Ontologos

Robert E. Kent

References

[1980] Robert E. Kent. *Category Theory and Algebra Applied to Dynamic Systems.* PhD thesis, University of California at Los Angeles, 1980.

> **Abstract:** This thesis initiates a categorical study of feedback design.

[1984] Robert E. Kent. Paths in trees: Greatest fixpoints and distributive laws. In *The Midwest Theory of Computation Symposium*, Chicago, Illinois, 1984.

[1984a] Robert E. Kent. Observational equivalence of concurrent processes is the kernel of a morphism of abstract tree datatypes. In *Proceedings of the International Computer Symposium*, Taipei, Taiwan, 1984.

[1987] Robert E. Kent. The metric closure powerspace construction. *Lecture Notes in Computer Science*, 298:173–199, April 1987. Proceedings of the third workshop on the Mathematical Foundations of Programming Language Semantics.

> **Abstract:** In this paper we develop a natural powerobject construction in the context of enriched categories, a context which generalizes the traditional order-theoretic and metric space contexts. This powerobject construction is a subobject transformer involving the dialectical flow of closed subobjects of enriched categories. It is defined via factorization of a comprehension schema over metrical predicates, followed by the fibrational inverse image of metrical predicates along character, the left adjoint in the comprehension schema. A fundamental continuity property of this metrical powerobject construction vis-a-vis greatest fixpoints is established by showing that it preserves the limit of any *Cauchy* ω^{op}*-diagram*. Using this powerobject construction we unify two well-known fixpoint semantics for concurrent interacting processes.

[1987a] Robert E. Kent. Introduction to dialectical nets. *Proceedings of the 25th Allerton Conference on Communication, Control, and Computing*, pages 1204–1213, October 1987.

> **Abstract:** This paper initiates the dialectical approach to net theory. This approach views nets as special, but very important and natural, dialectical systems. By following this approach, a suitably generalized version of nets, called *dialectical nets*, can be defined in terms of the "fundamental contradiction" inherent in the structure of *closed preorders*. Dialectical nets are the least conceptual upper bound subsuming the notions of Petri nets, Kan quantification and transition systems. The nature of dialectical nets is that of logical dynamics, and is succinctly defined and summarized in the statement that "dialectical nets are transition systems relativized to closed preorders, and hence are general predicate transformers".

[1988] Robert E. Kent. The logic of dialectical processes. In *The fourth workshop on the Mathematical Foundations of Programming Language Semantics*, University of Colorado, Boulder, 1988. Technical report, Digital Systems Laboratory, Helsinki University of Technology, Helsinki, Finland (1989).

[1989] Robert E. Kent. The standard aspect of dialectical logic. In *The 1st International Conference on Algebraic Methodology and Software Technology (AMAST'89)*, University of Iowa, Iowa City, Iowa, 1989. Accepted for presentation.

> **Abstract:** *Dialectical logic* is the logic of dialectical processes. The goal of dialectical logic is to introduce dynamic notions into logical computational systems. The fundamental notions of *proposition* and *truth-value* in standard logic are subsumed by the notions of *process* and *flow* in dialectical logic. Dialectical logic has a standard aspect, which can be defined in terms of the "local cartesian closure" of subtypes. The standard aspect of dialectical logic provides a natural program semantics which incorporates Hoare's precondition/postcondition semantics and extends the standard Kripke semantics of dynamic logic. The goal of the standard aspect of dialectical logic is to unify the logic of small-scale and large-scale programming.

[1990] Robert E. Kent. Processes as 2-dimensional relational structures. In *The sixth workshop on the Mathematical Foundations of Programming Semantics*, Queens University, Kingston, Ontario, 1990.

[1992] Robert E. Kent. Adjointness in foundations. In *The 1992 Conference of the Western Social Science Association*, Denver, Colorado, 1992.

[1993] Robert E. Kent. Object-oriented software for the analysis of conceptual hierarchies in thesauri. In *Proceedings of the 1993 Symposium on Applied Computing (SAC'93)*, The Indiana Convention Center, Indianapolis, Indiana, February 1993.

[1993a] Robert E. Kent. Rough concept analysis. *Workshops in Computing: Rough Sets, Fuzzy Sets and Knowledge Discovery*, 1994. Conference Proceedings of the International Workshop on Rough Sets and Knowledge Discovery (RSKD'93).

> **Abstract:** The theory introduced, presented and developed in this paper, is concerned with Rough Concept Analysis. This theory is a synthesis of the theory of Rough Sets pioneered by Zdzislaw Pawlak with the theory of Formal Concept Analysis pioneered by Rudolf Wille. The theory of Rough Sets is used to model imprecise or incomplete knowledge and approximate classification. The theory of Formal Concept Analysis is used for data modeling, analysis and interpretation, and also for knowledge representation and knowledge discovery via the special technique of attribute exploration or the more general technique of concept exploration. The theory developed in this paper concerning Rough Concept Analysis, using ideas from type theory and the logical calculus of relations, provides an "approximation theory" for knowledge representation and knowledge discovery.

[1993b] Robert E. Kent and John Brady. Formal concept analysis with many-sorted attributes. In *Proceedings of the Fifth International Conference on Computing and Information (ICCI'93)*, pages 349–353, Sudbury, Ontario, Canada, May 1993. IEEE Computer Society Washington, DC, USA.

