JOWO 2018
The Joint Ontology Workshops

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Edited by

Ludger Jansen | Daniele P. Radicioni | Dagmar Gromann

and for

BOG | CAOS-CEX | EPINON II | Onto.Com | Ontology of Economics | FOIS Early-Career Symposium | Tutorials

http://www.iaoa.org/jowo2018/

JOWO Workshops

Giancarlo Guizzardi, Oliver Kutz, Rafael Peñaloza, Nicolas Troquard **(BOG)**

Maria M. Hedblom, Tarek R. Besold, Oliver Kutz **(CAOS-CEX)**

Daniele Porello, Claudio Masolo, Simon Scheider **(EPINON II)**

Sergio de Cesare, Frederik Gailly, Giancarlo Guizzardi, Mark Lycett, Chris Partridge, Oscar Pastor **(Onto.Com)**

Daniele Porello, Nicola Guarino, Giancarlo Guizzardi **(Ontology of Economics)**

Other FOIS Satellite Events

Maria M. Hedblom, Emilio Sanfilippo, Zubeida Khan **(Early-Career Symposium)**

Mike Bennett **(Conceptual Ontology Engineering Tutorial)**

David Toman, Grant Weddell **(Referring Expressions in Ontologies and Query Answering Tutorial)**

PREFACE

JOWO – The Joint Ontology Workshops

These proceedings include the papers presented at JOWO 2018, the Joint Ontology Workshops, together with papers from satellite events of the 10th International Conference on Formal Ontology and Information Systems (FOIS 2018) in Cape Town, with which it was collocated. JOWO 2018 was the fourth edition of the 'Joint Ontology Workshops', which comprised a confederation of five ontology workshops and an early career symposium. Previous editions of the JOWO series have been:

- The first JOWO edition was 'Episode 1: The Argentine Winter of Ontology', held in Buenos Aires, Argentina, in co-location with the 24th International Joint Conference on Artificial Intelligence (IJCAI 2015). The proceedings of JOWO 2015 appeared as volume 1517 of CEUR.[1]
- The second JOWO edition was 'Episode 2: The French Summer of Ontology', held in Annecy, France, in co-location with the 9th International Conference on Formal Ontology in Information Systems (FOIS 2016). The proceedings of JOWO 2016 appeared as volume 1660 of CEUR.[2].
- The third JOWO edition was 'Episode 3: The Tyrolean Autumn', hosted by the Free University of Bozen-Bolzano in Bolzano, Italy, from September 21–23, 2017. The proceedings of JOWO 2017 appeared as volume 2050 of CEUR.[3].

JOWO's mission is to provide a platform for the diverse communities interested in building, reasoning with, and applying formalised ontologies in the wide spectrum of Information Systems, Artificial Intelligence, Philosophy, Linguistics and Cognitive Science, both in theory and applications.

The 2018 edition of JOWO served as a platform for satellite events for FOIS 2018. It collocated workshops that cover a broad spectrum of contemporary applied ontology research, including its methodological foundations and quality evaluation (BOG), the application of ontologies in particular domains, such as economics (Ontology of Economics) or conceptual modeling (Onto.Com), the role of ontology in related research areas like cognition (CAOS-CEX), and the epistemological stance in formal ontology (EPINON II). A total of twenty-five papers were submitted to the workshops of which fifteen were accepted.

These proceedings document five JOWO 2018 workshops, the FOIS Early Career Symposium, and two FOIS tutorials, which will be described in more detail on the following pages:

[1] See http://ceur-ws.org/Vol-1517/.
[2] See http://ceur-ws.org/Vol-1660/
[3] See http://ceur-ws.org/Vol-2050/.

- **BOG** International Workshop on BadOntoloGy[4]
- **CAOS-CEX** International Workshop on Cognition and Ontologies & Comprehensibility and Explanation in AI and ML[5]
- **EPINON II** 2nd International Workshop on Epistemology in Ontologies[6]
- **Onto.Com** 6th Int. Workshop on Ontologies and Conceptual Modelling[7]
- **Ontology of Economics** International Workshop on Ontology of Economics[8]
- **Early Career** The Early Career Symposium[9]
- **Conceptual Ontology Engineering** Tutorial on Conceptual Ontology Engineering[10]
- **Referring Expressions in Ontologies and Query Answering** Tutorial on Referring Expressions in Ontologies and Query Answering[11]

Acknowledgements

We would like to thank all authors and speakers for their contributions, and the programme committee members and additional reviewers for their timely reviewing. Moreover, we would like to thank the local FOIS organiser, Maria C. Keets, and her team, for taking care of running the event smoothly in Cape Town, and the International Association for Ontology and its Applications (IAOA)[12], for providing generous financial support and facilities.

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[4] See http://bog.inf.unibz.it/.
[5] See http://caos.inf.unibz.it/.
[6] See http://www.loa.istc.cnr.it/workshops/epinon2018/home.html.
[7] See http://www.mis.ugent.be/ontocom2018/.
[8] See https://oe.inf.unibz.it/.
[9] See http://fois2018.cs.uct.ac.za/?page_id=236.
[10] See http://www.iaoa.org/jowo2018/?page_id=108.
[11] See http://www.iaoa.org/jowo2018/?page_id=83.
[12] See http://iaoa.org.

JOWO 2018 Workshops

BOG 2018

International Workshop on Bad OntoloGy

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Amanda Vizedom	Crédit Suisse, USA

As ontologies are adopted by new practitioners and as they grow in size, bad ontologies become an increasingly common reality. Bad ontologies may be inconsistent, have unwanted consequences, be ridden with anti-patterns. In general, bad ontologies present design mistakes that make their use and maintenance problematic or impossible.
Programming engineers have had access for some time to debuggers to help identify unwanted results and linters to identify stylistic errors and suspicious constructs. Ontology practitioners also need similar tools to aid them correcting bad ontologies. Researchers in ontology engineering have actively been working on engineering methods to assist in the repair of erroneous ontologies: diagnostic, explanation, anti-pattern detection, etc. The workshop welcomed original contri-

butions about all topics related to bad ontologies, including the cataloguing of ontology symptoms, symptoms detection, ontology quality measures, diagnostic methods to explain the symptoms, principled methods for building bad ontologies, or benchmarks of bad ontologies for evaluating repairing methods.
The workshop accepted two submissions. In *The Role of Foundational Ontologies for Preventing Bad Ontology Design*, Stefan Schulz reports on a method to use upper-level domain ontologies and Description Logic classifiers for the detection of modelling mistakes. Several prototypical and generalisable modelling mistakes are used to demonstrate the method. In *Applying evaluation criteria to ontology modules*, Zubeida Casmod Khan presents a set of evaluation criteria for ontology modules. They are all structured into categories and illustrated through a series of examples. The evaluation criteria are then used to experimentally evaluate the modules automatically generated by a modularisation tool.

CAOS-CEX 2018

Third International Workshop on Cognition and Ontologies &
Workshop on Comprehensibility and Explanation in AI and ML (CAOS-CEX)

Programme Chairs

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Tarek R. Besold	City University London, UK
Oliver Kutz	Free University of Bozen-Bolzano, Italy

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CAOS is a workshop devoted to bringing together research findings from areas in cognitive science with research on formal ontology. The workshop addresses the difficult question of how key cognitive phenomena and concepts (and the involved terminology) can be found across languages, psychology and reasoning and how this can be formally and ontologically understood, analysed and represented. The workshop devotes itself to investigations to model, simulate and represent a range of cognitive abilities, with the further aim to contribute with these findings to cognitive artificial intelligence.

This includes formal modeling of cognitive building blocks such as affordances and image schemas, the relationship between thought, language and representation, the formal simulation of cognitive abilities such as language acquisition and concept invention as well as formal modeling of socio-cognitive behaviors.
This year, CAOS runs its third edition and is joined by the workshop "Comprehensibility and Explanation in AI and ML" (CEX) which focuses on largely overlapping topics but from a more applied direction. The workshop gathered three papers of relevant topics for the research field: In "Ontology Of Social Service Needs: Perspective of a Cognitive Agent" Bart Gajderowicz, Mark Fox and Michael Gruninger introduce the first ontology of social services from a client's perspective; In "Modelling Affordances with Dispositions" Fumiaki Toyoshima investigates the formal realisation of affordances by comparing them to the state of the art in ontology representation, and Antony Galton contributes to the mereological debate of part-whole relationships in "Yet Another Taxonomy of Part-Whole Relations". We particularly thank our invited keynote speaker Alessandro Oltramari for his contribution to the success of the workshop.

EPINON II 2018

Second International Workshop on Epistemology in Ontologies (EPINON II)

Programme Chairs

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Claudio Masolo	Institute of Cognitive Sciences and Technologies (ISTC-CNR), Trento, Italy
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Programme Committee

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Laure Vieu	Institut de Recherche en Informatique de Toulouse (IRIT-CNRS), France

Formal ontologies and knowledge representation mainly focus on characterising how a given domain is structured, i.e., they identify a set of concepts, entities, and relations together with the constraints that hold for this domain. The structure of the characterisation is usually intended to reflect the point of view of significant experts or a realist view of how things about a particular domain are in reality.

The aim of this workshop is to explore an epistemological stance in formal ontology and knowledge representation and focus on the assessment of the modelling provided by the ontology designer. In particular, we are interested in fostering two intertwined research directions. Firstly, we are interested in promoting discussions about the epistemological foundations of formal ontologies and of knowledge representation. A number of timely important problems are related to this point, for instance: the investigations of cognitively adequate ontological representations, the investigations on the provenance of data, the problem of the reliability of the source of information (both human and artificial, e.g. sensors), the problem of the epistemic reliability of the classification provided by ontology users, the problem of finding epistemically and cognitively well-founded rationales for the integration of ontological representations with other representational formats (e.g. deep neural networks, vector space models etc.). Secondly, we are interested in formal and ontological approaches to the definitions of the concepts that are relevant to the assessment of the perspective of the ontology designer. Problems related to this direction include: ontology of general epistemological concepts (e.g. proof, argument, explanation, epistemic reliability, trust), ontology of cognitive concepts (perception, reasoning, sensations), ontology of data and measurements.
We aim to address to an interdisciplinary audience, by inviting scholars in philosophy, computer science, logic, conceptual modelling, knowledge representation, and cognitive science to contribute to the discussion.

Onto.Com 2018

Sixth International Workshop on Ontologies and Conceptual Modeling

Programme Chairs

Frederik Gailly	Ghent University, Belgium
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Mark Lycett	Royal Holloway, University of London, UK
Chris Partridge	BORO Solutions Ltd., UK
Oscar Pastor	Universitat Politecnica de Valencia, Spain, Spain
Sergio de Cesare	University of Westminster, UK

Programme Committee

Frederik Gailly	Ghent University, Belgium
Giancarlo Guizzardi	Federal University of Espirito Santo, Brazil
Mark Lycett	Royal Holloway, University of London, UK
Chris Partridge	BORO Solutions Ltd., UK
Oscar Pastor	Universitat Politecnica de Valencia, Spain, Spain
Sergio de Cesare	University of Westminster, UK

The role of formal ontology in Conceptual Modeling (CM) is increasingly being recognized as fundamental by both the research and practitioner communities.

Formal ontology, whose theoretical underpinnings are grounded in disciplines such as Philosophy, Cognitive Sciences and Linguistics, has led to the development of theoretical foundations for conceptual modeling. In particular, a number of ontological theories such as BORO, BWW, DOLCE, GFO and UFO have been successfully applied to the evaluation of conceptual modeling languages, frameworks and standards (e.g., UML, ORM, ER, REA, TROPOS, ARIS, BPMN, RM-ODP, Archimate, OWL and ISO 15926), and to the development of information systems engineering tools (e.g., methodological guidelines, modeling profiles, design patterns) that contribute to the theory and practice of conceptual modeling.
The objective of the OntoCom Workshop is to provide an international forum for exchanging ideas on the latest developments in the emerging area of Ontology-Driven Conceptual Modeling and to address specific questions of relevance to the body of knowledge of this emerging discipline.
The workshop received 7 submissions, from which the Program Chairs selected 6 high quality papers. The 18th of September 2018 the 6 papers will be presented in two separate sessions. The first session will focus on the metaphysical characteristics of some well-known foundational ontologies. The second session will focus on the application of ontology-driven conceptual modeling. We would like to express our gratitude to the authors for considering OntoCom as a forum to publish their research and the FOIS 2018 organizers for all their support.

Ontology of Economics 2018

First International Workshop on Ontology of Economics

Programme Chairs

Daniele Porello	Free University of Bozen-Bolzano, Italy
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Giancarlo Guizzardi	Free University of Bozen-Bolzano, Italy

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Understanding the ontological nature of economic concepts and institutions is crucial for providing principled modelling in many important domains such as enterprise modelling, business processes, and social ontology. A significant number of fundamental concepts that are ubiquitous in economics have only recently been approached from an ontological perspective.

For instance: value, risk, preference, utility, capability, good, service, exchange, transaction, competition. We offer a venue to gather the recent contributions to this important topic. We propose contributions from different areas such as (philosophy of) economics, decision theory, social choice theory, business, finance, accounting, economic sociology, and enterprise modelling, to promote the discussion on the ontological foundation of fundamental concepts in economics.

We aim to foster the discussion on both theoretical and methodological issues in the use of ontologies for modelling economic concepts and institutions, as well as the approaches presenting concrete use of ontologies in application to economic domains.

Other FOIS 2018 Satellite Events

FOIS 2018 Early Career Symposium

Programme Chairs

Maria M. Hedblom	Free University of Bozen-Bolzano, Italy
Emilio Sanfilippo	French National Center for Scientific Research (CNRS), France
Zubeida Khan	Council for Scientific and Industrial Research (CSIR), South Africa

For any conference, the Early Career Symposium (ECS) represents the investment done by the current generation of researchers into the future generations of the field. Arguably, while established researchers contribute to strengthen the fundamentals of the research field, it is often the young generation that provides innovation and groundbreaking ideas. In order to foster the state of art in ontology research, the ECS at FOIS welcomes early stage researchers working on innovative and novel research topics for presentation at the conference. The symposium encourages mentorship among established and emerging researchers towards constructive discussions surrounding novel research. As the future remains unwritten, the ECS accepts a wide variety of research topics focused on ontologies and knowledge representation. In particular, because of its contextualization within FOIS, it welcomes research addressed in an interdisciplinary way with an open-minded aptitude towards philosophical ontology, cognitive science, and linguistics. We wish to thank the PC members for their constructive feedback.

Tutorial on Conceptual Ontology Engineering

Organiser

Mike Bennett	Hypercube Limited, UK & EDM Council, UK

Conceptual modeling as defined within the discipline of software development is the exercise of creating computationally independent model artifacts against which to develop and validate logical and physical model design artifacts. The art of conceptual modeling is one that requires a clear understanding of the notion of a concept and an appreciation of the nature of concepts as distinct from words, labels or database element names. One powerful type of conceptual model is the 'ontology' where ontology is understood to be a formal specification of a conceptualization. The word 'ontology' is broadly used to cover a number of such specifications. The goal of this tutorial is to present a formal framework within which to understand these distinctions and to introduce techniques by which attendees may be able to develop ontologies that may serve as conceptual models, focusing on the less technical (and often overlooked) aspects of such ontology development, specifically the ability to appreciate concepts and to model these within the logical formalisms used in ontology development.

Tutorial on Referring Expressions in Ontologies and Query Answering

Organisers

David Toman	University of Waterloo, Canada
Grant Weddell	University of Waterloo, Canada

How individuals are identified when cooperating agents need to communicate is an inherent issue faced by the designers of information systems. Solutions to this problem range from insisting on global often opaque identifiers, such as URIs, to application specific ways of externally identifying individuals, such as primary keys in relational systems. The goal of this tutorial is to introduce a flexible framework based on *referring expressions* that unifies approaches that address these issues.

IAOA

The Role of Foundational Ontologies for Preventing Bad Ontology Design

Stefan SCHULZ [a,b,1]

[a] *Institute for Medical Informatics, Statistics and Documentation, Medical University of Graz, Austria*
[b] *AVERBIS GmbH, Freiburg, Germany*

Abstract. Ontology engineering is error-prone, and many published ontologies suffer from quality problems. This paper initiates a discussion about how axiomatically rich foundational ontologies can contribute to prevent and to detect bad ontology design. Examples T-boxes are presented, and it is demonstrated how typical design errors can be detected by upper-level axioms, in particular disjoint class axioms, existential and value restrictions. However, debugging large domain ontologies under an expressive top level raises scalability issues. During domain ontology design this can be mitigated by using small random ontology modules for debugging. For reasoning in applications, however, less expressive variants of such foundational ontologies are necessary.

Keywords. Foundational ontologies, description logics, quality assurance

1. Introduction

Constructing domain ontologies is a demanding endeavour. The formalization of basic regularities of a domain requires not only familiarity with the domain but also understanding of the basic principles of logic and formal ontology. This is especially the case if ontology engineering is understood not as building (closed-world) models limited to the support of well-delineated reasoning use cases in restricted domains, but as providing interoperable and re-usable (open world) representations of the domain itself.

This is a basic principle stressed not only by the defenders of so-called realist ontologies [1,2] but also by some (moderate) critics [3], which documents an increasing consensus on how to represent those areas of knowledge where people tend to agree on an observer-independent reality and benefit from standardised terms, such as in natural science and technology domains. An important tenet of these ontologies is collaborative ontology development and interoperability. Principles for this kind of ontology development have been formulated by the OBO Foundry consortium [4] and within the Good Ontology Design (GoodOD) guidelines [5]. Both propagate a concise foundational upper-level as a mainstay for interoperability, and there is also some evidence that foundational ontologies – domain-independent top-level or domain-related upper-level ontologies – speed up ontology development and improve quality [6].

[1] Corresponding Author: Stefan Schulz, Institute for Medical Informatics, Statistics and Documentation, Medical University of Graz, Auenbruggerplatz 2/V, 8036 Graz, Austria, E-mail: steschu@gmail.com

This paper is intended to initiate a discussion on how foundational ontologies can help prevent typical errors in domain ontologies. This is also the reason why prototypical, partly made-up but easily understandable examples are used.

2. Materials and Methods

The work is based on BioTopLite (BTL2), an upper-level ontology [7], linked to BFO [8], using description logics [9] with OWL-DL expressiveness [10]. BTL2 has been designed with the intent to provide a rich set of constraining axioms to enforce the consistency of ontologies modelled thereunder. Although BTL2 is, in principle, domain-independent, its content is geared to the domains of health care and biomedical research. This explains, e.g., the provision of more fine-grained classes for chemical and biological entities (e.g. ‘*mono molecular entity*’, *organism*, *cell*, *population*) as well as the disjunctive class *condition*, created in order to deal with the ontological heterogeneity of key medical concepts like diseases, signs, and symptoms. Fig. 1 provides Protégé screenshots of the class and relation hierarchies, together with sample axioms.

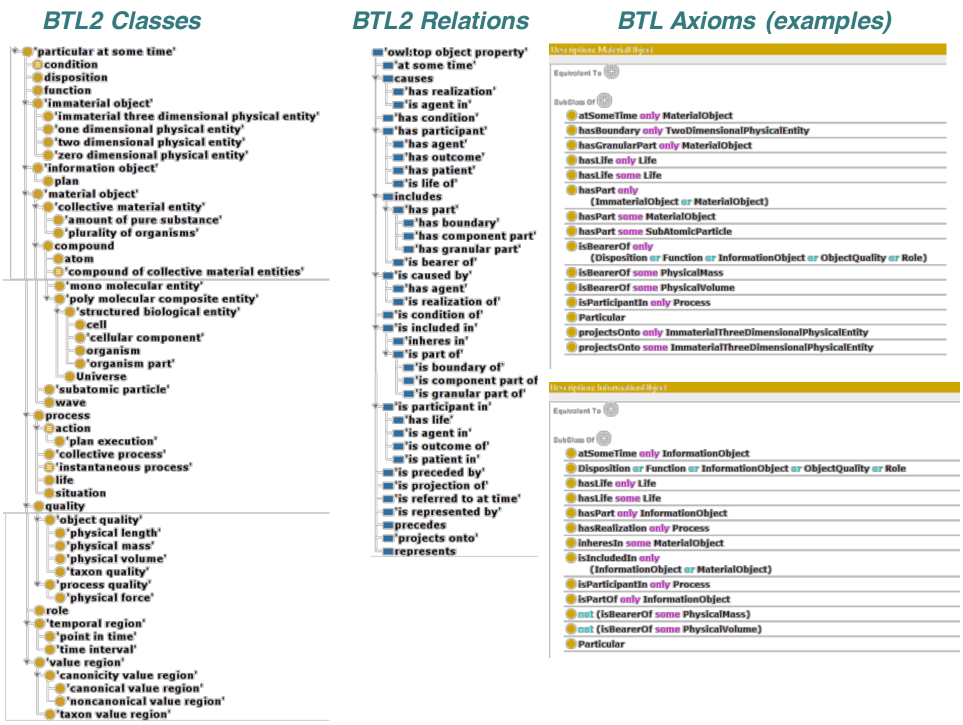

Figure 1. Classes, relations (object properties) and selected axioms in BioTopLite2 (BTL2)[7]

In order to test and demonstrate how BTL2 axioms are useful for preventing ontology design errors, T-boxes with typical examples of bad modelling will be presented in order to challenge the underlying foundational ontology. Some of these examples are formulated very abstractly due to their high level of generality; others use terms from a specific domain but are still understandable for a broader public.

Each T-box is modelled as an extension of BTL2. The HermIT [11] reasoner was used to detect inconsistencies. The explanation of inconsistencies follows Protégé's OWL entailment explanation feature [12]. The examples are provided together with their results in the following section. The presentation of the original OWL expressions, the entailments and their justifications is done in the following order:

- **SRC** – Axioms from ontology source (known satisfiable).
- **CHA** – New axioms added that challenge the satisfiability of **SRC**. Cases in which an axiom is only transiently added, are marked by **CHA-T**.
- **INF** – Inference, in particular the detection of classes that are unsatisfiable w.r.t. the T-box constituted by **SRC** and **CHA**.
- **EXP** – Explanations of **INF**, with axioms collected from the explanation plug-in [12].

3. Results

Reasoning examples under BTL2 are presented, in which deliberately erroneous axioms lead to an incoherent ontology, i.e., where one or more named classes turn out to be unsatisfiable, i.e. necessarily empty w.r.t. the T-box. This is expected to be detected by a DL classifier. In the following, a distinction is made between five error types, *viz.* (1) simple category errors, (2) value restrictions and transitive role errors, (3) complex domain/range constraint errors, (4) physical granularity errors, and (5) errors regarding unrealized realisables and non-referring information entities.

3.1. Simple category errors

A category error occurs whenever a class is a taxonomic descendent of upper-level classes that are modelled as mutually exclusive (Disjoint Classes in OWL). Such errors typically occur when ontology mapping and alignment is guided by lexical criteria. For instance, when mapping content of the clinical ontology SNOMED CT [13] (namespace sct:) to the foundational ontology BTL2 (namespace btl2:) one might be tempted to equate sct:*Process* with btl2:*process* and place 'sct: *Qualifier Value* (*qualifier value*)' under 'btl2:*quality*':

SRC	'sct:*Process* (*qualifier value*)' SubClassOf 'sct:*Qualifier Value* (*qualifier value*)'	(1a)
NEW	'sct:*Qualifier Value* (*qualifier value*)' SubClassOf btl2:*quality*	(1b)
NEW	'sct:*Process* (*qualifier value*)' EquivalentTo btl2:*process*	(1c)
INF	'sct:*Process* (*qualifier value*)' EquivalentTo owl:*Nothing*	(1d)
EXP	btl2:*quality* DisjointWith btl2:*process*	(1e)

The origin of such category errors may be manifold. A common cause is misleading class labelling. Ontology labels should be context-independent and self-explanatory, and they should avoid ambiguous terms [14]. A more severe problem – like here – arises where the ontologies to be aligned fundamentally differ in upper level assumptions. In SNOMED CT, e.g., the subhierarchy 'sct:*Qualifier Value* (*qualifier value*)' is currently a badly organized reservoir for the most diverse terms, and the reason why hierarchies of pathological and physiological processes are placed therein remains unclear[2].

3.2. Value restrictions and transitive roles

Value restrictions (universal constraints expressed by "only" in OWL Manchester syntax) restrict the range of allowed role fillers. It is tempting to use value restrictions together with mereological statements, e.g. stating that all members of a class have only parts of a certain kind, like in the following example:

SRC	btl2:*cell* SubClassOf btl2:*compound*	(2a)
SRC	'*cell culture*' SubClassOf 'btl2:*material object*'	(2b)
CHA	'*cell culture*' SubClassOf and ('btl2:**has part**' some btl2:*cell*) and ('btl2:**has part**' only btl2:*cell*)	(2c)
INF	'*cell culture*' EquivalentTo owl:*Nothing*	(2d)
EXP	'btl2:*material object*' SubClassOf 'btl2:**has part**' some 'btl2:*subatomic particle*'	(2e)
EXP	btl2:*compound* DisjointWith 'btl2:*subatomic particle*'	(2f)

Axiom like (2c) may fulfil their purpose in domain ontologies in which cells are the smallest objects, but as soon as smaller objects are allowed, the expression is inadequate – assuming **'has part'** being transitive. BTL2 obviates such a granularity restriction by stating that all material objects have subatomic particles as (transitive) parts.

3.3. Complex domain / range restrictions

Domain / range restrictions are a suitable means to avoid ontology errors. However, in ontologies that use a small number of object properties like BTL2, this resource may be not expressive enough. For instance, if the relations 'btl2:**is part of**' and 'btl2:**has part**' are valid for material objects, immaterial objects, as well as for processes and information objects, formulating just domain / range restrictions at the level of these relations would still be compatible with an (unintended) model in which an object is part of a process or vice versa. This is why BTL2 encodes these restrictions using axioms like the one in (3f).

SRC	*Object_A* SubClassOf 'btl2:*material object*'	(3a)
SRC	*Process_A* SubClassOf btl2:*process*	(3b)
CHA	*Object_A* SubClassOf 'btl2:**is part of**' some *Process_A*	(3c)
INF	*Object_A* EquivalentTo owl:*Nothing*	(3d)
EXP	'btl2:**has part**' InverseOf 'btl2:**is part of**'	(3e)
EXP	btl2:*process* SubClassOf 'btl2:**has part**' only btl2:*process*	(3f)
EXP	btl2:*process* DisjointWith 'btl2:*material object*'	(3g)

[2] Processes, like all kinds of entities, may play the role of values in information models, e.g., "Infectious process". Their confusion with their referents, i.e. domain entities proper (an infectious process in a patient) is a classic case of use-mention confusion, which still haunts many domain ontologies [15], especially those deriving from frames, thesauri and other knowledge organization systems.

A similar example is typical for medical ontologies, where domain experts are tempted to use "diagnosis" and "disease" interchangeably, and where signs and symptoms are referred to, in colloquial discourse, as being "parts" of diagnoses:

SRC	*Diagnosis_A* SubClassOf *Diagnosis*	(3h)
SRC	*Diagnosis* SubClassOf 'btl2:*information object*'	(3i)
SRC	*Symptom_A* SubClassOf *Symptom*	(3j)
SRC	*Symptom* SubClassOf btl2:*condition*	(3k)
CHA	*Diagnosis_A* SubClassOf 'btl2:**has part**' some *Symptom_A*	(3l)
INF	*Diagnosis_A* EquivalentTo owl:*Nothing*	(3m)
EXP	'btl2:*information object*' *SubClassOf* 'btl2:**has part**' only 'btl2:*information object*'	(3n)
EXP	btl2:*condition* EquivalentTo btl2:*function* or btl2:*disposition* or 'btl2:*material object*' or btl2:*process*	(3o)
EXP	DisjointClasses: 'btl2:*material object*', btl2:*process,* btl2:*function* or btl2:*disposition,* 'btl2:*information object*', 'btl2:*immaterial object*', btl2:*role,* btl2:*quality,* 'btl2:*temporal region*', 'btl2:*value region*'	(3p)

3.4. Physical granularity

Ontologies for natural sciences and technology deal largely with physical objects of several degrees of granularity. Levels of material granularity obey certain mereological constraints, e.g. that biological cells can be parts of organisms but not vice versa, or that polymolecular entities can never be part of single molecules. BTL2 incorporates such constraints. They help detect modelling errors like the following one.

SRC	*Chromosome* SubClassOf 'btl2:*poly molecular composite entity*'	(4a)
SRC	*ProteinMolecule* SubClassOf 'btl2:*mono molecular entity*'	(4b)
CHA	*Chromosome* SubClassOf 'btl2:**is part of**' some *ProteinMolecule*	(4c)
INF	*Chromosome* EquivalentTo owl:*Nothing*	(4d)
EXP	'btl2:*poly molecular composite entity*' *and* ('btl2:**is part of**' some (btl2:*atom* or 'btl2:*mono molecular entity*' or 'btl2:*subatomic particle*')) SubClassOf owl:*Nothing*	(4e)

3.5. Unrealised realisables and non-referring information entities

Realisable entities like functions and dispositions [16] depend on material entities and are realised in processes. However, the existence of realisables does not imply their realisation: The function of a screwdriver is to drive screws, and the disposition of a glass is to break under certain circumstances, but as there are screwdrivers that are never used and glasses that are never thrown to the floor. Because for all types of functions and dispositions there are instances that have never been realised, ontologies have to deal with unrealised realisables, which could be, e.g., expressed by (5a).

SRC	*Unrealized_Function* EquivalentTo btl2:*function* and not ('btl2:**has realization**' some owl:*thing*)	(5a)

In order not to preclude the possibility that dispositions and functions happen to be never realised, ontologies under BTL2 should define them using the value restriction constructor:

SRC btl2:*function* SubClassOf 'btl2:**has realization**' only btl2:*process* (5b)

SRC *Function*_A EquivalentTo btl2:*function* and ('btl2:**has realization**' only *Process_A*) (5c)

Nevertheless, BTL2 does not reject a definition using an existential quantifier like in the following definition:

CHA *Function*_A EquivalentTo btl2:*function* and ('btl2:**has realization**' some *Process_A*) (5d)

Function_A would then exclude all unrealised function instances. Such a class (which might be considered anti-rigid [17] if assuming that realisable entities are always unrealised when they come into existence) is most likely not intended by the modeller. The detection of these errors requires checking consistency after transiently adding axiom (5e).

CHA-T btl2:*function* EquivalentTo *Unrealized_Function* (5e)

INF btl2:*function* EquivalentTo owl:*Nothing* (5f)

The explanation is given by the conjunction of axioms (5a), (5d), and (5e).

The axiomatization of non-referring information entities follows the same pattern. Information entities can be referring and non-referring [18]. A typical example is medical diagnosis [19]. BTL2 here uses the relation *represents*. This relation connects information entities with domain entity they correctly characterise. This allows to distinguish wrong diagnoses from correct diagnoses.

SRC *Diagnosis* SubClassOf 'btl2:*information object* (5g)

SRC *False_diagnosis SubClassOf Diagnosis* and (not btl2:**represents** some btl2:*condition*) (5h)

SRC *Cancer_Diagnosis* EquivalentTo *Diagnosis and* btl2:**represents** only (*Cancer* or not btl2:*condition*) (5i)

CHA *Cancer_diagnosis* EquivalentTo *Diagnosis* and btl2:**represents** some *Cancer* (5j)

Challenged by the axiom (5k) the T-box becomes incoherent.

CHA-T *Diagnosis* EquivalentTo *False_Diagnosis* (5k)

INF *Cancer_Diagnosis* EquivalentTo owl:*Nothing*

The explanation is given by the conjunction of axioms (5h), (5i), and (5k).

4. Discussion and Further Work

It was shown how a highly axiomatised foundational ontology like BioTopLite (BTL2) can incorporate constraints that reject bad modelling decisions that lead to unsatisfiable classes. A distinction was made between those cases in which the upper level axioms suffice for detecting such inconsistencies and those in which additional "challenges", i.e. transiently added axioms are necessary.

Most of the former cases capitalise on disjoint class axioms present in the upper level ontology. This comes near to the so-called logical anti-patterns introduced by [20], all of which require disjoint class axioms in order to detect inconsistencies. In contrast to the work presented, anti-patterns are very abstract logical expressions and independent of foundational ontologies. OntoClean [17] was presented as a methodology for detecting improper subclass axioms based on philosophically inspired, domain-independent properties of classes, the metaproperties unity, identity and rigidity. Although DL reasoners do not support meta-level reasoning, it has to be investigated whether certain elements from OntoClean could also included in DL-based foundational ontologies, e.g. by reifying them in terms of additional top-level classes[3].

Several limitations of this work have to be highlighted:

- The typology presented is certainly non-exhaustive. It is primarily motivated by the author's experience and not yet by the relevance of those types of problems in ontologies employed in real-world applications. It could further be related to existing work in ontology evaluation, e.g., the OQuaRE framework [21].
- The proposed approach will probably fail if application ontologies bypass the partition of upper categories of the foundational ontology or introduce new object properties that are not subproperties of the existing ones. The BTL2 authors claim that their inventory of object properties is close to sufficient and recommend to introduce predicates required by the domain (e.g., in the biomedical domain: *treats*, *prevents*, *diagnoses*, *interacts*, *binds*) not as object properties but as subclasses of btl2:*process*.
- Important causes of bad ontology design cannot be prevented or remedied by a foundational ontology. This includes erroneous representation of individuals as classes or vice versa (a typical error would be an A-Box OWL expression like "*SodiumAtom* Type btl2:*atom*), bad naming and insufficient documentation, as well as constraints on a meta-class level like in OntoClean.
- Constraining axioms similar to the proposed ones can be added to domain ontologies, e.g. to assure mereotopological non-overlapping [22].
- Although BTL2 was used as a testbed, the proposed approach would lend itself to other ontologies as well. Especially BFO would benefit from a stronger axiomatization, as the most popular version, which is the umbrella of most OBO ontologies lacks axioms beyond subclass and disjoint class axioms. This deficiency has been addressed by the 2.0 version, which is, however, not fully available in OWL due to its use of ternary relations.
- The fact that BTL2 uses the whole range of constructors allowed by OWL-DL has a negative impact on reasoning performance. This makes debugging of large ontologies intractable. This was the case when aligning SNOMED CT with BTL2 [23]. The solution was to use small modules created from random

[3] Which would be orthogonal to the existing ones, e.g. 'rigid entity', 'anti-rigid entity', 'whole'

signatures as described in [24]. As a solution a two-step approach was proposed: (i) at design time using the rich foundational ontology for debugging random modules of a (large) domain ontology under construction, and (ii) at runtime placing the final domain ontology under a light version of the same foundational ontology for enabling efficient reasoning.

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Applying Evaluation Criteria to Ontology Modules

Zubeida Casmod KHAN [1]
Council for Scientific and Industrial Research, Pretoria, South Africa

Abstract. Modularity has been increasingly used as a solution to assist with the use and maintenance of large ontologies. However, there is lack of evaluation methods available for determining the quality of an ontology module. While initial work has been done on producing a comprehensive list of evaluation characteristics that can be used to check the quality of a module, certain aspects are still unclear. For instance, the initial list has not been structured into different groups for different types of evaluation criteria. It is also unclear on how to apply these characteristics to a particular module, and the metrics have not been experimentally validated for some types of ontology modules. In this paper, we structure the comprehensive evaluation criteria into groups, provide practical examples on how to use the evaluation characteristics to assess a module, and validate the evaluation characteristics with a set of ontology modules.

Keywords. ontology evaluation, ontology metrics, ontology modules, ontology modularisation

1. Introduction

Over the last few years, there has been a growth in using modularity to assist with maintaining and using large ontologies. The general concept of modularity refers to dividing and separating the components of a large system such that modules can be recombined. Modularity is used to simplify and downsize an ontology for the task at hand; to modularise a large ontology into smaller manageable ontologies. Modularity has been successfully applied to a number of different ontologies to improve usability and assist with complexity. Examples include the myExperiment ontology [16], which is a collaborative environment where scientists publish and share their work-flows and experiment plans among groups, the Semantic Sensor Net ontology where there are various modules to describe sensors and observations [9], and BioTop ontologies for life sciences in which the principle of modularisation have been applied [22].

An issue concerning ontology modules is the lack of evaluation metrics. The existing works on evaluation metrics focus on only some metrics that suit the modularisation technique [20,21,26], and there is not always a quantitative approach to calculate them. Overall, the metrics are not comprehensive enough to apply to a variety of modules. It is therefore not clear on how to determine whether a module is of good quality.

[1]Correspondance address: Zubeida Casmod Khan, Department of Computer Science, University of Cape Town, South Africa, and Council for Scientific and Industrial Research, Pretoria, South Africa. zkhan@csir.co.za

We have already published initial work done on determining whether a module is a good or bad module with evaluation metrics [10]. The initial study [10] revealed 13 criteria from the literature, and 3 new ones, some of which were short of a metric for quantitative evaluation that have now been devised. In this work, we categorise the 16 criteria into 5 broader categories to structure them so that ontology developers can easily identify which ones to use for an application. We also demonstrate usage of the criteria with practical examples. Lastly, we perform an experimentation evaluation on a set of ontology modules using the evaluation criteria revealing how the modules measure in terms of quality.

The remainder of the paper is structured as follows. We discuss related works in Section 2. This is followed by a section on the evaluation criteria in Section 3. In Section 4 we discuss the types of modules we are going to evaluate. The experimental evaluation using the evaluation metrics is performed in Section 5. Finally we conclude in Section 6.

2. Related Works

d'Aquin et. al [3] present some criteria for evaluating ontology modules including logical criteria, e.g., local correctness, structural criteria e.g., size of module, and intra-module distance, software criteria, e.g., encapsulation, and independence, quality criteria, e.g., module cohesion, and relational criteria, e.g., connectedness, and inter-module distance. The study [3] also revealed that existing criteria for ontology modularisation evaluation is not sufficient, and that not all the proposed criteria can be used on all ontology modules. In other work, Loebe [14], proposed a number of requirements for logical modules, such as logical correctness and completeness. Loebe also acknowledges that the requirements do not hold for all applications and that specialised methods should be applied for different applications.

Tartir et. al [23] propose richness criteria to measure the quality of ontologies. This criteria is based on how rich the ontology is with regard to attributes and subclasses. For cohesion metrics, Yao et. al propose metrics such as the number of root classes, number of leaf classes, and average depth of inheritance tree of all leaf node [26]. These metrics, however, does not reveal how the entities are related in a module as compared to the original ontology. The work done by Oh et. al on cohesion metrics, however, does measure the strength of the relations in a module [18]. To measure the coupling of an ontology, researchers propose metrics based on the number of externally defined referenced concepts [19]. This, however, does not take into account external links that different modules share. Oh and Ahn [17] have improved on this to consider the external links between different modules based on whether the link is hierarchical or relational. However, their metric is simply a sum value of the number of each type of links between modules, which does not measure the complete interdependence of a module since it only considers one type of variable in the module.

3. Evaluation Metrics for Modules

In previous work, we already defined a list of evaluation criteria alongside their mathematical metrics for modularity [10]. We now group them into categories of criteria, and provide some examples demonstrating how to use them. For the set of criteria, let O be an ontology with a corresponding set of axioms, $Axioms(O)$, and M be a module with a corresponding set of axioms, $Axioms(M)$. Let i, j be arbitrary entities in an ontology.

3.1. Structural Criteria

Structural criteria are calculated based on the structural and hierarchical properties of the module. These criteria are calculated by inspecting the syntax of the ontology. It is usually based on counting components of the ontology such as axioms, entities, etc., and is a numerical value. Calculating structural criteria involves evaluating the size, relations, and placement of entities within a module. We now list the structural criteria, alongside practical examples.

Size: Size is the number of entities in a module (the number of classes, object properties, data properties, and individuals in a module) [2,3,18,21,20].

Relative size: The relative size is the size of the module, i.e., the number of entities in a module compared to the original ontology [12].

$$\textit{Relative size(M)} = \frac{|M|}{|O|} \tag{1}$$

Example 1 *The GFO-Basic ontology [8] module contains 47 classes, 0 individuals, 41 object properties, and 0 data properties. The source ontology, GFO, contains 78 classes, 0 individuals, 67 object properties, and 0 data properties. Hence the relative size is* $\frac{47+0+41+0}{78+0+67+0}$ *= 0.61.*

Appropriateness: Appropriateness is measured by mapping the size of an ontology module to some appropriateness function value between 0 and 1 to reflect the defect density [21].

$$\textit{Appropriate(x)} = \frac{1}{2} - \frac{1}{2}cos(x.\frac{\pi}{250}) \tag{2}$$

where x is the number of axioms in the module. The authors propose the function with 250 axioms as it is based on the fact that the optimal size of software lines in a code is 200-300 lines [21].

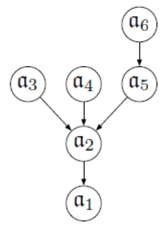
Example 2 *The Temporal Relations module of the DOLCE-ExtendedDnS descriptions and situations ontology [15] has 435 axioms. Therefore, based on the equation for calculating appropriateness, the value is* $\frac{1}{2} - \frac{1}{2}cos(435.\frac{\pi}{250})$ *= 0.16.*

Atomic size: The atomic size of a module is the average size of a group of interdependent axioms in a module. This is based on the notion of atoms in modules, which are defined as a group of axioms with dependencies between each other [24]. Dependent axioms are those that describe the same named entity.

$$\textit{Atomic Size(M)} = \frac{|Axiom|}{|Atom|} \tag{3}$$

Example 3 *Consider the example in Figure 1 of an atomic decomposition [25]. The number of atoms in the example is 6 and there are 7 axioms in total. The atomic size is hence* $\frac{7}{6} = 1.17$*. This tells us that there is an average of 1.17 axioms per atom for the example.*

$\alpha_1 =$ ‘$\texttt{Animal} \sqsubseteq (= 1\texttt{hasGender}.\top)$’,
$\alpha_2 =$ ‘$\texttt{Animal} \sqsubseteq (\geq 1\texttt{hasHabitat}.\top)$’,
$\alpha_3 =$ ‘$\texttt{Person} \sqsubseteq \texttt{Animal}$’,
$\alpha_4 =$ ‘$\texttt{Vegan} \equiv \texttt{Person} \sqcap \forall\texttt{eats}.(\texttt{Vegetable} \sqcup \texttt{Mushroom})$’,
$\alpha_5 =$ ‘$\texttt{TeeTotaller} \equiv \texttt{Person} \sqcap \forall\texttt{drinks}.\texttt{NonAlcoholicThing}$’,
$\alpha_6 =$ ‘$\texttt{Student} \sqsubseteq \texttt{Person} \sqcap \exists\texttt{hasHabitat}.\texttt{University}$’,
$\alpha_7 =$ ‘$\texttt{GraduateStudent} \equiv \texttt{Student} \sqcap \exists\texttt{hasDegree}.\{\text{BA, BS}\}$’



Here the $\bot$-atoms in the AD contain the following axioms respectively: $\mathfrak{a}_1 = \{\alpha_1, \alpha_2\}$, $\mathfrak{a}_2 = \{\alpha_3\}$, $\mathfrak{a}_3 = \{\alpha_4\}$, $\mathfrak{a}_4 = \{\alpha_5\}$, $\mathfrak{a}_5 = \{\alpha_6\}$, $\mathfrak{a}_6 = \{\alpha_7\}$.

Figure 1. An ontology’s atomic decomposition. See example 3 for details. Source: [25].

Intra-module distance: The intra-module distance in a module is the distance between entities in a module [3]. To measure it, Freeman’s farness equation is used to measure the sum of distances to all other nodes [4]; the full equation is in [12].

$$\textit{Intra-module distance}(M) = \sum_{i}^{|M|} \textit{Farness}(i) \tag{4}$$

Relative Intra-module distance: The relative intra-module distance is the difference between entities in a module and entities in a source ontology [12].

$$\textit{Relative intra-module distance}(M) = \frac{\textit{Intra-module distance}(O)}{\textit{Intra-module distance}(M)} \tag{5}$$

Example 4 *Consider the example of a source ontology O and a module M shown in Figure 2, and the farness values in Table 1. Using the farness values in the intra-module distance equation, we calculated the intra-module distance of the source ontology O to be 32 and of the module M to be 16. The relative intra-module distance is* $\frac{32}{16} = 2$, *hence the module entities are twice as close as the original ontology.*

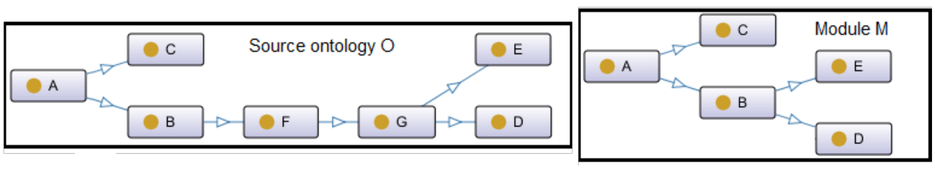


Figure 2. A source ontology and corresponding module for which we calculate intra-module distance. The arrows between the entities indicate the shortest-path relation between them.

Cohesion: Cohesion refers to the extent to which entities in a module are related to each other. [5,18,17,26]. To measure it, we use Oh et. al’s equation [18]; the full equation is in [12].

Table 1. The farness values for the source ontology and corresponding module alongside inverse farness values the corresponding module.

	Farness, *O*						**Farness,** *M*						**1/farness,** *M*					
	A	**B**	**C**	**D**	**E**	$\sum$	**A**	**B**	**C**	**D**	**E**	$\sum$	**A**	**B**	**C**	**D**	**E**	$\sum$
A	-	1	1	4	4	10	-	1	1	2	2	6	-	$\frac{1}{1}$	$\frac{1}{1}$	$\frac{1}{2}$	$\frac{1}{2}$	3
B	1	-	0	3	3	7	1	-	0	1	1	3	$\frac{1}{1}$	-	0	$\frac{1}{1}$	$\frac{1}{1}$	3
C	1	0	-	0	0	1	1	0	-	0	0	1	$\frac{1}{1}$	0	-	0	0	1
D	4	3	0	-	0	7	2	1	0	-	0	3	$\frac{1}{2}$	$\frac{1}{1}$	0	-	0	$\frac{3}{2}$
E	4	3	0	0	-	7	2	1	0	0	-	3	$\frac{1}{2}$	$\frac{1}{1}$	0	0	-	$\frac{3}{2}$
Intra-module distance(O)						32	*Intra-module distance(M)*					16	*1/farness (M)*					10

$$Cohesion(M) = \begin{cases} \sum\limits_{E_i \in M} \sum\limits_{E_j \in M} \frac{SR(e_i,e_j)}{|M|(|M|-1)} & if |M| > 1 \\ 1 & otherwise \end{cases} \tag{6}$$

Example 5 *Consider module M, from Figure 2. The sum of all the 1/farness values is 10 as shown in Table 1. The number of entities in M is 5. Hence the cohesion value is as follows: Cohesion =* $\frac{10}{5(4)}$ *= 0.5.*

3.2. Logical Criteria

By definition, an ontology is: “a logical theory accounting for the intended meaning of a formal vocabulary, i.e. its ontological commitment to a particular conceptualisation of the world” [7]. As such, it is possible to evaluate ontology modules by the logical criteria that they hold. We now list the logical criteria, alongside practical examples.

