Canada National Olympiad 2014

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1 Let $a_1, a_2, \ldots, a_n$ be positive real numbers whose product is 1. Show that the sum

$$\frac{a_1}{1+a_1}+\frac{a_2}{(1+a_1)(1+a_2)}+\frac{a_3}{(1+a_1)(1+a_2)(1+a_3)}+\cdots+\frac{a_n}{(1+a_1)(1+a_2)\cdots(1+a_n)}$$

is greater than or equal to $\frac{2^n-1}{2^n}$.

2 Let m and n be odd positive integers. Each square of an m by n board is coloured red or blue. A row is said to be red-dominated if there are more red squares than blue squares in the row. A column is said to be blue-dominated if there are more blue squares than red squares in the column. Determine the maximum possible value of the number of red-dominated rows plus the number of blue-dominated columns. Express your answer in terms of m and n.

3 Let p be a fixed odd prime. A p-tuple $(a_1, a_2, a_3, \ldots, a_p)$ of integers is said to be *good* if

- **(i)** $0 \le a_i \le p-1$ for all i, and
- **(ii)** $a_1+a_2+a_3+\cdots+a_p$ is not divisible by p, and
- **(iii)** $a_1a_2+a_2a_3+a_3a_4+\cdots+a_pa_1$ is divisible by p.

Determine the number of good p-tuples.

4 The quadrilateral $ABCD$ is inscribed in a circle. The point P lies in the interior of $ABCD$, and $\angle PAB = \angle PBC = \angle PCD = \angle PDA$. The lines AD and BC meet at Q, and the lines AB and CD meet at R. Prove that the lines PQ and PR form the same angle as the diagonals of $ABCD$.

5 Fix positive integers n and $k \ge 2$. A list of n integers is written in a row on a blackboard. You can choose a contiguous block of integers, and I will either add 1 to all of them or subtract 1 from all of them. You can repeat this step as often as you like, possibly adapting your selections based on what I do. Prove that after a finite number of steps, you can reach a state where at least $n-k+2$ of the numbers on the blackboard are all simultaneously divisible by k.