INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team Gyroweb

Dynamic graphs and large networks

Rocquencourt

THEME COM

Activity Report

2004

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1. Team

Gyroweb is a joined team between INRIA, CNRS and Paris 7 University, through the "laboratoire d'informatique algorithmique, fondements et applications", LIAFA *(UMR 7089).*

Head of project-team
Laurent Viennot [Research scientist (partner)]

Vice-head of project team
Dominique Fortin [Research scientist (partner)]

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Staff member CNRS
Matthieu Latapy [Research scientist (partner)]

Staff member Paris 7 University
Fabien de Montgolfier [Assistant professor]

Ph. D. student
Anh-Tuan Gai [BDI]
Jean-Loup Guillaume [ENS Cachan]
Fabien Mathieu [ENS Ulm]

Student intern
Stevens Le-Blond [Epitech]

2. Overall Objectives

The main objective of the project is to study the structure and the dynamics of the graphs appearing in large networks. The web graph defined by the web pages and the hyper-links between them is one of our main application field. Other natural subjects of interest include the Internet graph (defined by the connections between Internet routers), peer-to-peer networks (where a logical network links the peers together) and social networks.

The first problem comes from measuring such large structures. Usually made through crawling, the process of discovering the large graphs listed above is long and incomplete. How to define precisely what is measured, quantifying how accurate is a measure are still open problems.

The natural follow-up is to model such large networks. Recent work has exhibited power laws in degree distributions of these graphs. However, few efforts have been made on modeling the dynamics of these evolving graphs.

Finally, these graphs are linked to algorithms and protocols as page-rank for the web graph, routing for the Internet graph and indexing for peer-to-peer networks. Optimizing them by using the knowledge of the structure of the underlying graph is one of our goals.

3. Scientific Foundations

Keywords: *dynamic graphs*, *graph algorithms*, *matrix analysis*, *network protocols*, *stochastic models*.

The main competencies of the team are graph algorithms, networking protocols, matrix analysis, and stochastic models.

3.1.1. Networking protocols and graph theory

The design of networking protocols (such as ad hoc routing protocols or file sharing peer-to-peer protocols) often rely on distributed graph algorithms. Many invariants for the good functioning of them can be expressed as graph theoretical properties. Moreover, many observations of large graphs rely on the underlying protocols allowing to measure them (such as HTTP for crawling the web graph, or BGP and ICMP for discovering the Internet graph). Knowledge of these protocols and network constraints are fundamental when modeling these graphs.

3.1.2. Stochastic graph models

The popular random graph model of Erdõs and Rènyi does not capture the properties observed in real world complex networks (web graph, social graphs, etc). These properties are in general a power law degree distribution, a low diameter, and a high clustering. Consequently, there is a need to find new models for these graphs. The aim at finding such models is to understand the basic mechanisms behind their particular structure to predict their future evolution and to randomly generate graphs having the same properties. Although some results on graphs with power law degree distribution have been published, much still has to be done in this area.

3.1.3. Matrix and spectral analysis of large graphs

Matrix analysis reveals some important properties of large graphs through their adjacency matrix. The page-rank for example can be viewed as an eigenvector of a normalization of the adjacency matrix of the web graph. More generally, structural analysis splits into spectral analysis and actual domain approximation. In the former, we relate eigenvalues and eigenvectors to properties like maximum clique, maximum cut, etc..., while in the latter we devise simpler structures that leads to close approximations of general ones. Due to large sizes, both approaches are rather complementary than competitors.

3.1.4. Dynamic graphs

An abundant literature around fully dynamic algorithms treats the problem of updating a graph computation after slight modification of the graph. Another approach resides in considering a dynamic graph as an evolving structure and trying to characterize the properties of this evolution.

4. Application Domains

Keywords: *Internet reliability*, *mapping the web*, *peer-to-peer protocols*.

Application domains include mapping the web, evaluating Internet reliability, and the design of efficient peer-to-peer protocols.

