

Rajeev Atla

~~Settlers of Catan~~ A board game is played on a hexagonal grid of 19 tiles. A 'traveler' token starts on the center tile. Each turn a die is rolled to determine what neighboring tile the traveler moves to (all six directions equally likely). The turn that the traveler leaves the board, the game ends. What is the expected number of turns of the game?

A hexagonal grid of 19 cells, numbered 0 to 18. Cell 0 is the central cell. Cells 1 through 6 form a ring around cell 0. Cells 7 through 18 form an outer ring. Each cell contains a red dot and a number. The grid is surrounded by 19 green dots, numbered 20 through 38, each positioned adjacent to a cell in the outer ring.

We wish to find the expected value of the number of turns in the game, which we denote N .

The dice is truly random, so there is no upper bound on N . We note that this game is really akin to a Markov chain, in that it doesn't matter what the past states are.

Let $X_i \in [0, 36]$ be the current state, or position of the traveler. The traveler always starts at position $X_0 = 0$. The final state must be $X_N \in [19, 36]$.

Now that we've defined some notation, we can write the transition matrix P . Because a 37×37 matrix is cumbersome, we combine the states $[19, 36]$ into a

$$P = \begin{pmatrix} p_{0,0}=0 & p_{0,1}=\frac{1}{6} & p_{0,2}=\frac{1}{6} & p_{0,3}=\frac{1}{6} & p_{0,4}=\frac{1}{6} & p_{0,5}=\frac{1}{6} & p_{0,6}=\frac{1}{6} & p_{0,7}=0 & p_{0,8}=0 & p_{0,9}=0 & p_{0,10}=0 & p_{0,11}=0 & p_{0,12}=0 & p_{0,13}=0 & p_{0,14}=0 & p_{0,15}=0 & p_{0,16}=0 & p_{0,17}=0 & p_{0,18}=0 & p_{0,19}=0 \\ p_{1,0}=\frac{1}{6} & p_{1,1}=0 & p_{1,2}=\frac{1}{6} & p_{1,3}=0 & p_{1,4}=0 & p_{1,5}=0 & p_{1,6}=\frac{1}{6} & p_{1,7}=\frac{1}{6} & p_{1,8}=\frac{1}{6} & p_{1,9}=\frac{1}{6} & p_{1,10}=0 & p_{1,11}=0 & p_{1,12}=0 & p_{1,13}=0 & p_{1,14}=0 & p_{1,15}=0 & p_{1,16}=0 & p_{1,17}=0 & p_{1,18}=0 & p_{1,19}=0 \\ p_{2,0}=0 & p_{2,1}=\frac{1}{6} & p_{2,2}=0 & p_{2,3}=\frac{1}{6} & p_{2,4}=0 & p_{2,5}=0 & p_{2,6}=0 & p_{2,7}=0 & p_{2,8}=0 & p_{2,9}=\frac{1}{6} & p_{2,10}=\frac{1}{6} & p_{2,11}=\frac{1}{6} & p_{2,12}=0 & p_{2,13}=0 & p_{2,14}=0 & p_{2,15}=0 & p_{2,16}=0 & p_{2,17}=0 & p_{2,18}=0 & p_{2,19}=0 \\ p_{3,0}=\frac{1}{6} & p_{3,1}=0 & p_{3,2}=\frac{1}{6} & 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$$Q = \begin{pmatrix} P_{0,0} = 0 & P_{0,1} = \frac{1}{6} & P_{0,2} = \frac{1}{6} & P_{0,3} = \frac{1}{6} & P_{0,4} = \frac{1}{6} & P_{0,5} = \frac{1}{6} & P_{0,6} = \frac{1}{6} & P_{0,7} = 0 & P_{0,8} = 0 & P_{0,9} = 0 & P_{0,10} = 0 & P_{0,11} = 0 & P_{0,12} = 0 & P_{0,13} = 0 & P_{0,14} = 0 & P_{0,15} = 0 & P_{0,16} = 0 & P_{0,17} = 0 & P_{0,18} = 0 \\ P_{1,0} = \frac{1}{6} & P_{1,1} = 0 & P_{1,2} = 0 & P_{1,3} = 0 & P_{1,4} = 0 & P_{1,5} = 0 & P_{1,6} = \frac{1}{6} & P_{1,7} = \frac{1}{6} & P_{1,8} = \frac{1}{6} & P_{1,9} = \frac{1}{6} & P_{1,10} = 0 & P_{1,11} = 0 & P_{1,12} = 0 & P_{1,13} = 0 & P_{1,14} = 0 & P_{1,15} = 0 & P_{1,16} = 0 & P_{1,17} = 0 & P_{1,18} = 0 \\ P_{2,0} = \frac{1}{6} & P_{2,1} = \frac{1}{6} & P_{2,2} = 0 & P_{2,3} = \frac{1}{6} & P_{2,4} = 0 & P_{2,5} = 0 & P_{2,6} = 0 & P_{2,7} = 0 & P_{2,8} = 0 & P_{2,9} = \frac{1}{6} & P_{2,10} = \frac{1}{6} & P_{2,11} = \frac{1}{6} & P_{2,12} = 0 & P_{2,13} = 0 & P_{2,14} = 0 & P_{2,15} = 0 & P_{2,16} = 0 & P_{2,17} = 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= \frac{1}{6} & P_{15,6} = 0 & P_{15,7} = 0 & P_{15,8} = 0 & P_{15,9} = 0 & P_{$$

