Computational Geometry

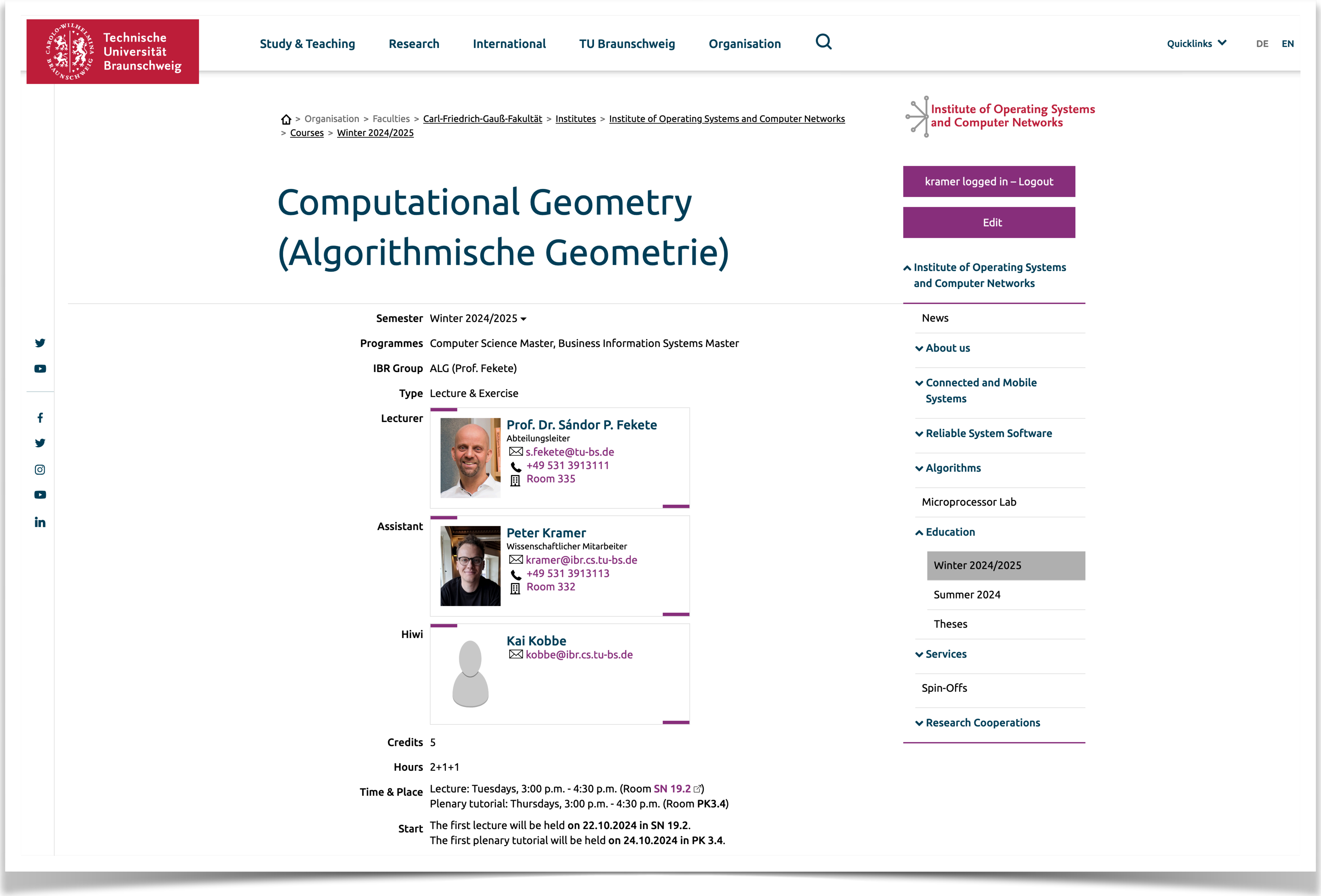
Tutorial #1 — Organisation and Convex Hulls

Institut für Betriebssysteme
und Rechnerverbund
Algorithmik

Peter Kramer | *October 24th, 2024*

Organisation

Website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Computational Geometry (Algorithmische Geometrie)
Semester Winter 2024/2025
Programmes Computer Science Master, Business Information Systems Master
IBR Group ALG (Prof. Fekete)
Type Lecture & Exercise
Lecturer
Prof. Dr. Sándor P. Fekete
Abteilungsleiter
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+49 531 3913111
Room 335
Assistant
Peter Kramer
Wissenschaftlicher Mitarbeiter
kramer@ibr.cs.tu-bs.de
+49 531 3913113
Room 332
Hiwi
Kai Kobbe
kobbe@ibr.cs.tu-bs.de
Credits 5
Hours 2+1+1
Time & Place Lecture: Tuesdays, 3:00 p.m. - 4:30 p.m. (Room SN 19.2)
Plenary tutorial: Thursdays, 3:00 p.m. - 4:30 p.m. (Room PK3.4)
Start The first lecture will be held on 22.10.2024 in SN 19.2.
The first plenary tutorial will be held on 24.10.2024 in PK 3.4.
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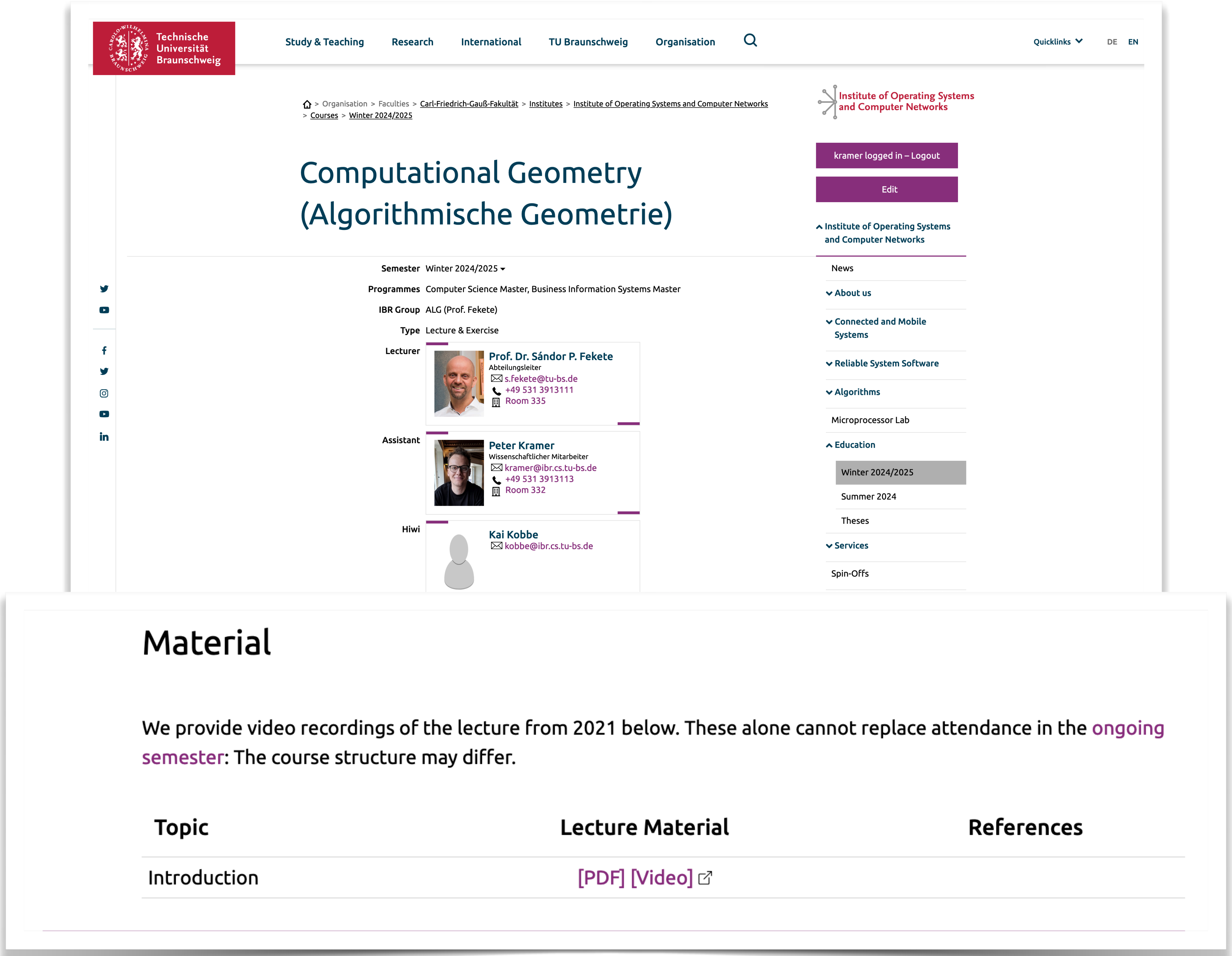

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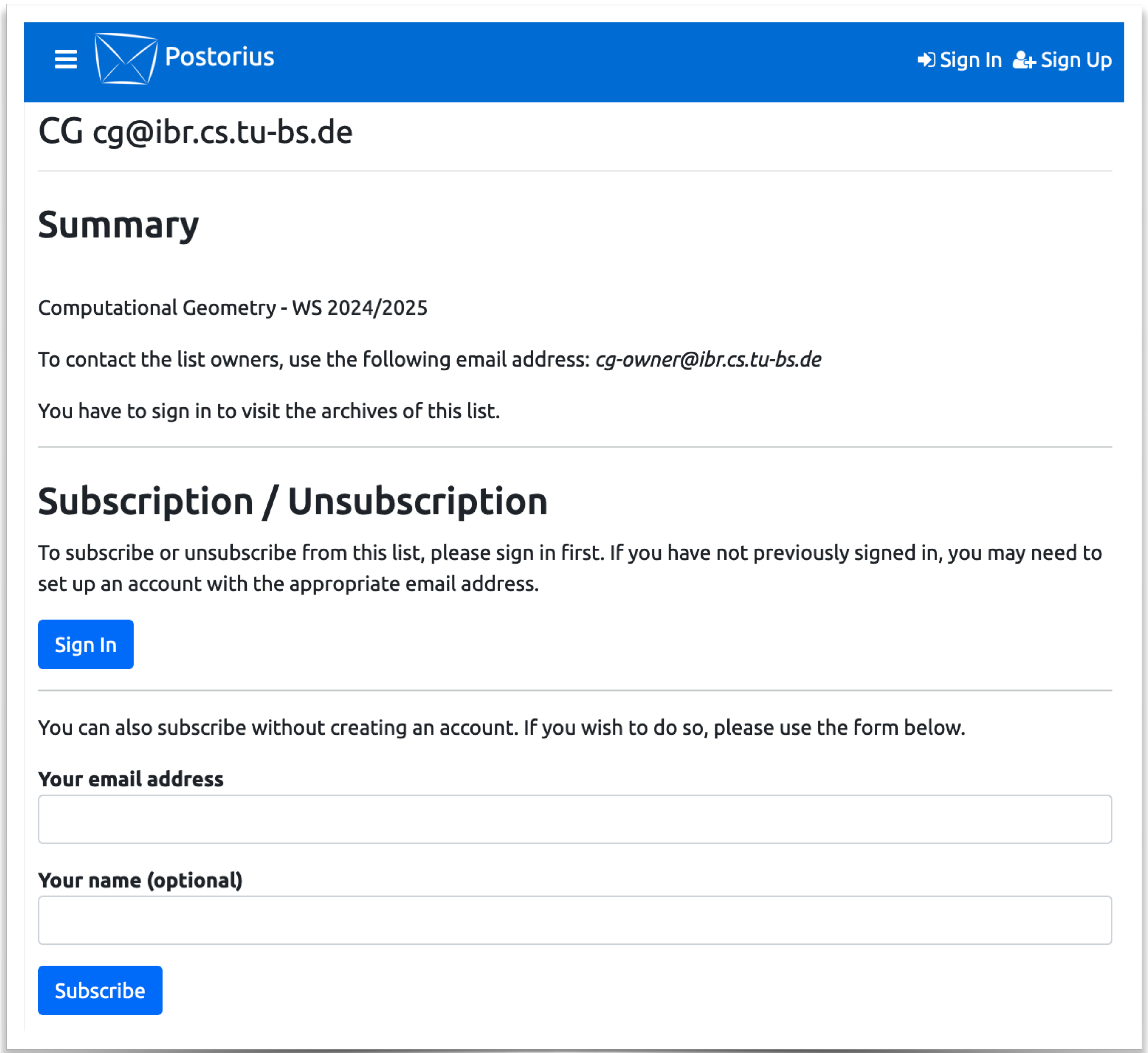
Material
We provide video recordings of the lecture from 2021 below. These alone cannot replace attendance in the ongoing semester: The course structure may differ.
Topic
Lecture Material
References
Introduction
[PDF] [Video]



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Summary
Computational Geometry - WS 2024/2025
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Tutorial

- **Every Thursday at 3pm** in this room, either a big or a small tutorial.
  - Depending on attendance, we might switch rooms.

