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Time Series

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Abstract:

Everything that happens is related to time. Any action, any change, anything really, will inevitably take place in an interval of time. Therefore, it is essential that we study events about time to identify the patterns in which they occur; learn from the past to improve our future. The purpose of this research is to apply our knowledge of a mathematical term called Time Series, which its sole existence is about data that is gathered about time. To make use of Time Series data it has to be analyzed, and here comes the importance of Time Series Analysis. With the patterns extracted from the Analysis, it's then used in forecasting, which is one of the many characteristics of the models of Time Series among many more. Time Series is composed of four variations which are the trend, seasonal, cyclic and irregular variations. Each of their contribution to the understanding of the data. The history of the Time Series shows how much it was needed as the prediction of weather was of great interest to cultured people like Aristotle, who had developed ideas about the causes and sequences of the weather. Since then, Time Series and its Analysis have expanded from just being about the weather to being applied in various applications such as sales, finance, heart rate measurement, stock prices, and much more. Moreover, it has entered countless fields and to name a few in the computer science fields there is machine learning, cybersecurity, the internet of things (IoT) and data mining. In this research, more in-depth details are given about each of these applications and fields regarding the use of Time Series. As great as Time Series is, there are cases in which its use is not optimal, and sometimes even downright useless, which is mostly decided with the Stationary and correlation attributes of the data thus needing to convert it to a suitable format. Graphs play a vital role in visualizing the output of such Analysis, consequently, it takes various shapes and forms according to the purpose of using it. Lastly, all this big data Analysis is based on theories. Math equations that describe the relationships that tie all this together.

Keywords: Time Series, Time Series Analysis, Forecasting,

Introduction

Time Series is the study of data observations due to a period, so it is important for a lot of different fields like machine learning, network, security, data mining, etc. In which we can predict future data after understanding and analyzing the previous history data over time. On the other hand, data collected irregularly or only once are not considered Time Series. An all-statistical Analysis of Time Series data is collected from a real-life thing we are interested in, the data is conditioned so, it can be used to make predictions of future values.

The simplest example of a Time Series that all of us come across on a day-to-day basis is the change in temperature through the day or week or month or year.

Definition of Time Series:

A Time Series is a set of Numerical Measurements of the same entity taken at equally spaced intervals over time, Time Series data could be collected yearly, monthly, or daily.

The Reason for choosing Time Series:

Time Series Analysis is special as it helps organizations understand the underlying causes of trends or systemic patterns over time. Using data visualizations, business users can see season trends and dig deeper into why these trends occur. Companies can also use Time Series Analysis to predict the likelihood of future events like upcoming trends in fashion and popular music albums.

The Goal of using Time Series Data:

Our aim is to use our previously collected data to predict what will occur in the future, in all fields, such as weather forecasting, or many machine learning application.

Time Series Analysis:

Time Series Analysis is a specific way of analyzing a sequence of data points collected over an interval of time to identify the common patterns displayed by the data.

In Time Series Analysis, analysts record data points at consistent intervals over a set period rather than just recording the data points intermittently or randomly.

However, this type of Analysis is not merely the act of collecting data over time.

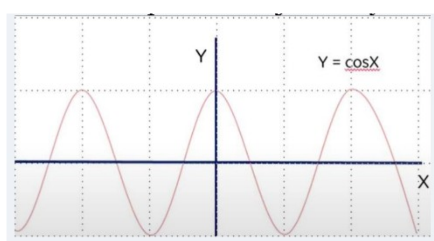
Time Series Analysis typically requires a large number of data points to ensure consistency and reliability. An extensive data set ensures you have a representative sample size and that Analysis can cut through noisy data. It also ensures that any trends or patterns discovered are not outliers and can account for seasonal variance. Additionally, Time Series data can be used for forecasting-predicting future data based on historical data, there's always the potential for correlation between variables in these charts because data points are collected in adjacent periods.

Some Time Series data is pointless to analyze:

Despite the Usefulness of Time Series Analysis, there are some cases that it can't be used:

1. When the values are constant over some time.

2. When values can be presented by known functions like sin x, cos x, etc.…



History

1. Time Series history

Time Series analysis theoretically development started early with stochastic processes.

1.1 John Graunt studied the death records that have been kept in London since the early 16^{th} century and in doing so he originated the discipline of demography study of population. In **1662** he published a book on natural political observations made upon bills of mortality.

1.2 In **1901,** the Time Series made its way to **medicine** when the first practical electrocardiogram(heart) study that can diagnose cardiac conditions was invented.

1.3 In **1924** electroencephalogram (brain) was introduced and its technique measures impulses in the brain.

1.4 In the 21^{st} century we see the development of wearable sensors this is a great way to collect longitudinal data about healthy and ailing populations.

1.5 In **300bc** predicting weather has been an interest since ancient times, the Greek philosopher Aristotle investigated weather in his treatise meteorology, and he developed ideas about the causes and sequences of the weather.

