

# SESSION 01

WORKSHOP

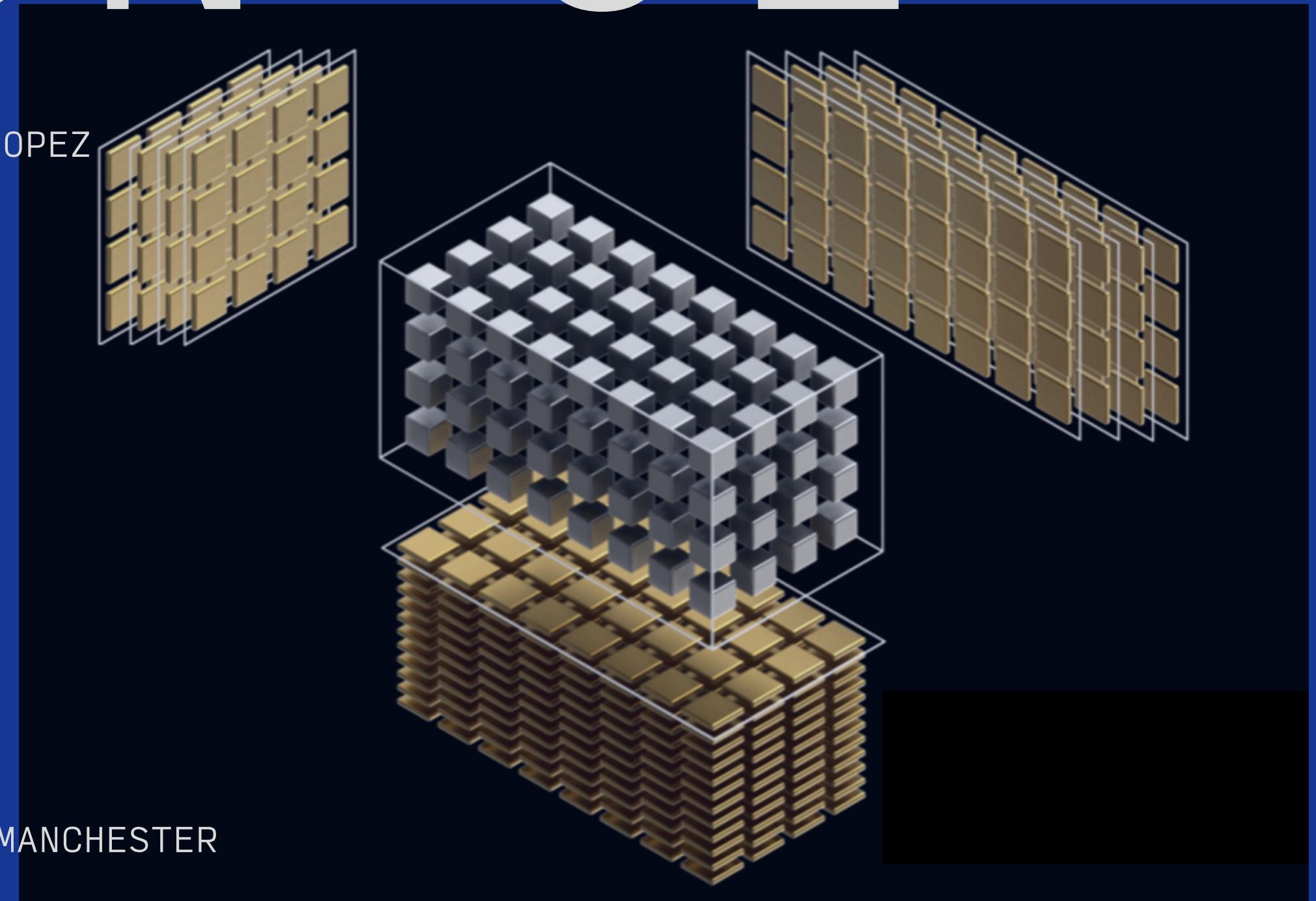
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## INTRODUCTION TO PYTORCH

