Constructive Computer Architecture

Tutorial 5

Epoch & Branch Predictor

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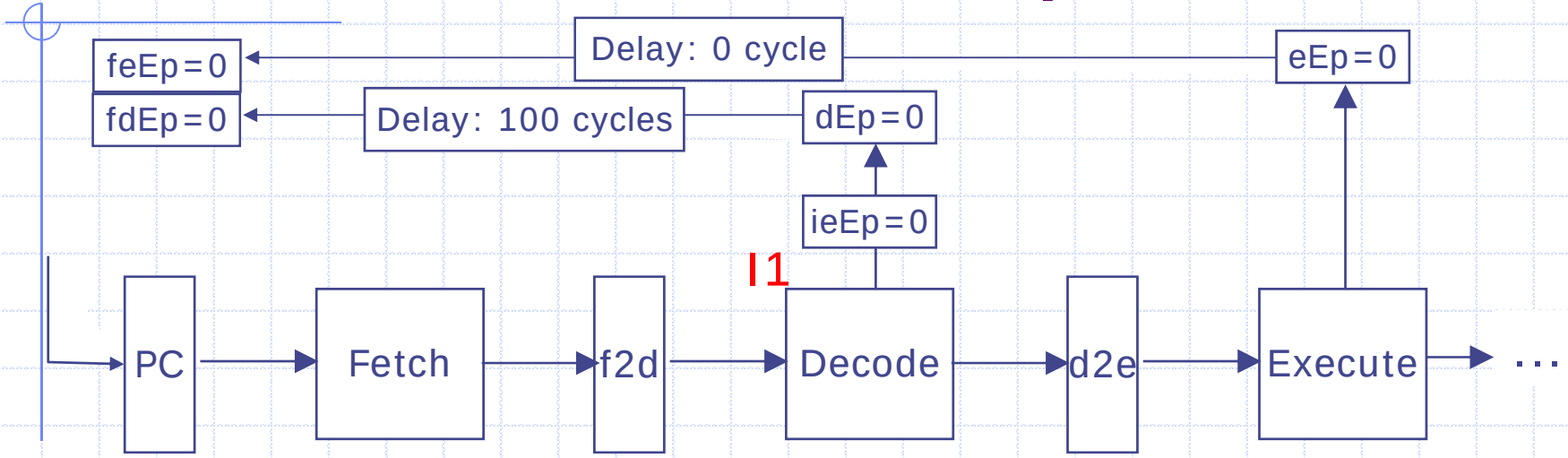
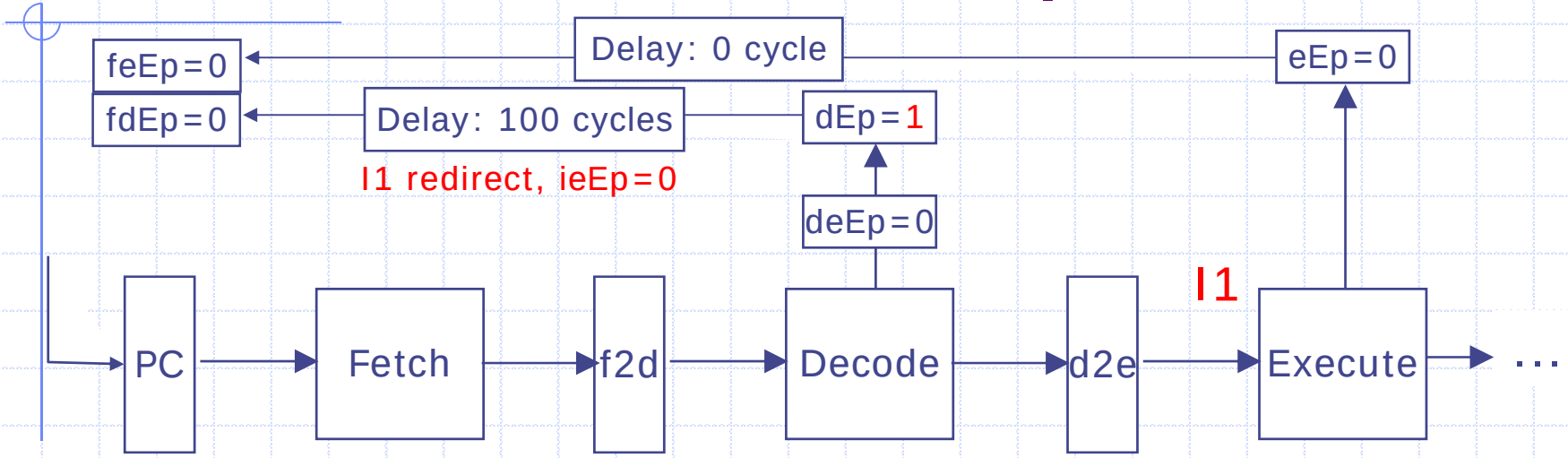
6.175 TA

1-bit Distributed Epochs



- Decode redirects I1 (ieEp=idEp=0)