> **Abstract:** This paper unites two problem-solving traditions in computer science: (1) constraint-based reasoning; and (2) formal concept analysis. For basic definitions and properties of networks of constraints, we follow the foundational approach of Montanari and Rossi. This paper advocates distributed relations as a more semantic version of networks of constraints. The theory developed here uses the theory of formal concept analysis pioneered by R. Wille and his colleagues, as a key for unlocking the hidden semantic structure within distributed relations. Conversely, this paper offers distributed relations as a seamless many-sorted extension to the formal contexts of formal concept analysis

[1993c] Robert E. Kent. Dialectical logic: The process calculus. *Studia Scientiarum Mathematicarum Hungarica*, 28(1–2):17–61, 1993. Invited paper.

> **Abstract:** *Dialectical logic* is the logic of dialectical processes. The goal of dialectical logic is to reveal the dynamical notions inherent in logical computational systems. The fundamental notions of *proposition* and *truth-value* in standard logic are subsumed by the notions of *process* and *flow* in dialectical logic. Standard logic motivates the core sequential aspect of dialectical logic. Horn-clause logic requires types and nonsymmetry and also motivates the parallel aspect of dialectical logic. The process logics of Milner and Hoare reveal the internal/external aspects of dialectical logic. The sequential internal aspect of dialectical logic should be viewed as a typed or distributed version of Girard's linear logic with nonsymmetric tensor. The simplest version of dialectical logic is inherently intuitionistic. However, by following Glivenko's approach in standard logic using double negation closure, we can define a classical version of dialectical logic.

[1994] Robert E. Kent. Rough concept analysis: a synthesis of rough sets and formal concept analysis. *Fundamenta Informaticae*, 27(2,3):169–181, 1996.

> **Abstract:** The theory introduced, presented and developed in this paper, is concerned with Rough Concept Analysis. This theory is a synthesis of the theory of Rough Sets pioneered by Zdzislaw Pawlak with the theory of Formal Concept Analysis pioneered by Rudolf Wille. The central notion in this paper of a *rough formal concept* combines in a natural fashion the notion of a rough set with the notion of a formal concept — to use a slogan: "rough set + formal concept = rough formal concept". This paper is an extension of the paper [1993a] presented at the international workshop on Rough Sets and Knowledge Discovery (RSKD'93). A related paper [1994a] using distributed constraints provides a synthesis of the two important data

modeling techniques: conceptual scaling of Formal Concept Analysis, and Entity-Relationship database modeling. A follow-up paper will extend rough concept analysis from formal contexts to distributed constraints.

[1994a] Robert E. Kent, F. Vogt, and R. Wille. Data modeling with constraints. This unwritten paper was to be based upon a series of lectures given by the first author to the Research Group in Formal Concept Analysis at the Technische Hochschule in Darmstadt, Germany, in the summer of 1993, when the first author was on a guest researchership there., 1994.

[1994b] Robert E. Kent. Enriched interpretation. In T.Y. Lin, editor, *Conference Proceedings of the Third International Workshop on Rough Sets and Soft Computing (RSSC'94)*, pages 116–123, San Jose State University, San Jose, California, USA, November 1994.

[1994c] Robert E. Kent. Enriched interpretation. In T.Y. Lin and A.M. Wildberger, editors, *Soft Computing: Third International Workshop on Rough Sets and Soft Computing (RSSC'94)*, pages 227–230. The Society for Computer Simulation, 1995.

Abstract: The theory introduced, presented and developed in this paper, is concerned with an enriched extension of the theory of Rough Sets pioneered by Zdzislaw Pawlak. The enrichment discussed here is in the sense of valuated categories as developed by F.W. Lawvere. This paper relates Rough Sets to an abstraction of the theory of Fuzzy Sets pioneered by Lotfi Zadeh, and provides a natural foundation for *soft computation*. To paraphrase Lotfi Zadeh, the impetus for the transition from a hard theory to a soft theory derives from the fact that both the generality of a theory and its applicability to real-world problems are substantially enhanced by replacing the various hard concepts with their soft counterparts. Here we discuss the corresponding enriched notions for indiscernibility, subsets, upper/lower approximations, and rough sets. Throughout, we indicate linkages with the theory of Formal Concept Analysis pioneered by Rudolf Wille. We pay particular attention to the all-important notion of a *linguistic variable* — developing its enriched extension, comparing it with the notion of conceptual scale from Formal Concept Analysis, and discussing the pragmatic issues of its creation and use in the interpretation of data.

[1994d] Robert E. Kent and Christian Neuss. Creating a Web Analysis and Visualization Environment. *Computer Networks and ISDN Systems*, 28:109–117, 1995. Also appears in the Electronic Proceedings of the Second International World Wide Web (WWW) Conference'94.

Abstract: Due to the rapid growth of the World-Wide Web, resource discovery has become an increasing problem. As an answer to the demand for information management, a third generation of World-Wide Web tools will evolve: information gathering and processing agents. This paper describes wave (Web Analysis and Visualization Environment), a 3D interface for World-Wide Web information visualization and browsing. It uses the mathematical theory of concept analysis to conceptually cluster objects. So-called "conceptual scales" for attributes, such as location, TITLE, keywords, topic, size, or modification time, provide a formal mechanism that automatically classifies and categorizes documents, creating a conceptual information space. A visualization shell serves as an ergonomically sound user interface for exploring this information space.