- **Big tutorial:** Expand upon and put concepts from the lecture to use.
- **Small tutorial:** Homework discussion.

October						
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

November						
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

13 Lectures

7 Big Tutorials

4 Small Tutorials

4 Sheets

December						
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

January						
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

Exam prep?

Tutorial

- **Every Thursday at 3pm** in this room, either a big or a small tutorial.
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- **Big tutorial:** Expand upon and put concepts from the lecture to use.
- **Small tutorial:** Homework discussion.

- **Studienleistung:** Four homework sheets.
  - Biweekly assignments to solve in pairs.
  - 50% of total possible points on the sheets; roughly 70 - 75 points.

Exam...

The form of exam depends on the number of attending students.

Announcement in an upcoming lecture.

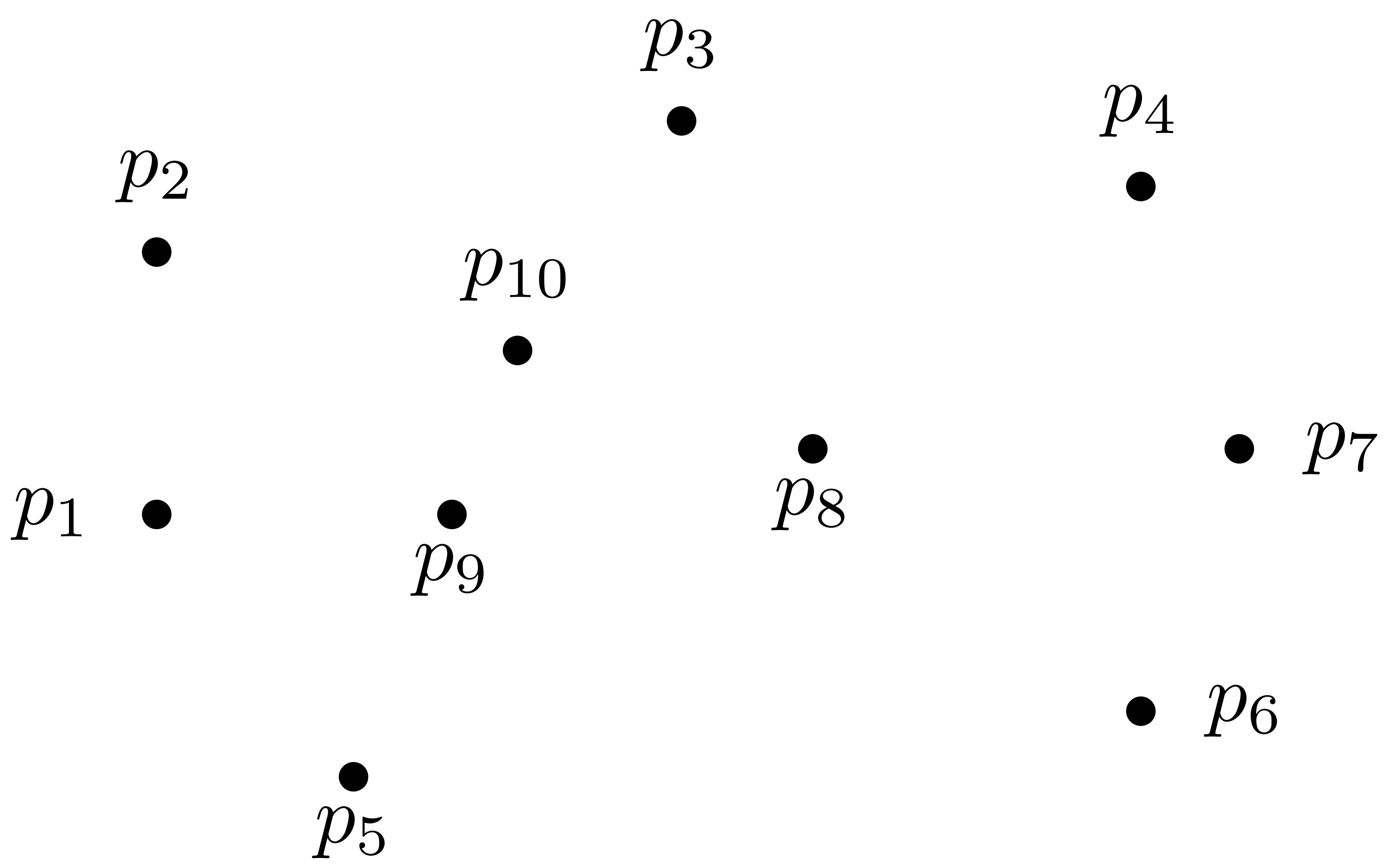
Convex Hulls

Peter Kramer | October 24th, 2024

The convex hull

… is a point set? A convex polygon? A subset?

- For a finite point set $\mathscr{P} := \{p_1, p_2, \ldots, p_n\} \subset \mathbb{R}^2$, $\operatorname{conv}(\mathscr{P}) = \ldots ?$



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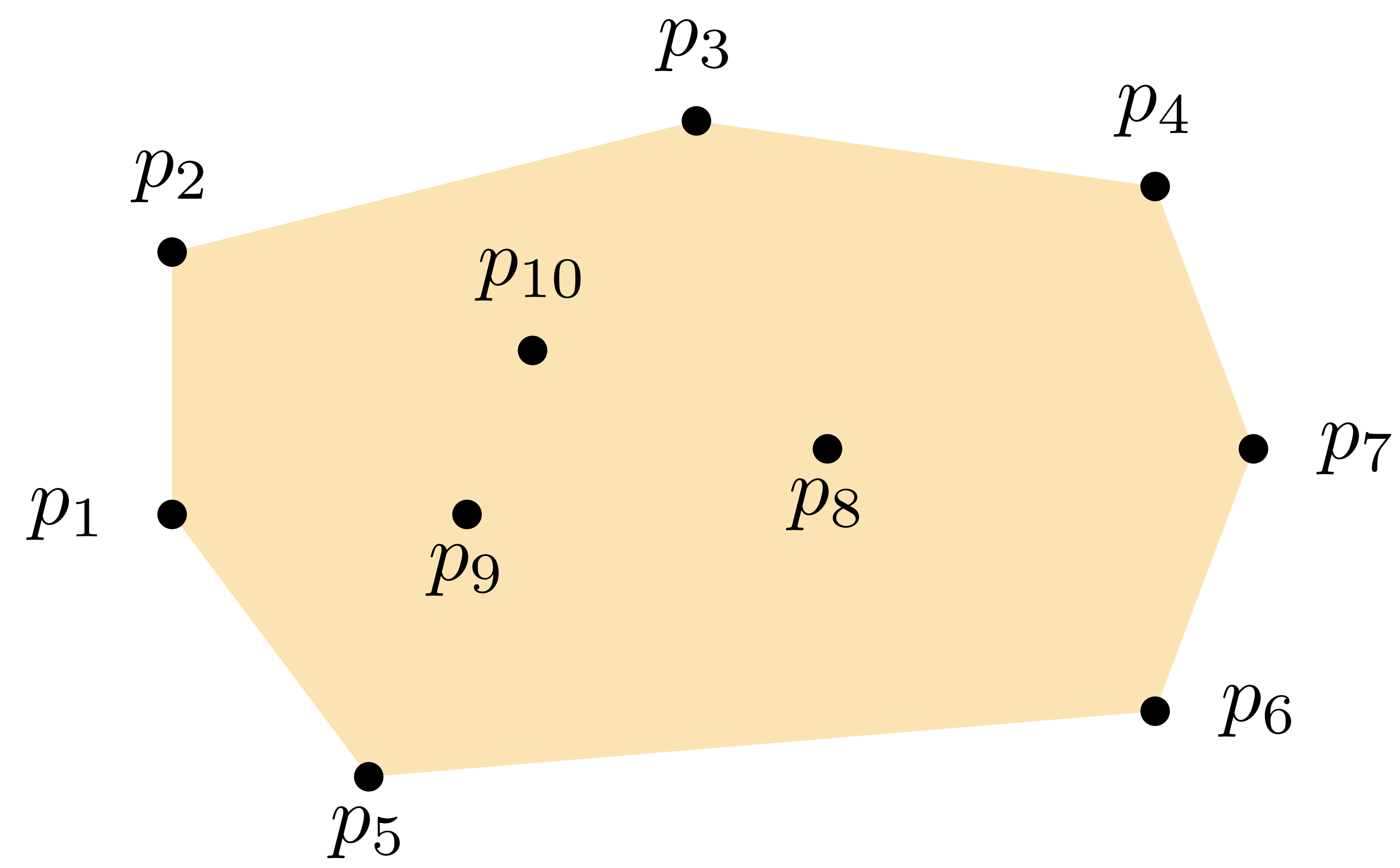

