Convex Points Thm Known as Happy Ending Thm

Exposition by William Gasarch

December 29, 2024

Convex Sets
And
Convex Hulls

Convex Sets

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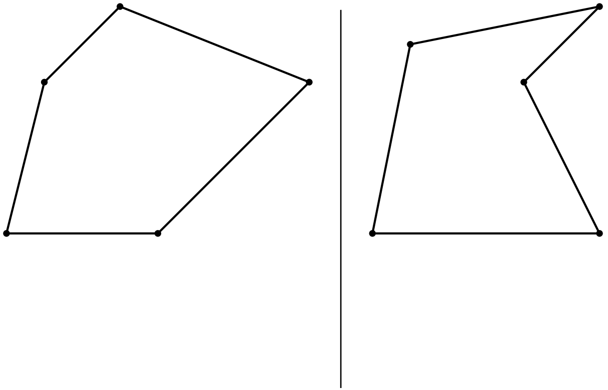
Convex and Non-Convex Sets on Next Slide.

Convex Set / Non-Convex Set



Left Region is Convex. Right Region is Not Convex.

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Def Let $X \subseteq \mathbb{R}^2$ (it will always be a finite set). The **Convex Hull of X** is the smallest convex set that contains all the points in X.

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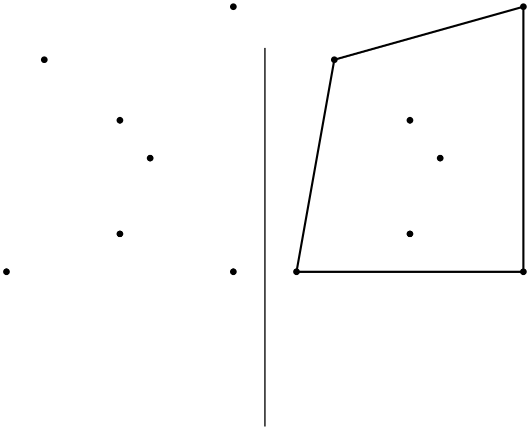
An Example is on Next Slide.

Size of a Convex Hull

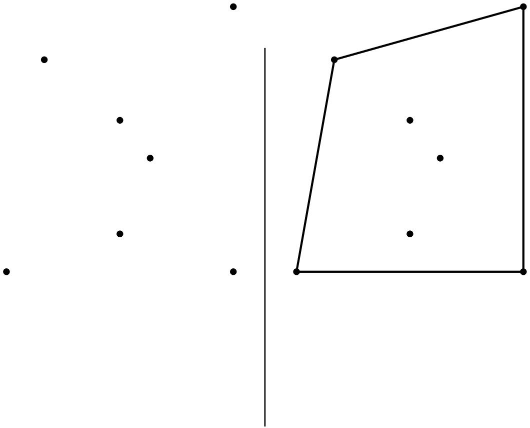
Def The **Size of a Convex Hull** is how many sides it has.

Example of A Convex Hull



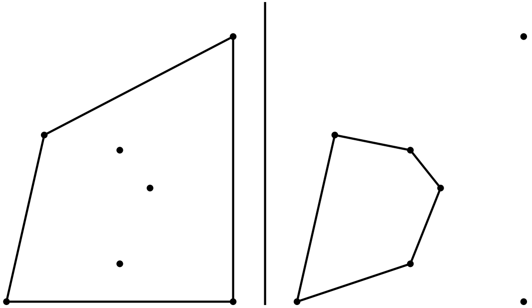
Region In Right Picture is Convex Hull of Points in Left Picture.

Example of A Convex Hull



Region In Right Picture is Convex Hull of Points in Left Picture.
RHS is a convex hull of size 4.

Convex Hull Not the Largest Convex Hull



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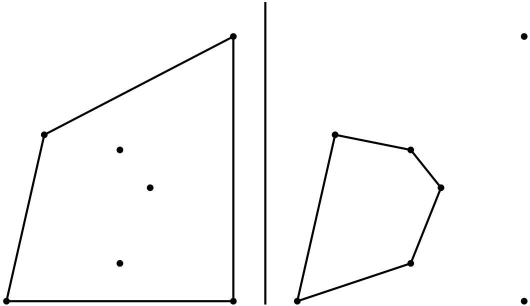

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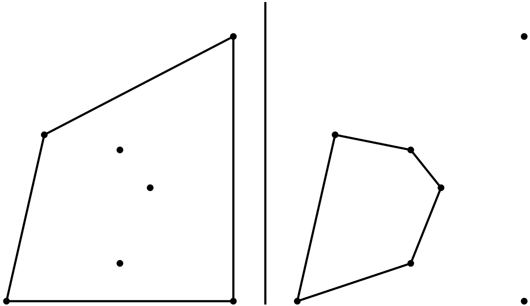

LHS: 7 points have a convex hull of size 4.

