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PROGRAM

Thursday, March 6th

9:00 – 10:00 Invited Talk*chair:* Anca MUSCHOLL

 Javier ESPARZA: *Keeping a crowd safe: on the complexity of parameterized verification*

We survey some results on the automatic verification of parameterized programs without identities. These are systems composed of arbitrarily many components, all of them running exactly the same finite-state program. We discuss the complexity of deciding that no component reaches an unsafe state. The note is addressed at theoretical computer scientists in general.

10:00 – 10:20 Coffee break**10:20 – 11:35 Session 1A: Logic***chair:* Heribert VOLLMER

 Matthew ANDERSON & Anuj DAWAR: *On symmetric circuits and fixed-point logics*

We study properties of relational structures such as graphs that are decided by families of Boolean circuits. Circuits that decide such properties are necessarily invariant to permutations of the elements of the input structures. We focus on families of circuits that are symmetric, i.e., circuits whose invariance is witnessed by automorphisms of the circuit induced by the permutation of the input structure. We show that the expressive power of such families is closely tied to definability in logic. In particular, we show that the queries defined on structures by uniform families of symmetric Boolean circuits with majority gates are exactly those definable in fixed-point logic with counting. This shows that inexpressibility results in the latter logic lead to lower bounds against polynomial-size families of symmetric circuits.

 Markus LOHREY & Georg ZETSCHE: *On Boolean closed full trios and rational Kripke frames*

A Boolean closed full trio is a class of languages that is closed under the Boolean operations (union, intersection, and complementation) and rational transductions. It is well-known that the regular languages constitute such a Boolean closed full trio. It is shown here that every such language class that contains any non-regular language already includes the whole arithmetical hierarchy (and even the one relative to this language).

A consequence of this result is that aside from the regular languages, no full trio generated by one language is closed under complementation.

Our construction also shows that there is a fixed rational Kripke frame such that assigning an arbitrary non-regular language to some variable allows the definition of any language from the arithmetical hierarchy in the corresponding Kripke structure using multimodal logic.

 Martin HUSCHENBETT & Manfred KUFLEITNER: *Ehrenfeucht-Fraïssé game on omega-terms*

Fragments of first-order logic over words can often be characterized in terms of finite monoids or finite semigroups. Usually these algebraic descriptions yield decidability of the question whether a given regular language is definable in a particular fragment. An effective algebraic characterization can be obtained from identities of so-called omega-terms. In order to show that a given fragment satisfies some identity of omega-terms, one can use EF games on word instances of the omega-terms. The resulting proofs often require a significant amount of book-keeping with respect to the constants involved. In this paper we introduce EF games on omega-terms. To this end we assign a labeled linear order to every omega-term. Our main theorem shows that a given fragment satisfies some identity of omega-terms if and only if Duplicator has a winning strategy for the game on the resulting linear orders. This allows to avoid the book-keeping.

As an application of our main result, we show that one can decide in exponential time whether all aperiodic monoids satisfy some given identity of omega-terms, thereby improving a result of McCammond (Int. J. Algebra Comput., 2001).

Ken-Ichi KAWARABAYASHI & Mikkel THORUP: *Coloring 3-colorable graphs with $o(n^{1/5})$ colors*

Recognizing 3-colorable graphs is one of the most famous NP-complete problems [Garey, Johnson, and Stockmeyer STOC'74]. The problem of coloring 3-colorable graphs in polynomial time with as few colors as possible has been intensively studied: $O(n^{1/2})$ colors [Wigderson STOC'82], $\tilde{O}(n^{2/5})$ colors [Blum STOC'89], $\tilde{O}(n^{3/8})$ colors [Blum FOCS'90], $O(n^{1/4})$ colors [Karger, Motwani, Sudan FOCS'94], $\tilde{O}(n^{3/14}) = O(n^{0.2142})$ colors [Blum and Karger IPL'97], $O(n^{0.2111})$ colors [Arora, Chlamtac, and Charikar STOC'06], and $O(n^{0.2072})$ colors [Chlamtac FOCS'07]. Recently the authors got down to $O(n^{0.2049})$ colors [FOCS'12]. In this paper we get down to $O(n^{0.19996}) = o(n^{1/5})$ colors.

Since 1994, the best bounds have all been obtained balancing between combinatorial and semi-definite approaches. We present a new combinatorial recursion that only makes sense in collaboration with semi-definite programming. We specifically target the worst-case for semi-definite programming: high degrees. By focusing on the interplay, we obtained the biggest improvement in the exponent since 1997.

Dmitry GAVINSKY & Pavel PUDLÁK: *Partition expanders*

We introduce a new concept, which we call *partition expanders*. The basic idea is to study quantitative properties of graphs in a slightly different way than it is in the standard definition of expanders. While in the definition of expanders it is required that the number of edges between any pair of sufficiently large sets is close to the expected number, we consider *partitions* and require this condition only for *most of the pairs* of blocks. As a result, the blocks can be substantially smaller.

We show that for some range of parameters, to be a partition expander a random graph needs *exponentially smaller* degree than any expander would require in order to achieve similar expanding properties.

We apply the concept of partition expanders in communication complexity. First, we give a PRG for the SMP model of the optimal seed length, $n + O \log k$. Second, we compare the model of SMP to that of Simultaneous Two-Way Communication, and give a new separation that is stronger both qualitatively and quantitatively than the previously known ones.

Julio ARAUJO, Nicolas NISSE & Stéphane PÉRENNES: *Weighted coloring in trees*

A proper coloring of a graph is a partition of its vertex set into stable sets, where each part corresponds to a *color*. For a vertex-weighted graph, the *weight of a color* is the maximum weight of its vertices. The *weight of a coloring* is the sum of the weights of its colors. Guan and Zhu defined the *weighted chromatic number* of a vertex-weighted graph G as the smallest weight of a proper coloring of G (1997). If vertices of a graph have weight 1, its weighted chromatic number coincides with its chromatic number. Thus, the problem of computing the weighted chromatic number, a.k.a. Max Coloring Problem, is NP-hard in general graphs. It remains NP-hard in some graph classes as bipartite graphs. Approximation algorithms have been designed in several graph classes, in particular, there exists a PTAS for trees. Surprisingly, the time-complexity of computing this parameter in trees is still open.

The Exponential Time Hypothesis (ETH) states that 3-SAT cannot be solved in sub-exponential time. We show that, assuming ETH, the best algorithm to compute the weighted chromatic number of n -node trees has time-complexity $n^{\Theta(\log n)}$. Our result mainly relies on proving that, when computing an optimal proper weighted coloring of a graph G , it is hard to combine colorings of its connected components.

11:35 – 11:50 Coffee break

11:50 – 12:40 Session 2A: Complexity*chair:* Luc SÉGOUFIN

 Robin KOTHARI: *An optimal quantum algorithm for the oracle identification problem*

In the oracle identification problem, we are given oracle access to an unknown N -bit string x promised to belong to a known set \mathcal{C} of size M and our task is to identify x . We present a quantum algorithm for the problem that is optimal in its dependence on N and M . Our algorithm considerably simplifies and improves the previous best algorithm due to Ambainis et al. Our algorithm also has applications in quantum learning theory, where it improves the complexity of exact learning with membership queries, resolving a conjecture of Hunziker et al.

The algorithm is based on ideas from classical learning theory and a new composition theorem for solutions of the filtered γ_2 -norm semidefinite program, which characterizes quantum query complexity. Our composition theorem is quite general and allows us to compose quantum algorithms with input-dependent query complexities without incurring a logarithmic overhead for error reduction. As an application of the composition theorem, we remove all log factors from the best known quantum algorithm for Boolean matrix multiplication.

 Dániel MARX & Michał PILIPCZUK: *Everything you always wanted to know about the parameterized complexity of subgraph isomorphism (but were afraid to ask)*

Given two graphs H and G , the SUBGRAPH ISOMORPHISM problem asks if H is isomorphic to a subgraph of G . While NP-hard in general, algorithms exist for various parameterized versions of the problem. However, the literature contains very little guidance on which combinations of parameters can or cannot be exploited algorithmically. Our goal is to systematically investigate the possible parameterized algorithms that can exist for SUBGRAPH ISOMORPHISM.

We develop a framework involving 10 relevant parameters for each of H and G (such as treewidth, pathwidth, genus, maximum degree, number of vertices, number of components, etc.), and ask if an algorithm with running time $f_1(p_1, p_2, \dots, p_\ell) \cdot n^{f_2(p_{\ell+1}, \dots, p_k)}$ exists, where each of p_1, \dots, p_k is one of the 10 parameters depending only on H or G . We show that *all* the questions arising in this framework are answered by a set of 11 maximal positive results (algorithms) and a set of 17 maximal negative results (hardness proofs); some of these results already appear in the literature, while others are new in this paper.

On the algorithmic side, our study reveals for example that an unexpected combination of bounded degree, genus, and feedback vertex set number of G gives rise to a highly nontrivial algorithm for SUBGRAPH ISOMORPHISM. On the hardness side, we present W[1]-hardness proofs under extremely restricted conditions, such as when H is a bounded-degree tree of constant pathwidth and G is a planar graph of bounded pathwidth.

11:50 – 12:40 Session 2B: Automata*chair:* Nathalie AUBRUN

 Nicolas BACQUEY: *Complexity classes on spatially periodic cellular automata*

This article deals with cellular automata (CA) working over periodic configurations, as opposed to standard CA, where the initial configuration is bounded by persistent symbols. We study the capabilities of language recognition and computation of functions over such automata, as well as the complexity classes they define over languages and functions. We show that these new complexity classes coincide with the standard ones starting from polynomial time. As a by-product, we present a CA that solves a somehow relaxed version of the density classification problem.

Diego FIGUEIRA & Leonid LIBKIN: *Synchronizing relations on words*

While the theory of languages of words is very mature, our understanding of *relations* on words is still lagging behind. And yet such relations appear in many new applications such as verification of parameterized systems, querying graph-structured data, and information extraction, for instance. Classes of well-behaved relations typically used in such applications are obtained by adapting some of the equivalent definitions of regularity of words for relations, leading to non-equivalent notions of recognizable, regular, and rational relations.

The goal of this paper is to propose a systematic way of defining classes of relations on words, of which these three classes are just natural examples, and to demonstrate its advantages compared to some of the standard techniques for studying word relations. The key idea is that of a *synchronization* of a pair of words, which is a word over an extended alphabet. Using it, we define classes of relations via classes of regular languages over a fixed alphabet, just $\{1, 2\}$ for binary relations. We characterize some of the standard classes of relations on words via finiteness of parameters of synchronization languages, called shift, lag, and shiftlag. We describe these conditions in terms of the structure of cycles of graphs underlying automata, thereby showing their decidability. We show that for these classes there exist canonical synchronization languages, and every class of relations can be effectively re-synchronized using those canonical representatives. We also give sufficient conditions on synchronization languages, defined in terms of injectivity and surjectivity of their Parikh images, that guarantee closure under intersection and complement of the classes of relations they define.

