

Past, Present, and Future of Time Series Forecasting

by

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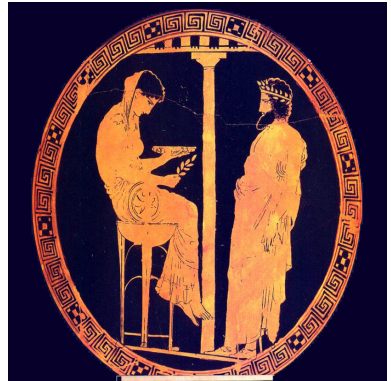
- ① **Statistics** is the study of the collection, analysis, interpretation, presentation and organization of data.
- ② **Data science** is the study of the generalizable extraction of knowledge from data, yet the key word is science.
- ③ **Machine learning** is the sub-field of computer science that gives computers the ability to learn without being explicitly programmed.
- ④ **Artificial Intelligence** research is defined as the study of intelligent agents: any device that perceives its environment and takes actions that maximize its chance of success at some goal.
- ⑤ **Forecasting** is estimating how the sequence of observations will continue into the future. (e.g., Forecasting of major economic variables like GDP, Unemployment, Inflation, Exchange rates, Production and Consumption).

- The Jewish prophet Isaiah wrote in about 700 BC "Tell us what the future holds, so we may know that you are gods." (Isaiah 41:23)
- One hundred years later, in ancient Babylon, forecasters would foretell the future based on the distribution of maggots in a rotten sheep's liver.
- Now in British Museum.



Forecasting by maggots: Clay model of sheep's liver

- Around the same time, people wanting forecasts would journey to Delphi in Greece to consult the Oracle, who would provide her predictions while intoxicated by **ethylene vapours**.



Forecasting by hallucination

- Forecasters had a tougher time under the emperor Constantius, who issued a decree in AD357 forbidding anyone “to consult a soothsayer, a mathematician, or a forecaster – May curiosity to foretell the future be silenced forever.”



Codex Theodosianus 9.16.4

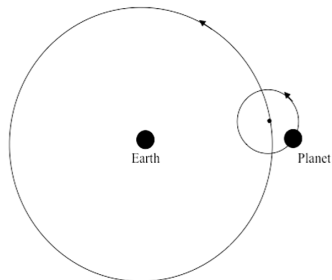
Forecasting. Prediction. Divination.

- A similar ban on forecasting occurred in England in 1736 when it became an offence to defraud by charging money for predictions. The British Vagrancy Act (1736) made it an offence to defraud by charging money for predictions. **The punishment was three months' imprisonment with hard labour!**



Vagrant forecasters

- Ancients Greeks developed predictive model of the cosmos, used for astrology.
- Celestial bodies moved around the Earth in circles (the most stable and symmetric of forms).
- Motion of planets required the use of epicycles.
- Final model by Ptolemy became the official model of the church, remained unquestioned until the Renaissance (Copernicus, Galileo, Kepler)



Vagrant forecasters

Reputations can be made and lost

“I think there is a world market for maybe five computers.”

(Chairman of IBM, 1943)

“There is no reason anyone would want a computer in their home.”

(President, DEC, 1977)

“There’s no chance that the iPhone is going to get any significant market share. No chance.”

(Steve Ballmer, CEO Microsoft, April 2007)

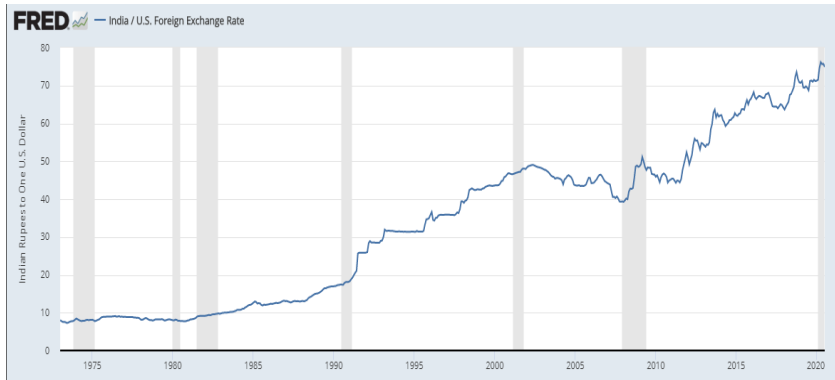
“We’re going to be opening relatively soon ... The virus ... will go away in April.”

