MONASH University

MONASH BUSINESS SCHOOL

Tidy Forecasting in R

Rob J Hyndman

ISF 2018

Outline

forecast package

Pre 2003	Private functions used for consulting projects
July/August 2003	**ets** and **thetaf** added
August 2006	v1.0 available on CRAN
May 2007	**auto.arima** added
May 2010	**arfima** added
Feb/March 2011	**tslm**, **stlf**, **naive**, **snaive** added
August 2011	v3.0. Box Cox transformations added
December 2011	**tbats** added
April 2012	Package moved to github
November 2012	v4.0. **nnetar** added
June 2013	Major speed-up of **ets**
February 2016	v7.0. Added ggplot2 graphics
February 2017	v8.0. Added **checkresiduals**, **tsCV** and **%>%**
April 2018	v8.3. Added **mstl**
June 2018	$\approx$ 100,000 package downloads per month

fable package

A replacement for the forecast package.

Why change?

- Integrating with tidyverse packages
- Designed for forecasting many related time series
- Consistency of interface using formulas
- Distribution forecasting rather than point + interval
- Flexible transformations
- Sub-daily data and multiple seasonal data handled more easily
- Simpler interface for forecast reconciliation

Outline

Example: Australian eating-out expenditure

```
fpp2::auscafe
```

```
##         Jan   Feb   Mar   Apr   May   Jun   Jul   Aug   Sep
## 1982                    0.342 0.342 0.329 0.339 0.332 0.342
## 1983 0.369 0.348 0.366 0.351 0.360 0.347 0.364 0.376 0.378
## 1984 0.389 0.377 0.398 0.383 0.414 0.382 0.393 0.409 0.395
## 1985 0.426 0.392 0.416 0.420 0.446 0.407 0.449 0.466 0.455
## 1986 0.504 0.453 0.480 0.497 0.531 0.485 0.526 0.538 0.537
## 1987 0.572 0.525 0.544 0.558 0.565 0.542 0.599 0.584 0.593
## 1988 0.605 0.586 0.625 0.612 0.630 0.635 0.659 0.656 0.660
## 1989 0.733 0.661 0.713 0.694 0.710 0.722 0.741 0.746 0.767
## 1990 0.858 0.764 0.840 0.805 0.809 0.799 0.815 0.828 0.812
## 1991 0.862 0.771 0.813 0.797 0.821 0.801 0.829 0.854 0.882
## 1992 0.938 0.862 0.936 0.932 0.929 0.869 0.891 0.875 0.914
## 1993 0.918 0.838 0.870 0.862 0.852 0.828 0.882 0.867 0.905
## 1994 0.985 0.902 1.015 0.939 0.941 0.935 1.013 1.018 1.041
## 1995 1.076 0.982 1.099 1.068 1.083 1.045 1.094 1.110 1.126
## 1996 1.213 1.128 1.180 1.169 1.146 1.109 1.138 1.146 1.105
## 1997 1.180 1.060 1.148 1.141 1.170 1.113 1.165 1.173 1.154
## 1998 1.186 1.050 1.141 1.107 1.144 1.088 1.162 1.145 1.149
## 1999 1.244 1.124 1.245 1.236 1.271 1.208 1.219 1.234 1.261
## 2000 1.297 1.207 1.325 1.252 1.282 1.275 1.318 1.329 1.432
```

Example: Australian eating-out expenditure

```
library(tsibble)
cafe <- as_tsibble(fpp2::auscafe)
cafe
```

```
## # A tsibble: 426 x 2 [1MONTH]
##         index value
##         <mth> <dbl>
##  1 1982 Apr 0.342
##  2 1982 May 0.342
##  3 1982 Jun 0.329
##  4 1982 Jul 0.338
##  5 1982 Aug 0.332
##  6 1982 Sep 0.342
##  7 1982 Oct 0.358
##  8 1982 Nov 0.375
##  9 1982 Dec 0.433
## 10 1983 Jan 0.369
## # ... with 416 more rows
```

Example: Australian eating-out expenditure

```
library(fable)
cafe %>% ETS(value)
```

```
## # A mable: 1 model [1MONTH]
##   data                  model
##   <list>                <model>
## 1 <tsibble [426 x 2]> ETS(M,A,M)
```

