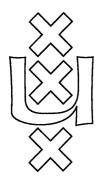
Institute for Language, Logic and Information

THE INCOMPLETE DATABASE

Karen L. Kwast

ITLI Prepublication Series for Computation and Complexity Theory CT-91-07



University of Amsterdam

```
The ITLI Prepublication Series
  1986
                                                                                        The Institute of Language, Logic and Information
  86-01
                                                                                        A Semantical Model for Integration and Modularization of Rules Categorial Grammar and Lambda Calculus
  86-02 Peter van Emde Boas
  86-03 Johan van Benthem
                                                                                        A Relational Formulation of the Theory of Types
Some Complete Logics for Branched Time, Part I
Logical Syntax
Forward looking Operators
 86-04 Reinhard Muskens

86-05 Kenneth A. Bowen, Dick de Jongh

86-06 Johan van Benthem

1987

87-01 Jeroen Groenendijk, Martin

Stokhoft
                                                                                        okhof Type shifting Rules and the Semantics of Interrogatives
Frame Representations and Discourse Representations
 87-02 Renate Bartsch
87-03 Jan Willem Klop, Roel de Vrijer
                                                                                        Unique Normal Forms for Lambda Calculus with Surjective Pairing
                                                                                        Polyadic quantifiers
 87-04 Johan van Benthem
87-05 Víctor Sánchez Valencia
                                                                                        Traditional Logicians and de Morgan's Example
Temporal Adverbials in the Two Track Theory of Time
 87-06 Eleonore Oversteegen
87-07 Johan van Benthem
                                                                                        Categorial Grammar and Type Theory
The Construction of Properties under Perspectives
Type Change in Semantics: The Scope of Quantification and Coordination
  87-08 Renate Bartsch
  87-09 Herman Hendriks
 1988 LP-88-01 Michiel van Lambalgen Logic, Semantics and Philosophy of Language: Algorithmic Information Theory
                                                                                        Expressiveness and Completeness of an Interval Tense Logic
Year Report 1987
 LP-88-02 Yde Venema
  LP-88-03
                                                                                        Going partial in Montague Grammar
Logical Constants across Varying Types
  LP-88-04 Reinhard Muskens
 LP-88-05 Johan van Benthem
                                                                                        Semantic Parallels in Natural Language and Computation Tenses, Aspects, and their Scopes in Discourse
  LP-88-06 Johan van Benthem
  LP-88-07 Renate Bartsch
                                                                                        Context and Information in Dynamic Semantics
A mathematical model for the CAT framework of Eurotra
 LP-88-08 Jeroen Groenendijk, Martin Stokhof
LP-88-09 Theo M.V. Janssen
 ML-88-01 Jaap van Oosten
ML-88-02 M.D.G. Swaen
ML-88-03 Dick de Joseph
                                                                              Ogic and Foundations: Lifschitz' Realizabillity

The Arithmetical Fragment of Martin Löf's Type Theories with weak Σ-elimination Provability Logics for Relative Interpretability

On the Early History of Intuitionistic Logic
  ML-88-03 Dick de Jongh, Frank Veltman
  ML-88-04 A.S. Troelstra
ML-88-05 A.S. Troelstra
                                                                                        Remarks on Intuitionism and the Philosophy of Mathematics
  CT-88-01 Ming Li, Paul M.B. Vitanyi Computation and Complexity Theory: Two Decades of Applied Kolmogorov Complexity CT-88-02 Michiel H.M. Smid

General Lower Bounds for the Partitioning of Range Trees
 CT-88-03 Michiel H.M. Smid, Mark H. Overmars

Leen Torenvliet, Peter van Emde Boas

Dynamic Data Structures

Dynamic Data Structures
                                                                                        Computations in Fragments of Intuitionistic Propositional Logic
 CT-88-04 Dick de Jongh, Lex Hendriks
Gerard R. Renardel de Lavalette
                                                                                        Machine Models and Simulations (revised version)
                                                               A Data Structure for the Union-find Problem having good Single-Operation Complexity
  CT-88-05 Peter van Emde Boas
 CT-88-06 Michiel H.M. Smid

A Data Structure for the Union-find Problem having good Single-Ope CT-88-07 Johan van Benthem

CT-88-08 Michiel H.M. Smid, Mark H. Overmars Multiple Representations of Dynamic Data Structures

Leen Torenvliet, Peter van Emde Boas

CT-88-09 Theo M.V. Janssen

Towards a Universal Parsing Algorithm for Functiona

Towards a Universal Parsing Algorithm for Functiona
 CT-88-09 Theo M.V. Janssen

Towards a Universal Parsing Algorithm for Functional Grammar
CT-88-10 Edith Spaan, Leen Torenvliet, Peter van Emde Boas Nondeterminism, Fairness and a Fundamental Analogy
CT-88-11 Sieger van Denneheuvel, Peter van Emde Boas
Towards implementing RL
X-88-01 Many Limited Other prepublications.
  X-88-01 Marc Jumelet Other prepublications:
                                                                                        On Solovay's Completeness Theorem
  1989 LP-89-01 Johan van Benthem Logic, Semantics and Philosophy of Language: The Fine-Structure of Categorial Semantics
                                                                        okhof Dynamic Predicate Logic, towards a compositional, non-representational semantics of discourse

Two-dimensional Modal Logics for Relation Algebras and Temporal Logic of Intervals
LP-89-04 Johan van Benthem
LP-89-05 Johan van Benthem
LP-89-06 Andreja Prijatelj
LP-89-07 Heinrich Wansing
LP-89-08 Víctor Sánchez Valencia
LP-89-09 Zhisheng Huang
ML-89-01 Dick de Jongh, Albert Visser
ML-89-03 Dick de Jongh, Franco Montagna
ML-89-04 Dick de Jongh, Marc Jumelet, Franco Montagna
ML-89-05 Pinch VI
  LP-89-02 Jeroen Groenendijk, Martin Stokhof
 ML-89-04 Dick de Jongh, Marc Jumelet, Franco Montagna
ML-89-05 Rineke Verbrugge

L 90 06 Marc Jumelet, Franco Montagna

L comple
                                                                                        Σ-completeness and Bounded Arithmetic
                                                                                        The Axiomatization of Randomness
 ML-89-06 Michiel van Lambalgen
                                                                           Elementary Inductive Definitions in HA: from Strictly Positive towards Monotone
 ML-89-07 Dirk Roorda
                                                       Investigations into Classical Linear Logic Provable Fixed points in I\Delta_0 + \Omega_1 Computation and Complexity Theory: Dynamic Deferred Data Structures
 ML-89-08 Dirk Roorda
 ML-89-09 Alessandra Carbone
 CT-89-01 Michiel H.M. Smid
                                                                                        Machine Models and Simulations
  CT-89-02 Peter van Emde Boas
                                                                                                                                           On Space Efficient Simulations
 CT-89-03 Ming Li, Herman Neuféglise, Leen Torenvliet, Peter van Emde Boas
                                                                                        A Comparison of Reductions on Nondeterministic Space
  CT-89-04 Harry Buhrman, Leen Torenvliet
 CT-89-05 Pieter H. Hartel, Michiel H.M. Smid
Leen Torenvliet, Willem G. Vree
                                                                                        A Parallel Functional Implementation of Range Queries
CT-89-07 Ming Li, Paul M.B. Vitanyi

CT-89-08 Harry Buhrman, Steven Homer
Leen Torenvliet

CT-89-09 Harry Buhrman, Edith Spaan, Leen Torenvliet On Adaptive Resource Bounded Computations

CT-89-10 Sieger van Denneheuvel

CT-89-11 Zhisheng Huang, Sieger van Denneheuvel Towards Functional Classification of Recursive Query Processing

Peter van Emde Boas

Other Prepublications:

Name Equadations

Name Equadations

A Theory of Learning Simple Concepts under Simple Distributions and Average Case Complexity for the Universal Distribution (Prel. Version)

An Ondeterminstic Complexity Classes

CT-89-09 Harry Buhrman, Edith Spaan, Leen Torenvliet

On Adaptive Resource Bounded Computations

The Rule Language RL/1

CT-89-11 Zhisheng Huang, Sieger van Denneheuvel Towards Functional Classification of Recursive Query Processing

Peter van Emde Boas

Other Prepublications:

An Orey Sentence for Predicative Arithmetic

Name Equadations

Name Equadations

Name Equadations

Name Equadations

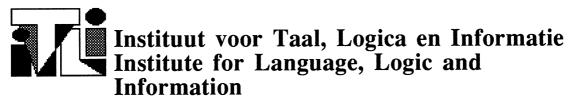
Name Equadations

Name Equadations

Name Equadations
                                                                                        New Foundations: a Survey of Quine's Set Theory
 X-89-02 G. Wagemakers
X-89-03 A.S. Troelstra
                                                                                       Index of the Heyting Nachlass
Dynamic Montague Grammar, a first sketch
 X-89-04 Jeroen Groenendijk, Martin Stokhof
                                                                                       The Modal Theory of Inequality
Een Relationele Semantiek voor Conceptueel Modelleren: Het RL-project
 X-89-05 Maarten de Rijke
X-89-06 Peter van Emde Boas
```

- : -

1990 SEE INSIDE BACK COVER



Faculteit der Wiskunde en Informatica (Department of Mathematics and Computer Science) Plantage Muidergracht 24 1018TV Amsterdam Faculteit der Wijsbegeerte (Department of Philosophy) Nieuwe Doelenstraat 15 1012CP Amsterdam

THE INCOMPLETE DATABASE

Karen L. Kwast

Department of Mathematics and Computer Science
University of Amsterdam



The incomplete database

Karen L. Kwast*
University of Amsterdam
Departments of Mathematics and Computer Science,
Plantage Muidergracht 24, 1018 TV, Amsterdam

Abstract

The introduction of *nulls* (unknown values) into the relational database calls for an extension of the theoretical foundation of the database model. Nulls are alien to classical logic, in which the relational database model is rooted. This has led to all sorts of counterintuitive *ad hoc* solutions, reasonable in one place, but awkward in others.

A sound model-theoretical foundation of nulls in a relational database based on modal logic is presented here. A modal interpretation of queries is easy to comprehend and intuitively correct. Partial interpretations, which are to be preferred from a computational point of view, are inadequate for arbitrary queries.

Formulas that have an identical partial and modal interpretation are called safe. Safety guarantees on the one hand that the partial answer is meaningful and on the other that the modal interpretation is finitely computable.

The suitability of modal logic to model nulls is illustrated by a short discussion of the effect of nulls on database integrity.

^{*}Preprint of IJCAI'91. Proceedings of the 12th International Joint Conference on Artificial Intelligence. To be published by Morgan Kaufmann, 1991.

1 Introduction

The relational database model has in recent years been extended to cope with missing data ([Codd, 1979]). A relation may contain incomplete tuples, because for some objects an attribute is inapplicable (name-of-spouse) or because it is unknown (blood-group). Absent data are unproblematic from a theoretical point of view (see [Lien, 1979]) and will not be discussed here. The mathematical properties of unknown data, however, are insufficiently known. As a consequence, the treatment of unknown values in relational databases tends to be illogical or unnatural (see [Date, 1989], [Codd, 1990]). This paper deals with the theoretical foundation of nulls in a relational database.

1.1 Unknown values

Let nulls $(\omega_1, \omega_2, ...)$ represent the unknown values in a relational database. Indices are used to distinguish between different unknown values and multiple occurrences of the same unknown value. These indices will be hidden from the user, but they are essential to preserve basic algebraic laws such as $R \subseteq \Pi_{XY}(R) \bowtie \Pi_{XY}(R)$.

The main problem with nulls is that they lack identity criteria: there is no way to decide whether ' $\omega = 5$ ' or rather ' $\omega \neq 5$ ', except by revealing ω 's identity. This means that ' $\omega = 5$ ' is neither true nor false, and thus contradicts the Law of the Excluded Middle. Unfortunately, the relational database model is firmly rooted in classical logic, so the introduction of nulls calls for major changes. The following sequence of equivalent terms, for instance, must be relinquished, since in the presence of nulls the first term is but a part of the last one:

$$\sigma_{A \ not \ null}(R) \equiv \sigma_{A=5}(R) \cup \sigma_{A\neq 5}(R) \equiv \sigma_{A=5 \lor A\neq 5}(R) \equiv \sigma_{\mathrm{TRUE}}(R) \equiv R$$

The precise point at which this sequence breaks down will depend on the type of logic that is adopted.

1.2 Choice of logic

Since the relational database model is set in classical logic, attempts have been made to incorporate nulls into classical logic. The simplest solution is to use defaults, reserved values like xxx or 999, providing no system support of nulls at all ([Date, 1989]). The relational tuples have been extended with additional attributes to encode the level of uncertainty ([Biskup, 1981], [Ola, 1989]). This does not suffice to preserve classical tautologies, such as ' $\omega = 5 \lor \omega \neq 5$ ', so equations have been interpreted through uniform null substitution ([Grant, 1979]) or normal form transformation ([Lipski, 1977], [Vassiliou, 1979]). There is no formal justification for the restriction of these variants of supervaluation to equational expressions. Moreover, supervaluation leads to an interpretation that is not compositional:

$$\sigma_{A=5}(R) \cup \sigma_{A\neq 5}(R) \not\equiv \sigma_{A=5 \vee A\neq 5}(R)$$

In recognition of $\omega=5$'s being neither true nor false, there have been proposals that use many-valued logic ([Codd, 1979],[Codd, 1986], [Zaniola, 1984]) or partial logic ([Demolombe et al., 1988]). The missing data create a gap in the truth value assignment, not only for equations but for relational literals as well. Unfortunately, this implies that classical tautologies are no longer valid, in that they have no truth value for tuples with nulls. Since query optimization heavily depends on term rewriting, this will have all sorts of unexpected side-effects:

$$\sigma_{A=5 \lor A \neq 5}(R) \not\equiv \sigma_{\text{TRUE}}(R) \equiv R$$

The third type of approach is based on *modal logic* ([Lipski, 1977],[Lipski, 1979], [Lipski, 1981], [Imielinski and Lipski, 1984b], [Levesque, 1984]). Modal logic is a conservative extension of classical logic, so all classical laws are preserved, and the correct inequivalence emerges:

$$\sigma_{A \ not \ null}(R) \not\equiv \sigma_{A=5}(R) \cup \sigma_{A\neq 5}(R)$$

A drawback of modal logic is its computational complexity. Nevertheless, it is the type of approach I advocate for nulls in a relational database, because it is the only one that is consistently intuitive and easy to comprehend.

1.3 Choice of paradigm

Under the database-as-theory paradigm (see [Reiter, 1984], [Demolombe et al., 1988]) nulls are Skolem constants and part of the language. This leads to 'extended relational theories' for which the Unique Names Axioms, which specify the identity criteria for constants and nulls, are no longer complete. As a consequence, the query evaluation algorithm is only 'sometimes' complete ([Reiter, 1986], [Vardi, 1986], [Demolombe et al., 1988]). This paper adheres to the database-as-model paradigm, but all results can be translated to the database-as-theory paradigm (cf [Vardi, 1986]). The choice between the two paradigms is irrelevant, as is illustrated by Demolombe & Fariñas del Cerro in [1988], where they discuss the 'extended Herbrand model'. One advantage of the database-as-model approach is that nulls need not be added to the query language, but may remain in the realm of the database implementation.

