MONASH University

Grammar of Experimental Design

実験計画法の「文法」

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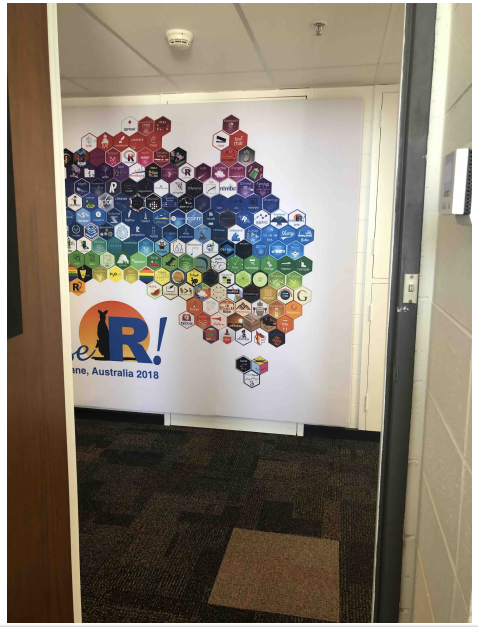
23 Jan 2021 @ TokyoR

A little about me

自己紹介

- オーストラリア育ちの日本語がイマイチなJapanese-Australianです🇯🇵🇦🇺
- ５年前に統計学の博士号を取得しました🎓
- Monash大学で働くため２０２０年１月シドニーからメルボルンへ引っ越しました📦

私のオフィスからの見晴らしです➔



その研究内容一つとは

Grammar of Experimental Design

実験計画法の「文法」

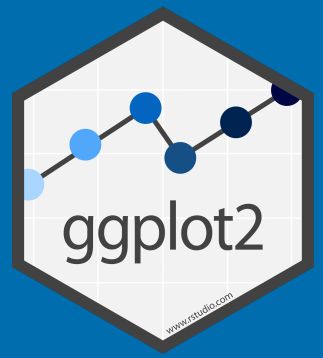
「文法」とはどういう意味なのでしょうか？

内容

1. **Grammar of Graphics** グラフィクスの文法
2. **Grammar of Data Manipulation** データ操作の文法
3. **Grammar of Experimental Design** 実験計画法の文法

1

Grammar of Graphics



Wickham (2016) ggplot2: Elegant Graphics for Data Analysis. *Springer-Verlag New York*

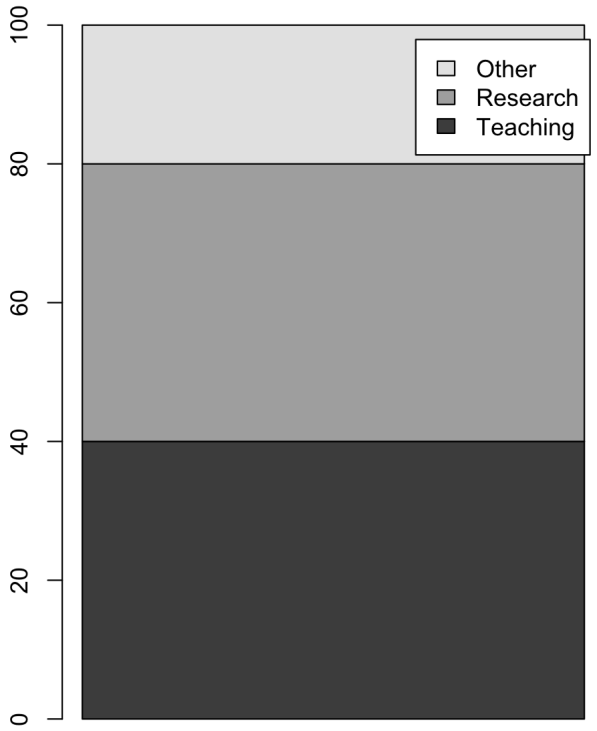
Wilkinson (2005) The Grammar of Graphics. *Statistics and Computing. Springer, 2nd edition.*

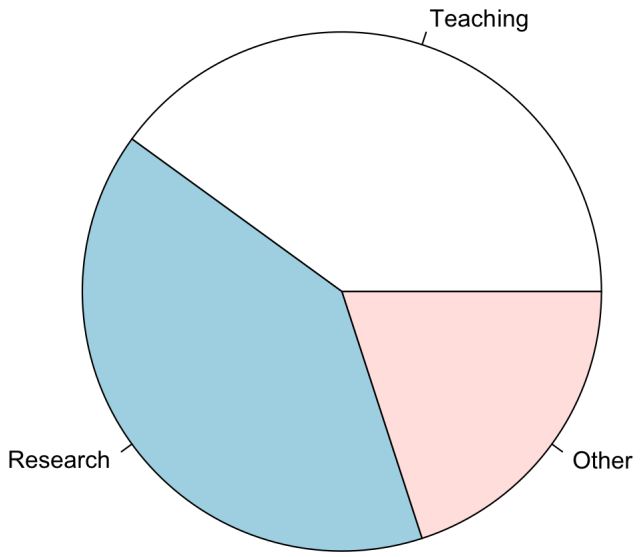
まずはデーターから

一般的なオーストラリアの大学で働いてる学者は時間を以下のように分けるよう期待されています：

- 40%教育、
- 40%研究と
- 20%その他。

この二つのプロットの違いとは？





Base R

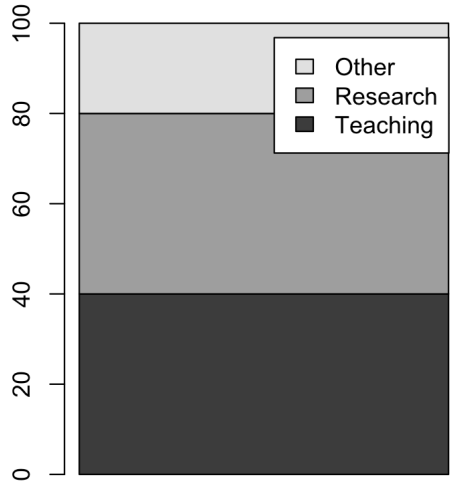
```
df
```

```
##       duty perc
## 1 Teaching   40
## 2 Research   40
## 3    Other   20
```