Example: Australian eating-out expenditure

```
cafe %>% ETS(value) %>% summary()
```

```
## ETS(M,A,M)
##
## Call:
##  ETS(data = ., formula = value)
##
##   Smoothing parameters:
##     alpha = 0.6263
##     beta  = 0.0065
##     gamma = 0.0755
##
##   Initial states:
##     l = 0.3477
##     b = 0.0038
##     s = 0.996 0.936 1.01 1.15 1.01 1.01
##           0.983 0.991 0.992 0.951 0.997 0.971
##
##   sigma:  0.0249
##
##  AIC AICc  BIC
## -319 -318 -250
```

Example: Australian eating-out expenditure

```
cafe %>% ETS(value) %>% forecast()
```

```
## # A fable: 1 forecast [1MONTH]
##   data                  model       forecast
##   <list>                <model>     <fc>
## 1 <tsibble [426 x 2]> ETS(M,A,M) ~N [h=24]
```

Example: Australian eating-out expenditure

```
cafe %>% ETS(value) %>% forecast() %>%
  summary()
```

```
## # A tsibble: 24 x 4 [1MONTH]
##        index  mean                 80%                 95%
##        <mth> <dbl>               <hilo>              <hilo>
##  1 2017 Oct  3.83 [3.71, 3.96]80 [3.65, 4.02]95
##  2 2017 Nov  3.81 [3.67, 3.96]80 [3.59, 4.03]95
##  3 2017 Dec  4.22 [4.04, 4.40]80 [3.94, 4.49]95
##  4 2018 Jan  3.83 [3.64, 4.01]80 [3.55, 4.10]95
##  5 2018 Feb  3.51 [3.33, 3.70]80 [3.24, 3.79]95
##  6 2018 Mar  3.87 [3.65, 4.09]80 [3.54, 4.20]95
##  7 2018 Apr  3.78 [3.56, 4.01]80 [3.44, 4.13]95
##  8 2018 May  3.81 [3.57, 4.05]80 [3.44, 4.18]95
##  9 2018 Jun  3.68 [3.43, 3.92]80 [3.30, 4.05]95
## 10 2018 Jul  3.88 [3.60, 4.15]80 [3.46, 4.29]95
## # ... with 14 more rows
```

