# Superpermutations and Superpatterns

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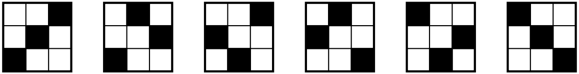

**Rényi Institute**

May 8, 2020

# Pattern Containment

We say that a permutation $p_1 p_2 \cdots p_n$ contains the shorter permutation $q_1 q_2 \cdots q_k$ as a pattern if there is a subsequence of entries in $p$ that relate to each other as the entries of $q$.

# PATTERN CONTAINMENT

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That is, $p$ contains $q$ as a pattern if there is a subsequence of $k$ entries $p_{i_1} p_{i_2} \cdots p_{i_k}$ so that $p_{i_a} < p_{i_b}$ if and only if $q_a < q_b$.

## Example

The permutation $p = 57821346$ contains the pattern $q = 132$ as shown in the figure.

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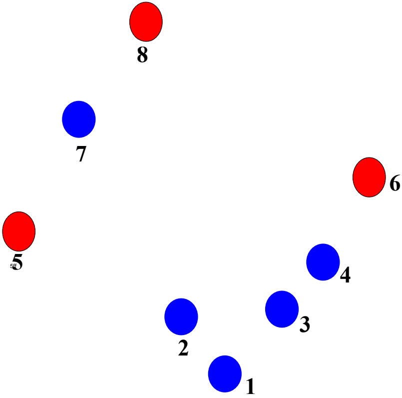


Figure: Containing the pattern 132.

# k-Superpatterns

What is the shortest permutation that contains all patterns of length $k$?

Let us call such a permutation a $k$-superpattern.

# Small values of $n$

It is easy to see that 132 is a 2-superpattern, and 25314 is a 3-superpattern.

Also, both are optimal for their $k$, so if $sp(k)$ is the length of the shortest $k$-superpattern, then $sp(1) = 1$, $sp(2) = 2$, and $sp(3) = 5$.

# A 3-superpattern

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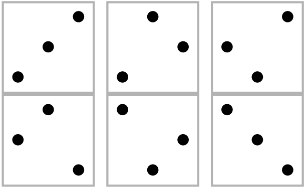
$\geqslant$



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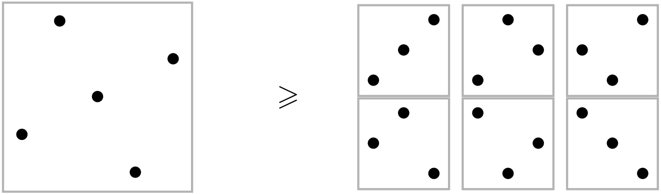

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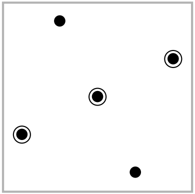
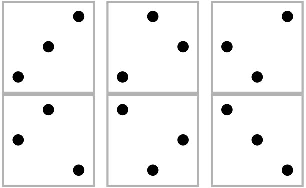


$\geqslant$



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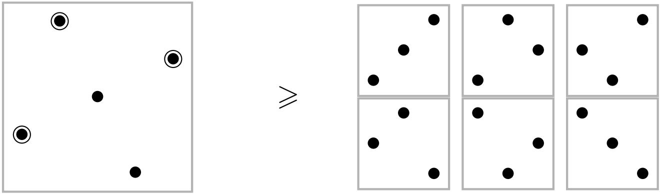

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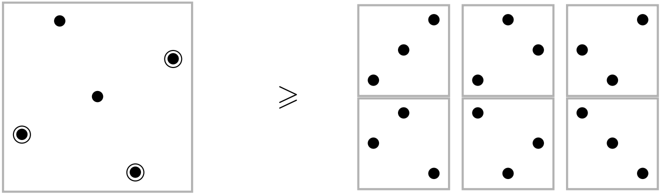

