PROGRAMMING WITH R
ANALYTIC QUESTIONS
EXPLORATORY DATA ANALYSIS
DATA REPRESENTATION
VECTORS
DATA FRAMES
LOAD DATA
TIDY DATA
STRINGS
TRANSFORM DATA
UNSTRUCTURED DATA
MACHINE LEARNING
VISUALIZE DATA
COMMUNICATE DATA

PROGRAMMING WITH R

variables

control structures

loops

functions

libraries

ANALYTIC QUESTIONS

did you summarize the data?

Quelle: Jeffery T. Leek, Roger D. Peng: What is the question? Science 20.03.2015: 1314-1315.

did you summarize the data? $\xrightarrow{\text{NO}}$ NOT a data analysis

Quelle: Jeffery T. Leek, Roger D. Peng: What is the question? Science 20.03.2015: 1314-1315.

did you summarize the data? $\xrightarrow{\text{NO}}$ NOT a data analysis

$\downarrow$ YES

did you report the summaries without interpretation?

Quelle: Jeffery T. Leek, Roger D. Peng: What is the question? Science 20.03.2015: 1314-1315.

did you summarize the data?

NO → NOT a data analysis

YES ↓

did you report the summaries without interpretation?

YES → DESCRIPTIVE

Quelle: Jeffery T. Leek, Roger D. Peng: What is the question? Science 20.03.2015: 1314-1315.

did you summarize the data?

NO → NOT a data analysis

YES ↓

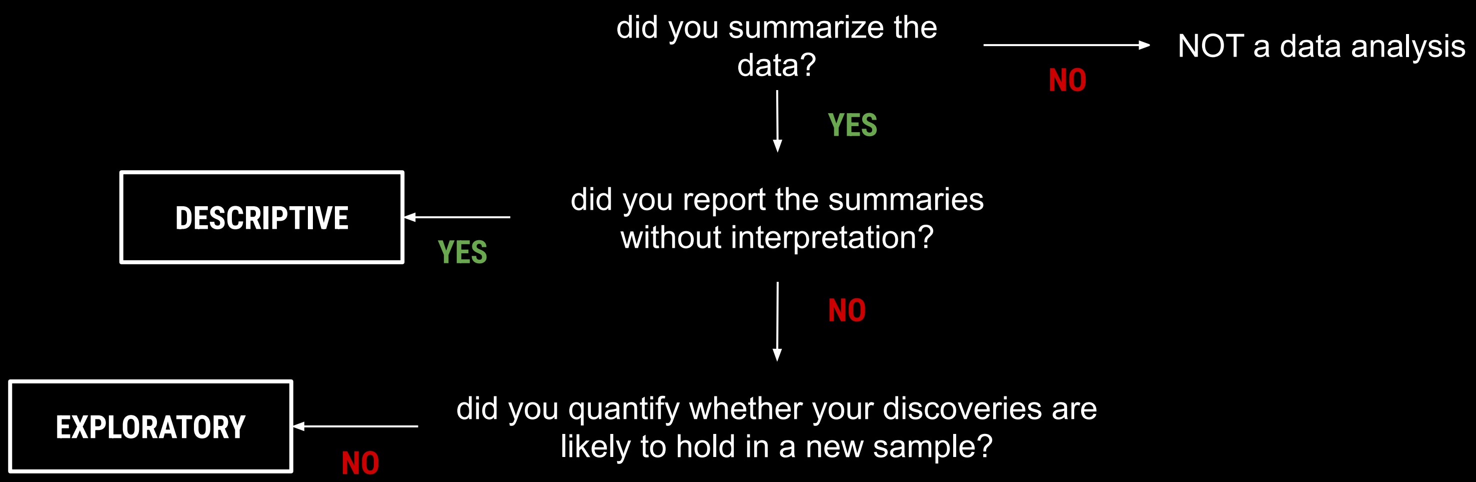
did you report the summaries without interpretation?

YES → **DESCRIPTIVE**

NO ↓

did you quantify whether your discoveries are likely to hold in a new sample?

Quelle: Jeffery T. Leek, Roger D. Peng: What is the question? Science 20.03.2015: 1314-1315.



Quelle: Jeffery T. Leek, Roger D. Peng: What is the question? Science 20.03.2015: 1314-1315.

did you summarize the data?

NO → NOT a data analysis

YES ↓

did you report the summaries without interpretation?

YES → **DESCRIPTIVE**

NO ↓

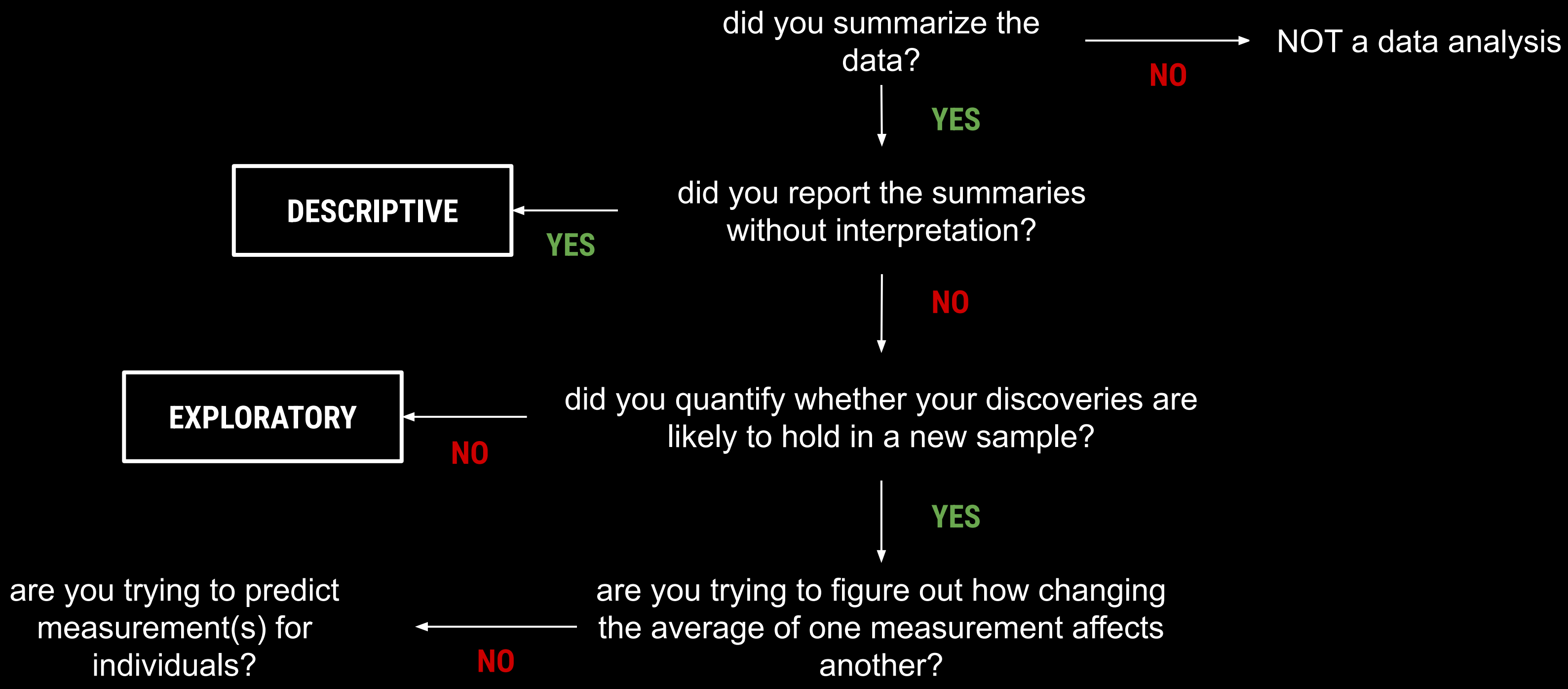
did you quantify whether your discoveries are likely to hold in a new sample?

NO → **EXPLORATORY**

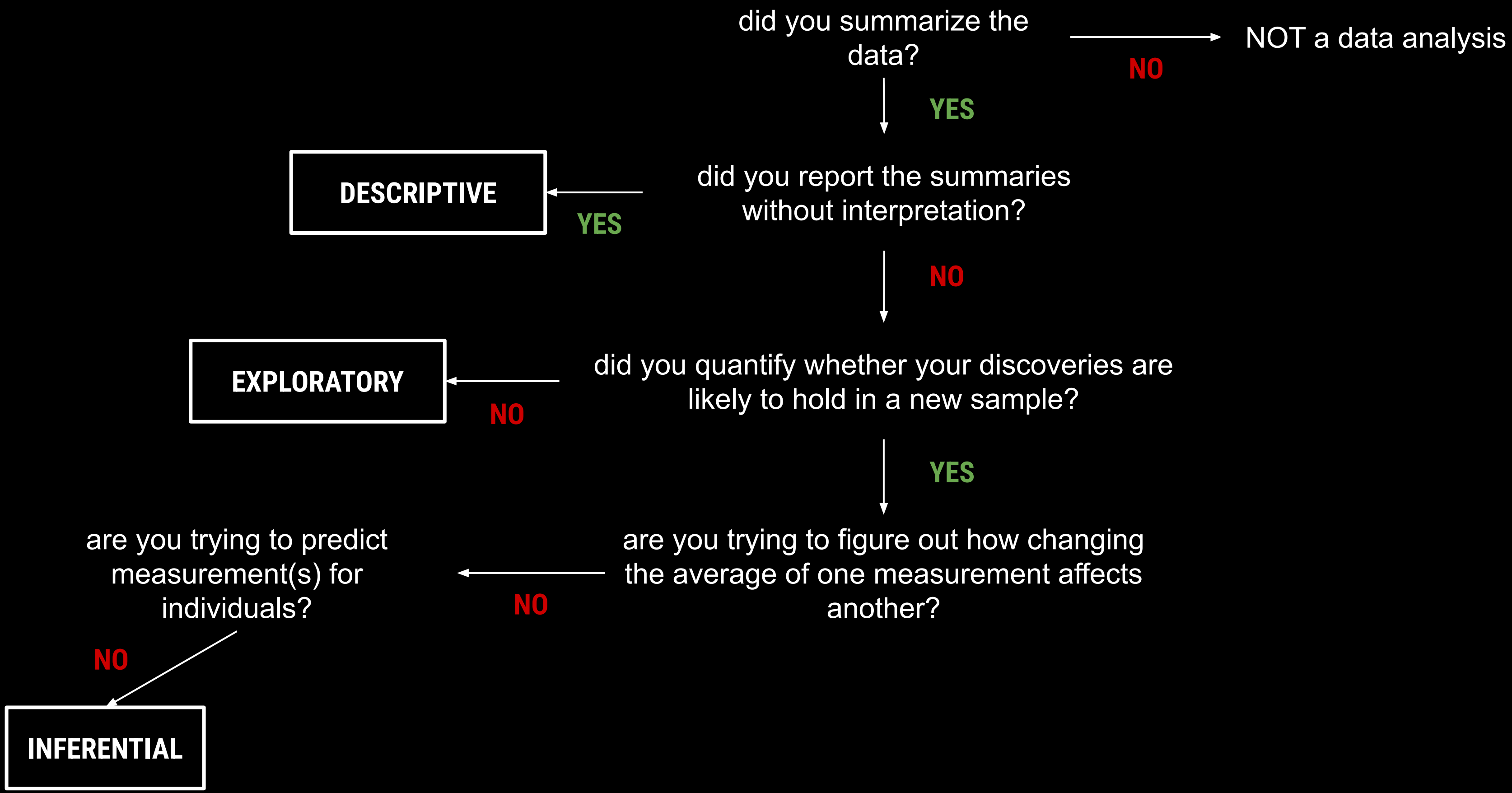
YES ↓

are you trying to figure out how changing the average of one measurement affects another?

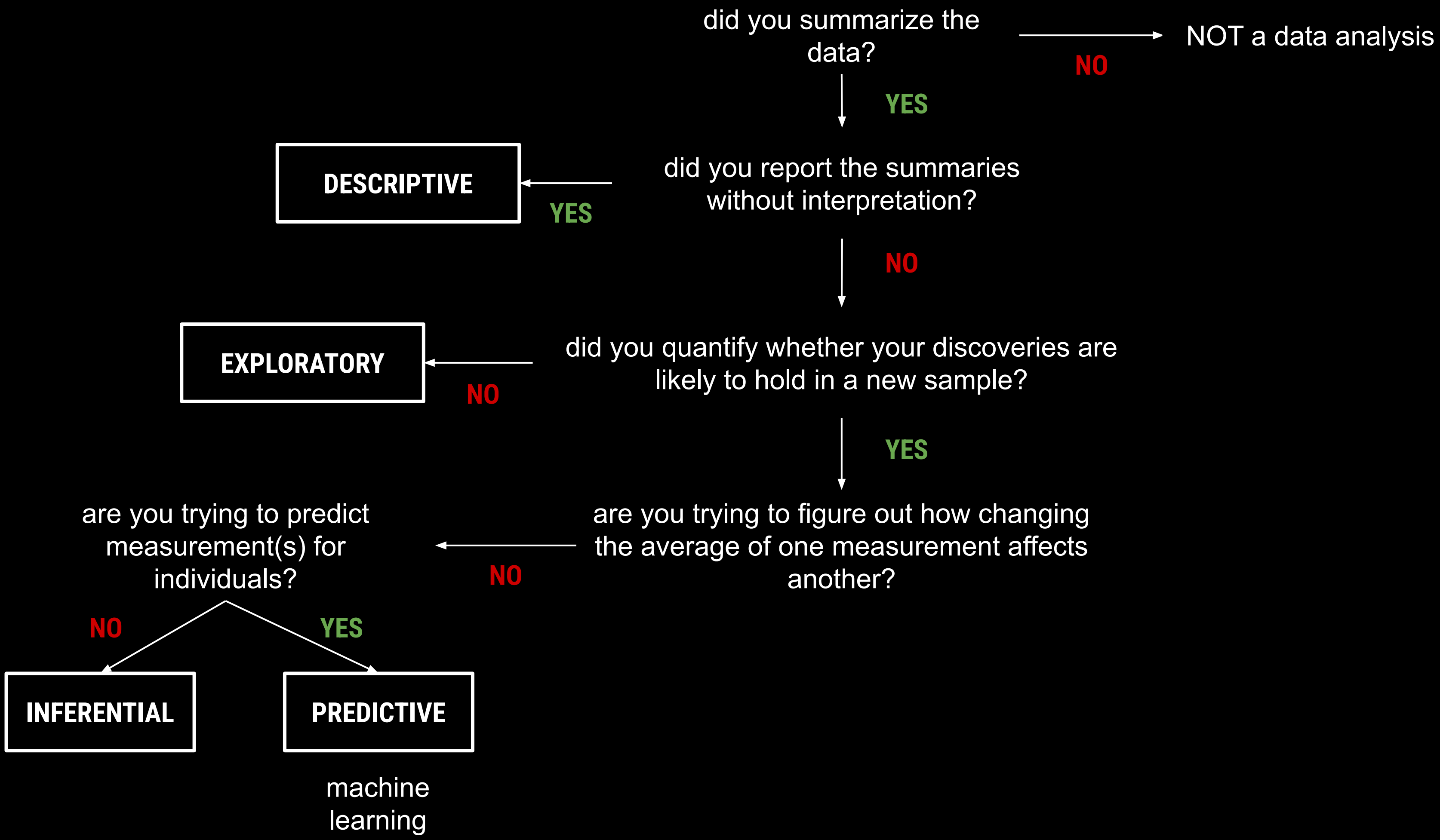
Quelle: Jeffery T. Leek, Roger D. Peng: What is the question? Science 20.03.2015: 1314-1315.



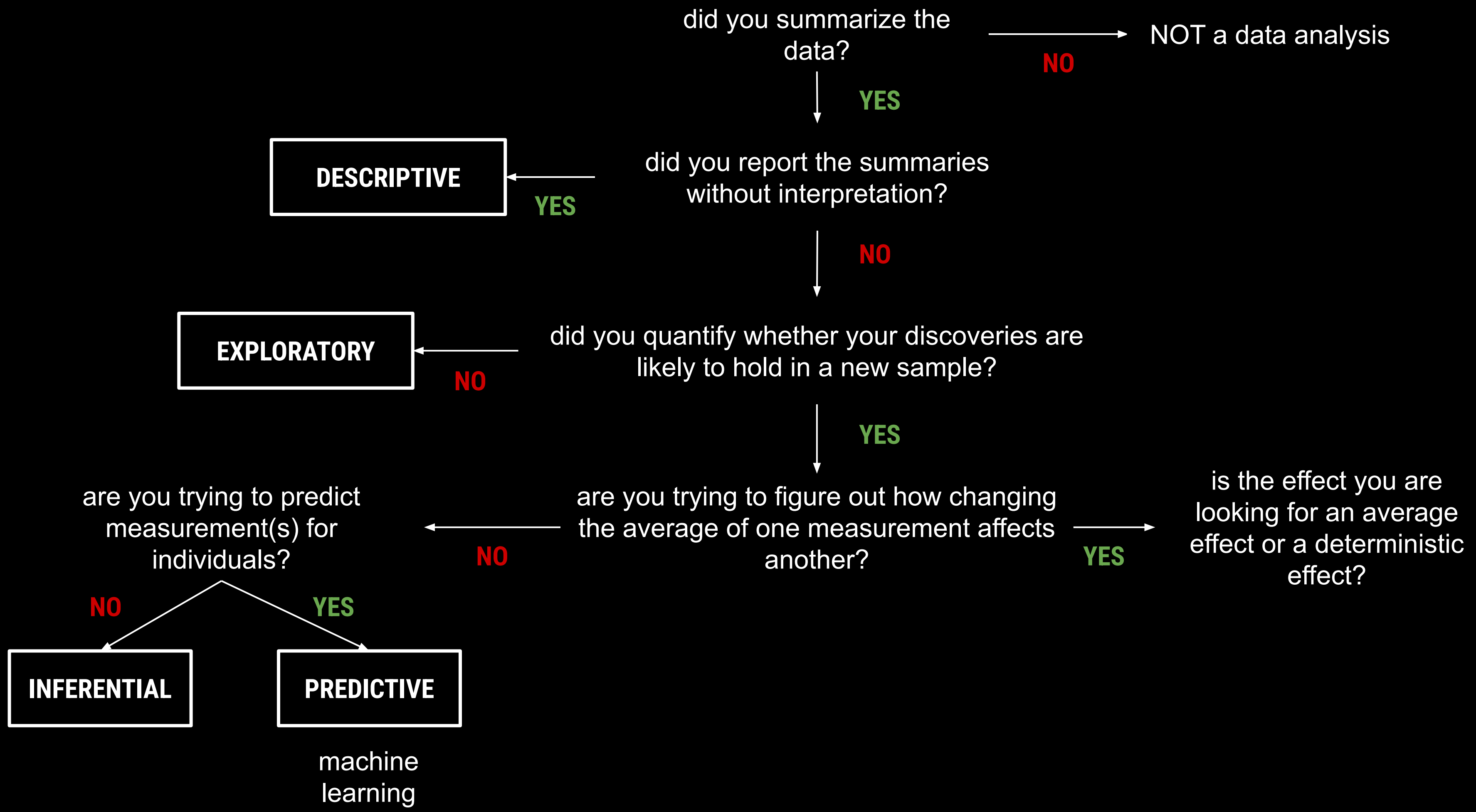
Quelle: Jeffery T. Leek, Roger D. Peng: What is the question? Science 20.03.2015: 1314-1315.



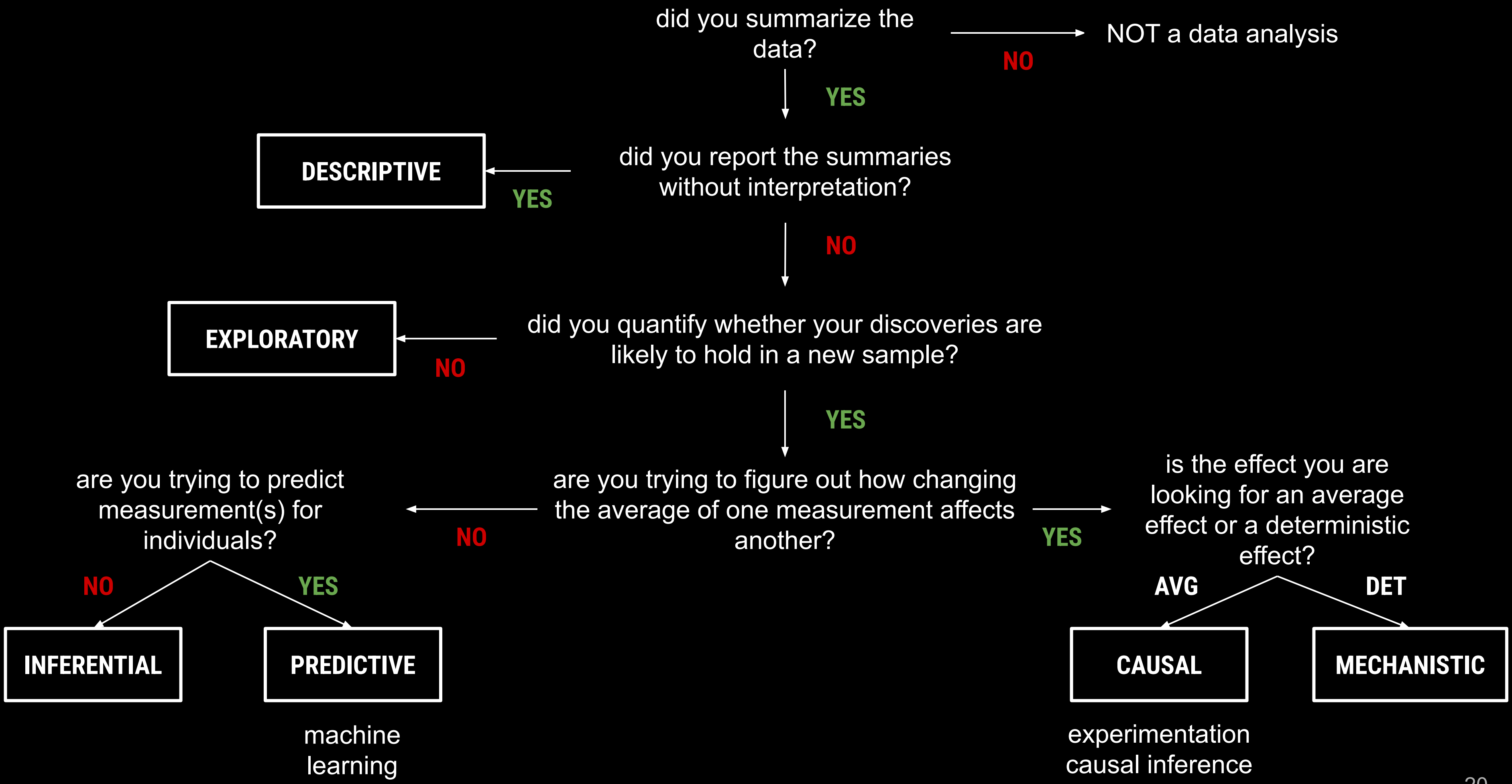
Quelle: Jeffery T. Leek, Roger D. Peng: What is the question? Science 20.03.2015: 1314-1315.



