

The `markovchain` Package: A Package for Easily Handling Discrete Markov Chains in R

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Abstract

The `markovchain` package aims to fill a gap within the R framework providing S4 classes and methods for easily handling discrete time Markov chains, homogeneous and simple inhomogeneous ones as well as continuous time Markov chains. The S4 classes for handling and analysing discrete and continuous time Markov chains are presented, as well as functions and method for performing probabilistic and statistical analysis. Finally, some examples in which the package's functions are applied to Economics, Finance and Natural Sciences topics are shown.

Keywords: discrete time Markov chains, continuous time Markov chains, transition matrices, communicating classes, periodicity, first passage time, stationary distributions.

1. Introduction

Markov chains represent a class of stochastic processes of great interest for the wide spectrum of practical applications. In particular, discrete time Markov chains (DTMC) permit to model the transition probabilities between discrete states by the aid of matrices. Various R packages deal with models that are based on Markov chains:

- `msm` (Jackson 2011) handles Multi-State Models for panel data.
- `mcmcR` (Geyer and Johnson 2013) implements Monte Carlo Markov Chain approach.
- `hmm` (Himmelman and www.linhi.com 2010) fits hidden Markov models with covariates.
- `mstate` fits 'Multi-State Models based on Markov chains for survival analysis (de Wreede, Fiocco, and Putter 2011).

Nevertheless, the R statistical environment (R Core Team 2013) seems to lack a simple package that coherently defines S4 classes for discrete Markov chains and allows to perform probabilistic analysis, statistical inference and applications. For the sake of completeness, `markovchain` is the second package specifically dedicated to DTMC analysis, being `DTMCPack` (Nicholson 2013) the first one. Notwithstanding, `markovchain` package (Spedicato 2017) aims to offer more flexibility in handling DTMC than other existing solutions, providing S4 classes for both homogeneous and non-homogeneous Markov chains as well as methods suited to perform statistical and probabilistic analysis.

The `markovchain` package depends on the following R packages: `expm` (Goulet, Dutang, Maechler, Firth, Shapira, Stadelmann, and expm-developers@lists.R-forge.R-project.org 2013)

to perform efficient matrices powers; **igraph** (Csardi and Nepusz 2006) to perform pretty plotting of **markovchain** objects and **matlab** (Roebuck 2011), that contains functions for matrix management and calculations that emulate those within MATLAB environment. Moreover, other scientific softwares provide functions specifically designed to analyze DTMC, as Mathematica 9 (Wolfram Research 2013b).

The paper is structured as follows: Section 2 briefly reviews mathematics and definitions regarding DTMC, Section 3 discusses how to handle and manage Markov chain objects within the package, Section 4 and Section 5 show how to perform probabilistic and statistical modelling, while Section 6 presents some applied examples from various fields analyzed by means of the **markovchain** package.

2. Review of core mathematical concepts

2.1. General Definitions

A DTMC is a sequence of random variables $X_1, X_2, \dots, X_n, \dots$ characterized by the Markov property (also known as memoryless property, see Equation 1). The Markov property states that the distribution of the forthcoming state X_{n+1} depends only on the current state X_n and doesn't depend on the previous ones $X_{n-1}, X_{n-2}, \dots, X_1$.

$$Pr(X_{n+1} = x_{n+1} | X_1 = x_1, X_2 = x_2, \dots, X_n = x_n) = Pr(X_{n+1} = x_{n+1} | X_n = x_n). \quad (1)$$

The set of possible states $S = \{s_1, s_2, \dots, s_r\}$ of X_n can be finite or countable and it is named the state space of the chain.

The chain moves from one state to another (this change is named either 'transition' or 'step') and the probability p_{ij} to move from state s_i to state s_j in one step is named transition probability:

$$p_{ij} = Pr(X_1 = s_j | X_0 = s_i). \quad (2)$$

The probability of moving from state i to j in n steps is denoted by $p_{ij}^{(n)} = Pr(X_n = s_j | X_0 = s_i)$.

A DTMC is called time-homogeneous if the property shown in Equation 3 holds. Time homogeneity implies no change in the underlying transition probabilities as time goes on.

$$Pr(X_{n+1} = s_j | X_n = s_i) = Pr(X_n = s_j | X_{n-1} = s_i). \quad (3)$$

If the Markov chain is time-homogeneous, then $p_{ij} = Pr(X_{k+1} = s_j | X_k = s_i)$ and $p_{ij}^{(n)} = Pr(X_{n+k} = s_j | X_k = s_i)$, where $k > 0$.

The probability distribution of transitions from one state to another can be represented into a transition matrix $P = (p_{ij})_{i,j}$, where each element of position (i, j) represents the transition probability p_{ij} . E.g., if $r = 3$ the transition matrix P is shown in Equation 4

$$P = \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix}. \quad (4)$$

The distribution over the states can be written in the form of a stochastic row vector x (the term stochastic means that $\sum_i x_i = 1, x_i \geq 0$): e.g., if the current state of x is s_2 , $x = (0 \ 1 \ 0)$. As a consequence, the relation between $x^{(1)}$ and $x^{(0)}$ is $x^{(1)} = x^{(0)}P$ and, recursively, we get $x^{(2)} = x^{(0)}P^2$ and $x^{(n)} = x^{(0)}P^n, n > 0$.

DTMC are explained in most theory books on stochastic processes, see Brémaud (1999) and Dobrow (2016) for example. Valuable references online available are: Konstantopoulos (2009), Snell (1999) and Bard (2000).

2.2. Properties and classification of states

A state s_j is said accessible from state s_i (written $s_i \rightarrow s_j$) if a system starting in state s_i has a positive probability to reach the state s_j at a certain point, i.e., $\exists n > 0 : p_{ij}^n > 0$. If both $s_i \rightarrow s_j$ and $s_j \rightarrow s_i$, then s_i and s_j are said to communicate.

A communicating class is defined to be a set of states that communicate. A DTMC can be composed by one or more communicating classes. If the DTMC is composed by only one communicating class (i.e., if all states in the chain communicate), then it is said irreducible. A communicating class is said to be closed if no states outside of the class can be reached from any state inside it.

If $p_{ii} = 1$, s_i is defined as absorbing state: an absorbing state corresponds to a closed communicating class composed by one state only.

The canonical form of a DTMC transition matrix is a matrix having a block form, where the closed communicating classes are shown at the beginning of the diagonal matrix.

A state s_i has period k_i if any return to state s_i must occur in multiples of k_i steps, that is $k_i = \gcd \{n : Pr(X_n = s_i | X_0 = s_i) > 0\}$, where \gcd is the greatest common divisor. If $k_i = 1$ the state s_i is said to be aperiodic, else if $k_i > 1$ the state s_i is periodic with period k_i . Loosely speaking, s_i is periodic if it can only return to itself after a fixed number of transitions $k_i > 1$ (or multiple of k_i), else it is aperiodic.

If states s_i and s_j belong to the same communicating class, then they have the same period k_i . As a consequence, each of the states of an irreducible DTMC share the same periodicity. This periodicity is also considered the DTMC periodicity. It is possible to classify states according to their periodicity. Let $T^{x \rightarrow x}$ is the number of periods to go back to state x knowing that the chain starts in x .

- A state x is recurrent if $P(T^{x \rightarrow x} < +\infty) = 1$ (equivalently $P(T^{x \rightarrow x} = +\infty) = 0$). In addition:
 1. A state x is null recurrent if in addition $E(T^{x \rightarrow x}) = +\infty$.
 2. A state x is positive recurrent if in addition $E(T^{x \rightarrow x}) < +\infty$.
 3. A state x is absorbing if in addition $P(T^{x \rightarrow x} = 1) = 1$.
- A state x is transient if $P(T^{x \rightarrow x} < +\infty) < 1$ (equivalently $P(T^{x \rightarrow x} = +\infty) > 0$).

It is possible to analyze the timing to reach a certain state. The first passage time (or hitting time) from state s_i to state s_j is the number T_{ij} of steps taken by the chain until it arrives for the first time to state s_j , given that $X_0 = s_i$. The probability distribution of T_{ij} is defined

by Equation 5

$$h_{ij}^{(n)} = Pr(T_{ij} = n) = Pr(X_n = s_j, X_{n-1} \neq s_j, \dots, X_1 \neq s_j | X_0 = s_i) \quad (5)$$

and can be found recursively using Equation 6, given that $h_{ij}^{(n)} = p_{ij}$.

$$h_{ij}^{(n)} = \sum_{k \in S - \{s_j\}} p_{ik} h_{kj}^{(n-1)}. \quad (6)$$

A commonly used quantity related to h is its average value, i.e. the *mean first passage time* (also expected hitting time), namely $\bar{h}_{ij} = \sum_{n=1 \dots \infty} n h_{ij}^{(n)}$.

If in the definition of the first passage time we let $s_i = s_j$, we obtain the first recurrence time $T_i = \inf\{n \geq 1 : X_n = s_i | X_0 = s_i\}$. We could also ask ourselves which is the *mean recurrence time*, an average of the mean first recurrence times:

$$r_i = \sum_{k=1}^{\infty} k \cdot P(T_i = k)$$

Revisiting the definition of recurrence and transience: a state s_i is said to be recurrent if it is visited infinitely often, i.e., $Pr(T_i < +\infty | X_0 = s_i) = 1$. On the opposite, s_i is called transient if there is a positive probability that the chain will never return to s_i , i.e., $Pr(T_i = +\infty | X_0 = s_i) > 0$.

Given a time homogeneous Markov chain with transition matrix P , a stationary distribution z is a stochastic row vector such that $z = z \cdot P$, where $0 \leq z_j \leq 1 \forall j$ and $\sum_j z_j = 1$.

If a DTMC $\{X_n\}$ is irreducible and aperiodic, then it has a limit distribution and this distribution is stationary. As a consequence, if P is the $k \times k$ transition matrix of the chain and $z = (z_1, \dots, z_k)$ is the unique eigenvector of P such that $\sum_{i=1}^k z_i = 1$, then we get

$$\lim_{n \rightarrow \infty} P^n = Z, \quad (7)$$

where Z is the matrix having all rows equal to z . The stationary distribution of $\{X_n\}$ is represented by z .

A matrix A is called primitive if all of its entries are strictly positive, and we write it $A > 0$. If the transition matrix P for a DTMC has some primitive power, i.e. it exists $m > 0 : P^m > 0$, then the DTMC is said to be regular. In fact being regular is equivalent to being irreducible and aperiodic. All regular DTMCs are irreducible. The counterpart is not true.

Given two absorbing states s_A (source) and s_B (sink), the *committor probability* $q_j^{(AB)}$ is the probability that a process starting in state s_i is absorbed in state s_B (rather than s_A) (Noé, Schütte, Vanden-Eijnden, Reich, and Weigl 2009). It can be computed via

$$q_j^{(AB)} = \sum_{k \ni A, B} P_{jk} q_k^{(AB)} \quad \text{with} \quad q_A^{(AB)} = 0 \quad \text{and} \quad q_B^{(AB)} = 1 \quad (8)$$

Note we can also define the hitting probability from i to j as the probability of ever reaching the state j if our initial state is i :

$$h_{i,j} = Pr(T_{ij} < \infty) = \sum_{n=0}^{\infty} h_{ij}^{(n)} \quad (9)$$

In a DTMC with finite set of states, we know that a transient state communicates at least with one recurrent state. If the chain starts in a transient element, once it hits a recurrent state, it is going to be caught in its recurrent state, and we cannot expect it would go back to the initial state. Given a transient state i we can define the *absorption probability* to the recurrent state j as the probability that the first recurrent state that the Markov chain visits (and therefore gets absorbed by its recurrent class) is j , $f_i^* j$. We can also define the *mean absorption time* as the mean number of steps the transient state i would take until it hits any recurrent state, b_i .

2.3. A short example

Consider the following numerical example. Suppose we have a DTMC with a set of 3 possible states $S = \{s_1, s_2, s_3\}$. Let the transition matrix be:

$$P = \begin{bmatrix} 0.5 & 0.2 & 0.3 \\ 0.15 & 0.45 & 0.4 \\ 0.25 & 0.35 & 0.4 \end{bmatrix}. \quad (10)$$

In P , $p_{11} = 0.5$ is the probability that $X_1 = s_1$ given that we observed $X_0 = s_1$ is 0.5, and so on. It is easy to see that the chain is irreducible since all the states communicate (it is made by one communicating class only).

Suppose that the current state of the chain is $X_0 = s_2$, i.e., $x^{(0)} = (0\ 1\ 0)$, then the probability distribution of states after 1 and 2 steps can be computed as shown in Equations (11) and (12).

$$x^{(1)} = (0\ 1\ 0) \begin{bmatrix} 0.5 & 0.2 & 0.3 \\ 0.15 & 0.45 & 0.4 \\ 0.25 & 0.35 & 0.4 \end{bmatrix} = (0.15\ 0.45\ 0.4). \quad (11)$$

$$x^{(2)} = x^{(1)} P \rightarrow (0.15\ 0.45\ 0.4) \begin{bmatrix} 0.5 & 0.2 & 0.3 \\ 0.15 & 0.45 & 0.4 \\ 0.25 & 0.35 & 0.4 \end{bmatrix} = (0.2425\ 0.3725\ 0.385). \quad (12)$$

If we were interested in the probability of being in the state s_3 in the second step, then $Pr(X_2 = s_3 | X_0 = s_2) = 0.385$.

3. The structure of the package

3.1. Creating markovchain objects

The package is loaded within the R command line as follows:

```
R> library("markovchain")
```

```
Loading required package: matlab
```

```
Attaching package: 'matlab'
```

```
The following object is masked from 'package:stats':
```

```
  reshape
```

```
The following objects are masked from 'package:utils':
```

```
  find, fix
```

```
The following object is masked from 'package:base':
```

```
  sum
```

The `markovchain` and `markovchainList` S4 classes ([Chambers 2008](#)) are defined within the **markovchain** package as displayed:

```
Class "markovchain" [package "markovchain"]
```

```
Slots:
```

Name:	states	byrow	transitionMatrix	name
Class:	character	logical	matrix	character

```
Class "markovchainList" [package "markovchain"]
```

```
Slots:
```

Name:	markovchains	name
Class:	list	character

The first class has been designed to handle homogeneous Markov chain processes, while the latter (which is itself a list of `markovchain` objects) has been designed to handle non-homogeneous Markov chains processes.

Any element of `markovchain` class is comprised by following slots:

1. `states`: a character vector, listing the states for which transition probabilities are defined.
2. `byrow`: a logical element, indicating whether transition probabilities are shown by row or by column.
3. `transitionMatrix`: the probabilities of the transition matrix.
4. `name`: optional character element to name the DTMC.

The `markovchainList` objects are defined by following slots:

1. `markovchains`: a list of `markovchain` objects.
2. `name`: optional character element to name the DTMC.

The `markovchain` objects can be created either in a long way, as the following code shows

```
R> weatherStates <- c("sunny", "cloudy", "rain")
R> byRow <- TRUE
R> weatherMatrix <- matrix(data = c(0.70, 0.2, 0.1,
R+           0.3, 0.4, 0.3,
R+           0.2, 0.45, 0.35), byrow = byRow, nrow = 3,
R+           dimnames = list(weatherStates, weatherStates))
R> mcWeather <- new("markovchain", states = weatherStates, byrow = byRow,
R+           transitionMatrix = weatherMatrix, name = "Weather")
```

or in a shorter way, displayed below

```
R> mcWeather <- new("markovchain", states = c("sunny", "cloudy", "rain"),
R+           transitionMatrix = matrix(data = c(0.70, 0.2, 0.1,
R+           0.3, 0.4, 0.3,
R+           0.2, 0.45, 0.35), byrow = byRow, nrow = 3),
R+           name = "Weather")
```

When `new("markovchain")` is called alone, a default Markov chain is created.

```
R> defaultMc <- new("markovchain")
```

The quicker way to create `markovchain` objects is made possible thanks to the implemented `initialize` S4 method that checks that:

- the `transitionMatrix` to be a transition matrix, i.e., all entries to be probabilities and either all rows or all columns to sum up to one.
- the columns and rows names of `transitionMatrix` to be defined and to coincide with `states` vector slot.

The `markovchain` objects can be collected in a list within `markovchainList` S4 objects as following example shows.

```
R> mcList <- new("markovchainList", markovchains = list(mcWeather, defaultMc),
R+           name = "A list of Markov chains")
```

3.2. Handling markovchain objects

Table 1 lists which methods handle and manipulate `markovchain` objects.

Method	Purpose
<code>*</code>	Direct multiplication for transition matrices.
<code>^</code>	Compute the power <code>markovchain</code> of a given one.
<code>[</code>	Direct access to the elements of the transition matrix.
<code>==</code>	Equality operator between two transition matrices.
<code>!=</code>	Inequality operator between two transition matrices.
<code>as</code>	Operator to convert <code>markovchain</code> objects into <code>data.frame</code> and <code>table</code> object.
<code>dim</code>	Dimension of the transition matrix.
<code>names</code>	Equal to <code>states</code> .
<code>names<-</code>	Change the <code>states</code> name.
<code>name</code>	Get the name of <code>markovchain</code> object.
<code>name<-</code>	Change the name of <code>markovchain</code> object.
<code>plot</code>	<code>plot</code> method for <code>markovchain</code> objects.
<code>print</code>	<code>print</code> method for <code>markovchain</code> objects.
<code>show</code>	<code>show</code> method for <code>markovchain</code> objects.
<code>sort</code>	<code>sort</code> method for <code>markovchain</code> objects, in terms of their states.
<code>states</code>	Name of the transition states.
<code>t</code>	Transposition operator (which switches <code>byrow</code> 'slot value and modifies the transition matrix coherently).

Table 1: `markovchain` methods for handling `markovchain` objects.

The examples that follow shows how operations on `markovchain` objects can be easily performed. For example, using the previously defined matrix we can find what is the probability distribution of expected weather states in two and seven days, given the actual state to be cloudy.

```
R> initialState <- c(0, 1, 0)
R> after2Days <- initialState * (mcWeather * mcWeather)
R> after7Days <- initialState * (mcWeather ^ 7)
R> after2Days
```

```
      sunny cloudy rain
[1,]  0.39  0.355 0.255
```

```
R> round(after7Days, 3)
```

```
      sunny cloudy rain
[1,] 0.462  0.319 0.219
```

A similar answer could have been obtained defining the vector of probabilities as a column vector. A column - defined probability matrix could be set up either creating a new matrix or transposing an existing `markovchain` object thanks to the `t` method.

```
R> initialState <- c(0, 1, 0)
R> after2Days <- (t(mcWeather) * t(mcWeather)) * initialState
R> after7Days <- (t(mcWeather) ^ 7) * initialState
R> after2Days
```

```
      [,1]
sunny 0.390
cloudy 0.355
rain   0.255
```

```
R> round(after7Days, 3)
```

```
      [,1]
sunny 0.462
cloudy 0.319
rain   0.219
```

The initial state vector previously shown can not necessarily be a probability vector, as the code that follows shows:

```
R> fvals<-function(mchain,initialstate,n) {
R+   out<-data.frame()
R+   names(initialstate)<-names(mchain)
R+   for (i in 0:n)
R+   {
R+     iteration<-initialstate*mchain^(i)
R+     out<-rbind(out,iteration)
R+   }
R+   out<-cbind(out, i=seq(0,n))
R+   out<-out[,c(4,1:3)]
R+   return(out)
R+ }
R> fvals(mchain=mcWeather,initialstate=c(90,5,5),n=4)
```

```
  i  sunny  cloudy  rain
1 0 90.00000  5.00000  5.00000
2 1 65.50000 22.25000 12.25000
3 2 54.97500 27.51250 17.51250
4 3 50.23875 29.88063 19.88062
5 4 48.10744 30.94628 20.94628
```

Basic methods have been defined for `markovchain` objects to quickly get states and transition matrix dimension.

```
R> states(mcWeather)

[1] "sunny" "cloudy" "rain"

R> names(mcWeather)

[1] "sunny" "cloudy" "rain"

R> dim(mcWeather)

[1] 3
```

Methods are available to set and get the name of `markovchain` object.

```
R> name(mcWeather)

[1] "Weather"

R> name(mcWeather) <- "New Name"
R> name(mcWeather)

[1] "New Name"
```

Also it is possible to alphabetically sort the transition matrix:

```
R> markovchain:::sort(mcWeather)
```

New Name

A 3 - dimensional discrete Markov Chain defined by the following states:

cloudy, rain, sunny

The transition matrix (by rows) is defined as follows:

	cloudy	rain	sunny
cloudy	0.40	0.30	0.3
rain	0.45	0.35	0.2
sunny	0.20	0.10	0.7

A direct access to transition probabilities is provided both by `transitionProbability` method and `"["` method.

```
R> transitionProbability(mcWeather, "cloudy", "rain")

[1] 0.3

R> mcWeather[2,3]

[1] 0.3
```

The transition matrix of a `markovchain` object can be displayed using `print` or `show` methods (the latter being less verbose). Similarly, the underlying transition probability diagram can be plotted by the use of `plot` method (as shown in Figure 1) which is based on `igraph` package (Csardi and Nepusz 2006). `plot` method for `markovchain` objects is a wrapper of `plot.igraph` for `igraph` S4 objects defined within the `igraph` package. Additional parameters can be passed to `plot` function to control the network graph layout. There are also `diagram` and `DiagrammeR` ways available for plotting as shown in Figure 2. The `plot` function also uses `communicatingClasses` function to separate out states of different communicating classes. All states that belong to one class have same color.

```
R> print(mcWeather)
```

```
      sunny cloudy rain
sunny  0.7   0.20 0.10
cloudy  0.3   0.40 0.30
rain    0.2   0.45 0.35
```

```
R> show(mcWeather)
```

```
New Name
```

```
A 3 - dimensional discrete Markov Chain defined by the following states:
```

```
sunny, cloudy, rain
```

```
The transition matrix (by rows) is defined as follows:
```

```
      sunny cloudy rain
sunny  0.7   0.20 0.10
cloudy  0.3   0.40 0.30
rain    0.2   0.45 0.35
```

```
Attaching package: 'igraph'
```

```
The following objects are masked from 'package:stats':
```

```
decompose, spectrum
```

```
The following object is masked from 'package:base':
```

```
union
```

```
Loading required package: shape
```

Import and export from some specific classes is possible, as shown in Figure 3 and in the following code.

```
R> mcDf <- as(mcWeather, "data.frame")
R> mcNew <- as(mcDf, "markovchain")
R> mcDf
```

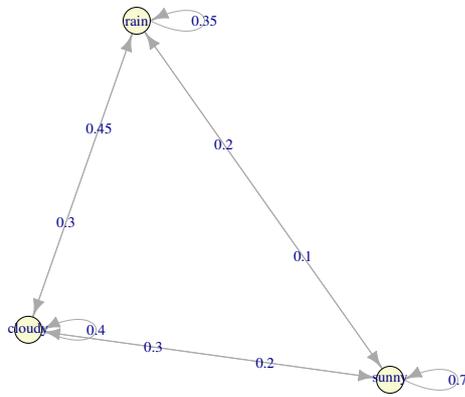


Figure 1: Weather example. Markov chain plot

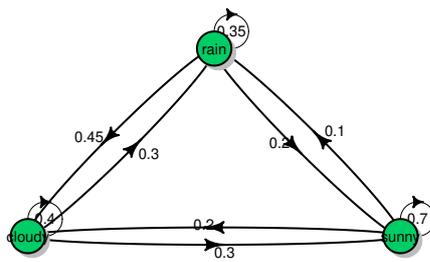


Figure 2: Weather example. Markov chain plot with diagram

```

      t0      t1 prob
1 sunny sunny 0.70
2 sunny cloudy 0.20
3 sunny rain 0.10
4 cloudy sunny 0.30
5 cloudy cloudy 0.40
6 cloudy rain 0.30
7 rain sunny 0.20
8 rain cloudy 0.45
9 rain rain 0.35

```

```
R> mcIgraph <- as(mcWeather, "igraph")
```

```

R> if (requireNamespace("msm", quietly = TRUE)) {
R+ require(msm)
R+ Q <- rbind ( c(0, 0.25, 0, 0.25),
R+             c(0.166, 0, 0.166, 0.166),
R+             c(0, 0.25, 0, 0.25),
R+             c(0, 0, 0, 0) )
R+ cavmsm <- msm(state ~ years, subject = PTNUM, data = cav, qmatrix = Q, death = 4)
R+ msmMc <- as(cavmsm, "markovchain")
R+ msmMc
R+ } else {
R+   message("msm unavailable")
R+ }

```

Loading required package: msm

Unnamed Markov chain

A 4 - dimensional discrete Markov Chain defined by the following states:

State 1, State 2, State 3, State 4

The transition matrix (by rows) is defined as follows:

	State 1	State 2	State 3	State 4
State 1	0.853958721	0.08836953	0.01475543	0.04291632
State 2	0.155576908	0.56663284	0.20599563	0.07179462
State 3	0.009903994	0.07853691	0.65965727	0.25190183
State 4	0.000000000	0.000000000	0.000000000	1.000000000

```

R> if (requireNamespace("etm", quietly = TRUE)) {
R+ library(etm)
R+ data(sir.cont)
R+ sir.cont <- sir.cont[order(sir.cont$id, sir.cont$time), ]
R+ for (i in 2:nrow(sir.cont)) {
R+   if (sir.cont$id[i]==sir.cont$id[i-1]) {
R+     if (sir.cont$time[i]==sir.cont$time[i-1]) {
R+       sir.cont$time[i-1] <- sir.cont$time[i-1] - 0.5

```

Import – Export from and to markovchain objects

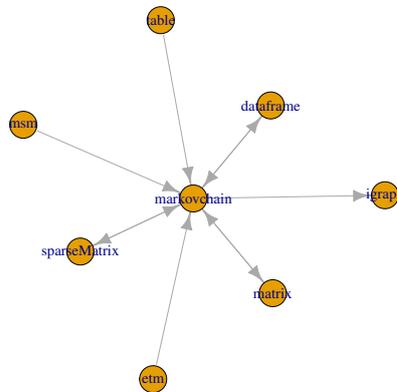


Figure 3: The markovchain methods for import and export

```

R+   }
R+   }
R+ }
R+ tra <- matrix(ncol=3,nrow=3,FALSE)
R+ tra[1, 2:3] <- TRUE
R+ tra[2, c(1, 3)] <- TRUE
R+ tr.prob <- etm(sir.cont, c("0", "1", "2"), tra, "cens", 1)
R+ tr.prob
R+ etm2mc<-as(tr.prob, "markovchain")
R+ etm2mc
R+   } else {
R+   message("etm unavailable")
R+ }