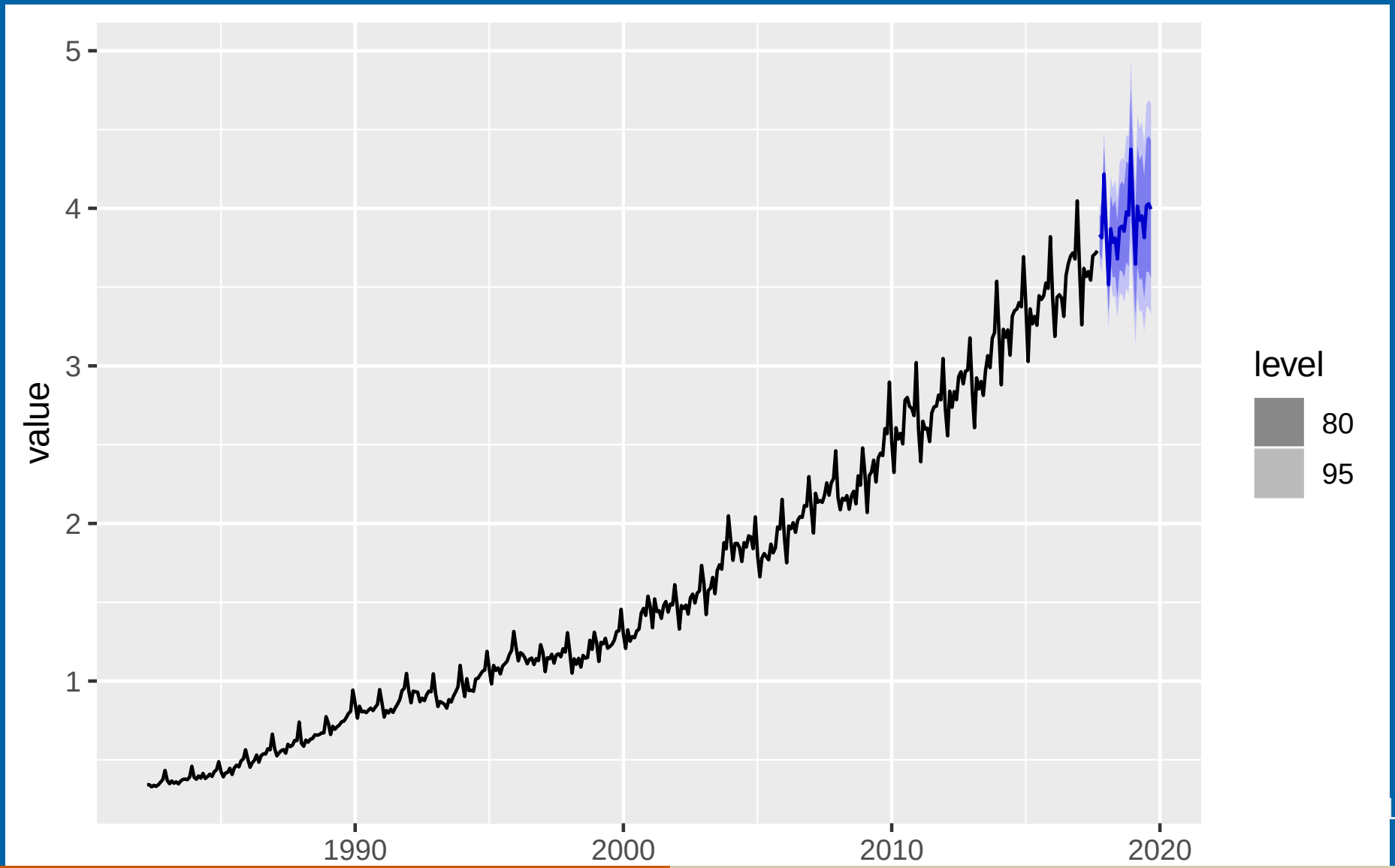
Example: Australian eating-out expenditure

```
cafe %>% ETS(value) %>% forecast() %>%
  summary(level=90)
```

```
## # A tsibble: 24 x 3 [1MONTH]
##        index  mean                 90%
##        <mth> <dbl>               <hilo>
##  1 2017 Oct  3.83 [3.68, 3.99]90
##  2 2017 Nov  3.81 [3.63, 4.00]90
##  3 2017 Dec  4.22 [3.99, 4.45]90
##  4 2018 Jan  3.83 [3.59, 4.06]90
##  5 2018 Feb  3.51 [3.28, 3.75]90
##  6 2018 Mar  3.87 [3.59, 4.15]90
##  7 2018 Apr  3.78 [3.49, 4.07]90
##  8 2018 May  3.81 [3.50, 4.12]90
##  9 2018 Jun  3.68 [3.36, 3.99]90
## 10 2018 Jul  3.88 [3.53, 4.22]90
## # ... with 14 more rows
```

Example: Australian eating-out expenditure

```
cafe %>% ETS(value) %>% forecast() %>% autoplot()
```



Example: Australian eating-out expenditure

```
cafe %>% ARIMA(log(value)) %>%
  forecast() %>% summary()
```

```
## # A tsibble: 24 x 4 [1MONTH]
##        index  mean                 80%                 95%
##        <mth> <dbl>               <hilo>              <hilo>
##  1 2017 Oct  3.81 [3.70, 3.93]80 [3.64, 3.99]95
##  2 2017 Nov  3.79 [3.65, 3.93]80 [3.58, 4.00]95
##  3 2017 Dec  4.17 [3.99, 4.34]80 [3.91, 4.43]95
##  4 2018 Jan  3.73 [3.55, 3.90]80 [3.46, 4.00]95
##  5 2018 Feb  3.40 [3.22, 3.57]80 [3.14, 3.67]95
##  6 2018 Mar  3.77 [3.56, 3.99]80 [3.46, 4.10]95
##  7 2018 Apr  3.70 [3.48, 3.93]80 [3.37, 4.05]95
##  8 2018 May  3.76 [3.52, 4.00]80 [3.40, 4.13]95
##  9 2018 Jun  3.66 [3.41, 3.90]80 [3.29, 4.04]95
## 10 2018 Jul  3.88 [3.61, 4.15]80 [3.48, 4.31]95
## # ... with 14 more rows
```

