

Chapter 0: Introduction to Engineering Software for Mechatronic Systems

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Learning Objectives

By the end of this chapter, you will:

- Understand the role of software in mechatronic systems
- Distinguish between scripting and control software
- Object-Oriented Programming (OOP)
- Compare procedural vs object-oriented programming paradigms
- Set up a professional development environment
- Initialize and manage a Git repository
- Organize a Python project structure

What is a Mechatronic System?

Definition: A system combining:

- **Mechanics** - Physical structures and components
- **Electronics** - Electrical hardware and controllers
- **Software** - Logic and decision making
- **Control** - Feedback loops and regulation

Real-World Examples

- Industrial robotic arms
- Autonomous vehicles
- Medical devices
- Manufacturing equipment

The Role of Software in Mechatronics

Software Functions

1. **Sensing** - Process sensor data from the environment
2. **Decision Making** - Plan actions based on current state
3. **Control** - Execute commands to actuators
4. **Monitoring** - Verify system health and safety

Why Software Matters

- Determines system behavior and capabilities
- Often determines product success/failure
- Must handle real-time constraints
- Needs to be maintainable and testable

Scripting vs Control Software

Scripting Software

Purpose: Automate repetitive tasks

- Simple, linear execution
- Direct user interaction
- High-level operations
- Example: Data processing scripts

```
# Simple scripting example
for measurement in sensor_readings:
    print(measurement)
    save_to_file(measurement)
```

Scripting vs Control Software (cont.)

Control Software

Purpose: Manage real-time system behavior

- Reactive to environment changes
- Runs continuously (loops/events)
- Strict timing requirements
- Complex state management
- Safety critical

Scripting vs Control Software (cont.)

Control Software

```
# Control software pattern
while system_running:
    sensor_data = read_sensors()
    decision = make_decision(sensor_data)
    execute_action(decision)
    check_safety_constraints()
```

Procedural Programming

Characteristics

- Functions are primary building blocks
- Code executed as sequence of procedures
- State shared via global variables
- Focus on **what** the code does

Advantages

- Straightforward for simple programs
- Easy to understand execution flow
- Minimal overhead

Procedural Programming

Disadvantages

- Difficult to maintain as complexity grows
- State management becomes chaotic
- Code reuse is limited
- Testing is challenging

Procedural Programming Example

```
# Procedural approach
temperature = 0
sensor_error = False

def read_temperature():
    global temperature, sensor_error
    try:
        temperature = get_raw_value()
        sensor_error = False
    except:
        sensor_error = True
        temperature = -999

def check_temperature():
    if not sensor_error:
        if temperature > 100:
            trigger_alarm()

# Main loop
while True:
    read_temperature()
    check_temperature()
```

Why Python in Programming Method 2 (After C++ in PM1)?

Context

Students have already completed **Programming Method 1 (C++)**, including:

- Variables and data types
- Control structures
- Functions and classes
- Compilation and memory concepts

→ This course **does not replace C++**

→ It **builds on that foundation**

Programming Method 2 — Python

Focus:

How engineers design control software systems

- Software architecture and structure
- Object-Oriented Programming (OOP)
- State modeling (FSMs)
- Algorithm clarity
- System integration
- Unit testing

Why Python Is Used in This Course

Python is chosen to:

- Remove **accidental complexity**
- Reduce syntactic overhead
- Highlight **engineering design concepts**
- Focus on **correctness, structure, and reasoning**

The goal is **better design**, not faster coding.

Key Takeaway

- **C++** teaches you *how programs run*
- **Python** teaches you *how systems are designed*

A professional mechatronics engineer must master **both**.

Object-Oriented Programming (OOP)