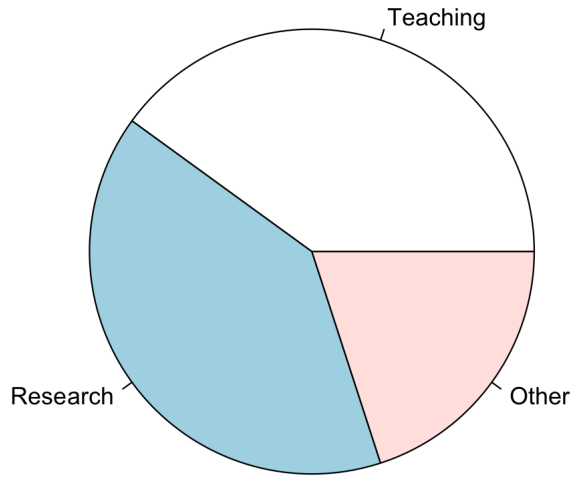
```
tibble::as_tibble(df)
```

```
## # A tibble: 3 x 2
##   duty      perc
##   <chr>    <dbl>
## 1 Teaching    40
```

```
barplot(as.matrix(df$perc),
        legend = df$duty)
```




```
pie(df$perc, labels = df$duty)
```



Single purpose functions
to generate "named plots"

ggplot2

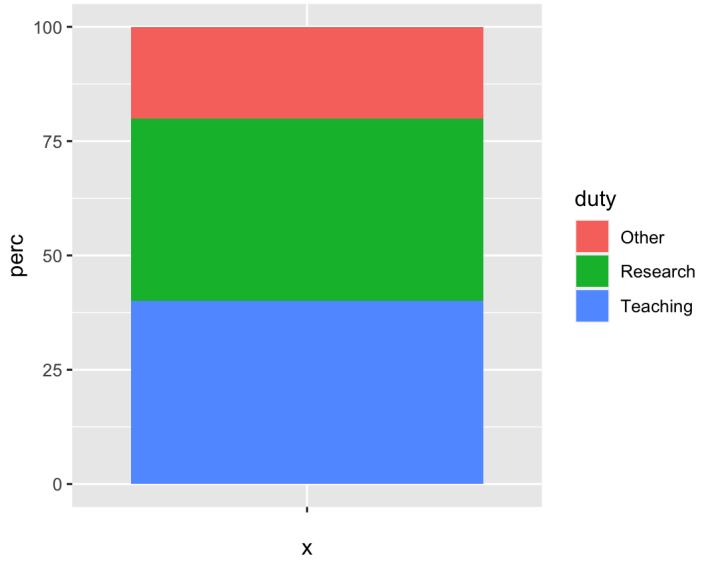
```
df
```

```
##       duty perc
## 1 Teaching   40
## 2 Research   40
## 3    Other   20
```

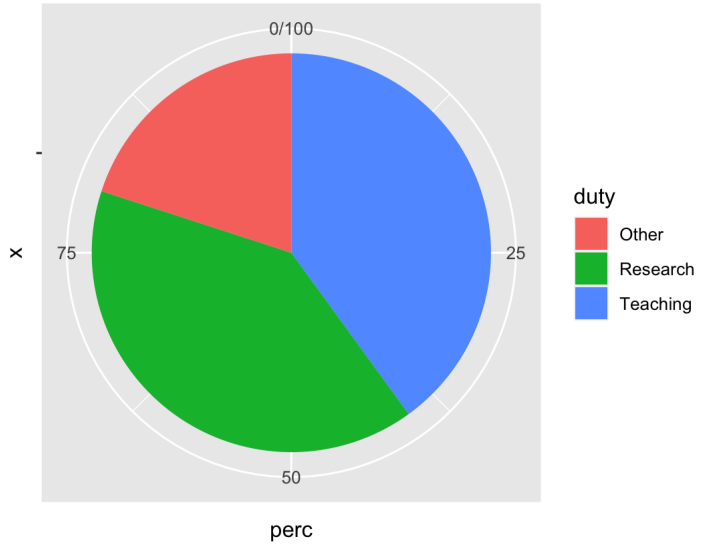
```
tibble::as_tibble(df)
```

```
## # A tibble: 3 x 2
##   duty      perc
##   <chr>    <dbl>
## 1 Teaching    40
## 2 Research    40
```

```
ggplot(df, aes(x = "", # dummy
               y = perc,
               fill = duty)) +
  geom_col()
```




```
ggplot(df, aes(x = "", # dummy
               y = perc,
               fill = duty)) +
  geom_col() +
  coord_polar(theta = "y")
```



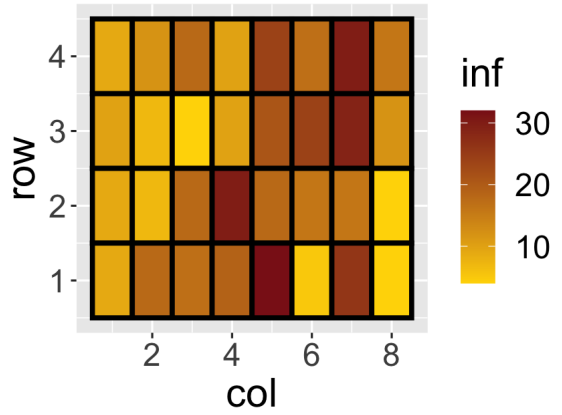
stacked barplotと**pie chart**の違いはcoordinate systemが**Cartesian coordinate**から**polar coordinate**と変わった

ポテトフィールド研究・このプロットはどうコードする？

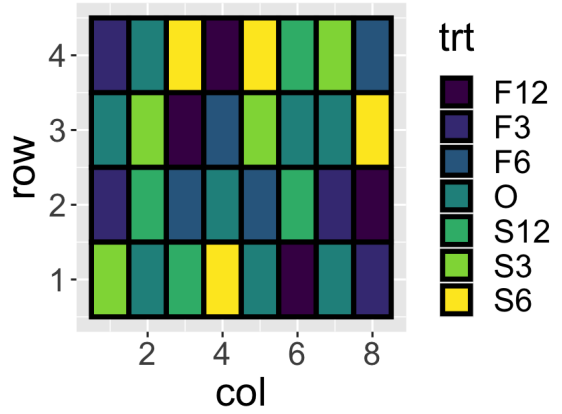
```
data(cochran.crd,
     package = "agridat")

cochran.crd
```

```
##    inf trt row col
## 1    9  F3   4   1
## 2   12   0   4   2
## 3   18  S6   4   3
## 4   10 F12   4   4
## 5   24  S6   4   5
## 6   17 S12   4   6
## 7   30  S3   4   7
## 8   16  F6   4   8
## 9   10   0   3   1
```




```
ggplot(cochran.crd,
       aes(x = col,
           y = row,
           fill = inf)) +
  geom_tile(color = "black", size = 1.2) +
  scale_fill_gradient(low = "gold",
                      high = "firebrick4") +
  theme(text = element_text(size = 20))
```




```
ggplot(cochran.crd,
       aes(x = col,
           y = row,
           fill = trt)) +
  geom_tile(color = "black", size = 1.2) +
  scale_fill_viridis_d() +
  theme(text = element_text(size = 20))
```


Kevin Wright (2020). agridat: Agricultural Datasets. R package version 1.17.
W.G. Cochran and G. Cox, 1957. Experimental Designs, 2nd ed. John Wiley, New York.