1.6 A greater formalization and infrastructure for weather recording came in **1850** when Robert Fitzroy was appointed the head of a new British government department to record and publish weather-related data for sailors and he established the custom of printing weather forecasts and newspapers, the first forecasts were printed in the Times of London and we can say the Fitzroy's is now celebrated as the father of forecasting.

1.7 Another application of Time Series is astronomy, astronomy has always heavily applauded object measurements over time and as an example of long history consider the sunspot Time Series, the famous Sunspot Time Series recorded in ancient China in **800 BC.**

Originally Time Series analysis had been more generally developed in areas such as engineering and economics before it came into widespread use in science research

2. Time Series analysis history

2.1 The beginning of the modern Time Series started in **1927** when George Udny Yuke invented autoregressive (AR) techniques, AR is the model where the past value influences current values using pendulum fluctuation.

2.2 The theoretical development in Time Series analysis started early with stochastic (random) processes. The first actual application of autoregressive models to data can be brought back to the work of George Udny Yule and john Walker in the **1920s and 1930s.**

2.3 During this time the moving average was introduced to remove periodic fluctuations in the Time Series, for example, fluctuations due to seasonality. Herman Wold introduced ARMA (Autoregressive Moving Average) models for stationary series but was unable to derive a likelihood function to enable maximum likelihood estimation of the parameters.

2.4 It took until **1970** before this was accomplished**.** At that time, the classic book "Time Series Analysis" by George Box and Jenkins Walker came out, containing the full modelling procedure for individual series: specification, estimation, diagnostics, and forecasting.

2.5 In the **1980s:** Outliers' detection-model diagnostics (**Chen 1988**).

2.6 Kalman filtering-Evaluation of the likelihood function and handling missing observations (**Jones 1980**), Kalman filtering introduced the Time Series analysis to evaluate efficiently by handling missing observations.

2.7 **Int The 1990s:** MCMC-Markov chain Monte Carlo (**Gelfand & Smith in 1990**), this method led to increasing use of simulation methods and Time Series analysis which was not possible in the past.

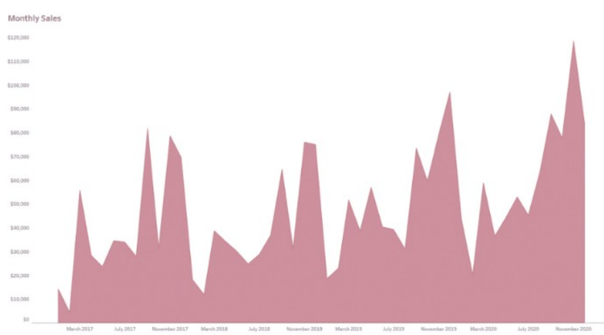
Main

The Time Series' Specialty:

1. **Their sequence matters for interpretation:** with Time Series the sequence of events is as meaningful as the events themselves. For example, the fact that a delivery delay occurred today and not yesterday is potentially crucial information for a supply chain manager. Whereas the fact that I posted my picture today and not yesterday doesn't affect fakebook's ability to tag me.

2. **Time Series analysis helps you identify patterns:** memories are fragile and prone to error. You may think that your sales peak before Christmas and hit their bottom in February……. but do they?

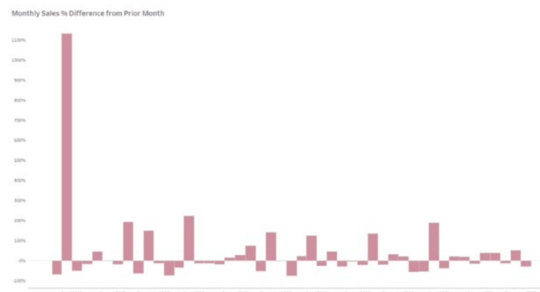
   The simplest and**,** in most cases the most effective form of Time Series analysis is simply plotting the data on a line chart. With this step, there will no longer be any doubts as to whether or not sales truly peak before Christmas and dip in February.

   Now that we have plotted out sales data, it becomes immediately clear what patterns we have. Sales are trending upward year-over-year, and seem to follow a regular yearly pattern. The months of January and February see the lowest sales figures and there is a major spike in November and December.

3. **Time Series analysis creates the opportunity to clean your data:** in the example above, we plotted actual sales figures for each month in the data set. If any observations were missing, the gap in the Time Series chart would show that right away. With any gaps in the data identified, it would be easy to impute those missing values.

Furthermore, we would be able to identify outliers in the data. Perhaps instead of looking at actual sales, it would make more sense to plot the percentage difference between observations. This is a technique that can help smooth out very noisy data.



In this case, Plotting the percentage difference in sales from month to month smoothed out much of the data except for the enormous spike in march **2017.** This is not necessarily a bad thing, however; without performing these analytic steps we may have been unaware that such a spike existed

As we can see from the mentioned above, Time Series has a great impact on our life, that’s why it is crucially important.