1-bit Distributed Epochs



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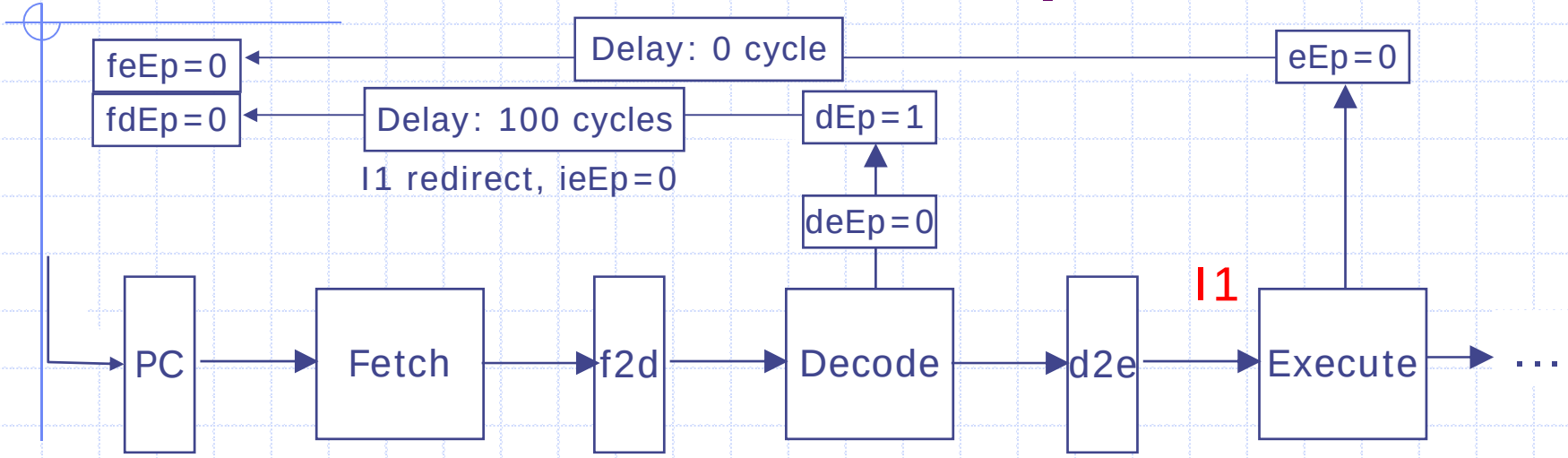
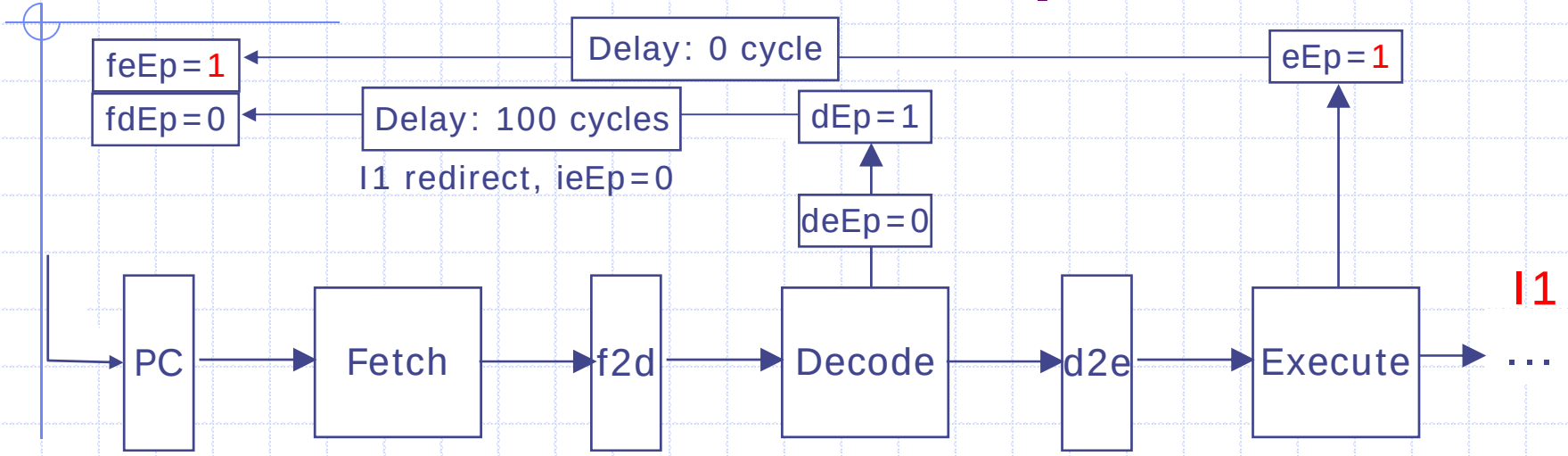


