Consider the Figure given in the next pages, in which the ID/EX stages have been simplified, e.g., the sign-extended immediate and branch logic are not drawn.

Also consider the following sequence of 8 instructions for the pipelined MIPS. Assume the pipeline is initially empty.

```
start:  lw  $s1,0($a0)  
       lw  $s2,4($a0)  
       add $t1,$s1,$s2  
       sub $t2,$s1,$s2  
       add $t3,$t1,$t2  
       sub $t4,$t1,$t2  
       add $t5,$t3,$t4  
       sw  $t5,8($a0)  
```

Show the values of ALL data, address, and control line/bus values using this figure (you can make as many copies as needed), as the instructions follow through the stages of pipeline. Make sure that data dependencies and hazards, and thus, appropriate forwarding of register values are also specified. Show the data and address lines more compactly using hexadecimal values. Draw a multiple-clock-cycle diagram (similar to Figure 4.52, in Page 305 on the book) to point out the cycles and units through which forwarding happens. Your grade depends on how complete the figures are in terms of the data, address, and control values, as these instructions move through the pipeline.
FIGURE 4.60 Pipelined control overview, showing the two multiplexors for forwarding, the hazard detection unit, and the forwarding unit.

Although the ID and EX stages have been simplified—the sign-extended immediate and branch logic are missing—this drawing gives the essence of the forwarding hardware requirements.

Elaboration: Regarding the remark earlier about setting control lines to 0 to avoid writing registers or memory: only the signals RegWrite and MemWrite need be 0, while the other control signals can be don't cares.

4.8 Control Hazards

Thus far, we have limited our concern to hazards involving arithmetic operations and data transfers. However, as we saw in Section 4.5, there are also pipeline hazards involving branches. Figure 4.61 shows a sequence of instructions and indicates when the branch would occur in this pipeline.

There are a thousand hacking at the branches of evil to one who is striking at the root.

Henry David Thoreau, Walden, 1854