General Information

Scientific Programme: The scientific programme consists of 6 invited talks, 1 Special Lecture and 56 contributed talks (33 in plenary sessions and 23 in parallel sessions). There will be parallel sessions on Tuesday and Thursday afternoons.

Invited talks: 50mn + 10mn for discussion.

Contributed talks: 25mn + 5mn for discussion.

All lecture rooms are equipped with a white or black board, a data-show and an overhead projector. Plenary talks will be in the Education Department in Room 5.2.22, and parallel sessions will be in the Mathematics Department in Rooms 11.1.3 and 11.1.10.

Social Events: The social programme includes a welcome reception at the terrace of the restaurant *Olá Ria* ((`www.ola-ria.com`) on Sunday, an excursion to the *Serra da Freita* (Freita mountains) on Wednesday afternoon and a dinner on Thursday in the restaurant *Olá Ria*. Detailed information will be given during the conference.

Coffee Breaks: Coffee breaks are to be held at *Bar da Matemática* located in the ground flour of the Department of Mathematics.

Lunches: Lunch will be served for all conference participants in the University Canteen (with either a fish/meat/vegetarian option).

Internet Facilities: Wifi "eduroam" is available in all Campus. If your institution does not provide "eduroam", you can use:

login: category.theory@visit.uaveiro.eu password: CT2015Aveiro

The following setting should work:

Wi-Fi security: WPA & WPA2 Enterprise

Authentification: PEAP No CA-certificate is required

PEAP version: Automatic

Inner authentification: MSCHAPv2

Bank: There is a branch of a Bank and several cash machines on campus: *Caixa Geral de Depósitos* is open from 8h30 until 15h00, Monday to Friday.

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PROGRAMME

Schedule

	Sunday	Monday	Tuesday		Wednesday	Thursday		Friday
08:30 – 09:00		Registration						
09:00 – 09:30		Opening	Böhm		Rodelo	Berger		Bergner
09:30 – 10:00		Garner						
10:00 – 10:30			Wood		Krause	Lack		Cockett
10:30 – 11:00		Paré	Johnstone			Bourn		Z. Janelidze
11:00 – 11:30		Coffee Break	Coffee Break		Coffee Break	Coffee Break		Coffee Break
11:30 – 12:00		Joyal	Lawvere		G. Janelidze	Rosolini		Riehl
12:00 – 12:30		Rosický			Brown	Sousa		Verity
12:30 – 13:00		Fiore	Menni		Lunch	Zawadowski		Lopez-Franco
13:00 – 14:00		Lunch	Lunch			Lunch		Lunch
14:00 – 14:30					Excursion (from 14:00)			
14:30 – 15:00		Leinster	Leung	Dostál		Martins-Ferreira	Obradovic	Cruttwell
15:00 – 15:30		Johnson	Low	Even		Slevin	Emir	Bourke
15:30 – 16:00		Adamek	Pareja-Tobes	Moss		Solovjovs	Prasma	González Rodríguez
16:00 – 16:30		Coffee Break	Coffee Break			Coffee Break		Coffee Break
16:30 – 17:00		Lucyshyn-Wright	Pinto	van Opdenbosch		Guallart	Abud Alcalá	Gurski
17:00 – 17:30		Metere	Lima	Montañez Puentes		Maruyama	Chikhladze	North
17:30 – 18:00		Montoli	Lucatelli			Koudenburg	Sattler	Avery
18:00 – 18:30	Reception (with Registration)	Duckerts-Antoine						Weber
18:30 – 19:00								
19:00 – 19:30								
19:30 – 20:00						Conference Dinner (from 19:30)		
20:00 –								

Sunday 14

Time	Programme
18:00 - 20:00	Welcome Reception / Registration

Monday 15

Time	Programme
08:30 - 09:00	Registration
09:00 - 09:30	Opening
09:30 - 10:30	R. Garner: The Campbell-Baker-Hausdorff adjunction
10:30 - 11:00	R. Paré: Skolem relations and profunctors
11:00 - 11:30	Coffee Break
11:30 - 12:00	A. Joyal: Witt vectors and the James construction
12:00 - 12:30	J. Rosický: Classification theory for accessible categories
12:30 - 13:00	M. Fiore: Theory of para-toposes
13:00 - 14:30	Lunch
14:30 - 15:00	T. Leinster: The reflexive completion
15:00 - 15:30	M. Johnson: Symmetrizing categories of lenses
15:30 - 16:00	J. Adámek: Reflective subcategories of locally presentable categories
16:00 - 16:30	Coffee Break
16:30 - 17:00	Lucyshyn-Wright: A general theory of measure and distribution monads founded on the notion of commutant of a subtheory
17:00 - 17:30	G. Metere: Aspects of strong protomodularity, actions and quotients
17:30 - 18:00	A. Montoli: On the “Smith is Huq” condition in S-protomodular categories
18:00 - 18:30	M. Duckerts-Antoine: A classification theorem for normal extensions

TUESDAY 16

Time	Programme	
09:00 - 10:00	G. Böhm: Hopf monoids in duoidal categories	
10:00 - 10:30	R. Wood: Waves and total distributivity	
10:30 - 11:00	P. Johnstone: Functoriality of modified realizability	
11:00 - 11:30	Coffee Break	
11:30 - 12:30	B. Lawvere: Alexander Grothendieck and the modern conception of Space	
12:30 - 13:00	M. Menni: An 'algebraic' model of a bidirectional Euler continuum	
13:00 - 14:30	Lunch	
	Room 11.1.3	**Room 11.1.10**
14:30 - 15:00	P. Leung: The free tangent structure	M. Dostál: Two-dimensional Birkhoff's theorem
15:00 - 15:30	Z. Low: Generalising the functor of points approach	V. Even: Central extensions and closure operators in the category of quandles
15:30 - 16:00	E. Pareja-Tobes: Dagger category theory	S. Moss: Another approach to the Kan-Quillen model structure
16:00 - 16:30	Coffee Break	
16:30 - 17:00	D. Pinto: An abstract approach to Glivenko's theorem	K. van Opdenbosch: Regularity for relational algebras and the case of approach spaces
17:00 - 17:30	G. Lima: Site characterisations for local geometric morphisms	J.R. Montañez Puentes: Some topoi generated by topological spaces
17:30 - 18:00	F. Lucatelli: Kan extensions and descent theory	

Wednesday 17

Time	Programme
09:00 - 10:00	D. Rodelo: A tour through n-permutability
10:00 - 11:00	H. Krause: Stratication of triangulated categories
11:00 - 11:30	Coffee Break
11:30 - 12:00	G. Janelidze: Exponentiable homomorphisms of algebras
12:00 - 12:30	R. Brown: A philosophy of modelling and computing homotopy types
12:30 - 14:00	Lunch
14:00	Excursion

Thursday 18

Time	Programme	
09:00 - 10:00	C. Berger: Algebraic and homotopical nilpotency	
10:00 - 10:30	S. Lack: Multiplier bimonoids, multiplier bicomonads, and comonads in a simplicial set	
10:30 - 11:00	D. Bourn: Partial Mal'tsevness and category of quandles	
11:00 - 11:30	Coffee Break	
11:30 - 12:00	G. Rosolini: Exact completions as homotopical quotients	
12:00 - 12:30	L. Sousa: Categories of "lax fractions"	
12:30 - 13:00	M. Zawadowski: Fibrations of polynomial and analytic functors and monads	
13:00 - 14:30	Lunch	
	Room 11.1.3	**Room 11.1.10**
14:30 - 15:00	N. Martins-Ferreira: Categories with 2-cell structures and their internal pseudocategories	J. Obradovic: On the various definitions of cyclic operads
15:00 - 15:30	P. Slevin: Cyclic homology arising from adjunctions	K. Emir: Pointed homotopy of 2-crossed module maps and groupoid structure
15:30 - 16:00	S. Solovjovs: On monoidal (co)nuclei and their applications	M. Prasma: The Grothendieck construction for model categories
16:00 - 16:30	Coffee Break	
16:30 - 17:00	N. Guallart: A comparison between ITT and CoC	R. Abud Alcalá: Comodules for coalgebroids
17:00 - 17:30	Y. Maruyama: Higher-order categorical substructural logics	D. Chikhladze: Another perspective on skew monoidal structures
17:30 - 18:00	S. Koudenburg: Yoneda embeddings in double categories	C. Sattler: Initial algebras for dependent from plain polynomial functors in quasicategories

19:30	Conference Dinner

Friday 19

Time	Programme
09:00 - 10:00	J. Bergner: Models for homotopical higher categories
10:00 - 10:30	R. Cockett: Itegories
10:30 - 11:00	Z. Janelidze: On a symmetric proof of the non-abelian snake lemma
11:00 - 11:30	Coffee Break
11:30 - 12:00	E. Riehl: Virtual equipments for ∞-categories
12:00 - 12:30	D. Verity: The calculus of modules for ∞-categories
12:30 - 13:00	I. López-Franco: Aspects of lax orthogonal factorisation systems
13:00 - 14:30	Lunch
14:30 - 15:00	G. Cruttwell: The Jacobi identity for tangent categories
15:00 - 15:30	J. Bourke: Skew structures in 2-category theory and homotopy theory
15:30 - 16:00	R. González Rodríguez: Equivalences and iterations for weak crossed products
16:00 - 16:30	Coffee Break
16:30 - 17:00	N. Gurski: Distributive laws for quasicategories
17:00 - 17:30	P. North: Weak factorization systems for intensional type theory
17:30 - 18:00	T. Avery: Codensity and the Giry monad
18:00 - 18:30	M. Weber: Internal algebra classifiers as codescent objects of crossed internal categories

ABSTRACTS

Ramón Abud Alcalá
Macquarie University

Comodules for coalgebroids

Quantum categories have been studied intensively by several authors in the past few years because of their relation to bialgebroids, skew monoidales, and small categories. In a monoidal bicategory, a quantum category (or rather its dual) is defined as an opmonoidal monad on a monoidale generated by a biduality $R \dashv R^o$. If we drop the monad requirement – and work with several bidualities at a time – we get what in the bicategory **Mod** Szlachányi calls an $S|R$-coalgebroid. Comodules for these $S|R$-coalgebroids are defined using only the underlying R-coring structure, but there is a theorem by Phùng which highlights the role of S by providing a forgetful functor from the category of comodules for an $S|R$-coalgebroid to the category of two-sided S-R-modules.

Now, given an opmonoidal arrow $C : S^o \otimes S \longrightarrow R^o \otimes R$ in a monoidal bicategory, we can express what a C-coaction for an arrow $S \longrightarrow R$ should be, and for the underlying "coring" $C' : R \longrightarrow R$ there is also a way to say what a C'-coalgebra should be. In this talk, we will examine the equivalence of this two notions under suitable assumptions on the bicategory. Finally, adding the monad axiom, we are able to provide the category of comodules for a quantum category with a monoidal structure such that the forgetful functor is monoidal.

Jiří Adámek*
Institut für Theoretische Informatik, Technische Universität Braunschweig

Reflective subcategories of locally presentable categories

For full subcategories $\mathcal{K}$ of a locally presentable category the Reflection Theorem of [1] states that $\mathcal{K}$ is reflective iff it is closed under limits and λ-filtered colimits for some λ. The proof is based on the fact that such a subcategory is closed under λ-pure subobjects (i.e. λ-filtered colimits of split monomorphisms). A beautiful result of Makkai and Pitts works with iso-full subcategories, which means that $\mathcal{K}$ contains every isomorphism of the larger category whose domain and codomain lie in $\mathcal{K}$. If such a subcategory is closed under limits and filtered colimits (here $\lambda = \omega$), then it is reflective, see [2]. The proof is based on the fact that such subcategories are closed under elementary embeddings. Can one generalize this result from ω to λ? Alas!, we do not know. But we prove that every iso-full subcategory closed under limits, λ-filtered colimits and λ-elementary embeddings is reflective.

