

$\mathbb{R}^n$  Bonus Problem #3

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## §1 Problem

~~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?

## §2 Diagram



## §3 Solution

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

$$\mathbb{E}(N) = \sum N \mathbb{P}(N)$$

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  $37 \times 37$  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} & 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}=\frac{1}{6} & p_{4,13}=\frac{1}{6} & p_{4,14}=\frac{1}{6} & p_{4,15}=0 & 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 & p_{6,7}=\frac{1}{6} & p_{6,8}=0 & p_{6,9}=0 & p_{6,10}=0 & p_{6,11}=0 & p_{6,12}=0 & p_{6,13}=0 & p_{6,14}=0 & p_{6,15}=0 & p_{6,16}=0 & p_{6,17}=\frac{1}{6} & p_{6,18}=\frac{1}{6} & p_{6,19}=0 \\ p_{7,0}=0 & p_{7,1}=\frac{1}{6} & p_{7,2}=0 & p_{7,3}=0 & p_{7,4}=0 & p_{7,5}=0 & p_{7,6}=\frac{1}{6} & p_{7,7}=0 & p_{7,8}=\frac{1}{6} & p_{7,9}=0 & p_{7,10}=0 & p_{7,11}=0 & p_{7,12}=0 & p_{7,13}=0 & p_{7,14}=0 & p_{7,15}=0 & p_{7,16}=0 & p_{7,17}=0 & p_{7,18}=\frac{1}{6} & p_{7,19}=\frac{1}{6} \\ p_{8,0}=0 & p_{8,1}=\frac{1}{6} & p_{8,2}=0 & p_{8,3}=0 & p_{8,4}=0 & p_{8,5}=0 & p_{8,6}=0 & p_{8,7}=\frac{1}{6} & p_{8,8}=0 & p_{8,9}=\frac{1}{6} & p_{8,10}=0 & p_{8,11}=0 & p_{8,12}=0 & p_{8,13}=0 & p_{8,14}=0 & p_{8,15}=0 & p_{8,16}=0 & p_{8,17}=0 & p_{8,18}=0 & p_{8,19}=\frac{1}{6} \\ p_{9,0}=0 & p_{9,1}=\frac{1}{6} & p_{9,2}=\frac{1}{6} & p_{9,3}=0 & p_{9,4}=0 & p_{9,5}=0 & p_{9,6}=0 & p_{9,7}=0 & p_{9,8}=\frac{1}{6} & p_{9,9}=0 & p_{9,10}=\frac{1}{6} & p_{9,11}=0 & p_{9,12}=0 & p_{9,13}=0 & p_{9,14}=0 & p_{9,15}=0 & p_{9,16}=0 & p_{9,17}=0 & p_{9,18}=0 & p_{9,19}=\frac{1}{6} \\ p_{10,0}=0 & p_{10,1}=0 & p_{10,2}=\frac{1}{6} & p_{10,3}=0 & p_{10,4}=0 & p_{10,5}=0 & p_{10,6}=0 & p_{10,7}=0 & p_{10,8}=0 & p_{10,9}=\frac{1}{6} & p_{10,10}=0 & p_{10,11}=\frac{1}{6} & p_{10,12}=0 & p_{10,13}=0 & p_{10,14}=0 & p_{10,15}=0 & p_{10,16}=0 & p_{10,17}=0 & p_{10,18}=0 & p_{10,19}=\frac{1}{6} \\ p_{11,0}=0 & p_{11,1}=0 & p_{11,2}=\frac{1}{6} & p_{11,3}=\frac{1}{6} & p_{11,4}=0 & p_{11,5}=0 & p_{11,6}=0 & p_{11,7}=0 & p_{11,8}=0 & p_{11,9}=0 & p_{11,10}=\frac{1}{6} & p_{11,11}=0 & p_{11,12}=\frac{1}{6} & p_{11,13}=0 & p_{11,14}=0 & p_{11,15}=0 & p_{11,16}=0 & p_{11,17}=0 & p_{11,18}=0 & p_{11,19}=\frac{1}{6} \\ p_{12,0}=0 & p_{12,1}=0 & p_{12,2}=0 & p_{12,3}=\frac{1}{6} & p_{12,4}=0 & p_{12,5}=0 & p_{12,6}=0 & p_{12,7}=0 & p_{12,8}=0 & p_{12,9}=0 & p_{12,10}=\frac{1}{6} & p_{12,11}=\frac{1}{6} & p_{12,12}=0 & p_{12,13}=\frac{1}{6} & p_{12,14}=0 & p_{12,15}=0 & p_{12,16}=0 & p_{12,17}=0 & p_{12,18}=0 & p_{12,19}=\frac{1}{6} \\ p_{13,0}=0 & p_{13,1}=0 & p_{13,2}=0 & p_{13,3}=\frac{1}{6} & p_{13,4}=\frac{1}{6} & p_{13,5}=0 & p_{13,6}=0 & p_{13,7}=0 & p_{13,8}=0 & p_{13,9}=0 & p_{13,10}=0 & p_{13,11}=0 & p_{13,12}=\frac{1}{6} & p_{13,13}=0 & p_{13,14}=\frac{1}{6} & p_{13,15}=0 & p_{13,16}=0 & p_{13,17}=0 & p_{13,18}=0 & p_{13,19}=\frac{1}{6} \\ p_{14,0}=0 & p_{14,1}=0 & p_{14,2}=0 & p_{14,3}=0 & p_{14,4}=\frac{1}{6} & p_{14,5}=0 & p_{14,6}=0 & p_{14,7}=0 & p_{14,8}=0 & p_{14,9}=0 & p_{14,10}=0 & p_{14,11}=0 & p_{14,12}=0 & p_{14,13}=\frac{1}{6} & p_{14,14}=0 & p_{14,15}=\frac{1}{6} & p_{14,16}=0 & p_{14,17}=0 & p_{14,18}=0 & p_{14,19}=\frac{1}{6} \\ p_{15,0}=0 & p_{15,1}=0 & p_{15,2}=0 & p_{15,3}=0 & p_{15,4}=\frac{1}{6} & p_{15,5}=\frac{1}{6} & p_{15,6}=\frac{1}{6} & p_{15,7}=0 & p_{15,8}=0 & p_{15,9}=0 & p_{15,10}=0 & p_{15,11}=0 & p_{15,12}=0 & p_{15,13}=0 & p_{15,14}=\frac{1}{6} & p_{15,15}=\frac{1}{6} & p_{15,16}=\frac{1}{6} & p_{15,17}=0 & p_{15,18}=0 & p_{15,19}=\frac{1}{6} \\ p_{16,0}=0 & p_{16,1}=0 & p_{16,2}=0 & p_{16,3}=0 & p_{16,4}=0 & p_{16,5}=\frac{1}{6} & p_{16,6}=0 & p_{16,7}=0 & p_{16,8}=0 & p_{16,9}=0 & p_{16,10}=$$

