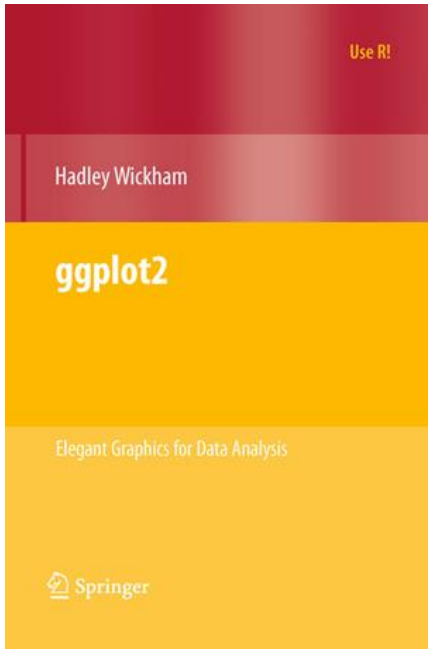
Part 1: Concepts and Terminology

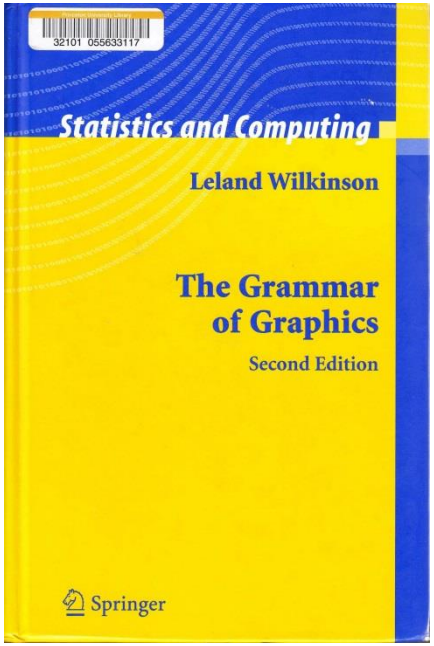
R Package: ggplot2



Used to produce statistical graphics, author = Hadley Wickham

"attempt to take the good things about base and lattice graphics and improve on them with a **strong, underlying model** "

based on *The Grammar of Graphics* by Leland Wilkinson, 2005



"... describes *the meaning* of what we do when we construct statistical graphics ... More than a taxonomy ... Computational system based on the underlying mathematics of representing statistical functions of data."

- does not limit developer to a set of pre-specified graphics

adds some concepts to grammar which allow it to work well with R

qplot()

ggplot2 provides two ways to produce plot objects:

qplot() # quick plot – not covered in this workshop

uses some concepts *of The Grammar of Graphics*, but doesn't provide full capability

and

designed to be very similar to plot() and simple to use

may make it easy to produce basic graphs

but

may delay understanding philosophy of ggplot2

ggplot() # grammar of graphics plot – focus of this workshop

provides fuller implementation of *The Grammar of Graphics*

may have steeper learning curve but allows much more flexibility when building graphs

Grammar Defines Components of Graphics

data: in ggplot2, data must be stored as an R data frame

coordinate system: describes 2-D space that data is projected onto
- for example, Cartesian coordinates, polar coordinates, map projections, ...

geoms: describe type of geometric objects that represent data
- for example, points, lines, polygons, ...

aesthetics: describe visual characteristics that represent data
- for example, position, size, color, shape, transparency, fill

scales: for each aesthetic, describe how visual characteristic is converted to display values
- for example, log scales, color scales, size scales, shape scales, ...

stats : describe statistical transformations that typically summarize data
- for example, counts, means, medians, regression lines, ...

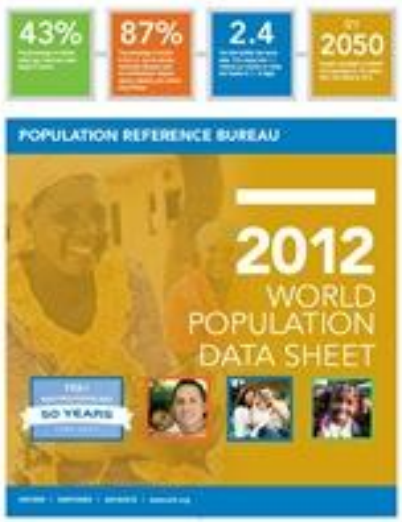
facets: describe how data is split into subsets and displayed as multiple small graphs

Workshop Data Frame

extract from 2012 World Population Data Sheet produced by Population Reference Bureau

includes 158 countries where mid-2012 population >= 1 million

for notes, sources and full definitions, see:
http://www.prb.org/pdf12/2012-population-data-sheet_eng.pdf



variables:

`country`	country name
`pop2012`	population mid-2012 (millions)
`imr`	infant mortality rate*
`tfr`	total fertility rate*
`le`	life expectancy at birth
`leM`	male life expectancy at birth
`leF`	female life expectancy at birth
`area`	(Africa, Americas, Asia & Oceania, Europe)
`region`	(Northern Africa, Western Africa, Eastern Africa, Middle Africa, North America, Central America, Caribbean, South America, Western Asia, South Central Asia, Southeast Asia, East Asia, Oceania, Northern Europe, Western Europe, Eastern Europe, Southern Europe)

*definitions: infant mortality rate – annual number of deaths of infants under age 1 per 1,000 live births
total fertility rate – average number of children a woman would have assuming that current age-specific birth rates remain constant throughout her childbearing years

ggplot()

creates a **plot object** that can be assigned to a variable

can specify data frame and aesthetics (visual characteristics that represent data)

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=le, y=tfr, color=area))
```

country	pop2012	tfr	le	area
Algeria	37.4	2.9	73	Africa
Egypt	82.3	2.9	72	Africa
Libya	6.5	2.6	75	Africa
Morocco	32.6	2.3	72	Africa
South Sudan	9.4	5.4	52	Africa
Sudan	33.5	4.2	60	Africa
Tunisia	10.8	2.1	75	Africa
Benin	9.4	5.4	56	Africa
Burkina Faso	17.5	6.0	55	Africa
Cote d'Ivoire	20.6	4.6	55	Africa
Gambia	1.8	4.9	58	Africa
Ghana	25.5	4.2	64	Africa
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.

le value is indicated by x-axis position
tfr value is indicated by y-axis position
area value is indicated by color

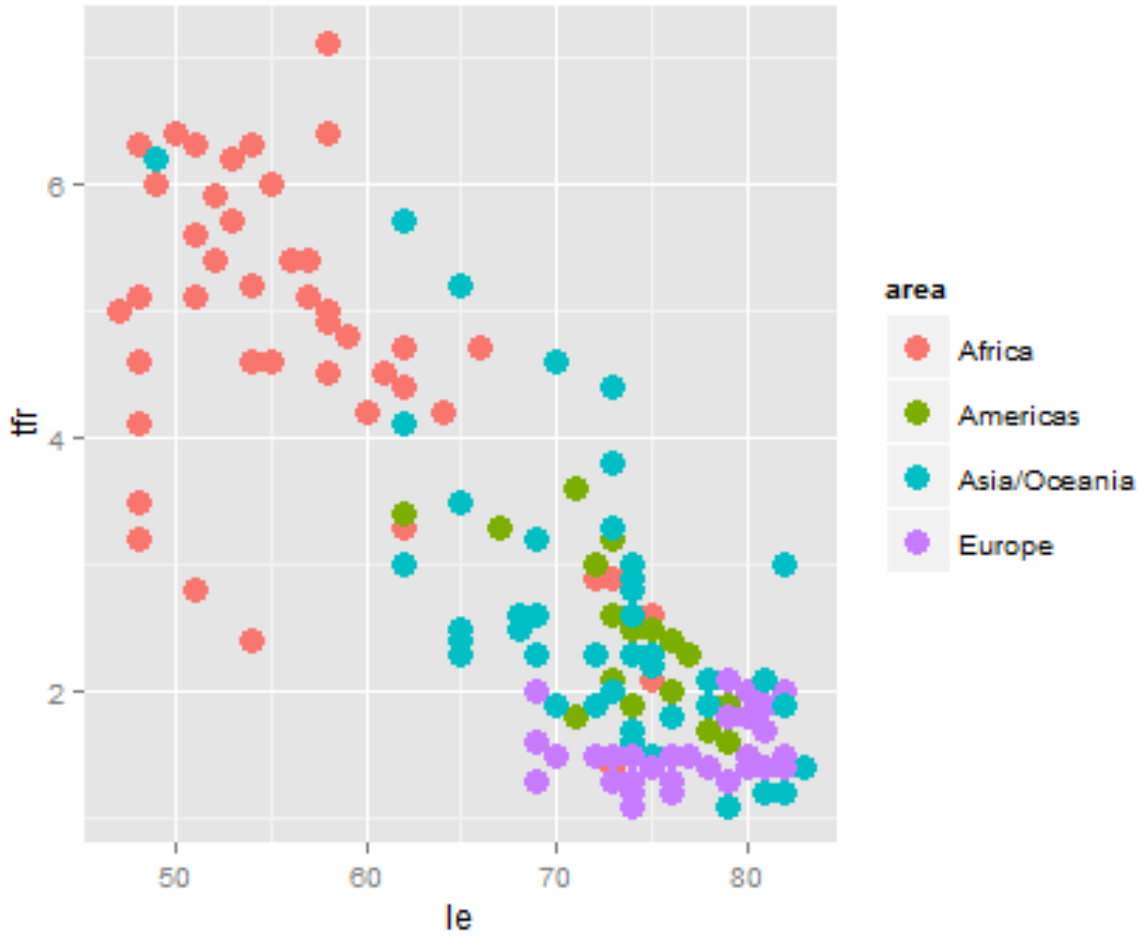
BUT

plot object p can not be displayed without adding at least one **layer**

at this point, there is nothing to see!

Add a Layer

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=le, y=tfr, color=area))
p + layer(geom="point", geom_params=list(size=4))
```



Layer

purpose:

display the data – allows viewer to see
patterns, overall structure, local structure, outliers, ...
display statistical summaries of the data – allows viewer to see
counts, means, medians, IQRs, model predictions, ...

full specification:

layer(geom, geom_params, stat, stat_params, data, mapping, position)

every layer specifies a *geom* or a *stat* or both

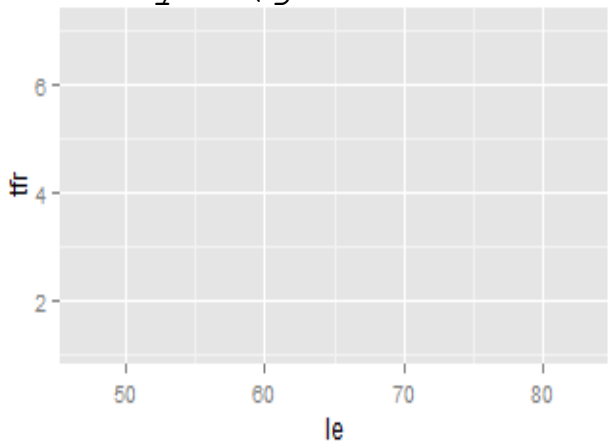
data and *mapping* (aesthetics) may be inherited from ggplot() object
or added/changed/dropped using layer()

position refers to method for adjusting overlapping objects

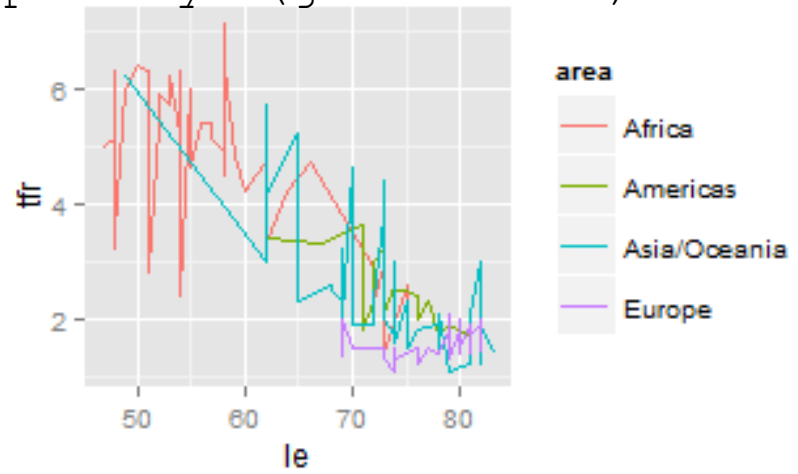
Add a *geom* Layer

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=le, y=tfr, color=area))
```

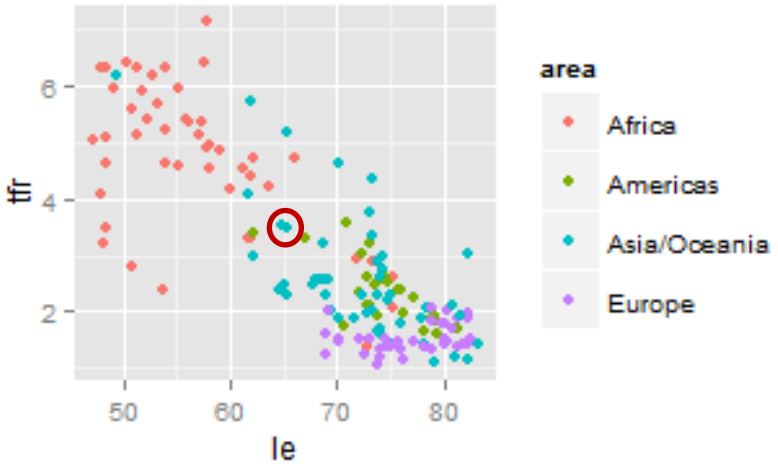
```
p + layer(geom="blank")
```



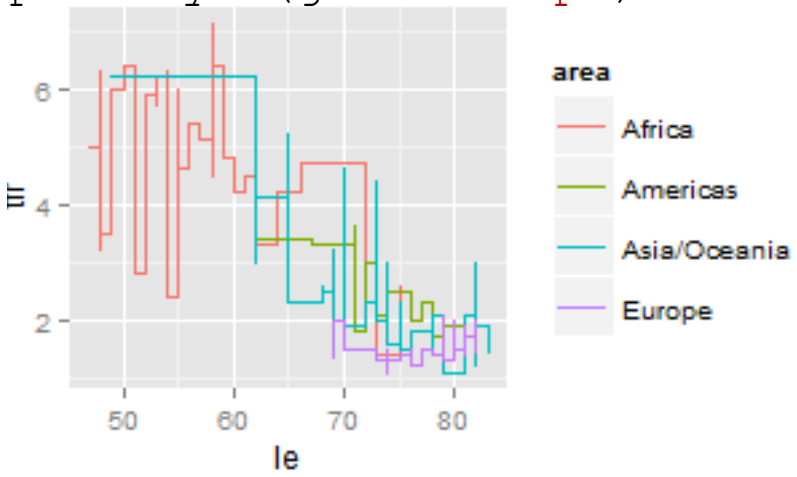

```
p + layer(geom="line")
```




```
p + layer(geom="jitter")
```



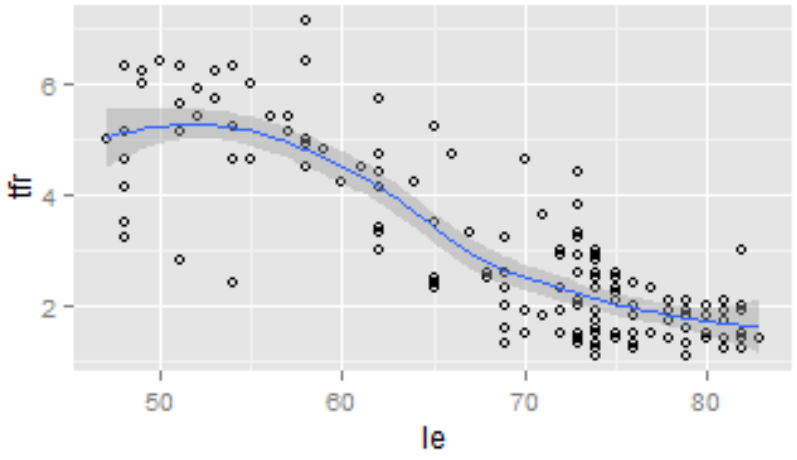

```
p + layer(geom="step")
```

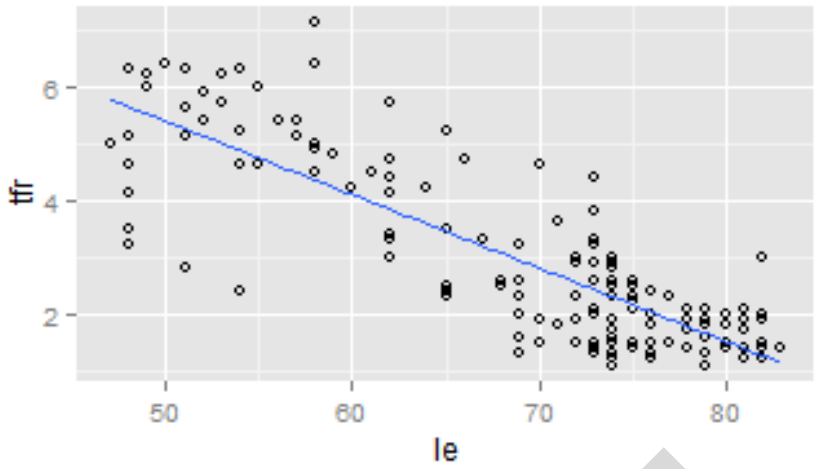


Add a *stat* Layer

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=le, y=tfr))

p + layer(geom="point",  geom_params=list(shape=1)) +
    layer(stat="smooth")
```

... group is <1000, so using loess. Use 'method = x' to change the smoothing method.





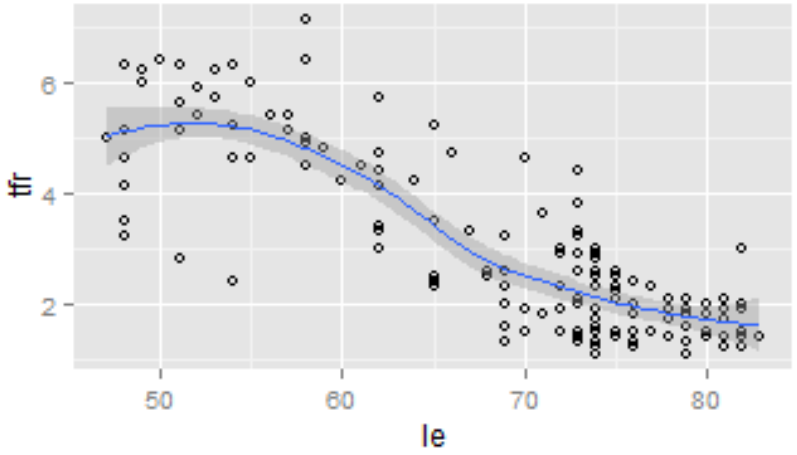

```
p + layer(geom="point",  geom_params=list(shape=1)) +
    layer(stat="smooth", stat_params=list(method="lm",se=FALSE))
```

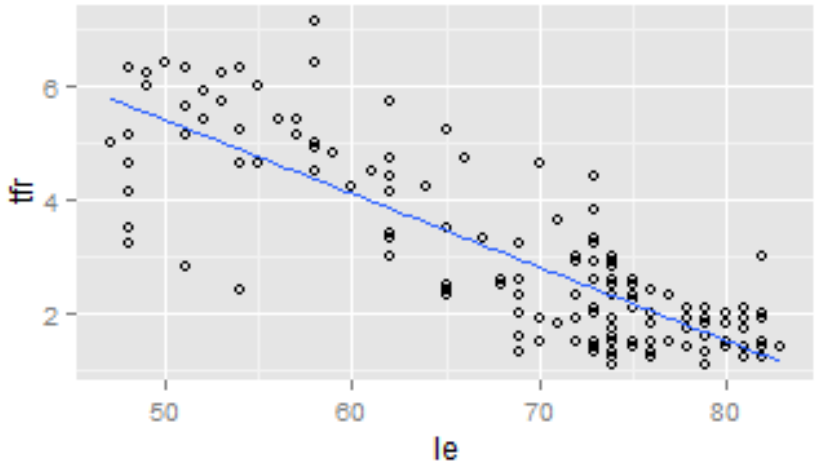
`geom_xxx` and `stat_xxx` Shortcut Functions

can use `geom_xxx()` and `stat_xxx()` shortcut functions rather than `layer()`...

much less typing!

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=le, y=tfr))
p + geom_point(shape=1) + stat_smooth()
```



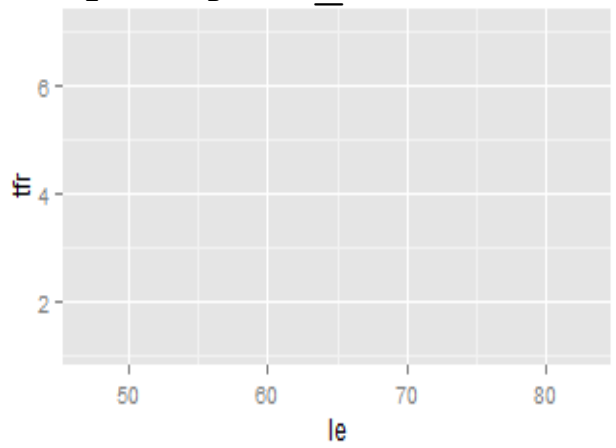



```
p + geom_point(shape=1) + stat_smooth(method="lm", se=FALSE)
```

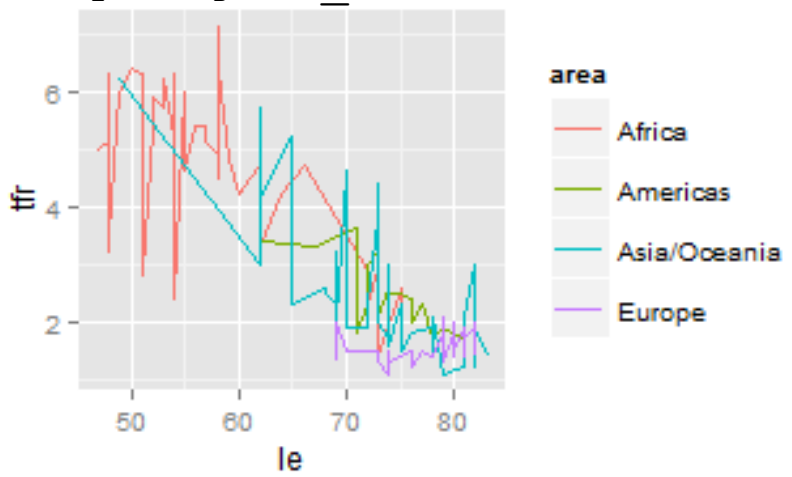
Shortcut Functions: Adding a *geom* Layer

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=le, y=tfr, color=area))
```

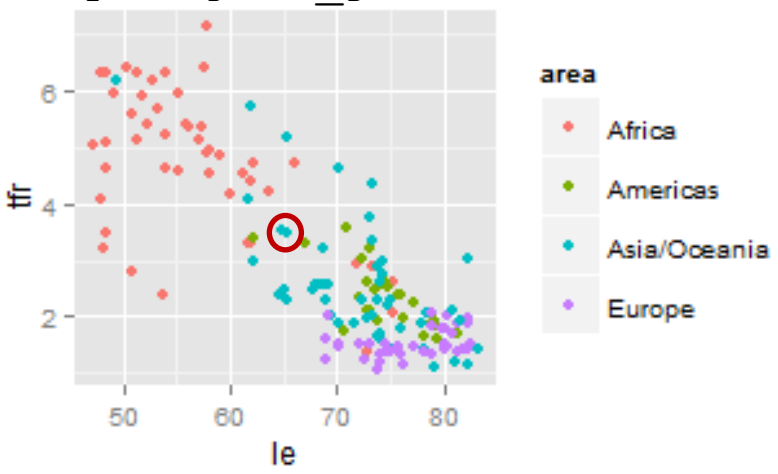
`p + geom_blank()`



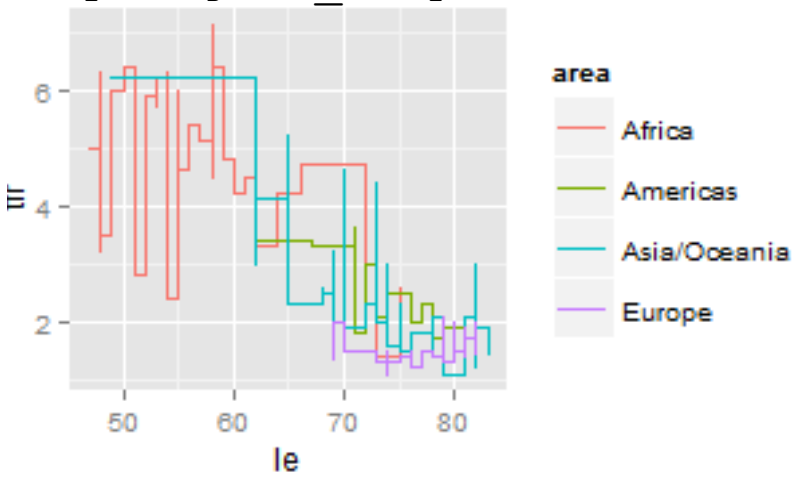
`p + geom_line()`



`p + geom_jitter()`



`p + geom_step()`



Add Layers Using Shortcut Functions

geom_xxx()
purpose: display the data –
allows viewer to see patterns, overall structure, local structure, outliers, ...

full specification: *geom_xxx(mapping, data, stat, position, ...)*

each geom_xxx() has a default *stat* (statistical transformation) associated with it,
but the default statistical transformation may be changed using *stat* parameter

stat_xxx()
purpose: display statistical summaries of the data –
allows viewer to see counts, means, medians, IQRs, model predictions, ...

full specification: *stat_xxx(mapping, data, geom, position, ...)*

each *stat_xxx()* has a default *geom* (geometric object) associated with it,
but the default geometric object may be changed using *geom* parameter

for a list of *geom_xxx()* and *stat_xxx()*, see `http://docs.ggplot2.org/current/`

```
geoms <- help.search("^geom_",  package = "ggplot2")
geoms$matches[, 1:2]
```

geom_*xxx*()

```
      topic                  title
 [1,] "geom_abline"     "Line specified by slope and intercept."
 [2,] "geom_area"       "Area plot."
 [3,] "geom_bar"        "Bars, rectangles with bases on x-axis"
 [4,] "geom_bin2d"      "Add heatmap of 2d bin counts."
 [5,] "geom_blank"      "Blank, draws nothing."
 [6,] "geom_boxplot"    "Box and whiskers plot."
 [7,] "geom_contour"    "Display contours of a 3d surface in 2d."
 [8,] "geom_crossbar"   "Hollow bar with middle indicated by horizontal line."
 [9,] "geom_density"    "Display a smooth density estimate."
[10,] "geom_density2d"  "Contours from a 2d density estimate."
[11,] "geom_dotplot"    "Dot plot"
[12,] "geom_errorbar"   "Error bars."
[13,] "geom_errorbarh"  "Horizontal error bars"
[14,] "geom_freqpoly"   "Frequency polygon."
[15,] "geom_hex"        "Hexagon bining."
[16,] "geom_histogram"  "Histogram"
[17,] "geom_hline"      "Horizontal line."
[18,] "geom_jitter"     "Points, jittered to reduce overplotting."
[19,] "geom_line"       "Connect observations, ordered by x value."
[20,] "geom_linerange"  "An interval represented by a vertical line."
[21,] "geom_map"        "Polygons from a reference map."
[22,] "geom_path"       "Connect observations in original order"
[23,] "geom_point"      "Points, as for a scatterplot"
[24,] "geom_pointrange" "An interval represented by a vertical line, with a point in the middle."
[25,] "geom_polygon"    "Polygon, a filled path."
[26,] "geom_quantile"   "Add quantile lines from a quantile regression."
[27,] "geom_raster"     "High-performance rectangular tiling."
[28,] "geom_rect"       "2d rectangles."
[29,] "geom_ribbon"     "Ribbons, y range with continuous x values."
[30,] "geom_rug"        "Marginal rug plots."
[31,] "geom_segment"    "Single line segments."
[32,] "geom_smooth"     "Add a smoothed conditional mean."
[33,] "geom_step"       "Connect observations by stairs."
[34,] "geom_text"       "Textual annotations."
[35,] "geom_tile"       "Tile plane with rectangles."
[36,] "geom_violin"     "Violin plot."
[37,] "geom_vline"      "Line, vertical."
```

```
stats <- help.search("^stat_", package= "ggplot2")
stats$matches[, 1:2]
```

stat_*xxx*()

```
 topic                    title
 [1,] "stat_abline"       "Add a line with slope and intercept."
 [2,] "stat_bin"          "Bin data."
 [3,] "stat_bin2d"        "Count number of observation in rectangular bins."
 [4,] "stat_bindot"       "Bin data for dot plot."
 [5,] "stat_binhex"       "Bin 2d plane into hexagons."
 [6,] "stat_boxplot"      "Calculate components of box and whisker plot."
 [7,] "stat_contour"      "Calculate contours of 3d data."
 [8,] "stat_density"      "1d kernel density estimate."
 [9,] "stat_density2d"    "2d density estimation."
[10,] "stat_ecdf"         "Empirical Cumulative Density Function"
[11,] "stat_function"     "Superimpose a function."
[12,] "stat_hline"        "Add a horizontal line"
[13,] "stat_identity"     "Identity statistic."
[14,] "stat_qq"           "Calculation for quantile-quantile plot."
[15,] "stat_quantile"     "Continuous quantiles."
[16,] "stat_smooth"       "Add a smoother."
[17,] "stat_spoke"        "Convert angle and radius to xend and yend."
[18,] "stat_sum"          "Sum unique values.  Useful for overplotting on scatterplots."
[19,] "stat_summary"      "Summarise y values at every unique x."
[20,] "stat_summary2d"    "Apply funciton for 2D rectangular bins."
[21,] "stat_summary_hex" "Apply funciton for 2D hexagonal bins."
[22,] "stat_unique"       "Remove duplicates."
[23,] "stat_vline"        "Add a vertical line"
[24,] "stat_ydensity"     "1d kernel density estimate along y axis, for violin plot."
```

Statistical Transformation

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=area))
```

country	pop2012	tfr	le	area
Algeria	37.4	2.9	73	Africa
Egypt	82.3	2.9	72	Africa
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
Canada	34.9	1.7	81	Americas
United States	313.9	1.9	79	Americas
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
Armenia	3.3	1.7	74	Asia/Oceania
Azerbaijan	9.3	2.3	74	Asia/Oceania
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
Denmark	5.6	1.8	79	Europe
Estonia	1.3	2.5	76	Europe
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.

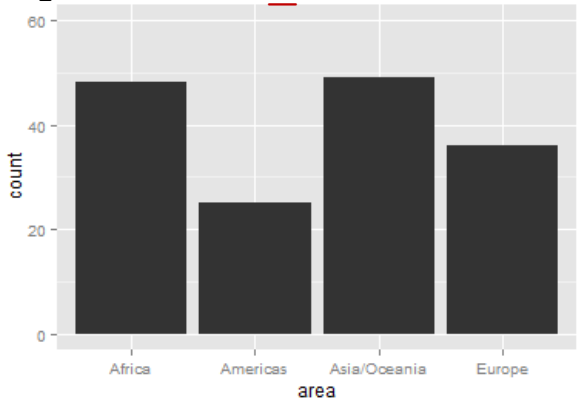
bin	area	..count..
1	Africa	48
2	Americas	25
3	Asia/Oceania	49
4	Europe	36

stat_bin()
statistical transformation

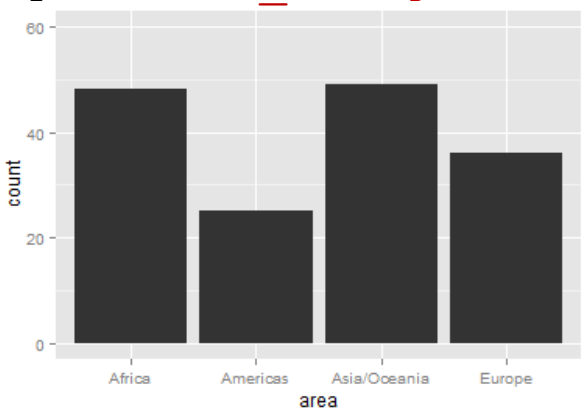
Change Default Geometric Object

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=area)) + ylim(0,60)
```

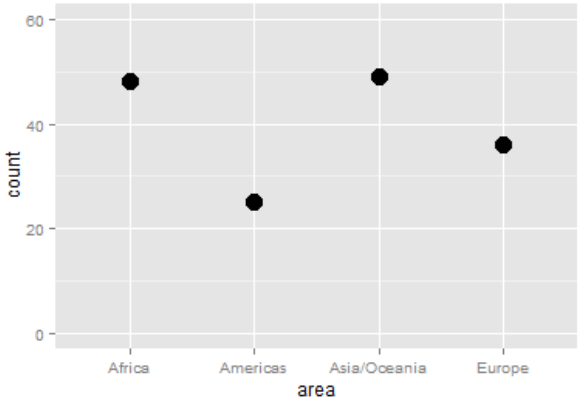
```
p + stat_bin()
```



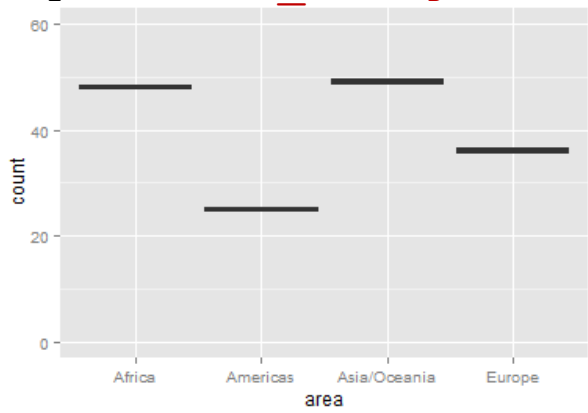

```
p + stat_bin(geom="bar")
```




```
p + stat_bin(geom="point", size=5)
```



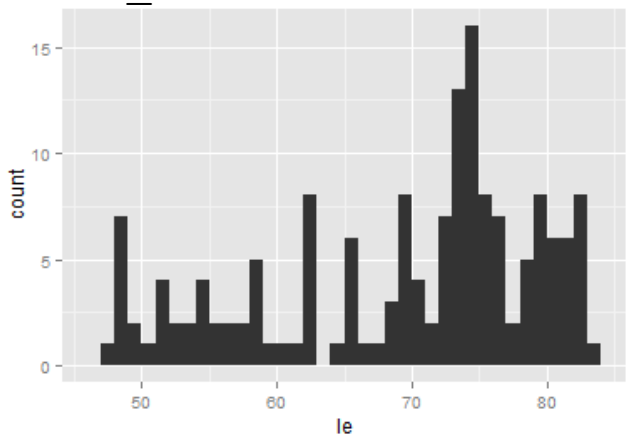

```
p + stat_bin(geom="tile")
```



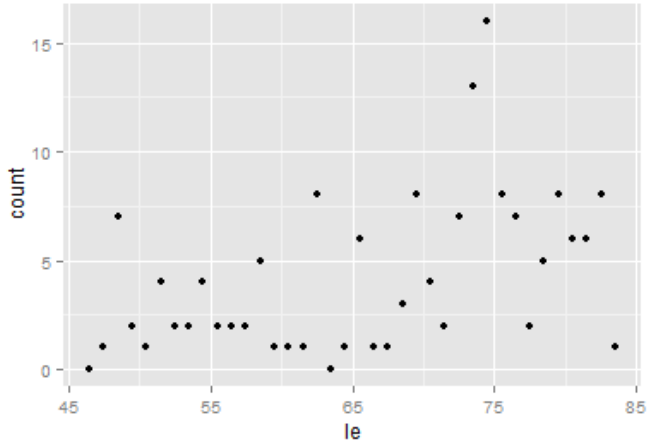
Change Default Geometric Object

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=le))
```

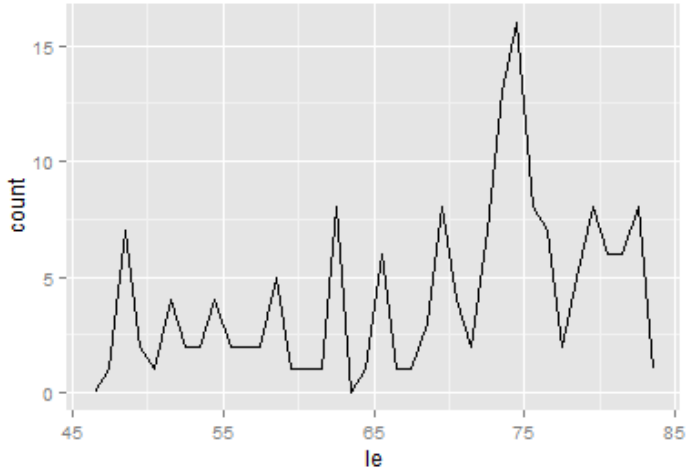
```
p + stat_bin(binwidth=1)
```



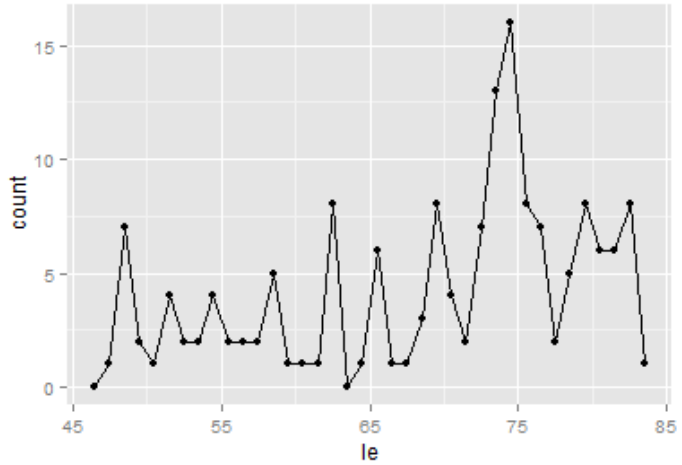

```
p + stat_bin(geom="point", binwidth=1)
```




```
p + stat_bin(geom="line", binwidth=1)
```




```
p + stat_bin(geom="line",binwidth=1)
 + stat_bin(geom="point",binwidth=1)
```

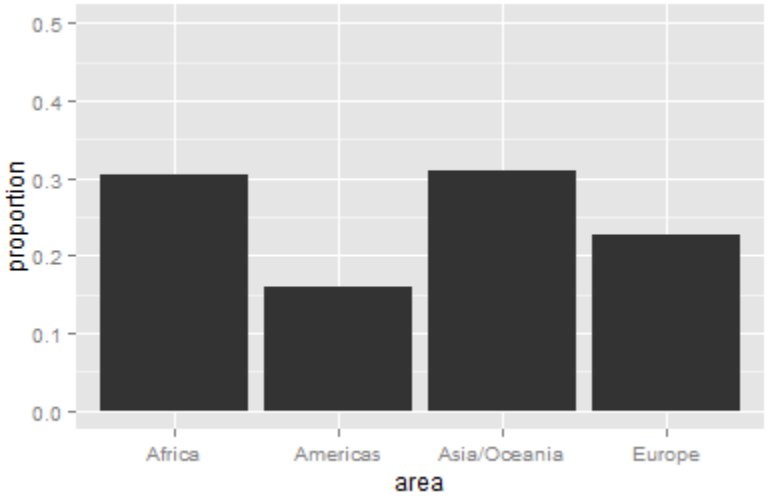


Use Variables Created by *stat_xxx()*

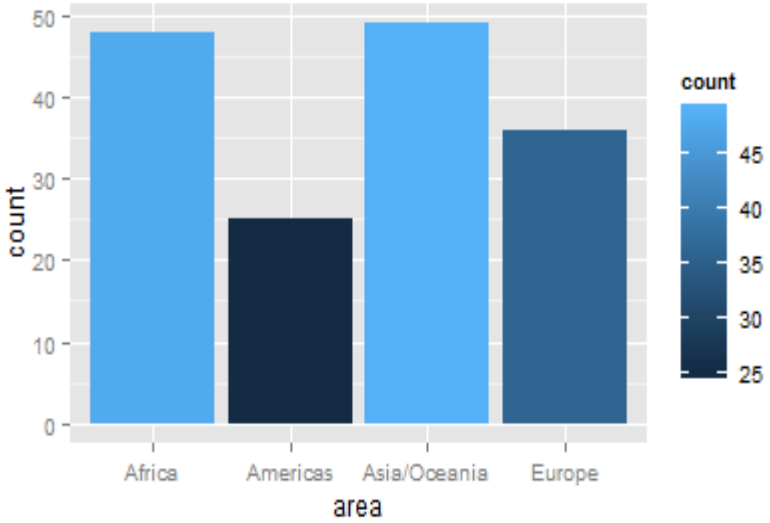
stat_xxx() may create new variables in transformed data frame
aesthetics may be mapped to these new variables

bin	area	..count..
1	Africa	48
2	Americas	25
3	Asia/Oceania	49
4	Europe	36

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=area))
p + stat_bin(aes(y = ..count../sum(..count..))) +
    ylab("proportion") + ylim(0,.5)
```




```
p + stat_bin(aes(fill=..count..))
```

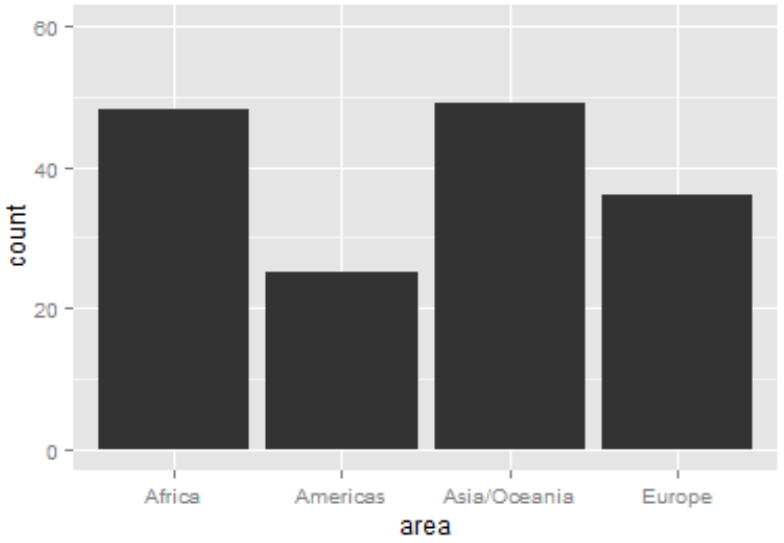


Already Transformed Data

```
wb <- read.csv(file="WDS2012areabins.csv", head=TRUE, sep=",")
wb
```

	bin	area	count
1	1	Africa	48
2	2	Americas	25
3	3	Asia/Oceania	49
4	4	Europe	36

```
p <- ggplot(data=wb, aes(x=area, y=count)) + ylim(0,60)
p + geom_bar(stat="identity")
```



Aesthetics

describe visual characteristics that represent data

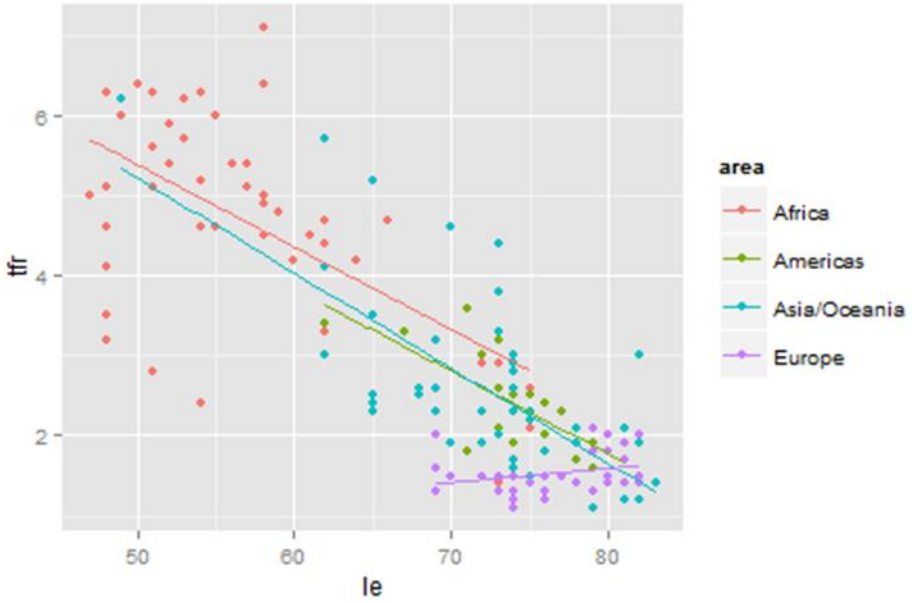
- for example, x position, y position, size, color (outside), fill (inside), point shape, line type, transparency

each layer inherits default aesthetics from plot object

- within each layer, aesthetics may added, overwritten, or removed

most layers have some required aesthetics and some optional aesthetics

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=le, y=tfr, color=area))
p + geom_point() + geom_smooth(method="lm", se=FALSE)
```

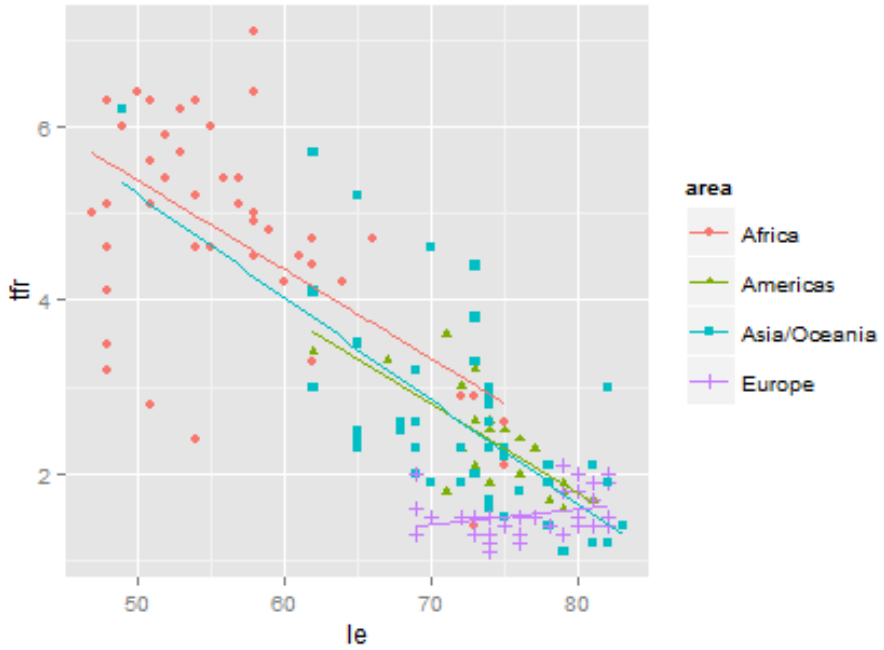


Add or Remove Aesthetic Mapping

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=le, y=tfr, color=area))
```

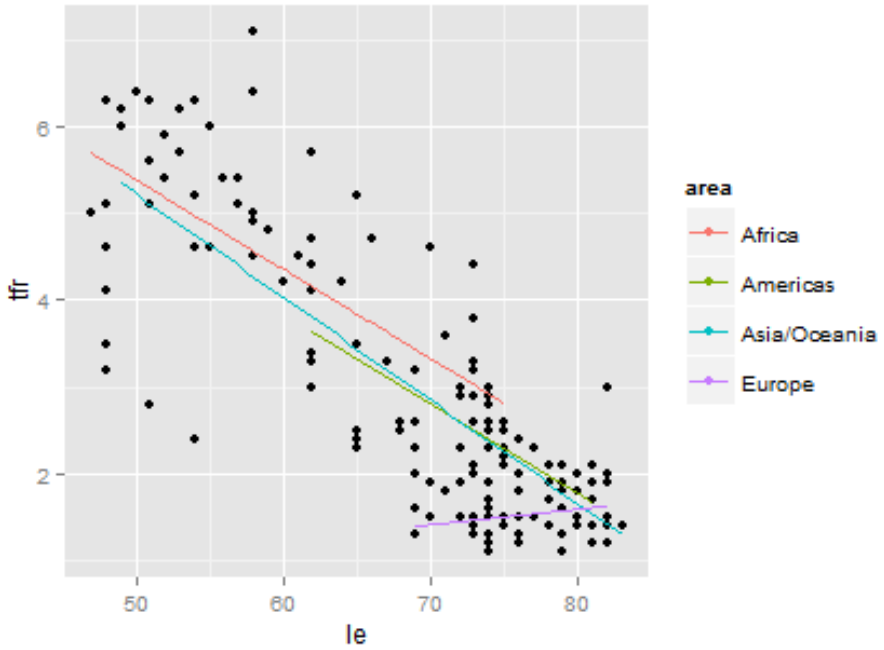
add aesthetic mapping

```
p + geom_point(aes(shape=area)) +
geom_smooth(method="lm",se=FALSE)
```



remove aesthetic mapping

```
p + geom_point(aes(color=NULL)) +
geom_smooth(method="lm", se=FALSE)
```



Aesthetic Mapping vs. Parameter Setting

aesthetic mapping
- data value determines visual characteristic
- use *aes()*

setting
- constant value determines visual characteristic
- use layer parameter

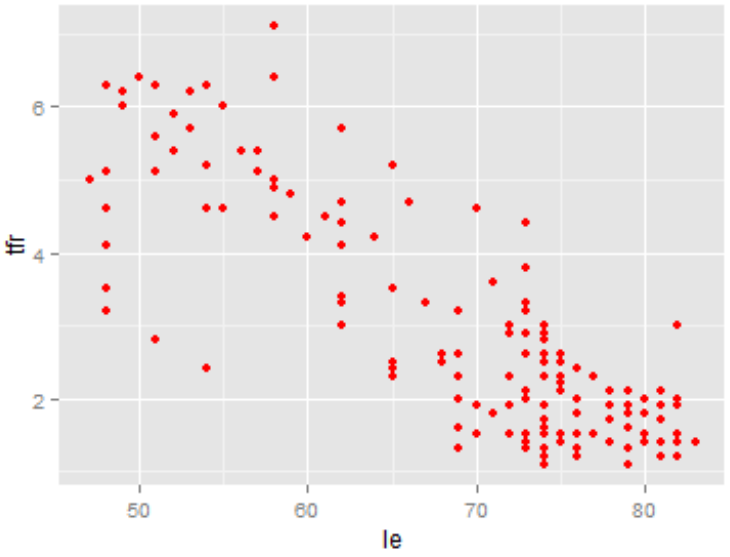
```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=le, y=tfr))
```

aesthetic mapping

```
p + geom_point(aes(color=area))
```

setting

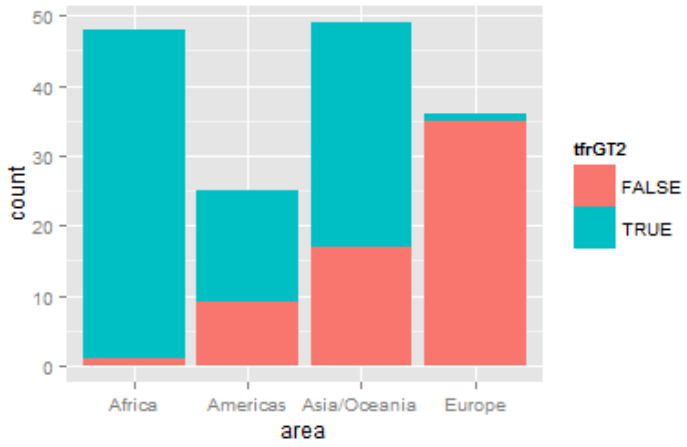
```
p + geom_point(color="red")
```



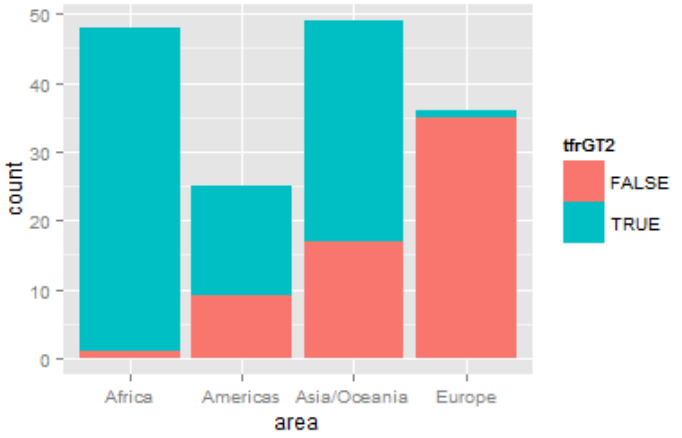
Position

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
w$tfrGT2 <- w$tfr > 2
p <- ggplot(data=w, aes(x=area, fill=tfrGT2))
```

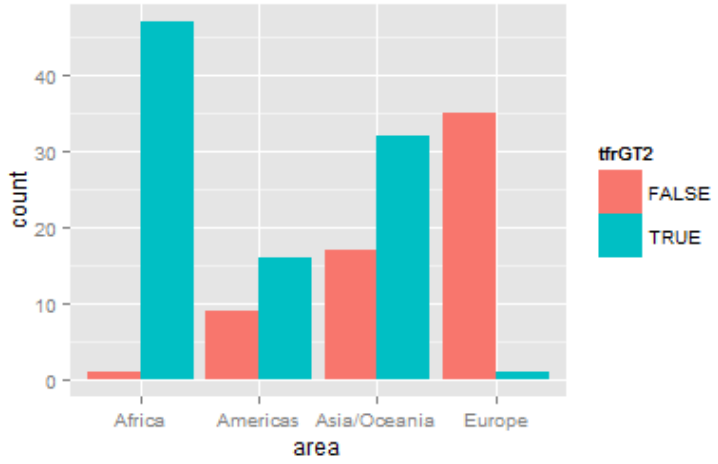
```
p + geom_bar()
```



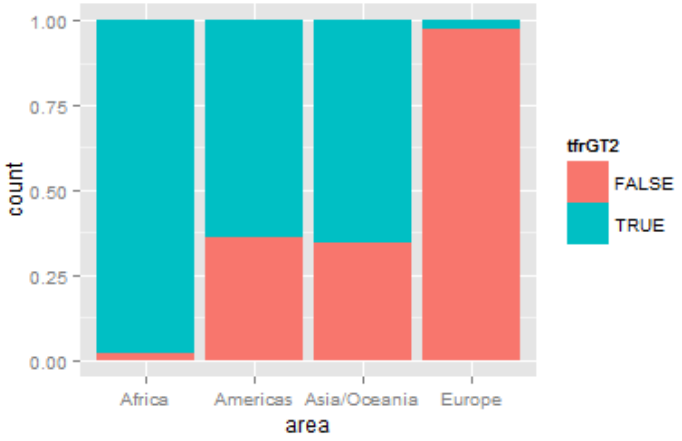

```
p + geom_bar(position="stack")
```




```
p + geom_bar(position="dodge")
```



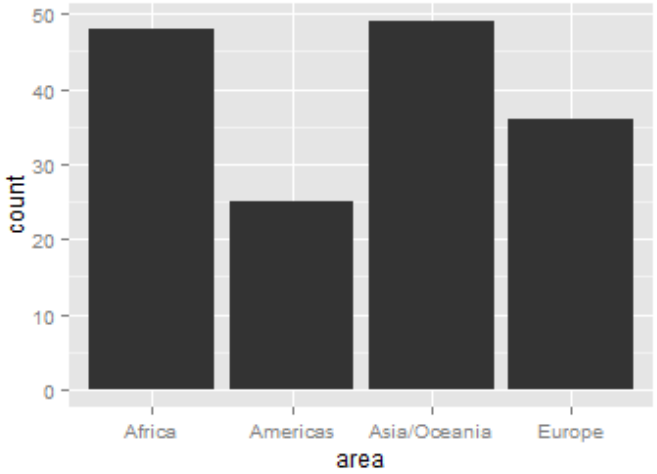

```
p + geom_bar(position="fill")
```



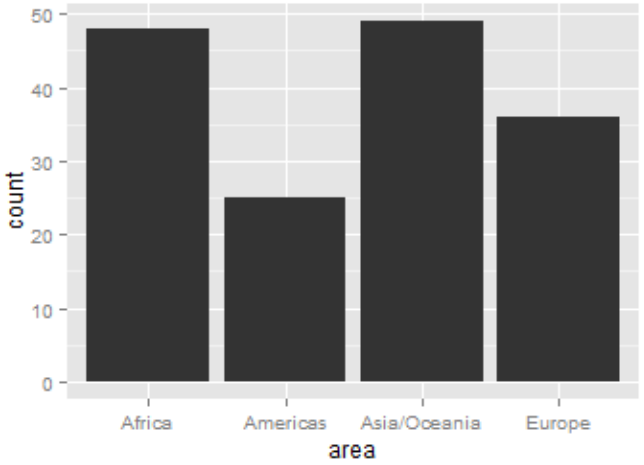
Bar Width

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=area))
```

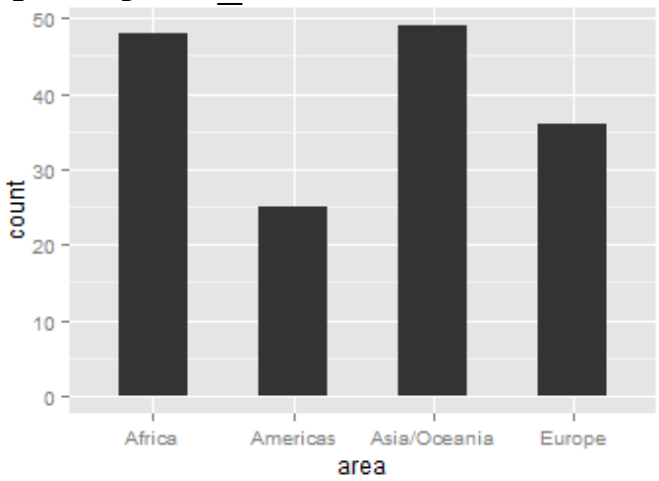
```
p + geom_bar()
```



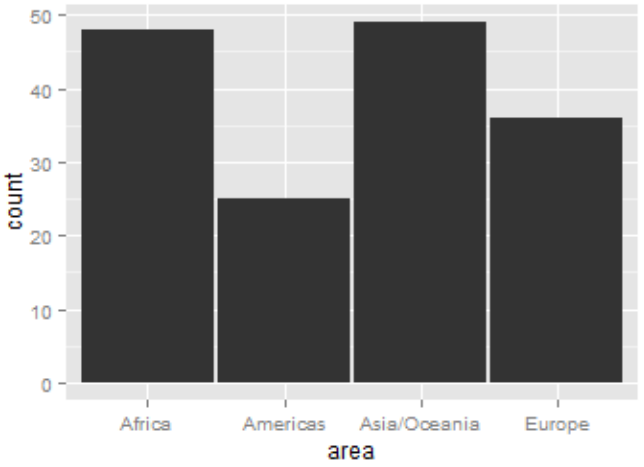

```
p + geom_bar(width=.9) # default
```




```
p + geom_bar(width=.5)
```

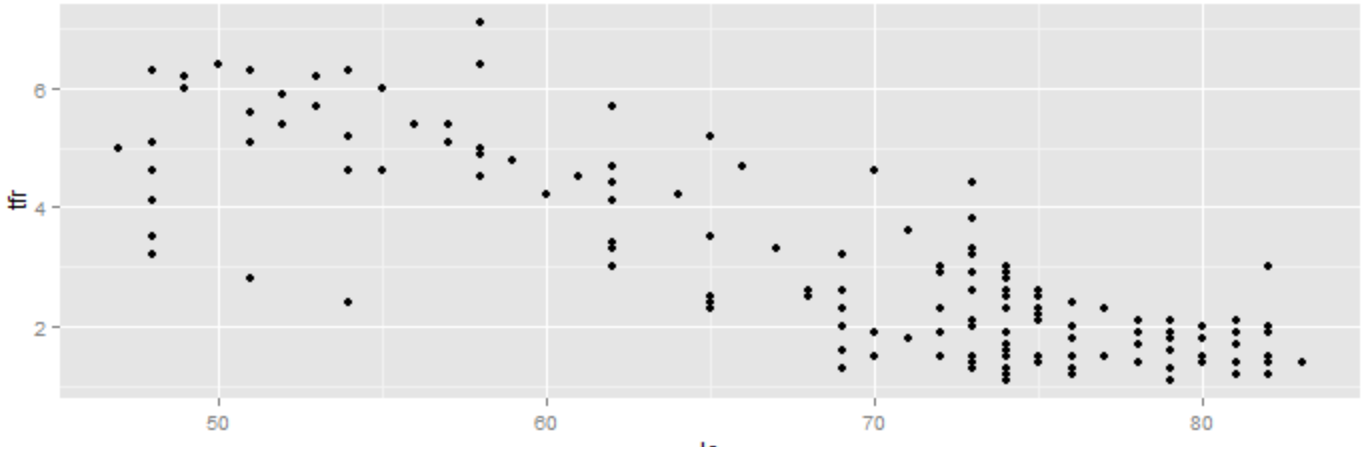



```
p + geom_bar(width=.97)
```

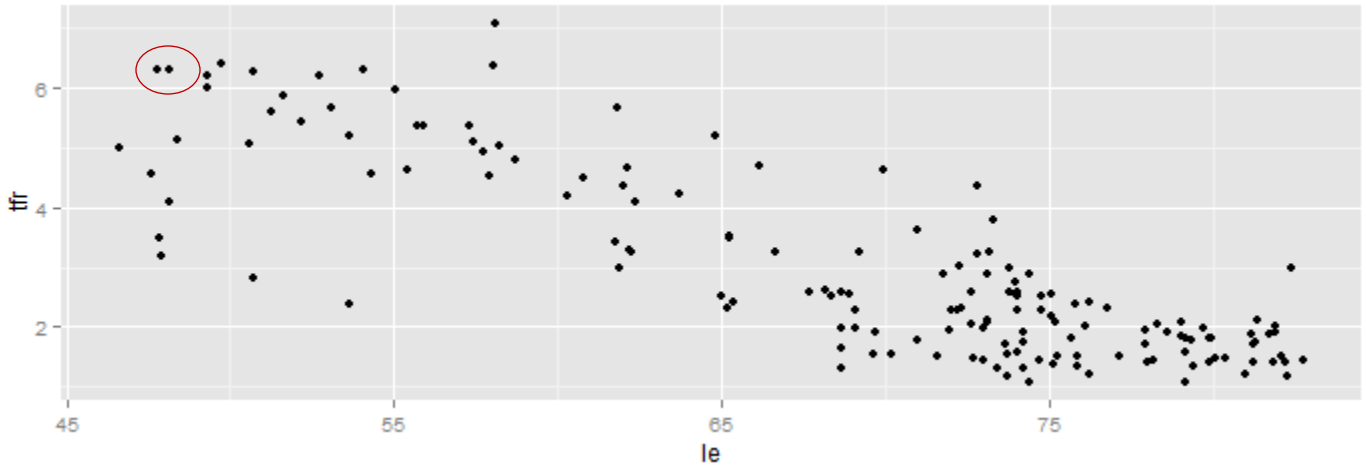


Position

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=le, y=tfr))
```




```
p + geom_point()
```



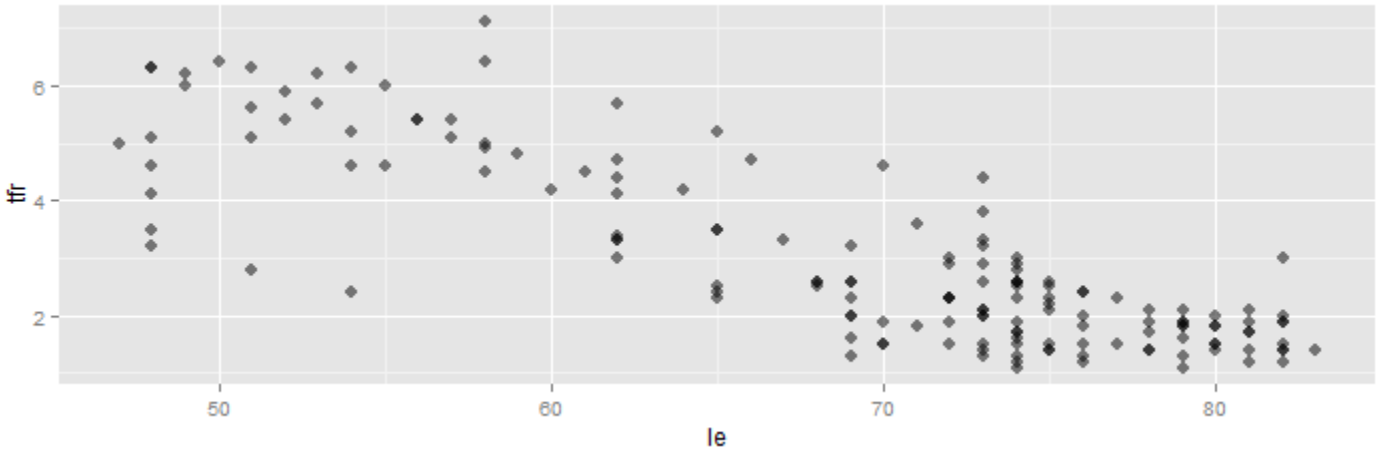

```
p + geom_point
(position="jitter")
```

equivalent to

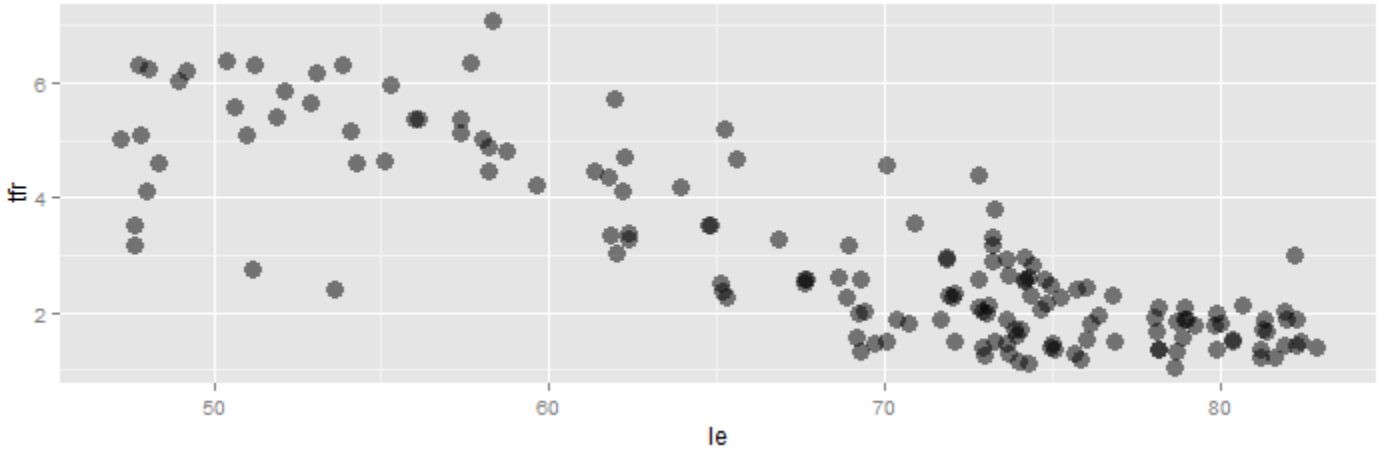
```
p + geom_jitter()
```

Transparency

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=le, y=tfr))
```




```
p + geom_point
(size=3,
alpha=1/2)
```



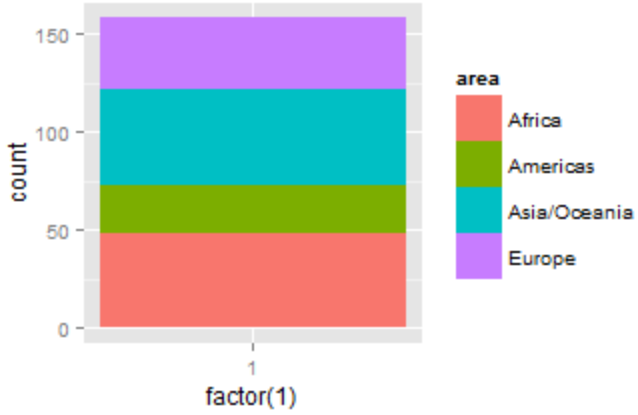

```
p + geom_jitter
(size=4,
alpha=1/2)
```

techniques for overplotting: adjusting symbol size, shape, jitter, and transparency

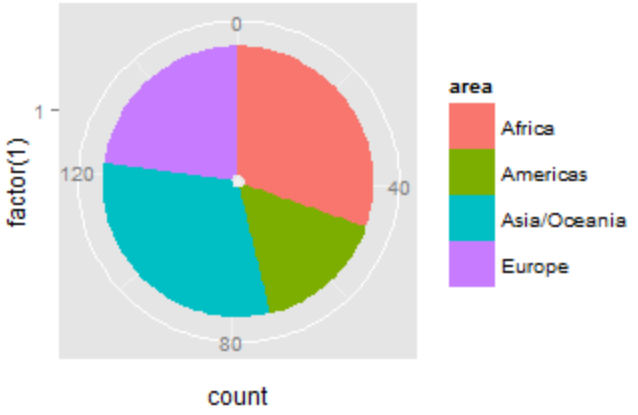
Coordinate System

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(w, aes(x=factor(1), fill=area))
```

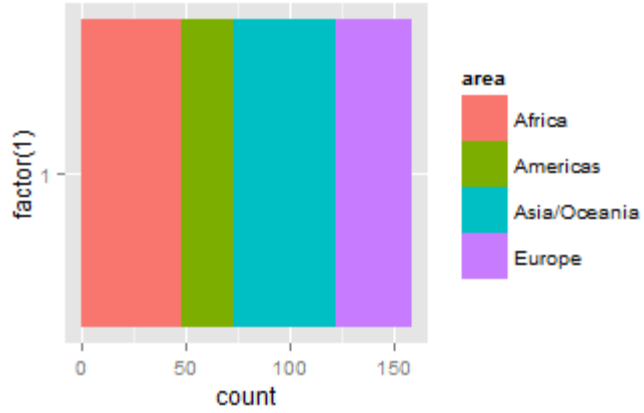
```
p + geom_bar()
```



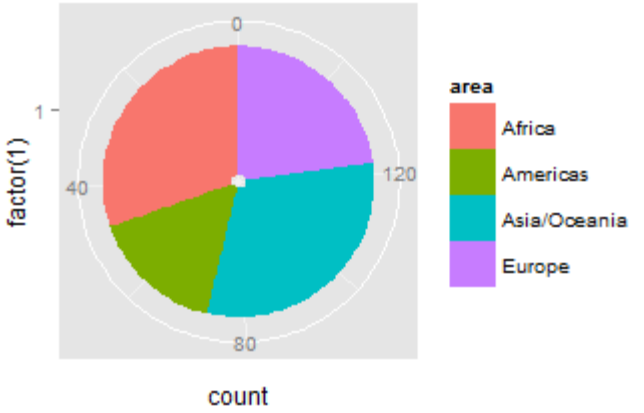

```
p + geom_bar() + coord_polar(theta="y")
```




```
p + geom_bar() + coord_flip()
```



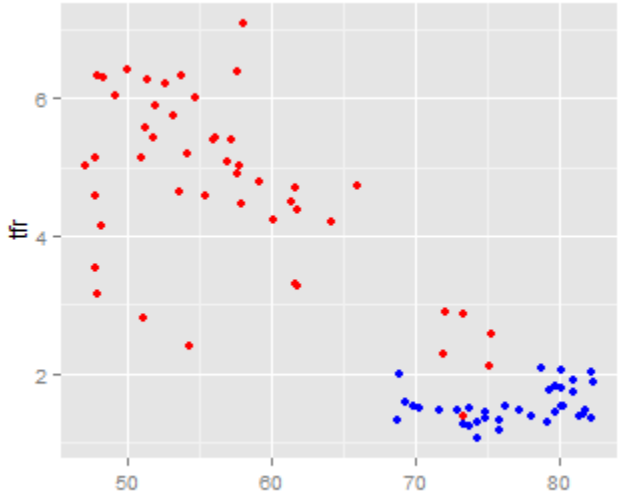

```
p + geom_bar() + coord_polar(theta="y",
                             direction=-1)
```



Data Frame

each plot layer may contain data from a different data frame

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
africa <- subset(w,area=="Africa")
europe <- subset(w,area=="Europe")

p <- ggplot(data=europe, aes(x=le, y=tfr))
p + geom_jitter(color="blue") +
    geom_jitter(data=africa, color="red")
```



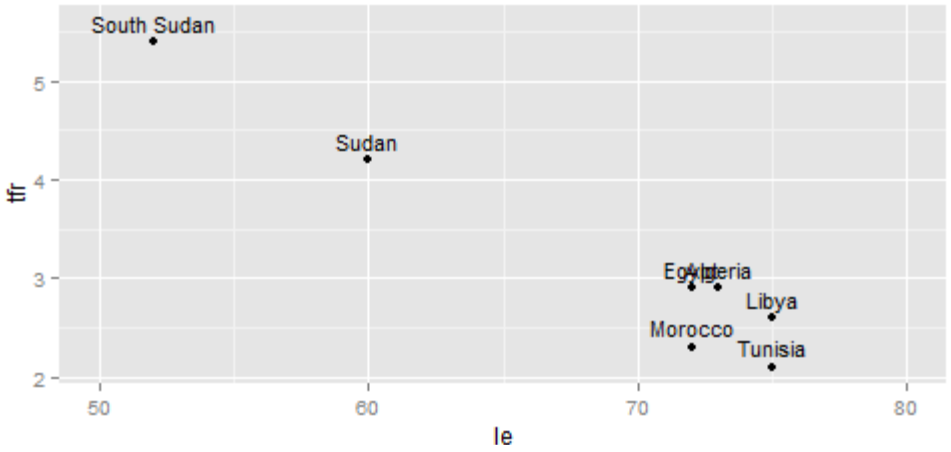

```
africa_europe <- rbind(africa, europe)
p <- ggplot(data=africa_europe, aes(x=le, y=tfr,
            color=area))
p + geom_jitter()
```

OR

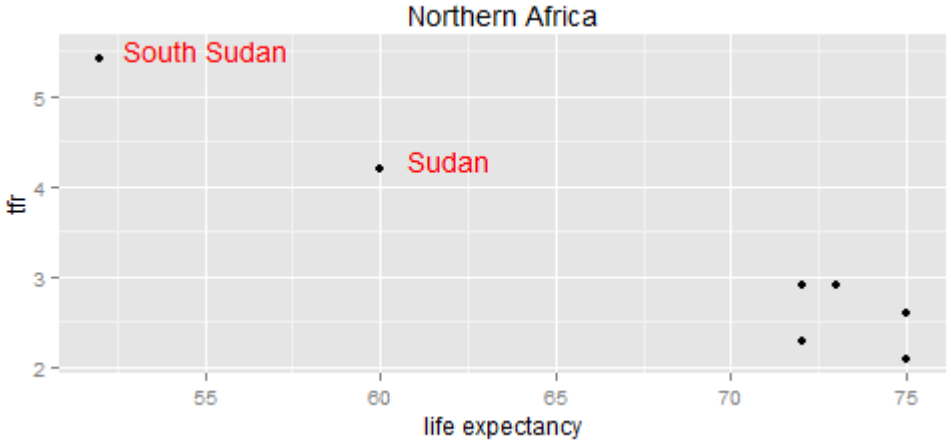
```
p <- ggplot(data=rbind(africa,europe), aes(le, y=tfr,
            color=area))
p + geom_jitter()
```

Labels

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
wna <- subset(w, region=="Northern Africa")
p <- ggplot(data=wna, aes(x=le, y=tfr))
```



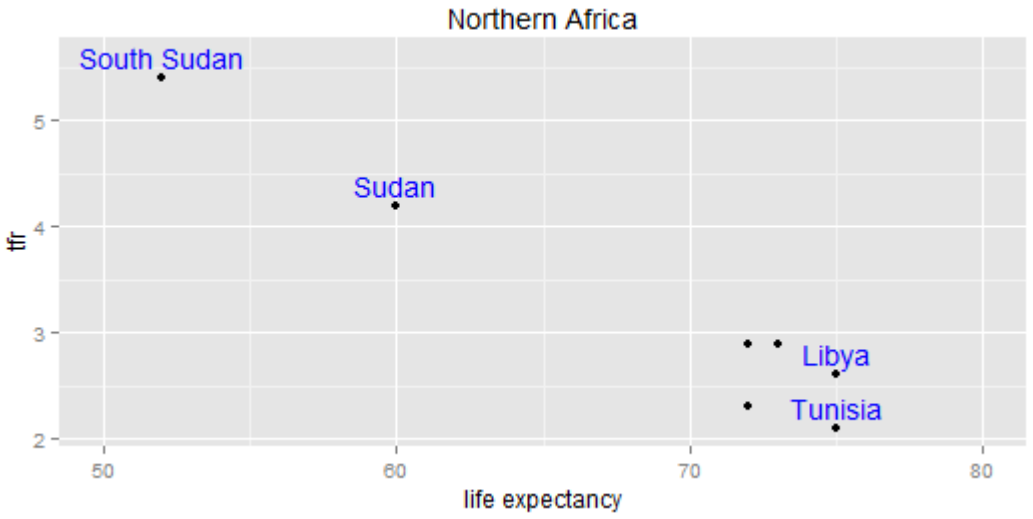

```
p + geom_point() +
    geom_text(aes(y=tfr + .2,
    label=country), size=4) +
    xlim(50,80)
```




```
p + geom_point() +
annotate("text", x=55, y=5.5,
label="South Sudan", color="red") +
annotate("text", x=62, y=4.3,
label="Sudan", color="red") +
ggtitle("Northern Africa") +
xlab("life expectancy")
```

Labels

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
labelset <-c("South Sudan", "Sudan", "Libya", "Tunisia")

p <- ggplot(data=subset(w,region=="Northern Africa"), aes(x=le, y=tfr))
p +
geom_point() +
geom_text(data=subset(w, country %in% labelset),
          aes(y=tfr + .2, label=country), color="blue") +
ggtitle("Northern Africa") + xlab("life expectancy") + xlim(50,80)
```



Scale

controls the mapping from data to aesthetic

"takes data and turns it into something that can be perceived visually"

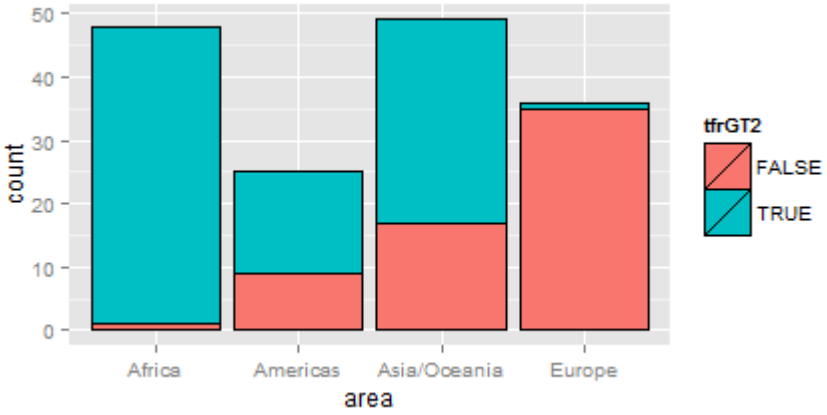
color and fill, shape, size, position

acts as a function from the data space to a place in the aesthetic space

provides axes or legends ("guides") to allow viewer to perform inverse mapping from aesthetic space back to data space

required for every aesthetic ... so ggplot2 always provides a default scale

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
w$tfrGT2 <- w$tfr > 2
p <- ggplot(data=w, aes(x=area, fill=tfrGT2))
```




```
p + geom_bar(color="black")
```

equivalent to

```
p + geom_bar(color="black") +
    scale_fill_discrete()
```

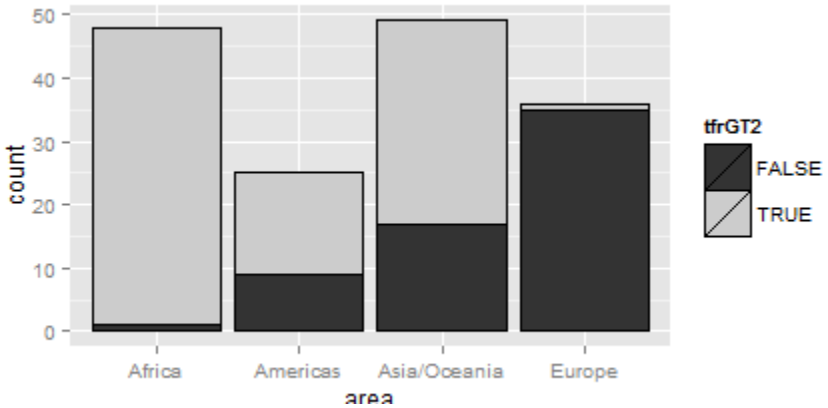
equivalent to

```
p + geom_bar(color="black") +
    scale_fill_hue()
```

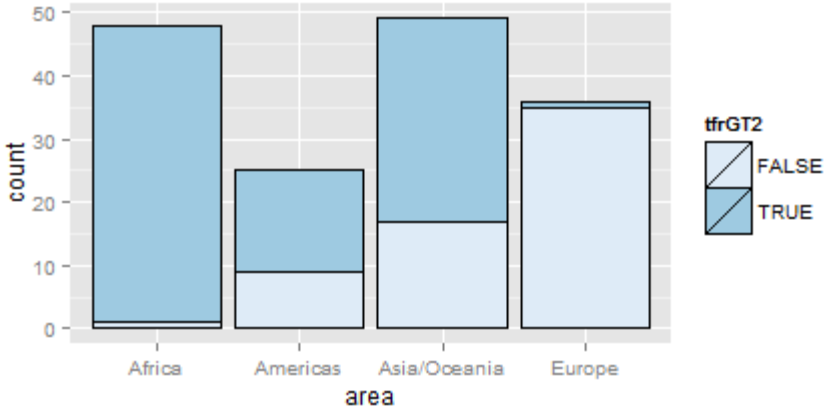
colors equally spaced around color wheel

Fill Scales

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
w$tfrGT2 <- w$tfr > 2
p <- ggplot(data=w, aes(x=area, fill=tfrGT2))
```




```
p + geom_bar(color="black") +
    scale_fill_grey()
```

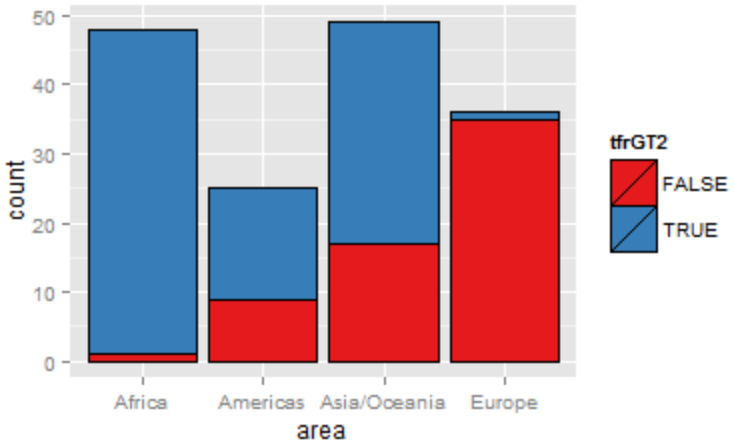


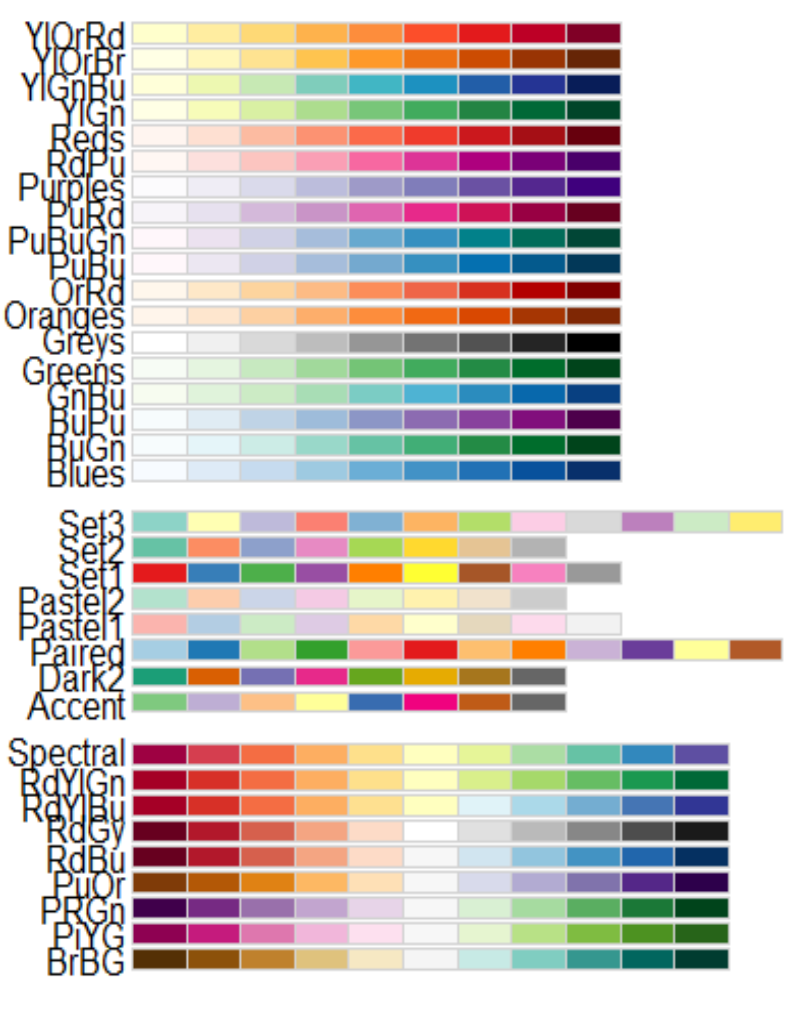

```
p + geom_bar(color="black") +
    scale_fill_brewer()
```

Fill Scales

```
library(RColorBrewer)
display.brewer.all()
```

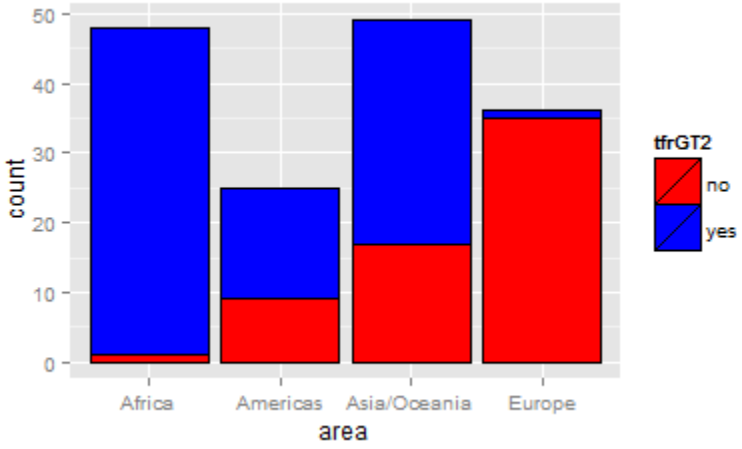
```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")
w$tfrGT2 <- w$tfr > 2

p <- ggplot(data=w,
     aes(x=area, fill=tfrGT2))

p + geom_bar(color="black") +
scale_fill_brewer(palette="Set1")
```





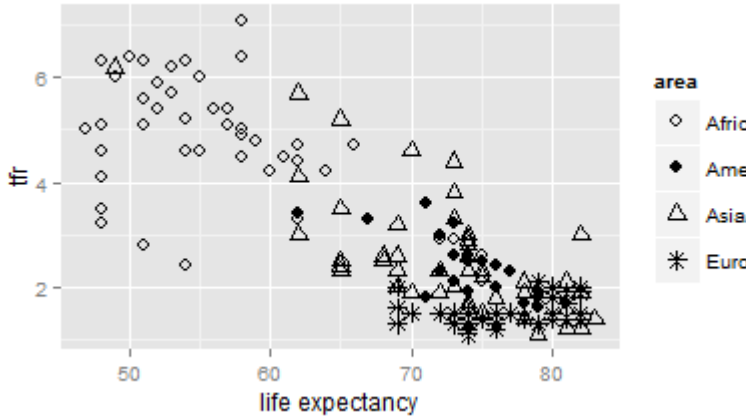
Manual Scales

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
w$tfrGT2 <- w$tfr > 2
p <- ggplot(data=w, aes(x=area, fill=tfrGT2))
```




```
p + geom_bar(color="black") +
scale_fill_manual(values=c("red","blue"),
                  labels=c("no", "yes"))
```

typical scale arguments: values
labels
breaks
limits
name

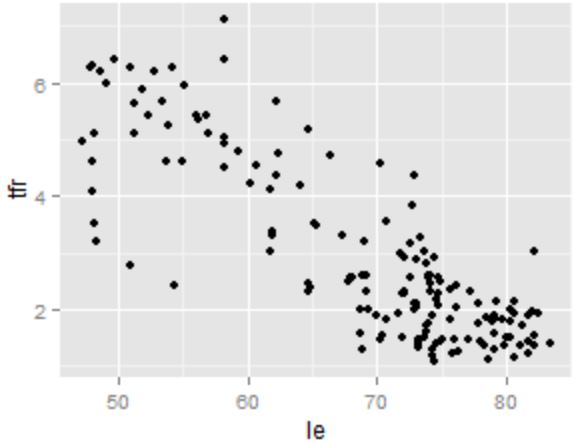



```
p + geom_point(aes(x=le, y=tfr,
    shape=area, fill=NULL), size = 3) +
    xlab("life expectancy") +
    scale_shape_manual(values=c(1,16,2,8))
```

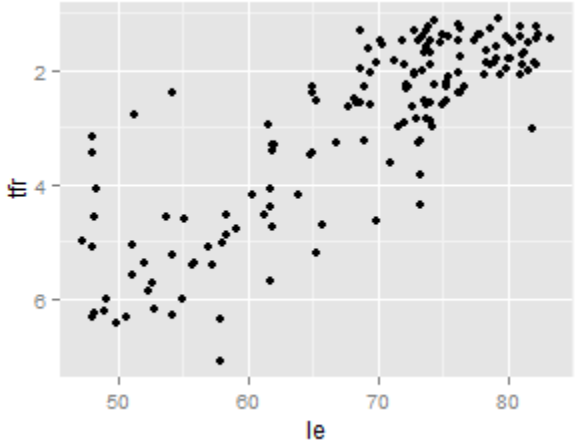
Position Scales

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
```

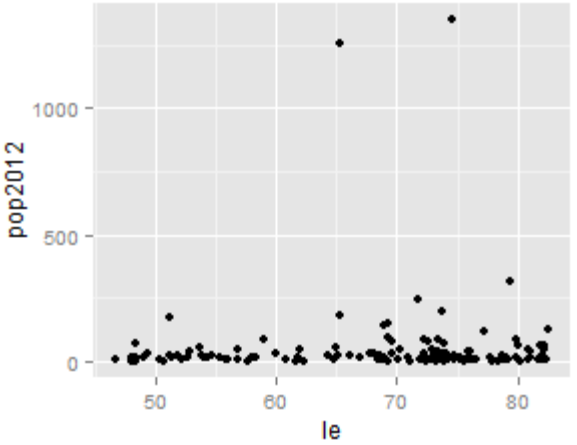
```
p <- ggplot(data=w, aes(x=le, y=tfr))
p + geom_jitter()
```



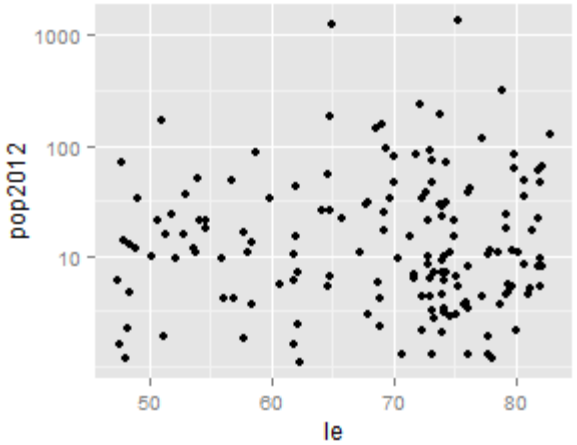

```
p + geom_jitter() +
    scale_y_reverse()
```




```
p <- ggplot(data=w,
            aes(x=le, y=pop2012))
p + geom_jitter()
```




```
p + geom_jitter() +
scale_y_log10(breaks=c(10, 100,
1000), labels=c(10,100,1000))
```

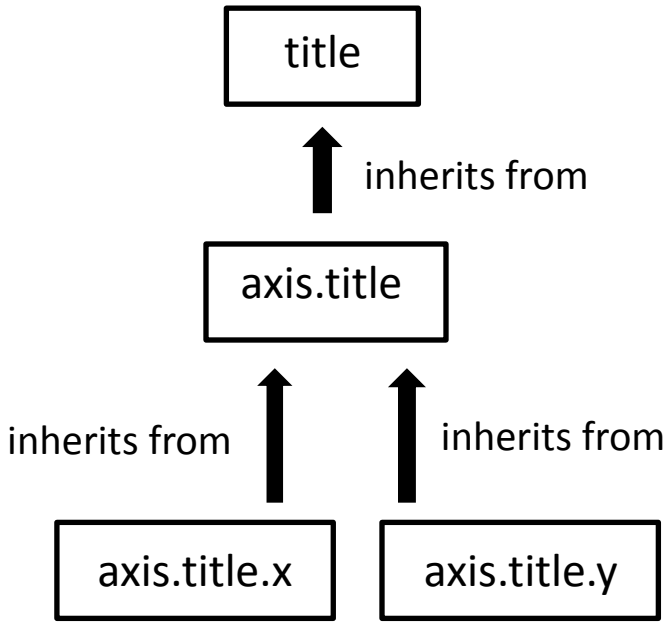


Theme

controls appearance of **non-data elements**
... does not affect how data is displayed by `geom_xxx()` or `stat_xxx()` functions

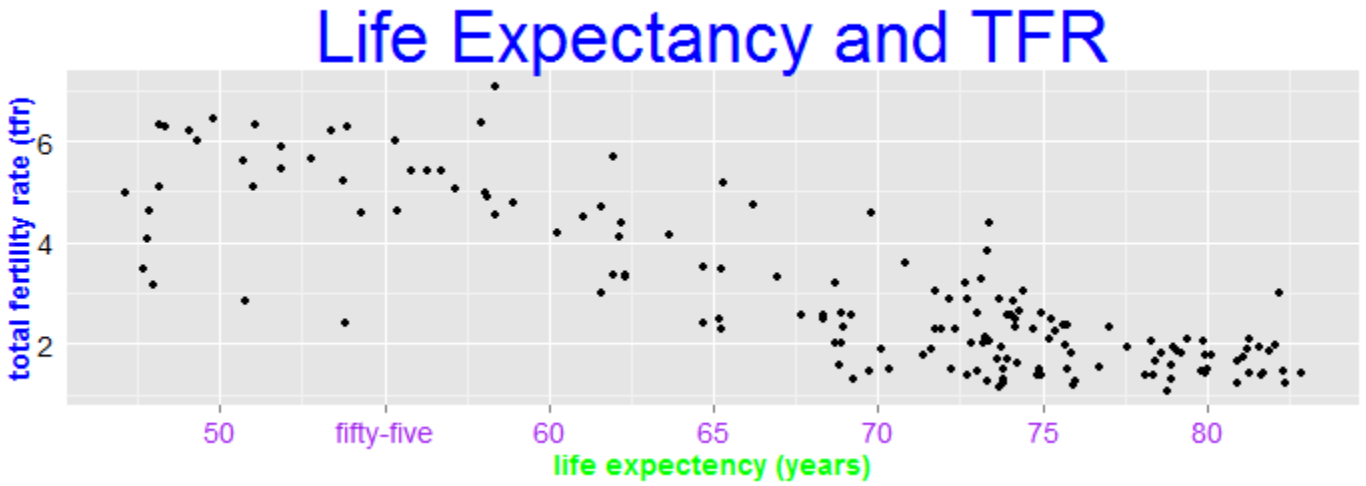
helps make plot visually pleasing by allowing addition/modification/deletion of titles, axis labels, tick marks, axis tick labels and legends

theme elements **inherit** properties from other theme elements, for example:



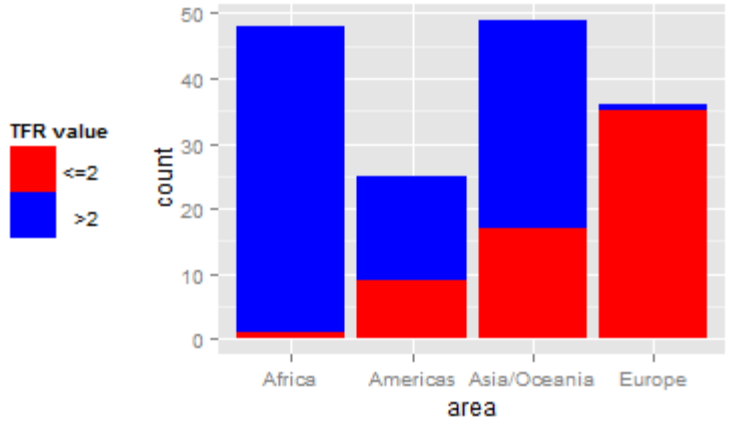
Theme: Titles, Tick Marks, and Tick Labels

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=le, y=tfr))
p + geom_jitter() + ggtitle("Life Expectancy and TFR") +
  xlab("life expectency (years)") + ylab("total fertility rate (tfr)") +
  scale_x_continuous(breaks=seq(50,80,by=5),
          labels=c(50,"fifty-five",60,65,70,75,80)) +
  theme(title=element_text(color="blue", size=30),
        axis.title=element_text(size=14,face="bold"),
        axis.title.x=element_text(color="green"),
        axis.text=element_text(size=14),
        axis.text.y=element_text(color="black"),
        axis.text.x=element_text(color="purple"),
        axis.ticks.y=element_blank())
```

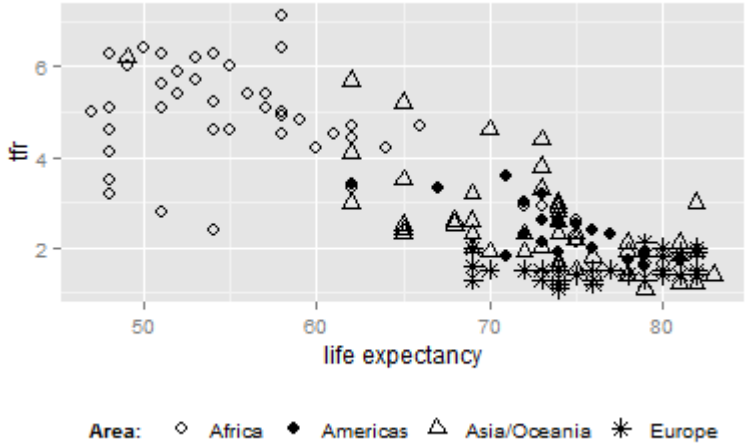


Theme: Legends

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
w$tfrGT2 <- w$tfr > 2
p <- ggplot(data=w, aes(x=area, fill=tfrGT2))
```




```
p + geom_bar() +
  scale_fill_manual(name="TFR value",
        values = c("red","blue"),
        labels=c("<=2", ">2")) +
  theme(legend.position="left",
        legend.text.align=1)
```

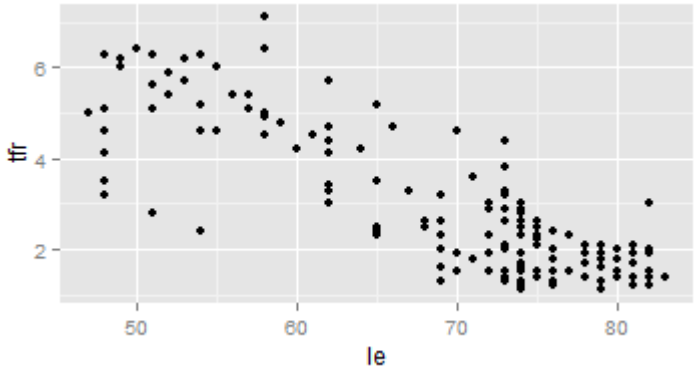



```
p + geom_point(aes(x=le, y=tfr,
    shape=area, fill=NULL), size = 3) +
  xlab("life expectancy") +
  scale_shape_manual(name="Area: ",
    values=c(1,16,2,8)) +
  theme(legend.key=element_blank(),
    legend.direction="horizontal",
    legend.position="bottom")
```

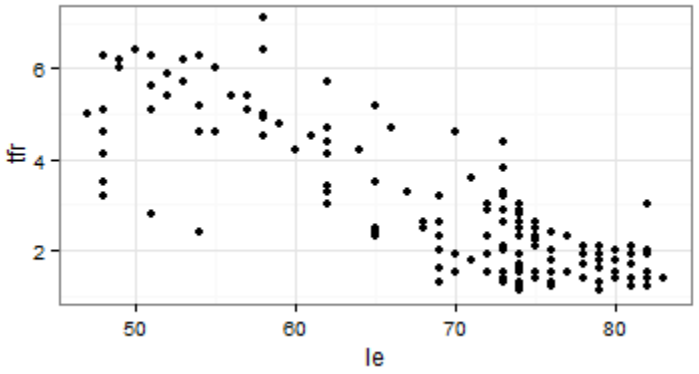
Theme: Overall Look

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=le, y=tfr))
```

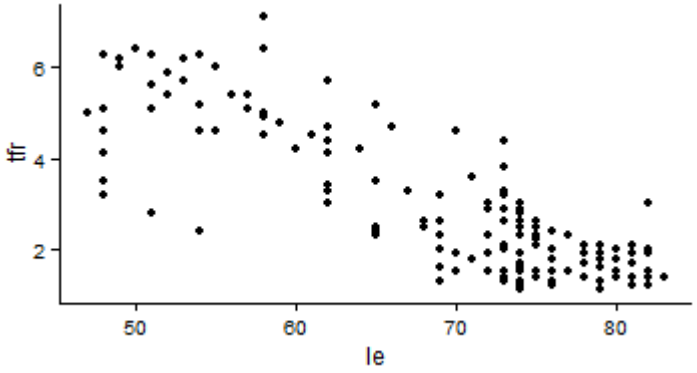
```
p + geom_point() + theme_gray()
```



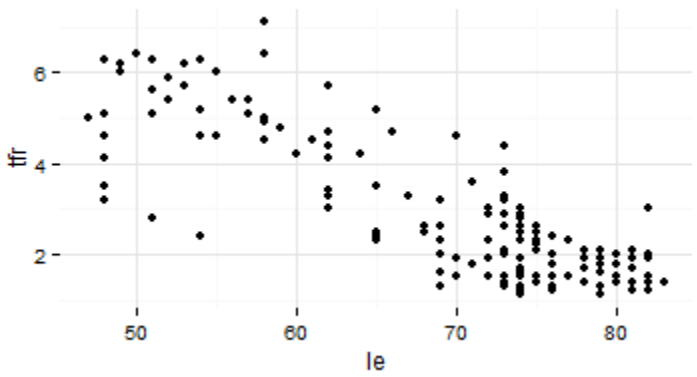

```
p + geom_point() + theme_bw()
```




```
p + geom_point() + theme_classic()
```




```
p + geom_point() + theme_minimal()
```



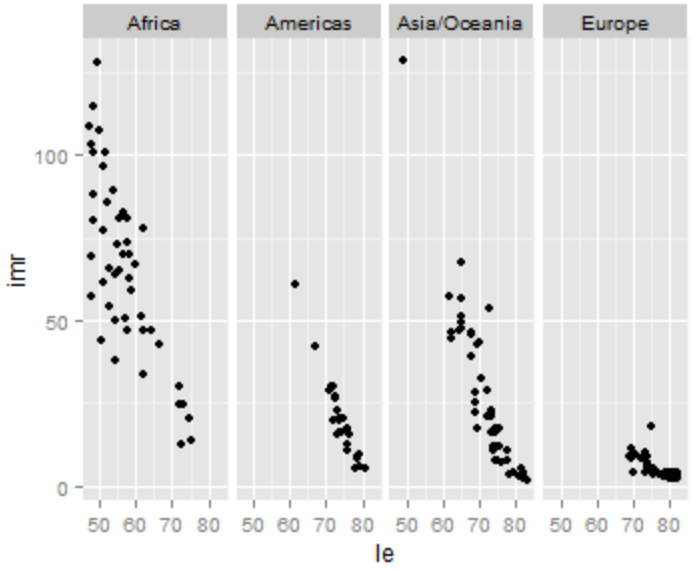
to change default theme use theme_set() ... for example, **`theme_set(theme_classic())`**

Facets

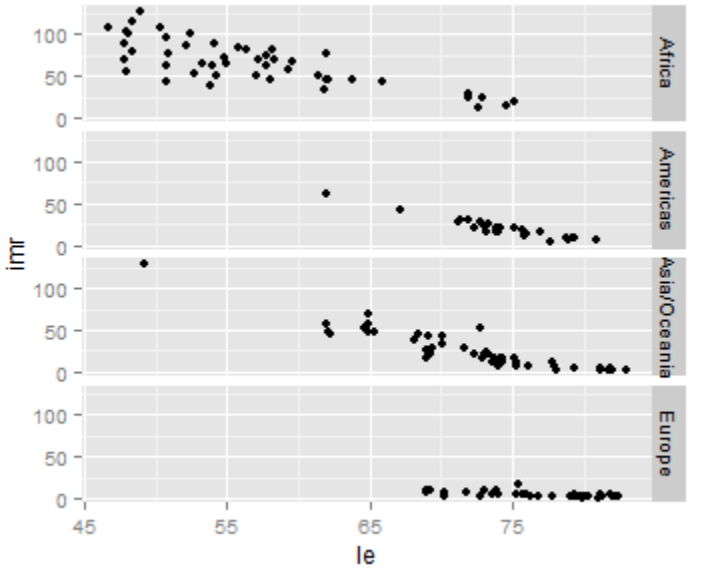
split data into subsets and plot each subset on a different panel
- show data as "small multiples"

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=w, aes(x=le, y=imr)) + geom_jitter()
```

```
p +  facet_grid(. ~ area)
```



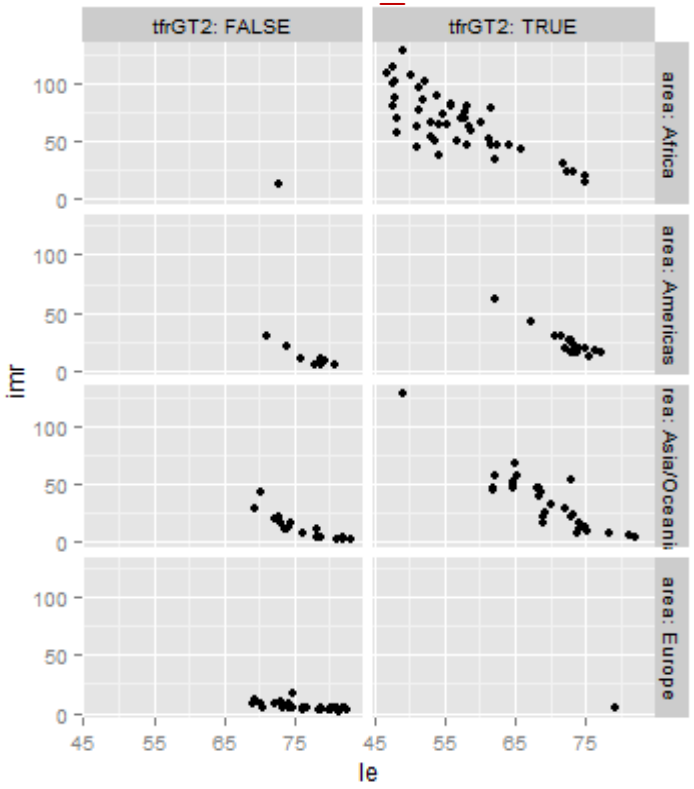

```
p + facet_grid(area ~ .)
```



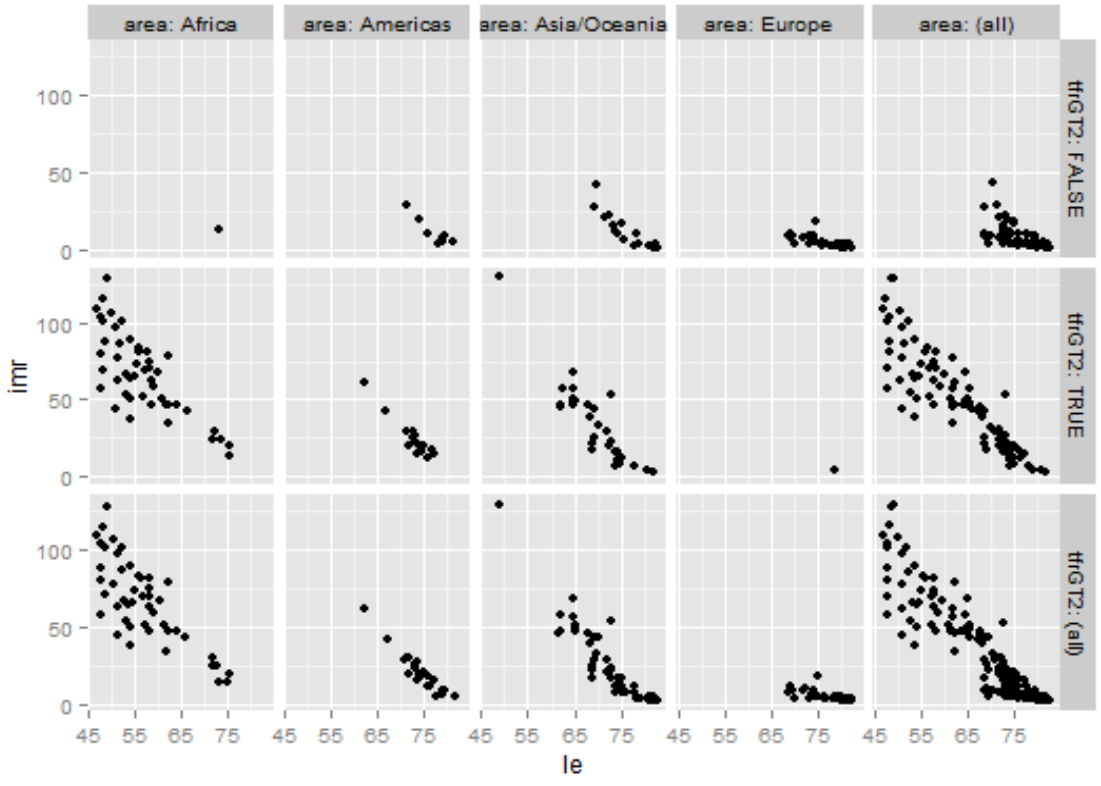
Facets

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
w$tfrGT2 <- w$tfr > 2
p <- ggplot(data=w, aes(x=le, y=imr)) + geom_jitter()
```

```
p + facet_grid(area ~ tfrGT2,
labeller="label_both")
```




```
p + facet_grid(tfrGT2 ~ area,
labeller="label_both", margins=TRUE)
```



Saving Graphs

ggsave()

- saves last plot displayed
- requires file name to be supplied
- uses file name extension to determine file type:

.ps .eps .tex .pdf .jpg .tiff .png .bmp .svg .wmf (windows only)

- uses size of current graphics device for default size

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
ggplot(data=w, aes(x=le, y=tfr, color=area)) + geom_point()

ggsave(file="le_tfr1.jpg")
ggsave(file="le_tfr2.jpg", scale=2)
ggsave(file="le_tfr3.jpg", width=5, height=5, unit="in")

ggsave(file="le_tfr4.png")
ggsave(file="le_tfr5.pdf")
```

Part 2: Examples

Contents and Purpose of ggplot2 Graphs

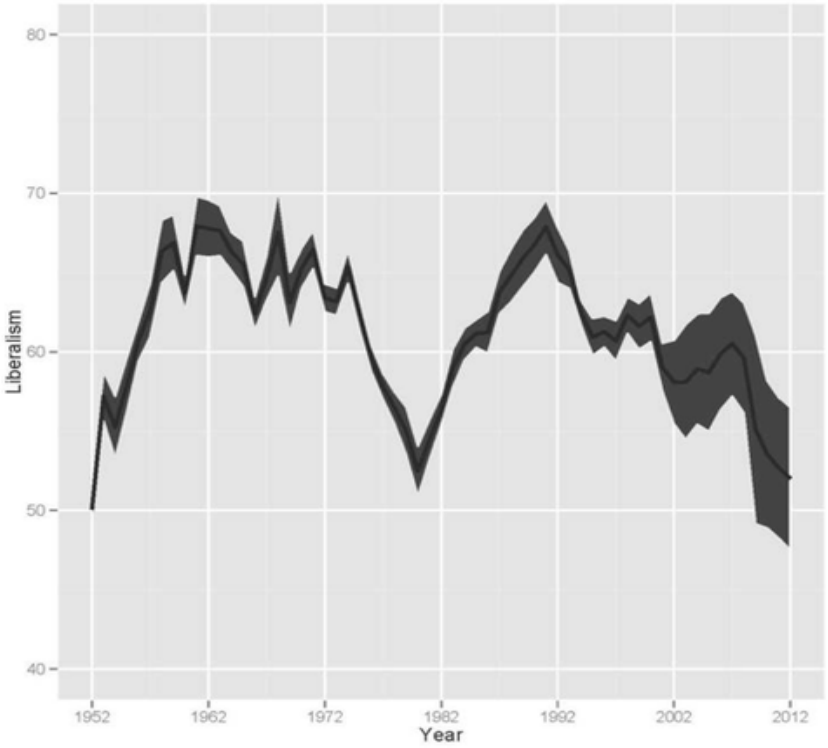
ggplot2 graph is typically created to show:

- data
- data + annotation
- statistical summary
- statistical summary + annotation
- data + statistical summary
- data + statistical summary + annotation

purpose of graph:

- **explore** data to
  increase understanding of data

- **communicate** about data ...
  often by showing data and/or
  statistical summary **plus** annotation

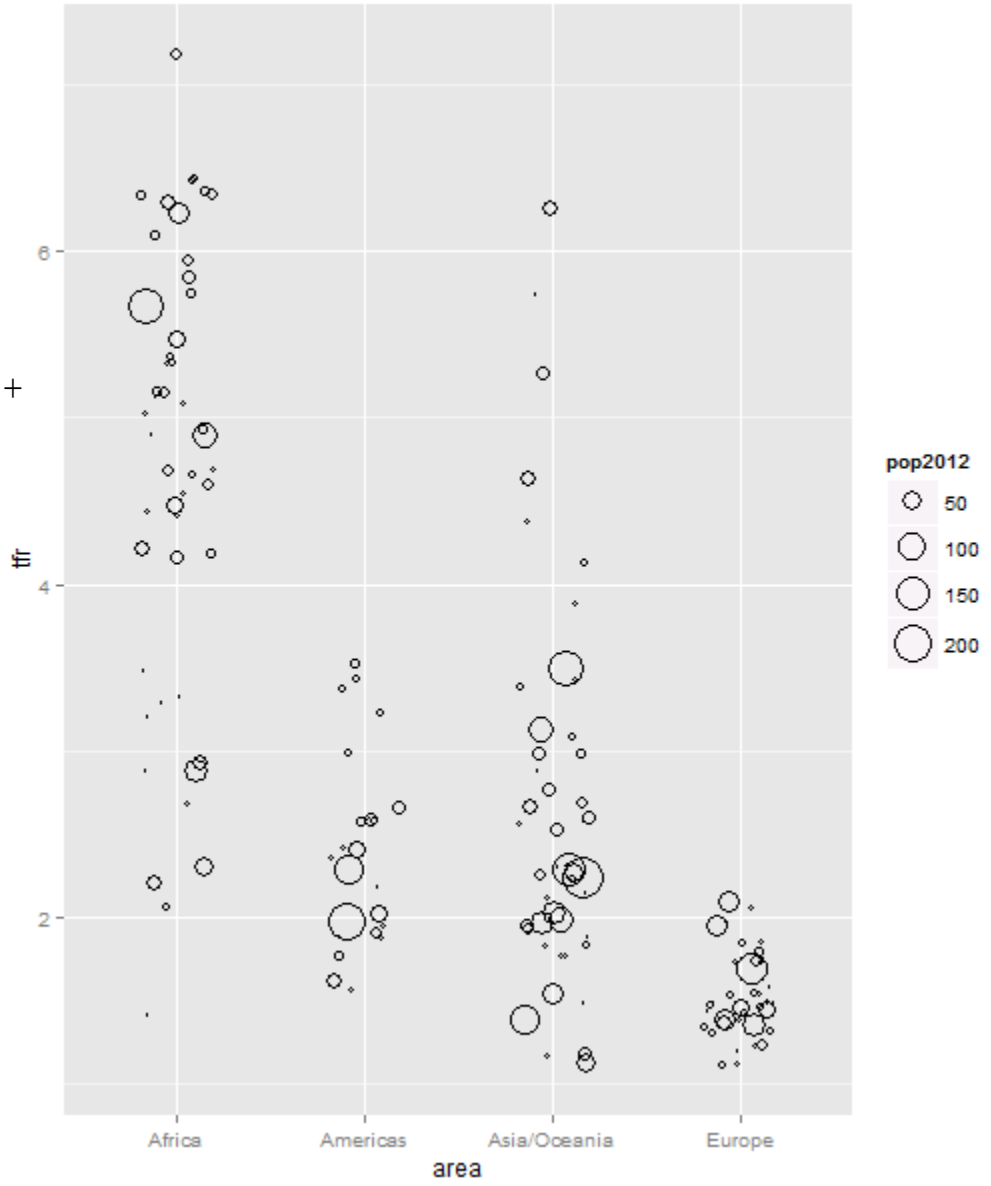


Graph associated with (online) NY Times Op-Ed piece by Thomas B. Edsall, "Does Rising Inequality Make Us Hardhearted?" December 10, 2013.

http://www.nytimes.com/imagepages/2013/12/11/opinion/11edsall-chart4.html?ref=opinion

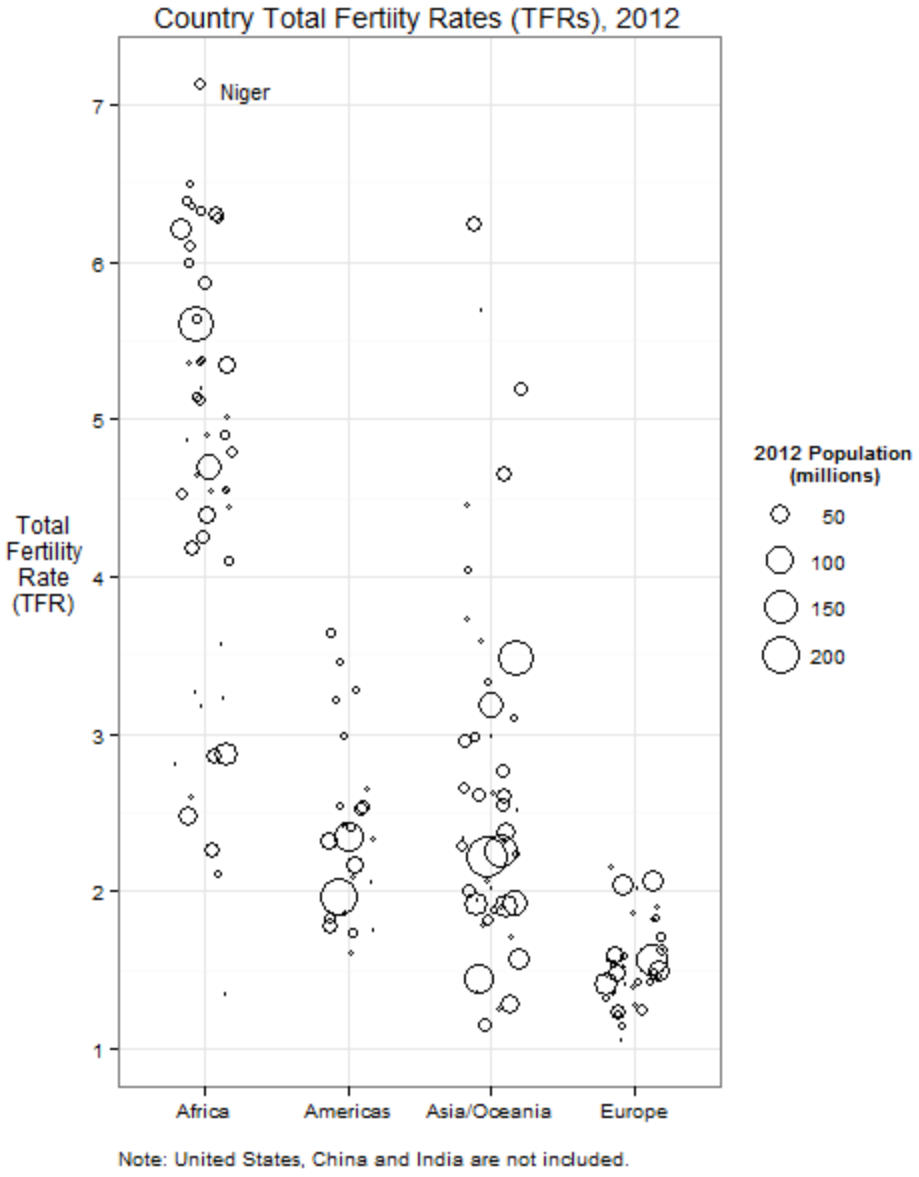
Show Data

```
w <- read.csv(file="WDS2012.csv",
head=TRUE, sep=",")
popLT300 <- subset(w,pop2012<300)

p <- ggplot(data=popLT300,
     aes(x=area, y=tfr, size=pop2012))
p + geom_jitter(position=
position_jitter(w=.2, h=.1),shape=21) +
scale_size_area(max_size=10)
```



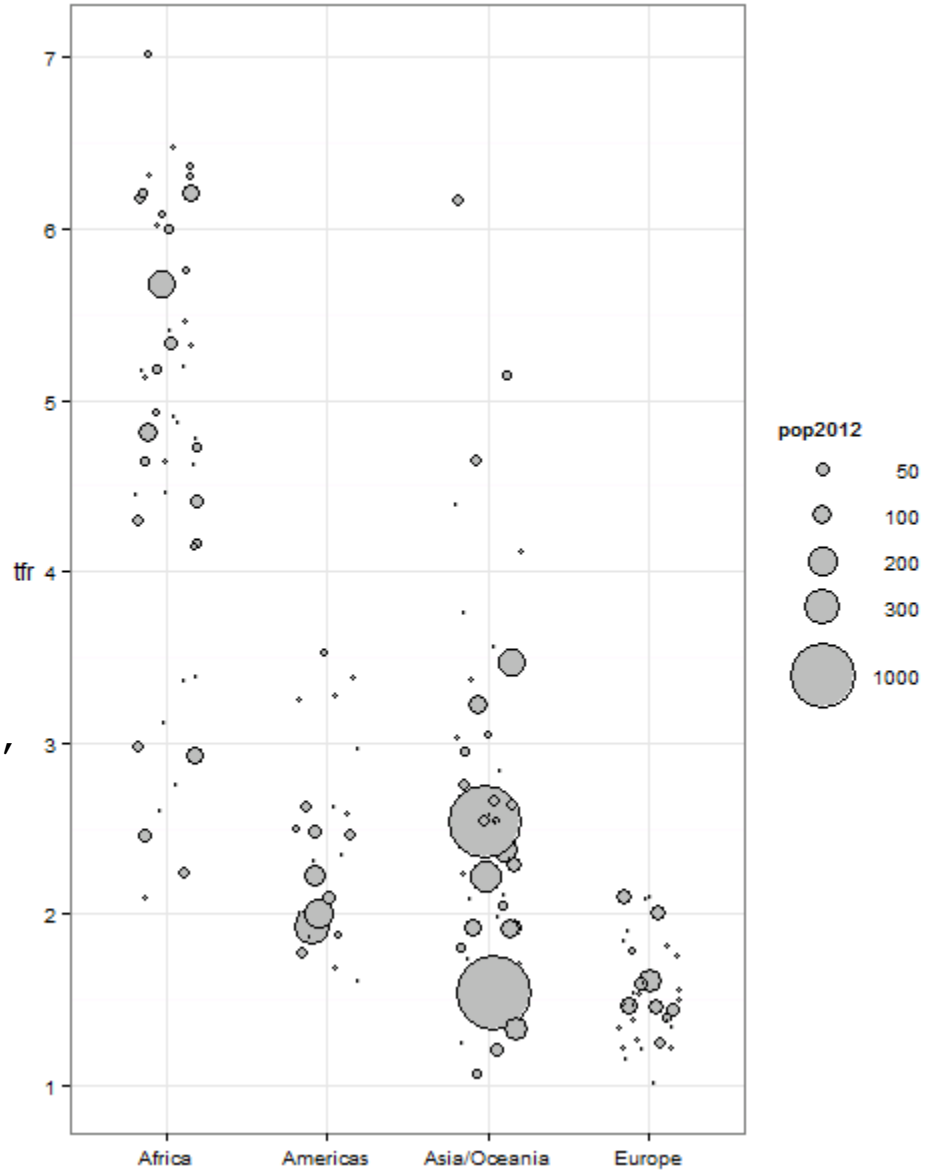
Data + Annotation

```
p <- ggplot(data=popLT300,
     aes(x=area, y=tfr, size=pop2012))
p + geom_jitter(position=
  position_jitter(w=.2, h=.1),shape=21) +
scale_y_continuous(breaks=
  c(1,2,3,4,5,6,7)) +
scale_size_area(max_size=10) +
annotate("text", x=1.3,y=7.1,
         label="Niger", size=4) +
labs(title="Country Total Fertiity Rates
     (TFRs), 2012",
     x="\nNote: United States, China and
     India are not included.",
     y="Total\nFertility\nRate\n(TFR)",
     size="2012 Population\n
      (millions)") +
theme_bw() +
theme(axis.title.x=element_text(size=10,
      hjust=0),
      axis.title.y=element_text(angle=0),
      legend.key=element_blank(),
      legend.text.align=1)
```



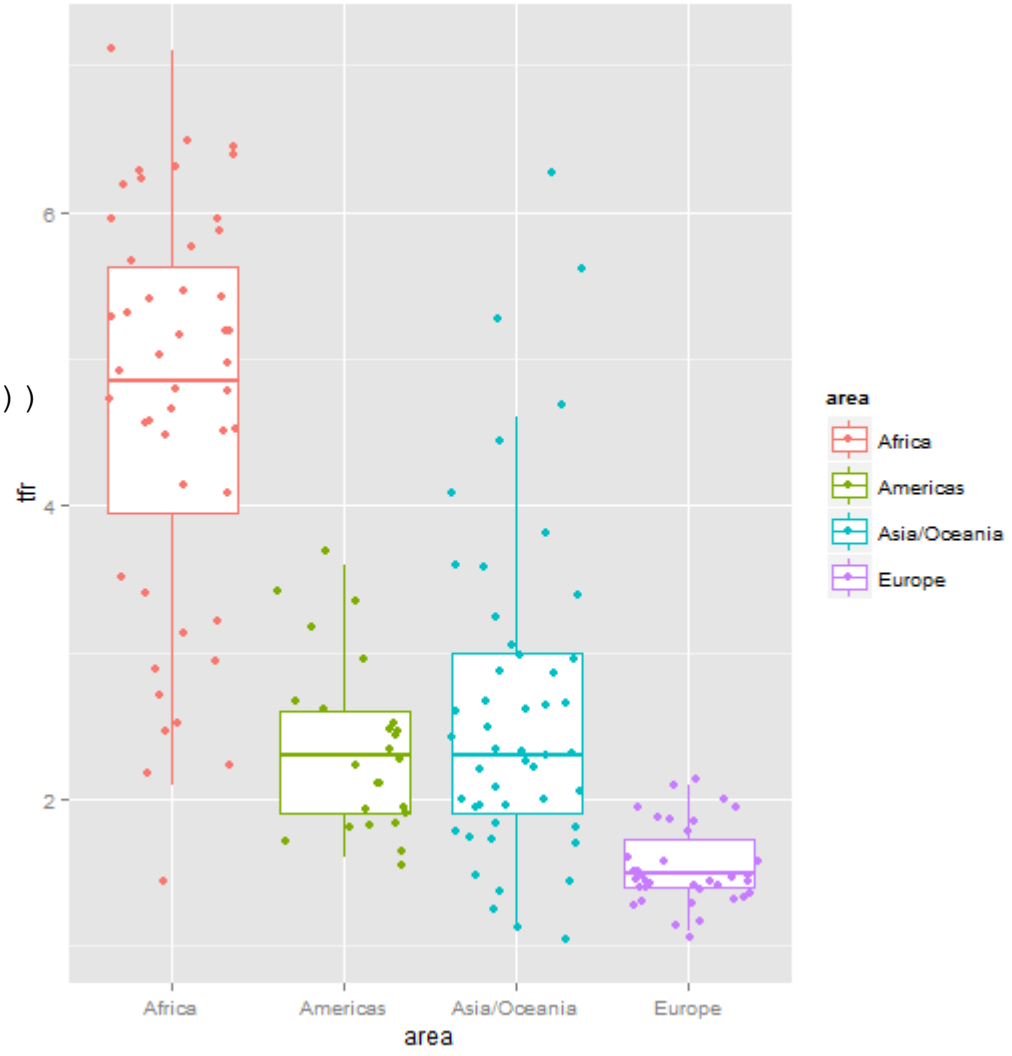
Show Data

```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")

p <- ggplot(data=w, aes(x=area, y=tfr,
            size=pop2012))
p + geom_jitter(position=
    position_jitter(w=.2, h=.1),
    shape=21, fill="gray") +
scale_y_continuous(breaks=
    c(1,2,3,4,5,6,7)) +
scale_size_area(breaks=
    c(50,100,200,300,1000),
    max_size=18) +
theme_bw() +
theme(axis.title.x=element_blank(),
      axis.title.y=element_text(angle=0),
      legend.key=element_blank(),
      legend.text.align=1)
```



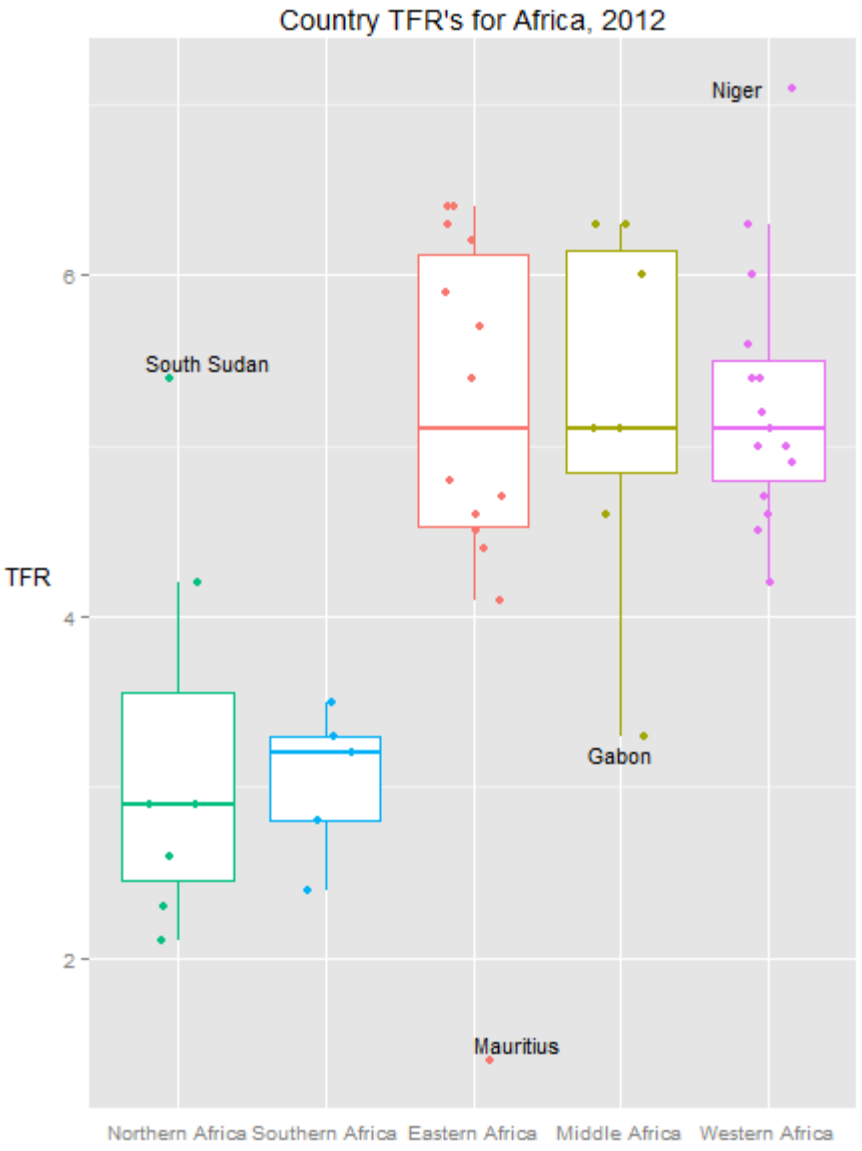
Data + Statistical Summary

```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")

p <- ggplot(w, aes(x=area,
                   y=tfr,color=area))
p +  geom_boxplot(outlier.size=0) +
     geom_jitter(position=
                 position_jitter(h=.1))
```



Data + Statistical Summary + Annotation

```
p <- ggplot(data=subset(w,area=="Africa"),
aes(x=reorder(factor(region),tfr,FUN=median),
                y=tfr, color=region))
p + geom_boxplot(outlier.size=0) +
    geom_jitter(position=
                position_jitter(w=.2,h=0)) +
annotate("text",x=1.2, y=5.5,
          label="South Sudan", size=4) +
annotate("text",x=3.3, y=1.5,
          label="Mauritius", size=4) +
annotate("text",x=4.8, y=7.1,
          label="Niger", size=4) +
annotate("text",x=4, y=3.2,
          label="Gabon", size=4) +
labs(title="Country TFR's for Africa, 2012",
     x="", y="TFR") +
theme(axis.ticks.x=element_blank(),
      axis.title.y=element_text(angle=0),
      legend.position="none")
```



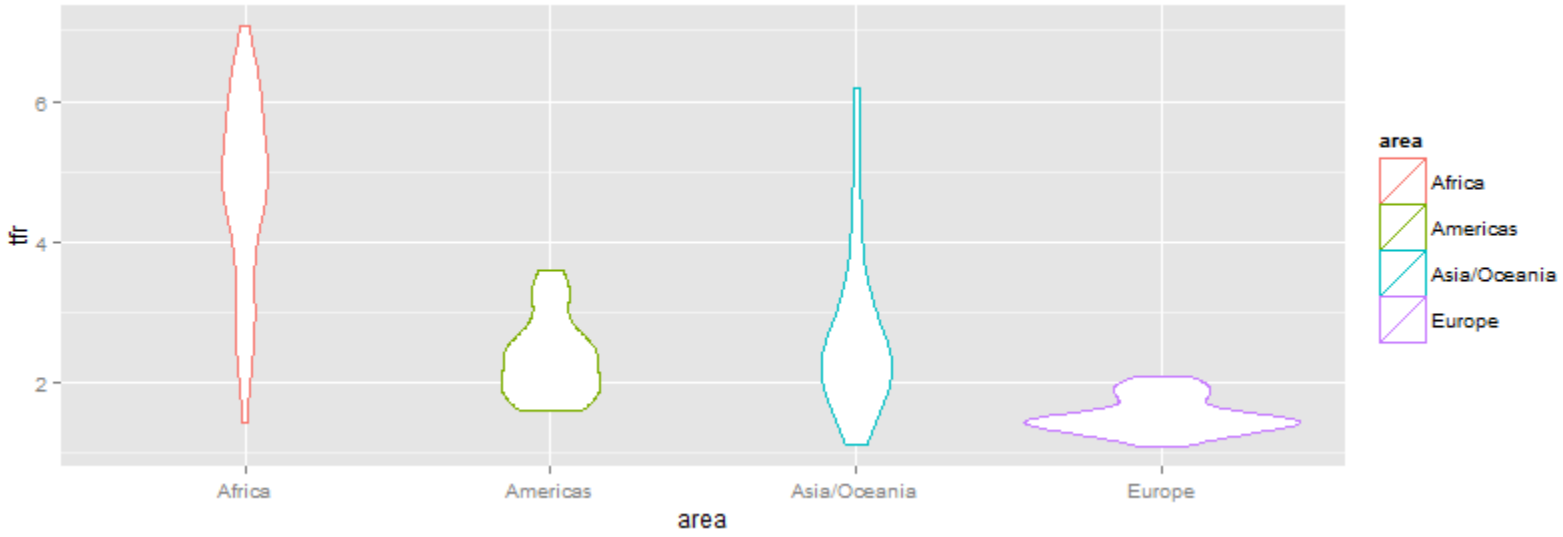
Statistical Summary

violin plot:

kernel density estimates, mirrored to have a symmetrical shape

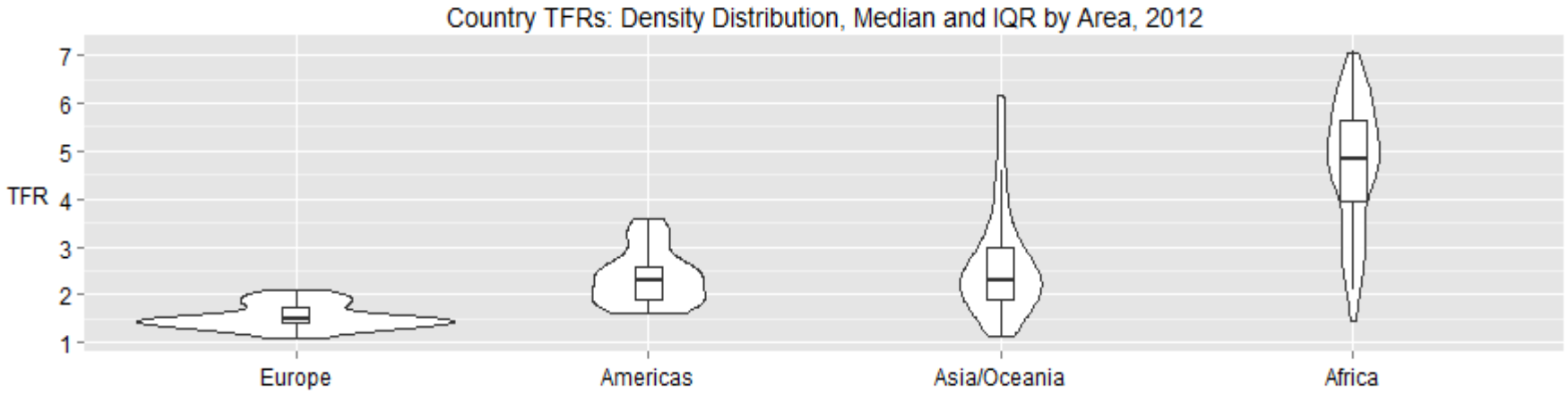
allows visual comparison of data distribution of several groups

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(w, aes(x=area, y=tfr, color=area))
p +  geom_violin()
```



Statistical Summaries

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")

p <- ggplot(w, aes(x=reorder(factor(area),tfr,FUN="median"), y=tfr))
p +  geom_violin() + geom_boxplot(width=.1, outlier.size=0) +
scale_y_continuous(breaks=c(1,2,3,4,5,6,7)) +
theme(axis.title.y=element_text(angle=0,size=12),
      axis.text.y=element_text(color="black", size=12),
      axis.text.x=element_text(color="black", size=12),
      legend.position="none") +
labs(title="Country TFRs: Density Distribution, Median and IQR by Area, 2012",
x="", y="TFR")
```

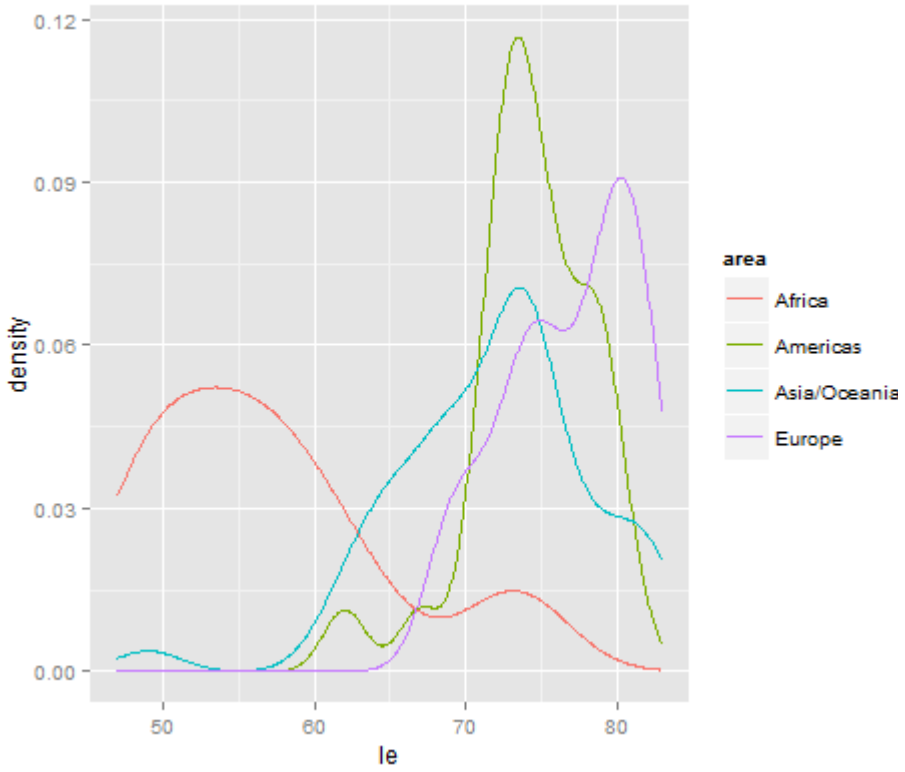


Statistical Summary

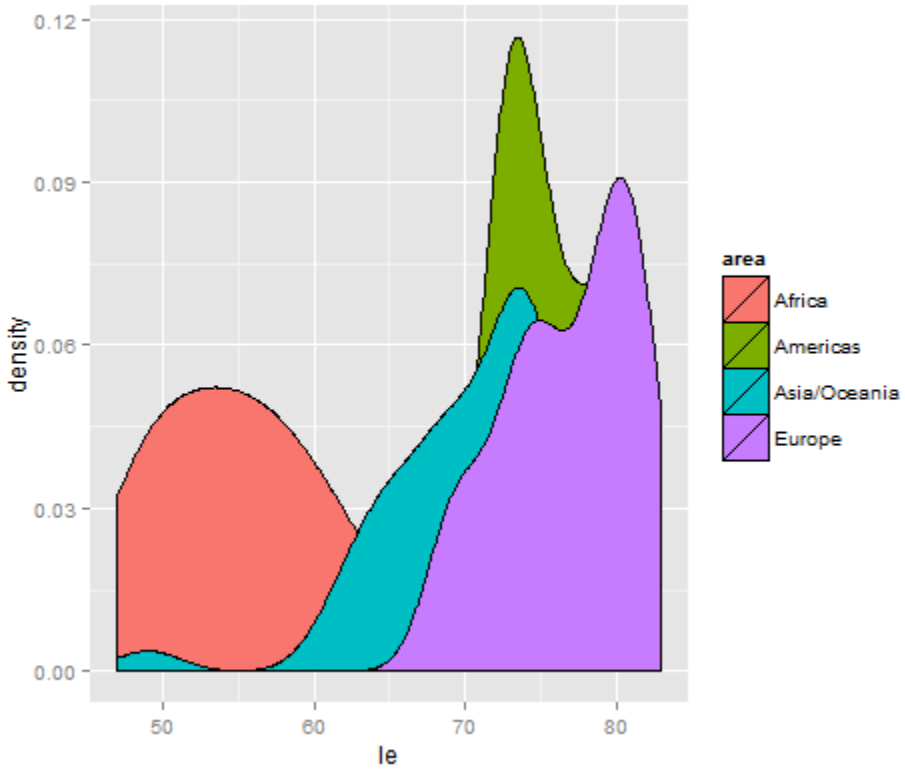
density distribution

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
```

```
p <- ggplot(w, aes(x=le, color=area))
p +  geom_line(stat="density")
```

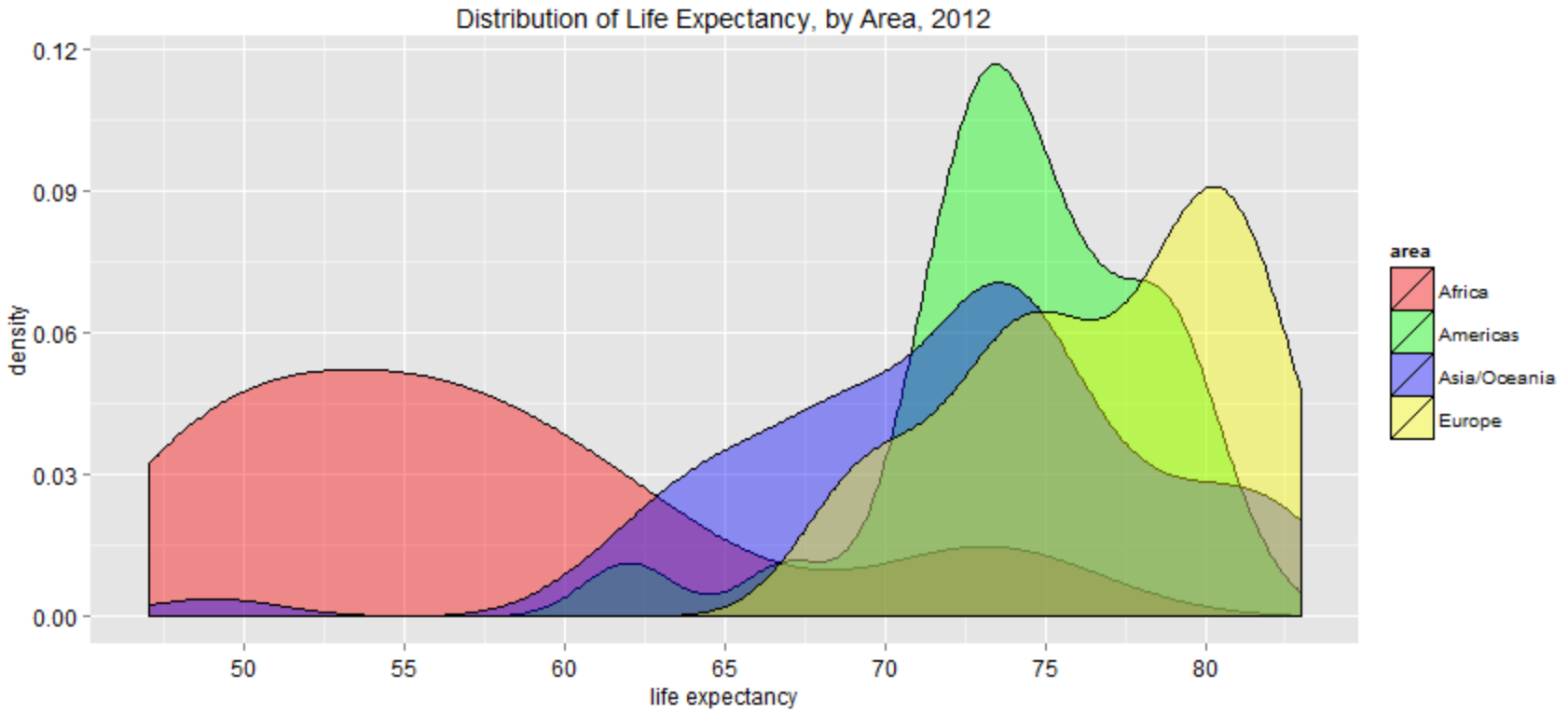



```
p <- ggplot(w, aes(x=le, fill=area))
p +  geom_density()
```



Statistical Summary + Annotation

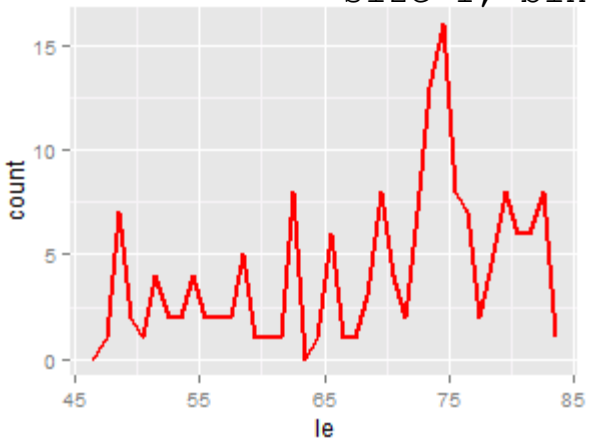
```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(w, aes(x=le, fill=area))
p +  geom_density(alpha=.4) +
  scale_fill_manual(values=c("red", "green", "blue", "yellow")) +
  scale_x_continuous(breaks=c(45,50,55,60,65,70,75,80,85)) +
  theme(axis.text=element_text(color="black", size=12)) +
  labs(title="Distribution of Life Expectancy, by Area, 2012", x="life expectancy")
```



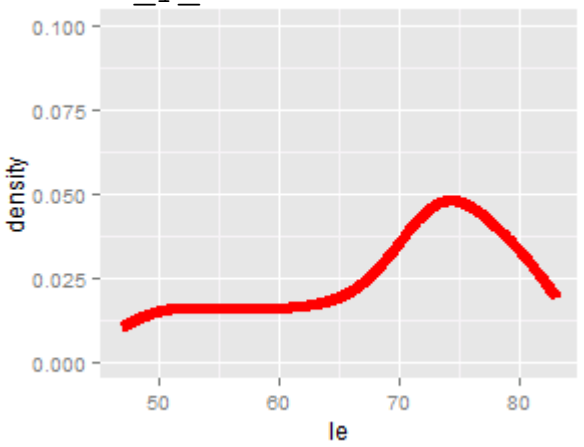
Statistical Summaries

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(w, aes(x=le))
```

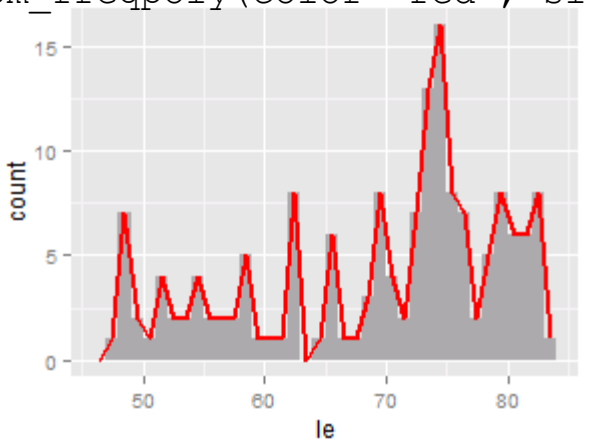
```
p + geom_freqpoly(color="red",
                  size=1, bin=1)
```



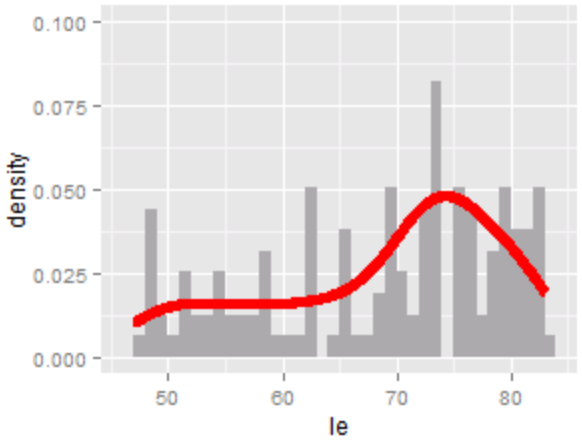

```
p +  geom_line(stat="density",
     color="red", size=2, bin=1) +
scale_y_continuous(limits=c(0,0.1))
```




```
p + geom_bar(fill="darkgray", bin=1) +
geom_freqpoly(color="red", size=1, bin=1)
```

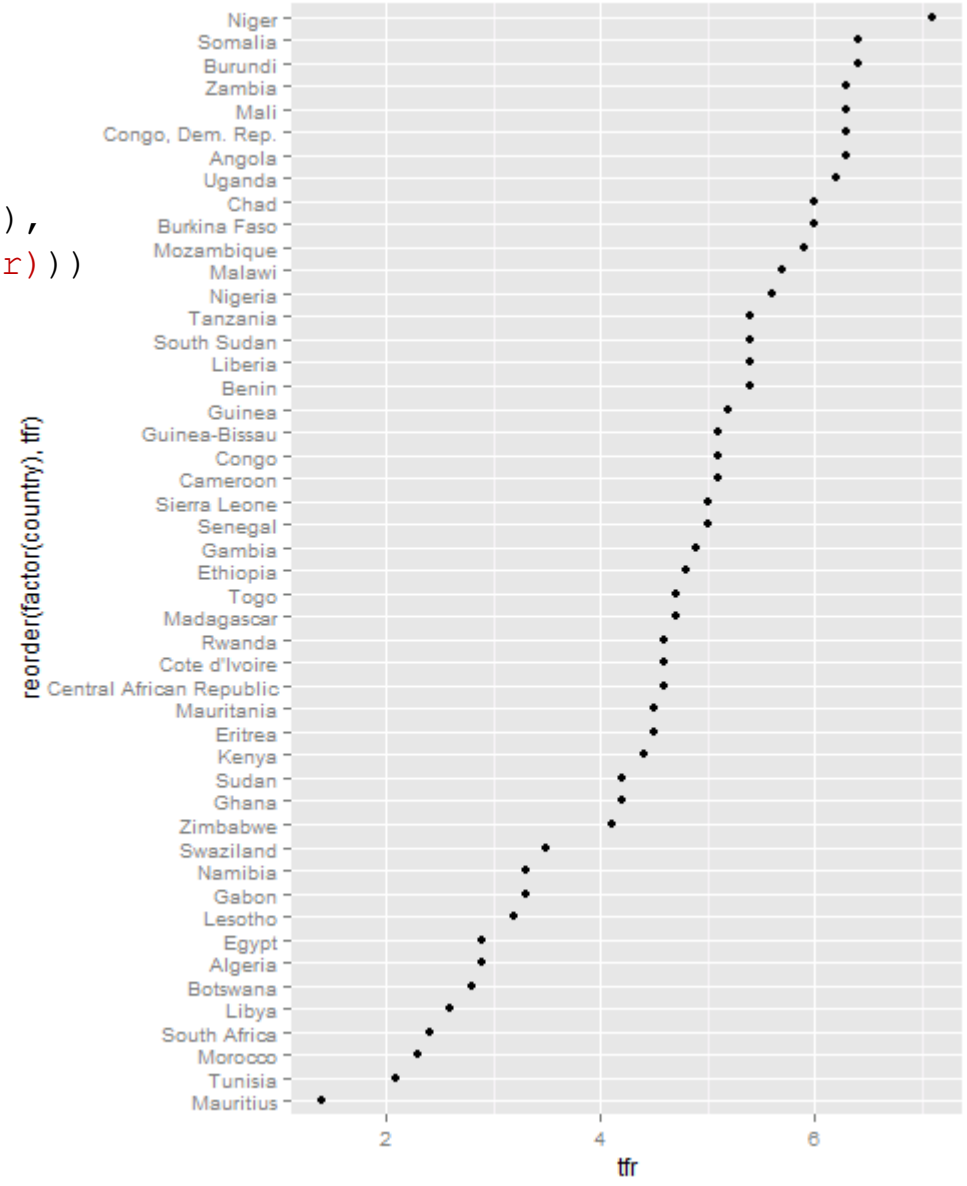



```
p +  geom_bar(aes(y=..density..),
     fill="darkgray", bin=1) +
geom_line(stat="density", color="red",
     size=2) + ylim(0,0.1)
```



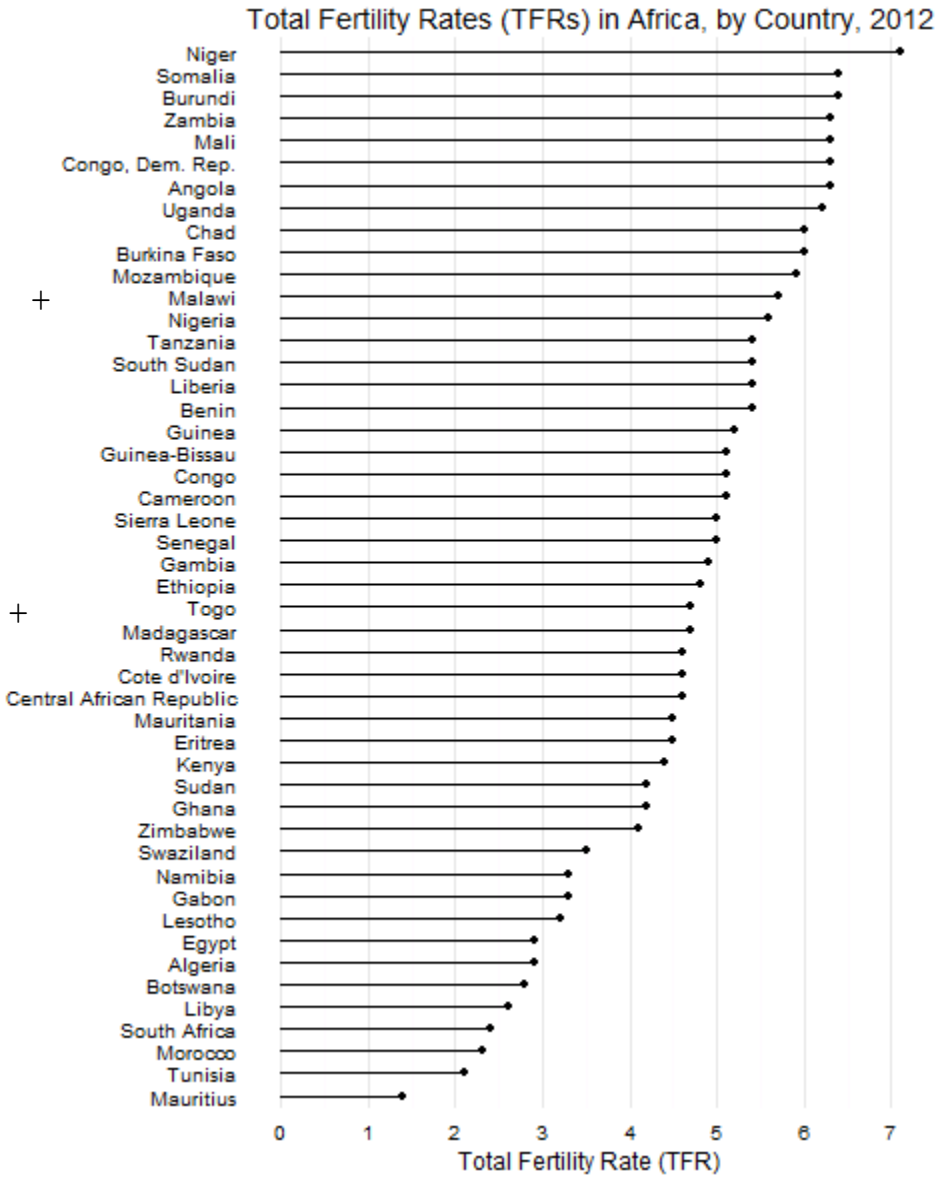
Show Data

```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")

p <- ggplot(data=subset(w,area=="Africa"),
  aes(x=tfr,y=reorder(factor(country),tfr)))

p + geom_point()
```



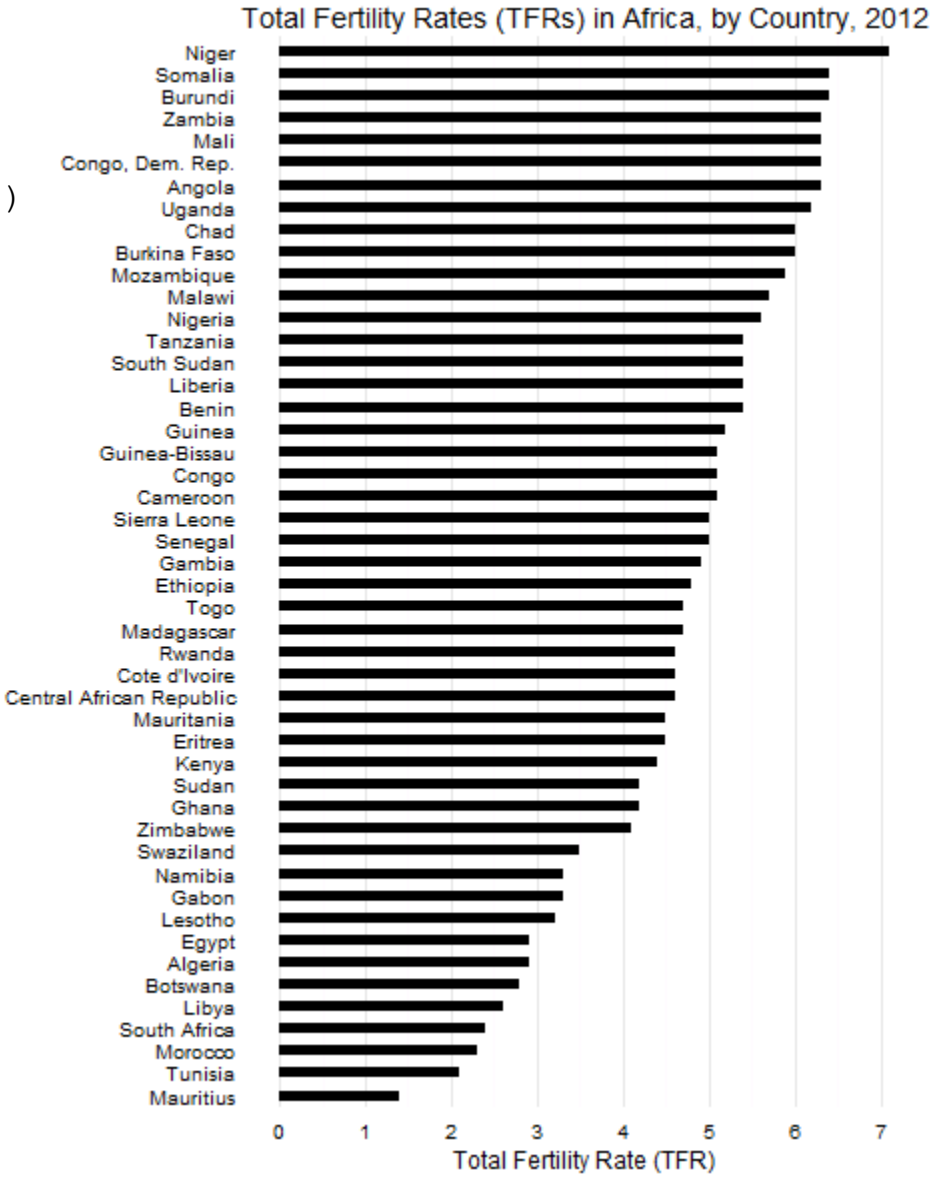
Show Data

```
w <- read.csv(file="WDS2012.csv",
     head=TRUE, sep=",")
p <- gplot(data=subset(w,area=="Africa"),
aes(x=tfr,y=reorder(factor(country),tfr)))

p + geom_segment(aes(yend=country,xend=0)) +
geom_point() +
theme_minimal() +
scale_x_continuous(breaks=
                   c(0,1,2,3,4,5,6,7)) +
labs(x="Total Fertility Rate (TFR)", y="",
     title="Total Fertility Rates (TFRs)
            in Africa, by Country, 2012") +
theme(panel.grid.major.y=element_blank(),
      axis.ticks=element_blank())
```