12:40 – 14:30 Lunch

14:30 – 15:45 Session 3A: Scheduling

chair: LORIS MARCHAL

ERIC ANGEL, EVRIPIDIS BAMPIS & VINCENT CHAU: *Throughput maximization in the speed-scaling setting*

We are given a set of n jobs and a single processor that can vary its speed dynamically. Each job J_j is characterized by its processing requirement (work) p_j , its release date r_j and its deadline d_j . We are also given a budget of energy E and we study the scheduling problem of maximizing the throughput (i.e. the number of jobs that are completed on time). While the preemptive energy minimization problem has been solved in polynomial time [Yao et al., FOCS'95], the complexity of the problem of maximizing the throughput remained open until now. We answer partially this question by providing a dynamic programming algorithm that solves the problem in pseudo-polynomial time. While our result shows that the problem is not strongly NP-hard, the question of whether the problem can be solved in polynomial time remains a challenging open question. Our algorithm can also be adapted for solving the weighted version of the problem where every job is associated with a weight w_j and the objective is the maximization of the sum of the weights of the jobs that are completed on time.

MARTIN SKUTELLA, MAXIM SVIRIDENKO & MARC UETZ: *Stochastic scheduling on unrelated machines*

Two important characteristics encountered in many real-world scheduling problems are heterogeneous processors and a certain degree of uncertainty about the sizes of jobs. In this paper we address both, and study for the first time a scheduling problem that combines the classical unrelated machine scheduling model with stochastic processing times of jobs. Here, the processing time of job j on machine i is governed by random variable P_{ij} , and its realization becomes known only upon job completion. With w_j being the given weight of job j , we study the objective to minimize the expected total weighted completion time $\mathbb{E}[\sum_j w_j C_j]$, where C_j is the completion time of job j . By means of a novel time-indexed linear programming relaxation, we compute in polynomial time a scheduling policy with performance guarantee $(3 + \Delta)/2 + \varepsilon$. Here, $\varepsilon > 0$ is arbitrarily small, and Δ is an upper bound on the squared coefficient of variation of the processing times. When jobs also have individual release dates r_{ij} , our bound is $(2 + \Delta) + \varepsilon$. We also show that the dependence of the performance guarantees on Δ is tight. Via $\Delta = 0$, currently best known bounds for deterministic scheduling on unrelated machines are contained as special case.

ANTONIOS ANTONIADIS, Neal BARCELO, Mario CONSUEGRA, Peter KLING, Michael NUGENT, Kirk PRUHS & Michele SCQUZZATO: *Efficient computation of optimal energy and fractional weighted flow trade-off schedules*

We give a polynomial time algorithm to compute an optimal energy and fractional weighted flow trade-off schedule for a speed-scalable processor with discrete speeds. Our algorithm uses a geometric approach that is based on structural properties obtained from a primal-dual formulation of the problem.

14:30 – 15:45 Session 3B: Graphs

chair: Christophe PAUL

Andreas GOEBEL, Leslie Ann GOLDBERG & David RICHERBY: *Counting homomorphisms to cactus graphs modulo 2*

A homomorphism from a graph G to a graph H is a function from $V(G)$ to $V(H)$ that preserves edges. Many combinatorial structures that arise in mathematics and computer science can be represented naturally as graph homomorphisms and as weighted sums of graph homomorphisms. In this paper, we study the complexity of counting homomorphisms modulo 2. The complexity of modular counting was introduced by Papadimitriou and Zachos and it has been pioneered by Valiant who famously introduced a problem for which counting modulo 7 is easy but counting modulo 2 is intractable. Modular counting provides a rich setting in which to study the structure of homomorphism problems. In this case, the structure of the graph H has a big influence on the complexity of the problem. Thus, our approach is graph-theoretic. We give a complete solution for the class of cactus graphs, which are connected graphs in which every edge belongs to at most one cycle. Cactus graphs arise in many applications such as the modelling of wireless sensor networks and the comparison of genomes. We show that, for some cactus graphs H , counting homomorphisms to H modulo 2 can be done in polynomial time. For every other fixed cactus graph H , the problem is complete for the complexity class $\oplus P$ which is a wide complexity class to which every problem in the polynomial hierarchy can be reduced (using randomised reductions). Determining which H lead to tractable problems can be done in polynomial time. Our result builds upon the work of Faben and Jerrum, who gave a dichotomy for the case in which H is a tree.

Michael BEKOS, Martin GRONEMANN & Chrysanthi RAFTOPOULOU: *Two-page book embeddings of 4-planar graphs*

Back in the eighties, Heath [PhDThesis, 1985] showed that every 3-planar graph is subhamiltonian and asked whether this result can be extended to a class of graphs of degree greater than three. In this paper we affirmatively answer this question for the class of 4-planar graphs. Our contribution consists of two algorithms: The first one is limited to triconnected graphs, but runs in linear time and uses existing methods for computing hamiltonian cycles in planar graphs. The second one, which solves the general case of the problem, is a quadratic-time algorithm based on the book embedding viewpoint of the problem.

Dariusz DERENIOWSKI, Adrian KOSOWSKI, Dominik PAJAŁK & Przemysław UZNAŃSKI: *Bounds on the cover time of parallel rotor walks*

The *rotor-router mechanism* was introduced as a deterministic alternative to the random walk in undirected graphs. In this model, a set of k identical walkers is deployed in parallel, starting from a chosen subset of nodes, and moving around the graph in synchronous steps. During the process, each node maintains a cyclic ordering of its outgoing arcs, and successively propagates walkers which visit it along its outgoing arcs in round-robin fashion, according to the fixed ordering.

We consider the *cover time* of such a system, i.e., the number of steps after which each node has been visited by at least one walk, regardless of the starting locations of the walks. In the case of $k = 1$, Yanovski et al. (2003) and Bampas et al. (2009) showed that a single walk achieves a cover time of exactly $\Theta(mD)$ for any n -node graph with m edges and diameter D , and that the walker eventually stabilizes to a traversal of an Eulerian circuit on the set of all directed edges of the graph. For $k > 1$ parallel walks, no similar structural behaviour can be observed.

In this work we provide tight bounds on the cover time of k parallel rotor walks in a graph. We show that this cover time is at most $\Theta(mD/\log k)$ and at least $\Theta(mD/k)$ for any graph, which corresponds to a speedup of between $\Theta(\log k)$ and $\Theta(k)$ with respect to the cover time of a single walk. Both of these extremal values of speedup are achieved for some graph classes. Our results hold for up to a polynomially large number of walks, $k = O(\text{poly}(n))$.

15:45 – 16:00 Coffee break

16:00 – 17:15 Session 4A: Game Theory*chair:* Laurent DOYEN

Haris AZIZ & Bart de KEIJZER: *Shapley meets Shapley*

This paper concerns the analysis of the *Shapley value* in *matching games*. Matching games constitute a fundamental class of cooperative games which help understand and model auctions and assignments. In a matching game, the value of a coalition of vertices is the weight of the maximum size matching in the subgraph induced by the coalition. The Shapley value is one of the most important solution concepts in cooperative game theory. After establishing some general insights, we show that the Shapley value of matching games can be computed in polynomial time for some special cases: graphs with maximum degree two, and graphs that have a small modular decomposition into cliques or cocliques (complete k -partite graphs are a notable special case of this). The latter result extends to various other well-known classes of graph-based cooperative games. We continue by showing that computing the Shapley value of unweighted matching games is $\#P$ -complete in general. Finally, a fully polynomial-time randomized approximation scheme (FPRAS) is presented. This FPRAS can be considered the best positive result conceivable, in view of the $\#P$ -completeness result.

Véronique BRUYÈRE, Emmanuel FILIOT, Mickael RANDOUR & Jean-François RASKIN: *Meet your expectations with guarantees: beyond worst-case synthesis in quantitative games*

Classical analysis of two-player quantitative games involves an adversary (modeling the environment of the system) which is purely antagonistic and asks for strict guarantees while Markov decision processes model systems facing a purely randomized environment: the aim is then to optimize the expected payoff, with no guarantee on individual outcomes. We introduce the beyond worst-case synthesis problem, which is to construct strategies that guarantee some quantitative requirement in the worst-case while providing an higher expected value against a particular stochastic model of the environment given as input. We consider both the mean-payoff value problem and the shortest path problem. In both cases, we show how to decide the existence of finite-memory strategies satisfying the problem and how to synthesize one if one exists. We establish algorithms and we study complexity bounds and memory requirements.

Tomas JELINEK, Marcus KLAAS & Guido SCHAEFER: *Computing optimal tolls with arc restrictions and heterogeneous players*

The problem of computing optimal network tolls that induce a Nash equilibrium of minimum total cost has been studied intensively in the literature, but mostly under the assumption that these tolls are unrestricted. Here we consider this problem under the more realistic assumption that the tolls have to respect some given upper bound restrictions on the arcs. The problem of taxing subnetworks optimally constitutes an important special case of this problem. We study the *restricted network toll problem* for both non-atomic and atomic (unweighted and weighted) players; our studies are the first that also incorporate *heterogeneous* players, i.e., players with different sensitivities to tolls.

For non-atomic and heterogeneous players, we prove that the problem is NP-hard even for single-commodity networks and affine latency functions. We therefore focus on parallel-arc networks and give an algorithm for optimally taxing subnetworks with affine latency functions. For weighted atomic players, the problem is NP-hard already for parallel-arc networks and linear latency functions, even if players are homogeneous. In contrast, for unweighted atomic and homogeneous players, we develop an algorithm to compute optimal restricted tolls for parallel-arc networks and arbitrary (standard) latency functions. Similarly, for unweighted atomic and heterogeneous players, we derive an algorithm for optimally taxing subnetworks for parallel-arc networks and arbitrary (standard) latency functions.

The key to most of our results is to derive (combinatorial) characterizations of flows that are inducible by restricted tolls. These characterizations might be of independent interest.