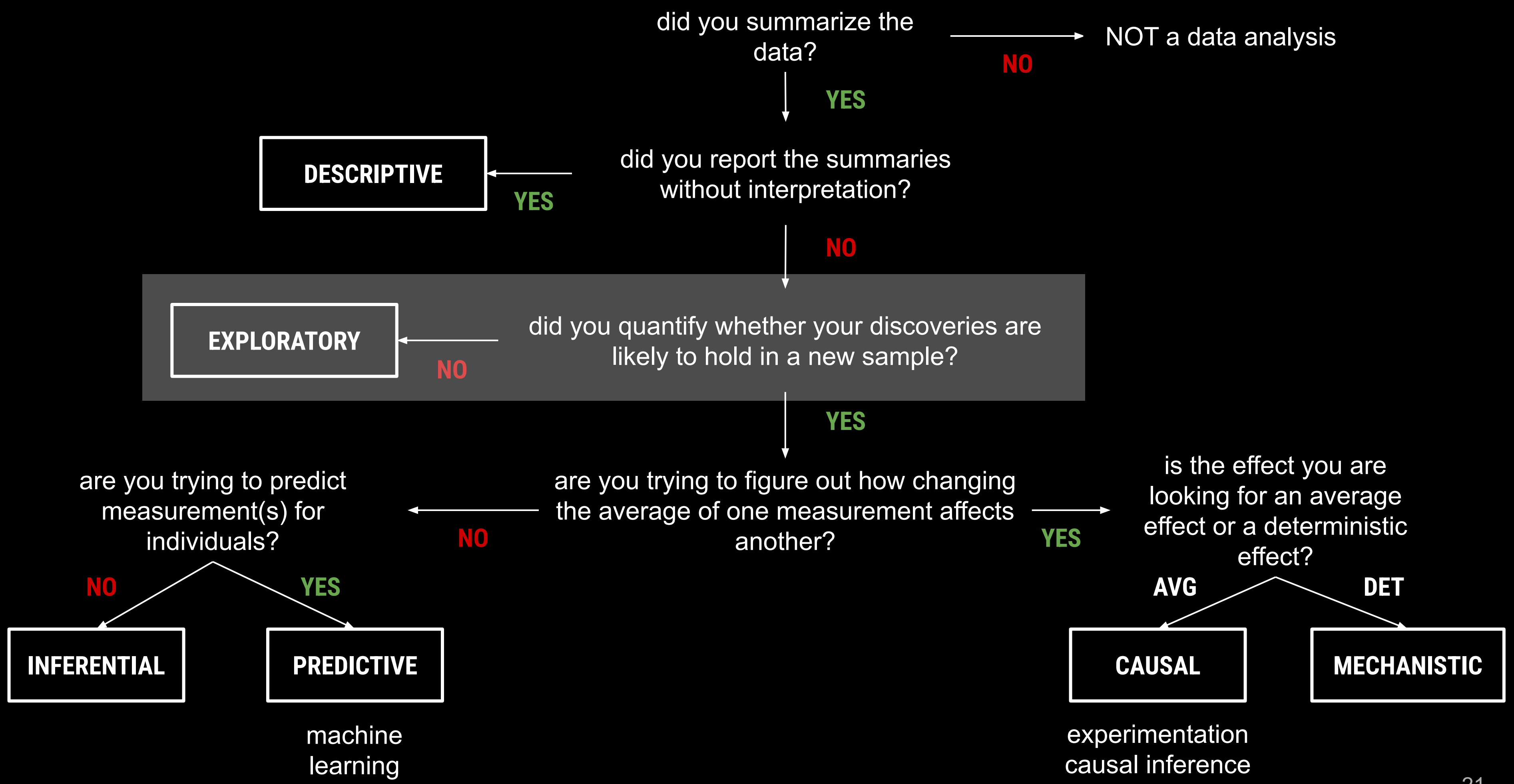
Quelle: Jeffery T. Leek, Roger D. Peng: What is the question? Science 20.03.2015: 1314-1315.



Quelle: Jeffery T. Leek, Roger D. Peng: What is the question? Science 20.03.2015: 1314-1315.



Source: Jeffery T. Leek, Roger D. Peng: What is the question? Science 20.03.2015: 1314-1315.

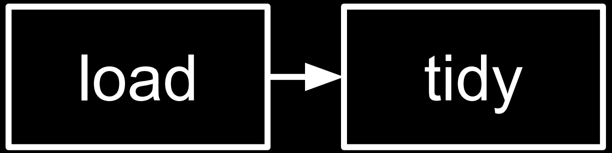


Quelle: Jeffery T. Leek, Roger D. Peng: What is the question? Science 20.03.2015: 1314-1315.

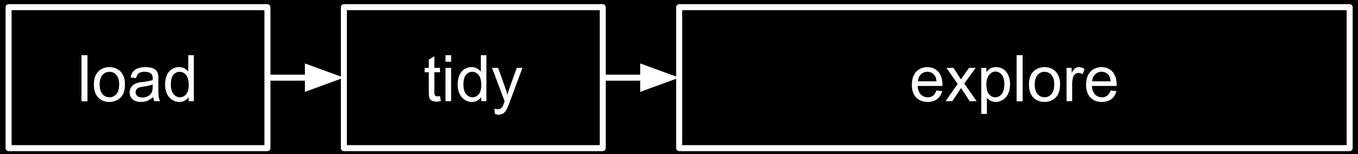
EXPLORATORY DATA ANALYSIS

load

Following Wickham, Hadley, et al. R for Data Science: Import, Tidy, Transform, Visualize, and Model Data. 2nd edition, O’Reilly Media, Inc, 2023.



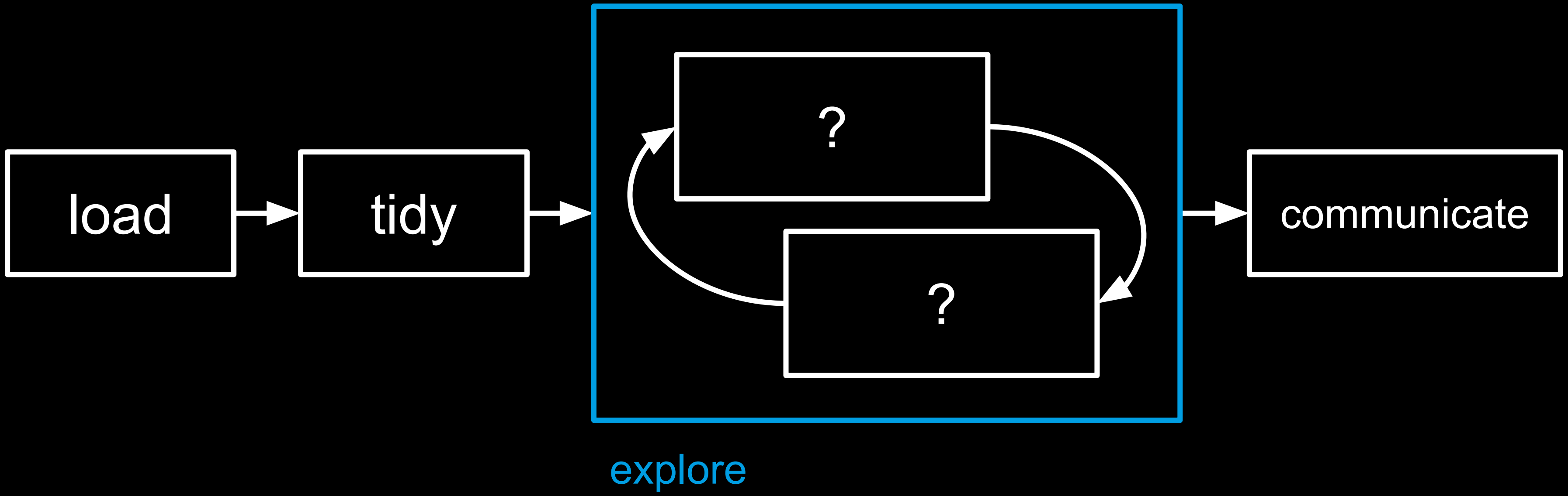
Following Wickham, Hadley, et al. R for Data Science: Import, Tidy, Transform, Visualize, and Model Data. 2nd edition, O’Reilly Media, Inc, 2023.



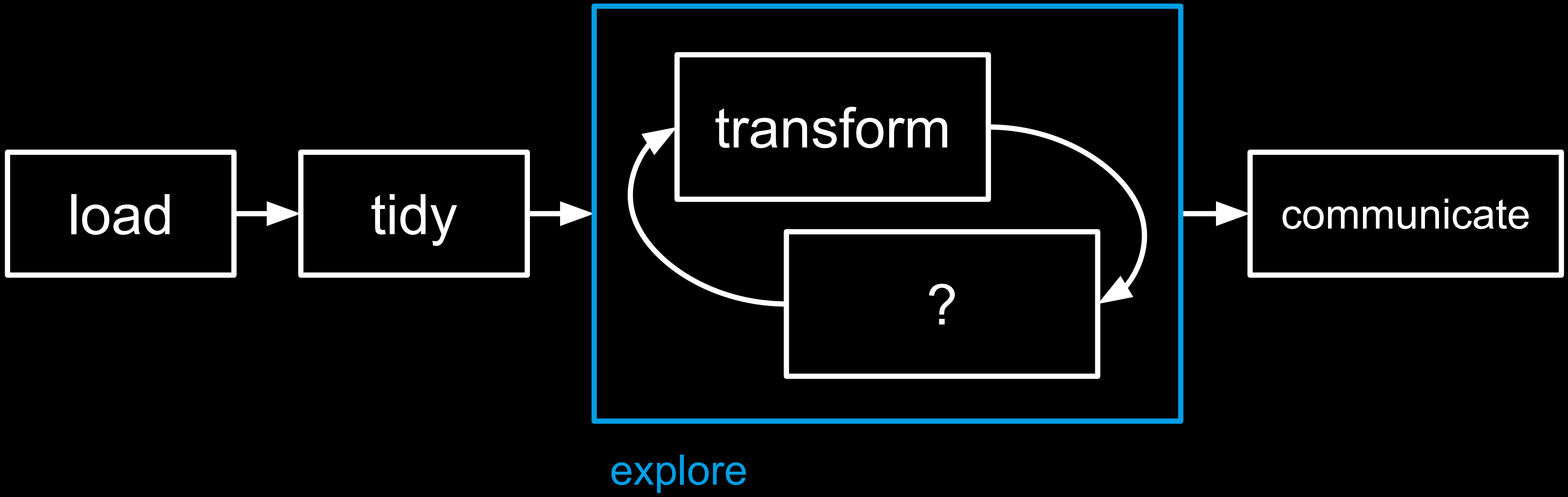
Following Wickham, Hadley, et al. R for Data Science: Import, Tidy, Transform, Visualize, and Model Data. 2nd edition, O'Reilly Media, Inc, 2023.

Following Wickham, Hadley, et al. R for Data Science: Import, Tidy, Transform, Visualize, and Model Data. 2nd edition, O’Reilly Media, Inc, 2023.

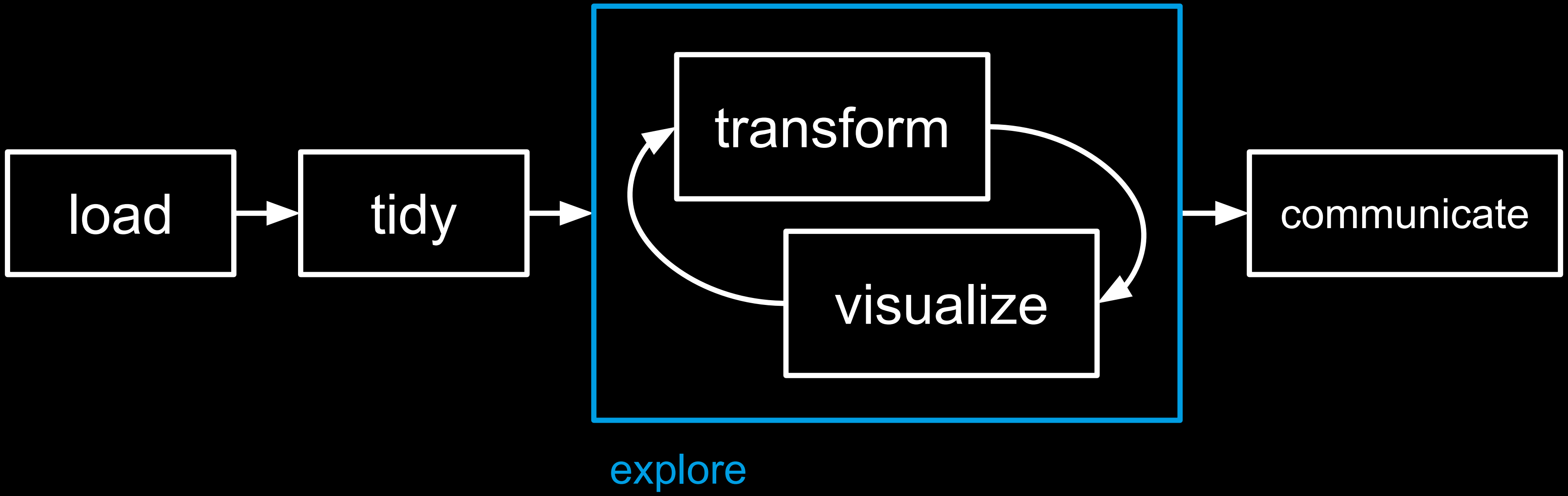
Following Wickham, Hadley, et al. R for Data Science: Import, Tidy, Transform, Visualize, and Model Data. 2nd edition, O'Reilly Media, Inc, 2023.



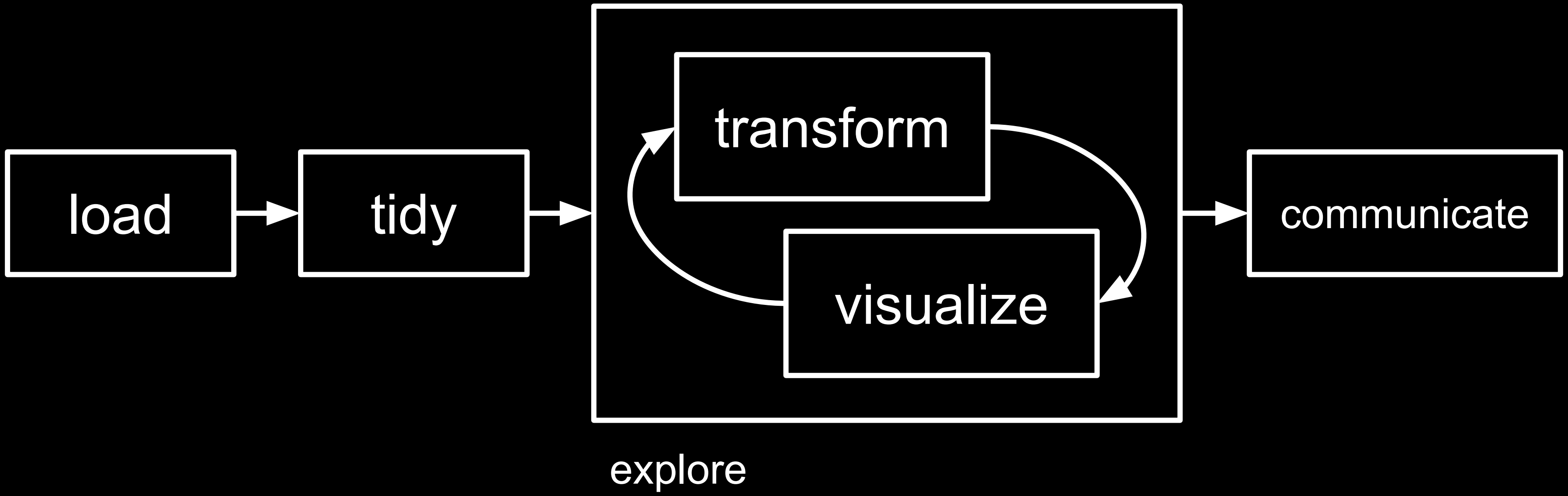
Following Wickham, Hadley, et al. R for Data Science: Import, Tidy, Transform, Visualize, and Model Data. 2nd edition, O'Reilly Media, Inc, 2023.



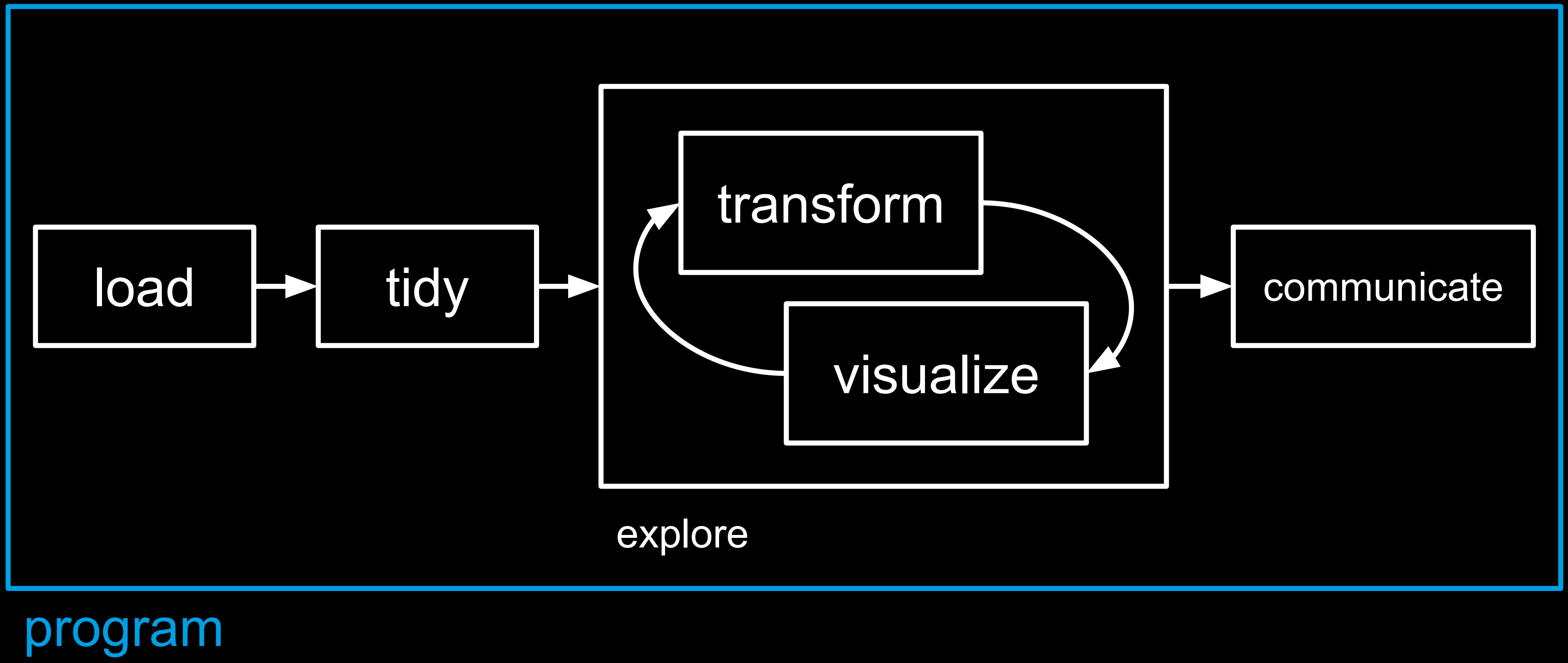
Following Wickham, Hadley, et al. R for Data Science: Import, Tidy, Transform, Visualize, and Model Data. 2nd edition, O’Reilly Media, Inc, 2023.



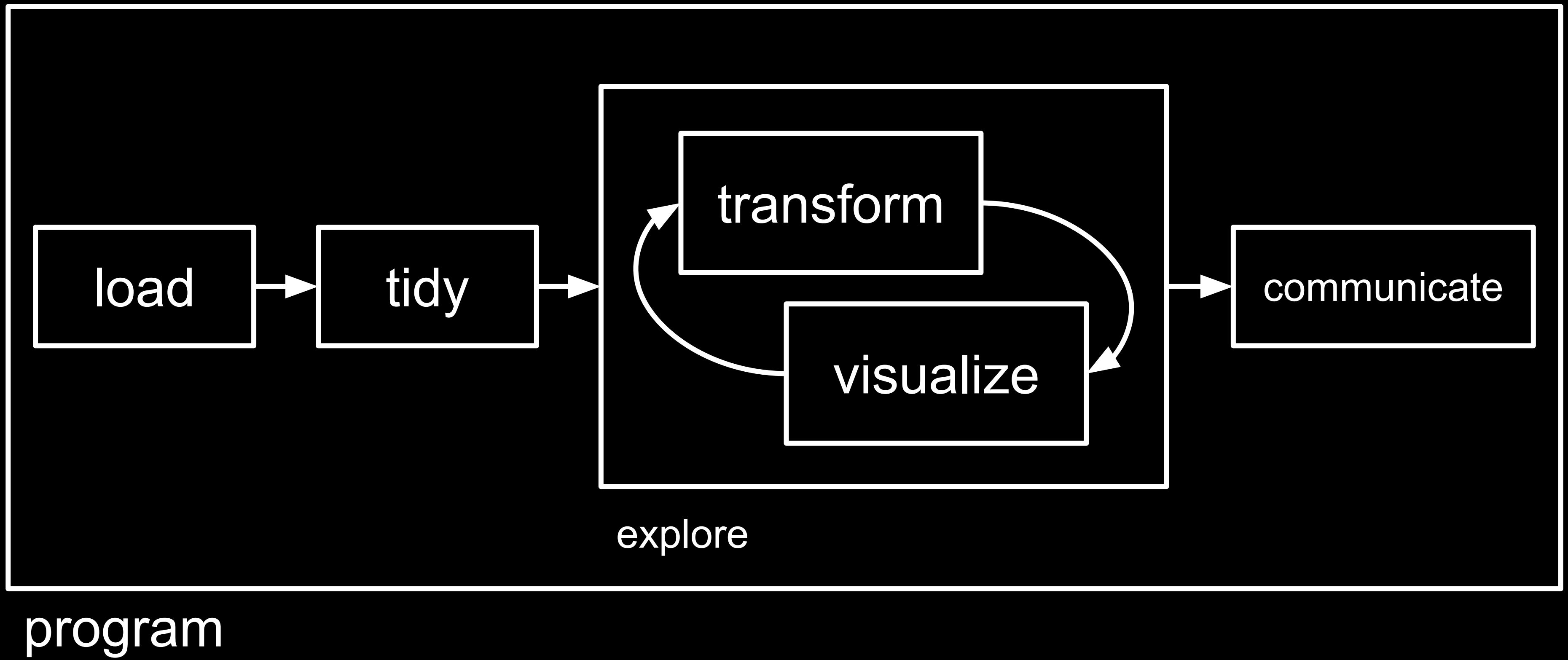
Following Wickham, Hadley, et al. R for Data Science: Import, Tidy, Transform, Visualize, and Model Data. 2nd edition, O'Reilly Media, Inc, 2023.



