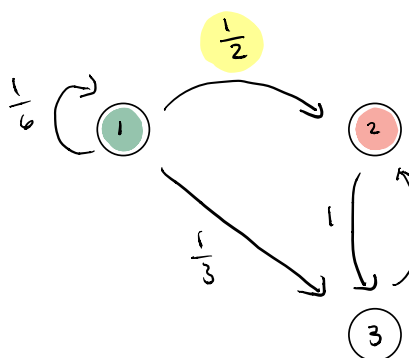


## Quick Review

A **Markov Chain** is a sequence of RVs  $X_1, \dots$  over a common **state space**  $\mathcal{X}$ , satisfying the **Markov Property**:

$$P[X_{n+1} = x_{n+1} | X_n = x_n] = P[X_{n+1} = x_{n+1} | X_n = x_n, X_{n-1} = x_{n-1}, \dots, X_0 = x_0]$$

- "Future is independent of the past given the present"
- Can also be described via a diagram + a **transition matrix**  $P$ :



$$P = \begin{matrix} & \begin{matrix} 1 & 2 & 3 \end{matrix} \\ \begin{matrix} 1 \\ 2 \\ 3 \end{matrix} & \begin{bmatrix} \frac{1}{6} & \frac{1}{2} & \frac{1}{3} \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix} \end{matrix}$$

$X_i$  describes location at time step  $i$

- Can describe an **initial distribution**  $\pi_0$  with a row vector of probabilities
- A **stationary distribution**  $\pi$  is a row vector of probabilities satisfying

$$\pi = \pi P$$



## 1 Markov Chain Basics

A Markov chain is a sequence of random variables  $X_n, n = 0, 1, 2, \dots$ . Here is one interpretation of a Markov chain:  $X_n$  is the state of a particle at time  $n$ . At each time step, the particle can jump to another state. Formally, a Markov chain satisfies the Markov property:

$$\mathbb{P}(X_{n+1} = j \mid X_n = i, X_{n-1} = i_{n-1}, \dots, X_0 = i_0) = \mathbb{P}(X_{n+1} = j \mid X_n = i), \quad (1)$$

for all  $n$ , and for all sequences of states  $i_0, \dots, i_{n-1}, i, j$ . In other words, the Markov chain does not have any memory; the transition probability only depends on the current state, and not the history of states that have been visited in the past.

(a) In lecture, we learned that we can specify Markov chains by providing three ingredients:  $\mathcal{X}$ ,  $P$ , and  $\pi_0$ . What do these represent, and what properties must they satisfy?

(b) If we specify  $\mathcal{X}$ ,  $P$ , and  $\pi_0$ , we are implicitly defining a sequence of random variables  $X_n, n = 0, 1, 2, \dots$ , that satisfies (1). Explain why this is true.

(c) Calculate  $\mathbb{P}(X_1 = j)$  in terms of  $\pi_0$  and  $P$ . Then, express your answer in matrix notation. What is the formula for  $\mathbb{P}(X_n = j)$  in matrix form?

## 2 Can it be a Markov Chain?

- (a) A fly flies in a straight line in unit-length increments. Each second it moves to the left with probability 0.3, right with probability 0.3, and stays put with probability 0.4. There are two spiders at positions 1 and  $m$  and if the fly lands in either of those positions it is captured. Given that the fly starts between positions 1 and  $m$ , model this process as a Markov Chain.
- (b) Take the same scenario as in the previous part with  $m = 4$ . Let  $Y_n = 0$  if at time  $n$  the fly is in position 1 or 2 and let  $Y_n = 1$  if at time  $n$  the fly is in position 3 or 4. Is the process  $Y_n$  a Markov chain?

## 3 Allen's Umbrella Setup

Every morning, Allen walks from his home to Soda, and every evening, Allen walks from Soda to his home. Suppose that Allen has two umbrellas in his possession, but he sometimes leaves his umbrellas behind. Specifically, before leaving from his home or Soda, he checks the weather. If it is raining outside, he will bring his umbrella (that is, if there is an umbrella where he currently is). If it is not raining outside, he will forget to bring his umbrella. Assume that the probability of rain is  $p$ .

- (a) Model this as a Markov chain. What is  $\mathcal{X}$ ? Write down the transition matrix.
- (b) What is the transition matrix after 2 trips?  $n$  trips? Determine if the distribution of  $X_n$  converges to the invariant distribution, and compute the invariant distribution. Determine the long-term fraction of time that Allen will walk through rain with no umbrella.