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$P_{0,0} = 45$	$P_{0,1} = 16$	$P_{0,2} = 3456$	$P_{0,3} = 16$	$P_{0,4} = 106714$	$P_{0,5} = 16$	$P_{0,6} = 17222$	$P_{0,7} = 16$	$P_{0,8} = 7$	$P_{0,9} = 5$	$P_{0,10} = 5$	$P_{0,11} = 7$	$P_{0,12} = 5$	$P_{0,13} = 7$	$P_{0,14} = 5$	$P_{0,15} = 7$	$P_{0,16} = 5$	$P_{0,17} = 7$	$P_{0,18} = 5$
$P_{1,0} = 16$	$P_{1,1} = 16$	$P_{1,2} = 3456$	$P_{1,3} = 16$	$P_{1,4} = 106714$	$P_{1,5} = 16$	$P_{1,6} = 17222$	$P_{1,7} = 16$	$P_{1,8} = 7$	$P_{1,9} = 5$	$P_{1,10} = 5$	$P_{1,11} = 7$	$P_{1,12} = 5$	$P_{1,13} = 7$	$P_{1,14} = 5$	$P_{1,15} = 7$	$P_{1,16} = 5$	$P_{1,17} = 7$	$P_{1,18} = 5$
$P_{2,0} = 16$	$P_{2,1} = 16$	$P_{2,2} = 3456$	$P_{2,3} = 16$	$P_{2,4} = 106714$	$P_{2,5} = 16$	$P_{2,6} = 17222$	$P_{2,7} = 16$	$P_{2,8} = 7$	$P_{2,9} = 5$	$P_{2,10} = 5$	$P_{2,11} = 7$	$P_{2,12} = 5$	$P_{2,13} = 7$	$P_{2,14} = 5$	$P_{2,15} = 7$	$P_{2,16} = 5$	$P_{2,17} = 7$	$P_{2,18} = 5$
$P_{3,0} = 16$	$P_{3,1} = 16$	$P_{3,2} = 3456$	$P_{3,3} = 16$	$P_{3,4} = 106714$	$P_{3,5} = 16$	$P_{3,6} = 17222$	$P_{3,7} = 16$	$P_{3,8} = 7$	$P_{3,9} = 5$	$P_{3,10} = 5$	$P_{3,11} = 7$	$P_{3,12} = 5$	$P_{3,13} = 7$	$P_{3,14} = 5$	$P_{3,15} = 7$	$P_{3,16} = 5$	$P_{3,17} = 7$	$P_{3,18} = 5$
$P_{4,0} = 16$	$P_{4,1} = 16$	$P_{4,2} = 3456$	$P_{4,3} = 16$	$P_{4,4} = 106714$	$P_{4,5} = 16$	$P_{4,6} = 17222$	$P_{4,7} = 16$	$P_{4,8} = 7$	$P_{4,9} = 5$	$P_{4,10} = 5$	$P_{4,11} = 7$	$P_{4,12} = 5$	$P_{4,13} = 7$	$P_{4,14} = 5$	$P_{4,15} = 7$	$P_{4,16} = 5$	$P_{4,17} = 7$	$P_{4,18} = 5$
$P_{5,0} = 16$	$P_{5,1} = 16$	$P_{5,2} = 3456$	$P_{5,3} = 16$	$P_{5,4} = 106714$	$P_{5,5} = 16$	$P_{5,6} = 17222$	$P_{5,7} = 16$	$P_{5,8} = 7$	$P_{5,9} = 5$	$P_{5,10} = 5$	$P_{5,11} = 7$	$P_{5,12} = 5$	$P_{5,13} = 7$	$P_{5,14} = 5$	$P_{5,15} = 7$	$P_{5,16} = 5$	$P_{5,17} = 7$	$P_{5,18} = 5$