References:

[1] J. Adámek and J. Rosický, Locally presentable and accessible categories, *Cambridge University Press*, 1994.

[2] M. Makkai and A. M. Pitts, Some results on locally finitely presentable categories, *Trans. Amer. Math. Soc.* 299 (1987) 473-496.

*Joint work with Jiří Rosický.

Tom Avery
University of Edinburgh

Codensity and the Giry monad

The Giry monad on the category of measurable spaces sends a space to the set of probability measures on it, equipped with a suitable measurable space structure. It provides a categorical context for probability theory, and is a member of a loose family of monads that we may think of as "measure monads". Perhaps the most primitive monad in this family is the ultrafilter monad on the category of sets; an ultrafilter is a finitely additive probability measure taking only the values 0 and 1. A theorem of Gildenhuys and Kennison describes the ultrafilter monad as the codensity monad of the inclusion of finite sets into sets. I will give a similar characterisation of the Giry monad and related measure monads (and hence also of the corresponding notions of measure and integration) in terms of codensity monads involving categories of convex sets.

References:

[1] T. Avery, Codensity and the Giry monad. *arXiv:1410.4432* (2014).

[2] M. Giry, A Categorical Approach to Probability Theory. In *Categorical aspects of topology and analysis,* volume 915 of *Lecture Notes in Mathematics.* Springer, (1982) 68–85.

[3] D. Gildenhuys and J. F. Kennison, Equational completion, model induced triples and pro-objects. *Journal of Pure and Applied Algebra* 1(4) (1971) 317–346.

Clemens Berger*
Université de Nice-Sophia Antipolis

Algebraic and homotopical nilpotency

We present a general concept of nilpotency for exact Mal'cev and semi-abelian categories, based on the notion of central extension. The reflection into the subcategory of n-nilpotent objects has several most specific properties. We discuss under which conditions this reflection may be characterized as the universal endofunctor with vanishing cross-effects of order $n+1$, where we use an algebraic version of Goodwillie's cubical cross-effects. Finally, several notions of homotopical nilpotency for the simplicial objects of a pointed Mal'cev variety are compared. In the case of simplicial groups, we recover as special instances the Berstein-Ganea nilpotency for loop spaces and the Biedermann-Dwyer nilpotency for homotopy nilpotent groups.

References:

[1] C. Berger and D. Bourn, Central reflections and nilpotency in exact Mal'cev categories, preprint 2015, 50 pages.

[2] T. Goodwillie, Calculus III. Taylor Series, *Geom. Topol.* 7 (2003), 645–711.

[3] I. Berstein and T. Ganea, Homotopical nilpotency, *Illinois J. Math.* 5 (1961), 99–130.

[4] G. Biedermann and W. Dwyer, Homotopy nilpotent groups, *Alg. & Geom. Topology* 10 (2010), 33–61.

*Joint work with Dominique Bourn.

Julie Bergner
University of California, Riverside

Models for homotopical higher categories

An (∞, n)-category should have morphisms at all levels, but those morphisms should be weakly invertible above level n. While the case of $n = 1$ is fairly well-understood, with several different models known to be equivalent, but there are many different ways to generalize each of them for higher n. Making these different models precise and giving explicit comparisons is currently being done by several different authors. In this talk we'll look at several of the approaches to (∞, n)-categories and known comparisons between them.

Gabriella Böhm*
Wigner RCP, Budapest

Hopf monoids in duoidal categories

There are similar principles distinguishing groups among monoids, groupoids among small categories, (weak) Hopf algebras among (weak) bialgebras, Hopf algebroids among bialgebroids, Hopf monads among opmonoidal monads (also known as bimonads) and so on. In each case, there are several equivalent characterizations which have, however, conceptually different meanings. The simplest one is the existence of a certain kind of 'antipode' generalizing the inverse operation in groups or groupoids.

All the above listed structures – monoids, small categories, (weak) bialgebras, bialgebroids and suitable opmonoidal monads – can be treated in the unifying framework of bimonoids in so-called duoidal categories [1]; that is, in categories carrying two different, compatible monoidal structures.

The talk will be devoted to the understanding of what equivalent properties distinguish Hopf monoids among bimonoids in duoidal categories. In particular, in duoidal categories stemming from naturally Frobenius map monoidales in monoidal bicategories as in [4] (covering all of the listed examples), a criterion in terms of an appropriately defined antipode is given.

References:

[1] Marcelo Aguiar and Swapneel Mahajan, *Monoidal Functors, Species and Hopf Algebras.* CRM Monograph Series 29, American Math. Soc. Providence, 2010.

[2] Gabriella Böhm, Yuanyuan Chen and Liangyun Zhang, *On Hopf monoids in duoidal categories*, J. Algebra 394 (2013), 139-172.

[3] Gabriella Böhm and Stephen Lack, *Hopf comonads on naturally Frobenius map-monoidales*, preprint available at `http://arxiv.org/abs/1411.5788`.

[4] Ross Street, *Monoidal categories in, and linking, geometry and algebra*, Bull. Belg. Math. Soc. Simon Stevin 19 (2012), 769-933.

*Based on joint works with Yuanyuan Chen and Liangyun Zhang [2]; and with Steve Lack [3].

John Bourke
Masaryk University, Brno

Skew structures in 2-category theory and homotopy theory

The notion of skew monoidal category was introduced by Szlachányi in the study of bialgebroids over rings. Street introduced skew closed categories and described, in contrast to the classical setting, a perfect correspondence between skew monoidal and skew closed structure. In this talk I will explain how skew monoidal and closed structures naturally appear in 2-category theory and how they illuminate classical constructions in the area. We will also take a look at skew structures arising in other homotopical contexts.

References:

[1] Szlachányi, K., Skew-monoidal categories and bialgebroids, *Advances in Mathematics* 231 (2012) 1694–1730.

[2] Street, Ross, Skew-closed categories, *Journal of Pure and Applied Algebra* 217 (2013) 973-988.

Dominique Bourn
Université du Littoral, Calais

Partial Mal'tsevness and category of quandles

A Mal'tsev category is a category in which any reflexive relation is an equivalence relation, see [3]. The categories *Gp* of groups and *K-Lie* of Lie algebras are major examples of Maltsev categories. A soon as a Maltsev category is regular, any pair (R, S) of equivalence relations on an object X does permute (i.e. $R \circ S = S \circ R$). Besides, it is a context which allows to deal intrinsically with the notion of centralization of equivalence relations. In [1], Mal'tsev categories were characterized by a property of the class of split epimorphisms.

The category of quandles, an algebraic structure introduced by Knot theorits, see [6], [5] and also [4], gives rise to an example of a new situation where the Mal'tsev condition of [1] is only satisfied by a subclass Σ of split epimorphisms which is stable under pullback and contains the isomorphisms.

We shall show here that this partial Mal'tsev condition implies, still in the regular context, the permutation of a certain subclass $\bar{\Sigma}$ of equivalence relations with any other equivalence relation and allows to deal intrinsically with the notion of centralization of the $\bar{\Sigma}$-equivalence relations with any other equvalence relation as well. Moreover if we call Σ-special an extention $f : X \to Y$ such that its kernel relation $R[f]$ lies in $\bar{\Sigma}$, then we get the Baer sums of abelian Σ-special extensions with a given direction on the model of [2], provided that the ground category is efficiently regular and the class Σ satisfies a further left exact condition.

References:

[1] D. Bourn, Mal'cev categories and fibration of pointed objects, *Appl. Categ. Structures* 4 (1996) 307–327.

[2] D. Bourn, Baer sums and fibered aspects of Mal'cev operations, *Cahiers de Top. et Géom. Diff.* 40 (1999), 297–316.

[3] A. Carboni, J. Lambek and M.C. Pedicchio, Diagram chasing in Mal'cev categories, *J. Pure Appl. Algebra* 69 (1991) 271–284.

[4] V. Even and M. Gran, On factorization systems for surjective quandle homomorphisms, *J. Knot Theory and its Ramifications* 23(11) (2014) 1450060.

[5] D. Joyce, A classifying invariant of knots, the knot quandle, *J. Pure Appl. Algebra* 23 (1982) 37–65.

[6] S.V. Matveev, Distributive groupoids in knot theory, *Mat. Sb. (N.S)* 119 (161) (1982) 78–88.

Ronald Brown
Bangor University

A philosophy of modelling and computing homotopy types

This philosophy involves homotopically defined functors $\mathbb{H}$ from (topological data) to (algebraic data), and conversely "classifying space" functors $\mathbb{B}$ from (algebraic data) to (topological data). These should satisfy:

1. $\mathbb{H}\mathbb{B}$ is naturally equivalent to 1.

2. $\mathbb{H}$ preserves certain colimits: this allows some computation.

3. The algebraic data splits into several equivalent kinds, ranging from "broad" to "narrow", related by non trivial Dold-Kan type equivalences. The broad data is used for conjecturing and proving theorems; the narrow data is used for calculations and relating to classical methods.

4. The topological data is of a structured type, involving dimensions, reflecting the fact that the data to specify a space often has an associated dimensionwise structure.

As an example we will consider n-cubes of pointed spaces, and the algebraic models of cat^n-groups, and crossed n-cubes of groups. For $n = 1$ we get maps of spaces, and crossed modules. Calculations of the 2-type of mapping cones of $\mathbb{B}f$ for f a morphism of groups have been made by Wensley and RB. I show how to extend these to determine the 3-type of a mapping cone of $\mathbb{B}f$ when f is a morphism of crossed modules, by using crossed squares.

Dimitri Chikhladze
Centre for Mathematics, University of Coimbra

Another perspective on skew monoidal structures

Following the work [1], we consider a certain perspective on skew monoidal structures in the sense of the series of papers starting from [2] by S. Lack and R. Street following the work of Szlachányi [3].

References:

[1] Dimitri Chikhladze, Lax formal theory of monads, monoidal approach to bicategorical structures and generalized operads, to appear in *Theory and Applications of Categories*, arXiv:1412.4628.

[2] S. Lack, R. Street, Skew monoidales, skew warpings and quantum categories, *Theory and Applications of Categories* 26 (2012) 385–402.

[3] Szlachányi, Skew-monoidal categories and bialgebroids, *Advances in Mathematics* 231 (2012) 1694–1730.

Robin Cockett*
University of Calgary

Itegories

In memory of Bob Walters.

Bob would not have said it this way nor necessarily would he have approved but an itegory – though he may not have known it – is something he certainly thought about. An itegory is a basic categorical setting for the semantics of (sequential) programs. It is –simply put—an extensive restriction category [2] with a trace (or an iteration) on the coproduct. Such a trace can be formulated as a "Kleene wand" which can be characterized by just two equations and a uniformity requirement. Its computational behaviour is essentially that of a "while loop".

In general, for an extensive restriction category, having a Kleene wand is structure rather than a property. However, having an *inductive* Kleene wand is a property. Furthermore, every extensive restriction category can be embedded into an extensive restriction category with an inductive wand. A natural way in which an inductive Kleene wands arise is when the category has a natural number object which is simultaneously a conatural number object: a situation which pertains to the partial map categories of toposes.

An important and general way to characterize computation [1] is as the computable maps of a Partial Combinatory Algebra (PCA). It is not the case that every itegory can represent all partial computable maps. For example, finite sets and partial maps form a perfectly good itegory, however, this category contains no non-trivial PCAs. On the other hand, once an itegory has an infinite object (in a certain sense), one can use the iteration to construct a PCA and thus show that all computations can be expressed in such categories.