Types of Time Series Data:

- Generally, Time Series data is classified into two types:

1. **A Stock Series** is a measure of certain attributes at a point in time and can be thought of as "Stock takes". For example, the monthly labour force survey is a stock measure because it takes stock of whether a person was employed in the reference week.

2. **A Flow Series** are series that are a measure of activity over a given period. For example, surveys of retail trade activity. Manufacturing is also a flow measure because a certain amount is produced each day, and then these amounts are summed to give a total value for production for a given reporting period.

The main difference between a stock and a flow series is that a flow series can contain effects related to the calendar (Trading Day Effects). Both types of series can still be seasonally adjusted using the same seasonal adjustment process.

- In addition to the above classification, Time Series data could also be classified into three types:

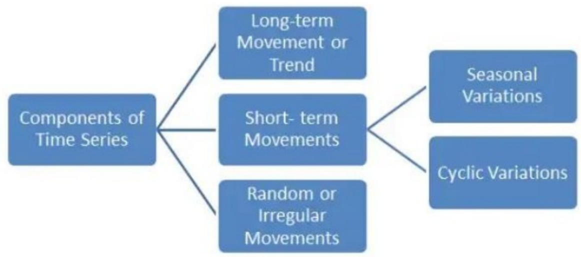
1. **Univariate:**
   A univariate Time Series consists of sequential measurements of a single variable over time. Consider a Time Series dataset that contains measurements of a person named mike, who has certain features (variables), such as gender, high, weight, and pulse. If we collect measurements of one of these variables, say mike's weight, over time, we have a univariate Time Series. Using these values of mike's weight, we can build a model to predict hit the future weight

2. **Multivariate (Bivariate):**
   A multivariate Time Series is multiple related variables over time. For example, mike's height and weight and we know that there is a relationship between the two variables (weight and height). In that case, we have a bivariate Time Series. And using these values of mike's weight and height, we can build a prediction model to determine his future weight or height.

3. **Multiple (Pooled Data):**
   It contains measurements of multiple entities that are independent. Now, let's build upon the univariate example, by including measurements about mike's neighbour's, and Kate's weight. Suppose we know that the measurements of these individuals are independent of each other. In that case, we can say that the dataset contains multiple univariate Time Series, and predicting the weight of an individual would depend on his or her previous weights alone.

Components of Time Series:

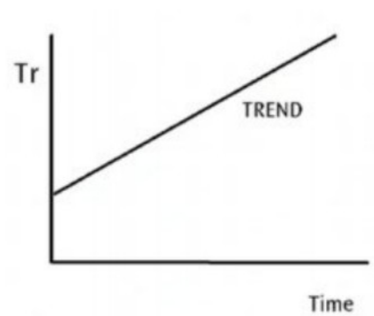
As study variables take different values in a particular time series. These differences in values are not due to only one component like time whereas it is also affected by more than one component or multiple components. These multiple components pull ups and downs the values of the characteristics under study.

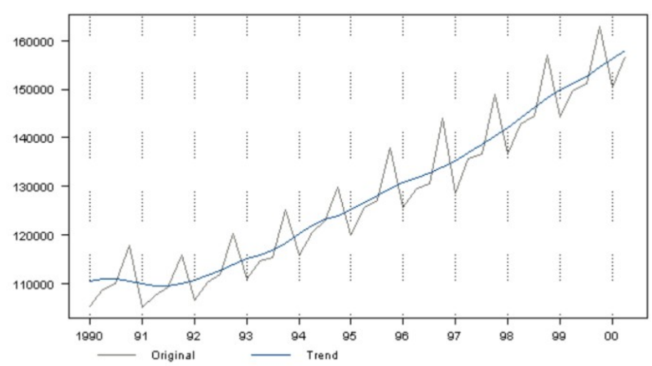


There are Four Main Components of the Time Series:

1. **Trend:** which describes the movement along the term, refers to long-term variations where the variable tends to increase or decrease over a long period

   The Trend line is the horizontal line that acts as a strong area of support and resistance. In the same way trend line also acts as dynamic support and resistance which are inclined at an angle, preferably at 45 angles.





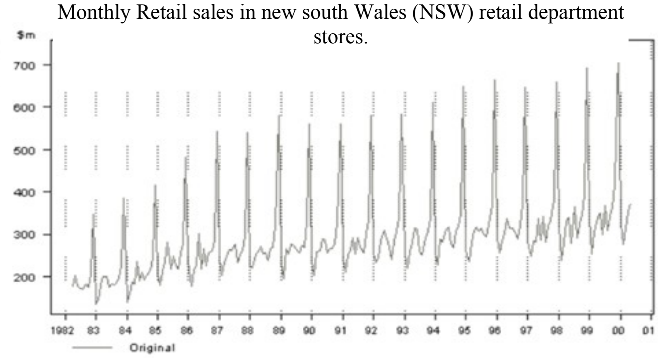
Trend Lines have two types:

1.1 Uptrend trend line: a slopping area on the chart showing an upward direction of the trend.

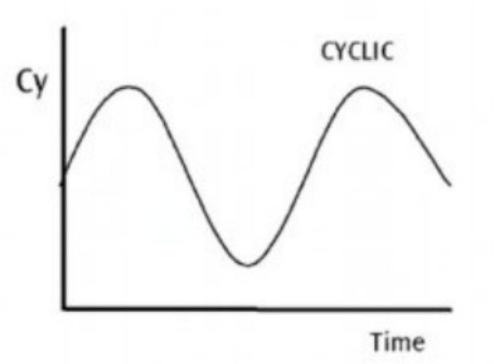
1.2 Downtrend line: a slopping area on the chart showing a downward direction of the trend**.**

2. **Seasonal Variations:** which represent seasonal changes, short-term periodic movements and regular in nature, involve patterns of change within a year that tend to be repeated from year to year.
   Seasonality in a time series can be identified by regularly spaced peaks and throughs which have a consistent direction and approximately the same magnitude every year, relative to the trend, the following diagram depicts a strongly seasonal series. There is a large seasonal increase in December retail sales in new south Wales due to Christmas shopping. In this example, the magnitude of the seasonal component increases over time, as does the trend.

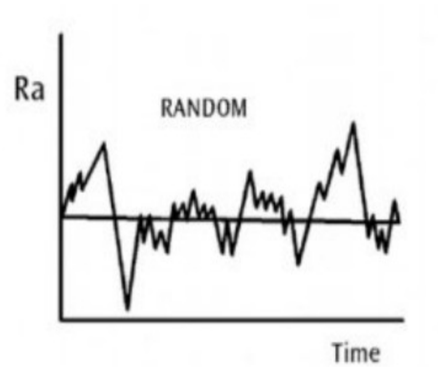
Monthly Retail sales in new south Wales (NSW) retail department stores.



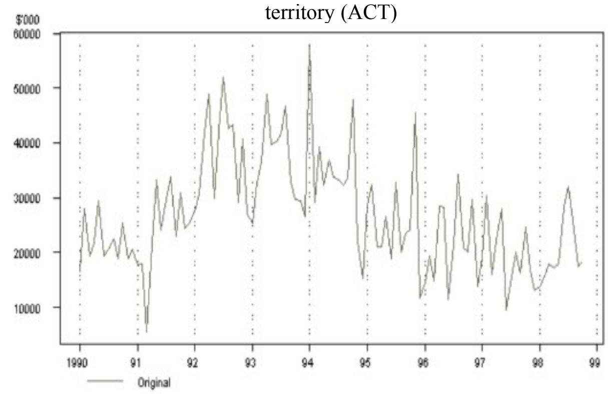
3. **Cyclic fluctuations:** correspond to periodic but not seasonal variations. Periodic movements in time series around the trend line, don't follow any regular pattern and move in somewhat unpredictable manners. The cyclic variation may be regular or irregular (periodic or not).



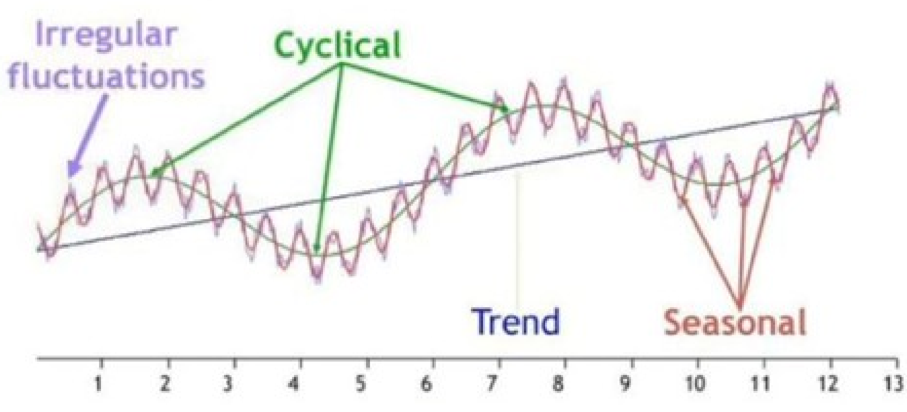
4. **Irregular (random) variants:** these are other nonrandom sources of variants of series, they are uncontrollable unexpected or unpredictable these forces are earthquakes, wars, floods, and any other disasters
The irregular component (sometimes also known as the residual) is what remains after the seasonal and trend components of a time series have been estimated and removed. It results from short-term fluctuations in the series which are neither systematic nor predictable. In a highly irregular series. These fluctuations can dominate movements, which will mask the trend and seasonality.



