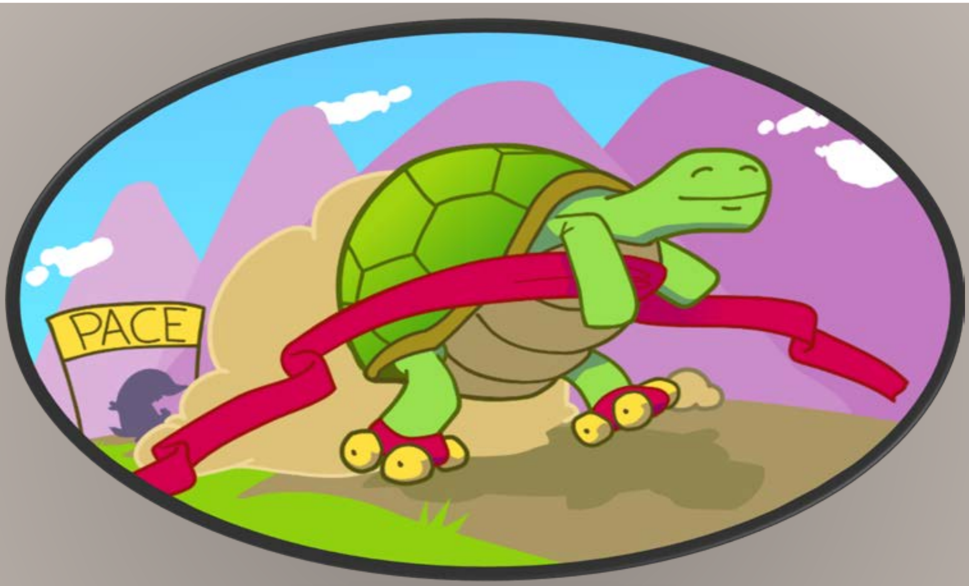
3rd Parameterized Algorithms & Computational Experiments Challenge

Where it came from, how it went, who won, and what's next



August 22nd, IPEC 2018, Helsinki, Finland

History of PACE

PACE was conceived in Fall 2015, borne from the feeling that:

"parameterized algorithmics should have a greater impact on practice"

Inspired by success of SAT-solving competitions

2015-2016: First iteration

- Track A: TREEWIDTH
- Track B: FEEDBACK VERTEX SET

2016-2017: Second iteration

- Track A: TREEWIDTH
- Track B: MINIMUM FILL-IN

2017-2018: Third iteration [STEINER TREE]

Goals

Investigate the applicability of algorithmic ideas from parameterized algorithmics

1. provide bridge between algorithm theory and algorithm engineering practice
2. inspire new theoretical developments
3. investigate the competitiveness of analytical and design frameworks
4. produce universally accessible libraries of implementations & benchmark inputs
5. encourage dissemination of the findings in scientific papers

Publications following the second PACE

SAT-Encodings of Tree Decompositions

Max Bannach
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Sebastian Berndt, Thorsten Ehlers and Dirk Nowotka
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Benchmarking treewidth as a practical component of tensor-network–based quantum simulation

Eugene F. Dumitrescu[1,†], Allison L. Fisher[2], Timothy D. Goodrich[2,*], Travis S. Humble[1,†], Blair D. Sullivan[2], Andrew L. Wright[2]

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An SMT Approach to Fractional Hypertree Width

Johannes K. Fichte, Markus Hecher,
Neha Lodha, and Stefan Szeider

Publications following the second PACE

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Computation and Growth of Road Network Dimensions

Johannes Blum(✉) and Sabine Storandt

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Würzburg, Germany
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Timothy D.
ght[2]

Computing Tree Width: From Theory to Practice and Back

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Computation and Growth of Road Network Dimensions

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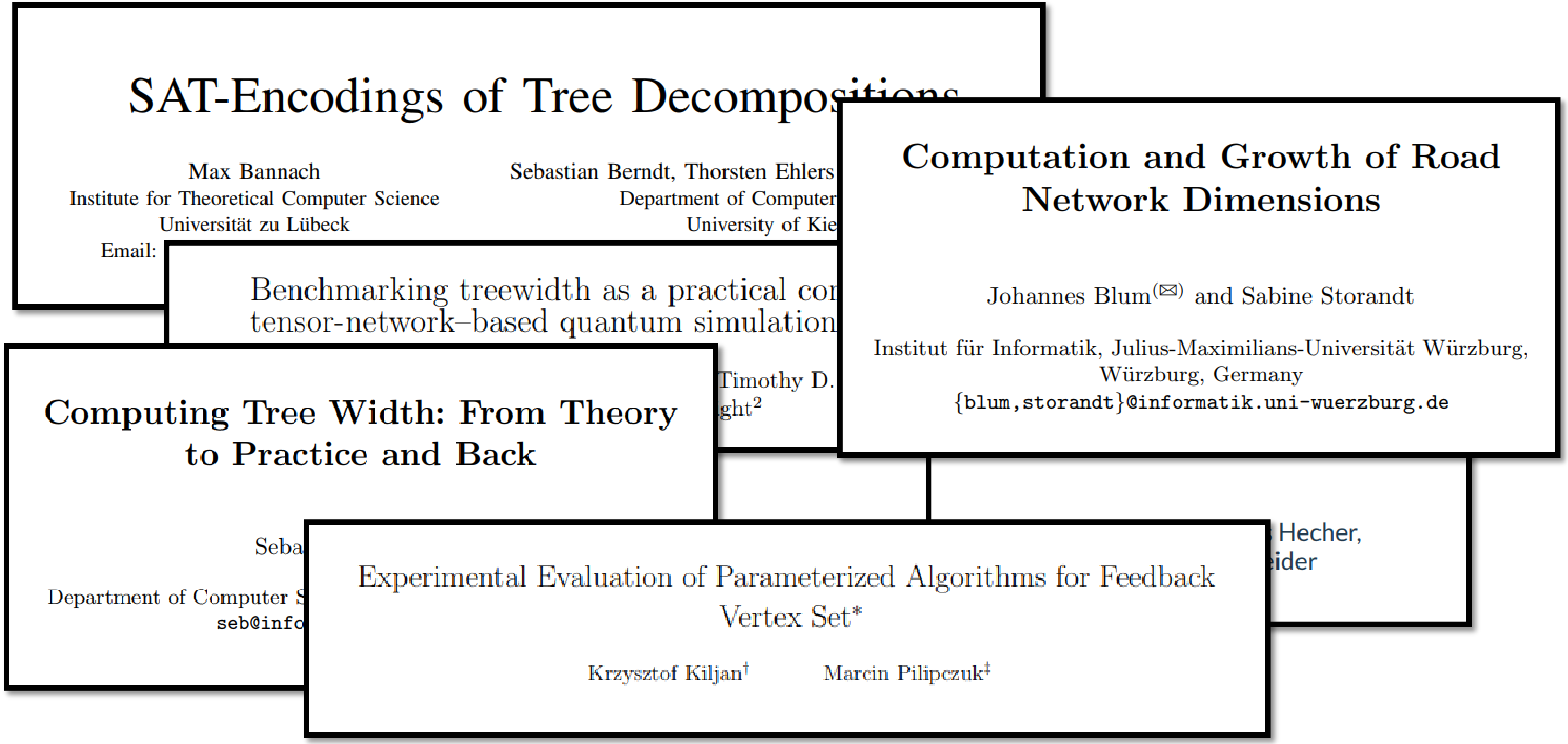
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Computing Tree Width: From Theory to Practice and Back

