PACE 2026

Rooted Maximum Agreement Forest

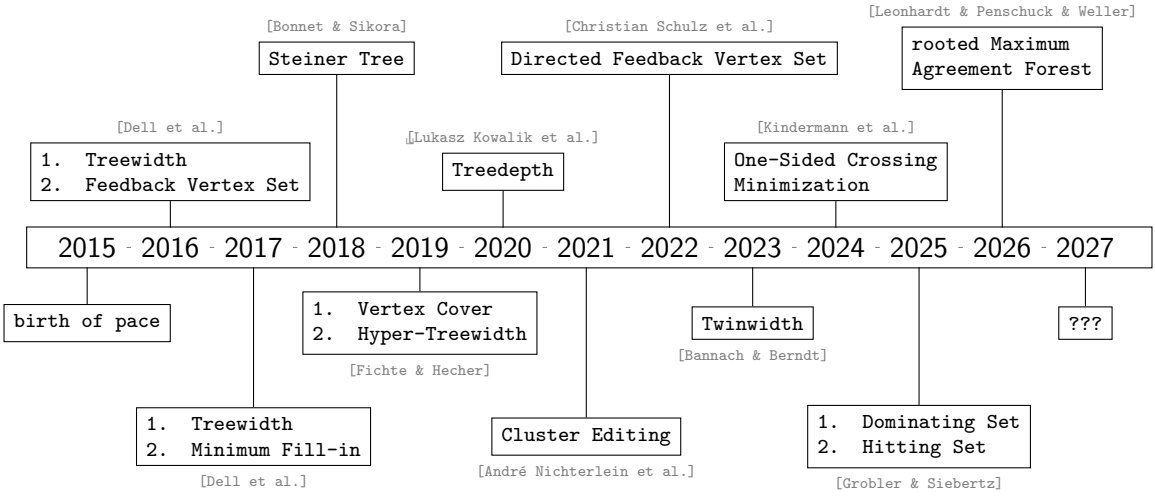
Alexander Leonhardt*, Manuel Penschuck†, Mathias Weller‡

* Goethe-Universität Frankfurt, Germany
† University of Southern Denmark
‡ CNRS, Université Gustave Eiffel, Paris, France

https://pacechallenge.org/

September 3, 2026

History of PACE



Impact of PACE

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Bart M. P. Jansen*	Eindhoven University of Technology
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Johannes Fichte	(2020-2023)	Frances Rosamond	(2016-2019)
Markus Hecher	(2020-2023)	Thore Husfeldt	(2016-2019)
Édouard Bonnet	(2017-2021)		

Sponsors. We thank . . .

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- Networks for sponsoring the prizes and travel stipends.

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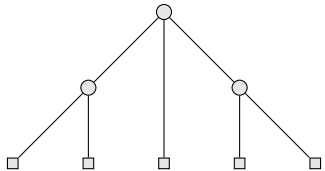
- UCloud (SDU) and GoetheNHR for providing more than 200k core-hours of compute.

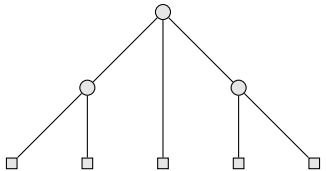
Problem: Maximum Rooted Agreement Forest

A phylogenetic tree is a tree.



Problem: Maximum Rooted Agreement Forest

A phylogenetic tree is a bijectively leaf-labelled tree.



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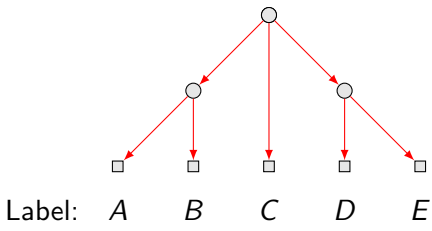
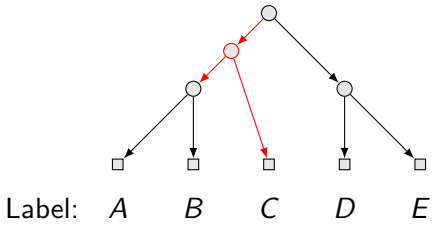


Problem: Maximum Rooted Agreement Forest

A phylogenetic tree is a rooted, bijectively leaf-labelled bifurcating tree.

inner out-deg(v)=2



Problem: Maximum Rooted Agreement Forest

- Input:

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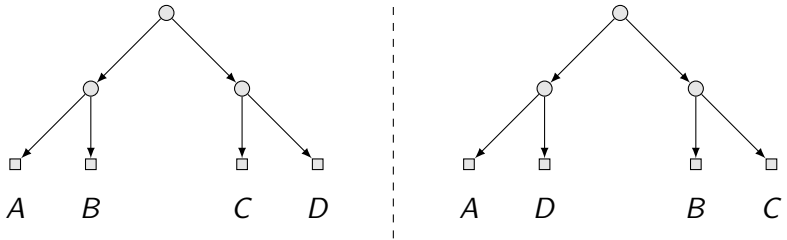

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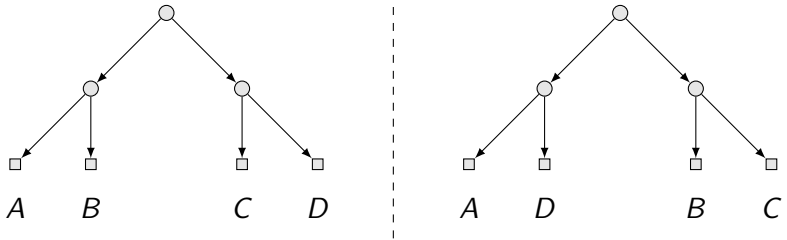

- Task: Find a minimum set of edges whose deletion produces the same isomorphic forest in all trees (after suppressing inner-vertices with out-degree 1).

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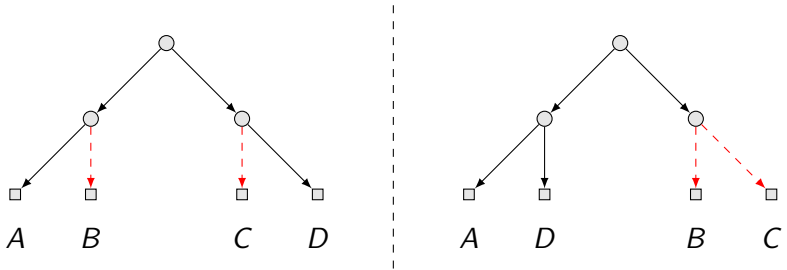

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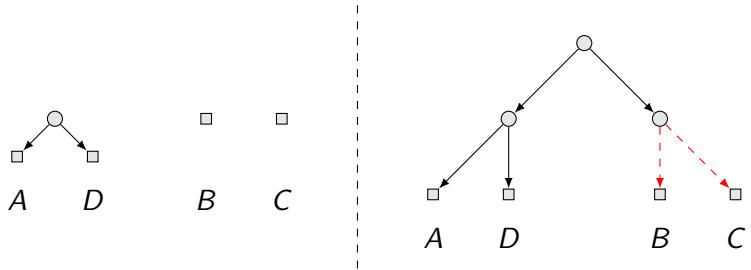

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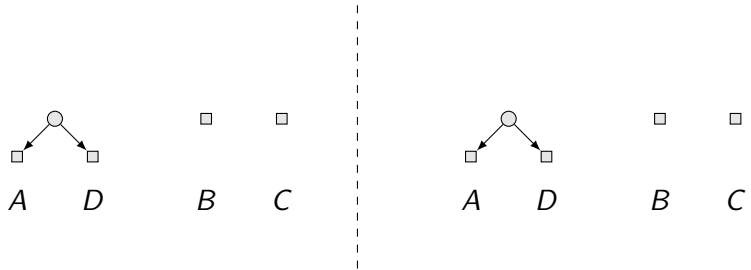

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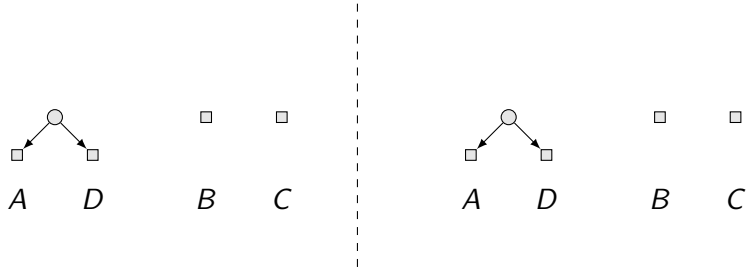

$$\mathcal{F} = \{\{A, B\}, \{C\}, \{D\}\}$$

Scientific Topic: Agreement Forests

Definition

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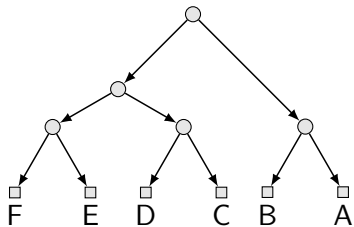

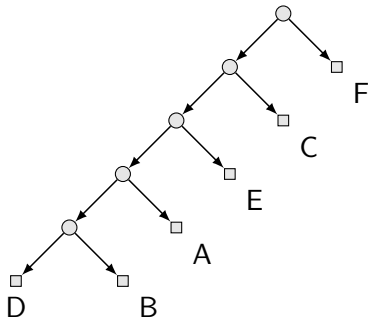

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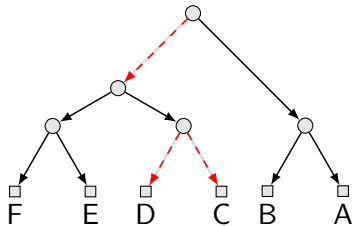