[1994e] Robert E. Kent. Implications and rules in thesauri. In *Knowledge Organization and Quality Management: Proceedings of the Third International ISKO Conference, 20–24 June 1994, Copenhagen, Denmark*, pages 154–160. INDEKS Verlag, Frankfurt/Main, 1994.

Abstract: A central consideration in the study of whole-language semantic space as encoded in thesauri is word-sense comparability. In this paper we show how word-sense comparability can be adequately expressed by the logical implications and rules from Formal Concept Analysis. Formal Concept Analysis, a new approach to formal logic initiated by Rudolf Wille, has been used for data modeling, analysis and interpretation, and also for knowledge representation and knowledge discovery [1993a]. We here demonstrate how Formal Concept Analysis can provide a principled approach to the study of rule generation in whole-language semantic space as encoded in thesauri.

[1995] Christian Neuss and Robert E. Kent. Conceptual analysis of resource meta-information. *Computer Networks and ISDN Systems*, 27:973–984, 1995. Also appears in the Electronic Proceedings of the Third International World Wide Web (WWW) Conference'95.

Abstract: With the continuously growing amount of Internet accessible information resources, locating relevant information in the World-Wide Web becomes increasingly difficult. Recent developments provide scalable mechanisms for maintaining indexes of network-accessible information. In order to implement sophisticated retrieval engines, a means of automatic analysis and classification of document meta-information has to be found. We propose the use of methods from the mathematical theory of concept analysis to analyze and interactively explore the information space defined by wide-area resource discovery services.

[1995a] Robert E. Kent and C. Mic Bowman. Digital libraries, conceptual knowledge systems, and the nebula interface. Technical report, Transarc Corporation, Pittsburgh, Pennsylvania, April 1995.

Abstract: Concept Analysis provides a principled approach to effective management of wide area information systems, such as the Nebula File System and Interface. This not only offers evidence to support the assertion that a digital library is a bounded collection of incommensurate information sources in a logical space, but also sheds light on techniques for collaboration through coordinated access to the shared organization of knowledge.

[1995b] Robert E. Kent. Automatic Classification. Technical report: Invited Intel survey paper, Intel Corporation, Hillsboro, Oregon, March 1995. Surveys classification from the standpoint of historical origins, logical foundations, and centers of excellence.

Abstract: Classification is an effective way to organize the knowledge in private, collaborative, and global information spaces. Both information retrieval and collaborative work require an effective organization of knowledge.

[1996] Robert E. Kent and Christian Neuss. Web conceptual space. In *Proceedings of WebNet'96, the World Conference of the WWW, Internet, and Intranet*, 1996. CD-ROM.

[1997] Robert E. Kent and Christian Neuss. Content is key: Viewing conceptualized content. In *Proceedings of WebNet'97, the World Conference of the WWW, Internet and Intranet*, 1997. CD-ROM.

[1997a] Robert E. Kent and Christian Neuss. Conceptual analysis of hypertext. In Charles Nicholas and James Mayfield, editors, *Intelligent Hypertext: Advanced Techniques for the World Wide Web*, volume 1326 of *Lecture Note Computer Science*, pages 70–89. Springer, 1997. Invited chapter.

Abstract: In this chapter tools and techniques from the mathematical theory of formal concept analysis are applied to hypertext systems in general, and the World Wide Web in particular. Various processes for the conceptual structuring of hypertext are discussed: summarization, conceptual scaling, and the creation of conceptual links. Well-known interchange formats for summarizing networked information resources as resource meta-information are reviewed, and two new interchange formats originating from formal concept analysis are advocated. Also reviewed is conceptual scaling, which provides a principled approach to the faceted analysis techniques in library science classification. The important notion of conceptual linkage is introduced as a generalization of a hyperlink. The automatic hyperization of the content of legacy data is described, and the composite conceptual structuring with hypertext linkage is defined. For the conceptual empowerment of the Web user, a new technique called conceptual browsing is advocated. Conceptual browsing, which browses over conceptual links, is dual mode (both extensional and intensional) and dual scope (both global and local).

[1997b] Jeffrey Olson and Robert E. Kent. Conceptual Knowledge Markup Language, an XML application. Technical report, Washington State University, 1997. Unpublished presentation, given at the XML Developers Day, August 21, 1997, Montreal, Canada.

[1998] Robert E. Kent. Organizing conceptual knowledge online: Metadata interoperability and faceted classification. In Widad Mustafa el Hadi, Jacques Maniez, and Steven Pollitt, editors, *Structures and Relations in Knowledge Organization: Proceedings of the Fifth International ISKO Conference, Lille, 25–29 August 1998*, volume 6 of *Advances in Knowledge Organization*, pages 388–395. ERGON Verlag, W'urzburg, August 1998.