References:

[1] Cockett and Hofstra, *Introduction to Turing categories*, APAL, 156(2-3):183-209, 2008.

[2] Cockett and Lack, *Restriction categories III: colimits, partial limits, and extensivity*, Mathematical Structures in Computer Science, 17(4):775-817, 2007.

*This is joint work with Pieter Hofstra, Chad Nester, and Michael St-Jules.

Geoff Cruttwell*
Mount Allison University

The Jacobi identity for tangent categories

A tangent category, first defined by Rosický [5], is a category equipped with an abstract analog of the tangent bundle functor. Examples of such categories include the ordinary category of smooth manifolds, the category of convenient smooth manifolds [4], categories in synthetic differential geometry [3], and Cartesian differential categories [1].

The Jacobi identity is one of the key results for the Lie bracket of vector fields on the tangent bundle. Rosický showed how to define the Lie bracket for vector fields in a tangent category, and gave a proof of the Jacobi identity in this setting; however, his proof required additional limit assumptions for the tangent category. In this talk, I'll present a proof of the Jacobi identity that does not require any additional assumptions on the tangent category.

References:

[1] Blute, R., Cockett, R. and Seely, R. Cartesian differential categories. *Theory and Applications of Categories*, **22**, pg. 622–672, 2008.

[2] Cockett, R. and Cruttwell, G. Differential structure, tangent structure, and SDG. *Applied Categorical Structures*, **22**, pg. 331–417, 2014.

[3] Kock, A. *Synthetic Differential Geometry*, Cambridge University Press (2nd ed.), 2006.

[4] Kriegl, A. and Michor, P. *The convenient setting of global analysis.* AMS Mathematical Surveys and monographs, vol. 53, 1997.

[5] Rosický, J. Abstract tangent functors. *Diagrammes*, 12, Exp. No. 3, 1984.

*Joint work with Robin Cockett.

Matěj Dostál
Czech Technical University in Prague

Two-dimensional Birkhoff's theorem

Birkhoff's theorem from classical universal algebra states that a subcategory of a category of (one-sorted) algebras is given by a set of equations if and only if it is closed under quotient algebras, subalgebras, and products. In the classical case, adding new equations to a theory given by a monad T corresponds to forming a quotient monad S of T. In the case of enrichment in categories, we follow this approach by considering quotient monad morphisms arising from the factorisation system (b. o. full, faithful) on Cat, which lifts to the 2-category of strongly finitary monads over Cat by results of [1]. We give a Birkhoff-style result in this setting: we characterise equationally defined subcategories of algebraic categories by their closure properties.

References:

[1] J. Bourke and R. Garner, Two-dimensional regularity and exactness, *J. Pure Appl. Algebra* 218 (2014) 1346–1371.

Mathieu Duckerts-Antoine*
Centre for Mathematics, University of Coimbra

A classification theorem for normal extensions

In [1], a generalized Galois theorem has been proved in the large context of so-called admissible Galois structures. These are adjunctions $\langle I, H\rangle \colon \mathscr{C} \rightharpoonup \mathscr{X}$ with classes of morphisms ("extensions") $\mathcal{E}$ and $\mathcal{Z}$ (of $\mathscr{C}$ and $\mathscr{X}$, respectively) satisfying suitable properties. In my talk, I will explain how we can obtain a similar classification theorem for normal extensions for a particular class of (not necessarily admissible) Galois structures. I will also give some criteria for the existence of a normalisation functor.

References:

[1] G. Janelidze, Pure Galois theory in categories, *J. Algebra* 132 (1990) 270–286.

*Joint work with Tomas Everaert.

Kadir Emir*
CMA, Universidade Nova de Lisboa and Eskişehir Osmangazi University

Pointed homotopy of 2-crossed module maps and groupoid structure

We address the homotopy theory of 2-crossed modules of commutative algebras, which are equivalent to simplicial commutative algebras with Moore complex of length two. In particular, we construct a homotopy relation between 2-crossed module maps, and prove that it yields an equivalence relation in very unrestricted cases, strictly containing the case when the domain 2-crossed module is cofibrant, defining, furthermore, a groupoid with objects the 2-crossed module maps between two fixed 2-crossed modules, the morphisms being their homotopies.

References:

[1] İ. Akça, J.F. Martins and K. Emir. Pointed homotopy of maps between 2-crossed modules of commutative algebras. *arXiv:1411.6931*.

[2] Z. Arvasi and T. Porter. Simplicial and crossed resolutions of commutative algebras. *J. Algebra*, 181(2):426–448, 1996.

*Joint work with İlker Akça and João Faria Martins.

Valérian Even*
Université catholique de Louvain

Central extensions and closure operators in the category of quandles

The aim of this talk is to present some recent results concerning two adjunctions: the first one between the category Qnd of quandles and its subcategory Qnd* of trivial quandles, and the second one between the category of quandles and its Mal'tsev subcategory of abelian symmetric quandles. We will show that these adjunctions are admissible in the sense of categorical Galois theory thanks to some results about the permutability of two different classes of congruences in the category of quandles [5, 2, 7]). We will then give an algebraic description of the corresponding central extensions [6], which for the first adjunction turn out to correspond [3] to the quandle coverings investigated in [2]. We will also examine closure operators for subobjects in the category of quandles. The regular closure operator and the pullback closure operator both corresponding to the reflector from Qnd to Qnd* coincide [4], and we will give an algebraic description of this closure operator. Finally, we will show that the category of connected quandles is a connectedness (see [1] for example) corresponding to the category of trivial quandles.

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*Joint work with M. Gran and A. Montoli.

Marcelo Fiore[*]
Computer Laboratory, University of Cambridge

Theory of para-toposes

A para-topos is a cartesian closed locally presentable category. Grothendieck toposes and quasi-toposes, frames, the category of small categories, and the category of ω-complete partial orders are examples. Every para-topos is a cartesian localisation of a presheaf category. Other examples include the category of algebraic models of the opposite of a small distributive category. A geometric morphism of para-toposes is defined as a pair of adjoint functors, with the left adjoint preserving finite products. We study exponentiable para-toposes. We show that the bicategory of free para-toposes (free over a cartesian category) is cartesian closed.

[*]Joint work with André Joyal.

Ramón González Rodríguez*
Universidade de Vigo

Equivalences and iterations for weak crossed products

Let A be a monoid and let V be an object living in a strict monoidal category $\mathcal{C}$ where every idempotent morphism splits. In [1] an associative product, called the weak crossed product of A and V, was defined on the tensor product $A \otimes V$ working with quadruples $A_V = (A, V, \psi_V^A, \sigma_V^A)$ where $\psi_V^A : V \otimes A \to A \otimes V$ and $\sigma_V^A : V \otimes V \to A \otimes V$ are morphisms satisfying some twisted-like and cocycle-like conditions. Associated to these morphisms we define an idempotent morphism $\nabla_{A \otimes V} : A \otimes V \to A \otimes V$ whose image, denoted by $A \times V$, inherits the associative product from $A \otimes V$. In order to define a unit for $A \times V$, and hence to obtain a monoid structure in this object, we complete the theory in [4] using the notion of preunit.

In this talk, we give a criterion that characterizes equivalent weak crossed products, and, as an application, we show that the main results proved by Panaite in [8], for Brzeziński's crossed products, admits a substantial improvement. On the other hand, we show how iterate weak crossed products with common monoid. More concretely, if $(A \otimes V, \mu_{A \otimes V})$ and $(A \otimes W, \mu_{A \otimes W})$ are weak crossed products, we find sufficient conditions to obtain a new weak crossed product $(A \otimes V \otimes W, \mu_{A \otimes V \otimes W})$. Also, we present the conditions under which there exists a preunit for $(A \otimes V \otimes W, \mu_{A \otimes V \otimes W})$ and we discuss some examples involving wreath products [4], weak wreath products [9], and the iteration process for Brzeziński crossed products proposed recently by Dăuş and Panaite in [3]. Finally, following the results proved in [5], we obtain a new characterization of the iteration process.

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*Joint work J.M. Fernández Vilaboa and A.B. Rodríguez Raposo.

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Richard Garner
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The Campbell–Baker–Hausdorff adjunction

The Lie algebra associated to a Lie group G encodes the first-order infinitesimal structure of G near the identity; on the other hand, the *formal group law* associated to G is a collection of formal power series which encode all finite-order infinitesimal behaviour. One obtains the formal group law from the Lie group by Taylor expanding the multiplication with respect to some chart around the identity; alternatively, one may obtain the formal group law from the Lie algebra by applying the *Campbell–Baker–Hausdorff* (CBH) formula, which expresses the group multiplication power series near the identity purely in terms of iterated Lie brackets.

There are a number of ways of deriving the CBH formula, some geometric and some algebraic in nature. The aim of this talk is to describe a categorical approach drawing on synthetic differential geometry. We consider a category $\mathcal{E}$ of microlinear spaces wherein formal group laws may be construed as genuine internal groups; we then construct an adjunction, the Campbell–Baker–Hausdorff adjunction of the title, between internal groups and internal Lie algebras in $\mathcal{E}$. Applying the left adjoint to a finite dimensional Lie algebra yields its associated formal group law; applying it to the free Lie algebra on two generators yields the free group on two non-commuting tangent vectors, whose multiplication may be seen as a pure combinatorial manifestation of the CBH formula.

Nino Guallart
Universidad de Sevilla

A comparison between ITT and CoC

Martin-Löf's intuitionistic type theory (ITT) and Coquand's calculus of constructions (CoC) are two well-known intuitionistic dependent type type theories (or maybe we should say families of type theories, since there are several versions of these systems) that share many features and have similar expressive power, yet there are noticeable differences between them, the main one being that ITT in its mature formulation is a predicative system in which propositions and the types of their proofs can be identified via Curry-Howard isomorphism (an earlier impredicative version showed to be inconsistent), whereas CoC is an impredicative system in which there are non-propositional types. Since the categorical semantics of extensional dependent type systems is given by locally Cartesian closed categories, the aim of this work is to sketch a comparison between these two systems, remarking both their similarities and their differences from a semantical point of view.

A practical application of this comparison can be given in computational terms. ITT and CoC are strongly normalising (and therefore non Turing-complete) type systems, so they can be seen as the basis for functional programing languages such as Coq or Agda. The Turing-incompleteness is not a flaw but an advantage if we apply these systems to fields such as proof theory or type checking. Therefore, the previous comparison between these systems can be extended to their computational implementations and their eventual uses.

Nick Gurski[*]
University of Sheffield

Distributive laws for quasicategories

Distributive laws are a tool for combining a pair of monads S, T on the same category. The fundamental results in the theory of distributive laws are that a distributive law $\lambda : ST \Rightarrow TS$ corresponds to a lift $\tilde{T}$ of T to the category of S-algebras, gives the composite TS the structure of a monad, and that TS-algebras are then the same as $\tilde{T}$-algebras. I will discuss work extending these results to homotopy-coherent monads on quasicategories.

[*]Joint work with James Cranch.

George Janelidze
University of Cape Town

Exponentiable homomorphisms of algebras

This is (the third part of) a joint work with Maria Manuel Clementino and Dirk Hofmann on the exponentiability of homomorphisms of algebras over monads, and, in particular, of classical algebraic structures; it partly uses the results of [1] and [2], and will be published in [3]. However, in contrast to [1], now we shall neither restrict our attention to the case of a weakly cartesian monads nor make any use of lax algebras. The case of semimodules is interesting again (as in [2]), while in 'almost semi-abelian' cases only isomorphisms are exponentiable.