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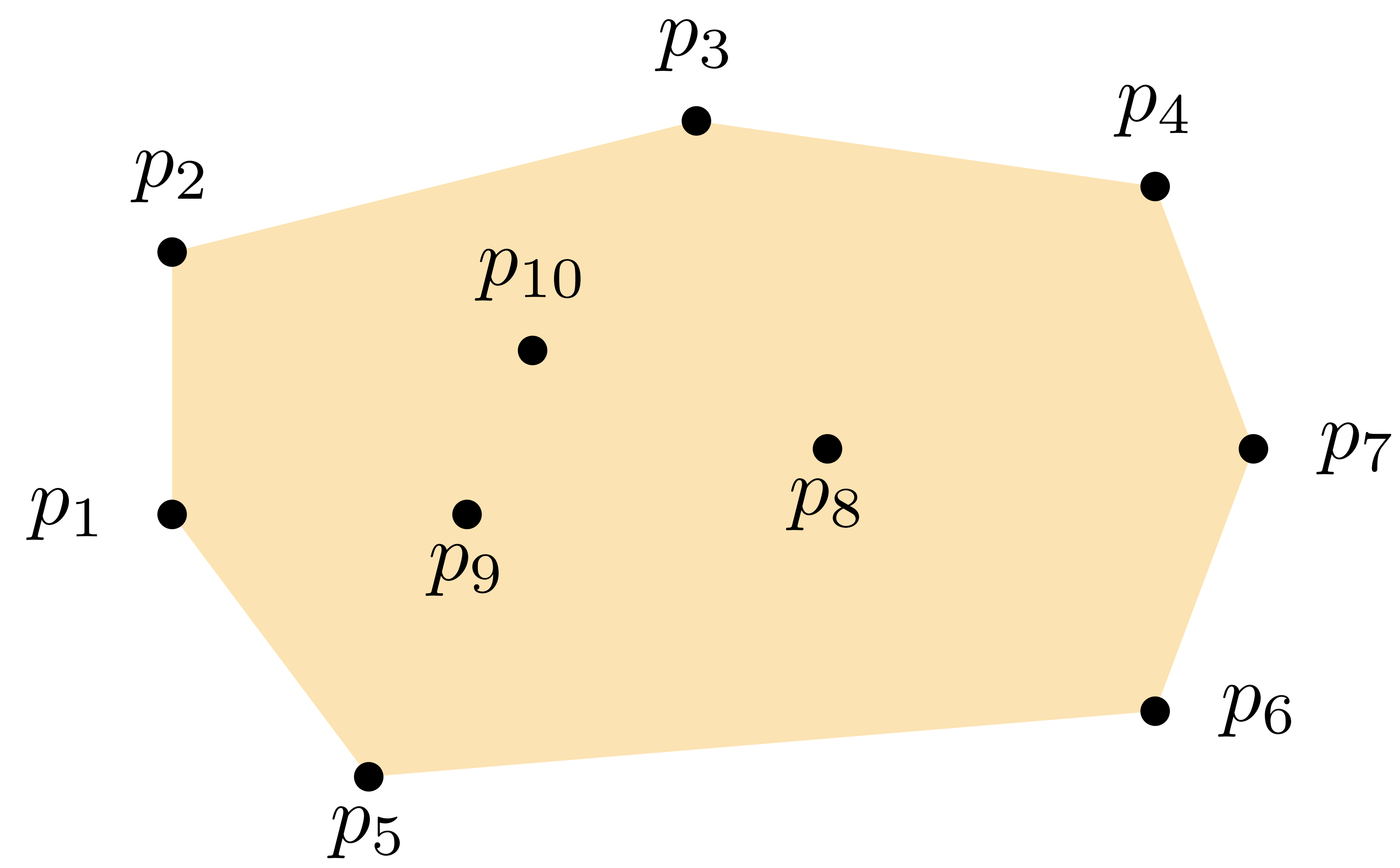
- For a finite point set $\mathscr{P} := \{p_1, p_2, \ \dots, p_n\} \subset \mathbb{R}^2$, $\mathrm{conv}(\mathscr{P}) = \ \dots$?
- *Definition 2.3:* $\mathrm{conv}(\mathscr{P}) = \{x \in \mathbb{R}^2 \mid x$ is a convex combination of $\mathscr{P}\}$.



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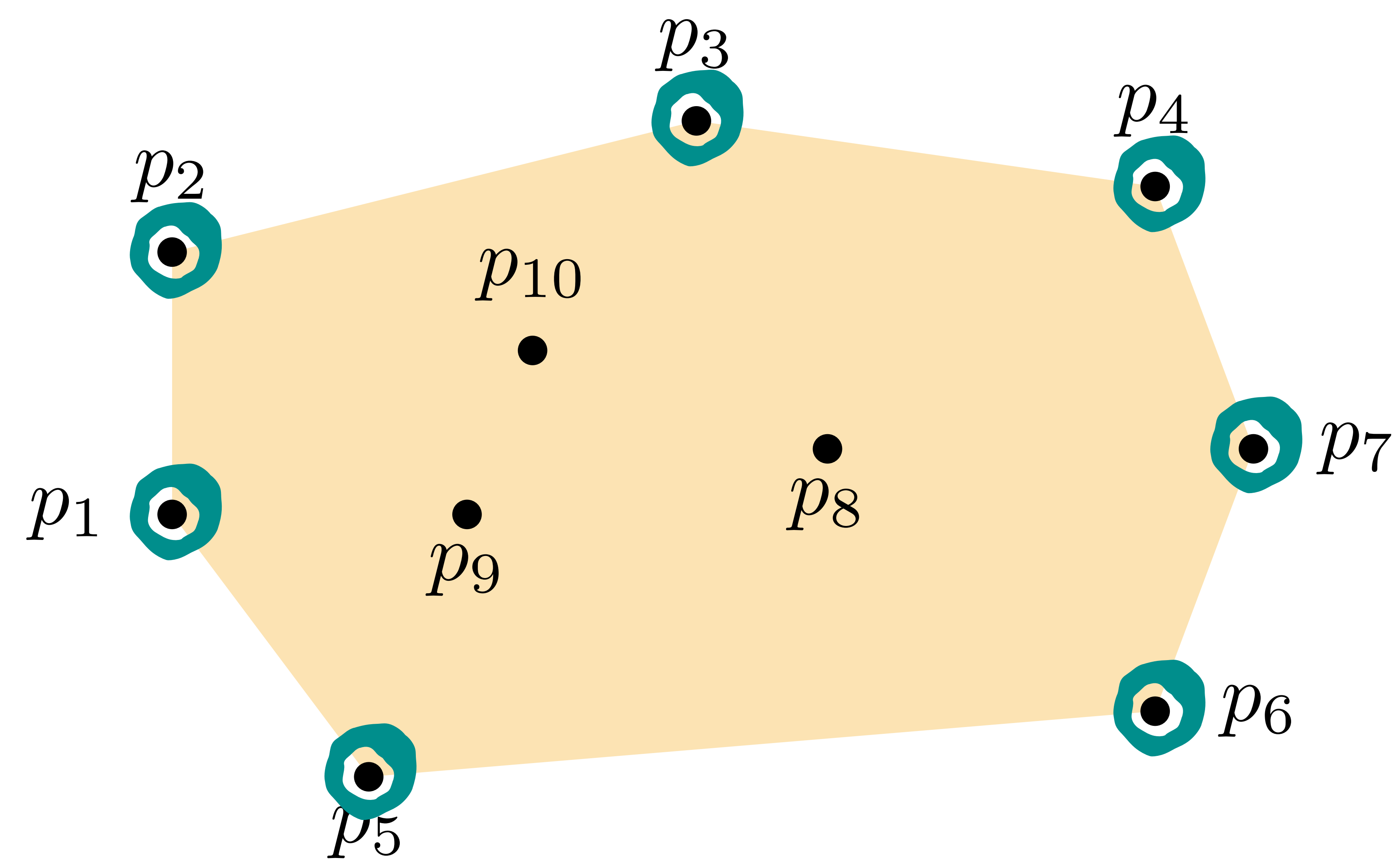
- *Definition 2.3:* $\mathrm{conv}(\mathscr{P}) = \{x \in \mathbb{R}^2 \mid x$ is a convex combination of $\mathscr{P}\}$.
- *This is an infinite set, but our algorithm(s) only give us points from $\mathscr{P}$!?*



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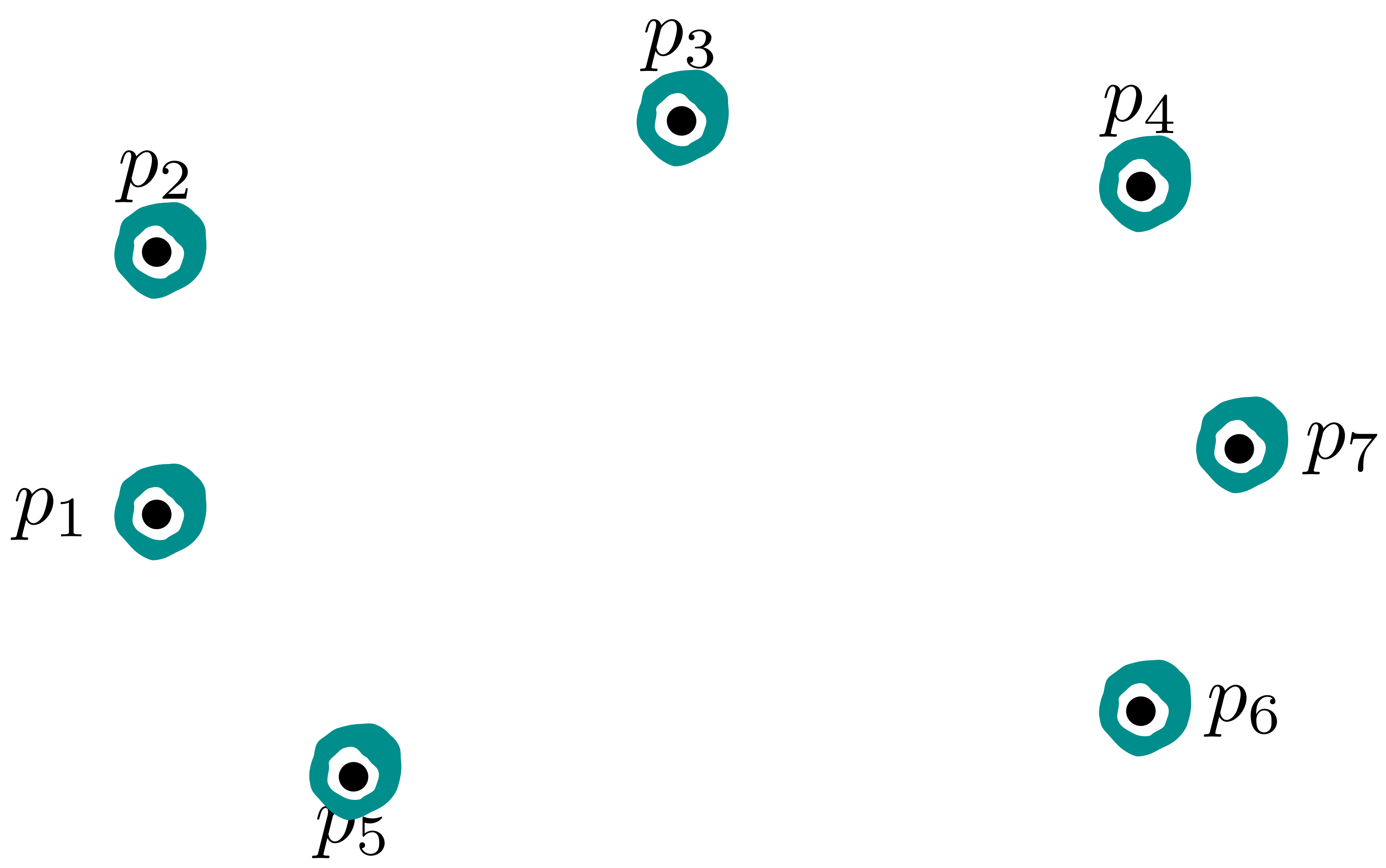
- *This is an infinite set, but our algorithm(s) only give us points from $\mathscr{P}$!?*
- $\mathrm{conv}(\mathscr{P}) = \mathscr{P}$ *???*

Point sets like this one are referred to as being in "convex position".



