

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?

The diagram shows a hexagonal lattice structure. The central cell is labeled 0. The cells are numbered 0 through 18. The vertices are numbered 19 through 37. The vertices are labeled with green dots and numbers. The cells are labeled with red dots and numbers.

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  $37 \times 37$  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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$\rho_{0,0} = 45$	$\rho_{0,1} = 16$	$\rho_{0,2} = 16$	$\rho_{0,3} = 16$	$\rho_{0,4} = 16$	$\rho_{0,5} = 16$	$\rho_{0,6} = 16$	$\rho_{0,7} = 7$	$\rho_{0,8} = 5$	$\rho_{0,9} = 7$	$\rho_{0,10} = 5$	$\rho_{0,11} = 7$	$\rho_{0,12} = 5$	$\rho_{0,13} = 7$	$\rho_{0,14} = 5$	$\rho_{0,15} = 7$	$\rho_{0,16} = 5$	$\rho_{0,17} = 7$	$\rho_{0,18} = 5$
$\rho_{1,0} = 34566$	$\rho_{1,1} = 107744$	$\rho_{1,2} = 34566$	$\rho_{1,3} = 107744$	$\rho_{1,4} = 34566$	$\rho_{1,5} = 107744$	$\rho_{1,6} = 34566$	$\rho_{1,7} = 14400$	$\rho_{1,8} = 22480$	$\rho_{1,9} = 14400$	$\rho_{1,10} = 22480$	$\rho_{1,11} = 14400$	$\rho_{1,12} = 22480$	$\rho_{1,13} = 14400$	$\rho_{1,14} = 22480$	$\rho_{1,15} = 14400$	$\rho_{1,16} = 22480$	$\rho_{1,17} = 14400$	$\rho_{1,18} = 22480$
$\rho_{2,0} = 115680$	$\rho_{2,1} = 34566$	$\rho_{2,2} = 115680$	$\rho_{2,3} = 34566$	$\rho_{2,4} = 115680$	$\rho_{2,5} = 34566$	$\rho_{2,6} = 115680$	$\rho_{2,7} = 14400$	$\rho_{2,8} = 22480$	$\rho_{2,9} = 14400$	$\rho_{2,10} = 22480$	$\rho_{2,11} = 14400$	$\rho_{2,12} = 22480$	$\rho_{2,13} = 14400$	$\rho_{2,14} = 22480$	$\rho_{2,15} = 14400$	$\rho_{2,16} = 22480$	$\rho_{2,17} = 14400$	$\rho_{2,18} = 22480$
$\rho_{3,0} = 34566$	$\rho_{3,1} = 107744$	$\rho_{3,2} = 34566$	$\rho_{3,3} = 107744$	$\rho_{3,4} = 34566$	$\rho_{3,5} = 107744$	$\rho_{3,6} = 34566$	$\rho_{3,7} = 14400$	$\rho_{3,8} = 22480$	$\rho_{3,9} = 14400$	$\rho_{3,10} = 22480$	$\rho_{3,11} = 14400$	$\rho_{3,12} = 22480$	$\rho_{3,13} = 14400$	$\rho_{3,14} = 22480$	$\rho_{3,15} = 14400$	$\rho_{3,16} = 22480$	$\rho_{3,17} = 14400$	$\rho_{3,18} = 22480$
$\rho_{4,0} = 115680$	$\rho_{4,1} = 34566$	$\rho_{4,2} = 115680$	$\rho_{4,3} = 34566$	$\rho_{4,4} = 115680$	$\rho_{4,5} = 34566$	$\rho_{4,6} = 115680$	$\rho_{4,7} = 14400$	$\rho_{4,8} = 22480$	$\rho_{4,9} = 14400$	$\rho_{4,10} = 22480$	$\rho_{4,11} = 14400$	$\rho_{4,12} = 22480$	$\rho_{4,13} = 14400$	$\rho_{4,14} = 22480$	$\rho_{4,15} = 14400$	$\rho_{4,16} = 22480$	$\rho_{4,17} = 14400$	$\rho_{4,18} = 22480$
$\rho_{5,0} = 34566$	$\rho_{5,1} = 107744$	$\rho_{5,2} = 34566$	$\rho_{5,3} = 107744$	$\rho_{5,4} = 34566$	$\rho_{5,5} = 107744$	$\rho_{5,6} = 34566$	$\rho_{5,7} = 14400$	$\rho_{5,8} = 22480$	$\rho_{5,9} = 14400$	$\rho_{5,10} = 22480$	$\rho_{5,11} = 14400$	$\rho_{5,12} = 22480$	$\rho_{5,13} = 14400$	$\rho_{5,14} = 22480$	$\rho_{5,15} = 14400$	$\rho_{5,16} = 22480$	$\rho_{5,17} = 14400$	$\rho_{5,18} = 22480$
$\rho_{6,0} = 115680$	$\rho_{6,1} = 34566$	$\rho_{6,2} = 115680$	$\rho_{6,3} = 34566$	$\rho_{6,4} = 115680$	$\rho_{6,5} = 34566$	$\rho_{6,6} = 115680$	$\rho_{6,7} = 14400$	$\rho_{6,8} = 22480$	$\rho_{6,9} = 14400$	$\rho_{6,10} = 22480$	$\rho_{6,11} = 14400$	$\rho_{6,12} = 22480$	$\rho_{6,13} = 14400$	$\rho_{6,14} = 22480$	$\rho_{6,15} = 14400$	$\rho_{6,16} = 22480$	$\rho_{6,17} = 14400$	$\rho_{6,18} = 22480$
$\rho_{7,0} = 34566$	$\rho_{7,1} = 107744$	$\rho_{7,2} = 34566$	$\rho_{7,3} = 107744$	$\rho_{7,4} = 34566$	$\rho_{7,5} = 107744$	$\rho_{7,6} = 34566$	$\rho_{7,7} = 14400$	$\rho_{7,8} = 22480$	$\rho_{7,9} = 14400$	$\rho_{7,10} = 22480$	$\rho_{7,11} = 14400$	$\rho_{7,12} = 22480$	$\rho_{7,13} = 14400$	$\rho_{7,14} = 22480$	$\rho_{7,15} = 14400$	$\rho_{7,16} = 22480$	$\rho_{7,17} = 14400$	$\rho_{7,18} = 22480$
$\rho_{8,0} = 115680$	$\rho_{8,1} = 34566$	$\rho_{8,2} = 115680$	$\rho_{8,3} = 34566$	$\rho_{8,4} = 115680$	$\rho_{8,5} = 34566$	$\rho_{8,6} = 115680$	$\rho_{8,7} = 14400$	$\rho_{8,8} = 22480$	$\rho_{8,9} = 14400$	$\rho_{8,10} = 22480$	$\rho_{8,11} = 14400$	$\rho_{8,12} = 22480$	$\rho_{8,13} = 14400$	$\rho_{8,14} = 22480$	$\rho_{8,15} = 14400$	$\rho_{8,16} = 22480$	$\rho_{8,17} = 14400$	$\rho_{8,18} = 22480$
$\rho_{9,0} = 34566$	$\rho_{9,1} = 107744$	$\rho_{9,2} = 34566$	$\rho_{9,3} = 107744$	$\rho_{9,4} = 34566$	$\rho_{9,5} = 107744$	$\rho_{9,6} = 34566$	$\rho_{9,7} = 14400$	$\rho_{9,8} = 22480$	$\rho_{$									

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

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