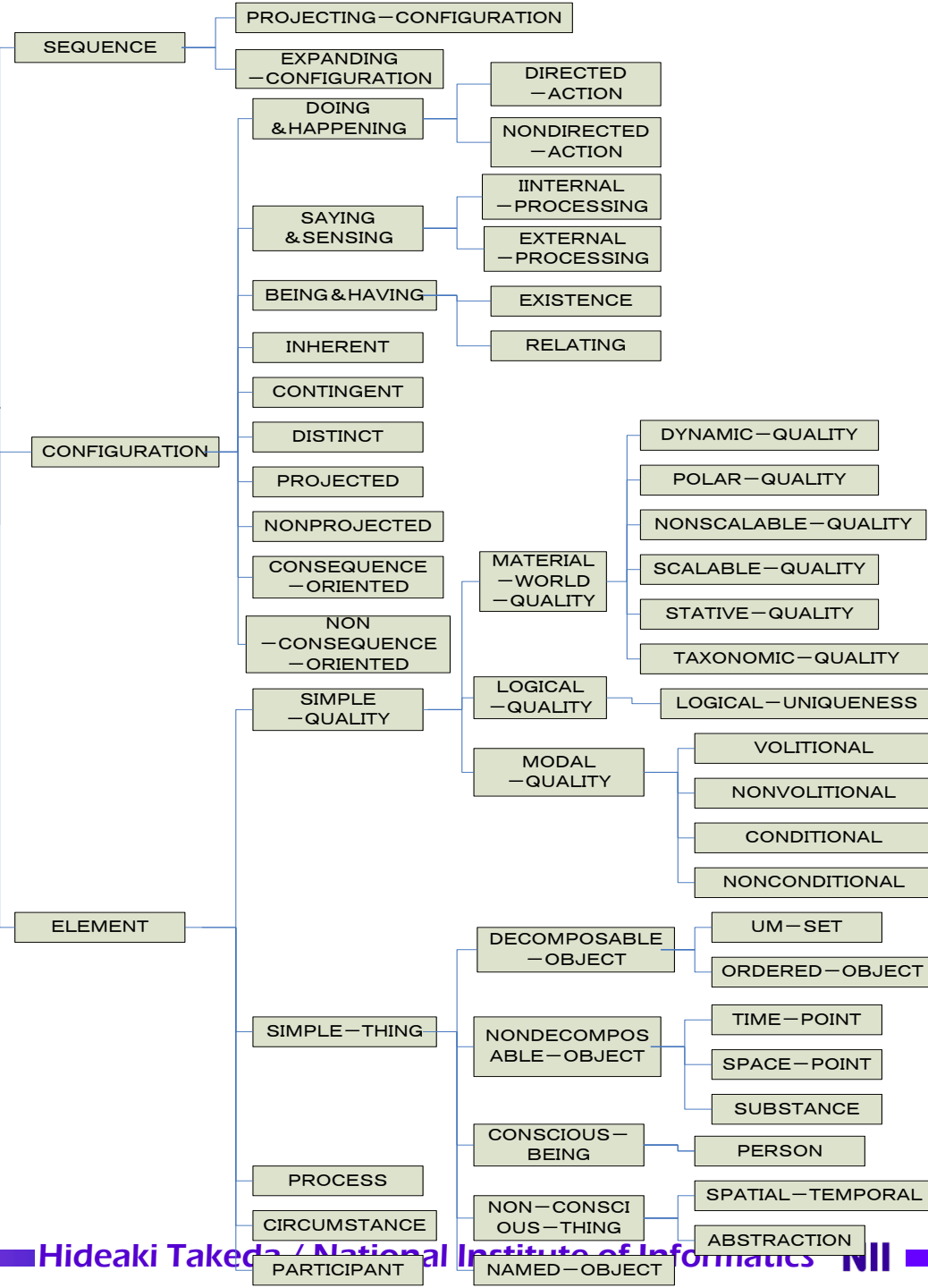S: (n) variation (the process of varying or being varied)

Ontologies

- Introduction of Ontology
  - What is Ontology?
  - Typology of Ontologies
- Top-level Ontologies
  - Formal Ontology
    - **DOLCE**
    - **BFO(Basic Formal Ontology**)
    - Sowa's top-level ontology
  - Pragmatic top-level ontology
    - SUMO
    - OpenCyc
  - Linguistic top-level ontology
    - **WordNet**
    - Penman Upper Model/The Generalized Upper Model

Linguistic top-level ontology

- Penman Upper Model/The Generalized Upper Model
  - ca. 250 concepts and their relations
  - Initially as a part of a natural language generation system
  - Things and processes

Top-level ontology

- Three approaches
  - Formal approach
    - Logical formalization
    - Fully Abstract
    - Pros: clean
    - Cons: hardly understandable
    - e.g., Sowa's top-level ontology, DOLCE, Basic Formal Ontology (BFO)
  - Pragmatic Approach
    - Use and extension of everyday concepts
    - Mostly general
    - Pros: understandable and applicable to all the world
    - Cons: lack of solid foundation
    - e.g. SUMO, OpenCyc, EDR
  - Linguistic approach
    - Use and extension of linguistic concepts
    - Partially abstract and partially general
    - Pros: understandable
    - Cons: limitation to the linguistic world
    - e.g., Penman Upper Model, WordNet

References

- DOLCE
  - Aldo Gangemi , Nicola Guarino , Claudio Masolo , Alessandro Oltramari , Luc Schneider, Sweetening Ontologies with DOLCE, Proceedings of the 13th International Conference on Knowledge Engineering and Knowledge Management. Ontologies and the Semantic Web, p.166-181, October 01-04, 2002 http://portal.acm.org/citation.cfm?id=650863&dl=GUIDE&coll=GUIDE&CFID=3917 4097&CFTOKEN=41128460
  - C. Masolo and S. Borgo and A. Gangemi and N. Guarino and A. Oltramari and L. Schneider, WonderWeb Deliverable D17. The WonderWeb Library of Foundational Ontologies and the DOLCE ontology (2002) .
- Ontology for Universals
  - Nicola Guarino , Christopher A. Welty, A Formal Ontology of Properties, Proceedings of the 12th European Workshop on Knowledge Acquisition, Modeling and Management, p.97-112, October 02-06, 2000 http://portal.acm.org/citation.cfm?id=650850&dl=&coll=GUIDE&CFID=39173867&C FTOKEN=59527108
- Ontoclean
  - N. Guarino and C. A. Welty, "An overview of OntoClean," in The Handbook on Ontologies, (S. Staab and R. Studer, eds.), pp. 151-172, Berlin: Springer-Verlag, 2004.

- BFO
  - P. Grenon, B. Smith and L. Goldberg, Biodynamic ontology: applying BFO in the biomedical domain, *Ontologies in medicine*, IOS Press, Amsterdam (2004), pp. 20–38.