Correctness: This states that every axiom that exists in the module also exists in the source ontology and that nothing new should be added to the module [14,1,3,20].

$$Correctness(M) = \begin{cases} true & if Axioms(M) \subseteq Axioms(O) \\ false & otherwise \end{cases} \tag{7}$$

Example 6 *The GFO-Abstract-Top ontology is a subset of the GFO ontology [8]. No new axioms have been added to the GFO-Abstract-Top ontology; it only contains those axioms which exist in the GFO ontology. Thus, the GFO-Abstract-Top ontology is logically correct. The GFO-Basic ontology, however, is a smaller module based on the GFO ontology but it also contains new axioms that do not exist in the GFO ontology. For instance, the entity* Processual Structure *exists in the GFO-Basic module but not in the source ontology, GFO. Thus, the logical correctness property does not hold for the GFO-Basic module.*

Completeness: Completeness is when the meaning of every entity in a module is preserved as in the source ontology [14,1,3,20].

$$Completeness(M) = \begin{cases} true & if \sum\limits_{i}^{|M|} Axioms(Entity_i(M)) \models Axioms(Entity_i(O)) \\ false & otherwise \end{cases} \tag{8}$$

Example 7 *Consider a source ontology, DOLCE-Lite [15], where the* endurant *entity is defined as follows:*

* $*$ *endurant* $\sqsubseteq \forall$ *part.endurant*
* $*$ *endurant* $\sqsubseteq$ *spatio-temporal-particular*
* $*$ *endurant* $\sqsubseteq \exists$ *participant-in.perdurant*
* $*$ *endurant* $\sqsubseteq \forall$ *specific-constant-constituent.endurant*
* $*$ *endurant* $\sqsubseteq \neg$ *quality*
* $*$ *endurant* $\sqsubseteq \neg$ *perdurant*
* $*$ *endurant* $\sqsubseteq \neg$ *abstract*

If DOLCE were to be modularised to create a branch module, containing only the branch of Endurant entities, with the removal of perdurant entities called DOLCE-endurants, then the endurant *entity is defined as follows:*

* $*$ *endurant* $\sqsubseteq \forall$ *part.endurant*
* $*$ *endurant* $\sqsubseteq$ *spatio-temporal-particular*
* $*$ *endurant* $\sqsubseteq \exists$ *participant-in.perdurant*

The meaning of the endurant *entity was not preserved in the module since the axiom* endurant $\sqsubseteq \forall$ specific-constant-constituent.endurant *existed in the original ontology but not in the module. Therefore the DOLCE-endurants module has a false value for the completeness metric.*

3.3. Relational Criteria

Relational criteria deal with the relations and behaviour that modules exhibit with other modules in a system of interrelated modules. We now list the relational criteria, alongside practical examples.

Inter-module distance: The inter-module distance in a set of modules has been described as the number of modules that have to be considered to relate two entities [2,3]. This is measured by calculating the sum of modules that have to be considered to relate two entities divided by the number of all possible relations in a set of modules.

$$\textit{Inter-module-distance(M)}= \begin{cases} \sum_{E_i,E_j \in (M_i,,M_n)} \frac{NM(E_i,E_j)}{|(M_i,..,M_n)|(|(M_i,..,M_n)|-1)} & |(M_i,..,M_n)| > 1 \\ 1 & otherwise \end{cases} \tag{9}$$

where $NM(E_i,E_j)$ is the number of modules to consider to relate entities i and j. The product of $|(M_i,..,M_n)|(|(M_i,..,M_n)|-1)$ represents the number of possible relations between entities in a set of modules $M_i,.,M_n$.

Example 8 *Consider the set of inter-related modules in Figure 3. For each entity pair, we have the number of modules, NM, that have to be considered to relate them in Table 2. The sum of NM is 126. The number of entities is 9, hence the* $|(M_i,..,M_n)|(|(M_i,..,M_n)|-1)$ *value = 9(8). Thus the inter-module distance is* $\frac{112}{9(8)} = 1.75$*. For the set, it takes 1.75 modules to relate two entities in the set.*

Coupling: A measure of the degree of interdependence of a module [5,18,17,19]. To measure the coupling of a module, we calculate a ratio of the number of external links between a modules to every possible external link between modules.

Table 2. The number of modules, *NM*, that have to be considered to relate two entities in the set of modules.

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**Sum**
A	-	1	2	2	2	1	2	2	2	14
B	1	-	2	2	2	1	2	2	2	14
C	2	2	-	2	2	2	2	1	1	14
D	2	2	2	-	1	2	1	2	2	14
E	2	2	2	1	-	2	1	2	2	14
F	1	1	2	2	2	-	2	2	2	14
G	2	2	2	1	1	2	-	2	2	14
H	2	2	1	2	2	2	2	-	1	14
I	2	2	1	2	2	2	2	1	-	14
$NM(E_i, E_j)$										126

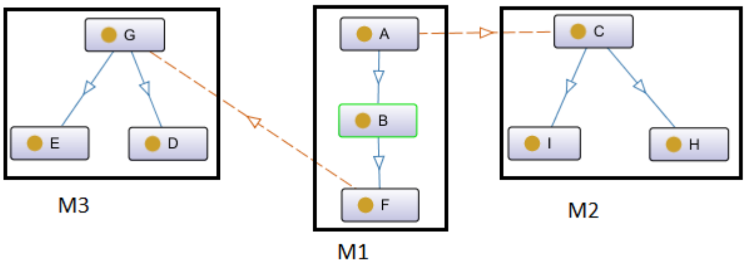


Figure 3. A set of modules with inter-related links. The plain arrow links between entities denote relations between entities in the same module while the red dotted arrow links denote relations between entities in different modules.

$$Coupling(M_i) = \begin{cases} \sum_{i=0}^{n} \sum_{\substack{j=0 \\ i \neq j}}^{n} \frac{NEL_{M_i,M_j}}{|M_i||M_j|} & NEL_{M_i,M_j} > 0 \\ 0 & otherwise \end{cases} \quad (10)$$

where $|M_i|$ is the number of entities in the current module and $|M_j|$ is the number of entities in a related module in the set of n modules.

Example 9 *Consider module M_1 from the set of inter-related modules in Figure 3. The number of external links that have to be considered to relate M_1 to other modules in the set, is 2. The number of possible external link between a module M_1 and the other modules in the system is calculated as follows: $|M_1|(|M_2|) + |M_1|(|M_3|) = 18$. Hence the coupling($M_1$) = $\frac{2}{18} = 0.11$ which indicates a low interdependence toward other modules in the system.*

Redundancy: Redundancy is the duplication of axioms within a set of ontology modules [21]. To measure redundancy in a set of modules, we calculate the fraction of duplicated axioms.

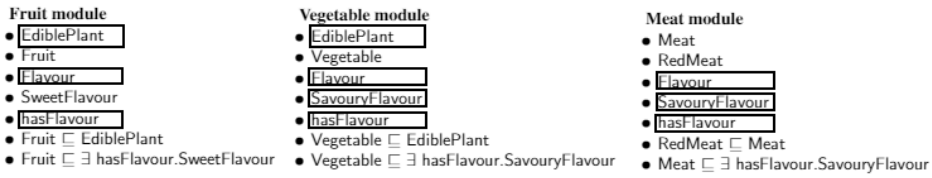


Figure 4. The axioms from a toy food ontology. The axioms in blocks are those that have been repeated more than once.

$$Redundancy(M) = \frac{(\sum_{i=1}^{k} n_i) - n}{\sum_{i=1}^{k} n_i} \tag{11}$$

where $\sum_{i=1}^{k} n_i$ is the total number of axioms and n is the number of distinct axioms in a module. The resulting fraction is a value of redundancy.

Example 10 *Consider the class declarations and axioms in the set of modules with no inter-related links that have been partitioned from a food ontology as shown in Figure 4. There are 3 ontology modules: Fruit, Vegetable, and Meat. Axioms that have been repeated more than once (redundant axioms) are shown in blocks. From the three modules, there is a total of 21 axioms, i.e., the Ax_t value is 21. There are 15 distinct axioms that exist in the set of modules (these axioms exist at most once and are those that are not blocks), hence Ax_d is 15. The redundancy of the set of partitioned modules is thus $\frac{21-15}{21} = 0.29$. Hence, 29% of the axioms in the set of modules are redundant.*

3.4. Information Hiding Criteria

Ontology modules sometimes deal with hiding aspects of the source ontology from the module for privacy and simplification reasons. Information hiding within modules assesses whether the module encapsulates all the information in the module such that the privacy is preserved for each module. We now list the information hiding criteria, alongside practical examples.

Encapsulation: Encapsulation is a metric that holds when "a module can be easily exchanged for another, or internally modified, without side-effects on the application can be a good indication of the quality of the module" [3]. It is measured using the number of axioms in the given module and the number of axioms that occur in both the given module and related modules.

$$Encapsulation(M\_i) = 1 - \frac{\sum_{j=1}^{n-1} \frac{|Ax_{ij}|}{|Ax_i|}}{n} \tag{12}$$

Example 11 *Consider the 3 ontology modules Fruit, Vegetable, and Meat, from Example 10. We calculate the encapsulation of the Fruit module as follows. There are 7 axioms in the Fruit module, i.e., the $Ax_i = 7$. In the Vegetable module, there* *are 3 overlapping axioms, i.e., they also exist in the Fruit module. In the Meat module, there are 2 overlapping axioms, i.e., they also exist in the Fruit module. Hence, the Encapsulation(Fruit) is calculated as* $1-\frac{\frac{3}{7}+\frac{2}{7}}{3}=0.76$*. Thus, 0.76 (76%), or a large amount of the domain knowledge is encapsulated in the Fruit module but the complete privacy of the Fruit module is not preserved.*

Independence: Independence evaluates whether a module is self-contained and can be updated and reused separately [3]. A module is independent if it has an encapsulation value of 1 and a coupling value of 0.

$$Ind(M\_i) = \begin{cases} true & Encapsulation(M_i) = 1 \text{ and } Coupling(M_i) = 0 \\ false & otherwise \end{cases} \tag{13}$$

where $|M_i|$ is the number of entities in the current module and $|M_j|$ is the number of entities in a related module in the set of n modules.

Example 12 *Consider the 3 ontology modules in Example 10. We have already worked out the encapsulation value for the Fruit module in Example 11 as 0.76. There are no inter-related links between the modules hence the coupling value is 0. Since the encapsulation value is not 1, the conditions for independence do not hold for the Fruit module hence it is not independent.*

3.5. Richness Criteria

The richness or amount of information in an ontology is designed as one aspect to measure the quality of an ontology. For modules, this is important to measure in cases where abstraction is employed to compare the granularity of the source ontology to that of the module. Tartir et al. [23] propose measurable richness schema metrics. We now list the richness criteria, alongside practical examples.

Attribute richness: Attribute richness is defined as the average number of attributes per class [23].

$$AR(M) = \frac{|att|}{|C|} \tag{14}$$

where *att* is measured by the number of data properties in the module $|DP|$ and $|C|$ is the number of classes in the module. In an ontology, an attribute is used to describe an entity and each attribute, or data type, has a name and value.

Example 13 *The pizza ontology has no data properties (attributes) defined. The AR value is 0, therefore there is no attribute richness in the pizza ontology.*

Inheritance richness: Inheritance richness is defined as the number of subclasses per class in an ontology [23].

$$IR_S(M) = \frac{\sum_{C_i \in C} |H^C(C_1, C_i)|}{|C|} \tag{15}$$

where $|H^C(C_1, C_i)|$ is the number of subclasses per class and $|C|$ is the total number of classes in the ontology.

Example 14 *Refer back to ontology O and module M from Figure 2. For module M, the entities which have subclasses are entity A with 2 subclasses, and entity B with 2 subclasses. Hence the sum of these subclasses is* $2+2=4$. *There are 5 classes in total in M. The inheritance richness value for M is thus* $\frac{4}{5}=0.8$. *Using the same method we work out the inheritance richness value for ontology O, which is* $\frac{6}{7}=0.85$.

To assist with the lack of evaluation metrics and corresponding formulae in ontology modules, we presented a comprehensive list of evaluation criteria for modules together with examples on how to operationalise them for ontology modules. To put context to the values for the metrics, experimentation was performed in other work stating which values are appropriate for the metrics for particular module types [12]. In Section 5, we show how each metric is used and what some expected values are.

4. Types of Modules for Evaluation

In this work, we focus on evaluating certain types of ontology modules, i.e., those that are lacking from an existing ontology modularisation framework and experiment [11]. The modules were generated using the NOMSA modularisation tool [2]. We briefly describe each module type here with its corresponding abbreviation which we will use to describe them in the remainder of the paper.

- Axiom abstraction (AxAbs): This is a module containing hierarchical relations between entities, i.e., other relations are removed resulting in a bare taxonomy.
- Vocabulary abstraction (VocAbs): This is a module where certain types of entities are removed, for instance, the object properties or data properties of an ontology.
- High-level abstraction (HLAbs): This is a module where entities at a higher level in the hierarchy have precedence over the others.
- Weighted abstraction (WeiAbs): This is a module where weighting is assigned to entities that are referenced by axioms more than others.
- Feature expressiveness (FeatExp): This is a module where some axioms of the ontology are removed based on its language features.

5. Experimental Evaluation

In order to uncover information about how evaluation metrics relate to ontology modules, we use the Tool for Ontology Modularity Metrics (TOMM) software tool [12] which encompasses all the evaluation metrics described in Section 3. In this experiment, we evaluate the module types from Section 4, in terms of its quality.

5.1. Materials and Methods

The method for the experiment is as follows:

[2] `http://www.thezfiles.co.za/modularisation/`

1. Take a set of modules.
2. Run the TOMM metrics tool [12] for the modules to acquire module metrics.
3. Conduct an analysis from the metrics for each module.

The materials used for the experiment were as follows: TOMM metrics tool [12], and a set of 128 ontologies that had been modularised using NOMSA ontology modularisation tool [2] but derived from the set of ontologies described elsewhere [6,13]. Our tests were carried out on a 3.00 GHz Intel Core 2 Duo PC with 4 GB of memory running Windows 7 Enterprise. All the test files are available at `http://www.thezfiles.co.za/modularisation/testfiles_NOMSA.zip`.

5.2. Results

Each of the modules were evaluated using the metrics that were implemented in the TOMM tool and the results for the numerical metrics are shown in Table 3. The atomic sizes of the modules indicates that there are on average between 2.34- 3.80 axioms that are grouped together in an atom for the modules. The appropriateness, which maps the size of the ontology module to a function is less than 0.3 for all the modules. Seeing that 1.0 is the optimal value for appropriateness, all the modules perform poorly for this metric. For a module to have an optimal value, it must have a value close to 250 axioms. The intra-module distance values which indicate the distance between entities in a module differ considerably, with the HLAbs modules having the lowest value of 142 698.4 and the AxAbs having the highest value of 866 354.60. The cohesion of a module indicates how closely related its entities are to each other, with higher values having a large number of relations among entities. The cohesion is small for all the modules in the set (less than 0.07). Most of the modules in this set do not contain attributes, as the attribute richness is less than 1 for all the modules. The number of subclasses per class is between 2.72 to 4.84 as indicated by the inheritance richness for the modules. In this set, all the modules were considerably smaller than the original ontologies, as indicated by relative size values that are less than 1. WeiAbs modules are the smallest at 0.26 (26% the size of the original ontology) while VocAbs modules are 0.85 (85% the size of the original ontology). It is also important to determine whether the entities in the modules have moved closer to each other in a module compared to the original ontology. AxAbs modules, VocAbs modules, and FeatExp modules have values less than 1 for the relative intra-module distance, which indicate that their entities are further in relation to the entities of the original ontology. While in HLAbs and WeiAbs the intra-module distance is larger, indicating that for these modules, the entities have moved closer as compared to the original ontology.

We have discussed the evaluation metric values for the set of ontology modules in isolation, i.e., without an indication of whether the modules in question appear to be good or of poor quality. To check if the modules are of good quality we refer to an existing benchmark dependency between the proposed ontology metrics and various types of ontology modules. The notion here is that for each module type, there is a pattern or dependencies between type and some set of metrics. This is shown in Table 4 with expected values for each type of module. The values that are underlined were not met for this experiment. For instance, reading Table 4, it states that for WeiAbs modules the cohesion value of range 0-0.25 and the relative size value of range 0.26-0.5 is met. However, for AxAbs, the cohesion value is met but the correctness value is not met.

Table 3. The average values for the metrics for all the generated modules; app. = appropriateness, cohes = cohesion, AR = attribute richness, IR = inheritance richness, rel = relative, IMD = intra-module distance.

	Size	Atomic size	App.	Intra-module distance	Cohes	AR	IR	Rel. size	Rel. IMD
AxAbs modules	238.04	2.34	0.19	866345.6	0.06	0.49	4.84	0.71	0.68
VocAbs modules	443.38	3.24	0.19	848372.2	0.06	0.45	4.78	0.85	0.79
HLAbs modules	202.77	3.48	0.24	166797.1	0.03	0.47	4.86	0.67	18.66
WeiAbs modules	138.58	3.40	0.30	142698.4	0.07	0.39	2.72	0.26	3.96
FeatExp modules	291.89	2.44	0.18	757305.1	0.06	0.25	4.80	0.72	0.70
Original ontologies	464.67	3.80	0.15	1866430	0.04	1.04	4.78	-	-

Table 4. The benchmark metrics and values for each module type. The metrics that are underlined are ones that fail for the set of modules that were evaluated.

	Cohesion	Correctness	Appropriateness	Relative size
AxAbs modules	0.00-0.25	true	-	-
VocAbs modules	0.00-0.25	true	0.75-1.00	-
HLAbs modules	0.00-0.25	-	0.75-1.00	-
WeiAbs modules	0.00-0.25	-	-	0.26-0.50
FeatExp modules	0.00-0.25	-	-	-

We now examine the failed metrics. For appropriateness, it appears that the number of axioms in a module need to be between 167- 333 to have a value of between 0.75-1. In some cases, the original ontologies were already less than 167 axioms in size, so there could never reach an appropriate value. For the case of ontology modules, which by definition are a reduction of an ontology, this appropriateness metric needs to be re-designed to include modules that are less than 167 axioms. The next failed metric is the correctness value, which needs to be true, but tested false for some modules, meaning that some new axioms were added to the modules, i.e., axioms that were not from the original ontology. An inspection of the log files for the metrics revealed that OWL enumeration was used to declare individuals in an original ontology. In resulting modules, when the collection of individuals were broken up, they were re-represented as named instances using class identifiers. This means that new knowledge was not added to the module, but because of language syntax, it appears so. The ontology metrics tool therefore needs to recognise that this is not a new axiom to measure the correctness value accurately.

5.3. Discussion

The evaluation criteria for ontology modules were already presented in previous work [10]. However, there was limited support for operationalising these metrics. In this paper, we provide practical examples on how the metrics can be applied to an ontology module to measure them. We also structured and grouped together the list of evaluation criteria to various higher level categories to differentiate those that examine, say structural aspects of a module (structural criteria) to those that examine how well the modules hide certain information of the source ontology (information hiding criteria). This could aid ontology developers in selecting the relevant evaluation criteria for their use-case.

We performed an experiment using various types of modules that were generated using NOMSA modularisation tool. The modules were evaluated with TOMM to reveal their metrics. The metrics indicate important information such as, the rate at which entities in a module move closer to each other (using the relative intra-module distance metrics), whether a module is rich with attributes, at what rate the size of the module differs as compared to the source ontology. These metrics are important for gauging how well the modules would fare with visualisation and comprehension tools or if there would be some performance issues due to redundancy, among other cases.

6. Conclusion

Initial work on evaluation criteria was refined by grouping the evaluation criteria list into categories to structure them to aid ontology developers. We summarised the list of evaluation criteria, together with practical examples on how to use them. An experimental evaluation revealed how the metrics can be used to evaluate modules and uncover information about how well certain modules fare for certain applications. We also identified a problem with the appropriateness value, which cannot be applied in some cases if a module has a small axiom size which needs to be changed. Another problem that was identified is that some knowledge is recognised as new knowledge by the evaluation metrics tool due to OWL representation issues.

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Yet Another Taxonomy of Part-Whole Relations

Antony GALTON
Department of Computer Science, University of Exeter, UK

Abstract. We propose a taxonomy of part-types based on the manner of attachment of a part to the rest of its parent whole, its degree of dependence on that whole or on external factors, and the temporal relation between its being a part and its being described as such.

Keywords. part-whole relations, dependent and independent parts, attachment

1. Introduction

Amongst existing classifications of parts and wholes we may distinguish two broad approaches. On the one hand there are formal mereologies, which typically embrace unrestricted summations and subdivisions, operating with a generalised notion of parthood which does not commit to any distinctions between kinds of parts other than proper vs improper parts and, in some systems, atomic vs non-atomic parts. On the other hand we find more nuanced approaches, typically motivated by cognitive or linguistic considerations, in which distinctions are drawn amongst an apparently disparate range of relations to which the term 'part' has been applied. Such approaches may distinguish, for example, between, *inter alia*, functional and spatial parts [3], or between components and portions [7]. Often included here is membership of a collection, and this is notable in that typically the members of a collection are spatially separated, whereas, for example, the components of an artefact are usually spatially contiguous. It is this aspect—the nature and extent of the spatial connections amongst the parts of some whole—on which the new taxonomy proposed here focuses; this constitutes a dimension of variation amongst different kinds of parts that has been comparatively neglected, yet is one that is clearly of considerable significance in our day-to-day deployment of the parthood concept. The closest existing work I have found to this approach is that of [6], though whereas that paper is concerned exclusively with parts of artefacts, my taxonomy is intended to be more broadly applicable.

The taxonomy proposed here is more narrowly focused than many, being concerned only with material objects and their material parts; and concerned with the latter primarily in respect of the nature of their attachment to the whole of which they are parts, and their degree of dependence thereon: but these aspects are considered in perhaps greater detail than is usually found in existing taxonomies.

2. Motivating discussion

Our starting point is the notion of a *unitary whole*, which consists of some (possibly variable, possibly heterogeneous) quantity of matter configured in such a way that, at an "everyday" (mesoscopic) level of granularity, it occupies a connected region of space, is bounded by a complete closed surface, and 'hangs together', i.e., retains these properties continuously over a sufficiently extended period of time. Examples include the computer on which I am typing these words, the table it is resting on, the chair I am sitting on, my bicycle and, indeed, me myself.[1] A *complex* comprises two or more unitary wholes which somehow "belong together" without necessarily together forming such a whole. An *independent whole* is either a unitary whole or a complex. For brevity I shall often abbreviate this to 'whole' except where it is important to stress its independent nature.

An independent whole may have various kinds of *parts*, which may or may not be independent wholes in their own right. I call the whole of which a part is a part its *parent whole*, where 'parent' is not, of course, to be understood in a generational sense. In the taxonomy we distinguish between dependent and independent parts. Many artefacts are brought into existence by assembling together, in a particular way, some collection of independent parts: such artefacts are *assemblies*. A bicycle, for example, is assembled from a definite number of independent parts; these are organised hierarchically, in that some subcollections of the parts form *subassemblies*—themselves independent parts—such as each of the wheels, whose parts include rim, spokes, hub, tyre, and inner tube. The truism that "the whole is greater than the sum of the parts", properly interpreted, means that the properties of the whole do not depend solely on the properties of its individual parts, but also on how they are put together to form the whole.[2] Independent parts retain their character as wholes even in the context of the composite whole of which they are part. Assemblies can typically be disassembled, without severing connections, and put together again; hence independent parts are generally *replaceable*.[3]

Many wholes do not have independent parts. This is necessarily true of the smallest independent parts of an assembly: a single spoke of a bicycle wheel is just a long thin cylinder of metal, all one piece. It is also very nearly true of most living organisms—indeed, an important difference between organisms and artefacts is that the parts of the former are typically dependent, those of the latter very often independent. None of my internal organs or external appendages is an independent whole. Both head and heart are joined seamlessly to the rest of the body, neither of them bounded by a closed surface. Since they are not independent parts of the body, but are evidently parts, we call them *dependent parts*. And since they are distinguished by means of rather natural, non-arbitrary criteria—which may relate to, amongst other things, geometry, material, or function—we call them *intrinsic dependent parts*. Living organisms typically have many intrinsic dependent parts, but some wholes have no such parts. A uniform metal sphere offers no intrinsic inhomogeneities for any distinction of parts to gain purchase.

[1] The term *integral object* has often been used in the literature—but depending on the author, this term may or may not refer to the same thing as what is here called a unitary whole. The difficulties inherent in pinning down these concepts are explored in Chapter 9 of [5].

[2] If one regards this structure or configuration as a part in its own right (but not, of course, a material part), then the whole is precisely the sum of its parts; this is a view that has been advocated by Koslicki [4], but I shall not follow it here.

[3] Simons and Dement [6] provide an insightful analysis of the mereology of artefacts.

As already suggested above, there are several different ways of distinguishing dependent parts, for example:

- *Geometrical*. If a strip of metal is bent in two to form a right angle, then the two "arms" thereby formed are distinguished dependent parts of the resulting whole.
- *Material*. A fingernail is distinguished from the rest of the finger by its different material composition. Note that it is not an independent part: the only way of removing the fingernail is by severing connections to form new surfaces.
- *Functional*. A wine glass has three functionally defined distinguished dependent parts: the bowl (for containing the wine), the stem (for holding the glass), and the base (for resting it on the table or other flat surface).[4]

As already hinted in the footnote, these criteria often work together: functional distinctions typically depend on geometrical or material distinctions.

Sometimes we want to refer to a part of some whole even when there exists no "natural" basis for distinguishing it from the remainder of the whole. This is what happens if I trace an outline on a pane of glass and refer to the part of the pane enclosed by the outline. That "part" only exists, as an object, insofar as I have designated it. Such parts will be called *designated parts*. They are *extrinsic* because they depend for their existence on some external means of designating them. A part may be *retrospectively designated* by being detached from its parent whole, thereby becoming a whole in its own right. Referring to the time before separation, we might now say that it was a part then, even though the designation on which it depended had not yet occurred. Retrospectively designated parts have only a tenuous claim to existence.

Michaelangelo is famously reported to have said that "every block of stone has a statue inside it and it is the task of the sculptor to discover it".[5] But from a commonsense point of view, before Michaelangelo began carving the *David*, the matter which later constituted the *David* did not constitute any object. Note that this flies in the face of the principle of unrestricted mereological fusion embraced by most formal mereologies, according to which the existence at the earlier time of the atoms that would subsequently make up the *David* implies the existence of an object composed precisely of those atoms, namely their mereological sum. As has often been pointed out, this leads to a highly profligate ontology which requires the existence of innumerable entities that not only do we never refer to, but we never *can* refer to.[6]

3. The Proposed Taxonomy

The taxonomy is shown diagrammatically in Figure 1. For expository purposes it is convenient to begin the discussion at the second division of the hierarchy rather than the first.

1. **Independent part**. A part which is itself an independent whole, such as the frame or a wheel of a bicycle. Types of independent parts are

[4] Of course, these parts can also be distinguished geometrically, but their *raison d'être* is primarily functional.

[5] *Ogni blocco di pietra ha una statua dentro di sé ed é compito dello scultore scoprirla*. Although widely cited, I have been unable to find the original source of this.

[6] Think of all the other possible sculptures, good, bad, or indifferent, which could have been carved from the block instead of the *David*—on one understanding of Michaelangelo's conceit, they were all *already there*.

- Part
  - Present part
    - Independent part
      - Unattached independent part
      - Attached independent part
        - Linked independent part
        - Adherent independent part
      - Formally-dependent independent part
    - Dependent part
      - Intrinsic dependent part
        - Integrated dependent part
        - Original dependent part
        - Differentiated dependent part ("Organic part")
      - Extrinsic dependent part
        - Designated part
        - Retrospectively designated part
  - Detached part
    - Detached independent part
    - Detached intrinsic part
    - Detached extrinsic part ("Fragment")
  - Prospective part

Figure 1. Taxonomy of part-types

(a) **Unattached independent part**. An independent part which is not attached to any other part of its parent whole. E.g., any of the pieces of a multi-piece object, such as the lid and body of a saucepan, the mattress and base of a bed, the top and bottom of a bikini. Unattached independent parts may or may not be in contact with the rest of their parent whole; in the case of a saucepan, it is an essential part of its functioning that the lid can both be separated from the body of the pan and sit tight over the opening.

(b) **Attached independent part**. An independent part which is attached to at least one other part of its parent whole. We distinguish two cases, depending on the nature of the attachment:

i. **Linked independent part**, in which the attachment is by contact, without adhesion, e.g., all the independent parts of a bicycle. This kind of attachment is typically accomplished by some kind of interlocking, e.g., the screw top of a jar or bottle, or by means of a connector such as a screw or nail. Typically, a linked independent part can easily be detached, thereby becoming an unattached part (as when the bottle-top is unscrewed).

ii. **Adherent independent part**, in which the attachment is by some form of reversible (non-disruptive) adhesion, as with many forms of glue. The part retains its full surface, part of which adheres to the rest of the parent whole by means of the bonding agent. In principle the part can be unattached without damaging it (e.g., by dissolving the glue).

(c) **Formerly-dependent independent part**. An originally dependent part which has become independent by the severing of connections with the rest of its parent whole, while remaining part of that whole. This is a somewhat recherché catgory, but there are some reasonably commonplace examples:

- A human club hair—this is a hair in the *telogen* phase, when it has stopped growing, the blood vessels connecting it to the follicle having atrophied and a new surface formed at the base; it remains linked to the body because the club-shaped base is held in place by the narrow aperture of the follicle.[7]
- Blood cells, which originate as dependent parts of the bone marrow; they remain joined to the rest of the body via the blood plasma, which being liquid allows the cells free movement while remaining parts of the body.
- The blocks of stone formed by erosion of a granite tor, which remain in place as parts of the tor even though no longer attached to each other.[8]

This subcategory cuts across the other subcategories of independent part: any formerly-dependent independent part must already belong to one of the other subcategories. A club hair, for example, *is* a linked independent part; the stones in the tor are unattached parts.

2. **Dependent part**. A part which is not an independent whole, its matter being continuous with that of the rest of its parent whole and therefore lacking a complete closed surface of its own. The boundary of a dependent part, where it does not coincide with a surface or other physical discontinuity, is typically somewhat indeterminate in location. Types of dependent parts are:

   (a) **Intrinsic dependent part**. A part distinguished by any (or several) of a variety of intrinsic factors such as geometry, material, texture, or function. From a cognitive point of view, some combination of such factors often results in the part so distinguished possessing a characteristic affordance. Types of intrinsic dependent part include:

      i. **Integrated**, or **formerly-independent**, **dependent part**, arising when an independent whole becomes integrated with other parts making up the parent whole by an irreversible process of fusion involving the destruction of part of the surfaces where they are joined (as for example in welding or brazing). Examples include the pieces of metal tubing that make up the frame of a bicycle; and the handle, spout, and body of an earthenware teapot.
      ii. **Original dependent part**, formed at the same time as the parent whole as a salient feature of it, e.g., the teeth of a comb, or the head of a statue that is cast in one piece or carved from a single block of stone.
      iii. **Differentiated dependent part**, formed during the growth of the parent whole: these are the body parts of living organisms, e.g., limbs, bones, internal organs, claws, horns, branches, leaves, etc., so long as these remain in situ. (These could also be called **organic parts**.)

   (b) **Extrinsic dependent part**, existing as a part by virtue of some relation or interaction between the parent whole and its environment. We distinguish:

[7] Eventually the hair will be shed, either by being pulled out, e.g., during brushing, or by being pushed out by the growth of a new hair once the follicle resumes its activity (at the *anagen* phase).
[8] There are many examples of such tors on Dartmoor, in Devon, UK.

i. **Designated part**. A part which exists only through being designated as such, typically by an act of human cognition, expressed verbally or by ostention, e.g., when someone traces an outline with their finger and says "this part"; or most geopolitical regions. In some cases nature itself can provide the designation, e.g., the part of an iceberg above the water.
ii. **Retrospectively designated dependent part**. A part which only exists as a part by virtue of its subsequently becoming an independent object, e.g., that part of a certain block of marble comprising all the matter that later constituted Michaelangelo's *David*. Retrospectively designated parts can only be referred to after they have ceased to be parts.

Extrinsic dependent parts in general do not have so strong a claim to being "real" parts as intrinsic or independent parts. We can say that an extrinsic dependent part is *part* of its parent whole, but not that it is *a part* of it.[9]

Independent and dependent parts may be called **present parts**, meaning that they are parts at the time they are so described. This constitutes one of the top-level divisions of the taxonomy. Sometimes, though, we refer to things as parts even though they are no longer, or are yet to become, parts of the parent wholes to which they are referred. These provide two more top-level categories for our taxonomy, as follows:

3. **Detached part**. An independent object that is not part of anything but which arose from the separation of a part from some parent whole. We distinguish:

    (a) **Detached independent part**, e.g., a hub-cap from a car, found lying by the side of the road.
    (b) **Detached intrinsic part**, e.g., hairs, teeth, bits of skin, leaves, fruit, pollen, etc, shed by a living organism. These originate as intrinsic dependent parts; but in some cases become independent parts before becoming detached.
    (c) **Detached extrinsic part**. This covers bits broken or cut off something, e.g., a chip from a ceramic plate, a shard of glass from a shattered window pane, a branch sawn off a tree, a piece of hair cut from a human head, a slice of bread,[10] a piece of cake. In many such cases, the parts that they formerly were are only retrospectively designated through the fact of their having been removed from their parent whole. Detached extrinsic parts are often called *pieces*,[11] though this word may also be used for unattached parts such as the

[9]Cf. Simons [5, p.235] — "the front half of a car, forward of some imaginary plane, is part of, but not a part of, the car". Note that this distinction works in English, but I am informed by one of the reviewers that it is lacking in other languages such as German.

[10]Sometimes bread is sold ready sliced, the slices held together in a packet. In this case, rather than calling the slices detached parts of an originally intact loaf, one might rather describe them as unattached parts (specifically, members) of a collection of formerly-dependent independent slices.

[11]"Suppose I take a hacksaw and cut a typewriter into two. Are the pieces I obtain 'parts' of the typewriter in the normal sense? Clearly not. In fact, the situation neatly differentiates the meanings of *piece* and *part*." [1]

pieces of a jigsaw puzzle;[12] other words for detached parts include *bit*, *fragment*, and *slice*.[13]

4. **Prospective part**. An independent whole that is destined or intended to become a part of something, e.g., a handlebar for a bicycle or a heating element for an electric kettle, prior to installation. This applies to manufactured components before assembly into some artefact, and also to "spare parts". In the case of prospective parts we typically speak of a part *for* something rather than *of* it; and whereas an actual part is always a part of some specific individual object, a prospective part is usually a part for a generic *type* of object (though in special cases a part may be manufactured for a specific "one-off" object, e.g., components produced as parts for some artwork). A prospective part may become either an independent part or a dependent part, depending on how it is incorporated into the whole. Because of the intentionality involved in characterising something as "destined" or "intended" to be a part, prospective parts do not occur in the natural world.[14]

4. Conclusion

The taxonomy proposed here is organised along rather different lines from most existing part-whole taxonomies, although many of the considerations advanced here have been previously noted. This taxonomy is advocated not as a replacement for any existing taxonomies but as providing a useful alternative perspective. In common with most cognitively-inspired taxonomies, the parthood relations discussed here may depart considerably from those found in typical formal mereologies, especially those which embrace unrestricted summations and subdivisions.

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[12] Cruse [2] suggests that the reason we call the elements of a jigsaw puzzle 'pieces' rather than 'parts' is that "the divisions are totally unmotivated with respect to the picture they go to make up". This is related to his observation that the boundaries of pieces are 'arbitrary' whereas those of parts are not.

[13] Note that whereas "detached" implies "formerly attached", "unattached" carries no such implication in general, though with a jigsaw puzzle its unattached parts were formerly attached since the pieces were produced by cutting up an original single object. But these are not detached parts in the sense intended here because they are still regarded as parts of the jigsaw puzzle, conceived as a complex of unattached independent parts.

[14] Though perhaps one could extend the definition to describe the haploid genome of a gamete as a prospective part of the diploid genome of a zygote which it may go on to form with a gamete of the opposite sex.

Ontology of Social Service Needs: Perspective of a Cognitive Agent

Bart GAJDEROWICZ [a,1] Mark S. FOX [a] and Michael GRÜNINGER [a]

[a] *Mechanical and Industrial Engineering Department, University of Toronto*

Abstract. This paper proposes an ontology of social service needs for the evaluation of social service providers. Existing ontologies in the social service domain define metrics to evaluate the efficient use of resources by service providers. The ontology presented here represents service provisioning from the perspective of a cognitive and goal-driven client to evaluate services based on how well they remove a client's constraints and meet client needs. This ontology is grounded in real-life requests made by participants of a Housing First intervention program, resulting in 57 different goal types. Each goal is mapped to one or more basic human need defined by Maslow's Hierarchy, as inferred from the goal's type, the motivation behind it, and the client's demographics. Finally, as clients interact with service providers, three different types of goal orderings are required to capture goal ranking during the planning and execution phases. These include the client's preferred order, Maslow's hierarchy order, and the practical order imposed by the logistical constraints of service providers.

Keywords. goals, agent-based simulation, cognition, ontology, human behaviour

1. Introduction

This paper proposes an ontology of needs for human-like agents that interact with a social service provisioning system. The ontology is based on data about the types of requests made by social service clients in a real-life intervention program. Existing ontologies focus on the process of service delivery, categorizing services and resources to ensure an efficient provisioning to incoming clients [1,15,11]. In the work proposed here, an ontology is created that allows for the evaluation of service provisioning from the client's perspective. By identifying goals of clients and the services that satisfy them, it is possible to create a high-fidelity client emulation model for the purpose of social service evaluation [3]. Towards such a model, the ontology presented here provides competencies not yet provided elsewhere. The ontology is used to identify relationships between clients and service providers, including client needs, constraints, and motivations. The ontology also differentiates service-side concepts like resources, programs, and a metric for client outcomes. To support a cognitive agent, the ontology makes a destination between three different goal ranking used for goal reasoning and planning [3]. First, the ontology can be used to infer correct needs associated with Maslow's hierarchy, by providing a set of

[1] Corresponding Author: Bart Gajderowicz, Mechanical and Industrial Engineering Department, University of Toronto, 5 King's College Rd, Toronto, ON M5S 3G8; E-mail: bartg@mie.utoronto.ca.

domain-specific mappings between data provided by services and the hierarchy based on theoretical analysis of needs [10]. Second, a client's own preferred ranking can be identified based on order requests are made on questionnaires and service request forms. Third, the practical ranking represents the order goals were actually satisfied in by services, as captured by service-side data, and takes into account environmental constraints imposed on the service provider.

Generally, human needs are difficult to capture. There are several theories that define motivation as "drives", but these are too vague and inflexible to construct a computational model of a cognitive agent's motivations and preferences [9]. Instead, goals are provided *a priori* and influence a goal-driven agent's behaviour [3]. By evaluating the social service delivery process through data provided by participants in a real-life intervention program, an ontology is developed that captures the relation between client goals and the services they use.

There are several ontologies that capture social service provisioning from the provider's perspective [1,15,11]. However, no ontology exists that focuses on client needs and motivations from the client's perspective. At the same time, human motivations have long been credited with influencing decision making in the social service domain [2]. To assess a client's current state, questionnaires such as the "Service Prioritization Decision Assistance Tool" (SPDAT) capture past and current needs. Once a client's state and outstanding needs have been identified, techniques like Motivational Interviewing and Acceptance and Commitment Therapy are used to facilitate change in their behaviour that aligns with the clients motivating factors [2].

The proposed ontology provides an ontological representation for four aspects of social service client needs missing today. First, client needs made up of 763 requests found in the data are categorized into 57 different goal types. Each type is defined by the agent's motivations, constraints, resources needed, and the services offering those resources. Second, the relation between a client and a service provider is based on the constraints faced by clients, not services. Third, each goal type has a homeless-specific mapping to one or more levels of Maslow's hierarchy. Such mappings are not trivial, and the ontology infers appropriate mappings based on request types and client characteristics. Fourth, three goal orderings are identified for different phases of a client's interaction with the provider. These include client preferences during the planning phase, Maslow's order during plan execution phase, and practical ordering based on logistical constraints placed on the service provider.

2. Method

To capture how a service provider satisfies goals of clients, this paper develops the Ontology of Social Service Needs (OSSN). The ontology is developed using the ontology engineering method. Ontology engineering is a systemic way of constructing and evaluating an ontological representation of a domain [6]. First, motivating scenarios are identified to define the scope and objectives the ontology is meant to resolve. Second, a set of informal competency questions are defined which the ontology should answer. Third, an ontology is constructed that represents knowledge required to answer identified competency questions. Finally, the informal competency questions are translated into formal competency questions using the terminology and formal language that allows for the automation of querying identified questions. The work presented here represents the ontology in OWL

BASIC NEEDS ASSISTANCE

What basic needs assistance have you received during the last 3 months?

☐ Child care ☐ Clothing ☐ Debt reduction ☐ Disability support ☐ Further education ☐ Employment training ☐ Food
☐ Furniture ☐ Housing supplement ☐ Identification ☐ Medication ☐ Rent arrears ☐ Rent shortfall/subsidy ☐ Security deposit
☐ Tenant insurance support ☐ Transportation ☐ Utility arrears ☐ None ☐ Other ____________
☐ Don't know ☐ Declined to answer

Figure 1. CHF version of SPDAT section for capturing requests for basic needs made by clients.

syntax. The SPARQL query language is used to represent formal competency questions, with a complete evaluation in Gajderowicz et al. [5].

2.1. Homeless Data

The Calgary Homeless Foundation (CHF) [2] has provided a dataset that captured information about clients as they participate in a "Housing First" (HF) intervention program administered by CHF. The CHF-HF dataset contains information on approximately 4,000 unique clients that participated in the HF program in Calgary, Canada from 2009 to 2015. The information was collected using SPDAT questionnaires. A complete description of the data and analysis is provided in [5]. Based on the data, the ontology categorizes clients according to fifteen key demographics. SPDAT also captures different client requests for basic needs, as per Figure 1. Participants were surveyed at program intake with follow-up interviews every three months until exiting the program. By grouping 763 unique requests captured, 57 need categories represent goal types in the ontology.

2.2. Motivating Scenarios

Motivating scenarios for the OSSN focus on the evaluation of social service policy from the perspective of clients that use them. These include:

- How to evaluate intervention programs in the social service space?
- How to monitor client progress?
- How to monitor service delivery performance?

The general approach to evaluating a program is to identify the percentage of clients who were successful [4]. The criteria for eligibility into a program is the probability a participant will be successful based on their information at intake. With the HF program, it is not clear which cohorts will be successful [14]. Since simply relying on demographics is not sufficient, the motivating scenarios arise from the need to understand the interaction between clients and services as they participate in the program to meet their needs.

2.3. Competency Questions

The focus of the competency questions for OSSN is to answer queries about the relationship between client needs and service providers captured by SPDAT questionnaires. Client questions address the three main concepts captured about clients, their needs, constraints, and demographics. For the complete list of questions see [5].

Q-1 Which demographic is asking for MH need X most?
Q-2 Does client X ask for goals in the same order as client Y?

[2]The Calgary Homeless Foundation: `http://calgaryhomeless.com/`.

Q-3 What constraints clients with demographic X?
Q-4 Are wrong conditional goals assigned to any client?
Q-5 What services are needed together to address "childcare goals"?
Q-6 What resources and service are needed to address a client's security level needs?
Q-7 How well do programs address physiological and security needs of clients?
Q-8 Are resources available when needed?

The first group is a sample of questions (Q-1 to Q-4) that examine the ontology's ability to represent data provided in the CHF-HF SPDAT dataset. Focus is placed on the requests made by clients. This includes mapping the requests to Maslow's hierarchy, capturing the order of requests, and associating them with possible motivations and constraints that prompted the requests. Using the provided demographics, OSSN infers the correct MH level to map participant requests to. The second group is a sample of questions (Q-5 to Q-8) that evaluate the ontology's ability to capture services available to clients. By associating services with client constraints, the objective is to answer questions about service provisioning from the perspective of the client.

3. Engineering the Ontology of Social Service Needs

To engineer our ontology of needs, we first analyze how Maslow's hierarchy can be applied to this domain to create a domain-specific mapping. We then identify high-level concepts required to categorize requests and present axioms included in the ontology.

3.1. Maslow's Needs for Homeless Clients

While basic motivation for human needs is ill-defined [9], there is some consensus that behaviour models can rely on theories like Maslow's hierarchy (MH) for grounding goals in basic human needs [10]. A need can be considered as a "master" goal, an innate requirement for an agent without a triggering activity. Such needs always exist with varying degrees of urgency. All other goals or sub-goals are regarded as tangible states that can be achieved and satisfied through a series of activities. MH categorizes tangible goals into five categories of basic human needs. While there is mostly consensus on the categories, there is less consensus on the correct order of MH levels and whether it can be applied universally across populations and cultures [13,7]. Generally, the first group of needs are short-term needs important to our survival. The second group includes long-term needs that serve to improve our life and society at large.

The mapping of goals to MH level needs is especially problematic for the homeless population. Mappings are conditional on a combination of demographics, goal types, and previously satisfied goals [12,7]. For example, *housing* (long term) and *housing temp(orary)* is only a physiological level need for absolutely homeless, and a security need for relatively homeless. Also, family needs are not necessarily a social level need. For example, when providing for a child's needs, the goal is mapped based on the needs of the child. However, any motivations and constraints are those of the agent. Also, not all mappings are direct, one-to-one mappings between a need and an MH level, as discussed in section 4. Some span multiple levels at once, while others are spread across multiple levels to be satisfied in a sequence over an extended period of time. For example, requesting *laundry* services impacts a client's self esteem, ability to socialize, and

Table 1. Maslow's hierarchy of needs mapped to SPDAT requests according to [5].

MH Need	SPDAT Request
None	None, declined to answer
Self-actualization	Addiction support, case management, child care, education, employment training, family support, goods misc, life skills, referral, social
Esteem	Computer, counseling, debt reduction, disability support (for relatively homeless), education, employment training, family support, forms, goods family, goods infant, goods misc, hygiene, identification, laundry, life skills, money family, money planning, money social, phone (for non-elderly), referral, tenant insurance support, transportation
Social	Aboriginal, child care, computer, counseling, disability support (for relatively homeless), education, forms, health support, hygiene, immigrant services, laundry, life skills, miscellaneous support, money family, money social, phone (for non-elderly), referral, social, social family, transportation, utility arrears
Security	Advocacy help, advocacy legal, child care, clothing, counseling, disability support (for absolutely homeless), don't know, forms, goods infant, goods misc, health support, housing (for relatively homeless), housing goods, housing maintenance, housing safety, housing supplement, housing temp (for relatively homeless), hygiene, identification, immigrant services, income, laundry, medication, mental issues, money goods, money health, moving, phone (for elderly), referral, rent arrears, rent shortfall/subsidy, security, security deposit, tenant insurance support, transportation, utility arrears
Physiological	Addiction support, food, furniture, home goods, housing (for absolutely homeless), housing temp (for absolutely homeless), mental issues

prevents violence from others, hence is spans the esteem, social, and security levels. The final mappings for 57 goal types consolidated from the 18 request types captured by the SPDAT questionnaire section in Figure 1, including 745 entered by clients in the "other" fields, are provided in Table 1 with a complete analysis in [5].

3.2. Ontology of Social Service Needs

Based on the client requests captured in the CHF-HF dataset and directly, conditionally or unconditionally mapped to MH levels, the following ontological entities are represented. An agent's relation to their goals and the services they use is represented by the Ontology of Social Service Needs (OSSN). This relation is comprised of its Maslow **need** and order ranking, followed by a concrete **goal** requested by a participant, personal **motivation** for that goal, and **constraints** preventing goals from being satisfied. The agent's need is mapped to an MH level. **Motivation** is a description of why an agent might want to pursue this goal. It provides additional information for mapping a goal to the appropriate MH level. For example, "childcare" is a broad category of needs associated with the agent's child's needs. The motivation to keep a child out of harm's way would associate a goal with the physiological level, as it prevents physical harm. This may include a request for emergency childcare and contacting child protective services. Child care may also be motivated by wanting to raise well-adjusted and social children and mapped to the agent's esteem level.

