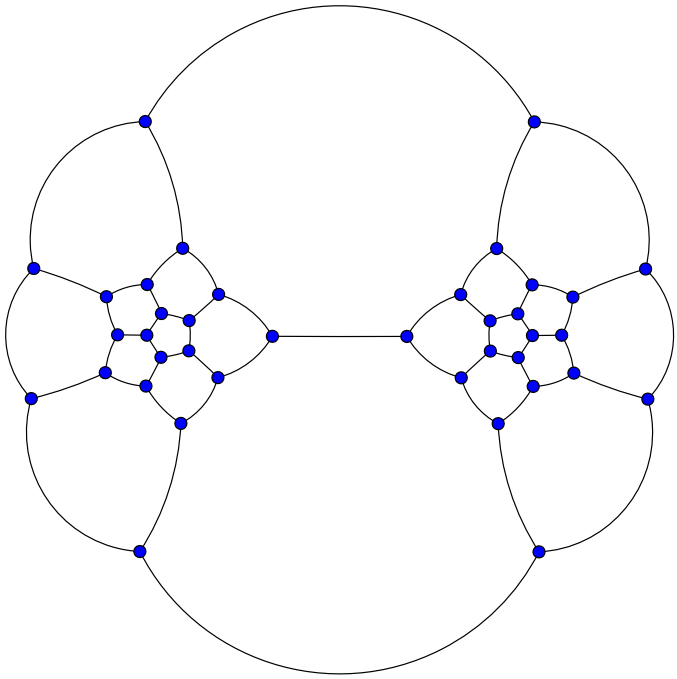
4^{th} Croatian Combinatorial Days, Zagreb, September 2022

CroCoDays 2022



Book of Abstracts

Impressum

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dinner

Contributed talks

Evaluating topological ordering in directed acyclic graphs

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(joint work with Damir Vukičević)

Directed acyclic graphs are often used to model situations and problems in real life. If we consider topological ordering of the graph as a process of arranging the vertices in best possible way considering the constraints caused by the direction of edges, then it makes sense to try to optimize this process by minimizing the distances between vertices in the ordering. For this purpose, we define measures based on distances between vertices in the topological ordering that allow us to construct a graph with optimal topological ordering regarding a specific measure thus minimizing the complexity of the system represented by the graph. We explore minimal and maximal values of the defined measures and comment on the topology of graphs for which maximal and minimal values are obtained. Potentially, the proved bounds could be used to benchmark existing algorithms, devise new approximation algorithms or branch–and–bound schemas for some scheduling problems that are usually of hard computational complexity.

Polyomino tilings: from combinatorics to topology

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(joint work with Edin Liđan)

A polyomino is a plane geometric figure formed by joining one or more equal squares edge to edge. The problem of tiling a region in a plane or a surface with square grid by the given set of polyomino shapes and questions of different number of tilings have been extensively studied in combinatorics. We introduce a simplicial complex related to the problem and it turns out that its combinatorics and topology have many interesting properties. For example, a face vector of a such complex reveals the number of different placements of a certain shapes on the region without overlapping. This large group of simplicial complexes fails in general to be Cohen-Macaulay, but in many cases they still have the homotopy type of a wedge of spheres. Morover, they can be considered as a natural generalization of the matching complex of a graph on a square grid which are studied a lot in the last years. Combinatorial, topological and algebraic properties of polyomino tilings complexes provide many interesting and nice applications we are going to talk about.

Symmetrizations of convex sets

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We investigate four different symmetrizations of a convex set C: the intersection, the arithmetic and harmonic means, and the convex hull of C and $-C$. Firey has shown that those symmetrizations build up a chain of subsets of a given order. We present reverse chains of subsets of those symmetrizations as well as tighten the forward ones.

Pairwise balanced designs and periodic Golay pairs

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(joint work with D. Crnković, R. Egan and A. Švob)

Let $a = [a_0, \ldots, a_{v-1}]$ be a $\{\pm 1\}$-sequence of length v. *The periodic autocorrelation function* of a with shift s is given by $\mathrm{PAF}_s(a) = \sum_{i=0}^{n-1} a_i a_{i+s}$, where the sequence indices are read modulo v. A pair (a, b) of $\{\pm 1\}$-sequences is a *periodic Golay pair* (PGP) if $\mathrm{PAF}_s(a) + \mathrm{PAF}_s(b) = 0$ for all $1 \leq s \leq v - 1$. PGPs generalize the Golay pairs which are known to have applications in multislit spectroscopy, signal processing, digital communications, etc.

