Welcome to CS152 - Neural Networks!

Spring 2025

Prof. Gabe Hope

Warm-up discussion

- What is an application, program or system that you *at least suspect* uses neural networks in some way?
  - Why is this system useful? Does it have an important benefit for society?
  - What risks does this system have? Is it used maliciously?

- **But first: Introductions!**
  - **Going around:** Introduce yourself with your name, year and major
  - *Optionally:* Is there something you are particularly excited to learn about in this class?

Applications of neural networks

Prediction

Predict output given an input

Image classification

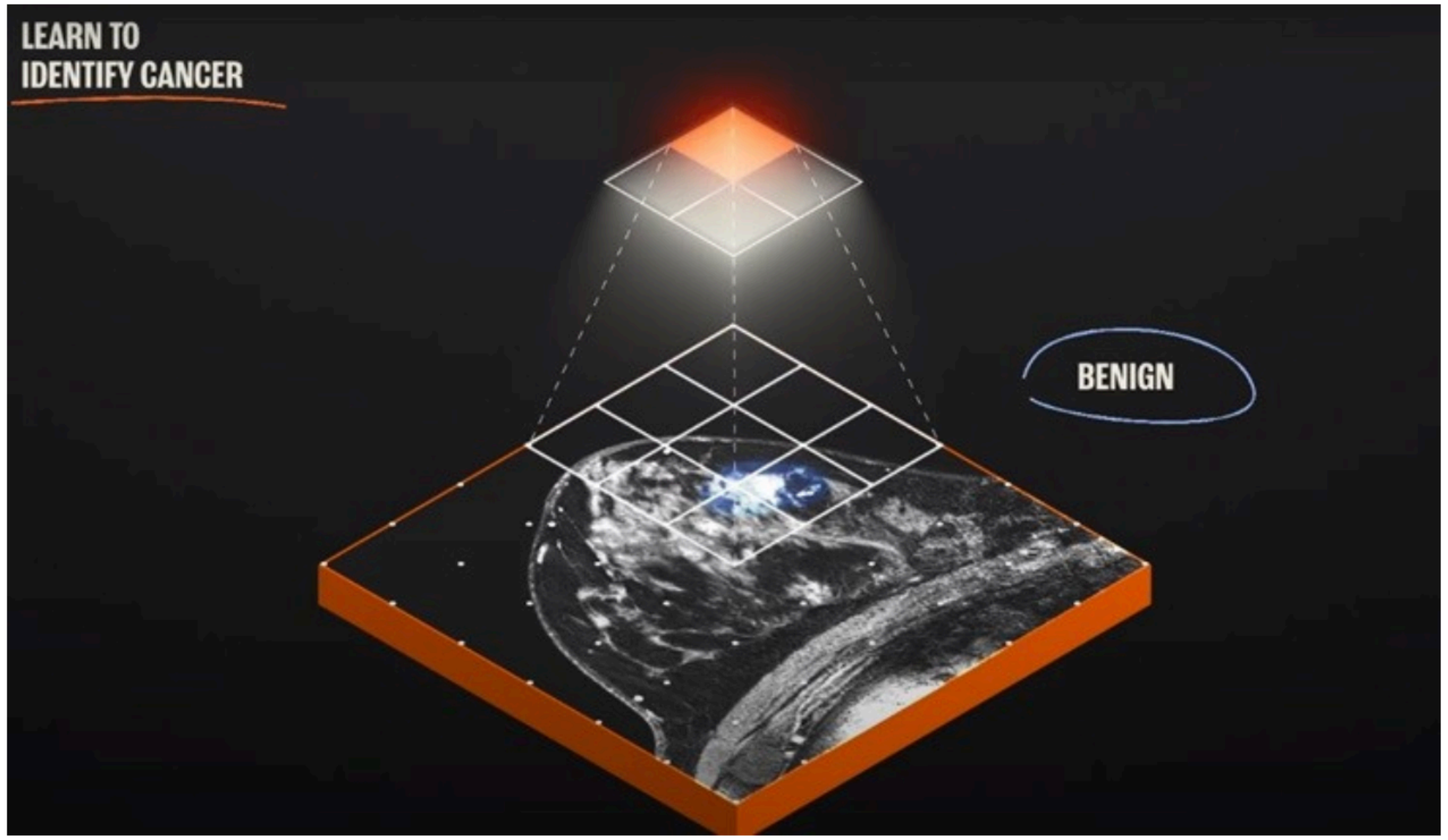
Example: Google lens

Identify plants and animals

Find out what plant is in your friend's apartment, or what kind of dog you saw in the park.

Medical diagnosis

Example: Breast cancer diagnosis from Microsoft Research



Transforming Breast Cancer Detection with AI

Weather prediction

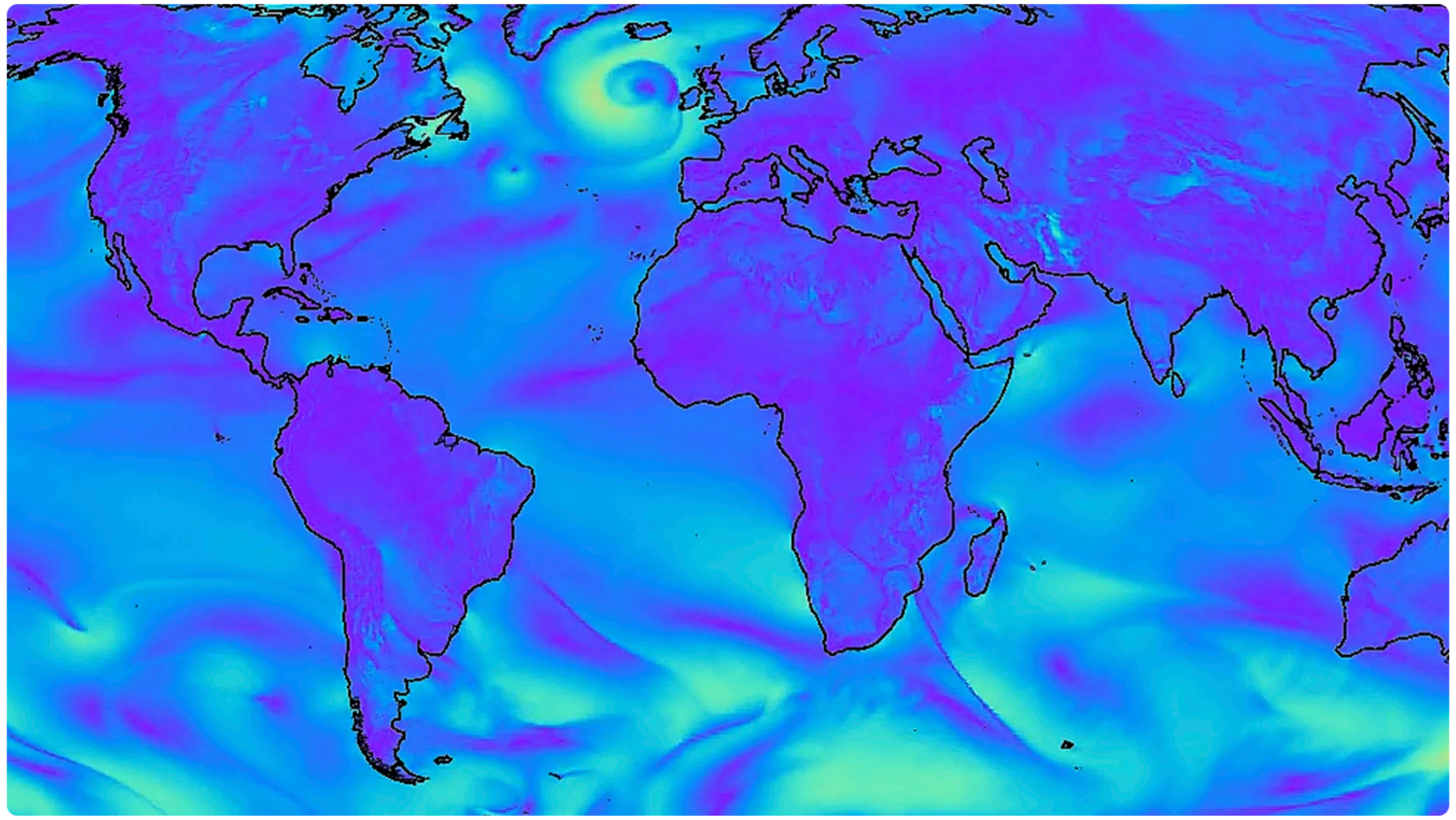
Example: GraphCast weather forecasting

GraphCast: AI model for faster and more accurate global weather forecasting

14 NOVEMBER 2023

Remi Lam on behalf of the GraphCast team

Share



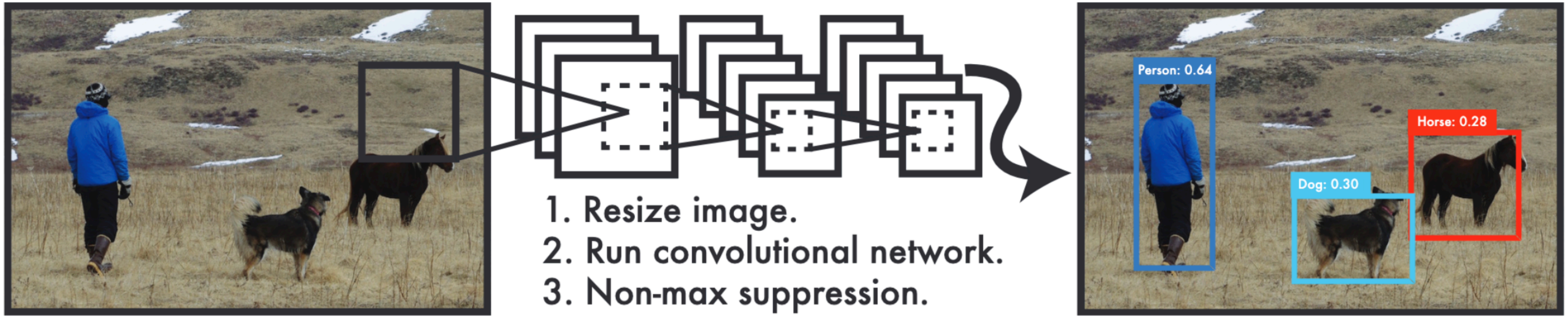
Detection

Find instances of a pattern

Object detection

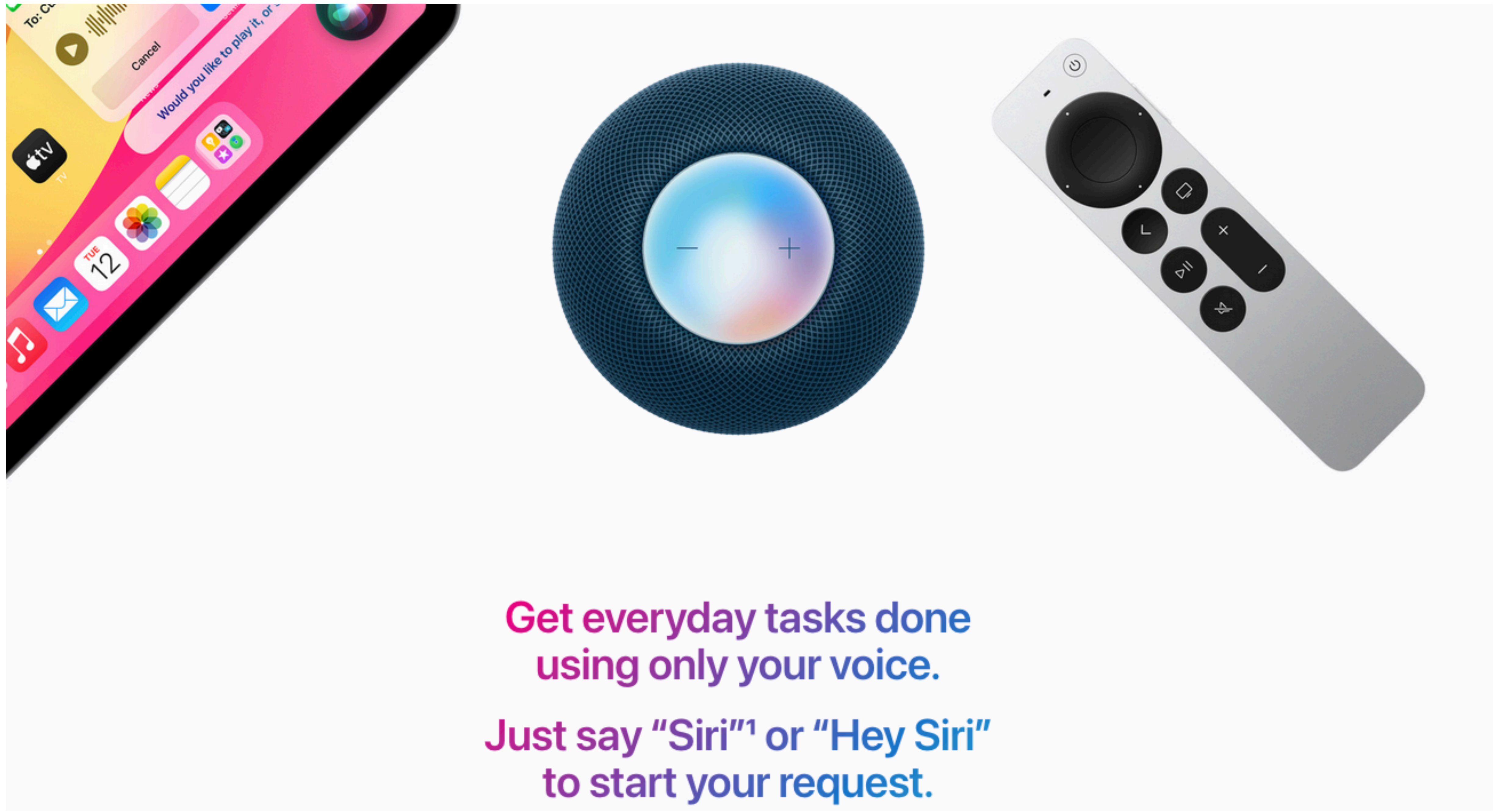
Example: YOLO (You Only Look Once)