Characteristics

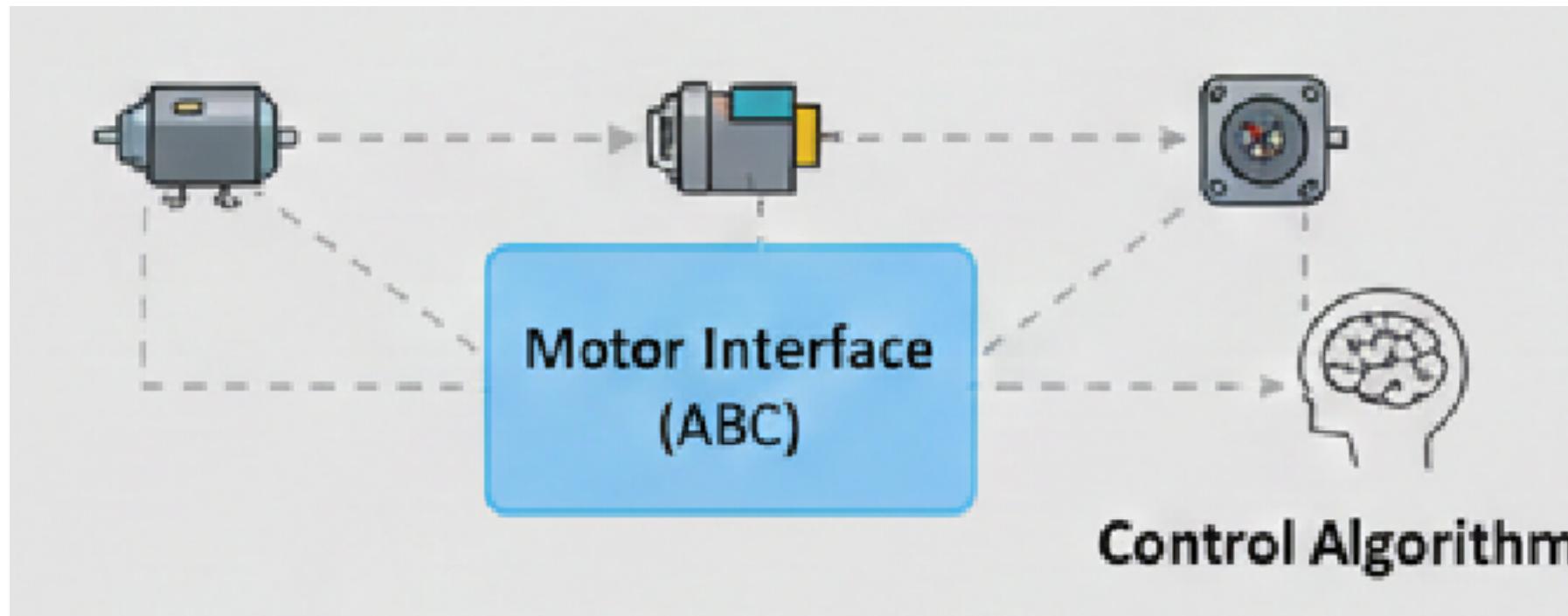
- Objects encapsulate data and behavior
- Code organized around entities/concepts
- Encapsulation hides internal details
- Focus on **objects** and their interactions

Core Principles

- **Abstraction** - Simplify complex systems, define what a component does
- **Encapsulation** - Hide complexity, protect how functions works internally
- **Inheritance** - Share common behavior
- **Polymorphism** - Flexible interfaces, use components interchangeably

Abstraction — Simplifying Complex Systems

Abstraction is the process of hiding implementation details and showing only the essential features of an object.



Abstraction — Simplifying Complex Systems (cont)

```
from abc import ABC, abstractmethod # ABC is Abstract Base Class in Python
class Motor(ABC):
    @abstractmethod
    def set_speed(self, rpm):
        """Every motor MUST implement this method"""
        pass
    @abstractmethod
    def stop(self):
        """Every motor MUST implement this method"""
        pass
```

The Motor abstract base class defines a *hardware-independent* interface for torque control. Allowing control algorithms to operate without knowledge of motor type, communication protocol, or simulation environment.

Astraction Extended Example

```
from abc import ABC, abstractmethod

# 2. CONCRETE IMPLEMENTATION A: Stepper Motor
class StepperMotor(Motor):
    def set_speed(self, rpm):
        # Hidden complexity: Step logic
        print(f">>> [Hardware Call] Pulsing GPIO pins for {rpm} RPM.")
        print(f"Stepper Motor: Moving at {rpm} RPM.")

    def stop(self):
        print("Stepper Motor: Engaging holding torque and stopping.")

# 3. CONCRETE IMPLEMENTATION B: DC Motor
class DCmotor(Motor):
    def set_speed(self, rpm):
        # Hidden complexity: PWM (Pulse Width Modulation) logic
        voltage = rpm * 0.01
        print(f">>> [Hardware Call] Setting PWM Duty Cycle to {voltage}V.")
        print(f"DC Motor: Spinning at {rpm} RPM.")

    def stop(self):
        print("DC Motor: Shorting terminals for dynamic braking.")
```

