



Forecasting: principles and practice

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1.1 Time series graphics

Outline

- 1 Time series in R
- 2 Time plots
- 3 Lab session 1
- 4 Seasonal plots
- 5 Seasonal or cyclic?
- 6 Lag plots and autocorrelation
- 7 White noise
- 8 Lab session 2

ts objects and ts function

A time series is stored in a ts object in R:

- a list of numbers
- information about times those numbers were recorded.

Example

Year	Observation
2012	123
2013	39
2014	78
2015	52
2016	110

```
y <- ts(c(123,39,78,52,110), start=2012)
```

ts objects and ts function

For observations that are more frequent than once per year, add a frequency argument.

E.g., monthly data stored as a numerical vector z:

```
y <- ts(z, frequency=12, start=c(2003, 1))
```

ts objects and ts function

ts(data, frequency, start)

Type of data	frequency	start	example
--------------	-----------	-------	---------

Annual

Quarterly

Monthly

Daily

Weekly

Hourly

Half-hourly

ts objects and ts function

ts(data, frequency, start)

Type of data	frequency	start example
Annual	1	
Quarterly		
Monthly		
Daily		
Weekly		
Hourly		
Half-hourly		

ts objects and ts function

ts(data, frequency, start)

Type of data	frequency	start	example
--------------	-----------	-------	---------

Annual	1	1995	
--------	---	------	--

Quarterly			
-----------	--	--	--

Monthly			
---------	--	--	--

Daily			
-------	--	--	--

Weekly			
--------	--	--	--

Hourly			
--------	--	--	--

Half-hourly			
-------------	--	--	--

ts objects and ts function

ts(data, frequency, start)

Type of data	frequency	start example
Annual	1	1995
Quarterly	4	
Monthly		
Daily		
Weekly		
Hourly		
Half-hourly		

ts objects and ts function

ts(data, frequency, start)

Type of data	frequency	start example
--------------	-----------	---------------

Annual	1	1995
--------	---	------

Quarterly	4	c(1995,2)
-----------	---	-----------

Monthly		
---------	--	--

Daily		
-------	--	--

Weekly		
--------	--	--

Hourly		
--------	--	--

Half-hourly		
-------------	--	--

ts objects and ts function

ts(data, frequency, start)

Type of data	frequency	start example
Annual	1	1995
Quarterly	4	c(1995,2)
Monthly	12	
Daily		
Weekly		
Hourly		
Half-hourly		

ts objects and ts function

ts(data, frequency, start)

Type of data	frequency	start example
Annual	1	1995
Quarterly	4	c(1995,2)
Monthly	12	c(1995,9)
Daily		
Weekly		
Hourly		
Half-hourly		

ts objects and ts function

ts(data, frequency, start)

Type of data	frequency	start example
Annual	1	1995
Quarterly	4	c(1995,2)
Monthly	12	c(1995,9)
Daily	7 or 365.25	
Weekly		
Hourly		
Half-hourly		

ts objects and ts function

ts(data, frequency, start)

Type of data	frequency	start example
Annual	1	1995
Quarterly	4	c(1995,2)
Monthly	12	c(1995,9)
Daily	7 or 365.25	1 or c(1995,234)
Weekly		
Hourly		
Half-hourly		

ts objects and ts function

ts(data, frequency, start)

Type of data	frequency	start example
Annual	1	1995
Quarterly	4	c(1995,2)
Monthly	12	c(1995,9)
Daily	7 or 365.25	1 or c(1995,234)
Weekly	52.18	
Hourly		
Half-hourly		

ts objects and ts function

ts(data, frequency, start)

Type of data	frequency	start example
Annual	1	1995
Quarterly	4	c(1995,2)
Monthly	12	c(1995,9)
Daily	7 or 365.25	1 or c(1995,234)
Weekly	52.18	c(1995,23)
Hourly		
Half-hourly		

ts objects and ts function

ts(data, frequency, start)

Type of data	frequency	start example
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Quarterly	4	c(1995,2)
Monthly	12	c(1995,9)
Daily	7 or 365.25	1 or c(1995,234)
Weekly	52.18	c(1995,23)
Hourly	24 or 168 or 8,766	
Half-hourly		

ts objects and ts function

ts(data, frequency, start)

Type of data	frequency	start example
Annual	1	1995
Quarterly	4	c(1995,2)
Monthly	12	c(1995,9)
Daily	7 or 365.25	1 or c(1995,234)
Weekly	52.18	c(1995,23)
Hourly	24 or 168 or 8,766	1
Half-hourly		

ts objects and ts function

ts(data, frequency, start)

Type of data	frequency	start example
Annual	1	1995
Quarterly	4	c(1995,2)
Monthly	12	c(1995,9)
Daily	7 or 365.25	1 or c(1995,234)
Weekly	52.18	c(1995,23)
Hourly	24 or 168 or 8,766	1
Half-hourly	48 or 336 or 17,532	

ts objects and ts function

ts(data, frequency, start)

Type of data	frequency	start example
Annual	1	1995
Quarterly	4	c(1995,2)
Monthly	12	c(1995,9)
Daily	7 or 365.25	1 or c(1995,234)
Weekly	52.18	c(1995,23)
Hourly	24 or 168 or 8,766	1
Half-hourly	48 or 336 or 17,532	1