FACULTY OF SCIENCE AND ENGINEERING

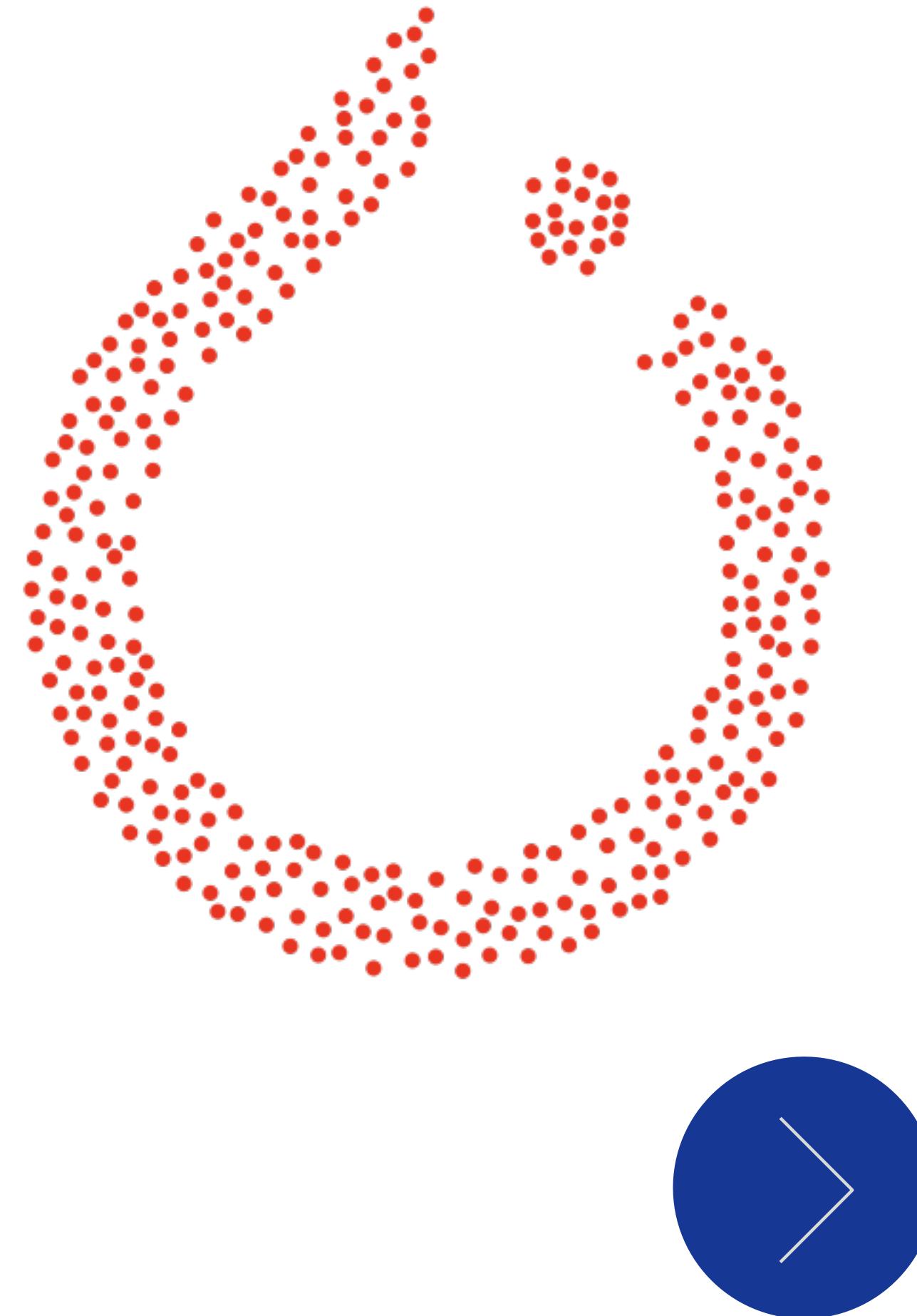
UNIVERSITY OF MANCHESTER



# AGENDA

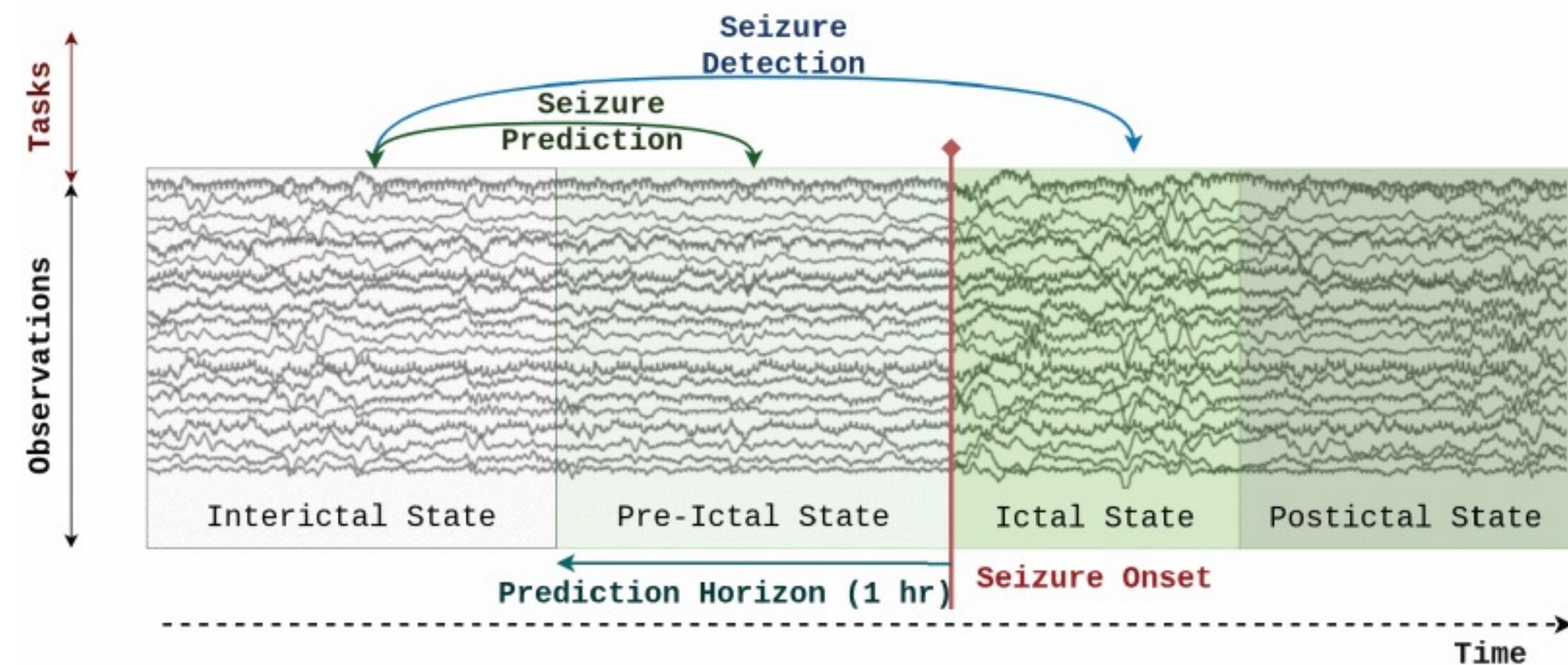
- pytorch fundamentals and advantages
- working with tensors