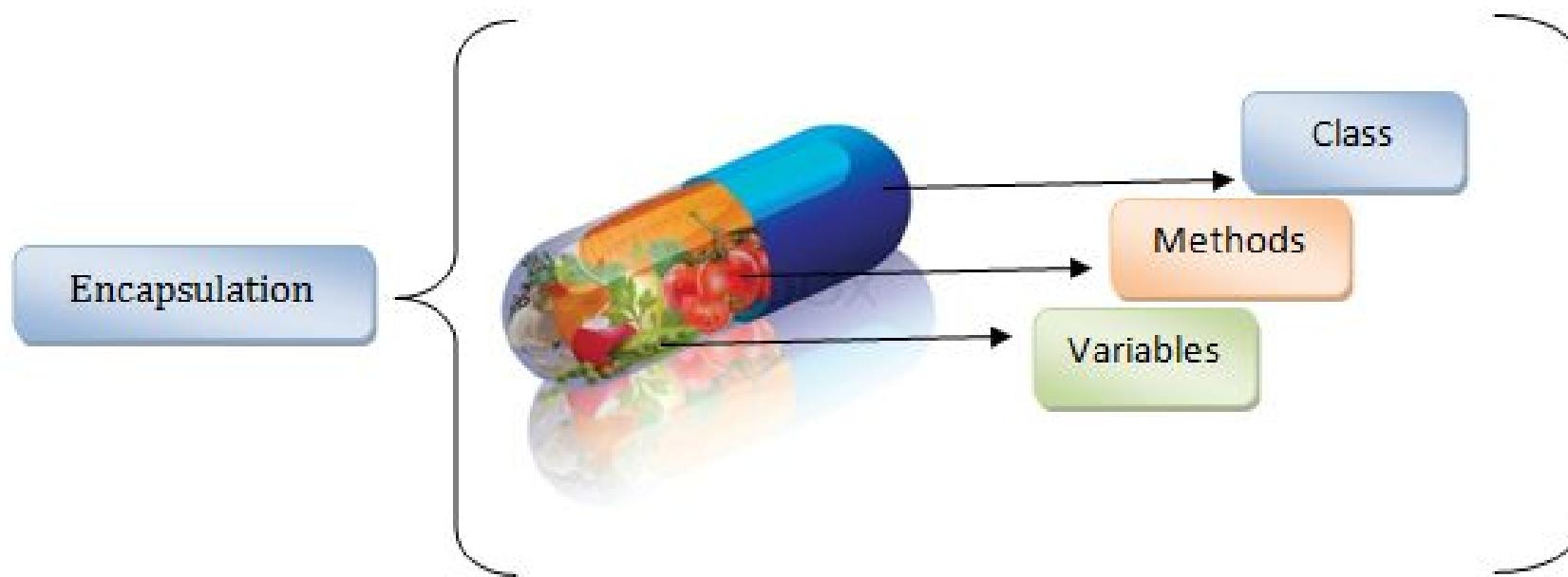
Astraction Print out result

```
--- Testing Stepper ---
>>> [Hardware Call] Pulsing GPIO pins for 1500 RPM.
Stepper Motor: Moving at 1500 RPM.
Stepper Motor: Engaging holding torque and stopping.

--- Testing DC Motor ---
>>> [Hardware Call] Setting PWM Duty Cycle to 30.0V.
DC Motor: Spinning at 3000 RPM.
DC Motor: Shorting terminals for dynamic braking.
```

Encapsulation

Encapsulation is the bundling of data (variables) and methods that operate on the data into a single unit, usually a class.



source: <https://logicmojo.com/encapsulation-in-oops>

Encapsulation Example

Encapsulation bundles the data (name, `_offset`, `_enable`) and methods (`enable`, `disable`) together

```
class Sensor:  
    def __init__(self, name: str, offset: float = 0.5):  
        self.name = name  
        self.__offset = offset      # private calibration parameter  
        self.__enabled = True       # private internal state  
  
    def enable(self):  
        self.__enabled = True  
  
    def disable(self):  
        self.__enabled = False
```

