

# **Applied Numerical Methods for Civil Engineering**

CGN 3405 - 0002

## **Week 3: Introduction to Python Programming: Part I**

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How to understand

## **Applied Numerical Methods for Civil Engineering?**

**Numerical methods** are techniques by which **mathematical problems** are formulated so that they can be solved with **arithmetic operations**.

# Programming Environment

- No prior programming experience required!
- Setting up your **environment**
  - Free, no installation
  - Cloud-based Jupyter notebooks
  - Access anywhere with browser
  - Link: <https://colab.research.google.com>

# Programming Environment

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- Try it now!

```
1 print('Hello Civil Engineering!')  
2 print('Welcome to Applied Numerical Methods')
```

- What is **print()**?
  - A **function** that displays text
  - Anything in quotes is text (string)

## Quizzes Now!

- **Today's participation** (ungraded survey): Please check out  
**"Class Participation Quiz 5"**  
Time slot: **2:30PM – 3:00PM**  
on Canvas.
- Online engagement (graded quizzes)  
**"Quiz 5"** (11 questions)  
Deadline: **11:59PM, January 26, 2026**  
on Canvas.

# Variables: Storing Data

Variables are containers for data

```
1 # Assign values to variables
2 length = 10.5          # meters
3 width = 5.2            # meters
4 material = 'Steel'
```

Rules for variable names:

1. Start with letter or underscore
2. Can contain letters, numbers, underscores
3. Case-sensitive: Length  $\neq$  length
4. Descriptive names recommended
5. Avoid Python keywords, e.g., lambda, class, list, def, etc.

Examples:

```
1 length = 4
2 Length = 4.5
3 print('length = {}'.format(length))
4 print('Length = {}'.format(Length))
```

# Basic Data Types

## Four essential types

- **Integers:** Whole numbers  $\dots, -2, -1, 0, 1, 2, \dots$

```
1 length = 4
```

- **Floats:** Decimal numbers

```
1 deflection = 0.025 # meters
```

- **Strings:** Text

```
1 material = 'Steel'
```

- **Booleans:** True/False

```
1 a = True
2 if a is True:
3     print(1)
4 else:
5     print(0)
```

## Checking Data Types

- Use `type()` function:

```
1 # Check types
2 length = 4
3 print(type(length))          # <class 'int'>
4
5 deflection = 0.025
6 print(type(deflection))     # <class 'float'>
7
8 material = 'Steel'
9 print(type(material))       # <class 'str'>
10
11 safe = True
12 print(type(safe))          # <class 'bool'>
```

- Why check types?
  - Different operations work with different types
  - Avoid errors like adding string to number
  - Understand what your code is doing

# Basic Arithmetic Operations

## Python programming example.

```
1 a = 2
2 b = 3
3 print(a + b) # plus
4 print(a - b) # minus
5 print(a * b) # product
6 print(a / b) # division
7 print(a ** 2) # quadratic function
8 print(a ** 3) # cubic function
```

## Corresponding arithmetic operations:

Line 3:  $a + b$

Line 6:  $\frac{a}{b}$

Line 4:  $a - b$

Line 7:  $a^2$

Line 5:  $a \cdot b$

Line 8:  $a^3$

Note:  $a ** n$  refers to  $a$  to the power of  $n$ , or  $a^n$  ( $n$  is not only an integer).

## Basic Arithmetic Operations

### Engineering example.

- Definition of normal stress:

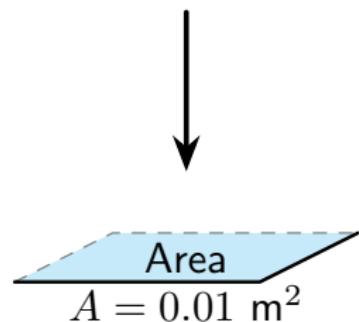
$$\sigma = \frac{F}{A}$$

$$F = 5000 \text{ N}$$

where

- $F = 5000 \text{ N}$  (force)
- $A = 0.01 \text{ m}^2$  (area)

```
1 force = 5000 # N
2 area = 0.01 # m^2
3 stress = force / area # Pa
4 print('stress = {}'.format(stress))
```



## Order of Operations

Python follows PEMDAS:

1. Parentheses ()
2. Exponents
3. Multiplication
4. Division
5. Addition
6. Subtraction

```
1 # Different results!
2 a1 = 10 + 5 * 2      # (5*2 first)
3 a2 = (10 + 5) * 2    # (parentheses first)
```

$$a_1 = 10 + 5 \times 2 \quad a_2 = (10 + 5) \times 2$$

# Order of Operations

Python follows PEMDAS:

