# Tidy data analysis for demography using R

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MONASH University

# Outline

# Outline

# tibble objects

## Australian Deaths 1901–2020

```
# A tibble: 145,440 x 7
    Year   Age Sex    State Mortality Exposure Deaths
   <int> <int> <chr>  <chr>     <dbl>    <dbl>  <dbl>
 1  1901     0 female WA      0.129       2511    325
 2  1901     0 male   WA      0.158       2634    416
 3  1901     1 female WA      0.0275      2219     61
 4  1901     1 male   WA      0.0391      2175     85
 5  1901     2 female WA      0.00688     2180     15
 6  1901     2 male   WA      0.0131      2208     29
 7  1901     3 female WA      0.00584     1884     11
 8  1901     3 male   WA      0.00503     1988     10
 9  1901     4 female WA      0.00290     1722      5
10  1901     4 male   WA      0.00287     1743      5
# i 145,430 more rows
```

# tsibble objects

## Australian Deaths 1901–2020

```
# A tsibble: 145,440 x 7 [1Y]
# Key:       Age, Sex, State [1,212]
    Year   Age Sex    State Mortality Exposure Deaths
   <int> <int> <chr>  <chr>     <dbl>    <dbl>  <dbl>
 1  1901     0 female WA      0.129       2511    325
 2  1901     0 male   WA      0.158       2634    416
 3  1901     1 female WA      0.0275      2219     61
 4  1901     1 male   WA      0.0391      2175     85
 5  1901     2 female WA      0.00688     2180     15
 6  1901     2 male   WA      0.0131      2208     29
 7  1901     3 female WA      0.00584     1884     11
 8  1901     3 male   WA      0.00503     1988     10
 9  1901     4 female WA      0.00290     1722      5
10  1901     4 male   WA      0.00287     1743      5
# i 145,430 more rows
```

# tsibble objects

## Australian Deaths 1901–2020

```
# A tsibble: 145,440 x 7 [1Y]
# Key:       Age, Sex, State [1,212]
    Year   Age Sex    State Mortality Exposure Deaths
   <int> <int> <chr>  <chr>     <dbl>    <dbl>  <dbl>
 1  1901     0 female WA      0.129       2511    325
 2  1901     0 male   WA      0.158       2634    416
 3  1901     1 female WA      0.0275      2219     61
 4  1901     1 male   WA      0.0391      2175     85
 5  1901     2 female WA      0.00688     2180     15
 6  1901     2 male   WA      0.0131      2208     29
 7  1901     3 female WA      0.00584     1884     11
 8  1901     3 male   WA      0.00503     1988     10
 9  1901     4 female WA      0.00290     1722      5
10  1901     4 male   WA      0.00287     1743      5
# i 145,430 more rows
```

### Variables

Index:

- Year

Keys:

- Age
- Sex
- State

# tsibble objects

## Australian Deaths 1901–2020

```
# A tsibble: 145,440 x 7 [1Y]
# Key:        Age, Sex, State [1,212]
    Year   Age Sex    State Mortality Exposure Deaths
   <int> <int> <chr>  <chr>     <dbl>    <dbl>  <dbl>
 1  1901     0 female WA      0.129       2511    325
 2  1901     0 male   WA      0.158       2634    416
 3  1901     1 female WA      0.0275      2219     61
 4  1901     1 male   WA      0.0391      2175     85
 5  1901     2 female WA      0.00688     2180     15
 6  1901     2 male   WA      0.0131      2208     29
 7  1901     3 female WA      0.00584     1884     11
 8  1901     3 male   WA      0.00503     1988     10
 9  1901     4 female WA      0.00290     1722      5
10  1901     4 male   WA      0.00287     1743      5
# i 145,430 more rows
```

### Variables

Index:

- Year

Keys:

- Age
- Sex
- State

Every row must have a unique combination of Index and Keys

# vital objects

## Australian Deaths 1901–2020

```
aus
```

```
# A vital: 145,440 x 7 [1Y]
# Key:      Age x (Sex, State) [101 x 12]
    Year   Age Sex    State Mortality Exposure Deaths
   <int> <int> <chr>  <chr>     <dbl>    <dbl>  <dbl>
 1  1901     0 female WA        0.129     2511    325
 2  1901     0 male   WA        0.158     2634    416
 3  1901     1 female WA        0.0275    2219     61
 4  1901     1 male   WA        0.0391    2175     85
 5  1901     2 female WA        0.00688   2180     15
 6  1901     2 male   WA        0.0131    2208     29
 7  1901     3 female WA        0.00584   1884     11
 8  1901     3 male   WA        0.00503   1988     10
 9  1901     4 female WA        0.00290   1722      5
10  1901     4 male   WA        0.00287   1743      5
# i 145,430 more rows
```

### Variables

Index:

- Year

Keys:

- Age
- Sex
- State

Every row must have a unique combination of Index and Keys

Variables denoting age, sex, deaths, births and population can also be specified.

# vital objects

```r
index_var(aus)
```

```
[1] "Year"
```

```r
key_vars(aus)
```

```
[1] "Age"   "Sex"   "State"
```

```r
vital_vars(aus)
```

```
        age         sex      deaths  population
      "Age"       "Sex"    "Deaths" "Exposure"
```

# Outline

# Human Mortality Database

mortality.org

HMD

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## Human Mortality Database

### Reliability and Accuracy Matter

The Human Mortality Database (HMD) is the world's leading scientific data resource on mortality in developed countries. The HMD provides detailed high-quality harmonized mortality and population estimates to researchers, students, journalists, policy analysts, and others interested in human longevity. The HMD follows open data principles.

- Short-Term Mortality Fluctuations
- Cause-of-Death Data Series
- Subnational Mortality Databases
- Citing HMD

Data by country or area

| | | | | |
|---|---|---|---|---|
| Australia | Denmark | Ireland | Norway | Switzerland |
| Austria | Estonia | Israel | Poland | Taiwan |
| Belarus | Finland | Italy | Portugal | U.K. |
| Belgium | France | Japan | Republic of Korea | U.S.A. |

# Human Fertility Database

humanfertility.org

HFD

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## Human Fertility Database

The Human Fertility Database (HFD) is the leading scientific data resource on fertility in the developed countries. This open access database provides detailed and high-quality historical and recent data on period and cohort fertility by age of mother and birth order. The HFD is entirely based on official vital statistics and places a great emphasis on rigorous data checking and documentation. The HFD adopts uniform methodology to warrant data comparability across time and between countries. The database follows open data principles.

- Short-Term Fertility Fluctuations
- Human Fertility Collection
- Citing HFD
- What's new

For users who seek fast access to the most commonly used summary indicators of period and cohort fertility, we provide excel tables comprising the following indicators for all the HFD countries:

**HFD summary indicators**

| | | | | | |
|---|---|---|---|---|---|
| Total fertility rate | Tempo-adjusted TFR | Mean age at birth | Mean age at first birth | Completed cohort fertility | Cohort parity |

# HMD imports

```
norway <- read_hmd(
  country = "NOR",
  username = "Nora.Weigh@mymail.com",
  password = "FF!5xeEFa6"
)
norway_births <- read_hmd(
  country = "NOR",
  username = "Nora.Weigh@mymail.com",
  password = "FF!5xeEFa6",
  variables = "Births"
)
```

- Uses `HMDHFDplus` package to handle the downloads.
- Default variables: `Deaths`, `Exposures`, `Population`, `Mx`
- Only 1x1 data supported.
- `read_hmd_files()` and `read_hfd_files()` allow reading of downloaded files.