1.4 Outline of this paper

It is well-known that the meaning of an incomplete relation is the set of its completions ([Biskup, 1981], [Vardi, 1986]). The main innovation of the present proposal is to use a set of revelations to represent those completions and to incorporate them explicitly into the interpretation of relational queries (\S 2). Query evaluation will be hard to compute inductively, and is therefore linked -by way of example- to a partial interpretation (\S 3). Working with a modal interpretation ensures that the limitations of using nulls can be established with greater ease and precision (\S 4). The intuitive correctness of employing modal logic to represent unknown values is illustrated in a discussion of database integrity (\S 5).

2 A relational model for nulls

When all is said and done, a complete relational database DB is just a set of tables, an *instance* of a database scheme Σ , *acceptable* if it satisfies some set of constraints \mathcal{X} . As such it is a model $< \mathcal{D}, \mathcal{I} >$, with \mathcal{D} the domain of relevant objects and \mathcal{I} the interpretation of relation names as relations over \mathcal{D} .

Each constant $c \in CON$ will denote a object $\underline{c} \in \mathcal{D}$, and each object $d \in \mathcal{D}$ must have a name. These assumptions are reasonable in a database context; if in addition all objects have different names, as required by the Unique Names Axioms, then the identity = is interpreted as

$$\{ \langle d, d \rangle \mid d \in \mathcal{D} \} = \{ \langle \underline{c}, \underline{c} \rangle \mid \underline{c} \in CON \}.$$

2.1 Extend the model, not the language

Suppose the database is provided with a *finite* set of nulls $\Omega = \{\omega_1, \ldots, \omega_k\}$. Then the model contains relations over the *extended domain* $\mathcal{D} \cup \Omega$, but the interpretation of = can not be $\{< d, d > \mid d \in \mathcal{D} \cup \Omega \}$, since that would make ' $\omega = 5$ ' false instead of unknown. Especially when ω ranges over a finite domain, such as days in the week, we cannot pretend that ω is different to them all.

There is no need to extend the query language with names for nulls. Queries that refer to nulls should be reformulated by means of existential quantification, addressing the null through its context, a partial tuple in an incomplete relation.

The identifying index is not relevant to external users. Indices are analogous to the surrogates used for tuple identification; they are there for the sake of the system, but the external user cannot address them. In other words, nulls are part of the incomplete relational *model*, not part of any relational query language.

2.2 Revelations

The ultimate meaning of the null is modeled by a set G of revelations. The term 'revelation' is chosen to indicate that the unknown identity of the nulls is revealed eventually, but we want to reason over the incomplete database without waiting for revelations (cf symbolic constraint solving, see [Denneheuvel et al., 1991]). Alternative terms would be 'null-assignment' or even 'substitution', though the latter term sounds more innocent than is justified by its elusive denotation.

A revelation $g: \Omega \to \mathcal{D}$ is a function that assigns a proper value to each null, thus resolving the nulls in the relations and completing the database: for each $g \in G$ and \underline{R} in DB, $g[\underline{R}]$ is a complete relation over \mathcal{D} .

The revelations G represent all possible *completions* of the database. Partial knowledge of the identity of the nulls can be encoded in G's structure. The database integrity constraints, for instance, may resolve some nulls, and rule others unequal (see § 5 below).

2.3 Truth definition

Queries to the database will be formulated in a Codd-complete query language, such as the relational algebra. Any query can be translated into first order predicate logic, however, so the truth definition is here recursive over logical connectives and quantifiers, extended -for the sake of the nulls- with the modal operators K for 'it is known that' and M for 'it is conceivable that'.

In the clauses below h is a standard assignment $h \in H$: VAR $\to \mathcal{D}$, to resolve free variables. Existential quantification is interpreted by means of x-cylindrification:

$$\mathcal{C}_{\boldsymbol{x}}\mathcal{I}(\varphi) := \{ \langle g, h \rangle \mid h =_{\bar{\boldsymbol{x}}} h' \langle g, h' \rangle \in \mathcal{I}(\varphi) \}$$

The symbol $=_{\bar{x}}$ denotes the equality of two assignments on all variables, with the possible exception of x.

Definition 1 incomplete instance

A model $\langle \mathcal{D} \cup \Omega, \mathcal{I}, G \rangle$ is an incomplete modal instance of a relational database scheme Σ iff every n-ary relation name R in Σ is interpreted by $\mathcal{I}(R) = \underline{R} \subseteq (\mathcal{D} \cup \Omega)^n$ and every formula φ by $\mathcal{I}(\varphi) \subseteq G \times H$, as follows:

```
 \begin{array}{lll} \mathcal{I}(Ra\ldots x) &:=& \{ < g,h > | < \underline{a},\ldots,h(x) > \in g[\underline{R}] \} \\ \mathcal{I}(a=b) &:=& \{ < g,h > | \ \underline{a}=\underline{b} \} \\ \mathcal{I}(x=b) &:=& G \times \{h \in H \mid h(x)=\underline{b} \} \\ \mathcal{I}(x=y) &:=& G \times \{h \in H \mid h(x)=h(y) \} \\ \mathcal{I}(\neg \varphi) &:=& G \times H \setminus \mathcal{I}(\varphi) \\ \mathcal{I}(\varphi \wedge \psi) &:=& \mathcal{I}(\varphi) \cap \mathcal{I}(\psi) \\ \mathcal{I}(\exists x \ \varphi) &:=& \mathcal{C}_x \mathcal{I}(\varphi) \\ \mathcal{I}(\mathbf{K}\varphi) &:=& G \times \{h \in H \mid G \times \{h \} \subseteq \mathcal{I}(\varphi) \} \\ \end{array}
```

Definition 1 can be explained as follows. The interpretation of formulas is presented in an algebraic manner, to emphasize the connection with the relational algebra. This is a matter of presentation only; it can also be given as a modal truth definition, since the revelations G represent a set of possible worlds $W \equiv \{ w_g \mid g \in G \}$, and the incomplete instance represents a Kripke model, which is of course an appropriate model for unknown values.

Lemma 1 $< \mathcal{D} \cup \Omega, \mathcal{I}, G > \equiv < \mathcal{D}, \mathcal{I}', W >$, in such a way that

- $W \equiv \{ w_g \mid g \in G \}$
- $\bullet \quad \mathcal{I}'(w_g)(R) = g[\underline{R}]$
- $\bullet \quad <\mathcal{D}, \mathcal{I}', W>, w_g \models \varphi[h] \quad \textit{iff} \quad < g, h> \in \mathcal{I}(\varphi)$

The model $\langle \mathcal{D}, \mathcal{I}', W \rangle$ is a connected S5 Kripke model, which yields a very simple model logic.

Nulls are modeled as parameters, and only through the revelations G are they existentially quantified. To describe the incomplete model, one can replace every ω

by an existentially quantified variable, but ' $\exists \omega \varphi$ ' makes no sense, since ω is not a variable in the query language.

Given lemma 1 it is easy to see that $\langle g, h \rangle \in \mathcal{I}(\varphi)$ has the intuitive meaning that the restriction of h to $FV(\varphi)$ denotes a tuple for which φ is true, provided that g is the correct revelation of unknown values.

Example 1 Let R(ABC) be interpreted as

$$\underline{R} = \{ \langle a, b, c \rangle, \langle d, \omega_{7639}, f \rangle \}.$$

$$\mathcal{I}(Rdxy) = \{ \langle g, h \rangle | h(x) = g(\omega_{7639}) \& h(y) = f \}$$

 $\mathcal{I}(\exists x \ Rdxy) = \{ \langle g, h \rangle | h(y) = f \}$

If the unknown B value happens to be e, then '< e, f>' is a correct answer to the query 'xy such that Rdxy'; f is a solution to the query 'y such that $\exists x \ Rdxy$ ' independent of the unknown value of the tuple.

The correct revelation g is not known, but by adding a modal operator K or M it becomes superfluous.

Example 2 The query 'Is it true that Rdef?' is not very satisfactorily answered by the condition ' $\omega \mapsto e$ ', that is 'yes, provided Rdef'. The modalized versions do make sense: the query 'Is it known that Rdef?' yields 'No ...', and 'Is it possible that Rdef?' receives a final 'Yes!'.

 $\mathcal{I}(\mathbf{K}\varphi)$ does not depend on g, and the answer to an open query is

$$\mathcal{I}_*(\varphi) := \{ h \in H \mid \langle g, h \rangle \in \mathcal{I}(\mathbf{K}\varphi) \}$$

and if necessary the dual $\mathcal{I}^*(\varphi)$, the projection of $\mathcal{I}(\mathbf{M}\varphi)$ on H. Unfortunately, it is not possible to compute \mathcal{I}_* by independent induction, that is, without first computing \mathcal{I} .

Example 3 Let R(ABC) be interpreted as before.

 $\mathcal{I}_*(Rdxy) = \emptyset$

$$\mathcal{I}_*(\exists x \ Rdxy) = \{h \in H \mid h(y) = f\}$$

$$\mathcal{I}_*(\neg Rdxy) = \{h \in H \mid h(y) \neq f\}$$

No tuple xy is known to satisfy Rdxy. Still, it is known that $y \mapsto f$ satisfies $\exists x \ Rdxy$, and it is known that h satisfies $\neg Rdxy$ as long as $y \not\mapsto f$, regardless of h(x).

3 Safe queries

The only drawback of modal logic is its computational complexity. In comparison it is very easy to compute a partial interpretation, namely by means of a finite induction. Queries φ on which these interpretations agree will be called *safe*.

3.1 Partial logic

A partial interpretation of open queries will either implicitly or explicitly make use of extended assignments H^+ : VAR $\to \mathcal{D} \cup \Omega$. The positive answers $\mathcal{J}_+(\varphi)$ are computed by straightforward induction, with an accompanying set of negative answers $\mathcal{J}_-(\varphi)$. This guarantees that all the de Morgan duality laws are validated, so each formula can be transformed into prenex normal form.

Definition 2 partial instance

A model $\langle \mathcal{D} \cup \Omega, \mathcal{J} \rangle$ is a partial instance of a relational database scheme Σ iff every n-ary relation name R in Σ is interpreted by $\mathcal{J}(R) = \underline{R} \subseteq (\mathcal{D} \cup \Omega)^n$ and every formula φ is interpreted by a pair $\mathcal{J}_+(\varphi), \mathcal{J}_-(\varphi) \subseteq H^+$, as follows:

```
\begin{array}{lll} \mathcal{J}_{+}(R(a\ldots x)) &:=& \{h\in H^{+} \mid <\underline{a}\ldots h(x)>\in \underline{R}\}\\ \mathcal{J}_{+}(x=y) &:=& \{h\in H^{+} \mid h(x)=h(y)\}\\ \mathcal{J}_{+}(x=a) &:=& \{h\in H^{+} \mid h(x)=\underline{a}\}\\ \mathcal{J}_{+}(a=b) &:=& \{h\in H^{+} \mid \underline{a}=\underline{b}\}\\ \mathcal{J}_{+}(\neg\varphi) &:=& \mathcal{J}_{-}(\varphi)\\ \mathcal{J}_{+}(\varphi\vee\psi) &:=& \mathcal{J}_{+}(\varphi)\cup\mathcal{J}_{+}(\psi)\\ \mathcal{J}_{+}(\exists x\,\varphi) &:=& \mathcal{J}_{+}(\varphi)\cap\mathcal{J}_{+}(\psi)\\ \mathcal{J}_{+}(\exists x\,\varphi) &:=& \mathcal{C}_{x}^{+}(\mathcal{J}_{+}(\varphi))\\ \mathcal{J}_{+}(\forall x\,\varphi) &:=& \mathcal{D}_{x}^{+}(\mathcal{J}_{+}(\varphi))\\ \mathcal{J}_{-}(x=y) &:=& \{h\in H^{+} \mid k(x)\neq h(y)\}\\ \mathcal{J}_{-}(x=y) &:=& \{h\in H^{+} \mid h(x)\neq\underline{a}\}\\ \mathcal{J}_{-}(a=b) &:=& \{h\in H^{+} \mid \underline{a}\neq\underline{b}\}\\ \mathcal{J}_{-}(\alpha\varphi\vee\psi) &:=& \mathcal{J}_{+}(\varphi)\\ \mathcal{J}_{-}(\varphi\vee\psi) &:=& \mathcal{J}_{-}(\varphi)\cap\mathcal{J}_{-}(\psi)\\ \mathcal{J}_{-}(\varphi\wedge\psi) &:=& \mathcal{J}_{-}(\varphi)\cup\mathcal{J}_{-}(\psi)\\ \mathcal{J}_{-}(\exists x\,\varphi) &:=& \mathcal{D}_{x}^{+}(\mathcal{J}_{-}(\varphi))\\ \mathcal{J}_{-}(\forall x\,\varphi) &:=& \mathcal{C}_{x}^{+}(\mathcal{J}_{-}(\varphi))\\ \mathcal{J}_{-}(\forall x\,\varphi) &:=& \mathcal{C}_{x}^{+}(\mathcal{J}_{-}(\varphi))\\ \mathcal{J}_{-}(\forall x\,\varphi) &:=& \mathcal{C}_{x}^{+}(\mathcal{J}_{-}(\varphi))\\ \end{array}
```

The cylindrifications C_x^+ and \mathcal{D}_x^+ are defined over the extended domain $\mathcal{D} \cup \Omega$. Inequality is defined over \mathcal{D} alone, so if $h(x) \neq h(y)$, then $h(x), h(y) \in \mathcal{D}$. Two tuples are inequal, $\langle d_1 \dots d_n \rangle \neq \langle e_1 \dots e_n \rangle$, if there is at least one place at which they disagree: for some i: $d_i \neq e_i$.

3.2 Comparison on H

To compare the modal and the partial interpretations we need to restrict the latter to H, see figure 1. This can be done without loss of expressibility, since any reference to nulls can be avoided by additional quantification.

$$\mathcal{J}_*(\varphi) := \mathcal{J}_+(\varphi) \cap H \qquad \mathcal{J}^*(\varphi) := H \setminus \mathcal{J}_-(\varphi).$$

Both the modal and the partial interpretation cannot be computed on H directly. The intersection of $\mathcal{J}_{+}(\varphi)$ with H interferes with quantification, but otherwise \mathcal{J}_{*}

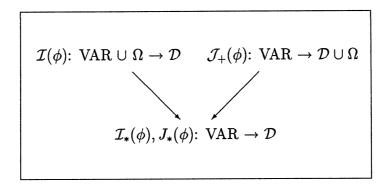


Figure 1: Restricted interpretations

can itself be computed by induction over the structure of the query. For modal logic, answers are lost in case of disjunction and existential quantification.

