Basic steps for effective and reproducible data visualization

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References used throughout the document

- Wilke, C. O. (2019). *Fundamentals of Data Visualization: A Primer on Making Informative and Compelling Figures*. O'Reilly Media.
- Rougier, N. P., Droettboom, M., & Bourne, P. E. (2014). Ten simple rules for better figures. PLoS Comput Biol 10(9): e1003833.
- Raab, G., Calitri, F., & Schiedung, M. (2019, April). *Visualizing Science*. Presentation at the European Geosciences Union General Assembly, Vienna, Austria.

Useful ressources

- Wilke, C. O. (2019). *Fundamentals of Data Visualization: A Primer on Making Informative and Compelling Figures*. O'Reilly Media.
  - Online version: https://serialmentor.com/dataviz/
- Link to useful R graphs:
  - https://www.r-graph-gallery.com/index.html
  - http://shinyapps.stat.ubc.ca/r-graph-catalog/#
- Rougier, N. P., Droettboom, M., & Bourne, P. E. (2014). Ten simple rules for better figures. PLoS Comput Biol 10(9): e1003833.
- https://wiki.qcbs.ca/r_workshop3
- https://rstudio.com/wp-content/uploads/2015/03/ggplot2-cheatsheet.pdf

Workshop outline

1. Rules for better figures
2. Using R

   2.1: Building your plot (Orange tree data)

   2.2: Building a 2nd graph (Temperature data)

   2.3: Plotting averages using ddply

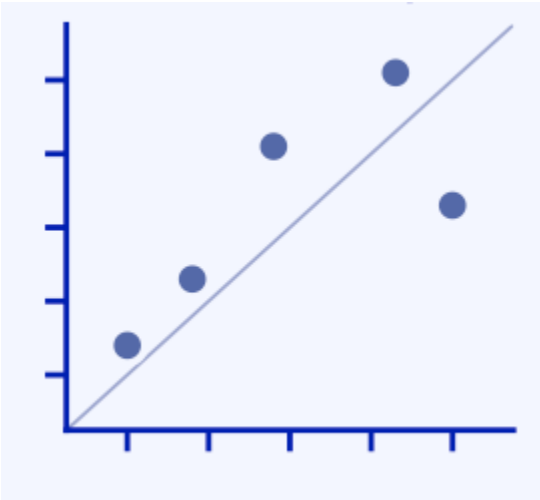
   2.4: Fitting a model (i.e. a logistical model)

   2.5: Saving your figure

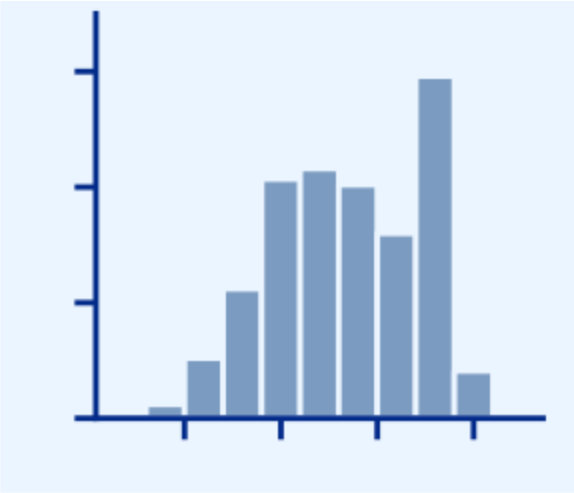
Part 1: Rules for better figures

1. What's your story?

Relationship



Distribution



Comparison

Figures: Wilke 2019

1. What's your story?

Caution!

@allison_horst

1. What's your story?

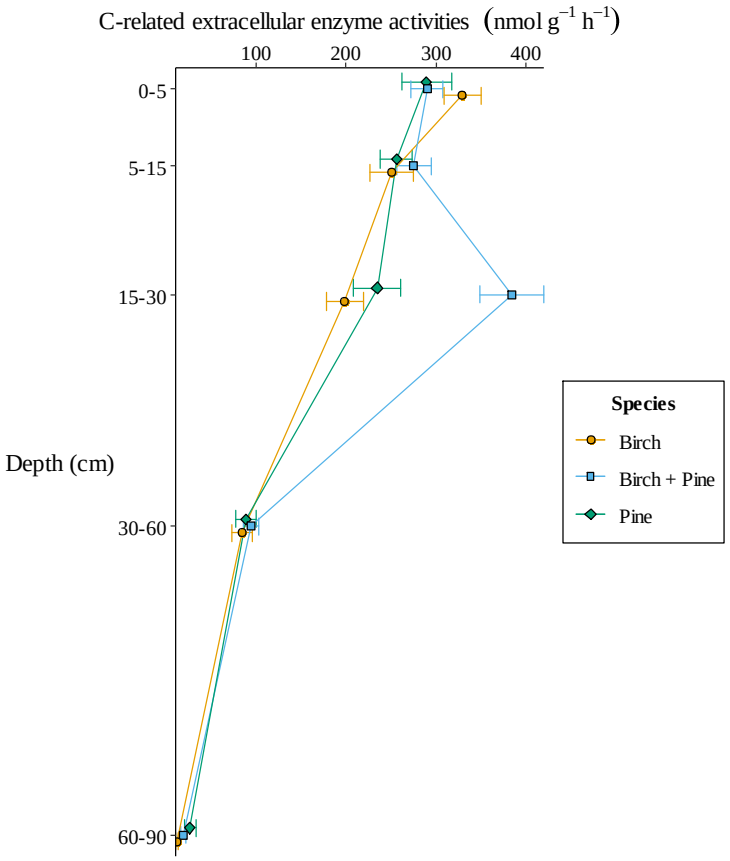
2. Know your audience

- Lab group
- Small conference
- Broad conference
- General public

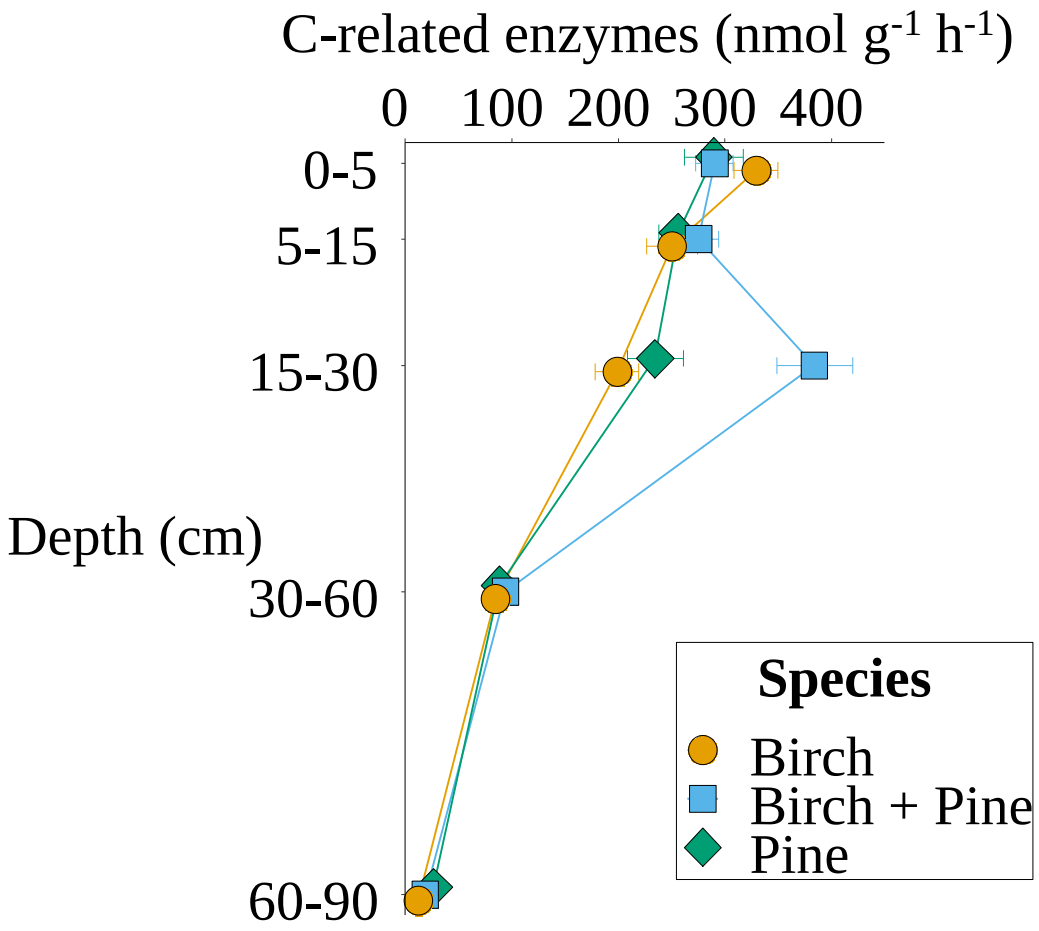
1. What's your story?

2. Know your audience

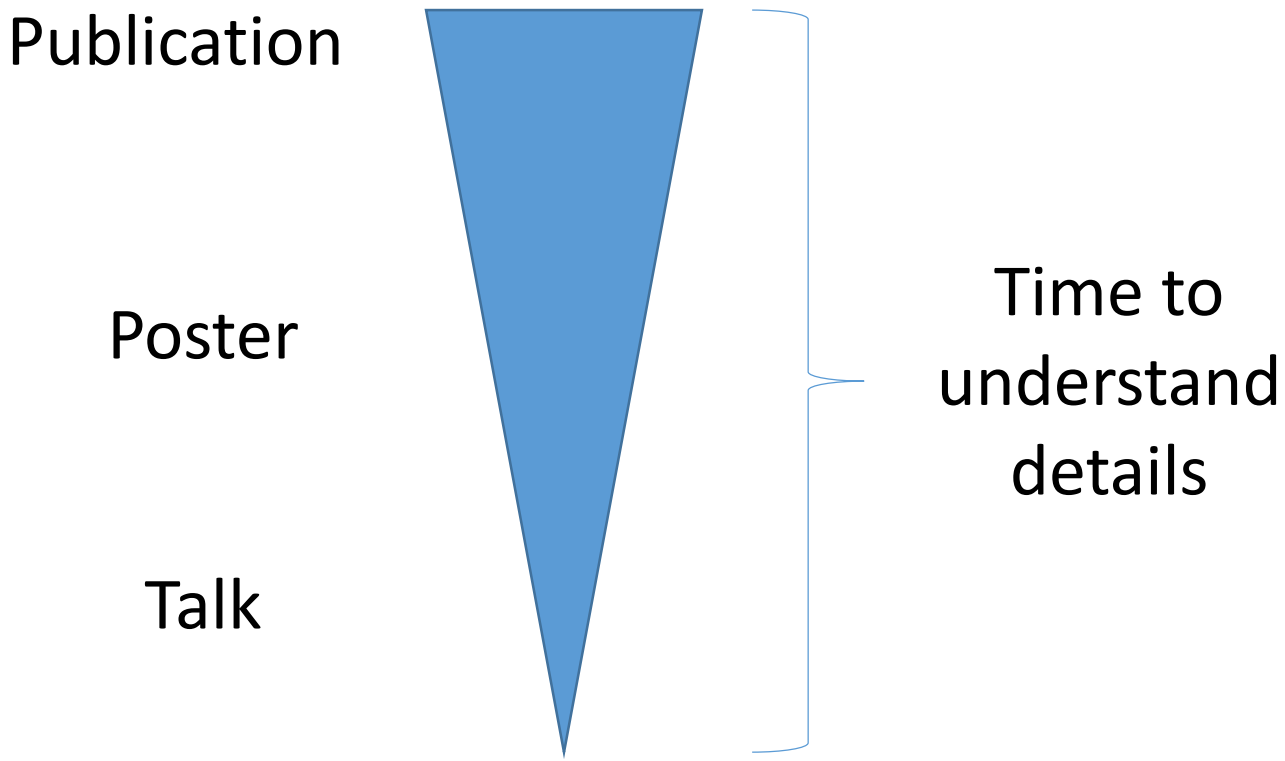
3. Adapt the figure



Maxwell et al. (2020)



3. Adapt the figure (cont.)



Raab et al. 2019, EGU

3. Adapt the figure (cont.)

4. Include Captions

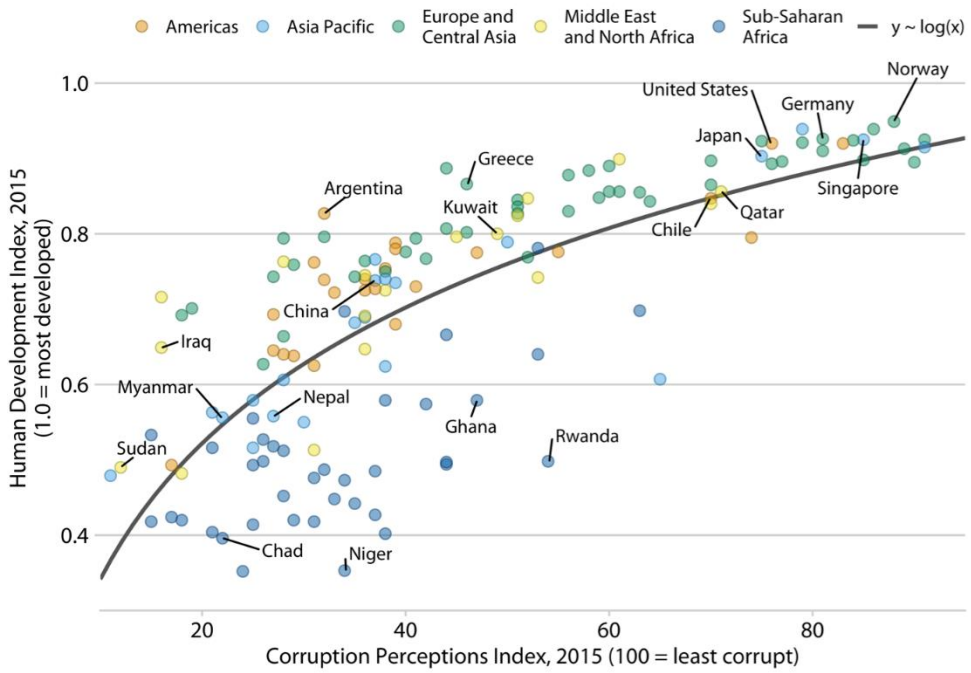
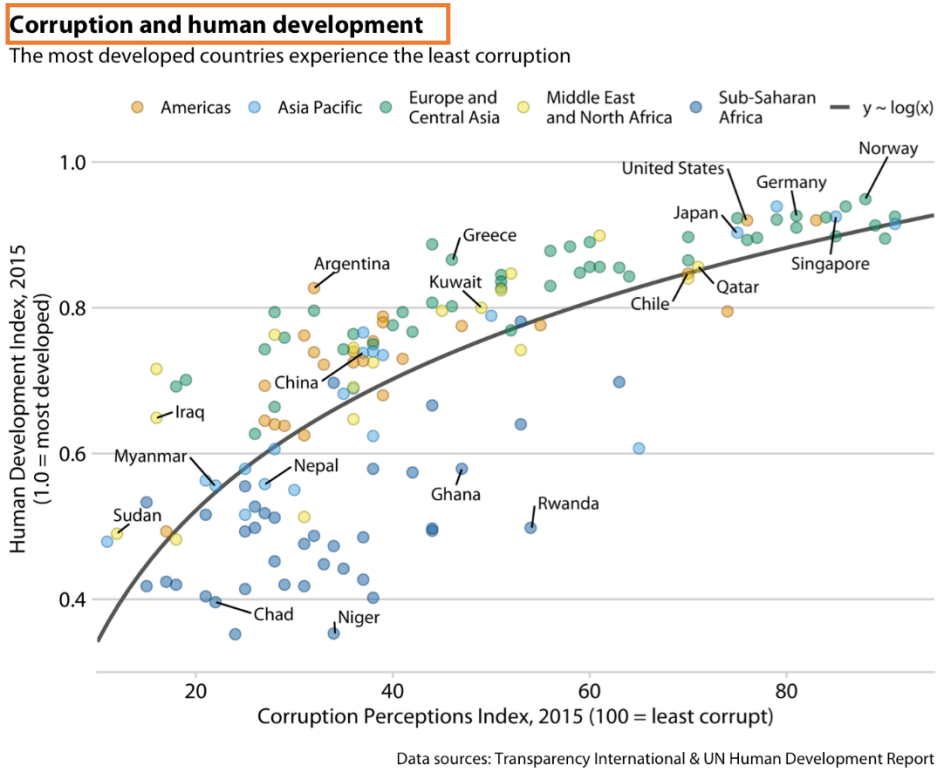


Figure 22.1: Corruption and human development: The most developed countries experience the least corruption. This figure was inspired by a posting in The Economist online (2011). Data sources: Transparency International & UN Human Development Report



Figures from Wilke (2019)

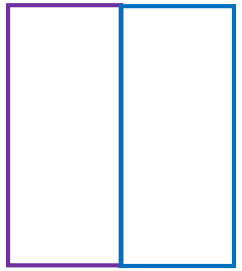
3. Adapt the figure (cont.)

4. Include Captions

5. Choose your Graph maker

Creating / editing figures manually

Excel



R

Image editor (i.e. Inkscape)

3. Adapt the figure (cont.)

4. Include Captions

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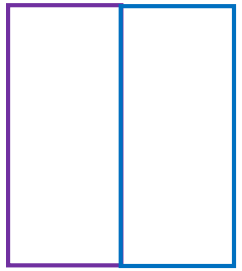
Creating / editing figures manually

Excel



R

Image editor (i.e. Inkscape)

1. Irreproducible
2. Unlikely to re-do figure if asked to be modified
3. You might forget what you did

3. Adapt the figure (cont.)

4. Include Captions

5. Choose your Graph maker

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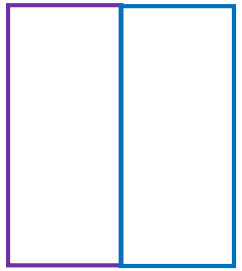
Excel



R

Image editor (i.e. Inkscape)

1. Irreproducible
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Figure preparation pipeline

R Ex: ggplot2

Reproducible

Part 2: Using R

@allison_horst

Part 2.1: Building your plot (Orange tree data)

```
tab<- Orange #import data from ‘datasets’ package

str(tab)
```

```
Classes ‘nfnGroupedData’, ‘nfGroupedData’, ‘groupedData’ and 'data.frame':   35 obs.
of  3 variables:
 $ Tree         : Ord.factor w/ 5 levels "3"<"1"<"5"<"2"<..: 2 2 2 2 2 2 2 4 4 4 ...
 $ age          : num  118 484 664 1004 1231 ...
 $ circumference: num  30 58 87 115 120 142 145 33 69 111 ...
```

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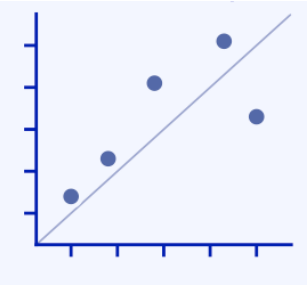
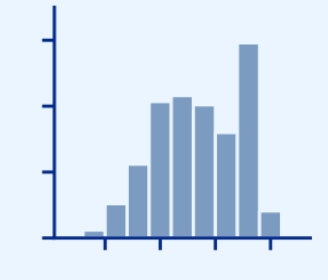
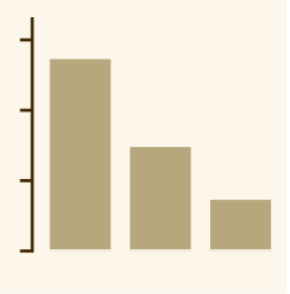
 $ age          : num  118 484 664 1004 1231 ...
 $ circumference: num  30 58 87 115 120 142 145 33 69 111 ...
```

Research question: how does circumference change with age?

→ How do I want to present my data?







Figures: Wilke 2019

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Research question: how does circumference change with age?

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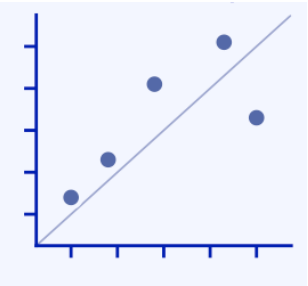


Figures: Wilke 2019

Basic ggplot structure

R

```
p<- ggplot(tab, aes(x=age, y=circumference))
p
```

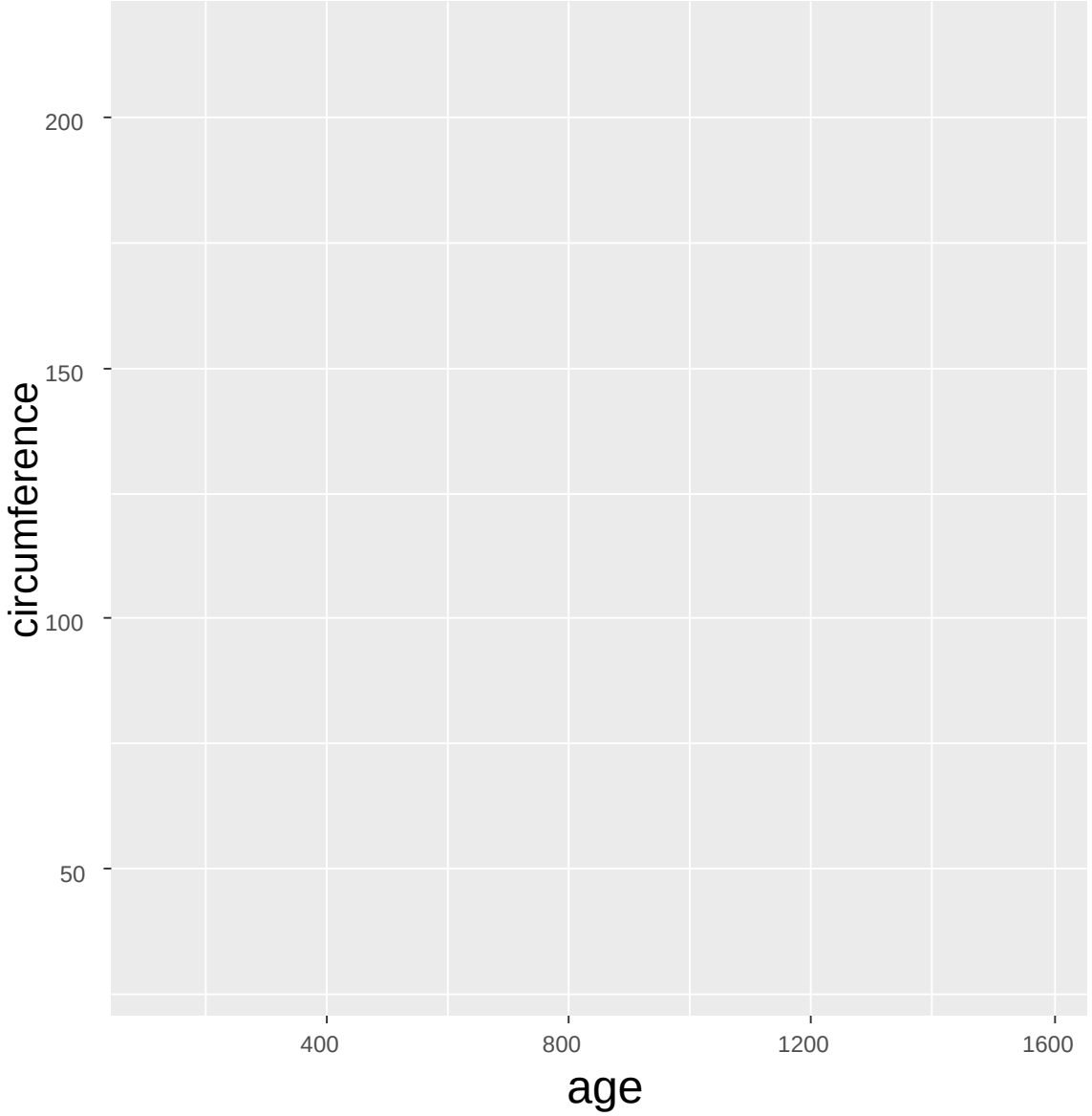
dataset

Coordinate system

Aesthetics = aes

- Quantifiable features

Place graph in an object named “p”;
Display the object



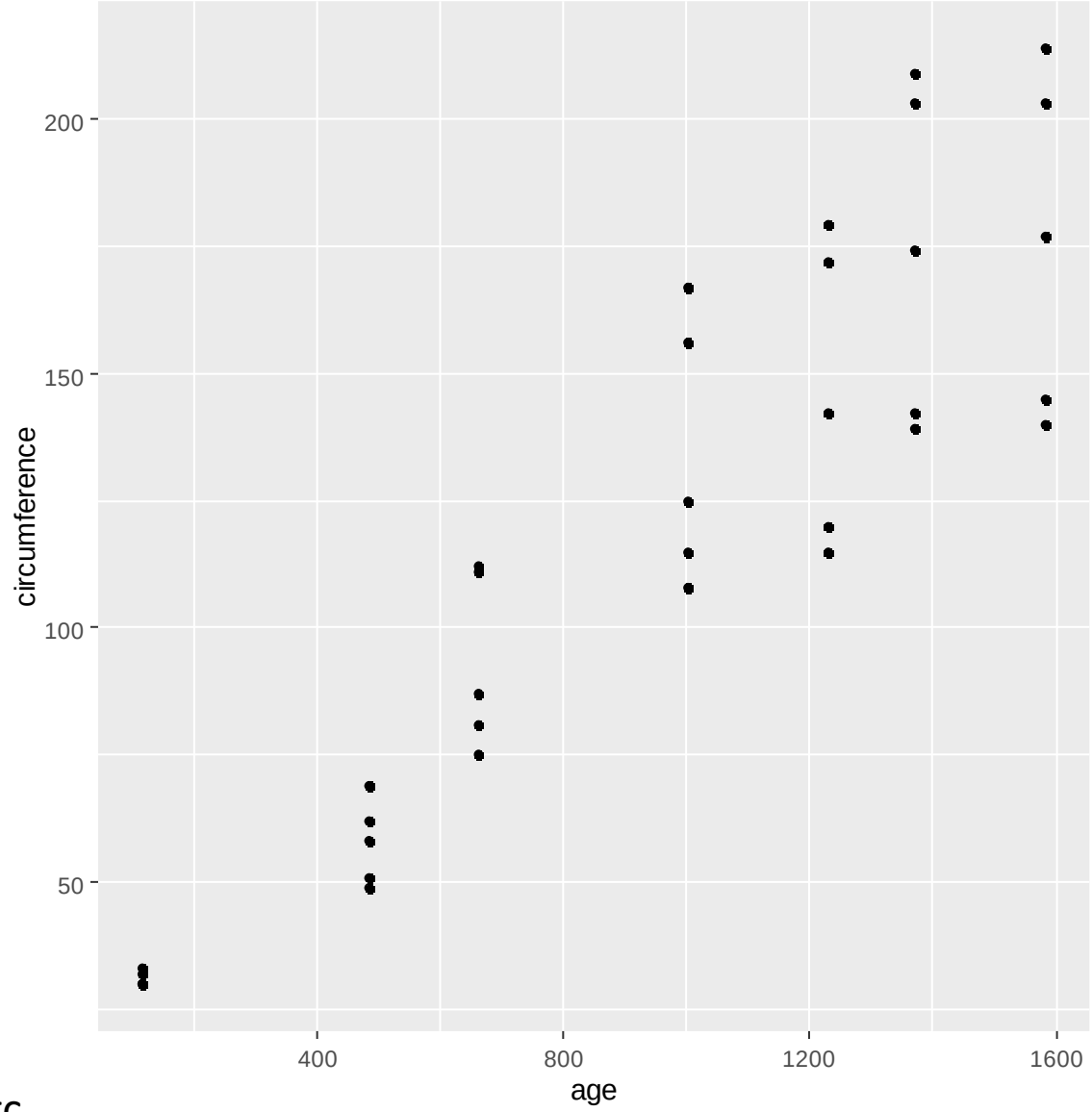
Adding geom_*

R

```
p<- ggplot(tab, aes(x=age, y=circumference))+
geom_point()
p
```

Geom_*
Visual mark that represents data

Adding layers



Geom_point, geom_line, geom_bar, geom_boxplot, geom_text, etc…

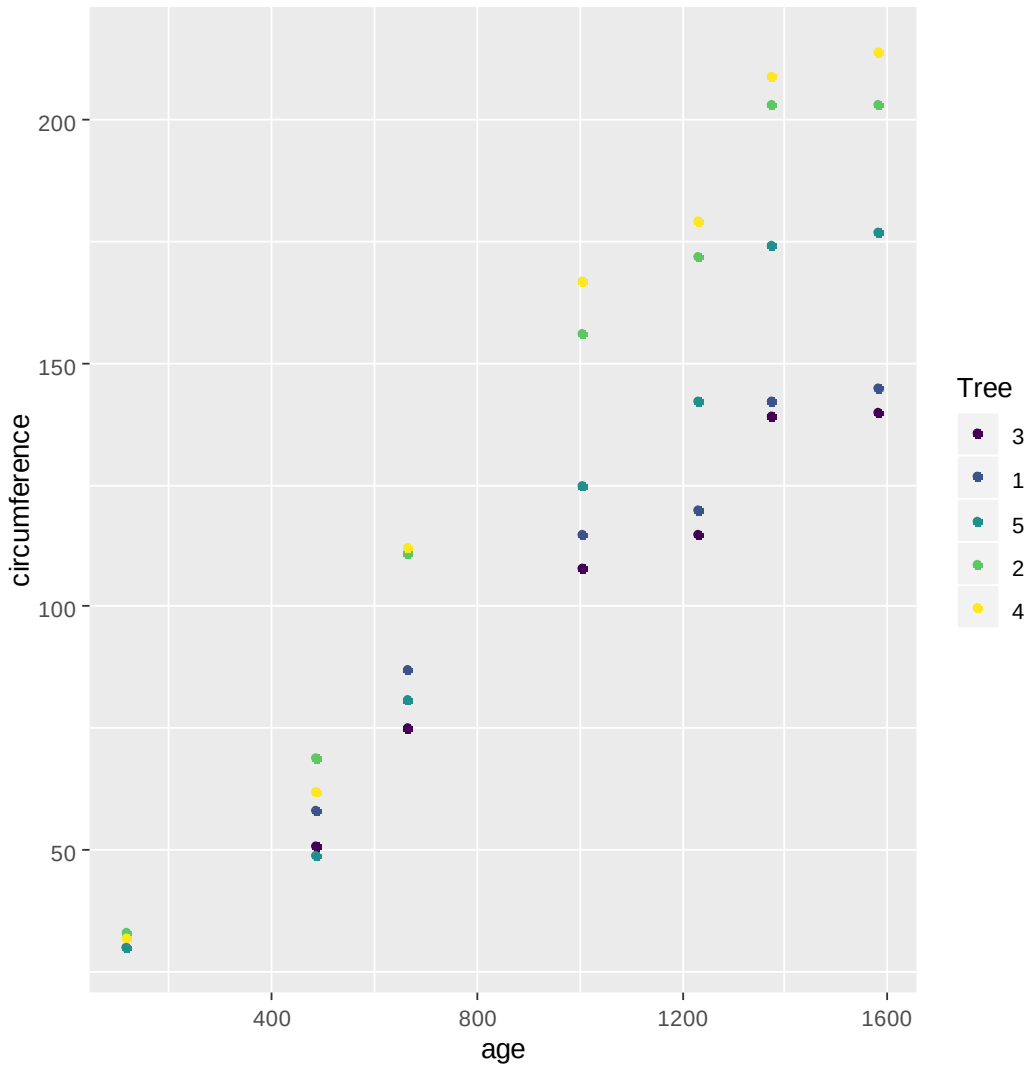
Grouping by a factor (i.e. Tree)

R

```
p<- ggplot(tab, aes(x=age, y=circumference))+
  geom_point(aes(group=Tree, color=Tree))
p
```

Geom_*
Visual mark that represents data

Adding layers

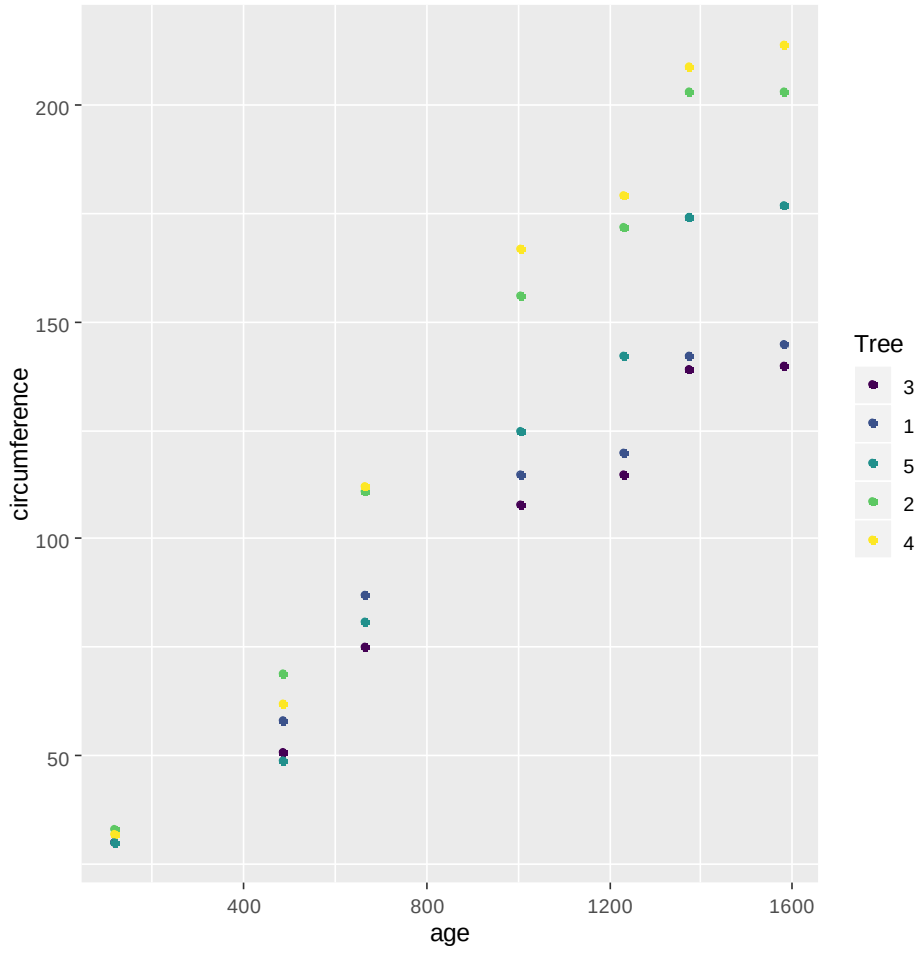


Why are the Trees in the order 3,1,5,2,4 ?

R

```
levels(tab$Tree)
```

```
p<- ggplot(tab, aes(x=age, y=circumference))+
  geom_point(aes(group=Tree, color=Tree))
p
```



Why are the Trees in the order 3,1,5,2,4 ?

R

```
tab$Tree <-factor(tab$Tree, levels = c("1","2","3","4","5"))
```

You can use specify the level order with the above function.

Tree graph reordered

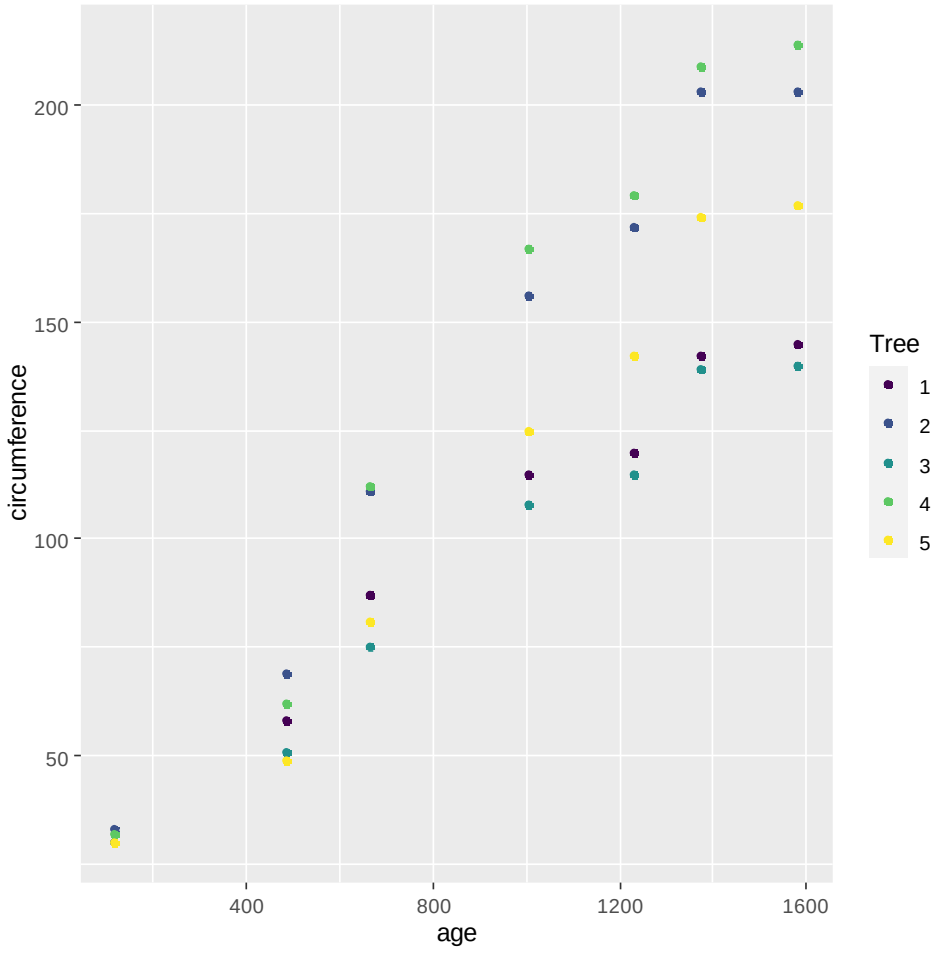
R

```
tab$Tree <-factor(tab$Tree, levels = c("1","2","3","4","5"))
```

You can use specify the level order with the above function.

Rerun your previous code

```
p<- ggplot(tab, aes(x=age, y=circumference))+
  geom_point(aes(group=Tree, color=Tree))
p
```



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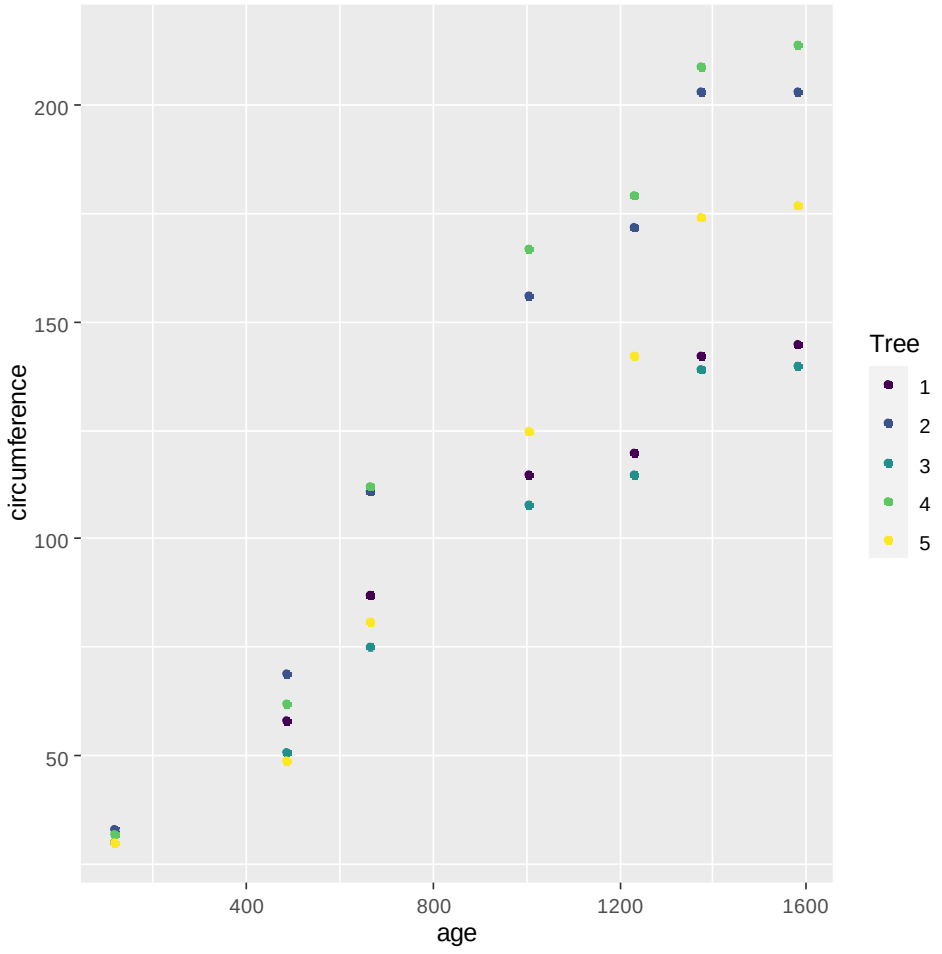
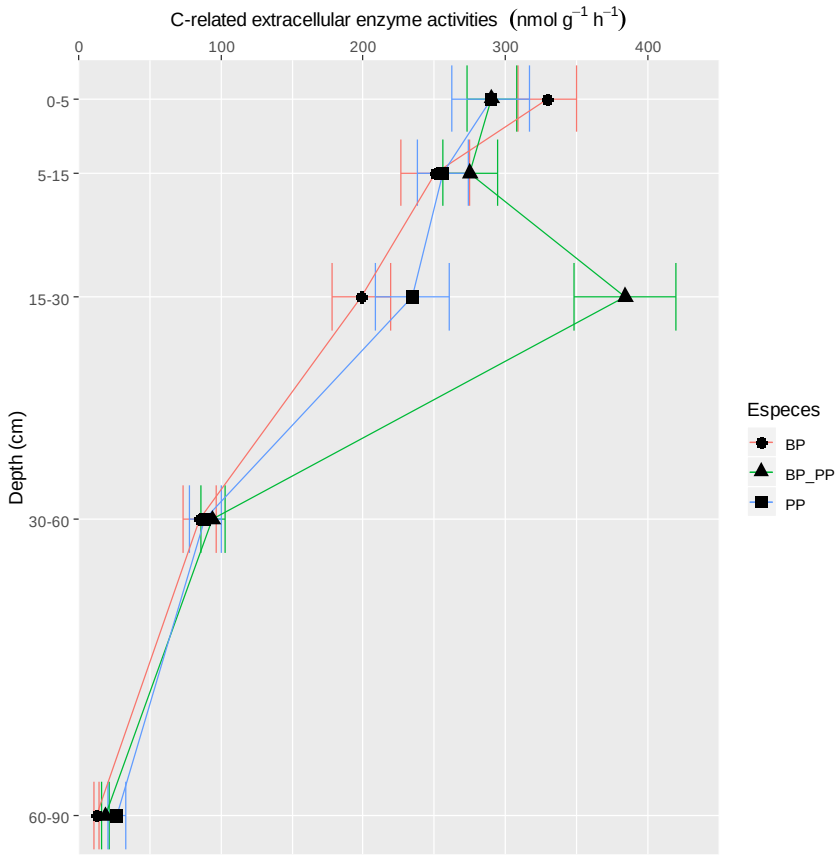
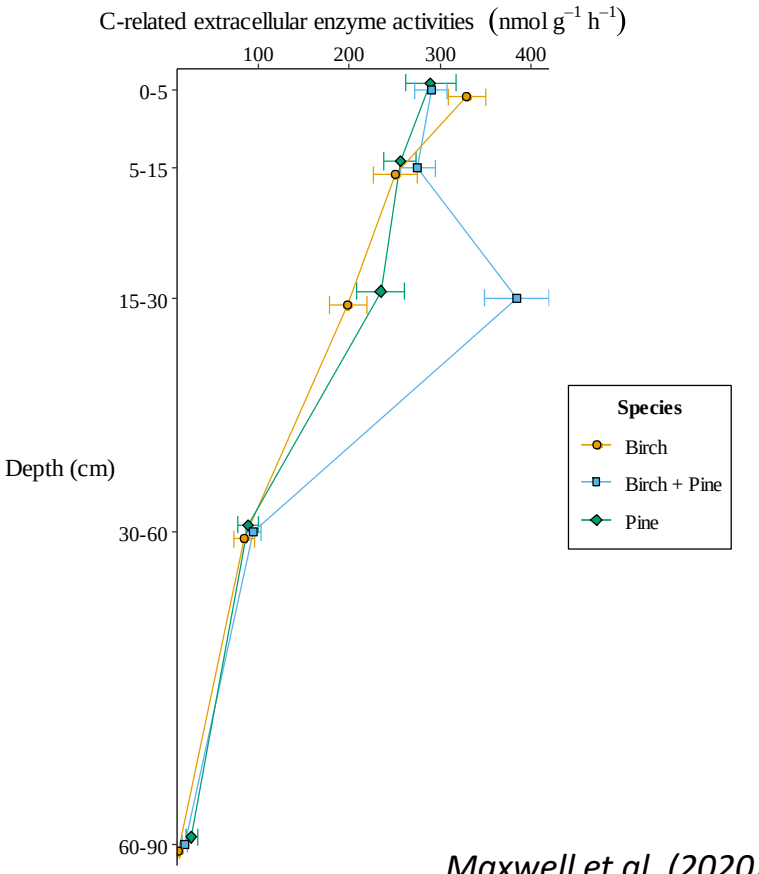


What can you notice about the order of the colors?

6. Don't trust default settings

Color, shape, axes, legend, etc…





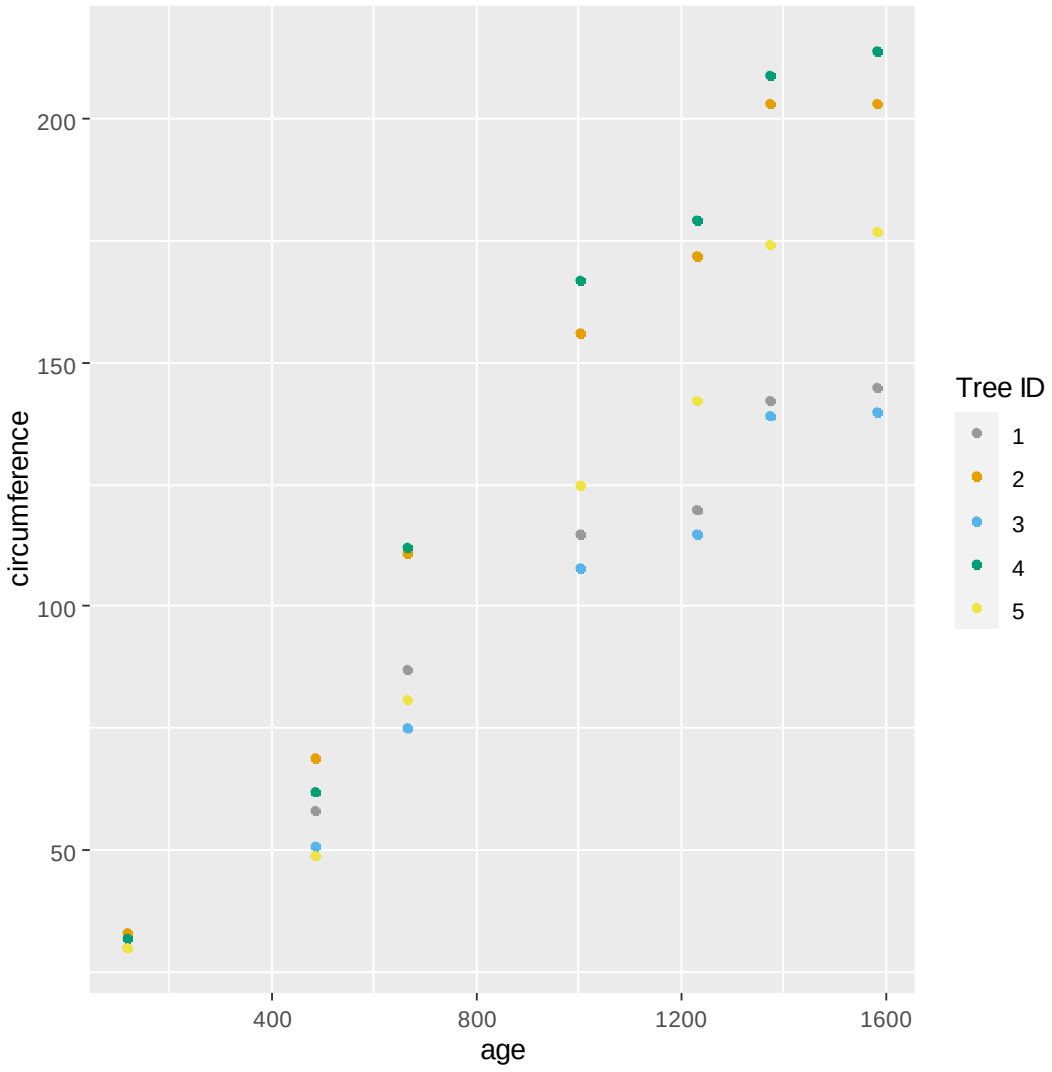
Maxwell et al. (2020)

Changing your colors

R

```
creating your own palette
cbPalette <- c("#999999", "#E69F00", "#56B4E9",
"#009E73", "#F0E442", "#0072B2", "#D55E00",
"#CC79A7")
```

http://www.cookbook-r.com/Graphs/Colors_(ggplot2)/#a-colorblind-friendly-palette



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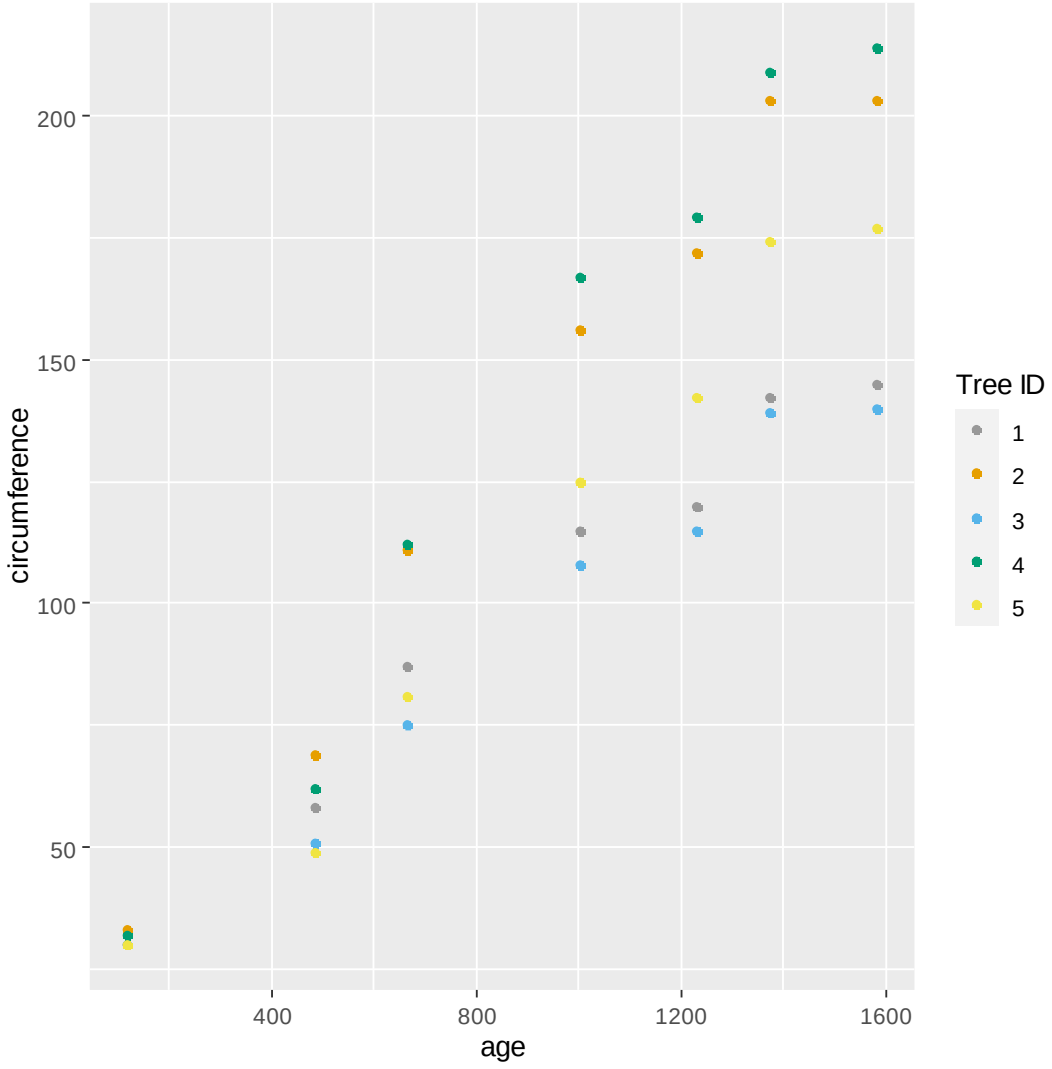
```

http://www.cookbook-r.com/Graphs/Colors_(ggplot2)/#a-colorblind-friendly-palette

```
Add to your previous graph
p<- ggplot(tab, aes(x=age, y=circumference))+
  geom_point(aes(group=Tree, color=Tree))+
  scale_color_manual(name = "Tree ID",
    values=cbPalette)
P
```

Add this to your code



Changing your colors

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cbPalette <- c("#999999", "#E69F00", "#56B4E9",
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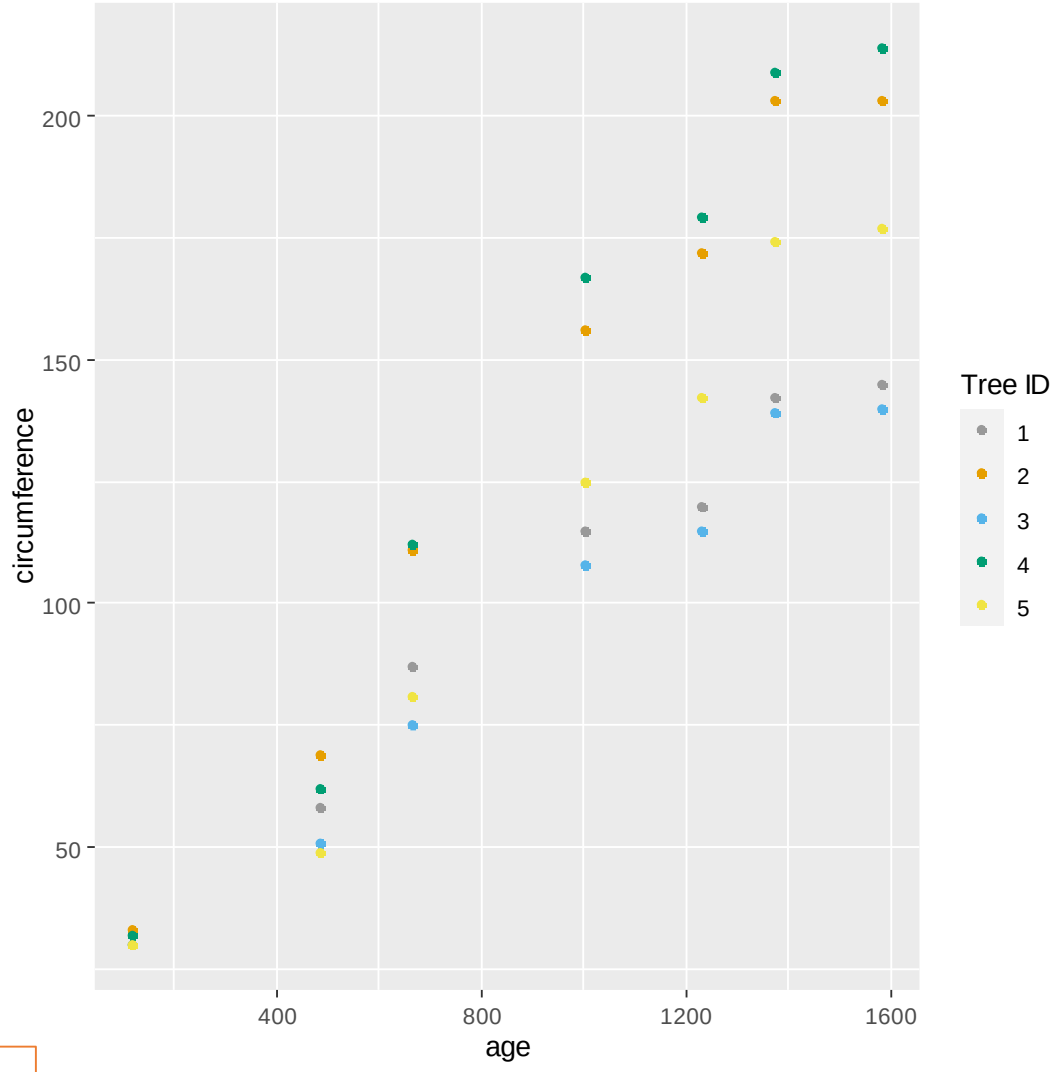
http://www.cookbook-r.com/Graphs/Colors_(ggplot2)/#a-colorblind-friendly-palette

```
Add to your previous graph
p<- ggplot(tab, aes(x=age, y=circumference))+
  geom_point(aes(group=Tree, color=Tree))+
  scale_color_manual(name = "Tree ID",
    values=cbPalette)
P
```

Note: since there are five levels of Trees, R will take the first five colors in your palette.

You can rename the legend title here



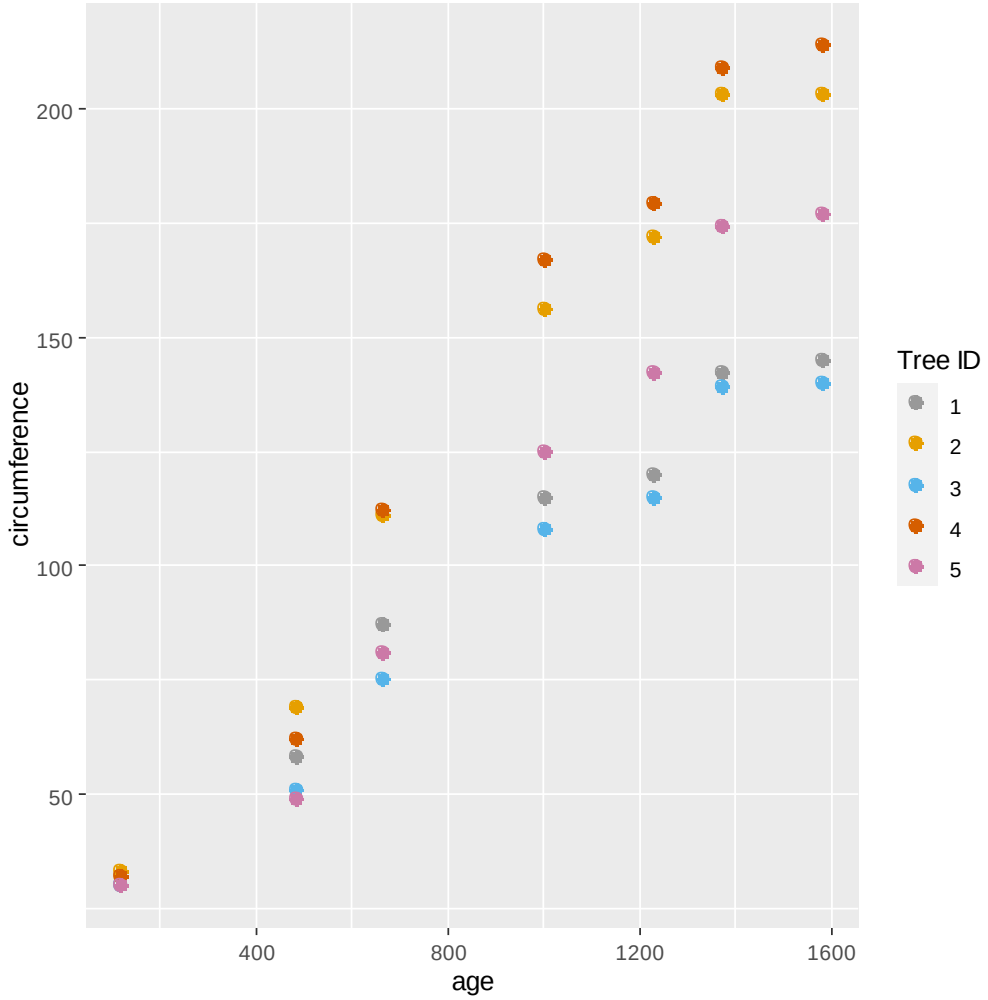
Changing your colors

R

```
p<- ggplot(tab, aes(x=age, y=circumference))+
  geom_point(aes(group=Tree, color=Tree), size =2.5)+
  scale_color_manual(name = " Tree ID", values =
    c("#999999", "#E69F00", "#56B4E9", "#D55E00",
    "#CC79A7"))
p
```

You can also add a list of colors with manual values

To increase your point size

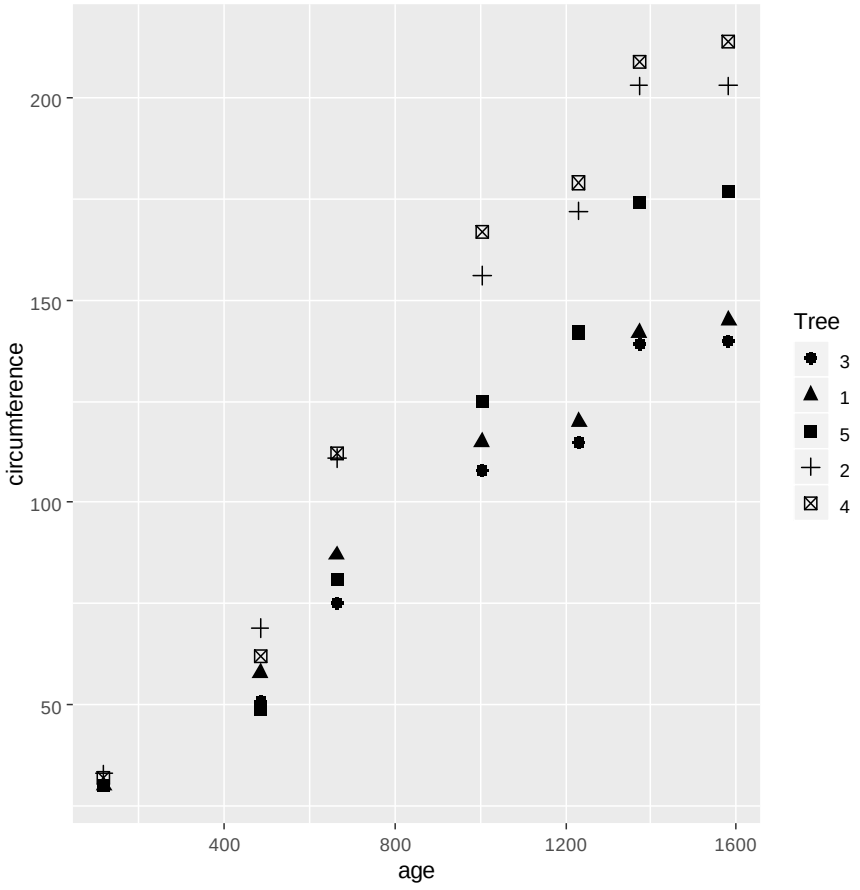


Resource to pick colors:

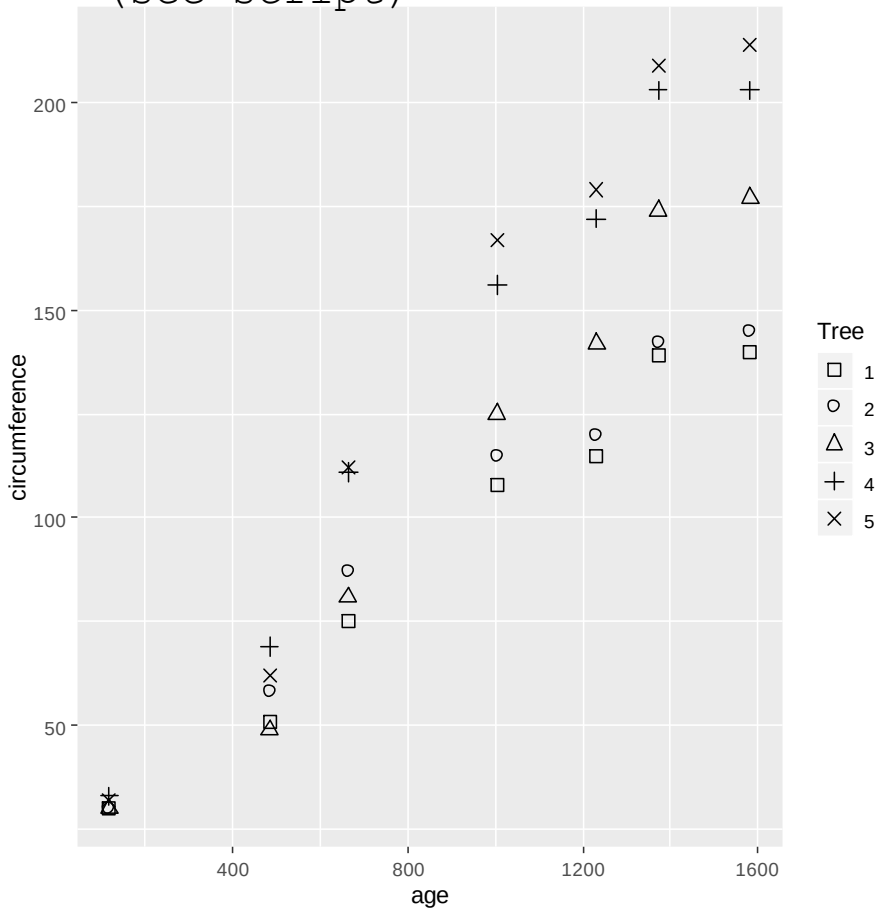
http://colorbrewer2.org/#type=sequential&scheme=BuGn&n=3

Or, you can group by shape

```
p<- ggplot(tab, aes(x=age, y=circumference))+
  geom_point(aes(group=Tree, shape=Tree),size=2.5)
p
```



Manually choosing shapes (see script)



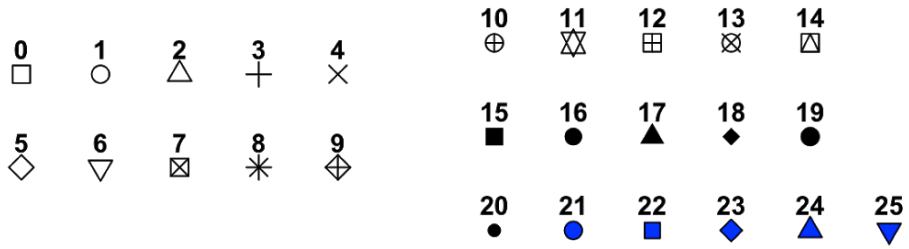
Grouping by color & shape - Caution

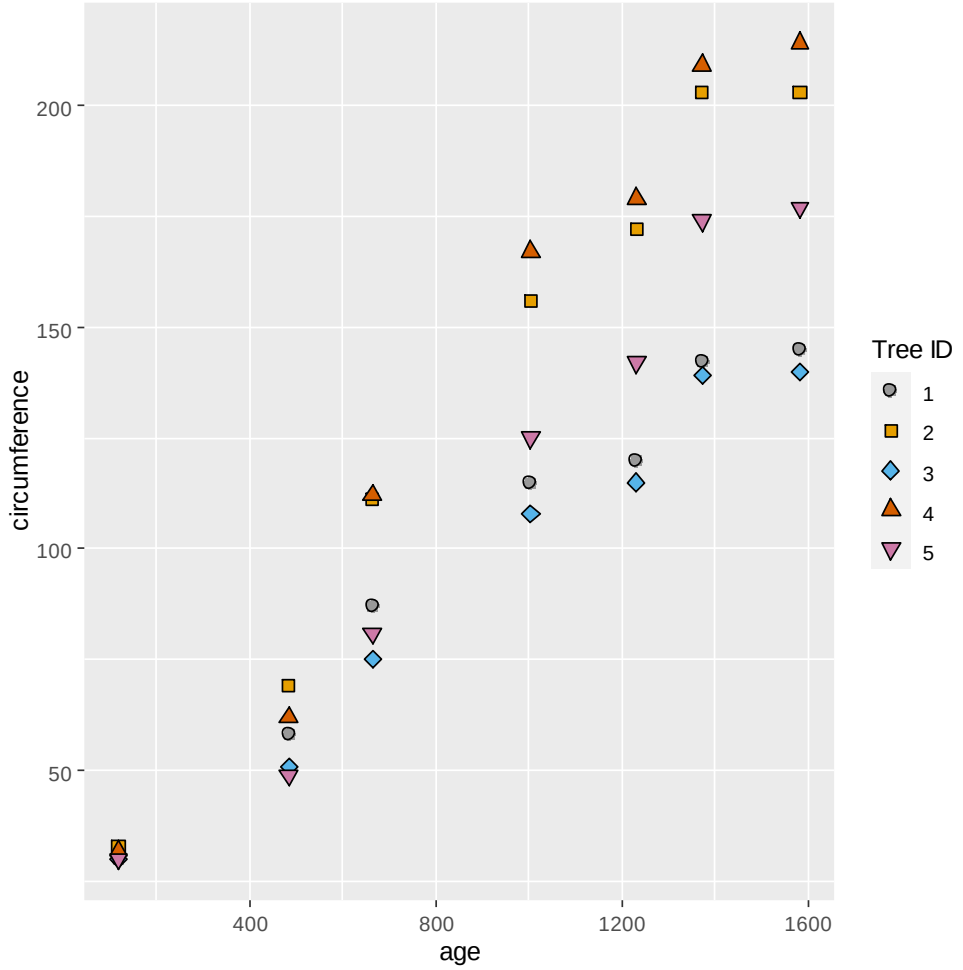
R

Our previous plot (shortened in presentation)

```
p<- p +
    scale_shape_manual(name = "Tree ID",
    values=c(21,22,23,24,25))+
    scale_fill_manual(name="Tree ID", values =
    c("#999999", "#E69F00", "#56B4E9", "#D55E00",
    "#CC79A7"))
p
```

These are different shape styles, which are identified by a number



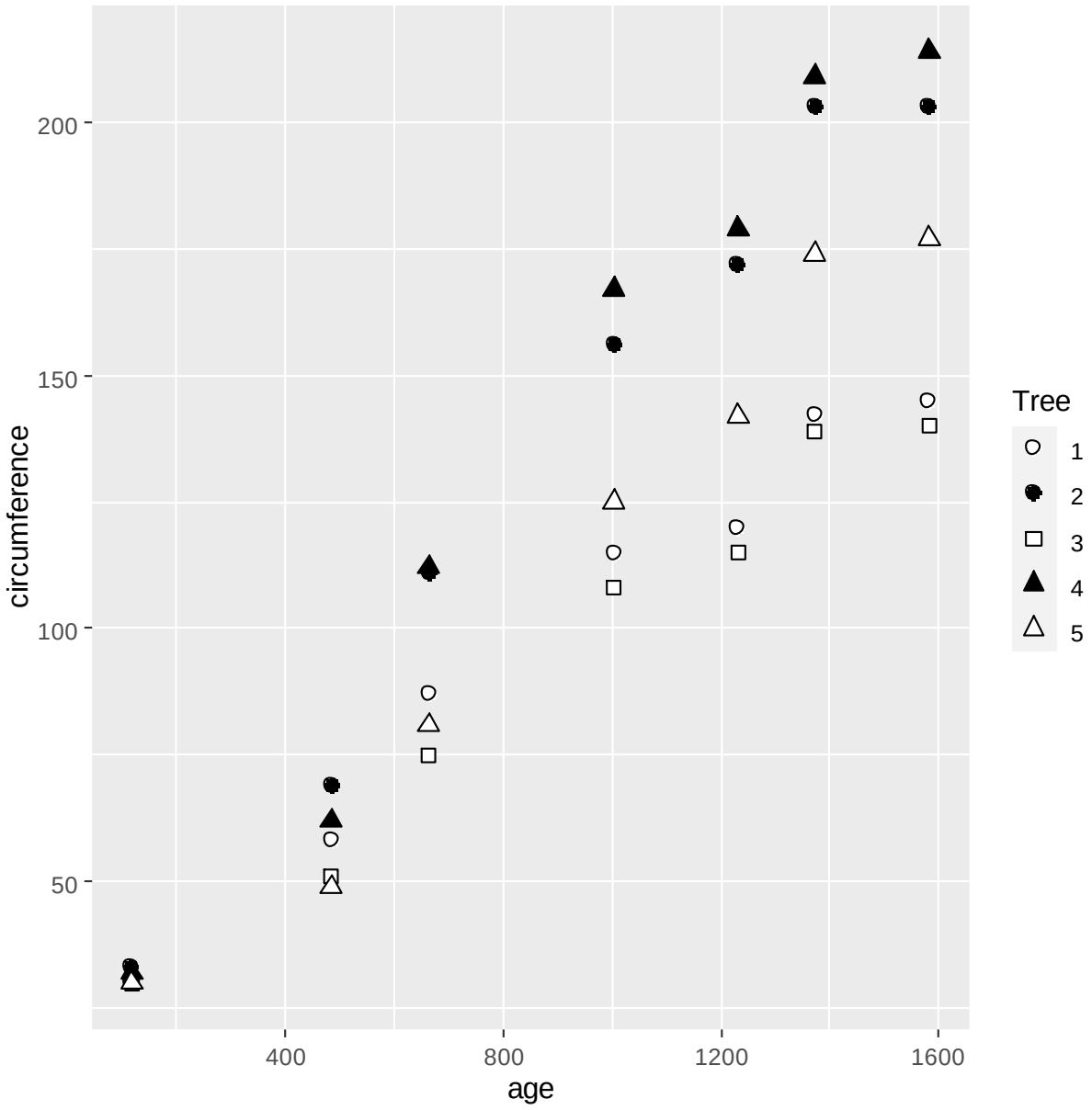


7. Use colors and symbols effectively

- Find the greyscale equivalent

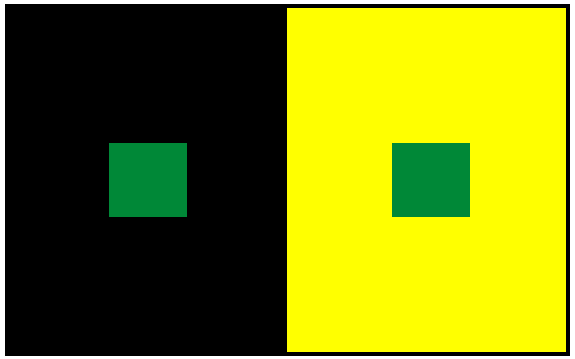
  https://toolstud.io/color/rgb.php

- Is black and white possible?

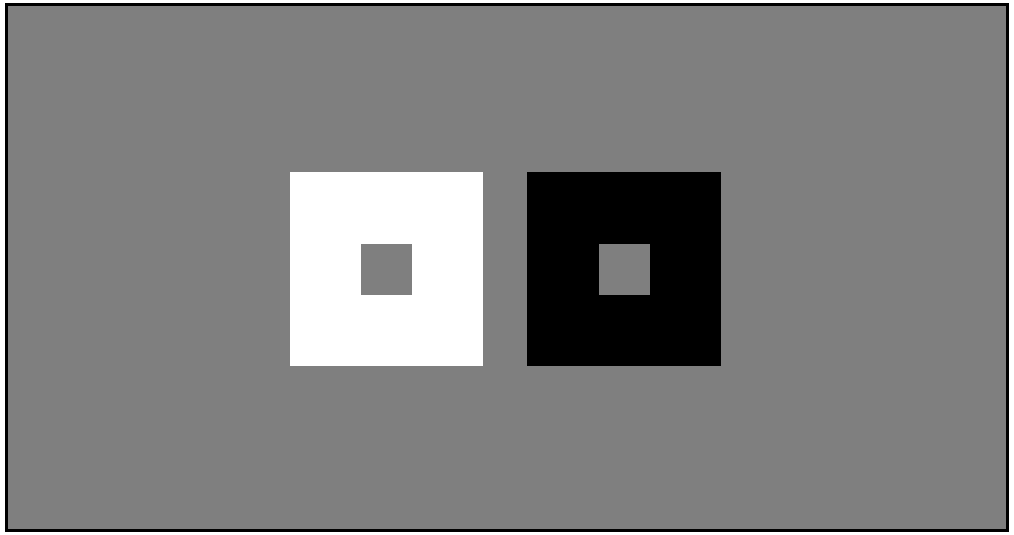


7. Use colors and symbols effectively

(Continued)



- Colors can change with background



- Think about overlap of points

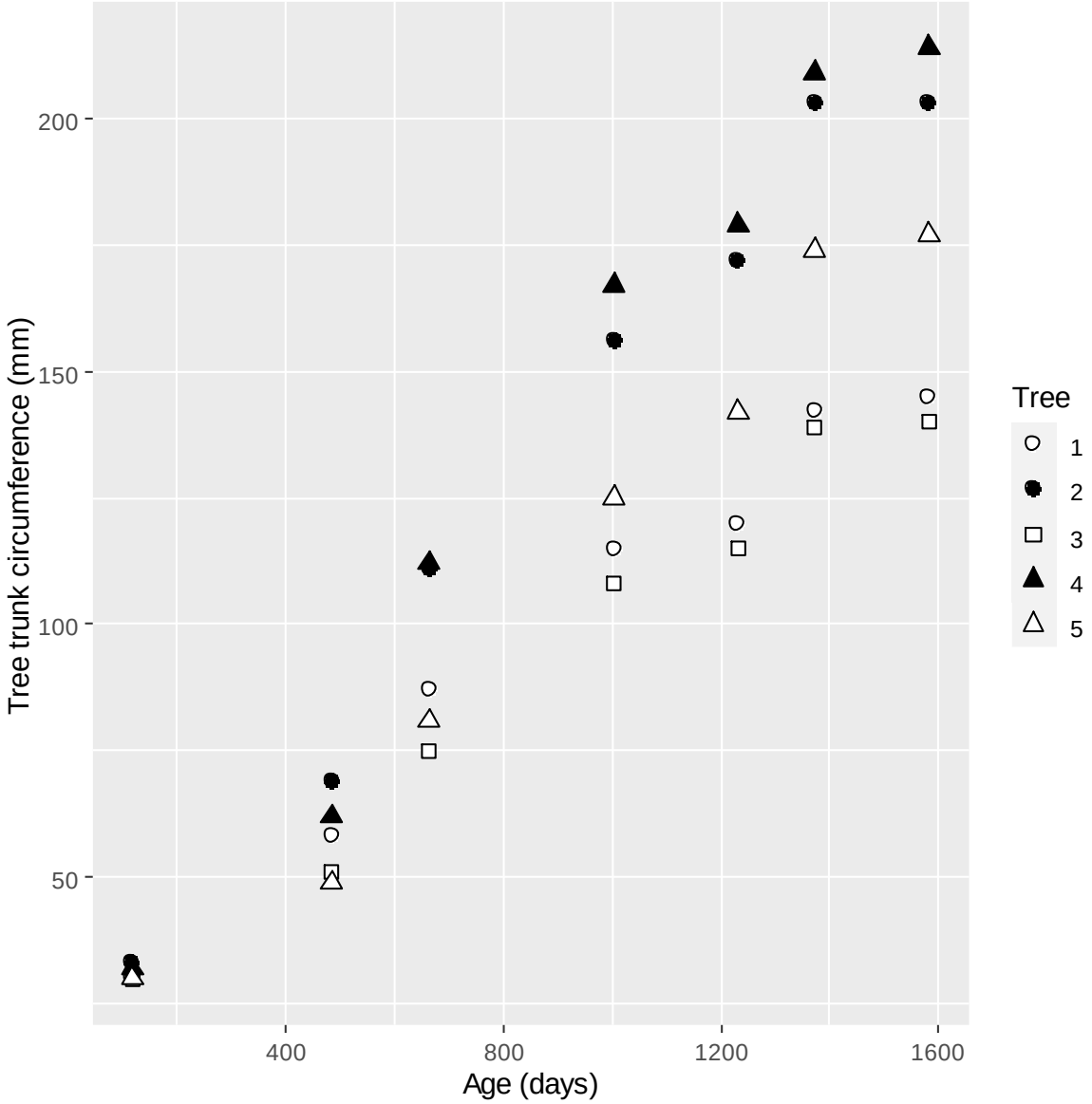
Images from: https://www.extremetech.com/extreme/49034-colors-affect-colors

Changing your axes

R

```
p<- p +
  labs(x="Age (days)", y="Tree trunk
    circumference (mm) ")
p
```

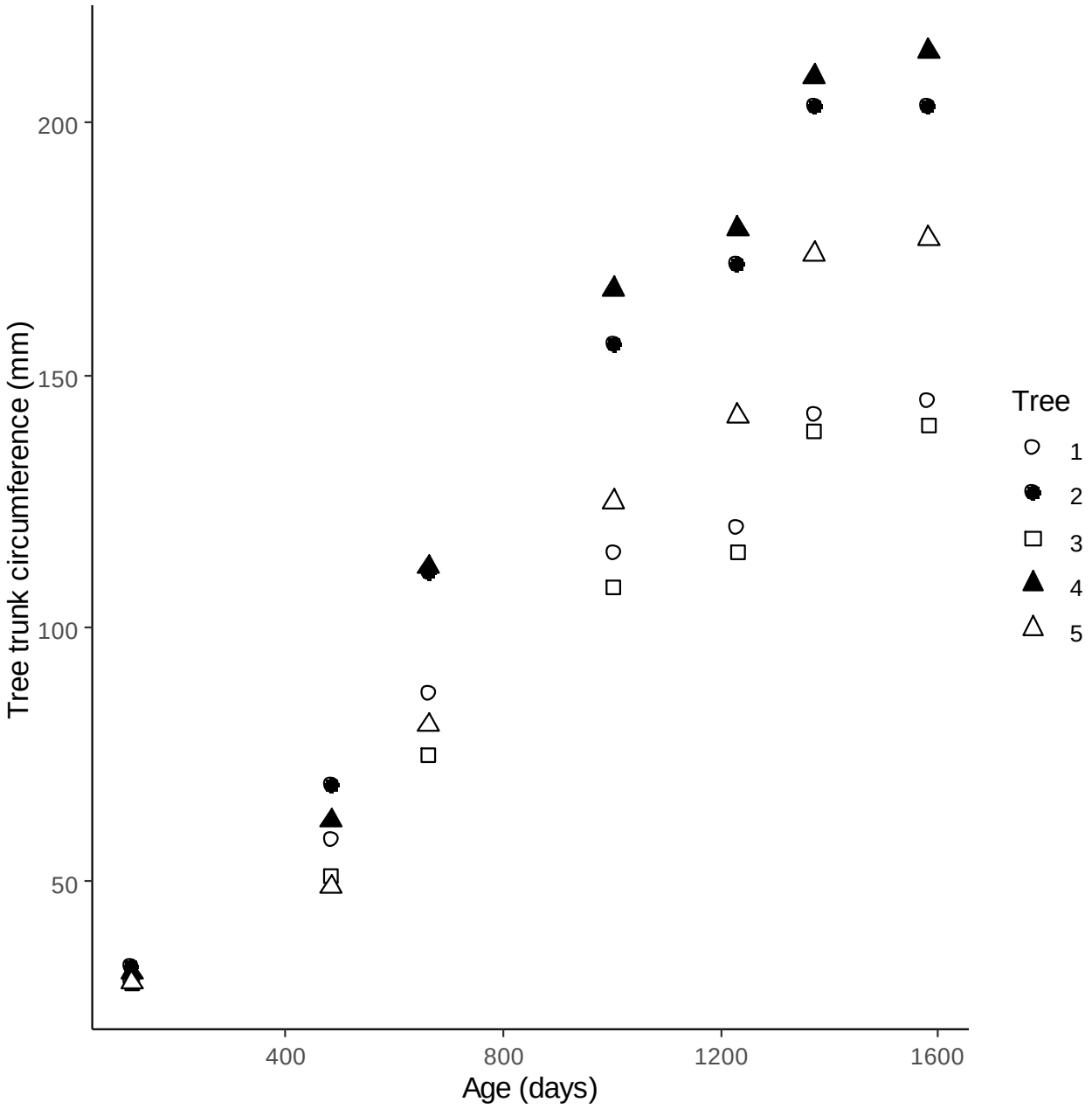
Give as much information to the reader as possible



Add a theme

```
p <- p +
  theme_classic()
p
```

One of the built-in ggplot themes

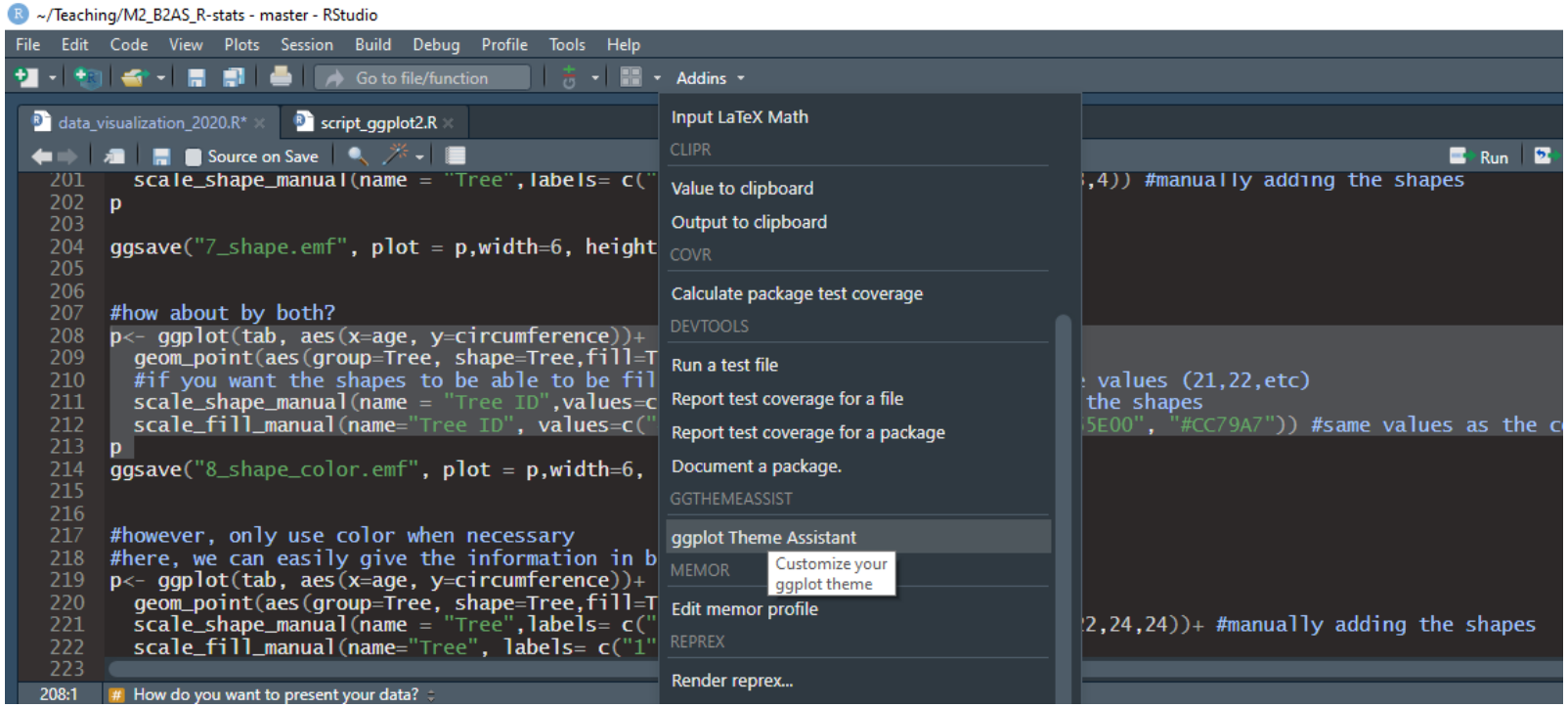


Personalize your themes

R

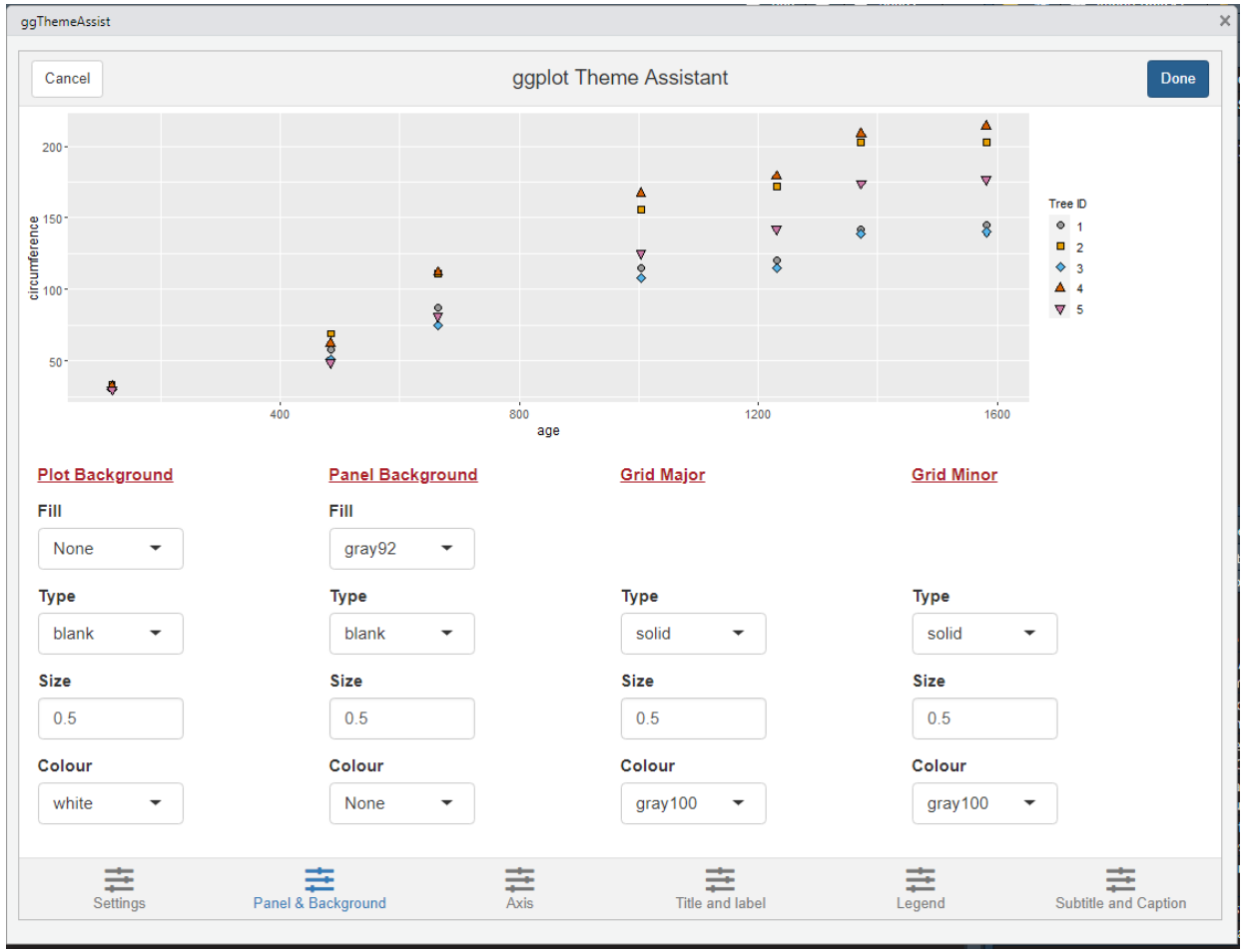
1. `library(ggThemeAssist)`

2. Select your script for your graph
3. Click on Addins → ggplot Theme Assistant



Personalize your themes

3. Using the visual interface, modify the style of your graph
4. Click ‘Done’
5. The script for the figure will be added to your script



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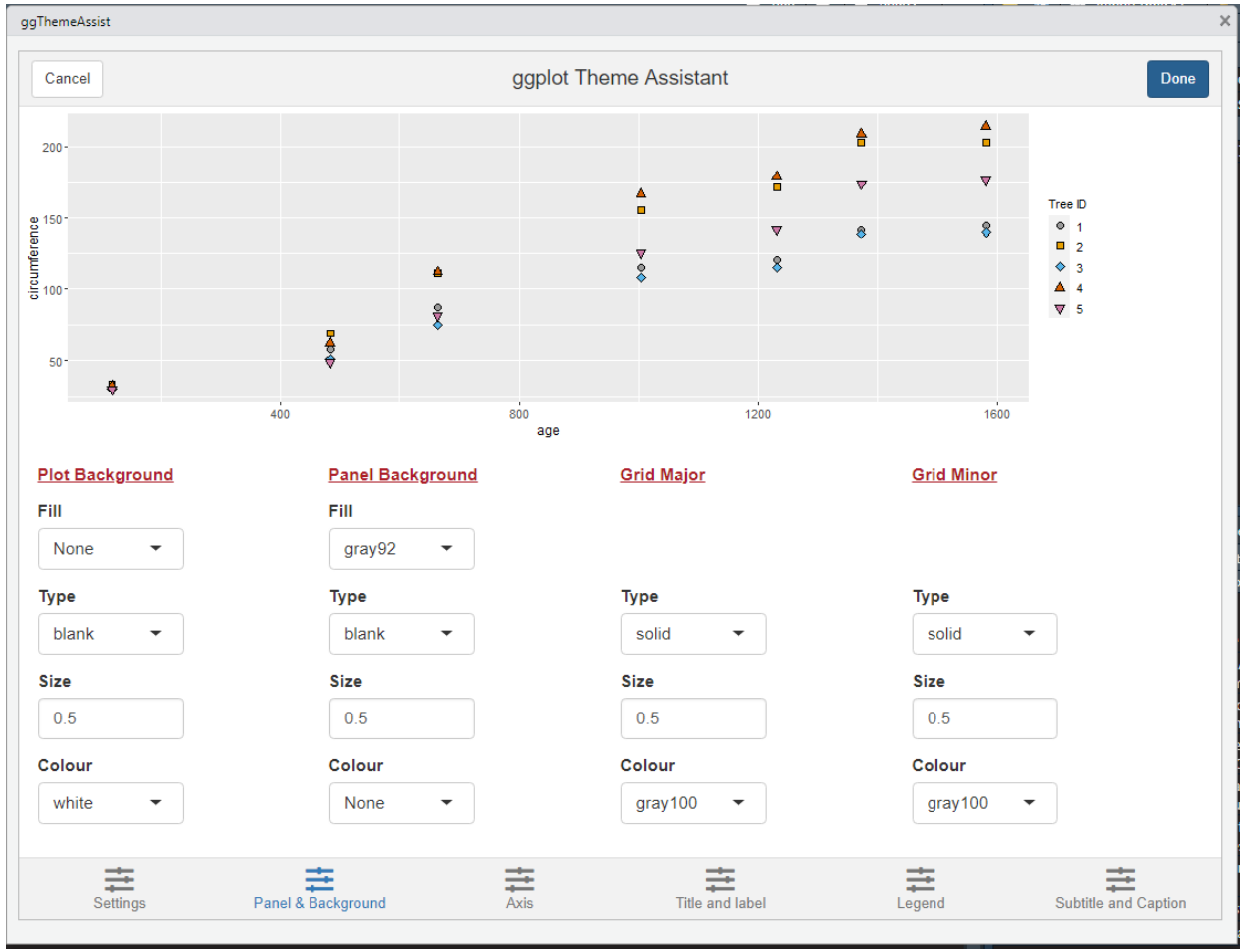
4. Click ‘Done’
5. The script for the figure will be added to your script



Note: I recommend doing this once for the basic information, which can be reusable in future graphs

- Panel & Background
- The size and color of font, axis and labels

You can save that theme and add it to any figure

NOTE: you can only save items which all fit within the "theme()" function (for example, can't save theme() + labs()

You can save your theme

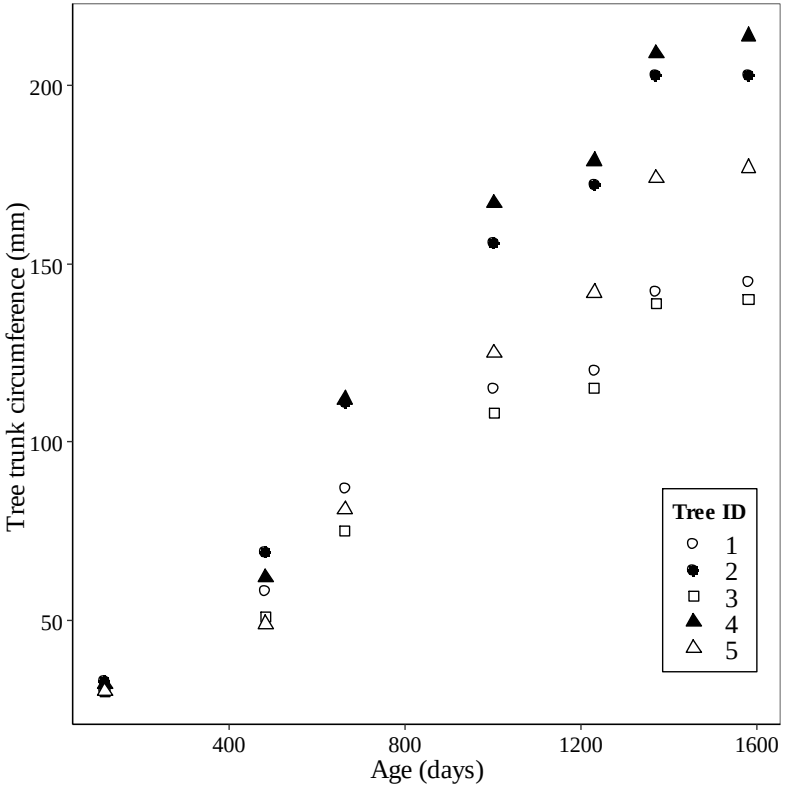
Make two themes:

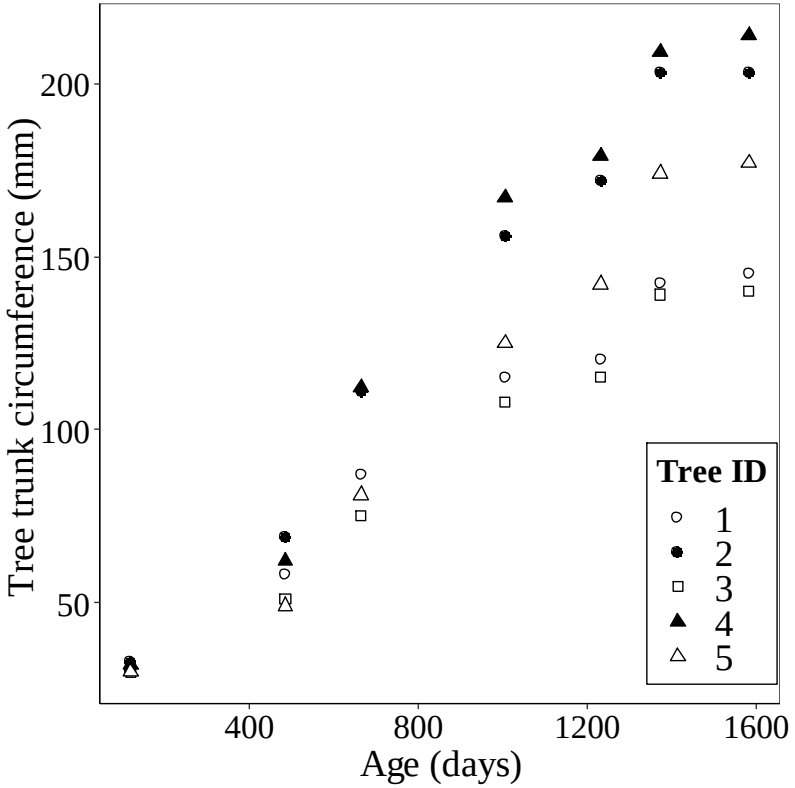
1. For figures to be printed
2. Figures for presentations

R

```
newtheme_print <- theme(...)

newtheme_pres <- theme(...)
```





You can save your theme

Make two themes:

1. For figures to be printed
2. Figures for presentations

R

```
newtheme_print <- theme(...)

newtheme_pres <- theme(...)
```

```
#Example: saving your theme
newtheme_print<-     theme_classic()+
  theme(panel.border = element_rect(linetype = "solid", fill = "NA"))+
  theme(axis.title.x=element_text(angle=0, size=14, family="serif",color = "black"),
        axis.text.x = element_text(angle =0, size=12,family="serif",color = "black"),
        axis.title.y=element_text(angle=90, size=14, hjust=.5, vjust=.5,family="serif",color = "black"),
        axis.text.y = element_text(size=12,family="serif",color = "black"),
        legend.title=element_text(size=12, face="bold", hjust=.5, family="serif"),
        legend.text=element_text(size=14, family="serif"),
        legend.background = element_rect(linetype="solid", colour ="black"),
        legend.key.size = unit(0.5,"cm"),
        legend.key.width = unit(0.8, "cm"),
        legend.position = c(0.9, 0.2))
```

Part 2.2 Building a 2nd graph (Temperature data)

Linking growth to annual temperature could be interesting?

Import new data set to create new graph

R

```
tab2<-as.data.frame(nhtemp)
str(tab2)
'data.frame': 60 obs. of  1 variable:
 $ x: Time-Series  from 1912 to 1971: 49.9 52.3 49.4 51.1 49.4...
```

Note: this data is unrelated

Part 2.2 Building a 2nd graph (Temperature data)

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tab2<-as.data.frame(nhtemp)
str(tab2)
'data.frame': 60 obs. of  1 variable:
 $ x: Time-Series  from 1912 to 1971: 49.9 52.3 49.4 51.1 49.4...

date<-list(1912:1971)
tab_temp<-cbind(date,tab2)
colnames(tab_temp) <- c("Year","Temperature")
```

Note: this data is unrelated

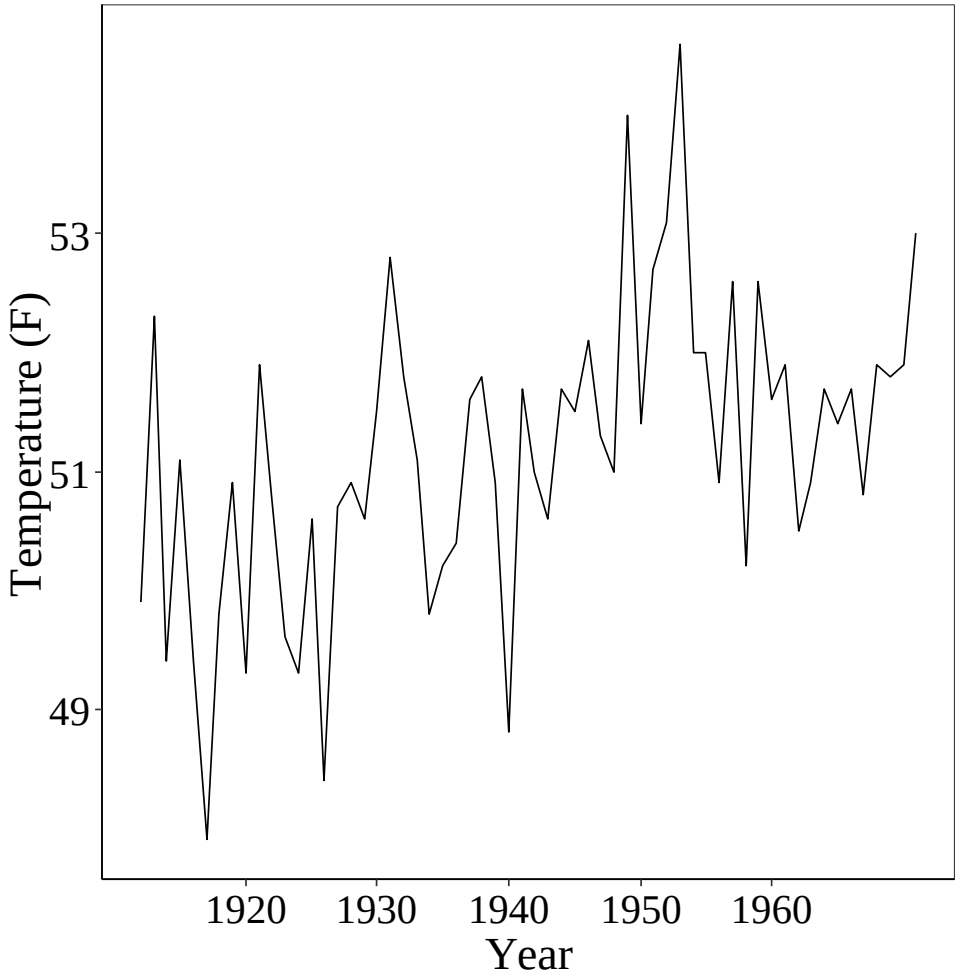
Basic plot using our theme

R

```
r<-ggplot(tab_temp, aes(x=Year, y=Temperature))+
  geom_line()+
  newtheme_print+
  scale_y_continuous(name="Temperature (F)")+
  scale_x_continuous(name="Year", limits =
    c(1912,1971),breaks=c(1920,1930,1940,1950,1960),
    labels=c("1920","1930","1940","1950","1960") )
r
```

This is the theme you saved

New: geom_line()

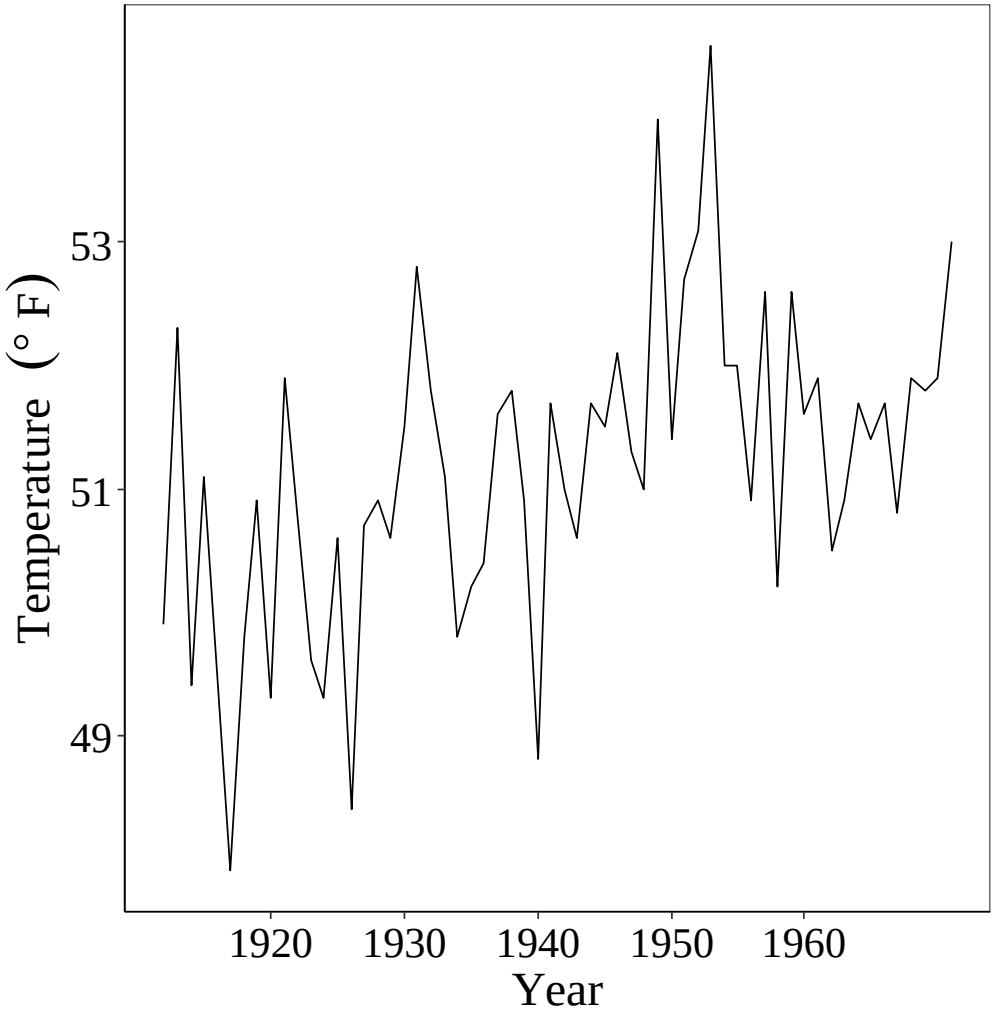


Adding special symbols

```
#create a variable called ylab_temp
ylab_temp <- expression("Temperature "~( degree~F))
#you can also add superscripts and greek letters

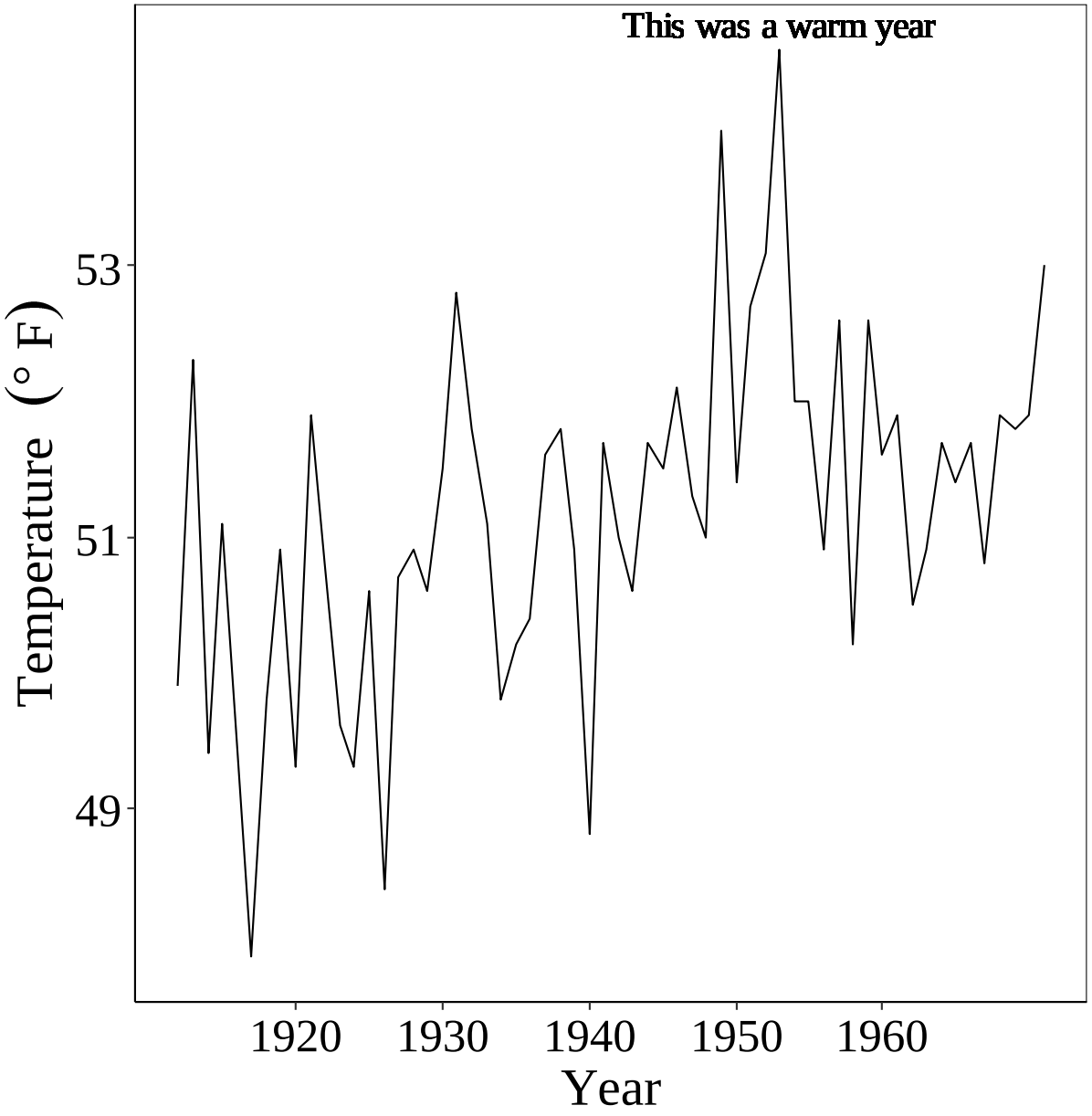
r<- r +
  scale_y_continuous(name = ylab_temp)

r
```



Adding text

```
r <- r +
  geom_text(x=1953, y=54.8,
    label="This was a warm year",
    size=5, color="black",
    family="serif")
r
```



Note: this is good for adding p-values directly only your graph

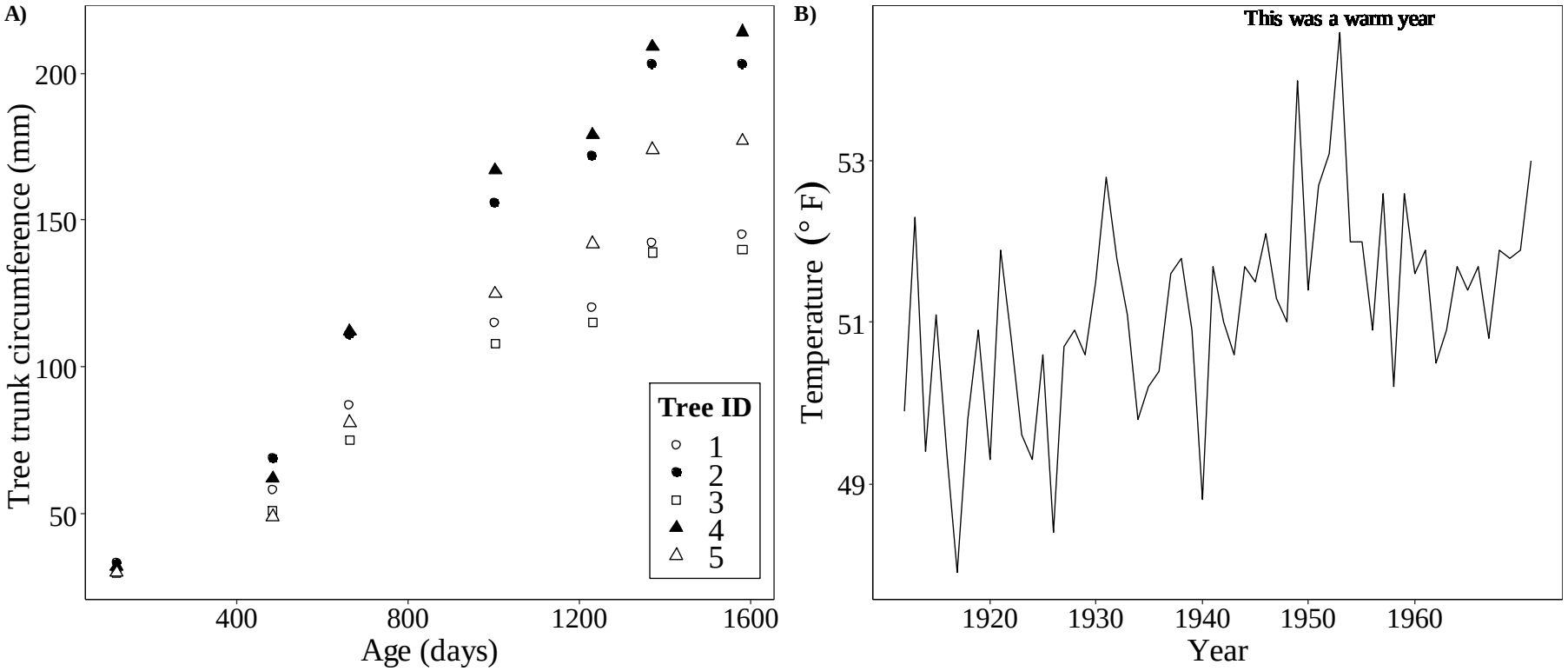
Exporting both graphs next to one another

```
figure<- ggarrange(p, r, labels = c("A)", "B)"), font.label = list (size=14,family="serif"),
                   ncol = 2, nrow = 1)
```

R

Can remove y or x-axis titles easily: r + rremove("y.title")

Ncol = number of columns
Nrow = number of rows



Part 2.3: Plotting averages using dplyr

With the Orange tree data frame = tab

R

```
p<- tab %>%
  group_by(age) %>%
  summarise_each(funs( n = n(), mean = mean(.), se = sd(.)/sqrt(n())), "circumference")
```

Part 2.3: Plotting averages using dplyr

With the Orange tree data frame = tab

R

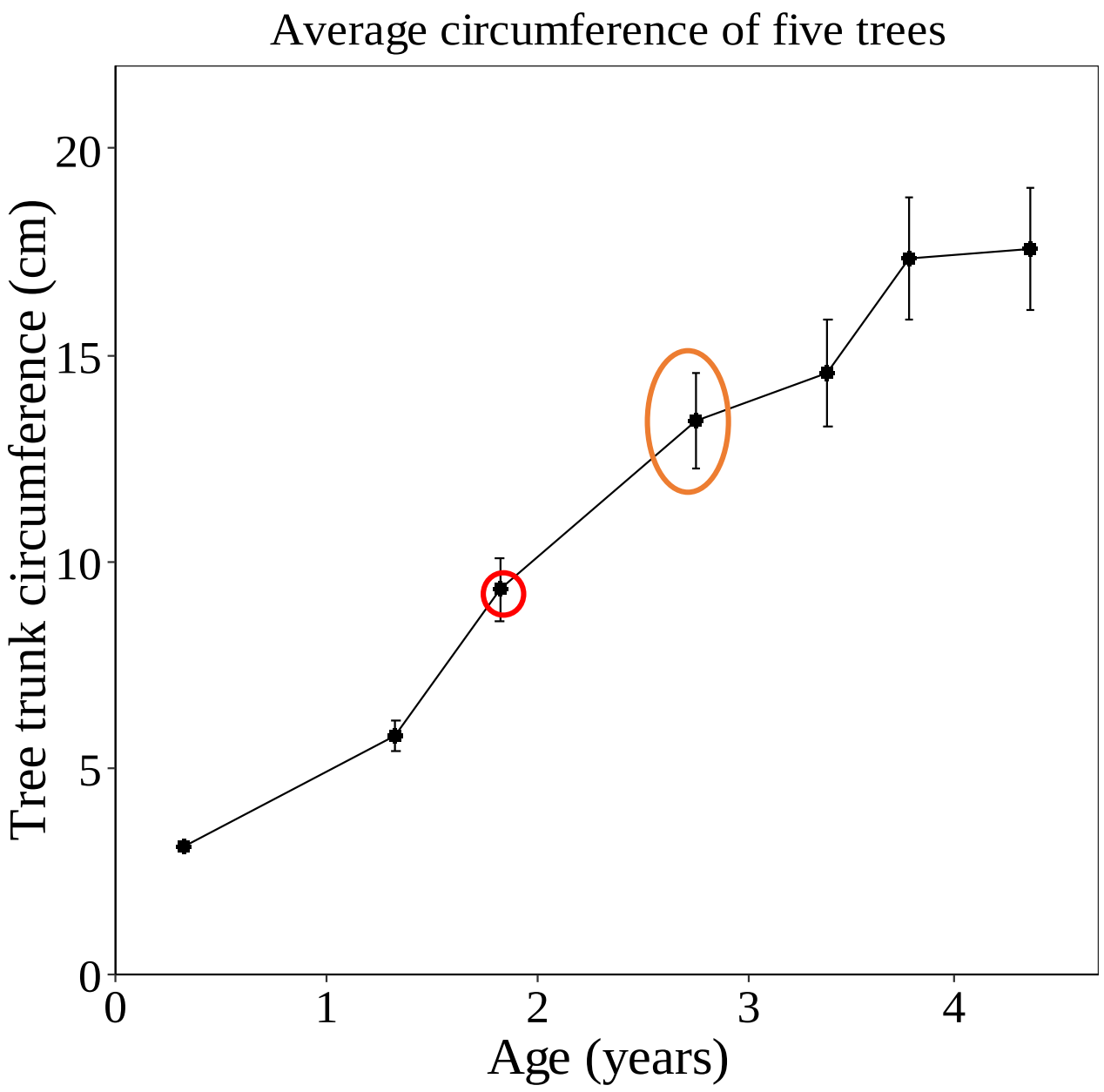
```
p<- tab %>%
  group_by(age) %>%
  summarise_each(funs( n = n(), mean = mean(.), se = sd(.)/sqrt(n())), "circumference") %>%
  ggplot(aes(x=age, y=mean))+
  geom_line() +
  geom_point(size=2.5,shape=16)+
  geom_errorbar(aes(ymin=mean-se, ymax=mean+se), size= 0.3, width=15)
```

Part 2.3: Plotting averages using dplyr

With the Orange tree data frame = tab

R

```
p<- tab %>%
  group_by(age) %>%
  summarise_each(funs( n = n(), mean = mean(.), se = sd(.)/sqrt(n())), "circumference") %>%
  ggplot(aes(x=age, y=mean))+
  geom_line() +
  geom_point(size=2.5,shape=16)+
  geom_errorbar(aes(ymin=mean-se, ymax=mean+se), size= 0.3, width=15)+
  newtheme_print+
  scale_x_continuous(name="Age (years)", limits=c(0,1700), expand=c(0,0),
breaks=c(0,365,730,1095,1450), labels=c("0","1", "2", "3","4"))+
  scale_y_continuous(name="Tree trunk circumference (cm)",limits=c(0,220),  expand=c(0,0),
                     breaks=c(0,50,100,150,200), labels=c("0","5", "10", "15","20"))+
  labs(title="Average circumference of five trees")+
  theme(plot.title = element_text(angle=0, size=18, family="serif",color = "black",hjust=0.5))
p
```


Average circumference of five trees
Tree trunk circumference (cm)
0
5
10
15
20
0
1
2
3
4
Age (years)

Part 2.4: Fitting a model (i.e. a logistical model)

R

Use dplyr to created a new data table with n, means, and se

```
cdata<- tab %>%
  group_by(age) %>%
  summarise_each(funs( n = n(), mean = mean(.), se = sd(.)/sqrt(n())), "circumference")
```

Part 2.4: Fitting a model (i.e. a logistical model)

R

Note: This model can be found within the datasets package for this dataset

```
cdata<- tab %>%
  group_by(age) %>%
  summarise_each(funs( n = n(), mean = mean(.), se = sd(.)/sqrt(n())), "circumference")


logistical_mod <- nls(mean ~ SSlogis(age, Asym, xmid, scal), data = cdata)
logistical_mod
```

Part 2.4: Fitting a model (i.e. a logistical model)

R

Note: This model can be found within the datasets package for this dataset

```
cdata<- tab %>%
  group_by(age) %>%
  summarise_each(funs( n = n(), mean = mean(.), se = sd(.)/sqrt(n())), "circumference")


logistical_mod <- nls(mean ~ SSlogis(age, Asym, xmid, scal), data = cdata)
logistical_mod


mod.predict <- cbind(data=cdata, predict(logistical_mod, interval = 'confidence'))

colnames(mod.predict) <- c("Age","N","mean","se","Predicted_values")

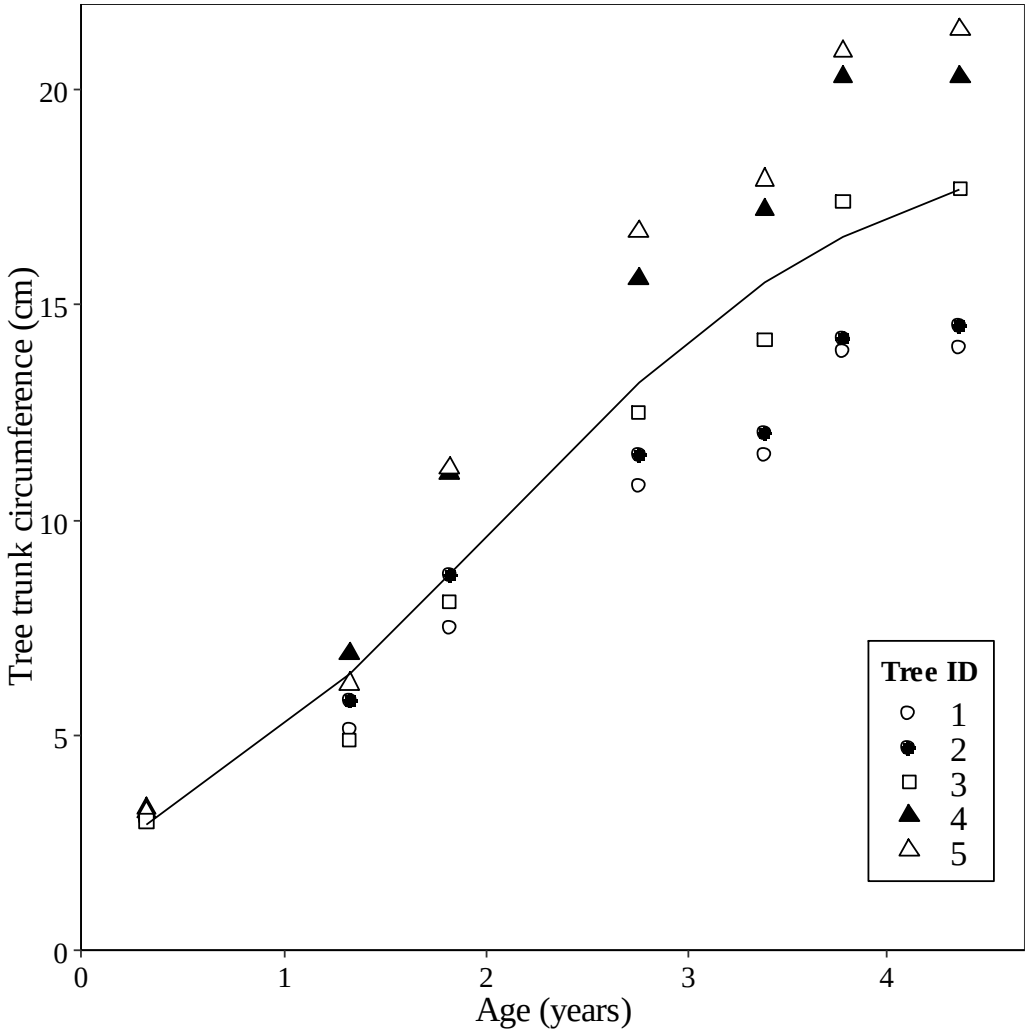
mod.predict
```

Fitting a model

R

```
p<- ggplot(tab, aes(x=age, y=circumference))+
    geom_point(aes(group=Tree,
    shape=Tree,fill=Tree),size=2.5) +
    …
    … +
    geom_line(data=mod.predict, aes(x=Age,
    y=Predicted_values))
p
```

Note: You can import data from different datasets



Part 2.5: Saving your figure

"tiff", "png", "jpeg","bmp"

Pixel-based

R

```
ggsave("Your_figure.png", plot=p, width=6, height=6, dpi=300, device="png")
```

You choose the figure name here

The name of your figure in R

Dimensions of the figure

Part 2.5: Saving your figure

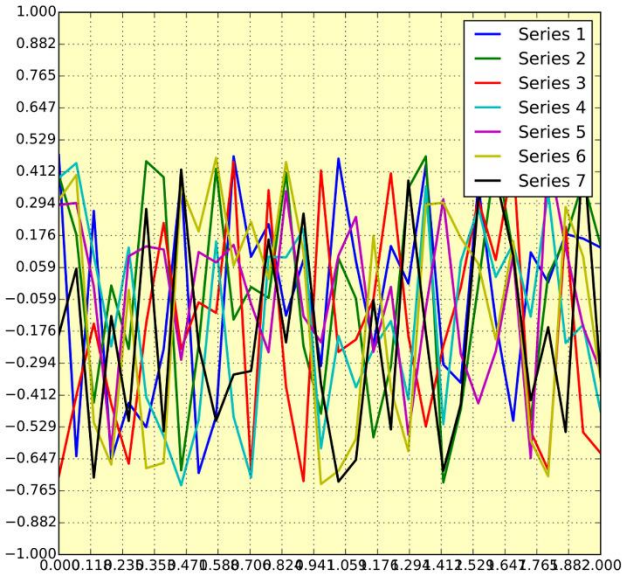
"pdf", "svg", "eps", "emf"

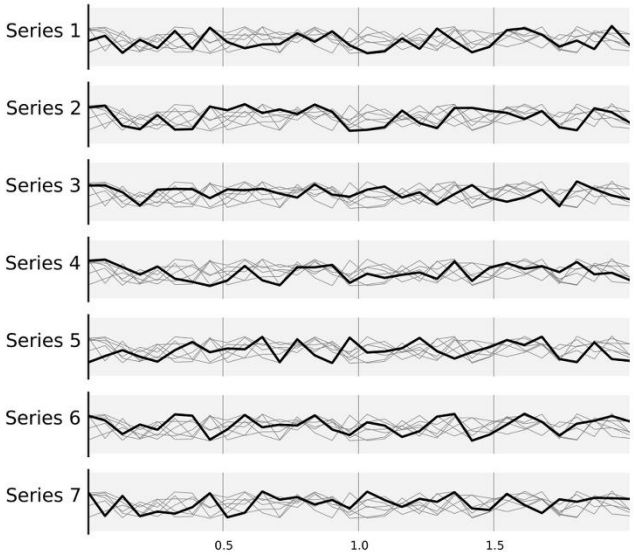
Vector-based

Can be used to add additional edits in other image editors (i.e. Inkscape, powerpoint, etc.)

Caution: this adds additional, non-reproducible work

8. Avoid ‘chartjunk’



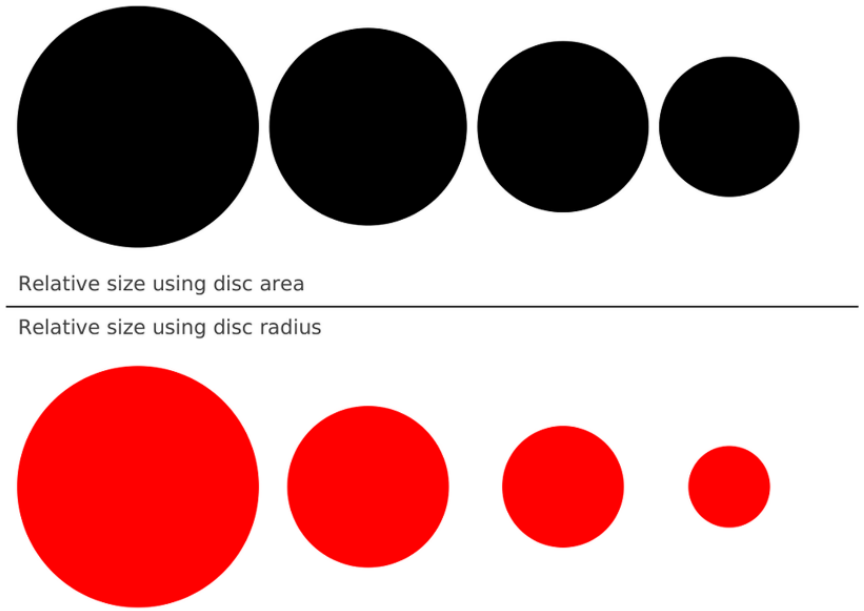


Examples from Rougier et al. 2014

8. Avoid ‘chartjunk’

9. Do not mislead the reader

Series of four values: 30, 20, 15, 10
Upper part: the disc area to represent the value
Lower part: the disc radius.

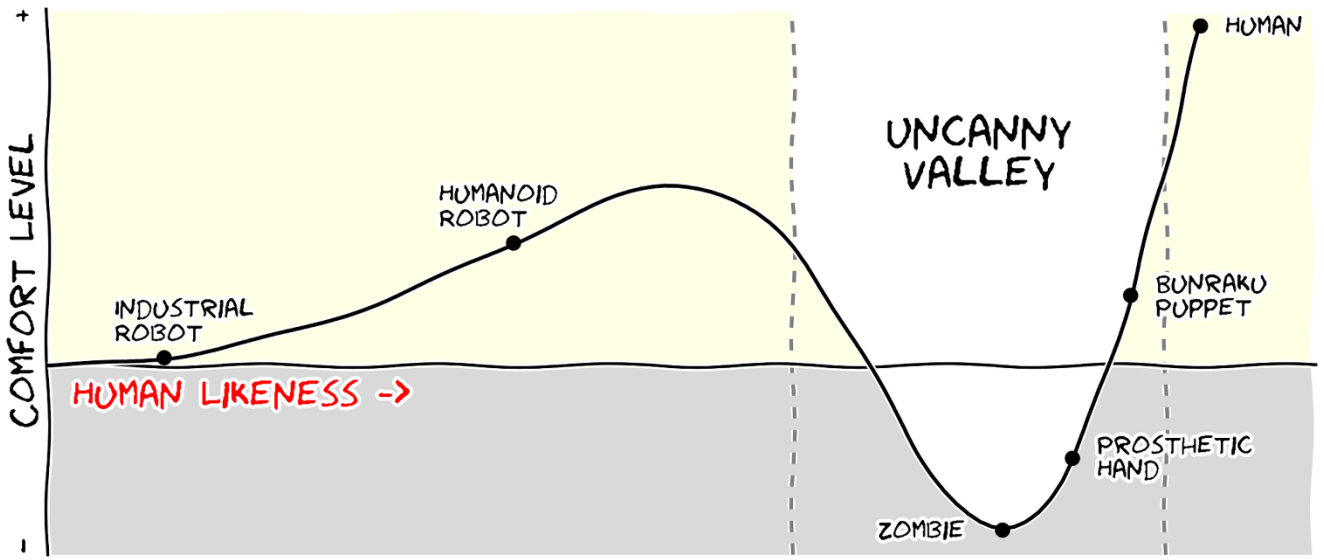


Examples from Rougier et al. 2014

8. Avoid ‘chartjunk’

9. Do not mislead the reader

10. Message over beauty



Example from Rougier et al. 2014

No class next week

Presentations on Monday, Nov. 29th

→ Focus on statistical analyses of the paper