Contents

October 10, 2016

J. Demongeot,
Honorary Fellow of the IUF
Professor Emeritus of the UJF
Faculté de Médecine de Grenoble
38700 La Tronche, France

J. Viret
Médecin Général Inspecteur
Professor of the Val-de Grâce
74 Boulevard de Port-Royal
75005 Paris, France

VolkswagenStiftung
Freigeist Fellowship Program
Kastanienallee 35,
30519 Hannover

Dear Committee of the Freigeist Fellowship Program,

We hereby commit ourselves, in the event that Dr Mathilde Noual's research project *Information in the dark – Articulating representations of interaction systems* is awarded funding from VolkswagenStiftung's Freigeist Fellowship Program, to provide advice and guidance, throughout the term of the project, both on the scientific and technical applications of the project (Prof. J. Demongeot) and on the project's fundamental and transdisciplinary scope (Prof. J. Viret).

We know M. Noual to be an independent researcher, and an especially creative one, able of choosing challenging research subjects and following through with them in a very competitive environment, thanks to the fresh perspectives she spontaneously takes. She has been contributing to the understanding and representation of interaction system dynamics. This is a difficult topic, generating a lot of research activity, especially through its applications to genetic, metabolic, physiologic and social networks, the theory of which is difficult both for biologists and physicians, but also for applied mathematicians. Its scope and impact on the biomedical community is sometimes underestimated.

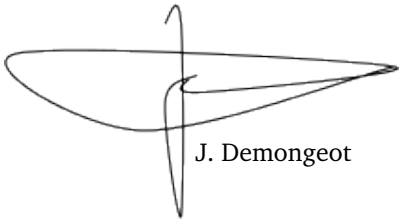
Many fundamental questions about interaction systems remain unanswered and present research is generating more open questions about particular models of real interaction systems. *How do we expel implausible attractors that are artifacts of the formal model, based on criteria formalised in the model such as the size of the attractor's attraction basin and the improbability of certain initial conditions it requires? What are the mechanisms (eg microRNAs) that regulate feedback loops in real interaction systems and how do they operate? How do continuous and discrete dynamics with identical Jacobian graphs relate? Does kinetic energy have an informative analogue (social, metabolic, etc.) that characterises observed dynamics of interaction systems, that is conserved in attractors and dissipated at the borders of their basins?* (this is a popular topic in fields studying neural networks and concerned with neurodegenerative diseases)... Those are questions requiring a broad scientific understanding. We need to address them with a diversity of scientific competences and perspectives. This is why we believe that the deliberately transdisciplinary aspect of M. Noual's strategy and choice of collaborators is very relevant. In addition, we support the project's innovative perspective on information. When the causality chain (essentially the sequence of causal mechanisms) behind the dynamical events observed in natural networks (genetic, neural, social, metabolic,...) is partially or totally unknown, it is often the case that the classical approach consisting in extracting cause and effect links from observations of the dynamical phenotype (*i.e.*, from the trajectories of the states of the individuals involved in the network)

is yielding too little knowledge. Then, rather than abandoning the underlying model and turning to a new formalisation or a different problem, M. Noual's project proposes another solution. In such apparently deadlocked situations, there still is information to exploit although to do so requires the shift of perspective conveyed by the concept of "information in the dark": information about the agents and their interactions that isn't contained in the model, about the system's environment and the external influences on its agents, about the experimental protocol of observation and the ensuing representations.

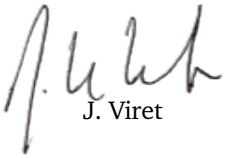
To conclude, *Information in the dark* is a theoretically crucial and necessary project for an efficient effective use of discrete models of interaction systems such as Boolean Networks in the fields of their applications. And the concept of information in the dark is of general scientific interest beyond the field of interaction systems. It raises the fundamental question of how scientific information is defined, produced and processed, and how the relativity of this information to the scientific paradigms it comes out of, can also be scientifically dealt with.

We warmly support M. Noual's proposal and agree to supervise the project's proceedings, to provide comprehensive support for it, suggest adjustments to its strategy when necessary, and of course provide our regular feedback on its progression.

Sincerely yours,



J. Demongeot



J. Viret

Personal information			
Form of address	Professor	First name, Name	Jacques, Demongeot
Institution/chair	Laboratoire AGEIS EA 7407 (Autonomie, Gérontologie, E-Santé, Imagerie & Société) Université Joseph Fourier		
Title	Honorary Fellow of the Institut Universitaire de France Professor Emeritus of the Université Joseph Fourier		
Contact information			
Adress	Faculté de Médecine de Grenoble, Domaine de la, Merci		
Postcode	38700	Town, country	La Tronche, France
Phone	+33(0)4 76 63 71 53	Email	Jacques.Demongeot@agim.eu
Project mentorship			
Scientific and technical applications			

Personal information			
Form of address (Mr/Ms)	General	First name, Name	Jacques, Viret
Institution/chair	École du Val-de-Grâce French Ministry of Defence Health Service (*"Service de Santé des Armées"*)		
Title	*Médecin Général Inspecteur* Professor of the Val-de Grâce		
Contact information			
Adress	Le vieux Saint-Maximin		
Postcode	38530	Town, country	Saint-Maximin, France
Phone	+33 (0) 4 76 97 32 78	Email	jacquesviret@free.fr
Project mentorship			
Transdisciplinary dialogue and foundations of science			

Freie Universität Berlin

October 11, 2016

Mathilde Noual
Arnimallee 6, 14195 Berlin
Phone: +49-30-419-57054
+49-30-838-75865
Email: m.noual@fu-berlin.de

VolkswagenStiftung
Freigeist Fellowship Program
Kastanienallee 35,
30519 Hannover

Dear Committee of the Freigeist Fellowship Program,

I would like to express my interest in the VolkswagenStiftung's Freigeist Fellowship position. The program was mentioned to me by an ex-member of the DFG, Dr B. Scholz on the occasion of a training session she was coaching at the Dahlem Research School of the Freie Universität, Berlin. Dr Scholz then strongly encouraged me to submit my research project to the VolkswagenStiftung. Thus, as discussed on the phone with Dr. Oliver Grewe, I am honoured today to be submitting to you a research proposal entitled "*Information in the dark (articulating representations of interaction systems)*".

The project is a Fundamental Computer Science research project backed up with a transdisciplinary platform that will be developed to take the theoretical research out where it can be of immediate service, and where it can benefit from being organically interwoven with applied research. As a whole, the project aims at providing a new well-tamed source of flexibility to the way scientists from different fields collectively make sense out of the science they contribute to. The project is especially meaningful to me because, for a number of years, I have had as principal preoccupation to create *a pretext* for scientists to communicate on a profound level, and make the scientific doxa acknowledge constructively the human sensitivity in them as part of science's primary defining assets (rather than taboo it awkwardly to the exclusive benefit of an allegedly sense-less '*R*eason' and at the expense of greater rigour). Science to me is a universal language, a reference point for communicating humans to meet, to agree on what they understand of the world and *to build things together* on the basis of their agreement – to build *on* the agreement, use it and expand it. I believe I owe my definition of science to Computer Science, the innately sensual simplicity of its foundational principles, and the characteristic perspective it takes on objects that humans are able to communicate on. The saddening gap between this definition and the one I've witnessed academia promote, has motivated some of the boldest decisions of my career and given birth to an incisive project named *In Case Of Peace* whose purpose is precisely to trigger massive in-depth discussions between academic scientists, about what we do, how we do it, and for whom[1]. Although the faith in science and humans inherent to this project still consequentially underlies all of my academic research plans, Project *Information in the dark*, has benefited from something new: the noteworthy and exceptional permission, granted here by the Freigeist Fellowship Program's offer, to let vision of science meet the trade of science-making.

Of course, I am convinced that my profile perfectly fits the Freigeist Fellowship Program's description of "Freigeist". But importantly, I also am convinced the Program offers a unique and especially appropriate opportunity for my research plans. I am very seduced by the VolkswagenStiftung's general effort at instilling

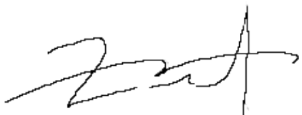
[1] Project *In Case Of Peace* and its relation to Project *Information in the dark* are explained in more detail here: incaseofpeace.com/betweenus.

fluidity within science-making institutions and communities. I am particularly drawn to its progressive, open-minded and ambitious view of science-making that encourages the expression of scientific personality in academic research to orient, structure and adapt it in relevant ways.

I believe that there are two main things that a Freigeist Fellowship can do to support further the implementation of my academic plans and the development of my research – things that a more classical academic funding to carry out purely mathematical research on "Boolean Automata Networks" (the mathematical objects my research is grounded on) can not at all. The first is to officially support the non-traditional scientific stance that characterises and powers my research. An official support given by an institution such as the VolkswagenStiftung to a project entitled "Information in the dark" meaning to consider scientists as part of their own equations would be immensely valuable and decisive. The second is to fund the development of the transdisciplinary platform so that this research can firmly anchor itself into the actual landscape of academic research that it is meant to serve and impact on.

I would welcome an opportunity to further discuss my research project with you. In the meantime, thank you for considering my application. I look forward to hearing from you.

Sincerely yours,



Mathilde Noual

Mathilde Noual

Date of birth: 13/07/1983
Nationality: French
Address: Arnimallee 6, 14195 Berlin
Tel.: +49 30 419 57054
+49 30 838 75865
Fax: +49 30 838 475870
Mail: m.noual@fu-berlin.de
Actual position: Postdoctoral fellow at the Freie Universität, Berlin
Associate member of the Laboratoire d'Informatique Fondamentale of Aix-Marseille University

Education & Positions

2015–2017	Dahlem Research School POINT fellowship at the Freie Universität, Berlin.
2012–2014	Postdoc at the Laboratoire d'Informatique, Signaux et Systèmes de Sophia Antipolis, Université Nice Sophia-Antipolis, France.
June 22, 2012	Defence of my Computer Science PhD thesis entitled "Updating Automata Networks" at the École Normale Supérieure de Lyon, France.
2009–2012	PhD in Lyon at the Laboratoire de l'informatique du parallélisme of the École Normale Supérieure de Lyon directed by Prof. É. Rémila and Prof. S. Sené.
	Research internship at the École Normale Supérieure de Lyon and at the Centro de Modelamiento Matemático in Santiago de Chile directed by Prof. J. Demongeot and Prof. E. Goles.
2008-2009	Masters degree in fundamental computer science at the École Normale Supérieure de Lyon – head of the class (*"major de promotion"*).
	Research internship directed by Prof. J. Aracena at the Universidad de Concepción, Chile.
2006–2007	BSc in mathematics by correspondence courses with the Université Pierre et Marie Curie – head of the class (*"major de promotion"*).
	Research internship directed by Prof. P. Lescanne at the École Normale Supérieure de Lyon.