You Only Look Once:
Unified, Real-Time Object Detection



Activation phrase recognition
Example: Siri

Siri

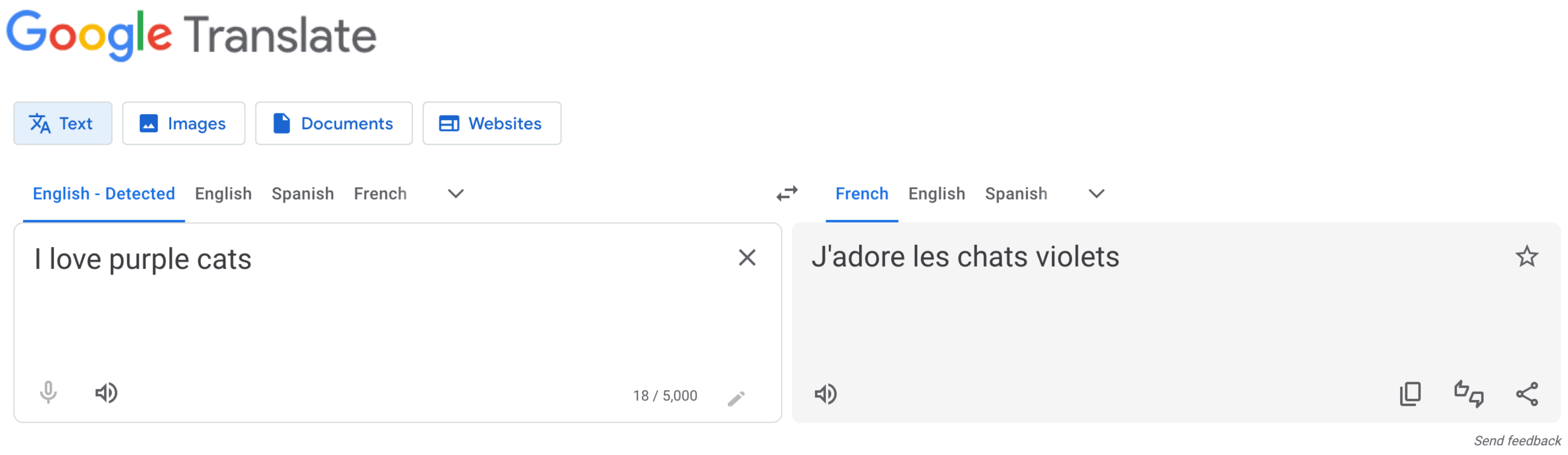


Transformation

Improve or translate an input in some way

Language translation

Example: Google Translate



Grammar checking

Example: Grammarly

grammarly

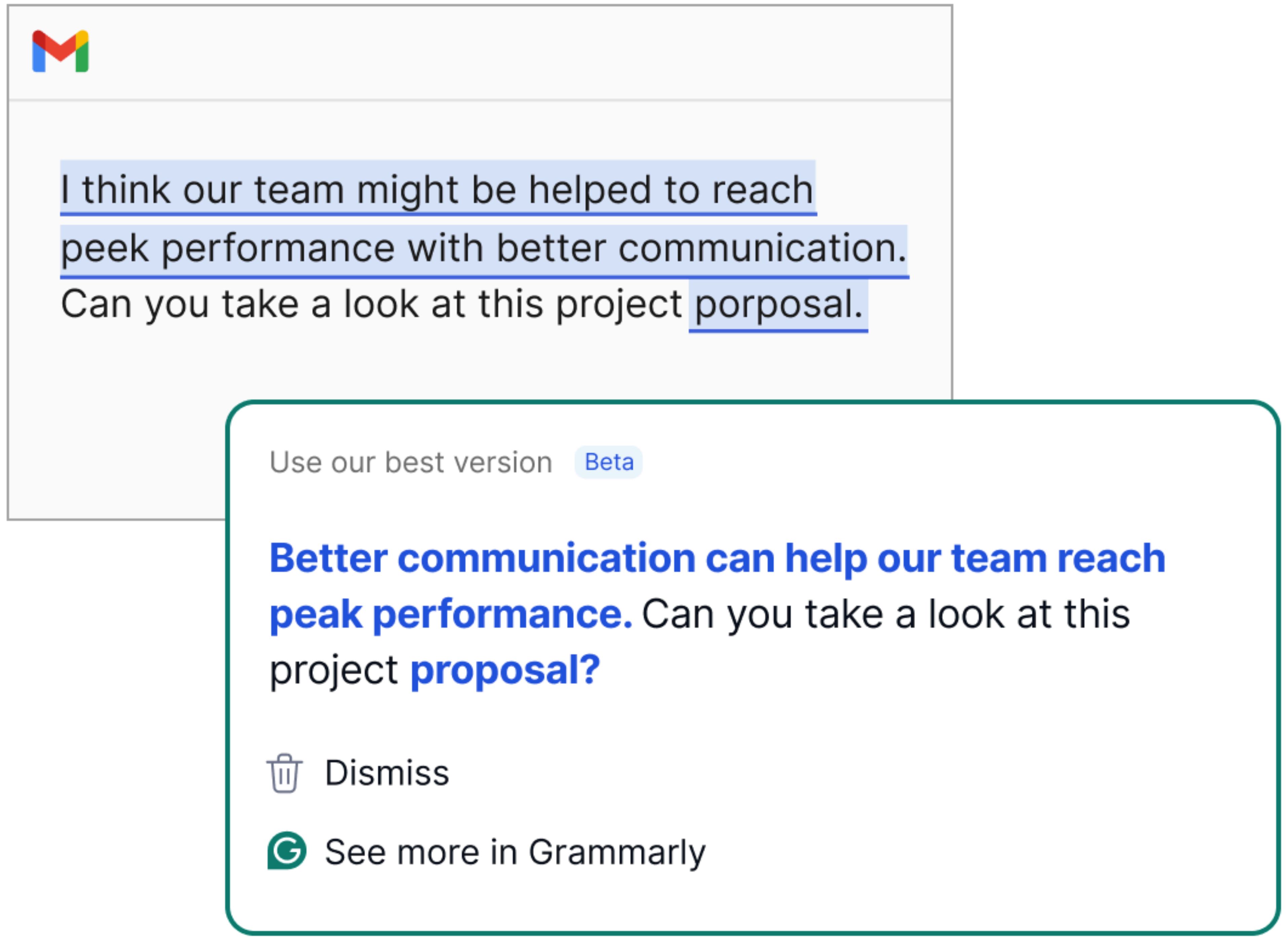
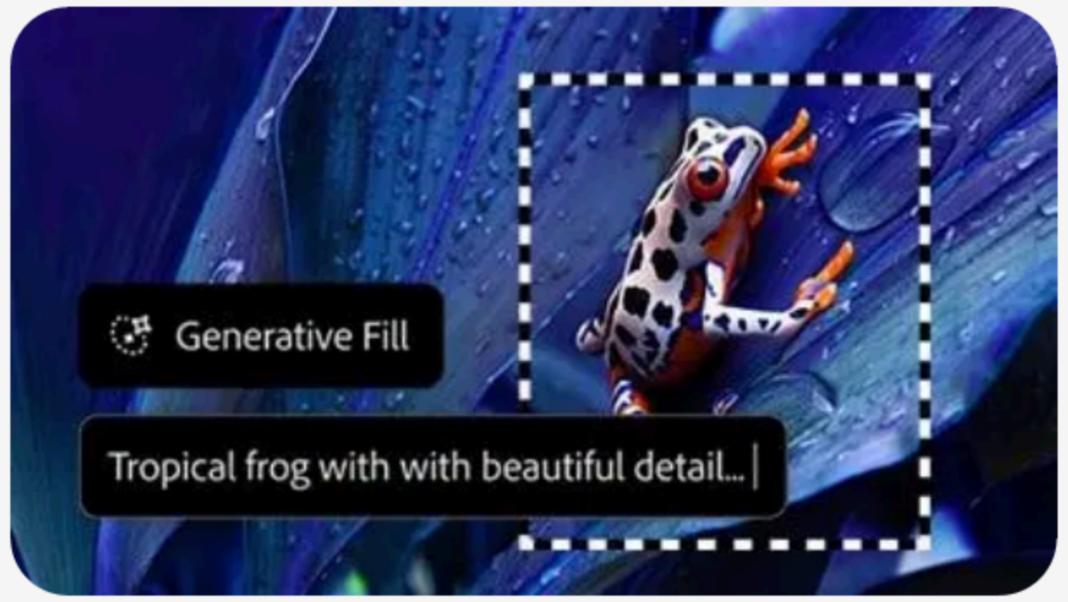


Photo enhancement

Example: AI tools in Photoshop

Photoshop



Next-gen Generative Fill.

Add rich, detailed elements that blend seamlessly into a scene using the most advanced Generative Fill yet. Now with the latest Adobe Firefly Image Model.

Add new backgrounds instantly.

Use Generate Background to swap your scenery for a new setting that seamlessly blends with your subject.

Remove wires and people.

Tidy up your scene in a click. Distraction Removal in the Remove tool automatically detects and deletes unwanted elements like wires and people in the background.

Generation

Create new data

Language models

Example: ChatGPT

ChatGPT

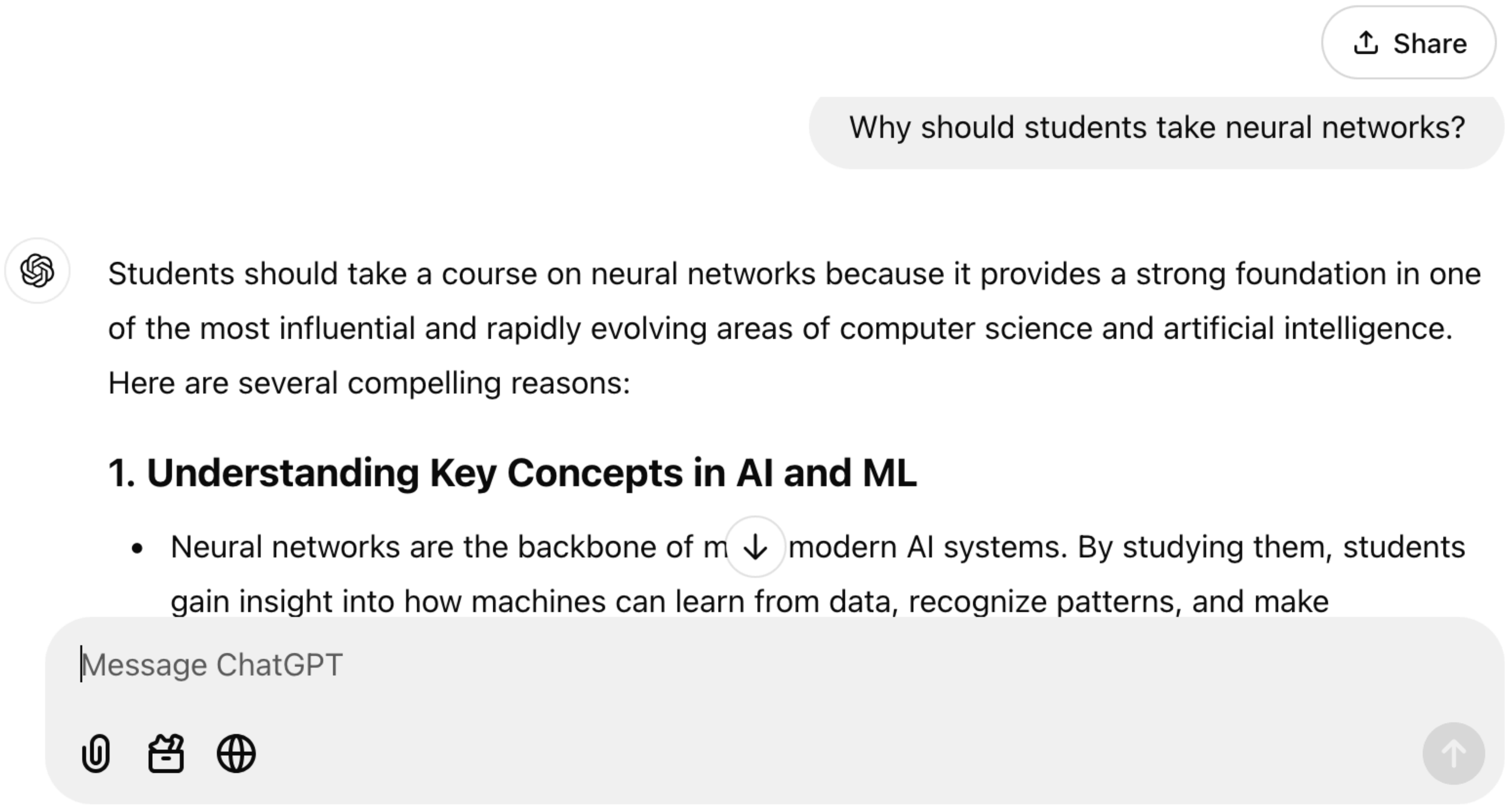
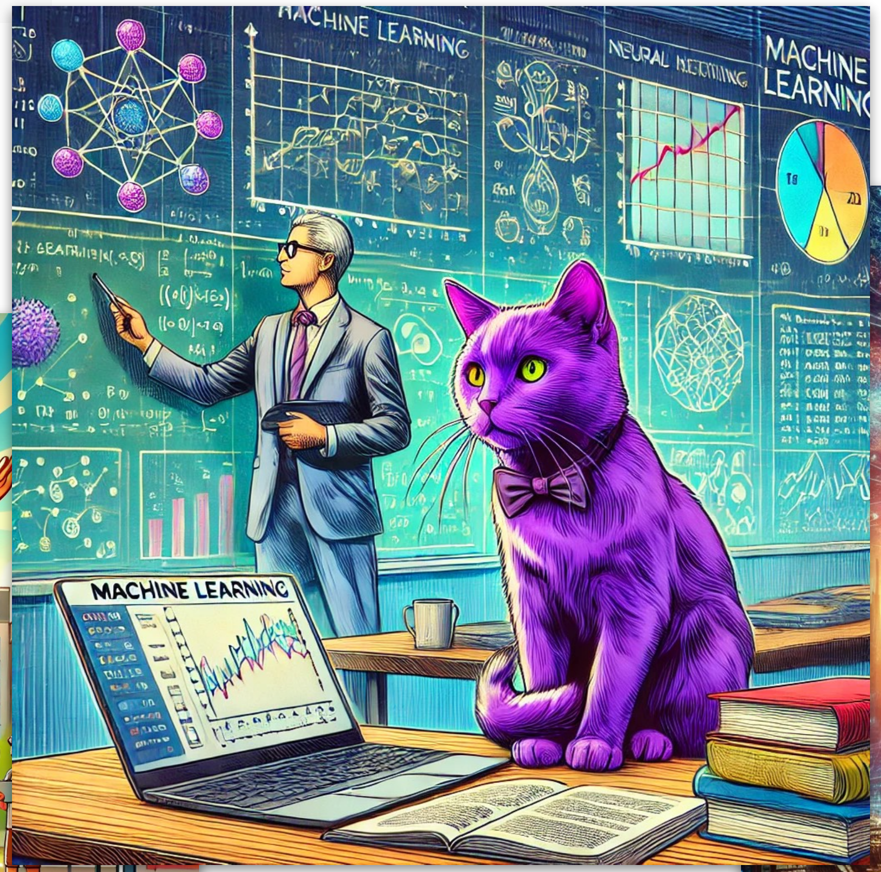