Monthly values of building approvals, Austrian capital territory (ACT)



Sum up The Graph of Time Series Data’s Components:

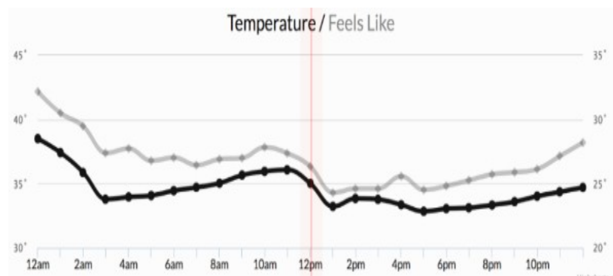


Examples of Time Series Data Analysis:

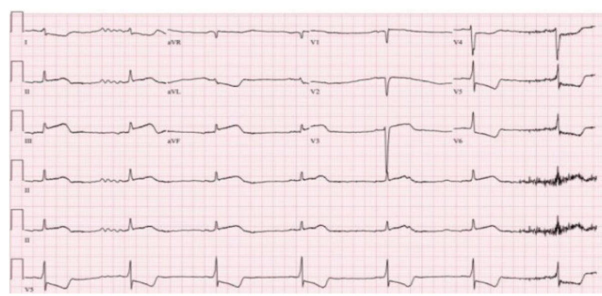
1. **Finance industry:**
   industries like finance and market analysis are perfect examples of using time series analysis because currency and stock markets are constantly changing.

2. **Weather Data:**
   Time series analysis is also used frequently by weathermen to predict what the temperatures will be during different months and seasons throughout the year.

3. **Temperature reading:**
   Can monitor and record every hour
   The temperature in a whole day.



4. **Heart Rate:**
   Time series analysis is also used in the medical field to monitor the heart rate of patients who may be on certain medications to make sure that the heart rate doesn't fluctuate too wildly during any given time of the day.



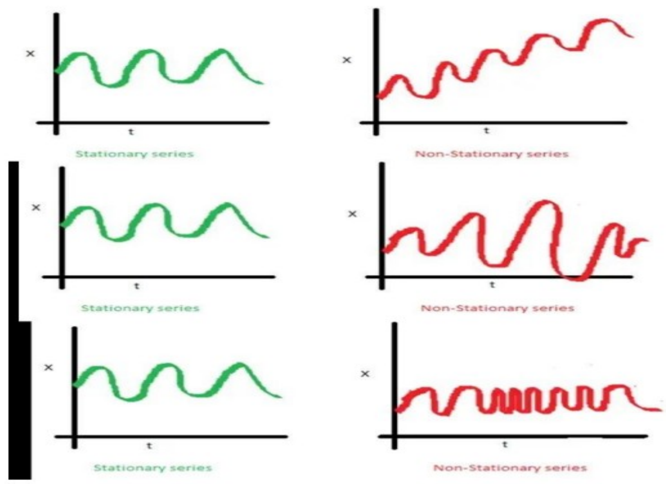
5. **Sales:**
   Retail stores use time series analysis to analyze how their total sales are trending over time. Time series analysis is useful for analyzing monthly, seasonal, and yearly trends in sales, This allows retail stores to be able to more accurately predict what their sales will be during an upcoming period and be able to more accurately predict how much inventory and staff they'll need during different periods of the year.

6. **Stock prices:**
   time series analysis is also used frequently by stock traders so they can gain a better understanding of the patterns in various stock prices
   Time series plots are helpful because they allow stock analysts and traders to understand the trend and direction of a certain stock price.

Stationary and Correlation in Time Series Models:

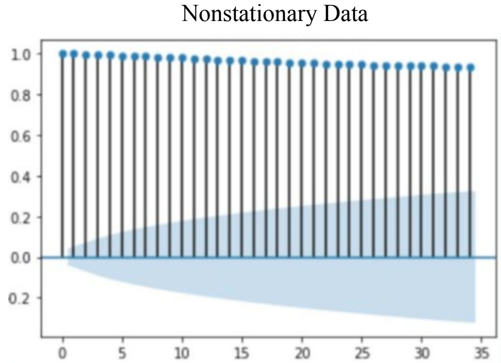
1. **Stationary:**
   Another important element in the Time Series is Stationarity. So, let's discuss this in a little more detail.

   A time series is said to be stationary when its statistical properties do not change over time. That is, its **Mean, Variance** and **Autocorrelation** are equally distributed over time.

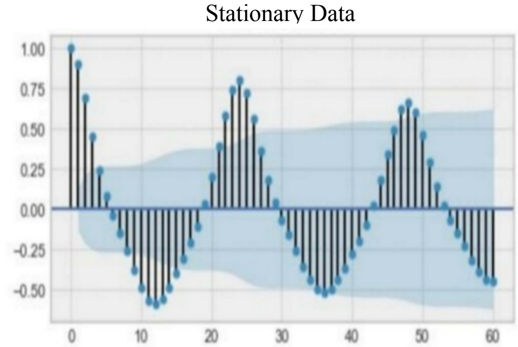


2. **Autocorrelation:**
   It can be seen as the measure of internal correlation in a time series. It is a way of measuring and explaining the internal association between observations. you could have a very strong and positive association, that the time series at one point is going to be the same as a point in some time in the future. Or it could be a very strong and negative association, that is the time series at one point is going to be completely different at a point in the future. Autocorrelation is always measured between +1 and -1.