- Decode redirects I1 (ieEp=idEp=0)
- Execute redirects I1

1-bit Distributed Epochs



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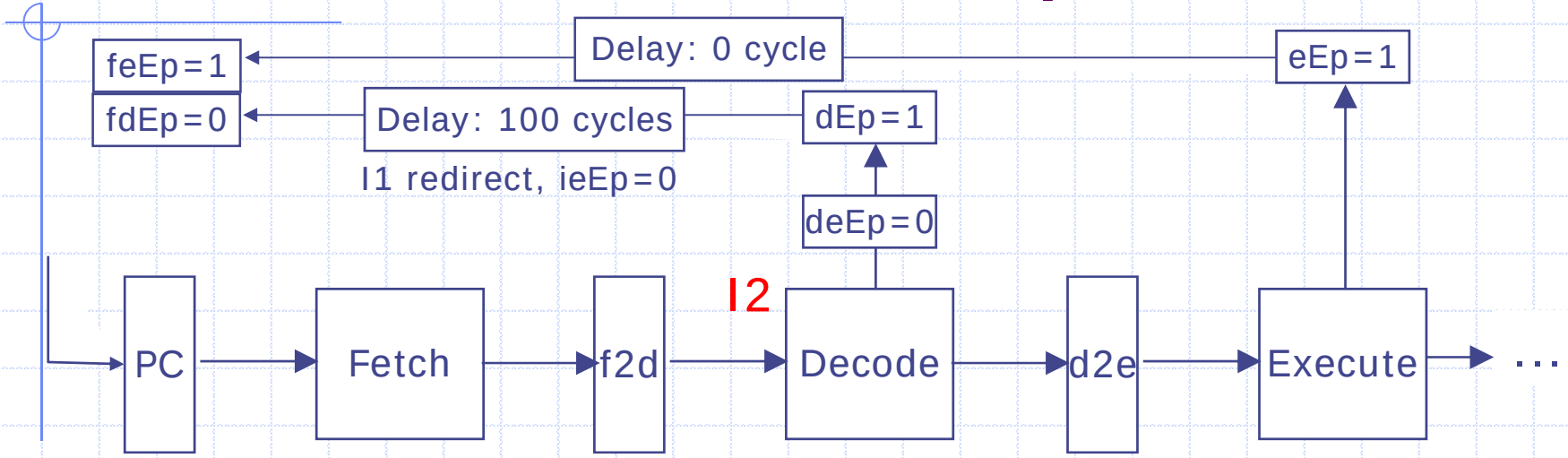
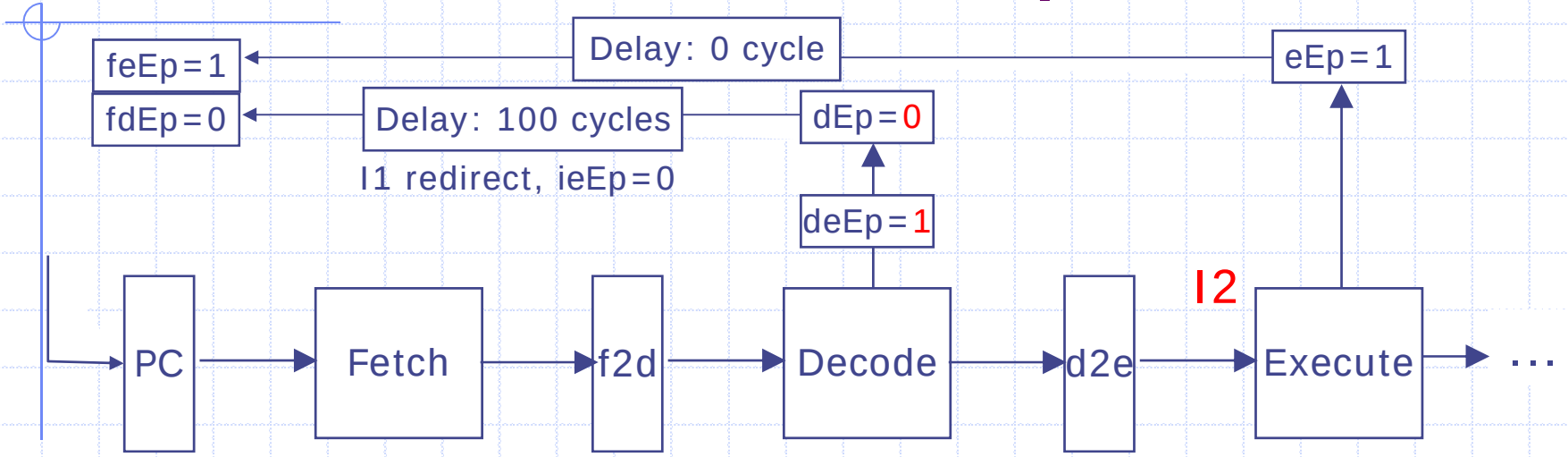


- Decode redirects I1 (ieEp=idEp=0)
- Execute redirects I1
- Correct-path I2 (ieEp=1,idEp=0) issues

1-bit Distributed Epochs



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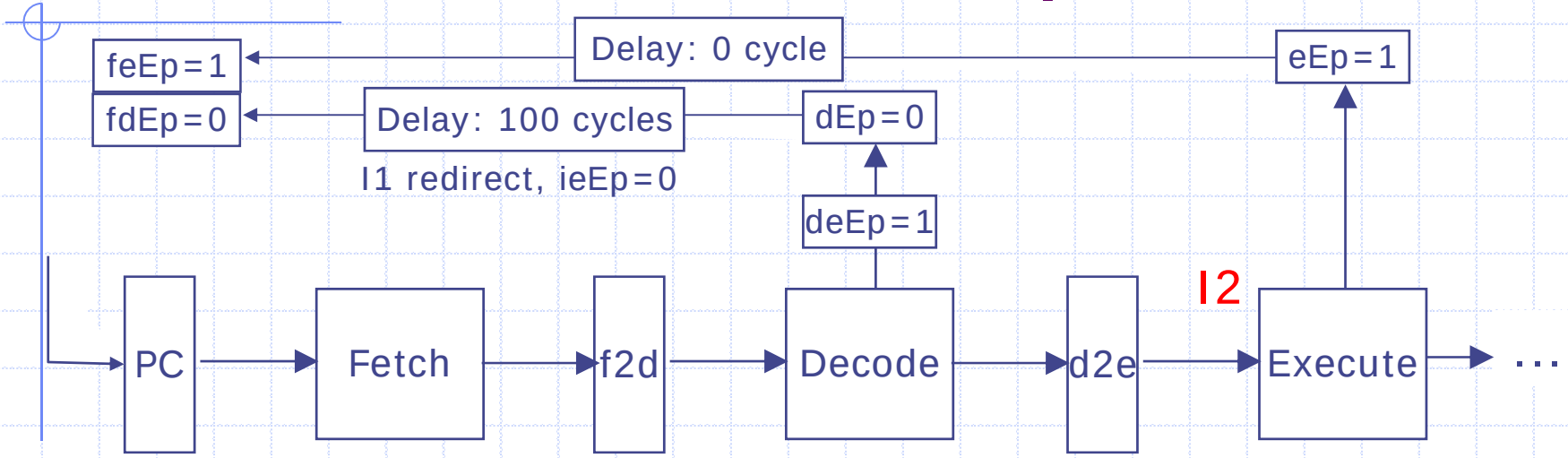
1-bit Distributed Epochs



