INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team Gang

Graphs, networks and algorithms

Paris - Rocquencourt

THEME COM

Activity Report

2007

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1. Team

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

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Laurent Viennot [Research Associate (CR Inria), HdR]

Vice-head of project team
Michel Habib [Professor (Paris Diderot Univ.), HdR]

Administrative assistant
Danielle Croisy [shared time (with Hipercom)]

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Pierre Charbit [Assistant professor (Paris Diderot Univ.)]
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Pierre Fraigniaud [Research Director (DR Cnrs), HdR]
Emmanuelle Lebhar [Research Associate (CR Cnrs)]
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2. Overall Objectives

2.1. Introduction

Our goal is to develop the field of graph algorithms for networks. Based on algorithmic graph theory and graph modeling we want to understand what can be done in these large networks and what cannot. Furthermore, we want to derive practical distributed algorithms from known strong theoretical results. Finally, we want to extract possibly new graph problems by focusing on particular applications.

The main goal to achieve in networks are efficient searching of nodes or data, and efficient content transfers. We propose to implement strong theoretical results in that domain to make significant breakthrough in large network algorithms. These results concern small world routing, low stretch routing in doubling metrics and bounded width classes of graphs. They are detailed in the next section. This implies several challenges:

- testing our target networks against general graph parameters known to bring theoretically tractability,
- implementing strong theoretical results in the dynamic and distributed context of large networks.

A complementary approach consists in studying the combinatorial and graph structures that appear in our target networks. These structures may have inherent characteristics coming from the way the network is formed, or from the design goals of the target application.

2.2. Highlights of the year

2.2.1. Project-team creation

Gang is officially created on July 2007.

3. Scientific Foundations

3.1. Scientific Foundations

Keywords: *doubling metrics*, *graph algorithms*, *network protocols*, *overlay*, *small world*.

3.1.1. Structured/Unstructured Overlays

Recent years have brought tremendous progress along the peer-to-peer paradigm allowing large scale decentralized application to be practically deployed. The main achievement of this trend is certainly efficient content distribution through the BitTorrent protocol [22]. The power of peer-to-peer content distribution is to rely on the upload capacity of the node interested in receiving the content. This allows to scale to very large number of participants. The main breakthrough of BitTorrent resides in its "tit for tat" strategy inspired from game theory to give incentive to cooperate. For that purpose, a peer preferentially uploads preferentially offering best reciprocity. This kind of preferences induces an interesting graph structure with ordered neighborhoods. Understanding the dynamic behavior of such affinity graphs is an important for stabilizing the performance of such protocols.

A second major achievement of the peer-to-peer paradigm concerns indexing with distributed hashtables [35], [37], [39]. The idea behind these proposals is to organize the peers into a structure close to well known graphs with low diameter such as hight dimension torus, hypercube or de Bruijn graph. Efficient routing to the node storing a given key is then guaranteed. This academic work has lead to practical basic indexing facilities by introducing redundancy in the structure [34]. This is typically the kind of approach we want to promote: from known efficient theoretical solutions to practical working protocols. We have contributed to this trend by introducing de Bruijn based solutions [29], [30] with redundancy in the contact graph to resist node churn.

3.1.2. Small World Phenomenon

Popularized emerging properties include degree distributions observed to be power law in many networks or clustering coefficient observed to be high in social networks or low average distances. This last point gave the denomination of "small worlds" for this type of networks. Some work [20], [40] try to give models that give raise to such statistical properties. In that line, numerous results such as [19] try to derive efficient algorithms based only on these statistical properties. This particular approach tends to concentrate load on nodes with high degrees and may not be suited for applications where nodes have similar capacities. Other interesting work [26] try to explain this statistical observation forms an inherent optimization problem operating when constructing the network.

On the other hand, in its seminal paper [32], Kleinberg focuses on the algorithmic aspects of such social networks and shows how adding random links to a torus can produce efficient greedy routing. This result has been extend to more general classes of graphs [38], [27] such as bounded growth metric graphs [25]. However, this augmentation process is not always feasible [28]. Such theoretical work is particularly interesting for overlay networks where this augmenting process simply consists in opening additional connections.

3.1.3. Doubling Metrics

Bounded growth and doubling metrics generalize Euclidean metrics. A metric has bounded growth if the size of any ball increases by a factor not larger than 2^d when its radius is doubled [31]. A metric is doubling if any set of diameter D can be covered with at most 2^d sets of diameter $D/2$ [21]. In both cases, the smallest acceptable value of d is called the dimension of the metric. The metric of any d dimensional Euclidean space has bounded growth dimension $O(d)$. Any bounded growth metric of dimension d has doubling dimension $O(d)$. The doubling metric is the most general and has the additional property of being inherited by subspaces: the metric induced by a doubling metric on a subset of nodes is also doubling. For example, sampling nodes in an Euclidean space always results in a doubling metric.