- tensor operations and manipulation
- automatic differentiation (autograd)
- moving from data to tensors
- gpu acceleration

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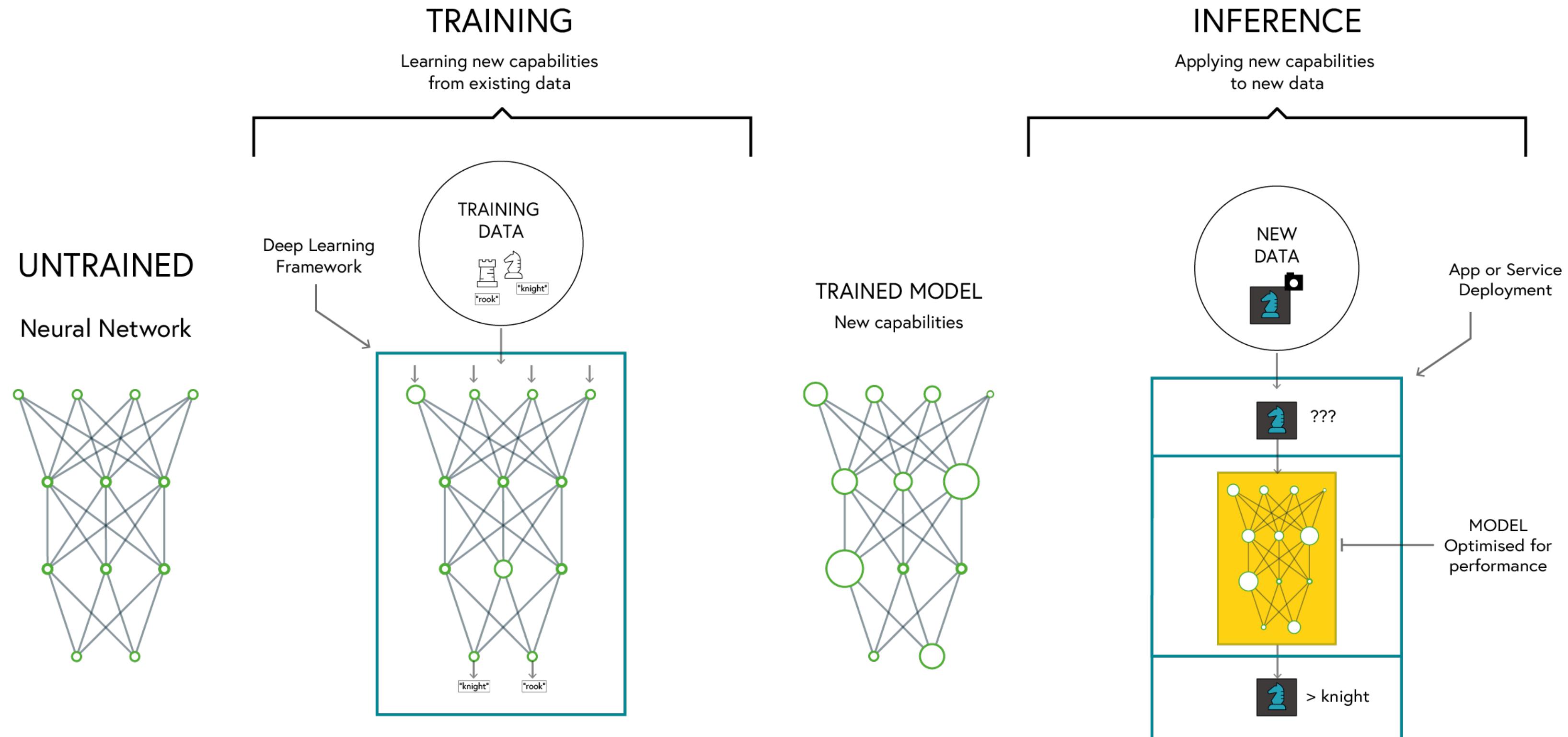