```

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

0, 1, 2

The transition matrix (by rows) is defined as follows:

	0	1	2
0	0.0000000	0.5000000	0.5000000
1	0.5000000	0.0000000	0.5000000
2	0.3333333	0.3333333	0.3333333

Coerce from `matrix` method, as the code below shows, represents another approach to create a `markovchain` method starting from a given squared probability matrix.

```
R> myMatr<-matrix(c(.1,.8,.1,.2,.6,.2,.3,.4,.3), byrow=TRUE, ncol=3)
```

```
R> myMc<-as(myMatr, "markovchain")
R> myMc
```

Unnamed Markov chain

```
A 3 - dimensional discrete Markov Chain defined by the following states:
s1, s2, s3
The transition matrix (by rows) is defined as follows:
  s1 s2 s3
s1 0.1 0.8 0.1
s2 0.2 0.6 0.2
s3 0.3 0.4 0.3
```

Non-homogeneous Markov chains can be created with the aid of `markovchainList` object. The example that follows arises from health insurance, where the costs associated to patients in a Continuous Care Health Community (CCHC) are modeled by a non-homogeneous Markov Chain, since the transition probabilities change by year. Methods explicitly written for `markovchainList` objects are: `print`, `show`, `dim` and `[`.

```
R> stateNames = c("H", "I", "D")
R> Q0 <- new("markovchain", states = stateNames,
R+   transitionMatrix =matrix(c(0.7, 0.2, 0.1,0.1, 0.6, 0.3,0, 0, 1),
R+   byrow = TRUE, nrow = 3), name = "state t0")
R> Q1 <- new("markovchain", states = stateNames,
R+   transitionMatrix = matrix(c(0.5, 0.3, 0.2,0, 0.4, 0.6,0, 0, 1),
R+   byrow = TRUE, nrow = 3), name = "state t1")
R> Q2 <- new("markovchain", states = stateNames,
R+   transitionMatrix = matrix(c(0.3, 0.2, 0.5,0, 0.2, 0.8,0, 0, 1),
R+   byrow = TRUE,nrow = 3), name = "state t2")
R> Q3 <- new("markovchain", states = stateNames,
R+   transitionMatrix = matrix(c(0, 0, 1, 0, 0, 1, 0, 0, 1),
R+   byrow = TRUE, nrow = 3), name = "state t3")
R> mcCCRC <- new("markovchainList",markovchains = list(Q0,Q1,Q2,Q3),
R+   name = "Continuous Care Health Community")
R> print(mcCCRC)
```

Continuous Care Health Community list of Markov chain(s)

Markovchain 1

state t0

```
A 3 - dimensional discrete Markov Chain defined by the following states:
H, I, D
The transition matrix (by rows) is defined as follows:
  H I D
H 0.7 0.2 0.1
I 0.1 0.6 0.3
D 0.0 0.0 1.0
```

Markovchain 2

```

state t1
A 3 - dimensional discrete Markov Chain defined by the following states:
H, I, D
The transition matrix (by rows) is defined as follows:
  H I D
H 0.5 0.3 0.2
I 0.0 0.4 0.6
D 0.0 0.0 1.0

```

Markovchain 3

```

state t2
A 3 - dimensional discrete Markov Chain defined by the following states:
H, I, D
The transition matrix (by rows) is defined as follows:
  H I D
H 0.3 0.2 0.5
I 0.0 0.2 0.8
D 0.0 0.0 1.0

```

Markovchain 4

```

state t3
A 3 - dimensional discrete Markov Chain defined by the following states:
H, I, D
The transition matrix (by rows) is defined as follows:
  H I D
H 0 0 1
I 0 0 1
D 0 0 1

```

It is possible to perform direct access to `markovchainList` elements, as well as to determine the number of `markovchain` objects by which a `markovchainList` object is composed.

```
R> mcCCRC[[1]]
```

```

state t0
A 3 - dimensional discrete Markov Chain defined by the following states:
H, I, D
The transition matrix (by rows) is defined as follows:
  H I D
H 0.7 0.2 0.1
I 0.1 0.6 0.3
D 0.0 0.0 1.0

```

```
R> dim(mcCCRC)
```

```
[1] 4
```

The `markovchain` package contains some data found in the literature related to DTMC models (see Section 6. Table 2 lists datasets and tables included within the current release of the package.

Dataset	Description
<code>blanden</code>	Mobility across income quartiles, Jo Blanden and Machin (2005) .
<code>craigsendi</code>	CD4 cells, B. A. Craig and A. A. Sendi (2002) .
<code>kullback</code>	raw transition matrices for testing homogeneity, Kullback, Kupperman, and Ku (1962) .
<code>preproglucacon</code>	Preproglucacon DNA basis, P. J. Avery and D. A. Henderson (1999) .
<code>rain</code>	Alofi Island rains, P. J. Avery and D. A. Henderson (1999) .
<code>holson</code>	Individual states trajectories.
<code>sales</code>	Sales of six beverages in Hong Kong Ching, Ng, and Fung (2008) .

Table 2: The `markovchain` `data.frame` and `table`.

Finally, Table 3 lists the demos included in the demo directory of the package.

R Code File	Description
<code>bard.R</code>	Structural analysis of Markov chains from Bard PPT.
<code>examples.R</code>	Notable Markov chains, e.g., The Gambler Ruin chain.
<code>quickStart.R</code>	Generic examples.
<code>extractMatrices.R</code>	Generic examples.

Table 3: The `markovchain` demos.

4. Probability with markovchain objects

The `markovchain` package contains functions to analyse DTMC from a probabilistic perspective. For example, the package provides methods to find stationary distributions and identifying absorbing and transient states. Many of these methods come from MATLAB listings that have been ported into R. For a full description of the underlying theory and algorithm the interested reader can overview the original MATLAB listings, [Feres \(2007\)](#) and [Montgomery \(2009\)](#).

Table 4 shows methods that can be applied on `markovchain` objects to perform probabilistic analysis.

4.1. Conditional distributions

The conditional distribution of weather states, given that current day's weather is sunny, is given by following code.

```
R> conditionalDistribution(mcWeather, "sunny")
```

```
sunny cloudy rain
  0.7    0.2   0.1
```

Method	Returns
<code>absorbingStates</code>	the absorbing states of the transition matrix, if any.
<code>steadyStates</code>	the vector(s) of steady state(s) in matrix form.
<code>meanFirstPassageTime</code>	matrix or vector of mean first passage times.
<code>meanRecurrenceTime</code>	vector of mean number of steps to return to each recurrent state
<code>hittingProbabilities</code>	matrix of hitting probabilities for a Markov chain.
<code>meanAbsorptionTime</code>	expected number of steps for a transient state to be absorbed by any recurrent class
<code>absorptionProbabilities</code>	probabilities of transient states of being absorbed by each recurrent state
<code>committorAB</code>	committor probabilities
<code>communicatingClasses</code>	list of communicating classes. s_j , given actual state s_i .
<code>canonicForm</code>	the transition matrix into canonic form.
<code>is.accessible</code>	checks whether a state j is reachable from state i .
<code>is.irreducible</code>	checks whether a DTMC is irreducible.
<code>is.regular</code>	checks whether a DTMC is regular.
<code>period</code>	the period of an irreducible DTMC.
<code>recurrentClasses</code>	list of recurrent communicating classes.
<code>transientClasses</code>	list of transient communicating classes.
<code>recurrentStates</code>	the recurrent states of the transition matrix.
<code>transientStates</code>	the transient states of the transition matrix, if any.
<code>summary</code>	DTMC summary.

Table 4: **markovchain** methods: statistical operations.

4.2. Stationary states

A stationary (steady state, or equilibrium) vector is a probability vector such that Equation 13 holds

$$\begin{aligned} 0 &\leq \pi_j \leq 1 \\ \sum_{j \in S} \pi_j &= 1 \\ \pi \cdot P &= \pi \end{aligned} \tag{13}$$

Steady states are associated to P eigenvalues equal to one. We could be tempted to compute them solving the eigen values / vectors of the matrix and taking real parts (since if $u + iv$ is a eigen vector, for the matrix P , then $Re(u + iv) = u$ and $Im(u + iv) = v$ are eigen vectors) and normalizing by the vector sum, this carries some concerns:

1. If $u, v \in \mathbb{R}^n$ are linearly independent eigen vectors associated to 1 eigen value, $u + iv$, $u + iu$ are also linearly independent eigen vectors, and their real parts coincide. Clearly if we took real parts, we would be losing an eigen vector, because we cannot know in advance if the underlying algorithm to compute the eigen vectors is going to output something similar to what we described. We should be agnostic to the underlying eigen vector computation algorithm.
2. Imagine the identity P of dimensions 2×2 . Its eigen vectors associated to the 1 eigen

value are $u = (1, 0)$ and $v = (0, 1)$. However, the underlying algorithm to compute eigen vectors could return $(1, -2)$ and $(-2, 1)$ instead, that are linear combinations of the aforementioned ones, and therefore eigen vectors. Normalizing by their sum, we would get: $(-1, 2)$ and $(2, -1)$, which obviously are not probability measures. Again, we should be agnostic to the underlying eigen computation algorithm.

- Algorithms to compute eigen values / vectors are computationally expensive: they are iterative, and we cannot predict a fixed number of iterations for them. Moreover, each iteration takes $\mathcal{O}(m^2)$ or $\mathcal{O}(m^3)$ algorithmic complexity, with m the number of states.

We are going to use that every irreducible DTMC has a unique steady state, that is, if M is the matrix for an irreducible DTMC (all states communicate with each other), then it exists a unique $v \in \mathbb{R}^m$ such that:

$$v \cdot M = v, \quad \sum_{i=1}^m v_i = 1$$

Also, we'll use that a steady state for a DTMC assigns 0 to the transient states. The canonical form of a (by row) stochastic matrix looks alike:

$$\left(\begin{array}{c|c|c|c|c} M_1 & 0 & 0 & \dots & 0 \\ \hline 0 & M_2 & 0 & \dots & 0 \\ \hline 0 & 0 & M_3 & \dots & 0 \\ \hline \vdots & \vdots & \vdots & \ddots & \vdots \\ \hline A_1 & A_2 & A_3 & \dots & R \end{array} \right)$$

where M_i corresponds to irreducible sub-chains, the blocks A_i correspond to the transitions from transient states to each of the recurrent classes and R are the transitions from the transient states to themselves.

Also, we should note that a Markov chain has exactly the same name of steady states as recurrent classes. Therefore, we have coded the following algorithm ¹:

- Identify the recurrent classes $[C_1, \dots, C_l]$ with `recurrentClasses` function.
- Take each class C_i , compute the sub-matrix corresponding to it M_i .
- Solve the system $v \cdot C_i = v$, $\sum_{j=1}^{|C_i|} v_j = 1$ which has a unique solution, for each $i = 1, \dots, l$.
- Map each state v_i to the original order in P and assign a 0 to the slots corresponding to transient states in the matrix.

The result is returned in matrix form.

```
R> steadyStates(mcWeather)
```

¹We would like to thank Prof. Christophe Dutang for his contributions to the development of this method. He coded a first improvement of the original `steadyStates` method and we could not have reached the current correctness without his previous work

```

      sunny    cloudy    rain
[1,] 0.4636364 0.3181818 0.2181818

```

It is possible for a Markov chain to have more than one stationary distribution, as the gambler ruin example shows.

```

R> gamblerRuinMarkovChain <- function(moneyMax, prob = 0.5) {
R+   m <- matlab::zeros(moneyMax + 1)
R+   m[1,1] <- m[moneyMax + 1,moneyMax + 1] <- 1
R+   states <- as.character(0:moneyMax)
R+   rownames(m) <- colnames(m) <- states
R+
R+   for(i in 2:moneyMax){
R+     m[i,i-1] <- 1 - prob
R+     m[i, i + 1] <- prob
R+   }
R+
R+   new("markovchain", transitionMatrix = m,
R+       name = paste("Gambler ruin", moneyMax, "dim", sep = " "))
R+ }
R>
R> mcGR4 <- gamblerRuinMarkovChain(moneyMax = 4, prob = 0.5)
R> steadyStates(mcGR4)

      0 1 2 3 4
[1,] 0 0 0 0 1
[2,] 1 0 0 0 0

```

4.3. Classification of states

Absorbing states are determined by means of `absorbingStates` method.

```

R> absorbingStates(mcGR4)

[1] "0" "4"

R> absorbingStates(mcWeather)

character(0)

```

The key function in methods which need knowledge about communicating classes, recurrent states, transient states, is `.commclassKernel`, which is a modification of Tarjan's algorithm from [Tarjan \(1972\)](#). This `.commclassKernel` method gets a transition matrix of dimension n and returns a list of two items:

1. `classes`, an matrix whose (i, j) entry is `true` if s_i and s_j are in the same communicating class.

2. `closed`, a vector whose i -th entry indicates whether the communicating class to which i belongs is closed.

These functions are used by two other internal functions on which the `summary` method for `markovchain` objects works.

The example matrix used in [Feres \(2007\)](#) well exemplifies the purpose of the function.

```
R> P <- matlab::zeros(10)
R> P[1, c(1, 3)] <- 1/2;
R> P[2, 2] <- 1/3; P[2,7] <- 2/3;
R> P[3, 1] <- 1;
R> P[4, 5] <- 1;
R> P[5, c(4, 5, 9)] <- 1/3;
R> P[6, 6] <- 1;
R> P[7, 7] <- 1/4; P[7,9] <- 3/4;
R> P[8, c(3, 4, 8, 10)] <- 1/4;
R> P[9, 2] <- 1;
R> P[10, c(2, 5, 10)] <- 1/3;
R> rownames(P) <- letters[1:10]
R> colnames(P) <- letters[1:10]
R> probMc <- new("markovchain", transitionMatrix = P,
R+           name = "Probability MC")
R> summary(probMc)
```

Probability MC Markov chain that is composed by:

Closed classes:

```
a c
b g i
f
```

Recurrent classes:

```
{a,c},{b,g,i},{f}
```

Transient classes:

```
{d,e},{h},{j}
```

The Markov chain is not irreducible

The absorbing states are: f

All states that pertain to a transient class are named “transient” and a specific method has been written to elicit them.

```
R> transientStates(probMc)
```

```
[1] "d" "e" "h" "j"
```

`canonicForm` method that turns a Markov chain into its canonic form, reordering the states to have first the recurrent classes and then the transient states.

```
R> probMcCanonic <- canonicForm(probMc)
R> probMc
```

Probability MC

A 10 - dimensional discrete Markov Chain defined by the following states:

a, b, c, d, e, f, g, h, i, j

The transition matrix (by rows) is defined as follows:

	a	b	c	d	e	f	g	h	i	j
a	0.5	0.0000000	0.50	0.0000000	0.0000000	0	0.0000000	0.00	0.0000000	0.0000000
b	0.0	0.3333333	0.00	0.0000000	0.0000000	0	0.6666667	0.00	0.0000000	0.0000000
c	1.0	0.0000000	0.00	0.0000000	0.0000000	0	0.0000000	0.00	0.0000000	0.0000000
d	0.0	0.0000000	0.00	0.0000000	1.0000000	0	0.0000000	0.00	0.0000000	0.0000000
e	0.0	0.0000000	0.00	0.3333333	0.3333333	0	0.0000000	0.00	0.3333333	0.0000000
f	0.0	0.0000000	0.00	0.0000000	0.0000000	1	0.0000000	0.00	0.0000000	0.0000000
g	0.0	0.0000000	0.00	0.0000000	0.0000000	0	0.2500000	0.00	0.7500000	0.0000000
h	0.0	0.0000000	0.25	0.2500000	0.0000000	0	0.0000000	0.25	0.0000000	0.2500000
i	0.0	1.0000000	0.00	0.0000000	0.0000000	0	0.0000000	0.00	0.0000000	0.0000000
j	0.0	0.3333333	0.00	0.0000000	0.3333333	0	0.0000000	0.00	0.0000000	0.3333333

```
R> probMcCanonic
```

Probability MC

A 10 - dimensional discrete Markov Chain defined by the following states:

a, c, b, g, i, f, d, e, h, j

The transition matrix (by rows) is defined as follows:

	a	c	b	g	i	f	d	e	h	j
a	0.5	0.50	0.0000000	0.0000000	0.0000000	0	0.0000000	0.0000000	0.00	0.0000000
c	1.0	0.00	0.0000000	0.0000000	0.0000000	0	0.0000000	0.0000000	0.00	0.0000000
b	0.0	0.00	0.3333333	0.6666667	0.0000000	0	0.0000000	0.0000000	0.00	0.0000000
g	0.0	0.00	0.0000000	0.2500000	0.7500000	0	0.0000000	0.0000000	0.00	0.0000000
i	0.0	0.00	1.0000000	0.0000000	0.0000000	0	0.0000000	0.0000000	0.00	0.0000000
f	0.0	0.00	0.0000000	0.0000000	0.0000000	1	0.0000000	0.0000000	0.00	0.0000000
d	0.0	0.00	0.0000000	0.0000000	0.0000000	0	0.0000000	1.0000000	0.00	0.0000000
e	0.0	0.00	0.0000000	0.0000000	0.3333333	0	0.3333333	0.3333333	0.00	0.0000000
h	0.0	0.25	0.0000000	0.0000000	0.0000000	0	0.2500000	0.0000000	0.25	0.2500000
j	0.0	0.00	0.3333333	0.0000000	0.0000000	0	0.0000000	0.3333333	0.00	0.3333333

The function `is.accessible` permits to investigate whether a state s_j is accessible from state s_i , that is whether the probability to eventually reach s_j starting from s_i is greater than zero.

```
R> is.accessible(object = probMc, from = "a", to = "c")
```

```
[1] TRUE
```

```
R> is.accessible(object = probMc, from = "g", to = "c")
```

```
[1] FALSE
```

In Section 2.2 we observed that, if a DTMC is irreducible, all its states share the same periodicity. Then, the `period` function returns the periodicity of the DTMC, provided that it is irreducible. The example that follows shows how to find if a DTMC is reducible or irreducible by means of the function `is.irreducible` and, in the latter case, the method `period` is used to compute the periodicity of the chain.

```
R> E <- matrix(0, nrow = 4, ncol = 4)
R> E[1, 2] <- 1
R> E[2, 1] <- 1/3; E[2, 3] <- 2/3
R> E[3,2] <- 1/4; E[3, 4] <- 3/4
R> E[4, 3] <- 1
R>
R> mcE <- new("markovchain", states = c("a", "b", "c", "d"),
R+   transitionMatrix = E,
R+   name = "E")
R> is.irreducible(mcE)

[1] TRUE

R> period(mcE)

[1] 2
```

The example Markov chain found in Mathematica web site ([Wolfram Research 2013a](#)) has been used, and is plotted in Figure 4.

```
R> require(matlab)
R> mathematicaMatr <- zeros(5)
R> mathematicaMatr[1,] <- c(0, 1/3, 0, 2/3, 0)
R> mathematicaMatr[2,] <- c(1/2, 0, 0, 0, 1/2)
R> mathematicaMatr[3,] <- c(0, 0, 1/2, 1/2, 0)
R> mathematicaMatr[4,] <- c(0, 0, 1/2, 1/2, 0)
R> mathematicaMatr[5,] <- c(0, 0, 0, 0, 1)
R> statesNames <- letters[1:5]
R> mathematicaMc <- new("markovchain", transitionMatrix = mathematicaMatr,
R+   name = "Mathematica MC", states = statesNames)
```

Mathematica MC Markov chain that is composed by:

Closed classes:

c d

e

Recurrent classes:

{c,d},{e}

Transient classes:

{a,b}

The Markov chain is not irreducible

The absorbing states are: e

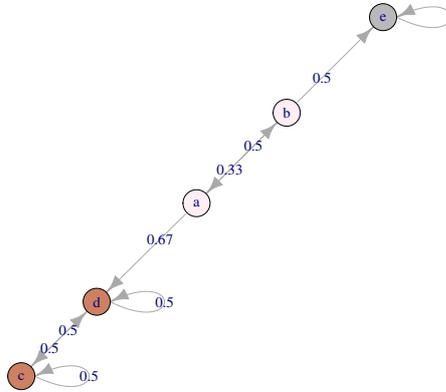


Figure 4: Mathematica 9 example. Markov chain plot.

4.4. First passage time distributions and means

Feres (2007) provides code to compute first passage time (within $1, 2, \dots, n$ steps) given the initial state to be i . The MATLAB listings translated into R on which the `firstPassage` function is based are:

```

R> .firstpassageKernel <- function(P, i, n){
R>   G <- P
R>   H <- P[i,]
R>   E <- 1 - diag(size(P)[2])
R>   for (m in 2:n) {
R>     G <- P %*% (G * E)
R>     H <- rbind(H, G[i,])
R>   }
R>   return(H)
R> }

```

We conclude that the probability for the *first* rainy day to be the third one, given that the current state is sunny, is given by:

```

R> firstPassagePdF <- firstPassage(object = mcWeather, state = "sunny",
R+                               n = 10)
R> firstPassagePdF[3, 3]

```

```
[1] 0.121
```

To compute the *mean* first passage times, i.e. the expected number of days before it rains given that today is sunny, we can use the `meanFirstPassageTime` function:

```
R> meanFirstPassageTime(mcWeather)
```

```
      sunny  cloudy   rain
sunny 0.000000 4.285714 6.666667
cloudy 3.725490 0.000000 5.000000
rain   4.117647 2.857143 0.000000
```

indicating e.g. that the average number of days of sun or cloud before rain is 6.67 if we start counting from a sunny day, and 5 if we start from a cloudy day. Note that we can also specify one or more destination states:

```
R> meanFirstPassageTime(mcWeather, "rain")
```

```
      sunny  cloudy
6.666667 5.000000
```

The implementation follows the matrix solutions by (Grinstead and Snell 2006). We can check the result by averaging the first passage probability density function:

```
R> firstPassagePdf.long <- firstPassage(object = mcWeather, state = "sunny", n = 100)
R> sum(firstPassagePdf.long[, "rain"] * 1:100)
```

```
[1] 6.666664
```

4.5. Mean recurrence time

The `meanRecurrenceTime` method gives the first mean recurrence time (expected number of steps to go back to a state if it was the initial one) for each recurrent state in the transition probabilities matrix for a DTMC. Let's see an example:

```
R> meanRecurrenceTime(mcWeather)
```

```
      sunny  cloudy   rain
2.156863 3.142857 4.583333
```

Another example, with not all of its states being recurrent:

```
R> recurrentStates(probMc)
```

```
[1] "a" "b" "c" "f" "g" "i"
```

```
R> meanRecurrenceTime(probMc)
```

```
      f      b      g      i      a      c
1.000000 2.555556 2.875000 3.833333 1.500000 3.000000
```

4.6. Absorption probabilities and mean absorption time

We are going to use the Drunkard's random walk from (Grinstead and Snell 2006). We have a drunk person walking through the street. Each move the person does, if they have not arrived to either home (corner 1) or to the bar (corner 5) could be to the left corner or to the right one, with equal probability. In case of arrival to the bar or to home, the person stays there.

```
R> drunkProbs <- matlab::zeros(5, 5)
R> drunkProbs[1,1] <- drunkProbs[5,5] <- 1
R> drunkProbs[2,1] <- drunkProbs[2,3] <- 1/2
R> drunkProbs[3,2] <- drunkProbs[3,4] <- 1/2
R> drunkProbs[4,3] <- drunkProbs[4,5] <- 1/2
R>
R> drunkMc <- new("markovchain", transitionMatrix = drunkProbs)
R> drunkMc
```

Unnamed Markov chain

A 5 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3, 4, 5

The transition matrix (by rows) is defined as follows:

	1	2	3	4	5
1	1.0	0.0	0.0	0.0	0.0
2	0.5	0.0	0.5	0.0	0.0
3	0.0	0.5	0.0	0.5	0.0
4	0.0	0.0	0.5	0.0	0.5
5	0.0	0.0	0.0	0.0	1.0

Recurrent (in fact absorbing states) are:

```
R> recurrentStates(drunkMc)
```

```
[1] "1" "5"
```

Transient states are the rest:

```
R> transientStates(drunkMc)
```

```
[1] "2" "3" "4"
```

The probability of either being absorbed by the bar or by the sofa at home are:

```
R> absorptionProbabilities(drunkMc)
```

	1	5
2	0.75	0.25
3	0.50	0.50
4	0.25	0.75

which means that the probability of arriving home / bar is inversely proportional to the distance to each one.

But we also would like to know how much time does the person take to arrive there, which can be done with `meanAbsorptionTime`:

```
R> meanAbsorptionTime(drunkMc)
```

```
2 3 4
3 4 3
```

So it would take 3 steps to arrive to the destiny if the person is either in the second or fourth corner, and 4 steps in case of being at the same distance from home than to the bar.

4.7. Committed probability

The committed probability tells us the probability to reach a given state before another given. Suppose that we start in a cloudy day, the probabilities of experiencing a rainy day before a sunny one is 0.5:

```
R> committedAB(mcWeather,3,1)
```

```
sunny cloudy rain
0.0    0.5    1.0
```

4.8. Hitting probabilities

Rewriting the system (9) as:

$$A = \left(\begin{array}{c|c|c|c} A_1 & 0 & \dots & 0 \\ \hline 0 & A_2 & \dots & 0 \\ \hline \vdots & \vdots & \ddots & 0 \\ \hline 0 & 0 & \dots & A_n \end{array} \right)$$

$$\begin{aligned}
A_1 &= \begin{pmatrix} -1 & p_{1,2} & p_{1,3} & \cdots & p_{1,n} \\ 0 & (p_{2,2} - 1) & p_{2,3} & \cdots & p_{2,n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & p_{n,2} & p_{n,3} & \cdots & (p_{n,n} - 1) \end{pmatrix} \\
A_2 &= \begin{pmatrix} (p_{1,1} - 1) & 0 & p_{1,3} & \cdots & p_{1,n} \\ p_{2,1} & -1 & p_{2,3} & \cdots & p_{2,n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ p_{n,1} & 0 & p_{n,3} & \cdots & (p_{n,n} - 1) \end{pmatrix} \\
&\vdots \\
&\vdots \\
A_n &= \begin{pmatrix} (p_{1,1} - 1) & p_{1,2} & p_{1,3} & \cdots & 0 \\ p_{2,1} & (p_{2,2} - 1) & p_{2,3} & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ p_{n,1} & p_{n,2} & p_{n,3} & \cdots & -1 \end{pmatrix} \\
&\vdots \\
&\vdots \\
X_j &= \begin{pmatrix} h_{1,j} \\ h_{2,j} \\ \vdots \\ h_{n,j} \end{pmatrix} \quad C_j = - \begin{pmatrix} p_{1,j} \\ p_{2,j} \\ \vdots \\ p_{n,j} \end{pmatrix}
\end{aligned}$$

we end up having to solve the block systems:

$$A_j \cdot X_j = C_j \tag{14}$$

Let us imagine the i -th state has transition probabilities: $(0, \dots, 0, 1, 0, \dots, 0)$. Then that same row would turn into $(0, 0, \dots, 0)$ for some block, thus obtaining a singular matrix. Another case which may give us problems could be: state i has the following transition probabilities: $(0, \dots, 0, 1, 0, \dots, 0)$ and the state j has the following transition probabilities: $(0, \dots, 0, 1, 0, \dots, 0)$. Then when building some blocks we will end up with rows:

$$\begin{aligned}
&(0, \dots, 0, \underset{i}{-1}, 0, \dots, 0, \underset{j}{1}, 0, \dots, 0) \\
&(0, \dots, 0, \underset{i}{1}, 0, \dots, 0, \underset{j}{-1}, 0, \dots, 0)
\end{aligned}$$

which are linearly dependent. Our hypothesis is that if we treat the closed communicating classes differently, we *might* delete the linearity in the system. If we have a closed communicating class C_u , then $h_{i,j} = 1$ for all $i, j \in C_u$ and $h_{k,j} = 0$ for all $k \notin C_u$. Then we can set X_u appropriately and solve the other X_v using those values.