The convex hull

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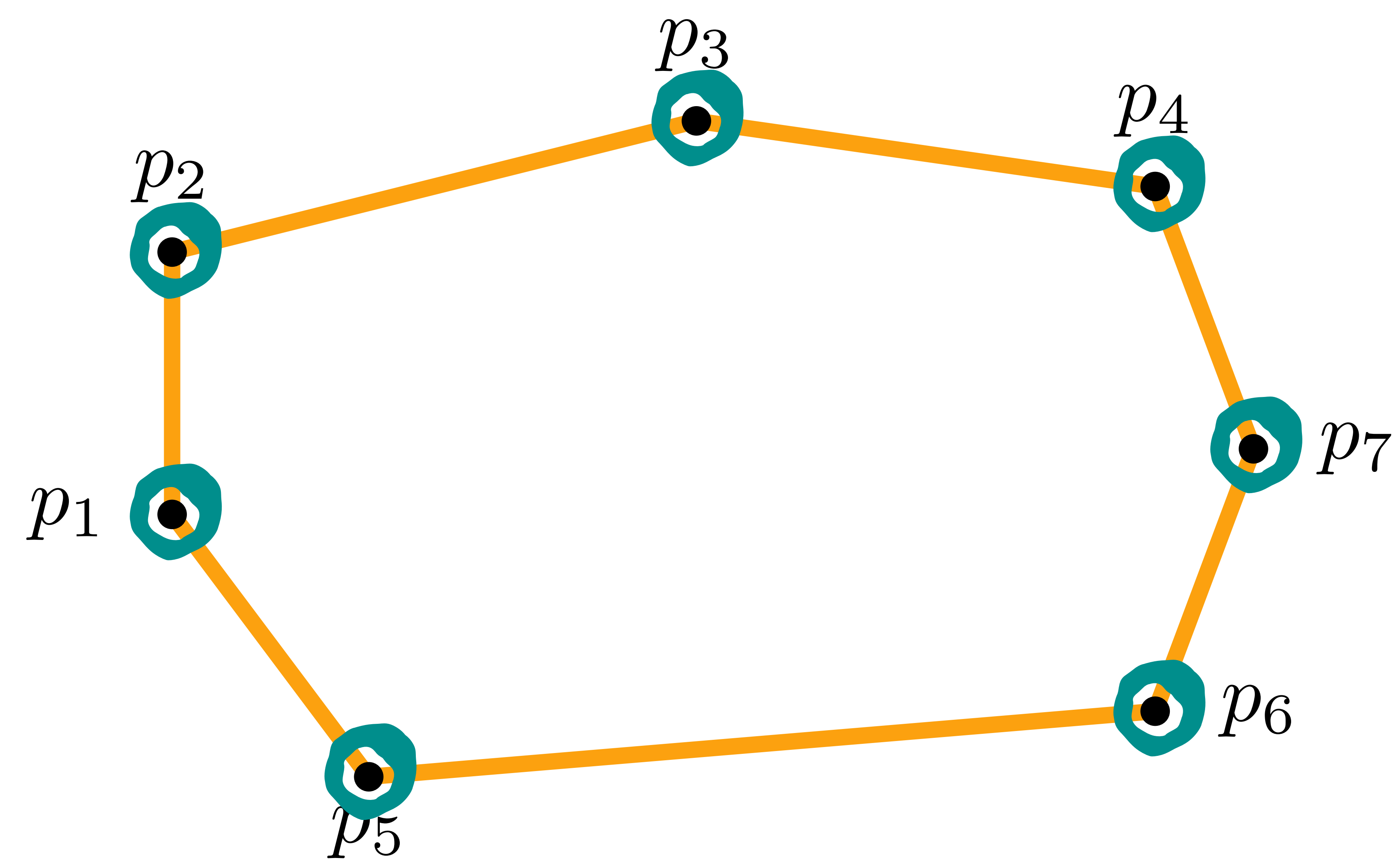
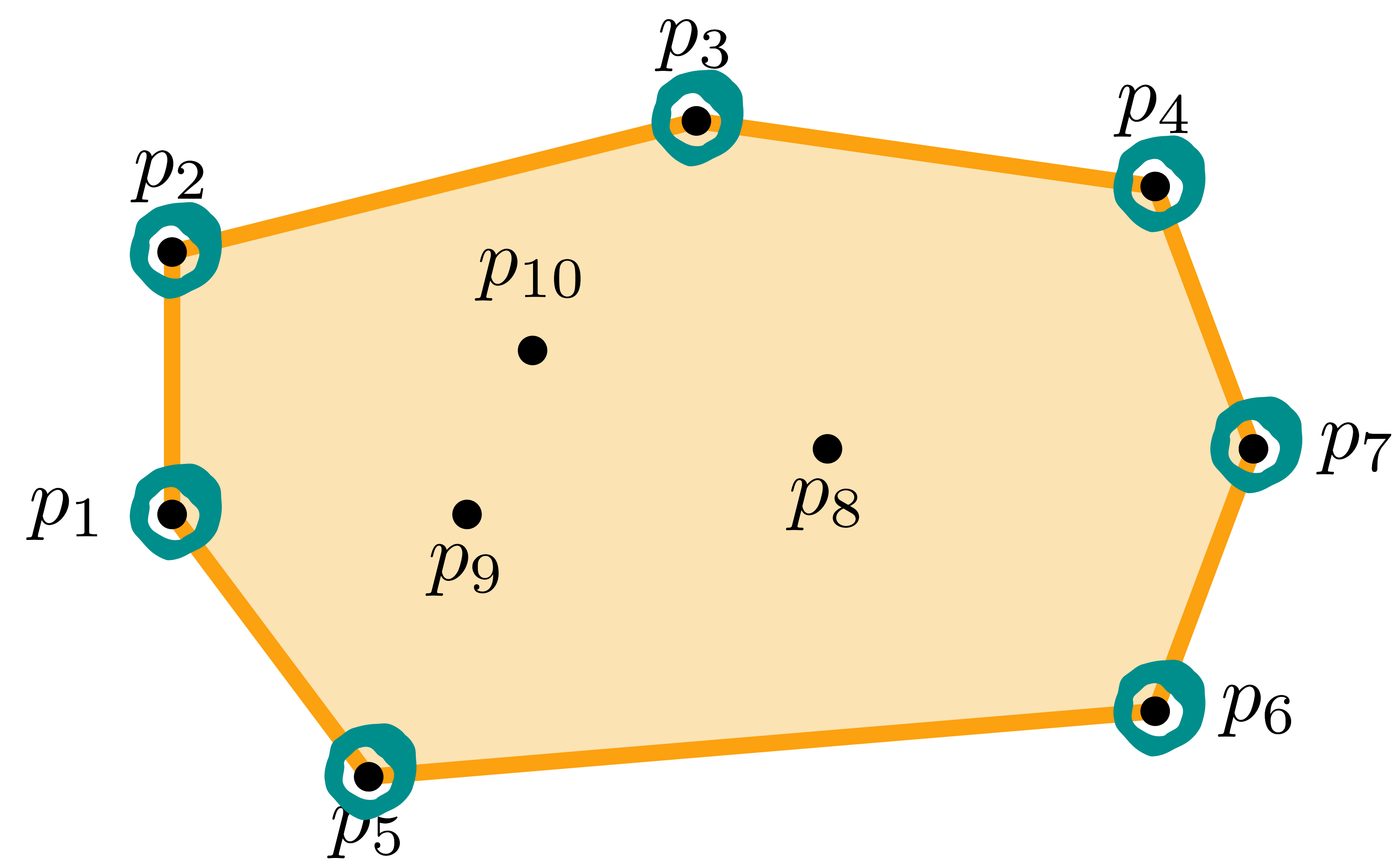
- *This is an infinite set, but our algorithm(s) only give us points from $\mathscr{P}$!?*
- ~~$\text{conv}(\mathscr{P}) = \mathscr{P}$~~ *???*



The convex hull

… is a (usually infinite) point set, described by a convex polygon.

- Given a finite point set $\mathscr{P} := \{p_1, p_2, \ldots, p_n\} \subset \mathbb{R}^2$.
- *Definition 2.3:* $\text{conv}(\mathscr{P}) = \{x \in \mathbb{R}^2 \mid x$ is a convex combination of $\mathscr{P}\}$
- *Our algorithms compute the boundary set* $\delta\,\text{conv}(\mathscr{P})$ *as a convex polygon!*



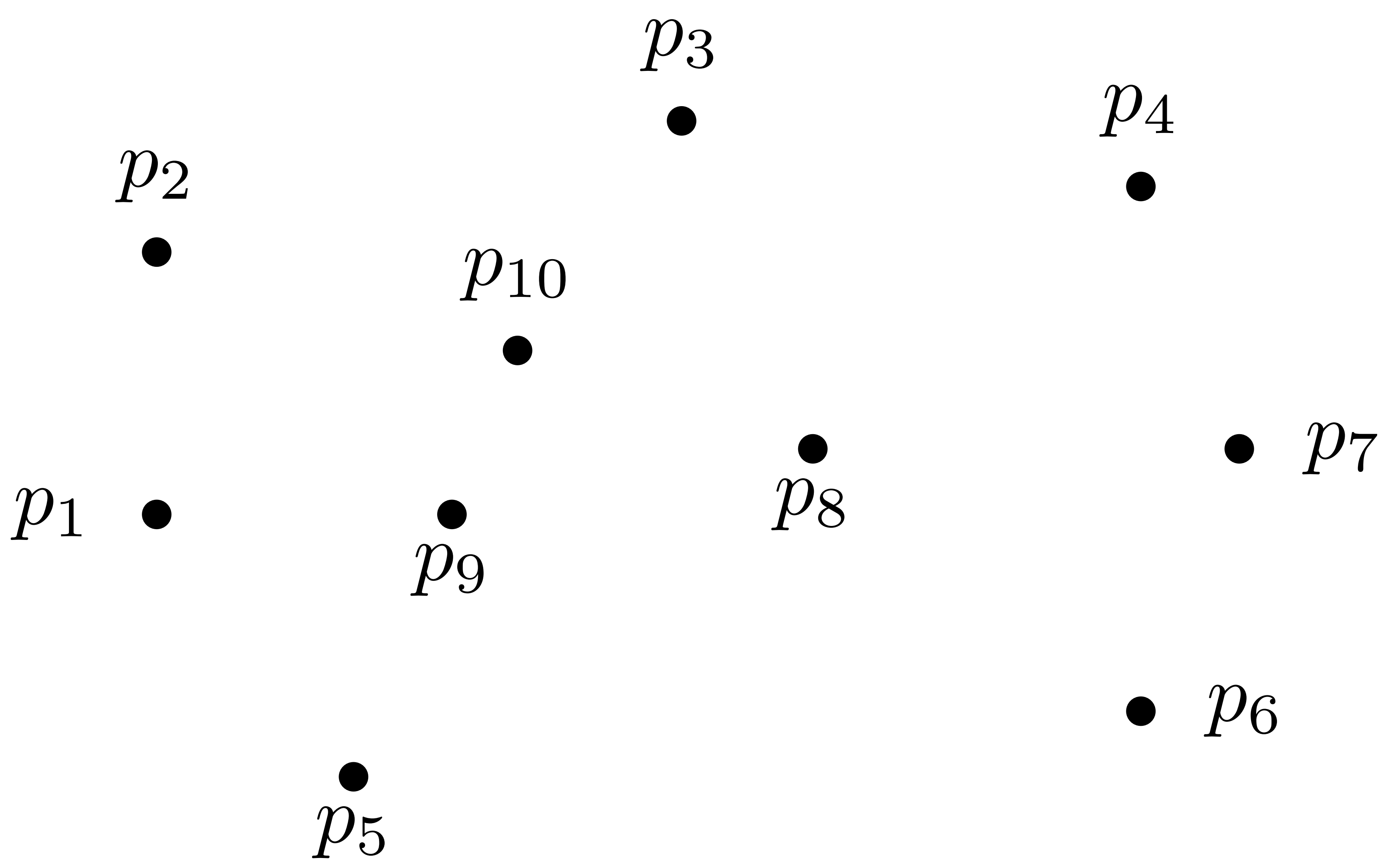
Detour: Point sets & Polygons

Peter Kramer | October 24th, 2024

Point sets & Polygons

What's the difference?

- Consider a finite point set $\mathscr{P} := \{p_1, p_2, \ldots, p_n\} \subset \mathbb{R}^2$.
- What's a polygon P using these points?