1. Parentheses
2. Exponents
3. Multiplication
4. Division
5. Addition
6. Subtraction

Which one is correct?

$$c = \frac{w}{24 \cdot E \cdot I}$$

```
1 w = 10 ** 4          # uniform load
2 E = 2 * 10 ** 11      # modulus
3 I = 3.25 * 10 ** (-4) # moment of inertia
4 c1 = w / 24 * E * I
5 c2 = w / (24 * E * I)
```

## Lists: Storing Multiple Values

- Lists store collections of data

```
1 # List of beam deflections (mm)
2 deflections = [12.3, 15.7, 18.2, 14.9, 16.5]
3 print(deflections) # [12.3, 15.7, 18.2, 14.9, 16.5]
4
5 # List of materials
6 materials = ['Steel', 'Concrete', 'Timber', 'Aluminum']
7
8 # Access elements (0-indexed!)
9 print(deflections[0]) # First: 12.3
10 print(deflections[-1]) # Last: 16.5
```

## Lists: Storing Multiple Values

- Lists store collections of data

```
1 # List of beam deflections (mm)
2 deflections = [12.3, 15.7, 18.2, 14.9, 16.5]
3 print(deflections)  # [12.3, 15.7, 18.2, 14.9, 16.5]
4
5 # List of materials
6 materials = ['Steel', 'Concrete', 'Timber', 'Aluminum']
7
8 # Access elements (0-indexed!)
9 print(deflections[0])    # First: 12.3
10 print(deflections[-1])   # Last: 16.5
```

- List operations for engineering data

```
1 print(len(deflections))      # Number of deflections
2 print(min(deflections))      # Minimum deflection
3 print(max(deflections))      # Maximum deflection
4 print(sum(deflections))       # Total
5 print(sum(deflections)/len(deflections))  # Average
```

## Conditionals (if/elif/else)

- Make decisions in code:

```
1 stress = 235 # MPa
2
3 if stress > 250:
4     print('WARNING: Stress exceeds yield strength!')
5 elif stress > 200:
6     print('Alert: Stress approaching limit')
7 else:
8     print('Stress within safe limits')
```

## Conditionals (if/elif/else)

- Make decisions in code:

```
1 stress = 235 # MPa
2
3 if stress > 250:
4     print('WARNING: Stress exceeds yield strength!')
5 elif stress > 200:
6     print('Alert: Stress approaching limit')
7 else:
8     print('Stress within safe limits')
```

- Comparison operators:

- > greater than
- < less than
- >= greater or equal
- <= less or equal
- == equal to
- != not equal to

## Logical Operators (and/or/not)

- Use the logical operator `and`:

```
1 stress = 235
2
3 if stress <= 250 and stress > 200:
4     print('Alert!')
5 else:
6     print('Others')
```

- Use the logical operator `or`:

```
1 stress = 235
2
3 if stress > 250 or stress > 200:
4     print('At least alert!')
5 else:
6     print('Safe!')
```

## for Loop: Repeating Tasks

- Process each item in a sequence:

```
1 # List of beam deflections
2 deflections = [12.3, 15.7, 18.2, 14.9, 16.5]    # mm
3
4 # Check each beam
5 for d in deflections:
6     if d > 15:
7         print('Deflection exceeds limit')
8     else:
9         print('Deflection is OK')
```

- Common pattern: Process each item in experimental data

## range() Function for Numerical Loops

- Generate sequences of numbers:

```
1 # Count from 0 to 4
2 for i in range(5):
3     print(i)
4
5 # With start and end
6 for i in range(2, 6):
7     print(i)
8
9 # With step
10 for i in range(0, 10, 2):
11     print(i)
```

## range() Function for Numerical Loops

- Generate sequences of numbers:

```
1 # Count from 0 to 4
2 for i in range(5):
3     print(i)
4
5 # With start and end
6 for i in range(2, 6):
7     print(i)
8
9 # With step
10 for i in range(0, 10, 2):
11     print(i)
```

Line 2-3 Result: 0, 1, 2, 3, 4

Line 6-7 Result: 2, 3, 4, 5

Line 10-11 Result: 0, 2, 4, 6, 8

## while Loop: Repeat Until Condition

- Repeat while condition is true:

```
1 a = [1, 2, 3, 4, 5, 6, 7, 8]
2 i = 0
3 while a[i] < 6:
4     print(a[i])
5     i = i + 1
```

