



Science Knowledge Infrastructure Ontology 3.0

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14-05-2009

Abstract:

This report provides a partial description of the ontology for Science Knowledge Infrastructure (SKIo), an ontology that represents science knowledge primitives such as theory, prediction, geoscience model, observation. SKIo is developed to enhance digital representation and use of such knowledge in e-Science environments. It is specified in this report via a UML representation, including class diagrams and related text descriptions. A full description of SKIo can be obtained by using this report in conjunction with the accompanying OWL-DL representation.

UK e-Science Technical Report Series

Report UKeS-2008-03

Available from http://www.nesc.ac.uk/technical_papers/UKeS-2008-03.pdf

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Purpose and Scope of this Report

This report provides a partial description of the ontology for Science Knowledge Infrastructure (SKI), an ontology that represents basic science knowledge elements such as theory, hypothesis, geoscience model, observation. The ontology is specified in this report via an UML representation, including class diagrams and a text description for each class. A full description of SKI can be obtained by using this report in conjunction with the accompanying OWL-DL formalization of SKI.

Terminology

For convenience, the term “class” is used throughout this document in the UML sense to refer to an abstraction that is part of the SKI ontology, and the term “relation” is used to refer to an association between classes. The phrase “Science Knowledge Infrastructure” is borrowed from Hars (2001), where it refers to the science knowledge rudiments required to support e-science.

Scope

As SKI is an extension of the DOLCE foundational ontology (Gangemi, *et al.*, 2003; Masolo, *et al.*, 2003), key DOLCE classes and relations are represented and described in this report, in addition to the SKI components. In particular, the top DOLCE classes are included as well as intermediary DOLCE subclasses that are immediately superordinate to each SKI class. In some cases other intermediary classes (between the top and superordinate DOLCE classes) are omitted for space reasons.

Mechanics

The UML class diagrams and descriptions were developed and automatically generated using Enterprise Architect (version 7.0.816, Build 816) (<http://www.sparxsystems.com.au/>). The OWL-DL formalization was manually generated from the UML using Protégé (OWL Plugin 3.3.1, Build 430) (<http://protege.stanford.edu/overview/protege-owl.html>).

Motivation for SKI

SKI is developed to further the goals of e-science—cyber-based scientific knowledge discovery (Hey & Trefethen, 2005)—by enabling generic science knowledge elements and associated reasoning steps to be formally represented via an extension to a foundational ontology. This expands the scope of existing science ontologies by additionally including cross-disciplinary elements such as theories, models and observations, which in turn can be specialized to represent the theories, models, etc., of a specific discipline. Existing science ontologies typically represent concepts from a single scientific discipline (geoscience examples include Bittner (2007) and Raskin & Pan (2005)) and are at present mainly used to annotate data repositories or cyber-based services, to facilitate interoperability of both data and services (geoscience examples include Ludäscher, *et al.*, 2006; Lutz & Klien, 2006; McGuinness, *et al.*, 2006). In contrast, while foundational ontologies do contain concepts that can be specialized by many (all) disciplines, they do not possess a full suite of generic science knowledge elements, though could potentially be extended to do so. SKI realizes this potential and fills the obvious gap between foundational ontologies and disciplinary ontologies by providing a foundational ontology for scientific knowledge, one that is intended to aid cyber-based scientific research.

The SKI Ontology

SKI contains basic knowledge elements common to all sciences, with some specializations particularly for geoscience. SKI contents are drawn from summaries of computational accounts of the scientific knowledge cycle (Hars, 2001; 2003; Langley, 2000; Shrager & Langley, 1990; Sowa, 2000; 2006; Thagard, 1988). These summaries begin to distil the numerous and complex philosophical approaches to scientific knowledge into representations amenable to computation. SKI continues this distillation by bringing a relatively modest subset of the key concepts into a formal framework, under the DOLCE foundational ontology. The central concepts represented in SKI are shown in Figure 1; these are mainly modifications of Sowa (2006) and Hars (2003). They constitute a knowledge cycle in which: (1) empirical patterns are induced from observed data, (2) theoretical statements are abduced from all prior

knowledge, (3) predictions about the real world are deduced from empirical patterns or theoretical statements, and (4) predictions are verified through further interaction with the world, which involves activities such as data collection, problem finding, and building models of the world.

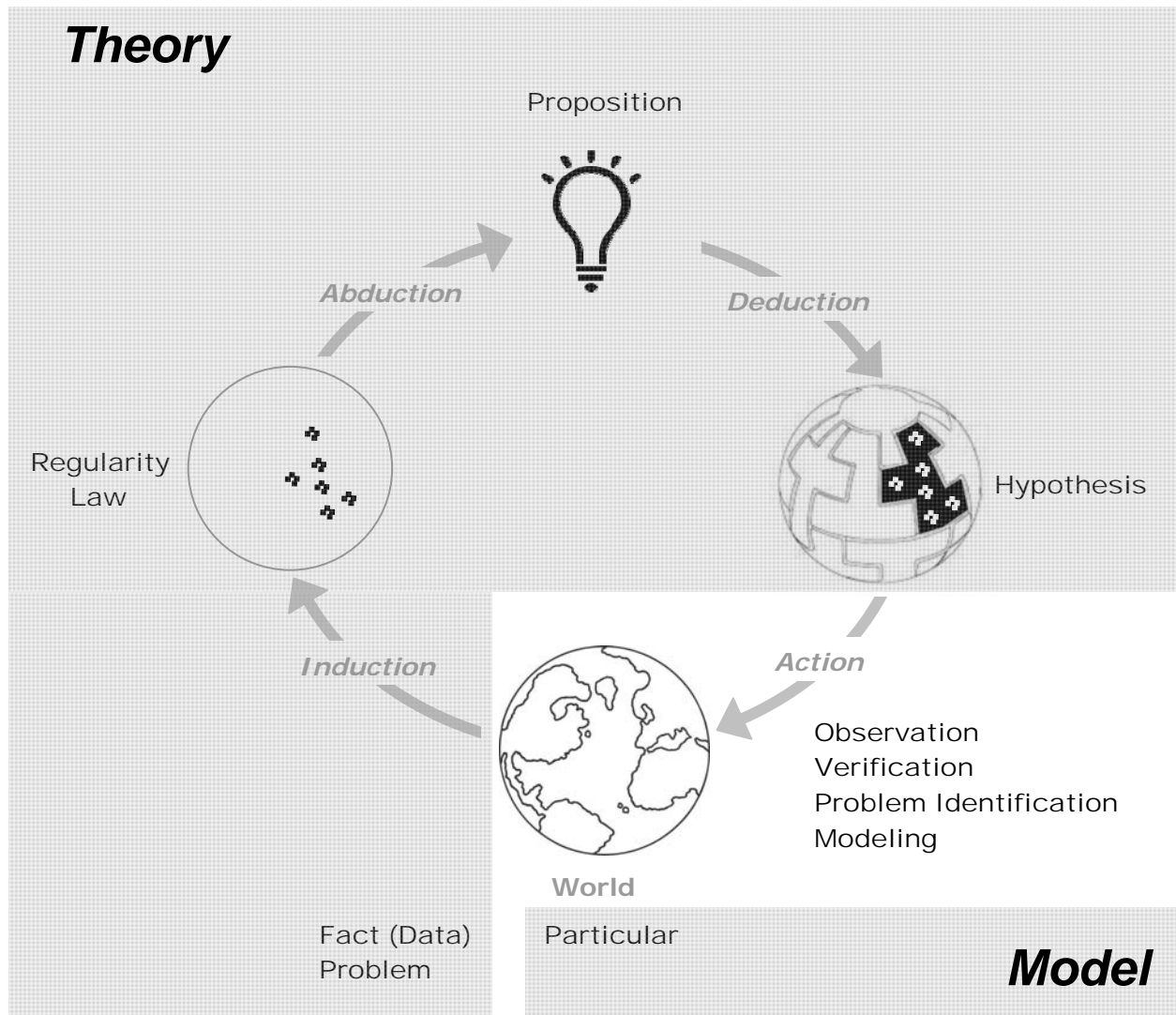


Figure 1: basic elements of science knowledge cycle in SKI (after Sowa, 2000).

A key notion is that scientific ideas are expressed by scientific statements, such as those found in papers and reports, and these statements are explained by cognitive agents in conceptualized descriptions of the world called theories. Importantly, the same description can play different roles in the same or different theories, for example, a description might be treated as an unproven proposition, a locally verified regularity, or a universally applicable law, and any of these might be assumed as verified, or identified as being a problem. Table 1 briefly introduces these roles. Another important notion is the distinction between a scientific theory and a model, in that a model is extensional and a theory is intensional: a model contains particulars which satisfy (are deducible from) some theory, a theory contains descriptions which are satisfied by (can be used to deduce) the particulars in the model, and a description contains concepts that classify the particulars in a model. When the description itself is a concept definition, then any satisfying model is part of the extension of the concept, because each particular in the extension (in the model) can be deductively classified from the concept definition.

