TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI

VICTORIA
UNIVERSITY OF WELLINGTON

EXAMINATIONS – 2019

TRIMESTER 1

SWEN 326

SAFETY-CRITICAL SYSTEMS

Time Allowed: TWO HOURS

CLOSED BOOK

Permitted materials: No calculators permitted.
Non-electronic Foreign language to English dictionaries are allowed.

Instructions: Answer all questions

Question	Topic	Marks
1.	Risk, Hazards and Failure	30
2.	Testing	30
3.	Static Analysis	30
4.	Design Validation	30
	Total	120

1. Risk, Hazards and Failure **(30 marks)**

(a) Consider the following description of a system for controlling a *water boiler*.

"The water boiler is operated by a *software controller*. If the *sensor* reports that the water temperature is too low, the heater should be *turned on*. Likewise if the temperature is too hot, the heater should be *turned off*. Under no circumstance should the water temperature be allowed to reach boiling point."

i. **(2 marks)** Following the terminology of IEC61508, identify the *Equipment Under Control* for the water boiler system.

ii. **(2 marks)** Identify an important *hazard* for the water boiler system.

iii. **(4 marks)** Briefly, discuss how the *risk* of the above hazard occurring might be estimated.

iv. **(2 marks)** Briefly, discuss how the above hazard is *mitigated* in the system.

(Question 1 continued on next page)

(Question 1 continued)

v. **(2 marks)** When calculating risk, one will often consider only a *single component failure*. Briefly, discuss what such an analysis might conclude for the water boiler system.

vi. **(2 marks)** Briefly, outline one simple approach for mitigating against a single component failure.

(b) Software bugs pose considerable risk to safety-critical systems.

i. **(4 marks)** Briefly, discuss the following statement:

"Catching errors at runtime may be too late."

ii. **(4 marks)** Briefly, discuss the following statement:

"Catching errors at compile time reduces overall risk."

(Question 1 continued on next page)

(Question 1 continued)

(c) The *"Power-of-Ten"* rules provide a simple set of coding guidelines for developing safety-critical software.

i. **(4 marks)** Rule 1 prohibits the use of *"direct or indirect recursion"*. Briefly, discuss the motivation behind this rule.

ii. **(4 marks)** Rule 2 requires that *"all loops must have a fixed upper-bound"*. Briefly, discuss the motivation behind this rule.

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Specify the question number for work that you do want marked.

2. Testing **(30 marks)**

(a) Consider the following Java class which compiles without error:

```java
public static final int RED = 0;
public static final int GREEN = 1;
public static final int BLUE = 2;

public static int[] countRGB(int[] items) {
   int[] cs = new int[3]; // counts
   //
   for(int i=0;i!=items.length;++i) {
      switch(items[i]) {
      case RED:
         cs[RED] = cs[RED] + 1;
         break;
      case GREEN:
         cs[GREEN] = cs[GREEN] + 1;
         break;
      case BLUE:
         cs[BLUE] = cs[BLUE] + 1;
         break;
      default:
         // Do nothing
      }
   }
   return cs;
}
```

i. **(8 marks)** Draw the *control-flow graph* for the `countRGB(int[])` method.

(Question 2 continued on next page)

(Question 2 continued)

ii. **(3 marks)** Give test inputs which achieve 100% *branch coverage* of `countRGB()`.

iii. **(4 marks)** Briefly, state the *prime path coverage* criterion.

iv. **(5 marks)** Identify five *prime paths* for `countRGB()`:

(1)

(2)

(3)

(4)

(5)

(Question 2 continued on next page)

(Question 2 continued)

(b) Consider testing the following method using the Modified Condition / Decision Coverage (MC/DC) criterion.

```
public static int max3(int x, int y, int z) {
   if(x <= z && y <= z) {
      return z;
   } else if(x <= y) {
      return y;
   } else {
      return x;
   }
}
```

i. **(3 marks)** MC/DC requires all *decisions* and *conditions* take every possible outcome. Briefly, discuss what this means using the above example to illustrate.

ii. **(3 marks)** Give test inputs which achieve 100% for the MC/DC criterion.

iii. **(4 marks)** Fuzz testing is a simple form of *random testing*. Briefly, discuss the challenges faced in fuzz testing the `max3` method.

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3. Static Analysis **(30 marks)**

An important form of static analysis for embedded systems is *Control-Flow Analysis*.

```
0x0000:  rjmp 7
0x0001:  rjmp -1
0x0002:  cp r24, r22
0x0003:  cpc r25, r23
0x0004:  brge 1
0x0005:  movw r16, r12
0x0006:  ret
0x0007:  rjmp -1
0x0008:  push r28
0x0009:  push r29
0x000A:  movw r24, r8
0x000B:  rcall -10
0x000C:  mov r22, r28
0x000D:  pop r29
0x000E:  pop r28
0x000F:  rjmp -1
```

(a) **(5 marks)** Using the above to illustrate, briefly discuss what a Control-Flow Analysis does.

