GGTW 2017

Ghent Graph Theory Workshop on Structure and Algorithms

16-18 August 2017
Ghent University

GHENT
UNIVERSITY

Contents

Welcome

Welcome to Ghent, and welcome to the second edition of the Ghent Graph Theory Workshop. This year, it is our pleasure to greet three distinguished main speakers, Professors McKay, Pach, and Thomassen, together with more than forty participants from fourteen countries on four continents.

We hope everyone finds something interesting in this programme – or at least a good restaurant. Speaking of food: the conference dinner will be on Thursday at 7 p.m.

If you would like to join us on our visit to the beautiful town of Bruges on Saturday (we'll be back before 2 p.m.), please put your name on the "Bruges List", which you find in the conference room.

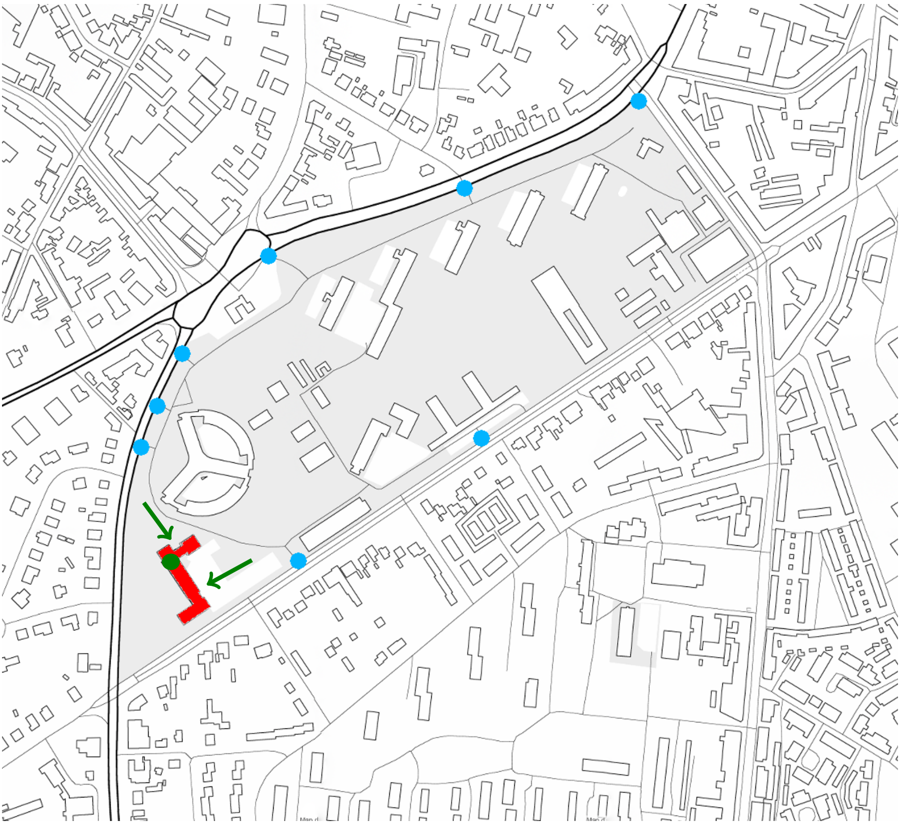
Finally, if you have any problems – mathematical or non-mathematical –, suggestions, or just want to chat, please do not hesitate to contact us.