Table 1: SKI science roles

SKI Concept	Description
assumption	A science statement asserted to be true and treated as a theory primitive
science problem	A science statement whose veracity is in question
fact	A science statement describing an individual verified by observation
proposition	A science statement abduced from other theory parts
hypothesis	A prediction about the world
empirical regularity	A pattern induced from observations that is not universal
science law	A pattern induced from data that is universal

SKling with DOLCE

A reasonable first step in the formalization of the key scientific knowledge elements might be to directly re-use the machinery of logical theories for scientific theories, but this proves problematic in its raw form because logical theories are constructed around the relationship between a language and some model of reality, while scientific theories are constructed around the relationship between concepts and the real world (or models of the real world). Foundational ontologies provide a bridge between the two types of theories, in that foundational ontologies use logical theories to represent the relation between concepts and the real world (Guarino, 1998). DOLCE in particular is built around notions of representing the interaction of cognizing agents with the real world, and has the potential to be extended to the representation of scientific interactions with the real world. SKI capitalizes on these notions by heavily using two parts of DOLCE: (1) core entities that are object-like (endurants), process-like (perdurants), characteristics (qualities) or their values (regions); and (2) theories about groups of core entities generated by some agent to describe and explain the entities (descriptions and situations). SKI includes specializations of the core entities for scientific activities such as observation, verification, inference, problem identification and modeling, and for physical objects such as instruments of observation as well as geoscience objects. Specializations of the theoretic entities include data, scientific statements, science theories and models, and the various roles a scientific statement can play within a theory.

Example

Consider the example of a geologic map (Brodaric & Hastings, 2002):

- **GeoScienceModel:** the collection of rock bodies represented on the map denotes a geoscience model, which satisfies the theory summarized in the map legend. Satisfaction means in this case that the rock bodies (model) do not contradict the classes (geologic units) and relations specified in the legend (theory).
- **GeoScienceTheory:** the collection of classes and relations in the map legend partially denote a geoscience theory, one that is satisfied by the rock bodies on the map. Each class has a definition supplied in the legend, which contains a description of the permissible spatio-temporal relations with other classes.
- **ScienceRoles:** each class in the map legend plays the role of both a *Definition* and a *Proposition*. Each is a definition because the text in the legend defines the class; hence the model represents a partial extension for each class. Each class is also a *Proposition* because it is abduced—while the qualities of each class might be induced from data, the process history for each class (which defines its spatio-temporal relations with other classes) is pieced together from various clues about the past. Also, behind all the classes is the general law of superposition, an *Assumption*, which says that rock bodies that are spatially underneath other rock bodies are temporally older (except in certain circumstances).
- **Data:** field observations about the physical or temporal qualities of the rocks provide evidential support to the rock bodies and related classes. For example, rock body boundaries are often depicted on maps with dashed or solid lines to denote whether they are inferred or observed, respectively. In SKI, an inferred boundary is one that is discovered by a Hypothesis, whereas an observed boundary is one that is discovered by a Fact, which is a role played by some observed data within the theory (that is partly expressed in the map legend).

It is common for a geographical area to be re-mapped geologically. In doing so some of the original knowledge elements are frequently re-used and combined with new elements to form new models and theories, and thus a new map and scientific interpretation of the area. With SKI the original and successive interpretations can be clearly and precisely represented, making them available for processing by emerging cyber tools in support of e-science.

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SKI Ontology 3.0

Science Knowledge Infrastructure Ontology 3.0--with an emphasis on geoscience knowledge.

SKI Core Entities 3.0

Contains core DOLCE and related SKI entities, such as observation, data, inference, etc.

SKI Core Diagram

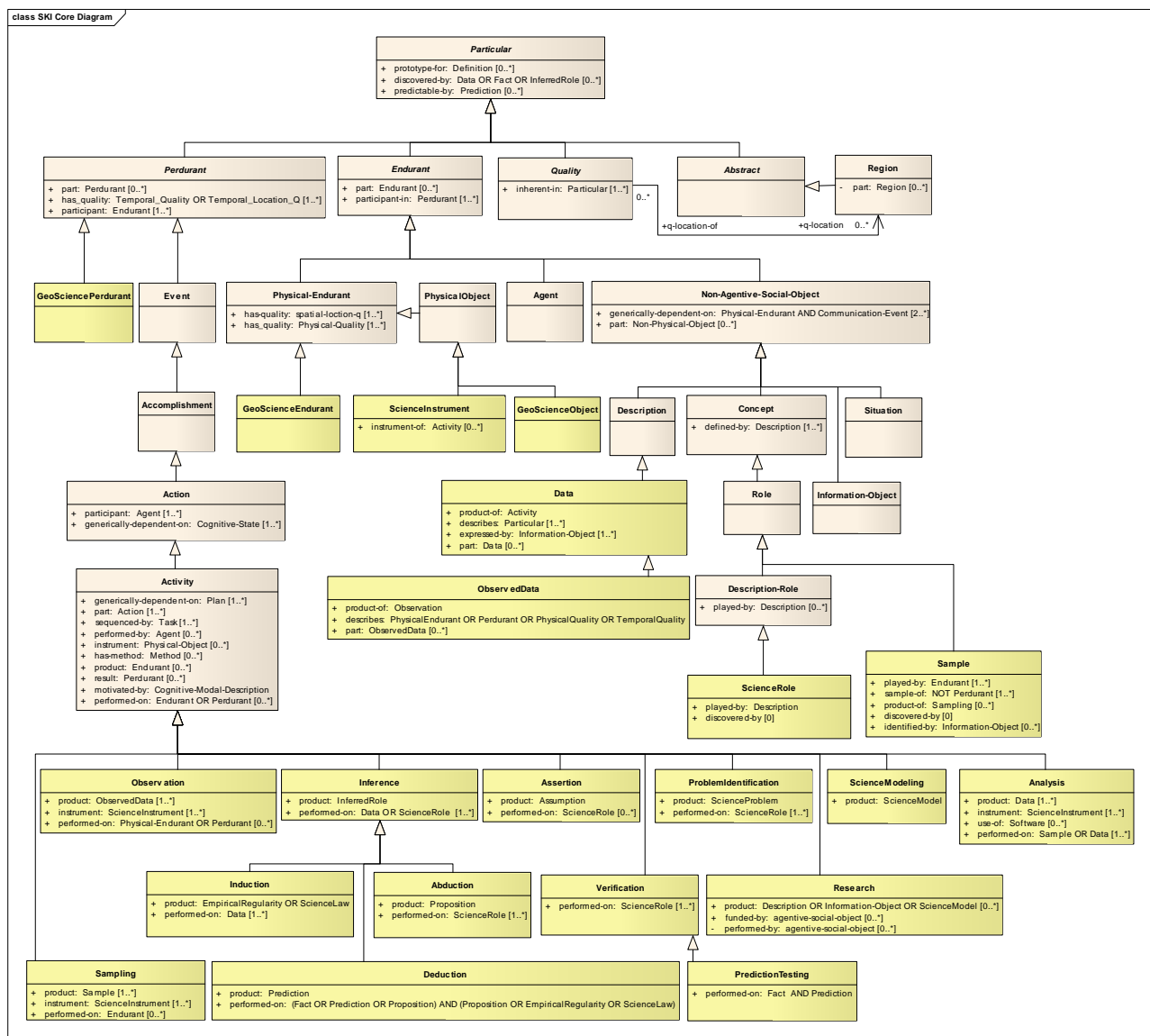


Figure: 1

Abduction

Type: **Class** **Inference**

Involves guessing a Proposition to enable coherence of discordant scientific knowledge elements. Logical abduction is reverse deduction: in a deduction of the form $T \wedge a1 \rightarrow b1$, as above, where T and b1 are known, then guess the missing instance a1. Pragmatic abduction, on the other hand, is more concerned with guessing theory T via conceptual transformations from radically different prior knowledge (often via analogy ~): e.g. given $T1:C \rightarrow D$, and $A \sim C \wedge B \sim D$, then $T2:A \rightarrow B$. SKIo Abduction encompasses both logical and pragmatic abduction, such that the resultant Proposition refers to either a1 (an instance) or T2 (a theoretical relation).

Connections

Connector	Source	Target
Generalization Source -> Destination	Abduction	Inference

Attributes

Attribute	Notes
product Proposition	The product of an abduction is some new theoretic role which is empirically untested---in SKI this new role is called a Proposition.
performed-on ScienceRole [1..*]	The inputs to an abduction are existing theory components (science roles)--including theoretical roles such as propositions, regularities, and science laws, empirical roles such as predictions and facts, and primitives such as assumptions and problems.

