Summary

This document describes a proposal for the course Fundamentals of Computing for the 2010-11 MAP-I edition. The proposal is supported by a team from Aveiro University (Dep. of Mathematics) and Minho University (Dep. of Informatics) to be included on the MAP-I.

1 Context and Objectives

An increasing number of computer based systems rely on the cooperation of distributed, heterogeneous components or services organised into open software architectures that, moreover, can survive in loosely-coupled environments and be easily adapted to changing application requirements. Such is the case, for example, of applications designed to take advantage of the increased computational power provided by massively parallel systems or of the whole business of Internet-based software development. In order to develop such systems in a systematic way, the focus of development methods has switched, along the last decade, from functional to architectural issues: both data and processes are encapsulated into software units which are connected into large systems resorting to a number of techniques intended to support reusability and modifiability. This encapsulation principle is essential to both the object-oriented and the more recent component-based software engineering paradigms.

This entails the need for semantic techniques able to cope either with date structuring and prescription of functionality, as well as with specification and analysis of (externally observable) behaviour.

If on data-intensive applications the main element to tackle is the structure of information and its transformations, in dynamic, reactive computing the focus is placed on system’s behaviours and their interactions. Quoting Robin Milner, in his Turing Award Lecture, computing science has become a structural theory of interaction: Thus software, from being a prescription for how to do something — in Turing’s terms a “list of instructions” — becomes much more akin to a description of behaviour, not only programmed on a computer, but occurring by hap or design inside or outside it.

Both initial algebras and final coalgebras provide abstract descriptions of a variety of phenomena in programming, in particular of data and behavioural structures, respectively. As universal properties, they both entail definitionial and proof principles, i.e., a basis for the development of program calculi directly based on (actually driven by) type specifications. Moreover, such properties can be turned into programming combinators and used, not only to calculate programs, but also to program with. In functional programming the role of such universals has been fundamental to a whole discipline of algorithm derivation and transformation. On the other hand, coalgebraic modelling of dynamical systems and reasoning by coinduction has recently emerged as an active area of research.

This course explores the role of such algebraic and coalgebraic structures, and corresponding logics, in program development. As expected, initial algebras turn out to be inductive data types, i.e., abstract descriptions of data structures. Dually, final coalgebras entail a notion of coinductive, behaviour types, representing the dynamics of systems. Therefore, the course will cover the core ideas, techniques and results in
• Algebraic specification, induction and equational logic
• Coalgebraic specification, coinduction and modal logic for coalgebras

In both cases exposition will resort to suitable tool support (namely, OBJ, BOBJ and Circus). To provide a common background to formulate and discuss the topics above, the course will also include a brief

• Introduction to category theory

A particular emphasis will be placed on observational semantics. As a matter of fact, there are several phenomena in computing which are hardly definable (or even simply not definable) in terms of a complete set of constructors and in an essentially finitary process. Such is the case of, for example, processes, transition systems, objects, stream-like structures used in lazy programming languages, ‘infinite’ or non well-founded objects arising in semantics. Such ‘systems’ are inherently dynamic, do possess an observable behaviour, but their internal configurations remain hidden and have therefore to be identified if not distinguishable by observation. Therefore, the study of behavioural satisfaction refinement of algebraic specifications, and coalgebraic methods, will be particularly targeted in the course.

The course will build a roadmap to the broad area of algebraic and coalgebraic methods in software development, not only by providing an introductory survey, but also by exposing students to cutting-edge research topics and open problems, eventually leading to the formulation of a few specific research plans.

2 Learning outcomes

• Familiarity with the main topics, research questions and scientific challenges in the covered area (algebraic and coalgebraic methods);
• Ability to apply them to building and reasoning about, abstract models for software, its functionality, behaviour and composition.
• Ability to extract information from scientific papers in the area.
• Enhanced technical writing and presentation skills.

