Project Name: Build a Virtual CPU Emulator

Week 04: Instruction Execution

Objective: The objective for this week is to develop the instruction fetch-decode-execute cycle, a fundamental component of the CPU's operation. The focus will be on implementing an efficient mechanism for fetching instructions, decoding them to understand their purpose, and executing them using the Arithmetic Logic Unit (ALU) and registers. This will establish the core functionality required for program execution and will be tested using simple programs.

1. Implement the instruction fetching mechanism.

The instruction-fetching mechanism is a critical component of a processor's control unit, responsible for fetching instructions from memory for execution. Here's an implementation of an instruction-fetching mechanism at a high level, often used in computer architecture.

Steps of Instruction Fetching

- **Program Counter (PC):** Holds the address of the next instruction.
- **Instruction Memory Access:** Access the instruction stored at the address in the PC.
- **Instruction Register (IR):** The read instruction is stored in another special register in the CPU, called the instruction register.

Without the instruction fetching process, the CPU cannot understand the instructions of a program and cannot act on them. This is the first and very important step in program execution.

2. Decode instructions and execute them using the ALU and registers.

Decoding and executing instructions using the Arithmetic Logic Unit (ALU) and registers is a key part of a computer's Instruction Execution Cycle. Here's a breakdown of the process:

A. **Fetch Stage**
The CPU fetches the next instruction from memory (pointed to by the **Program Counter (PC)**) and stores it in the **Instruction Register (IR)**.

B. **Decode Stage**
The instruction is decoded to determine:
   - The operation to be performed (e.g., addition, subtraction, logical operations).
   - The source and destination registers or memory addresses.
   - Whether immediate values (constants) are involved.

C. **Execute Stage (Using ALU and Registers)**
The execution process involves the **ALU**, **Registers**, and sometimes **Memory**:

1. **Identify the Operand Sources:**

- Operands are fetched from **registers** or **memory**, based on the instruction.
- Some instructions might include immediate values that are directly available in the instruction itself.

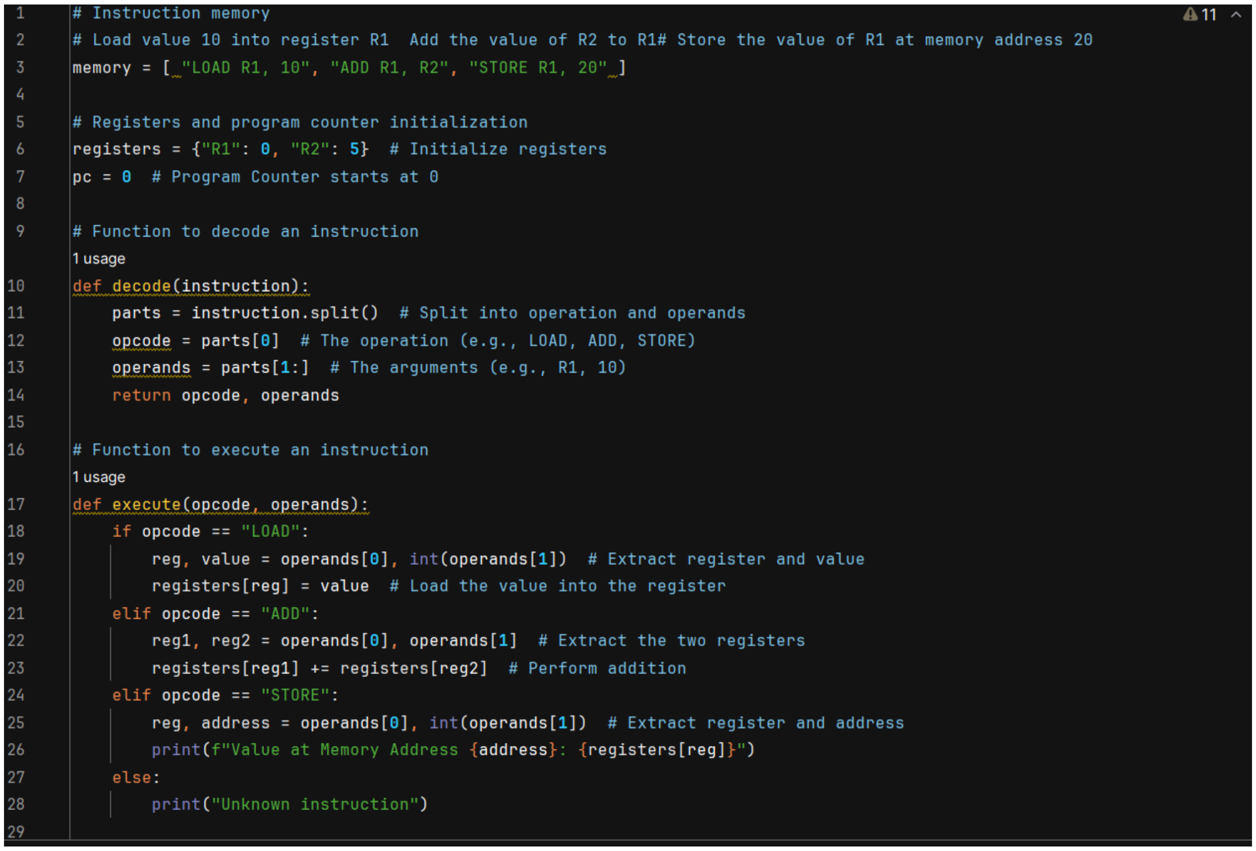
2. **ALU Performs the Operation:**
    - The ALU performs the operation specified in the instruction (e.g., addition, subtraction, AND, OR, etc.).
    - Control signals from the **Control Unit** dictate the type of operation.
3. **Store the Result:**
    - The result of the ALU operation is stored in a destination register or written back to memory.

