Workshop on Graph Classes, Width Parameters and Optimization 2005

Jan Kára, ed.

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Dear Friends,

Almost four years have passed since we organized the first edition of this workshop in Barcelona. Many things have happened since then. A special volume of Discrete Applied Mathematics 145(2) containing materials from the workshop was finally published earlier this year. Prague has survived a flood (other cities in the world were flooded, too). The Strong Perfect Graph Conjecture has been proved, and a polynomial time algorithm for recognizing perfect graphs has been found. Clique-width has finally been proved NP-complete. Cognizant of all these events, we have decided that time was ripe for a continuation of our workshop, and your participation shows that the Graph Theory community agrees.

The program of the workshop reflects hot research topics in our area, even though not all main players were able to join us. A plenary talk of Takao Nishizeki will open the day of Optimization talks. Among other themes, we are going to hear about exact algorithms and a talk on distance constrained graph labelings will link us with one of the main themes of the previous workshop. The plenary talk on the Width Parameters day will be given by Dimitrios Thilikos. We are pleased to see that the previous workshop stimulated new progress in branchwidth, we will hear about other width parameters, not only for graphs, but also in the matroid setting. Maria Chudnovsky kindly accepted our invitation to deliver the plenary talk on the Graph Classes day. During that day, a subset of the perfect graph team is going to present results on other graph classes: claw-free graphs and balanced graphs. Finally, the Problem Session planned for the first day will introduce problems whose solutions will perhaps be presented at the third edition of the workshop.

We again plan to gather the papers presented here in a special volume of an international journal, most likely Discrete Applied Mathematics. The volume will be also open to all colleagues who could not take part in the event due to their other duties. We will issue a call for papers shortly after the conclusion of the workshop.

We gratefully acknowledge the support of DIMATIA, Institute for Theoretical Computer Science ITI (project 1M0021620808) and Research Project MSM0021620838. We wish you all a fruitful and pleasant time in Prague.

Jan Kratochvíl, Andrzej Proskurowski and Oriol Serra.

Workshop program

Monday — Optimization

8:30	**Registration**
9:30	**T. Nishizeki: Part. Graphs of Supply and Demand**
10:30	Coffee break
11:00	P. Heggernes: Exact Algorithms for Graph Homomorphisms
	D. Kráľ: Distance Constraint Labeling of Planar Graphs
	F. Dorn: Subexp. Algorithms for Planar Hamiltonicity
12:30	Lunch
14:30	D. Kratsch: Measure and Conquer: Domination...
	D. Lokstanov: Finding the Longest Isometric Cycle in a Graph
	S. Zaks: Properties of Optimal Path Layouts...
	P. Fraigniaud: Greedy Routing in Tree-Decomposed Graphs
	Problem session
18:00	Welcome party

Tuesday — Width Parameters

9:30	**D. Thilikos: Monotonicity and Connectivity...**
10:30	Coffee break
11:00	P. Rossmanith: Treewidth and Pathwidth of Sparse Graphs
	S. Oum: Recognizing Rank-width Quickly
	F. V. Fomin: Pathwidth of 3-regular Graphs and Exact Algs
12:30	Lunch
14:30	C. Paul: New Tools and Simpler Algorithms for Branchwidth
	J. A. Telle: Explaining Branchwidth...
	P. Hliněný: On a Matroid View of Tree-width
	M. Rao: $MSOL_1$-partition Problem...
18:00	Concert and banquet in Michna Palace

Wednesday — Graph Classes

9:30	**M. Chudnovsky: The Structure of Clawfree Graphs**
10:30	Coffee break
11:00	I. Todinca: Minimal Interval Completion
	J. Fiala: Degree Structure of a Graph and Degree Matrice
	S. Klavžar: Distance-balanced Graphs
12:30	Lunch
14:30	J. Kratochvíl: Max-tolerance Graphs...
	N. Nisse: Nondeterministic Graph Searching...
	P. Seymour: Balanced Graphs
	Discussions and problem solving
18:00	Farewell party

Abstracts

The Structure of Clawfree Graphs

Maria Chudnovsky

A graph is said to be clawfree if it has no induced subgraph isomorphic to $K_{1,3}$. Line graphs are one well-known class of clawfree graphs, but there others, such as circular arc graphs and subgraphs of the Schläfli graph. It has been an open question to describe the structure of all clawfree graphs. Recently, in joint work with Paul Seymour, we were able to prove that all clawfree graphs can be constructed from basic pieces (which include the graphs mentioned above, as well as a few other ones) by gluing them together in prescribed ways. In this talk we will survey some ideas of the proof, and present examples of clawfree graphs that turned out to be of importance in the description of the general structure. We will also describe some new properties of clawfree graphs, that we learned while working on the subject.