Following Wickham, Hadley, et al. R for Data Science: Import, Tidy, Transform, Visualize, and Model Data. 2nd edition, O'Reilly Media, Inc, 2023.



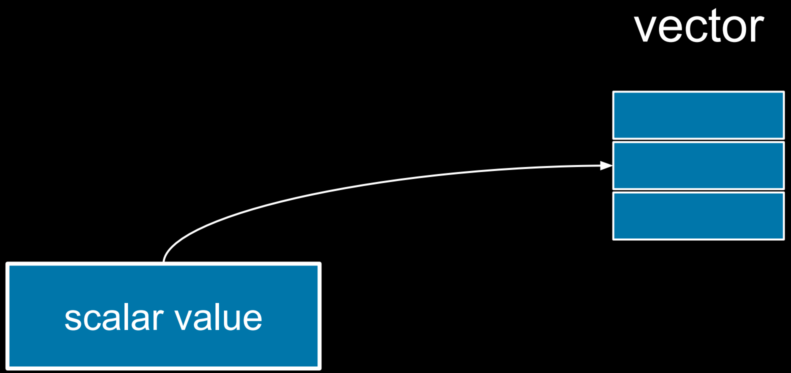
Following Wickham, Hadley, et al. R for Data Science: Import, Tidy, Transform, Visualize, and Model Data. 2nd edition, O’Reilly Media, Inc, 2023.

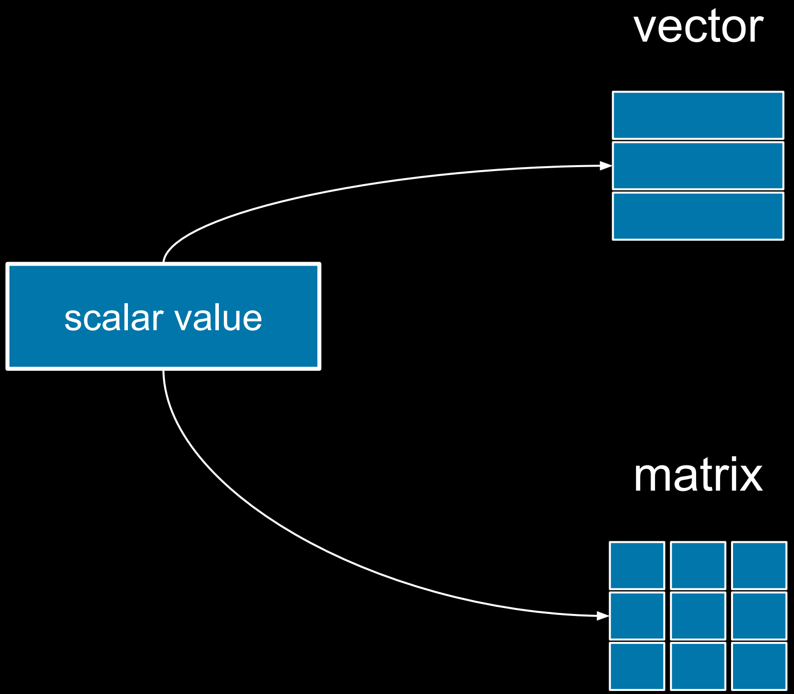


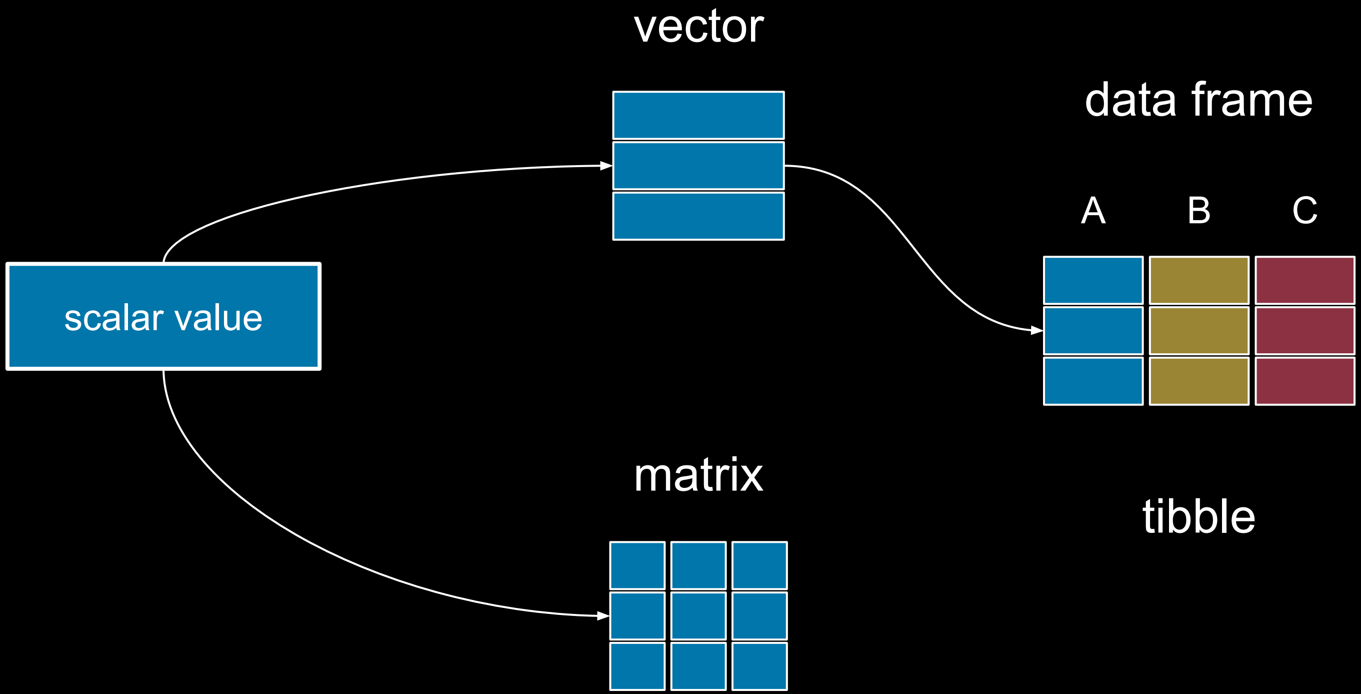
Following Wickham, Hadley, et al. R for Data Science: Import, Tidy, Transform, Visualize, and Model Data. 2nd edition, O’Reilly Media, Inc, 2023.

DATA REPRESENTATION

scalar value


vector
scalar value


vector
scalar value
matrix


vector
data frame
A
B
C
scalar value
matrix
tibble

VECTORS

apple
pear
orange

list of values with
the same storage mode

list of values with
the same storage mode

character
double
integer
logical

```
v <- c("apple", "pear", "orange")
```

`v[1]`

apple
pear
orange

`v[2]`

apple
pear
orange

`v[3]`

apple
pear
orange

```
weight <- c(91, 75.5, 61, 88.5, 120)
```

```
weight <- c(91, 75.5, 61, 88.5, 120)
mean(weight)
```

```
sum       length
mean      sort
median    cumsum
sd        prod
var       quantile
min       abs
max       range
```

91
75.5
61
88.5
120

```
weight_after_diet <-
   c(89.5, 75, 56, 96.5, 115)
```

weight		weight_after_diet
91		89.5
75.5		75
61	−	56
88.5		96.5
120		115

weight		weight_after_diet		weight_loss
91		89.5		1.5
75.5		75		0.5
61	−	56	=	5
88.5		96.5		-8
120		115		5

```
weight_loss <-
   weight - weight_after_diet
```

subsetting vectors

```
weight[1]
```

```
weight[1]

weight[-1]
```

```
weight[1]

weight[-1]

weight[2:5]
```

```
weight[1]

weight[-1]

weight[2:5]

weight[1:length(weight)-1]
```

```
weight[1]

weight[-1]

weight[2:5]

weight[1:length(weight)-1]

weight[c(TRUE, FALSE, TRUE, TRUE, FALSE)]
```

```r
weight[1]

weight[-1]

weight[2:5]

weight[1:length(weight)-1]

weight[c(TRUE, FALSE, TRUE, TRUE, FALSE)]

weight[weight > 80]
```

```
weight[1]

weight[-1]

weight[2:5]

weight[1:length(weight)-1]

weight[c(TRUE, FALSE, TRUE, TRUE, FALSE)]

weight[weight > 80]

weight[weight > 80 & weight < 100]
```

special values

```
NA
NULL
NaN
Inf
-Inf
```

factors

```r
category <- factor(c("heavy", "medium", "light", "medium", "heavy"))
```

```r
category <- factor(c("heavy", "medium", "light", "medium", "heavy"))

levels(weight_category)
```

```r
category <- factor(c("heavy", "medium", "light", "medium", "heavy"))

levels(weight_category)

category_reordered <- factor(category,
                             levels = c("light", "medium", "heavy"))
```

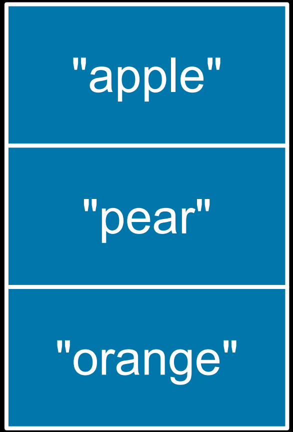
```r
category <- factor(c("heavy", "medium", "light", "medium", "heavy"))

levels(weight_category)

category_reordered <- factor(category,
                             levels = c("light", "medium", "heavy"))

category_ordered <- factor(category,
                           levels = c("light", "medium", "heavy"),
                           ordered = TRUE)
```

{{ forcats }}

```
as_factor()
```

```
fct_reorder
fct_relevel
fct_infreq
fct_rev
fct_lump
```

DATA FRAMES


"apple"
"pear"
"orange"

"apple"	TRUE
"pear"	TRUE
"orange"	FALSE

"apple"	TRUE	10.0
"pear"	TRUE	16.5
"orange"	FALSE	14.0

fruit		
"apple"	TRUE	10.0
"pear"	TRUE	16.5
"orange"	FALSE	14.0

fruit	domestic	
"apple"	TRUE	10.0
"pear"	TRUE	16.5
"orange"	FALSE	14.0

fruit	domestic	sugar
"apple"	TRUE	10.0
"pear"	TRUE	16.5
"orange"	FALSE	14.0

fruit	domestic	sugar
"apple"	TRUE	10.0
"pear"	TRUE	16.5
"orange"	FALSE	14.0

data frame "fruits"

fruit	domestic	sugar
"apple"	TRUE	10.0
"pear"	TRUE	16.5
"orange"	FALSE	14.0

creating data frames

```
data.frame()
read.csv()
```

comma separated values (CSV)

data frame meta data

```
ncol()
nrow()
dim()
colnames()
```

accessing data frames

accessing data frames

accessing columns

```r
monty$prize_door
monty$contestant_choice
monty$decision
```

```
monty$prize_door
monty$contestant_choice
monty$decision
```

return a vector

```
monty["prize_door"]
monty["contestant_choice"]
monty["decision"]
```

```
monty["prize_door"]
monty["contestant_choice"]
monty["decision"]
```

return a data frame

```r
# multiple columns by name
monty(c("prize_door", "contestant_choice"))
```

```r
monty[, 1]                 # first column
monty[, 1:2]               # first two columns
monty[, ncol(monty)]       # last column
```

accessing data frames

accessing rows

```
monty[1,]                   # first row
monty[1:10,]                # first 10 rows
monty[nrow(monty),]         # last row
```

changing columns

```r
monty$decision <- as.factor(monty$decision)
```

adding columns

```
monty$correct_guess <-
   monty$contestant_choice == monty$prize_door
```

rename columns

```r
colnames(monty)[2] <- "choice"
```

subsetting data frames

```
switched <-
   monty[monty_hall$decision == "switch, ]
```

```
switched <-
   monty[
      monty_hall$decision == "switch &
      monty$won == TRUE, ]
```

```
subset()
```

```
subset(monty, decision == "switch")
```

```r
subset(
      monty,
      decision == "switch" & won == TRUE
)
```

sorting rows

```
monty[order(monty$prize_door),]
```

```
monty[order(monty$prize_door),]

monty[order(
          monty$prize_door,
          decreasing = TRUE
          ),]
```

saving data frames

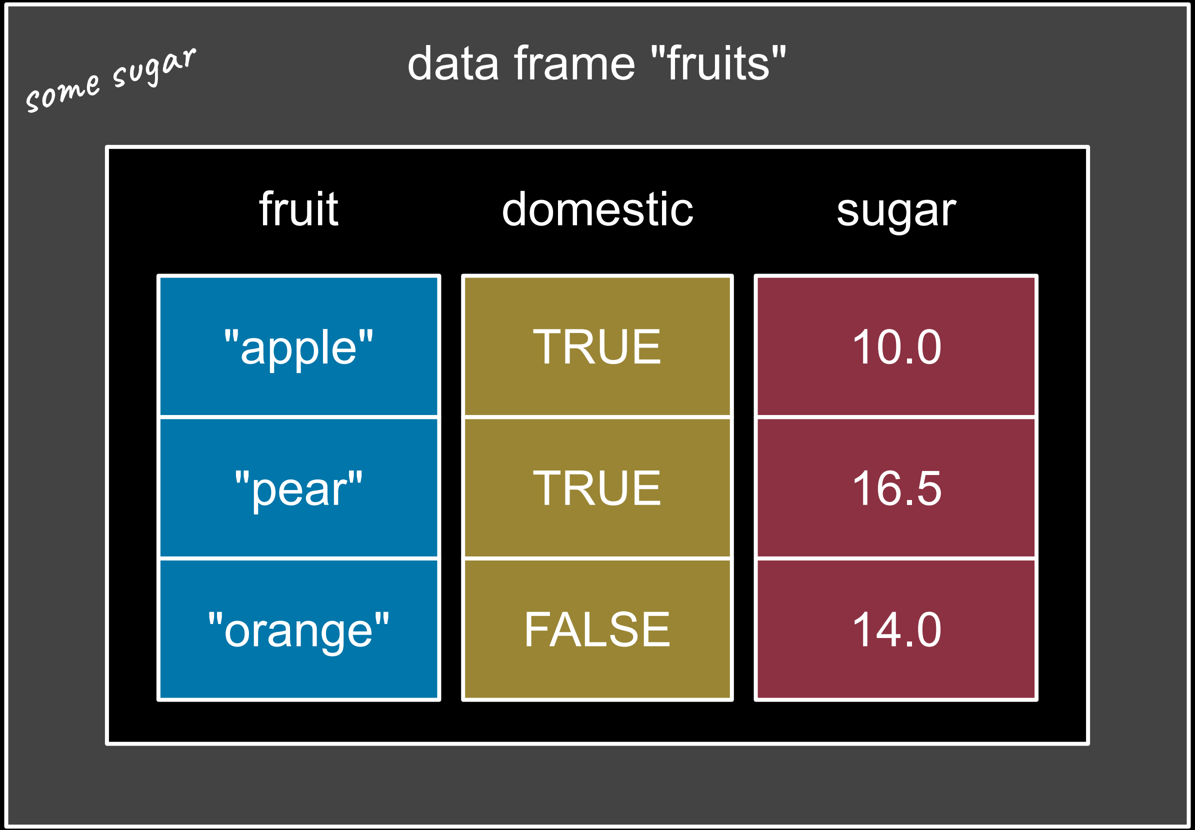
```
write.csv()
```

tibbles

{{ tibble }}

data frame "fruits"

fruit	domestic	sugar
"apple"	TRUE	10.0
"pear"	TRUE	16.5
"orange"	FALSE	14.0



tibble "tbl_fruits"

```
as_tibble()
```

some sugar

better printing
subsets stay tibbles
better data type guessing
support for extended data types
…

LOAD DATA

{{ readr }}

```
read_csv()
read_delim()
```

{{ readxl }}

```
read_excel()
```

TIDY DATA

tidy data

each variable is a column;
each column is a variable.

each observation is a row;
each row is an observation.

each value is a cell;
each cell is a single value.

country	year	cases	population
Afghanistan	1999	745	19987071
Afghanistan	2000	2666	20595360
Brazil	1999	37737	172006362
Brazil	2000	80488	174504898

Example from: Wickham, Hadley, et al. R for Data Science: Import, Tidy, Transform, Visualize, and Model Data. 2nd edition, O'Reilly Media, Inc, 2023. Chapter 5.

country	year	cases	population
Afghanistan	1999	745	19987071
Afghanistan	2000	2666	20595360
Brazil	1999	37737	172006362
Brazil	2000	80488	174504898

variables

country	year	cases	population
Afghanistan	1999	745	19987071
Afghanistan	2000	2666	20595360
Brazil	1999	37737	172006362
Brazil	2000	80488	174504898

observations

country	year	cases	population
Afghanistan	1999	745	19987071
Afghanistan	2000	2666	20595360
Brazil	1999	37737	172006362
Brazil	2000	80488	174504898

values

country	year	type	count
Afghanistan	1999	cases	745
Afghanistan	1999	population	19987071
Afghanistan	2000	cases	2666
Afghanistan	2000	population	20595360
Brazil	1999	cases	37737
Brazil	1999	population	172006362
Brazil	2000	cases	80488
Brazil	2000	population	174504898

longer

country	year	type	count
Afghanistan	1999	cases	745
Afghanistan	1999	population	19987071
Afghanistan	2000	cases	2666
Afghanistan	2000	population	20595360
Brazil	1999	cases	37737
Brazil	1999	population	172006362
Brazil	2000	cases	80488
Brazil	2000	population	174504898

wider

country	cases_1999	cases_2000	pop_1999	pop_2000
Afghanistan	745	2666	19987071	20595360
Brazil	37737	172006362	80488	174504898

compressed

country	year	rate
Afghanistan	1999	745 / 19987071
Afghanistan	2000	2666 / 20595360
Brazil	1999	37737 / 172006362
Brazil	2000	80488 / 174504898

tidy

country	year	cases	population
Afghanistan	1999	745	19987071
Afghanistan	2000	2666	20595360
Brazil	1999	37737	172006362
Brazil	2000	80488	174504898

tidy

country	year	cases	population
Afghanistan	1999	745	19987071
Afghanistan	2000	2666	20595360
Brazil	1999	37737	172006362
Brazil	2000	80488	174504898

vector

{{ tidyr }}

`pivot_wider()`

`pivot_longer()`

STRINGS

{{ stringr }}

```
str_trim()
str_squish()
```

```
str_starts()
str_ends()
str_detect()
```

“Annabel Miller”

“Annabel Miller”

```
str_starts(txt, "Anna")
```

“Annabel Miller”

```
str_ends(txt, "Miller")
```

“Annabel Miller”

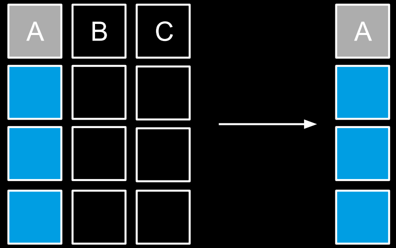
```
str_detect(txt, "Mill")
```

TRANSFORM DATA

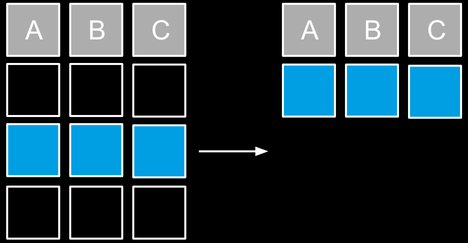
{{ dplyr }}

types of transformations

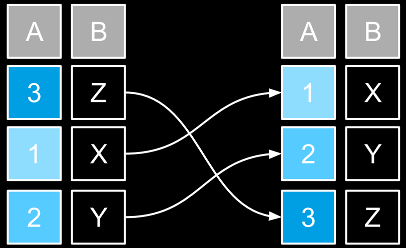
select()



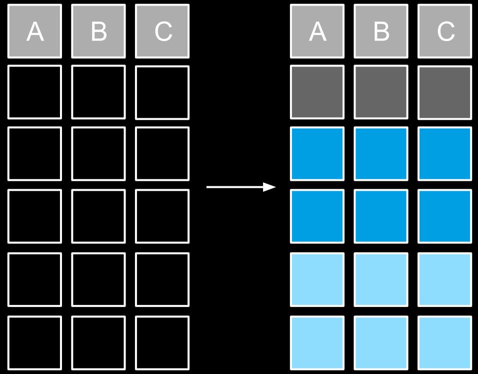
filter()



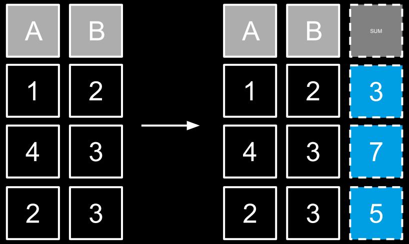
arrange()



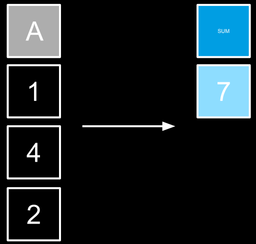
group_by()



