Biological Stats II : Lab 1

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01/18/2023

Lab schedule

1/18: Introduction to R and R Studio, working with data
1/25: Intro to Visualization
2/01: Probability, linear modeling
2/08: Data wrangling, model summaries
2/15: Iteration
2/22: Creating functions, debugging
3/01: Simulation, Resampling
3/15: Flex: more modeling (brms, glmmTMB)
3/29: Spatial data or tidymodeling

Format for lab component

Description/overview of concepts by instructor

Live coding. Interactive, follow along yourselves

Lab exercises to practice material

Assignment each week is to finish the exercises

Extra credit: #TidyTuesday

Community support
"*Try stuff and see what happens*"

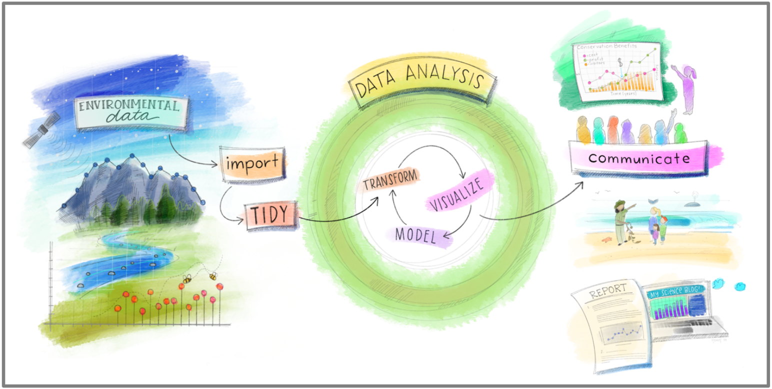
Why R ?

- Reproducible Science!
- Full data science workflow
- Language & environment for statistical computing & graphic
- Open source & Free
- Lots of scientists use it!
- AMAZING online community
- Works well with other tools

Artwork by @allison_horst

RStudio

Why R ?



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RStudio

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RStudio

Why R?

Reproducible
- command line interface encourages organization
- scripts allow others (and you!) to reproduce analyses from end-to-end
- integration of analysis with document creation

Extensible
- new methods delivered as developed
- continual expansion through new packages

Open-source
- all code can be examined by the user

Free
- available to large set of users (and therefore developers)

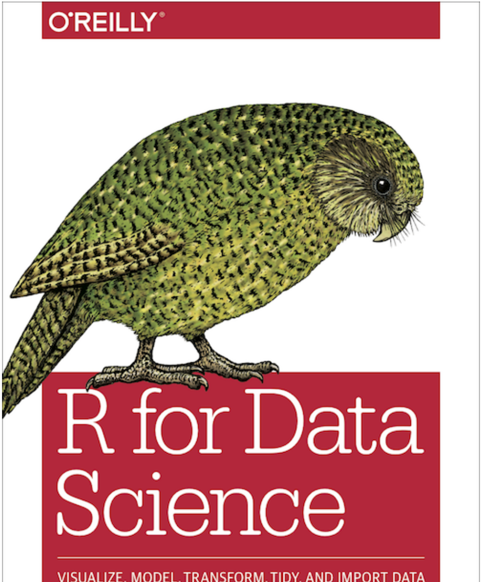
R is not the only solution out there.
The real goal is not to teach R, but concepts that all programming depends on.

Trevor Branch rule:

> *"Every analysis you do on a dataset will have to be redone 10–15 times before publication. Plan accordingly."*

Recommended reading

R for Data Science, 2017 (Wickham and Grolemund)
https://r4ds.had.co.nz/



Recommended reading

An introduction to R (Venables et al.)
– http://cran.r-project.org/doc/manuals/R-intro.pdf

R reference card 2.0 (Baggott)
– http://cran.r-project.org/doc/contrib/Baggott-refcard-v2.pdf
– Extremely useful handout: put on wall in view of your desk

Cheatsheets
- https://posit.co/resources/cheatsheets/

There are many (many) R books out there. Good for reference. e.g.
- The R Book, 2007 (Crawley)
- Modern Applied Statistics with S, 20002 (Venables and Ripley)
- Introductory Statistics with R, 2002 (Dalgaard)