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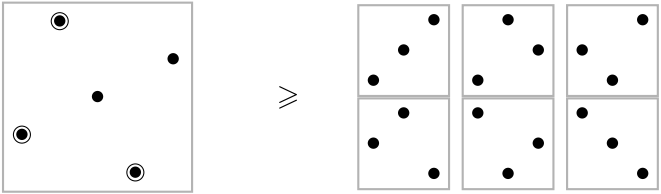

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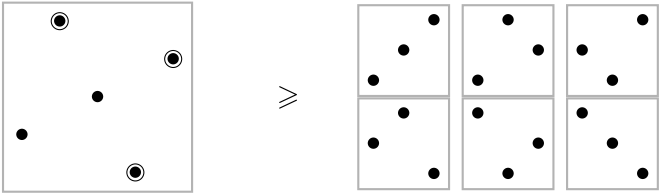

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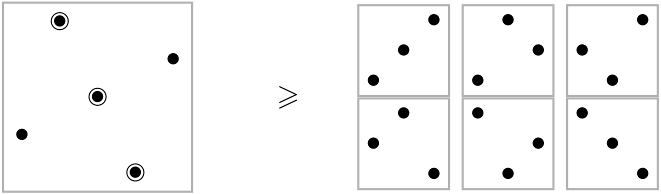

An exhaustive search is feasible by computer for the next two values of $n$, resulting in $sp(4) = 9$ and $sp(5) = 13$.

# Upper Bounds

- The upper bound $sp(k) \leqslant k^2$ is trivial. See 1 4 7 2 5 8 3 6 9. This was pointed out by Richard Arratia, who posed the problem of superpatterns in 1999.
- Eriksson, Eriksson, Linusson, and Wästlund proved an upper bound of (approximately) $2k^2/3$ in 2007.

# Allison Miller (2009)

**Theorem.** *The inequality* $\mathrm{sp}(k) \leqslant \frac{k^2+k}{2}$ *holds.*

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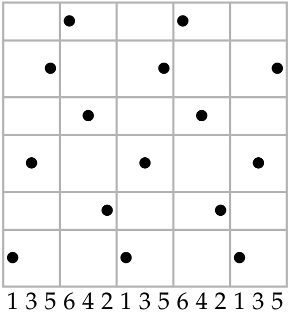
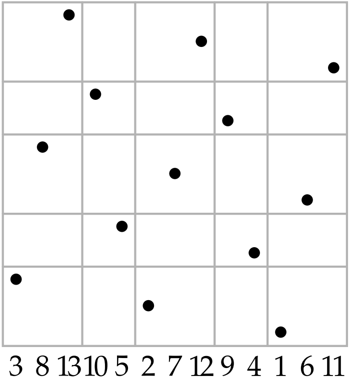
**Theorem.** *The inequality* $\mathrm{sp}(k) \leqslant \dfrac{k^2+k}{2}$ *holds.*

**Observation.** *What Miller actually proves is that there is a word of this length over the alphabet* $[k+1]$ *that contains all patterns of length* $k$ *as subsequences.*



# Engen and Vatter (2019)

**Theorem.** *The inequality* $\mathrm{sp}(k) \leqslant \left\lceil \frac{k^2+1}{2} \right\rceil$ *holds.*



Is This It?

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No. For $k = 6$, this bound is 19, but there is a 6-superpattern of length 17,

6 14 10 2 13 17 5 8 3 12 9 16 1 7 11 4 15,

found by Arnar Arnarson at *Permutation Patterns 2018*.

## Is This It?

No. For $k = 6$, this bound is 19, but there is a 6-superpattern of length 17,

$$6\ 14\ 10\ 2\ 13\ 17\ 5\ 8\ 3\ 12\ 9\ 16\ 1\ 7\ 11\ 4\ 15,$$

found by Arnar Arnarson at *Permutation Patterns 2018*. This turns out to be optimal, after a gigantic computation.

