Graphs ALgorithms and Combinatorics

Florent Hivert

November 27-28, 2013

Contents

The Galac Team

- Evolution: from the Algo&Graphs teams to the GALaC Team
- Research subject
- Scientific production

Scientific Focuses

- Deepening Ramsey and Turán theory
- Sorting monoids and software for computer exploration

The five year plan

- The future of the GALaC team
- Self assessment
- Strategy

The Galac Team: Permanent Members

Professors	Senior Researchers (DR-CNRS)
Evelyne FLANDRIN (em)	
Dominique GOUYOU-BEAUCHAMPS	
Florent HIVERT	Antoine DEZA (Jan. 2014)
Yannis MANOUSSAKIS	Hao LI
Fabio MARTIGNON (IUF)	
Nicolas THIÉRY	

Associate Professors (MdC)	Researchers (CR-CNRS)
Lin CHEN	Nathann COHEN
Sylvie DELAËT (HdR)	Johanne COHEN (HdR - Sept. 2013)
Selma DJELLOUL	Réza NASERASR
Francesca FIORENZI	
David FORGE	

Galac: PhD students and Postdocs

PhD students (11):

Jean-Alexandre ANGLES D'AURIAC
Andrea Giuseppe ARALDO
Yandong BAI
Weihua HE
Sylvain LEGAY
Michele MANGILI
Jean-Baptiste PRIEZ
Qiang SUN
Aladin VIRMAUX
Weihua YANG
Jihong YU

Postdocs (2):

Meirun CHEN
Leandro Pedro MONTERO

Evolution: From Algo & Graph ...

Departures

- Sylvie CORTEEL (Sept. 2009), Jean-Paul ALLOUCHE (Sept. 2010), Pascal Ochem (Sept. 2011);
- Miklos SANTHA, Frédéric MAGNIEZ, Jordanis KERENIS, Julia KEMPE, Adi ROSEN and Michel de ROUGEMONT (Nov. 2010); Sophie LAPLANTE (Sept. 2012)
- Retirement: Charles DELORME (Sept. 2013), Mekkia KOUIDER (Sept. 2010), Jean-François SACLÉ (Sept. 2012)

Arrivals

Florent HIVERT (Sept. 2011)
Nicolas THIÉRY (Sept. 2012)
Nathann COHEN (Oct. 2012)
Johanne COHEN (Sept. 2013)
Antoine DEZA (Jan. 2014)

... to the GALaC Team

June 2013: The Algo team is merging with

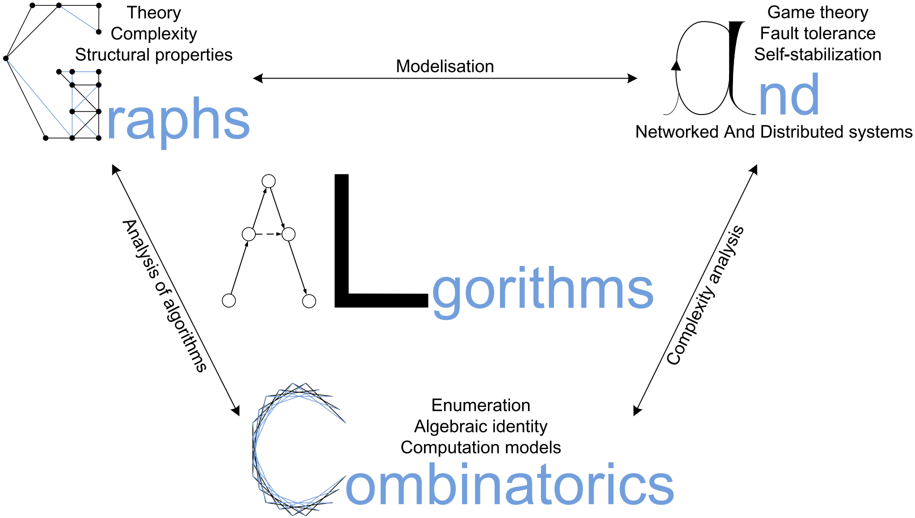
- From the former *GraphComb* team:

  Selma DJELLOUL
  Evelyne FLANDRIN
  David FORGE
  Hao LI
  Reza NASERASR (Oct. 2011)

- From the former *Réseaux and Parall* teams:

  Lin CHEN (Sept. 2009)
  Sylvie DELAËT
  Fabio MARTIGNON (Sept. 2011)

Graphs, ALgorithms and Combinatorics



Graphs Algorithms and Combinatorics

Note: Former activity “**Quantum algorithms and complexity**”.

