

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?

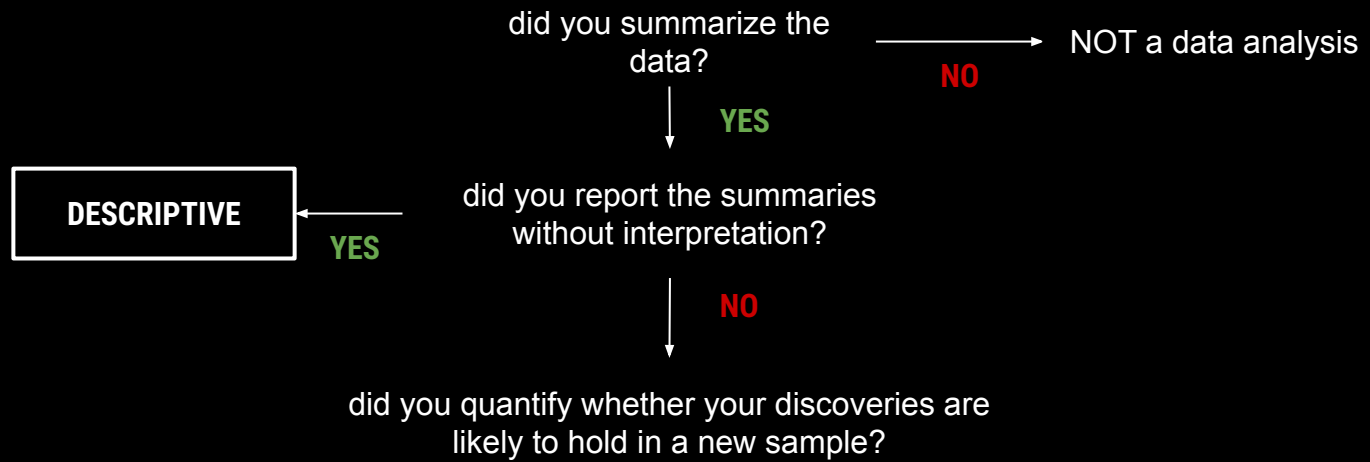
did you summarize the
data?