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Experimental Evaluation of Parameterized Algorithms for Feedback Vertex Set*

Krzysztof Kiljan† Marcin Pilipczuk‡

Publications following the second PACE

SAT-Encodings of Tree Decompositions

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Weighted Model Counting on the GPU by Exploiting Small Treewidth

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Comput

Department

Hecher,
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d Algorithms for Feedback

Krzysztof Kiljan[†] Marcin Pilipczuk[‡]

People behind PACE

Program committee chairs for 2017-2018:

Édouard Bonnet	ENS de Lyon
Florian Sikkora	Université Paris-Dauphine

Steering committee

Holger Dell	Saarland Informatics Campus
Bart M. P. Jansen*	Eindhoven University of Technology
Thore Husfeldt	ITU Copenhagen and Lund University
Petteri Kaski	Aalto University
Christian Komusiewicz	Philipps-Universität Marburg
Frances A. Rosamond	University of Bergen

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Center for Mathematics and
Computer Science (CWI)

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data experts

Systemberatung
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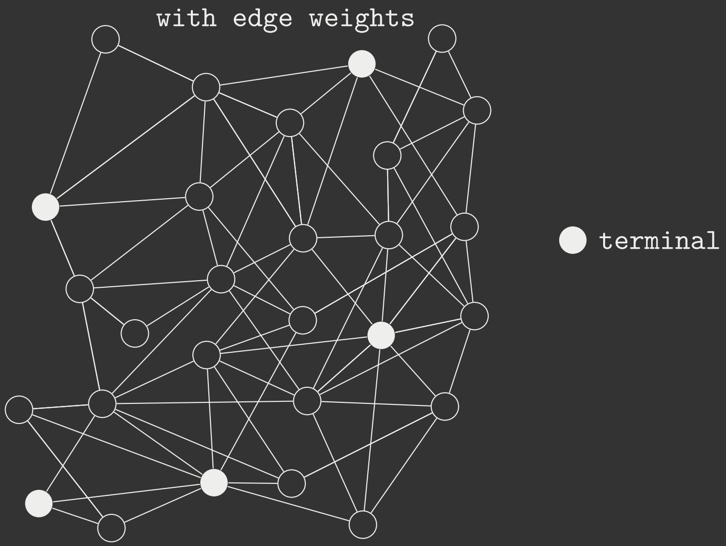
Informationsverarbeitung

HOW IT WENT & WHO WON

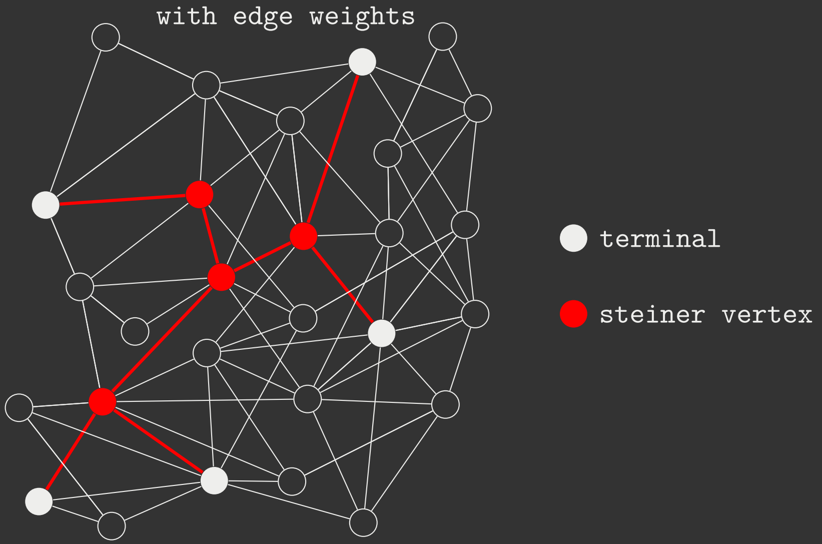
>>> The 3rd Parameterized Algorithms and Computational Experiments Challenge: Steiner Tree

Name: Édouard Bonnet and Florian Sikora (ENS de Lyon and Université Paris-Dauphine)
Date: August 22nd 2018, Helsinki

>>> Challenge Problem: Steiner Tree



>>> Challenge Problem: Steiner Tree



find the lightest tree spanning the terminals

>>> **Why Steiner Tree?**

* Real-life applications: design of VLSI, optical and wireless communication systems, transport networks.