Encapsulation Example (Check jupyter notebook)

```
class Sensor:
    def __init__(self, name: str, offset: float = 0.5):
        self.name = name
        self.__offset = offset      # private calibration parameter
        self.__enabled = True       # private internal state

    def enable(self):
        self.__enabled = True

    def disable(self):
        self.__enabled = False

    def calibrate(self, new_offset: float):
        if not isinstance(new_offset, (int, float)):
            raise TypeError("Offset must be numeric")

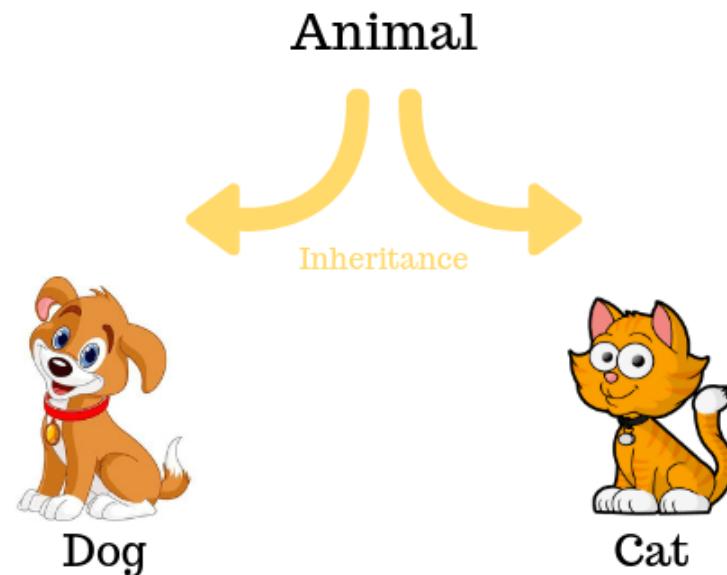
        if abs(new_offset) > 10.0:
            raise ValueError("Calibration offset out of range")

        self.__offset = new_offset

    def get_calibrated_value(self, raw_value: float) -> float:
        if not self.__enabled:
            raise RuntimeError(f"Sensor {self.name} is disabled")
        return raw_value - self.__offset
```

Inheritance

Inheritance is the mechanism of basing an object or class upon another object (prototype-based inheritance) or class (class-based inheritance), retaining similar implementation.



Inheritance Example

Inheritance allows a specific type of **Sensor** to "inherit" the properties of a general sensor without rewriting code.

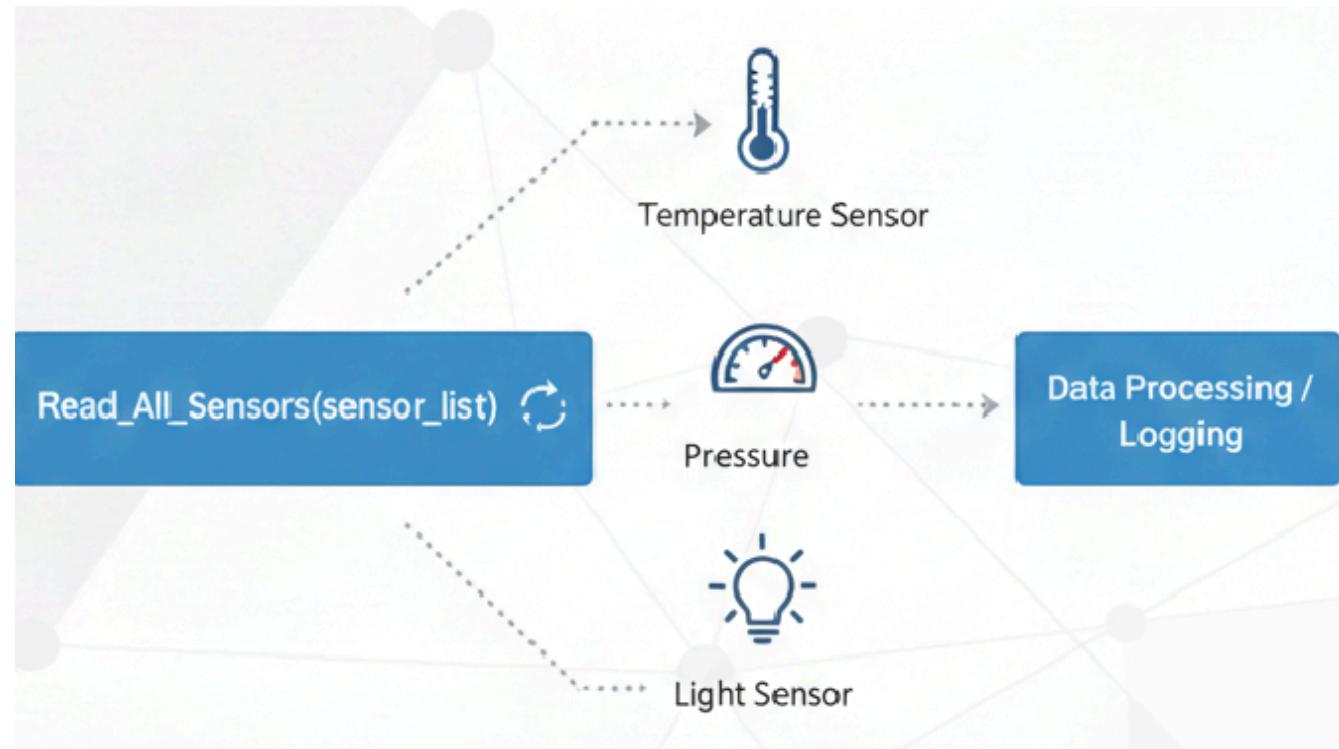
```
class UltrasonicSensor(Sensor):
    def __init__(self, name, pin):
        super().__init__(name) # Inherit from parent
        self.pin = pin

    def ping(self):
        return "Sending sonic pulse..."

dist_sensor = UltrasonicSensor("HC-SR04", 12)
print(dist_sensor.name) # Accessed from parent
print(dist_sensor.ping()) # Own unique method
```