# HMD imports

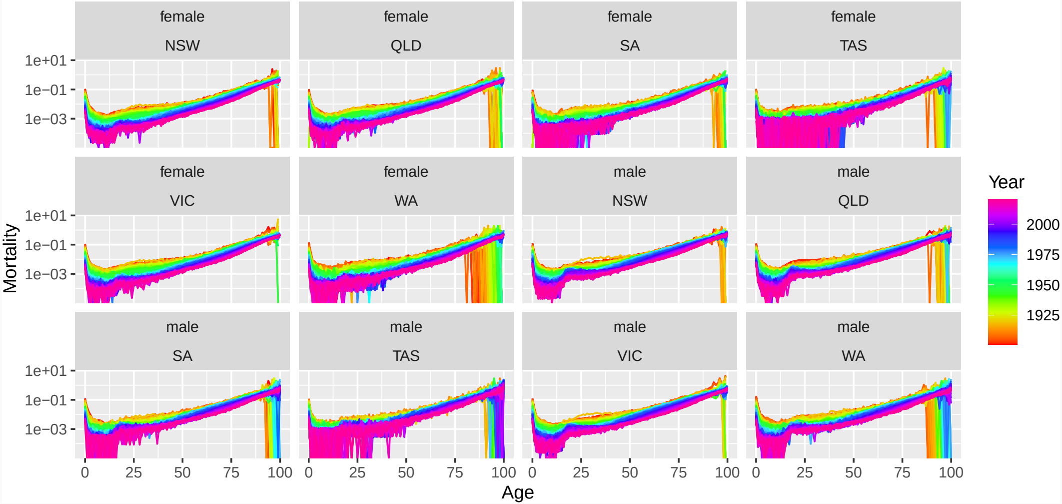
```
norway_births
```

```
# A vital: 531 x 3 [1Y]
# Key:       Sex [3]
    Year Sex     Births
   <int> <chr>    <int>
 1  1846 Female   20156
 2  1846 Male     21372
 3  1846 Total    41528
 4  1847 Female   20199
 5  1847 Male     21411
 6  1847 Total    41610
 7  1848 Female   19686
 8  1848 Male     20868
 9  1848 Total    40554
10  1849 Female   21424
# i 521 more rows
```

# Outline

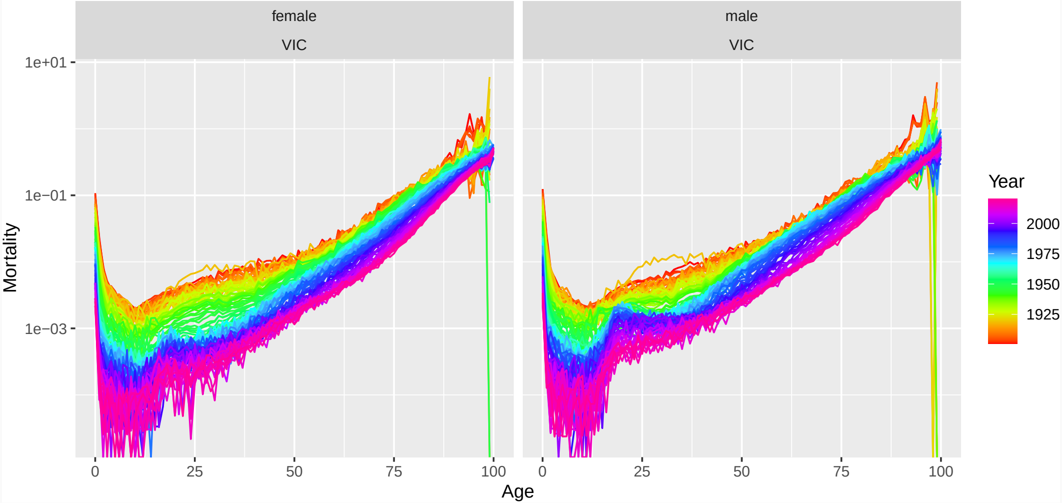
# Rainbow plots

```r
aus |> autoplot(Mortality) + scale_y_log10()
```