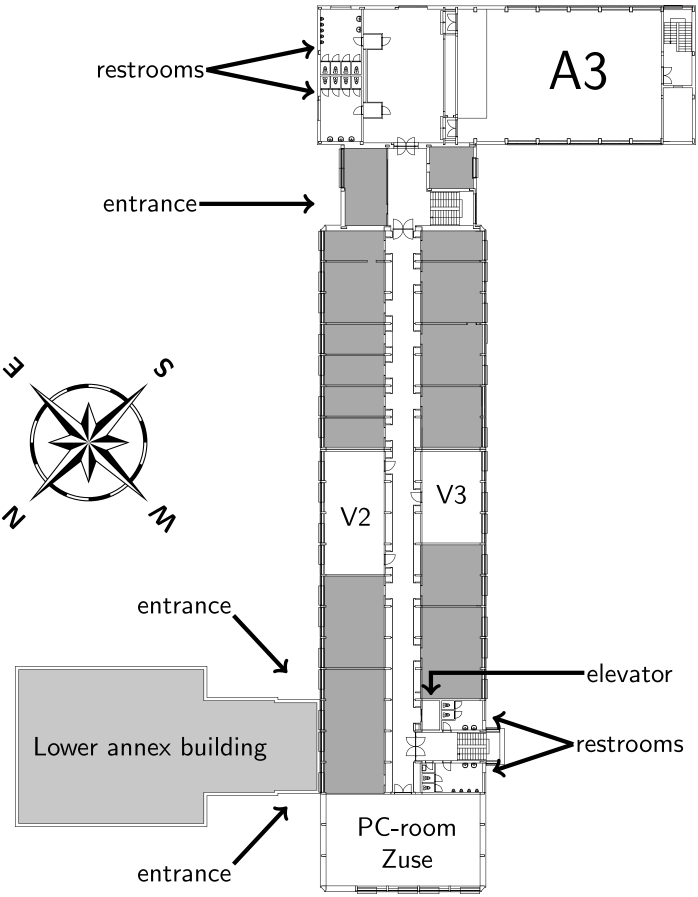
Wishing you an excellent time in Ghent,

Jan Goedgebeur • Nico Van Cleemput • Carol Zamfirescu

Venue

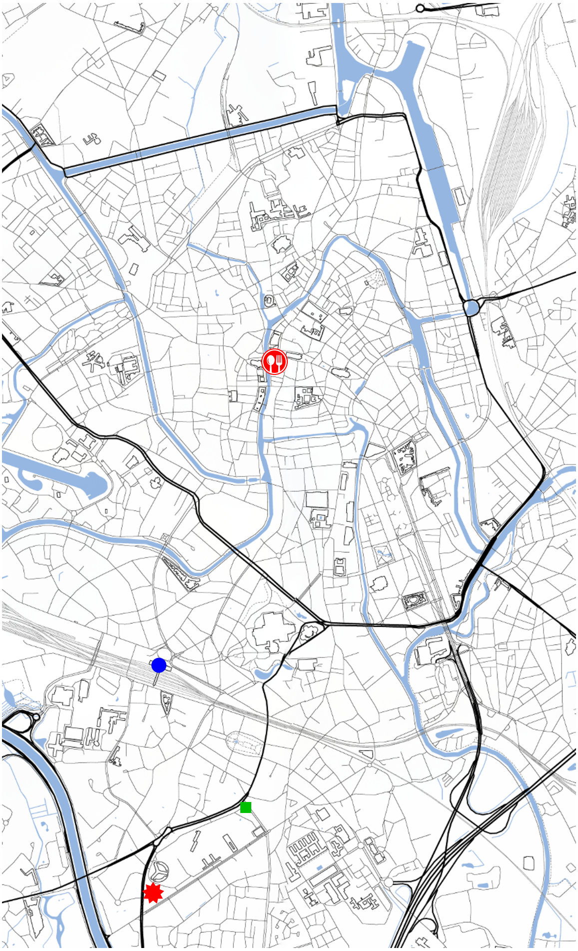
The scientific part of the Ghent Graph Theory Workshop takes place on the third floor in the S9 building of Campus De Sterre (Krijgslaan 281, 9000 Ghent). Below you can see the campus in grey. The access points to the campus are shown with blue dots. The S9 building is shown in red, and the green arrows show the entrances of the building. The elevator is located at the green dot.





All academic activities for the workshop will happen on the **third floor** of the S9 building. Above you see a map of that floor. The grey areas are offices which are not accessible for participants of the workshop.

All talks will be held in auditorium A3. The coffee breaks will be in room V2, and room V2 and V3 are available for discussions. PC-room Zuse is available as a silent working space. Eduroam is available on the whole floor.



(red star)	S9
(green square)	Main campus entrance
(restaurant icon)	Pakhuis
(blue dot)	Gent-Sint-Pieters train station

This map situates the workshop venue (S9) in reference to the city center. On Thursday at 17h45 we will meet at the main campus entrance for a group walk to the restaurant *Pakhuis* for the conference dinner. You can either join this group walk, or come to the restaurant directly. The walk will take roughly 1 hour.

On Saturday at 9h we will meet in the main hall of Gent-Sint-Pieters train station for the survivors excursion to Bruges. Of course, everybody is welcome to join.

Schedule

Wednesday August 16

Time	Talk	
09:15 - 09:55	*Registration*	
09:55 - 10:00	*Opening*	
10:00 - 10:55	**Graph generation and Ramsey numbers** Brendan McKay	p. 9
10:55 - 11:20	*Coffee break*	
11:20 - 11:45	**Recent progress towards a proof of the 4-4-4-Conjecture** František Kardoš	p. 9
11:50 - 12:15	**Colourings of cubic graphs inducing isomorphic monochromatic subgraphs** Domenico Labbate	p. 10
12:15 - 14:30	*Lunch*	
14:30 - 14:55	**Snarks that cannot be covered with four perfect matchings** Edita Máčajová	p. 10
15:00 - 15:25	**Construction of snarks with circular flow number 5** Giuseppe Mazzuoccolo	p. 11
15:30 - 15:55	**Smallest snarks with oddness 4** Martin Škoviera	p. 12
15:55 - 16:10	*Coffee break*	
16:10 - 16:35	**Extension of graphs on surfaces to 3-colorable triangulations** Kenta Ozeki	p. 12
16:40 - 17:05	**Some Folkman Problems** Stanisław Radziszowski	p. 13

Thursday August 17

Time	Talk	
10:00 - 10:55	**Nash-Williams' cycle decomposition theorem** Carsten Thomassen	p. 13
10:55 - 11:20	*Coffee break*	
11:20 - 11:45	**Longer Cycles in Essentially 4-Connected Planar Graphs** Jens M. Schmidt	p. 14
11:50 - 12:15	**On the number of type-0 triangles** Gunnar Brinkmann	p. 14
12:15 - 14:30	*Lunch*	
14:30 - 14:55	**Minimum leaf number of cubic graphs** Gábor Wiener	p. 15
15:00 - 15:25	**A 7/6-approximation algorithm for 2EC in 3-edge connected cubic graphs** Roman Čada	p. 15
15:30 - 15:55	**2-factors and independent sets in edge-chromatic critical graphs** Eckhard Steffen	p. 16
15:55 - 16:10	*Coffee break*	
16:10 - 17:00	**Problem session**	
19:00 - 22:00	*Conference dinner*	

The conference dinner will take place at the restaurant **Pakhuis** (Schuurkenstraat 4, 9000 Ghent). There is an optional group walk from the campus to the restaurant. This walk will leave at 17h45 and roughly take one hour. See page 5 for a map situating the start of the group walk and the restaurant.

Friday August 18

Time	Talk
10:00 - 10:55	**Crossing Lemmas** János Pach p. 16
10:55 - 11:20	*Coffee break*
11:20 - 11:45	**Finding Triangles for Maximum Planar Subgraphs** Andreas Schmid p. 17
11:50 - 12:15	**Strengthening some complexity results on toughness of graphs** Kitti Varga p. 18
12:15 - 14:30	*Lunch*
14:30 - 14:55	**Data reduction and combinatorics of the 3-colorability problem** Oliver Schaudt p. 18
15:00 - 15:25	**Equitable 3-Colorability for P_5-free graphs** Vera Weil p. 18
15:30 - 15:55	**Graph isomorphism and asymmetric graphs** Pascal Schweitzer p. 19
15:55 - 16:10	*Coffee break*
16:10 - 16:35	**An asymptotically improved upper bound on the diameter of polyhedra** Noriyoshi Sukegawa p. 19
16:40 - 17:05	**PHOEG Helps Obtaining Extremal Graphs** Hadrien Mélot p. 20
17:05 - 17:20	*Closing remarks*

Abstracts

Wednesday August 16

Graph generation and Ramsey numbers

Brendan D. McKay *Joint work with: Vigleik Angeltveit*

We begin by describing the canonical construction path method of generating combinatorial objects with efficient isomorph rejection. Then we give some examples in computational Ramsey theory.