TOMOHIRO I, Juha KÄRKKÄINEN & Dominik KEMPA: *Faster sparse suffix sorting*

The sparse suffix sorting problem is to sort $b = o(n)$ arbitrary suffixes of a string of length n using $o(n)$ words of space in addition to the string. We present an $\mathcal{O}(n)$ time Monte Carlo algorithm using $\mathcal{O}(b \log b)$ space and an $\mathcal{O}(n \log b)$ time Las Vegas algorithm using $\mathcal{O}(b)$ space. This is a significant improvement over the best prior solutions by Bille et al. [ICALP 2013]: a Monte Carlo algorithm running in $\mathcal{O}(n \log b)$ time and $\mathcal{O}(b^{1+\epsilon})$ space or $\mathcal{O}(n \log^2 b)$ time and $\mathcal{O}(b)$ space, and a Las Vegas algorithm running in $\mathcal{O}(n \log^2 b + b^2 \log b)$ time and $\mathcal{O}(b)$ space. All the above results are obtained with high probability not just in expectation.

Paweł GAWRYCHOWSKI, Florin MANEA & Dirk NOWOTKA: *Testing generalised freeness of words*

Pseudo-repetitions are a natural generalisation of the classical notion of repetitions in sequences: they are the repeated concatenation of a word and its encoding under a certain morphism or antimorphism (anti-/morphism, for short). We approach the problem of deciding efficiently, for a word w and a literal anti-/morphism f , whether w contains an instance of a given pattern involving a variable x and its image under f , i.e., $f(x)$. Our results generalise both the problem of finding fixed repetitive structures (e.g., squares, cubes) inside a word and the problem of finding palindromic structures inside a word. For instance, we can detect efficiently a factor of the form xx^Rxxx^R , or any other pattern of such type. We also address the problem of testing efficiently, in the same setting, whether the word w contains an arbitrary pseudo-repetition of a given exponent.

Francine BLANCHET-SADRI, Michelle BODNAR & Benjamin De WINKLE: *Prefix arrays, graphs, and indeterminate strings*

We extend earlier works on the relation of prefix arrays of indeterminate strings to undirected graphs and border arrays. If integer array y is the prefix array for indeterminate string w , then we say w satisfies y . We use a graph theoretic approach to construct a string on a minimum alphabet size which satisfies a given prefix array. We relate the problem of finding a minimum alphabet size to finding edge clique covers of a particular graph, allowing us to bound the minimum alphabet size by $n + \sqrt{n}$ for indeterminate strings, where n is the size of the prefix array. When we restrict ourselves to prefix arrays for partial words, we bound the minimum alphabet size by $\lceil \sqrt{2n} \rceil$. Moreover, we show that this bound is tight up to a constant multiple by using Sidon sets. We also study the relationship between prefix arrays and border arrays. We show that the slowly-increasing property completely characterizes border arrays for indeterminate strings, whence there are exactly C_n distinct border arrays of size n for indeterminate strings (here C_n is the n th Catalan number). We also bound the number of prefix arrays for partial words of a given size using Stirling numbers of the second kind.

18:15 Social event: *guided visit of the old city center of Lyon*

Yann DISSER, Max KLIMM, Nicole MEGOW & Sebastian STILLER: *Packing a knapsack of unknown capacity*

We study the problem of packing a knapsack without knowing its capacity. Whenever we attempt to pack an item that does not fit, the item is discarded; if the item fits, we have to include it in the packing. We show that there is always a policy that packs a value within factor 2 of the optimum packing, irrespective of the actual capacity. If all items have unit density, we achieve a factor equal to the golden ratio $\varphi \approx 1.618$. Both factors are shown to be best possible.

In fact, we obtain the above factors using packing policies that are *universal* in the sense that they fix a particular order of the items and try to pack the items in this order, independent of the observations made while packing. We give efficient algorithms computing these policies. On the other hand, we show that, for any $\alpha > 1$, the problem of deciding whether a given universal policy achieves a factor of α is coNP-complete. If α is part of the input, the same problem is shown to be coNP-complete for items with unit densities. Finally, we show that it is coNP-hard to decide, for given α , whether a set of items admits a universal policy with factor α , even if all items have unit densities.

Nabil MUSTAFA & Saurabh RAY: *Near-optimal generalisations of a theorem of Macbeath*

The existence of Macbeath regions is a classical theorem in convex geometry (“A Theorem on non-homogeneous lattices”, *Annals of Math*, 1952). We refer the reader to the survey of I. Barany for several applications [Stochastic Geometry, 2007]. Recently there have been some striking applications of Macbeath regions in discrete and computational geometry.

In this paper, we study Macbeath’s problem in a more general setting, and not only for the Lebesgue measure as is the case in the classical theorem. We prove near-optimal generalizations for several basic geometric set systems. The problems and techniques used are closely linked to the study of ε -nets for geometric set systems.

Karl BRINGMANN, Thomas SAUERWALD, Alexandre STAUFFER & He SUN: *Balls into bins via local search: cover time and maximum load*

We study a natural process for allocating m balls into n bins that are organized as the vertices of an undirected graph G . Balls arrive one at a time. When a ball arrives, it first chooses a vertex u in G uniformly at random. Then the ball performs a local search in G starting from u until it reaches a vertex with local minimum load, where the ball is finally placed on. Then the next ball arrives and this procedure is repeated. For the case $m = n$, we give an upper bound for the maximum load on graphs with bounded degrees. We also propose the study of the *cover time* of this process, which is defined as the smallest m so that every bin has at least one ball allocated to it. We establish an upper bound for the cover time on graphs with bounded degrees. Our bounds for the maximum load and the cover time are tight when the graph is vertex transitive or sufficiently homogeneous. We also give upper bounds for the maximum load when $m \geq n$.

Pål Grønås DRANGE, Fedor V. FOMIN, Michał PILIPCZUK & Yngve VILLANGER: *Exploring subexponential parameterized complexity of completion problems*

Let \mathcal{F} be a family of graphs. In the \mathcal{F} -COMPLETION problem, we are given an n -vertex graph G and an integer k as input, and asked whether at most k edges can be added to G so that the resulting graph does not contain a graph from \mathcal{F} as an induced subgraph. It appeared recently that special cases of \mathcal{F} -COMPLETION, the problem of completing into a chordal graph known as MINIMUM FILL-IN, corresponding to the case of $\mathcal{F} = \{C_4, C_5, C_6, \dots\}$, and the problem of completing into a split graph, i.e., the case of $\mathcal{F} = \{C_4, 2K_2, C_5\}$, are solvable in parameterized subexponential time $2^{\mathcal{O}(\sqrt{k} \log k)} n^{\mathcal{O}(1)}$. The exploration of this phenomenon is the main motivation for our research on \mathcal{F} -COMPLETION.

In this paper we prove that completions into several well studied classes of graphs without long induced cycles also admit parameterized subexponential time algorithms by showing that:

- The problem TRIVIAALLY PERFECT COMPLETION is solvable in parameterized subexponential time $2^{\mathcal{O}(\sqrt{k} \log k)} n^{\mathcal{O}(1)}$, that is \mathcal{F} -COMPLETION for $\mathcal{F} = \{C_4, P_4\}$, a cycle and a path on four vertices.
- The problems known in the literature as PSEUDOSPLIT COMPLETION, the case where $\mathcal{F} = \{2K_2, C_4\}$, and THRESHOLD COMPLETION, where $\mathcal{F} = \{2K_2, P_4, C_4\}$, are also solvable in time $2^{\mathcal{O}(\sqrt{k} \log k)} n^{\mathcal{O}(1)}$.

We complement our algorithms for \mathcal{F} -COMPLETION with the following lower bounds:

- For $\mathcal{F} = \{2K_2\}$, $\mathcal{F} = \{C_4\}$, $\mathcal{F} = \{P_4\}$, and $\mathcal{F} = \{2K_2, P_4\}$, \mathcal{F} -COMPLETION cannot be solved in time $2^{o(k)} n^{\mathcal{O}(1)}$ unless the Exponential Time Hypothesis (ETH) fails.

Our upper and lower bounds provide a complete picture of the subexponential parameterized complexity of \mathcal{F} -COMPLETION problems for $\mathcal{F} \subseteq \{2K_2, C_4, P_4\}$.

Valentin GARNERO, Christophe PAUL, Ignasi SAU & Dimitrios M. THILIKOS: *Explicit linear kernels via dynamic programming*

Several algorithmic meta-theorems on kernelization have appeared in the last years, starting with the result of Bodlaender *et al.* [FOCS 2009] on graphs of bounded genus, then generalized by Fomin *et al.* [SODA 2010] to graphs excluding a fixed minor, and by Kim *et al.* [ICALP 2013] to graphs excluding a fixed topological minor. Typically, these results guarantee the existence of linear or polynomial kernels on sparse graph classes for problems satisfying some generic conditions but, mainly due to their generality, it is not clear how to derive from them constructive kernels with explicit constants.

In this paper we make a step toward a fully constructive meta-kernelization theory on sparse graphs. Our approach is based on a more explicit protrusion replacement machinery that, instead of expressibility in CMSO logic, uses dynamic programming, which allows us to find an explicit upper bound on the size of the derived kernels. one has just to define the tables to solve Π via dynamic programming on graphs of bounded treewidth, check that these tables satisfy two simple natural conditions, and then our results provide a linear-time algorithm that replaces large protrusions with graphs whose size is bounded by an explicit constant, and that updates the parameter of Π appropriately. This protrusion replacer can then be used, for instance, whenever one is able to find a linear protrusion decomposition of the input graphs of Π on some sparse graph class. We demonstrate the usefulness of our techniques by providing the first explicit linear kernels for r -DOMINATING SET and r -SCATTERED SET on apex-minor-free graphs, and for PLANAR- \mathcal{F} -DELETION on graphs excluding a fixed (topological) minor in the case where all the graphs in \mathcal{F} are connected.

Yixin CAO & Dániel MARX: *Chordal editing is fixed-parameter tractable*

Graph modification problems are typically asked as follows: is there a set of k operations that transforms a given graph to have a certain property. The most commonly considered operations include vertex deletion, edge deletion, and edge addition; for the same property, one can define significantly different versions by allowing different operations. We study a very general graph modification problem which allows all three types of operations: given a graph G and integers k_1 , k_2 , and k_3 , the CHORDAL EDITING problem asks if G can be transformed into a chordal graph by at most k_1 vertex deletions, k_2 edge deletions, and k_3 edge additions. Clearly, this problem generalizes both CHORDAL VERTEX/EDGE DELETION and CHORDAL COMPLETION (also known as MINIMUM FILL-IN). Our main result is an algorithm for CHORDAL EDITING in time $2^{O(k \log k)} \cdot n^{O(1)}$, where $k := k_1 + k_2 + k_3$; therefore, the problem is fixed-parameter tractable parameterized by the total number of allowed operations. Our algorithm is both more efficient and conceptually simpler than the previously known algorithm for the special case CHORDAL DELETION.