Abstract

Type: **Class** **Particular**

Abstract entities do not exist in space nor time, e.g. mathematical entities like numbers, sets (from DOLCE, Masolo, et al., p.8). They cannot have spatial or temporal qualities, but can have abstract qualities.

Connections

Connector	Source	Target
Generalization Source -> Destination	Abstract	Particular
Generalization Source -> Destination	Region	Abstract

Accomplishment

Type: **Class** **Event**

from DOLCE: an event that is not atomic, i.e. can have parts.

Connections

Connector	Source	Target
Generalization Source -> Destination	Action	Accomplishment
Generalization Source -> Destination	Accomplishment	Event

Action

Type: **Class** **Accomplishment**

from DOLCE: "A Perdurant that exemplifies the intentionality of an agent. Could it be aborted, incomplete, mislead, while remaining a (potential) accomplishment ... The point here is that having a result depends on a method, then an action remains an action under incomplete results. As a matter of fact, if we neutralize intentionality, a purely topological, post-hoc view is at odds with the notion of incomplete accomplishments."

Connections

Connector	Source	Target
Generalization Source -> Destination	Activity	Action
Generalization Source -> Destination	Action	Accomplishment

Attributes

Attribute	Notes
participant Agent [1..*]	The agents who are involved in the action, including the initiator of the action.
generically-dependent-on Cognitive-State [1..*]	Denotes the disposition of the agent regarding the action. Assumes a cognitive agent is performing the action, even if the action is carried out by an instrument. For a scientist performing an action this state might be one of inquiry, investigation, etc.

Activity

Type: **Class** **Action**

from DOLCE: "In dependency terms, an activity is an action that is generically constantly dependent on a (at least partly) shared plan adopted by participants. This condition implies that an action must be sequenced by a task. Intuitively, activities are complex actions that are at least partly conventionally planned."

Additions:

motivated-by: indicates the purpose for the action

performed-on: indicates the object on which the action is being performed.

Notes: for our purposes we can assume that the plan (which can be part of a method) required by an activity is some research plan or project, which contains certain tasks that are carried out; the activity represents the carrying out (sequencing) of these tasks.

Connections

Connector	Source	Target
Generalization Source -> Destination	Activity	Action
Generalization Source -> Destination	Research	Activity

Connector	Source	Target
<u>Generalization</u> Source -> Destination	Inference	Activity
<u>Generalization</u> Source -> Destination	ProblemIdentification	Activity
<u>Generalization</u> Source -> Destination	Verification	Activity
<u>Generalization</u> Source -> Destination	Assertion	Activity
<u>Generalization</u> Source -> Destination	Observation	Activity
<u>Generalization</u> Source -> Destination	Analysis	Activity
<u>Generalization</u> Source -> Destination	Sampling	Activity
<u>Generalization</u> Source -> Destination	ScienceModeling	Activity

Attributes

Attribute	Notes
generically-dependent-on Plan [1..*]	A plan made by the participants--this implies activities are at least partly planned in some way by them, e.g. a research plan, a flight path for a remote sensing satellite, etc. The plan d-uses the task.
part Action [1..*]	Activities are complex, not atomic, hence must have at least one part that is an action.
sequenced-by Task [1..*]	Because activities are complex, their components are sequenced by a task which is defined by a plan, e.g. an observation method might result in a plan which defines and d-uses several tasks, and each task is sequenced (realized) by a certain action.
performed-by Agent [0..*]	The agent performing the activity.
instrument Physical-Object [0..*]	The instrument being used by the agent to perform the activity.
has-method Method [0..*]	The broader method from which the plan is generated..
product Endurant [0..*]	A enduring produced by this activity, e.g. ObservedData is produced from an observation/measurement.
result Perdurant [0..*]	A perdurant that is a consequence of this activity.
motivated-by Cognitive-Modal-Description	The motivation of the agent(s) performing the activity. Subclasses of cognitive-modal-description include desire, goal, commitment, promise, responsibility.

Attribute	Notes
performed-on Endurant OR Perdurant [0..*]	The target of the activity--the entity upon which the activity is performed (i.e. the receiver of the activity), e.g. in an observation this is the entity being observed or measured.

Agent

Type: **Class** **Endurant**

from DOLCE: "A catch-all class used to join agentive objects (either physical or social). Agents are dispositionally so, in the sense that they internally represent descriptions, and in particular plans, goals and possible actions, but they do not necessarily act."

An issue needing clarification is the notion that agents seem to be roles that can be played by endurants, but are not modeled as such in DOLCE.

Connections

Connector	Source	Target
Generalization Source -> Destination	Agent	Endurant

Analysis

Type: **Class** **Activity**

The activity of carrying out analysis of samples or data, using an instrument and possibly some software, resulting in data being produced.

Connections

Connector	Source	Target
Generalization Source -> Destination	Analysis	Activity

Attributes

Attribute	Notes
product Data [1..*]	Analyses produce data.
instrument ScienceInstrument [1..*]	The physical instrument used to carry out the analysis, e.g. a lab machine, or a computer.
use-of Software [0..*]	The software used to carry out the analysis.
performed-on Sample OR Data [1..*]	The samples or data being analysed.

Assertion

Type: **Class** Activity

An activity that produces a scientific assumption. The assertion may be performed on some existing scientific statement to indicate the statement is being treated as TRUE.

Connections

Connector	Source	Target
Generalization Source -> Destination	Assertion	Activity

Attributes

Attribute	Notes
product Assumption	The product of an assertion is an assumption used within a science theory.
performed-on ScienceRole [0..*]	The science roles that are assumed to be TRUE in the produced assumption.

Concept

Type: **Class** Non-Agentive-Social-Object

from DOLCE: "A non-physical object that is defined by a description s, and whose function is classifying entities from a ground ontology in order to build situations that can satisfy s"

Connections

Connector	Source	Target
Generalization Source -> Destination	Role	Concept
Generalization Source -> Destination	Concept	Non-Agentive-Social-Object

Attributes

Attribute	Notes
defined-by Description [1..*]	Denotes the conceptualization in which the concept is defined---e.g. a theory.

Data

Type: **Class** Description

A description typically containing the qualities associated with some particulars. Data about physical and temporal qualities can often be observed, while data about abstract qualities (associated with e.g. social objects) are typically inferred (from observed data).

Although, strictly speaking, only qualities are observable, for generality data includes descriptions of any particular, including endurants, perdurants, qualities and abstracts. Data is more specific than a Description only in that Data describes some specific particular as a result of some activity leading to the description.

Connections

Connector	Source	Target
Generalization Source -> Destination	Data	Description
Generalization Source -> Destination	ObservedData	Data

Attributes

Attribute	Notes
product-of Activity	Data is the product-of some activity.
describes Particular [1..*]	The particular being described in the data.
expressed-by Information-Object [1..*]	The physical expression of the data in some paper, database, etc.
part Data [0..*]	Data can only have other data as a part.

Deduction

Type: Class Inference

Involves generating a prediction about the world using existing theory and data. Logically, given theory $T: A \rightarrow B$ (A and B are classes) and instance a_1 (of A), then b_1 (of B) is deduced: $T \wedge a_1 \rightarrow b_1$. In SKIo Deduction, T is realized as a theoretical science role (Proposition, EmpiricalRegularity, ScienceLaw), a_1 as a science role about an observed or inferred instance (Fact, Prediction, Proposition), and b_1 as the resultant Prediction

Pragmatic and Logical deduction are completely aligned, hence Deduction here encompasses both. The product of Deduction is a prediction, which is a statement about the state of the world, generally (in the geosciences) about the values of qualities of instances of physical endurants or perdurants

Connections

Connector	Source	Target
Generalization Source -> Destination	Deduction	Inference

Attributes

Attribute	Notes
product Prediction	The product of a deduction is a prediction about empirical reality, meaning about the qualities of some perdurant or endurant.
performed-on (Fact OR Prediction OR Proposition) AND (Proposition OR EmpiricalRegularity OR ScienceLaw)	Deductions require as input a theoretical element, such as a proposition or regularity, and an instance-like element such as a fact or prediction--the latter is intended to be plugged into the theoretical element to enable the inference.

Description-Role

Type: **Class** **Role**

from DOLCE: "A role played by descriptions only. Usable for metalinguistic notions, like those that deal with granular partitions of knowledge, strata of reality, argumentation, etc."

Connections

Connector	Source	Target
Generalization Source -> Destination	ScienceRole	Description-Role
Generalization Source -> Destination	Description-Role	Role

Attributes

Attribute	Notes
played-by Description [0..*]	Denotes the description that is playing the role.