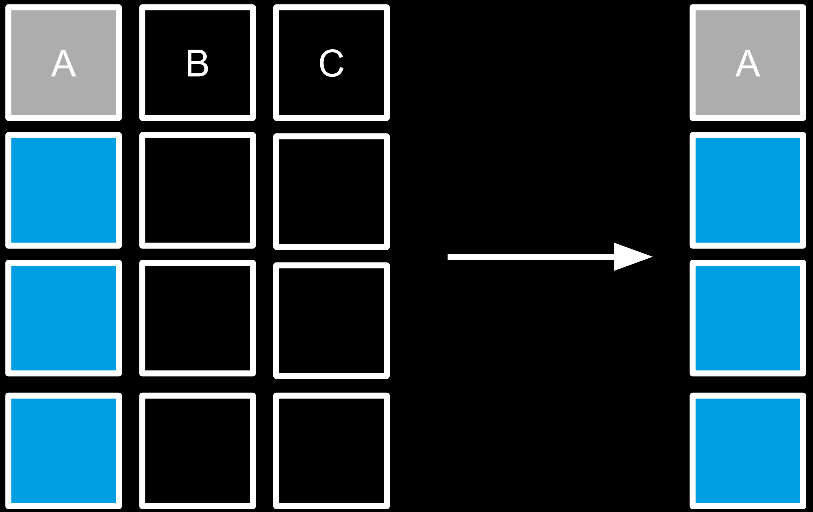
mutate()



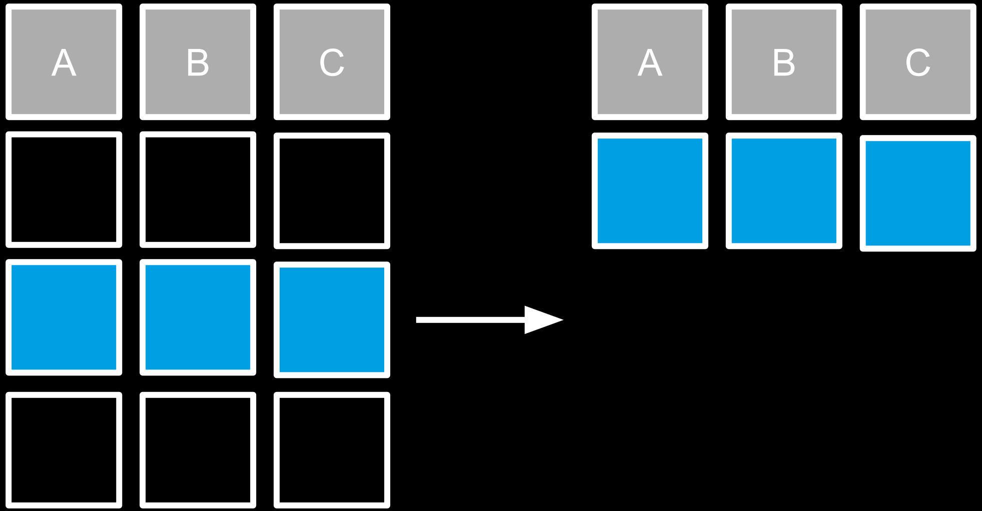
summarize()



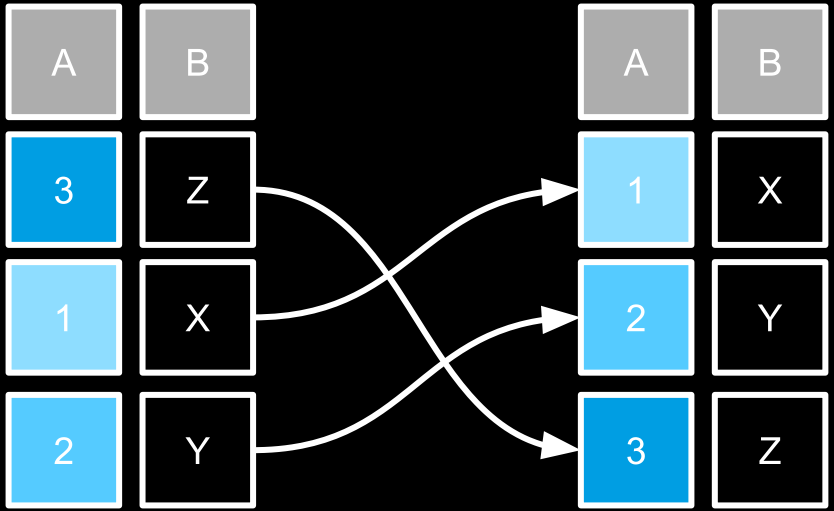
select()



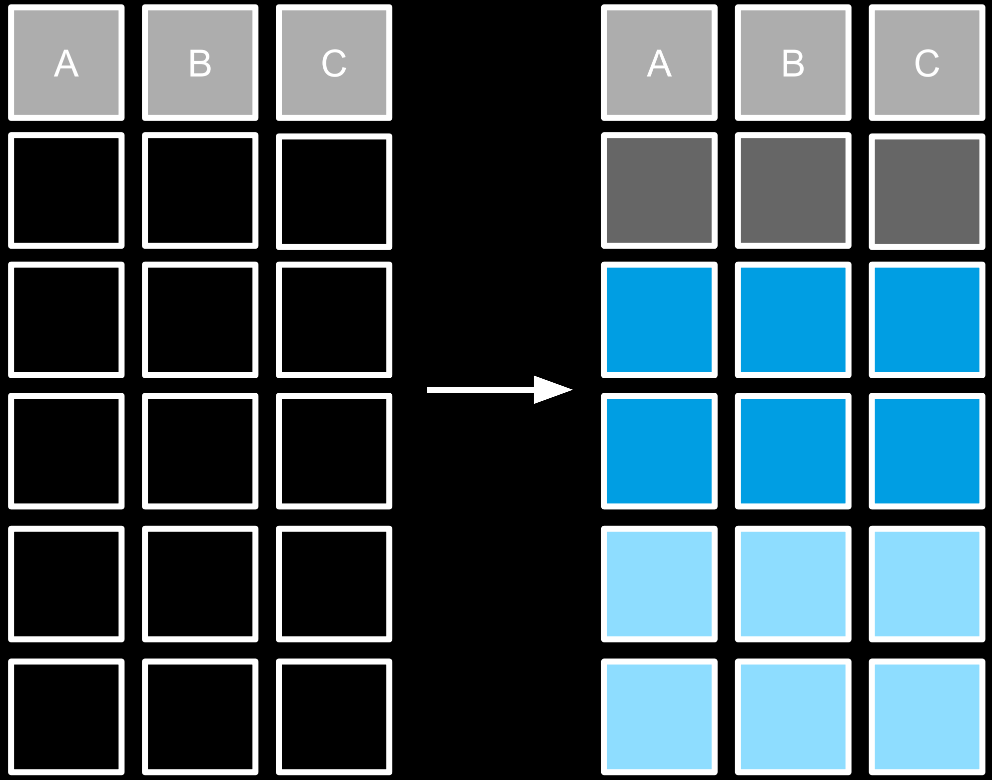
filter()



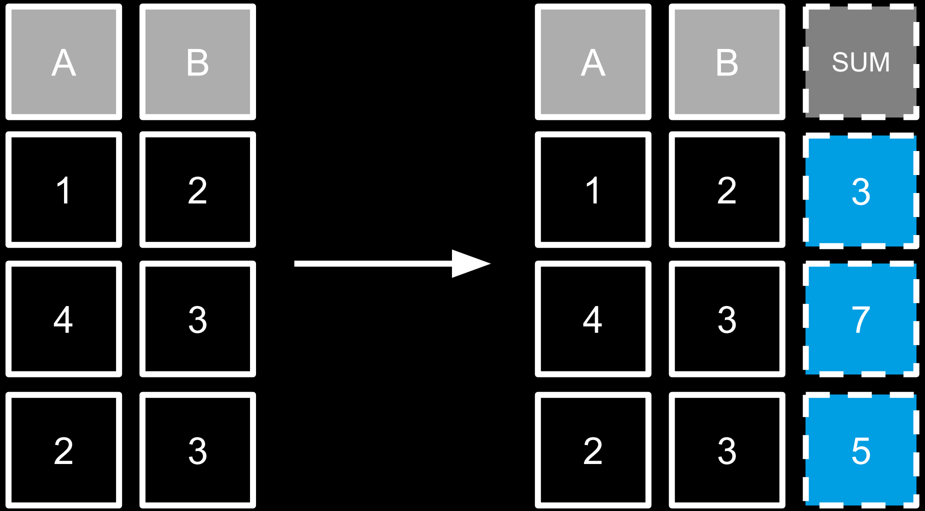
`arrange()`



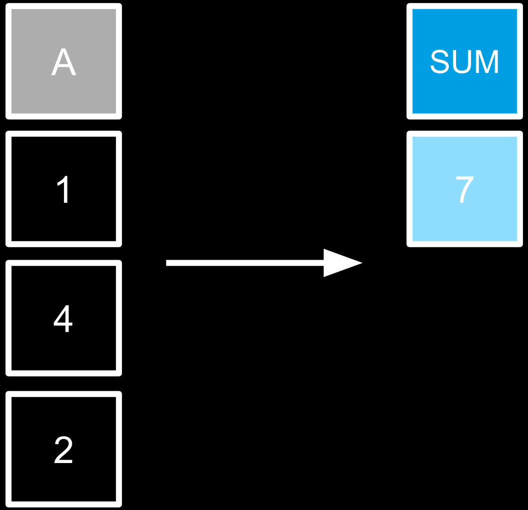
`group_by()`



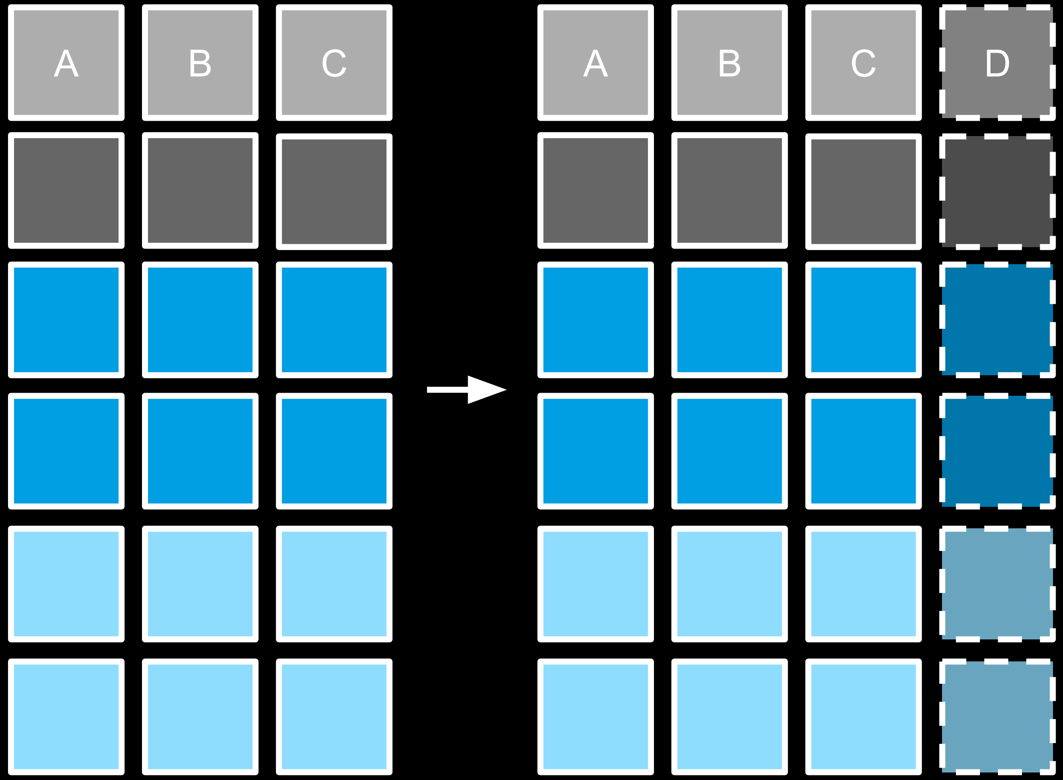
`mutate()`



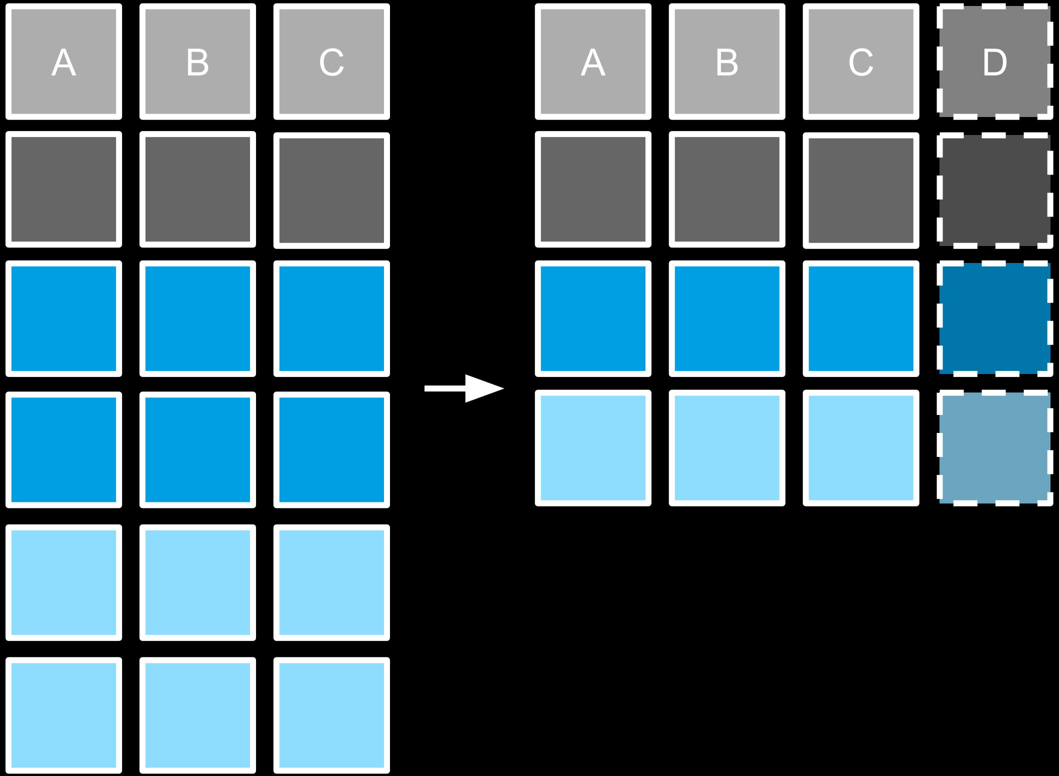
summarize()



group_by()
+
mutate()

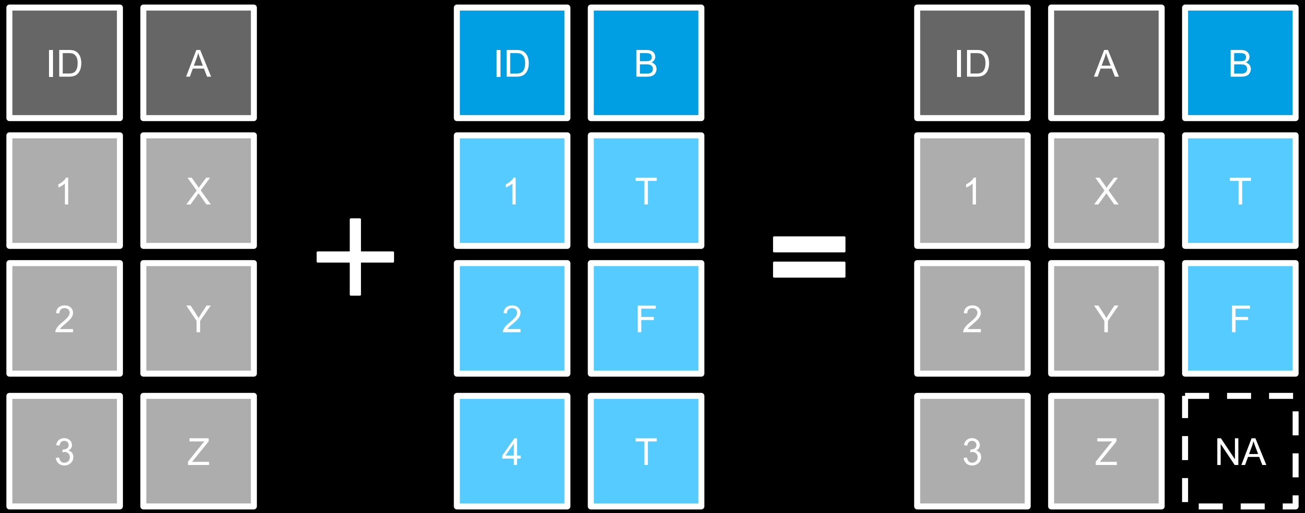


group_by()
+
summarize()



joining data

```
left_join()
```


ID
A
1
X
2
Y
3
Z
+
ID
B
1
T
2
F
4
T
=
ID
A
B
1
X
T
2
Y
F
3
Z
NA

```
inner_join()
```