The method in charge of that in `markovchain` package is `hittingProbabilities`, which receives a Markov chain and computes the matrix $(h_{ij})_{i,j=1,\dots,n}$ where $S = \{s_1, \dots, s_n\}$ is the set of all states of the chain.

For the following chain:

```
R> M <- matlab::zeros(5, 5)
R> M[1,1] <- M[5,5] <- 1
R> M[2,1] <- M[2,3] <- 1/2
R> M[3,2] <- M[3,4] <- 1/2
R> M[4,2] <- M[4,5] <- 1/2
R>
R> hittingTest <- new("markovchain", transitionMatrix = M)
R> hittingProbabilities(hittingTest)
```

```
      1      2      3      4      5
1 1.0 0.000 0.000 0.0000000 0.0
2 0.8 0.375 0.500 0.3333333 0.2
3 0.6 0.750 0.375 0.6666667 0.4
4 0.4 0.500 0.250 0.1666667 0.6
5 0.0 0.000 0.000 0.0000000 1.0
```

we want to compute the hitting probabilities. That can be done with:

```
R> hittingProbabilities(hittingTest)
```

```
      1      2      3      4      5
1 1.0 0.000 0.000 0.0000000 0.0
2 0.8 0.375 0.500 0.3333333 0.2
3 0.6 0.750 0.375 0.6666667 0.4
4 0.4 0.500 0.250 0.1666667 0.6
5 0.0 0.000 0.000 0.0000000 1.0
```

In the case of the `mcWeather` Markov chain we would obtain a matrix with all its elements set to 1. That makes sense (and is desirable) since if today is sunny, we expect it would be sunny again at certain point in the time, and the same with rainy weather (that way we assure good harvests):

```
R> hittingProbabilities(mcWeather)
```

```
      sunny cloudy rain
sunny      1      1      1
cloudy      1      1      1
rain        1      1      1
```

5. Statistical analysis

Table 5 lists the functions and methods implemented within the package which help to fit, simulate and predict DTMC.

Function	Purpose
<code>markovchainFit</code>	Function to return fitted Markov chain for a given sequence.
<code>predict</code>	Method to calculate predictions from <code>markovchain</code> or <code>markovchainList</code> objects.
<code>rmarkovchain</code>	Function to sample from <code>markovchain</code> or <code>markovchainList</code> objects.

Table 5: The **markovchain** statistical functions.

5.1. Simulation

Simulating a random sequence from an underlying DTMC is quite easy thanks to the function `rmarkovchain`. The following code generates a year of weather states according to `mcWeather` underlying stochastic process.

```
R> weathersOfDays <- rmarkovchain(n = 365, object = mcWeather, t0 = "sunny")
R> weathersOfDays[1:30]

 [1] "sunny" "sunny" "rain"   "cloudy" "cloudy" "cloudy" "rain"   "rain"
 [9] "rain"  "cloudy" "rain"   "rain"   "rain"   "rain"   "cloudy" "cloudy"
[17] "sunny" "sunny" "sunny"  "sunny"  "sunny"  "cloudy" "sunny"  "sunny"
[25] "sunny" "cloudy" "sunny"  "rain"   "rain"   "rain"
```

Similarly, it is possible to simulate one or more sequences from a non-homogeneous Markov chain, as the following code (applied on CCHC example) exemplifies.

```
R> patientStates <- rmarkovchain(n = 5, object = mcCCRC, t0 = "H",
R+                               include.t0 = TRUE)
R> patientStates[1:10,]

  iteration values
1         1      H
2         1      D
3         1      D
4         1      D
5         1      D
6         2      H
7         2      H
8         2      I
9         2      D
10        2      D
```

Two advance parameters are available to the `rmarkovchain` method which helps you decide which implementation to use. There are four options available : R, R in parallel, C++ and C++ in parallel. Two boolean parameters `useRcpp` and `parallel` will decide which implementation will be used. Default is `useRcpp = TRUE` and `parallel = FALSE` i.e. C++ implementation. The C++ implementation is generally faster than the R implementation. If you have multicore processors then you can take advantage of `parallel` parameter by setting

it to TRUE. When both `Rcpp=TRUE` and `parallel=TRUE` the parallelization has been carried out using **RcppParallel** package (Allaire, Francois, Ushey, Vandenbrouck, Geelnard, and Intel 2016).

5.2. Estimation

A time homogeneous Markov chain can be fit from given data. Four methods have been implemented within current version of **markovchain** package: maximum likelihood, maximum likelihood with Laplace smoothing, Bootstrap approach, maximum a posteriori.

Equation 15 shows the maximum likelihood estimator (MLE) of the p_{ij} entry, where the n_{ij} element consists in the number sequences ($X_t = s_i, X_{t+1} = s_j$) found in the sample, that is

$$\hat{p}_{ij}^{MLE} = \frac{n_{ij}}{\sum_{u=1}^k n_{iu}}. \quad (15)$$

Equation (16) shows the `standardError` of the MLE (Skuriat-Olechnowska 2005).

$$SE_{ij} = \frac{\hat{p}_{ij}^{MLE}}{\sqrt{n_{ij}}} \quad (16)$$

```
R> weatherFittedMLE <- markovchainFit(data = weathersOfDays, method = "mle", name = "Weather")
R> weatherFittedMLE$estimate
```

Weather MLE

A 3 - dimensional discrete Markov Chain defined by the following states:

cloudy, rain, sunny

The transition matrix (by rows) is defined as follows:

	cloudy	rain	sunny
cloudy	0.4102564	0.34188034	0.2478632
rain	0.4315789	0.42105263	0.1473684
sunny	0.1842105	0.09868421	0.7171053

```
R> weatherFittedMLE$standardError
```

	cloudy	rain	sunny
cloudy	0.05921541	0.05405603	0.04602705
rain	0.06740131	0.06657427	0.03938587
sunny	0.03481252	0.02548015	0.06868623

The Laplace smoothing approach is a variation of the MLE, where the n_{ij} is substituted by $n_{ij} + \alpha$ (see Equation 17), being α an arbitrary positive stabilizing parameter.

$$\hat{p}_{ij}^{LS} = \frac{n_{ij} + \alpha}{\sum_{u=1}^k (n_{iu} + \alpha)} \quad (17)$$

```
R> weatherFittedLAPLACE <- markovchainFit(data = weathersOfDays,
R+                                     method = "laplace", laplacian = 0.01,
R+                                     name = "Weather LAPLACE")
R> weatherFittedLAPLACE$estimate
```

Weather LAPLACE

A 3 - dimensional discrete Markov Chain defined by the following states:

cloudy, rain, sunny

The transition matrix (by rows) is defined as follows:

	cloudy	rain	sunny
cloudy	0.4102367	0.34187815	0.2478852
rain	0.4315479	0.42102494	0.1474271
sunny	0.1842400	0.09873051	0.7170295

(NOTE: The Confidence Interval option is enabled by default. Remove this option to fasten computations.) Both MLE and Laplace approach are based on the `createSequenceMatrix` functions that returns the raw counts transition matrix.

```
R> createSequenceMatrix(stringchar = weathersOfDays)
```

	cloudy	rain	sunny
cloudy	48	40	29
rain	41	40	14
sunny	28	15	109

`stringchar` could contain NA values, and the transitions containing NA would be ignored.

An issue occurs when the sample contains only one realization of a state (say X_β) which is located at the end of the data sequence, since it yields to a row of zero (no sample to estimate the conditional distribution of the transition). In this case the estimated transition matrix is corrected assuming $p_{\beta,j} = 1/k$, being k the possible states.

Create sequence matrix can also be used to obtain raw count transition matrices from a given $n * 2$ matrix as the following example shows:

```
R> myMatr<-matrix(c("a", "b", "b", "a", "a", "b", "b", "b", "b", "a", "a", "a", "b", "a"), ncol=2)
R> createSequenceMatrix(stringchar = myMatr, toRowProbs = TRUE)
```

	a	b
a	0.6666667	0.3333333
b	0.5000000	0.5000000

A bootstrap estimation approach has been developed within the package in order to provide an indication of the variability of \hat{p}_{ij} estimates. The bootstrap approach implemented within the **markovchain** package follows these steps:

1. bootstrap the data sequences following the conditional distributions of states estimated from the original one. The default bootstrap samples is 10, as specified in `nboot` parameter of `markovchainFit` function.

2. apply MLE estimation on bootstrapped data sequences that are saved in `bootStrapSamples` slot of the returned list.
3. the $p^{BOOTSTRAP}_{ij}$ is the average of all p^{MLE}_{ij} across the `bootStrapSamples` list, normalized by row. A `standardError` of $p^{\hat{MLE}}_{ij}$ estimate is provided as well.

```
R> weatherFittedBOOT <- markovchainFit(data = weathersOfDays,
R+                               method = "bootstrap", nboot = 20)
R> weatherFittedBOOT$estimate
```

BootStrap Estimate

A 3 - dimensional discrete Markov Chain defined by the following states:

cloudy, rain, sunny

The transition matrix (by rows) is defined as follows:

	cloudy	rain	sunny
cloudy	0.4157240	0.32558044	0.2586955
rain	0.4314429	0.43353348	0.1350236
sunny	0.2011393	0.09714363	0.7017171

```
R> weatherFittedBOOT$standardError
```

	cloudy	rain	sunny
cloudy	0.008619212	0.007458442	0.008230809
rain	0.011101363	0.010771502	0.010903673
sunny	0.009353447	0.004539744	0.010628300

The bootstrapping process can be done in parallel thanks to **RcppParallel** package (Allaire *et al.* 2016). Parallelized implementation is definitively suggested when the data sample size or the required number of bootstrap runs is high.

```
R> weatherFittedBOOTParallel <- markovchainFit(data = weathersOfDays,
R>                               method = "bootstrap", nboot = 200,
R>                               parallel = TRUE)
R> weatherFittedBOOTParallel$estimate
R> weatherFittedBOOTParallel$standardError
```

The parallel bootstrapping uses all the available cores on a machine by default. However, it is also possible to tune the number of threads used. Note that this should be done in R before calling the `markovchainFit` function. For example, the following code will set the number of threads to 4.

```
R> RcppParallel::setNumThreads(2)
```

For more details, please refer to **RcppParallel** web site.

For all the fitting methods, the `logLikelihood` (Skuriat-Olechnowska 2005) denoted in Equation 18 is provided.

$$LLH = \sum_{i,j} n_{ij} * \log(p_{ij}) \quad (18)$$

where n_{ij} is the entry of the frequency matrix and p_{ij} is the entry of the transition probability matrix.

```
R> weatherFittedMLE$logLikelihood
```

```
[1] -340.3603
```

```
R> weatherFittedBOOT$logLikelihood
```

```
[1] -340.6464
```

Confidence matrices of estimated parameters (parametric for MLE, non - parametric for Boot-Strap) are available as well. The `confidenceInterval` is provided with the two matrices: `lowerEndpointMatrix` and `upperEndpointMatrix`. The confidence level (CL) is 0.95 by default and can be given as an argument of the function `markovchainFit`. This is used to obtain the standard score (z-score). From classical inference theory, if ci is the level of confidence required assuming normal distribution the $zscore(ci)$ solves $\Phi\left(1 - \left(\frac{1-ci}{2}\right)\right)$ Equations 19 and 20 (Skuriat-Olechnowska 2005) show the `confidenceInterval` of a fitting. Note that each entry of the matrices is bounded between 0 and 1.

$$LowerEndpoint_{ij} = p_{ij} - zscore(CL) * SE_{ij} \quad (19)$$

$$UpperEndpoint_{ij} = p_{ij} + zscore(CL) * SE_{ij} \quad (20)$$

```
R> weatherFittedMLE$confidenceInterval
```

```
NULL
```

```
R> weatherFittedBOOT$confidenceInterval
```

```
$confidenceLevel
```

```
[1] 0.95
```

```
$lowerEndpointMatrix
```

	cloudy	rain	sunny
cloudy	0.4015467	0.31331240	0.2451570
rain	0.4131828	0.41581594	0.1170886
sunny	0.1857542	0.08967642	0.6842351

```
$upperEndpointMatrix
```

	cloudy	rain	sunny
cloudy	0.4299014	0.3378485	0.2722340
rain	0.4497031	0.4512510	0.1529585
sunny	0.2165243	0.1046108	0.7191991

A special function, `multinomialConfidenceIntervals`, has been written in order to obtain multinomial wise confidence intervals. The code has been based on and Rcpp translation of package's **MultinomialCI** functions Villacorta (2012) that were themselves based on the Sison and Glaz (1995) paper.

```
R> multinomialConfidenceIntervals(transitionMatrix =
R+   weatherFittedMLE$estimate@transitionMatrix,
R+   countsTransitionMatrix = createSequenceMatrix(weathersOfDays))
```

```
$confidenceLevel
[1] 0.95
```

```
$lowerEndpointMatrix
      cloudy      rain      sunny
cloudy 0.3162393 0.24786325 0.15384615
rain   0.3368421 0.32631579 0.05263158
sunny  0.1184211 0.03289474 0.65131579
```

```
$upperEndpointMatrix
      cloudy      rain      sunny
cloudy 0.5098498 0.4414738 0.3474567
rain   0.5460851 0.5355588 0.2618746
sunny  0.2569922 0.1714659 0.7898870
```

The functions for fitting DTMC have mostly been rewritten in C++ using **Rcpp** Eddelbuettel (2013) since version 0.2.

It is also possible to fit a DTMC object from `matrix` or `data.frame` objects as shown in following code.

```
R> data(holson)
R> singleMc<-markovchainFit(data=holson[,2:12],name="holson")
```

The same applies for `markovchainList`.

```
R> mcListFit<-markovchainListFit(data=holson[,2:6],name="holson")
R> mcListFit$estimate
```

```
holson list of Markov chain(s)
Markovchain 1
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1
```

Markovchain 2

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 3

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.8 0.2

2 0.5 0.5

Markovchain 4

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 5

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 6

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.8 0.2

2 0.5 0.5

Markovchain 7

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

1 2
1 1 0
2 1 0

```

Markovchain 8

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 9

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

1 3
1 0.0 1.0
3 0.5 0.5

```

Markovchain 10

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

1 3
1 0.5 0.5
3 1.0 0.0

```

Markovchain 11

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 12

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

1 2
1 0.8 0.2
2 0.5 0.5

```

Markovchain 13

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.5000000	0.5000000
2	0.0000000	0.0000000	1.0000000
3	0.3333333	0.3333333	0.3333333

Markovchain 14

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 15

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.2000000	0.8000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 16

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	0.7500000	0.2500000	0.0000000

Markovchain 17

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1		
2		

1 1 0
2 1 0

Markovchain 18

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 19

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 20

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3
1 0.0 1.0
3 0.5 0.5

Markovchain 21

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3
1 0.5 0.5
3 1.0 0.0

Markovchain 22

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 23

Unnamed Markov chain

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

```

Markovchain 24

Unnamed Markov chain

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

```

Markovchain 25

Unnamed Markov chain

```

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
      1      2      3
1 0.000000 0.800000 0.200000
2 0.333333 0.333333 0.333333
3 0.333333 0.333333 0.333333

```

Markovchain 26

Unnamed Markov chain

```

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
      1      2      3
1 0.333333 0.333333 0.333333
2 0.750000 0.250000 0.000000
3 1.000000 0.000000 0.000000

```

Markovchain 27

Unnamed Markov chain

```

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
      1      2
1 0.5 0.5
2 1.0 0.0

```

Markovchain 28

Unnamed Markov chain

```

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

```

The transition matrix (by rows) is defined as follows:

```

1 2
1 1 0
2 1 0

```

Markovchain 29

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 30

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 31

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 32

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 33

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

1 3
1 0.0 1.0
3 0.5 0.5

```

Markovchain 34

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

3

The transition matrix (by rows) is defined as follows:

3

3 1

Markovchain 35

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.5 0.5

3 1.0 0.0

Markovchain 36

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.6 0.4

2 0.5 0.5

Markovchain 37

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0 1

2 0 1

Markovchain 38

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.5 0.5

2 1.0 0.0

Markovchain 39

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 40

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```
1
The transition matrix (by rows) is defined as follows:
```

```
1
1 1
```

Markovchain 41

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```
1
The transition matrix (by rows) is defined as follows:
```

```
1
1 1
```

Markovchain 42

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```
1
The transition matrix (by rows) is defined as follows:
```

```
1
1 1
```

Markovchain 43

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```
1
The transition matrix (by rows) is defined as follows:
```

```
1
1 1
```

Markovchain 44

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```
1
The transition matrix (by rows) is defined as follows:
```

```
1
1 1
```

Markovchain 45

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```

1
The transition matrix (by rows) is defined as follows:
  1
1 1

Markovchain 46
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3
The transition matrix (by rows) is defined as follows:
  1  3
1 0.0 1.0
3 0.5 0.5

Markovchain 47
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3
The transition matrix (by rows) is defined as follows:
  1  3
1 0.5 0.5
3 1.0 0.0

Markovchain 48
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.2 0.8
2 0.5 0.5

Markovchain 49
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 1 0
2 1 0

Markovchain 50
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1

```

1 1

Markovchain 51

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 52

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 53

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 54

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 55

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 56

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 57

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 58

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 59

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 60

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

1 3
1 0.0 1.0
3 0.5 0.5

```

Markovchain 61

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

1 3
1 0.5 0.5
3 1.0 0.0

```

Markovchain 62

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
 1, 2
 The transition matrix (by rows) is defined as follows:
 1 2
 1 0.4 0.6
 2 0.5 0.5

Markovchain 63

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
 1, 2
 The transition matrix (by rows) is defined as follows:
 1 2
 1 1 0
 2 1 0

Markovchain 64

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 65

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
 1, 2
 The transition matrix (by rows) is defined as follows:
 1 2
 1 0.0 1.0
 2 0.5 0.5

Markovchain 66

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
 1, 2
 The transition matrix (by rows) is defined as follows:
 1 2
 1 0.5 0.5
 2 1.0 0.0

Markovchain 67

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 68

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 69

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 70

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 71

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 72

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 73

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.2000000	0.8000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 74

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 75

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 76

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 77

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.0	1.0
2	0.5	0.5

Markovchain 78

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1	2
---	---

```
1 0.5 0.5
2 1.0 0.0
```

Markovchain 79

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
1 3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 80

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
1 3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 81

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
1 2
1 0.8 0.2
2 0.5 0.5
```

Markovchain 82

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
1 2
1 1 0
2 1 0
```

Markovchain 83

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 84

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 85

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 86

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 87

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.6 0.4

2 0.5 0.5

Markovchain 88

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.000000 0.666667 0.333333

2 0.000000 0.500000 0.500000

3 0.333333 0.333333 0.333333

Markovchain 89

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 90

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 91

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.2000000	0.8000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 92

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 93

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 94

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 95

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 96

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 97

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 0.8 0.2
2 0.5 0.5

Markovchain 98

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 0.75 0.25
2 1.00 0.00

Markovchain 99

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 1 0
2 1 0

Markovchain 100

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
  1  3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 101

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
  1  3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 102

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 103

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 104

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 105

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
```

1 1

Markovchain 106

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 107

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 108

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 0.8 0.2
2 0.5 0.5

Markovchain 109

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 1 0
2 1 0

Markovchain 110

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3
1 0.0 1.0
3 0.5 0.5

Markovchain 111

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

```

  1  3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 112

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

```

      1      2      3
1 0.0000000 0.8000000 0.2000000
2 0.3333333 0.3333333 0.3333333
3 0.3333333 0.3333333 0.3333333
```

Markovchain 113

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

```

      1      2      3
1 0.3333333 0.3333333 0.3333333
2 0.7500000 0.2500000 0.0000000
3 1.0000000 0.0000000 0.0000000
```

Markovchain 114

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

The transition matrix (by rows) is defined as follows:

```

  1  2
1 1 0
2 1 0
```

Markovchain 115

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1

The transition matrix (by rows) is defined as follows:

```

  1
1 1
```

Markovchain 116

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```

1, 3
The transition matrix (by rows) is defined as follows:
  1  3
1 0.0 1.0
3 0.5 0.5

Markovchain 117
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3
The transition matrix (by rows) is defined as follows:
  1  3
1 0.5 0.5
3 1.0 0.0

Markovchain 118
Unnamed Markov chain
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
      1      2      3
1 0.0000000 0.6000000 0.4000000
2 0.3333333 0.3333333 0.3333333
3 0.3333333 0.3333333 0.3333333

Markovchain 119
Unnamed Markov chain
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
      1      2      3
1 0.3333333 0.3333333 0.3333333
2 0.6666667 0.3333333 0.0000000
3 0.0000000 1.0000000 0.0000000

Markovchain 120
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 1 0
2 1 0

Markovchain 121
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:

```

```
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.0 1.0
2 0.5 0.5

Markovchain 122
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
2
The transition matrix (by rows) is defined as follows:
  2
2 1

Markovchain 123
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.5 0.5
2 1.0 0.0

Markovchain 124
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1

Markovchain 125
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.8 0.2
2 0.5 0.5

Markovchain 126
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 1 0
```

2 1 0

Markovchain 127

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 128

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 129

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 130

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 0.4 0.6
2 0.5 0.5

Markovchain 131

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 1 0
2 1 0

Markovchain 132

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```

1, 3
The transition matrix (by rows) is defined as follows:
  1  3
1 0.8 0.2
3 0.5 0.5

Markovchain 133
Unnamed Markov chain
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
  1  2  3
1 0.7500000 0.2500000 0.0000000
2 0.3333333 0.3333333 0.3333333
3 1.0000000 0.0000000 0.0000000

Markovchain 134
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 1 0
2 1 0

Markovchain 135
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1

Markovchain 136
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1

Markovchain 137
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2

```

```
1 0.6 0.4
2 0.5 0.5
```

Markovchain 138

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.33333333	0.66666667	0.00000000
2	0.00000000	0.50000000	0.50000000
3	0.33333333	0.33333333	0.33333333

Markovchain 139

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0	0	1
2	0	0	1
3	0	0	1

Markovchain 140

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.33333333	0.33333333	0.33333333
2	0.33333333	0.33333333	0.33333333
3	0.60000000	0.40000000	0.00000000

Markovchain 141

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	0
2	1	0

Markovchain 142

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 143

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

      1   3
1 0.0 1.0
3 0.5 0.5

```

Markovchain 144

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

      1   3
1 0.5 0.5
3 1.0 0.0

```

Markovchain 145

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

      1       2       3
1 0.0000000 0.6000000 0.4000000
2 0.3333333 0.3333333 0.3333333
3 0.3333333 0.3333333 0.3333333

```

Markovchain 146

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

      1       2       3
1 0.3333333 0.3333333 0.3333333
2 1.0000000 0.0000000 0.0000000
3 1.0000000 0.0000000 0.0000000

```

Markovchain 147

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

      1   3

```

```
1 0.0 1.0
3 0.5 0.5
```

Markovchain 148

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
1 3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 149

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
1 3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 150

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
1 2 3
1 0.3333333 0.3333333 0.3333333
2 0.3333333 0.3333333 0.3333333
3 0.2000000 0.4000000 0.4000000
```

Markovchain 151

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
1 2 3
1 1 0 0
2 1 0 0
3 1 0 0
```

Markovchain 152

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
```

1 1

Markovchain 153

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.0	1.0
3	0.5	0.5

Markovchain 154

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
3

The transition matrix (by rows) is defined as follows:

	3
3	1

Markovchain 155

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	0.3333333	0.3333333	0.3333333
3	0.6000000	0.4000000	0.0000000

Markovchain 156

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.0000000	1.0000000
2	0.0000000	0.0000000	1.0000000
3	0.3333333	0.3333333	0.3333333

Markovchain 157

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.5	0.5
3	1.0	0.0

Markovchain 158

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 159

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 160

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 161

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.0 1.0

3 0.5 0.5

Markovchain 162

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.5 0.5

3 1.0 0.0

Markovchain 163

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 164

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```
1
The transition matrix (by rows) is defined as follows:
```

```
1
1 1
```

Markovchain 165

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```
1, 3
The transition matrix (by rows) is defined as follows:
```

```
1 3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 166

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```
1, 3
The transition matrix (by rows) is defined as follows:
```

```
1 3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 167

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

```
1, 2, 3
The transition matrix (by rows) is defined as follows:
```

```
1 2 3
1 0.0000000 0.4000000 0.6000000
2 0.3333333 0.3333333 0.3333333
3 0.3333333 0.3333333 0.3333333
```

Markovchain 168

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

```
1, 2, 3
The transition matrix (by rows) is defined as follows:
```

```
1 2 3
1 0.3333333 0.3333333 0.3333333
```

```
2 1.0000000 0.0000000 0.0000000
3 1.0000000 0.0000000 0.0000000
```

Markovchain 169

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 170

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 171

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 172

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 173

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
1 3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 174

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

  1  3
1 0.5 0.5
3 1.0 0.0

```

Markovchain 175

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

  1  3
1 0.0 1.0
3 0.5 0.5