Endurant

Type: **Class** **Particular**

See DOLCE (Masolo, et al., 2003, p. 11)--endurants are wholly present at any point in time, e.g. rocks, lakes, roads.

from DOLCE: "The main characteristic of endurants is that all of them are independent essential wholes. This does not mean that the corresponding property (being an endurant) carries proper unity, since there is no common unity criterion for endurants. Endurants can 'genuinely' change in time, in the sense that the very same endurant as a whole can have incompatible properties at different times. To see this, suppose that an endurant - say 'this paper' - has a property at a time t 'it's white', and a different, incompatible property at time t' 'it's yellow': in both cases we refer to the whole object, without picking up any particular part of it. Within endurants, we distinguish between physical and non-physical endurants, according to whether they have direct spatial qualities. Within physical endurants, we distinguish between amounts of matter, objects, and features."

Connections

Connector	Source	Target
Generalization Source -> Destination	Endurant	Particular
Generalization Source -> Destination	Physical-Endurant	Endurant
Generalization Source -> Destination	Non-Agentive-Social-Object	Endurant
Generalization Source -> Destination	Agent	Endurant

Attributes

Attribute	Notes
part Endurant [0..*]	Only other endurants can be parts.
participant-in Perdurant [1..*]	Refers minimally to the lifetime of the endurant--each endurant must minimally participate in its life.

Event

Type: **Class** Perdurant

from DOLCE: "An occurrence-type is stative or eventive according to whether it holds of the mereological sum of two of its instances, i.e. if it is cumulative or not. A sitting occurrence is stative since the sum of two sittings is still a sitting occurrence"

Connections

Connector	Source	Target
Generalization Source -> Destination	Event	Perdurant
Generalization Source -> Destination	Accomplishment	Event

GeoScienceEndurant

Type: **Class** Physical-Endurant

Intuitively, a non-process-like geoscience entity: an endurant consisting of the union of geoscience physical bodies, amounts of matter that constitute geoscience bodies, and features that host geoscience bodies. Used to constrain the contents of geoscience models to these entities.

Connections

Connector	Source	Target
Generalization Source -> Destination	GeoScienceEndurant	Physical-Endurant

GeoScienceObject

Type: **Class** PhysicalObject

A basic geoscientific object. Refers to any solid, oceanic or atmospheric physical body that is produced as a consequence of natural processes, rather than social or mental processes. It is disjoint with biological and chemical physical bodies. Examples include rock bodies, bodies of water, bodies of air, etc.

Connections

Connector	Source	Target
Generalization Source -> Destination	GeoScienceObject	PhysicalObject

GeoSciencePerdurant

Type: **Class** **Perdurant**

A perdurant with only GeoScienceEndurants as participants, i.e. a natural process or event.

Connections

Connector	Source	Target
Generalization Source -> Destination	GeoSciencePerdurant	Perdurant

Induction

Type: **Class** **Inference**

Finding patterns in data (logical induction), or dis/confirming a pattern via data collection (pragmatic induction). Here, in SKIo, induction is explicitly used in the first sense as a means of finding patterns in data, and implicitly used in the second sense via the verification activity which dis/confirms a scientific statement (relative to a fact) or finds that it in/coheres with other statements.

In logical induction: given data { (a1, b1), (a2, b2), (a3, b3) } then infer T (A, B), where T is some theoretical relation over concepts A, B, and ai and bi are their respective instances. In pragmatic induction: given T (A, B), note in newly observed data { (a1, b1), (a2, b2), (a3, b3) } and infer T (A, B) is TRUE (or FALSE if disconfirmed), or given a1 note in data { a1, a1, ... } and infer a1 = TRUE (or FALSE if disconfirmed). SKIo Induction refers to logical induction performed on Data where the induced T is an EmpiricalRegularity or ScienceLaw, while Verification encompasses pragmatic induction resulting in dis/confirmation of a science role. In addition to testing against data, Verification also encompasses testing for in/coherency of theoretical relations against each other.

Connections

Connector	Source	Target
Generalization Source -> Destination	Induction	Inference

Attributes

Attribute	Notes
product EmpiricalRegularity OR ScienceLaw	The product of an induction is a pattern recognized in empirical reality, i.e. amongst the values of qualities of endurants or perdurants.
performed-on Data [1..*]	The input to an induction is data (values of qualities of endurants or perdurants described in some way).

Inference

Type: **Class** **Activity**

A reasoning step performed by some rational agent as part of some plan. For our purposes this includes both sentient biological agents and machine agents. This assumes all inferences follow a plan, in the sense that they follow some prior strategy or pattern, rather than in the sense that they are predicted or predetermined. For example, a plan might be some rendition of the general scientific method in which the different inference types are used within specific stages--e.g. abduction is used for theory discovery, deduction for predictions about the world, and induction for prediction testing (Sowa, 2000).

There 3 basic types of inference, according to Sowa (<http://www.jfsowa.com/talks/souprepr.htm>):

1. Induction or learning:
Start with observations.
Look for commonalities.
Derive a theory that summarizes the data.
2. Deduction or inference:
Start with a theory.
Observe some new data.
Use the theory to deduce the implications.
3. Abduction or guessing:
Start with disconnected observations.
Guess (hypothesize) a theory that relates them.
Test the hypothesis by induction and deduction.

Connections

Connector	Source	Target
Generalization Source -> Destination	Inference	Activity
Generalization Source -> Destination	Deduction	Inference
Generalization Source -> Destination	Induction	Inference
Generalization Source -> Destination	Abduction	Inference

Attributes

Attribute	Notes
product InferredRole	The product of an inference is a specific scientific role.
performed-on Data OR ScienceRole [1..*]	Inferences have as inputs either data or specific scientific roles (propositions, hypotheses, etc.)

Information-Object

Type: **Class** Non-Agentive-Social-Object

InformationObject in DOLCE: "Information objects are social objects. They are realized by some entity. They are ordered (expressed according to) by some system for information encoding. Consequently, they are dependent from an encoding as well as from a concrete realization. They can express a description (the ontological equivalent of a meaning/conceptualization), can be about any entity, and can be interpreted by an agent. From a communication perspective, an information object can play the role of "message". From a semiotic perspective, it plays the role of "expression"

An expression of an idea (Description), produced by some agent, about any entity, with some physical manifestation (realized-by) in reality (Endurant).

Connections

Connector	Source	Target
Generalization Source -> Destination	ScienceStatement	Information-Object
Association Unspecified	expresses Description	expressed-by Information-Object
Generalization Source -> Destination	SciencePublication	Information-Object
Generalization Source -> Destination	Software	Information-Object
Generalization Source -> Destination	Information-Object	Non-Agentive-Social-Object
Generalization Source -> Destination	Dataset	Information-Object

Attributes

Attribute	Notes
part Information-Object [0..*]	Can have only other information objects as parts.
realized-by Physical-Realization [1..*]	The physical artefact that contains the statement. For digital statements (e.g. web pages, e-publication) this could refer to the machine hosting the statement. For papers it would refer to the physical journal publication.
ordered-by Description [1..*]	The method of encoding of the object--e.g. ascii, html, etc.

Non-Agentive-Social-Object

Type: **Class** **Endurant**

from DOLCE: "A social object that is not agentive in the sense of adopting a plan or being acted by some physical agent."

Connections

Connector	Source	Target
Generalization Source -> Destination	Concept	Non-Agentive-Social-Object
Generalization Source -> Destination	Situation	Non-Agentive-Social-Object
Generalization Source -> Destination	Information-Object	Non-Agentive-Social-Object
Generalization Source -> Destination	Non-Agentive-Social-Object	Endurant
Generalization Source -> Destination	Description	Non-Agentive-Social-Object

Attributes

Attribute	Notes
generically-dependent-on Physical-Endurant AND Communication-Event [2..*]	Refers to the agent(s) that conceptualized the endurant, and the communication event in which the conceptualization is expressed. E.g. the agent might be the authors of a science model or theory, and the event might be publication of the model. (e.g. a map could be a model).
part Non-Physical-Object [0..*]	Can have only non-physical-objects as parts.

Observation

Type: **Class** **Activity**

An observation or measurement activity that produces observed data. Implicit in this is the idea that only qualities of physical-endurants or perdurants can be observed, but this is relaxed such that the physical-endurants or perdurants can also be observed.

Connections

Connector	Source	Target
Generalization Source -> Destination	Observation	Activity

Attributes

Attribute	Notes
product ObservedData [1..*]	The product of an observation / measurement is Observed Data.
instrument ScienceInstrument [1..*]	The observing or measuring instrument.
performed-on Physical-Endurant OR Perdurant [0..*]	The physical endurant or perdurant that is being observed.