ID	A
1	X
2	Y
3	Z

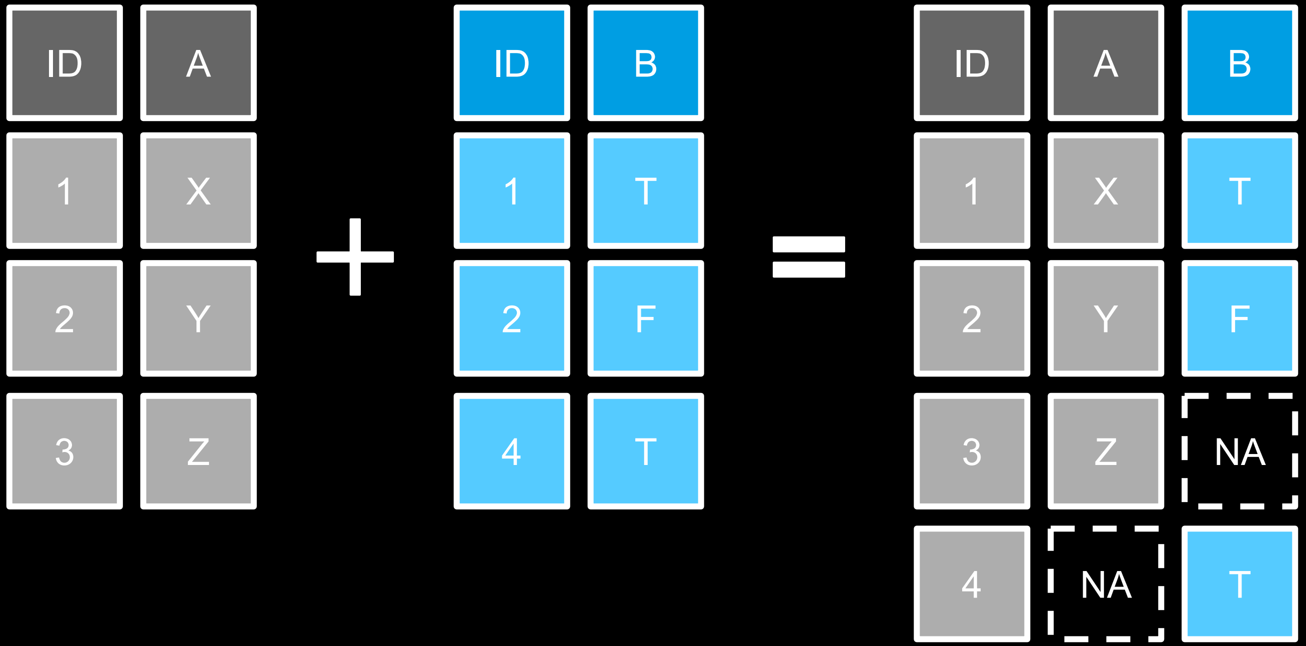
+

ID	B
1	T
2	F
4	T

=

ID	A	B
1	X	T
2	Y	F

```
full_join()
```


ID
A
1
X
2
Y
3
Z
+
ID
B
1
T
2
F
4
T
=
ID
A
B
1
X
T
2
Y
F
3
Z
NA
4
NA
T

UNSTRUCTURED DATA

unstructured
data

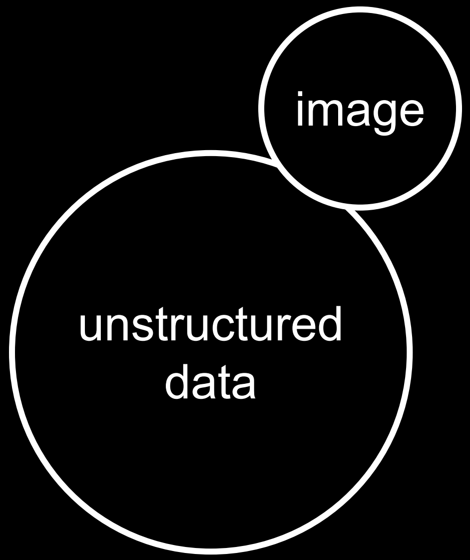


image
unstructured data

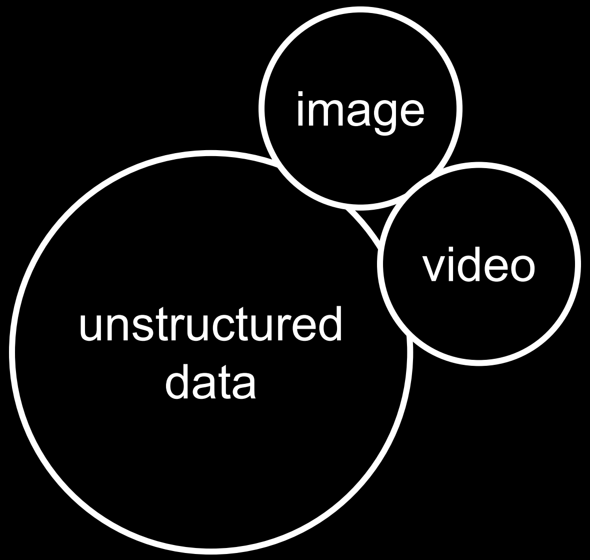


image
video
unstructured
data

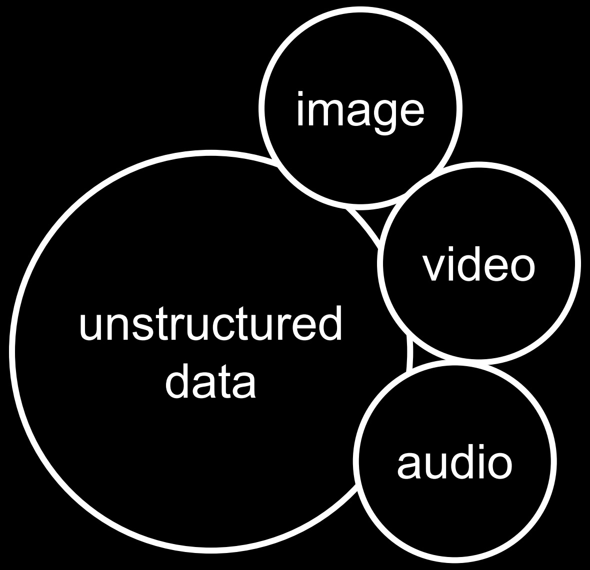


image
video
unstructured data
audio

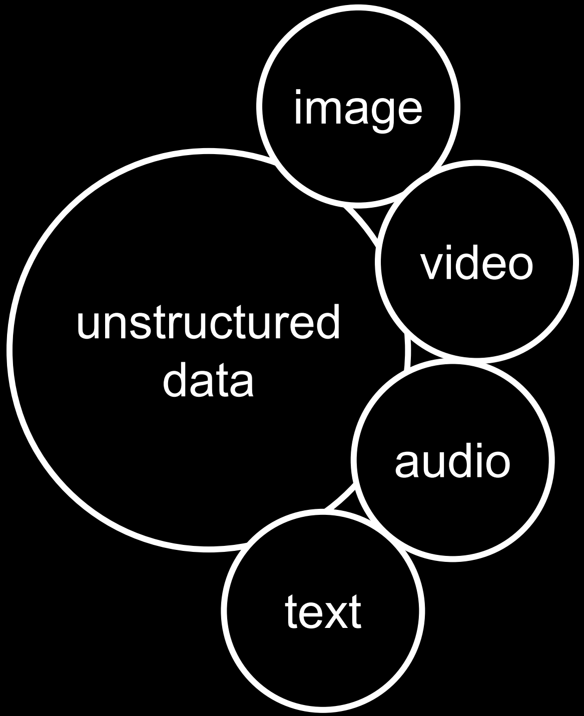
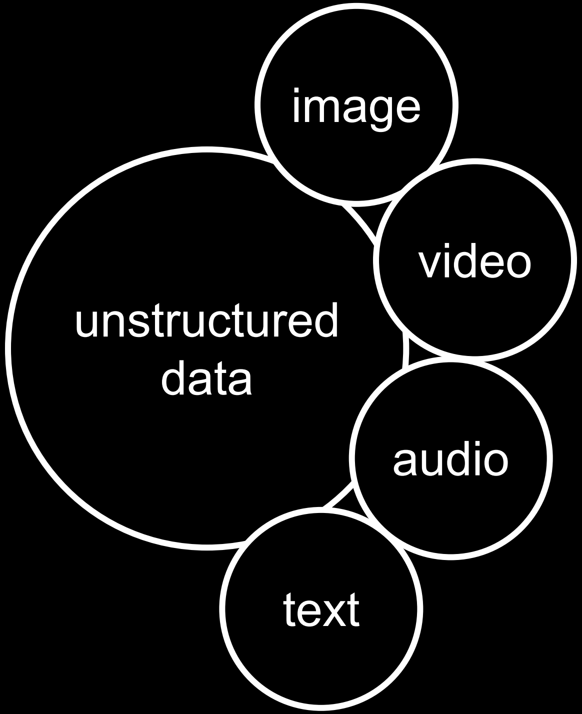
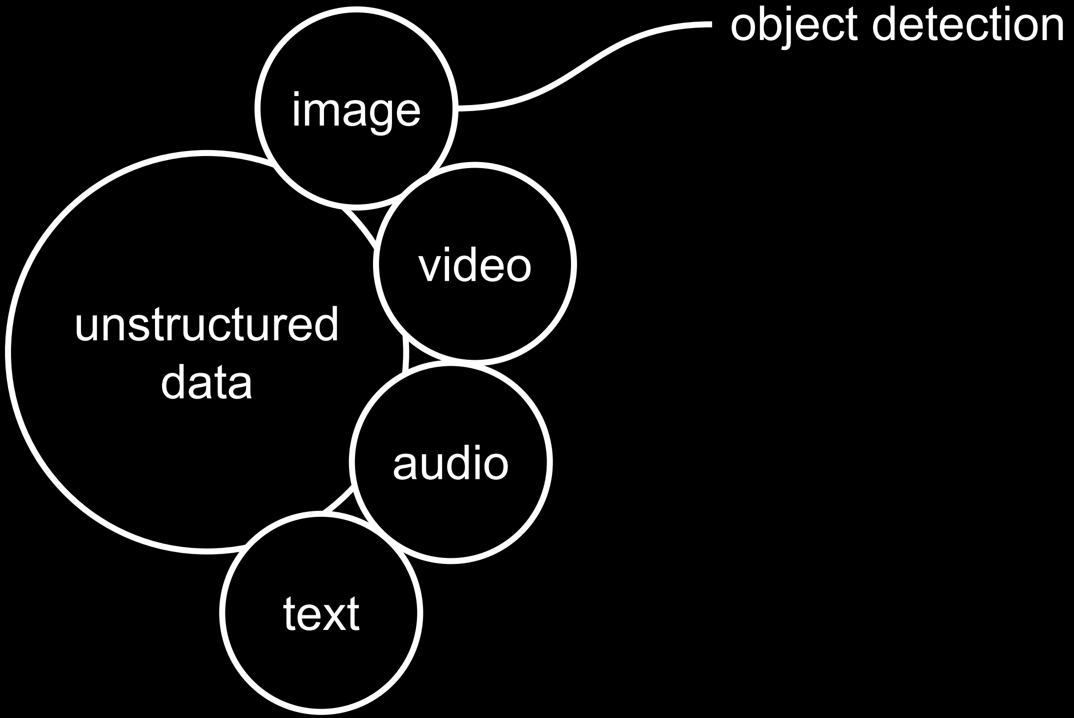


image
video
unstructured data
audio
text

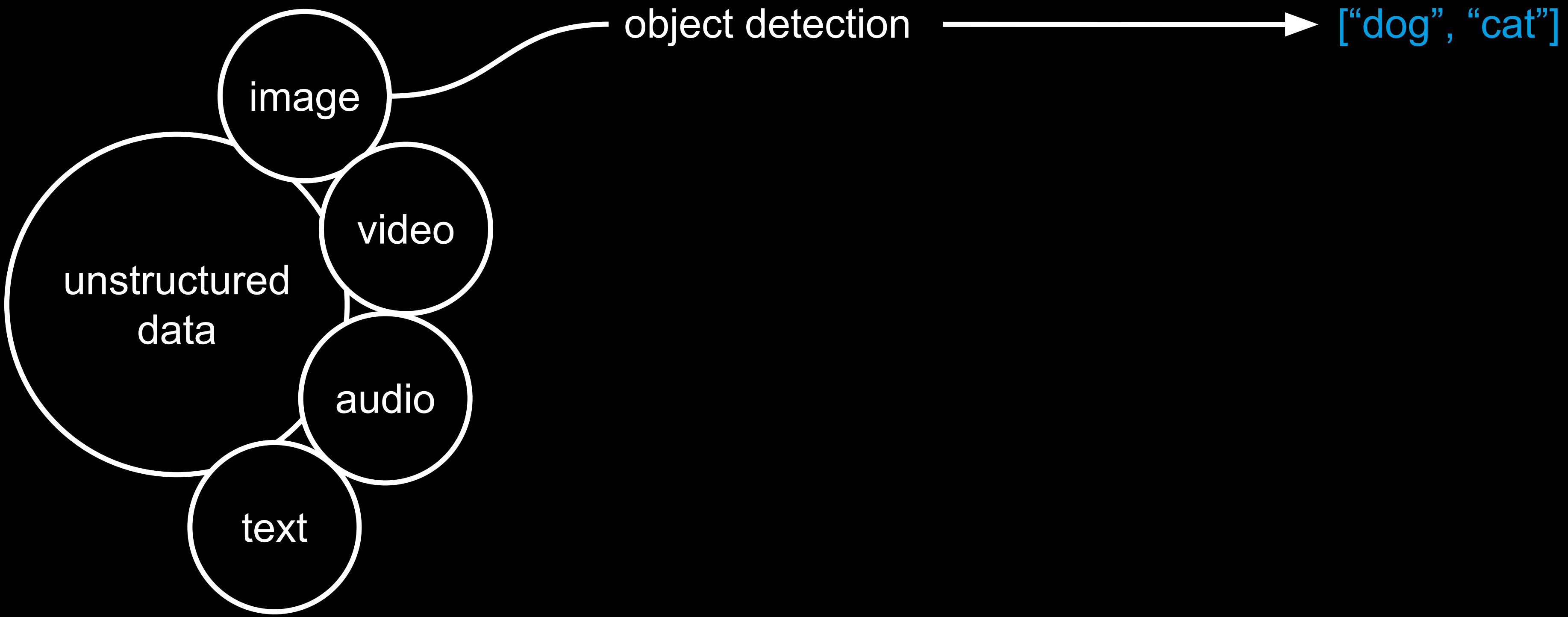
no handles to grab



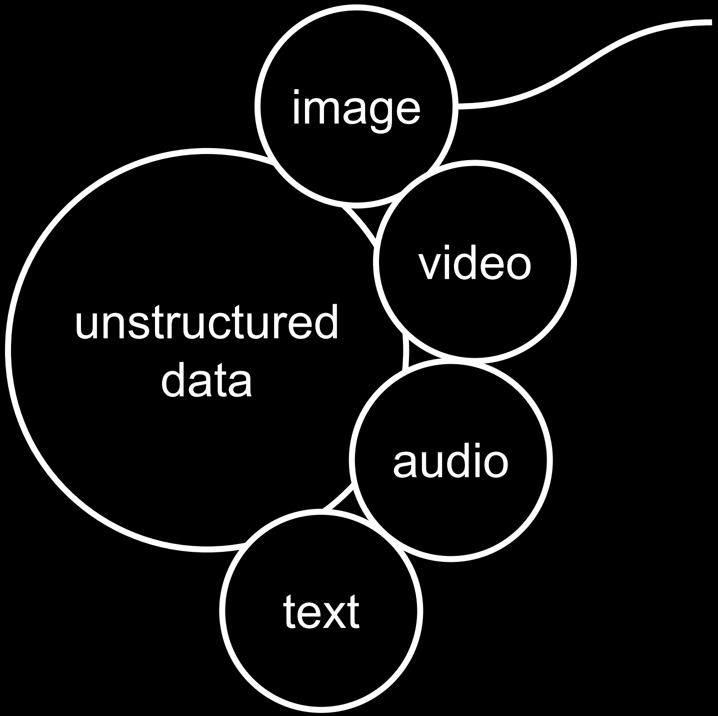
no handles to grab



no handles to grab

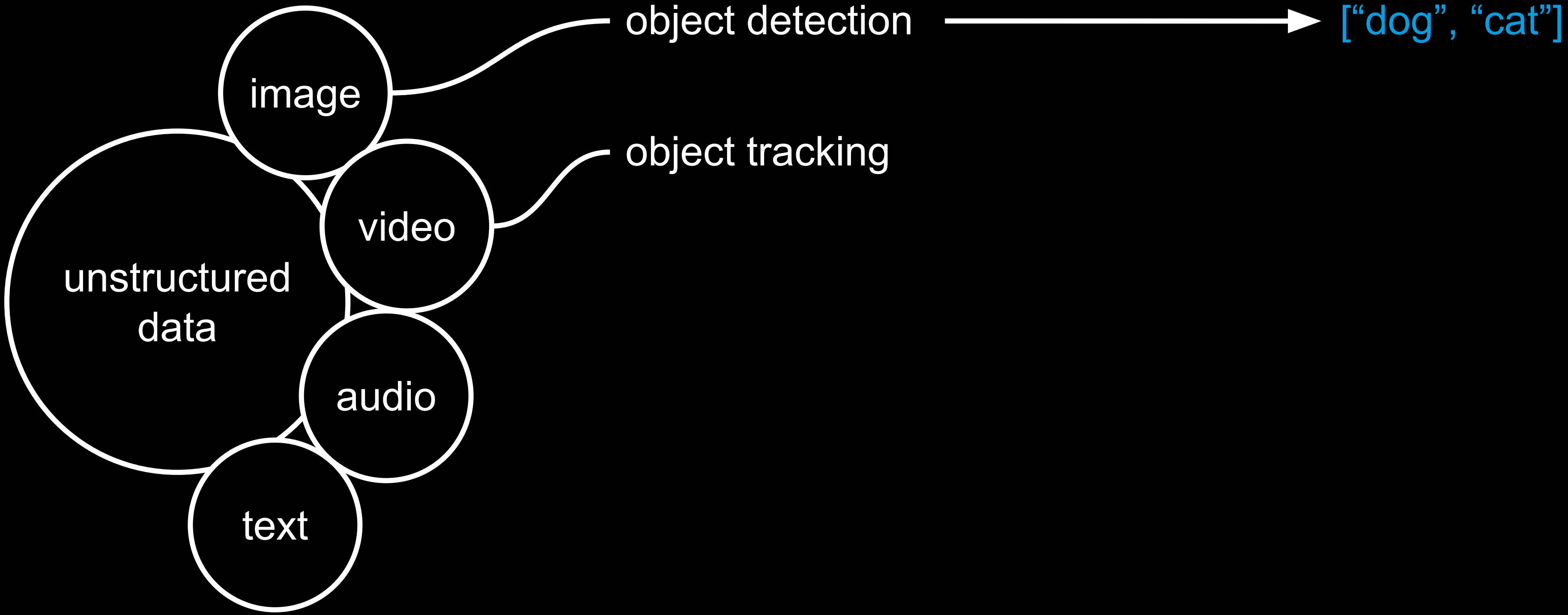


no handles to grab | algorithm | extracted, structured information



object detection → [“dog”, “cat”]

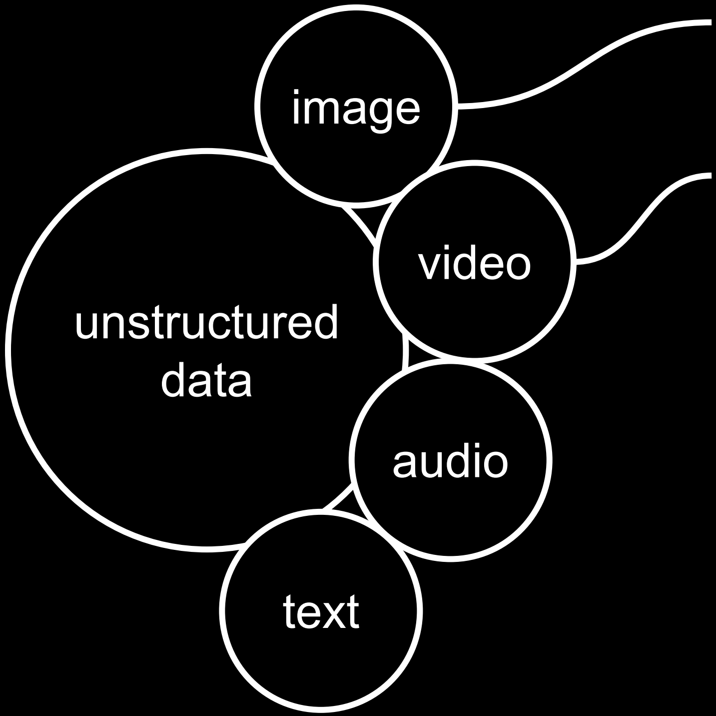
no handles to grab | algorithm | extracted, structured information



no handles to grab

algorithm

extracted, structured information

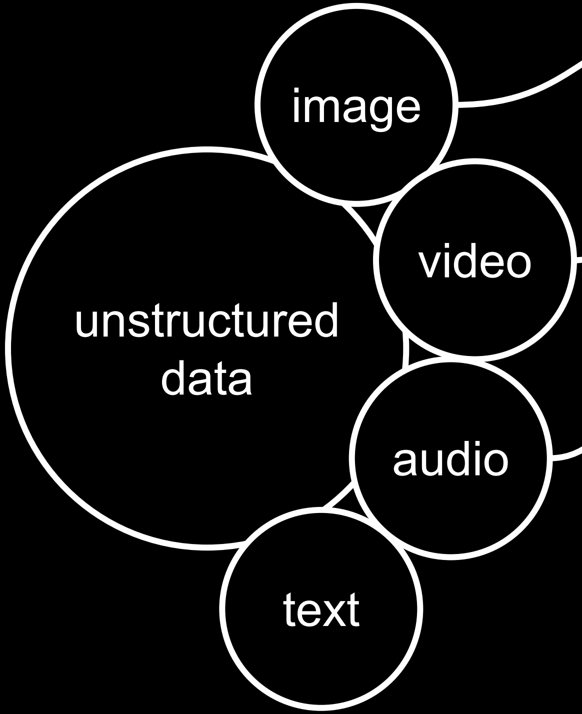


object detection → ["dog", "cat"]

object tracking → { "t": 2.41, "x": 34, "y": 55 } no handles to grab

algorithm

extracted, structured information



object detection → ["dog", "cat"]

object tracking → { "t": 2.41, "x": 34, "y": 55 }

speech-to-text → { "t": 0.3, "text": "Guten Abend" }

no handles to grab | algorithm | extracted, structured information

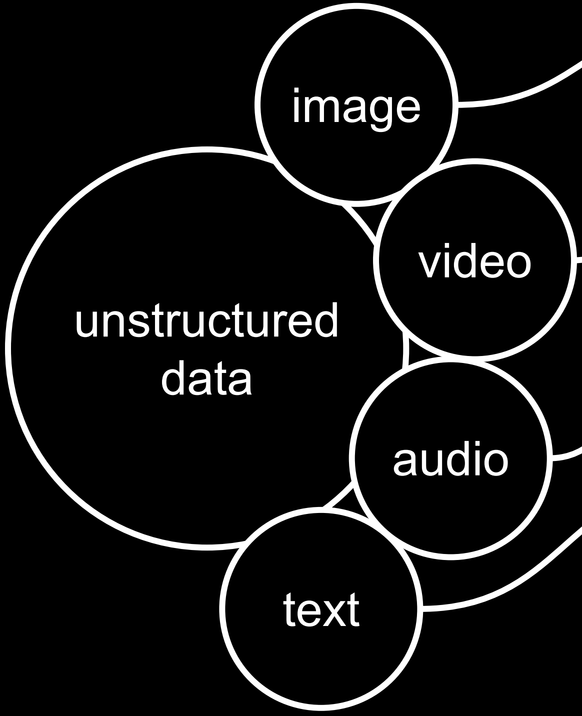
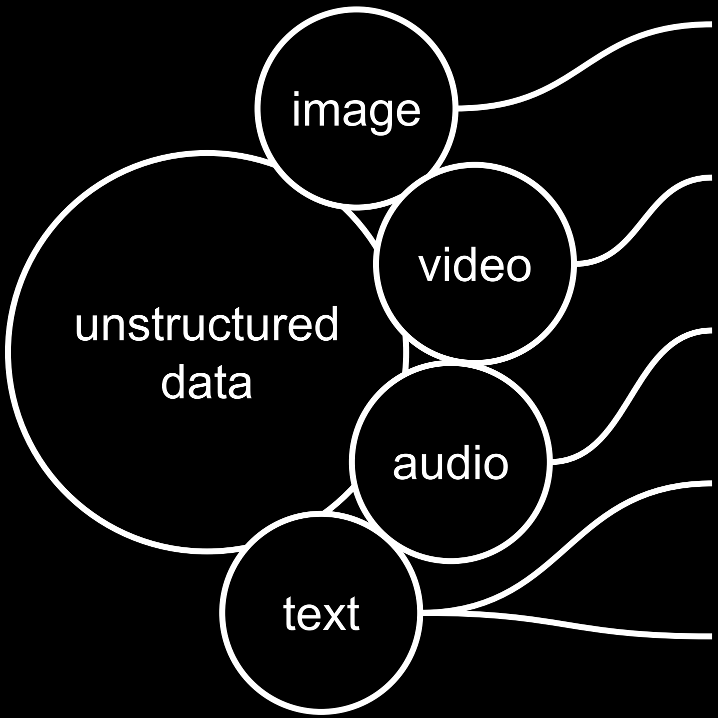
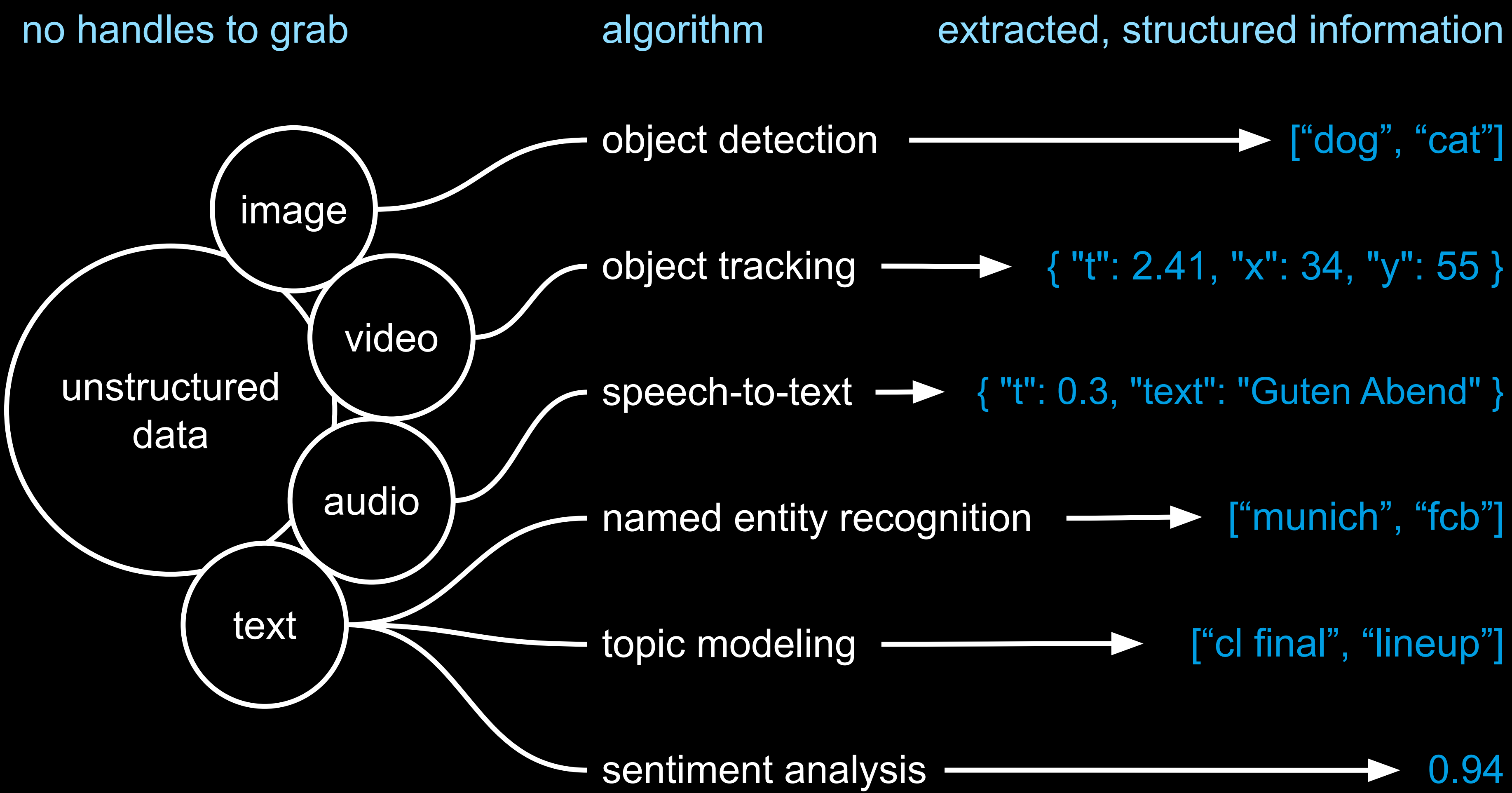
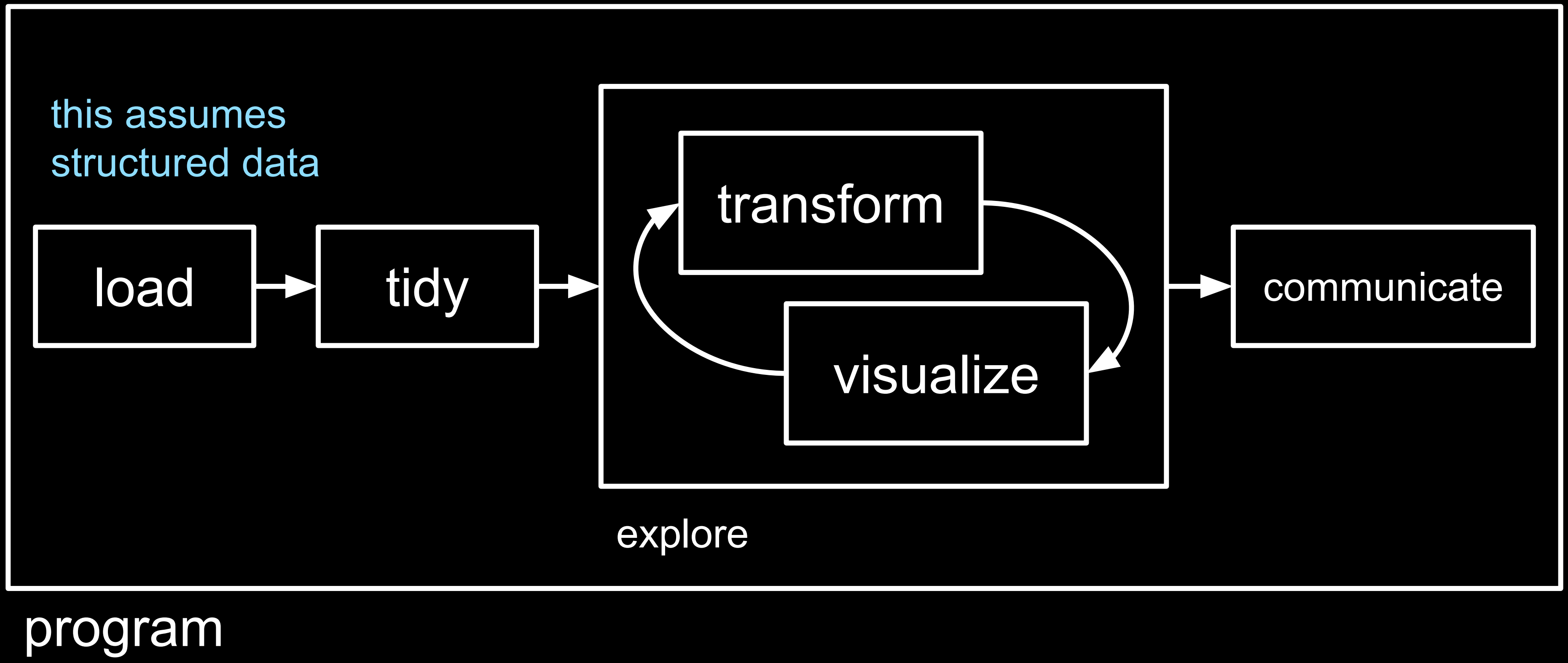