deep learning is a subset of machine learning where models learn directly from data. inspired by the structure and function of the human brain.

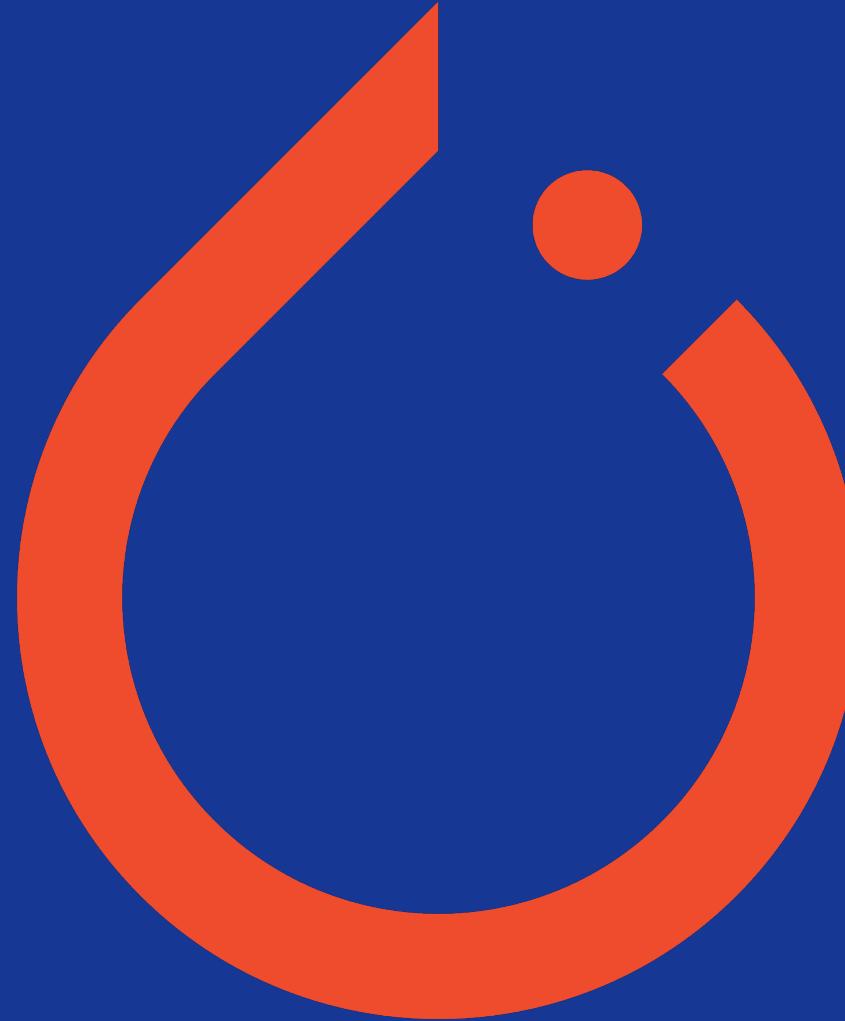
just like humans learn to recognize cats by seeing many pictures of cats, deep learning models learn patterns from data – not rules programmed by hand.