RHS: 5 of those 7 point have a convex hull of size 5.

We Want Large Convex Hulls
Concrete Examples

Given n Points in $\mathbb{R}^2$ Want Large Convex Hull

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Answer on Next Slides.

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Hence $f(4) \geq 5$.

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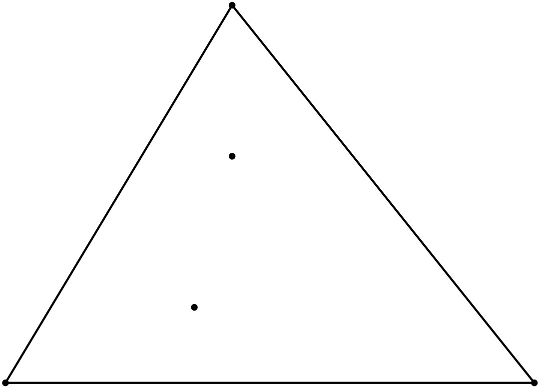
General proof left to the reader.

Two Points Inside a 3-gon



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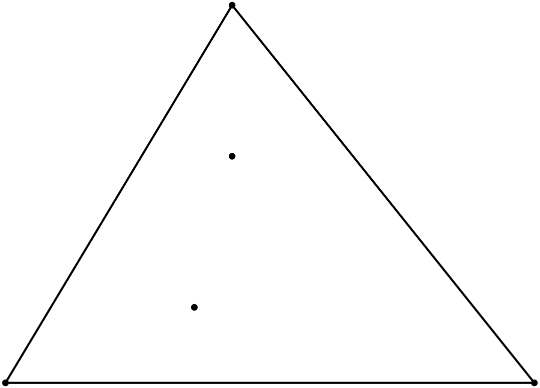
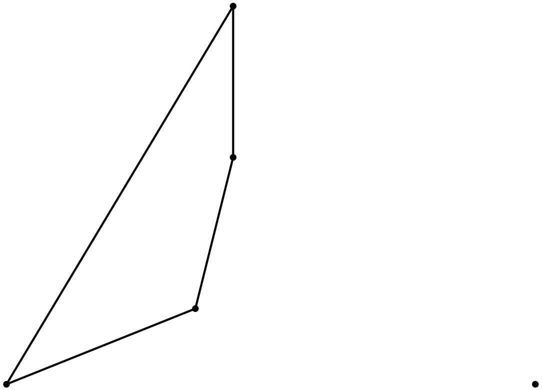


See Next Slide for the Amazing 4-Gon!

The Amazing 4-Gon



We Want Large Convex Hulls For General k

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Proof Using $R_4(5, k)$

This proof is by Erdös-Szekeres
Recall Let $n = R_4(5, k)$. Then for all $\mathrm{COL}\colon \binom{[n]}{4} \rightarrow [2]$ there is EITHER a RED homog set of size 5 or a BLUE homog set of size k.

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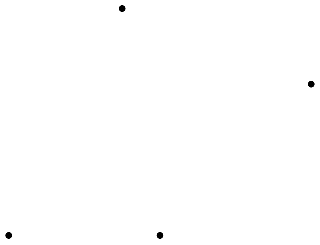
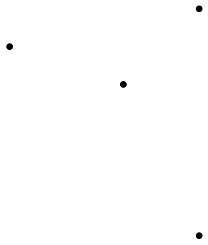
Given $X \subseteq \mathbb{R}^2$, $|X| = n$, define the following coloring:
Let $Z \in \binom{X}{4}$.

$$\mathrm{COL}(Z) = \begin{cases} \mathrm{CONV} \text{ if } Z \text{ forms a convex quadrilateral} \\ \mathrm{NOTCONV} \text{ otherwise} \end{cases} \tag{1}$$

Example Of the Coloring



Colored CONV.



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Exercise Show that if every 4-subset of H is a convex 4-gon then H is a convex hull of size k.

Proof Using $R_3(k,k)$ (by P. Johnson (1986))

Recall Let $n = R_3(k,k)$. Then for all $\mathrm{COL}\colon \binom{[n]}{3} \rightarrow [2]$ there is EITHER a **R** homog set of size k or a **B** homog set of size k.