NO

→ NOT a data analysis

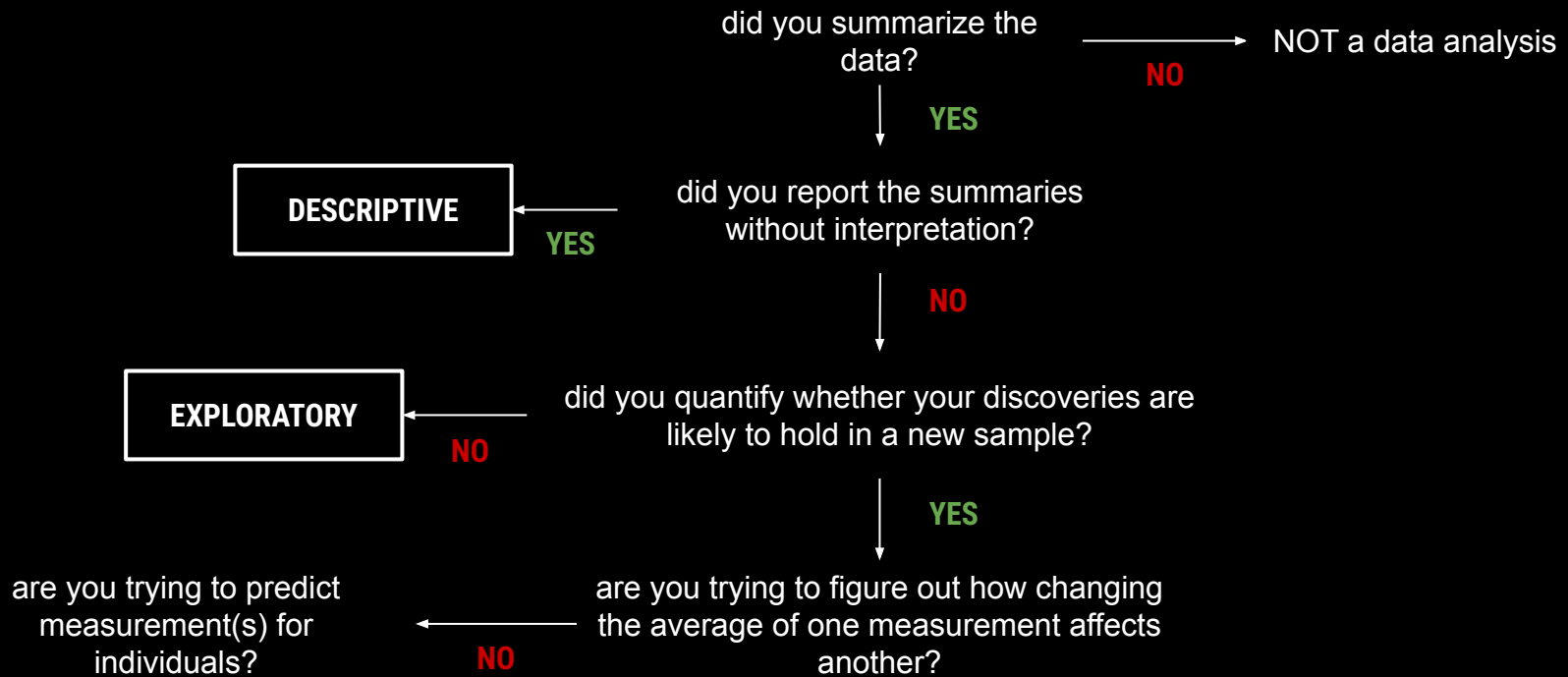










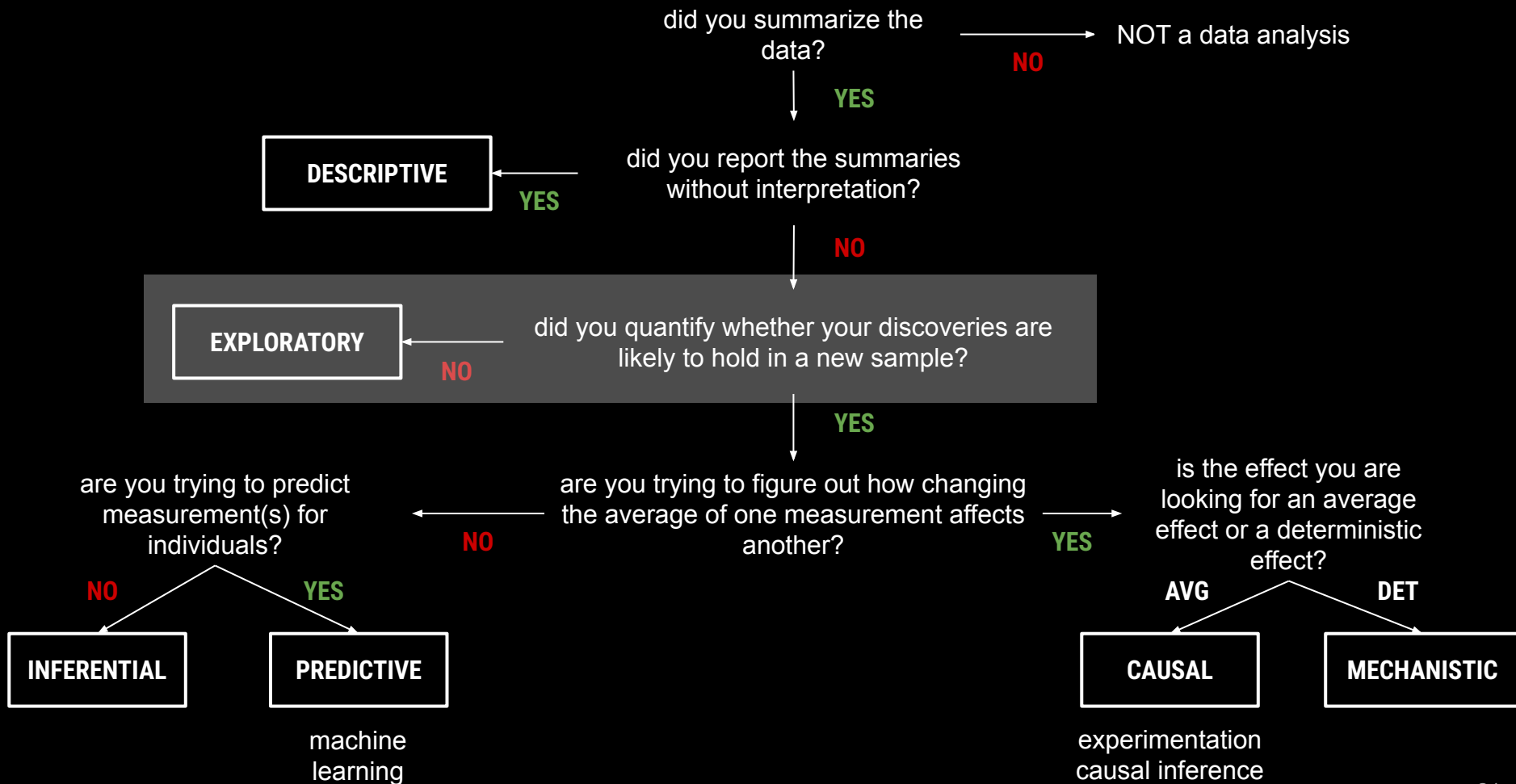






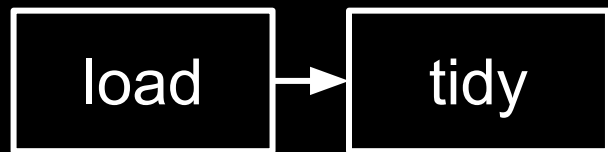


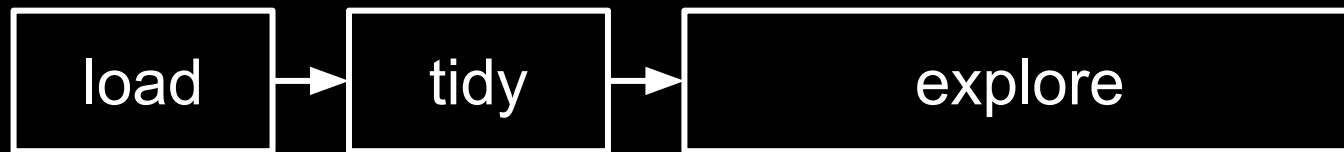




EXPLORATORY DATA ANALYSIS

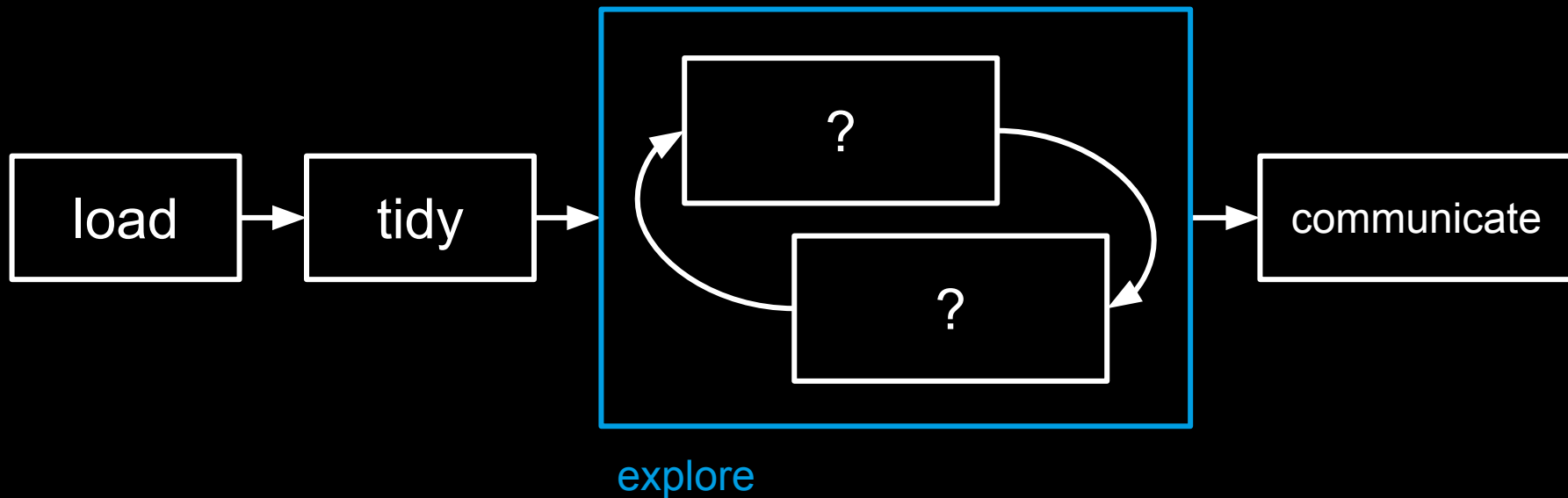
load

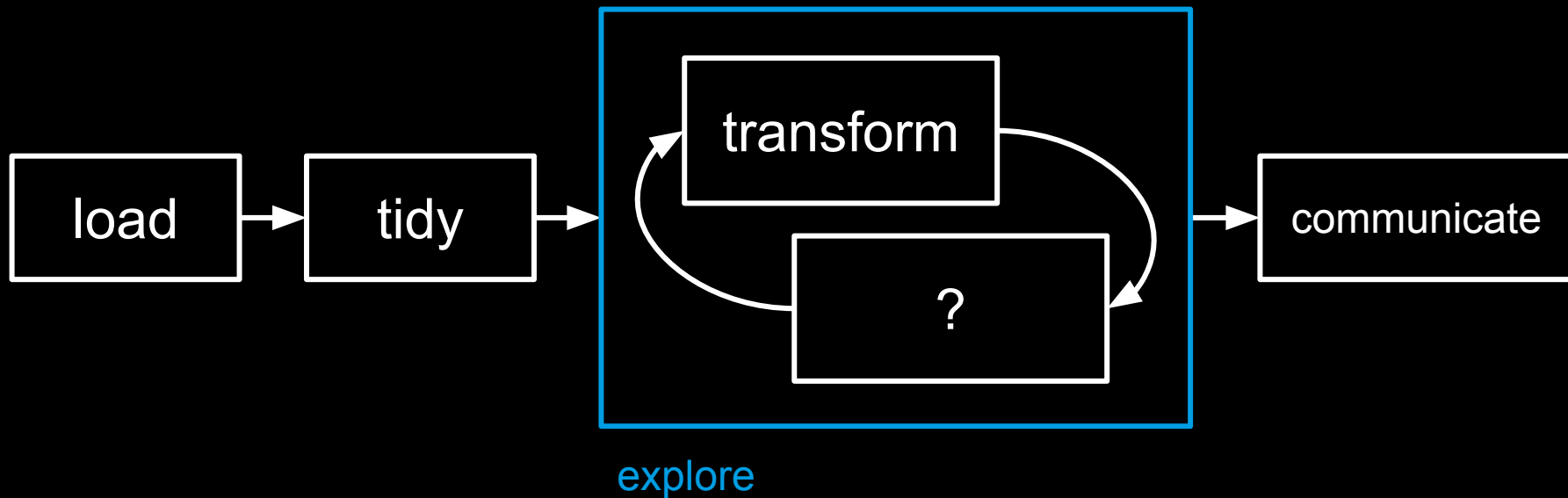


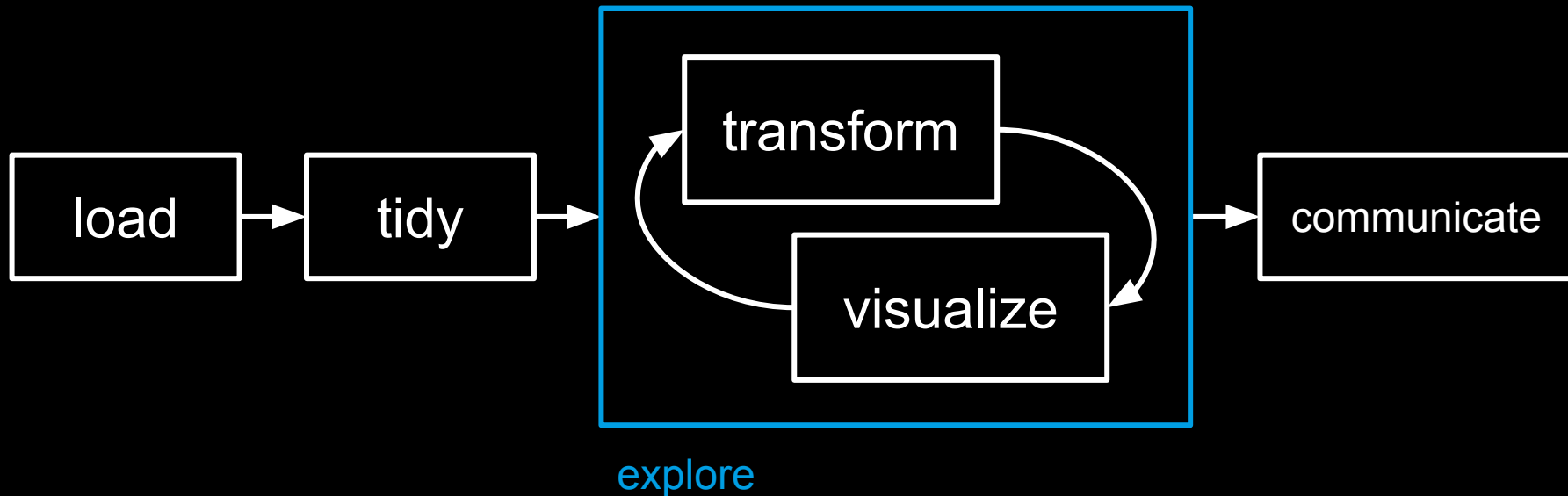


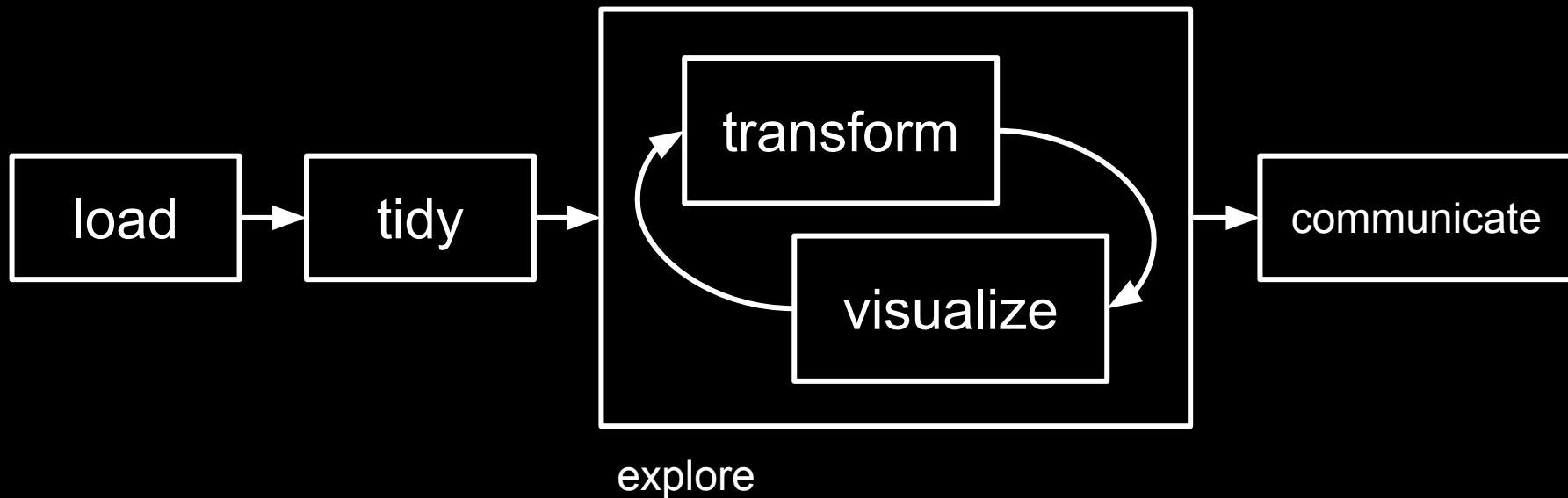


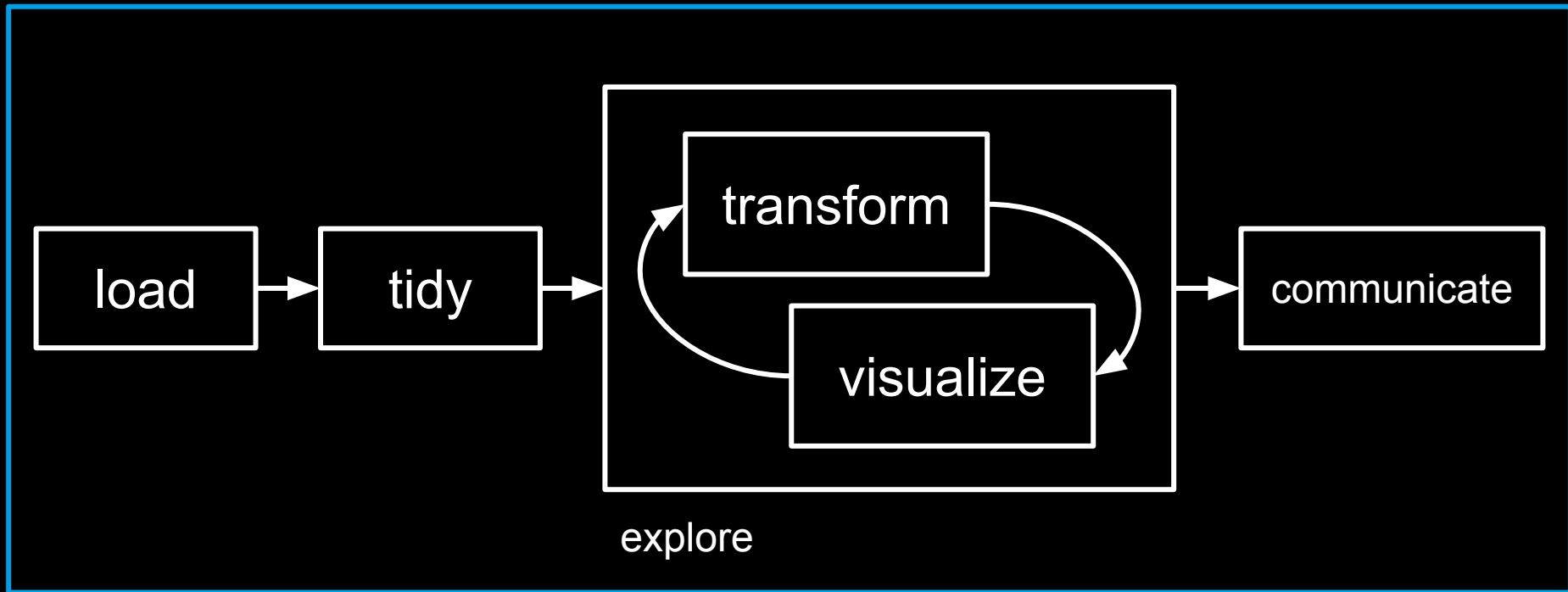




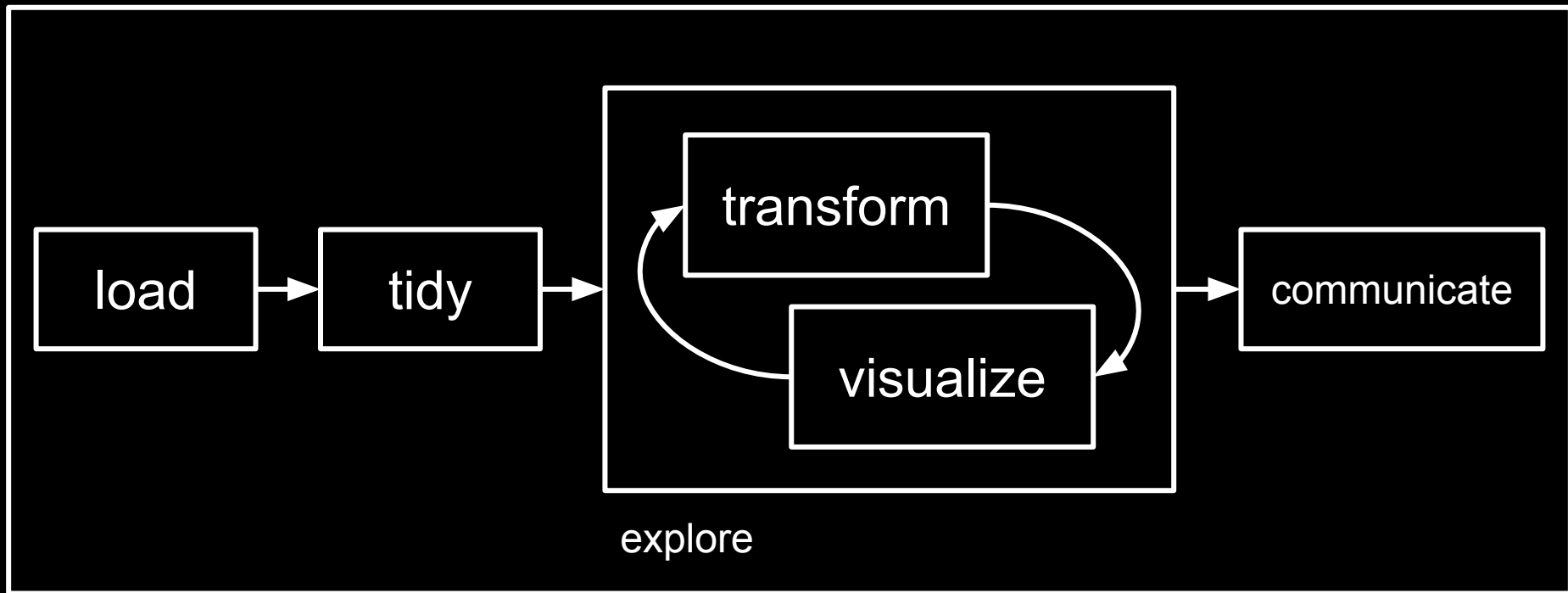








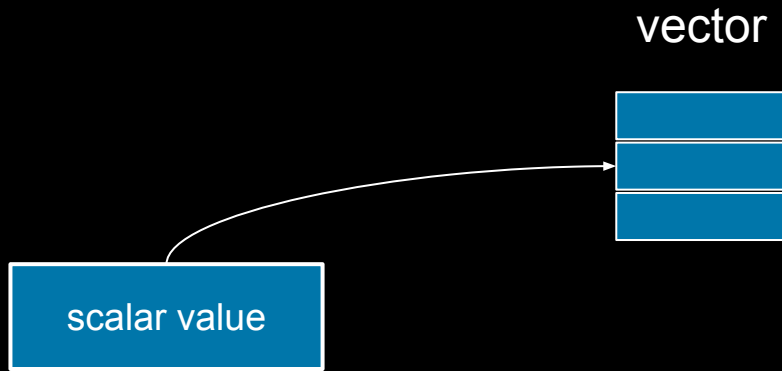
program

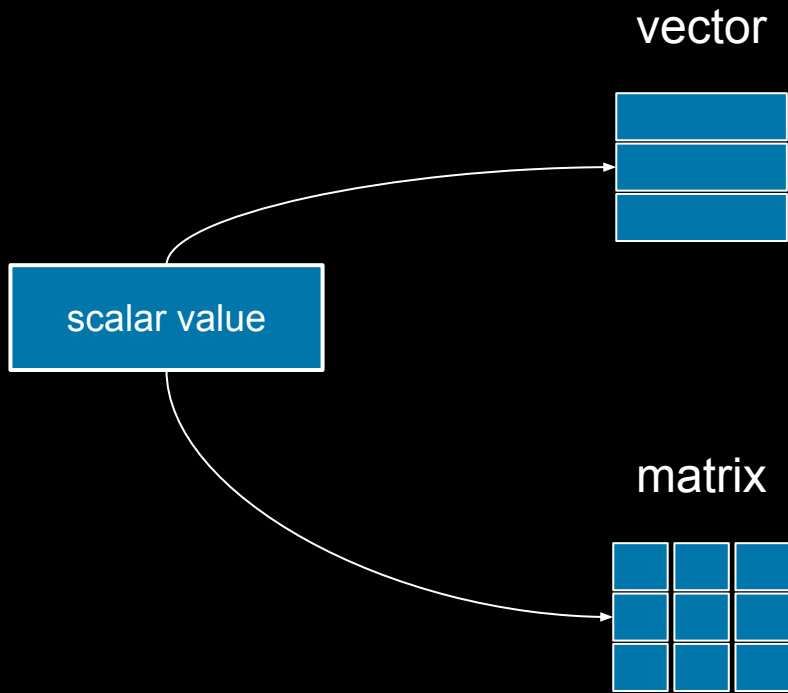


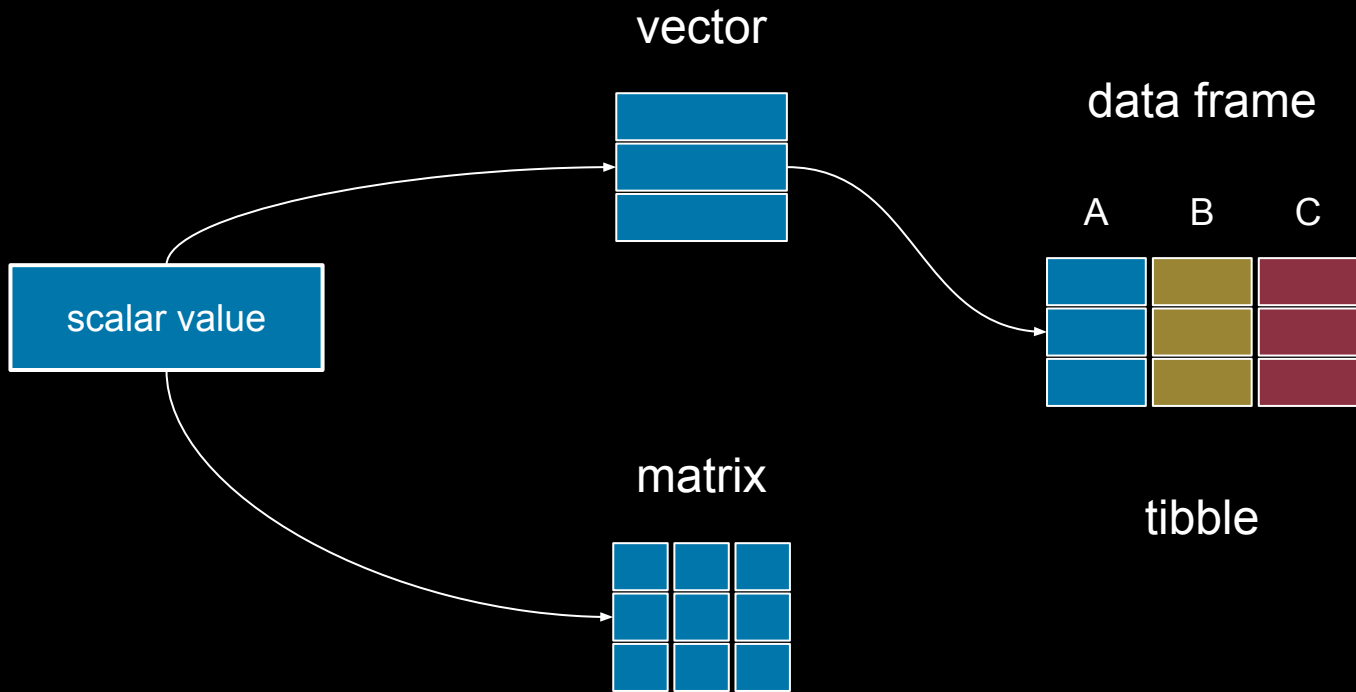
program

DATA REPRESENTATION

scalar value







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
75.5
61
88.5
120

—

89.5
75
56
96.5
115

weight

91
75.5
61
88.5
120

weight_after_diet

89.5
75
56
96.5
115

weight_loss

1.5
0.5
5
-8
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)]
```

```
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

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

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

```
levels(weight_category)
```

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

```
levels(weight_category)
```

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

```
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


```
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

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

```
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

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

adding columns

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

rename columns

```
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")
```

```
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

some sugar

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



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	1997071
Afghanistan	2000	2666	2995360
Brazil	1999	37737	17296362
Brazil	2000	60488	17494898

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



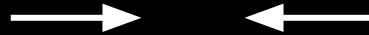
country	year	type	count
Afghanistan	1999	cases	745
Afghanistan	1999	population	19987071
Afghanistan	2000	cases	2666
Afghanistan	2000	population	20595360
Brazil	1999	cases	37737
Brazil	1999	population	172006362
Brazil	2000	cases	80488
Brazil	2000	population	174504898