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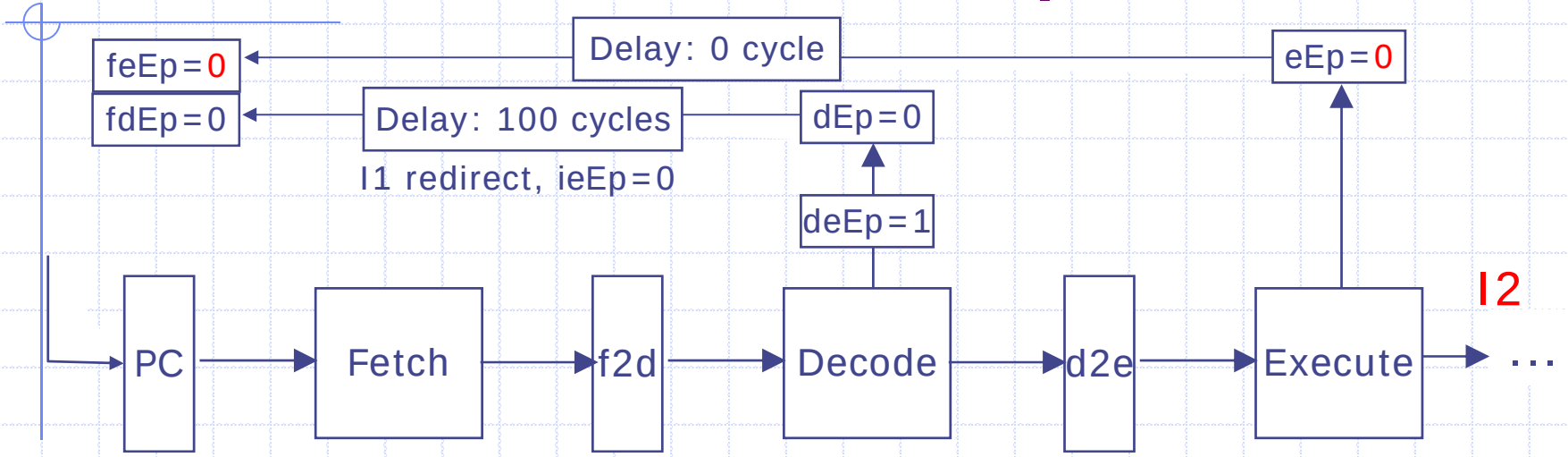
1-bit Distributed Epochs



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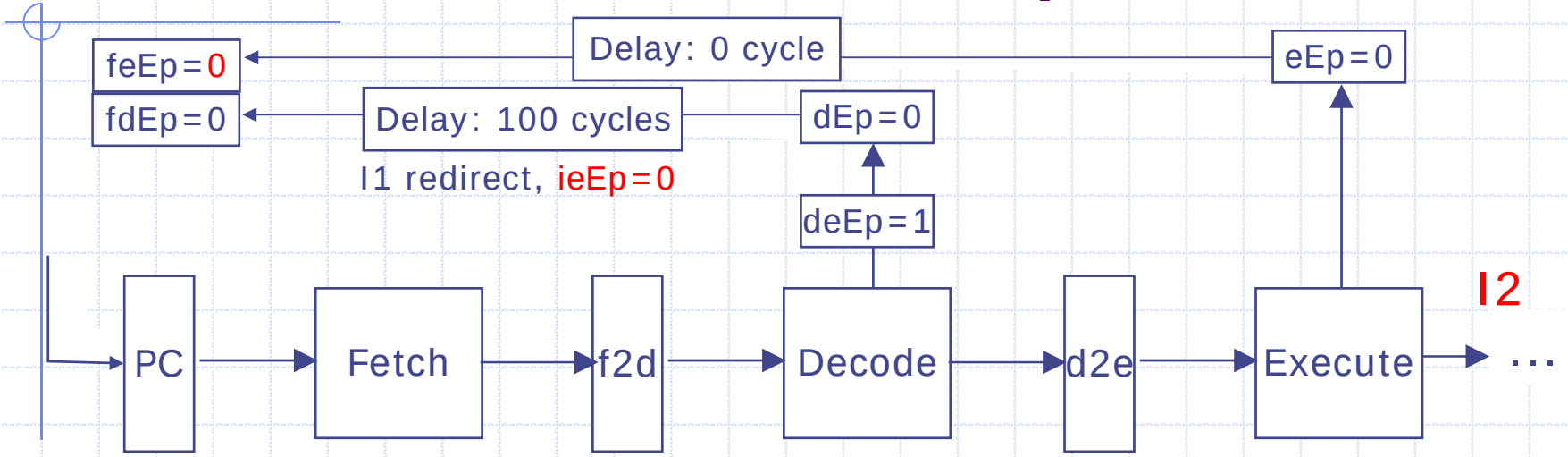
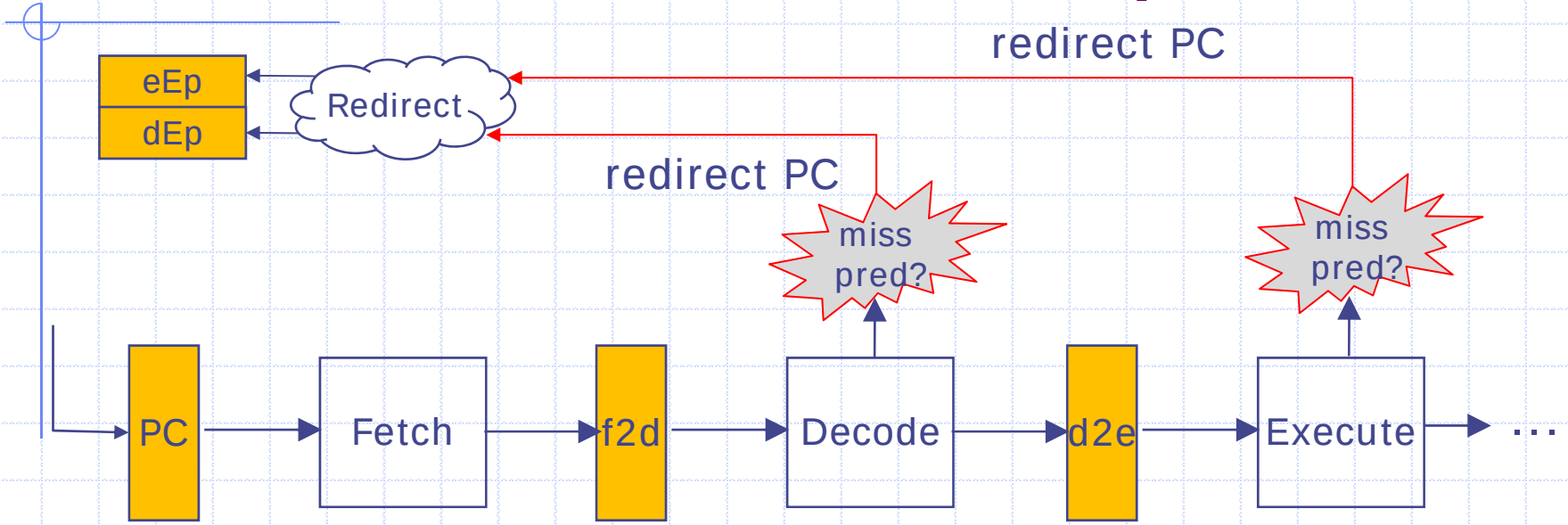
1-bit Distributed Epochs