Example: ADD Instruction

Instruction: ADD R1, R2, R3

1. **Fetch:** The CPU fetches the instruction ADD R1, R2, R3.
2. **Decode:**
    - Operation: ADD
    - Operands: R2 and R3
    - Destination: R1
3. **Execute:**
    - Fetch values from R2 and R3 registers.
    - Add value in the ALU: ValueR2 + ValueR3.
    - Store the result in R1.

3. Test with simple programs.



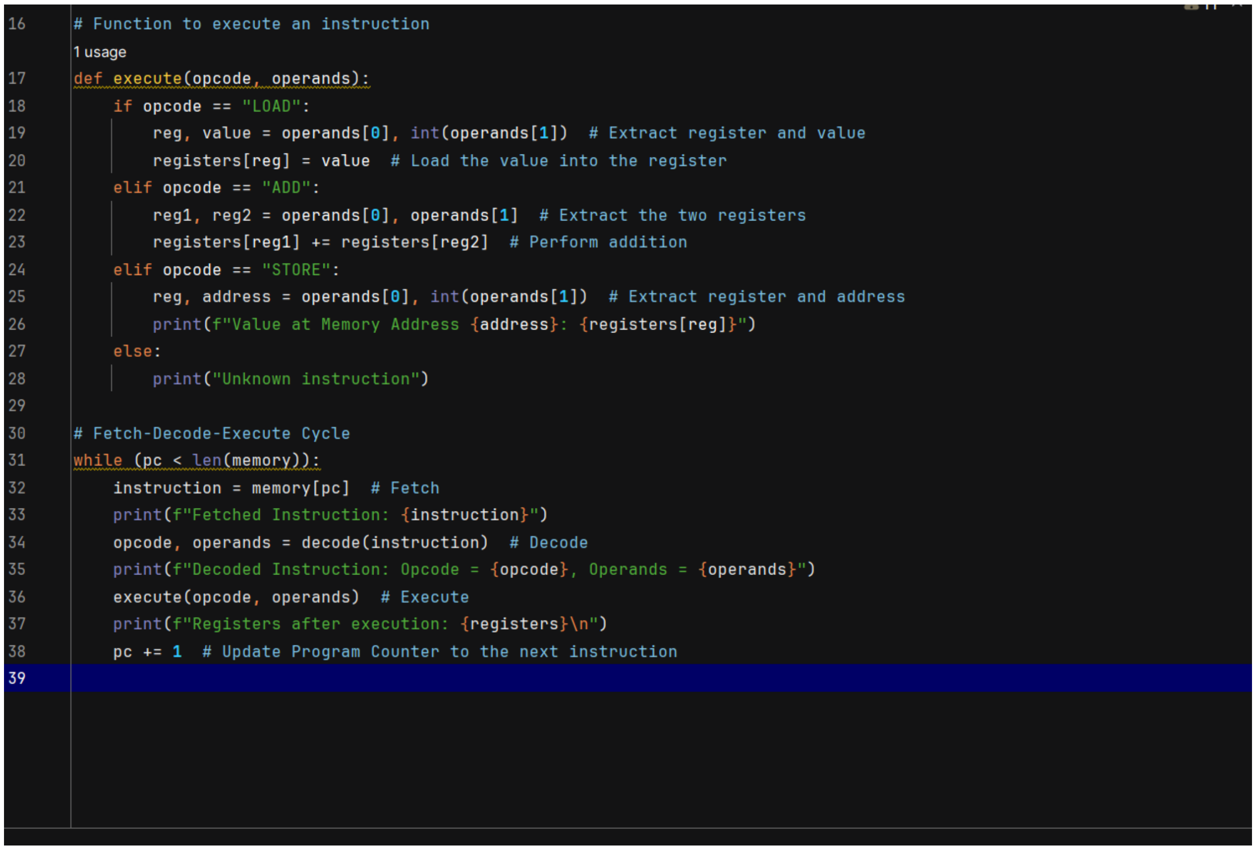
```python
# Instruction memory
# Load value 10 into register R1  Add the value of R2 to R1# Store the value of R1 at memory address 20
memory = [ "LOAD R1, 10", "ADD R1, R2", "STORE R1, 20" ]

# Registers and program counter initialization
registers = {"R1": 0, "R2": 5}  # Initialize registers
pc = 0  # Program Counter starts at 0

# Function to decode an instruction
1 usage
def decode(instruction):
    parts = instruction.split()  # Split into operation and operands
    opcode = parts[0]  # The operation (e.g., LOAD, ADD, STORE)
    operands = parts[1:]  # The arguments (e.g., R1, 10)
    return opcode, operands

# Function to execute an instruction
1 usage
def execute(opcode, operands):
    if opcode == "LOAD":
        reg, value = operands[0], int(operands[1])  # Extract register and value
        registers[reg] = value  # Load the value into the register
    elif opcode == "ADD":
        reg1, reg2 = operands[0], operands[1]  # Extract the two registers
        registers[reg1] += registers[reg2]  # Perform addition
    elif opcode == "STORE":
        reg, address = operands[0], int(operands[1])  # Extract register and address
        print(f"Value at Memory Address {address}: {registers[reg]}")
    else:
        print("Unknown instruction")

```



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        print(f"Value at Memory Address {address}: {registers[reg]}")
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# Fetch-Decode-Execute Cycle
while (pc < len(memory)):
    instruction = memory[pc]  # Fetch
    print(f"Fetched Instruction: {instruction}")
    opcode, operands = decode(instruction)  # Decode
    print(f"Decoded Instruction: Opcode = {opcode}, Operands = {operands}")
    execute(opcode, operands)  # Execute
    print(f"Registers after execution: {registers}\n")
    pc += 1  # Update Program Counter to the next instruction

```