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

{{ tidyrr }}

```
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”

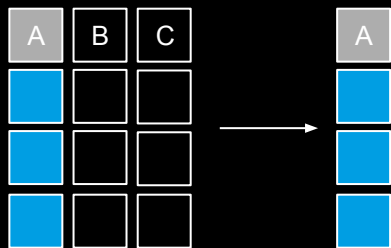
```
str_detect(txt, "Mill")
```

TRANSFORM DATA

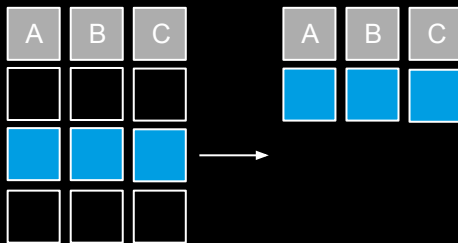
{{ dplyr }}

types of transformations

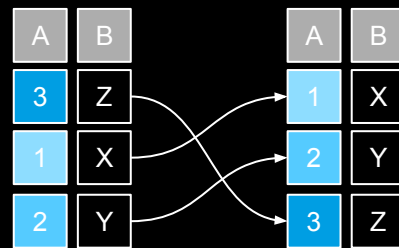
`select()`



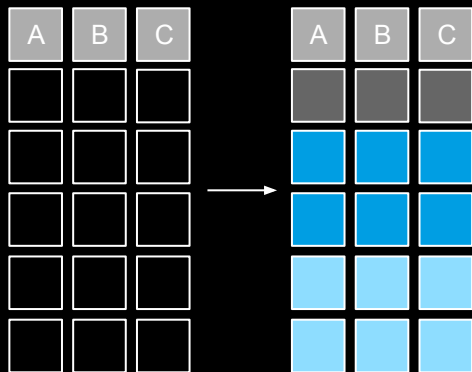
`filter()`



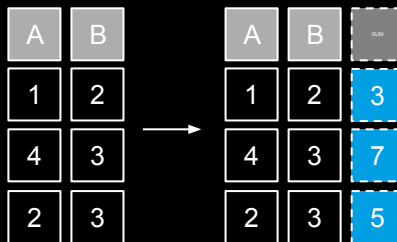
`arrange()`



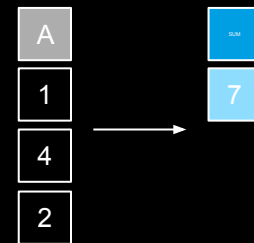
`group_by()`



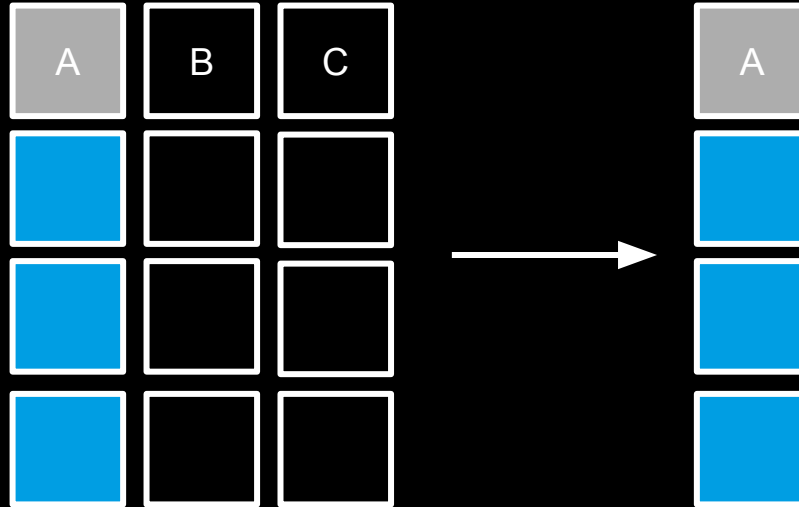
`mutate()`



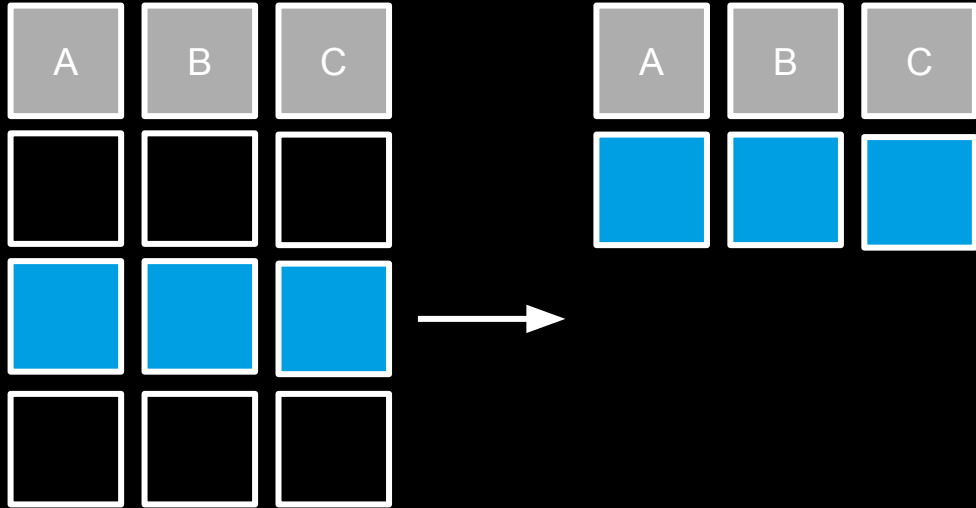
`summarize()`



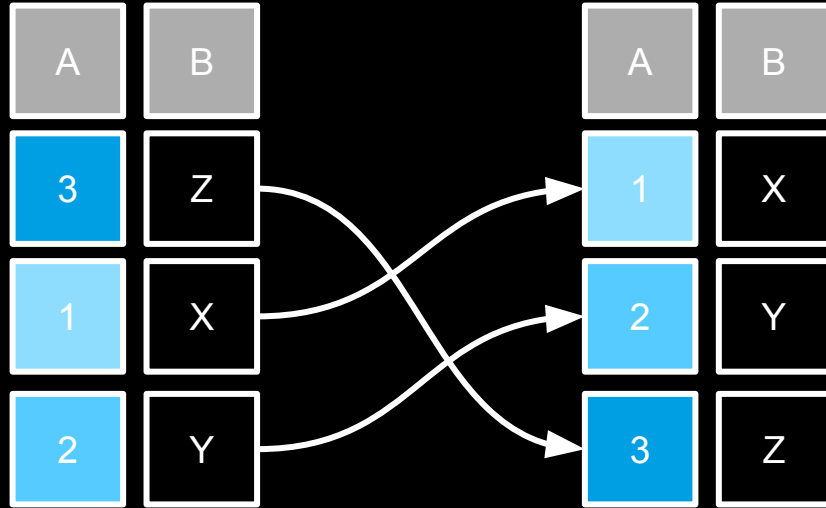
`select()`



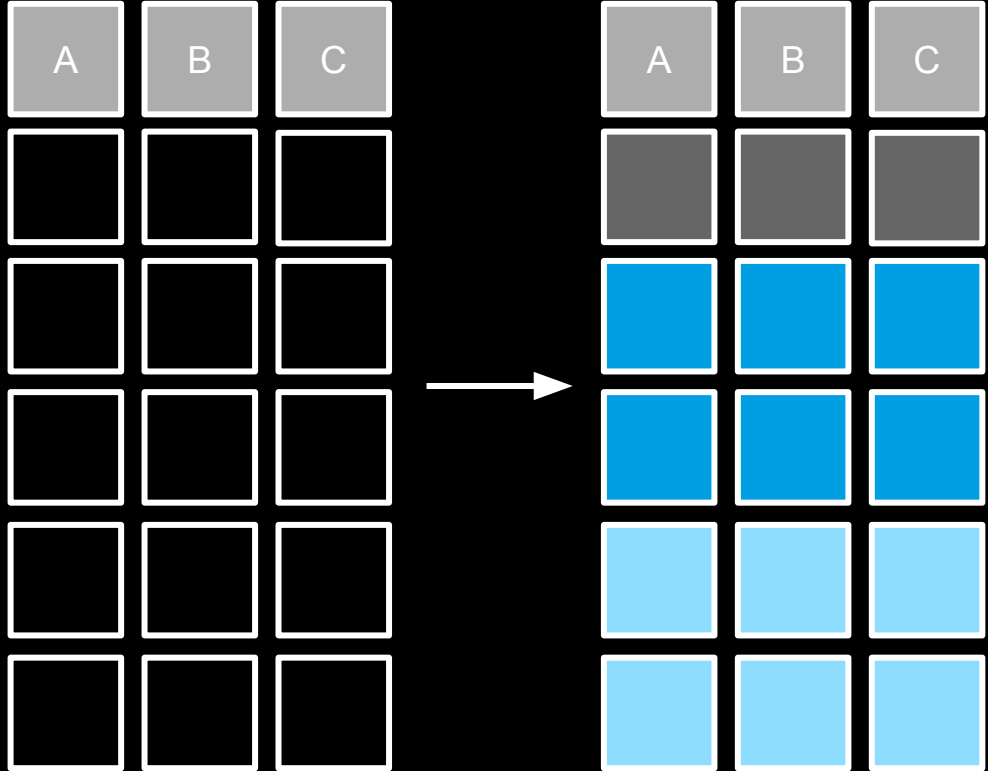
`filter()`



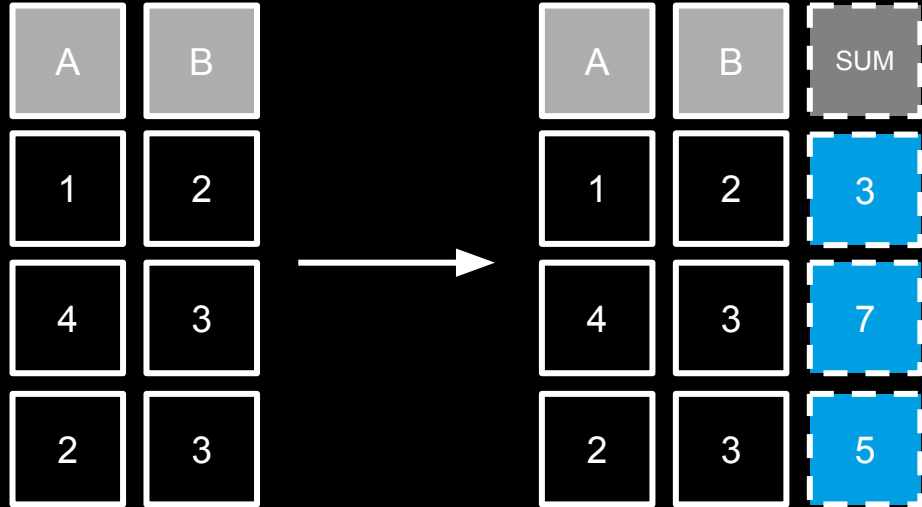
arrange()



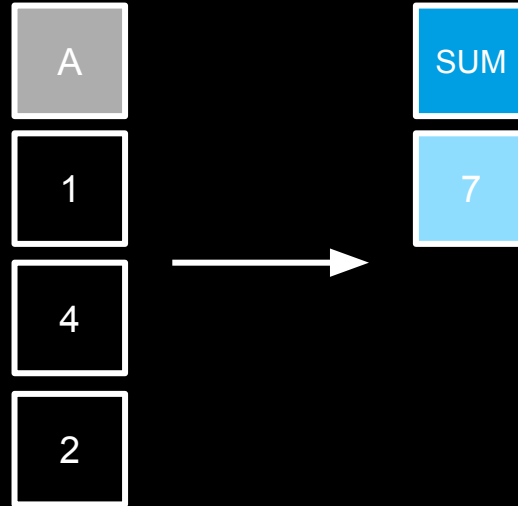
`group_by()`



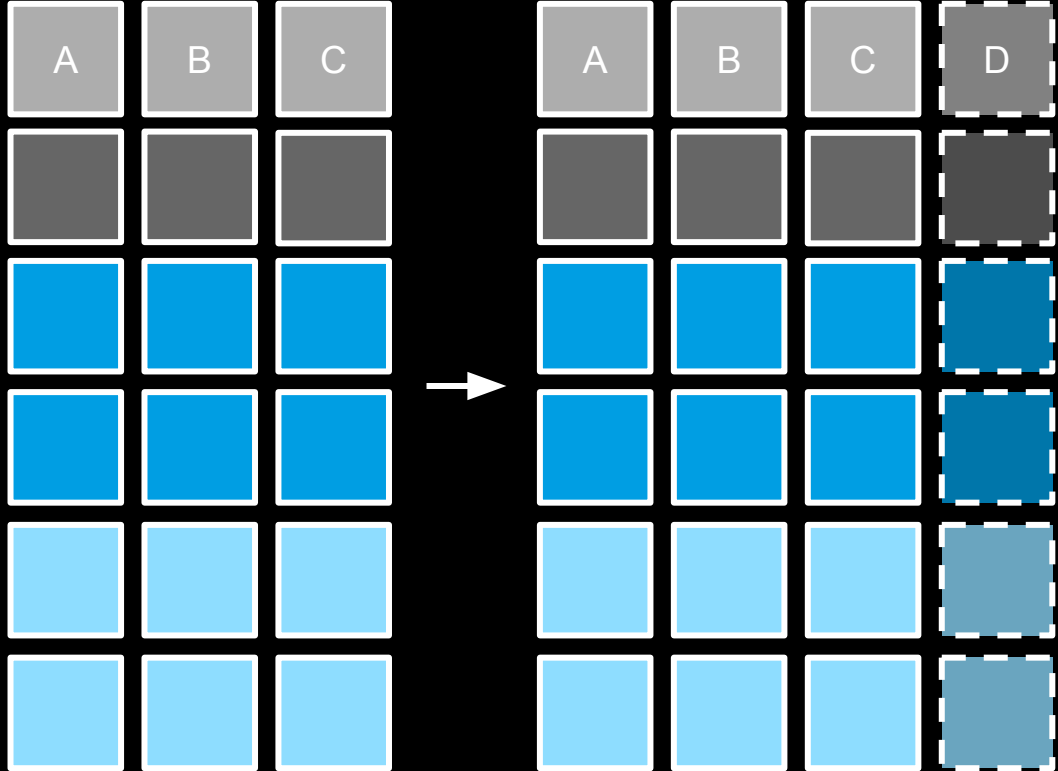
mutate()



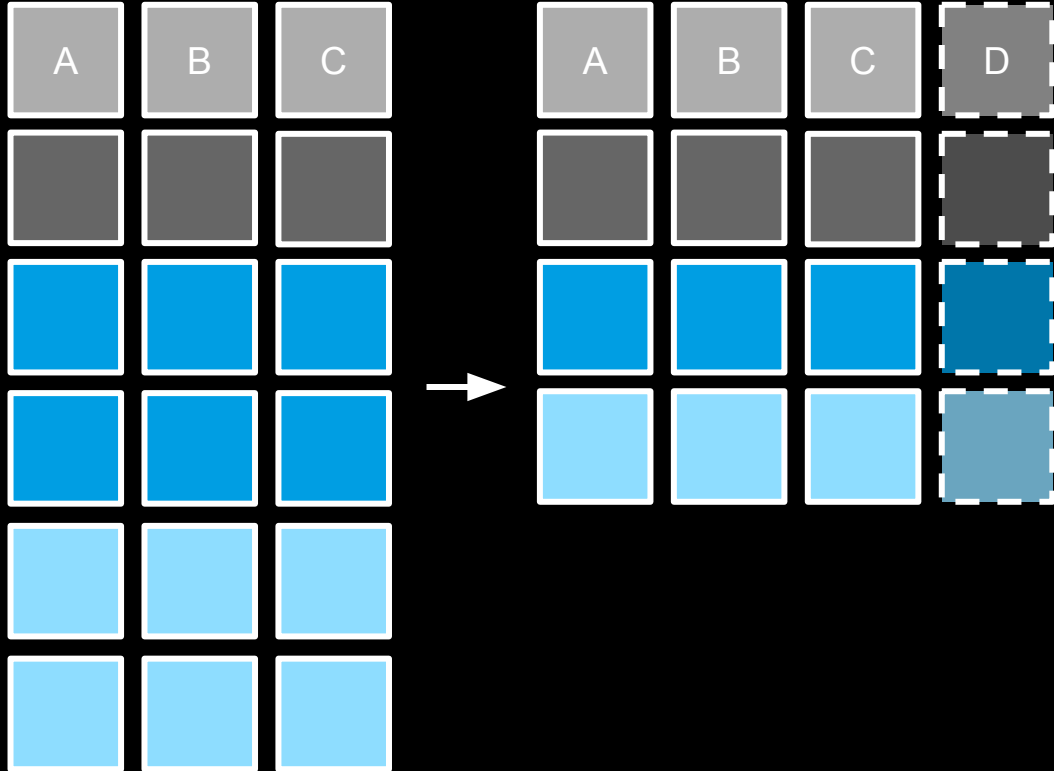
`summarize()`



`group_by()`
+
`mutate()`

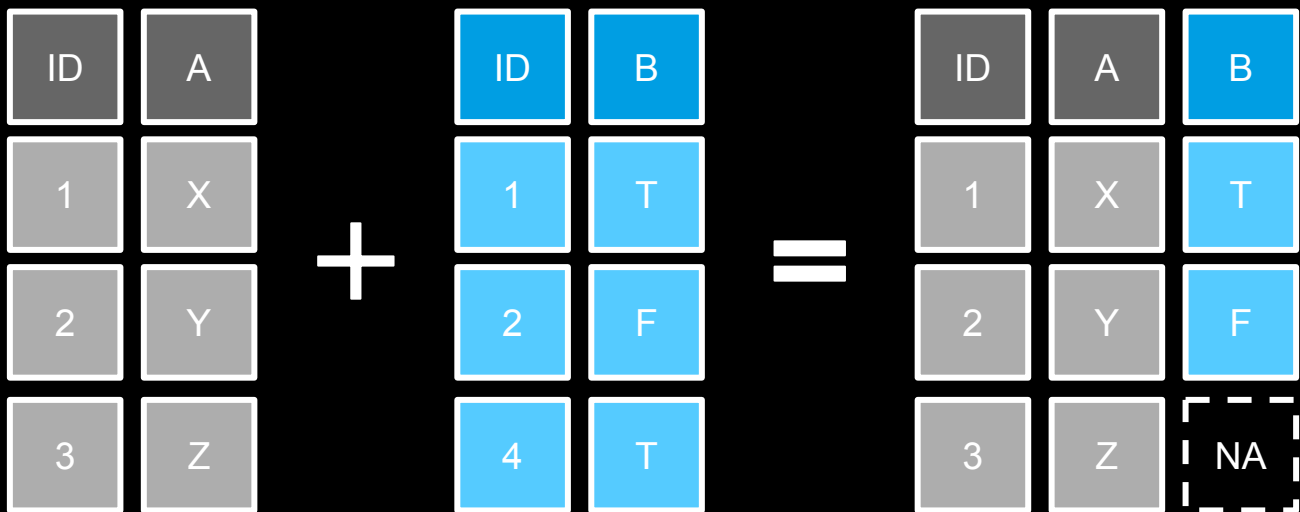


`group_by()`
+
`summarize()`

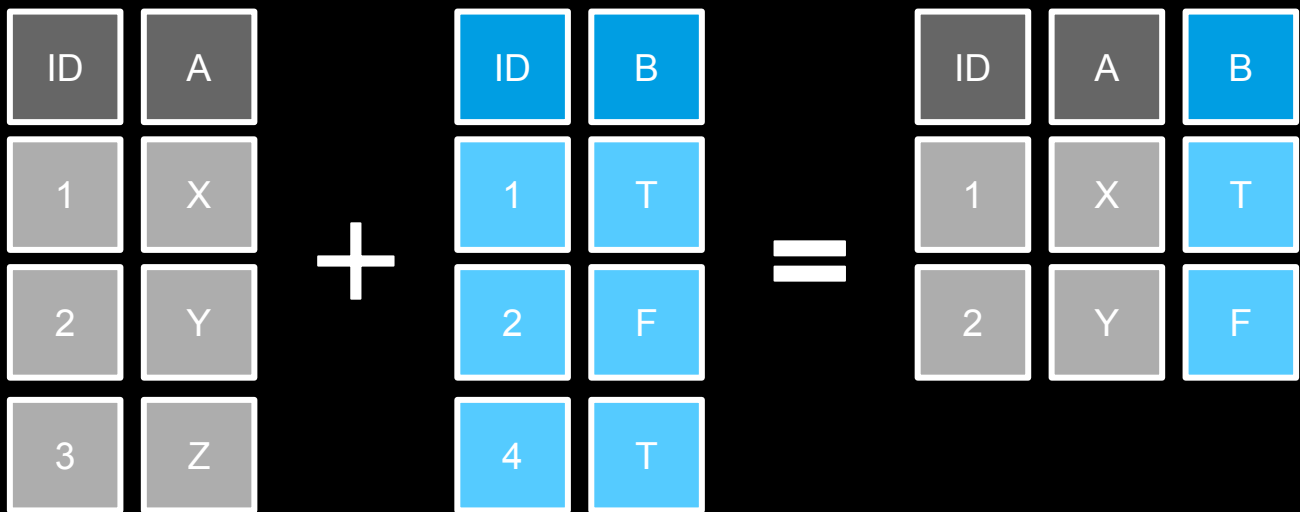


joining data

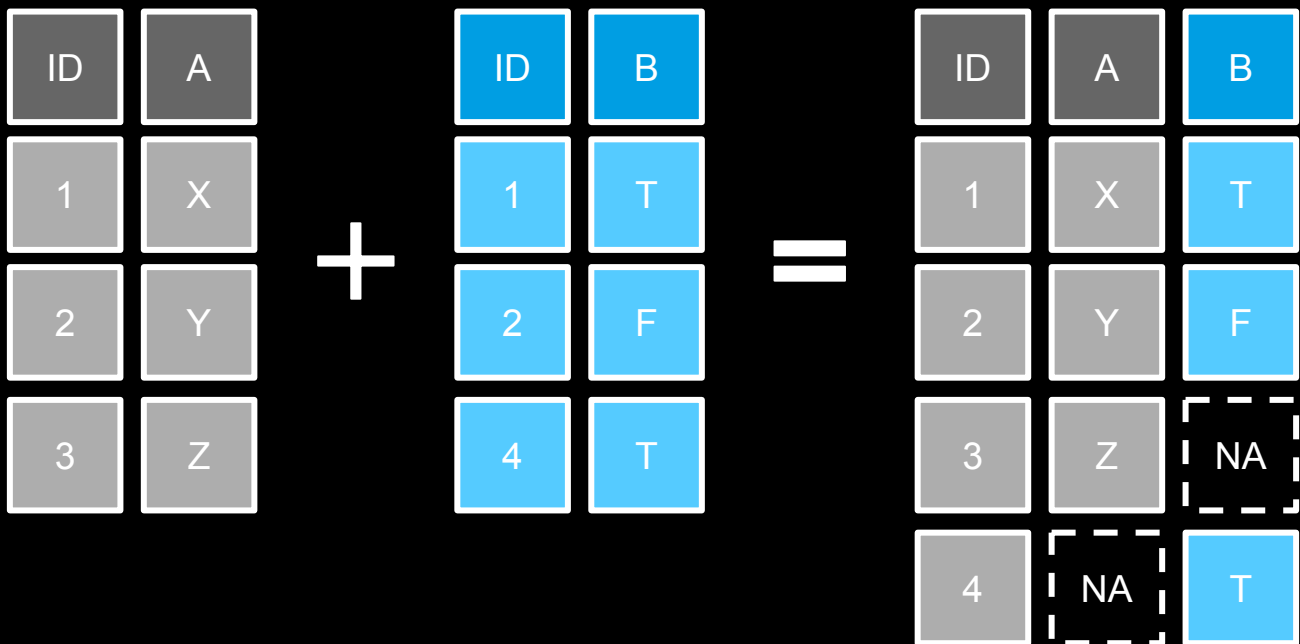
`left_join()`



`inner_join()`



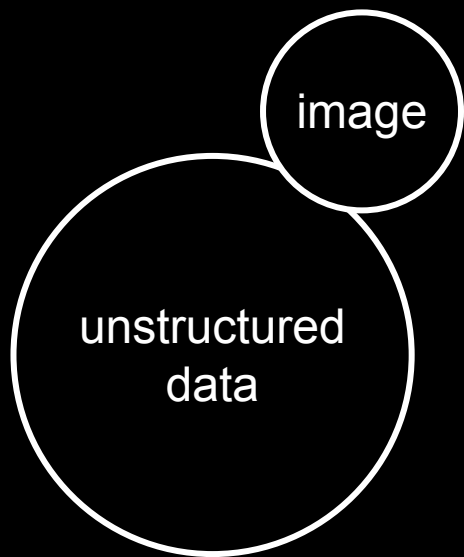
```
full_join()
```

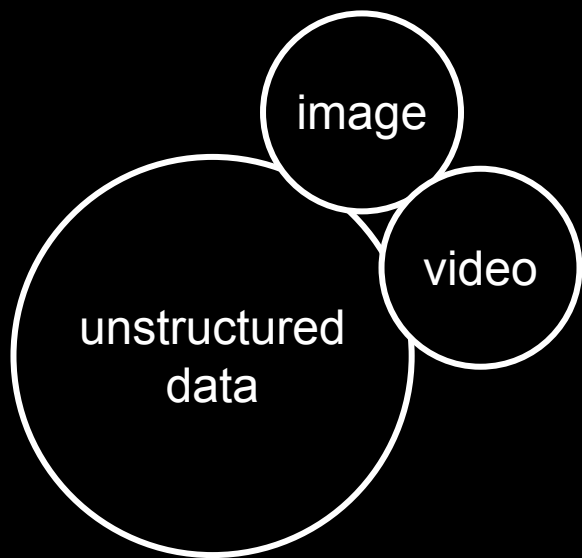


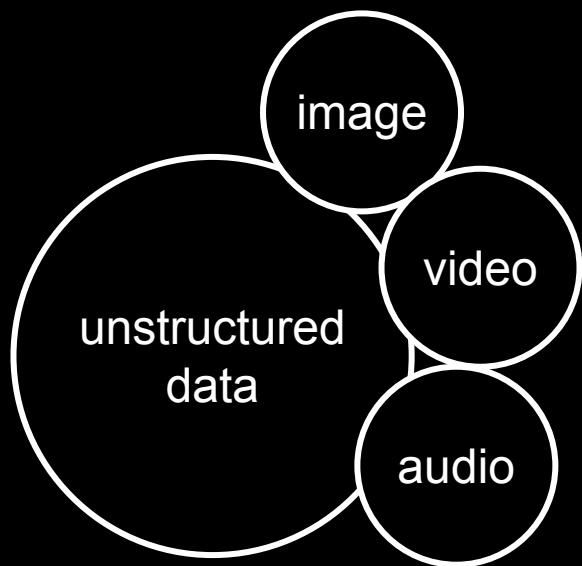
UNSTRUCTURED DATA

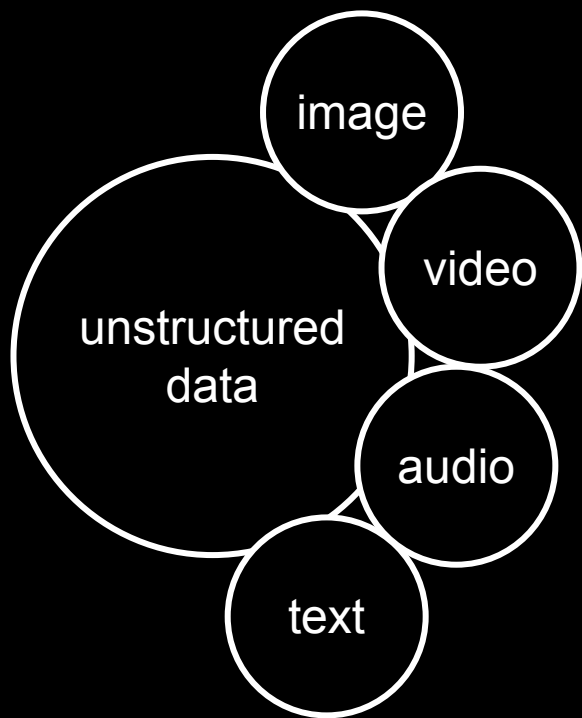


unstructured
data

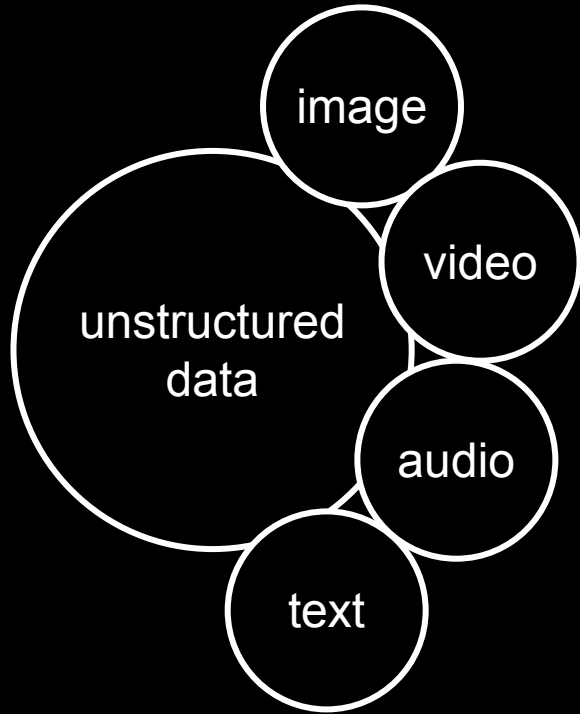




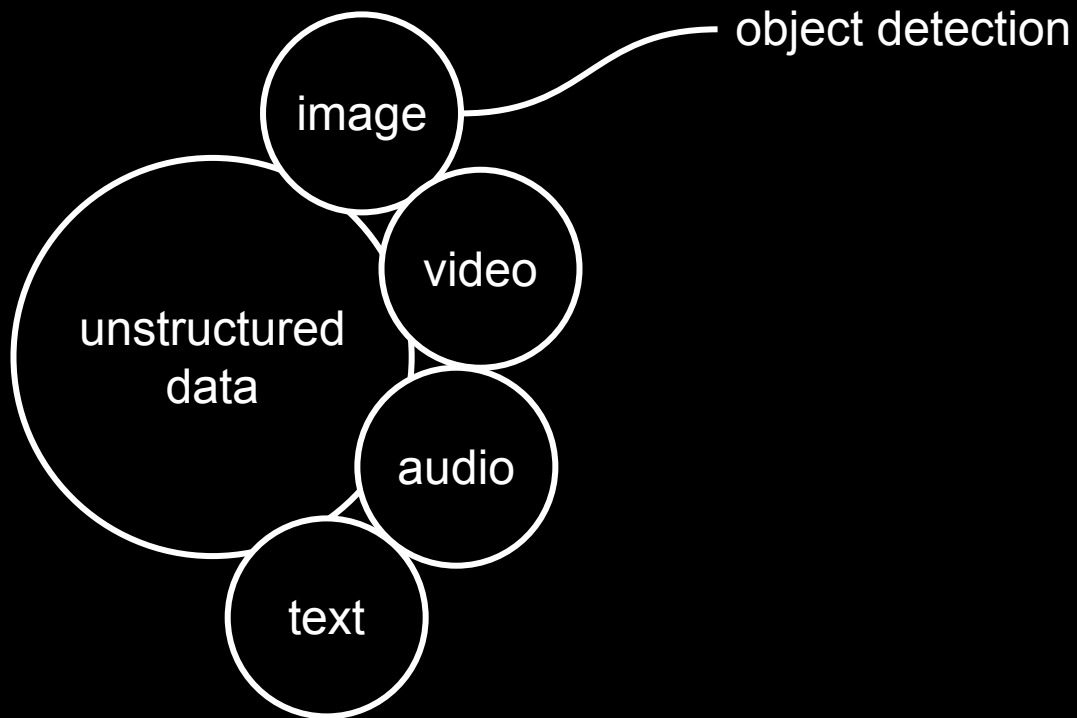




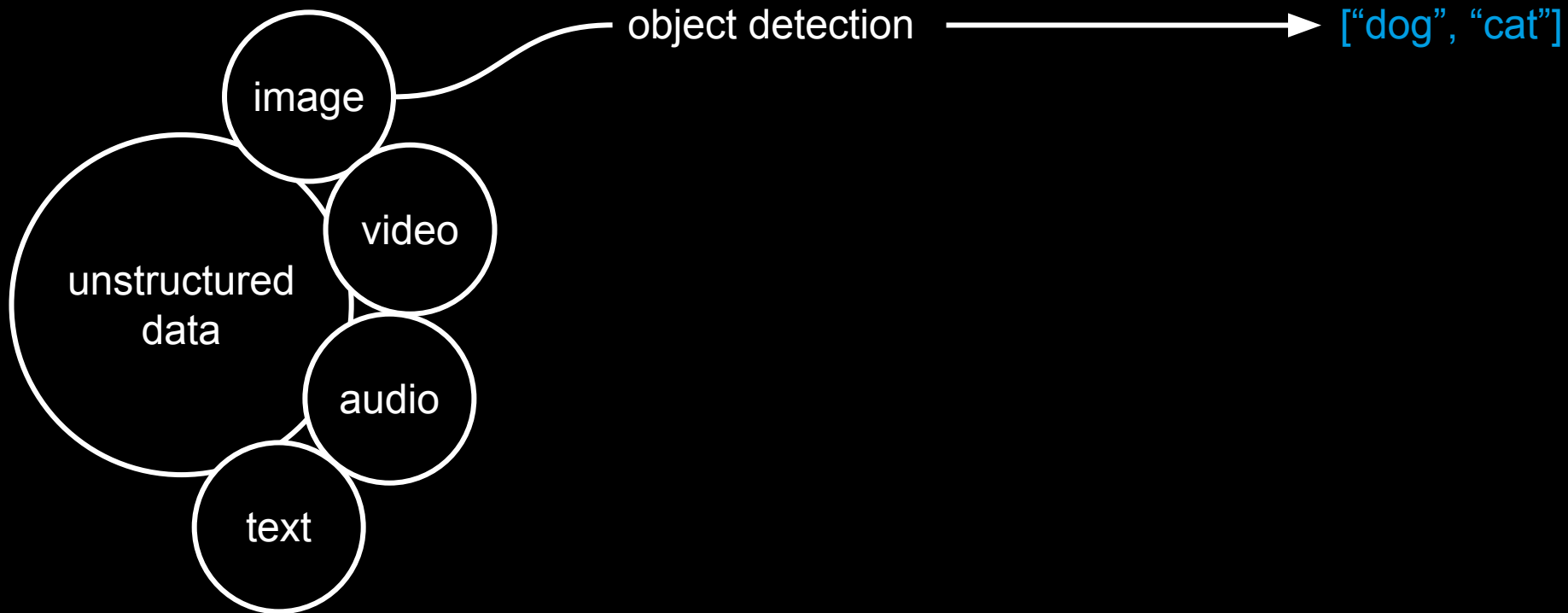
no handles to grab



no handles to grab