- The main application of studying the web graph resides in evaluating the importance of web pages (as popularized by the PageRank of Google). A long term application goal is to map the web: that is to identify automatically sites and links between them.
- Modeling the Internet graph main application is to allow realistic simulation of Internet protocols. Another interesting field resides in evaluating the reliability of the Internet connectivity.
- Peer-to-peer protocols are based on a all equal paradigm that allows to design highly reliable and scalable applications. Besides the file sharing application, peer-to-peer solutions could take over in web content dissemination resistant to high demand bursts or in mobility management.

5. Software

The team develops internal tools for crawling and generating large random networks.

- Jean-Loup Guillaume has developed random graph generators http://www.liafa.jussieu.fr/~guillaume/programs/.
- Stevens Le-Blond has developped a prototype for crawling the Gnutella network.

6. New Results

6.1. Peer to peer

6.1.1. Distributed Hash Tables

Keywords: *distributed hash tables*, *peer-to-peer*.

Participants: Laurent Viennot, Anh-Tuan Gai.

In [8], we describe a peer-to-peer protocol based on the De-Bruijn topology allowing a distributed hashtable to be maintained in a loose manner. Each association is stored on k nodes to allow higher reliability with regard to node failures. Redundancy is also used when storing contacts, avoiding complex topology maintenance for node departures and arrivals. Moreover, the protocol allows load balancing of hotspots of requests for a given key as well as hotspots of key collisions. The goal is to obtain a protocol as practical as Kademlia based on the De-Bruijn topology. This results in smaller routing tables.

6.1.2. Analysis of P2P traces

Keywords: *P2P*, *graph dynamics*, *social networks*, *statistical analysis*.

Participants: Jean-Loup Guillaume, Matthieu Latapy, Stevens Le-Blond.

P2P exchanges nowadays represent most of the Internet traffic. It is therefore a key issue to understand them, which is very difficult because of the distributed nature of such systems. Some currently running systems, however, are semi-centralized (they rely on several severs, or on clients which may play the role of servers). It is therefore possible to collect some data by capturing usage traces on such servers. Other techniques are used, but this one appears to be among the most relevant ones despite it also has its own drawbacks.

We collected such a trace and then used the huge amount of data obtained to analyze several aspects of the system and the peers behaviors. We used an approach based on complex network tools, considering for instance the exchange graph (two peers are linked if they exchanged a data), the data graph (two data are connected if they are provided by a same peer), and the peers-data graph (each peer is linked to the data it provides).

We produced several results from these analysis. For instance, we identified peers with atypical behaviors, peers with unfair software, etc [10][12]. Going further, this case study was the occasion to introduce original tools for the analysis of time-evolving graphs, which may be of general interest.

6.2. Web Graph, Internet Topology and power-law networks

6.2.1. The BackRank Algorithm: Using Backoff Process to Improve PageRank

Keywords: *BackRank*, *PageRank*, *web graph*.

Participants: Fabien Mathieu, Mohamed Bouklit [LIRMM, Montpellier].

An enhanced version of the PageRank algorithm using a realistic model for the *Back* button is introduced [14], thus improving the random surfer model. We have showed that in the special case where the history is bound to an unique page (you cannot use the *Back* button twice in a row), we can produce an algorithm that does not need much more resources than a standard PageRank. This algorithm, BackRank, can converge up to 30% faster than a standard PageRank and suppress most of the drawbacks induced by the existence of pages without links. This work extends a previous work on the subject.

6.2.2. Internet topology metrology

Keywords: *Internet topology*, *simulation*, *traceroute*.

Participants: Jean-Loup Guillaume, Matthieu Latapy.

The fully distributed nature of the Internet makes it very difficult to collect significant information on its topology (routers and physical or logical links between them). To achieve this, the most widely used technique is to massively use the `traceroute` tool to collect large sets of paths between routers, and then to merge these paths.

This methods however suffers from several drawbacks. First, it is not possible for a given person to run `traceroute` from many machines on the Internet, therefore the measurements generally rely on a few sources and many destinations (today most extensive explorations use a few dozens of sources and several hundreds of thousands destinations). Moreover, several technical points (like the fact that a router generally has several addresses, or the presence of various tunneling subnetworks) induce some bias in the obtained view of the Internet topology.