The service provider is represented with resources and services that relieve an agent's constraints. A **constraint** is a high-level summary of unsatisfied preconditions preventing an agent from achieving their goals. The preconditions are satisfied by social services that provide **resources**. For example, the constraint preventing an agent from providing toys or social activities for their children might be a lack of money or not

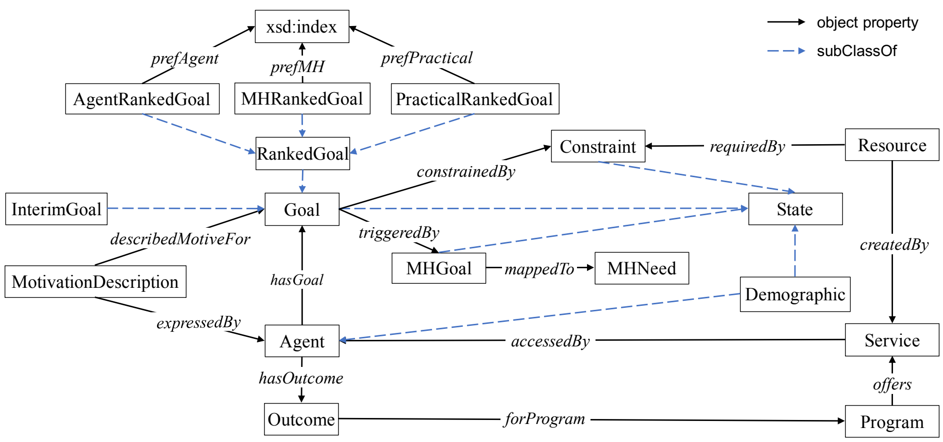

Figure 2. Ontology of Social Service Needs knowledge graph.

knowing about available activities (i.e. lack of information). The **service** represents the service provider, program, or department that makes the resource available to the agent.

3.3. OSSN: Formal Definitions

This section provides the formal definitions for OSSN, represented in OWL syntax [8]. The OWL (Web Ontology Language) was chosen since it is one of the most common ontology languages on the Semantic Web. Main OSSN classes and properties are represented in Figure 2. **Agents and Goals** Clients are represented as human-like and goal-driven agents. Hence, the property *hasGoal* defines the *Agent* class as one that has at least one *Goal* state, as per Axiom 1. Axiom 2 defines the *Goal* class as a state triggered by some underlying MH need, but constrained from being true. The $MotivationDescription$ class captures the agent's expressed motivation for requesting a goal, as per Axiom 3.

$$Agent \sqsubseteq \exists hasGoal.Goal \tag{1}$$
$$Goal \sqsubseteq State \sqcap \exists triggeredBy.MHGoal \sqcap \exists constrainedBy.Constraint \tag{2}$$
$$MotivationDescription \sqsubseteq \exists describedMotiveFor.Goal \sqcap \exists expressedBy.Agent \tag{3}$$

Goal Constraints A goal state is constrained by the $Constraint$ class, a state that summarizes unmet preconditions that prevent the goal state from being true. For example, an agent cannot buy food from a store if they do not have money. Having money is a precondition state that must be true before purchasing food. The state $lackOfMoney$ is a $Constraint$ that prevents the *Goal* class *moneyForFood* from becoming true. For a state to be a constraint, it must also be resolvable by a resource. A non-resolvable constraint identifies an incorrect goal or action. For example, requesting legal advocacy from a housing worker describes an incorrect action if the goal is to find housing. Hence a $Constraint$ class is a $State$ class that requires a *Resource* class ($requiredBy^{-}.Resource$) and is actively constraining a *Goal* class ($constrainedBy^{-}.Goal$), as defined in Axiom 4.

$$Constraint \sqsubseteq State \sqcap \exists requiredBy^{-}.Resource \sqcap constrainedBy^{-}.Goal \tag{4}$$

MH Goals And Interim Goals Requests made by agents to satisfy expressed goals are triggered by an underlying MH level need associated with it. $MHGoal$ represents such a need that triggers the requested goal. Each *MHGoal* is mapped to one or more MH levels. For example, while *moneyForFood* is a *Goal*, *notBeHungry* is the *MHGoal* state that triggers it. *notBeHungry* is then mapped to the "physiological" MH level. In OSSN, the *triggeredBy* property captures the relation between a requested *Goal* and its underlying *MHGoal*. The *mappedTo* property captures the relation between the *MHGoal* and its underlying MH level class *MHNeed*. These classes are defined in Axioms 5 and 6.

$$MHGoal \sqsubseteq \exists triggeredBy^{-}.Goal \sqcap \exists mappedTo.MHNeed \quad (5)$$

$$MHNeed \equiv \exists mappedTo^{-}.MHGoal \sqcap \{physiological \sqcup security \sqcup social \sqcup esteem \sqcup selfActualization\} \quad (6)$$

$$InterimGoal \sqsubseteq Goal \sqcap \neg \forall mappedTo.MHNeed \quad (7)$$

Finally, interim goals are sub-goals required to satisfy preconditions of actions that satisfy existing goals. For example, walking to the store to buy food is an interim goal. The *InterimGoal* class is defined as a subclass of *Goal* that is *not* mapped directly to an MH level, as defined by Axiom 7.

Agent Demographics An agent's demographics are used to automatically infer conditional mapping. A conditional goal is a type of *MHGoal* class mapped to an MH level based on an agent's *Demographic* class. For example, consider the examples in section 3.1. The goal of temporary shelter for agents in the "absolutely homeless" demographic is mapped to the physiological MH level. For agents in the "relatively homeless" it is mapped to the security MH level. A *Demographic* is a subclass of *State* class that defines the state of an agent, as per Axiom 8.

$$Demographic \sqsubseteq State \quad (8)$$

$$\top \sqsubseteq \forall homelessState.\{abs, rel\} \quad (9)$$

$$AbsHomeless \equiv Demographic \sqcap homelessState : abs \quad (10)$$

$$RelHomeless \equiv Demographic \sqcap homelessState : rel \quad (11)$$

$$AbsHomelessAgent \sqsubseteq Agent \sqcap AbsHomeless \quad (12)$$

$$RelHomelessAgent \equiv Agent \sqcap RelHomeless \quad (13)$$

$$\bot \sqsubseteq AbsHomeless \sqcap RelHomeless \quad (14)$$

Demographic properties define the actual "demographic" state true for the agent. For example, the following axioms define how to identify an agent as either absolutely or relatively homeless. First, the property *homelessState* in Axiom 9 has a range of "abs" and "rel" to represent an absolutely and relatively homeless status, respectively. Next, Axiom 10 defines the *AbsHomelessState* class as the intersection of the *Demographic* class and a class for which *homelessState=abs*. Similarly, Axiom 11 defines the *RelHomelessState* class as the intersection of the *Demographic* class and a class for which *homelessState=rel*.

Next, to assert that an agent is absolutely homeless, *AbsHomelessAgent* is the subclass of the intersection between the *Agent* and *AbsHomeless* classes, as defined in Axiom 12. For some agent *A* the assertion *AbsHomelessAgent*(*A*) categorizes *A* as an absolutely homeless agent. Its relatively homeless counterpart is defined in Axiom 13. Since absolutely and relatively homeless types are disjoint sets, having the same agent classified as both produced an inconsistent ontology, as per Axiom 14.

Service Provider and Resources The service provider is represented by the *Service* class. A service is something that can be accessed by an agent and creates resources, as defined in Axiom 15. For example, a "social worker" is a multi-functional service offered by a shelter. A social worker can provide a variety of resources, such as booking a bed, information about childcare, or finding a suitable mentor. It follows then, that the *Resource* class is defined as something a service creates and that is required by a *Constraint* class, as defined by Axiom 16.

$$Service \sqsubseteq \exists accessedBy.Agent \sqcap \exists createdBy^{-}.Resource \tag{15}$$
$$Resource \sqsubseteq \exists createdBy.Service \sqcap \exists requiredBy.Constraint \tag{16}$$

Program and Agent Outcome The last set of main classes OSSN supports are those that capture an agent's outcome in a program that offers multiple services. An agent can access a service, but their outcome is evaluated in the context of the program. Hence, a *Program* class is defined as the intersection of classes that offer a *Service* and have an *Outcome*, as per Axiom 17. The *Outcome* class relates an agent's status to a program, as per Axiom 18, with possible statuses as *success*, *fail*, *missing*, or *active*.

$$Program \equiv \exists offers.Service \sqcap \exists forProgram^{-}.Outcome \tag{17}$$
$$Outcome \equiv \exists forProgram.Program \sqcap \exists hasOutcome^{-}.Agent \tag{18}$$

3.4. Ranked Goals

Ranking goals allows a cognitive agent to reason about goals in terms of their importance to the agent [3]. A goal state can be preferred over another. If a preference is assigned to a goal it is considered a subclass of the *RankedGoal* class, with a unique ordering relation. A *RankedGoal* is any goal that has an integer preference assigned to it with the *pref* data property, as defined by Axiom 19. However, goals can be ranked based on one of three order relations.

$$RankedGoal \sqsubseteq Goal \sqcap \exists pref : xsd{:}integer \tag{19}$$
$$AgentRankedGoal \sqsubseteq RankedGoal \sqcap \exists hasGoal^{-}.Agent \sqcap \exists prefAgent : xsd{:}integer \tag{20}$$
$$MHRankedGoal \sqsubseteq RankedGoal \sqcap \exists prefMH : xsd{:}integer \tag{21}$$
$$PracticalRankedGoal \sqsubseteq RankedGoal \sqcap \exists prefPractical : xsd{:}integer \tag{22}$$

First, during the planning phase, the agent uses their own preferred goal order to calculate the utility of each plan. The agent's preferred ranking is represented by the *AgentRankedGoal* class as defined in Axiom 20. It is a subclass of the intersection between a *RankedGoal*, and a class with both *prefAgent* and *hasGoal* relations. For example, given *Goal* states s_i and s_j along with the assertions $hasGoal(A, s_i)$, $hasGoal(A, s_j)$, $prefAgent(s_i, 1)$, and $prefAgent(s_j, 2)$, the goal state s_i is preferred by agent A over s_j.

During the plan execution phase, Maslow's classical order is used to calculate the utility of goal state as actions to satisfy them are executed. The MH order is represented by the property *prefMH*. A goal ranked by MH is an *MHRankedGoal* class as defined in Axiom 21. It is a subclass of the intersection between a *RankedGoal* and a class with *prefMH* relation to an integer value. For example, the goal *Food* is an *MHGoal* mapped to the physiological *MHNeed*. The assertion $prefMH(Food, 1)$ would specify that the physiological level *Food* is mapped to is the most important. For each MH level, a specific ranking class that relates prefMH to the type of *MHGoal* it is triggered by:

$$GoalPhysiological \sqsubseteq prefMH:1 \sqcap \exists triggeredBy.MHGoalPhysiological \quad (23a)$$
$$GoalSecurity \sqsubseteq prefMH:2 \sqcap \exists triggeredBy.MHGoalSecurity \quad (23b)$$
$$GoalSocial \sqsubseteq prefMH:3 \sqcap \exists triggeredBy.MHGoalSocial \quad (23c)$$
$$GoalEsteem \sqsubseteq prefMH:4 \sqcap \exists triggeredBy.MHGoalEsteem \quad (23d)$$
$$GoalSelfActualization \sqsubseteq prefMH:5 \sqcap \exists triggeredBy.MHGoalSelfActualization \quad (23e)$$

Finally, the practical ranking of goals represents the order in which goals were satisfied during plan execution. This order is observed in the outcome of a plan following its execution. The data property *prefPractical* captures this relation, as defined in Axiom 22. The practical rank is captured by logging the execution of a plan. For example, the goals s_i and s_j ranked by agent A above can be satisfied in reverse order. The assertions $prefPractical(s_i, 2)$ and $prefPractical(s_j, 1)$ capture this order.

4. Mapping CHF-HF Data to OSSN

An application of OSSN is to infer the mapping of requests captured by CHF-HF data in using an ontological representation. All recorded requests were combined into 57 basic needs associated with one or more levels of Maslow's hierarchy. A sixth level was added for non-answers like "Don't know". The entire mapping between CHF-HF basic needs and MH levels is provided in [5]. The following sections provide ontological definitions required to map goals directly, conditionally, or to multiple MH levels.

4.1. Mapping Direct Goals In OSSN

Direct-mapping goals are those directly associated with a single MH level. Consider the following OWL examples of clothing and advocacy needs. A request made for an article of clothing is directly mapped to the security level, as defined by Maslow [10], hence a request for clothing is the expressed **goal** and **MH goal** mapped to the security **MH need**. The agent's **motivation** for clothing is simply to "be clothed." The concrete **goal** requested is to get "help with buying or receiving clothing." The **constraint** faced by an agent is "lack of money." The **resource** where an agent can receive information about obtaining clothing without money is a "charity." Finally, the **service** offered by the charity that provides clothing is a "donation centre." As a direct mapping, any goals of type *GoalClothing* are mapped to the same security level. Hence, any *MHGoal* triggered by a *GoalClothing* type is equivalent to a security class, with no other properties required, as per Axiom 24.

$$MHGoalClothing \equiv MHGoalSecurity \sqcap \exists triggeredBy^{-}.GoalClothing \quad (24)$$

4.2. Mapping Conditional Goals In OSSN

Conditional goal-mapping requires some agent specific condition to identify which MH level a requested need is mapped to. Unlike the directly mapped goals for clothing, conditional mappings are inferred from the intersection of an agent's demographic and their specific need. Consider a request for "temporary housing" at some shelter. Such requests are categorized differently for absolutely and relatively homeless clients. For absolutely homeless it is a physiological **MH need**, while for the relatively homeless it is a security **MH need**. In OSSN an agent's homeless state is a demographic defined by Axioms 12 and 13 for absolutely and relatively homeless respectively. For both types of homeless agents, the **MH goal** is to find "temp housing shelter" **motivated** by wanting "temporary housing for a short time." The requested **goal** is "get help to find temp housing." The **constraint** faced by the agent is not knowing which beds are available and in which shelters. The **resource** is a temporary bed available at a shelter. The **service** is a social worker that provides information about the bed. Mapping the MH goal to an MH level is inferred from the agent's homeless state and goal type, as per Axioms 25 to 29.

$$GoalForAbsHomeless \sqsubseteq \exists hasGoal^{-}.AbsHomelessAgent \tag{25}$$

$$MHGoalTempHousingPhysiological \sqsubseteq MHGoalPhysiological \sqcap \exists triggeredBy^{-}.GoalForAbsHomeless \sqcap \exists triggeredBy^{-}.GoalTempHousing \tag{26}$$

$$MHGoalTempHousingPhysiological \sqsubseteq MHGoalPhysiological \sqcap MHGoalPhysiological \tag{27}$$

$$MHGoalTempHousingSecurity \sqsubseteq MHGoalSecurity \sqcap \exists triggeredBy^{-}.GoalForRelHomeless \sqcap \exists triggeredBy^{-}.GoalTempHousing \tag{28}$$

$$MHGoalTempHousingSecurity \sqsubseteq MHGoalSecurity \tag{29}$$

First, an absolutely homeless goal class *GoalForAbsHomeless* is any goal that is requested by an absolutely homeless agent, as per Axiom 25. Second, a request for temporary housing, say $getTempHousing2$, is asserted as $GoalTempHousing(getTempHousing)$. Mapping this goal to the physiological MH level is conditional on the agent being absolutely homeless as per Axiom 26. The *MHGoalTempHousingPhysiological* class, as per Axiom 27, is also defined as the subclass of $MHGoalPhysiological$. For relatively homeless agents, temp housing goals are mapped to the security level, as per Axiom 28. Similarly to the physiological goal in Axiom 27, the $MHGoalTempHousingSecurity$ class is also defined as the subclass of $MHGoalSecurity$ in Axiom 29.

4.3. Mapping Unconditional Goals In OSSN

Many OSSN needs are mapped to multiple MH levels at once. For example, doing laundry is mapped to security, social, and esteem MH level needs. Laundry is a request that impacts at multiple MH level **needs**, mainly security, social, and esteem. Each is mapped to the same **MH goal** to "feel safe with others," as per the assertions in Axioms 30 a to c. The **constraint** faced by the agent is that they do not have money to pay for their own laundry. The **resource** is the free laundry facility they can access. Finally, the **service** provider is a shelter that is offering free laundry service.

$$MHGoalLaundrySecurity(feelSafeWithOthers) \tag{30a}$$

$$MHGoalLaundrySocial(feelSafeWithOthers) \tag{30b}$$

$$MHGoalLaundryEsteem(feelSafeWithOthers) \tag{30c}$$

5. Discussion

The OSSN provides an ontological representation of a client's motivations, goals, and different ways goals are ranked. The focus is placed on how the service can relieve constraints exhibited by the agent, which resources are required, and which services provide those resources. The service provisioning is not centred around service efficiency, but on satisfying the underlying constraints faced by clients. To this end, the CHF-HF dataset captures client needs as they participate in the housing first intervention program. Since needs were collected every three months, the data also captures how a client's needs change over time. By identifying three different goal orderings, changing order of goals and their rankings can be represented and used for goal reasoning by a cognitive agent. Depending on the agent's demographics, OSSN infers how goals should be mapped to Maslow's hierarchy.

Following the ontology engineering method, motivating scenarios proposed in section 2.2 identify the scope and focus for the development of OSSN. Competency questions identify issues that should be addressed and what vocabulary is required to answer them. For lack of space, the complete results and analysis are presented in [5]. Overall, the ontology performs well on questions that relate to client and service types. The relationship between clients and goals is well represented, where SPARQL queries are able to ask and answer questions about demographics and goals. OSSN is also capable of answering queries about service provisioning. By relying on the *Outcome* class, OSSN can answer some queries that relate to the progress participants make in a program. OSSN has several limitations. Any questions with a temporal dimension are not supported by OSSN. For example, the rate at which resources are used or when they become unavailable cannot be answered by OSSN.

6. Related Work

Several ontologies overlap with the proposed ontology and address some of the competency questions. These, however, are service-oriented, focusing on modelling processes and constraints of the service provider rather than the impact on client outcomes. The Open Eligibility Project (OEP) is a taxonomy of service categories offered to clients [1]. The agent is represented by the "human situations" category. It includes age group, citizenship status, criminal history, disabilities, health, household, and urgency. However, each term lacks a definition leaving them open to interpretation. For example, emergencies are simply qualified as "In Crisis," "In Danger," or "Emergency." The GCI ontology focuses on housing and classifies clients as absolutely or relatively homeless [15]. The resources available to the clients are different types of housing. The competency questions GCI addresses focus on details about specific households and aggregate information about city resources and household types. For example, GCI can answer who the individuals in a particular household are and whether that household is considered a "slum household." The INSPIRE ontology captures processes and resources of service providers focusing on elderly and adults living with disabilities [11]. Client needs can be categorized as physical or social, or a combination of the two, along with an urgency indicator. This is used to efficiently identify the appropriate department to transfer a client. The competency questions INSPIRE can answer focus on service assignment. Services and internal workflows are well represented, while client needs and underlying symptoms are not.

7. Conclusion and Future Work

Up to now, the client's perspective of social service policy evaluation has been missing. The work presented here fills this gap by providing an ontological representation of a client's motivations, goals, and different ways goals are ranked. The Ontology of Social Service Needs (OSSN) identifies the semantic relations between requests made by a client to a service provider, based on data provided by real-life clients about their changing needs while participating in a real intervention program. The ontology provides a goal ranking used by cognitive agents to prioritize goals while planning their actions. The ontology was evaluated by answering certain competency questions. The questions that were not answered are the basis for future work. This involves goal reasoning and planning to simulate a client's interaction with service providers.

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Modeling Affordances with Dispositions

Fumiaki TOYOSHIMA [1]
Graduate School of Advanced Science and Technology, JAIST, Japan

Abstract. Affordance remains obscure conceptually and formally notwithstanding its paramountcy to the ecological approach to perception, cognition, and action. This paper aims to offer a preliminary work to a full-fledged formal modeling of affordance. Characteristic of the approach of the paper is to base M. T. Turvey's dispositional theory of affordance upon the formal representation of dispositions that is elaborated in the existing ontology research. This work will contribute to the research to which the agent-environment interaction is integral.

Keywords. affordance, disposition, environment, perception, formal modeling

1. Introduction

The term 'affordance' was coined by Gibson [1] to pin down precisely the interaction between animals and the environment: "The *affordances* of the environment are what it *offers* the animal, what it *provides* or *furnishes*, either for good or ill" [1, p. 119]. For instance, a gap affords hiding when it is of a certain size relative to the size of a person and a stair affords climbing when it is a certain proportion of a person's leg length.

The notion of affordance has been since utilized in a number of different domains, ranging from philosophy and cognitive science to engineering fields such as robotics [2,3]. It would be therefore valuable to axiomatize this cross-disciplinary notion in order to conceptualize the real world coherently. This would help to provide a general framework for enhancing the integration of empirical data on agents' cognition. The ontological nature of affordance is nonetheless such a highly controversial subject that one can nowadays find numerous theories of affordance (e.g., [4,5,6,7]).

In this paper I offer a preliminary formalization of the notion of affordance so that its full-fledged version will be implementable and available in information systems. I begin by presenting Turvey's [8] dispositional account of affordance, which would fit well with the formal ontological conception of affordance (Section 2). Then I attempt a formal characterization of the affordance concept (Section 3) and provide a brief, opinionated survey of related work (Section 4). I conclude the paper with some brief remarks on future directions of research (Section 5).

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[1] Corresponding Address: Graduate School of Advanced Science and Technology, Japan Advanced Institute of Science and Technology (JAIST), 1-1 Asahidai, Nomi, 923-1292, Japan; E-mail: fumiaki.toyoshima@jaist.ac.jp, fumiakit@buffalo.edu.

2. Affordances and Dispositions

Turvey [8] offers a dispositional theory of affordance. Here I detail the notion of disposition for the sake of my future argument. A disposition is an intrinsic property with a 'causal profile' [9,10].[2] In more detail, it is a property of some object ('bearer') which brings about some state of affairs ('realization') when it is stimulated ('triggered') by some state of affairs under some specific circumstances ('background conditions'). It is additionally based on some non-dispositional (categorical) property ('base') [12].[3]

Examples include the flammability of a match. The flammability disposition of the match (bearer) is realized when it is struck against a suitable surface (trigger) in an oxygenated environment (background condition), thereby bringing about the production of fire (realization). It is also based on a particular molecule structure (base) of the match. Moreover, some dispositions are *reciprocal*: they are *mutually* realized when matched with their 'partner' dispositions [14]. For instance, the disposition of salt to dissolve is realized when met with the disposition of solvent (e.g., water) to dissolve a solid.

Turvey's fundamental presumption is that one of the key features of animal activity is its prospective control (PC): "control concerned with future events, usually interpretable as goals to be realized" [8, p. 174]. To walk across a cluttered room, for instance, an agent needs to know what (bodily movement) is *possible*. The ecological approach to PC therefore requires that affordances be perceivable in such a way that they are closely linked with the possibilities of the environment with respect to which PC is conducted.

Granted that dispositions essentially carry inside them potency, all these considerations lead to the idea that an affordance is the kind of disposition whose reciprocal disposition (what Turvey calls 'effectivity') has as bearer an organism.[4] For instance, the affordance of the stairs is their disposition to move an organism upward. It is based on the physical structure (i.e. a set of steps) of the stairs and it is realized only when an organism that has the disposition (effectivity) to move upward locates itself in the vicinity of the stairs. The affordance disposition of the stairs and the organism's effectivity disposition are mutually realized, thereby bringing about the organism's climbing the stairs.

A dispositional theory of affordance would mesh well with the formal ontological treatment of affordance in some respects, although its theoretical validity is a contentious matter (but see Section 4). First, the concept of disposition has been so extensively exploited in the ontology research (e.g., in the biomedical [15] and engineering [16] domains) that it would be more acceptable to employ dispositions than to introduce some new concept.[5] Second, a formal representation of dispositions has been investigated [13,18] well enough to enable us to have a rich formalization of affordances as dispositions in the long run.

[2] As the standard account goes, a property is intrinsic if an entity's having that property depends on what the entity is like and not on anything else outside the object. See e.g., Francescotti [11] for detailed discussions on intrinsic properties.

[3] I follow Röhl and Jansen's [13] terminology for dispositions because it is widely used in formal ontology, although I myself prefer to use the terms 'power' and 'manifestation' instead of 'disposition' and 'realization', respectively.

[4] Strictly speaking, there is a subtle but non-trivial difference between Turvey's [8] own claim that affordances and effectivities are *complementary* and my reinterpretation of his dispositional view of affordances based on the notion of reciprocal dispositions. While leaving a close analysis of this point for future work, I would say that I am making his theory more defensible by softening the claim under consideration.

[5] Note the noticeable skepticism over dispositions in the context of formal ontology, however (e.g., [17]).

3. Preliminary Formalization

3.1. Basic Assumptions

I provide a preliminary first-order formalization of the dispositional conception of affordance along Turvey's [8] line of argument. All the variables presented below should be read as particulars (at the instance level) rather than universals (at the class level).

I commence with the basic categories and relations that are comparatively widespread in upper ontologies. Concrete individuals fall into two types: continuants (aka endurants) (CONT) and occurrents (aka perdurants) (OCUR). Generally speaking, continuants exist in time, whereas occurrents extend through time. One major subcategory of continuants is objects (OBJ). As for the relations, I introduce the participation-in relation $\mathsf{participates\_in}(x,y,t)$ where x is an object, y is an occurrent, and t is a time.

As for dispositions (DISP), I use Röhl and Jansen's [13] formal relations and assume their axioms (which I omit to present owing to spatial limitations). That is to say, a disposition is a property of ($\mathsf{inheres\_in}$) some object; it can be realized in ($\mathsf{has\_realization}$) some occurrent; and it is also triggered by ($\mathsf{has\_trigger_D}$) some occurrent.

I additionally introduce the relation ($\mathsf{backcon\_of}$) between a background condition of a disposition and the disposition. I leave open whether the former is a continuant or an occurrent, partly because of its general conceptual underdevelopment[6]:

$$\mathsf{backcon\_of}(x,y) \rightarrow (\mathsf{CONT}(x) \vee \mathsf{OCUR}(x)) \wedge \mathsf{DISP}(y) \tag{1}$$

3.2. Formal Characterization

First of all, there exist an organism, or more generally an agent (AGE), and a non-agentive object such as the stairs. Agents are objects. For the sake of simplicity I introduce the predicate NAG for a non-agentive object, which is straightforwardly defined as follows:

$$\mathsf{AGE}(x) \rightarrow \mathsf{OBJ}(x) \tag{2}$$

$$\mathsf{NAG}(x) \leftrightarrow \mathsf{OBJ}(x) \wedge \neg\mathsf{AGE}(x) \tag{3}$$

Most importantly, affordances (AFOD) are dispositions that inhere in non-agentive objects and effectivities (EFEC) are dispositions that inhere in agents:

$$\mathsf{AFOD}(x) \rightarrow \mathsf{DISP}(x) \wedge \exists y(\mathsf{NAG}(y) \wedge \mathsf{inheres\_in}(x,y)) \tag{4}$$

$$\mathsf{EFEC}(x) \rightarrow \mathsf{DISP}(x) \wedge \exists y(\mathsf{AGE}(y) \wedge \mathsf{inheres\_in}(x,y)) \tag{5}$$

Since Turvey focuses mainly on affordances for actions (ACT), which would be interpreted as occurrents in which an agent participates, a realization of an affordance is an action and so is a realization of an effectivity:

$$\mathsf{ACT}(x) \rightarrow \exists y(\mathsf{AGE}(y) \wedge \mathsf{participates\_in}(y,x)) \tag{6}$$

$$\mathsf{AFOD}(x) \wedge \mathsf{has\_realization}(x,y) \rightarrow \mathsf{ACT}(y) \tag{7}$$

[6] See e.g., Barton, Rovetto and Mizoguchi [19] for some thoughts on a background condition of a disposition.

$$\mathsf{EFEC}(x) \wedge \mathsf{has\_realization}(x,y) \rightarrow \mathsf{ACT}(y) \tag{8}$$

It is rather difficult to specify the reciprocal relationship between affordances and effectivities within the present framework.[7] Here I impose the following constraints on the relationship between them. The triggering occurrent of an affordance has as participant a bearer of some effectivity and vice versa. In addition, a realization of an affordance is also a realization of some effectivity and vice versa:

$$\mathsf{AFOD}(x) \wedge \mathsf{has\_trigger_D}(x,y) \rightarrow \exists z,w(\mathsf{EFEC}(z) \wedge \mathsf{inheres\_in}(z,w) \wedge \mathsf{participates\_in}(w,y)) \tag{9}$$

$$\mathsf{EFEC}(x) \wedge \mathsf{has\_trigger_D}(x,y) \rightarrow \exists z,w(\mathsf{AFOD}(z) \wedge \mathsf{inheres\_in}(z,w) \wedge \mathsf{participates\_in}(w,y)) \tag{10}$$

$$\mathsf{AFOD}(x) \wedge \mathsf{has\_realization}(x,y) \rightarrow \exists z(\mathsf{EFEC}(z) \wedge \mathsf{has\_realization}(z,y)) \tag{11}$$

$$\mathsf{EFEC}(x) \wedge \mathsf{has\_realization}(x,y) \rightarrow \exists z(\mathsf{AFOD}(z) \wedge \mathsf{has\_realization}(z,y)) \tag{12}$$

I finally consider the environment (ENV). From the current perspective, the environment would be seen as a continuant that is a background condition of an effectivity disposition:

$$\mathsf{ENV}(x) \rightarrow \mathsf{CONT}(x) \tag{13}$$

$$\mathsf{ENV}(x) \rightarrow \exists y(\mathsf{EFEC}(y) \wedge \mathsf{backcon\_of}(x,y)) \tag{14}$$

When Mary is about to climb the stairs, for instance, her environment contains the available space between the stairs and her, but not the surface of the planet Mars. This is, on the present interpretation, because the former (but not the latter) is part of the background condition of Mary's effectivity disposition to climb the stairs. Given the systematicity of a background condition of a disposition, this view of the environment matches the intuition that the environment is something systematic.[8]

4. Related Work

As for conceptual work, Reed [4] considers affordances as the resources of the environment that are encountered by animals.[9] His theory would however imply the primacy

[7] It would be necessary to introduce, for instance, the reciprocal relation between dispositions [20, p. 104], but a full discussion of this topic is beyond the scope of my investigation.

[8] Built in alignment with the upper ontology Basic Formal Ontology (BFO) [20], for instance, the environmental ontology [21,22] defines the class *environmental system* (which is synonymous with the environment) as a 'system which has the disposition to environ one or more material entities' where a system is a 'material entity (note: the BFO category) consisting of multiple components that are causally integrated'.

[9] "The fundamental hypothesis of ecological psychology (...) is that *affordances and only the relative availability (or nonavailability) of affordances create selection pressure on the behavior of individual organisms; hence, behavior is regulated with respect to the affordances of the environment for a given animal*." [4, p. 18]

of the environment over animals in tension with the ecological approach to the animal-environment interaction. Sanders [5] maintains that “affordances are ideal primitives for general ontology” [5, p. 103], but this claim is too extreme to fit well with my aim to give a formal-ontological modeling of affordance. Stoffregen [6] argues that affordances are properties of the animal-environment system: they are *emergent properties* that do not inhere in either the environment or the animal.[10] The ontological nature or even the existence of emergent properties is nonetheless highly debatable (see e.g., [23]).[11]

As for formal work, Steedman [24] formalizes affordances using the Linear Dynamic Event Calculus: a formalism for reasoning about causal relations over events. My proposal may be said to underlie his model because the triggering occurrent of the affordance disposition bears a causal relation to its realization occurrent (cf. [25]). Galton [26] formally addresses the question of where a given surface layout of an object determines and possesses a particular group of affordances. My formalization could be harmonized with Galton’s in such a way that he investigates the relation between the affordance disposition and its physical base from the viewpoint of knowledge representation.

Şahin et al. [27] formalize affordances based on three perspectives on them (the second of which they take to be central to Turvey’s account): *agent perspective*, *environmental perspective*, and *observer perspective*. Capturing the first perspective in terms of Turvey’s original idea of the effectivity disposition (which tends to be neglected in the literature), my formal modeling can be coherently enlarged to accommodate the third one, together with the auxiliary claim that the *capacity disposition* (e.g., [28]) of the observer is necessary for the mutual realization of the affordance and effectivity dispositions.

Ortmann and Kuhn’s [29] extension of their ontology of observations to include Turvey’s view of affordance is fairly close to, but nevertheless differs relevantly from my approach in the sense of focusing more on the agentive and perceptual facet of affordances than their ontological (dispositional) one. This may be partly due to their compliance with the DOLCE [30] upper ontology, which purports to represent the categories with a clear cognitive bias and which does not explicitly have the disposition category.

5. Conclusion

I have proposed a preliminary formalization of the affordance concept based on Turvey’s dispositional account of affordances, borrowing a formal representation of dispositions from the existing ontology research. In the future I will deepen the formal modeling of affordances, e.g., by having a more expressive formalization of dispositions. Once the (full) formalization is available, I will apply it to, e.g., the implementation of the robot’s dynamic interaction with its environment and other agents (including humans) [2,3,27].

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[11] Moreover, the emergent properties of the animal-environment system may be, if any, better explicable in terms of its *collective disposition* [15]: the disposition of the animal-environment system in virtue of the affordance disposition of the environment and the effectivity disposition of the animal.

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First Steps Towards an Ontology of Belief

Adrien BARTON[a,1], William DUNCAN[b,1], Fumiaki TOYOSHIMA[c] and Jean-François ETHIER[a,1]
[a] *GRIIS, Université de Sherbrooke, Québec, Canada*
[b] *Roswell Park Comprehensive Cancer Center, Buffalo, NY, USA*
[c] *Graduate School of Advanced Science and Technology, JAIST, Japan*

Abstract. This paper presents first steps towards a formalization of beliefs. It argues for the multiple nature of beliefs: the term "belief" can refer to a mental process of taking something to be the case, or to a disposition realized by such a mental process. The categorical basis of a disposition-belief has as part the concretization of an information content entity, which is in a relation of aboutness with the entities concerned by this belief.

Keywords. Belief, disposition, process, plan, intention, information content entity, aboutness, quality

1. Introduction

Belief is a central construct in several artificial intelligence models of agency – such as the Belief-Desire-Intention (BDI) model [1]; an ontological formalization of beliefs would therefore be highly valuable. For example, we might want to formalize patient's beliefs underlying their adherence or non-adherence to medication prescriptions [2] (e.g. beliefs about a medication's efficacy). Currently, the Mental Functioning Ontology (MF [3]), an OBO Foundry candidate [4], classifies belief as a *Mental disposition*, without further analysis (but see the recent [13]). This paper will present why it makes sense to classify belief as a disposition, and argues that there is also another kind of belief, namely occurrent belief. It should also be possible to extend this account to other ontological frameworks formalizing dispositions, such as UFO [5] – a foundational ontology tailored for general conceptual modeling languages.

The term "belief" is polysemous. Suppose that Mary believes that amoxicillin cures bronchitis. The term "Mary's belief" may refer to the content of Mary's belief, or it may also refer to an entity in Mary's mind. The philosophical literature standardly takes the former entity to be a proposition, and the latter entity to be a cognitive attitude towards this proposition. The ontological nature of propositions is a highly complex topic, and we will not delve into it in this paper, building instead in section 3 upon information content entities ("ICE"), as defined by the Information Artifact Ontology (IAO [6]). As a matter of fact, there are several ontologies based on the theory of ICEs,

[1] Corresponding Authors, E-mails: adrien.barton@gmail.com; william.duncan@roswellpark.org; ethierj@gmail.com. Adrien Barton acknowledges financial support by the CIHR-funded Quebec SPOR Support Unit. William Duncan acknowledges partial support from the Roswell Park Comprehensive Cancer Center Biomedical Data Science Shared Resource that is funded in part by Cancer Center Support Grant NCI P30CA16056.

such as the Prescription of Drugs Ontology (PDRO [2]), where an ontology of belief would be useful. We will first show in section 2 that beliefs in the second sense have both a dispositional and occurrent nature. We will suggest here first steps in developing a formalization in OWL (and point to some insufficiencies of this language to formalize beliefs). In the remainder of the paper, universals or classes will be italicized and capitalized, and names of particulars will be written in bold.

2. The Dual Nature of Beliefs

In the Basic Formal Ontology (BFO [7]), a realizable entity is as an entity that is manifested or exhibited during some process, but continues to exist even when it is not participating in a process (where a process is a temporally extended entity, whose existence depends on at least one material entity). Realizable entities are further specialized into dispositions and roles. Dispositions are realizable entities "that exists because of certain features of the physical makeup of the independent continuant that is its bearer" (such as being flammable), whereas roles exist because the bearer is in special physical, social, or institutional circumstances (such as being an employee). Given this, we classify beliefs in BFO as a subtype of dispositions. My belief that amoxicillin cures bronchitis exists even when sleeping – that is, even when I am not consciously thinking it – and exists in virtue of the physical makeup of my neuronal system.

Next let us consider how beliefs (as dispositions) are realized. A proposal [8] is that beliefs are dispositions to physically perform certain kinds of actions (that is, dispositions to behave in a certain way). My belief that amoxicillin cures bronchitis, then, is realized when I perform the action of taking amoxicillin when I have bronchitis.

This approach, however, does not seem to account for the nature of beliefs. I can have a belief that amoxicillin cures bronchitis even if I'm totally paralytic and not able to take amoxicillin. To answer this objection, one might argue that beliefs are dispositions to act if further conditionalized: my belief that amoxicillin cures bronchitis is a disposition to take amoxicillin if I have bronchitis *and* I am not paralyzed. However, this proposal only seems to capture the practical dimension of beliefs (how they relate to action), not how they relate to the purely theoretical attitude of taking some state of affairs to be the case. Consider the fictional counter-example of a supernatural spirit with no power of action at all, who would have many beliefs about the world (e.g. that the sea is mostly composed of water, etc.), but no disposition to act.

Thus, following a classical philosophical distinction [8,9], we hold that dispositional beliefs are not realized by physically performing actions, but by some occurrent mental process that we call "occurrent belief", namely the cognitive process of taking it to be the case that amoxicillin cures bronchitis. For example, Jones may believe that amoxicillin is helpful to cure his bronchitis, but this (dispositional) belief is not being continuously activated (or said differently, realized) in his mind. At t_1 (see figure 1 below), he deliberates whether he should take amoxicillin, and his dispositional belief is realized by a process of him taking amoxicillin to be helpful to cure his bronchitis. His dispositional belief is then realized a second time at t_2 by a similar process. Thus, a person may have a dispositional belief that amoxicillin cures bronchitis even when sleeping or unconscious. We can then suggest the following definitions:

- Dispositional belief: A disposition that can be realized in an occurrent belief.

- Occurrent belief: A MF:*Mental process* of taking something to be the case.

The difficulty here would be to analyze what it means to take something to be the case, which might involve a cognitive attitude towards a proposition – two complex notions. This will remain out of scope of this paper, which will instead analyze how beliefs can be articulated with IAO's theory of ICEs.

3. Information Content Entities and Beliefs

In the following, we will use single quotes such as in 'amoxicillin' to refer to an ICE instance. ICEs are *about* something (see [6] and the two senses of aboutness they introduce, at the level of reference and the level of compound expression). For example, the ICE 'aspirin' on a drug product monograph is an ICE that is about the class of aspirin drug products. Following Smith and Ceusters [6], an ICE is concretized by one or several instances of a specific subclass of BFO:*Quality* named *Information Quality Entity* (*IQE*). For example, if Dr. Jones writes the word "amoxicillin" on a white paper, the ICE 'amoxicilin' that refers to the active ingredient amoxicilin is concretized by some qualities inhering in the mereological sum of ink molecules on this paper. Not all qualities of the ink are relevant from an informational point of view: for example, writing the dot on the "i" slightly more to the left or to the right is not relevant in this sense. According to IAO's theory, ICEs might also be concretized by a neuronal configuration. There is an important distinction between ICEs and IQEs. IQEs *specifically* depend on their bearer; that is, an instance of an IQE exists only as long as the unique entity it depends on exists. On the other hand, ICEs *generically* depend on their bearer: they can be copied or migrate on another bearer.

We hypothesize that a belief involves the concretization of an ICE in one's brain: if I believe that amoxicillin cures bronchitis, my brain must carry some associated information. For example, let's define 'Amoxicillin cures bronchitis' as $\mathbf{ICE_1}$, and 'L'amoxicilline soigne les bronchites.' (the French translation) as $\mathbf{ICE_2}$. Thus, if I believe that amoxicillin cures bronchitis, my brain may bear $\mathbf{ICE_1}$ or $\mathbf{ICE_2}$[2].

However, having $\mathbf{ICE_1}$ (or $\mathbf{ICE_2}$) concretized in one's brain does not imply that the person believes that amoxicillin cures bronchitis. Suppose that John holds at t_0 the $\mathbf{belief_0}$ that amoxicillin does not cure bronchitis, but after attending to a conference on the topic, holds at t_1 the $\mathbf{belief_1}$ that amoxicillin does cure bronchitis (note that holding $\mathbf{belief_1}$ is stronger than simply not holding $\mathbf{belief_0}$ anymore). At t_0, some ICE such as $\mathbf{ICE_0}$ 'Amoxicillin does not cure bronchitis' is concretized in John's brain by $\mathbf{IQE_0}$, and he holds a belief attitude towards it. At t_1, $\mathbf{ICE_0}$ might still be concretized in his brain occasionally (as it was presumably concretized in your brain when you read the sentence), but he does not hold a belief attitude towards it. Said differently, a mental representation of some information does not imply a belief in the veracity of the represented information. I can have a mental representation of the statement 'the Earth is flat' (and thus, I can have the ICE 'the Earth is flat' concretized in my brain), even if I do not believe it.

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[2] This shows how a theory of proposition would help to complement this account, as those two ICEs arguably express the same proposition.

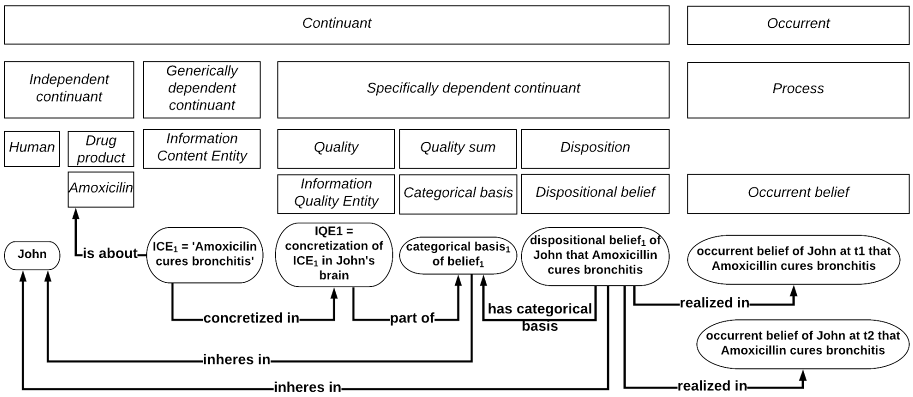

Figure 1: Relevant classes and instances (*Bronchitis* is omitted)

To connect a belief with its informational content, we will compare the qualities underlying the former with the qualities underlying the latter. Barton et al. [11] define the "categorical basis" of a disposition as the quality (or sum of qualities) in virtue of which this disposition obtains (and which therefore inheres in a part of the disposition's bearer named by BFO the "material basis" of this disposition [7]). For example, the categorical basis of a glass' fragility is constituted by some features of its molecular structure. Thus, the categorical basis of a belief is a sum of qualities of a brain – namely, those qualities in virtue of which this belief exists. The connection between **belief$_0$** and its informational content **ICE$_0$** can be formalized by stating that the quality **IQE$_0$** concretizing **ICE$_0$** in John's brain is a part at t_0 of the categorical basis of his **belief$_0$**.

Figure 1 illustrates how our formalization can be used to relate a belief to the object(s) of this belief. **ICE$_1$**, for example, is about the class *Amoxicillin* and the class *Bronchitis* (at the level of reference, cf. [6]). Therefore, **belief$_1$** can be connected to the classes *Amoxicillin* and *Bronchitis* by stating that **belief$_1$** has as categorical basis a sum of qualities that have as part **IQE$_1$**, and **IQE$_1$** is the concretization of **ICE$_1$** that is about the class *Amoxicillin* and about the class of *Bronchitis*[3].

4. Conclusion

In this paper, we have put forth the beginnings of a theory for representing two important ways that we understand beliefs: dispositional beliefs and occurrent beliefs. A dispositional belief exists even when we are not actively thinking it, and when we are actively thinking about a belief, we engage in an occurrent belief process during which we take something to be the case. Dispositional and occurrent beliefs are related using BFO's **realized in** relation: an instance of a dispositional belief is realized in an instance of an occurrent belief.

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[3] Note that **ICE$_1$** is also about the state of affairs of amoxicillin having a disposition to cure bronchitis (in the sense of aboutness at the level of compound expression [6]). This is however presently not easily formalizable in OWL. Also, relating a particular such as **ICE$_1$** with classes such as *Amoxicillin* and *Bronchitis* is not easily formalizable in OWL, although one could use the inverse relation of **is_about** to solve this difficulty [12].

Our analysis left open whether a dispositional belief could be causally active even if it is not realized. For example, I may believe that (*ceteris paribus*) massive objects accelerate towards the Earth. This belief certainly has a causal influence on some of my actions, even when I do not consciously deliberate about it. As a consequence, if one endorses a purely dispositional theory of causation, a dispositional belief is realized in an occurrent belief whenever it is causally active, even when the person having this belief does not consciously deliberate about it.

To relate our dispositional beliefs to the entities that are targets of our beliefs, we incorporate IAO's theory of ICEs, which enables us to e.g. relate $\mathbf{belief_0}$ and $\mathbf{belief_1}$ with the classes *Amoxicillin* and *Bronchitis*. A theory of proposition would be helpful to proceed further and be able to relate beliefs not only with the entities they concern, but also with their substantial content, such as the propositions "Amoxicillin does not cure bronchitis" (related to $\mathbf{belief_0}$) and "Amoxicillin cures bronchitis" (related to $\mathbf{belief_1}$) – the former being especially complex to analyze in a realist ontology, as it does not describe a state of affairs that obtains.

Finally, the present account has defined beliefs independently of practical rationality, that is, independently of any intention to act on it. However, beliefs do frequently play a role in motivating action. Future work should also examine how dispositional beliefs can lead to an intention to act, by being realized by an occurrent belief that is part of a plan making process, that leads to an OBI:*Plan* (as formalized by the Ontology for Biomedical Investigations [10]).

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Ontological Problems of Economics

Leonid TUTOV[a,1] Varvara ROGOZHNIKOVA [b]
[a] *Lomonosov Moscow State University, Russian Federation*
[b] *Lomonosov Moscow State University*

Abstract. This paper develops some results of a study of philosophical and methodological prerequisites of economic knowledge, held by several researchers of Lomonosov Moscow State University in 2015-2017. This study was partly published in 2017 in the first Russian textbook for postgraduates of Lomonosov Moscow State University, "Philosophy and methodology of economics". The paper aims to light up some interestingand serious problems of economic ontology.

Keywords. Economic ontology, philosophy and methodology of economics, ontological problems of economics.

1. Introduction

Firstly, there is a need to define the central notion of the paper – economic ontology. Philosophically, ontology is a doctrine of the objective reality in whole. But it is only one definition; the second one treats ontology as a theoretical construct of the explored reality. The first understanding of ontology connected with the notion of substance, while the second one implies the role of subject and language in the process of cognition. These interpretations are equal for analysis of ontology and ontological problems in any science.

In economics, also, these two interpretations are also applied. Economic ontology is a notion of the part (or aspect) of reality, analyzing by economists, or a notion designating economic view on the reality. Besides the view itself, the last aspect of economic ontology also includes prerequisites of this view. Both of these aspects are studied in the field of philosophy of economics [1].

Thus, economic ontology is, in one hand, the picture of economic reality, and, in the other hand, subjective and objective prerequisites of this picture. By the way, using the notion "picture" nowadays is not quite appropriate for this term reflects the opposition of the subject and object, formed in the works of Descartes. But this opposition is more specific for the classical science. In our opinion, it is better to use term "theoretical construct" to emphasize this aspect of the notion "economic ontology".