# Lower Bounds

Clearly, if there exists a $k$-superpattern of length $n$, then $n$ has to be long enough to contain $k!$ distinct patterns of length $k$.

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So

$$k! \leqslant \binom{n}{k},$$

and that leads to

$$\frac{k^2}{e^2} \leqslant n,$$

So $k^2/e^2 \leqslant sp(k)$.

# Chroman, Kwan, and Singhal (2020)

Interestingly, this trivial lower bound is quite difficult to improve, because most ideas do not lead to an improvement that is significant enough to increase the constant $1/e^2$.

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**Theorem.** *The inequality* $1.000076k^2/e^2 \leqslant \mathrm{sp}(k)$ *holds.*

# Superpermutations

Posed by Karp, and included by Knuth in a 1972 Stanford technical report entitled "Selected Combinatorial Research Problems".

> *What is the shortest string of* $\{1, 2, \ldots, n\}$ *containing all permutations on* $n$ *elements as subsequences? (For* $n = 3$, 1213121*; for* $n = 4$, 123412314321*; for* $n = 5$*, M. Newey claims the shortest has length* 19*.)*

Still to this day, the only exact values known are those for $n \leqslant 7$, which were computed by Newey to be

$$1, 3, 7, 12, 19, 28, 39$$

in his 1973 Stanford technical report.

# Superpermutations

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**Theorem.** (Mohanty 1980) $\leqslant n^2 - 2n + 4$.

# Mohanty's construction

Write down $n$ copies of 1, and between two consecutive 1s, insert any permutation of the set $\{2, 3, \cdots, n\}$. This is a string of $n^2 - n + 1$ entries.

Remove $n - 3$ entries as follows. Let $1 < i < n - 1$. Remove an entry $j$ from the $i$th segment, then in segment $i - 1$, move the entry $j$ of that segment into the last position, and in segment $i + 1$ move the entry $j$ of that segment into the first position.

12345 1 2345 1 2345 1 2345 1

12345 1 234 1 523 1 42351

**Theorem.** (Zălinescu 2011) $\leqslant n^2 - 2n + 3$ *for* $n \geqslant 10$.

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**Theorem.** (Radomirović 2012) $\leqslant \left\lceil n^2 - \frac{7n}{3} + \frac{19}{3} \right\rceil$ *for* $n \geqslant 7$.

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**Theorem.** (Kleitman and Kwiatkowski 1976) $\geqslant n^2 - c_\epsilon n^{7/4+\epsilon}$.

# Containing as Factors, Over $[n]$ (Superfactors)

**Theorem (Ashlock and Tillotson 1993).** *There is a word of length*

$$n! + (n-1)! + (n-2)! + \cdots + 2! + 1$$

*over the alphabet* $[n]$ *that contains all permutations of* $[n]$ *contiguously.*

**Conjecture (Ashlock and Tillotson 1993).** *The above construction is best possible.*

**Proposition (Ashlock and Tillotson 1993).** *Any such word has length at least* $n! + (n-1)! + n - 2$.

**Proposition (Houston 2014).** *There is a word of length*

$$6! + 5! + 4! + 3! + 2! = \mathbf{872}$$

*over the alphabet* $[6]$ *that contains all permutations of* $[6]$ *contiguously.*

# The Crackpot Index

**John Baez**

**A simple method for rating potentially revolutionary contributions to physics:**

1. A -5 point starting credit.
2. 1 point for every statement that is widely agreed on to be false.
3. 2 points for every statement that is clearly vacuous.
4. 3 points for every statement that is logically inconsistent.
5. 5 points for each such statement that is adhered to despite careful correction.
6. 5 points for using a thought experiment that contradicts the results of a widely accepted real experiment.
7. 5 points for each word in all capital letters (except for those with defective keyboards).
8. 5 points for each mention of "Einstien", "Hawkins" or "Feynmann".
9. 10 points for each claim that quantum mechanics is fundamentally misguided (without good evidence).
10. 10 points for pointing out that you have gone to school, as if this were evidence of sanity.
11. 10 points for beginning the description of your theory by saying how long you have been working on it. (

**John Carlos Baez**
@johncarlosbaez

Follow

If you don't believe me, see my next tweet.

