Computational Geometry

Tutorial #2

Written Exam

terminplaner DFN

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DEUTSCH

ENGLISH

Written Exam CG 25/26

Who invites: Peter Kramer

Please mark ALL dates that are feasible!
We have a large number of participants, be fair :)

Location: TBD

Appointment selection:

	February 2026					March 2026		
	Mon. 16	Tue. 17	Tue. 24	Wed. 25	Fri. 27	Mon. 2	Tue. 3	Thu. 5
0 participants	11:00->14:00	11:00->14:00	10:00->13:00	09:00->12:00	09:00->12:00	09:00->12:00	09:00->12:00	12:00->15:00
Name	☐	☐	☐	☐	☐	☐	☐	☐

Submit

Point sets, hulls, and polygons

Refresh: What's the difference?

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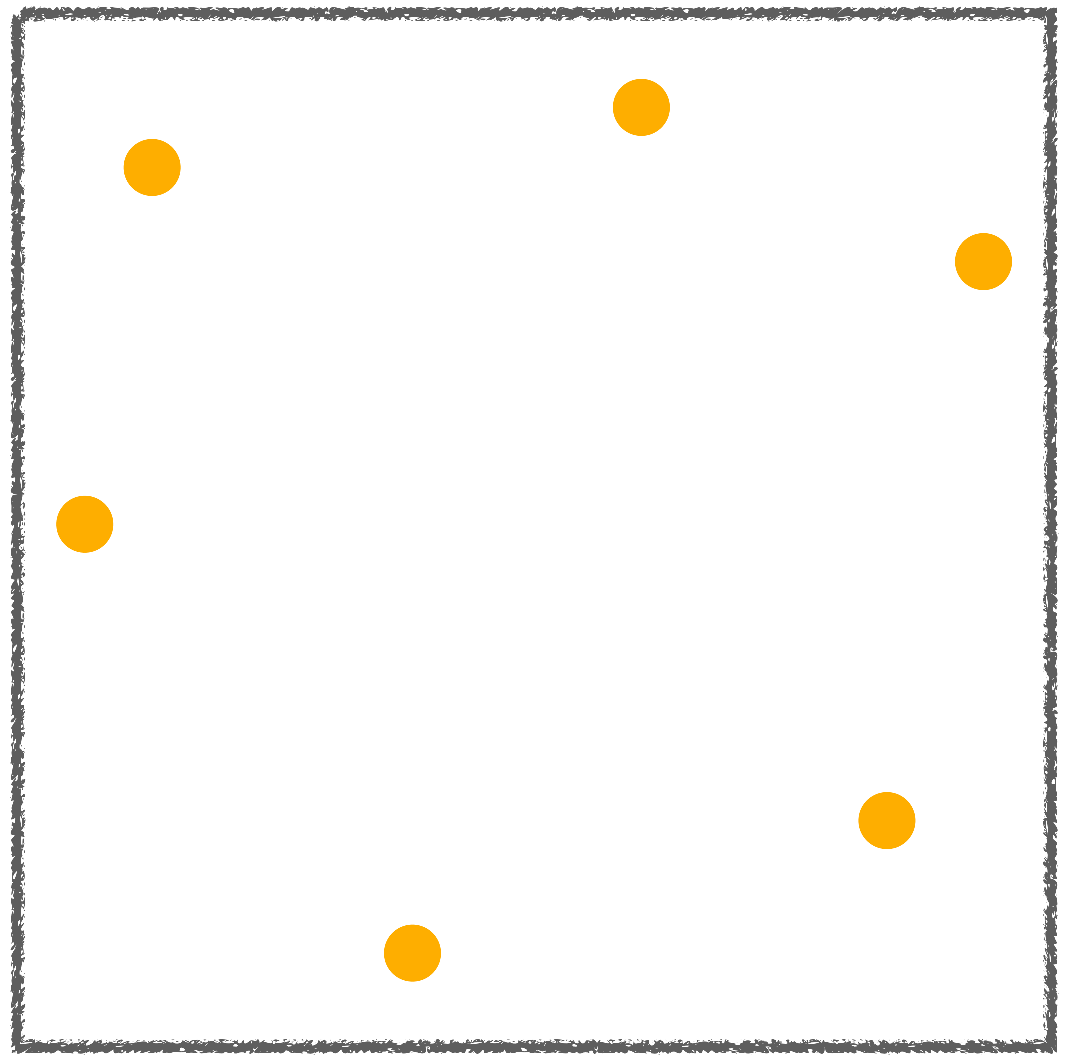
- 

A point set $\mathscr{P}$

Point sets, hulls, and polygons

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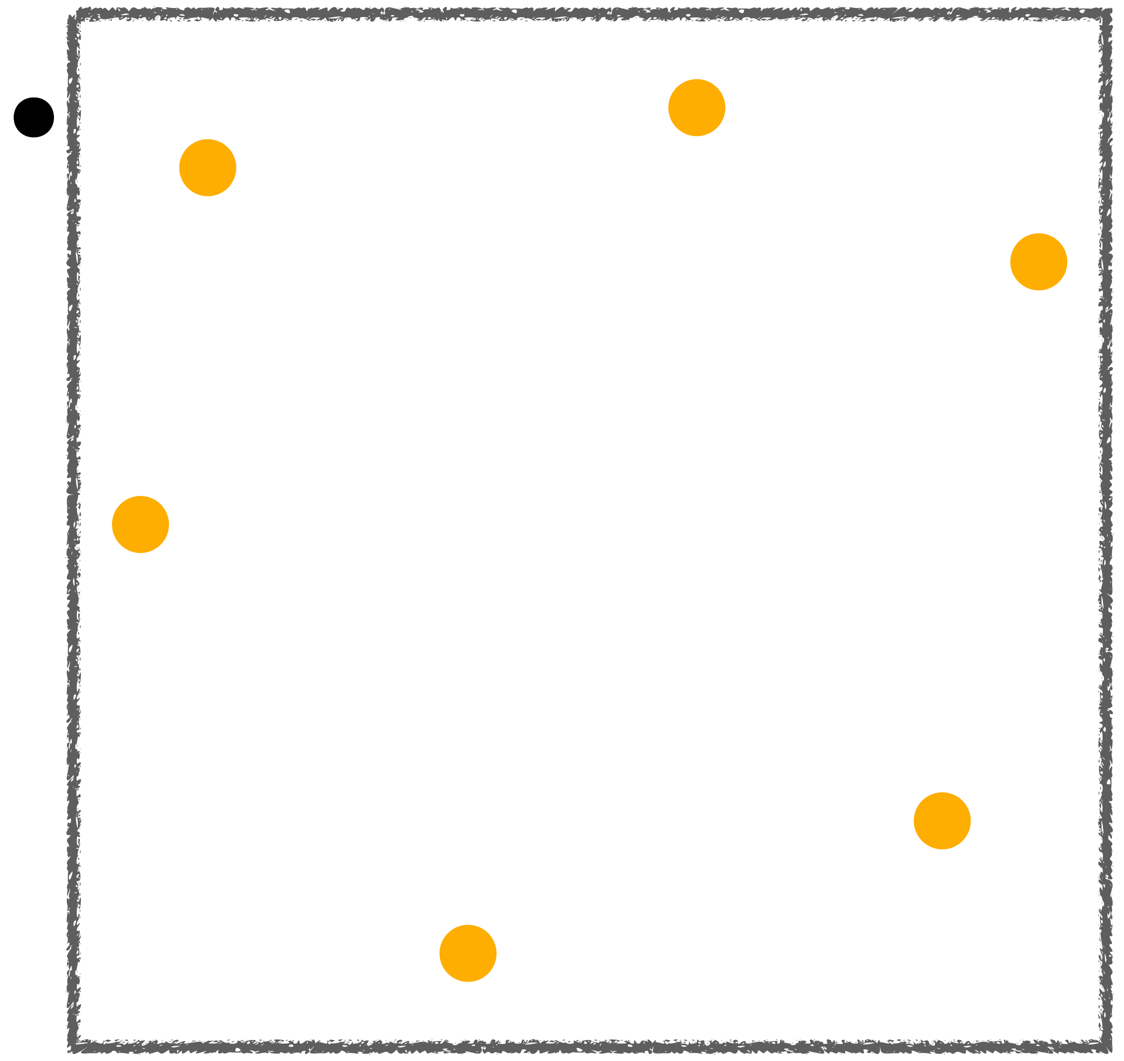

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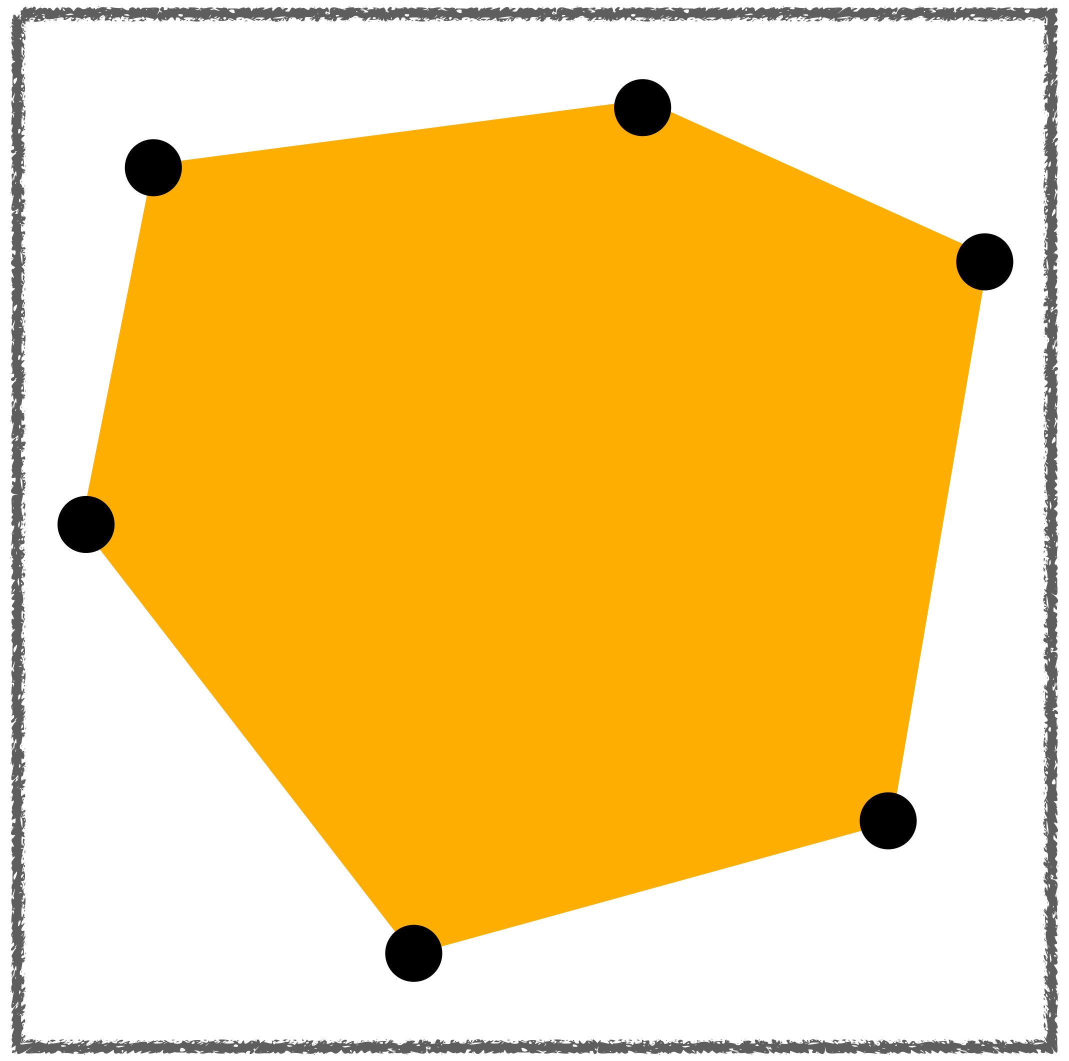

$\mathrm{conv}(\mathscr{P})$

Point sets, hulls, and polygons

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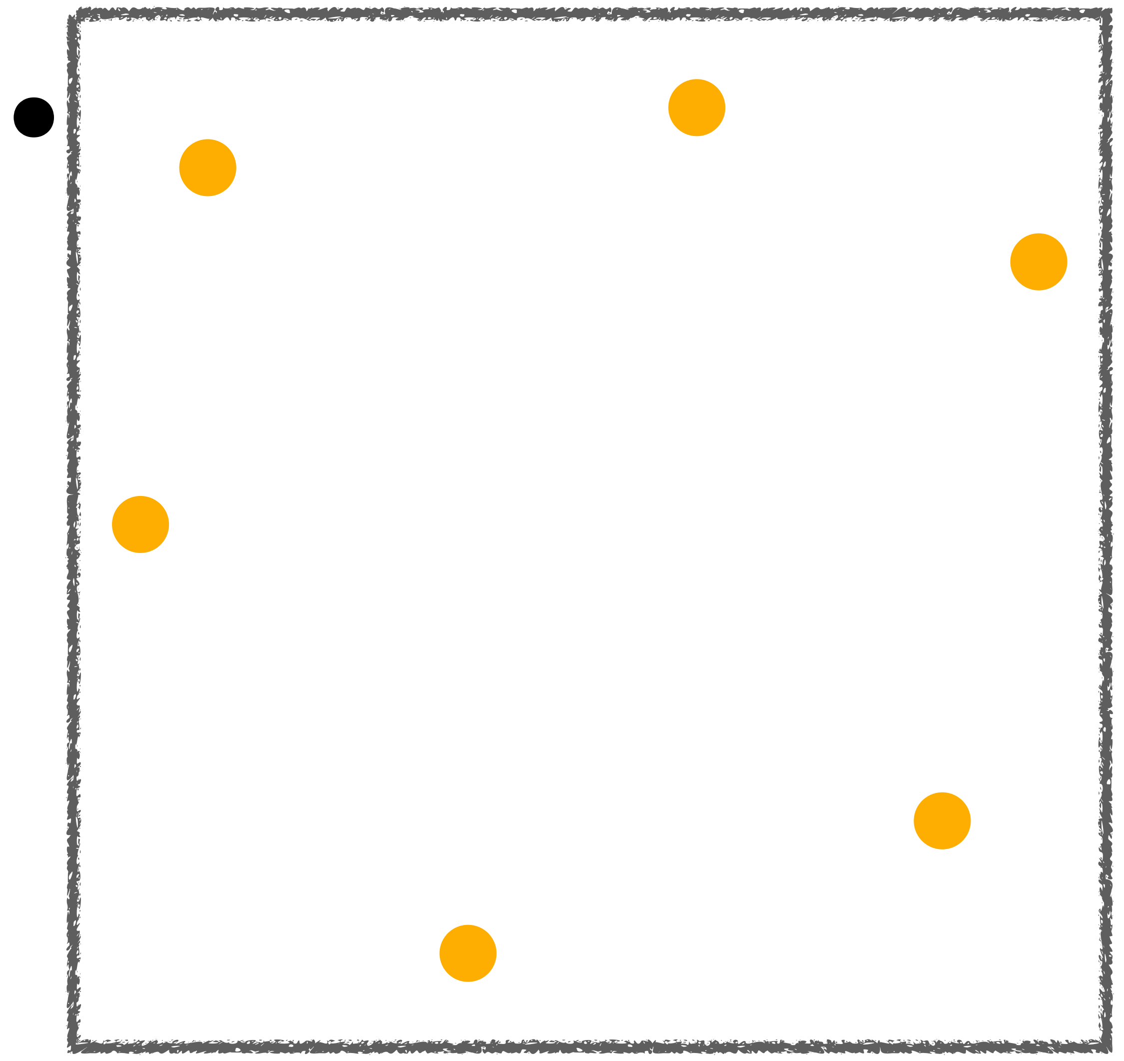

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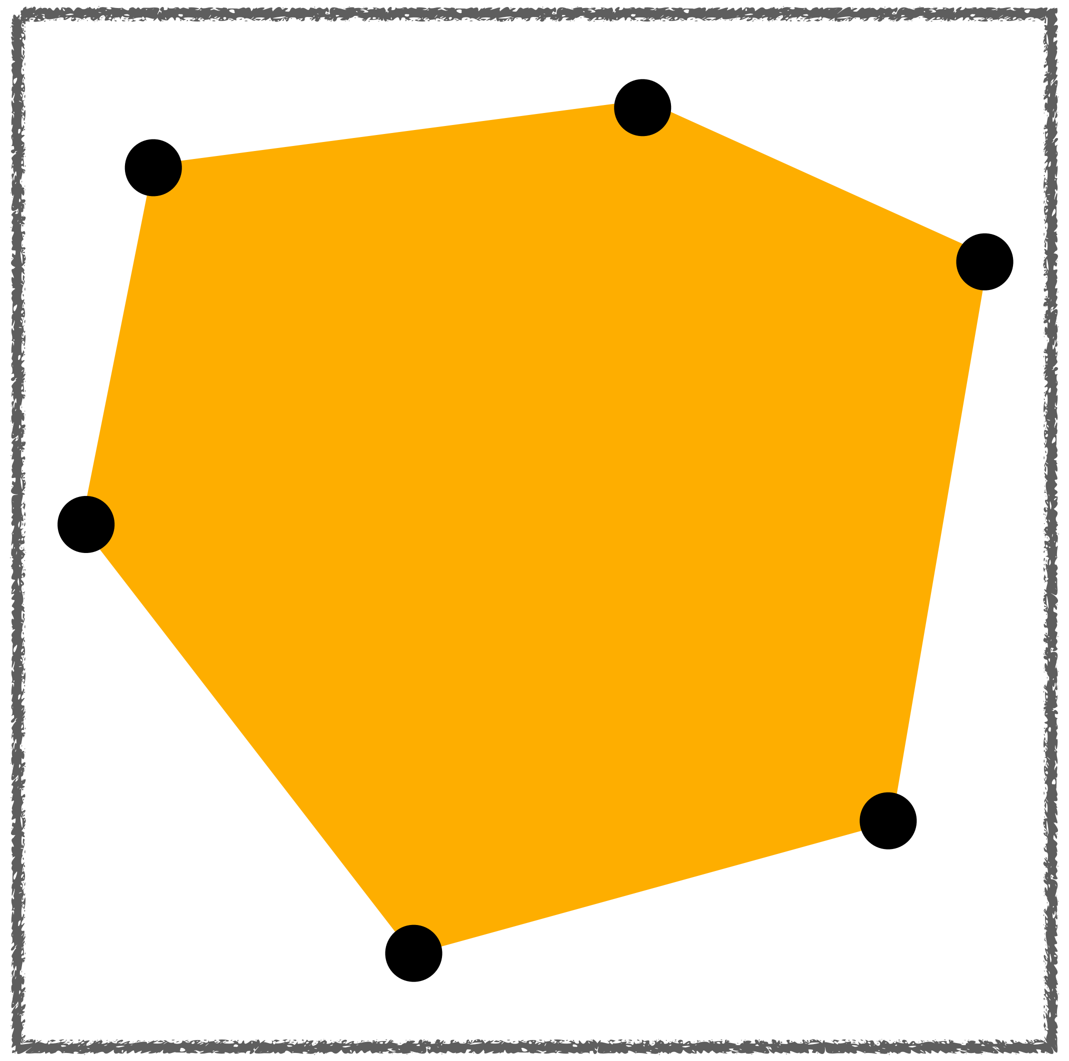

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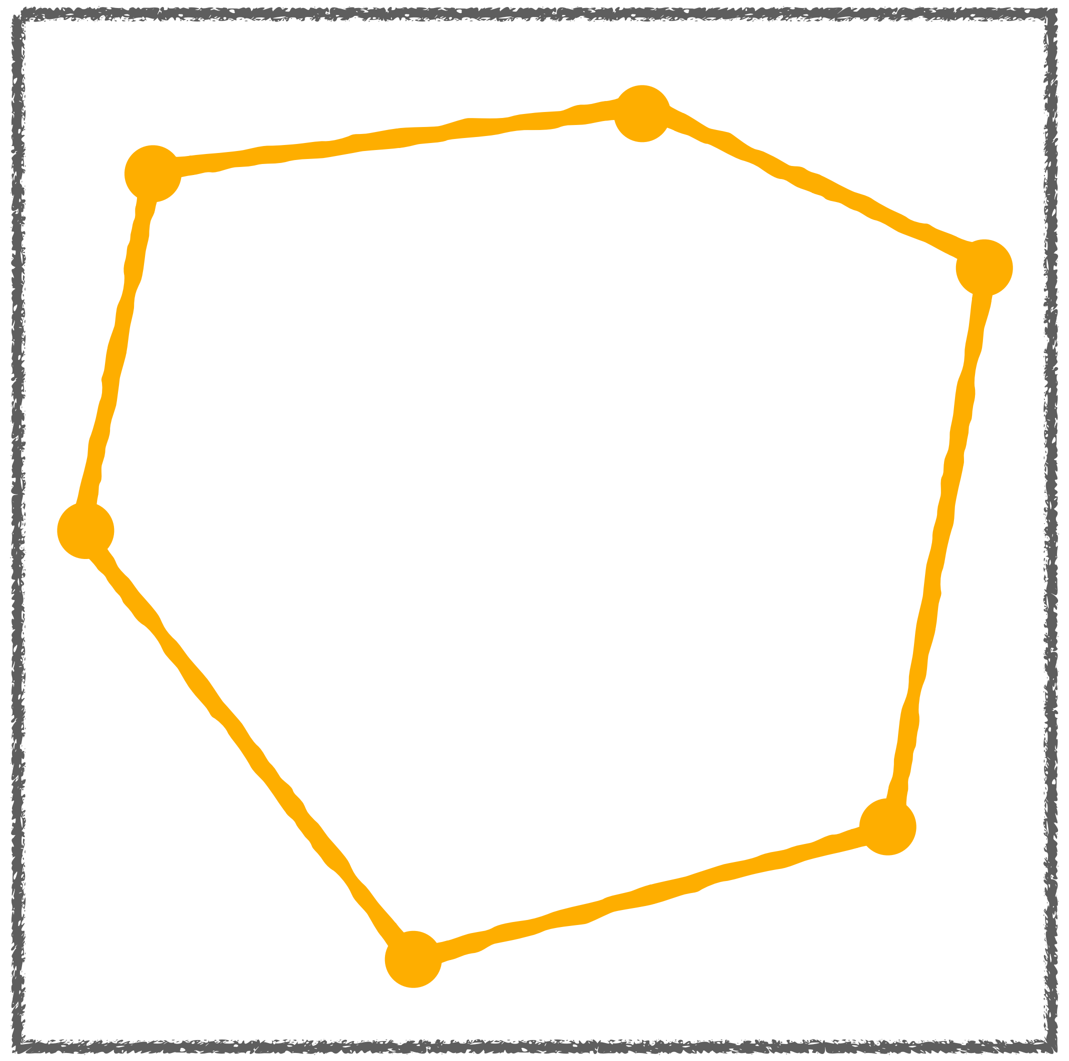


A polygon P on $\mathscr{P}$

Farthest point pairs
What we know

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 $\mathrm{conv}(\mathcal{P})$.