10:15 – 10:30 Coffee break

10:30 – 11:20 Session 6A: Words

chair: Michaël RAO

Moshe LEWENSTEIN, Yakov NEKRICH & Jeff VITTER: *Space-efficient string indexing for wildcard pattern matching*

In this paper we describe compressed indexes that support pattern matching queries for strings with wildcards. For a constant size alphabet our data structure uses $O(n \log^\varepsilon n)$ bits for any $\varepsilon > 0$ and reports all *occ* occurrences of a wildcard string in $O(m + \sigma^g \cdot \mu(n) + \text{occ})$ time, where $\mu(n) = o(\log \log \log n)$, σ is the alphabet size, m is the number of alphabet symbols and g is the number of wildcard symbols in the query string. We also present an $O(n)$ -bit index with $O((m + \sigma^g + \text{occ}) \log^\varepsilon n)$ query time and an $O(n(\log \log n)^2)$ -bit index with $O((m + \sigma^g + \text{occ}) \log \log n)$ query time. These are the first non-trivial data structures for this problem that need $o(n \log n)$ bits of space.

Artur JEŻ & Markus LOHREY: *Approximation of smallest linear tree grammar*

A simple linear-time algorithm for constructing a linear context-free tree grammar of size $\mathcal{O}(r^2 g \log n)$ for a given input tree T of size n is presented, where g is the size of a minimal linear context-free tree grammar for T , and r is the maximal rank of symbols in T (which is a constant in many applications). This is the first example of a grammar-based tree compression algorithm with an approximation ratio polynomial in g . The analysis of the algorithm uses an extension of the recompression technique (used in the context of grammar-based string compression) from strings to trees.

10:30 – 11:20 Session 6B: Algebraic Complexity*chair:* Neeraj KAYAL

Suryajith CHILLARA & Partha MUKHOPADHYAY: *Depth-4 lower bounds, determinantal complexity: a unified approach*

Tavenas has recently proved that any $n^{O(1)}$ -variate and degree n polynomial in VP can be computed by a depth-4 $\Sigma\Pi^{[O(\sqrt{n})]}\Sigma\Pi^{[\sqrt{n}]}$ circuit of size $2^{O(\sqrt{n}\log n)}$ [Tavenas, MFCS '13]. So, to prove $VP \neq VNP$ it is sufficient to show that an explicit polynomial in VNP of degree n requires $2^{\omega(\sqrt{n}\log n)}$ size depth-4 circuits. Soon after Tavenas' result, for two different explicit polynomials, depth-4 circuit size lower bounds of $2^{\Omega(\sqrt{n}\log n)}$ have been proved (see [Kayal et al., ECCC '13] and [Fournier et al., ECCC '13]). In particular, using combinatorial design Kayal et al. construct an explicit polynomial in VNP that requires depth-4 circuits of size $2^{\Omega(\sqrt{n}\log n)}$ and Fournier et al. show that the iterated matrix multiplication polynomial (which is in VP) also requires $2^{\Omega(\sqrt{n}\log n)}$ size depth-4 circuits.

In this paper, we identify a simple combinatorial property such that any polynomial f that satisfies this property would achieve a similar depth-4 circuit size lower bound. In particular, it does not matter whether f is in VP or in VNP. As a result, we get a simple unified lower bound analysis for the above mentioned polynomials.

Another goal of this paper is to compare our current knowledge of the depth-4 circuit size lower bounds and the determinantal complexity lower bounds. Currently the best known determinantal complexity lower bound is $\Omega(n^2)$ for Permanent of a $n \times n$ matrix (which is a n^2 -variate and degree n polynomial) [Cai et al., STOC '08]. We prove that the determinantal complexity of the iterated matrix multiplication polynomial is $\Omega(dn)$ where d is the number of matrices and n is the dimension of the matrices. So for $d = n$, we get that the iterated matrix multiplication polynomial achieves the current best known lower bounds in both fronts: depth-4 circuit size and determinantal complexity. Our result also settles the determinantal complexity of the iterated matrix multiplication polynomial to $\Theta(dn)$.

To the best of our knowledge, a $\Theta(n)$ bound for the determinantal complexity for the iterated matrix multiplication polynomial was known only for any constant $d > 1$ [Jansen, TCS '11].

Gábor IVANYOS, Marek KARPINSKI, Youming QIAO & Miklos SANTHA: *Generalized Wong sequences and their applications to Edmonds' problems*

We design two deterministic polynomial time algorithms for variants of a problem introduced by Edmonds in 1967: determine the rank of a matrix M whose entries are homogeneous linear polynomials over the integers. Given a linear subspace \mathcal{B} of the $n \times n$ matrices over some field \mathbb{F} , we consider the following problems: *symbolic matrix rank* (SMR) is the problem to determine the maximum rank among matrices in \mathcal{B} , while *symbolic determinant identity testing* (SDIT) is the question to decide whether there exists a nonsingular matrix in \mathcal{B} . The constructive versions of these problems are asking to find a matrix of maximum rank, respectively a nonsingular matrix, if there exists one.

Our first algorithm solves the *constructive* SMR when \mathcal{B} is spanned by unknown rank one matrices, answering an open question of Gurvits. Our second algorithm solves the constructive SDIT when \mathcal{B} is spanned by triangularizable matrices, but the triangularization is not given explicitly. Both algorithms work over finite fields of size at least $n + 1$ and over the rational numbers, and the first algorithm actually solves (the non-constructive) SMR independent of the field size. Our main tool to obtain these results is to generalize Wong sequences, a classical method to deal with pairs of matrices, to the case of pairs of matrix spaces.

11:20 – 11:40 Coffee break**11:40 – 12:40 Invited Talk***chair:* Marie-Pierre BÉAL

LUC SEGOUFIN: *A glimpse on constant delay enumeration*

We survey some of the recent results about enumerating the answers to queries over a database. We focus on the case where the enumeration is performed with a constant delay between any two consecutive solutions, after a linear time preprocessing.

This cannot be always achieved. It requires restricting either the class of queries or the class of databases. We describe here several scenarios when this is possible.

12:40 – 12:50 **Group photo**

12:50 – 14:30 **Lunch**

14:30 – 15:45 **Session 7A: Algorithms**

chair: Markus LOHREY

Marek CYGAN & Tomasz KOCIUMAKA: *Constant factor approximation for capacitated k -center with outliers*

The k -center problem is a classic facility location problem, where given an edge-weighted graph $G = (V, E)$ one is to find a subset of k vertices S , such that each vertex in V is “close” to some vertex in S . The approximation status of this basic problem is well understood, as a simple 2-approximation algorithm is known to be tight. Consequently different extensions were studied.

In the capacitated version of the problem each vertex is assigned a capacity, which is a strict upper bound on the number of clients a facility can serve, when located at this vertex. A constant factor approximation for the capacitated k -center was obtained last year by Cygan, Hajiaghayi and Khuller [FOCS’12], which was recently improved to a 9-approximation by An, Bhaskara and Svensson [arXiv’13].

In a different generalization of the problem some clients (denoted as outliers) may be disregarded. Here we are additionally given an integer p and the goal is to serve exactly p clients, which the algorithm is free to choose. In 2001 Charikar et al. [SODA’01] presented a 3-approximation for the k -center problem with outliers.

In this paper we consider a common generalization of the two extensions previously studied separately, i.e. we work with the capacitated k -center with outliers. We present the first constant factor approximation algorithm with approximation ratio of 25 even for the case of non-uniform hard capacities.

Marek ADAMCZYK, Maxim SVIRIDENKO & Justin WARD: *Submodular stochastic probing on matroids*

In a *stochastic probing* problem we are given a universe E , where each element $e \in E$ is *active* independently with probability $p_e \in [0, 1]$, and only a *probe* of e can tell us whether it is active or not. On this universe we execute a process that one by one probes elements — if a probed element is active, then we have to include it in the solution, which we gradually construct. Throughout the process we need to obey *inner* constraints on the set of elements taken into the solution, and *outer* constraints on the set of all probed elements. This abstract model was presented by Gupta and Nagarajan [IPCO’13], and provides a unified view of a number of problems. Thus far all the results in this general framework pertain only to the case in which we are maximizing a linear objective function of the successfully probed elements. In this paper we generalize the stochastic probing problem by considering a monotone submodular objective function. We give a $(1 - 1/e) \cdot 1/(k^{in} + k^{out})$ -approximation algorithm for the case in which we are given $k^{in} \geq 0$ matroids as inner constraints and $k^{out} \geq 1$ matroids as outer constraints. There are two main ingredients behind this result. First is a previously unpublished stronger bound on the continuous greedy algorithm due to Vondrak. Second is a rounding procedure that also allows us to obtain an improved $1/(k^{in} + k^{out})$ -approximation for linear objective functions.

John MITCHELL & Joe ZIMMERMAN: *Data-oblivious data structures*

An algorithm is called *data-oblivious* if its control flow and memory access pattern do not depend on its input data. Data-oblivious algorithms play a significant role in secure cloud computing, since programs that are run on secret data—as in fully homomorphic encryption or secure multi-party computation—must be data-oblivious. In this paper, we formalize three definitions of data-obliviousness that have appeared implicitly in the literature, explore their implications, and show separations. We observe that data-oblivious algorithms often compose well when viewed as data structures. Using this approach, we construct data-oblivious stacks, queues, and priority queues that are considerably simpler than existing constructions, as well as improving constant factors. We also establish a new upper bound for oblivious data compaction, and use this result to show that an “offline” variant of the Oblivious RAM problem can be solved with $O(\log n \log \log n)$ expected amortized time per operation—as compared with $O(\log^2 n / \log \log n)$, the best known upper bound for the standard online formulation.

14:30 – 15:45 Session 7B: Computabilitychair: Peter Bro MILTERSEN

Benoit MONIN: *Higher randomness and forcing with closed sets*

Kechris showed in [Transaction of AMS, 1975] that there exists a largest Π_1^1 set of measure 0. An explicit construction of this largest Π_1^1 nullset has later been given by Hjorth and Nies [Jour. of London Math. Soc., 2007]. Due to its universal nature, it was conjectured by many that this nullset has a high Borel rank (the question is explicitly mentioned by [Chong and Yu] and Yu [Fund. Math., 2011]). In this paper, we refute this conjecture and show that this nullset is merely Σ_3^0 . Together with a result of Liang Yu, our result also implies that the exact Borel complexity of this set is Σ_3^0 .

To do this proof, we develop the machinery of effective randomness and effective Solovay genericity, investigating the connections between those notions and effective domination properties.

