## MARKOV CHAIN MODEL

**Definition**

A Markov process is a [stochastic process](https://en.wikipedia.org/wiki/Stochastic_process) that satisfies the [Markov property](https://en.wikipedia.org/wiki/Markov_property) (sometimes characterized as "[memorylessness](https://en.wikipedia.org/wiki/Memorylessness)"). In simpler terms, it is a process for which predictions can be made regarding future outcomes based solely on its present state and—most importantly—such predictions are just as good as the ones that could be made knowing the process's full history. In other words, [conditional](https://en.wikipedia.org/wiki/Conditional_probability) on the present state of the system, its future and past states are [independent](https://en.wikipedia.org/wiki/Independence_(probability_theory)).

A Markov chain is a type of Markov process that has either a discrete [state space](https://en.wikipedia.org/wiki/State_space) or a discrete index set (often representing time), but the precise definition of a Markov chain varies. For example, it is common to define a Markov chain as a Markov process in either [discrete or continuous time](https://en.wikipedia.org/wiki/Continuous_or_discrete_variable) with a countable state space (thus regardless of the nature of time), but it is also common to define a Markov chain as having discrete time in either countable or continuous state space (thus regardless of the state space).

**Types of Markov chains**

The system's [state space](https://en.wikipedia.org/wiki/State_space) and time parameter index need to be specified. The following table gives an overview of the different instances of Markov processes for different levels of state space generality and for discrete time v. continuous time:

|  |  |  |
| --- | --- | --- |
|  | Countable state space | Continuous or general state space |
| Discrete-time | (discrete-time) Markov chain on a countable or finite state space | [Markov chain on a measurable state space](https://en.wikipedia.org/wiki/Markov_chains_on_a_measurable_state_space) (for example, [Harris chain](https://en.wikipedia.org/wiki/Harris_chain)) |
| Continuous-time | Continuous-time Markov process or Markov jump process | Any [continuous stochastic process](https://en.wikipedia.org/wiki/Continuous_stochastic_process) with the Markov property (for example, the [Wiener process](https://en.wikipedia.org/wiki/Wiener_process)) |

Note that there is no definitive agreement in the literature on the use of some of the terms that signify special cases of Markov processes. Usually the term "Markov chain" is reserved for a process with a discrete set of times, that is, a discrete-time Markov chain (DTMC), but a few authors use the term "Markov process" to refer to a continuous-time Markov chain (CTMC) without explicit mention. In addition, there are other extensions of Markov processes that are referred to as such but do not necessarily fall within any of these four categories (see [Markov model](https://en.wikipedia.org/wiki/Markov_model)). Moreover, the time index need not necessarily be real-valued; like with the state space, there are conceivable processes that move through index sets with other mathematical constructs. Notice that the general state space continuous-time Markov chain is general to such a degree that it has no designated term.

While the time parameter is usually discrete, the [state space](https://en.wikipedia.org/wiki/State_space) of a Markov chain does not have any generally agreed-on restrictions: the term may refer to a process on an arbitrary state space. However, many applications of Markov chains employ finite or [countably infinite](https://en.wikipedia.org/wiki/Countable_set) state spaces, which have a more straightforward statistical analysis. Besides time-index and state-space parameters, there are many other variations, extensions and generalizations (see [Variations](https://en.wikipedia.org/wiki/Markov_chain#Variations)). For simplicity, most of this article concentrates on the discrete-time, discrete state-space case, unless mentioned otherwise.

## Applications

Research has reported the application and usefulness of Markov chains in a wide range of topics such as physics, chemistry, biology, medicine, music, game theory and sports.

### Physics

### Markovian systems appear extensively in [thermodynamics](https://en.wikipedia.org/wiki/Thermodynamics) and [statistical mechanics](https://en.wikipedia.org/wiki/Statistical_mechanics), whenever probabilities are used to represent unknown or unmodelled details of the system, if it can be assumed that the dynamics are time-invariant, and that no relevant history need be considered which is not already included in the state description. For example, a thermodynamic state operates under a probability distribution that is difficult or expensive to acquire. Therefore, Markov Chain Monte Carlo method can be used to draw samples randomly from a black-box to approximate the probability distribution of attributes over a range of objects.

### The paths, in the path integral formulation of quantum mechanics, are Markov chains. Markov chains are used in [lattice QCD](https://en.wikipedia.org/wiki/Lattice_QCD) simulations.