image	object detection →	["dog", "cat"]
video	object tracking →	{ "t": 2.41, "x": 34, "y": 55 }
audio	speech-to-text →	{ "t": 0.3, "text": "Guten Abend" }
text	named entity recognition →	["munich", "fcb"]

no handles to grab	algorithm	extracted, structured information
	object detection	[“dog”, “cat”]
	object tracking	{ "t": 2.41, "x": 34, "y": 55 }
	speech-to-text	{ "t": 0.3, "text": "Guten Abend" }
	named entity recognition	[“munich”, “fcb”]
	topic modeling	[“cl final”, “lineup”]



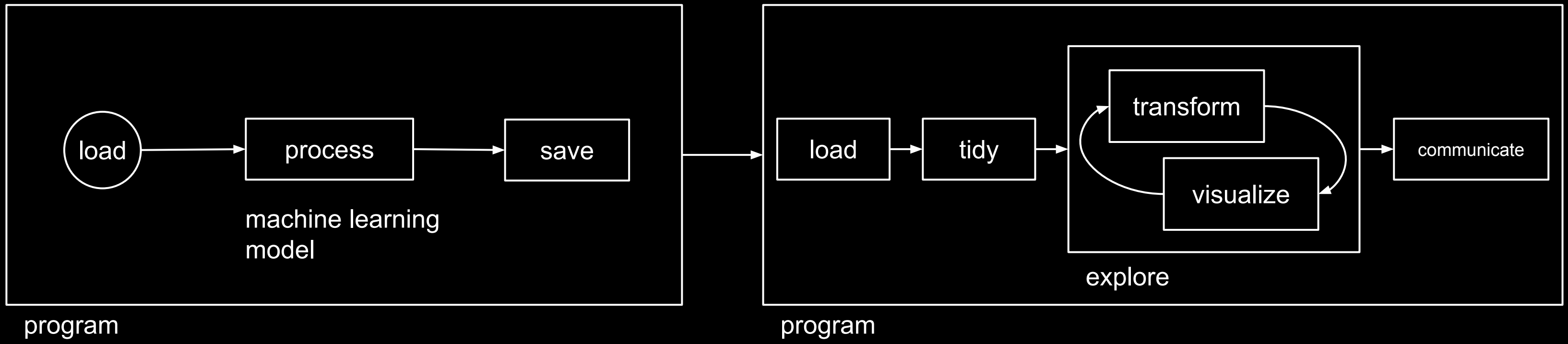

no handles to grab
algorithm
extracted, structured information
unstructured data
image
video
audio
text
object detection
["dog", "cat"]
object tracking
{ "t": 2.41, "x": 34, "y": 55 }
speech-to-text
{ "t": 0.3, "text": "Guten Abend" }
named entity recognition
["munich", "fcb"]
topic modeling
["cl final", "lineup"]
sentiment analysis
0.94



this assumes
structured data
load
tidy
transform
visualize
explore
communicate
program

