BILL, RECORD LECTURE!!!!

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Introduction to the La-Lb Problem

Exposition by William Gasarch-U of MD

Chromatic Number of the Plane

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Thm $\forall\ \mathrm{COL}\colon \mathbb{R}^2 \to [2]\ \exists$ 2 points, same color, 1 inch apart.

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2) ℓ_3 is three colinear points p_1, p_2, p_3 where $d(p_1, p_2) = d(p_2, p_3) = 1$.

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3) You can define ℓ_k.
4) Given a $\mathrm{COL}\colon \mathbb{R}^2 \to [2]$ a **Red** $\boldsymbol{\ell_k}$ is an ℓ_k where all the points in it are **Red**. Similar for a **Blue** $\boldsymbol{\ell_k}$

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Is the following true:
$\forall$ COL: $\mathbb{R}^2 \to [2]$ $\exists$ either a **Red** ℓ_2 or a **Blue** ℓ_3.
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Let COL: $\mathbb{R}^2 \to [2]$.

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Is the following true:
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Let $\mathrm{COL}\colon \mathbb{R}^2 \to [2]$.

Case 1 There exists a **Blue** ℓ_3.

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Let $\mathrm{COL}\colon \mathbb{R}^2 \to [2]$.

Case 1 There exists a **Blue** ℓ_3. Then done.

Question

Is the following true:
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Thm $\forall\ \mathrm{COL}\colon \mathbb{R}^2 \rightarrow [2]\ \exists$ either a **Red** ℓ_2 or a **Blue** ℓ_3.

Let $\mathrm{COL}\colon \mathbb{R}^2 \rightarrow [2]$.

Case 1 There exists a **Blue** ℓ_3. Then done.

Case 2 There is no **Blue** ℓ_3.

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Let $\mathrm{COL}\colon \mathbb{R}^2 \to [2]$.

Case 1 There exists a **Blue** ℓ_3. Then done.

Case 2 There is no **Blue** ℓ_3.

Hence for all points $(x, y) \in \mathbb{R}^2$,

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Let $\mathrm{COL}\colon \mathbb{R}^2 \to [2]$.

Case 1 There exists a **Blue** ℓ_3. Then done.

Case 2 There is no **Blue** ℓ_3.

Hence for all points $(x, y) \in \mathbb{R}^2$,
at least one of (x, y), $(x, y + 1)$, $(x, y + 2)$ is **R**.

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Is the following true:
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Let $\mathrm{COL} \colon \mathbb{R}^2 \to [2]$.

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Hence for all points $(x, y) \in \mathbb{R}^2$,
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We define $\mathrm{COL}' \colon \mathbb{R}^2 \to [3]$ as follows:

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Let $\mathrm{COL}\colon \mathbb{R}^2 \to [2]$.

Case 1 There exists a **Blue** ℓ_3. Then done.

Case 2 There is no **Blue** ℓ_3.

Hence for all points $(x,y) \in \mathbb{R}^2$,
at least one of (x,y), $(x,y+1)$, $(x,y+2)$ is **R**.

We define $\mathrm{COL}'\colon \mathbb{R}^2 \to [3]$ as follows:

$\mathrm{COL}'(x,y)$ is the least $i \in \{0,1,2\}$ such that $\mathrm{COL}(x,y+i) =$ **R**.

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Is the following true:
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Let $\mathrm{COL}\colon \mathbb{R}^2 \to [2]$.

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Hence for all points $(x, y) \in \mathbb{R}^2$,
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We define $\mathrm{COL}'\colon \mathbb{R}^2 \to [3]$ as follows:

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This is well defined because of the case we are in.

Use That Chromatic Number of Plane is ≤ 3

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$\mathrm{COL}'(x, y)$ is the least $i \in \{0, 1, 2\}$ such that $\mathrm{COL}(x, y + i) = \textbf{R}$.