3 Pre-requisites

The course is almost self-contained, assuming only familiarity with elementary discrete mathematics at undergraduate level. Some previous experience on semantics of programming languages will help.

4 Format

Tutorial module, supported with demos and experimental lab work.

5 Grading

Assessment on base of an individual report on a research paper and a set of written exercises.
6 Course Contents

Plan

1. Introduction to category theory for computer science
   (a) Universal properties; categories; isomorphism; monomorphisms and epimorphisms.
   (b) Constructions in categories: duality, products, sums, limits and colimits.
   (c) Functors and natural transformations
   (d) The Yoneda lemma
   (e) Adjoint functors and adjoint functor theorems
   (f) Cartesian closed categories and λ-calculus

2. Algebras and algebraic specification
   (a) Signatures, models
   (b) Equational logic
   (c) Signature morphisms
   (d) Refinements
   (e) Introduction to the theory of institutions
   (f) Behavioural specifications

3. Coalgebras and coalgebraic specification
   (a) Coalgebras
   (b) Bisimulation
   (c) Coinduction, final coalgebras
   (d) Logics for coalgebras
   (e) Applications

Textbooks and Reading Material

On category theory : [3, 30, 18, 2]

On algebraic specification : [11, 13, 12, 8, 29]

On coalgebraic modelling and coinduction : [28, 16, 17, 1]

7 Team

Luis Soares Barbosa (Coordinator) is Associate Professor, with tenure, at the Department of Informatics of Minho University, and a researcher at CCTC (area of Theory and Formal Methods). His research interests are related to program semantics and calculi applied to systems understanding and rigorous software construction. A particular application area concerns the development of formal models and calculi for software components, services and architectures. On this topic he has published over the past 4 years more than 15 papers in several journals and conferences. He has supervised 2 PhD thesis (1 in the area of the current proposal) and is currently supervising 5 PhD projects (2 in the area of the current proposal). Selected relevant publications on coalgebraic modelling and coinductive reasoning: [4, 5, 25, 27, 6, 26, 7, 23, 22].
Dirk Hofmann is Assistant Professor at Department of Mathematics at the University of Aveiro, and researcher at the Center for Research and Development in Mathematics and Applications. His main interests of research focus on the development and application of categorical methods in Mathematics, more specifically in algebra, topology and domain theory. On this topic he has published more than ten papers in several journals over the past 4 years. He has supervised 4 Msc thesis and is currently supervising 1 PhD project. **Selected relevant publications** on category theory: [15, 9, 10, 14].

Coordinator:

Manuel António Martins is Assistant Professor at the Department of Mathematics of Aveiro University, and a researcher at the Center for Research and Development in Mathematics and Applications. His research interests are related to Abstract Algebraic Logic (AAL) and Algebraic Specification of abstract data types; namely on the application of tools and results of AAL to the specification and verification of software systems. On this topic he has published 6 papers in international journals. He has supervised 4 MSc thesis (2 in the area of the current proposal) and is currently supervising 2 PhD projects (1 in the area of the current proposal). **Selected relevant publications** on specification and verification of software systems: [19, 24, 20, 21, 23, 22].

**References**


CURRICULUM VITÆ

I Personal Data

Name: Manuel António Gonçalves Martins
Data of Birth: 23 de Setembro de 1972.
Tel : 351.234.370658;
Address: Department of mathematics,
Campus Universitário de Santiago
University of Aveiro
3810 - 193 Aveiro Portugal
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II Academic Data

• PhD in Mathematics, area of Algebra, Logic and Foundations, University of Lisbon, 2004.

III Current Position

• Auxiliar Professor, Department of Mathematics, University of Aveiro, since 2004.

IV Research

Main Research Area:

• Algebraic logic.
• Algebraic specification of abstract data types.
• Supported teaching and eLearning.

Affiliation. I am a member of the Center for Research and Development in Mathematics and Applications of the Department of Mathematics of the University of Aveiro.

Refereeing. I have refereed for Studia logica.