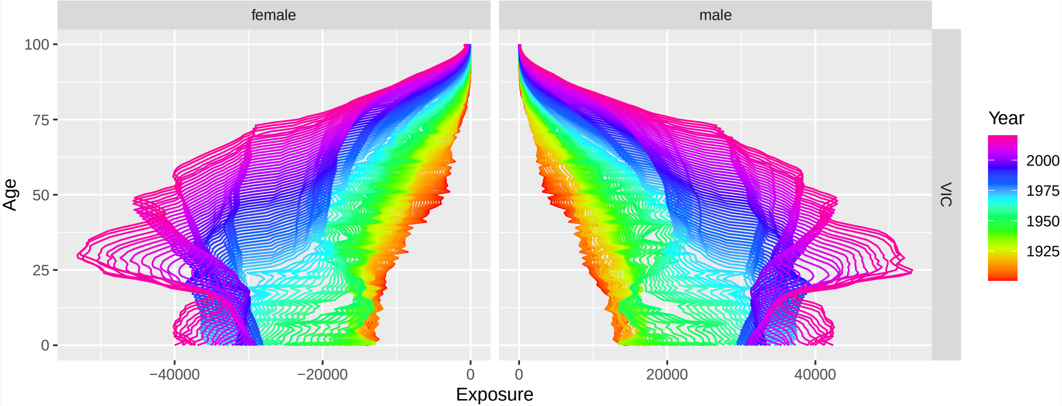
# Rainbow plots

```
aus |> filter(State == "VIC") |> autoplot(Mortality) + scale_y_log10()
```



# Rainbow plots

```
aus |> filter(State == "VIC") |>
  mutate(Exposure = if_else(Sex == "female", -Exposure, Exposure)) |>
  autoplot(Exposure) +
  facet_grid(State ~ Sex, scales = "free_x") + coord_flip()
```



# Outline

# Life tables

```
life_table(aus)
```

```
# A vital: 145,440 x 14 [1Y]
# Key:      Age x (Sex, State) [101 x 12]
    Year   Age Sex   State       mx      qx    lx      dx    Lx    Tx    ex    rx
   <int> <int> <chr> <chr>    <dbl>   <dbl> <dbl>   <dbl> <dbl> <dbl> <dbl> <dbl>
 1  1901     0 fema~ NSW   0.107   0.100   1     1.00e-1 0.935  56.2  56.2 0.935
 2  1901     1 fema~ NSW   0.0247  0.0244  0.900 2.20e-2 0.889  55.3  61.5 0.951
 3  1901     2 fema~ NSW   0.00686 0.00683 0.878 6.00e-3 0.875  54.4  62.0 0.984
 4  1901     3 fema~ NSW   0.00441 0.00441 0.872 3.84e-3 0.870  53.5  61.4 0.994
 5  1901     4 fema~ NSW   0.00374 0.00374 0.868 3.24e-3 0.867  52.7  60.7 0.996
 6  1901     5 fema~ NSW   0.00274 0.00274 0.865 2.37e-3 0.864  51.8  59.9 0.997
 7  1901     6 fema~ NSW   0.00252 0.00251 0.863 2.17e-3 0.861  50.9  59.1 0.997
 8  1901     7 fema~ NSW   0.00216 0.00216 0.860 1.86e-3 0.859  50.1  58.2 0.998
 9  1901     8 fema~ NSW   0.00169 0.00169 0.859 1.45e-3 0.858  49.2  57.3 0.998
10  1901     9 fema~ NSW   0.00109 0.00109 0.857 9.36e-4 0.857  48.4  56.4 0.999
# i 145,430 more rows
```

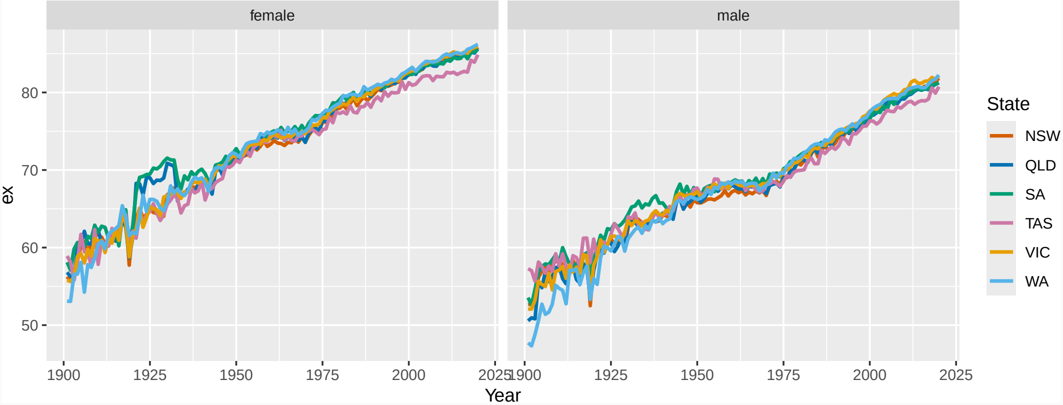
# Life expectancy

```
life_expectancy(aus)
```

```
# A vital: 1,440 x 8 [1Y]
# Key:     Age x (Sex, State) [1 x 12]
    Year   Age Sex    State    ex    rx    nx    ax
   <int> <int> <chr>  <chr> <dbl> <dbl> <dbl> <dbl>
 1  1901     0 female NSW    56.2 0.935     1 0.352
 2  1901     0 female QLD    56.8 0.937     1 0.338
 3  1901     0 female SA     58.1 0.939     1 0.324
 4  1901     0 female TAS    58.9 0.946     1 0.275
 5  1901     0 female VIC    55.8 0.937     1 0.334
 6  1901     0 female WA     53.1 0.922     1 0.35
 7  1901     0 male   NSW    52.6 0.925     1 0.33
 8  1901     0 male   QLD    50.6 0.924     1 0.33
 9  1901     0 male   SA     53.5 0.922     1 0.33
10  1901     0 male   TAS    57.3 0.930     1 0.33
# i 1,430 more rows
```

