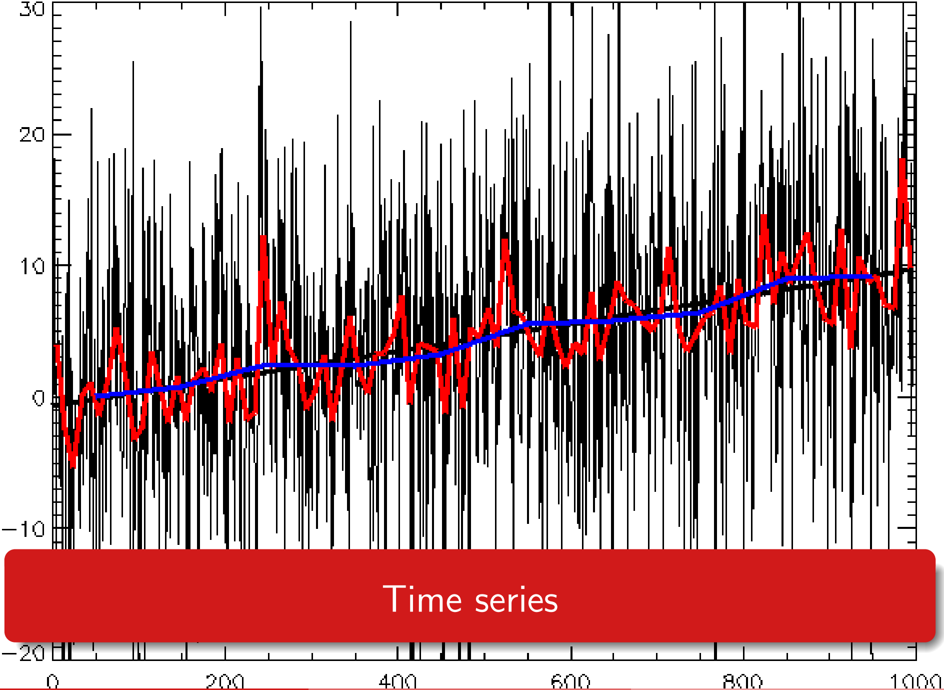


Time series

Time series definition [1]

Informal definition

A time-series is a set of observation x_t each one being recorder at a specific time t.

Formal definition

A time series model for the observed data x_t is a specification of the joint distribution (or possibile only the mens covariance) of a sequence of random variable X_t of which x_t is postulated to be a realization

A binary process

Consider the sequence of iid random variables, with $P[X_t = 1] = p$ and $P[X_t = -1] = 1 - p$

Random walk

The random walk is obtained by cumulatevely summing iid random variables. Thus a random walk with zero mean is obtained by defining

Stationarity, autocovariance and autocorrelation[1]

Mean Function

Let X_t be a time series with $E(x_t^2 < \infty$ The mean function of X_t is $\mu_X(t) = E(X_t)$. The covariance function of X_t is $\gamma_X(r,s) = Cov(X_r, X_S) = E[(X_r - \mu_X(r))(X_s - \mu_X(s))] \quad \forall r, s$

Weakly stationary TS

X_t is weakly stationary if i) $\mu_X(t)$ is indipendent from time t and ii) $\gamma_X(t+h)$ is indipendent of t $\forall h$

Autocovariance function

At lag h the autocovariance function is defined as $\gamma_X(h) = Cov(X_{t+h}, X_t)$

Autocorellation function

At lag h the autocorrelation function is defined as

$$\rho(h)_X = \frac{\gamma_X(h)}{\gamma_X(0)} = Cor(X_{t+h}, X_t)$$

Stationarity, autocovariance and autocorrelation [1]