Scope & recognition

2009 – 2013	Invited for several research stays at the Department of Mathematics and Computer Science of the Freie Universität, Berlin, at the Centro de Modelamiento Matemático (Chile), at the Universidad Adolfo Ibánez (Chile), at the mathematics departments of the Durham University (UK) and of the University of Southern Denmark.
	Invited speaker at regular group and/or laboratory seminars on those occasions.
	Invited speaker at the Colloque d'informatique de l'Université Pierre et Marie Curie.

Invited speaker at the Journées d'Informatique Fondamentale de Paris Diderot on the occasion of the inauguration of the new premisses of the Laboratoire d'Informatique Algorithmique: Fondements et Applications and the Laboratoire Preuves, Programmes, Systèmes (now IRIF) of the Université Paris Diderot.

Speaker in other various computer science and mathematics workshops, events, laboratory seminars and research group seminars in France – *e.g.* the days of Workgroup Systèmes Dynamiques, Automates et Algorithmes of the CNRS's Groupement De Recherche Informatique Mathematique (GDR-IM) in Caen and in Nice, the IXth forum of young mathematicians in Paris, the GREYC's laboratory seminar in Caen, the Symbiose seminar of the Institut de Recherche en Informatique et Systèmes Aléatoires in Rennes, the IBISC laboratory seminar in Évry, the seminars of research group *Equipe Systèmes Complexes, Automates et Pavages* of the Laboratoire d'Informatique Fondamentale de Marseille, the seminars of research group *Algorithmique distribuée et graphes* of the Laboratoire d'Informatique Algorithmique: Fondements et Applications in Paris.

Speaker in interdisciplinary contexts in France, Chile and Morocco – *e.g.* the annual seminars of the Société Francophone de Biologie Théorique in Saint Flour, France, Workshop "Dynamics of a landscape" at the École Normale Supérieure des Arts Décoratifs in Paris, Workshop *Formalisme logique, apports et défis pour la modélisation de réseaux de régulation biologique* in Rabat, Workshop *Autour des réseaux booléens* in Santiago de Chile.

2012 PhD commendation (Gilles Kahn – Académie des Sciences) awarded by the Société Informatique de France.

PhD award ("Information and communication sciences and technologies") given by the European Aeronautic Defence and Space foundation.

Other Professional Experiences

2009-2014 Teaching assistant for several computer science undergraduate and graduate courses at the École Normale Supérieure de Lyon and at the Université de Lyon – *e.g. operating systems*, *software and hardware architectures*, *foundations of computer science*, *algorithmics and programming*, *algorithmic complexity*, *set theory, computability theory, proof theory, order theory, denotation/axiomatic/operational semantics, etc*.

Reviews for various scientific journals and conferences.

Member of the board of the Laboratoire de l'informatique du parallélisme.

Organisation of the regular seminars of the research group Modèles de calcul, Complexité, Combinatoire (MC2) of the Laboratoire de l'informatique du parallélisme.

Co-direction of a BSc internship and supervision of a short high school internship.

Writing and organisation of Project MAAJES funded by the Institut Rhône-alpin des Systèmes Complexes (IXXI).

2002–2006 Various non-academic professional experiences – *e.g.* waitress, sales assistant, factory worker, school monitor, monitor in vacations for disabled adults and in vacations for disabled children, *etc*.

Publications

International Journals

[1] M. Noual and S. Sené. Sensitivity to synchronism in Boolean automata networks. Accepted at *Natural Computing*, 2016.

[2] A. Lagoutte, M. Noual, and É Thierry. Flooding games on graphs. *Discrete Applied Mathematics*, 164(2):532–538, 2014. Extended version of the LAGOS'2011 paper.

[3] M. Noual, D. Regnault, and S. Sené. About non-monotony in Boolean automata networks. *Theoretical Computer Science*, 504:12 – 25, 2013.

[4] J.-P. Comet, M. Noual, A. Richard, J. Aracena, L. Calzone, D. Demongeot, M. Kaufman, A. Naldi, E.H. Snoussi, and D. Thieffry. On circuit functionality in Boolean networks. *Bulletin of Mathematical Biology*, 75(6):906–19, 2013.

[5] E. Goles and M. Noual. Disjunctive networks and update schedules. *Advances in Applied Mathematics*, 48(5):646 – 662, 2012.

[6] J. Aracena, É. Fanchon, M. Montalva, and M. Noual. Combinatorics on update digraphs in Boolean networks. *Discrete Applied Mathematics*, 159:401–409, 2011.

[7] J. Demongeot, A. Elena, M. Noual, S. Sené, and F. Thuderoz. "Immunetworks", intersecting circuits and dynamics. *Journal of Theoretical Biology*, 280:19–33, 2011.

[8] J. Demongeot, M. Noual, and S. Sené. Combinatorics of Boolean automata circuits dynamics. *Discrete Applied Mathematics*, 160:398–415, 2010.

[9] J. Demongeot, E. Goles, M. Morvan, M. Noual, and S. Sené. Attraction basins as gauges of robustness against boundary conditions in biological complex systems. *PLoS One*, 5:e11793, 2010.

[10] J. Demongeot, H. Ben Amor, A. Elena, P. Gillois, M. Noual, and S. Sené. Robustness in regulatory interaction networks. A generic approach with applications at different levels: physiologic, metabolic and genetic. *International Journal of Molecular Sciences*, 10:4437–4473, 2009.

International Conferences with Proceedings

[11] T. Melliti, M. Noual, D. Regnault, S. Sené, and J. Sobieraj. Asynchronous Dynamics of Boolean Automata Double-Cycles. In *Unconventional Computation and Natural Computation (UCNC)*, volume 9252 of *Lecture Notes in Computer Science (LNCS)*, pages 250–262. Springer International Publishing, 2015.

[12] M. Noual, D. Regnault, and S. Sené. Boolean networks synchronism sensitivity and XOR circulant networks convergence time. In *AUTOMATA & JAC*, volume 90 of *Electronic Proceedings in Theoretical Computer Science (EPTCS)*, pages 37–52. Open Publishing Association, 2012.

[13] M. Noual. Dynamics of circuits and intersecting circuits. In *Language and Automata Theory and Applications (LATA)*, volume 7183 of *Lecture Notes in Computer Science (LNCS)*, pages 433–444. Springer-Verlag, 2012.

[14] A. Lagoutte, M. Noual, and É. Thierry. Flooding games on graphs. In *Latin American Algorithms, Graphs, and Optimization Symposium (LAGOS)*, 2011.

[15] E. Goles and M. Noual. Block-sequential update schedules and Boolean automata circuits. In *AUTOMATA*, pages 41–50. Discrete Mathematics & Theoretical Computer Science (DMTCS), 2010.

Research reports

[16] M. Noual. Perspectives on Interaction Systems, and Boolean Automata Networks. Research report, 2016.

[17] M. Noual. Causality and Boolean Automata Networks. Research report, 2016.

[18] M. Noual. Shortest Trajectories and Reversibility in Boolean Automata Networks. Research report, 2016.

[19] M. Noual. A combinatorial problem concerning binary necklaces and attractors of Boolean automata networks. Research report, 2013.

[20] M. Noual and S. Sené. Towards a theory of modelling with Boolean automata networks - I. Theorisation and observations. Research report, 2011.

[21] M. Noual. Synchronism *vs* asynchronism in Boolean networks. Research report, 2011.

[22] M. Noual. General transition graphs and Boolean circuits. Research report, 2010.

Theses

[23] M. Noual. Updating Automata Networks. PhD thesis, École normale supérieure de Lyon, 2012.

[24] M. Noual. On the dynamics of two particular classes of Boolean automata networks: Boolean automata circuits and OR networks. Master's thesis, M2, École normale supérieure de Lyon, 2009.

[25] M. Noual. On update schedules and dynamics of Boolean networks. Master's thesis, M1, École normale supérieure de Lyon, 2008.

BUDGET JUSTIFICATION

1. Scientific Personnel (scientist appointments, scholarships, student assistants)

- Principal investigator's 5-year TV-L 14 position ..... 378000 €
- Postdoctoral fellow's 2-year TV-L 13 position ..... 132000 €

  The latter cost is the salary of a postdoctoral fellow who will apply his own interdisciplinary research, situated at the intersection of mathematics, fundamental sociology and philosophy, to the development of methodological tools for uncovering information from the dark despite the interaction system prototype of Boolean Automata Networks not necessarily immediately applying. This postdoctoral fellow will collaborate with me on the conception and testing of the series of transdisciplinary workshops, for the initial two year phase of the project.

TOTAL ..... 510000 €

Below, PI ≡ Principal Investigator and PF ≡ Postdoctoral fellow.

2. Travel Costs (project meetings, conference visits, research stays, workshops)

Costs below are calculated based on the number of persons travelling, on the accommodation and daily allowances provided for in the *Bundesreisekostengesetz*, and on approximations of air and ground travel costs depending on destination.

- Bi-annual project meetings ..... 17600 €

This amount will allow the project's main investigators (the PI and the PF) to meet twice a year during the 5 year term of the project, with the project's mentors in France or in Germany.

- Visits of invited project collaborators ..... 18100 €

This is an estimation of the cost of inviting project collaborators and contributing to their travel expenses. It includes visits of workshop collaborators and guest animators of the workshop (starting end of year 2, *cf.* working plan) and visits of the interaction designer in charge of the project's platform and of the development of online animations which need to be visualised in the making.

- PI's and PF's research and workshop visits ..... 33500 €

This amount is an estimation of the cost of the PI's and the PF's travel expenses for research collaboration stays and workshop facilitation in different European academic institutions (in particular in the institutions of French and English collaborators mentioned in Section 1.3.3 of the project description, and also in the institutions the PF will be entertaining connections with such as the Université Jean Moulin in Lyon and the Institut d'Étude des Crises) and oversees (regular visits to Chile are planed, in order to entertain collaborations with members of the Universidad Adolfo Ibáñez and the Universidad de Concepción, see Section 1.3.3, and visits to US institutes such as the Santa Fe Institute are also expected).