In modern economic science there are two mainstream ontologies: behavioral and institutional. The notion of economic reality can be defined as "the sphere of human activity within which the decisions connected with creation and use of the benefits satisfying human wants are made and carried out" [2]. This definition is obviously behavioral, and to cover other aspects of economic reality it is needed to add into this notion nature and society. Staying inside the neoclassical – behavioral – economic ontology, we often use models to create "logically possible worlds" [3]. It may move us

[1] Leonid Tutov, Economics Faculty, Lomonosov Moscow State University, Leninskie Gory 1-46, 119991, Moscow, Russian Federation; E-mail: l.tutov@yandex.ru.

away from reality, and thus, from fundamental science which observes the economic reality as whole. Economic science becomes a mere set of different, and even contradictory, theories. This is the other view on economic science, for example the view of D. Rodrik [4]. He writes that economic science is in progress when there is a constant increment of the various models and theories. This position reminds us the one of P. Feyerabend, because he wrote that theories might coexist, and not compete [5], and of course can be regarded as interesting way to answer on the question of the nature of economics and economic reality. Nevertheless, there is a problem in the relationship between theory and practice in economics, and it is still not resolved. We think the solution can be found on the border of economics and other sciences.

Bearing all this in mind, we would like to emphasize the following ontological problems of economics.

2. Ontological Problems of Economics.

2.1. Ontological Bases of the Scope and Method of Economic Science.

Here, ontological bases are the reality which economics studies. There are several questions we should answer in this section: a) ontological status of economic objects, whether they exists or not, and why; b) structure of economic actuality, or how the objects of economics are connected, and if there is an order of their appearance in different economic theories and in economic science at all; c) which is the vision of the economic reality in the certain economic theory, and how this vision can influence on the way certain scientist studies scientific problems; d) how is the economic reality connected with the models economists use in their theories; e) which are the goals of economic policy and economic science and how they influence on the ways economists achieve them; f) which are the processes taking place in the economic reality, and how they are connected with institutes, laws and mores.

2.2. Space and Time in Economic Science.

These are two terms which came in economics from philosophy, and they have specified value in economic science. Any kind of reality has its structure, and there is space and time structure in economic reality. Which are the elements of this kind of reality? There are individuals, companies, multinational corporations, states, i.e. economic agents. Are there also institutes, social processes? Is there any sense to study the history of economic reality, and if it is, how can it be useful today? What about the future of economic reality, what can we say about trends, future problems and risks, and what is the prediction term? Or maybe it is not the purpose of economic science, to predict anything? There are also less philosophical questions, for example, how to allocate resources effectively, or what should we do to make the infrastructure work better? These kinds of questions are usually studied by spatial economics, logistics and so on.

2.3. The Language of Economic Science.

It may seem it is not the ontological problem at all. But we use language to express our knowledge about reality, so we could say language is the “place” where subject and objects are tussle and come to compromise. It is significant that the language of economic science is not a totally artificial one, but there is a huge influence of natural language. The last one is a living tissue of economic science, and the first one helps us to reflect especially economic aspects of our reality. In economics, there are also the notions from other sciences, for example, from philosophy, law, physics, biology etc. This fact can be taken as a condition of possible interdisciplinary correlation between these sciences and economics, i.e. of the common ground for future cooperation.

To be such a fruitful space, economic language should be equal to the following requirements: precision and clarity of its notions, forms, and sentences; a balance between abstractness and haecceity; ability to change itself when it is necessary, for example when the reality has changed.

At least, we cannot ignore the theory of D. McCloskey, interpreting economic science as a complex of rhetoric instruments [6]. If she is right, then we should understand which instruments we use, and why. One of the most interesting problems here is the question about how these rhetoric instruments can help of block our intention to find a truth about economic reality.

2.4. Correlation Between Economic Ontology and Economic Reality.

But what is the economic reality and how it differs from the economic actuality? We can define economic reality as a sphere of human activity in which we provide processes of production, consumption, exchange, allocation of different resources, goods and service activities. While economic actuality is a certain spatiotemporal characteristic of economic reality, i.e. concrete conditions of economic processes, its instantiation. Thus, we can say, ontology could be viewed as a treatment of both.

2.5. Correlation Between Economic Ontology and Ethics.

Ethical problems of economics in this scope connected with the division of economic science in the positive and normative aspects. Positive economics don`t deal with ethical questions, studying just what exists, while normative one is about what our economic reality should (and could) be like. Usually, normative economics is all about goals of economic policy. In neoclassical economics, there is a strong lack of ethical understanding of human behavior, though this behavior is in the scope of neoclassical economic theory. But today there are more and more researches of ethical aspects of human behavior. There are at least three themes of such a study: a) normative aspect of economic knowledge; b) ethics of economic publications; c) professional ethics of an economist. For example, there is a very interesting research at the Global Priorities Institute in London, UK. According to its agenda, scientists of this Institute study "theoretical issues that arise for actors who wish to use some of their scarce resources to do as much good as possible" [7], i.e. there are prioritization problem, cross-cutting considerations, and the problem of effective altruism. As we think, all these themes can be understood as a scope of normative economics.

It is interesting, how T. Lawson defines scientific and philosophical ontology: he actually connects scientific ontology and positive economics, and philosophical ontology and normative economics. He is also known as one of founders of social ontology, which he defines as "1) the study of what is, or what exists, in the social domain; the study of social entities or social things; and 2) the study of what all the social entities or things that are have in common" [8]. We suppose this line of research could be considered as an important connection between philosophy and economics, because it gives them a chance to find a common ground for the explanation of social processes. Very fruitful discussion on these questions can be found in [9].

2.6. Human Model in Economics.

Human being is the part of reality. Today there are different ways of studying human, for example, as a person, or as an individuum, as a completely social being, or as an animal. One of the most discussing approach here is sociobiology [10]. Today this approach has a lot of in common with neuroeconomics, that is why it again brings up a question of the place of human being in reality. In the modern economic science, especially in neoclassical economics, individuum is like A and W. But the principle of methodological individualism is often called into question today. Aiming to understand human behavior, we ought to ask ourselves, which are the limits of economic view on it. It is no doubt that economic understanding of human behavior based on the certain philosophical views on human nature. We have to reveal these views and realize how they influence on the economic way of thinking of human being. Here we can search for answer with the help of sociology and, particularly, economic sociology. In our opinion, natural sciences can also help us in this question, but we should know they are as positive as modern economics tries to be, and what we need to resolve this problem, is to include normative topics in our study of human behavior.

The most prospective scopes of research in this field are: a) neuroeconomics; b) economic psychology; c) economic sociology. We believe a lot of new ideas will come from the research of artificial intelligence, because it could completely change our knowledge about human being.

Maybe the most important problem here to resolve is the problem of ontological prerequisites of new economic approaches to human behavior.

2.7. Philosophical and economic ontologies.

The key difference between the two kinds of ontology is that economic ontology belongs to the class of scientific ones, and science deals with physical world, which should be accessible to observation. That is why economic study of human behavior in neoclassical economics based on behaviorism theory, and that is why economics feels itself so close to the neuroscience.

Philosophical ontologies are less connected to the formalization of our knowledge and to the observation of reality.

Conclusion

The questions about ontological problems of economics are very important in any time. But nowadays, there is a strong need to arise them because of the problematic status of the modern economic science itself. Today, mainstream economics make an accent on the modeling processes, creating a wide variety of possible situations taking place in economy. Nevertheless, the most of these situations are happen just once and are reflected in ad hoc models. There is a problem of connecting such models with reality. And of course, we need to produce an integrated representation of the economic reality to develop our knowledge of economic problems.

Studying of ontological problems of economics could help us to systematize our ideas about different aspects of economic reality. And it is important to understand that this systematization can be done just with the support of other sciences – both natural and social, especially philosophy. Studying economic ontology and its problems assumes understanding of how diverse and complex the reality is, including the economic one.

We believe studying of economic ontology as a very prospective scope in modern economic science also because of such new and breathtaking fields of research as artificial intelligence, digital economics, neuroeconomics, and bioeconomics. And it is obviously an interdisciplinary field of research. Philosophy and methodology of economics has an advantage in studying of all these fields, because it allows to provide a holistic approach to them.

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Economizing on Virtue

Judith WÜRGLER[1]
Department of Philosophy, University of Neuchâtel, Switzerland

Abstract. The paper starts by describing a strong argument in favor of the "self-interest hypothesis" that we find in economics. This argument argues that any realistic political theory should "economize on virtue". The present paper criticizes this argument in two ways: first, supposing that people are exclusively motivated by self-interest can have (four) socially bad consequences. Second, the argument that realistic political theories need to economize on virtue can be turned *against* the self-interest hypothesis; such hypothesis is (in four ways) not realistic enough. The concluding part of the paper then suggests that an appropriate conception of political *realism* does not support the self-interest hypothesis.

Keywords. Self-interest, feasibility, moral fallacy, unintended consequences,

1. The Feasibility Argument for Self-Interest

As Martin Hollis convincingly formulates it, a political theory always offers a recipe for a "socializing syrup" that is expected to render a particular human nature apt for social life.

> Recipes for the Good Society […] have produced many classic dishes in political theory. […] [T]he magic formula for the socializing syrup varies with the analysis of human nature. For instance, if men are essentially greedy egoists in pursuit of riches, fame and honour, then the syrup will be a blend of repression through fear and reward for cooperation. If men are born free, equal and good, they need only to be stewed in Enlightened education amid democratic institution. If men are by nature the sinful children of God, then a conservative chef will distil his brew from notions like law, authority, tradition, property and patriotism, tinged with distrust of reason. [1]

Economics also relies on a specific conception of human nature, namely that human beings are exclusively self-interested. This self-interested motivation can be described as either indifference to the well-being of others or as containing a necessary reference to one's personal well-being. Most of the time, the considered well-being is measured by material possessions.

Many arguments have been given to justify such a conception of human nature. For example, it has been argued that it is a descriptively accurate first approximation of human behavior, or that it enables us to achieve a mathematical representation of choice [2] or that we can make pretty good predictions based on it [3]. Yet, there is another very good *normative* argument in favor of the self-interest assumption. Such argument possesses a long history, but is only seldom directly used in the economic literature – surely because normative arguments are not considered as objectively

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[1] Judith Würgler, Department of Philosophy, University of Neuchâtel, Espace Louis-Agassiz 1, 2000 Neuchâtel, Switzerland; E-mail: judith.wurgler@unine.ch. The writing of this paper has been generously supported by the Swiss National Science Foundation (SNSF).

assessable. This argument says that any political theory should respect a “feasibility constraint”, that is, its policy recommendations should be based on a realistic conception of the world and not on some nice but wishful thinking. Respecting such constraint is a moral obligation for a social planner – and a social scientist.

> [The] ethical observer who misspecifies the feasible set [of alternatives] will typically make a moral mistake.[4]

As a consequence, concerning possible human motivations, a good social planner should base his decisions and predictions on a representation of human nature that “economize on virtue”, that is, that does not rely on the (utopian) expectation that citizens and economic actors will act from some kind of moral motivation or from some interest for the public good.

> Compliance with morality, even one that the agents regard as ‘true’, simply cannot be taken for granted. ‘If men were angels’, the economist is inclined to argue, things might be different; but in the real world we must determinedly set aside heroic conceptions of human nature and deal with human behavior as it is, warts and all. To do so commits the economist to a particular interest in institutions, which, as economists often put it, ‘economize’ on virtue. […][4]

Such an argument argues that a legislator who hopes that people will act as they are morally required, even when that implies giving up some personal advantages, is committing what we can call a “moralistic fallacy”. As Ingo Pies expresses it concerning firms:

> A moral fallacy occurs when we expect firms to act differently without having changed incentives, rather than to change incentives in a way that makes it imperative (and actually attractive) for them to act differently. The alternative at issue here can be formally formulated: change of attitude versus change of conditions. [5][2]

A legislator should not wishfully believe that, just because it is morally required not to act in a way that damages the public good, economic actors will be motivated not to act this way. Such a reasoning derives an “is” (i.e. “economic actors *do* not act against the common good”) from an “ought” (i.e. “economic actors *ought* not to act against the common good”). Such a derivation is logically illegitimate – just as the converse “naturalistic fallacy”, deriving an “ought” from an “is”, is logically illegitimate. Therefore, governments should never expect agents to behave as they morally should. Rather, they need to expect them to be exclusively motivated by their personal, private advantage. As a consequence, society should be organized in a way that makes individual self-interest serve the public good.

> Economics insists on the necessity to make sure that individual objectives are aligned with collective objectives. [6][3]

> Attention is therefore directed toward the question of how arrangements might be made to bend private interests to the service of the public interest – to secure benign consequences from human interactions, despite the impaired motivations of the participants. [4]

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[2] Translated from German.
[3] Translated from French.

The underlying idea is: if a society can work and materially prosper without any moral motivation, it is more sustainable than a society that is wholly dependent on people's dispositions to care about the public good.

The rest of the paper is divided into two parts. The first shows that representing agents as exclusively self-interested can lead to dangerous consequences for society. We will explore four such consequences. We conclude that, given those bad consequences, it cannot just be taken for granted that self-interest is a more realistic hypothesis than, say, universal moral motivation. Instead, this thesis needs to be *proved* by an argument.

The second part of the paper shows that, besides its dangerous social consequences, the "self-interest hypothesis" fails by its own light – i.e. it is not a very "realistic" (or "not-too-optimistic") hypothesis regarding human motivations. We will consider four objections of this second kind. We will then conclude that, since the hypothesis fails by its own light, it is very important to look for other plausible motivational basis for a viable society.

2. Some Socially Dangerous Consequences

Representing citizens and economic actors as motivated solely by self-interest leads to four possible dangerous consequences: (a) moral considerations might simply disappear from private consciousness, (b) agents might become slowly unable to think about the moral dimension of their actions, (c) developing an incentive-based society might be connected with high costs, both in in terms of money and in terms of liberty and (d) moral responsibility for failures to achieve the common good might move from private actors to the State.

2.1. The Disappearance of Value

The risk that moral values disappear from individual consciousness arises when one is allowed to *pay for* getting the right to do an immoral action. When a monetary price is attached to an immoral action, it can be interpreted as buying the right to perform an action that was first morally forbidden. Said differently, the action changes from having the property "morally wrong" to having the property "morally permissible" when one pays the monetary penalties attached to it.

The disappearance of moral value has been observed, for example, in a case where a nursery decided to introduce a fine for parents being late at the end of the day.

> The fine seems to have undermined the parent's sense of ethical obligation to avoid inconveniencing the teachers and led them to think of lateness as just another commodity they could purchase. [7]

The existence of a price made the "sense of ethical obligation disappear". This fact, i.e. that paying is considered as providing a right to do an immoral action, is by itself problematic. There is however an even more serious reason to worry. Indeed, the risks runs that the total number of bad actions increases rather than decreases after the introduction of "moral" penalties– contrary to expectations. Once one can buy a "right to do wrong", the wrongness dimension of the action disappears from consciousness and people feel comfortable doing bad actions. Consequently, people no longer feel any moral pressure not to do the action, and just start doing it or, for those who already did it, start doing it more frequently. In the case of the nursery, not only did the *number* of people being late increase, but the *time* of lateness also increased.[4]

We could hope that, after having realized the self-defeating effect of monetary incentives, we could come back to the initial state of affairs by suppressing them; if the number of cases has increased by introducing fines, then the number of cases should decrease by suppressing fines again. Unfortunately, evidences show rather that we can expect the number of cases to *increase* to an even higher point. The fact that taxes have made the moral aspects of action disappear from consciousness explains the fact that, when such actions become *free* again, their moral dimension nevertheless remains invisible and the number of cases *increases* again. In other terms, the action had first a *moral value*, then a *price*, and, at the end *neither a moral value nor a price*.

Table 1: The evolution of the value of an action and of the number of actions related to the introduction of monetary incentives

	First stage	**Second stage: introduction of taxes/penalties**	**Third stage: suppression of taxes/penalties**
Value of action of type X	Moral value, no price	Price, no moral value	No moral value, no price
Number of actions of type X	n	m where m>n	p where p>m>n

The action had therefore become, from a self-interested point of view, very attractive. As a conclusion, incentive-based policies that aim at directing self-interest toward the public good can be self-defeating and therefore lead to socially bad consequences.

2.2. The Disappearance of Moral Capacities

The risk that people lose their capacities for moral reflection comes from a slightly different aspect. When a State does not expect its citizens to be motivated by something else than their personal well-being, citizens can legitimately believe that the responsibility for moral reflection lies completely in the State's hands. They know the State has the function of making sure incentives provide the correct direction for individual actions. They thus come to believe that they can quietly follow their self-interest, because the State ensures that it serves the common good. Discharged from the

[4] The same results have been observed in situations of the "tragedy of the commons" type; the introduction of penalties made the situation even worse. [7]. Furthermore, the argument about the self-defeating effect of monetary incentives can also be made concerning morally *good* actions; attaching a price to blood or charity donations, for example, makes the number of donations decrease rather than increase. [8]

responsibility for moral thinking, they do not make use of their moral competences anymore. In the end, people become unable to distinguish what is right from what is wrong without the help of incentives.

> By claiming exclusiveness for his private interest, the economic Subject, in liberal theory, is not aware that he damages the interests of other economic subjects. He even knows that it is be following his interests as a producer or consumer that he contributes to the general prosperity. [9][5]

We can even come to a point where following incentives can appear as a *duty* of economic actors. If they fail to maximize their own advantage, they run the risk of failing to maximize the public interest too. Maximizing profit – or desire satisfaction – is therefore taken also as a moral duty toward society. At the end, economic theory might end up justifying morally bad practices.

> Economists who analyze the self-interested reasons for cheating and who explore their implications while ignoring or dismissing "moral" reasons may, perhaps unintentionally, wind up justifying the practice. If there is sufficiently large expected return, then cheating is rational from the point of view of an individual concerned only with personal net income. From the perspective of such materially self-interested individual, the only thing wrong with cheating is the risk of getting caught. On the assumption that everyone is materially self-interested, those found evading their taxes are either incautious or unlucky. [10]

2.3. High Costs

Monitoring individual behavior in order to make self-interest serve the common good can cost to the State more than to let people sometimes act against the common good. Indeed, monitoring economic activities in a way that guarantees that *everyone always* respects the rules requires an omniscient and omnipotent State, with the capacity to reprimand every wrong action and/or to reward every good action. Besides the high implausibility of such a god-like State, this solution can be very costly both in term of individual liberty and in term of money.

> From the point of view of legal norms, we can already doubt that they will be obeyed only through the use of external constraints. Without a minimum of honesty and decency would a huge State supervision and tracing apparatus become necessary, to force citizens to comply with the law. Such a device would be very costly […] and quite probably little effective. [11][6]

Someone might argue that a policy based on *rewarding* appropriate behaviors requires less State control than a policy based on punishing illegal behavior. Indeed, in such cases, the burden of proof is attributed entirely to firms, who can decide whether they want the State to look at their activities or not. Their independence from the State is therefore preserved.

The problem is that rewards require a lot of money and cannot always be put in place. Indeed, rewards have to be sufficiently high to guarantee that doing an illegal action ceases to be an option for economic agents. This is very demanding. Moreover, many actions cannot be accounted for in terms of "reward" and can only be associated with "penalties". For example, what would it mean to "reward" a corporation for not having taken advantage of a monopolistic situation or of informational asymmetries?

[5] Translated from French.
[6] Translated from German.

Would that mean offering to the corporation as much money – or even more – as what it would have gained by violating market rules? But if so, that means society has lost at least as much money as it would have lost had the corporation violated market rules. It becomes, therefore, more costly to reward corporations than to let them violate market rules. That means the only solution in these situations is to use penalties rather than rewards. But penalties have their own deficiencies. Indeed, even though it might happen that *punishing* bad actions is cheaper than *rewarding* good actions – this is a highly contingent proposition – punishing would require an involvement of the State in economic activities that might not be realizable and that is incompatible with a "free-market" economy.

In conclusion, rewards might be less intrusive than penalties, but they are costly and difficult to put into practice. On the other hand, penalties might be less costly that rewards, but they require a very intrusive State control, which appears both implausible and undesirable.

2.4. Responsibility Displacement

Finally, the "self-interest hypothesis" is associated with the very dangerous consequence of making moral responsibility move from economic actors to political actors. Indeed, under that assumption, the fact that some individual undertakes a bad action can only mean that State incentives were badly organized.

> To the degree that economists assume that the only reasons to be sought in explaining the firm's behavior are self-interested reasons […] their analysis will tend to excuse or justify the firm's behavior and to locate responsibility for the pollution not with the firm but entirely with the government for failing to set the firm's incentives properly. [10]

Economic actors can no longer be held responsible for the socially bad consequences of their self-interested actions. The State is fully responsible. This consequence is more than a logically possible one, but is actually much visible in economic writings. For example, Jean Tirole's book *L'Economie du bien commun* is full of passages where some morally bad behavior on the part of economic actors are taken to be nothing more than bad incentive management from on the part of the State.

> Relationships between employers and employees are very bad in France…except when they agree with one another at the expense of the [State] employment insurance. But, as always, economic agents react to the incentives they face. It is therefore our institutions who are guilty in this regard, because they encourage concerted manipulations between employers and employees within the firm. [6][7]

In conclusion, we have seen that the economic conception of human nature may lead to some socially undesirable consequences. Such undesirable consequences cannot count, by themselves, as reasons to *give up* the "self-interest hypothesis", but they offer reason to *consider seriously* the question as to whether relying on people's moral motivations really cannot be a "realistic" or "feasible" option.

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[7] Translated from French.

3. The Feasibility Argument Against Self-Interest

Consider now a situation where the "self-interested hypothesis" is not associated with dangerous social consequences. It would still be possible to raise objections against this hypothesis. The objections we are going to study take the "no-optimism" – or "feasibility" – argument in favor of self-interest and turn it against itself. We will cover four objections of this kind. They all support the conclusion that a motivational conception of human nature as exclusively self-interested is, in various respects, still much too optimistic. This open the way for an inquiry into more realistic conceptions of human motivation – where "realistic" means "corresponding to reality" and does not simply mean "pessimistic".

3.1. Anti-social and Anti-moral Motivations

The first way in which self-interest appears as still a too naive conception of human nature relates to the fact that human beings are driven by other, much anti-social and anti-moral, motivations, such as jealousy, envy, racism, nationalism, sexism, domination, power, etc. By ignoring all motivations that are related to the well-being of others, "self-interest" as depicted in economics ignores not only *positive* care for the well-being of others, but also *negative* motivations toward the well-being of others. [8] Hence, if "being realistic" means "taking men as they could be *at worst*", then economics should rely on anti-social and anti-moral motivations rather than on a "disinterested motivation".

There is a ready answer to such worries. It says that self-interest should be precisely conceived as *the only possible* passion capable of opposing or retaining the most destructive passions of mankind. The role of the social planner is to find a way to restrain the wildest passions and, in this regard, self-interest fares much better than, say, moral or impartial considerations or benevolence. As Dennis C. Rasmussen indicates, the first economists looked at self-interest as the only passion that could prevent more dangerous passions from threatening social life.

> Extensive commerce might be incompatible with strict republican virtue, [Hume and Smith]acknowledged, but they also believed that a focus on material self-interest would help to replace dangerous and divisive passions such as xenophobia, religious intolerance, and the thirst for military glory. Moreover, they argued that commercial society helps to promote the "bourgeois" virtues of reliability, decency, cooperativeness, and so on – moral and social good that were comparatively lacking in pre-commercial societies. [13][9]

3.2. The "Double Standard" Objection

The second objection against self-interest as a "realistic" hypothesis is the well-known libertarian objection according to which there exist no principled reasons to limit the scope of the self-interest hypothesis to economic agents without extending it to political agents. There is no ground to make a motivational distinction between

[8] The fact that indifference excludes both benevolent *and* malevolent motivations is often explicitly recognized in economics: "I shall usually assume that people's preferences are free of both benevolence and malevolence. That is, the fact that one person is enjoying the consumption of a good does not *in itself* increase or decrease anyone's utility" [12].

[9] Translated from French.

economics and politics; in both spheres self-interest should be considered as being the exclusive motive of action. Supposing that political actors are preoccupied by the common good just because that is what they *ought* to be preoccupied with is to commit again the "moralistic fallacy".

> An individual's nature does not change just because he moves from the private to the public sector. It is always the same individual with the exact same motivations and concerns, just doing another job for another employer. There is no reason to believe that by working for the public sector he will cease to be motivated by his self-interest and act only according to the public interest, up to the point of neglecting his own interests. [14][10]

> In this naive conception of reality, we attribute to the government the task of taking care of the public good and we presuppose that all its actions will result in an increase of well-being for society. We think of the government as a benevolent and omnipotent despot whose actions are always dedicated to the public interest. [14]

This objection rightly points to some arbitrary distinction between the moral dispositions of private and public actors – private agents having *no* moral dispositions and public agents being moved *only* by moral considerations. The mere fact that public actors *ought to* care about the common good is taken as a reason to believe that they *are* indeed *motivated* by the public good. Yet the "feasibility constraint" requires *not* picturing people as if they were naturally disposed to act as they ought to, but rather picturing them as self-interested beings. Therefore there is no reason to arbitrary limit self-interest to the market and not to extend it to the public sphere.

3.3. A Stronger Form of Egoism

The third objection turning the feasibility constraint against the "self-interest hypothesis" of economics is slightly different: it considers that the kind of self-interest described in economics, that is, as indifference to the well-being of others, is a very weak conception of egoism as compared to the *real-world* egoism of human beings. Indeed, the value people take themselves to possess is not appropriately described by the "self-interested hypothesis". The real value that human beings believe to have is much greater: they take their own existence to be something of value *in the world,* or even *in the* universe.[11] Yet this incredibly high importance we take to possess cannot be described by self-interest. As Thomas Nagel formulates it, the importance we believe to have is far bigger than just being able to satisfy our desires. We consider that we have value *in ourselves* and not just *for ourselves.*

> I believe, as did Kant, that what drives us in the direction of universalizability is the difficulty each person has in regarding himself as having value only for himself, but not in himself. If people are not ends in themselves—that is, impersonally valuable—they have a much lower order of worth. Egoism amounts to a devaluation of oneself, along with everyone else. [16]

Egoism in economics means that everyone cares only for his own well-being. This means that everyone has value only *for himself* – but has no value from some impersonal point of view. In contrast, real-life egoism contains more: everyone considers that he has value *in himself.* That makes a big difference concerning the kind

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[10] Translated from French.

[11] "Human beings take themselves generally to be the center of the world.". [15]. Translated from German.

of world in which one lives: a self-interested individual lives in a world where he can pursue his personal advantage but runs the risk of being used in the name of someone else's advantage – or in the name of collective interest. A real-life egoist, on the contrary, lives in a world where he is recognized to have intrinsic value. His life gets therefore protected by basic rights. He cannot be used to foster either someone else's well-being or some "collective well-being".

From the point of view of real-life egoism, we should "distinguish the desirability of not being tortured [or murdered] from the desirability of its being impermissible to torture [or murder] us". [16] In the first case, the evil lies in the fact that something bad *happens to* us. In the second case, the evil lies in the fact of "*being someone it is not wrong to torture*". [16] In other words, a real-life egoist prefers to live in a world where it is *impermissible* to torture him rather than in a world where it is *permissible* to torture, and such preference does not depend on *whether* his is *actually* tortured or not. As a consequence, the strong version of egoism implies that persons are attributed the property of "being inviolable". Strong egoism contains moral constraints that cannot be extracted from the weaker self-interested conception of egoism that we find in economics; therefore – quite paradoxically – the stronger form of egoism leads more directly to morality than the weaker.

3.4. The Moral Foundation of the Market

The last objection is also quite common. It points to the fact that the market works only if market actors do actually possess some basic moral motivation. Indeed, the market is based on one basic moral norm which holds that economic actors ought not to take advantage of situations of market deficiencies.

> The regulatory framework governing commercial activities is itself very imperfect. It cannot wholly correct market deficiencies and thus cannot eliminate the whole set of morally reprehensible practices that can emerge in market relations. In this case, market actors have an obligation *not to* take advantage of non-corrected market deficiencies. [17][12]

For example, as noted by Kenneth Arrow regarding informational asymmetries between firms and consumers or workers, the ideal conditions of market efficiency require that consumers and workers are perfectly informed about relevant aspects of their decision. Yet in the real world this condition is not realized – i.e. prices do not necessarily reflect every relevant piece of information. A free market does not on its own provide the whole relevant information for consumers and workers. Therefore it is a duty of firms to realize those efficiency conditions by delivering to consumers and workers every useful piece of information.

> There is clearly an obligation to reveal […] truth, even at the expense of profits, for the market will generally do very poorly in sorting out the facts when the buyers are uninformed. […] Similarly, the firm knows, by experience, the safety conditions in its plants more than workers can. Hence, the conditions that the market works are violated, and moral obligation should take its place. [18]

In the real world, firms are better informed about their products and about safety conditions on the work place than consumers and workers – and that violates ideal

[12] Translated from French.

market conditions. Therefore this creates for firms a *moral obligation* to inform both consumers and workers about their products and working conditions, even at the expense of profit maximization.

The market thus works under the assumption that market actors do not violate the fundamental market norm of "not taking advantage of market deficiencies". This requires agents on the market to be disposed to respect a moral norm even when that implies giving up some possible "easy profit". That is, market agents need to possess a fundamental moral motivation – exactly the kind of motivation that economics was supposed to "economize" on. In this sense, economics fails by its own lights, that is, fails to meet the "feasibility constraints" that justified the "self-interest hypothesis".

The fact that without such basic norm the market in real circumstances – where ideal conditions are not satisfied – does not lead to collective prosperity is a well-recognized fact in economics. [6].If market actors did not respect the "rules of the game", efficiency could not be reached. It is therefore surprising that respect for rules is something taken for granted. Indeed, market rules seem often to be treated in economics as if they functioned exactly like natural laws. It is as if the mere existence of rules could guarantee that agents will follow them.[13] Yet such a naive conception of rule-following represents exactly the kind of credulity that was supposed to justify a self-interested representation of human motivation.

A possible explanation of why respect for rules is taken for granted might come from a kind of misconception of rules in economics, where legal norms are treated as if they were laws of nature; both are taken as *constraints on choice,* among other kinds of constraints.[14] Such confusion appears quite often, as we can observe in the following quotation, where respect for institutional rules is taken for granted:

> Individuals pursuing their own self-interest within an institutional setting of property, contract, and consent will produce an overall order that, although not in their intention, enhances the public good. [20]

In the quotation, property contract and consent seem to operate exactly in the same way as do natural constraints. Yet natural constraints – such as scarcity – and legal constraints – such as property rights – do not operate in the same way at all. Whereas the first *cannot* – physically – be violated, the second *by definition* – as *norms* rather than *necessities* – can be violated, manipulated or modified.[15] And to believe that firms do not try to violate and manipulate rules, or to modify them by political pressure, constitutes a very naive conception of self-interest.

The moral motivation required in this context – when, for example, firms ought to give up an opportunity for "easy profit" – is not a kind of self-abnegation, a renunciation of every kind of personal advantage. The motivation here in play is only a moral *limitation* of self-interest in the name of social prosperity. Firms are still *allowed*

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[13] Some economists explicitly accept that they treat rules as exogenous factors of choice. This can be justified in some circumstances, but not when a self-interested conception of human nature is justified by the argument that we should "economize" on virtue. [2]

[14] "The constraints that restrict the set of feasible choice options may be imposed by nature, by history, by a sequence of past choices, by other persons, by laws and institutional arrangements, or even by custom and conventions." [19]

[15] As Pierre-Yves Néron points it out, the moral obligation of firms that they should not take advantage of market deficiencies does not have implication only for the way in which firm interact with other agents on the market, but also have *political implications.* The main one concerns lobbying practices: "[M]arket actors have a moral obligation *not to create* market deficiencies through their political activity (or not to oppose new regulations that aim at correcting such deficiencies." [17] Translated from French.

to make profit but only within certain limits. And those limits need to be *intentionally* respected. That is, there is a need for market actors to *intentionally* give up the possibility of personal advantage in the name of the public good. This is nothing less than a need for a fundamental *moral motivation*. The public good cannot emerge as the *unintended consequence* self-interest.

We believe that the attractiveness of self-interest comes from the idea that the only alternative to a system based on self-interest is a system that leaves *no room* for individual pretentions – and communism represents this anti-individualist system.[16] In other words, self-interest gains his attractiveness from the fear of communism. However, such fear is based on a false dichotomy between self-interest and self-abnegation; if we allow a mid-way between self-interest *maximization* and *no* self-interest *at all*, that is, if we allow for a morally constrained self-interest, we can start contemplating the possibility of a society based on the moral motivation of its members.

4. Conclusion

The appeal of the "self-interest hypothesis" comes from the idea that avoiding a misplaced optimism about human nature requires attributing to human beings (morally) *bad* motivations. That is, being "realistic" requires being pessimistic. Yet we see this conception of political "realism" as mistaken, as long as one has not provided *independent support* for the idea that *moral motivation* cannot play the most important role in sustaining a viable society. According to us, supporting a realistic conception of human nature requires to support a conception of motivation that is both *true of* human nature *and* that is capable of *making society sustainable*. It says nothing about whether these motivations are good or bad, noble or corrupted. As Bernard Williams expresses it, considering the motivations that people have in terrible and unusual conditions as being the most representative of human nature is a deeply flawed conception of realism.

> If the test of what men are *really* like is made […] in conditions of great stress, deprivation, or scarcity (the test that Hobbes, in this picture of the state of nature, imposed), one can only ask again, why should that be the test? Apart from the unclarity of its outcome, why it the test even appropriate? Conditions of great stress and deprivation are not the conditions for observing the typical behaviour of any animal nor for observing other characteristics of human beings. If someone says that if you want to see what men are *really* like, see them after they have been three weeks in a lifeboat, it is unclear why that is any better a maxim with regard to their motivations than it is with regard to their physical conditions. [22]

The work to be done now consists in exploring arguments showing that some *good* or *positive* motivations really belong to human nature and are susceptible of making life in society viable.

As a final remark, our presentation only showed two things: that the "self-interest hypothesis" can have significant social dangerous consequences and that this hypothesis does not completely satisfy its own criterion of "feasibility constraint". Yet the fact that economics might not be able to *get rid* of moral motivation does not yet

[16] "Soviet Union thinkers originally supposed that their system could forgo incentives, which are so central in a free economy and take their source in the individual's egoism. They thought socialist enthusiasm and conscience could substitute for them. This conception was soon confronted with the real data about human nature, which is far from being guided by some sublime abnegation." [21] Translated from French.

prove that such moral motivation really exists and that is can offer the desired support for a sustainable and peaceful society. On the contrary, if we cannot prove that a society based on moral motivation is viable, then it might be that we really need a very strong, omniscient, omnipotent and all-good State. But such a conclusion would appear to be nothing more than putting God back into the foundation of morality.

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Conceptualizing Resources and Claims in Consensual Economic Exchanges

Ivars BLUMS [a,1] Hans WEIGAND [b] and Aleksandrs BLUMS [c]
[a] *SIA ODO, Riga, Latvia*
[b] *University of Tilburg, The Netherlands*
[c] *London School of Economics, United Kingdom*

Abstract. The Core Ontology for Financial Reporting Information Systems (COFRIS) is grounded on Unified Foundational Ontology (UFO). In this paper, we build on COFRIS and attempt to detail the concepts of Economic Resources and Claims found in accounting frameworks, and to extract their features which are common to accounting and reporting standards. Economic Resources (Claims) are conceptualized as extensions of Complex Social and Legal Relators of UFO, within the consensual transaction-centric model. The application of this conceptualization and COFRIS in general aims to assist with standard-setting and the development of information systems, to facilitate understandability and reuse. The conceptualization is illustrated by examples presented in an ontology-inspired Event Table and is used to analyze the revised IASB® Conceptual Framework for Financial Reporting.

Keywords. Accounting Information System, UFO, COFRIS

1. Introduction

Recently, even the international accounting and financial reporting standard-setters board (IASB®) has acknowledged that massive changes in relation to technology will have an impact on accounting and corporate reporting. The standard-setters in their efforts need to account for the existence of the computational accounting systems and technologies including the shared ledger [e.g., 1] and data analytics [e.g., 2], as well as ontology engineering methods and tools, which have proven to cope with difficult standardization issues [e.g., 3, 4, 5].

Information systems were traditionally held inside an enterprise and represented the company perspective on economic exchanges. Evidence from the environment, e.g. invoices from suppliers, was used by the enterprise's auditors and considered important, but there was no systematic connection between the invoices sent in company A with the invoices recorded in company B. The shared ledger concept, with immutability and consensus of such transactions and involved resources (claims) with the required addition of party-specific asset (liability) information, may provide a better foundation for Financial Reporting (FR), than independent reporting by each individual participant.

[1] Corresponding Author.

Recent versions of international accounting standards which encompass the whole life of a contract cannot be implemented by accounting departments alone. Accordingly, SAP's is developing software on revenue standards implementation [6] which delegates the main part of *recognition* to the Sales [Purchase] department, but *measurement* to the Accounting department. Thus, accounting needs to be interpreted in a wider than traditional sense and is an important part of an enterprise conceptual model, and FR concepts must have enterprise-wide understandability. Presently, in the Enterprise Architecture (EA) realm, the shared ledger as well as the FR perspective is not always recognized, and the concepts of economic resources (claims), assets (liabilities), are often treated differently than within Financial Reporting.

At the same time, the conceptualization of present FR per se must be much broader than the *recognized* five elements (assets, liabilities, equity, income, and expenses) defined by CF required for FR *presentation*, but as a minimum should include intentional, contractual and other "un-recognized" phases of economic exchanges and involved resources (claims), required for FR *disclosure* in the *Notes* of Financial Statements.

The Core Ontology for Financial Reporting Information Systems (COFRIS) [7,8] is grounded on Unified Foundational Ontology (UFO) [3]. In this paper, we build on COFRIS and attempt to detail the concepts of economic resources and claims found in accounting frameworks, as well as to extract their features common to accounting and reporting standards. Economic resources (Claims) are conceptualized as extensions of Complex Social and Legal relators of UFO, and within the consensual transaction-centric model. The application of this conceptualization and COFRIS in general aims to assist at standard-setting to engineer domain ontologies of particular (more than 80) International FR standards (IFRS) [9, 10] (see Fig.1), enterprise policies, and with the development of information systems, to facilitate understandability and reuse.

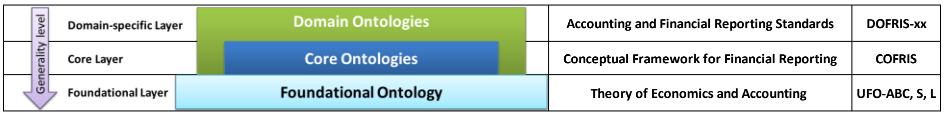

Figure 1. Architecture and Foundations of Financial Reporting Ontology Network (based on [11]).

Section 2 provides a brief overview of the UFO ontologies used and previous works on accounting ontology. In Section 3 we introduce the concepts of Economic resources (claims) and detail their usage in Economic exchanges. Section 4 illustrates their usage through examples and presents an ontology inspired Event Table. Section 5, as a partial validation, compares the introduced consensual and correlative multi-level resources (claims) with the revised IASB Conceptual Framework for FR.

2. Background: COFRIS and the UFO Ontology Network

2.1. OntoUML

OntoUML [5] is an ontologically well-founded version of UML whose metamodel reflects a number of ontological distinctions and axioms put forth by UFO [3, 4]. In OntoUML, class constructs stereotyped by «Kind» represent object types that supply a uniform principle of identity for their instances. Specializations of classes representing kinds are stereotyped as «SubKind», «Role», or «Phase». Instances of «Role» and «Phase» types can cease to be instances of these types without ceasing to exist and without altering their identity. Instances of «Phase» types are characterized by a change of their intrinsic property(s), instances of «Role» types are characterized by a relational property(s) acquired in relationships with other entities. «Mixin» types are universals that aggregate properties that are common to different Kinds and do not provide a uniform principle of identity for their instances; instead, they just classify things that share common properties, but which obey different principles of identity. «Category» and «RoleMixin» types represent an abstraction of properties that are common to multiple «Kind» types and, therefore, do not carry a unique principle of identity for their instances.

A particular *mixin object* pattern, analogous to [21], combines object types with higher-order types (or even generalized to Orderless Class). Such a combination is often required in COFRIS to model market participants and the underlying objects of resources (claims) and is depicted in Fig. 2. For example, an underlying singular object, such as a *car*, can be type-specified in the agreement phase but identified in the fulfillment phase. Another example for market participants is the statement from [10] that "It is not necessary to know the identity of the party (or parties) to whom the obligation is owed", but is important, when it is fulfilled.

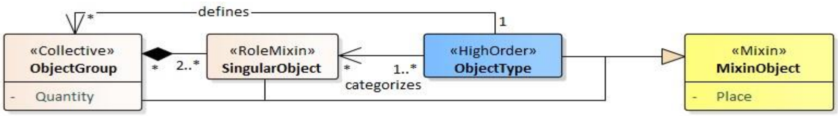

Figure 2. Mixin object pattern.

In addition to the object types, OntoUML class elements represent types of existentially dependent individuals that can only exist by inhering in other individuals, called *moments*. Those moments that inhere in one single individual are categorized as «Mode» or «Quality» types. While (individual) qualities are moments that change in a space of possible values (e.g. a color, a temperature, a weight), modes are complex individual moments that can have their own qualities that take their respective values in multiple independent value dimensions (e.g., a capacity, a complex intention). While inhering in a single individual, some modes and qualities can externally depend on other individuals that are independent from their bearers. Moments that existentially depend on two or more individuals are categorized as «Relator » types.

Instances of «Event» types [11] are perdurants. Perdurants unfold in time accumulating temporal parts. They are defined by the sum of their parts (their constituent subevents) and they bear to each other several temporal ordering and causality relations. Perdurants are manifestations of dispositional properties of moments (qualities, modes, and relators). Finally, perdurants are immutable in all their parts and all their properties.

In a social context, UFO [4] distinguishes between agentive and non-agentive substantial individuals. Agentive individuals can bear special kind of moments named *intentional moments* that are further specialized into *mental moments* (including *beliefs*, *desires* and *intentions*) and *social moments*. Each type of intentional moments necessarily has a propositional content, which may be matched by certain situations in reality. Among other types of intentional moments, *Intentions* refer to the desired state of affairs to which an agent *internally commits* at pursuing. For this reason, intentions cause the agent to perform *actions*. *Actions* are intentional events, with the specific purpose of satisfying the propositional content of some intention of an agent. The propositional content of an intention is termed a *goal*. UFO contemplates a relation between *situations* and goals such that a situation may satisfy a goal. *Communicative acts* (special kinds of actions) can create *social moments* (*commitments* and *claims*) inhering in the agents involved in these communicative acts. Two or more pairs of mutually dependent commitments and claims form a kind of social relationship between involved social individuals, termed a *social relator*. A commitment (internal or social) is *fulfilled* by an agent A if this agent performs an action x such that the post-state of that action is a situation that satisfies that commitment's goal. Social relationships and interactions are further extended in several UFO grounded core ontologies, such as UFO-S [13] and UFO-L [14].

UFO-S is the core reference ontology on services [13], which characterizes the service phenomena as *activity* by considering service *commitments* and *claims* established between the service *provider* and *customer* along the service life phases: *offering*, *negotiation*/*agreement* and *delivery*.

Legal aspects of UFO-S contracts are elaborated in [14] within the UFO-L Legal ontology, that is based on Hohfeld's/Alexy's theory of fundamental legal concepts. The legal positions of UFO-L in addition to claims and commitments from UFO-S (i.e., right and duty) include pairs of other elements: permission and no-right, power and subjection, immunity and disability. All these legal relators originate from two classes of *entitlement* and *burden/lack*, which we refer to further as rights and obligations respectively. The above-mentioned right and obligation pairs form correlative associations [14], which are legal foundations for a shared ledger view [1]. In the core of UFO-L lays the concept of the *Legal Relator* as an extension of the social relator, which mediates two parties involved in correlative legal positions. In Fig. 3, the UFO-L Legal Service Agreement Ontology from [14] is depicted. Complementing UFO-S and thus diagram in [14], we regard an agreement (contract) not as a relator of four different modes, but as a relator of entitlement and burden/lack reciprocal legal relators each containing pairs of legal moments (as added in the Fig. 3). The exercising of rights and fulfilling obligations advances the phases of legal relators.

In [4], the UFO grounded ontological analysis of a resource was provided in the enterprise architecture and ArchiMate® framework context, that defined a resource as "a type-level entity, capturing the *role* of an (agentive or non-agentive) object in a particular context of usage".

The *underlying object* type is restricted to an "allowed type", and the context of usage is defined in the scope of a material relation (or in the scope of an event).

The *legal* and the *holder-specific* aspect of the resource as "an asset owned or controlled" was also regarded, but given the context, was not revealed to enough level of detail required for FR. For example, the employment contract, mentioned in the article, in the agreement (executory) phase is usually not regarded as an asset in Financial Reporting.

The *economic* aspect of a resource, that in an exchange, for a resource transfer or use, the right to receive another resource of a certain value is obtained, was outside the scope of that article.

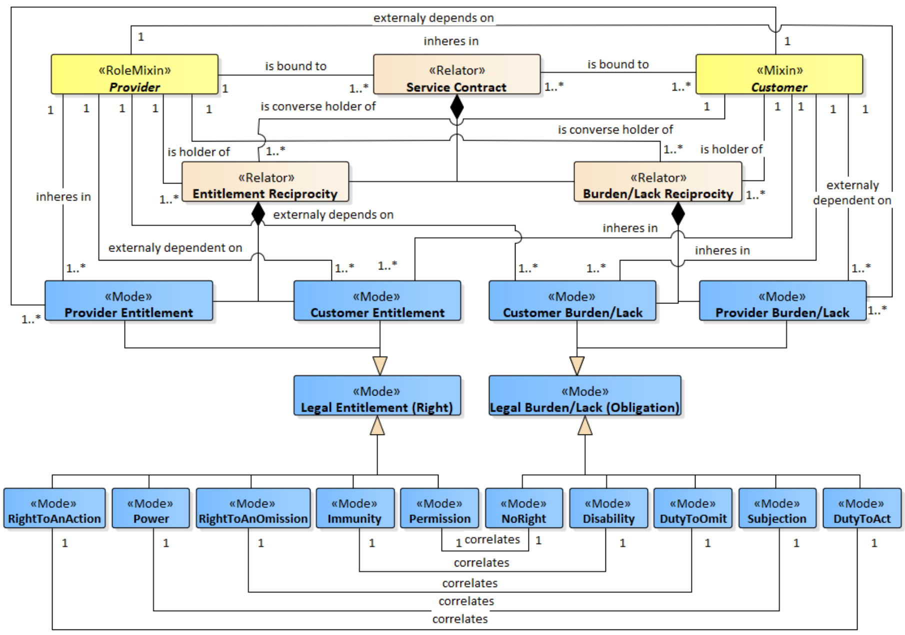

Figure 3. Legal Service Agreement Ontology in UFO-L. Adapted from [14]. Legal Relators added.

2.2. Other Previous Work

Recently, within the VMBO Workshop (see https://vmbo2018.e3value.com), there was a growing interest in the conceptual modeling of accounting, financial reporting, and economic resources, using the UFO Foundational Ontology. The models presented were largely based on Ijiri's economic exchange conceptualization [18] and the REA Framework [15]. These efforts covered fragments of the existing FR domain, represented by IFRS Standards [9] and their Conceptual Framework [10] and (while suggesting alternative ways) were sometimes not reasonably compliant with existing accounting frameworks.

