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EE488 - Computer Architecture
Homework Assignment #6

Due day: 5/4/2025

Instruction:

1. **The homework answer sheet should contain the original questions and corresponding answers.**
2. **The answer sheet must be in MS-Word file format with Github links for the programming questions. As follows is the answer sheet name format.** ***<course_id>_week<week_number>_StudentID_FirstName_LastName.pdf***
3. **The program name in Github must follow the format like** ***<course_id>_week<week_number>_q<question_number>_StudentID_FirstName_LastName***
4. **Show screenshot of all running results, including the system date/time.**
5. **The calculation process must be typed if needed, handwriting can't be accepted.**
6. **Only accept homework submission uploaded via Canvas.**
7. **Overdue homework submission can't be accepted.**
8. **Takes academic honesty and integrity seriously (Zero Tolerance of Cheating & Plagiarism)**

1. Write Python def function to design 8-bits ALU based on the following opcodes. Note: The input parameters for A and B need to be converted to binary number in def function

Opcode	Operations
0000	Out = A + B
0001	Out = A - B
0010	Out = A * B
0011	Out = A / B
0100	Out = A << 1
0101	Out = A >> 1
0110	Out = A rotated left by 1
0111	Out = A rotated right by 1
1000	Out = A and B
1001	Out = A or B
1010	Out = A xor B

1011	Out = A nor B
1100	Out = A nand B
1101	Out = A xnor B
1110	Out = 1 if A>B else 0
1111	Out = 1 if A=B else 0

```python
def alu(opcode: str, A: int, B: int) -> str:
    """
    8-bit ALU.
    opcode: 4-bit string, e.g. '0000'
    A, B: integer inputs (any range)
    Returns: 8-bit binary string of the result.
    """
    # --- convert inputs to 8-bit values ---
    a = int(format(A & 0xFF, '08b'), 2)
    b = int(format(B & 0xFF, '08b'), 2)

    # --- decode opcode and compute out (may exceed 8 bits) ---
    if   opcode == '0000':  # add
        out = a + b
    elif opcode == '0001':  # sub
        out = a - b
    elif opcode == '0010':  # mul
        out = a * b
    elif opcode == '0011':  # div (integer)
        out = a // b if b != 0 else 0
    elif opcode == '0100':  # shift left logical
        out = (a << 1)
    elif opcode == '0101':  # shift right logical
        out = (a >> 1)
    elif opcode == '0110':  # rotate left by 1
        out = ((a << 1) & 0xFF) | ((a >> 7) & 0x01)
    elif opcode == '0111':  # rotate right by 1
        out = ((a >> 1) & 0x7F) | ((a & 0x01) << 7)
    elif opcode == '1000':  # and
        out = a & b
    elif opcode == '1001':  # or
        out = a | b
    elif opcode == '1010':  # xor
        out = a ^ b
    elif opcode == '1011':  # nor = ¬(A ∨ B)
        out = ~(a | b)
    elif opcode == '1100':  # nand = ¬(A ∧ B)
        out = ~(a & b)
    elif opcode == '1101':  # xnor = ¬(A ⊕ B)
```

