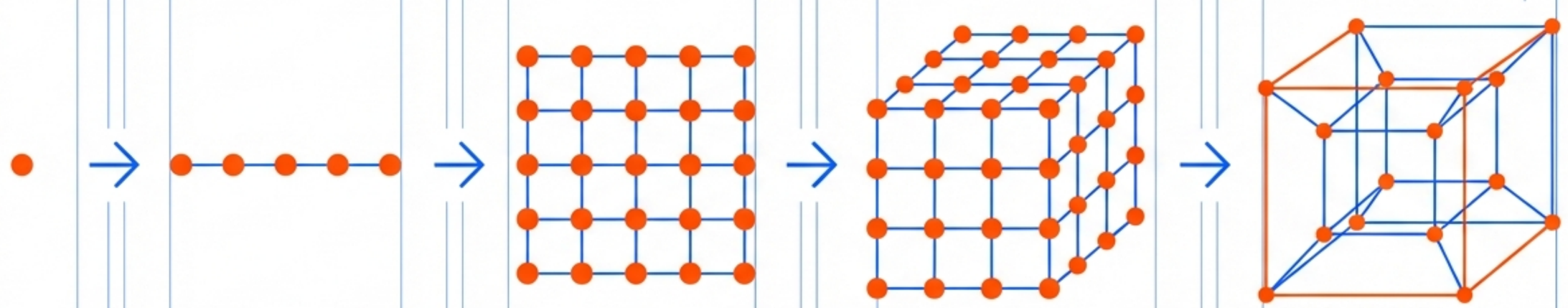
From Scalars to 5D Video

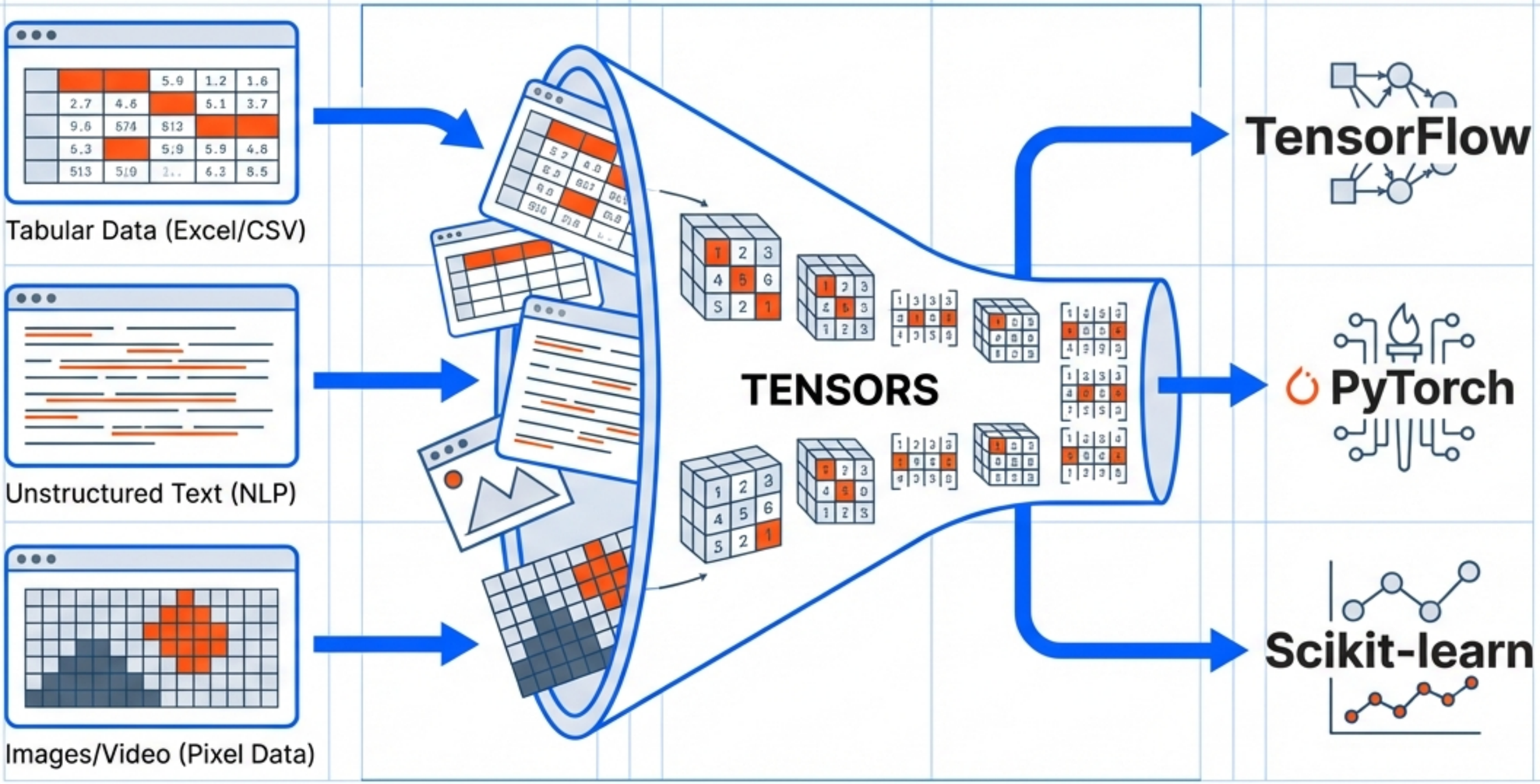


The Architecture of Machine Learning Data

Based on the technical deep-dive by CampusX

The Universal Language of Modern AI

Whether you are building simple regression models or training Generative AI, the fundamental unit of information exchange is the