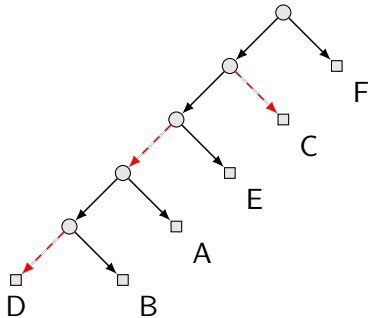

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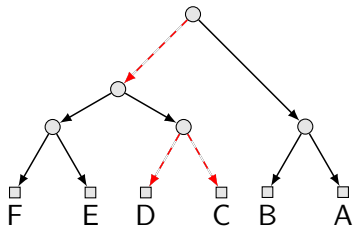
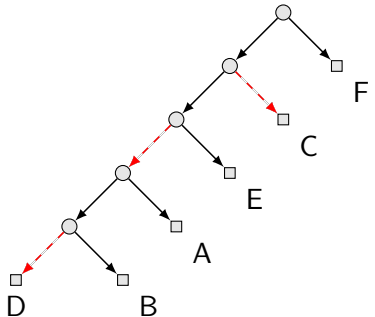
- The number of phylogenetic trees in an agreement forest F is called its size. If F has minimum size (maximizes the agreement), it is called a maximum-agreement forest.





Problem: Agreement Forest $t = 2$

Results for $t = 2$, $\mathrm{MAF}(T, T') = k$

- NP-hard

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During the challenge

- Branch-and-Price solver — Frohn et al.'25

Problem: Agreement Forest $t = k$

Results for MAF$(T_1, T_2, \ldots, T_t) = k$

- $O(3^k n^2 t)$ time — Shi et al. '14
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- problem kernel with $\mathcal{O}(t \cdot r \cdot l)$ — Kelk et al., '26

Track description

Exact track

- time:
  30min/instance

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- time:
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- score:
  one point per solved instance

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- time:
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Heuristic track

- time:
  5min/instance

Track description

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Heuristic track

- time:
  5min/instance
- score:
  $\max(0, (u-k)/(u-k^*))^2$
  - k: produced size

Track description

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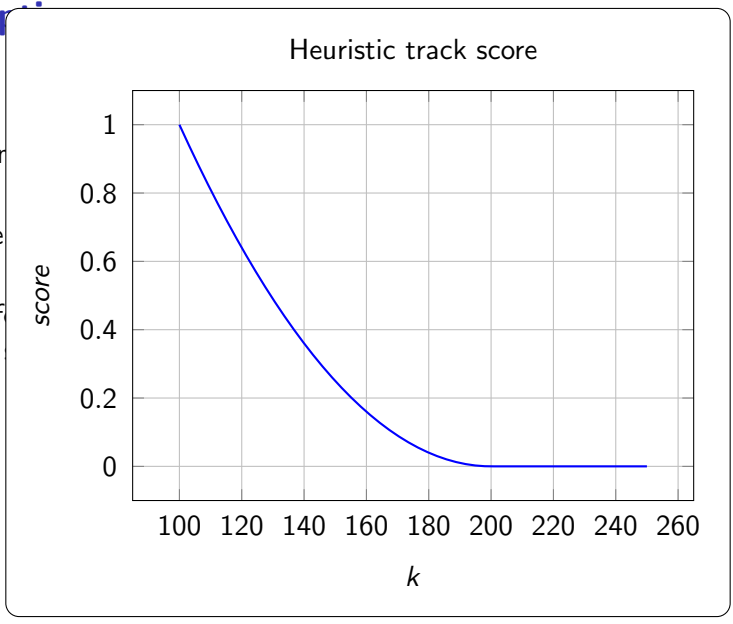

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Lower Bound track

- time:
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Track description

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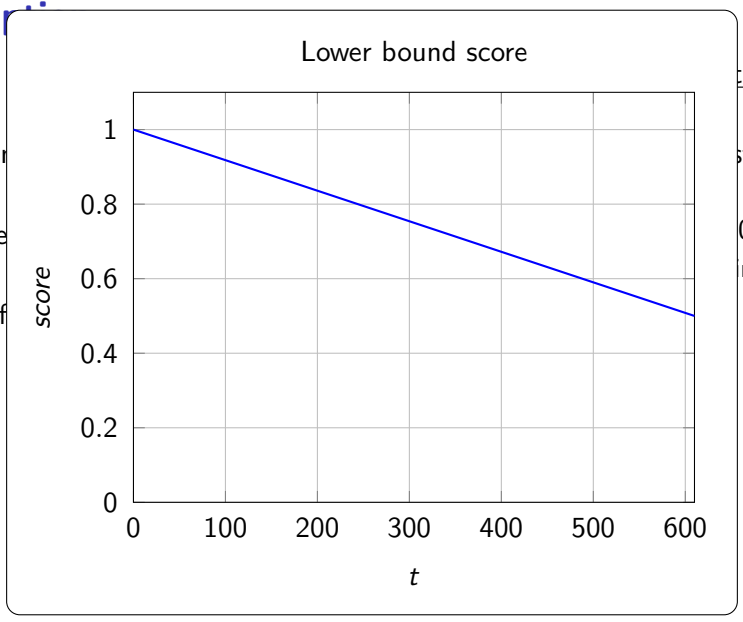
Lower Bound track

- time:
  10min/instance
- score:
  $(2 - t/610)/2$

Track descri

Exact track

- time: 30min/instar
- score: one point pe instance
- disqualified f infeasible or solution



rack

stance

0)/2

me in seconds

Track description

Exact track

- time:
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- score:
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Lower Bound track

- time:
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- score:
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  - t is time in seconds
- Condition: $\lfloor ak^* \rfloor + b$

Track description

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- Condition: $\lfloor ak^* \rfloor + b$
  - $1 \leq a < 1.5$
  - $b \geq 0$
- disqualified for:
  too large or infeasible solution

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- 8GB RAM in all tracks

Comparison with prior Challenges

- Reduced 16GB RAM $\rightarrow$ 8GB RAM

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  - New (practical?) algorithms for industry and practitioners

Comparison with prior Challenges

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  - Find solution for practically sufficient constraints fast!
  - New (practical?) algorithms for industry and practitioners
- Larger Benchmark sets
  - 150 public instances
  - 150 private instances
  - 100 hard instances (selected per solver)
  - Run thrice

Quality assurance

- Provided approx. 20k test instances

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- Peer review

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Result

- Received 14 bug fixes

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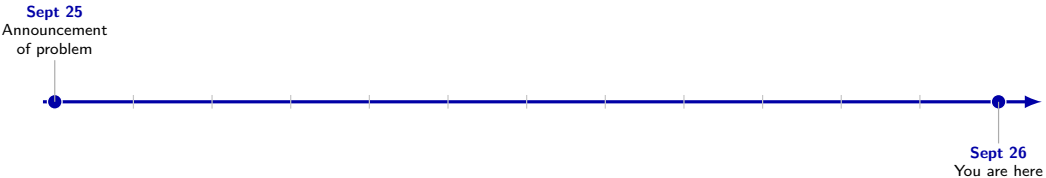
Result

- Received 14 bug fixes
- Disqualifications
  - 4 (out of 18) in Exact Track
  - 1 (out of 18) in Heuristic Track
  - 3 (out of 10) in Lower Bound Track