Finally, current maps of the Internet topology are *partial* and *biased* by the exploration process. Estimating and correcting the impact of this is a current challenge of the domain and has received much attention for a few years.

In particular, several groups propose to develop massively distributed explorations, based on the use of many collaborative sources. We contributed to the domain [9][18] by making an extensive empirical study aimed at determining, on the one hand which observed properties are reliable (*i.e.* are not or little biased by the exploration process), and on the other hand which graph properties make the network difficult to explore. We conduced our simulations using several high-level models, as well as real-world data.

6.2.3. Robustness of random and power-law networks

Keywords: *attacks*, *failures*, *networking*, *power-law graphs*, *random graphs*.

Participants: Jean-Loup Guillaume, Matthieu Latapy, Clémence Magnien.

A network (like the Internet, P2P systems, but also social or biological networks) may experiment failures and malicious attacks. One may model these networks as graphs, the failures as random removals of nodes and/or links, and the attacks as directed removals of nodes and/or links (according to a given strategy). The network efficiency may then be measured by the size of its largest connected component (*i.e.* the number of nodes which can communicate through a path in the network).

Several recent study have shown that random networks behave in a similar way in case of failures and of attacks. On the contrary, real-world networks (like the ones cited above) are very robust in case of failures but very sensitive to attacks. This can be viewed as a consequence of their highly heterogeneous degree distributions, since similar behaviors are observed on random scale-free networks.

These behaviors can be studied formally, and several researchers, mainly from statistical mechanics, proposed such analysis. However, some intuitive explanations have been given which are still not well understood.

We contributed to the domain [19][11] by giving a very detailed survey of the formal results in the field, and then by extending them. This made it possible to understand precisely what properties of scale-free networks are responsible for their behavior in case of failures and attacks. In particular, we moderate several common claims, which we prove to be abusive.

6.3. Discrete metrics

Keywords: *Quantum inequalities*, *divisive clustering*, *extremal rays; correlation*, *matchings*, *multiway discrimination; Bell*.

Participants: Dominique Fortin, Ider Tseveendorj [Laboratoire PRISM université de Versailles Saint Quentin en Yvelines].

6.3.1. Clustering

Participants: Dominique Fortin, Ider Tseveendorj [Laboratoire PRISM université de Versailles Saint Quentin en Yvelines].

Let a set of *observables* be stored in a matrix $A = [a_{kj}] \in \mathbf{R}^{m \times n}$ where rows are meant for quantitative variables. In this article we address the question to normalize observables and to find some independent measure space to better explain dependencies or find clusters. A global optimization approach to this problem is $\max \sum_{k=1}^{m} \left| \sum_{j=1}^{n} a_{kj} x^j \right|^2$ subject to $\left| x^j \right|^2 = 1, j = 1, ..., n$, a non convex objective under a product of sphere constraints. The focus in [7] is twofold: retrieve local solution to above hard problem and propose a compound discrimination variable in a divisive approach to clustering. Fisher's Iris data provide a testbed for validating this approach and exhibit promising computational results.

6.3.2. Bell's polytopes

Participant: Dominique Fortin.

It is widely believed that Quantum computing breakthrough comes from entanglement: in classical computing, states are well separated while in quantum computing all the states are combined at the same time in a possibly non separable way (entanglement). In his seminal work, Bell exhibited a linear inequality that is fulfilled by classical computing and possibly violated by quantum mechanics. Since then, it has been proved that some entangled states fulfill Bell inequality giving rise to *entanglement distillation*; among classes of such situations are partial positive transpose and $U \otimes U$ unitary invariant states. In [6], we study a hierarchy of polytopes as an alternate distillation/ classification tool to entangled states classification. For binary random variables X, Y, Z centrally distributed, the Bell triangle inequality $| \langle X,Y \rangle - \langle X,Z \rangle | + \langle Y,Z \rangle \leq 1$ over 2-dimensional correlation $\langle ., . \rangle$ and Bell quadrangle inequality (also known as CHSH) $| \langle X,Y \rangle + \langle Y,Z \rangle + \langle Z,T \rangle - \langle X,T \rangle | \leq 2$ are carried over more points on a polyhedral combinatorics setting; we rephrase them in multivalued case as well as in higher dimensional case.

