

## Exercise sheet 7: Markov chains

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### Exercise 1 - Up-to-date or Behind

Alex is taking a bioinformatics class and in each week he can be either up-to-date or he may have fallen behind. If he is up-to-date in a given week, the probability that he will be up-to-date in the next week is 0.75. If he is behind in the given week, the probability that he will be up-to-date in the next week is 0.5.

If we assume that these probabilities do not depend on whether he was up-to-date or behind in previous weeks, we can model the problem using a Markov chain.

1a)

Draw a Markov chain that models the states of being Up-to-date or behind

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Solution

1b)

Assume Alex is up-to-date in the first class; what is the probability that he is up-to-date two classes later?

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Hint : Formulae

$$\pi(0) : \text{initial probabilities} \tag{1}$$

$$P : \text{transition matrix} \tag{2}$$

$$\pi(t) = \pi(0) * P^t \tag{3}$$

**Solution** The Probability is 0.6875

$$\pi(0) = \begin{pmatrix} 1 & 0 \end{pmatrix} \quad (4)$$

$$(5)$$

$$P = \begin{pmatrix} 0.75 & 0.25 \\ 0.5 & 0.5 \end{pmatrix} \quad (6)$$

$$(7)$$

$$\pi(2) = \pi(0) \times P^2 \quad (8)$$

$$= \begin{pmatrix} 0.6875 & 0.3125 \end{pmatrix} \quad (9)$$

1c)

What is the expected probability that he is behind after an infinitely long semester?

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**Hint : Formulae**

$$\pi(0) : \text{initial probabilities} \quad (10)$$

$$P : \text{transition matrix} \quad (11)$$

$$\lim_{x \rightarrow \infty} \pi(t) = \pi(0) * P^t \quad (12)$$

**Solution** The Probability is 2/3

$$\lim_{t \rightarrow \infty} \pi(t) = \pi(0) * P^t = \begin{pmatrix} 2/3 & 1/3 \end{pmatrix}$$

1d)

What is the transition probability matrix product for limit of  $P^t$  as  $t$  approaches infinity?

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**Solution**

$$\lim_{t \rightarrow \infty} P^t = \begin{pmatrix} 2/3 & 1/3 \\ 2/3 & 1/3 \end{pmatrix} \quad (13)$$

## Exercise 2 - Stationary distribution

Consider a three-state Markov chain having the following transition probability matrix:

$$\begin{pmatrix} 0.5 & 0.4 & 0.1 \\ 0.3 & 0.4 & 0.3 \\ 0.2 & 0.3 & 0.5 \end{pmatrix}$$

2a)

In the long run, what proportion of time is the process in each of the three states?

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**Hint: Formulae** See Question 1B

**Correct Answer**

$$\lim_{x \rightarrow \infty} P^t = \begin{pmatrix} 0.339 & 0.371 & 0.290 \\ 0.339 & 0.371 & 0.290 \\ 0.339 & 0.371 & 0.290 \end{pmatrix} \quad (14)$$

(15)

$$\lim_{t \rightarrow \infty} \pi(t) = (0.339 \quad 0.371 \quad 0.290) \quad (16)$$

**Note**

$$\lim_{t \rightarrow \infty} \pi(t)$$

is independent of  $\pi(0)$  as long as  $P$  does not contain disconnected subgraphs and only if the limit exists.

## Exercise 3 - Reversibility

Consider a three-state Markov chain having the following transition probability matrix

$$\begin{pmatrix} 0 & 1 & 0 \\ \frac{1}{3} & 0 & \frac{2}{3} \\ 0 & 1 & 0 \end{pmatrix}$$

3a)

Draw the Markov chain for this problem

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**Solution**

**3b)**

Given the stationary distribution  $\left(\frac{1}{6} \quad \frac{1}{2} \quad \frac{1}{3}\right)$ , is this Markov chain reversible and what does this property tell you?

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**Hint** A markov chain is reversible if:

$$\pi_i^* P_{i,j} = \pi_j^* P_{j,i}$$

Easiest way is to calculate it for all pairs of  $i$  and  $j$

**Solution** Because  $\pi_i^* P_{i,j} = \pi_j^* P_{j,i} \forall i, j$  the Markov chain is reversible

$$\pi_1^* P_{1,2} = \frac{1}{6} \times 1 = \frac{1}{6} = \frac{1}{2} \times \frac{1}{3} = \pi_2^* P_{2,1} \quad (17)$$

$$\pi_1^* P_{1,3} = \frac{1}{6} \times 0 = 0 = \frac{1}{3} \times 0 = \pi_3^* P_{3,1} \quad (18)$$

$$\pi_2^* P_{2,3} = \frac{1}{2} \times \frac{2}{3} = \frac{1}{3} = \frac{1}{3} \times 1 = \pi_3^* P_{3,2} \quad (19)$$

## Exercise 4 - Markov chain representation

**4a)**

Decide which of the following figures represents a valid Markov Chain

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**Solution**

- ☒ i
- ☐ ii - initial probabilities add up to 0.2
- ☐ iii - transition probabilities for states A and B do not add up to 1
- ☐ iv - duplicate state A
- ☐ v - initial probabilities add up to 1.1
- ☒ vi
- ☐ vii missing transition probabilities (0.1) for state C

4b)

Which of these statements about Markov Chains are valid?

**Statements**

- ☐ In the graph representation of Markov chains, a single state cannot have more than 3 outgoing edges.
- ☐ In the matrix representation of Markov chains, rows have to add up to 1.
- ☐ In the matrix representation of Markov chains, columns have to add up to 1.
- ☐ The diagonal entries of the Markov chain matrix represent the transition probability of remaining in the current state.
- ☐ In the graph representation of Markov chains, a single state cannot have more than 3 ingoing edges.
- ☐ The graph representation of Markov chains is directed and acyclic by definition.

**Solution**

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