Result: 0, 1, 2, 3, 4, 5

## Functions: Reusable Code Blocks

- **Quadratic formula.** Given  $ax^2 + bx + c = 0$  ( $a \neq 0$ ), the quadratic formula is

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

```
1 import numpy as np
2
3 def quad_formula(a, b, c):
4     t = np.sqrt(b**2 - 4*a*c)
5     x1 = (-b + t) / (2*a)
6     x2 = (-b - t) / (2*a)
7     return x1, x2
```

Line 4 Compute  $t = \sqrt{b^2 - 4ac}$

Line 5 Compute  $x_1 = \frac{-b + t}{2a}$

Line 6 Compute  $x_2 = \frac{-b - t}{2a}$

## Functions: Reusable Code Blocks

- Given **parameters**: uniform load  $w = 1 \times 10^4 \text{ kg/m}$ , modulus  $E = 2 \times 10^{11} \text{ Pa}$ , and moment of inertia  $I = 3.25 \times 10^{-4} \text{ m}^4$ .
- Compute the **constant factor**:

$$c = \frac{w}{24 \cdot E \cdot I} = \frac{10^4}{24 \times (2 \times 10^{11}) \times (3.25 \times 10^{-4})} = 6.41 \times 10^{-6}$$

```
1 import numpy as np
2
3 def const(w, E, I):
4     return w / (24 * E * I)
5
6 w = 10 ** 4                  # uniform load
7 E = 2 * 10 ** 11             # modulus
8 I = 3.25 * 10 ** (-4)       # moment of inertia
9 c = const(w, E, I)          # constant factor
10 print(c)
```

## Quick Summary

### Monday's Class:

- Python environment (no installation with Colab)
- Introduction to Python: Variables, data types (integer, float, string, and Boolean).
- Arithmetic operations, order of operations.
- Storing multiple values with lists
- Logical operators (`for` and `while`)
- Defining functions by yourself

# Assignment 1

- **Correction: Question 1b.**

Euler's Method for a Simple ODE (Numerical Computing).

$$\frac{dy}{dx} = x + y, \quad y(0) = 1$$

The analytical solution is

$$y(x) = 2e^x - x - 1$$

because

$$\frac{dy}{dx} = 2e^x - 1 = x + (2e^x - x - 1) = x + y$$

- **Questions 2b, 3b.** Please use Python programming

- Bungee jumping velocity model: Time step size  $\Delta t = 0.1\text{ s}$
- Cantilever beam deflection: Step size  $\Delta x = 0.125\text{ m}$

## Exam 1

- Exam Information
  - Date: February 20, 2026
  - Time: 2:30PM – 3:20PM
  - **Written Exam**
  - **15%** in your final score
- Format
  - **20 quiz questions (40 points)** in total: All selected from the quizzes sessions
  - **Numerical computing tests ( $\approx 45$  points)**
  - **Python programming tests ( $\approx 15$  points)**: I will give you Python codes, please write down the results.
- How can I help?
  - Review classes on February 16/18, 2026
- **Maximum Tolerance:** Given the scores of Exam 1 and Exam 2 as  $a$  and  $b$ , respectively, only in the case of  $b > a$ , then your score for both exams will become  $b$ .

## Quizzes Now!

- **Today's participation** (ungraded survey): Please check out  
**"Class Participation Quiz 6"**  
Time slot: **2:30PM – 3:00PM**  
on Canvas.
- Online engagement (graded quizzes)  
**"Quiz 6"** (13 questions)  
Deadline: **11:59PM, January 28, 2026**  
on Canvas.

## Learning Objectives

You should be able to:

- Understand the difference among one-, two- and  $n$ -dimensional arrays in NumPy
- Understand how to apply some linear algebra operations to  $n$ -dimensional arrays without using `for`-loops
- Understand axis and shape properties for  $n$ -dimensional arrays

## Basics

- Why NumPy for Civil Engineering?
  - Numerical Computing: Solve engineering equations efficiently
  - Matrix Operations: Structural analysis, stiffness matrices
  - Data Processing: Sensor data, experimental results
  - Performance: **50x faster** than Python lists for numerical computing
- What is NumPy?
  - Numerical Python library
  - *n*-dimensional arrays as core data structure
  - Mathematical functions optimized for arrays

## Importing NumPy

- Import convention:

```
1 import numpy as np
```

- Why np?
  - Standard convention in scientific Python
  - Shorter than typing `numpy` every time
  - Everyone uses this convention