The *complete 3-uniform hypergraph* $K_n^{(3)}$ with n vertices is the set of all 3-subsets ("triples") of an n-set. If colours are assigned to the triples of $K_n^{(3)}$, then a *monochromatic quadruple* is a 4-subset whose 3-subsets all have the same colour. A *good colouring* of $K_n^{(3)}$ is a colouring of the triples using two colours such that there are no monochromatic quadruples. McKay and Radziszowski proved in 1991 that $K_{12}^{(3)}$ has good colourings but $K_{13}^{(3)}$ does not. Here we complete the catalogue of good colourings of $K_{12}^{(3)}$ and determine how close it is possible to get to a good colouring of $K_{13}^{(3)}$.

The classical numbers $R(s,t)$ are more familiar. $R(s,t)$ is the least n such that every red-green colouring of the edges of the complete graph K_n has either a red s-clique or a blue t-clique. No exact value has been found since McKay and Radziszowski proved $R(4,5) = 25$ in 1995. Here we describe improvements on upper bounds starting with a combinatorial search that established $R(5,5) \geq 48$. Further search combined with linear programming established $R(4,6) \leq 40$. Then we recursively apply a linear programming approach of McKay and Radziszowski to improve the upper bounds on $R(s,t)$ for many other small values of s and t.

Recent progress towards a proof of the 4-4-4-Conjecture

František Kardoš *Joint work with: A. Gallastegui*

The 4-4-4-Conjecture (of unclear origin, sometimes attributed to Vizing) states that planar graphs of girth (at least) 4 and maximum degree 4 are class 1, i.e., 4-edge-colorable. If one of the two parameters is increased to 5, it is known to be true, and if one of them is decreased to 3, it is known to be false – the case of 4 and 4 remains the last open case.

We present some first steps towards an attempt to attack the conjecture: Inspired by the computer-assisted proof of the Four Color Theorem, we have developed a program to check reducibility of configurations with respect to 4-edge-coloring. We have found some new reducible configurations using this tool.

Colourings of cubic graphs inducing isomorphic monochromatic subgraphs

Domenico Labbate *Joint work with: M. Abreu, J. Goedgebeur, G. Mazzuoccolo*

A k*–bisection* of a bridgeless cubic graph G is a 2–colouring of its vertex set such that the colour classes have the same cardinality and all connected components in the two subgraphs induced by the colour classes (i.e. *monochromatic components*) have order at most k. Ban and Linial conjectured that *every bridgeless cubic graph admits a* 2*–bisection except for the Petersen graph*. A similar problem for the edge set of cubic graphs has been studied: Wormald conjectured that *every cubic graph* G *with* $|E(G)| \equiv 0 \mod 2$ *has a* 2*–edge colouring such that the two monochromatic subgraphs are isomorphic linear forests* (i.e. a forest whose components are paths). Finally, Ando conjectured that *every cubic graph admits a bisection such that the two induced monochromatic subgraphs are isomorphic.*

In this talk, we deal with these conjectures by giving a detailed insight into the conjecture of Ban–Linial and of Wormald and provide evidence of a strong relation of both of them with Ando's conjecture. Furthermore, we also give computational and theoretical evidence in their support. As a result, we pose some open problems stronger than the above cited conjectures.

Snarks that cannot be covered with four perfect matchings

Edita Máčajová *Joint work with: M. Škoviera*

The celebrated Berge-Fulkerson conjecture suggests that every bridgeless cubic graph can have its edges covered with at most five perfect matchings. Since three perfect matchings suffice if and only if the graph in question is 3-edge-colourable, uncolourable cubic graphs fall into two classes: those that can be covered with four perfect matchings, and those that require at least five. Cubic graphs that cannot be covered with four perfect matchings are extremely rare. Among the 64326024 snarks (uncolourable cyclically 4-edge-connected cubic graphs with girth at least five) on up to 36 vertices there are only *two* graphs that cannot be covered with four perfect matchings – the Petersen graph and a snark of order 34.

In this talk we show that coverings with four perfect matchings can be described in terms of flows whose values lie in the configuration of six lines spanned by four points of the 3-dimensional projective geometry $PG(3,2)$ in general position. This characterisation provides a convenient tool for investigation of graphs that do not admit such a cover and enables a great variety of constructions of snarks that cannot be covered with four perfect matchings. In particular, with the combined forces of several constructions we can prove that for each even integer $n \geq 44$ there exists at least one snark of order n that has no cover with four perfect matchings.

Construction of snarks with circular flow number 5

Giuseppe Mazzuoccolo

Given a real number $r \geq 2$, a *circular nowhere-zero r-flow* (in short, an r-CNZF) in a graph $G = (V, E)$ is an assignment $f : E \to [1, r-1]$ and an orientation D of the edges of G, such that f is a *flow* in D. That is, for every vertex $x \in V$, $\sum_{e \in E^+(x)} f(e) = \sum_{e \in E^-(x)} f(e)$, where $E^+(x)$, respectively $E^-(x)$, are the sets of edges directed from, respectively towards x in D. Accordingly defined, the *circular flow number* $\phi_c(G)$ of a graph G is the infimum number r, for which G admits an r-CNZF. A long-standing conjecture of Tutte (5-flow Conjecture) is that every bridgeless graph has circular flow number at most 5. For some time the Petersen graph has been the only known snark with circular flow number 5, but, in 2006, infinitely many such snarks were presented by Máčajová and Raspaud in [1]. More recently, new infinite families of snarks with circular flow number 5 are obtained in [2]. Here, we summarize the arsenal of methods for constructing snarks with circular flow number 5, we propose some variations of previous constructions and, finally, we propose a tentative unified description of all such methods.