# Life expectancy

```r
life_expectancy(aus) |>
  ggplot(aes(x = Year, y = ex, colour = State)) +
  geom_line(linewidth = 1) +
  facet_grid(. ~ Sex)
```



# Outline

# Benchmark models

```
fit <- aus |>
  model(
    naive = FNAIVE(Mortality),
    mean = FMEAN(Mortality)
  )
fit
```

```
# A mable: 12 x 4
# Key:     Sex, State [12]
   Sex    State    naive     mean
   <chr>  <chr>  <model> <model>
 1 female NSW   <FNAIVE> <FMEAN>
 2 female QLD   <FNAIVE> <FMEAN>
 3 female SA    <FNAIVE> <FMEAN>
 4 female TAS   <FNAIVE> <FMEAN>
 5 female VIC   <FNAIVE> <FMEAN>
 6 female WA    <FNAIVE> <FMEAN>
```

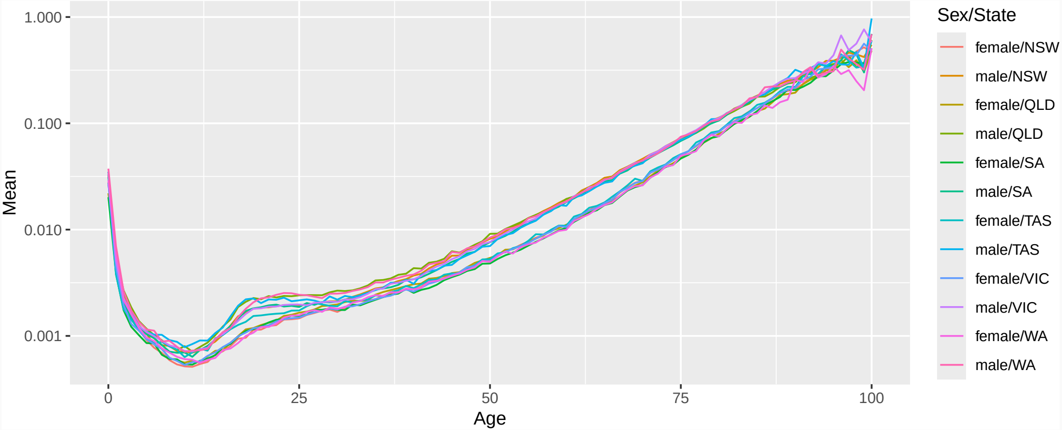
# Benchmark models

```
fit |>
  filter(Sex == "female", State == "NSW") |>
  select(mean) |>
  report()
```

```
Series: Mortality
Model: FMEAN

# A tibble: 101 x 3
     Age     mean    sigma
   <int>    <dbl>    <dbl>
 1     0 0.0279   0.0256
 2     1 0.00528  0.00648
 3     2 0.00223  0.00245
 4     3 0.00145  0.00151
 5     4 0.00115  0.00116
 6     5 0.000915 0.000913
```