Point sets & Polygons

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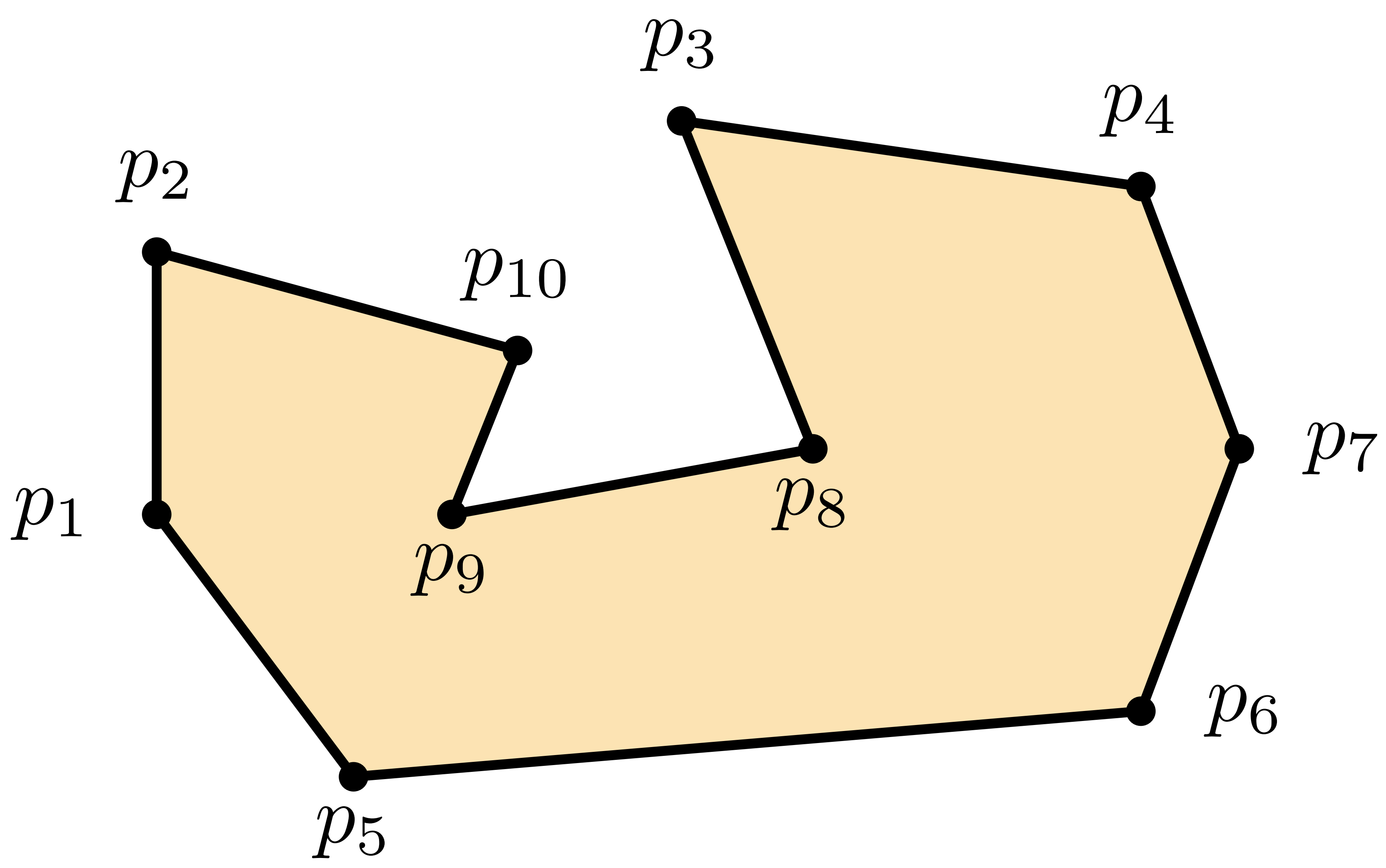
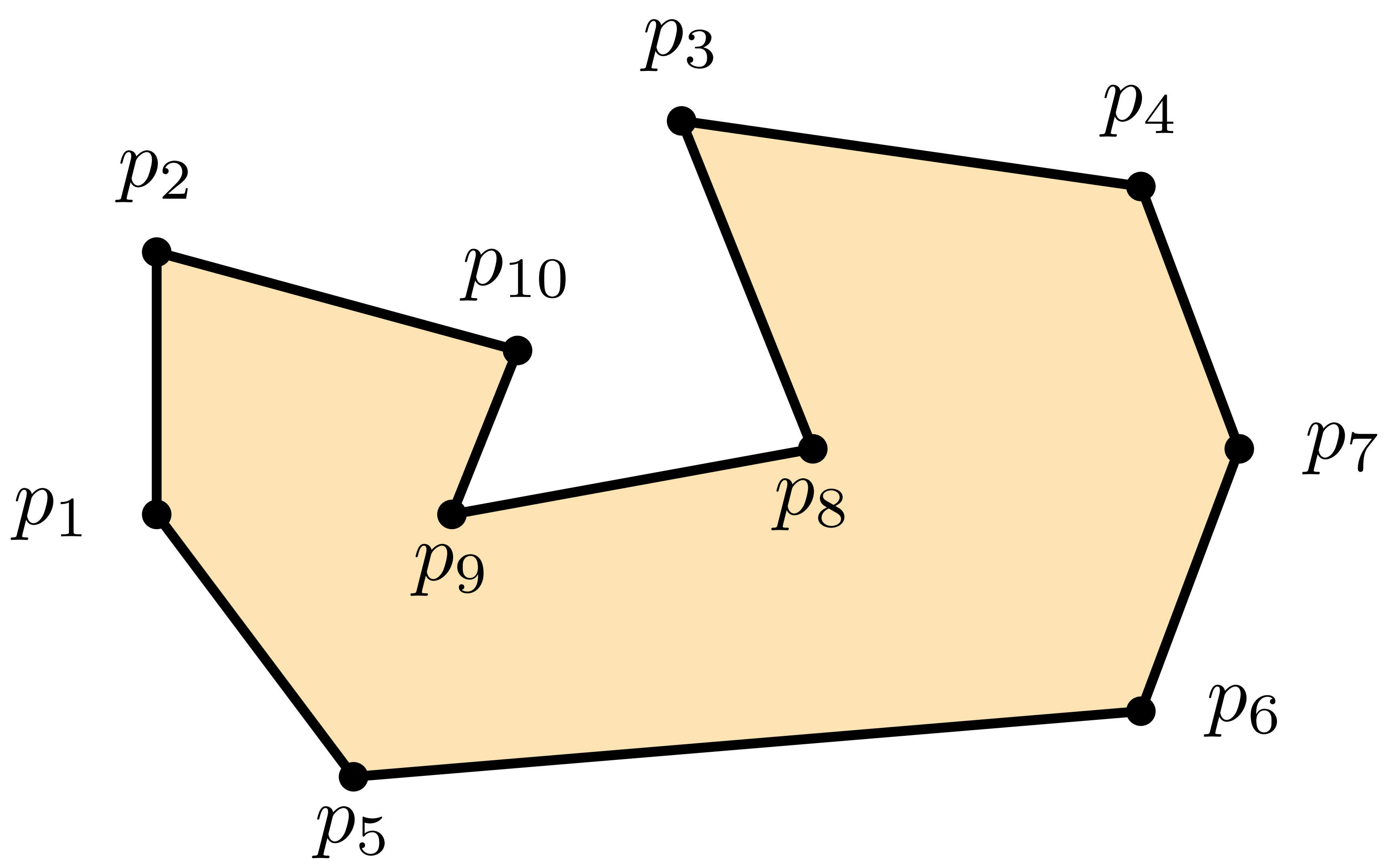


Point sets & Polygons

What's the difference?

- Consider a finite point set $\mathscr{P} := \{p_1, p_2, \ldots, p_n\} \subset \mathbb{R}^2$.
- An ordered sequence $P := p_{\pi(1)}, p_{\pi(2)}, \ldots, p_{\pi(n)} \in (\mathbb{R} \times \mathbb{R})^n$ is a polygon.



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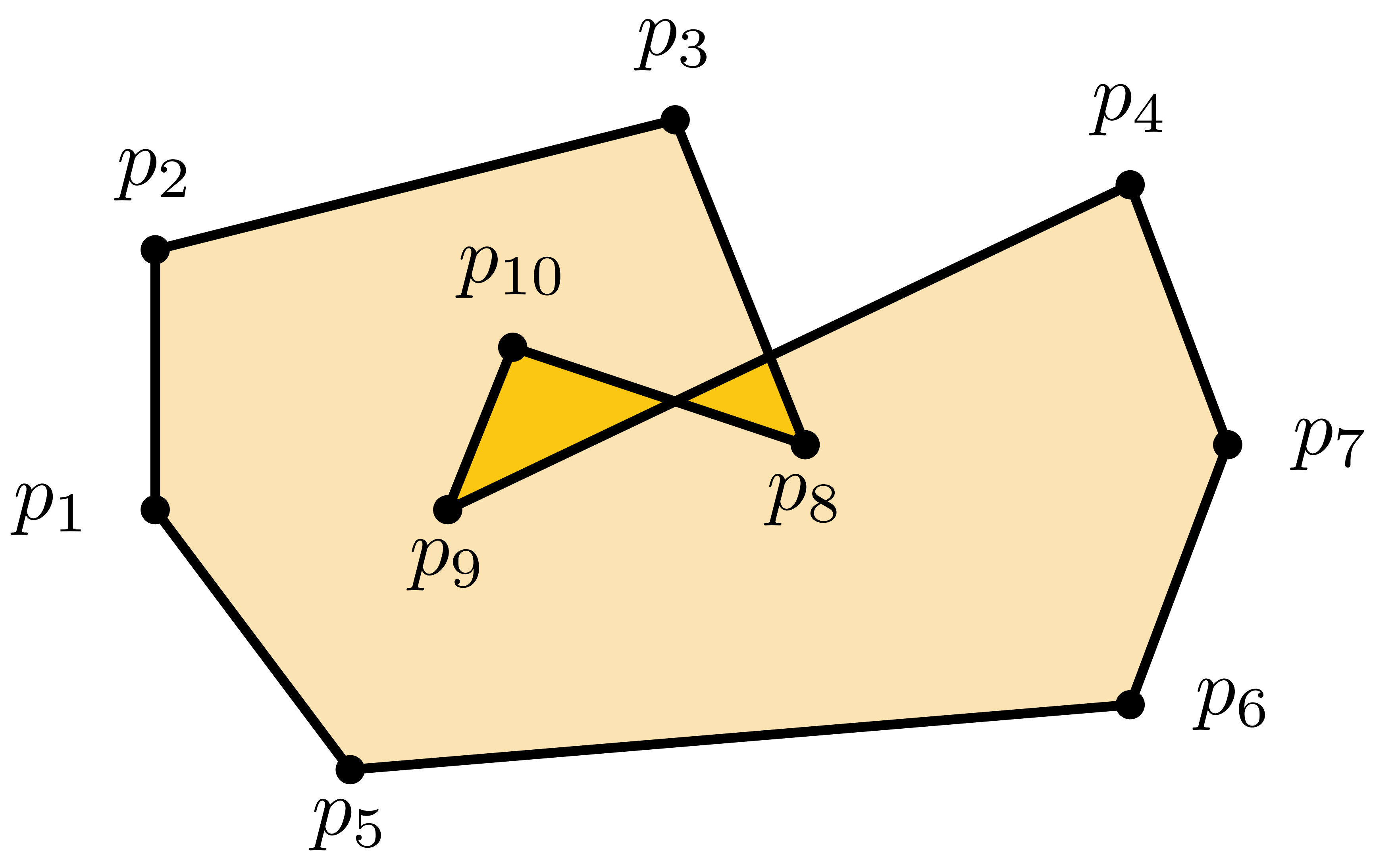