Australian GDP

```
ausgdp <- ts(x, frequency=4, start=c(1971,3))
```

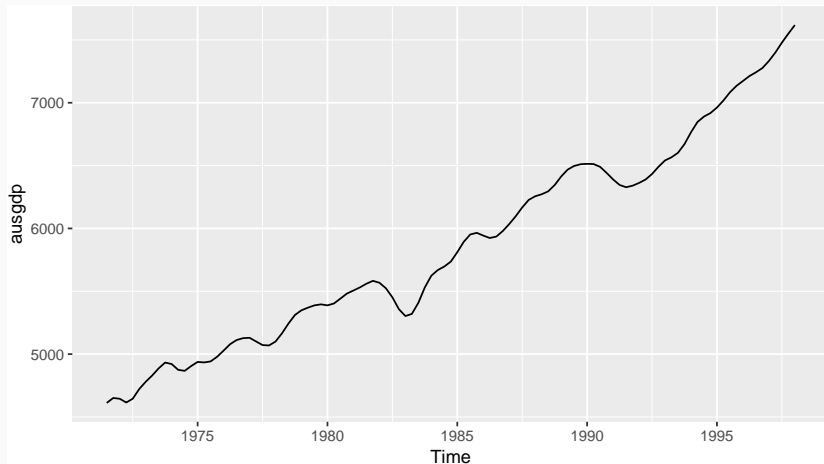
- Class: "ts"
- Print and plotting methods available.

```
ausgdp
```

```
##           Qtr1 Qtr2 Qtr3 Qtr4
## 1971                4612 4651
## 1972 4645 4615 4645 4722
## 1973 4780 4830 4887 4933
## 1974 4921 4875 4867 4905
## 1975 4938 4934 4942 4979
## 1976 5028 5079 5112 5127
```

Australian GDP

```
autoplot(ausgdp)
```



Residential electricity sales

```
elecsales
```

```
## Time Series:
```

```
## Start = 1989
```

```
## End = 2008
```

```
## Frequency = 1
```

```
## [1] 2354.34 2379.71 2318.52 2468.99 2386.0
```

```
## [6] 2569.47 2575.72 2762.72 2844.50 3000.7
```

```
## [11] 3108.10 3357.50 3075.70 3180.60 3221.6
```

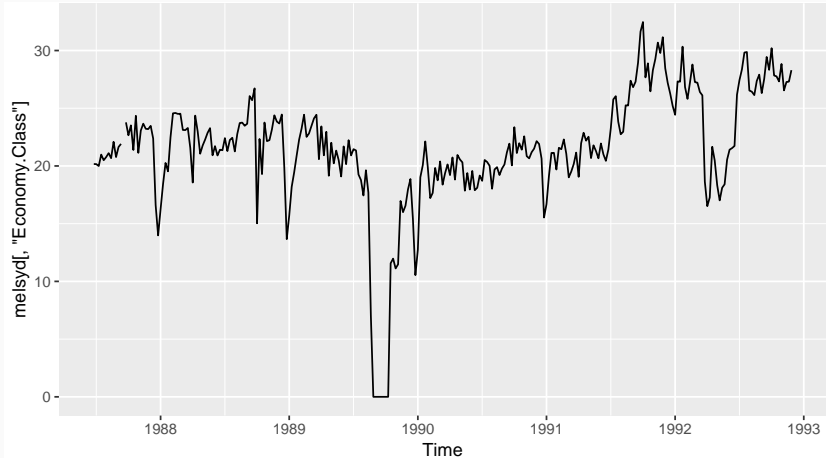
```
## [16] 3176.20 3430.60 3527.48 3637.89 3655.0
```

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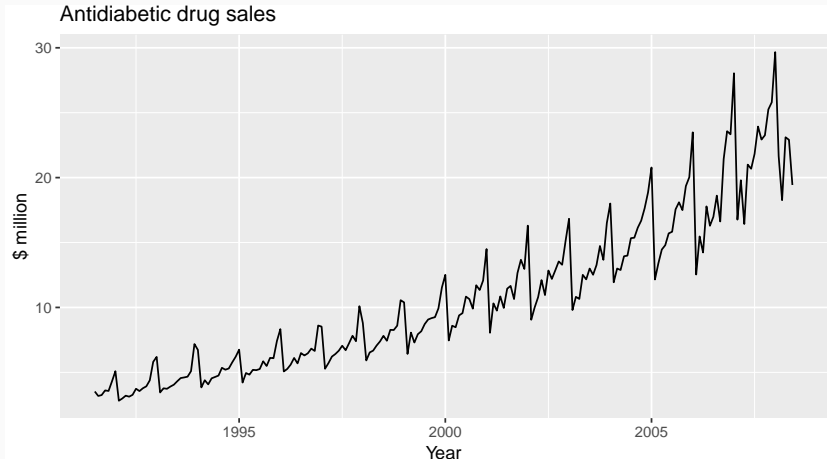
Time plots

```
autoplot(mel_syd[, "Economy.Class"])
```



Time plots

```
autoplot(a10) + ylab("$ million") + xlab("Year") +  
  ggtitle("Antidiabetic drug sales")
```