Tensor. Leading libraries rely on Tensors as their primary data structure.



Insight:

Tensors are nothing but a data structure—a container for numbers.

A Tensor is a Container for Numbers

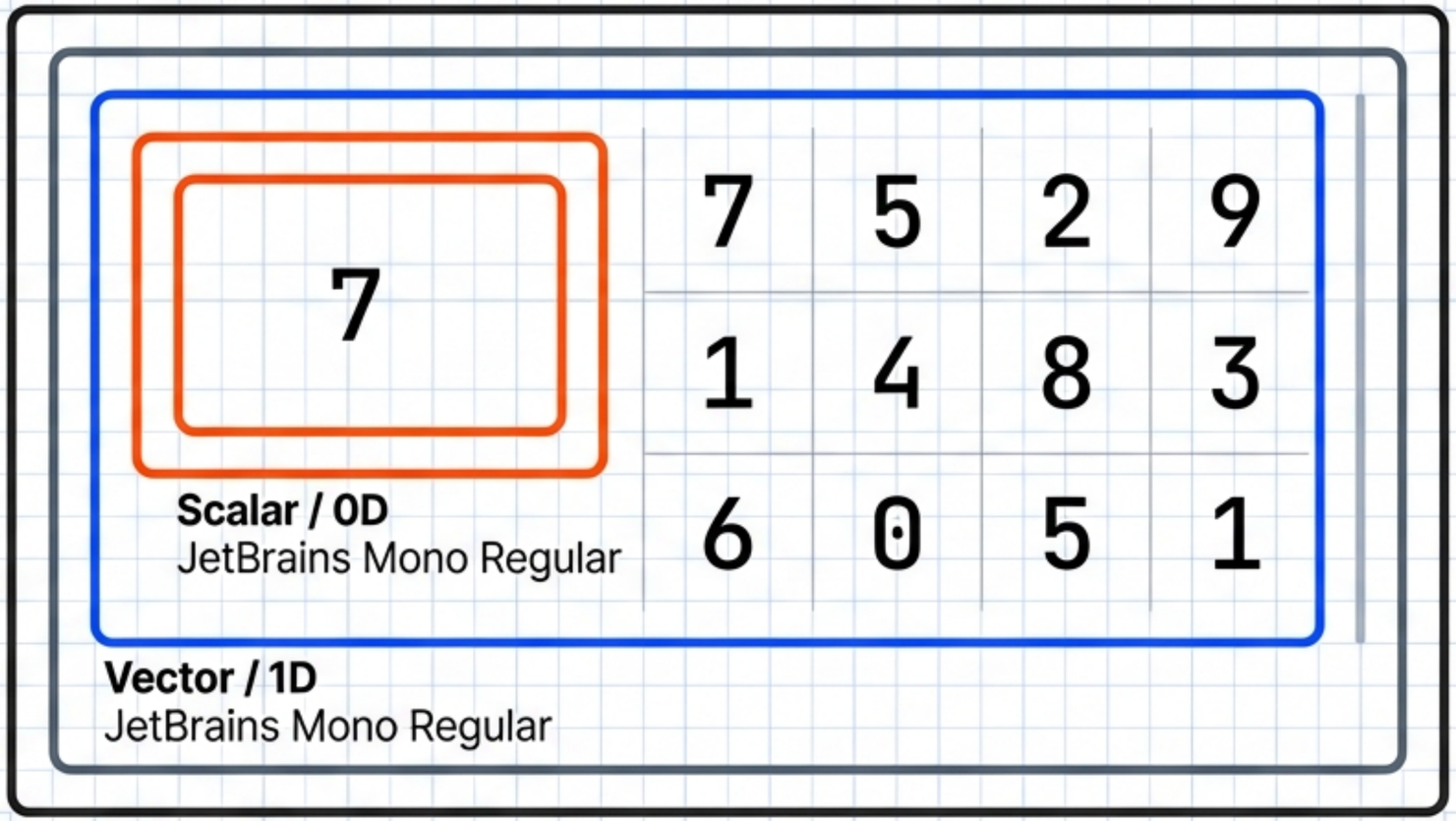
In Computer Science, Tensors represent N-dimensional arrays. They are the generalized form of the data structures you already know.