(Donald Trump, February 2020)

- **News report on 16 August 2006:** A Russian woman is suing weather forecasters for wrecking her holiday. A court in Uljanovsk heard that Alyona Gabitova had been promised 28 degrees and sunshine when she planned a camping trip to a local nature reserve, newspaper Nowyje Iswestija said. But it did nothing but pour with rain the whole time, leaving her with a cold. Gabitova has asked the court to order the weather service to pay the cost of her travel.
- “There are four ways economists can lose their reputation. Gambling is the quickest, sex is the most pleasurable and drink the slowest. But forecasting is the surest.” (Max Walsh, The Age, 1993)

A Forecasting Problem: India / U.S. Foreign Exchange Rate (EXINUS)

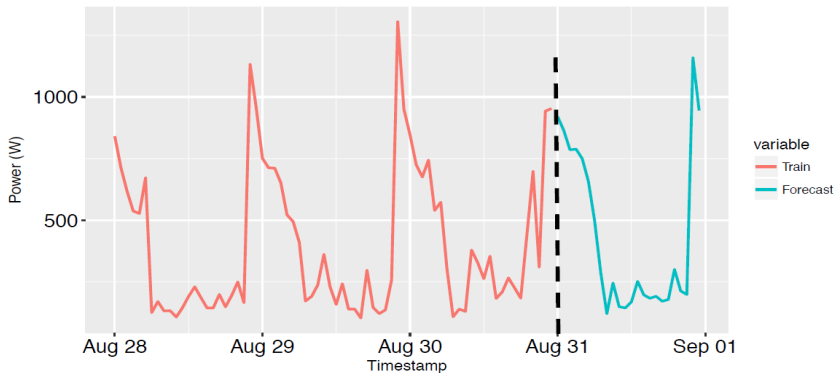
- Source : **FRED ECONOMICS DATA** (Shaded-areas indicate US recessions)
- Units : **Indian Rupees to One U.S. Dollar, Not Seasonally Adjusted**
- Frequency : **Monthly (Averages of daily figures)**



- **Time series** is a set of observations, each one being recorded at a specific time. (e.g., Annual GDP of a country, Sales figure, etc)
- **Discrete time series** is one in which the set of time points at which observations are made is a discrete set. (e.g., All above including irregularly spaced data)
- **Continuous time series** are obtained when observations are made continuously over some time intervals. (e.g., ECG graph)
- **Forecast** is an estimate of the probability distribution of a variable to be observed in the future.
- **Forecasting** is very difficult, since it's about the future !
- **Forecasting** has fascinated people for thousands of years, sometimes being considered a **sign of divine inspiration**, and sometimes being seen as a **criminal activity**.

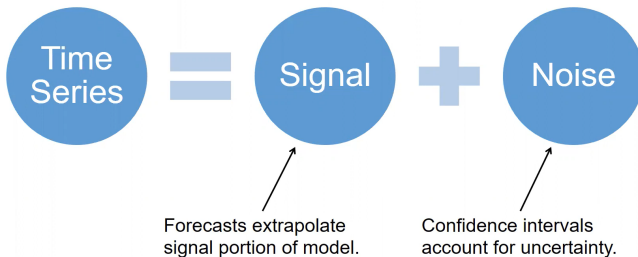
Forecasting : Assumptions

- Time series Forecasting : Data collected at regular intervals of time (e.g., Weather and Electricity Forecasting).
- Assumptions: (a) Historical Information is available; (b) Past patterns will continue in the future.