Graph Theory and algorithms

Goal: Algorithmic and structural study of graphs

- Edge-colored, signed, random graphs
- Hamiltonian cycles and paths
- Algorithms, complexity
- Extremal theory, Ramsey type theorems
- Tools: Matroids, Linear optimization

Graph Theory and algorithms

Some results:

- Introduction of new classes of Ramsey-Turan problems (included in Shelp's 18 new question and conjectures) *(cf. focus)*

- Dirac-type sufficient conditions on the colored degree of an edge colored graph for having Hamiltonian cycles and paths.

Toward applications:

- Social networks
- Biology

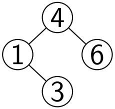
Combinatorics

Algebraic and enumerative aspects of combinatorics in relation to dynamical systems, numeration, and complexity analysis.

Goal: Relations between *algorithms* and *algebraic identities*

Example: Binary search vs rational fractions:

$$1364 \quad + \quad 1634 \quad + \quad 6134 \quad =$$



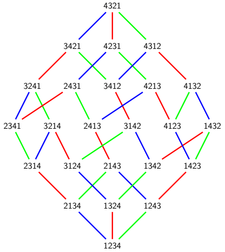
$$\frac{1}{x_1(x_1+x_3)(x_1+x_3+x_6)} + \frac{1}{x_1(x_1+x_6)(x_1+x_6+x_3)} + \frac{1}{x_6(x_6+x_1)(x_6+x_1+x_3)} = \frac{1}{x_3x_6(x_1+x_3)}$$

Some results:

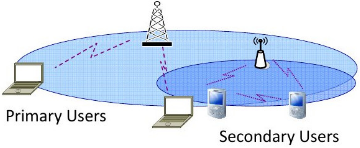
- Combinatorial Hopf algebra and representation theory: Definition and in depth study of *Bi-Hecke algebra and Monoid (cf. focus)*
- Tableau, Partitions combinatorics
- Dynamical systems and combinatorics on words
- Cellular automata on Cayley graphs

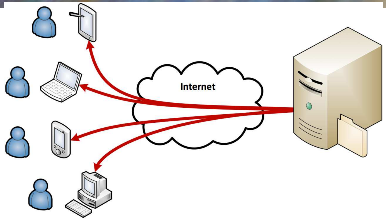
Applications:

- Statistical physics
- Analysis of algorithms



Algorithms for Networked Systems





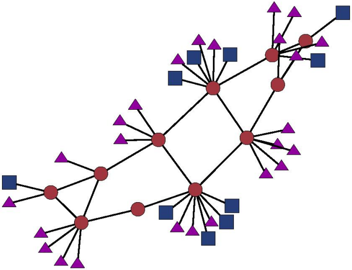
Problem: Concurrence, Selfishness, Local view

- Design efficient *modeling*, *control*, and *performance optimization* algorithms for networks
- Development of new mathematical techniques and *proofs*

Algorithms for Networked Systems

Tailored for:

- networked systems
- distributed systems
- robust, secure systems



Applications:

- Development of innovative tools for the optimal planning and resource allocation of *Cognitive, opportunistic wireless* and *content-centric networks*

Scientific production (Algo + Graph)

- Research papers:
  - Major international: 49 + 80
  - Other: 18 + 46
- Books and book chapters: 3
- Conferences papers:
  - Major international: 21 + 5
  - Other: 26 + 5
- Book edition: 3
- Software: Sage-Combinat (70 tickets, 30000 lines)