As networks are embedded in our usual three dimensional space, it is legitimate to think than some network metrics may be modeled through doubling metrics. Recent results thus investigate network problems for the restricted classes of graphs with bounded growth or doubling metric [38], [18], [31], [33]. However, the doubling nature of large networks such as the Internet has still not be tested.

3.1.4. Bounded Width Classes of Graphs

Many graph parameters such as treewidth, branchwidth, rankwidth, cutwidth, cliquewidth ...have been introduced in recent years [36], [24] to measure the structure of a given graph. These parameters are of course NP-complete to compute, but when it can be proved that for a given class of graphs the parameter is bounded by a constant then it can be proved using graph grammars (see Courcelle's fundamental work) that most of the optimization problems on this class are polynomially tractable, and sometimes we know the existence of a linear algorithm (but the hidden constant can be very high !)

The most famous parameter, namely the treewidth captures the distance of the graph to a tree, and therefore when the treewidth is small a dynamic programming approach can be used [23].

Despite some promising results, applications of these notions has still to be done for networks, in a practical perspective.

4. Application Domains

4.1. Application Domains

Keywords: *Internet*, *large scale ad hoc*, *peer-to-peer applications*, *telecommunications*, *web graph*.

Application domains include evaluating Internet performances, the design of new peer-to-peer applications, enabling large scale ad hoc networks and mapping the web.

- The application of measuring and modeling Internet metrics such as latencies and bandwidth is to provide tools for optimizing Internet applications. This concerns especially large scale applications such as web site mirroring and peer-to-peer applications.
- 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. Envisioned peer-to-peer applications include video on demand, streaming, exchange of classified ads,...
- Wifi networks have entered our every day life. However, enabling them at large scale is still a challenge. Algorithmic breakthrough in large ad hoc networks would allow to use them in fast and economic deployment of new radio communication systems.
- The main application of the web graph structure consists in ranking pages. Enabling site level indexing and ranking is a possible application o f such studies.

5. Software

5.1. Palabre/Peerple : a Cooperative Peer-to-peer Platform

Participants: Anh-Tuan Gai, Anne-Marie Kermarrec, Fabrice Le-Fessant, Laurent Viennot.

The peer-to-peer paradigm can be used to duplicate sensible data. Free disk space can be exchanged to ensure cooperative reliable storage. Anh-Tuan Gai, Fabrice Le-Fessant and Laurent Viennot are developing a peer-to-peer client for personal files sharing and backup. Anh-Tuan Gai has obtained an industrial postdoctoral position in order to create a startup company based on this prototype. Research aspects are developed in tight collaboration with Anne-Marie Kermarrec and Fabrice Le-Fessant (Asap).

Peerple is an open-source project http://peerple.gforge.inria.fr/.

Several improvements are forecast:

- cooperative caching,
- indexing facilities allowing peer search and distributed DNS,
- improvement of the backup system for dedicated environments such as universities or companies (where many computers may share the same files).

Anh-Tuan Gai is creating a start-u company based on this software.

5.2. Internal tools

- For use in Cplex optimization suite, Dominique Fortin has implemented in java 1.5, Field and Ring operations that support arbitrary precision (using Apfloat machinery). It is meant for quaternion or Eisenstein-like cases, e.g. $a + b\sqrt{n}$ for a fixed n which is involved in extreme points enumeration of a polyhedral cone.
- Yacine Boufkhad, Mehdi Nafa and Fabien de Montgolfier have realized a BitTorrent protocol simulator.

6. New Results

6.1. Small world networks structure

Keywords: *augmented graphs*, *routing algorithm*, *small world*.

Participants: Pierre Fraigniaud, Cyril Gavoille, Adrian Kosowski, Emmanuelle Lebhar, Zvi Lotker.

6.1.1. Small world routing

Following the result that we obtained last year showing that it is not possible to augment any graph by random shortcuts to get a small world behavior, paper [7] tackles the question of *universal* augmentation with relaxed guaranties. Specifically, it was known that any graph can be augmented to achieve $O(\sqrt{n})$-length greedy paths between any pair, and that it is not possible to design a universal augmentation achieving a greedy path length less than $\Omega(n^{1/\sqrt{\log n}})$ between any pair. Our paper breaks the $\sqrt{n}$-barrier by showing that it is possible to design a universal augmentation achieving $O(n^{1/3})$-length greedy path between any pair. This paper obtained the best paper award of the conference SPAA'07.