Chrom number of plane is ≤ 3, so $\exists$ (x_1, y_1), (x_2, y_2) such that

Use That Chromatic Number of Plane is ≤ 3

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Chrom number of plane is ≤ 3, so $\exists$ (x_1, y_1), (x_2, y_2) such that

1) $d((x_1, y_1), (x_2, y_2)) = 1$, and

Use That Chromatic Number of Plane is ≤ 3

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2) $\mathrm{COL}'(x_1, y_1) = \mathrm{COL}'(x_2, y_2) = i$.

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2) $\mathrm{COL}'(x_1, y_1) = \mathrm{COL}'(x_2, y_2) = i$.

Hence $\mathrm{COL}(x_1, y_1 + i) = \mathbf{R}$ and $\mathrm{COL}(x_2, y_2 + i) = \mathbf{R}$

Use That Chromatic Number of Plane is ≤ 3

$\mathrm{COL}'(x,y)$ is the least $i \in \{0,1,2\}$ such that $\mathrm{COL}(x,y+i) = \mathbf{R}$.

Chrom number of plane is ≤ 3, so $\exists$ (x_1,y_1), (x_2,y_2) such that

1) $d((x_1,y_1),(x_2,y_2)) = 1$, and

2) $\mathrm{COL}'(x_1,y_1) = \mathrm{COL}'(x_2,y_2) = i$.

Hence $\mathrm{COL}(x_1,y_1+i) = \mathbf{R}$ and $\mathrm{COL}(x_2,y_2+i) = \mathbf{R}$

Since $d((x_1,y_1),(x_2,y_2)) = 1$, $d((x_1,y_1+i),(x_2,y_2+i)) = 1$,

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1) $d((x_1, y_1), (x_2, y_2)) = 1$, and

2) $\mathrm{COL}'(x_1, y_1) = \mathrm{COL}'(x_2, y_2) = i$.

Hence $\mathrm{COL}(x_1, y_1 + i) =$ **R** and $\mathrm{COL}(x_2, y_2 + i) =$ **R**

Since $d((x_1, y_1), (x_2, y_2)) = 1$, $d((x_1, y_1 + i), (x_2, y_2 + i)) = 1$,

So $(x_1, y_1 + 1)$ and $(x_2, y_2 + 1)$ are a **Red** ℓ_2.

Use That Chromatic Number of Plane is ≤ 3

$\mathrm{COL}'(x,y)$ is the least $i \in \{0,1,2\}$ such that $\mathrm{COL}(x,y+i) =$ **R**.

Chrom number of plane is ≤ 3, so $\exists$ (x_1,y_1), (x_2,y_2) such that

1) $d((x_1,y_1),(x_2,y_2)) = 1$, and

2) $\mathrm{COL}'(x_1,y_1) = \mathrm{COL}'(x_2,y_2) = i$.

Hence $\mathrm{COL}(x_1,y_1+i) =$ **R** and $\mathrm{COL}(x_2,y_2+i) =$ **R**

Since $d((x_1,y_1),(x_2,y_2)) = 1$, $d((x_1,y_1+i),(x_2,y_2+i)) = 1$,

So (x_1,y_1+1) and (x_2,y_2+1) are a **Red** ℓ_2. Done!

Can Prove Result About (ℓ_2, ℓ_4)

Using that the Chromatic Number of the Plane (χ) is ≤ 4 one can easily prove the following:
Thm $\forall\ \mathrm{COL}\colon \mathbb{R}^2 \rightarrow [2]\ \exists$ either a **Red** ℓ_2 or a **Blue** ℓ_4.

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Using that the Chromatic Number of the Plane (χ) is ≤ 4 one can easily prove the following:

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Juhasz prove the above theorem without using $\chi \leq 4$. In fact, he prove the theorem in 1979, 39 years before $\chi \leq 4$ was proven.

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We proved $\mathbb{R}^2 \to (\ell_2, \ell_3)$.

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We proved $\mathbb{R}^2 \to (\ell_2, \ell_3)$.

We will soon present statements about $\mathbb{R}^2 \to (\ell_2, \ell_n)$

Notes About the Statements

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The next two slides have statements about what is known.

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All of the papers referred to are on this website:

`https://www.cs.umd.edu/~gasarch/TOPICS/ERT/ert.html`

$\mathbb{R}^2 \to (\ell_2, \ell_n)$?