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Zurab Janelidze
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On a symmetric proof of the non-abelian snake lemma

In this talk we present a non-abelian calculus of subquotients, which leads to a "symmetric" proof of the non-abelian snake lemma. The categorical context in which this is carried out is a self-dual generalization of the context of a semi-abelian category, proposed in my CT2013 talk. It also generalizes the context of a Grandis exact category, in which case the proof obtains a simpler and known self-dual form.

Michael Johnson*
Macquarie University

Symmetrizing categories of lenses

So called *lenses* arise in applications where data needs to be synchronised between two otherwise independent systems. A variety of kinds of lenses have been introduced (examples include [1], [2] and [4]), but in each case lenses compose and form a category, typically with sets or categories as objects. When the categories of lenses have sets as their objects the lenses are called *set-based*, and when they have categories as their objects they are called *category-based*.

Commonly lenses are asymmetric in that the data synchronisation is simple in one direction, but requires some kind of lifting property in the other direction. An example of a lens familiar to category theorists is a split fibration — the total space is fibred over a base space with the functor giving synchronisation in one direction and the chosen cartesian liftings representing synchronisation in the other direction. In system terms such lenses are master-slave systems — the total space is the complete system with full information, and the base space is some kind of view, that is a partial representation of the data.

More generally interactions between systems are symmetric in that synchronisation in each direction requires a mixture of some simple data manipulation and some liftings. Researchers have therefore repeatedly taken some category $\mathcal{C}$ of asymmetric lenses and, largely in an ad-hoc way, constructed corresponding categories of symmetric lenses. The authors have argued previously that these constructions should all be made via a bicategory $\mathrm{Sp}\,\mathcal{C}$ of spans in $\mathcal{C}$, and we have studied appropriate equivalences among spans which reduce the bicategory to the expected category of symmetric lenses. The goal has been a unified category theoretic process for symmetrizing categories of lenses.

Naturally an appropriate equivalence of spans would include the usual isomorphisms of spans, but the isomorphisms themselves are too fine an equivalence relation for the applications since the same symmetric lens — the same bidirectional synchronisation of data — can be achieved through non-isomorphic spans. A natural and appealing generalisation of the isomorphism equivalence relation arises by using certain non-trivial lenses themselves to generate the equivalence relation. This suggestion has been very well-received in the bidirectional transformation community, and corresponds to the intuition that lenses are themselves a desirable generalisation of isomorphism of systems, providing as they do bidirectional data synchronisation. Indeed we had proposed [6] a unified process for symmetrizing categories of lenses by constructing $\mathrm{Sp}\,\mathcal{C}$ and reducing the hom sets by the equivalence relation generated by those non-trivial lenses of $\mathcal{C}$. We demonstrated that for a variety of kinds of set-based lenses the process yielded the known categories of symmetric lenses, and showed how it could be applied to other categories of set-based lenses to provide an appropriate symmetrization, avoiding further ad-hoc definitions of symmetric set-based lenses.

*Joint work with Robert Rosebrugh.

We present here a study of category-based asymmetric and symmetric lenses and provide a counter-example that demonstrates that the equivalence referred to in the previous paragraph is still too fine an equivalence relation for the category-based lens applications. Our analysis leads to a coarser equivalence relation $\mathcal{E}$ for the category-based symmetrizing process. When $\mathcal{C}$ is the category of Diskin et al's asymmetric delta lenses [2] our main theorem provides an isomorphism between Diskin et al's symmetric delta lenses [3] and

$$(\mathrm{Sp}\,\mathcal{C})/\mathcal{E}.$$

Further we illustrate the equivalence relation in the special case of spans of split fibrations.

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Functoriality of modified realizability

Recent work of the author [1], building on earlier work of Longley and of Hofstra & van Oosten, has completely solved the problem of describing the geometric morphisms between ordinary realizability toposes: up to equivalence of categories, they correspond to quasi-surjective (applicative) morphisms between the underlying Schönfinkel algebras. In addition, the identification of the 'Herbrand realizability toposes' of van den Berg with the Gleason covers of ordinary realizability toposes [2] shows that Herbrand realizability is also a 2-functor on the 2-category of Schönfinkel algebras and quasi-surjective morphisms, although we cannot assert that all geometric morphisms between such toposes arise in this way. Although the notion of modified realizability has been extensively studied by van Oosten and by Hyland and Ong, up to now little attention has been paid to its functoriality. In this talk I shall present a partial solution to the problem; it turns out to be complicated by the fact that a modified realizability topos depends, not only on the choice of a Schönfinkel algebra, but also on the choice of a 'right ideal' of distinguished elements which are always available as potential realizers.

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André Joyal*
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Witt vectors and the James construction

The Witt vectors construction is a comonad on the category of commutative rings [1] [2]. We show that the comonad is cofreely cogenerated by a pointed endo-functor. The proof uses an abstract version of the James construction in topology [2] and the theory of Tall and Wraith [4].

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*Joint work with Pierre Cartier, IHES.

Seerp Roald Koudenburg

Yoneda embeddings in double categories

We will consider the notion of yoneda embedding in a double category $\mathcal{K}$. Then, given a monad T on $\mathcal{K}$, we describe the lifting of such yoneda embeddings along the forgetful functor $U\colon \mathsf{Alg}(T) \longrightarrow \mathcal{K}$, where $\mathsf{Alg}(T)$ is the double category of algebras of T.

To recover a well-known example we look at the monad for monoidal categories. In that case the lifting of the yoneda embedding $\mathrm{y}\colon A \longrightarrow [A^{\mathrm{op}}, \mathsf{Set}]$ of a monoidal category A equips $[A^{\mathrm{op}}, \mathsf{Set}]$ with Day's convolution tensor product [1]. From our point of view $\mathrm{y}\colon A \longrightarrow [A^{\mathrm{op}}, \mathsf{Set}]$, with the convolution structure on $[A^{\mathrm{op}}, \mathsf{Set}]$, lifts to form a yoneda embedding, and consequently defines $[A^{\mathrm{op}}, \mathsf{Set}]$ as the free cocompletion of A, in the double category of monoidal categories. This sheds new light on classical results such as those in [2].

By taking the monad for double categories instead we obtain a notion of yoneda embedding for double categories which is closely related to, and gives further insight into, a similar notion studied by Paré [3].

This work is a continuation of my study of 'formal category theory' within double categories [4, 5].

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Henning Krause
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Stratification of triangulated categories

For an additive category it is a fundamental question to ask when there are non-zero morphisms between two given objects. Support theory for triangulated categories provides answers to this question. My talk will give an introduction to this subject, covering examples from commutative algebra, stable homotopy theory, and modular representation theory.

Steve Lack*
Macquarie University

Multiplier bimonoids, multiplier bicomonads, and comonads in a simplicial set

For a finite group G and a commutative ring k, both the group algebra $k[G]$ and the algebra of functions k^G can be made into Hopf algebras. For infinite G there is still a Hopf algebra $k[G]$, but the situation with the algebra of functions (with finite support) is more complicated; in general it has neither a unit nor a comultplication. The concept of multiplier Hopf algebra was introduced by van Daele to deal with this situation.

This concept of multiplier bialgebra can be developed in the context of a general braided monoidal category. Furthermore, just as tensoring with a bialgebra gives a monoidal comonad (also known as a bicomonad), so tensoring with a multiplier bialgebra gives something called a multiplier bicomonad. Unlike the classical case, these multiplier bicomonads do not seem to be comonads in any bicategory, but it turns out they can be seen as "comonads in a simplicial set". Just as comonads (and monads) in bicategories can be classified using the Catalan simplicial set, so too can comonads in simplicial sets.

*Joint work with Gabriella Böhm.

F. William Lawvere
University at Buffalo

Alexander Grothendieck and the modern conception of Space

Already before 1960, the profound innovation by Eilenberg and Mac Lane had inspired further work that still plays a basic role in our present advances. I refer to the results of Kan, Isbell, Yoneda, and Grothendieck. Grothendieck's Tohoku article introduced the notion of subobject (still not grasped by many writers) and an emphasis on functor categories as a key method of construction. Grothendieck's elaborate construction of algebraic geometry via local ringed spaces, was rejected by himself already in 1973 in his lecture in Buffalo; efforts to take that qualitative leap into account have so far been incomplete.

Although in the 1950's Grothendieck was considered to be one of the leaders of functional analysis, recent journalistic accounts of his career seem to view that as a youthful deviation from his path to algebraic geometry. However, closer attention reveals that among his several advances in functional analysis was his calculation of the dual space of a space of analytic functions, specifically revealing it concretely as another space of analytic functions on a domain complementary to the original domain of definition. The study of the shapes of these domains led to a concentration on analytic geometry, where some of the first toposes emerged (but NOT as 'generalized spaces'). The close connection between compact analytic spaces and algebraic spaces emphasized the contrast between the two realms with respect to an implicit function theorem, leading to the other original class of toposes, namely the étale, which indeed constitutes a kind of generalized space, but not a localic one.

A serious re-elaboration of the history of Grothendieck's career will be a necessary part of the program to re-establish the foundations of geometry in a way that is in accord with Grothendieck's basic insights, but that makes maximum use of recent clarifying advances. Also helpful will be a more responsible use of the undefined term 'generalization'.

I propose to continue the following dialog: 'What is a Space?' 'A space is an object in a category of spaces.' 'So what is a category of spaces?'

Tom Leinster*
University of Edinburgh

The reflexive completion

A fundamental operation of category theory is Isbell conjugacy, which turns a covariant set-valued functor into a contravariant one and vice versa. The reflexive completion of a category **C** consists of those set-valued functors on **C** that are canonically isomorphic to their double conjugate. As the name suggests, and as Isbell proved, this 'completion' process is idempotent. It is a larger completion than the Cauchy completion.

Fundamental as reflexive completion is, it has been little studied and exhibits some surprising behaviour. For example, the reflexive completion of a category always has initial and terminal objects, as well as absolute (co)limits, but seemingly need not have any other limits or colimits.

I will begin by introducing Isbell conjugacy and reflexive completion. I will then present some new results with Tom Avery, including (i) some alternative characterizations of the reflexive completion, and (ii) a necessary and sufficient condition for the reflexive completions of two given categories to be equivalent. Finally, I will state some open questions about this basic concept.

*Joint work with Tom Avery.

Poon Leung
Macquarie University

The free tangent structure

There has been much recent work into generalising the structures involved in the study of differential geometry. One approach, which has been very influential, is synthetic differential geometry.

Another, due to Rosický, focused more directly on the tangent functor with the structure of (an abelian) group bundle, which in more recent times has been further generalised by Cockett-Cruttwell, to give a structure involving the use of additive bundles (commutative monoids).

This type of structure in fact is compatible with many existing definitions of differentiability, including those used in computer science and combinatorics, the manifolds in differential and algebraic geometry and also the abstract definitions in synthetic differential geometry.

These tangent structures may be defined by giving an underlying category $\mathcal{M}$ and a tangent functor

$$T : \mathcal{M} \to \mathcal{M}$$

along with a list of natural transformations and a set of axioms to be satisfied.

My work so far has involved restructuring the ideas underlying tangent structures in terms of Weil algebras. More specifically, there is a particular full subcategory of the Weil algebras with a universal property relative to all tangent structures, and conversely, this (sub)category within itself has encoded the ideas of tangent structures.

More recently, I have been looking at a way to extend the scope of tangent structures by extending the class of Weil algebras under consideration to incorporate more of the ideas underlying synthetic differential geometry. An important goal in doing so is to illustrate a more explicit connection between the two.

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Guilherme Frederico Lima
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Site characterisations for local geometric morphisms

In SGA 4, Grothendieck and Verdier defined a local topos as one where the canonical geometric morphism into **Set** has an extra right adjoint. One can generalise this definition by using an arbitrary topos instead of **Set**, and thus define a local geometric morphism between two toposes. It was shown in [1] that such a geometric morphism is always connected, i.e. that the extra adjoint is full and faithful, and this implies that the codomain is a subtopos of the domain. Thus one can view a local geometric morphism as an essential inclusion where the extra left adjoint preserves finite limits.