V PhD Supervisions

V.1 On-going

• PhD: Alexandre Madeira, co-supervision with Luís S. Barbosa, Department of Informatics, Minho University. Theme: Behavioural Certification of Evolving Software Requirements (Feb 2009).
• PhD: Jacinta Poças, co-supervision with Carlos Caleiro, IST, Technical University of Lisbon. Theme: Semantics for Behavioural Abstract Algebraic Logic (Jan 2010).
VI  MSc Supervisions

VI.1  Concluded

- Nílide Barreto, co-supervision with David Vieira, Theme: \textit{Análise estruturada e formal das provas} (concluded at 9 July 2009).
- Sandra Ramos, co-supervision with Luís Descalço, Theme: \textit{Monóide bicíclico} (concluded at 9 July 2008).
- Alexandre Madeira, co-supervision with Luís Descalço, Theme: \textit{Equivalência Comportamental; uma perspectiva algébrica} (concluded at 11 June 2008).

VII  Member of Funded Projects

- Completeness Notions. Principal investigator: Maria Manzano, University of Salamanca, Spain (2010-13).

VIII  Publications

VIII.1  Jornal papers

VIII.2 Conference Papers


VIII.3 Other papers


VIII.4 Editor of proceedings


IX Communications in conferences


- *To prove a tautology* (joint work E.G. Hernández-Manfredini), International Conference in Mathematics, Sciences and Science Education - ICMSE’06, University of Aveiro, 12 June, 2006.

• Applying abstract algebraic logic to behavioral reasoning, Second International Congress on Tools for Teaching Logic University of Salamanca, 29 September, 2006.

• Behavioral algebraization, Second World Congress on Universal Logic - UNILOG’07, Northwestern Polytechnical University, Xi’an - China, 21 August, 2007.

• Observational stepwise refinement process (joint work with A. Madeira), Days in Logic08, Instituto Superior Técnico, Lisbon, Portugal. 17 January, 2008; (presented by A. Madeira)

• Automata theory within abstract algebraic logic (joint work with A. Madeira and L. Descalço), SATA 2008, School on Algebraic Theory of Automata, Lisbon, Portugal. 3 September 2008; (presented by A. Madeira)

• Refinement by interpretation in a general setting (joint work with A. Madeira and L. S. Barbosa) Refinement Workshop, Eindhoven, Netherlands. 3 November 2009. (presented by A. Madeira)

• Refinement via interpretation (joint work with A. Madeira and L. S. Barbosa) 7th IEEE Int. Conf. on Software Engineering and Formal Methods, Hanoi, Vietnam, November, 2009. (presented by A. Madeira)

• Interpretations on formal software development (joint work with A. Madeira and L. S. Barbosa), Days in Logic10, DCC U.Porto, Porto, Portugal. 29 January, 2010; (presented by A. Madeira)

• Interpretation as coalgebra morphisms (joint work with A. Madeira and L. S. Barbosa), CMCS10-coalgebraic methods on computer science, (co-located with ETAPS 2010) Paphos, Cyprus, 27 March, 2010. (presented by A. Madeira)

CURRICULUM VITÆ

I Personal Data

Name: Luís Manuel Dias Coelho Soares Barbosa
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Affiliations
FME (Formal Methods Europe Association)
EATCS (European Association for Theoretical Computer Science)

II Current Position

• Associate Professor (with tenure), School of Engineering, U. Minho, since 2007.
• Deputy Head of Department, Informatics Department, U. Minho, since 2002.

III Previous Positions

• Invited Lecturer, Department of Engineering Mathematics, Bristol University, UK (1992 – 2004).
• Assistant Professor, School of Engineering, U. Minho, since 2001 (with tenure since 2006).

IV Research

Main Research Area. Program semantics and calculi applied to systems understanding and rigorous software construction.

Other Scientific Interests.

• Reactive programming.
• Mathematical modelling and proof. Problem solving.