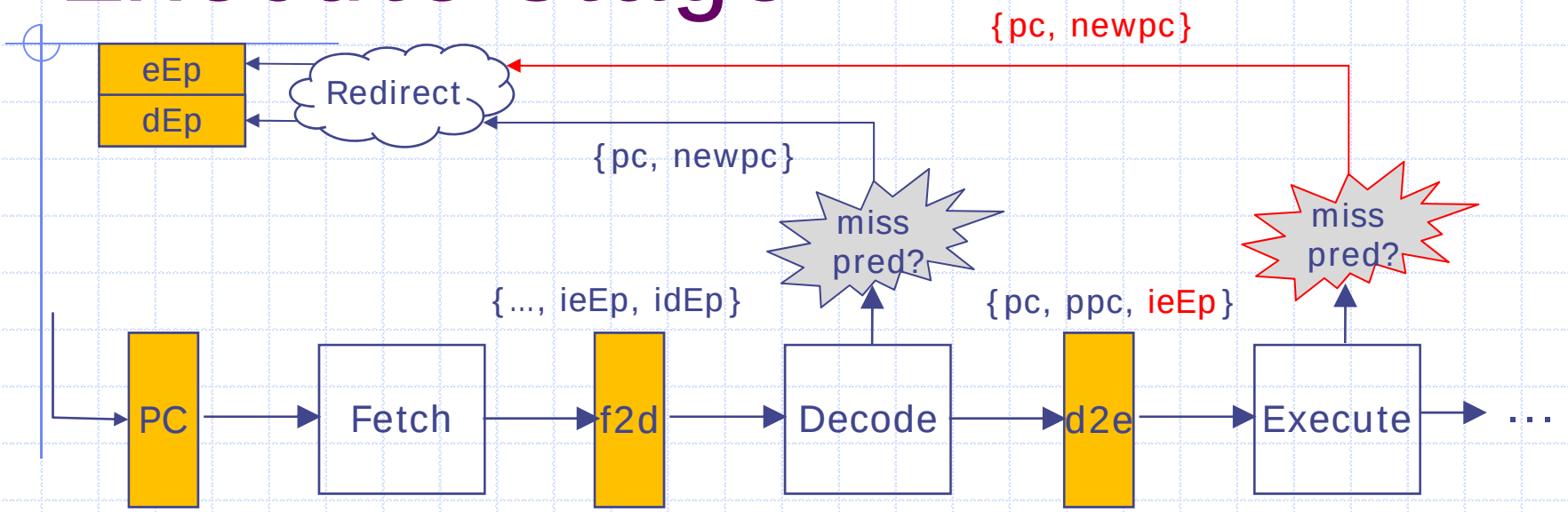
- Decode redirects I1 (ieEp=idEp=0)
- Execute redirects I1
- Correct-path I2 (ieEp=1,idEp=0) issues
- Execute redirects I2
- I1 redirect arrives at Fetch (ieEp == feEp)
  - change PC to a wrong value

Unbounded Global Epochs



- Both Decode and Execute can redirect the PC
  - Execute redirect should never be overruled
- Global epoch for each redirecting stage
  - eEpoch: incremented when redirect from Execute takes effect
  - dEpoch: incremented when redirect from Decode takes effect
  - Initially set all epochs to 0

Execute stage



Is ieEp == eEp?