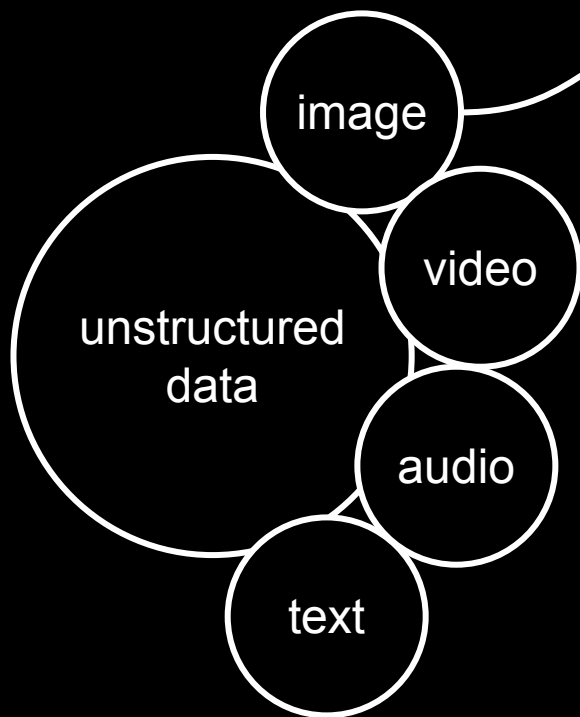
no handles to grab



no handles to grab

algorithm

extracted, structured information



object detection

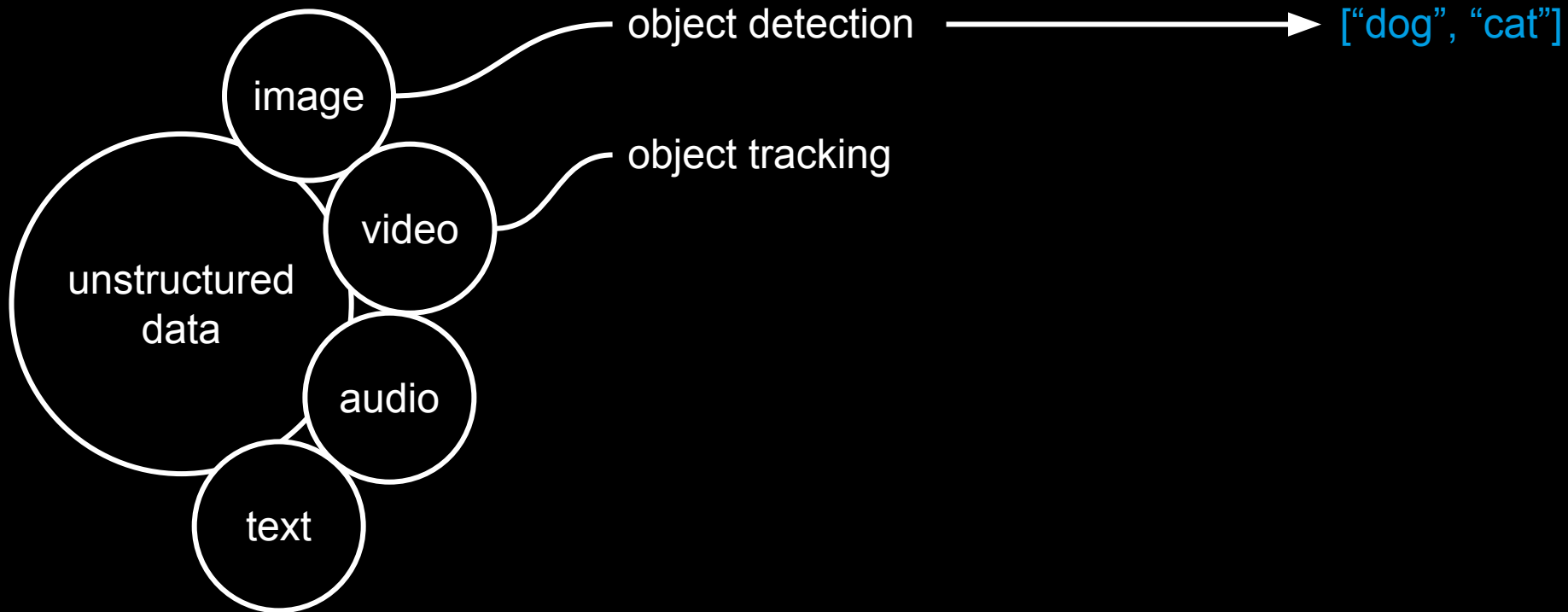


`["dog", "cat"]`

no handles to grab

algorithm

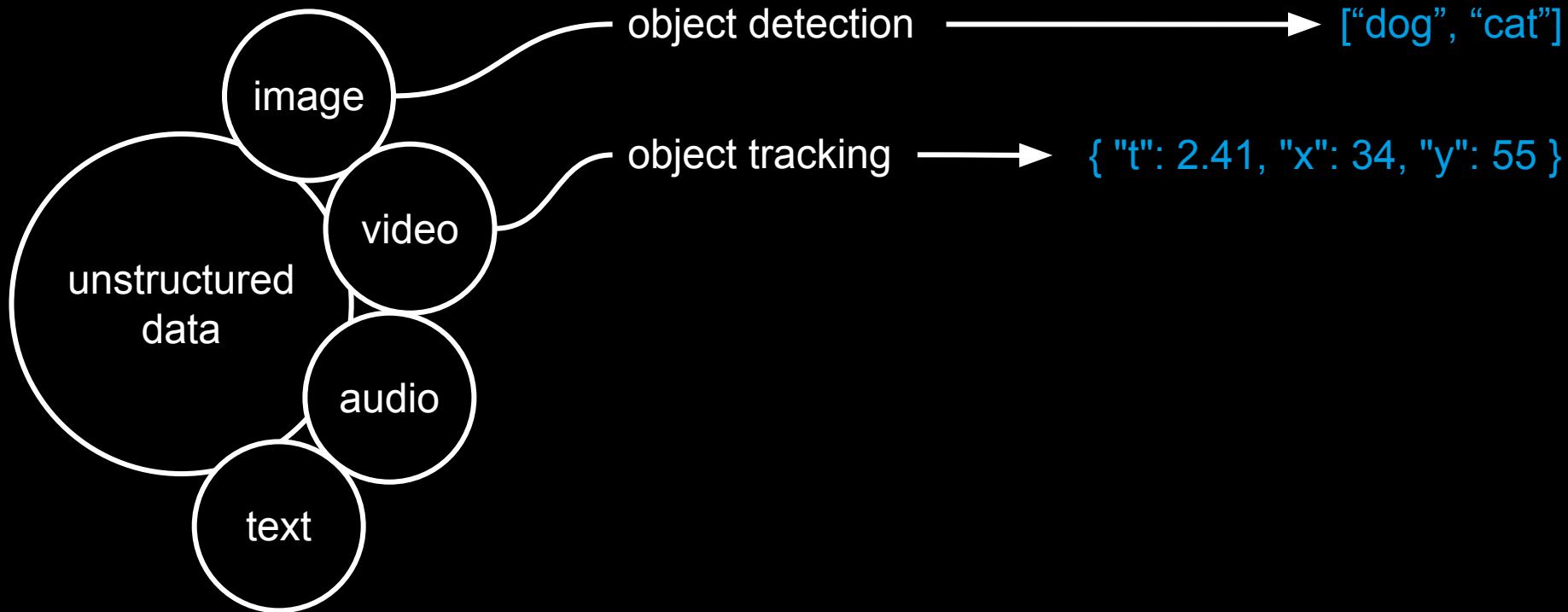
extracted, structured information



no handles to grab

algorithm

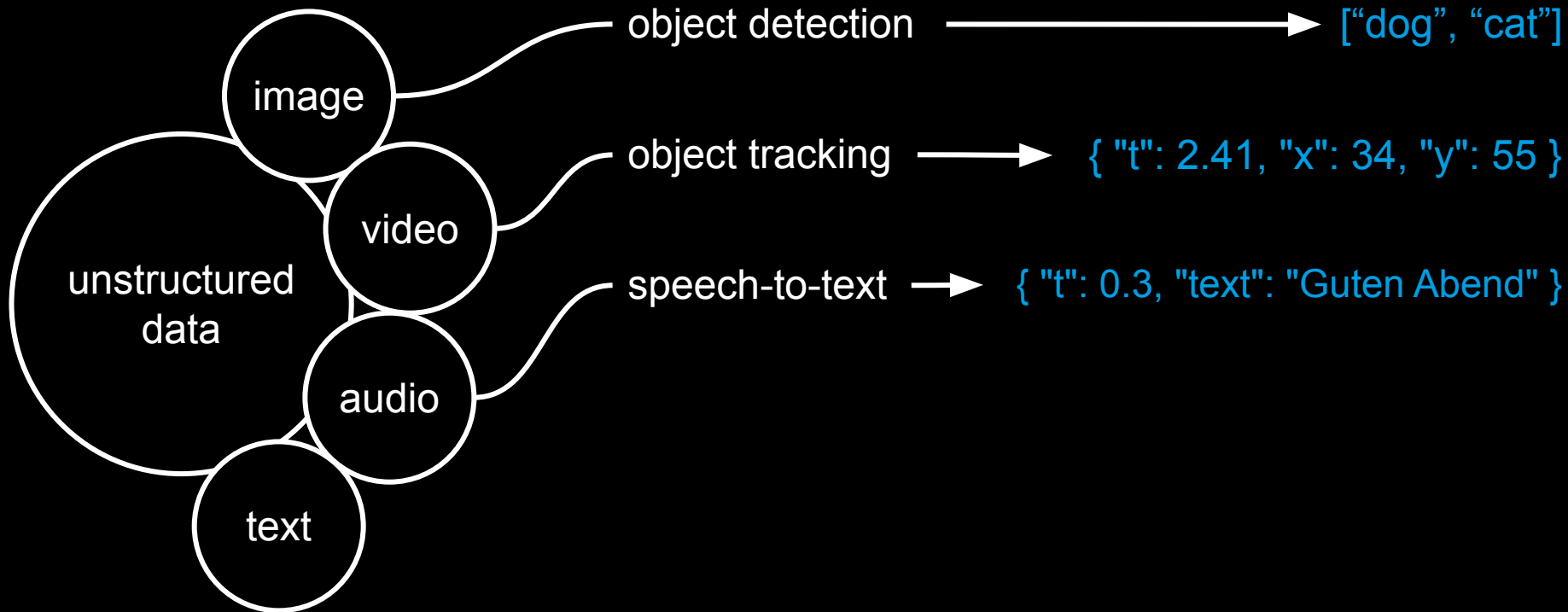
extracted, structured information



no handles to grab

algorithm

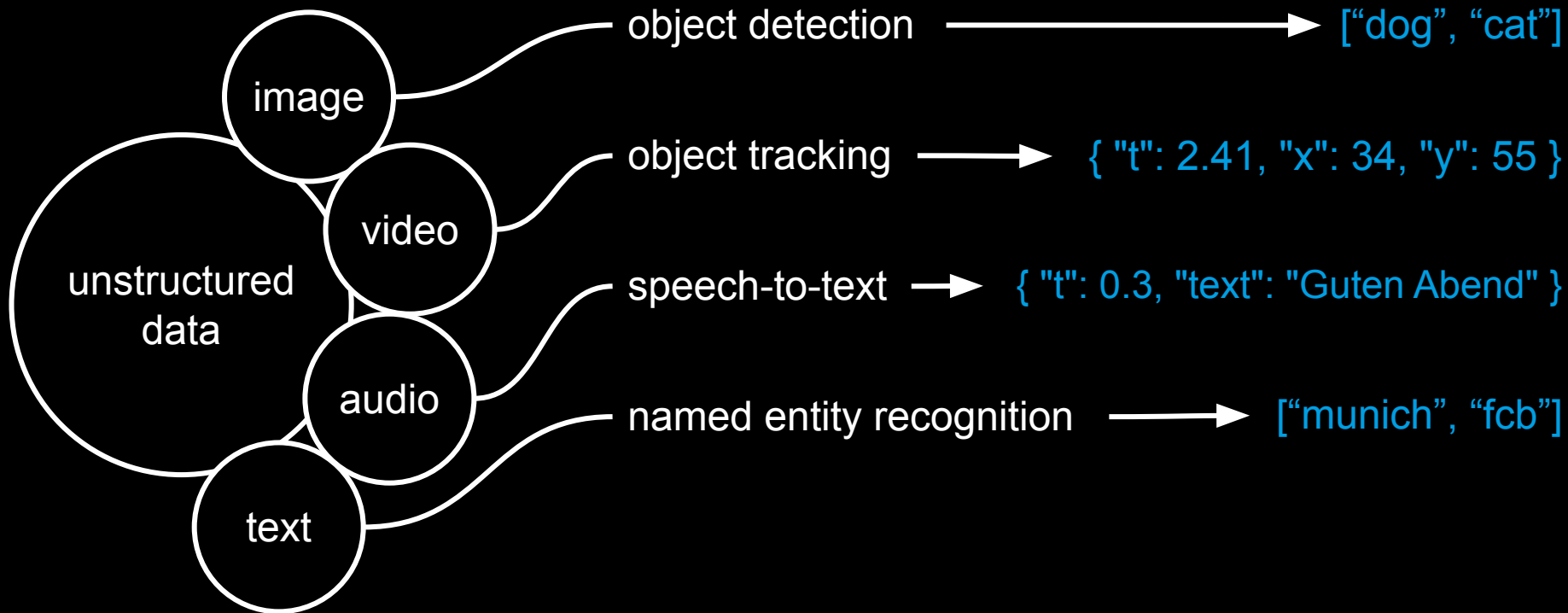
extracted, structured information



no handles to grab

algorithm

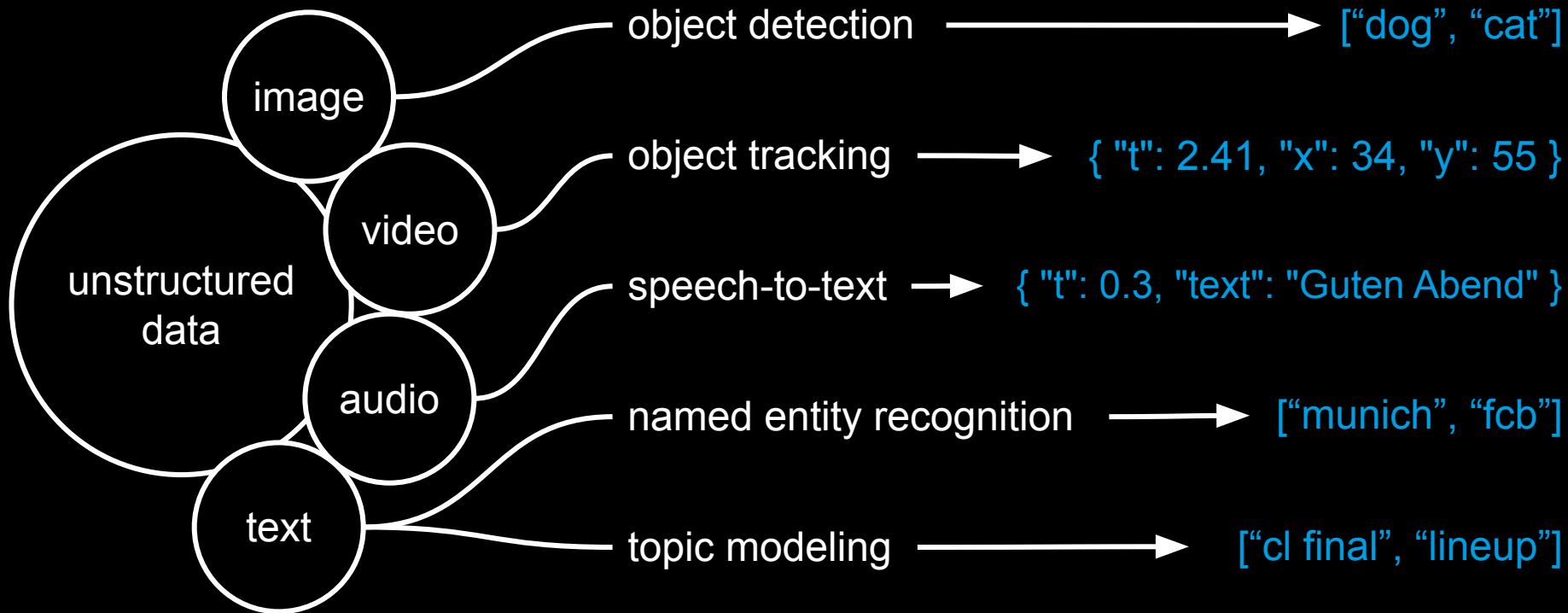
extracted, structured information



no handles to grab

algorithm

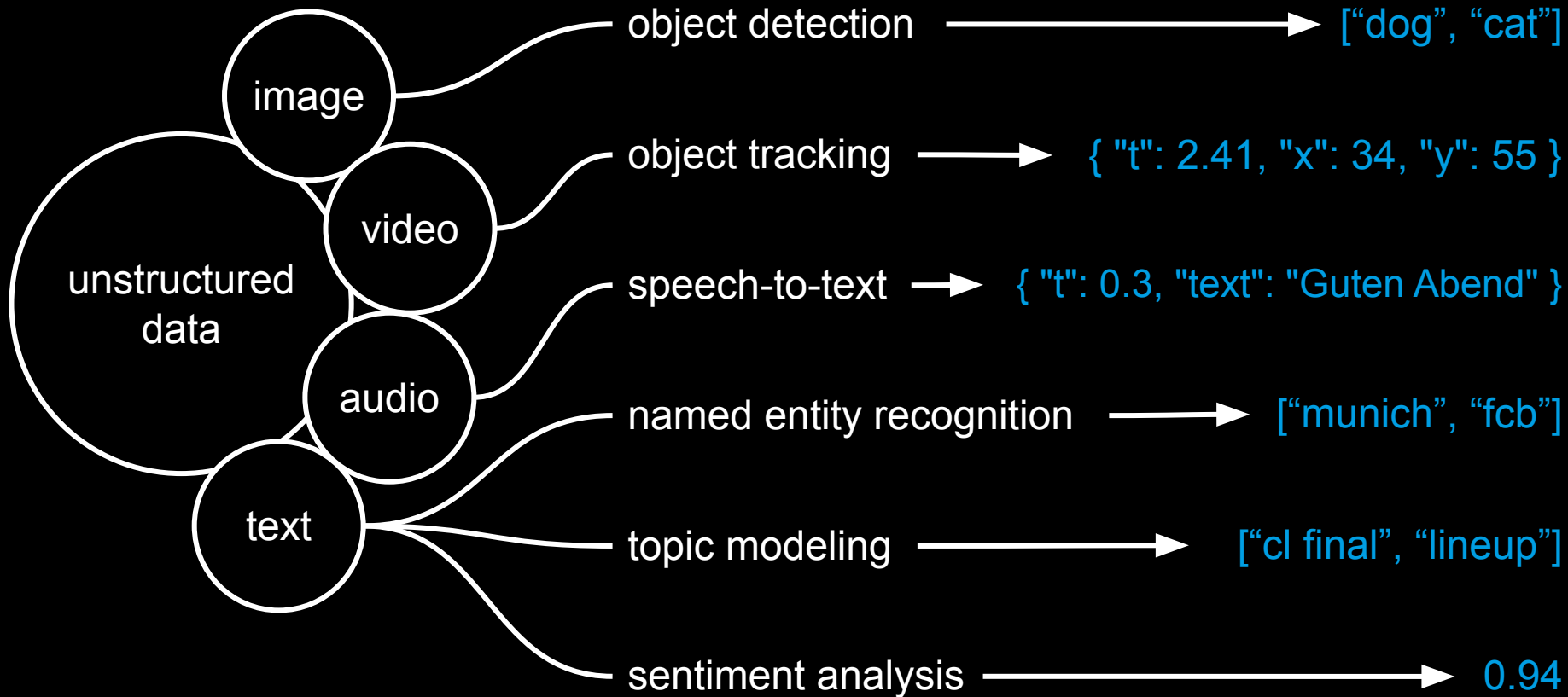
extracted, structured information



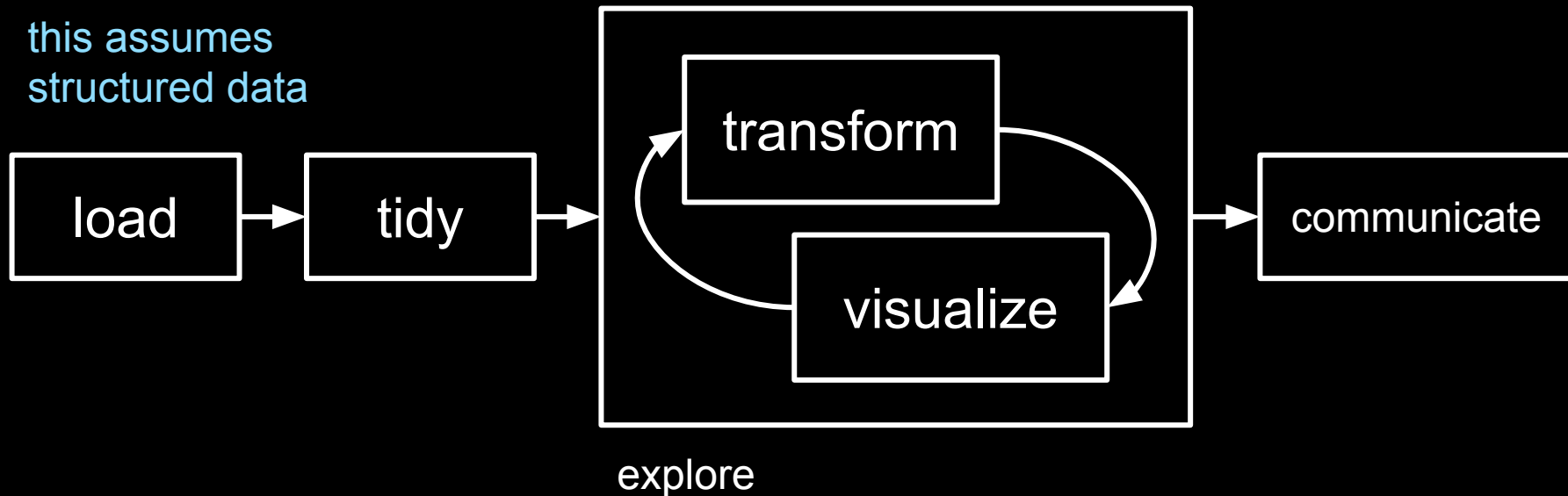
no handles to grab

algorithm

extracted, structured information

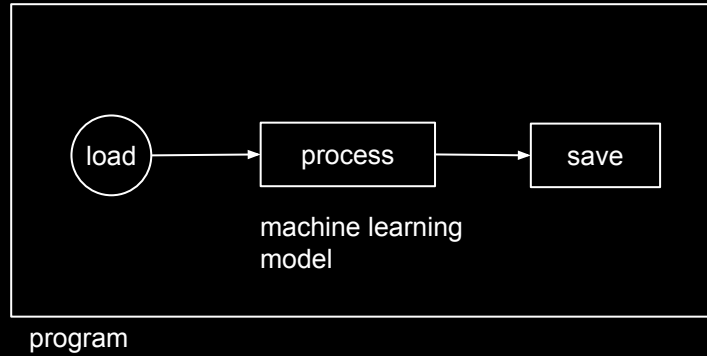


this assumes
structured data

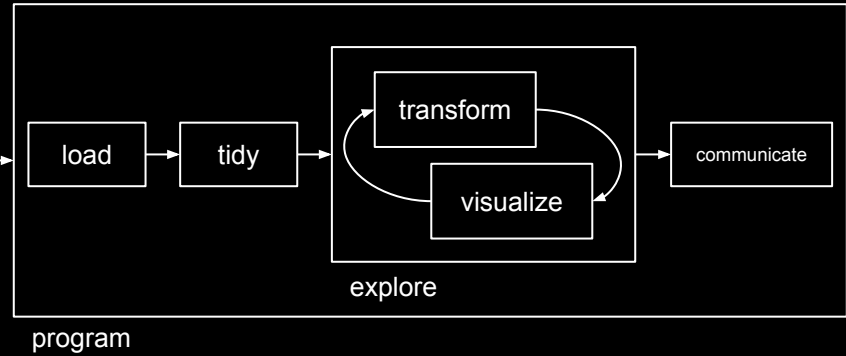


program

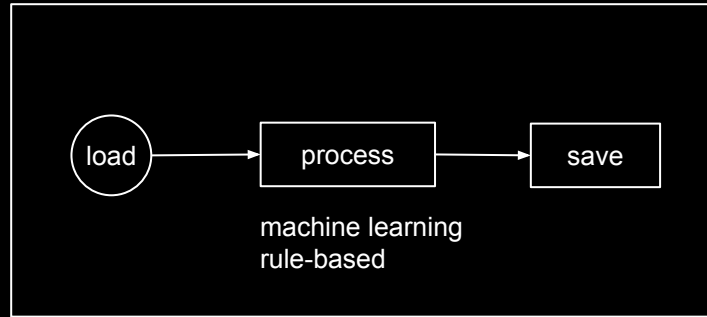
pre-process
unstructured data



exploratory data
analysis



pre-process
unstructured data



program

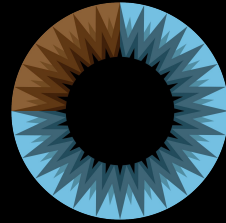


exploratory data
analysis



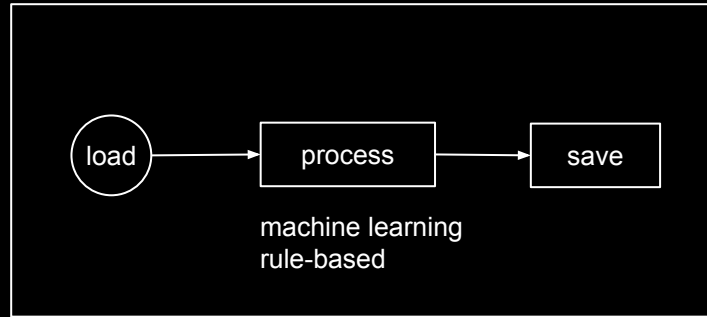
MACHINE LEARNING

Highly recommended for
background information



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

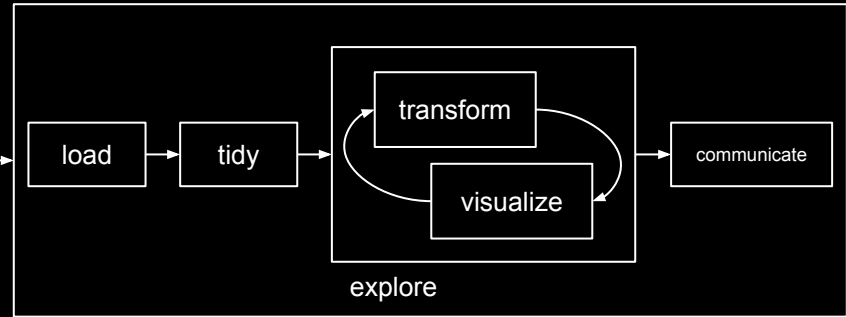
pre-process
unstructured data



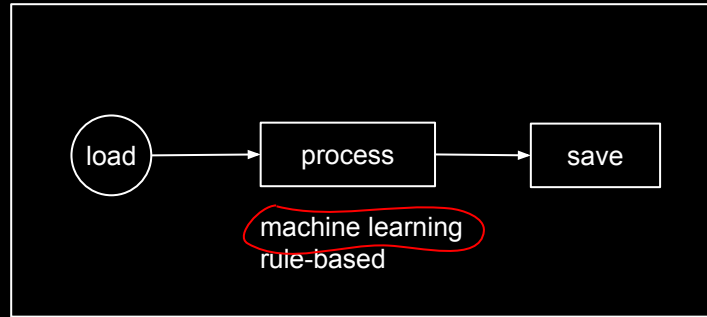
program



exploratory data
analysis



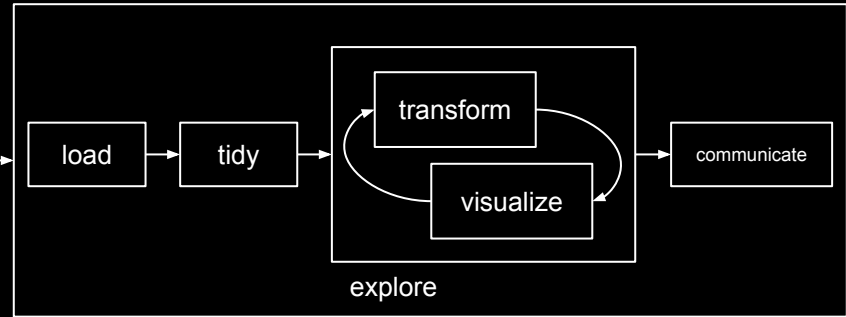
pre-process
unstructured data



program