Abstract: Conceptual Knowledge Markup Language (CKML), an application of (XML), is a new standard being proposed for the specification of online conceptual knowledge (Kent and Shrivastava, "Metadata Interoperability: A Conceptual Knowledge Processing Perspective"). CKML follows the philosophy of Wille's Conceptual Knowledge Processing, a principled approach to knowledge representation and data analysis, which advocates the development of

methodologies and technologies to support people in their rational thinking, judgement and actions. CKML was developed and is being used in the WAVE networked information discovery and retrieval system (Kent and Neuss [1994d]) as a standard for the specification of conceptual knowledge.

[1999] Robert E. Kent. Soft concept analysis. In Sankar K. Pal and Andrzej Skowron, editors, *Rough-Fuzzy Hybridization: New Trend in Decision-Making*, pages 215–232. Springer-Verlag, Singapore, June 1999.

Abstract: In this chapter we discuss soft concept analysis, a study which identifies an enriched notion of *conceptual scale* as developed in formal concept analysis with an enriched notion of *linguistic variable* as discussed in fuzzy logic. The identification *enriched conceptual scale* ≡ *enriched linguistic variable* was made in a previous paper [1994b]. In this chapter we offer further arguments for the importance of this identification by discussing the philosophy, spirit, and practical application of conceptual scaling to the discovery, conceptual analysis, interpretation, and categorization of networked information resources. We argue that a linguistic variable, which has been defined at just the right generalization of valuated categories, provides a natural definition for the process of soft conceptual scaling. This enrichment using valuated categories models the relation of indiscernability, a notion of central importance in rough set theory. At a more fundamental level for soft concept analysis, it also models the derivation of formal concepts, a process of central importance in formal concept analysis. Soft concept analysis is synonymous with enriched concept analysis. From one viewpoint, the study of soft concept analysis that is initiated here extends formal concept analysis to soft computational structures. From another viewpoint, soft concept analysis provides a natural foundation for soft computation by unifying and explaining notions from soft computation in terms of suitably generalized notions from formal concept analysis, rough set theory and fuzzy set theory.

[1999a] Robert E. Kent. Conceptual Knowledge Markup Language: The central core. *Electronic Proceedings of the Twelfth Workshop on Knowledge Acquisition, Modeling and Management (KAW'99)*, 1999.

Abstract: The conceptual knowledge framework OML/CKML needs several components for a successful design [1999]. One important, but previously overlooked, component is the central core of OML/CKML. The central core provides a theoretical link between the ontological specification in OML and the conceptual knowledge representation in CKML. This paper discusses the formal semantics and syntactic styles of the central core, and also the important role it plays in defining interoperability between OML/CKML, RDF/S and Ontolingua.

[2000] Robert E. Kent. The information flow foundation for conceptual knowledge organization. In *Dynamism and Stability in Knowledge Organization*, volume 7 of *Advances in Knowledge Organization*, pages 111–117. Ergon Verlag, 2000. Proceedings of the Sixth International ISKO Conference.

Abstract: The sharing of ontologies between diverse communities of discourse allows them to compare their own information structures with that of other communities that share a common terminology and semantics — ontology sharing facilitates interoperability between online knowledge organizations. This paper demonstrates how ontology sharing is formalizable within the conceptual knowledge model of Information Flow (IF). Information Flow indirectly represents sharing through a specifiable, ontology extension hierarchy augmented with synonymic type equivalencing — two ontologies share terminology and meaning through a common generic ontology that each extends. Using the paradigm of participant community ontologies formalized as IF logics, a common shared extensible ontology formalized as an IF theory, participant community specification links from the common ontology to the participating community ontology formalizable as IF theory interpretations, this paper argues that ontology sharing is concentrated in a virtual ontology of community connections, and demonstrates how this virtual ontology is computable as the fusion of the participant ontologies — the quotient of the sum of the participant ontologies modulo the ontological sharing structure.

[2001] Robert E. Kent. An SUO-KIF formalization for the IFF category theory ontology. In *Workshop on the IEEE Standard Upper Ontology*, 2001. Cached online at: `http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.21.2072&rep=rep1&type=pdf`.

Abstract: This paper begins the discussion of how the Information Flow Framework can be used to provide a principled foundation for the metalevel (or structural level) of the Standard Upper Ontology (SUO). This SUO structural level can be used as a logical framework for manipulating collections of ontologies in the object level of the SUO or other middle level or domain ontologies.

From the Information Flow perspective, the SUO structural level resolves into several metalevel ontologies. This paper discusses a KIF formalization for one of those metalevel categories, the Category Theory Ontology.

[2002] Robert E. Kent. Distributed conceptual structures. In Harre de Swart, editor, *Sixth International Workshop on Relational Methods in Computer Science*, volume 2561 of *Lecture Notes in Computer Science*, pages 104–123. Springer, 2002.

Abstract: The theory of distributed conceptual structures, as outlined in this paper, is concerned with the distribution and conception of knowledge. It rests upon two related theories, Information Flow and Formal Concept Analysis, which it seeks to unify. Information Flow is concerned with the distribution of knowledge. The foundations of Information Flow are explicitly based upon the Chu Construction in *-autonomous categories and implicitly based upon the mathematics of closed categories. Formal Concept Analysis is concerned with the conception and analysis of knowledge. In this paper, we connect these two studies by categorizing the basic theorem of Formal Concept Analysis, thus extending it to the distributed realm of Information Flow. The main result is the representation of the basic theorem as a categorical equivalence at three different levels of functional and relational constructs. This representation accomplishes a rapprochement between Information Flow and Formal Concept Analysis.