## NumPy Arrays vs. Python Lists

- Python Lists

```
1 a = [2.2, 3.3, 4.1, 5.2, 6.1]
2 b = [1.5, 2.1, 3.8, 4.3, 5.2]
3 c = []
4 for i in range(5):
5     c.append(a[i] * b[i]) # Inefficient!
```

## NumPy Arrays vs. Python Lists

- Python Lists

```
1 a = [2.2, 3.3, 4.1, 5.2, 6.1]
2 b = [1.5, 2.1, 3.8, 4.3, 5.2]
3 c = []
4 for i in range(5):
5     c.append(a[i] * b[i]) # Inefficient!
```

- NumPy Arrays

```
1 import numpy as np
2
3 a = np.array([2.2, 3.3, 4.1, 5.2, 6.1])
4 b = np.array([1.5, 2.1, 3.8, 4.3, 5.2])
5 c = a * b # Fast!
```

- Key Advantage: **Vectorization → Faster computation, cleaner code**

## Algebraic Data → NumPy Arrays

- Scalar, e.g.,  $x = 1$

```
1 import numpy as np
2
3 x = np.array(1)
```

- Vector, e.g.,  $x = \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{bmatrix}$  of length 6

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

- Matrix, e.g.,  $X = \begin{bmatrix} 1 & 3 & 5 \\ 2 & 4 & 6 \end{bmatrix}$  of 2 rows and 3 columns

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

# Algebraic Data → NumPy Arrays

- Scalar, e.g.,  $x = 1$

```
1 import numpy as np
2
3 x = np.array(1)
```

$$\begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{bmatrix}$$

- Vector, e.g.,  $x = \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{bmatrix}$  of length 6

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

- Matrix, e.g.,  $X = \begin{bmatrix} 1 & 3 & 5 \\ 2 & 4 & 6 \end{bmatrix}$  of 2 rows and 3 columns

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

- Data type (integer, float, string, or boolean?)

```
1 print(type(x))
```

# Algebraic Data → NumPy Arrays

## A system of linear equations.

- Let's solve:

$$\begin{cases} 3x + 2y = 5 \\ x - y = 0 \end{cases} \Rightarrow \begin{bmatrix} 3 & 2 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 5 \\ 0 \end{bmatrix}$$

- Try to solve by hand, and then check with Python.
- Define matrix  $A$  and vector  $b$ :

Line 3:  $A = \begin{bmatrix} 3 & 2 \\ 1 & -1 \end{bmatrix}$

Line 4:  $b = \begin{bmatrix} 5 \\ 0 \end{bmatrix}$

```
1 import numpy as np
2
3 A = np.array([[3, 2], [1, -1]])
4 b = np.array([5, 0])
5 solution = np.linalg.solve(A, b)
6 print('Solution (x, y):', solution)
```

## Creating Arrays with Built-In Functions

- Line 3: Matrix of ones (Fill with ones)

$$\mathbf{A} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix}$$

- Line 4: Matrix of zeros (Filling with zeros)

$$\mathbf{B} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

- Line 5: Identify matrix (1 on the diagonal and 0 otherwise)

$$\mathbf{C} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

```
1 import numpy as np
2
3 A = np.ones((2, 4)) # (number of rows, number of
        columns)
4 B = np.zeros((2, 4)) # (number of rows, number of
        columns)
5 C = np.eye(3)         # number of rows/columns
```

## Creating Sequences with np.arange()

- `np.arange()`: Like Python's `range()`, but returns array

```
1 import numpy as np
2
3 # Bungee jumping velocity
4 delta_t = 0.1
5 t_start = 0
6 t_end = 20
7 time_step = np.arange(t_start, t_end, delta_t)
8 print(time_step)
```