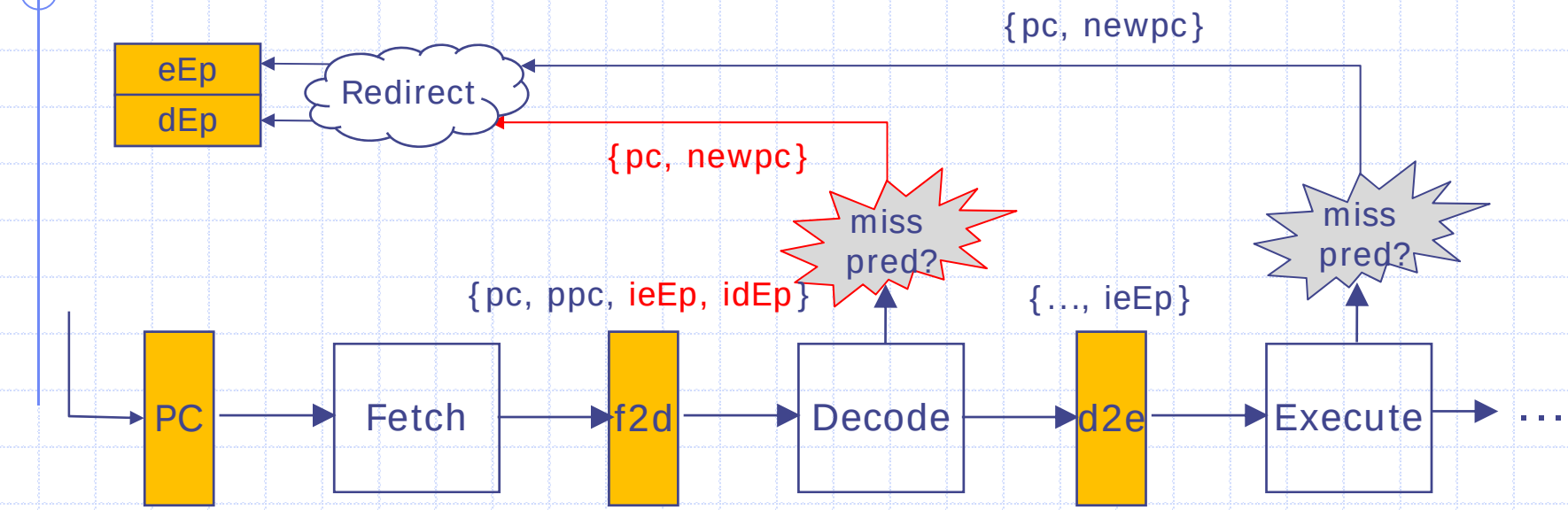
yes

Current instruction is OK; check the ppc prediction by execution, signal a redirect message (by writing EHR) on misprediction

no

Wrong path instruction; poison it

Decode Stage



Is ieEp == eEp && idEp == dEp ?

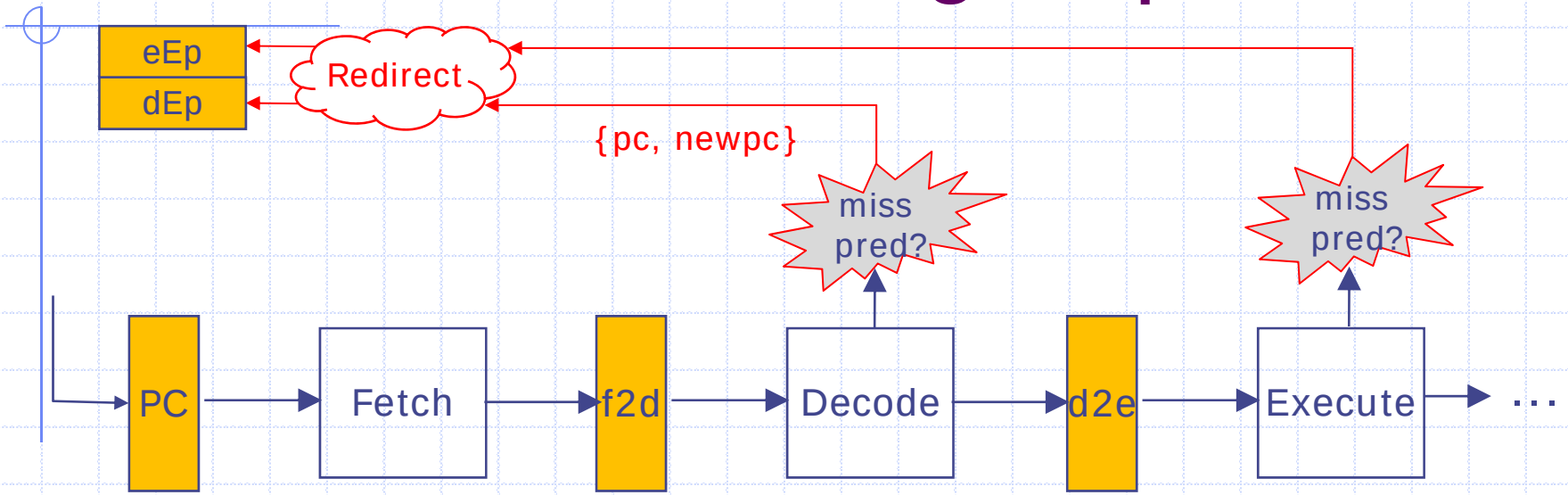
yes

Current instruction is OK; check the ppc prediction via BHT, signal a redirect message (by writing EHR) on misprediction

no

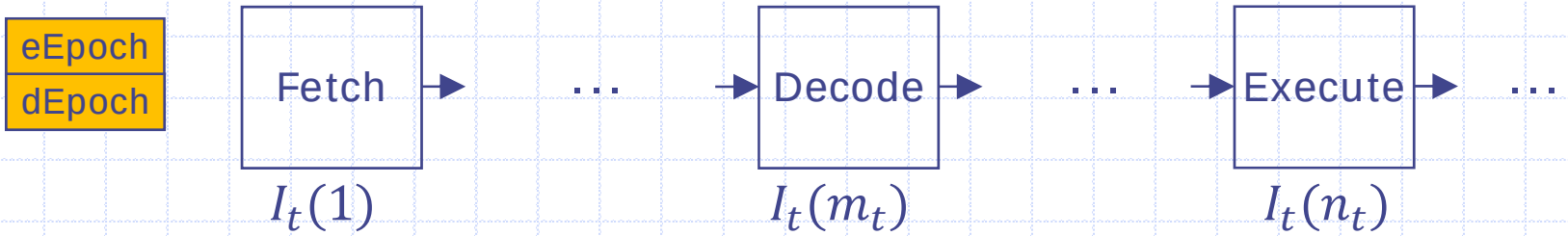
Wrong path instruction; drop it

Fetch stage: Redirect PC, Change Epoch



- If there is redirect message from Execute
  - Set PC to correct value, increment eEp
- Else if there is redirect message from Decode
  - Set PC to correct value, increment dEp
- We can always request IMem to fetch new instruction
  - New instruction will be tagged with current eEpoch and dEpoch
  - PC redirection overrides next-PC prediction
  - When PC redirects, new instruction must be killed at Decode stage

