VRIJE UNIVERSITEIT AMSTERDAM

LOGIC AS A TOOL FOR MODELLING

SYLLABUS

VU Amsterdam Summer School

21 July – 04 August 2024

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Any general questions for the Summer School support team? Contact amsterdamsummerschool@vu.nl.

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Course Details

You can recycle the information that can be found on the webpage to fill in the following sections. Please bear in mind that the syllabus is a key element of the course that helps students to decide whether this course is appropriate for them and can really help them when deciding to join. Make sure to be as detailed as possible.

Title	Logic as a Tool for Modelling
Coordinator(s)	Dr Apostolos Tzimoulis
Other lecturers	Dr Giuseppe Greco, Mattia Panettiere, Andrea De Domenico, Krishna Manoorkar, Dmitriy Danilov
Study credits	*3 ECTS*
Form(s) of tuition	On campus lectures, tutorials, and exercise sessions
Approximate contact hours	45 hours
Approximate self-study hours	25 hours

Teaching staff (in order of appearance)

	Dr Apostolos Tzimoulis a.tzimoulis@vu.nl *Course coordinator and Lecturer* Apostolos Tzimoulis is an assistant professor at the Department of Ethics, Governance and Society, School of Business and Economics, Vrije Universiteit Amsterdam. His research focuses on formal models and theories for understanding multi-agent interaction and social behaviour.
	Dr Giuseppe Greco g.greco@vu.nl *Lecturer* Giuseppe Greco is an assistant professor at the Department of Ethics, Governance and Society, School of Business and Economics, Vrije Universiteit Amsterdam. His interests span

	from non-classical logic (proof-theoretic and algebraic approaches to agency, information flow, and reasoning under uncertainty) to computational linguistics (proof-theoretic and compositional distributional approaches to the study of natural languages).
	Mattia Panettiere mailto:m.panettiere@vu.nl *Guest Lecturer* Mattia Panettiere is a Ph.D. student at the Department of Ethics, Governance and Society, School of Business and Economics, Vrije Universiteit Amsterdam. His research revolves around non-classical logics and formal methods applied to a broad range of practical fields including social and business sciences.
	Andrea De Domenico a.de.domenico@vu.nl *Guest Lecturer* Andrea De Domenico is Ph.D. student at the Department of Ethics, Governance and Society, School of Business and Economics, Vrije Universiteit Amsterdam. One of the main themes of his research is the study of formal and computational methods applied to social interactions and decision-making.
	Krishna B. Manoorkar k.b.manoorkar@vu.nl *Guest lecturer* Krishna Manoorkar is a Ph.D. student at the Department of Ethics, Governance and Society, School of Business and Economics, Vrije Universiteit Amsterdam. His research focuses

	on formal models for evidential reasoning and decision making under uncertainty.

Course description

Logic is the study of different types of reasoning. Logic is also a tool for elegantly modelling diverse phenomena. The aim of the course is to introduce you to this tool and to explain how it can be used. The course is divided into 3 parts.

We will introduce Classical Logic and show how many different systems of reasoning (logics) arise as variations. We will study two fundamental ways of studying logic, via semantics and syntax. The latter is naturally suited to modelling and automated reasoning.

We will also discuss applications in the social sciences focussing on agency and information flow. We will introduce logical formalisms that allow us to model situations in which truth is socially constructed and develop notions such as knowledge and group and common knowledge.

The overarching theme in the handling of applications is the notion of categories and categorisation. Categorisation is the activity of placing things such as objects or ideas into categories based on their similarities or common criteria. We will formally introduce categorisation theory, starting from the classical theory of Aristotle right up to prototype and exemplar theory. We will formalise these notions and explain how the tools of logics could be used to incorporate vagueness in this theory.

The third part of the course uses the foundational development from Part 1 and the modelling intuitions from Part 2. We will introduce the study of formal linguistics where words are classified in terms of the role, they play in the sentence formation. A word can be categorised as a noun phrase, a transitive verb, etc. Syntactic categories are then combined, accordingly, to rules of formation, to build complex expressions. We will see how a grammatically correct sentence can then be captured by a formal proof or a process of computation and how different readings correspond to different proofs.

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Learning objectives

By the end of this course, students will be able to:

- Understand what is meant by the study of logic and summarize how different systems of reasoning (logics) come about, and outline how they can be studied.
- Explain the relationship of proof theory and logic.
- List and compare a number of different logics and illustrate how they differ from classical logic.
- Show how logic can be used to model diverse phenomena.
- Distinguish the dual role of logic as an idealized form of reasoning and a modelling tool.
- Develop a maturity concerning abstract modelling and argumentation.