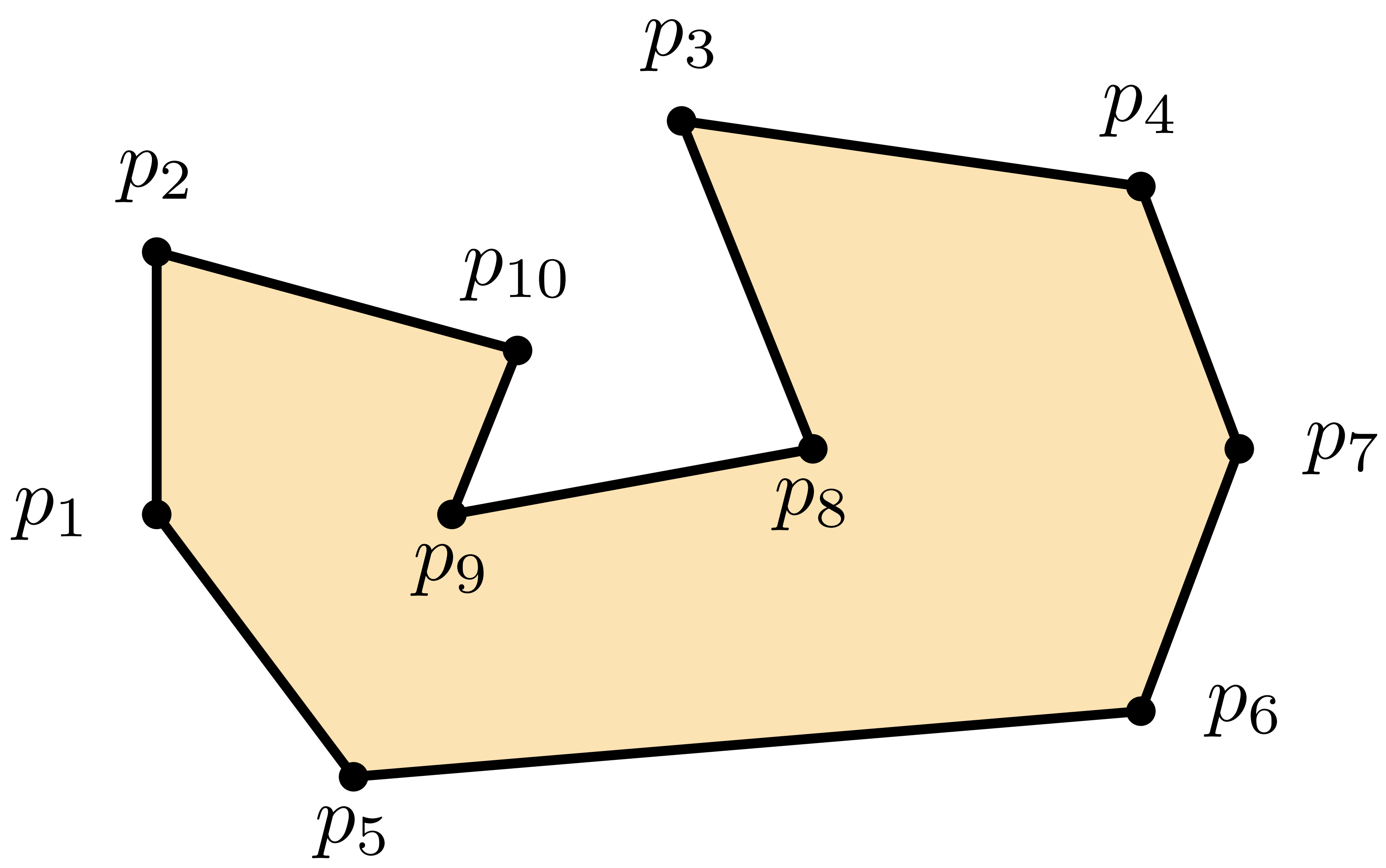
Point sets & Polygons

What's the difference?

- Consider a finite point set $\mathscr{P} := \{p_1, p_2, \ldots, p_n\} \subset \mathbb{R}^2$.
- A *simple* polygon P does not self-intersect.

Note: We will encounter further types of polygons later on :)

Typically, we describe polygons in CCW order:
$(p_1, p_5, p_6, p_7, p_4, p_3, p_8, p_9, p_10, p_2)$



Homework Sheet #1

Peter Kramer | October 24th, 2024

Computational Geometry – Sheet 1 **Winter 2024/2025**

Prof. Dr. Sándor P. Fekete **Due** 14.11.2024

Peter Kramer **Discussion** 21.11.2024

Please submit your handwritten answers in pairs, *using the box in front of IZ338* before *the exercise timeslot on the due date above. Make sure to include your* full names, matriculation numbers, *and the* programmes *that you are enrolled in.*

*In accordance with the **guidelines** of the TU Braunschweig, using AI tools to solve any part of the exercises is **not permitted**.*

Exercise 1. **(5 points)**

Refer to *Definitions 2.2 and 2.3* from the lecture. Prove or disprove: The intersection of two convex hulls according to *Definition 2.3* is itself convex for all finite sets $\mathcal{P}, \mathcal{Q} \subset \mathbb{R}^2$, i.e.,

$$\text{conv}(\text{conv}(\mathcal{P}) \cap \text{conv}(\mathcal{Q})) = \text{conv}(\mathcal{P}) \cap \text{conv}(\mathcal{Q}).$$

(Hint: Review the properties of convex hulls and combinations carefully.)

Definition E1 (General position). When investigating a problem, we often assume that the input data obeys *general position*, which excludes specific edges cases and simplifies analysis. For this sheet, a point set obeys general position if and only if no three points in it are collinear.

Exercise 2 (Point in Convex Polygon Problem). **(15 points)**

Using only the known predicates, design an $\mathcal{O}(\log n)$ algorithm for the following problem. Given a convex polygon $P = (p_1, p_2, \ldots, p_n) \in (\mathbb{R} \times \mathbb{R})^n$ and a point $q \in \mathbb{R}^2$, does P contain q? You may assume that the point set $\{p_1, p_2, \ldots, p_n, q\}$ obeys general position.

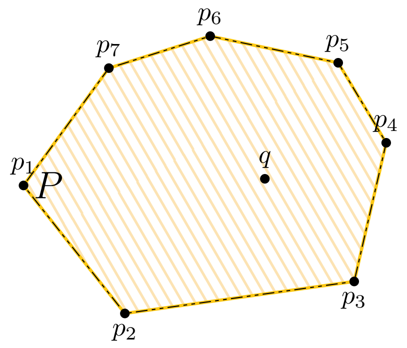


Figure 1: Example: the point q is located inside the convex polygon P.

Exercise 3 (Farthest Point Pairs). **(5+10 points)**

Given a set $\mathcal{P}$ of n points in the Euclidean plane, two points $p, q \in \mathcal{P}$ are a *farthest pair* in $\mathcal{P}$ if

$$\forall\, u, v \in \mathcal{P}: \quad |p - q| \geq |u - v|.$$

The Euclidean distance between p and q is then also called the *diameter* of $\mathcal{P}$.

a) Prove that all farthest pairs in $\mathcal{P}$ are vertices of the convex hull $\text{conv}(\mathcal{P})$.

b) Design an $\mathcal{O}(n)$ algorithm that approximates the diameter of $\mathcal{P}$ up to a constant factor. Briefly explain approximation factor and runtime!

1/1

Three weeks!

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These sheets are about logical deduction, so LLMs will most likely just generate plausible-sounding garbage.

Please save us the headache :)

Translation services such as DeepL are allowed, of course.
If you so prefer, you may write your solutions in german.

Prof. Dr. Sándor P. Fekete
Peter Kramer

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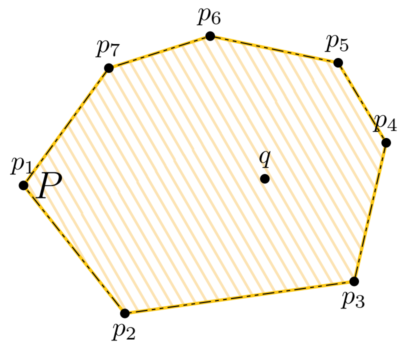

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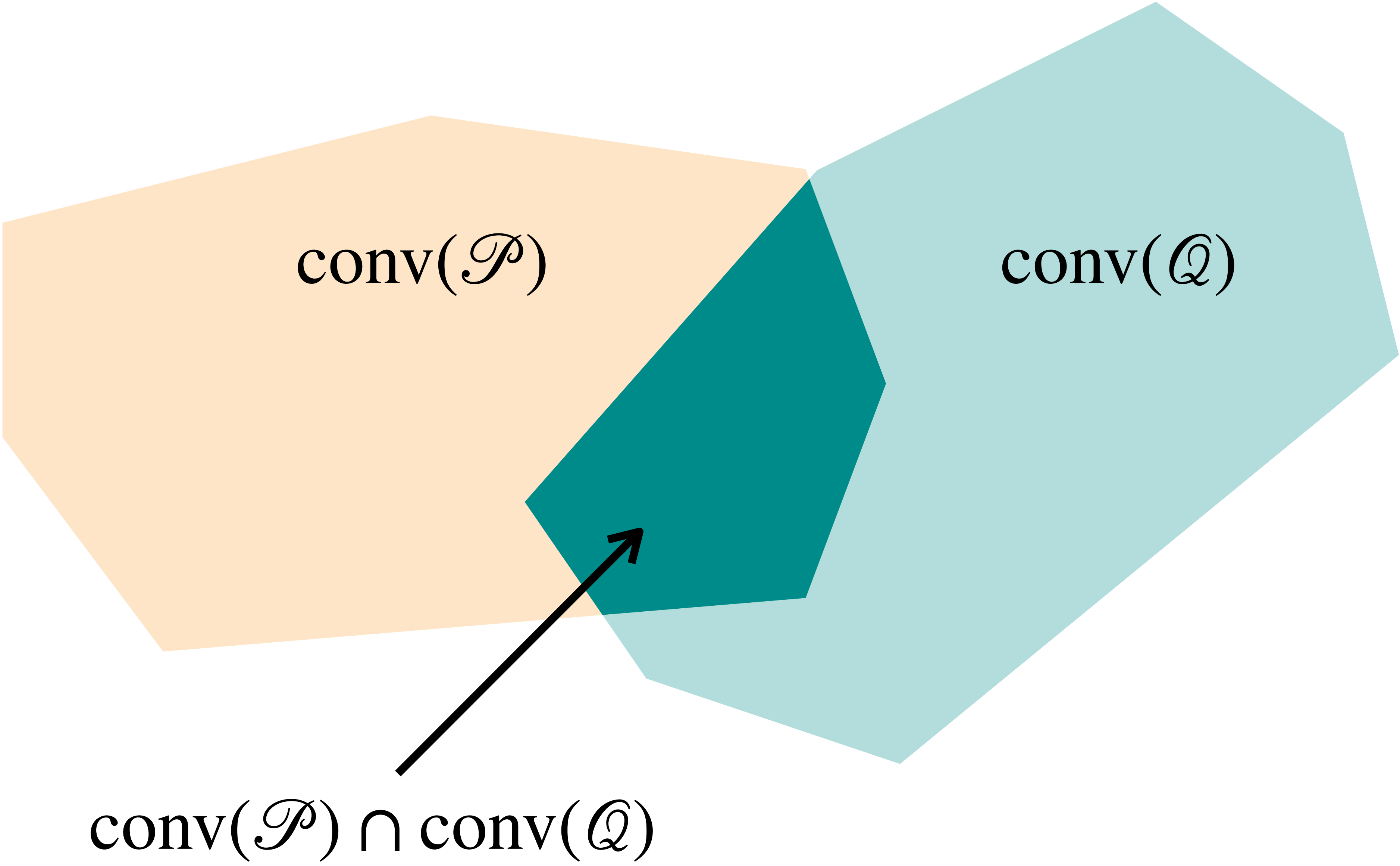
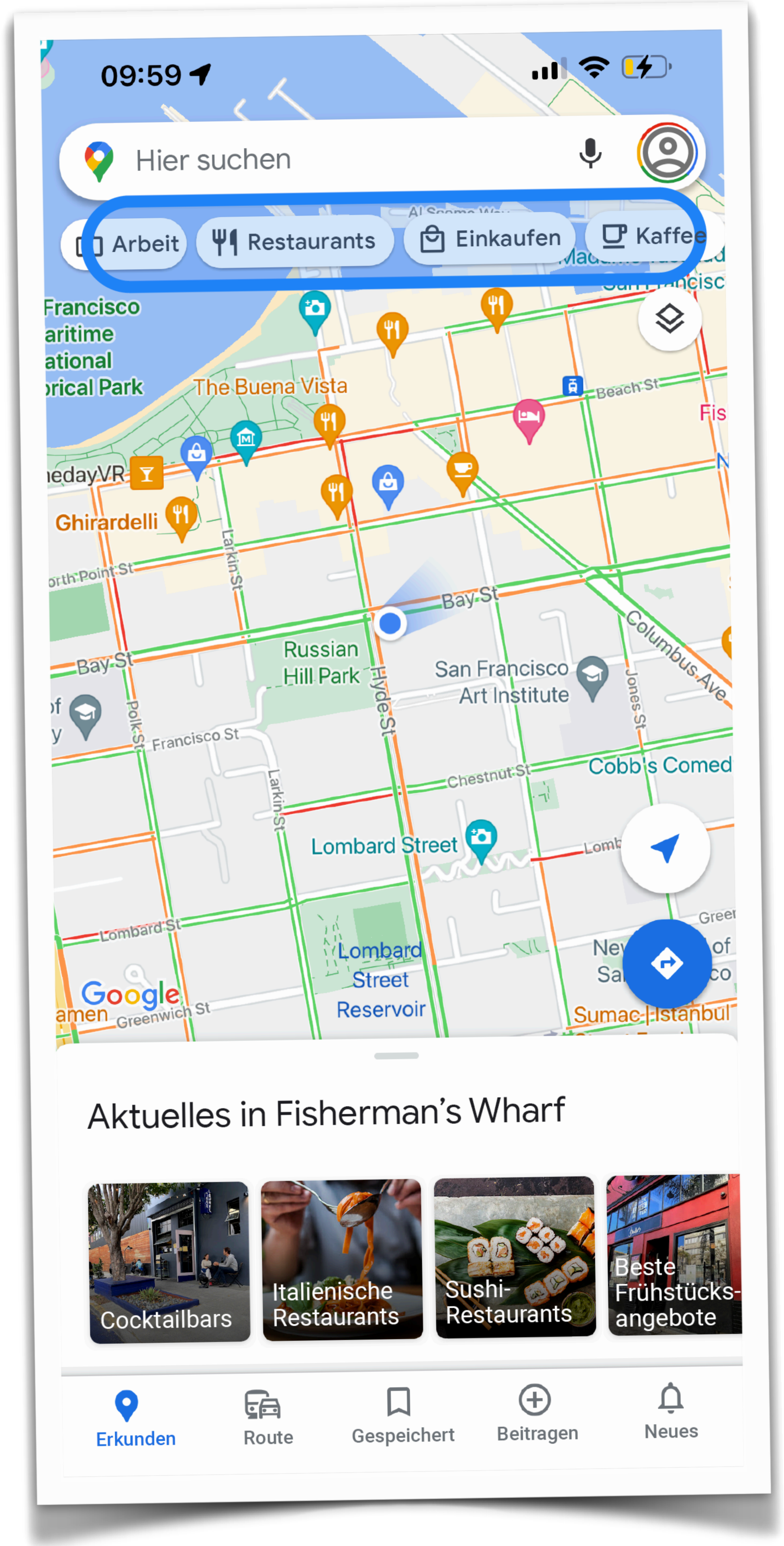