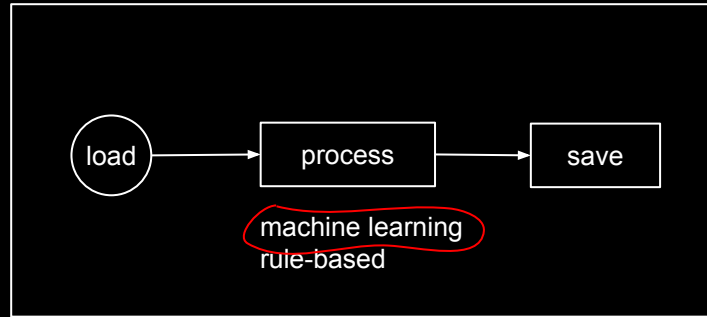
exploratory data
analysis



program



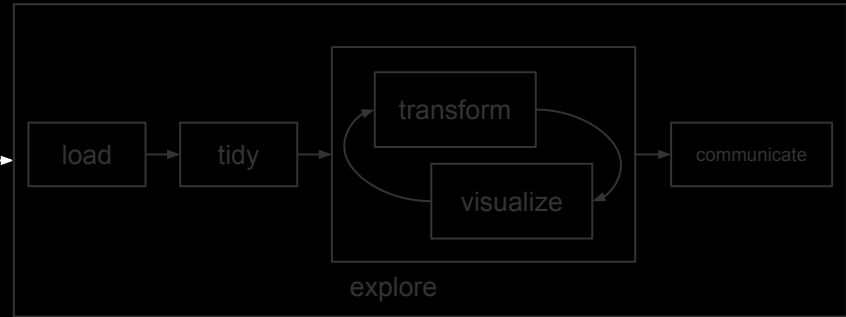
pre-process
unstructured data



program



exploratory data
analysis



program





machine learning

program



YouTube



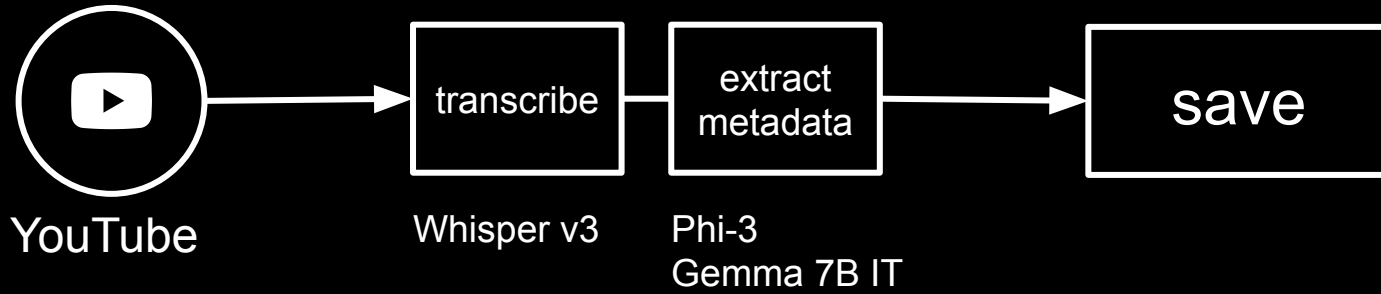
process

machine learning

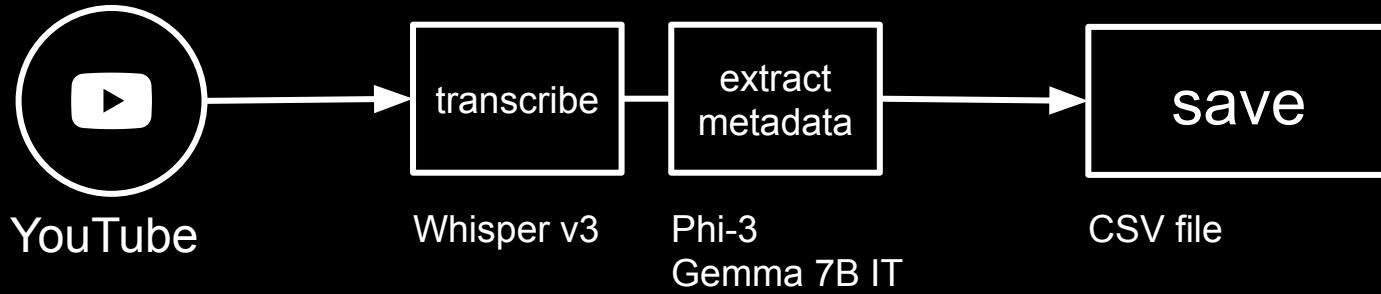


save

program



program



program

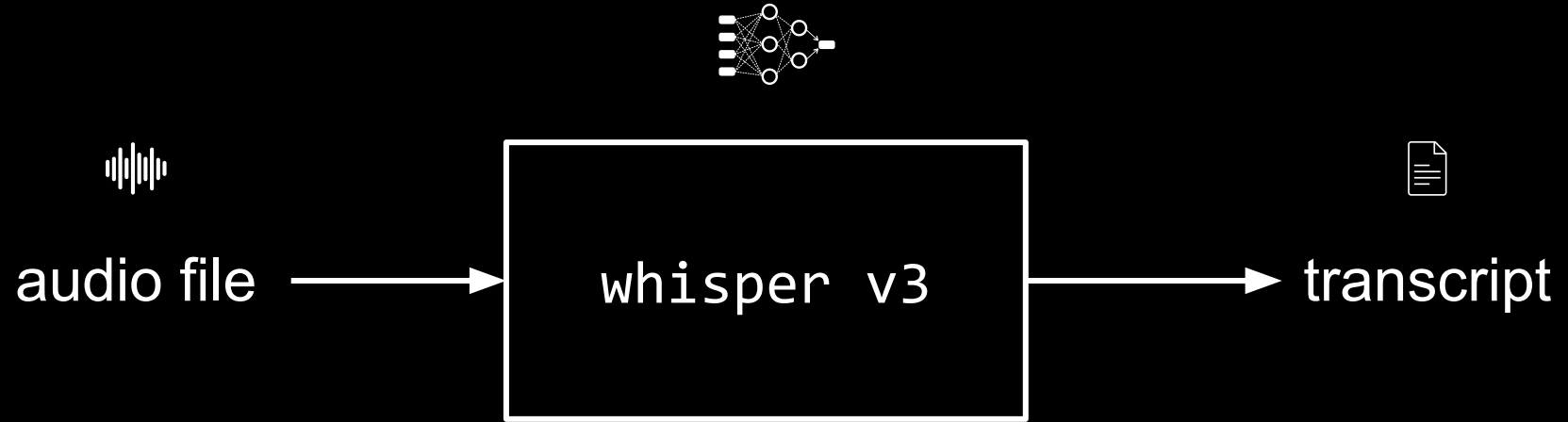
YouTube API

Whisper v3

<https://arxiv.org/abs/2212.04356>



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



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/>



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

<instruction>

<context>

<input data>

<output indicator>

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>

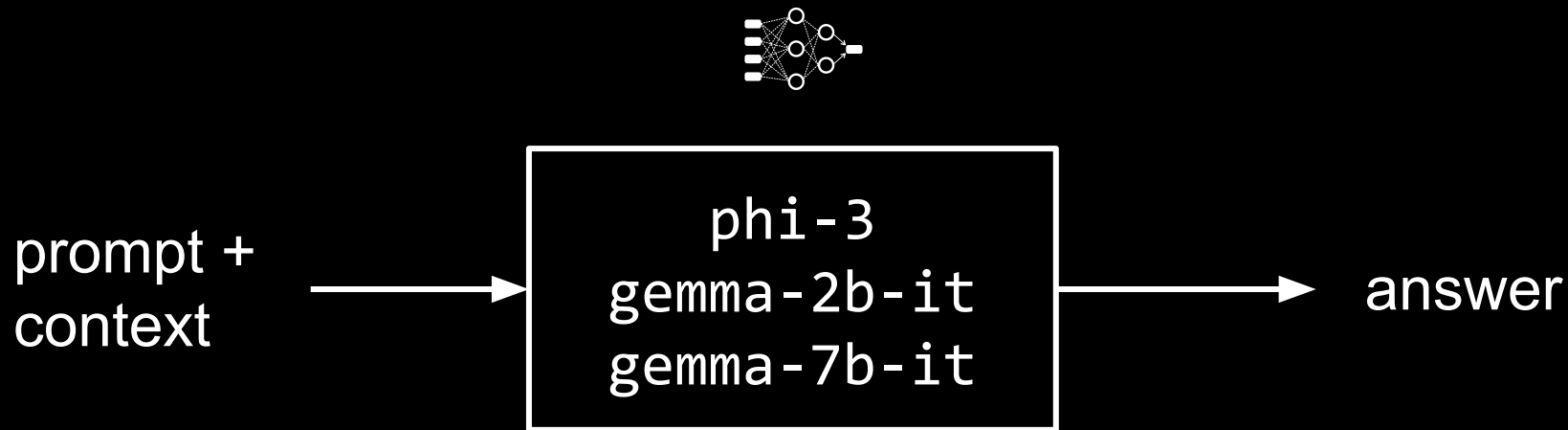
Gemma 2B / 7B Instruct

<https://arxiv.org/abs/2403.08295>



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

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



OpenAI's GPT-4.1 family

<https://platform.openai.com/docs/models>

4.1 nano

GPT-4.1 nano

Default

Fastest, most cost-effective GPT-4.1 model

Compare

Try in Playground

INTELLIGENCE

Average

SPEED

Very fast

PRICE

\$0.1 • \$0.4

Input • Output

INPUT

Text, image

OUTPUT

Text

GPT-4.1 nano is the fastest, most cost-effective GPT-4.1 model.

✦ 1,047,576 context window

↪ 32,768 max output tokens

🗓 Jun 01, 2024 knowledge cutoff

Pricing

Pricing is based on the number of tokens used. For tool-specific models, like search and computer use, there's a fee per tool call. See details in the [pricing page](#).

