1. (14 pts.) For each of the following, give appropriate pre- and post-conditions for the functions described.
   
   a. Set variable LAST to the index of the last instance of Y in the non-empty array A[1:N]. Leave LAST unchanged if there is no occurrence of Y in A.

   b. Perform integer subtraction using the arithmetic primitive "subtract 1" and a while loop. Let M be the minuend, S be the subtrahend (the number subtracted), and D be the difference. Assume that the subtrahend is nonnegative.
2. (3 pts.) Recall the conditional function \( f = (y \geq 0 \rightarrow x, y := x+y, 0) \) used in class to illustrate concurrent assignment statements. Is \( f \) equivalent to the function computed by the following program? (Simply indicate “yes” or “no” and briefly explain your answer.)

\[
\text{if } y \geq 0 \text{ then } \\
\quad x := x+y \\
\quad y := 0 \\
\text{end_if}
\]

3. (3 pts.) In addition to a simple linked list, Sommerville also illustrates how one can use algebraic specification in a critical system specification. What, specifically, was the example used for this purpose?

4. (8 pts.) Using a conditional function with one or more concurrent assignment rules, provide a function-based specification for the program, \( P \), given below. That is, give an intended function, \( f \), such that \( f=\lbrack P \rbrack \). Variables \( x \) and \( y \) are assumed to represent INTEGERS.

\[
P: \text{ while } y<>0 \text{ do } \\
\quad x := x+1 \\
\quad y := y-1 \\
\text{end_while}
\]

Hint: Your specification should reflect the function of the while-do statement as a whole (not just the loop body!), which can be easily deduced by considering what the final values of \( x \) and \( y \) are for various initial values of \( y \).

5. (3 pts.) Briefly explain why \( \text{wp(paint the living room ceiling, the house is all painted)} \) is NOT: “The whole house, except for the living room ceiling, is all painted.”
6. (14 pts.) Match each description below to the **SINGLE MOST APPROPRIATE TERM** among the following. (Note: terms may apply to none, one, or more than one description.)

A. predicate  
B. universal quantifiers  
C. constructor operations  
D. operational specification  
E. axioms  
F. pre-condition  
G. model-based specification  
H. post-condition  
J. assignment function  
K. Lotos, RSL/RSA  
L. inspection operations  
M. function-based specification  
N. existential quantifiers  
O. operation signatures  
P. algebraic specification  
Q. VDM, B  
S. schema signature

___ A specification approach that defines required program behavior in terms of **intended program functions**

___ That part of a schema which defines conditions that are always true

___ A specification approach whereby a system is specified in terms of a **state model** and operations are defined in terms of **changes to system state**

___ Guttag first discussed this approach for the specification of abstract data types. Cohen, et al., showed how the technique can be extended to complete system specification using an example of a document retrieval system.

___ Expresses obligatory conditions / relationships among program variables **after** execution in model-based specification

___ Relate the operations used to construct entities of the defined sort with operations used to inspect its values.

___ A specification approach whereby a system is specified in terms of its operations and their relationships via **axioms**

___ Defines the interface **syntax** of an object class or abstract data type

___ Mature notations for developing model-based specification.

___ This specification approach can become cumbersome when object operations are not independent of object state.

___ Expresses constraints on program variables that an implementer may assume will hold **before** program execution

___ Used to assert that some predicate holds FOR AT LEAST ONE or FOR SOME member of a given set

___ Used to specify program data mappings; its domain corresponds to the initial data states that would be transformed into final data states by a suitable program

___ Defines the entities that make up the state of the system being specified using Z
NOTE: if you have already taken CEN 4072/6070, Software Testing and Verification, DO NOT work problems 7-10! (Work problems 11-17 instead.)