### Chemistry

### {\displaystyle {\ce {{E}+{\underset {Substrate \atop binding}{S<=>E}}{\overset {Catalytic \atop step}{S->E}}+P}}}[Michaelis-Menten kinetics](https://en.wikipedia.org/wiki/Michaelis-Menten_kinetics). The enzyme (E) binds a substrate (S) and produces a product (P). Each reaction is a state transition in a Markov chain.

### A reaction network is a chemical system involving multiple reactions and chemical species. The simplest stochastic models of such networks treat the system as a continuous time Markov chain with the state being the number of molecules of each species and with reactions modeled as possible transitions of the chain. Markov chains and continuous-time Markov processes are useful in chemistry when physical systems closely approximate the Markov property. For example, imagine a large number *n* of molecules in solution in state A, each of which can undergo a chemical reaction to state B with a certain average rate. Perhaps the molecule is an enzyme, and the states refer to how it is folded. The state of any single enzyme follows a Markov chain, and since the molecules are essentially independent of each other, the number of molecules in state A or B at a time is *n* times the probability a given molecule is in that state.

### The classical model of enzyme activity, [Michaelis–Menten kinetics](https://en.wikipedia.org/wiki/Michaelis%E2%80%93Menten_kinetics), can be viewed as a Markov chain, where at each time step the reaction proceeds in some direction. While Michaelis-Menten is fairly straightforward, far more complicated reaction networks can also be modeled with Markov chains.

### An algorithm based on a Markov chain was also used to focus the fragment-based growth of chemicals [in silico](https://en.wikipedia.org/wiki/In_silico) towards a desired class of compounds such as drugs or natural products. As a molecule is grown, a fragment is selected from the nascent molecule as the "current" state. It is not aware of its past (that is, it is not aware of what is already bonded to it). It then transitions to the next state when a fragment is attached to it. The transition probabilities are trained on databases of authentic classes of compounds.

### Also, the growth (and composition) of [copolymers](https://en.wikipedia.org/wiki/Copolymer) may be modeled using Markov chains. Based on the reactivity ratios of the monomers that make up the growing polymer chain, the chain's composition may be calculated (for example, whether monomers tend to add in alternating fashion or in long runs of the same monomer). Due to [steric effects](https://en.wikipedia.org/wiki/Steric_effects), second-order Markov effects may also play a role in the growth of some polymer chains.

### Similarly, it has been suggested that the crystallization and growth of some epitaxial [superlattice](https://en.wikipedia.org/wiki/Superlattice) oxide materials can be accurately described by Markov chains.

### Biology

### Markov chains are used in various areas of biology. Notable examples include:

### [Phylogenetics](https://en.wikipedia.org/wiki/Phylogenetics) and [bioinformatics](https://en.wikipedia.org/wiki/Bioinformatics), where most [models of DNA evolution](https://en.wikipedia.org/wiki/Models_of_DNA_evolution) use continuous-time Markov chains to describe the [nucleotide](https://en.wikipedia.org/wiki/Nucleotide) present at a given site in the [genome](https://en.wikipedia.org/wiki/Genome).

### [Population dynamics](https://en.wikipedia.org/wiki/Population_dynamics), where Markov chains are in particular a central tool in the theoretical study of [matrix population models](https://en.wikipedia.org/wiki/Matrix_population_models).

### [Neurobiology](https://en.wikipedia.org/wiki/Neurobiology), where Markov chains have been used, e.g, to simulate the mammalian neocortex.

### [Systems biology](https://en.wikipedia.org/wiki/Systems_biology), for instance with the modeling of viral infection of single cells.

### [Compartmental models](https://en.wikipedia.org/wiki/Compartmental_models_in_epidemiology) for disease outbreak and epidemic modeling.

### Testing

### Several theorists have proposed the idea of the Markov chain statistical test (MCST), a method of conjoining Markov chains to form a "[Markov blanket](https://en.wikipedia.org/wiki/Markov_blanket)", arranging these chains in several recursive layers ("wafering") and producing more efficient test sets—samples—as a replacement for exhaustive testing. MCSTs also have uses in temporal state-based networks; Chilukuri et al.'s paper entitled "Temporal Uncertainty Reasoning Networks for Evidence Fusion with Applications to Object Detection and Tracking" (ScienceDirect) gives a background and case study for applying MCSTs to a wider range of applications.