Subexponential Algorithms for Planar Hamiltonicity

Frederic Dorn

(joint work with Eelko Penninkx, Hans Bodlaender and Fedor Fomin)

Divide-and-conquer strategy based on variations of the Lipton-Tarjan planar separator theorem has been one of the most common approaches for solving planar graph problems for more than 20 years. We present a new framework for designing fast subexponential exact and parameterized algorithms on planar graphs. Our approach is based on geometric properties of planar branch decompositions obtained by Seymour & Thomas, combined with new techniques of dynamic programming on planar graphs. Compared to divide-and-conquer algorithms, the main advantages of our method are:

1. it is a generic method which allows to attack broad classes of problems;
2. the obtained algorithms provide a better worst case analysis.

To exemplify our approach we show how to obtain an $O(2^{6.903\sqrt{n}}n^{3/2} + n^3)$ time algorithm solving weighted Hamiltonian Cycle. Our technique can be used to solve Planar Graph TSP in time $O(2^{10.8224\sqrt{n}}n^{3/2} + n^3)$ and parameterized Planar $k-$cycle in time $O(2^{13.6\sqrt{k}}\sqrt{k}n + n^3)$ for a given k.

Degree Structure of a Graph and Degree Matrices

Jiří Fiala

In the talk we review the notion of degree partition (also known as equitable partition) of a graph and the matrix that desribes adjacencies in such a partition. We show several algorithms that transforms these matrices. Further we provide some graph constructions based on degree matrices and finally we pose few problems in this area.

Pathwidth of 3-regular Graphs and Exact Algorithms

Fedor V. Fomin

(joint work with Kjartan Høie)

We prove that for any $\varepsilon > 0$ there exists an integer n_ε such that the pathwidth of every 3-regular graph on $n > n_\varepsilon$ vertices is at most $(1/6+\varepsilon)n$. Based on this bound we improve the worst case time analysis for a number of exact exponential algorithms on graphs of maximum vertex degree three.

Greedy Routing in Tree-Decomposed Graphs

Pierre Fraigniaud

We propose a new perspective on the small world phenomenon by considering arbitrary graphs augmented according to probabilistic distributions guided by tree-decompositions of the graphs. We show that, for any n-node graph G of treewidth $\leq k$, there exists a tree-decomposition-based distribution $\mathcal{D}$ such that greedy routing in the augmented graph $(G, \mathcal{D})$ performs in $O(k \log^2 n)$ expected number of steps. We also prove that if G has chordality $\leq k$, then the tree-decomposition-based distribution $\mathcal{D}$ insures that greedy routing in $(G, \mathcal{D})$ performs in $O((k + \log n) \log n)$ expected number of steps. In particular, for any n-node graph G of chordality $O(\log n)$ (e.g., chordal graphs), greedy routing in the augmented graph $(G, \mathcal{D})$ performs in $O(\log^2 n)$ expected number of steps.

Exact Algorithms for Graph Homomorphisms

Pinar Heggernes

(joint work with Fedor Fomin and Dieter Kratsch)

Graph homomorphism, also called H-coloring, is a natural generalization of graph coloring: There is a homomorphism from a graph G to a complete graph on k vertices if and only if G is k-colorable. During the recent years the topic of exact (exponential-time) algorithms for NP-hard problems in general, and for graph coloring in particular, has led to extensive research. Consequently, it is natural to ask how the techniques developed for exact graph coloring algorithms can be extended to graph homomorphisms. By the celebrated result of Hell and Nešetřil, for each fixed simple graph H, deciding whether a given simple graph G has a homomorphism to H is polynomial-time solvable if H is a bipartite graph, and NP-complete otherwise.

The case where $H = C_5$, i.e. a cycle of length 5, is the first NP-hard case different from graph coloring. We show that for odd integer $k \geq 5$, whether input graph G is homomorphic to C_k, a cycle of length k, can be decided in time $\min\{\binom{n}{n/k}, 2^{n/2}\} \cdot n^{O(1)}$. We extend the results obtained for cycles, which are graphs of treewidth two, to graphs of bounded treewidth as follows: If H is of treewidth at most t, then whether input graph G is homomorphic to H can be decided in time $(2t+4)^n \cdot n^{O(1)}$.