ObservedData

Type: **Class** **Data**

The product of an observation, which is typically some description of the observed values of some physical or temporal quality. It is internally represented by some observing agent, e.g. the scientist doing fieldwork, or the memory chip of a remote sensing unit. More specifically, observed data is the representation in some description of the values of physical qualities inherent in physical endurants or the value of temporal qualities inherent in perdurants. For flexibility, observed data can also be seen to describe the physical endurant or perdurant that exhibit those qualities.

Connections

Connector	Source	Target
Generalization Source -> Destination	ObservedData	Data

Attributes

Attribute	Notes
product-of Observation	The observation that produced the observed data.

Attribute	Notes
describes PhysicalEndurant OR Perdurant OR PhysicalQuality OR TemporalQuality	The physical or temporal quality whose values are being described by the observed data, or the physical endurant or perdurant exhibiting those qualities.
part ObservedData [0..*]	ObservedData can only have parts that are ObservedData.

Particular

Type: Class

A particular is an abstraction about single entities (see Masolo et al, 2003). There are 4 main subtypes in DOLCE: abstracts, qualities, endurants and perdurants.

Particulars can be prototype instances for some concept definition, and all prototypes (except science roles) can be discovered by scientific means, through inference or observation. Science roles are not discoverable, rather they are producible via scientific activity. Production (product-of) and discovery (discovered-by) are distinct here: production refers to activity by which some particular is created, whereas discovery refers to the activity by which some particular is realized to exist. For scientific roles, the two are equivalent, i.e. product-of = discovery-by, because the products of science are newly discovered knowledge elements. Hence, discovery is disallowed from science roles. Also, when a particular is a member of science model it is deducible from the science theory that is satisfied by the model.

Connections

Connector	Source	Target
<u>Generalization</u> Source -> Destination	Quality	Particular
<u>Generalization</u> Source -> Destination	Abstract	Particular
<u>Generalization</u> Source -> Destination	Perdurant	Particular
<u>Generalization</u> Source -> Destination	Endurant	Particular

Attributes

Attribute	Notes
prototype-for Definition [0..*]	A particular can be a prototypical example for some concept definitions.
discovered-by Data OR Fact OR InferredRole [0..*]	A relation between a particular and the observation or science role in which the particular is discovered, e.g. a rock body is discovered via observation (a Fact or Data) or via inference (Prediction, Proposition,...).
predictable-by Prediction [0..*]	A relation between a particular and some prediction from which particular (or its properties) can be deduced.

Perdurant

Type: **Class** **Particular**

See DOLCE (Masolo, et al., 2003, p. 11)--perdurants are not wholly present at any point in time, e.g. processes such as continental drift.

from DOLCE: "Perdurants (AKA occurrences) comprise what are variously called events, processes, phenomena, activities and states. They can have temporal parts or spatial parts. For instance, the first movement of (an execution of) a symphony is a temporal part of the symphony. On the other hand, the play performed by the left side of the orchestra is a spatial part. In both cases, these parts are occurrences themselves. We assume that objects cannot be parts of occurrences, but rather they participate in them. Perdurants extend in time by accumulating different temporal parts, so that, at any time they are present, they are only partially present, in the sense that some of their proper temporal parts (e.g., their previous or future phases) may be not present. E.g., the piece of paper you are reading now is wholly present, while some temporal parts of your reading are not present yet, or any more. Philosophers say that endurants are entities that are in time, while lacking temporal parts (so to speak, all their parts flow with them in time). Perdurants, on the contrary, are entities that happen in time, and can have temporal parts (all their parts are fixed in time)."

Connections

Connector	Source	Target
<u>Generalization</u> Source -> Destination	Event	Perdurant
<u>Generalization</u> Source -> Destination	Perdurant	Particular
<u>Generalization</u> Source -> Destination	GeoSciencePerdurant	Perdurant

Attributes

Attribute	Notes
part Perdurant [0..*]	Can have only perdurants as parts.
has_quality Temporal_Quality OR Temporal_Location_Q [1..*]	Must have one temporal quality.
participant Endurant [1..*]	Must have at least one endurant which participate in it.

Physical-Endurant

Type: **Class** **Endurant**

from DOLCE: "An endurant having a direct physical (at least spatial) quality."

Connections

Connector	Source	Target
<u>Generalization</u> Source -> Destination	GeoScienceEndurant	Physical-Endurant
<u>Generalization</u> Source -> Destination	Physical-Endurant	Endurant

Connector	Source	Target
Generalization Source -> Destination	PhysicalObject	Physical-Endurant

Attributes

Attribute	Notes
has-quality spatial-loction-q [1..*]	Must be located in physical space.
has_quality Physical-Quality [1..*]	

PhysicalObject

Type: **Class** Physical-Endurant

from DOLCE: "No easy definition of artifactual properties is possible, hence it is better to rely on alternative descriptions and roles: a physical object that shows or is known to have an artifactual origin that counts in the tasks an ontology is supposed to support, will be a material artifact. On the other hand, physical objects that do not show that origin, or that origin is unimportant for the task of the ontology, will be physical bodies. Formally, a restriction is provided here that requires that the collection whose members are (at least some of the) proper parts of a material artifact is *unified* by a plan or project.."

Connections

Connector	Source	Target
Generalization Source -> Destination	GeoScienceObject	PhysicalObject
Generalization Source -> Destination	SamplingInstrument	PhysicalObject
Generalization Source -> Destination	ScienceInstrument	PhysicalObject
Generalization Source -> Destination	PhysicalObject	Physical-Endurant

PredictionTesting

Type: **Class** Verification

Involves testing a prediction against a fact (data in the context of some theory). The result is a confirmation or disconfirmation of the prediction. This is achieved by adding a confirmed-by or disconfirmed-by relation to the prediction, one that has as range the relevant verification activity.

Connections

Connector	Source	Target
Generalization Source -> Destination	PredictionTesting	Verification

Attributes

Attribute	Notes
performed-on Fact AND Prediction	Prediction testing is performed on a fact and a prediction, and results in the dis/confirmation of the prediction

ProblemIdentification

Type: **Class** **Activity**

The activity of identifying a scientific problem. Scientific problems are identified when certain scientific statements are designated as being problematic--these are statements which are disconfirmed-by empirical facts or are found to be incoherent with other relevant theory. Generally speaking such disconfirmations and inconsistencies are produced by verification.

Connections

Connector	Source	Target
Generalization Source -> Destination	ProblemIdentification	Activity

Attributes

Attribute	Notes
product ScienceProblem	The product of the ProblemIdentification activity is a science problem.
performed-on ScienceRole [1..*]	The inputs to the activity are science roles--the activity identifies those roles which are disconfirmed by facts or incoherent with other inferred roles.

Quality

Type: **Class** **Particular**

A measurable or observable aspect of a concept. Often maps onto a variable in an equation.

A property that consists of one or more integral dimensions that form its quality space (Gardenfors, 2000; Masolo et al, 2003)

E.g. color, temperature, speed, thickness, size.

E.g. color has a quality space consisting of dimensions = {hue, saturation, brightness}, which can be modeled as qualities of the color quality.

from DOLCE: "Qualities can be seen as the basic entities we can perceive or measure: shapes, colors, sizes, sounds, smells, as well as weights, lengths, electrical charges... 'Quality' is often used as a synonymous of 'property', but this is not the case in this upper ontology: qualities are particulars, properties are universals. Qualities inhere to entities: every entity (including qualities themselves) comes with certain qualities, which exist as long as the entity exists."

Connections

Connector	Source	Target
Generalization Source -> Destination	Quality	Particular
Association Source -> Destination	q-location-of Quality	q-location Region

Connector	Source	Target

Attributes

Attribute	Notes
inherent-in Particular [1..*]	Qualities inhere-in (are dependent on) on the perdurant or endurant that they help characterize.

Region

Type: Class Abstract

from DOLCE: "We distinguish between a quality (e.g., the color of a specific rose), and its value (e.g., a particular shade of red). The latter is called quale, and describes the position of an individual quality within a certain conceptual space (called here quality space) Gardenfors (2000). So when we say that two roses have (exactly) the same color, we mean that their color qualities, which are distinct, have the same position in the color space, that is they have the same color quale."

A region is a position/subspace in a quality space.

Connections

Connector	Source	Target
Generalization Source -> Destination	Region	Abstract
Association Source -> Destination	q-location-of Quality	q-location Region

Attributes

Attribute	Notes
part Region [0..*]	Can have only regions as parts.

Research

Type: Class Activity

Refers here to a specific research activity, or a collection of activities, such as undertaken during a research project. Research produces descriptions (such as theories or data), information objects (such as databases or publications), or science models.

Connections

Connector	Source	Target
Generalization Source -> Destination	Research	Activity

Attributes

Attribute	Notes
product Description OR Information-Object OR ScienceModel [0..*]	The products of research are descriptions (data, theories, methods, etc.) or information-objects (datasets, publications, etc.)