### Solar irradiance variability

### Solar irradiance variability assessments are useful for [solar power](https://en.wikipedia.org/wiki/Solar_power) applications. Solar irradiance variability at any location over time is mainly a consequence of the deterministic variability of the sun's path across the sky dome and the variability in cloudiness. The variability of accessible solar irradiance on Earth's surface has been modeled using Markov chains, also including modeling the two states of clear and cloudiness as a two-state Markov chain.

### Speech recognition

### [Hidden Markov models](https://en.wikipedia.org/wiki/Hidden_Markov_model) are the basis for most modern [automatic speech recognition](https://en.wikipedia.org/wiki/Speech_recognition#Hidden_Markov_models) systems.

### Information theory

### Markov chains are used throughout information processing. [Claude Shannon](https://en.wikipedia.org/wiki/Claude_Shannon)'s famous 1948 paper [A Mathematical Theory of Communication](https://en.wikipedia.org/wiki/A_Mathematical_Theory_of_Communication), which in a single step created the field of [information theory](https://en.wikipedia.org/wiki/Information_theory), opens by introducing the concept of [entropy](https://en.wikipedia.org/wiki/Information_entropy) through Markov modeling of the English language. Such idealized models can capture many of the statistical regularities of systems. Even without describing the full structure of the system perfectly, such signal models can make possible very effective [data compression](https://en.wikipedia.org/wiki/Data_compression) through [entropy encoding](https://en.wikipedia.org/wiki/Entropy_encoding) techniques such as [arithmetic coding](https://en.wikipedia.org/wiki/Arithmetic_coding). They also allow effective [state estimation](https://en.wikipedia.org/wiki/State_estimation) and [pattern recognition](https://en.wikipedia.org/wiki/Pattern_recognition). Markov chains also play an important role in [reinforcement learning](https://en.wikipedia.org/wiki/Reinforcement_learning).

### Markov chains are also the basis for hidden Markov models, which are an important tool in such diverse fields as telephone networks (which use the [Viterbi algorithm](https://en.wikipedia.org/wiki/Viterbi_algorithm) for error correction), speech recognition and [bioinformatics](https://en.wikipedia.org/wiki/Bioinformatics) (such as in rearrangements detection).

### The [LZMA](https://en.wikipedia.org/wiki/Lempel%E2%80%93Ziv%E2%80%93Markov_chain_algorithm) lossless data compression algorithm combines Markov chains with [Lempel-Ziv compression](https://en.wikipedia.org/wiki/LZ77_and_LZ78) to achieve very high compression ratios.

### Queueing theory

### Main article: [Queueing theory](https://en.wikipedia.org/wiki/Queueing_theory)

### Markov chains are the basis for the analytical treatment of queues ([queueing theory](https://en.wikipedia.org/wiki/Queueing_theory)). [Agner Krarup Erlang](https://en.wikipedia.org/wiki/Agner_Krarup_Erlang) initiated the subject in 1917. This makes them critical for optimizing the performance of telecommunications networks, where messages must often compete for limited resources (such as bandwidth).

### Numerous queueing models use continuous-time Markov chains. For example, an [M/M/1 queue](https://en.wikipedia.org/wiki/M/M/1_queue) is a CTMC on the non-negative integers where upward transitions from *i* to *i* + 1 occur at rate *λ* according to a [Poisson process](https://en.wikipedia.org/wiki/Poisson_process) and describe job arrivals, while transitions from *i* to *i* – 1 (for *i* > 1) occur at rate *μ* (job service times are exponentially distributed) and describe completed services (departures) from the queue.

### Internet applications

### [https://upload.wikimedia.org/wikipedia/commons/thumb/a/a9/PageRank_with_Markov_Chain.png/220px-PageRank_with_Markov_Chain.png](https://en.wikipedia.org/wiki/File:PageRank_with_Markov_Chain.png)

### A state diagram that represents the PageRank algorithm with a transitional probability of M, or {\displaystyle {\frac {\alpha }{k\_{i}}}+{\frac {1-\alpha }{N}}}.

### The [PageRank](https://en.wikipedia.org/wiki/PageRank) of a webpage as used by [Google](https://en.wikipedia.org/wiki/Google) is defined by a Markov chain. It is the probability to be at page {\displaystyle i} in the stationary distribution on the following Markov chain on all (known) webpages. If {\displaystyle N} is the number of known webpages, and a page {\displaystyle i} has {\displaystyle k\_{i}} links to it then it has transition probability {\displaystyle {\frac {\alpha }{k\_{i}}}+{\frac {1-\alpha }{N}}} for all pages that are linked to and {\displaystyle {\frac {1-\alpha }{N}}} for all pages that are not linked to. The parameter {\displaystyle \alpha } is taken to be about 0.15.