On a Matroid View of Tree-width

Petr Hliněný

(joint work with G. Whittle)

We show how the definition of tree-width can be extended to matroids. This extension is not at all straightforward, and since the width exactly equals traditional tree-width on graphs, our definition provides a new, "vertex-free" view of tree-decompositions. Regarding this definition, we mention what k-trees are for represented matroids, and ask for a good corresponding definition of "chordal" matroids.

Distance-balanced Graphs

Sandi Klavžar

(joint work with Janja Jerebic (University of Maribor, Slovenia) and Douglas F. Rall (Furman University, USA))

Distance-balanced graphs are graphs in which every edge uv has the following property: the number of vertices closer to u than to v is equal to the number of vertices closer to v than to u. Basic properties of these graphs will be presented. This metric concept will be connected with symmetry conditions in graphs and local operations on graphs will be studied with respect to it. Distance-balanced Cartesian and lexicographic products of graphs will also be characterized and some open problems will be posed.

Distance Constraint Labeling of Planar Graphs

Daniel Král'

(joint work with subsets of Peter Bella (Charles University, Prague), Zdeněk Dvořák (Charles University, Prague), Bojan Mohar (University of Ljubljana, Ljubljana and Simon Fraser University, Burnaby), Pavel Nejedlý (Charles University, Prague), Katarína Quittnerová (Charles University, Prague), Riste Škrekovski (University of Ljubljana, Ljubljana))

Distance constraint labeling is an important graph theory model in optimization related to the channel assignment problem. An $L(p,q)$-labeling of a graph G is labeling of its vertices by non-negative integers (that represent frequencies of transmitters) such that the integers assigned to adjacent vertices differ by at least p and those assigned to vertices at distance two differ by at least q. The minimum length of an interval needed for such an assignment is called the span of the problem and denoted by $\lambda_{p,q}(G)$.

In this talk, we focus on $L(p,q)$-labeling of various classes of planar graphs. In the first part of the talk, we show that the conjecture of Griggs and Yeh [SIAM J. Discrete Math. 5 (1992), 586–595] holds for planar graphs with maximum degree $\Delta \neq 3$. Recall that the conjecture asserts that every graph has an $L(2,1)$-labeling of span Δ^2 where Δ is its maximum degree. In the second part of the talk, we focus our attention to planar graphs without short cycles. Our research is motivated by a conjecture of Wang and Lih [SIAM J. Discrete Math. 17(2) (2003), 264–275] that for every $g \geq 5$, there exists an integer $M(g)$ such $\lambda_{1,1}(G) = \Delta$ for every planar graph G with maximum degree $\Delta \geq M(g)$ and girth at least g. We prove the conjecture for $g \geq 7$ and show that it is false for $g = 5$ and $g = 6$. However, we show that the conjecture becomes true for $g = 6$ when Δ is replaced by $\Delta + 1$. For a general value of p, we show that $\lambda_{p,1}(G) \leq 2p + \Delta - 2$ for planar graphs G of girth 7 and sufficiently large maximum degree. This bound is also the best possible.

Max-tolerance Graphs as Geometric Intersection Graphs

Jan Kratochvíl

(based on joint work with Michael Kaufmann, Katharina Anna Lehmann and Amarendran R. Subramanian)

Definition 1 *A graph $G = (V, E)$ is a* max-tolerance *graph if every vertex $u \in V$ can be assigned a real interval I_u and a real number t_u (called the* tolerance *of u) so that*

$$uv \in E \leftrightarrow |I_u \cap I_v| \geq \max\{t_u, t_v\}.$$

Max-tolerance graphs model natural questions arising in comparison of DNA sequences, or more broadly in the field of bioinformatics. We show that max-tolerance graphs can be viewed as intersection graphs of congruent triangles.

This geometric view helps understanding the structure of max-tolerance graphs and exploiting it, we prove the following results. First of all we utilize the known NP-hardness reduction for intersection graphs of pseudodisks to show that recognition of max-tolerance graphs is an NP-hard problem. To answer an open problem of Golumbic and Trenk from their recent book Tolerance Graphs, we show that complements of long cycles are not max-tolerance graphs. On the positive side we show that max-tolerance graphs have polynomial number of maximal cliques, and thus the CLIQUE problem can be solved in polynomial time in this class of graphs.

Measure and Conquer: Domination – A Case Study

Dieter Kratsch

Davis-Putnam-style exponential-time backtracking algorithms are among the most common algorithms used for finding exact solutions of NP-hard problems. The analysis of such recursive algorithms is based on the bounded search tree technique: a measure of the size of the subproblems is defined;

this measure is used to lower bound the progress made by the algorithm at each branching step.