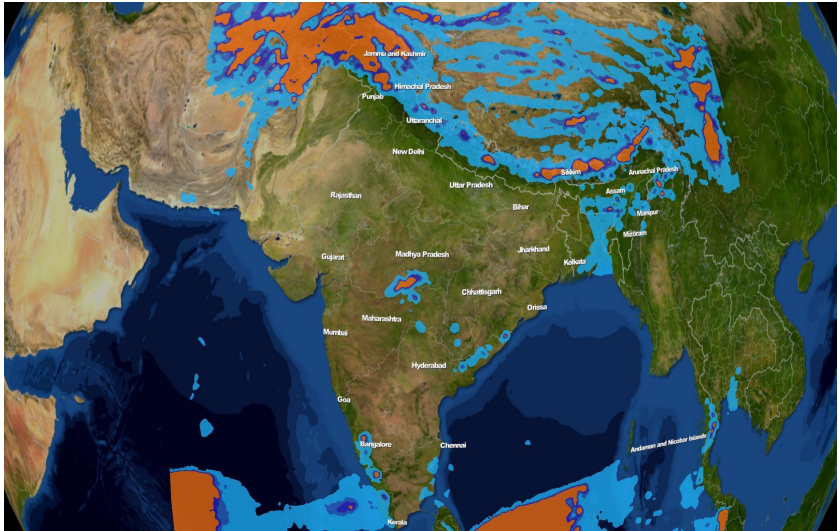


- **Trend (T_t)** : pattern exists when there is a long-term increase or decrease in the data.
- **Seasonal (S_t)** : pattern exists when a series is influenced by seasonal factors (e.g., the quarter of the year, the month, or day of the week).
- **Cyclic (C_t)** : pattern exists when data exhibit rises and falls that are not of fixed period (duration usually of at least 2 years).
- **Decomposition** : $Y_t = f(T_t, S_t, C_t, I_t)$, where Y_t is data at period t and I_t is irregular component at period t .
- **Additive decomposition** : $Y_t = T_t + S_t + C_t + I_t$.
- **Multiplicative decomposition** : $Y_t = T_t \times S_t \times C_t \times I_t$.
- **A stationary series is**: roughly horizontal, constant variance and no patterns predictable in the long-term.

Statistical Forecasting



What can we forecast? - Weather



What can we forecast? - Stock Price



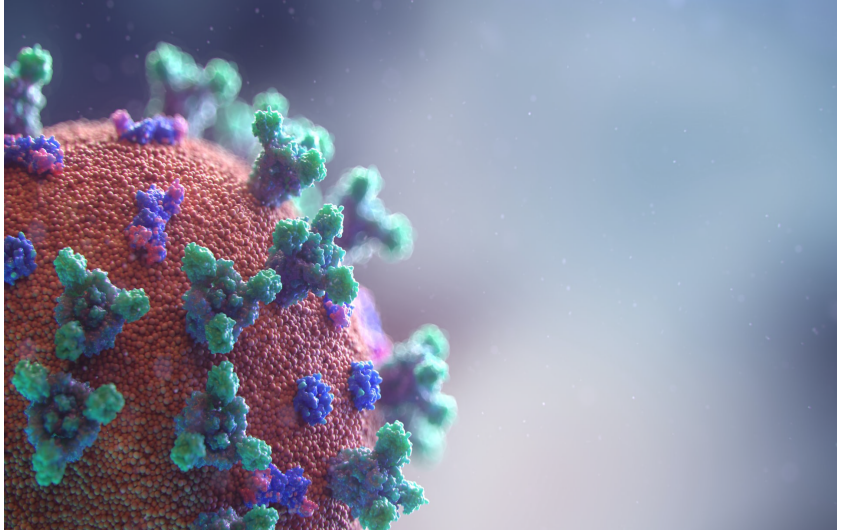
What can we forecast? - Sales



What can we forecast? - Electricity



What can we forecast? - COVID-19



Which is easiest to forecast? (Easy to Tough)