Assignments and Assessment

Students are expected to attend all lectures. Students have to submit 2 homework sets, one at the end of the first week and one at the end of the second. Students also need to read (part of) an academic article or a book chapter on the topics that will be taught in class and on the last day of the school give a short presentation (around 15 minutes) where they discuss the article that they read. We provide an attachment with a list of topics and potential readings, but students are also welcome to find articles on the course's topics that pertain more to their own interests.

The exercises consist 80% of the grade and the presentations 20%.

	Mon, 22 July	Tue, 23 July	Wed, 24 July	Thu, 25 July	Fri, 26 July
09.30-10.00	No class	Classical (FO) logic (Apostolos Tzimoulis)	Computational Ontologies (ACL) I (Andrea De Domenico)	Epistemic Modal Logic (Apostolos Tzimoulis)	Categorization and Formal Concept Analysis I (Apostolos Tzimoulis)
10.00-11.00	Welcoming. Introduction to modelling via logic I (Apostolos Tzimoulis)				
11.15-12.00	Introduction to modelling via logic II (Apostolos Tzimoulis)	Exercises	Computational Ontologies (ACL) II (Andrea De Domenico)	Exercises	Exercises
Lunch break					
13.30-15.00	Exercises	Introduction to modal logic(s) (Mattia Panettiere)	No class	Dynamic Modal Logic (Apostolos Tzimoulis)	Categorization and Formal Concept Analysis II (Apostolos Tzimoulis)
15.15-16.00	No class	Exercises	No class	Exercises	Exercises
	Mon, 29 July	Tue, 30 July	Wed, 31 July	Thu, 1 August	Fri, 2 August
09.30-11.00	Fuzzy categories and fuzzy logics I (Apostolos Tzimoulis)	Introduction to proof theory and sub-structural logics (Giuseppe Greco)	Logic in Open-Source intelligence (Dmitriy Danilov)	Dempster-Shafer theory on categories I (Krishna Manoorkar)	Students' presentations
11.15-12.00	Exercises	Exercises	Exercises	Dempster-Shafer theory on categories II (Krishna Manoorkar)	Students' presentations
Lunch break					
13.30-15.00	Fuzzy categories and fuzzy logics II (Apostolos Tzimoulis)	Computational linguistics via logic (Giuseppe Greco)	No class	No class	Discussion. Closing remarks
15.15-16.00	Exercises	Exercises	No class	No class	No class

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Using logic as a tool for modelling

Syllabus

Topics and recommended (not compulsory) readings

Introduction to modelling via logic (classical first order logic)

- J. van Benthem, H. van Ditmarsch, J. van Eijck, J. Jaspars. *Logic in Action - an open course in logic.*

Substructural logics

- Stanford Encyclopedia entries

  Substructural logics

  Intuitionistic logic

  Relevant logics

  Fuzzy logics

  Linear logic

- H. Ono. Substructural Logics and Residuated Lattices – an Introduction. In: Hendricks, V.F., Malinowski, J. (eds) Trends in Logic. Trends in Logic, vol 21. Springer, Dordrecht. 2003

- F. Paoli. Substructural Logics: A Primer. Dordrecht: Kluwer, 2002.

- G. Restall. An Introduction to Substructural Logics. London: Routledge, 2000.

- N. Galatos, P. Jipsen, T. Kowalski, & H. Ono. Residuated lattices: an algebraic glimpse at substructural logics. Elsevier, 2007.

Ontologies

- Protégé: free open-source ontology editor

- J. Hendler, F. Gandon, D. Allemang. *Semantic Web for the Working Ontologist: Effective Modeling for Linked Data, RDFS, and OWL.* ACM Books, 2020.

- F. Baader, I. Horrocks, C. Lutz, U. Sattler. *An Introduction to Description Logic.* Cambridge University Press, 2017.

Modal logics

- P. Blackburn, M. Rijke, Y. Venema. *Modal Logic.* Cambridge Tracts in Theoretical Computer Science, Cambridge University Press, 2001. doi:10.1017/CBO9781107050884

More about Epistemic Logic:

- F. Ronald, J.Y. Halpern, Y. Moses, M.Y. Vardi. *Reasoning About Knowledge.* MIT Press 1995, ISBN 9780262562003. doi:10.7551/mitpress/5803.001.0001
- E. Pacuit. *Dynamic Epistemic Logic I: Modeling Knowledge and Belief.* Philosophy Compass, 2013.
- E. Pacuit. *Dynamic Epistemic Logic II: Logics of Information Change.* Philosophy Compass, 2013.