* Among Karp's 21 NP-complete problems: one of the most fundamental graph problems

* Established benchmark and strong programs: 11th DIMACS implementation challenge

>>> Why Steiner Tree?

* Real-life applications: design of VLSI, optical and wireless communication systems, transport networks.

* Among Karp's 21 NP-complete problems: one of the most fundamental graph problems

* Established benchmark and strong programs: 11th DIMACS implementation challenge

* and, of course, fixed-parameter algorithms

>>> Choice of the tracks

n: number of vertices

m: number of edges

t: number of terminals

Algorithms:

- Dreyfus-Wagner, Erickson-Monma-Veinott $3^t n + 2^t(n \log n + m)$

Tracks:

- Track A, few terminals

>>> Choice of the tracks

n: number of vertices

m: number of edges

t: number of terminals

w: treewidth

Algorithms:

* Dreyfus-Wagner, Erickson-Monma-Veinott $3^t n + 2^t (n \log n + m)$
* DP $O^*(w^w)$, improved to $2^{O(w)} n$ by the rank-based approach

Tracks:

* Track A, few terminals
* Track B, low treewidth

>>> Choice of the tracks

n: number of vertices
m: number of edges
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Algorithms:

* Dreyfus-Wagner, Erickson-Monma-Veinott $3^t n + 2^t(n \log n + m)$
* DP $O^*(w^w)$, improved to $2^{O(w)}n$ by the rank-based approach
* constant approximations, fixed-parameter approximations

Tracks:

* Track A, few terminals
* Track B, low treewidth
* Track C, heuristics

>>> Instances

100 public and 100 private instances (from Steinlib & Vienna)

* grid graphs with rectangular holes and ℓ_1-weights
* Wire-routing problems from industry
* random sparse instances resistent to preprocessing
* Rectilinear instances with low treewidth
* Real-world telecommunication networks

>>> Instances and rules

100 public and 100 private instances (from Steinlib & Vienna)

* grid graphs with rectangular holes and ℓ_1-weights
* Wire-routing problems from industry
* random sparse instances resistent to preprocessing
* Rectilinear instances with low treewidth
* Real-world telecommunication networks

Rules:

* All tracks: 30 minutes per instance, final score on the 100 private instances
* Tracks A and B: number of solved instances
* Track C: sum of the ratios opt/sol

A wrong answer disqualifies in Tracks A and B, and gives 0 for that instance in Track C

>>> Selection of the instances

* Track A: few terminals, high treewidth
* Track B: low treewidth, many terminals
* Track C: many terminals, high treewidth, unsolved

Track	$\mathbb{E}[n]$	$\mathbb{E}[m]$	$\mathbb{E}[t]$	median t	$\mathbb{E}[w]$	median w
A	1.5K	8.5K	19.4	16	$\approx$ 100	$\approx$ 25
B	1.5K	2.8K	606	100	14.9	19.5
C	27K	48K	1114	360	$\approx$ 150	$\approx$ 50

In Track B, a tree-decomposition was given with the input computed by Tamaki's and Strasser's codes of PACE 2017

>>> The OPTIL.io platform hosted all three tracks

* Many languages supported; added more upon request
* Extra PACE participants among the OPTIL.io habitués
* Alleviates our workload in organizing PACE

OPTIL.io ABOUT CONTESTS PROBLEMS STANDING

OPTIMAL STEINER TREE: PACE 2018 C

By Florian Sikora[1], Edouard Bonnet[2]

DESCRIPTION RUNS STANDING SUBMIT DISCUSS

TLE = Time Limit Exceeded, **WA** = Wrong Answer, **RTE** = Runtime Error, **MLE** = Memory Limit Exceeded, **OLE** = Output Limit Exceeded, **PLE** = Processes Limit Exceeded, more help...

First 1 Last

#	USER	LANGUAGE	SCORE	TIME [S]	1	2	3	4	5	6	7	8
1	CIMAT_Team	C++	**99.91**	180,011.54	15,076.00	23,765.00	27,684.00	20,678.00	13,309,487.00	50,605.00	75.00	14,171,206.(
2	reko	Static binary	**99.89**	107,315.80	15,076.00	23,765.00	27,685.00	20,678.00	13,309,487.00	50,617.00	75.00	14,171,206.(
3	Martin_J_Geiger	VB.NET	**99.78**	150,654.81	15,076.00	23,765.00	27,684.00	20,678.00	13,309,487.00	50,559.00	75.00	14,171,206.(
4	Tarken	CMake package	**99.70**	177,706.78	15,076.00	23,765.00	27,684.00	20,678.00	13,309,487.00	50,656.00	75.00	14,171,206.(
5	mucha	C++	**99.63**	179,328.03	15,076.00	23,765.00	27,684.00	20,719.00	13,309,487.00	50,639.00	75.00	14,171,774.(
6	Gardeners	Static binary	**99.32**	134,615.66	15,076.00	23,765.00	27,684.00	20,678.00	13,309,487.00	50,559.00	75.00	14,171,206.(
7	Radewoosh	C++	**99.12**	173,225.90	15,076.00	23,779.00	27,855.00	20,721.00	13,309,487.00	51,111.00	75.00	14,171,445.(
8	Johnson_Johnson	Jar file	**98.52**	149,378.01	15,514.00	24,169.00	27,823.00	20,814.00	13,309,487.00	51,245.00	75.00	14,173,383.(
9	UWarsaw	C++	**98.25**	150,506.07	15,076.00	23,765.00	27,785.00	20,719.00	13,309,487.00	50,808.00	75.00	14,173,996.(

Many thanks to Szymon Wasik and Jan Badura!