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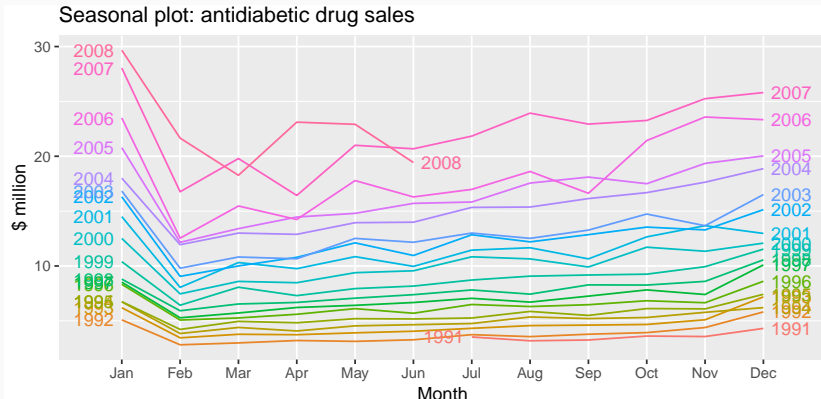
Lab Session 1

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Seasonal plots

```
ggseasonplot(a10, ylab="$ million",  
  year.labels=TRUE, year.labels.left=TRUE) +  
  ggtitle("Seasonal plot: antidiabetic drug sales")
```

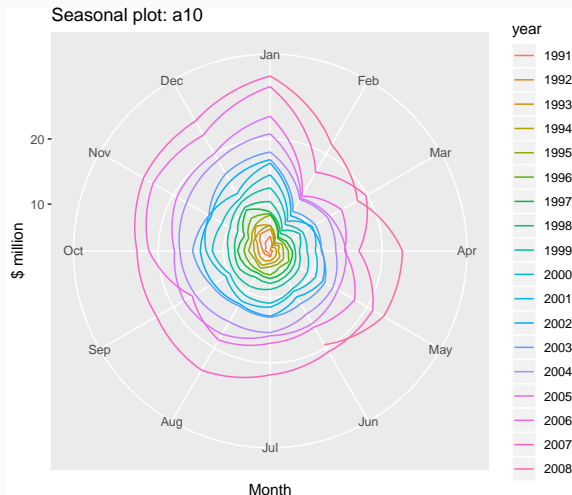


Seasonal plots

- Data plotted against the individual “seasons” in which the data were observed. (In this case a “season” is a month.)
- Something like a time plot except that the data from each season are overlapped.
- Enables the underlying seasonal pattern to be seen more clearly, and also allows any substantial departures from the seasonal pattern to be easily identified.
- In R: `ggseasonplot`

Seasonal polar plots

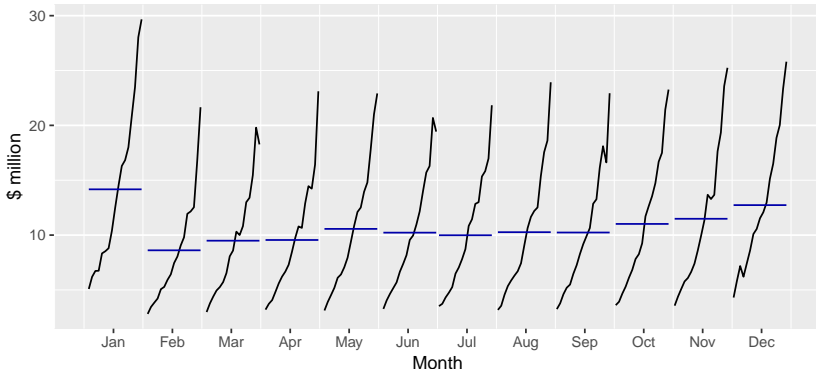
```
ggseasonplot(a10, polar=TRUE) + ylab("$ million")
```



Seasonal subseries plots

```
ggsubseriesplot(a10) + ylab("$ million") +  
  ggtitle("Seasonal subseries plot: antidiabetic drug sales")
```

Seasonal subseries plot: antidiabetic drug sales

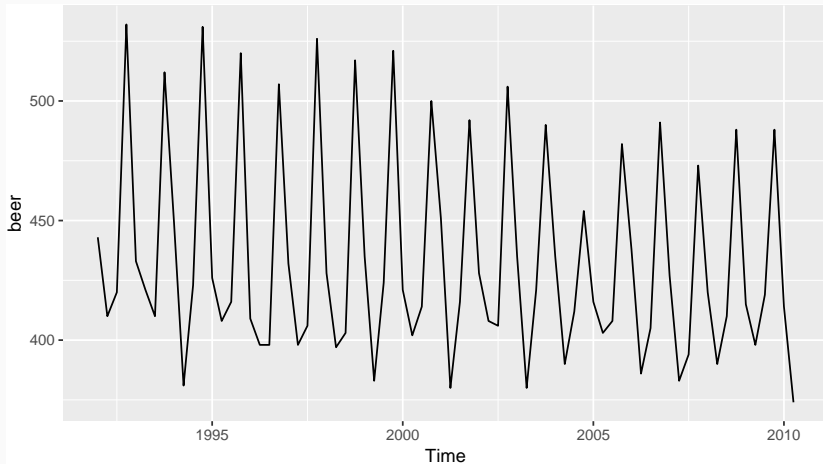


Seasonal subseries plots

- Data for each season collected together in time plot as separate time series.
- Enables the underlying seasonal pattern to be seen clearly, and changes in seasonality over time to be visualized.
- In R: `ggsubseriesplot`