References

[1] E. Máčajová and A. Raspaud. On the strong circular 5-flow conjecture, *J. Graph Theory* **52** (2006), 307–316.

[2] L.Esperet, G.Mazzuoccolo and M.Tarsi, The structure of graphs with Circular flow number 5 or more, and the complexity of their recognition problem, *Journal of Combinatorics* **7** (2016), 453–479.

Smallest snarks with oddness 4

Martin Škoviera *Joint work with: J. Goedgebeur, E. Máčajová*

The oddness of a bridgeless cubic graph G is the smallest number of odd circuits in a 2-factor of G. Oddness is one of the most important invariants of snarks because several important conjectures in graph theory can be reduced to snarks of oddness 4 or larger. In this talk we deal with the problem of determining the smallest order of a nontrivial snark of oddness 4. (Here 'nontrivial' means girth at least 5 and cyclic connectivity at least 4.) We prove that the smallest order of a nontrivial snark with oddness 4 and cyclic connectivity 4 is 44, and characterise all snarks of order 44 with this property. The proof relies on a detailed analysis of 3-edge-colourings conflicting on a cycle-separating 4-edge-cut, an extensive computer search, and a closure theorem for cubic graphs with cyclic connectivity 4 due to Andersen, Fleischner, and Jackson (1988).

Extension of graphs on surfaces to 3-colorable triangulations

Kenta Ozeki *Joint work with: Atsuhiro Nakamoto (Yokohama National University), Kenta Noguchi (Tokyo Denki University)*

In order to attack some problems in computational geometry, Hoffmann and Kriegel [SIAM J. Discrete Math. 9 (1996) 210–224] considered the problem of whether a plane map can be extended to a 3-colorable triangulation by adding edges. In this paper, we improve their results to maps on non-spherical surfaces, by showing a necessary and sufficient condition for a mosaic, i.e., a map on a surface each of whose faces is triangular or quadrangular. Furthermore, we obtain an explicit formula for calculating the number of distinct 3-colorable triangulations extended from a given mosaic on a surface. These results suggest a significant gap between the planar case and the non-spherical case. We also show that they improve several known results and have an application to polychromatic coloring.

Some Folkman Problems

Stanisław Radziszowski *Joint work with: Xiaodong Xu, Meilian Liang*

For an undirected simple graph G, we write $G \rightarrow (H_1, H_2)^v$ if and only if for every red-blue coloring of its vertices there exists a red H_1 or a blue H_2. The generalized vertex Folkman number $F_v(H_1, H_2; H)$ is defined as the smallest integer n for which there exists an H-free graph G of order n such that $G \rightarrow (H_1, H_2)^v$. The generalized edge Folkman numbers $F_e(H_1, H_2; H)$ are defined similarly, when colorings of the edges are considered.

Perhaps the most wanted Folkman number is $F_e(K_3, K_3; K_4)$, for which 50 years of efforts of many researches brought the bounds down to $20 \leq F_e(K_3, K_3; K_4) \leq 785$. This number is equal to the smallest order n of a K_4-free graph which is not a union of two triangle-free graphs. We present history of work, state of the art, and some possible directions of further research.

New insight might be gained by studying related cases with similar parameters. We show that $F_e(K_{k+1}, K_{k+1}; K_{k+2} - e)$ and $F_v(K_k, K_k; K_{k+1} - e)$ are well defined for $k \geq 3$. We prove the nonexistence of $F_e(K_3, K_3; H)$ for some H, in particular for $H = B_3$, where B_k is the book graph of k triangular pages, and for $H = K_1 + P_4$. We pose three problems on generalized Folkman numbers, including the existence question of edge Folkman numbers $F_e(K_3, K_3; B_4)$, $F_e(K_3, K_3; K_1 + C_4)$ and $F_e(K_3, K_3; \overline{P_2 \cup P_3})$. Our results lead to some general inequalities involving two-color and multicolor Folkman numbers.

Thursday August 17

Nash-Williams' cycle decomposition theorem

Carsten Thomassen

Nash-Williams proved in 1960 that a graph has an edge-decomposition into cycles if and only if it has no odd edge-cut. Laviolette found in 2005 a remarkable application of Nash-Williams' theorem, namely that every graph can be edge-decomposed into cut-faithful graphs. (A subgraph H of a graph G is cut-faithful if every finite minimal cut in H is also a cut in G.) An immediate consequence of Laviolette's theorem is that every k-edge-connected graph has an edge-decomposition into countable k-edge-connected subgraphs.

In this talk we indicate a short direct proof of Laviolette's theorem and use it to find a short proof (using only very elementary set theory) of Nash-Williams' theorem.

Laviolette's theorem is useful in reducing problems on infinite graphs to the countable case. We demonstrate that by the following (new) theorem: Every bridgeless graph has a collection of cycles such that every edge is in at least one and at most 7 of the cycles.

Longer Cycles in Essentially 4-Connected Planar Graphs

Jens M. Schmidt *Joint work with: Igor Fabrici, Jochen Harant, Samuel Mohr*

We survey old and propose new results on longest cycles in essentially 4-connected planar graphs.

A planar 3-connected graph G is called *essentially 4-connected* if, for every 3-separator S, at least one of the two components of $G - S$ is an isolated vertex. Jackson and Wormald proved that the length $circ(G)$ of a longest cycle of any essentially 4-connected planar graph on n vertices is at least $\frac{2n+4}{5}$. We improve this result to $circ(G) \geq \frac{3(n+4)}{5}$ and beyond.

On the number of type-0 triangles

Gunnar Brinkmann *Joint work with: Kenta Ozeki, Nico Van Cleemput*

In the problem session of the Ghent Graph Theory Workshop 2016 Kenta Ozeki posed the following problem:

Let $F(G)$ denote the number of faces of a 4-connected plane triangulation G. For a given hamiltonian cycle in a triangulation a triangle is said to be type-0 if it contains no edge of the hamiltonian cycle.