### Markov models have also been used to analyze web navigation behavior of users. A user's web link transition on a particular website can be modeled using first- or second-order Markov models and can be used to make predictions regarding future navigation and to personalize the web page for an individual user.

### Statistics

### Markov chain methods have also become very important for generating sequences of random numbers to accurately reflect very complicated desired probability distributions, via a process called Markov chain Monte Carlo (MCMC). In recent years this has revolutionized the practicability of [Bayesian inference](https://en.wikipedia.org/wiki/Bayesian_inference) methods, allowing a wide range of [posterior distributions](https://en.wikipedia.org/wiki/Posterior_distribution) to be simulated and their parameters found numerically.

### Economics and finance

### Markov chains are used in finance and economics to model a variety of different phenomena, including the distribution of income, the size distribution of firms, asset prices and market crashes. [D. G. Champernowne](https://en.wikipedia.org/wiki/D._G._Champernowne) built a Markov chain model of the distribution of income in 1953. [Herbert A. Simon](https://en.wikipedia.org/wiki/Herbert_A._Simon) and co-author Charles Bonini used a Markov chain model to derive a stationary Yule distribution of firm sizes. [Louis Bachelier](https://en.wikipedia.org/wiki/Louis_Bachelier) was the first to observe that stock prices followed a random walk. The random walk was later seen as evidence in favor of the [efficient-market hypothesis](https://en.wikipedia.org/wiki/Efficient-market_hypothesis) and random walk models were popular in the literature of the 1960s. Regime-switching models of business cycles were popularized by [James D. Hamilton](https://en.wikipedia.org/wiki/James_D._Hamilton) (1989),who used a Markov chain to model switches between periods high and low GDP growth (or alternatively, economic expansions and recessions). A more recent example is the [Markov switching multifractal](https://en.wikipedia.org/wiki/Markov_switching_multifractal) model of [Laurent E. Calvet](https://en.wikipedia.org/wiki/Laurent_E._Calvet) and Adlai J. Fisher, which builds upon the convenience of earlier regime-switching models. It uses an arbitrarily large Markov chain to drive the level of volatility of asset returns.

### Dynamic macroeconomics makes heavy use of Markov chains. An example is using Markov chains to exogenously model prices of equity (stock) in a [general equilibrium](https://en.wikipedia.org/wiki/General_equilibrium) setting.

### [Credit rating agencies](https://en.wikipedia.org/wiki/Credit_rating_agency) produce annual tables of the transition probabilities for bonds of different credit ratings.

### Social sciences

### Markov chains are generally used in describing [path-dependent](https://en.wikipedia.org/wiki/Path-dependent) arguments, where current structural configurations condition future outcomes. An example is the reformulation of the idea, originally due to [Karl Marx](https://en.wikipedia.org/wiki/Karl_Marx)'s [*Das Kapital*](https://en.wikipedia.org/wiki/Das_Kapital), tying [economic development](https://en.wikipedia.org/wiki/Economic_development) to the rise of [capitalism](https://en.wikipedia.org/wiki/Capitalism). In current research, it is common to use a Markov chain to model how once a country reaches a specific level of economic development, the configuration of structural factors, such as size of the [middle class](https://en.wikipedia.org/wiki/Middle_class), the ratio of urban to rural residence, the rate of [political](https://en.wikipedia.org/wiki/Political) mobilization, etc., will generate a higher probability of transitioning from [authoritarian](https://en.wikipedia.org/wiki/Authoritarian) to [democratic regime](https://en.wikipedia.org/wiki/Democratic_regime).

### Games

### Markov chains can be used to model many games of chance.[[1]](https://en.wikipedia.org/wiki/Markov_chain#cite_note-:0-1) The children's games [Snakes and Ladders](https://en.wikipedia.org/wiki/Snakes_and_Ladders) and "[Hi Ho! Cherry-O](https://en.wikipedia.org/wiki/Hi_Ho!_Cherry-O)", for example, are represented exactly by Markov chains. At each turn, the player starts in a given state (on a given square) and from there has fixed odds of moving to certain other states (squares).

