

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 diagram of a hexagonal lattice with 36 numbered cells. The cells are arranged in a honeycomb pattern. Each cell contains a number from 0 to 35. The cells are colored: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36. The cells are arranged in a hexagonal pattern with 6 cells in the center and 30 cells on the outer boundary. The numbers are arranged in a specific pattern that suggests a sequence or a mapping.

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

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

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

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