

NZ Math Olympiad Training Programme 2004

Assignment 2: Combinatorics

Problems & Solutions

1. In a rectangular $m \times n$ table the number of columns n is at least the number of rows m . This table is filled with zeros and ones in such a way that no two rows are equal. Prove that it is possible to cross out one of the columns so that no two rows will be equal again.

Solution: Let us denote the table as T . We will prove the statement by induction on m . For $m = 2$, the statement is obvious because there is a column in T where the two rows differ and there is at least one other column, which can be removed. Suppose $m > 2$. Remove the first column of T to obtain T_1 . If all rows of T_1 are still different, there is nothing to prove. If not, remove those rows of T , which repeat, leaving in a new table T_2 the rows of T_1 without repetitions. The table T_2 has $k \leq m - 1$ rows and at least $m - 1$ columns. We use induction hypothesis to find a column that can be removed leaving all rows different. This column can be also removed from the original table T .

2. 22 points are chosen from the 7×7 grid of points (i, j) , where $1 \leq i \leq 7$ and $1 \leq j \leq 7$. Prove that four of the chosen points are the vertices of a rectangle with horizontal and vertical sides. Show that this might not be the case, if 21 vertices are chosen.

Solution: Let n_i be the number of points chosen from row i . Then

$$\sum_{i=1}^7 \binom{n_i}{2} = \sum_{i=1}^7 \frac{n_i(n_i - 1)}{2} \geq 7 \frac{\binom{22}{7} - 1}{2} = 23\frac{4}{7}$$

by Jensen's inequality. (The function $f(x) = x(x - 1)/2$ is convex.) Since $23\frac{4}{7} > 21 = \binom{7}{2}$, the desired rectangle exists.

The following set of 21 points do not satisfy the property:

$$\begin{array}{ccccccc} (1, 1) & (1, 2) & (1, 3) & (2, 3) & (2, 4) & (2, 5) & (3, 1) \\ (3, 5) & (3, 6) & (4, 1) & (4, 4) & (4, 7) & (5, 2) & (5, 5) \\ (5, 7) & (6, 3) & (6, 6) & (6, 7) & (7, 2) & (7, 4) & (7, 6). \end{array}$$

3. Prove that for $n \geq 5$, every graph with n vertices and $\lfloor n^2/4 \rfloor + 2$ edges contains a bowtie (i.e., two triangles with exactly one vertex in common).

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Wolfgang Guggemos



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Table of Contents Olympiad Combinatorics Problems Solutions

1. Understanding the eBook Olympiad Combinatorics Problems Solutions
 - The Rise of Digital Reading Olympiad Combinatorics Problems Solutions
 - Advantages of eBooks Over Traditional Books
2. Identifying Olympiad Combinatorics Problems Solutions
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Olympiad Combinatorics Problems Solutions
 - User-Friendly Interface
4. Exploring eBook Recommendations from Olympiad Combinatorics Problems Solutions
 - Personalized Recommendations
 - Olympiad Combinatorics Problems Solutions User Reviews and Ratings
 - Olympiad Combinatorics Problems Solutions and Bestseller Lists

5. Accessing Olympiad Combinatorics Problems Solutions Free and Paid eBooks
 - Olympiad Combinatorics Problems Solutions Public Domain eBooks
 - Olympiad Combinatorics Problems Solutions eBook Subscription Services
 - Olympiad Combinatorics Problems Solutions Budget-Friendly Options
6. Navigating Olympiad Combinatorics Problems Solutions eBook Formats
 - ePub, PDF, MOBI, and More
 - Olympiad Combinatorics Problems Solutions Compatibility with Devices
 - Olympiad Combinatorics Problems Solutions Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Olympiad Combinatorics Problems Solutions
 - Highlighting and Note-Taking Olympiad Combinatorics Problems Solutions
 - Interactive Elements Olympiad Combinatorics Problems Solutions
8. Staying Engaged with Olympiad Combinatorics Problems Solutions
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Olympiad Combinatorics Problems Solutions
9. Balancing eBooks and Physical Books Olympiad Combinatorics Problems Solutions
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Olympiad Combinatorics Problems Solutions
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Olympiad Combinatorics Problems Solutions
 - Setting Reading Goals Olympiad Combinatorics Problems Solutions
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Olympiad Combinatorics Problems Solutions
 - Fact-Checking eBook Content of Olympiad Combinatorics Problems Solutions
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
- Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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