V PhD Supervisions

V.1. – Concluded

• Sun Meng, on Coalgebra Theory and its Application to Component Software. Co-supervision with Dr. Berhard Aichernig (IIST/UNU, Macau) and Prof. Zhang Naixiao (School of Mathematical Sciences, Peking University, China), concluded 7th September 2009 on 12 November 2004.


• Marco Antonio Castro Barbosa, on A Refinement Calculus for Software Components and Architectures, concluded 7th September 2009
Curriculum Vitae of Lus Manuel Dias Coelho Soares Barbosa

V.2. – On-going

• Joo Fernando Peixoto Ferreira, on Algorithmic Problem Solving: Principles and Applications co-supervision with Prof. Roland Backhouse (School of Computer Science and Information Technology, University of Nottingham, UK), started December 2005.

• Alexandra Martins Silva on Kripke coalgebras. Co-supervision with Prof. J. J. M. M. Ruten (CWI and Vrije Universiteit Amsterdam, Amsterdam), started May 2006.

• Alexandre Madeira on Behavioural Certification of Evolving Software Requirements. Co-supervision with Prof. Manuel Antonio Martins (Mathematics Department of Aveiro University) started January 2009.

• Alejandro Sanchez on A Calculus of Coordination Patterns. started September 2009.

VI Coordination of Funded Projects

starting January, 2010
Principal researcher of Foundations for architectural design — MONDRIAN. FCT (contract PTDC/EIA-CCO/108302/2008).

starting January, 2010

starting January, 2009
Principal researcher of Reinvigorating Mathematics for the Information Society — MATISSE. FCT (contract PTDC/EIA/73252/2006).

2005 – 2008
Coordinator of the Portuguese Hub of LERNET, ALFA Network for Joint European - Latin American PhD Programme in Language Engineering and Rigorous Software Development.

2005 – 2008
Coordinator of Formal Foundations for Component-based Programming. Technological and Scientific Co-operation between Portugal and the P. R. of China (contract GRICES-00342).

2003 – 2006
Principal researcher of Program Understanding and Re-engineering: Calculi and Applications — PURE. FCT (contract POSI/HS/44304/2002).

VII Selected Publications relevant to the present proposal


CURRICULUM VITÆ

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Date of Birth: December 16, 1970
Citizenship: German

1. Education

Supervisor: Prof. Dr. Hans-Eberhard Porst.
The thesis project was supported by a grant of the foundation “Ernst A.C. Lange”.

M.Sc. (Diplom) in Mathematics. University of Bremen, Germany, October 1995.
Supervisor: Prof. Dr. Horst Herrlich.
Thesis: Ringe stetiger Funktionen (Rings of continuous functions).

2. Work Experience

2001 – present. Assistant Professor (Professor Auxiliar), Department of Mathematics, University of Aveiro, Portugal.

2000 – 2001. Assistant Professor (Assistente Convidado), Department of Mathematics, University of Coimbra, Portugal.

1999 – 2000. Postdoctoral Fellow, Department of Mathematics, University of Coimbra, Portugal.

1996 – 1999. Doctoral Fellow, Department of Mathematics, University of Bremen, Germany.

3. Research

Affiliation. I am a member of the research center Mathematics and Applications of the Department of Mathematics of the University of Aveiro. I am also collaborator of the research center Center for Mathematics of the department of Mathematics of the University of Coimbra.

Conference Organisation. I was member of the Organisation Comitee of IV Congresso Ibero-Americano de Topologia e suas Aplicações, University of Coimbra, Portugal, April 18 – 21, 2001.

Conference Presentations.