Theorem 2 Comparison of the 2 interpretations

```
1. answers known to be true
                                                                                                 \mathcal{I}_*(\varphi) \subseteq \mathcal{I}^*(\varphi)
\mathcal{J}_*(\varphi) \subseteq \mathcal{J}^*(\varphi)
\mathcal{J}_*(\neg\varphi) = \mathbf{H} \setminus \mathcal{J}^*(\varphi)
                                                                                                 \mathcal{I}_*(\neg \varphi) = \mathbf{H} \setminus \mathcal{I}^*(\varphi)
\mathcal{J}_{*}(\varphi \vee \psi) = \mathcal{J}_{*}(\varphi) \cup \mathcal{J}_{*}(\psi) \qquad \mathcal{I}_{*}(\varphi \vee \psi) \supseteq \mathcal{I}_{*}(\varphi) \cup \mathcal{I}_{*}(\psi)
\mathcal{J}_*(\varphi \wedge \psi) = \mathcal{J}_*(\varphi) \cap \mathcal{J}_*(\psi) \qquad \mathcal{I}_*(\varphi \wedge \psi) = \mathcal{I}_*(\varphi) \cap \mathcal{I}_*(\psi)
                                                                                               \mathcal{I}_*(\exists x \ \varphi) \supseteq \mathcal{C}_x(\mathcal{I}_*(\varphi))
\mathcal{J}_*(\exists x \ \varphi) \supseteq \mathcal{C}_x(\mathcal{J}_*(\varphi))
                                                                                                \mathcal{I}_*(\forall x \ \varphi) = \mathcal{D}_x(\mathcal{I}_*(\varphi))
\mathcal{J}_*(\forall x \ \varphi) \subseteq \mathcal{D}_x(\mathcal{J}_*(\varphi))
2. answers that may be true
                                                                                               \mathcal{I}^*(\neg \varphi) = \mathbf{H} \setminus \mathcal{I}_*(\varphi)
\mathcal{J}^*(\neg \varphi) = \mathbf{H} \setminus \mathcal{J}_*(\varphi)
\mathcal{J}^*(\varphi \vee \psi) = \mathcal{J}^*(\varphi) \cup \mathcal{J}^*(\psi) \quad \mathcal{I}^*(\varphi \vee \psi) = \mathcal{I}^*(\varphi) \cup \mathcal{I}^*(\psi)
\mathcal{J}^*(\varphi \wedge \psi) = \mathcal{J}^*(\varphi) \cap \mathcal{J}^*(\psi) \quad \mathcal{I}^*(\varphi \wedge \psi) \subseteq \mathcal{I}^*(\varphi) \cap \mathcal{I}^*(\psi)
                                                                              \mathcal{I}^*(\exists x \ \varphi) = \mathcal{C}_x(\mathcal{I}^*(\varphi))
\mathcal{I}^*(\forall x \ \varphi) = \mathcal{C}_x(\mathcal{I}^*(\varphi))
\mathcal{J}^*(\exists x \ \varphi) \supseteq \mathcal{C}_x(\mathcal{J}^*(\varphi))
                                                                                                \mathcal{I}^*(\forall x \ \varphi) \subseteq \mathcal{D}_x(\mathcal{I}^*(\varphi))
\mathcal{J}^*(\forall x \ \varphi) \subseteq \mathcal{D}_x(\mathcal{J}^*(\varphi))
```

Theorem 2 can be found in several places in the literature ([Lipski, 1977], [Reiter, 1986], [Demolombe et al., 1988]), though the precise details will depend on the details of the particular model. Consider for instance the set of answers (see [Reiter, 1986]) that can be deduced from the database:

$$\parallel\varphi\parallel:=\ \{h\in H^+\mid DB\ \vdash\ \varphi[h]\ \}.$$

The evaluation algorithm proposed is \mathcal{J}_+ ; completeness is guaranteed if \mathcal{I}_* -inequalities do not arise.

All classes of unproblematic queries suggested in the literature are *safe* under the present definition.

Definition 3 A formula φ is safe if for every partial \mathcal{J} and modal \mathcal{I} : $\mathcal{J}_*(\varphi) = \mathcal{I}_*(\varphi)$, provided that $\mathcal{J}(R) = \mathcal{I}(R)$ for every relation name R.

3.3 Unsafe queries

Before searching for classes of safe queries, let me first give an example of an unsafe query, which is incorrectly answered under the partial interpretation \mathcal{J}_* .

Example 4 Any comparison expression F is safe, but F cannot be safely combined with a relational atom. If $\underline{R} = \{ \langle a, b, \omega \rangle \}$:

```
\mathcal{J}_*(\exists y \ R(axy)) = \mathcal{I}_*(\exists y \ R(axy)) = \{x \mapsto b\}
\mathcal{I}_*(\exists y : \ R(axy) \land \ (y = 5 \lor y \neq 5)) = \{x \mapsto b\}
\mathcal{J}_*(\exists y : \ R(axy) \land \ (y = 5 \lor y \neq 5)) = \emptyset
```

The partial instance as defined here does not make use of the set of revelations G, so any query that depends indirectly on the structure of this G cannot be correctly evaluated. The next example shows that, unless some sort of fairness condition is laid on G, even a relational atom may be unsafe.

```
Example 5 Let \underline{R} = \{ \langle a, \omega_1, c \rangle, \langle a, b, \omega_2 \rangle \}.
Suppose that for all g \in G either g(\omega_1) = b or g(\omega_2) = c.
Then \mathcal{J}_*(Rxbc) = \emptyset \neq \{x \mapsto a\} = \mathcal{I}_*(Rxbc).
```

To get at a fair comparison it will be assumed here that G is the full set \mathcal{D}^{Ω} .

3.4 Classes of safe queries

Positive selections in combination with union, join and projection can be evaluated over incomplete relations (see [Imielinski and Lipski, 1984b]). These relational terms correspond roughly with positive queries as defined by Reiter (see below), and with formulas without negation. The translation of positive selections is of the format $\varphi \wedge E$, with E an equational expression.

Definition 4 positive

A relational atom is positive.

If φ and ψ are positive, then $\exists \mathbf{x} \varphi, \forall \mathbf{x} \varphi, \varphi \land E, \varphi \land \psi$, and $\varphi \lor \psi$, are all positive.

Reiter allows restricted quantification only, to avoid unreasonable queries. He defines positive queries accordingly ([Reiter, 1986]):

Definition 5 Reiter's positive

An atomic formula is positive.

If φ and ψ are positive and T is a finite type, then $\varphi \wedge \psi$, $\varphi \vee \psi$, $\exists x \in T : \varphi$, and $\forall x \in T : \varphi$, are all positive.

One would like to see that all literals are safe. Since conjunction and universal quantification are unproblematic, then so are conjunctive queries:

Definition 6 Reiter's conjunctive

A formula φ is conjunctive iff φ is of the format $\forall \mathbf{x} \in \mathbf{T} : \psi_1 \wedge \ldots \wedge \psi_n$, where each conjunct ψ_i is a literal (: an atom or a negated atom).

Demolombe & Fariñas del Cerro ([1988]) define a larger set of conjunctive queries.

Definition 7 A formula φ is conjunctive

iff φ is a conjunction of $[\neg][\exists \mathbf{x}] \psi$, with ψ a disjunction of atoms and \mathbf{x} free in one of the disjuncts.

In order to prove that a negated atom such as $\neg Rxab$ is safe, we need to sharpen the basic clause \mathcal{J}_{-} a little, as can be seen from the following example.

Example 6 Let
$$\underline{R} = \{ \langle k, \omega_{245}, \omega_{245} \rangle \}$$
.
 $\mathcal{I}_*(\neg Rxab) = H \neq \{ h \mid h(x) \neq k \} = \mathcal{J}_*(\neg Rxab)$

To counter this example it suffices to redefine the notion of tuple inequality:

Definition 8 uniform tuple inequality

$$< d_1 \dots d_n > \neq < e_1 \dots e_n > :=$$

 $\forall g \in \mathcal{D}^{\Omega} : < g(d_1) \dots g(d_n) > \neq < g(e_1) \dots g(e_n) >$

This is a generalization of strong tuple inequality, since $d_i \neq e_i$ implies that $d_i, e_i \in \mathcal{D}$, so for all revelations $g(d_i) \neq g(e_i)$.

The change is significant. Apparently we need a little modal information even for a simple literal. It is not much, just the set of all possible revelations \mathcal{D}^{Ω} , but it is a clear indication that modal logic will become indispensable when queries get more complex.

Once the partial interpretation is adapted in this manner, we can prove that all given sets of queries are safe:

Theorem 3 If φ is a positive or conjunctive query, then $\mathcal{J}_*(\varphi) = \mathcal{I}_*(\varphi)$.

The set of semantically safe queries can easily be extended using modal equivalences, leading to larger syntactic sets of queries (see [Kwast, 1999]).

```
Definition 9 OK, XDE OK \rightarrow positive | OK \wedge OK | \forallxOK | \negXDE XDE \rightarrow rel. atom | XDE \vee XDE | \existsxXDE | \negOK
```

Theorem 4 Let φ be OK, then $\mathcal{I}_*(\varphi) = \mathcal{J}_*(\varphi)$.

4 Interpretation versus computation

There are two ways to appreciate safety. On the one hand, safe queries are queries for which the modal interpretation gives the intuitive *meaning* of the partial interpretation. This feeling is strengthened by the fact that the partial interpretation of an unsafe query equals the modal interpretation of a modalized version of the query, as in the following example.

```
Example 7 Let \underline{R} = \{ \langle a, \omega_{111} \rangle, \langle b, \omega_{111} \rangle \}.

\mathcal{J}_{*}(\exists x \neg Rax) = \mathcal{I}_{*}(\exists x \mathbf{K} \neg Rax) \neq \mathcal{I}_{*}(\exists x \neg Rax).

\mathcal{J}_{*}(\exists x : (Rax \land x = 5) \lor (Rbx \land x \neq 5))

= \mathcal{I}_{*}(\mathbf{K}(\exists x Rax \land x = 5) \lor \mathbf{K}(\exists x Rbx \land x \neq 5))

\neq \mathcal{I}_{*}(\exists x (Rax \land x = 5) \lor (Rbx \land x \neq 5)).
```

As is suggested by the second query, there is, unfortunately, no *uniform* translation from one type of logic to the other. Every partial answer can be expressed by a modalized formula, of course, but by which formula in particular cannot be predicted. It must be concluded that there remains a class of queries for which the partial interpretation is inappropriate. Some answer is computed, but there is no intuitive idea about what it might be.

4.1 Finite domains

Obviously, the definition of a partial model can be changed, for instance by the addition of G into the interpretation of \mathcal{J}_+ and/or \mathcal{J}_- . To be sure, in [Demolombe *et al.*, 1988] the partial induction has access to G to determine the basic clauses.

In this manner the partial interpretation is set on a modal base. This does not suffice to make it modal logic, of course. For one thing, partial logic cannot cope with finite domains:

```
Example 8 Let \mathcal{D} = \{a, b, c\} and \underline{R} = \{\langle \omega, c \rangle\}.

\mathcal{J}_*(Rac \lor Rbc \lor Rcc) = \emptyset \neq H = \mathcal{J}_*(\exists x Rxc)

\mathcal{I}_*(Rac \lor Rbc \lor Rcc) = \mathcal{I}_*(\exists x Rxc) = H
```

In a database context many nulls will refer to a finite domain, such as day-in-theweek or blood-group. A partial interpretation, even when set on a modal base, is not adequate for queries in which finite domains are involved.

4.2 Reasonable queries

If there is no uniform translation from partial logic into modal logic, we may turn in the opposite direction and use partial logic to *compute* the modal interpretation. Obviously, this only works for safe and 'reasonable' queries, queries which can be finitely computed if the database is complete. If there is no other simple way to compute the modal interpretation, then that is a good reason to forbid the query. It might be cheaper to try and find out what the missing data should have been by using the telephone or a nationwide poll.

4.3 Supervaluation

A good example of a computation method for a distinct class of queries is normal form transformation used to evaluate projection-selection queries. Imielinski & Lipski prove that $< @-tables, Rep, \{\Pi \ \sigma\} >$ is a representation system ([1984b]). This means that projection-selection queries can be correctly represented by functions on

@-tables, relations with unindexed nulls. In our terminology: PS-queries are safe, on the assumption that all nulls occur uniquely in the tables, to guarantee that two nulls need never be identified. As was shown before (see example 4), PS-queries are not safe with respect to the partial interpretation, but they are safe with respect to supervaluation of the normalized form.

5 Nulls and integrity

The effect of nulls on integrity has not drawn as much attention as the problems of query evaluation. The traditional definition of a database satisfying its constraints is not adequate (see [Reiter, 1988]). Codd's suggestion ([1979], [1986]) that nulls should just be ignored, suspending judgement until the moment of their revelation, is no solution either. Not every incomplete tuple may be added to the database.

The model for nulls presented here is well suited to describe database integrity.

Definition 10 An incomplete database is acceptable iff there exists an acceptable revelation, that is, one that yields a database that satisfies all its constraints.

This simple definition can be compared to the definitions proposed in the literature (see [Reiter, 1988]): it is not enough if the atomic facts plus constraints are satisfiable; they must be satisfied by a completion deriving from a revelation. Still, the atomic facts could never imply the constraints. So definition 10 is a suitable adaptation of the Closed World Assumption.

5.1 What should hold

The set of constraints will divide the set of revelations in two: acceptable and unacceptable revelations. Relative to the former set we define a modal operator X with the intended meaning what should hold, that is, what holds in all acceptable completions.

Definition 11 $DB \models \mathbf{X}\varphi$ iff $\exists g \in G : g$ acceptable, and $\forall g \in G : g$ acceptable $\Rightarrow DB, g \models \varphi$.

This definition, being based on Kripke semantics, captures the interaction of integrity constraints with unknown values in an intuitive manner (see [Kwast, 1999]).

Example 9 Suppose
$$R(ABCD): A \to B, C \to D$$

and let $\underline{R} = \{ \langle a, b, \omega_1, d \rangle, \langle a, \omega_2, p, q \rangle \}.$
 $DB \models \mathbf{X}Rabpq$ $(: \omega_2 = b)$
 $DB \models \mathbf{X} \neg Rabpd$ $(: \omega_1 \neq p)$
 $DB \models \mathbf{X} \forall x: Rabxd \supset x \neq p$

The insertion of the tuple $< e, f, \omega_1, r > into \underline{R}$ will make the database unacceptable.

5.2 Queries versus constraints

To distinguish formulas that denote constraints, such as $R: X \to Y$, from relational facts and queries, the former will contain a leading X operator:

$$\mathbf{X}(\forall x, y, y', z, z' Rxyz \land Rxy'z' \supset y = y')$$

Queries are practically never formulated with the help of X, or any analogous operator. Evaluated over total relations X is vacuous, of course, but in the presence of nulls the interpretation of a query φ which does not involve X will contain answers that contradict the relational dependencies, and it will miss others that should have been there. Unfortunately, it cannot be hoped that integrity considerations are actually employed in answering queries, on account of the ensuing complexity.