Outline

Example: Australian prison population

```
fpp2::prisonLF
```

```
## # A tibble: 1,536 x 5
##    state gender legal    t          count
##    <fct> <fct>  <fct>    <date>     <dbl>
##  1 ACT   Female Remanded 2005-03-01     2
##  2 ACT   Female Remanded 2005-06-01     4
##  3 ACT   Female Remanded 2005-09-01     1
##  4 ACT   Female Remanded 2005-12-01     4
##  5 ACT   Female Remanded 2006-03-01     4
##  6 ACT   Female Remanded 2006-06-01     6
##  7 ACT   Female Remanded 2006-09-01     9
##  8 ACT   Female Remanded 2006-12-01     6
##  9 ACT   Female Remanded 2007-03-01     4
## 10 ACT   Female Remanded 2007-06-01     4
## # ... with 1,526 more rows
```

Example: Australian prison population

```
prison <- fpp2::prisonLF %>%
  mutate(qtr=yearquarter(t)) %>%
  select(-t) %>%
  as_tsibble(index=qtr, key=id(state,gender,legal))
prison
```

```
## # A tsibble: 1,536 x 5 [1QUARTER]
## # Key:       state, gender, legal [32]
##    state gender legal    count     qtr
##    <fct> <fct>  <fct>    <dbl>   <qtr>
##  1 ACT   Female Remanded     2 2005 Q1
##  2 ACT   Female Remanded     4 2005 Q2
##  3 ACT   Female Remanded     1 2005 Q3
##  4 ACT   Female Remanded     4 2005 Q4
##  5 ACT   Female Remanded     4 2006 Q1
##  6 ACT   Female Remanded     6 2006 Q2
##  7 ACT   Female Remanded     9 2006 Q3
```

Example: Australian prison population

```
prison %>% ETS(count)
```

```
## # A mable: 32 models [1QUARTER]
## # Key:     state, gender, legal [32]
##    state gender legal     data                 model
##    <fct> <fct>  <fct>     <list>               <model>
##  1 ACT   Female Remanded  <tsibble [48 x 2]> ETS(M,A,N)
##  2 ACT   Female Sentenced <tsibble [48 x 2]> ETS(A,A,N)
##  3 ACT   Male   Remanded  <tsibble [48 x 2]> ETS(M,N,N)
##  4 ACT   Male   Sentenced <tsibble [48 x 2]> ETS(A,N,N)
##  5 NSW   Female Remanded  <tsibble [48 x 2]> ETS(M,N,M)
##  6 NSW   Female Sentenced <tsibble [48 x 2]> ETS(M,N,M)
##  7 NSW   Male   Remanded  <tsibble [48 x 2]> ETS(M,A,A)
##  8 NSW   Male   Sentenced <tsibble [48 x 2]> ETS(M,A,A)
##  9 NT    Female Remanded  <tsibble [48 x 2]> ETS(M,N,N)
## 10 NT    Female Sentenced <tsibble [48 x 2]> ETS(M,A,A)
## # ... with 22 more rows
```

Example: Australian prison population

```
prison %>% ETS(count) %>% forecast()
```

```
## # A fable: 32 forecasts [1QUARTER]
## # Key:     state, gender, legal [32]
##    state gender legal     data           model       forecast
##    <fct> <fct>  <fct>     <list>         <model>     <fc>
##  1 ACT   Female Remanded  <tsibble [48~ ETS(M,A,N) ~N [h=8]
##  2 ACT   Female Sentenced <tsibble [48~ ETS(A,A,N) ~N [h=8]
##  3 ACT   Male   Remanded  <tsibble [48~ ETS(M,N,N) ~N [h=8]
##  4 ACT   Male   Sentenced <tsibble [48~ ETS(A,N,N) ~N [h=8]
##  5 NSW   Female Remanded  <tsibble [48~ ETS(M,N,M) ~N [h=8]
##  6 NSW   Female Sentenced <tsibble [48~ ETS(M,N,M) ~N [h=8]
##  7 NSW   Male   Remanded  <tsibble [48~ ETS(M,A,A) ~N [h=8]
##  8 NSW   Male   Sentenced <tsibble [48~ ETS(M,A,A) ~N [h=8]
##  9 NT    Female Remanded  <tsibble [48~ ETS(M,N,N) ~N [h=8]
## 10 NT    Female Sentenced <tsibble [48~ ETS(M,A,A) ~N [h=8]
## # ... with 22 more rows
```

Aggregation and reconciliation not yet implemented.