In this talk, a relationship between pairwise balanced designs with v points and PGPs of length v will be presented, in order to classify periodic Golay pairs of length less than 40. Using the theory of orbit matrices and using isomorph rejection which is compatible with equivalence of corresponding PGPs, all pairwise balanced designs with v points under specific block conditions having an assumed cyclic automorphism group are constructed. Similar tools to construct new periodic Golay pairs of lengths greater than 40 are used, but classifications remain incomplete. Under some extra conditions on its automorphism group, a PGP of length 90 does not exist, but length 90 still remains the smallest length for which the existence of a PGP is undecided.

Practical computations with indefinite forms

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An indefinite lattice is a integral valued quadratic form on $\mathbb{Z}^n$ of signature (p, q) with $p, q > 0$. We consider following problems for them:

1. Compute a generating set of the group of inversible integral transformations preserving q.
2. Given two forms A_1 and A_2 test if there is an inversible integral transformation ϕ such that $A_2[x] = A_1[\phi(x)]$.
3. Given $C \neq 0$ find the orbit representatives of solutions of $A[x] = C$.
4. Find the orbit representatives of solutions of $A[x] = 0$ with x primitive.
5. For $k \geq 2$ find the orbit representatives of k totally isotropic planes.

We provide some methods that allow to resolve such questions. This is based on polyhedral, lattice, group theoretic techniques.

If time allows I will also explain how the edgewalk algorithm of Allcock gives a subgroup of $Aut(L)/Cox(L)$.

Total and double total dominations in some chemical graphs

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(joint work with Antoaneta Klobučar)

Let G be a graph with the vertex set $V(G)$. A set $D \subset V(G)$ is a total dominating set if every vertex $v \in V(G)$ has a neighbor in D. The total domination number $\gamma_t(G)$ is the cardinality of the smallest total dominating set. Further, a set $D \in V(G)$ is a total k-dominating set if every vertex $v \in V(G)$ has at least k neighbors in D. The total k-domination number $\gamma_{kt}(G)$ is the cardinality of the smallest total k-dominating set. For $k = 2$ the total 2-dominating set is a called double total dominating set.

In this work, we study total and double total dominations on different chemical graphs such as hexagonal grid, pyrene network and hexabenzocoronene. We give the lower and the upper bound for total and double total numbers on mentioned graphs. All mentioned graphs are obtained by arranging congruent regular hexagons in a plane. They are of significant importance in theoretical chemistry as a natural graph representation of benzenoid hydrocarbons.

Equidistant walks to infinity

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Arithmetical progressions can be considered as equidistant walks to infinity with the common difference being the length of the step. We use equidistant walks of odd and even numbers to construct grids with a finite or infinite number of columns. Further, we describe zigzag pattern walks over grids with a finite number of columns and show that they can be identified with diagonal walks in infinite grids. Infinite grids are said to be equidistant if all (diagonal) walks in them are equidistant; we give a condition that ensures this. We also comment on the total number of equidistant grids for the fixed difference of initial terms of equidistant walks that constitute the grid. Furthermore, we define products with overlapping factors of consecutive odd and consecutive even numbers. It turns out that differences of successive overlapping products are equidistant walks; we establish the distance between them.

Prescribed Automorphism Groups: A GAP Package

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Prescribed Automorphism Groups (PAG) is a package for constructing combinatorial objects written for the computer algebra system GAP [1]. We will demonstrate some features that have been implemented so far, notably constructions of combinatorial designs using the Kramer-Mesner method. We will also outline plans for future development of the PAG package.

Simplicial complex of polyomino type tilings $K_P(\mathbb{T}_{2\times n})$

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(joint work with Đorđe Baralić)

In this talk, we consider placement of polyomino shapes on square torus grid of dimension $2 \times n$ without overlapping. By placing one polyomino shape on the torus grid, we will have 0-simplex; by placing two polyomino shapes 1-simplex, etc. From such tilings, simplicial complex of polyomino type tilings arise, and are denoted them with $K_P(\mathbb{T}_{2\times n})$, where P denotes polyomino shapes.

For the introduced simplicial complex of polyomino type tilings $K_P(\mathbb{T}_{2\times n})$ we will calculate $\mathbf{f}$–vectors for some n. We will consider some properties of $K_P(\mathbb{T}_{2\times n})$ (flag, balanced, homology, and Cohen-Macualay properties). For given properties, we will give proof for some n which of these simplicial complex have these properties and which not.