Timeline



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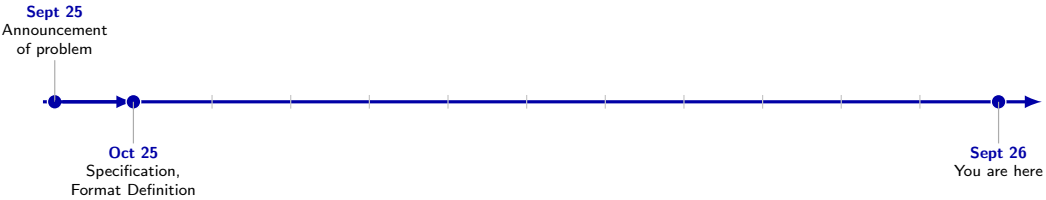
Sept 25
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Oct 25
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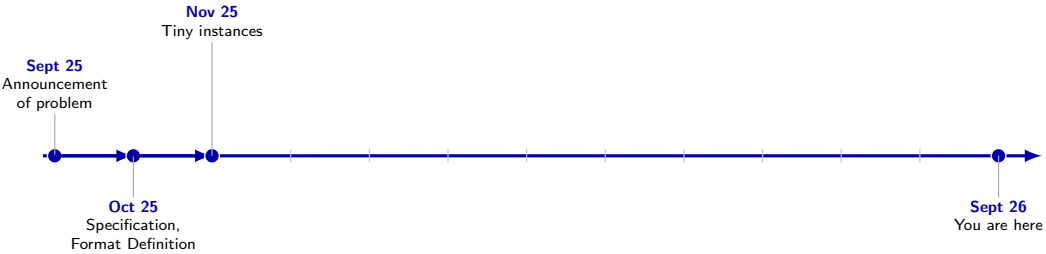
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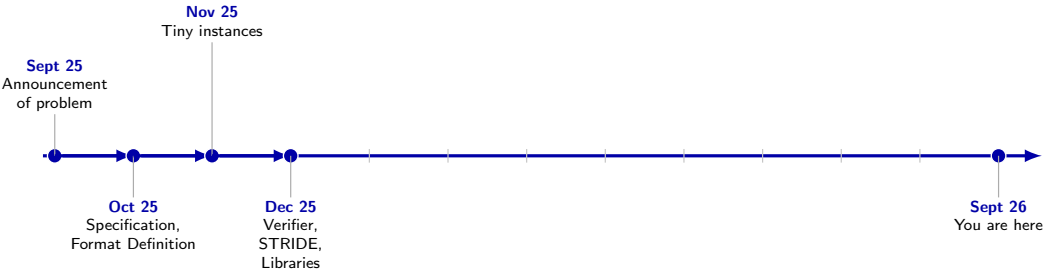
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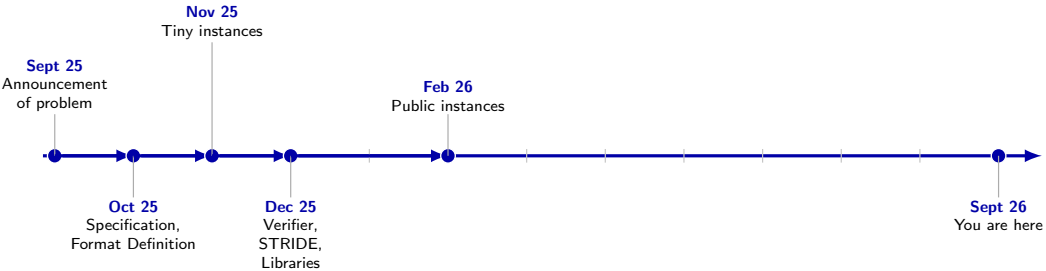
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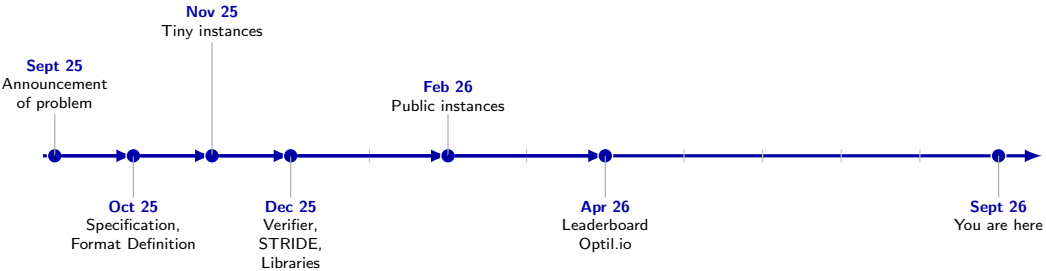
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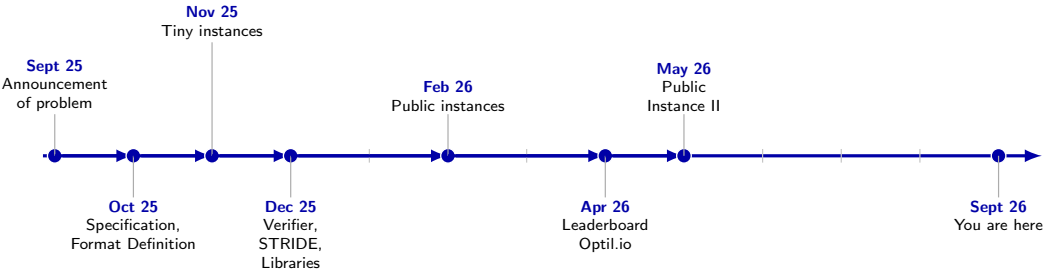
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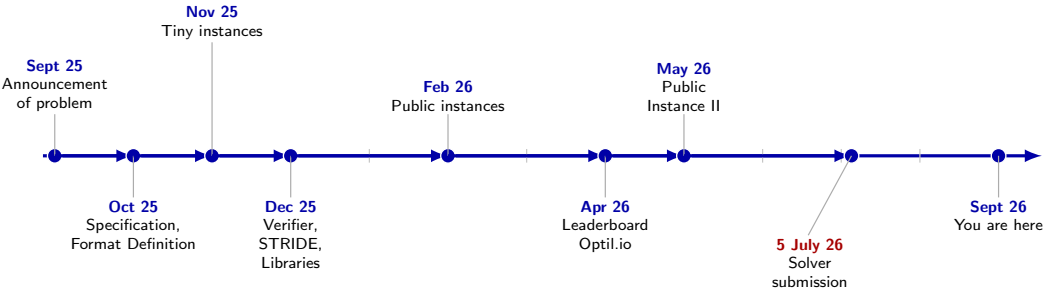
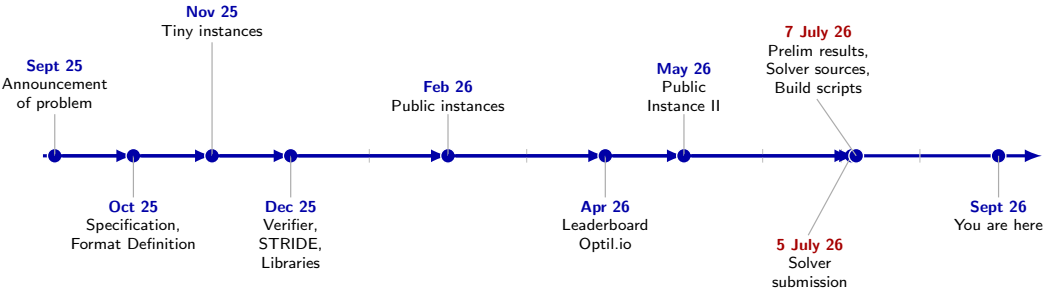
Leaderboard Optil.io
May 26
Public Instance II
Sept 26
You are here

Timeline


Sept 25
Announcement of problem
Oct 25
Specification, Format Definition
Nov 25
Tiny instances
Dec 25
Verifier, STRIDE, Libraries
Feb 26
Public instances
Apr 26
Leaderboard Optil.io
May 26
Public Instance II
5 July 26
Solver submission
Sept 26
You are here

Timeline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Prelim results, Solver sources, Build scripts
5 July 26
Solver submission
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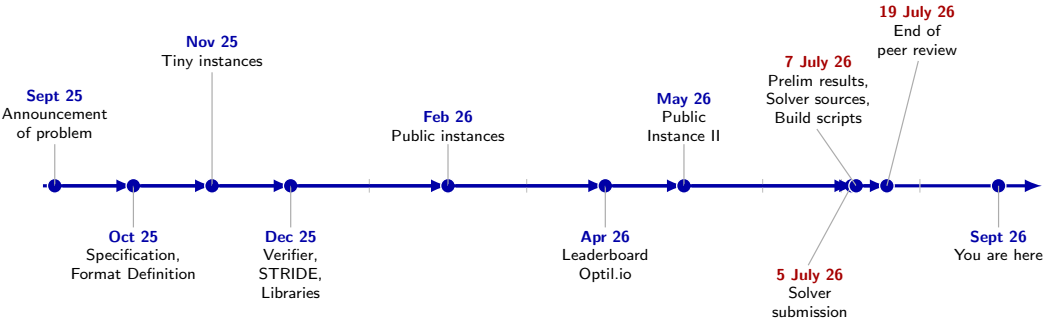
You are here

Timeline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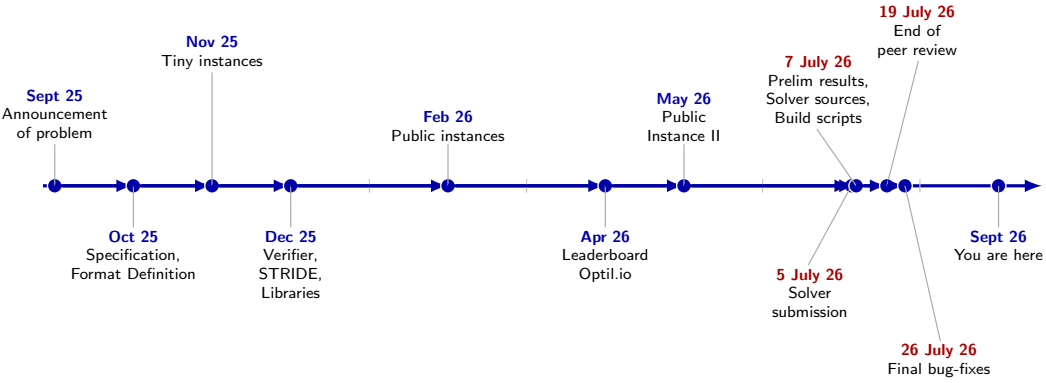
Public Instance II
5 July 26
Solver submission
7 July 26
Prelim results, Solver sources, Build scripts
19 July 26
End of peer review
Sept 26
You are here

