BILL, RECORD LECTURE!!!!

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The Probabilistic Method

Exposition by William Gasarch

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3) We will show some of its uses outside of Ramsey Theory.

DISTINCT DIFF SETS

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Can we do better?
STUDENTS break into small groups and try to either do better OR show that you best you can do is $O(\log n)$.

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What is the probability that all of the diffs in A are distinct?

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KEY: If the prob is strictly greater than 0 then there must be SOME set of a elements where all of the diffs are distinct.

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We hope the Prob is strictly LESS THAN 1.

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We only need to show that the prob is LESS THAN 1.

Review a Little Bit of Combinatorics

The number of ways to CHOOSE y elements out of x elements is

$$\binom{x}{y} = \frac{x!}{y!(x-y)!}.$$

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Two ways to create a set with a diff repeated:
Way One:

- Pick $x < y$. There are $\binom{n}{2} \le n^2$ ways to do that.
- Pick diff d such that $x + d \ne y$, $x + d \le n$, $y + d \le n$. Can do $\le n$ ways. Put $x, y, x + d, y + d$ into A.
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Way Two: Pick $x < y$. Let $d = y - x$ (so we do NOT pick d). Put $x, y = x + d, y + d$ into A. Pick $a - 3$ more elements out of the $n - 3$ left.

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Determining the Prob II

If you pick a RANDOM $A \subseteq \{1, \ldots, n\}$ of size a then a bound on the probability that all of the diffs in A are NOT distinct is

$$\frac{n^3 \times \binom{n-4}{a-4} + n^2 \times \binom{n-3}{a-3}}{\binom{n}{a}} = \frac{n^3 \times \binom{n-4}{a-4}}{\binom{n}{a}} + \frac{n^2 \times \binom{n-3}{a-3}}{\binom{n}{a}}$$

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$$\leq \frac{32a^4}{n} \text{ Need some Elem Algebra and uses } n \geq 5.$$

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UPSHOT: For all $n \ge 5$ there exists a all-diff-distinct subset of $\{1, \ldots, n\}$ of size roughly $n^{1/4}$.

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- Caveat: If the Prob Proof has high prob of getting the object, then seems constructive. If all you prove is nonzero, than maybe not.

Actually Can Do Better

- With a maximal set argument can do $\Omega(n^{1/3})$.
- Better is known: $\Omega(n^{1/2})$ which is optimal.
  (That is a result by Kolmos-Sulyok-Szemeredi from 1975)

SUM FREE SET PROBLEM

Exposition by William Gasarch

Sum Free Set Problem

A More Sophisticated Use of Prob Method.

Definition: A set of numbers A is *sum free* if there is NO $x, y, z \in A$ such that $x + y = z$.

Example: Let $y_1, \ldots, y_m \in (1/3, 2/3)$ (so they are all between 1/3 and 2/3). Note that $y_i + y_j > 2/3$, hence $y_i + y_j \notin \{y_1, \ldots, y_m\}$.

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Lemma: If y_1, y_2, y_3 are such that
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Proof: STUDENTS DO THIS. ITS EASY.
Example: Let $A = \{y_1, \ldots, y_m\}$ all have fractional part in $(1/3, 2/3)$. A is sum free by above Lemma.

QUESTION

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VOTE:

1. There is a sumfree set of size roughly $n/3$.
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STUDENTS - WORK ON THIS IN GROUPS.

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Theorem For all $\epsilon > 0$, for all A that are a set of n real numbers, there is a sum-free subset of A of size $(1/3 - \epsilon)n$.

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Proof: Let L be LESS than everything in A and U be BIGGER than everything in A. We will make $U - L$ LARGE later.
For $a \in [L, U]$ let

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$$B_a = \{x \in A : \mathrm{frac}(ax) \in (1/3, 2/3)\}.$$

For all a, B_a is sum-free by Lemma above.
SO we need an a such that B_a is LARGE.