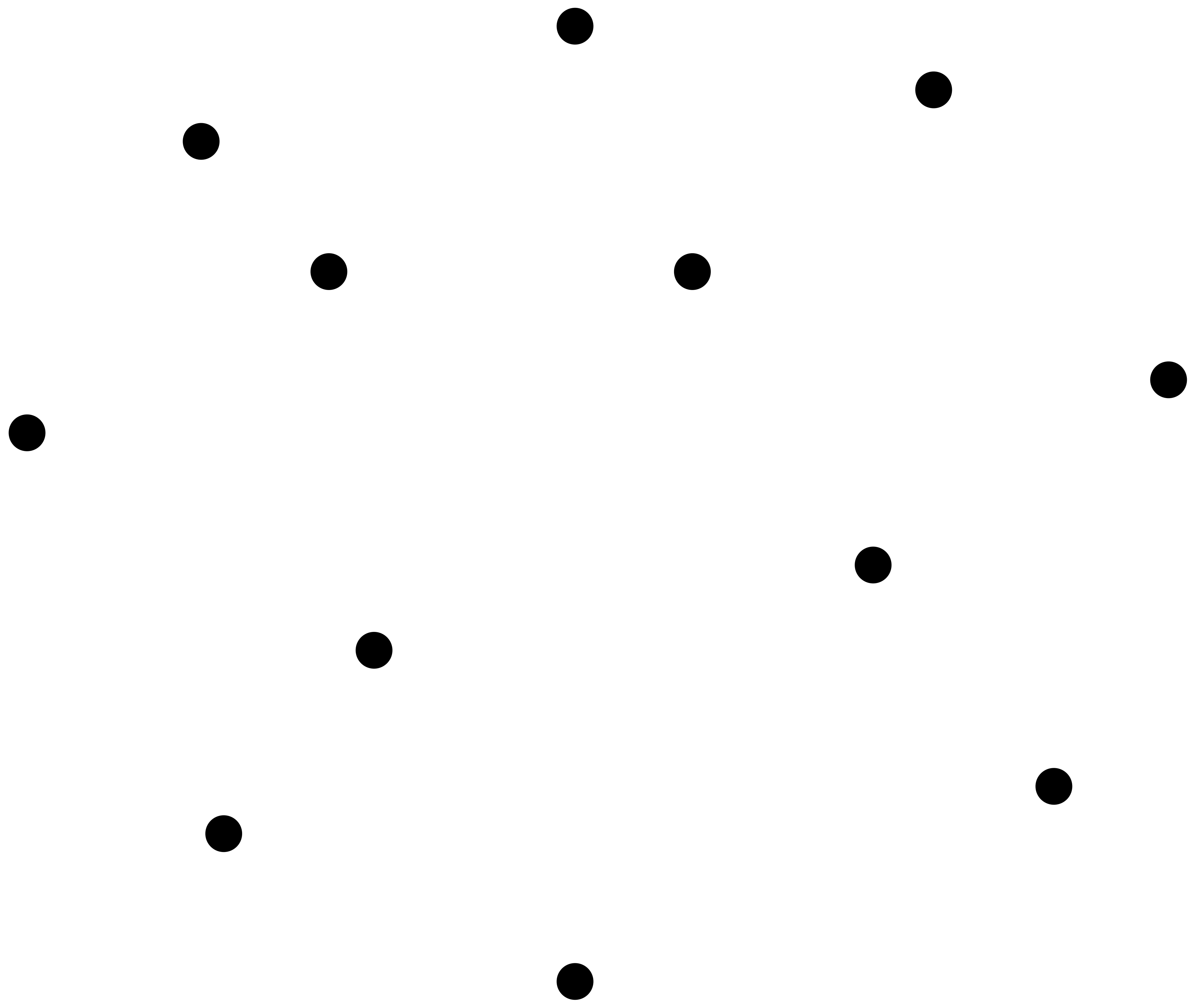
b) Design an $\mathcal{O}(n)$ algorithm that approximates the diameter of $\mathcal{P}$ up to a constant factor. Argue its correctness, approximation factor, and runtime!

- We will assume that **a)** is true — Discussion next week :)
- An greedy $\mathcal{O}(n^2)$ time algorithm is trivial. Today, we'll try to do better.

Farthest point pairs
Convex hull

Let $\mathscr{P}$ be set of n points in the Euclidean plane $\mathbb{R}^2$, in general position*.

Lemma E3.1 All farthest pairs of $\mathscr{P}$ consist of two vertices of the convex hull $\operatorname{conv}(\mathscr{P})$.



** no three points in $\mathscr{P}$ are collinear.*

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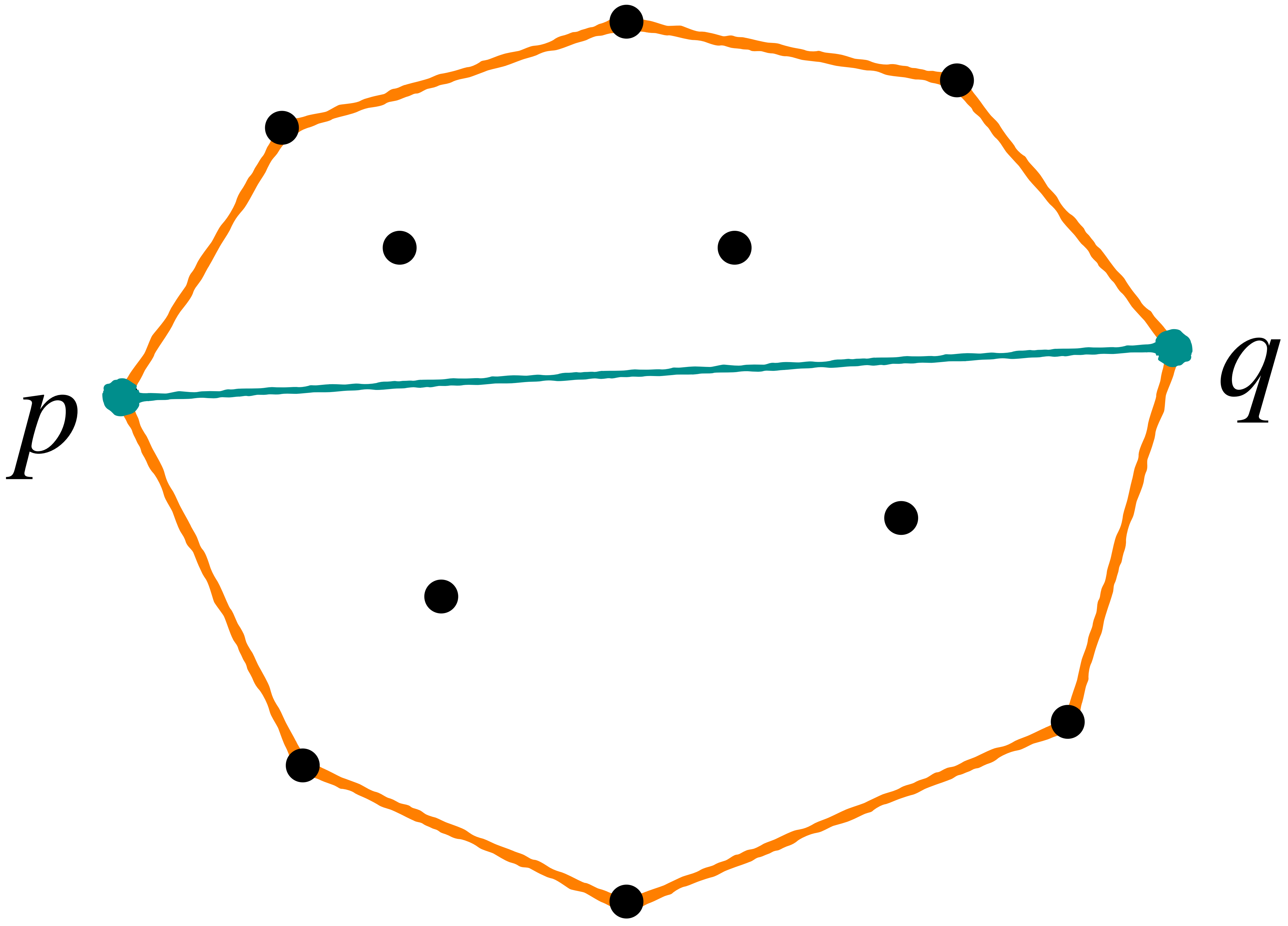

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Farthest point pairs

Antipodal pairs

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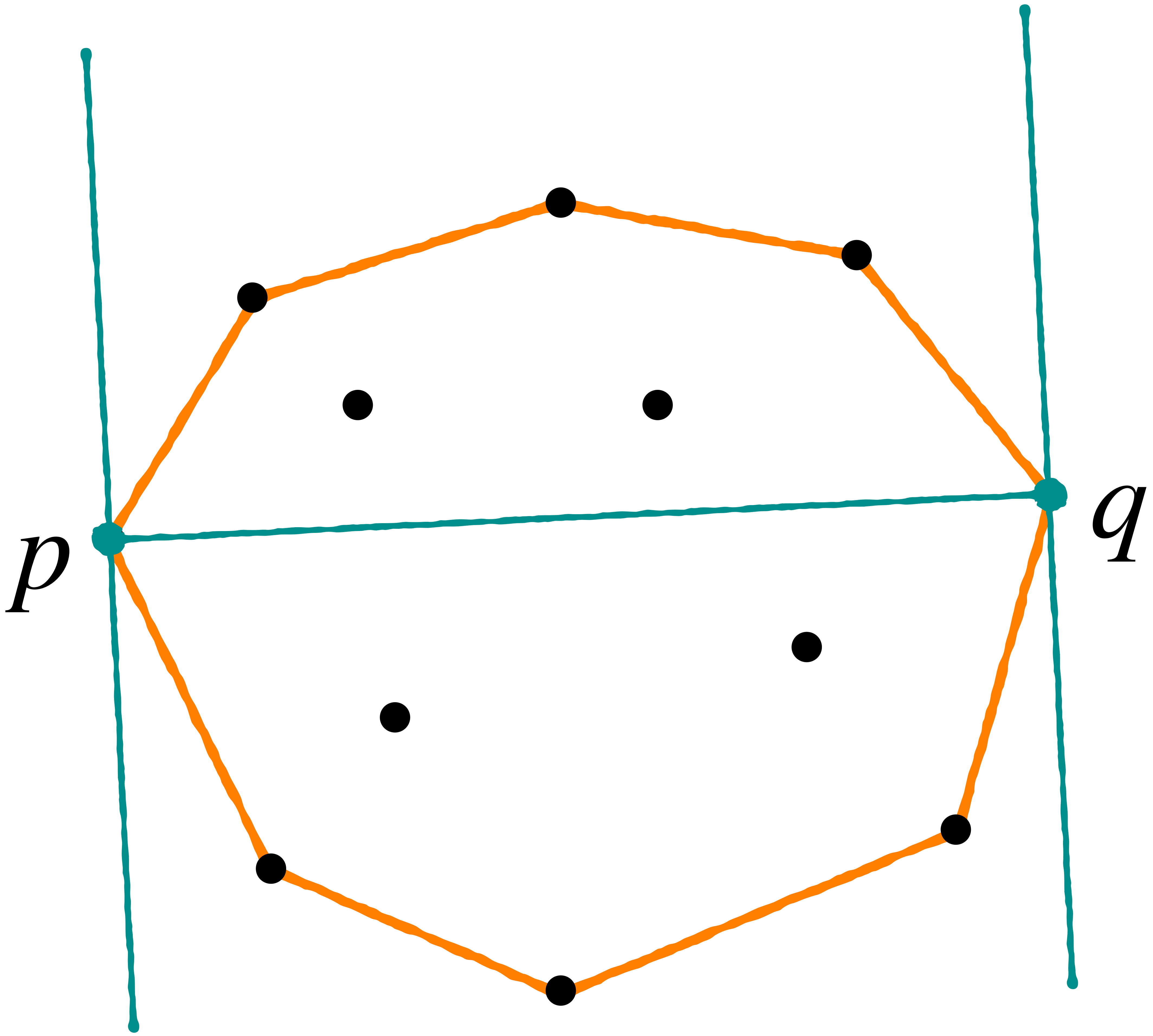
Definition. Two points $p, q \in \mathscr{P}$ are **antipodal** if there exist parallel **supporting lines** through them which touch, but do not cut the convex hull.



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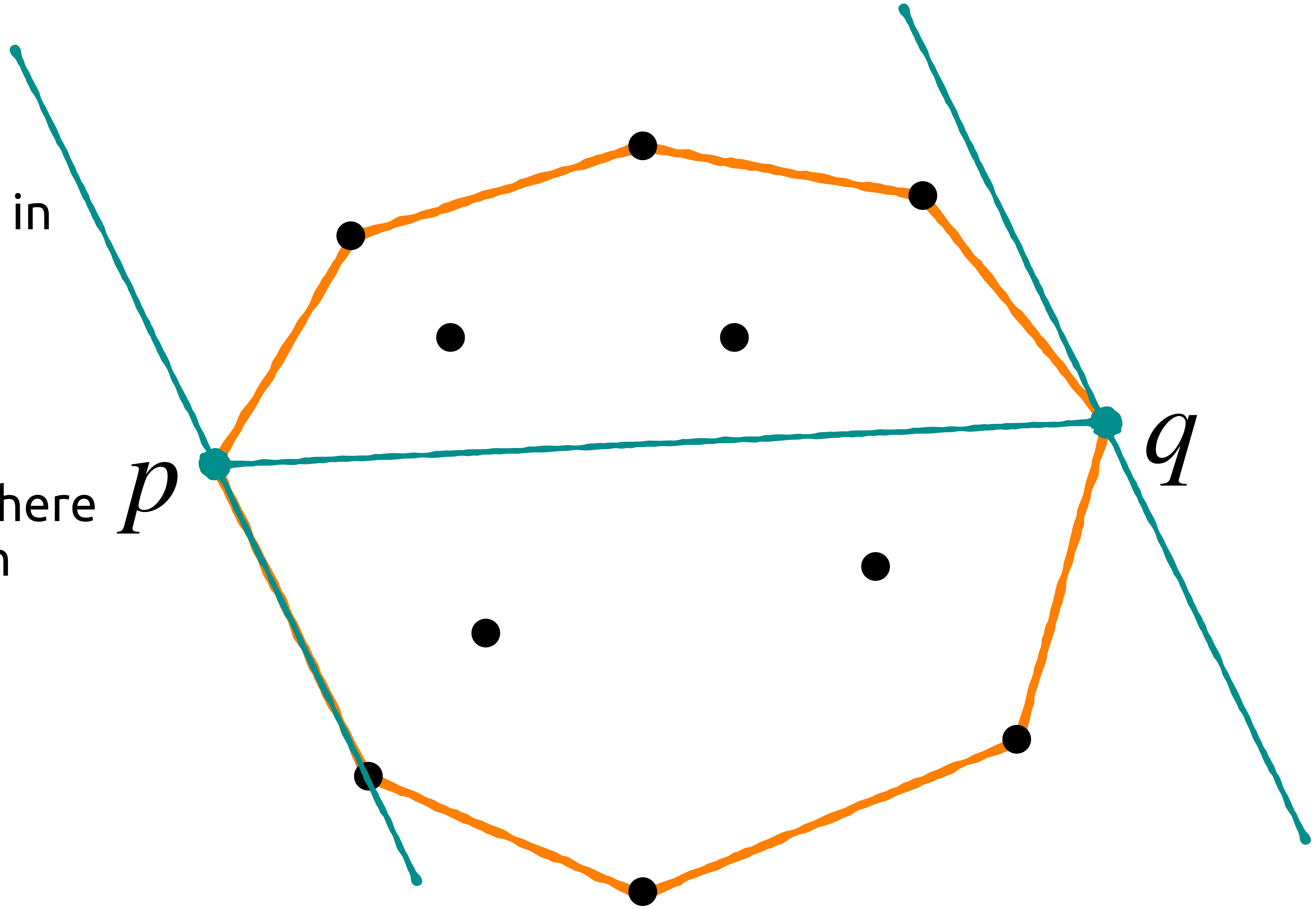

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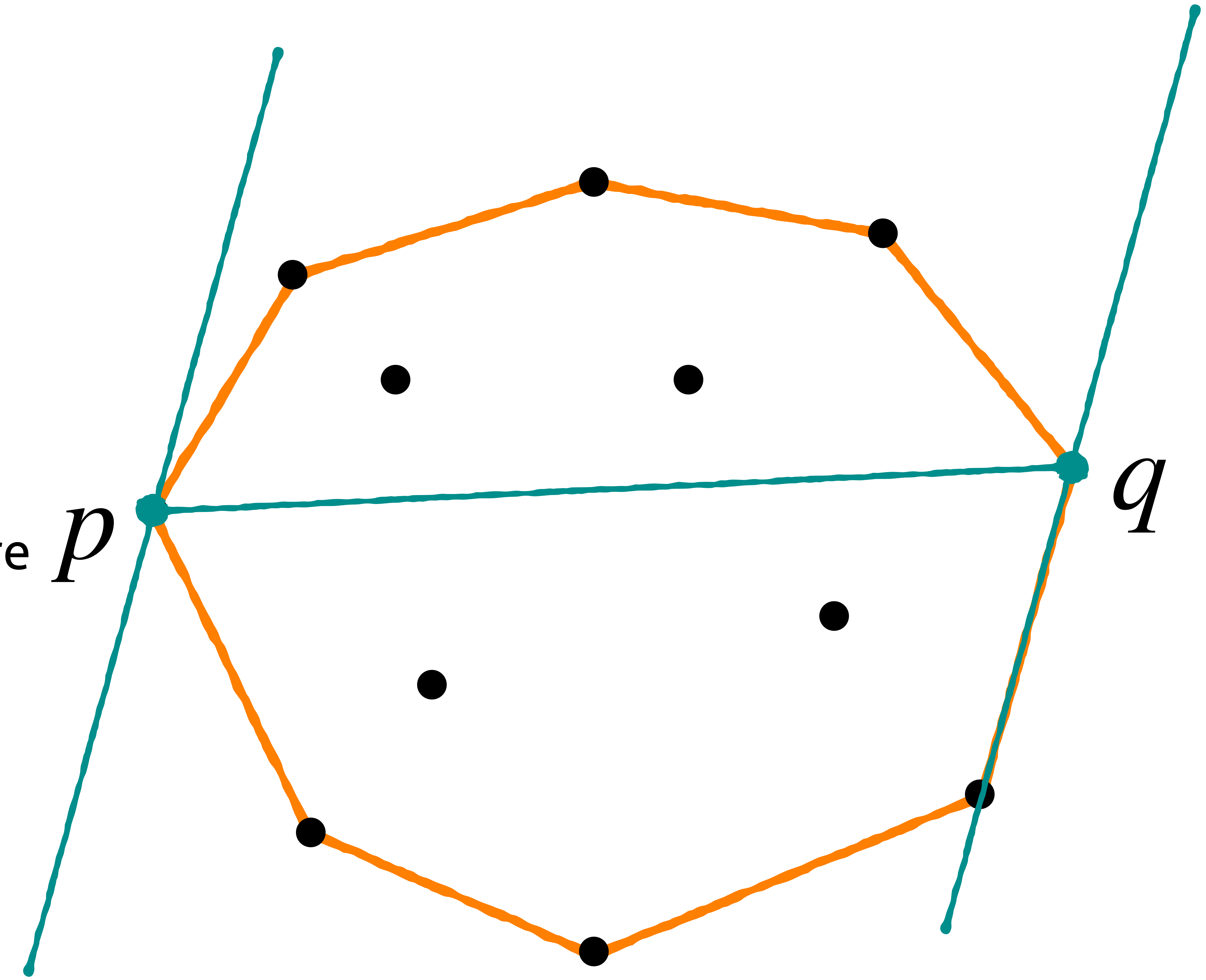

