Data Structures in Deep Learning

Understanding Tensors: Dimensions C, B, T, S

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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.

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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:

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

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'.

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MATLAB: The dlarray Object

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

```
% Example: 100 samples of 3-axis accelerometer data (5 seconds @ 50Hz)
numSamples = 100;     % Batch (B)
numSensors = 3;       % Channels (C)
timeSteps = 250;      % Time (T) -> 5s * 50Hz

% Create Random Data
rawData = randn(numSensors, numSamples, timeSteps);

% Convert to labeled Deep Learning Array
X = dlarray(rawData, "CBT"); % Ordering: Channel, Batch, Time

disp("Tensor Dimensions: " + dims(X))

```

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:

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

```

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.

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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.