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$$\Pr_{a \in [L,U]}(\mathrm{frac}(ax) \in (1/3, 2/3))$$

We take $U - L$ large enough so that this prob is $\geq (1/3 - \epsilon)$.

$$E(|B_a|) = \sum_{x \in A} \Pr_{a \in [L,U]}(\mathrm{frac}(ax) \in (1/3, 2/3))$$
$$= \sum_{x \in A} (1/3 - \epsilon)$$
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So THERE EXISTS an a such that $|B_a| \geq (1/3 - \epsilon)n$.
What is a? I DON"T KNOW AND I DON"T CARE!
End of Proof

Turan's Theorem

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more easily using Probability, but first need a lemma. The proof

we give is due to Ravi Boppana and appears in the Alon-Spencer book on *The Probabilistic Method*

Lemma

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$$\sum_{v \in V} deg(v) = 2e.$$

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Proof: Try to count the edges by summing the degrees at each vertex. This counts every edge TWICE.

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Proof: Take the graph and RANDOMLY permute the vertices.

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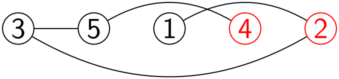

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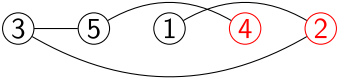

The set of vertices that have NO edges coming out on the right form an Ind Set. Call this set I.

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WRONG QUESTION!

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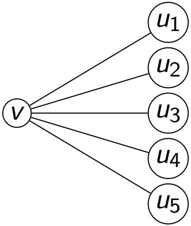
WRONG QUESTION!

What is the EXPECTED VALUE of the size of I.

(NOTE- we permuted the vertices RANDOMLY)

What is Prob $v \in I$

Let $v \in V$. What is prob that $v \in I$



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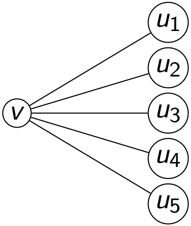

v has degree d_v. How many ways can v and its vertices be laid out: $(d_v + 1)!$. In how many of them is v on the right? $d_v!$.

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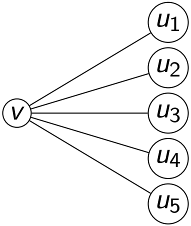

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$$\Pr(v \in I) = \frac{d_v!}{(d_v + 1)!} = \frac{1}{d_v + 1}.$$

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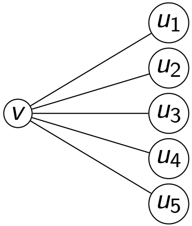
Let $v \in V$. What is prob that $v \in I$



v has degree d_v. How many ways can v and its vertices be laid out: $(d_v + 1)!$. In how many of them is v on the right? $d_v!$.

$$\Pr(v \in I) = \frac{d_v!}{(d_v + 1)!} = \frac{1}{d_v + 1}.$$

Hence

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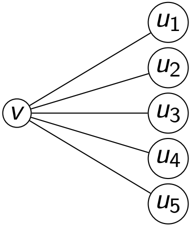

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$$E(|I|) = \sum_{v \in V} \frac{1}{d_v + 1}.$$

How Big is this Sum?

Need to find lower bound on

$$\sum_{v \in V} \frac{1}{d_v + 1}.$$

Rephrase

NEW PROBLEM:
Minimize

$$\sum_{v \in V} \frac{1}{x_v + 1}$$

relative to the constraint:

$$\sum_{v \in V} x_v = 2e.$$

KNOWN: This sum is minimized when all of the x_v are $\frac{2e}{|V|} = \frac{2e}{n}$.
So the min the sum can be is

$$\sum_{v \in V} \frac{1}{\frac{2e}{n} + 1} = \frac{n}{\frac{2e}{n} + 1}.$$

Recap and Done

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$$E(I) \ge \sum_{v \in V} \frac{1}{x_v + 1} \ge \sum_{v \in V} \frac{1}{\frac{2e}{n} + 1} = \frac{n}{\frac{2e}{n} + 1}.$$

END OF THIS TALK/TAKEAWAY

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TAKEAWAY: There are TWO ways (probably more) to show that an object exists using probability.

1. Show that the probability that it exists is NONZERO. Hence there must be some set of random choices that makes it exist. We did this for the distinct-sums problem.
2. You want to show that an object of a size $\geq s$ exists. Show that if you do a probabilistic experiment then you (a) always get the object of the type you want, and (b) the expected size is $\geq s$. Hence again SOME set of random choices produces an object of size $\geq s$.