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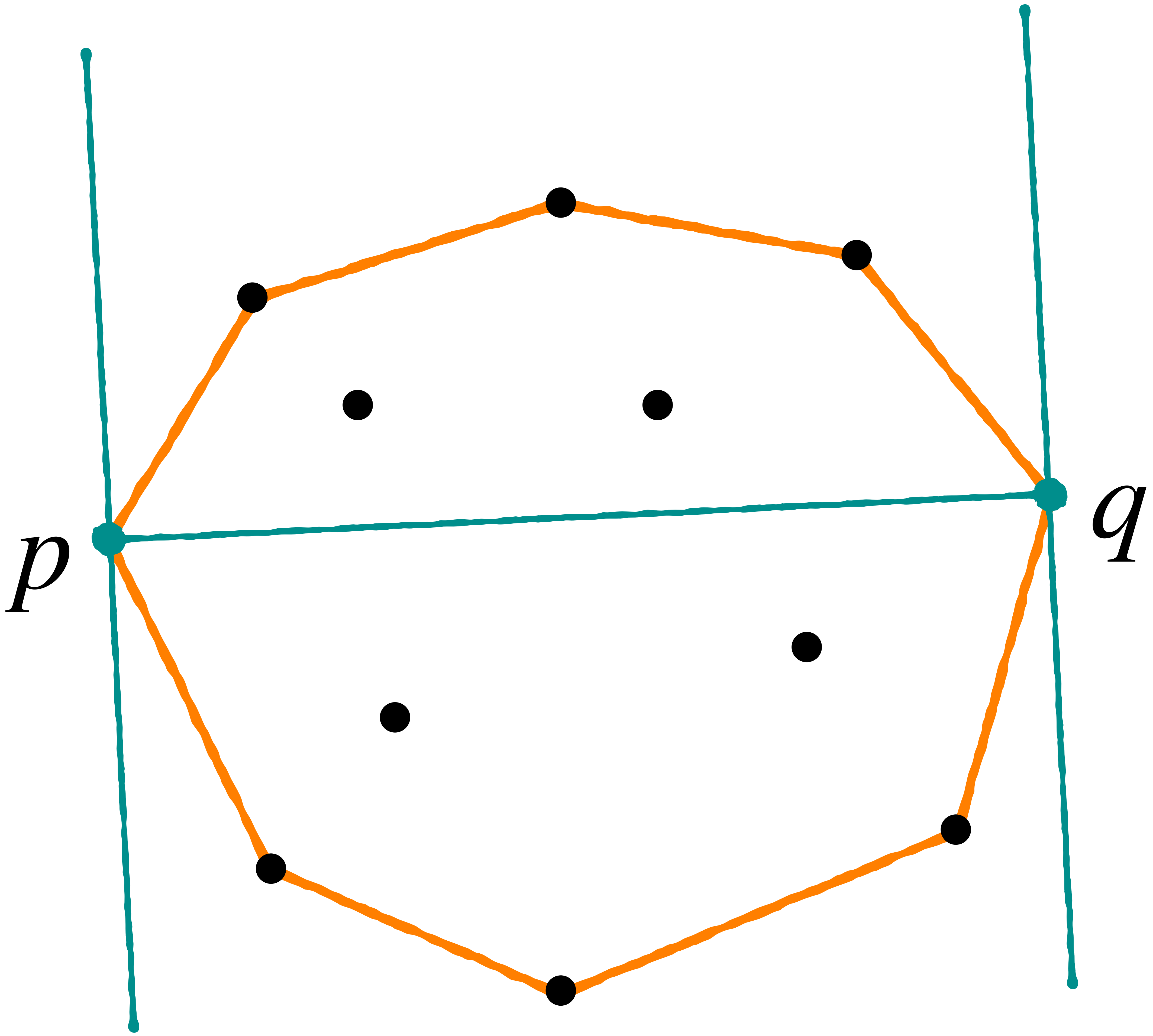

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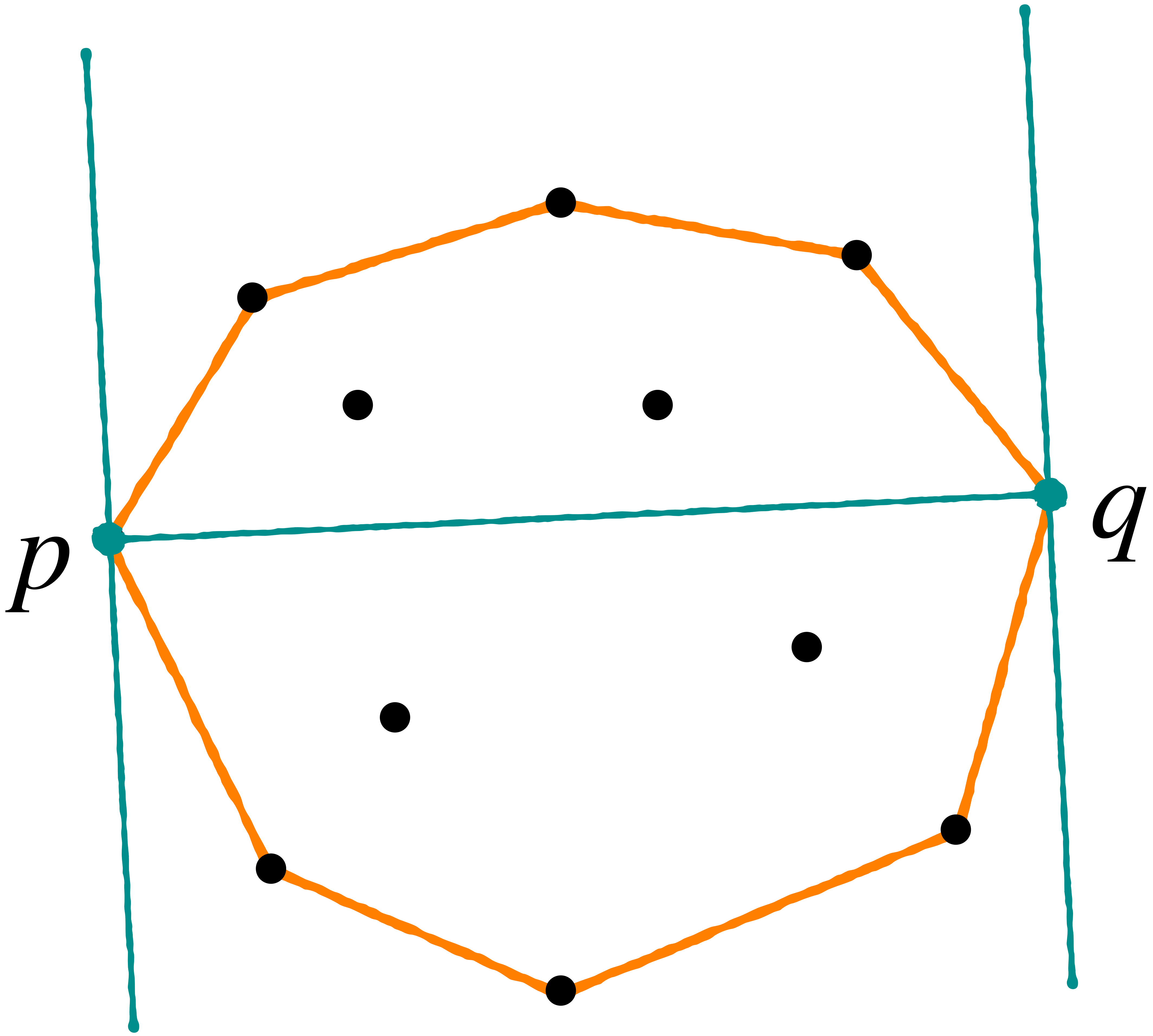
Lemma E3.2 All farthest pairs of $\mathscr{P}$ are also antipodal.



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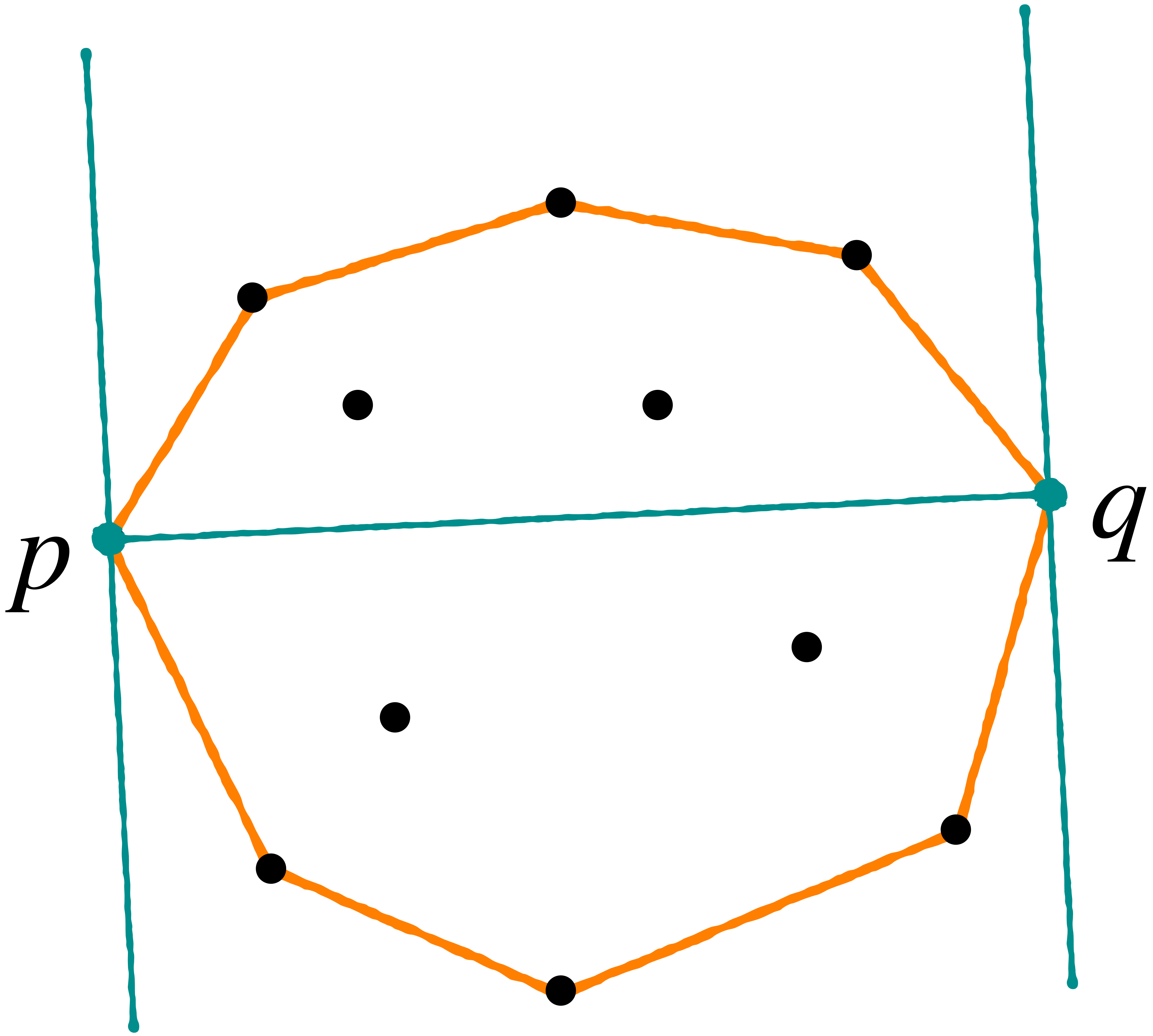
Take 10 minutes to think about this and discuss :)



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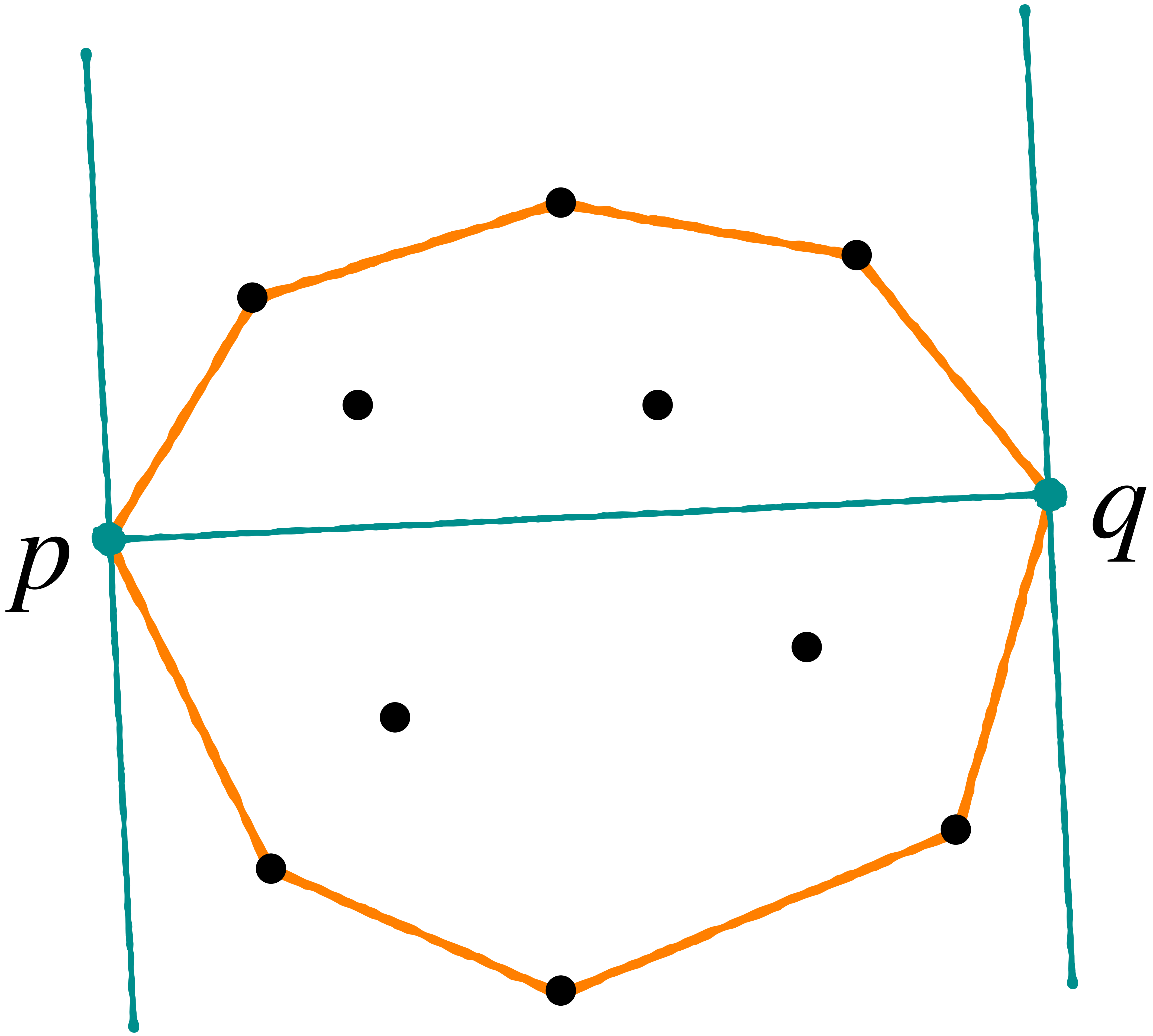

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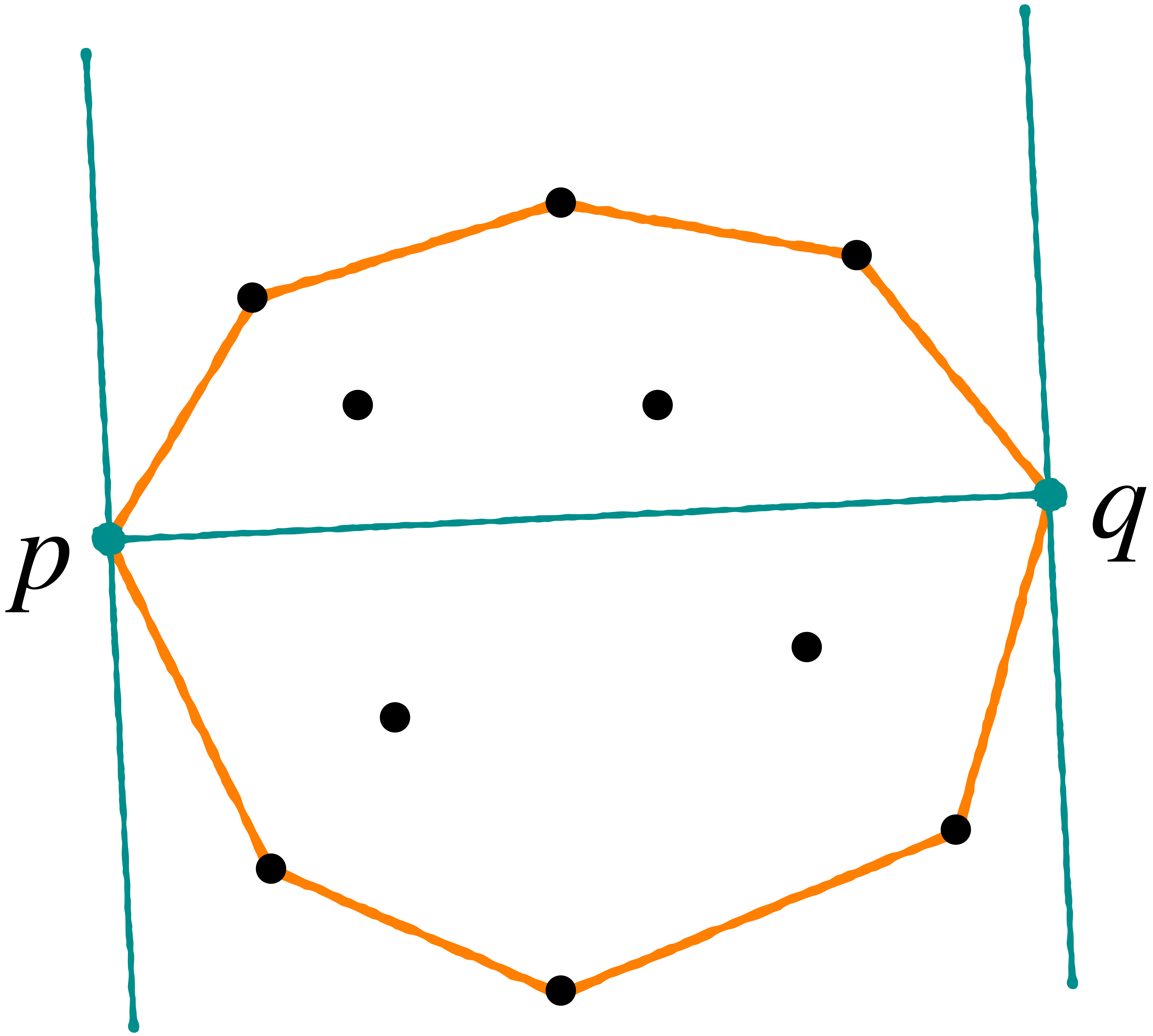
Lemma E3.3 There are $\mathcal{O}(n)$ antipodal pairs in $\mathscr{P}$.



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Michael Shamos, 1978

Let $\mathscr{P}$ be set of n points in the Euclidean plane $\mathbb{R}^2$, in general position*.

Theorem E3.4 All farthest pairs and the diameter of $\mathscr{P}$ can be computed in $\mathcal{O}(n \log n)$.

Idea: Compute the convex hull of $\mathscr{P}$, then enumerate **all** antipodal pairs and track the farthest by "rotating" parallel supporting lines around the hull, like calipers.