Nonstationary Data



Stationary Data



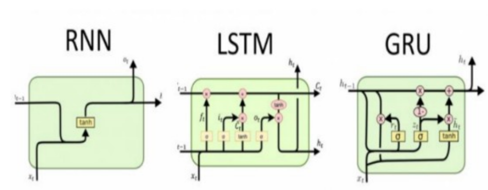
Before performing any time series analysis, the data must be stationary and typically time series data is not stationary… so we should convert it.

Time Series in Computer Science Fields:

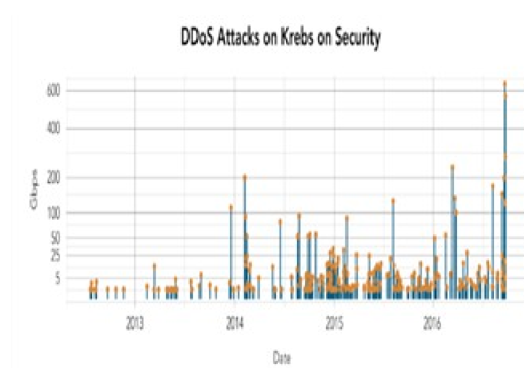
1. **Machine learning (ML):**
   The predictive models based on machine learning found wide implementations in time series projects required by various businesses for facilitating the predictive distribution of time and resources.
   Its methods:

   1.1 **Recurrent neural network (RNN):** RNNs are neural networks with memory that can be used for predicting time-dependent targets. Recurrent neural networks can memorize the preciously captured state of the input to decide for the future time step. Recently, lots of variations have been introduced to adapt recurrent networks to a variety of domains.

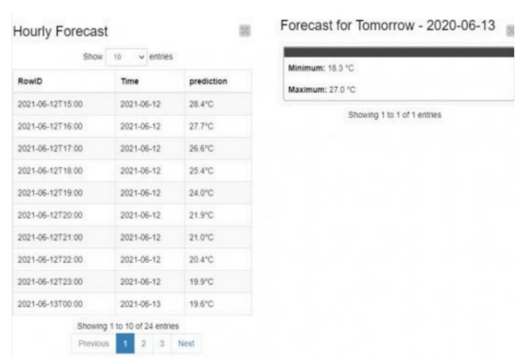
   1.2 **Long short-term memory (LSTM):** special RNN cells were developed to find the solution to the issue with gradients by presenting several gates to help the model decide on what information to mark as significant and what information to ignore. GRU is another type of gated recurrent network.



2. **Cyber security and network:** computer attacks interrupt day-to-day services and cause data losses and network interruption. Time series analyses are popular machine learning methods that help to quantitatively detect anomalies or outliers in data, by either data fitting or forecasting. Time series analysis helps thwart compromises and keep information loss to a minimum.
   The following graph shows the attacks mitigated on a routed platform.



3. **Internet of things (IoT):** IOT prediction can play a key role to enable companies to plan and operate more efficiently.
   IOT-based temperature prediction is already being used successfully by manufacturers in collecting weather data via a sensor board to store and analyze the same data for next-day predictions.



RowID	Time	prediction
2021-06-12T15:00	2021-06-12	28.4°C
2021-06-12T16:00	2021-06-12	27.7°C
2021-06-12T17:00	2021-06-12	26.6°C
2021-06-12T18:00	2021-06-12	25.4°C
2021-06-12T19:00	2021-06-12	24.0°C
2021-06-12T20:00	2021-06-12	21.9°C
2021-06-12T21:00	2021-06-12	21.0°C
2021-06-12T22:00	2021-06-12	20.4°C
2021-06-12T23:00	2021-06-12	19.9°C
2021-06-13T00:00	2021-06-13	19.6°C

Time Series Patterns and Graphs:

1. Patterns:

A time series pattern is the pattern of the data and is an important factor in understanding how the time series has behaved in the past.
If such behaviour can be expected to continue in the future, we can use the past pattern to guide us in selecting an appropriate forecasting method it’s important to understand the patterns because it helps us understand the data and to predict how it’s going to be in the future which helps us in forecasting.

Types of time series patterns:

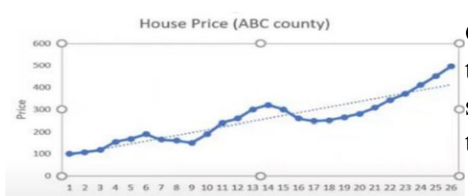
1.1 **Horizontal pattern:** a horizontal pattern exists when the data fluctuate around a constant mean.

1.2 **Trend pattern:** when there are gradual shifts or movements to relatively higher or lower values over a longer period.

1.3 **Seasonal Pattern:** it is recognized by seeing the same repeating patterns over successive periods for example a manufacturer of swimming pools expects low sales activity in the fall and winter months.