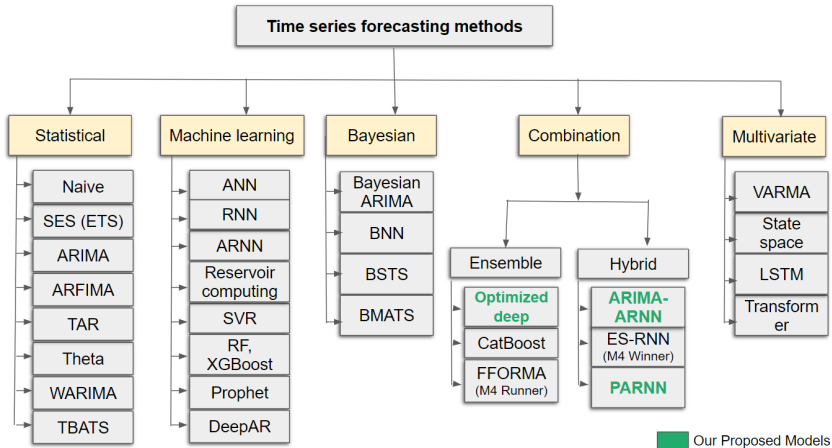
- 1 Time of sunrise this day next year.
- 2 Maximum temperature tomorrow.
- 3 Daily electricity demand in 3 days time.
- 4 Google stock price tomorrow.
- 5 Exchange rate of USD/INR next week.
- 6 Google stock price in 6 months time.

Something is easier to forecast if:

- ① We have a good understanding of the factors that contribute to it, and can measure them.
- ② There is lots of data available.
- ③ The future is somewhat similar to the past.
- ④ The forecasts cannot affect the thing we are trying to forecast.

- Exponential smoothing (Brown, 1959).
- ARIMA models (Box, Jenkins, 1970).
- VAR models (Sims, Granger, 1980).
- non-linear models (Granger, Tong, Hamilton, Teräsvirta, 1980s).
- ARCH/GARCH (Engle, Bollerslev, 1982).
- neural networks (Rumelhart, 1986).
- state space models (Harvey, West, Harrison, 1989).
- nonparametric forecasting (Tjøstheim, Härdle, Tsay, 1995s).
- etc...

Various Forecasting Models



Advantages of stochastic models

- ① Based on empirical data
- ② Objective measure of uncertainty.
- ③ Computable, Replicable, Testable.
- ④ Able to compute prediction intervals.

- 1 Smart algorithms, few assumptions and applied to huge data sets.
- 2 Solve problems which traditional statistical methods can't handle (largely due to size of data sets).
- 3 Strong emphasis on out-of-sample predictive performance (the test data).
- 4 Recognition that many problems are about prediction not p-values.

- **Models for annual data:** Exponential Smoothing State Space (ETS), ARIMA, Dynamic regression, ARNN and LSTM model.
- **Models for quarterly, monthly data:** ETS, ARIMA/SARIMA, Dynamic regression, Seasonal and Trend decomposition using Loess (STL), ARNN and LSTM model.
- **Models for weekly, daily, hourly data:** ARIMA/SARIMA, Dynamic regression, STL.
- A Survey paper with implementation of some of the above-discussed forecasting models (with codes) are available here :
[Nowcasting of COVID-19 confirmed cases: Foundations, trends, and challenges \(Chakraborty et al., Modelling, Control and Drug Development for COVID-19 Outbreak Prevention, 2021\) \(Read online\).](#)

- What about interpretable neural networks and deep learning?
- Will we ever be able to forecast “black swans”?
- Does more data mean better forecasts?
- Will AI take over forecasting?
- Are there many jobs for forecasters?

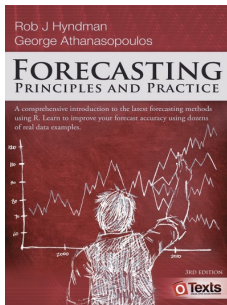
Some further thoughts on Forecasting

- Most statistical problems are better expressed as prediction problems.
- Machine Learning and statistics will converge.
- It will become common to compute prediction intervals for data mining (ML) methods.
- Statisticians will place less emphasis on p-values and more emphasis on predictive ability of models.
- Statisticians need to learn what ML-based forecasters are doing and contribute to the development of methods.
- We need to teach ML methods alongside statistical methods in universities.

FINAL COMMENTS (ANONYMOUS)

"A good forecaster is not smarter than everyone else, he merely has his ignorance better organised."

Start with the most practical and useful book on Forecasting with R codes :



Link to read the book for FREE : <https://otexts.com/fpp3/>

A very updated Survey Paper :
<https://doi.org/10.1016/j.ijforecast.2021.11.001>