Image models

Example: Dall-e 3

DALL·E 3



Approximation

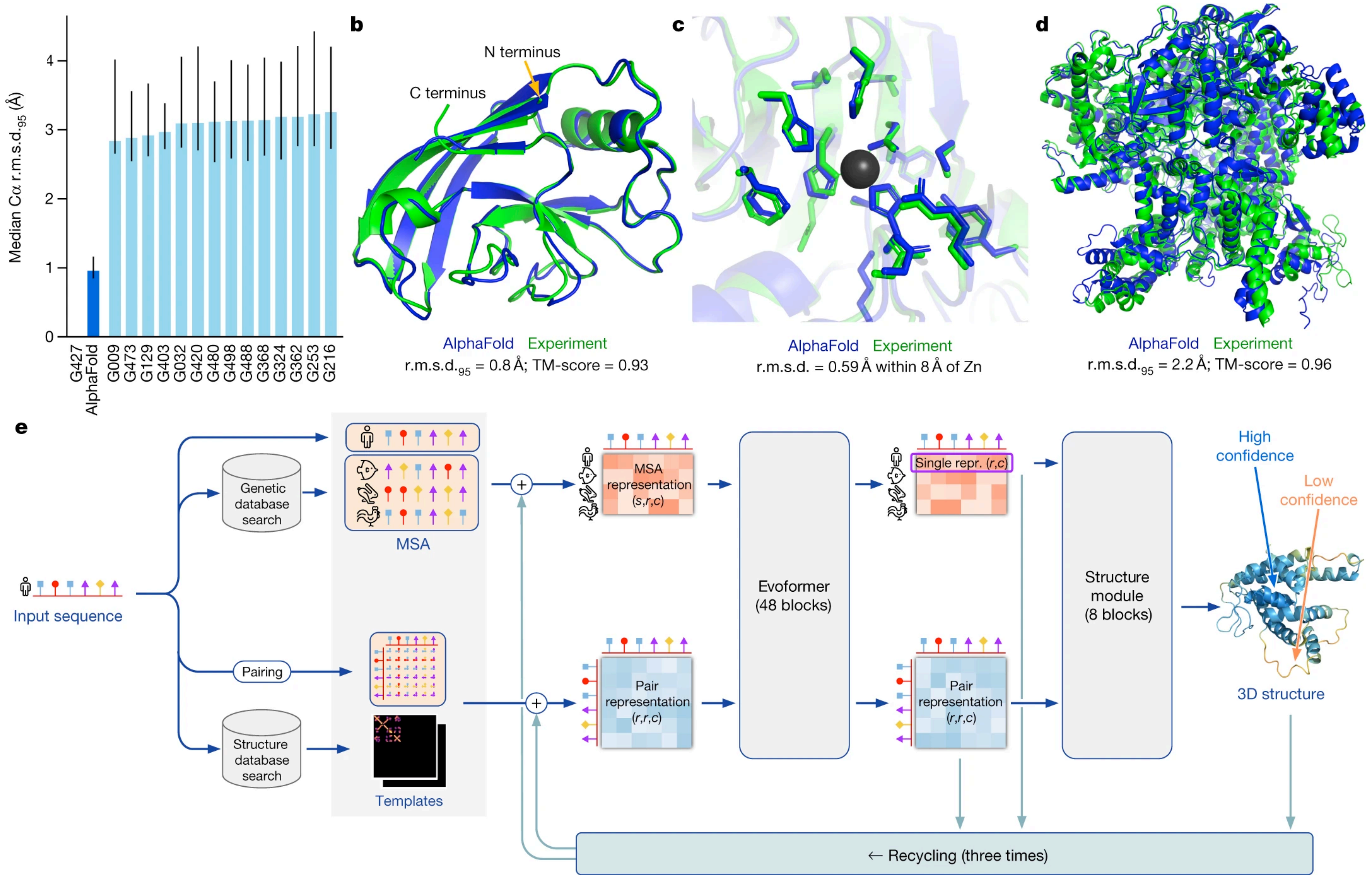
Approximate complex physical systems

Molecular dynamics simulation

Example: AlphaFold

AlphaFold

Accelerating breakthroughs in biology with AI

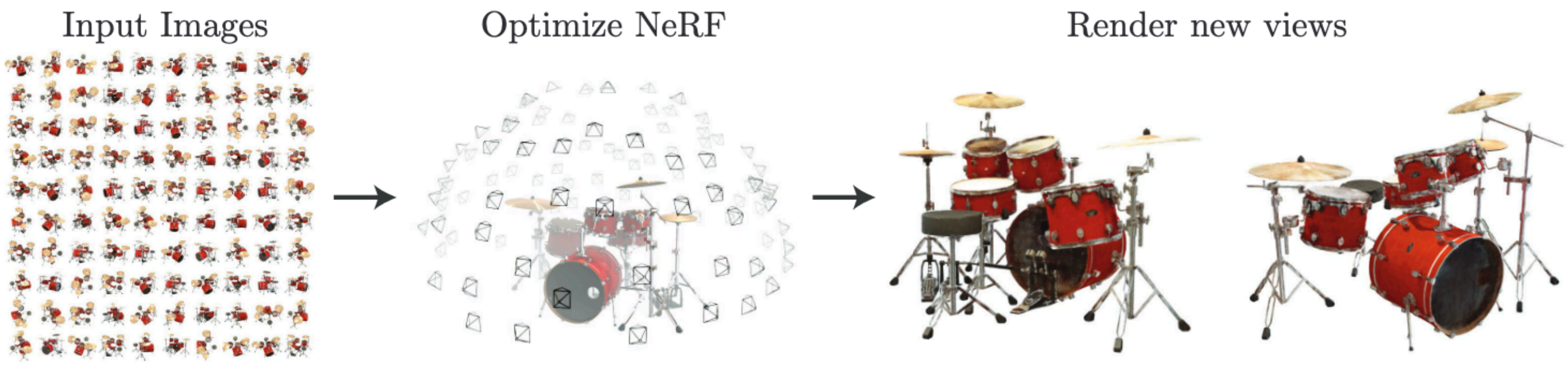


Multi-view simulation

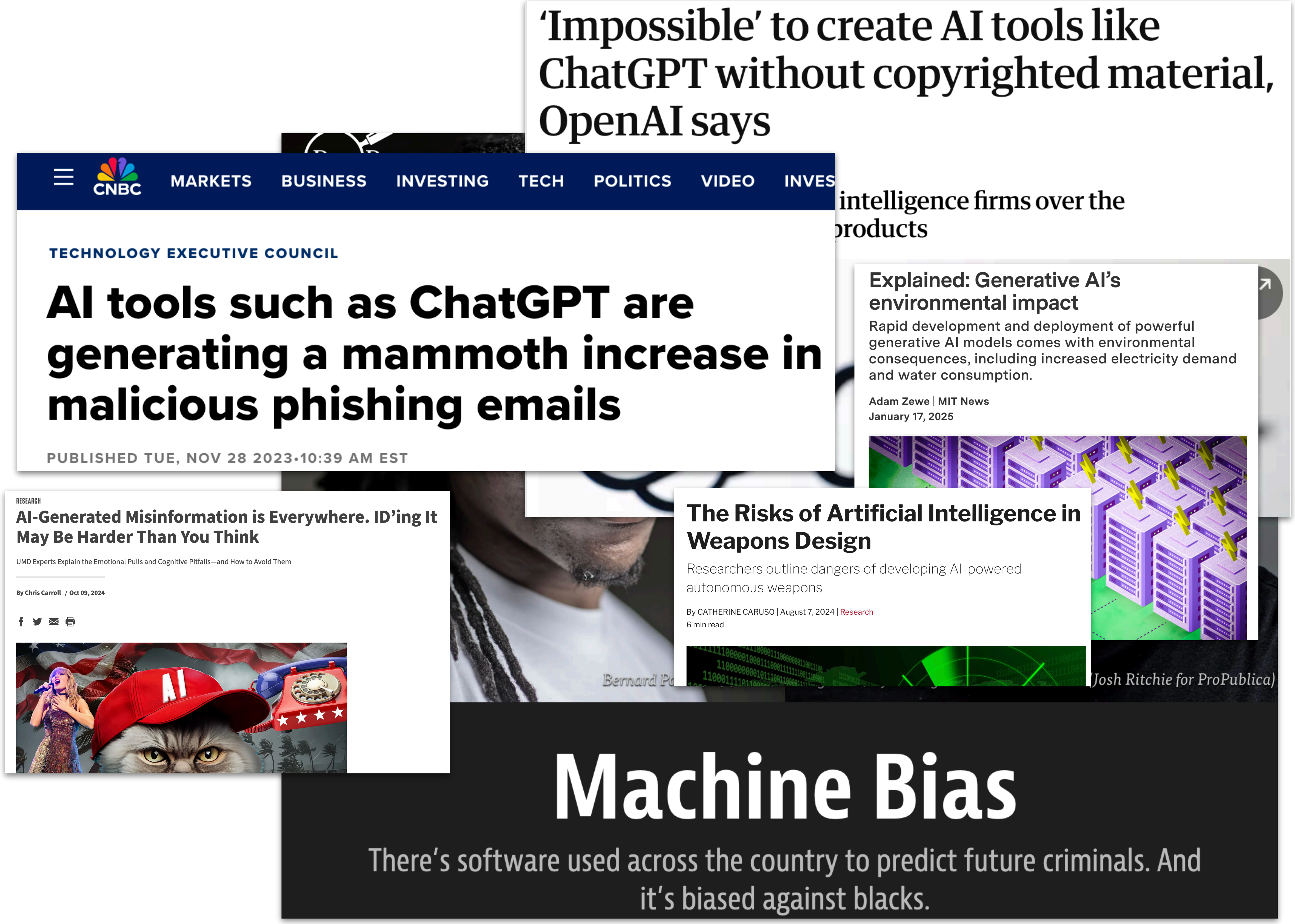
Example: Neural Radiance Fields

NeRF

Representing Scenes as Neural Radiance Fields for View Synthesis

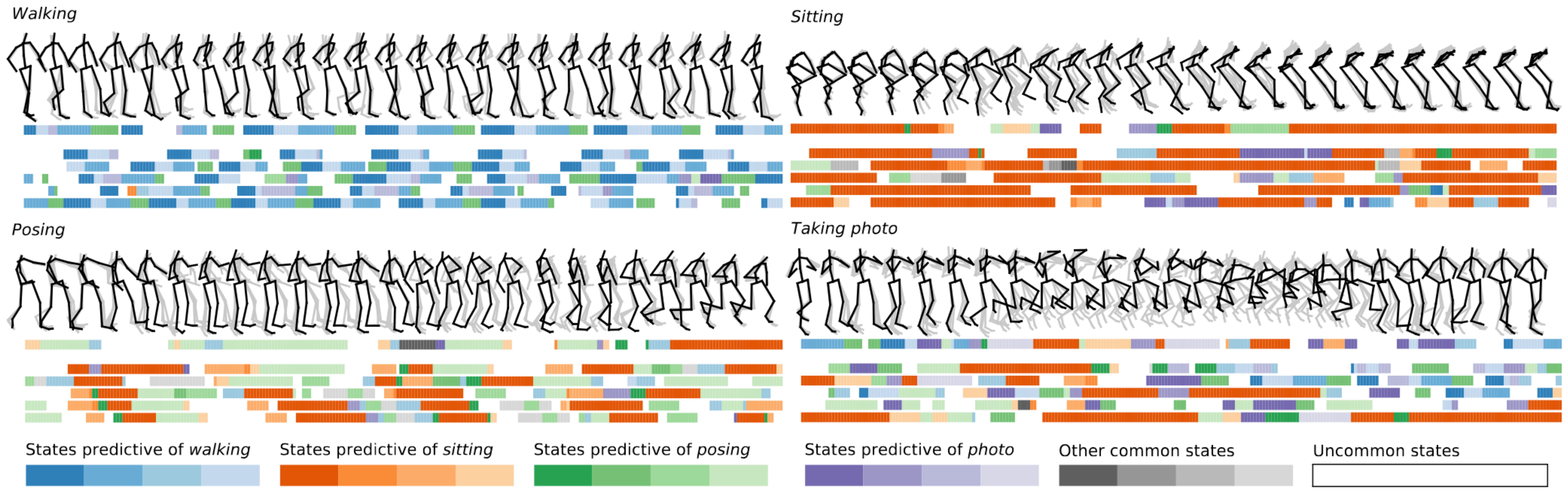


Neural networks have implications

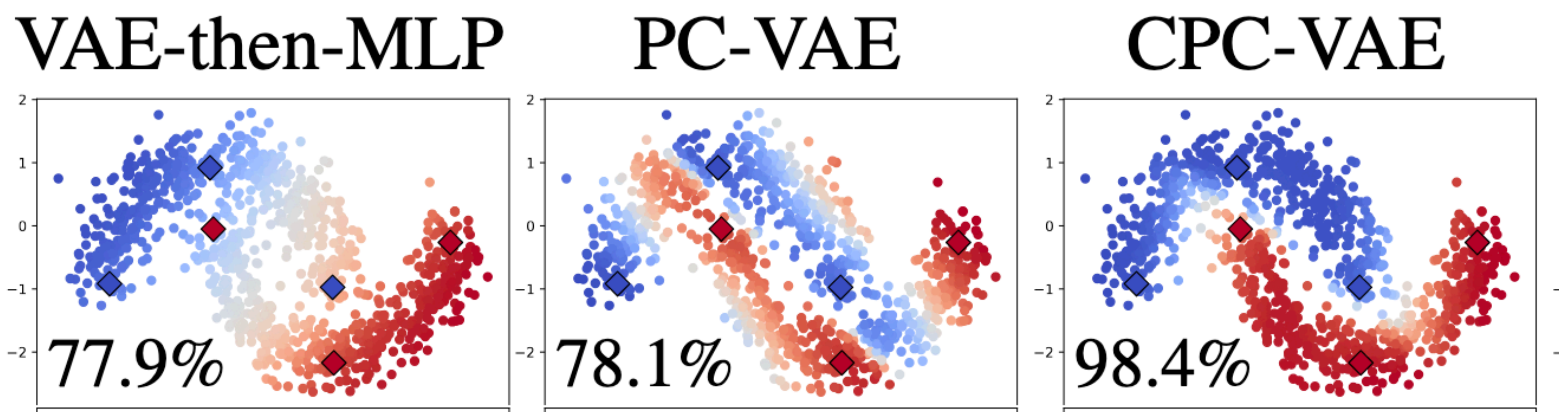


My work

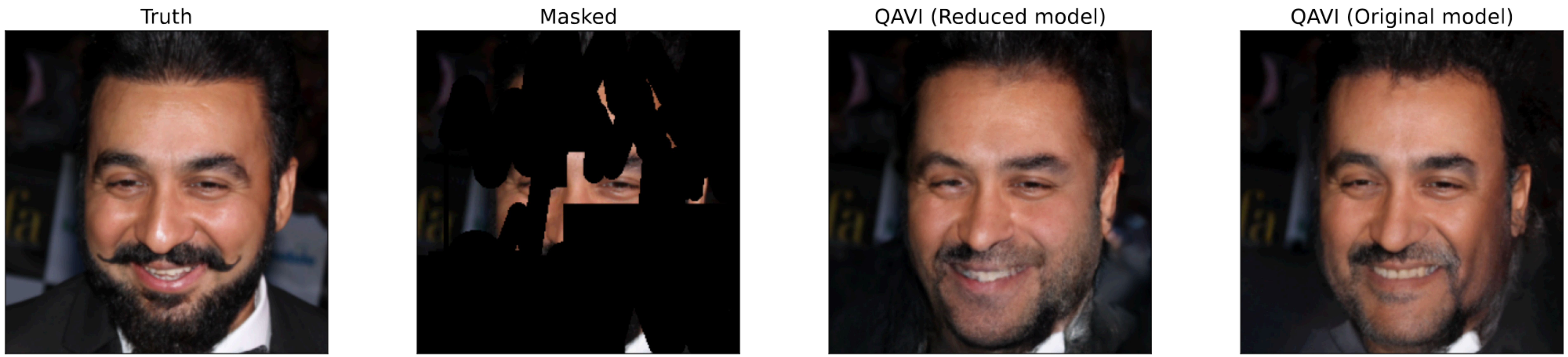
Timeseries analysis



Semi-supervised learning



Imputation



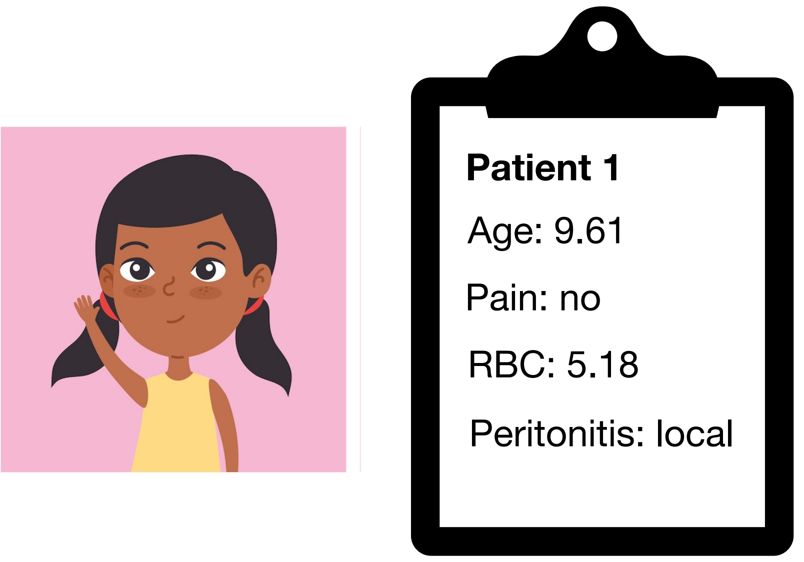
Course Logistics (website)