- PI's and PF's conferences ..... 10500 €

On average, the PI expects to submit a paper each year to an Computer Science/Discrete Mathematics international conference for publication in its proceedings, and the PF expects to participate in three conferences during his two year fellowship (particular targets are the colloquiums of the Université Interdisciplinaire de Paris and *The Interdisciplinary Social Sciences Conference*).

TOTAL ..... 79700 €

3. Science Communication Measures (public relation measures, publication costs)

- Publication costs ..... 3000 €

The cost above corresponds to the registration fees of the conferences mentioned in the previous section where the PI and the PF will submit papers for publication in the conferences' proceedings.

TOTAL ..... 3000 €

4. Other Recurring Costs (consumables and the like, contracts for work and services)

As part of the project, the PI and the PF will run a regular, local workshop and gradually develop it into a conference format with a large academic transdisciplinary outreach (essentially, an interactive version of the TED talks, *cf.* working plan). One important aspect of the project's strategy is the very high quality of the service it means to propose. This is why training in workshop facilitation will be needed:

- Training ..... 5000 €

Among other recurring costs, there are the contracts for the design and development of the online toolkit and of the recurrent workshop website. Those costs are distributed as follows:

- General website infrastructure and design ..... 19000 €

This corresponds to the initial costs of general branding, user experience and interface design of the website, including production deployment and testing of standard / static web pages for the presentation of the research, and a page for the presentation and online presence of the workshop.

- Design and development of the core applications ..... 74000 €

The cost above is for the implementation of the three programs mentioned in Section 1.3.6 and of the "reverse Turing test" mentioned in Section 1.3.5. The development of these includes the implementation of machine learning algorithms (including natural language processing) and human-based computation techniques). The design and development process will be informed by the progress made by the research.

- Design and development of two supplementary applications ..... 13000 €

Those additional applications are an interactive Catastrophe-Theory-based application, and an application to collect sketches of researchers representations of "the modelling process".

- Design and development of additional applications, updates of the online toolkit and unplanned features . . . . . 30000 €

The online toolkit is meant to showcase as well as implement the progress made by the project's research and by the recurrent workshop's proceedings. Thus, during the course of the project new enhancements of the online toolkit will regularly be called for. The amount above takes this into account.

TOTAL . . . . . 141000 €

5. Other Non-recurring Costs (literature and other acquisitions)

- Purchases of project relevant books and access to publications . . . . . 2000 €

TOTAL . . . . . 2000 €

6. Institutional contribution

- . . . . . 20000 €

A part of this sum will be invested in German lessons for the PI. The rest of the Freie Universität's contribution will be saved as potential start-off funding for the organisation of a workshop-conference event.

TOTAL . . . . . 20000 €

GRAND TOTAL . . . . . 755700 €

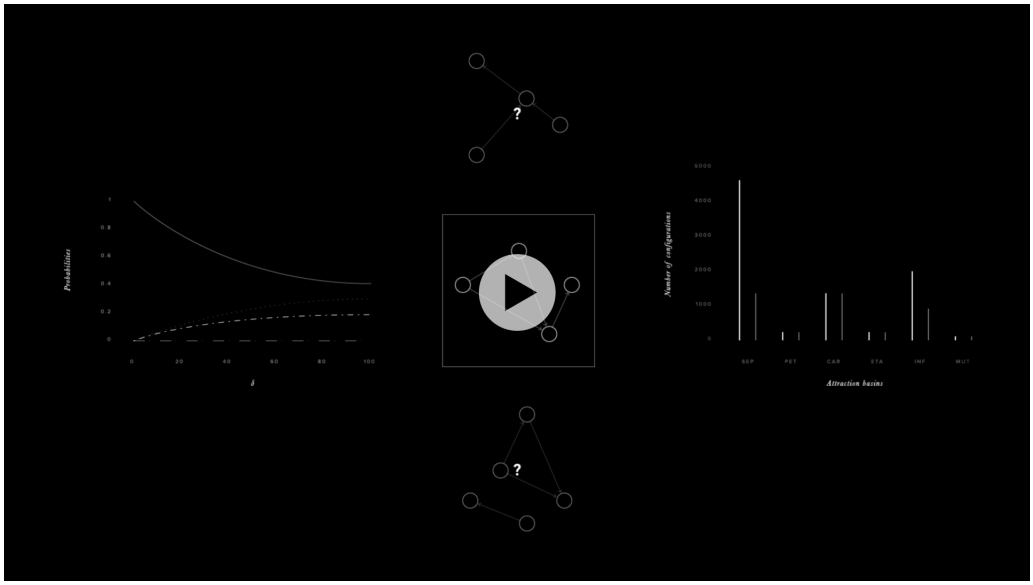
Information in the dark

(articulating representations of interaction systems)

PROJECT PRESENTATION

The presentation of the project in layman's terms is the video that can be found at the following url:

https://vimeo.com/187144113/



Information in the dark

(articulating representations of interaction systems)

SUMMARY

Scientific progress owes a lot to scientists changing perspectives on the objects they study. By focusing on objects that qualify as **interaction systems**, this project means to make **perspective-changing** a deliberate scientific process. It explores the relations between different perspectives on the same interaction systems and endeavours to distinguish (1) the information we have that concerns the systems *per se*, from (2) the information that concerns our perspective on the systems and the ensuing representation we make of them. The first kind of information is what scientists traditionally turn to first when they want to derive more information. The project will show how to make a practical systematic use of the second kind of information – the information concerning the way we look at systems and represent them. It will develop a methodology for extracting out of it new **information that concerns the systems** but isn't *explicitly* suggested by the information we already have on them, namely **information in the dark**.

To that end, the project will address a set of specific Fundamental Computer Science problems, using a minimalist mathematical prototype of interaction systems called **Boolean Automata Networks**. With a **Computability Theory like approach**, it will uncover and study the **building blocks** of interaction systems, *i.e.* the fundamental generating mechanisms that can be held responsible for the notable effects we observe in a system *as a consequence of it being an interaction system*. And it will explore the different ways of representing those fundamental building blocks through structural and temporal media. This theoretical research will translate into a **transdisciplinary platform** addressed to members of the *Automata Networks* community, to working groups of Freie Universität PhD students, and to a larger academic public. The platform will be implemented as an **online toolkit** and as a **recurrent workshop** with a common *modus operandi*. It will consist in a collection of semi-automatic means promoting the theoretical research in a transdisciplinary context where it can serve other research on interaction systems (and translate in particular into a *Dictionary of Interaction Systems* and a *formalism-free* simulation programs of interaction systems), and where ready-to-use feedback can be organically integrated into the research on Boolean Automata Networks.

As a whole, the project will simultaneously address three urgent needs of contemporary academic science. **(1)** The first is the need to firmly expand **the scope of Computer Science**'s fundamental understanding of information and systems well outside of its purely theoretical homeland, and well beyond how it presently applies and serves through opaque computer simulations and models. **(2)** The second is academic science's great need of rigorous **dialogue across disciplines** founded *not* on what characterises and distinguishes each discipline, but on the contrary, on what essentially is shared by them and on a constructive and **positive management of information lack**. **(3)** The third urgent need of modern science is to develop a modern science approach to the question of **how scientists are involved in the information they manipulate**.

The project is designed to be carried out over a **5 year period**. It will be hosted by the Department of Mathematics and Computer Science of the **Freie Universität, Berlin**. It relies on the Volkswagen Foundation's Freigeist Fellowship Program to grant a financial support of 755700 € to cover for: my own position as principal investigator, a 2 year postdoctoral position to help with the transdisciplinary scope of the project, the development of the online toolkit, and some complementary expenses.

Information im Dunklen

(Darstellungsweisen von Interaktionssystemen)

ZUSAMMENFASSUNG

Wissenschaftlicher Fortschritt hängt zu einem großen Teil davon ab, dass Wissenschaftler die Perspektiven auf die Gegenstände wechseln, die sie untersuchen. Durch die Fokussierung auf Gegenstände, die als **Interaktionssysteme** beschrieben werden können, zielt dieses Projekt darauf ab, den **Wechsel der Perspektiven** zu einem planvollen wissenschaftlichen Prozess zu machen. Es untersucht die Beziehungen zwischen unterschiedlichen Perspektiven auf ein und dasselbe Interaktionssystem und strebt an, die Information (1) , die wir von den Systemen als solche haben, von der Information (2) zu unterscheiden, die mit unserer Perspektive auf diese Systeme zu tun hat und der sich daraus ergebenden Darstellung der Systeme. Die erste Art von Information ist diejenige, auf die sich Wissenschaftler traditionell richten, wenn sie neue Information herleiten wollen. Dieses Projekt hingegen wird zeigen, wie sich die zweite Art von Information systematisch in der Praxis nutzen lässt – die Information über die Art und Weise, wie wir Systeme betrachten und diese darstellen. Es wird eine Methodologie entwickeln, um hieraus eine neue Art von Information herzuleiten, die durchaus die Systeme betrifft, nicht aber *explizit* in der Information vorliegt, die wir bereits über sie besitzen. Wir nennen dies die **Information im Dunklen**.

Zu diesem Zweck wird das Projekt spezifische Fragestellungen aus dem Bereich der Grundlagen der Informatik behandeln, unter Verwendung eines minimalistischen, mathematischen Prototyps von Interaktionssystemen, sogenannter **Boolescher Automatennetzwerke**. Mit einem **an die Berechenbarkeitstheorie angelehnten Ansatz** sollen die **Bausteine** von Interaktionsnetzwerken freigelegt und untersucht werden, d.h. die grundlegenden Erzeugungsmechanismen, die für die maßgeblichen Wirkungen verantwortlich sind, die in einem System beobachtet werden können *als Folge davon, dass es ein Interaktionssystem ist*. Zusätzlich werden wir die verschiedenen Darstellungsweisen dieser grundlegenden Bausteine durch strukturelle und temporale Mittel erforschen. Der theoretische Teil des Projekts soll in eine **transdisziplinäre Plattform** übersetzt werden, die sich an Wissenschaftler im Bereich der Automatennnetzwerke richtet, an Doktorandengruppen der Freien Universität Berlin und eine breitere akademische Öffentlichkeit. Die Plattform soll online abrufbar sein und von einem **wiederkehrenden Workshop** mit einem gemeinsamen *modus operandi* begleitet werden. Sie wird in einer Sammlung halbautomatischer Mittel zur Förderung theoretischer Forschung in einem transdisziplinären Kontext bestehen, wo sie anderer Forschung an Interaktionssystemen dienen (insbesondere ist dabei an ein *Wörterbuch für Interaktionssysteme* und an formalismusfreie Simulationsprogramme für Interaktionssysteme gedacht) und wo umsetzbarer Feedback nahtlos in die Forschung über Boolesche Automatennetzwerke integriert werden kann.