```

Markovchain 176

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

  1  3
1 0.5 0.5
3 1.0 0.0

```

Markovchain 177

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

  1  3
1 0.0 1.0
3 0.5 0.5

```

Markovchain 178

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

3

The transition matrix (by rows) is defined as follows:

```

  3
3 1

```

Markovchain 179

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

  1  3

```

```
1 0.5 0.5
3 1.0 0.0
```

Markovchain 180

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 181

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
1 2
1 0.2 0.8
2 0.5 0.5
```

Markovchain 182

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
1 2
1 1 0
2 1 0
```

Markovchain 183

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
1 3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 184

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

2, 3

The transition matrix (by rows) is defined as follows:

```
2 3
2 0.5 0.5
3 0.2 0.8
```

Markovchain 185

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
2, 3

The transition matrix (by rows) is defined as follows:

```
      2    3
2 0.00 1.00
3 0.75 0.25
```

Markovchain 186

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
2, 3

The transition matrix (by rows) is defined as follows:

```
      2 3
2 0 1
3 0 1
```

Markovchain 187

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

```
      1    3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 188

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1

The transition matrix (by rows) is defined as follows:

```
      1
1 1
```

Markovchain 189

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

```
      1    3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 190

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

2, 3
 The transition matrix (by rows) is defined as follows:
 2 3
 2 0.5 0.5
 3 0.2 0.8

Markovchain 191
 Unnamed Markov chain
 A 2 - dimensional discrete Markov Chain defined by the following states:
 2, 3
 The transition matrix (by rows) is defined as follows:
 2 3
 2 0 1
 3 0 1

Markovchain 192
 Unnamed Markov chain
 A 2 - dimensional discrete Markov Chain defined by the following states:
 1, 3
 The transition matrix (by rows) is defined as follows:
 1 3
 1 0.5 0.5
 3 1.0 0.0

Markovchain 193
 Unnamed Markov chain
 A 2 - dimensional discrete Markov Chain defined by the following states:
 1, 3
 The transition matrix (by rows) is defined as follows:
 1 3
 1 0.0 1.0
 3 0.5 0.5

Markovchain 194
 Unnamed Markov chain
 A 2 - dimensional discrete Markov Chain defined by the following states:
 1, 3
 The transition matrix (by rows) is defined as follows:
 1 3
 1 0.5 0.5
 3 1.0 0.0

Markovchain 195
 Unnamed Markov chain
 A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 196

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 197

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 198

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

1 2
1 0.0 1.0
2 0.5 0.5

```

Markovchain 199

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

1 2
1 0.5 0.5
2 1.0 0.0

```

Markovchain 200

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 201

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
1 2
1 0.6 0.4
2 0.5 0.5

Markovchain 202

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
1 2
1 1 0
2 1 0

Markovchain 203

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 204

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 205

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 206

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 207

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1  2
1 0.8 0.2
2 0.5 0.5
```

Markovchain 208

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1  2
1 0.75 0.25
2 1.00 0.00
```

Markovchain 209

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1  2
1 1 0
2 1 0
```

Markovchain 210

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 211

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 212

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 213
 Unnamed Markov chain
 A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 214
 Unnamed Markov chain
 A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 215
 Unnamed Markov chain
 A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 216
 Unnamed Markov chain
 A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 217
 Unnamed Markov chain
 A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 218
 Unnamed Markov chain

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

```

Markovchain 219

Unnamed Markov chain

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

```

Markovchain 220

Unnamed Markov chain

```

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
1 2
1 0.6 0.4
2 0.5 0.5

```

Markovchain 221

Unnamed Markov chain

```

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
1 2
1 1 0
2 1 0

```

Markovchain 222

Unnamed Markov chain

```

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
1 2
1 0.2 0.8
2 0.5 0.5

```

Markovchain 223

Unnamed Markov chain

```

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
1 2

```

1 1 0
2 1 0

Markovchain 224

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 225

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 226

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 227

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 228

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 229

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 230

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```
1
The transition matrix (by rows) is defined as follows:
```

```
1
1 1
```

Markovchain 231

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```
1, 3
The transition matrix (by rows) is defined as follows:
```

```
1 3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 232

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```
1, 3
The transition matrix (by rows) is defined as follows:
```

```
1 3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 233

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

```
1, 2, 3
The transition matrix (by rows) is defined as follows:
```

```
1 2 3
1 0.0000000 0.2000000 0.8000000
2 0.3333333 0.3333333 0.3333333
3 0.3333333 0.3333333 0.3333333
```

Markovchain 234

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

```
1, 2, 3
The transition matrix (by rows) is defined as follows:
```

```
1 2 3
1 0.3333333 0.3333333 0.3333333
```

```

2 1.0000000 0.0000000 0.0000000
3 1.0000000 0.0000000 0.0000000

```

Markovchain 235

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 236

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 237

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
--	---	---	---

1	0.2000000	0.2000000	0.6000000
---	-----------	-----------	-----------

2	0.3333333	0.3333333	0.3333333
---	-----------	-----------	-----------

3	0.3333333	0.3333333	0.3333333
---	-----------	-----------	-----------

Markovchain 238

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
--	---	---	---

1	1	0	0
---	---	---	---

2	1	0	0
---	---	---	---

3	1	0	0
---	---	---	---

Markovchain 239

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
--	---	---

1	0.6	0.4
---	-----	-----

2	0.5	0.5
---	-----	-----

Markovchain 240

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 241

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 242

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 243

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.6 0.4

2 0.5 0.5

Markovchain 244

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 245

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```

1, 3
The transition matrix (by rows) is defined as follows:
  1  3
1 0.0 1.0
3 0.5 0.5

Markovchain 246
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
3
The transition matrix (by rows) is defined as follows:
  3
3 1

Markovchain 247
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3
The transition matrix (by rows) is defined as follows:
  1  3
1 0.5 0.5
3 1.0 0.0

Markovchain 248
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1

Markovchain 249
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1

Markovchain 250
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1

```

Markovchain 251

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.8	0.2
2	0.5	0.5

Markovchain 252

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.5	0.5
2	0.0	1.0

Markovchain 253

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.0000000	1.0000000
2	0.0000000	0.0000000	1.0000000
3	0.3333333	0.3333333	0.3333333

Markovchain 254

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.5	0.5
3	1.0	0.0

Markovchain 255

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 256

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.2000000	0.6000000	0.2000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 257

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	1	0	0
2	1	0	0
3	1	0	0

Markovchain 258

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.2000000	0.4000000	0.4000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 259

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	1	0	0
2	1	0	0
3	1	0	0

Markovchain 260

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 261

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.4000000	0.6000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 262

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 263

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.6	0.4
2	0.5	0.5

Markovchain 264

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.0000000	1.0000000
2	0.0000000	0.0000000	1.0000000
3	0.3333333	0.3333333	0.3333333

Markovchain 265

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	0.3333333	0.3333333	0.3333333
3	0.8000000	0.2000000	0.0000000

Markovchain 266

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 267

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.6 0.4

2 0.5 0.5

Markovchain 268

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.6666667 0.3333333

2 0.5000000 0.5000000

Markovchain 269

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 270

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.8 0.2

2 0.5 0.5

Markovchain 271

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 272

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 273

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 274

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.8 0.2

2 0.5 0.5

Markovchain 275

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.000000 0.750000 0.250000

2 0.000000 0.000000 1.000000

3 0.333333 0.333333 0.333333

Markovchain 276

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 277

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.0	1.0
2	0.5	0.5

Markovchain 278

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

2, 3

The transition matrix (by rows) is defined as follows:

	2	3
2	0.0	1.0
3	0.5	0.5

Markovchain 279

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.5	0.5
3	1.0	0.0

Markovchain 280

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.6000000	0.4000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 281

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 282

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.2000000	0.8000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 283

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 284

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 285

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.6000000	0.4000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 286

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	0.3333333	0.6666667	0.0000000
3	0.0000000	1.0000000	0.0000000

Markovchain 287

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	0
2	1	0

Markovchain 288

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 289

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 290

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 291

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.6	0.4

2 0.5 0.5

Markovchain 292

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0 1

2 0 1

Markovchain 293

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.5 0.5

2 1.0 0.0

Markovchain 294

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.2 0.8

2 0.5 0.5

Markovchain 295

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.000000 1.000000 0.000000

2 0.000000 0.000000 1.000000

3 0.3333333 0.3333333 0.3333333

Markovchain 296

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

2, 3

The transition matrix (by rows) is defined as follows:

2 3

2 1.00 0.00

3 0.75 0.25

Markovchain 297

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 298

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.6	0.4
2	0.5	0.5

Markovchain 299

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	0
2	1	0

Markovchain 300

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 301

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 302

Unnamed Markov chain

```
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.4 0.6
2 0.5 0.5
```

Markovchain 303

Unnamed Markov chain

```
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 1 0
2 1 0
```

Markovchain 304

Unnamed Markov chain

```
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1
```

Markovchain 305

Unnamed Markov chain

```
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1
```

Markovchain 306

Unnamed Markov chain

```
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1
```

Markovchain 307

Unnamed Markov chain

```
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.8 0.2
```

2 0.5 0.5

Markovchain 308

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.2500000	0.7500000	0.0000000
2	0.0000000	0.0000000	1.0000000
3	0.3333333	0.3333333	0.3333333

Markovchain 309

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	1	0	0
2	1	0	0
3	1	0	0

Markovchain 310

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 311

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 312

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.8000000	0.2000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 313

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
2, 3

The transition matrix (by rows) is defined as follows:

```

  2 3
2 0 1
3 0 1

```

Markovchain 314

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
2, 3

The transition matrix (by rows) is defined as follows:

```

  2 3
2 0.5 0.5
3 0.6 0.4

```

Markovchain 315

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

```

      1      2      3
1 0.3333333 0.3333333 0.3333333
2 1.0000000 0.0000000 0.0000000
3 1.0000000 0.0000000 0.0000000

```

Markovchain 316

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1

The transition matrix (by rows) is defined as follows:

```

  1
1 1

```

Markovchain 317

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1

The transition matrix (by rows) is defined as follows:

```

  1
1 1

```

Markovchain 318

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 319

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 320

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
 1, 2
 The transition matrix (by rows) is defined as follows:
 1 2
 1 0.6 0.4
 2 0.5 0.5

Markovchain 321

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
 1, 2, 3
 The transition matrix (by rows) is defined as follows:
 1 2 3
 1 0.000000 0.000000 1.000000
 2 0.000000 0.000000 1.000000
 3 0.333333 0.333333 0.333333

Markovchain 322

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
 1, 3
 The transition matrix (by rows) is defined as follows:
 1 3
 1 0.5 0.5
 3 1.0 0.0

Markovchain 323

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
 1, 2, 3
 The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.6000000	0.4000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 324

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
2, 3

The transition matrix (by rows) is defined as follows:

2	3
2	0 1
3	0 1

Markovchain 325

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
3

The transition matrix (by rows) is defined as follows:

3
3 1

Markovchain 326

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
3

The transition matrix (by rows) is defined as follows:

3
3 1

Markovchain 327

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
3

The transition matrix (by rows) is defined as follows:

3
3 1

Markovchain 328

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

1	3
1	0.5 0.5
3	1.0 0.0

Markovchain 329

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 330

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 331

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 332

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 333

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 334

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.2 0.8

2 0.5 0.5

Markovchain 335

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0 1

2 1 0

Markovchain 336

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.0000000 0.2500000 0.7500000

2 0.0000000 1.0000000 0.0000000

3 0.3333333 0.3333333 0.3333333

Markovchain 337

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.3333333 0.3333333 0.3333333

2 0.5000000 0.5000000 0.0000000

3 0.0000000 0.6666667 0.3333333

Markovchain 338

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.0000000 1.0000000 0

2 0.6666667 0.3333333 0

3 1.0000000 0.0000000 0

Markovchain 339

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0
2 1 0

Markovchain 340

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 341

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3
1 0.0 1.0
3 0.5 0.5

Markovchain 342

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3
1 0.5 0.5
3 1.0 0.0

Markovchain 343

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 344

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 345

Unnamed Markov chain

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

```

Markovchain 346

Unnamed Markov chain

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

```

Markovchain 347

Unnamed Markov chain

```

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
      1      2      3
1 0.000000 0.400000 0.600000
2 0.333333 0.333333 0.333333
3 0.333333 0.333333 0.333333

```

Markovchain 348

Unnamed Markov chain

```

A 2 - dimensional discrete Markov Chain defined by the following states:
2, 3
The transition matrix (by rows) is defined as follows:
  2 3
2 0 1
3 0 1

```

Markovchain 349

Unnamed Markov chain

```

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3
The transition matrix (by rows) is defined as follows:
  1 3
1 0.5 0.5
3 1.0 0.0

```

Markovchain 350

Unnamed Markov chain

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:

```

1
1 1

Markovchain 351

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 352

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 0.4 0.6
2 0.5 0.5

Markovchain 353

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 0 1
2 0 1

Markovchain 354

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 0.5 0.5
2 0.4 0.6

Markovchain 355

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	1.0000000	0.0000000
2	0.0000000	0.0000000	1.0000000
3	0.3333333	0.3333333	0.3333333

Markovchain 356

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
2, 3

The transition matrix (by rows) is defined as follows:

	2	3
2	1.0000000	0.0000000
3	0.6666667	0.3333333

Markovchain 357

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	0.2500000	0.7500000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 358

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	0
2	1	0

Markovchain 359

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.0	1.0
3	0.5	0.5

Markovchain 360

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
3

The transition matrix (by rows) is defined as follows:

	3
3	1

Markovchain 361

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

2, 3

The transition matrix (by rows) is defined as follows:

	2	3
2	0.5	0.5
3	0.2	0.8

Markovchain 362

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	0.2500000	0.7500000	0.0000000

Markovchain 363

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1.0000000	0.0000000
2	0.6666667	0.3333333

Markovchain 364

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	0
2	1	0

Markovchain 365

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 366

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
  1  3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 367

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

2, 3

The transition matrix (by rows) is defined as follows:

```
  2  3
2 0.5 0.5
3 1.0 0.0
```

Markovchain 368

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1  2
1 0.5 0.5
2 1.0 0.0
```

Markovchain 369

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 370

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 371

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 372

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.4000000	0.4000000	0.2000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 373

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.5	0.5	0
2	1.0	0.0	0
3	1.0	0.0	0

Markovchain 374

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.25	0.75
2	0.00	1.00

Markovchain 375

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.00	1.00
2	0.75	0.25

Markovchain 376

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.3333333	0.6666667
2	0.5000000	0.5000000	0.0000000

```
3 0.3333333 0.3333333 0.3333333
```

```
Markovchain 377
```

```
Unnamed Markov chain
```

```
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
```

```
The transition matrix (by rows) is defined as follows:
```

```
  1 2 3
1 1 0 0
2 1 0 0
3 1 0 0
```

```
Markovchain 378
```

```
Unnamed Markov chain
```

```
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3
```

```
The transition matrix (by rows) is defined as follows:
```

```
  1 3
1 0.0 1.0
3 0.5 0.5
```

```
Markovchain 379
```

```
Unnamed Markov chain
```

```
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
```

```
The transition matrix (by rows) is defined as follows:
```

```
  1 2 3
1 0.3333333 0.3333333 0.3333333
2 0.3333333 0.3333333 0.3333333
3 0.4000000 0.4000000 0.2000000
```

```
Markovchain 380
```

```
Unnamed Markov chain
```

```
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
```

```
The transition matrix (by rows) is defined as follows:
```

```
  1 2 3
1 1 0 0
2 1 0 0
3 1 0 0
```

```
Markovchain 381
```

```
Unnamed Markov chain
```

```
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
```

```
The transition matrix (by rows) is defined as follows:
```

```
  1 2 3
```

```

1 0.0000000 0.2000000 0.8000000
2 0.3333333 0.3333333 0.3333333
3 0.3333333 0.3333333 0.3333333

```

Markovchain 382

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

           1         2         3
1 0.3333333 0.3333333 0.3333333
2 1.0000000 0.0000000 0.0000000
3 1.0000000 0.0000000 0.0000000

```

Markovchain 383

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 384

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 385

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

           1         2
1 0.8 0.2
2 0.5 0.5

```

Markovchain 386

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

           1         2
1 1 0
2 1 0

```

Markovchain 387

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 388

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.8 0.2

2 0.5 0.5

Markovchain 389

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 390

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.0 1.0

3 0.5 0.5

Markovchain 391

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

2, 3

The transition matrix (by rows) is defined as follows:

2 3

2 0.5 0.5

3 0.2 0.8

Markovchain 392

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 393

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 394

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 395

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 396

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.2	0.8
2	0.5	0.5

Markovchain 397

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	2

```
1 1 0
2 1 0
```

Markovchain 398

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 399

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
1 2
1 0.0 1.0
2 0.5 0.5
```

Markovchain 400

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

2

The transition matrix (by rows) is defined as follows:

```
2
2 1
```

Markovchain 401

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
1 2
1 0.5 0.5
2 1.0 0.0
```

Markovchain 402

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
1 2 3
1 0.000000 0.800000 0.200000
2 0.333333 0.333333 0.333333
3 0.333333 0.333333 0.333333
```

Markovchain 403

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 404

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.8	0.2
2	0.5	0.5

Markovchain 405

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.0000000	1.0000000
2	0.0000000	0.0000000	1.0000000
3	0.3333333	0.3333333	0.3333333

Markovchain 406

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.5	0.5
3	1.0	0.0

Markovchain 407

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.8	0.2
2	0.5	0.5

Markovchain 408

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1  2
1 0.5 0.5
2 0.0 1.0
```

Markovchain 409

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
      1      2      3
1 0.000000 0.500000 0.500000
2 0.333333 0.333333 0.333333
3 0.333333 0.333333 0.333333
```

Markovchain 410

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
  1  2  3
1 1 0.0 0.0
2 0 1.0 0.0
3 0 0.5 0.5
```

Markovchain 411

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
  1  2  3
1 1 0 0
2 1 0 0
3 1 0 0
```

Markovchain 412

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 413

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 414

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.2000000 0.6000000 0.2000000

2 0.3333333 0.3333333 0.3333333

3 0.3333333 0.3333333 0.3333333

Markovchain 415

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0 1 0

2 0 1 0

3 0 0 1

Markovchain 416

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

2, 3

The transition matrix (by rows) is defined as follows:

2 3

2 1 0

3 1 0

Markovchain 417

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

2, 3

The transition matrix (by rows) is defined as follows:

2 3

2 0.2 0.8

3 0.5 0.5

Markovchain 418

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 419

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.8	0.2
2	0.5	0.5

Markovchain 420

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	0
2	1	0

Markovchain 421

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 422

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.8	0.2
2	0.5	0.5

Markovchain 423

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```

1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.75 0.25
2 0.00 1.00

Markovchain 424
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.0 1.0
2 0.5 0.5

Markovchain 425
Unnamed Markov chain
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
  1      2      3
1 0.0000000 0.0000000 1.0000000
2 0.0000000 0.5000000 0.5000000
3 0.3333333 0.3333333 0.3333333

Markovchain 426
Unnamed Markov chain
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
  1      2      3
1 0.3333333 0.3333333 0.3333333
2 1.0000000 0.0000000 0.0000000
3 1.0000000 0.0000000 0.0000000

Markovchain 427
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1

Markovchain 428
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1

```

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 429

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
1 2
1 0.6 0.4
2 0.5 0.5
```

Markovchain 430

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
1 2
1 1 0
2 1 0
```

Markovchain 431

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 432

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 433

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
1 2 3
1 0.0000000 0.8000000 0.2000000
2 0.3333333 0.3333333 0.3333333
3 0.3333333 0.3333333 0.3333333
```

Markovchain 434

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 435

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 436

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 437

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.6	0.4
2	0.5	0.5

Markovchain 438

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1	1	0
2	1	0

Markovchain 439

Unnamed Markov chain

```
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1
```

Markovchain 440

Unnamed Markov chain

```
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1
```

Markovchain 441

Unnamed Markov chain

```
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1
```

Markovchain 442

Unnamed Markov chain

```
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1
```

Markovchain 443

Unnamed Markov chain

```
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1
```

Markovchain 444

Unnamed Markov chain

```
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1
```

Markovchain 445

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 446

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 0.4 0.6
2 0.5 0.5

Markovchain 447

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 1 0
2 1 0

Markovchain 448

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 449

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 450

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 451

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.2 0.8

2 0.5 0.5

Markovchain 452

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 453

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 454

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 455

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.2 0.8

2 0.5 0.5

Markovchain 456

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
 1, 2
 The transition matrix (by rows) is defined as follows:
 1 2
 1 1 0
 2 1 0

Markovchain 457

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
 1, 2
 The transition matrix (by rows) is defined as follows:
 1 2
 1 0.4 0.6
 2 0.5 0.5

Markovchain 458

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
 1, 2, 3
 The transition matrix (by rows) is defined as follows:
 1 2 3
 1 0.000000 0.500000 0.500000
 2 0.000000 0.000000 1.000000
 3 0.333333 0.333333 0.333333

Markovchain 459

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
 1, 2, 3
 The transition matrix (by rows) is defined as follows:
 1 2 3
 1 0.333333 0.333333 0.333333
 2 1.000000 0.000000 0.000000
 3 1.000000 0.000000 0.000000

Markovchain 460

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 461

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```
1
The transition matrix (by rows) is defined as follows:
  1
1 1

Markovchain 462
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1

Markovchain 463
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.8 0.2
2 0.5 0.5

Markovchain 464
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 1 0
2 1 0

Markovchain 465
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1

Markovchain 466
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.6 0.4
2 0.5 0.5
```

Markovchain 467

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.6666667	0.3333333
2	1.0000000	0.0000000

Markovchain 468

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	0
2	0	1

Markovchain 469

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	0
2	1	0

Markovchain 470

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 471

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 472

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```

1
The transition matrix (by rows) is defined as follows:
  1
1 1

Markovchain 473
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.8 0.2
2 0.5 0.5

Markovchain 474
Unnamed Markov chain
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
  1      2      3
1 0.2500000 0.5000000 0.2500000
2 0.0000000 1.0000000 0.0000000
3 0.3333333 0.3333333 0.3333333

Markovchain 475
Unnamed Markov chain
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
  1 2 3
1 1 0 0
2 1 0 0
3 1 0 0

Markovchain 476
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1

Markovchain 477
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:

```

1
1 1

Markovchain 478

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3
1 0.0 1.0
3 0.5 0.5

Markovchain 479

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3
1 0.5 0.5
3 1.0 0.0

Markovchain 480

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 481

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 482

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 483

Unnamed Markov chain

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

```

Markovchain 484

Unnamed Markov chain

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

```

Markovchain 485

Unnamed Markov chain

```

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
1 2
1 0.2 0.8
2 0.5 0.5

```

Markovchain 486

Unnamed Markov chain

```

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
1 2
1 0.00 1.00
2 0.25 0.75

```

Markovchain 487

Unnamed Markov chain

```

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
1 2 3
1 0.000000 1.000000 0.000000
2 0.000000 0.500000 0.500000
3 0.333333 0.333333 0.333333

```

Markovchain 488

Unnamed Markov chain

```

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:

```

	1	2	3
1	0.33333333	0.33333333	0.33333333
2	1.00000000	0.00000000	0.00000000
3	1.00000000	0.00000000	0.00000000

Markovchain 489

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 490

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.4 0.6

2 0.5 0.5

Markovchain 491

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 492

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.8 0.2

2 0.5 0.5

Markovchain 493

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 494

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 495

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.6000000	0.2000000	0.2000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 496

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0	0.6666667	0.3333333
2	0	0.0000000	1.0000000
3	0	0.0000000	1.0000000

Markovchain 497

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 498

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.4	0.6

2 0.5 0.5

Markovchain 499

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.5000000	0.5000000
2	0.0000000	0.0000000	1.0000000
3	0.3333333	0.3333333	0.3333333

Markovchain 500

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 501

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 502

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 503

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 504

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

  1  2
1 0.8 0.2
2 0.5 0.5
```

Markovchain 505

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

  1  2
1 1 0
2 1 0
```

Markovchain 506

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

  1
1 1
```

Markovchain 507

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

      1      2      3
1 0.6000000 0.2000000 0.2000000
2 0.3333333 0.3333333 0.3333333
3 0.3333333 0.3333333 0.3333333
```

Markovchain 508

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

  1  2  3
1 1 0 0
2 1 0 0
3 1 0 0
```

Markovchain 509

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 510

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 511

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 512

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
 1, 2
 The transition matrix (by rows) is defined as follows:
 1 2
 1 0.8 0.2
 2 0.5 0.5

Markovchain 513

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
 1, 2
 The transition matrix (by rows) is defined as follows:
 1 2
 1 1 0
 2 1 0

Markovchain 514

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 515

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 516

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 517

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.8 0.2

3 0.5 0.5

Markovchain 518

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0 1

3 0 1

Markovchain 519

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

3

The transition matrix (by rows) is defined as follows:

3

3 1

Markovchain 520

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

  1  3
1 0.5 0.5
3 1.0 0.0

```

Markovchain 521

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

  1
1 1

```

Markovchain 522

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

  1  2
1 0.6 0.4
2 0.5 0.5

```

Markovchain 523

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

  1  2
1 1 0
2 1 0

```

Markovchain 524

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

      1      2      3
1 0.0000000 0.2000000 0.8000000
2 0.3333333 0.3333333 0.3333333
3 0.3333333 0.3333333 0.3333333

```

Markovchain 525

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

      1      2      3

```

```

1 0.3333333 0.3333333 0.3333333
2 1.0000000 0.0000000 0.0000000
3 0.0000000 0.5000000 0.5000000

```

Markovchain 526

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

      1  2 3
1 1.0 0.0 0
2 1.0 0.0 0
3 0.5 0.5 0

```

Markovchain 527

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

      1  2
1 0.75 0.25
2 1.00 0.00

```

Markovchain 528

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

      1  2
1 0 1
2 0 1

```

Markovchain 529

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

      1  2
1 0.5 0.5
2 1.0 0.0

```

Markovchain 530

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1

```

1 1

Markovchain 531

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.0	1.0
3	0.5	0.5

Markovchain 532

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.5	0.5
3	1.0	0.0

Markovchain 533

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 534

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.6	0.4
2	0.5	0.5

Markovchain 535

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.0000000	1.0000000
2	0.0000000	0.0000000	1.0000000
3	0.3333333	0.3333333	0.3333333

Markovchain 536

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	0.3333333	0.3333333	0.3333333
3	0.8000000	0.2000000	0.0000000