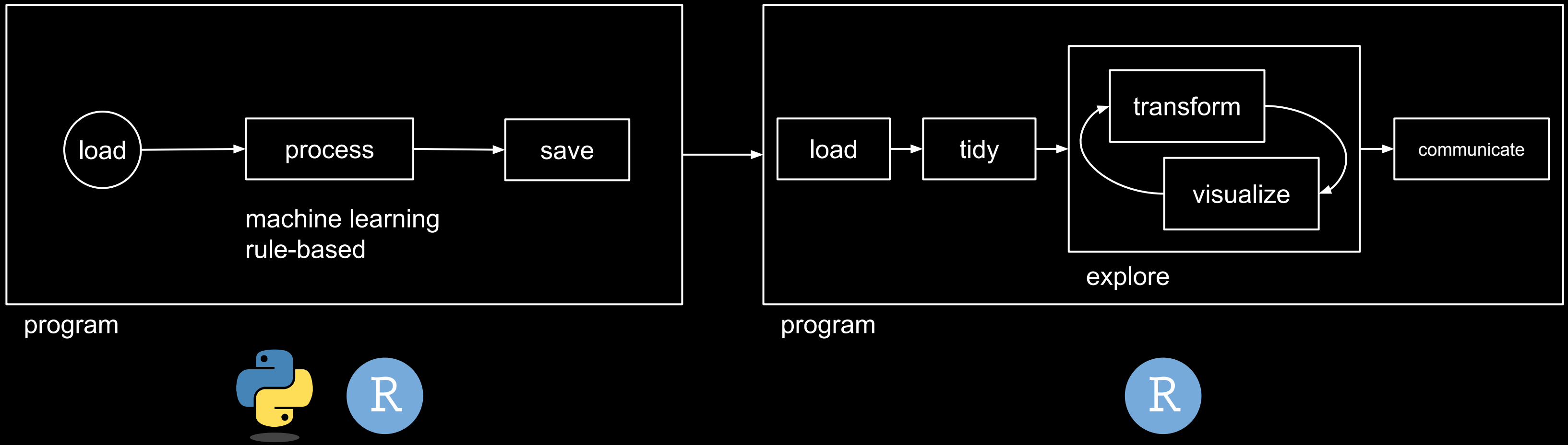
pre-process unstructured data

exploratory data analysis



pre-process
unstructured data

exploratory data
analysis



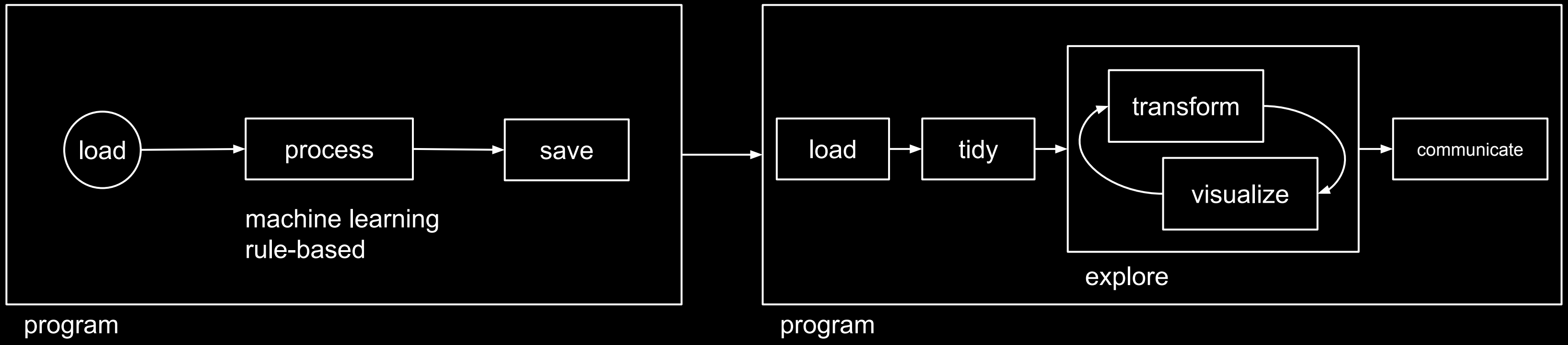
MACHINE LEARNING

Highly recommended for background information

3Blue1Brown's YouTube Course on Neural Networks and Deep Learning

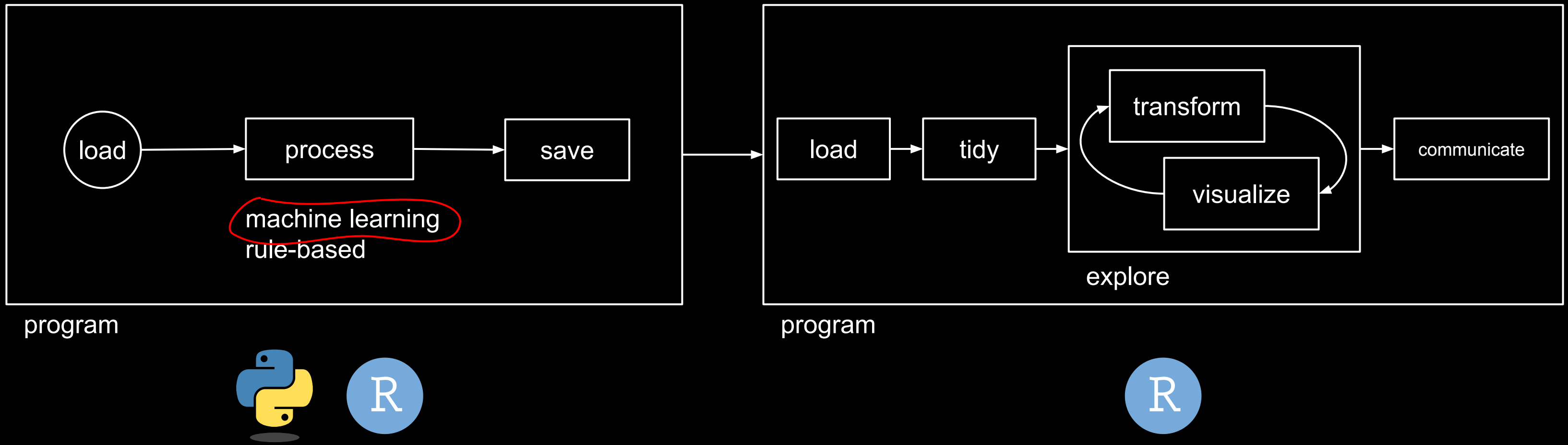
pre-process
unstructured data

exploratory data
analysis



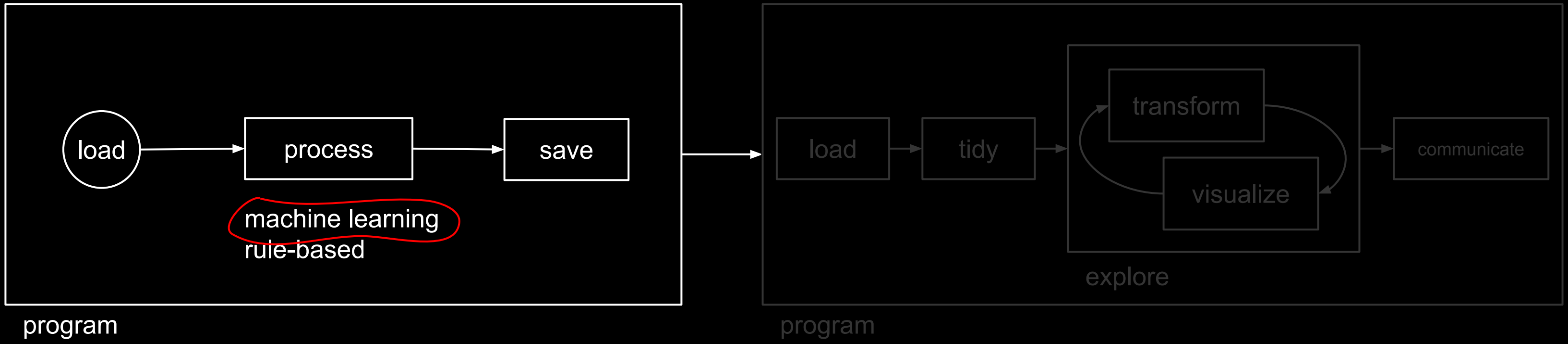
pre-process unstructured data

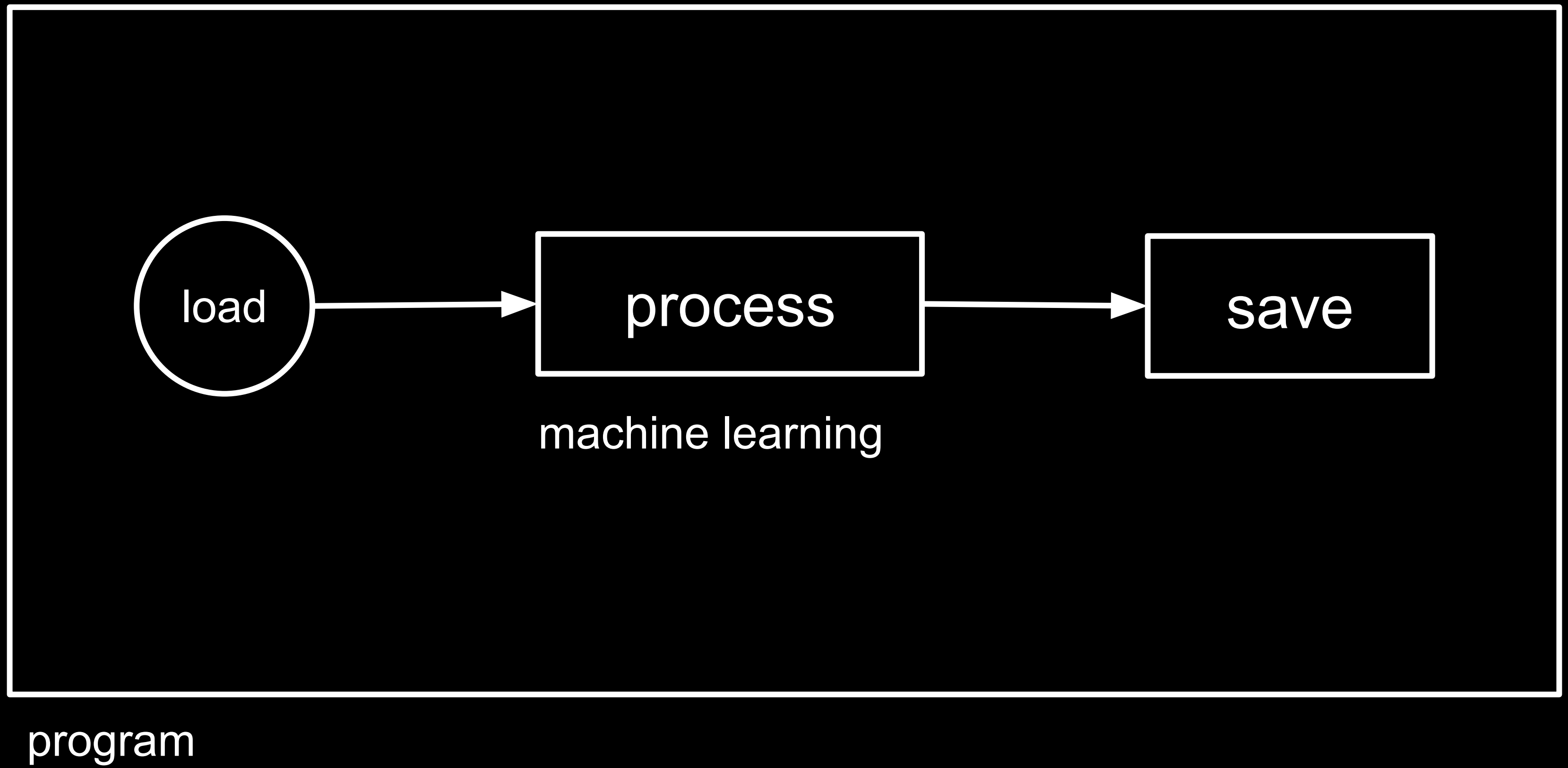
exploratory data analysis

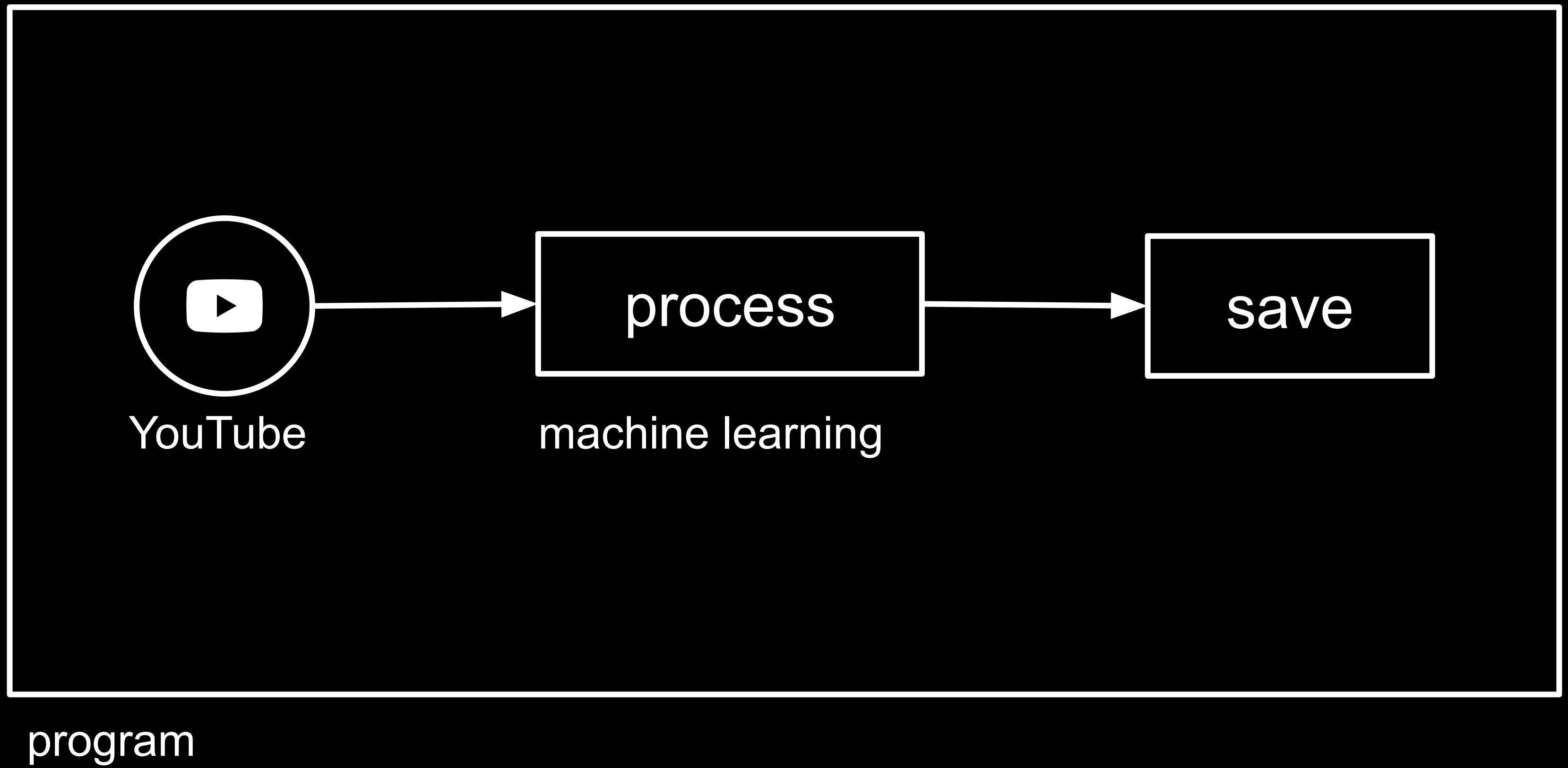


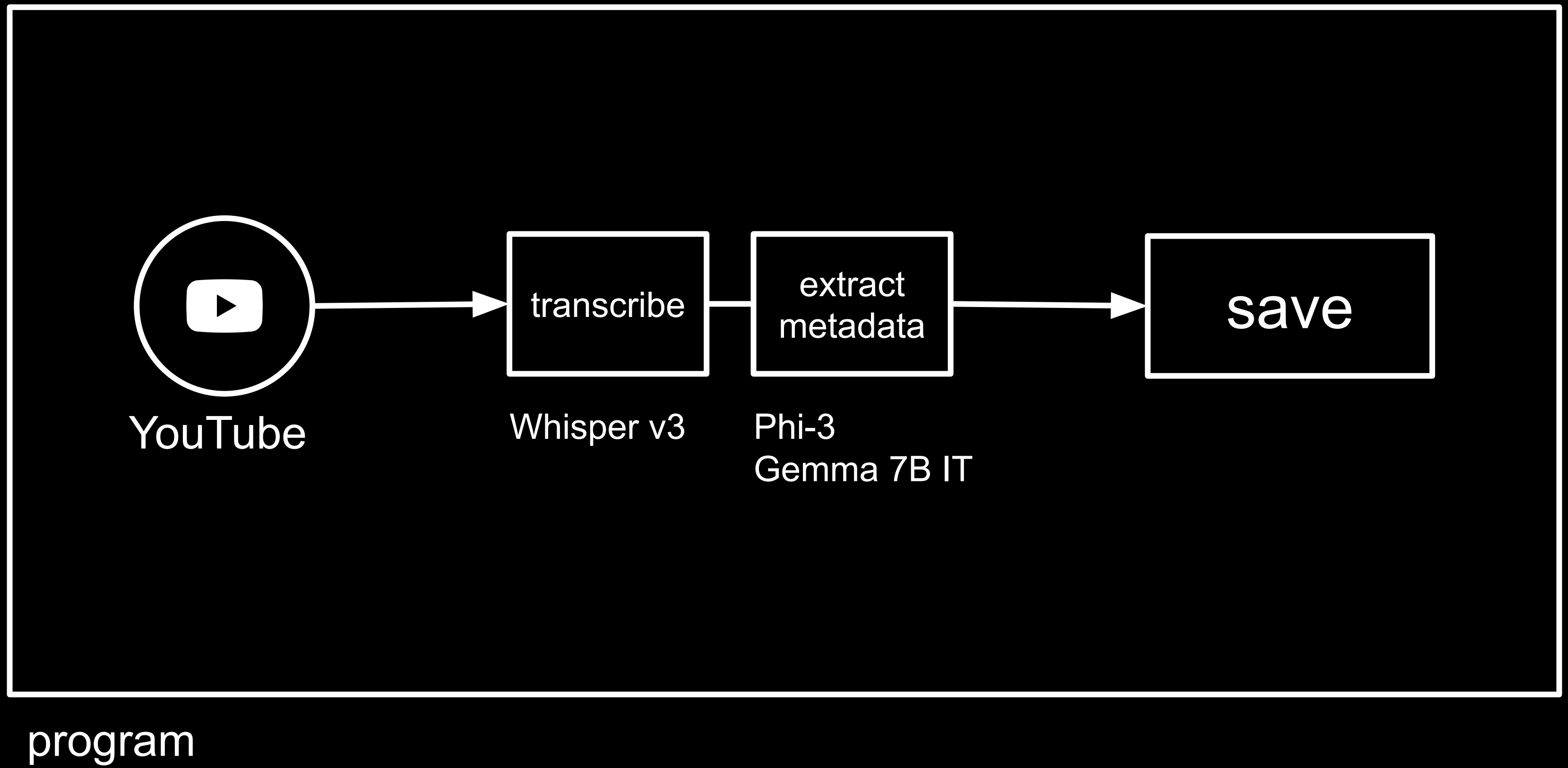
pre-process unstructured data

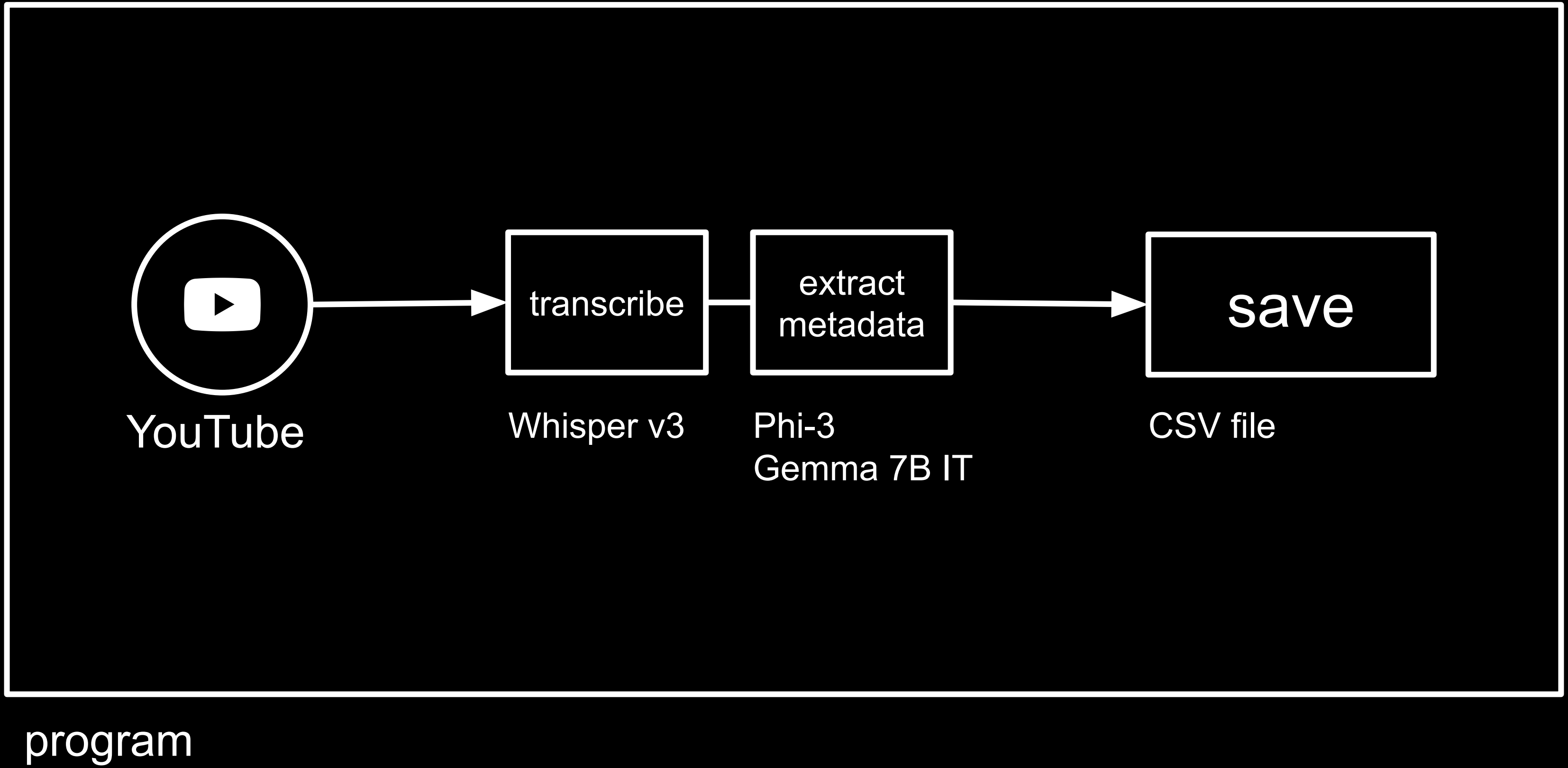
exploratory data analysis




load
process
save
machine learning
program


process
save
YouTube
machine learning
program


transcribe
extract metadata
save
YouTube
Whisper v3
Phi-3
Gemma 7B IT
program


transcribe
extract metadata
save
YouTube
Whisper v3
Phi-3
Gemma 7B IT
CSV file
program

YouTube API

Whisper v3

https://arxiv.org/abs/2212.04356

https://huggingface.co/openai/whisper-large-v3


audio file
whisper v3
transcript

Large Language Models (LLM)

what has been said so far?

(*prompt / context*)

what has been said so far?
(*prompt / context*)

prediction of next token based on
learnt probability distribution

what has been said so far?
(*prompt / context*)

➡

prediction of next token based on
learnt probability distribution

+

(randomness)

what has been said so far?
(*prompt / context*)

➡

prediction of next token based on
learnt probability distribution

+

(randomness)

+

(filter)

(discriminating, insulting content)

what has been said so far?
(*prompt / context*)

prediction of next token based on learnt probability distribution

\+

(randomness)

\+

(filter)

(discriminating, insulting content)

next word (*token*)

what has been said so far?
(*prompt / context*)

prediction of next token based on
learnt probability distribution

+

(randomness)

+

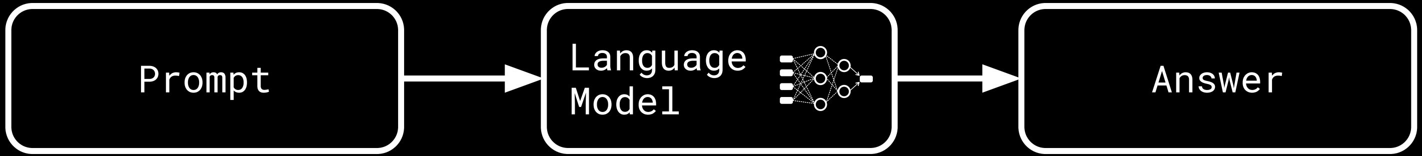
(filter)

(discriminating, insulting content)

next word (*token*)

PROMPTING

https://www.promptingguide.ai/


Prompt
Language
Model
Answer

elements of a prompt

<instruction>

<context>

<input data>

<output indicator>

elements of a prompt

<instruction>

<context>

<input data>

<output indicator>

example prompt

`Explain the binary number system.`

elements of a prompt

<instruction>

<context>

<input data>

<output indicator>

example prompt

Explain the binary number system.

start simple

elements of a prompt

<instruction>

<context>

<input data>

<output indicator>

example prompt

```
You are a friendly tutor and your
task is to explain complex
concepts as simple as possible.

Explain the binary number system.
```

elements of a prompt

<instruction>

<context>

<input data>

<output indicator>

example prompt

```
You are a friendly tutor and your
task is to explain complex
concepts as simple as possible.

Your answers are never longer
than 10 sentences.

Explain the binary number system.
```

ZERO-SHOT PROMPTING

elements of a prompt

```
&lt;instruction&gt;

&lt;context&gt;

&lt;input data&gt;

&lt;output indicator&gt;
```

example prompt

```
Classify the text into neutral,
negative or positive.

Text: "What a great dinner!"

Sentiment:
```

elements of a prompt

<instruction>

<context>

<input data>

<output indicator>

example prompt

```
Classify the text into neutral,
negative or positive.

Text: "What a great dinner!"

Sentiment:
```

this will be replaced with data later…

FEW-SHOT PROMPTING

IN-CONTEXT LEARNING

examples in the context to learn from

```
Extract all references to countries and their continent in the following text
using the format from the examples below.

Example 1: "They played the team called 'Die Mannschaft' in the world cup final"
Correct answer: Germany, Europe

Example 2: "The Three Lions once again lost to Germany in a semi final"
Correct answer: England, Europe, Germany, Europe

Text: "The Selecao was destroyed 1:7 by the DFB selection in their home stadium."
Answer:
```

examples in the context to learn from

```
Extract all references to countries and their continent in the following text
using the format from the examples below.

Example 1: "They played the team called 'Die Mannschaft' in the world cup final"
Correct answer: Germany, Europe

Example 2: "The Three Lions once again lost to Germany in a semi final"
Correct answer: England, Europe, Germany, Europe

Text: "The Selecao was destroyed 1:7 by the DFB selection in their home stadium."
Answer:
```

more prompting strategies

chain-of-thought (CoT)
self-consistency
generate knowledge prompting
prompt chaining (subtasks)
tree-of-thoughts (ToT)
retrieval-augmented-generation (RAG)
…

Phi-3

https://arxiv.org/abs/2404.14219

~~https://huggingface.co/microsoft/Phi-3-mini-128k-instruct~~

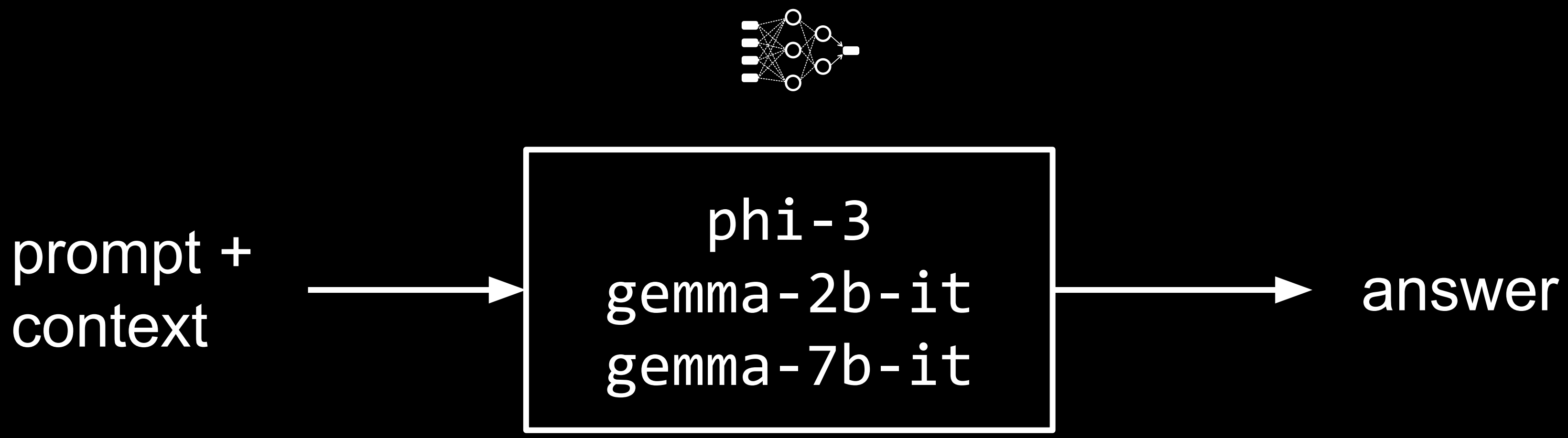
https://huggingface.co/microsoft/Phi-3-medium-128k-instruct

