

Data Structures in Deep Learning

Understanding Tensors: Dimensions C, B, T, S

Prof. D.Sc. BARSEKH-ONJI Aboud

Facultad de Ingeniería
Universidad Anáhuac México

January 15, 2026

Agenda

- 1 Fundamentals of Tensors
- 2 The Core Dimensions
- 3 Implementation in MATLAB
- 4 Conclusion

Beyond the Matrix

What is a Tensor?

In computational intelligence, a tensor is a generalization of scalars, vectors, and matrices to higher dimensions. It is the fundamental data structure for Deep Learning frameworks (MATLAB, PyTorch, TensorFlow).

Rank	Name	MATLAB Representation
0	Scalar	Single value (1x1)
1	Vector	Array (1xN)
2	Matrix	Grayscale Image (MxN)
3+	Tensor	Color Image / Batch Data

Why Dimensions Matter?

The "Dimension Mismatch" Problem

Most compilation errors in Deep Network Designer arise from incompatible tensor shapes. Understanding the labels **C**, **B**, **T**, **S** is crucial for:

- Connecting layers correctly (e.g., LSTM to Dense Layer).
- Shaping input data from sensors.
- Debugging memory errors in GPUs.

Agenda

- 1 Fundamentals of Tensors
- 2 The Core Dimensions
- 3 Implementation in MATLAB
- 4 Conclusion

The C-Dimension (Channel)

C: Channel / Features

Represents the "depth" of information at a single point. This dimension is **fixed** by the network architecture.

- **In Time Series:** The number of sensors or variables.
 - Accelerometer (x, y, z) $\rightarrow C = 3$.
 - Medical Data (HR, Temp, SPO2) $\rightarrow C = 3$.
- **In Vision:** The color planes (RGB $\rightarrow C = 3$).

The B-Dimension (Batch)

B: Batch / Observation

The dimension of **computational parallelism**. It defines how many independent examples are processed simultaneously by the GPU.

- **Batch Training:** Instead of updating weights after 1 sample, we average the gradient of N samples (MiniBatchSize).
- **Impact:** Higher B improves stability and speed but requires more VRAM.
- During inference (real-time use), usually $B = 1$.

The T-Dimension (Time)

T: Time / Sequence

Exclusive to Sequence Models (RNN, LSTM, GRU). Represents the duration of the event.

- **Variable Length:** Unlike C , T can vary. A trained LSTM can process a signal of $T = 50$ and then $T = 500$.
- **Recurrent Processing:** The network unfolds loop T times:

$$h_t = \sigma(Wx_t + Uh_{t-1} + b) \quad (1)$$

where t iterates from 1 to T .

The S-Dimension (Spatial)

S: Spatial (H/W)

Represents geometric dimensions (Height and Width).

- **Context:** Convolutional Neural Networks (CNNs).
- **Deep Network Designer:**
 - Images: $H \times W \times C \times B$ ('SSCB').
 - Time Series: Spatial dimension is implicitly 1. Usually labeled just 'CBT'.

Agenda

- 1 Fundamentals of Tensors
- 2 The Core Dimensions
- 3 Implementation in MATLAB
- 4 Conclusion

MATLAB: The dlarray Object

Modern MATLAB (R2023a+) uses formatted 'dlarray' objects to explicitly handle these dimensions.

```
1 % Example: 100 samples of 3-axis accelerometer data (5 seconds @ 50Hz)
2 numSamples = 100;      % Batch (B)
3 numSensors = 3;        % Channels (C)
4 timeSteps = 250;       % Time (T) -> 5s * 50Hz
5
6 % Create Random Data
7 rawData = randn(numSensors, numSamples, timeSteps);
8
9 % Convert to labeled Deep Learning Array
10 X = dlarray(rawData, "CBT"); % Ordering: Channel, Batch, Time
11
12 disp("Tensor Dimensions: " + dims(X))
13
```

Listing 1: Creating a labeled Tensor for LSTM training

Analyzing Dimensions in Network Analyzer

When designing a network (e.g., for 'WaveformData'), check the input layer:

```
1 layer = sequenceInputLayer(3, "Name", "input");  
2 % Here '3' fixes the C-dimension.  
3
```

Validation Rules

- 1 Input Check:** Your data's C must match the input layer's size exactly.
- 2 Output Check:** The classification layer must match the number of classes.
- 3** B and T are flexible during design but consume memory during execution.

Agenda

- 1 Fundamentals of Tensors
- 2 The Core Dimensions
- 3 Implementation in MATLAB
- 4 Conclusion

Summary

- **Tensors** are the fuel of Neural Networks.
- **C (Channels)**: Structural depth (sensors/features). Fixed by design.
- **B (Batch)**: Parallel observations. affects training speed/stochasticity.
- **T (Time)**: Sequence length. Handles dynamic temporal patterns.
- **S (Spatial)**: Geometric layout for vision tasks.