Bruno BAUWENS: *Asymmetry of the Kolmogorov complexity of online predicting odd and even bits*

Symmetry of information states that $C(x) + C(y|x) = C(x, y) + O(\log C(x))$. In [Chernov, Shen, Vereshchagin and Vovk, ALT '08] an online variant of Kolmogorov complexity is introduced and we show that a similar relation does not hold. Let the even (online Kolmogorov) complexity of an n -bitstring $x_1x_2 \dots x_n$ be the length of a shortest program that computes x_2 on input x_1 , computes x_4 on input $x_1x_2x_3$, etc; and similar for odd complexity. We show that for all n there exists an n -bit x such that both odd and even complexity are almost as large as the Kolmogorov complexity of the whole string. Moreover, flipping odd and even bits to obtain a sequence $x_2x_1x_4x_3 \dots$, decreases the sum of odd and even complexity to $C(x)$. Our result is related to the problem of inference of causality in time series.

Timo KÖTZING: *A solution to Wiehagen's thesis*

Wiehagen's *Thesis in Inductive Inference* (1991) essentially states that, for each learning criterion, learning can be done in a normalized, enumerative way. The thesis was not a formal statement and thus did not allow for a formal proof, but support was given by examples of a number of different learning criteria that can be learned enumeratively.

Building on recent formalizations of learning criteria, we are now able to formalize Wiehagen's Thesis. We prove the thesis for a wide range of learning criteria, including many popular criteria from the literature. We also show the limitations of the thesis by giving four learning criteria for which the thesis does not hold (and, in two cases, was probably not meant to hold). Beyond the original formulation of the thesis, we also prove stronger versions which allow for many corollaries relating to *strongly decisive* and *conservative* learning.

15:45 – 16:00 Coffee break

YOSSI AZAR, Matthias ENGLERT, Iftah GAMZU & Eytan KIDRON: *Generalized reordering buffer management*

An instance of the generalized reordering buffer management problem consists of a service station that has k servers, each configured with a color, and a buffer of size b . The station needs to serve an online stream of colored items. Whenever an item arrives, it is stored in the buffer. At any point in time, a currently pending item can be served by switching a server to its color. The objective is to serve all items in a way that minimizes the number of servers color switches. This problem generalizes two well-studied online problems: the paging problem, which is the special case when $b = 1$, and the reordering buffer problem, which is the special case when $k = 1$.

In this paper, we develop a randomized online algorithm that obtains a competitive ratio of $O(\sqrt{b} \ln k)$. Note that this result beats the easy deterministic lower bound of k whenever $b < k^{2-\epsilon}$. We complement our randomized approach by presenting a deterministic algorithm that attains a competitive ratio of $O(\min\{k^2 \ln b, kb\})$. We further demonstrate that if our deterministic algorithm can employ $k/(1 - \delta)$ servers where $\delta \in (0, 1)$, then it achieves a competitive ratio of $O(\min\{\ln b/\delta^2, b/\delta\})$ against an optimal offline adversary that employs k servers.

Jian-Jia CHEN, Mong-Jen KAO, Der-Tsai LEE, Ignaz RUTTER & Dorothea WAGNER: *Online dynamic power management with hard real-time guarantees*

We consider the problem of online dynamic power management that provides hard real-time guarantees for multi-processor systems. In this problem, a set of jobs, each associated with an arrival time, a deadline, and an execution time, arrives to the system in an online fashion. The objective is to compute a non-migrative preemptive schedule of the jobs and a sequence of power on/off operations of the processors so as to minimize the total energy consumption while ensuring that all the deadlines of the jobs are met. We assume that we can use as many processors as necessary. In this paper we examine the complexity of this problem and provide online strategies that lead to practical energy-efficient solutions for real-time multi-processor systems.

First, we consider the case for which we know in advance that the set of jobs can be scheduled feasibly on a single processor. We show that, even in this case, the competitive factor of any online algorithm is at least 2.06. On the other hand, we give a 4-competitive online algorithm that uses at most two processors. For jobs with unit execution times, the competitive factor of this algorithm improves to 3.59.

Second, we relax our assumption by considering as input multiple streams of jobs, each of which can be scheduled feasibly on a single processor. We present a trade-off between the energy-efficiency of the schedule and the number of processors to be used. More specifically, for k given job streams and h processors with $h > k$, we give a scheduling strategy such that the energy usage is at most $4 \cdot \left\lceil \frac{k}{h-k} \right\rceil$ times that used by any schedule which schedules each of the k streams on a separate processor. Finally, we drop the assumptions on the input set of jobs. We show that the competitive factor of any online algorithm is at least 2.28, even for the case of unit job execution times for which we further derive an $O(1)$ -competitive algorithm.

Dennis KOMM, Tobias MOEMKE, Rastislav KRALOVIC & Richard KRALOVIC: *Randomized online algorithms with high probability guarantees*

We study the relationship between the competitive ratio and the tail distribution of randomized online problems. To this end, we define a broad class of online problems that includes some of the well-studied problems like paging, k -server and metrical task systems on finite metrics, and show that for these problems it is possible to obtain, given an algorithm with constant expected competitive ratio, another algorithm that achieves the same solution quality up to an arbitrarily small constant error with high probability; the “high probability” statement is in terms of the optimal cost. Furthermore, we show that our assumptions are tight in the sense that removing any of them allows for a counterexample to the theorem.

Mathieu HOYRUP: *Irreversible computable functions*

The strong relationship between topology and computations has played a central role in the development of several branches of theoretical computer science: foundations of functional programming, computational geometry, computability theory, computable analysis. Often it happens that a given function is not computable simply because it is not continuous. In many cases, the function can moreover be proved to be non-computable in the stronger sense that it does not preserve computability: it maps a computable input to a non-computable output. To date, there is no connection between topology and this kind of non-computability, apart from Pour-El and Richards “First Main Theorem”, applicable to linear operators on Banach spaces only.

In the present paper, we establish such a connection. We identify the discontinuity notion, for the inverse of a computable function, that implies non-preservation of computability. Our result is applicable to a wide range of functions, it unifies many existing *ad hoc* constructions explaining at the same time what makes these constructions possible in particular contexts, sheds light on the relationship between topology and computability and most importantly allows us to solve open problems. In particular it enables us to answer the following open question in the negative: if the sum of two shift-invariant ergodic measures is computable, must these measures be computable as well? We also investigate how generic a point with computable image can be. To this end we introduce a notion of genericity of a point w.r.t. a function, which enables us to unify several finite injury constructions from computability theory.

André NIES: *Differentiability of polynomial time computable functions*

We show that a real z is polynomial time random if and only if each nondecreasing polynomial time computable function is differentiable at z . This establishes an analog in feasible analysis of a recent result of Brattka, Miller and Nies, who characterized computable randomness in terms of differentiability of nondecreasing computable functions.

Further, we show that a Martin-Löf random real z is a density-one point if and only if each interval-c.e. function is differentiable at z . (To say z is a density-one point means that every effectively closed class containing z has density one at z . The interval-c.e. functions are, essentially, the variation functions of computable functions.)

The proofs are related: they both make use of the analytical concept of porosity in novel ways, and both use a basic geometric fact on shifting dyadic intervals by $1/3$.

Emmanuel JEANDEL: *Computability of the entropy of one-tape Turing machines*

We prove that the maximum speed and the entropy of a one-tape Turing machine are computable, in the sense that we can approximate them to any given precision ϵ . This is counterintuitive, as all dynamical properties are usually undecidable for Turing machines. The result is quite specific to one-tape Turing machines, as it is not true anymore for two-tape Turing machines by the results of Blondel et al., and uses the approach of crossing sequences introduced by Hennie.

19:00 Conference Dinner at *Le Caro de Lyon*

9:00 – 10:15 Session 9A: Online Algorithms

chair: Pablo ARRIGHI

Jun'ichi YAMAMOTO, TOMOHIRO I, Hideo BANNAI, Shunsuke INENAGA & Masayuki TAKEDA: *Faster compact on-line Lempel-Ziv factorization*

We present a new on-line algorithm for computing the Lempel-Ziv factorization of a string that runs in $O(N \log N)$ time and uses only $O(N \log \sigma)$ bits of working space, where N is the length of the string and σ is the size of the alphabet. This is a notable improvement compared to the performance of previous on-line algorithms using the same order of working space but running in either $O(N \log^3 N)$ time (Okanojima & Sadakane 2009) or $O(N \log^2 N)$ time (Starikovskaya 2012). The key to our new algorithm is in the utilization of an elegant but less popular index structure called Directed Acyclic Word Graphs, or DAWGs (Blumer et al. 1985). We also present an opportunistic variant of our algorithm, which, given the run length encoding of size m of a string of length N , computes the Lempel-Ziv factorization of the string on-line, in $O\left(m \cdot \min\left\{\frac{(\log \log m)(\log \log N)}{\log \log \log N}, \sqrt{\frac{\log m}{\log \log m}}\right\}\right)$ time and $O(m \log N)$ bits of space.

Petra BERENBRINK, Funda ERGÜN, Frederik MALLMANN-TRENN & Erfan Sadeqi AZER: *Palindrome recognition in the streaming model*

A palindrome is defined as a string which reads forwards the same as backwards, like, for example, the string “racecar”. In the *Palindrome Problem*, one tries to find all *palindromes* in a given string. In contrast, in the case of the *Longest Palindromic Substring Problem*, the goal is to find an arbitrary one of the longest palindromes in the string.

In this paper we present three algorithms in the streaming model for the the above problems, where at any point in time we are only allowed to use sublinear space. We first present a one-pass randomized algorithm that solves the *Palindrome Problem*. It has an *additive* error and uses $O(\sqrt{n})$ space. We also give two variants of the algorithm which solve related and practical problems. The second algorithm determines the exact locations of *all* longest palindromes using two passes and $O(\sqrt{n})$ space. The third algorithm is a one-pass randomized algorithm, which solves the *Longest Palindromic Substring Problem*. It has a *multiplicative* error using only $O(\log(n))$ space.

Joan BOYAR, Shahin KAMALI, Kim S. LARSEN & Alejandro LOPEZ-ORTIZ: *Online bin packing with advice*

We consider the online bin packing problem under the advice complexity model where the “online constraint” is relaxed and an algorithm receives partial information about the future requests. We provide tight upper and lower bounds for the amount of advice an algorithm needs to achieve an optimal packing. We also introduce an algorithm that, when provided with $\log n + o(\log n)$ bits of advice, achieves a competitive ratio of $3/2$ for the general problem. This algorithm is simple and is expected to find real-world applications. We introduce another algorithm that receives $2n + o(n)$ bits of advice and achieves a competitive ratio of $4/3 + \varepsilon$. Finally, we provide a lower bound argument that implies that advice of linear size is required for an algorithm to achieve a competitive ratio better than $9/8$.