Find the infimum $c(F(G))$ such that every 4-connected plane triangulation G contains a Hamiltonian cycle having at most $c(F(G))$ type-0 triangles.

In this talk we will present an answer to this question.

Minimum leaf number of cubic graphs

Gábor Wiener *Joint work with: J. Goedgebeur, K. Ozeki, N. Van Cleemput*

The minimum leaf number $\mathrm{ml}(G)$ of a connected graph G is defined as the minimum number of leaves of the spanning trees of G. This notion is one of the most natural extensions of traceability (i.e. the existence of a hamiltonian path).

Hamiltonian properties of cubic planar graphs have been studied extensively due to Tait's attempt to prove the four color conjecture based on the conjecture that all 3-connected cubic planar graphs are hamiltonian. Much less is known about the hamiltonian properties of cubic, but not necessarily planar graphs. In 1971 Tutte conjectured that 3-connected bipartite cubic graphs are hamiltonian, for which a counterexample was provided by Baraev and Faradzhev (in Russian, 1978) and by Horton (1982). In 1981 Asano, Exoo, Harary, and Saito showed that the (unique) smallest nonhamiltonian, cubic, planar, bipartite graph has order 26.

Concerning the minimum leaf number of connected cubic graphs, in 2015 Zoeram and Yaqubi showed that $\mathrm{ml}(G) \leq \frac{2n}{9} + \frac{4}{9}$ and conjectured that $\mathrm{ml}(G) \leq \frac{n}{6} + \frac{1}{3}$. They also provided an example with $\frac{n}{6} + \frac{1}{3}$ leaves.

Actually, Salamon and Wiener in 2008 proved that $\mathrm{ml}(G) \leq \frac{n}{6} + \frac{4}{3}$ for connected cubic graphs.

In 2014 Boyd, Sitters, van der Ster, and Stougie (based on a result of Mömke and Svensson) proved that if G is a 2-connected cubic multigraph, then $\mathrm{ml}(G) \leq \frac{n}{6} + \frac{2}{3}$.

In the talk we prove the Zoeram-Yaqubi conjecture (for which we only need a slight improvement of the Salamon-Wiener result) and show that if G is 2-connected and cubic, then $\mathrm{ml}(G) \leq \frac{n}{6.157}$. We also give some conjectures and examples concerning the tightness of the conjectures.

A 7/6-approximation algorithm for 2EC in 3-edge connected cubic graphs

Roman Čada

We present ideas leading to a 7/6-approximation algorithm for the minimum 2-edge connected spanning subgraph problem in 3-edge connected cubic graphs. We also discuss related topics.

2-factors and independent sets in edge-chromatic critical graphs

Eckhard Steffen

About 1965 Vizing stated two conjectures: (1) Every edge-chromatic critical graph has a 2-factor. (2) Every independent set of an edge-chromatic critical graph contains at most half of its vertices.

We briefly survey the main results that have been derived till date on these conjectures and then formulate some statements which are equivalent to them.

Friday August 18

Crossing Lemmas

János Pach

A useful tool in topological graph theory is the so-called *Crossing Lemma* of Ajtai, Chvátal, Newborn, Szemerédi (1982) and Leighton (1983). It states, roughly speaking, that if a graph drawn in the plane has much more edges than vertices, then the number of crossings between its edges is much larger than the number of edges.

Natan Rubin, Gábor Tardos and the speaker discovered a similar phenomenon for families of curves in the plane. If two curves have precisely one point p in common, and at this point they do not properly cross, then p is called a *touching point*. Any other point that belongs to two curves is called an *intersection point*. Let X and T stand for the number of intersection points and touching points, respectively, in a family of n curves, no three of which pass through the same point. If T/n is larger than a fixed constant, then $X \geq \Omega(T(\log\log(T/n))^{1/336})$. In particular, if $T/n \to \infty$, then the number of intersection points is much larger than the number of touching points.

What happens if, instead of the number X of crossing *points*, we want to estimate the number x of crossing *pairs* of curves? Obviously, we have $x \leq X$. In a joint paper with Géza Tóth, it was shown that $x \geq \Omega(T^2/n^2)$. The order of magnitude of this bound is best possible.

Finding Triangles for Maximum Planar Subgraphs

Andreas Schmid *Joint work with: Parinya Chalermsook*

In the Maximum Planar Subgraph MPS problem, we are given a graph G, and our goal is to find a planar subgraph H with a maximum number of edges. Besides being a basic problem in graph theory, MPS has many applications including, for instance, circuit design, factory layout, and graph drawing, so it has received a lot of attention from both theoretical and empirical literature. Since the problem is NP-hard, past research has focused on approximation algorithms. The current best known approximation ratio is $\frac{4}{9}$ obtained two decades ago (Călinescu et al. SODA 1996) based on computing as many edge-disjoint triangles in an input graph as possible. The factor of $\frac{4}{9}$ is also the limit of this "disjoint triangles" approach.

We present a new viewpoint that highlights the essences of known algorithmic results for MPS, as well as suggesting new directions for breaking the $\frac{4}{9}$ barrier. In particular, we introduce the Maximum Planar Triangles MPT problem: Given a graph G, compute a subgraph that admits a planar embedding with as many triangular faces as possible. Roughly speaking, any ρ-approximation algorithm for MPT can easily be turned into a $\frac{1}{3} + \frac{2\rho}{3}$ approximation for MPS. We illustrate the power of the MPT framework by "rephrasing" some known approximation algorithms for MPS as approximation algorithms for MPT (solving MPS as by-products). This motivates us to perform a further rigorous study on the approximability of MPT and show the following results:

- MPT is NP-hard, giving a simplified NP-hardness proof for MPS as a by-product.
- We propose a natural class of greedy algorithms that captures all known greedy algorithms that have appeared in the literature. We show that a very simple greedy rule gives better approximation ratio than all known greedy algorithms (but still worse than $\frac{4}{9}$).