To some extent summarizing these efforts, which are closely related to ours, Nicola Guarino in [19] admitted that "mapping the REA primitives on the UFO primitives was not an easy task, so that different choices were made". Overall, the *role* aspect of the economic resource was emphasized, that is indeed true for depicting a role (e.g., a fuel) that an object (e.g., the oil) plays in a particular usage case (e.g., a transportation). However, we view the following as additionally important for FR:

- possible exchange actions of the resource usage – functionality;
- permitted exchange actions – rights to transfer and use resource;
- intended exchange actions – purpose and ability to transfer and use resource;
- the phases of such exchanges, including the levels and phases of their fulfillment;
- the rights, amount, timing and uncertainty of a party to receive value from a counterparty, resulting from such exchanges, that from our view requires a complex social relator model of the economic resources (claims).

REA ontology generally doesn't regard Economic Resources as rights and views Claims as derivable, not ontological objects. Valuation related concepts are not explicitly regarded in the REA ontology. In [20] an attempt to bring REA ontology closer to accounting concepts was made, under the umbrella of UFO. While several choices, such as regarding resource as <<Kind>> were criticized in [19], an important conclusion from currency swap accounting was made about the phases: "The *Economic Resource* is typified into *Phase* classes according to the economic value specialization condition for distinguishing between Asset, Liability, Equity and Claim whereas this condition is considered as an intrinsic property of the resources" [20].

However, the economic resource, in this case is the underlying object, but not the bundle of rights. Considering that assets are economic resources controlled by an enterprise, while liabilities and equity are claims against an enterprise, we introduce the concept of an *Economic relator* that has Economic Resource and/or Claim phases.

3. Economic Phenomena

Most accounting frameworks [10, 12] state that the objective of *financial reporting* is to provide financial information about the reporting enterprise that is useful to existing and potential investors, lenders and other creditors in making decisions relating to providing resources to the enterprise, and the assessment of *amount*, *timing* and *uncertainty* of returns to be received in exchange for their investments. FR provides information about the economic resources of the enterprise, claims against the enterprise and changes in those resources and claims. It defines Economic Resources as sets of rights that have a potential to produce economic benefits and Claims as obligations to transfer Economic Resources.

3.1. Market Participants and Economic Exchanges

A Reporting enterprise that operates in an economic market, plays the role of a *market participant*. *Mixin market participants* are enterprises and physical persons, groups of enterprises and physical persons, and society at large, and their high-order types. Market participants hold resources (claims) - economic relationships, regulated by norms, over underlying objects, and are valuated in a certain currency of particular market. Market participants are able to commit and fulfil their commitments to exchange use and ownership of resources (claims) they control (indebt). At a macro level, as for national accounts, we can depict economic exchanges as valued (money mediated) transactions among market participants over a year or other period. More specifically for FR we can observe exchanges in which a particular market participant is involved. Participant's exchange efforts or other events provide value inflow and outflow of its resources (claims). The smallest exchange disposition inheres in a resource (claim).

The *contractual* economic exchange process involves two market participants and fulfils a contract. Those performed events that cannot be ascribed to a *contractual* or a *scheduled* (within an enterprise) exchange, are allocated to participant's exchange with society for a *period*. In [7] we follow UFO-S and treat exchange process as mutual provision of services among parties based on an *Offering* of interaction made by an offer from one of two parties, followed by its acceptance (agreement) by the counterparty resulting in a *Contract* (of reciprocal obligations and rights to exchange rights and the use of rights over underlying objects, for mutual benefit), that is fulfilled through the *Exchange process*.

As in [16] exchange can be regarded as a production: "the buyer performs 'strictly an act of production', by converting stockings, for example, into money". On the other hand, Ijiri [18] has used the term *exchange* "to mean not only exchanges in the market, but also exchanges in production which may be considered exchanges between the entity and nature", that include internal production within an enterprise. Both interpretations prompt exchange generalization possibilities used in COFRIS, regarded as interactions of two parties. The parties can be non-related, related, or different roles of the same market participant.

3.2. Economic Relators, Resources and Claims

Economic relationships in COFRIS are represented by Economic Relators as extensions of Reciprocal Legal Relators. Generally, economic relationships have legal form, but also include *constructive* obligations and rights [10] built by economic necessity when a permitted action is in fact prohibited because of the economic loss consequences, nevertheless the obligation/right concept *assumes* a legal ontology.

An *Economic Relator* or *Resource (Claim)* is a reciprocal legal relator between parties whose purpose is to mediate a potential holder's transfer or use of rights[2] over an underlying object, and a counterparty's reciprocal obligation valued in money, that is fulfilled and manifests itself through economic exchange events (see Fig. 4).

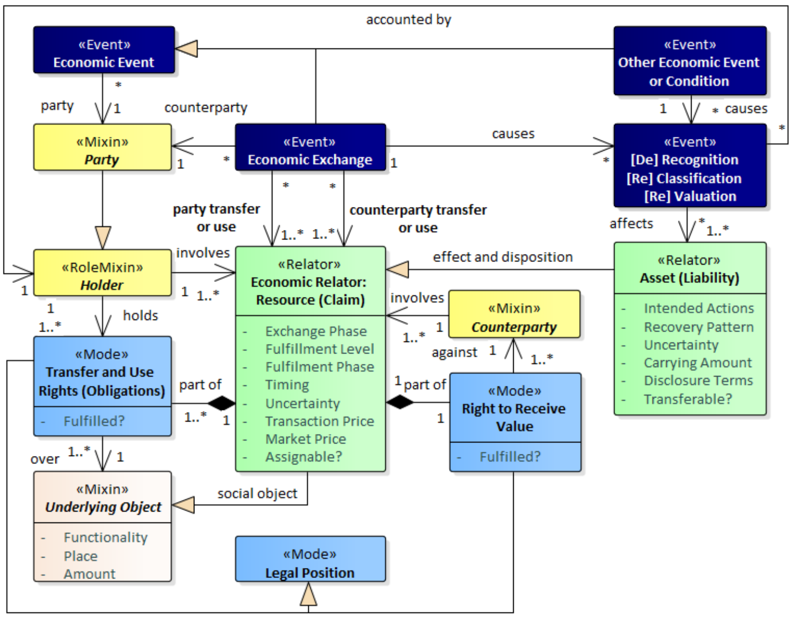

Figure 4. Economic Relators in green. Market Participants in yellow.

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[2] Includes 'Claims to transfer and use rights'

Next, we define the *fulfillment phases* of the Economic Relator:

- An *Economic Resource* represents a holder's [rights over an object that have a potential to be transferred or used to the benefit of a counterparty in exchange for an] economic claim against a counterparty – the right to receive value measured in money.
- An *Economic Claim* represents a holder's obligation to transfer or use rights over an object to the benefit of a counterparty.
- An *Economic Resource and Claim* represents a holder's obligation to transfer or use rights over an object to the benefit of a counterparty in exchange for an economic claim against a counterparty.
- A *Recognized Asset* is a present economic resource controlled by the holder (in the role of a creditor) as a result of past exchanges.
- A *Recognized Liability* is a present economic claim against the holder (in the role of a debtor) as a result of past exchanges.

For example, ownership[3] of an object is a permission to use and a power to transfer the object rights (the use protected from third parties by claim-rights and the transfer by immunity) in exchange for the right to receive economic benefits, subject to agreement of the counterparty. In a contract there is an economic resource and a claim – ownership and the right to receive value. If ownership rights are transferred, the right to receive value is accrued, if the right to receive value is received first, then the claim to transfer ownership rights is enforced.

Resources (Claims) are offered or consensual exchange future or actual action participants, while Assets (Liabilities) represent holder-specific *effects* and *dispositions* of exchange actions.

The *Underlying object* or simply a *Resource* is a Physical or Social Object and is characterized by its *Functionality*, and:

- *Quantity* (of collective objects, but the *Amount* of matter, time, or value) of underlying objects or a feature [of part] of the object, such as kWh for electricity, and is regarded as additive and holds some relation with the price;
- *Place* or *Container* that denotes the [fiat] location at [and in] which the object is or will be available for control.

Usual object classification in EA [17] precludes resource (claim) classification and includes ownership or rights of use of tangible objects: financial, i.e., present rights to receive cash or other resources (e.g., cash, securities, borrowing capacity), physical, i.e. has an opportunity to generate an inflow of cash or another resources (plant, equipment, land, mineral reserves), intangible objects: technology (patents, copyrights, trade secrets), reputation (e.g., brand, relationships; culture), and human skills.

An economic relator itself can be an underlying object thus modeling situations of power, e.g., when a debt (a right to receive from a converse holder) is transferred from one holder to a counterparty, or e.g., a note payable in Government bonds (an underlying object) gives the note holder the right to receive and the holder of the

[3] We assume that the relation between ownership and right to receive value from an unknown counterparty is material, because some exchange value (probably uncertain) of the ownership rights should exist in society which can be assessed, e.g., as the market value or as regulated price or as entry price or as accumulated labor [16] or determined by a court.

Government bonds the obligation to transfer Government bonds. The converse holder of the bonds is the Government, but the underlying object is a cash. A chain of rights/obligations to receive, transfer/exchange resources (claims) is itself a resource (claim).

Timing (*Condition*) denotes a [due] date or period, condition, and order of expected entitlement of rights. E.g., a Financial guarantee is a right of the lender to receive cash from the guarantor, and a corresponding obligation of the guarantor to pay the lender, if the borrower defaults (a condition).

The valuation of Resources (Claims) is based at the carrying amount (for use, or e.g. cost-plus contracts), transaction price, or market price. The *Market Price* (*Fair Value* [9]) is the value of receipt rights (transfer obligations) for a transferred resource (claim) in an orderly exchange between market participants at the measurement date and could be regarded as being *in consensus with society*. The *Transaction Price* is the price agreed on between the parties when a contract is made and is *in consensus with the counterparty*.

The Resource (Claim) and its features concepts are consensual and correlative – agreed among the holders and converse holders, contract parties, and counterparties.

Assets (Liabilities and Equity Claims) are holder specializations of controlled (indebted) and recognized Resources (Claims) depicting *Intended exchange actions* and the *roles* in these actions (within rights) and object roles, subject to the business model, restrictions and capabilities of the holder, *Carrying amount* (Cost)*, Uncertainty* (Risk), *Recovery* (*Settlement*) *pattern* and other holder-specific qualities. *Cost* is used as a base for a measure of the added value of enterprise performance.

Some examples of economic relators with corresponding legal positions:

- A holder is at *permission* to use or consume the object, having disposition to receive (produce) benefits, valued at the carrying amount.
- A holder has the *claim-right* against another market participant to exclusive control of the object, i.e., other market participants would have an obligation not to use or consume the object in any way. The violation of this right has the disposition to produce an enforceable claim against others, valued at the carrying amount or market price.
- A holder has the *power* to transfer all (or some) of the rights over the object to the counterparty, in exchange for an enforceable right to receive against the counterparty, valued at the transaction or market price.
- A holder has the *immunity* from the involuntary expropriation of rights over the object by other market participants.

Economic Resources that are immediately consumed as transferred, for example, services, or not capitalized, for example, office supplies, are called *momentarily* assets in [10, 12]. Our interpretation is that in the first case there is a use of the rights, but no transfer of rights, and thus no assets. Likewise, liabilities are not only the "obligations to transfer" [10], but also could be obligations to use rights.

Economic Resources (Claims) play two major roles in economic exchanges, they are *factors* and *products* of some production processes. Production, while in many cases being trivial (i.e. consisting of property rights transfers plus transfers of transfer efforts transfers), is regarded here as a contracted or scheduled *performance* process where the Economic Resources (Claims) play the role of the *factors* to produce (or combine into) another Resource (Claim) – a *product.* As stated in e.g., Archimate® [17] a *product* represents [rights for] a coherent collection of services and/or passive structure elements [goods], accompanied by a contract/set of agreements which is offered as a whole to (internal or external) customers.

3.3. Resources (Claims) in a Consensual Economic Exchange

As for other information systems, e.g., [11] one can distinguish between the standard, intended and scheduled, and performed processes of economic exchanges. We regard standard processes, involving market participants as actors, and economic relator participation. The exchange processes containing economic events are standardized through law, accounting standards and enterprise policies. These processes are intended and scheduled:

- by adapting standard processes;
- by offerings of the parties (providers) to their counterparties (customers) which specify the performance obligations and rights, and
- by contracts – accepted offerings by customers (see Fig. 5).

Legally speaking, an *offering* transfers power on the offeree, who by accepting it, creates an obligation and a right to exchange – a *contract*, in the offeror. As depicted by reified exchange events in Fig. 5, we distinguish the following contract (economic exchange) phases: *offered, lapsed, agreed, suspended, transferor breached, transferee breached, realized, settled*.

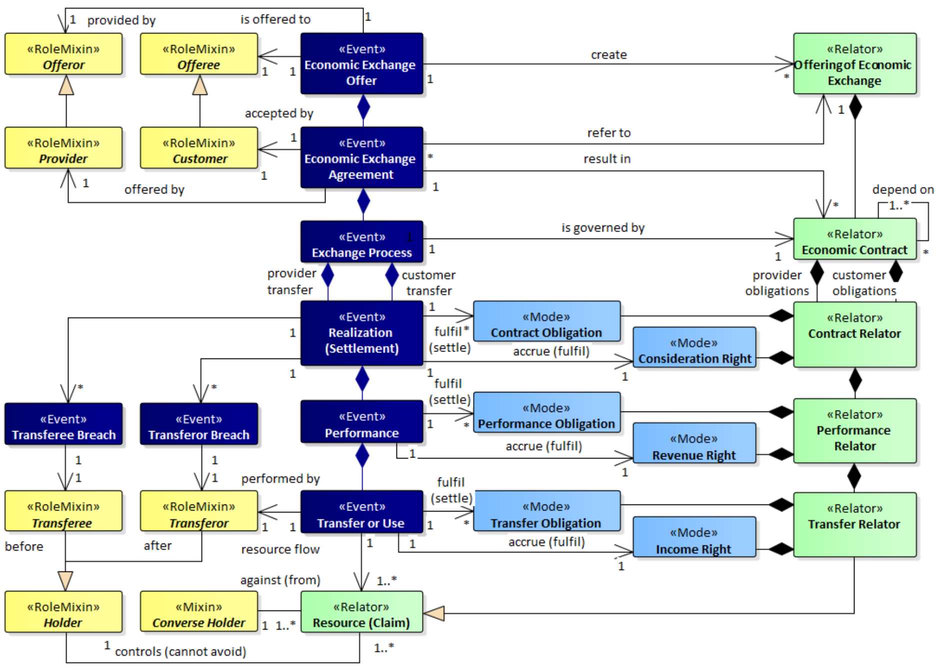

Figure 5. The economic exchange life and affected economic relator fulfillment levels.

The Resources (Claims) and their exchange-affected Assets (Liabilities) in addition to the *fulfillment phases*, are also characterized by above-listed *exchange phases*, complementing FR, where only recognized assets (liabilities) are *presented* while others are *disclosed*, but not conceptualized in CF.

Performed processes fulfil open or closed contract and performance obligations (POs) by transfer or use actions. A transfer action event conveys the role of the holder the economic relator from a transferor to a transferee and in return accrues a right to receive value – an Income Right against the transferee.

If some PO is wholly fulfilled by the transfers or uses, the Performance (Revenue recognition) event accrues a Revenue Right.

If all POs of one party are fulfilled, a Realization (Receivable recognition) event takes place that, brings the party's Contract relator to the Consideration Resource phase and counterparty's Contract relator to Contract Claim phase. The latter implies that all the remaining counterparty's now enforceable obligations to transfer should be settled by transfers that would conclude the exchange process.

In general, the results of several performance processes of transfer and use actions are combined in economic exchanges, in order to receive rights for results of other performance processes of equal value. Thus, for exchange process (contract fulfilment) we have provider and customer action plans, each comprising of three *fulfillment levels*: contract obligation realization (consideration settlement) of the whole contract, performance obligation fulfilment, and fulfilment of transfer and use obligations.

A consensual price – a right to receive value is ascribed to each obligation and is specified directly or as dependent on other prices, or counterparty obligation prices, or market prices. Higher level prices are aggregates of lower level prices, including the transfer of a combination effort component and the time value of money. For the contract as a whole provider rights value is normally equal to customer rights value.

Contract breaches can occur for each obligation type. As a general rule we argue for the following:

- If contract is in breach for the reasons other than counterparty nonperformance, by the transferee, the transferor has an enforceable right for all income rights;
- If contract is in breach for the reasons other than counterparty nonperformance, by the transferor, the transferor has an enforceable right for revenue rights of all performance obligations wholly fulfilled.

The rationale for the first case is that transferor has lost value due to the transferee, and for the second that, while having not wholly fulfilled the contract, the transferor has created the contracted performance value for the transferee.

4. Illustration

Example 1. As a simple example let us regard a smart vending machine that transparently prepares different sorts of coffee drinks. The potential customer (a Person or an Enterprise that has installed the machine for its employees) is addressed by the vendor through a touchscreen offering. When choosing the options, she comes to an agreement to receive a coffee drink, e.g., cappuccino, in exchange for a money transfer at the listed price. Next, different ingredients (factors) of the product are transferred to the customer – a container (a cup), milk, foaming service and finally the coffee. Notice that some of the ingredients are prepared internally by the vendor such as the fresh-grind of the coffee, while others are transferred to the customer and then used for production, the latter being of little separate use for the customer.

The payment could be another "process" consisting of a cash payment and change, or payment by credit card. If the smart vending machine is connected to a shared Vendor's (and Customer's) Information System with shared ledgers of the supplier contracts, a VAT reporting system, and a Banking system, by some automatic tagging we can have all the information in consensus and in an immutable state for Financial Reporting. In addition, if the vendor is leasing the vending machine, or using some patent, the transaction can be shared with the lessor (patent holder) for pay per use accrual.

If we imagine a situation, where payment takes place after the delivery (e.g., by initially providing credit card details, but the actual withdrawal occurring later), she may order three cups of coffee, but if the coffee machine is out of some ingredients after the first two and a half cups (a contract breach by the transferor), she would be charged for the two delivered cups, because each of them constitutes a product under standard conditions.

Example 2. To depict the contracts and resource (claim) exchange instances in a more concise way we introduce an Event Table (see Fig.6)

EID:11	ProviderAgreement		01.01.2018			CU:	k€	Provider: P			k€	Customer: C			k€
Fulfil	**Obligation**	**PO**	**Timing**	**Control**	**Object**	**Qty**	**Value**	**Place**	**Debited**	**Credited**	**Amt**	**Place**	**Debited**	**Credited**	**Amt**
10	Contract		2018-2019	Control	Hospital	1	1000	Site 1	Receivable	Contract Asset	1000	Site 2	Contract Liability	Payable	1000
	Performance	1	2018	Control	Building	1	600		Income	Revenue	600		Building	Construction	600
	Transfer	1	2018	Service	Construction	120d	600		Contract Asset	Income	600		Construction	Contract Liability	600
									Expenses	Construction	500				
	Performance	2	2019	Control	Equipment	1	400		Income	Revenue	400		Equipment	PPE in Process	400
	Transfer	2	31.12.2018	Control	Procurement	1	300		Contract Asset	Income	300		PPE in Process	Contract Liability	300
									Expenses	Procurement	200				
	Transfer	2	2019	Service	Installation	20d	100		Contract Asset	Income	100		PPE in Process	Contract Liability	100
									Expenses	Labor	70				
	Consideration		31.12.2019	Control	Cash in Bank		1000	IBAN 1	Contract Liability	Receivable	1000	IBAN 2	Payable	Contract Asset	1000
	Receipt		01.01.2018	Control	Cash in Bank		400		Cash in bank	Contract Liability	400		Contract Asset	Cash in bank	400
	Receipt		31.12.2019	Control	Cash in Bank		600		Cash in bank	Contract Liability	600		Contract Asset	Cash in bank	600
EID:12	Customer Transfer		**01.01.2018**			**CU:**	**k€**	**Provider: P**			**k€**	**Customer: C**			**k€**
Fulfil	**Obligation**	**PO**	**Timing**	**Control**	**Object**	**Qty**	**Value**	**Place**	**Debited**	**Credited**	**Amt**	**Place**	**Debited**	**Credited**	**Amt**
11	Transfer		01.01.2019	Control	Cash		400	IBAN 1	Cash in bank	Contract Liability	400	IBAN 2	Contract Asset	Cash in bank	400
EID:13	Provider Transfer		**29.12.2018**			**CU:**	**k€**	**Provider: P**			**k€**	**Customer: C**			**k€**
Fulfil	**Obligation**	**PO**	**Timing**	**Control**	**Object**	**Qty**	**Value**	**Place**	**Debited**	**Credited**	**Amt**	**Place**	**Debited**	**Credited**	**Amt**
11	Transfer	1	2018	Service	Construction	120d	600		Contract Asset	Income	600		Construction	Contract Liability	600
									Expenses	Construction	500				
	Performance	1	2018	Control	Building	1	600		Income	Revenue	600		Building	Construction	600
EID:14	Provider Transfer		**29.12.2018**			**CU:**	**k€**	**Provider: P**			**k€**	**Customer: C**			**k€**
Fulfil	**Obligation**	**PO**	**Timing**	**Control**	**Object**	**Qty**	**Value**	**Place**	**Debited**	**Credited**	**Amt**	**Place**	**Debited**	**Credited**	**Amt**
11	Transfer	2	31.12.2018	Control	Procurement	1	300		Expenses	Equipment	200		PPE in Process	Contract Liability	300
									Contract Asset	Income	300				
EID:15	Provider Transfer		**31.12.2019**			**CU:**	**k€**	**Provider: P**			**k€**	**Customer: C**			**k€**
Fulfil	**Obligation**	**PO**	**Timing**	**Control**	**Object**	**Qty**	**Value**	**Place**	**Debited**	**Credited**	**Amt**	**Place**	**Debited**	**Credited**	**Amt**
11	Transfer	2	2019	Service	Installation	20d	100		Expenses	Labor	70		PPE in Process	Contract Liability	100
									Contract Asset	Income	100				
	Performance	2	2019	Control	Equipment	1	400		Income	Revenue	400		Equipment	PPE in Process	400
	Contract		2018-2019	Control	Hospital	1	1000	Site 1	Receivable	Contract Asset	1000	Site 2	Contract Liability	Payable	1000
EID:16	Customer Transfer		**01.01.2020**			**CU:**	**k€**	**Provider: P**			**k€**	**Customer: C**			**k€**
Fulfil	**Obligation**	**PO**	**Timing**	**Control**	**Object**	**Qty**	**Value**	**Place**	**Debited**	**Credited**	**Amt**	**Place**	**Debited**	**Credited**	**Amt**
11	Transfer		31.12.2019	Control	Cash in Bank		600		Cash in bank	Contract Liability	400		Contract Asset	Cash in bank	400
	Consideration		31.12.2019	Control	Cash in Bank		1000	IBAN 1	Contract Liability	Receivable	1000	IBAN 2	Payable	Contract Asset	1000

Figure 6. Economic event table for Example 2.

In the header (in dark blue) of an economic event, we have an Event identifier (EID), and a Transferor type – Provider or Customer, that specifies the context. Further header attributes are:

- The Resource (Claim) Transfer Event type - *Offer*, *Agreement*, [Partial] *Transfer* or *Use*, *Performance* (Revenue Recognition), *Realization or Settlement*, or
- Asset (Liability) *Revaluation or Reclassification* Event type.

Date or Period, Transaction Currency Unit, Provider and Customer identification and their Local Currency Units with their spot exchange Rates, conclude the event header.

Event detail lines depict events that fulfil the contract, performance (PO) or transfer/use obligations identified by the referenced event and PO number, by transferring or using a promised resource (claim) in exchange for accruing consideration, revenue or income rights. The *Timing*, *Rights* (Control), *Object*, *Quantity* (Qty), *Price*, and *Place* concepts are described in Section 3. The Provider and Customer have their specific columns (in light blue) that depict the involved Debited/Credited Accounts and Amounts. However, those accounts should be regarded in the context of consensual columns (in dark blue).

Next, we describe the events of the example depicted in Fig. 6.

- EID:11 - An enterprise P enters into a contract to build a hospital for a customer C, (to fulfil some offering with EID:10), whereby P obliges to provide construction as a separate performance (project) within 2018, but the equipment procurement and installation project in 2019. The consideration for the whole contract comprises of a prepayment on 01.01.2018 and a final payment at the completion of the contract. These rights/obligations are depicted in the agreement details, but the effect of their fulfillment is specified by the *planned* accounts and amounts of the provider and customer.
- EID:12 C fulfils the obligation to transfer prepayment to P's bank account and accrues income claim against P for this amount.
- EID:13 P fulfils obligation by transferring goods and services for hospital construction promised in the EID:11 and accrues P's income claim of PO:1, thus completing the PO:1 fulfillment and recognizing revenue claim.
- EID:14 P transfers equipment.
- EID:15 P, by transferring the installation services, completes the PO:2 of equipment project that leads to overall contract fulfillment and accrual of consideration rights.
- EID:16 C completes the settlement and the whole exchange by cash payment to P's bank account.

5. IASB Conceptual Framework Resource Definition Analysis

In March 2018 IASB finally released the revised version of the Conceptual Framework (CF) for Financial Reporting [10]. The revised framework contains several conceptual improvements, including new resource (as rights that have the potential to produce economic benefits), asset and liability definitions. Our goal is to be reasonably compliant with the framework in engineering COFRIS. Another goal is to see where the CF could benefit from our ontological analysis. We list the following suggestions:

Firstly, Financial reporting should aggregate *transaction-centric* plus enterprise-specific, but not enterprise effect-centric information. Thus, economic exchange should be introduced as a unifying concept. Aggregating consensual transactions for FR, instead of accounts, would provide additional opportunities for comparability with other enterprise processes, possibilities of application of process mining methods, and insights into the value co-creation processes.

Secondly, competitive *consensuality* (meaning that among parties there is an agreed shared ledger of contracts and their fulfillment, including provider and customer resources (claims) and required asset (liability) information) should be a quality aspect, even within the old context of audit reconciliations. Consensuality should be added to comparability, verifiability, timeliness, and understandability as qualitative characteristic that enhances the usefulness of information that both is relevant and provides a faithful representation of what it purports to represent and reduces *reporting uncertainty*.

Thirdly, *correlativity* in economic relationships, should be a standard-setting principle. The important intermediate resources (claims) of contract realization, performance and transfer should be defined. When correlativeness and consensus are not regarded as a principle, deficiencies emerge in standards already discussed by us elsewhere, such as concerning leases [11], contract assets and revenue [3].

Fourthly, Assets (Liabilities) are conceptualized only as recognized, while the other phases of exchange (contract), depicted in disclosures, should be conceptualized.

And fifthly, a unifying concept of an *Economic relator* should be introduced. A partial effort in the framework has been made by defining the concept of a Unit of Account as a group of related rights and/or obligations. The difference is that the economic relator is a more atomic building block that shows the value relationship, from which more complex units of account such as the contract (of three levels and phases of fulfillment, as shown in this paper), investment portfolio, cash-generating unit, and enterprise as complex economic relators can be built.

6. Conclusion

Financial reporting standard-setting, implementation and the corresponding information system development is at present a partially informal and long process and, as exemplified by other domains, may be improved using ontology-driven conceptual modeling approaches. Existing foundational and core ontologies, as shown by UFO ontology network usage, provide upper-level patterns from foundational UFO – A, B, C, and several UFO grounded ontologies, such as services, legal, transaction, enterprise, exchange, value and even software [11], for representing FR concepts and relationships.

An Economic relationship as a disposition of economic exchange events, is a fundamental and reuse facilitating pattern of capturing economic phenomena for FR. By extending the general exchange pattern it is possible to build patterns for particular standards to facilitate reuse. An ontological analysis allows for the explication of the core contract creation and fulfillment phases, economic relators – resources (claims), assets (liabilities) to capture the full partition of the economic phenomena which can be used for FR. Aligning FR concepts with UFO allows for better understanding of the meaning of FR concepts and their classification in the enterprise domain, for instance, for OMG Standards for EA. Elaboration of correlative associations between the enterprise and the counterparty, based on the legal and economic relator concepts, may lay a foundation for consensus-based accounting in a shared ledger environment, where the conceptualization of assets (liabilities) will reveal holder-specific and potentially sensitive or shareable parts for contracts and FR.

Our first suggestions are described in Section 5, furthermore, a full validation of Resource (Claim) concepts of COFRIS by modeling most IFRS standards is needed.

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A Comparative Illustration of Foundational Ontologies: BORO and UFO

Michael VERDONCK[1], Tiago Prince SALES[2] and Frederik GAILLY[1]
[1]*Ghent University, Belgium;* [2]*University of Trento, Italy*

Abstract. This paper investigates the differences that exist between a 3D and a 4D ontology. We examine these differences by comparing both ontologies through the metaphysical choices each ontology makes and explore the composing characteristics that define them. More specifically, the differences between the ontologies were illustrated through several modeling fragments that were derived from a modeling case presented at the 5th OntoCom workshop. Each of these modeling fragments focused on the metaphysical choices that the ontologies make – Essence and Identity, Relationships and Time. These comparisons highlighted the different ontological approaches and structures that exist between the ontologies. Moreover, depending on the ontology, the resulting conceptual model could differ substantially, confirming the impact and importance of the choice of a certain ontology. The observed differences between both ontologies eventually led us to formulate three discussion points that question the applicability of certain metaphysical choices in certain circumstances, and that can serve as a basis for future discussion or future research studies in the domain of ODCM.

Keywords. Foundational ontologies, metaphysical choices, 3D ontology, 4D ontology

1. Introduction

Ontology can be broadly defined as "the set of things whose existence is acknowledged by a particular theory or system of thought" [1]. Research on ontologies has become increasingly widespread in the computer science community, gaining importance in research fields such as Knowledge Engineering, Knowledge Representation and Information Modeling [2]. More specifically in the field of Conceptual Modeling, ontologies provide a foundational theory that articulates and formalizes the conceptual modeling grammars needed to describe the structure and behavior of the modeled domain [3]. As defined by [4], conceptual modeling is the activity of representing aspects of the physical and social world for the purpose of communication, learning and problem solving among human users. The ontological foundation in conceptual modeling manifests itself by means of a formal specification of the semantics of models and describe precisely which modeling constructs represent which phenomena. In this paper we shall refer to all techniques where ontological theories are applied – e.g. evaluation, analysis or theoretical foundation – to improve either the quality of the conceptual modeling process or the quality of the conceptual model, as ontology-driven conceptual modeling (ODCM).

Based upon their level of dependence of a particular task or point of view, different types of ontologies can be distinguished and applied in ODCM [5]. In this article however, we will focus solely on foundational ontologies. Different kinds of foundational ontologies can be adopted in order to perform ODCM. For instance, based upon the endurantism-perdurantism paradigm, we can differentiate between 3D and 4D ontologies. *3D ontologies* view individual objects as three-dimensional, having only spatial parts, and wholly exist at each moment of their existence. *4D ontologies* on the other hand see individual objects as four-dimensional, having spatial and temporal parts, and existing immutably in space-time [6]. While most research in ODCM has been performed with 3D ontologies [7], 4D ontologies have gained more popularity in recent years [8]–[10]. Several studies [9], [11] have already demonstrated that applying different ontologies can lead to diverse kinds of conceptualizations. Furthermore, the application of a certain ontology can ultimately even influence the model comprehension of the resulting ontology-driven models on its users [12].

In order to further explore and discover the differences between adopting different kinds of foundational ontologies, the 5th International Workshop on Ontologies and Conceptual Modeling (OntoCom) dedicated their full program on this topic at the 36th International Conference on Conceptual Modeling. Leading ontologists and conceptual modelers were invited to discuss and analyze the differences between 3D and 4D foundational ontologies. More specifically, the workshop provided a written modeling case to which participants of the workshop were invited to develop an ontology-driven conceptual model that faithfully represents the case according to the rules and constraints of either the 3D or 4D ontology.

This paper builds further upon this workshop by comparing the differences between the models that were composed during this workshop using both 3D and 4D ontologies. By comparing these models, we aim to highlight the different ontological approaches and structures that exist between their underlying ontologies. Moreover, we will compare these ontologies by emphasizing their ontological commitments and exploring their main characteristics. More specifically, we will focus on the ontological differences that exist between the BORO ontology [13] and the Unified Foundational Ontology (UFO) [14]. By comparing these ontologies, we seek to clarify and determine the differences that arise in the resulting conceptual models when applying a 3D or 4D ontology. We would like to remark that the purpose of this article is not to determine the superiority of a particular ontology over another, but to simply increase awareness and transparency in applying different types of ontologies.

In section 2 we will briefly discuss the UFO and BORO ontology. Section 3 will then compare these ontologies through the metaphysical choices they make and illustrate the differences of these choices with certain modeling fragments from the OntoCom modeling case. In section 4, we will discuss the impact of these metaphysical choices, and also compose several questions that arose from the comparison and which can serve as the basis for future research. Finally, in section 5 we summarize the findings of this paper.

2. The BORO and UFO ontologies

During the OntoCom workshop, two foundational ontologies – i.e. BORO and UFO – were emphasized and applied for the development of the ontology-driven conceptual models based upon the modeling case. Comparing these two ontologies makes sense since they are built upon completely different paradigms – i.e. BORO is a 4D ontology while UFO is a 3D ontology. Since they adopt different interpretations on real-world phenomena, it makes them quite interesting to compare. Moreover, they were also developed to fulfil entirely different purposes. On the one hand, UFO was developed to provide sound ontological foundations for various domains (domain appropriateness) and conceptual clarity (comprehensibility appropriateness) of modeling languages [15]. BORO on the other hand, was designed to support information systems re-engineering and integration in a transparent and straightforward manner [13].

BORO distinguishes three main categories [16]: Elements, Types, and tuples. Every object belongs to one of these categories. *Elements* are individual objects whose identity is given by the element's spatiotemporal extent i.e. the space and time it occupies. An example of an element would be the person John. *Types* are collections of any type of object (in other words, objects of any of the three categories). The identity of a type is determined by its extension, the collection of its instances or members. For example, the extension of the type Persons is the set of all people. Finally, *Tuples* are relations between objects. The identity of a tuple is defined by the places in the tuple. An example is (Mary, John) in which the elements Mary and John occupy places 1 and 2 in the tuple, respectively. Tuples can be collected into types, called tuple types. An example is parentOf, which is the collection of all relations between parents and their children.

UFO is a much more complex ontology, being composed of three core modules, namely UFO-A, an ontology of endurants (objects) [14]; UFO-B, an ontology of perdurants (events) [17]; and UFO-C and ontology of social entities that specializes the former two [18]. UFO's most fundamental distinction is between individuals and universals. *Universals* are abstract patterns of features that can be realized in a number of different *individuals*. In UFO, the identity of universals is separated from their extensions, allowing, for instance, that the extension of a universal changes through time, as well as that two universals have the same extension at a given moment.

A second fundamental distinction in UFO is that between endurants and perdurants. *Endurants* are individuals that are wholly present whenever they are present (e.g a ball, a person), whilst *perdurants* are individuals extended in time, through which they accumulate temporal parts (e.g. a football match, a party). UFO further categories endurants into substantials and moments. *Substantials* are existentially-independent endurants (e.g., an animal, a table), whilst *moments* are individuals that necessarily inhere in others, their bearers, to which they are existentially-dependent on (e.g., the color of an object, the weight of a person). In UFO, endurants can be characterized by both essential and contingent properties, which means that they can genuinely change while keeping their identity [14]. For instance, being a mammal is an essential property for dogs, whilst being overweight is a contingent one. Thus, no dog can change in such a way that it ceases to be a mammal, whilst any dog can change its weight and remain the same individual. Perdurants, conversely, are exclusively characterized by essential properties, thus they cannot genuinely change) [17].

Perhaps the main differentiation between both ontologies arrives through the different underlying paradigms on which they define and classify concepts and phenomena. While the UFO ontology adopts an endurantist approach (3D), the BORO ontology corresponds with a perdurantist view (4D). In endurantism an individual thing such as for example John Doe endures through time and is regarded as totally present at any moment in its lifetime. In a perdurantist ontology, an individual thing perdures through time and is extended in time, and so can be said to be only partially present at any moment in time – e.g. the whole of John extends over time from his birth to his death. Thus, while 3D ontologies view objects only from the present and assume that the same object can exist over time and may be fully identified at different points in time, the 4D ontological view emphasizes the continuity of objects over space-time, where these objects exist immutably. These differences between endurants and perdurants determine whether and how objects exist in different ways in the past, present and future. Or in other words these differences determine how an ontology is formed. In the section below, we will discuss the different metaphysical choices that shape the fundamentals of an ontology through several illustrations that are based upon the case study of the OntoCom workshop. Finally, since we will not cover all the concepts of both ontologies in this paper, we like to refer the reader for a more detailed reading of the BORO ontology to [13], [19] and for the UFO ontology to [14], [15].

3. Metaphysical Choices

In this section, we will focus on the different metaphysical choices the BORO and UFO ontology make, and illustrate these differences based upon modeling fragments of the modeling case that was given at the OntoCom 2017 workshop. We would like to emphasize that these models were based upon the same case. The case itself describes the University domain. This domain was chosen deliberately in order to exclude any advantages concerning specific domain knowledge. Since most of the participants at the workshop were professors themselves, the University domain and its structure were rather well known.

3.1. Essence and Identity

The notion of identity and essence-defining characteristics – better known as essential properties in 3D ontologies – regards how the ontology assigns a principle of identity to its concepts and dictates whether a certain phenomenon is represented through one or multiple objects. For instance, in the perdurantist view, where all individual objects are four-dimensional and have spatial and temporal parts, objects do not (explicitly) have properties such as weight, height etc. Instead, their features and characteristics are derived from the spatial and temporal parts that are formed with other objects. Another example of how the notion of identity is represented by 3D and 4D ontologies can be demonstrated through the representation of temporary conditions such as roles, states and phases of an element. In a 4D ontology, John as a child and John as an adult are separate elements (i.e. states), that become – temporarily – part of John as a whole. Conversely, in a 3D ontology, John as a child is the same as John as an adult since the essential properties of John do not change. In a 4D ontology, John is wholly present from his birth to his death. John as a child and John as an adult represent temporal parts of John as a whole.

To demonstrate how these ontological distinctions impact conceptual models that follow them, we use a simple scenario in which a person, named John, is a student at a given moment in time, and a professor at another. The corresponding UFO-based and BORO-based models are depicted in Figure 1 and Figure 2, respectively. In Figure 1, we can observe that the concept of PERSON is represented as a Kind and specialized into two subclasses, namely the STUDENT and a PROFESSOR Roles. Note that, at the instance level of this model fragment, an individual can simultaneously instantiate PERSON, STUDENT and/or PROFESSOR. In the figure, we represent that JOHN, an instance of PERSON, instantiates the STUDENT Role at time t_1 and the PROFESSOR Role at time t_2.

In UFO, a Kind is a rigid category that provides an identity principle to its instances. By rigid category, we mean that all individuals that instantiate a given Kind must do so in all possible worlds in which they exist. Thus, by modeling PERSON as a Kind and asserting that JOHN is an instantiation, it follows that JOHN cannot cease to be a PERSON while he exists. Conversely, UFO Roles are anti-rigid and relationally dependent categories. This means that individuals instantiate them "accidentally" and in virtue of a relational change. Thus, in our scenario, a STUDENT is a role that a PERSON plays (instantiates) when related to an EDUCATIONAL INSTITUTION by means of a student ENROLLMENT (omitted from the figure). PROFESSOR is another role which is also relationally depends on an EDUCATIONAL INSTITUTION, but by means of an EMPLOYMENT CONTRACT (also omitted from the figure).

The BORO representation in Figure 2 follows a rather different approach. In the BORO ontology, STUDENT and PROFESSOR are specializations of PERSONSTATES, which is an Element. PERSONS and PERSONSTATES form a relation through the tuple PERSONTEMPORALWHOLEPART (i.e. PERSONTP). TEMPORALWHOLEPARTS is a tupleType that represents relations between objects that temporarily form a WHOLEPART relation with one another. It is important to realize that PERSONSTATES is a different object from PERSONS itself and is not existentially nor relationally dependent upon it. As such, in this approach, collections are more like sets, and the identity criteria of the collection-set can be its members. In the figure, JOHN, PROFESSOR JOHN, and STUDENT JOHN are instances. The element '(JOHN, STUDENT JOHN)' also represents an instance, more specifically that of a TupleType.

Additionally, we would like to remark that we have assigned colors to the different objects in these diagrams in order to emphasize the nature of these entities. More specifically, red represents endurants, green represents relationships or tuples while yellow corresponds to perdurants. This differentiation in colors immediately draws our attention for example to the fact that how an exact same case is completely represented by only Endurants in UFO, while in BORO the diagram is composed out of entities that are either Perdurants or Tuples. Moreover, note that instances are represented with slightly darker shades of the color assigned to the types they instantiate – relations which are represented in the figures through dotted lines with the 'iof' label.

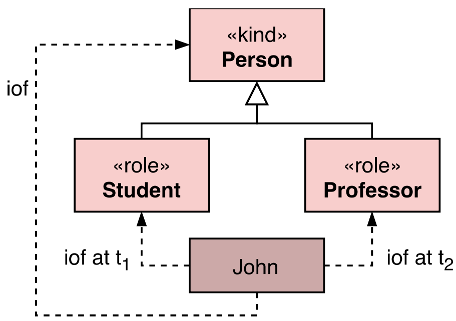

Figure 1: Roles in UFO

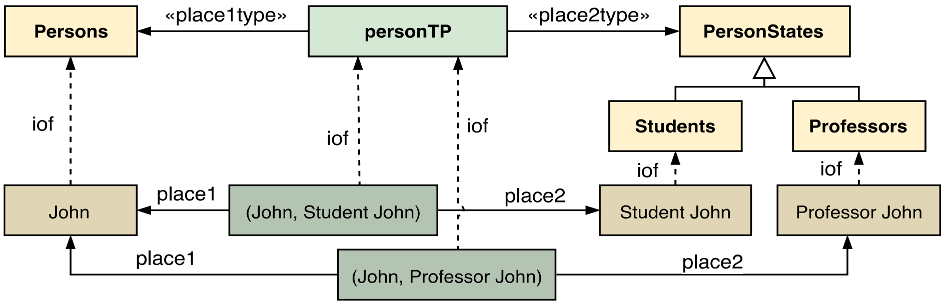

Figure 2: States in BORO, based upon [16].

3.2. Relationships

Similarly to the notion of identity, the metaphysical choice of both ontologies concerning the formation of *relationships* defines the way entities can become part of each other or separate from one another. In UFO, relationships can be distinguished based upon a certain meaning that is derived from the kinds of entities they link together. One concept in the UFO ontology – the Relator – forms an important element in relating entities. Relators are moment universals that represent the objectification of a relational property, which are existentially dependent on a multitude of individuals, as such, mediating them. Relators are the truth makers of the so-called material relations [20]. In BORO, relationships are defined as tuples that aggregate any kinds of entities. The identity of a tuple is defined by the places in the tuple. A tuple (or tupleType) defines the types that the places of its instances must instantiate. Different kinds of tuples exist. For instance, the wholeParts tuple represents a relation between two elements in which the 4D extent of one element is completely contained within that of another element for the entire existence of both. The example of John and his brain would fit this kind of tuple. TemporalWholeParts tuples are a subtype of the tuple type WholeParts, and represent relationships of two elements in which the 4D extent of one element is completely contained within that of another element, but only for a particular period of time.

To illustrate the conceptual differences that rise between both ontologies, we represent the modeling fragment of John being enrolled at the UGent (University Ghent) by the UFO ontology in Figure 3 and by the BORO ontology in Figure 4. Similar to the example above, STUDENT is represented as a Role, which is derived from the Kind PERSON. This Role is then connected with a UNIVERSITY through a Relator which represents the ENROLLMENT relationship. A Relator idiosyncratically binds two elements with one material relation and two mediation relation. While the material relation is directly derived from the relator, the mediation relation is a formal relation – a specific type of existential dependence that takes place between a Relator and the element it mediates. Finally, JOHN, UGENT and JOHN'S ENROLLMENT AT UGENT represent the instances from the Kind, Role and Relator.

Regarding the BORO fragment in Figure 4, the enrollment between a PERSON and a UNIVERSITY is represented through the tuple ENROLLEDAT. A tuple can consist of two or more 'places' that define the identity of the tuple. In this case, the tuple can be filled with two states, on the instance level being UGENT STUDENT JOHN and UGENT HOSTING JOHN. We would like to remark that the order of the places in the tuple carry meaning: JOHN (place 1) is enrolled at the UGENT (place 2). The opposite would have an entirely different meaning and would make no sense in this example.

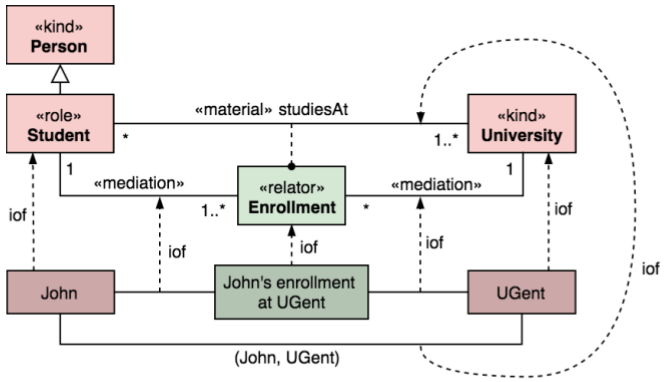

Figure 3: Student enrollment as represented by the UFO ontology

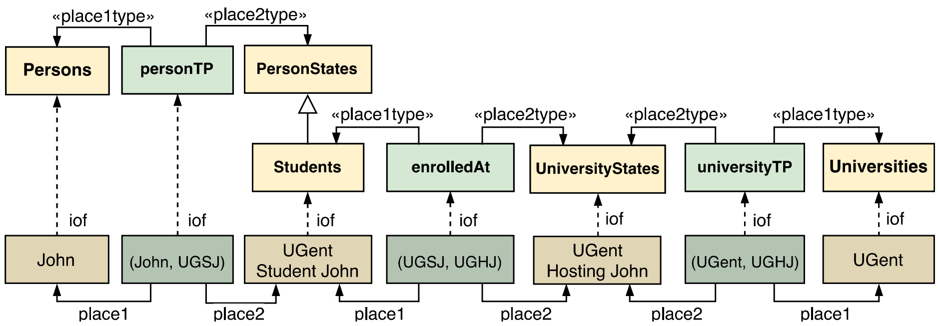

Figure 4: Student enrollment as represented by the BORO ontology

3.3. Time

The metaphysical choice of an ontology concerning time determines how entities begin and cease to exist over *time*, and how they define events and changes. In a 4D ontology, objects and relationships are represented immutably in space-time while 3D ontologies represent these objects and relationships in the present, with their current traits and characteristics. In the UFO ontology, time-related elements are represented through Events, which are individuals composed of temporal parts. They happen in time in the sense that they extend in time accumulating temporal parts. The interactions between events and their relationships are derived from the base relations in Allen's interval algebra for temporal reasoning [21]. Events can be atomic or complex, depending on their mereological structure. Whilst atomic events have no proper parts, complex events are aggregations of at least two disjoint events. This composition implies that whenever an event is present, it is not necessarily the case that all its temporal parts are present. For instance, childhood and adulthood can be considered as Complex Events that are composed of a series of disjoint Atomic Events. As stated above, an element in BORO is defined by its spatiotemporal extent – i.e. the space and time it occupies – where the element extends through time and is not fully present at any instant in time (excluding elements with a zero temporal extent). Moreover, different segments of space-time are elements themselves. Consequently, a temporal slice (e.g. a second, a day or a century) can therefore be seen as 4D extensions. In order to represent occurrences or time intervals, BORO applies upper-level patterns such as 'happensIn' in order to represent the occurrence of an element in a specific time period or instant. In fact, these happensIn patterns are simple wholePart tuples. Similarly, in order to represent temporal sequencing, BORO provides the 'before-after' pattern to represent such changes, which is essentially just a tuple.