International cooperations

- Graphs:
  - John Hopcroft (Cornell University, USA, Turing Award)
  - Marek Karpinski (University of Bonn, Germany)
  - Raquel Agueda Mate (University of Toledo, Spain)
- Combinatorics:
  - Paul Schupp (University of Illinois at Urbana-Champaign)
  - Anne Schilling (University of California at Davis, USA)
  - Francois Bergeron (UQÀM, Québec)
  - Arvin Ayyer (Institute of Science, Bangalore)
  - Vic Reiner (Minneapolis)
- Algorithms for Networked Systems:
  - Antonio Capone (Politecnico di Milano, Italy)
  - Wei Wang (University of Zhejiang, China)
  - Alfredo Goldman (Sao Paulo University, Brazil)
  - Shlomi Dolev (Rita Altura Trust Chair, Ben Gurion University)

Scientific focus

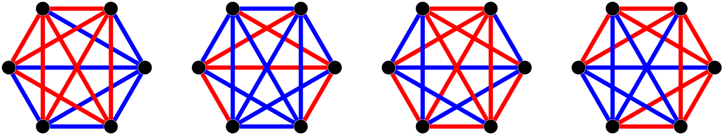
Deepening Ramsey and Turán theory

Hao Li

Background: Ramsey and Turán Theory

Theorem. (Ramsey, 1930)

For any $r, s \in \mathbb{N}$, there is a R such that any red/blue coloring of the edges of K_R contains either a blue K_r or a red K_s (picture: r=s=3)



Known: $R(3,3) = 6$. $R(3,4) = 9$, $R(3,5) = 14$, $R(4,4) = 18$, $R(4,5) = 25$, $43 \leq R(5,5) \leq 49$, $102 \leq R(6,6) \leq 165$.

Erdös : Imagine a powerful alien force landing on Earth and demanding the value of $R(5,5)$ for NOT destroying our planet. We should marshal all our computers and mathematicians and compute it. If they ask for $R(6,6)$ instead, then we have to fight back.

Background: Ramsey Turán Theory

A highly studied topic in Ramsey Theory:

Consider cycles subgraphs instead of complete graphs

Example: *On cycle-complete graph ramsey numbers*

(Erdös, Faudree,Rousseau, Schelp)

Theorem. (Turán, 1941)

Any graph G on n vertices not containing a K_k, $k \leq n$ satisfies:

$$|E(G)| \leq e(T_{n;k-1})$$

This bound is only reached by $T_{n;k-1}$.

Background: Ramsey and Turán Theory

- *Simonovits and Sós:* "Ramsey theorem and Turán extremal graph theorem are both among the basic theorems of graph theory. Both served as starting points of whole branches in graph theory and both are applied in many fields of mathematics. In the late 1960s a whole new theory emerged, connecting these fields."
- *Martin:* With its branches reaching areas as varied as algebra, combinatorics, set theory, logic, analysis, and geometry, Ramsey theory has played an important role in a plethora of mathematical developments throughout the last century.
- The theory was subsequently developed extensively by *Erdös*.
- *Szemerédi was awarded the 2012 Abel Prize* for his celebrated proof of the Erdös-Turán Conjecture and his Regularity Lemma.

Conjecture and Results

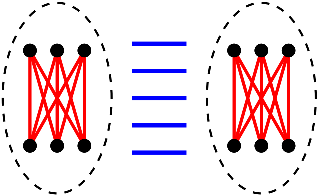
A new class of Ramsey-Turán problems

H. Li, V. Nikiforov, R.H. Schelp, Discrete Mathematics (2010)

Conjecture. (Li, Nikiforov and Schelp, 2010)

Let G be a graph on $n \geq 4$ vertices with minimum degree $\delta(G) > 3n/4$.
For any red/blue coloring of the edges of G and every $k \in [4, \lceil n/2 \rceil]$, G has a red C_k or a blue C_k.

Tightness: Let $n = 4p$, color the edges of the complete bipartite graph $K_{2p,2p}$ in blue, and insert a red $K_{p,p}$ in each vertex class.