JUST WHEN YOU THOUGHT
YOU UNDERSTOOD THE PATTERN

The smallest number with the digits from 1 to 2 arranged in all possible orders has $1! + 2! = 3$ digits: 121.

The smallest number with the digits from 1 to 3 arranged in all possible orders has $1! + 2! + 3! = 9$ digits: 123121321.

The smallest number with the digits from 1 to 4 arranged in all possible orders has $1! + 2! + 3! + 4! = 33$ digits: 123412314231243121342132413214321.

The smallest number with the digits from 1 to 5 arranged in all possible orders has $1! + 2! + 3! + 4! + 5! = 153$ digits.

Does the smallest number with the digits from 1 to 6 arranged in all possible orders have $1! + 2! + 3! + 4! + 5! + 6! = 873$ digits?

No: 872 is enough. Or maybe even fewer — nobody knows yet!

3:54 PM - 26 Sep 2018

**56** Retweets **121** Likes

## JUST WHEN YOU THOUGHT YOU UNDERSTOOD THE PATTERN

**The smallest number with the digits from 1 to 2 arranged in all possible orders has $1! + 2! = 3$ digits: 121.**

**The smallest number with the digits from 1 to 3 arranged in all possible orders has $1! + 2! + 3! = 9$ digits: 123121321.**

**The smallest number with the digits from 1 to 4 arranged in all possible orders has $1! + 2! + 3! + 4! = 33$ digits: 123412314231243121342132413214321.**

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**Does the smallest number with the digits from 1 to 6 arranged in all possible orders have $1! + 2! + 3! + 4! + 5! + 6! = 873$ digits?**

**No: 872 is enough. Or maybe even fewer — nobody knows yet!**

**Theorem (Egan, 19 October 2018).** *There is a word of length* $n! + (n-1)! + (n-2)! + (n-3)! + n - 3$ *over the alphabet* $[n]$ *that contains all permutations of* $[n]$ *contiguously.*

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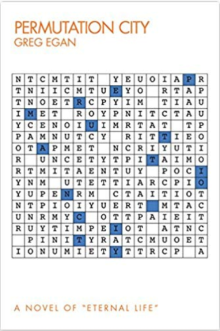


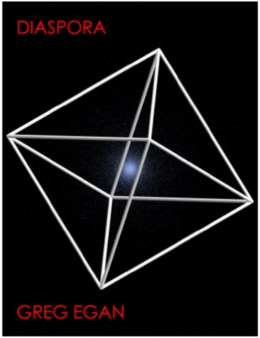


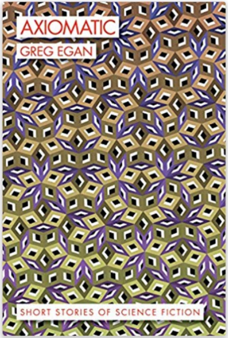

# The Lower Bound

**Proposition (Ashlock and Tillotson 1993).** $\geqslant n! + (n-1)! + n - 2$.

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**Question on 4Chan (2011).**

*You have an* $n$ *episode tv series. You want to watch the episodes in every order possible. What is the least number of episodes that you would have to watch?*

*Over lapping is allowed. For example, in the case of* $n = 2$, *watching episode* 1, *then* 2, *then* 1 *again, would fit the criteria.*

*The orders must be continuous. For example,* $(1, 2, 1, 3)$ *does NOT contain the sequence* $(1, 2, 3)$.

# THE 4CHAN LOWER BOUND

**Lower bounds** **Anonymous** Sat Sep 17 08:35:54 2011 No.3751197

Quoted by: >>3751366 >>3751370 >>3752047_2 >>3752047_25

I think I have a proof of the lower bound n! + (n-1)! + (n-2)! + n-3 (for <span class="math">n \geq 2[/spoiler]). I'll need to do this in multiple posts. Please look it over for any loopholes I might have missed.