Installing R and R Studio

R (http://r-project.org)
- download appropriate version for your OS

R Studio (https://posit.co/download/rstudio-desktop/)
- a very good Integrated Development Environment (IDE) for R

provides:
- text editor
- syntax highlighting
- seamless code execution with R

You can use other text editors with R, but RStudio is well organized.
(also looks the same regardless of Operating System)

Using R today: RStudio Cloud

An alternative:

- web browser interface
  https://rstudio.cloud/spaces/47288/project/856390

Getting started

Enter instructions at R console command line prompt (>):
e.g. type

```
> 2 + 2
```

R acts as a calculator and returns (prints) the result.

```
> 2 + 2
[1] 4
```

Simple commands

```
> 3^2
[1] 9
> 2*(2+2)
[1] 8
> 2*2+2
[1] 6
> log(10)
[1] 2.302585
> exp(1)
[1] 2.718282
> x <- 3
> 2*x
[1] 6
```

The <- means ‘assign’. i.e. ‘assign a value of 3 to the variable x’.
<- is preferable to using =

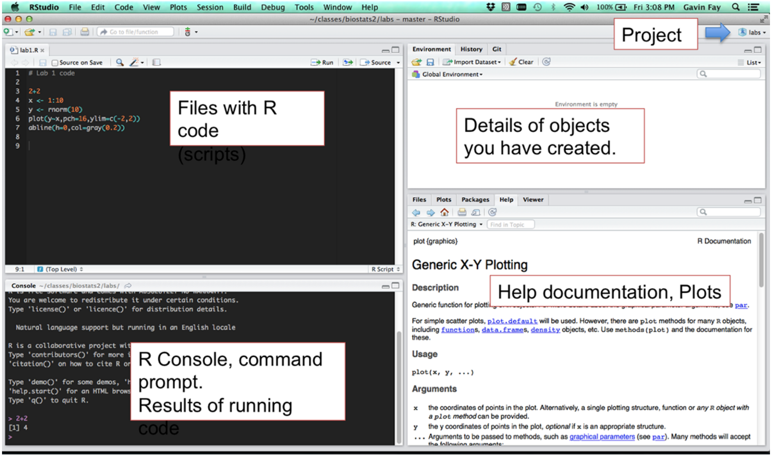
Scripts and RStudio

- Typing commands into the console can get tedious.
- Scripts are text files containing lines of code.
- Scripts provide a complete record of analyses.
- Code can be run (executed) from these files repeatedly.
- Scripts can be created in a text editor and copied into the R console.

Or. . .

- RStudio integrates scripts, R console, and output in a user-friendly development environment.
- To run code in RStudio, select code and type
  `Ctrl+Enter` (Windows)
  `Command+Enter` (Mac)
  The code will run in the R console.

RStudio


Project
Files with R code (scripts)
Details of objects you have created.
R Console, command prompt.
Results of running code
Help documentation, Plots

Projects in RStudio

Good to keep all the files associated with a particular project organized together – input data, R scripts, analytical results, figures.

RStudio has built-in support for this via its projects.

Projects provide an easy organization of your files and analyses.

R runs from a working directory, the location (folder) on your computer that R will use as a default when looking for data files, producing output, etc.

Project files (`.Rproj`)

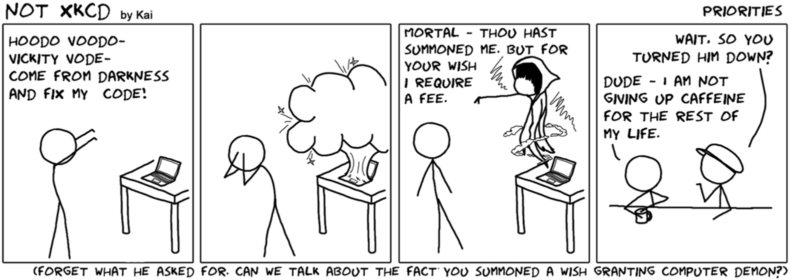
When you open a project, RStudio sets the working directory to the folder in which the `.Rproj` file exists.

Using projects can be VERY helpful.

Getting Help in R

R is a programming language, there is a learning curve.

Fortunately, there are lots of resources:



Don't summon a wish-granting computer demon.