Markovchain 537

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.0000000	1.0000000
2	0.0000000	0.0000000	1.0000000
3	0.3333333	0.3333333	0.3333333

Markovchain 538

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.5	0.5
3	1.0	0.0

Markovchain 539

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.6	0.4
2	0.5	0.5

Markovchain 540

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	0
2	1	0

Markovchain 541

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 542

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 543

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.0 1.0

3 0.5 0.5

Markovchain 544

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.5 0.5

3 1.0 0.0

Markovchain 545

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 546

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

```
Markovchain 547
```

```
Unnamed Markov chain
```

```
A 1 - dimensional discrete Markov Chain defined by the following states:
```

```
1
```

```
The transition matrix (by rows) is defined as follows:
```

```
1
1 1
```

```
Markovchain 548
```

```
Unnamed Markov chain
```

```
A 3 - dimensional discrete Markov Chain defined by the following states:
```

```
1, 2, 3
```

```
The transition matrix (by rows) is defined as follows:
```

```
      1      2      3
1 0.000000 0.400000 0.600000
2 0.333333 0.333333 0.333333
3 0.333333 0.333333 0.333333
```

```
Markovchain 549
```

```
Unnamed Markov chain
```

```
A 3 - dimensional discrete Markov Chain defined by the following states:
```

```
1, 2, 3
```

```
The transition matrix (by rows) is defined as follows:
```

```
      1      2      3
1 0.333333 0.333333 0.333333
2 1.000000 0.000000 0.000000
3 1.000000 0.000000 0.000000
```

```
Markovchain 550
```

```
Unnamed Markov chain
```

```
A 1 - dimensional discrete Markov Chain defined by the following states:
```

```
1
```

```
The transition matrix (by rows) is defined as follows:
```

```
1
1 1
```

```
Markovchain 551
```

```
Unnamed Markov chain
```

```
A 1 - dimensional discrete Markov Chain defined by the following states:
```

```
1
```

```
The transition matrix (by rows) is defined as follows:
```

```
1
1 1
```

Markovchain 552

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 553

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.4000000 0.4000000 0.2000000

2 0.3333333 0.3333333 0.3333333

3 0.3333333 0.3333333 0.3333333

Markovchain 554

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 1 0 0

2 1 0 0

3 1 0 0

Markovchain 555

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 556

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.0 1.0

3 0.5 0.5

Markovchain 557

Unnamed Markov chain

```
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3
The transition matrix (by rows) is defined as follows:
  1  3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 558

Unnamed Markov chain

```
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.8 0.2
2 0.5 0.5
```

Markovchain 559

Unnamed Markov chain

```
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 1 0
2 1 0
```

Markovchain 560

Unnamed Markov chain

```
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1
```

Markovchain 561

Unnamed Markov chain

```
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1
```

Markovchain 562

Unnamed Markov chain

```
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
```

1 1

Markovchain 563

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.6 0.4

2 0.5 0.5

Markovchain 564

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 565

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 566

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 567

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.8 0.2

2 0.5 0.5

Markovchain 568

Unnamed Markov chain

```

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.5 0.5
2 0.0 1.0

```

```
Markovchain 569
```

```
Unnamed Markov chain
```

```

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
  1      2      3
1 0.0000000 0.0000000 1.0000000
2 0.0000000 0.0000000 1.0000000
3 0.3333333 0.3333333 0.3333333

```

```
Markovchain 570
```

```
Unnamed Markov chain
```

```

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3
The transition matrix (by rows) is defined as follows:
  1  3
1 0.5 0.5
3 1.0 0.0

```

```
Markovchain 571
```

```
Unnamed Markov chain
```

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1

```

```
Markovchain 572
```

```
Unnamed Markov chain
```

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1

```

```
Markovchain 573
```

```
Unnamed Markov chain
```

```

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3
The transition matrix (by rows) is defined as follows:

```

```

    1  3
1 0.0 1.0
3 0.5 0.5

```

Markovchain 574

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

    1  3
1 0.5 0.5
3 1.0 0.0

```

Markovchain 575

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

    1  2
1 0.2 0.8
2 0.5 0.5

```

Markovchain 576

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

    1  2
1 1 0
2 1 0

```

Markovchain 577

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

    1  2
1 0.0 1.0
2 0.5 0.5

```

Markovchain 578

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

    1  2
1 0.5 0.5

```

2 1.0 0.0

Markovchain 579

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 580

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 0.2 0.8
2 0.5 0.5

Markovchain 581

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.0000000	1.0000000
2	0.0000000	0.0000000	1.0000000
3	0.3333333	0.3333333	0.3333333

Markovchain 582

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3
1 0.5 0.5
3 1.0 0.0

Markovchain 583

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 584

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 585

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 586

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 0.8 0.2
2 0.5 0.5

Markovchain 587

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 1 0
2 1 0

Markovchain 588

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.2000000	0.6000000	0.2000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 589

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

  1 2 3
1 1 0 0
2 1 0 0
3 1 0 0

```

Markovchain 590

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

          1          2          3
1 0.0000000 0.2000000 0.8000000
2 0.3333333 0.3333333 0.3333333
3 0.3333333 0.3333333 0.3333333

```

Markovchain 591

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

          1          2          3
1 0.3333333 0.3333333 0.3333333
2 0.0000000 0.0000000 1.0000000
3 0.5000000 0.2500000 0.2500000

```

Markovchain 592

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

  1 2 3
1 1 0 0
2 1 0 0
3 1 0 0

```

Markovchain 593

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

  1
1 1

```

Markovchain 594

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 595
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 596
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 597
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 598
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 599
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 600
Unnamed Markov chain

```
A 1 - dimensional discrete Markov Chain defined by the following states:  
1  
The transition matrix (by rows) is defined as follows:  
1  
1 1
```

```
Markovchain 601  
Unnamed Markov chain  
A 1 - dimensional discrete Markov Chain defined by the following states:  
1  
The transition matrix (by rows) is defined as follows:  
1  
1 1
```

```
Markovchain 602  
Unnamed Markov chain  
A 1 - dimensional discrete Markov Chain defined by the following states:  
1  
The transition matrix (by rows) is defined as follows:  
1  
1 1
```

```
Markovchain 603  
Unnamed Markov chain  
A 1 - dimensional discrete Markov Chain defined by the following states:  
1  
The transition matrix (by rows) is defined as follows:  
1  
1 1
```

```
Markovchain 604  
Unnamed Markov chain  
A 1 - dimensional discrete Markov Chain defined by the following states:  
1  
The transition matrix (by rows) is defined as follows:  
1  
1 1
```

```
Markovchain 605  
Unnamed Markov chain  
A 1 - dimensional discrete Markov Chain defined by the following states:  
1  
The transition matrix (by rows) is defined as follows:  
1  
1 1
```

```
Markovchain 606
```

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 607

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3
1 0.0 1.0
3 0.5 0.5

Markovchain 608

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3
1 0.5 0.5
3 1.0 0.0

Markovchain 609

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 610

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 611

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

```
1 0.0 1.0
3 0.5 0.5
```

Markovchain 612

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

```
1 3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 613

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 614

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 615

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

```
1 2 3
1 0.000000 0.400000 0.600000
2 0.333333 0.333333 0.333333
3 0.333333 0.333333 0.333333
```

Markovchain 616

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
2, 3

The transition matrix (by rows) is defined as follows:

```
2 3
2 0.5 0.5
3 1.0 0.0
```

Markovchain 617

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	0.2500000	0.5000000	0.2500000
3	0.0000000	1.0000000	0.0000000

Markovchain 618

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	1	0	0
2	1	0	0
3	1	0	0

Markovchain 619

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 620

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 621

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.2	0.8
2	0.5	0.5

Markovchain 622

Unnamed Markov chain

```
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 1.00 0.00
2 0.75 0.25
```

Markovchain 623

Unnamed Markov chain

```
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 1 0
2 1 0
```

Markovchain 624

Unnamed Markov chain

```
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.2 0.8
2 0.5 0.5
```

Markovchain 625

Unnamed Markov chain

```
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 1 0
2 1 0
```

Markovchain 626

Unnamed Markov chain

```
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
      1      2      3
1 0.0000000 0.6000000 0.4000000
2 0.3333333 0.3333333 0.3333333
3 0.3333333 0.3333333 0.3333333
```

Markovchain 627

Unnamed Markov chain

```
A 3 - dimensional discrete Markov Chain defined by the following states:
```

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 628

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 629

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 630

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 631

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 632

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 633

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 634

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 635

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 636

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.4000000	0.4000000	0.2000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 637

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 1 0 0

2 1 0 0

3 1 0 0

Markovchain 638

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.2000000	0.8000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 639

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

2, 3

The transition matrix (by rows) is defined as follows:

	2	3
2	1	0
3	1	0

Markovchain 640

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.5	0.5
2	1.0	0.0

Markovchain 641

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 642

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 643

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

1 1

Markovchain 644

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.2000000	0.2000000	0.6000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 645

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	1	0	0
2	1	0	0
3	1	0	0

Markovchain 646

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.0	1.0
3	0.5	0.5

Markovchain 647

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.5	0.5
3	1.0	0.0

Markovchain 648

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 649

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 650

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.000000 0.800000 0.200000

2 0.333333 0.333333 0.333333

3 0.333333 0.333333 0.333333

Markovchain 651

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.333333 0.333333 0.333333

2 1.000000 0.000000 0.000000

3 1.000000 0.000000 0.000000

Markovchain 652

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 653

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.0 1.0

2 0.5 0.5

Markovchain 654

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

2, 3

The transition matrix (by rows) is defined as follows:

	2	3
2	0.2	0.8
3	0.5	0.5

Markovchain 655

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 656

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.4	0.6
2	0.5	0.5

Markovchain 657

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	0
2	1	0

Markovchain 658

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 659

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```

1
The transition matrix (by rows) is defined as follows:
  1
1 1

Markovchain 660
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.4 0.6
2 0.5 0.5

Markovchain 661
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1      2
1 1.0000000 0.0000000
2 0.6666667 0.3333333

Markovchain 662
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 1 0
2 1 0

Markovchain 663
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.0 1.0
2 0.5 0.5

Markovchain 664
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2

```

```
1 0.5 0.5
2 1.0 0.0
```

Markovchain 665

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 666

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
          1          2          3
1 0.0000000 0.6000000 0.4000000
2 0.3333333 0.3333333 0.3333333
3 0.3333333 0.3333333 0.3333333
```

Markovchain 667

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
          1          2          3
1 0.3333333 0.3333333 0.3333333
2 1.0000000 0.0000000 0.0000000
3 1.0000000 0.0000000 0.0000000
```

Markovchain 668

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
  1  3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 669

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

3

The transition matrix (by rows) is defined as follows:

```
  3
3 1
```

Markovchain 670

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.5 0.5

3 1.0 0.0

Markovchain 671

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.0 1.0

3 0.5 0.5

Markovchain 672

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.5 0.5

3 1.0 0.0

Markovchain 673

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 674

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 675

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```

1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 676
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 677
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 678
Unnamed Markov chain
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
      1      2      3
1 0.000000 0.600000 0.400000
2 0.333333 0.333333 0.333333
3 0.333333 0.333333 0.333333

Markovchain 679
Unnamed Markov chain
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
      1      2      3
1 0.333333 0.333333 0.333333
2 1.000000 0.000000 0.000000
3 1.000000 0.000000 0.000000

Markovchain 680
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
1 2

```

```
1 0.6 0.4
2 0.5 0.5
```

Markovchain 681

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
1 2
1 0.0 1.0
2 0.5 0.5
```

Markovchain 682

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
1 2
1 1 0
2 1 0
```

Markovchain 683

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 684

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
1 2
1 0.4 0.6
2 0.5 0.5
```

Markovchain 685

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
1 2
1 1 0
2 1 0
```

Markovchain 686

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 687

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 688

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 689

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 690

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.6 0.4

2 0.5 0.5

Markovchain 691

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

```
1 1 0
2 1 0
```

Markovchain 692

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 693

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
1 2
1 0.8 0.2
2 0.5 0.5
```

Markovchain 694

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
1 2 3
1 0.2500000 0.5000000 0.2500000
2 0.0000000 1.0000000 0.0000000
3 0.3333333 0.3333333 0.3333333
```

Markovchain 695

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
1 2 3
1 0 1 0
2 0 1 0
3 1 0 0
```

Markovchain 696

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
1 2
1 1 0
```

2 1 0

Markovchain 697

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 698

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 699

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 700

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3
1 0.0 1.0
3 0.5 0.5

Markovchain 701

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3
1 0.5 0.5
3 1.0 0.0

Markovchain 702

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 703

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 704

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 705

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 706

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 707

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2
 The transition matrix (by rows) is defined as follows:
 1 2
 1 0.4 0.6
 2 0.5 0.5

Markovchain 708

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 709

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 710

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 711

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 712

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 713

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 714

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.2000000	0.8000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 715

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 716

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 717

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 718

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 719

Unnamed Markov chain

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

```

Markovchain 720

Unnamed Markov chain

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

```

Markovchain 721

Unnamed Markov chain

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

```

Markovchain 722

Unnamed Markov chain

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

```

Markovchain 723

Unnamed Markov chain

```

A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

```

Markovchain 724

Unnamed Markov chain

```

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
      1      2      3
1 0.4000000 0.4000000 0.2000000
2 0.3333333 0.3333333 0.3333333
3 0.3333333 0.3333333 0.3333333

```

Markovchain 725

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
  1 2 3
1 1 0 0
2 1 0 0
3 1 0 0
```

Markovchain 726

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 727

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 728

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 729

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 730

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 731

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
1 2
1 0.8 0.2
2 0.5 0.5
```

Markovchain 732

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
1 2 3
1 0.2500000 0.7500000 0.0000000
2 0.0000000 0.0000000 1.0000000
3 0.3333333 0.3333333 0.3333333
```

Markovchain 733

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
1 2 3
1 1 0 0
2 1 0 0
3 1 0 0
```

Markovchain 734

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 735

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
1 2 3
```

```

1 0.0000000 0.6000000 0.4000000
2 0.3333333 0.3333333 0.3333333
3 0.3333333 0.3333333 0.3333333

```

Markovchain 736

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

           1         2         3
1 0.3333333 0.3333333 0.3333333
2 1.0000000 0.0000000 0.0000000
3 1.0000000 0.0000000 0.0000000

```

Markovchain 737

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 738

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

1
1 1

```

Markovchain 739

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

           1         2
1 0.6 0.4
2 0.5 0.5

```

Markovchain 740

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

           1         2         3
1 0.0000000 0.0000000 1.0000000
2 0.0000000 0.0000000 1.0000000

```

```
3 0.3333333 0.3333333 0.3333333
```

```
Markovchain 741
```

```
Unnamed Markov chain
```

```
A 2 - dimensional discrete Markov Chain defined by the following states:  
1, 3
```

```
The transition matrix (by rows) is defined as follows:
```

```
      1  3  
1 0.5 0.5  
3 1.0 0.0
```

```
Markovchain 742
```

```
Unnamed Markov chain
```

```
A 2 - dimensional discrete Markov Chain defined by the following states:  
1, 2
```

```
The transition matrix (by rows) is defined as follows:
```

```
      1  2  
1 0.4 0.6  
2 0.5 0.5
```

```
Markovchain 743
```

```
Unnamed Markov chain
```

```
A 3 - dimensional discrete Markov Chain defined by the following states:  
1, 2, 3
```

```
The transition matrix (by rows) is defined as follows:
```

```
      1      2      3  
1 0.000000 0.000000 1.000000  
2 0.000000 0.000000 1.000000  
3 0.333333 0.333333 0.333333
```

```
Markovchain 744
```

```
Unnamed Markov chain
```

```
A 2 - dimensional discrete Markov Chain defined by the following states:  
2, 3
```

```
The transition matrix (by rows) is defined as follows:
```

```
      2  3  
2 0.5 0.5  
3 0.2 0.8
```

```
Markovchain 745
```

```
Unnamed Markov chain
```

```
A 2 - dimensional discrete Markov Chain defined by the following states:  
2, 3
```

```
The transition matrix (by rows) is defined as follows:
```

```
      2  3  
2 1 0  
3 1 0
```

Markovchain 746

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.5	0.5
2	1.0	0.0

Markovchain 747

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 748

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 749

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 750

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 751

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
      1  2
1 0.6 0.4
2 0.5 0.5
```

Markovchain 752

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
      1  2
1 1 0
2 1 0
```

Markovchain 753

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
      1
1 1
```

Markovchain 754

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
      1  2
1 0.2 0.8
2 0.5 0.5
```

Markovchain 755

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
      1  2
1 0.0 1.0
2 0.5 0.5
```

Markovchain 756

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
      1  2
1 1 0
2 1 0
```

Markovchain 757

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 758

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 759

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 760

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.6 0.4

2 0.5 0.5

Markovchain 761

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.6666667 0.3333333

2 0.5000000 0.5000000

Markovchain 762

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

  1 2
1 1 0
2 1 0

```

Markovchain 763

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

  1 2
1 0.4 0.6
2 0.5 0.5

```

Markovchain 764

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

  1 2
1 0.5000000 0.5000000
2 0.6666667 0.3333333

```

Markovchain 765

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

  1 2
1 1 0
2 1 0

```

Markovchain 766

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

  1 2 3
1 0.0000000 0.4000000 0.6000000
2 0.3333333 0.3333333 0.3333333
3 0.3333333 0.3333333 0.3333333

```

Markovchain 767

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.33333333	0.33333333	0.33333333
2	1.00000000	0.00000000	0.00000000
3	1.00000000	0.00000000	0.00000000

Markovchain 768

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.0	1.0
3	0.5	0.5

Markovchain 769

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.5	0.5
3	1.0	0.0

Markovchain 770

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.00000000	0.20000000	0.80000000
2	0.33333333	0.33333333	0.33333333
3	0.33333333	0.33333333	0.33333333

Markovchain 771

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.33333333	0.33333333	0.33333333
2	0.00000000	1.00000000	0.00000000
3	0.75000000	0.25000000	0.00000000

Markovchain 772

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

The transition matrix (by rows) is defined as follows:

```
      1      2
1 0.666667 0.333333
2 0.500000 0.500000
```

Markovchain 773

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

The transition matrix (by rows) is defined as follows:

```
  1 2
1 1 0
2 1 0
```

Markovchain 774

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 775

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

The transition matrix (by rows) is defined as follows:

```
  1 2
1 0.4 0.6
2 0.5 0.5
```

Markovchain 776

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

The transition matrix (by rows) is defined as follows:

```
  1 2
1 1 0
2 1 0
```

Markovchain 777

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

The transition matrix (by rows) is defined as follows:

```
  1 2
1 0.2 0.8
```

2 0.5 0.5

Markovchain 778

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0 1

2 0 1

Markovchain 779

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

2, 3

The transition matrix (by rows) is defined as follows:

2 3

2 0.6 0.4

3 0.5 0.5

Markovchain 780

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

2, 3

The transition matrix (by rows) is defined as follows:

2 3

2 0.6666667 0.3333333

3 0.5000000 0.5000000

Markovchain 781

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.3333333 0.3333333 0.3333333

2 1.0000000 0.0000000 0.0000000

3 1.0000000 0.0000000 0.0000000

Markovchain 782

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.4 0.6

2 0.5 0.5

Markovchain 783

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 784

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 785

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 786

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.0000000 0.6000000 0.4000000

2 0.3333333 0.3333333 0.3333333

3 0.3333333 0.3333333 0.3333333

Markovchain 787

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.3333333 0.3333333 0.3333333

2 1.0000000 0.0000000 0.0000000

3 1.0000000 0.0000000 0.0000000

Markovchain 788

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
1 3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 789

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
1 3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 790

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
1 3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 791

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
1 3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 792

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
1 3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 793

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```

  1  3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 794

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

  1
1 1
```

Markovchain 795

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

      1      2      3
1 0.000000 0.800000 0.200000
2 0.333333 0.333333 0.333333
3 0.333333 0.333333 0.333333
```

Markovchain 796

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

      1      2      3
1 0.333333 0.333333 0.333333
2 1.000000 0.000000 0.000000
3 1.000000 0.000000 0.000000
```

Markovchain 797

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```

  1
1 1
```

Markovchain 798

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 799

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.6000000	0.4000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 800

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 801

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.0	1.0
3	0.5	0.5

Markovchain 802

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.5	0.5
3	1.0	0.0

Markovchain 803

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 804

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.4 0.6

2 0.5 0.5

Markovchain 805

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 806

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.2000000 0.4000000 0.4000000

2 0.3333333 0.3333333 0.3333333

3 0.3333333 0.3333333 0.3333333

Markovchain 807

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 1 0 0

2 1 0 0

3 1 0 0

Markovchain 808

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 809

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.0 1.0

2 0.5 0.5

Markovchain 810

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

2, 3

The transition matrix (by rows) is defined as follows:

2 3

2 0.0 1.0

3 0.5 0.5

Markovchain 811

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.5 0.5

3 1.0 0.0

Markovchain 812

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 813

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 814

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```
1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 815
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 816
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 817
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
1
1 1

Markovchain 818
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
1 2
1 0.6 0.4
2 0.5 0.5

Markovchain 819
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
1 2
1 1 0
2 1 0
```

Markovchain 820

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 821

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 822

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 823

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 824

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 825

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 826

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 827

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 828

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.8 0.2

2 0.5 0.5

Markovchain 829

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 830

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.6 0.4

2 0.5 0.5

Markovchain 831

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```

1, 2
The transition matrix (by rows) is defined as follows:
  1 2
1 1 0
2 1 0

```

Markovchain 832

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

  1 2
1 0.8 0.2
2 0.5 0.5

```

Markovchain 833

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```

  1 2
1 0.5 0.5
2 1.0 0.0

```

Markovchain 834

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

      1      2      3
1 0.000000 0.333333 0.666667
2 1.000000 0.000000 0.000000
3 0.333333 0.333333 0.333333

```

Markovchain 835

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```

  1 2 3
1 1 0 0
2 1 0 0
3 1 0 0

```

Markovchain 836

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
  1  3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 837

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
  1  2  3
1 0.3333333 0.3333333 0.3333333
2 0.3333333 0.3333333 0.3333333
3 0.2000000 0.8000000 0.0000000
```

Markovchain 838

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1  2
1 1 0
2 1 0
```

Markovchain 839

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1  2
1 0.4 0.6
2 0.5 0.5
```

Markovchain 840

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1  2
1 1 0
2 1 0
```

Markovchain 841

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.2000000	0.6000000	0.2000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 842

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	1	0	0
2	1	0	0
3	1	0	0

Markovchain 843

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 844

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 845

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 846

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 847

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 848

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 849

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.6 0.4

2 0.5 0.5

Markovchain 850

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.0000000 0.0000000 1.0000000

2 0.0000000 0.0000000 1.0000000

3 0.3333333 0.3333333 0.3333333

Markovchain 851

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.5 0.5

3 1.0 0.0

Markovchain 852

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
 1, 2
 The transition matrix (by rows) is defined as follows:
 1 2
 1 0.8 0.2
 2 0.5 0.5

Markovchain 853

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
 1, 2
 The transition matrix (by rows) is defined as follows:
 1 2
 1 1 0
 2 1 0

Markovchain 854

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
 1
 The transition matrix (by rows) is defined as follows:
 1
 1 1

Markovchain 855

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
 1, 2, 3
 The transition matrix (by rows) is defined as follows:
 1 2 3
 1 0.000000 0.800000 0.200000
 2 0.333333 0.333333 0.333333
 3 0.333333 0.333333 0.333333

Markovchain 856

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
 1, 2, 3
 The transition matrix (by rows) is defined as follows:
 1 2 3
 1 0.333333 0.333333 0.333333
 2 1.000000 0.000000 0.000000
 3 1.000000 0.000000 0.000000

Markovchain 857

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.4000000	0.6000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 858

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 859

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 860

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 861

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 862

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

1 1

Markovchain 863

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 864

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 865

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 866

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 867

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 0.4 0.6
2 0.5 0.5

Markovchain 868

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1 2
1 1 0
2 1 0
```

Markovchain 869

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1 2
1 0.0 1.0
2 0.5 0.5
```

Markovchain 870

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1 2
1 0.5 0.5
2 1.0 0.0
```

Markovchain 871

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 872

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 873

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 874

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 875

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.0 1.0

3 0.5 0.5

Markovchain 876

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.5 0.5

3 1.0 0.0

Markovchain 877

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.2 0.8

2 0.5 0.5

Markovchain 878

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 879

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1  2
1 0.4 0.6
2 0.5 0.5
```

Markovchain 880

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1  2
1 1 0
2 1 0
```

Markovchain 881

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1  2
1 0.8 0.2
2 0.5 0.5
```

Markovchain 882

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1  2
1 0.75 0.25
2 1.00 0.00
```

Markovchain 883

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

```
  1  2
1 1 0
2 1 0
```

Markovchain 884

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 885

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 886

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 0.4000000 0.4000000 0.2000000

2 0.3333333 0.3333333 0.3333333

3 0.3333333 0.3333333 0.3333333

Markovchain 887

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

1 2 3

1 1 0 0

2 1 0 0

3 0 1 0

Markovchain 888

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 889

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 890

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.6	0.4
2	0.5	0.5

Markovchain 891

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.3333333	0.6666667
2	0.0000000	1.0000000

Markovchain 892

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	0
2	1	0

Markovchain 893

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.2	0.8
3	0.5	0.5

Markovchain 894

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	1.0000000	0.0000000
2	0.3333333	0.3333333	0.3333333
3	0.7500000	0.2500000	0.0000000

Markovchain 895

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.0000000	1.0000000
2	0.0000000	0.0000000	1.0000000
3	0.3333333	0.3333333	0.3333333

Markovchain 896

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

3

The transition matrix (by rows) is defined as follows:

3	1
---	---

Markovchain 897

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.5	0.5
3	1.0	0.0

Markovchain 898

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 899

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 900

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 901

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```
1
The transition matrix (by rows) is defined as follows:
1
1 1
```

Markovchain 902

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```
1, 3
The transition matrix (by rows) is defined as follows:
1 3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 903

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```
1, 3
The transition matrix (by rows) is defined as follows:
1 3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 904

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```
1, 3
The transition matrix (by rows) is defined as follows:
1 3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 905

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```
1, 3
The transition matrix (by rows) is defined as follows:
1 3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 906

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.0	1.0
2	0.5	0.5

Markovchain 907

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.5	0.5
2	0.8	0.2

Markovchain 908

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.0000000	1.0000000
2	0.0000000	0.0000000	1.0000000
3	0.3333333	0.3333333	0.3333333