6 Conclusion

The overall conclusion of this paper is that any sound model-theoretic foundation of nulls in a relational database must be based on modal logic. That modal logic is appropriate is obvious, but it is necessary as well, as there is no other way to assess the intuitive correctness of an evaluation method for wide classes of queries.



The ITLI Prepublication Series

Lp-90-02 Jencen Groennedijk, Martin Stothed Lp-90-02 Jencen Groennedijk, Martin Stothed Lp-90-03 Rema Bartsch Lp-90-03 Rema Bartsch Lp-90-03 Rema Bartsch Lp-90-03 Rema Bartsch Lp-90-04 Amne Bartsch Lp-90-05 Genman Chierchia Lp-90-06 Genman Chierchia Lp-90-06 Genman Chierchia Lp-90-06 Genman Chierchia Lp-90-07 Lp-90-		Prepublication Series
Li-90-01 Jap van der Does Li-90-02 Feren Groeiendijk, Martin Stolhof Li-90-04 Aume Ranta Li-90-04 Aume Ranta Li-90-05 Ternic Blackburn Li-90-05 Ternic Blackburn Li-90-06 Ternic Blackburn Li-90-06 Ternic Blackburn Li-90-06 Ternic Blackburn Li-90-07 Gernaro Christia Li-90-08 Ternic Blackburn Li-90-09 Terni Decker Li-90-08 Ternic Blackburn Li-90-09 Terni Decker Li-90-09 Terni Deck	1990	
D.P.9-0.12 Jerome Gronendijk, Martin Stokhof Dynamic Montague (Francisco Dynamic Montague (Francisco Dynamic Montague) Dynamic Montague		A Generalized Quantifier Logic for Naked Infinitives
Intuitionistic Categorial Grammar Post Of Partics Backhom Post Of Grammar Chiterichia Post Of Grammar Hendriks Post Of Grammar Chiteria Post Of Development Post Of Grammar Chiteria Post Of Development Post Of Dev	LP-90-02 Jeroen Groenendijk, Martin Stokhof	Dynamic Montague Grammar
LP-99-06 Farrick Blackburn LP-90-06 Homan Hendriks LP-90-07 Homan Hendriks		Concept Formation and Concept Composition Intuitionistic Categorial Grammar
LP-99-06 Gennaro Chierchia LP-90-07 The protection of the Perspective of the Perspect		
Ep-90.08 Hemma Hendriks Flexible Montague Grammar Debeter Flexible Montague Grammar Flexible Montague Gram	LP-90-06 Gennaro Chierchia	The Variability of Impersonal Subjects
The Scope of Negation in Discourse, towards a flexible dynamic Montague grammar Models for Discourse Markers		Flexible Montague Grammar
LP-90-11 I Johan van Benthem LP-90-12 I Stept Lapierre LP-90-15 I Stept Lapierre LP-90-15 I Stantard eR Rijke LP-90-16 Zhisheng Huang, Karen Kwast LP-90-17 Karen I Dekker LP-90-16 Zhisheng Huang, Karen Kwast LP-90-17 Karen I Dekker LP-90-18 Local Part LP-90-19 Local Part LP-90-1	LP-90-09 Paul Dekker	The Scope of Negation in Discourse, towards a flexible dynamic Montague grammar
I.P.90. 12 Serge Laplerre I.P.90. 12 Series Laplerre I.P.90. 13 Chibsing Huang I.P.90. 14 Jeroen Greenendist, Martin Stoth of Part I.P.90. 14 Jeroen Greenendist, Martin Stoth of Part I.P.90. 14 Jeroen Greenendist, Martin Stoth of Part I.P.90. 15 Jeroen Greenendist, Martin Stoth of Part I.P.90. 15 Jeroen Greenendist, Martin Stoth of Martin de Rijke I.P.90. 15 Jeroen I.P.90. 16		
Lp-90-13 Zhisheng Huang Logos for Belief Dependence Logos for Belief Dependence Lp-90-14 Lp-90-15 Zhisheng Huang Karen Kwast Lp-90-16 Zhisheng Huang Law Logos for Building Log	LP-90-12 Serge Lapierre	A Functional Partial Semantics for Intensional Logic
I. P. 90-15 Mastren de Rijke Planug, Karen Kwast I. P. 90-17 Paul Dekker Planug Karen Kwast I. P. 90-17 Paul Dekker Planug Karen Kwast I. P. 90-18 Planug Schelins Mi. 90-00 Manten de Rijke Mi. 90-00 Michiel van Lambalo Mi. 90-00 Michiel van Lambalo Mi. 90-00 Manten de Rijke Mi. 90-00 Michiel van Lambalo Mi. 90-00 M	LP-90-13 Zhisheng Huang	
1.P.9.0.1 Fax blacker Logic and Foundations		The Modal Logic of Inequality
Mathematical Logic and Foundations ML-90-02 Jany van Oosten ML-90-03 power op Standella ML-90-05 Domenico Zambella ML-90-05 Domenico Zambella ML-90-06 Domenico Zambella ML-90-07 Maaren de Rijke ML-90-06 Domenico Zambella ML-90-07 Maaren de Rijke ML-90-07 Maaren de Rijke ML-90-07 Maaren de Rijke ML-90-07 Maaren de Rijke ML-90-08 Dick de Jongh, Duccio Fanigiani ML-90-08 Dick de Jongh, Duccio Fanigiani ML-90-09 Dick de Jongh, Duccio Fanigiani ML-90-09 Dick de Jongh, Duccio Fanigiani ML-90-01 Martin Complexity Theory CT-90-09 Rich de Virgi Osamu Watanabe, José L. Baledzar CT-90-01 Idun Tromp, Peter van Ende Boas CT-90-03 Riedra Gavalda, Leen Torenviet Osamu Watanabe, José L. Baledzar CT-90-04 Fred de Geus, Ernest Rotterdam, Sieger van Demeheuvel, Karen Kwast CT-90-08 Fred de Geus, Ernest Rotterdam, Sieger van Demeheuvel, Faren Kwast S-90-04 NS. Troelstra X-90-05 Sieger van Demeheuvel, Faren Kwast X-90-05 Valentin Goranko, Solomon Passy X-90-07 V.Yu, Shavrukov X-90-08 L.D. Beldemishev X-90-09 Sieger van Demeheuvel, Feter van Emde Boas X-90-06 Valentin Goranko, Solomon Passy X-90-07 V.Yu, Shavrukov X-90-08 L.D. Beldemishev X-90-08 L. Balesmar Carbone X-90-19 Maarten de Rijke X-90-19 L. Beldemishev X-90-19 Martin German, Sieger van Demeheuvel, Peter van Emde Boas X-90-19 Sieger van Demeheuvel, P	LP-90-16 Zhisheng Huang, Karen Kwast	Awareness, Negation and Logical Omniscience Evidential Disclosure, Implicit Arguments in Dynamic Semantics
M. 9-04 Marten de Bijke M. 9-04 Demenico Zambella M. 9-04 Marten de Rijke M. 9-06 Sap van Oosten M. 9-06 Marten de Rijke M. 9-06 Sap van Oosten M. 9-06 Marten de Rijke M. 9-06 Sap van Oosten M. 9-07 De Marten de Rijke M. 9-06 Sap van Oosten M. 9-07 De Marten de Rijke M. 9-08 Harold Schellhr M. 9-08 Harold Schellhr M. 9-08 Harold Schellhr M. 9-09 Sap van Demeker of Harold M. 9-01 Michiel van Lambalgen M. 9-01 Sap van Demekervel, Gerard R. Samanical States of the Sap van Demekervel, Gerard R. Samanical States of the Sap van Demekervel, Gerard R. Samanical States of the Sap van Demekervel, Gerard R. Samanical States of the Sap van Demekervel, Gerard R. Samanical States of the Sap van Demekervel, Gerard R. Samanical States of the Sap van Demekervel, Gerard R. Samanical States of the Sap van Demekervel, Gerard R. Samanical States of the Sap van Demekervel, Gerard R. Samanical States of the Sap van Demekervel, Gerard R. Samanical States of the Sap van Demekervel, Gerard R. Samanical States of the Sap van Demekervel, Gerard R. Samanical States of the Sap van Demekervel, Karen Kwast CT-9-04 Steel de Geus, Emes Rotterdam, Sieger Van Demekervel, Karen Kwast CT-9-05 Roel de Vrijer Opher Prepsikajinaria X-9-04 V. V. Sabarnikov X-9-05 V. V. Sabarnikov X-9-05 V. V. Sabarnikov X-9-06 V. V. Sabarnikov X-9-07 V. V. Sabarnikov X-9-08 V. V. Sabarnikov X-9-09 V. Sabarnikov X-9-09 V. V. Sabarnikov X-9-		
ML-90-03 Yale Venerna ML-90-05 Domenico Zambella ML-90-06 Domenico Zambella ML-90-06 Domenico Zambella ML-90-06 Diacy and Oosten ML-90-07 Maarten de Rijke ML-90-08 Dick de Jongh, Duccio Planigiani ML-90-09 Dick de Jongh, Duccio Planigiani ML-90-09 Dick de Jongh, Duccio Planigiani ML-90-01 Pland C. Gilmore ML-90-01 Pland C. Gilmore ML-90-01 Pland C. Gilmore ML-90-02 Sieger van Denneheuvel, Gerard R. Cr. Cr-90-03 Kieger van Denneheuvel, Gerard R. Cr. Cr-90-03 Kieger van Denneheuvel, Gerard R. Cr. Cr-90-04 Sieger van Denneheuvel, Gerard R. Cr. Cr-90-05 Robert of Michiel Span, Lear Towney ML-90-05 Maken de Rijke ML-90-06 Michiel Smid, Peter van Emde Boas Cr-90-08 Fred de Geus, Emest Rotterdam, Sieger Cr-90-08 Fred de Geus, Emest Rotterdam, Sieger ML-90-08 Valentin Spank Lear ML-90-09 Valentin Shehtman ML-90-08 Valentin Shehtman ML-90-09 Valentin Goranko, Solomon Passy ML-90-09 Valentin Shehtman ML-90-09 Shehtman ML-90-09 Shehtman ML-90-09 Shehtman ML-90-09	ML-90-01 Harold Schellinx	Isomorphisms and Non-Isomorphisms of Graph Models
M90.07 Marten de Rijke M90.08 Harrol de Schelinx M90.10 Michiel van Lambalgen M90.10 Michiel Smit from Michiel S		
ML-90.06 Janp van Oosten ML-90.08 Harold Septilox ML-90.18 Harold Septilox ML-90.19 Martier de Rijke ML-90.18 Harold Septilox ML-90.19 Michiel van Lambalgen ML-90.10 Michiel Smith Theory Computation and Complexity Theory The Consistency of an Extended NaDSet C19-04 Sieger van Demeheuvel, Karen Kwast Efficient Normal Form for PCSJ Expressions C19-04 Harry Buhrman, Edith Spaan, Leen Torenvilet McC19-04 Harry Buhrman, Edith Spaan, Leen Torenvilet McC19-04 Michiel Smid, Peter van Emde Boas C19-04 Michiel Smid, Peter van Emde Boas C19-04 Michiel Smid, Peter van Emde Boas C19-04 Michiel Smid, Peter van Emde Boas C19-05 Michiel Smid, Peter van Emde Boas C19-06 Michiel Smid, Peter van Emde Boas C19-06 Michiel Smid, Peter van Emde Boas C19-07 Michiel Smid, Peter van Emde Boas C19-08 Roed de Vrije. C19-09 Roed de Vije. C1	ML-90-04 Maarten de Rijke	Unary Interpretability Logic
MI90-07 Maarten de Rijke MI90-08 Harold Schellinx MI90-11 Paul C Gilnore Computation and Complexity Theory CT-90-01 John Tromp, Peter van Emde Boas CT-90-03 Ricard Gavaldà, Leen Torenvilet CT-90-03 Ricard Gavaldà, Leen Torenvilet CT-90-04 Sieger van Demebeuvel, Gerard R. Reaardel de Lavalette A Normal Form for PCSJ Expressions CT-90-03 Ricard Gavaldà, Leen Torenvilet CT-90-05 Sieger van Demebeuvel, Gerard R. Reaardel de Lavalette A Normal Form for PCSJ Expressions CT-90-06 Sieger van Demebeuvel, Gerard Cavalette A Normal Form for PCSJ Expressions CT-90-07 Kees Doets CT-90-09 Rei de Vrijer Olden Freughligtenten CT-90-09 V. V. Shavnakov CX-90-03 L. D. Beklemishev XX-90-03 L. D. Beklemishev XX-90-04 V. V. Shavnakov XX-90-05 V. J. D. Beklemishev XX-90-05 V. J. D. Beklemishev XX-90-07 V. V. Shavnakov XX-90-07 V.		Sequences with Simple Initial Segments Extension of Lifschitz' Realizability to Higher Order Arithmetic.
ML-90-07 Maarten de Rijke ML-90-09 Dick de Jongh, Duccio Pianigiani ML-90-11 Paul C. Gilmore ML-90-01 Paul C. Gilmore ML-90-02 Sieger van Denneheuvel, Gerard R. Cenardic C. 19-0-02 Sieger van Denneheuvel, Feter van Emde Boas CT-90-02 Sieger van Denneheuvel, Karen Kwass CT-90-03 Sieger van Denneheuvel, Karen Kwass CT-90-04 Sieger van Denneheuvel, Karen Kwass CT-90-05 Sieger van Denneheuvel, Karen Kwass CT-90-05 Sieger van Denneheuvel, Karen Kwass CT-90-06 Sieger van Denneheuvel, Karen Kwass CT-90-08 Fred de Geus, Ernest Rotterdam, Sieger van Denneheuvel, Peter van Emde Boas CT-90-08 Fred de Geus, Ernest Rotterdam, Sieger van Denneheuvel, Peter van Emde Boas CT-90-09 Colleger van Denneheuvel, Peter van Emde Boas CT-90-09 Sieger van Denneheuvel, Peter van Emde Boas CT-90-09 Sieger van Denneheuvel, Peter van Emde Boas CT-90-09 Roed de Vrijer Onter Prepublications X-90-01 Sieger van Denneheuvel, Peter van Emde Boas CT-90-07 V.Yu. Shavukov X-90-05 Valentin Grantok, Solomon Passy X-90-07 V.Yu. Shavukov X-90-08 V.Yu. Shavukov X-90-08 Sieger van Denneheuvel, Peter van Emde Boas CT-90-09 Keept in Denneheuvel, Peter van Emde Boas CT-90-09 V.Yu. Shavukov X-90-08 V.Yu. Shavukov X-90-09 V.Yu. Shavukov X-90-08 V.Yu. Shavukov X-90-09 V.Yu. Shavukov X-90-08 V.Yu. Shavukov X-90-09 V.Yu. Shavukov X-90-08 V.Y	VIL-90-00 Jaap van Oosten	and a Solution to a Problem of F. Richman
M.19-0.09 Dick de Jongh, Duccio Pianigiani M.19-01 Paul C. Gilmore Computation and Completity Theory CT-90-01 John Tromp, Peter van Mee Boas CT-90-01 John Tromp, Peter van Mee Boas CT-90-01 John Tromp, Peter van Mee Boas CT-90-03 Sieger van Denneheuvel, Karen Kwast Efficient Normalization of Database and Constraint Expressions CT-90-05 Sieger van Denneheuvel, Karen Kwast Efficient Normalization of Database and Constraint Expressions CT-90-07 Kees Doets CT-90-08 Robel de Geus, Ernest Rotterdam, Sieger van Denneheuvel, Karen Kwast Efficient Normalization of Database and Constraint Expressions CT-90-08 Robel de Geus, Ernest Rotterdam, Sieger van Denneheuvel, Peter van Ende Boas CT-90-09 Role de Vrijer Ophop Prepublications X-90-09 Nord Staben S		A Note on the Interpretability Logic of Finitely Axiomatized Theories
M.B90-10 Michiel van Lambalgen M.B90-11 Paul C. Gilmore Computation and Complexity Theory Computation and Complexity Theory Computation and Complexity Theory Computation and Complexity Theory CT-90-03 Ricard Gavaldà, Leen Torenvilet CT-90-03 Ricard Gavaldà, Leen Torenvilet CT-90-04 Harry Buhrman, Edith Spaan, Leen CT-90-05 Michiel Smid, Peter van Emde Boas CT-90-06 Michiel Smid, Peter van Emde Boas CT-90-06 Michiel Smid, Peter van Emde Boas CT-90-06 Michiel Smid, Peter van Emde Boas CT-90-08 Fred de Geus, Ernest Rotterdam, CT-90-08 Fred de Vrijer CT-90-08 Fred de Reisk CT-90-08 Fred de Geus, Ernest Rotterdam, CT-90-08 Fred de Geus, Ernest Rotterdam, CT-90-09 Revel de Vrijer CT-90-08 Fred de Geus, Ernest Rotterdam, CT-90-08 Fred de Geus, Ernest Rotterdam, CT-90-08 Fred de Vrijer CT-90-08 Fred de Geus, Ernest Rotterdam, CT-90-08 Fred de Vrijer CT-90-08 Fred de Geus, Ernest Rotterdam, CT-90-08 Fred de Geus, Ernest Rotterdam, CT-90-08 Fred de Vrijer CT-90-08 Fred de Vrijer CT-90-08 Fred de Geus, Ernest Rotterdam, CT-90-08 Fred de Vrijer CT-90-08 Fred de Vrijer CT-90-08 Fred de Grujer CT-90-08 Fred de Vrijer CT-90-08 Fred de Vrijer CT-90-08 Fred de Vrijer CT-90-08 Fred d	ML-90-08 Harold Schellinx MI -90-09 Dick de Jongh, Duccio Pianigiani	Solution of a Problem of David Guaspari
Computation and Complexity Theory CT-90-01 John Tromp, Peter van Emde Boas CT-90-02 Sieger van Denneheuvel, Gerard R. Ren CT-90-03 Karard Gavalda, Leen Torerview CT-90-04 Harry Buhrman, Edith Span, Leen van Emde Boas CT-90-05 Sieger van Denneheuvel, Karen Kwast CT-90-05 Sieger van Denneheuvel, Karen Kwast CT-90-06 Sieger van Denneheuvel, Karen Kwast CT-90-08 Fred de Geus, Ernest Rotterdam, Sieger CT-90-08 Ab. Troelstra X-90-01 Ab. Troelstra X-90-02 Maarten de Rijke X-90-02 Maarten de Rijke X-90-03 VY VY Sharvikov X-90-04 VY VY Sharvikov X-90-04 VY Sharvikov X-90-05 V Shartin Shehtman X-90-06 V Salentin Shehtman X-90-07 Shartin Shehtman X-90-08 WY VY Sharvikov X-90-09 WY VY Sharvikov X-90-10 Kasten de Rijke X-90-13 K.N. Ignatiev Thought Shartin Shehtman X-90-10 Yek Venema ML-91-02 Ab. S. Troelstra ML-91-03 Kasten de Rijke X-90-13 K.N. Ignatiev Thought Shartin Shehtman X-90-10 Material Shartin Shehtman X-90-10 Material Shehtman X-90-10 Materi	ML-90-10 Michiel van Lambalgen	Randomness in Set Theory
CT-90-03 Isom Tomp, Peter van Ende Boas CT-90-03 Ricard Gavaldà, Leen Torenviet CT-90-03 Ricard Gavaldà, Leen Torenviet CT-90-04 Harry Buhrman, Edith Spaan, Leen Torenviet CT-90-05 Seger van Denneheuwel, Karen Kwast Efficient Normalizardinon of Database and Constraint Expressions CT-90-06 Michiel Smid, Peter van Ende Boas CT-90-06 Michiel Smid, Peter van Ende Boas CT-90-06 Michiel Smid, Peter van Ende Boas CT-90-07 Michiel Smid, Peter van Ende Boas CT-90-08 Roed de Vrijer Cher Propublications X-90-09 Roed de Vrijer Cher Propublications X-90-09 Roed de Vrijer Cher Propublications X-90-01 A.S. Troelstra X-90-03 L.D. Beklemishev X-90-03 L.D. Beklemishev X-90-03 L.D. Beklemishev X-90-05 Valentin Goranko, Solomon Passy X-90-07 V.Yu. Shavrukov X-90-09 V.Yu. Shavrukov X-90-09 V.Yu. Shavrukov X-90-10 A.S. Troelstra CX-90-13 K.N. Ignatiev X-90-13 K.N. Ignatiev X-90-14 A.S. S. Troelstra Mathon and Complexity Theory CT-91-01 Ming Li, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast CT-91-05 Sieger van Denneheuvel, Karen Kwast CT-91-05 Sieger van Denneheuvel, Karen Kwast Michael Zakharyaschev Michael Zakharyaschev Michael Zakharyaschev Michael Zakharyaschev Michael Zakharyaschev M-91-06 A.S. Troelstra X-91-07 V.Yu. Shavrukov X-91-08 Research Remedial Reprosession of Arithmetical Completeness for Interpretability Logic On the Complexity of Constructives of the Ruile Language RL/1 Provable Fixed points in Log-10-10-10-10-10-10-10-10-10-10-10-10-10-		The Consistency of an Extended NaDSet
CT-90-02 Sieger van Denneheuvel, Gerard R. Renardel de Lavalette A Normal Form for PCP Expressions CT-90-03 Martanabe, José L. Balcdzar CT-90-04 Harry Buhrman, Edith Spaan, Lean Torenylet CT-90-05 Sieger van Denneheuvel, Karen Kwast Weak Equivalence CT-90-05 Sieger van Denneheuvel, Roren Kwast Weak Equivalence CT-90-06 Ford de Cous, Ernest Rotterdam, Sieger van Denneheuvel, Peter van Emde Boas CT-90-08 Fred de Ceus, Ernest Rotterdam, Sieger van Denneheuvel, Peter van Emde Boas CT-90-08 Fred de Ceus, Ernest Rotterdam, Sieger van Denneheuvel, Peter van Emde Boas CT-90-08 Ab. Troelstra X-90-08 Lab. Beklemishev X-90-01 Maarten de Rijke X-90-02 Maarten de Rijke X-90-03 Maarten de Rijke X-90-03 Maarten de Rijke X-90-03 Maarten de Rijke X-90-03 Maarten de Rijke X-90-11 Alessandra Carbone X-90-10 Sieger van Denneheuvel, Peter van Emde Boas CT-90-08 Fred de Complexity Theory CT-91-08 Fred de Complexity Theory CT-91-01 Ming Li, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast Ohan Prepublications X-91-04 Kenader Laprus (L. Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast Ohan Prepublications X-91-04 A.S. Troelstra X-91-04 A.S. Troelstra X-91-04 A.S. Troelstra X-91-04 A.S. Troelstra X-91-05 A.B. Troelstra X-91-06 X-91-06 A.S. Troelstra X-91-06 X-91-07 A.S. Troelstra X-91-06 X-91-07 A.S. Troelstra X-91-07 A.S. Troelstra X-91-08 Frequential Complexity Theory X-91-09 A.S. Troelstra X-91-09 A.S. Troelstra X-91-09 A.S. Troelstra X-91-00 A.S. Troelstra X-91-0	CT-90-01 John Tromp. Peter van Emde Boas	Associative Storage Modification Machines
Osamu Watanabe, José L. Balcázar CT-90-05 Sieger van Denneheuvel, Karen Kwast Efficient Normalization of Database and Constraint Expressions CT-90-06 Michiel Smid, Peter van Emde Boas CT-90-07 Kees Doets CT-90-08 Fred de Geus, Ernest Rotterdam, Sieger van Denneheuvel, Fred de Geus, Ernest Rotterdam, Sieger van Denneheuvel, Peter van Emde Boas CT-90-08 Roel de Vrijer Onher Prepublications X-90-01 AS. Troelstra X-90-08 L.D. Beklemishev X-90-03 L.D. Beklemishev X-90-08 L.D. Beklemishev X-90-08 L.D. Beklemishev X-90-08 L.D. Beklemishev X-90-10 Sieger van Denneheuvel, Peter van Emde Boas X-90-10 Sieger van Denneheuvel, Peter van Emde Boas X-90-11 AS. Troelstra L.90-11 Vide Venema ML-91-02 Alessandro Berarducci, Rineke Verbrugge ML-91-03 Domenico Zambella ML-91-04 Raymond Hoofman, Harold Schellins ML-91-04 Raymond Hoofman, Harold Schellins ML-91-05 Ringe Li, Paul M.B. Vitanyi CT-91-04 Karen L. Kwast Order Propublications X-91-04 AS. Troelstra X-91-04 AS. Troelstra X-91-05 Abn van Benthem X-91-06 Abn van Benthem X-91-06 A.S. Troelstra X-91-07 A.S. Troelstra X-91-06 A.S. Troelstra X-91-07 A.S. Troelstra X-91-06 A.S. Troelstra X-91-07 A.S. Troelstra X-91-08 A.S. Troelstra X-91-09 A.S. Troelstra X-91-09 A.S. Troelstra X-91-00 A.S. Tro	CT-90-02 Sieger van Denneheuvel, Gerard R. Re	nardel de Lavalette A Normal Form for PCSJ Expressions
CT-90-04 Marry Buhrman, Edith Spaan, Leen Torenvliet CT-90-06 Michiel Smid, Peter van Emde Boas CT-90-06 Michiel Smid, Peter van Emde Boas CT-90-06 Michiel Smid, Peter van Emde Boas CT-90-08 Fred de Geus, Ernest Rotterdam, Sieger van Denneheuvel, Rees Doets CT-90-08 Fred de Geus, Ernest Rotterdam, Sieger van Denneheuvel, Peter van Emde Boas CT-90-08 Peed de Vrijer Other Prepublications X-90-01 AS. Troelstra X-90-02 Maarten de Rijke X-90-02 Maarten de Rijke X-90-03 Valentin Shehtman X-90-04 Valentin Goranko, Solomon Passy X-90-05 Valentin Goranko, Solomon Passy X-90-06 Valentin Goranko, Solomon Passy X-90-08 L.D. Beklemishev X-90-08 L.D. Beklemishev X-90-08 L.D. Beklemishev X-90-08 L.N. Beklemishev X-90-08 L.N. Beklemishev X-90-10 Sieger van Denneheuvel, Peter van Emde Boas Conditional, a case study in conditional rewriting X-90-07 Vy u. Shavukov X-90-10 Sieger van Denneheuvel, Peter van Emde Boas X-90-10 Sieger van Denneheuvel, Peter van Em		