will not count `t_end = 20.`

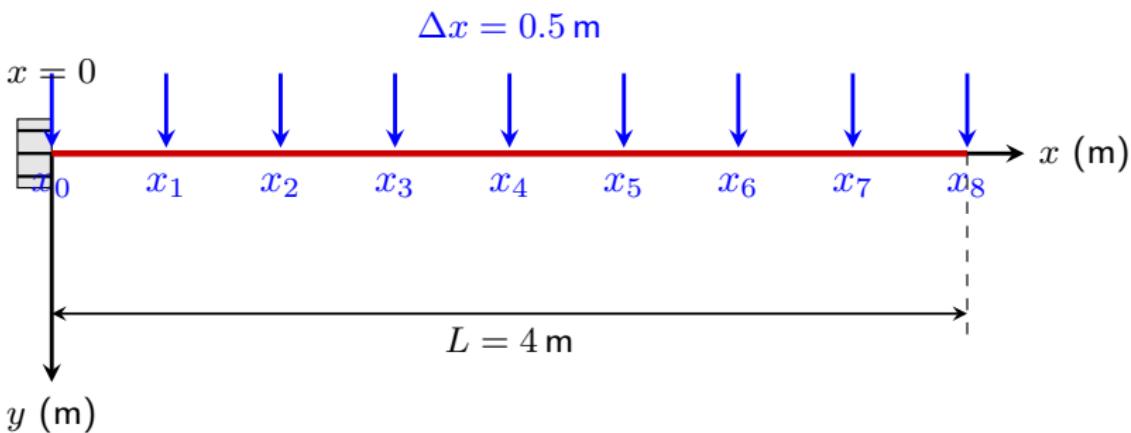
- Toy examples:

```
1 import numpy as np
2
3 a = np.arange(1, 10, 2) # step size: 2
4 b = np.arange(1, 10, 2.5) # step size: 2.5
```

$$\mathbf{a} = (1, 3, 5, 7, 9)^{\top} \quad \mathbf{b} = (1, 3.5, 6, 8.5)^{\top}$$

## np.linspace(): Specifying Number of Points

Given  $\Delta x = 0.5$ , the number of steps is  $L/\Delta x = 8$ .



```
1 import numpy as np
2
3 # Equally spaced points between 0 and 4
4 x = np.linspace(0, 4, 5)  # 4 / 1 + 1 = 5
5 x = np.linspace(0, 4, 9)  # 4 / 0.5 + 1 = 9
```

## Basic Operations: Element-Wise Product

- Vectors of the same length, e.g.,

$$\mathbf{a} = (20, 30, 40, 50)^\top \quad \mathbf{b} = (0, 1, 2, 3)^\top$$

```
1 import numpy as np
2
3 a = np.array([20, 30, 40, 50])
4 b = np.array([0, 1, 2, 3])
5 # b = np.arange(4)
6 c = a * b # new array
7 print(c)
```

## Basic Operations: Element-Wise Product

- Vectors of the same length, e.g.,

$$\mathbf{a} = (20, 30, 40, 50)^\top \quad \mathbf{b} = (0, 1, 2, 3)^\top$$

```
1 import numpy as np
2
3 a = np.array([20, 30, 40, 50])
4 b = np.array([0, 1, 2, 3])
5 # b = np.arange(4)
6 c = a * b # new array
7 print(c)
```

- Matrices of the same size, e.g.,

$$\mathbf{A} = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \quad \mathbf{B} = \begin{bmatrix} 5 & 6 \\ 7 & 8 \end{bmatrix}$$

```
1 A = np.array([[1, 2], [3, 4]])
2 B = np.array([[5, 6], [7, 8]])
3 C = A * B
4 print(c)
```

# Matrix-Vector Multiplication

## A system of linear equations.

- Let's solve:

$$\begin{cases} 3x + 2y = 5 \\ x - y = 0 \end{cases} \Rightarrow \begin{bmatrix} 3 & 2 \\ 1 & -1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 5 \\ 0 \end{bmatrix} \Rightarrow \begin{cases} x = 1 \\ y = 1 \end{cases}$$

```
1 import numpy as np
2
3 A = np.array([[3, 2], [1, -1]])
4 xy = np.array([1, 1])
5 b = A @ x # multiplication with the symbol @
6 print(b)
```

## np.random.rand(): Generating Random Values

np.random.rand() creates an array of the given shape and populate it with random samples from a **uniform distribution** over [0, 1).

- np.random.seed() function is used to initialize the pseudo-random number generator in NumPy
- Generate a **vector**:

```
1 import numpy as np
2 np.random.seed(0)
3
4 a = np.random.rand(4)
```

$$\mathbf{a} = (0.5488135, 0.71518937, 0.60276338, 0.54488318)^\top$$

- Generate a **matrix**:

```
1 import numpy as np
2 np.random.seed(0)
3
4 A = np.random.rand(2, 3)
```

$$\mathbf{A} = \begin{bmatrix} 0.5488135 & 0.71518937 & 0.60276338 \\ 0.54488318 & 0.4236548 & 0.64589411 \end{bmatrix}$$