For the last 30 years the research on exact algorithms has been mainly focused on the design of more and more sophisticated algorithms. However, measures used in the analysis of backtracking algorithms are usually very simple. In this talk we stress that a more careful choice of the measure can lead to a significantly better worst case time analysis.

As an example, we consider the minimum dominating set problem. The currently fastest algorithm for this problem has been shown to have running time $O(1.81^n)$ (up to polynomial factor) on n-vertex graphs. By measuring the progress of the (same) algorithm in a different way, we refine the time bound to (1.52^n) (up to polynomial factor).

Finding the Longest Isometric Cycle in a Graph

Daniel Lokshtanov

Induced cycles in graphs is a well-studied topic in graph theory and graph related algorithms. One could think of an induced cycle as a cycle having no shortcuts. However, this notion of "shortcuts" only captures those of length one. In order to define "shortcut-free" cycles in a better way, we say that a graph H is an *isometric* subgraph of G if the shortest path between any pair of vertices in H only goes along edges in H. An isometric cycle in G is a cycle C satisfying the above condition. Having defined isometric cycles, we are interested in an efficient algorithm that finds the longest isometric cycle of a graph. We show that one can solve this problem in polynomial time.

Partitioning Graphs of Supply and Demand

Takao Nishizeki

(joint work with T. Ito and X. Zhou)

Assume that each vertex of a graph G is either a supply vertex or a demand vertex and is assigned a positive number, called a supply or a demand. Each demand vertex can receive "power" from at most one supply vertex. We thus wish to partition G into connected components by deleting edges from G so that each component C has exactly one supply vertex whose supply is no less than the sum of demands of all demand vertices in C. The partition problem is a decision problem to ask whether G has such a partition. The partition problem is NP-complete even for series-parallel graphs and strong NP-complete for general graphs. If G has no such partition, we wish to partition G into connected components so that each component C either has no supply vertex or has exactly one supply vertex whose supply is no less than the sum of demands in C, and wish to maximize the sum of demands in all components with supply vertices. Such a maximization problem is called the maximum partition problem, which is NP-hard even for trees and strong NP-hard for general graphs.

In this talk, we first explain the following three results on trees: the partition problem can be solved in linear time for trees; the maximum partition problem can be solved in pseudo-polynomial time for trees if the demands and supplies are integers; and there is a fully polynomial-time approximation scheme (FPTAS) for the maximum partition problem on trees. We then explain the following result on series-parallel graphs and partial k-trees: both the partition problem and the maximum partition problem can be solved in pseudo-polynomial time for series-parallel graphs and partial k-trees, that is, graphs with bounded tree-width, if the demands and supplies are integers.

Nondeterministic Graph Searching: From Pathwidth to Treewidth

Nicolas Nisse

We introduce nondeterministic graph searching with a controlled amount of nondeterminism and show how this new tool can be used in algorithm design and combinatorial analysis applying to both pathwidth and treewidth. We prove equivalence between this game-theoretic approach and graph decompositions called q-*branched* tree decompositions, which can be interpreted as a parameterized version of tree decompositions. Path decomposition and (standard) tree decomposition are two extreme cases of q-branched tree decompositions. The equivalence between nondeterministic graph searching and q-branched tree decomposition enables us to design an exact (exponential time) algorithm computing q-branched treewidth for all $q \geq 0$, which is thus valid for both treewidth and pathwidth. This algorithm performs as fast as the best known exact algorithm for pathwidth. Conversely, this equivalence also enables us to design a lower bound on the amount of nondeterminism required to search a graph with the minimum number of searchers.

Recognizing Rank-width Quickly

Sang-il Oum

In this talk we discuss the current fastest algorithm that recognizes graphs of rank-width at most k for fixed k. To do so, we reduce this problem into matroid branch-width and then use the algorithm by Hliněný.

New Tools and Simpler Algorithms for Branchwidth

Christophe Paul

(joint work with J. A. Telle)

We provide new tools, such as k-troikas and good subtree-representations, that allow us to give fast and simple algorithms computing branchwidth. We show that a graph G has branchwidth at most k if and only if it is a subgraph of a chordal graph in which every maximal clique has a k-troika respecting its minimal separators. Moreover, if G itself is chordal with clique tree T, then such a chordal supergraph exists having clique tree a minor of T.