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

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$$N = \begin{array}{c} \begin{array}{c} P_{0,0} = \frac{45}{16} \\ P_{0,1} = \frac{3456}{16} \\ P_{0,2} = \frac{10714}{16} \\ P_{0,3} = \frac{19198}{16} \\ P_{0,4} = \frac{24999}{16} \\ P_{0,5} = \frac{29799}{16} \\ P_{0,6} = \frac{33599}{16} \\ P_{0,7} = \frac{36399}{16} \\ P_{0,8} = \frac{38199}{16} \\ P_{0,9} = \frac{39099}{16} \\ P_{0,10} = \frac{39599}{16} \\ P_{0,11} = \frac{39799}{16} \\ P_{0,12} = \frac{39899}{16} \\ P_{0,13} = \frac{39999}{16} \\ P_{0,14} = \frac{40099}{16} \\ P_{0,15} = \frac{40199}{16} \\ P_{0,16} = \frac{40299}{16} \\ P_{0,17} = \frac{40399}{16} \\ P_{0,18} = \frac{40499}{16} \\ P_{0,19} = \frac{40599}{16} \\ P_{0,20} = \frac{40699}{16} \\ P_{0,21} = \frac{40799}{16} \\ P_{0,22} = \frac{40899}{16} \\ P_{0,23} = \frac{40999}{16} \\ P_{0,24} = \frac{41099}{16} \\ P_{0,25} = \frac{41199}{16} \\ P_{0,26} = \frac{41299}{16} \\ P_{0,27} = \frac{41399}{16} \\ P_{0,28} = \frac{41499}{16} \\ P_{0,29} = \frac{41599}{16} \\ P_{0,30} = \frac{41699}{16} \\ P_{0,31} = \frac{41799}{16} \\ P_{0,32} = \frac{41899}{16} \\ P_{0,33} = \frac{41999}{16} \\ P_{0,34} = \frac{42099}{16} \\ P_{0,35} = \frac{42199}{16} \\ P_{0,36} = \frac{42299}{16} \\ P_{0,37} = \frac{42399}{16} \\ P_{0,38} = \frac{42499}{16} \\ P_{0,39} = \frac{42599}{16} \\ P_{0,40} = \frac{42699}{16} \\ P_{0,41} = \frac{42799}{16} \\ P_{0,42} = \frac{42899}{16} \\ P_{0,43} = \frac{42999}{16} \\ P_{0,44} = \frac{43099}{16} \\ P_{0,45} = \frac{43199}{16} \\ P_{0,46} = \frac{43299}{16} \\ P_{0,47} = \frac{43399}{16} \\ P_{0,48} = \frac{43499}{16} \\ P_{0,49} = \frac{43599}{16} \\ P_{0,50} = \frac{43699}{16} \\ P_{0,51} = \frac{43799}{16} \\ P_{0,52} = \frac{43899}{16} \\ P_{0,53} = \frac{43999}{16} \\ P_{0,54} = \frac{44099}{16} \\ P_{0,55} = \frac{44199}{16} \\ P_{0,56} = \frac{44299}{16} \\ P_{0,57} = \frac{44399}{16} \\ P_{0,58} = \frac{44499}{16} \\ P_{0,59} = \frac{44599}{16} \\ P_{0,60} = \frac{44699}{16} \\ P_{0,61} = \frac{44799}{16} \\ P_{0,62} = \frac{44899}{16} \\ P_{0,63} = \frac{44999}{16} \\ P_{0,64} = \frac{45099}{16} \\ P_{0,65} = \frac{45199}{16} \\ P_{0,66} = \frac{45299}{16} \\ P_{0,67} = \frac{45399}{16} \\ P_{0,68} = \frac{45499}{16} \\ P_{0,69} = \frac{45599}{16} \\ P_{0,70} = \frac{45699}{16} \\ P_{0,71} = \frac{45799}{16} \\ P_{0,72} = \frac{45899}{16} \\ P_{0,73} = \frac{45999}{16} \\ P_{0,74} = \frac{46099}{16} \\ P_{0,75} = \frac{46199}{16} \\ P_{0,76} = \frac{46299}{16} \\ P_{0,77} = \frac{46399}{16} \\ P_{0,78} = \frac{46499}{16} \\ P_{0,79} = \frac{46599}{16} \\ P_{0,80} = \frac{46699}{16} \\ P_{0,81} = \frac{46799}{16} \\ P_{0,82} = \frac{46899}{16} \\ P_{0,83} = \frac{46999}{16} \\ P_{0,84} = \frac{47099}{16} \\ P_{0,85} = \frac{47199}{16} \\ P_{0,86} = \frac{47299}{16} \\ P_{0,87} = \frac{47399}{16} \\ P_{0,88} = \frac{47499}{16} \\ P_{0,89} = \frac{47599}{16} \\ P_{0,90} = \frac{47699}{16} \\ P_{0,91} = \frac{47799}{16} \\ P_{0,92} = \frac{47899}{16} \\ P_{0,93} = \frac{47999}{16} \\ P_{0,94} = \frac{48099}{16} \\ P_{0,95} = \frac{48199}{16} \\ P_{0,96} = \frac{48299}{16} \\ P_{0,97} = \frac{48399}{16} \\ P_{0,98} = \frac{48499}{16} \\ P_{0,99} = \frac{48599}{16} \end{array} \end{array}$$

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

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