Attribute	Notes
funded-by agentive-social-object [0..*]	Research activity can be funded by some agent (or agency).
performed-by agentive-social-object [0..*]	The agents performing the research.

Role

Type: **Class** **Concept**

from DOLCE "A concept that classifies (in particular, it is 'played by') endurants, as used in some description."

Connections

Connector	Source	Target
Generalization Source -> Destination	Role	Concept
Generalization Source -> Destination	Description-Role	Role
Generalization Source -> Destination	Sample	Role

Sample

Type: **Class** **Role**

A sample is a role played by a specimen of some enduring entity. Here we distinguish between the object denoting the sample, and the aspect of that entity that is the objective for the sampling: for example, if a rock is sampled for its color, then the rock is distinguished from its role as a sample vs a paperweight, and from its color quality that the objective of the sample. Thus, the Sample is played-by the rock, and it is a sample-of the Color of the rock.

Connections

Connector	Source	Target
Generalization Source -> Destination	Sample	Role

Attributes

Attribute	Notes
played-by Endurant [1..*]	The actual entity that is the sample--i.e. the actual piece of rock collected as a sample.
sample-of NOT Perdurant [1..*]	The aspect of the entity that is the objective for the sampling, e.g. the color of the rock that is sampled.
product-of Sampling [0..*]	The activity in which the sample was collected.
discovered-by [0]	Samples are not discovered, they are collected (i.e. they a product of a sampling activity).
identified-by Information-Object [0..*]	A sample often has a unique name, represented as an information object.

Sampling

Type: Class Activity
The activity of taking samples.

Connections

Connector	Source	Target
Generalization Source -> Destination	Sampling	Activity

Attributes

Attribute	Notes
product Sample [1..*]	Sampling produces samples.
instrument ScienceInstrument [1..*]	The scientific instrument that collects the samples.
performed-on Endurant [0..*]	The endurant which is being sampled, e.g. the outcrop from which a rock sample is taken.

SamplingInstrument

Type: Class PhysicalObject

Connections

Connector	Source	Target
Generalization Source -> Destination	SamplingInstrument	PhysicalObject

Attributes

Attribute	Notes
instrument-of Sampling [0..*]	

ScienceInstrument

Type: Class PhysicalObject
A physical instrument which is used to make a scientific observation or measurement.

Connections

Connector	Source	Target
Generalization Source -> Destination	ScienceInstrument	PhysicalObject

Attributes

Attribute	Notes
instrument-of Activity [0..*]	The observation, measurement, or other science activity.

ScienceModeling

Type: **Class** **Activity**

The general activity of producing science models, which are collections of particulars that satisfy science theories. Could include 'simulation' as a subtype. Because science models are collections of particulars in which each particular is discovered-by a fact or prediction, science modeling is the activity of configuring these particulars into a whole such that the whole satisfies some science theory.

In a logical sense satisfaction implies the presence of some interpretation (or denotation) function between a syntax + grammar and a model, but in a scientific sense satisfaction implies here that a particular in a model can be deduced from a theoretic role (proposition, regularity, law) that is part of the satisfying theory. For example, in the case of classification a particular passes a classification rule that places the particular in the extension for a concept. The classification rule can be based on similarity to examples, necc. & suff. conditions, or some other criteria. In SKI, the rule can be represented as a concept definition that plays the role of proposition, regularity or law within a theory, and the extension can be represented as a science model.

Connections

Connector	Source	Target
<u>Generalization</u> Source -> Destination	ScienceModeling	Activity

Attributes

Attribute	Notes
product ScienceModel	The product of science modeling is a science model which satisfies some science theories.

Verification

Type: **Class** **Activity**

The activity of testing scientific statements against Facts, or against other theoretic statements (InferredRoles). This activity could result in added properties to a tested statement, indicating the statement is dis/confirmed-by or rendered in/coherent-by the verification activity. Note that testing against Facts can implicitly equate to testing against models, inasmuch as the particular being described by the data playing the Fact can exist in models. Of the four types of verification listed below, only prediction testing is explicitly represented in SKI:

(1) Testing Fact vs Fact: involves checking whether observations are consistent. Implies one or both Facts can be dis/confirmed by the other.

(2) Testing Fact vs a role about individuals: involves Prediction testing, such that the Prediction can be dis/confirmed by the fact, or Proposition testing such that the Proposition can be dis/confirmed by the Fact. Note for Prediction testing this further implies the deduction components are possibly dis/confirmed by the Fact--i.e. the theoretical entity (Proposition, Regularity, ScienceLaw) and empirical entity (Fact, Prediction) from which the prediction is deduced are thus in question and one or both could be dis/confirmed by the Fact.

(3) Testing Fact vs theoretic role (Proposition, ScienceRegularity, or ScienceLaw): involves checking whether a Prediction can be deduced from the theory such that the Prediction is dis/confirmed by the Fact,

i.e. whether the Fact falls into the deductive closure of the theoretic role (i.e. theorem proving).

(4) Testing theoretic roles against each other: involves doing consistency checking for logical consistency. Another form of testing here is model-checking, where theoretic roles are consistent (coherent) if they satisfy the same models, which is similar to (3) in the sense that scientific satisfaction entails that the model component can be deduced from the theoretic role, but where the model component is not necessarily observed (i.e. is either observed (Fact) or inferred (Prediction, Proposition)).

Connections

Connector	Source	Target
Generalization Source -> Destination	PredictionTesting	Verification
Generalization Source -> Destination	Verification	Activity

Attributes

Attribute	Notes
performed-on ScienceRole [1..*]	

Assumption

Type: **Class** **ScienceRole**

A statement that is considered to be a primitive within a theory, i.e. it is declared via an assertion without empirical proof and without being necessarily inferred from some other element. To be maximally useful, assumptions should be accompanied by roles that describe the function of the statement within the theory, e.g. if a science law is assumed to be true it is likely advantageous to include the original science law role (which is inferred), to enhance overall explanation of the statement.

Connections

Connector	Source	Target
Generalization Source -> Destination	Assumption	ScienceRole

Attributes

Attribute	Notes
product-of Assertion	Assumptions are produced by assertion, not inference or observation.

Dataset

Type: **Class** **Information-Object**

The physical expression (encoding) of a collection of data. The same data could be encoded using different physical expressions--i.e. there could be syntactic or structural differences (but not semantic differences).

Connections

Connector	Source	Target
Generalization Source -> Destination	Dataset	Information-Object

Attributes

Attribute	Notes
product-of Activity	
expresses Data [1..*]	

Definition

Type: **Class** **Description**

The definition of a concept in some description, such as in a science theory. May include reference to other concepts (e.g. to define necessary or sufficient condition) and/or prototypical instances.

Connections

Connector	Source	Target
Generalization Source -> Destination	Definition	Description

Attributes

Attribute	Notes
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Attribute	Notes
defines Concept	The concept that is being defined.
prototype Particular [0..*]	The prototypical instances of the concept being defined.

Description

Type: **Class** Non-Agentive-Social-Object

Analogous to "Idea" in Hars (2003).

"A description is a social object which represents a conceptualization (e.g. a mental object or state), hence it is generically dependent on some agent and communicable. Descriptions define or use concepts or figures, are expressed by an information object and can be satisfied by situations. The typology of descriptions is still preliminary." (DOLCE 397

"A description is an entity that partly represents a (possibly formalized) theory T (or one of its elements) that can be "conceived" by an agent: either human, collective, social, or artificial. ... Examples: a diagnosis, a climate change theory, etc." (Gangemi & Mika, 2003)

"Descriptions and concepts are two (disjoint) sub-classes of DOLCE's category of nonagentive social objects." (Masolo, et al, 2004)

Descriptions use concepts (d-uses) in their body.

Connections

Connector	Source	Target
<u>Association</u> Unspecified	expresses Description	expressed-by Information-Object
<u>Generalization</u> Source -> Destination	Definition	Description
<u>Generalization</u> Source -> Destination	Data	Description
<u>Association</u> Source -> Destination	satisfied-by Situation	satisfies Description
<u>Generalization</u> Source -> Destination	Method	Description
<u>Generalization</u> Source -> Destination	Theory	Description
<u>Generalization</u> Source -> Destination	Description	Non-Agentive-Social-Object

Attributes

Attribute	Notes
d-uses Concept [1..*]	Refers to the concepts used in the description.
internally-represented-in Agentive-Physical-Object [1..*]	Refers to the agent that conceptualized the description, e.g. the author of the paper.