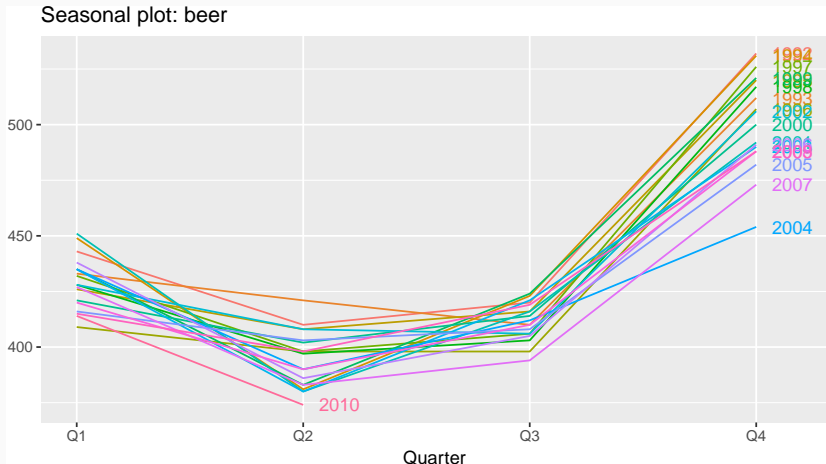
Quarterly Australian Beer Production

```
beer <- window(ausbeer, start=1992)  
autoplot(beer)
```



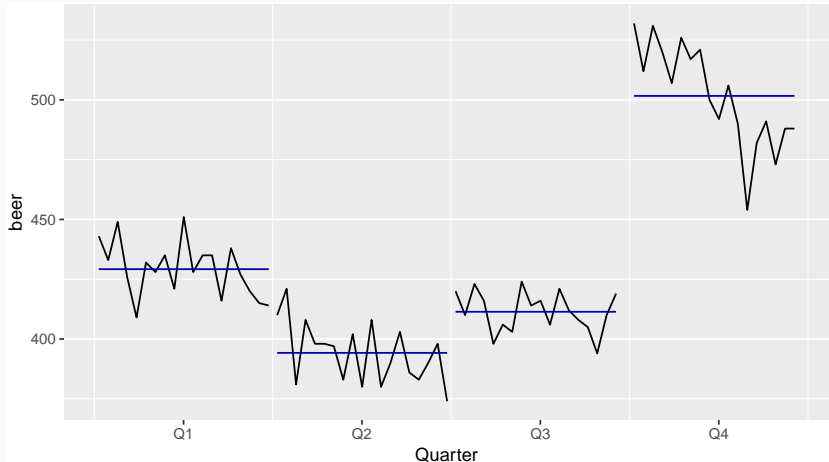
Quarterly Australian Beer Production

```
ggseasonplot(beer, year.labels=TRUE)
```



Quarterly Australian Beer Production

```
ggsubseriesplot(beer)
```



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Time series patterns

Trend pattern exists when there is a long-term increase or decrease in the data.

Seasonal 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 pattern exists when data exhibit rises and falls that are *not of fixed period* (duration usually of at least 2 years).

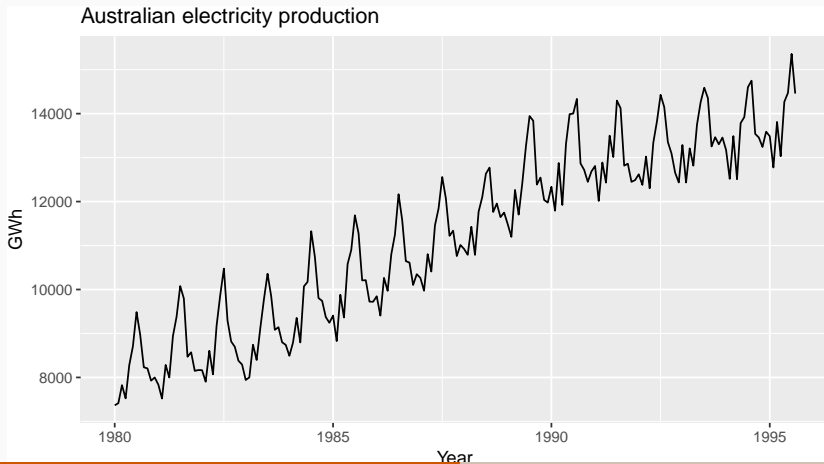
Time series components

Differences between seasonal and cyclic patterns:

- seasonal pattern constant length; cyclic pattern variable length
- average length of cycle longer than length of seasonal pattern
- magnitude of cycle more variable than magnitude of seasonal pattern