[2002c] Robert E. Kent. The IFF approach to semantic integration. Invited talk (powerpoint presentation) hosted by Mike Uschold and given at the Boeing Mini-Workshop on Semantic Integration, 7 November 2002., 2005.

[2003] Robert E. Kent. The IFF foundation for ontological knowledge organization. In Nancy J. Williamson and Clare Beghtol, editors, *Knowledge Organization and Classification in International Information Retrieval*, volume 37 of *Cataloging & Classification Quarterly*, pages 187–203. Haworth, 2003. Invited chapter.

Abstract: This chapter discusses an axiomatic approach for the semantic integration of ontologies, an approach that extends to first order logic a previous approach [2000] based on information flow. This axiomatic approach is represented in the Information Flow Framework (IFF), a metalevel framework for organizing the information that appears in digital libraries, distributed databases and ontologies [IFF]. The paper argues that the semantic integration of ontologies is the two-step process of alignment and unification. Ontological alignment consists of the sharing of common terminology and semantics through a mediating ontology. Ontological unification, concentrated in a virtual ontology of community connections, is fusion of the alignment diagram of participant community ontologies — the quotient of the sum of the participant portals modulo the ontological alignment structure.

[2003a] Robert E. Kent. Semantic integration in the IFF. In AnHai Doan, Alon Halevy, and Natasha Noy, editors, *Semantic Integration 2003*, volume 82 of *CEUR Workshop Proceedings*. Sun SITE Central Europe (CEUR), 2003. Proceedings of the Semantic Integration Workshop at ISWC-03, Sanibel Island, Florida, USA, October 20, 2003.

Abstract: The IEEE P1600.1 Standard Upper Ontology (SUO) project aims to specify an upper ontology that will provide a structure and a set of general concepts upon which domain ontologies could be constructed. The Information Flow Framework [IFF], which is being developed under the auspices of the SUO Working Group, represents the structural aspect of the SUO. The IFF is based on category theory. Semantic integration of object-level ontologies in the IFF is represented with its fusion construction. The IFF maintains ontologies using powerful composition primitives, which includes the fusion construction.

[2004] Robert E. Kent. The Information Flow Framework: A descriptive category metatheory (`http://arxiv.org/abs/1108.4133`). In *International Category Theory Conference (CT 2004)*, 2004. Slides for the CT 2004 presentation located online: `http://suo.ieee.org/IFF/metastack/CT04%20Presentation.pdf`; See also `http://suo.ieee.org/IFF/metastack/CT04%20Paper.dvi`.

Abstract: The Information Flow Framework [IFF] is a descriptive category metatheory. It is an experiment in foundations, which follows a bottom-up approach to logical description. The IFF forms the structural aspect of the IEEE P1600.1 Standard Upper Ontology (SUO) project. The categorical approach of the IFF provides a principled framework for the modular design of object-level ontologies. The IFF represents metalogic, and as such operates at the structural level of ontologies. In the IFF, there is a precise boundary between the metalevel and

the object level. The modular architecture of the IFF consists of metalevels, namespaces and meta-ontologies. Each metalevel services the levels below by providing a metalanguage used to declare and axiomatize those levels. Corresponding to the metalevels are nested metalanguages, where each metalanguage axiomatization includes specialization of the one immediately above. Within each metalevel, the terminology is partitioned into namespaces, and various namespaces are collected together into meaningful composites called meta-ontologies. All of the various meta-ontologies in the IFF are anchored to the IFF metastack. The IFF development is largely driven by the principles of *conceptual warrant*, *categorical design* and *institutional logic*.

[2004a] Robert E. Kent. Semantic integration in the Information Flow Framework. In Y. Kalfoglou, M. Schorlemmer, A. Sheth, S. Staab, and M. Uschold, editors, *Semantic Interoperability and Integration*, number 04391 in Dagstuhl Seminar Proceedings, Dagstuhl, Germany, 2005. Internationales Begegnungs - und Forschungszentrum für Informatik (IBFI). Available online: `http://drops.dagstuhl.de/opus/frontdoor.php?source_opus=41`.

Abstract: The Information Flow Framework [IFF] is a descriptive category metatheory, which is being offered as the structural aspect of the Standard Upper Ontology (SUO). The architecture of the IFF is composed of metalevels, namespaces and meta-ontologies. The main application of the IFF is institutional: the notion of institutions and their morphisms are being axiomatized in the upper metalevels of the IFF, and the lower metalevel of the IFF has axiomatized various institutions in which semantic integration has a natural expression as the colimit of theories.

[2005] Robert E. Kent. Truth factors. Preprint, 2005.