6.4. Graph decompositions

Participants: Fabien de Montgolfier, Jean-Luc Fouquet [LIFO, Orléans], Michel Habib [LIRMM, Montpellier], Ross McConnell [CS dept, Colorado State University], Christophe Paul [LIRMM, Montpellier], Jean-Marie Vanherpe [LIFO, Orléans].

Modular decomposition is a recursive graph decomposition. It is studied since it allows linear-time resolution for hard graph problems (like maximal clique, coloring...) on special graph classes. In [4] the first linear-time modular decomposition algorithm is provided for directed graphs, allowing more problems to be solved in linear time.

Linear-time modular decomposition algorithms are knows since the mid 1990's but are hard to implement, and simpler algorithms are still looked for. In [13] such an algorithm is proposed, using *factorizing permutations* as intermediary step.

Bipartite graphs have a very poor modular decomposition, because the decomposition sets, the *module*, are not very relevant in that context. In [15] we define *bimodules* instead, and show how the bimodular decomposition tree can be build in polynomial time and helps solving a few bipartite graphs problems.

6.5. SAT related problems

Keywords: *cardinality constraints*, *encoding*, *phase transition*, *satisfiability*, *upper bound*.

Participants: Yacine Boufkhad, Olivier Bailleux [LERSIA, Bourgogne], Olivier Dubois [LIP6], Yannet Interian [Cornell University], Bart Selman [Cornell University].

6.5.1. The Satisfiability phase transition

In [16], we consider a model for generating random k-SAT formulas in which each literal occurs approximately the same number of times in the formula (regular random k-SAT). Our experimental results show that such regular random k-SAT instances are much harder than the usual uniform random k-SAT problems. The balancing constraints add a dependency between variables that complicates a standard analysis. Regular random 3-SAT exhibits a phase transition as a function of the ratio alpha of clauses to variables. The transition takes place approximately at $\alpha = 3.5$. We show that for $\alpha > 3.7822...$ w.h.p. random Regular 3-SAT formulas are unsatisfiable. We also show by analyzing a greedy algorithm that formulas with ratio $\alpha < 2.46$, a satisfying assignment can be found with positive probability.

6.5.2. Encoding problems into satisfiability

In [5], we show that a full cnf encoding of some optimization problems can be competitive, and on some cases outperforms, the specialized methods that are hybrid constraints representations (clausal+arithmetic). This encoding requires a slight modification that can be implemented in any DLL based SAT solver. The use of a homogeneous CNF representation allow the techniques that are responsible for the performance in SAT solvers to be fully operational.

6.6. Broadcasting in Ad Hoc Networks

Participants: Laurent Viennot, Philippe Jacquet [INRIA, Hipercom], Cedric Adjih [INRIA, Hipercom].

Multipoint relays offer an optimized way of flooding packets in a radio network. However, this technique requires the last hop knowledge: to decide whether or not a flooding packet is retransmitted, a node needs to know from which node the packet was received. When considering broadcasting at IP level, this information may be difficult to obtain. In [3], we propose a scheme for computing an optimized connected dominating set from multipoint relays. Proof of correctness and simulations are given for all these broadcasting mechanisms.

7. Other Grants and Activities

7.1. National initiatives

7.1.1. PERSI Ministry Grant

Matthieu Latapy is the head of a national project called PERSI centered on the interdisciplinary study of social networks which appear on the Internet. See Persi

7.1.2. MetroSec Ministry Grant

Matthieu Latapy is the head of the LIAFA part in the MetroSec project, aimed at using Internet metrology to detect and prevent anormal events like failures, attacks, etc. See Metrosec

7.1.3. PairAPair Ministry Grant

Laurent Viennot is the head of the PairAPair national project. Anh-Tuan Gai is funded by this project.