## np.reshape(): Reshaping Arrays

- Converting matrix into vector

Given a matrix  $A = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix}$ , there are two strategies:

```
1 import numpy as np
2
3 A = np.array([[1, 2, 3], [4, 5, 6]])
4 a1 = np.reshape(A, (6)) # C-like index ordering
5 print(a1)
6 a2 = np.reshape(A, (6), order = 'F') # Fortran-like
    index ordering
7 print(a2)
```

$$\mathbf{a}_1 = (1, 2, 3, 4, 5, 6)^\top \quad \mathbf{a}_2 = (1, 4, 2, 5, 3, 6)^\top$$

## np.reshape(): Reshaping Arrays

- Converting vector into matrix

How about this?

$$\mathbf{a}_1 = (1, 2, 3, 4, 5, 6)^\top$$

```
1 A1 = np.reshape(a1, (2, 3)) # C-like index ordering
2 print(A1)
3 A2 = np.reshape(a1, (2, 3), order = 'F') # Fortran-like
   index ordering
4 print(A2)
```

$$\mathbf{A}_1 = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix} \quad \mathbf{A}_2 = \begin{bmatrix} 1 & 3 & 5 \\ 2 & 4 & 6 \end{bmatrix}$$

# Indexing

- Given a vector

```
1 import numpy as np
2 np.random.seed(0)
3
4 a = np.random.rand(10)
5 print(a)
```

Result:

```
1 [0.5488135  0.71518937  0.60276338  0.54488318  0.4236548
   0.64589411  0.43758721  0.891773    0.96366276
   0.38344152]
```

- Indexing

```
1 i = 1
2 j = 7
3 print(a[i])      # 2nd
4 print(a[j])      # 8th
5 print(a[i :])    # 2nd to the last
6 print(a[: j])    # 1st to 7th
7 print(a[i : j])  # 2nd to 7th
```

# Indexing

- Given a matrix

```
1 import numpy as np
2 np.random.seed(0)
3
4 A = np.random.rand(7, 5)
5 print(A)
6 print(A[2 : 4, 3 : 5])
```

$$A = \begin{bmatrix} 0.5488135 & 0.71518937 & 0.60276338 & 0.54488318 & 0.4236548 \\ 0.64589411 & 0.43758721 & 0.891773 & 0.96366276 & 0.38344152 \\ 0.79172504 & 0.52889492 & 0.56804456 & 0.92559664 & 0.07103606 \\ 0.0871293 & 0.0202184 & 0.83261985 & 0.77815675 & 0.87001215 \\ 0.97861834 & 0.79915856 & 0.46147936 & 0.78052918 & 0.11827443 \\ 0.63992102 & 0.14335329 & 0.94466892 & 0.52184832 & 0.41466194 \\ 0.26455561 & 0.77423369 & 0.45615033 & 0.56843395 & 0.0187898 \end{bmatrix}$$

## Quick Summary

### Wednesday's Class:

- Difference between NumPy array and Python list
- Writing of algebraic data with NumPy arrays
- Built-in functions, e.g., `np.ones()`, `np.zeros()`, and `np.eye()`
- NumPy sequences with `np.arange()` (set step size)
- NumPy sequences with `np.linspace()` (set the number of steps)
- Basic operations: Element-wise product `*` and matrix-vector multiplication `@` (“at” symbol)
- Random value generation with `np.random.rand()`
- Reshaping arrays (matrix to vector, or vector to matrix): `np.reshape()`
- Indexing

# Indexing

- Given a matrix

```
1 import numpy as np
2 np.random.seed(0)
3
4 A = np.random.rand(7, 5)
5 print(A)
6 print(A[2, 4]) # 3rd row, 5th column
```

$$A = \begin{bmatrix} 0.5488135 & 0.71518937 & 0.60276338 & 0.54488318 & 0.4236548 \\ 0.64589411 & 0.43758721 & 0.891773 & 0.96366276 & 0.38344152 \\ 0.79172504 & 0.52889492 & 0.56804456 & 0.92559664 & 0.07103606 \\ 0.0871293 & 0.0202184 & 0.83261985 & 0.77815675 & 0.87001215 \\ 0.97861834 & 0.79915856 & 0.46147936 & 0.78052918 & 0.11827443 \\ 0.63992102 & 0.14335329 & 0.94466892 & 0.52184832 & 0.41466194 \\ 0.26455561 & 0.77423369 & 0.45615033 & 0.56843395 & 0.0187898 \end{bmatrix}$$