Observation



- At cycle t, n_t instructions between Fetch and Execute: $I_t(1 \ldots n_t)$
  - $I_t(1)$ at Fetch, $I_t(n_t)$ at Execute, $I_t(m_t)$ at Decode
- Invariant:
  - $eEp = I_t(1).ieEp \geq I_t(2).ieEp \geq \cdots \geq I_t(n_t).ieEp \geq eEp - 1$
  - $dEp = I_t(1).idEp \geq I_t(2).idEp \geq \cdots \geq I_t(m_t).idEp \geq dEp - 1$
- Proved by induction on t
  - At cycle t, both Decode and Execute redirect
  - $I_t(n_t).ieEp = eEp \Longrightarrow eEp = I_t(1).ieEp = I_t(2).ieEp = \cdots = I_t(n_t).ieEp$
  - $I_t(m_t).idEp = dEp \Longrightarrow dEp = I_t(1).idEp = I_t(2).idEp = \cdots = I_t(m_t).idEp$
  - $eEp \leftarrow eEp + 1$, invariants still hold at cycle $t + 1$

1-bit Global Epochs

- The max difference of values of one type of epoch is 1
  - Only need 1 bit to encode each epoch
  - Increment epoch → flip epoch

4-stage Pipeline: Code Sketch

```
module mkProc(Proc);
  // stage 1: Fetch
  // stage 2: Decode & read register
  // stage 3: Execute & access memory
  // stage 4: Commit (write register file)
  Ehr#(2, Addr)     pc <- mkEhr(?);
  IMemory          iMem <- mkIMemory;
  ...
  Fifo#(2, Fetch2Decode)   f2d <- mkCFFifo;
  Fifo#(2, Decode2Execute) d2e <- mkCFFifo;
  Fifo#(2, Execute2Commit) e2c <- mkCFFifo;
  Reg#(Bool) eEpoch <- mkReg(False);
  Reg#(Bool) dEpoch <- mkReg(False);
  Ehr#(2, Maybe#(ExeRedirect)) exeRedirect <- mkEhr(Invalid);
  Ehr#(2, Maybe#(DecRedirect)) decRedirect <- mkEhr(Invalid);
  BTB#(16)   btb <- mkBTB;
  BHT#(1024) bht <- mkBHT;
```

Execute Stage

```
rule doExecute;
    d2e.deq; let x = d2e.first;
    if(x.ieEp == eEpoch) begin
        let eInst = exec(...);
        if(eInst.mispredict)
            exeRedirect[0] <= Valid ({pc: x.pc,
                                      newpc: eInst.addr});
      ...
    end
    else e2c.enq(Exec2Commit{poisoned: True, ...});
        // wrong path instruction, poison it
endrule
```

BHT training will be in lab

Decode Stage

```
rule doDecode;
    f2d.deq; let x = f2d.first;
    if(x.ieEp == eEpoch && x.idEp == dEpoch) begin
        let stall = ...; // check scoreboard for stall
        if(!stall) begin
            if(x.iType == Br) begin
                let bht_ppc = ...; // BHT prediction
                if(bht_ppc != x.ppc)
                    decRedirect[0] <= Valid ({pc: x.pc,
                                              newpc: bht_ppc});
            end
            ...
            d2e.enq(Decode2Execute{ieEp: x.ieEp, ...});
        end
    end
    // else: wrong path instruction, killed
endrule
```

Fetch Stage

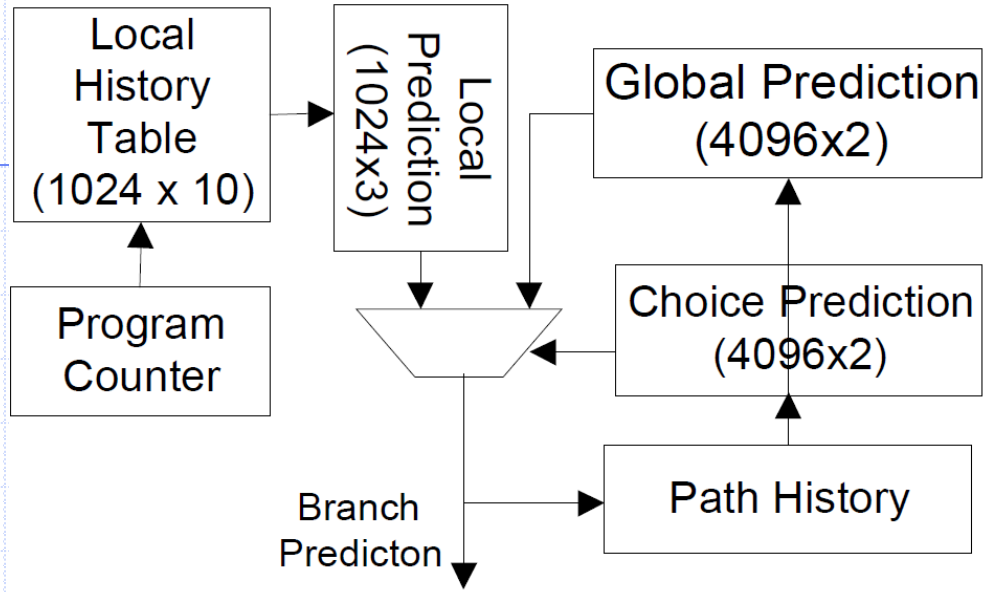
```
rule doFetch;
    let inst = iMem.req(pc[0]);
    let ppc = btb.predPc(pc[0]);
    pc[0] <= ppc;
    f2d.enq(Fetch2Decode{pc: pc[0], ppc: ppc, inst: inst,
                         ieEp: eEpoch, idEp: dEpoch});
endrule

rule cononicalizeRedirect;
    if(exeRedirect[1] matches tagged Valid .r) begin
        pc[1] <= r.newpc; btb.update(r.pc, r.newpc);
        eEpoch <= !eEpoch;
    end else if(decRedirect[1] matches tagged Valid .r) begin
        pc[1] <= r.newpc; btb.update(r.pc, r.newpc);
        dEpoch <= !dEpoch;
    end
    exeRedirect[1] <= Invalid; decRedirect[1] <= Invalid;
endrule
```