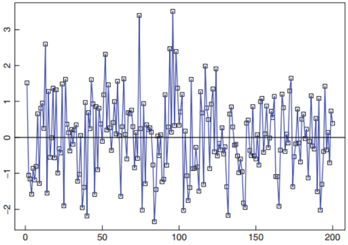


Figure 1-12
200 simulated values of IID N(0,1) noise

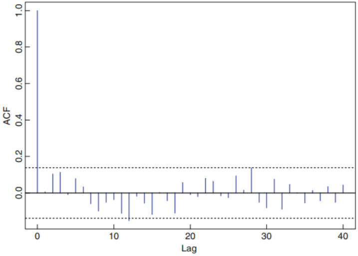
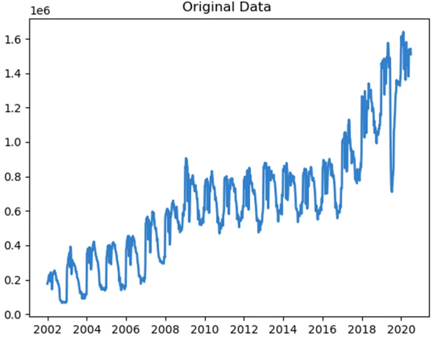
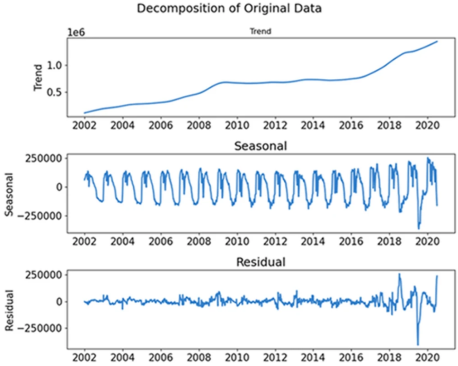


Figure 1-13
The sample autocorrelation function for the data of Figure 1-12 showing the bounds $\pm 1.96/\sqrt{n}$

Stationarity, autocovariance and autocorrelation [2]



(a)



(b)

Definition [1]

Linear process

Time series X_t is a linear process if it has the representation

$$X_t = \sum_{j=-\infty}^{\infty} \psi_j Z_{t-j}$$

for all t, where $Z_t \approx \mathrm{WN}(0, \sigma^2)$ and ψ_j is a sequence of costants with $\sum_{j=-\infty}^{\infty} \psi_j < \infty$. In terms of backward shift operator B $BX_t = X_{t-1}$ we have $X_t = \phi(B)Z_t$ Therefore the previous definition can be casted as $X_t = \phi(B)Z_t$ in which $\phi(B)$ can be thought as a linear filter that when applied to the white noise input series Z_t produces the output X_t

Definition [1]

Linear process

The time series X_t is an ARMA(1,1) process if its stationary and satisfiy (for every t)

$$X_t - \phi X_{t-1} = Z_t + \phi Z_{t-1}$$

where $Z_t \approx \mathrm{WN}(0, \phi^2)$ and $\phi + \theta \neq 0$ or in terms of filters ϕ and θ

$$\phi(B)X_t = \theta(B)Z_t$$

Causality [1]

Remarks

- A stationary solution of the ARMA(1,1) equation exists if and only if $\phi \neq \pm 1$
- If $|\phi| < 1$, then the unique stationary solution is given by $X_t = Z_t + (\phi + \theta) \sum_{j=1}^{\infty} \phi^{j-1} Z_{t-j}$. In this case we say that X_t is causal or a causal function of Z_t or a causal function of Z_t since X_t can be espressd in terms of the current and past values Z_s, $s \leq t$
- If $|\phi| > 1$, then the unique stationary solution is given by $X_t = -\theta\phi^{-1} Z_t - (\phi + \theta) \sum_{j=1}^{\infty} \phi^{-j-1} Z_{t-j}$. The solution is noncausal, since X_t is then a functional of Z_s $s \geq t$

Wold decomposition [1]

Prediction operator based on the infinite past $X_t, -\infty < t < n$

$\tilde{P}_n X_{n+h} = \lim_{m \to -\infty} P_{m,n} X_{n+h}$

Wold decomposition $X_t, -\infty < t < n$

X_t is a non-deterministic stationary time series, then

$$X_t = \sum_{j=0}^{\infty} \psi_j Z_{t-j} + V_t$$

where V_t is deterministic

Definition [1]

Bibliography I

[1] Peter J Brockwell e Richard A Davis. *Introduction to time series and forecasting*. Springer, 2002.

[2] Jianhua Hao e Fangai Liu. "Improving long-term multivariate time series forecasting with a seasonal-trend decomposition-based 2-dimensional temporal convolution dense network". In: *Scientific Reports* 14.1 (2024), p. 1689.