スライドは emitanaka.org/slides/TokyoR2021

2

Grammar of Data Manipulation

Wickham, François, Henry & Müller (2020) dplyr: A Grammar of Data Manipulation. R-package version 1.0.0.

このコードは何をしてる？アウトプットは何を期待しますか？

```
tapply(cochran.crd$inf, cochran.crd$trt, mean)

##    F12     F3     F6      O    S12     S3
##  5.750  9.500 15.500 22.625 14.250 16.750 1

tapply(cochran.crd$inf, cochran.crd$trt, sd)

##       F12        F3        F6         O
##  2.872281  4.932883  3.785939  8.365533  4.

tapply(cochran.crd$inf, cochran.crd$trt,
       function(x) c(avg = mean(x), sd = sd(x)

## $F12
##      avg       sd
## 5.750000 2.872281
##
```

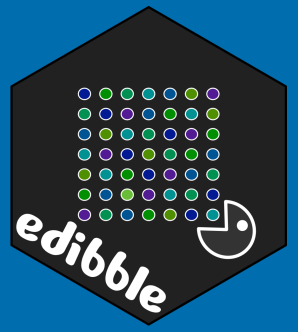
```
library(dplyr)
cochran.crd %>%
  group_by(trt) %>%
  summarise(avg = mean(inf),
            sd = sd(inf))

## # A tibble: 7 x 3
##   trt     avg    sd
## * <fct> <dbl> <dbl>
## 1 F12    5.75  2.87
## 2 F3     9.5   4.93
## 3 F6    15.5   3.79
## 4 O     22.6   8.37
## 5 S12   14.2   4.86
## 6 S3
## 7 S6
```

右の方が意図が分かりやすいです

3

Grammar of Experimental Design



Work-In-Progress

実験計画法の一般的なコース

(例えばシドニー大学2017-2019)

教える内容：

- Completely Randomised Design
- Randomised Complete Block Design
- Latin Square Design
- Balanced Incomplete Block Design
- Factorial Design
- ~~2^k Factorial Design~~ (２０１８年以降取り除いた)
- Split-plot Design (私が２０１８年に追加した)

Completely Randomised Design (CRD)

- t treatments randomised to n units

$$\texttt{observation} = \texttt{mean} + \texttt{treatment} + \texttt{error}$$

(with constraints and distributional assumptions)

ANOVA

Source	df	SS	MS	F	P-value
Treatment	$t-1$	TSS	MST	f = MST / MSR	$P(F_{t-1,n-t} > f)$
Residual	$n-t$	RSS	MSR		

Randomised Complete Block Design (RCBD)

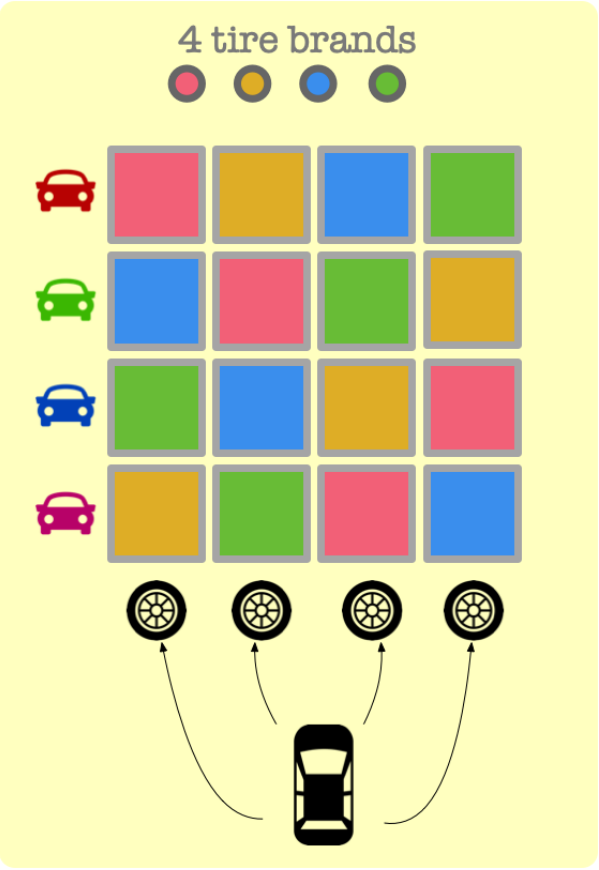
- b blocks of size t
- t treatments randomised to t units within each block

$$\texttt{observation} = \texttt{mean} + \texttt{treatment} + \texttt{block} + \texttt{error}$$

ANOVA

Source	df	SS	MS	F	P-value
Treatment	$t-1$	TSS	MST	f = MST / MSR	$P(F_{t-1,(b-1)(t-1)} > f)$
Block	$b-1$	BSS	MSB		
Residual	$(b-1)(t-1)$	RSS	MSR		

Latin Square Design (LSD)