Timeline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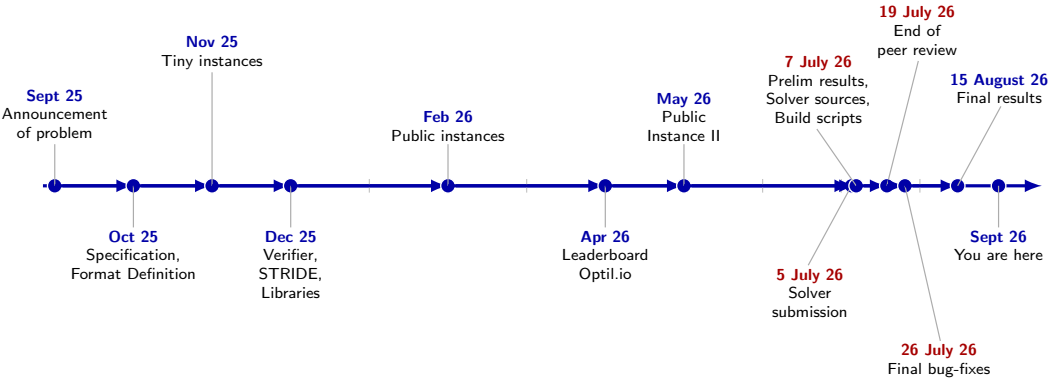
7 July 26
Prelim results, Solver sources, Build scripts
5 July 26
Solver submission
19 July 26
End of peer review
26 July 26
Final bug-fixes
Sept 26
You are here

Timeline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May 26
Public Instance II
5 July 26
Solver submission
7 July 26
Prelim results, Solver sources, Build scripts
19 July 26
End of peer review
26 July 26
Final bug-fixes
15 August 26
Final results
Sept 26
You are here

STRIDE

- Tool for participants to ...
  - Download instances
  - Run solver (in parallel, with timeout)
  - Verify solution
  - Collect statistics

STRIDE

- Tool for participants to . . .
  - Download instances
  - Run solver (in parallel, with timeout)
  - Verify solution
  - Collect statistics

  - Share results

STRIDE

- Tool for participants to ...
  - Download instances
  - Run solver (in parallel, with timeout)
  - Verify solution
  - Collect statistics
  - Share results
- Server verify solutions again and gives best known scores and metrics
- Data dump together with proceedings

STRIDE

Num. Instances	36 709
Num. Jobs	12 650 695
Num. Unique solutions	1 600 053
Total Walltime	7.2 years

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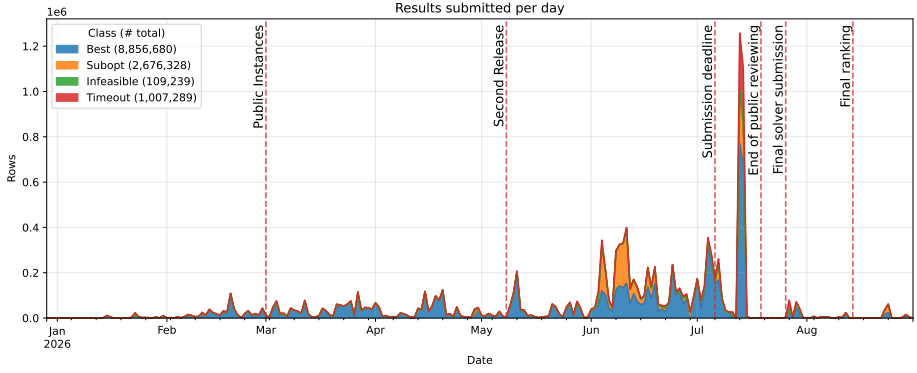

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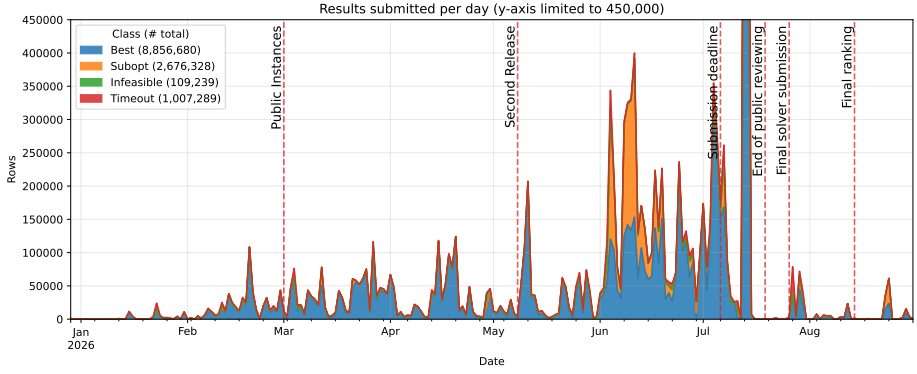
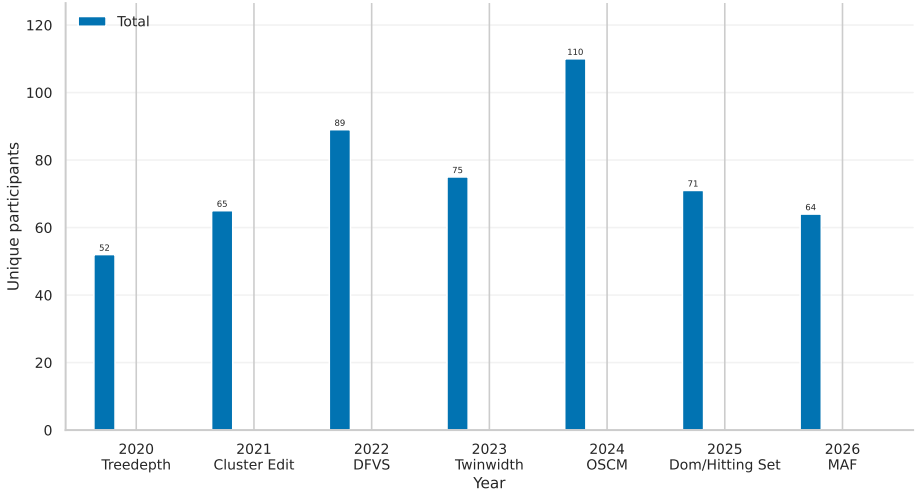
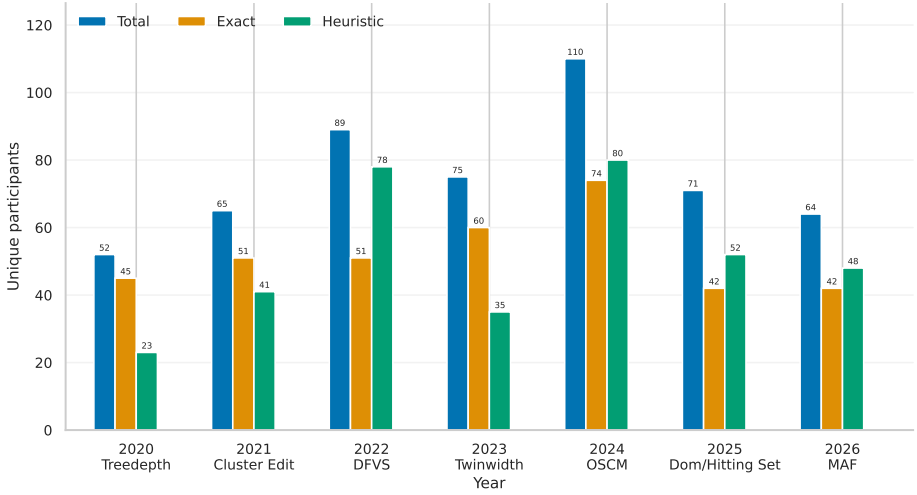