9:00 – 10:15 Session 9B: Complexity

chair: Ernst MAYR

Dung NGUYEN & Alan SELMAN: *Non-autoreducible sets for NEXP*

We investigate autoreducibility properties of complete sets for NEXP under different polynomial-time reductions. Specifically, we show that under some polynomial-time reductions there are complete sets for NEXP that are not autoreducible. We show that settling the question whether every \leq_{dt}^p -complete set for NEXP is \leq_{NOR-tt}^p -autoreducible either positively or negatively would lead to major results about the exponential time complexity classes.

Hannes UPPMAN: *Computational complexity of the minimum cost homomorphism problem on three-element domains*

In this paper we study the computational complexity of the extended *minimum cost homomorphism problem* (Min-Cost-Hom) as a function of a constraint language, i.e. a set of constraint relations and cost functions that are allowed to appear in instances. A wide range of natural combinatorial optimisation problems can be expressed as extended Min-Cost-Homs and a classification of their complexity would be highly desirable, both from a direct, applied point of view as well as from a theoretical perspective.

The extended Min-Cost-Hom can be understood either as a flexible optimisation version of the *constraint satisfaction problem* (CSP) or a restriction of the (general-valued) *valued constraint satisfaction problem* (VCSP). Other optimisation versions of CSPs such as the *minimum solution problem* (Min-Sol) and the *minimum ones problem* (Min-Ones) are special cases of the extended Min-Cost-Hom.

The study of VCSPs has recently seen remarkable progress. A complete classification for the complexity of finite-valued languages on arbitrary finite domains has been obtained Thapper and Živný [STOC'13]. However, understanding the complexity of languages that are not finite-valued appears to be more difficult. The extended Min-Cost-Hom allows us to study problematic languages of this type without having to deal with the full generality of the VCSP. A recent classification for the complexity of three-element Min-Sol, Uppman [ICALP'13], takes a step in this direction. In this paper we generalise this result considerably by determining the complexity of three-element extended Min-Cost-Hom.

Thomas WATSON: *The complexity of deciding statistical properties of samplable distributions*

We consider the problems of deciding whether the joint distribution sampled by a given circuit satisfies certain statistical properties such as being i.i.d., being exchangeable, being pairwise independent, having two coordinates with identical marginals, having two uncorrelated coordinates, and many other variants. We give a proof that simultaneously shows all these problems are $C=P$ -complete, by showing that the following promise problem (which is a restriction of all the above problems) is $C=P$ -complete: Given a circuit, distinguish the case where the output distribution is uniform and the case where every pair of coordinates is neither uncorrelated nor identically distributed. This completeness result holds even for samplers that are depth-3 circuits.

We also consider circuits that are d -local, in the sense that each output bit depends on at most d input bits. We give linear-time algorithms for deciding whether a 2-local sampler's joint distribution is fully independent, and whether it is exchangeable.

We also show that for general circuits, certain approximation versions of the problems of deciding full independence and exchangeability are SZK-complete.

We also introduce a bounded-error version of $C=P$, which we call $BC=P$, and we investigate its structural properties.

10:15 – 10:30 Coffee break

10:30 – 11:20 Session 10A: Algorithms and Communication Lower Bounds *chair: E. MAYR*

Adeline PIERROT & Dominique ROSSIN: *2-stack sorting is polynomial*

This article deals with deciding whether a permutation is sortable with two stacks in series. Whether this decision problem lies in P or is NP-complete is a longstanding open problem since the introduction of serial compositions of stacks by Knuth in *The Art of Computer Programming* in 1973. We hereby prove that this decision problem lies in P by giving a polynomial algorithm to solve it. This algorithm uses the concept of pushall sorting, which was previously defined and studied by the authors in [PhD Thesis, 2013] and [ArXiv, 2013].

Michele SCQUZZATO & Francesco SILVESTRI: *Communication lower bounds for distributed-memory computations*

In this paper we propose a new approach to the study of the communication requirements of distributed computations, which advocates for the removal of the restrictive assumptions under which earlier results were derived. We illustrate our approach by giving tight lower bounds on the communication complexity required to solve several computational problems in a distributed-memory parallel machine, namely standard matrix multiplication, stencil computations, comparison sorting, and the Fast Fourier Transform. Our bounds rely only on a mild assumption on work distribution, and significantly strengthen previous results which require either the computation to be balanced among the processors, or specific initial distributions of the input data, or an upper bound on the size of processors' local memories.

10:30 – 11:20 Session 10B: Complexity

chair: Marius ZIMAND

Kazuo IWAMA & Atsuki NAGAO: *Read-once branching programs for tree evaluation problems*

Toward the ultimate goal of separating **L** and **P**, Cook, McKenzie, Wehr, Braverman and Santhanam introduced the *tree evaluation problem (TEP)*. For fixed $h, k > 0$, $FT_h(k)$ is given as a complete, rooted binary tree of height h , in which each internal node is associated with a function from $[k]^2$ to $[k]$, and each leaf node with a number in $[k]$. The value of an internal node v is defined naturally, i.e., if it has a function f and the values of its two child nodes are a and b , then the value of v is $f(a, b)$. Our task is to compute the value of the root node by sequentially executing this function evaluation in a bottom-up fashion. The problem is obviously in **P** and if we could prove that any branching program solving $FT_h(k)$ needs at least $k^{r(h)}$ states for any unbounded function r , then this problem is not in **L**, thus achieving our goal. The above authors introduced a restriction called *thrifty* against the structure of BP's (i.e., against the algorithm for solving the problem) and proved that any thrifty BP needs $\Omega(k^h)$ states. This paper proves a similar lower bound for *read-once* branching programs, which allows us to get rid of the restriction on the order of nodes read by the BP that is the nature of the thrifty restriction.

Yuval FILMUS, Massimo LAURIA, Mladen MIKSA, Jakob NORDSTROM & Marc VINYALS: *From small space to small width in resolution*

In 2003, Atserias and Dalmau resolved a major open question about the resolution proof system by establishing that the space complexity of formulas is always an upper bound on the width needed to refute them. Their proof is beautiful but somewhat mysterious in that it relies heavily on tools from finite model theory. We give an alternative, completely elementary, proof that works by simple syntactic manipulations of resolution refutations. As a by-product, we develop a "black-box" technique for proving space lower bounds via a "static" complexity measure that works against any resolution refutation—previous techniques have been inherently adaptive. We conclude by showing that the related question for polynomial calculus (i.e., whether space is an upper bound on degree) seems unlikely to be resolvable by similar methods.

11:20 – 11:40 Coffee break

11:40 – 12:40 Invited Talk

chair: Martin DIETZFELBINGER

Peter Bro MILTERSEN: *Semi-algebraic geometry in computational game theory – a consumer's perspective*

We survey recent applications of real algebraic and semi-algebraic geometry in (computational) game theory.

TUTORIAL AND MINIWORKSHOP ON ARITHMETIC CIRCUIT COMPLEXITY

Wednesday, March 5th

TUTORIAL

A *tutorial on arithmetic circuit complexity* will be given on Wednesday, March 5th, by Neeraj KAYAL, Microsoft Research India. It will start at 10:00 in amphitheater Mérieux (see map p. 32) and is included on a miniworkshop on arithmetic circuit complexity (see below).

Description: Arithmetic Circuits compute polynomial functions over their inputs via a sequence of arithmetic operations (additions, subtractions, multiplications, divisions, etc.). This tutorial will give an overview of arithmetic circuit complexity, focusing on the problem of proving lower bounds for arithmetic circuits.

In the first part, we begin with a few nontrivial upper bounds — matrix multiplication and the computation of symmetric polynomials. We then motivate some open problems we deal with in arithmetic circuit complexity. We will look at the problem of polynomial identity testing — motivating it by its application to bipartite matching, the problem of learning arithmetic circuits or circuit reconstruction and the problem of proving lower bounds for arithmetic circuits (motivating it via the problem of computing the permanent and the Hamiltonian polynomials). We will also see depth reduction for circuits — the tradeoffs involved (with respect to size) in squashing a circuit into one with smaller depth.

In the second part, we will see some classical lower bounds. In particular, we will see lower bounds for monotone arithmetic circuits and multilinear formulas. We then give a very quick overview of approaches being investigated (including geometric complexity theory and τ -conjecture) aiming to prove lower bounds.

In the third part, we begin with a warm-up by proving lower bounds for homogeneous depth three circuits. We will then see recent lower bounds for homogeneous depth four circuits and its consequences.

MINIWORKSHOP

Arithmetic circuits provide a simple and natural model for computing polynomials. Two of the main open problems in this field are:

- The complexity of the permanent polynomial: can it be computed by polynomial-size arithmetic circuits? This problem can be viewed as an algebraic version of \mathbf{P} versus \mathbf{NP} (or perhaps more accurately, as an algebraic version of \mathbf{NC} versus $\#\mathbf{P}$).
- Derandomization of Polynomial Identity Testing. There is a simple and well-known randomized algorithm for this problem (evaluate your circuit at random points), and it forms a building block in the design of many other randomized algorithms. This problem is connected to the first one via hardness versus randomness tradeoffs.

While these outstanding problems remain open, significant progress has been made in the last few years. We hope to share these exciting developments with a wide audience. In order to make the workshop easily accessible to non-experts, we will begin the day with the traditional 3-hour STACS tutorial. This year's topic is arithmetic circuit complexity, and the tutorial (see above) will be delivered by Neeraj KAYAL (Microsoft Research India). The tutorial starts at 10:00 in the amphitheater Mérieux. We will continue with contributed talks in amphitheater B. Topics of interest for the workshop include:

- Arithmetic circuit models such as: arithmetic formulas, arithmetic branching programs, multilinear circuits, bounded-depth circuits...
- Upper and lower bounds for the permanent, the determinant and other explicit polynomials.
- Polynomial identity testing, hardness versus randomness tradeoffs.
- Related topics, *e.g.*, the complexity of matrix multiplication.

This workshop is supported by CompA, a research project funded by the Agence Nationale de la Recherche (ANR).