To exemplify the concepts of both ontologies, we display a fragment that outlines the situation where a THESIS DEFENSE precedes GRADUATION for UFO in Figure 5 and for BORO in Figure 6. As can be seen in the UFO diagram, both DEFENSE and GRADUATION are depicted as Events. These Events can be either atomic or complex, depending on the interpretation of the modeler. The before-after relation represents the order of the Events in which they should take place. In the BORO fragment, DEFENSE and GRADUATION are separate Elements. To represent the temporal sequencing of both Elements, the before-after pattern is applied, which relates both instances JOHN'S DEFENSE and JOHN'S GRADUATION. Again, the order of the places in the tuple are important since they determine which Element precedes the other (before-after).

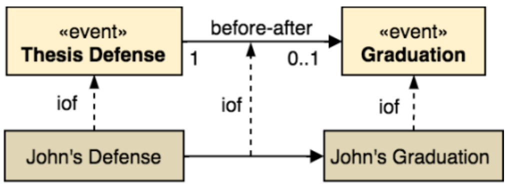

Figure 5: Temporal concepts and sequencing in UFO

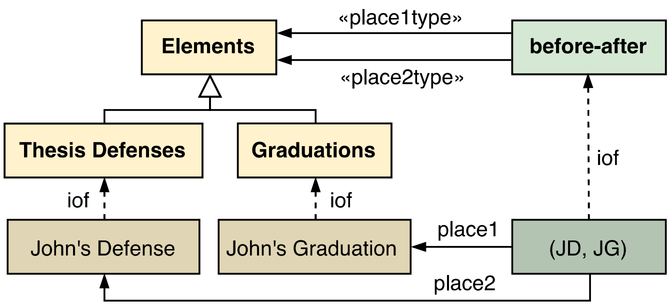

Figure 6: Temporal concepts and sequencing in BORO

4. Discussion

Based upon the metaphysical choices discussed above, and the different conceptual representations that were created from the same case study, we will discuss both ontologies and list several questions that can serve as a basis for future discussion or future research studies.

A first distinction we can make between both models is that their overall structure differs rather substantially. UFO distinguishes several principal identity-bearing concepts – e.g. Person and University – where other concepts can borrow their principle of identify from (e.g. STUDENT or PROFESSOR). Between these concepts relationships are formed that are either represented through Relators, specialization relationships or simple association relationships. In BORO, we can observe an overall rather different structure. In the modeling fragments, all concepts are independent elements (i.e. PERSONS, PERSONSTATES, UNIVERSITIES) that interact with one another through WHOLEPART and TEMPORALPART relationships, which are represented through tuples. While UFO also allows the modeling of temporal parts of event [22], the frequent use of WHOLEPART and TEMPORALPART relationships in BORO emphasizes the perception and enduring of time concerning the concepts. Additionally, the common use of STATES (e.g. PERSONSTATES, UNIVERSITYSTATES) also accentuates the perduring and changing nature of several concepts. This observation is in line with the literature involving 4D ontologies, where Hales & Johnson (2003) affirm that since 4D ontologies emphasize the continuity of objects over space-time, they are more suitable to express time-related concepts. Therefore, the first question we can formulate based upon the modeling fragments and assumptions of existing literature is the following:

- *Does the BORO application of states, wholePart and temporalPart relationships allow of a more systematic representation of temporal aspects of concepts compared to the UFO ontology?*

Next, adopting the BORO and UFO ontology leads to quite different outcomes concerning the identity of certain entities. For instance, UFO assumes that STUDENT (a Role) is a specialization of PERSON (a Kind). Thus, an instance of STUDENT is also an instance of PERSON. In BORO however, these are different elements with their own identity – or spatio-temporal extents – a PERSON, and STUDENT as a personState. The main difference here is that these objects are not related through a specialization relationship, but through a temporalWholePart relationship. In other words, UFO builds upon the intuition that a Professor is a way of being while BORO sees them as different things. Moreover, according to the study of [9] this differentiation in identity criteria would even lead to a more difficult characterization of sub-roles with the UFO ontology compared to the BORO ontology. On the other hand, as mentioned by [23], this paradigm of viewing every entity as a separate element can lead to the disadvantage that the ontology feels rather counterintuitive, since objects and processes are not distinguished and thus things that are typically regarded as objects have temporal parts. As such, our second question can be defined as following:

- *In which cases is the adoption of the BORO or UFO ontology concerning the ontological differentiation in identity preferred to form a representation?*

Finally, our last question involves a more philosophical distinction, namely the modeling of modality – both temporal modality as well as alethic modality (i.e. modality that connotes the estimation of the logical necessity, possibility or impossibility) – or how individual objects can possibly differ and how they are extended across many possible worlds. This is an important feature since modeling possible or future scenarios occurs often, for instance in the case of not knowing the time when two parties will agree to their contractual obligations. In UFO, individual objects are world-indexed, meaning that they are part of a snapshot that is world-bound (i.e. in a particular world at a particular time). These objects however are not 'locked' inside a particular world. In UFO, an instance of a Kind can exist in different possible worlds as long as they keep being instances of that Kind. The only way that they can be re-identified as the very same entity in different worlds is because of the principle of identity provided by that Kind. BORO on the opposite adopts Lewis' (1986) theory of possible worlds and counterparts. In

BORO, all objects are separate elements, and they each have counterparts in other possible worlds to represent such scenarios. This different paradigm in modality between both ontologies has already given rise to several arguments favoring the modality of a particular ontology. For instance, one can question if the modality in BORO is not of a more fragile nature. In UFO endurants are the natural bearers of modal properties, there exists a cross-world identity between them. Endurants can change due to the distinction between essential and accidental properties [22]. In BORO however, objects are immutable, meaning that they cannot change and as such cannot be different in any way. Consequently, there is no cross-world identity between objects in BORO. Moreover, when one would ask the question 'What kind of changes can something undergo and still be the same?', the answer for the BORO ontology would be none due the immutability of objects. In UFO, this change would depend on the type of entity and its composing properties. These arguments give raise to the doubt if BORO can properly represent modality, and as such we formulate our last question as follows:

- *Does the UFO ontology allow for a more appropriate representation of modality compared to the BORO ontology?*

5. Conclusion

In this paper, we compared the differences that exist between a 3D and a 4D ontology according to the metaphysical choices that they make and that defines the structure and composition of these ontologies. More specifically, we compared the BORO and the UFO ontology, and investigated the differences between them through several modeling fragments that were derived from a modeling case presented at the 5th OntoCom workshop. Each of these modeling fragments focused on the metaphysical choices that the ontologies make, i.e. Essence and Identity, Relationships and Time. By comparing these models, we could highlight the different ontological approaches and structures that exist between these ontologies. For instance, the modeling fragments illustrated the intensive use of the BORO ontology of wholePart and temporalWholeParts relationships between entities. Moreover, practically all entities in BORO are seen as separate elements, while UFO distinguishes several principal identity-bearing entities (Kinds) where other concepts can borrow their principle of identify from (Roles or Phases). The observed differences between both ontologies eventually led us to formulate three questions that challenge the applicability of certain metaphysical choices in certain circumstances, and that can serve as a basis for future discussion or future research studies in the domain of ODCM. Moreover, future research efforts could also focus on comparing different kinds of ontologies (e.g. not only 3D and 4D ontologies; or other specific ontologies rather than the BORO and UFO ontology) or could examine different metaphysical choices (for instance how ontologies deal with parthood, dependency and unity). Finally, we would like to emphasize that the purpose of this paper was to clarify and determine the differences of applying different kinds of ontologies and their influence on the resulting conceptual models. It was not our intention to advocate the superiority of a certain ontology, but rather to simply increase awareness and transparency in applying different types of ontologies.

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What's the Damage? Abnormality in Solid Physical Objects

Yi RU and Michael GRÜNINGER
Mechanical and Industrial Engineering, University of Toronto, Canada

Abstract. The representation of damage to solid physical objects is complex in nature. Beginning with real world usecases of partially damaged used goods, we derive the description of damage through the approach of representing partial abnormality. We propose four predicates for partial abnormality corresponding to the fundamental characteristics and parthood relationships within solid physical objects: $ab\_portion, ab\_piece, ab\_component$, and $ab\_containment$. Such parthood relations and mereological pluralism concepts are drawn from the Ontology of Solid Physical Objects (SoPhOs), a general suite of upper ontology modules we proposed and axiomatized in First Order Logic. This paper reviews the SoPhOs ontologies that axiomatize parthood, spatial parthood and parthood connection theories and the foundational matter and shape characteristic ontologies that support them. We map the foundational solid physical object ontology to solving the problem of representing damaged goods in various domains including manufacture and e-commerce.

Keywords. Damage, Solid Physical Objects, Parthood, Mereology Pluralism, Ontology, Domain Application, Used Good

1. Introduction

An interesting challenge in conceptual modelling is the representation of some notion of ideal objects and their relationship to actual objects whose properties diverge from the specification of the ideal. Such a distinction plays a role in a wide range of applications, from manufacturing quality to commonsense reasoning with everyday objects. As such, the distinction between ideal and actual objects can refer to an object that is simply created in a way that violates the specification of the ideal, or it may refer to objects that have been changed in damaged through use. The notion of damage we present in this paper concretely arises from the representation of used goods in The Social Needs Marketplace (SNM)[9], which is an online marketplace exchange to offer and receive used goods for people who live under the poverty line. The match between supply and demand of used goods requires a detailed representation for damage of solid physical objects. However, the terminology people use for these descriptions is rife with ambiguity and always ad hoc and arbitrary. It is essential to derive an applicable approach for representing damaged goods for SNM.

From the motivating scenarios listed in the second section, we narrow our scope to the description of partially damaged goods. The specification of damage condition requires a comprehensive description to parthood relationships beyond mereological monism[1]. The relationship between the detachable leg of a table and the table itself is fundamentally distinct from the relationship between the table and a portion of the table that has been chipped off. In this paper we will focus on the representation of damage from the approach of pluralism to abnormality of solid physical objects, based on the multiple parthood relations raised from Ontology of Solid Physical Objects (SoPhOs). SoPhOs is a general suite of upper ontology modules that support the specification of the parthood relations for solid physical objects and used goods within the scope of SNM.

Our approach falls into what is often called the family of three-dimensional representation of physical objects, in which all of an object's parts exist at any point in time. This approach can also be seen in the BFO [4] and DOLCE [16] upper ontologies, although these upper ontologies are based on a time-indexed version of mereological monism.

2. Motivating Scenarios

Below are some scenarios that happened in SNM, and served as the motivation for the approach taken in this paper.

- Expectant parents are looking for children's furniture for their soon to arrive baby. They log into the SNM portal and search for a children's bed with complete safety measures. The supply of children's beds on the portal is limited returning only two partial matches to this family's needs. A family whose children are now of school age is offering a single child's bed with headboard missing, while another family is offering a bunk style bed for twins but it is convertible into a single bed.
- A furniture wholesale store is looking to relocate its warehouse due to the increasing rent, the store owner decides to mark down the selling prices heavily on most items stored in the warehouse to reduce the moving cost. However, some items are damaged because of improper storage or transportation, some tables have the corners cut out, some chairs have dents on the legs, and a sofa is also broken with filling coming out. For these items with minor damage, the store owner requests the warehouse manager to list them up on the SNM for donation.
- A retired couple is looking to clean up their garage and donate some of their old time favorite tablewares. Among them are a ceramic coffee mug with a handle broken but that has interesting pattern on it, a crystal wine decanter with the detachable stand missing, an emptied cookie can that could be used as a daily container, and a dish with a chipped corner. They log in the portal and listed these items with detailed description.

3. Ontological Commitments

The ontological commitments are semantic requirements we recognized from the motivating scenarios.

1. Damage to solid physical objects is determined comparing to the design.

[1] Mereological monism denotes that there is a single parthood relation. Approaches based on classical mereology [24] tend to use a single parthood relation to specify parthood relationships.

2. A partially damaged object can be presented in precise ways in terms of characteristics of solid physical objects.
3. There are multiple parthood relations of solid physical objects, and they are all distinct relations, each of which is synonymous with a mereology theory. Furthermore, there is no taxonomy of parthood relations.
4. There is different mereology for each part, and each mereology has different spatial ontology (radical pluralism).
5. In the scope of solid physical objects, each parthood relation is independently axiomatized with different characteristic module ontologies.
6. Each abnormality parthood relation is associated with a distinct parthood relation of solid physical object.

4. Ontology of Solid Physical Objects (SoPhOs)

The seminal work of Winston et al. [25] identified multiple relations that capture intuitions about parts and wholes, we follow this approach of mereological pluralism and propose each parthood relation corresponds to a generic module of upper ontologies. We adopt the sideways approach to upper ontologies [12], and focus on those modules that axiomatize intuitions about solid physical objects, which is organized into the Ontology of Solid Physical Objects (SoPhOs).

The design of the Ontology of Solid Physical Objects (SoPhOs) follows the principle that each module of SoPhOs axiomatizes necessary conditions for solid physical objects. We define a solid physical object as *an object that is made of some material, has some shape, and occupies some space*. SoPhOs is built to expand the definition with two modules: matter module and shape module. Each module features a characteristic ontology in the upper ontology and gives rise to corresponding parthood relations: [*portionOf*, *pieceOf*, *componentOf*] for parthood on solid physical objects, and [*confinedIn*, *containedIn*] for spatial parthood, respectively. The current design of the Ontology of Solid Physical Objects is shown below in Figure 1 and Figure 2. SoPhOs is fully axiomatized in First Order Logic[2].

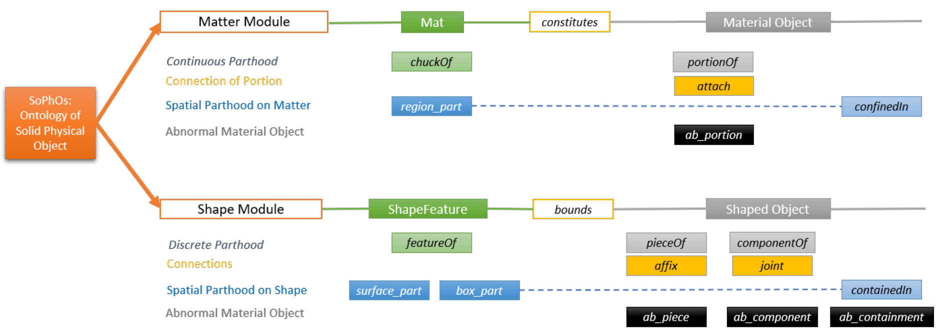

Figure 1. Structure of Relations within Ontology of Solid Physical Objects (SoPhOs)

[2] colore.oor.net/sophos/sophos.clif

	Characteristic	Parthood on Characteristic	Parthood on Characteristic with Spatial Relationship	Characteristic vs. Object	Defined Parthood on Characteristic Object	Parthood on Characteristic Object with Location	Connection on Characteristic	Damage Related
Ontologies	**Matter Module**	$T_{\text{Material Object}}$	T_{occupy} (adjusted)	$T_{\text{Material Object}}$	T_{Portion}	$T_{\text{confinement}}$	T_{Attach}	Removal of material
Relations	*Mat* (continuous)	*chunkOf*	*region_part*	*constitutes*	*portionOf* Damage: *ab_portion*	*confinedIn* Damage: *ab_confinement*	*attach*	
Ontologies	**Shape Module**	T_{Feature} (extended T_{BoxWorld})	$T_{\text{MT Multidimensional Object Mereotopology}}$	T_{Bounds}	T_{Piece}	$T_{\text{Containment}}$	T_{Affix}	Handle of mug; Dent in chair leg; Egg in box;
Relations	*ShapeFeature* (discrete, no metric)	*featureOf*	*surface_part* *box_part*	*bounds*	*pieceOf* Damage: *ab_piece* $T_{\text{component}}$ *componentOf* Damage: *ab_component*	*containedIn* (convex hull) Damage: *ab_containment*	*affix* $T_{\text{Mereotopology}}$ *joint*	

Figure 2. Module Ontologies in Ontology of Solid Physical Objects (SoPhOs)

Our approach can be seen as a development along the lines mentioned in Artale's work [3]: "The particular behaviour of the different part-whole relations may lie, among other things, in the ontological nature of both the whole and the part", namely, the ontological nature of the whole and part are captured by the generic modules of the upper ontology.

Definition 4.1. Let **R** be a binary relation, and let $\mathfrak{M}^{\mathbf{R}}$ be a class of structures with signature $\langle \mathbf{R} \rangle$.

The relation **R** is a parthood relation iff $Th(\mathfrak{M}^{\mathbf{R}})$ is synonymous with a theory in the $\mathbb{H}^{mereology}$ Hierarchy[3].

All of the parthood relations are given conservative definitions in their respective generic ontology modules, and hence are treated as defined relations. Real world physical examples of some parthood relation are shown below in Figure 3.

Figure 3. Physical Examples of Parthood Relations of Objects

4.1. Matter Module

A solid physical object is a material object. Matter constitutes solid physical objects and is one of the prime characteristics we determine for solid physical objects. Under the matter module we have The Material Object Ontology, which axiomatizes the constitution relation *constitutes* between *Mat* (matter) and *MaterialObject*, and defines *chunkOf* as the parthood relation within matter. The Portion Ontology contains the corresponding continuous parthood relation *portionOf* for the material objects. An example of *portionOf* a material object is a one person portion of pizza in a whole pizza, or a bite of

[3] `colore.oor.net/mereology`

an apple is a portion of the apple. The Attach Ontology features the connection relation *attach* between material objects. Incorporating the spatial parthood relation *region_part* from Occupy Ontology[2], the Confinement Ontology defines *confinedIn* to denote the parthood relationship between two material objects that the space occupied by one material object is in the region of the space occupied by the other material object (e.g. a chunk of pineapple is confined in the whole pineapple).

4.2. Shape Module

The shape module of SoPhOs starts from the Feature Ontology which is an extension to the BoxWorld[10] with *ShapeFeature* and *featureOf*. *ShapeFeature* is a primitive class, it can be individual non-enclosed basic shape in BoxWorld (point/edge/surface) or the union of any adjacent non-enclosed shape or the box. Adjacent non-enclosed shapes are defined to be connected by at least one lower dimensional shape, as from examples in Figure 4, (i.e. two edges that meets at a point/vertex in i, two surfaces that meet at one edge and two points in ii, one edge and one surface that meet at one point in iv). *featureOf* is primitive parthood relation for *ShapeFeature*, it is a predicate between one *ShapeFeature* and another *ShapeFeature* at a higher dimension or the same dimension. Every *ShapeFeature* is a *featureOf* itself (including points).

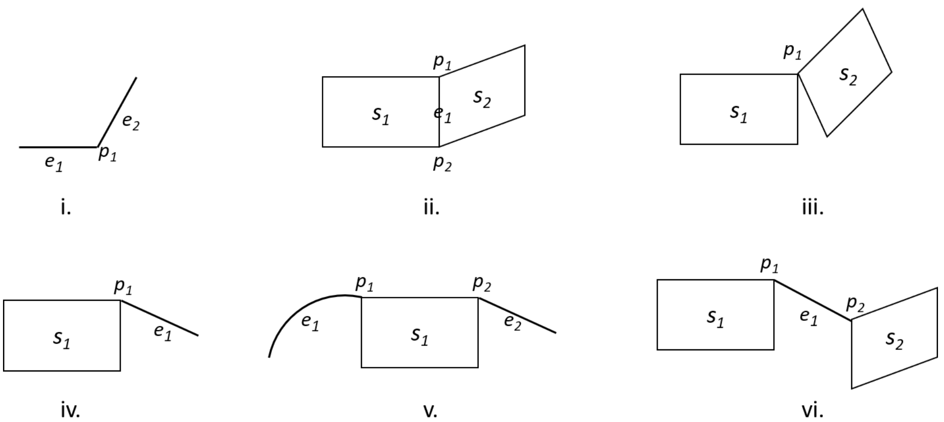

Figure 4. Examples of *ShapeFeature*

The Bounds Ontology describes the relationship between the shaped object and the shape feature that bounds it. For the multidimensional parthood of solid physical objects regarding shape, we have Piece Ontology and Component Ontology based on dimensionality. We use *pieceOf* for shaped objects in different dimensions below or at three-dimension, and *componentOf* between three-dimensional shaped objects and a set of three-dimensional shaped objects. For instance the mug example in Figure 5, if we say the shape feature that bounds a non-detachable handle of a mug is the two dimensional cylinder surface s_1 and the whole mug is bounded by a three dimensional box b_1, then the handle of the mug is a piece of the mug in terms of shape. However, if we are talking about the three dimensional box b_2 bounded cap and the whole mug with cap which is bounded by a poly[4] p_1, we use *componentOf* to define the parthood between the cap and the whole mug with cap. The cube in Figure 5 shows three instances of *featureOf*: $featureOf(f_1,b_1) \wedge featureOf(f_2,b_1) \wedge featureOf(f_3,b_1)$.

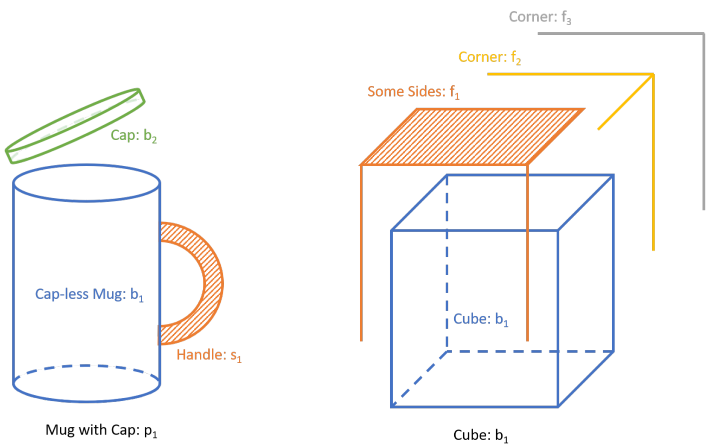

Figure 5. Distinguishing *featureOf* and *componentOf*

We use *affix* to denote the connection between pieces, and components are *joint* together, where *joint* is synonymous with *ec* (external connection) from classic mereotopology. Last but not least, we also have *containedIn* to describe the spatial parthood when the space occupied by the shape of one solid physical object is fully enclosed in the convex space occupied by the shape of another solid physical object (e.g. an egg is contained in the lunch box).

5. Abnormality of Solid Physical Objects

We find it is ambiguous to take ”ideal object” as the standard for determining abnormality. In real world, a chair can be designed in multiple different styles, it can have four legs, three legs, no legs like sofa, or one leg with four to six wheeled arms like an office chair; it is difficult and inaccurate to determine one specific design as a general ”ideal chair”. In contrast, we define the abnormality in terms of the intended properties instead of type or class, and differentiate abnormality with characteristics of the object.

Reiter [22] used *AB* to distinguish normal and abnormal conditions in diagnosis reasoning systems with examples of faulty circuits. We follow this approach and extend its use to abnormal conditions on solid physical objects. We propose four predicates in correspondence with four of our parthood relations for solid physical objects, *ab_portion*, *ab_piece*, *ab_component* and *ab_containment*, to denote an abnormal portion/piece/component/containment of the whole in terms of standard design. We don’t represent an abnormal confinement since the definitive nature that confinement describes the relationship that some matter M_1 located inside the space occupied by another matter

[4]Poly is defined as the shape of a set of three dimensional physical objects, and is considered as one dimension higher than a three dimensional box.

M_2, but in terms of solid physical objects, the spatial relationship between M_1 and M_2 cannot be changed unless the shape of M_2 is altered. We use the notion $\neg Ab$ to describe the condition when an object coincides with its design, that is, it is not abnormal, or "ideal".

Of course, some change/abnormality of characteristics will lead to inevitable change of other characteristics. The correlation between different characteristics are shown in Table 1. From the table we can conclude that the occurrence of *ab_portion*, *ab_component* or *ab_containment* would all result in one or more *ab_piece*, but an occurrence of *ab_piece* might not cause any other partial abnormalities. The occurrence of either *ab_component* or *ab_containment* would result in both some *ab_portion* and *ab_piece*, but the former two are isolated from any subsequent occurrences.

Table 1. Relativeness Chart of Change for Solid Physical Objects

Resulting Abnormality	new *ab_portion*	new *ab_piece*	new *ab_component*	new *ab_containment*	Examples
ab_portion	-	Y	N	N	Add/Remove Material
ab_piece	N	-	N	N	Bent, Dent
ab_component	Y	Y	-	N	Replaced Component
	Y	Y	-	N	Add/Remove Component
ab_containment	Y	Y	N	-	Add/Remove Containment

It is important to distinguish our use of abnormality predicates from their earlier use in nonmonotonic reasoning. We are *not* using abnormality to represent typicality (e.g. a typical chair has four legs, a typical dining room table is made of wood, a typical bookshelf does not have wheels). Instead, we are using abnormality predicates to specify the intended properties of an (ideal) object, so that any divergence from the specification of these properties (e.g. missing or spurious parts) are indications of damage. If a particular class of chairs is designed to have three legs, then it is not considered to be damaged when an instance of this class has three legs, even if a typical chair has four legs. On the other hand, if a class of chairs is designed to have four legs, then an instance of this class is indeed damaged if it is missing a leg.

6. Damage of Solid Physical Objects

In the motivating scenarios from SNM specified in Section 2, we need to describe partially damaged object (i.e. a bed with the headboard missing, a mug with the handle broken or a chipped dish), where the "partially damaged" here might have different meanings: partially missing, partially broken, or material partially removed. We apply abnormality to scenarios of damages. A standard design of My Chair with three legs is represented in Axiom (1)-(3) as in Figure 6 below, showing the intended properties of components, pieces and portions respectively.

Axiom (4)-(8) in Figure 7 below showed example representations of damaged chairs. C_1 denotes an replaced leg resulting an abnormal component; C_2 denotes a dent in one leg of a three-leg chair resulting an abnormal piece; C_3 denotes one leg missing; C_4 denotes when there is an extra leg; last but not least, C_5 denotes some additional matter is added to the chair.

Each class of solid physical objects is axiomatized by sentences of the form seen in Figure 6. By using the abnormality predicate Ab, we allow the existence of objects

$$MyChair(x) \supset (\neg Ab(x)$$
$$\equiv (\exists y_1, y_2, y_3) Leg(y_1) \wedge Leg(y_2) \wedge Leg(y_3) \wedge (y_1 \neq y_2) \wedge (y_1 \neq y_3) \wedge (y_2 \neq y_3)$$
$$\wedge componentOf(y_1, x) \wedge componentOf(y_2, x) \wedge componentOf(y_3, x)$$
$$\wedge((\forall z) componentOf(z, x) \supset z = y_1 \vee z = y_2 \vee z = y_3)) \quad (1)$$
$$Leg(x) \supset (\neg Ab(x)$$
$$\equiv (\exists y_1, y_2, y_3) bottom(y_1) \wedge side(y_2) \wedge top(y_3) \wedge (y_1 \neq y_2) \wedge (y_1 \neq y_3) \wedge (y_2 \neq y_3)$$
$$\wedge pieceOf(y_1, x) \wedge pieceOf(y_2, x) \wedge pieceOf(y_3, x)$$
$$\wedge((\forall z) pieceOf(z, x) \supset z = y_1 \vee z = y_2 \vee z = y_3)) \quad (2)$$
$$MyChair(x) \supset (\neg Ab(x)$$
$$\equiv (\exists y) Mat(y) \wedge constitutes(y, x) \wedge ((\forall z) portionOf(z, x) \equiv chunkOf(z, y))) \quad (3)$$

Figure 6. $T_{mychair}$: Representation of Standard MyChair Design

$$MyChair(C_1) \wedge Leg(L_1) \wedge Leg(L_2) \wedge Leg(L_3)$$
$$\wedge ab\_component(L_1, C_1) \wedge componentOf(L_2, C_1) \wedge componentOf(L_3, C_1) \supset Ab(C_1) \quad (4)$$
$$MyChair(C_2) \wedge Leg(L_4) \wedge Leg(L_5) \wedge Leg(L_6)$$
$$\wedge component(L_4, C_2) \wedge componentOf(L_5, C_2) \wedge componentOf(L_6, C_2)$$
$$\wedge Dent(P_1) \wedge Bottom(P_2) \wedge Side(P_3) \wedge Top(P_4)$$
$$\wedge ab\_piece(P_1, L_4) \wedge pieceOf(P_2, L_4) \wedge pieceOf(P_3, L_4) \wedge pieceOf(P_4, L_4) \supset Ab(C_2) \quad (5)$$
$$MyChair(C_3) \wedge Leg(L_7) \wedge Leg(L_8) \wedge componentOf(L_7, C_3) \wedge componentOf(L_8, C_3)$$
$$\supset Ab(C_3) \quad (6)$$
$$MyChair(C_4) \wedge Leg(L_9) \wedge Leg(L_{10}) \wedge Leg(L_{11}) \wedge Leg(L_{12})$$
$$\wedge ab\_component(L_9, C_4) \wedge componentOf(L_{10}, C_4) \wedge componentOf(L_{11}, C_4) \wedge componentOf(L_{12}, C_4)$$
$$\supset Ab(C_4) \quad (7)$$
$$MyChair(C_5) \wedge constitutes(M_1, C_5) \wedge chunkOf(M_2, M_1) \wedge ab\_portion(M_2, C_5) \supset Ab(C_5) \quad (8)$$

Figure 7. $T_{chairexample}$: Representation of Damaged MyChair Examples

in a class even if they do not satisfy the conditions for the ideal object in that class; inconsistency is avoided since such an object is simply an abnormal instance of the class. Furthermore, we can use the parthood relations in SoPhOs to identify the nature of the abnormality – missing matter vs. spurious matter, missing shape feature vs. unintended shape features, missing components vs. extra components.

Recall the motivating scenarios mentioned in Section 2, we can now help the SNM users to describe the damages in used goods (the actual terminology can be more userfriendly and easier to interpret by daily users, depends on the wording selection of the application designer):

- The expectant parents can eliminate the single children's bed with missing headboard by adding a filter to their request that map into the category with $\neg ab\_components$.
- The warehouse manager can list the tables with corners cut out and the chairs with dents on the legs in the category of *ab_piece*, and the sofa is broken with some *ab_portion* forms came out.
- The kind retired couple can donate the ceramic coffee mug with a handle broken as an entry with *ab_piece*, the crystal wine decanter with the detachable stand missing as with *ab_component*, the emptied cookie can as having *ab_containment*, and the dish with a chipped corner as havng either *ab_portion* or *ab_piece*.

7. Relationship between Previous Work and Our Work

Our representation of damage follows Reiter's[22] approach of abnormality and applies it to solid physical objects. There are limited previous studies that proposed a complete representation of damage for solid physical objects, but there are a few approaches for constructing an ontology of physical objects.

Many representations of solid physical objects involve time as a fourth dimension. Bennett[5] founds the representation to physical objects on a theory of the spatio-temporal distribution of matter types and proposes a characterization of various degrees of physical damage based on this theory. In the book that proposed his Four-dimensional Ontology of Physical Objects[14], Heller argues that physical objects are four-dimensional hunks of matter and that objects like chairs do not exist. To realize the application in SNM however, we need the existence of such physical entities of tables and chairs to describe the motivation scenarios. We do not consider time as a characteristic or dimension in SoPhOs at this stage, and consider all of an object's parts exist at any point in time. Other upper ontologies BFO [4] and DOLCE [16] also follow this approach but they are based on a time-indexed version of mereological monism.

Some three-dimensional representations to physical objects define by matter and space. In Borgo's approach, the concrete existence of physical object is determined by the material object that is a piece of matter and occupies a region of space. [7] One could say that SoPhOs is following the definition of *stratified ontology*[5] Borgo adopted, where the distinct classes of parthood relations correspond to different identity criteria of characteristics of solid physical objects, and the ontological dependencies among the criteria of characteristics are explicit. However, resulting from the difference in scope, SNM requires further mereological pluralism beyond matter and location.

Existing studies in mereology usually either have a single *part-of* relation to summarize all parthood relations as mereological monism following the classical mereology[24], or adopt a taxonomy of parthood relations that all other parthood relations are specializations or sub-relations of a general top level *part-of* relation. This is

[5] Stratified Ontology is denoted as "an ontology where classes corresponding to different identity criteria are kept carefully disjoint and represent the roots of separate hierarchies called strata, and where the ontological dependencies among strata are made explicit." [7]

not a viable approach if we are to support application domains such as damage representation in SNM. The earliest work in this area was by Winston [25], who presented a taxonomy of part-whole relations as specializations of a general *part-of* relation. Winston's approach was informal, and was based on a series of examples that motivated the types of parthood relationships. Later, Odell[20] also proposes six parthood relationships. Despite the lack of axiomatization, these taxonomies are not specific to physical objects and not suitable for our practice for SNM. Upper ontology SUMO [19] contains the relation *part* as a spatial relation and a set of other relations that specialize it. In more recent work, Keet [15] introduced a taxonomy as summarization of Odell's approach to types of part-whole relations, and also provided OWL axiomatizations of the taxonomy. However, to solve our problem in SNM, the taxonomy approach cannot adequately capture the relationships between the different axiomatizations. Bittner and Donnelly [6] have also presented an axiomatization that follows mereological pluralism, and which does not strictly adhere to a taxonomy of parthood relations. Nevertheless, they still use a general *PP* relation which does not itself correspond to any generic ontology for objects, and the other two parthood relations are not grounded in a generic ontology.

This paper continues the approach of characteristic upper ontologies modules supported multiple distinct parthood relations from Ru and Grüninger[23].

8. Future Research

Ideally, we want to incorporate the Process Specification Language[13] to describe the process from before to after of a damage, and map the occurrence of damage to the repairing process. Some further topics that would be interesting to look at is the determination of whether a damaged physical object is still functional at a certain degree, and if it regains its full functionality after repair. One potential solution to this problem is a scale of condition of damage in terms of functionality. Another direction of future research would be water damage. Different types of water damage can lead to varies results, just to name a few, matter can be changed due to chemical reaction, shape can be altered due to resolving and liquidizing, or neither matter or shape is changed but the water damage creates electronically malfunction from short circuit. Damages due to both environment and time are also on future research. Hardening and color changing of form are mostly due to wear out over time, rust on metallic items are also typically resulting from exposure of oxygen and moisturizing environment over time. Future work on SoPhOs will include a surface module ontology to capture color and surface damage such as stains and scratches.

9. Conclusion

What's the damage? We can now represent both the chair with a dent in one leg and the mug with a handle broken with having abnormal pieces comparing to their intended properties. Starting from the motivating scenarios of partially damaged furnitures from Social Needs Marketplace, we have proposed a representation of damage deriving from partial abnormality. We have described the abnormality of solid physical objects based on the Ontology of Solid Physical Objects (SoPhOs), a general suite of upper ontology modules we proposed and axiomatized in First Order Logic. SoPhOs is a complete system of ontologies featuring the characteristic parthood, spatial parthood, parthood connection theories, and the foundational matter and shape characteristic ontologies that support them. We employ the approach of mereological pluralism, in which each mereological relation corresponds to one characteristic of the solid physical object, and the characteristics are formalized in different modules within an upper ontology. Damage of used goods can be represented in terms of the partial abnormal characteristics. We have introduced four predicates for partial abnormality corresponding to the fundamental characteristics and parthood relationships within solid physical objects: $ab\_portion, ab\_piece, ab\_component$, and $ab\_containment$.

The current framework presented in this paper is able to represent different conditions of partially damaged objects and solve the scenarios raised in SNM. This domain will also serve as a testbed for identifying new concepts in upper ontologies required for the representation of damages in everyday objects.

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Towards an Ontology of Categories and Relations

Frank LOEBE [1,2]

Computer Science Institute, University of Leipzig, Germany

Abstract. Categorization and association are fundamental for our understanding of the world, for which reason notions such as category, individual and relation are of major importance, for applied and formal ontology as well as for conceptual modeling. Several of the available foundational ontologies consider those notions at the meta level (only) and focus on individuals as their overall domain. This notwithstanding, we see a need for establishing well-founded ontological theories of categories and relations within the field of applied ontology, not at least as a foundation for conceptual modeling.

In this paper we report on our work on an ontology of categories and relations (and cognate notions), abbreviated $\mathcal{CR}$, which is intended to serve as a module for foundational ontologies. The approach has its background in the development of the General Formal Ontology (GFO) as well as in ontological semantics, a novel account of establishing semantics for representation or modeling languages on the basis of ontologies. The conceptual foundations of the ontology are introduced and we present initial axiomatization efforts.

Keywords. ontology, foundational ontology, top-level ontology, meta ontology, category, relation, relator

1. Introduction

Ontologies continue to be on the advance in many areas. Creating ontologies means to analyze a certain domain of interest in terms of the conceptual constituents by means of which the ontology is going to be formed. The major basic constituents of most ontologies today are *categories* and *relations*.[3] This is not surprising, as categorization / classification[4] and association are fundamental for our understanding of the world. Accor-

[1]Correspondence Address: Augustusplatz 10, 04109 Leipzig, Germany
Email: `frank.loebe@informatik.uni-leipzig.de`

[2]Parts of this submission are based on sections of [1] that have not been presented nor published elsewhere.

[3]Especially at this point, we assume only a rather weak semantic import of the words ‘category’ and ‘relation’. There are various alternative words / denominations in the literature that may be used for what we intend to refer to by those two, while one must be aware that all those denominations come with several more specialized readings in distinct contexts. Examples, ordered alphabetically, of alternatives for category are ‘class’, ‘concept’, ‘kind’, ‘notion’, ‘term’ (in a semantic reading), ‘type’ and ‘universal’. For relation, there are ‘association’, ‘property’ and ‘role’, among others. However, note already that ‘role’ is used to refer to another important notion herein, which is most closely related with relations.

[4]We use the word ‘categorization’ as a synonym of ‘classification’ herein. However, we employ only ‘category’ for a broadly conceived notion of instantiable entities. ‘Class’ is reserved for several notions that

dingly, they rank equally important in formal and applied ontology. We see it as a (if not *the*) central task of ontological analysis of any subject to address the questions of "Which (categories of) entities are there?" and "How are those entities interrelated?".

Basically the same questions – we claim – are likewise present, at least implicitly, in almost all modeling enterprises. They are thus of similarly central nature for conceptual modeling, in particular, and for modeling in computer and information sciences in general. There the notions of category and relation frequently appear together among the very basic concepts of modeling approaches – of course, with varying terminology. For example, John Mylopoulos [3] reports that one novelty in M. Ross Quillian's proposal of semantic networks [4] was to organize the information base in terms of 'concepts' and 'associations' [3, p. 131]. He further points out the distinction of 'entities' and 'relationships' in Peter P. Chen's Entity-Relationship (ER) model [5]. From both, semantic networks and ER models, it seems to be only a short step in this regard to the Ontology Definition Metamodel (ODM) [6,7] and its meta model foundation, the Meta Object Facility (MOF) [8,9], which includes 'classes' and 'associations'. Altogether, we see strong evidence for the fundamental importance of categories and relations, such that a well-founded theory of these notions appears desirable.

Categories and relations are further two highly generic/abstract notions, which leads us to top-level ontologies (TLOs) as well as to meta ontologies. TLOs are ontologies concerned with notions of very high generality, typically aiming at entities that appear in a large number of domain-specific areas. A meta ontology should provide notions that serve to characterize the constituents of an ontology and their interplay, which frequently also relates to language constructs that are employed in representing ontologies. The preceding considerations that categories and relations account for basic constituents of ontologies may thus suggest a meta-ontological nature of themselves, cf. also [1, sect. 2.3.3] and [10]. Indeed, for a number of the available TLOs the choice was made to focus solely on *individuals*/particulars[5] as entities that are subject to categorization and to being interrelated. But thereby categories and relations are used in many cases without a well-founded ontological understanding, which, we argue, should be developed. Especially if one aims at TLOs that are capable of classifying / covering all entities whatsoever,[6] analyzing category and relation as such remains an immediate (top-level) ontological problem, the solution of which may affect meta-ontological investigations nevertheless.

The overall goal of our work is to establish an ontology of categories and relations, which involves further cognate notions resulting from the analysis. There is a direct connection to the field of top-level ontologies, on the one hand, and to meta-ontological and semantic considerations, on the other hand. First of all, the project has emerged in the much wider context of constructing the General Formal Ontology (GFO) [11,12,13], see also [1, sect. 1.1.5]. GFO includes category and relation in its taxonomy, but that part still lacks an elaborate axiomatization yet. Hence we aim at proposing a corresponding ontology as a module for GFO. Due to the high degree of abstraction, it will be rather independent of other GFO specificities and may therefore be considered (1) in combi-

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arise in specific contexts in information and computer sciences, e.g. concerning the Semantic Web [2], object-orientation, and mathematical set or class theory.

[5]These two words are used interchangeably herein, albeit in-depth philosophical analyses may allow for distinguishing differing understandings. The term *logical individual*, however, leads to formal logic and Tarskian model theory, where it refers to a member of the universe of a formal model / interpretation structure.

[6]Surely, limitations based on the current state of science and knowledge apply.

nation with further TLOs and (2) as an ontological foundation for, primarily, meta modeling. The latter point has yet another intimate connection, namely to a novel semantic account that we propose in [1], called *ontological semantics*.[7] In a first step, such a semantics is intended to be defined for languages for ontology representation, before it can be extended to representations in general via translations. That first step requires itself an ontology to start from, which leads back to meta-ontological and meta-modeling issues.

In this paper we report on preliminary work in progress towards an ontology of categories and relations, named/abbreviated $\mathcal{CR}$. The conceptual foundations of the ontology are elaborated in sect. 2. Sect. 3 first summarizes a partial formalization which utilizes description logic / OWL2, which covers primarily a taxonomic fragment of the ontology. Secondly, a short preview on an axiomatization in first-order logic (FOL) is included. A discussion, also comprising some pointers to related work, is given in sect. 4 before the paper concludes with sect. 5.

2. Basic conceptions of categories and relations

2.1. Preliminary considerations and desiderata

Before expounding the view of categories and relations as it constitutes $\mathcal{CR}$, let us highlight some aspects that have an impact on developing the ontology. First of all, for both notions there is a large amount of material available in philosophy, cognitive science, computer and information sciences as well as in further areas that aims at defining or characterizing these notions. The amount becomes vast if we broaden the scope to literature which uses one or both notions or which is otherwise closely linked to them or just to aspects that one could consider in order to develop an ontology of categories and relations. Surveying even a fragment of this body of work deserves its own publication and cannot be accomplished herein. Therefore we present the subsequent theory of categories and relations without delivering a prior state of the art, while we shall mention connections to a very focused set of approaches in sect. 4.

That variety of literature comes along with an actual variety of differing views and understandings of categories and relations, e.g., cf. the analysis in [15] of seven of the many positions on the ontological status of categories within the philosophical literature. One intention that we should stress at this point is that especially for categories we are rather interested in a weak theory, such that various more specialized notions can fit under the $\mathcal{CR}$ notion of category. For relations we adopt a more specific account which involves relation instances (called relators) that are composed of roles. This approach is already present in very early versions of GFO, where it was limited to so-called material relations. Besides finding the overall approach of role-based relations with relators very flexible and powerful, cf. e.g. [16, sect. 3.3], we drop that limitation and extend the approach to all relations.

Another guiding aspect is the desideratum of establishing a theory capable of self-reflection / self-analysis. More precisely, categorizing and interrelating the constituents of $\mathcal{CR}$ should not require additional notions that are not already covered by $\mathcal{CR}$. That desideratum results from the more influential aim to eventually utilize the ontology in

[7] It is not in any form closer related to the Ontological Semantics by Sergei Nirenburg, Victor Raskin and others [14], an approach for meaning extraction and representation from natural language texts.

the kind of "bootstrapping account" of semantics that is presented as ontological semantics in [1, ch. 4][8]. We cannot sufficiently sketch ontological semantics here, given the spatial limitations. But such a self-reflective ontology can serve as a starting point for an ontological semantics, where certain notions of the ontology would serve as primitives in defining the semantics. This is not only another motivation for a clarified account of categories and relations, but it likewise yields a connection to meta-ontological matters, which is briefly reconsidered in sect. 4, with $\mathcal{CR}$ already available. Yet, for all subsequent sections one should keep in mind that all constituents of $\mathcal{CR}$ are also subject to the intended domain of discourse of that theory.

As a final note, we admit that the phrase "ontology of categories and relations" may cause expectations to find an in-depth classification or taxonomy of kinds of categories, relations or further constituents of the theory. To counteract such expectation, let us state already that this is not the case, although occasionally we draw inspiration from having special cases in mind. But first of all, herein we are interested in the notions (which we deem relevant) in themselves and an axiomatic characterization of them. A limited taxonomy emerges on that basis nevertheless, yet substantial extensions, e.g. analyzing different kinds of categories, remain future tasks.

2.2. *Entities, categories, individuals and instantiation*

In the domain "surrounding" the term 'category', we first identify four principal notions, namely entity, category, individual, and instantiation, depicted together with major interdependencies in Fig. 1.[9] As a kind of minimal consensus for *categories* we merely require that they are subject to being instantiated[10], hence to the *instantiation* / categorization relation in a specific way. This relation, in Fig. 1 shown as the UML association named by the double colon :: (as in the FOL formalization of $\mathcal{CR}$), links entities to the categories that they instantiate. In this connection an entity is called an *instance*[11] of a category. Remembering the intent to constrain categories as weakly as possible, no assumptions are made regarding the degree of generality of categories. Insofar they can be very specific, e.g., (for another ontology than $\mathcal{CR}$) as determined by the phrase "female lion that lived in South Africa between 1994 and 1999", or they can be highly abstract categories as in top-level ontologies.

Indeed, *entity* is the category that is instantiated by anything as soon as that anything exists. Existence is thereby understood in the broadest conceivable sense, following GFO's recourse to, a.o., Roman Ingarden and different modes of existence [19]. Consequently, literally everything is an instance of entity, i.e., entity is a *universal category*.

[8] Alternatively, [17] outlines the general approach much more compactly, with core ideas already present in that earlier state of development.

[9] We employ class diagrams of the Unified Modeling Language version 2 (UML2) [18] solely for visualization purposes, assuming that the constraints so specified can be easily grasped by the reader. However, at the latest with hindsight of the overall conception of $\mathcal{CR}$, we interpret the diagrams within $\mathcal{CR}$ itself.

[10] Note here already that "being subject to" does neither imply that every category *is instantiated*, nor even that it *can possibly be instantiated*, because neither non-instantiated categories are to be excluded, nor such that cannot be instantiated at all, like 'round square'.

[11] The UML rolenames (following the terminology as in [18, p. 576 ff.], although 'association end name' is official for UML2) can better or only be explained after some parts of sect. 2.3. Besides the mnemonic parts of the role names, it may suffice here that the suffix 'RL' stands for 'role' itself and the difference between instance as just introduced and the instance role becomes clear in the section below.

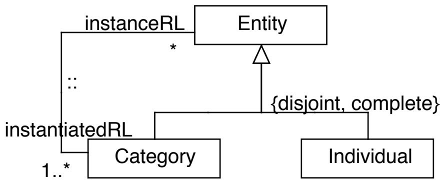

Figure 1. Entities, Categories and Individuals in $\mathcal{CR}$.

Thus categories cannot only be instantiated, but they are instances themselves. Not at least, any category instantiates the category Category (indicating a technical $\mathcal{CR}$ name by this font), which may be in conflict with one or another TLO. In line with many TLOs, however, $\mathcal{CR}$ includes (also) *individuals* / particulars, i.e., entities that are instances of categories, but are not subject to being instantiated themselves. Entity is partitioned into categories and individuals, which entails that every entity instantiates either Category or Individual. In contrast, it is not enforced that categories must have any instances.