Getting Help in R

R is a programming language, there is a learning curve.

Fortunately, there are lots of resources:
- help files
- online search results
- books
- colleagues
- RStudio Community

```
> ?(mean)
> help("mean")
```

The above both get help for the function `mean`.
Use `help.search("function.name")` to search across packages.

`str(object.name)` shows the structure of an object.

R Help files (`?mean`)

Common format:

- Description (what the function does)
- Usage (how to use it)
- Arguments (what the function needs, options)
- Value (what does the function return)
- See Also (related functions)
- Examples (sample code showing how the function works)

Read function documentation and explore behavior by running examples!

Lab exercise 1/4

(Instructions also in lab-exercise-01.pdf)

Start a new project. (call it biostats2 or something similar)
Open a new R markdown file. Save it. (name it lastname_lab1.Rmd or something similar)
At the top of the script, add comments with your name and lab 1.
Work in pairs or individually.
Submit your .Rmd file via myCourses before lab next week.

Write code that evaluates the following when run.

$$7 + 5(4 + 3)$$

$$e^{-5(0.2+0.15)}$$

$$\frac{\sqrt{1 + 2(3 + 2)}}{\ln(3^2 + 2)}$$

Objects

Common types of objects
- Numbers
- Characters (i.e. text or strings)
- Tables
- Vectors and matrices
- Plots
- Statistical output
- Functions

Objects in R are global

Viewing objects: In RStudio see top-right Workspace tab
More generally:

```
>   print(myobject)
>   myobject
```

`ls()` lists all objects in the workspace.
Use `rm()` to remove an object.

Data types (modes)

Describe how objects are stored in computer memory.

In R you do ***not*** need to specify the data type.

Common data types:

- Numeric (integer, floating point numbers or doubles)
- Logical (Boolean, true or false)
- Characters (text or string data)

Types are not always obvious in R, but can be important to know.

Data types II

```
> myobject <- log(10)
> mode(myobject)
[1] "numeric"
> is.numeric(myobject)
[1] TRUE
> typeof(myobject)
[1] "double"
> newobject <- as.integer(myobject)
> typeof(newobject)
[1] "integer"
> is.character(myobject)
[1] FALSE
> typeof("hello world")
[1] "character"
```

Vectors

```
> weights <- c(2.3,5.4,7.5,9)
> print(weights)
[1] 2.3 5.4 7.5 9.0
> years <- 2007:2016
> print(years)
 [1] 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
> years <- seq(from=2000,to=2016,by=2)
> print(years)
[1] 2000 2002 2004 2006 2008 2010 2012 2014 2016
> x <- rep(3,times=10)
> print(x)
 [1] 3 3 3 3 3 3 3 3 3 3
> rep(1:3,times=3)
[1] 1 2 3 1 2 3 1 2 3
> rep(1:3,length=10)
 [1] 1 2 3 1 2 3 1 2 3 1
```

More on Vectors

Vectors are ordered and can be referred to by element(s) using

```
> (years <- 2007:2016)
 [1] 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
> years[3]
[1] 2009
> years[5:6]
[1] 2011 2012
> which(years==2010)
[1] 4
> years[-c(2,4)] # A negative index excludes elements
[1] 2007 2009 2011 2012 2013 2014 2015 2016
```

Vector operations are element-wise

```
> (x <- 1:5)
[1] 1 2 3 4 5
> 2*x
```

Lab exercise 2/4

(Instructions also in lab-exercise-01.pdf)

Create vectors using `seq()`, `rep()`, and mathematical operators.
Only use `c()` when absolutely necessary.
hint Remember you can get help on a function by typing `?functionname`

- Positive integers from 1 to 99
- Odd integers between 1 and 99
- The numbers 1,1,1, 2,2,2, 3,3,3
- The numbers -5,-4,-3,-5,-4,-3,-5,-4,-3
- The fractions 1, 1/2, 1/3, 1/4, . . . , 1/10
- The cubes 1, 8, 27, 64, 125, 216