# DEEP LEARNING



# PYTORCH



- **dynamic computation graph**  
easier debugging and flexible model building
- **pythonic and intuitive api:**  
seamless integration with python libraries
- **strong research and industry adoption**  
used by major companies and researchers
- **excellent gpu acceleration**  
optimised for performance on gpus and tpus

# WHY PYTORCH

FEATURE	PYTORCH	TENSORFLOW	KERAS
EASE OF USE	high (pythonic, dynamic computation graph)	moderate (static graph by default, more setup)	very high (high-level api)
FLEXIBILITY	high	moderate	low (abstracted api)
PERFORMANCE	high	very high (optimized for deployment)	moderate
DEBUGGING	easy (eager execution)	harder (graph-based execution)	easy
GPU SUPPORT	excellent	excellent	good
INDUSTRY USE	research, prototyping	production, deployment	rapid prototyping

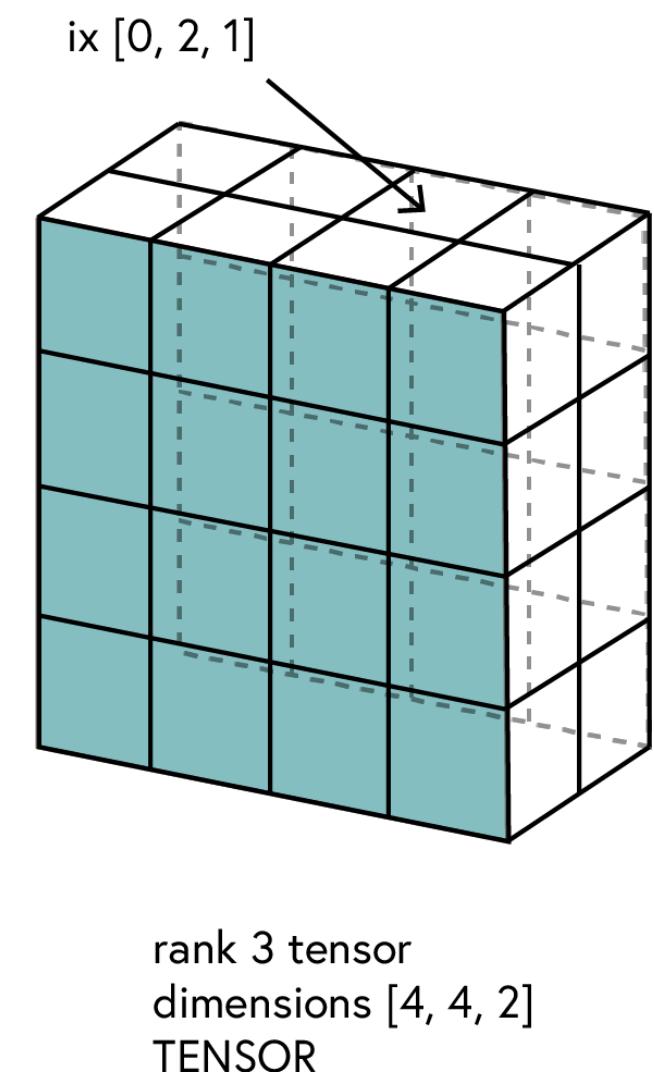
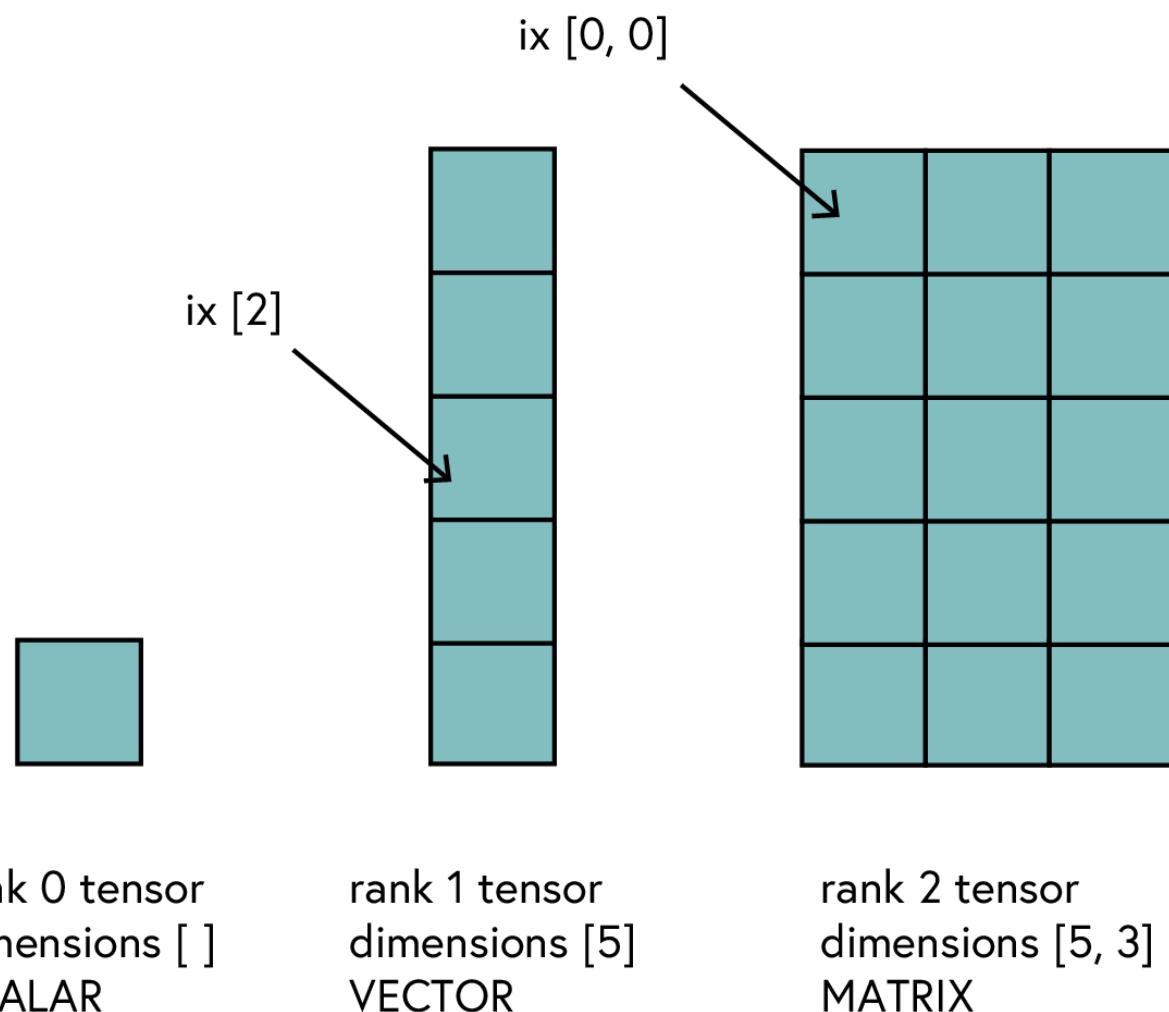
# TENSORS