Considering instantiation anew, the above paragraphs imply that $\mathcal{CR}$ yields no stratified nor well-founded account of instantiation. Without further restrictions, there may be instantiation chains of arbitrary length, as well as instantiation cycles. For example, we subscribe to the facts that Entity instantiates Entity (cycle of length 1), and that Entity instantiates Category and Category instantiates Entity (length 2). This is not too uncommon in applied ontology and possibly even more accepted in knowledge representation and the Semantic Web, cf. e.g. the notion of Resource in the Resource Description Framework (RDF) [2, ch. 2–3]. Without room for going into details (cf. [1, sect. 2.4.2.3] for a bit more), this affects relationships between $\mathcal{CR}$ and set theory, for instance, if the notion of the *extension* of a category is considered, defined as the set of all and exactly the instances of this category. Then, relying on a wellfounded set theory, not every category may be equipped with a proper extension, or one adopts an alternative set-theoretic approach, such as non-wellfounded set theory [20].

A related and here final aspect is that of comprehension axioms for categories, which may easily lead to inconsistency of the theory, e.g., in analogy to Russell's paradox [21]. At the present stage we expect to circumvent corresponding problems by not adopting any axioms for category comprehension for $\mathcal{CR}$.

2.3. Relations, relators, roles and non-relating entities

As already indicated in sect. 2.1, the part of $\mathcal{CR}$ on relations is more specifically determined than the deliberately weak theory of categories. The basic view on relations combines a positionalist account[12] with one of individualized properties. More precisely, *relations* in $\mathcal{CR}$ are categories which are instantiated by individuals, called *relators*, that are composed of roles and that have the power of relating / mediating between / gluing together arbitrary entities. Relators establish the relation that they instantiate between the entities / arguments / relata that they connect. At the categorial level, one may consider different kinds of relator categories, but relations are special insofar that they capture the connecting character of their instances among the entities related.

[12] See [22, esp. sect. 3.2] for a condensed exposition of that stance within conceptual modeling, with pointers to treatments in philosophy.

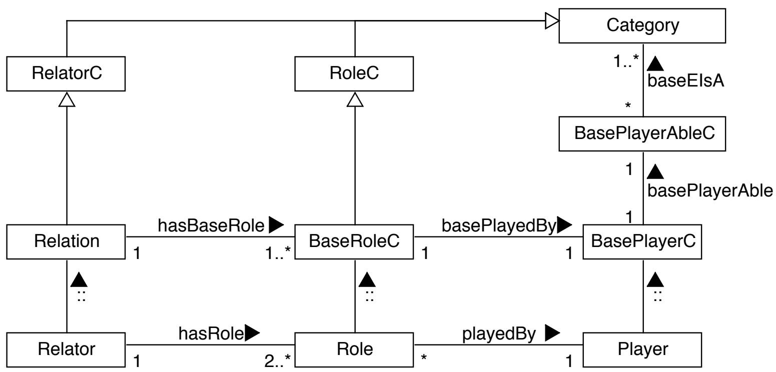

Figure 2. Relations with role base notions and corresponding categories of individuals. A C at the end of a name stands for category. Instantiation applies at the categorial level here, e.g., relators instantiate relations.

To discuss a concrete example and at the same time to demonstrate a case that is commonly seen as a formal relation (which holds immediately as soon as the relata are given), we consider in the domain of natural numbers that 1 is less than 2, commonly written $1 < 2$. Analyzing this fact in $\mathcal{CR}$, we can first distinguish four entities, namely the numbers 1 and 2, the less-than relation $<$, and a particular relator $r^<$ instantiating $<$ and mediating particularly between 1 and 2. With just that relator available, it is not clear in which – potentially distinct – ways 1 and 2 participate in the relation.

This is accounted for by *roles* (and so-called *base role categories* at the level of categories / relations), of which there is one per argument. Roles are individuals that can be seen as parts of relators, although within $\mathcal{CR}$ we name that relation *role of*, symbolized by $\multimap$ in the FOL formalization, or *has role*, denoted by $\multimapinv$, in inverse reading.[13] In the example, $r^<$ is composed of two roles, say, q_g and q_l. However, (grasping) the "semantics" / "nature" of the two regarding $<$ relies on specific role categories that they instantiate. Indeed, the overall semantics of $<$ depends on determining role categories such that relators composed of roles of those categories adequately reflect in which way each single argument participates in the relator (and thereby / loosely speaking, "in the relation"). We say in such cases that a role category is a *base role category* for a relation. For $<$ let us name its base role categories less and $\mathsf{greater}$.

Another connection is required to / from a role w.r.t. the corresponding argument of the relator, e.g., from q_l to 1. This connection is called *plays / plays role / fills role*, with the FOL predicate symbol $\rightsquigarrow$ (or $\leftsquigarrow$, if read reversely). To conclude our example coherently, we need $1 \rightsquigarrow q_l$ and $2 \rightsquigarrow q_g$. Overall, the role analysis of $1 < 2$ yields the subsequent formula, where all ${}^{\#}\cdot$ denote constant symbols with the same intended meaning of categories or relations as the predicate symbols without the prescript, thus reifying the latter (cf. also sect. 3).

$$r^< :: {}^{\#}{<} \,\wedge\, q_l :: {}^{\#}\mathsf{less} \,\wedge\, q_g :: {}^{\#}\mathsf{greater} \,\wedge\, 1 \rightsquigarrow q_l \,\wedge\, q_l \multimap r^< \,\wedge\, r^< \multimapinv q_g \,\wedge\, q_g \leftsquigarrow 2$$

Meanwhile, not only are the three fundamental relations for $\mathcal{CR}$ introduced, namely instantiation, role-playing and role-having, but the bottom layer of Fig. 2 is already cove-

[13] Importantly, this inversion is merely one of expressing the relation in a linear language, while 'role of' and 'has role' refer to the very same relation, from a positionalist stance. Cf. also [23, esp. sect. 4.1] on this aspect.

red by the preceding paragraphs. Even base role categories are mentioned above, yet they deserve further consideration. They capture the different ways / kinds in which entities may be involved in the specific relation, contributing to the comprehensibility of a relation. Their name originates from the notion of a *role base* for a relation, which comprises not only the base role categories, but possibly further constraints, cf. [1, sect. 2.4.3.3].

Here we restrict ourselves to considering the additional categories BasePlayerC and BasePlayerAbleC in Fig. 2, which should be less common (even under different names), but are likewise informative w.r.t. relations as well as useful in expressing certain connections. All three kinds of categories result from a trichotomy derivable from understanding role notions. Take 'instance' as an example, already introduced above, and observe that the role name near Entity in Fig. 1 is instanceRL, where RL abbreviates 'role'. First, 'instance' may be said to be a role / base role category itself (and thus an appropriate UML rolename). If $\mathcal{CR}$ is applied to instantiation itself, indeed, there is an instance role within any instantiation relator, which is played by the entity that instantiates something in virtue of that relator. Secondly, in $r^< :: {}^\# {<}$ we would say that $r^<$ *is* the instance. From this point of view 'instance' is rather a category of (primarily) non-role entities that actually stand in the instantiation relation (to other entities). This categorization is one from the point of view of the relation. For that reason we use instanceRL for the role category, reserving 'instance' for the players of that role / base role category. Thirdly and associated with common domain and range specifications for relations, there is the question of which entities are at all subject to playing a role of a relation. That question can typically be given an answer from the point of view of the relation or the role. For example, all entities that can be instances are 'categorizable'. Everything that can be instantiated is 'instantiable'. These are cases of BasePlayerAbleC. Note that those are always role- or relation-based categories, in contrast to categories of role- and relation-*independent* entities. Claiming that Instantiable is equivalent to Category then yields that all and only categories are subject to being Instantiated, i.e., to playing the InstantiatedRL. Table 1 accounts for key components of the role bases of the three fundamental $\mathcal{CR}$ relations.

Relation	BaseRoleC	BasePlayerC	BasePlayerAbleC	Category
::	InstanceRL	Instance	Categorizable	Entity
::	InstantiatedRL	Instantiated	Instantiable	Category
$\rightsquigarrow$	PlayerRL	Player	PlayerAble	Entity
$\rightsquigarrow$	PlayedRL	Played	Playable	Role
$\multimap$	RoleRL	RoleRole	RoleBeAble	Role
$\multimap$	ContextRL	Context	RoleHaveAble	Relator

Table 1. Role base notions of instantiation (::), plays role ($\rightsquigarrow$) and role of ($\multimap$), following Fig. 2. The suffix C in three column heads stands for 'category', RL in the base role column originates from 'role'.

3. Towards formalizing the theory $\mathcal{CR}$

Our primary aim in formalizing $\mathcal{CR}$ is to develop its axiomatization in first-order logic (FOL). Beforehand, we started with a partial axiomatization in description logic (DL). For the purposes of this paper, all formalizations are solely considered under standard set-theoretic semantics.

3.1. Taxonomic fragment in OWL

The informal exposition of $\mathcal{CR}$ involves a number of[14] categories in intertwined ways. Therefore we focused on the taxonomy first, limited to DL and by utilizing Protégé [25] as OWL2 editor equipped with the HermiT reasoner [26,27] in version 1.3.8, for a first check for potentially unexpected effects.

The corresponding theory in DL is presented in [1, App. B, p. 281–283], such that we do not include specific DL axioms here. Moreover, this version of the ontology is available as an OWL2 file, see [24]. It is worth noting that this DL version does not include any self-reflection of $\mathcal{CR}$, for example, no DL individuals intended to reify $\mathcal{CR}$ categories and/or relations. A corresponding extension is a future task for further testing, while the present version may be more amenable for reuse in other ontologies.

Still, some observations about this version of $\mathcal{CR}$ appear to be of interest. First of all, the reasoner succeeded in classifying the ontology file without reporting inconsistency of the overall file, and without detecting incoherent, i.e., unsatisfiable DL concepts. A larger fragment of the resulting classified taxonomy of $\mathcal{CR}$ is depicted in Fig. 3. It still includes some auxiliary notions that turned out useful in the course of the axiomatization. In particular, we expect that the categories Relating (orange; the union of Role and Relator) and NonRelating (blue; the complement of Relating relative to Entity / OWL Thing) are widely usable, e.g., as NonRelating is silently assumed in many cases of referring to Individual. Two major partitionings of Entity are (1) that into categories and individuals as in Fig. 1 and (2) that into non-relating entities, roles and relators.

[14]Indeed, not all categories discussed in [1, sect. 2.4 and 6.1] or contained in the OWL file `cr-dl.owl` [24] (therein 38 in total) could be discussed in the present paper.

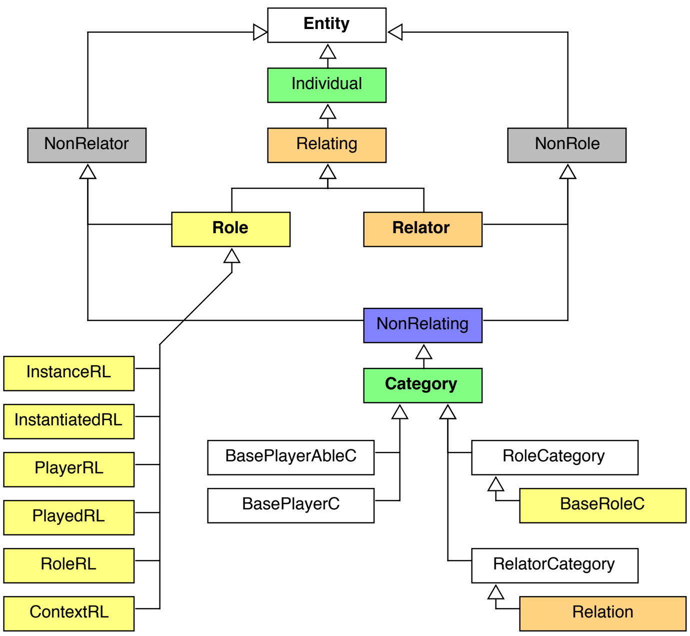

Figure 3. Taxonomy fragment of selected $\mathcal{CR}$ categories, as classified by HermiT [26]. Bold-face labels are representatives of groups of equivalent named categories. Colors provide only a vaguely defined grouping.

Overall, Fig. 3 corresponds well to our expectations. Yet there is one result that was not immediately obvious from the DL axioms, because it grows out of the domain and range constraints of $\mathcal{CR}$ relations and some axioms about the notions introduced as role bases of those relations, cf. Table 1. In summary, the reasoner concludes the subsequent (extensional) equivalences among $\mathcal{CR}$ categories. Each line corresponds to one of those nodes in Fig. 3 labeled in bold face. Although this high number of equivalent categories may seem awkward for an ontology in general, inspection shows that all of them are (in the light of $\mathcal{CR}$) reasonable cases of intensionally distinct, but coextensional categories.

$$\mathsf{Entity} \equiv \mathsf{Categorizable} \equiv \mathsf{Instance} \equiv \mathsf{PlayerAble} \equiv \mathsf{Player} \tag{1}$$

$$\mathsf{Category} \equiv \mathsf{Instantiable} \tag{2}$$

$$\mathsf{Relator} \equiv \mathsf{Context} \equiv \mathsf{RoleHaveAble} \tag{3}$$

$$\mathsf{Role} \equiv \mathsf{Playable} \equiv \mathsf{Played} \equiv \mathsf{RoleRole} \equiv \mathsf{RoleBeAble} \tag{4}$$

3.2. Signature $\Sigma^{\mathcal{CR}}$ and preview on axioms in FOL

The axiomatization in first-order logic (FOL) is still in a preliminary stage, first of all. It follows the ideas of ontological semantics [1, ch. 4–5], which implies some methodological specialties. Nevertheless, all formulas specified in this section can properly be considered under classical set-theoretic semantics. We consider three binary relations of $\mathcal{CR}$ as *fundamental relations*, which are the only ones that are solely axiomatically characterized. These relations are instantiation (::), role playing ($\rightsquigarrow$) and role having ($\multimap$), where those symbols are binary predicate symbols that are used in infix notation.

Every other $\mathcal{CR}$ notion is first reified by a logical constant symbol and thus subject to the domain of discourse.[15] Moreover, predicate symbols are typically introduced for convenience, but all of them must be "explained" by being equipped with a so-called *predication definition*, intended to fix the "semantics" of atomic formulas with that predicate. Notationally, like in sect. 2.3, we adopt the convention to let reifying constants be preceded by # . For example, if Ent is a unary predicate symbol intended to denote the $\mathcal{CR}$ category Entity, then #Ent is a logical constant for which there is the same intent. $Pred(\cdot)$ denotes all predicates of / in the argument, $Const(\cdot)$ all constant symbols, $ar(\cdot)$ the arity of its argument.

Subsequently we specify a very limited, selective preview on the FOL axiomatization over the signature $\Sigma^{\mathcal{CR}}$. Formulas that are / were intended as axioms, but are already shown to be entailed by others, are kept in the list of "axioms" / formulas, yet numbered with prefix C (with references to entailing formulas in their description), whereas the numbering of non-entailed and thus proper axioms has prefix A, that of definitions D.

Definitions

D1. $\{P(x) \leftrightarrow_{df} x :: {}^{\#}P \mid P \in Pred(\Sigma^{\mathcal{CR}}), ar(P) = 1\}$
(uniform predication definitions for all unary predicates)

D2. $\mathsf{Ent}(x) \leftrightarrow_{df} \exists y \,.\, y = x$ (x is an entity :iff x exists)

[15] Introducing a constant symbol and thus reification applies likewise to the fundamental relations.

Axioms and consequences

A1. $\{{}^{\#}P \neq {}^{\#}Q \mid {}^{\#}P, {}^{\#}Q \in Const(\Sigma^{\mathcal{CR}})\}$ (any two constants refer to distinct entities)
A2. $\{\exists x \,.\, P(x) \mid P \in Pred(\Sigma^{\mathcal{CR}}), ar(P) = 1\}$ (all $\Sigma^{\mathcal{CR}}$ categories are instantiated)
C1. $\{\mathsf{Cat}({}^{\#}P) \mid P \in Pred(\Sigma^{\mathcal{CR}}), ar(P) = 1\}$
(categorization of constants as categories [A2, D1, A4])
C2. $\mathsf{Ent}(x)$ (everything is an entity [D2])
A3. $\neg\exists x \,.\, \mathsf{Role}(x) \wedge \mathsf{Relator}(x)$ (role and relator are disjoint categories)
A4. $x :: y \to \mathsf{Ent}(x) \wedge \mathsf{Cat}(y)$ (instantiation relates entities with categories)
A5. $x :: y \wedge \mathsf{Relation}(y) \to \mathsf{Relator}(x)$ (instantiation of relations yields relators)
A6. $x :: y \wedge \mathsf{RoleCat}(y) \to \mathsf{Role}(x)$ (instantiation of role categories yields roles)
A7. $x \rightsquigarrow y \to \mathsf{Ent}(x) \wedge \mathsf{Role}(y)$ (plays relates entities with roles)
A8. $x \multimap y \to \mathsf{Role}(x) \wedge \mathsf{Relator}(y)$ (role-of relates roles with relators)
A9. $\mathsf{Relator}(x) \to \exists y \,.\, \mathsf{Relation}(y) \wedge x :: y$ (every relator instantiates ≥ 1 relation)
A10. $x \multimap y \wedge x \multimap z \to y = z$ (the relator of a role is uniquely determined)
C3. $x \multimap y \to (\neg\exists u\, u \multimap x) \wedge (\neg\exists v\, v \multimap y)$ (role-of is a single-step relation [A3])
C4. $(\exists y \,.\, y :: x) \to \mathsf{Cat}(x)$ (if an entity is instantiated, it is a category [A4])
C5. $\mathsf{Ent}(x) \leftrightarrow \exists y \,.\, \mathsf{Cat}(y) \wedge x :: y$
(every entity instantiates a category [C2, D1 for Ent, A4])

Admittedly, this is just a minimal selection of axioms, primarily demonstrating some axioms resulting from the reification aspect and then focusing on constraints of the fundamental relations. One can observe that some assumptions on the reifying constants have already effects on those relations. More of that can already be found in [1, sect. 6.1.2], e.g., where most of the common properties of orderings turn out not to be satisfied by instantiation, based on few axioms, a.o., having entity as a universal category.

The full theory is still under development. This goes in tandem with working on a consistency proof for the FOL theory.

4. Discussion and related work

With $\mathcal{CR}$ we aim at a theory of categories and relations that is well-suited as a foundation for the semantics of languages as well as for other ontologies. The latter aspect concerns meta-ontological capabilities of $\mathcal{CR}$, i.e., $\mathcal{CR}$ notions lend themselves to an ontological analysis of the constituents of ontologies. That aim of serving as a foundation for other ontologies is as broad as to cover arbitrary ontologies, including $\mathcal{CR}$ itself. It is therefore pursued by proposing a self-contained / self-analytic theory. As may be clear from the sections above, all notions of $\mathcal{CR}$ are themselves considered to be in the intended domain of discourse of the theory, such that, for example, all $\mathcal{CR}$ constituents can be categorized by $\mathcal{CR}$ categories. Moreover, literally *all* relations of $\mathcal{CR}$ are subject to the same analytic account based on relators composed of roles. This applies even to the three fundamental binary relations, cf. the discussion of that aspect in [1, sect. 2.4.4.3 and near the end of sect. 6.1.2]. A price to be paid for this is that $\mathcal{CR}$ is subject to infinite regresses, which lead not only to infinite (logical) models of the full theory, but which are often considered as harmful, if not necessary to be avoided. Unfortunately, we lack the space herein to argue in detail against necessarily seeing a problem with the particular regresses that occur, on philosophical, but also logical grounds. At least, we accept them in favor of the – for us – very attractive feature that $\mathcal{CR}$ does not rely on any additional assumptions nor on any kinds of entities that are considered solely external to the theory or that are declared to be not analyzable.

A few words remain to be devoted to related work. Focusing on applied ontology and existing ontologies first, we mention the Unified Foundational Ontology (UFO) [28] as the TLO with the most elaborate accounts of categories and relations that we are aware of. Therefore, UFO is the prime candidate for an in-depth comparison after $\mathcal{CR}$ is fully established. A few other TLOs cover notions that $\mathcal{CR}$ deals with, as well, e.g., the Suggested Upper Merged Ontology (SUMO) [29].

In the domain of conceptual modeling, we see two closely related lines of research. Admittedly, only recently having become much more clearly aware of the abundance of modeling and meta modeling approaches involving a positionalist account of relations (and thus roles), see e.g. [22, esp. sect. 3.2], one may consider to what extent $\mathcal{CR}$ might yield novel contributions conceptually, for instance, remembering the discussion of base role, base player and base playerable categories, and / or whether it may serve as a foundation for ontology-driven conceptual (meta) modeling, e.g., in the sense of [22]. Similarly, we see a connection to fairly recent work on multi-level modeling such as [30], as $\mathcal{CR}$ allows for complex categorization levels.

5. Conclusions

In this paper we argue for the striking importance of well-developed accounts of categories and relations and the remaining need to establish formal ontological theories for this subject matter. We are in the process of working on one candidate theory, abbreviated as $\mathcal{CR}$. Primarily its conceptual approach is elaborated herein to some extent, following [1], accompanied by reports on the status of our formalization efforts.

Not surprisingly, we consider $\mathcal{CR}$ as a promising approach, while that largely remains a claim herein. Our next steps comprise of completing the first-order axiomatization and its meta-theoretic analysis. Afterwards or possibly starting in parallel, it will be instructive to apply and relate $\mathcal{CR}$ not only to itself, but to other ontologies as well as in the foundation of conceptual modeling.

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Three Facets of Roles in Foundational Ontologies

Fumiaki TOYOSHIMA [1]
Graduate School of Advanced Science and Technology, JAIST, Japan

Abstract. Roles remain such a nebulous concept notwithstanding its ubiquity in a wide variety of domains, including conceptual modeling, that no clear consensus exists over the nature of roles in the foundational ontology research. In this paper I argue that there are three closely intertwined, but conceptually separate role-related notions: a *role specification*, a *role position*, and a *role performance*. I further contend that different accounts of roles might depend on which of the three concepts takes priority over the other two. Additionally I propose that there be three possible interpretations of the ontological nature of roles, each of which requires careful cost-benefit analysis: a family resemblance concept, a functionally definable concept, and a practically unifiable concept.

Keywords. role, foundational ontology, grounding, specification, family resemblance

1. Introduction

The notion of role is present in a number of different domains, ranging from knowledge representation [1] and conceptual modeling [2] to cognitive science and linguistics. Accordingly there is a high demand for a common definition of role that would helps us address the problem of semantic interoperability among information systems [3]. To meet this need, roles have been extensively researched in formal ontology for the last few decades and virtually all foundational ontologies nowadays have the role category. The role concept nonetheless remains so elusive that the understanding of role can vary greatly from one foundational ontology to another.[2]

Intimately connected to this topic is the extant issue of whether a single definition of role is possible [3]. Despite some attempts to define roles explicitly (e.g., [2,6]), for instance, Loebe [7, p. 144] says: "there is no single kind of roles, and no unique kind of entities on which roles depend." If the answer to this question is no, then the challenge to be met is (how to build a model for specifying) how roles are to be individuated or

[1]Corresponding Address: Graduate School of Advanced Science and Technology, Japan Advanced Institute of Science and Technology (JAIST), 1-1 Asahidai, Nomi, 923-1292, Japan; E-mail: fumiaki.toyoshima@jaist.ac.jp, fumiakit@buffalo.edu.

[2]For instance, Guarino [4, p. 14] says: "I have been always fascinated by the subtle aspects of this notion [role], and by its ubiquitous relevance for practical applications. (...) It is not a surprise therefore to see roles appearing in BFO [Basic Formal Ontology [5]], but their characterization as realizable specifically-dependent continuants reflects a very peculiar understanding of the role notion which, although useful, would require a broader framework." Note that we will later look at the BFO conception of role.

classified. Some noteworthy related studies (e.g., [8]) notwithstanding, it is still largely unexplored how a certain theory of role is connected to the *meta-ontological choices* [9] behind the general ontological background against which the theory is constructed.

In this paper I endeavor to investigate the nature of role from the perspective of foundational ontology. To do so, I leverage the notion of *grounding* that has been recently developed in the field of philosophical ontology. As we will see below, grounding is supposed to specify how some phenomena (e.g., a table exists) hold *in virtue of* more fundamental phenomena (e.g., subatomic particles are 'arranged table-wise') and, quite importantly, to be closely linked to the notion of explanation (which may be called 'ontological explanation') in philosophical ontology.[3]

More specifically, I consider what grounds the concept of *role-playing* that is central to the general discussion on role. This work amounts to an attempt to seek an adequate explanation of role-playing, thus leading to a better understanding of role. It is found on close examination that there are three notions (which I call the 'role triad') that ground role-playing: a *role specification*, a *role position*, and a *role performance*. Defying easy analysis, each of the role triad is to be elucidated by analogy and with examples.

Then I hypothesize that different accounts of role might hinge on which of the role triad is ontologically prior to the other two concepts. To illustrate this, I explore three theories of roles and which element of the role triad each theory take to be primary. I further clarify that and how each theory's 'role choice' is conceptually firmly glued to the (meta-ontological choices of) foundational ontology on which the theory is based.

I finally suggest that there be three possible interpretations of the nature of role: a family resemblance concept, a functionally definable concept, and a practically unifiable concept. As will be detailed below, each of them has both advantages and disadvantages. For instance, a family resemblance conception of role lacks practical virtue while it is arguably most theoretically tenable. All these findings will contribute to bridging the gulf between foundational investigation into the nature of role and and modeling processes associated with roles in various application domains.

The paper is structured as follows. Section 2 offers some preliminary knowledge on basic ontological assumptions and grounding. Section 3 presents and elucidates each of the role triad. Section 4 illustrates, with three selected accounts of roles, the relationship between meta-ontological choices in foundational ontologies and their 'role choices'. Section 5 proposes three possible understandings of the nature of role. Section 6 concludes the paper with some brief remarks on future directions of research.

2. Preliminaries

2.1. Basic Ontological Assumptions

Since this paper is partly devoted to comparative analysis of foundational ontologies, I assume only the basic categories and relations that are relatively widespread in foundational ontologies. Concrete individuals (which exist in space and/or time) fall into two types: *continuants* (aka endurants) such as *objects* and *occurrents* (aka perdurants). Characteristically, continuants can persist, whereas occurrents extend through time. Continuants (e.g., a stone) can *participate in* occurrents (e.g., a fall of the stone).

[3] I borrow the expression of the form 'arranged X-wise' from van Inwagen [10].

I stipulate throughout the paper that roles are continuants, since roles are most frequently take to be a special kind of properties (in the broad sense of the term) in the relevant literature on role (e.g., [6,11]). I also assume that a role is a continuant *to be played* by something (*player*), since the notion of role-playing is generally thought to be a key to a deeper understanding of the nature of role.[4]

2.2. Grounding as a Conceptual Tool

As a conceptual tool for my investigation, I exploit the notion of grounding that is supposed to provide ontological explanation.[5] In particular, I employ its most standard version: *fact-grounding* [16,17]. According to this doctrine, grounding is a relation between the more fundamental fact and the less fundamental fact. For instance, the fact that a table exists is grounded in the fact that some subatomic particles are arranged table-wise.

This theory is typically coupled with the claim that the notion of grounding *is* (a kind of) ontological explanation (e.g., [17]). In the example of the table, the latter fact grounds, and *ipso facto* explains ontologically, the former fact.[6] In addition, the grounding relation is strict partial ordering (i.e. irreflexive and transitive), as the received view [18] goes.

To be concrete, I will examine which fact grounds the fact that Mary is a student, given that a student is paradigmatic example of a role. For the sake of simplicity I introduce the notation '<>' to refer to facts: e.g., <Mary is a student>. More specifically, I will consider which fact grounds <Mary plays a student role>, which is plausibly taken to ground <Mary is a student>. The gist of my argument is that there are three candidate facts which correspond to the role triad and which ground <Mary plays a student role> and, by the transitivity of grounding, <Mary is a student>.

3. Three Facets of Roles

3.1. Role Specification

What grounds <Mary plays a student role>? In order to be a student, Mary *must* gain admission to the university (say 'ABC-U') of her choice. To attain this goal, she *needs* to read and understand the admission policy and then make an effort to satisfy all its requirements. Mary's role-playing has, in this respect, a deontic or normative dimension.

This observation may lead us to interpret role-playing as meeting the constraints or conditions that are 'embedded' in the role. In my terminology, role-playing in this sense is *meeting* a *role specification*, or the specification that is determined by the role. Therefore <Mary plays a student role> is grounded in <Mary meets a role specification>.

I appeal to the notion of specification to capture the above-mentioned normative feature of role. The ontological nature of a specification remains obscure, but Turner [19] argues that a specification is something that has "correctness jurisdiction over an arte-

[4]As we will see in Section 4, however, Basic Formal Ontology [5] exceptionally specifies the *role-having* relation, but not the role-playing one [12, p. 58].

[5]For an introduction to the general notion of grounding, see e.g., Schneider and Correia [13], Trogden [14], and Raven [15].

[6]The proponent of this view might argue that, just as *some* kind of causal explanation is given merely by stating the causal relation (what causes what), so *some* kind of ontological explanation is given merely by stating the grounding relation (what grounds what) [15].

fact" [19, p. 147]. By 'correctness jurisdiction' Turner means that the specification places "empirical demands on the physical device" [19, p. 144]. If an artifact is not built to a specification, then the artifact is defective with respect to that specification.[7]

A role specification is thus well understood with an analogy with artifacts (cf. [21]). In the U.S., for instance, an aircraft has to satisfy the strict specifications laid down by the Federal Aviation Administration (FAA). This means that an aircraft-like aggregate of mechanical parts is not an aircraft unless it is built exactly to the FAA specifications. Similarly, Mary fails to play a student role (and to be a student) unless she meets the role specification (admission requirements) given by ABC-U.

Not surprisingly, the specification view of role-playing fits well with the notion of *social role* (e.g., president) because a specification is determined by our intentionality.[8] To paraphrase in my framework, <Mary plays a student role> is grounded in <Mary meets a role specification>, which is in turn grounded (via a complex chain of grounding relations) in some relevant social facts: e.g., <ABC-U is nationally authorized>.

3.2. Role Position

There is nevertheless another candidate for what grounds <Mary plays a student role>. As an ABC-U student, Mary can use various facilities and enjoy educational opportunities (e.g., taking classes). Seen from another perspective, she locates herself, in playing a student role, in a specific *situation* where she can do something role-related.

Following this intuition, one may think that Mary's role-playing consist in her *occupying* the kind of special place (which I call a '*role position*') that allows her to do something that is associated with the role. For this reason one may say that <Mary plays a student role> is grounded in <Mary occupies a student role position>.

A role position can be elucidated by an analogy with a *relative place* [22]. Given the Newtonian conception of absolute space, both *absolute* places and *relative* places persist and may be occupied by various (material) objects at various times. Unlike absolute places (which are parts of absolute space that are independent of objects), relative places stands in fixed spatial relations with one or more objects (*reference objects* [22]). Examples include places in and around a ship whose reference object is the ship.

A role position is like a relative place. Role positions stand in a fixed conceptual relation towards one or more entities (which I call '*role reference entities*' and which are sometimes called 'context' in the literature [7,23]).[9] In playing a student role, Mary occupies the student role position that exists relative to ABC-U.

The analogy between role positions and relative places offers an interesting interpretation of the alleged relational nature of roles [3,6,11]. One salient feature of relative places is that they may move relative to one another when their reference objects move relative to one another. Using Donnelly's [22] example, when a ship moves relative to the

[7] Duncan [20, pp. 16-17] illustrates this point: "For example, if I build a physical implementation of a stack and the device does not allow me to add and remove items from the top of the device, my device is defective relative to the specification of a stack." It is also well worth noting his ontological interpretation (which I do not present owing to spatial limitations) of Turner's conception of specification based on some categories taken from Basic Formal Ontology [5].

[8] Turner [19, p. 147] says: "Our intentional stance determines what we take to be the specification: something is a specification if we give it normal force over the construction of an artefact."

[9] I am using the term 'conceptual' in the very broad sense of the term. It may be argued that the partisan of role positions is responsible for clarifying the relationship between them and their role reference entities.

earth, places with the ship as their reference object (e.g. the ship's hold) move relative to places with the earth as their reference object.

Similarly, role positions may 'conceptually move' (e.g., changes their related functions) relative to one another when their role reference entities 'conceptually move' relative to one another, although the notion of conceptual movement is currently a placeholder and it is to be further clarified. For instance, when a human resource department changes its importance with respect to its company, personnel director role positions (whose role reference entity is the human resource department) change their relationship with executive role positions (whose role reference entity is the company).

The positional view of role-playing has two characteristics. First, it would lead to a classification of roles according to what role reference entities are and what the 'occupiers' of role positions are (e.g., [24]). Second, and reasonably, it meshes with the notion of *relational role* (e.g., the *lover* and the *lovee* in a love relationship). This is supported by the observation that an ontological commitment to relational roles presupposes *positionalism*, according to which "the distinction between the claims made in, for example, 'Abelard loves Eloise' and 'Eloise loves Abelard' is explained by differences in the *roles* (or *positions*) attributed to the relata" [25, p. 80, my emphasis added].[10]

3.3. Role Performance

There is yet another possibility for what grounds <Mary plays a student role>. As said above, Mary *can do* many things (e.g., getting a student discount) because she is an ABC-U student. A clearly visible difference between Mary and non-ABC-U students is, for instance, that she is *able* to acquire a degree from ABC-U, whereas they are not.

This consideration may result in the idea that Mary's role-playing resides essentially in her role-related performance, or rather her 'power' to do something role-related.[11] I say that, generally speaking, role-playing in this sense is *giving* a *role performance*. Thus <Mary plays a student role> is grounded in <Mary gives a student role performance>.

It is important to note that a player of a role (performance) has only to possess the role-related 'power' instead of actually demonstrating it, although I use the phrase 'give a role performance' for the sake of simplicity. In playing a student role, Mary does not need to use any facility or take any class; she only needs to be able to do them.[12] In this sense, the notion of a role performance may be intimately related to *deontic powers* [28,29] in the context of social ontology.

On the one hand, the performance view of role-playing would be easier to understand than the other two approaches discussed above, since it is explicable in terms of an analogy with the intuitively less complicated notion of 'power' than a specification or a relative place. On the other hand, the onus is on the proponent of this view to pin down

[10] See Marmodoro and Yates [26] for an introduction to ontology of relations. See Fine [27] for a critique of positionalism (which he formulates). See also Donnelly [25] for a revised version of positionalism.

[11] Boella, Torre and Verhagen [3, p. 5] say: "(...) behavior should not be disregarded as a main feature of roles."

[12] Strictly speaking, Mary would have to comply with the rules and regulations imposed by ABC-U in order to play a student role. It could be therefore argued that, in general, a player of a role needs to give some sort of role performance, however trivial it may be.

precisely the interrelationship between a role performance and its intimately related concepts: e.g., dispositions, functions, and capabilities.[13]

4. Case Studies

4.1. A Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE)

Masolo et al. [6] propose a general formal framework for social roles in compliance with a Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE) [37]. The basic idea is that social roles are (social) *concepts* which are defined by *descriptions* and which, in virtue of those descriptions, classify in a time-relative way continuants (other than concepts; which I will henceforth omit to mention). In other words, a social role is a concept that classifies continuants at time t in such a way that they satisfy at t 'all the constraints stated in the description' of that concept.

A concept and a description both fall into the DOLCE category of *non-agentive social concept*: "an endurant that: (i) is not directly located in space and, in general, has no direct spatial qualities; (ii) has no intentionality; (iii) depends on a community of intentional agents, e.g., a law, an economic system, a currency, an asset ..." [6, p. 272]. Furthermore, some basic features of descriptions are offered as follows [6, p. 271]:

- descriptions are created by (communities of) intentional agents at the time of their first encoding in an expression of a 'public' (formal or informal) language
- different expressions (possibly in different languages) can be associated to the same description, provided they have the same semantic content. I.e., descriptions have a unique semantic content
- descriptions must be encoded on (possibly multiple) physical supports [Original footnote: "Printed or recorded texts obviously count as physical support, but memory or other cognitive processes should probably be considered as well (think of orally transmitted tales, rules and contracts)"]
- descriptions are usually accepted (adopted) by (communities of) intentional agents, but a description can exist even if no one accepts it, as long as it remains encoded; acceptation can change in time
- descriptions cease to exist when their last physical support ceases to exist

It is not hard to see that the approach by Masolo et al. to social roles pivots around a role specification in the role triad. My notion of role specification coincides with the DOLCE notion of description. Both of them are based on agents' intentionality and aim to specify how continuants *should* be like by satisfying the constraints provided by the role specifications and the descriptions, respectively.

On my view, the choice by Masolo et al. of a role specification is not only because they focus primarily on social roles but also because they take DOLCE as a general

[13] On dispositions: see e.g., Mumford [30] and Molnar [31] for a general introduction to dispositions. See Röhl and Jansen [32] for a formal application of dispositions to the (biomedical) ontology research. On functions: see Röhl and Jansen [33] for a survey of theories of functions in philosophy as well as in formal ontology. On capabilities: see Daniel [34] and Smith [35] for an ontological (dispositional) approach to capabilities in accordance with Basic Formal Ontology [5]. It is interesting to note Wahlberg's [36] claim that deontic powers may be sometimes mistakenly identified with dispositions (causal powers).

ontological setting. DOLCE claims to represent the categories with a clear cognitive bias that are associated with, e.g., human cognition and socio-cultural artifacts.[14] In the role triad, a role specification is arguably the most cognitive and linguistic element.

4.2. General Formal Ontology (GFO)

Loebe [7] provides a general account of roles in alignment with General Formal Ontology (GFO) [38]. According to his basic role model, an entity (player) plays a role such that that role bears the *role-of* relation with a *context*. This view of role centers on a role position in the role triad, as evidenced by his explicit reference to the notion of context, which I take to be a role reference entity as a key term for a role position.

Loebe also offers a classification of roles according to the kinds of the player, role-playing relation, the role-of relation, and the context. This is, as said above, characteristic of the positional view of role-playing. Roles fall into *social roles* and *abstract roles*, the latter being in turn classified into *relational roles* and *processual roles*.[15] Processual roles are, roughly, roles that are participated in (played) by objects and that bear the parthood (role-of) relation with occurrents (context).[16] For instance: "When John moves his pen, he and the pen form participants of that process, and the processual role which John plays captures what John does in that participation" [7, p. 135].

The GFO theory of role would deal better with abstract roles than social roles.[17] This can be seen as a consequence of GFO's choice of a role position in the role triad. As was above pointed out, relational roles are well treated with a role position, whereas social roles with a role specification.[18] Processual roles are sufficiently characterized in terms of a role position because they consist in having occurrents as role reference entities.

Finally, part of the reason why the GFO account of role is committed to a role position may lie in GFO's meta-ontological choice of what it calls 'integrative realism'.

[14]"Regarding the content of the ontology, the aim of DOLCE is to capture the intuitive and cognitive bias underlying common-sense while recognizing standard considerations and examples of linguistic nature. DOLCE does not commit to a strong referentialist metaphysics (it does not make claims on the intrinsic nature of the world) and does not take a scientific perspective (it is not an ontology of, say, physics or of social sciences). Rather, it looks at reality from the mesoscopic and conceptual level aiming at a formal description of a particular, yet fairly natural, conceptualization of the world" [37, pp. 279-280].

[15]Loebe [7, p. 137] explains abstract roles as follows: "Due to their similarity, relational and processual roles are subsumed by a role type called *abstract roles* which is contrasted with social roles. Abstract roles can be functionally characterized in a uniform manner, namely as a mechanism of viewing some entity - namely the player - in a defined context, i.e., in a more complex entity with interrelated other "notional components". Put differently, players of abstract roles are looked at in an *external* manner in contrast to viewing them as self-contained entities focusing on their *internals* like their properties or parts."

[16]I am using the word 'roughly' because, assuming the type level, a player of a processual role is the GFO notion of *persistant* and its context is the GFO notion of *process*. See Herre [38] for details on those GFO categories. This does not have much bearing on my argument, however.

[17]Loebe [7, p. 136] says: "Social roles appear to be the least understood role type in our model. For instance, switching to *role-of*, we must admit that contexts remain fairly obscure for social roles."

[18]Loebe [7, pp. 137-138] says: "(...) encouraged by the diverging ontological categories of contexts, we believe that it will be hard to find further commonalities, especially between abstract and social roles. It may thus be difficult to add much more to a general theory of roles, at least as long as a similarly broad range of examples is to be covered." Loebe [7, p. 154] also says: "In our opinion, it turns out that the aspects of abstract and social roles are intermingled in the literature, especially concerning relational and social roles." I would submit that the same roles (e.g., student roles and professor roles) are interpretable in terms of a role specification as well as in terms of a role position.

Herre [38, pp. 303-304] elucidates this doctrine by comparing it with what he calls 'Smithian realism' [40] (which I will below discuss): "No definition for *reality representation* is provided. This fundamental gap can never be closed without the use of concepts, i.e. there is no representation of reality without concepts."[19] By my lights, one advantage of a role position would be to afford us a moderate stance on ontology, disentangling us from a forced choice between pure conceptualism (cf. [39]), which would lead to a role specification, and robust realism, which would lead to a role performance.

4.3. Basic Formal Ontology (BFO)

Basic Formal Ontology (BFO) defines a role as follows: "A realizable entity that (1) exists because the bearer is in some special physical, social, or institutional set of circumstances in which the bearer does not have to be, and (2) is not such that, if this realizable entity ceases to exist, then the physical make-up of the bearer is thereby changed. A role is thus always optional" [5, p. 184].

A realizable entity is: "A specifically dependent continuant entity that has at least one independent continuant as its bearer, and whose instances can be realized (manifested, actualized, executed) in associated processes of specific correlated types in which the bearer participates" [5, p. 183]. A specifically dependent continuant is then: "A continuant entity that depends on precisely one independent continuant for its existence. The former is dependent on the latter in the sense that, if the latter ceases to exist, then the former will as a matter of necessity cease to exist also" [5, p. 185].

The BFO conception of role clearly focuses on a role performance in the role triad. An entity *a* plays a role because, for an external reason, *a* has a BFO-role which is unique to *a* and which can be realized in the kind of occurrents (typically *a*'s behaviors) in which *a* participates. For instance, Mary is a student in virtue of her student role that can be realized in, for instance, her behavior of taking classes.

BFO's 'role choice' would be primarily motivated by its meta-ontological adoption of *ontological realism*: "The realist methodology is based on the idea that the most effective way to ensure mutual consistency of ontologies over time and to ensure that ontologies are maintained in such a way as to keep pace with advances in empirical research is to view ontologies as representations of the reality that is described by science. This is the *fundamental principle* of ontological realism" [40, p. 139]. In the role triad, a role performance is arguably most likely to be the object of empirically scientific inquiry.

I make two further comments on BFO-roles that would help us understand better the relationship between meta-ontological choices and their related 'role choices'. First, BFO specifies the *role-having* relation, but not the role-playing relation: "An entity is sometimes said to play a role, as when a passenger plays the role of a pilot on a commercial plane in an emergency, or a pyramidal neuron plays the role occupied by a damaged

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[19] Herre [38, p. 305] further elucidates integrative realism as follows: "the nodes in an ontology are labeled by terms that denote concepts. Some of these concepts, notably natural concepts, are related to invariants of material reality. Concepts are represented in individual minds and are founded in society. The same is true for individuals to which individual concepts correspond. The interrelations between universals, concepts, symbols and society are realized by various relations, including the relation of correspondence (between concepts and universals, and individual concepts and real individuals), the relation of representation (between concept and individual mind), the relation of foundedness (between concept and society), and the instantiation relation. We summarize that the restricted view of Smithian realism cannot be an ontological-philosophical foundation for the field of conceptual modeling and, in particular, for computer-science ontologies."

stellar neuron in the brain; but neither the person nor the pyramidal neuron *have* those roles. BFO 2.0 only specifies the **has_role** relation" [12, p. 58].

Seen from the viewpoint of grounding, the former 'pilot-role fact' and the latter 'neuron-role fact' are better grounded in <A passenger *meets* the pilot *role specification*> and <A pyramidal neuron *occupies* the stellar neuron *role position*> than <A passenger gives the pilot role performance> and <A pyramidal neuron gives the stellar neuron role performance>, respectively.

BFO's specification of the role-having (but not role-playing) relation implies that BFO-roles focus primarily on a role performance, but neither a role specification nor a role position. Using the Mary-student example, <Mary plays a student role> is grounded in <Mary gives a student role performance>, which is in turn grounded, within the BFO framework, in <Mary's student role is (can be, more precisely) realized>.

Second, it is suggested that some usages of the term 'role' be covered in another way than BFO-roles: "The term "role" can, however, be used in a different sense in contexts such as Jane's being the seventh person to fill the role of director of this institute, or Joe's being the third person to play a particular role in a play. "Role" in this sense is being used to designate what BFO calls a *generically* dependent continuant" [5, pp. 100-101].

A generically dependent continuant is: "A continuant that is dependent on one or other independent continuants and can migrate from one bearer to another through a process of copying. We can think of generically dependent continuants as complex continuant patterns either of the sort created by authors or designers or (in the case of DNA sequences) brought into being through the processes of evolution" [5, p. 179].

It is not hard to see a close conceptual affinity between the BFO notion of generically dependent continuant and the DOLCE notion of description. It could be argued that a DOLCE-description is the sort of BFO-generically dependent continuant that is connected to agents' intentionality. In this respect, BFO attempts to ground, e.g., <Jane fills the role of director of this institute> and <Joe play a particular role in a play> in <Jane meets the director role specification provided by this institute> and <Joe meets a role specification provided in a play>, respectively.

5. Three Conceptions of Roles

5.1. Family Resemblance Concept

All the arguments given above would reveal the ontological nature of role: roles are *family resemblance concepts* [41, Section 3]. As shown above, there are *equally plausible* facts in which <Mary plays a student role> could be grounded. This means that there is no single privileged concept of role; the role notion is merely partly unified by the role triad. Moreover, different meta-ontological choices in foundational ontologies lead to different choices in the role triad. Granted that those meta-ontological choices are equally reasonable from a theoretical perspective, so are the associated 'role choices'.

The family resemblance view of role is a direct consequence of the present work and it is arguably most convincing. It lacks practical virtue, however. As said, there is considerable need for formalizing this cross-disciplinary notion in order to conceptualize the world coherently. However theoretically tenable it may be, it would be of little help for actual modeling processes to say just that roles are family resemblance concepts.

5.2. *Functionally Definable Concept*

I said that <Mary plays a student role> is grounded in either <Mary meets a student role specification>, <Mary occupies a student role position>, or <Mary gives a student role performance>. Instead of taking a family resemblance view of role, one may then attempt to offer a *functional definition* [42] of the role-playing concept.

The core part of my argument over role can be simplified as follows:

> For any an (individual) entity x, if x plays a role, then either x meets a specification determined by that role; x occupies a position determined by that role; or x gives a performance determined by that role.[20]

Replace the term ‘role’ with a variable R, and then existentially quantify it, as follows:

> $\exists R$ (if x plays R, then either x meets a specification determined by R; x occupies a position determined by R; or x gives a performance determined by R).

Then define the role-playing notion as follows:

> x plays a role =def. $\exists R$ [(if x plays R, then either x meets a specification determined by R; x occupies a position determined by R; or x gives a performance determined by R) and x plays R].

The view of role as a functionally definable concept may be a practical advance from its family resemblance conception. Even if there may some room for improvement in the formalization of the term ‘specification’ (e.g., [43]) and perhaps other relevant terms, however, it does not seem that the functional definition of role will be practically usable enough to help domain-specific modeling processes.

5.3. *Practically Unifiable Concept*

One may still wish to provide a unified concept or definition of role even at the price of theoretical rigor. This task requires considering carefully which ‘role choice’ is practically appropriate. For instance, one may choose a role specification, based on the intuition that <Mary meets a student role specification> grounds <Mary gives a student role performance>. For another example, one may take a role position because it fits well with an apparently widely acceptable, moderate stance on ontology. This line of investigation is to be pursued together with careful cost-benefit analysis.