Als Ganzes soll das Projekt gleichzeitig drei dringende Notwendigkeiten der gegenwärtigen akademischen Wissenschaft aufgreifen. (1) Die Notwendigkeit, die **Anwendung des in der Informatik** erworbenen grundlegenden Verständnisses von Information und Systemen über seine theoretischen Ursprünge hinaus grundlegend zu erweitern und dabei die gegenwärtige Beschränkung auf opake Computersimulationen und Modelle zu überwinden. (2) Die große Notwendigkeit der akademischen Wissenschaft eines strengen **Dialogs über die Disziplinen** hinaus, der nicht darin begründet ist, was die einzelnen Disziplinen unterscheidet und auszeichnet, sondern im Gegenteil in ihren wesentlichen Gemeinsamkeiten und einem konstruktiven und **positiven Umgang mit Mangel an Information**. (3) Schließlich die dringende Notwendigkeit für die moderne Wissenschaft sich mit der Frage zu befassen, **wie Wissenschaftler in die Information verwickelt sind, die sie handhaben**.

Das Projekt ist auf **fünf Jahre** angelegt und am Fachbereich Mathematik und Informatik der **Freien Universität Berlin** angesiedelt. Es stützt sich auf das Freigeist-Fellowship-Programm der VolkswagenStiftung für einen finanziellen Beitrag in Höhe von 755700 €. Dieser Betrag wird benötigt für meine eigene Position als Projektleiter, eine Postdoc-Stelle für zwei Jahre, die Entwicklung der Online-Plattform, sowie verschiedene Zusatzausgaben.

“Why Freigeist?”

My research project shares its mathematical framework with a large range of well-established theoretical research. Nonetheless . . .

1. In the capacity of a project about formal interaction systems, it is original in that it does *not* seek to promote, nor even refine knowledge about yet another relevant mathematical model of an interaction system. It proposes instead to understand *modelling* itself and develop practical methodological solutions to catalyse an organic unification of what the different models of interaction systems reveal.
2. In the capacity of a Fundamental Computer science project, it is original in that it takes this young science’s unique, inherent executive understanding of systems and information out of its asepticised theoretical homeland to make it serve the older sciences (without the intermediary of computers).
3. In the capacity of an academic transdisciplinary project it is original in that it is not an interdisciplinary project. Interdisciplinarity essentially relies on, and draws its sense out of the existence of distinct disciplines in order to make their respective specialisms *relay* one another; this project relies on, and emphasises what disciplines already have in common.
4. In the capacity of a natural science project, it is original in that it considers scientists as part of their own equations. And not only does it face *with a scientific approach* the possibility that this might matter much more than we usually dare to think, it also proposes to draw a practical scientific benefit out of it. With a resolutely positive view on information lack, it will prove that new information can generally be drawn out of what what we believe to be ’closed cases’. And conversely, it will soften contemporary science’s haunting obsession with clearing data deficits, by stressing the ineluctability and the *efficacy* of scientists’ blind spots, and endeavouring to morph the traditional *theory/reality* opposition into a view that considers objects as abstractions of one another and enables precise, deliberate and controlled perspective shifts. I believe investing in this project thereby means investing in a source of scientific advancements that will remain untapped unless carried out as laid down in my proposal.
5. In the capacity of a modern science project, my project also is original in that it reconciles science with a more sensual, instinctive, and essentially adaptive form of understanding that it is crucial to acknowledge for the sake of greater scientific rigour, as this project will prove through a ’popperianly’ experimental approach to the question of how science manages to make scientific sense.
6. In the capacity of an academic research project, this project is original because it makes a strategic use of available 21st century communication tools, not only to systematise and streamline *the involvement of other researcher’s in the decomposition and management of the project’s own specific difficulties*, but also more generally, to get *science-making* out of the closet of overly specialistic peer-review journals and conferences and allow in-depth cross-specialism collaborations.

Moreover, about the possibility of “failing this project resoundly”: in fundamental computer science research, negative and positive answers are equally informative. Failure takes the form of unexpectedly difficult questions (like the million dollar question about P and NP) which are so fundamental they shape the discipline.

Failing resoundly with the interface system would mean not succeeding to generate constructive interactions across academic specialisms, not even within my own scientific community. This would be very significant. At best it would mean great inconsistency within my community. At worst it would mean that academic research is even more in need of “interface systems” than we think, and my approach is in need of substantial reinforcements. In any case, the project will provide a detailed account of subtle differences in perspectives and in reasoning that explain the deadlocks encountered and the investigations that need to be carried out in order to resolve them.

Information in the dark

(articulating representations of interaction systems)

Research Project proposed to
the Volkswagen Foundation's Freigeist Fellowship Program
by Mathilde Noual

Contents

1 Project Description

1.1 Statement of reasons

Science owes a lot to scientists changing perspectives on the objects they study. Scientific progress does not all boil down to following leads in uncharted territories, discovering objects previously unheard of, and increasing the stock of knowledge accumulated so far by adding brand new free-standing bits to it. Scientific progress also comes from seeing differently the things we already know. This project is about the information that we get from doing that – changing perspectives on the objects we study – namely *information in the dark* (for short: *dark information*). And the objects this project focuses on are those that it is relevant to regard as an *interaction system*. An interaction system is a set of entities/parameters that we consider as a whole for the following reason: we presume that the changes underwent by the entities in the set are 'causally' related to one another and account for the global system changes that we are interested in. Many objects are interaction systems.

The nature of this project and the brevity of this presentation requires an informal use of a certain number of terms denoting concepts whose definitions could well be the object of extensive epistemological discussions. However, this is a Fundamental Computer Science research project. Concepts referred to draw their importance not so much in what they are supposed to mean objectively, as in what we can formally build with them in a specific well-defined context. Here, the context is that of *Boolean Automata Networks*. Boolean Automata Networks (BANs) are prototypes of interaction systems (formally defined in Section 1.3.1). This means that they not only can serve as minimalist models of 'real' interaction systems as they traditionally do in a number of research fields[1–6]. They also capture the core of what an interaction system is. And considering the notion of perspective, BANs demonstrate that the information we have on an interaction system is not necessarily just *about* the interaction system. It can also be about our perspective on it and the ensuing representation we have of it [7] . This involvement we have in the information we manipulate calls for invested interest not just in the "missing information" we don't yet have about a system, as defined by the "non-missing information" we do have, but also in the information about the system that we neither have nor *explicitly* miss.

Because of the vast interdisciplinary attention (Boolean) Automata Networks are receiving[8–31], it is essential to investigate how precisely the perspective we informally take on these formal objects affects their expressivity [7] . But the concept of interaction system far exceeds the framework of (B)ANs so it also is essential to be aware of the extent to which what we know of the interaction systems we study – what their defining parts and properties are – actually depends on the formal representations we make of them and how we spontaneously interpret them. Perhaps even more crucial is the need for science to finally recover from scientism's neat opposition between "Reality" on one side, and

its alleged objective theoretical representation on the other. BANs offer clear, multiple evidence of this opposition's limits (see the five observations about interaction systems listed and illustrated with BANs in [7]). This evidence is a timely call to substantiate an alternative view, and to start doing this with a scientific – not just epistemological – approach. It stresses the absolute necessity and urgency there is to adopt a rigorous informational approach to the question of how scientists interact with the scientific information they manipulate. And this call is made all the more pressing by the quantity and diversity of scientific communities existing in academia, and of their defining models, tools, formalisms, perspectives, epistemologies... Indeed, science's characteristic multiplicity tends to induce wild "knowledge bulimia' and the production of intractable quantities of highly specialised information. With it comes a tacit illusory rivalry between adjacent scientific communities striving to promote their own version of "the most valid perspective". The new specialism introduced by the discipline of interdisciplinarity is presently evidencing that if we want to make the interests of distinct academic fields coincide – and not just *at best* punctually relay each other – then we are going to need a much better, more fundamental, solution than interdisciplinarity. If we want to preserve the multiplicity of science as a scientific asset, and even make optimal use of it, we are going to need to find something else to structure science with than more facts and statements that only specialists can manipulate. My proposition is fundamental, *ipso facto* transdisciplinary understanding.

1.2 Main objectives of the project

Precisely, within the scope of this project, I propose to develop a fundamental understanding of the interplay of semantics and formalism that constitutes the information we have on interaction systems – that is: *the "semantics" dictated by the perspective we take on the interaction system, associated to the formal object supposed to represent it*, and *the "formalism" of the representation, i.e. the formal system used to express it*. And I propose to explicit ways of taking advantage of this interplay and extracting new information out of it. This can be done by addressing in terms of BANs the following series of partially overlapping questions about interaction systems.

O1 *Under what conditions does the present state of a system not convey all the information about the history of local changes that were made in it to get it from the state it was last observed in, into its present state? – i.e. when do local changes not all leave a trace of their occurrence in the global outcome observed?*

O2 *What are the fundamental information-processing mechanisms of interaction systems (e.g. selection, reversal, recycling, entropy reduction, recursion)? and what are the different ways of implementing them (e.g. through negative feedback loops, precedence of some change's occurrence over some other's, non-monotonous interactions, intersections of information pathways)? Knowing the "computational complexity" of a given observed effect in terms of the mechanisms needed to produce it, how ambiguous does the "cause" of this effect remain?*

O3 *What information does the present of a system convey about its future? How does a system's current*

state with all the potentialities of local change it is comprised of relate to the degree of determinism in its final global states and in the trajectories leading to them?

O4 *How do the structural, causal and temporal constraints in an interaction system relate to one another and possibly translate into one another? What leeway do these relations provide us with?*

O5 *What are the effects of observing a system's behaviour "loosely"? What liberty do we have in observing systems without loosing significant information about them?*

O6 *Conversely, once we have all the desired information about a system, what liberty do we have in representing it by a structurally simpler one? Where do we add ambiguity when we do that, and with what consequences?*

Each of these six topics/objectives defines the subject of a summarising paper that I will submit to an international journal or conference of Theoretical Computer Science or Discrete Mathematics. Now, the research I propose relies on theoretical tools but isn't theoretical in itself. Addressing the six objectives O1 – O6 rather is applied fundamental research. And for the reasons stated in the previous section, I claim that it has long-term significance well outside of its original highly formalised setting. For that reason, it must be carried out *in vivo*, *i.e.* in a transdisciplinary framework where it may already serve and coordinate with specialised research, and feed on concerns that are foreign to BANs.