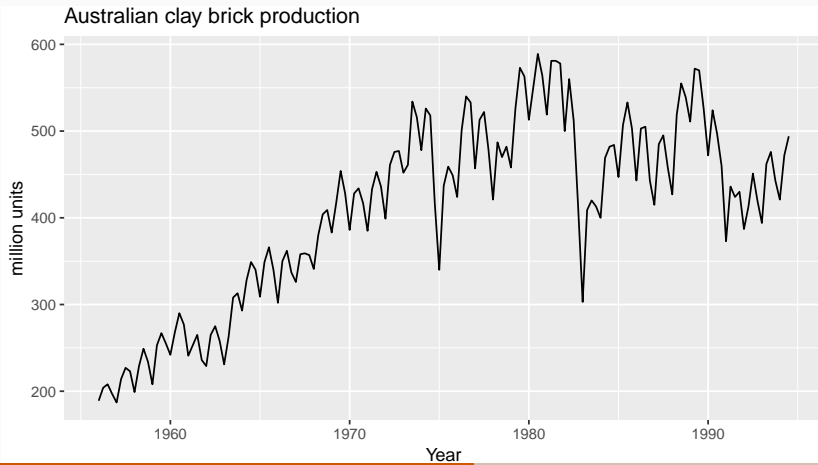
Time series patterns

```
autoplot(window(elec, start=1980)) +  
  ggtitle("Australian electricity production") +  
  xlab("Year") + ylab("GWh")
```



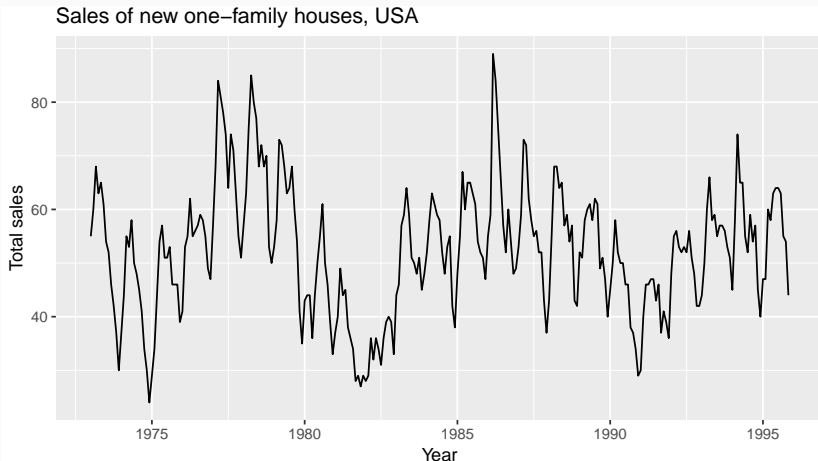
Time series patterns

```
autoplot(bricksq) +  
  ggtitle("Australian clay brick production") +  
  xlab("Year") + ylab("million units")
```



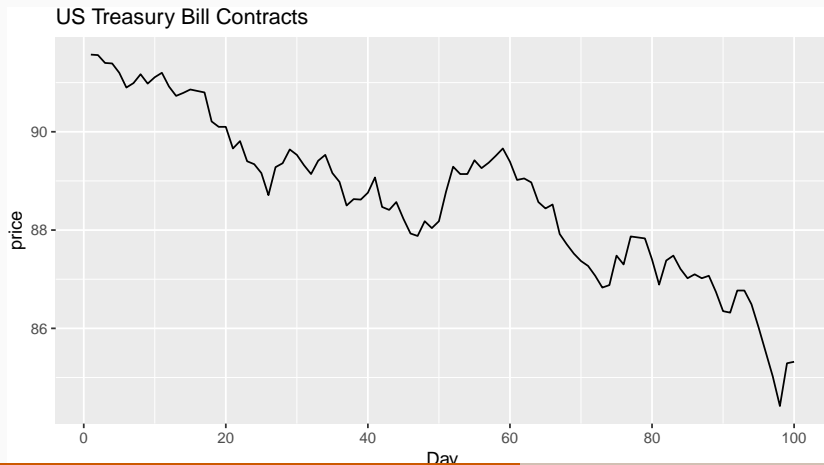
Time series patterns

```
autoplot(hsales) +  
  ggtitle("Sales of new one-family houses, USA") +  
  xlab("Year") + ylab("Total sales")
```



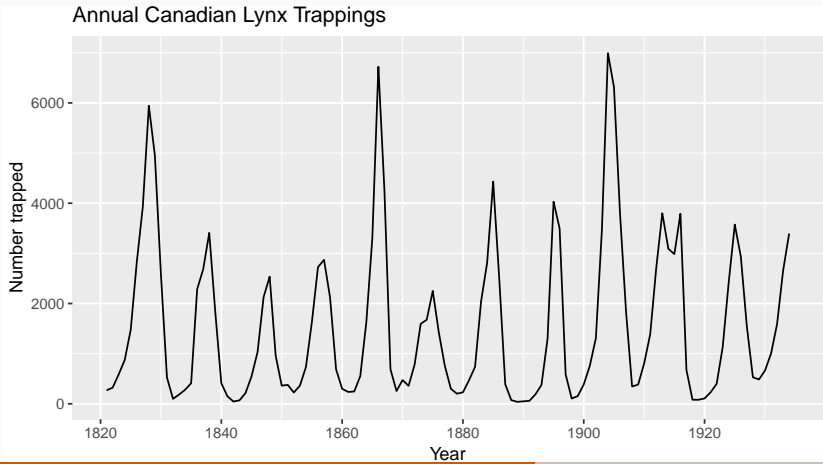
Time series patterns

```
autoplot(ustreas) +  
  ggtitle("US Treasury Bill Contracts") +  
  xlab("Day") + ylab("price")
```



Time series patterns

```
autoplot(lynx) +  
  ggtitle("Annual Canadian Lynx Trappings") +  
  xlab("Year") + ylab("Number trapped")
```



Seasonal or cyclic?

