MONASH University

MONASH BUSINESS SCHOOL

# Forecasting: principles and practice

Rob J Hyndman

1.2 Time series graphics

# Outline


1 Time series in R

2 Lab session 1

3 Seasonal plots

4 Lab session 2

5 Seasonal or cyclic?

6 Lag plots and autocorrelation

7 White noise

8 Lab session 3

# `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 |

```r
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 |
|---|---|---|
| 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 | |
| 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

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

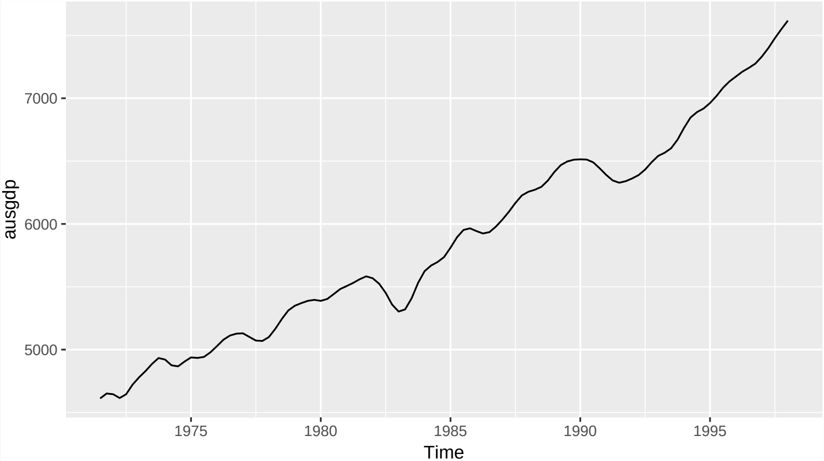
- Class: “ts”
- Print and plotting methods available.

```r
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
```

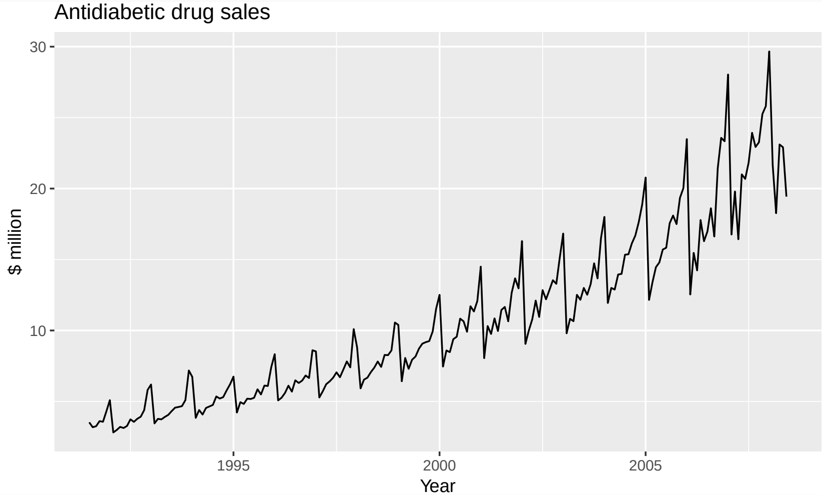
```
## Time Series:
## Start = 1989
## End = 2008
## Frequency = 1
##  [1] 2354 2380 2319 2469 2386 2569 2576 276
## [11] 3108 3358 3076 3181 3222 3176 3431 352
```

# Time plots