EmpiricalRegularity

Type: Class InferredRole

An empirical pattern that is produced by induction, but which is valid only for a subset of the possible entities that could satisfy it; i.e. it is a correlation that holds locally amongst some empirical entities, but does not necessarily hold universally for all the empirical entities to which the regularity might apply. If the regularity is expressed as a relation amongst concepts, then the relation is present only amongst some situations in which instances of the concepts are jointly present, and not in all situations where the concept instances are jointly present. This is formalized by the notion that the existence of the regularity is dependent on specific instances, but not all valid instances. It might not hold universally because of insufficient confirmation (i.e. confirmed only in a few situations), or because the pattern can only occur in a local situation (specific space-time region) because it is an artifact of a particular historical process.

Connections

Connector	Source	Target
<u>Generalization</u> Source -> Destination	EmpiricalRegularity	InferredRole

Attributes

Attribute	Notes
product-of Induction	The induction which generated the regularity.
confirmed-by Verification [1..*]	States that regularities are empirically tested conjectures, i.e. have been verified.
existentially-dependent-on Endurant OR Perdurant [1..*]	States the regularity is only valid among some but not all instances in which it could possibly be valid, e.g. if the regularity is stated as a relation between concepts, then the regularity is present in some but not all situations where the concept instances are jointly present. This is formalized here by stating the regularity's existence is dependent on specific instances of its constituent concepts (and not others).

Fact

Type: Class ScienceRole

Facts are roles played by data as part of some science theory. In this case facts are always "theory-laden" in the sense that they are intrinsically part of some theory. In terms of basic characterization, facts are an empirical statement supported by observed data, i.e. a statement about the real world that has been verified scientifically via observation. They are often considered to refer to a single enduring or perdurant (Hars 2003), but this restriction is not formalized here. The discovery relation in a fact refers to a particular that is discovered as a result of this fact, e.g. the value of a quality of an enduring (rock, water body, etc.) or the enduring that is itself identified in the observation.

Connections

Connector	Source	Target
Generalization Source -> Destination	Fact	ScienceRole

Attributes

Attribute	Notes
played-by Data	The data which is playing the role of a fact in a theory.
verified-by Verification [0..*]	Denotes the science roles that are confirmed (empirically supported, consistent with) the data playing the fact.
discovery particular [0..*]	The particular that is discovered (identified, observed) by this data.

GeoScienceModel

Type: **Class** ScienceModel

A geoscience model is a collection of geoscience particulars that satisfy a geoscience theory. Geoscience particulars include geoscience physical bodies, amounts of matter, features that host geoscience bodies, and perdurants in which geoscience bodies participate.

Connections

Connector	Source	Target
Generalization Source -> Destination	GeoScienceModel	ScienceModel

Attributes

Attribute	Notes
satisfies GeoScienceTheory [1..*]	The geoscience science theories that satisfy the model, i.e. each geoscience particular in the model can be deduced from a part of each of the theories that it satisfies.
setting-for GeoScienceEndurant OR GeoSciencePerdurant [1..*]	The geoscience entities that are part of the model.

GeoScienceTheory

Type: **Class** ScienceTheory

A science theory that is satisfied only by a geoscience model.

Connections

Connector	Source	Target
Generalization Source -> Destination	GeoScienceTheory	ScienceTheory

Attributes

Attribute	Notes
satisfied-by GeoScienceModel [0..*]	The geoscience models that are satisfied by the geoscience theory, i.e. the collection of geoscience particulars (instances) that can be deduced from the parts of the geoscience theory.

InferredRole

Type: **Class** **ScienceRole**

A science role that is produced via an inference instead of asserted or observed. The discovery relation refers to a particular that is discovered as a result of this inference, e.g. a specific rock body or process that is discovered as a result of the inference.

Connections

Connector	Source	Target
<u>Generalization</u> Source -> Destination	Proposition	InferredRole
<u>Generalization</u> Source -> Destination	EmpiricalRegularity	InferredRole
<u>Generalization</u> Source -> Destination	ScienceLaw	InferredRole
<u>Generalization</u> Source -> Destination	Prediction	InferredRole
<u>Generalization</u> Source -> Destination	InferredRole	ScienceRole

Attributes

Attribute	Notes
product-of Inference	The inference that produced the role.
verified-by Verification [0..*]	The activity in which the role is verified, i.e. in which it is dis/confirmed against facts or found to be in/coherent with other inferred roles.
discovery particular [0..*]	The particular that is discovered by the inference.

Method

Type: **Class** **Description**

from DOLCE: "A description that contains a specification to do, realize, behave, etc. Subclasses are plan, technique, practice, project, etc."

Could be a scientific method, technique, etc.

Connections

Connector	Source	Target
<u>Generalization</u> Source -> Destination	Method	Description

Prediction

Type: **Class** InferredRole

A testable conjecture about observable entities (perdurants and endurants, and their qualities), that is the product of a deduction (Sowa, 2000). It can be empirically tested and must be logically consistent, or coherent, with some existing theory or theories (after Hars, 2003), which are usually used to originally deduce the prediction.

Connections

Connector	Source	Target
Generalization Source -> Destination	Prediction	InferredRole

Attributes

Attribute	Notes
product-of Deduction	The deduction from which the prediction is inferred.
predictable Particular [0..*]	The particulars that satisfy this prediction.

Proposition

Type: **Class** InferredRole

A conjecture generated from an inference by abduction (Sowa, 2000), which is not necessarily empirically verified, and from which verifiable hypotheses can be generated (Hars, 2003).

Propositions may contain any concepts. Propositions may not be empirically proven, but should be logically consistent, or coherent, with existing relevant theories. Propositions might be valid locally or universally; i.e. they may or may not be situated, that is, dependent on specific endurants or perdurants.

Scientific propositions are analogous to logical propositions in the following way: scientific propositions are eventually verifiable (are testable against the world) while logical propositions are eventually resolvable to True or False (are testable against a logical system).

Connections

Connector	Source	Target
Generalization Source -> Destination	Proposition	InferredRole

Attributes

Attribute	Notes
product-of Abduction	The Abduction from which the proposition is inferred.
existentially-dependent-on Endurant OR Perduant [0..*]	Propositions might be valid locally or universally; i.e. they may or may not be situated, that is, dependent on specific endurants or perdurants.

ScienceLaw

Type: Class InferredRole

An empirical pattern that is highly confirmed by many observations and that is universal. It relates concepts whose instances are observable. (after Hars, 2003; Shrager and Langley, 1990). The pattern is often stated as a relation amongst concepts. This relation holds globally for objects at a certain granularity, such that the relation is always present when the instances of its concepts are present. This universality is formalized here via negation: the existence of a science law is not dependent on any specific observable entities.

Connections

Connector	Source	Target
<u>Generalization</u> Source -> Destination	ScienceLaw	InferredRole

Attributes

Attribute	Notes
product-of Induction	The induction by which the science law is inferred.
confirmed-by Verification [1..*]	States that science laws are empirically tested conjectures, i.e. have been highly verified.
existentially-dependent-on NOT Endurant OR Perdurant	States that a science law is valid among all instances in which it could possibly be valid, e.g. if the regularity is stated as a relation between concepts, then the regularity is present in all situations where the concept instances are jointly present. This is formalized via negation: the science law's existence does NOT depend on any specific instances of its constituent concepts.

ScienceModel

Type: Class Situation

A collection of particulars (instances) that are satisfied by a science theory, where each particular is discovered by a Fact, Prediction or Proposition, and is deducible (can be the result) from a Prediction that uses the science theory that is satisfied by the model. The science model itself is produced by a scientific modeling activity.

In a logical sense satisfaction implies the presence of some interpretation (or denotation) function between a syntax + grammar and a model, but in a scientific sense satisfaction implies here that a particular in a model can be deduced from a theoretic role (proposition, regularity, law) that is part of the satisfying theory. For example, in the case of classification a particular passes a classification rule (theoretic role) associated a concept, which places the particular in the extension (model) for the concept. The classification rule can be based on similarity to examples, necc. & suff. conditions, or some other criteria. In SKI, the rule can be associated with the concept as a concept definition that plays the role of proposition, regularity or law within a theory.

For a quick survey see 'Models in Science': <http://plato.stanford.edu/entries/models-science/>. There, models in science have 2 roles which can overlap: (a) representing some aspect of reality, or its data, or

(b) instantiating (satisfying) a theory. Lee (1999) also looks at types of models.

The spirit of (b) is adopted here (as per DOLCE): a model is a collection of instances, which satisfy one or more theories. This is also totally consistent with (a) since a theory in most cases only predicts some aspects of reality and cannot make statements about others. It is also consistent with (a) because in DOLCE a model is a representation of reality.