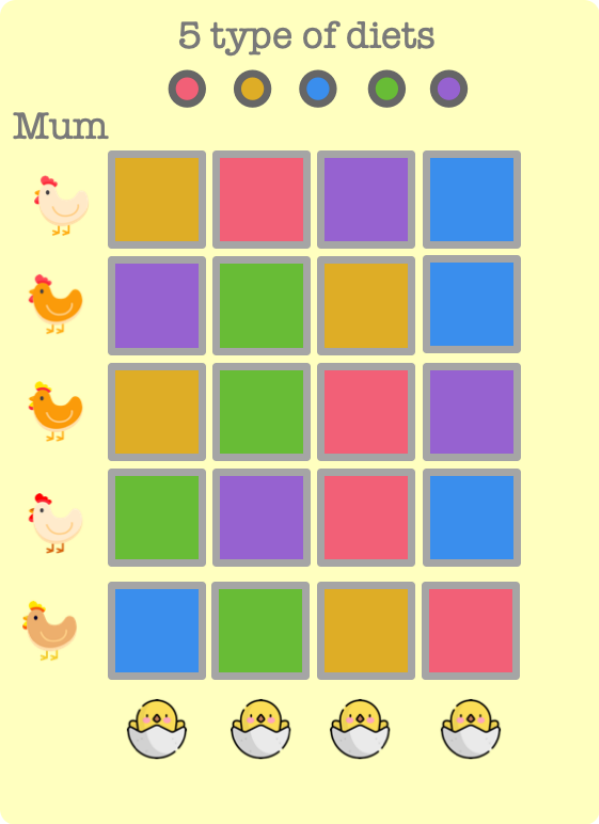
- two orthogonal blocks of size t
- t treatments randomised to units such that every treatment appears exactly once in each block

$$\texttt{observation} = \texttt{mean} + \texttt{treatment} + \texttt{row} + \texttt{column} + \texttt{error}$$

ANOVA

Source	df	SS	MS	F	P-value
Treatment	$t-1$	TSS	MST	f = MST / MSR	$P(F_{t-1,(t-2)(t-1)} > f)$
Row	$t-1$	RowSS	MSRow		
Column	$t-1$	ColSS	MSCol		
Residual	$(t-2)(t-1)$	RSS	MSR		

Balanced Incomplete Block Design (BIBD)



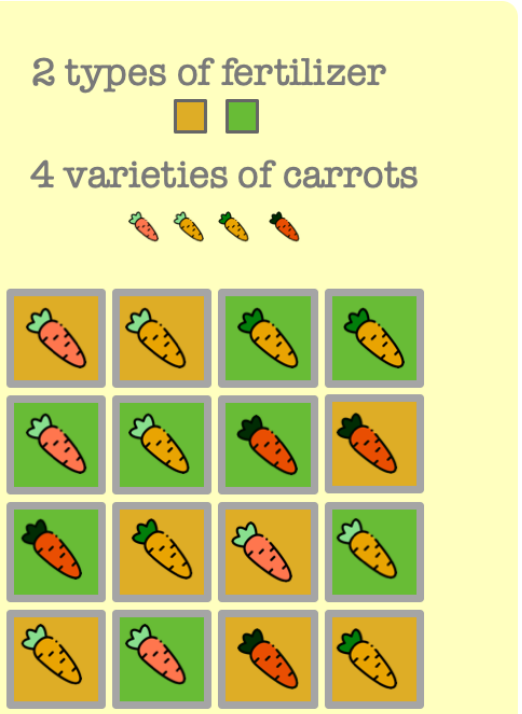
- b blocks of size $k < t$
- t treatments randomised to units within each block such that every pair of treatment appears the same number of times across blocks

$$\texttt{observation} = \texttt{mean} + \texttt{block} + \texttt{treatment} + \texttt{error}$$

ANOVA

Source	df	SS	MS	F	P-value
Block	$b-1$	BSS	MSB		
Treatment	$t-1$	TSS | Block	MST	f = MST / MSR	$P(F_{t-1,n-b-t+1} > f)$
Residual	$n-b-t+1$	RSS	MSR		

Factorial Design



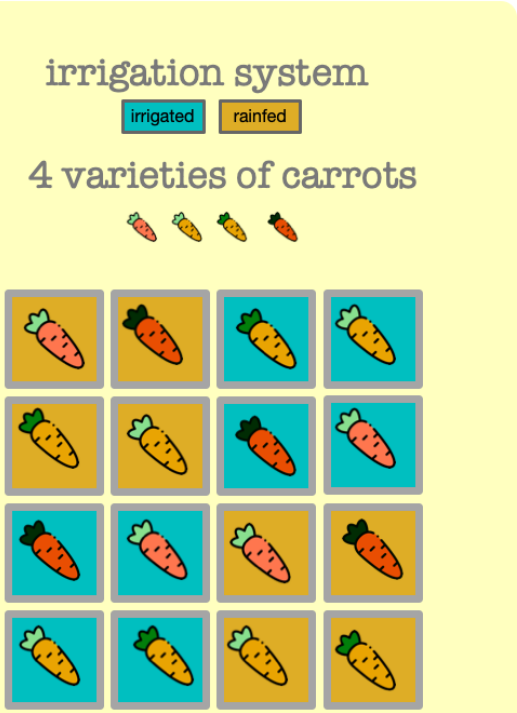
- $ab = t$ treatments randomised to n units
- treatment is every combination of two factors A and B

$$\texttt{observation} = \texttt{mean} + \texttt{A} + \texttt{B} + \texttt{A:B} + \texttt{error}$$

ANOVA

Source	df	SS	MS	F	P-value
Treatment	$ab - 1$	TSS	MST	f = MST / MSR	$P(F_{ab-1,n-ab} > f)$
Residual	$n - ab$	RSS	MSR		

Split-plot Design



- n_1 whole plots consisting of b sub plots
- in total there are n sub plots
- treatment factor A is randomised to whole plots
- treatment factor B is randomised to sub plots within each whole plot

$$\texttt{observation} = \texttt{mean} + \texttt{A} + \texttt{WP} + \texttt{B} + \texttt{A:B} + \texttt{error}$$

Not the same definition as in sample surveys

ANOVA

Stratum	Source	df	SS	MS	F	P-value
Whole Plot (WP)	Irrigation (A)	$a-1$	A-SS	MSA		
	WP Residual	n_1-a	WP-SS	MSR-WP		
Sub Plot (SP)	Variety (B)	$b-1$	B-SS	MSB		
	A:B	$(a-1)(b-1)$	AB-SS	MSAB	$f^* =$ MSAB / MSR-SP	$P(F_{(a-1)(b-1),n-ab-n_1+a} > f^*)$
	SP Residual	$n-ab-(n_1-a)$	SP-RSS	MSR-SP		