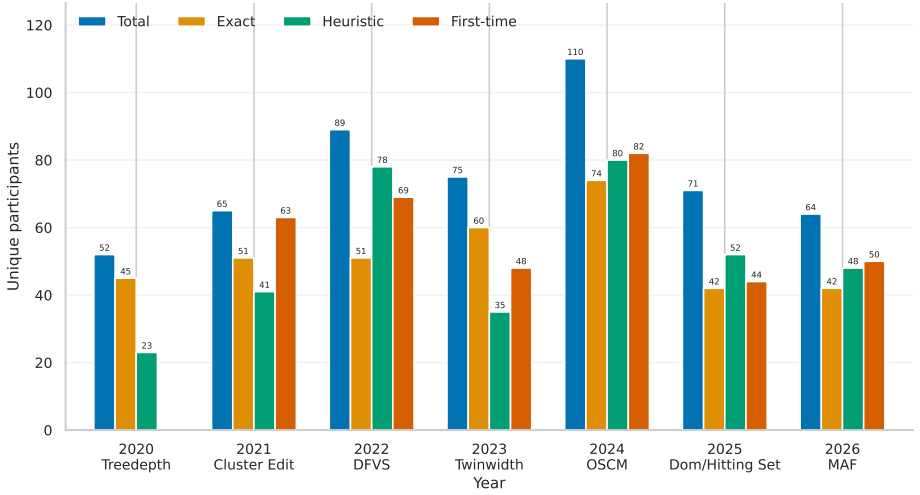
Participation: Authors



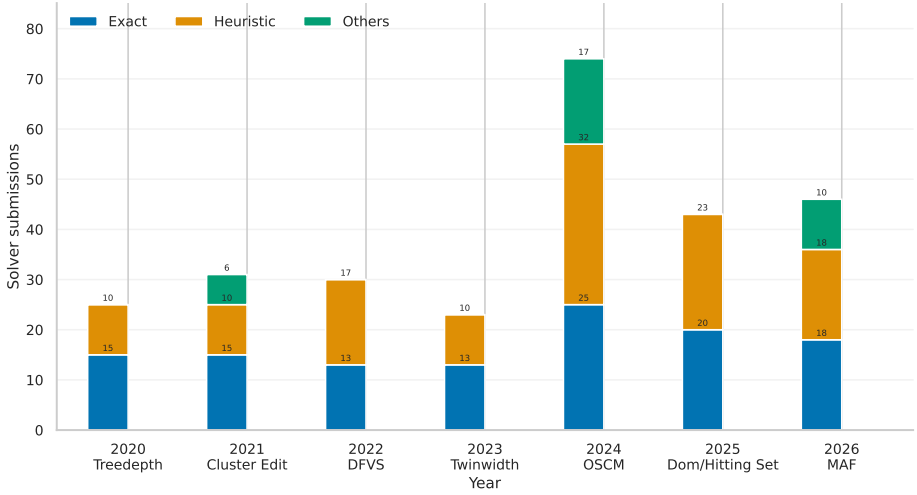
Participation: Authors



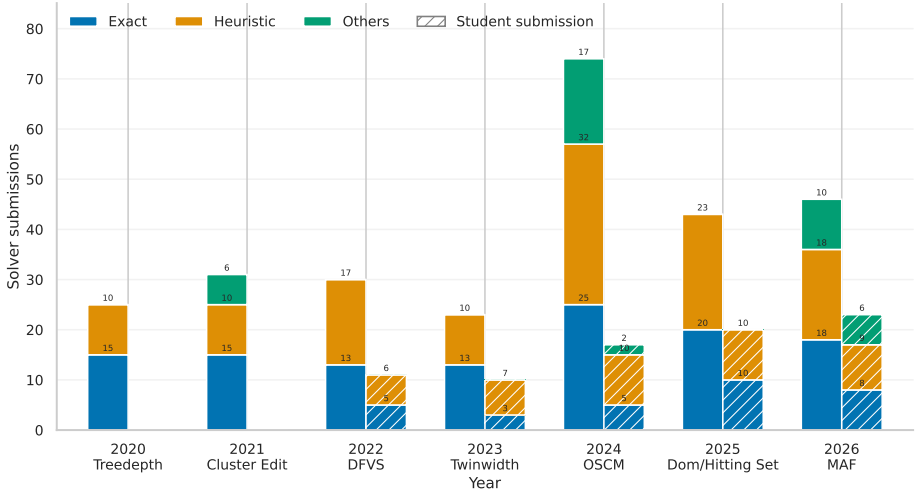
Participation: Authors



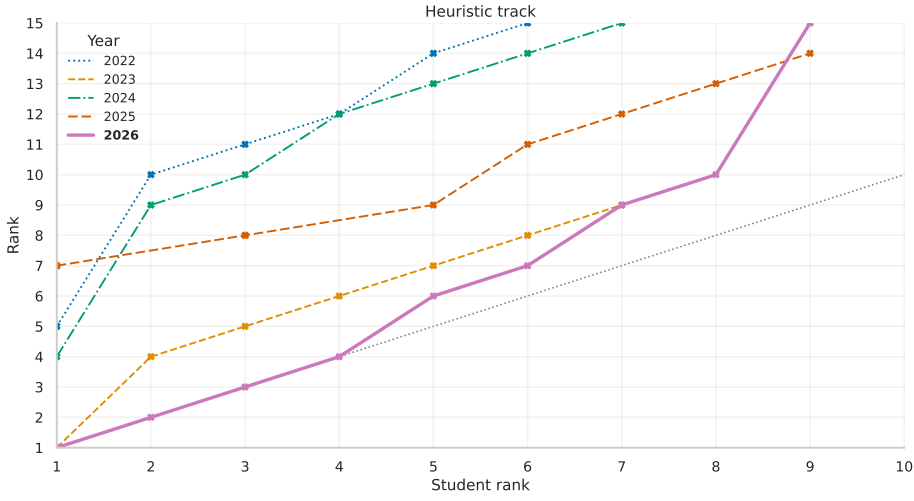
Participation: Solvers



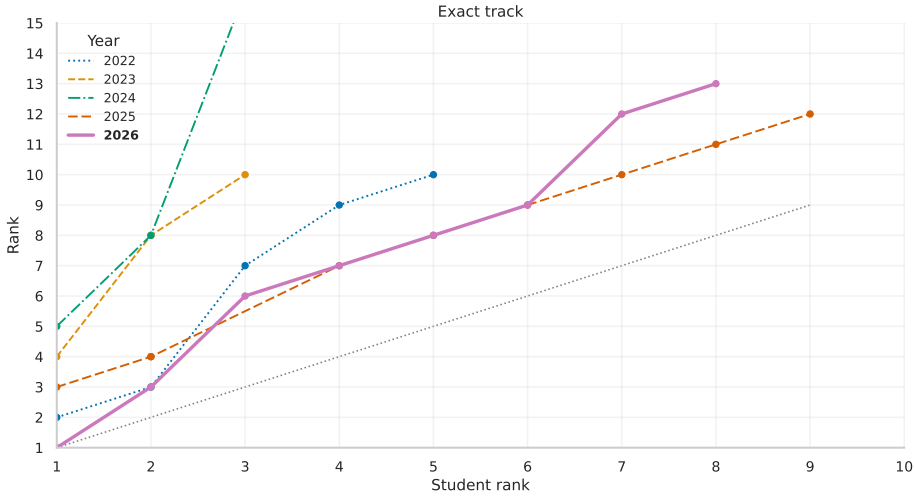
Participation: Solvers



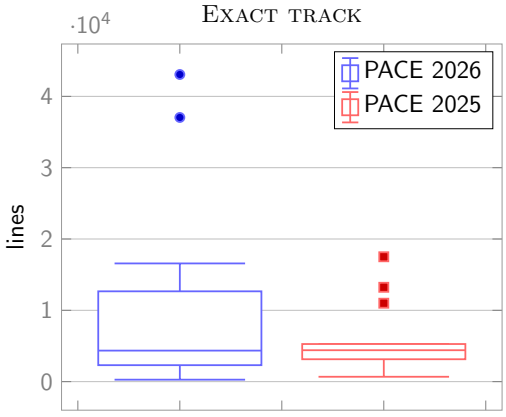
Participation: Student performance



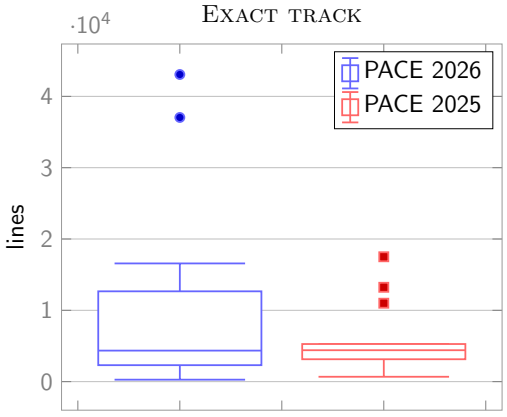
Participation: Student performance

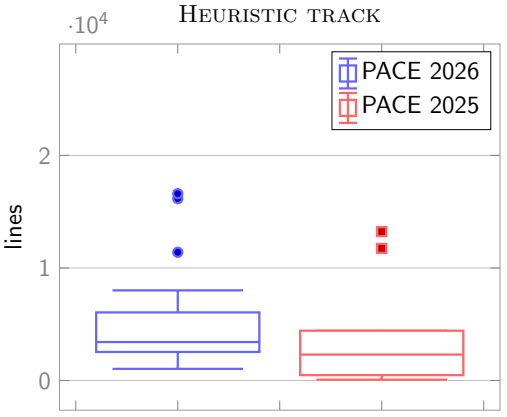


Submissions: Lines of Code

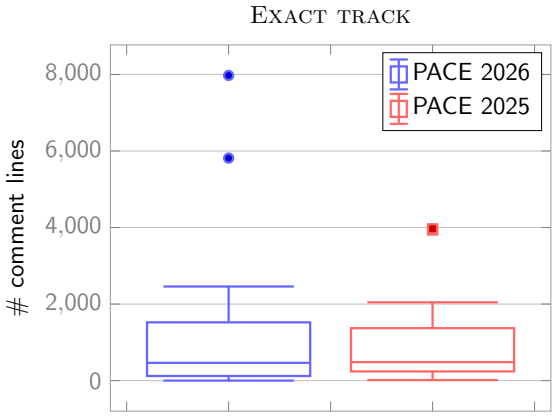


Submissions: Lines of Code





Submissions: Lines of Code



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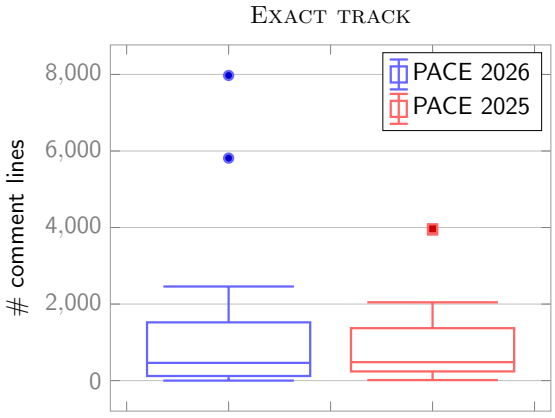
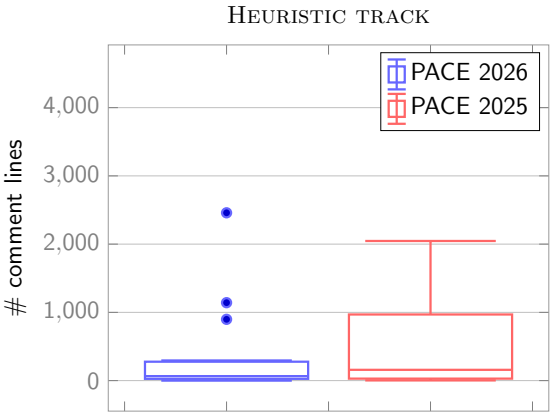
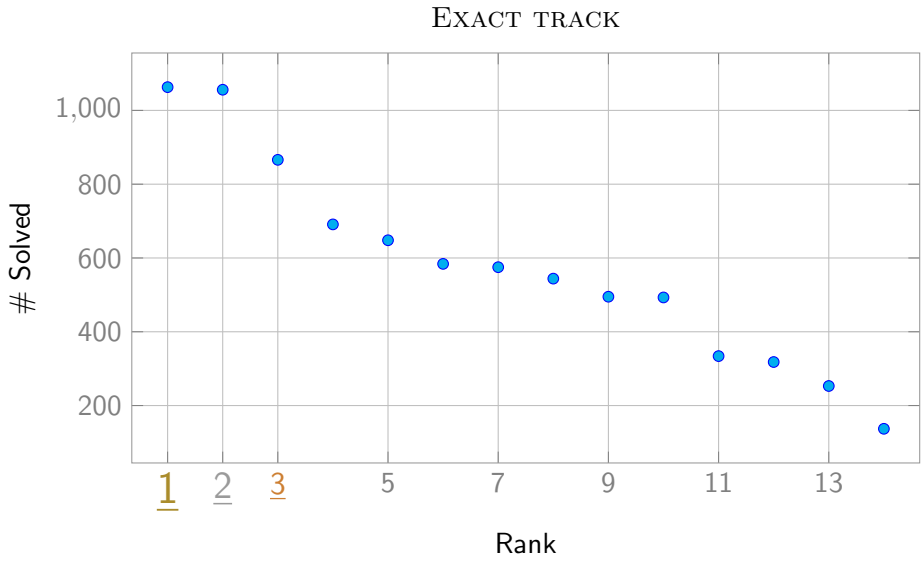
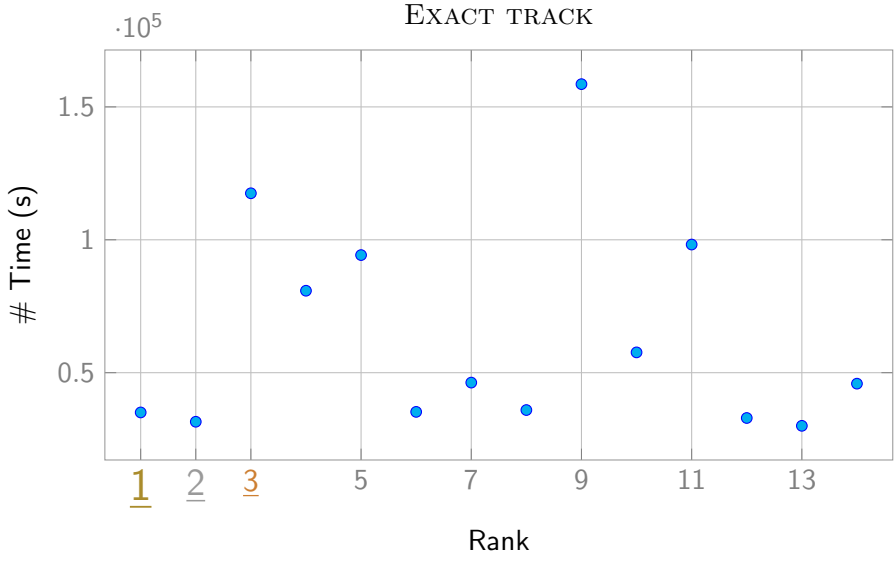




Solver scores (exact)



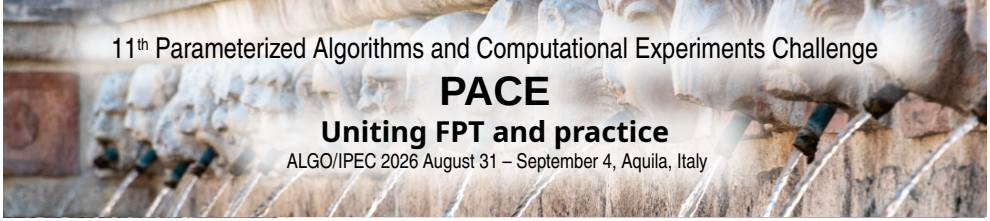
Solver runtimes (exact)



Exact track

Kevin Buchin
Mart Hagedoorn
Marius Maximilian Hille
Christian Inhetveen
Marcin Mennemann

3



This is to certify that the 2026 PACE Program Committee recognizes

Kevin Buchin, Mart Hagedoorn, Marius Maximilian Hille, Christian Inhetveen, Marcin Mennemann

Technical University of Dortmund, Germany

for

Third Place in the Exact Track

€ 200,-