**definition:** a generalization of vectors and matrices to higher dimensions

**why tensors?**

efficient representation of multi-dimensional data

optimized for computation (cpu & gpu)



```

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import torch
# Different tensor ranks
scalar = torch.tensor(42)                      # Rank 0
vector = torch.tensor([1, 2, 3])                # Rank 1
matrix = torch.tensor([[1, 2], [3, 4]])          # Rank 2
tensor_3d = torch.tensor([[[1, 2], [3, 4]], [[5, 6], [7, 8]]]) # Rank 3t-wise addition

```

# CREATING TENSORS

- `torch.tensor()` -> from existing data
  - `torch.zeros()`, `torch.ones()` -> filled tensors
  - `torch.rand()`, `torch.randn()` -> random tensors
  - `torch.arange()`, `torch.linspace()` -> sequences
  - `torch.eye()` -> identity matrices
- data types can be specified with `dtype` parameter



```
# Creating different tensors
data_tensor = torch.tensor([1, 2, 3, 4])
zeros = torch.zeros(2, 3)
ones = torch.ones(2, 3)
random_uniform = torch.rand(2, 3)          # Values from U(0,1)
random_normal = torch.randn(2, 3)          # Values from N(0,1)
sequence = torch.arange(0, 10, step=2) # [0, 2, 4, 6, 8]
linspace = torch.linspace(0, 1, steps=5) # 5 evenly spaced points
identity = torch.eye(3)                  # 3x3 identity matrix
```

# TENSOR PROPERTIES

working with tensor attributes

- **shape:** `tensor.shape`
- data type: `tensor.dtype`
- **device:** `tensor.device`
- **accessing values:**  
`tensor.item()` for scalars
- **converting types:**  
`tensor.float()`, `tensor.int()`

```
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# Exploring tensor properties  
x = torch.tensor([[1, 2], [3, 4]], dtype=torch.float32)  
print(f"Shape: {x.shape}") # Shape: torch.Size([2, 2])  
print(f"Data type: {x.dtype}") # Data type: torch.float32  
print(f"Device: {x.device}") # Device: cpu  
  
# Converting types  
x_int = x.int()  
x_double = x.double() # or x.to(torch.float64)
```