CRAN Task View of Design of Experiments

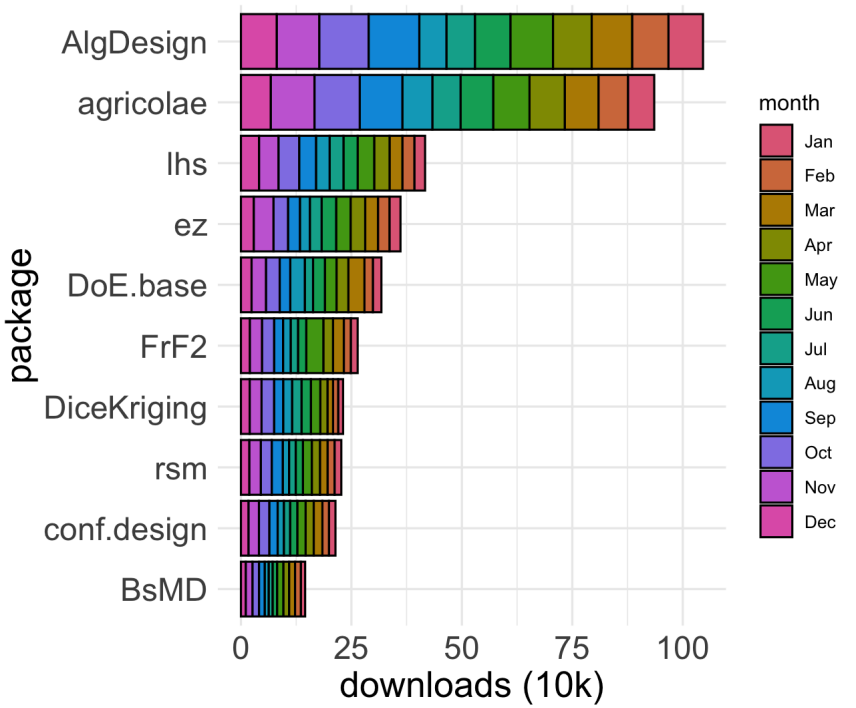
contains

224 R-packages

as of 2021-01-21

(Please note that there may be some webscrapping error)

ダウンロードされたR-packagesトップ１０



`AlgDesign` and `agricolae` are the most downloaded

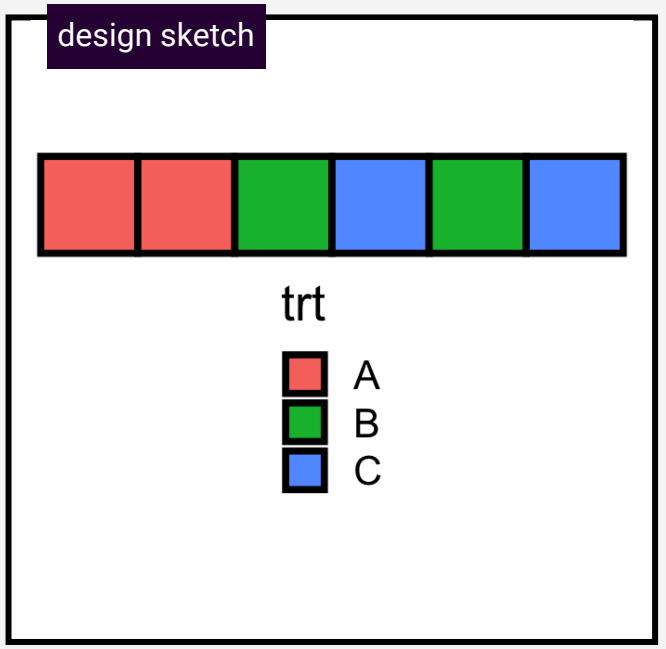
(data from `cranlogs` from 2015-01-01 to 2020-12-31)

agricolae::design.crd

Completely randomised design for $t = 3$ treatments with 2 replicates each

```
trt <- c("A", "B", "C")
agricolae::design.crd(trt = trt, r = 2) %>% glimpse()
```

```
## List of 2
##  $ parameters:List of 7
##   ..$ design: chr "crd"
##   ..$ trt   : chr [1:3] "A" "B" "C"
##   ..$ r     : num [1:3] 2 2 2
##   ..$ serie : num 2
##   ..$ seed  : int 2074805913
##   ..$ kinds : chr "Super-Duper"
##   ..$       : logi TRUE
##  $ book      :'data.frame':    6 obs. of  3 variables:
```

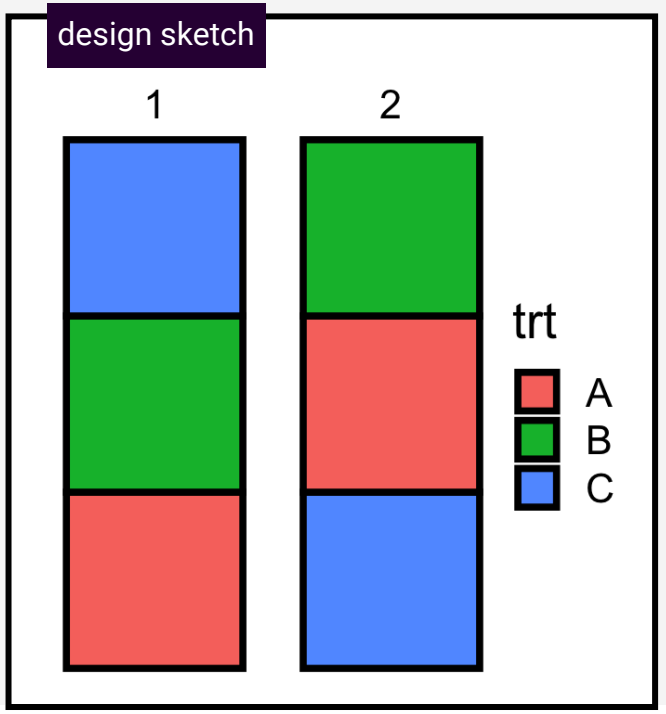


agricolae::design.rcbd

Randomised complete block design for $t = 3$ treatments with 2 blocks

```
trt <- c("A", "B", "C")
agricolae::design.rcbd(trt = trt, r = 2) %>% glimpse()

## List of 3
##  $ parameters:List of 7
##   ..$ design: chr "rcbd"
##   ..$ trt   : chr [1:3] "A" "B" "C"
##   ..$ r     : num 2
##   ..$ serie : num 2
##   ..$ seed  : int 490734433
##   ..$ kinds : chr "Super-Duper"
##   ..$       : logi TRUE
##  $ sketch    : chr [1:2, 1:3] "A" "C" "B" "A"
```

