Exercise 1 (Parameters of Estimation Methods) Table 1 shows the estimated and measured execution times $T_{ex}$ for four design points. Determine the accuracies for the single estimations as well as the fidelity for the estimation method based on the four design points.

<table>
<thead>
<tr>
<th>Design Point</th>
<th>estimated $T_{ex}$</th>
<th>measured $T_{ex}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_1$</td>
<td>112</td>
<td>109</td>
</tr>
<tr>
<td>$D_2$</td>
<td>128</td>
<td>137</td>
</tr>
<tr>
<td>$D_3$</td>
<td>139</td>
<td>121</td>
</tr>
<tr>
<td>$D_4$</td>
<td>205</td>
<td>132</td>
</tr>
</tbody>
</table>

Table 1: Design points with estimated and measured execution times

Exercise 2 (Estimation of Execution Time) Given is the sequence graph in Fig. 1. The implementation can use two multipliers (for multiplication) and one ALU (for addition, subtraction and compare operations). The execution time for a multiplication is 163 ns, for an ALU operation 56 ns. Multipliers and ALUs cannot be internally pipelined. Estimate the execution time by

1. method of maximum operator delay
2. method of clock slack minimization in the interval: $28\, \text{ns} \leq T \leq 163\, \text{ns}$.

Determine first the clock period for both methods and then the number of required clock steps (by list scheduling) and execution time. As priority criterion use the number of successor nodes.
Exercise Sheet # 7

Exercise 3 (WCET Estimation I) Given is the following piece of code:

```c
s = 0;
WHILE (k < 5) {
    IF (f==1)
        j = j + 1;
    ELSE {
        j = 0;
        f = 1;
    }
    k = k + 1;
    s = s + k;
}
```

• Determine the basic blocks and construct the control-flow graph for this program.

• Assume that the cost for each basic block equals the number of its 3-address instructions. Write down the structural constraints and the ILP to determine the WCET of the program.
• The programmer provides us with the information that \( k \) is in the range \([1, 12]\) before the program is called. What can be said about the WCET now?

• Can you identify another additional constraint by studying the program?

Exercise 4 (WCET Estimation II)  
Consider again the program from the previous exercise.

• Use static value analysis to determine the intervals for each variable at each program point, given the initial value descriptions \( s, j \in (-\infty, +\infty), f \in [0, 1], \) and \( k \in [1, 12] \).

• Use cache MUST analysis to determine the worst-case execution time for each basic block under the following machine model:
  
  - the processor has no pipeline
  - the processor has no registers, i.e., all variables are stored in memory
  - all instructions access variables from right to left
  - all instructions take 1 cycle excluding load/store of variables
  - consider only the data cache: 4 blocks, 1 word/block, fully associative, LRU replacement
  - a cache hit takes 1 cycle; a cache miss takes 40 cycles

Initially, the cache is empty.

• Unroll the loop once. Can you improve the worst-case execution time for the basic blocks?