6. Conclusion

I have argued for three claims. First, there are three role-related concepts (the role triad): a role specification, a role position, and a role performance. Second, different accounts of role might depend which notion in the role triad is ontologically prior to the other two, as illustrated with close examination of three theories of role which are based on (the meta-ontological choices of) DOLCE, GFO, and BFO, respectively. Third, there are

[20]To simplify matters, I am setting aside the issue of whether logical entailment fully captures the notion of grounding that I have exploited so far.

three possible understandings of the ontological nature of role: a family resemblance concept, a functionally definable concept, and a practically unifiable concept.

This work on role will bring us to many future directions of research and, in particular, there are many thorny questions to be answered regarding various associated modeling processes. For instance, the topic of *qua-individuals* [44] (e.g., Mary-*qua*-student) has wide implications for a representation of roles.[21] The idea of the role triad will shed light on qua-individuals, contributing possibly to a novel approach to them.[22]

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Providing Conceptual Disambiguation for Terms in Reusable Ontologies: A Case Study from FIBO

Michael G. BENNETT

mbennett@hypercube.co.uk
Hypercube Limited, London, England

Abstract. This paper describes a number of design techniques employed in the Financial Industry Business Ontology (FIBO) series of standards. These are compared to the notion of a conceptual ontology as a computationally independent artefact. An example is given in the applications of the Interest Rate Swaps (IR Swaps) FIBO ontology, where some ontology elements may be re-used to represent different concepts in different kinds of ontology application. Some proposals are outlined for the use of a higher-level industry concept ontology to provide disambiguation between the concepts referred to in different ontology applications. This paper is intended to promote discussion on possible cross-domain and upper ontology components for use across these different kinds of ontology application.

Keywords. FIBO, Conceptual Ontology, Ontology Reuse, Top Level Ontology.

1. Introduction

The Financial Industry Business Ontology (FIBO) [1] is an industry initiative with the original stated intent to standardize the terms used in the financial services industry.

The notion of a 'term' as used in the financial industry is only loosely defined and the original work on what was to become FIBO took the approach that what was needed was a model of the concepts represented by words or 'terms' in industry data and communications. That is, the objective pursued by this author in the original development of FIBO was to provide a reference model for semantic interoperability across a range of technologies by providing conceptual clarification and disambiguation of concepts and by defining the formal real-world semantics of concepts in the financial domain. This style of ontology is referred to in this paper as a 'conceptual ontology'. Elsewhere, terms like 'business concept model' are used to avoid confusion with other uses of the word 'conceptual' among IT practitioners.

FIBO as published is intended to provide a number of ontologies in the Web Ontology Language (OWL) [2] that may be used in a range of inference processing and semantic querying applications. This represents a different requirement to that against which FIBO was originally developed, with implications that are explored in this paper.

1.1. Industry Appetite for Conceptual Ontology

There is a growing awareness in the financial industry of the need for a more concept-focused kind of ontology to provide formal semantics for industry terms. For example in ISO TC68 SC9 Working Group 1 [3], the working group tasked with considering the application of semantics to the ISO 20022 financial industry messaging standard [4], there has been informal discussion of the need for a future 'New Work Item Proposal' (the ISO term for potential new standardization work), to cover what is referred to there as an 'Upper' ontology [5]. It has also been suggested that the proposed NWIP could form a possible contribution to the ISO 28138 Top Level Ontologies emerging standard [6].

The use of the term 'Upper Ontology' in these business contexts should be interpreted as referring to a combination of top level and cross domain ontologies, the purpose of which is to provide a computationally independent representation of the semantics of the domain of discourse, in this case the domain of finance and commerce. This would be a 'conceptual ontology' in the sense that that term is used in this paper.

1.2. Aims of This Paper

This paper looks at the balance of concerns between conceptual (computationally independent) ontologies and those ontologies design for a specific purpose or range of purposes (informally, 'operational ontologies'). Some distinctions observed between conceptual and operational ontologies in the FIBO ecosystem are given as an illustration of the kinds of issues that arise in determining how instance data (individuals) are to be populated in applications of the latter. Here we have chosen one aspect of these differences, namely the way in which certain classes of the operational ontology appear to be intended to be used for more than one kind of thing in the domain of discourse. The assertion explored here is that a conceptual ontology needs to have a good set of upper and cross-domain ontologies in order to provide the kind of information needed by implementers of operational ontologies (including implementers of the published FIBO standards material) in order to correctly assign data to classes and properties.

This paper explores the implications of these design arrangements and proposes the use of computationally independent conceptual ontologies including the framing of their concepts within a set of top level ontology partitions, as a means to provide management and oversight of these applications.

Taking a specific example observed in these ontologies during some proof of concept work for Blockchain applications [7], we explore the dangers inherent in the existing approach. The aim of this paper is to consider how the principled use of conceptual ontology would either avoid operational ontology designs that would cause issues when populating such ontologies with ABox data for individuals, or would allow for traceability of the intended business semantics of such applications without the need to overload the application itself with these considerations.

1.3. How This Paper Is Structured

Section 2 gives an overview of the FIBO standard, describing the evolution of FIBO from a computationally independent conceptual ontology to a set of ontologies intended for use in OWL based applications.

Section 3 introduces the design conventions followed in the released OWL components of FIBO, based on observations of the differences between FIBO as a released standard and the original conceptual ontologies developed for the industry.

Section 4 goes on to focus on one specific design convention, whereby certain classes and properties are seen to be conflate concepts, presumably by design. This is illustrated by an example from the financial instrument class of Interest Rate Swaps, where the re-usability or under-specification of some classes was observed during a proof of concept activity. The weaknesses of this design convention are explored, in particular the way that the precise semantics of these concepts are left to the implementers of future applications.

The need for a conceptual ontology is asserted, and in Section 5 a number of application contexts are given for the financial industry and beyond, that would need to be taken into account in understanding how operational ontologies are likely to be deployed in industry applications.

Section 6 sets out a minimum requirement for set of upper and cross domain ontologies to be used in business ontologies and suggests how these would address the weaknesses described in Section 4.

Section 7 sets out the core proposition of this paper, that industry should work towards a consensus set of re-usable cross domain ontologies integrated within a suitable simple upper ontology partitioning layer.

Section 8 sets out the conclusions of the paper and aims to frame further discussion on these topics.

2. FIBO Development and Evolution

FIBO was originally conceived as a computationally independent conceptual ontology, but was modeled using the basic constructs of the OWL language within a business-facing presentation format. This was known as the 'Semantic Repository' [8].

During initial socialization of this work it was challenging to explain to the potential users of these models that what was being proposed was not in fact a data model. A number of potential arrangements were explored during 2007 and 2008 for the modeling of formal semantics of concepts in the financial services domain. One additional instruction given to the author was to 'Keep the philosophy out of sight' (private correspondence with the author); it was not practicable to simply represent the industry concepts in formal logic, there needed to be tool support for presentation and business validation of the model content.

As described in [9] the project selected the OWL language partly because something was needed that had the necessary tooling support, and partly because the use of OWL and in particular the class of 'Thing' made it possible to explain that what was being proposed was not a data model. OWL was not a direct match for the requirements of this initiative but was selected as the most immediately usable alternative available at that time.

One challenge in using OWL for computationally independent ontologies is the expressive power of the language: not everything that needs to be said about the business problem domain can be said in the sub-set of logic that OWL represents. The initial FIBO conceptual ontologies were therefore considered as being a sort of conceptual core around which other kinds of assertion might be made.

Another potential issue with the use of OWL was the lack of any methodological support for concept representation, leaving it the individual modeler to find the best ways to represent things in the problem domain. This was not considered to be a weakness but rather an absence: for the early conceptual work on what was to become FIBO, the beginnings of a conceptual modeling framework were drafted to address these matters, although as noted above these were of no interest to the end users of the models. OWL itself was simply considered as one syntax in which model content could be represented.

Although OWL was considered as the underlying language for the model content, even the existing OWL tooling was considered to be inadequate for a 'technology free' business presentation and so the OWL constructs were rendered in UML tooling using the Ontology Definition Metamodel (ODM) [10] from the Object Management Group (OMG) [11].

The FIBO ontology was originally conceived as a computationally independent reference ontology. The concepts were framed within a fairly basic set of upper ontology partitions, based on the top layer of John F Sowa's 'Knowledge Representation" lattice of theories [12]. These included among other things the distinction between independently defined things and contextually-dependent concepts such as entities playing roles or entities defined by their function. Similarly, the distinction between 'Continuant' and 'Occurrent' was employed to mark out the distinction between things that persist over time and event and process concepts such as corporate actions, transaction events and securities issuance processes.

The documented basis for most of the concepts in the initial parts of FIBO is that these represent the commitments enshrined in the terms and conditions of contracts. This forms the basis for the definition of financial instruments, as these are all contracts of one sort or another. Other components of FIBO deal with corporate actions, securities issuance processes and securities transactions. The intent with these is to provide a comparable real-world grounding of the concepts in terms of events and activities.

The FIBO standard ontologies that are made available via the OMG in contrast provide a set of ontology design artefacts for use in inference processing. These may be considered as designed artifacts comparable with logical designs in other technologies and are sometimes referred to as 'operational' ontologies, though this term is not used within the FIBO ecosystem itself. A more detailed treatment of the distinctions between these kinds of ontologies is given in [13].

Certain design decisions have been made for this FIBO standards content which distinguish them from a computationally independent model of the subject matter as originally envisioned. According to some recent statements these design decisions include the use of certain classes to represent more than one set of things in the domain of discourse[1]. This stated design approach has implications for the management of application ontologies and their data.

3. FIBO Standards Design Conventions

As part of the process of submitting FIBO to the OMG as a series of standards, the focus of FIBO has shifted from the use of OWL as a means to frame conceptual meaning, to the application of design rules suitable for OWL-based ontologies for inference processing and reasoning.

The design conventions for this style of OWL in FIBO have not been formally documented but may be discerned by considering the changes made from the original conceptual framing of FIBO to the style of ontology considered suitable for release as an OWL-based standard. These design changes include but are not limited to:

1. Removal of references to upper ontology material
2. Removal of domains and ranges from many object properties
3. Object properties whose domain is a union of unrelated classes
4. Substitution of ontological representations of information constructs such as names, for simple datatype properties with 'string' as their range
5. Substitution of social constructs (where these give the business semantics of a concept) for data elements that may provide evidence of the existence of such constructs
6. Conflation of similar concepts, for example combining into one class the notion of a clearing house as a functionally defined entity and the role of that clearing house in some securities transaction.

It is not the intent of this paper to critique those design decisions. For the most part we assume that these decisions are reasonable for the perceived range of competency questions and usages to which these ontologies are to be put. We also note that these design decisions are a principled application of the computational constraints of the design of an OWL based solution or set of solutions.

These are therefore not computationally independent models. Rather they are derived from the earlier computationally independent models that made up the initial conceptual FIBO material.

4. Reusability in FIBO

One of the design conventions observed in the published FIBO OWL standards is the apparent intention that certain classes and properties may be considered to be polysemic.

An example of reusable concepts occurs in the area of Interest Rate Swaps (IR Swaps) [14]. An IR Swap is a bilateral agreement in which two parties agree to exchange a series of cashflows that are based on the interest payments streams of some

[1] Subsequent to writing the initial draft of this paper some of the specific examples of this practice, which was explicitly justified by one of the OWL modelers at the time, have been backed out in the model content.

loan. For example one party may have a loan on which they are paying variable interest and wish to exchange this payment stream with another party that has a comparable loan with fixed interest payments, such that both parties end up paying interest on terms more in line with their preferred balance of risk and returns, hedging against changes in the underlying interest rate against which the variable amounts are pegged. The loan principal itself is generally not exchanged, unless these are in different currencies.

IR Swaps are effectively transactions and like most transactions these have a corresponding contract, usually made up of an over-arching master agreement plus transaction-specific terms in a separate message that is deemed to have contractual standing. There are terms for interest rates, interest amount accruals and payments, these rates and accrued amounts being accrued and paid down on a periodic basis. In FIBO the semantics of contracts is focused around the notion of a 'commitment' and draws upon the REA Ontology [15]. For a similar but distinct treatment of contractual elements in the context of service agreements see also [16].

In FIBO the definitions of the terms for IR Swaps, being the terms of a contract, are definitions of the commitments made by each party to the other.

Meanwhile there is a business requirement for reporting on the interest accruals and payments that happen during the life of the swap [17]. These are very similar in form to the descriptions of the commitments made, since these events are the actual occurrences of the promised payments of accrued amounts.

In the released FIBO as currently designed, it is seemingly possible to take the same ontology and populate it with data (OWL Individuals) representing different semantics, specifically terms definitional of the contract and terms for reporting of individual transactions.

Assuming this practice persists, one can reasonably ask why an ontology is used at all and not simply a data model? Given the current practice, users need to be aware that wherever classes are or might be populated with different data in different usage contexts, data from one such application cannot be interoperable with data from the other. This need not be an issue as long as users of the standard are aware of this feature. However, the use of the same namespace for a multiplicity of incompatible applications' data clearly represents a risk for data management, reporting and compliance.

Ontologically there are two distinct kinds of 'things that happen' that are both of relevance to IR Swaps. As conceptualized in the original FIBO conceptual modeling, there are things that should happen (prescriptive) as in a business process workflow description or in this case the required payments, accrued obligations and so on as prescribed in the terms and conditions of the contract. Then there are the things that do or will happen: the actual occurrences whether past, present or anticipated in the future. These are events or activities with dates, specific amounts of interest accrued at specific calculated rates, monies owed or accrued as of a given date and so on. For a separate but comparable treatment of these considerations see also [18].

In the published Interest Rate Swaps FIBO ontologies the same classes appear to be intended to be used for both. There are at the time of writing some inconsistencies in the concepts that are ancestral to these concepts in IR Swaps, but there is also (by design) no use of upper ontology and consequently no means to distinguish between intended and actual occurrents, although there are the concepts of 'Occurrence' and 'Occurrence Kind' that partially allow this distinction to be made. It is assumed that these questions are left to implementers of ontology-based applications that would re-use FIBO components.

The intended occurrents modeled here would be framed in some upper ontologies not as occurrents at all but as dispositional notions (commitments being dispositions, along with beliefs, tendencies etc.). Other upper ontologies, including the prior FIBO conceptual work would define these commitments as kinds of social construct, with a relationship to the concept of an event that 'should' happen. There is a range of valid ways to frame these concepts but the published FIBO standards, being intended to operationalize OWL, leave these distinctions to the end user. The intended semantics of a given class therefore depend on the context in which data is assigned to these classes and their related properties.

Given that FIBO has the stated policy not to use upper ontology or cross-domain abstractions (particularly social constructs and most things that are not materialized as data), it is recommended that operational ontologies like FIBO and those derived from it should have some traceability to an explicitly conceptual ontology. This would address not only the above observed example of polysemy but also other common design patterns seen in OWL ontologies used for applications, such as the reduced use of property domains and ranges, the use of data surrogates for real world social constructs, and others as noted previously.

While some examples of such polysemy have been removed from the FIBO models since this example was uncovered, the design justification for doing so has been clearly stated in correspondence with the author, though not formally documented. Other examples have been identified in the area of 'values', where a given class may be taken to represent the prescription of a value or an actual occurrence or measurement having such a value. It should be noted that these distinctions were not made in the original conceptual models, where these were simply regarded as the concept of a value or other such matter without reference to context or usage. Subsequent research and feedback, in particular with reference to the proposed Semantics for Information Modeling and Federation (SMIF) standard [19] at the OMG has led this author to the conclusion that these distinctions should be clearly demarcated in conceptual ontologies.

The reusability of ontologies is not the same thing as the reusability of classes and properties to mean different things in different contexts as indicated by the example explored in this paper, and should not require this. Clearer guidance and design conventions are clearly needed for end user developers in order for these operational ontologies to be reusable in different contexts. The use of a separate conceptual ontology should therefore enable re-use of operational OWL ontologies such as those published as parts of FIBO.

5. Identifying Conceptual Requirements from Context

In order to identify the range of possible concepts needed in the proposed upper and cross-domain ontologies, the first step would be to catalog the range of ways in which a given set of operational ontologies may be used. The relevant high-level concepts can be identified from these. For example in the IR Swaps case one would identify the need for prescriptive and descriptive occurrent partitions.

The kinds of contexts required for financial applications would include:

1. Reporting, including trade reporting
2. Transaction processing (straight through processing) and associated messaging
3. Risk management and reporting
4. Regulatory compliance
5. Integration of new and existing data feeds, applications etc. across different systems (middle, front and back office).
6. Mergers and acquisitions
7. Customer relationships management, cross-selling and up-selling
8. Know your customer (KYC) compliance and reporting
9. General Data Protection (GDPR) and the privacy of individuals' data
10. Loan applications, other applications and proposals
11. Product management (including retail financial products)

Each of these and others will determine the concepts that need to be stood up in the cross-domain ontologies in order to provide the contexts needed to distinguish between separate concepts that may use the same words in data models or reports, for example, a loan as a product versus a loan as a contract between parties.

The polysemic application of such words or terms in language should not be taken as a reason to create ontology classes and properties that correspond to words and are overloaded in a similar way. Inspection of some part of FIBO suggests (perhaps incorrectly) that this has sometimes been the approach taken by model designers, which if it were the case would call into question why ontology is being used at all. Instead of focusing on words, any operational ontology should focus on concepts, ideally framed with reference to some conceptual ontology.

Some of these contextual distinctions are clearly demarcated within FIBO and comparable ontologies while others may not be. Relevant contexts would include process contexts (such as loan applications, transaction workflows), data usage contexts, risk versus real events, planning and scheduling and so on.

6. Industry Core Ontology Requirements

The distinction between conceptual and operational ontologies is explored in [20]. One of the recommendations in that paper is that conceptual (reference) ontologies and operational (application) ontologies be given separate namespaces.

It should be possible to apply this approach to the deployment of FIBO ontologies that have overloaded semantics and other design features. In this case, an operational ontology would be stood up in its own namespace, using a localized copy of the relevant FIBO ontology supplemented by a suitable core ontology consisting of cross-domain ontologies integrated within a set of top level ontology partitions.

To support such arrangements, the industry needs to be able to refer to a core ontology that integrates and distinguishes between different contextually sensitive material. In the example given for Interest Rate Swaps, these would include distinctions between:

1. Prescriptive Occurrents: definitions of things that are prescribed as needing to happen, or as being mandated by some party or committed to by some party;
2. Descriptive Occurrents: definitions of things that actually happen, on some given dates in the past, present or some projected future, and having specific

values for interest rates, accrued monetary amounts, netted payments and so on, as of those dates.

Similar sets of upper ontology material would be needed in other places where FIBO consciously conflates concepts, such as the observed conflation of parties in roles and functional entities for participants in the securities transaction lifecycle.

6.1. Candidate Terms

One proposed solution to the IR Swaps example can be found in work carried out within the FIBO Foundations Content Team, in which the class of 'Occurrent' was sub-classified into several sets of pairwise disjoint facets, including those of Prescriptive Occurrent versus Descriptive Occurrent, described briefly in the submission to [21]. These facets were arrived at following a detailed analysis of the DOLCE [22] partitions in this area, where it was determined that some of the DOLCE concepts combined more than one primitive semantic. These concepts were not and will not be part of the formal FIBO release, as the policy whereby 'conceptual' and 'upper ontology' material are ruled out of scope is extended to sub-partitions of 'Occurrent'.

Other sub-partitioning of the Occurrent partition of a suitable top-level ontology would also be suitable for this requirement.

7. Proposition

It should be realistic to come up with a definitive set of core ontologies for use across business, finance and commerce, including for example insurance, logistics, real estate and financial services. Given the nature of business concerns (profit and loss, risk, legal interactions, regulatory conformance, supply chain management, customer relations and so on), as compared with the diversity of theories that underpin physics for example, it is this author's contention that this undertaking would be simpler than trying to achieve this across the realms of physics, chemistry or biology.

Such a core ontology should focus explicitly on the notion of the 'concept', since many of the concerns of business relate to planning, risk, strategy, commitment and other management concerns in which the enterprise must necessarily form the concept of some matter whether or not that matter is ever present in some real or imagined world.

It should be feasible to integrate the best of breed of the concepts across the available top level ontologies. The pre-existing 'conceptual' work carried out during the earlier part of the development of FIBO may also inform the process of selecting from and integrating between these concepts. Available cross-domain ontologies are also of value and could ideally be integrated within a common set of top level ontology partitions, in particular REA [15], LKIF [23] PSL [24] and would be integrated as seen in OntoUML [25]. Ongoing work from the VMBO series of conferences such as [26] (in draft) also provides comparable material for the definition of concepts for value, risk and others.

It is recommended that solutions that make use of operational or design ontologies be framed within a broader conceptual ontology framework, without the contents of such a framework needing to be included within the assertions that any such application will refer to. The conceptual ontologies referred to would exist in a separate namespace from the operational or application ontologies, so that conceptual assertions are not imported into the application.

This approach would enable operational ontologies to be re-usable and also help to identify when a given operational ontology should not be used in a given context, or should only be used with careful isolation of the resulting data, that is, not treating the data itself as reusable across more business contexts than the semantics of those data elements would support.

Ideally, application-specific (operational) ontologies would be derived from the conceptual ontology in such a way that the design is fully traceable and the data from any one application can be maintained separately to the data from any other application even when the same operational ontologies are employed. Suitable metadata relationships can be derived to represent something similar to the 'trace' relationship in UML (for example 'implemented as') relationships.

For many of the design conventions employed in FIBO released ontologies and other comparable ontologies, it should be feasible to come up with a number of repeatable heuristics for deriving suitable design patterns from the conceptual representations of things in the world. Specific examples are out of the scope of this paper but could include for example deriving end user context-specific, simple sets of classes and relationships from concepts defined 'in the round' with reference to 'relative things', 'role mixins' or other conceptual patterns. Some of the design patterns observed in the FIBO released standards, including the polysemic use of some classes and properties, may turn out to have been mistakes; some principled application of the relationships between conceptual and operational ontologies would provide some guidance and design auditability that would avoid or expose the possible unintended consequences of this approach.

8. Conclusions

The specific design approaches taken for FIBO standards are not in question. These ontologies are intended to provide a set of ontologies that may be re-used across a range of financial industry applications that make use of Semantic Web technology. However the particular example whereby certain classes are observed as being able to be used to frame similar concepts in different application contexts is considered risky at best and this author would recommend that this be avoided.

The creation and use of a common, cross-industry core ontology is recommended as the next component in enabling industry to roll out a range of compliance and reporting applications that make use of semantic technology and that are able to leverage the in some cases under-specified elements of the FIBO standards as well as to support re-use where this is appropriate and to signal when it is not.

This approach is also indicated for other design patterns such as properties with no domain and/or range, the use of data surrogates in place of the truth makers of a given concept and so on. In this way, designers of ontology-based applications may take account of the technical limitations imposed by any solution architecture without losing the ability to trace classes and individuals and their properties to the original business meanings of the concepts concerned. Failure to do this may in some cases result in ontology-based data that is not as reusable as they might appear from a casual inspection of the content.

There is considerable scope for further investigation and research in these areas as well as in the potential for providing practical methodological support for ontologies across the engineering development lifecycle.

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Vaiśeṣika Graph Grammar (VGG) System

Rajesh TAVVA[a,1] and Navjyoti SINGH[a]

[a] *Center for Exact Humanities, International Institute of Information Technology, Hyderabad, Telangana, India*

Abstract. Graph grammars, being a natural extension of string grammars as well as tree grammars, are highly expressive as well as powerful enough to capture the generative structure of a wide variety of scenarios - both simple and complex. But, unfortunately, we do not find many instances which leverage this power graph grammars provide us. Most of the graph grammars available so far are either toy grammars or limited to addressing highly specialized problems. In this paper, we present Vaiśeṣika Graph Grammar (VGG) system, which is as wide as any graph grammar can get i.e., a grammar for reality as theorized in Vaiśeṣika - the foundational ontology found in Indian analytic tradition. This paper extends the work presented in [1]. In [1], the generative as well as the interpretation rules of this system were presented. Here, apart from briefly discussing some of these rules, we also present a parser for such a system which makes it extremely powerful in terms of its ability to classify an input graph as a valid Vaiśeṣika graph or an invalid one which, in itself, is an immensely significant breakthrough for any ontological application. Apart from that, we also present a verification mechanism to verify the interpretations of graphs generated by the generative rules. This is done, at least statistically, if not formally, to give a statistical proof of the soundness of the system (that every generated graph has at least one Vaiśeṣika interpretation, and no useless graphs are generated.)

Keywords: Vaiśeṣika, Graph Grammar, Generative Ontology, Parser

1. Introduction

The notion of a grammar in itself is quite intriguing. It is a finite number of rules which can generate a (potentially) infinite number of sentences. It is something which brings parsimony into the system. A grammar captures the repeating patterns in a system and encodes them into a finite set of rules. It is extremely simple and yet highly powerful.

Graph grammars, compared to string and tree grammars, are more powerful, expressive and intuitive. Yet, there are very few instances of uses of graph grammars in real world. In this paper, we present the parser for Vaiśeṣika Graph Grammar (VGG) system[2] whose generation rules (GRs) and interpretation rules (IRs) were already presented in [1]. This is a grammar for reality itself based on Vaiśeṣika - the foundational ontology found in Indian analytic tradition.

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[1]Corresponding author, Center for Exact Humanities, IIIT-Hyderabad, Gachibowli, Hyderabad, Telangana, India; E-mail: vrktavva@research.iiit.ac.in

[2] One can find a working prototype of this system here: http://ceh.iiit.ac.in/vgg

In ontology engineering, a fairly recent discipline, one of the fundamental questions is how to construct ontologies as well as how to analyze a given scenario or state-of-affairs (SOAs) in terms of known ontological categories. Currently these problems are addressed mostly manually or, even if done automatically, involve a lot of human intervention at various stages. Hence there are various problems like interoperability issues, internal contradictions within the systems etc. One way to overcome these problems is to minimise human intervention as much as possible, and what better way can be there to do it than to construct grammars for such systems where the human intervention is minimal, and is required only at the beginning of building the grammar. Once the generation or parsing process is set in motion, the system is on its own and requires no human intervention in between.

We presented one such system, a novel idea called Generative Ontology, based on Vaiśeṣika in [1] in which the GRs and IRs of the system are presented. But they only enable one to generate graph structures as well as interpret them according to Vaiśeṣika system. There is still one crucial step left to complete the system i.e., to give it an ability to decide whether any given graph is derivable within the system or not. This eliminates the burden of generating every possible graph and matching it with the input graph to decide upon its derivability. It is similar to the role which a parser plays in compilers in programming languages. It parses a program in a particular language and identifies syntax errors in it saving a lot of resources to the system. In that sense, a parser is an immensely useful and necessary tool and it gives enormous power to the existing system.

In this paper, we present the parser for VGG as well as give a statistical proof for the soundness of VGG. Since this is an extension of the work done in [1], we will provide a brief overview of it in Section 2, and then move on to present the parser in Section 3, and then present the results and conclusion in Section 4.

2. Overview

2.1. Vaiśeṣika System

Since a significant portion of the system (Vaiśeṣika categories, Generative Rules and Interpretation Rules) are formally presented in [1] already, we give a brief overview of them here in a more informal manner for the comprehension of the rest of the paper.

Vaiśeṣika system is a foundational ontology which classifies all the entities in reality into 6 categories[3]: (1) Substance (e.g: material entities like ball, car as well as non-material entities like soul, space and time) (2) Quality (e.g: color, size) (3) Action (e.g: rising up, falling down, motion) (4) Universal (e.g: car-ness, ball-ness, red-ness) (5) Ultimate Differentiator (located in each ultimate substance (explained below) and differentiates one from the other) and (6) Inherence (explained below).

Before comprehending any of the Vaiśeṣika categories, the first category we need to understand is ‘inherence’. Inherence is one of the primary relations of Vaiśeṣika

[3] It is actually a six-plus-one category system. The seventh category i.e., absence is considered to be added later to the list of fundamental categories. The complete list of Vaiśeṣika categories and subcategories can be found in [13].

system. It is the second most prevalent relation in reality after self-linking relation[4]. Some instances of inhering can be color inhering in a rose, treeness inhering in all the trees, a whole inhering in its parts etc., (inherence needs to be understood as something located in something, but in an aspatial manner).

Substance, philosophically speaking, is that *which stands below* i.e., all other categories ride on it or are dependent on it while this doesn't ride on anything else. Similarly, an ultimate substance, in Vaiśeṣika, is that category which *stands below* everything else - even other substances. It needs to be understood in terms of inherence - as something inhering in something. In Vaiśeṣika, qualities and actions inhere in substances; universals inhere in qualities, actions and substances; while some substances (wholes) inhere in other substances (parts). These latter substances in which other things can inhere, but they don't inhere anywhere else, are called ultimate substances (USs).

Among USs, there are two types: ubiquitous ultimate substances (UUSs) and mobile ultimate substance (MUSs). UUSs are those which are either in contact or in disjunct with all other substances. MUSs are those which are in contact with some while in disjunct with other substances. These are formal definitions of UUS and MUS provided in [1]. Not only these, but all the fundamental categories as well as some subcategories of Vaiśeṣika are defined formally, in terms of inherence, in [1]. For instance, *universal (U)* is something which inheres in 2 or more entities, but nothing inheres in it. In this way, many categories and subcategories of Vaiśeṣika are defined formally, purely using the idea of inherence, conjunct (contact) and disjunct - i.e., how many entities inhere in a given entity, what is the configuration of contacts, disjuncts etc.[5]

The Interpretation Rules (IRs) of VGG can be considered to be a visualization of the formal definitions of Vaiśeṣika categories and subcategories. So a quick look at them can enable us to understand these definitions easily. They are presented in Section 3.2 of [1].

Like in [1], this paper's focus is not on defending Vaiśeṣika description of reality or the rationale behind its categorial system. One can refer to [5] and [14] for that. The idea of this paper is to show the possibility of an ontological system in which the SOAs can be generated, interpreted and also parsed.

2.2. Generation and Interpretation Rules of Vaisesika

As mentioned in Section 2.1, many Vaiśeṣika categories and subcategories can be defined formally in terms of inherence, contact and disjunct. Actually these also form the fundamental relations in the system apart from the self-linking relation. Their formal definitions can be found in Section 2 of [1].

A punctuator is a boundary which separates as well as brings two entities into some relationship. Its structure is like <x|y,R> where x and y are the entities being punctuated, and *R* is the relational context in which they are punctuated. Here *R*

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[4] Self-linking relation is not a Vaiśeṣika category since it is not an entity. In other words, it requires no other relational entity to bring together the two relata. It is both the relata themselves put together. For the structure of self-linking relation, see [1].

[5] Refer to Section 2 of [1] for all the formal definitions of Vaiśeṣika categories and subcategories.

constitutes the entire rest of the universe which itself is a set of all the chains of entities and punctuators between x and y. So a punctuator has a recursive structure.

Given the recursive structure of punctuator and the complex nature of its relational context as a web of entities and punctuators, it is best imagined as a graph (made up of nodes and edges) which can also be understood as a state-of-affair (SOA). It is shown in [1] that the three simple punctuators - (1) self-linking (2) inherence and (3) conjunct-disjunct punctuators - constitute the building blocks for all the complex punctuators (SOAs) in Vaiśeṣika. It is also shown how these complex punctuators can be generated from the simple punctuators (alphabet) using generative rules (GRs), and then interpreted with Vaiśeṣika categories using interpretation rules (IRs).

GRs can be considered as the syntactic portion of reality whereas IRs can be considered the semantic portion of it. GRs generate pure structures with no inherent meaning whereas IRs give meaning to them by labeling them with Vaiśeṣika categories. In [1], it is shown that all the graphs generated by GRs could be interpreted using IRs with Vaiśeṣika categories, but the validity of those interpretations is provided here, in this paper, in Section 4. VGG uses Single Pushout (SPO) approach [8] for graph transformations.

A screenshot of an interpreted graph in VGG system is provided in Figure 1.

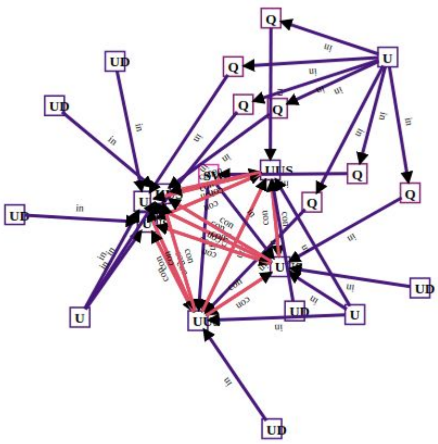


Figure 1. A graph generated in VGG followed by interpretation with Vaiśeṣika categories. Here the following categories are depicted - UD (Ultimate Differentiator), Q (Quality), SW (Substantial Whole), UUS (Ubiquitous Ultimate Substance), U (Universal). And the edges 'in' and 'con' stand for inherence and contact respectively.

In this paper, we present the parser for VGG which completes the system and gives it real power in terms of recognizing an input graph to be derivable or non-derivable within the system using the GRs of the system.

3. Parser

While building a system like VGG, one needs to distinguish two questions here:

- Whether a graph is derivable within the system or not?
- Whether all the graphs derivable within the system are Vaiśeṣika graphs or not?

Both the questions are independent of each other and hence require different approaches to address them. The first one is purely a structural or a syntactic question whereas the second one is a semantic one. The first one is a question of decidability whereas the second one is a question of soundness. The first one is answered by constructing a parser which parses the structure of a given graph to decide if it belongs to the language (the set of graphs generated) of the system. The second one is answered by verifying whether all the generated graphs (using the generative rules of VGG) are interpretable (using the interpretation rules of VGG) i.e., is there a correlation between the generation rules and the interpretation rules. This can be done by verifying if there is a consistency in the generative labels (intermediate labels used in generative grammars) and the interpretation labels (the Vaiśeṣika labels used to categorize nodes after interpretation). If there is a consistency, then the insight used while generating the graphs matches with the insight while interpreting them though both are starting from completely different directions. We show that, at least statistically, the system has soundness since there is a consistent mapping between the generative labels and the interpretation labels.

The parser, like generative as well as interpretation grammars, is a grammar, and hence consists of a set of graph transformation rules which apply on the input graph and stop after all the rules are exhausted. The parser, as mentioned above, addresses a decidability problem and hence is supposed to recognize a graph as belonging to the system or not based purely on its structure and not its labels. The rules of the parser are arrived at, broadly, by reversing the generative rules of VGG as well as the LHS and RHS of each rule, though not mechanically. One has to add/delete some NACs[6] in the generative grammar to formulate the parser rules. An input graph to a parser is said to belong to the generative grammar of VGG if the process of parsing ends at the start graph of the generative grammar of VGG. If not, the input graph to the parser is a non-derivable graph i.e., such a structure will never be generated by the generative grammar of VGG.

We claim that the parser identifies only the right graphs with the right combination of labels as valid graphs generated by the generative rules of VGG. It would reject both (1) graphs with wrong structures as well as (2) graphs with right structures but wrong combination of labels - as non-derivable graphs.

In our grammar, the node-labels are Ω_V = {g, C, D, h, i, p, q, r, s, u, v, e} and edge-labels are Ω_E = {in, con, dis}. Each of the node-labels stands for the following: g – start node (this is the only node in the start graph of generative grammar of VGG, but

[6] An NAC is a Negative Application Condition which is also a graph. If an NAC matches with the graph in question along with its LHS, then the rule cannot be applied. So one should check for this condition as well before applying a rule.

this should become the end graph in the parser if the parsing is done successfully), C – conjunct entity, D – disjunct entity, h, i, p, q, r, s, u, v – are all various node labels used in the process of parsing. These are taken from generation grammar itself and their corresponding Vaiśeṣika categories which they are intended to stand for, is also kept intact. The node labels used during generation (or pre-interpretation) stage are supposed to map to the following Vaiśeṣika categories after interpretation (post-interpretation) stage, as shown in Table 1.

Table 1. Mapping between pre-interpretation (syntactic) and post-interpretation (semantic) labels

Pre-interpretation label (purely syntactic)	**Post-interpretation label (semantic)**	**Corresponding Vaiśeṣika category**
g (start node)	not applicable	not applicable
h	not applicable	not applicable
i	not applicable	not applicable
p	MUS	Mobile Ultimate Substance
q	SW	Substantial Whole
r	UUS	Ubiquitous Ultimate Substance
s	U	Universal
u	Q	Quality
v	UD	Ultimate Differentiator

At the end of the generation all the (pre-interpretation) labels were replaced by a common label, e, to show that the nodes they were labeling can be interpreted later based purely on their structures and not on their labels. Now we will use the same ‘e’ to start the process of parsing! And the edge labels stand for the following: in – inherence relation, con – conjunct relation, dis – disjunct relation. But in the rules below we have differentiated edges based on their arrows instead of their labels for aesthetic purposes. An inherence relation has one arrow (since it is an asymmetric relation), conjunct relation has two arrows and a thick line whereas disjunct relation has two arrows and a dashed line (both are symmetric relations).

No two entities have more than one edge (of any type) between them. That is a default NAC for every rule and hence not being specified with each rule.

Since we are interested in only the structure of the input graph, we can assume all the nodes of the input graph are either anonymous or uniformly labeled (except those of C and D since they, anyway, are revealed by their corresponding edges and cannot be otherwise). We will assume all the nodes (except that of C and D) are labeled uniformly, with the label ‘e’ (the same label with which we homogenized all the nodes at the end of generation. From here, we will try to backtrack the generation process with the hope of reaching the start graph of generation grammar of VGG. For this, we will apply the generation rules in reverse, though, with some changes in their NACs. So the first layer of parser rules will be the last layer of generative rules and so on. We will look at the parser rules (PRs) now.

The concept of layers is such that once we reach layer ‘n’, we cannot apply rules of layers 1 to n-1. A layer can have one or more rules. The rules in a given layer can be applied in any order.

The first layer consists of six rules corresponding to the six labels that the nodes can take during the generation mechanism in VGG. These six can be applied in any order to give us all possible graphs with all possible combinations of node-labels. Here we combine all these six rules into a single rule for optimizing the space. The square bracket in the below rule indicates ‘or’ i.e., the label ‘e’ in LHS can be replaced with any one of the labels listed between the square brackets in the RHS.

Table 2. PRs Layer 1, Rules 1 to 6

LHS	RHS
○1:e	1:[p,q,r,s,u,v]○

An important point to note here is that the parser, like any graph transformational system, can take multiple paths in the process of transformation. Even if one of these paths ends at the start graph of generative grammar of VGG, the parsed graph is said to be derivable in our system i.e., it would be generated by the generative rules of VGG.

The second layer is about ultimate differentiator (v). Wherever it is found, we will just delete it. This layer has two rules which are applied on the TGs[7] of first layer. Again, representing both these rules together for parsimony purposes.

Table 3. PRs Layer 2, Rules 1 and 2

LHS	RHS
1:[p,r] ○←○ 2:v	1:[p,r]○

The above rule states whenever a ‘v’ is found in a ‘p’ (or ‘r’), just delete it. Its edges get deleted with it automatically since the grammar does not allow the possibility of dangling edges.

There are 3 NACs associated with this rule:

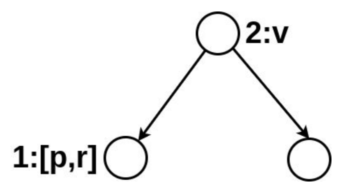
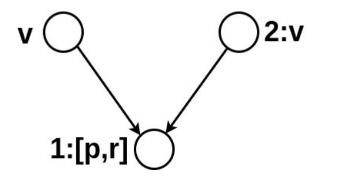
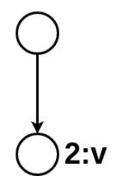
1. v should not inhere in any other node (when we say ‘v should not inhere’, we mean ‘v like structure should not inhere’. The parser makes sure of that!)

[7] TGs (Terminal Graphs) of a given layer are those graphs on which the rules of that particular layer are no more applicable. NTGs (Non-Terminal Graphs) of a given layer are those on which the rules of that particular layer can still apply.

2. No other v should inhere in this p (or r) in which this v is inhering.
3. Nothing should inhere in this v.

The anonymous nodes in NAC_1 and NAC_3 stand for any node, like in interpretation rules of VGG.

Table 4. PRs Layer 2, NACs of Rules 1 and 2

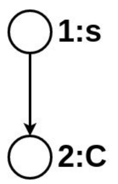
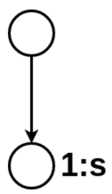
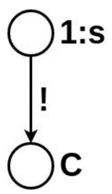
NAC_1	NAC_2	NAC_3
		

The next few layers (3 to 8) are about universals (s). We will look for the nodes corresponding to universals and remove them.

Layer 3 has only one rule. It checks if ‘s’ inheres in all Cs, and if yes, deletes ‘s’ directly. This rule has two NACs.

1. Nothing should inhere in this s.
2. It should inhere in every C i.e., there should be no C in which it is not inhering.

Table 5. PRs Layer 3, Rule 1 with NACs

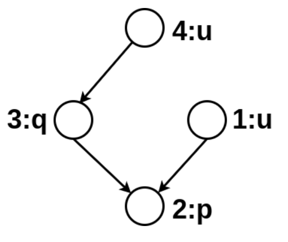
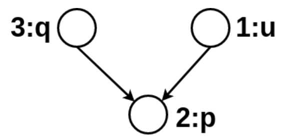
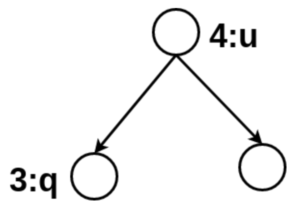
LHS	RHS	NAC_1	NAC_2
			

The exclamation mark (!) in NAC_2 indicates ‘not’ operator. So NAC_2 reads as ‘1:s not inhering in C’. So if NAC_2 is true i.e., if there is a C in which 1:s does not inhere, then the rule will not be applicable.

The layers 4 to 8 are quite similar to layer 3, except that ‘C’ is replaced by ‘D’ (for disjunct), ‘p’ (for MUS), ‘q’ (for SW), ‘r’ (for UUS), ‘u’ (for Q) respectively in each layer. So not listing those layers separately here.

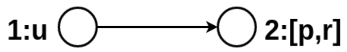
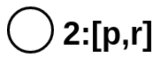
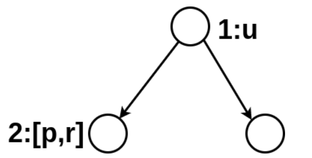
Layer 9 deals with the deletion of quality (u) from a substantial whole (q). It has only one rule which says that while a quality (u) is inhering in a MUS (p), and another quality (u) inhering in a substantial whole (q), remove the quality from SW under the condition that this quality (u) does not inhere anywhere else (this condition constitutes the unique NAC of this rule).

Table 6. PRs Layer 9, Rule 1 with NAC

LHS	RHS	NAC_1
		

Layer 10 deals with the deletion of quality (u) from MUS (p) and UUS (r). Actually both these are separate rules, but combined into one for parsimony purpose. The combined rule is presented below.

Table 7. PRs Layer 10, Rules 1 and 2 with NAC

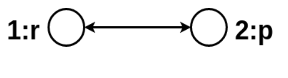
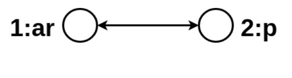
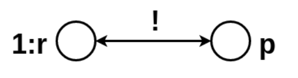
LHS	RHS	NAC_1
		

So the rule in layer 10 states that remove quality (u) from MUS (p) or UUS (r) under the condition that it does not inhere anywhere else (the condition that constitutes the unique NAC of this rule).

The next layer i.e., layer 11 has two rules which deal with deleting the contacts among MUSs (p) and UUSs (r). Since UUSs (r) should be in contact (or in disjunct, which will be handled in the next layer) with ALL the MUSs (p) we need to check if that condition is satisfied or not. But since we are not using logical quantifiers like universal quantifier or existential quantifier, we need to rely on some other technique to verify that condition. One simple method we would use is to rename ‘r’ to ‘ar’ if it is in contact with all the ‘p’s. Then we would delete the contacts among ‘ar’s and ‘p’s one by one. At the end, we would rename ‘ar’ back to ‘r’ to accommodate the rest of the rules based on ‘r’ (this rule would be part of layer 13).

The first rule of this layer renames ‘r’ to ‘ar’ if ‘r’ is in contact with all the ‘p’s. One way to do this is to make sure that there is no ‘p’ with which it is not in contact (this condition constitutes the unique NAC of this rule).

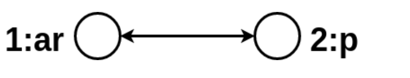
Table 8. PRs Layer 11, Rule 1 with NAC

LHS	RHS	NAC_1
		

Please note that the ‘p’ in RHS is mapped to the ‘p’ in LHS (with the number ‘2’) whereas the ‘p’ in NAC_1 is not mapped to the ‘p’ in LHS (with any number). This is to indicate that the ‘r’ in LHS should not be in non-contact with *any* ‘p’, not just the particular ‘p’ which is under consideration in the LHS. Hence it is not restricted by mapping it to the ‘p’ in LHS with a number.

While the first rule of this layer is mostly a verification condition, the second rule is where the actual action happens. This rule states that the contact between ‘ar’ and ‘p’ should be deleted one by one. This rule is run till the end, until there are no more contacts between any pair of ‘ar’ and ‘p’. It has no NACs associated with it.

Table 9. PRs Layer 11, Rule 2

LHS	RHS
	

Layer 12 is very similar to layer 11 except that contact should be replaced by disjunct here everywhere in the rules. The way contacts between ‘r’s and ‘p’s are removed in layer 11, in the same way disjuncts will be removed between ‘r’s and ‘p’s in layer 12. Other than that, everything is same in both the layers. So not listing layer 12 and its rules separately, and moving on to layer 13 directly.

Layer 13 has only one rule - to rename all ‘ar’s back to ‘r’s to continue with the process of parsing and enabling the application of rules based on the label ‘r’. This will be applicable only on the TGs of layer 12. It has no NACs.

Table 10. PRs Layer 13, Rule 1

LHS	RHS
	

The remaining rules are not being presented here due to space constraints. For the full list of PRs, one can refer to [15].

4. Results and Conclusion

Using this parser, we tested around 100k graphs (98,634 to be precise) generated by the generative rules of VGG and found that every single one of them is a derivable graph (because the parser could parse each one of them and found at least one path where it landed up at the start graph). We then manually gave some graphs as input to the parser which, we know, are not generated by the GRs of VGG. As expected, they are classified as non-derivable graphs by this parser. This shows that the parser is powerful enough to differentiate the graphs generated by the GRs of VGG from those not generated by it.

But our goal is something bigger. We need to also ensure that these graphs generated by GRs are actually Vaiśeṣika graphs and not some arbitrary graphs. In other words, are they interpretable in terms of Vaiśeṣika categories, and if yes, how to verify that.

We interpreted each of these 100k graphs using our IRs and found that every single node of it being labeled with one of the Vaiśeṣika categories. Around 4 million nodes (3,886,374 nodes, to be precise) are labeled. To validate this labeling, we checked for the correspondence between the generative labels (like p,q,r etc.) and the interpretation labels (like UD, MUS, UUS etc.) and found that there is a one-to-one correspondence between the labels presented in the following pairs: (p, MUS), (q, SW), (r, UUS), (s, U), (u, Q), (v, UD). This is a resounding (statistical) proof of the soundness of the system - that every graph generated by the GRs of VGG is a valid Vaiśeṣika graph!

Using both the above results - (1) Given an input graph, with its structure alone, the parser can classify if it is derivable i.e., generated by the GRs of the system or not, and (2) All the graphs generated by the system are valid Vaiśeṣika graphs - one can actually verify whether an input graph is a valid Vaiśeṣika graph or not. This, in itself, is a significant result from an ontology engineering perspective since distinction of valid state-of-affairs from invalid ones is immensely useful for many rich applications like semantic search, machine translation, object recognition, text summarization etc.

But we have a long way to go before we build such applications. The work presented here formalizes a very small, but foundational, portion of reality, and we need to formalize much larger portions of reality to make such complex applications possible. We are working in that direction, and hope this work also encourages others to look at the possibility of generative ontology more seriously.

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