7. (6 pts.) Consider each of the following assertions and circle either “true” or “false” as appropriate. (Note: “<>” means “NOT EQUAL TO.”) To compensate for random guessing, your score in points will be 2 times the number of [correct minus incorrect] answers, or 0 – whichever is greater. Therefore, if you are not more than 50% sure of your answer, consider skipping the problem.

a. \{x\leq 10\} while x <> 5 do x := x+17 \{x=5\} false
b. \{x=17\} S \{y=3 \land x=17\} \Rightarrow \{x>0\} S \{x\geq 0\} true
c. \{a<xy\} a := a-x; y := y+1 \{a\leq xy-2x\} true

8. a. (3 pts.) Give the antecedents to complete the while-loop Rule of Inference (ROI):

\begin{align*}
\{P\} & \quad \text{while } b \quad \text{do } S \quad \{Q\}
\end{align*}

b. (7 pts.) Prove the assertion of weak correctness below using the while-loop Rule of Inference with the invariant: x=5-y. SHOW AND JUSTIFY ALL STEPS AND CASES AS ILLUSTRATED IN CLASS.

\{true\}
\begin{align*}
y & := 5 \\
x & := 0 \\
\text{while } y<>0 \text{ do } \\
\quad x & := x+1 \\
\quad y & := y-1 \\
\end{align*}
\text{end}_\text{while}
\{x=5\}
9. (8 pts.) Use the **WEAKEST PRECONDITION-BASED METHOD** to prove:

\[ \{ x = 5 - y \land y \neq 0 \} \quad x := x + 1; \quad y := y - 1 \quad \{ x = 5 - y \} \]

**SHOW AND JUSTIFY ALL STEPS AND CASES AS ILLUSTRATED IN CLASS.**

10. (8 pts.) Prove \( f = [P] \) where \( f = (x, y, \text{temp} := y, x, x) \) and \( P \) is the compound program:

\[
\text{temp} := x; \quad x := y; \quad y := \text{temp}
\]

**SHOW AND JUSTIFY ALL STEPS AND CASES AS ILLUSTRATED IN CLASS.**

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**NOTE:** Do NOT work problems 11-17 unless you have already taken CEN 4072/6070, Software Testing and Verification!

11. (3 pts.) Which one of the following is NOT usually a component of a RTOS? (Circle one only.)

   a. a real-time clock
   b. an interrupt handler
   c. an aspect weaver
   d. a scheduler
   e. a resource manager
   f. a process dispatcher
12. a. (3 pts.) Sommerville notes that object-oriented development may not be usable for hard real-time systems. Briefly explain why this is so.

b. (3 pts.) However, a version of Java (“Real-time Java”) has been designed for embedded system development. Briefly describe the important modifications mentioned by Sommerville that make it suitable for this purpose.

13. Sommerville describes and provides examples that illustrate three commonly used real-time architectural patterns: *Observe and React*, *Environmental Control*, and *Process Pipeline*.

   a. (4 pts.) Briefly describe the *Environmental Control* pattern. (Indicate its constituent elements and their roles, and for what type/class of system the pattern is normally used.)

   b. (2 pts.) What specific system was used by Sommerville to illustrate the *Environmental Control* pattern?

14. (3 pts.) Briefly describe the point Sommerville makes using the figure below.

--- please do not write below this line ---
15. (3 pts.) Sommervilles notes that while the price of a software product to a customer should, in principle, simply be the cost of development plus profit for the developer, in practice, factors such as market opportunity, cost estimate uncertainty, contractual terms, requirements volatility, and financial health must also be taken into account. Briefly describe the specific example he uses to illustrate how contractual terms could affect the price charged for software.

16. a. (2 pts.) Briefly describe what the term “planning game” refers to.

b. (6 pts.) Briefly explain the ideas of “effort points” and “velocity” in this context. (What are they and what, specifically, are they used to do?)

17. (3 pts.) Explain what the “Precedentedness” scale factor represents and how it is used in the COCOMO II post-architecture model.

On my honor, I have neither given nor received unauthorized aid on this exam and I pledge not to divulge information regarding its contents to those who have not yet taken it.

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SIGNATURE