Advanced Branch Predictor

- BHT cannot predict very accurately
  - Need more sophisticated schemes
- Global branch history
  - taken/not token for previous branches
- Local branch history
  - taken/not token for previous occurrences of the same branch
- Tournament branch predictor
  - Use both global and local history
  - Alpha 21264

Tournament Predictor

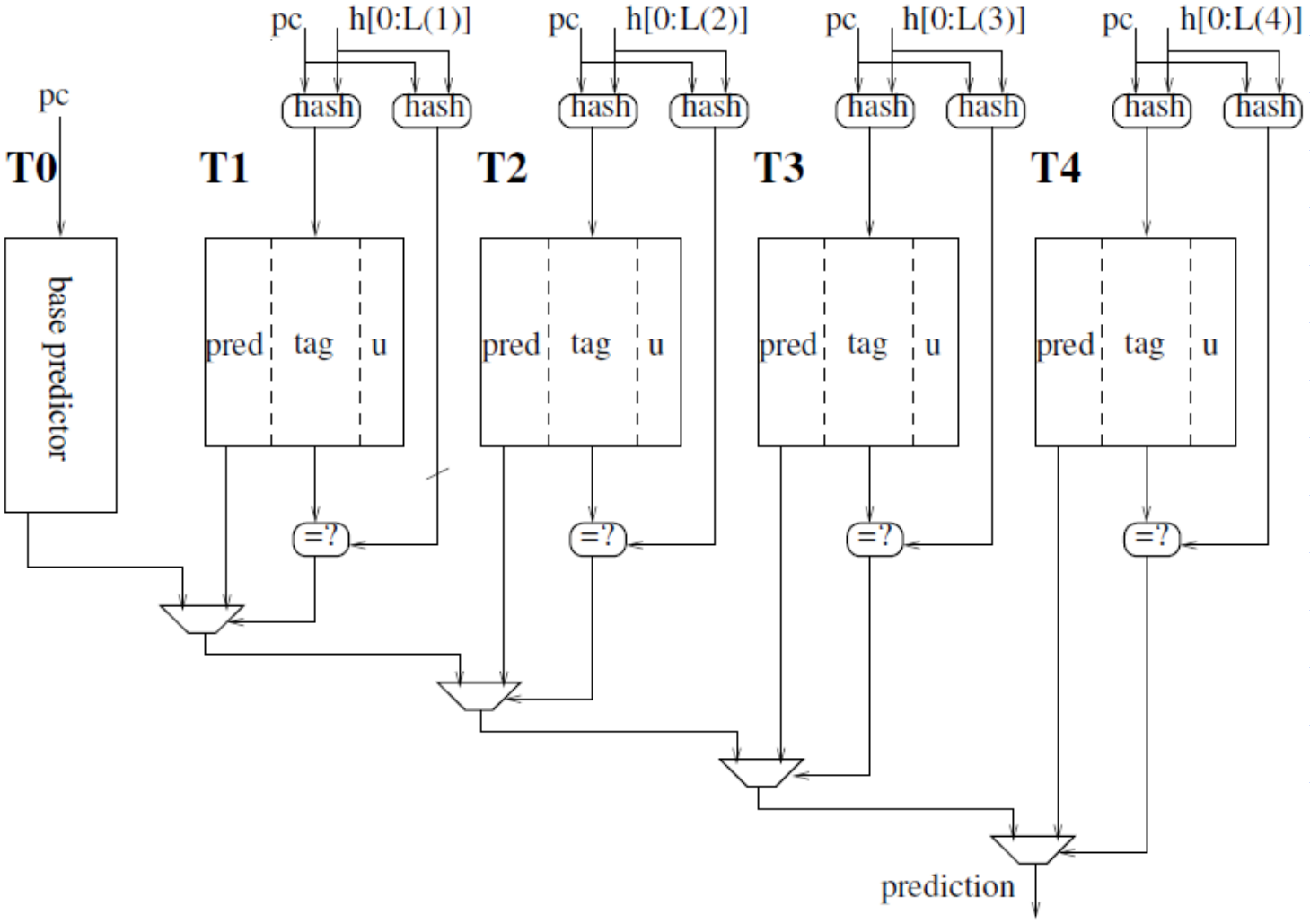


"The Alpha 21264 Microprocessor Architecture"

- 10-bit PC: index 1024 x 10-bit local history table
- 10-bit local history
  - Index 1024 x 3-bit BHT: prediction 1
- 12-bit global history
  - Index 4096 x 2-bit BHT: prediction 2
  - Index 4096 x 2-bit BHT: select between predictions 1, 2

TAGE Branch Predictors

- TAGE (Tagged Geometric history length)



"A case for partially tagged geometric history length branch prediction"

Other Predictors

- Perceptron-based predictors
  - Classification problem in machine learning
- Championship Branch Predictor
  - Papers
  - Slides
  - simulation codes

Return Address Stack

- Use a stack to store return address from function call
  - Push when function is called
  - Pop when returning from a function
- Instruction to return from function call
  - JALR: rd = x0, rs1 = x1 (ra)
- Instruction to initiate function call
  - JAL: rd = x1
  - JALR: rd = x1