6.1.2. Small world structure

On the other hand, the paper [17] study the possibility of checking the validity of the augmented graph model. precisely, we show that it is possible to design an algorithm which, given an augmented graph, extracts almost all its random shortcuts, and more interestingly that the base graph that it outputs cannot affect the supposed routing performances of the input graph by more than a poly-logarithmic factor. This question was first asked by Jon Kleinberg in 2006 and this is the first result achieving a partial answer to it, to our knowledge.

6.2. Peer-to-Peer

6.2.1. Modelling preference systems in P2P applications

Keywords: *BitTorrent protocol*, *Peer-to-peer (P2P)*, *overlay network*, *stable mariage theory*, *stable matchings*.

Participants: Anh-Tuan Gai, Dmitry Lebedev, Fabien Mathieu, Fabien de Montgolfier, Julien Reynier, Laurent Viennot.

In P2P applications, the actual connections between peers (i.e. the overlay network) is the result of many decisions and randomness among peers and network. We are interested in one of the major parameters: the *preference system*. It models how, in a P2P application, each peer ranks other peers, as a peer wants to connect with the *best* other ones.

The formalism is presented in [13], where we explore an evolution model derived from the *stable roommates* problem. Some stability and convergence properties for the corresponding overlay network can then be derived.

The *acyclic* preference systems are further studied in [9]. We show that the preference system of most P2P application fits indeed in that formalism. That allows to infer some stability and convergence properties for the corresponding overlay network, and to predict some network topological features (like small-world phenomenon).

The special case of BitTorrent-like preference systems, based on a Tit-for-Tat policy, is investigated in [10]. Mathematical tools can then been used for predicting convergence speed, or for proving the *stratification conjecture* : peers connect with other peers having the same bandwidth. Optimisation of the BitTorrent connection protocol can be derived.

6.2.2. Unstructured P2P live streaming systems

Keywords: *BitTorrent protocol*, *Peer-to-peer (P2P)*, *overlay network*, *streaming*.

Participants: Diego Perino, Ernst Biersack, Fabien Mathieu, Fabio Pianese.

In [15] we present PULSE un unstructured mesh-based P2P live streaming system. In PULSE a source divides the stream in a series of FEC encoded pieces that are exchanged among peers in order to retrieve the complete sequence. The data exchanges are dynamics: the system continuously adapts the mesh network using a peer selection mechanism based on data availability and incentives. We analyze - the system performance through simulations and experiments. We show the system has a best-effort response to system-wide resource scarcity, high resilience to node churn, and good hop-count properties of the average data distribution paths In [16] we deep study the role of incentives and locality awareness mechanisms in an unstructured P2P live streaming system. We perform the study through experiments by using PULSE as system example. We show incentive mechanisms can lead to a global content distribution mesh which has properties similar to tree-based structured systems. Moreover the use of latency awareness improve the locality of data exchanges: this leads to better overlay performance and reduces the overlay impact on the underlay. We move to a more theoretical study of unstructured P2P live streaming systems. First results are reported in [4]. In this paper we analyze the diffusion trees of unstructured P2P live streaming systems by using PULSE as system example. In unstructured systems every block follows a different path from source to nodes. However, it is possible to study average properties of these distribution trees. We show unstructured trees have properties like disjointness, length, width, similar to the ones of structured systems and PULSE achieves a diffusion delay close to the theoretical ones of a structured approach.

6.3. Distributed computing

Keywords: *distributed algorithm*, *minimum spanning tree*.

Participants: Pierre Fraigniaud, Amos Korman, Emmanuelle Lebhar.

6.3.1. Minimum spanning tree computation

In [8], we are interested in studying the efficiency of the crucial problem of the minimum spanning tree (MST) under the new framework of *advising schemes*. Specifically, while it is known that it takes at least $\sqrt{n}$ rounds to compute an MST in a distributed way without being given any bit of advice in the nodes, we show that, by providing only a constant number of bits of advice in each node, it is possible to compute an MST in a distributed way in just $O(\log n)$ rounds.

6.4. Web Graph

Keywords: *crawl*, *local structure*, *pagerank*, *random graphs*, *scale-free*, *web graph*.

Participants: Toufik Bennouas, Fabien de Montgolfier.