O7 Thus, another main objective of my project is to: *materialise an interface between (i) fundamental computer science research on interaction systems formalised by BANs, and (ii) research from the so-called "applied" sciences that it applies to.* The interface will take the shape of the system described in Section 1.3.5. It will be both implemented and fine-tuned through a progressive online toolkit and a complementary recurrent transdisciplinary workshop (*cf.* Sections 1.3.6 and 1.3.7). I expect the data collected and organised systematically by the toolkit, and the *Dictionary of Interaction Systems* elaborated throughout the workshop's sessions (*cf.* p.10) to constitute matter for publications in Information Science journals, and in Philosophy of Research and Epistemology journals. But in how they intertwine with this project's BAN-based research, the toolkit and the workshop are expected to have much more immediate and impactful outcomes as highlighted in sections 1.3.5–1.3.7.

1.3 Details of methods, structure and course of the project

1.3.1 The BAN terminology

The major part of this research project relies on the formalism of BANs. But since the objectives of the project are not specifically about BANs, I endeavour to avoid BAN specific terminology throughout this presentation. Certain notions are however more efficiently expressed in terms of "interaction graph", "transitions", "updates", and "instabilities". So here is a very concise and dry presentation of the BAN terminology which can be completed if necessary and for instance with Section 2 of [7]. Formally, a BAN is a set of Boolean functions $\mathcal{N} = \{f_i : \mathbb{B}^n \to \mathbb{B} \,|\, i \in V\}$ where $\mathbb{B} = \{0, 1\}$,

$n \in \mathbb{N}$. $V = [\![1, n]\!]$ is the set of automata of the BAN. $G = (V, A)$ is its interaction graph where $A = \{(i, j) \in V \times V : f_j(x) \text{ depends on } x_i\}$. In $\mathcal{N}'s$ state $x = (x_1, \ldots, x_n) \in \mathbb{B}^n$, automaton $j \in V$ changes its state from x_j to $\neg x_j$ if and only if: (a) it can, *i.e.* j is unstable in x: $j \in U(x) = \{i \in V : f_i(x) \neq x_i\}$, and (b) its state is updated. The definition of $\mathcal{N}$ does not specify anything about updates. It does not define a dynamic. Instead it defines what are the *possible* transitions $x \to y$ of $\mathcal{N}$, *i.e.* what are the couples $(x, y) \in \mathbb{B}^n \times \mathbb{B}^n$ such that $\forall i \in V : x_i \neq y_i \Rightarrow i \in U(x)$.

1.3.2 General Approach of the BAN-based research

Computability Theory identified a minimal collection of basic computing mechanisms and theorised that those mechanisms are exactly the building blocks of anything that can possibly be computed algorithmically [32, 33]. The same approach can be used to provide a basis to a theory of dark information. Replace (i) '*Computable by an algorithm*' with (ii) '*Generatable by an interaction system*', and (i) '*Computable function*' with (ii) '*Generatable effect or property*'. The objective becomes: (1) to identify a minimal collection of basic generating mechanisms that can account for any effect possibly observed in a system *as a result of the system being an interaction system* (see [34] for an example where the generatable effect E is 'asymptotic oscillations', and the generating mechanism $M(E)$ of E is 'a systematic consequent dissociation between the result of a change and the information of this change'). Research towards this and the following complementary objective will specify where dark information can be found: (2) to identify and list the different ways of implementing each mechanism (through properties of the interaction structure, the relative order of local changes and updates, and/or the f_i functions). Indeed, if E is an effect observed in a interaction system S, and if the fundamental generating mechanism $M(E)$ of E is not fully accounted for in the formalisation of S, then this is enough to tell that something important has been left aside or implicit. What is more, we know exactly where to look for the missing part of E's explanation since we know what form $M(E)$ may come in – for instance, a feedback loop is not enough to explain asymptotic oscillations because in itself it doesn't dissociate the effect of a change and of communicating the information of the change; in this case, the missing part of the explanation can be found in the form of temporal constraints [34] . While an intuitive notion of computation guided Computability Theory's progress, as illustrated in [34], an intuitive notion of causality (to be formalised into the notion of "generation" in interaction systems) can similarly be used to guide the research of this project, specifically, by paying attention to effects that are explained differently in different contexts, and to properties that are invoked as the causes of different effects.

1.3.3 Specific problems and expected BAN-based results

With this general Computability Theory-like approach, we can uncover the fundamental principles of interaction systems (*cf.* O2 on p.2). We can also methodically address the questions of Section 1.2 (*cf.* O1 – O6), and understand what fundamentally constitutes the information we have on interaction

R1 systems in order to explicit where to find more of it. Indeed, one of the candidate generating mechanisms for the collection mentioned above is *reversal*, *i.e.* making local state changes ($x_i \rightsquigarrow \neg x_i$) and then cancelling them out ($\neg x_i \rightsquigarrow x_i$) resulting in them leaving no trace of their occurrence (*cf.* O1). By pursuing work on lengths of shortest asynchronous trajectories [35] , and work initiated in collaboration with Dr H. Klarner (FU Berlin), Dr A. Richard (I3S, Nice) and Prof. H. Siebert (FU), borrowing some concepts from Computer Arithmetic (to explain what makes trajectories long), we will: (a) identify the conditions under which reversal is necessary to perform a global system change $x \in \mathbb{B}^n \rightarrow \ldots \rightarrow y \in \mathbb{B}^n$, (b) classify the effects of reversal as I did with synchronism [36] (from mere elongation of trajectories to asymptotically decisive effects like determinism), and (c) determine the extent to which sensitivity to reversal is a property attributable to the endpoints x and y of the trajectory along which reversal occurs, as opposed to a property of the BAN. And in relation to reversal, I will introduce the notion of *trajectorial recursion* and express trajectory lengths in terms of recursion depth. I expect to confirm recursion's fundamental generating role in interaction systems.

R2 A monotone BAN is one for which all defining functions $f_i : \mathbb{B}^n \rightarrow \mathbb{B}^n$ are monotone. Monotony and non-monotony are important properties (see [7,34]) that I have been studying with Prof. S. Sené (Université d'Aix-Marseille) and Dr D. Regnault (Université d'Evry-Val-d'Essone) [37–39] . In completion of [35–37], I intend to: (a) formalise a definition of "the non-monotonous effect" capturing the behavioural possibilities that we observe in non-monotone BANs and tend to attribute the responsibility of to non-monotone f_i's, (b) list the different monotone ways of generating this effect, and (c) uncover the more subtle, unknown, fundamental mechanisms that the non-monotony of f_i's accounts for by determining what mechanisms need to be added to positive BANs – a class of monotone BANs with minimal computational capacity – (*e.g.* crossing of information pathways, furtive communication between an automaton's inputs, inconsistent process of an information, restocking and recycling) to make them reproduce effects observed in non-monotone BANs. I expect this work to confirm that in the absence of any form of non-monotony, only two atemporal factors[34] determine the final outcome of a trajectory T from $x \in \mathbb{B}^n$ to $y \in \mathbb{B}^n$: (1) *in situ* information in x, and (2) a mechanism of selection (possibly implemented through precedence) of the surviving part of the *in situ* information that overwrites on the information y contains no trace of. This line of research is also expected to confirm non-monotony's strong involvement in: sensitivity to reversal and the lengths of long trajectories, the mechanism of recursion, sensitivity to precedence [36,37] , sensitivity to the *quantity* of synchronism, and sensitivity to "abstractability" (*cf.* below). The theme of non-monotony will therefore be ubiquitous in the project.

R3 Different lines of research independently carried out or initiated with my Chilean collaborators [40–42] , with different groups of French collaborators [43–46, 47], and more recently with my German collaborators [21, 48], have consistently raised the question of how (a) local, punctual instabilities relate to (b) general, global instability in BANs (*cf.* O3). As, part of this project, I will study this rela-

tion and more precisely the relation between (a) a possibility of synchronism (a.k.a. a punctual degree $|U(x)| > 1$ of local freedom/ambiguity), and (b) the BAN's asymptotic behavioural possibilities, especially the number and diversity of its attractors (which convey its general degree of freedom/ambiguity). This will specify: (i) the information that (a) conveys about (b), (ii) how trajectories and the sequentialisation of changes inherent to them carry (a) and turn it into (b), and (iii) the extent to which having more of (a) translates into having more ways of producing the same global change (a form of *trajectorial robustness*) or into having a greater number of possible global changes with less ways of actually performing each (a form of *trajectorial sensitivity*).

R4 Results on BANs[41,49,50] show in different ways that 'spatial' constraints (constraints on interaction structures) can be encoded into temporal properties of BANs (properties of updating modes). I will explore this further, and start exploring the converse too: *how can structural properties generate what usually is considered to be temporal constraints?* (*cf.* O4). In particular, this will specify the connection between (a) adding interactions between feedback loops, and (b) making the network asynchronous in the sense that it only ever contains one local instability at a time. More generally, this work will specify the connection between (a) the interaction structure and (b) the quantity of movement $|U(x)|$ in the network. In the same lines, I will investigate how possibility of synchronism (which conveys an absence of temporal constraints and of cause/effect relations [7]), can be encoded into spatial constraints. Spontaneous collaborations on this with Prof. J. Demongeot (Université de Grenoble) and Prof. S. Sené will be possible in the direct lines of our previous collaboration [43,44,49,51].

R5 As emphasised in [52], depending on the setting and on the update schedules we choose, the transitions $x \to y$ we consider represent either (1) a *sequence* of local changes that might need one another to occur, starting in x, ending in y, or (2) one or several independent changes already possible in x. This varying degree of atomicity of transitions captures a very significant difference between various traditional AN (Automata Network) frameworks. As part of the project, I will study it rigorously, with attention to the effect it has on network's apparent behaviours. To this end, I will introduce the property of *temporal abstractability* referring to a BAN's insensitivity to the non-atomicity of its transitions (*cf.* O5). And pursuing classic research on update schedules[25,53–57], including studies I carried out with Prof. E. Goles (UAI, Chile) and Prof. J. Aracena (Universidad de Concepción) [40–42], I will (1) compare (general) transition graphs [58] of BANs with their "contracted versions" obtained by alleviating atomicity, (2) specify the degree of non-atomicity allowed before "substantial information" on how the BAN works is lost, or before enough information to recognise non-ambiguously a specific mechanism or feature of the BAN (*e.g.* a negative cycle, the non-monotony of f_i) is lost, and (3) relate non-abstractability to: (3.1) 'sensitivity to ordering', (3.2) non-monotony, and (3.3) the maximal degree of possible synchronism $max_{x \in \mathbb{B}^n}\{|U(x)|\}$ (3.3 will specify the extent to which abstractability requires the lack of causality conveyed by possibility of synchronism [7]).

Thanks to the general approach described in Section 1.3.2, the work on temporal abstractability is expected to provide insights on how 'abstraction-induced disappearances of causes' relates to 'abstraction-induced disappearance of their effects'. It will interweave with the work on reversal and long trajectories (*cf.* R1 and O1) through the answers it will provide to the following question: *When is it sufficient to know that a state $y \in \mathbb{B}^n$ is reachable from a state $x \in \mathbb{B}^n$, in order to infer the trajectory through which y can effectively be reached from x?*

R6 Another part of my research will consist in defining *canonical* constructive and modular representations of networks to enable the comparison of their respective computational capacities. The idea is inspired by Shift Register Machines[59]. It consists in separating mechanisms structurally without changing anything to the BAN's behavioural possibilities, except possibly in time related terms of efficiency. To start, the mechanisms considered will simply be: (1) information relay, (2) negation, (3) copy and redistribution, and (4) the actual computation comprised of Boolean connectors at different levels of nestedness that will also be emphasised structurally. Practically, comparing the original (reality-modelling) version of a network's representation, with the canonical version will draw attention to whatever explains the difference between the two representations, and whatever makes the difference actually significant if it is. The definition of those canonical representations of BANs will also help define formally and in structural terms an appropriate notion of computational complexity for interaction systems. This will complement a line of investigations that was inspired by perspectives discussed at length with Prof. J. Demongeot following [43, 44], that is set in the immediate sequel of [46, 49, 50, 60], and that benefits from my collaboration with Prof. T. Ward (Durham University). The idea is to focus on what can be called *elementary BANs* – very simple, essentially scalable BANs, with very simple scalable interaction structures (*e.g.* cycles, trees) – and to take an original interest in the effects of combining these BANs, starting with the most simple, essentially scalable ways of doing that: using what can be called *elementary connections* connecting elementary BANs. The aim is to define a grammar generating all BANs of a certain kind (*e.g.* biologically pertinent [43], or computationally complete). This is what [49, 50, 60] have started to do, having introduced the notion of *order of a BAN* and shown that for simple BANs, it is more relevant to compare BANs of same order than BANs of same size. Based on [49, 50, 60], I will formalise a definition for a relation of *approximation* $\lhd$ between BANs of same order – that is, a relation that preserves generating mechanisms while *simplifying* their implementation, according to a well defined notion of *structural simplicity* $\delta_s(\mathcal{N})$. Straightforwardly, δ_s and thereby $\lhd$ will define a notion of *structural abstraction*. I will study (a) how structural abstraction impacts on the behaviour of the network and (b) what becomes of recurrent states and attractors of a network when it is approximated by a simpler one. (c) I expect a proof of the conjecture saying that a greater structural simplicity δ_s implies a greater capacity to approximate other BANs (*i.e.* more behavioural complexity/freedom/ambiguity). And (d) in order to

make all those results useful in practise, a set of elementary operations (*e.g.* remove/add elementary connections) will be defined, to be applied to the interaction structure of a BAN to turn it into one of its approximations. (e) This will naturally provide the notion of *emergence* with a formal definition specifying how, why and *where exactly the emerging actually takes place* (between levels of abstraction of the δ_s-scale) and qualifying the notable BAN properties that are not scalable all over the δ_s-scale.

1.3.4 Mathematical tools for the BAN-based research

Just like [49,50,60], the specific problems of R6 will substantially rely on Combinatorics on Words[61] and Number Theory. They might also need to borrow tools from Information Theory and from Symbolic Dynamics[62] – a closely neighbouring field that [60] started explicitly relating to the field of (B)ANs. Generally, the mathematical tools that this project's research involves is Graph Theory (to describe properties of BANs' interaction graphs), Abstract Rewriting theory (to describe properties of the state transition systems that represent BANs' behavioural possibilities), and Boolean Function Theory[63] (to describe properties of the defining mechanisms of BANs).

1.3.5 The streamlining interface system (IFS)

Owing to the generality of the questions it raises (*cf.* Section 1.2), the technical problems involved by my research usually intersect naturally other (B)AN investigations and are easy to collaborate on (*cf.* Section 1.3.3). Experience has taught me however that to collaborate on, let alone discuss fundamental/transdisciplinary motivating questions (*cf.* Section 1.2) scientifically requires a strategy of its own. This project proposes one in the form of the "interface system".

The interface system (IFS) is a coherent system of interactive modules (didactic demonstrations, simulation programs, questionnaires *etc*) that will be implemented as the online toolkit (OT) of applications detailed in Section 1.3.6, and will define the *modus operandi* of the recurrent workshop (RW) described in Section 1.3.7. In a consistent manner, it will: (a) present to a transdisciplinary public the research of this project *without diluting the semantic contents of its results,* (b) set the level of abstraction at which the fundamental issues raised by the research can effectively be discussed, and (c) collect, format and organise information and feedback in a highly methodical way. While doing that, the IFS will offer users of the OT and participants of the RW an opportunity to (i) acquire methods and tools to facilitate exportation of their specialised results about particular interaction systems, (ii) resolve interdisciplinary problems with transdisciplinary (*i.e.* fundamental) reasoning, (iii) be made to look at their objects of study from a different angle, and (iv) get support and relevant constructive prompting in the process of formalising their ideas and consistent modellings of their systems.

An advantage of addressing fundamental questions is that it facilitates the task of stripping the mathematical BAN-specific formalism off of the results derived in answer to them and extracting their fundamental meaning. The IFS will exploit this advantage to take the communication of the

fundamental computer science research a step further. It will present to users/participants, non-mathematical non-specific translations of research results that users/participants can effortlessly transpose into the terms they are the most familiar with so that they can exploit the results for their own research. To that end, in collaboration with a user-interface/user-experience designer (*cf.* Section 4), I have started exploring sensory and interactive means to convey subtle nuances in BAN-related information that I have been finding close to impossible to convey verbally and with the mathematics[1] (*cf.* incaseofpeace.com/birdman/[2] for a demonstration). Because the communication of these nuances is absolutely primordial for the communication of the general understanding produced by my research and for collaborating on more than just technicalities, the project will pursue methodically this exploration. In the process of doing that, it will design modules specifically to draw attention on traditionally neglected aspects of interaction systems (*e.g.* the possible lack of symmetry between the way change and absence of change are accounted for) and their consequences (*cf.* incaseofpeace.com/quiz/).

Conversely, the IFS will ensure users/participants can influence and enlighten the BAN-based research with their insights and with fundamental information about interaction systems that the BAN formalism fails to convey. This will require to screen out unnecessary complexity induced by disciplinary specifics, and guide the user/participant's expressions of their ideas/statements/explanations/interpretations into a standard template. In collaboration with postdoc Dr C. Morier (*cf.* Section 4), carefully designed series of guidelining questions made to ensure this will be experimented with, in particular as part of the RW. The modules of the IFS will accompany the users/participants' train of thought step by step through personalised circuits tailored to their inputs (*cf.* incaseofpeace.com/quiz/). The atomicity of the points made and of the information sought at each step is crucial. It will ensure the inputs recorded are indeed ready-to-use feedback. It will also make it possible to address relevant questions to the users/participants, cut straight out of their inputs. Because of how the modules will be designed, and because of the users/participants interest in them, those relevant questions will instantiate the precise points where the users/participants' research intersects research on dark information and where the two can effectively contribute to one another.

To collect the data, the IFS will work as an "inverse Turing test" focusing on the information that the user/participant has but the system and the underlying BAN-formalism don't – for instance, information on how specificities of the users/participants' research domain fundamentally influence the perspective on formalism that is traditionally taken in that domain. The IFS will parse inputs and test them for exploitable inconsistencies. It will thus give users/participants an opportunity to formalise informal aspects of their perspectives, possibly draw new information out of them, and test

ITT

[1] Mathematical formalism has a strong tendency to convey semantics with a great uniformity that only the obstructive traditional blind spots and semantic pre-conceptions like those mentioned in [7, 34] ever manage to interrupt.

[2] For an explanation of this website's name and of the project it hosts see incaseofpeace.com/betweenus.

whether their conclusions remain coherent once decomposed and combed through by the system. In the OT, conformity of the user's perspective with the system's decomposition of it will be recorded to build statistical support in favour of the user's perspective. In the RW sessions, conformity will translate into participants agreeing on a common formalisable view of a notion/object/property. Such agreements will act as a measure of the progress made during the successive sessions. They will be used to select consensual definitions that will increase efficiency in finding common grounds for further transdisciplinary discussions and workshop sessions. They will be meticulously documented into a progressive 'Dictionary of Interaction Systems' organising in consensual terms what we collectively understand so far of interaction systems.

In short, the IFS is a system that combines human and algorithmic capacities to create an *ad hoc* context in which the BAN-based research on dark information can be showcased, discussed, and spontaneously made use of. It automatises feedback collection and the research's promotion. More than that, it streamlines the work-flow of the whole project. It will therefore have an appreciable administrative impact on the BAN-based research work, the lattice of questions it addresses and the format of answers it produces, orienting it towards a practical method for uncovering dark information and adapting it just-in-time to other actual scientific investigations.

In the earliest stages of its development, the IFS will be tuned and experimented with from within my close (yet large) scientific community, *i.e.* among researchers working with discrete models of biological regulation systems. This public can immediately benefit from the project because the BAN-based research on dark information can uncover new facets of the objects they study and suggest new questions about them (*cf.* [7]). The IFS is a natural tool for them to weave their results organically and methodically into a wider academic range. The transdisciplinary scope of the IFS will expand with the contributions of PhD students. RW sessions will be addressed specifically to them and will eventually organise into a working group at the Freie Universität, Berlin (*cf.* working plan). For this public, the IFS will serve as a way to acquire a generic method for investigating interaction systems and generating new questions systematically, and also potentially, a way to start a collaborative scientific network of their own independent of that of their official scientific supervision. Eventually, the IFS, and more specifically the RW, will be advertised to a larger public as a 'computer science crash course', that *doesn't* teach the competences of a computer scientist, but instead communicates their live perspective on information and on systems, *i.e.* the *ad hoc* part of their fundamental understanding as it applies *in vivo*.

1.3.6 The toolkit, or online implementation of the interface system (OT)

The online toolkit (OT) is the straightforward, carefully styled online implementation of the IFS organised into a tree-like structure of modules (and presented to the user as an "interactive book").

It simultaneously promotes, prepares, backs up, prolongs and to some extent automatises the RW. Its development by a user-interface and user-experience web designer will ultimately take the IFS a step further by enhancing the interactive experience with Machine Learning and Human-Based Computation (HBC) techniques. As part of the OT, two programs will be developed on the basis of a common motor dictated by the building blocks/generating mechanisms of interaction systems mentioned in Section 1.3.2, and by the *Dictionary of Interaction Systems*. mentioned on page 10. One of the programs will allow the user to manipulate the building blocks, combine them, experiment with them, and build a visual representation of the clockworks of their own interaction system, without any (textual/mathematical) formalism. The other will output a collection of various formal representations of the interaction system inputted by the user (*cf.* [7]). A third program will provide a practical challenge to the following assumption: *"The formalisation $\mathcal{F}(s)$ of a statement/idea/explanation s (about an interaction system) is able to convey completely and explicitly the meaning $\mathcal{M}(s)$ of s"* ($\mathcal{M}(s) \subseteq \mathcal{F}(s)$). The program will decompose and parse the user's input statement s (*cf.* Section 1.3.5, p.9), and it will compile it into a set of non-textual, highly portable alternative formulations of s (according to principles similar to those underlying incaseofpeace.com/birdman). The user will will be asked to compare the alternative formulations of their own s. This feedback on the challenge's outcome for a specific s will provide precious help to understand where dark information primarily lies in practise.

P1 P2 P3

1.3.7 The recurrent workshop, or live implementation of the interface system (RW)

The live version of the IFS will be designed as a set of stand-alone recurrent workshop sessions (RW). The idea is to form workgroups out of the attendees of the same sessions and tailor the subsequent sessions to them so as to benefit from followed-up discussions and previous agreements.

Globally, the sessions will be organised into different themes. Most of them will ensue immediately from the BAN-based research on interaction systems – *e.g.* causality, abstraction, time flow (*cf.* working plan) and will coincide with the central themes of the project's postdoctoral fellow's own research (*cf.* Section 4). The postdoc and I will collaborate on both the preparation and the facilitation of RW sessions. We will also experiment separately with more specialised versions of the RW sessions addressed more specifically to workgroups closer to our respective original scientific communities (*cf.* working plan). Still, the overarching objective of all RW sessions will be *to practise, test and establish common methodological landmarks for carrying out effectively constructive interactions within transdisciplinary groups of researchers gathered together to research information in the dark*. So on the basis of the ongoing transdisciplinary dialogue the RW will occasion between the postdoc and I (an ongoing transdisciplinary dialogue that we will necessarily have to learn to tame rigorously, and ensure the efficiency of through well-identified communication techniques), we will be drawing conclusions together, and in particular, ensuring on the fly that the concept of *information in the dark* takes roots and feeds from research fields beyond that of interaction systems.

T

Locally, the structure of the RW proceedings will be dictated by the IFS. Extensive use of the preliminary data collected online will be made (i) to determine where to set the debate so it can smoothly take place and be supervised, (ii) to determine the degree of formalism needed and the extent to which the theory can be bypassed, (iii) to select the more successful exercises and questionnaires of the IFS, and generally (iv) to foresee and prepare for the way researchers receive certain pieces of information, the difficulties to expect, the objections that will need answering, and the discomforts that will need dissipating. The firm framework the IFS will give to the RW proceedings will enable a discursive process that is organic, yet still highly methodical and closely supervised. To guard it from becoming overly influenced by my Computer Science-induced understanding of interaction systems, my input to the RW (namely, the IFS) will be complemented by: (a) the postdoc's contribution, (b) interactive exercises setting discussions precisely where my input can straightforwardly be challenged by participants, and (c) occasional one-off sessions handed out to a guest or volunteer chair.

On top of creating an opportunity for other researchers to experiment with the IFS and contribute first-hand to its fine-tuning, the RW is meant to be an opportunity to collect live intuitive feedback on how the theoretical research on dark information relates to other research, what questions need more urgent attention and what deadlocks can more easily be resolved for a greater immediate impact. A session log and an updated version of the *Dictionary of Interaction Systems* will be kept online. In collaboration with the postdoc, the knowledge and understanding thus produced by the RW will gradually be reinvested into the preparation of a new concept of international transdisciplinary conference in between the Cybernetics Macy Conferences and the TED talks (*cf.* working plan). So with the help of the OT, extreme care will generally be invested into the organisation of that knowledge and understanding.

E

1.3.8 Quality assurance measures

Precisely, the project is structured by the IFS, and in itself the IFS (through both the OT and the RW) acts a system of risk management and quality assurance measures.

1.4 Potential and anticipated impact

My research focuses on fundamental notions (*e.g.* synchronism, instability, abstraction, precedence, reversal, networkness) and it makes a point of relying as little as possible on formalism specifics. Because of this, not only does the ensuing understanding have the rigour of mathematics, it also has the property of being especially portable and easy to manipulate intuitively. And it considers *effects* that are essentially scalable[3], so conveniently it uncovers *causes* that also are essentially scalable.

I1

This research thereby materialises the possibility of organising the literature's plethora of results concerning ANs. In the form of a progressive collection of common meaningful notions and non-specific mechanisms, it provides middle grounds for these results to be formally related, uni-

[3]Since BANs simulate ANs, scalability is one of several important arguments in favour of the BAN formalism.

fied, pooled and possibly generalised. In the framework of ANs, research on dark information

I2 serves an additional purpose because it consists in studying the restrictions/assumptions that are usually made on ANs, rather than studying the ANs under those restrictions/assumptions. Thus, it allows to specify the information i that is conveyed by a given mathematical result r, the extent to which i concerns the objects that r is meant to be about, and the extent to which i concerns the restrictions/assumptions under which r is proven (*cf.* [34], sections 7 and 8). This helps to choose intuitively tractable and viable restrictions/assumptions under which generalisable results can be derived.

I3 The strict focus on *fundamental* notions and mechanisms will also impact beyond the framework of BANs thanks to (and as evidenced by) the IFS: this focus promotes non-vulgarising communication of scientific information to non-specialists. Within the five year term of this project, I expect a habit of

I4 organised transdisciplinary dialogue to develop beyond the scope of my actual scientific community. The growing network of RW participants and potential collaborators entertaining this tradition will find a lasting infrastructure in the form of the IFS's online version. The workshop will also, if not federate, then at least provide a well prepared audience to apposite research which, like dark information research, promotes a rigorously adaptive version of science with less platonic claims to absolute objectivity than requirements of present relevance.

I5 An important aspect of this project is how it actively promotes Computer Science in a landscape comprised of older sciences. It puts forward the Computer Science understanding of systems and information – as opposed to a mathematical understanding of the system's models possibly backed up with interdisciplinary understanding of some rudiments of the modelling's specifics. Research on dark information gives to Computer Scientists the responsibility for parts of reasonings traditionally considered the exclusivity of the "applied" sciences. So, far from restricting Computer Scientists to the role of "experimental data representator", it places them in a pivotal position where they might call into question "applied" scientists' understandings on their own grounds of their own knowledge. What is more, the project's IFS means to institute a discipline of fundamental reasoning. The feasibility of the initiative essentially relies on investing the characteristic interests of Computer Science (*e.g.* formalisations *versus* semantics, expressivity, information equivalences, consistency, complexity and how to avoid it) in the defining of a rigorous framework for transdisciplinary interactions and knowledge to be orchestrated in. Giving the initial impetus and then supervising the initiative during its early stages is thus a task for a Computer Scientist, that will promote a Computer Science epistemology.

I6 One of the major interests in interfacing purely Computer Scientific research with other research as sections 1.3.5 and 1.3.7 propose to do, is to avoid the burden of "real-world complexity" while also avoiding the risk of doing too much of that (of avoiding the burden of real-world complexity). By organically weaving external scientific interests into Computer Science research on dark information, we can learn about limits of each key component of the interface, starting with (a) the limits of the BAN

formalism, (b) the limits of the interaction system perspective – especially, what are the fundamental properties of objects that cannot relevantly be seen as interaction systems, and what are the kinds of things we say about them that cannot naturally be conveyed in an interaction system formalisation of these objects – and finally, (c) the limits of fundamental reasoning (*i.e.* reasoning shared across disciplines) and what it can apprehend – especially, what explicitly, are the fundamental differences between the *formalising and sense-making mechanisms* characteristic to each scientific specialism. Pin-pointing all these limits precisely will consolidate transdisciplinary communication by providing theoretical landmarks for it. It will also prepare for the future research on information in the dark beyond the interaction systems setting chosen for the present project.

2 Teaching Concept

I propose to teach a course named "Time in Computer Science". Many academic sciences tend to consider time as a fundamental parameter of nature indisputably pre-existing the systems that are studied. Computer Science's executive approach to systems, and its essentially discrete definition of information bestow upon it a characteristically diversified perspective on the notion of time. The course will use this to navigate through a range of foundational fields of Contemporary Computer Science – including Concurrency and Trace Theory, Complexity Theory, Automata Theory, and some Bio-informatics applications – and develop a more flexible and thorough understanding of *what time accounts for* in those contexts. The course will be proposed as a semestrial module (5ECTS) of 4 weekly hours (2h of lectures + 2h of exercises) in the Computer Science Master program. Depending on needs, I might also participate in the teaching of pre-existing compulsory modules of this program and of the Bioinformatics program.

3 Host institution and research infrastructure

Because this project makes an extensive use of theoretical tools and theories, ideally, it should be hosted by a Mathematics and Computer Science department like that of the Freie Universität, Berlin. For the project's transdisciplinary pursuit to fully develop, it also should preferably be set in an environment that cultivates a variety of scientific interests like the Freie Universität's Institute of Bioinformatics. This institute is especially fitting because it hosts two groups that are of particular interest to my research project: Prof. H. Siebert's Discrete Biomathematics group and Prof. A. Bockmayr's Mathematics in Life Sciences group. The research fostered by these two groups relates naturally to my own through their common formal tools and common interests in ANs and in ANs' relation to a biological reality. The opportunity of regularly confronting the fundamental approach of my project to the significantly more extensional approaches of these groups, is one that I count on to ensure a tight, spontaneous interweaving of (a) the new fundamental understanding I propose to produce using purely formal prototypes, with (b) experienced practical understanding of interaction systems issues that a prototype alone cannot hint at. What is more, the concerns of those two research groups

make them ideal starting points for the immediate launching of and experimenting with the IFS.