Markovchain 909

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	0.3333333	0.3333333	0.3333333
3	0.4000000	0.6000000	0.0000000

Markovchain 910

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	0
2	1	0

Markovchain 911

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 912

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.0 1.0

3 0.5 0.5

Markovchain 913

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

1 3

1 0.5 0.5

3 1.0 0.0

Markovchain 914

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 915

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.8 0.2

2 0.5 0.5

Markovchain 916

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```

1, 2
The transition matrix (by rows) is defined as follows:
  1 2
1 1 0
2 1 0

Markovchain 917
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1 2
1 0.8 0.2
2 0.5 0.5

Markovchain 918
Unnamed Markov chain
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
  1 2 3
1 0.2500000 0.0000000 0.7500000
2 0.0000000 0.0000000 1.0000000
3 0.3333333 0.3333333 0.3333333

Markovchain 919
Unnamed Markov chain
A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3
The transition matrix (by rows) is defined as follows:
  1 2 3
1 1.0000000 0.0000000 0.0000000
2 0.3333333 0.3333333 0.3333333
3 0.7500000 0.2500000 0.0000000

Markovchain 920
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1 2
1 1 0
2 1 0

Markovchain 921
Unnamed Markov chain
A 3 - dimensional discrete Markov Chain defined by the following states:

```

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.6000000	0.2000000	0.2000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 922

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0	0	1
2	0	1	0
3	0	1	0

Markovchain 923

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	0.5000000	0.5000000	0.0000000
3	0.0000000	1.0000000	0.0000000

Markovchain 924

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	0
2	1	0

Markovchain 925

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 926

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```

1
The transition matrix (by rows) is defined as follows:
  1
1 1

Markovchain 927
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.8 0.2
2 0.5 0.5

Markovchain 928
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.75 0.25
2 1.00 0.00

Markovchain 929
Unnamed Markov chain
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 1 0
2 1 0

Markovchain 930
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1

Markovchain 931
Unnamed Markov chain
A 1 - dimensional discrete Markov Chain defined by the following states:
1
The transition matrix (by rows) is defined as follows:
  1
1 1

```

Markovchain 932

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 933

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.2 0.8

2 0.5 0.5

Markovchain 934

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 1 0

2 1 0

Markovchain 935

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1

1 1

Markovchain 936

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2

1 0.2 0.8

2 0.5 0.5

Markovchain 937

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.000000	1.000000	0.000000
2	0.000000	0.250000	0.750000
3	0.333333	0.333333	0.333333

Markovchain 938

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.333333	0.333333	0.333333
2	1.000000	0.000000	0.000000
3	1.000000	0.000000	0.000000

Markovchain 939

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 940

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.000000	0.600000	0.400000
2	0.333333	0.333333	0.333333
3	0.333333	0.333333	0.333333

Markovchain 941

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.333333	0.333333	0.333333
2	0.333333	0.333333	0.333333
3	1.000000	0.000000	0.000000

Markovchain 942

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

```
  1 2 3
1 1 0 0
2 1 0 0
3 1 0 0
```

Markovchain 943

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

The transition matrix (by rows) is defined as follows:

```
  1  2
1 0.6 0.4
2 0.5 0.5
```

Markovchain 944

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

The transition matrix (by rows) is defined as follows:

```
  1 2
1 1 0
2 1 0
```

Markovchain 945

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 946

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1

The transition matrix (by rows) is defined as follows:

```
  1
1 1
```

Markovchain 947

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:
1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 948

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 949

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 950

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 951

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 0.2 0.8
2 0.5 0.5

Markovchain 952

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 1 0
2 1 0

Markovchain 953

Unnamed Markov chain

```
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.4 0.6
2 0.5 0.5
```

Markovchain 954

Unnamed Markov chain

```
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 1 0
2 1 0
```

Markovchain 955

Unnamed Markov chain

```
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2
The transition matrix (by rows) is defined as follows:
  1  2
1 0.0 1.0
2 0.5 0.5
```

Markovchain 956

Unnamed Markov chain

```
A 2 - dimensional discrete Markov Chain defined by the following states:
2, 3
The transition matrix (by rows) is defined as follows:
  2  3
2 0.0 1.0
3 0.5 0.5
```

Markovchain 957

Unnamed Markov chain

```
A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3
The transition matrix (by rows) is defined as follows:
  1  3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 958

Unnamed Markov chain

```
A 1 - dimensional discrete Markov Chain defined by the following states:
1
```

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 959

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```
1
The transition matrix (by rows) is defined as follows:
```

```
1
1 1
```

Markovchain 960

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```
1, 2
The transition matrix (by rows) is defined as follows:
```

```
1 2
1 0.8 0.2
2 0.5 0.5
```

Markovchain 961

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

```
1, 2
The transition matrix (by rows) is defined as follows:
```

```
1 2
1 1 0
2 1 0
```

Markovchain 962

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```
1
The transition matrix (by rows) is defined as follows:
```

```
1
1 1
```

Markovchain 963

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

```
1
The transition matrix (by rows) is defined as follows:
```

```
1
1 1
```

Markovchain 964

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 965

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 0.8 0.2
2 0.5 0.5

Markovchain 966

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

1 2
1 1 0
2 1 0

Markovchain 967

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 968

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.6000000	0.4000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 969

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 970

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 971

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 972

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	0.8	0.2
2	0.5	0.5

Markovchain 973

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	0
2	1	0

Markovchain 974

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

	1
1	1

Markovchain 975

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.4000000	0.6000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 976

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:
1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	0.6666667	0.3333333	0.0000000

Markovchain 977

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 2

The transition matrix (by rows) is defined as follows:

	1	2
1	1	0
2	1	0

Markovchain 978

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
1, 3

The transition matrix (by rows) is defined as follows:

	1	3
1	0.0	1.0
3	0.5	0.5

Markovchain 979

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:
2, 3

The transition matrix (by rows) is defined as follows:

	2	3
2	0.5	0.5
3	0.4	0.6

Markovchain 980

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.33333333	0.33333333	0.33333333
2	1.00000000	0.00000000	0.00000000
3	1.00000000	0.00000000	0.00000000

Markovchain 981

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 982

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 983

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 984

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1	1
---	---

Markovchain 985

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 986

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
1 3
1 0.0 1.0
3 0.5 0.5
```

Markovchain 987

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
1 3
1 0.5 0.5
3 1.0 0.0
```

Markovchain 988

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 989

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 990

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 991

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 992

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 993

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

1
1 1

Markovchain 994

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.0000000	0.2000000	0.8000000
2	0.3333333	0.3333333	0.3333333
3	0.3333333	0.3333333	0.3333333

Markovchain 995

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

	1	2	3
1	0.3333333	0.3333333	0.3333333
2	1.0000000	0.0000000	0.0000000
3	1.0000000	0.0000000	0.0000000

Markovchain 996

Unnamed Markov chain

A 1 - dimensional discrete Markov Chain defined by the following states:

1

The transition matrix (by rows) is defined as follows:

```
1
1 1
```

Markovchain 997

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
      1      2      3
1 0.000000 0.200000 0.800000
2 0.333333 0.333333 0.333333
3 0.333333 0.333333 0.333333
```

Markovchain 998

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

1, 2, 3

The transition matrix (by rows) is defined as follows:

```
      1      2      3
1 0.333333 0.333333 0.333333
2 1.000000 0.000000 0.000000
3 1.000000 0.000000 0.000000
```

Markovchain 999

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

1, 3

The transition matrix (by rows) is defined as follows:

```
      1      3
1 0.0 1.0
3 0.5 0.5
```

Finally, given a list object, it is possible to fit a `markovchain` object or to obtain the raw transition matrix.

```
R> c1<-c("a","b","a","a","c","c","a")
R> c2<-c("b")
R> c3<-c("c","a","a","c")
R> c4<-c("b","a","b","a","a","c","b")
R> c5<-c("a","a","c",NA)
R> c6<-c("b","c","b","c","a")
R> mylist<-list(c1,c2,c3,c4,c5,c6)
R> mylistMc<-markovchainFit(data=mylist)
R> mylistMc
```

`$estimate`

MLE Fit

A 3 - dimensional discrete Markov Chain defined by the following states:
a, b, c

The transition matrix (by rows) is defined as follows:

	a	b	c
a	0.4	0.2000000	0.4000000
b	0.6	0.0000000	0.4000000
c	0.5	0.3333333	0.1666667

\$standardError

	a	b	c
a	0.2000000	0.1414214	0.2000000
b	0.3464102	0.0000000	0.2828427
c	0.2886751	0.2357023	0.1666667

\$confidenceLevel

[1] 0.95

\$lowerEndpointMatrix

	a	b	c
a	0.008007122	0	0.008007122
b	0.000000000	0	0.000000000
c	0.000000000	0	0.000000000

\$upperEndpointMatrix

	a	b	c
a	0.7919929	0.4771808	0.7919929
b	1.0000000	0.0000000	0.9543616
c	1.0000000	0.7953014	0.4933274

The same works for markovchainFitList.

```
R> markovchainListFit(data=mylist)
```

\$estimate

list of Markov chain(s)

Markovchain 1

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

a, b, c

The transition matrix (by rows) is defined as follows:

	a	b	c
a	0.5	0.5	0.0
b	0.5	0.0	0.5
c	1.0	0.0	0.0

Markovchain 2

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

a, b, c

The transition matrix (by rows) is defined as follows:

	a	b	c
a	0.3333333	0.3333333	0.3333333
b	1.0000000	0.0000000	0.0000000
c	0.0000000	1.0000000	0.0000000

Markovchain 3

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

a, b, c

The transition matrix (by rows) is defined as follows:

	a	b	c
a	0.5000000	0.0000000	0.5000000
b	0.5000000	0.0000000	0.5000000
c	0.3333333	0.3333333	0.3333333

Markovchain 4

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

a, c

The transition matrix (by rows) is defined as follows:

	a	c
a	0.5	0.5
c	1.0	0.0

Markovchain 5

Unnamed Markov chain

A 2 - dimensional discrete Markov Chain defined by the following states:

a, c

The transition matrix (by rows) is defined as follows:

	a	c
a	0	1
c	0	1

Markovchain 6

Unnamed Markov chain

A 3 - dimensional discrete Markov Chain defined by the following states:

a, b, c

The transition matrix (by rows) is defined as follows:

	a	b	c
a	0.3333333	0.3333333	0.3333333
b	0.3333333	0.3333333	0.3333333
c	0.5000000	0.5000000	0.0000000

If any transition contains NA, it will be ignored in the results as the above example showed.

5.3. Prediction

The n -step forward predictions can be obtained using the `predict` methods explicitly written for `markovchain` and `markovchainList` objects. The prediction is the mode of the conditional distribution of X_{t+1} given $X_t = s_j$, being s_j the last realization of the DTMC (homogeneous or non-homogeneous).

Predicting from a markovchain object

The 3-days forward predictions from `markovchain` object can be generated as follows, assuming that the last two days were respectively “cloudy” and “sunny”.

```
R> predict(object = weatherFittedMLE$estimate, newdata = c("cloudy", "sunny"),
R+         n.ahead = 3)
```

```
[1] "sunny" "sunny" "sunny"
```

Predicting from a markovchainList object

Given an initial two years health status, the 5-year ahead prediction of any CCRC guest is

```
R> predict(mcCCRC, newdata = c("H", "H"), n.ahead = 5)
```

```
[1] "H" "D" "D"
```

The prediction has stopped at time sequence since the underlying non-homogeneous Markov chain has a length of four. In order to continue five years ahead, the `continue=TRUE` parameter setting makes the `predict` method keeping to use the last `markovchain` in the sequence list.

```
R> predict(mcCCRC, newdata = c("H", "H"), n.ahead = 5, continue = TRUE)
```

```
[1] "H" "D" "D" "D" "D"
```

5.4. Statistical Tests

In this section, we describe the statistical tests: assessing the Markov property (`verifyMarkovProperty`), the order (`assessOrder`), the stationary (`assessStationarity`) of a Markov chain sequence, and the divergence test for empirically estimated transition matrices (`divergenceTest`). Most of such tests are based on the χ^2 statistics. Relevant references are [Kullback *et al.* \(1962\)](#) and [Anderson and Goodman \(1957\)](#).

All such tests have been designed for small samples, since it is easy to detect departures from Markov property as long as the sample size increases. In addition, the accuracy of

the statistical inference functions has been questioned and will be thoroughly investigated in future versions of the package.

Assessing the Markov property of a Markov chain sequence

The `verifyMarkovProperty` function verifies whether the Markov property holds for the given chain. The test implemented in the package looks at triplets of successive observations. If x_1, x_2, \dots, x_N is a set of observations and n_{ijk} is the number of times t ($1 \leq t \leq N - 2$) such that $x_t = i, x_{t+1} = j, x_{t+2} = k$, then if the Markov property holds n_{ijk} follows a Binomial distribution with parameters n_{ij} and p_{jk} . A classical χ^2 test can check this distributional assumption, since $\sum_i \sum_j \sum_k \frac{n_{ijk} - n_{ij}p_{jk}}{n_{ij}p_{jk}} \sim \chi^2(|S|^3)$ where $|S|$ is the cardinality of the state space.

```
R> sample_sequence<-c("a", "b", "a", "a", "a", "a", "b", "a", "b", "a",
R+                    "b", "a", "a", "b", "b", "b", "a")
R> verifyMarkovProperty(sample_sequence)
```

Warning in `verifyMarkovProperty(sample_sequence)`: The accuracy of the statistical inference functions has been questioned. It will be thoroughly investigated in future versions of the package.

Testing markovianity property on given data sequence

Chi - square statistic is: 0.28

Degrees of freedom are: 8

And corresponding p-value is: 0.9999857

Assessing the order of a Markov chain sequence

The `assessOrder` function checks whether the given chain is of first order or of second order. For each possible present state, we construct a contingency table of the frequency of the future state for each past to present state transition as shown in Table 6.

past	present	future	
		a	b
a	a	2	2
b	a	2	2

Table 6: Contingency table to assess the order for the present state a.

Using the table, the function performs the χ^2 test by calling the `chisq.test` function. This test returns a list of the chi-squared value and the p-value. If the p-value is greater than the given significance level, we cannot reject the hypothesis that the sequence is of first order.

```
R> data(rain)
R> assessOrder(rain$rain)
```

Warning in `assessOrder(rain$rain)`: The accuracy of the statistical inference functions has been questioned. It will be thoroughly investigated in future versions of the package.

The `assessOrder` test statistic is: 26.09575
 The Chi-Square d.f. are: 12
 The p-value is: 0.01040395

Assessing the stationarity of a Markov chain sequence

The `assessStationarity` function assesses if the transition probabilities of the given chain change over time. To be more specific, the chain is stationary if the following condition meets.

$$p_{ij}(t) = p_{ij} \quad \text{for all } t \quad (21)$$

For each possible state, we construct a contingency table of the estimated transition probabilities over time as shown in Table 7.

time (t)	probability of transition to a	probability of transition to b
1	0	1
2	0	1
.	.	.
.	.	.
.	.	.
16	0.44	0.56

Table 7: Contingency table to assess the stationarity of the state a.

Using the table, the function performs the χ^2 test by calling the `chisq.test` function. This test returns a list of the chi-squared value and the p-value. If the p-value is greater than the given significance level, we cannot reject the hypothesis that the sequence is stationary.

```
R> assessStationarity(rain$rain, 10)
```

```
Warning in assessStationarity(rain$rain, 10): The accuracy of the statistical
inference functions has been questioned. It will be thoroughly investigated in
future versions of the package.
```

```
Warning in chisq.test(mat): Chi-squared approximation may be incorrect
```

```
Warning in chisq.test(mat): Chi-squared approximation may be incorrect
```

```
Warning in chisq.test(mat): Chi-squared approximation may be incorrect
```

```
The assessStationarity test statistic is: 4.181815
The Chi-Square d.f. are: 54
The p-value is: 1
```

Divergence tests for empirically estimated transition matrices

This section discusses tests developed to verify whether:

1. An empirical transition matrix is consistent with a theoretical one.
2. Two or more empirical transition matrices belongs to the same DTMC.

The first test is implemented by the `verifyEmpiricalToTheoretical` function. Being f_{ij} the raw transition count, Kullback *et al.* (1962) shows that $2 * \sum_{i=1}^r \sum_{j=1}^r f_{ij} \ln \frac{f_{ij}}{f_{i.} P(E_j|E_i)} \sim \chi^2(r * (r - 1))$. The following example is taken from Kullback *et al.* (1962):

```
R> sequence<-c(0,1,2,2,1,0,0,0,0,0,0,1,2,2,2,1,0,0,1,0,0,0,0,0,0,1,1,
R+ 2,0,0,2,1,1,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,1,1,1,0,0,0,0,2,1,0,
R+ 0,2,1,0,0,0,0,0,0,0,1,1,1,2,2,0,0,2,1,1,1,1,2,1,1,1,1,1,1,1,1,1,0,2,
R+ 0,1,1,0,0,0,1,2,2,0,0,0,0,0,0,0,2,2,2,1,1,1,1,0,1,1,1,1,0,0,2,1,1,
R+ 0,0,0,0,0,2,2,1,1,1,1,1,2,1,2,0,0,0,1,2,2,2,0,0,0,1,1)
R> mc=matrix(c(5/8,1/4,1/8,1/4,1/2,1/4,1/4,3/8,3/8),byrow=TRUE, nrow=3)
R> rownames(mc)<-colnames(mc)<-0:2; theoreticalMc<-as(mc, "markovchain")
R> verifyEmpiricalToTheoretical(data=sequence,object=theoreticalMc)
```

Warning in `verifyEmpiricalToTheoretical(data = sequence, object = theoreticalMc)`: The accuracy of the statistical inference functions has been questioned. It will be thoroughly investigated in future versions of the package.

Testing whether the

```
  0  1  2
0 51 11  8
1 12 31  9
2  6 11 10
```

transition matrix is compatible with

```
  0    1    2
0 0.625 0.250 0.125
1 0.250 0.500 0.250
2 0.250 0.375 0.375
```

```
[1] "theoretical transition matrix"
```

ChiSq statistic is 6.551795 d.o.f are 6 corresponding p-value is 0.3642899

```
$statistic
```

```
  0
6.551795
```

```
$dof
```

```
[1] 6
```

```
$pvalue
```

```
  0
0.3642899
```

The second one is implemented by the `verifyHomogeneity` function, inspired by (Kullback *et al.* 1962, section 9). Assuming that $i = 1, 2, \dots, s$ DTMC samples are available and that the cardinality of the state space is r it verifies whether the s chains belongs to the same unknown one. Kullback *et al.* (1962) shows that its test statistics follows a chi-square law, $2 * \sum_{i=1}^s \sum_{j=1}^r \sum_{k=1}^r f_{ijk} \ln \frac{n * f_{ijk}}{f_{i..} * f_{.jk}} \sim \chi^2 (r * (r - 1))$. Also the following example is taken from Kullback *et al.* (1962):

```
R> data(kullback)
R> verifyHomogeneity(inputList=kullback,verbose=TRUE)
```

```
Warning in verifyHomogeneity(inputList = kullback, verbose = TRUE): The
accuracy of the statistical inference functions has been questioned. It will be
thoroughly investigated in future versions of the package.
```

```
Testing homogeneity of DTMC underlying input list
ChiSq statistic is 275.9963 d.o.f are 35 corresponding p-value is 0
```

```
$statistic
[1] 275.9963
```

```
$dof
[1] 35
```

```
$pvalue
[1] 0
```

5.5. Continuous Times Markov Chains

Intro

The **markovchain** package provides functionality for continuous time Markov chains (CTMCs). CTMCs are a generalization of discrete time Markov chains (DTMCs) in that we allow time to be continuous. We assume a finite state space S (for an infinite state space wouldn't fit in memory). We can think of CTMCs as Markov chains in which state transitions can happen at any time.

More formally, we would like our CTMCs to satisfy the following two properties:

- The Markov property - let $F_{X(s)}$ denote the information about X up to time s . Let $j \in S$ and $s \leq t$. Then, $P(X(t) = j | F_{X(s)}) = P(X(t) = j | X(s))$.
- Time homogeneity - $P(X(t) = j | X(s) = k) = P(X(t - s) = j | X(0) = k)$.

If both the above properties are satisfied, it is referred to as a time-homogeneous CTMC. If a transition occurs at time t , then $X(t)$ denotes the new state and $X(t) \neq X(t-)$.

Now, let $X(0) = x$ and let T_x be the time a transition occurs from this state. We are interested in the distribution of T_x . For $s, t \geq 0$, it can be shown that $P(T_x > s+t | T_x > s) = P(T_x > t)$

This is the memory less property that only the exponential random variable exhibits. Therefore, this is the sought distribution, and each state $s \in S$ has an exponential holding parameter $\lambda(s)$. Since $ET_x = \frac{1}{\lambda(x)}$, higher the rate $\lambda(x)$, smaller the expected time of transitioning out of the state x .

However, specifying this parameter alone for each state would only paint an incomplete picture of our CTMC. To see why, consider a state x that may transition to either state y or z . The holding parameter enables us to predict when a transition may occur if we start off in state x , but tells us nothing about which state will be next.

To this end, we also need transition probabilities associated with the process, defined as follows (for $y \neq x$) - $p_{xy} = P(X(T_s) = y | X(0) = x)$. Note that $\sum_{y \neq x} p_{xy} = 1$. Let Q denote this transition matrix ($Q_{ij} = p_{ij}$). What is key here is that T_x and the state y are independent random variables. Let's define $\lambda(x, y) = \lambda(x)p_{xy}$

We now look at Kolmogorov's backward equation. Let's define $P_{ij}(t) = P(X(t) = j | X(0) = i)$ for $i, j \in S$. The backward equation is given by (it can be proved) $P_{ij}(t) = \delta_{ij}e^{-\lambda(i)t} + \int_0^t \lambda(i)e^{-\lambda(i)s} \sum_{k \neq i} Q_{ik}P_{kj}(t-s)ds$. Basically, the first term is non-zero if and only if $i = j$ and represents the probability that the first transition from state i occurs after time t . This would mean that at t , the state is still i . The second term accounts for any transitions that may occur before time t and denotes the probability that at time t , when the smoke clears, we are in state j .

This equation can be represented compactly as follows $P'(t) = AP(t)$ where A is the *generator* matrix.

$$A(i, j) = \begin{cases} \lambda(i, j) & \text{if } i \neq j \\ -\lambda(i) & \text{else.} \end{cases}$$

Observe that the sum of each row is 0. A CTMC can be completely specified by the generator matrix.

Stationary Distributions

The following theorem guarantees the existence of a unique stationary distribution for CTMCs. Note that $X(t)$ being irreducible and recurrent is the same as $X_n(t)$ being irreducible and recurrent.

Suppose that $X(t)$ is irreducible and recurrent. Then $X(t)$ has an invariant measure η , which is unique up to multiplicative factors. Moreover, for each $k \in S$, we have

$$\eta_k = \frac{\pi_k}{\lambda(k)}$$

where π is the unique invariant measure of the embedded discrete time Markov chain X_n . Finally, η satisfies

$$0 < \eta_j < \infty, \forall j \in S$$

and if $\sum_i \eta_i < \infty$ then η can be normalized to get a stationary distribution.

Estimation

Let the data set be $D = \{(s_0, t_0), (s_1, t_1), \dots, (s_{N-1}, t_{N-1})\}$ where $N = |D|$. Each s_i is a state from the state space S and during the time $[t_i, t_{i+1}]$ the chain is in state s_i . Let the parameters be represented by $\theta = \{\lambda, P\}$ where λ is the vector of holding parameters for each state and P the transition matrix of the embedded discrete time Markov chain.

Then the probability is given by

$$Pr(D|\theta) \propto \lambda(s_0)e^{-\lambda(s_0)(t_1-t_0)}Pr(s_1|s_0) \cdot \dots \cdot \lambda(s_{N-2})e^{-\lambda(s_{N-2})(t_{N-1}-t_{N-2})}Pr(s_{N-1}|s_{N-2})$$

Let $n(j|i)$ denote the number of $i \rightarrow j$ transitions in D , and $n(i)$ the number of times s_i occurs in D . Let $t(s_i)$ denote the total time the chain spends in state s_i .

Then the MLEs are given by

$$\hat{\lambda}(s) = \frac{n(s)}{t(s)}, Pr(\hat{j}|i) = \frac{n(j|i)}{n(i)}$$

Expected Hitting Time

The package provides a function `ExpectedTime` to calculate average hitting time from one state to another. Let the final state be j , then for every state $i \in S$, where S is the set of all states and holding time $q_i > 0$ for every $i \neq j$. Assuming the conditions to be true, expected hitting time is equal to minimal non-negative solution vector p to the system of linear equations:

$$\begin{cases} p_k = 0 & k = j \\ -\sum_{l \in I} q_{kl}p_k = 1 & k \neq j \end{cases} \quad (22)$$

Probability at time t

The package provides a function `probabilityatT` to calculate probability of every state according to given `ctmc` object. Here we use Kolmogorov's backward equation $P(t) = P(0)e^{tQ}$ for $t \geq 0$ and $P(0) = I$. Here $P(t)$ is the transition function at time t . The value $P(t)[i][j]$ at time $P(t)$ describes the probability of the state at time t to be equal to j if it was equal to i at time $t = 0$. It takes care of the case when `ctmc` object has a generator represented by columns. If initial state is not provided, the function returns the whole transition matrix $P(t)$.

Examples

To create a CTMC object, you need to provide a valid generator matrix, say Q . The CTMC object has the following slots - states, generator, by row, name (look at the documentation object for further details). Consider the following example in which we aim to model the transition of a molecule from the σ state to the σ^* state. When in the former state, if it absorbs sufficient energy, it can make the jump to the latter state and remains there for some time before transitioning back to the original state. Let us model this by a CTMC:

```
R> energyStates <- c("sigma", "sigma_star")
R> byRow <- TRUE
```

```
R> gen <- matrix(data = c(-3, 3,
R+                   1, -1), nrow = 2,
R+                   byrow = byRow, dimnames = list(energyStates, energyStates))
R> molecularCTMC <- new("ctmc", states = energyStates,
R+                   byrow = byRow, generator = gen,
R+                   name = "Molecular Transition Model")
```

To generate random CTMC transitions, we provide an initial distribution of the states. This must be in the same order as the dimnames of the generator. The output can be returned either as a list or a data frame.