CT-90-06 Michiel Smid, Peter van Emde Boas CT-90-08 Fred de Geus, Emest Rotterdam, Sieger states Fixed Points of Logic Programs CT-90-08 Fred de Geus, Emest Rotterdam, Sieger van Denneheuvel, Peter van Emde Boas X-90-04 R.A. Troelstra X-90-04 Maarten de Rijke X-90-04 Maarten de Rijke X-90-05 Valentin Shehtman X-90-04 Valentin Goranko, Solomon Passy X-90-06 Valentin Goranko, Solomon Passy X-90-07 V.Yu. Sharvukov X-90-08 L.D. Beklemishev X-90-08 L.D. Beklemishev X-90-08 L.D. Beklemishev X-90-09 V.Yu. Sharvukov X-90-10 Sieger van Denneheuvel, Peter van Emde Boas X-90-10 Sieger van Denneheuvel, Peter van Emde Boas X-90-09 V.Yu. Sharvukov X-90-10 Sieger van Denneheuvel, Peter van Emde Boas X-90-10 Sieger van Denneheuvel, Karen Kwast Crepton Schon View of the Provosition Scholary Schol	CT-90-04 Harry Buhrman, Edith Spaan, Leen To	prenyliet Bounded Reductions
CT-90-07 Kees Doets CT-90-08 Fred de Geus, Emest Rotterdam, Sieger van Denneheuvel, Peter van Emed Boas X-90-08 Maarten de Rijke X-90-03 L.D. Beklemishev X-90-05 Valentin Shehtma X-90-05 Valentin Granko, Solomon Passy X-90-07 V.Yu. Shavrukov X-90-09 V.Yu. Shavrukov X-90-09 V.Yu. Shavrukov X-90-09 V.Yu. Shavrukov X-90-11 Alexander Deigle X-90-13 K.N. Ignatiev X-90-13 K.N. Ignatiev X-90-14 L.A. Chagrova X-90-14 L.A. Chagrova X-90-14 L.A. Chagrova X-90-14 V. Alexander Deigle Mathematical Logic and Foundations ML-91-01 Yde Venema ML-91-03 Domenico Zambella M1-91-03 Domenico Zambella M1-91-04 Raymond Hoofman, Harold Schellinx Collapsing Graph Models by Proorders ML-91-05 A.S. Troelstra M1-91-04 Sieger van Denneheuvel, Karen Kwast Week Equivalence CT-91-04 Sieger van Denneheuvel, Karen Kwast Week Equivalence X-91-04 K.N. Ignatiev X-90-10 Karen L. Kwast CT-91-04 Karen L. Kwast Week Equivalence X-91-04 K.N. Ignatiev X-91-05 Valeantin Repressions of Modal Logic X-90-10 K.S. Troelstra X-90-10 Karen L. Kwast Unique Normal Forms for Combinatory Logic with Parallel Unique Normal Forms for Combinatory Logic with Parallel Unique Normal Forms for Combinatory Logic withing Arable Wesse study in conditional reads the Philosophy of Mathematics, Revised Version Some Chapters on Interpretations of Modal Logic On the Complexity of Arithmetical Interpretations of Modal Formulae Annual Report 1989 Derived Sets in Euclidean Spaces and Modal Logic On the Complexity of Arithmetical Interpretations of Modal Logic On the Complexity Prodicate X-90-09 V.Yu. Shavrukov X-90-13 K.N. Ignatiev X-90-14 L.A. Chagrov A-90-15 K.S. Troelstra Cylindric Modal Logic Dahardaze's Polymodal Logic Arithmetical Completeness for Interpretability Logic On the Modal Logic Arithmetical Completeness for Interpretability Logic On the Modal Logic Arithmetical Completeness for Interpretability Logic On the Modal Logic Arithmetical Completeness for Interpretability Logic On the Mo		Dynamic Data Structures on Multiple Storage Media, a Tutorial
CT-90-09 Roel de Vrijer Chep Prepublications X-90-01 A.S. Troelstra X-90-01 A.S. Troelstra X-90-01 A.S. Troelstra X-90-03 L.D. Beklemishev X-90-03 L.D. Beklemishev X-90-05 Valentin Shehtman X-90-05 Valentin Goranko, Solomon Passy X-90-06 Valentin Goranko, Solomon Passy X-90-06 Valentin Goranko, Solomon Passy X-90-08 L.D. Beklemishev X-90-08 L.D. Beklemishev X-90-09 V.Yu. Shavrukov X-90-08 L.D. Beklemishev X-90-10 Sieger van Denneheuvel, Peter van Ende Boas X-90-10 Sieger van Denneheuvel, Peter van Ende Boas X-90-12 Maarten de Rijke X-90-14 L.A. Chagrova X-90-15 A.S. Troelstra In-91-02 Alessandro Bernrducci, Rineke Verbruga ML-91-03 A.S. Troelstra ML-91-04 Raymond Hoofman, Harold Schellinx ML-91-04 Raymond Hoofman, Harold Schellinx X-91-104 King Li, John Tromp, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast Weak Equivalence X-91-04 K.N. Ignatiev X-90-10 Sieger van Denneheuvel, Karen Kwast	CT-90-07 Kees Doets	Greatest Fixed Points of Logic Programs
Conditional, a case study in conditional rewriting Revised Version Some Chapters on Interpretability Logic On the Complexity of Arithmetical Interpretations of Modal Formulae Annual Report 1989 X-90-05 Valentin Shehtman X-90-06 Valentin Goranko, Solomon Passy X-90-07 V.Yu. Shavrukov X-90-08 L.D. Beklemishev X-90-08 L.D. Beklemishev X-90-08 L.D. Beklemishev X-90-10 Sieger van Denneheuvel, Peter van Emde Boas An Overview of the Rule Language RL/1 Provability Logics for Natural Turing Progressions of Arithmetical Theories On Rosser's Provability Pedicate Provability Logics for Natural Turing Progressions of Arithmetical Theories On Rosser's Provability Logics for Natural Turing Progressions of Arithmetical Theories On Rosser's Provability Logics for Natural Turing Progressions of Arithmetical Theories On Rosser's Provability Logics for Natural Turing Progressions of Arithmetical Completeness of Using the Universal Modality: Gains and Questions The Lindenbaum Fixed Point Algebra is Undecidable Provability Logics for Natural Turing Progressions of Arithmetical Theories On Rosser's Provability Logics for Natural Turing Progressions of Arithmetical Completeness of Interpretability Logic Provability Logic Provability Logic Daparatics Polymodal Logic: Arithmetical Completeness, Fixed Point Property, Craig's Property Undecidable Provability Logic Daparatics Polymodal Logic: Arithmetical Completeness for Interpretability Logic On the Metamathematics of Weak Theories On the Metamathematics of Weak Theories On the Metamathematics of Weak Theories On the Metamathematics of Interpretability Logic On the Metamathematics of Interpretability Logic On the Metamathematics of Interpretability Logic On the Metamathematics of Weak Theories On the Provise of Arithmetical Completeness for Interpretability Logic On the Metamathematics of Weak Theories On the Metamathematics of Weak Theories On the Provise of Arithmetical Completeness for Interpretability Logic On the Metamathematics of Weak Theories On the Metamathematics of Weak Theori		er van Denneheuvel, Peter van Emde Boas Physiological Modelling using KL Unique Normal Forms for Combinatory Logic with Parallel
X-90-01 A.S. Troelstra X-90-03 L.D. Beklemishev X-90-03 L.D. Beklemishev X-90-05 Valentin Shehrman X-90-06 Valentin Goranko, Solomon Passy X-90-07 V.Yu. Shavrukov X-90-08 L.D. Beklemishev X-90-09 V.Yu. Shavrukov X-90-14 L.B. Beklemishev X-90-14 L.S. Troelstra X-90-15 V.Seger van Denneheuvel, Peter van Emde Boas X-90-16 V.Seger van Denneheuvel, Peter van Emde Boas X-90-12 Maarten de Rijke X-90-13 K.N. Ignatiev X-90-14 L.A. Chagrova X-90-15 A.S. Troelstra M-91-92 Alessandro Berarducci, Rineke Verbruge M-19-102 Alessandro Berarducci, Rineke Verbruge M-19-103 Domenico Zambella M-19-104 Raymond Hoofman, Harold Schellinx M-19-104 Raymond Hoofman, Harold Schellinx M-19-106 Ming Li, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast Weak Equivalence CT-91-05 Sieger van Denneheuvel, Karen Kwast Weak Equivalence C-19-105 Sieger van Denneheuvel, Karen Kwast Weak Equivalence C-19-105 Dan van Benthem X-91-04 K.N. Ignatiev X-90-14 K.N. Ignatiev X-90-15 A.S. Troelstra X-90-16 K.S. Troelstra X-90-16 K.S. Troelstra X-90-17 V.Yu. Shavrukov X-90-10 Salentin Spaan X-90-10 V.Yu. Shavrukov X-90-10 Sieger van Denneheuvel, Karen Kwast Weak Equivalence for Constraint Sets C-91-05 Dan van Benthem X-91-06 Edifi Spaan CT-91-07 A.S. Troelstra X-90-16 K.S. Troelstra X-90-16 K.S. Troelstra	Other Prepublications	Conditional, a case study in conditional rewriting
X-90-03 L.D. Beklemishev X-90-05 Valentin Shehtman X-90-06 Valentin Goranko, Solomon Passy X-90-07 V.Yu. Shavrukov X-90-08 L.D. Beklemishev X-90-08 L.D. Beklemishev X-90-10 Sieger van Denneheuvel, Peter van Emde Boas X-90-11 Alessandra Carbone X-90-12 Maarten de Rijke X-90-12 Maarten de Rijke X-90-13 A.S. Troelstra Mahematical Logic and Foundations ML-91-01 Yde Venema ML-91-01 Yde Venema ML-91-01 AS A.S. Troelstra ML-91-03 A.S. Troelstra ML-91-03 Ming Li, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast Cr-91-05 Sieger van Denneheuvel, Karen Kwast Other Prepublications X-91-01 Alexander Chagroy X-91-03 V. Yu. Shavrukov X-91-03 V. Yu. Shavrukov X-91-03 V. Yu. Shavrukov X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev On the Complexity of Arithmetical Interpretations of Modal Logic Unit visual Modality: Gains and Questions The Lindenbaum Fixed Point Algebra is Undecidable Provability Logics for Natural Turing Progressions of Arithmetical Theories On Rosser's Provability Predicate Provability Predicate An Overview of the Rule Language RL/1 Provable Fixed points in Idophint Tring Progressions of Arithmetical Theories On Rosser's Provability Predicate Provability Predicate An Overview of the Rule Language RL/1 Provable Fixed points in Idophint Tring Progressions of Arithmetical Completeness An Overview of the Rule Language RL/1 Provable Fixed points in Idophint Tring Progressions of Arithmetical Completeness An Overview of the Rule Language RL/1 Provable Fixed points in Idophint Tring Progressions of Arithmetical Completeness An Overview of the Rule Language RL/1 Provable Fixed points Algebra is Undecidable Provable is Undecidable Provable Fixed point Algebra is Undecidable Provable Independence Cylindric Modal Logic Anovable Provability Logic Modal Logic Arithmetical Completeness On the Metamathematics of Weak Theories On the Metamathematics of Weak Theories On the Proofs of Arithmetical Completeness for Interpretability Logic On	X-90-01 A.S. Troelstra	Remarks on Intuitionism and the Philosophy of Mathematics, Revised Version
X-90-05 Valentin Shehtman X-90-05 Valentin Goranko, Solomon Passy X-90-06 Valentin Goranko, Solomon Passy X-90-07 V.Yu. Shavrukov X-90-08 L.D. Beklemishev X-90-08 L.D. Beklemishev X-90-10 Sieger van Denneheuvel, Peter van X-90-11 Alessandra Carbone X-90-12 Maarten de Rijke X-90-13 K.N. Ignatiev X-90-13 K.N. Ignatiev X-90-13 K.N. Ignatiev X-90-14 L.A. Chagrov X-90-15 A.S. Troelstra X-90-14 L.A. Chagrov X-90-14 L.A. Chagrov X-90-15 A.S. Troelstra X-90-10 Yde Venema MI-91-01 Yde Venema MI-91-02 Alessandro Berarducci, Rineke Verbrugge MI-91-03 Domenico Zambella MI-91-04 S.A. S. Troelstra MI-91-04 Sieger van Denneheuvel, Karen Kwast CT-91-04 Sieger van Denneheuvel, Karen Kwast CT-91-05 Sieger van Denneheuvel, Karen Kwast CT-91-05 Sieger van Denneheuvel, Karen Kwast Other Prepublications X-90-06 K.N. Ignatiev Michael Zakharyaschev Michael Zakharyaschev Michael Zakharyaschev M-91-06 X-91-06 X.N. Ingatiev M-91-06 X-91-07 A.S. Troelstra M-91-07 A.S. Troelstra M-91-07 A.S. Troelstra M-91-07 A.S. Troelstra M-91-07 A.S. Troelstra M-91-06 X-90-08 L.D. Beklemishev X-90-08 L.D. Beklemishev Using the Universal Modality: Gains and Questions The Lindenbaum Fixed Point Algebras in Undecidable Provability Logics for Natural Turing Progressions of Arithmetical Theories On Rosser's Provability Predicate Using the Universal Modality: Gains and Questions The Lindenbaum Fixed Point Algebras in Undecidable Provability Logics for Natural Turing Progressions of Arithmetical Theories On Rosser's Provability Logic and Folymodal Logic Polymodal Logic Antimetical Completeness, Pived Point Algebras of Werker Werker Indeptity Prodicate Cylindric Modal Logic On the Metamathematics of Weak Theories On the Proposity of Arithmetical Completeness, Privad Point Algebras Craige Arithmetical Completeness, Privad Point Algebras of Natural Turing Progressions of Arithmetical Theories On Rosser's Provability Logic Ser Arithmetical Completions Cylindric Modal Logic On the Metamathematics of Weak Theories On the Proposity of Arithmetical Completeness, Pr		On the Complexity of Arithmetical Interpretations of Modal Formulae
X-90-06 Valentin Goranko, Solomon Passy X-90-07 V.Yu. Shavrukov X-90-08 L.D. Beklemishev X-90-09 V.Yu. Shavrukov X-90-10 Sieger van Denneheuvel, Peter van Emde Boas An Overview of the Rule Language RL/1 X-90-11 Alessandra Carbone X-90-13 K.N. Ignatiev X-90-13 K.N. Ignatiev X-90-14 L.A. Chagrova X-90-15 A.S. Troelstra Indecidable Provable Fixed points in Lap-40,; revised version Indecidable Provable Fixed points in Lap-40,; revised	X-90-04	Annual Report 1989
X-90-07 V.Yu. Shavrukov X-90-09 V.Yu. Shavrukov X-90-09 V.Yu. Shavrukov X-90-10 Sieger van Denneheuvel, Peter van Emde Boas X-90-11 Alessandra Carbone X-90-12 Maarten de Rijke X-90-12 Maarten de Rijke X-90-13 K.N. Ignatiev X-90-14 L.A. Chagrova X-90-15 A.S. Troelstra 1991 Mathematical Logic and Foundations ML-91-10 Yele Venema ML-91-10 Yele Venema ML-91-04 Raymond Hoofman, Harold Schellint Computation and Complexity Theory CT-91-10 Ming Li, Paul M.B. Vitanyi CT-91-03 Ming Li, John Tromp, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast Weak Equivalence CT-91-05 Sieger van Denneheuvel, Karen Kwast Weak Equivalence X-91-04 Alexander Chagrov Michael Zakharyaschev X-91-05 Johan van Benthem X-91-05 Johan van Benthem X-91-06 A.S. Troelstra The Lindenbaum Fixed Point Red Point Provability Logics or Natural Turing Progressions of Arithmetical Theories On Rosser's Provability Predicate Non Rosser's Provability Predicate Non-10-10 A Language RL/1 Provable Fixed points in Id., 4-Ω, revised version Bi-Unary Interpretability Logics Polymodal Logic: Antitume Houndeness, Fixed point Propressional Logics On the Metamathematics of Weak Theories On the Prepublication State Proposition of Arithmetical Completeness, Fixed point Proposition of New Amount Interpretability Logics On the Undecidability of the Disjunction Property of Intermediate Propositional Logics On the Undecidabili	X-90-05 Valentin Shehtman	Derived Sets in Euclidean Spaces and Modal Logic Using the Universal Modality: Gains and Questions
X-90-09 V.Yu. Shavrukov X-90-10 Sieger van Denneheuvel, Peter van Emde Boas An Overview of the Rule Language RL/1 X-90-11 Alessandra Carbone X-90-12 Maarten de Rijke X-90-13 K.N. Ignatiev X-90-14 L.A. Chagrova X-90-15 A.S. Troelstra 1991 Mathematical Logic and Foundations ML-91-01 Yde Venema ML-91-01 Yde Venema ML-91-03 Domenico Zambella ML-91-03 Domenico Zambella ML-91-04 Raymond Hoofman, Harold Schellinx Computation and Complexity Theory CT-91-05 Ming Li, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast Weak Equivalence CT-91-05 Edith Spaan CT-91-07 Karen L. Kwast Other Prepublications X-91-06 K.N. Ignatiev X-91-05 Johan van Benthem X-91-07 A.S. Troelstra Cylindric Modal Logic Drah Models by Preorders History of Constructivism in the Twentieth Century Finite Type Structures within Combinatory Algebras Complexity Complexity under the Universal Distribution Equals Worst Case Complexity Census Techniques on Relativized Space Classes The Incomplete Database Other Prepublications X-91-04 K.N. Ignatiev X-91-05 Johan van Benthem X-91-07 A.S. Troelstra Cremporal Logic Annual Report 1990 Lectures on Linear Logic. Arithmetical Completeness, Fixed Point Preputy, Craig's Property Undecidable Prolems in Correspondence Theory Lectures on Linear Logic Arithmetical Completeness, Fixed Point Property, Craig's Property Undecidable Prolems in Correspondence Theory Lectures on Linear Logic: Arithmetical Completeness, Fixed Point Property, Craig's Property Undecidable Prolems in Correspondence Theory Undecidable Prolems in Correspondence Theory Cylindric Modal Logic On the Metamathematics of Weak Theories On the Metamatical Completeness for Interpretability Logic On the Undecidable Prologition Interpretability Interpretability Interpretability I		The Lindenbaum Fixed Point Algebra is Undecidable
X-90-10 Sieger van Denneheuvel, Peter van Emde Boas X-90-11 Alessandra Carbone X-90-12 Maarten de Rijke X-90-13 K.N. Ignatiev Drovable Fixed points in IA ₂ +C ₂ , revised version Bi-Unary Interpretability Logic X-90-13 K.N. Ignatiev Draparidze's Polymodal Logic: Arithmetical Completeness, Fixed Point Property, Craig's Property Undecidable Problems in Correspondence Theory Lectures on Linear Logic X-90-15 A.S. Troelstra Lectures on Linear Logic ML-91-01 Yde Venema Cylindric Modal Logic ML-91-02 Alessandro Berarducci, Rineke Verbruge ML-91-03 Domenico Zambella ML-91-04 Raymond Hoofman, Harold Schellinx ML-91-05 A.S. Troelstra ML-91-05 A.S. Troelstra ML-91-06 Inge Bethke Computation and Complexity Theory CT-91-01 Ming Li, Paul M.B. Vitanyi CT-91-02 Ming Li, John Tromp, Paul M.B. Vitanyi CT-91-03 Sieger van Denneheuvel, Karen Kwast CT-91-05 Sieger van Denneheuvel, Karen Kwast CT-91-05 Eiger van Denneheuvel, Karen Kwast CT-91-05 Alexander Chagrov, Michael Zakharyaschev X-91-04 K.N. Ignatiev X-90-14 L.A. Chagrova Draparidze's Polymodal Logic: Arithmetical Completeness, Fixed Point Property, Craig's Property Undecidable Problems in Correspondence Theory Lectures on Linear Logic Cylindric Modal Logic On the Metamathematics of Weak Theories On the Weak Equivalence On the Metamathematics of Weak Theories On the Weak Equivalence On Standard Hagory On the Weak Equivalence On Dennico Vanical M		Provability Logics for Natural Turing Progressions of Arithmetical Theories
X-90-13 Maarten de Rijke X-90-13 K.N. Ignatiev X-90-14 L.A. Chagrova X-90-15 A.S. Troelstra 1991 Mathematical Logic and Foundations ML-91-01 Yde Venema ML-91-01 Yde Venema ML-91-03 Domenico Zambella ML-91-03 Domenico Zambella ML-91-06 Inge Bethke Computation and Complexity Theory CT-91-01 Ming Li, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast CT-91-05 Edith Spaan CT-91-06 Edith Spaan CT-91-07 Karen L. Kwast Other Prepublications Ng-91-05 A.S. Troelstra CT-91-07 Karen L. Kwast Other Prepublications Ng-91-05 A.S. Troelstra CT-91-05 Johan van Benthem X-91-05 Johan van Benthem X-91-07 A.S. Troelstra CT-91-07 A.S. Troelstra CT-91-07 A.S. Troelstra CT-91-07 A.S. Troelstra CT-91-07 A.S. Troelstra CT-91-05 Johan van Benthem X-91-07 A.S. Troelstra CT-91-07 A.S. Troelstra CT-91-07 A.S. Troelstra CT-91-07 A.S. Troelstra CT-91-07 Logic CT-91-06 Edith Spaan CT-91-07 A.S. Troelstra CT-91-07 Logic CT-91-07 L	X-90-09 V. Yu. Shavrukov X-90-10 Sieger van Denneheuvel. Peter van Emo	the Boas An Overview of the Rule Language RL/1
X-90-13 K.N. Ignatiev X-90-14 L.A. Chagrova X-90-15 A.S. Troelstra 1991 Mathematical Logic and Foundations ML-91-01 Yde Venema ML-91-02 Alessandro Berarducci, Rineke Verbrugge ML-91-03 Domenico Zambella ML-91-04 Raymond Hoofman, Harold Schellinx ML-91-06 Inge Bethke Computation and Complexity Theory CT-91-02 Ming Li, Paul M.B. Vitanyi CT-91-02 Ming Li, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast CT-91-05 Sieger van Denneheuvel, Karen Kwast CT-91-06 Eddith Spaan CT-91-07 A.S. Troelstra MI-91-03 Johan van Benthem X-91-05 Johan van Benthem X-91-05 Johan van Benthem X-91-06 Johan van Benthem X-91-06 Johan van Benthem X-91-07 A.S. Troelstra Dzhaparidze's Polymodal Logic: Arithmetical Completeness, Fixed Point Property, Craig's Property Undecidable Problems in Correspondence Theory Lectures on Linear Logic Cylindric Modal Logic On the Metamathematics of Weak Theories On the Proofs of Arithmetical Completeness, Fixed Point Propetty, Craig's Property On the Metamathematics of Weak Theories On the Metamathematics of Weak Theories On the Proofs of Arithmetical Completeness of Interpretability Logic On the Proofs of Arithmetical Completeness of Interpretability Logic On the Proofs of Arithmetical Completeness of Interpretability Logic On the Proofs of Arithmetical Completeness of Interpretability Logic On the Proofs of Arithmetical Completeness of Interpretability Logic On the Proofs of Arithmetical Completeness of Interpretability Logic On the Proofs of Arithmetical Completeness of Interpretability Logic On the Proofs of Arithmetical Completeness of Interpretability Logic On the Proofs of Arithmetical Completeness of Interpretability Logic On the Proofs of Arithmetical Completeness of	X-90-11 Alessandra Carbone	Provable Fixed points in $I\Delta_0 + \Omega_1$, revised version