0D Tensor = Scalar (One number)
JetBrains Mono Regular

1D Tensor = Vector (1D Array)
JetBrains Mono Regular

2D Tensor = Matrix (2D Array)
JetBrains Mono Regular

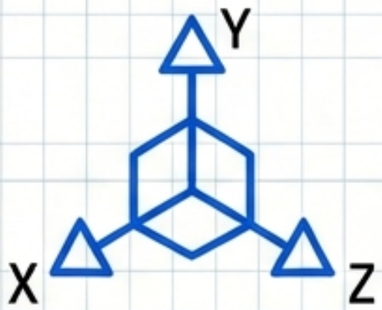
nD Tensor = n-Dimensional Array
JetBrains Mono Regular



The Vocabulary of Dimensions

How to read the map.

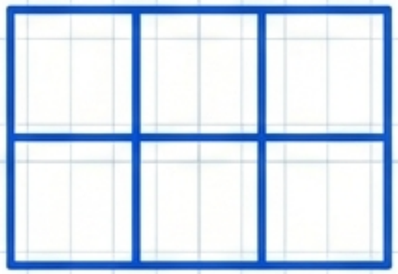
Rank (Axes)



The number of directions data flows (Dimensions).

Synonyms: “ndim”, Number of Axes.

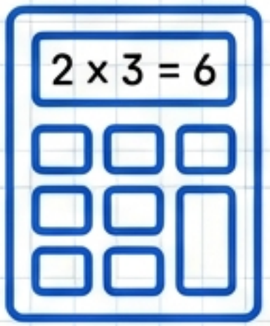
Shape



How many items exist along each specific axis.

Example: A matrix with 2 rows and 3 columns has shape (2, 3).