It is well known that, given a site of definition, a subtopos of a Grothendieck topos can be obtained by strengthening the Grothendieck topology. Now one can ask what more can be said about the stronger topology when the geometric morphism is also local. Partial results of this nature have already been achieved by Kelly and Lawvere in [2].

I will show how using the axiomatisation of elementary local toposes given by Birkedal in [3] and [4] one can characterise the relationship between the sites of definition for geometric morphisms between localic toposes and between Grothendieck toposes.

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Ignacio López Franco *

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Aspects of lax orthogonal factorisation systems

An algebraic weak factorisation systems (AWFSs) – [1, 3] – on a 2-category is lax orthogonal when either its 2-comonad part or its 2-monad part is lax idempotent. In this talk, after introducing the basic definitions, I characterise them as those AWFSs whose diagonal fillers satisfy an extra universal property, similar to that of a left Kan extension; ie as those AWFSs for which the canonical lifting operation on each right map is a so-called KZ lifting operation. A basic example of a lax orthogonal AWFS is that which factorises a morphism as a left adjoint coretract followed by a split opfibration. We describe a method of transferring, or pulling back, this basic AWFS through a left adjoint 2-functor using the new notion of simple 2-monad – a two-dimensional analogue of the simple reflections of [4] – which generates a number of examples: on **Cat**, on **Top** and on Lawvere's metric spaces. All this can be found in the preprint [2]. I hope to end with a few words on the appropriate notion of cofibrant generation for lax orthogonal AWFSs.

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*Joint work with Maria Manuel Clementino.

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Generalising the functor of points approach

The passage from commutative rings to schemes has three main steps: first, one identifies a distinguished class of ring homomorphisms corresponding to open immersions of schemes; second, one defines the notion of an open covering in terms of these distinguished homomorphisms; and finally, one embeds the opposite of the category of commutative rings in an ambient category in which one can glue (the formal duals of) commutative rings along (the formal duals of) distinguished homomorphisms. Traditionally, the ambient category is taken to be the category of locally ringed spaces, but following [1], one could equally well work in the category of sheaves for the large Zariski site – this is the so-called 'functor of points approach'.

The three procedures described above can be generalised to other contexts. The first step essentially amounts to reconstructing the class of open embeddings from the class of closed embeddings. Once we have a suitable class of open embeddings, the class of open coverings is a subcanonical Grothendieck pretopology. We then define a notion of 'charted space' in the category of sheaves. This gives a uniform way of defining locally Hausdorff spaces, schemes, locally finitely presented C^∞-schemes etc. as special sheaves on their respective categories of local models, taking as input just the class of closed embeddings. We can also get many variations on manifolds by skipping the first step and working directly with a given class of open embeddings.

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Kan extensions and descent theory

There are two main constructions in classical descent theory: the category of algebras and the descent category (see, for instance, [6, 2]). These constructions are known to be examples of 2-limits (see, for instance, [6, 7, 1]). This work aims to investigate whether pure formal methods and commuting properties of limits are useful in proving classical and new theorems of descent theory in the classical context of [2, 3].

Willing to give such formal approach, we employ the concept of Kan extensions. However, since we only deal with pseudo-limits and bilimits (see [8] for pseudo-limits) and we need some good properties w.r.t. pointwise equivalences, we use an weaker notion: pseudo-Kan extensions, which is stronger than the notion of lax-Kan extensions, already considered by John Gray in [2]. In particular, in this presentation, we shall talk about the pseudo-Kan extensions and give a proof of the Bénabou-Roubaud theorem.

This work is part of my PhD work under supervision of Maria Manuel Clementino.

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A general theory of measure and distribution monads founded on the notion of commutant of a subtheory

Extending work of Anders Kock [1] and of the speaker [2], we outline a general theory of measure and distribution monads on closed categories that specializes to capture in a canonical way the notions of Radon probability measure, compactly supported Radon measure (in each of its positive, signed, and probabilistic variants), compactly supported Schwartz distribution, ultrafilter, and filter. We work with a given closed category $\mathscr{X}$ of 'spaces', a commutative $\mathscr{X}$-enriched algebraic theory $\mathscr{T}$, and a suitable $\mathscr{T}$-algebra S. First defining in a general setting the notion of *commutant* of a subtheory (or submonad), we define the *natural distribution monad* $\mathbb{D}$ by

$$DX = \mathscr{T}^{\perp}\text{-Alg}(S^X, S) \qquad (X \in \mathscr{X})$$

where $\mathscr{T}^{\perp}$ denotes the commutant of $\mathscr{T}$ in the 'full' theory of S in $\mathscr{X}$. We define specific algebraic theories $\mathscr{T}$ that determine general notions of *affine space* over a rig in $\mathscr{X}$ and, in particular, of *convex space* over a preordered ring in $\mathscr{X}$. We study the functional analysis intrinsic to the category $\mathscr{T}$-Alg of $\mathscr{T}$-algebras (e.g., linear/affine/convex spaces) and the object S, including suitable notions of *completeness* of $\mathscr{T}$-algebras [3]. We outline how much of the speaker's work in [2] extends to this setting, yielding a theory of *vector-valued integration* in $\mathscr{T}$-algebras, where this generalized notion of 'integration' specializes to not only the *Pettis integral* in vector spaces, but also the *barycentre* operation in suitable convex spaces, ultrafilter convergence in compact Hausdorff spaces (following ideas of Kock and of Leinster), and the 'lim-inf' operation in continuous lattices.

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Categories with 2-cell structures and their internal pseudocategories

In this talk we will survey on the work [1] where the notion of pseudocategory is extended from the context of a 2-category to the more general one of a sesquicategory, which is considered as a category equipped with a 2-cell structure. Some particular examples of 2-cells arising from internal transformations in internal categories, conjugations in groups, derivations in crossed-modules or homotopies in abelian chain complexes are studied in this context, namely their behaviour as abstract 2-cells in a 2-cell structure. Issues such as naturality of a 2-cell structure are investigated. This work is intended as a preliminary starting step towards the study of the geometric aspects of the 2-cell structures from an algebraic point of view.

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Higher-order categorical substructural logics

Whereas the concept of topos is seemingly difficult to generalise beyond higher-order intuitionisitc logic and its variants, the concept of tripos or higher-order hyperdoctrine, which allows us to present all toposes via the tripos-to-topos construction (but not *vice versa*), is based on a more general, fibrational mechanism, thus looking more promising for developing "categorical universal logic" (the concept of tripos was originally introduced in Hyland-Johnstone-Pitts [2], then extended to allow for general base categories).

In this talk, we introduce the concept of full Lambek tripos, and show that full Lambek triposes give complete semantics for higher-order full Lambek calculus HoFL. Relativising this result to different classes of additional axioms, we can obtain higher-order categorical completeness theorems for a broad variety of logical systems, including classical, intuitionistic, fuzzy, relevant, paraconsistent, and (both commutative and non-commutative) linear logics. The general framework thus developed allows us to give a tripos-theoretical account of Girard's and Gödel's translation for higher-order logic.

Higher-order full Lambek calculus HoFL extends quantified full Lambek calculus FL (see Galatos et al. [1] or Ono [6]) so that HoFL equipped with all the structural rules boils down to higher-order intuitionistic logic, the logic of topos (see Lambek-Scott [4]). HoFL is a so-called "logic over type theory" or "logic-enriched type theory" in Aczel's terms; there is an underlying type theory, upon which logic is built (see Jacobs [3]). The type theory of HoFL is given by simply typed λ-calculus extended with finite product types (i.e., 1 and $\times$; these amount to the structure of Cartesian closed categories), and moreover, with the special, distinguished type

$$\mathrm{Prop}$$

which is a "proposition" type, intended to represent a truth-value object Ω on the categorical side. The logic of HoFL is given by full Lambek calculus FL. The Prop type plays the key rôle of reflecting the logical or propositional structure into the type or term structure: every formula or proposition φ may be seen as a term of type Prop.

The algebras of propositional FL are FL algebras. The algebras of first-order FL are FL hyperdoctrines as argued in Maruyama [5]; note that complete FL algebras only give us completeness in the presence of the *ad hoc* condition of so-called safe valuations, and yet FL hyperdoctrines allow us to prove completeness without any such *ad hoc* condition, and at the same time, to recover the complete FL algebra semantics as a special, set-theoretical instance of the FL hyperdoctrine semantics (in a nutshell, the condition of safe valuations is only necessary to show completeness with respect to the restricted class of FL hyperdoctrines with the category of sets their base categories). FL triposes introduced in this talk are arguably the (fibred) algebras of higher-order FL, allowing us to prove higher-order completeness, again without any *ad hoc* condition such as safe valuations or Henkin-style restrictions on quantification (set-theoretical semantics is only complete under this condition).

FL hyperdoctrines and triposes are defined as follows. An FL hyperdoctrine is a contravariant functor

$$P : \mathbf{C}^{\mathrm{op}} \longrightarrow \mathbf{FL}$$

such that the base category $\mathbf{C}$ of P is a category with finite products, and that the adjointness conditions to express quantifiers are satisfied (see Maruyama [5]). Now, an FL tripos, or higher-order FL hyperdoctrine, is an FL hyperdoctrine $P : \mathbf{C}^{\mathrm{op}} \longrightarrow \mathbf{FL}$ such that:

- The base category $\mathbf{C}$ is a CCC (Cartesian Closed Category);
- There is an object $\Omega \in \mathbf{C}$ such that

$$P \simeq \mathrm{Hom}_{\mathbf{C}}(\text{-}, \Omega).$$

We then call Ω the truth-value object of the FL tripos P. Building upon these concepts, we establish the following two results in this talk: (i) higher-order completeness via full Lambek tripos, which can be instantiated for any of classical, intuitionistic, fuzzy, relevant, paraconsistent, and (both commutative and non-commutative) linear logics; (ii) tripos-theoretical accounts of Girard's ! translation and Gödel's $\neg\neg$ translation for higher-order logic, in which the internal language of tripos is at work. As illustrated by this account of logical translation, the general framework thus developed allows us to compare different categorical logics within the one universal setting.

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An 'algebraic' model of a bidirectional Euler continuum

It is stated in [3] that "The 1973 Buffalo Colloquium by Alexander Grothendieck had as its main theme that the 1960 definition of scheme [...] should be abandoned AS the FUNDAMENTAL one and replaced by the simple idea of a good functor from rings to sets". Lawvere also suggests in [3] that "Grothendieck's point of view could be applied to real algebraic geometry as well" by concentrating on the "nature of positive quantities" and gives a definite proposal in terms of *really local rigs*. Motivated by this suggestion we construct a site of finitely presented $\mathbb{R}_+$-rigs 'without -1' and a uniquely-pointed object T in the induced pre-cohesive [2, 4] topos $p : \mathcal{E} \to \mathbf{Set}$ such that: the (commutative!) submonoid $R \to T^T$ of Euler reals [1] has a retraction, its domain is connected (i.e. $p_!R = 1$), and the subgroup $U \to R$ of invertible elements satisfies that $p_!U$ is the cyclic group of order 2. The last fact is what intuition suggests for a 'bidirectional line', and contrasts with the case of algebraic geometry over the real field $\mathbb{R}$, where $p_!U = 1$. It also holds that R has a ring structure and a subrig $R_+ \to R$ that is disjoint from the connected component of U where -1 lies.

