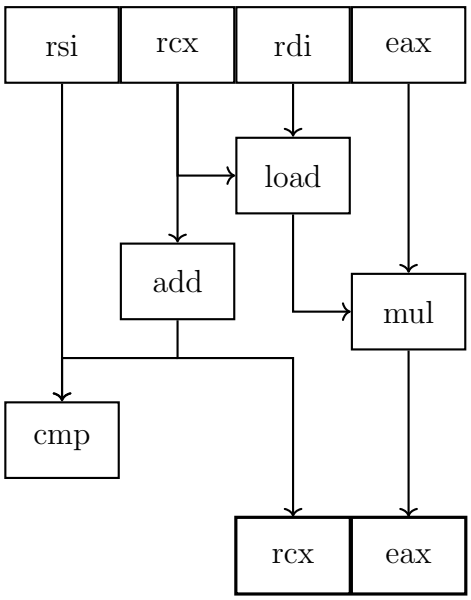
Name: SOLUTIONS	UID: CS 33

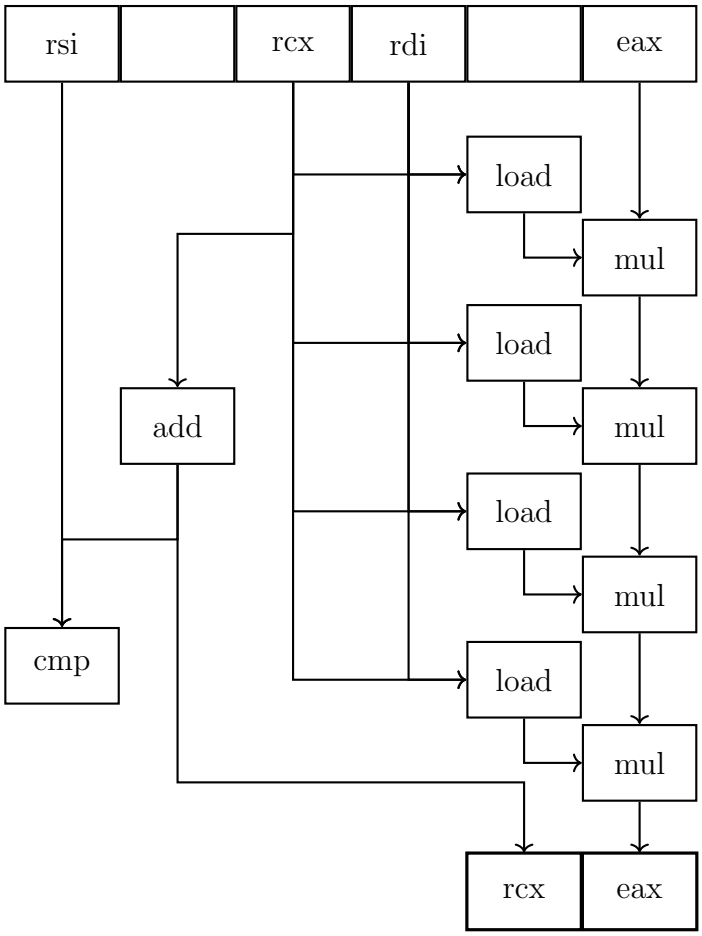
1. Drawing the Diagrams

For each program, create a diagram of the data dependencies.

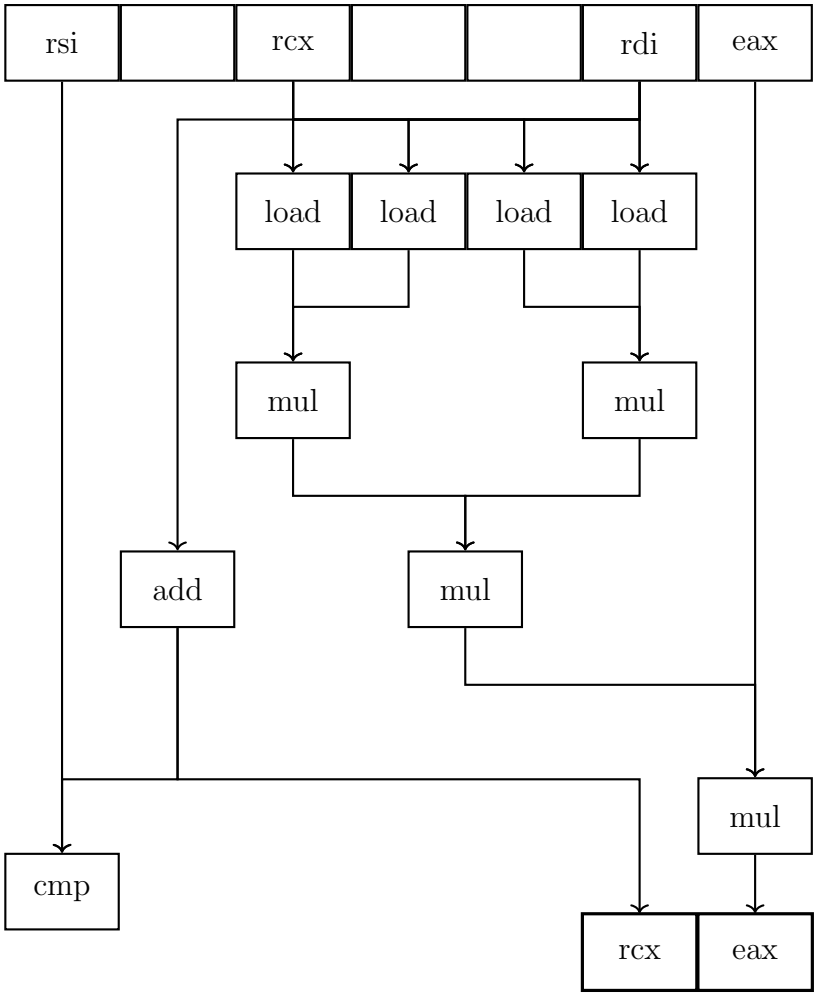
a.
```
.L1:
    imull   (%rdi,%rcx,4), %eax      ; Loop (scalar)
    addq    $1, %rcx                 ; t = t * d[i]
    cmpq    %rcx, %rsi               ; i++
    jl      .L1                      ; Compare i:length
                                     ; If <, goto Loop
```