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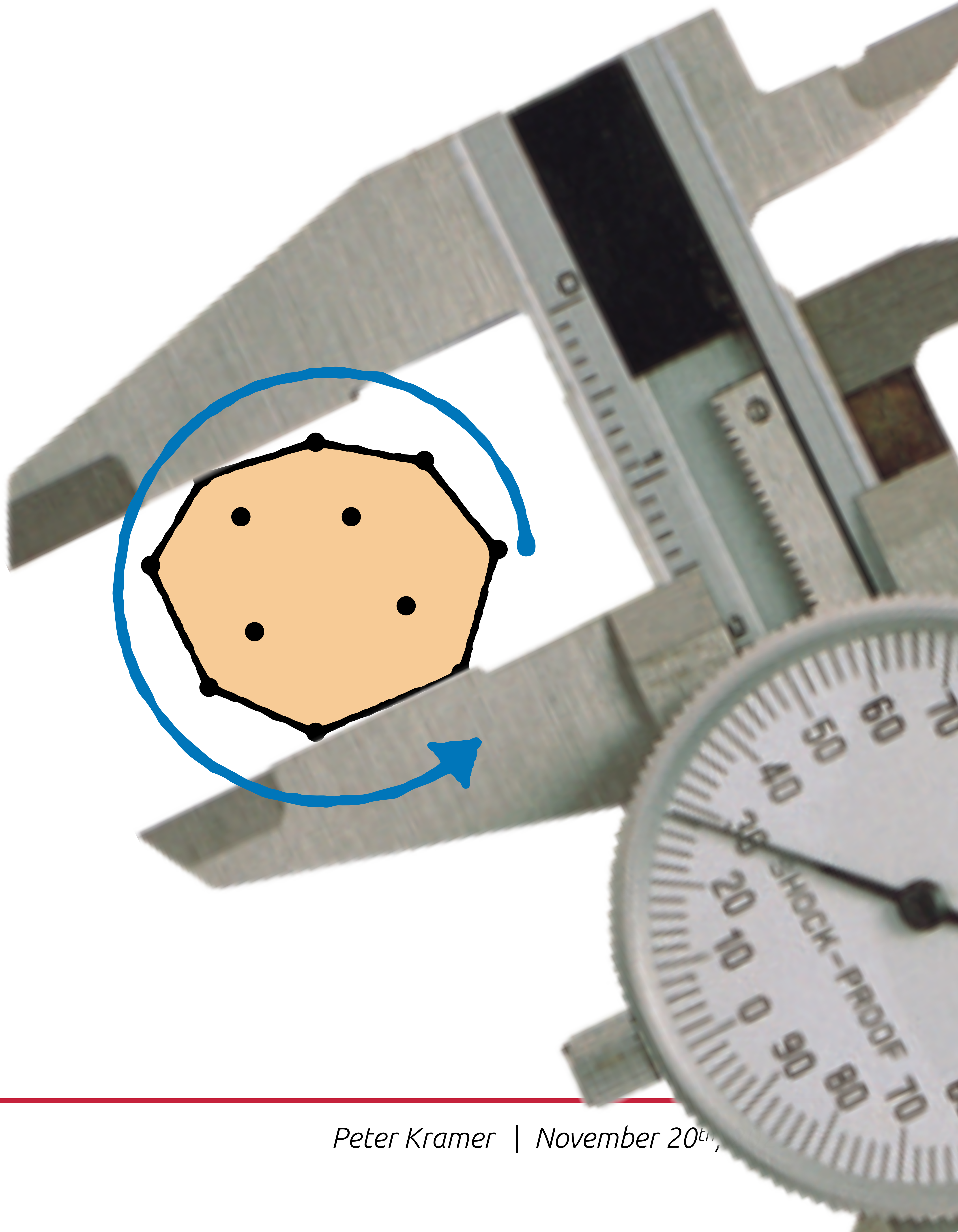

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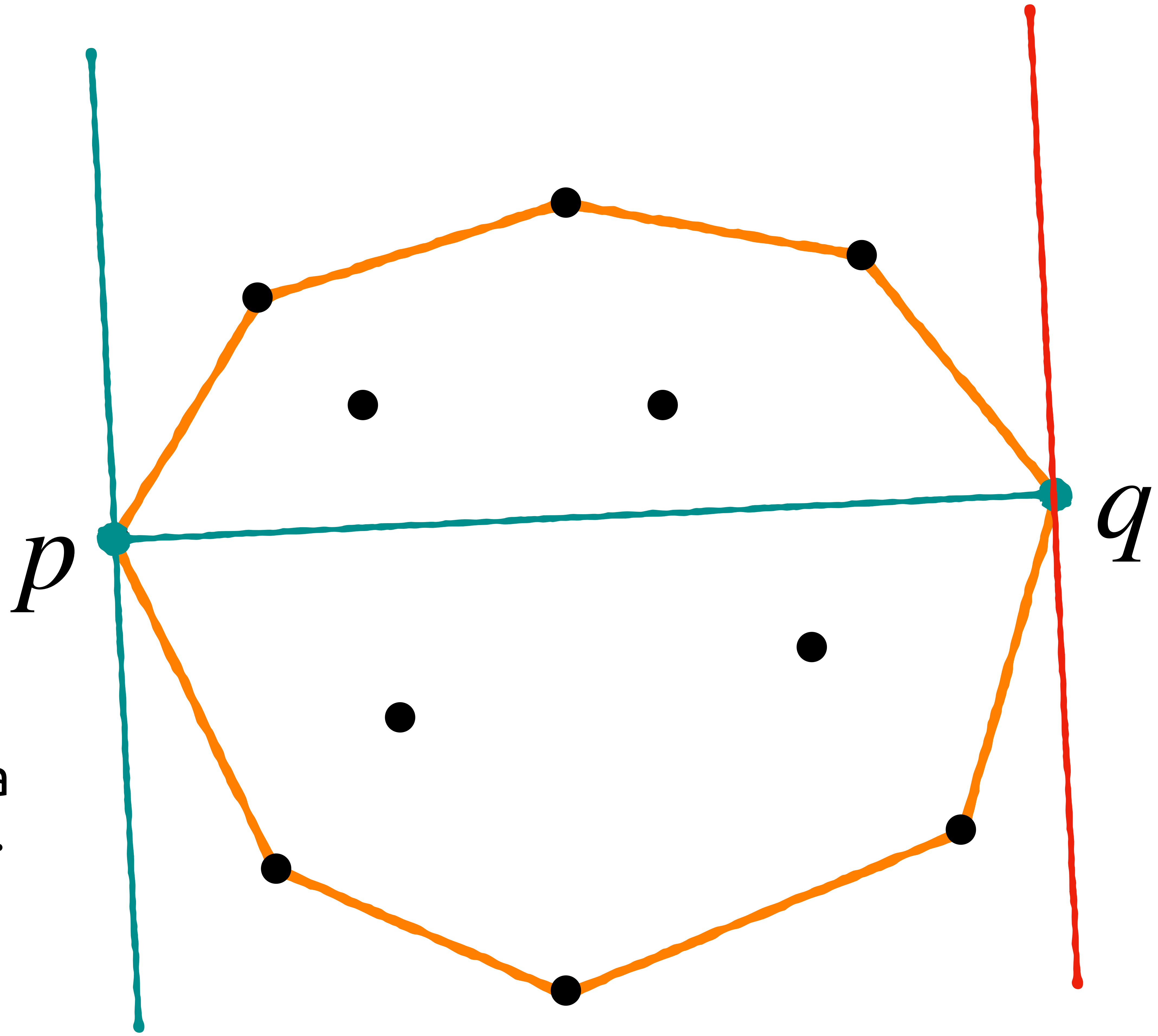

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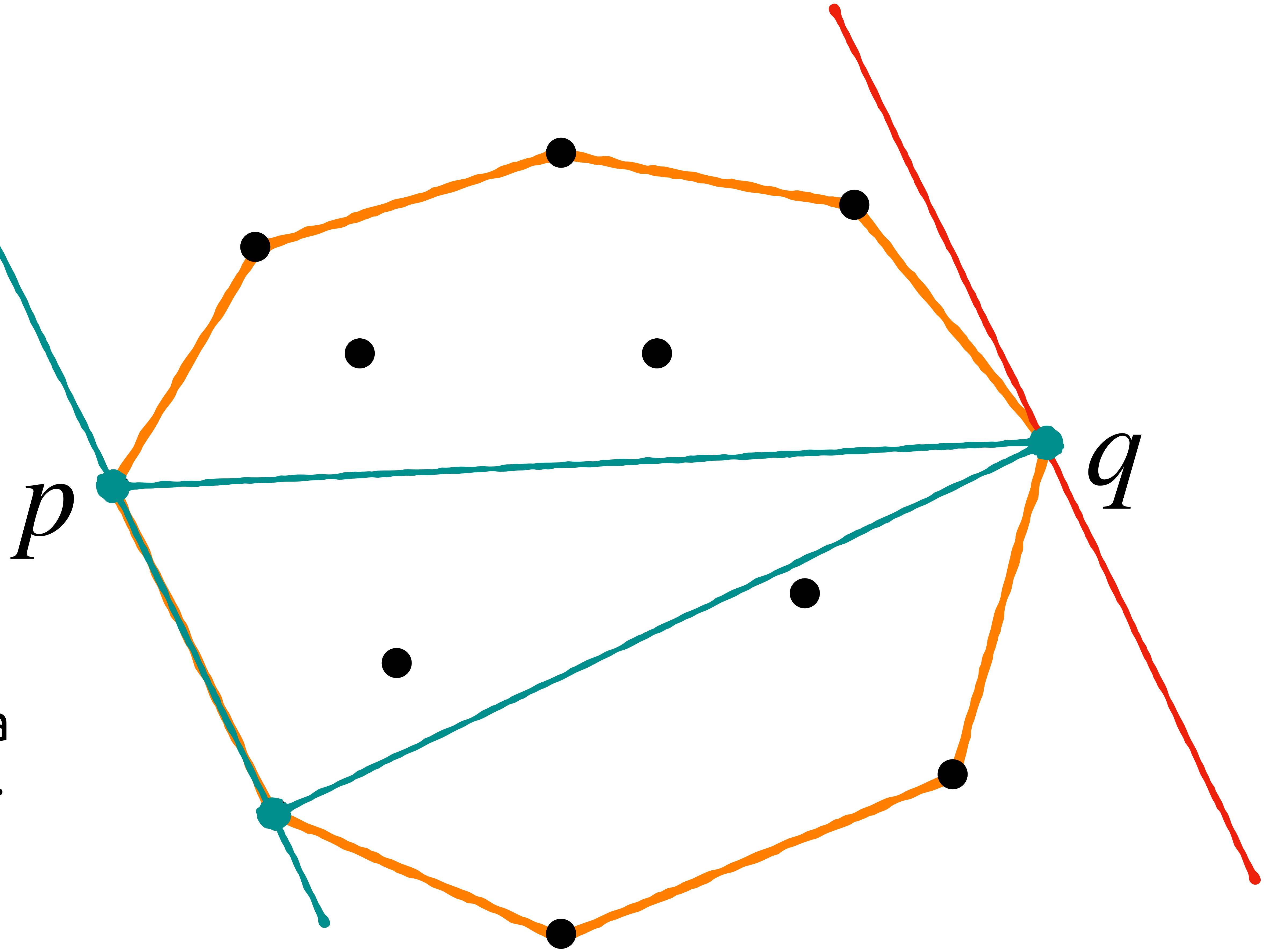

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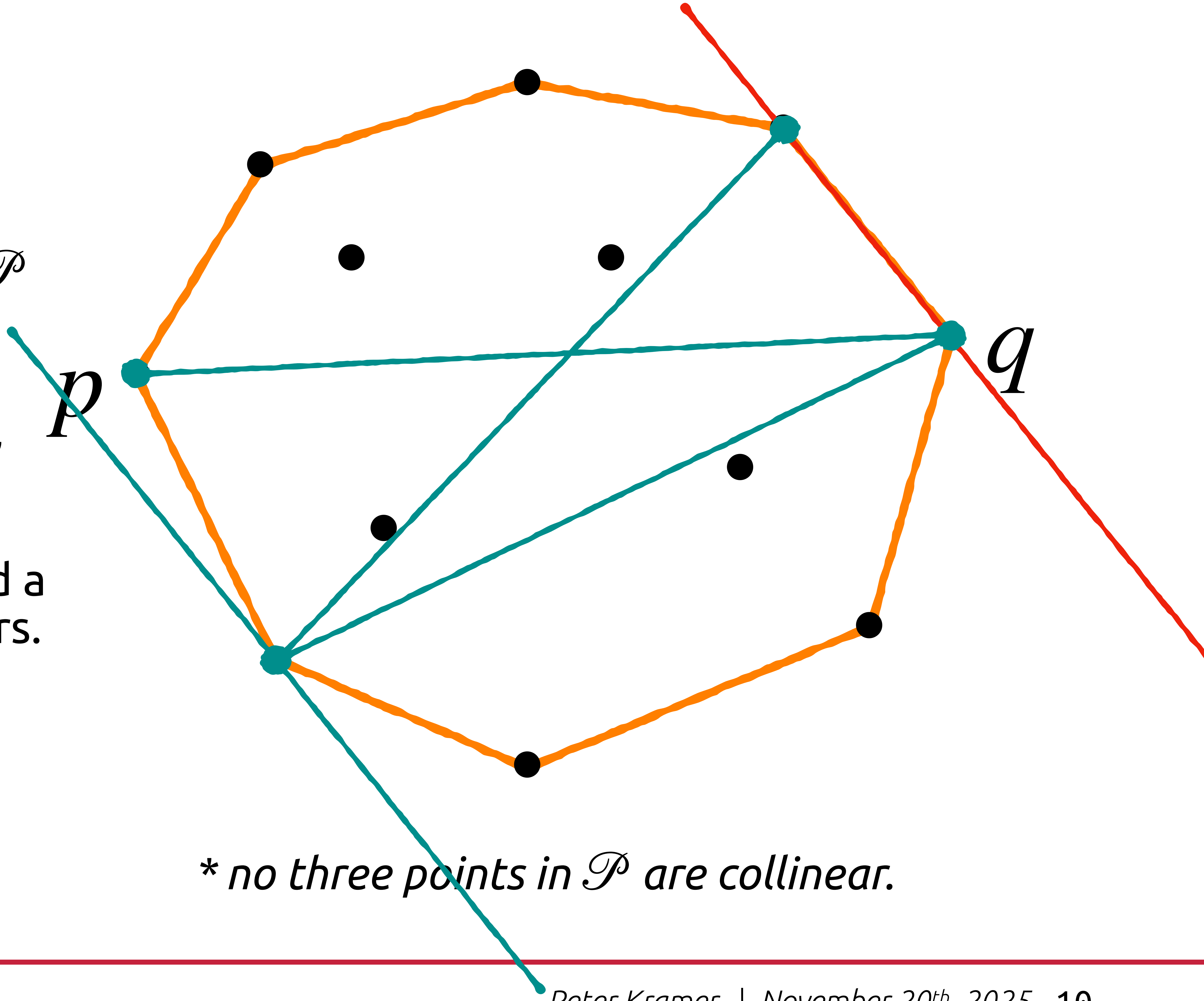

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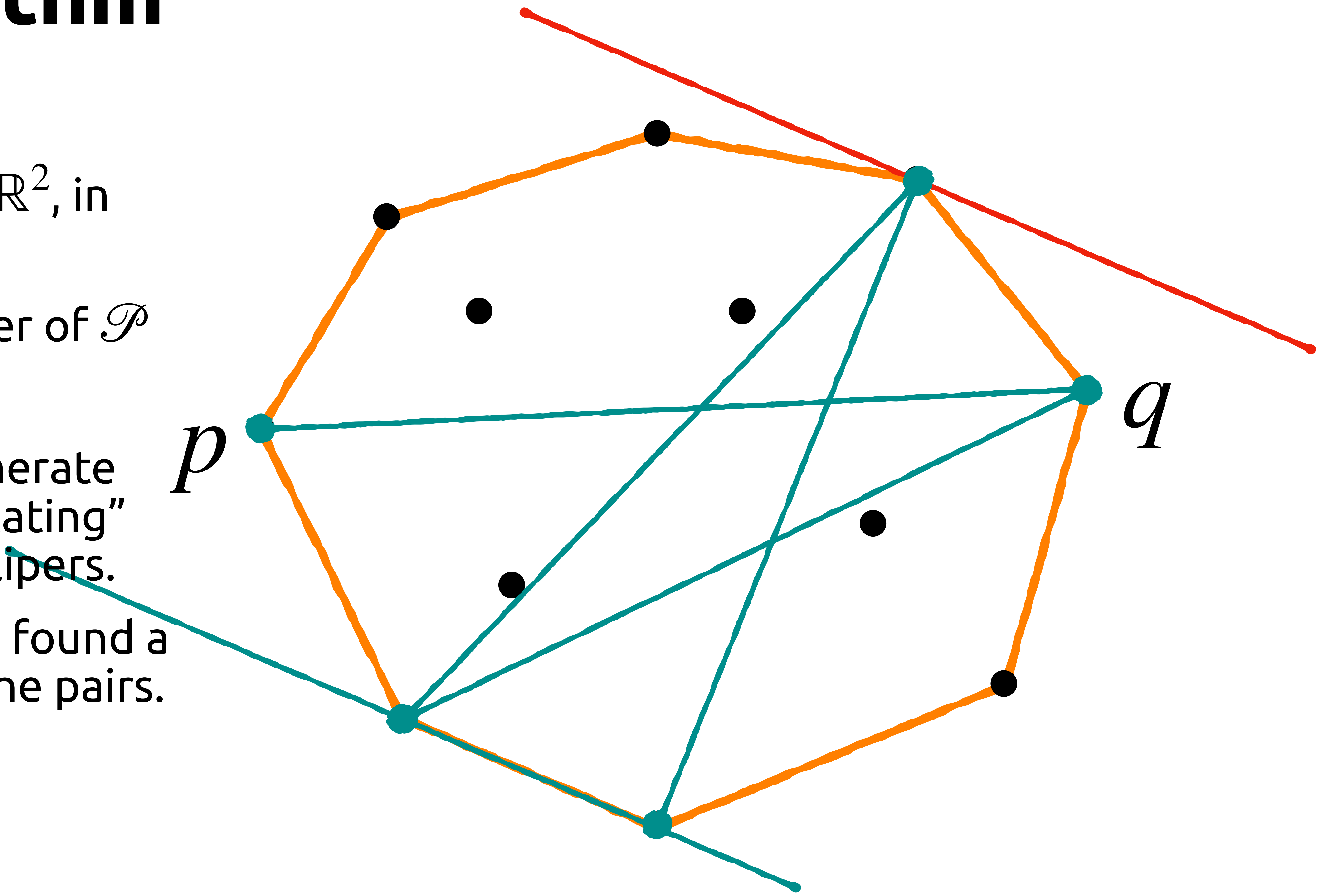

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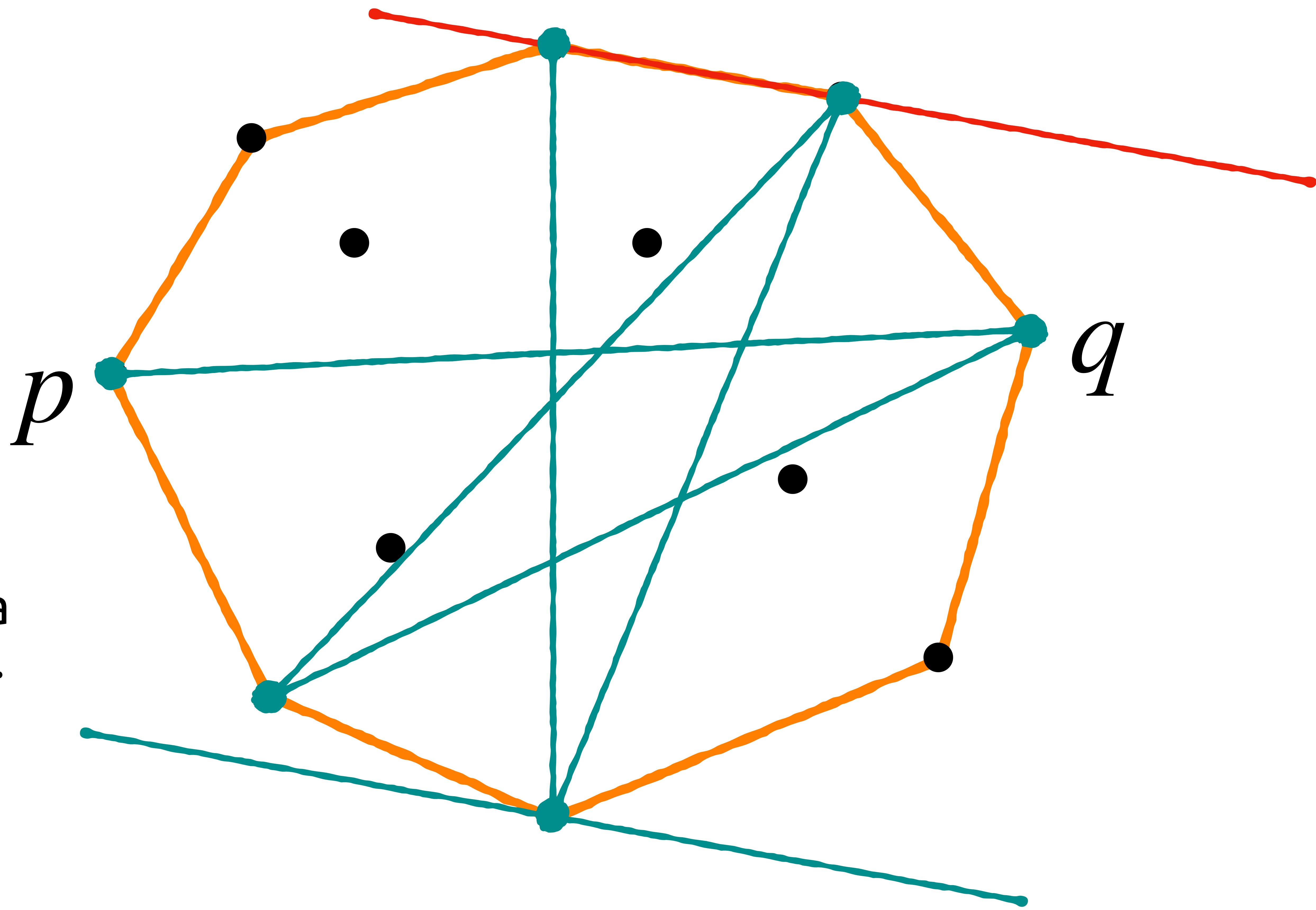