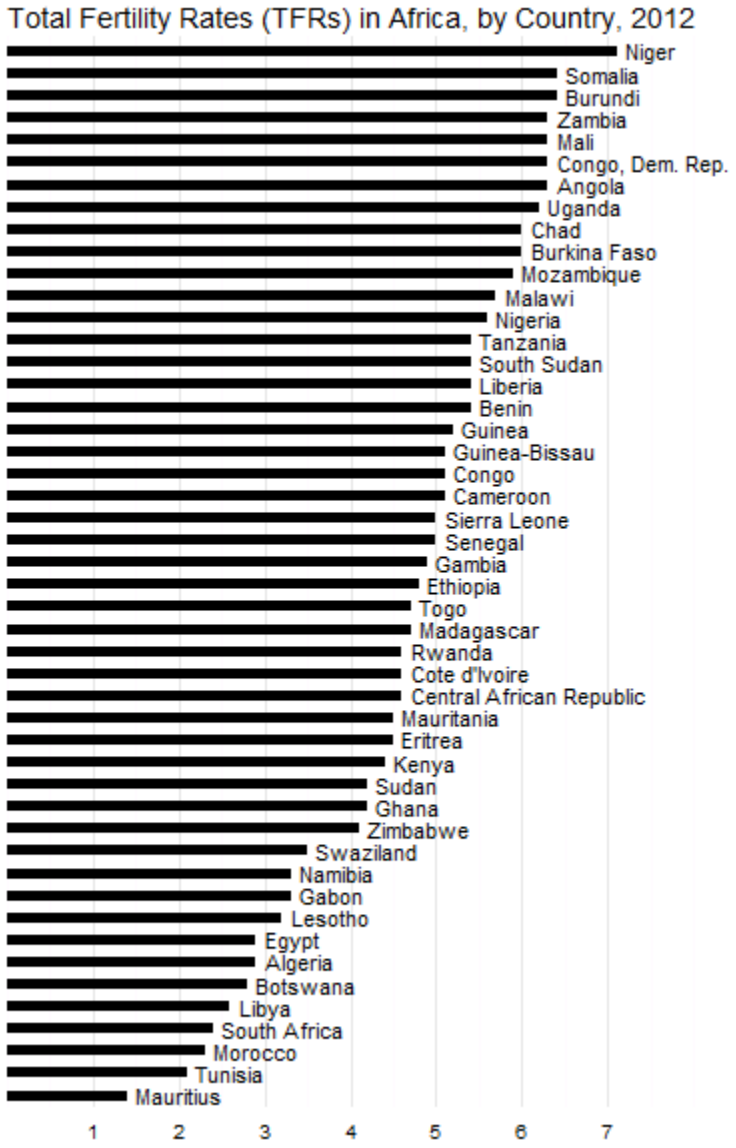
Show Data

```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")
p <- ggplot(data=subset(w,area=="Africa"),
aes(x=tfr, y=reorder(factor(country),tfr)))

p + geom_segment(aes(yend=country,xend=0),
    size=2) +
theme_minimal() +
scale_x_continuous(breaks=
                   c(0,1,2,3,4,5,6,7)) +
labs(x="Total Fertility Rate (TFR)", y="",
title="Total Fertility Rates (TFRs)
       in Africa, by Country, 2012") +
theme(panel.grid.major.y=element_blank(),
      axis.ticks=element_blank())
```



Show Data

```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")

p <- ggplot(data=subset(w,area=="Africa"),
            aes(x=tfr,
                y=reorder(factor(country),tfr)))
p + geom_text(aes(x=tfr+.1, label=country,
              hjust=0), size=4) +
geom_segment(aes(yend=country,xend=0), size=2) +
theme_minimal() +
scale_x_continuous(breaks=c(1,2,3,4,5,6,7),
                   limits=c(0,8)) +
labs(x="", y="",
     title="Total Fertility Rates (TFRs)
            in Africa, by Country, 2012") +
theme(panel.grid.major.y=element_blank(),
      axis.text.y=element_blank(),
      axis.ticks=element_blank())
```



Show Data

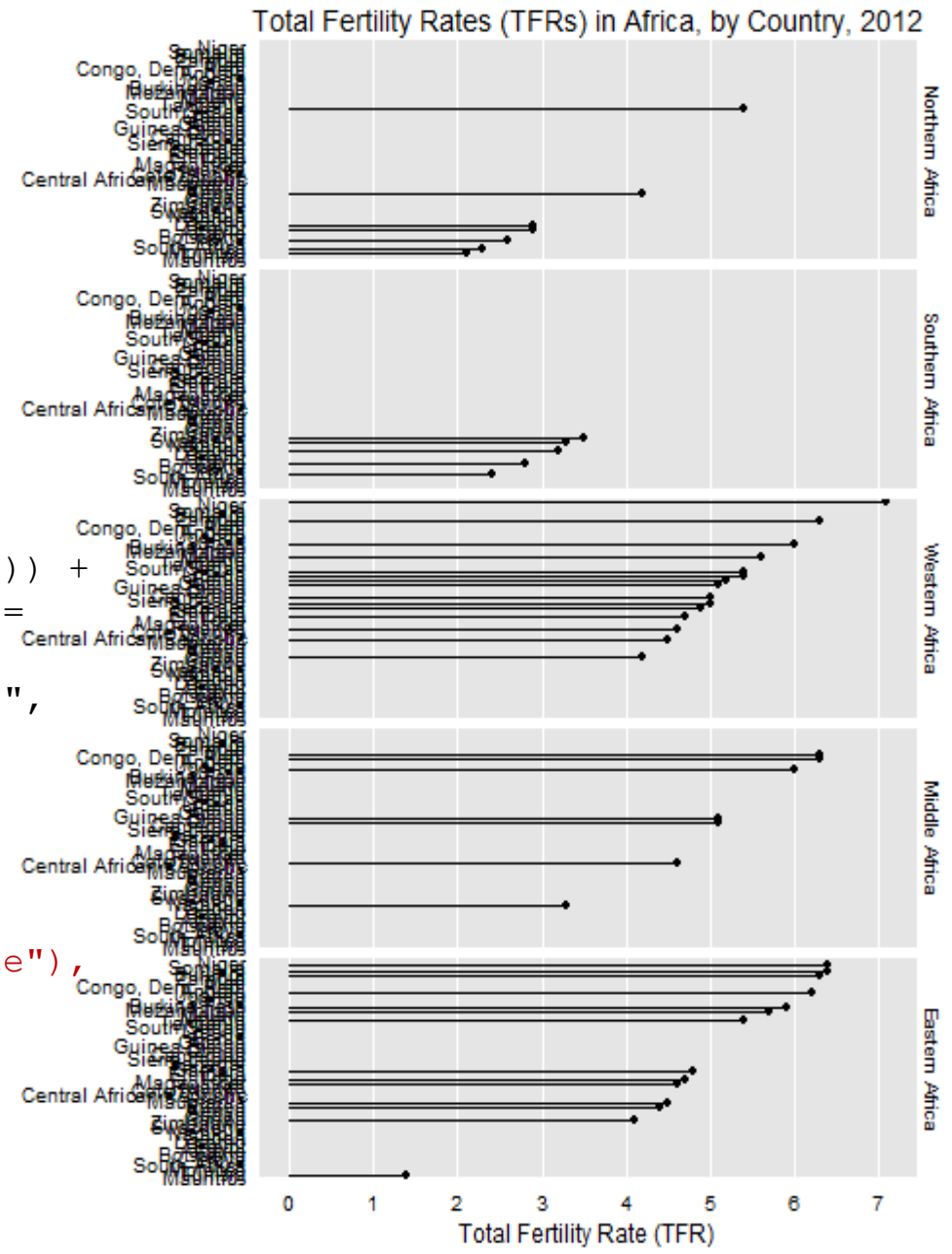
```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")

p <- ggplot(data=subset(w,area=="Africa"),
aes(x=tfr, y=reorder(factor(country),tfr)))

p + geom_text(aes(x=tfr-.1, label=country,
                  hjust=1), size=4) +
geom_point() +
theme_minimal() +
scale_x_continuous(breaks=c(1,2,3,4,5,6,7),
                   limits=c(0,8)) +
labs(x="", y="",
     title="Total Fertility Rates (TFRs) in
      Africa, by Country, 2012") +
theme(panel.grid.major.y=element_blank(),
      axis.text.y=element_blank(),
      axis.ticks=element_blank())
```

Show Data

```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")

p <- ggplot(data=subset(w,area=="Africa"),
aes(x=tfr, y=reorder(factor(country),tfr)))

p +  geom_text(aes(x=tfr+.1, label=country,
                   hjust=0), size= 4) +
geom_point() +
theme_minimal() +
scale_x_continuous(breaks=c(1,2,3,4,5,6,7),
                   limits=c(0,8)) +
labs(x="", y="",
     title="Total Fertility Rates (TFRs)
      in Africa, by Country, 2012") +
theme(panel.grid.major.y=element_blank(),
      axis.text.y=element_blank(),
      axis.ticks=element_blank())
```

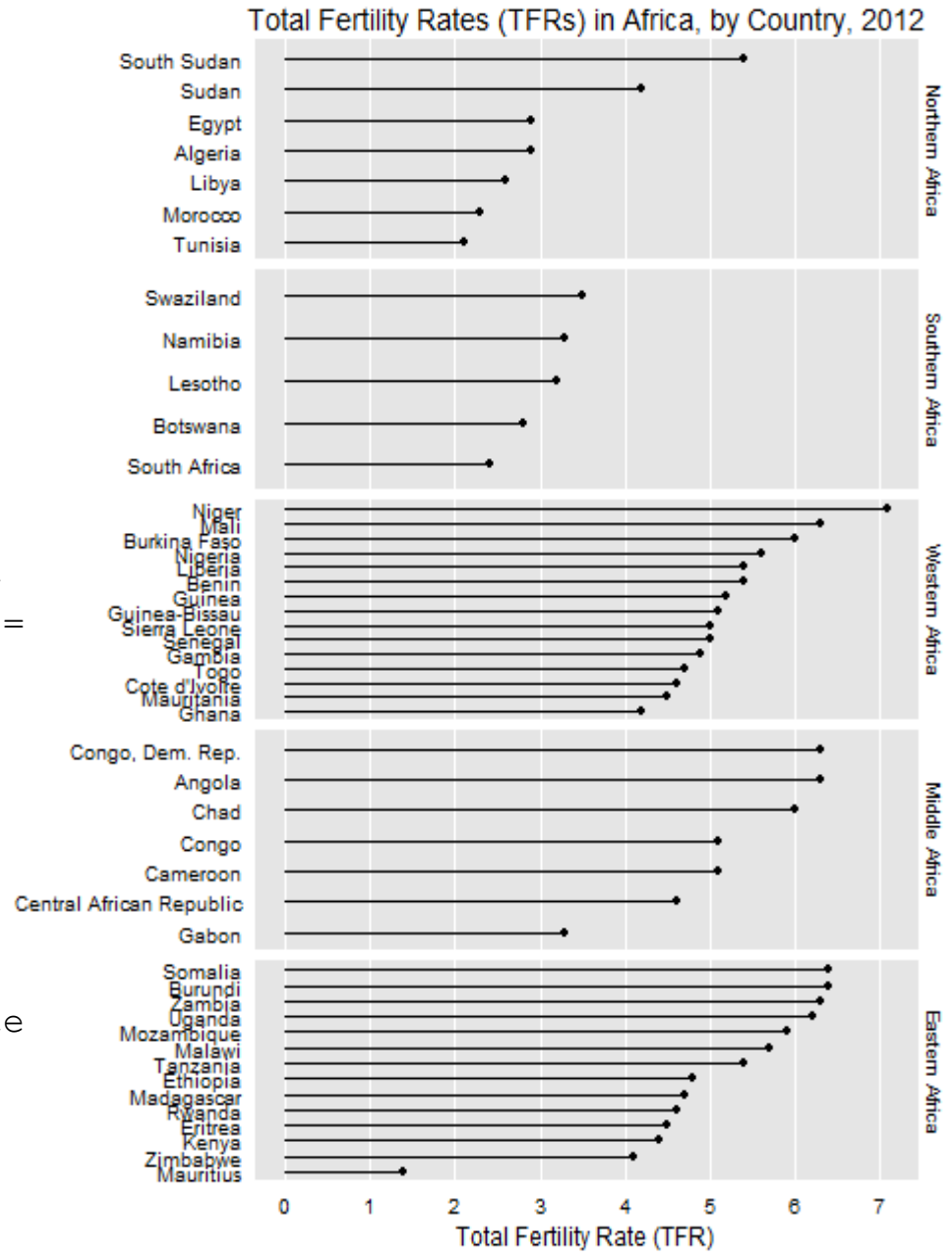
Show Data

```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")
a <- subset(w,area=="Africa")
a$region <- factor(a$region,levels=
c("Northern Africa","Southern Africa",
"Western Africa", "Middle Africa",
"Eastern Africa" ))
p <- ggplot(data=a,aes(x=tfr,
     y=reorder(factor(country),tfr)))
p + geom_segment(aes(yend=country,xend=0)) +
geom_point() + scale_x_continuous(breaks=
               c(0,1,2,3,4,5,6,7)) +
labs(x="Total Fertility Rate (TFR)", y="",
title="Total Fertility Rates (TFRs) in
       Africa, by Country, 2012") +
theme(
axis.text=element_text(color="black"),
strip.text.y=element_text(size=9),
strip.background=element_rect(fill="white"),
panel.grid.major.y=element_blank(),
panel.grid.minor.x=element_blank(),
axis.ticks=element_blank()) +
facet_grid(region ~ .)
```



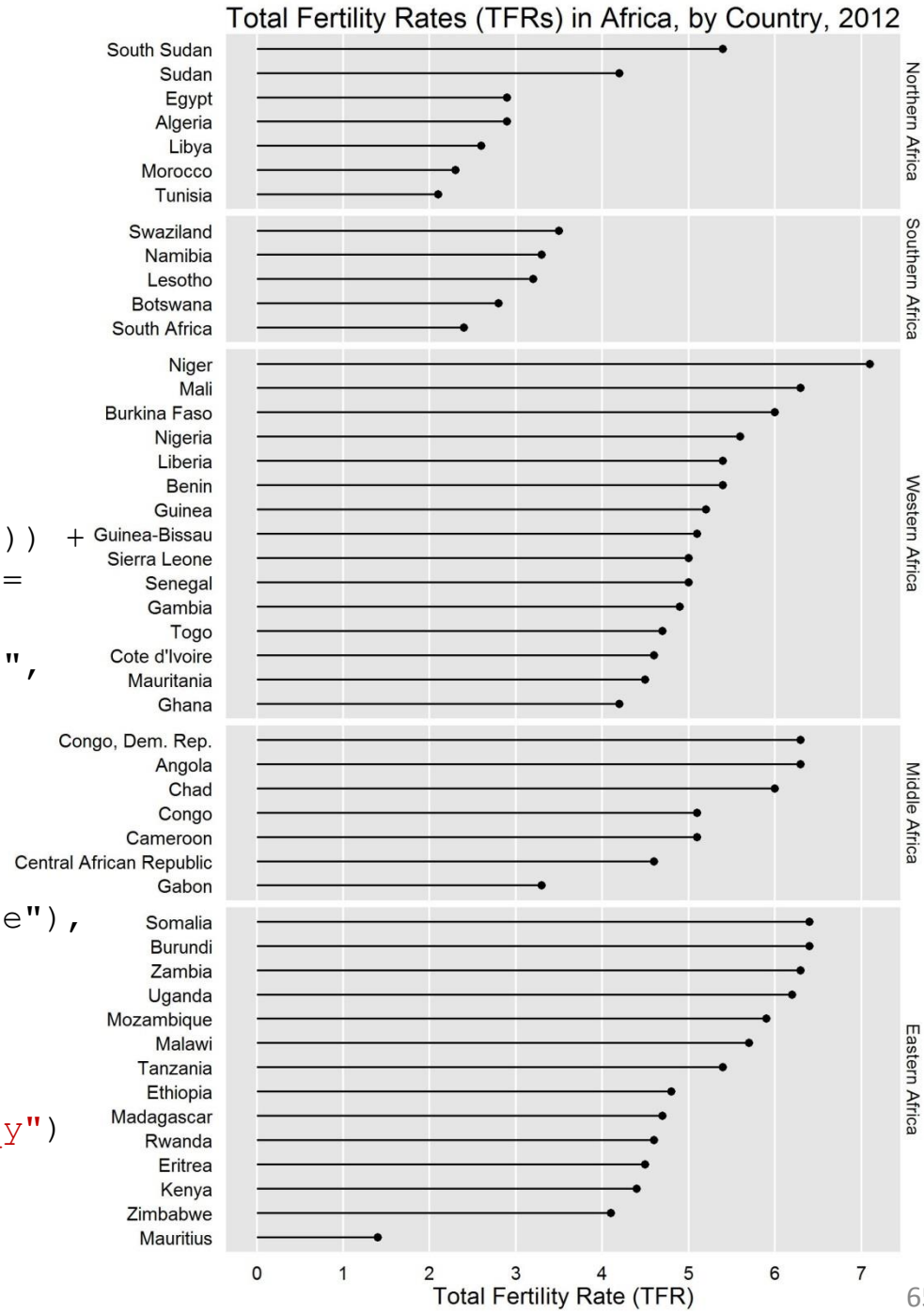
Show Data

```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")
a <- subset(w,area=="Africa")
a$region <- factor(a$region,levels=
c("Northern Africa","Southern Africa",
"Western Africa", "Middle Africa",
"Eastern Africa" ))
p <- ggplot(data=a,aes(x=tfr,
     y=reorder(factor(country),tfr)))
p +
geom_segment(aes(yend=country,xend=0)) +
geom_point() + scale_x_continuous(breaks=
               c(0,1,2,3,4,5,6,7)) +
labs(x="Total Fertility Rate (TFR)",
y="",
title="Total Fertility Rates (TFRs) in
       Africa, by Country, 2012") +
theme(
axis.text=element_text(color="black"),
strip.text.y=element_text(size=9),
strip.background=element_rect(fill="white
"),
panel.grid.major.y=element_blank(),
panel.grid.minor.x=element_blank(),
axis.ticks=element_blank()) +
facet_grid(region ~ ., scales="free_y")
```



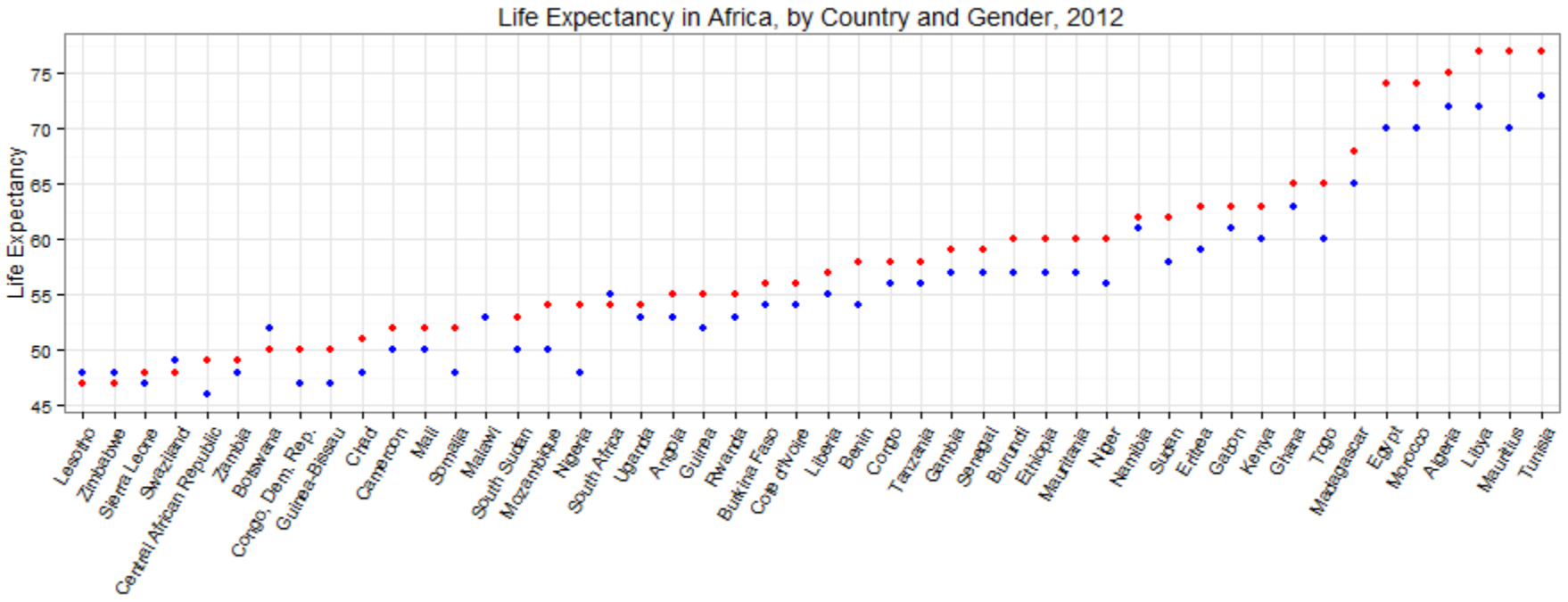
Show Data

```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")
a <- subset(w,area=="Africa")
a$region <- factor(a$region,levels=
c("Northern Africa","Southern Africa",
"Western Africa", "Middle Africa",
"Eastern Africa" ))
p <- ggplot(data=a,aes(x=tfr,
     y=reorder(factor(country),tfr)))
p + geom_segment(aes(yend=country,xend=0)) +
geom_point() + scale_x_continuous(breaks=
               c(0,1,2,3,4,5,6,7)) +
labs(x="Total Fertility Rate (TFR)", y="",
title="Total Fertility Rates (TFRs) in
       Africa, by Country, 2012") +
theme(
axis.text=element_text(color="black"),
strip.text.y=element_text(size=9),
strip.background=element_rect(fill="white"),
panel.grid.major.y=element_blank(),
panel.grid.minor.x=element_blank(),
axis.ticks=element_blank()) +
facet_grid(region ~ .,
           scales="free_y", space="free_y")
```



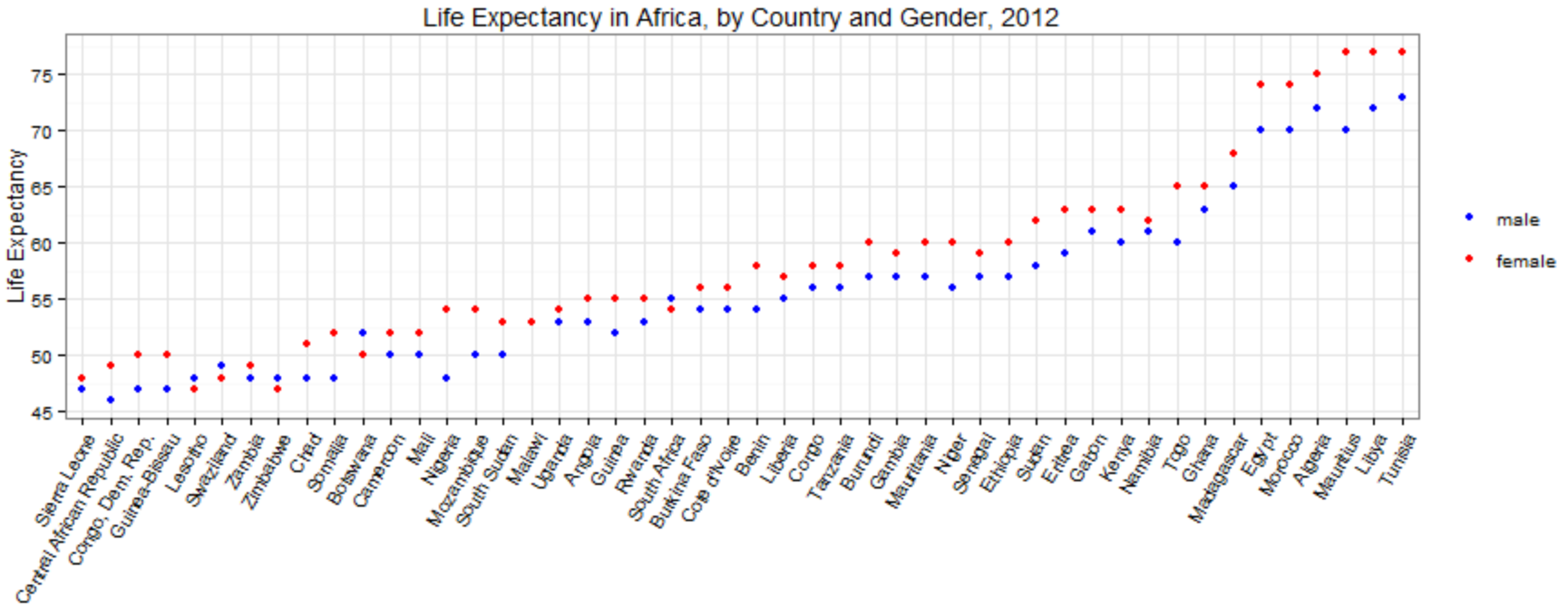
Show Data

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=subset(w,area=="Africa"),
aes(x=reorder(factor(country),leF),y=leF))
p + geom_point(color="red") +
    geom_point(aes(y=leM), color="blue") +
theme_bw() +
scale_y_continuous(breaks=c(45,50,55,60,65,70,75,80)) +
labs(x="", y="Life Expectancy",
     title="Life Expectancy in Africa, by Country and Gender, 2012") +
theme(axis.text.x=element_text(angle=60, hjust=1),
      axis.text=element_text(color="black"))
```



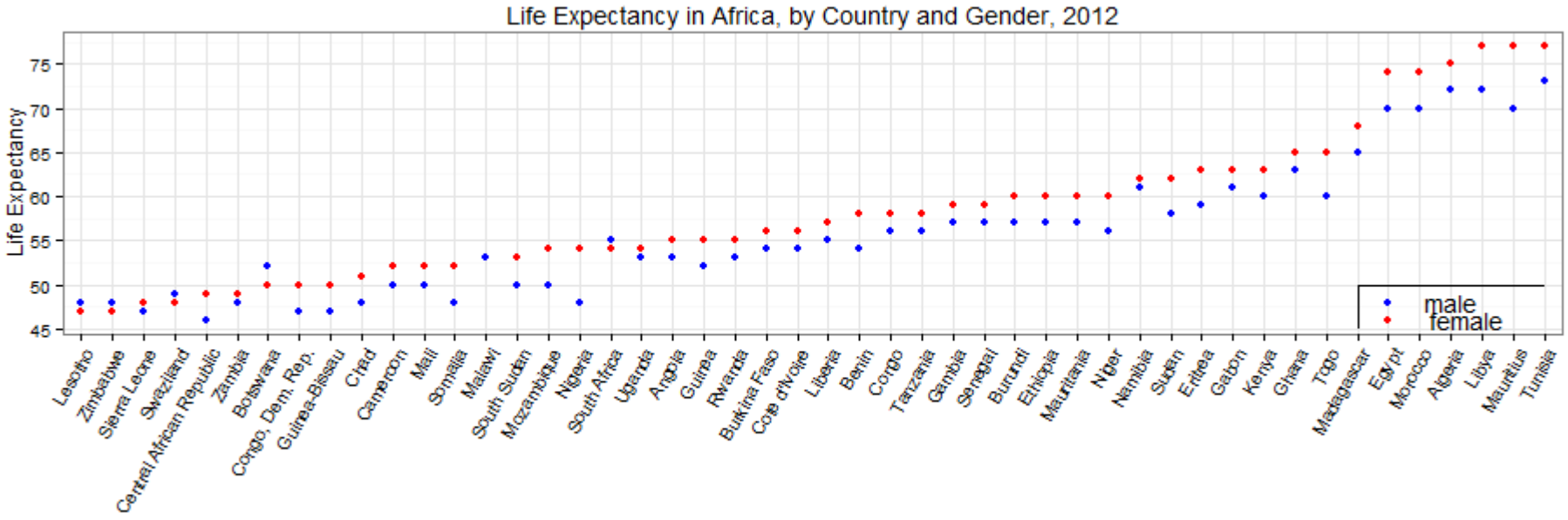
Show Data