>>> Participation

Country	Teams	Participants
Austria	2	4
Brazil	1	3
Canada	1	1
Czechia	2	4
Denmark	1	1
England	1	1
Finland	1	1
France	4	7
Germany	4	5
India	6	12
Japan	4	8
Mexico	1	4
Netherlands	2	6
Norway	2	4
Poland	2	11
Romania	1	3

Complete submissions

Track A: 12
Track B: 8
Track C: 13

>>> Implementations

A lot of preprocessing and...

FPT algorithms:

* DW(++)/EMV(++): 1st, 2nd, 4th to 9th in Track A, 2nd, 3rd, 4th in Track B
* DP $O^*(w^w)$: 2nd in Track B
* rank-based approach: 3rd to 8th in Track B
  solved instances that were not solved by other programs
* FPT approximation: 4th Track C

or other approaches:

* Branch-and-Cut: 3rd in Track A, 1st in B, 2nd in C
* Evolutionary algorithm: 1st in Track C
* Iterated local search with noising: 3rd in Track C

SCIP-Jack: A general Steiner tree solver

Daniel Rehfeldt · Thorsten Koch

Zuse Institute Berlin

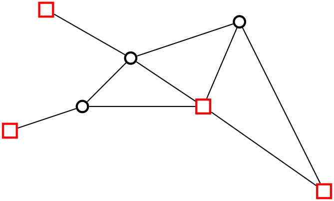
Technische Universität Berlin

Berlin Mathematical School

IPEC, Helsinki, August 2018

Given:

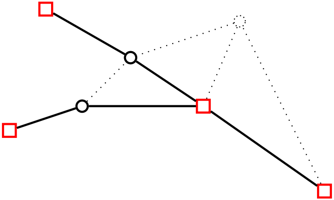
- ▷ $G = (V, E)$: undirected graph
- ▷ $T \subseteq V$: subset of vertices
- ▷ $c \in \mathbb{R}^{E}_{>0}$: positive edge costs



The Steiner tree problem in graphs

Given:

- ▷ $G = (V, E)$: undirected graph
- ▷ $T \subseteq V$: subset of vertices
- ▷ $c \in \mathbb{R}^E_{>0}$: positive edge costs



A tree $S \subseteq G$ is called Steiner tree in (G, T, c) if $T \subseteq V(S)$

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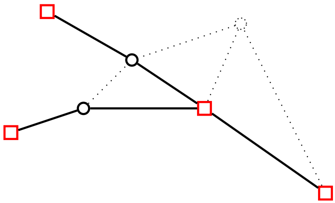


A tree $S \subseteq G$ is called Steiner tree in (G, T, c) if $T \subseteq V(S)$

Steiner tree Problem in Graphs (SPG)

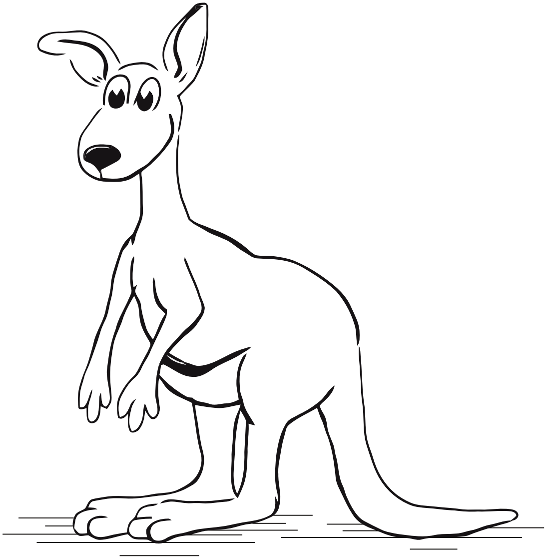
Find a Steiner tree S in (G, T, c) with minimum edge costs $\sum_{e \in E(S)} c(e)$

SPG is one of the classical combinatorial optimization problems; decision variant is one of Karp's 21 $\mathcal{NP}$-complete problems.

SCIP-Jack:

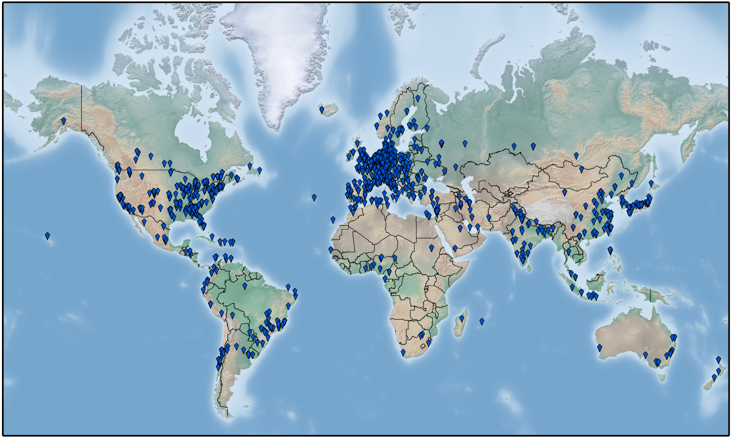
- ▷ Solver for Steiner tree (and 11 related) problems
- ▷ part of the SCIP Optimization Suite
- ▷ was used with our LP solver SoPlex[1] (default is CPLEX)

[1] current developers: Leon Eifler, Matthias Miltenberger, D.R.



Some facts about SCIP

- general setup
  - plugin based system
  - default plugins handle MIPs and nonconvex MINLPs
  - support for branch-and-price and custom relaxations
- documentation and guidelines
  - more than 500 000 lines of C code, 20% documentation
    - 36 000 assertions, 5 000 debug messages
  - HowTos: plugins types, debugging, automatic testing
  - 11 examples and 5 applications illustrating the use of SCIP
  - active mailing list `scip@zib.de` (300 members)
- interface and usability
  - user-friendly interactive shell
  - interfaces to AMPL, GAMS, ZIMPL, MATLAB, Python and Java
  - C++ wrapper classes
  - LP solvers: CLP, CPLEX, Gurobi, MOSEK, QSopt, SoPlex, Xpress
  - over 1 600 parameters and 15 emphasis settings



over 10 000 downloads per year

Why not using a general MIP solver?