Differences between seasonal and cyclic patterns:

- seasonal pattern constant length; cyclic pattern variable length
- average length of cycle longer than length of seasonal pattern
- magnitude of cycle more variable than magnitude of seasonal pattern

Seasonal or cyclic?

Differences between seasonal and cyclic patterns:

- seasonal pattern constant length; cyclic pattern variable length
- average length of cycle longer than length of seasonal pattern
- magnitude of cycle more variable than magnitude of seasonal pattern

The timing of peaks and troughs is predictable with seasonal data, but unpredictable in the long term with cyclic data.

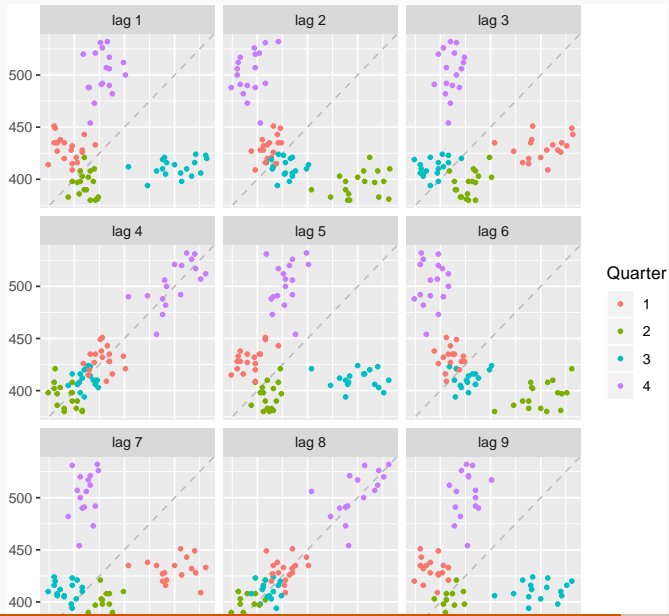
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Example: Beer production

```
beer <- window(ausbeer, start=1992)
gglagplot(beer, lags=9, do.lines=FALSE,
          continuous=FALSE)
```


Example: Beer production



Lagged scatterplots

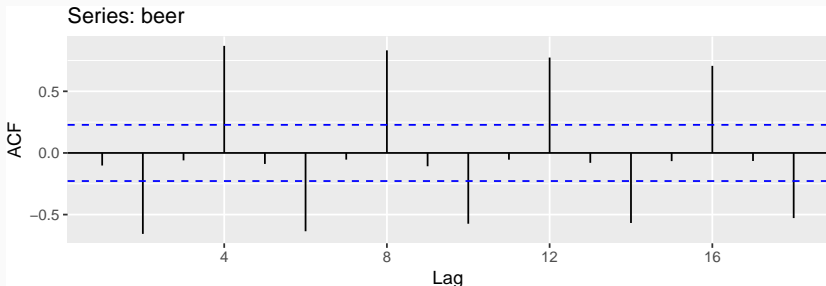
- Each graph shows y_t plotted against y_{t-k} for different values of k .
- The autocorrelations are the correlations associated with these scatterplots.
- ACF (autocorrelation function):
 - $r_1 = \text{Correlation}(y_t, y_{t-1})$
 - $r_2 = \text{Correlation}(y_t, y_{t-2})$
 - $r_3 = \text{Correlation}(y_t, y_{t-3})$
 - etc.
- If there is **seasonality**, the ACF at the seasonal lag (e.g., 12 for monthly data) will be **large and positive**.

Autocorrelation

Results for first 9 lags for beer data:

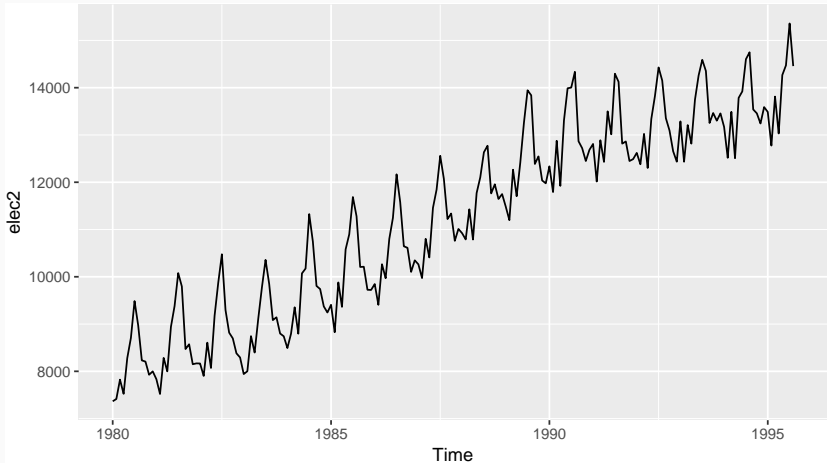
r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9
-0.102	-0.657	-0.060	0.869	-0.089	-0.635	-0.054	0.832	-0.108