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Theorem. (Li, Nikiforov and Schelp, 2010)

Let $\varepsilon > 0$. Let G be a sufficiently large graph on n vertices, $\delta(G) > 3n/4$.
For any red/blue coloring of the edges of G and $k \in [4, \lfloor (1/8 - \varepsilon)n \rfloor]$, G has a red C_k or a blue C_k.

More results

Benevides, Luczak, Scott, Skokan and White proved our conjecture in 2012, for sufficiently large n

Monochromatic cycles in 2-coloured graphs
Combinatorics, Probability and Computing (2012)

Open Questions

Question :

Let $0 < c < 1$ and G be a graph of sufficiently large order n. If $\delta(G) > cn$ and $E(G)$ is 2-colored, how long are the monochromatic cycles?

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We conjectured

Existence of monochromatic cycles of length $\geq cn$

✗ Disproved

The monochromatic circumference of 2-coloured graphs Matthew White, to appear in Journal of Graph Theory.

Open Questions

Based on our conjecture and the conjectures and open questions existing in Ramsey Theory, Schelp made 18 conjectures and open questions on more general Ramsey-Turán theory with similar ideas.

Some Ramsey-Turán Type Problems and Related Questions

Discrete Mathematics

Sorting monoids &
Software for computer exploration

Nicolas M. Thiéry

A story about

- Monoids arising from sorting algorithms
- Representation theory
- Computer exploration & `Sage-Combinat`
- Applications: Markov chains, ...

Bubble sort algorithm

4321

Bubble sort algorithm

4321

Bubble sort algorithm

4312

Bubble sort algorithm

4132

Bubble sort algorithm

1432

Bubble sort algorithm

1432

Bubble sort algorithm

1423

Bubble sort algorithm

1243

Bubble sort algorithm

1243

Bubble sort algorithm

1234

Bubble sort algorithm

1234

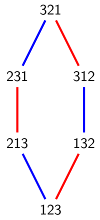
Bubble sort algorithm

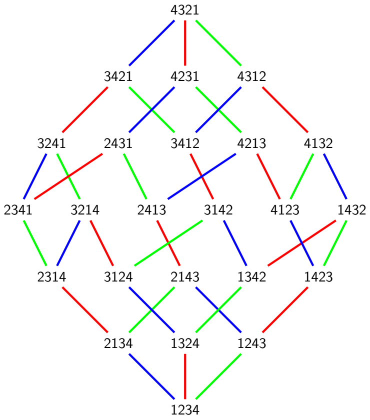
$$1234$$

Underlying algebraic structure: the right permutahedron

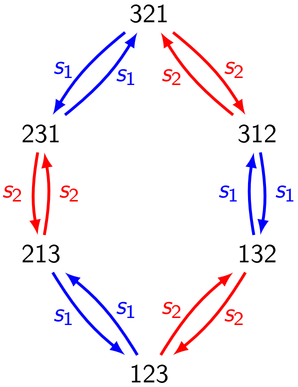
1234

Underlying algebraic structure: the right permutahedron





The permutohedron, as an automaton



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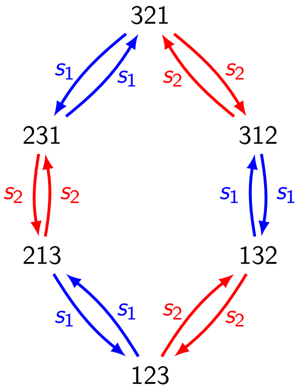

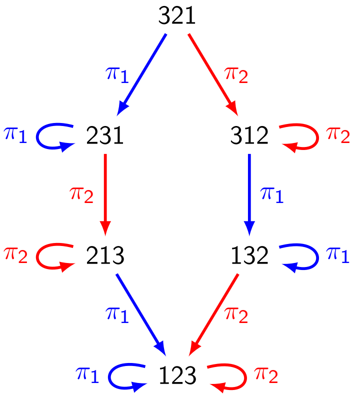

Definition (Monoid)