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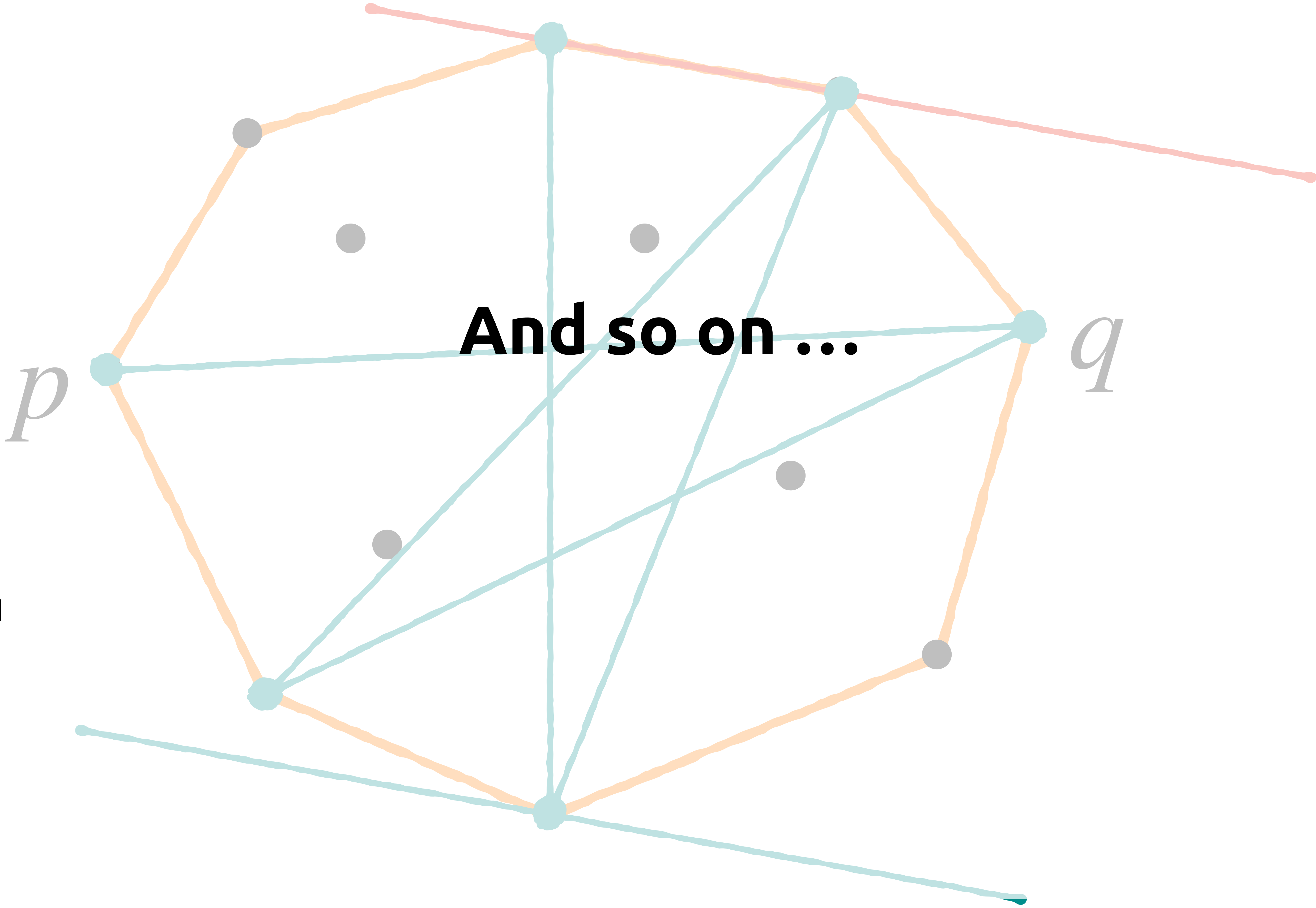

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```
Diameter(n: number, (p₁, …, pₙ): convex_hull) : number {
   // Linear probing / brute force – implicitly, i = 1
   find first (i,j) such that (pᵢ,pⱼ) is antipodal
   let diameter = 0
   while (j != n) {
      // Which edge do we hit?
      if A(Δ(pᵢ, pᵢ₊₁, pⱼ₊₁)) > A(Δ(pᵢ, pᵢ₊₁, pⱼ)) {
         ++j
      } else {
         ++i
      }
      // pᵢ,pⱼ is a farthest pair!
      diameter = max(diameter, d(pᵢ,pⱼ))
      // [… edge case handling for parallel lines: Up to 3 more pairs]
   }
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}
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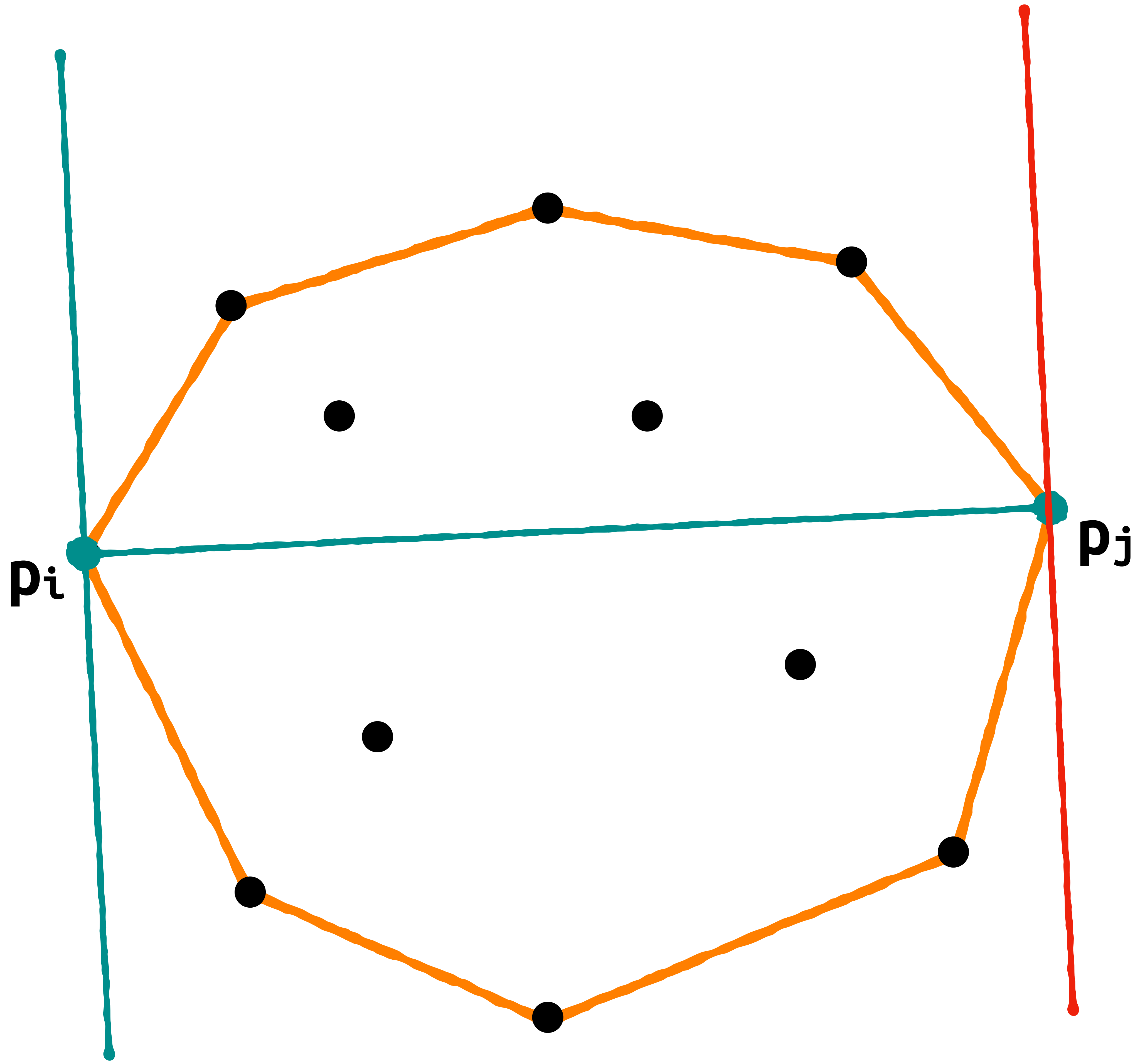

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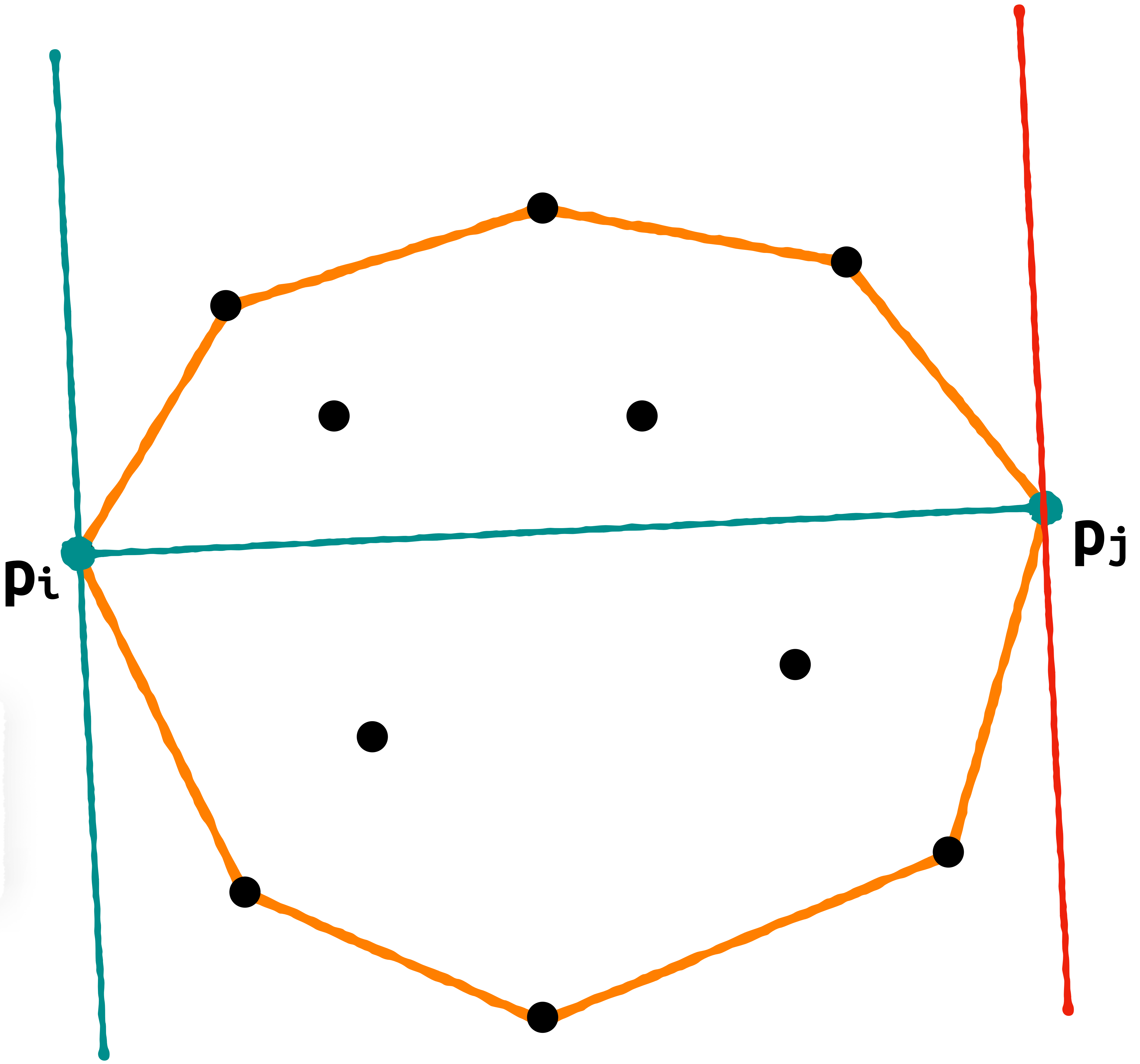
$A(\triangle(p,q,r)) > 0 \Leftrightarrow p,q,r$ oriented in counterclockwise (CCW) order

- $A(\triangle(p,q,r)) \begin{Bmatrix} > 0 \\ = 0 \\ < 0 \end{Bmatrix} \Leftrightarrow p,q,r \begin{Bmatrix} \text{Left turn} \\ \text{collinear} \\ \text{Right turn} \end{Bmatrix}$



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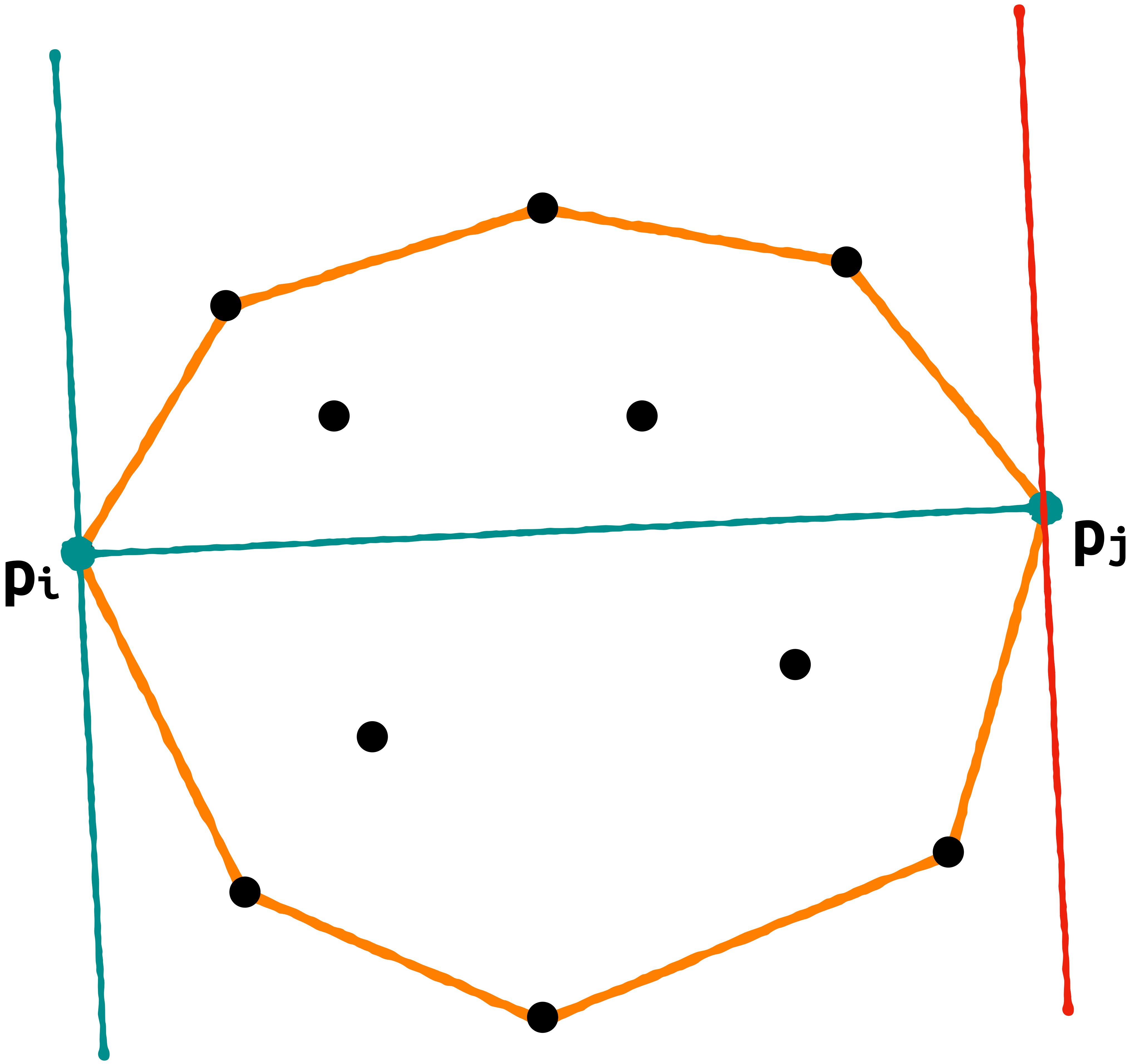

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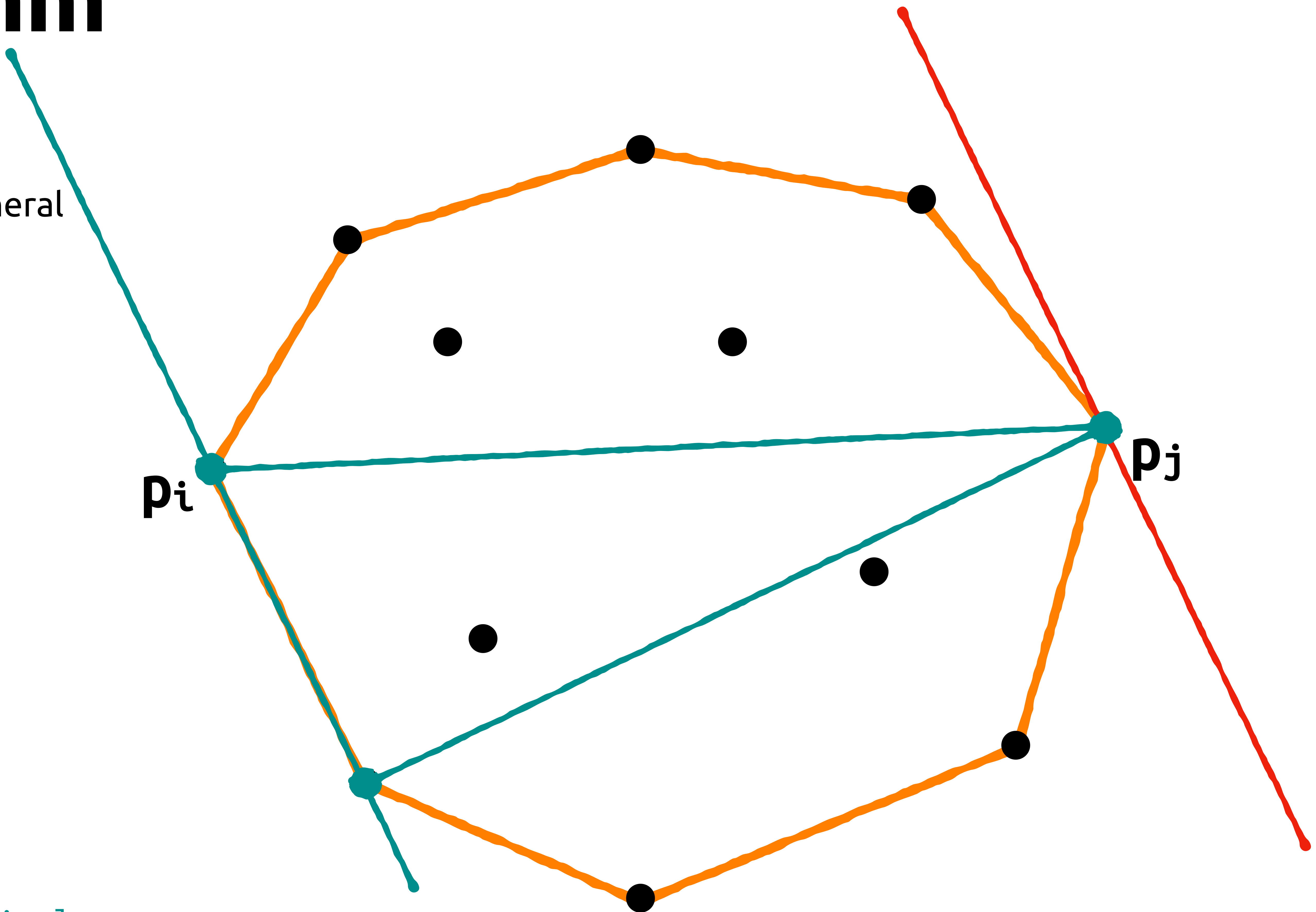