`ggAcf(beer)`



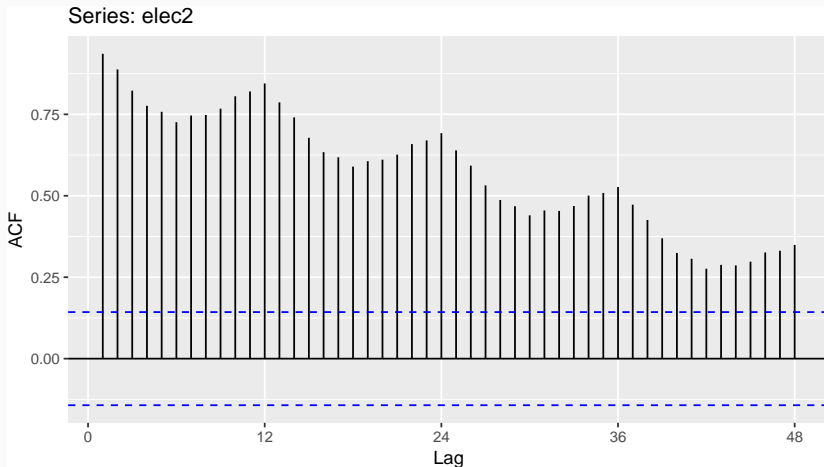
Aus monthly electricity production

```
elec2 <- window(elec, start=1980)  
autoplot(elec2)
```



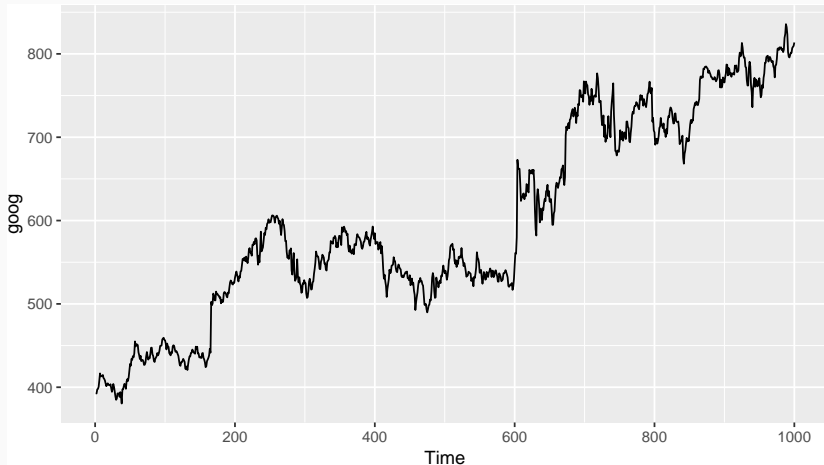
Aus monthly electricity production

```
ggAcf(elec2, lag.max=48)
```



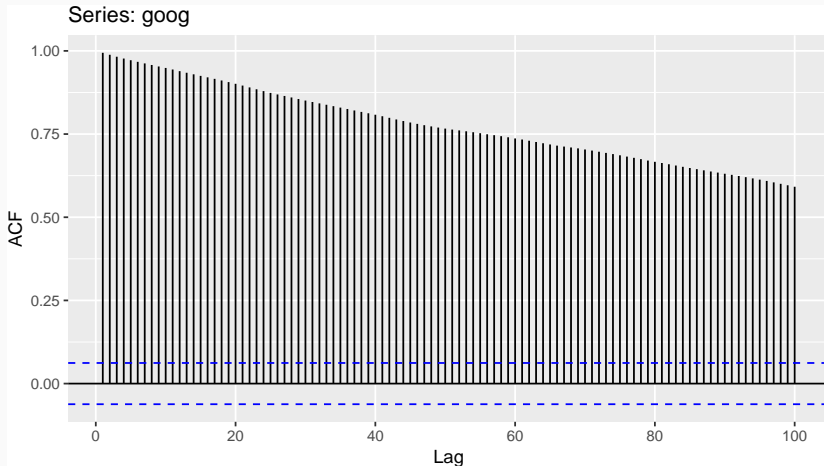
Google stock price

```
autoplot(goog)
```



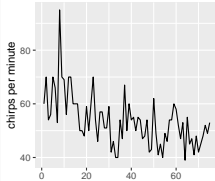
Google stock price

```
ggAcf(goog, lag.max=100)
```

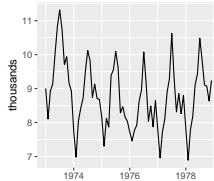


Which is which?