A set $(M, \cdot, 1)$

- $\cdot$ an associative binary operation
- 1 a unit for $\cdot$

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Example: the transition monoid of a deterministic automaton

Transition functions: $f_a : \begin{cases} \{\text{states}\} & \longmapsto \{\text{states}\} \\ q & \xrightarrow{a} q' \end{cases}$

Transition monoid: $(\langle f_a \rangle_{a \in A}, \circ)$

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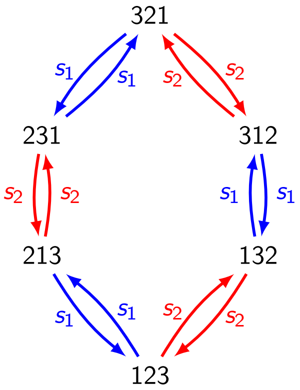
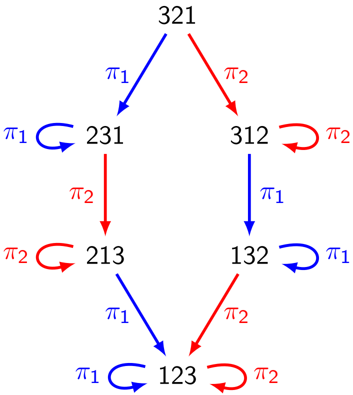
Motivation

- Study all the possible ways to compose operations together
- E.g. all algorithms built from certain *building blocks*
- Contains information about the language of the automaton

Sorting monoids





$$s_i^2 = 1$$

$$s_1 s_2 s_1 = s_2 s_1 s_2$$

Symmetric group $\mathfrak{S}_3$

$$\pi_i^2 = \pi_i$$

$$\pi_1 \pi_2 \pi_1 = \pi_2 \pi_1 \pi_2$$

0-Hecke monoid $H_0(\mathfrak{S}_3)$

The 0-Hecke monoid

Theorem (Norton 1979)

$|H_0(\mathfrak{S}_n)| = n! + \textit{lots of nice properties}$

The 0-Hecke monoid

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Motivation

- Same relations as the *divided difference* operators:

$$\partial_i := \frac{f(x_i, x_{i+1}) - f(x_{i+1}, x_i)}{x_{i+1} - x_i}$$

(multivariate *discrete derivatives* introduced by Newton)

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- Appears in analysis, algebraic combinatorics, probabilities, mathematical physics, ...

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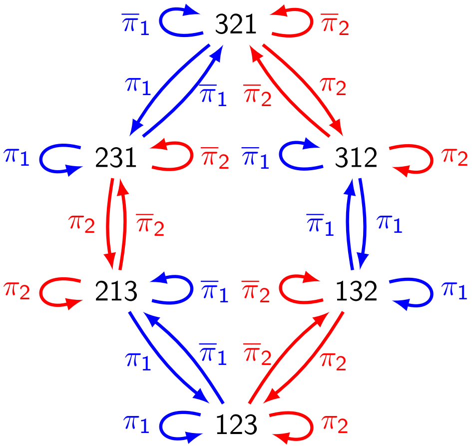
- Appears in analysis, algebraic combinatorics, probabilities, mathematical physics, ...
- Bubble sort: simple combinatorial model

A strange cocktail: the biHecke monoid



What's the transition monoid?

The biHecke monoid

Question

Structure of $M(\mathfrak{S}_n) := \langle \pi_1, \pi_2, \ldots, \overline{\pi}_1, \overline{\pi}_2, \ldots \rangle$ *?*

The biHecke monoid

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- Computer exploration
  $|M(\mathfrak{S}_n)| = 1, 3, 23, 477, 31103, \ldots$

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The biHecke monoid

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- Generators and relations (no usable structure)
- Representation theory

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Theorem (Hivert, Schilling, Thiéry (FPSAC'10, ANT 2012))

$M(\mathfrak{S}_n)$ admits $n!$ simple / indecomposable projective modules

$$|M(\mathfrak{S}_n)| = \sum_{w \in \mathfrak{S}_n} \dim S_w . \dim P_w$$

Question

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Problem

How to understand the product of a monoid?