### Music

### Markov chains are employed in [algorithmic music composition](https://en.wikipedia.org/wiki/Algorithmic_composition), particularly in [software](https://en.wikipedia.org/wiki/Software) such as [Csound](https://en.wikipedia.org/wiki/Csound), [Max](https://en.wikipedia.org/wiki/Max_(software)), and [SuperCollider](https://en.wikipedia.org/wiki/SuperCollider). In a first-order chain, the states of the system become note or pitch values, and a [probability vector](https://en.wikipedia.org/wiki/Probability_vector) for each note is constructed, completing a transition probability matrix (see below). An algorithm is constructed to produce output note values based on the transition matrix weightings, which could be [MIDI](https://en.wikipedia.org/wiki/MIDI) note values, frequency ([Hz](https://en.wikipedia.org/wiki/Hertz)), or any other desirable metric.

|  |  |  |  |
| --- | --- | --- | --- |
| 1st-order matrix | | | |
| Note | A | C♯ | E♭ |
| A | 0.1 | 0.6 | 0.3 |
| C♯ | 0.25 | 0.05 | 0.7 |
| E♭ | 0.7 | 0.3 | 0 |
|  |  |  |  |
|  |  |  |  |

|  |  |  |  |
| --- | --- | --- | --- |
| 2nd-order matrix | | | |
| Notes | A | D | G |
| AA | 0.18 | 0.6 | 0.22 |
| AD | 0.5 | 0.5 | 0 |
| AG | 0.15 | 0.75 | 0.1 |
| DD | 0 | 0 | 1 |
| DA | 0.25 | 0 | 0.75 |
| DG | 0.9 | 0.1 | 0 |
| GG | 0.4 | 0.4 | 0.2 |
| GA | 0.5 | 0.25 | 0.25 |
| GD | 1 | 0 | 0 |

### 

### A second-order Markov chain can be introduced by considering the current state *and* also the previous state, as indicated in the second table. Higher, *n*th-order chains tend to "group" particular notes together, while 'breaking off' into other patterns and sequences occasionally. These higher-order chains tend to generate results with a sense of [phrasal](https://en.wikipedia.org/wiki/Phrase_(music)) structure, rather than the 'aimless wandering' produced by a first-order system. Markov chains can be used structurally, as in Xenakis's Analogique A and B. Markov chains are also used in systems which use a Markov model to react interactively to music input.

### Usually musical systems need to enforce specific control constraints on the finite-length sequences they generate, but control constraints are not compatible with Markov models, since they induce long-range dependencies that violate the Markov hypothesis of limited memory. In order to overcome this limitation, a new approach has been proposed.

### Baseball

### Markov chain models have been used in advanced baseball analysis since 1960, although their use is still rare. Each half-inning of a baseball game fits the Markov chain state when the number of runners and outs are considered. During any at-bat, there are 24 possible combinations of number of outs and position of the runners. Mark Pankin shows that Markov chain models can be used to evaluate runs created for both individual players as well as a team.[[99]](https://en.wikipedia.org/wiki/Markov_chain#cite_note-99) He also discusses various kinds of strategies and play conditions: how Markov chain models have been used to analyze statistics for game situations such as [bunting](https://en.wikipedia.org/wiki/Bunt_(baseball)) and [base stealing](https://en.wikipedia.org/wiki/Base_stealing) and differences when playing on grass vs. [AstroTurf](https://en.wikipedia.org/wiki/AstroTurf).

### Markov text generators

### Markov processes can also be used to [generate superficially real-looking text](https://en.wikipedia.org/wiki/Natural_language_generation) given a sample document. Markov processes are used in a variety of recreational "[parody generator](https://en.wikipedia.org/wiki/Parody_generator)" software (see [dissociated press](https://en.wikipedia.org/wiki/Dissociated_press), Jeff Harrison, [Mark V. Shaney](https://en.wikipedia.org/wiki/Mark_V._Shaney), and Academias [Neutronium](https://en.wikipedia.org/wiki/Neutronium)). Several open-source text generation libraries using Markov chains exist, including [The RiTa Toolkit](https://en.wikipedia.org/w/index.php?title=The_RiTa_Toolkit&action=edit&redlink=1).

### Probabilistic forecasting

### Markov chains have been used for forecasting in several areas: for example, price trends, wind power, and solar irradiance. The Markov chain forecasting models utilize a variety of settings, from discretizing the time series, to hidden Markov models combined with wavelets, and the Markov chain mixture distribution model (MCM).

## ****How is it applied?****

Markov analysis is usually provided as a module within integrated reliability software suites such as Isograph’s Reliability Workbench and Item’s ToolKit. These provide a graphical user interface to facilitate the definition of system states and the possible transitions between them, and the failure and repair rate are usually then imported from the suite’s database of values.