PROGRAM OF THE WORKSHOP ON ARITHMETIC CIRCUIT COMPLEXITY

9:30 – 10:00	Welcoming of participants
10:00 – 11:00	TUTORIAL PART 1 (amphi Mérieux)
11:15 – 12:15	TUTORIAL PART 2 (amphi Mérieux)
12:15 – 13:15	Lunch
13:15 – 14:15	TUTORIAL PART 3 (amphi Mérieux)
14:30 – 15:30	CONTRIBUTED TALKS (amphi B)
	Suryajith CHILLARA: <i>On the limits of depth reduction at depth 3 over small finite fields</i> Hervé FOURNIER: <i>Lower bounds for depth 4 formulas computing iterated matrix multiplication</i>
15:30 – 15:45	Coffee break
14:30 – 15:30	CONTRIBUTED TALKS (amphi B)
	Youming QIAO: <i>On symbolic determinant identity test problem</i> Miklos SANTHA: <i>Hidden symmetry subgroups and hidden polynomials</i>

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SOCIAL EVENTS

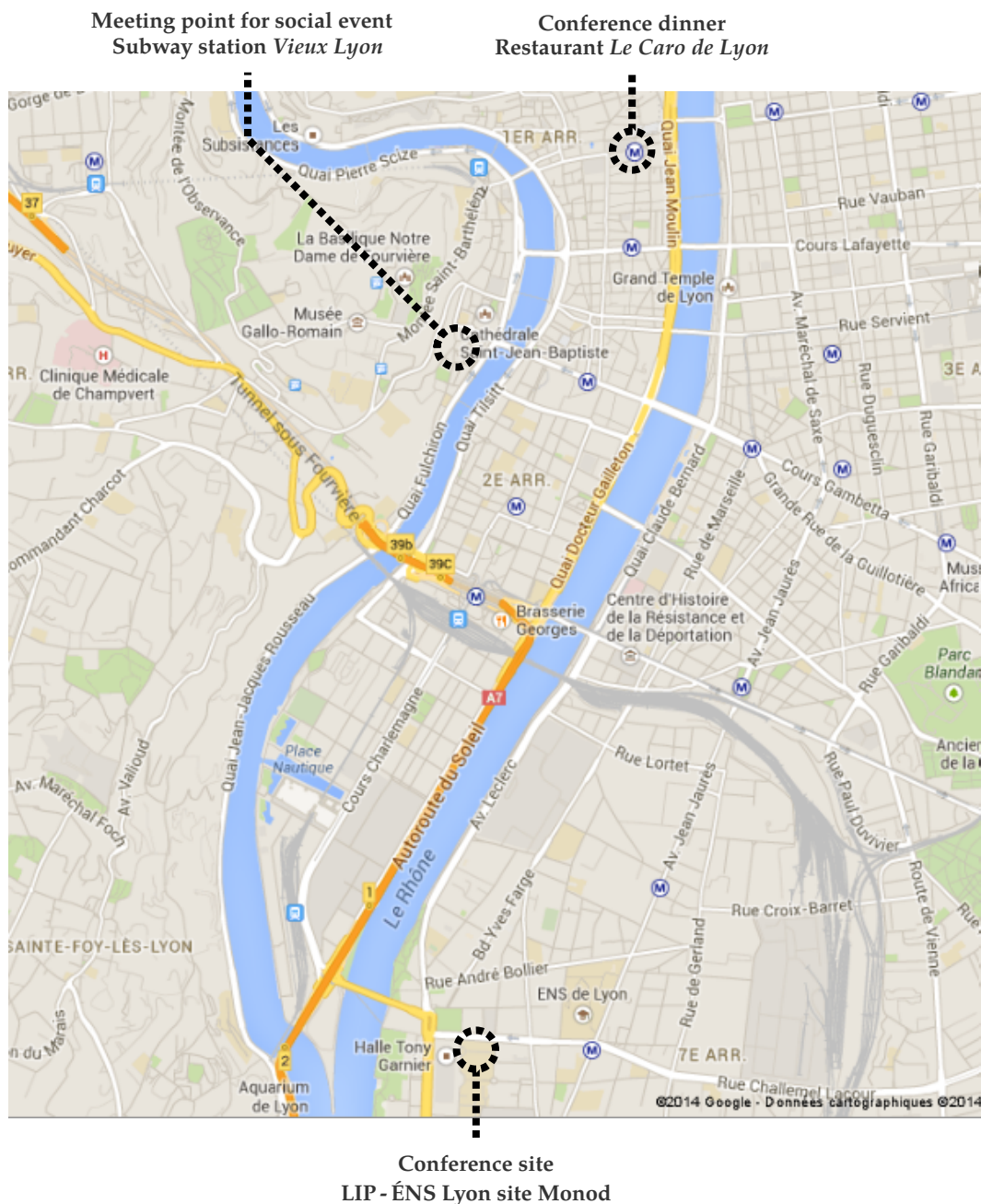
VISIT OF THE CITY CENTER

As social event, we propose you to discover a part of the city center during a guided visit on Thursday, March 6th. This tour will include, among other sites: the *cathedral Saint-Jean*, the *Vieux Lyon* (old city center), the *place des Terreaux* and the *Opéra*. The visit is planned to start at 18:15 and participants must be at 18:00 at the exit of the subway station *Vieux Lyon* (subway line D).

Duration: 1H30.

CONFERENCE DINNER AT LE CARO DE LYON

The conference dinner takes place on Friday, March 7th at 19:00, at the restaurant **Le Caro de Lyon**, 25 Rue du Bât d'Argent, 69001 LYON. It is located near the subway station *Hôtel de Ville – Louis Pradel* (subway line A).



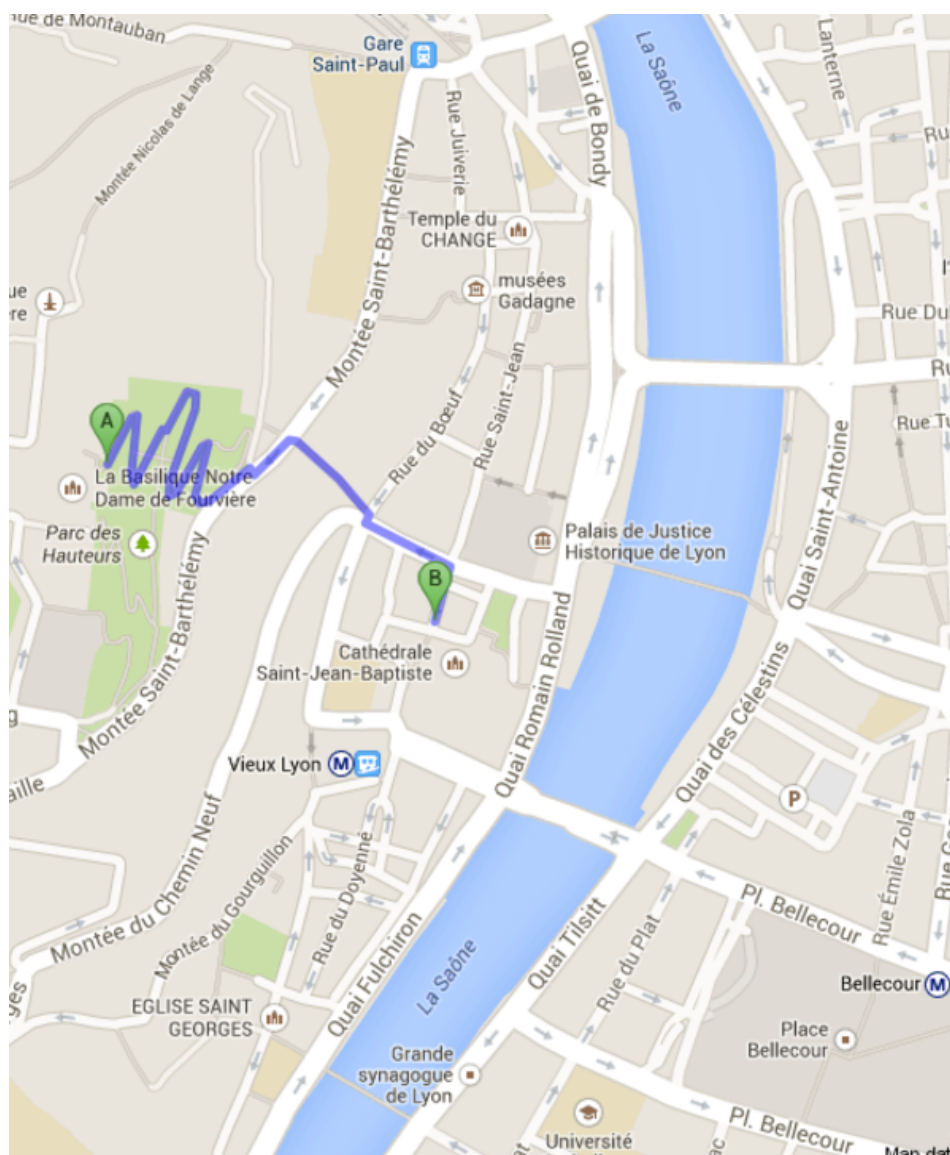
USEFUL INFORMATION AND TOURISM

Each participant will receive, at the reception desk, a bag containing a guide given by the tourist office (which includes an almost exhaustive list of restaurants in Lyon), a three-days subway ticket (valid for subway, bus, tramway and funicular), a WiFi login and a map of public transport. Electronic version of the LIPICS proceedings of STACS 2014 can be found online [here](#), but some USB keys containing it can also be borrowed at the reception desk. For any other information, ask at the reception desk.

CLIMBING TO THE FOURVIÈRE BASILICA

You can discover the most famous church of Lyon, the basilica *Notre Dame de Fourvière*, by a small itinerary given below. From the subway station *Vieux Lyon*, take the funicular railway to the *Fourvière* hill. Once arrived at the top of the hill, you can visit the *Fourvière* basilica (point A on the map) and enjoy a nice view of the whole city. Then you can go back to *Vieux Lyon* and to the *Saint Jean cathedral* (point B on the map) by going down through the garden (you can also take the garden to climb to the basilica, but the bottom entry of the garden is not easy to find, and obviously, it is always easier to go down than to climb up). Please note that the visit of the *Saint Jean cathedral*, which is near the station *Vieux Lyon*, is included in the guided tour of the social event. The map given below can also be found at: <http://tinyurl.com/paltnmw>