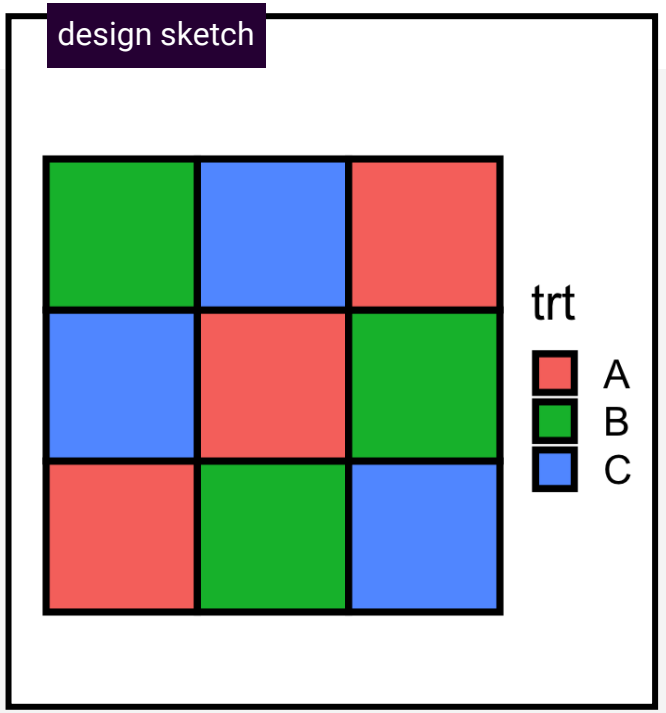


agricolae::design.lsd()

Latin square design for $t = 3$ treatments

```
trt <- c("A", "B", "C")
agricolae::design.lsd(trt = trt) %>% glimpse()

## List of 3
##  $ parameters:List of 7
##   ..$ design: chr "lsd"
##   ..$ trt   : chr [1:3] "A" "B" "C"
##   ..$ r     : int 3
##   ..$ serie : num 2
##   ..$ seed  : int -338489375
##   ..$ kinds : chr "Super-Duper"
##   ..$       : logi TRUE
##  $ sketch    : chr [1:3, 1:3] "A" "C" "B" "B"
```

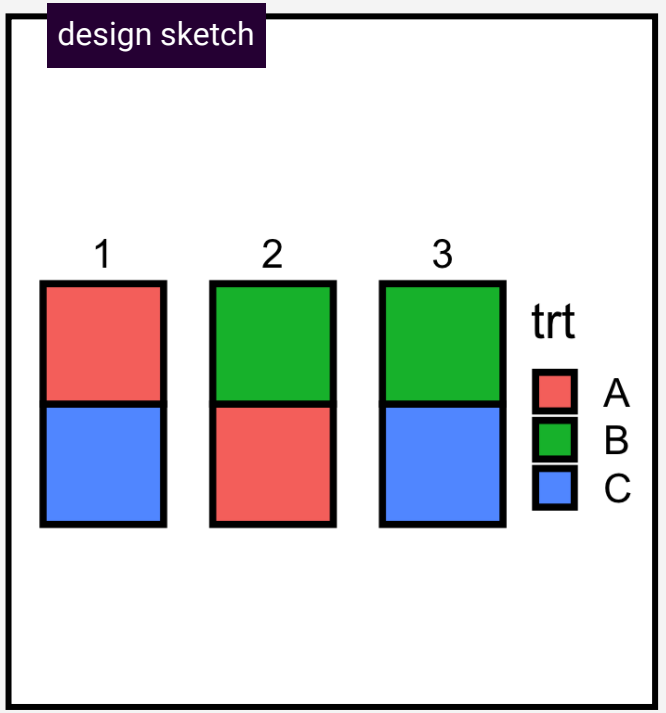


agricolae::design.bib()

Balanced incomplete block design for $t = 3$ treatments with block size of 2

```
trt <- c("A", "B", "C")
agricolae::design.bib(trt = trt, k = 2) %>% glimpse()

## [1] "No improvement over initial random design."
##
## Parameters BIB
## ==============
## Lambda     : 1
## treatmeans : 3
## Block size : 2
## Blocks     : 3
## Replication: 2
##
```

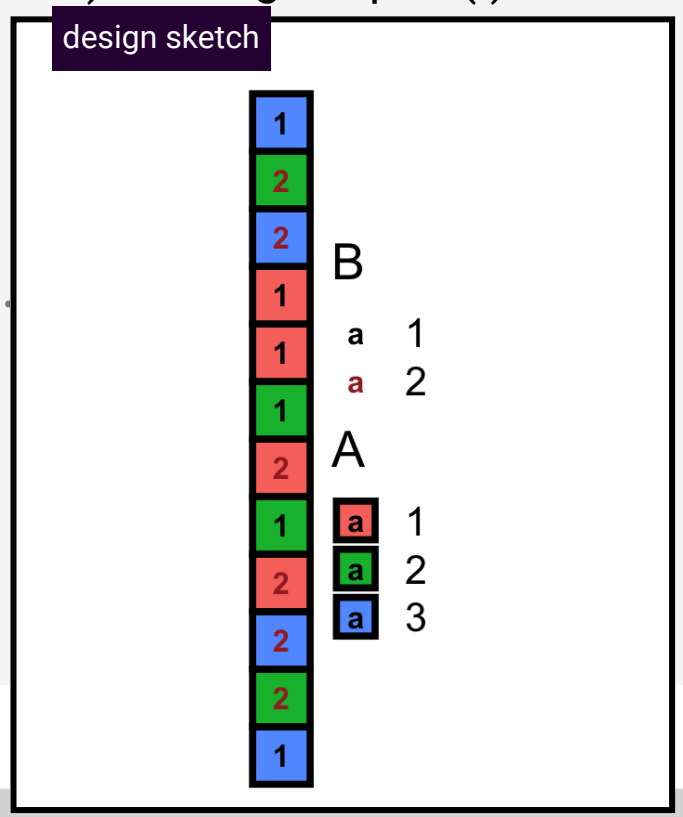


agricolae::design.ab()

Factorial design for $t = 3 \times 2$ treatments with 2 replication for each treatment

```
agricolae::design.ab(trt = c(3, 2), r = 2, design = "crd") %>% glimpse()
```

```
## List of 2
##  $ parameters:List of 8
##   ..$ design : chr "factorial"
##   ..$ trt    : chr [1:6] "1 1" "1 2" "2 1" "2 2" ...
##   ..$ r      : num [1:6] 2 2 2 2 2 2
##   ..$ serie  : num 2
##   ..$ seed   : int -751356955
##   ..$ kinds  : chr "Super-Duper"
##   ..$        : logi TRUE
##   ..$ applied: chr "crd"
```