# TENSOR INDEXING

accessing tensor data

- **basic indexing:** `tensor[i, j]`
- **slicing:** `tensor[1:3]`
- **boolean masks:** `tensor[tensor > 0]`
- **negative indexing:**  
`tensor[-1]` (last element)
- **using ellipsis:** `tensor[..., 0]`

```
# Various indexing techniques
matrix = torch.tensor([[1, 2, 3], [4, 5, 6], [7, 8, 9]])

# Basic indexing and slicing
element = matrix[1, 2]      # Value at row 1, column 2: 6
row = matrix[1]              # Second row: [4, 5, 6]
column = matrix[:, 1]        # Second column: [2, 5, 8]
submatrix = matrix[0:2, 1:]  # Top-right 2x2: [[2, 3], [5, 6]]

# Advanced indexing
mask = matrix > 5          # Boolean mask
values = matrix[mask]        # Values > 5: [6, 7, 8, 9]
corners = matrix[[0, -1], [0, -1]]  # Diagonal corners: [1, 9]
```

# TENSOR OPERATIONS

## Common Operations

- **Arithmetic:** `+, -, *, /`
- **Element-wise operations:**  
`torch.sqrt()`, `torch.pow()`
- **Reduction:** `torch.sum()`, `torch.mean()`
- **Comparisons:** `>`, `<`, `==`
- **In-place operations:**  
`tensor.add_(1)` (note the underscore)



```
# Basic operations
a = torch.tensor([1, 2, 3])
b = torch.tensor([4, 5, 6])

c = a + b                      # [5, 7, 9]
d = a * b                      # [4, 10, 18] (element-wise)
e = torch.sqrt(b)               # [2.0, 2.236, 2.449]

# Reduction operations
total = torch.sum(a)           # 6
mean_value = torch.mean(a.float()) # 2.0

# In-place operations
a.add_(10)                      # a becomes [11, 12, 13]
```

# MATRIX OPERATIONS

linear algebra with pytorch

- **matrix multiplication:**

  @ or `torch.matmul()`

- **transposition:** `.T` or `torch.transpose()`

- **inverse:** `torch.inverse()`

- **determinant:** `torch.det()`

- **eigenvalues:** `torch.eig()`

- **svd:** `torch.svd()`



```
# Linear algebra operations
a = torch.tensor([[1, 2], [3, 4]], dtype=torch.float32)
b = torch.tensor([[5, 6], [7, 8]], dtype=torch.float32)

# Matrix multiplication
c = a @ b                      # or torch.matmul(a, b)
# Result: [[19, 22], [43, 50]]

# Other operations
a_transpose = a.T                 # [[1, 3], [2, 4]]
a_inv = torch.inverse(a)          # [[-2.0, 1.0], [1.5, -0.5]]
det_a = torch.det(a)              # -2.0

# SVD decomposition
U, S, V = torch.svd(a)
```

# BROADCASTING

working with different shapes

- automatic expansion of smaller tensors
- rules follow numpy broadcasting
- eliminates need for explicit reshaping

examples:

- add scalar to matrix
- multiply matrix by row/column vector
- scale batches of data

$$\begin{array}{c}
 \text{np.arange(3)} + 5 \\
 \begin{array}{|c|c|c|} \hline 0 & 1 & 2 \\ \hline \end{array} + \begin{array}{|c|c|c|} \hline 5 & 5 & 5 \\ \hline \end{array} = \begin{array}{|c|c|c|} \hline 5 & 6 & 7 \\ \hline \end{array}
 \end{array}$$
  

$$\begin{array}{c}
 \text{np.ones((3, 3))} + \text{np.arange(3)} \\
 \begin{array}{|c|c|c|} \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array} + \begin{array}{|c|c|c|} \hline 0 & 1 & 2 \\ \hline 0 & 1 & 2 \\ \hline 0 & 1 & 2 \\ \hline \end{array} = \begin{array}{|c|c|c|} \hline 1 & 2 & 3 \\ \hline 1 & 2 & 3 \\ \hline 1 & 2 & 3 \\ \hline \end{array}
 \end{array}$$
  

$$\begin{array}{c}
 \text{np.arange(3).reshape((3, 1))} + \text{np.arange(3)} \\
 \begin{array}{|c|c|c|} \hline 0 & 0 & 0 \\ \hline 1 & 1 & 1 \\ \hline 2 & 2 & 2 \\ \hline \end{array} + \begin{array}{|c|c|c|} \hline 0 & 1 & 2 \\ \hline 0 & 1 & 2 \\ \hline 0 & 1 & 2 \\ \hline \end{array} = \begin{array}{|c|c|c|} \hline 0 & 1 & 2 \\ \hline 1 & 2 & 3 \\ \hline 2 & 3 & 4 \\ \hline \end{array}
 \end{array}$$