```
R> statesDist <- c(0.8, 0.2)
R> rctmc(n = 3, ctmc = molecularCTMC, initDist = statesDist, out.type = "df", include.TO =

      states          time
1 sigma_star 0.0426796986647132
2      sigma  0.440718898076582
3 sigma_star  1.73288680186201
```

n represents the number of samples to generate. There is an optional argument T for `rctmc`. It represents the time of termination of the simulation. To use this feature, set n to a very high value, say `Inf` (since we do not know the number of transitions before hand) and set T accordingly.

```
R> statesDist <- c(0.8, 0.2)
R> rctmc(n = Inf, ctmc = molecularCTMC, initDist = statesDist, T = 2)

[[1]]
[1] "sigma"      "sigma_star" "sigma"

[[2]]
[1] 0.000000 1.383179 1.806847
```

To obtain the stationary distribution simply invoke the `steadyStates` function

```
R> steadyStates(molecularCTMC)

      sigma sigma_star
[1,] 0.25      0.75
```

For fitting, use the `ctmcFit` function. It returns the MLE values for the parameters along with the confidence intervals.

```
R> data <- list(c("a", "b", "c", "a", "b", "a", "c", "b", "c"),
R+             c(0, 0.8, 2.1, 2.4, 4, 5, 5.9, 8.2, 9))
R> ctmcFit(data)
```

```

$estimate
An object of class "ctmc"
Slot "states":
[1] "a" "b" "c"

Slot "byrow":
[1] TRUE

Slot "generator":
      a      b      c
a -0.9090909  0.6060606  0.3030303
b  0.3225806 -0.9677419  0.6451613
c  0.3846154  0.3846154 -0.7692308

Slot "name":
[1] ""

$errors
$errors$dtmcConfidenceInterval
$errors$dtmcConfidenceInterval$confidenceLevel
[1] 0.95

$errors$dtmcConfidenceInterval$lowerEndpointMatrix
  a b c
a 0 0 0
b 0 0 0
c 0 0 0

$errors$dtmcConfidenceInterval$upperEndpointMatrix
      a b      c
a 0.0000000 1 0.9866548
b 0.9866548 0 1.0000000
c 1.0000000 1 0.0000000

$errors$lambdaConfidenceInterval
$errors$lambdaConfidenceInterval$lowerEndpointVector
[1] 0.04576665 0.04871934 0.00000000

$errors$lambdaConfidenceInterval$upperEndpointVector
[1] 0.04576665 0.04871934 -0.12545166

```

One approach to obtain the generator matrix is to apply the `logm` function from the **expm** package on a transition matrix. Numeric issues arise, see [Israel, Rosenthal, and Wei \(2001\)](#). For example, applying the standard `method` ('Higham08') on `mcWeather` raises an error, whilst the alternative method (eigenvalue decomposition) is OK. The following code estimates the

generator matrix of the mcWeather transition matrix.

```
R> mcWeatherQ <- expm::logm(mcWeather@transitionMatrix,method='Eigen')
R> mcWeatherQ
```

```
      sunny    cloudy    rain
sunny -0.863221  2.428723 -1.565502
cloudy  4.284592 -20.116312  15.831720
rain   -4.414019  24.175251 -19.761232
```

Therefore, the “half - day” transition probability for mcWeather DTMC is

```
R> mcWeatherHalfDayTM <- expm::expm(mcWeatherQ*.5)
R> mcWeatherHalfDay <- new("markovchain",transitionMatrix=mcWeatherHalfDayTM,name="Half Day")
R> mcWeatherHalfDay
```

Half Day Weather Transition Matrix

A 3 - dimensional discrete Markov Chain defined by the following states:

sunny, cloudy, rain

The transition matrix (by rows) is defined as follows:

```
      sunny    cloudy    rain
sunny  0.81598647  0.1420068  0.04200677
cloudy  0.21970167  0.4401492  0.34014916
rain   0.07063048  0.5146848  0.41468476
```

The **ctmcd** package (Pfeuffer 2017) provides various functions to estimate the generator matrix (GM) of a CTMC process using different methods. The following code provides a way to join **markovchain** and **ctmcd** computations.

```
R> require(ctmcd)
```

Loading required package: ctmcd

```
R> require(expm)
```

Loading required package: expm

Loading required package: Matrix

Attaching package: 'expm'

The following object is masked from 'package:Matrix':

```
expm
```

```

R> #defines a function to transform a GM into a TM
R> gm_to_markovchain<-function(object, t=1) {
R+   if(!(class(object) %in% c("gm", "matrix", "Matrix")))
R+     stop("Error! Expecting either a matrix or a gm object")
R+   if ( class(object) %in% c("matrix", "Matrix")) generator_matrix<-object else generator
R+   #must add importClassesFrom("markovchain",markovchain) in the NAMESPACE
R+   #must add importFrom(expm, "expm")
R+   transitionMatrix<-expm(generator_matrix*t)
R+   out<-as(transitionMatrix, "markovchain")
R+   return(out)
R+ }
R> #loading ctmc dataset
R> data(tm_abs)
R> gm0=matrix(1,8,8) #initializing
R> diag(gm0)=0
R> diag(gm0)=-rowSums(gm0)
R> gm0[8,]=0
R> gmem=gm(tm_abs, te=1, method="EM", gmguess=gm0) #estimating GM
R> mc_at_2=gm_to_markovchain(object=gmem, t=2) #converting to TM at time 2

```

5.6. Pseudo - Bayesian Estimation

Hu, Kiesel, and Perraudin (2002) shows an empirical quasi-Bayesian method to estimate transition matrices, given an empirical \hat{P} transition matrix (estimated using the classical approach) and an a - priori estimate Q . In particular, each row of the matrix is estimated using the linear combination $\alpha \cdot Q + (1 - \alpha) \cdot P$, where α is defined for each row as Equation 23 shows

$$\begin{cases} \hat{\alpha}_i = \frac{\hat{K}_i}{v^{(i)} + \hat{K}_i} \\ \hat{K}_i = \frac{v^{(i)^2} - \sum_j Y_{ij}^2}{\sum_j (Y_{ij} - v^{(i)} q_{ij})^2} \end{cases} \quad (23)$$

The following code returns the pseudo Bayesian estimate of the transition matrix:

```

R> pseudoBayesEstimator <- function(raw, apriori){
R+   v_i <- rowSums(raw)
R+   K_i <- numeric(nrow(raw))
R+   sumSquaredY <- rowSums(raw^2)
R+   #get numerator
R+   K_i_num <- v_i^2 - sumSquaredY
R+   #get denominator
R+   VQ <- matrix(0, nrow= nrow(apriori), ncol=ncol(apriori))
R+   for (i in 1:nrow(VQ)) {
R+     VQ[i,]<-v_i[i]*apriori[i,]
R+   }
R+ }

```

```

R+ K_i_den<-rowSums((raw - VQ)^2)
R+
R+ K_i <- K_i_num/K_i_den
R+
R+ #get the alpha vector
R+ alpha <- K_i / (v_i+K_i)
R+
R+ #empirical transition matrix
R+ Emp<-raw/rowSums(raw)
R+
R+ #get the estimate
R+ out<-matrix(0, nrow= nrow(raw),ncol=ncol(raw))
R+ for (i in 1:nrow(out)) {
R+   out[i,]<-alpha[i]*apriori[i,]+(1-alpha[i])*Emp[i,]
R+ }
R+ return(out)
R+ }

```

We then apply it to the weather example:

```

R> trueMc<-as(matrix(c(0.1, .9,.7,.3),nrow = 2, byrow = 2),"markovchain")
R> aprioriMc<-as(matrix(c(0.5, .5,.5,.5),nrow = 2, byrow = 2),"markovchain")
R>
R> smallSample<-rmarkovchain(n=20,object = trueMc)
R> smallSampleRawTransitions<-createSequenceMatrix(stringchar = smallSample)
R> pseudoBayesEstimator(
R+ raw = smallSampleRawTransitions,
R+ apriori = aprioriMc@transitionMatrix
R+ ) - trueMc@transitionMatrix

          s1          s2
s1 -0.1000000 0.1000000
s2 -0.1972376 0.1972376

R> biggerSample<-rmarkovchain(n=100,object = trueMc)
R> biggerSampleRawTransitions<-createSequenceMatrix(stringchar = biggerSample)
R> pseudoBayesEstimator(
R+ raw = biggerSampleRawTransitions,
R+ apriori = aprioriMc@transitionMatrix
R+ ) - trueMc@transitionMatrix

          s1          s2
s1 0.019471768 -0.019471768
s2 -0.007429331 0.007429331

R> bigSample<-rmarkovchain(n=1000,object = trueMc)
R> bigSampleRawTransitions<-createSequenceMatrix(stringchar = bigSample)

```

```
R> pseudoBayesEstimator(
R+   raw = bigSampleRawTransitions,
R+   apriori = aprioriMc@transitionMatrix
R+ ) - trueMc@transitionMatrix

           s1           s2
s1 0.013707983 -0.013707983
s2 0.003767055 -0.003767055
```

5.7. Bayesian Estimation

The **markovchain** package provides functionality for maximum a posteriori (MAP) estimation of the chain parameters (at the time of writing this document, only first order models are supported) by Bayesian inference. It also computes the probability of observing a new data set, given a (different) data set. This vignette provides the mathematical description for the methods employed by the package.

Notation and set-up

The data is denoted by D , the model parameters (transition matrix) by θ . The object of interest is $P(\theta|D)$ (posterior density). \mathcal{A} represents an alphabet class, each of whose members represent a state of the chain. Therefore

$$D = s_0 s_1 \dots s_{N-1}, s_t \in \mathcal{A}$$

where N is the length of the data set. Also,

$$\theta = \{p(s|u), s \in \mathcal{A}, u \in \mathcal{A}\}$$

where $\sum_{s \in \mathcal{A}} p(s|u) = 1$ for each $u \in \mathcal{A}$.

Our objective is to find θ which maximizes the posterior. That is, if our solution is denoted by $\hat{\theta}$, then

$$\hat{\theta} = \underset{\theta}{\operatorname{argmax}} P(\theta|D)$$

where the search space is the set of right stochastic matrices of dimension $|\mathcal{A}| \times |\mathcal{A}|$. $n(u, s)$ denotes the number of times the word us occurs in D and $n(u) = \sum_{s \in \mathcal{A}} n(u, s)$. The hyper-parameters are similarly denoted by $\alpha(u, s)$ and $\alpha(u)$ respectively.

Methods

Given D , its likelihood conditioned on the observed initial state in D is given by

$$P(D|\theta) = \prod_{s \in \mathcal{A}} \prod_{u \in \mathcal{A}} p(s|u)^{n(u,s)}$$

Conjugate priors are used to model the prior $P(\theta)$. The reasons are two fold:

1. Exact expressions can be derived for the MAP estimates, expectations and even variances
2. Model order selection/comparison can be implemented easily (available in a future release of the package)

The hyper-parameters determine the form of the prior distribution, which is a product of Dirichlet distributions

$$P(\theta) = \prod_{u \in \mathcal{A}} \left\{ \frac{\Gamma(\alpha(u))}{\prod_{s \in \mathcal{A}} \Gamma(\alpha(u, s))} \prod_{s \in \mathcal{A}} p(s|u)^{\alpha(u, s)-1} \right\}$$

where $\Gamma(\cdot)$ is the Gamma function. The hyper-parameters are specified using the `hyperparam` argument in the `markovchainFit` function. If this argument is not specified, then a default value of 1 is assigned to each hyper-parameter resulting in the prior distribution of each chain parameter to be uniform over $[0, 1]$.

Given the likelihood and the prior as described above, the evidence $P(D)$ is simply given by

$$P(D) = \int P(D|\theta)P(\theta)d\theta$$

which simplifies to

$$P(D) = \prod_{u \in \mathcal{A}} \left\{ \frac{\Gamma(\alpha(u))}{\prod_{s \in \mathcal{A}} \Gamma(\alpha(u, s))} \frac{\prod_{s \in \mathcal{A}} \Gamma(n(u, s) + \alpha(u, s))}{\Gamma(\alpha(u) + n(u))} \right\}$$

Using Bayes' theorem, the posterior now becomes (thanks to the choice of conjugate priors)

$$P(\theta|D) = \prod_{u \in \mathcal{A}} \left\{ \frac{\Gamma(n(u) + \alpha(u))}{\prod_{s \in \mathcal{A}} \Gamma(n(u, s) + \alpha(u, s))} \prod_{s \in \mathcal{A}} p(s|u)^{n(u, s) + \alpha(u, s) - 1} \right\}$$

Since this is again a product of Dirichlet distributions, the marginal distribution of a particular parameter $P(s|u)$ of our chain is given by

$$P(s|u) \sim \text{Beta}(n(u, s) + \alpha(u, s), n(u) + \alpha(u) - n(u, s) - \alpha(u, s))$$

Thus, the MAP estimate $\hat{\theta}$ is given by

$$\hat{\theta} = \left\{ \frac{n(u, s) + \alpha(u, s) - 1}{n(u) + \alpha(u) - |\mathcal{A}|}, s \in \mathcal{A}, u \in \mathcal{A} \right\}$$

The function also returns the expected value, given by

$$E_{\text{post}}p(s|u) = \left\{ \frac{n(u, s) + \alpha(u, s)}{n(u) + \alpha(u)}, s \in \mathcal{A}, u \in \mathcal{A} \right\}$$

The variance is given by

$$\text{Var}_{\text{post}}p(s|u) = \frac{n(u, s) + \alpha(u, s)}{(n(u) + \alpha(u))^2} \frac{n(u) + \alpha(u) - n(u, s) - \alpha(u, s)}{n(u) + \alpha(u) + 1}$$

The square root of this quantity is the standard error, which is returned by the function. The confidence intervals are constructed by computing the inverse of the beta integral.

Predictive distribution

Given the old data set, the probability of observing new data is $P(D'|D)$ where D' is the new data set. Let $m(u, s), m(u)$ denote the corresponding counts for the new data. Then,

$$P(D'|D) = \int P(D'|\theta)P(\theta|D)d\theta$$

We already know the expressions for both quantities in the integral and it turns out to be similar to evaluating the evidence

$$P(D'|D) = \prod_{u \in \mathcal{A}} \left\{ \frac{\Gamma(\alpha(u))}{\prod_{s \in \mathcal{A}} \Gamma(\alpha(u, s))} \frac{\prod_{s \in \mathcal{A}} \Gamma(n(u, s) + m(u, s) + \alpha(u, s))}{\Gamma(\alpha(u) + n(u) + m(u))} \right\}$$

Choosing the hyper-parameters

The hyper parameters model the shape of the parameters' prior distribution. These must be provided by the user. The package offers functionality to translate a given prior belief transition matrix into the hyper-parameter matrix. It is assumed that this belief matrix corresponds to the mean value of the parameters. Since the relation

$$E_{\text{prior}}p(s|u) = \frac{\alpha(u, s)}{\alpha(u)}$$

holds, the function accepts as input the belief matrix as well as a scaling vector (serves as a proxy for $\alpha(\cdot)$) and proceeds to compute $\alpha(\cdot, \cdot)$.

Alternatively, the function accepts a data sample and infers the hyper-parameters from it. Since the mode of a parameter (with respect to the prior distribution) is proportional to one less than the corresponding hyper-parameter, we set

$$\alpha(u, s) - 1 = m(u, s)$$

where $m(u, s)$ is the $u \rightarrow s$ transition count in the data sample. This is regarded as a 'fake count' which helps $\alpha(u, s)$ to reflect knowledge of the data sample.

Usage and examples

```
R> weatherStates <- c("sunny", "cloudy", "rain")
R> byRow <- TRUE
R> weatherMatrix <- matrix(data = c(0.7, 0.2, 0.1,
R+                               0.3, 0.4, 0.3,
R+                               0.2, 0.4, 0.4),
R+                               byrow = byRow, nrow = 3,
R+                               dimnames = list(weatherStates, weatherStates))
```

```
R> mcWeather <- new("markovchain", states = weatherStates,
R+           byrow = byRow, transitionMatrix = weatherMatrix,
R+           name = "Weather")
R> weathersOfDays <- rmarkovchain(n = 365, object = mcWeather, t0 = "sunny")
```

For the purpose of this section, we shall continue to use the weather of days example introduced in the main vignette of the package (reproduced above for convenience).

Let us invoke the fit function to estimate the MAP parameters with 92% confidence bounds and hyper-parameters as shown below, based on the first 200 days of the weather data. Additionally, let us find out what the probability is of observing the weather data for the next 165 days. The usage would be as follows

```
R> hyperMatrix<-matrix(c(1, 1, 2,
R+           3, 2, 1,
R+           2, 2, 3),
R+           nrow = 3, byrow = TRUE,
R+           dimnames = list(weatherStates,weatherStates))
R> markovchainFit(weathersOfDays[1:200], method = "map",
R+           confidencelevel = 0.92, hyperparam = hyperMatrix)
```

\$estimate

Bayesian Fit

A 3 - dimensional discrete Markov Chain defined by the following states:

cloudy, rain, sunny

The transition matrix (by rows) is defined as follows:

	cloudy	rain	sunny
cloudy	0.3442623	0.2950820	0.3606557
rain	0.4000000	0.3250000	0.2750000
sunny	0.2169811	0.0754717	0.7075472

\$expectedValue

	cloudy	rain	sunny
cloudy	0.3437500	0.29687500	0.3593750
rain	0.3953488	0.32558140	0.2790698
sunny	0.2201835	0.08256881	0.6972477

\$standardError

	[,1]	[,2]	[,3]
[1,]	0.05891140	0.05666911	0.05951401
[2,]	0.07370829	0.07064285	0.06762024
[3,]	0.03950865	0.02624209	0.04380674

\$confidenceInterval

\$confidenceInterval\$confidenceLevel

[1] 0.92

```
$confidenceInterval$lowerEndpointMatrix
```

```
      [,1]      [,2]      [,3]
[1,] 0.2517858 0.2034964 0.2679995
[2,] 0.2897553 0.2151572 0.1658589
[3,] 0.1478835 0.0000000 0.6344258
```

```
$confidenceInterval$upperEndpointMatrix
```

```
      [,1]      [,2]      [,3]
[1,] 0.4627250 0.4020441 0.4834475
[2,] 0.5827801 0.4669714 0.4011024
[3,] 0.2859395 0.1215932 1.0000000
```

```
$logLikelihood
```

```
[1] -181.8872
```

```
R> predictiveDistribution(weathersOfDays[1:200],
R+                          weathersOfDays[201:365],hyperparam = hyperMatrix)
```

```
[1] -150.4915
```

The results should not change after permuting the dimensions of the matrix.

```
R> hyperMatrix2<- hyperMatrix[c(2,3,1), c(2,3,1)]
R> markovchainFit(weathersOfDays[1:200], method = "map",
R+                  confidencelevel = 0.92, hyperparam = hyperMatrix2)
```

```
$estimate
```

```
Bayesian Fit
```

A 3 - dimensional discrete Markov Chain defined by the following states:

cloudy, rain, sunny

The transition matrix (by rows) is defined as follows:

```
      cloudy      rain      sunny
cloudy 0.3442623 0.2950820 0.3606557
rain   0.4000000 0.3250000 0.2750000
sunny  0.2169811 0.0754717 0.7075472
```

```
$expectedValue
```

```
      cloudy      rain      sunny
cloudy 0.3437500 0.29687500 0.3593750
rain   0.3953488 0.32558140 0.2790698
sunny  0.2201835 0.08256881 0.6972477
```

```
$standardError
```

```

      [,1]      [,2]      [,3]
[1,] 0.05891140 0.05666911 0.05951401
[2,] 0.07370829 0.07064285 0.06762024
[3,] 0.03950865 0.02624209 0.04380674

```

```
$confidenceInterval
```

```
$confidenceInterval$confidenceLevel
```

```
[1] 0.92
```

```
$confidenceInterval$lowerEndpointMatrix
```

```

      [,1]      [,2]      [,3]
[1,] 0.2517858 0.2034964 0.2679995
[2,] 0.2897553 0.2151572 0.1658589
[3,] 0.1478835 0.0000000 0.6344258

```

```
$confidenceInterval$upperEndpointMatrix
```

```

      [,1]      [,2]      [,3]
[1,] 0.4627250 0.4020441 0.4834475
[2,] 0.5827801 0.4669714 0.4011024
[3,] 0.2859395 0.1215932 1.0000000

```

```
$logLikelihood
```

```
[1] -181.8872
```

```
R> predictiveDistribution(weathersOfDays[1:200],
R+                        weathersOfDays[201:365],hyperparam = hyperMatrix2)
```

```
[1] -150.4915
```

Note that the predictive probability is very small. However, this can be useful when comparing model orders. Suppose we have an idea of the (prior) transition matrix corresponding to the expected value of the parameters, and have a data set from which we want to deduce the MAP estimates. We can infer the hyper-parameters from this known transition matrix itself, and use this to obtain our MAP estimates.

```
R> inferHyperparam(transMatr = weatherMatrix, scale = c(10, 10, 10))
```

```
$scaledInference
```

```

      cloudy rain sunny
cloudy    4    3    3
rain      4    4    2
sunny     2    1    7

```

Alternatively, we can use a data sample to infer the hyper-parameters.

```
R> inferHyperparam(data = weathersOfDays[1:15])
```

```
$dataInference
      cloudy rain sunny
cloudy   1    2    3
rain     2    1    1
sunny    4    1    8
```

In order to use the inferred hyper-parameter matrices, we do

```
R> hyperMatrix3 <- inferHyperparam(transMatr = weatherMatrix,
R+                               scale = c(10, 10, 10))
R> hyperMatrix3 <- hyperMatrix3$scaledInference
R> hyperMatrix4 <- inferHyperparam(data = weathersOfDays[1:15])
R> hyperMatrix4 <- hyperMatrix4$dataInference
```

Now we can safely use `hyperMatrix3` and `hyperMatrix4` with `markovchainFit` (in the `hyperparam` argument).

Supposing we don't provide any hyper-parameters, then the prior is uniform. This is the same as maximum likelihood.

```
R> data(preproglucacon)
R> preproglucacon <- preproglucacon[[2]]
R> MLEest <- markovchainFit(preproglucacon, method = "mle")
R> MAPest <- markovchainFit(preproglucacon, method = "map")
R> MLEest$estimate
```

MLE Fit

A 4 - dimensional discrete Markov Chain defined by the following states:

A, C, G, T

The transition matrix (by rows) is defined as follows:

	A	C	G	T
A	0.3585271	0.1434109	0.16666667	0.3313953
C	0.3840304	0.1558935	0.02281369	0.4372624
G	0.3053097	0.1991150	0.15044248	0.3451327
T	0.2844523	0.1819788	0.17667845	0.3568905

```
R> MAPest$estimate
```

Bayesian Fit

A 4 - dimensional discrete Markov Chain defined by the following states:

A, C, G, T

The transition matrix (by rows) is defined as follows:

	A	C	G	T
A	0.3585271	0.1434109	0.16666667	0.3313953
C	0.3840304	0.1558935	0.02281369	0.4372624
G	0.3053097	0.1991150	0.15044248	0.3451327
T	0.2844523	0.1819788	0.17667845	0.3568905

6. Applications

This section shows applications of DTMC in various fields.

6.1. Weather forecasting

Markov chains provide a simple model to predict the next day's weather given the current meteorological condition. The first application herewith shown is the “Land of Oz example” from J. G. Kemeny, J. L. Snell, and G. L. Thompson (1974), the second is the “Alofi Island Rainfall” from P. J. Avery and D. A. Henderson (1999).

Land of Oz

The Land of Oz is acknowledged not to have ideal weather conditions at all: the weather is snowy or rainy very often and, once more, there are never two nice days in a row. Consider three weather states: rainy, nice and snowy. Let the transition matrix be as in the following:

```
R> mcWP <- new("markovchain", states = c("rainy", "nice", "snowy"),
R+       transitionMatrix = matrix(c(0.5, 0.25, 0.25,
R+                               0.5, 0, 0.5,
R+                               0.25, 0.25, 0.5), byrow = T, nrow = 3))
```

Given that today it is a nice day, the corresponding stochastic row vector is $w_0 = (0, 1, 0)$ and the forecast after 1, 2 and 3 days are given by

```
R> W0 <- t(as.matrix(c(0, 1, 0)))
R> W1 <- W0 * mcWP; W1
```

```
      rainy nice snowy
[1,]  0.5   0   0.5
```

```
R> W2 <- W0 * (mcWP ^ 2); W2
```

```
      rainy nice snowy
[1,] 0.375 0.25 0.375
```

```
R> W3 <- W0 * (mcWP ^ 3); W3
```

```
      rainy   nice   snowy
[1,] 0.40625 0.1875 0.40625
```

As can be seen from w_1 , if in the Land of Oz today is a nice day, tomorrow it will rain or snow with probability 1. One week later, the prediction can be computed as

```
R> W7 <- W0 * (mcWP ^ 7)
R> W7
```

```

      rainy      nice      snowy
[1,] 0.4000244 0.1999512 0.4000244

```

The steady state of the chain can be computed by means of the `steadyStates` method.

```

R> q <- steadyStates(mcWP)
R> q

```

```

      rainy nice snowy
[1,]  0.4  0.2  0.4

```

Note that, from the seventh day on, the predicted probabilities are substantially equal to the steady state of the chain and they don't depend from the starting point, as the following code shows.

```

R> R0 <- t(as.matrix(c(1, 0, 0)))
R> R7 <- R0 * (mcWP ^ 7); R7

```

```

      rainy      nice      snowy
[1,] 0.4000244 0.2000122 0.3999634

```

```

R> S0 <- t(as.matrix(c(0, 0, 1)))
R> S7 <- S0 * (mcWP ^ 7); S7

```

```

      rainy      nice      snowy
[1,] 0.3999634 0.2000122 0.4000244

```

Alofi Island Rainfall

Alofi Island daily rainfall data were recorded from January 1st, 1987 until December 31st, 1989 and classified into three states: "0" (no rain), "1-5" (from non zero until 5 mm) and "6+" (more than 5mm). The corresponding dataset is provided within the **markovchain** package.

```

R> data("rain", package = "markovchain")
R> table(rain$rain)

```

```

 0 1-5 6+
548 295 253

```

The underlying transition matrix is estimated as follows.

```

R> mcAlofi <- markovchainFit(data = rain$rain, name = "Alofi MC")$estimate
R> mcAlofi

```

Alofi MC

A 3 - dimensional discrete Markov Chain defined by the following states:

0, 1-5, 6+

The transition matrix (by rows) is defined as follows:

	0	1-5	6+
0	0.6605839	0.2299270	0.1094891
1-5	0.4625850	0.3061224	0.2312925
6+	0.1976285	0.3122530	0.4901186

The long term daily rainfall distribution is obtained by means of the `steadyStates` method.