As in other posts, let n (lowercase) = the number of symbols; there are n! permutations to iterate through.

The obvious lower bound is n! + n-1. We can obtain this as follows:

Let
L = the running length of the string
<span class="math">N_0[/spoiler] = the number of permutations visited
<span class="math">X_0 = L - N_0[/spoiler]

When you write down the first permutation, <span class="math">X_0[/spoiler] is already n-1. For each new permutation you visit, the length of the string must increase by at least 1. So <span class="math">X_0[/spoiler] can never decrease. At the end, <span class="math">N_0 = n![/spoiler], giving us <span class="math">L \geq n! + n-1[/spoiler].

I'll use similar methods to go further, but first I'll need to explain my terminology...

# The 4Chan Lower Bound

**Lower bounds** Anonymous Sat Sep 17 08:35:54 2011 No.3751199
Quoted by: >>3751366

Edges:

I'm picturing the ways to get from one permutation to the next as a directed graph where the nodes correspond to permutations and the edges to ways to get from one to the next. A k-edge is an edge in which you move k symbols from the beginning of the permutation to the end; for example,

1234567 -> 4567321

would be a 3-edge. Note that I don't include edges like

12345 -> 34512

in which you pass through through a permutation in the middle (in this case 23451). This example would be considered two edges:

12345 -> 23451
23451 -> 34512

From every node there is exactly one 1-edge, e.g.:

12345 -> 23451

# The 4Chan Lower Bound

**Lower bounds** **Anonymous** Sat Sep 17 08:37:54 2011 No.3751204
Quoted by: >>3751366 >>3751541

1-loops:

I call the set of n permutations connected by a cyclic path of 1-edges a 1-loop. There are (n-1)! 1-loops.

The concept of 1-loops is enough to get the next easiest lower bound of n! + (n-1)! + n-2. That's because to pass from one 1-loop to another, it is necessary to take a 2-edge or higher. Let us define:

<span class="math">N_1[/spoiler] = the number of 1-cycles completed or that we are currently in
<span class="math">X_1 = L - N_1 - N_2[/spoiler]

The definition of <span class="math">N_1[/spoiler] is a bit more complicated than we need for this proof, but we'll need it later. You might ask, isn't <span class="math">N_1[/spoiler] just one more than the number of completed 1-cycles? No! When we have just completed a 1-cycle, it is equal to the number of completed 1-cycles.

In order to increment <span class="math">N_1[/spoiler], we have to take a 2-edge, which increases L by 2 instead of 1. Therefore <span class="math">X_1[/spoiler] can never decrease. Since <span class="math">X_1[/spoiler] starts out with the value n-2,

# The 4Chan Lower Bound

**Lower bounds** **Anonymous** Sat Sep 17 08:37:54 2011 No.3751205

Quoted by: >>3751366

2-loops:

Suppose we enter a 1-loop, iterate through all n nodes (as is done in the greedy palindrome algorithm), and then take a 2-edge out. The edge we exit by is determined by the entry point. The permutation that the 2-edge takes us to is determined by taking the entry point and rotating the first n-1 characters, e.g.:

12345
is taken by n-1 1-edges to
51234
which is taken by a 2-edge to
23415

If we repeat this process, it takes us around in a larger loop passing through n(n-1) permutations. I call this greater loop a 2-loop.

The greedy palindrome algorithm uses ever-larger loops; it connects (n-k+1) k-loops via (k+1)-edges to make (k+1)-loops. But I haven't been able to prove anything about these larger loops yet.