_____
Alexander Leonhardt, Manuel Penschuck, Mathias Weller
2026 PACE Program Committee Chairs

_____
Bart M. P. Jansen, TU Eindhoven
PACE Steering Committee Chair

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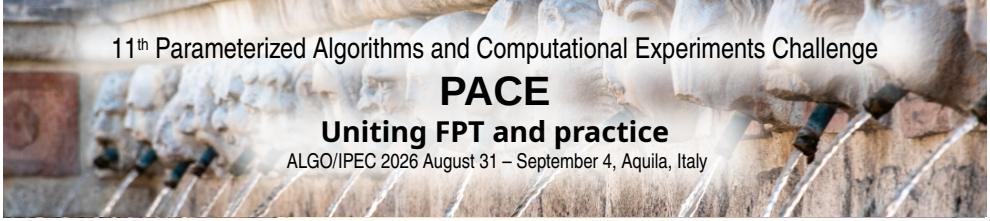
Exact Track

Kevin Buchin
Mart Hagedoorn
Marius Maximilian Hille
Christian Inhetveen
Marcin Mennemann

3

Johannes Varga
Enrico Iurlano
Hai Xia

2



This is to certify that the 2026 PACE Program Committee recognizes

Johannes Varga, Enrico Iurlano, Hai Xia

Technical University Wien, Austria

for

Second Place in the Exact Track

€ 250,-

_____
Alexander Leonhardt, Manuel Penschuck, Mathias Weller
2026 PACE Program Committee Chairs

_____
Bart M. P. Jansen, TU Eindhoven
PACE Steering Committee Chair

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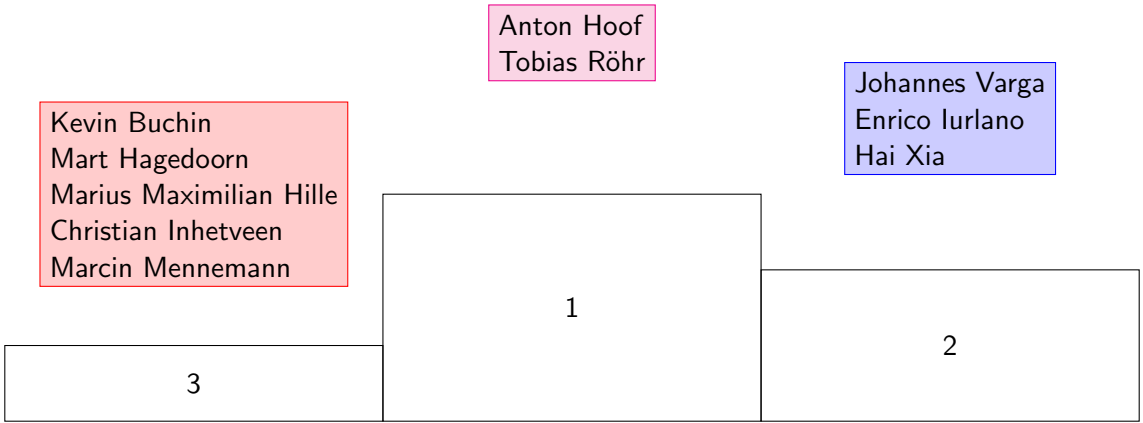
Exact track


Anton Hoof
Tobias Röhr
Johannes Varga
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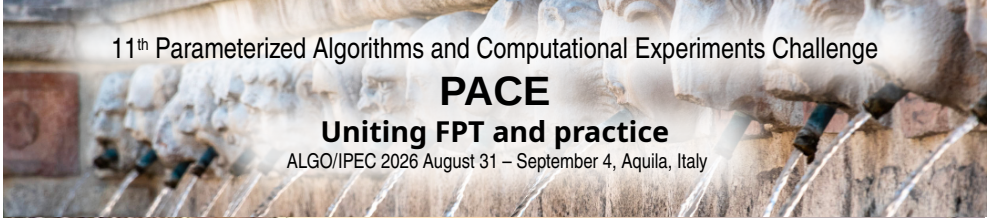
1
2
3



This is to certify that the 2026 PACE Program Committee recognizes

Anton Hoof and **Tobias Röhr**

Friedrich-Alexander-Universität Erlangen-Nürnberg — Hasso Plattner Institute, Germany

for

First Place in the Exact Track

€ 300,-

Alexander Leonhardt, Manuel Penschuck, Mathias Weller
2026 PACE Program Committee Chairs