Our greedy results, despite not improving the approximation factor, illustrate the advantage of overlapping triangles in the context of greedy algorithms. The MPT viewpoint offers various new angles that might be useful in designing a better approximation algorithm for MPS.

Strengthening some complexity results on toughness of graphs

Kitti Varga

Let t be a positive real number. A graph is called t-tough, if the removal of any cutset S leaves at most $|S|/t$ components. The toughness of a graph is the largest t for which the graph is t-tough. We prove that for any positive rational number t, deciding whether $\tau(G) = t$ is DP-complete, and if $t < 1$, this problem remains DP-complete for bipartite graphs. We also show that for any integer $r \geq 4$, if G is an r-regular bipartite graph, deciding whether $\tau(G) = 1$ is coNP-complete, and for any integer $k \geq 2$ and positive rational number $t \leq 1$, if G is a k-connected bipartite graph, deciding whether $\tau(G) \geq t$ is coNP-complete.

Data reduction and combinatorics of the 3-colorability problem

Oliver Schaudt *Joint work with: Maria Chudnovsky, Jan Goedgebeur, Mingxian Zhong*

I will talk about an interesting connection between the parameterized complexity of the 3-colorability problem and the number of minimal obstructions against list 3-colorability.

This talk is based on work by Jansen and Kratsch and joint work with Chudnovsky, Goedgebeur and Zhong.

Equitable 3-Colorability for P_5-free graphs

Vera Sharon Weil *Joint work with: O. Schaudt, R. Scheidweiler*

Imagine the following situation. We have n tasks to assign to k workers. Every task implies roughly the same workload. Moreover, due to time constraints, some of the tasks stand in conflict to each other. Our goal is now to create some kind of fairness with respect to the workload: We want to decide whether it is possible to assign workers to the tasks in such a way that - if we consider the workers pairwise - the amounts of received tasks differ by at most 1.

Embedding this load-balancing problem into a graph-theoretic context leads to the following. A feasible coloring of a graph is the assignment of a color to each vertex such that no two adjacent vertices receive the same color. In the k-COLORABILITY problem, we want to decide whether a feasible coloring is possible by using not more than k

colors. This problem is NP-complete for every $k \geq 3$. However, by a result of Randerath and Schiermeyer (2001), 3-COLORABILITY is decidable in polynomial time if the graph is P_6-free, that is, if the graph does not contain a path on 6 vertices as induced subgraph.

The EQUITABLE k-COLORABILITY problem is the k-COLORABILITY problem plus a further condition: the sizes of the color classes differ pairwise by at most 1. Based on the result for k-COLORABILITY, it is easy to see that EQUITABLE k-COLORABILITY is also NP-hard, for $k \geq 3$.

We show that EQUITABLE 3-COLORABILITY is solvable in polynomial time given that the graph is P_5-free. In fact, we can prescribe any size for the color classes and verify in polynomial time whether there is a feasible coloring with 3 colors of the P_5-free graph that obeys the constraints for the color class sizes.

This work in progress is joint work with Oliver Schaudt and Robert Scheidweiler.

Graph isomorphism and asymmetric graphs

Pascal Schweitzer

The graph isomorphism problem can be interpreted as the algorithmic task to detect the symmetries of a graph or more generally a combinatorial object. In the talk I will discuss the significance of asymmetric graphs in the context of the graph isomorphism problem.

To this end I will elaborate on the intricate relationship between the algorithmic tasks of determining isomorphism and the recognition of asymmetric graphs. The talk will also briefly touch properties of asymmetric graphs and why they appear when one is interested in difficult isomorphism instances.

An asymptotically improved upper bound on the diameter of polyhedra

Noriyoshi Sukegawa

Kalai and Kleitman proved in 1992 that the maximum possible diameter of a d-dimensional polyhedron with n facets is at most $n^{2+\log(d)}$. In 2014, Todd improved the Kalai-Kleitman bound to $(n-d)^{\log(d)}$. Todd's bound is tight in low dimensions, and has been improved in higher dimensions by the subsequent studies. The current best upper bound is, however, still in the form of $(n-d)^{\log O(d)}$. This paper shows an asymptotically improved upper bound of $(n-d)^{\log O(d/\log d)}$.

PHOEG Helps Obtaining Extremal Graphs

Hadrien Mélot *Joint work with: G. Devillez, P. Hauweele*

Extremal graph theory aims to determine bounds for graph invariants as well as the graphs that attain those bounds. Some invariants may be hard to compute and it might be difficult for a human to develop intuitions about how they meld with graph structure.

There is thus a need for tools to help researchers explore the intricacies of these invariants. There already are attempts to reach that goal, e.g., Graph, Grinvin, Graffiti, AutoGraphiX, Digenes, GraPHedron. However those tools do not fully meet our needs to obtain extremal graphs in an exact manner and to explore graph transformations. Being able to quickly make queries on graph invariants is also an interesting feature to quickly lighten or kill ideas in a research discussion, e.g., "which graphs are local minima for some transformation with respect to some invariant?" or "on which connected graphs are two invariants equal?".

In an attempt to answer such questions (and others), we are currently developing the Phoeg system, which can be viewed as a successor to GraPHedron. It uses a big database of graphs and works with the convex hull of the graphs as points in the invariants space in order to exactly obtain the extremal graphs (of small order) and infer optimal bounds on the invariants. This database also allows us to make queries on graphs. Phoeg goes one step further by helping in the process of designing a proof guided by successive applications of transformations from any graph to an extremal graph.

Food options

Near the campus

As the group would be too large to go for lunch together, we encourage you to split up in smaller groups and have lunch in one of the restaurants near the campus. Feel free to speak to us about suggestions.

On page 22 you can see a map of the campus and its surroundings. The campus is shown in grey, all talks are in the red building (S9), and the access points to the campus are shown in blue.

Below is an overview of the restaurants/shops near the campus. For each one we note whether it is take-out (TO) or eat-in (EI). If you buy take-out, you can eat it in one of the rooms at the university, or – in case of good weather – there are several picnic tables in the garden behind the S9 building.