1.4 **Trend and Seasonal Pattern:** the combination of a trend and seasonal pattern.

1.5 **Cyclic Pattern**: a cyclic pattern exists if the time series plot shows an alternating sequence of points below and above the trend line lasting more than one year.



2. Graphs:

2.1 Line Graphs:

A line graph is the simplest way to represent time series data. easy to create, and helps the viewer get a quick sense of how something has changed over time.
A line graph uses points connected by lines (also called trend lines) to show how dependent variables and independent variables changed. An independent variable, true to its name, remains unaffected by other parameters, whereas the dependent variable depends on how the independent variable changes**.**

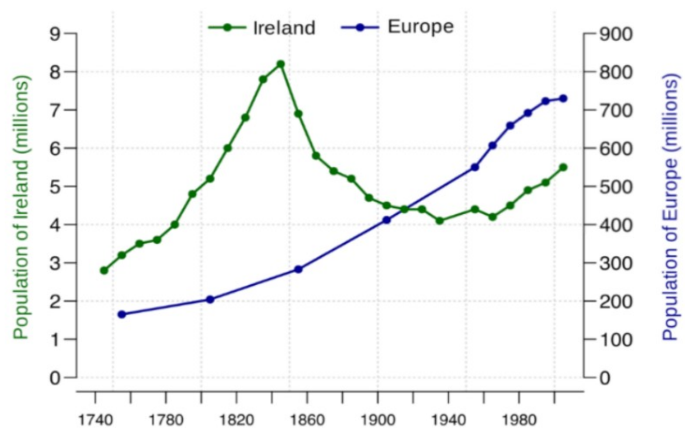


Illustration of the graph: This graph captures the population growth in Europe and Ireland from 1740 to around 2010. It clearly highlights the sudden drop in Ireland's population in the 1840s. History books will tell you this was the result of the devastating Irish Potato Famine, a period of mass starvation, disease, and emigration in Ireland between 1845 and 1852. Note that this graph uses different y-axis scales for its two dependent variables — the populations of Europe and Ireland. If the viewer doesn't pay attention to the difference in the scales, they could be led to the conclusion that until about 1920, Ireland's population was greater than that of Europe.

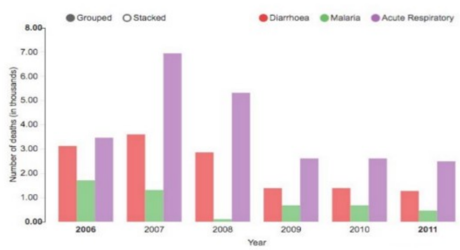
2.2 Stacked area chart:

Stacked area chart: An area chart is like a line chart in that it has points connected by straight lines on a two-dimensional chart.
It also puts time as the independent variable on the x-axis and the dependent variable on the y-axis. However, in an area chart, multiple variables are "stacked" on top of each other, and the area below each line is colored to represent each variable. Stacked area charts are useful to show. how both a cumulative total and individual component of that total changed over time.

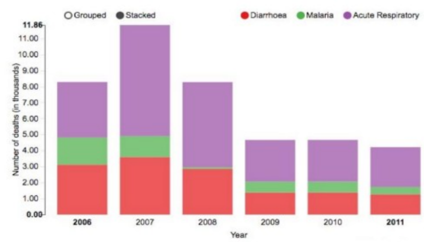
2.3 Bar chart: Bar charts represent data as horizontal or vertical bars. The length of each bar is proportional to the value of the variable at that point in time. A bar chart is a right choice for you when you wish to look at how the variable moved over time or when you wish to compare variables versus each other. Grouped or stacked bar charts help you combine both these purposes in one chart while keeping your visualization simple and intuitive.

Grouped

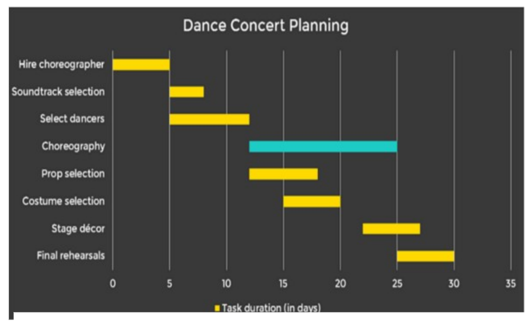
2.4



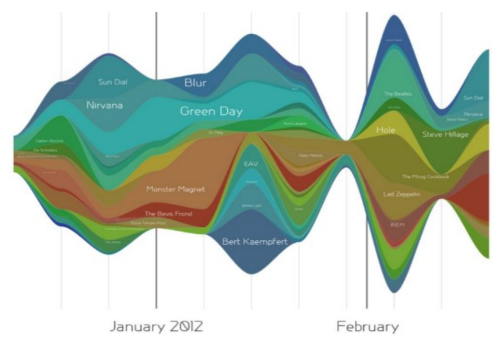
Stacked



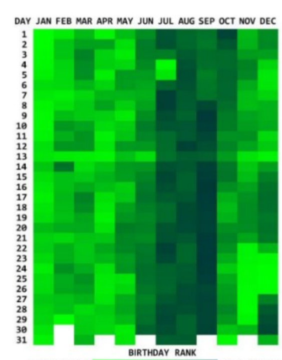
Gantt chart: A Gantt chart is a horizontal bar chart showing work completed in a certain period concerning the time allocated for that task. It is named after the American engineer and management consultant Henry Gantt who extensively used this framework for project management.