Some implications:

- a 'mathematical model'--a set of a related equations--is a theory.
- a mathematical equation is a statement within a theory (a part of a mathematical theory).
- the set of data which satisfies the mathematical theory is a model
- a physical model of the world (e.g. made with Lego) is a model which satisfies some theory (i.e. an architectural philosophy or movement (art deco?))
- in a computer simulation of physical reality: the configuration of physical entities constitute the model, the code, types and rules that govern entity behavior are its theory.
- the geospatial objects on a map are a model, and the legend consisting of class definitions is a theory (Brodaric & Hastings, 2002)

Some similar views:

Sowa (2000): a model in Logic consists of a collection of entities in a 'world' as well as a denotation function that maps those entities to terms in logical statements such that the statements evaluate to TRUE--the collection of statements form a theory. The model is extensional, representing the world, and the theory is intensional, representing abstractions about the world. (a model instantiates a theory)

Shrager & Langley (1990): "a model is required to indicate the manner in which a law or theory applies to a particular situation". (a model instantiates a theory).

Connections

Connector	Source	Target
Generalization Source -> Destination	ScienceModel	Situation
Generalization Source -> Destination	GeoScienceModel	ScienceModel

Attributes

Attribute	Notes
product-of ScienceModeling	The modeling activity that produced the model. Could be a manual activity or a computer-driven activity such as a simulation.
satisfies ScienceTheory [1..*]	The science theories that satisfy the model, i.e. each particular in the model can be deduced from a part of each of the theories that it satisfies.
setting-for (discovered-by Fact OR Prediction OR Proposition) AND (predictable-by Prediction) [1..*]	Each particular in a science model is discovered by a Fact, Prediction, or Proposition, and can be predicted by a Prediction involving a theory which satisfies the model.

ScienceProblem

Type: Class ScienceRole

A problem statement---any science statement whose truth value is being questioned (Hars, 2003, p.169),

because of disconfirming facts or because it is incoherent with inferred statements. This is formalized here by the requirement that statements have a 'problem-in' facts that are 'disconfirmed-by' other facts, or are incoherent with other inferred statements. A science problem signals the need for a revision of a theory or fact, such that the disconfirmations or incoherencies are resolved. Note that the notion of disconfirmation and incoherence also takes into account the inconsistency between theories and models:

- (1) theory: the science role that is being disconfirmed is a theory part;
- (2) model: the fact responsible for the disconfirmation can represent data about an observed particular that can exist in models; or the prediction responsible for the inconsistency can refer to a hypothetical particular that can exist in models.

Connections

Connector	Source	Target
Generalization Source -> Destination	ScienceProblem	ScienceRole

Attributes

Attribute	Notes
product-of ProblemIdentification	The activity by which the science problem is identified.
problem-in Fact OR InferredRole [1..*]	The facts or inferred roles disconfirmed against facts, or inconsistent with theory, as a result of a verification activity.

SciencePublication

Type: **Class Information-Object**

The entity in which statements are published. Publication refers loosely to any entity that is accessible and that hosts science statements. Contains only a representative suite of properties, as this is just a placeholder for a more extensive metadata schema--this is also why the properties are all strings rather than Objects (e.g. authored-by could have as range Agent rather than string).

Connections

Connector	Source	Target
Generalization Source -> Destination	SciencePublication	Information-Object

Attributes

Attribute	Notes
product-of Activity	The activity that produced the publication.
authored-by char	The authors of the publication.
titled-by char	The title.
published-by char	The publisher.
published-during dateTime	The date of publication.
web-located-at char	Web location of the publication.

Attribute	Notes
part ScienceStatement [0..*]	Refers to the statements that comprise the publication.

ScienceRole

Type: **Class** Description-Role

The functional role played by a theory or its part. e.g. some theory might assume a statement (Assumption), others might target the statement as a problem (ScienceProblem), and others might not believe it to be only locally applicable (Empirical Regularity), while in others its considered a science law and universally applicable.

A statement can play different roles in different theories, and can evolve to play different roles in time within a single theory. For example, a statement that is an empirical regularity could evolve to a law with more verification, and any statement could play the role of a science problem if disconfirmed via facts or shown to be logically inconsistent with some theory part. Also, science roles cannot be discovered independent of being produced, because the products of science are newly discovered knowledge elements; hence 'discovered-by' is not allowable for science roles, while its inverse of 'discovery' is allowed because it refers to the particulars that are discovered as a result of the scientific statement.

Science roles are related in two ways to a theory: (1) as a role played by a whole theory (or some other description) or by its part, or (2) as a component of a whole theory. The first involves role-playing while the second involves a whole-part relation. Thus a science role can be played-by by certain theories or its parts, or it can be part of certain theories.

Connections

Connector	Source	Target
Generalization Source -> Destination	Assumption	ScienceRole
Generalization Source -> Destination	ScienceRole	Description-Role
Generalization Source -> Destination	ScienceProblem	ScienceRole
Association Unspecified	component ScienceRole	component-of ScienceTheory
Generalization Source -> Destination	Fact	ScienceRole
Generalization Source -> Destination	InferredRole	ScienceRole

Attributes

Attribute	Notes
played-by Description	The description that is being played-by this role. Roles can be played-by theories, methods, definitions, or other descriptions, allowing flexibility in the composition of a science theory.

Attribute	Notes
discovered-by [0]	Specifies that science roles cannot use the discovered-by relation, in order to avoid circularity, because the notion of discovery of science roles is captured in the product-of relation--i.e. for science roles their production is equivalent to their discovery, which is not the case for non-science roles; for example, a geoscientific entity is produced by a natural process but discovered to exist by a scientist at some time point.

ScienceStatement

Type: **Class** **Information-Object**

Scientific statements express a scientific idea as a relation amongst scientific knowledge elements (after Hars, 2003, p 144) in some real scientific artefact such as a paper, report, map, etc.

Connections

Connector	Source	Target
Generalization Source -> Destination	ScienceStatement	Information-Object

Attributes

Attribute	Notes
body char	The body of the statement expressed in text.
part-of SciencePublication	The publication that contains the statement. Publication is used loosely to mean any accessible document.

ScienceTheory

Type: **Class** **Theory**

In general, a theory is a collection of coherent (broadly self-consistent) scientific statements that describe the structure or behavior of some aspect of reality in sufficient generality such as to be applied in a wide number of real-world instances or models (after Hars, 2003). See notes on 'ScienceModel' for more about models and theories.

Specifically, a science theory, or part of a theory, is here an entity satisfied only by a science model. A science theory can then refer to a whole theory (the container) or to any of its parts. The functional role the part plays in the theory is specified by its ScienceRole. A theory (container) also keeps track of all of the science roles played by itself and its parts, via the component relation. The scientific discovery of the whole theory or a part is usually specified in the role, via the product-of relation, but could equivalently be specified by the discovered-by relation. It is possible then for the theory to play a science role, which can specify how the role and thus theory is produced, and for the theory to be discovered-by the same science role—in both cases the net effect is to specify how the theory comes to be.

Connections

Connector	Source	Target
Generalization Source -> Destination	ScienceTheory	Theory
Association Unspecified	component ScienceRole	component-of ScienceTheory

Connector	Source	Target
Generalization Source -> Destination	GeoScienceTheory	ScienceTheory

Attributes

Attribute	Notes
part Description [0..*]	One or more theory parts, which must be descriptions, e.g. methods, theories, definitions, etc.
part-of Description [0..*]	The science theory of which this theoretical element is a part.
satisfied-by ScienceModel [0..*]	The models that satisfy the theory-i.e. the collection of particulars (instances) that can be deduced from the parts of the theory.
plays ScienceRole [0..*]	The functional roles played by the theoretical statement in one or more theories.
component Concept [0..*]	An index of the concepts that are components of the theory.

Situation

Type: **Class** Non-Agentive-Social-Object

from DOLCE: "A situation is a social object that appears in the domain of an ontology only because there is a description whose components can 'carve up' a view (setting) on that domain. A situation has to satisfy a description..."

Connections

Connector	Source	Target
Generalization Source -> Destination	ScienceModel	Situation
Generalization Source -> Destination	Situation	Non-Agentive-Social-Object
Association Source -> Destination	satisfied-by Situation	satisfies Description

Attributes

Attribute	Notes
setting-for particular [1..*]	

Software

Type: **Class** Information-Object

The physical expression (encoding) of some method, which can be executed by a computing device

Connections

Connector	Source	Target
Generalization Source -> Destination	Software	Information-Object

Attributes

Attribute	Notes
product-of Activity	The activity in which the software code was produced.
expresses Method [1..*]	The abstract method which is expressed by the software code.

Theory

Type: **Class** **Description**

from DOLCE: "This is used in a wide cultural sense: a theory about something, expressed in a rather systematic way, but not necessarily public (although communicable in principle). An axiomatic theory is not a theory in this sense, although we can expect an axiomatic theory to be the formal representation of a generic theory."

Connections

Connector	Source	Target
<u>Generalization</u> Source -> Destination	ScienceTheory	Theory
<u>Generalization</u> Source -> Destination	Theory	Description