Text tokens

Per 1M tokens • Batch API price

Input

\$0.10

Cached input

\$0.025

Output

\$0.40

<https://platform.openai.com/docs/models/gpt-4.1-nano>

1 mio. token →
~2500 pages

GPT-4.1 nano Default ⓘ ⓘ
Fastest, most cost-effective GPT-4.1 model

Compare Try in Playground

INTELLIGENCE	SPEED	PRICE	INPUT	OUTPUT
● ● Average	⚡ ⚡ ⚡ ⚡ ⚡ Very fast	\$0.1 • \$0.4 Input • Output	📄 🖼️ 🗑️ Text, image	📄 🗑️ 🗑️ Text

GPT-4.1 nano is the fastest, most cost-effective GPT-4.1 model.

- ✦ 1,047,576 context window
- ↪ 32,768 max output tokens
- 🗓 Jun 01, 2024 knowledge cutoff

Pricing

Pricing is based on the number of tokens used. For tool-specific models, like search and computer use, there's a fee per tool call. See details in the [pricing page](#).

Text tokens Per 1M tokens • Batch API price ☐

Input	Cached input	Output
\$0.10	\$0.025	\$0.40

<https://platform.openai.com/docs/models/gpt-4.1-nano>

1 mio. token →
~2500 pages

roughly 10 cents
as input

The screenshot shows the OpenAI GPT-4.1 nano model page. It features a header with the model name, a 'Default' dropdown, and a 'Try in Playground' button. Below this is a comparison table with columns for Intelligence, Speed, Price, Input, and Output. The Price column shows '\$0.1 • \$0.4' for 'Input • Output'. The Input column shows 'Text, image' and the Output column shows 'Text'. A text block below the table states 'GPT-4.1 nano is the fastest, most cost-effective GPT-4.1 model.' and lists '1,047,576 context window', '32,768 max output tokens', and 'Jun 01, 2024 knowledge cutoff'. A 'Pricing' section explains that pricing is based on the number