# Benchmark models

```
fit |>
  select(mean) |>
  autoplot() + scale_y_log10()
```



# Lee-Carter models

```
fit <- aus |>
  model(
    naive = FNAIVE(Mortality),
    mean = FMEAN(Mortality),
    lc = LC(log(Mortality))
  )
fit
```

```
# A mable: 12 x 5
# Key:     Sex, State [12]
   Sex    State    naive    mean      lc
   <chr>  <chr>  <model> <model> <model>
 1 female NSW   <FNAIVE> <FMEAN>    <LC>
 2 female QLD   <FNAIVE> <FMEAN>    <LC>
 3 female SA    <FNAIVE> <FMEAN>    <LC>
 4 female TAS   <FNAIVE> <FMEAN>    <LC>
 5 female VIC   <FNAIVE> <FMEAN>    <LC>
```

# Lee-Carter models

```
fit |>
  filter(Sex == "female", State == "NSW") |>
  select(lc) |>
  report()
```

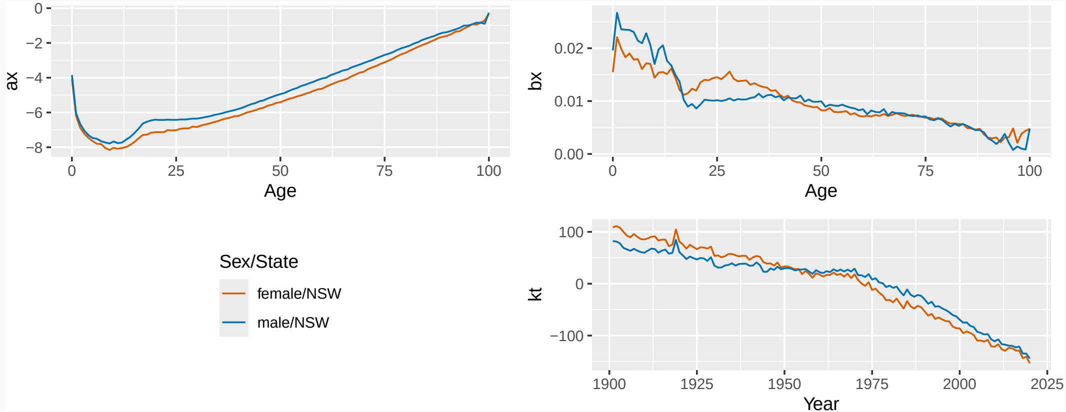
```
Series: Mortality
Model: LC
Transformation: log(Mortality)

Options:
  Adjust method: dt
  Jump choice: fit

Age functions
# A tibble: 101 x 3
    Age     ax      bx
  <int> <dbl>   <dbl>
1     0 -4.07 0.0155
2     1 -6.20 0.0221
```

# Lee-Carter models

```
Age functions
# A tibble: 101 × 3
    Age    ax     bx
  <int> <dbl>  <dbl>
1     0 -4.07 0.0155
2     1 -6.20 0.0221
3     2 -6.89 0.0199
# i 98 more rows

Time coefficients
# A tsibble: 120 x 2 [1Y]
   Year    kt
  <int> <dbl>
1  1901 109.
2  1902 111.
3  1903 108.
# i 117 more rows

Time series model: RW w/ drift

Variance explained: 86.61%
```

# Lee-Carter models

```
fit |>
  filter(State == "NSW") |>
  select(lc) |>
  autoplot()
```



# Lee-Carter models

```
fit |> select(lc) |> age_components()
```

```
# A tibble: 1,212 x 5
   Sex    State   Age    ax     bx
   <chr>  <chr> <int> <dbl>  <dbl>
 1 female NSW       0 -4.07 0.0155
 2 female NSW       1 -6.20 0.0221
 3 female NSW       2 -6.89 0.0199
 4 female NSW       3 -7.24 0.0183
 5 female NSW       4 -7.47 0.0190
 6 female NSW       5 -7.65 0.0178
 7 female NSW       6 -7.80 0.0179
 8 female NSW       7 -7.81 0.0160
 9 female NSW       8 -8.05 0.0171
10 female NSW       9 -8.15 0.0170
# i 1,202 more rows
```