2.5 Stream graph: A stream graph is essentially a stacked area graph but displaced around a central horizontal axis. The stream graph looks like flowing liquid, hence the name. Below is a stream graph showing a randomly chosen listener's last.FM music-listening habits over time. Stream graphs are great to represent and compare time series data for multiple variables**.**



2.6 Heat Map: Geospatial visualizations often use heat maps since they quickly help identify "hot spots" or regions of high concentrations of a given variable. When adapted to temporal visualizations, heat maps can help us explore two levels of time in a 2D array. This heat map visualizes birthdays for babies born in the United States between 1973 and 1999. The vertical axis represents the 31 days in a month while the horizontal axis represents the 12 months in a year. This chart quickly helps. us identify that many babies were born in the latter half of July, August, and September. (Usually used in large not continuous data).



Modelling

1. Model Characteristics:

Each model can make any of these characteristics.

1.1 **Classifications:** identifies and assigns categories to the data.

1.2 **Curve fitting:** plots the data along a curve to study the relationships of variables within the Data.

1.3 **Descriptive analysis:** identifies patterns in time series data, like trends, cycles, or seasonal variations.

1.4 **Explanative analysis:** attempts to understand the data and the relationships within it. As well as cause and effect.

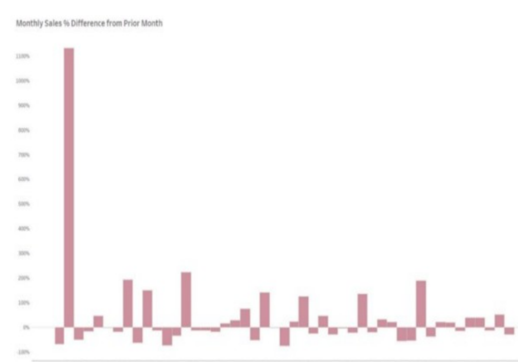
1.5 **Exploratory analysis:** highlights the main characteristics of the time series data, usually in a visual format.

1.6 **Forecasting:** predicts future data, this type is based on historical trends. use historical data as a model for future data, predicting scenarios that could happen along future plot points.
Time series forecasting is the process of analyzing time series data using statistics and modelling to make predictions and inform strategic decision-making. It’s not always an exact prediction.
Organizations analyze data over consistent intervals. They can also use time series forecasting to predict the likelihood of future events. Time series forecasting is part of predictive analysis. It can show likely changes in the data, like seasonality or cyclic behaviour, which provides a better understanding of data variables and helps forecast better.

1.7 **Intervention analysis:** studies how an event can change the data.

1.8 **Segmentation:** splits the data into segments to show the underlying properties of the source information

Note that you should clean your data, we would be able to identify outliers in the data. perhaps instead of looking at actual sales, it would make more sense to plot the percentage difference between observations. this is a technique that can help smooth out very noisy data. In this case, by plotting the percentage difference in sales from month to month we smoothed out much of the data – except for the enormous spike in March 2017. This is not necessarily a bad thing. however, without performing these analytic steps we may have been unaware that such a spike existed.



2. Famous Models & Techniques:

Just as there are many types and models. There are also a variety of methods to study data. Here are the three most common.

1.1 **Box-Jenkins ARIMA Models:** these **univariate** models are used to better understand a single time-dependent variable, such as temperature over time, and to predict future data points of variables. These models work on the assumption that the data is stationary. Analysts have to account for and remove as many differences and seasonalities in past data points as they can. Thankfully, the ARIMA model includes terms to account for **Moving Averages**, **Seasonal Difference Operators**, and **Autoregressive** terms within the Model.

1.2 **Box-Jenkins Multivariate Models:** are used to analyze more than one time-dependent variable, such as temperature and humidity, over time.

1.3 **Holt-Winters Method:** this is an exponential smoothing technique. It is designed to predict
outcomes provided that the data points include **seasonality**.

Theory of Time Series

A time series model postulates a relationship amongst several temporal sequences or time series. An example is provided by the simple regression model

$$Y(t) = X(t)B + E(t)$$

Where y(t) = {yt; t = 0, +-1, +-2…} is a sequence, indexed by the time subscript t, which is a combination of an observable signal sequence x(t) = {xt} and an unobservable white-noise sequence e(t) = {et} of independently and identically distributed random variables, a more general model, which we shall call the general temporal regression model, postulates a relationship comprising any number of consecutive elements of x(t), y(t) and e(t). the model may be represented by the equation.

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