The tricky thing about 2-loops is that which 2-loop you're in depends on the point at which you entered the current 1-loop. Each of the n possible entry points to a 1-loop

# The 4Chan Lower Bound

Anonymous Sat Sep 17 08:38:54 2011 No.3751207

Show apps

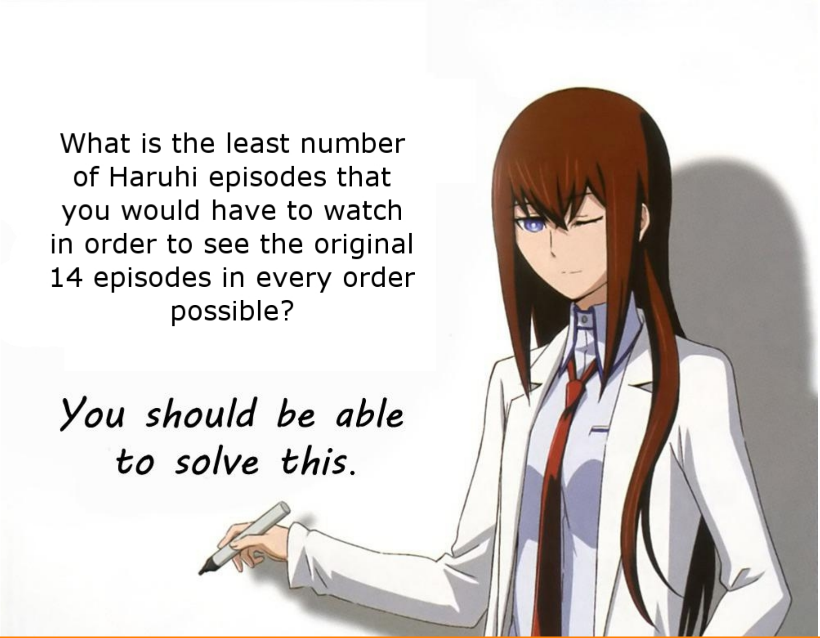
Quoted by: >>3751366

And now for the proof of the n! + (n-1)! + (n-2)! lower bound...

To review:
n = alphabet length
L = running string length
<span class="math">N_0[/spoiler] = number of permutations visited
<span class="math">X_0 = L - N_0[/spoiler]
<span class="math">N_1[/spoiler] = number of 1-cycles completed or that we are currently in
<span class="math">X_1 = L - N_1 - N_2[/spoiler]

In order to increase <span class="math">N_1[/spoiler], you must jump to a new 1-cycle -- having completed the one you are leaving. That means the next permutation P' in the 1-cycle (following your exit point P) is one you have already visited. Either you have at some point entered the 1-cycle at P', or this is the second or greater time you've visited P. If you have ever entered the 1-cycle at P', leaving at P by a 2-edge will not take you to a new 2-cycle; you will be in the same 2-cycle you were in when you entered at P'.

So these are the available ways to enter a 2-cycle you've never been in before:
* take a 3-edge or higher
* take a 2-edge but don't increase <span class="math">N_1[/spoiler]
* take a 2-edge from a permutation P that you were visiting for the second or greater


What is the least number of Haruhi episodes that you would have to watch in order to see the original 14 episodes in every order possible?
You should be able to solve this.

**Robin Houston**
@robinhouston

Following

A curious situation. The best known lower bound for the minimal length of superpermutations was proved by an anonymous user of a wiki mainly devoted to anime.


**The Haruhi Problem | /sci/ - Math & Science Wiki | ...**
More formally, "what is the shortest string containing all permutations of a set of n elements?" Started by:ニア愛!pQsULI4sXc
mathsci.wikia.com

12:37 AM - 23 Oct 2018

**4,530** Retweets **9,378** Likes

107 4.5K 9.4K

MATH comments

An anonymous user on 4chan solved an interesting problem, but no one knows how to cite them. (twitter.com)

3339 submitted 9 days ago by Araraguy

248 comments share save hide give gold report crosspost

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save content policy formatting help