Size

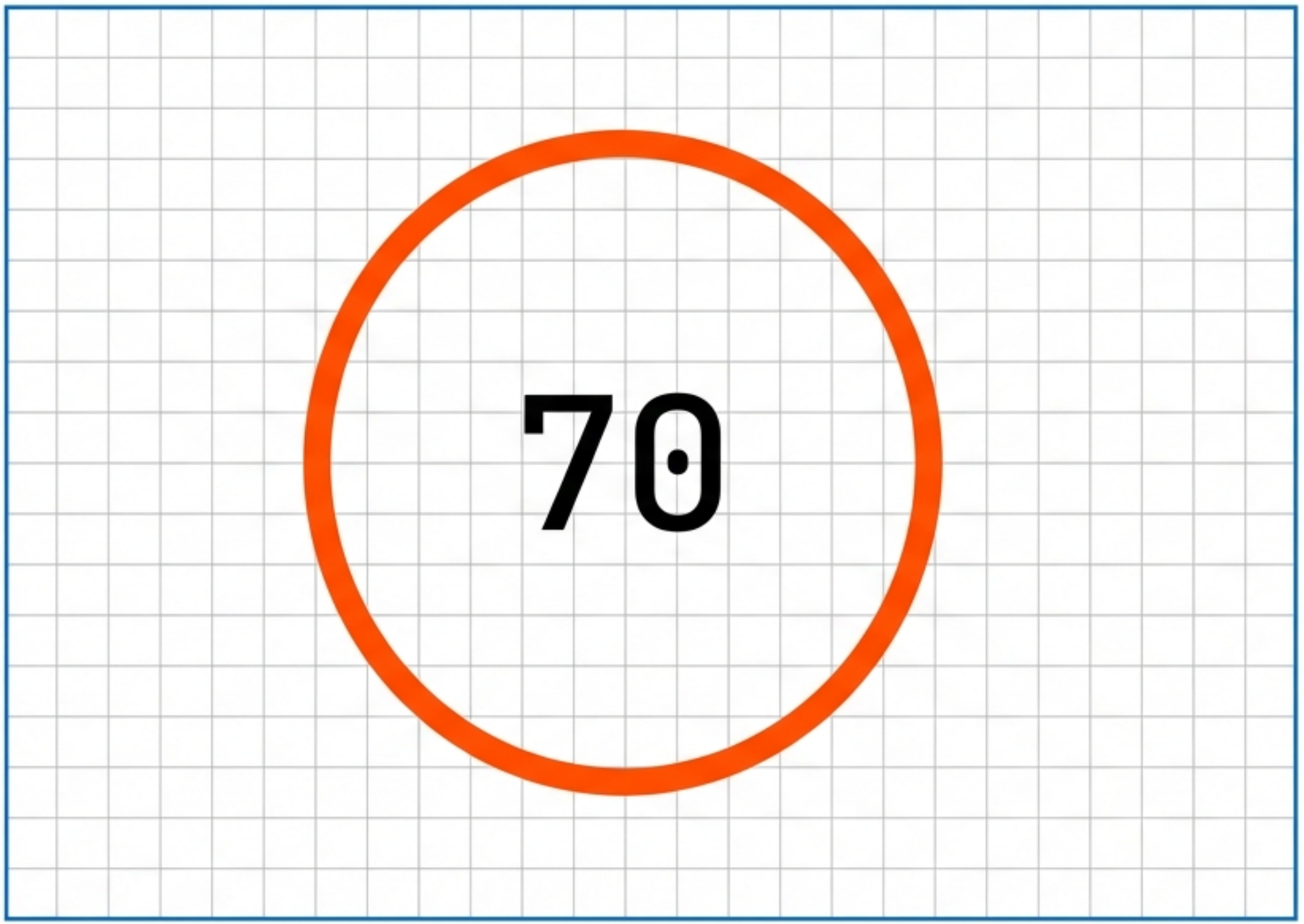


The total item count within the tensor.

Calculation: The product of the shape values.

We will track these three properties for every dimension from 0D to 5D.

Rank 0: The Scalar



Stat Block

PROPERTIES

Rank: 0

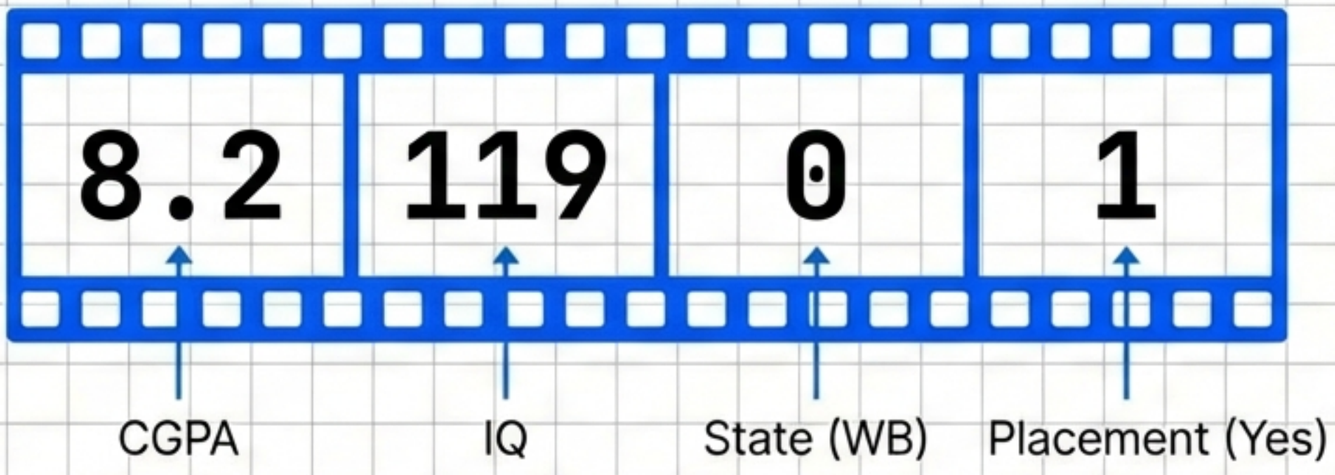
Shape: ()

Size: 1

Context: Scalars are used for single values like a loss score, a bias term, or a hyperparameter.

```
import numpy as np
scalar = np.array(70)
print(scalar.ndim)
# Output: 0
```

Rank 1: The Vector (1D Tensor)



Geometry vs. Code

This single student represents a point in 4-dimensional feature space (Geometry), but in code, this is a 1D Tensor (Rank 1).

Rule: A 1D Tensor has one axis, regardless of how many numbers it contains.