Point Location Problems

"Where am I?"

- Given geometric information such as a map in the plane, how can we decide **where** we are?



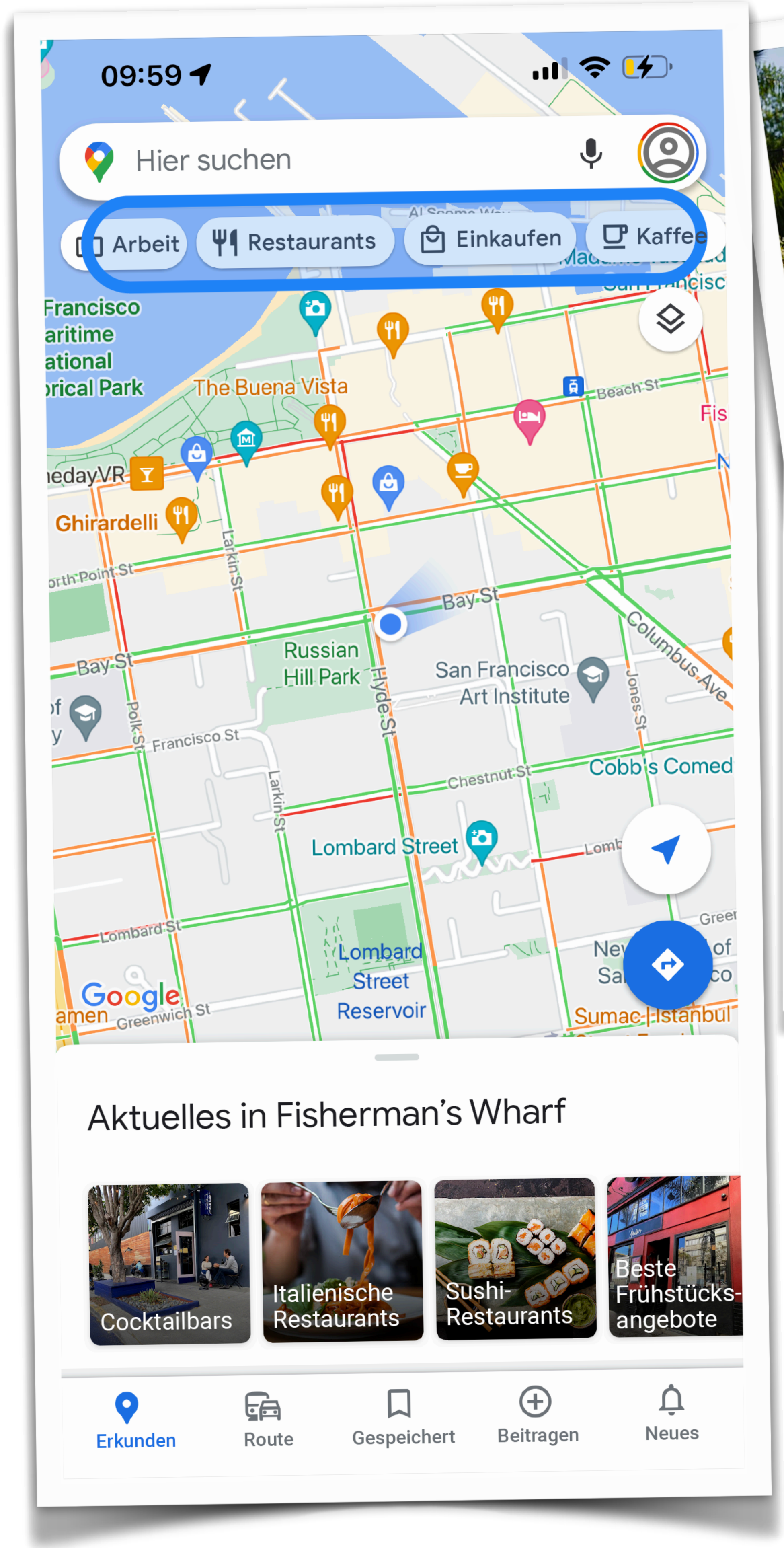
Point Location Problems

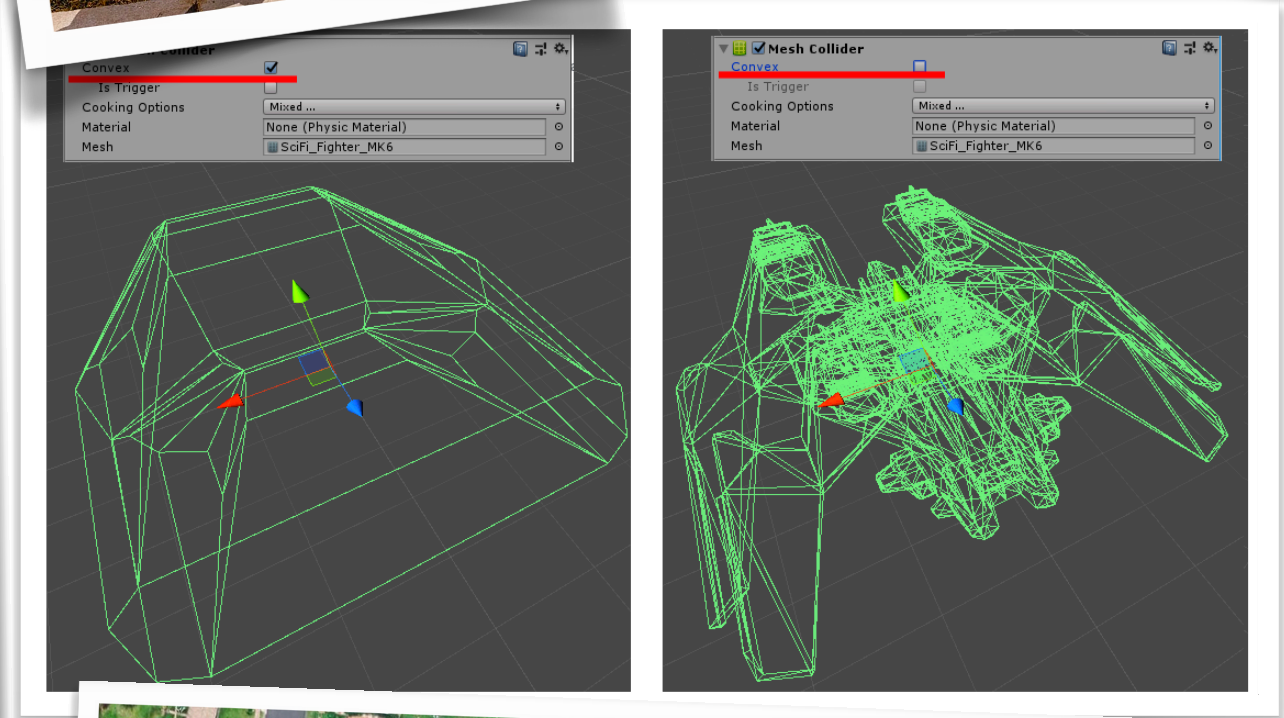
"Where am I?"

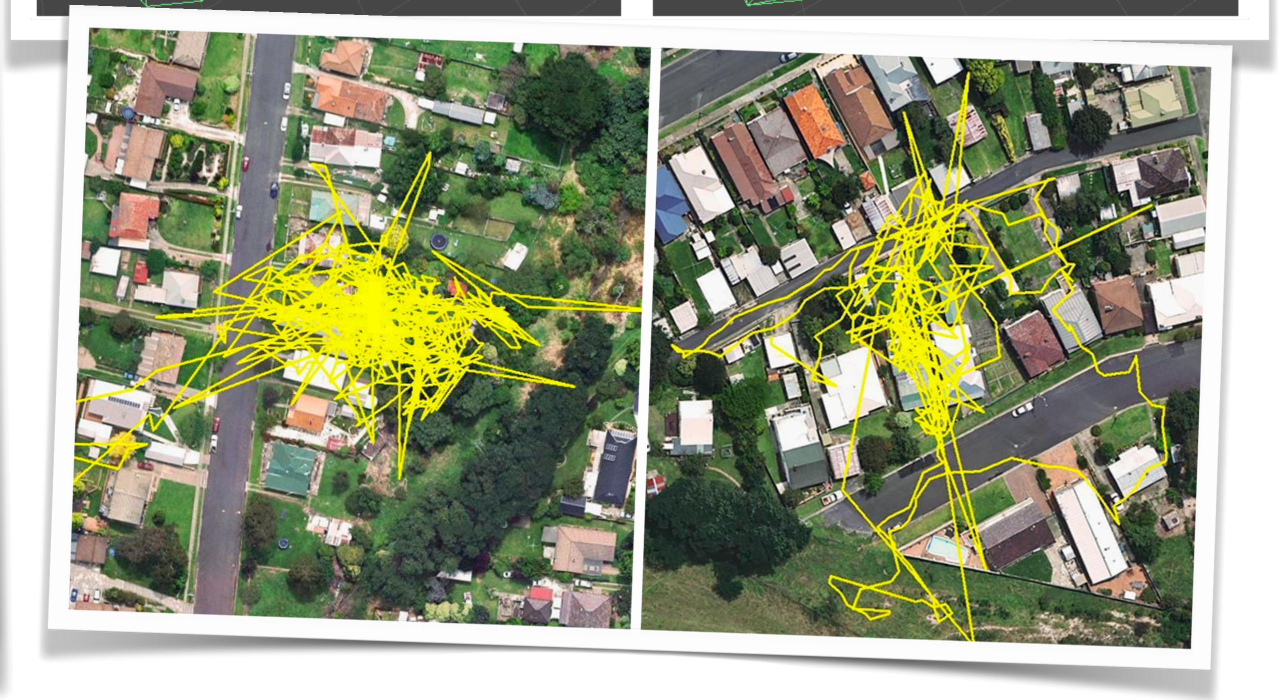
- Given geometric information such as a map in the plane, how can we decide **where** we are?