Useful functions

```
> x <- c(5,3,2,6,3,9,1,18)
> length(x)  # length of vector x
[1] 8
> sort(unique(x))  # sorted vector of unique values in x
[1]  1  2  3  5  6  9 18
> min(x)     # minimum value in x
[1] 1
> max(x)     # maximum value in x
[1] 18
> mean(x)    # mean of x
[1] 5.875
> median(x)  # median of x
[1] 4
> sd(x)      # standard deviation of x
[1] 5.514591
> range(x)   # range of values in x
[1]  1 18
> range(x)[2]  # 2nd element of values returned by range()
[1] 18
> quantile(x) # optional argument 'probs' can be handy
   0%   25%   50%   75%  100%
 1.00  2.75  4.00  6.75 18.00
```

Boolean logic operators

<table>
<tr><th>Operator</th><th>R Code</th></tr>
<tr><td>AND</td><td>& (&&)</td></tr>
<tr><td>OR</td><td>| (||)</td></tr>
<tr><td>NOT</td><td>!</td></tr>
<tr><td>less than</td><td><</td></tr>
<tr><td>greater than</td><td>></td></tr>
<tr><td>less than or equal</td><td><=</td></tr>
<tr><td>greater than or equal</td><td>>=</td></tr>
<tr><td>equals</td><td>==</td></tr>
<tr><td>NOT equal</td><td>!=</td></tr>
</table>

&& and || are used when asking IF statements.
These only use a single value, not a vector.

Boolean examples

```
> x <- 7
> x == 7
[1] TRUE
> x < 10
[1] TRUE
> x < -3
[1] FALSE
> x > 0 & x <= 12
[1] TRUE
> x >= 10 | x < 0
[1] FALSE
```

```
> y <- c(4,8)
> y > 5   #returns a logical vector
[1] FALSE  TRUE
> y[y>5]  #returns elements of y that meet condition
[1] 8
> which(y>5) #index of y that meets condition
[1] 2
> any(y>5)
[1] TRUE
> all(y>5)
[1] FALSE
```

Lab exercise 3/4

Complete the following using the vector `y`:

```
y <- c(3,2,15,-1,22,1,9,17,5)
```

- Display the first and last values.
- Find the last value for a vector of any length.
- Display the values that are greater than the mean of `y`.
- Display the positions (indices) of the values greater than the mean.
- Are all the values positive?
- Are any of the values equal to the mean?
- Are any of the values equal to the median?

Other types of objects

matrices (more generally, arrays)
- multi-dimensional generalizations of vectors.
- are vectors that can be indexed by two or more indices.

factors
- compact ways to handle categorical data.

lists
- general form of vector, elements need not be the same type.
- elements often themselves vectors or lists.
- convenient way to return results of statistical computations.

dataframes
- matrix-like structures, columns can be of different types.
- often 'data matrices' with one row per observational unit but with (possibly) both numerical and categorical variables.
- experiments are often best described by data frames: treatments are categorical but the response is numeric.

functions
- are themselves objects in R which can be stored in the project's workspace.
- provide a simple and convenient way to extend R.

Dataframes

There are lots of data set examples in R.

e.g. record times for 35 Scottish hill races

```
> library(MASS)
> head(hills,n=3) # shows first few lines. Also tail()
              dist climb   time
Greenmantle    2.5   650 16.083
Carnethy       6.0  2500 48.350
Craig Dunain   6.0   900 33.650
> names(hills)  # get the names of the data frame
[1] "dist"  "climb" "time"
```

Creating dataframes

```
> fish <- c("cod","haddock","dogfish","pollock")
> length <- c(34,23,75,18)
> age <- c(6,3,17,2)
> fish.data <- data.frame(fish=fish,length=length,age=age)
> head(fish.data)
     fish length age
1     cod     34   6
2 haddock     23   3
3 dogfish     75  17
4 pollock     18   2
```

Extracting information from data frames

Use the $ to extract vectors from a data frame

```
> hills$dist
 [1]  2.5  6.0  6.0  7.5  8.0  8.0 16.0  6.0  5.0  6.0 28.0  5.0
[14]  6.0  4.5 10.0 14.0  3.0  4.5  5.5  3.0  3.5  6.0  2.0  3.0
[27]  6.0  5.0  6.5  5.0 10.0  6.0 18.0  4.5 20.0
```