Polymorphism

Polymorphism allows a value or variable to have more than one type and allows a given operation to be performed on values of more than one type.



Polymorphism Example (check Jupyter)

Polymorphism allows different objects to be treated the same way. In mechatronics, you might want to "read" all sensors in a loop, regardless of whether they are Temperature, Pressure, or Light sensors.

```
class TemperatureSensor:  
    def read(self):  
        return "24°C"  
  
class PressureSensor:  
    def read(self):  
        return "101.3 kPa"  
  
# Polymorphism in action  
sensors = [TemperatureSensor(), PressureSensor()]  
  
for s in sensors:  
    print(s.read()) # Same method name, different behaviors
```

Why Polymorphism Critical in Robotics

Without polymorphism ✗:

```
if sensor_type == "ultrasonic":  
    read_ultrasonic()  
elif sensor_type == "temperature":  
    read_temperature()
```

With polymorphism ✓:

```
sensor.read()
```

Object-Oriented Programming Example

```
# Object-oriented approach
class TemperatureSensor:
    def __init__(self):
        self._value = 0
        self._error = False

    def read(self):
        try:
            self._value = self._get_raw_value()
            self._error = False
        except Exception as e:
            self._error = True
            self._value = -999

    def is_valid(self):
        return not self._error

    def get_value(self):
        return self._value if self.is_valid() else None

# Usage is cleaner and more intuitive
sensor = TemperatureSensor()
sensor.read()
if sensor.is_valid():
    print(sensor.get_value())
```

Apply Pseudocode Before Coding in Python

What is Pseudocode

Pseudocode is a **human-readable way** to describe the steps of an algorithm using programming-like structures (assignments, conditions, loops) **without strict syntax**.

<https://en.wikipedia.org/wiki/Pseudocode>

Pseudocode Cheat Sheet (Main Syntax)

Start/End Program

```
BEGIN PROGRAM  
SET x ← value  
READ input  
PRINT output  
END PROGRAM
```

Conditional

```
IF condition THEN  
action  
ELSE  
action  
END IF
```

Comparison Operators

= ≠ < ≤ > ≥

Loop

```
WHILE condition DO  
action  
END WHILE
```

```
FOR i ← start TO end DO  
action  
END FOR
```

```
REPEAT  
action  
UNTIL condition
```

Case Selection

```
CASE variable OF  
value1: action  
value2: action  
DEFAULT: action  
END CASE
```

Function

```
FUNCTION name(parameters)  
statements  
RETURN value  
END FUNCTION
```

How We Apply Pseudocode Before Coding in Python

- **Step 1 — Understand the Problem**

- Example problem:

```
Read a temperature sensor and convert °C to °F with F = (C × 9/5) + 32  
Ask:
```

What inputs exist?

What outputs are required?

What rules or formulas apply?

- **Step 2 — Identify Data and States**

```
INPUT: temperature in Celsius
```

```
OUTPUT: temperature in Fahrenheit
```

```
#Variables
```

```
temperature_c
```

```
temperature_f
```

How We Apply Pseudocode Before Coding in Python (cont.)

- Step 3 — Write the Pseudocode

```
BEGIN PROGRAM
```

```
    FUNCTION celsius_to_fahrenheit with temperature_c
```

```
        READ temperature sensor → temperature_c
```

```
        temperature_f ← celsius_to_fahrenheit(temperature_c)
```

```
        PRINT temperature_c and temperature_f
```

```
    END PROGRAM
```

Full Pseudocode of logging simple sensor

```
BEGIN PROGRAM

    FUNCTION celsius_to_fahrenheit(temp_c)
        RETURN (temp_c × 9 / 5) + 32
    END FUNCTION

    READ temperature sensor → temperature_c

    temperature_f ← celsius_to_fahrenheit(temperature_c)

    PRINT "Temperature:"
    PRINT temperature_c + " °C"
    PRINT temperature_f + " °F"

END PROGRAM
```