Bart M. P. Jansen, TU Eindhoven
PACE Steering Committee Chair

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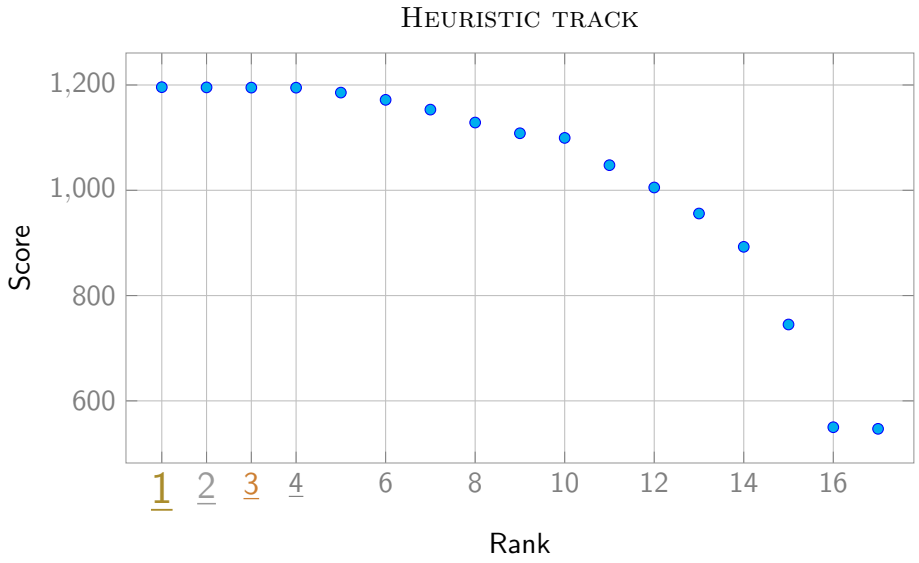
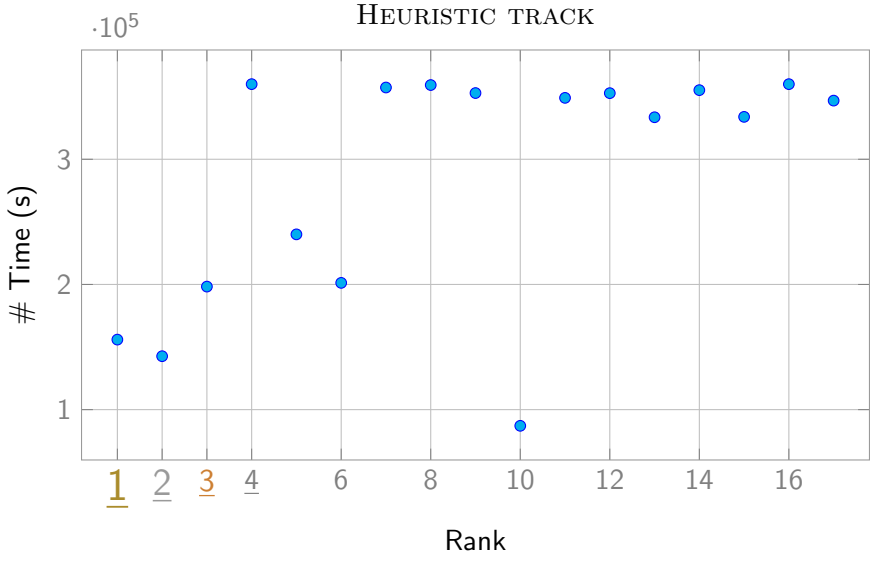
Solver score (heuristic)



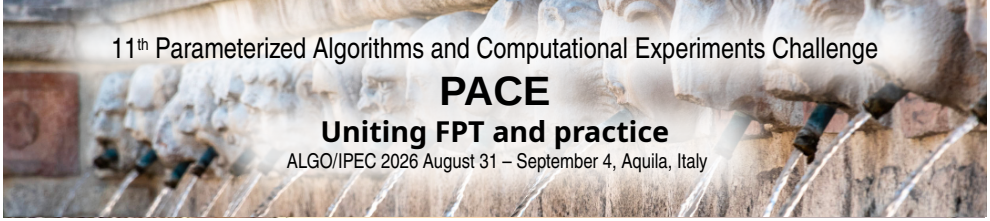
Solver runtime (heuristic)



Heuristic Track

Jakub Dziura
Tomáš Masaříkm

4



This is to certify that the 2026 PACE Program Committee recognizes

Jakub Dziura, **Tomáš Masařík**

University of Warsaw, Poland
for

Fourth Place in the Heuristic Track

€ 150,-

_____
Alexander Leonhardt, Manuel Penschuck, Mathias Weller
2026 PACE Program Committee Chairs

_____
Bart M. P. Jansen, TU Eindhoven
PACE Steering Committee Chair

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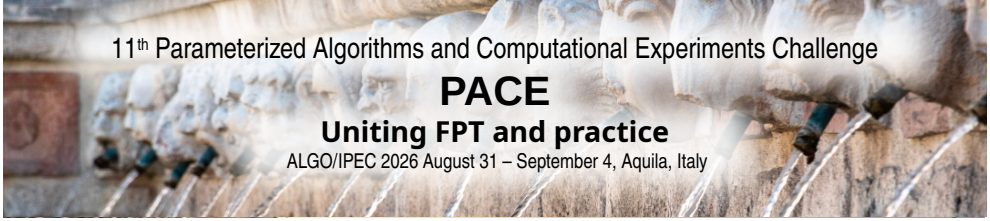
Heuristic Track

Jakub Dziura
Tomáš Masaříkm

4

Daniel Busch

3



This is to certify that the 2026 PACE Program Committee recognizes

Daniel Busch

University of Tübingen, Germany

for

Third Place in the Heuristic Track

€ 200,-

_____

Alexander Leonhardt, Manuel Penschuck, Mathias Weller
2026 PACE Program Committee Chairs

_____

Bart M. P. Jansen, TU Eindhoven
PACE Steering Committee Chair

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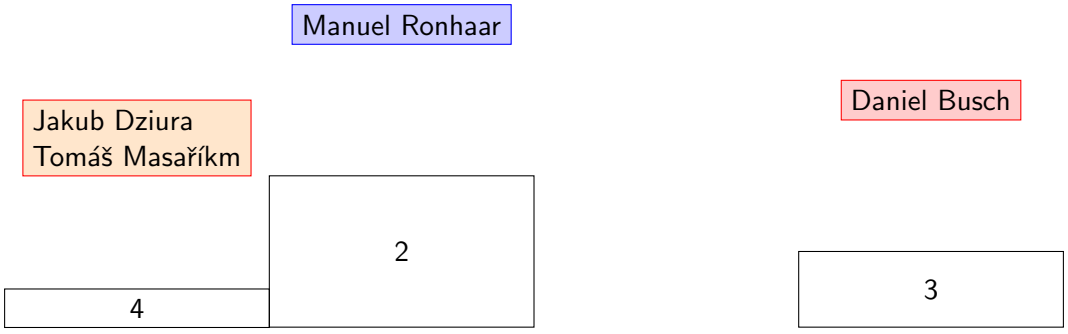
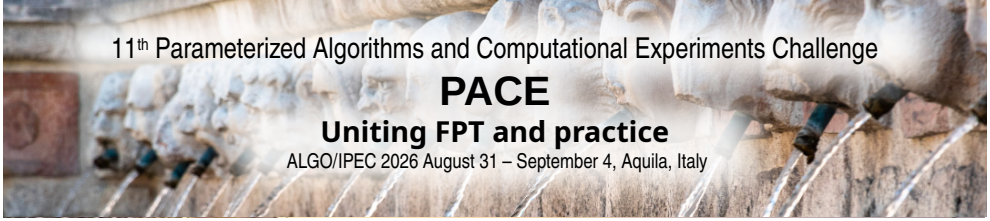
Heuristic Track





This is to certify that the 2026 PACE Program Committee recognizes

Manuel Ronhaar

Utrecht University, Netherlands

for

Second Place in the Heuristic Track

€ 250,-

_____

Alexander Leonhardt, Manuel Penschuck, Mathias Weller
2026 PACE Program Committee Chairs

_____

Bart M. P. Jansen, TU Eindhoven
PACE Steering Committee Chair

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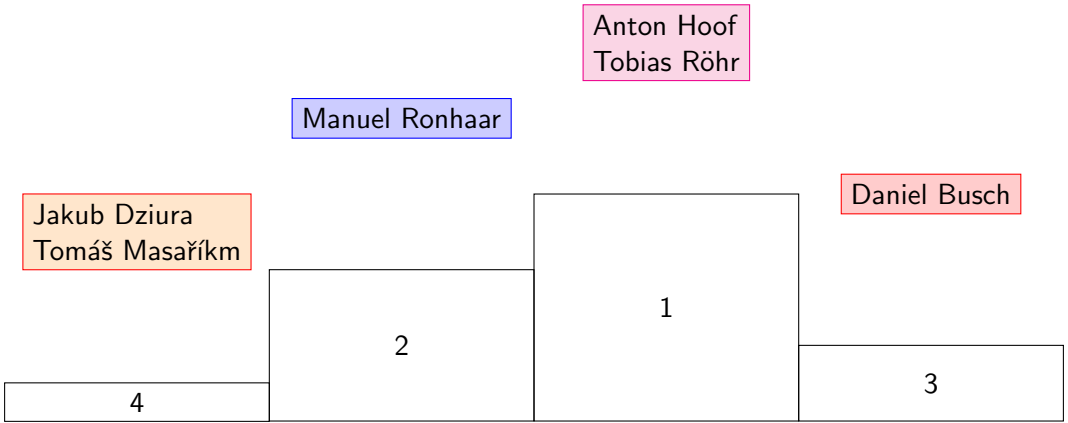
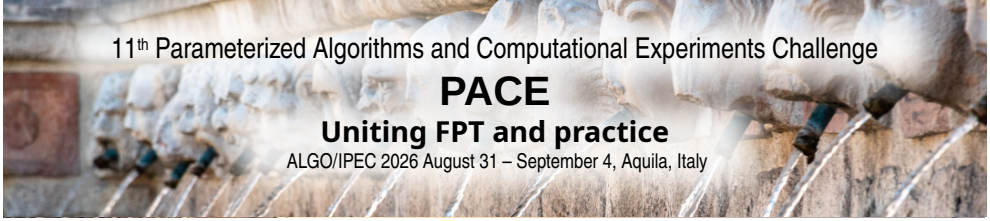
Heuristic Track