We use these tools to give a straightforward $O(m + n + q^2)$ algorithm computing branchwidth for an interval graph on m edges, n vertices and q maximal cliques.

$MSOL_1$-partition Problem on Bounded Clique-width Graphs

Michael Rao

A problem P is a $MSOL_1$*-partition problem* if there is a $MSOL$ formula $\varphi(X)$ with free variable X such that P can be expressed in the following form: Given a graph $G = (V, E)$ and an integer k, can V be partitioned into $\{V_1, V_2 \ldots, V_k\}$ such that for all $i \in \{1, 2 \ldots, k\}$, $G(\tau_1) \models \varphi(V_i)$?

For example, coloring, H-free coloring and domatic number are $MSOL_1$-partition problems.

We show that every $MSOL_1$-partition problem is solvable in polynomial time on bounded clique-width graphs.

Treewidth and Pathwidth of Sparse Graphs

Peter Rossmanith

If a graph has few edges, its treewidth must also be small. The exact relationship between treewidth (or pathwidth) and the number of edges is, however, not yet well understood. In this talk upper and lower bounds, as well as algorithmic consequences are discussed.

Balanced Graphs

Paul Seymour

A bipartite graph is *balanced* if every induced cycle has length a multiple of four; and *balanceable* if its edges can be given weights 1 and -1 such that every induced cycle has total weight divisible by four. This talk is an account of the efforts of Maria Chudnovsky and the speaker to understand the structure of such graphs.

Explaining Branchwidth by Concepts Familiar from Treewidth

Jan Arne Telle

(joint work with C. Paul and A. Proskurowski)

This talk will report on recent joint work with C. Paul and A. Proskurowski that aims to explain the branchwidth parameter by concepts analogous to those familiar from the treewidth setting, like k-trees. Several tools and characterizations will be presented, culminating in a non-deterministic generation algorithm that yields as output exactly the edge-maximal graphs of branchwidth k. A comparison with the analogous algorithm for generating k-trees (Start with K_{k+1}; Repeatedly choose a k-clique C and add a new vertex adjacent to vertices in C) reveals striking differences.

Monotonicity and Connectivity for Width Parameters

Dimitrios Thilikos

The notion of an expansion is a useful framework for defining several known width parameters on graphs. We survey the relation of such parameters with search and conquer games. The goal in these games is to systematically maneuver searches in order to capture a fugitive who flees around the graph or alternatively to organize a gradual occupation of the graph while minimizing specific cost functions. An important question is the so called "monotonicity question": does it cost more to search/conquer a graph if we do not allow the fugitive to visit again "clean" locations? Another question is the "connectivity question": does it cost more to search/conquer a graph if we demand "clean" positions to induce a connected part of the graph? We use expansions to settle the monotonicity and the connectivity questions and we comment related recent results and open problems on their study.

Minimal Interval Completions

Ioan Todinca

(joint work with P. Heggernes, K. Suchan and Y. Villanger)

We study the problem of adding edges to an arbitrary graph so that the resulting graph is an interval graph. Our objective is to add an inclusion minimal set of edges, which means that no proper subset of the added edges can result in an interval graph when added to the original graph.

This problem is closely related to the problem of adding an inclusion minimal set of edges to a graph to obtain a chordal graph, which is a well studied problem and which motivates an analogous study of minimal interval completions. However, whereas there are nice properties that result in efficient algorithms for obtaining a chordal graph in this way, the same problem for obtaining an interval graph is more difficult, and its computational complexity has been open until now.

We give a polynomial time algorithm to obtain a minimal interval completion of an arbitrary graph, thereby resolving the complexity of this problem.

Properties of Optimal Path Layouts for Chain ATM Networks

Shmuel Zaks

(joint work with Marcelo Feighelstein)

In the area of virtual path layouts one constructs a set of paths, that serve to connect pairs of vertices in the network by concatenation them into channels. The parameters of interest are those of load (the number of paths that go through any single edge), hop count (the number of paths composing a channel), and stretch factor (the ratio between the length of a channel and the shortest distance between its endpoints). Given bounds on the load and the number of hops in the layout, families of optimal tree layouts are known for the case of stretch factor of one (that is, routing along shortest paths), and for the case of a general stretch factor. Both solutions exhibit duality between the two parameters of hop count and load. We present some properties of these two families of layouts. We present a simple recursive explanation for the duality properties presented in these two families of trees, we analyze the stretch factor and the average load and hop count obtained by the optimal solution of the general case, and we supply an alternative proof for these measures for the case of stretch factor of one.