Lab 1: Development Environment Setup

Requirements

1. Python 3.8+ interpreter
2. A code editor (VS Code, PyCharm)
3. Git version control
4. Project directory structure

Installation Steps

1. Download Python from python.org
2. Install IDE of choice
3. Install Git: <https://git-scm.com/>
4. Verify installations with version commands

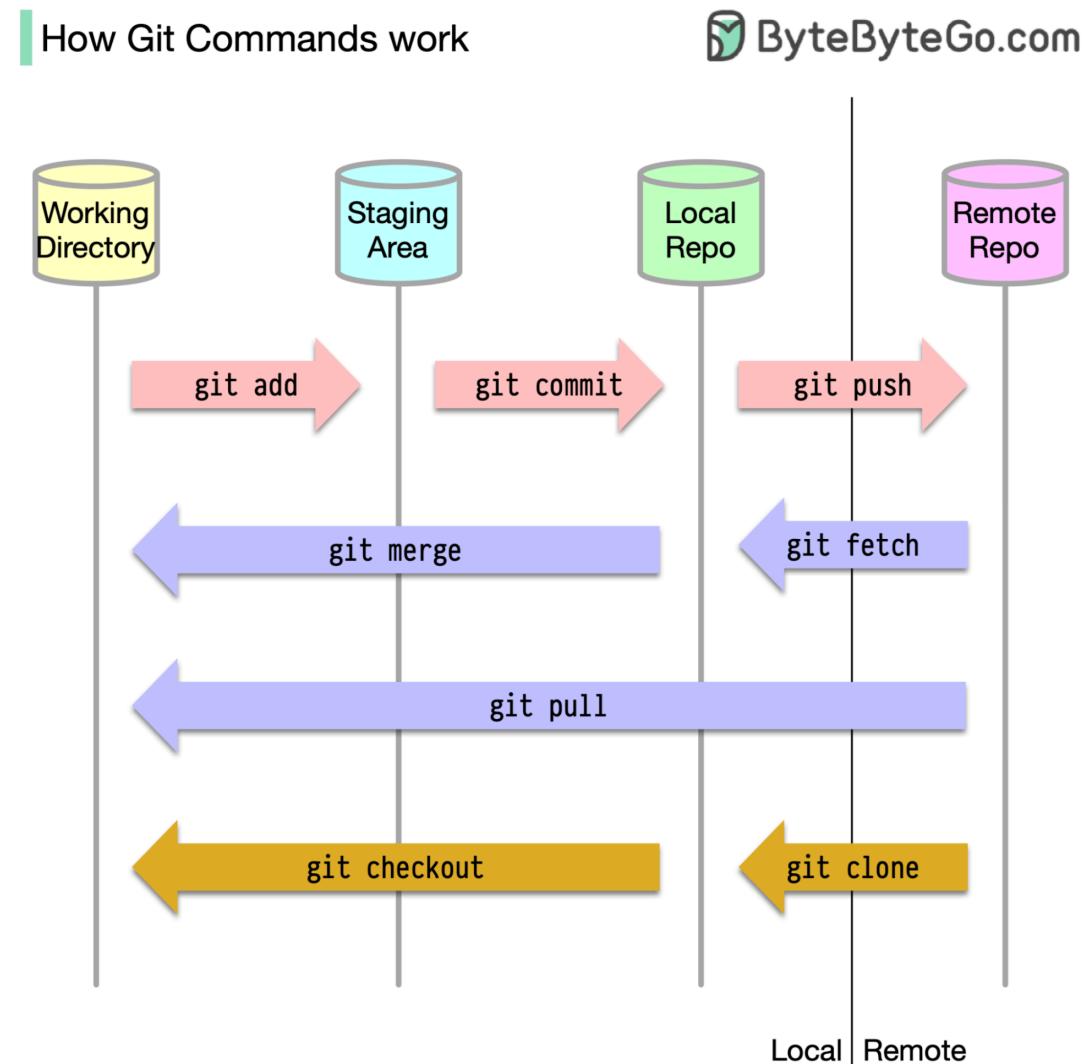
Verification Commands

```
# Check Python installation
python --version
# Output: Python 3.10.0 (or newer)

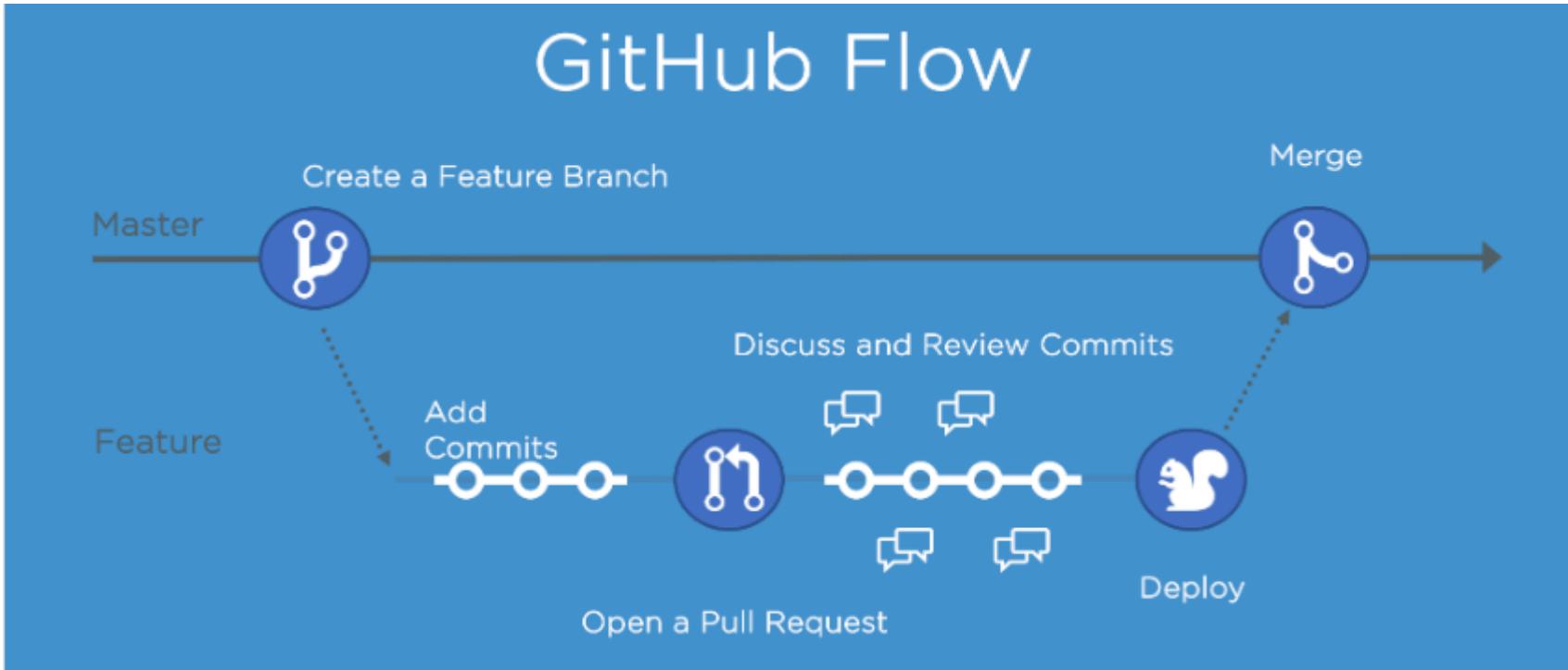
# Check Git installation
git --version
# Output: git version 2.34.1 (or newer)

# Create test directory
mkdir mechatronics-lab-0
cd mechatronics-lab-0
```