A. **Eetoile** *(Oudenaardsesteenweg 34, 9000 Gent)* TO/EI
Healthy foodbar: has salads, quiches, wraps, and soups.
http://www.eetoile.be

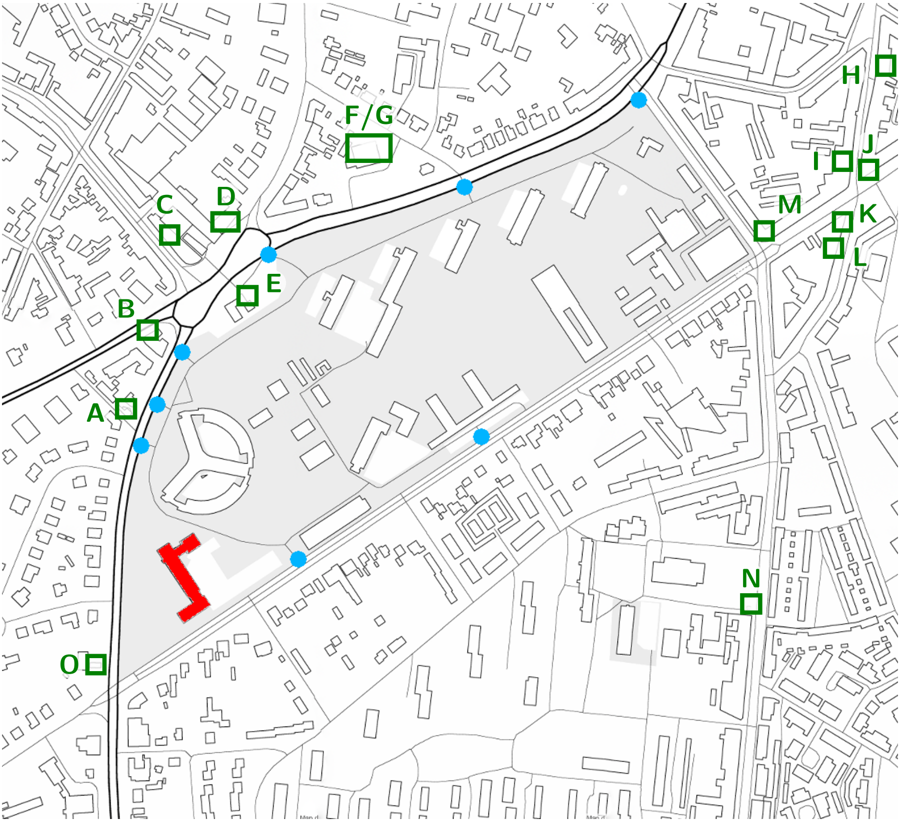
B. **Fenikshof** *(Kortrijksesteenweg 857, 9000 Gent)* EI
Classic belgian cuisine.
http://www.taverne-fenikshof.be

C. **De Fritoloog** *(Voskenslaan 413, 9000 Gent)* TO/EI
A Belgian-style friterie.
https://www.facebook.com/voskenslaan413gent

D. **Delhaize** *(Kortrijksesteenweg 906, 9000 Gent)* TO
A large supermarket that also sells sandwiches and salads to go.
http://www.delhaize.be

E. **Select Shop (Shell)** *(Kortrijksesteenweg 831, 9000 Gent)* TO
A gas-station shop that also sells sandwiches.

F. **Pizza Hut** *(Pacificatielaan 6, 9000 Gent)* TO/EI
American-style pizzas. At lunchtime they have an all-you-can-eat buffet.
https://www.pizzahut.be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G. **Lunch Garden** *(Pacificatielaan 6, 9000 Gent)* EI
A self-service restaurant offering lunch at a reasonable price.
http://www.lunchgarden.com

H. **Ocean Garden** *(Zwijnaardsesteenweg 399, 9000 Gent)* TO
Chinese take-out restaurant.
http://oceangarden.byethost3.com

I. **Bizar Cafe** *(Zwijnaardsesteenweg 454, 9000 Gent)* EI
Alcohol-free bar which offers snacks and desserts (also has a selection of gluten-free and lactose-free food).
http://www.bizarcafe.be

J. **De Pinte** *(De Pintelaan 172, 9000 Gent)* EI
Café serving some simple dishes.
https://www.facebook.com/brasseriedepinte

K. **Uniq** *(Zwijnaardsesteenweg 458, 9000 Gent)* TO/EI
Kebab and grill snack bar.
http://www.uniqkebab.be

L. **Pizza Carlo** *(Zwijnaardsesteenweg 462/1, 9000 Gent)* TO/EI
Very good Italian pizzas, but limited number of tables.
https://www.facebook.com/pizzacarlogent

M. **Sim Pizza** *(De Pintelaan 252, 9000 Gent)* TO/EI
Italian-style pizzas and some other snacks
http://www.sim-pizza.be

N. **'t Kot** *(Rerum-Novarumplein, 9000 Gent)* TO/EI
A Belgian-style friterie. Large portions.

O. **Go (Texaco)** *(Oudenaardse Steenweg 77-89, 9000 Gent)* TO
A gas-station shop that also sells sandwiches.

For people with special dietary requirements (vegan, vegetarian, ...) or who are looking for a specific cuisine (Greek, Indian, ...), there are some options which are slightly further away, but still manageable for lunch. Please contact us for directions.

In the city center

Belgians are Burgundian people, so you shouldn't have any problem finding restaurants in the city center. Below we list some personal favorites and some restaurants for people with special dietary requirements. In the era of Google Maps, TripAdvisor, and the rest of the internet you shouldn't have any difficulty locating them, but please feel free to contact us to help you find them on a map.

Belgian food

The Belgian cuisine is hard to define, since it has many influences from neighbouring countries. Nevertheless for those willing to sample the local food, we list some restaurants which serve typical Belgian dishes.