# Indexing

- Given a matrix

```
1 import numpy as np
2 np.random.seed(0)
3
4 A = np.random.rand(7, 5)
5 print(A)
6 print(A[:, 4]) # 5th column
```

$$A = \begin{bmatrix} 0.5488135 & 0.71518937 & 0.60276338 & 0.54488318 & 0.4236548 \\ 0.64589411 & 0.43758721 & 0.891773 & 0.96366276 & 0.38344152 \\ 0.79172504 & 0.52889492 & 0.56804456 & 0.92559664 & 0.07103606 \\ 0.0871293 & 0.0202184 & 0.83261985 & 0.77815675 & 0.87001215 \\ 0.97861834 & 0.79915856 & 0.46147936 & 0.78052918 & 0.11827443 \\ 0.63992102 & 0.14335329 & 0.94466892 & 0.52184832 & 0.41466194 \\ 0.26455561 & 0.77423369 & 0.45615033 & 0.56843395 & 0.0187898 \end{bmatrix}$$

# Indexing

- Given a matrix

```
1 import numpy as np
2 np.random.seed(0)
3
4 A = np.random.rand(7, 5)
5 print(A)
6 print(A[:, : 4]) # 1st to 4th columns
```

$A =$

0.5488135	0.71518937	0.60276338	0.54488318	0.4236548
0.64589411	0.43758721	0.891773	0.96366276	0.38344152
0.79172504	0.52889492	0.56804456	0.92559664	0.07103606
0.0871293	0.0202184	0.83261985	0.77815675	0.87001215
0.97861834	0.79915856	0.46147936	0.78052918	0.11827443
0.63992102	0.14335329	0.94466892	0.52184832	0.41466194
0.26455561	0.77423369	0.45615033	0.56843395	0.0187898

## np.where(): Performing Conditional Operations

- It acts as a vectorized alternative to standard `if-else` loops
- It allows for data filtering, conditional value replacement, and index retrieval based on specific conditions
- The basic syntax for `np.where()`:

```
1 import numpy as np
2 np.random.seed(0)
3
4 a = np.random.rand(5)
5 print(a)
6 index = np.where(a > 0.5)
7 print(index)
```

- Condition:  $a > 0.5$

$$\mathbf{a} = (0.5488135, 0.71518937, 0.60276338, 0.54488318, 0.4236548)^\top$$

- Output: `print(index)`

```
1 array([0, 1, 2, 3]),)
```

## np.where(): Performing Conditional Operations

- It acts as a vectorized alternative to standard `if-else` loops
- It allows for data filtering, conditional value replacement, and index retrieval based on specific conditions
- The basic syntax for `np.where()`:

```
1 import numpy as np
2 np.random.seed(0)
3
4 a = np.random.rand(5)
5 print(a)
6 index = np.where((a > 0.5) & (a < 0.7))
7 print(index)
```

- Condition:  $a > 0.5$  and  $a < 0.7$

$$\mathbf{a} = (0.5488135, 0.71518937, 0.60276338, 0.54488318, 0.4236548)^T$$

- Output: `print(index)`

```
1 array([0, 2, 3]),)
```

## np.where(): Performing Conditional Operations

- The basic syntax for `np.where()`:

```
1 import numpy as np
2
3 A = np.array([[1, 2, 3], [4, 5, 6]])
4 index = np.where((A > 1) & (A < 5))
5 print(index)
```

- Condition:  $A > 1$  and  $A < 5$

$$A = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix}$$

- The index set:  $\{(1, 2), (1, 3), (2, 1)\}$

## np.where(): Performing Conditional Operations

- The basic syntax for `np.where()`:

```
1 import numpy as np
2
3 A = np.array([[1, 2, 3], [4, 5, 6]])
4 index = np.where((A > 1) & (A < 5))
5 print(index)
```

- Condition:  $A > 1$  and  $A < 5$

$$A = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix}$$

- The index set:  $\{(1, 2), (1, 3), (2, 1)\}$
- How about the index set in `np.where()`?  
`print(index)`

```
1 (array([0, 0, 1]), array([1, 2, 0]))
```

row index + column index!!!