```r
autoplot(melsyd[,"Economy.Class"])
```

# Time plots

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



# Outline

1 Time series in R

2 Lab session 1

3 Seasonal plots

4 Lab session 2

5 Seasonal or cyclic?

6 Lag plots and autocorrelation

7 White noise

8 Lab session 3

# Lab Session 1

# Outline

1 Time series in R

2 Lab session 1

3 **Seasonal plots**

4 Lab session 2

5 Seasonal or cyclic?

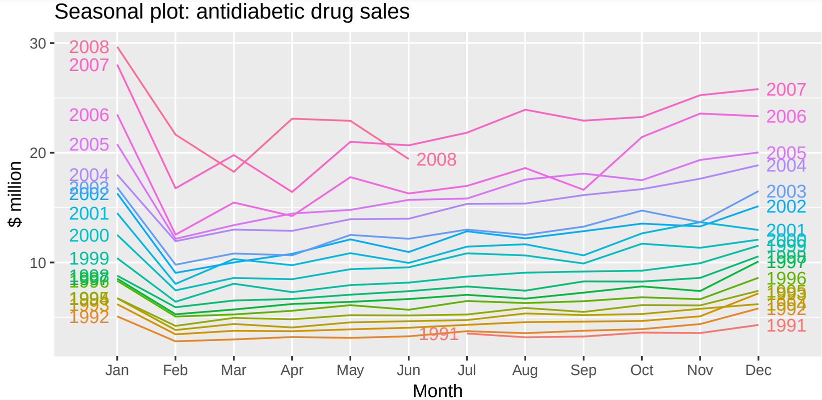
6 Lag plots and autocorrelation

7 White noise

8 Lab session 3

# Seasonal plots

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

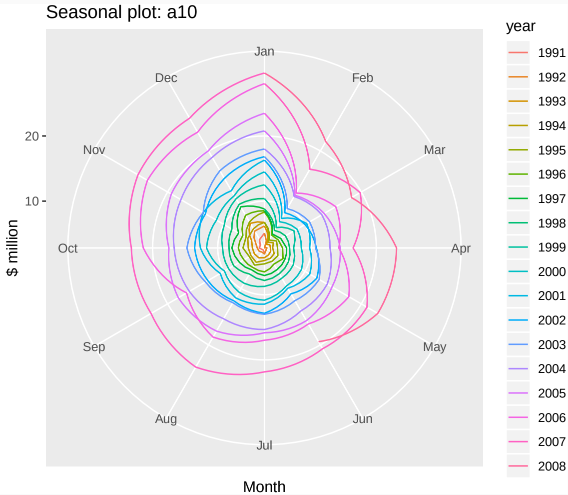


# Seasonal plots

- 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`