Prediction problems

Setup

Example: Appendicitis diagnosis

Input



Patient

Neural network

Prediction

Appendicitis?

Yes / No

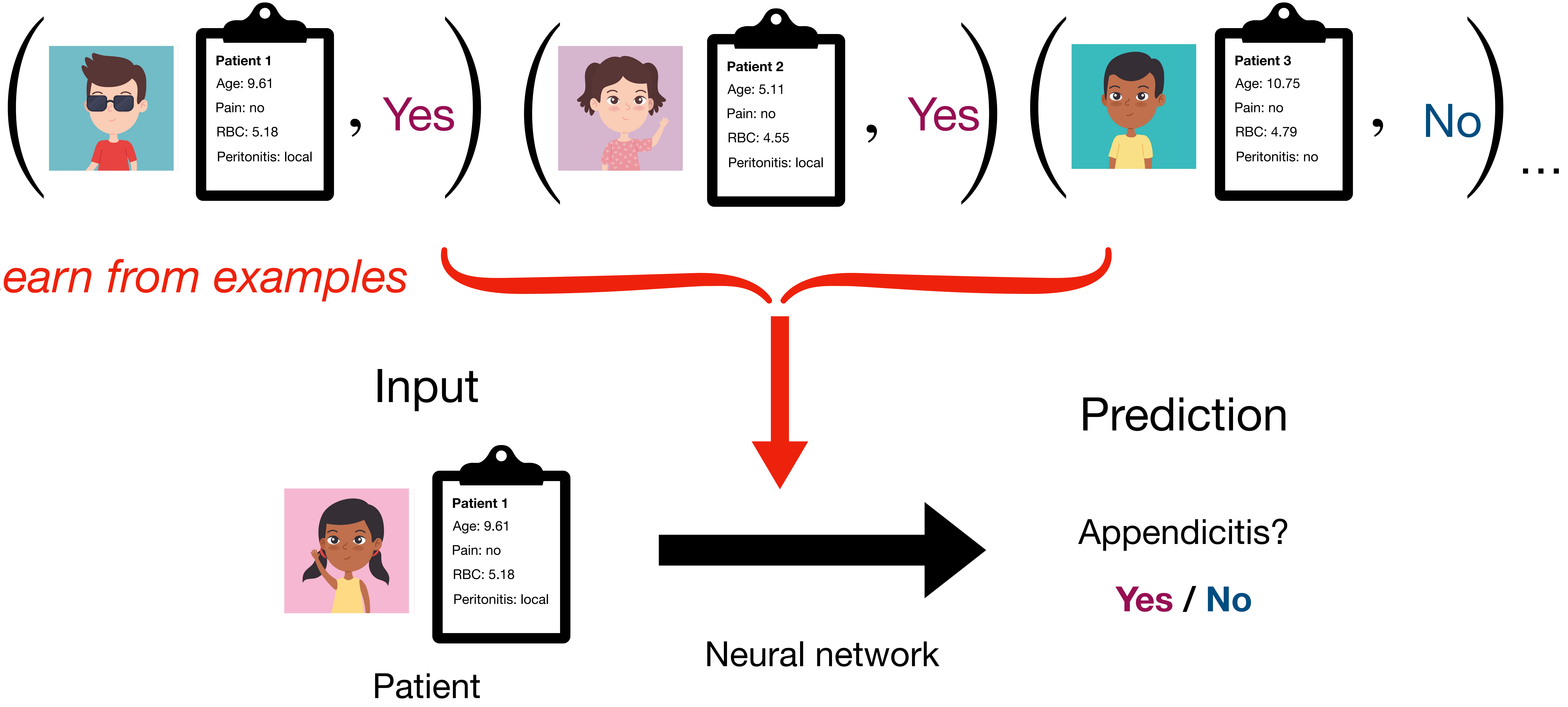
Some notation:

$$\text{Input: } \mathbf{x} \underset{predict}{\longrightarrow} \text{Output: } y, \qquad y = f(\mathbf{x})$$

Prediction *function*

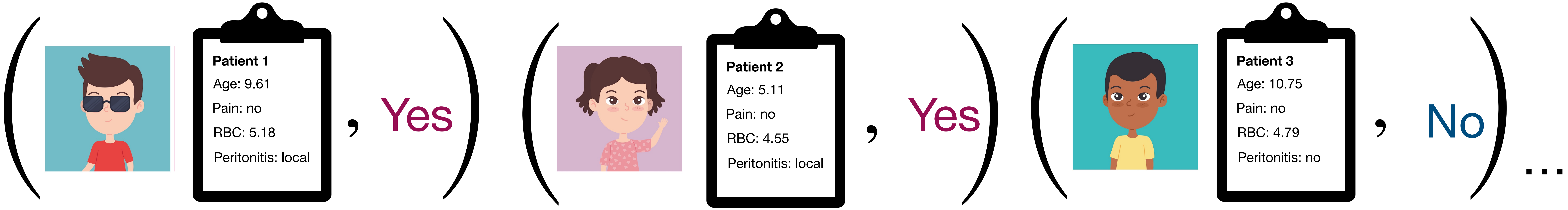
Preview: Machine learning

How do we find a good prediction function?



Dataset

Set of known inputs and outputs



Some notation:

$$\mathcal{D} = \{(\mathbf{x}_1, y_1),\ (\mathbf{x}_2, y_2),\ \dots\ (\mathbf{x}_N, y_N)\}$$

Types of data

Tabular

Records: e.g. Excel, SQL, Pandas

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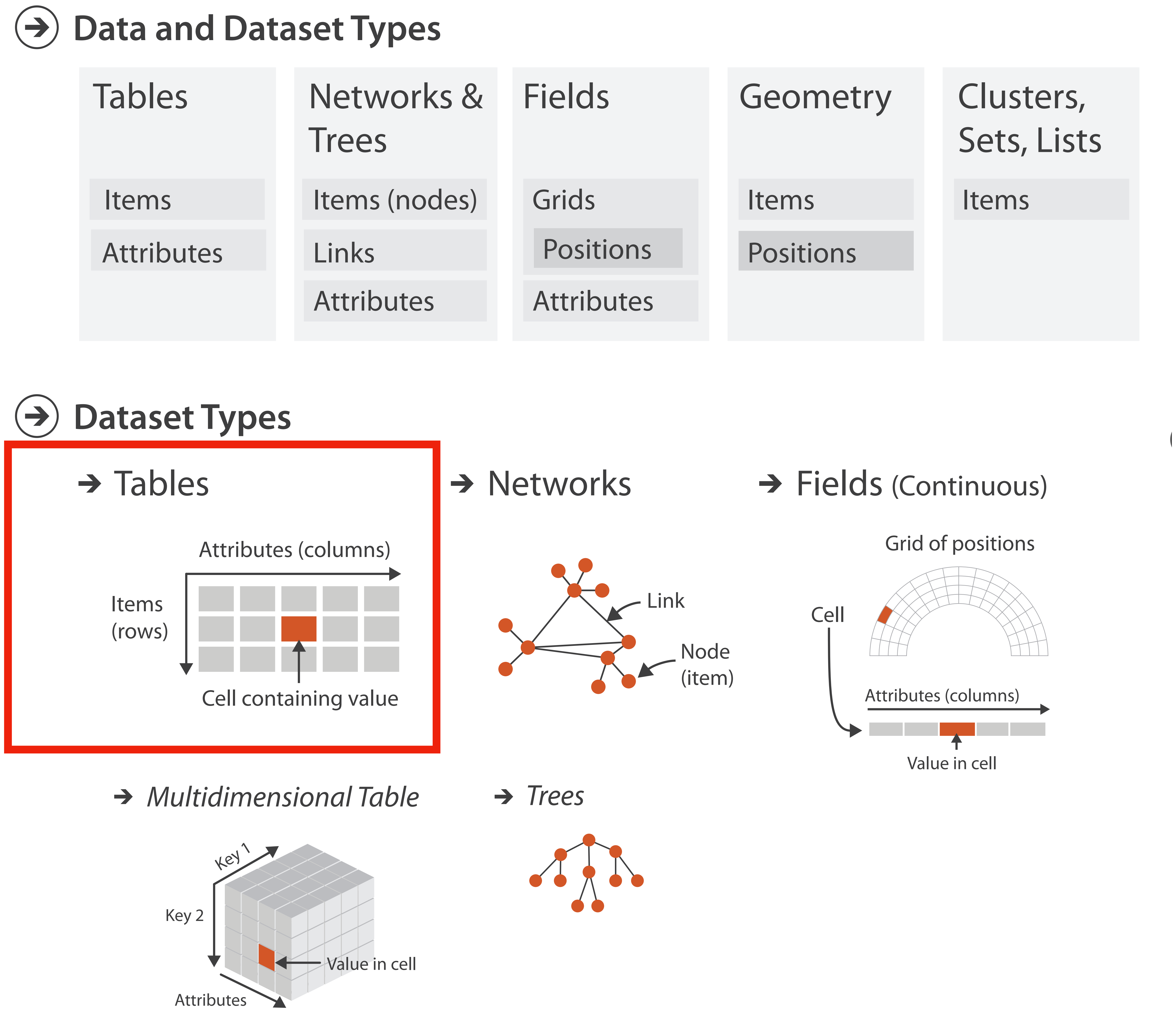
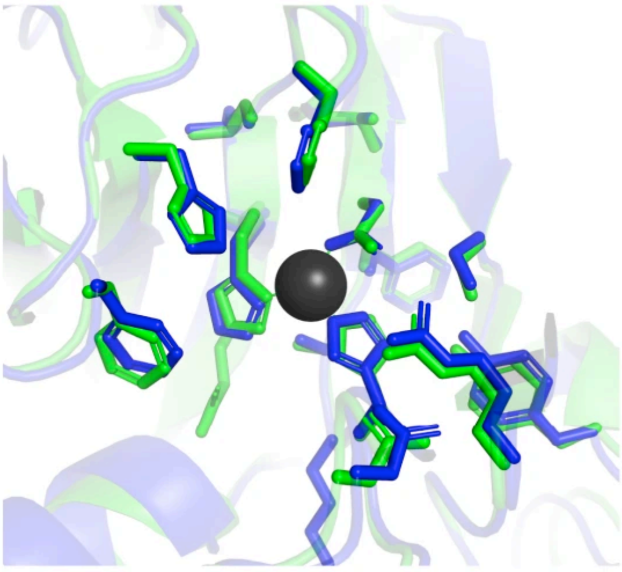