Coloring edges of subcubic graphs with five colors

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A proper edge-coloring of a graph is an assignment of colors to its edges such that adjacent edges receive distinct colors. Vizing's theorem implies that every graph with maximum degree 3 admits a proper edge-coloring using at most 4 colors. It turns out that by allowing just one additional color (i.e., using 5 colors), we are able to add many interesting constraints to our edge-coloring setting and still be able to complete the coloring. In the talk, we will survey results about the most studied edge-coloring variations; we will begin with a recent result on the strong edge-coloring, and continue by considering normal and adjacent vertex-distinguishing edge-colorings. Although a considerable amount of research was done on the mentioned topics, there are still many interesting open problems waiting to be solved.

Šoltés's problem: towards the solution

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The *total distance* or *Wiener index* $W(G)$ of a connected graph G is defined as the sum of distances between all (unordered) pairs of vertices in G. In 1991, Šoltés posed the following problem:

Find all such graphs G that the equality $W(G) = W(G - v)$ holds for all their vertices v.

Untill now, only one such graph is known: it is a cycle with 11 vertices. We give an overview of results that were obtained so far which mainly concern finding a large proportion of vertices whose removal keep Wiener index unchanged.

On some constructions of strongly regular graphs

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(joint work with Dean Crnković)

In this talk we give a classification of strongly regular graphs with parameters (49,18,7,6) that have an automorphism of order six, and talk about the nonexistence of strongly regular graphs with parameters (99,14,1,2) that have a certain automorphism group. For this construction, we used a method to construct strongly regular graphs from orbit matrices admitting an automorphism group of composite order. This method is a generalisation of the work of C. Lam and M. Behbahani, who in 2011 introduced an algorithm for constructing orbit matrices of strongly regular graphs with an assumed prime order automorphism group.

On divisibility properties of some binomial sums connected with the Catalan and Fibonacci numbers

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We show that an alternating binomial sum which is connected with the Catalan numbers is divisible by n. A natural generalization of this sum is connected with the generalized Catalan numbers and also divisible by n. A new class of binomial sums is used. Furthermore, by using new class of binomial sums, we study a sum which is closely related with the Binet's formula for the Fibonacci numbers.

Self-avoiding walks with wrong steps

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(joint work with L. Major, A. Pahikkala and L. Szalay)

The investigation of self-avoiding walks on graphs has an extensive literature. We study the notion of wrong steps of self-avoiding walks on rectangular shape $n \times m$ grids of square cells (Manhattan graphs) and examine some general and special cases. We determine the number of self-avoiding walks with one and with two wrong steps in general. We establish some properties, like unimodality and sum of the rows of the Pascal-like triangles corresponding to the walks. We also present particular recurrence relations on the number of self-avoiding walks on the $n \times 2$ grids with any specified number of wrong steps.

On a Linear Recurrence Relation

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We study the six-parameter linear recurrence relation defined for all $n \geq 1$ by

$$f(1) = \zeta,\ f(2n) = \alpha f(n) + \beta,\ f(2n+1) = \gamma f(n) + \delta f(n+1) + \varepsilon$$

with $\alpha, \beta, \gamma, \delta, \varepsilon, \zeta \in \mathbb{Z}$. We determine its generating fucntion which shows that the sequence is of the divide-and-conquer type. Then we discuss some interesting special cases such as the Josephus problem, the number of 1's in the binary expression of $n \in \mathbb{N}$, the Gros sequence in the Tower of Hanoi with 3 pegs, the Prouhet-Morse-Thue sequence, Stern's diatomic sequence and others. We give its solution at first for the special case $\delta = 0$ and then for $\delta \neq 0$. Moreover, for $\varepsilon = \beta = 0$ and $\alpha \neq 0$, we derive a second-order recurrence relation and give the solution by means of continued fractions. Finally, we indicate a generalization.

Schneider's p-adic continued fractions

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We study Schneider's version of p-adic continued fractions. We are interested in the finiteness of rational number expansion, the quality of approximation by convergents, the irrationality exponent of a number with a given continued fraction expansion, and the convergence of Schneider's continued fractions in the field of real numbers. The main requirement for all of these problems is a good estimate of growth for the sequences of numerators and denominators of convergents. These sequences satisfy second order linear recurrence relations with nonconstant coefficients.