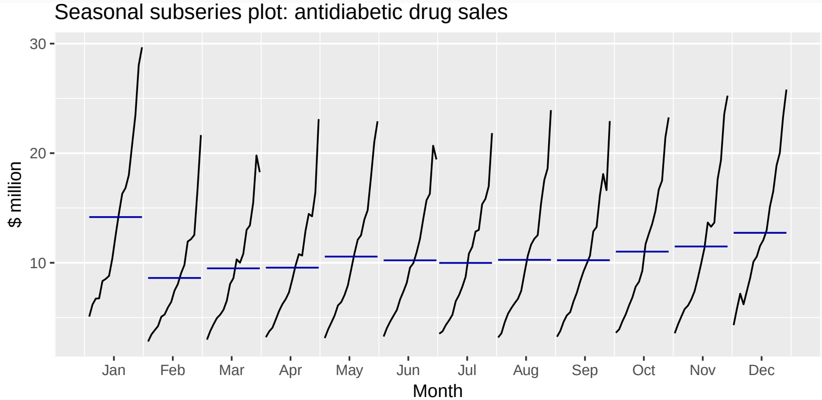
# Seasonal polar plots

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



# Seasonal subseries plots

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

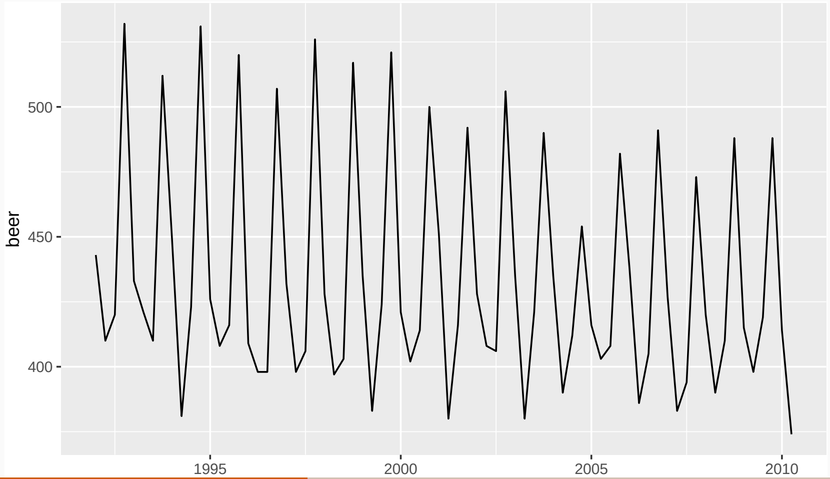


# Seasonal subseries plots

- 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`

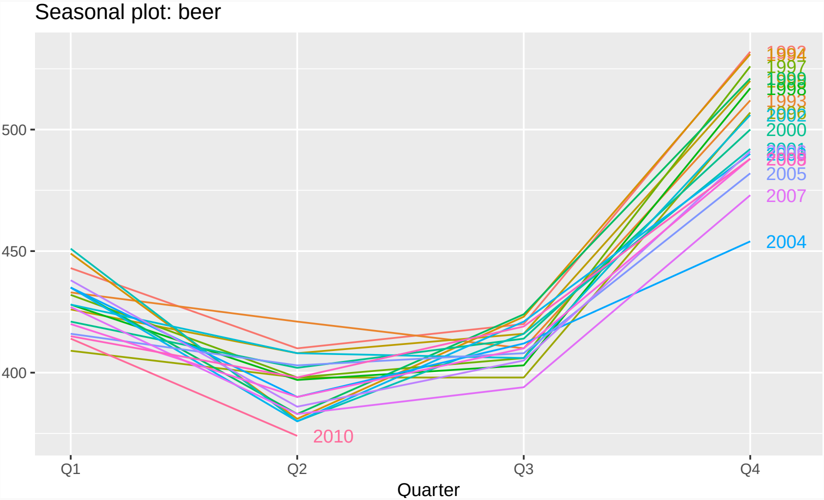
# Quarterly Australian Beer Production

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



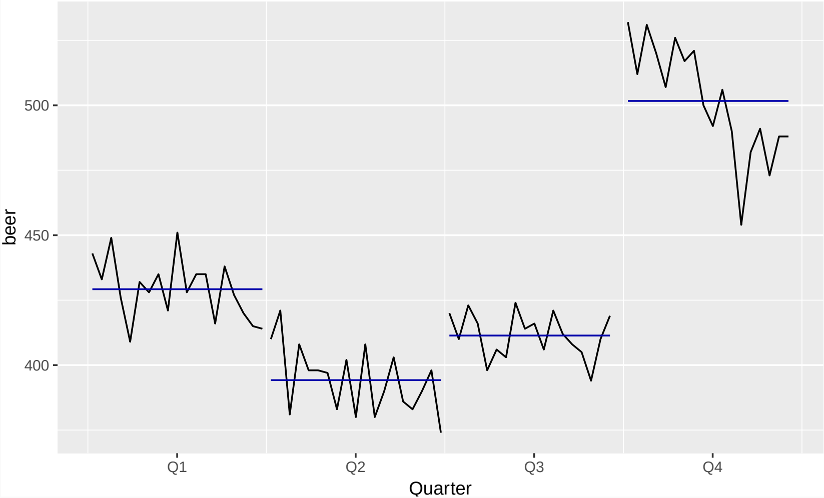
# Quarterly Australian Beer Production

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



# Quarterly Australian Beer Production