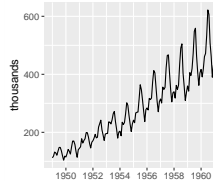
1. Daily temperature of cow



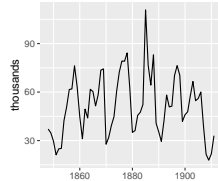
2. Monthly accidental deaths



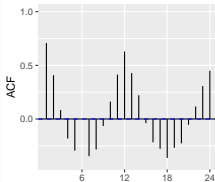
3. Monthly air passengers



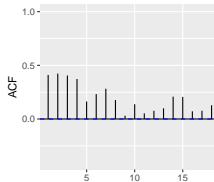
4. Annual mink trappings



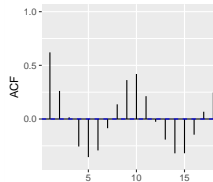
A



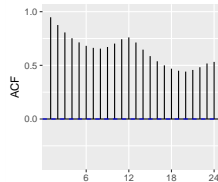
B



C



D

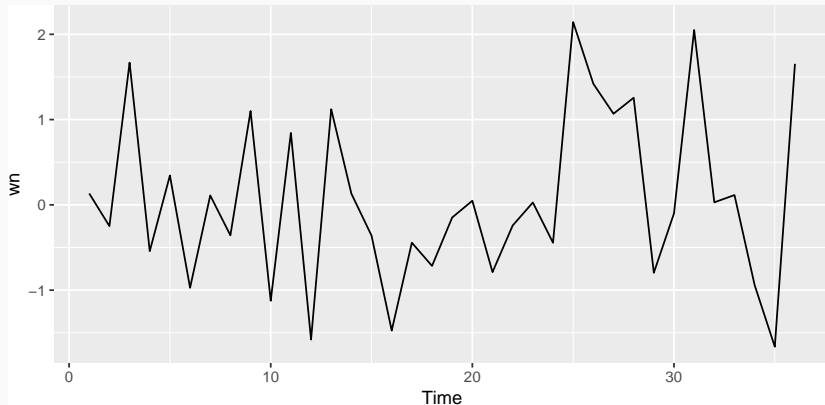


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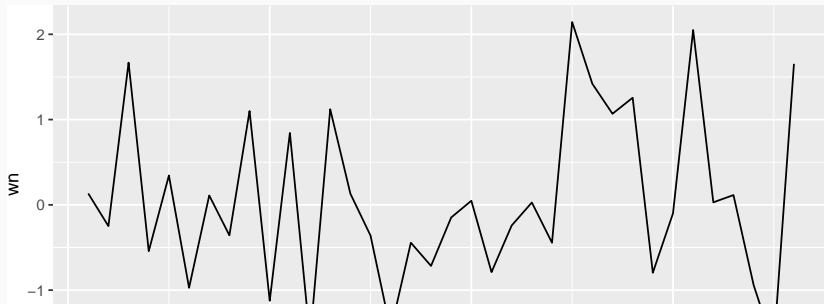
Example: White noise

```
wn <- ts(rnorm(36))  
autoplot(wn)
```



Example: White noise

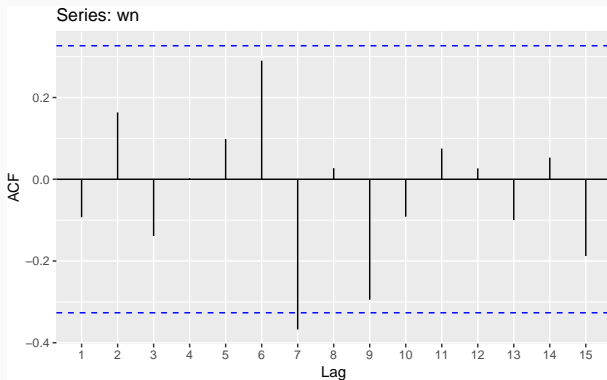
```
wn <- ts(rnorm(36))  
autoplot(wn)
```



White noise data is uncorrelated across time with zero mean and constant variance.
(Technically, we require independence as well)

Example: White noise

r_1	-0.09
r_2	0.16
r_3	-0.14
r_4	0.00
r_5	0.10
r_6	0.29
r_7	-0.37
r_8	0.03
r_9	-0.29
r_{10}	-0.09



- Sample autocorrelations for white noise series.
- Expect each autocorrelation to be close to zero.
- Blue lines show 95% critical values.

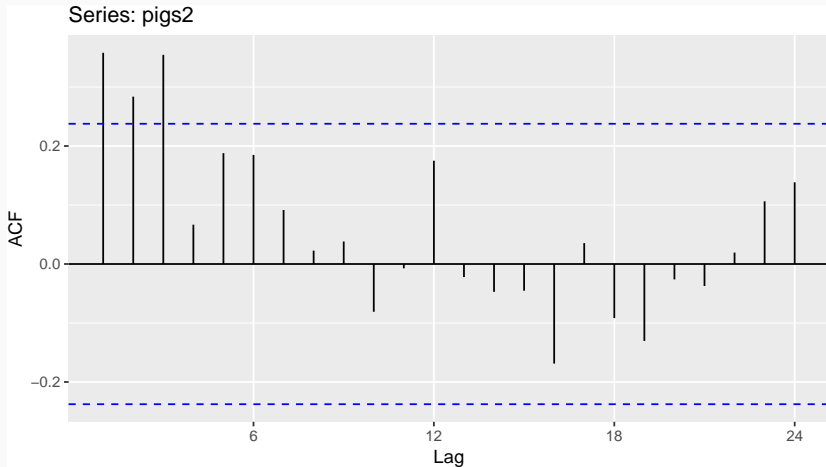
Example: Pigs slaughtered

```
pigs2 <- window(pigs, start=1990)
autoplot(pigs2) +
  xlab("Year") + ylab("thousands") +
  ggtitle("Number of pigs slaughtered in Victoria")
```



Example: Pigs slaughtered

```
ggAcf(pigs2)
```



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Lab Session 2