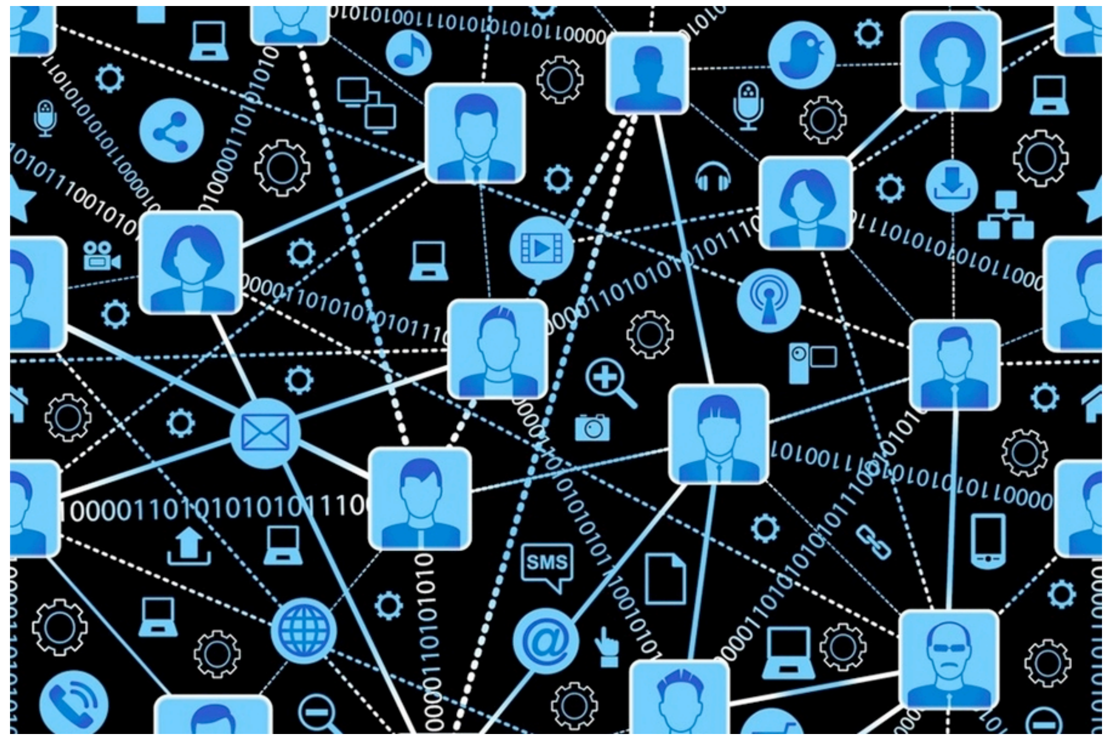
Credit: Tamara Munzer

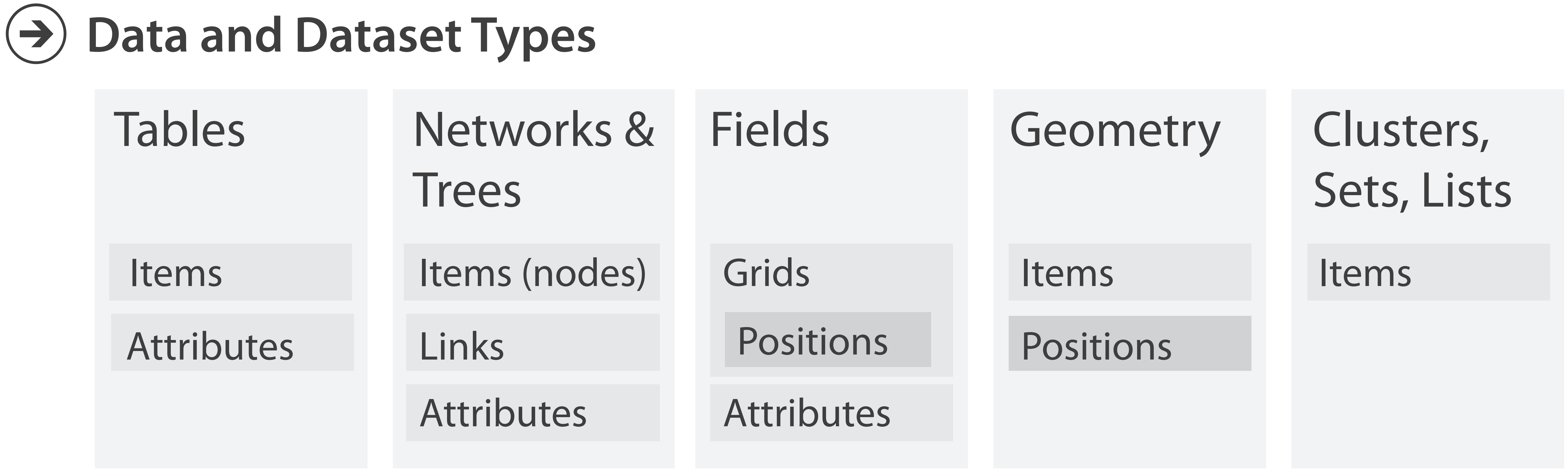
Types of data

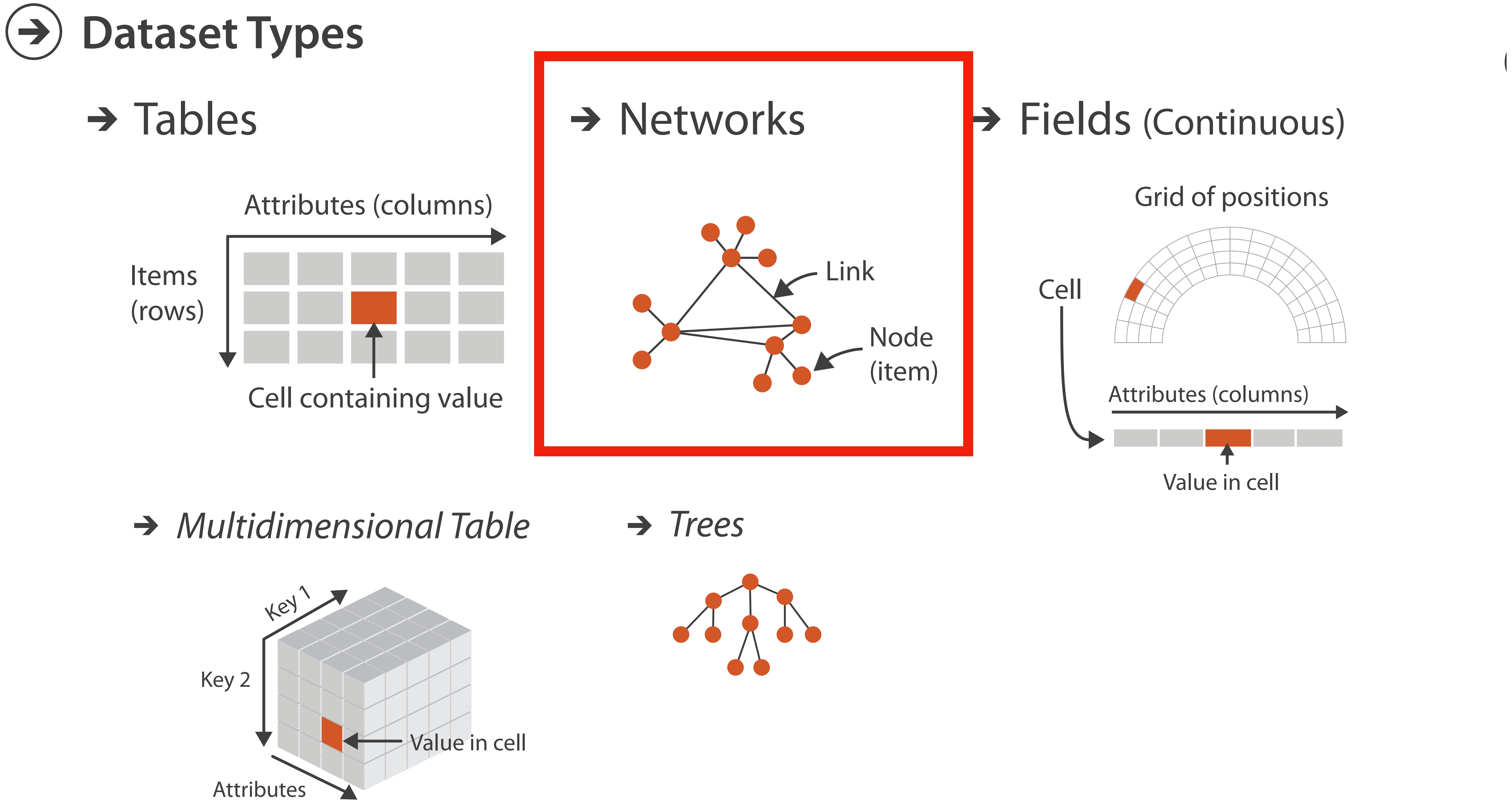
Networks

Molecules, social networks, etc.









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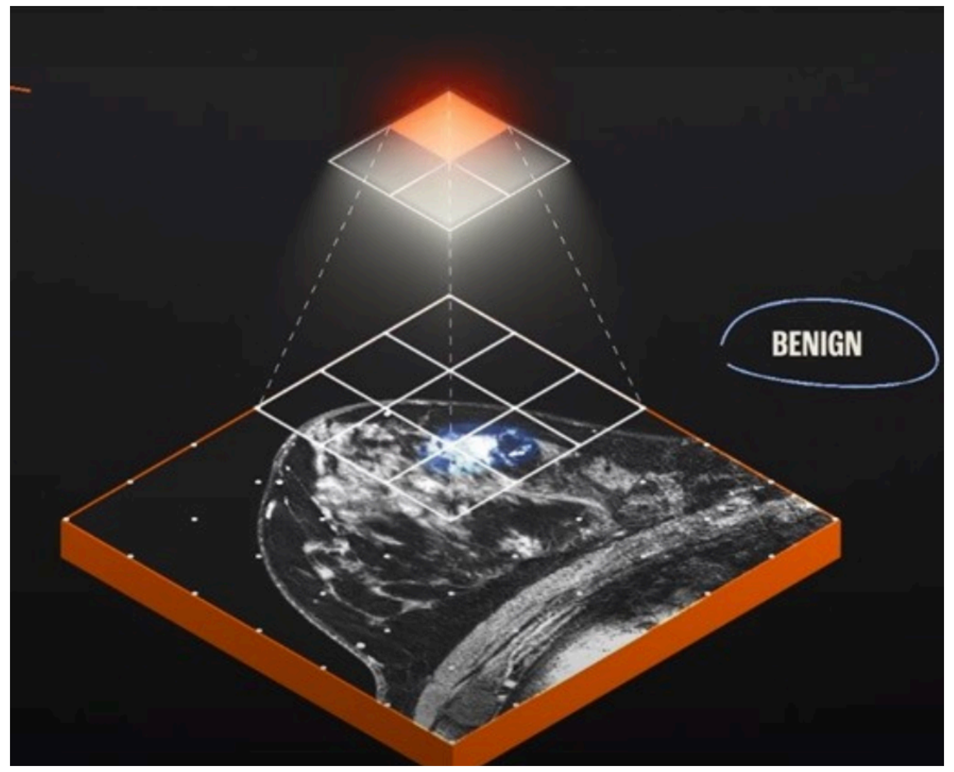
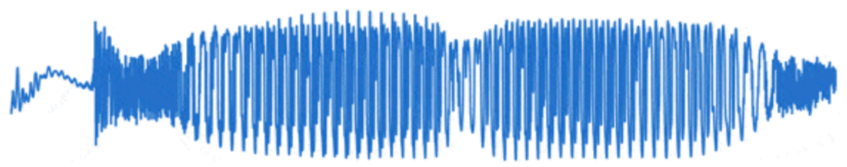
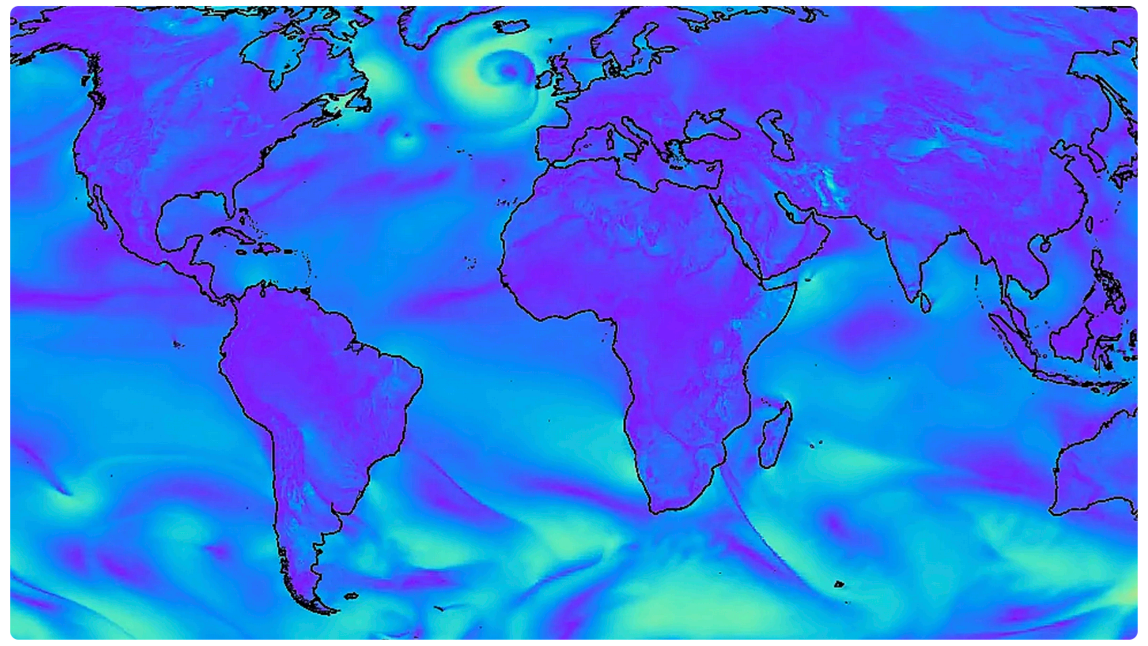
Types of data

Fields

Images, audio, medical scans, etc.