```
ggsubseriesplot(beer)
```



# Outline

1 Time series in R

2 Lab session 1

3 Seasonal plots

4 **Lab session 2**

5 Seasonal or cyclic?

6 Lag plots and autocorrelation

7 White noise

8 Lab session 3

# Lab Session 2

# Outline

1 Time series in R

2 Lab session 1

3 Seasonal plots

4 Lab session 2

5 **Seasonal or cyclic?**

6 Lag plots and autocorrelation

7 White noise

8 Lab session 3

# 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).

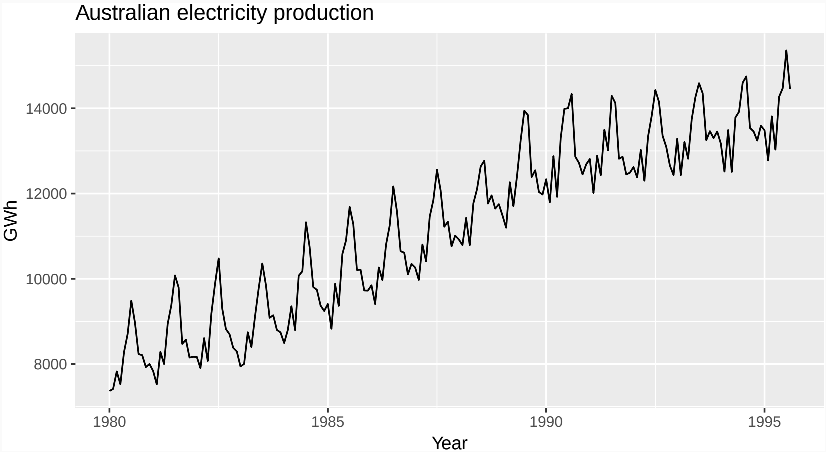
# Time series components

**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

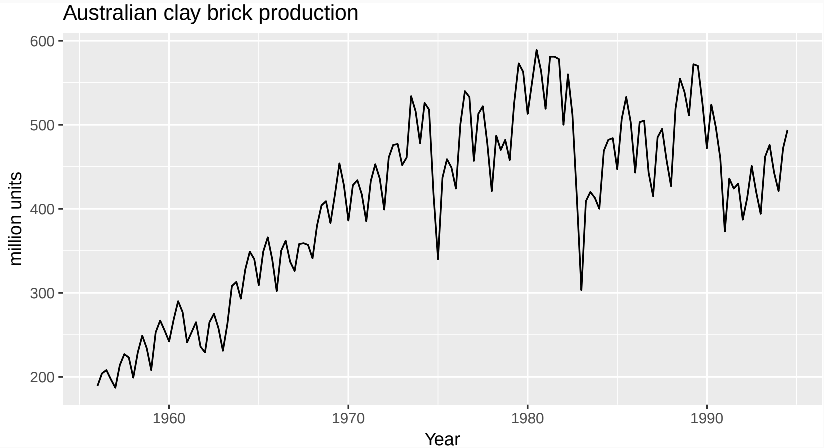
# Time series patterns

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



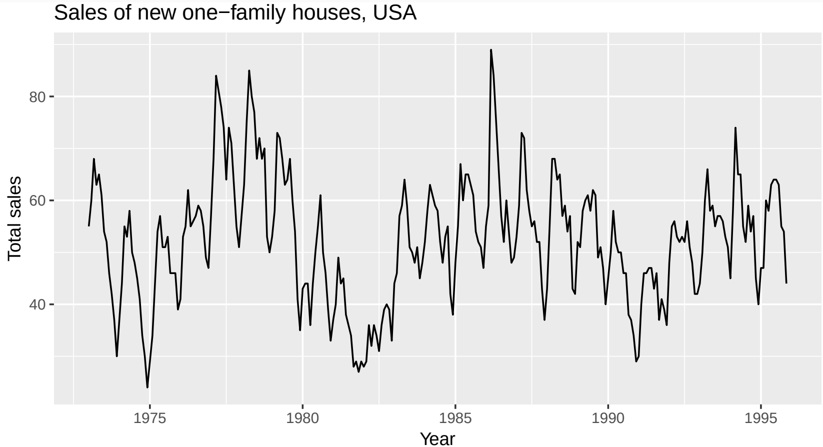
# Time series patterns

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



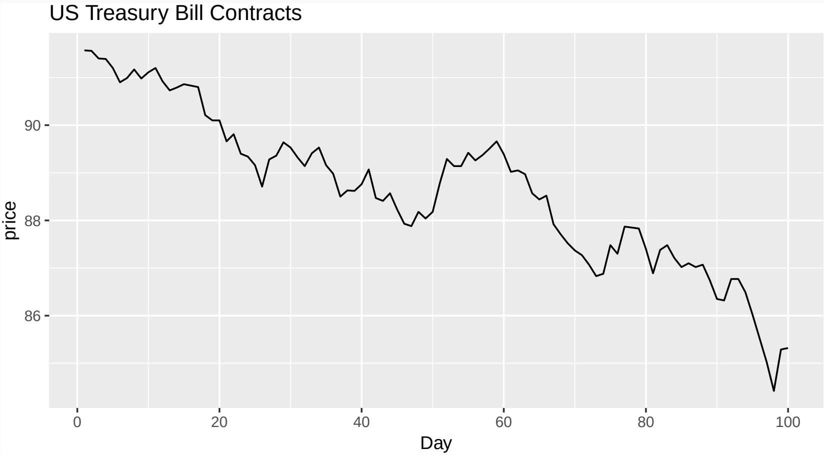
# Time series patterns

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



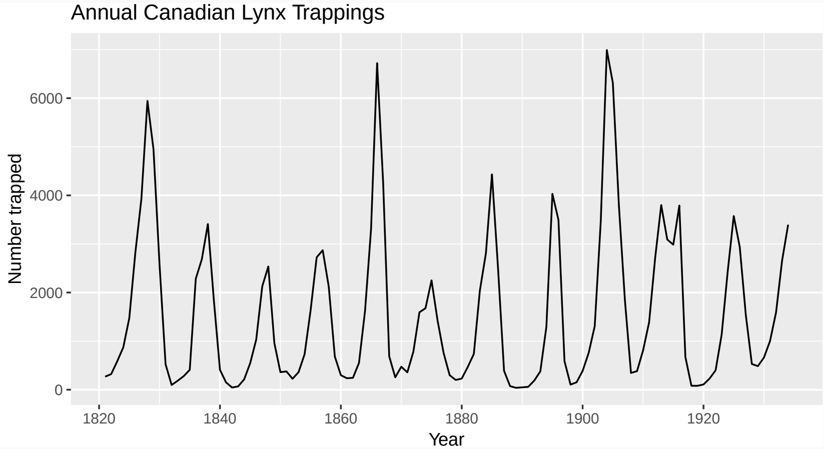
# Time series patterns

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



# Time series patterns