```
library(reshape2)
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
w.melt <- melt(w, measure.vars=c("leM", "leF"))
p <- ggplot(data=subset(w.melt,area=="Africa"),
            aes(x=reorder(factor(country),le), y=value, color=variable))
p + geom_point() + theme_bw() +
scale_y_continuous(breaks=c(45,50,55,60,65,70,75,80)) +
scale_color_manual(values=c("blue", "red"), name="", labels=c("male", "female")) +
labs(x="", y="Life Expectancy",
     title="Life Expectancy in Africa, by Country and Gender, 2012") +
theme(axis.text.x=element_text(angle=60, hjust=1),
      axis.text=element_text(color="black"), legend.key=element_blank())
```



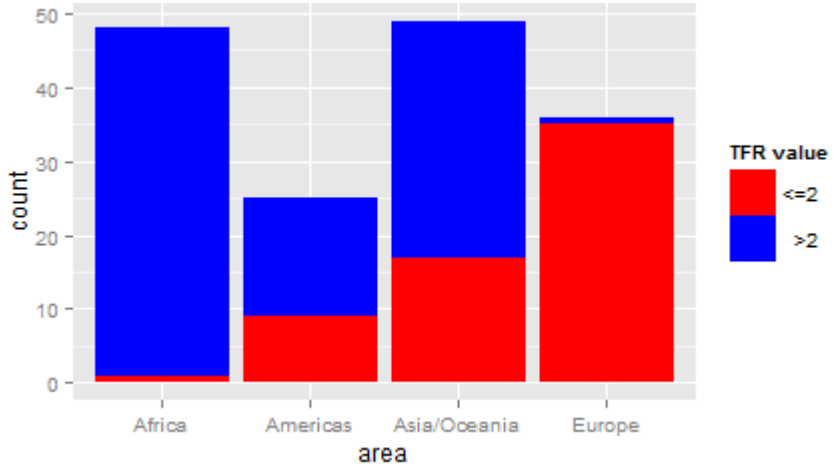
Show Data

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
p <- ggplot(data=subset(w,area=="Africa"),
aes(x=reorder(factor(country),leF),y=leF))
p + geom_point(color="red") + geom_point(aes(y=leM), color="blue") +
geom_point(x=43, y=48, color="blue") + geom_point(x=43, y=46, color="red") +
annotate("text", x=45, y=48, label="male", color="black") +
annotate("text", x=45.5, y=46, label="female", color="black") +
geom_segment(y=50,x=42,yend=50,xend=48 )+ geom_segment(y=50,x=42,yend=45,xend=42) +
theme_bw() + scale_y_continuous(breaks=c(45,50,55,60,65,70,75,80)) +
labs(x="", y="Life Expectancy",
     title="Life Expectancy in Africa, by Country and Gender, 2012") +
theme(axis.text.x=element_text(angle=60, hjust=1),
      axis.text=element_text(color="black"))
```

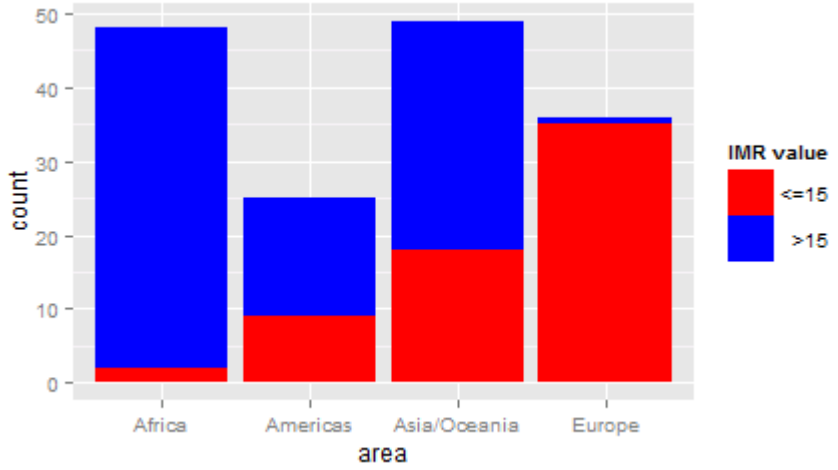


Statistical Summary

```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")
w$tfrGT2 <- w$tfr > 2
p <- ggplot(data=w,
            aes(x=area, fill=tfrGT2))
p + geom_bar() +
scale_fill_manual(name="TFR value",
values = c("red","blue"),
labels=c("<=2", ">2")) +
theme(legend.text.align=1)
```

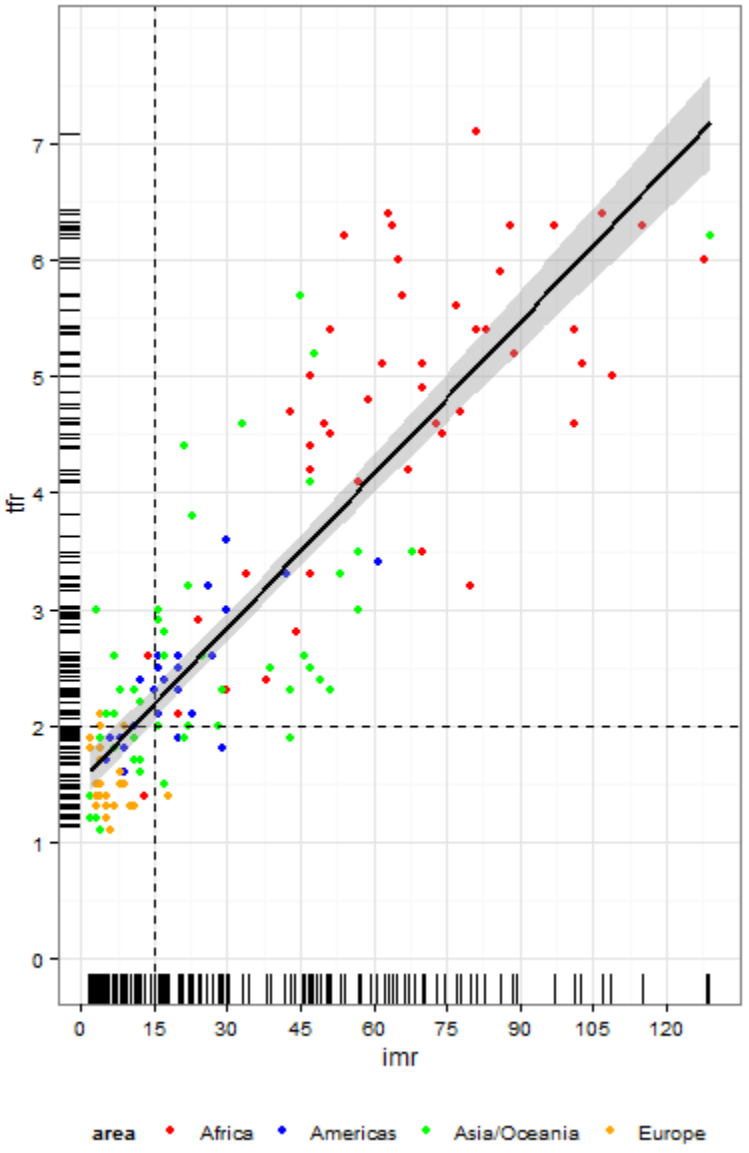



```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")
w$imrGT15 <- w$imr > 15
p <- ggplot(data=w,
            aes(x=area, fill=imrGT15))
p + geom_bar() +
scale_fill_manual(name="IMR value",
values = c("red","blue"),
labels=c("<=15", ">15")) +
  theme(legend.text.align=1)
```



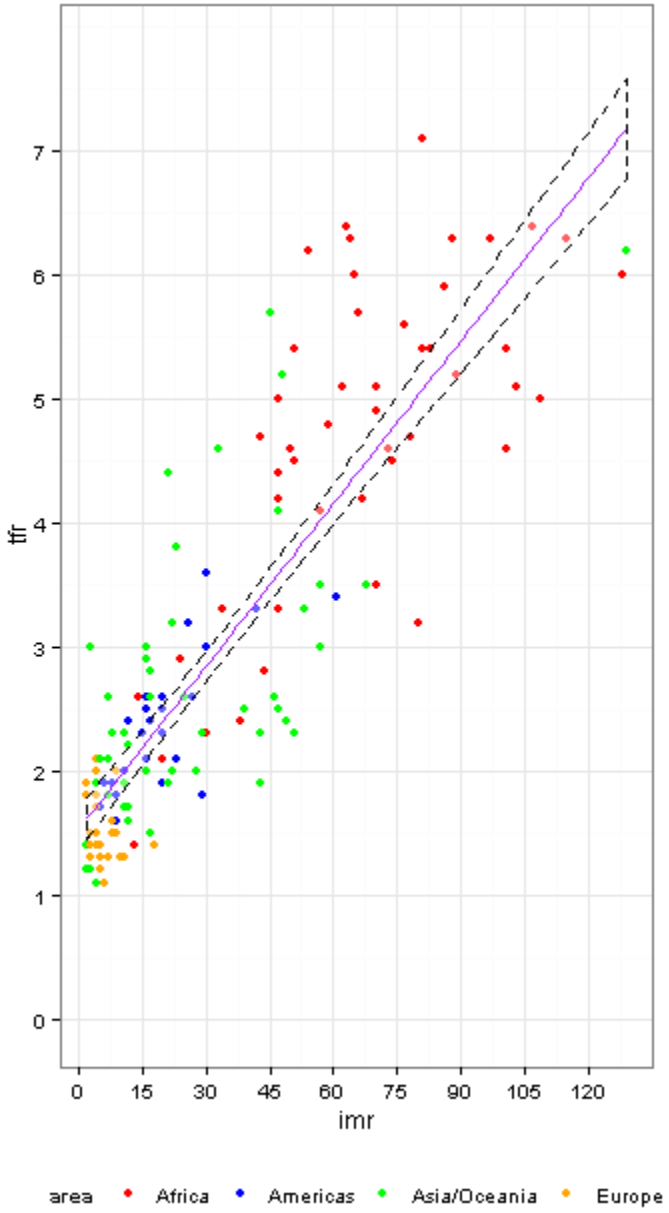
Data + Statistical Summary + Annotation

```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")

p <- ggplot(data=w, aes(x=imr,y=tfr))
p + geom_point(aes(color=area)) +
scale_color_manual(values=
      c("red", "blue", "green", "orange")) +
scale_y_continuous(breaks=c(0,1,2,3,4,5,6,7),
                   limits=c(0,7.8)) +
scale_x_continuous(breaks=
        c(0,15,30,45,60,75,90,105,120)) +
theme_bw() +
theme(legend.position="bottom",
      legend.direction="horizontal",
      legend.key=element_blank()) +
geom_vline(x=15,linetype="dashed") +
geom_hline(y=2,linetype="dashed") +
stat_smooth(method="lm", color="black", size=.8) +
geom_rug(position="jitter", size=.1)
```



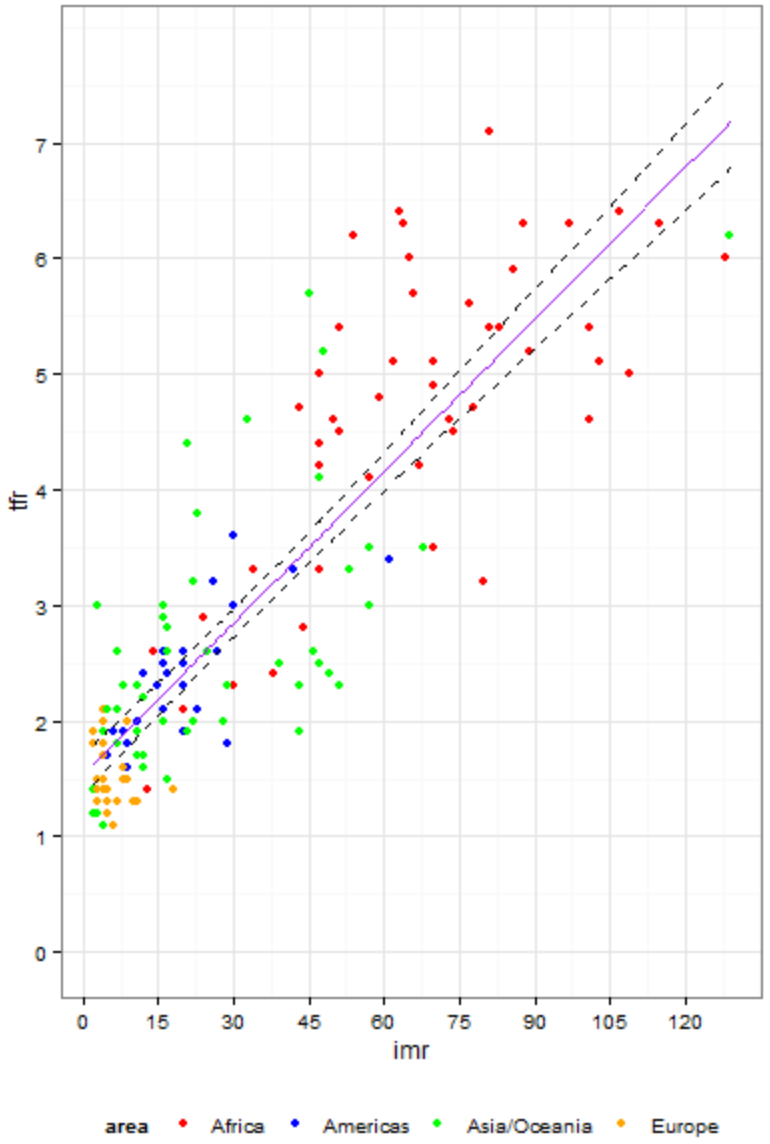
Data + Statistical Summary

```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")

p <- ggplot(data=w, aes(x=imr,y=tfr))

p + geom_point(aes(color=area)) +
stat_smooth(method="lm", fill=NA,
            color="purple") +
stat_smooth(method="lm", fill=NA, color="black",
            linetype="dashed", geom="ribbon") +
scale_color_manual(values=c("red", "blue",
                            "green", "orange")) +
scale_y_continuous(breaks=c(0,1,2,3,4,5,6,7),
                   limits=c(0,7.8)) +
scale_x_continuous(breaks=c(0,15,30,45,60,75,
                            90,105,120)) +
theme_bw() +
theme(legend.position="bottom",
      legend.direction="horizontal",
      legend.key=element_blank())
```



Data + Statistical Summary

```
w <- read.csv(file="WDS2012.csv",
              head=TRUE, sep=",")
m <- lm(tfr ~ imr, data=w)
mp <- predict(m, interval="confidence")
wp <- cbind(w, mp)

p <- ggplot(data=wp, aes(x=imr,y=tfr))
p + geom_point(aes(color=area)) +
geom_line(aes(y = upr),  linetype = "dashed") +
geom_line(aes(y = lwr),  linetype = "dashed") +
geom_line(aes(y = fit), color="purple") +
scale_color_manual(values=
      c("red", "blue", "green", "orange")) +
scale_y_continuous(breaks=c(0,1,2,3,4,5,6,7),
                   limits=c(0,7.8)) +
scale_x_continuous(breaks=c(0,15,30,45,60,75,
                            90,105,120)) +
theme_bw() +
theme(legend.position="bottom",
      legend.direction="horizontal",
      legend.key=element_blank())
```



Graphing Regression Diagnostics

approach: make diagnostic data easily available

use all ggplot2 capabilities to visualize data

diagnostic data and visual representation are separate

flexibility

`fortify(model)`

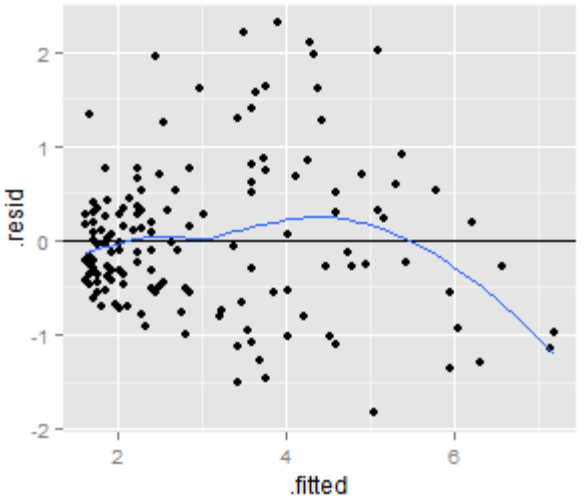
provides data frame containing variables used in model and columns containing regression diagnostics:

.fitted	fitted values from the model
.resid	residuals
.stdresid	standardized residuals
.hat	diagonal of the hat matrix
.cooksd	estimate of effect of deleting an observation (influence)
.sigma	estimate of residual standard deviation when observation dropped from model

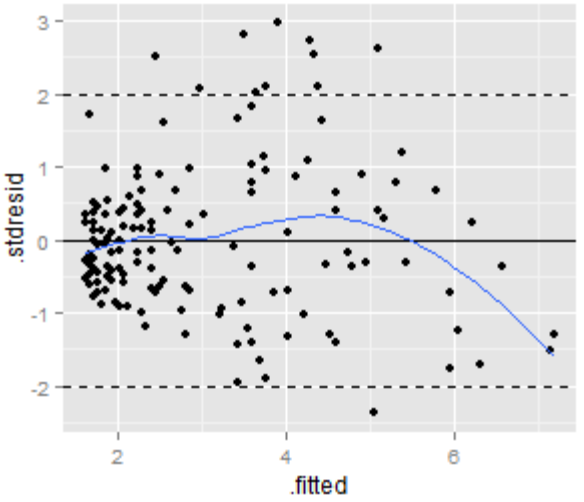
(Regression Diagnostic) Data + Statistical Summary + Annotation

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
m <- lm(tfr ~ imr, data=w)
mf <- fortify(m)
```

```
p <- ggplot(data=mf, aes(x=.fitted,y=.resid))
p + geom_point() +
geom_hline(y = 0) +
geom_smooth(se = FALSE)
```



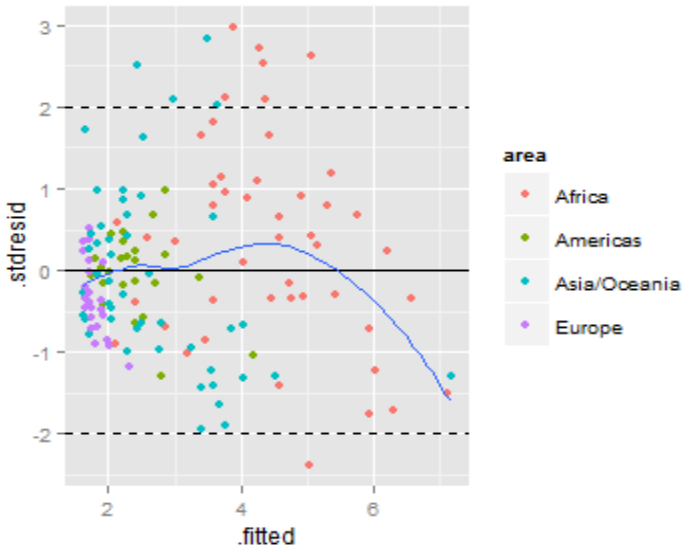

```
p <- ggplot(data=mf, aes(x=.fitted,y=.stdresid))
p + geom_point() +
geom_hline(y=0) +
geom_hline(y=2,  linetype="dashed") +
geom_hline(y=-2, linetype="dashed") +
geom_smooth(se = FALSE)
```



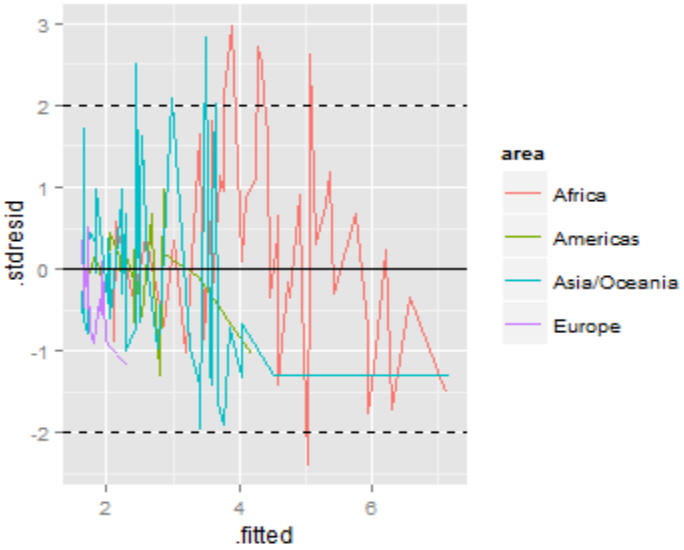
(Regression Diagnostic) Data + Statistical Summary + Annotation

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=" ")
m <- lm(tfr ~ imr, data=w)
wf <- fortify(m,w)
```

```
p <- ggplot(data=wf, aes(x=.fitted, y=.stdresid))
p + geom_point(aes(color=area)) +
geom_hline(y = 0) +
geom_hline(y=2,  linetype="dashed") +
geom_hline(y=-2, linetype="dashed") +
geom_smooth(se = FALSE)
```

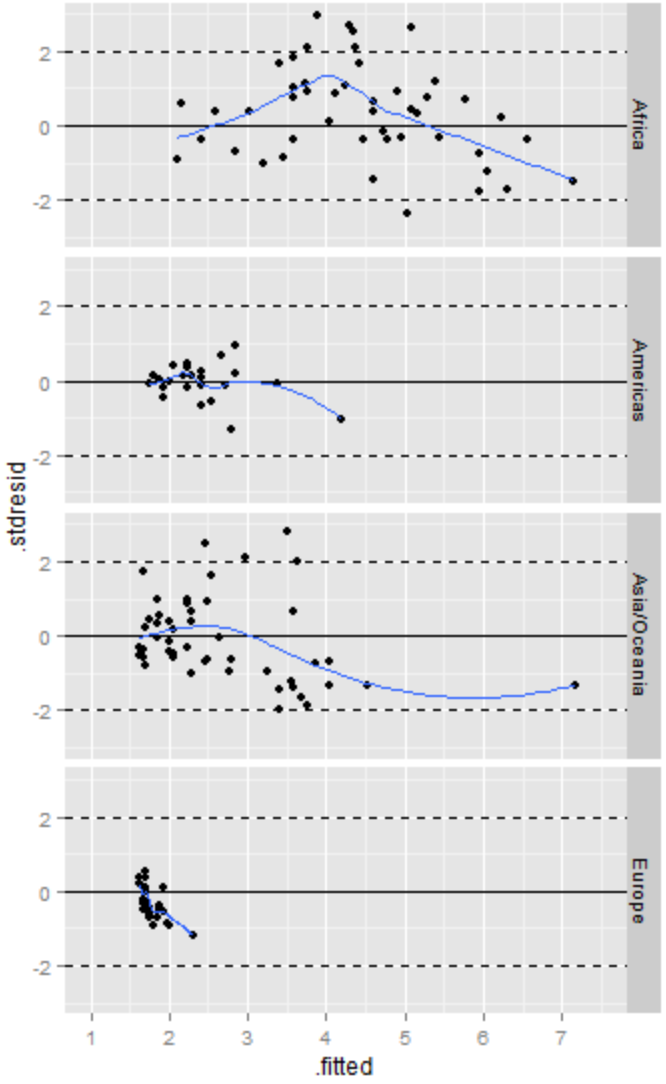



```
p <- ggplot(data=wf, aes(x=.fitted, y=.stdresid))
p + geom_line(aes(color=area)) +
geom_hline(y = 0) +
geom_hline(y=2,  linetype="dashed") +
geom_hline(y=-2, linetype="dashed")
```



(Regression Diagnostic) Data + Statistical Summary + Annotation

```
w <- read.csv(file="WDS2012.csv", head=TRUE, sep=",")
m <- lm(tfr ~ imr, data=w)
wf <- fortify(m,w)


p <- ggplot(data=wf, aes(x=.fitted, y=.stdresid))
p + geom_point() +
scale_x_continuous(limits=c(1, 7.5),
                   breaks=c(1,2,3,4,5,6,7)) +
scale_y_continuous(limits=c(-3, 3)) +
geom_hline(y = 0) +
geom_hline(y=2, linetype="dashed") +
geom_hline(y=-2, linetype="dashed") +
geom_smooth(se = FALSE) + facet_grid(area ~ .)
```

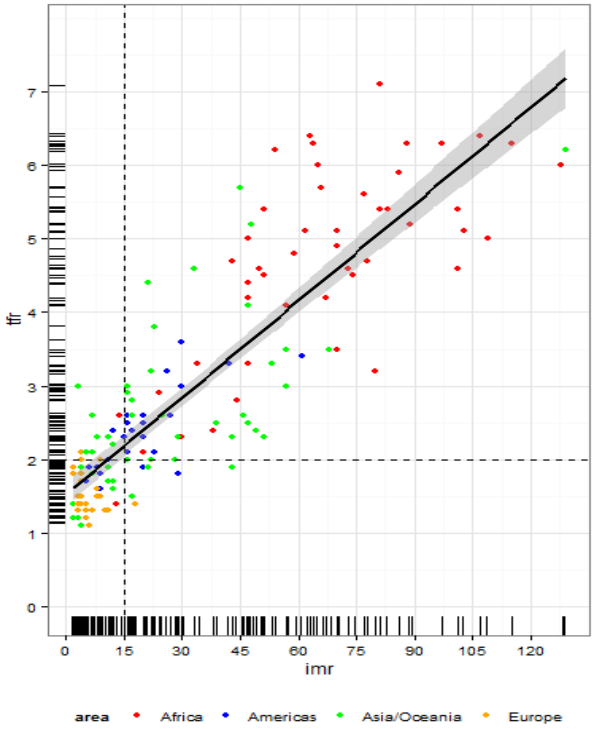


Part 3: Recap and Additional Resources

Recap

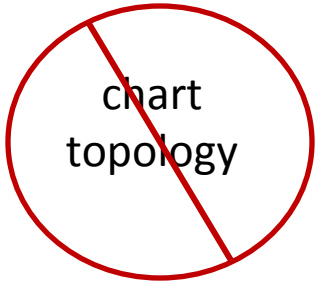
country	tfr	imr	area
Algeria	2.9	24	Africa
Egypt	2.9	24	Africa
.	.	.	.
.	.	.	.
.	.	.	.
Canada	1.7	5.1	Americas
United States	1.9	6.0	Americas
.	.	.	.
.	.	.	.
.	.	.	.
Armenia	1.7	11	Asia/Oceania
Azerbaijan	2.3	11	Asia/Oceania
.	.	.	.
.	.	.	.
.	.	.	.
Denmark	1.8	3.5	Europe
Estonia	2.5	3.3	Europe
.	.	.	.
.	.	.	.
.	.	.	.

ggplot2



construct graphs by considering:

- coordinate system
- statistical transformations of data
- which values will be represented by various visual characteristics (aesthetics)
- how values will mapped to visual characteristics (scales)
- geometric rendering
- whether data might be displayed as “small multiples” (facets)
- adding additional annotation



Additional Resources

official "Package ggplot2" documentation and help
- http://cran.r-project.org/web/packages/ggplot2/ggplot2.pdf
- http://docs.ggplot2.org/current/

online ggplot2 user community
- http://groups.google.com/group/ggplot2
- http://stackoverflow.com/tags/ggplot2

books
- *ggplot2: Elegant Graphics for Data Analysis* by Hadley Wickham. Springer, 2009.
- *R Graphics Cookbook* by Winston Chang. O'Reilly, 2012.
- *The Grammar of Graphics* by Leland Wilkinson. Springer, 2005.

videos
- A Backstage Tour of ggplot2 with Hadley Wickham, Feb. 2012.
  http://www.youtube.com/watch?v=RHu5vgBZ1yQ
- Plotting with ggplot2: Part 2 with Roger Peng, Johns Hopkins University, Oct. 2013.
  http://www.youtube.com/watch?v=n8kYa9vu1l8

online tutorials and slide presentations
- Visualizing Data by Garrett Grolemund, Rstudio, July 2013.
  http://www.edii.uclm.es/~useR-2013/Tutorials/Grolemund.html
- AVML 2012: ggplot2 by Josef Fruehwald, University of York, 2012.
  http://www.ling.upenn.edu/~joseff/avml2012/
- Introduction to R Graphics with ggplot2 by IQSS, Harvard University.
  http://www.slideshare.net/izahn/rgraphics-12040991
- ggplot2 Quick Reference by SAPE Research Group.
  http://sape.inf.usi.ch/quick-reference/ggplot2