Abstract: Tarski's semantic definition of truth is the composition of its extensional and intensional aspects. Abstract satisfaction, the core of the semantic definition of truth, is the basis for the theory of institutions. The satisfaction relation for first order languages (the truth classification), and the preservation of truth by first order interpretations (the truth infomorphism), form a key motivating example in the theory of Information Flow (IF). The concept lattice notion, which is the central structure studied by the theory of Formal Concept Analysis (FCA), is constructed by the polar factorization of derivation. The study of classification structures (IF) and the study of conceptual structures (FCA) provide a principled foundation for the logical theory of knowledge representation and organization. In an effort to unify these two areas, the paper "Distributed Conceptual Structures" [2002] abstracted the basic theorem of FCA in order to established three levels of categorical equivalence between classification structures and conceptual structures. In this paper, we refine this approach by resolving the equivalence as the category-theoretic factorization of the Galois connection of derivation. The equivalence between classification and conceptual structures is mediated by the opposite motions of factorization and composition. Abstract truth factors through the concept lattice of theories in terms of its extensional and intensional aspects.

[2005a] Robert E. Kent. The characterization of abstract truth and its factorization. Preprint, 2005.

Abstract: Human knowledge is made up of the conceptual structures of many communities of interest. In order to establish coherence in human knowledge representation, it is important to enable communcation between the conceptual structures of different communities The conceptual structures of any particular community is representable in an ontology. Such a ontology provides a formal linguistic standard for that community. However, a standard community ontology is established for various purposes, and makes choices that force a given interpretation, while excluding others that may be equally valid for other purposes. Hence, a given representation is relative to the purpose for that representation. Due to this relativity of representation, in the larger scope of all human knowledge it is more important to standardize methods and frameworks for relating ontologies than to standardize any particular choice of ontology. The standardization of methods and frameworks is called the semantic integration of ontologies. "Truth Factors" [2005], makes two advances: it develops the notion of the lattice of theories (LOT) facterization, and it offers an order-enriched axiomatization that characterizes conceptual structures and the lattice of theories.

[2005b] Robert E. Kent. Conceptua: Institutions in a topos. Preprint, 2005.

Abstract: This paper gives the theory of institutions in a topos. By varying the base topos, we get institutions that represent fuzzy sets, temporal structures, etc.

[2005c] Robert E. Kent. The Information Flow Framework (IFF). Invited talk (powerpoint presentation) given at LISTIC, Laboratoire d'Informatique, Systèmes, Traitement de l'Information et de la Connaissance., 2005.

[2006] Robert E. Kent. The Information Flow Framework: New architecture. In *International Category Theory Conference (CT 2006) at White Point, Nova Scotia, June 25 - July 1, 2006.*, 2006. Slides for the CT 2006 presentation located online: `http://www.mscs.dal.ca/~selinger/ct2006/slides/CT06-Kent.pdf`.

Abstract: This presentation discusses a new, modular, more mature architecture for the Information Flow Framework (IFF). The IFF uses institution theory as a foundation for the semantic integration of ontologies. It represents metalogic, and as such operates at the structural level of ontologies. The content, form and experience of the IFF could contribute to the development of a standard ontology for category theory. The foundational aspect of the IFF helps to explain the relationship between the fundamental concepts of set theory and category theory. The development of the IFF follows two design principles: conceptual warrant and categorical design. Both are limitations of the logical expression. Conceptual warrant limits the content of logical expression, by requiring us to justify the introduction of new terminology (and attendant axiomatizations). Categorical design limits the form of logical expression (of all mathematical concepts and constraints) to atomic expressions: declarations, equations or relational expressions. The IFF is a descriptive category metatheory. It is descriptive, since it follows the principle of conceptual warrant; it is categorical, since it follows the principle of categorical design; and it is a metatheory, since it provides a framework for all theories.

[2008] Robert E. Kent. The institutional approach. In Roberto Poli, Michael Healy, and Achilles Kameas, editors, *Theory and Applications of Ontology: Computer Applications*, volume 2, chapter 23, pages 533–563. Springer, 2010. Invited chapter.

Abstract: This chapter discusses the institutional approach for organizing and maintaining ontologies. The theory of institutions was named and initially developed by Joseph Goguen and Rod Burstall. This theory, a metatheory based on category theory, regards ontologies as logical theories or local logics. The theory of institutions uses the category-theoretic ideas of fibrations and indexed categories to develop logical theories. Institutions unite the lattice approach of Formal Concept Analysis of Ganter and Wille with the distributed logic of Information Flow of Barwise and Seligman. The institutional approach incorporates locally the lattice of theories idea of Sowa from the theory of knowledge representation. The Information Flow Framework, which was initiated within the IEEE Standard Upper Ontology project, uses the institutional approach in its applied aspect for the comparison, semantic integration and maintenance of ontologies. This chapter explains the central ideas of the institutional approach to ontologies in a careful and detailed manner.

[2008a] Robert E. Kent. Distributed logic: Information flow in logical environments. Preprint, 2008.

Abstract: The information integration in distributed systems of ontologies or databases (see "Semantic Integration in the Information Flow Framework" [2004a]) can be abstractly defined in any logical environment. The central notion in such information integration is the logical closure over distributed systems. One of the central problems in distributed systems is to understand how diverse parts of the system logically and semantically affect one another. This paper solves this problem at the abstract level of logical environments in terms of the information flow within the closure of an information system. Here we introduce distributed logic, which involves information flow within logical environments. Logical environments are a semantic-oriented version of institutions. The theory of institutions, which was initiated by Goguen and Burstall, is abstract model theory. The theory of information flow, the logic of distributed systems, was first defined by Barwise and Seligman. Information flow is the flow of information in channels over distributed systems. The semantic integration of distributed systems, be they ontologies, databases or other information resources, can be defined in terms of the channel theory of information flow. As originally defined, the theory of information flow used only a very specific logical environment. This paper shows how information flow can be defined in an arbitrary logical environment.