Consider (small-scale) network design instance with:

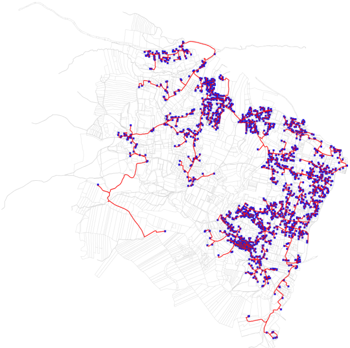
$$|V| = 12\,715$$

$$|E| = 41\,264$$

$$|T| = 475$$

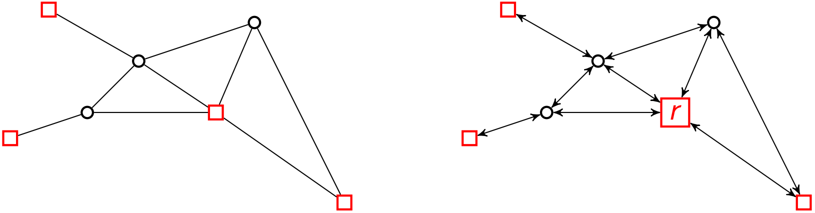
- ▷ CPLEX 12.7.1: Runs out of memory after 14 h
- ▷ SCIP-Jack: Solves to optimality in 7.5 seconds

For larger problems CPLEX runs out of memory almost immediately (largest real-world instance SCIP-Jack solved so far has 64 million edges, 11 million vertices)



Network telecommunication design for Austrian cities, see *New Real-world Instances for the Steiner Tree Problem in Graphs* (Leitner et al., 2014)

- transform each SPG into Steiner arborescence problem and ...



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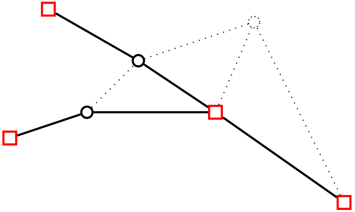
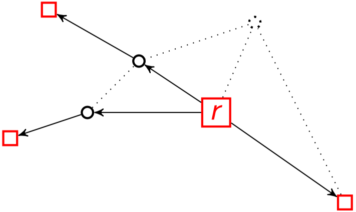




... use cutting plane algorithm based on flow balance directed-cut formulation:

Formulation

$$
\begin{array}{rcll}
\min c^T y & & & \\
y(\delta_W^+) & \geqslant & 1 & \text{for all } W \subset V, r \in W, (V \setminus W) \cap T \neq \emptyset \\
y(\delta_v^-) & \leqslant & y(\delta_v^+) & \text{for all } v \in V \setminus T \\
y(\delta_v^-) & \geqslant & y(a) & \text{for all } a \in \delta_v^+, v \in V \setminus T \\
y(a) & \in & \{0,1\} & \text{for all } a \in A
\end{array}
$$

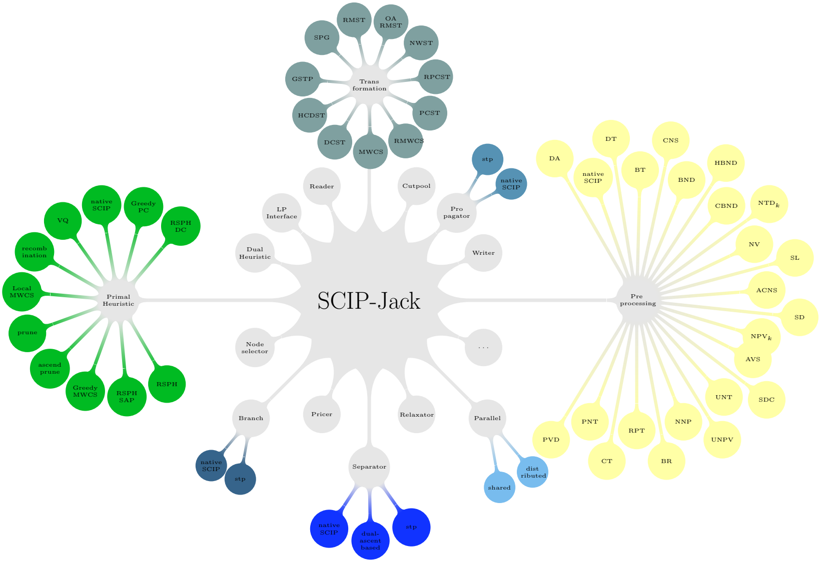
main features of SCIP-Jack for SPGs:

[2] Latest version was not used at PACE 2018

main features of SCIP-Jack for SPGs:

- very fast separator routine based on new max-flow implementation[2]
- preprocessing routines
- domain propagation routines
- primal and dual heuristics
- shared and distributed memory parallelizations

[2] Latest version was not used at PACE 2018


SCIP-Jack
Trans formation
RMST
OA RMST
SPG
NWST
RPCST
GSTP
HCDST
PCST
DCST
MWCS
RMWCS
Reader
Cutpool
LP Interface
Pro pagator
stp
native SCIP
Dual Heuristic
Writer
Primal Heuristic
native SCIP
Greedy PC
VQ
RSPH DC
recomb ination
Local MWCS
prune
ascend prune
Greedy MWCS
RSPH SAP
RSPH
Node selector
. . .
Branch
native SCIP
stp
Pricer
Relaxator
Parallel
shared
dist ributed
Separator
native SCIP
dual-ascent based
stp
Pre processing
DA
DT
CNS
native SCIP
BT
HBND
BND
CBND
NTD$_k$
NV
SL
ACNS
SD
NPV$_k$
AVS
UNT
SDC
PVD
PNT
RPT
NNP
UNPV
CT
BR