- *"In which country am I right now?"*
  "Can I leave this scooter here?"
  "Do these virtual objects collide?"

- ***"Is point p inside of region P?"***







Applications: Geofencing, Navigation, Simulation Software, Outlier Detection, …

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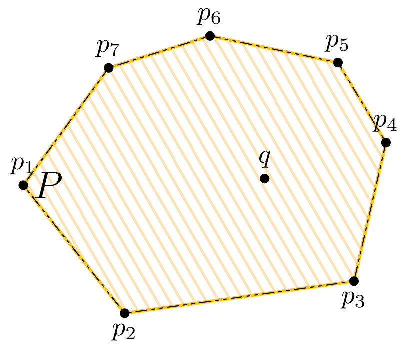

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Using only the known predicates, design an $\mathcal{O}(\log n)$ algorithm for the following problem. Given a convex polygon $P = (p_1, p_2, \ldots, p_n) \in (\mathbb{R} \times \mathbb{R})^n$ and a point $q \in \mathbb{R}^2$, does P contain q? You may assume that the point set $\{p_1, p_2, \ldots, p_n, q\}$ obeys general position.

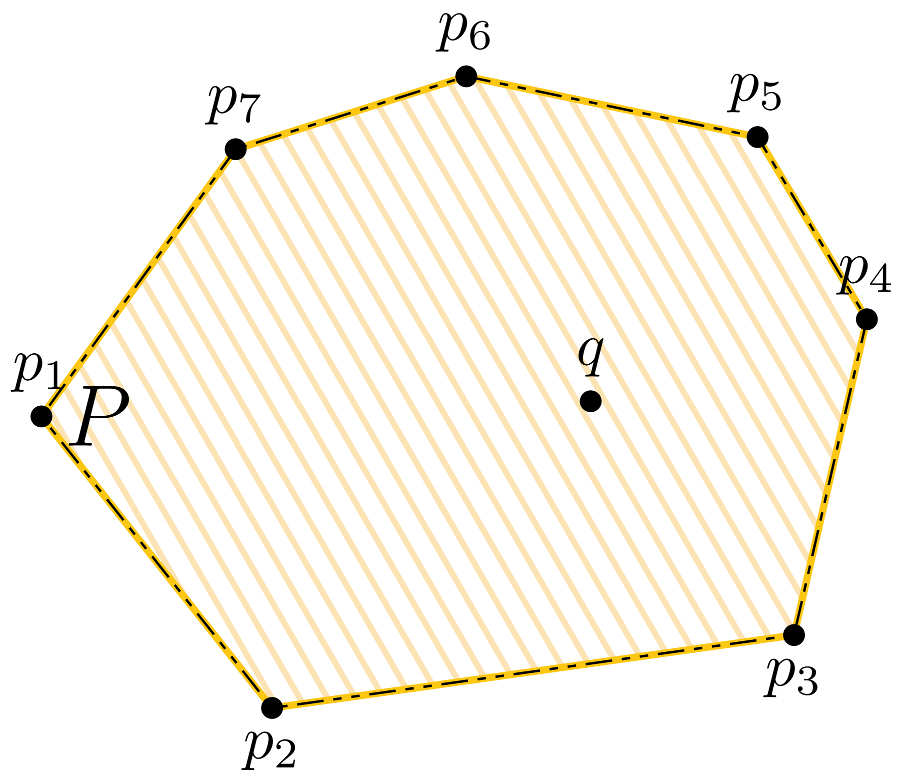

Figure 1: Example: the point q is located inside the convex polygon P.

Computational Geometry – Sheet 1 **Winter 2024/2025**
Prof. Dr. Sándor P. Fekete **Due** 14.11.2024
Peter Kramer **Discussion** 21.11.2024

Please submit your handwritten answers in pairs, using the box in front of `IZ338` *before the exercise timeslot on the due date above. Make sure to include your full names, matriculation numbers, and the programmes that you are enrolled in.*

In accordance with the `guidelines` *of the TU Braunschweig, using AI tools to solve any part of the exercises is* ***not permitted****.*

Exercise 1. **(5 points)**

Refer to *Definitions 2.2 and 2.3* from the lecture. Prove or disprove: The intersection of two convex hulls according to *Definition 2.3* is itself convex for all finite sets $\mathcal{P}, \mathcal{Q} \subset \mathbb{R}^2$, i.e.,

$$\operatorname{conv}(\operatorname{conv}(\mathcal{P}) \cap \operatorname{conv}(\mathcal{Q})) = \operatorname{conv}(\mathcal{P}) \cap \operatorname{conv}(\mathcal{Q}).$$

(Hint: Review the properties of convex hulls and combinations carefully.)

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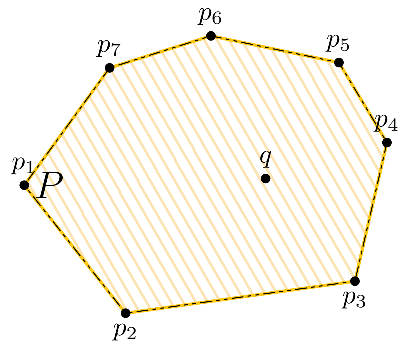

Figure 1: Example: the point q is located inside the convex polygon P.

Exercise 3 (Farthest Point Pairs). **(5+10 points)**

Given a set $\mathcal{P}$ of n points in the Euclidean plane, two points $p, q \in \mathcal{P}$ are a *farthest pair* in $\mathcal{P}$ if

$$\forall\, u, v \in \mathcal{P}: \quad |p - q| \ \geq\ |u - v|.$$

The Euclidean distance between p and q is then also called the *diameter* of $\mathcal{P}$.

a) Prove that all farthest pairs in $\mathcal{P}$ are vertices of the convex hull $\operatorname{conv}(\mathcal{P})$.

b) Design an $\mathcal{O}(n)$ algorithm that approximates the diameter of $\mathcal{P}$ up to a constant factor. Briefly explain approximation factor and runtime!

1/1

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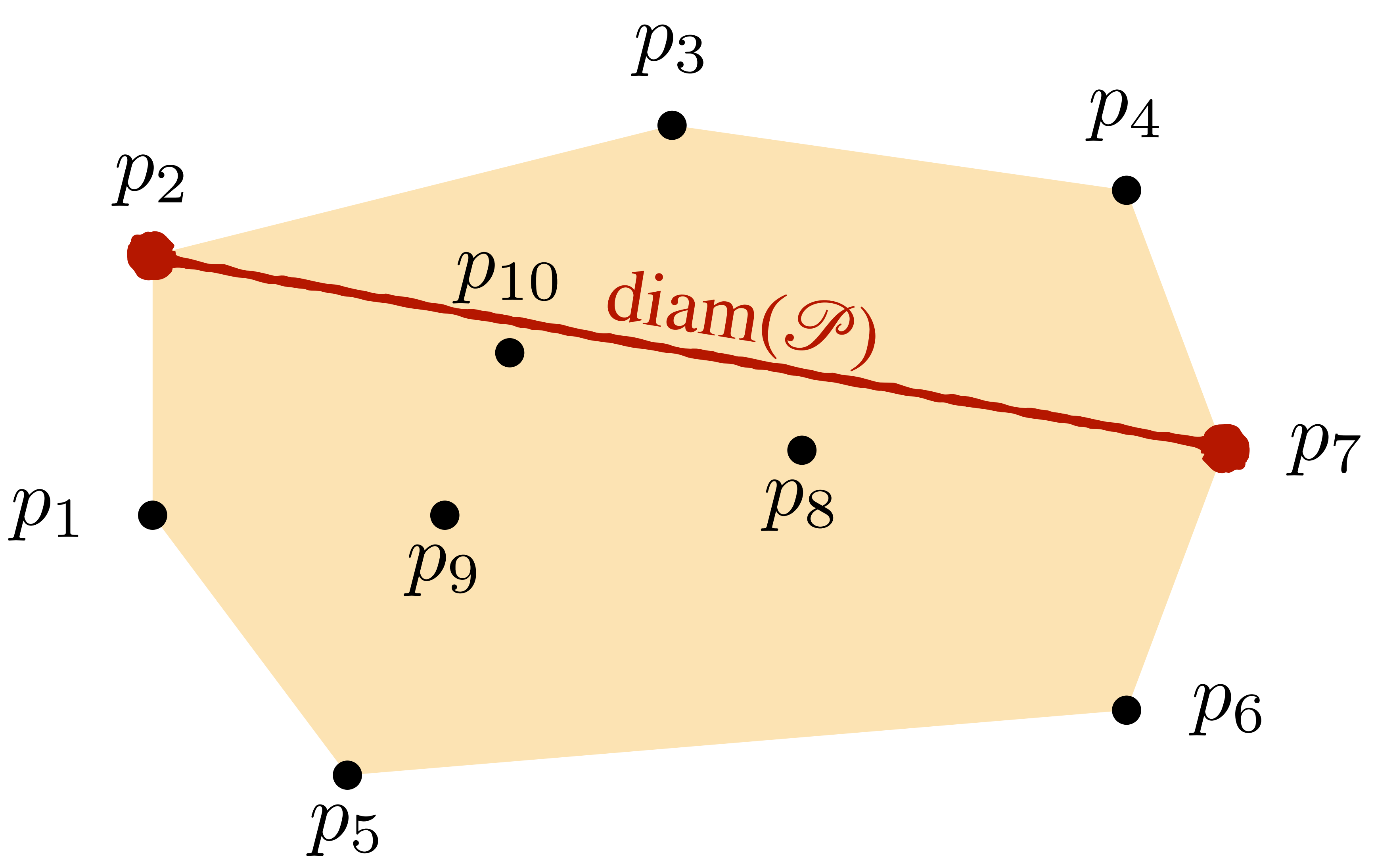

For a c-approximation, argue that your algorithm's output is

- at most $c \cdot \operatorname{diam}(\mathscr{P})$, and
- at least $\frac{1}{c} \cdot \operatorname{diam}(\mathscr{P})$.

TL;DL

The important parts

- **Sign up for the mailing list!**
- One tutorial a week (except holidays).
- Biweekly homework: **Find partners!**
- First **sheet is out now**, due in 3 weeks.
- Material can be found on the website.
  - Slides, videos, and homework sheets.

- Any questions? Ask Peter or Kai:
  - kramer@ibr.cs.tu-bs.de
  - kobbe@ibr.cs.tu-bs.de

October						
28	29	30	31			

November						
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

Extra slides

Big O Notation

Catching up, if necessary.

- If you speak German: There is plenty of material on the course website of “Algorithmen und Datenstrukturen”

Institut für Betriebssysteme
und Rechnerverbund
Algorithmik

- If you don’t: There is plenty of other courseware (e.g., from MIT) available!

MIT OpenCourseWare

- There also exist a variety of short-form explanation videos, such as: