COMPLEXYS - Research Institute for Complex Systems
Multidisciplinarity serving society

An Institute of the Université de Mons, COMPLEXYS brings together over 100 researchers (including 55 doctorates) spread over 2 research centres and 5 faculties. Its international recognition is evidenced by more than 170 publications in 2014 and an impressive collection of prestigious prizes.

The COMPLEXYS institute is distinguishable by the calibre of its members: Mickael Randour, 2015 Ackerman Prize for the best thesis in the field of logic in computer science and Quentin Menet, 2015 Antonella Prize winner, both participated in the Heidelberg Laureate Forum. For her part, post doctorate Jenifer Rubio-Magnieto was selected to participate in the 65th Conference of Nobel Laureates. And the list goes on. These honours are due to the high level of research conducted at the Institut Complexys.

Composed of numerous organisations interacting on a local level and producing global properties, complex systems like the brain, an economic market and biological ecosystems are the object of multidisciplinary research: nonlinear physics, mathematics and computer science come together to analyse, model and simulate numerous complex systems within exact sciences, engineering sciences, life sciences and human and social sciences.

The research from the COMPLEXYS institute can be placed into two categories: upstream, this is the study of fundamental theoretical tools; downstream, more applicative research using existing models and techniques to analyse complex systems whose function is not yet fully understood, for example the organisation of smart cities, education systems, the evolution of software systems and the structure of the universe and its constituents…

Natural ecosystems and software ecosystems

Head of the Numerical Ecology of Aquatic Systems group, Professor Philippe Grosjean has developed a partnership based on software ecosystems with Professor Tom Mens, head of the Software Engineering Laboratory. Both started from one observation: the extreme complexity of open source software mobilising thousands of developers and hundreds of millions of lines of code. By applying data mining and mathematical modelling of complex systems to software, they hope to improve the way it is designed, maintained and re-engineered in order to increase its reliability and scalability.

Backed by researchers of the universities of Eindhoven, Rey Juan Carlos de Madrid, Paris Diderot and the Université Polytechnique de Montréal, the two professors are relying on the obvious affinity between software environments and natural ecosystems. This is the challenge of ECOS: a collaborative research funded at UMONS by the Fédération Wallonie-Bruxelles for 5 years, this project is studying different software ecosystems including Gnome, a graphic desktop environment for the Linux operating system, and Debian, a package-based distribution of Linux.

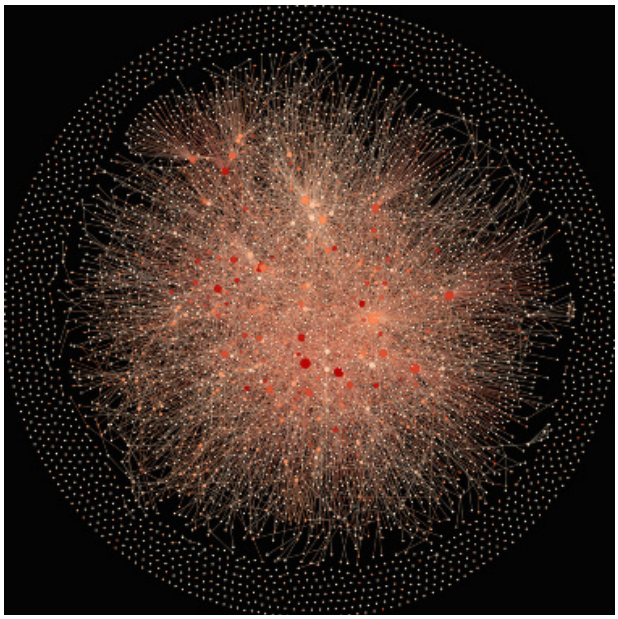
The ECOS project also includes the study of the R software environment for statistical and data analysis, with the same challenge of co-existence and co-evolution of software packages that will facilitate the addition of new functionality. R relies on a code-distribution website (CRAN) and software development forges (such as Github).

ECOS is expected to help inform package developers so they can make their software more maintainable (with the *maintaineR* software analysis tool) and more scalable. But other challenges are already looming: the processing and sharing of big data, not to mention the reproducibility of research so that the best tools can be provided for the study of complex systems, medicine, and science in general.

Smart cities

Making cities smart is one of the objectives pursued by Professor Thomas Brihaye's team, president of the COMPLEXYS institute, who is working on the application of the game theory to computer science, micro-finance, architecture and urbanism.