Central feature: Reduction techniques

- reduction techniques try to transform an instance to an equivalent smaller one (e.g. by deleting edges or vertices)
- reduction techniques of SCIP-Jack typically reduce # edges by more than 70 %

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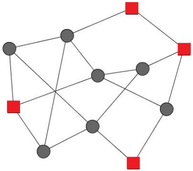
original instance (5000 edges)



reduced instance (less edges)

Example for (new) SPG reduction technique, implemented for PACE 2018:

Terminal regions decomposition

Example for (new) SPG reduction technique, implemented for PACE 2018:

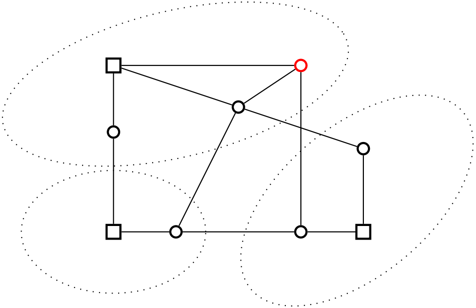
Define distance function $\underline{d} : V \times V \mapsto \mathbb{R} \cup \{\infty\}$:

$\underline{d}(v_i, v_j) := \inf\{P(Q) \mid Q \text{ is a } (v_i, v_j)\text{-path and } (V(Q) \setminus \{v_i, v_j\}) \cap T = \emptyset\}$

Define decomposition $H = \{H_{t_i} \subseteq V \mid T \cap H_{t_i} = \{t_i\}\}$ of V such that for each $t_i \in T$ the subgraph $(H_{t_i}, E[H_{t_i}])$ is connected.

Define radius:

$$r_H(t_i) := \min\{\underline{d}(t_i, v_k) \mid \exists\{v_j, v_j\} \in E, v_j \in H_{t_i}, v_k \notin H_{t_i}\}$$



Proposition

Let H be a terminal regions decomposition and assume that $|T| \geqslant 2$. Let $v_i \in V \setminus T$, assume for each optimal solution S that $v_i \in V(S)$. Then

$$\sum_{t \in T} r_H(t) - \max\{r_H(t) + r_H(t') \mid t, t' \in T,\ t \neq t'\} + \underline{d}(v_i, \underline{v}_{i,1}) + \underline{d}(v_i, \underline{v}_{i,2})$$

is lower bound on the weight of S.

Finding an optimal terminal regions decomposition is NP-hard!

Using reduction techniques in domain propagation

Each SCIP-Jack Steiner tree reduction transforms SPG (V, E, T, c) to SPG (V', E', T', c') and provides function $p : E' \rightarrow \mathcal{P}(E)$ such that for each (optimal) solution $S' \subseteq E'$ to transformed problem, set $\bigcup_{e \in S'} p(e)$ is (optimal) solution to original problem.

Observation

Let (V, E, T, c), (V', E', T', c'), and p as above. Define
$E'' := \bigcup_{e \in E'} p(e)$,
$V'' := \{v \in V \mid \exists (v, w) \in E'', w \in V\}$,
$T'' := \{t \in T \mid \exists (t, w) \in E'', w \in V\}$,
$c'' := c|_{E''}$.
Each (optimal) solution to (V'', E'', T'', c'') is (optimal) solution to (V, E, T, c).

$\Rightarrow$ allows to translate reductions into variable fixings during branch-and-bound

Futher uses of reducion techniques

- Primal heuristics: Several heuristics of SCIP-Jack create subproblems (e.g. by merging feasible solutions), reduction techniques are vital to finding a good solution there
- Branch-and-bound: SCIP-Jack branches on vertices, providing new opportunities for reduction techniques

For PACE 2018

- new reduction techniques were designed and implemented (suitable for but not restricted to problems with few terminals)

For PACE 2018

- new reduction techniques were designed and implemented (suitable for but not restricted to problems with few terminals)
- reduction techniques and heuristics were performed far more aggressively to compensate for slower LP solver SoPlex
- ...still SCIP-Jack/CPLEX shows a far stronger performance

For PACE 2018

- new reduction techniques were designed and implemented (suitable for but not restricted to problems with few terminals)
- reduction techniques and heuristics were performed far more aggressively to compensate for slower LP solver SoPlex
- ...still SCIP-Jack/CPLEX shows a far stronger performance
- most new algorithms are included in latest SCIP release **http://scip.zib.de**

Thanks to the organizers of PACE 2018!

...thanks to NETWORKS for travel support!

...and thank you for your attention!

>>> Track A results

* **9th place, 48:** Saket Saurabh, P. S. Srinivasan, and Prafullkumar Tale

>>> Track A results

* **6th place, 66:** Suhas Thejaswi
* **6th place, 66:** Peter Mitura and Ondřej Suchý
* **6th place, 66:** Johannes Varga
* **9th place, 48:** Saket Saurabh, P. S. Srinivasan, and Prafullkumar Tale

\>>> Track A results

* **5th place, 67:** Krzysztof Kiljan, Dominik Klemba, Marcin Mucha, Wojciech Nadara, Marcin Pilipczuk, Mateusz Radecki, and Michał Ziobro
* **6th place, 66:** Suhas Thejaswi
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* **6th place, 66:** Johannes Varga
* **9th place, 48:** Saket Saurabh, P. S. Srinivasan, and Prafullkumar Tale

>>> Track A results

* **4th place, 92:** Andre Schidler, Johannes Fichte, and Markus Hecher

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* **6th place, 66:** Suhas Thejaswi
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Andre Schidler, Johannes Fichte, and Markus Hecher