Peer-to-peer networks have become the heaviest source of traffic in the Internet through the use of file sharing applications (such as Gnutella or Kazaa for example). However the protocols behind these applications are still too greedy and waste a lot of the Internet resources. On the other hand, theoretical solutions based on distributed hash tables exist but cannot be used practically. The PairAPair project aims at bridging efficient theoretical solutions to practical applications such as file sharing.

The main goal of the project concerns the conception of peer-to-peer protocols. A first approach consists in optimizing algorithms for existing protocols (without changing the communication rules). Another way consists in developing new protocols based on efficient theoretical solutions. Also important aspects of peer-to-peer networks concerns ethics: how to accept sharing one's resources if they can be used for non moral purposes? Designing protocols allowing the respect of certain rules will be another goal of the PairAPair project. Finally, analyzing and optimizing protocols requires models. For that purpose, crawling of existing peer-to-peer networks is envisioned.

The PairAPair project gathers members of four teams: Gyroweb (INRIA–LIAFA), GraFComm (LRI), Graphes (LABRI) and Hipercom (INRIA). More information is vailable at http://gyroweb.inria.fr/pairapair/.

8. Dissemination

8.1. Conferences, meetings and tutorial organization

Multimedia conference Dominique Fortin has made his work on spectral analysis of maximum clique problem and regularization issues about non diagonal perturbation available as a multimedia presentation [17].

Vulgarization Laurent Viennot has been scientific adviser of a vulgarization movie on peer-to-peer [20].

8.2. Teaching

Master MPRI, Paris 7 University, Ecole Polytechnique, ENS Ulm, ENS Cachan The course dynamics and algorithmics of networks includes the participation of Laurent Viennot on the web graph and ad hoc networks (6 hours) and Matthieu Latapy on complex networks (3 hours).

Master IFA, Marne-la-Vallee University Laurent Viennot teaches peer-to-peer protocols (10 hours).

D.E.S.S. Fundamental Software, Paris 7 University Matthieu Latapy has given a professional conference (2 hours) in 2003–2004, and is giving a course on *Large graphs in practice* in 2004–2005 (24 hours).

D.E.A. History and Civilisation, EHESS Matthieu Latapy is giving a course on *Social network* in 2004-2005 (10 hours).

Ecole Polytechnique Laurent Viennot is teaching foundations of computer science, java and networks (90 hours). Anh-Tuan Gai is teaching foundations of computer science (30 hours).

D.U.T. Paris 7 University Yacine Boufkhad is teaching scientific computer science and networks (192 hours).

D.E.U.G. Paris 7 University Fabien de Montgolfier is teaching foundation of computer science and algorithmics (192 hours).

D.E.U.G. Paris 7 University Jean-Loup Guillaume is teaching unix, automata and programming (64 hours).

8.3. Theses and Internships

8.3.1. Theses defenses

- Jean-Loup Guillaume, *Analyse statistique et modélisation des grands réseaux d'interactions*, Paris 7 University, December 2004.
- Fabien Mathieu, *Graphes du Web, mesures d'importance à la PageRank*, Montpellier 2 University, December 2004.

8.3.2. Ongoing theses

- Anh-Tuan Gai, *Protocoles pair-à-pair*, granted by ACI PairAPair, Rocquencourt.

9. Bibliography

Doctoral dissertations and Habilitation theses

[1] J.-L. GUILLAUME. *Analyse statistique et modélisation des grands réseaux d'interactions*, Ph. D. Thesis, Université Paris 7, Décembre 2004.

[2] F. MATHIEU. *Graphes du Web, mesures d'importance à la PageRank*, Ph. D. Thesis, Université Montpellier 2 - LIRMM, Décembre 2004.

Articles in referred journals and book chapters

[3] C. ADJIH, P. JACQUET, L. VIENNOT. *Computing connected dominated sets with multipoint relays*, in "Ad Hoc and Sensor Wireless Networks", to appear, 2005.

[4] R. M. MCCONNELL, F. DE MONTGOLFIER. *Linear-time modular decomposition of directed graphs*, in "Discrete Applied Mathematics", vol. 145, n° 2, january 2005, p. 198-209, http://www.sciencedirect.com/science/article/B6TYW-4DFT4SJ-1/2/026a31a55cb4be17d0212c0b467d1525.