Fixed Point Property, Craig's Property X-90-14 L.A. Chagrova X-90-15 A.S. Troelstra Lectures on Linear Logic Mathematical Logic and Foundations ML-91-01 Yde Venema ML-91-02 Alessandro Berarducci, Rineke Verbrugge ML-91-03 Domenico Zambella ML-91-04 Raymond Hoofman, Harold Schellinx ML-91-05 A.S. Troelstra ML-91-06 Inge Bethke Computation and Complexity Theory CT-91-02 Ming Li, John Tromp, Paul M.B. Vitanyi CT-91-02 Ming Li, John Tromp, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-05 Sieger van Denneheuvel, Karen Kwast Weak Equivalence CT-91-06 Edith Spaan CT-91-07 Alexander Chagrov, Michael Zakharyaschev X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev X-91-05 Johan van Benthem X-91-07 A.S. Troelstra Fixed Point Propetty, Craig's Property Undecidable Problems in Correspondence Theory Lectures on Linear Logic Cylindric Modal Logic On the Metamathematics of Weak Theories On the Proors of Arithmetical Completeness for Interpretability Logic On the Proors of Arithmetical Completeness for Interpretability Logic On the Proors of Constructivism in the Twentieth Century Finite Type Structures within Combinatory Algebras Computation and Complexity Theory CT-91-02 Ming Li, John Tromp, Paul M.B. Vitanyi Kolmogorov Complexity Arguments in Combinatorics Complexity Kolmogorov Complexity Arguments in Combinatorics Complexity Kolmogorov Complexity under the Universal Distribution Equals Worst Case Complexity CT-91-04 Sieger van Denneheuvel, Karen Kwast Weak Equivalence CT-91-05 Sieger van Denneheuvel, Karen Kwast Weak Equivalence CT-91-06 Edith Spaan CT-91-07 Alexander Chagrov, Michael Zakharyaschev Nichael Zakharyaschev N		Dzhanaridze's Polymodal Logic: Arithmetical Completeness.
X-90-15 A.S. Troelstra 1991 Mathematical Logic and Foundations ML-91-01 Yde Venema ML-91-02 Alessandro Berarducci, Rineke Verbrugge ML-91-03 Domenico Zambella ML-91-04 Raymond Hoofman, Harold Schellinx ML-91-06 Inge Bethke Computation and Complexity Theory CT-91-01 Ming Li, Paul M.B. Vitanyi CT-91-02 Ming Li, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-05 Sieger van Denneheuvel, Karen Kwast CT-91-07 Karen L. Kwast Other Prepublications X-91-03 I. Alexander Chagrov Michael Zakharyaschev X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev X-91-05 Siohan van Benthem X-91-06 X-91-07 A.S. Troelstra Lectures on Linear Logic Cylindric Modal Logic On the Metamathematics of Weak Theories On the Preorders History of Constructivism in the Twentieth Century Finite Type Structures within Combinatory Algebras History of Constructivism in the Twentieth Century Finite Type Structures within Combinatory Algebras History of Constructivism in the Twentieth Century Finite Type Structures within Combinatory Algebras History of Constructivism in the Twentieth Century How to Share Concurrent Wait-Free Variables Kolmogorov Complexity Arguments in Combinatorics Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Weak Equivalence Cr-91-04 Sieger van Denneheuvel, Karen Kwast Weak Equivalence Cr-91-05 Sieger van Denneheuvel, Karen Kwast Weak Equivalence Cr-91-07 Karen L. Kwast On the Metamathematics of Weak Theories Average Case Complexity and remained the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Cr-91-04 K.P. Indented Case Complexity Cr-91-05 Sieger van Denneheuvel, Karen Kwast Weak Equivalenc	X-70-13 K.14. Ignatic	Fixed Point Property, Craig's Property
Mathematical Logic and Foundations ML-91-01 Yde Venema ML-91-03 Domenico Zambella ML-91-04 Raymond Hoofman, Harold Schellinx ML-91-06 Inge Bethke Computation and Complexity Theory CT-91-01 Ming Li, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-05 Sieger van Denneheuvel, Karen Kwast CT-91-06 Edith Spaan CT-91-07 Karen L. Kwast Other Prepublications X-91-01 Alexander Chagrov Michael Zakharyaschev X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev X-91-05 Johan van Benthem X-91-06 X-91-07 A.S. Troelstra Cylindric Modal Logic On the Metamathematics of Weak Theories On the Proofs of Arithmetical Completeness for Interpretability Logic On the Proofs of Arithmetical Completeness for Interpretability Logic On the Twentieth Century Finite Type Structures within Combinatory Algebras Concurrent Wait-Free Variables Kolmogorov Complexity Arguments in Combinatorics Complexity Kolmogorov Complexity under the Universal Distribution Equals Worst Case Complexity Cr-91-03 Ming Li, Paul M.B. Vitanyi Kolmogorov Complexity under the Universal Distribution Equals Worst Case Complexity Census Techniques on Relativized Space Classes The Incomplete Database On the Undecidability of the Disjunction Property of Intermediate Propositional Logics North P	X-90-14 L.A. Chagrova	
Mathematical Logic and Foundations MIL-91-01 Yde Venema Cylindric Modal Logic MIL-91-02 Alessandro Berarducci, Rineke Verbrugge On the Metamathematics of Weak Theories MIL-91-03 Domenico Zambella On the Proofs of Arithmetical Completeness for Interpretability Logic MIL-91-04 Raymond Hoofman, Harold Schellinx MIL-91-05 A.S. Troelstra History of Constructivism in the Twentieth Century History of Constructivism in the Twentieth Century Finite Type Structures within Combinatory Algebras Computation and Complexity Theory CT-91-01 Ming Li, Paul M.B. Vitanyi CT-91-02 Ming Li, John Tromp, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast CT-91-05 Sieger van Denneheuvel, Karen Kwast CT-91-07 Karen L. Kwast Other Prepublications X-91-01 Alexander Chagrov Michael Zakharyaschev Michael Zakharyaschev X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev X-91-05 Johan van Benthem X-91-06 X-91-07 A.S. Troelstra Cylindric Modal Logic On the Metamathematics of Weak Theories On the Proposition Models by Preorders Arithmetical Completeness for Interpretability Logic Arithmetical Completeness for Interpretability Logic On the Twendelian Models by Preorders History of Constructivism in the Twentieth Century Finite Type Structures within Combinatory Algebras Kolmogorov Complexity Arguments in Combinatorics Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Weak Equivalence Cr-91-05 Sieger van Denneheuvel, Karen Kwast Census Techniques on Relativized Space Classes The Incomplete Database On the Undecidability of the Disjunction Property of Intermediate Propositional Logics Subalgebras of Diagonizable Algebras of Theories containing Arithmetic Partial Conservativity and Modal Logics Temporal Logic Annual Report 1990 Lectures on Linear Logic, Errata and Supplement		Lettiles on Linear Logic
ML-91-01 Yde Venema ML-91-02 Alessandro Berarducci, Rineke Verbrugge ML-91-03 Domenico Zambella ML-91-04 Raymond Hoofman, Harold Schellinx ML-91-05 A.S. Troelstra ML-91-05 A.S. Troelstra ML-91-05 Inge Bethke Computation and Complexity Theory CT-91-01 Ming Li, Paul M.B. Vitanyi CT-91-02 Ming Li, John Tromp, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast CT-91-05 Sieger van Denneheuvel, Karen Kwast CT-91-06 Edith Spaan CT-91-07 Karen L. Kwast Other Prepublications X-91-01 Alexander Chagrov, Michael Zakharyaschev Michael Zakharyaschev X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev X-91-05 Johan van Benthem X-91-06 X-91-07 A.S. Troelstra Cylindric Modal Logic On the Metamathematics of Weak Theories Collapsing Graph Models by Preorders History of Constructivism in the Twentieth Century Finite Type Structures within Combinatory Algebras Kolmogorov Complexity Arguments in Combinatorics Kolmogorov Complexity Arguments in Combinatorics Kolmogorov Complexity under the Universal Distribution Equals Worst Case Complexity Complexity Average Case Concurrent Wait-Free Variables Complexity under the Universal Distribution Equals Worst Case Complexity Cersus Techniques on Relativized Space Classes The Incomplete Database On the Undecidability of the Disjunction Property of Intermediate Propositional Logics On the Undecidability of the Disjunction Property of Intermediate Propositional Logics Temporal Logic Annual Report 1990 Lectures on Linear Logic, Errata and Supplement		
ML-91-03 Domenico Zambella ML-91-04 Raymond Hoofman, Harold Schellinx ML-91-05 A.S. Troelstra ML-91-06 Inge Bethke ML-91-06 Inge Bethke Computation and Complexity Theory CT-91-01 Ming Li, Paul M.B. Vitanyi CT-91-02 Ming Li, John Tromp, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast Weak Equivalence CT-91-05 Sieger van Denneheuvel, Karen Kwast Weak Equivalence CT-91-05 Sieger van Denneheuvel, Karen Kwast Weak Equivalence CT-91-06 Edith Spaan CT-91-07 Karen L. Kwast Other Prepublications X-91-01 Alexander Chagrov, Michael Zakharyaschev Michael Zakharyaschev X-91-03 V. Yu. Shavrukov Michael Zakharyaschev X-91-04 K.N. Ignatiev X-91-06 X-91-07 A.S. Troelstra On the Proofs of Arithmetical Completeness for Interpretability Logic Collapsing Graph Models by Preorders History of Constructivism in the Twentieth Century Finite Type Structures within Combinatory Algebras Kolmogorov Complexity Arguments in Combinatorics Complexity Kolmogorov Complexity Arguments in Combinatorics Complexity Under the Universal Distribution Equals Worst Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity Av	ML-91-01 Yde Venema	
ML-91-06 Inge Bethke Computation and Complexity Theory CT-91-01 Ming Li, Paul M.B. Vitanyi CT-91-03 Ming Li, John Tromp, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast CT-91-05 Sieger van Denneheuvel, Karen Kwast CT-91-06 Edith Spaan CT-91-07 Karen L. Kwast Other Prepublications X-91-01 Alexander Chagrov Michael Zakharyaschev X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev X-91-06 K91-06 Singation X-91-07 A.S. Troelstra History of Constructivism in the Twenfieth Century Finite Type Structures within Combinatory Algebras Kolmogorov Complexity Arguments in Combinatorics Complexity Kolmogorov Complexity Arguments in Combinatorics Complexity Kolmogorov Complexity Arguments in Combinatorics Complexity Kolmogorov Complexity Arguments in Combinatorics Average Case Comcurrent Wait-Free Variables Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Cr-91-04 Sieger van Denneheuvel, Karen Kwast Weak Equivalence Cr-91-05 Edith Spaan Cr-91-07 Karen L. Kwast Other Prepublications Cr-91-05 Edith Spaan Cr-91-07 Karen L. Kwast Other Prepublications Cr-91-06 Edith Spaan Cr-91-07 Karen L. Kwast Other Prepublications Cr-91-07 Karen L. Kwast Other Prepublications Cr-91-08 Edith Spaan Cr-91-09 Edith Spaan Cr-91-09 Edith Spaan Cr-91-09 Edith Spaan	ML-91-03 Domenico Zambella	On the Proofs of Arithmetical Completeness for Interpretability Logic
ML-91-06 Inge Bethke Computation and Complexity Theory CT-91-01 Ming Li, Paul M.B. Vitanyi CT-91-02 Ming Li, John Tromp, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast Weak Equivalence CT-91-05 Sieger van Denneheuvel, Karen Kwast Weak Equivalence CT-91-07 Karen L. Kwast CT-91-07 Karen L. Kwast CT-91-07 Karen L. Kwast CT-91-07 Lalexander Chagrov, Michael Zakharyaschev Michael Zakharyaschev X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev X-91-05 Johan van Benthem X-91-06 X-91-07 A.S. Troelstra Finite Type Structures within Combinatory Algebras Kolmogorov Complexity Arguments in Combinatorics Kolmogorov Complexity on Linear Logics Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Poperson Average Case Complexity under the	ML-91-04 Raymond Hoofman, Harold Schelling	c Collapsing Graph Models by Preorders History of Constructivism in the Twentieth Century
CT-91-01 Ming Li, Paul M.B. Vitanyi CT-91-02 Ming Li, John Tromp, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast CT-91-05 Sieger van Denneheuvel, Karen Kwast CT-91-06 Edith Spaan CT-91-07 Karen L. Kwast Ct-91-07 Karen L. Kwast Ct-91-07 Alexander Chagrov Michael Zakharyaschev X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev X-91-05 Johan van Benthem X-91-06 X-91-06 X-91-07 A.S. Troelstra Kolmogorov Complexity Arguments in Combinatorics Average Case Conplexity under the Universal Distribution Equals Worst Case Complexity CT-91-04 Sieger van Denneheuvel, Karen Kwast Weak Equivalence CT-91-05 Sieger van Denneheuvel, Karen Kwast Weak Equivalence CT-91-05 Edith Spaan Census Techniques on Relativized Space Classes The Incomplete Database On the Undecidability of the Disjunction Property of Intermediate Propositional Logics Subalgebras of Diagonizable Algebras of Theories containing Arithmetic Partial Conservativity and Modal Logics Annual Report 1990 Lectures on Linear Logic, Errata and Supplement		Finite Type Structures within Combinatory Algebras
CT-91-02 Ming Li, John Tromp, Paul M.B. Vitanyi CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast CT-91-05 Sieger van Denneheuvel, Karen Kwast CT-91-06 Edith Spaan CT-91-07 Karen L. Kwast Other Prepublications X-91-01 Alexander Chagrov, Michael Zakharyaschev Michael Zakharyaschev Michael Zakharyaschev X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev X-91-05 Johan van Benthem X-91-06 X-91-07 A.S. Troelstra Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case Complexity Average Case Complexity under the Universal Distribution Equals Worst Case	Computation and Complexity Theory	
CT-91-03 Ming Li, Paul M.B. Vitanyi CT-91-04 Sieger van Denneheuvel, Karen Kwast CT-91-05 Sieger van Denneheuvel, Karen Kwast CT-91-06 Edith Spaan CT-91-07 Karen L. Kwast Ct-91-07 Karen L. Kwast Ct-91-07 Karen L. Kwast Ct-91-07 Karen L. Kwast Ct-91-08 Edith Spaan CT-91-07 Karen L. Kwast Ct-91-07 Karen L. Kwast Ct-91-07 Karen L. Kwast Ct-91-07 Karen L. Kwast Ct-91-08 Edith Spaan Ct-91-07 Karen L. Kwast Ct-91-07 Karen L. Kwast Ct-91-07 Karen L. Kwast Ct-91-08 Edith Spaan Ct-91-07 Karen L. Kwast Census Techniques on Relativized Space Classes The Incomplete Database Chapter Ct-91-07 Karen L. Kwast Chesting Construction Property of Intermediate Propositional Logics Subalgebras of Diagonizable Algebras of Theories containing Arithmetic Partial Conservativity and Modal Logics Temporal Logic Annual Report 1990 Chesting Case Complexity Construction Property of Intermediate Propositional Logics Subalgebras of Diagonizable Algebras of Theories containing Arithmetic Partial Conservativity and Modal Logics Annual Report 1990 Chesting Construction Property of Intermediate Propositional Logics Chesting Chesting Construction Property of Intermediate Propositional Logics Chesting Chest	CT-91-01 Ming Li, Paul M.B. Vitanyi CT-91-02 Ming Li, John Tromp, Paul M.B. Vit	anyi How to Share Concurrent Wait-Free Variables
CT-91-04 Sieger van Denneheuvel, Karen Kwast Weak Equivalence CT-91-05 Sieger van Denneheuvel, Karen Kwast Weak Equivalence for Constraint Sets CT-91-06 Edith Spaan Census Techniques on Relativized Space Classes CT-91-07 Karen L. Kwast Census Techniques on Relativized Space Classes The Incomplete Database Census Techniques on Relativized Space Classes The Incomplete Database Census Techniques on Relativized Space Classes The Incomplete Database Other Prepublications X-91-01 Alexander Chagrov, Michael Zakharyaschev Michael Zakharyaschev X-91-02 Alexander Chagrov Michael Zakharyaschev X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev X-91-05 Johan van Benthem X-91-06 X-91-06 X-91-07 A.S. Troelstra Census Techniques on Relativized Space Classes The Incomplete Database On the Undecidability of the Disjunction Property of Intermediate Propositional Logics Subalgebras of Diagonizable Algebras of Theories containing Arithmetic Partial Conservativity and Modal Logics Temporal Logic Annual Report 1990 Lectures on Linear Logic, Errata and Supplement	CT-91-03 Ming Li, Paul M.B. Vitanyi	Average Case Complexity under the Universal Distribution Equals Worst Case
CT-91-05 Sieger van Denneheuvel, Karen Kwast CT-91-06 Edith Spaan CT-91-07 Karen L. Kwast Ctr-91-07 Karen L. Kwast Ctr-91-07 Karen L. Kwast Ctr-91-07 Karen L. Kwast Ctr-91-07 Karen L. Kwast Ctr-91-08 Ctr-91-09 Kwast Ctr-91-09 Kwast Ctr-91-09 Karen L. Kwast Ctr-91-09 Karen L. Kwast Ctr-91-09 Ctr-	CT 01 04 Sieger von Denneheuwel Koren Kwas	Complexity Weak Equivalence
CT-91-06 Edith Spaan CT-91-07 Karen L. Kwast Other Prepublications X-91-01 Alexander Chagrov, Michael Zakharyaschev Michael Zakharyaschev X-91-02 Alexander Chagrov Michael Zakharyaschev X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev X-91-05 Johan van Benthem X-91-06 X-91-07 A.S. Troelstra Census Techniques on Relativized Space Classes The Incomplete Database The Disjunction Property of Intermediate Propositional Logics On the Undecidability of the Disjunction Property of Intermediate Propositional Logics Subalgebras of Diagonizable Algebras of Theories containing Arithmetic Partial Conservativity and Modal Logics Annual Report 1990 Lectures on Linear Logic, Errata and Supplement	CT-91-05 Sieger van Denneheuvel, Karen Kwas	t Weak Equivalence for Constraint Sets
Other Prepublications X-91-01 Alexander Chagrov, Michael Zakharyaschev X-91-02 Alexander Chagrov Michael Zakharyaschev X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev X-91-05 Johan van Benthem X-91-06 X-91-07 A.S. Troelstra The Disjunction Property of Intermediate Propositional Logics On the Undecidability of the Disjunction Property of Intermediate Propositional Logics Propositional Logics Propositional Logics On the Undecidability of the Disjunction Property of Intermediate Propositional Logics Proposition	CT-91-06 Edith Spaan	Census Techniques on Relativized Space Classes
X-91-01 Alexander Chagrov, Michael Zakharyaschev X-91-02 Alexander Chagrov Michael Zakharyaschev Nichael Zakharyaschev X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev X-91-05 Johan van Benthem X-91-06 X-91-07 A.S. Troelstra The Disjunction Property of Intermediate Propositional Logics Propositional Log		•
Michael Zakharyaschev X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev X-91-05 Johan van Benthem X-91-06 X-91-07 A.S. Troelstra Michael Zakharyaschev Propositional Logics Subalgebras of Diagonizable Algebras of Theories containing Arithmetic Partial Conservativity and Modal Logics Temporal Logic Annual Report 1990 Lectures on Linear Logic, Errata and Supplement	X-91-01 Alexander Chagrov, Michael Zakharyas	chev The Disjunction Property of Intermediate Propositional Logics
X-91-03 V. Yu. Shavrukov X-91-04 K.N. Ignatiev X-91-05 Johan van Benthem X-91-06 X-91-07 A.S. Troelstra Subalgebras of Diagonizable Algebras of Theories containing Arithmetic Partial Conservativity and Modal Logics Temporal Logic Annual Report 1990 Lectures on Linear Logic, Errata and Supplement	X-91-U2 Alexander Chagrov Michael Zakharvaschev	Propositional Logics
X-91-04 K.N. Ignatiev Partial Conservativity and Modal Logics X-91-05 Johan van Benthem Temporal Logic Annual Report 1990 X-91-07 A.S. Troelstra Lectures on Linear Logic, Errata and Supplement	X-91-03 V. Yu. Shavrukov	Subalgebras of Diagonizable Algebras of Theories containing Arithmetic
X-91-06 Annual Report 1990 X-91-07 A.S. Troelstra Lectures on Linear Logic, Errata and Supplement	X-91-04 K.N. Ignatiev	
X-91-07 A.S. Troelstra Lectures on Linear Logic, Errata and Supplement	X-91-06	Annual Report 1990
V-21-00 Otorsic Danabatitize Tosic of Lorentaire	X-91-07 A.S. Troelstra	Lectures on Linear Logic, Errata and Supplement
	A-71-00 Givigio Deliapation	—-