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Aspects of strong protomodularity, actions and quotients

We study the problems of extending action along a quotient of the acted object and a quotient of the acting object. We obtain a characterization of protomodular categories among pointed regular ones, and, in the semi-abelian case, a characterization of strong protomodularity. Some applications are given and some generalizations are discussed.

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Some topoi generated by topological spaces

This work suggests a topoi construction methods through topological spaces.

Given a topological monoid M, forgetting the topology of M, it determines the topos M - Sets. Using the topology of M and final topologies, the objects of this topos remains enriched with a topology in such way that the actions remains continuous respect to the topology of the tensor product and the morphisms in this topos also remains continuous. A topos equivalent to one of this form is what we have been called a Geometric Topos. Now, a Topological Topos is the one which contains a homeomorphic subcategory to the reflective subcategory of Top. For example, given a topological space whose open sets are compact, the monoid of continuous functions of this space with the compact open topology is a topological monoid. In this case, the topos obtained is both a geometric topos and topological topos.

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On the "Smith is Huq" condition in S-protomodular categories

The "Smith is Huq" condition, which says that two equivalence relations on the same object centralize each other (in the Smith-Pedicchio sense [1, 2]) as soon as their normalizations commute (in the Huq sense [3]), has proved to have several important algebraic consequences. For example, it allows to simplify the description of internal categories, internal groupoids and crossed modules: see [4] for a detailed account of these properties in semi-abelian categories, and [5] for an extension to the case of pointed Mal'tsev categories.

In this talk we consider a relative version of the "Smith is Huq" condition in the context of pointed S-protomodular categories [6]: two S-equivalence relations centralize each other as soon as their normalizations commute. As proved in [6], in a S-protomodular category the fact that two S-equivalence relations centralize each other is a property, like for equivalence relations in Mal'tsev categories. We show that the categories of monoids, of semirings, and, more generally, all categories of monoids with operations (in the sense of [7]) are S-protomodular categories satisfying the "Smith is Huq" condition. We explore then some consequences dealing with the description of internal structures.

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*Joint work with Nelson Martins-Ferreira.

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Another approach to the Kan-Quillen model structure

Model categories were introduced by Quillen in [1] where it is shown that sSet, the category of simplicial sets, admits a model structure. However, that proof uses the theory of minimal fibrations and so relies heavily on the axiom of choice. Some accounts, for example [2], employ a category of topological spaces. One might expect it possible to give an explicit proof that uses only the intrinsic combinatorics of simplicial sets.

I present an approach which completely avoids both minimal fibrations and topological spaces. By careful analysis of the embedding of a simplicial set X into a Kan complex $\mathsf{Ex}^{\infty} X$ given by Kan in [3], we obtain a new proof that it is a weak equivalence. In fact it is a *strong anodyne extension*, i.e. a relative cell-complex of horn inclusions (without retracts). This description as a cell-complex is powerful enough that we can quickly deduce the model structure axioms given just a few combinatorial facts from the classical theory of simplicial sets.

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Weak factorization systems for intensional type theory.

In *Category Theory 2014*, I gave a talk entitled “Moore factorization systems”. In that talk, I sought to describe weak factorization systems on a category $\mathcal{M}$ which are given by an endofunctor $\mathtt{Id} : \mathcal{M} \longrightarrow \mathcal{M}$ equipped with enough algebraic structure to generate a weak factorization system with a factorization analogous to the one given through the space of Moore paths in the category of topological spaces [1]. The objective was to understand those weak factorization systems which could interpret Martin-Löf intensional type theory [2, 3].

In this talk, I will report on further progress. These Moore factorization systems have two important properties as weak factorization systems: (1) every object is fibrant, and (2) the left maps are stable under pullback along right maps. It turns out that any weak factorization system with these two properties can be given as a Moore factorization system. This gives a full characterization of the weak factorization systems which can interpret intensional type theory. If time permits, I will also discuss the categories of internal categories and presheaves in a category with a Moore factorization system.

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On the various definitions of cyclic operads

We view cyclic operads as structures combining operations that have only (named) entries and no distinguished output. Starting from a contravariant (and non-skeletal) version $S : \mathbf{Bij}^{op} \to \mathbf{Set}$ of Joyal's species of structures, partial compositions and identities are defined, as done, say, by Markl in the appendix of [1]. This leads to a natural combinator syntax . But we found it convenient to introduce as well a λ-calculus-style syntax, called μ-syntax, that allows a crisp and economical formulation of the laws to be satisfied. Instead of dealing only with operators $f \in S(X)$, the μ-syntax involves two kinds of expressions:

$$c ::= \langle s|t\rangle \mid f\{t_x|x \in X\} \quad \text{and} \quad s,t ::= x \mid \mu x.c\,,$$

called *commands* (which mimick operators themselves, with no entry selected), and *terms* (representing operators with one selected entry), respectively, these being subject to the following set of equations:

$$\langle s|t\rangle = \langle t|s\rangle, \quad \langle \mu x.c|s\rangle = c[s/x] \quad \text{and} \quad \mu x.\langle x|y\rangle = y\,.$$

We prove that the set of commands of our syntax, quotiented by the given equations, is in one-to-one correspondence with the set of unrooted trees with nodes decorated by operations and half-edges labeled by names, thereby proving the equivalence between the partial (or biased) presentation and the (unbiased) definition of (cyclic) operads as algebras over a monad. Our proof makes use of rewriting. The equations of the μ-syntax give rise to a (non-confluent) critical pair

$$c_1[\mu x.c_2/y] \leftarrow \langle \mu y.c_1|\mu x.c_2\rangle \to c_2[\mu y.c_1/x]\,.$$

The distinct normal forms of a command correspond in a natural way to enumerations of the nodes of the corresponding tree.

In addition, we also discuss two monoidal-like definitions, guided by the "microcosm principle" of Baez (like Fiore did for ordinary symmetric operads and dioperads): according to the first one, a cyclic operad is a pair $(S,\ \nu : S\triangle S \to S)$ where $S\triangle T = (\partial S) \otimes (\partial T)$, and where ν commutes (in an appropriate sense) with the "associativity-like" isomorphism

$$(S\triangle T)\triangle U + T\triangle(S\triangle U) + (T\triangle U)\triangle S \cong S\triangle(T\triangle U) + (S\triangle U)\triangle T + U\triangle(S\triangle T)\,.$$

The second one will be presented in the talk.

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*Joint work with Pierre-Louis Curien.

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Skolem relations and profunctors

We develop, in parallel, two general distributive laws, one for intersection over union in a topos, the other for limits over colimits in sets.

The key ingredient in the topos case is that of Skolem relation. Classical distributivity for arbitrary intersections over unions involves choice functions and requires the axiom of choice. We generalize this to an arbitrary topos by replacing the choice functions by relations. We show how this reduces to the classical result in the presence of choice.

For distributivity of limits over colimits in sets, we get analogous results by replacing choice functions by profunctors. The similarities and differences of the two theories will be discussed.

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Dagger category theory

Dagger categories are the basis of categorical approaches to quantum mechanics [1], and are starting to see applications in fields such as reversible computing [2] or linguistics [3].

In this talk we show how by essentially doing formal category in a 2-category $\mathbf{Cat}_{\dagger}$ of dagger categories in the spirit of [5], we can give a more conceptual basis to standard constructions with dagger categories; yielding for example, a general definition of dagger-limit extending the somewhat ad-hoc definitions of dagger biproducts or dagger kernels proposed in the literature.

We end with some speculations related to a Yoneda structure on $\mathbf{Cat}_{\dagger}$, and what is the right setting for formal dagger category theory.

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An abstract approach to Glivenko's theorem

The main motivation to study category of logics are methods of combining logics. The initial steps on "global" approach to categories of logics have appeared in dual aspect. On one hand appear a category of logic with strict morphisms $\mathcal{L}_s$. The object in this category are logics viewed like pairs $(\Sigma, \vdash)$ such that Σ is a signature and $\vdash$ is a tarskian consequence operator. The morphisms $f : (\Sigma, \vdash) \longrightarrow (\Sigma', \vdash')$ are sequences of functions $f : \Sigma \longrightarrow \Sigma'$ where Σ is a sequence of pairwise disjoint sets $\Sigma = (\Sigma_n)_{n\in\mathbb{N}}$ and $f = (f_n)_{n\in\mathbb{N}}$ such that $f_n : \Sigma_n \longrightarrow \Sigma_n$. This functions extend to formulas $\hat{f} : F(\Sigma) \longrightarrow F(\Sigma')$ and given $\Gamma \cup \{\varphi\} \subseteq F(\Sigma)$ then $\Gamma \vdash \varphi \Rightarrow \hat{f}[\Gamma] \vdash' \hat{f}(\varphi)$, such morphism f is called a logical translation. This category has "good" categorial properties but unsatisfactory treatment of the "identity problem" of logics [1]. On the other hand appear a category with flexible morphism $\mathcal{L}_f$ having a satisfactory treatment of "identity problem" but it does not have "good" categorial properties ([3]). The objects in $\mathcal{L}_f$ are the same in $\mathcal{L}_s$ but the morphisms are logical translations such that $c_n \in \Sigma_n \mapsto \varphi'_n \in F(\Sigma')[n]$ where $F(\Sigma)[n]$ is the set of formulas in $\{x_0, \cdots, x_{n-1}\}$.

On these categories, it is possible building others categories like:

$\mathcal{A}_s(respect.\mathcal{A}_f)$, the category strict (respect. flexible) of (Blok-Pigozzi) BP- algebraizable logics [2]. In this category a morphism $f : l \to l'$; $f \in \mathcal{L}_s(l, l')(\mathcal{L}_f(l, l'))$ "preserves algebraizing pair". $Q\mathcal{L}_f$: "quotient" category: $f \sim g$ iff $\check{f}(\varphi) \dashv'\vdash \check{g}(\varphi)$. The logics l and l' are equipollent ([3]) iff l and l' are $Q\mathcal{L}_f$-isomorphic. $\mathcal{L}^c_f \subseteq \mathcal{L}_f$: "congruential" logics: Logics which the relation $\dashv\vdash$ is a congruence relation over the connectives. $Lind(\mathcal{A}_f) \subseteq \mathcal{A}_f$: "Lindenbaum algebraizable" logics: $\varphi \dashv\vdash \psi \Leftrightarrow \vdash \varphi\Delta\psi$. $Q\mathcal{L}^c_f$ (or simply $\mathcal{Q}^c_f$): "good" category of logics: represents the major part of logics; has good categorial properties (is an accessible category complete/cocomplete); solves the identity problem for the presentations of classical logic in terms of isomorphism; allows a good notion of algebraizable logic [5].

The concern to study of category of logics is describe translation of meta-logics and logic properties between logics. In this work arise a way to obtain a notion of Abstract Glivenko's Theorem to algebraizable logics. To do this, we use a categorial framework called *Institution* [4] whose allows treat the semantic and syntactic parts of a logic in a same time. An Institution $I = (\mathbb{S}ig, Sen, Mod, \models)$ consist of: a category $\mathbb{S}ig$, whose the objects are called *signature*; a functor $Sen : \mathbb{S}ig \longrightarrow \mathbb{S}et$, for each signature a set whose elements are called *sentence* over the signature; a functor $Mod : (\mathbb{S}ig)^{op} \longrightarrow \mathbb{C}at$, for each signature a category whose the objects are called *model*; a relation $\models_\Sigma \subseteq |Mod(\Sigma)| \times Sen(\Sigma)$ for each $\Sigma \in |\mathbb{S}ig|$, called Σ-*satisfaction*, such that for each morphism $h : \Sigma \longrightarrow \Sigma'$, the compatibility condition $M' \models_{\Sigma'} Sen(h)(\phi)$ *if and only if* $Mod(h)(M') \models_\Sigma \phi$ holds for each $M' \in |Mod(\Sigma')|$ and $\phi \in Sen(\Sigma)$.

