Understanding NumPy: A Comprehensive Guide

Introduction

If you work in data analysis or machine learning using Python, you've likely encountered two essential libraries: NumPy and Pandas. This lecture will focus on NumPy (Numerical Python), an indispensable library that enhances efficiency and scalability in numerical computations. We'll cover its installation, core features, benefits, and practical applications with examples.

Why Use NumPy?

1. Memory Efficiency

NumPy arrays occupy significantly less memory compared to Python lists. This is because Python lists store heterogeneous data types with additional metadata, while NumPy arrays store homogeneous data types in contiguous memory locations.

Example:

```
import sys
import numpy as np

python_list = list(range(100))
list_size = sys.getsizeof(python_list[0]) * len(python_list)

numpy_array = np.arange(100)
numpy_size = numpy_array.nbytes

print(f"Python list size: {list_size} bytes")
print(f"NumPy array size: {numpy_size} bytes")
```

Output:

```
Python list size: 2400 bytes
NumPy array size: 400 bytes
```

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2. Faster Computations

NumPy's arrays are implemented in C, enabling faster operations compared to Python lists. For instance, element-wise operations can be performed efficiently without using loops.

Example:

```
import time

# Python lists
L1 = list(range(1_000_000))
L2 = list(range(1_000_000))

start = time.time()
L3 = [x + y for x, y in zip(L1, L2)]
print(f"Python list computation: {time.time() - start:.5f} seconds")

# NumPy arrays
A1 = np.arange(1_000_000)
A2 = np.arange(1_000_000)

start = time.time()
A3 = A1 + A2
print(f"NumPy array computation: {time.time() - start:.5f} seconds")
```

Output:

```
Python list computation: 0.05000 seconds
NumPy array computation: 0.00200 seconds
```

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3. Convenience with Built-In Functions

NumPy supports a range of mathematical and statistical operations, enabling vectorized computations.

Example:

```
A1 = np.array([1, 2, 3])
A2 = np.array([4, 5, 6])

# Element-wise operations
sum_array = A1 + A2
product_array = A1 * A2

# Aggregate operations
mean_value = A1.mean()
std_deviation = A1.std()

print("Sum:", sum_array)
print("Product:", product_array)
print("Mean:", mean_value)
print("Standard Deviation:", std_deviation)
```

Output:

```
Sum: [5 7 9]
Product: [ 4 10 18]
Mean: 2.0
Standard Deviation: 0.816496580927726
```

Core Features of NumPy

1. Array Creation

NumPy provides multiple methods for creating arrays:

- **Manual creation:** `np.array()`
- **Range-based creation:** `np.arange()`
- **Linearly spaced values:** `np.linspace()`
- **Default values:** `np.zeros()`, `np.ones()`

Example:

```
# Different ways to create arrays
manual_array = np.array([10, 20, 30])
range_array = np.arange(1, 10, 2)
linspace_array = np.linspace(0, 1, 5)
zeros_array = np.zeros((2, 3))
ones_array = np.ones((2, 3))

print("Manual Array:", manual_array)
print("Range Array:", range_array)
print("Linspace Array:", linspace_array)
print("Zeros Array:\n", zeros_array)
print("Ones Array:\n", ones_array)
```

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2. Array Indexing and Slicing

Access specific elements or subsets of an array using Python-like slicing.

Example:

```
array = np.array([[1, 2, 3], [4, 5, 6], [7, 8, 9]])

# Access specific elements
print("Element at [1, 2]:", array[1, 2])

# Slicing
print("First row:", array[0, :])
print("Second column:", array[:, 1])
print("Sub-matrix:\n", array[0:2, 1:3])
```

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3. Reshaping and Flattening

Reshape arrays without altering data or flatten them for simpler processing.

Example:

```
array = np.array([[1, 2, 3], [4, 5, 6]])

reshaped = array.reshape((3, 2))
flattened = array.flatten()

print("Reshaped Array:\n", reshaped)
print("Flattened Array:", flattened)
```

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4. Element-Wise Operations

Perform operations directly on arrays without loops.

Example:

```
array = np.array([1, 2, 3, 4, 5])
squared = array ** 2
sqrt = np.sqrt(array)

print("Squared:", squared)
print("Square Root:", sqrt)
```

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5. Statistical Methods

NumPy simplifies statistical analysis.

Example:

```
array = np.array([10, 20, 30, 40, 50])

print("Mean:", np.mean(array))
print("Standard Deviation:", np.std(array))
print("Max:", np.max(array))
print("Index of Max:", np.argmax(array))
```

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6. Matrix Operations

Efficiently perform dot products, cross products, and other matrix manipulations.

Example:

```
 matrix_1 = np.array([[1, 2], [3, 4]])
matrix_2 = np.array([[5, 6], [7, 8]])

# Dot product
result = np.dot(matrix_1, matrix_2)
print("Dot Product:\n", result)

# Cross product
vector_1 = np.array([1, 2, 3])
vector_2 = np.array([4, 5, 6])

cross_result = np.cross(vector_1, vector_2)
print("Cross Product:", cross_result)
```

Advanced Features

1. Broadcasting

Perform operations on arrays of different shapes by stretching smaller arrays to match the larger array.

Example:

```
 A = np.array([[1, 2, 3], [4, 5, 6]])
B = np.array([1, 2, 3])

result = A + B
print("Broadcasted Result:\n", result)
```

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2. Stacking and Splitting

Combine or divide arrays efficiently.

Example:

```
 A = np.array([[1, 2], [3, 4]])
B = np.array([[5, 6]])

# Vertical stacking
v_stacked = np.vstack((A, B))

# Horizontal stacking
h_stacked = np.hstack((A, B.T))

print("Vertically Stacked:\n", v_stacked)
print("Horizontally Stacked:\n", h_stacked)

# Splitting
split_A, split_B = np.hsplit(A, 2)
print("Split Arrays:", split_A, split_B)
```

Application in Real-Life Scenarios

1. Financial Analytics

Task: Combine sales data for analysis.

Example:

```
Q1 = np.array([[200, 220, 250], [150, 180, 200]])
Q2 = np.array([[209, 230, 261], [155, 185, 205]])

total_sales = Q1 + Q2
growth = ((Q2 - Q1) / Q1) * 100

print("Total Sales:\n", total_sales)
print("Growth Percentage:\n", growth)
```

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2. Machine Learning

Task: Compute dot product for predictions.

Example:

```
features = np.array([[2000, 3], [1800, 2]])
weights = np.array([150, 50000])

prices = np.dot(features, weights)
print("Predicted Prices:", prices)
```

Practice Tasks

1. **Easy:** Create a NumPy array of 10 random integers between 1 and 100, then find the mean, minimum, and maximum values.
2. **Medium:** Create a 3x3 identity matrix and perform element-wise addition with a 3x3 matrix filled with random integers between 1 and 10.
3. **Challenging:** Generate a 5x5 matrix with values ranging from 0 to 24. Replace all even numbers with -1.
4. **Hard:** Given a 6x6 matrix, calculate the sum of the border elements (first and last rows, first and last columns).
5. **Extreme:** Implement matrix multiplication for two matrices using only NumPy indexing (avoid using built-in dot or matmul functions).

Conclusion

NumPy provides robust tools for numerical computations, offering significant improvements in speed, memory efficiency, and convenience. It forms the backbone of scientific computing and machine learning in Python. By mastering NumPy's core functionalities, you build a strong foundation for further exploration into data analysis and machine learning.

In the next lecture, we will dive into Pandas, extending your capability to work with tabular data.