b.
```
.L2:                                        ; Loop
    imull   (%rdi,%rcx,4), %eax             ; t = t * d[i]
    imull   4(%rdi,%rcx,4), %eax            ; t = t * d[i+1]
    imull   8(%rdi,%rcx,4), %eax            ; t = t * d[i+2]
    imull   12(%rdi,%rcx,4), %eax           ; t = t * d[i+3]
    addq    $4, %rcx                        ; i += 4
    cmpq    %rcx, %rsi                      ; Compare i:length
    jl      .L2                             ; If <, goto Loop
```



c.
```
.L3:                                        ; Loop
    mov     (%rdi,%rcx,4), %e8d             ; e8d = d[i]
    imull   4(%rdi,%rcx,4), %e8d            ; e8d = d[i+1] * d[i]
    mov     8(%rdi,%rcx,4), %e9d            ; e9d = d[i+2]
    imull   12(%rdi,%rcx,4), %e9d           ; e9d = d[i+3] * d[i+2]
    imull   %e8d,  %e9d                     ; e9d = e8d * e9d
    imull   %e9d, %eax                      ; rax = rax * e9d
    addq    $4, %rcx                        ; i += 4
    cmpq    %rcx, %rsi                      ; Compare i:length
    jl      .L3                             ; If <, goto Loop
```



2. Two Bounds

Given the following table for latency table:

Instruction	**Latency** (Cycles)	**Cycles/Issue**	**Count** (#)
Arithmetic (except multiply)	1	1	2
Multiply	2	2	4
Load/Store	4	4	8

For each prior program, provide the Cycles per Element (CPE), Throughput Bound, and Latency Bound.

For Cycles per Element, $max(LB, TB)$ / # *Elems*.
For Latency-Bound, calculate the latency among the critical path (register to register).
For Throughput-Bound, use the formula: $max(\frac{(Cycles/Issue) * Ops\ Required}{\#\ Resource\ Count})$ for each resource.

a. CPE: 2 | Throughput: 1 | Latency: 2

Throughput-Bound Calculation:

- $TB_{ALU} = \frac{1*2}{2} = 1$
- $TB_{MUL} = \frac{2*1}{4} = \frac{1}{2}$
- $TB_{LOAD/STORE} = \frac{4*1}{8} = \frac{4}{8}$
- $max(TB_{ALU}, TB_{MUL}, TB_{LOAD/STORE}) = 1$

Latency-Bound Calculation:

- $LB = EAX \rightarrow MUL \rightarrow EAX$
- $LB = 2$

b. CPE: 2 | Throughput: 2 | Latency: 8

Throughput-Bound Calculation:

- $TB_{ALU} = \frac{1*2}{2} = 1$
- $TB_{MUL} = \frac{2*4}{4} = 2$
- $TB_{LOAD/STORE} = \frac{4*4}{8} = 2$
- $max(TB_{ALU}, TB_{MUL}, TB_{LOAD/STORE}) = 2$

Latency-Bound Calculation:

- $LB = EAX \rightarrow MUL \rightarrow MUL \rightarrow MUL \rightarrow MUL \rightarrow EAX$
- $LB = 8$

c.

CPE: .5	Throughput: 2	Latency: 2

Throughput-Bound Calculation:

- $TB_{ALU} = \frac{1*2}{1} = 2$
- $TB_{MUL} = \frac{2*4}{4} = 2$
- $TB_{LOAD/STORE} = \frac{4*4}{8} = 2$
- $max(TB_{ALU}, TB_{MUL}, TB_{LOAD/STORE}) = 2$

Latency-Bound Calculation:

- $LB = EAX \rightarrow MUL \rightarrow EAX$
- $LB = 2$