*Joint work with Hugo Luiz Mariano.

An Institution morphism $(\Phi, \alpha, \beta) : I \longrightarrow I'$ consist of: a functor $\Phi : \mathbb{S}ig \longrightarrow \mathbb{S}ig'$; a natural transformation $\alpha : Sen' \circ \Phi \Rightarrow Sen$; a natural transformation $\beta : Mod \Rightarrow Mod' \circ \Phi^{op}$, such that the following *compatibility condition* holds: $M' \models'_{\Sigma'} \alpha_\Sigma(\varphi) \ \ iff \ \ \beta_{\Sigma'}(M') \models_{\Phi(\Sigma')} \varphi$

We use this notion to define the *institutions of Lindenbaum algebraizable logics* which is: Given $a \in Lind(\mathcal{A}_f)$. I_a defines the Institution of Lindenbaum algebraizable associated to a where:

$\mathbb{S}ig$ is the category whose the objects are $a_1 = (\Sigma_1, \vdash_1) \in Lind(\mathcal{A}_f)$, that are isomorphic to a in the quotient category $QLind(\mathcal{A}_f)$ and the morphisms are only the isomorphisms in $QLind(\mathcal{A}_f)$, $Mod : \mathbb{S}ig^{op} \longrightarrow \mathbb{C}at$ such that $Mod(a_1) = QV(a_1)$ for all $a_1 \in |\mathbb{S}ig|$ and $Mod(a_1 \stackrel{[h]}{\to} a_2) = (QV(a_2) \stackrel{h^\star\!\upharpoonright}{\to} QV(a_1))$ and $Sen : \mathbb{S}ig \longrightarrow \mathbb{S}et$ such that $Sen(a_1)$ is the set all tuples

$$(([\alpha_0], [\beta_0]), \cdots, ([\alpha_{n-1}], [\beta_{n-1}]); ([\alpha], [\beta]))$$

that represents quasi-equations, i.e., $Eq_0 \wedge ... \wedge Eq_{n-1} \to Eq$ such that $[\alpha_i], [\beta_j]$ belongs to $F(\Sigma_1)(X)/ \dashv\vdash$, the free $QV(a_1)$-structure on the set X, and $\alpha_i = \varepsilon(\varphi_i), \beta_i = \delta(\varphi_i)$, for some algebraizable pair of a_1, $((\varepsilon, \delta), \Delta)$.

Then we are to able to define and prove the following:

Definition 0.1. *A* ***Glivenko's context*** *is a pair* $\mathbb{G} = (h : a \longrightarrow a', \rho)$ *where* $h \in Lind(\mathcal{A}_f)(a, a')$ *and* $\rho : h^\star\!\upharpoonright \circ L_h \Rightarrow Id$ *is a natural transformation that is a* section *of the unit of the adjunction* $(L_h, h^\star\!\upharpoonright)$.

Theorem 0.2. *Each* $\mathbb{G} = (h : a \longrightarrow a', \rho)$ ***Glivenko's context*** *induces a institutions morphism* $M_G : I_a \to I_{a'}$.

Corollary 0.3. *For each Glivenko's context* $\mathbb{G} = (h : a \longrightarrow a', \rho)$*, is associated an abstract Glivenko's theorem between* a *and* a' *i.e; given* $\Gamma \cup \{\varphi\} \subseteq F(X)$ *then*

$$\rho_{F(X)}[\Gamma] \vdash \rho_{F(X)}(\varphi) \ \Leftrightarrow \ \check{h}[\Gamma] \vdash' \check{h}(\varphi)\,.$$

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The Grothendieck Construction for Model Categories

The Grothendieck construction is a classical correspondence between diagrams of categories and coCartesian fibrations over the indexing category. In this paper we consider the analogous correspondence in the setting of model categories. As a main result, we establish an equivalence between suitable diagrams of model categories indexed by $\mathcal{M}$ and a new notion of **model fibrations** over $\mathcal{M}$. When $\mathcal{M}$ is a model category, our construction endows the Grothendieck construction with a model structure which gives a presentation of Lurie's ∞-categorical Grothendieck construction and enjoys several good formal properties. We apply our construction to various examples, yielding model structures on strict and weak group actions and on modules over algebra objects in suitable monoidal model categories.

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[*] Joint work with Y. Harpaz.

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Virtual equipments for ∞-categories

We reclaim the terms ∞-*category* and ∞-*functor* to mean objects and morphisms in a suitable *context*: a category that is strictly enriched over André Joyal's quasi-categories with a distinguished class of isofibrations satisfying familiar axioms. Examples include quasi-categories, complete Segal spaces, Segal categories, marked simplicial sets, n-fold complete Segal spaces, and slices of all of these over a fixed object. Thus, our meaning of ∞-category is both more restrictive, in that it only includes certain models of $(\infty, 1)$-categories, and more general, in that it includes models of (∞, n)-categories, than Jacob Lurie's.

The advantage of our approach is it allows for greater precision when generalizing ordinary category theory to ∞-categories. Relative to our axiomatization for a context, we develop a formal category theory of ∞-categories and ∞-functors that makes no use of the combinatorial details that differentiate each model. Our strategy is to work inside the *homotopy 2-category*, a strict 2-category associated to each context, first introduced in the context of quasi-categories by Joyal. Each homotopy 2-category admits weak comma ∞-categories, which are used to develop the theory of adjunctions, (co)limits, fibrations, and the Yoneda lemma. We define modules between ∞-categories to be two-sided discrete fibrations, meant here in a suitably weak sense, and prove that modules assemble into a virtual equipment, as defined by Geoff Cruttwell and Michael Shulman. Dominic Verity will explain the virtues of this framework in his talk.

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*Joint work with Dominic Verity.

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A tour through n-permutability

The aim of this talk is to gather the, more or less, recent results concerning n-permutable categories that we have developed in the past few years. As so, it is a joint work with the authors listed in the references below.

For $n \geqslant 2$, an n-permutable category is a regular category such that the composition of (effective) equivalence relations R and S on a same object is n-permutable: $RSR \cdots = SRS \cdots$, each composite involving n factors. The 2-permutable categories are better known as Mal'tsev categories, while the strictly weaker 3-permutable categories are usually called Goursat categories. For each n, an n-permutable category is necessarily an $(n+1)$-permutable, but the converse fails to be true.

The Mal'tsev (=2-permutability) property has been widely studied over the past years; first in a varietal context, then later generalised to a categorical one. As first in the list, they are naturally endowed with simplest property: $RS = SR$, the commutativity of the composition of (effective) equivalence relations R and S on a same object. As a consequence, their study developed remarkably and lead to a big contribution to categorical algebra.

Next in the list we have Goursat categories (=3-permutable categories). Although closely related to Mal'tsev categories, Goursat categories turned out to be more difficult to handle and were therefore less popular. Two natural question arising are: Which are the typical properties of Goursat categories? Which properties known for Mal'tsev categories still hold in Goursat categories? We answer these question by providing some new characterisations of Goursat categories in terms of natural constructions involving pushouts and pullbacks, by investigating the internal categorical structures, and by establishing some new homological type lemmas. Some of these results are then extended to a context where pointed and non-pointed algebra can be treated simultaneously, while others are extended further to the general context of n-permutable categories.

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Classification theory for accessible categories

This is a continuation of my talk given at CT2014 where I presented a hierarchy spanning from accessible categories with directed colimits to abstract elementary classes in the sense of Shelah. A prominent role was played by accessible categories with concrete directed colimits. Our aims are twofold – on one hand, we show how particular members of this hierarchy are closed under constructions of limit type. The main result is that abstract elementary classes are closed under PIE-limits, which improves the approach of [3]. On the other hand, the recent interest in metric abstract elementary classes (see [1], [4]), which may be thought as a kind of amalgam of abstract elementary classes with the program of continuous logic, prompts an extension of our approach: metric abstract elementary classes do not, in general, have concrete directed colimits. Consequently, we consider accessible categories with directed colimits which are concrete only if sufficiently highly directed, i.e. κ-directed for some regular cardinal κ. In the case of metric abstract elementary classes, in particular, we have $\kappa = \omega_1$. Using results of [2], we produce, for a start, a categorical analogue of Shelah's Presentation Theorem and an associated Ehrenfeucht-Mostowski functor.

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*Joint work with M. Lieberman.

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Exact completions as homotopical quotients

Following recent work by Steve Awodey and the author [1], we retrace an idea of Aurelio Carboni that the equivalence determining the maps of an exact completion (see [2]) is obtained from a homotopy.

We show that the exact completion of an arithmetic universe $\mathcal{A}$ is the homotopical quotient of a category of weak 2-groupoids on $\mathcal{A}$ with respect to a specific notion of interval.

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Initial algebras for dependent from plain polynomial functors in quasicategories

Let $\mathcal{C}$ be a locally cartesian-closed category. Gambino and Hyland [1] construct initial algebras for dependent polynomial functors

$$\mathcal{C}/I \xrightarrow{s^*} \mathcal{C}/B \xrightarrow{f_*} \mathcal{C}/A \xrightarrow{t_!} \mathcal{C}/I$$

from initial algebras for non-dependent ones (where $I = 1$) in a locally cartesian-closed category. Their motivation came from dependent type theory: here plain polynomial functors model ordinary W-types, while dependent polynomial functors model indexed W-types.

Recent work by Szumiło [4] and Kapulkin (unpublished) exhibits the syntax of intensional type theory with function extensionality as a locally cartesian-closed quasicategory. In relating ordinary and indexed notions of W-types in homotopy type theory [2], one is thus naturally led to continue the categorical analysis of type theoretic concepts of [1] and study the relation of initial algebras for plain and dependent polynomial functors in arbitrary locally-cartesian closed quasicategories.

We first illuminate a deeper categorical nature of the 1-categorical construction [1], which originally was very much hands-on, giving a significantly more abstract presentation. A key step is an intriguing application of the rolling rule [3], with a reduction to certain fibrational arguments. The resulting level of conceptuality then makes the proof amendable to quasicategorification, which we hope to sketch in the second half of the talk. A crucial distinction is the need to replace a certain equalizer by a coreflexive one, these concepts not coinciding in the higher categorical context.

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Paul Slevin *

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Cyclic homology arising from adjunctions

Given a monad and a comonad, one obtains a distributive law between them from lifts of one through an adjunction for the other. In particular, this yields for any bialgebroid the Yetter-Drinfel'd distributive law between the comonad given by a module coalgebra and the monad given by a comodule algebra. It is this self-dual setting that reproduces the cyclic homology of associative and of Hopf algebras in the monadic framework of Böhm and Ştefan [2]. In fact, their approach generates two duplicial objects and morphisms between them which are mutual inverses if and only if the duplicial objects are cyclic. In my talk, I will discuss the above in detail and give a 2-categorical perspective on the process of twisting coefficients [4, 5].

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*Joint work with Niels Kowalzig and Ulrich Kraehmer.

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On monoidal (co)nuclei and their applications

Quantic (co)nuclei provide a convenient technique for constructing quotients and subquantales of quantales [3]. This talk shows its analogue for the monoidal approach to topology of [2] in the form of the categories (T, V)-**Cat**, the latter based in a monad T on **Set** and a unital quantale V. As a consequence, we get a machinery for constructing quotient categories and subcategories of the categories (T, V)-**Cat**, thereby providing a common framework for several of the already defined ones in the literature (for example, sets, preordered sets, metric spaces, topological spaces, V-closure spaces, V-weighted H-labelled graphs, and V-enriched multi-ordered sets). We also get a representation theorem for the categories (T, V)-**Cat**, which arises as an analogue of the quantale representation theorem of [3]. We then apply our (co)nuclei technique to the (op-)canonical extensions of monads of G. Seal [4, 5] and the topological theories of D. Hofmann [1], thereby providing quotient categories and subcategories of (T, V)-**Cat** in the form of $(\mathsf{T}, 2)$-**Cat** for the two-element quantale 2.