- [Lipski, 1981] W. Lipski. On databases with incomplete information. In: Journal of the ACM, Vol. 28. 1981
- [Ola, 1989] A. Ola & G. Ozsoyoglu. A family of incomplete database models. In: P. Apers & G. Wiederhold (ed.) Proceedings of the 15 VLDB. 1989
- [Reiter, 1984] R. Reiter. Towards a logical reconstruction of relational database theory. In: M. Brodie et. al. (eds.) On Conceptual Modeling. Springer Verlag, 1984
- [Reiter, 1986] R. Reiter. A Sound and Sometimes Complete Query Evaluation Algorithm for Relational Databases with Null Values. In: Journal of the ACM, Vol. 33. 1986
- [Reiter, 1988] R. Reiter. On Integrity Constraints. In: M. Vardi (ed.) Proc. of the 2nd conf. on Theoretical Aspects of Reasoning about Knowledge, 1988
- [Vardi, 1986] M. Vardi. Querying Logical Databases. In: Journal of Computer & System Sciences, Vol. 33. 1986
- [Vassiliou, 1979] Y. Vassiliou. Null values in data base management / a denotational approach. In: ACM SIGMOD 1979
- [Zaniola, 1984] C. Zaniola. Database relations with null values. In: Journal of Computer and System Sciences, Vol. 28. 1984