(Fuzzy) Categorization and formal concept analysis

- M.T. Hannan, G. Le Mens, Greta Hsu, Balazs Kovács, G. Negro, L. Pólos, E. Pontikes, & A.J. Sharkey.*Concepts and categories: Foundations for sociological and cultural analysis.* Columbia University Press, 2019.
- P. Gardenfors. *Conceptual spaces as a framework for knowledge representation.* Mind and Matter 2.2 (2004): 9-27.
- B. Ganter & R. Wille. *Formal concept analysis: mathematical foundations.* Springer Science & Business Media, 2012.
- W. Conradie, S. Frittella, A. Palmigiano, M. Piazzai, A. Tzimoulis, & N.M. Wijnberg. *Categories: how I learned to stop worrying and love two sorts.* In International Workshop on Logic, Language, Information, and Computation, pp. 145-164. Springer, Berlin, Heidelberg, 2016.
- W. Conradie, S. Frittella, A. Palmigiano, M. Piazzai, A. Tzimoulis, & N.M. Wijnberg. *Toward an epistemic-logical theory of categorization.* Proceedings TARK, 2017.
- B. Radim. *Fuzzy Galois connections.* Mathematical Logic Quarterly 45, no. 4 (1999): 497-504.
- W. Conradie, A. Palmigiano, C. Robinson, A. Tzimoulis, & N. Wijnberg. *Modelling sociopolitical competition.* Fuzzy Sets and Systems 407 (2021): 115-141.
- W. Conradie, S. Frittella, K. Manoorkar, S. Nazari, A. Palmigiano, A. Tzimoulis, & N.M. Wijnberg. *Rough concepts.* Information Sciences 561 (2021): 371-413.
- R. Fagin, J.Y. Halpern, & N. Megiddo. *A logic for reasoning about probabilities.* Information and computation 87, no. 1-2 (1990): 78-128.

Computational linguistics via logic

Typeological grammar and structural control (where the first two are the original papers of Lambek):

- J. Lambek, *The mathematics of sentence structure.* American Mathematical Monthly 65:154-179, 1958.

- J. Lambek. *On the calculus of syntactic types.* In R. Jakobson, editor, Structure of Language and its Mathematical Aspects, volume XII of Proceedings of Symposia in Applied Mathematics, pp. 166–178. American Mathematical Society, 1961.
- M. Moortgat, *Typelogical grammar*, Stanford Encyclopedia of Philosophy (this entry of the Stanford Encyclopedia is all you need).
- R. Moot and Ch. Retoré, *The logic of categorial grammar.* LNCS 6850, 2012 (recommended book on the subject).

More about structural control in logic and structural proof theory:

- Ph. Wadler, *A taste of linear logic.*
- G. Greco, A. Palmigiano. *Linear logic properly displayed.*
- R. Goré, *Substructural logics on display.* Logic Journal of IGPL, 6(3), pp. 451-504, 1998 (in particular, Sections 1-5: capturing substructural logics via display calculi and section 11: adding exponentials).
- S. Frittella, G. Greco, A. Kurz, A. Palmigiano, V. Sikimić. *Multi-type sequent calculi.* Trends in Logic XIII, A. Indrzejczak, J. Kaczmarek, M. Zawidski eds, pp. 81-93, 2014.
- G. Greco, M. Ma, A. Palmigiano, A. Tzimoulis, Z. Zhao. *Unified correspondence as a proof-theoretic tool.* Journal of Logic and Computation, 28(7), pp. 1367-1442, 2018

More about compositional distributional semantics:

- M. Baroni, R. Bernardi, R. Zamparelli. *Frege in space: a program for compositional distributional semantics.* Linguistic Issues in Language Technology, 9(241?346), 2014.
- B. Coecke, M. Sadrzadeh, S. Clark. *Mathematical foundations for a compositional distributional model of meaning.*
- B. Coecke, E. Grefenstette, M. Sadrzadeh. *Lambek vs. Lambek: Functorial vector space semantics and string diagrams for Lambek calculus.* Annals of Pure and Applied Logic, 164(11):1079?1100, 2013.
- G. Greco, F. Liang, M. Moortgat, A. Palmigiano, A. Tzimoulis. *Vector Spaces as Kripke Frames.* Journal of Applied Logics, Journal of Logics and their Applications, 7(5): 853-873, 2020.

Dempster-Shafer theory

- K. Sentz, & S. Ferson. Combination of evidence in Dempster-Shafer theory. 2002