# Lee-Carter models

```
fit |> select(lc) |> time_components()
```

```
# A tsibble: 1,440 x 4 [1Y]
# Key:       Sex, State [12]
   Sex    State  Year    kt
   <chr>  <chr> <int> <dbl>
 1 female NSW    1901 109. 
 2 female NSW    1902 111. 
 3 female NSW    1903 108. 
 4 female NSW    1904 100. 
 5 female NSW    1905  92.7
 6 female NSW    1906  89.5
 7 female NSW    1907  95.7
 8 female NSW    1908  90.5
 9 female NSW    1909  85.9
10 female NSW    1910  85.4
# i 1,430 more rows
```

# Functional data models

```
fit <- aus |>
  model(
    naive = FNAIVE(Mortality),
    mean = FMEAN(Mortality),
    lc = LC(log(Mortality)),
    hu = FDM(log(Mortality))
  )
fit
```

```
# A mable: 12 x 6
# Key:     Sex, State [12]
   Sex    State    naive    mean      lc      hu
   <chr>  <chr>  <model> <model> <model> <model>
 1 female NSW   <FNAIVE> <FMEAN>    <LC>   <FDM>
 2 female QLD   <FNAIVE> <FMEAN>    <LC>   <FDM>
 3 female SA    <FNAIVE> <FMEAN>    <LC>   <FDM>
 4 female TAS   <FNAIVE> <FMEAN>    <LC>   <FDM>
```

# Functional data models

```
fit |>
  filter(Sex == "female", State == "NSW") |>
  select(hu) |>
  report()
```

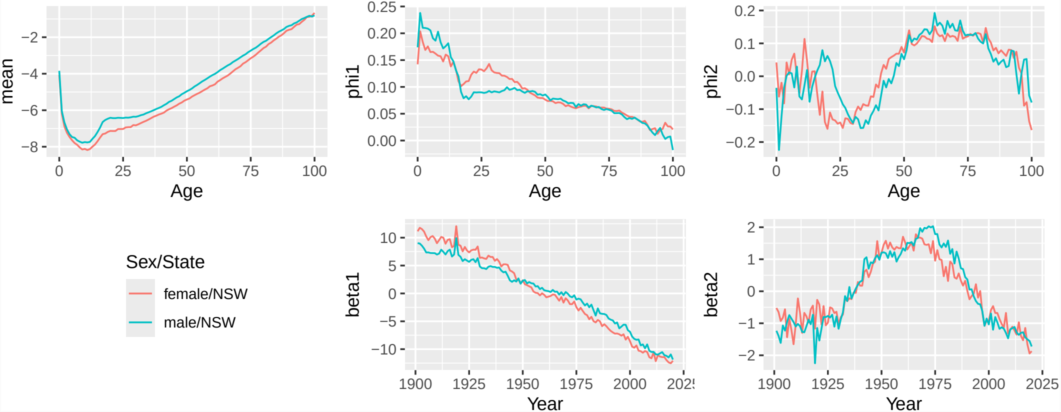
```
Series: Mortality
Model: FDM
Transformation: log(Mortality)

Basis functions
# A tibble: 101 x 8
    Age  mean  phi1    phi2    phi3    phi4    phi5    phi6
  <int> <dbl> <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>
1     0 -4.07 0.142  0.0420 -0.0182  0.0386  0.0500 -0.0107
2     1 -6.19 0.204 -0.0620 -0.0677 -0.0519  0.111   0.0226
3     2 -6.88 0.184 -0.0197 -0.0769  0.0181 -0.0201  0.0169
4     3 -7.23 0.169 -0.0825 -0.0790 -0.137   0.311   0.154
5     4 -7.46 0.176  0.0420 -0.163  -0.128   0.384   0.102
# i 96 more rows
```