6.4.1. Modeling crawling

In [2] we present a model of Web crawls. Lot of existing papers present *Web graph* models, beyond classical Erdös-Reyni random graphs, using preferential attachment model or copy model. I.e. they make sociological assumptions on how the Web pages are written. They they can show that their random graphs share lot of properties with real crawls (like a small diameter, a bow-tie structure, and so on) and thus that their modeling is good. On the other hand, we model the crawling structure instead. And we proof that a *random crawl*, a graph constructed by crawling and whose degrees follow a power law, share all known properties of Web crawls. Consequently, it is not possible to tell whether the well-known properties of the Web graph are genuine properties or crawling artifacts.

6.5. Efficient graph spanners

6.5.1. Optimized ad hoc networks and k-connectivity

Keywords: *ad hoc*, *bi-connectivity*, *k-connectivity*, *spanner*.

Participants: Christophe Guettier, Jacques Yelloz, Laurent Viennot, Philippe Jacquet.

Optimized routing protocols such as OLSR for ad hoc networks, can distributively construct a sub-topology sufficient for routing. In graph terms OLSR constructs a spanner that preserves shortest paths. We study in [12] how the topology construction of OLSR can be tuned to preserve bi-connectivity or k-connectivity. We show how such tuning can improve the reliability of the network in a military context [11].

6.6. Understanding graph decompositions

Keywords: *NLC decomposition*, *efficient graph algorithms*, *graph decompositions*, *modular decomposition*.

Participants: Binh-Minh Bui-Xuan, Michel Habib, Vincent Limouzy, Fabien de Montgolfier, Michael Rao.

6.6.1. NLC decomposition

Many *width* graph decompositions have been proposed. Thanks to Courcelle theorem, they allow to efficiently solve many hard (NP-complete) problems for graph classes, provided the decomposition width is bounded. NLC decomposition is a variation of cliquewidth, where the decomposition is a labelled tree. In [14], the recognition of graphs of NLC 2 is addressed. The previous time complexity is improved to (n^2m), and the algorithm is robust.

6.6.2. Umodular decomposition

A new decomposition of combinatorial structures is presented in [3]. Is is based on a generalisation of the modular decomposition. When applied to undirected graph, it gives the bijoin decomposition, and when applied to tournaments, it gives a new decomposition. We present proofs of existence and uniqueness of a decomposition tree, and polynomial-time algorithms.

6.7. Discrete Optimization Algorithms

Keywords: *0-1 programming*, *global optimization*.

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

For $0 - 1$ optimization problems

$$\begin{cases} \min & f(x) \\ \text{s.t.} & x \in D \\ & x \in \{0,1\}^n, \end{cases} \qquad \text{(P)}$$

where $f(\cdot)$ is a convex function and D is a convex body in $\mathbf{R}^n$, the difficulty lies in binary constraint $x \in \{0,1\}^n$, a non-convex and discrete domain. We can write it in three different ways for an equivalent but continuous formulation:

$$x_i \in \{0,1\} \Leftrightarrow \quad \begin{array}{rl} i) & x_i(x_i-1)=0, \\ ii) & x_i(x_i-1) \le 0, x_i \le 0 \text{ or } x_i \ge 1, \\ iii) & x_i(x_i-1) \ge 0, 0 \le x_i \le 1, \end{array}$$

While the first is celebrated under the lift-and-project approach, we focused on the second, in the recent past, from the piecewise convex maximization optimization point of view; as for the third, it suggests to split the interval $[0,1]$ in $[0,\epsilon], [\epsilon, 1-\epsilon], [1-\epsilon, 1]$ and to record how many times a variable has been assigned to 0, middle value or 1 value in the continuous relaxation. It gives rise to an adaptive branch-and-bound strategy, independent of the problem itself, that interestingly competes with dedicated heuristics [6].

For global optimization problems, we improve our generic piecewise convex maximization algorithm by adding on demand, a new piece that allows to escape from a local optimum and give first result on simplest case when the problem reduces to $\max f(x), x \in D$ for f, D both convex [5].

7. Contracts and Grants with Industry

7.1. Collaboration with France Telecom (CRC Mardi)

Participants: Anh-Tuan Gai, Diego Perino, Dmitry Lebedev, Fabien Mathieu, Fabien de Montgolfier, Julien Reynier, Laurent Viennot, Simon Gwendal.

MARDI is a collaboration contract between Inria and France Telecom. It gathers Gang and Spontex (FT) around the study of decentralized networks over Internet. Spontex is a transversal project on cooperative networks. Diego Perino is funded through this collaboration and co-supervised by Fabien Mathieu and Laurent Viennot.

7.1.1. Measuring Internet with and for peer-to-peer networks

A first aspect of the project consist in studying Internet latencies in order to understand how logical overlays can be optimized with respect to delays. A possible track for gathering valuable large scale measures is to use a peer-to-peer network for measuring latencies. Interestingly, it is possible to find shortcuts in the Internet where the route through a relay can be faster than the direct route.