You can also specify the row index, column index, or both
`object[row,column]`

```
> # extract the element in row 1, column 2
> hills[1,2]
[1] 650
> hills$climb[1]
[1] 650
> # extract the first row
> hills[1,]
           dist climb   time
Greenmantle  2.5   650 16.083
```

```
> # extract all of column 2
> hills[,2]   # also hills[,"climb"]
 [1]  650 2500  900  800 3070 2866 7500  800  800  650 2100 2000
[14]  500 1500 3000 2200  350 1000  600  300 1500 2200  900  600
[27]  800  950 1750  500 4400  600 5200  850 5000
> # exclude column 1, but retain the other columns (1st 3 rows)
> hills[1:3,-1]
             climb   time
Greenmantle    650 16.083
Carnethy      2500 48.350
Craig Dunain   900 33.650
> # extract rows 4 and 7
> hills[c(4,7),]
             dist climb    time
Ben Rha       7.5   800  45.600
Bens of Jura 16.0  7500 204.617
> # extract the rows that are specified by the object x
> x <- c(4,7,nrow(hills))
> hills[x,]
             dist climb    time
Ben Rha       7.5   800  45.600
Bens of Jura 16.0  7500 204.617
Moffat Chase 20.0  5000 159.833
```

Extracting information from data frames (2)

The ‘tidyverse’ is a popular set of R packages for interacting with data and performing statistical analyses.

Data frames are commonly used in a structure called a ‘tibble’

```
> #install.packages('tidyverse')
> library(tidyverse)
```

```
> hills_tbl <- as_tibble(hills)
> hills_tbl
# A tibble: 35 x 3
    dist climb  time
   <dbl> <int> <dbl>
 1   2.5   650  16.1
 2   6    2500  48.4
 3   6     900  33.6
 4   7.5   800  45.6
 5   8    3070  62.3
 6   8    2866  73.2
 7  16    7500 205.
 8   6     800  36.4
 9   5     800  29.8
10   6     650  39.8
# ... with 25 more rows
```

Extract variables using the `select` verb function in the `dplyr` package

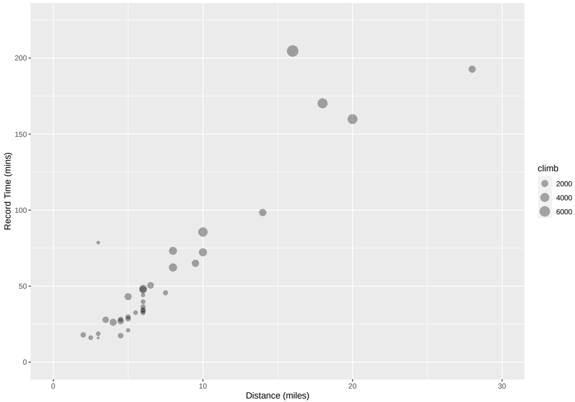
```
> dplyr::select(hills,dist)
                 dist
Greenmantle       2.5
Carnethy          6.0
Craig Dunain      6.0
Ben Rha           7.5
Ben Lomond        8.0
Goatfell          8.0
Bens of Jura     16.0
Cairnpapple       6.0
Scolty            5.0
Traprain          6.0
Lairig Ghru      28.0
Dollar            5.0
Lomonds           9.5
Cairn Table       6.0
Eildon Two        4.5
Cairngorm        10.0
Seven Hills      14.0
Knock Hill        3.0
Black Hill        4.5
Creag Beag        5.5
Kildcon Hill      3.0
```

Create a new variable of the race names

```
>   hills_tbl <- mutate(hills_tbl,race=rownames(hills))
>   hills_tbl <- dplyr::select(hills_tbl,race,everything())
>   hills_tbl
# A tibble: 35 x 4
   race            dist climb  time
   <chr>          <dbl> <int> <dbl>
 1 Greenmantle      2.5   650  16.1
 2 Carnethy         6    2500  48.4
 3 Craig Dunain     6     900  33.6
 4 Ben Rha          7.5   800  45.6
 5 Ben Lomond       8    3070  62.3
 6 Goatfell         8    2866  73.2
 7 Bens of Jura    16    7500 205.
 8 Cairnpapple      6     800  36.4
 9 Scolty           5     800  29.8
10 Traprain         6     650  39.8
# ... with 25 more rows
```