Technische Universität Wien

for

Fourth Place in Track A: Exact Steiner Tree with Few Terminals

€ 225,-

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>>> Track A results

* **3rd place, 93:** Thorsten Koch and Daniel Rehfeldt
* **4th place, 92:** Andre Schidler, Johannes Fichte, and Markus Hecher
* **5th place, 67:** Krzysztof Kiljan, Dominik Klemba, Marcin Mucha, Wojciech Nadara, Marcin Pilipczuk, Mateusz Radecki, and Michał Ziobro
* **6th place, 66:** Suhas Thejaswi
* **6th place, 66:** Peter Mitura and Ondřej Suchý
* **6th place, 66:** Johannes Varga
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Third Place in Track A: Exact Steiner Tree with Few Terminals

€ 300,-

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>>> Track A results

* **2nd place, 94:** Krzysztof Maziarz and Adam Polak
* **3rd place, 93:** Thorsten Koch and Daniel Rehfeldt
* **4th place, 92:** Andre Schidler, Johannes Fichte, and Markus Hecher

* **5th place, 67:** Krzysztof Kiljan, Dominik Klemba, Marcin Mucha, Wojciech Nadara, Marcin Pilipczuk, Mateusz Radecki, and Michał Ziobro
* **6th place, 66:** Suhas Thejaswi
* **6th place, 66:** Peter Mitura and Ondřej Suchý
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Krzysztof Maziarz and Adam Polak

Jagiellonian University

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Second Place in Track A: Exact Steiner Tree with Few Terminals

€ 350,-

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Florian Sikora, Université Paris-Dauphine

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>>> Track A results

* **1st place, 95:** Yoichi Iwata and Takuto Shigemura
* **2nd place, 94:** Krzysztof Maziarz and Adam Polak
* **3rd place, 93:** Thorsten Koch and Daniel Rehfeldt
* **4th place, 92:** Andre Schidler, Johannes Fichte, and Markus Hecher

* **5th place, 67:** Krzysztof Kiljan, Dominik Klemba, Marcin Mucha, Wojciech Nadara, Marcin Pilipczuk, Mateusz Radecki, and Michał Ziobro
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National Institute of Informatics, Japan — University of Tokyo

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First Place in Track A: Exact Steiner Tree with Few Terminals

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>>> Track A results - 2

* **Honorable mention:** Sharat Ibrahimpur solved 69 out of 100 instances but was incorrect on one instance

* **11th place, 14:** S. Vaishali and Rathna Subramanian
* **12th place, 9:** R. Vijayaragunathan, N. S. Narayanaswamy, and Rajesh Pandian M.

The winning heuristic for Track C actually solved all 100 private[1] instances in track A!

[1] it returned a wrong answer on some public instance

>>> Track B results

* **7th place, 33:** Krzysztof Kiljan, Dominik Klemba, Marcin Mucha, Wojciech Nadara, Marcin Pilipczuk, Mateusz Radecki, and Michał Ziobro
* **7th place, 33:** Dilson Guimarães, Guilherme Gomes, João Gonçalves, and Vinícius dos Santos

>>> Track B results

* **6th place, 49:** Akio Fujiyoshi
* **7th place, 33:** Krzysztof Kiljan, Dominik Klemba, Marcin Mucha, Wojciech Nadara, Marcin Pilipczuk, Mateusz Radecki, and Michał Ziobro
* **7th place, 33:** Dilson Guimarães, Guilherme Gomes, João Gonçalves, and Vinícius dos Santos

>>> Track B results

* **4th place, 52:** Peter Mitura and Ondřej Suchý
* **4th place, 52:** Yasuaki Kobayashi
* **6th place, 49:** Akio Fujiyoshi
* **7th place, 33:** Krzysztof Kiljan, Dominik Klemba, Marcin Mucha, Wojciech Nadara, Marcin Pilipczuk, Mateusz Radecki, and Michał Ziobro
* **7th place, 33:** Dilson Guimarães, Guilherme Gomes, João Gonçalves, and Vinícius dos Santos

>>> Track B results

* **3rd place, 58:** Tom van der Zanden
* **4th place, 52:** Peter Mitura and Ondřej Suchý
* **4th place, 52:** Yasuaki Kobayashi
* **6th place, 49:** Akio Fujiyoshi
* **7th place, 33:** Krzysztof Kiljan, Dominik Klemba, Marcin Mucha, Wojciech Nadara, Marcin Pilipczuk, Mateusz Radecki, and Michał Ziobro
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Tom van der Zanden

Utrecht University

for

Third Place in Track B: Exact Steiner Tree with Small Treewidth

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>>> Track B results

* **2nd place, 77:** Yoichi Iwata and Takuto Shigemura
* **3rd place, 58:** Tom van der Zanden

* **4th place, 52:** Peter Mitura and Ondřej Suchý
* **4th place, 52:** Yasuaki Kobayashi
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>>> Track C results

* **13th place, 80.73:** Harumi Haraguchi, Hiroshi Arai, Shiyougo Akiyama, and Masaki Kubonoya

>>> Track C results

* **12th place, 82.61:** Saket Saurabh, P. S. Srinivasan, and Prafullkumar Tale
* **13th place, 80.73:** Harumi Haraguchi, Hiroshi Arai, Shiyougo Akiyama, and Masaki Kubonoya

>>> Track C results

* **11th place, 94.37:** Sharat Ibrahimpur
* **12th place, 82.61:** Saket Saurabh, P. S. Srinivasan, and Prafullkumar Tale
* **13th place, 80.73:** Harumi Haraguchi, Hiroshi Arai, Shiyougo Akiyama, and Masaki Kubonoya

\>>> Track C results

* **10th place, 94.57:** R. Vijayaragunathan, N. S. Narayanaswamy, and Rajesh Pandian M.
* **11th place, 94.37:** Sharat Ibrahimpur
* **12th place, 82.61:** Saket Saurabh, P. S. Srinivasan, and Prafullkumar Tale
* **13th place, 80.73:** Harumi Haraguchi, Hiroshi Arai, Shiyougo Akiyama, and Masaki Kubonoya