Clearly any transition can only occur from the current state of the system so the transition rates are only effective from the current state at any given time, i.e. they are conditional on the state from which they emanate being the current state. This means that dormant as well as active standby systems can be modelled in a Markov system. More difficult, but nevertheless still possible to model, are buffers such as storage tanks which gradually empty when certain types of failure occur and refill when the fault is repaired.

Common cause failures can also be modelled by suitably defining transitions from one system state to another that correspond to multiple failures. For example, if the current system state includes a duty and standby both working, a common cause failure would be represented by a transition from this system state directly to the state in which both the duty and standby have failed.

It can therefore be seen that there is great flexibility in what can be included in the model of a Markov system. Even degraded performance of components in a system can be modelled rather than simply the binary “working” and “failed” states that are normally considered in reliability analysis. Greater detail in the model however must be accompanied by more detailed knowledge of transition rates, so in practice the level of detail will be limited by the level of knowledge and available data on transition rates.

### USES

### Predicting traffic flows

### Communications networks

### Genetic issues

### Queues

### This are examples where Markov chains can be used to model performance

## ****Advantages and disadvantages****

Markov analysis has the advantage of being an analytical method which means that the reliability parameters for the system are calculated in effect by a formula. This has the considerable advantages of speed and accuracy when producing results. Speed is especially useful when investigating many alternative variations of design or exploring a range of sensitivities. In contrast accuracy is vitally important when investigating small design changes or when the reliability or availability of high integrity systems are being quantified. Markov analysis has a clear advantage over MCS in respect of speed and accuracy since MCS requires longer simulation runs to achieve higher accuracy and, unlike Markov analysis, does not produce an “exact” answer.

As in the case of applying MCS, Markov analysis requires great care during the model building phase since model accuracy is all-important in obtaining valid results. The assumptions implicit in Markov models that are associated with memorilessness and the Exponential distribution to represent times to failure and repair provide additional constraints to those within MCS. Markov models can therefore become somewhat contrived if these implicit assumptions do not reflect sufficiently well the characteristics of a system and how it functions in practice. In order to gain the benefits of speed and accuracy that it can offer, Markov analysis depends to a greater extent on the experience and judgement of the modeller than MCS. Also, whilst MCS is a safer and more flexible approach, it does not always offer the speed and accuracy that may be required in particular system studies.

## Conclusion

Now that you know the basics of Markov chains, you should now be able to easily implement them in a language of your choice. If coding is not your forte, there are also many more advanced properties of Markov chains and Markov processes to dive into. In my opinion, the natural progression along the theory route would be toward Hidden Markov Processes or MCMC. Simple Markov chains are the building blocks of other, more sophisticated, modeling techniques, so with this knowledge, you can now move onto various techniques within topics such as belief modeling and sampling.

* The most important property of the Markov chain is that the future state will defends upon the only on the current state not the steps before
* The second important property is that the sum of the outgoing arrows from any state is equal to 1. This has to be true because they represent probabilities

It is very useful in

1. Bioinformatics
2. Natural language processing
3. Speech recognition
4. [thermodynamics](https://en.wikipedia.org/wiki/Thermodynamics)
5. [statistical mechanics](https://en.wikipedia.org/wiki/Statistical_mechanics)
6. [physics](https://en.wikipedia.org/wiki/Physics)
7. [chemistry](https://en.wikipedia.org/wiki/Chemistry)
8. [economics](https://en.wikipedia.org/wiki/Economics), [finance](https://en.wikipedia.org/wiki/Finance)
9. [signal processing](https://en.wikipedia.org/wiki/Signal_processing)
10. [information theory](https://en.wikipedia.org/wiki/Information_theory)
11. [handwriting](https://en.wikipedia.org/wiki/Handwriting_recognition)
12. [gesture recognition](https://en.wikipedia.org/wiki/Gesture_recognition)
13. [part-of-speech tagging](https://en.wikipedia.org/wiki/Part-of-speech_tagging)
14. [partial discharges](https://en.wikipedia.org/wiki/Partial_discharge)

So the states of the markov chain are unknown or hidden from us but we can observe some variables that are dependent on the states

|  |
| --- |
| HMM =Hidden MC + Observed Variables |

In other words a hidden markov model consists of an ordinary markov chain and a set of observed variables

In this we observe the sequence of ‘y’ that’s why x given is the equation

Arg max P(X = X1,X2,X3,….XN | Y = Y1,Y2,Y3,…YN)