- Workshop on Categorical Topology, Ponta Delgada, Azores, March 18 – 20, 2010; where I was invited speaker and presented the talk Duality-TV (http://www.mat.uc.pt/~catop/).
- Aspects of contemporary topology IV, University of Antwerp, Belgium, December 14 – 19, 2009; where I presented the talk Quantitative domain theory.
- PSSL 89 – Peripatetic Seminar on Sheaves and Logic, Louvain-la-Neuve, Belgium, December 12 – 13, 2009; where I presented the talk More on completely distributive spaces.
- VI Portuguese Category Seminar, University of Coimbra, July 23, 2009; where I presented the talk An unnatural duality.
- 24th Summer Conference on Topology and its Applications, Brno, Czech Republic, July 14 – 17, 2009; where I was invited speaker and presented the talk 'Distributors at work' in Topology (http://www.vutbr.cz/SUMTOP2009).
- CIC '09, Coinduction, Interaction and Composition, Braga, Portugal, May 7 – 8, 2009; where I presented the talk Quantitative domain theory.
- Domains IX, Brighton, United Kingdom, September 22 – 24, 2008; where I presented the talk Continuous V-categories.
- UltraMath 2008 – Applications of Ultrafilters and Ultraproducts in Mathematics, University of Pisa, Italy, June 1 – 7, 2008; where I presented the talk Some aspects of ultrafilter convergence in Topology.
- Aspects of contemporary topology III, University of Antwerp, Belgium, December 10 – 15, 2007; where I presented the talk Completion of Remarks about Completeness.
- Categorical Methods in Algebra, Topology and Computer Science (workshop in honour of Jiří Adámek and Walter Tholen, on the occasion of their sixtieth birthday), University of Coimbra, Portugal, October 26 – 28, 2007; where I presented the talk Cocomplete T-categories, injectivity, and Kan-extensions.
- 22nd Summer Conference on Topology and its Applications, UniversidadJaime I de Castellón, Spain, July 24 – 27, 2007; where I presented the talk A unified treatment of function space structures.
- IV Portuguese Category Seminar, University of Coimbra, December 11, 2006; where I presented the talk Categorical notions in T-categories.
- 21st Summer Conference on Topology and its Applications, Georgia Southern University, Statesboro, GA, July 6 – 9, 2006; where I presented the talk Completeness, Duality, and Injectivity.
- Aspects of contemporary topology II, University of Antwerp, Belgium, December 11 – 17, 2005; where I presented the talk Incomplete remarks about completeness.
- Categorical Methods in Algebra, Topology and Logic, University of Coimbra, Portugal, April 8 and 15, 2005; where I presented the talk Axioms for sequential convergence.
- 19th ‘Summer’ Conference on Topology and its Applications, Capetown, South Africa, July 5 – 9, 2004; where I presented the talk Exponentiation for (weak) transitive structures. (The participation was supported by a grant of the foundation “Calouste Gulbenkian”.)
- **II Portuguese Category Seminar**, University of Coimbra, June 18, 2004; where I presented the talk *Exponentiability in topology*.
- **Aspects of contemporary topology**, University of Antwerp, Belgium, December 14 – 20, 2003; where I presented the talk *From preorders to topological spaces and further*.
- **European Category Theory Meeting**, Haute-Bodeux, Belgium, September 7 – 13, 2003; where I presented the talk *On lax extensions of monads*.
- **V Congresso Ibero-Americano de Topologia e suas Aplicações**, Lorca, Spain, June 10 – 14, 2003; where I presented the talk *Topological quotient maps via ultrafilters*.
- **Workshop on Algebraic homotopy**, Galois theory and Descent, University of Coimbra, January 22, 2003; where I presented the talk *Regular epimorphisms of lax algebras*.
- **Workshop on Categorical Structures for Descent and Galois Theory**, Hopf Algebras and Semialbelian Categories, Fields Institute, Toronto, Canada, September 23 – 28, 2002; where I presented the talk *Descent Theory for Lax Algebras*.
- **5th Annual Workshop on Applications and Generalisations of Complex Analysis**, University of Coimbra, Portugal, March 16, 2002; where I presented the talk *Natural Dualities*.
- **9th Prague Topological Symposium**, Prague, Czech Republic, August 19 – 25, 2001; where I presented the talk *Lax algebras*.
- **IV Congresso Ibero-Americano de Topologia e suas Aplicações**, University of Coimbra, Portugal, April 18 – 21, 2001; where I presented the talk *Topological features of lax algebras*.
- **CatMAT 2000 – Categorical Methods in Algebra and Topology**, University of Bremen, Germany, August 21 – 25, 2000; where I presented the talk *Ultrarelational spaces and triquotient maps*.
- **CT99 – International Category Theory Meeting**, University of Coimbra, Portugal, July 19 – 24, 1999; where I presented the talk *Natural dualities*.
- **Norddeutsches Kategorienseminar**, University of Braunschweig, Germany, February 20 – 21, 1999; where I presented the talk *Stone-type dualities*.
- **II Encontro Projecto ACL Algebraic Combination of Logics**, Figueira da Foz, Portugal, June 22 – 23, 1998; where I presented the talk *Generalised Stone dualities*.
- **International Symposium on Applications of Categorial Methods**, University of Antwerp, Belgium, March 23 – 27, 1998; where I presented the talk *New Proofs for Old Duality Theorems*.