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Anton Hoof and **Tobias Röhr**

Friedrich-Alexander-Universität Erlangen-Nürnberg — Hasso Plattner Institute, Germany

for

First Place in the Heuristic Track

€ 300,-

Alexander Leonhardt, Manuel Penschuck, Mathias Weller
2026 PACE Program Committee Chairs

Bart M. P. Jansen, TU Eindhoven
PACE Steering Committee Chair

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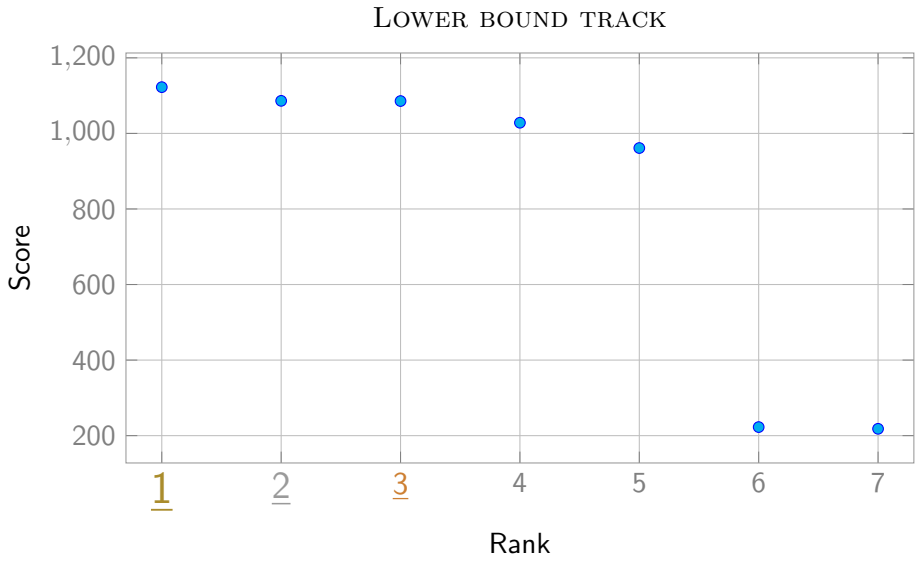
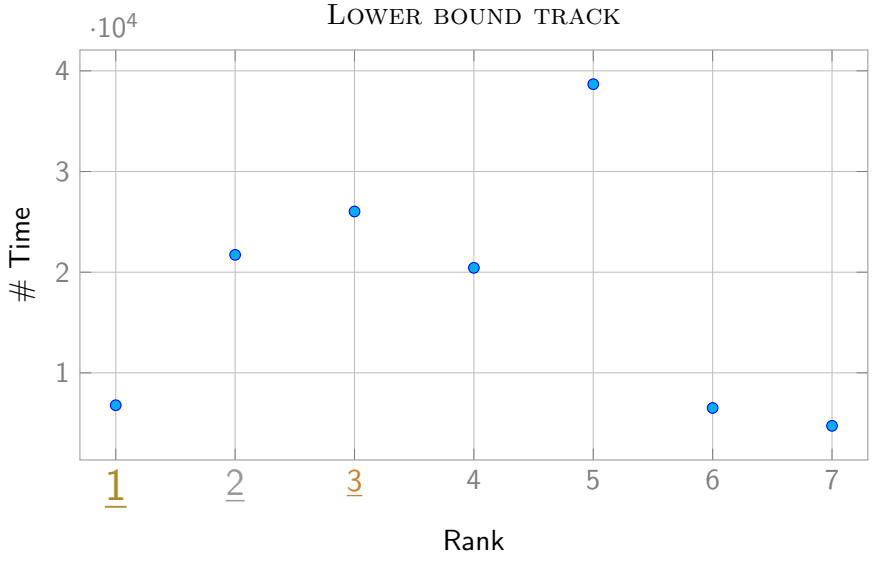
Solver score (lower bound)



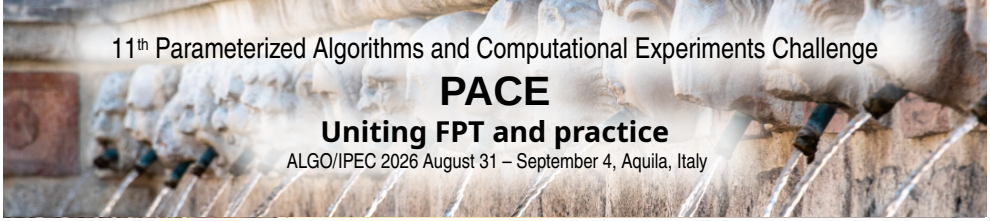
Solver runtime (lower bound)



Lower bound track

Manuel Ronhaar

3



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Manuel Ronhaar

Utrecht University, Netherlands

for

Third Place in the Lower Bound Track

€ 200,-

_____

Alexander Leonhardt, Manuel Penschuck, Mathias Weller
2026 PACE Program Committee Chairs

_____

Bart M. P. Jansen, TU Eindhoven
PACE Steering Committee Chair

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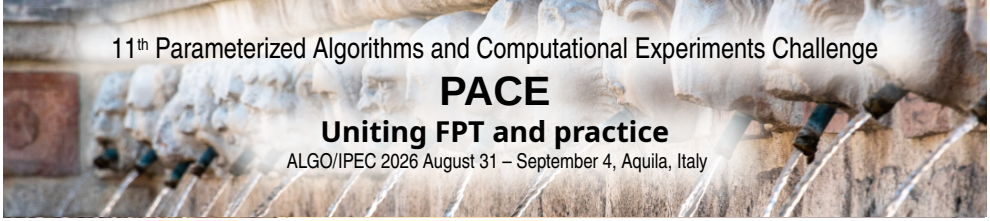
Lower bound track

Jakub Dziura
Tomáš Masařík

Manuel Ronhaar



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Jakub Dziura, **Tomáš Masařík**

University of Warsaw, Poland

for

Second Place in the Lower Bound Track

€ 250,-

Alexander Leonhardt, Manuel Penschuck, Mathias Weller
2026 PACE Program Committee Chairs

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PACE Steering Committee Chair

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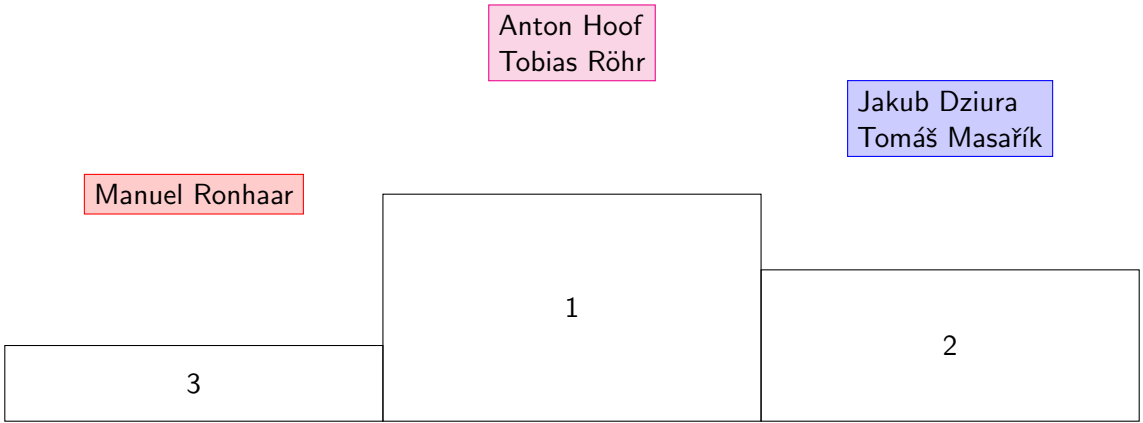
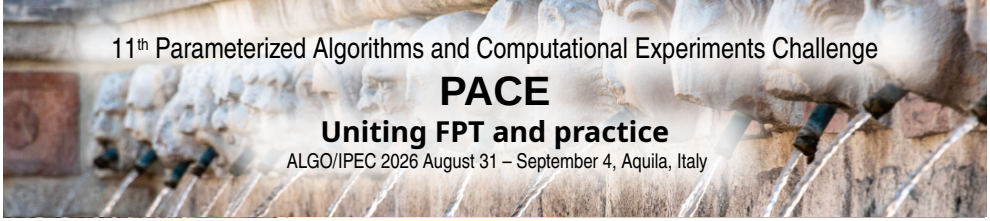
Lower bound track





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PACE Steering Committee Chair

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