```r
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.

# Outline


1 Time series in R

2 Lab session 1

3 Seasonal plots

4 Lab session 2

5 Seasonal or cyclic?

6 **Lag plots and autocorrelation**

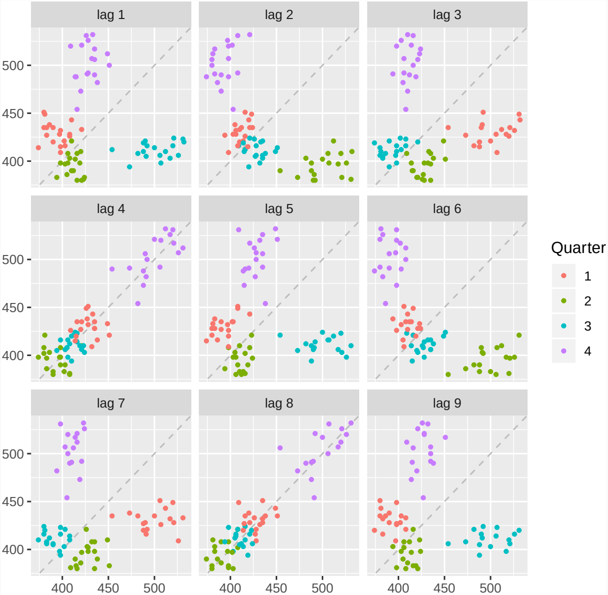
7 White noise

8 Lab session 3

# Example: Beer production

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

# Example: Beer production



# Lagged scatterplots

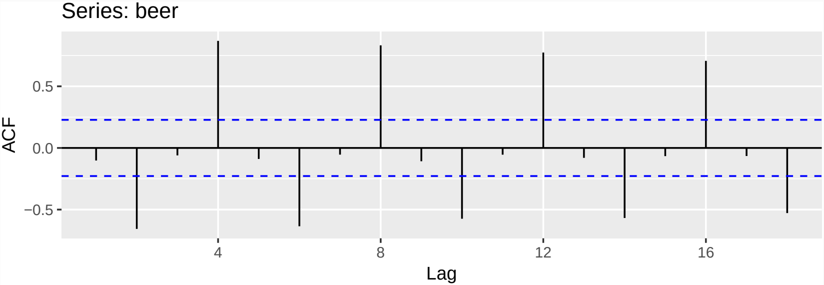
- Each graph shows $y_t$ plotted against $y_{t-k}$ for different values of $k$.
- The autocorrelations are the correlations associated with these scatterplots.
- ACF (autocorrelation function):
  - $r_1 = \text{Correlation}(y_t, y_{t-1})$
  - $r_2 = \text{Correlation}(y_t, y_{t-2})$
  - $r_3 = \text{Correlation}(y_t, y_{t-3})$
  - 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:

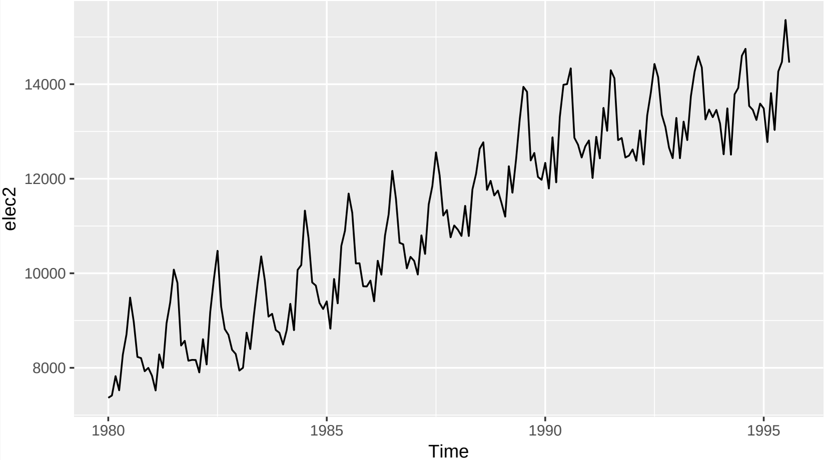
| $r_1$ | $r_2$ | $r_3$ | $r_4$ | $r_5$ | $r_6$ | $r_7$ | $r_8$ | $r_9$ |
|---|---|---|---|---|---|---|---|---|
| -0.102 | -0.657 | -0.060 | 0.869 | -0.089 | -0.635 | -0.054 | 0.832 | -0.108 |

```
ggAcf(beer)
```