De Frietketel The best place to get the typical Belgian fries, since it was elected best friterie of Flanders this year. They have a large range of home-made snacks to accompany the fries including a large selection of vegetarian options. Make sure to taste their "stoverijsaus" to dip your fries in together with mayonnaise for the ultimate Belgian experience.
https://www.facebook.com/De-Frietketel-34597147572/

Balls & Glory Real comfort food for Belgians. You get a meatball (meat/chicken/veggie) with a liquid filling (the options change each day) together with mashed potatoes-and-vegetables ("stoemp") accompanied by a gravy and a creamy curry sauce. Or, if you don't like stoemp or aren't that hungry, you can choose a salad to go with your meatball. An ideal spot if you don't want to waste too much time eating. Also well-suited for larger groups.
https://www.facebook.com/ballsnglorygent/

Het Pakhuis A classic "brasserie" with French and Belgian dishes as we would have them going out for dinner. When you're not looking for creative cooking, but like the classics well prepared, this is a good place to go. Also the venue is quite big, so you have a good chance of finding a spot. **This is also the venue for the conference dinner.**
https://www.facebook.com/pakhuisGent/

Meme Gusta Food like our grandma would prepare it. All the classic flavours of the Belgian cuisine. You might need to make a reservation as we all love grandma's kitchen.

https://www.facebook.com/janennele/

Vegetarian/vegan

Ghent has several restaurants which are either completely vegetarian or vegan, or offer a vegetarian or vegan option. A more complete list can be found on the website http://www.evavzw.be/resto. Unfortunately, this website is only available in Dutch and French, so contact us if you need help navigating it. Below are some of our favourite places.

Greenway Burgers, wraps and salads that taste great. Not a place to wine and dine, but excellent if you want to have a quick meal.

https://www.facebook.com/greenwaygent/

Lokaal Charming place for honest food and delicious tea. Small choice of dishes, but prepared with lots of love.

https://www.facebook.com/LokaalGent/

De Appelier You can get a daily special or a pasta over here. The special is a plate full of different veggies and grains and something like a homemade meat replacer or quiche. There's soup and a dessert of the day as well. Food is served fast here, so if you're in a hurry, this is very healthy fast food!

https://www.facebook.com/www.deappelier.be/

Trendy places

Ghent is also a hip and happening city. If you want to be a part of this, then below are some places you should really visit.

Holy Food Market Housed in a former chapel there are food stalls here with food from all over the world. You can sit and have bits and pieces from different places. Choosing is the hard part.

https://www.facebook.com/holyfoodmarket/

Mosquito Coast A travel café where you can have cocktails and tapas but also a decent meal. You might want to make a reservation.

https://www.facebook.com/mosquitocoastofficial/

De Superette The project of Michelin star chef Kobe Desramaults with an affordable and more simple menu. The atmosphere is easy going and you get to see bread and pizzas being baked in the oven which has a central place in the restaurant.

https://www.facebook.com/desuperettegent/

Eat Love Pizza Trendy pizza place with quite expensive pizzas but some interesting flavours. You can also choose to have two halves of different flavours instead of picking just one. They also opened a new place Eat Love Lasagna which serves lasagnas.

https://www.facebook.com/eatlovepizzaGent/
https://www.facebook.com/EatLoveLasagna/

Meat lovers

If you got an insatiable desire for meat, then one of the following restaurants might be ideal for you.

Amadeus This is an all-you-can-eat restaurant for ribs. They are prepared with a sweet marinade and come with a jacket-potato with some curried cream inside. There are different restaurants of this chain in Ghent. They have a charming interior, but service is usually more pragmatic.

https://www.facebook.com/Amadeus.Gent.2/

De Gekroonde Hoofden This is another all-you-can-eat restaurant for ribs. They have different kind of preparations (honey, somewhat spicy, sweet-and-sour or without marinade) and serve them with Turkish pide bread, a hot tomato and some salad.

https://www.facebook.com/pages/De-Gekroonde-Hoofden/141602035906247

Pampas This is an all-you-can-eat Brazilian grill restaurant. Giant skewers of meat are being grilled in the kitchen and the waiters go from table to table to slice off a piece for you. Theres also fish and prawns on the skewers and grilled vegetables and fruit. This is served with a salad and fries or a jacket-potato.

https://www.facebook.com/pages/Pampas-Rodizio/285253598228573

Ankara This is a Turkish restaurant known for its "plateau du chef" which is a huge platter with a combination of different mezzes and grilled meats. Kudos to you if you manage to finish it! You can of course just order a simple dish as well.

https://www.facebook.com/restaurantankara/

Gastronomy & Co

You might have high standards when it comes to dining. Well, then these restaurants are ideal for you. Note that you will most likely need to make a reservation at least a day in advance, and that these restaurants tend to be quite pricey.

Vrijmoed Michelin star restaurant by young chef Michael Vrijmoed, former sous-chef of Michelin 3-star restaurant Hof van Cleve. There are two set menus from which you can choose: vegetarian or non-vegetarian. Each menu comes in either five, six, or seven courses.

https://www.facebook.com/restaurantvrijmoed/

Karel de Stoute Located in the picturesque 'Patershol', this restaurant offers haute cuisine at an 'affordable' price. They only offer the set menu (ranging from two to five courses).

http://www.restkareldestoute.be

Publiek Publiek is the Michelin star restaurant of Flemish Foodie Olly Ceulenaere and Kelly Dehollander. At noon they serve a healthy lunch. In the evening you can either take the six course menu or just a part of it.
http://www.publiekgent.be/

Beer

After all this food you might be thirsty, and looking to sample some Belgian beers.

Waterhuis aan de Bierkant Idyllically located next to the water, this bar has a large selection of Belgian beers. It can however get very crowded during the tourist season.
https://www.facebook.com/pages/Waterhuis-aan-de-Bierkant/171209319595287

Het Trappistenhuis This bar lies outside of the historic center, and is therefor less visited by tourist. It has more than 170 special Belgian beers.
https://nl-nl.facebook.com/Trappistenhuis/

Trollekelder A favourite both with tourists and locals. Ideal place to sample a Belgian beer and have a nice chat.
https://nl-nl.facebook.com/trollekelder/

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