Real-Time Systems

Exercise #4

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WCET Analysis using Shaw's Method

"The estimated WCET is the execution time of the longest structural path through the program."

The following example is based on Problem 3 in the Exercise Compendium (Collection of Examples).

Example: WCET analysis

Problem: Consider the function `Calculate()`.

a) Using Shaw's method, estimate the WCET for function `Calculate()` in terms of 'Z' (with Z ≥ 0).

```
int Calculate (int Z){
   int R;
   if(Z == 0)
      R = 1;
   else if (Z == 1)
      R = 1;
   else
      R = Calculate(Z-1) + Calculate(Z-2);
   return R;
}
```

Example: WCET analysis

Problem: Consider the function `Calculate()`.

a) Using Shaw's method, estimate the WCET for function `Calculate()` in terms of 'Z' (with $Z \geq 0$).

- Each *declaration* or *assignment* statement costs 1 time unit
- Each *compare* statement costs 1 time unit
- Each *return* statement costs 1 time unit
- Each *addition* or *subtraction* operation costs 4 time units.
- A *function call* costs 2 time units plus WCET for the function in question.
- All other language constructs can be assumed to take 0 time units to execute.

Example: WCET analysis

Problem: Consider the function `Calculate()`.

b) Function `main()` calls function `Calculate()` with parameter 5. What is the WCET of function `main()`?

c) The deadline for executing function `main()` is 180 time units. Determine whether the deadline is met or not.

```
int main(){
    int ans;
    ans = Calculate(5);
}
```

Example: WCET analysis

Problem: Now the program runs on a new processor that has a faster ALU. The execution costs of addition and subtraction are equal, but smaller than that of the older processor.

Let ‘x’ represent the execution time of an addition/subtraction operation. All other language constructs are assumed to have the same cost as in sub-problem a).

d) What is the WCET for function `main()` in terms of ‘x’?

e) What is the maximum cost of an addition/subtraction operation so that the deadline of function `main()` is met?

Example: WCET analysis

a) Derive WCET for Calculate(Z)

```
Case 1: Z == 0

WCET(Calculate(0)) = {declare, R} + {compare, Z==0} +
       {assign, R} + {return, R} = 1 + 1 + 1 + 1 = 4


Case 2: Z == 1

WCET(Calculate(1)) = {declare, R} + {compare, Z==0} + {compare, Z==1} +
       {assign, R} + {return, R} = 1 + 1 + 1 + 1 + 1 = 5
```

Example: WCET analysis

Case 3: Z > 1

Let x represent the cost for addition and subtraction.

```
WCET(Calculate(Z>1)) = {declare, R} + {compare, Z==0} + {compare, Z==1} +
       {subtract, Z-1} + {call, Calculate(Z-1)} + WCET(Calculate(Z-1)) +
       {subtract, Z-2} + {call, Calculate(Z-2)} + WCET(Calculate(Z-2)) +
       {add, Calculate(Z-1)+Calculate(Z-2)} + {assign, R} + {return, R} =

       1 + 1 + 1 + x + 2 + WCET(Calculate(Z-1)) +
              x + 2 + WCET(Calculate(Z-2)) + x + 1 + 1 =

       9 + 3*x + WCET(Calculate(Z-1)) + WCET(Calculate(Z-2))
```

Example: WCET analysis

WCET(Calculate(2)) =

9 + 3*x + WCET(Calculate(1)) + WCET(Calculate(0))

WCET(Calculate(3)) = 9 + 3*x + WCET(Calculate(2)) + WCET(Calculate(1)) =

2(9 + 3*x) + 2*WCET(Calculate(1)) + WCET(Calculate(0))

WCET(Calculate(4)) = 9 + 3*x + WCET(Calculate(3)) + WCET(Calculate(2)) =

4(9 + 3*x) + 3*WCET(Calculate(1)) + 2*WCET(Calculate(0))

WCET(Calculate(5)) = 9 + 3*x + WCET(Calculate(4)) + WCET(Calculate(3)) =

7(9 + 3*x) + 5*WCET(Calculate(1)) + 3*WCET(Calculate(0)) =

63 + 21*x + 5*5 + 3*4 = 63 + 21*x + 25 + 12 = **100 + 21*x**

Example: WCET analysis

b) Derive WCET for main()

Let x = 4

WCET(Calculate(5)) = 100 + 21*x = 100 + 84 = 184

WCET(main()) = {declare, ans} + {call, Calculate(5)} +
WCET(Calculate(5)) + {assign, ans} =
1 + 2 + WCET(Calculate(5)) + 1 = 4 + WCET(Calculate(5)) =
4 + 100 + 21*x = 104 + 21*x = 104 + 84 = 188

c) Check deadline for main()

WCET(main()) = 188, which exceeds the deadline of 180

Example: WCET analysis

d) Derive WCET for main()

According to subproblem b):

WCET(main()) = 4 + WCET(Calculate(5)) = 4 + 100 + 21*x = 104 + 21*x

e) Find maximum cost x

WCET(main()) = 104 + 21*x ≤ 180 ⇒ 21*x ≤ 76

That is, **x ≤ 76/21** ≈ 3.6

If x can be a non-integer number select x = 3.6 in order to meet deadline.
If x must be an integer number select x = 3 in order to meet deadline.