4 Details of cooperation partners

As suggested in Section 1.3.3, this project occasions collaborations with a certain number of international collaborators, including collaborators from France, Germany, Chile and the UK. As suggested in sections 1.3.5–1.3.7, two additional collaborators will play a key role in streamlining the project's objectives through the IFS. The first is a postdoc, namely Dr C. Morier, who will contribute to the project through his own human science's based approach to the concept of *dark information*, and through his complementary non-interaction systems perspective that focuses on perceived variation of change rather than on formalised consequences of change. Dr C. Morier is a social-scientist qualified by the French Ministry of Research and Education's in both philosophy and epistemology. He has experience in organising interdisciplinary events. His research on *the shape of change* as represented by Catastrophe Theory also consists in representing change at a fundamental level where new angles of specific models can be considered, precisely, *without putting any emphasis on the specifics of the phenomena they model*. In other terms, his research *prototypes* fundamental changes rather than models specific cases of it, in the aim of shifting the attention onto neglected phenomena. Dr C. Morier's research is expected to provide substantial support for this project in the form of additional means of orchestrating transdisciplinary dialogue. The second key collaborator is user-interface/user-experience designer and web developer A. Borrego with whom I have been extensively collaborating for over a year and who was contracted by the Dahlem Research School in September 2016 to work on a showcase version of the IFS. On top of having a convenient working understanding of λ-calculus, logic, BANs, and of my research interests, A. Borrego has an interaction designer's concern for the strong dependency there is between the impact of a piece of information, and the form in which it is presented to and received by its recipient. The concept of *Information in the dark* represents the natural intersection of our interests.

5 Information on where this proposal has been and will be sent to for funding

I sent a very partial 'proto-version' of the present proposal (mainly Section 1.3.3) entitled *Causality, Time flow and Abstraction in Networks* to the DFG. I haven't yet planed to propose the project on *information in the dark* to another specific institution, but I will be looking for appropriate international opportunities.

	Task [1]	year 1				year 2				year 3				year 4				year 5			
BAN research (mostly my work)	Initiate research and corresponding collaborations on specific topic (see project description, Section 1.3.3):	R1 R2				R3				R4				R5				R6[2] (updated)			
	Submit summarising paper (and conclude research) [3]			R1	R2 (so far)				R3				R4				R5	R2			R6[2]
	File report on arxiv.org and update/rewrite work schedule + Prepare and submit follow-up research proposal					mid-term			term				mid-term	next proposal			term				term
	Produce interface-system-compatible presentations of formal results, insights, and difficulties so far																				
OT (mostly designer's work)	Design and development of . . .																				
	General website infrastructure [4]																				
	Core applications (*cf.* Sections 1.3.5 and 1.3.6) [5]			ITT							P1+P2				P3						
	Misc. applications [5]	B							CT					MP							
	Submit for publication [3]							T1-3				DIS	OT		M			S		T1-6	
RW (with postdoc)	Prepare and start running sessions on themes [6]	T1	T2			T3				T4				T5				T6			
	Start *event workshops* promotion campaign [7]												E								

OT = online toolkit (*cf.* Section 1.3.6) and RW = recurrent workshop (*cf.* Section 1.3.7).

1 In the first two columns, tasks on a green background are those that will be carried out by myself in collaboration with the researchers mentioned in Section 1.3.3 of the project description. Tasks on a yellow background will be carried out mainly by the interaction designer collaborating on the project (*cf.* Section 4). Tasks on a purple background will be carried out in collaboration with the postdoctoral fellow primarily (*cf.* Section 4), and with collaborators of the network developed through the IFS.

2 A significant part of R6 consists in producing representations of Boolean Automata Networks evidencing the fundamental sort of understanding produced by my research. R6 will significantly benefit from progress in R1 – R5, so R6's strategy described in Section 1.3.3 will need to be updated. I expect R6 to divide into several lines of research as a result of that.

3 R1 – R6 refers to publications in journals of my field (*e.g. Theoretical Computer Science, Discrete Mathematics*). Integrating the progress made through the IFS, each of those papers might yield an additional paper to be submitted to a journal outside of my field. DIS, M and T- refer to "The Dictionary of Interaction Systems", to a paper describing the ins and outs of the methodological framework of the RW, and the reports of the RW's progression on the different themes. Those documents are expected to be the object of publications in journals of Information Science, Philosophy of Research and/or Epistemology journals (*e.g. The British Journal for the Philosophy of Science, Qualitative Research, Journal of information science*). OT refers to the publication of the advances of the OT and of their contributions to the fields of Philosophy of Computer Science and Artificial Intelligence (*e.g.* in *Minds and Machines*). S refers to the publication of the data collected by the OT, and of the method and programs devised for the collection and organisation of knowledge on interaction systems (*e.g.* in *Synthese* or in *Foundations of Science*).

4 This includes a page for the RW with a calendar, a well-organised forum, a template for the "Dictionary of Interaction Systems", a log for the workshop sessions, a (voting) system to collect requests and suggestions for the workshop (*e.g.* topics, methodology adjustments). It also includes an underlying tree-like structure organising applications of the OT and their presentation to the user as an "interactive book". The user's experience of browsing through the book will be tailored to his/her inputs, and eventually experimented with in the aim of determining the extent to which the success of the communications taken in charge by the interactive book depends on parameters such as the relative order of these communications.

5 This includes CT: an interactive Catastrophe Theory based application to visualise the form of a process (the BAN formalism can only rigorously represent series of independent snapshot forms with an informational perspective, so this application will help complete the BAN-based applications of the OT), MP: an attractive and playful application to collect, format and organise sketches of how researchers represent for themselves the modelling process, and B: the general presentations of BANs, of the theoretical research, of the overall project, and of the project's progress as it takes

its course. ITT is a system that interacts with the user and translates user inputs into relevant surveys. P1 – P3 are the programs mentioned in Section 1.3.6.

The themes addressed in the RW are the following.

T1 *What is and what isn't an interaction system?* Saying something new, producing a new piece of communicable information requires observing a change, identifying a difference somewhere, somehow. What kind of difference/change is that in each field? Sessions on this theme will be designed to understand the fundamental differences of reasoning across disciplines and the limits of my perspective on BANs. They will circumscribe the public directly concerned by my project.

T2 *Ignorance and Abstraction.* This theme concerns lack of information, surviving possibilities, and alternative explanations [7] .

T3 *Intuitions, preferences, causality and definitions.* This theme which might be broken up into several concerns: (a) interactions of intuition with pre-existing formalisation, (b) the modelling of the modeller's preferences, (c) the impact and use [34] of the specific notion of causality we implicitly use, (d) the consequences of the precise formal definitions of the objects we study.

T4 *Time flow.* Sessions on this theme will revisit interaction system modelling with an informational approach to time flow. They will emphasise in particular the coincidence of our observations and interests with the events we talk about and model.

T5 *What a model can say, what it cannot, and what it can say that hasn't anything to with the modelling.* This concerns the expressivity of models and the consistency of modellings.

T6 *Axiomatisation of the interaction systems modelling process*. This theme will be approached in the lines of [52, 64], using Model Theory as a template to make the apparent multitude of scientific conceptions of "modelling" converge consistently.

In collaboration with the postdoc, I will successively address RW sessions on those themes to the following work-groups: (i) a local group of members of the Mathematics in Life Sciences and Discrete Biomathematics research groups of the Freie Universität, Berlin (FU), (ii) a group comprised of Dahlem Research School fellows, (iii) one or several transdisciplinary group(s) of PhD students of the FU (work-groups to be created), (iv) one or several transdisciplinary groups of FU researchers (to be created), (v) an international group of members of the Automata Networks scientific community. On top of that, the postdoc, namely Dr C. Morier, will propose the creation of a work-group to members of the FU from the Department of Philosophy and Humanities, the division *Methods and Evaluation* of the Department of Psychology, the research unit *Peace and Conflict Studies* associated to the Otto Suhr Institute of Political Science, and the Institute of Social and Cultural Anthropology. In immediate lines with his research, he will propose to address the questions of how causality, abstraction levels, and time flow are formalised and intuitively dealt with in academic research – in particular how does the intrinsically *relative* notion of time flow assumed by this project – and defined *by* the specific set of events considered – apply beyond the scope of interaction systems[65]. The idea is to take a Laennec-like perspective on the human sciences. And just like the stethoscope "*substituted a botany of symptoms by a grammar of signs*" in medicine[66] and "*shifted the attention of the physician towards the sickness and away from the sick person's explicit description of it*"[67], Dr C. Morier proposes to use the qualitative mathematics of Catastrophe Theory as a tool to circumvent the taxonomy of isolated models meant to describe dynamics of the social-human dimension from outside of it, and replace it by a "grammar of internal transformation forms", thereby shifting the attention away from the complexity and specifics of particular changes and of particular vehicles of change, towards the process of change itself.

The concept of interaction system although very general and fundamental creates a bias in the way the notions of *change* and *interaction* (/*cause*) are regarded. The purpose of this project on information in the dark is of course *not* to avoid biases (any more than it is to avoid taking particular interests). Scientific reasonings are founded on definitions crystallising biases. This project is about developing flexibility and rigour around them. It proposes to extend Popper's criterion of refutability to the necessity of *the definitions that we ground our scientific models on* in order to address the need for *a practical scientific method that is independent insofar as possible, of our scientist's interests and of the objects our definitions are about.* The very purpose of this project thus makes it necessary to identify the biases it is creating along its course. Insofar as possible, this will be made possible by my collaboration with Dr C. Morier on the "interaction-system" based themes T1 – T6 and by his experimenting of analogue themes with the less formalised sciences.

The "*event workshops*" refers to the concept mentioned in Section 1.3.7: a *new Macy Conferences* actualised with – and based on the knowledge produced by the project on how to orchestrate productive transdisciplinary interactions. The concept is comparable to an interactive version of the TED talks for (young) researchers where instead of having one person engaged in a well framed monologue, we have a group of researchers engaged in a a well framed discussion. The concept will be developed, tested and fine-tuned in collaboration with the postdoc during the RW proceedings. We aim at hosting at least one event workshop E during the course of the project. We will look for sponsors to help us ensure the viability of this concept beyond the scope of the present project. The Wissenschaftsvermittlung und -kommunikation of the VolkswagenStiftung will for instance be approached for support.

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