Gemma 2B / 7B Instruct

https://arxiv.org/abs/2403.08295

https://huggingface.co/google/gemma-2b-it

https://huggingface.co/google/gemma-7b-it

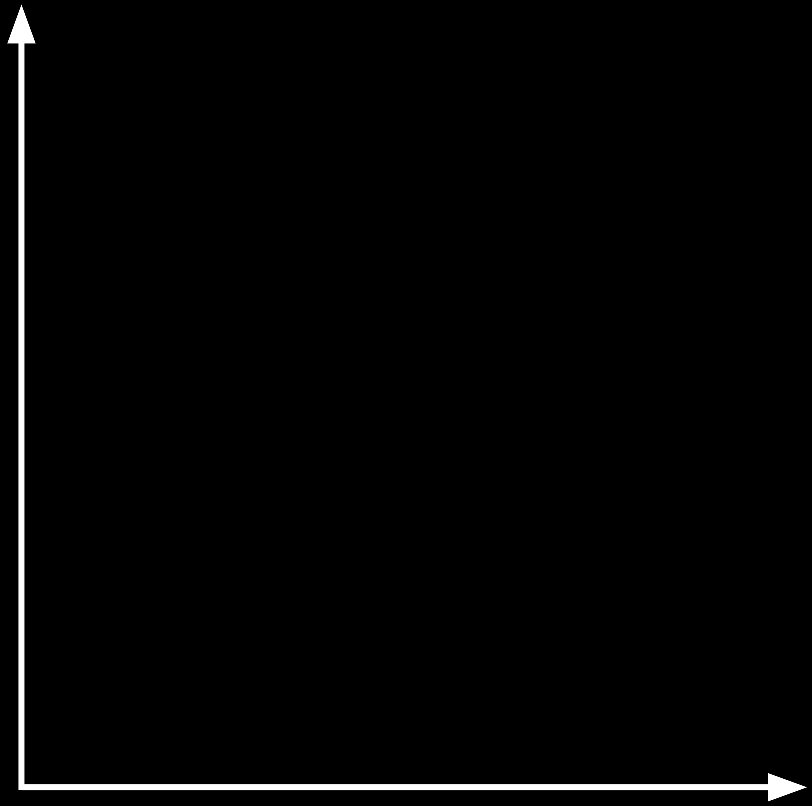

prompt +
context
phi-3
gemma-2b-it
gemma-7b-it
answer

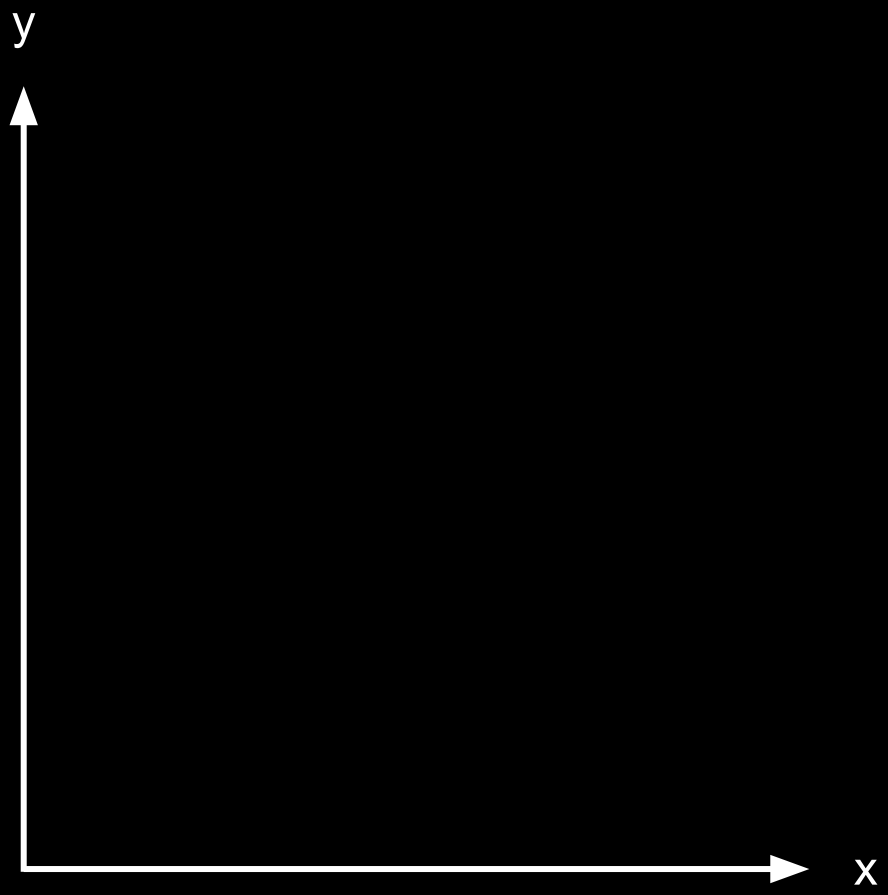
OpenAI GPT-4o

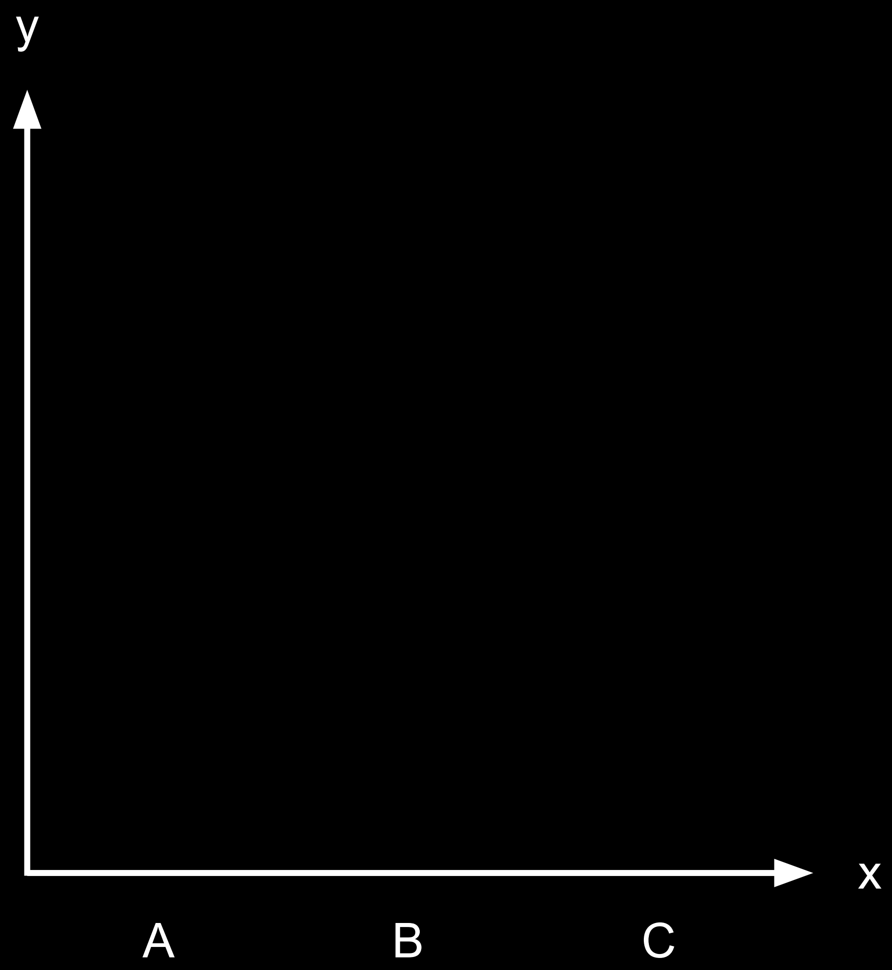
VISUALIZE DATA

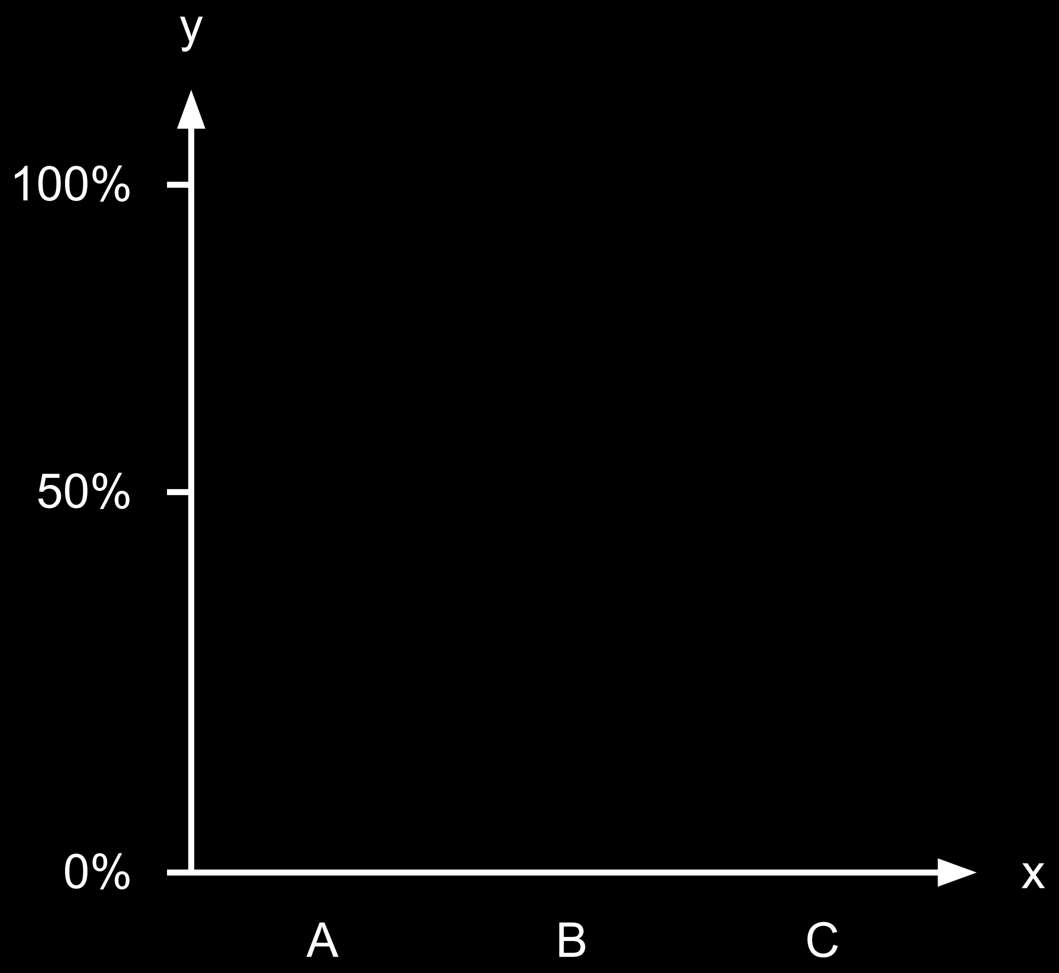
data

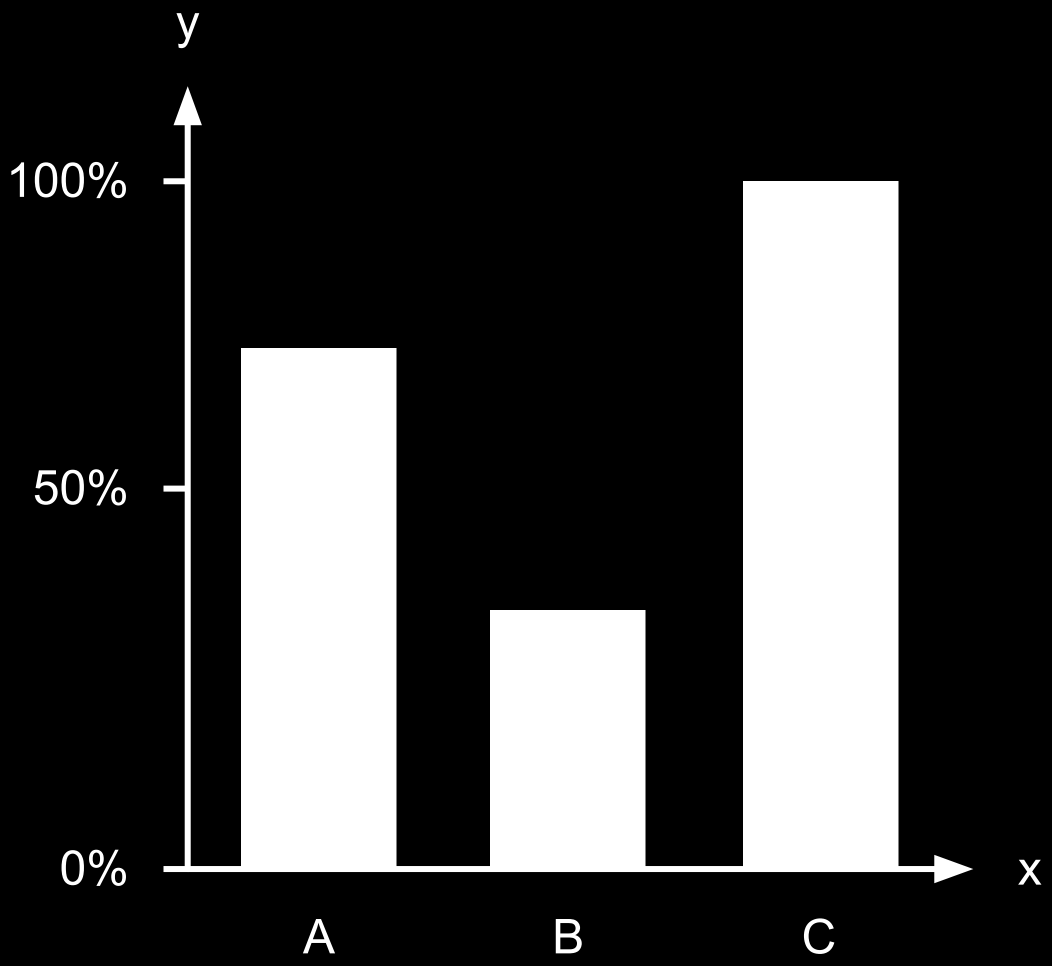
category	pct
A	75
B	33
C	100



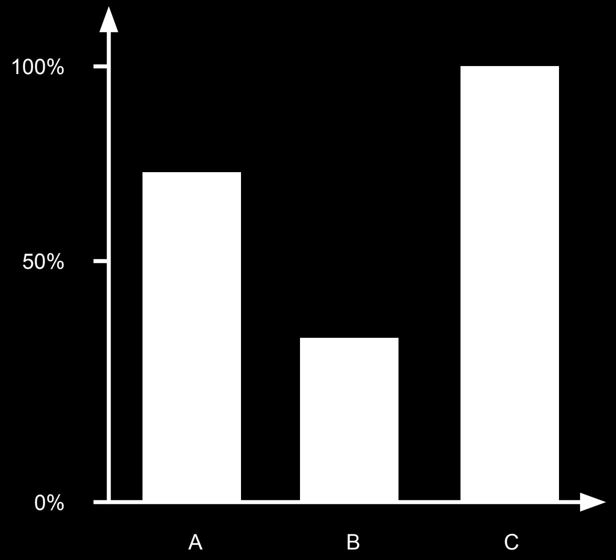

y
x


y
x
A
B
C


y
100%
50%
0%
x
A
B
C


y
100%
50%
0%
x
A
B
C

category	pct
A	75
B	33
C	100



{{ ggplot2 }}

why visualize?

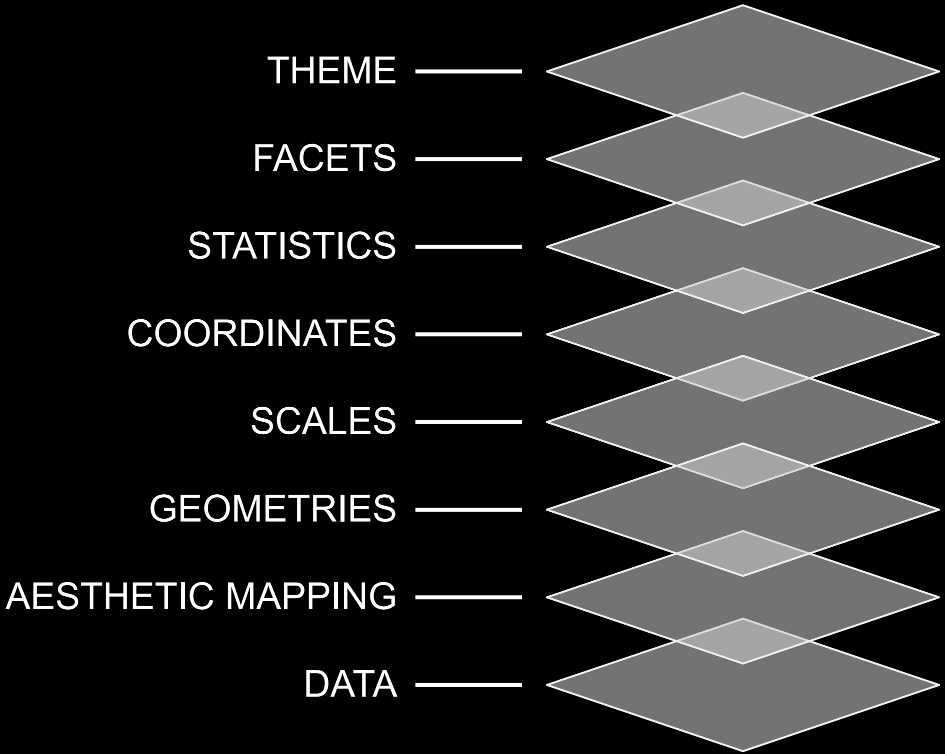
{{ ggplot2 }}

grammar of graphics

any

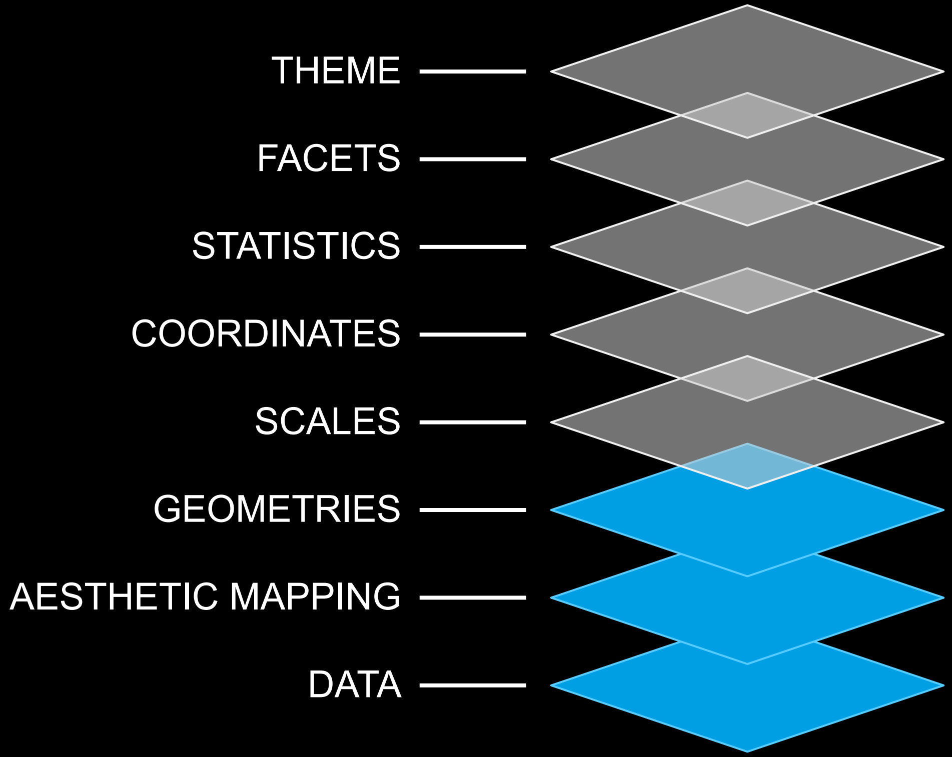
data

visualization



has useful defaults

mandatory

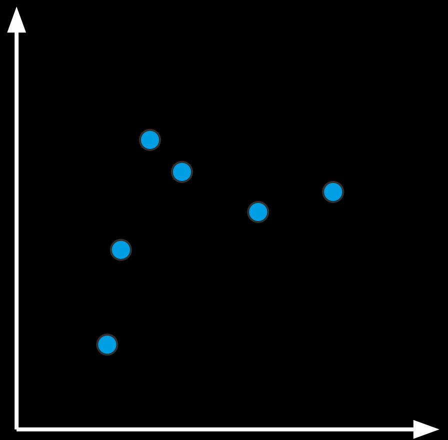


```
ggplot()
```

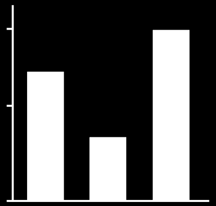
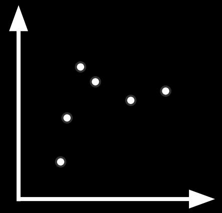
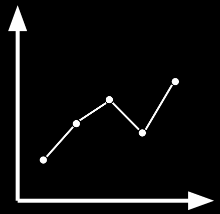
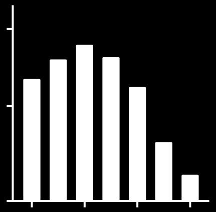
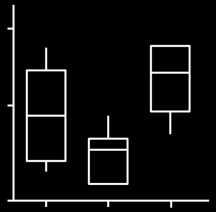
```
ggplot() +
  aes()
```

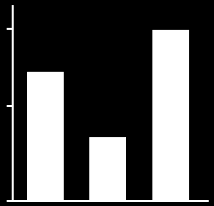
```
ggplot() +
  aes() +
  geom_point()
```

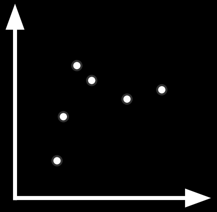
```
ggplot() +
  aes() +
  geom_point()
```

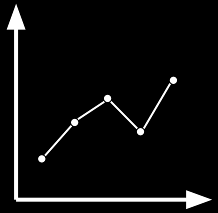


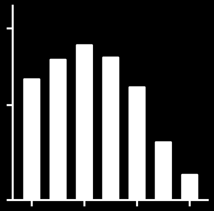
basic plots

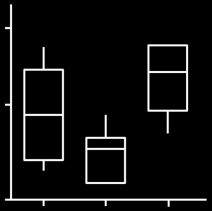







bar chart

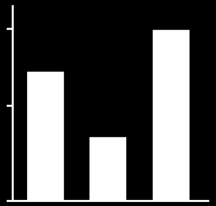

scatter plot


line chart


histogram

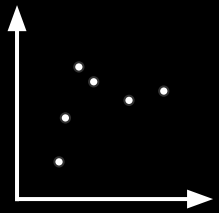

box plot

amounts
proportions
distributions (discrete)



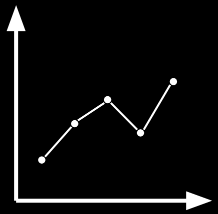
bar chart

associations
patterns



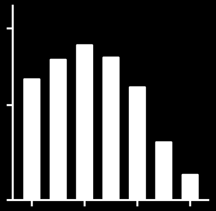
scatter plot

trends
developments



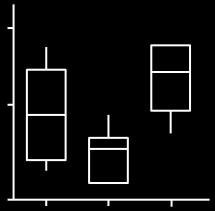
line chart

distributions (continuous)



histogram

compare distributions (continuous)



box plot

COMMUNICATE DATA

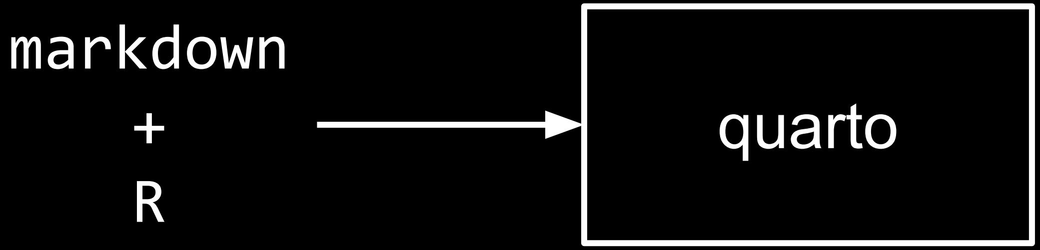
quarto

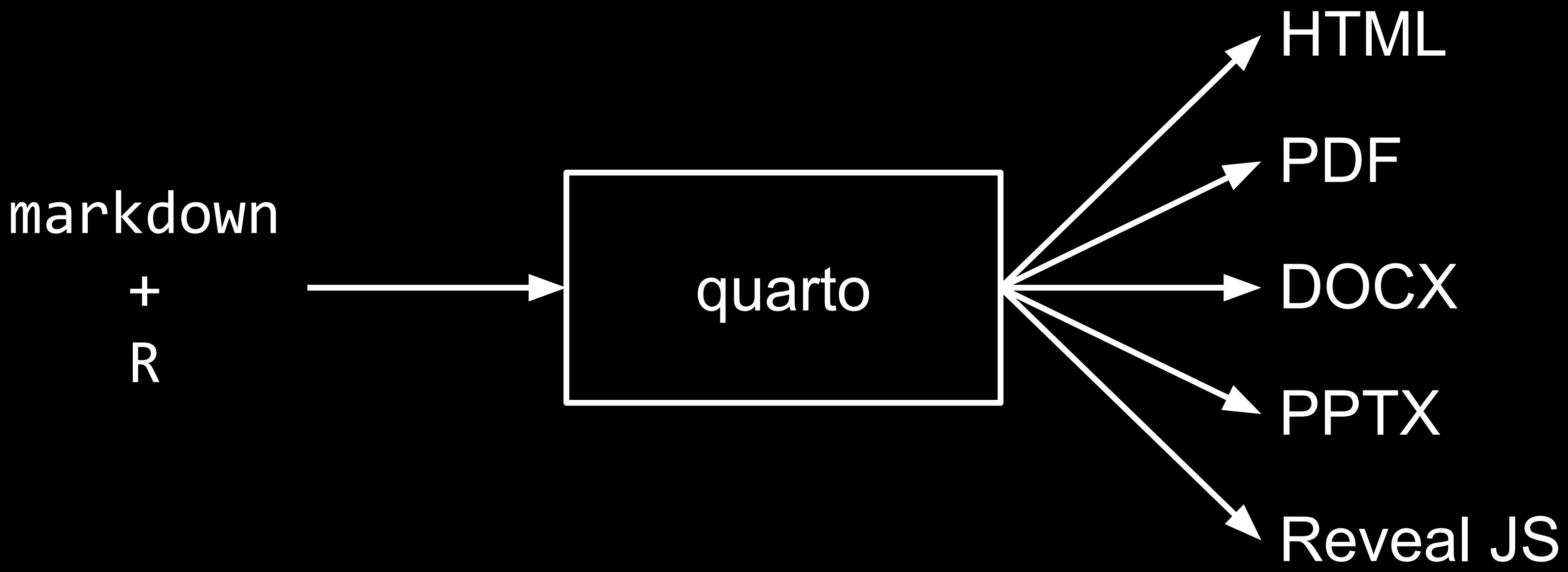
{{ quarto }}

markdown

+

R


markdown
+
R
quarto


markdown
+
R
quarto
HTML
PDF
DOCX
PPTX
Reveal JS

markdown

```
# Heading 1

## Heading 2

### Heading 3

#### Heading 4
```

This is *italic*,

and this **bold**

This is rendered as `code`.

- List item A
- List item B
- List item C

1. First
2. Second
3. Third

```
![Image title](path/to/image.png)
```

```
![Image title](path/to/image.png){width=200}
```

```
![Image title](path/to/image.png){#fig-myimage}

For more details see @fig-myimage.
```

```
[Linked text](https://quarto.org)
```

````
```{r}
1 + 1
```
````

code options

````
```{r}
#| echo: false
1 + 1
```
````

````
```{r}
#| eval: false
x <- 1 + 1
```
````

````
```{r}
#| include: false
library(tidyverse)
```
````

````
```{r}
#| message: false
data <- read_csv("data.csv")
```
````

````
```{r}
#| warning: false
data <- read_csv("data.csv")
```
````

figures

````
```{r}
#| label: fig-tweets-per-user
#| fig-cap: "Tweets per User"
tweets |>
  ggplot() +
  aes(x = screen_name) +
  geom_bar()
```
````

````
```{r}
#| code-fold: true
#| code-summary: "Show code"
tweets |>
  ggplot() +
  aes(x = screen_name) +
  geom_bar()
```
````

cross references

````
```{r}
#| label: fig-tweets-per-user
#| fig-cap: "Tweets per User"
…
```
````

In @fig-tweets-per-user you can see an overview of the number of tweets per user in the data set.

```
# Introduction {#sec-introduction}
…

# Analysis
As stated in @sec-introduction, the goal of this paper is
to analyze the user behavior with regard to the content
they tweet.
```

citation & bibliography

https://quarto.org/docs/authoring/citations.html

output formats