Outline

Example: Half-hourly electricity demand

```
elecdemand
```

```
## # A tsibble: 17,520 x 4 [30MINUTE]
##    index               Demand Temperature WorkDay
##    <dttm>               <dbl>       <dbl>   <dbl>
##  1 2014-01-01 00:00:00   3.91        18.2       0
##  2 2014-01-01 00:30:00   3.67        17.9       0
##  3 2014-01-01 01:00:00   3.50        17.6       0
##  4 2014-01-01 01:30:00   3.34        16.8       0
##  5 2014-01-01 02:00:00   3.20        16.3       0
##  6 2014-01-01 02:30:00   3.10        16.6       0
##  7 2014-01-01 03:00:00   3.04        16.6       0
##  8 2014-01-01 03:30:00   3.01        16.7       0
##  9 2014-01-01 04:00:00   3.02        16.2       0
## 10 2014-01-01 04:30:00   3.03        16.6       0
## # ... with 17,510 more rows
```

Example: Half-hourly electricity demand

```
fit2 <- ARIMA(elecdemand,
  Demand ~ Temperature + I(Temperature^2) + WorkDay)
summary(fit2)
```

```
## Series: Demand
## Regression with ARIMA(1,1,0)(2,0,2)[2] errors
##
## Coefficients:
##         ar1    sar1   sar2    sma1    sma2  Temperature
##       0.853  -0.181  0.523  -0.066  -0.792       -0.009
## s.e.  0.005   0.015  0.012   0.012   0.011        0.002
##       I(Temperature^2)  WorkDay
##                      0    0.016
## s.e.                 0    0.006
##
## sigma^2 estimated as 0.00846:  log likelihood=16949
## AIC=-33881   AICc=-33881   BIC=-33811
##
## Training set error measures:
##                      ME  RMSE    MAE      MPE MAPE  MASE  ACF1
## Training set 6.51e-06 0.092 0.0634 0.00633 1.39 0.292 0.103
```

```
forecast(fit2, newdata=elecdemandfuture) %>% autoplot()
```

Outline

Equivalent methods: forecast $\longrightarrow$ fable

```
auto.arima ⟶ ARIMA
ets        ⟶ ETS
tslm/lm    ⟶ LM
tbats      ⟶ TBATS
nnetar     ⟶ NNAR
stlm       ⟶ STL %>%
                modelcomponents(
                  ETS(seasadj),SNAIVE(season))
```

- All functions have a formula interface with automatic modelling if no formula provided.
- All functions produce `mable` class objects.
- Some of these functions not yet implemented

Equivalent methods: forecast ⟶ fable

```
naive   ⟶ NAIVE %>% forecast
snaive  ⟶ SNAIVE %>% forecast
thetaf  ⟶ THETA %>% forecast
stlf    ⟶ STL %>%
            modelcomponents(
              ETS(seasadj),SNAIVE(season)) %>%
            forecast
hw      ⟶ HW %>% forecast
holt    ⟶ HOLT %>% forecast
ses     ⟶ SES %>% forecast
splinef ⟶ SPLINE %>% forecast
croston ⟶ CROSTON %>% forecast
```

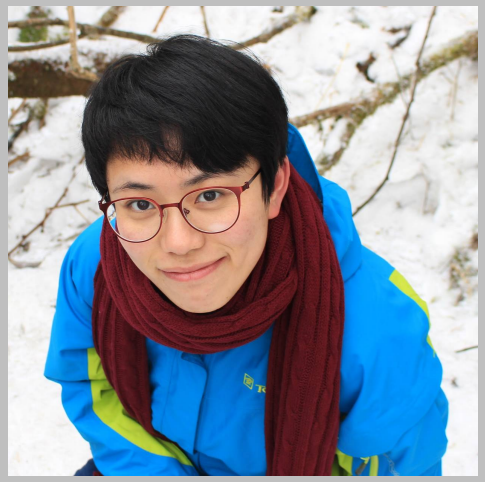
- `forecast` produces `fable` class objects.

Outline

More information


```
devtools::install_github("tidyverts/tsibble")
devtools::install_github("tidyverts/fable")
```

Di Cook



Earo Wang

Mitchell O'Hara-Wild

Follow our progress

- tidyverts.org
- robjhyndman.com/hyndsight