```
R> steadyStates(mcAlofi)
```

	0	1-5	6+
[1,]	0.5008871	0.2693656	0.2297473

6.2. Finance and Economics

Other relevant applications of DTMC can be found in Finance and Economics.

Finance

Credit ratings transitions have been successfully modeled with discrete time Markov chains. Some rating agencies publish transition matrices that show the empirical transition probabilities across credit ratings. The example that follows comes from **CreditMetrics** R package (Wittmann 2007), carrying Standard & Poor's published data.

```
R> rc <- c("AAA", "AA", "A", "BBB", "BB", "B", "CCC", "D")
R> creditMatrix <- matrix(
R+   c(90.81, 8.33, 0.68, 0.06, 0.08, 0.02, 0.01, 0.01,
R+     0.70, 90.65, 7.79, 0.64, 0.06, 0.13, 0.02, 0.01,
R+     0.09, 2.27, 91.05, 5.52, 0.74, 0.26, 0.01, 0.06,
R+     0.02, 0.33, 5.95, 85.93, 5.30, 1.17, 1.12, 0.18,
R+     0.03, 0.14, 0.67, 7.73, 80.53, 8.84, 1.00, 1.06,
R+     0.01, 0.11, 0.24, 0.43, 6.48, 83.46, 4.07, 5.20,
R+     0.21, 0, 0.22, 1.30, 2.38, 11.24, 64.86, 19.79,
R+     0, 0, 0, 0, 0, 0, 0, 100
R+   )/100, 8, 8, dimnames = list(rc, rc), byrow = TRUE)
```

It is easy to convert such matrices into `markovchain` objects and to perform some analyses

```
R> creditMc <- new("markovchain", transitionMatrix = creditMatrix,
R+               name = "S&P Matrix")
R> absorbingStates(creditMc)
```

```
[1] "D"
```

Economics

For a recent application of **markovchain** in Economic, see [Jacob \(2014\)](#).

A dynamic system generates two kinds of economic effects ([Bard 2000](#)):

1. those incurred when the system is in a specified state, and
2. those incurred when the system makes a transition from one state to another.

Let the monetary amount of being in a particular state be represented as a m -dimensional column vector c^S , while let the monetary amount of a transition be embodied in a C^R matrix in which each component specifies the monetary amount of going from state i to state j in a single step. Henceforth, Equation (24) represents the monetary of being in state i .

$$c_i = c_i^S + \sum_{j=1}^m C_{ij}^R p_{ij}. \quad (24)$$

Let $\bar{c} = [c_i]$ and let e_i be the vector valued 1 in the initial state and 0 in all other, then, if f_n is the random variable representing the economic return associated with the stochastic process at time n , Equation (25) holds:

$$E[f_n(X_n) | X_0 = i] = e_i P^n \bar{c}. \quad (25)$$

The following example assumes that a telephone company models the transition probabilities between customer/non-customer status by matrix P and the cost associated to states by matrix M .

```
R> statesNames <- c("customer", "non customer")
R> P <- zeros(2); P[1, 1] <- .9; P[1, 2] <- .1; P[2, 2] <- .95; P[2, 1] <- .05;
R> rownames(P) <- statesNames; colnames(P) <- statesNames
R> mcP <- new("markovchain", transitionMatrix = P, name = "Telephone company")
R> M <- zeros(2); M[1, 1] <- -20; M[1, 2] <- -30; M[2, 1] <- -40; M[2, 2] <- 0
```

If the average revenue for existing customer is +100, the cost per state is computed as follows.

```
R> c1 <- 100 + conditionalDistribution(mcP, state = "customer") %*% M[1,]
R> c2 <- 0 + conditionalDistribution(mcP, state = "non customer") %*% M[2,]
```

For an existing customer, the expected gain (loss) at the fifth year is given by the following code.

```
R> as.numeric((c(1, 0)* mcP ^ 5) %*% (as.vector(c(c1, c2))))
```

```
[1] 48.96009
```

6.3. Actuarial science

Markov chains are widely applied in the field of actuarial science. Two classical applications are policyholders' distribution across Bonus Malus classes in Motor Third Party Liability (MTPL) insurance (Section 6.3.1) and health insurance pricing and reserving (Section 6.3.2).

MPTL Bonus Malus

Bonus Malus (BM) contracts grant the policyholder a discount (enworsen) as a function of the number of claims in the experience period. The discount (enworsen) is applied on a premium that already allows for known (a priori) policyholder characteristics (Denuit, Maréchal, Pitrebois, and Walhin 2007) and it usually depends on vehicle, territory, the demographic profile of the policyholder, and policy coverage deep (deductible and policy limits). Since the proposed BM level depends on the claim on the previous period, it can be modeled by a discrete Markov chain. A very simplified example follows. Assume a BM scale from 1 to 5, where 4 is the starting level. The evolution rules are shown in Equation 26:

$$bm_{t+1} = \max(1, bm_t - 1) * (\tilde{N} = 0) + \min(5, bm_t + 2 * \tilde{N}) * (\tilde{N} \geq 1). \quad (26)$$

The number of claim \tilde{N} is a random variable that is assumed to be Poisson distributed.

```
R> getBonusMalusMarkovChain <- function(lambda) {
R+  bmMatr <- zeros(5)
R+  bmMatr[1, 1] <- dpois(x = 0, lambda)
R+  bmMatr[1, 3] <- dpois(x = 1, lambda)
R+  bmMatr[1, 5] <- 1 - ppois(q = 1, lambda)
R+
R+  bmMatr[2, 1] <- dpois(x = 0, lambda)
R+  bmMatr[2, 4] <- dpois(x = 1, lambda)
R+  bmMatr[2, 5] <- 1 - ppois(q = 1, lambda)
R+
R+  bmMatr[3, 2] <- dpois(x = 0, lambda)
R+  bmMatr[3, 5] <- 1 - dpois(x=0, lambda)
R+
R+  bmMatr[4, 3] <- dpois(x = 0, lambda)
R+  bmMatr[4, 5] <- 1 - dpois(x = 0, lambda)
R+
R+  bmMatr[5, 4] <- dpois(x = 0, lambda)
R+  bmMatr[5, 5] <- 1 - dpois(x = 0, lambda)
R+  stateNames <- as.character(1:5)
R+  out <- new("markovchain", transitionMatrix = bmMatr,
R+           states = stateNames, name = "BM Matrix")
R+  return(out)
R+ }
```

Assuming that the a-priori claim frequency per car-year is 0.05 in the class (being the class the group of policyholders that share the same common characteristics), the underlying BM transition matrix and its underlying steady state are as follows.

```
R> bmMc <- getBonusMalusMarkovChain(0.05)
R> as.numeric(steadyStates(bmMc))
```

```
[1] 0.895836079 0.045930498 0.048285405 0.005969247 0.003978772
```

If the underlying BM coefficients of the class are 0.5, 0.7, 0.9, 1.0, 1.25, this means that the average BM coefficient applied on the long run to the class is given by

```
R> sum(as.numeric(steadyStates(bmMc)) * c(0.5, 0.7, 0.9, 1, 1.25))
```

```
[1] 0.534469
```

This means that the average premium paid by policyholders in the portfolio almost halves in the long run.

Health insurance example

Actuaries quantify the risk inherent in insurance contracts evaluating the premium of insurance contract to be sold (therefore covering future risk) and evaluating the actuarial reserves of existing portfolios (the liabilities in terms of benefits or claims payments due to policyholder arising from previously sold contracts), see [Deshmukh \(2012\)](#) for details.

An applied example can be performed using the data from [De Angelis, Paolo and Di Falco, L. \(2016\)](#) that has been saved in the `exdata` folder.

```
R> ltcDemoPath<-system.file("exdata", "ltdItaData.txt",
R+                               package = "markovchain")
R> ltcDemo<-read.table(file = ltcDemoPath, header=TRUE,
R+                       sep = ";", dec = ".")
R> head(ltcDemo)
```

	age	pAD	pID	pAI	pAA
1	20	0.0004616002	0.01083364	0.0001762467	0.9993622
2	21	0.0004824888	0.01079719	0.0001710577	0.9993465
3	22	0.0004949938	0.01177076	0.0001592333	0.9993458
4	23	0.0005042935	0.01159394	0.0001605731	0.9993351
5	24	0.0005074193	0.01260574	0.0001606504	0.9993319
6	25	0.0005154267	0.01526364	0.0001643603	0.9993202

The data shows the probability of transition between the state of (A)ctive, to (I)ll and Dead. It is easy to complete the transition matrix.

```
R> ltcDemo<-transform(ltcDemo,
R+                       pIA=0,
R+                       pII=1-pID,
R+                       pDD=1,
R+                       pDA=0,
R+                       pDI=0)
```

Now we build a function that returns the transition during the $t + 1$ th year, assuming that the subject has attained year t .

```
R> possibleStates<-c("A", "I", "D")
R> getMc4Age<-function(age) {
R+   transitionsAtAge<-ltcDemo[ltcDemo$age==age,]
R+
R+   myTransMatr<-matrix(0, nrow=3, ncol = 3,
R+                       dimnames = list(possibleStates, possibleStates))
R+   myTransMatr[1,1]<-transitionsAtAge$pAA[1]
R+   myTransMatr[1,2]<-transitionsAtAge$pAI[1]
R+   myTransMatr[1,3]<-transitionsAtAge$pAD[1]
R+   myTransMatr[2,2]<-transitionsAtAge$pII[1]
R+   myTransMatr[2,3]<-transitionsAtAge$pID[1]
R+   myTransMatr[3,3]<-1
R+
R+   myMc<-new("markovchain", transitionMatrix = myTransMatr,
R+             states = possibleStates,
R+             name = paste("Age",age,"transition matrix"))
R+
R+   return(myMc)
R+ }

```

Cause transitions are not homogeneous across ages, we use a `markovchainList` object to describe the transition probabilities for a guy starting at age 100.

```
R> getFullTransitionTable<-function(age){
R+   ageSequence<-seq(from=age, to=120)
R+   k=1
R+   myList=list()
R+   for ( i in ageSequence) {
R+     mc_age_i<-getMc4Age(age = i)
R+     myList[[k]]<-mc_age_i
R+     k=k+1
R+   }
R+   myMarkovChainList<-new("markovchainList", markovchains = myList,
R+                           name = paste("TransitionsSinceAge", age, sep = ""))
R+   return(myMarkovChainList)
R+ }
R> transitionsSince100<-getFullTransitionTable(age=100)

```

We can use such transition for simulating ten life trajectories for a guy that begins “active” (A) aged 100:

```
R> rmarkovchain(n = 10, object = transitionsSince100,
R+             what = "matrix", t0 = "A", include.t0 = TRUE)

```

```

      [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9] [,10] [,11] [,12] [,13]
[1,] "A"  "A"  "A"  "A"  "A"  "I"  "I"  "D"  "D"  "D"  "D"  "D"  "D"
[2,] "A"  "A"  "A"  "I"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"
[3,] "A"  "A"  "D"  "D"
[4,] "A"  "A"  "D"  "D"
[5,] "A"  "A"  "A"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"
[6,] "A"  "A"  "A"  "A"  "A"  "A"  "I"  "D"  "D"  "D"  "D"  "D"  "D"
[7,] "A"  "A"  "D"  "D"
[8,] "A"  "A"  "A"  "A"  "A"  "I"  "I"  "D"  "D"  "D"  "D"  "D"  "D"
[9,] "A"  "D"  "D"
[10,] "A"  "A"  "A"  "I"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"
      [,14] [,15] [,16] [,17] [,18] [,19] [,20] [,21] [,22]
[1,] "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"
[2,] "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"
[3,] "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"
[4,] "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"
[5,] "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"
[6,] "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"
[7,] "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"
[8,] "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"
[9,] "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"
[10,] "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"  "D"

```

Lets consider 1000 simulated live trajectories, for a healthy guy aged 80. We can compute the expected time a guy will be disabled starting active at age 80.

```

R> transitionsSince80<-getFullTransitionTable(age=80)
R> lifeTrajectories<-rmarkovchain(n=1e3, object=transitionsSince80,
R+                               what="matrix",t0="A",include.t0=TRUE)
R> temp<-matrix(0,nrow=nrow(lifeTrajectories),ncol = ncol(lifeTrajectories))
R> temp[lifeTrajectories=="I"]<-1
R> expected_period_disabled<-mean(rowSums((temp)))
R> expected_period_disabled

```

```
[1] 1.247
```

Assuming that the health insurance will pay a benefit of 12000 per year disabled and that the real interest rate is 0.02, we can compute the lump sum premium at 80.

```

R> mean(rowMeans(12000*temp%*%( matrix((1+0.02)^-seq(from=0, to=ncol(temp)-1))))))

```

```
[1] 12391.18
```

6.4. Sociology

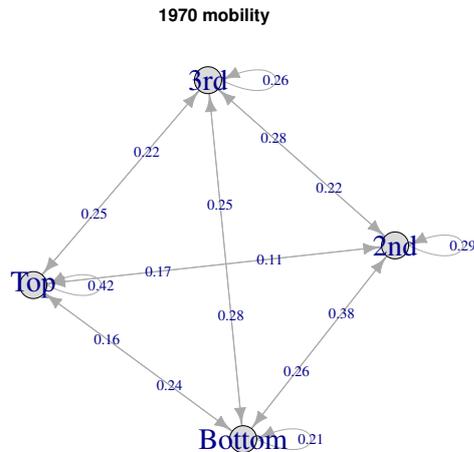


Figure 5: 1970 UK cohort mobility data.

Markov chains have been actively used to model progressions and regressions between social classes. The first study was performed by [Glass and Hall \(1954\)](#), while a more recent application can be found in [Jo Blanden and Machin \(2005\)](#). The table that follows shows the income quartile of the father when the son was 16 (in 1984) and the income quartile of the son when aged 30 (in 2000) for the 1970 cohort.

```
R> data("blanden")
R> mobilityMc <- as(blanden, "markovchain")
R> mobilityMc
```

Unnamed Markov chain

A 4 - dimensional discrete Markov Chain defined by the following states:
Bottom, 2nd, 3rd, Top

The transition matrix (by rows) is defined as follows:

	2nd	3rd	Bottom	Top
Bottom	0.2900000	0.2200000	0.3800000	0.1100000
2nd	0.2772277	0.2574257	0.2475248	0.2178218
3rd	0.2626263	0.2828283	0.2121212	0.2424242
Top	0.1700000	0.2500000	0.1600000	0.4200000

The underlying transition graph is plotted in [Figure 5](#).

The steady state distribution is computed as follows. Since transition across quartiles are shown, the probability function is evenly 0.25.

```
R> round(steadyStates(mobilityMc), 2)
```

```
      Bottom 2nd 3rd Top
[1,]  0.25 0.25 0.25 0.25
```

6.5. Genetics and Medicine

This section contains two examples: the first shows the use of Markov chain models in genetics, the second shows an application of Markov chains in modelling diseases' dynamics.

Genetics

P. J. Avery and D. A. Henderson (1999) discusses the use of Markov chains in model Preproglucacon gene protein bases sequence. The `preproglucacon` dataset in `markovchain` contains the dataset shown in the package.

```
R> data("preproglucacon", package = "markovchain")
```

It is possible to model the transition probabilities between bases as shown in the following code.

```
R> mcProtein <- markovchainFit(preproglucacon$preproglucacon,
R+                          name = "Preproglucacon MC")$estimate
R> mcProtein
```

Preproglucacon MC

A 4 - dimensional discrete Markov Chain defined by the following states:

A, C, G, T

The transition matrix (by rows) is defined as follows:

	A	C	G	T
A	0.3585271	0.1434109	0.16666667	0.3313953
C	0.3840304	0.1558935	0.02281369	0.4372624
G	0.3053097	0.1991150	0.15044248	0.3451327
T	0.2844523	0.1819788	0.17667845	0.3568905

Medicine

Discrete-time Markov chains are also employed to study the progression of chronic diseases. The following example is taken from B. A. Craig and A. A. Sendi (2002). Starting from six month follow-up data, the maximum likelihood estimation of the monthly transition matrix is obtained. This transition matrix aims to describe the monthly progression of CD4-cell counts of HIV infected subjects.

```
R> craigSendiMatr <- matrix(c(682, 33, 25,
R+                          154, 64, 47,
R+                          19, 19, 43), byrow = T, nrow = 3)
R> hivStates <- c("0-49", "50-74", "75-UP")
R> rownames(craigSendiMatr) <- hivStates
R> colnames(craigSendiMatr) <- hivStates
R> craigSendiTable <- as.table(craigSendiMatr)
R> mcM6 <- as(craigSendiTable, "markovchain")
R> mcM6@name <- "Zero-Six month CD4 cells transition"
R> mcM6
```

Zero-Six month CD4 cells transition

A 3 - dimensional discrete Markov Chain defined by the following states:

0-49, 50-74, 75-UP

The transition matrix (by rows) is defined as follows:

	0-49	50-74	75-UP
0-49	0.9216216	0.04459459	0.03378378
50-74	0.5811321	0.24150943	0.17735849
75-UP	0.2345679	0.23456790	0.53086420

As shown in the paper, the second passage consists in the decomposition of $M_6 = V \cdot D \cdot V^{-1}$ in order to obtain M_1 as $M_1 = V \cdot D^{1/6} \cdot V^{-1}$.

```
R> eig <- eigen(mcM6@transitionMatrix)
```

```
R> D <- diag(eig$values)
```

```
R> V <- eig$vectors
```

```
R> V %*% D %*% solve(V)
```

	[,1]	[,2]	[,3]
[1,]	0.9216216	0.04459459	0.03378378
[2,]	0.5811321	0.24150943	0.17735849
[3,]	0.2345679	0.23456790	0.53086420

```
R> d <- D ^ (1/6)
```

```
R> M <- V %*% d %*% solve(V)
```

```
R> mcM1 <- new("markovchain", transitionMatrix = M, states = hivStates)
```

7. Discussion, issues and future plans

The **markovchain** package has been designed in order to provide easily handling of DTMC and communication with alternative packages.

The package has known several improvements in the recent years: many functions added, porting the software in Rcpp **Rcpp** package (Eddelbuettel 2013) and many methodological improvements that have improved the software reliability.

8. Acknowledgments

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References

- Allaire J, Francois R, Ushey K, Vandenbrouck G, Geelnard M, Intel (2016). *RcppParallel: Parallel Programming Tools for 'Rcpp'*. R package version 4.3.19, URL <http://rcppcore.github.io/RcppParallel/>.
- Anderson TW, Goodman LA (1957). "Statistical inference about Markov chains." *The Annals of Mathematical Statistics*, pp. 89–110.
- B A Craig, A A Sendi (2002). "Estimation of the Transition Matrix of a Discrete-Time Markov Chain." *Health Economics*, **11**, 33–42.
- Bard JF (2000). "Lecture 12.5 - Additional Issues Concerning Discrete-Time Markov Chains." URL http://www.me.utexas.edu/~jensen%20/ORMM/instruction/powerpoint/or_models_09/12.5_dtmc2.ppt.
- Brémaud P (1999). "Discrete-Time Markov Models." In *Markov Chains*, pp. 53–93. Springer.
- Chambers J (2008). *Software for Data Analysis: Programming with R*. Statistics and computing. Springer-Verlag. ISBN 9780387759357.
- Ching WK, Ng MK, Fung ES (2008). "Higher-order multivariate Markov chains and their applications." *Linear Algebra and its Applications*, **428**(2), 492–507.
- Csardi G, Nepusz T (2006). "The **igraph** Software Package for Complex Network Research." *InterJournal, Complex Systems*, 1695. URL <http://igraph.sf.net>.
- De Angelis, Paolo, Di Falco, L (2016). *Assicurazioni sulla salute: caratteristiche, modelli attuariali e basi tecniche*. Il Mulino. Il Mulino. ISBN 9788815260840. URL <https://books.google.it/books?id=D56bjgEACAAJ>.
- de Wreede LC, Fiocco M, Putter H (2011). "**mstate**: An R Package for the Analysis of Competing Risks and Multi-State Models." *Journal of Statistical Software*, **38**(7), 1–30. URL <http://www.jstatsoft.org/v38/i07/>.
- Denuit M, Maréchal X, Pitrebois S, Walhin JF (2007). *Actuarial modelling of claim counts: Risk classification, credibility and bonus-malus systems*. Wiley.
- Deshmukh S (2012). *Multiple Decrement Models in Insurance: An Introduction Using R*. SpringerLink : Bücher. Springer-Verlag. ISBN 9788132206590.
- Dobrow RP (2016). *Introduction to Stochastic Processes with R*. John Wiley & Sons.
- Eddelbuettel D (2013). *Seamless R and C++ Integration with **Rcpp***. Springer-Verlag, New York. ISBN 978-1-4614-6867-7.
- Feres R (2007). "Notes for Math 450 MATLAB Listings for Markov Chains." URL <http://www.math.wustl.edu/~feres/Math450Lect04.pdf>.
- Geyer CJ, Johnson LT (2013). *mcmc: Markov Chain Monte Carlo*. R package version 0.9-2, URL <http://CRAN.R-project.org/package=mcmc>.

- Glass D, Hall JR (1954). “Social Mobility in Great Britain: A Study in Intergenerational Change in Status.” In *Social Mobility in Great Britain*. Routledge and Kegan Paul.
- Goulet V, Dutang C, Maechler M, Firth D, Shapira M, Stadelmann M, expm-developers@listsR-forgeR-projectorg (2013). *expm: Matrix Exponential*. R package version 0.99-1, URL <http://CRAN.R-project.org/package=expm>.
- Grinstead CM, Snell LJ (2006). *Grinstead and Snell’s Introduction to Probability*. Version dated 4 July 2006 edition. American Mathematical Society. URL <http://math.dartmouth.edu/~prob/prob/prob.pdf>.
- Himmelmann SSDDL, wwwlinhicom (2010). *HMM: HMM - Hidden Markov Models*. R package version 1.0, URL <http://CRAN.R-project.org/package=HMM>.
- Hu YT, Kiesel R, Perraudin W (2002). “The estimation of transition matrices for sovereign credit ratings.” *Journal of Banking and Finance*, **26**(7), 1383–1406. ISSN 03784266. doi: [10.1016/S0378-4266\(02\)00268-6](https://doi.org/10.1016/S0378-4266(02)00268-6).
- Israel RB, Rosenthal JS, Wei JZ (2001). “Finding generators for Markov chains via empirical transition matrices, with applications to credit ratings.” *Mathematical finance*, **11**(2), 245–265.
- J G Kemeny, J L Snell, G L Thompson (1974). *Introduction to Finite Mathematics*. Prentice Hall.
- Jackson CH (2011). “Multi-State Models for Panel Data: The **msm** Package for R.” *Journal of Statistical Software*, **38**(8), 1–29. URL <http://www.jstatsoft.org/v38/i08/>.
- Jacob I (2014). “Is R Cost Effective?” Electronic. Presented on Manchester R Meeting, URL <http://www.rmanchester.org/Presentations/Ian%20Jacob%20-%20Is%20R%20Cost%20Effective.pdf>.
- Jo Blanden PG, Machin S (2005). “Intergenerational Mobility in Europe and North America.” *Technical report*, Center for Economic Performances. URL <http://cep.lse.ac.uk/about/news/IntergenerationalMobility.pdf>.
- Konstantopoulos T (2009). “Markov Chains and Random Walks.” *Lecture notes*.
- Kullback S, Kupperman M, Ku H (1962). “Tests for Contingency Tables and Markov Chains.” *Technometrics*, **4**(4), 573–608.
- Montgomery J (2009). “Communication Classes.” URL <http://www.ssc.wisc.edu/~jmontgom/commclasses.pdf>.
- Nicholson W (2013). *DTMCPack: Suite of Functions Related to Discrete-Time Discrete-State Markov Chains*. R package version 0.1-2, URL <http://CRAN.R-project.org/package=DTMCPack>.
- Noé F, Schütte C, Vanden-Eijnden E, Reich L, Weikl TR (2009). “Constructing the equilibrium ensemble of folding pathways from short off-equilibrium simulations.” *Proceedings of the National Academy of Sciences*, **106**(45), 19011–19016. ISSN 0027-8424, 1091-6490. doi: [10.1073/pnas.0905466106](https://doi.org/10.1073/pnas.0905466106). URL <https://www.pnas.org/content/106/45/19011>.

- P J Avery, D A Henderson (1999). “Fitting Markov Chain Models to Discrete State Series.” *Applied Statistics*, **48**(1), 53–61.
- Pfeuffer M (2017). *ctmcd: Estimating the Parameters of a Continuous-Time Markov Chain from Discrete-Time Data*. R package version 1.1, URL <https://CRAN.R-project.org/package=ctmcd>.
- R Core Team (2013). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. URL <http://www.R-project.org/>.
- Roebuck P (2011). *matlab: MATLAB emulation package*. R package version 0.8.9, URL <http://CRAN.R-project.org/package=matlab>.
- Sison CP, Glaz J (1995). “Simultaneous confidence intervals and sample size determination for multinomial proportions.” *Journal of the American Statistical Association*, **90**(429), 366–369.
- Skuriat-Olechnowska M (2005). *Statistical inference and hypothesis testing for Markov chains with Interval Censoring*. diploma thesis, Delft University of Technology.
- Snell L (1999). “Probability Book: chapter 11.” URL http://www.dartmouth.edu/~chance/teaching_aids/books_articles/probability_book/Chapter11.pdf.
- Spedicato GA (2017). “Discrete Time Markov Chains with R.” *The R Journal*. URL <https://journal.r-project.org/archive/2017/RJ-2017-036/index.html>.
- Tarjan R (1972). “Depth-First Search and Linear Graph Algorithms.” *SIAM Journal on Computing*, **1**(2), 146–160. doi:10.1137/0201010. URL <https://doi.org/10.1137/0201010>.
- Villacorta PJ (2012). *MultinomialCI: Simultaneous confidence intervals for multinomial proportions according to the method by Sison and Glaz*. R package version 1.0, URL <http://CRAN.R-project.org/package=MultinomialCI>.
- Wittmann A (2007). *CreditMetrics: Functions for Calculating the CreditMetrics Risk Model*. R package version 0.0-2.
- Wolfram Research I (2013a). URL <http://www.wolfram.com/mathematica/new-in-9/markov-chains-and-queues/structural-properties-of-finite-markov-processes.html>.
- Wolfram Research I (2013b). *Mathematica*. Wolfram Research, Inc., ninth edition.

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