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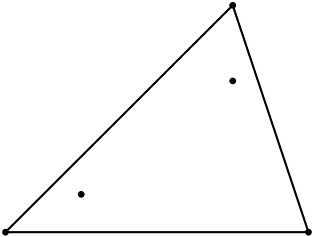
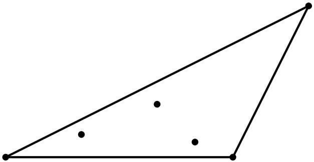
$$\mathrm{COL}(Z) = \begin{cases} \mathrm{EVEN} \text{ if the numb of points of } X \text{ in triangle } Z \text{ is even} \\ \mathrm{ODD} \text{ if the numb of points of } X \text{ in triangle } Z \text{ is odd} \end{cases}$$

Example of The Coloring



Colored EVEN.



Colored ODD.

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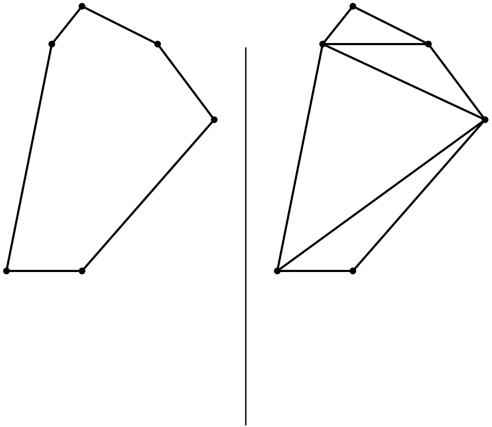
So every 3-subset of H has an odd number of points inside.
We Proof there are no points of H in the convex hull of H and hence we have a convex hull of size k.

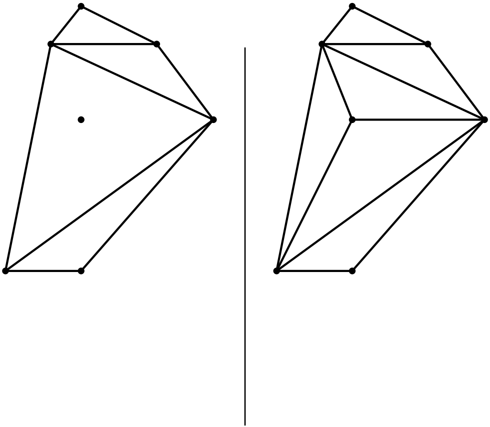
Convex Hull of H and its Triangulation



Convex Hull of H. Triangulation.

We need to prove that there are no points of H in the convex hull.

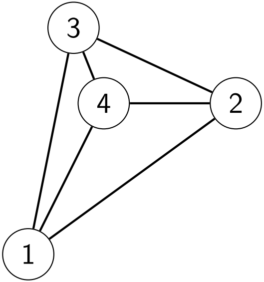
Assume There is a Point of H in the Convex Hull



Which △ point is in. More Triangulation.

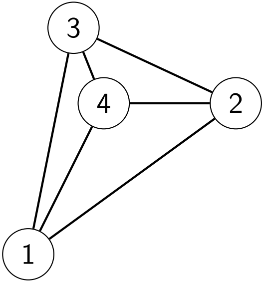
Need just the new point and its neighbors, and need labels.

Parity Argument



All these points are in H.

Parity Argument



All these points are in H. Assume all $\triangle$ colored EVEN.

$1 - 2 - 4$ has an even number of points

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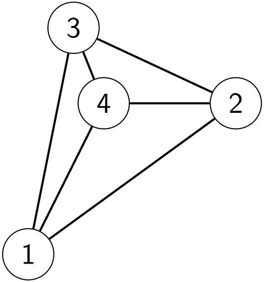

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$1-2-4$ has an even number of points

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$1-2-3$ has an even number of points.

Not possible. $1-2-3$ has the points of $1-2-4$ AND $2-3-4$ AND $1-3-4$ AND the point 4. Thats Odd!

Third Proof

The Third Proof will be on the HW

APPLICATION?

Vote

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Thm $(\forall k)(\exists n)(\forall X \subseteq \mathbb{R}^n)(\exists Y \subseteq X)$ such that $|Y| = k$ and the convex hull of Y has size k.

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1) Application.

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Vote
1) Application.
2) "Application"

Vote

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1) Application.

2) “Application”

3) ““Application””

A Bit More History

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The proof that Erdös-Szekeres had was the $R_4(5, k)$.

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Calling the proof **an application of Ramsey Theory** is a bit odd since it is really **one of the two reasons Ramsey Theory was invented** (the other was Ramsey's problem in logic).