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Chile

Tyrš House — Michna Palace

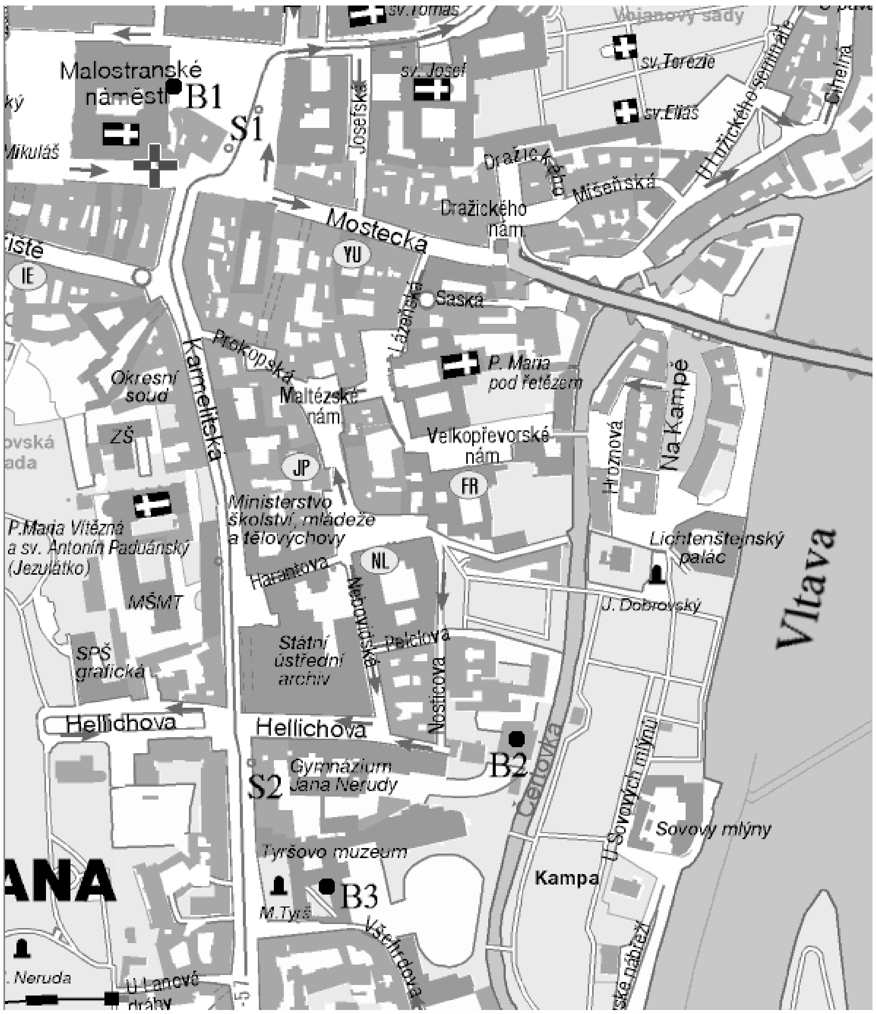
In 1623 Michna family bought a picturesque Renaissance building constructed in 1580 at the location of the current palace. The building was rebuilt in 1631–1650 creating one of the most beautiful Baroque palaces in Prague. The main facade of the building is oriented towards the Vltava river, overlooking a park and the riverbank. The main building has four wings and a central courtyard. Inside the East wing, there is a very well preserved stucco decoration from 1644, probably by Domenico Galli.

Due to financial difficulties, the Michnas had to sell the unfinished palace in the second half of the 17th century and the property then kept changing owners over years, until it was sold to the Habsburg Army in 1767. The following 150 years of ownership resulted in such a devastation that the palace was described as a "ruin" when it was sold to Czech "Sokol" in 1921.

The Sokols renamed the palace to Tyrš House, restored it and, among other additions, built a modern gymnasium and swimming pool inside the palace.

The military misuse in the 19th century was not the only hard period the palace went through. In the time of Nazi occupation the garden was brutally destroyed, all trees were cut down and the area was changed to a training ground for Hitlerjugend. The garden, the basement and the ground floor were badly damaged in 2002 during the famous Prague flood that also destroyed the Mathematical Library of the Charles University. However, the palace is now completely restored and can host our workshop's concert and banquet in its freshly painted Baroque halls.

Map of Malá Strana



B1 – Building of Faculty of Mathematics and Physics
B2 – Small Nostic Theater
B3 – Michna Palace
S1 – tram station Malostranské Náměstí
S2 – tram station Hellichova