$P_{6,0} = 16$	$P_{6,1} = 16$	$P_{6,2} = 3456$	$P_{6,3} = 16$	$P_{6,4} = 106714$	$P_{6,5} = 16$	$P_{6,6} = 17222$	$P_{6,7} = 16$	$P_{6,8} = 7$	$P_{6,9} = 5$	$P_{6,10} = 5$	$P_{6,11} = 7$	$P_{6,12} = 5$	$P_{6,13} = 7$	$P_{6,14} = 5$	$P_{6,15} = 7$	$P_{6,16} = 5$	$P_{6,17} = 7$	$P_{6,18} = 5$
$P_{7,0} = 16$	$P_{7,1} = 16$	$P_{7,2} = 3456$	$P_{7,3} = 16$	$P_{7,4} = 106714$	$P_{7,5} = 16$	$P_{7,6} = 17222$	$P_{7,7} = 16$	$P_{7,8} = 7$	$P_{7,9} = 5$	$P_{7,10} = 5$	$P_{7,11} = 7$	$P_{7,12} = 5$	$P_{7,13} = 7$	$P_{7,14} = 5$	$P_{7,15} = 7$	$P_{7,16} = 5$	$P_{7,17} = 7$	$P_{7,18} = 5$
$P_{8,0} = 16$	$P_{8,1} = 16$	$P_{8,2} = 3456$	$P_{8,3} = 16$	$P_{8,4} = 106714$	$P_{8,5} = 16$	$P_{8,6} = 17222$	$P_{8,7} = 16$	$P_{8,8} = 7$	$P_{8,9} = 5$	$P_{8,10} = 5$	$P_{8,11} = 7$	$P_{8,12} = 5$	$P_{8,13} = 7$	$P_{8,14} = 5$	$P_{8,15} = 7$	$P_{8,16} = 5$	$P_{8,17} = 7$	$P_{8,18} = 5$
$P_{9,0} = 16$	$P_{9,1} = 16$	$P_{9,2} = 3456$	$P_{9,3} = 16$	$P_{9,4} = 106714$	$P_{9,5} = 16$	$P_{9,6} = 17222$	$P_{9,7} = 16$	$P_{9,8} = 7$	$P_{9,9} = 5$	$P_{9,10} = 5$	$P_{9,11} = 7$	$P_{9,12} = 5$	$P_{9,13} = 7$	$P_{9,14} = 5$	$P_{9,15} = 7$	$P_{9,16} = 5$	$P_{9,17} = 7$	$P_{9,18} = 5$
$P_{10,0} = 16$	$P_{10,1} = 16$	$P_{10,2} = 3456$	$P_{10,3} = 16$	$P_{10,4} = 106714$	$P_{10,5} = 16$	$P_{10,6} = 17222$	$P_{10,7} = 16$	$P_{10,8} = 7$	$P_{10,9} = 5$	$P_{10,10} = 5$	$P_{10,11} = 7$	$P_{10,12} = 5$	$P_{10,13} = 7$	$P_{10,14} = 5$	$P_{10,15} = 7$	$P_{10,16} = 5$	$P_{10,17} = 7$	$P_{10,18} = 5$
$P_{11,0} = 16$	$P_{11,1} = 16$	$P_{11,2} = 3456$	$P_{11,3} = 16$	$P_{11,4} = 106714$	$P_{11,5} = 16$	$P_{11,6} = 17222$												

$$t \equiv N\mathbf{1}$$
[illegible]

Finally, we see that $t_0 = \boxed{\frac{213}{29} \approx 7.345}$