Quickly visualize the dataset

```
library(ggplot2)
ggplot(data = hills_tbl, mapping = aes(x=dist,y=time)) +
  geom_point(aes(size = climb), alpha = 1/3) +
  xlab("Distance (miles)") +
  ylab("Record Time (mins)") +
  xlim(0,30) + ylim(0,225)
```



Extracting elements logically

```
> fish <- c("cod","haddock","dogfish","pollock")
> length <- c(34,23,75,18)
> age <- c(6,3,17,2)
> fish_data <- tibble(fish=fish,length=length,age=age)
> fish_data$age   # a vector
[1]  6  3 17  2
> fish_data$age > 5  # a logical vector
[1]  TRUE FALSE  TRUE FALSE
> filter(fish_data, age>5) #avoids having to create a logical vector
# A tibble: 2 x 3
  fish    length   age
  <chr>    <dbl> <dbl>
1 cod         34     6
2 dogfish     75    17
> # combining conditions
> filter(fish_data, age > 5, fish == "dogfish")
# A tibble: 1 x 3
  fish    length   age
  <chr>    <dbl> <dbl>
1 dogfish     75    17
> filter(fish_data, length < 25 | length >= 50)
# A tibble: 3 x 3
  fish    length   age
  <chr>    <dbl> <dbl>
1 haddock     23     3
```

Using the Pipe

Combine verb operations with the pipe operator (|>) e.g.

```
> fish_data |>
+   mutate(weight = (length/100)^3) |>
+   filter(age > 5)
# A tibble: 2 x 4
  fish    length   age weight
  <chr>    <dbl> <dbl>  <dbl>
1 cod         34     6 0.0393
2 dogfish     75    17 0.422
```

The pipe passes the result from one function call to the next.
Can be read as "and then".
(also the older tidyverse pipe: %>%)

Summarizing Data

After selecting data we might like to perform analyses on it.
We can use group_by() to recognize structure in the data.
Then apply functions to variables using summarize()
Recall gapminder data, find the average life expectancy in 2007 for each continent

```
> #install.packages('gapminder')
> library(gapminder)
> gapminder |>
+   filter(year == 2007) |>
+   group_by(continent) |>
+   summarize(avg_lifeExp = mean(lifeExp))
# A tibble: 5 x 2
  continent avg_lifeExp
  <fct>           <dbl>
1 Africa           54.8
2 Americas         73.6
3 Asia             70.7
4 Europe           77.6
5 Oceania          80.7
```

Tips and Tricks

Comments
Use comments within R code to document the purpose of your code. Anything on a line after a # is ignored by R. RStudio uses a different color to help readability.

SAVE your scripts(!), not workspaces. Use meaningful variable names. Adopt a coding style and use consistently.
(e.g. https://google.github.io/styleguide/Rguide.xml)

The `str()` function can be incredibly helpful when querying objects.

```
> str(hills)
'data.frame':   35 obs. of  3 variables:
 $ dist : num  2.5 6 6 7.5 8 8 16 6 5 6 ...
 $ climb: int  650 2500 900 800 3070 2866 7500 800 800 650 ...
 $ time : num  16.1 48.4 33.6 45.6 62.3 ...
```

Make use of `help()` documentation.

There are almost always multiple ways of getting the same result.
We'll mostly use low level functions to help you understand how R works.
Some advanced functions are cleaner and do things more quickly.

Lab exercise 4/4 (data frames using `hills`)

1. Display the first 5 rows of the `hills` dataframe.
2. Find the fastest time.
3. Display the hill races (and distance, climbs, and times) with the 3 fastest times.
4. Extract and display the record time for Cairngorm.
5. Find how many hill races have a climb greater than the mean.
6. Display the names of the hill races that have a climb greater than the mean.
7. Display the names and times of the races that are at least 10 miles long and have a climb greater than 4000 feet.
8. Find the positions (indices) of hills that either have a climb greater than 5000 feet or have a record time less than 20 minutes.
9. Find the standard deviation of the record times for all races except for the highest climb, the Bens of Jura.
10. Display the range (minimum and maximum) of the average speed for the races.
11. Find the race that had the fastest average speed.
12. **BONUS** Find the mean of the record times for races whose names start with letters A through K.

Next time. . .

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