Publications in Conferences and Workshops

[5] O. BAILLEUX, Y. BOUFKHAD. *Problem encoding into SAT : the counting constraints case*, in "The Seventh International Conference on Theory and Applications of Satisfiability Testing (SAT 2004)", 2004.

[6] D. FORTIN. *On Bell's polytopes: entanglement distillation*, in "FRANCORO'2004", Université de Fribourg,Switzerland, August 2004.

[7] D. FORTIN, I. TSEVEENDORJ. *Non convex optimization on a product of spheres: application to multiway discrimination*, in "MCO'2004", L. THI, P. D. TAO (editors)., Hermes science, LITA - UFR MIM Universite de Metz, France, July 2004, p. 153–162.

[8] A. GAI, L. VIENNOT. *Broose: A Practical Distributed Hashtable based on the De-Brujin Topology*, in "The Fourth IEEE International Conference on Peer-to-Peer Computing", 2004.

[9] J.-L. GUILLAUME, M. LATAPY. *Relevance of Massively Distributed Explorations of the Internet Topology: Simulation Results*, in "Proceedings of the 24-th IEEE Infocom'05 international conference", Conference version, 2005.

[10] J.-L. GUILLAUME, M. LATAPY, S. LE-BLOND. *Statistical analysis of a P2P query graph based on degrees and their time-evolution*, in "Lecture Notes in Computer Science (lncs), special issue, proceedings of the 6-th International Workshop on Distributed Computing iwdc'04", 2004.

[11] J.-L. GUILLAUME, M. LATAPY, C. MAGNIEN. *Comparison of Failures and Attacks on Random and Scale-free Networks*, in "Lecture Notes in Computer Science (lncs), special issue, proceedings of the 8-th International Conference On Principles Of Distributed Systems opodis'04", Conference version, 2004.

[12] J.-L. GUILLAUME, S. LE-BLOND. *Statistical Properties of Exchanges in P2P systems*, in "Proceedings of

the International Conference on Parallel and Distributed Processing Techniques and Applications pdpta'04", 2004.

[13] M. HABIB, F. DE MONTGOLFIER, C. PAUL. *A Simple Linear-Time Modular Decomposition Algorithm for Graphs, Using Order Extension*, in "SWAT, scandinavian workshop on algorithm theory", T. HAGERUP, J. KATAJAINEN (editors)., Lecture Notes in Computer Science, vol. 3111, Springer, 2004, p. 87-198.

[14] F. MATHIEU, M. BOUKLIT. *The effect of the back button in a random walk: application for pagerank*, in "Alternate track papers & posters of the 13th international conference on World Wide Web", ACM Press, 2004, p. 370–371.

[15] F. DE MONTGOLFIER, J.-L. FOUQUET, M. HABIB, J.-M. VANHERPE. *Bimodular decomposition of bipartite graphs*, in "WG2004, 30th International Workshop on Graph-Theoretic Concepts in Computer Science", to appear in LNCS, 2004.

Miscellaneous

[16] Y. BOUFKHAD, O. DUBOIS, Y. INERIAN, B. SELMAN. *Regular random k-SAT: properties of balanced formulas*, Submitted, 2004.

[17] D. FORTIN. *Quelques enjeux du calcul de clique maximum*, 2003, http://www.inria.fr/multimedia/Didactheque/4-Docmnt-Didact/0009/0009-fra.html.

[18] J.-L. GUILLAUME, M. LATAPY. *Relevance of Massively Distributed Explorations of the Internet Topology: Simulation Results*, Submitted, 2005.

[19] J.-L. GUILLAUME, M. LATAPY, C. MAGNIEN. *Comparison of Failures and Attacks on Random and Scale-free Networks*, Submitted, 2004.

[20] L. VIENNOT, R. CARDIN, A. LEVEILLÉ, R. CHABASSOL, A. GOMART, A. MOUSSAY, O. LAUSECKER, B. HIDOINE. *Il était une fois le peer-to-peer*, Inria-Multimédia, 2004, http://interstices.info/, Vulgarization movie to appear on.