Some Identities Involving Fibonacci Numbers and Sequences with Similar Recursions

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(joint work with Tomislav Došlić)

Tilings or tesselations appear as natural solutions of many practical problems and their aesthetic appeal motivates the interest that goes way beyond the limits of their practical relevance. The substrate (i.e., the area to be tiled) is a honeycomb strip composed of n regular hexagons arranged in two rows in which the hexagons are numbered starting from the bottom left corner. We investigate two types of tilings and derive some closed form formulas for the number of tilings. Furthermore, we obtain some new identities involving tribonacci numbers, Padovan numbers and Narayana's cow sequence and present combinatorial proofs for several known identities about those numbers. Finally, some of these identities we were able to generalize for full-history Horadam sequences, i.e. sequences defined with recursive relation $S_n = a_1 S_{n-1} + \cdots + a_n S_0$.

On the Maximum Value of $W(L(G))/W(G)$

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(joint work with Riste Škrekovski)

The line graph $L(G)$ of a graph G is defined as a graph having vertex set identical with the set of edges of G and two vertices of L(G) are adjacent if and only if the corresponding edges are incident in G. Higher iteration $L^i(G)$ is obtained by repeatedly applying the line graph operation i times. Wiener index $W(G)$ of a graph G is defined as the sum of distances which runs over all pairs of vertices in G. The problem of establishing the extremal values and extremal graphs for the ratio $W(L^i(G))/W(G)$ was proposed by Dobrynin and Melnikov [Mathematical Chemistry Monographs, Vol. 12, 2012, pp. 85-121]. For $i = 1$, we establish the maximum value and characterize the extremal graphs. In doing so, we derive unexpectedly an interesting relation that involves the Gutman index and the first Zagreb index.

Visibility in restricted involutions

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We enumerate involutions avoiding any single pattern of length three according to the statistic "number of visible pairs", namely, the number of non-adjacent columns in the bargraph representation of a given permutation that are mutually visible to each other. The proofs are combinatorial and reside on well-known bijections between pattern avoiding involutions and lattice paths.

On the explicit intrinsic formulas for hyperbolic Atiyah determinants for up to four points

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In 2001 Sir Michael Atiyah, inspired by physics (Berry Robbins problem related to spin statistics theorem of quantum mechanics) associated a remarkable determinant to any n distinct points in Euclidean 3-space (or hyperbolic 3-space), via an elementary construction.By recalling some hyperbolic geometry (a la Fenchel) of tetrahedra we will explain a new intrinsic formula for the hyperbolic Atiyah determinant for any hyperbolic tetrahedron.

On automorphisms of a Fano plane 2-analog design

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It has been recently shown, using a computer power based approach, that a 2-analog of a Fano plane is almost rigid. It has an automorphism group of a size at most 2. In this talk we shall present some theoretical results that can be used to construct an algebraic proof that a 2-analog of a Fano plane is almost rigid.

Planets are (almost certainly) in star orbits

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The probability that a randomly and uniformly chosen point from the circumball of a tetrahedron lies outside of the inscribed ball of the tetrahedron can be estimated very sharply from below in terms of the edge lengths of the tetrahedron. One can imagine four stars in the Universe (vertices) with known mutual distances and a small (exo-) planet orbiting between them within the circumsphere. The least probability that the planet is outside of the insphere, i.e. closer to one of the stars is given in terms of the distances of the stars. The least probability occurs for the regular tetrahedron and it is 0.962962.... So, almost certainly planets are in vicinity of stars and then in orbits arranged later by gravity rules. Geometrically, this is a tricky corollary of the (refinements) of the famous Euler's inequality: circumradius is at least three times bigger than the inradius of a tetrahedron with equality for a regular tetrahedron. The Euler inequality can be extended to Euclidean simplices in all dimensions and to non-Euclidean geometries with the most relevant cases of 3D and 4D being in accordance with the relativity theory.

Adriatic graphs

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(joint work with Perica Bošković)

Let F be a family of graphs. Adriatic graph $A(F)$ is a graph which vertices are ordered pairs of graphs in F that have the same number of vertices.

Two vertices (G_1, G_2) and (H_1, H_2) are adjacent if:

1. There is a non-pendant vertex v_i in graph G_i which all neighbors except exactly one are leaves, $i = 1, 2$;
2. v_1 and v_2 have same degrees;
3. Graph obtained by replacing one pendant vertex of v_i by path of length two is isomorphic to h_i.