Author and Year	Result	About $\mathbb{R}^2$
Positive Results		

$\mathbb{R}^2 \to (\ell_2, \ell_n)$?

Author and Year	Result	About $\mathbb{R}^2$
Positive Results		
Szlam, 1999	$(\forall X)[\lvert X\rvert = 3]$ $\mathbb{R}^2 \to (\ell_2, X)$	$\mathbb{R}^2 \to (\ell_2, \ell_3)$

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Tsaturian, 2017	$\mathbb{R}^2 \to (\ell_2, \ell_5)$	$\mathbb{R}^2 \to (\ell_2, \ell_5)$

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Juhasz, 1979	$(\forall X)[\lvert X\rvert = 4]$ $\mathbb{R}^2 \rightarrow (\ell_2, X)$	$\mathbb{R}^2 \rightarrow (\ell_2, \ell_4)$
Tsaturian, 2017	$\mathbb{R}^2 \rightarrow (\ell_2, \ell_5)$	$\mathbb{R}^2 \rightarrow (\ell_2, \ell_5)$
Arman-Tsaturian, 2017	$\mathbb{R}^3 \rightarrow (\ell_2, \ell_6)$	NONE

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Szlam, 1999	$(\forall X)[\|X\| = 3]$ $\mathbb{R}^2 \to (\ell_2, X)$	$\mathbb{R}^2 \to (\ell_2, \ell_3)$
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Tsaturian, 2017	$\mathbb{R}^2 \rightarrow (\ell_2, \ell_5)$	$\mathbb{R}^2 \rightarrow (\ell_2, \ell_5)$
Arman-Tsaturian, 2017	$\mathbb{R}^3 \rightarrow (\ell_2, \ell_6)$	NONE
Negative Results		
Csizmadia-Togh 1994	$\exists X \subseteq \mathbb{R}^2$, $\|X\| = 8$ $\mathbb{R}^2 \not\rightarrow (\ell_2, X)$	NONE

$\mathbb{R}^2 \rightarrow (\ell_2, \ell_n)$?

Author and Year	Result	About $\mathbb{R}^2$
Positive Results		
Szlam, 1999	$(\forall X)[\|X\| = 3]$ $\mathbb{R}^2 \rightarrow (\ell_2, X)$	$\mathbb{R}^2 \rightarrow (\ell_2, \ell_3)$
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Tsaturian, 2017	$\mathbb{R}^2 \rightarrow (\ell_2, \ell_5)$	$\mathbb{R}^2 \rightarrow (\ell_2, \ell_5)$
Arman-Tsaturian, 2017	$\mathbb{R}^3 \rightarrow (\ell_2, \ell_6)$	NONE
Negative Results		
Csizmadia-Togh 1994	$\exists X \subseteq \mathbb{R}^2$, $\|X\| = 8$ $\mathbb{R}^2 \not\rightarrow (\ell_2, X)$	NONE
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$\mathbb{R}^2 \rightarrow (\ell_2, \ell_n)$?

Author and Year	Result	About $\mathbb{R}^2$
Positive Results		
Szlam, 1999	$(\forall X)[\|X\| = 3]$ $\mathbb{R}^2 \rightarrow (\ell_2, X)$	$\mathbb{R}^2 \rightarrow (\ell_2, \ell_3)$
Juhasz, 1979	$(\forall X)[\|X\| = 4]$ $\mathbb{R}^2 \rightarrow (\ell_2, X)$	$\mathbb{R}^2 \rightarrow (\ell_2, \ell_4)$
Tsaturian, 2017	$\mathbb{R}^2 \rightarrow (\ell_2, \ell_5)$	$\mathbb{R}^2 \rightarrow (\ell_2, \ell_5)$
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Csizmadia-Togh 1994	$\exists X \subseteq \mathbb{R}^2$, $\|X\| = 8$ $\mathbb{R}^2 \not\rightarrow (\ell_2, X)$	NONE
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Currier et al., 2026	$\mathbb{R}^2 \not\rightarrow (\ell_2, \ell_{6330})$	$\mathbb{R}^2 \not\rightarrow (\ell_2, \ell_{6330})$