7.1.2. Modeling node and connection dynamics

This item is connected to the affinity model where peers tend to connect preferentially to some peers based on some measured or inferred criteria. Connecting peers according to delays is a special case of affinity where a peer connects preferentially to peers with low RTT. Additional properties can be proven for this case to prove the convergence of a dynamic system following this low RTT strategy.

7.1.3. Peer-to-peer application design

The third part of the project aims at designing efficient structuring algorithm for decentralized applications. It relies on the previous parts. Measuring and modeling Internet latencies can be used to obtain a first coarse solution to a fast overlay, and the affinity models can be use to tune the solution and to adapt it under node churn.

8. Other Grants and Activities

8.1. National initiatives

8.1.1. ANR grant Graph Decomposition and Algorithms (GRAAL)

Participants: Binh-Minh Bui-Xuan, Bruno Courcelle, Chritophe Paul, Cyril Gavoille, Fabien de Montgolfier, Michel Habib, Pierre Charbit, Stephan Thomasse, Vincent Limouzy.

GRAAL is an ANR project "blanc" (i.e. fundamental research) about graph decompositions with LABRI (Bordeaux) and LIRMM (Montpellier). This project deals with fundamental aspects of computer science, namely theoretical and algorithmic aspects of decomposition methods for graphs and various combinatorial structures and extensions such as matroids, countable graphs... It proposes to combine approaches issued from graphs, discrete algorithms, formal languages and logic theory. We believe that major contributions to decomposition methods are no longer possible if each of these theories is considered separately.

8.1.2. ANR Algorithm Design and Analysis for Implicitly and Incompletely Defined Interaction Networks (ALADIN)

Participants: Cyril Gavoille, Dominique Fortin, Emmanuelle Lebhar, Laurent Viennot, Michel Habib, Pierre Charbit, Pierre Fraigniaud, Vincent Limouzy.

Pierre Fraigniaud is leading an ANR project "blanc" (i.e. fundamental research) about the fundamental aspects of large interaction networks enabling massive distributed storage, efficient decentralized information retrieval, quick inter-user exchanges, and/or rapid information dissemination. The project is mostly oriented towards the design and analysis of algorithms for these (logical) networks, by taking into account proper ties inherent to the underlying infrastructures upon which they are built. The infrastructures and/or overlays considered in this project are selected from different contexts, including communication networks (from Internet to sensor networks), and societal networks (from the Web to P2P networks).

8.2. Actions Funded by the EC

8.2.1. COST 295 – Dynamo (2005-2009)

Dynamo is an action of the European COST program (European Cooperation in the Field of Scientific and Technical Research) inside of the Telecommunications, Information Science and Technology domain (TIST). It is leaded by Pierre Fraigniaud (Chair of the managing committee). It gather more than 30 sites all over Europe around Dynamic Communication Networks. The Action is motivated by the need to supply a convincing theoretical framework for the analysis and control of all modern large networks. This will be induced by the interactions between decentralised and evolving computing entities, characterised by their inherently dynamic nature.

9. Dissemination

9.1. Services to the scientific community

- Laurent Viennot is a scientific editor of the)i(nterstices (http://interstices.info/) vulgarization site initiated by Inria in collaboration with french universities and Cnrs.
- Michel Habib is member of the steering committee of STACS (Symposium on Theoretical Aspects of Computer Science) and also of WG (International Workshop on Graph-Theoretic Concepts in Computer Science).

9.2. Teaching

Master MPRI Michel Habib is in charge of a course entitled “graph algorithms”. Laurent Viennot teaches ad hoc and web graph algorithms in the “networks dynamics” course.

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

Computer Science U.F.R., Paris Diderot University Fabien de Montgolfier is teaching foundation of computer science, algorithmics, and computer architecture (192 hours).

Professional Master, Paris Diderot University Michel Habib is in charge of two courses untitled: Search Engines; Parallelism and mobility, which includes peer-to-peer overlay networks.

9.3. Theses

9.3.1. Ongoing theses

- Vincent Limouzy *Algorithmes de décomposition de graphes* (MENRT).
- Diego Perino *Mesures dans Internet par et pour les réseaux decentralisés* (CIFRE FranceTelecom).
- Mauricio Soto *Algorithmes de pair à pair et analyse de la structure d'Internet* (Chile-France Allocation).
- Anh Hoang Phan *Overlays structurés en pair à pair* (BDI).
- Hien Hu To *Decomposition de graphes* (AMX).

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