[2009] Robert E. Kent. System consequence. In S. Rudolph, F. Dau, and S. Kuznetsov, editors, *Conceptual Structures: Leveraging Semantic Technologies*, volume 5662 of *Lecture Notes in Computer Science*, pages 201–218. Springer, 2009. The Proceedings of the 17th International Conference on Conceptual Structures (ICCS 2009), Moscow, Russia. Slides for the ICCS 2009 presentation located online: `http://www.hse.ru/data/708/792/1224/system-consequence_Robert_E_Kent.pdf`.

Abstract: This paper discusses system consequence, a central idea in the project to lift the theory of information flow to the abstract level of universal logic and the theory of institutions. The theory of information flow is a theory of distributed logic. The theory of institutions is abstract model theory. A system is a collection of interconnected parts, where the whole may have properties that cannot be known from an analysis of the constituent parts in isolation. In an information system, the parts represent information resources and the interconnections represent constraints between the parts. System consequence, which is the extension of the consequence operator from theories to systems, models the available regularities represented by an information system as a whole. System consequence (without part-to-part constraints) is defined for a specific logical system (institution) in the theory of information flow. This paper generalizes the idea of system consequence to arbitrary logical systems.

[2010] Robert E. Kent. The architecture of truth. Preprint, 2010.

Abstract: The theory of institutions is framed as an indexed/fibered duality, where the indexed aspect specifies the fibered aspect. Tarski represented truth in terms of a satisfaction relation. The theory of institutions encodes satisfaction as its core architecture in the indexed aspect. Logical environments enrich this truth architecture by axiomatizing the truth adjunction in the fibered aspect. The truth architecture is preserved by morphisms of logical environments. not every institution is a logical environment, each institution has an associated logical environment defined via the intent of the structures of the institution, and each institution is represented by an indexed functor into the structure category of the classification logical environment `Cls`.

[2011] Robert E. Kent. Database semantics. Preprint, 2011.

Abstract: This paper, the first step to connect relational databases with systems consequence (Kent [2009]), is concerned with the semantics of relational databases. It aims to to study system consequence in the logical/semantic system of relational databases. The paper, which was inspired by and which extends a recent set of papers on the theory of relational database systems (David I. Spivak "Simplicial Databases" (`http://arxiv.org/abs/0904.2012`) and "Functorial Data Migration" (`http://arxiv.org/abs/1009.1166`)), is linked with work on the Information Flow Framework (IFF [IFF]) connected with the ontology standards effort (SUO), since relational databases naturally embed into first order logic. The database semantics discussed here is concerned with the conceptual level of database architecture. We offer both an intuitive and technical discussion. Corresponding to the notions of primary and foreign keys, relational database semantics takes two forms: a distinguished form where entities are distinguished from relations, and a unified form where relations and entities coincide. The distinguished form corresponds to the theory presented in (Spivak "Simplicial Databases"). The unified form, a special case of the distinguished form, corresponds to the theory presented in (Spivak "Functorial Data Migration"). A later paper will discuss various formalisms of relational databases, such as relational algebra and first order logic, and will complete the description of the relational database logical environment.

[2011a] David I. Spivak and Robert E. Kent. Ologs: a categorical framework for knowledge representation. *PLoS ONE*, 2011. Accepted for publication.

Abstract: In this paper we introduce the olog, or ontology log, a category-theoretic model for knowledge representation (KR). Grounded in formal mathematics, ologs can be rigorously formulated and cross-compared in ways that other KR models (such as semantic networks) cannot. An olog is similar to a relational database schema; in fact an olog can serve as a data repository if desired. Unlike database schemas, which are generally difficult to create or modify, ologs are designed to be user-friendly enough that authoring or reconfiguring an olog is a matter of course rather than a difficult chore. It is hoped that learning to author ologs is much simpler than learning a database definition language, despite their similarity. We describe ologs carefully and illustrate with many examples. As an application we show that any primitive recursive function can be described by an olog. We also show that ologs can be aligned or connected together into a larger network using functors. The various methods of information flow and institutions can then be used to integrate local and global world-views. We finish by providing several different avenues for future research.

[IFF] IFF Editorial Committee. The Information Flow Framework (IFF). In *Starter Documents*. IEEE P1600.1 Standard Upper Ontology Working Group (SUO WG), 2001. The IFF is described and discussed in the presentations [2004] and [2006]. Site address: `http://suo.ieee.org/IFF/`.

[IFF:ARCH] Robert E. Kent. The IFF architecture. Technical report, Standard Upper Ontology Working Group (SUO WG), September 2006. Available online: `http://suo.ieee.org/IFF/architecture.html`.

Abstract: This document discusses the modular architecture of the IFF, separated vertically into metashell, natural part and object levels. It briefly discusses the natural part, separated horizontally into pure and applied aspects, with the pure aspect separated into core and structural components. It also dicusses the design goals and principles of the IFF, its logical expression, and the transitional connection with an older architecture.