>>> Track C results

* **9th place, 96.92:** Dimitri Watel and Marc-Antoine Weisser
* **10th place, 94.57:** R. Vijayaragunathan, N. S. Narayanaswamy, and Rajesh Pandian M.
* **11th place, 94.37:** Sharat Ibrahimpur
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>>> Track C results

* **8th place, 97.15:** Max Hort, Marciano Geijselaers, Joshua Scheidt, Pit Schneider, and Tahmina Begum
* **9th place, 96.92:** Dimitri Watel and Marc-Antoine Weisser
* **10th place, 94.57:** R. Vijayaragunathan, N. S. Narayanaswamy, and Rajesh Pandian M.
* **11th place, 94.37:** Sharat Ibrahimpur
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* **11th place, 94.37:** Sharat Ibrahimpur
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* **13th place, 80.73:** Harumi Haraguchi, Hiroshi Arai, Shiyougo Akiyama, and Masaki Kubonoya

>>> Track C results

* **6th place, 98.27:** Krzysztof Kiljan, Dominik Klemba, Marcin Mucha, Wojciech Nadara, Marcin Pilipczuk, Mateusz Radecki, and Michał Ziobro
* **7th place, 97.54:** Stéphane Grandcolas
* **8th place, 97.15:** Max Hort, Marciano Geijselaers, Joshua Scheidt, Pit Schneider, and Tahmina Begum
* **9th place, 96.92:** Dimitri Watel and Marc-Antoine Weisser
* **10th place, 94.57:** R. Vijayaragunathan, N. S. Narayanaswamy, and Rajesh Pandian M.
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* **12th place, 82.61:** Saket Saurabh, P. S. Srinivasan, and Prafullkumar Tale
* **13th place, 80.73:** Harumi Haraguchi, Hiroshi Arai, Shiyougo Akiyama, and Masaki Kubonoya

>>> Track C results

* **5th place, 98.93:** Mateus Oliveira and Emmanuel Arrighi
* **6th place, 98.27:** Krzysztof Kiljan, Dominik Klemba, Marcin Mucha, Wojciech Nadara, Marcin Pilipczuk, Mateusz Radecki, and Michał Ziobro
* **7th place, 97.54:** Stéphane Grandcolas
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>>> Track C results - 2

The top 4 got an average ratio above 0.997

* **4th place, 99.72:** Radek Hušek, Tomáš Toufar, Dušan Knop, Tomáš Masařík, and Eduard Eiben

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Radek Hušek, Tomáš Toufar, Tomáš Masarík, Dušan Knop, and Eduard Eiben

Charles University & University of Bergen, Norway

for

Fourth Place in Track C: Heuristic Steiner Tree

€ 225,-

Édouard Bonnet, ENS de Lyon

Florian Sikora, Université Paris-Dauphine

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>>> Track C results - 2

The top 4 got an average ratio above 0.997

* **3rd place, 99.80:** Martin J. Geiger
* **4th place, 99.72:** Radek Hušek, Tomáš Toufar, Dušan Knop, Tomáš Masařík, and Eduard Eiben

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Martin Geiger

Helmut Schmidt Universität, Hamburg

for

Third Place in Track C: Heuristic Steiner Tree

€ 300,-

Édouard Bonnet, ENS de Lyon

Florian Sikora, Université Paris-Dauphine

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>>> Track C results - 2

The top 4 got an average ratio above 0.997

* **2nd place, 99.85:** Thorsten Koch and Daniel Rehfeldt
* **3rd place, 99.80:** Martin J. Geiger
* **4th place, 99.72:** Radek Hušek, Tomáš Toufar, Dušan Knop, Tomáš Masařík, and Eduard Eiben

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Second Place in Track C: Heuristic Steiner Tree

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>>> Track C results - 2

The top 4 got an average ratio above 0.997

* **1st place, 99.93:** Emmanuel Romero Ruiz, Emmanuel Antonio Cuevas, Irwin Enrique Villalobos López, and Carlos Segura González
* **2nd place, 99.85:** Thorsten Koch and Daniel Rehfeldt
* **3rd place, 99.80:** Martin J. Geiger
* **4th place, 99.72:** Radek Hušek, Tomáš Toufar, Dušan Knop, Tomáš Masařík, and Eduard Eiben

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Emmanuel Romero Ruiz, Emmanuel Antonio Cuevas,
Irwin Enrique Villalobos Lopez, and Carlos Segura González

Center for Research in Mathematics, Guanajuato, Mexico

for

First Place in Track C: Heuristic Steiner Tree

€ 450,-

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Markus Hecher	TU Wien
Johannes Fichte	TU Dresden

The next PACE

PACE 2018-2019 program committee

Markus Hecher TU Wien
Johannes Fichte TU Dresden

Vertex Cover

&

...-width

PACE timeline in 2018-2019

Tentative time schedule

- Today: Announcement of the PC & challenge problem
- October 1st 2018: Announcement of challenge problems & tracks
- November 1st 2018: Announcement of detailed problem setting and inputs
- At least 2 weeks before IPEC deadline: Result communicated to participants
- September 10-14 2019: Award ceremony at IPEC

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Eindhoven University of Technology
Leiden University
Center for Mathematics and
Computer Science (CWI)

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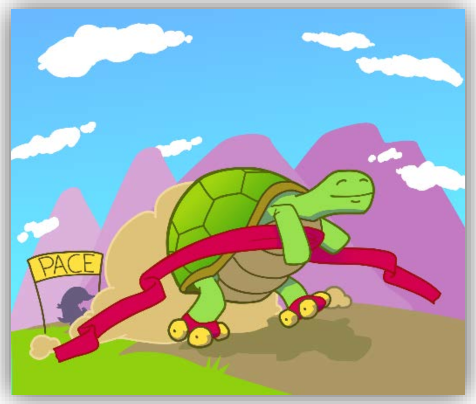

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