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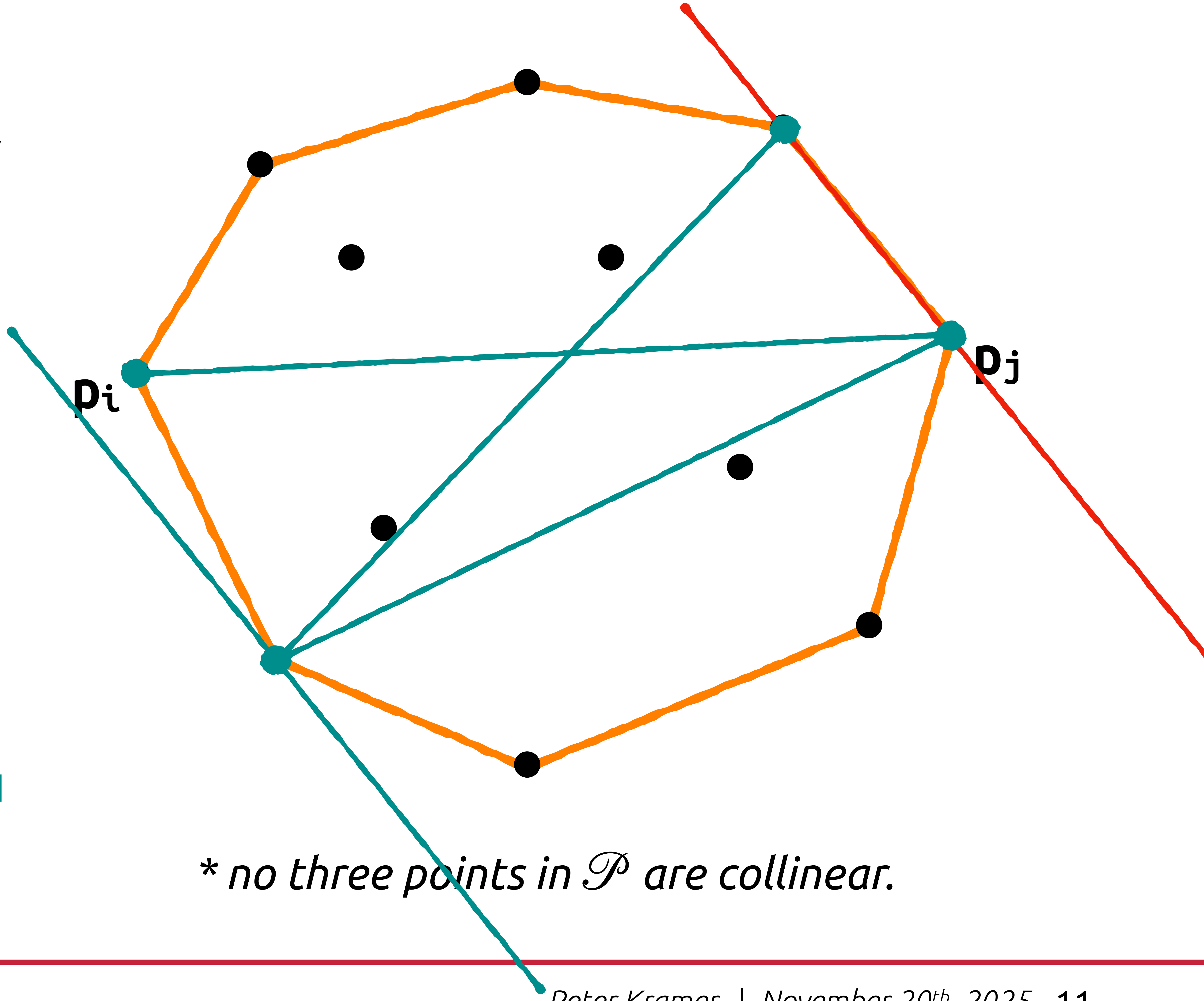

* no three points in $\mathscr{P}$ are collinear.

Rotating Calipers Algorithm
Michael Shamos, 1978

Theorem E3.4 All farthest pairs and the diameter of of n points $\mathscr{P}$ in general position in the Euclidean plane $\mathbb{R}^2$ can be computed in $\mathcal{O}(n \log n)$.

```
Diameter(n: number, (p₁, …, pₙ): convex_hull) : number {
   // Linear probing / brute force – implicitly, i = 1
   find first (i,j) such that (pᵢ,pⱼ) is antipodal
   let diameter = 0
   while (j != n) {
      // Which edge do we hit?
      if A(Δ(pᵢ, pᵢ₊₁, pⱼ₊₁)) > A(Δ(pᵢ, pᵢ₊₁, pⱼ)) {
         ++j
      } else {
         ++i
      }
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      diameter = max(diameter, d(pᵢ,pⱼ))
      // [… edge case handling for parallel lines: Up to 3 more pairs]
   }
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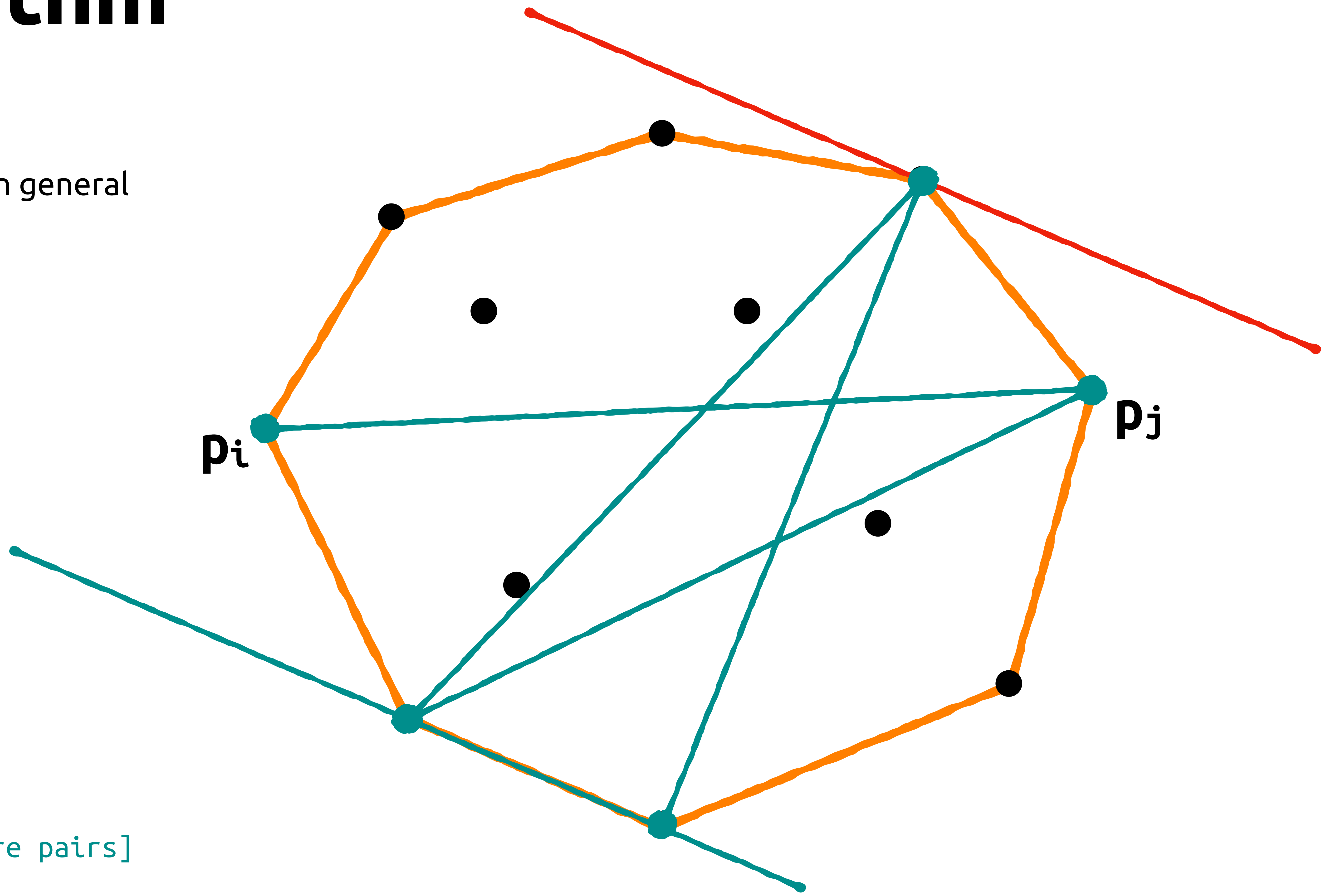
```



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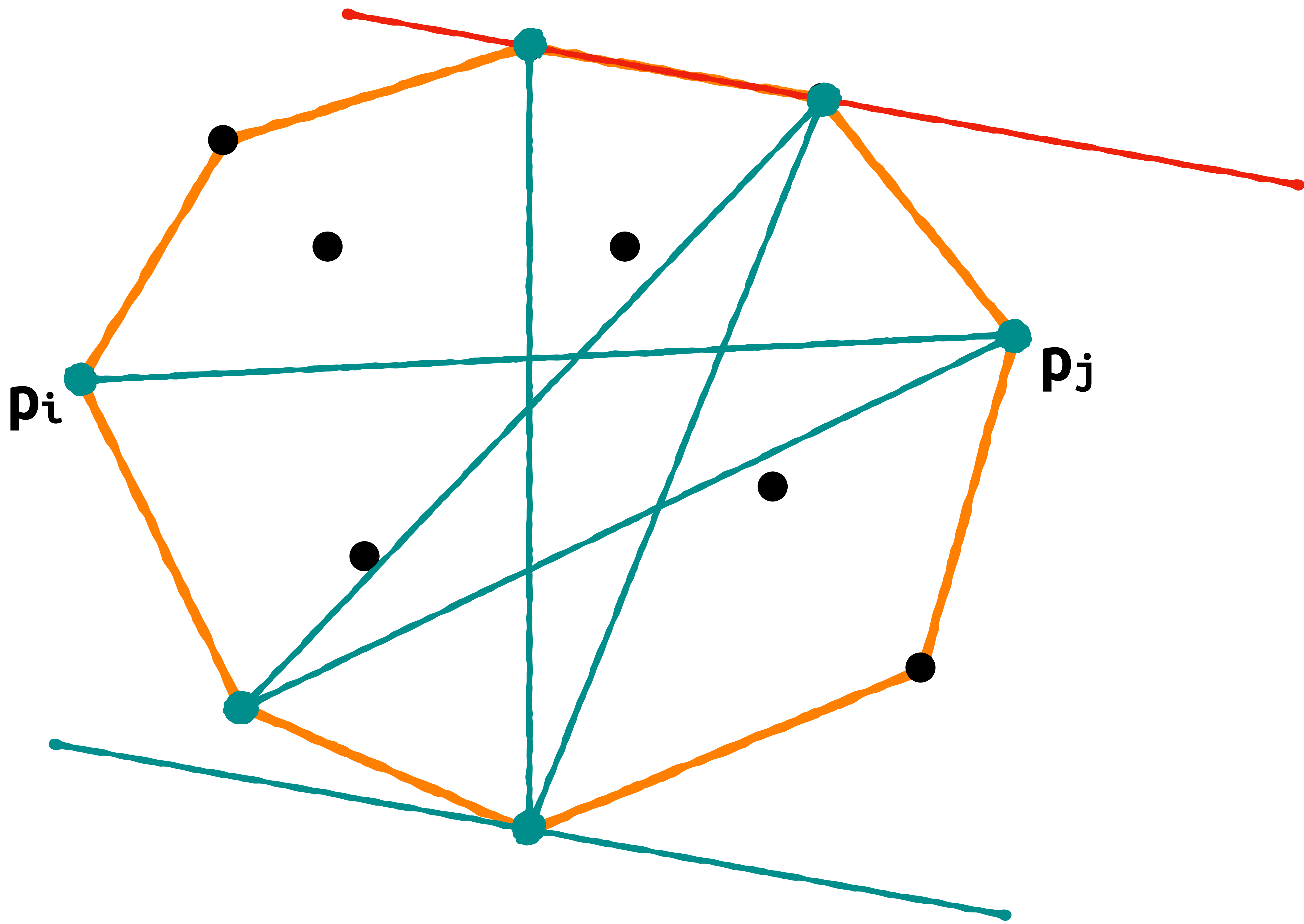

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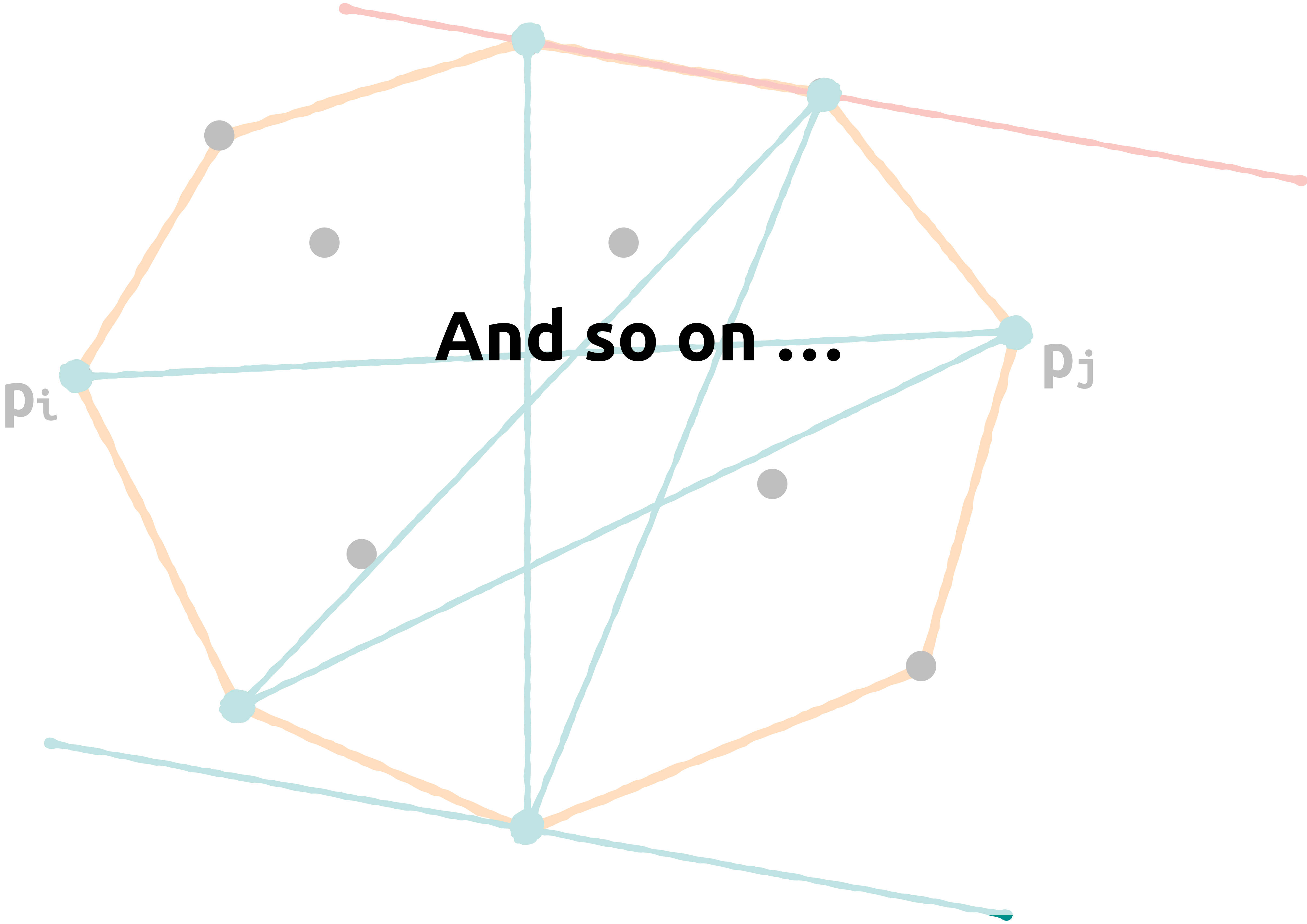

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Farthest point pairs
Convex hull

Let $\mathscr{P}$ be set of n points in the Euclidean plane $\mathbb{R}^2$, in general position*.

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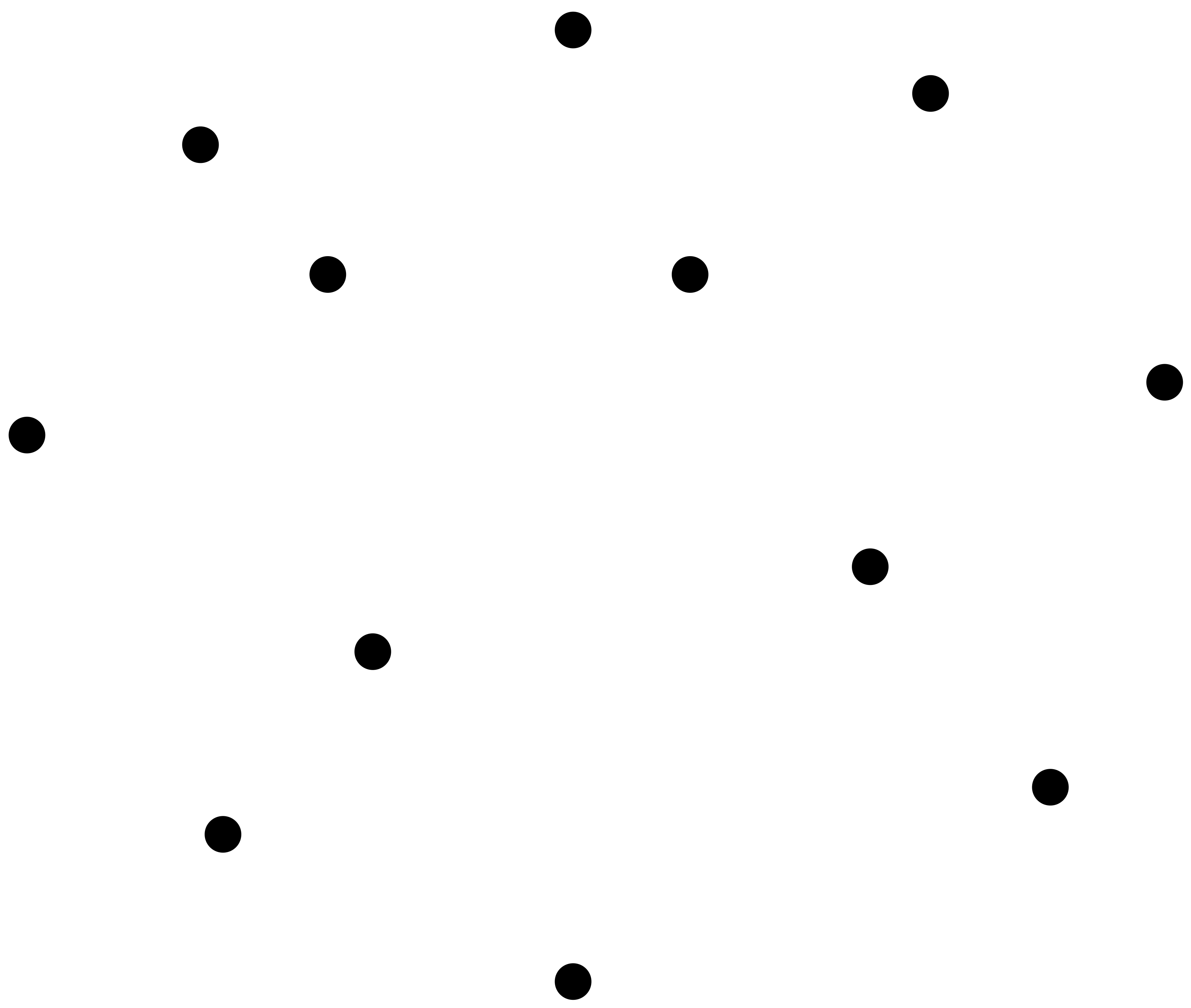