## Transposing Arrays

- Transpose of matrix:

$$\mathbf{A} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix} \quad \Rightarrow \quad \mathbf{A}^T = \begin{bmatrix} 1 & 4 \\ 2 & 5 \\ 3 & 6 \end{bmatrix}$$

```
1 import numpy as np
2
3 A = np.array([[1, 2, 3], [4, 5, 6]])
4 print(A.T)
```

- An alternative:

```
1 print(A.transpose())
```

## np.flip(): Flipping Arrays

- Flip or reverse a vector

```
1 import numpy as np
2
3 a = np.array([1, 2, 3, 4, 5, 6, 7, 8])
4 # a = np.arange(1, 9)
5 a_flip = np.flip(a)
6 print(a_flip)
```

$$\mathbf{a} = (1, 2, 3, 4, 5, 6, 7, 8)^\top \Rightarrow \mathbf{a}_{\text{flip}} = (8, 7, 6, 5, 4, 3, 2, 1)^\top$$

## np.flip(): Flipping Arrays

- Flip **only the rows** of a matrix:

$$\mathbf{A} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix} \quad \Rightarrow \quad \mathbf{A}_{\text{row}} = \begin{bmatrix} 4 & 5 & 6 \\ 1 & 2 & 3 \end{bmatrix}$$

```
1 import numpy as np
2
3 A = np.array([[1, 2, 3], [4, 5, 6]])
4 A_row = np.flip(A, axis = 0)
5 print(A_row)
```

## np.flip(): Flipping Arrays

- Flip **only the columns** of a matrix:

$$\mathbf{A} = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix} \quad \Rightarrow \quad \mathbf{A}_{\text{column}} = \begin{bmatrix} 3 & 2 & 1 \\ 6 & 5 & 4 \end{bmatrix}$$

```
1 import numpy as np
2
3 A = np.array([[1, 2, 3], [4, 5, 6]])
4 A_column = np.flip(A, axis = 1)
5 print(A_column)
```

## np.flip(): Flipping Arrays

- Flip **rows and columns** of a matrix simultaneously:

$$A = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix} \quad \Rightarrow \quad A_{\text{flip}} = \begin{bmatrix} 6 & 5 & 4 \\ 3 & 2 & 1 \end{bmatrix}$$

```
1 import numpy as np
2
3 A = np.array([[1, 2, 3], [4, 5, 6]])
4 A_flip = np.flip(A)
5 print(A_flip)
```

## Stacking Together Different Arrays

`np.vstack()`

- Stacking two arrays (**same number of columns**) **vertically**:

```
1 import numpy as np
2
3 A = np.array([[1, 2, 3], [4, 5, 6]])
4 B = np.array([[10, 11, 12], [13, 14, 15], [16, 17,
   18]])
5 C = np.vstack((A, B))
6 print(C)
```

- Stacking  $A$  and  $B$  vertically

$$A = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \end{bmatrix} \quad B = \begin{bmatrix} 10 & 11 & 12 \\ 13 & 14 & 15 \\ 16 & 17 & 18 \end{bmatrix} \quad \Rightarrow \quad C = \begin{bmatrix} 1 & 2 & 3 \\ 4 & 5 & 6 \\ 10 & 11 & 12 \\ 13 & 14 & 15 \\ 16 & 17 & 18 \end{bmatrix}$$

with 5 rows and 3 columns.

## Stacking Together Different Arrays

### np.hstack()

- Stacking two arrays (**same number of rows**) **horizontally**:

```
1 import numpy as np
2
3 A = np.array([[1, 2], [3, 4]])
4 B = np.array([[10, 11, 12], [13, 14, 15]])
5 C = np.hstack(A, B)
6 print(C)
```

- Stacking  $A$  and  $B$  horizontally

$$A = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \quad B = \begin{bmatrix} 10 & 11 & 12 \\ 13 & 14 & 15 \end{bmatrix} \quad \Rightarrow \quad C = \begin{bmatrix} 1 & 2 & 10 & 11 & 12 \\ 3 & 4 & 13 & 14 & 15 \end{bmatrix}$$

with 2 rows and 5 columns.

## Basic Statistics

Given a vector  $(x_1, x_2, \dots, x_n)^\top$  of length  $n$ :

- Sum

$$\sum_{i=1}^n x_i$$

```
1 import numpy as np
2
3 x = np.arange(10)
4 print(np.sum(x))
```

- Mean

$$\frac{1}{n} \sum_{i=1}^n x_i$$

```
1 print(np.mean(x))
```

- Minimum and maximum values

```
1 print(np.min(x))
2 print(np.max(x))
```

## Basic Statistics

cov, std, var

TBD

## Saving and Loading Arrays

## How to save and load NumPy objects?

## The deflection of cantilever beam

.npy, .csv, .txt