[–] TheCatcherOfThePie Undergraduate 356 points 9 days ago*

For anyone wondering why the proof appeared on an anime wiki of all places: "The Melancholy of Haruhi Suzumiya" is an anime which has multiple orders in which it can be watched (the main two are broadcast order and chronological order). This question is a joke asking how many episodes you would need to watch in order to see every possible watch order.

permalink embed save report give gold reply

[–] Aenonimos 102 points 9 days ago

Yeah that was the joke. In 2011 there was 4chan meme with the format <difficult problem> "you should be able to

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# An anonymous 4chan post could help solve a 25-year-old math mystery

*An anime math problem*

By Mary Beth Griggs | Oct 24, 2018, 4:33pm EDT

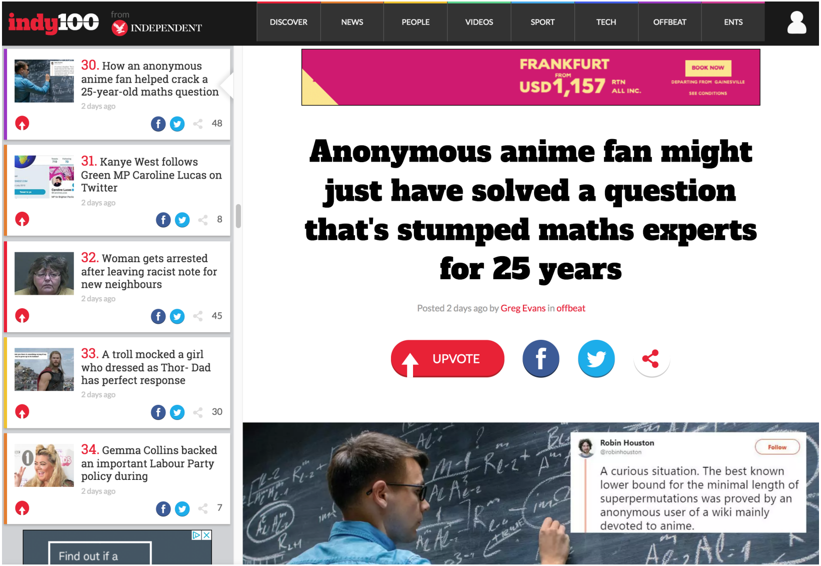
Tech Trending News



Tech

# Anonymous 4chan user solves 25 year old math problem

Pranav on October 25, 2018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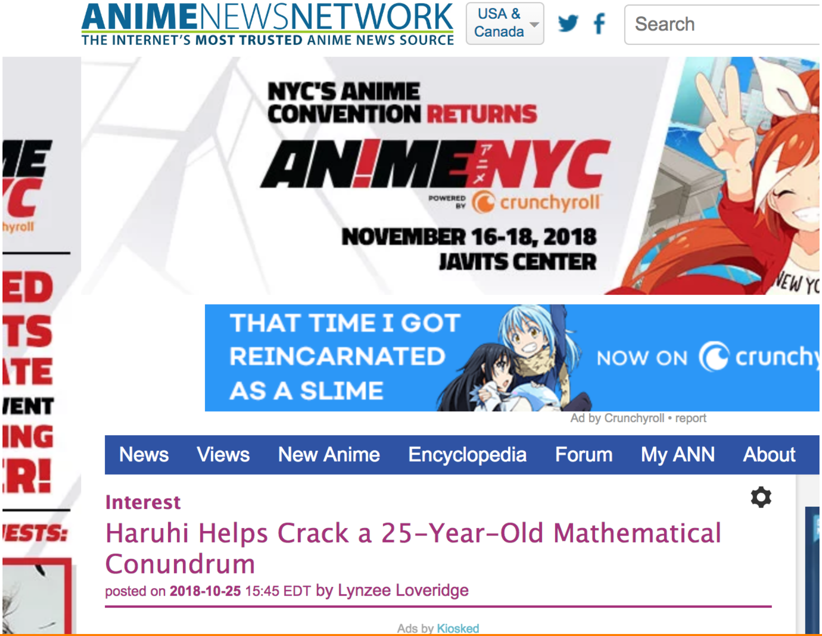
A curious situation. The best known lower bound for the minimal length of superpermutations was proved by an anonymous user of a wiki mainly devoted to anime.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# Infamous Math Problem Finally Gets Solved by Fan in Anime Chatroom

By NICK VALDEZ - October 27, 2018

Anime fans surprise all the time with the variety of fans there are, and one fan just might have used anime to help solve a tricky problem mathematicians have been trying to solve for the past 25 years.