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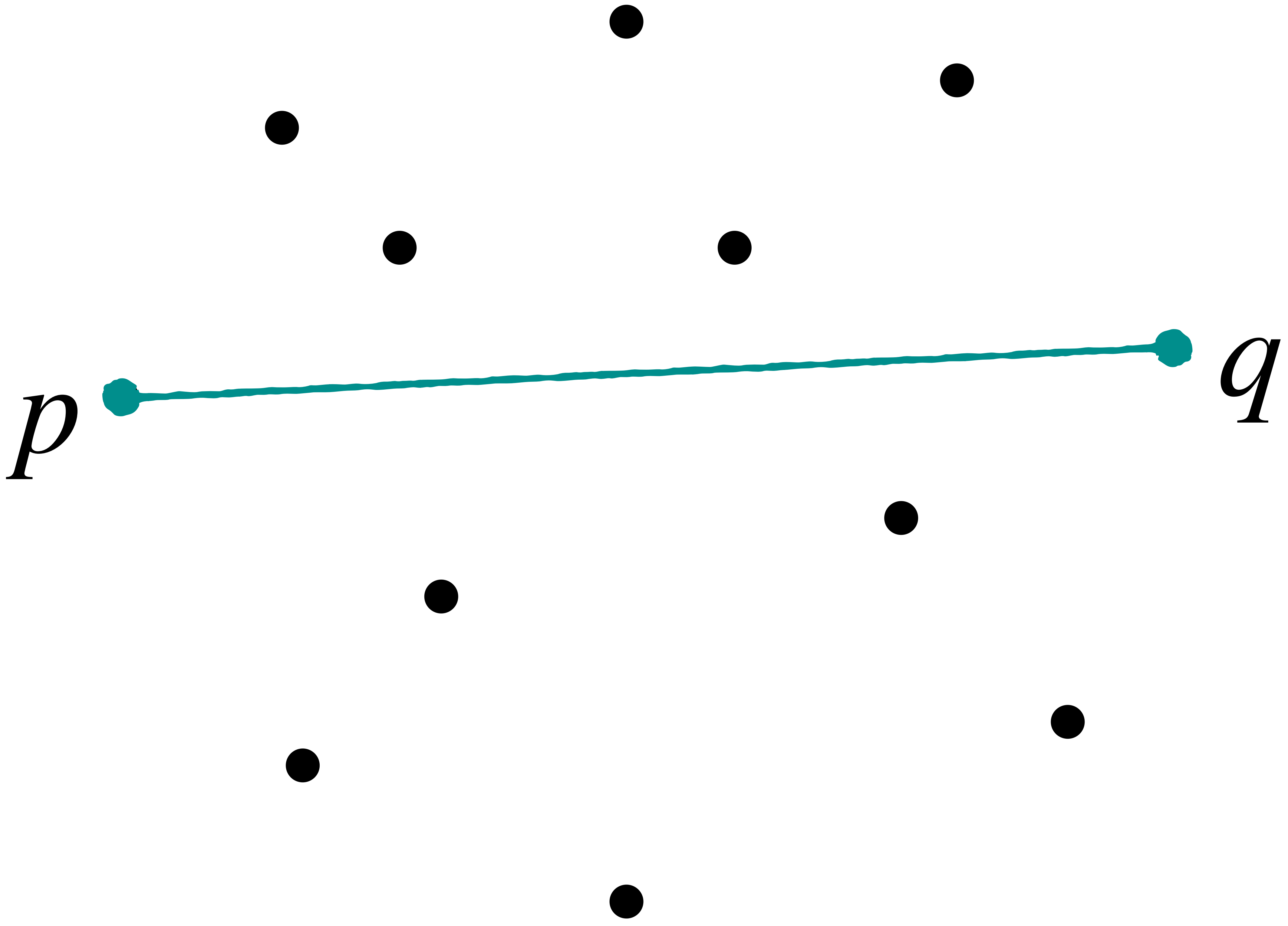

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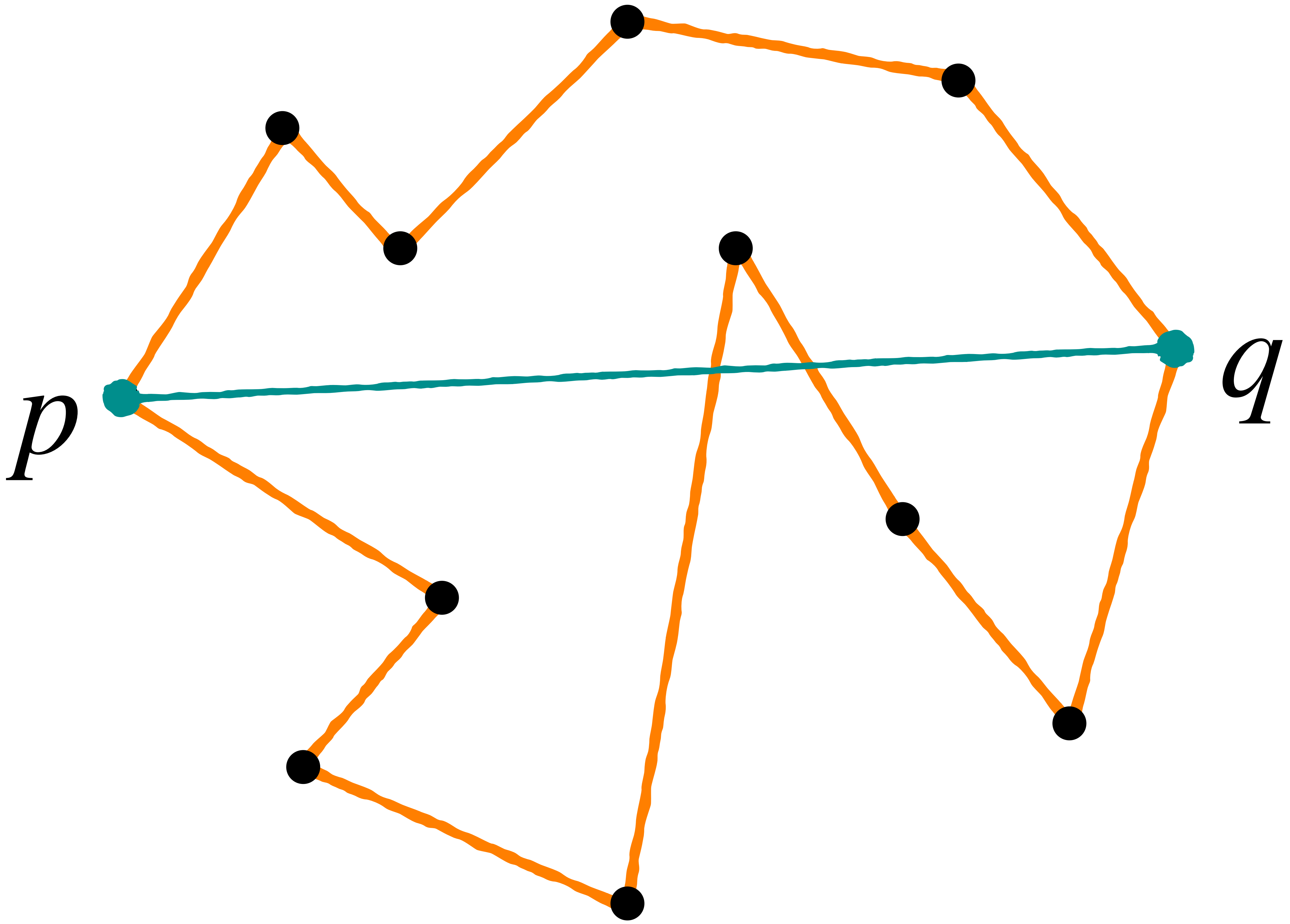
Theorem E3.5 All farthest pairs and the diameter of an n-vertex simple polygon P can be computed in ...?



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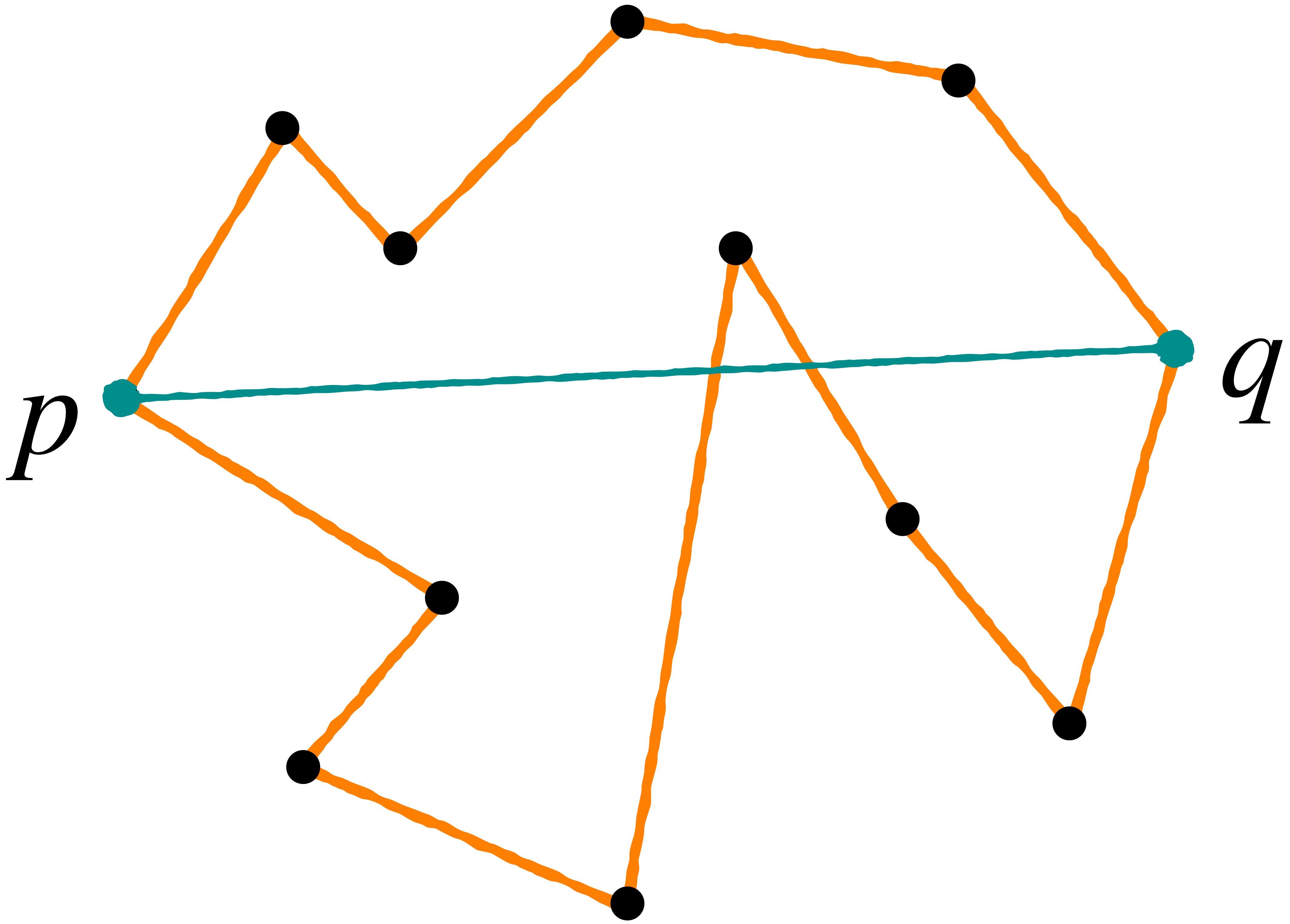
Theorem E3.5 All farthest pairs and the diameter of an n-vertex simple polygon P can be computed in …?

Crucial: Convex hull of P faster than $\Omega(n \log n)$?



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Rotating Calipers Algorithm
Michael Shamos, 1978

Distances [edit]

- Diameter (maximum width) of a convex polygon[6][7]
- Width (minimum width) of a convex polygon[8]
- Maximum distance between two convex polygons[9][10]
- Minimum distance between two convex polygons[11][12]
- Widest empty (or separating) strip between two convex polygons (a simplified low-dimensional variant of a problem arising in support vector machine based machine learning)
- Grenander distance between two convex polygons[13]
- Optimal strip separation (used in medical imaging and solid modeling)[14]

Bounding boxes [edit]

- Minimum area oriented bounding box
- Minimum perimeter oriented bounding box

Triangulations [edit]

- Onion triangulations
- Spiral triangulations
- Quadrangulation
- Nice triangulation
- Art gallery problem
- Wedge placement optimization problem[15]

Multi-polygon operations [edit]

- Union of two convex polygons
- Common tangents to two convex polygons
- Intersection of two convex polygons[16]
- Critical support lines of two convex polygons
- Vector sums (or Minkowski sum) of two convex polygons[17]
- Convex hull of two convex polygons

Traversals [edit]

- Shortest transversals[18][19]
- Thinnest-strip transversals[20]

Others [edit]

- Non parametric decision rules for machine learned classification[21]
- Aperture angle optimizations for visibility problems in computer vision[22]
- Finding longest cells in millions of biological cells[23]
- Comparing precision of two people at firing range
- Classify sections of brain from scan images

Rotating Calipers Algorithm
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Homework Sheet #2

Peter Kramer | November 20th, 2025

Computational Geometry – Sheet 2 **Winter 2025/2026**

Prof. Dr. Sándor P. Fekete **Due** 04.12.2024

Peter Kramer **Discussion** 11.12.2024

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Exercise 1 (Geometric Predicates). **(5 points)**

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$$\operatorname{conv}(p, q) \cap \operatorname{conv}(u, v, w) = \varnothing\ ?$$

You may assume that (u, v, w) are in counterclockwise order and that no three points are collinear. Please explain your solution and briefly argue its correctness.

Exercise 2 (Partitioning Points). **(15 points)**

Consider a set $\mathcal{P}$ in the Euclidean plane $\mathbb{R}^2$ in general position according to *Definition E1*.

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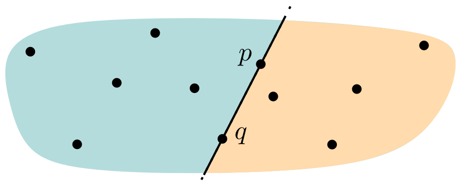

b) Design an algorithm that finds p and q in $\mathcal{O}(n)$ time for $n = |\mathcal{P}|$.

(Hint: Start with **b)**, a good correctness proof can also give you a constructive proof of existence.)

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The *convex layers* of a finite point set $\mathcal{P}$ in the plane correspond to a decomposition of $\mathcal{P}$ into nested, convex polygons (*layers*). The outermost layer L_0 consists exactly of the extremal points defining $\operatorname{conv}(P)$. The next layer is recursively defined as points defining $\operatorname{conv}(P \setminus L_0)$, meaning

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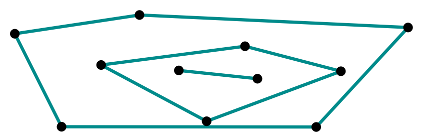

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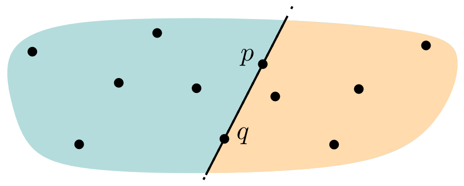

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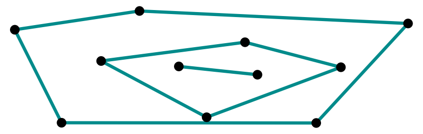

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1/1

Computational Geometry – Sheet 2 **Winter 2025/2026**

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Two weeks!

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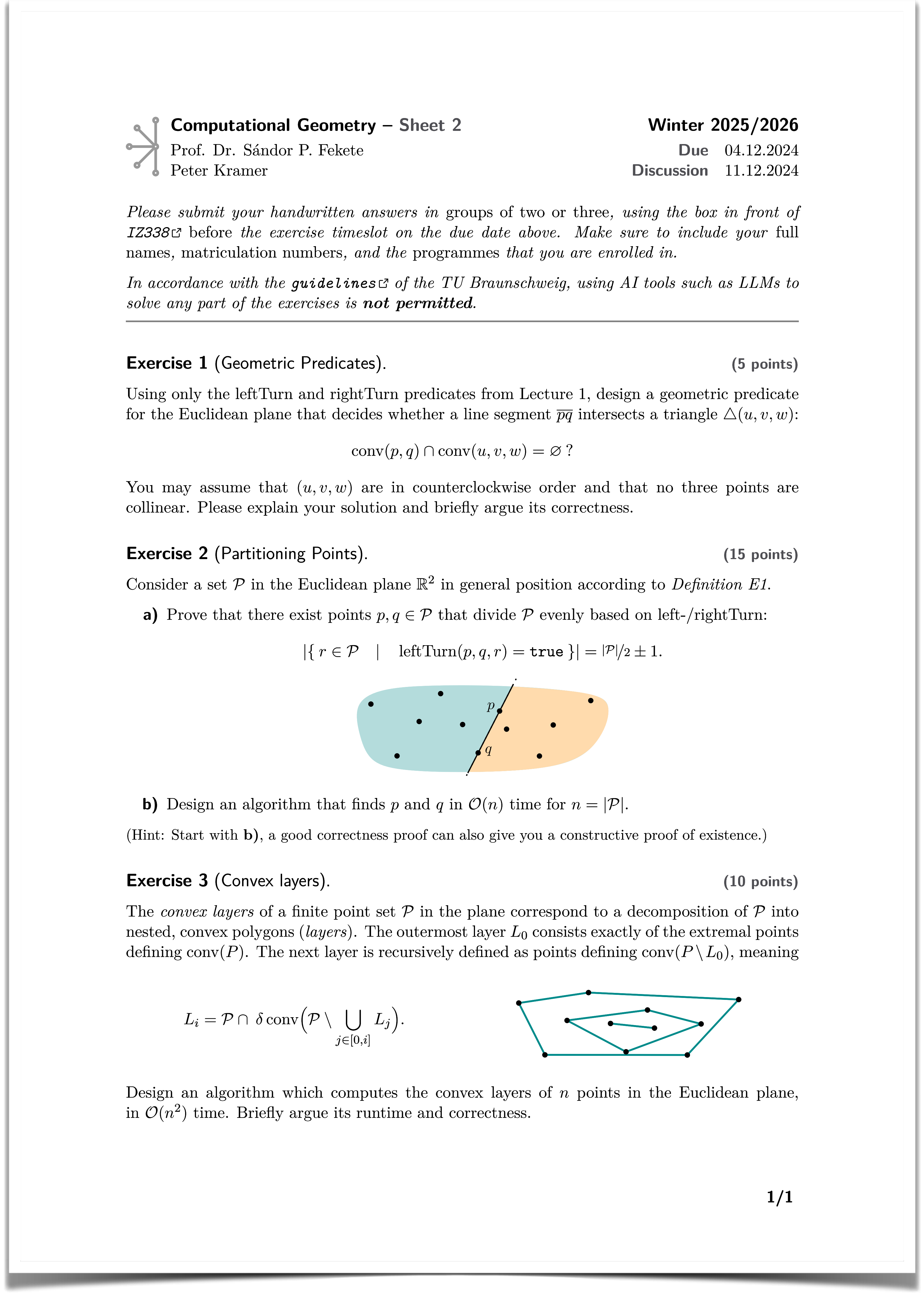
- You may change homework partners at any time. Grading is tracked individually, not by group.
- A total of **75 points across all sheets** is sufficient for the coursework / Studienleistung.
- **So far:** 35 points, this sheet: 30 points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1/1

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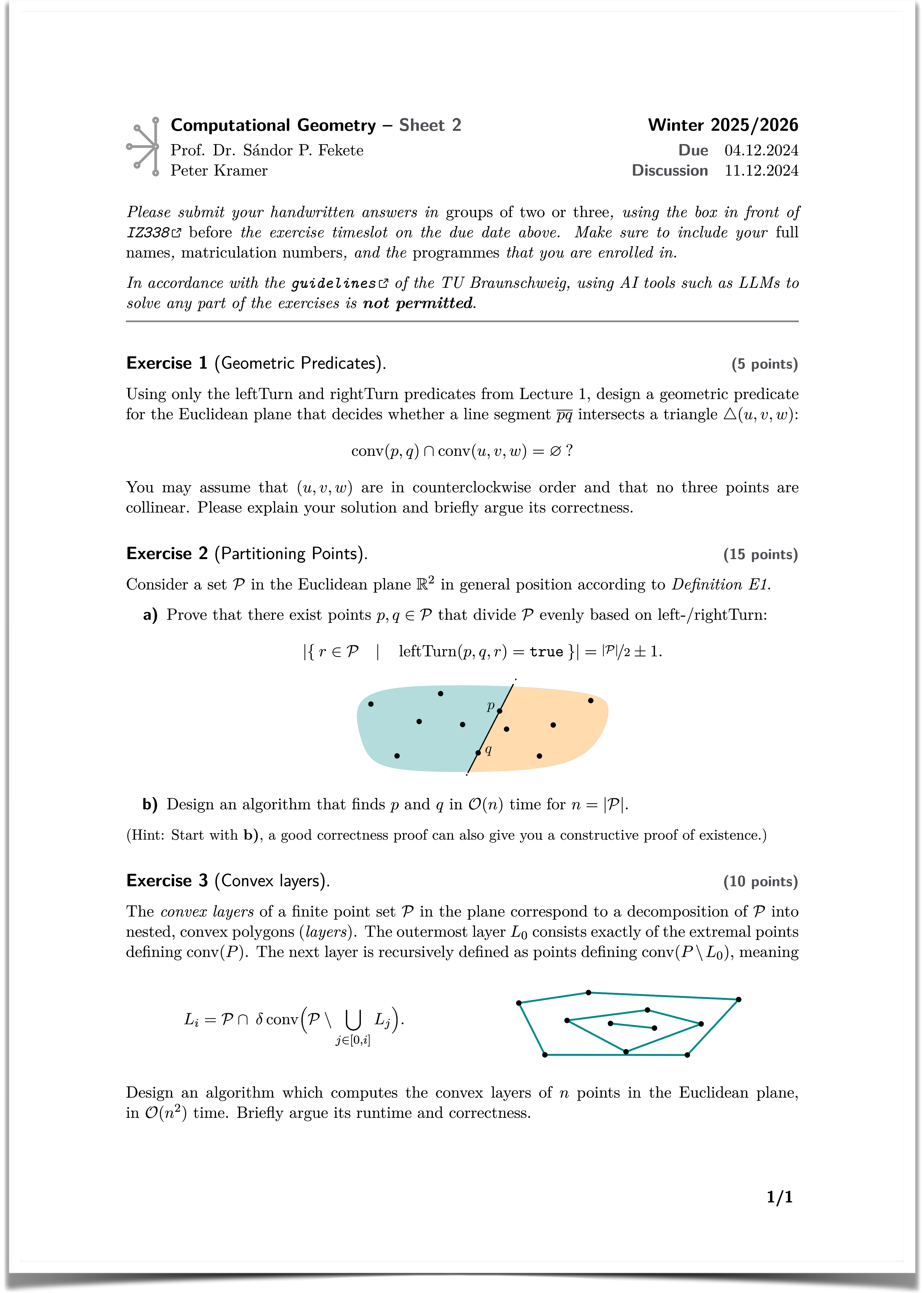