of tokens used and provides a table for 'Text tokens' with 'Per 1M tokens' and 'Batch API price' columns. The 'Input' column shows '\$0.10', 'Cached input' shows '\$0.025', and 'Output' shows '\$0.40'. Two orange arrows point from the text on the left to the '\$0.10' and '1,047,576 context window' values.

GPT-4.1 nano Default

Fastest, most cost-effective GPT-4.1 model

Compare Try in Playground

INTELLIGENCE	SPEED	PRICE	INPUT	OUTPUT
 Average	 Very fast	\$0.1 • \$0.4 Input • Output	 Text, image	 Text

GPT-4.1 nano is the fastest, most cost-effective GPT-4.1 model.

- ✦ 1,047,576 context window
- ↪ 32,768 max output tokens
- 📅 Jun 01, 2024 knowledge cutoff

Pricing

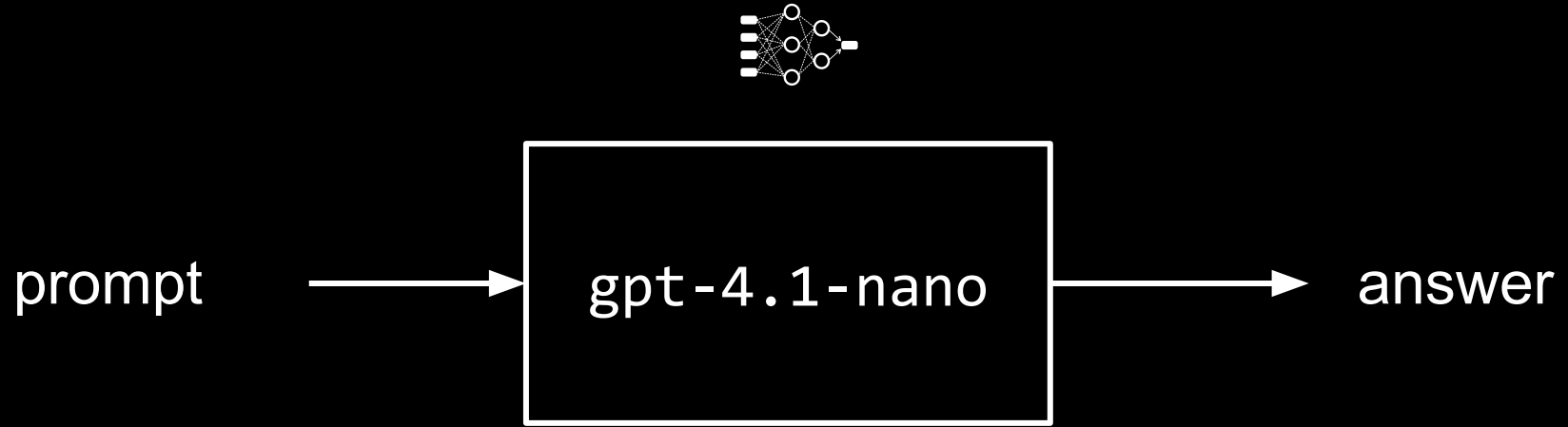
Pricing is based on the number of tokens used. For tool-specific models, like search and computer use, there's a fee per tool call. See details in the [pricing page](#).

Text tokens

Per 1M tokens • Batch API price ☐

Input \$0.10	Cached input \$0.025	Output \$0.40
-----------------	-------------------------	------------------

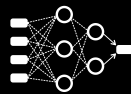
<https://platform.openai.com/docs/models/gpt-4.1-nano>



prompt +
image



answer



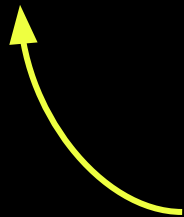
prompt +
image



gpt-4.1-nano



answer

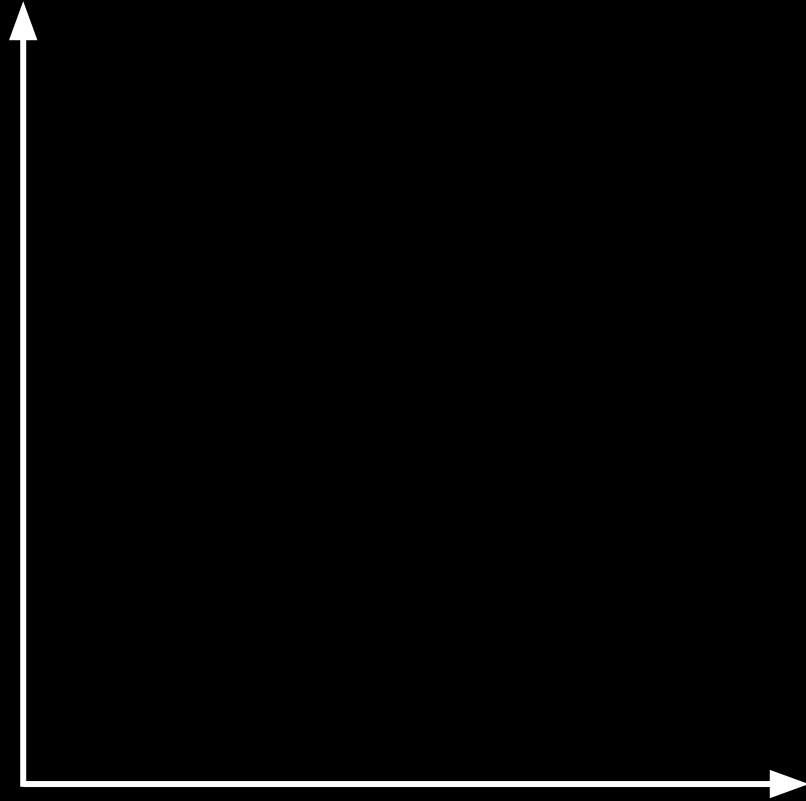


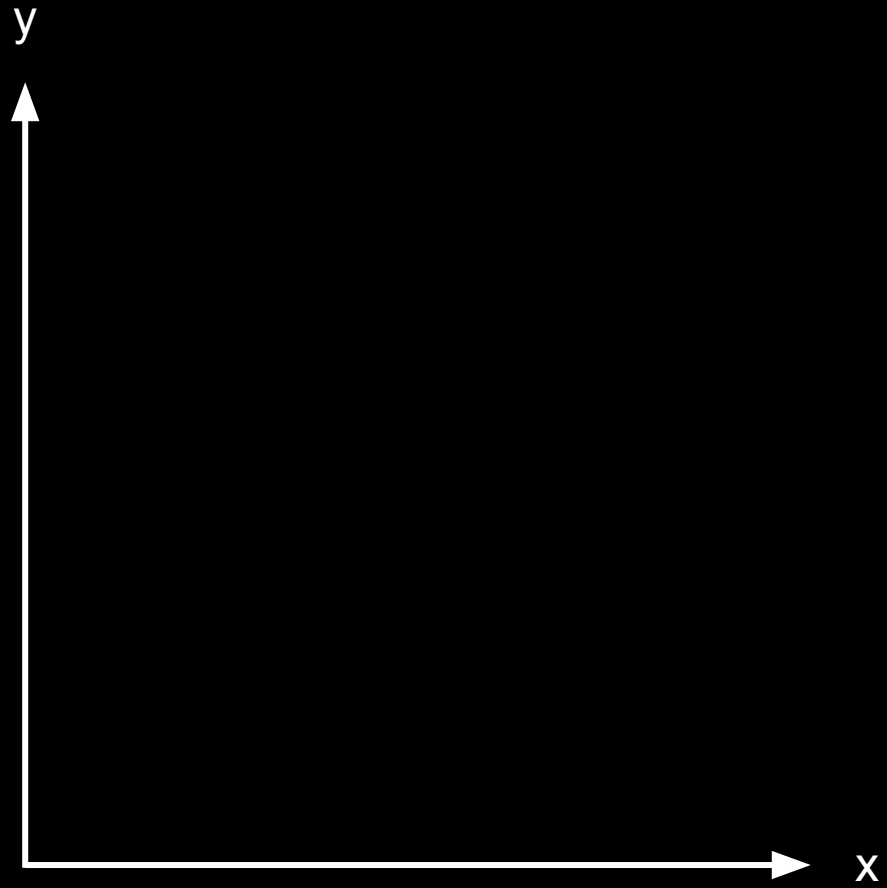
multimodality

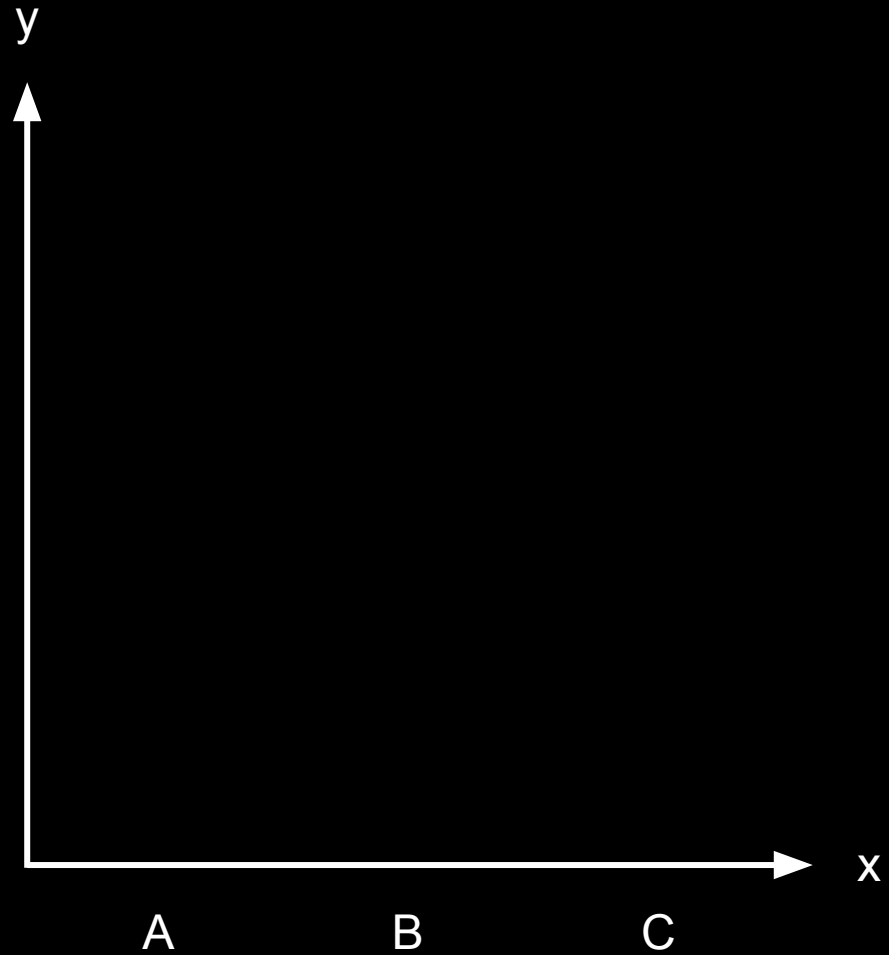
VISUALIZE DATA

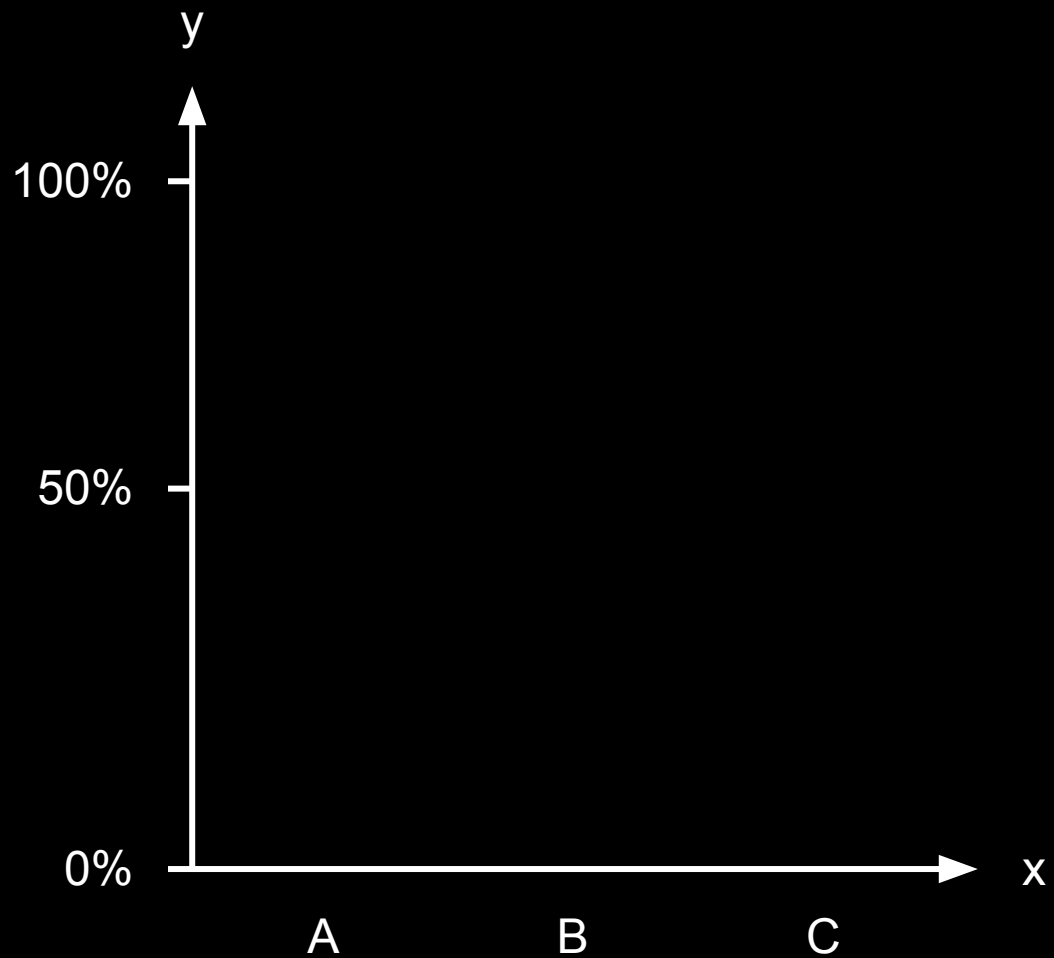
data

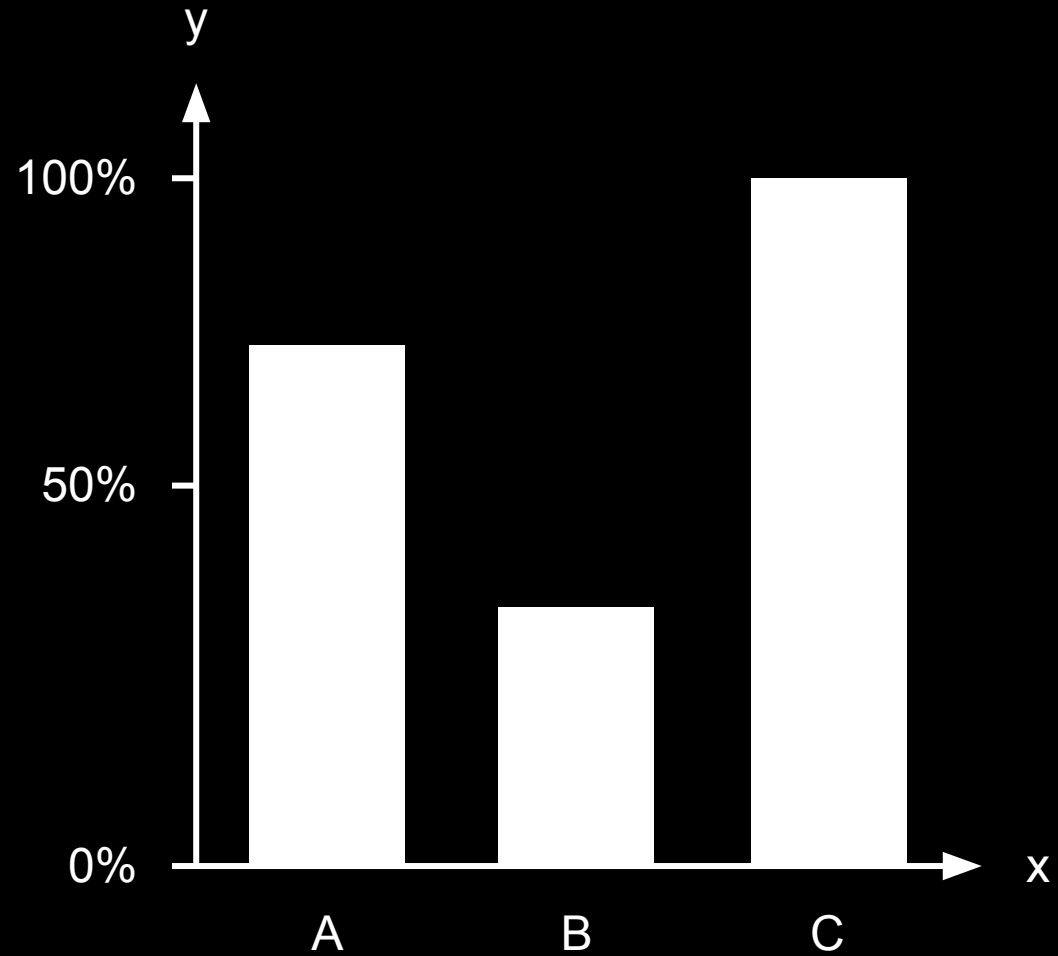
category	pct
A	75
B	33
C	100



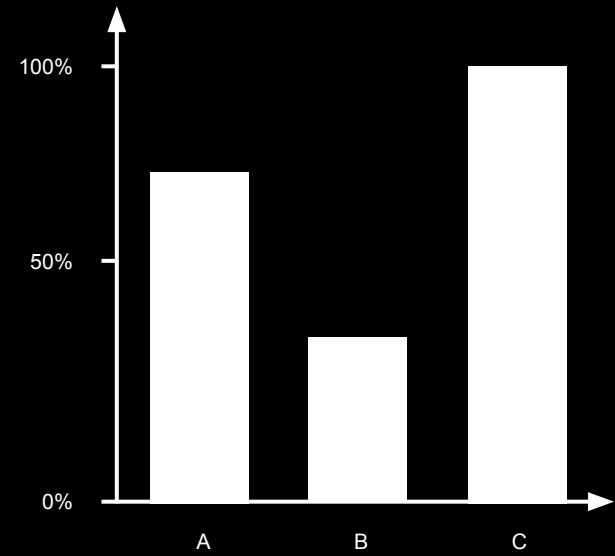








category	pct
A	75
B	33
C	100