[IFF:DEV] Robert E. Kent. The IFF development. Technical report, Standard Upper Ontology Working Group (SUO WG), October 2007. Available online: `http://suo.ieee.org/IFF/notes/development.html`.

Abstract: This document discusses various aspects of the IFF development, starting from the initial IFF ontology axiomatizing category theory, the development of (i) the IFF modular structure, (ii) the IFF design principles, and (iii) a simple KIF-like logical language with EBNF grammar, and ending with the transition from an old to a new architecture for the IFF.

[IFF:EBNF] Robert E. Kent. The IFF grammar. Technical report, Standard Upper Ontology Working Group (SUO WG), February 2006. Available online: `http://suo.ieee.org/IFF/grammar.html`.

Abstract: This document discusses the IFF grammar. The IFF language (or logical notation), which is a vastly simplified and modified version of KIF, also has a LISP-like format. The IFF language contains both logical code and comments. Both nested namespaces and metalevels are specified by prefixes. The IFF grammar which specifies the syntax of the IFF language, is written in Extended Backus Naur Form (EBNF).

[IFF:INS] Robert E. Kent. The IFF Institution (meta) Ontology (IFF-INS). Technical report, Standard Upper Ontology Working Group (SUO WG), October 2004. Available online: `http://suo.ieee.org/IFF/work-in-progress/INS/version20041014.pdf`.

Abstract: Institutions formalize the intuitive notion of an abstract logical system. This includes syntax, semantics and satisfaction. For more information, see any paper listed on the Theory of Institutions web page, such as the paper Institutions: Abstract Model Theory for Specification and Programming by Goguen and Burstall. Possibly every researcher in the theory of logic has used institutions either directly or indirectly, whether consciously or not. The first person to use institutions was Tarski. However, he did not view these abstractly and did not use morphisms either within or without. The discoverers of institutions were Goguen and Burstall.

[IFF:LOT] Robert E. Kent. The IFF approach to the lattice of theories (LOT). Technical report, Standard Upper Ontology Working Group (SUO WG), April 2003. Available online: `http://suo.ieee.org/IFF/work-in-progress/LOT/lattice-of-theories.pdf`.

Abstract: This document discusses the lattice of theories (LOT) construction of Sowa, and its connection with entailment order and the truth concept lattice. It situates the lattice of theories within the category of theories. The LOT describes a modular framework for ontologies. According to John Sowa, the various methods used in nonmonotonic logic and the operators for belief revision correspond to movement through the LOT.

[IFF:META] Robert E. Kent. The IFF metashell. Technical report, Standard Upper Ontology Working Group (SUO WG), February 2006. Available online: `http://suo.ieee.org/IFF/metashell/metashell.html`.

Abstract: This document discusses the IFF metashell, the supra-natural part of the IFF, which consists of only three levels: the top `iff` level, the middle `type` level and the bottom `meta` level. The various parts of the IFF metashell are closely related to the IFF grammar, which specifies the correct form for IFF expressions. The `iff` level (5 terms) provides the terminology for the fundamental ideas of set and function via a (directed) graph of such. The `type` level ($\sim$ 450 terms) provides typing terminology for the `meta` level by representing a finitely-complete category of abstract sets and functions; it introduces the categorical representation of subsets and set membership for generalized elements. The `meta` level ($\sim$ 2000 terms, with $\sim$ 500 terms in the kernel) services the natural part of the IFF, consisting of an infinite number $(n \mid n \in \aleph)$ of generic metalevels, by representing a topos of Cantorian feartureless abstract sets and functions (following the adjunctive style of axiomatization).

[IFF:OO] Robert E. Kent. The IFF Ontology (meta) Ontology (IFF-OO). Technical report, Standard Upper Ontology Working Group (SUO WG), December 2002. Available online: `http://suo.ieee.org/IFF/metalevel/lower/metatheory/ontology/version20021205.pdf`.

Abstract: This document discusses a rigorous category-theoretic foundation for the IFF Ontology (meta) Ontology. The IFF Ontology (meta) Ontology (IFF-OO) contains axiomatizations for the notions of first order language, first order model-theoretic structure, first order theory and first order logic. These notions and the IFF-OO itself are first order representations for the theory of Information Flow. The goal is to provide a categorical representation for all four concepts (language, model, theory and logic) that faithfully represents the fundamentals of these notions, where appropriate categories are both cocomplete and/or complete, and where suitable free notions, hence adjunctions, exist. To follow the IFF approach to semantic integration, we need all of these properties.

[IFF:UR] Robert E. Kent. The IFF foundation ontology. Technical report, Standard Upper Ontology Working Group (SUO WG), July 2001. Available online: `http://suo.ieee.org/IFF/version/20010720.pdf`.

Abstract: This was the starter document and served as a prototype for the IFF. The IFF Foundation Ontology has been described as a metatheory that is capable of representing and reasoning about relations between various ontologies. As such, its axiomatization will prove useful in the implmentation of a framework for a lattice of theories (ontologies) that are internally consistent along the entailment (conceptual) order of the lattice, but possibly inconsistent across the order.