Observing connected components of Adriatic graph and identifying pairs that do not behave as the remainders of pairs in the same component may be of use when one tries to identify incorrect entries in NIST database (one of the most important chemical databases). Combining this approach with multilinear modeling using molecular descriptors, we have detected five suspicious values of entropies of vaporizations in the family of alkanes having 6 to 10 C atoms. Further, Adriatic graphs and directed Adriatic graphs of trees are interesting mathematical objects with abundance of properties that may be researched. Some extremal results will be given here and some open problems will be presented.

Mathematical modelling of corrosion inhibitors

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(joint work with Matjaž Finšgar, Slavko Radenković, Izudin Redžepović and Niko Tratnik)

Organic molecules are generally modelled with simple graphs but in the case of heteroatomic molecules there is some ambiguity in modelling such graphs. Such molecules are also corrosion inhibitors and we use vertex-weighted graphs for their modelling. Different topological indices of these molecules are calculated and compared with their experimentally measured corrosion inhibition effectiveness. The regression analysis is used to determine the best predictors for it.

Combinatorial settlement model - a variant of Flory model

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(joint work with Tomislav Došlić, Mate Puljiz and Stjepan Šebek)

In this talk we present a combinatorial settlement model which arises after imposing certain intuitive constraints on the configurations of built buildings on certain grids of lots. We provide the answers to some questions regarding the support of the building densities of maximal configurations and relate the model to the already well-studied combinatorial models. The main focus of the talk is the analysis of the 1D version of combinatorial settlement model, which we refer to as the Riviera model, together with some interesting results regarding its connection with other combinatorial objects.

Posters

On a coloring problem in the plane

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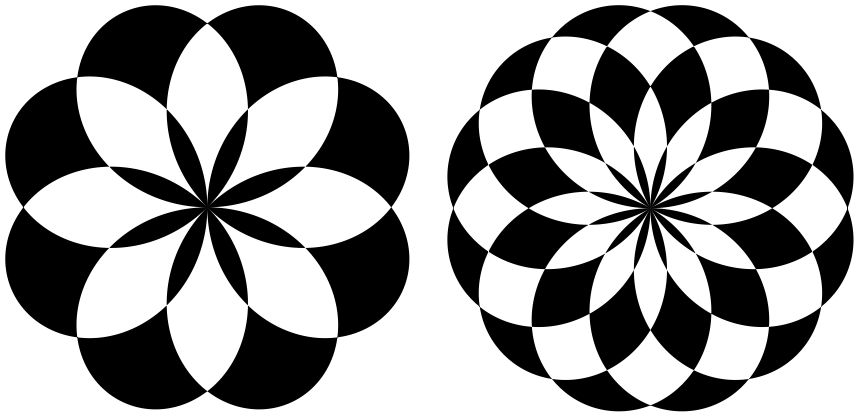
(joint work with Tomislav Došlić)

Gregory Dresden of Washington & Lee University has mentored numerous undergraduate research projects. In March 2022 he posted on his website the following problem:

Shown below (from left to right) are graphs of $r = \sin(4\theta/3)$ and $r = \sin(6\theta/5)$, where every other adjacent region (starting from the outside) is shaded black. Find the total shaded area for any such graph $r = \sin\frac{k+1}{k}\theta$, where $k > 0$ is an odd integer and θ ranges from 0 to $2k\pi$.



This also appeared in print as problem 1221 in the March, 2022 issue of the College Math Journal.

In this contribution we present an elementary solution to the problem and explore several possible generalizations.

Random Walks on Integers and Generalization of Eulerian Distribution

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(joint work with Tomislav Došlić)

We consider the following coin-tossing game. To play the game, we will begin with a graph that has origin node at position 0, absorbing node at position -1 and infinitely many unoccupied nodes on right side. Above the origin, there is a queue of particles that will perform random walks on the graph. We imagine dropping the first particle in the queue onto the origin, and since at first all sites are unoccupied, particle settles. Then the second particle in the queue drops onto the origin. Flipping heads will move the particle one position to the right and flipping tails will move it one position to the left. The game consists of flipping a coin repeatedly until the particle reaches an unoccupied site or vanishes if it reaches the absorbing node. Once an unoccupied site is reached, the particle settles there and occupies it. At that moment, new particle above the origin is ready to preform random walk. For any $n \leq 1$ and $1 \leq k \leq n$, let $P(n,k)$ denote the probability that, after releasing n particles, k of them are settled. We present closed form formula for $P(n,k)$.

Furthermore, we generalize our model where absorbing node can be anywhere left of the origin, i.e., at position $-m$ and we present connection between this model and Eulerian distribution.

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Notes