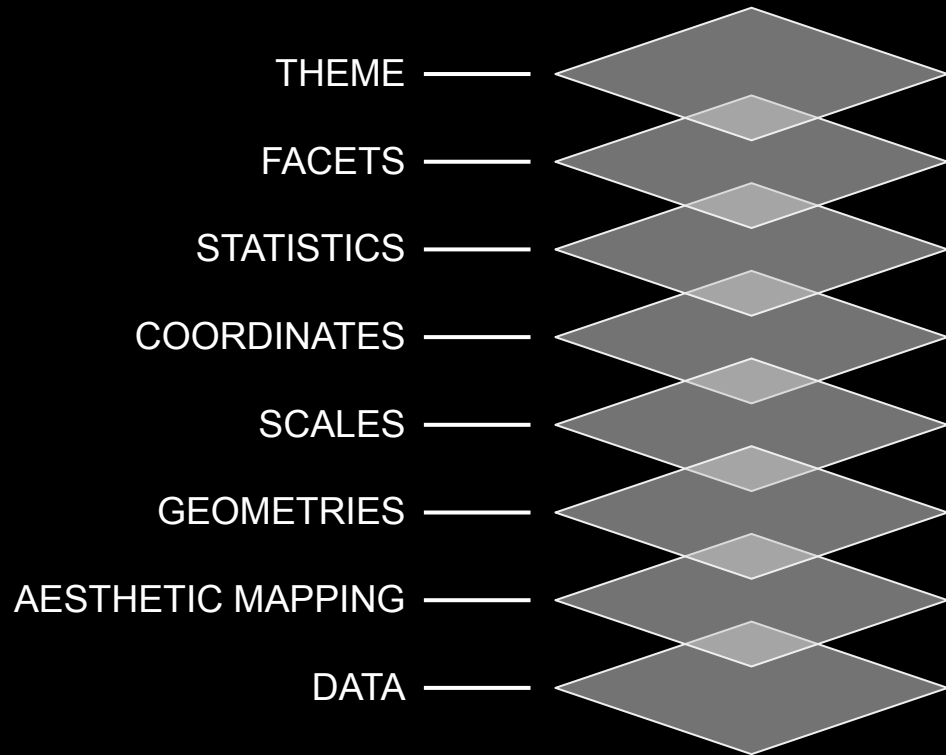
{{ ggplot2 }}

why visualize?

{{ ggplot2 }}

grammar of graphics

any
data
visualization



has useful defaults

mandatory



THEME

FACETS

STATISTICS

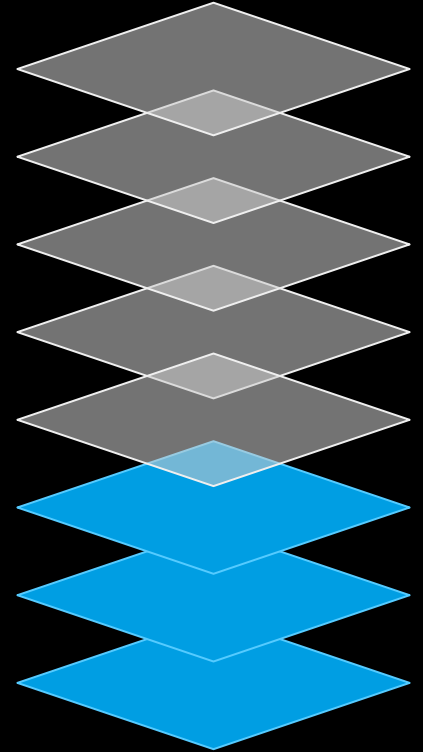
COORDINATES

SCALES

GEOMETRIES

AESTHETIC MAPPING

DATA

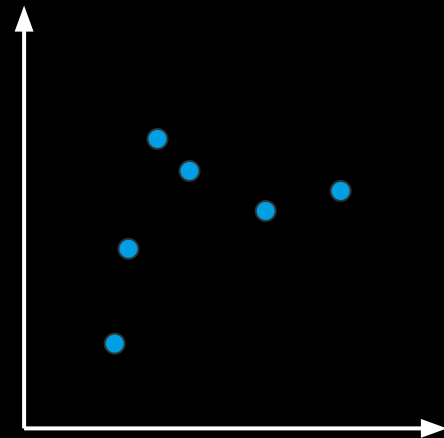


`ggplot()`

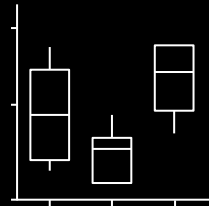
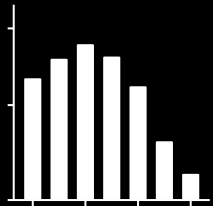
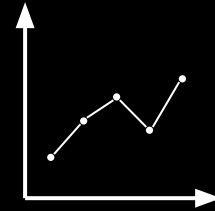
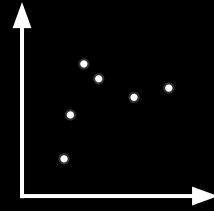
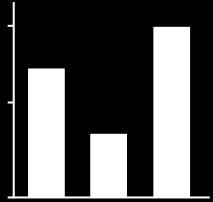
```
ggplot() +  
  aes()
```

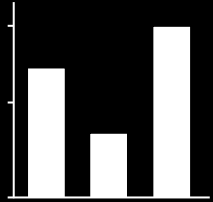
```
ggplot() +  
  aes() +  
  geom_point()
```

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

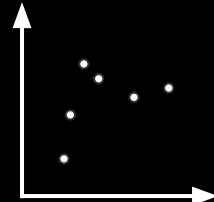


basic plots

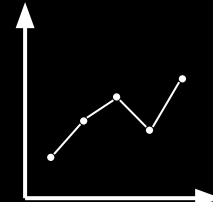




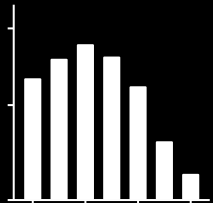
bar chart



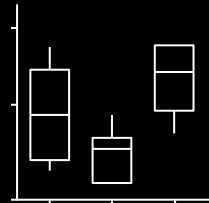
scatter plot



line chart

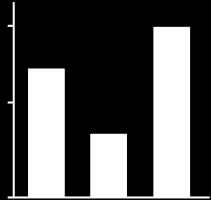


histogram



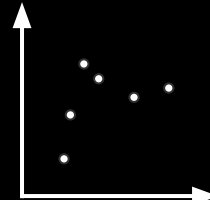
box plot

amounts
proportions
distributions (discrete)



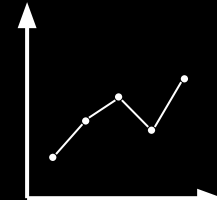
bar chart

associations
patterns



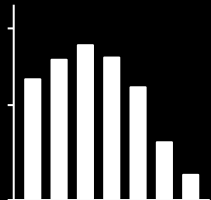
scatter plot

trends
developments



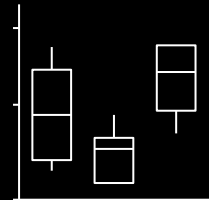
line chart

distributions (continuous)



histogram

compare distributions (continuous)



box plot

COMMUNICATE DATA

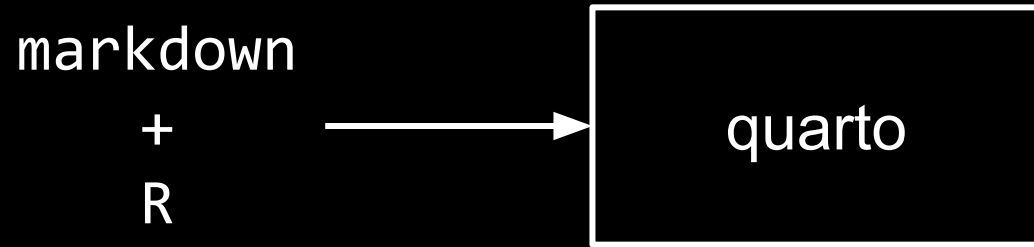
quarto

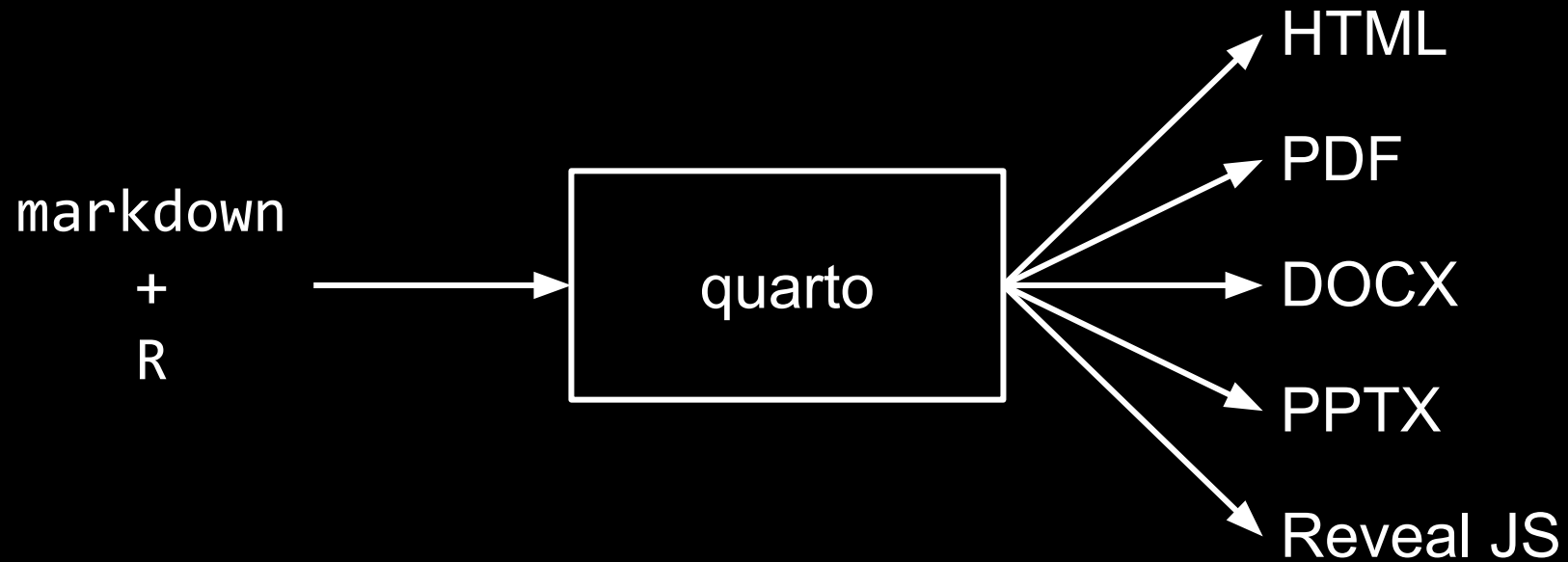
{{ quarto }}

markdown

+

R





markdown

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