How git command works



git work flow



Lab 2: Git Repository Initialization

Initialize Repository

```
# Navigate to project directory
cd mechatronics-lab-0

# Initialize git repository
git init

# Configure git (one time setup)
git config user.name "Your Name"
git config user.email "your.email@example.com"

# Verify configuration
git config --list
```

Understanding Git Basics

Key Concepts

- **Repository** - Local copy of project with history
- **Commit** - Snapshot of changes with message
- **Branch** - Independent line of development
- **Remote** - Shared repository (GitHub, GitLab)

Common Workflow

```
git add <files>          # Stage changes
git commit -m "message"   # Save changes locally
git push origin main      # Upload to remote
git pull origin main      # Download updates
```

Lab 3: Python Project Structure

Recommended Organization

```
mechatronics-lab-0/
├── .git/                      # Git metadata
├── .gitignore                 # Files to ignore
├── README.md                  # Project description
├── requirements.txt            # Dependencies
└── src/
    ├── __init__.py
    ├── main.py
    └── sensors.py
└── tests/                     # Test files
    ├── __init__.py
    └── test_sensors.py
└── docs/                      # Documentation
```

Project Structure Details

.gitignore - Essential Entries

```
# Python
__pycache__/
*.pyc
*.pyo
*.egg-info/
.pytest_cache/
# IDE
.vscode/
.idea/
# Environment
venv/
env/
.env
# OS
.DS_Store
Thumbs.db
```

Python Package Structure

`__init__.py` - Makes package importable

```
# src/__init__.py
"""
Mechatronic Systems Control Package
Version 1.0
"""

__version__ = "1.0.0"
__author__ = "Your Name"

# Expose main classes/functions
from .sensors import TemperatureSensor
from .controllers import MotorController

__all__ = ['TemperatureSensor', 'MotorController']
```

Project Requirements File

requirements.txt

```
# Core dependencies
numpy>=1.19.0
scipy>=1.5.0
```

Installation

```
pip install -r requirements.txt
```

Best Practices for Mechatronic Software

Code Quality

- 1. Clear Names** - Use intention-revealing names
- 2. Small Functions** - Single responsibility principle
- 3. Comments** - Explain why, not what
- 4. Testing** - Write tests before code (TDD)
- 5. Documentation** - Document interfaces and APIs

Best Practices for Mechatronic Software (Cont.)

Version Control

1. Commit frequently with clear messages
2. One feature per branch
3. Review code before merging
4. Tag releases with version numbers

Clean Code Principles

For Mechatronic Systems

- **Reliability** - Code must work under stress
- **Readability** - Future maintainers will thank you
- **Testability** - Facilitate automated testing
- **Safety** - Handle edge cases and failures
- **Performance** - Real-time constraints matter

The Boy Scout Rule

"Leave the code a little cleaner than you found it"

Deliverable Checklist

Lab Deliverables

- [] Development environment installed (Python, Git, IDE)
- [] Verified all tools with version commands
- [] Git repository initialized with proper configuration
- [] `.gitignore` file created
- [] Project directory structure created
- [] README.md written with project description
- [] `requirements.txt` with dependencies listed
- [] `src/__init__.py` and main module structure

Deliverable Verification

Test Your Setup

```
# Test Python
python -c "print('Python works!')"

# Test Git
git status
git log --oneline

# Test project import
cd ..
python -c "from mechatronic_project import TemperatureSensor"

# Create first commit
git add .
git commit -m "Initial project setup"
git log --oneline
```

Summary

Key Takeaways

1. Mechatronic systems require careful software architecture
2. Scripting and control software serve different purposes
3. OOP provides better structure for complex systems
4. Professional development practices matter
5. Version control and testing are essential
6. Clean code principles improve maintainability

Remember

"Any fool can write code that a computer can understand. Good programmers write code that humans can understand." - Martin Fowler

Questions & Discussion

Topics for Lab Session:

- Installation troubleshooting
- Git workflow questions
- Python project organization tips
- Development environment preferences

Resources:

- Python docs: <https://docs.python.org/3/>
- Git tutorial: <https://git-scm.com/docs>
- GitHub: <https://github.com>
- Stack Overflow: <https://stackoverflow.com>

Appendix: Useful Commands Reference

Git Commands

```
git init                                # Initialize repo  
git clone <url>                          # Clone existing repo  
git add <file>                            # Stage changes  
git commit -m "msg"                         # Commit changes  
git push origin main                      # Push to remote  
git pull origin main                      # Pull from remote  
git branch <name>                          # Create branch  
git checkout <branch>                     # Switch branch  
git status                                 # Check repo status  
git log --oneline                         # View history
```

Python Commands

```
python --version          # Check version  
python <file>.py        # Run script  
python -m pytest         # Run tests  
python -m pip install <pkg> # Install package  
python -c "code"          # Run inline code  
python -m venv venv       # Create virtual env  
source venv/bin/activate # Activate venv
```

Appendix: Setup Troubleshooting

Issue: Python not found

Solution: Add Python to PATH environment variable

Issue: Git commits show wrong author

Solution: Set global git config

```
git config --global user.name "Your Name"  
git config --global user.email "your.email@example.com"
```

Issue: Import errors

Solution: Ensure `__init__.py` exists in package directories

Recommended Reading

- **Clean Code: A Handbook of Agile Software Craftsmanship** Robert C. Martin
- **Software Modeling and Design: UML, Use Cases, Patterns, and Software Architectures** Hassan Gomaa
- **Fluent Python: Clear, Concise, and Effective Programming** Luciano Ramalho
- **Robotics, Vision and Control: Fundamental Algorithms in Python** Peter Corke

Online

- Real Python: <https://realpython.com>
- Python official docs: <https://docs.python.org>
- GitHub Learning: <https://github.com/skills>