Stat Block

PROPERTIES

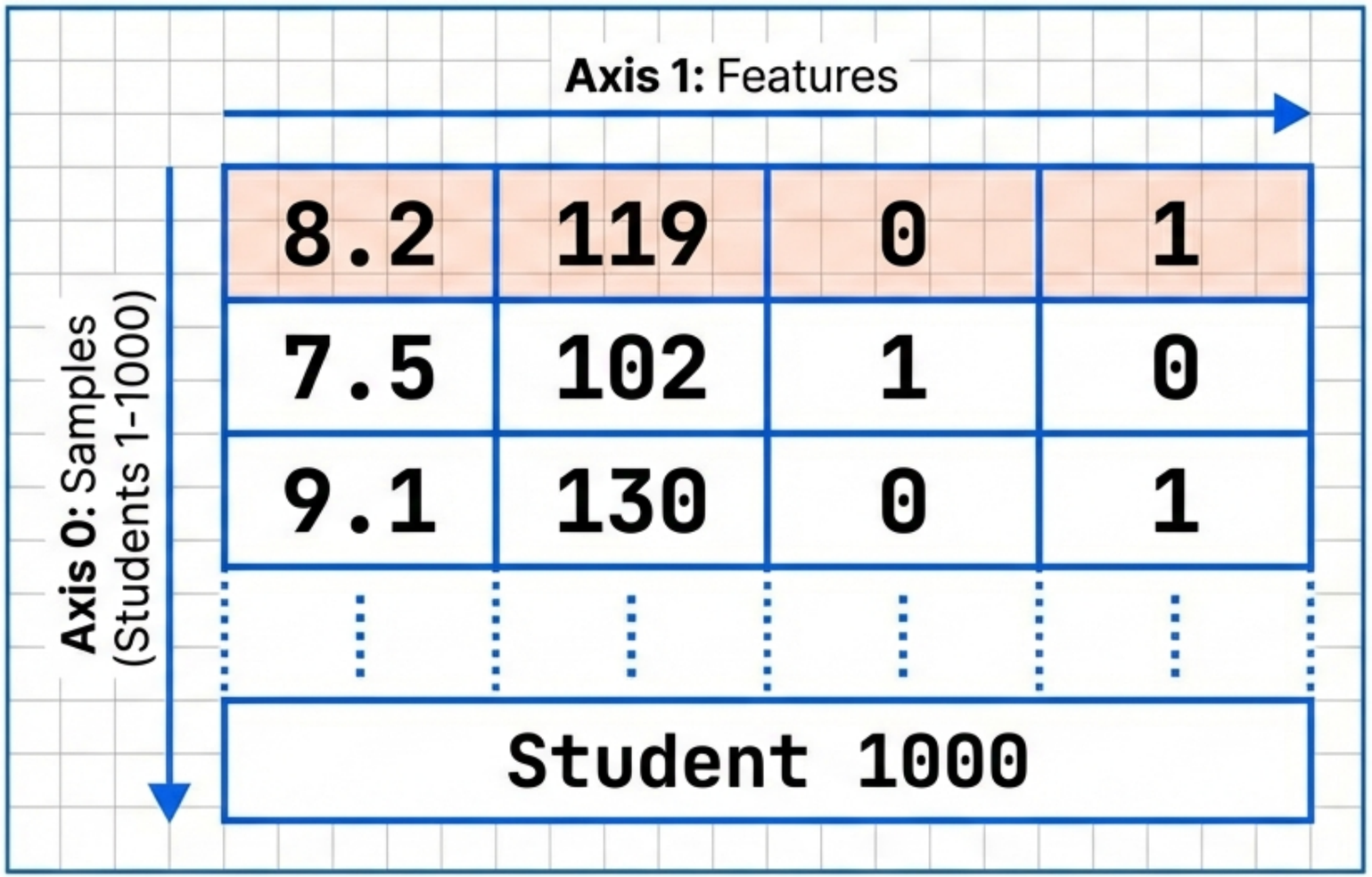
Rank: 1

Shape: `(4,)`

Size: 4

A collection of Scalars creates a Vector.

Rank 2: The Matrix (2D Tensor)



Stat Block

PROPERTIES

Rank: 2

Shape: `(1000, 4)`

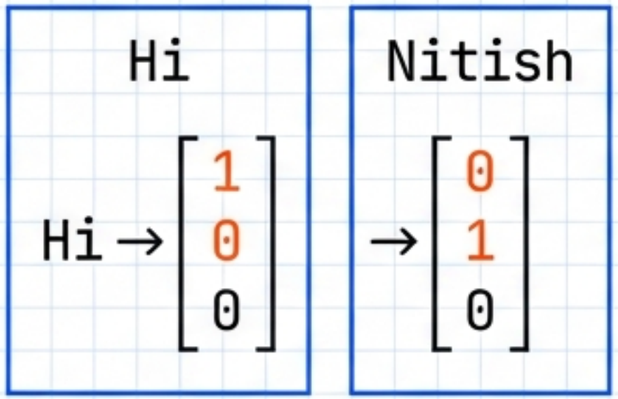
Size: `4000`

Stacking vectors gives us a **Matrix**. This is the standard format for Excel sheets and Pandas DataFrames.

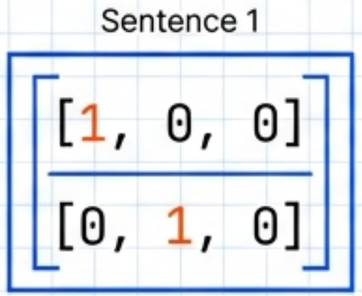
A collection of Vectors creates a Matrix.

Rank 3: Sequence Data (NLP)

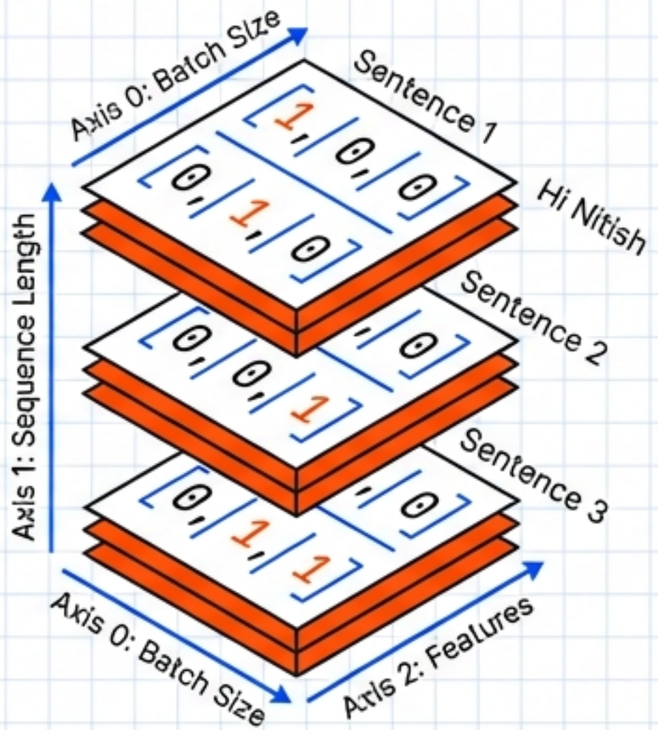
Word Level



Sentence Level (Matrix)



Batch Level (3D Tensor)



Stat Block

PROPERTIES

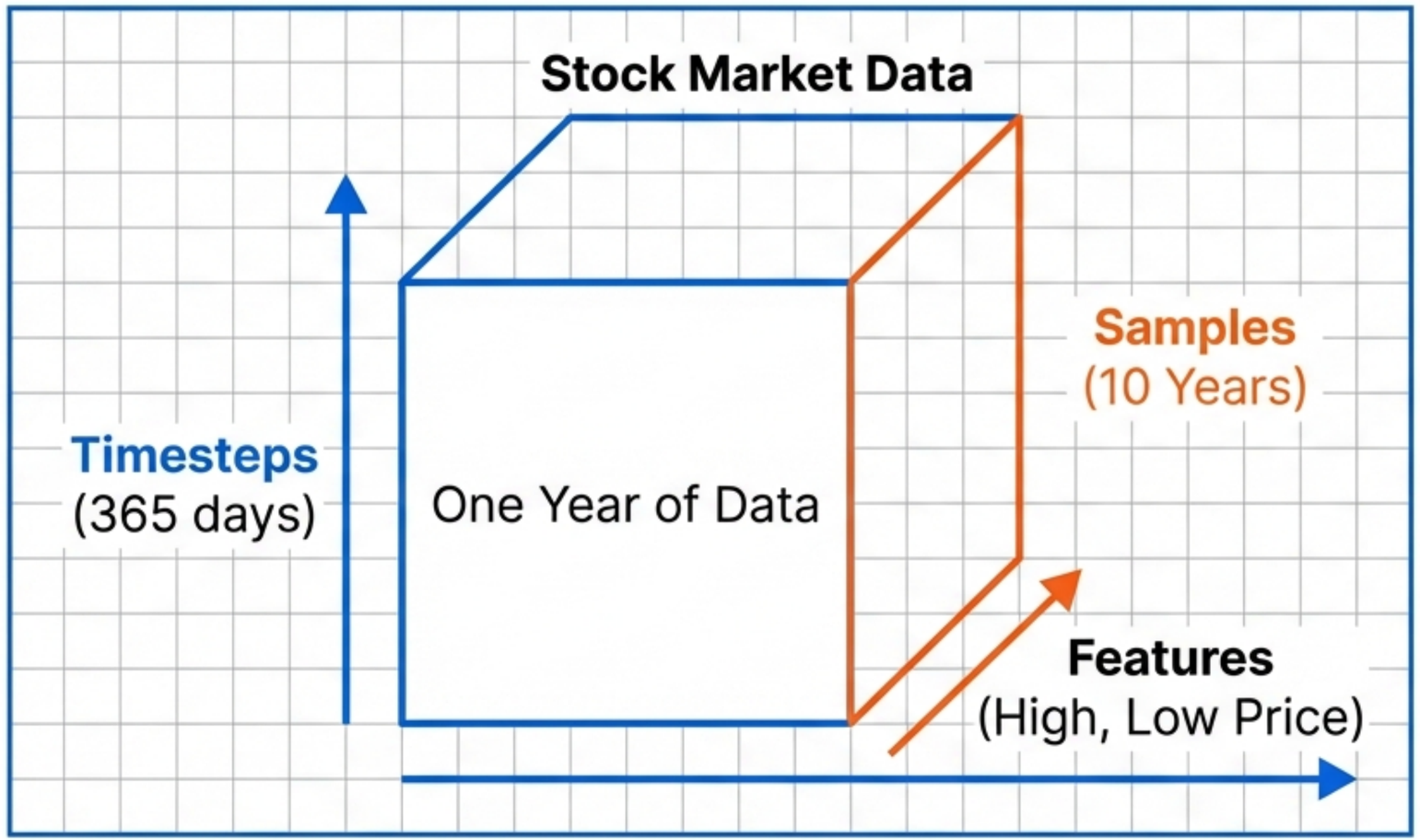
Rank: 3

Shape: (Batch Size, Sequence Length, Features)

Size: Varies

A single sentence is a Matrix. A collection of sentences (Batch) creates a 3D Tensor.

Rank 3: Time Series Data



Stat Block

PROPERTIES

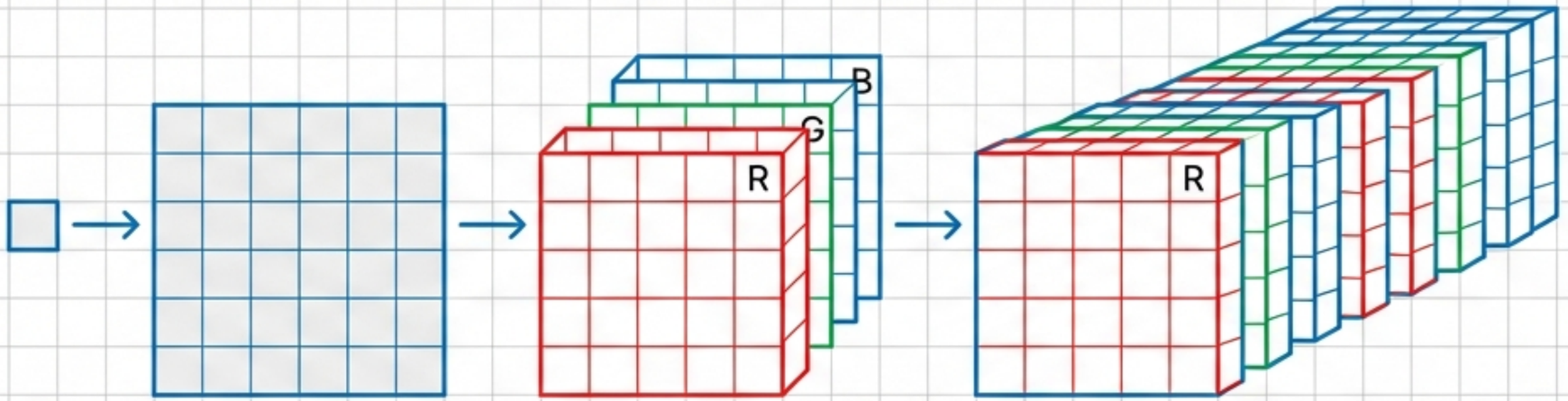
Rank: 3

Shape: `(10, 365, 2)`

Size: `7,300`

In time-series analysis, the third dimension captures the progression of history across multiple distinct samples (years).

Rank 4: Image Batches (Computer Vision)



Pixel
(Scalar)

Grayscale Image
(2D - HxW)

Colour Image
(3D - HxWx3)

Image Batch
(4D)