**Colloquia and Seminars.**

- **Triquotient maps via ultrafilter convergence**, Georgia Southern University, Statesboro, USA, April 28, 2008.
- **Continuous V-categories**, University of Coimbra, Portugal, April 22, 2008.
- **Variações sobre um lema de Yoneda** (Variations about a Lemma of Yoneda), University of Lisbon, Portugal, March 28, 2008.
- **De álgebras a Co-álgebras** (From Algebras to Coalgebras), University of Aveiro, Portugal, April 10 and April 23, 2007.
- **Isbell Duality and Compactness**, York University, Toronto, Canada, February 20, 2007.
- **Was ist ein Cauchy-vollständiger topologischer Raum?** (What is a Cauchy-complete topological space?), University of Bremen, Germany, June 7, 2005 (Kolloquium).
- **Folgenbestimmte Räume und ihre Folgen** (Sequential spaces and their (con)sequences), University of Bremen, Germany, June 7, 2005.
- **Einige (unvollständige) Bemerkungen zur Vollständigkeit** (Some incomplete remarks about completeness), University of Bremen, Germany, January 4, 2005.
• Mais notas sobre exponenciabilidade (More remarks about exponentiability), University of Coimbra, Portugal, April 14, 2004.
• Algumas notas sobre exponenciabilidade (Some remarks about exponentiability), University of Aveiro, Portugal, November 21, 2003.
• Eine Beschreibung lokaler Homöomorphismen mittels Ultrafiltern (A description of local homeomorphism via ultrafilters), University of Bremen, Germany, May 14, 2003.
• Topologia sob o ponto de vista da Álgebra (Topology under the point of view of Algebra), University of Aveiro, April 4, 2003.
• Quotient maps between lax algebras, York University, Toronto, Canada, February 6, 2003.
• Various classes of effective descent maps in categories of lax algebras, University of Coimbra, Portugal, June 11, 2002.
• Sobre uma caracterização de aplicações quociente em termos de ultrafiltros (On a characterisation of quotient maps via ultrafilters), University of Coimbra, Portugal, January 15, 2002.
• Lax algebras, University of Antwerp, Belgium, June 11, 2001.
• Topological examples of lax algebras, University of Coimbra, Portugal, February 14, 2001.
• Limit stability of classes of quotient maps, University of Coimbra, Portugal, September 20, 2000.
• Characterisations of special classes of quotient maps via convergence II, University of Coimbra, Portugal, May 10, 2000.
• Natural Dualities, University of Braunschweig, Germany, November 10, 1998.
• Concrete dualities, University of Coimbra, Portugal, April 17, 1998.

4. Publications

Articles in Books.


Articles in Journals (accepted).


Articles in Journals (published).


Submitted Articles.