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```
# Broadcasting examples
matrix = torch.tensor([[1, 2], [3, 4]])
scalar = torch.tensor(10)
row = torch.tensor([10, 20])
column = torch.tensor([[10], [20]])

# Broadcasting in action
matrix + scalar           # Add 10 to each element
# Result: [[11, 12], [13, 14]]

matrix * row               # Multiply each row by [10, 20]
# Result: [[10, 40], [30, 80]]

matrix + column            # Add column to each column
# Result: [[11, 12], [23, 24]]

# 3D example
batch = torch.randn(32, 3, 224, 224) # Batch of images
scale = torch.tensor([0.5, 1.0, 0.8]) # Per-channel scale
scale = scale.view(1, 3, 1, 1)       # Reshape for broadcasting
normalized = batch * scale         # Scale each channel separately
```

# RESHAPING

## changing tensor dimensions

- `reshape()` – new shape, possibly new memory
- `view()` – new shape, same memory (must be contiguous)
- `squeeze()` – remove dimensions of size 1
- `unsqueeze()` – add dimension of size 1
- `expand()` – broadcast dimensions without copying

```
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# Reshaping examples
x = torch.tensor([1, 2, 3, 4, 5, 6])

# Different reshape methods
reshaped = x.reshape(2, 3)          # [[1, 2, 3], [4, 5, 6]]
viewed = x.view(3, 2)              # [[1, 2], [3, 4], [5, 6]]

# Adding/removing dimensions
x_unsqueezed = x.unsqueeze(0)      # Add dimension: [1, 2, 3, 4, 5, 6] -> [[1, 2, 3, 4, 5, 6]]
single_dim = torch.tensor([7])      # Shape: [1]
squeezed = single_dim.squeeze()    # Shape: [] (scalar)

# Expand example
a = torch.tensor([1, 2, 3])        # Shape: [3]
b = a.unsqueeze(0)                # Shape: [1, 3]
expanded = b.expand(4, 3)          # Shape: [4, 3], repeated rows without copying data
```

# AUTOGRAD

## computing gradients

- enable tracking with `requires_grad=True`
- build computation graph through operations
- call `backward()` to compute gradients
- access gradients via `tensor.grad`

```
# Complex function with multiple inputs
x = torch.tensor(2.0, requires_grad=True)
y = torch.tensor(3.0, requires_grad=True)

# f(x, y) = x2y + y3
z = x*x*y + y*y*y

# Compute gradients
z.backward()

# ∂z/∂x = 2xy = 2*2*3 = 12
# ∂z/∂y = x2 + 3y2 = 4 + 3*9 = 31
print(f"∂z/∂x: {x.grad}") # 12.0
print(f"∂z/∂y: {y.grad}") # 31.0

# Gradient accumulation
x = torch.tensor(1.0, requires_grad=True)
y = x * 2
y.backward()
print(f"First gradient: {x.grad}") # 2.0

# Gradient accumulation (need to zero first)
x.grad.zero_()
z = x * 3
z.backward()
print(f"Second gradient: {x.grad}") # 3.0
```

# LOADING DATA

raw data to tensors

- common data sources: csv, images, text

converting pandas frames to tensors:

- `df = pd.read_csv('data.csv')`
- `tensor = torch.tensor(df.values)`

```
import pandas as pd

# Load CSV data
df = pd.read_csv('data.csv')
print(f"DataFrame shape: {df.shape}")

# Convert specific columns to tensors
features = torch.tensor(df[['feature1', 'feature2', 'feature3']].values, dtype=torch.float32)
labels = torch.tensor(df['target'].values, dtype=torch.float32)

print(f"Features shape: {features.shape}")
print(f"Labels shape: {labels.shape}")
```

# GPU

leveraging hardware

- check availability:

```
torch.cuda.is_available()
```

- select device:

```
device = torch.device('cuda')
```

- move tensors to device:

```
tensor = tensor.to(device)
```

when to use gpu:

- large tensors/datasets
- computationally expensive operations
- deep learning model training
- keep all tensors on same device for efficiency

```
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# GPU handling  
device = torch.device('cuda' if torch.cuda.is_available() else 'cpu')  
print(f"Using device: {device}")  
  
# Create tensor and move to appropriate device  
x = torch.randn(1000, 1000)  
x = x.to(device)  
  
# Create model and move to device  
model = MyNeuralNetwork().to(device)  
  
# Check device of tensor  
print(f"Tensor is on: {x.device}")  
  
# Multiple GPUs  
if torch.cuda.device_count() > 1:  
    print(f"Using {torch.cuda.device_count()} GPUs!")
```