References

- [Biskup, 1981] J. Biskup. A formal approach to null values in database relations. In: H.Gallaire et al. (eds.) Advances in database theory, Vol. 1. 1981
- [Codd, 1979] E.F. Codd. Extending the relational database model to capture more meaning. In: ACM Transactions on Database Systems, Vol. 4. 1979
- [Codd, 1986] E.F. Codd. Missing information (applicable and inapplicable) in relational databases. In: ACM SIGMOD, Vol. 15. 1986
- [Codd, 1990] E.F. Codd. The Relational Model for Database Management: version 2. Addison-Wesley, 1990
- [Date, 1989] C.J. Date. Null Values in Database Management. In: Relational Database: Selected Writings. Addison-Wesley, 1986
- [Demolombe et al., 1988] R. Demolombe & L. Fariñas del Cerro. An algebraic evaluation method for deduction in incomplete databases. In: Journal of Logic Programming, Vol. 5. 1988
- [Denneheuvel et al., 1991] S. van Denneheuvel & K.L. Kwast. Weak equivalence for constraint sets. In: Proceedings of IJCAI'91, Morgan Kaufmann, 1991
- [Grant, 1979] J. Grant. Null values in the relational database. In: Information Processing Letters, Vol. 6, 1979
- [Imielinski and Lipski, 1984a] T. Imielinski & W. Lipski. The relational model of data and cylindric algebras. In: Journal of Computer and System Sciences, Vol. 28. 1984
- [Imielinski and Lipski, 1984b] T. Imielinski & W. Lipski. Incomplete information in relational databases. In: Journal of the ACM, Vol. 31. 1984
- [Kwast, 1999] K.L. Kwast. Nulls in a relational database. Forthcoming.
- [Levesque, 1984] H. Levesque. Foundations of a functional approach to knowledge representation. In: Artificial Intelligence, Vol. 23. 1984
- [Lien, 1979] Y. Edmund Lien. Multivalued dependencies with null values in relational databases. In: Proceedings of IEEE, 1979
- [Lipski, 1977] W. Lipski. On the logic of incomplete information. In: T. Gruska (ed.) Proc. of the 6th symp. on Math. Found. of Comp. Science, LNCS, Springer Verlag. 1977
- [Lipski, 1979] W. Lipski. On semantic issues connected with incomplete information databases. In: ACM Transactions on Database Systems, Vol. 4. 1979