Professor Brihaye mainly contributes to the CASSTING project: an FP7 project part of the FoCAS collaborative action, a Future and Emerging Technologies Proactive Initiative,



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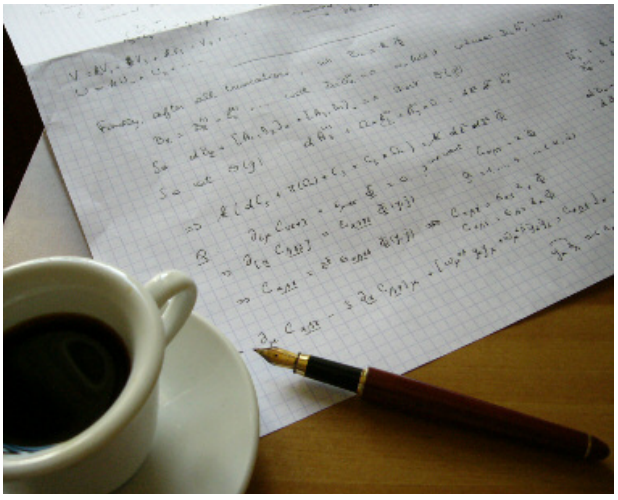
Graph of dependencies between packages in the R software ecosystem (on CRAN)

CASSTING involves CNRS (France), Université de Mons (Belgium), Université Libre de Bruxelles (Belgium), RWTH Aachen (Germany) and Aalborg Universitet (Denmark) as academic partners, and Seluxit (Denmark) and Energi Nord (Denmark) as industrial partners. The objective of CASSTING is to develop a novel approach for analysing and designing collective adaptive systems in their totality, by setting up a game theoretic framework. Here components are viewed as players, their behaviour is captured by strategies, system runs are plays, and specifications are winning conditions. CASSTING will develop formalisms for modelling collective adaptive systems as games, and algorithms for synthesising optimal strategies (and components).

Towards a quantum theory of gravity

Studying fundamental interactions and their unification: such is the ambition of the working group headed by Nicolas Boulanger, F.R.S.-FNRS Research Associate and winner of the 2015 Théophile De Donder Prize, a prize that rewards the best original work in mathematical physics and the first 15 years of the career of a researcher in that field. If the 4 fundamental interactions (electromagnetic, strong nuclear, weak nuclear, gravitation) are (relatively) well known, a challenge remains: the quantization of gravity via the elaboration of a mathematical model compatible with quantum mechanics and Einstein's theory of general relativity. Nicolas Boulanger's group is using string theory to work on this.

This theory is compatible with the rules of quantum mechanics and describes, among other things, a massless, spin 2 particle. In the past, Nicolas Boulanger and his collaborators have shown that the existence of such a particle automatically leads to General Relativity. This particle is called "graviton". String theory predicts other particles in addition to the graviton, this time with spin values of 3, 4, 5 etc., to infinity. These particles are called "high spin particles". It is the theories governing interactions between the graviton and high spin particles that Nicolas Boulanger and his collaborators are actively working on.



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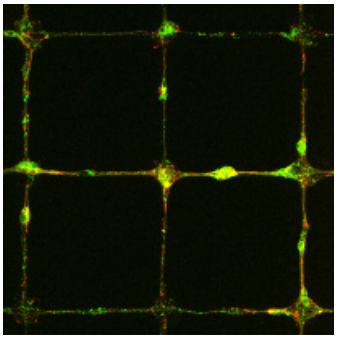
Theoretical physics research into fundamental interactions

Nicolas Boulanger's group has developed numerous collaborations with the ULB (Université libre de Bruxelles), the VUB (Vrije Universiteit Brussel), the KUL (University of Leuven) and UGent (Ghent University), as well as with researchers of all origins in France, Germany, Italy, England, Russia, China, the US and Chile. He is showcasing his work through presentations at conferences and summer schools and through publications.

Far from being fruitless, fundamental research always eventually leads to practical benefits. For example, Einstein's theory enabled the existence of GPS, present in many of today's cars, something Einstein would never have imagined at the start of the last century. By creating evermore advanced mathematical models, theoretical physics of fundamental interactions help solve problems that were hitherto unsolvable, as well as aiding a deeper understanding of the Universe and giving rise, in turn, to brand new questions.



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Fluorescent image of a network of cortical neurons grown on an adhesive micropattern deposited on a soft polyacrylamide hydrogel

Partnerships and challenges

Supported by the F.R.S.-FNRS, the COMPLEXYS institute has developed a number of partnerships with Belgian universities (eg UNamur, UCL, ULB, UGent) and international universities (eg ENS Cachan, Oxford University, Technische Universiteit Eindhoven, Università degli Studi di Verona, Universidad de Buenos Aires, Ecole Polytechnique de Montréal) with a special mention for CETIC and NASA's Goddard Space Flight Center.

These partnerships will be a welcome help in facing the many challenges of research into complex systems. For example, the human brain: Sylvain Gabriele's team recently achieved results that contribute towards elucidating the cellular mechanisms underlying mild traumatic brain injury (MTBI). Another challenge concerns the increasing ubiquity of evermore complex computing systems in our daily lives: automatic pilots, medical devices, electronic transactions… systems yet to prove their reliability. The challenge of automatically generated software remains in order to ensure its proper construction.

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