(b) **(3 marks)** Identify the two *unreachable* instructions a Control-Flow Analysis would uncover for the above.

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(Question 3 continued)

(c) **(5 marks)** A Control-Flow Analysis is said to be *conservative*. Using an example to illustrate, briefly discuss what this means.

(d) Indirect jumps pose a significant challenge for Control-Flow Analysis.

i. **(3 marks)** Briefly, discuss what the problem is with indirect jumps.

ii. **(4 marks)** Jump tables are often implemented with indirect jumps. Briefly, discuss what a jump table is and why they are relatively easy to reason about.

(Question 3 continued on next page)

(Question 3 continued)

(e) Control-Flow Analysis can be used to determine the *worst-case stack usage* of an embedded program.

i. **(4 marks)** Briefly, discuss what this means.

ii. **(3 marks)** Briefly, discuss why loops and recursive methods present a challenge for determining the worst-case stack usage.

The following function uses a *stack allocated array*:

```
void rotate(int data[]) {
  int tmp[16];
  for(int i=0;i<16;++i) {
     tmp[i] = data[i];
  }
  for(int i=0;i<4;++i) {
   for(int j=0;j<4;++j) {
     data[(i*4)+j] = tmp[(j*4)+i];
} } }
```

iii. **(3 marks)** Briefly, discuss why stack allocated arrays present another challenge for determining the worst-case stack usage.

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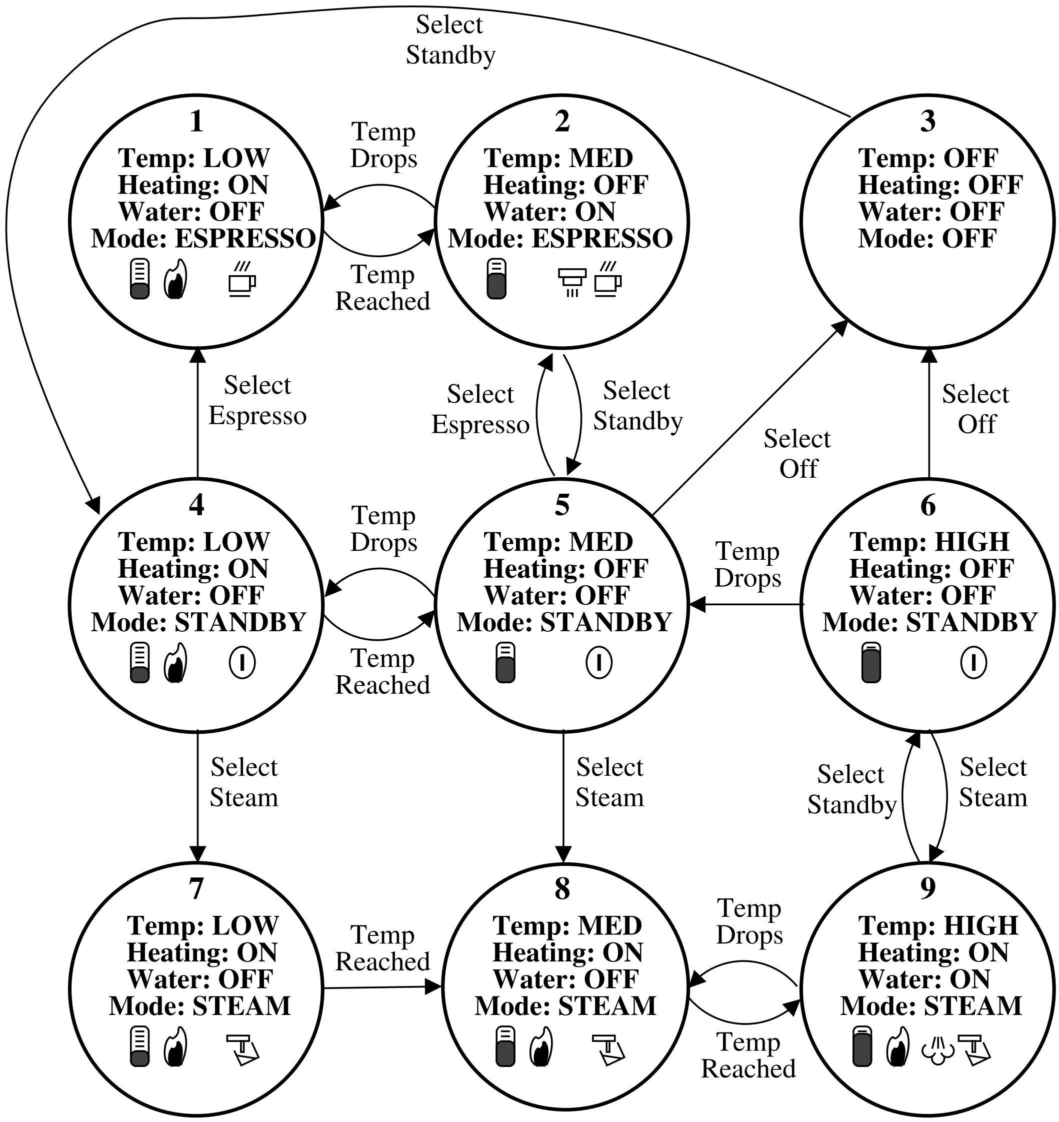
4. Design Validation **(30 marks)**