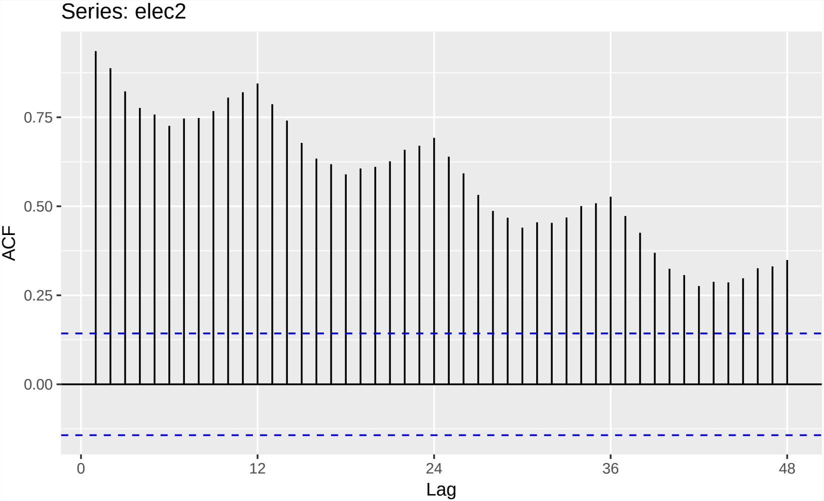
# Aus monthly electricity production

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



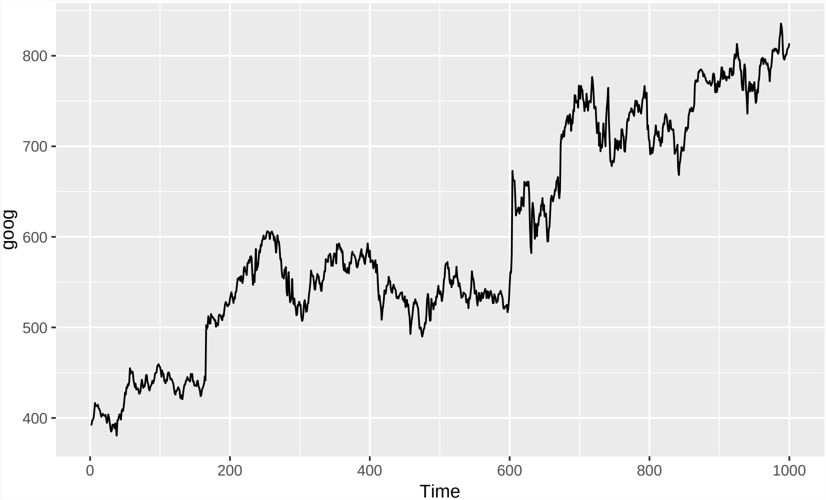
# Aus monthly electricity production

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



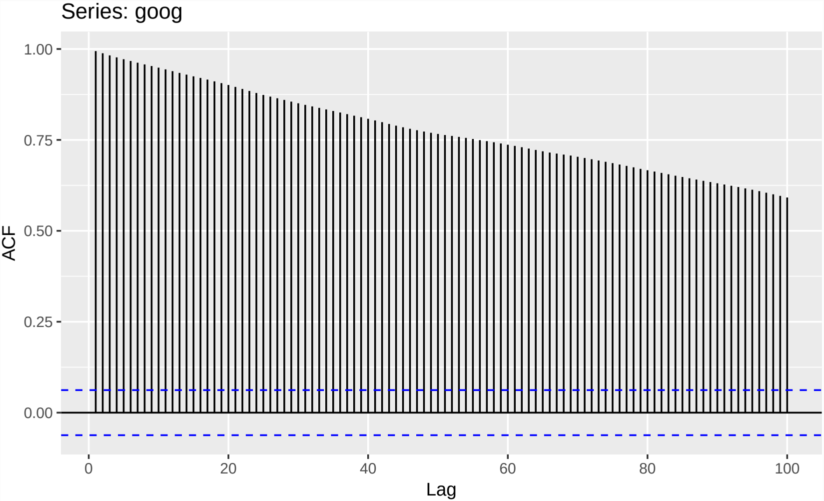
# Google stock price

```r
autoplot(goog)
```