Stat Block

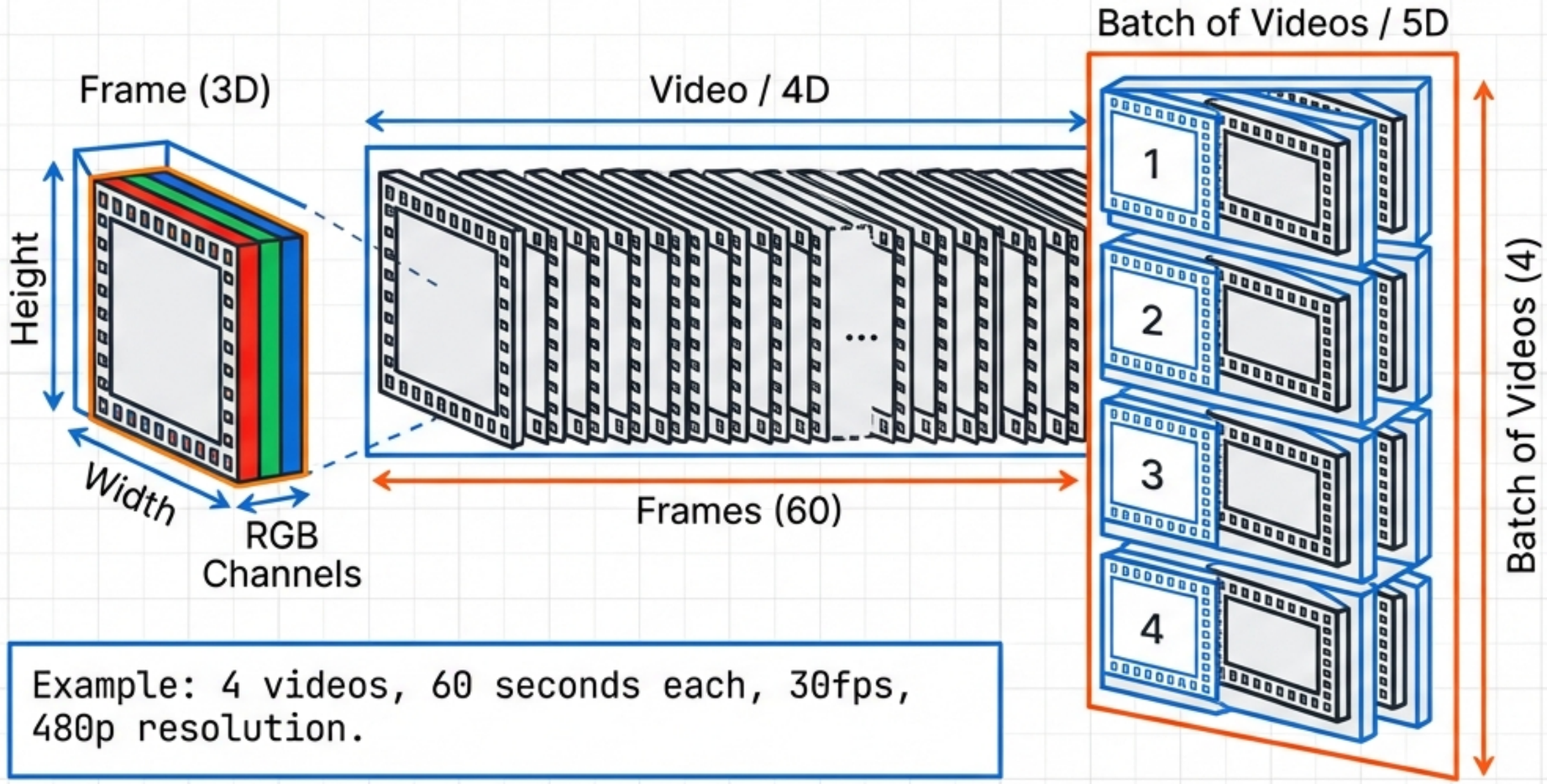
PROPERTIES

Rank: 4
Shape:
(50, 100, 100, 3)

Legend:
(Batch Size, Height, Width, Channels)

A collection of 3D Tensors (Colour Images) creates a 4D Tensor.
This is the standard input for Convolutional Neural Networks (CNNs).

Rank 5: Video Data



PROPERTIES

Rank: 5

Shape:
`(4, 1800, 480, 720, 3)`

Legend:
`(Batch, Frames, Height, Width, Channels)`

`Example: 4 videos, 60 seconds each, 30fps, 480p resolution.`

A collection of 4D Tensors creates a 5D Tensor. Used in Video Analytics.

The Cost of Dimensionality

Input: 4 videos × 1800 frames × 480 × 720 × 3 channels

↓

Total Items: ~1,866,240,000 numbers

↓

Storage (Float32): $1.8B \times 32 \text{ bits} \div 8 \div 1024^3$

↓

~27.8 GB of RAM

Impact: Storing raw 5D tensors is computationally expensive. This necessitates compression codecs (MP4) and efficient streaming logic in ML pipelines.

The Dimensional Cheatsheet

Rank	Name	Shape Pattern	Typical Use Case
0	Scalar	`()`	Loss, Bias
1	Vector	`(Features,)`	One Student, Audio Signal
2	Matrix	(Samples, Features)	Excel Sheet, Dataset
3	3D Tensor	`(Batch, Sequence, Features)`	NLP Text, Time Series
4	4D Tensor	(Batch, Height, Width, Channels)	Image Batch (CNNs)
5	5D Tensor	`(Batch, Frames, H, W, C)`	Video Batch

Just Buckets of Numbers

We climbed from a single digit to 5-dimensional video structures, but the logic remained consistent: every dimension is just a collection of the previous dimension.

Call to Action:

Open NumPy or Google Colab today. Create a tensor, and check your work using:

```
print(tensor.ndim)
print(tensor.shape)
```

Understanding the shape of your data is half the battle in Machine Learning.

Visuals and Narrative adapted from CampusX