Consider the following description of a simple *coffee machine*:

> "The Espresso Machine makes coffee by pushing hot water through ground coffee beans. A steam function is provided for steaming milk. A *control dial* is used to operate the machine. It has four positions: *Standby*, *Espresso*, *Steam* and *Off*. In *Standby mode*, the water is heated, and a *heat sensor* turns the heating off when the temperature is reached, and on again when it drops. In *Espresso mode* the machine passes hot water out into the ground coffee, whilst in *Steam mode* it shoots very hot steam out into the milk."

A *state machine diagram* for the coffee machine has been provided:



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(a) For each of the following statements, indicate whether you think it is a true or false statement based on the state machine diagram.

i. **(2 marks)** The machine continuously heats the water when “Steam” is selected.

ii. **(2 marks)** The water achieves the highest temperature when “Espresso” is selected.

iii. **(2 marks)** When “Espresso” is selected, the machine always pushes water out immediately.

iv. **(2 marks)** After steaming milk, the machine must cool down before it can make espresso again.

v. **(2 marks)** When the machine overheats, it automatically shuts down.

(b) Provide a suitable *execution trace* for the following scenarios. Your execution trace may start from whichever state you chose.

i. **(2 marks)**
“John selected steam, but the machine was cold and it took a long time before he got steam.”

ii. **(2 marks)**
“Jane turned the machine on in the morning. When she selected Espresso later on, water came out immediately.”

(Question 4 continued on next page)

(Question 4 continued)

(c) Consider the following (Whiley) model of the espresso machine state:

```
type AbstractState is {bool heating, bool water, int mode}
where mode >= 0 && mode <= 3

type State is (AbstractState s)
where (s.mode == OFF) ==> !(s.water || s.heating)
where (s.mode == STANDBY) ==> !s.water
where (s.mode == ESPRESSO) ==> (s.heating != s.water)
where (s.mode == STEAM) ==> s.heating

function tempChange(State s1, int sensor) -> (State s2)
// Event doesn't change operating mode
ensures (s1.mode == s2.mode):
   //
   AbstractState s = s1
   //
   if s1.mode == STANDBY:
      s.heating = (sensor < MED)
   else if s1.mode == ESPRESSO:
      s.heating = (sensor < MED)
      s.water = (sensor >= MED) && (sensor < HIGH)
   else if s1.mode == STEAM:
      s.water = (sensor >= HIGH)
      s.heating = true
   //
   return s

function selectStandby(State s1) -> (State s2)
// Resulting mode must be standby
ensures s2.mode == STANDBY:
   //
   State s = {mode: STANDBY, heating: false, water: false}
   //
   if s1.mode == OFF:
      s.heating = true
   else if s1.mode == ESPRESSO:
      s.heating = s1.heating
   //
   return s
```

i. **(2 marks)** Give a valid instance of `State` which corresponds to state five from the diagram on page 14.

(Question 4 continued on next page)

(Question 4 continued)

ii. **(2 marks)** Give a valid instance of `AbstractState` which does not correspond to *any* state from the diagram on page 14.

iii. **(4 marks)** Complete the following function to model the "Select Espresso" transition from the diagram on page 14.

```
function selectEspresso(State s1) -> (State s2)
requires s1.mode == STANDBY:
ensures s2.mode == ESPRESSO:
```

iv. **(4 marks)** Briefly, discuss why attempting to verify `tempChange()` produces the following error:

```
error:25: type invariant may not be satisfied
    return s
           ^
```

v. **(4 marks)** Currently, `selectStandby()` does not handle `s1.mode==STEAM`. Briefly, discuss why this is difficult to do.

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