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Categories of "lax fractions"

The concept of orthogonality is closely linked to full reflective subcategories (and, thus, to idempotent monads). The concept of Kan-injectivity plays for KZ-monads (or lax-idempotent monads) the same role as orthogonality for the idempotent ones, as demonstrated in the papers [2, 1] in the case of order-enriched categories (i.e., categories enriched in **Pos**).

In an order-enriched category $\mathcal{X}$, an object A is said to be (left) Kan-injective with respect to a morphism $f : X \longrightarrow Y$, if the **Pos**-morphism $\mathcal{X}(f, A) : \mathcal{X}(Y, A) \longrightarrow \mathcal{X}(X, A)$ is a right adjoint retraction. And a morphism $k : A \longrightarrow B$ is Kan-injective with respect to f if it satisfies the equality $(\mathcal{X}(f, B))^* \cdot \mathcal{X}(X, k) = \mathcal{X}(Y, k) \cdot (\mathcal{X}(f, A))^*$, where $(\mathcal{X}(f, A))^*$ denotes the left adjoint of $\mathcal{X}(f, A)$. For a given subcategory $\mathcal{A}$, we study the class $\mathcal{A}^{KInj}$ of all morphisms with respect to which all objects and morphisms of $\mathcal{A}$ are Kan-injective. In particular, we show that $\mathcal{A}^{KInj}$ is, in a certain sense, closed under weighted colimits. In the case of $\mathcal{A}$ being a KZ-monadic subcategory of $\mathcal{X}$, we construct a category of "lax fractions" for $\mathcal{A}^{KInj}$. This construction resembles the one of a category of fractions for the class of morphisms inverted by a reflector into a full reflective subcategory.

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Regularity for relational algebras and the case of approach spaces

Topological and approach spaces are known to be relational $\mathbb{T}$-algebras for suitable monads $\mathbb{T}$ on Set, laxly extended to Rel.

Top is known to be isomorphically described as $(\beta, 2) - \mathsf{Cat}$ for the ultrafiltermonad with the Barr extension [1] or as $(\mathbb{F}, 2) - \mathsf{Cat}$ for the filtermonad [7]. App can be isomorphically described as $(\mathbb{B}, 2) - \mathsf{Cat}$ for the prime functional ideal monad $\mathbb{B}$ [6] or as $(\mathbb{I}, 2) - \mathsf{Cat}$ for the functional ideal monad $\mathbb{I}$ [2], [3]. Both $\mathbb{F}$ and $\mathbb{I}$ are power-enriched monads and their extension to Rel is the Kleisli extension. For the monad $\mathbb{B}$, we use the initial extension to Rel.

In this talk we look at objects in $(\mathbb{T}, 2) - \mathsf{Cat}$ as spaces and we explore the topological property of $\mathbb{T}$-regularity. When applied to $(\beta, 2) - \mathsf{Cat}$, β-regularity is known to be equivalent to the usual regularity of the topological space [5].

Consider now a monad $\mathbb{T}$, power-enriched by the monad morphism $\tau : \mathbb{P} \longrightarrow \mathbb{T}$, with the Kleisli extension. We prove that under mild conditions, even when abandoning improper elements, $\mathbb{T}$-regularity is too strong since it implies the space to be indiscrete. Both $\mathbb{I}$ and $\mathbb{F}$ satisfy these mild conditions. In the case of the functional ideal monad $\mathbb{I}$, we present weaker conditions in order to describe the usual notion of regularity in App.

For the prime functional ideal monad $\mathbb{B}$, a submonad of $\mathbb{I}$, the situation is different. Again abandoning improper elements to avoid uninteresting results, we explain that $\mathbb{B}$-regularity is equivalent to the approach space being topological and regular. We also present weaker conditions based on the monad $\mathbb{B}$ describing the usual regularity in App.

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*Joint work with Eva Colebunders and Robert Lowen.

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The calculus of modules for ∞-categories

Under very general conditions one may start with a theory of ∞-categories, such as n-fold Segal spaces (a model of (∞, n)-catgories), and derive an associated rich calculus of modules dubbed a *virtual equipment* by Geoff Cruttwell and Michael Shulman. This opens up the prospect of developing the foundations of ∞-category theory in a *model agnostic* way, which allows it to be applied equally to a very diverse range of higher ∞-categorical structures.

In this talk we examine how this calculus may be deployed to provide an entirely elementary development of a number of the key ingredients that should be present in any self respecting ∞-category theory. As exemplars, we develop the theory of exact squares and finality, weighted (co)limits and pointwise Kan extensions. Furthermore, we demonstrate that this theory coincides with established accounts in the special case of quasi-category theory to be found in the work of Joyal, Lurie and others.

While this gets us a long way, it is just a first step towards providing a full account of the foundations of ∞-category theory at this level of model agnostic generality. If time permits, we will briefly touch upon extensions of this work which encompasses questions of size and free co-completion.

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*Joint work with Emily Riehl.

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Internal algebra classifiers as codescent objects of crossed internal categories

This talk is a report on the work contained in the preprint [3]. In this work the setting of an *adjunction of 2-monads* is proposed as a general context for speaking about internal structures within an ambient structure. The problem of constructing the universal ambient structure containing the prescribed internal structure is studied. Following the work of Lack [2], these universal objects must be constructed as codescent objects of simplicial objects arising from our setting. We isolate the extra structure present on these simplicial objects which enable their codescent objects to be computed. These are the *crossed internal categories* of the title, and generalise the crossed simplicial groups of Loday and Fiedorowicz [1].

The most general results of this work are concerned with how to compute such codescent objects in 2-categories of internal categories, and on isolating conditions on our monad-theoretic situation which enable these results to apply. Combined with earlier work [4] in which operads are seen as polynomial 2-monads, our results are then applied to the theory of non-symmetric, symmetric and braided operads. In particular, the well-known construction of a PROP from an operad is recovered, as an illustration of our techniques.

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Waves and total distributivity

Following joint work with Francisco Marmolejo and Bob Rosebrugh on "Completely and totally distributive categories", I reported at CT2013 on the *wave functor* $W : \mathscr{K} \to \widehat{\mathscr{K}} = \mathbf{set}^{\mathscr{K}^{\mathrm{op}}}$ of a totally cocomplete category $\mathscr{K}$. Indeed, if the defining property of $\mathscr{K}$ is given by an adjunction $\bigvee \dashv Y : \mathscr{K} \to \widehat{\mathscr{K}}$, where Y is the Yoneda functor, then W is given for objects A and K in $\mathscr{K}$ by

$$W(A)(K) = \mathbf{set}^{\widehat{\mathscr{K}}}(\mathscr{K}(A,-).\bigvee, [K,-])$$

where $[K,-]$ denotes evaluation of an object of $\widehat{\mathscr{K}}$ at K. **set** denotes the category of *small sets* and it requires some work to show that W is well-defined. W arises along with natural transformations $\beta : W\bigvee \to 1_{\widehat{\mathscr{K}}}$ and $\gamma : \bigvee W \to 1_{\mathscr{K}}$ that satisfy $\bigvee\beta = \gamma\bigvee$ and $\beta W = W\gamma$. A total $\mathscr{K}$ is said to be *totally distributive* if $\bigvee$ has a left adjoint. It was shown that $\mathscr{K}$ is totally distributive iff γ is invertible iff $W \dashv \bigvee$.

For any total $\mathscr{K}$ there is a well-defined, associative composition of waves. If we write $\widetilde{\mathscr{K}} : \mathscr{K} \nrightarrow \mathscr{K}$ for the small profunctor determined by W then composition becomes an arrow $\circ : \widetilde{\mathscr{K}} \circ_{\mathscr{K}} \widetilde{\mathscr{K}} \to \widetilde{\mathscr{K}}$, although $\widetilde{\mathscr{K}} \circ_{\mathscr{K}} \widetilde{\mathscr{K}}$ is not in general small. Moreover, there is also an augmentation $(\bar{-}) : \widetilde{\mathscr{K}}(-,-) \to \mathscr{K}(-,-)$, corresponding to a natural transformation $\delta : W \to Y$ constructed via β. We will show that if $\mathscr{K}$ is totally distributive then $\circ : \widetilde{\mathscr{K}} \circ_{\mathscr{K}} \widetilde{\mathscr{K}} \to \widetilde{\mathscr{K}}$ is invertible, meaning that composition of waves is *interpolative*, and $\widetilde{\mathscr{K}}$ thus supports an idempotent comonad structure. In fact, $\widetilde{\mathscr{K}} \circ_{\mathscr{K}} \widetilde{\mathscr{K}} = \widetilde{\mathscr{K}} \circ_{\widetilde{\mathscr{K}}} \widetilde{\mathscr{K}}$ so that $\widetilde{\mathscr{K}}$ becomes a *taxon* structure, in the sense of Koslowski, on the objects of $\mathscr{K}$. In the paper with Marmolejo and Rosebrugh we showed that, for any small taxon $\mathscr{T}$, the category of taxon functors $\mathbf{Tax}(\mathscr{T}^{\mathrm{op}}, \mathbf{set})$ is totally distributive. To this we now add, for any totally distributive $\mathscr{K}$, there is an equivalence of categories $\mathscr{K} \to \mathbf{Tax}(\widetilde{\mathscr{K}}^{\mathrm{op}}, \mathbf{set})$.

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Fibrations of polynomial and analytic functors and monads

It is well known that many notions like monad, Kleisli and Eilenebrg-Moore category, mnonidal category, category of monoids, action of a monoidal category and category of actions along an action introduced in the context of the 2-category **Cat**, when suitably internalized, make sense in any 2-category $\mathcal{A}$ with finite (2-dimensional) products. Moreover, we can say that a 0-cell in $calA$ has some limits and/or colimits if the category $\mathcal{A}(\mathcal{X}, \mathcal{C})$ has such limits for any 0-cell $\mathcal{X}$ in $\mathcal{A}$ and/or colimits and the precomposing functors preserve them. This permits to internalize to any 2-category with finite products several arguments that holds true in **Cat** and use them directly in different contexts.

We have shown, among other things, that if we have a monoidal monad $(\mathcal{R}, \phi, \eta, \mu)$ on a monoidal object $(\mathcal{C}, \otimes, I, \alpha, \lambda, \rho)$ so that $\mathcal{C}$ has reflexive coequalizers, both structures respect them, and $(\mathcal{R}, \eta, \mu)$ admits an Eilenberg-Moore object in $\mathcal{A}$, then $(\mathcal{R}, \phi, \eta, \mu)$ admits an Eilenberg-Moore object in the 2-category $Mon(\mathbf{Cat})$ of monoidal objects, (lax) monoidal functors, and monoidal transformations in $\mathcal{A}$. This extends earlier results due to F. Linton, R. Guitar, and G. Seal, as well as some of our earlier results. A similar result for the Kleisli object is also true and it is of a much simpler nature. Both Eilenberg-Moore and Kleisli objects lift along 2-fibration to a 2-category of lax slices, and similar results also hold for the 2-category of (lax) actions of monoidal objects on a given 0-cell.

The development of this abstract theory was inspired by the theory of polynomial and analytic functors and monads. When applied to a symmetrization monad on a fibration of signatures in a (suitable) 2-category of fibrations, it shows in a natural way how these notions arise and how they are related to each other. The theory applies to some other natural cases of monoidal monads, as well. For example, it gives rise to the semi-analytic and all finitary functors and monads on slices of Set.

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