Representation theory

Problem

How to understand the product of a monoid?

Answer

Relate it with the product of some well know structure!

Representation theory

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Answer

Relate it with the product of some well know structure!

Representation theory

Study all morphisms from M to $\mathrm{End}(V)$
E.g. *represent* the elements of the monoid as matrices
Make use of all the power of *linear algebra*

Side products and applications

Aperiodic monoids (Thiéry, FPSAC'12)

Algorithm for computing the *Cartan matrix*

$|M| = 31103$: computation in one hour instead of weeks

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J-trivial monoids (Denton, Hivert, Schilling, Thiéry, keynote FPSAC 2010, SLC 2011)

Purely combinatorial description of the representation theory

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Towers of monoids (Virmaux, submitted)

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Toward the categorification of Combinatorial Hopf algebras

Discrete Markov chains (Ayyer, Steinberg, Schilling, Thiéry)

- Directed Sandpile Models (submitted)
- R-Trivial Markov chains (in preparation)

Computer exploration requirements

A wide set of features

- Groups, root systems, ...
- Monoids of transformations, automatic monoids
- Automatons
- Graphs: standard algorithmic, isomorphism, visualization
- Posets, lattices
- Representations of monoids
- Linear algebra (vector spaces, morphisms, quotients, ...)
- Serialization, Parallelism, ...

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A tight modelling of mathematics

Birth of the `Sage-Combinat` projet

Mission statement (Hivert, Thiéry 2000)

"To improve `MuPAD/Sage` as an extensible toolbox for computer exploration in combinatorics, and foster code sharing among researchers in this area"

Birth of the Sage-Combinat projet

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"To improve MuPAD/Sage as an extensible toolbox for computer exploration in combinatorics, and foster code sharing among researchers in this area"

Strategy

- Free and open source to share widely
  While remaining pragmatic in collaborations
- International and decentralized development
  Warranty of independence
- Developed by researchers, for researchers
  With a view toward broad usage
- Core development done by permanent researchers
  PhD students shall focus on their own needs
- Each line of code justified by a research project
  With a long term vision (agile development)
- State of the art computer science practices
  Cooperative development model and tools, methodology, ...

Sage-Combinat: 13 years after

In a nutshell

- MuPAD-Combinat: 115k lines of MuPAD, 15k lines of C++, 32k lines of tests, 600 pages of doc
- Sage-Combinat: 300 tickets / 250k lines integrated in Sage
- Sponsors: ANR, PEPS, NSF, Google Summer of Code, ...

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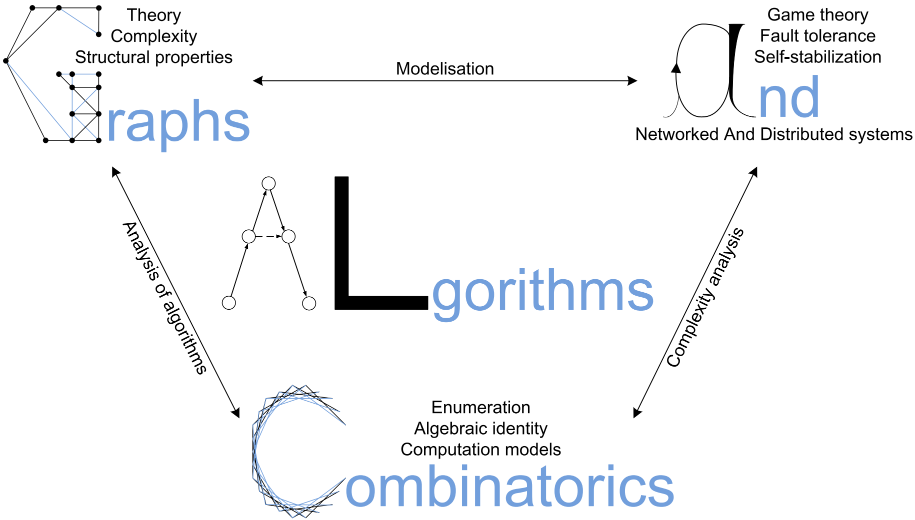
- **100+ research articles**
- **Research-grade software design challenges**