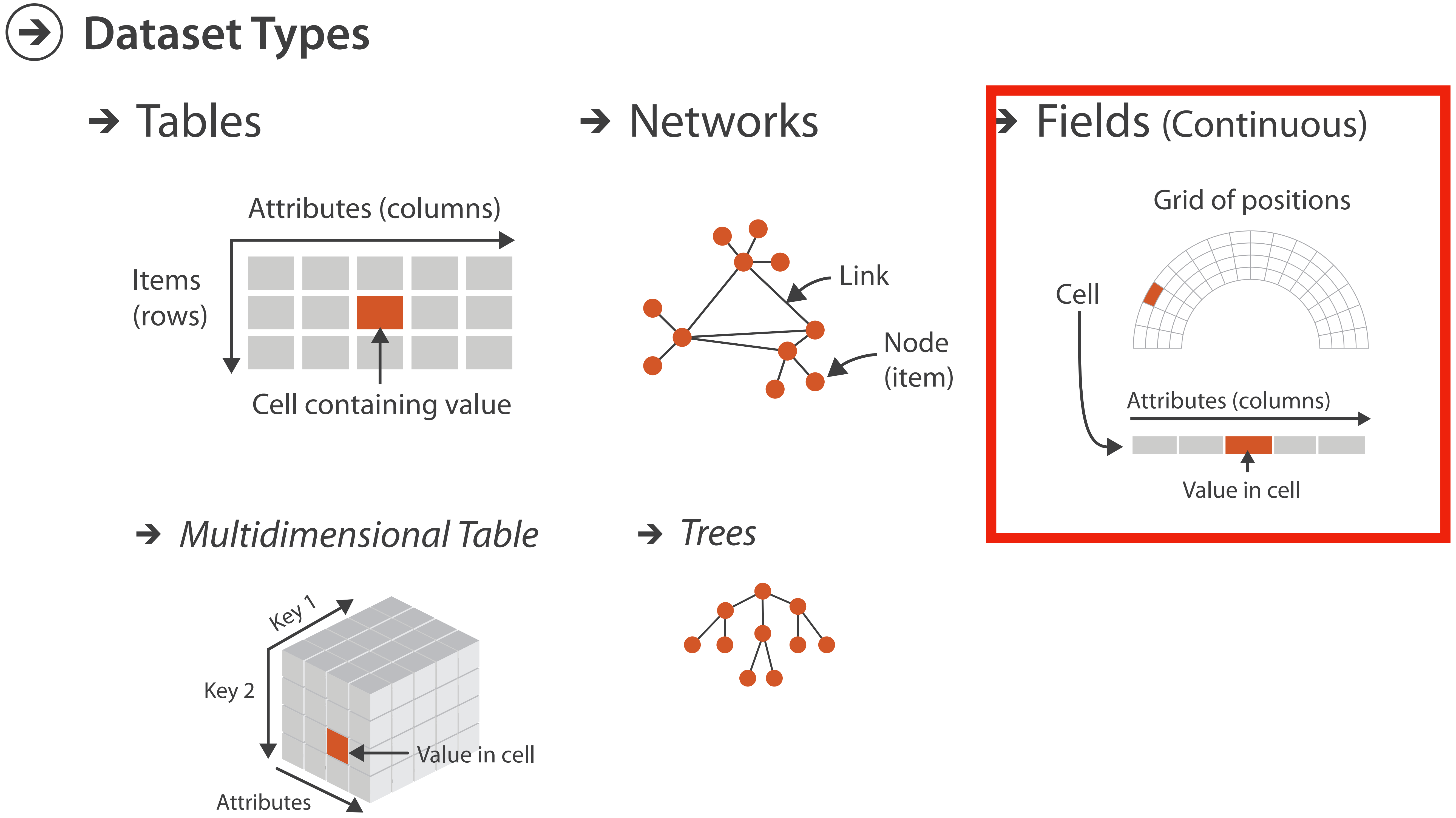






Data and Dataset Types

Tables	Networks & Trees	Fields	Geometry	Clusters, Sets, Lists
Items	Items (nodes)	Grids	Items	Items
Attributes	Links	Positions	Positions	
	Attributes	Attributes		



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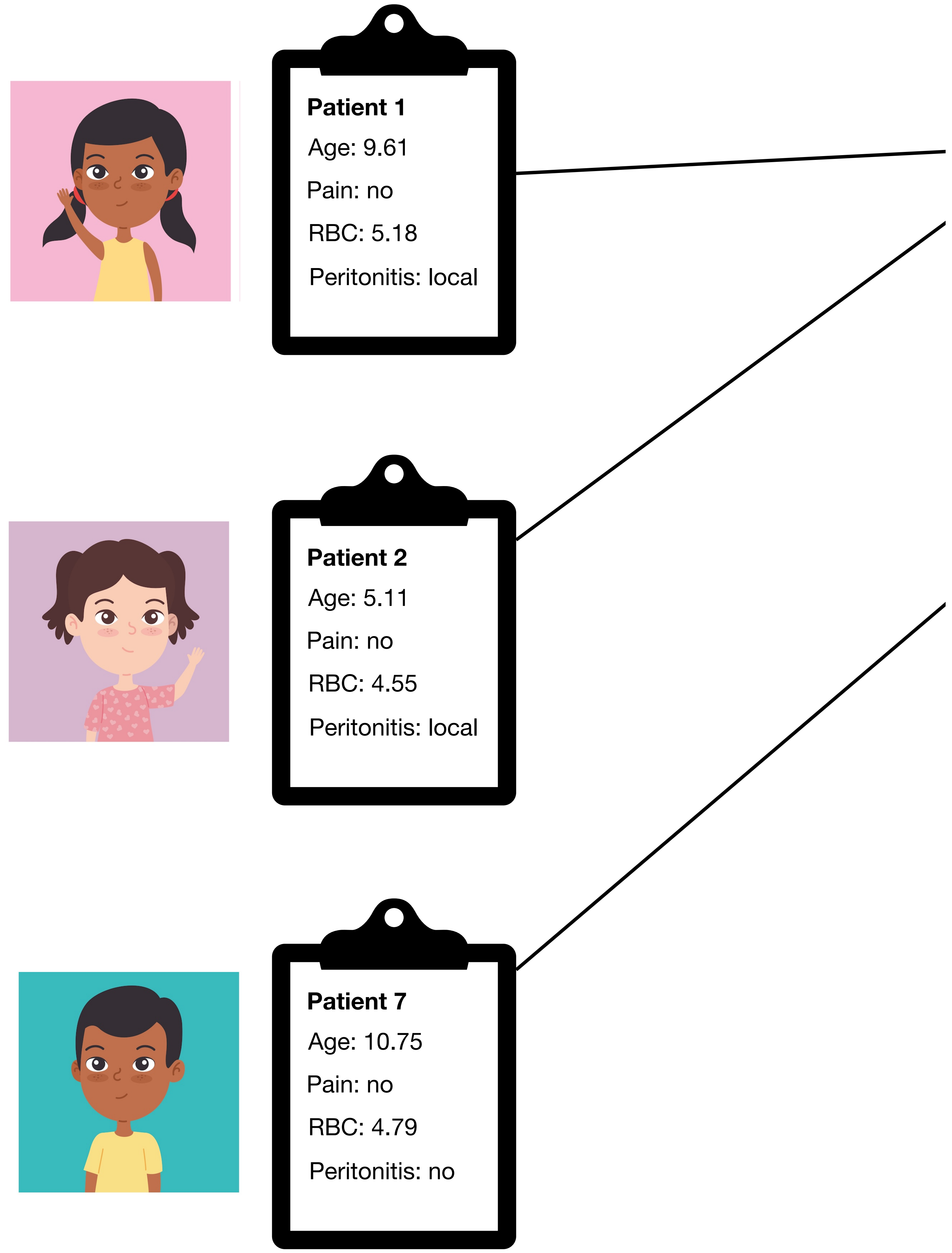

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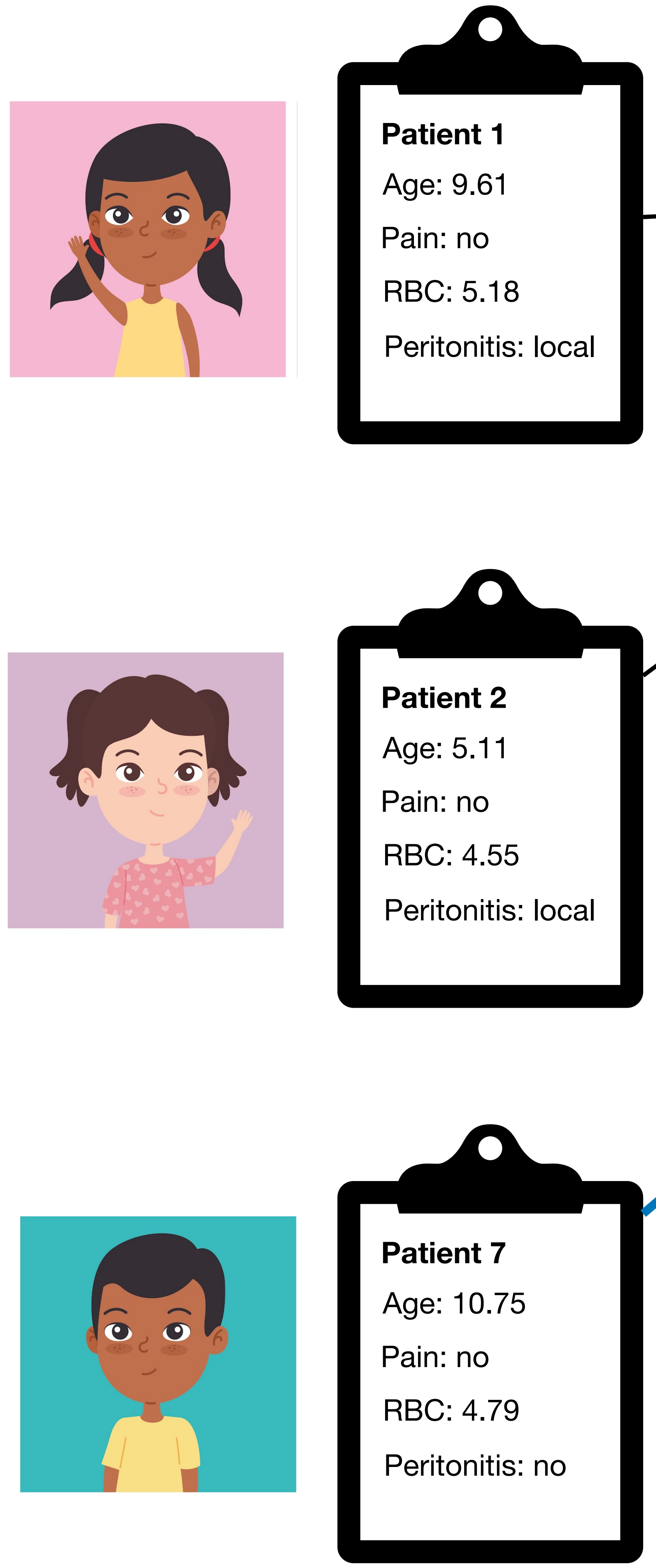
Patients

Table

Tabular data



Patients

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Observation

Table

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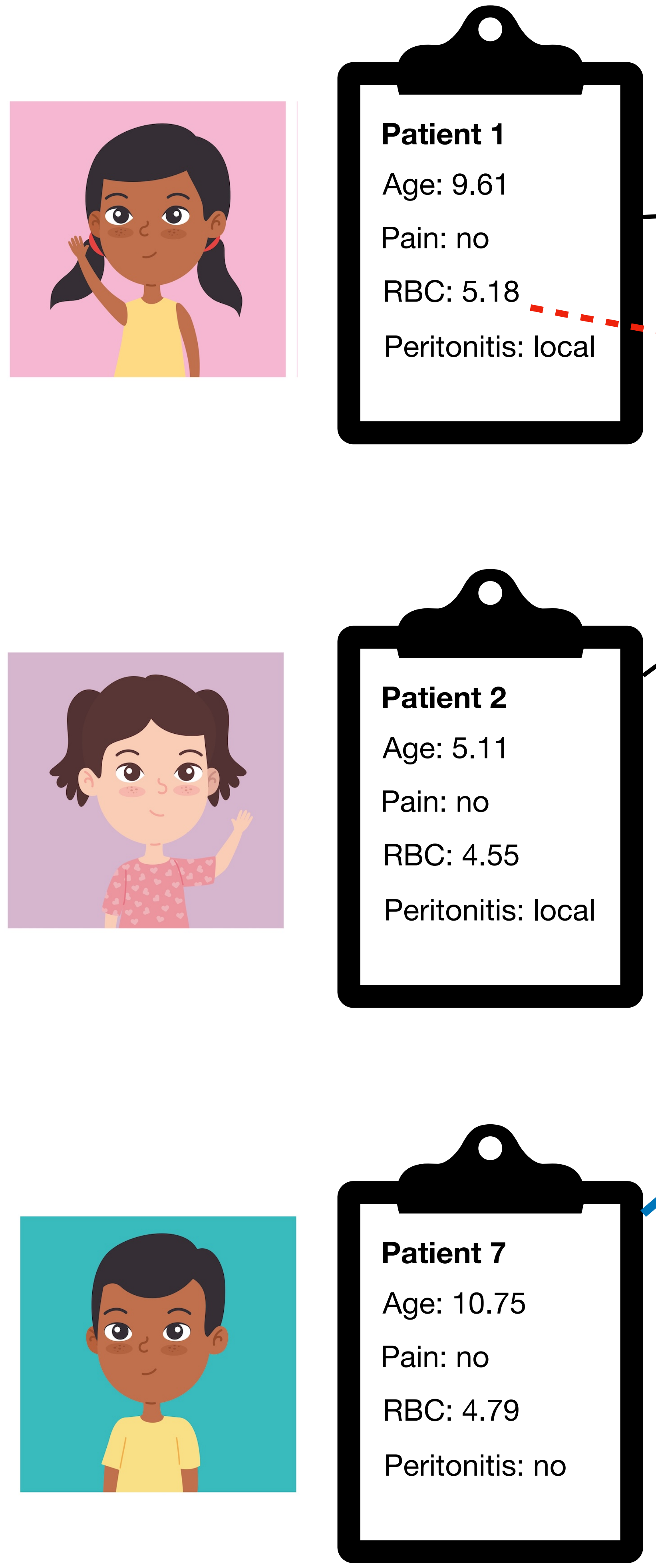