Although the fan just used the equation to figure out the best way to watch every order of *The Melancholy of Haruhi Suzumiya* in the shortest time possible, now mathematicians are wondering how to progress with this solved equation from an anonymous fan.

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# 4chan solved part of math problem puzzling scientists for decades

Published time: 26 Oct, 2018 17:54
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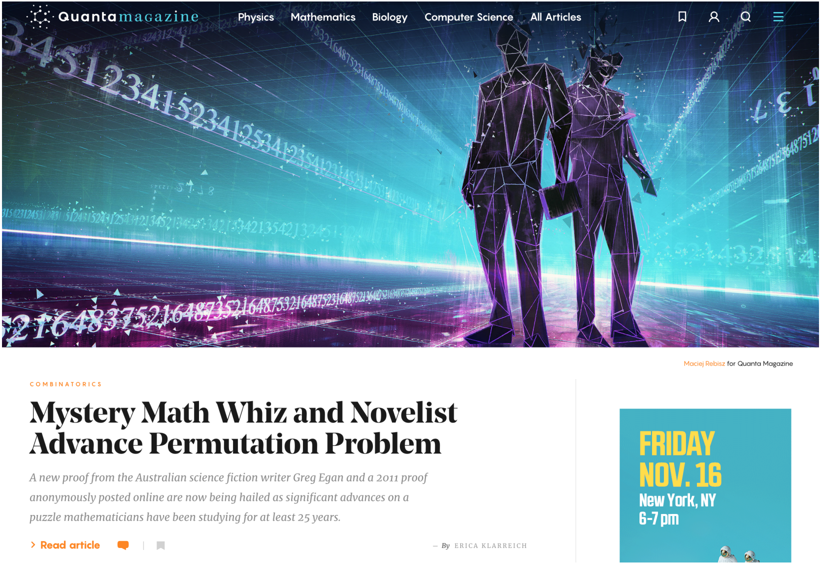
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A new proof from the Australian science fiction writer Greg Egan and a 2011 proof anonymously posted online are now being hailed as significant advances on a puzzle mathematicians have been studying for at least 25 years.
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# A lower bound on the length of the shortest superpermutation

Anonymous 4chan Poster, Michael Albert, Robin Houston, Jay Pantone, and Vince Vatter

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# A lower bound on the length of the shortest superpermutation

Anonymous 4chan Poster, Michael Albert, Robin Houston, Jay Pantone, and Vince Vatter

**Upper bound (as of now).** $\leqslant n!+(n-1)!+(n-2)!+(n-3)!+n-3.$

**Lower bound (as of now).** $\geqslant n!+(n-1)!+(n-2)!+n-3.$

**Conjecture.** $n!+(n-1)!+(n-2)!+(n-3)!+n-4.$
This conjecture was disproved by Robin Houston for $n=7$.


# A lower bound on the length of the shortest superpermutation

Anonymous 4chan Poster, Michael Albert, Robin Houston, Jay Pantone, and Vince Vatter

**Upper bound (as of now).** $\leqslant n! + (n-1)! + (n-2)! + (n-3)! + n - 3.$

**Lower bound (as of now).** $\geqslant n! + (n-1)! + (n-2)! + n - 3.$

**Conjecture.** $n! + (n-1)! + (n-2)! + (n-3)! + n - 4.$
This conjecture was disproved by Robin Houston for $n = 7$.

Thank you.