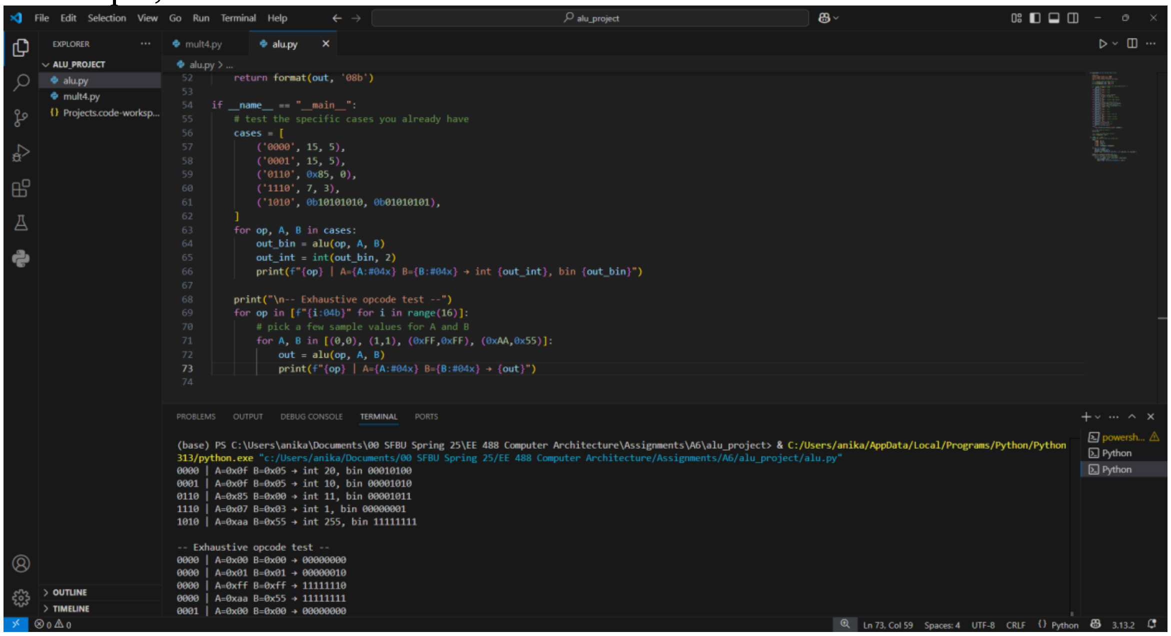
```
        out = ~(a ^ b)
    elif opcode == '1110':  # A > B ?
        out = 1 if a > b else 0
    elif opcode == '1111':  # A == B ?
        out = 1 if a == b else 0
    else:
        raise ValueError(f"Unknown opcode '{opcode}'")

    # --- mask result to 8 bits ---
    out &= 0xFF

    # --- return as 8-bit binary string ---
    return format(out, '08b')

if __name__ == "__main__":
    # test the specific cases you already have
    cases = [
        ('0000', 15, 5),
        ('0001', 15, 5),
        ('0110', 0x85, 0),
        ('1110', 7, 3),
        ('1010', 0b10101010, 0b01010101),
    ]
    for op, A, B in cases:
        out_bin = alu(op, A, B)
        out_int = int(out_bin, 2)
        print(f"{op} | A={A:#04x} B={B:#04x} → int {out_int}, bin
{out_bin}")

    print("\n-- Exhaustive opcode test --")
    for op in [f"{i:04b}" for i in range(16)]:
        # pick a few sample values for A and B
        for A, B in [(0,0), (1,1), (0xFF,0xFF), (0xAA,0x55)]:
            out = alu(op, A, B)
            print(f"{op} | A={A:#04x} B={B:#04x} → {out}")
```



2. Write Python programs to design a 4-bits multiplier which implements Booth's algorithm and one of multiplication algorithms from 3 versions shown in the handout of *Lec06-alu.pdf*, respectively.

```python
# mult4.py

def mult4_shiftadd(x: int, y: int) -> int:
    """
    4-bit unsigned shift-add multiplier (Version 1).
    Implements:
      for i in 0..3:
        if y[i] == 1: product += (x << i)
      shift y right each cycle.
    Returns 8-bit product of x * y (0..15 × 0..15 → 0..255).
    """
    mcand = x & 0xF      # 4-bit multiplicand
    mult  = y & 0xF      # 4-bit multiplier
    prod  = 0
    for _ in range(4):
        if mult & 1:
            prod += mcand
        mcand <<= 1
        mult  >>= 1
    return prod & 0xFF   # mask to 8 bits


def mult4_booth(x: int, y: int) -> int:
    """
    4-bit signed Booth's algorithm multiplier.
```

```
    x, y are treated as signed 4-bit (-8..+7). Returns signed 8-bit Python int.

    Algorithm (per Booth’s rules):
      - Examine (Q0, Q-1):
        01 → add  M into A
        10 → sub  M from A
        00 or 11 → no op
      - Arithmetic right shift of [A(5b), Q(4b), Q-1]
      - Repeat 4 times.
    """
    def to_u4(v): return v & 0xF
    def to_s4(u): return u - 0x10 if (u & 0x8) else u

    M   = to_s4(to_u4(x))     # signed multiplicand
    Q   = to_u4(y)            # unsigned bits of multiplier
    A   = 0
    Q_1 = 0

    for _ in range(4):
        q0 = Q & 1
        # Booth step :contentReference[oaicite:4]{index=4}:contentReference[oaicite:5]{index=5}
        if   q0 == 1 and Q_1 == 0:
            A = (A - M) & 0x1F
        elif q0 == 0 and Q_1 == 1:
            A = (A + M) & 0x1F

        # pack [A(5b), Q(4b), Q-1] into 10 bits and arithmetic shift right by 1
        combo = (A << 5) | (Q << 1) | Q_1
        msb   = (combo >> 9) & 1
        combo = (combo >> 1) | (msb << 9)

        A   = (combo >> 5) & 0x1F
        Q   = (combo >> 1) & 0xF
        Q_1 = combo & 1

    # combine and sign-extend to Python int
    result = ((A & 0x1F) << 4) | Q
    result &= 0xFF
    if result & 0x80:
        result -= 0x100
    return result

```

```python
if __name__ == "__main__":
    # Demo of both multipliers
    print("Unsigned shift-add (0..15 × 0..15):")
    for a, b in [(3,6), (7,7), (15,15)]:
        print(f"  {a:2d} × {b:2d} = {mult4_shiftadd(a,b):3d}")

    print("\nBooth’s algorithm (-8..+7 × -8..+7):")
    for a, b in [(-7,3), (7,-3), (-8,7), (-8,-8)]:
        print(f"  {a:3d} × {b:3d} = {mult4_booth(a,b):4d}")

```

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