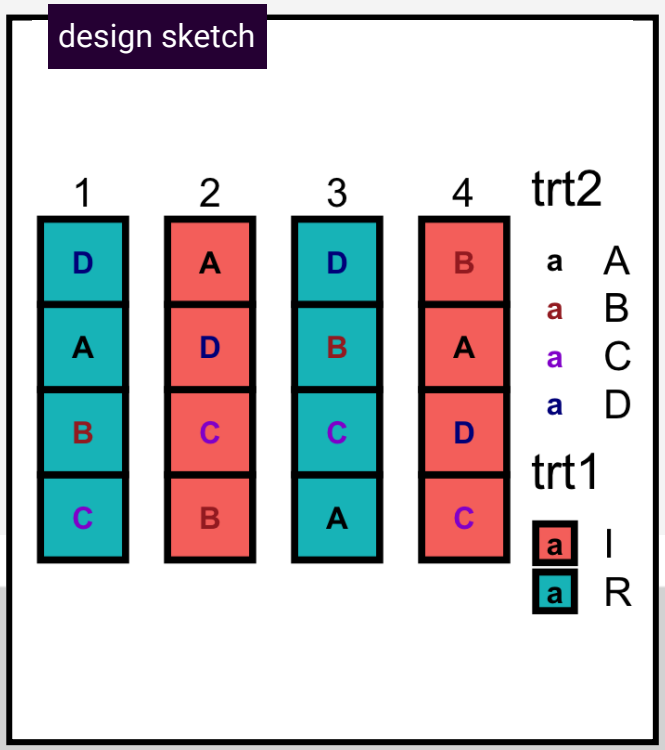
Note *not* A/B testing!

agricolae::design.split()

Split-plot design for $t = 2 \times 4$ treatments with 2 replication for each treatment

```
trt1 <- c("I", "R"); trt2 <- LETTERS[1:4]
agricolae::design.split(trt1 = trt1, trt2 = trt2, r = 2, design = "crd") %>%
    glimpse()

## List of 2
##  $ parameters:List of 8
##   ..$ design : chr "split"
##   ..$        : logi TRUE
##   ..$ trt1   : chr [1:2] "I" "R"
##   ..$ applied: chr "crd"
##   ..$ r      : num [1:2] 2 2
##   ..$ serie  : num 2
```



実験計画法の文法とは

- Base R プロット覚えてますか？ ▸ base plot
- 🤔 "named experimental design" functions (`agricolae::design.crd`, etc.) are like "named statistical graphic" functions (`pie`, `barplot`)
- 💡🔧 このコンセプトが `edibble` R-packageのもとです https://github.com/emitanaka/edibble

名前の元

- `tibble` R-package とは modern reimagining of the `data.frame`
- `edibble` とは **e**xperimental **d**esign t**ibble**

edibble プロトタイプ

- Consider a field experiment with 32 plots
- There are 7 different treatments
- Allocate treatments to plots
- Randomise treatments to plots
- The result is a **completely randomised design**

```
library(edibble)
start_design(name = "cochran.crd") %>%
  set_units(plot = 32) %>%
  set_trts(trt = c("F12", "F3", "F6", "O",
                   "S12", "S3", "S6")) %>%
  allocate_trts(~ plot) %>%
  randomise_trts() %>%
  serve_table()
```

```
## # An edibble: 32 x 2
##    plot       trt
##    <unit(32)> <trt(7)>
##  1 plot1      F12
##  2 plot2      S6
##  3 plot3      F6
##  4 plot4      O
##  5 plot5      S6
```

edibble プロトタイプ

- Consider a field experiment with 2 blocks each with 16 plots
- There are 7 different treatments
- Allocate treatments to plots
- Randomise treatments to plots within blocks
- Resulting design is a **randomised block design**

前の実験研究法とどう違うか分かりますか？

```
library(edibble)
start_design(name = "cochran.crd") %>%
  set_units(block = c("B1", "B2"),
            plot = nested_in(block, 16)) %>%
  set_trts(trt = c("F12", "F3", "F6", "O",
                   "S12", "S3", "S6")) %>%
  allocate_trts(~ plot) %>%
  randomise_trts() %>%
  serve_table()
```

```
## # An edibble: 32 x 3
##    block     plot        trt
##    <unit(2)> <unit(32)> <trt(7)>
##  1 B1        plot1      S6
##  2 B1        plot2      S3
##  3 B1        plot3      F12
##  4 B1        plot4      F6
```

edibble ユニット・ストラクチャー

```
start_design("complex unit structure") %>%
  set_units(city = c("tokyo", "nagano", "sydney", "melbourne", "washington"),
            school = nested_in(city,
                               "tokyo"  ~ 4,
                               "sydney" ~ 1,
                                      . ~ 2)) %>%
  serve_table()
```

```
## # An edibble: 11 x 2
##    city       school
##    <unit(5)>  <unit(11)>
##  1 tokyo      school1
##  2 tokyo      school2
##  3 tokyo      school3
##  4 tokyo      school4
```

edibble トリートメント・ストラクチャー

```
des <- start_design(name = "Effective teaching") %>%
    set_units(class = 4,
              student = nested_in(class, 30)) %>%
    set_trts(style = c("flipped", "traditional"),
             exam = c("take-home", "open-book", "closed-book")) %>%
    allocate_trts(style ~ class,
                  exam ~ student) %>%
    randomise_trts()

print(serve_table(des), n = 120)
```

```
## # An edibble: 120 x 4
##     class     student     style       exam
##     <unit(4)> <unit(120)> <trt(2)>    <trt(3)>
##   1 class1    student1    flipped     closed-book
```