# Functional data models

```
Coefficients
# A tsibble: 120 x 8 [1Y]
   Year  mean beta1  beta2   beta3     beta4   beta5   beta6
  <int> <dbl> <dbl>  <dbl>   <dbl>     <dbl>   <dbl>   <dbl>
1  1901     1  11.1 -0.522 -0.0553  0.207    0.358    0.0305
2  1902     1  11.8 -0.649  0.399   0.856    0.0319   0.422
3  1903     1  11.5 -0.930 -0.485   0.398    0.399   -0.376
4  1904     1  11.1 -0.827 -0.214  -0.000305 0.00125 -0.0783
5  1905     1  10.2 -0.563 -0.105   0.324    0.122    0.0478
# i 115 more rows
# i Use `print(n = ...)` to see more rows

Time series models
   beta1 : ARIMA(0,1,1) w/ drift
   beta2 : ARIMA(0,2,2)
   beta3 : ARIMA(1,0,1)
   beta4 : ARIMA(0,0,2)
   beta5 : ARIMA(0,0,0)
   beta6 : ARIMA(2,0,2)

Variance explained
  91.38 + 1.81 + 0.58 + 0.49 + 0.42 + 0.39 = 95.06%
```

# Functional data models

```
fit |>
  filter(State == "NSW") |>
  select(hu) |>
  autoplot()
```



# Functional data models

```r
fit |> select(hu) |> age_components()
```

```
# A tibble: 1,212 x 10
   Sex    State   Age  mean phi1     phi2    phi3    phi4    phi5    phi6
   <chr>  <chr> <int> <dbl> <dbl>   <dbl>   <dbl>   <dbl>   <dbl>   <dbl>
 1 female NSW       0 -4.07 0.142  0.0420 -0.0182  0.0386  0.0500 -0.0107
 2 female NSW       1 -6.19 0.204 -0.0620 -0.0677 -0.0519  0.111   0.0226
 3 female NSW       2 -6.88 0.184 -0.0197 -0.0769  0.0181 -0.0201  0.0169
 4 female NSW       3 -7.23 0.169 -0.0825 -0.0790 -0.137   0.311   0.154
 5 female NSW       4 -7.46 0.176  0.0420 -0.163  -0.128   0.384   0.102
 6 female NSW       5 -7.64 0.165  0.00566  0.0486  0.0449  0.179  -0.339
 7 female NSW       6 -7.80 0.165  0.0504   0.147  -0.225  -0.369  -0.161
 8 female NSW       7 -7.89 0.162  0.0688   0.232  -0.0113 -0.181  -0.265
 9 female NSW       8 -8.04 0.158  0.00194 -0.351   0.226  -0.0622 -0.141
10 female NSW       9 -8.15 0.157 -0.0517  -0.525   0.0234 -0.297   0.182
# i 1,202 more rows
```

# Functional data models

```
fit |> select(hu) |> time_components()
```

```
# A tsibble: 1,440 x 10 [1Y]
# Key:       Sex, State [12]
   Sex    State  Year  mean beta1  beta2   beta3     beta4    beta5   beta6
   <chr>  <chr> <int> <dbl> <dbl>  <dbl>   <dbl>     <dbl>    <dbl>   <dbl>
 1 female NSW    1901     1 11.1  -0.522 -0.0553  0.207     0.358    0.0305
 2 female NSW    1902     1 11.8  -0.649  0.399   0.856     0.0319   0.422
 3 female NSW    1903     1 11.5  -0.930 -0.485   0.398     0.399   -0.376
 4 female NSW    1904     1 11.1  -0.827 -0.214  -0.000305  0.00125 -0.0783
 5 female NSW    1905     1 10.2  -0.563 -0.105   0.324     0.122    0.0478
 6 female NSW    1906     1  9.55 -1.44   0.263  -0.126    -0.0777  -0.331
 7 female NSW    1907     1 10.1  -0.857  0.812   1.30      0.347    0.740
 8 female NSW    1908     1 10.3  -1.21   0.662   0.767    -0.374    0.115
 9 female NSW    1909     1  9.83 -1.65   0.925   2.80     -0.0228   1.45
10 female NSW    1910     1  9.01 -1.04  -0.0934 -0.793    -0.109   -0.346
# i 1,430 more rows
```

# Coherent FDM (generalizing Lee-Li)

# Outline

# Future plans

- Stochastic population forecasting (as per Booth-Hyndman 2008)
- StMoMo
- other tools in the demography package
- demography package to be maintained but not developed