CSC236 Tutorial Exercises, July 5

(Sample Solution)

1. Consider the following algorithm:

```
func(n):
    # Pre: n is a natural number
    x = 0
    i = 0
    while i < n:
        i = i + 1
        x = x + i
    return x
```

(a) State preconditions and postconditions for this algorithm.

Postconditions: $x = \sum_{i=0}^{n} i$

(b) Use induction to prove the loop invariants $i \leq n$ and $x = \sum_{j=0}^{i} j$ for the while loop.

Let $k \geq 0$. Assume $H(k)$: $i_k \leq n$ and $x_k = \sum_{j=0}^{i_k} j$.

Want to show that $i_{k+1} \leq n$ and $x_{k+1} = \sum_{j=0}^{i_{k+1}} j$

Case: There is no $k+1$th iteration. Then $i_{k+1} = i_k$ and $x_{k+1} = x_k$, so the loop invariant holds.

Case: There is a $k+1$th iteration of the loop.

Then, i_k was such that the loop test passed, ie. $i_k < n$. Thus, $i_{k+1} = i_k + 1 \leq n$.

$x_{k+1} = x_k + i_{k+1}$ (since $i = i + 1$ is first)

$= \sum_{j=0}^{i_k} j + i_{k+1}$ (by $H(k)$)

$= \sum_{j=0}^{i_{k+1}} j$

So, the loop invariant holds in all cases.

Base case: Let $k = 0$. $i_0 = 0 \leq n$ because $n \in \mathbb{N}$.

$x_0 = 0 = \sum_{j=0}^{0} j = \sum_{j=0}^{i_0} j$.

So the loop invariant holds in all cases.

(c) Prove that the loop terminates.

Let $E_k = n - i_k$.

Need to show that (1) $E_k \in \mathbb{N}$, $\forall k$ and (2) $E_{k+1} < E_k$, if there is a $k+1$th iteration.

(1): $i_k, n \in \mathbb{N}$, and $i_k \leq n$ $\forall k$ by part (b). Thus, $E_k \in \mathbb{N}$, and $E_k \geq 0$, $\forall k$.

(2): If there is a $k+1$th iteration, then $E_{k+1} = n - i_{k+1} = n - (i_k + 1) = n - i_k - 1 < n - i_k = E_k$.

Thus, the loop terminates.

2. Prove that the following function is correct (by showing partial correctness and termination), according to its pre- and postconditions.

```
def f(A):
    # Pre: A is a list of integers
    # Post: Returns true if and only if there is an even number of positive
    # numbers in A
    even = True
    i = 0
    while i < A.length:
        if A[i] > 0:
            even = not even
        i = i + 1
    return even
```

Partial Correctness: Consider the loop invariant $i \leq$ A.length and even is True iff there are an even number of positive numbers in A[0..i-1].

Proof of loop invariant: Let $k \geq 0$.

Assume $H(k)$: $i_k \leq$ A.length and $even_k$ is True iff there are an even number of positive numbers in A[0..i_k-1].

Show $H(k) \to C(k)$: $i_{k+1} \leq$ A.length and $even_{k+1}$ is True iff there are an even number of positive numbers in A[0..i_{k+1}-1].

Case: There is no $k+1$th iteration. Then $i_{k+1} = i_k$ and the loop invariant holds.

Case: There is a $k+1$th iteration. Then the loop condition passed, so $i_k <$ A.length and $i_{k+1} = i_k + 1 \leq$ A.length.

If A[i_{k+1}] is non-positive, then $even_{k+1} = even_k$, and by $H(k)$ represents the number of positive numbers in A[0..i_k], which is the same as the number of positive numbers in A[0..i_{k+1}].

If A[i_{k+1}] is positive, then $even_k$ is negated. There is one more positive number in A[0..i_{k+1}] than there was in A[0..i_k]. By $H(k)$, $even_k$ was True if there were an even number of positive numbers in A[0..i_k], and so there are an odd number of positive numbers in A[0..i_{k+1}], and $even_{k+1}$ is False. A symmetric argument can be made if $even_k$ was False.

Base Case: Let $k = 0$. $i_0 = 0 \leq$ A.length. $even_0$ is True, because there are 0 positive numbers in an empty subarray.

Thus, in all cases, the loop invariant holds.

The loop terminates when $i \geq$ A.length. By the proof of the loop invariant, $i \leq$ A.length. So, the loop terminates when $i =$ A.length. Thus, by the loop invariant, even represents the number of positive numbers in all of A.

Termination : Let $E_k =$ A.length$-i$. By loop invariant, $i \leq$ A.length. So $E_k \geq 0 \to E_k \in \mathbb{N}$, $\forall k$.

If there is a $k+1$th iteration, then $E_{k+1} =$ A.length$-i_{k+1} =$ A.length$-(i_k + 1) <$ A.length$-i_k = E_k$.

Thus, the loop terminates.