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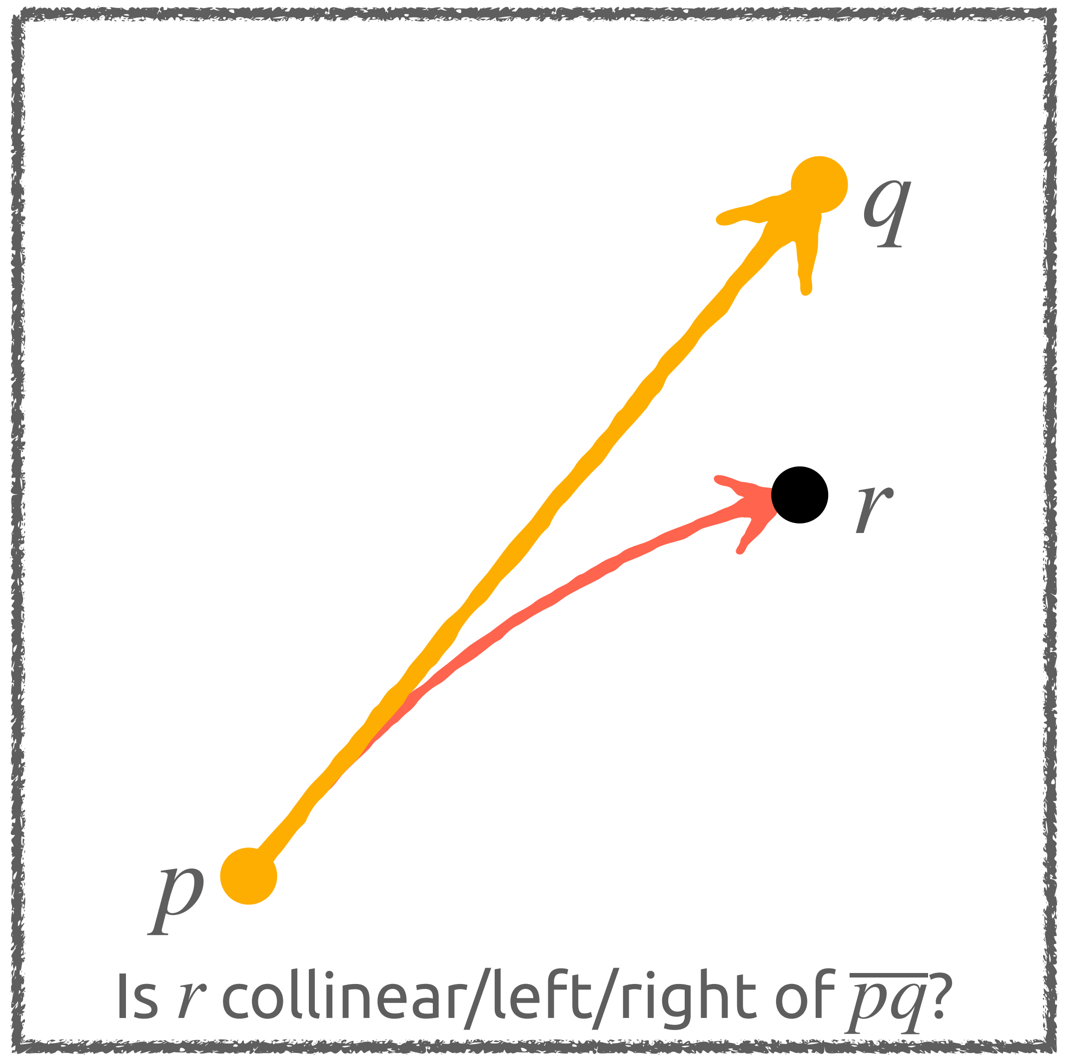
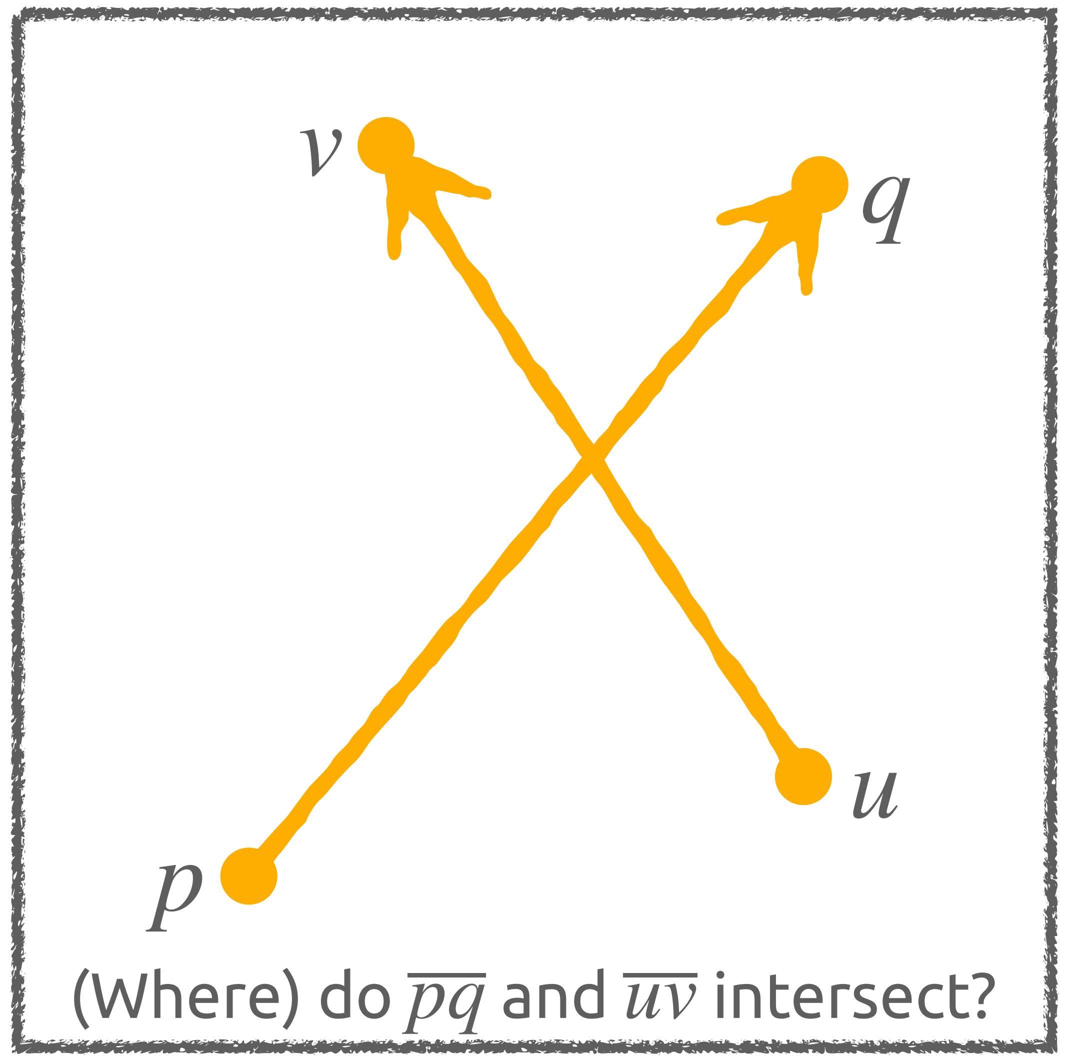
Point-Line Test



Intersection Test



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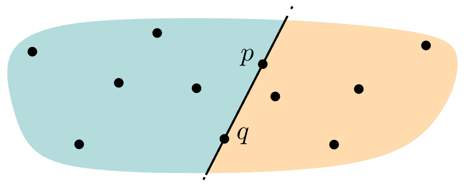

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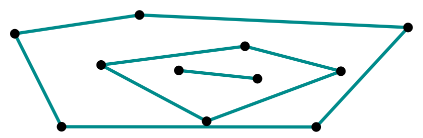

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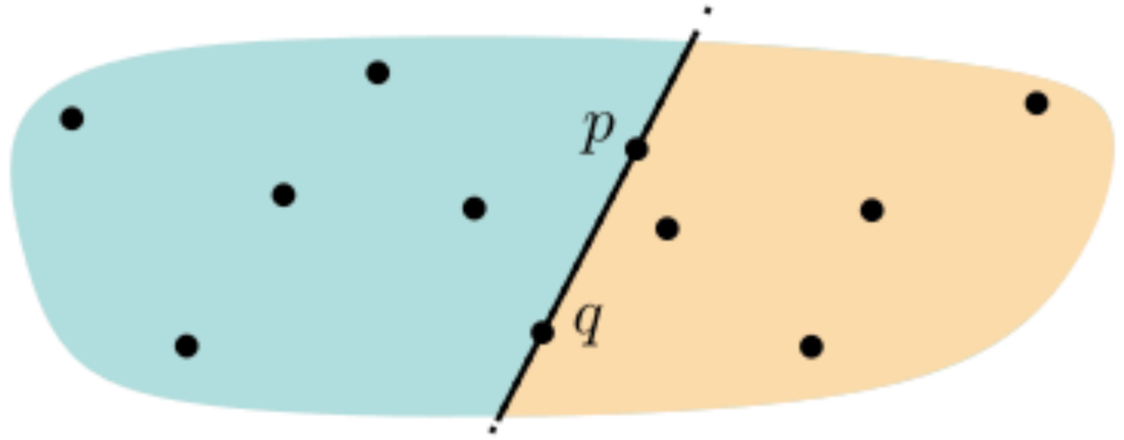

b) Design an algorithm that finds p and q in $\mathcal{O}(n)$ time for $n = |\mathcal{P}|$.

(Hint: Start with **b)**, a good correctness proof can also give you a constructive proof of existence.)

Prof. Dr. Sándor P. Fekete
Peter Kramer

Due 04.12.2024
Discussion 11.12.2024

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Exercise 1 (Geometric Predicates). **(5 points)**

Using only the leftTurn and rightTurn predicates from Lecture 1, design a geometric predicate for the Euclidean plane that decides whether a line segment $\overline{pq}$ intersects a triangle $\triangle(u,v,w)$:

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You may assume that (u,v,w) are in counterclockwise order and that no three points are collinear. Please explain your solution and briefly argue its correctness.

Exercise 2 (Partitioning Points). **(15 points)**

Consider a set $\mathcal{P}$ in the Euclidean plane $\mathbb{R}^2$ in general position according to *Definition E1*.

a) Prove that there exist points $p, q \in \mathcal{P}$ that divide $\mathcal{P}$ evenly based on left-/rightTurn:

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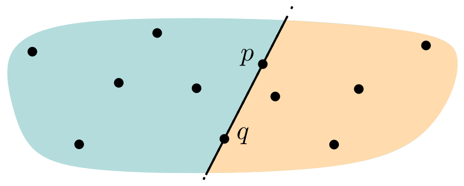

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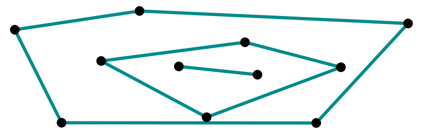
Exercise 3 (Convex layers). **(10 points)**

The *convex layers* of a finite point set $\mathcal{P}$ in the plane correspond to a decomposition of $\mathcal{P}$ into nested, convex polygons (*layers*). The outermost layer L_0 consists exactly of the extremal points defining conv(P). The next layer is recursively defined as points defining conv$(P \setminus L_0)$, meaning

$$L_i = \mathcal{P} \cap \delta\,\text{conv}\Big(\mathcal{P} \setminus \bigcup_{j\in[0,i]} L_j\Big).$$



Design an algorithm which computes the convex layers of n points in the Euclidean plane, in $\mathcal{O}(n^2)$ time. Briefly argue its runtime and correctness.

1/1

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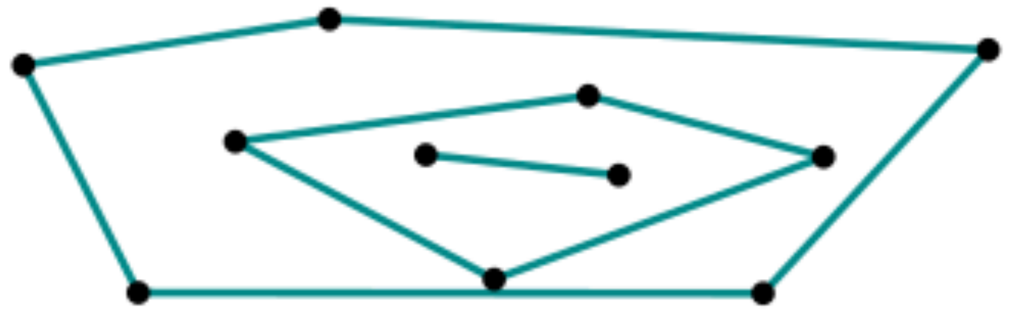

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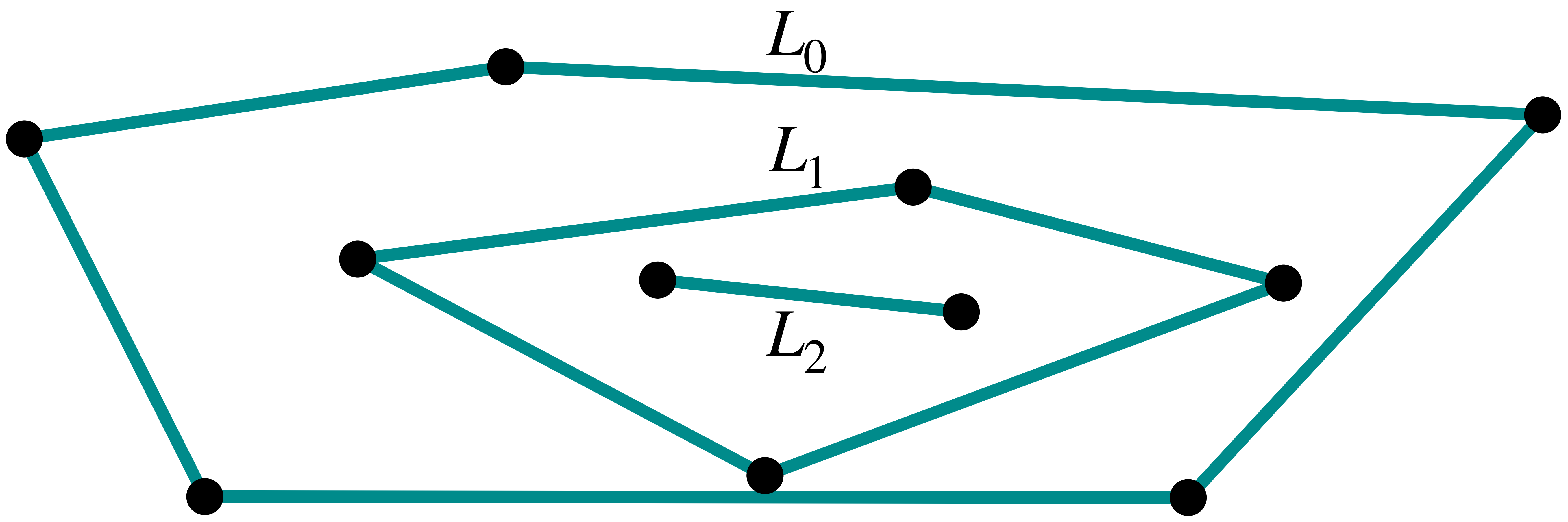

Computational Geometry – Sheet 2 | **Winter 2025/2026**

Prof. Dr. Sándor P. Fekete | **Due** 04.12.2024

Peter Kramer | **Discussion** 11.12.2024

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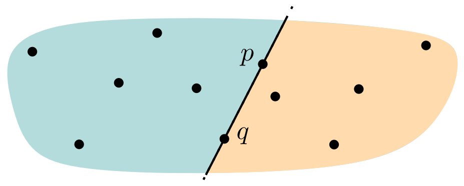

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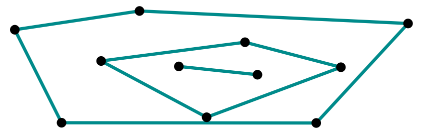

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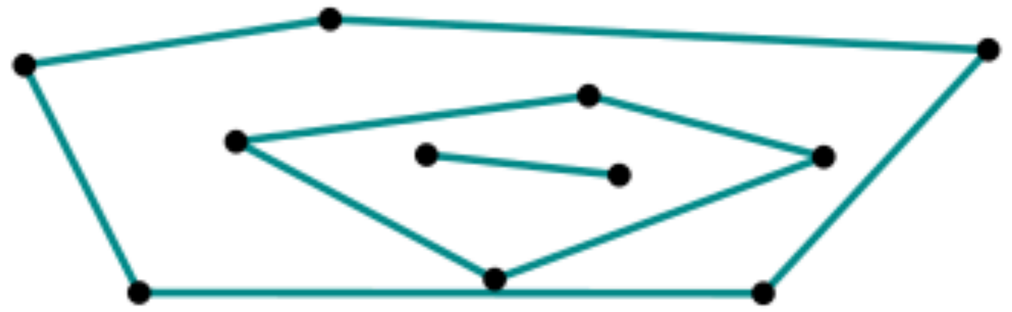

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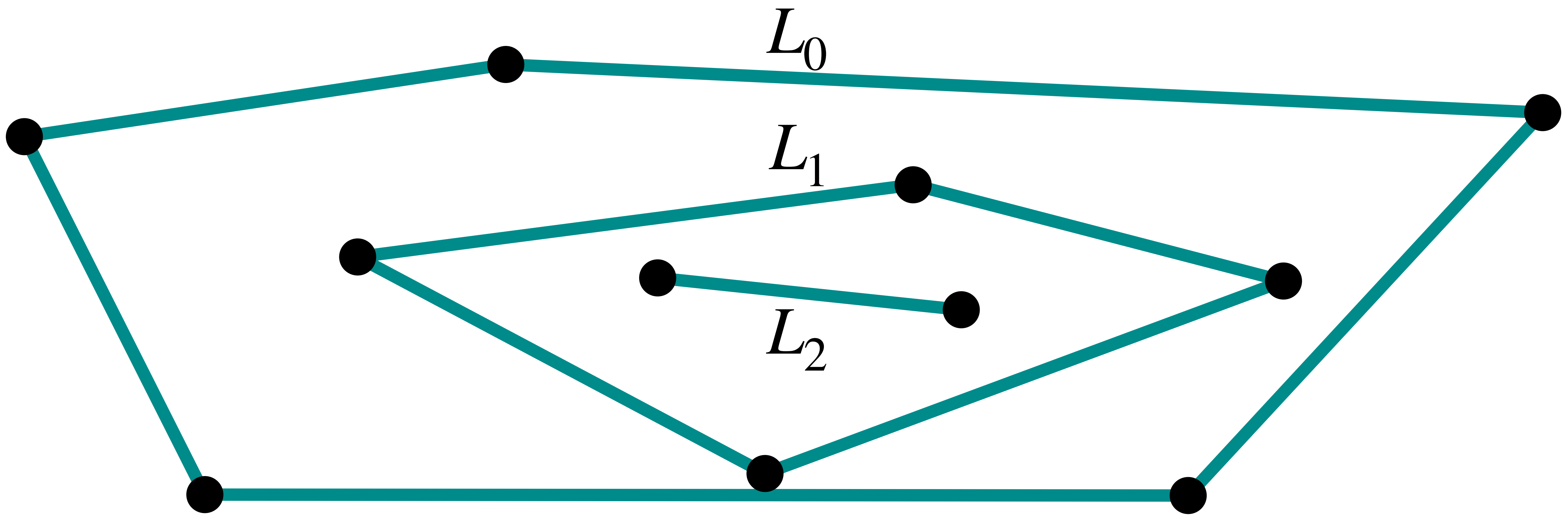

Thank you for today :)