Course: BCT 2408 COMPUTER ARCHITECTURE
Student: MURAGURI JOEL KARIUKI — SCT 212-0042/2020
Topic: Loop Pipeline Execution Performance

Given Loop Code:

```
loop: LD R1, 0(R2)
      DADDI R1, R1, 1
      SD 0(R2), R1
      DADDI R2, R2, 4
      DSUB R4, R3, R2
      BNEZ R4, loop
```

Initial Condition:
`R3 = R2 + 396`

Iterations:
Each loop adds 4 to R2 → `396 / 4 = 99 iterations`

Case A: No Forwarding, Branch in ID Stage

Assumptions:

- Pipeline stages: `IF, ID, EX, MEM, WB`
- **No forwarding** = data hazards cause **2 stall cycles** each
- Branch resolved in `ID`, misprediction = **2-cycle flush**

Hazards:

1. `LD → DADDI`: R1 RAW hazard → 2 stalls
2. `DADDI → SD`: R1 RAW hazard → 2 stalls
3. `DADDI R2 → DSUB`: R2 RAW hazard → 2 stalls
4. `DSUB → BNEZ`: R4 RAW hazard → 2 stalls

Per Iteration:

- Instruction cycles: 6 × 5 = 30
- Stalls: 4 × 2 = 8
- Branch penalty = 2
  ➡️ **Total per iteration** = 30 + 8 + 2 = **40 cycles**

➡️ **Total for 99 iterations** = 99 × 40 = **3960 cycles**

Case B: With Forwarding + Predict-Not-Taken

Assumptions:

- Forwarding removes most stalls
- **Load-use hazard** remains: 1 stall
- Branch misprediction = 2-cycle penalty

Hazards:

- `LD → DADDI`: 1 stall (load-use hazard)
- All other hazards resolved via forwarding

Per Iteration:

- Instruction cycles = 6
- Stalls = 1
  Branch penalty = 2
  Total per iteration = 6 + 1 + 2 = **9 cycles**
  Total for 99 iterations = 99 × 9 = **891 cycles**

Case C: Delayed Branch with Forwarding

Assumptions:

- Forwarding in place
- Delay slot filled by a useful instruction or `NOP`
- No misprediction penalty if delay slot is used properly

Rewritten with Delay Slot:

```
loop: LD R1, 0(R2)
    DADDI R1, R1, 1
    SD 0(R2), R1
    DADDI R2, R2, 4
    DSUB R4, R3, R2
    DADDI R5, R5, 0   ; delay slot filler (NOP or useful)
    BNEZ R4, loop
```

Per Iteration:

- Load-use hazard = 1 stall
- Delay slot used → no branch penalty
  Total per iteration = 6 + 1 = **7 cycles**
  Total for 99 iterations = 99 × 7 = **693 cycles**

Summary Table:

Scenario	Stalls	Branch Penalty	Total per Iteration	Total (99 Iterations)
A. No Forwarding + ID Branch	8	2	40	3960
B. Forwarding + Predict-NT	1	2	9	891
C. Forwarding + Delayed Branch	1	0	7	693