Recording variables in `edibble` • 記録

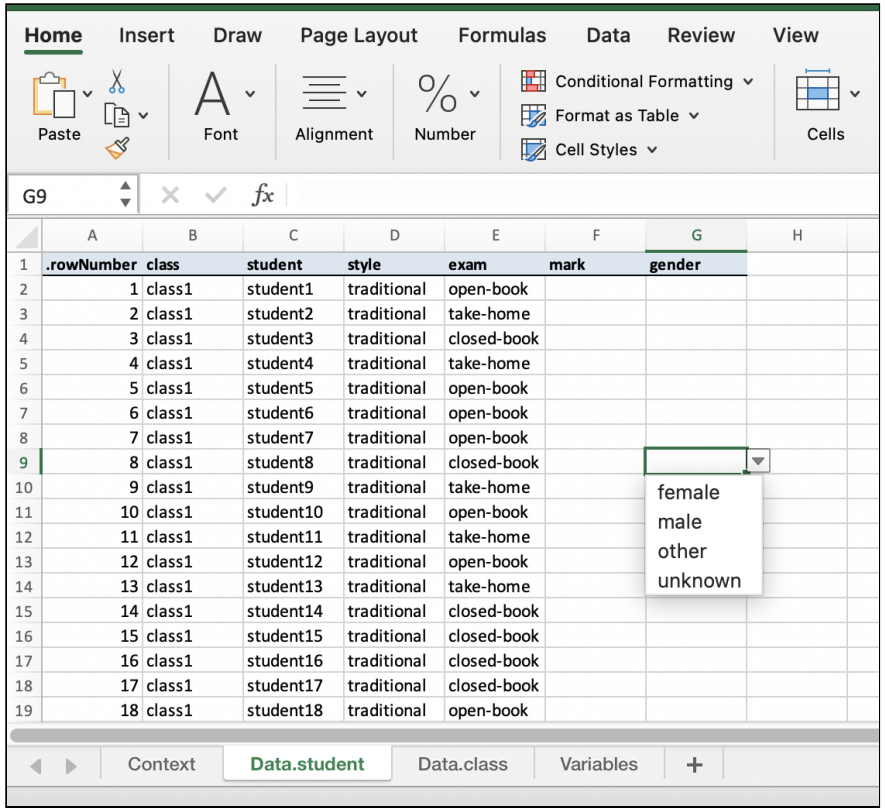
```
out <- des %>%
    record_vars(student = c(mark, gender),
                class = teacher) %>%
    expect_vars(mark = to_be_numeric(with_value(between = c(0, 100))),
              gender = to_be_factor(levels = c("female", "male", "other", "unknown"))) %>%
    serve_table()

out
```

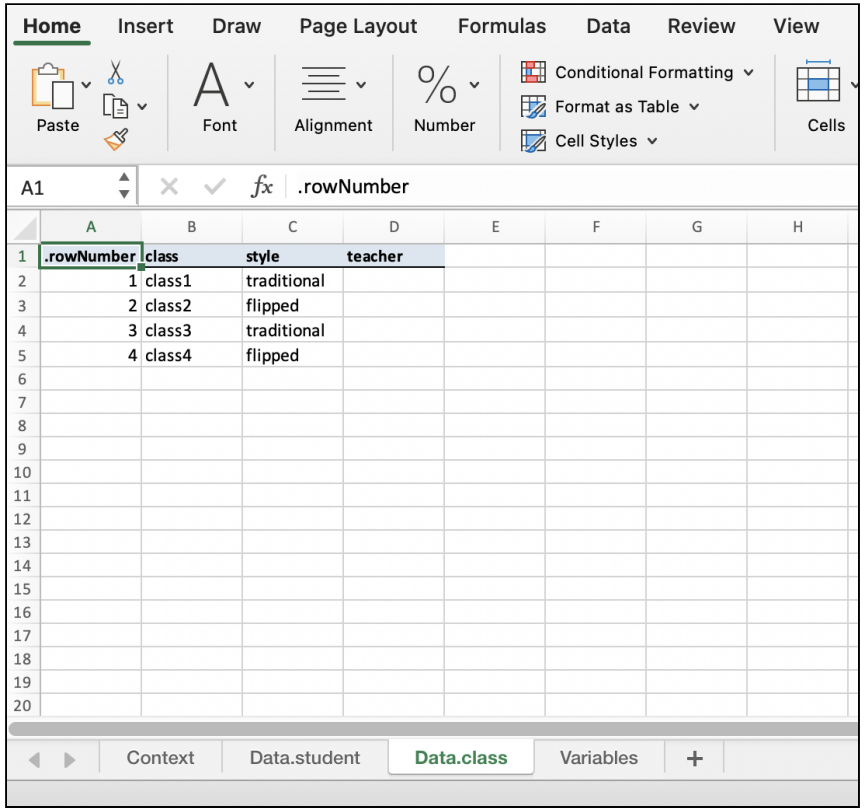
```
## # An edibble: 120 x 7
##    class     student     style    exam          mark gender teacher
##    <unit(4)> <unit(120)> <trt(2)> <trt(3)>    <rcrd> <rcrd>  <rcrd>
##  1 class1    student1    flipped  closed-book      ▪      ▪       ▪
##  2 class1    student2    flipped  closed-book      ▪      ▪       x
##  3 class1    student3    flipped  open-book        ▪      ▪       x
##  4 class1    student4    flipped  open-book        ▪      ▪       x
##  5 class1    student5    flipped  open-book        ▪      ▪       x
```

edibble アウトプット

```
export_design(out, file = "design.xlsx")
```



	A	B	C	D	E	F	G	H
1	.rowNumber	class	student	style	exam	mark	gender	
2	1	class1	student1	traditional	open-book			
3	2	class1	student2	traditional	take-home			
4	3	class1	student3	traditional	closed-book			
5	4	class1	student4	traditional	take-home			
6	5	class1	student5	traditional	open-book			
7	6	class1	student6	traditional	open-book			
8	7	class1	student7	traditional	open-book			
9	8	class1	student8	traditional	closed-book			
10	9	class1	student9	traditional	take-home			
11	10	class1	student10	traditional	open-book			
12	11	class1	student11	traditional	take-home			
13	12	class1	student12	traditional	open-book			
14	13	class1	student13	traditional	take-home			
15	14	class1	student14	traditional	closed-book			
16	15	class1	student15	traditional	closed-book			
17	16	class1	student16	traditional	closed-book			
18	17	class1	student17	traditional	closed-book			
19	18	class1	student18	traditional	open-book			



	A	B	C	D	E	F	G	H
1	.rowNumber	class	style	teacher				
2	1	class1	traditional					
3	2	class2	flipped					
4	3	class3	traditional					
5	4	class4	flipped					

実験計画は重要です!

`edibble`の目的は実験計画を容易にする事です

🔗 edibble.emitanaka.org

🚧 `edibble`は開発中です

コメントとフィードバックを歓迎します！

MONASH University

This slide is made using the `xaringan` R-package and found at

emitanaka.org/slides/TokyoR2021

Thank you!

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