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Observation

Feature

Table

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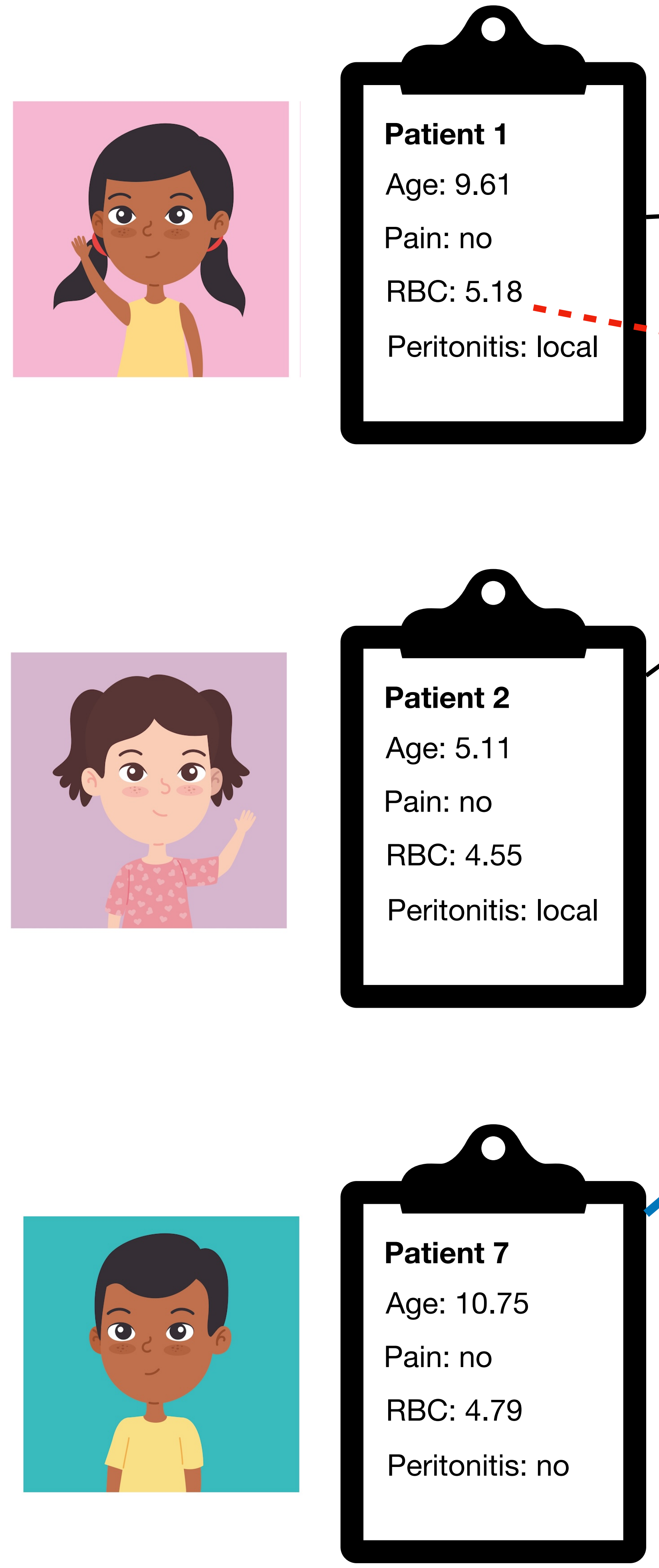

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Cell

Observation

Feature

Table

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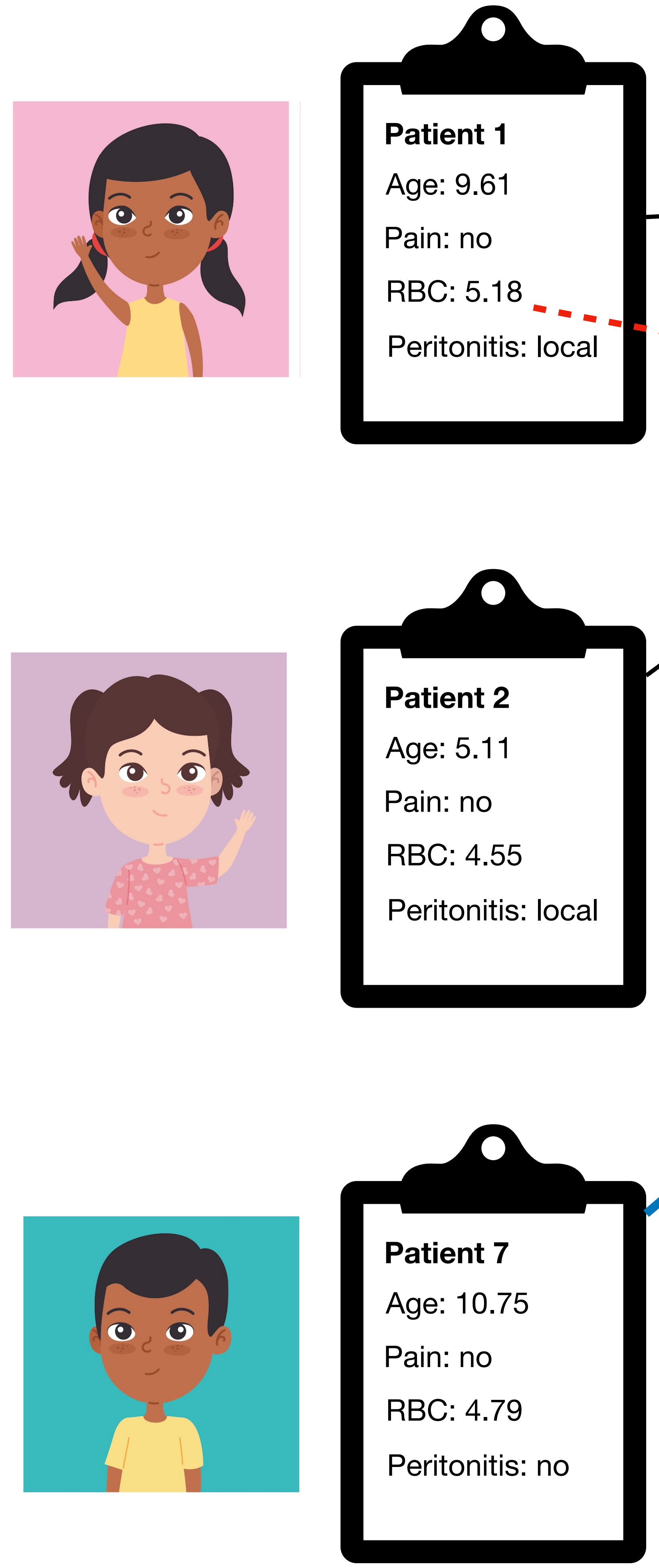

Patients

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```python
@dataclass
class Patient:
    age: float
    pain: bool
    rbc_count: float
    rbc_urine: int
```

Cell

Observation

Feature

Table

Types of features

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Quantitative

E.g. 3, 2.7, -43, 8.2, etc.

Categorical (or Boolean)

E.g. True/False, {"*local*", "*generalized*", …}

Ordinal

E.g. *{low, medium, high…}*

Types of features

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3	10.51	9.0	no	5.03	none	local
4	7.3	6.2	yes	4.64	low	no
5	15.21	8.5	yes	4.62	low	no
6	15.83	12.0	yes	4.33	high	no
7	9.58	7.0	yes	5.04	low	generalized
8	10.37	5.5	no	4.8	none	no
9	16.66	9.0	yes	5.31	none	no
10	14.52	4.5	yes	4.9	none	no
11	10.74	9.0	no	5.66	none	local
12	12.41	3.7	no	5.49	none	no
13	6.67	3.5	no	5.27	none	no
14	14.36	9.0	yes	4.84	low	local
15	9.04	5.3	yes	4.92	low	no
16	12.43	12.0	yes	4.62	none	generaliz

Easier to assume everything is quantitative!

Quantitative

E.g. 3, 2.7, -43, 8.2, etc.

Categorical (or Boolean)

E.g. True/False, {"*local*", "*generalized*", …}

Ordinal

E.g. *{low, medium, high…}*

$$\text{Input: } \mathbf{x} \underset{predict}{\longrightarrow} \text{Output: } y, \quad y = f(\mathbf{x})$$

Prediction *function*

Converting non-quantitative features

Patients with abdominal pain

	Age	Appendix Size	Migratory Pain	RBC Count	RBC Urine	Peritonitis
0	9.61	9.0	no	5.18	high	local
1	5.11	7.0	no	4.55	medium	local
2	10.75	5.0	no	4.79	none	no
3	10.51	9.0	no	5.03	none	local
4	7.3	6.2	yes	4.64	low	no
5	15.21	8.5	yes	4.62	low	no
6	15.83	12.0	yes	4.33	high	no
7	9.58	7.0	yes	5.04	low	generalized
8	10.37	5.5	no	4.8	none	no
9	16.66	9.0	yes	5.31	none	no
10	14.52	4.5	yes	4.9	none	no
11	10.74	9.0	no	5.66	none	local
12	12.41	3.7	no	5.49	none	no
13	6.67	3.5	no	5.27	none	no
14	14.36	9.0	yes	4.84	low	local
15	9.04	5.3	yes	4.92	low	no
16	12.43	12.0	yes	4.62	none	generalized

$$\begin{cases} \text{no} \to 0 \\ \text{yes} \to 1 \end{cases}$$

Boolean features:
Convert to 0/1

Ordinal features:
Convert to sequential integers 0, 1, 2, 3…

Patients with abdominal pain

	Age	Appendix Size	Migratory Pain	RBC Count	RBC Urine	No Peritonitis	Local Peritonitis	Gen. Peritonitis
0	9.61	9.0	0	5.18	3	0	1	0
1	5.11	7.0	0	4.55	2	0	1	0
2	10.75	5.0	0	4.79	0	1	0	0
3	10.51	9.0	0	5.03	0	0	1	0
4	7.3	6.2	1	4.64	1	1	0	0
5	15.21	8.5	1	4.62	1	1	0	0
6	15.83	12.0	1	4.33	3	1	0	0
7	9.58	7.0	1	5.04	1	0	0	1
8	10.37	5.5	0	4.8	0	1	0	0
9	16.66	9.0	1	5.31	0	1	0	0
10	14.52	4.5	1	4.9	0	1	0	0
11	10.74	9.0	0	5.66	0	0	1	0
12	12.41	3.7	0	5.49	0	1	0	0
13	6.67	3.5	0	5.27	0	1	0	0
14	14.36	9.0	1	4.84	1	0	1	0
15	9.04	5.3	1	4.92	1	1	0	0
16	12.43	12.0	1	4.62	0	0	0	1

Categorical features:
Create 1 boolean feature per possible value

$$\begin{cases} \text{Peritonitis} = \text{no} \to 1 \\ \text{otherwise} \to 0 \end{cases}$$

$$\begin{cases} \text{Peritonitis} = \text{local} \to 1 \\ \text{otherwise} \to 0 \end{cases}$$

$$\begin{cases} \text{Peritonitis} = \text{generalized} \to 1 \\ \text{otherwise} \to 0 \end{cases}$$

Mathematical abstraction

As table

Patients with abdominal pain

	Age	Appendix Size	Height	Weight	RBC Count	Temperature	WBC Count
0	16.66	9.0	174.0	65.0	5.31	36.6	6.6
1	10.74	9.0	146.0	57.5	5.66	37.3	10.2
2	9.04	5.3	134.0	29.4	4.92	36.0	5.1
3	10.75	5.0	155.0	54.5	4.79	37.7	10.3
4	7.3	6.2	123.0	23.5	4.64	37.4	21.1
5	5.11	7.0	116.0	22.0	4.55	40.2	19.4
6	14.36	9.0	163.0	50.0	4.84	37.5	14.3
7	9.61	9.0	140.0	29.2	5.18	38.7	14.3
8	15.83	12.0	153.0	59.0	4.33	36.7	12.8
9	9.58	7.0	132.0	24.7	5.04	38.4	13.5
10	10.37	5.5	156.0	39.0	4.8	37.4	5.6
11	14.52	4.5	181.0	55.0	4.9	37.0	9.0
12	12.41	3.7	150.5	42.5	5.49	37.2	9.1
13	6.67	3.5	124.0	38.5	5.27	39.6	16.8
14	15.21	8.5	155.0	85.0	4.62	36.8	12.4
15	12.43	12.0	157.0	46.0	4.62	37.1	16.4
16	10.51	9.0	134.5	27.0	5.03	37.4	12.8

Observation

Feature

As matrix

Observation

$$\mathbf{X} = \begin{bmatrix} 16.66 & 9.0 & 174.0 & 65.0 & 5.31 & 36.6 & 6.6 \\ 10.74 & 9.0 & 146.0 & 57.5 & 5.66 & 37.3 & 10.2 \\ 9.04 & 5.3 & 134.0 & 29.4 & 4.92 & 36.0 & 5.1 \\ 10.75 & 5.0 & 155.0 & 54.5 & 4.79 & 37.7 & 10.3 \\ 7.3 & 6.2 & 123.0 & 23.5 & 4.64 & 37.4 & 21.1 \\ 5.11 & 7.0 & 116.0 & 22.0 & 4.55 & 40.2 & 19.4 \\ 14.36 & 9.0 & 163.0 & 50.0 & 4.84 & 37.5 & 14.3 \\ 9.61 & 9.0 & 140.0 & 29.2 & 5.18 & 38.7 & 14.3 \\ 15.83 & 12.0 & 153.0 & 59.0 & 4.33 & 36.7 & 12.8 \\ 9.58 & 7.0 & 132.0 & 24.7 & 5.04 & 38.4 & 13.5 \\ 10.37 & 5.5 & 156.0 & 39.0 & 4.8 & 37.4 & 5.6 \\ 14.52 & 4.5 & 181.0 & 55.0 & 4.9 & 37.0 & 9.0 \\ 12.41 & 3.7 & 150.5 & 42.5 & 5.49 & 37.2 & 9.1 \\ 6.67 & 3.5 & 124.0 & 38.5 & 5.27 & 39.6 & 16.8 \\ 15.21 & 8.5 & 155.0 & 85.0 & 4.62 & 36.8 & 12.4 \\ 12.43 & 12.0 & 157.0 & 46.0 & 4.62 & 37.1 & 16.4 \\ 10.51 & 9.0 & 134.5 & 27.0 & 5.03 & 37.4 & 12.8 \end{bmatrix}$$

N

(Obs.)

Feature

d

(features)

N x d Matrix: $\mathbf{X} \in \mathbb{R}^{N \times d}$

Matrix, vector and scalar notation

As matrix

Observation

$$
\mathbf{X} = \begin{bmatrix}
16.66 & 9.0 & 174.0 & 65.0 & 5.31 & 36.6 & 6.6 \\
10.74 & 9.0 & 146.0 & 57.5 & 5.66 & 37.3 & 10.2 \\
9.04 & 5.3 & 134.0 & 29.4 & 4.92 & 36.0 & 5.1 \\
10.75 & 5.0 & 155.0 & 54.5 & 4.79 & 37.7 & 10.3 \\
7.3 & 6.2 & 123.0 & 23.5 & 4.64 & 37.4 & 21.1 \\
5.11 & 7.0 & 116.0 & 22.0 & \text{[illegible]} & \text{[illegible]} & 19.4 \\
14.36 & 9.0 & 163.0 & 50.0 & \text{[illegible]} & 37.5 & 14.3 \\
9.61 & 9.0 & 140.0 & \boxed{29.2} & 5.18 & 38.7 & 14.3 \\
15.83 & 12.0 & 153.0 & 59.0 & 4.33 & 36.7 & 12.8 \\
9.58 & 7.0 & 132.0 & 24.7 & 5.04 & 38.4 & 13.5 \\
10.37 & 5.5 & 156.0 & 39.0 & 4.8 & 37.4 & 5.6 \\
14.52 & 4.5 & 181.0 & 55.0 & 4.9 & 37.0 & 9.0 \\
12.41 & 3.7 & 150.5 & 42.5 & 5.49 & 37.2 & 9.1 \\
6.67 & 3.5 & 124.0 & 38.5 & 5.27 & 39.6 & 16.8 \\
15.21 & 8.5 & 155.0 & 85.0 & 4.62 & 36.8 & 12.4 \\
12.43 & 12.0 & 157.0 & 46.0 & 4.62 & 37.1 & 16.4 \\
10.51 & 9.0 & 134.5 & 27.0 & 5.03 & 37.4 & 12.8
\end{bmatrix}
$$

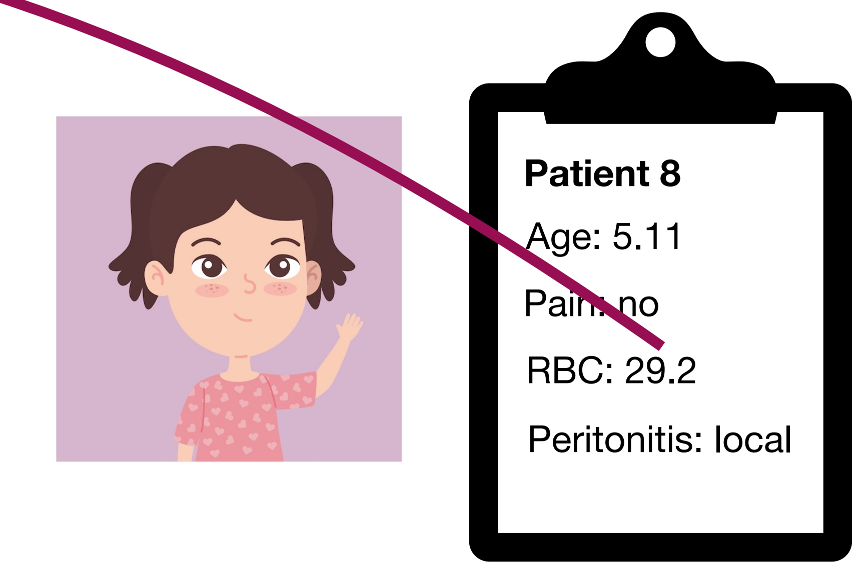
Cell

$$x_{84} = 29.2$$

Row (Obs.) Column (Feature)

$$\mathbf{x}_8 = \begin{bmatrix} 9.61 \\ 9.0 \\ 140.0 \\ 29.2 \\ 5.18 \\ 38.7 \\ 14.3 \end{bmatrix}$$

Row (Obs.)



Patient

Notation warning!

As matrix

Observation

$$\mathbf{X} = \begin{bmatrix} 16.66 & 9.0 & 174.0 & 65.0 & 5.31 & 36.6 & 6.6 \\ 10.74 & 9.0 & 146.0 & 57.5 & 5.66 & 37.3 & 10.2 \\ 9.04 & 5.3 & 134.0 & 29.4 & 4.92 & 36.0 & 5.1 \\ 10.75 & 5.0 & 155.0 & 54.5 & 4.79 & 37.7 & 10.3 \\ 7.3 & 6.2 & 123.0 & 23.5 & 4.64 & 37.4 & 21.1 \\ 5.11 & 7.0 & 116.0 & 22.0 & 4.55 & 40.2 & 19.4 \\ 14.36 & 9.0 & 163.0 & 50.0 & 4.84 & 37.5 & 14.3 \\ 9.61 & 9.0 & 140.0 & 29.2 & 5.18 & 38.7 & 14.3 \\ 15.83 & 12.0 & 153.0 & 59.0 & 4.33 & 36.7 & 12.8 \\ 9.58 & 7.0 & 132.0 & 24.7 & 5.04 & 38.4 & 13.5 \\ 10.37 & 5.5 & 156.0 & 39.0 & 4.8 & 37.4 & 5.6 \\ 14.52 & 4.5 & 181.0 & 55.0 & 4.9 & 37.0 & 9.0 \\ 12.41 & 3.7 & 150.5 & 42.5 & 5.49 & 37.2 & 9.1 \\ 6.67 & 3.5 & 124.0 & 38.5 & 5.27 & 39.6 & 16.8 \\ 15.21 & 8.5 & 155.0 & 85.0 & 4.62 & 36.8 & 12.4 \\ 12.43 & 12.0 & 157.0 & 46.0 & 4.62 & 37.1 & 16.4 \\ 10.51 & 9.0 & 134.5 & 27.0 & 5.03 & 37.4 & 12.8 \end{bmatrix}$$

Vector

Notation:

$$\mathbf{x}_8 = \begin{bmatrix} 9.61 \\ 9.0 \\ 140.0 \\ 29.2 \\ 5.18 \\ 38.7 \\ 14.3 \end{bmatrix}$$

Row (Obs.)

In Python:

```
X[7]
✓ 0.0s                                                    Python
array([ 9.61,   9.  , 140.  ,  29.2 ,   5.18,  38.7 ,  14.3 ])
```

Column vector (d x 1 matrix)

Notation:

$$\mathbf{x}_8 = \begin{bmatrix} 9.61 \\ 9.0 \\ 140.0 \\ 29.2 \\ 5.18 \\ 38.7 \\ 14.3 \end{bmatrix}$$

Same! Treat vectors as column vectors where applicable

In Python:

```
X[7][:, None]
✓ 0.0s                                                    Python
[[  9.61]
 [  9.  ]
 [140.  ]
 [ 29.2 ]
 [  5.18]
 [ 38.7 ]
 [ 14.3 ]]
```

Row vector (1 x d matrix)

Notation:

$$\mathbf{x}_8^T = [9.61 \quad 9.0 \quad 140.0 \quad 29.2 \quad 5.18 \quad 38.7 \quad 14.3]$$

In Python:

```
X[7][None, :]
✓ 0.0s                                                    Python
array([[  9.61,   9.  , 140.  ,  29.2 ,   5.18,  38.7 ,  14.3 ]])
```

Dataset

Set of known inputs and outputs

(

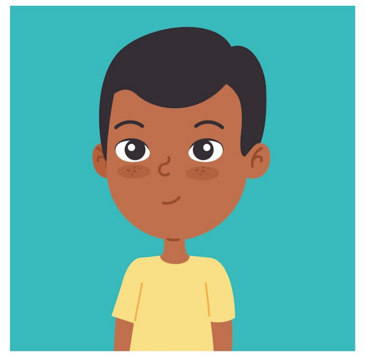

Patient 1
Age: 9.61
Pain: no
RBC: 5.18
Peritonitis: local

, Yes)

(


Patient 2
Age: 5.11
Pain: no
RBC: 4.55
Peritonitis: local

, Yes)

(


Patient 3
Age: 10.75
Pain: no
RBC: 4.79
Peritonitis: no

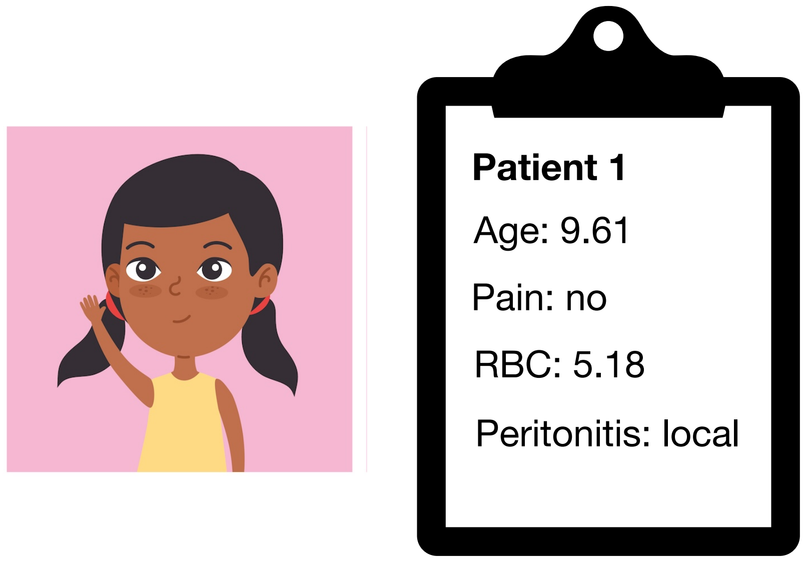
, No) ...

Some notation:

$$\mathcal{D} = \{(\mathbf{x}_1, y_1),\ (\mathbf{x}_2, y_2),\ \ldots\ (\mathbf{x}_N, y_N)\}$$

Quantitative outputs: *Regression*

Input



Patient

Neural network

Prediction
(*Regression*)

Length of hospital stay

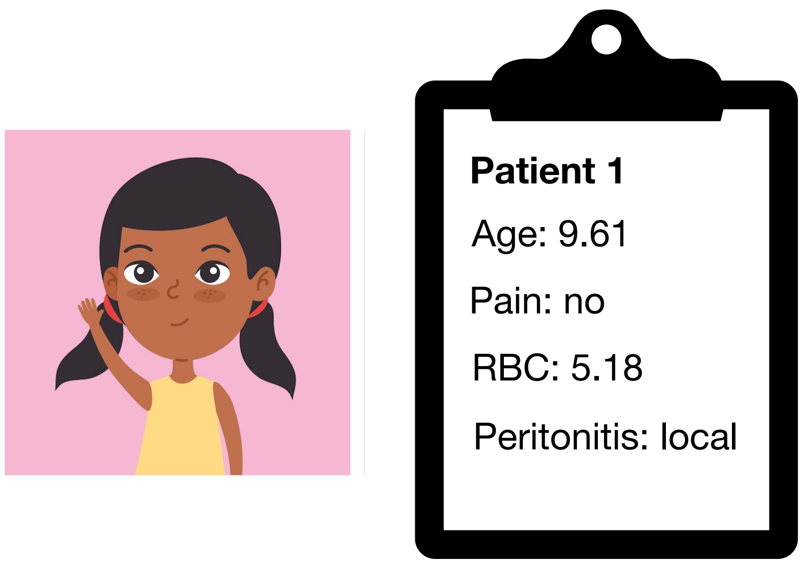
24hrs? 36hrs? …

$$\mathcal{D} = \{(\mathbf{x}_1, y_1),\ (\mathbf{x}_2, y_2),\ \ldots\ (\mathbf{x}_N, y_N)\}$$

Output domain: $y \in \mathbb{R}$

Categorical outputs: *Classification*

Input



Patient

Neural network

Prediction
(*Classification*)

Appendicitis?

Yes / **No**

$$\mathcal{D} = \{(\mathbf{x}_1, y_1),\ (\mathbf{x}_2, y_2),\ \ldots\ (\mathbf{x}_N, y_N)\}$$

Output domain: $y \in \{0,1\}$

Dataset

Set of known inputs and outputs

(

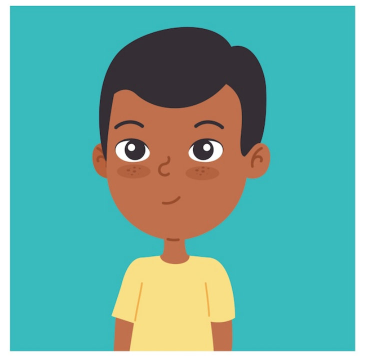
Patient 1
Age: 9.61
Pain: no
RBC: 5.18
Peritonitis: local

, Yes)

(

Patient 2
Age: 5.11
Pain: no
RBC: 4.55
Peritonitis: local

, Yes)

(

Patient 3
Age: 10.75
Pain: no
RBC: 4.79
Peritonitis: no

, No) …

Input table

Patients with abdominal pain

	Age	Appendix Size	Migratory Pain	RBC Count	RBC Urine	Peritonitis
0	9.61	9.0	no	5.18	high	local
1	5.11	7.0	no	4.55	medium	local
2	10.75	5.0	no	4.79	none	no
3	10.51	9.0	no	5.03	none	local
4	7.3	6.2	yes	4.64	low	no
5	15.21	8.5	yes	4.62	low	no
6	15.83	12.0	yes	4.33	high	no
7	9.58	7.0	yes	5.04	low	generalized
8	10.37	5.5	no	4.8	none	no
9	16.66	9.0	yes	5.31	none	no
10	14.52	4.5	yes	4.9	none	no
11	10.74	9.0	no	5.66	none	local
12	12.41	3.7	no	5.49	none	no
13	6.67	3.5	no	5.27	none	no
14	14.36	9.0	yes	4.84	low	local
15	9.04	5.3	yes	4.92	low	no
16	12.43	12.0	yes	4.62	none	generalized

Output table

Diagnosis

	Diagnosis
0	appendicitis
1	no appendicitis
2	no appendicitis
3	no appendicitis
4	appendicitis
5	no appendicitis
6	no appendicitis
7	no appendicitis
8	no appendicitis
9	appendicitis
10	appendicitis
11	no appendicitis
12	no appendicitis
13	no appendicitis
14	appendicitis
15	no appendicitis
16	appendicitis

Mathematical abstraction

Labels become a vector

Patient 5
Age: 5.11
Pain: no
RBC: 4.55
Peritonitis: local

, Yes

Output table

Diagnosis

	Diagnosis
0	appendicitis
1	no appendicitis
2	no appendicitis
3	no appendicitis
4	appendicitis
5	no appendicitis
6	no appendicitis
7	no appendicitis
8	no appendicitis
9	appendicitis
10	appendicitis
11	no appendicitis
12	no appendicitis
13	no appendicitis
14	appendicitis
15	no appendicitis
16	appendicitis

Converted

Diagnosis

	Diagnosis
0	1
1	0
2	0
3	0
4	1
5	0
6	0
7	0
8	0
9	1
10	0
11	0
12	0
13	0
14	1
15	0
16	1

$$\mathbf{y} = \left.\begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ \boxed{1} \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 1 \\ 0 \\ 0 \\ 0 \\ 1 \\ 0 \\ 1 \end{bmatrix}\right\} N \text{ (Obs.)}$$

$$y_5 = 1$$

Index
(Obs.)