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Conlon-Fox, 2018	$(\forall n \geq 2)$ $\mathbb{R}^n \not\rightarrow (\ell_2, \ell_{10^{10}})$	$\mathbb{R}^2 \not\rightarrow (\ell_2, \ell_{10^{50}})$
Currier et al., 2026	$\mathbb{R}^2 \not\rightarrow (\ell_2, \ell_{6330})$	$\mathbb{R}^2 \not\rightarrow (\ell_2, \ell_{6330})$
Hu, 2026	$\mathbb{R}^2 \not\rightarrow (\ell_2, \ell_{175})$	$\mathbb{R}^2 \not\rightarrow (\ell_2, \ell_{175})$

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Hu, 2026	$\mathbb{R}^2 \not\rightarrow (\ell_2, \ell_{175})$	$\mathbb{R}^2 \not\rightarrow (\ell_2, \ell_{175})$

Open Narrow the gap between $\mathbb{R}^2 \rightarrow (\ell_2, \ell_5)$ and $\mathbb{R}^2 \not\rightarrow (\ell_2, \ell_{175})$.

$\mathbb{R}^2 \to (\ell_3, \ell_n)$?

All of the negative results hold for all $n \geq 2$. Our interest is in the $n = 2$ case.

Author and Year	Result
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Open Problems

Narrow the gap between $\mathbb{R}^2 \to (\ell_3, \ell_3)$ and $\mathbb{R}^2 \not\to (\ell_3, \ell_{20})$.

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Open Problems

Narrow the gap between $\mathbb{R}^2 \to (\ell_3, \ell_3)$ and $\mathbb{R}^2 \not\to (\ell_3, \ell_{20})$.

The results of Fuhrer-Togh and Currie-Moore-Yip are messy. For some reasonable values of n find nice proofs that $\mathbb{R}^2 \not\to (\ell_3, \ell_n)$.

One More Result

Author and Year	Result
Negative Results	
Erdos et al. See Below	$\mathbb{R}_2 \not\to (\ell_6, \ell_6)$

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Erdös, Graham, Montgomery, Rothchild, Spencer, Strauss.

The title of the paper is **Euclidean Ramsey Theorems I (1973)** and was (obviously) an early paper on Euclidean Ramsey Theory.

Open Problems about ℓ_2, ℓ_3

ℓ_2

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ℓ_2

Known $\mathbb{R}^2 \to (\ell_2, \ell_5)$

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Open Problems about ℓ_2, ℓ_3

ℓ_2
Known $\mathbb{R}^2 \rightarrow (\ell_2, \ell_5)$
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Open Narrow the Gap.

Open Problems about ℓ_2, ℓ_3

ℓ_2

Known $\mathbb{R}^2 \to (\ell_2, \ell_5)$

Known $\mathbb{R}^2 \not\to (\ell_2, \ell_{175})$

Open Narrow the Gap.

ℓ_3

Open Problems about ℓ_2, ℓ_3

ℓ_2
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ℓ_3
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Open Problems about ℓ_2, ℓ_3

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Open Problems about ℓ_4, ℓ_5

ℓ_4

Open Problems about ℓ_4, ℓ_5

$\ell_{\mathbf{4}}$

Known (not) Do not know any $a \ge 4$ with $\mathbb{R}^2 \rightarrow (\ell_4, \ell_a)$

Open Problems about ℓ_4, ℓ_5

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Open Problems about ℓ_4, ℓ_5

ℓ_4
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Might be $\mathbb{R}^2 \not\rightarrow (\ell_4, \ell_4)$ so there is no such a.

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ℓ_5

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ℓ_6

Open Problems about ℓ_4, ℓ_5

ℓ_4

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Known $\mathbb{R}^2 \not\to (\ell_4, \ell_{18})$
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ℓ_6

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Known $\mathbb{R}^2 \not\rightarrow (\ell_6, \ell_6)$.
No Open Problem.

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Open Get nicer proofs.

Open In some cases get nicer proofs of weaker results.

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Conjectures? None.