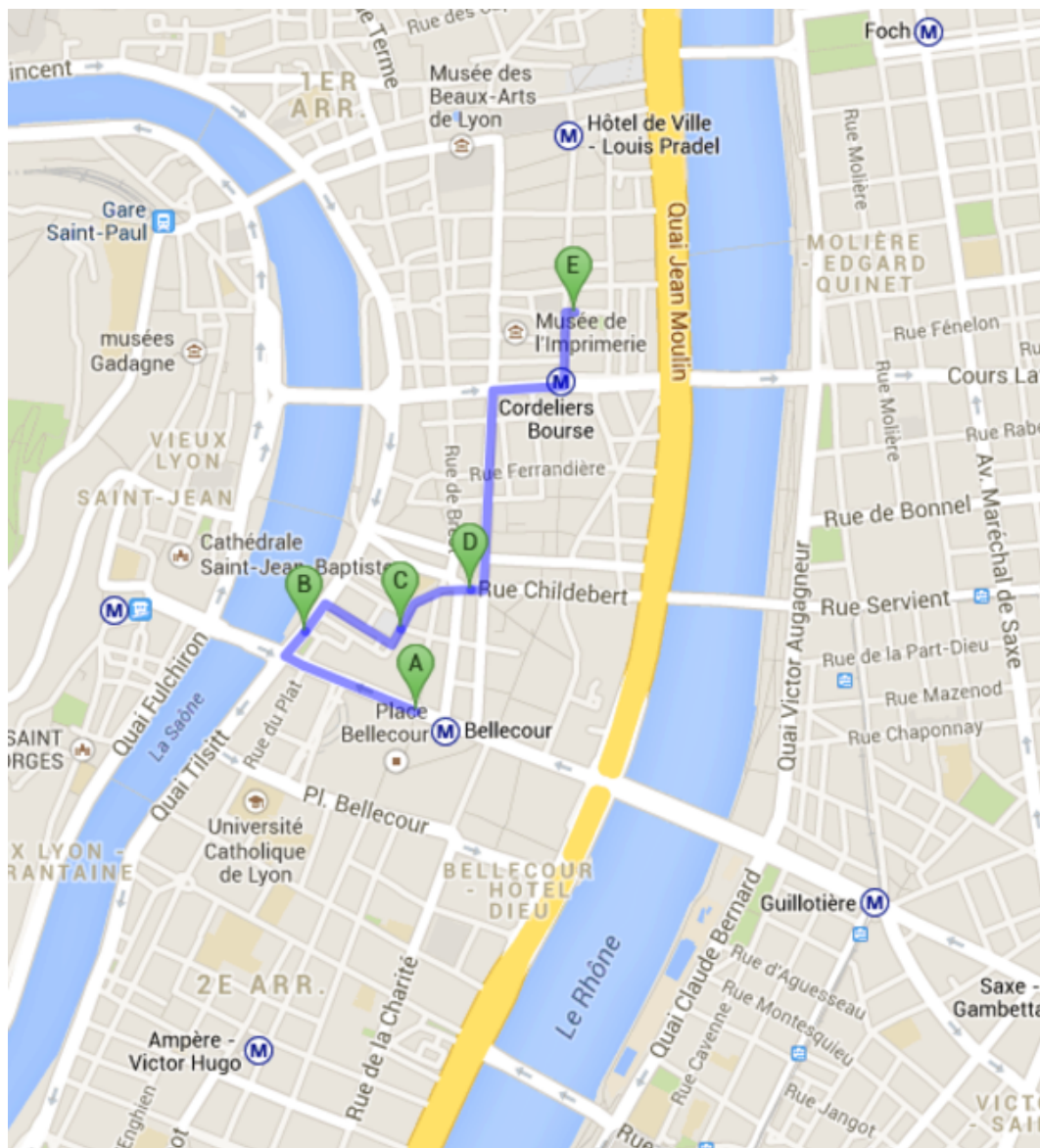
Duration: around 45 minutes starting from the subway station *Vieux Lyon*.



WALKING IN THE PRESQU'ILE

The *Presqu'île*, the city center located between the two rivers the *Saône* and the *Rhône*, can be discovered by a small walk like the one given on the map below. By this itinerary, you will successively go through the *place Bellecour* (point A on the map), the docks of the *Saône* river (point B), the *théâtre des Célestins* (point C), the *place des Jacobins* (point D), the street *rue de la République* (with a lot of shops), and you will finally arrive at the *place de la Bourse* (point E). Once arrived, you can go to the street called *rue Mercière*, near the *place de la Bourse*, where you can find a lot of restaurants. The map given below can also be found at: <http://tinyurl.com/npmaaf3>

Duration: around 35 minutes starting from the *Place Bellecour*.



SOME OTHER TYPICAL STREETS AND NEIGHBOURHOODS OF LYON

- The neighbourhood of *Vieux Lyon* and the *quartier Saint Jean* (both included in the guided tour)
- The street *rue des Marronniers* (a walking street with restaurants)
- The street *rue Mercière* (a street with a lot of restaurants)
- The docks of the *Rhône* river (by walk or by bike)
- Streets around *place des Terreaux*, like *rue Sainte Catherine* or *rue Pizay* (small streets with pubs)
- The *Parc de la Tête d'Or* (a free parc with a zoo)

Restaurants in Lyon

Most of the restaurants and bars in LYON are located in the old city center and in the *Presqu'île* (1st and 2nd arrondissements). We propose below few restaurants near the conference site. For more suggestions or restaurants in the old city center, please check either the tourist office paper guide given to each participant, or the online list from the tourist office which can be found at: www.lyon-france.com/Restaurants

RESTAURANTS NEAR THE CONFERENCE SITE (see map p. 32):

- **Ninkasi-Le Silo**, 267 Rue Marcel Mérieux, 69007 LYON (around 20€)
- **René Gamboni**, 241 Rue Marcel Mérieux, 69007 LYON (around 30-35€)
- **Carnegie Hall**, 253 rue Marcel Mérieux, 69007 LYON (mainly meat, around 30-35€)
- **Jols**, 283 Avenue Jean Jaurès, 69007 LYON (mainly fish and seafood, around 30-35€)



LYON – A view on the *Part-Dieu* tower with the *Alpes* mountains in background (courtesy J-M. MULLER)

COMING TO THE CONFERENCE SITE

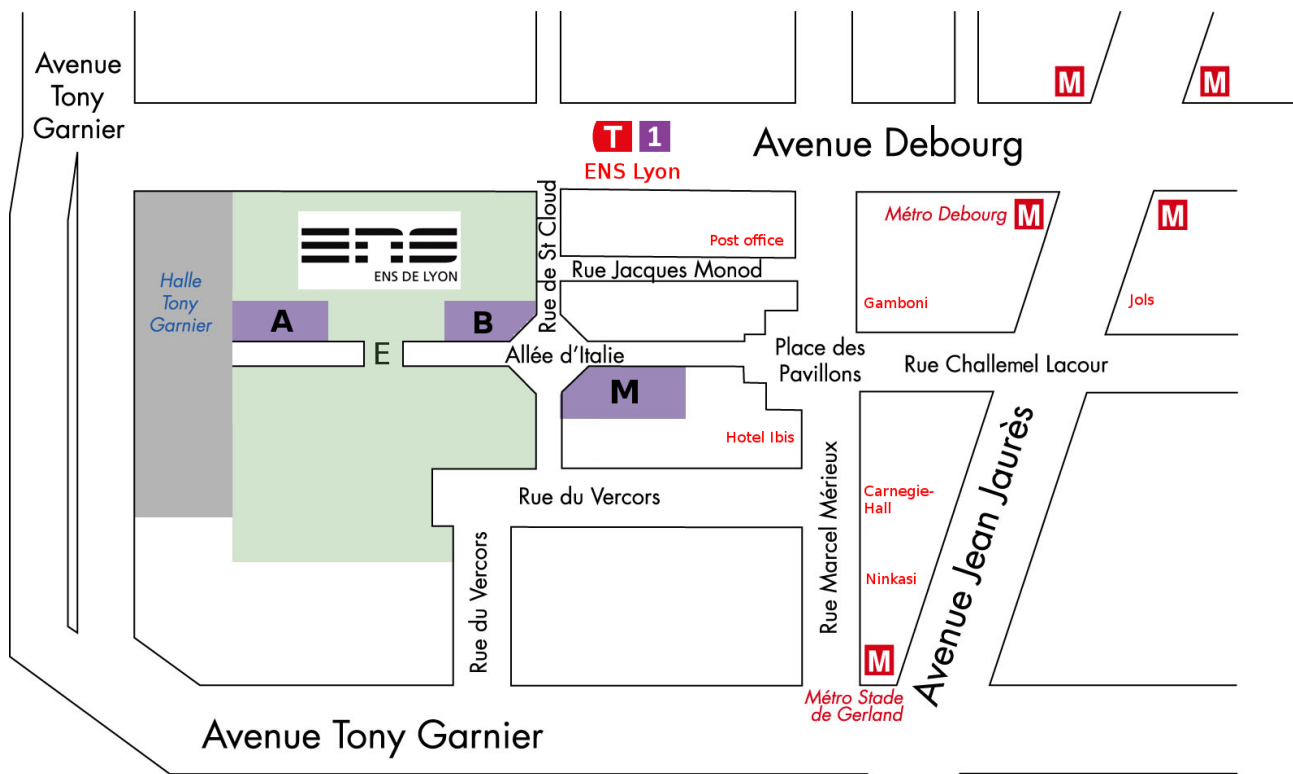
The closest airport is *Lyon Saint-Exupéry* (remember The Little Prince by Antoine de Saint-Exupéry? Saint-Exupéry was from Lyon!). There is also a TGV train station near the airport. The tramway takes you directly to one of Lyon downtown train stations, *Lyon Part-Dieu*. From there you can take the subway B for a short ride to the conference site.

Be careful: there are **two different sites** for the ÉNS Lyon, **site Monod** for sciences and site Descartes for literature. STACS takes place at the **site Monod**.

How to get to the ÉNS Lyon, site Monod, 46 allée d'Italie

- **From the Lyon-Saint Exupéry Airport:** take the Rhône Express from the airport to the Part-Dieu train station.
- **From the Lyon Part-Dieu train station:** take the Vivier Merle exit of the train station, then take the subway, line B in the direction of *Gare d'Oullins*. Get down at the *Debourg* stop. Then follow this way <http://tinyurl.com/pdv542s> (see also below) to come to the conference site.
- **From the Lyon Perrache train station, by bus:** go to the bus station and take the bus line C22. Get down at the *Halle Tony Garnier* stop. Then follow this way <http://tinyurl.com/po97juq> to come to the conference site.
- **From the Lyon Perrache train station, by tramway:** take the tramway line T1 at the station *Perrache* or at the outdoor tramway station *Suchet*. Get down at the *ÉNS Lyon* stop (see below).
- **From anywhere by Vélov' bike:** you can use the city bikes system, called *Vélov'*. See [the website of Vélov'](#) for details (how to rent a bike, prices and delay, stations with available bikes...).

The following link provides a detailed way with pictures to come from the subway station *Debourg* to the LIP: <http://tinyurl.com/orv8akk>



- **M:** amphitheater Mérieux, entry by the fountain place. For invited talks, registration, buffets and coffee breaks.
- **A:** amphitheater A, 3rd floor. For all the sessions A.
- **B:** amphitheater B, 3rd floor. For all the sessions B.
- **E:** building entry for amphitheatres A and B, ground floor, under the bridge.