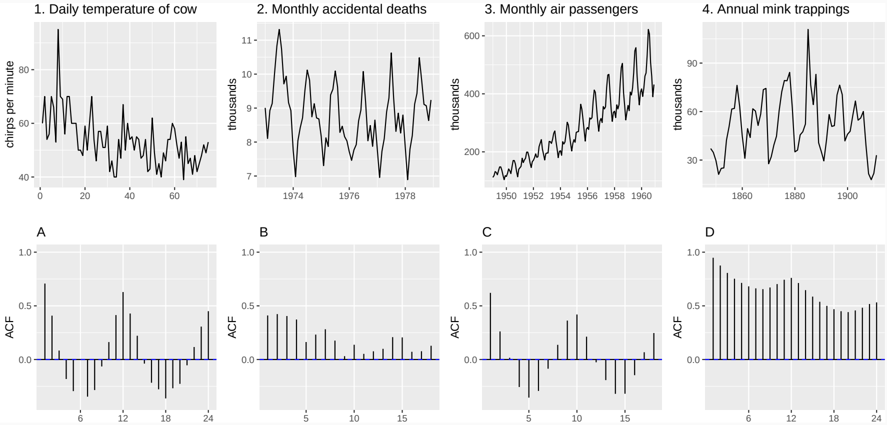


# Google stock price

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



# Which is which?

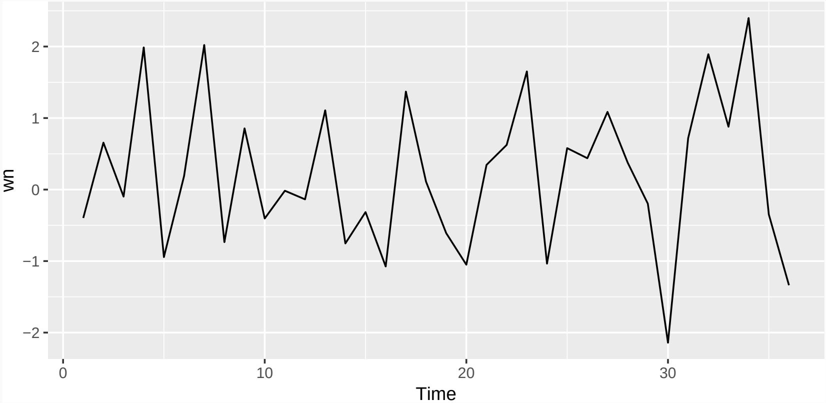


# Outline

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

# Example: White noise

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



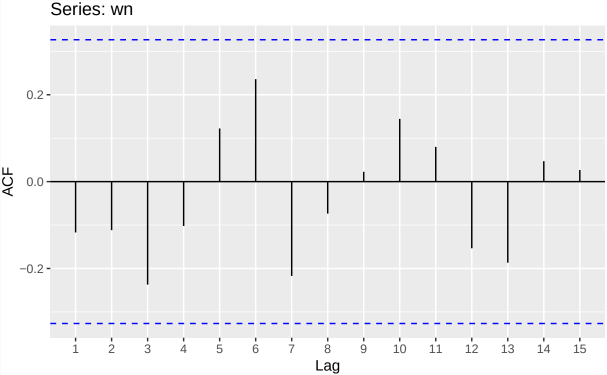
# Example: White noise

```r
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

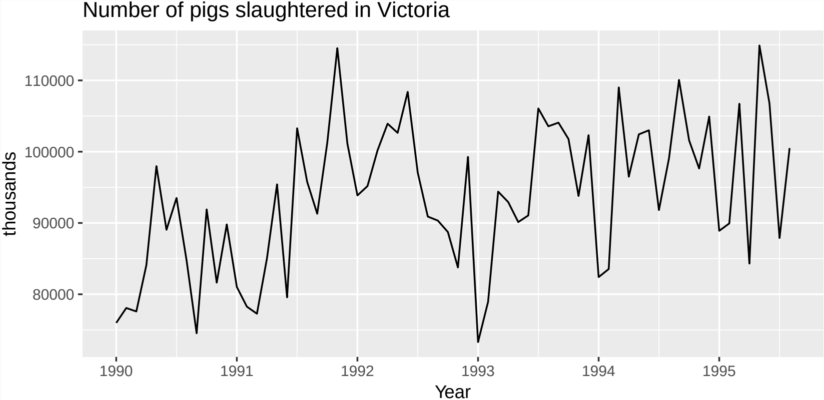
| | |
|---|---|
| $r_1$ | -0.12 |
| $r_2$ | -0.11 |
| $r_3$ | -0.24 |
| $r_4$ | -0.10 |
| $r_5$ | 0.12 |
| $r_6$ | 0.24 |
| $r_7$ | -0.22 |
| $r_8$ | -0.07 |
| $r_9$ | 0.02 |
| $r_{10}$ | 0.14 |




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

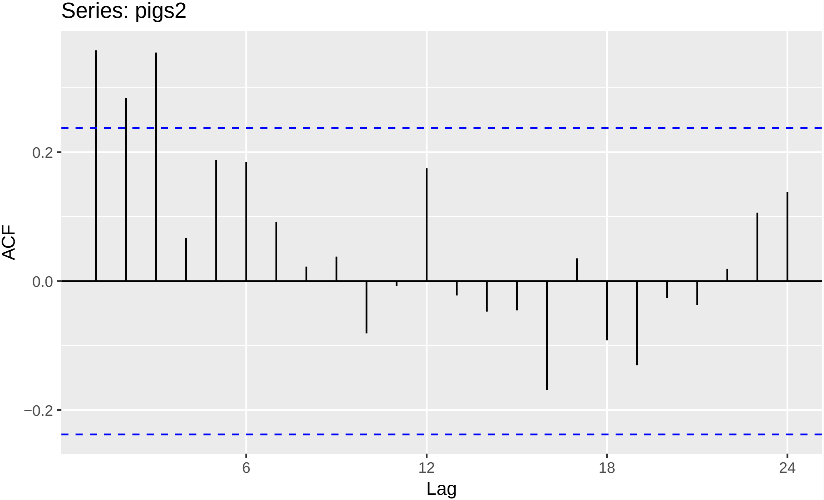
# Example: Pigs slaughtered

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



# Example: Pigs slaughtered

```r
ggAcf(pigs2)
```



# Outline


1 Time series in R

2 Lab session 1

3 Seasonal plots

4 Lab session 2

5 Seasonal or cyclic?

6 Lag plots and autocorrelation

7 White noise

8 **Lab session 3**

# Lab Session 3