An international community (Australia, Canada, USA, ...):

Nicolas Borie, Daniel Bump, Jason Bandlow, Adrien Boussicault, Frédéric Chapoton, Vincent Delecroix, Paul-Olivier Dehaye, Tom Denton, François Descouens, Dan Drake, Teresa Gomez Diaz, Valentin Feray, Mike Hansen, Ralf Hemmecke, Florent Hivert, Brant Jones, Sébastien Labbé, Yann Laigle-Chapuy, Éric Laugerotte, Patrick Lemeur, Andrew Mathas, Xavier Molinero, Thierry Monteil, Olivier Mallet, Gregg Musiker, Jean-Christophe Novelli, Janvier Nzeutchap, Steven Pon, Viviane Pons, Franco Saliola, Anne Schilling, Mark Shimozono, Christian Stump, Lenny Tevlin, Nicolas M. Thiéry, Justin Walker, Qiang Wang, Mike Zabrocki, ...

Graphs, ALgorithms and Combinatorics



The future of the GALaC team

A newly created team with many recent recruit

- Reinforce and unite
- Keep a very high production level and international visibility

Scientific goal: developing the theory of efficient algorithms.

- Algorithms, analysis, models, combinatorics, mathematical tools
- Coordination of `Sage-Combinat`
  Mutualized software development for combinatorics, Sage platform

Graphs theory and algorithms

Structural and Algorithmic point of view:

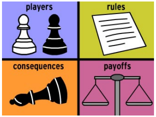
- Finding sufficient and computationally tractable conditions for a graph to be Hamiltonian (Thomassen's conjecture)
- Edge and signed colored graphs, random signed graphs
- Combinatorial, computational, and geometric aspects of linear optimization, application to graph algorithms
- Software experimentation.

Application:

- Bio-computing, Web, and distributed/networked system

Algorithms for Networked Systems

- Establish *theoretical building blocks* for the design and optimization of networked systems, including:



  - Algorithmic Game Theory
  - Distributed Algorithms (Self-stabilization, Fault Tolerance)
  - Discrete Event Simulation, Markov Chains

- Design novel, efficient *algorithms and protocols* based on the developed theoretical framework
  - evaluate their performance in practical networked and distributed scenarios
  - thanks to graphs tools, combinatorics, algorithms analysis

Combinatorics

- Algebraic structures (Combinatorial Hopf Algebras, Operads, Monoids, Markov chains…) related to algorithms
- Enumerative combinatorics and symbolic dynamics

Objectives:

- Generalization of the notion of generating series, application to fine *analysis of algorithms*
- Applications of algorithms to algebraic identities (representation theory, statistical physics)

New research theme:

- Object/aspect oriented design patterns for modeling mathematics

Self assessment

Strengths

- Very high quality in research production
- High international visibility
- High attractivity
- Leader in development of combinatorics software (Sage-Combinat)

Weaknesses

- Lots of movements, the team is in stabilization process
- Few young researchers
- Few industrial contact

Self assessment (2)

Risks

- Integration of the team: complete reorganization + environment (plateau de Saclay)
- Currently missing some access to Master courses

Opportunity

- Building of the Plateau de Saclay

Strategy

- **Recruitment**
  New associate professor in June 2014. Hdhire more young researchers in the GALaC Team within the next five years.
- **Séminaire Algorithmique et Complexité du plateau de Saclay**
  Founded in october 2011 by the Algorithmic and Complexity team of the LRI, Évry, LIX, PRISM, and Supélec.
- **Master MIFOSA**
  Coordinators: Y. Manoussakis, S. Conchon
  Creation of a new Master in theoretical computer science on the "Plateau de Saclay" involving two Universities (Evry, Paris-Sud) and five "Grandes Écoles" (Centrale, Supelec, ENSTA, Télécom ParisTech, Télécom SudParis), with the support of INRIA, Alcatel and EDF.