NATIONAL UNIVERSITY OF SINGAPORE

SCHOOL OF COMPUTING

EXAMINATION FOR
Semester 2: 2013/2014

CS3211 - Parallel and Concurrent Programming

May 2014 Time allowed: 2 hours

INSTRUCTIONS TO CANDIDATES

This examination paper contains **SIX (6)** sections totalling **FIFTY (50)** marks, and comprises **FOURTEEN (14)** printed pages including this one.

This is an **OPEN BOOK** examination, and you are to answer **ALL** questions. You may cite any result in the textbook, lecture notes or tutorials. Answer **ALL** questions within the space provided in this booklet (write on the backs of pages if you need more room).

Please write your Matriculation Number below.

MATRICULATION NO: ____________________

This portion is for examiners use only.

Question		Marks	Remark
General topics, short answers	Q1 (6)		
Process algebra	Q2 (7)		
Modelling	Q3 (12)		
Java programming	Q4 (7)		
Parallel computing	Q5 (10)		
MPI	Q6 (8)		
Total:	Q1-6 (50)		

Q1 (Short Answer Questions) (6 marks)

In the following 6 short questions, write a brief answer in the box provided. Each answer is worth 1 (ONE) mark.

1.1 In a CSP# program you find the code `P() = ||x:{0..2}@Q(x);` Show the expansion of the expression. What is the programmer doing?

Answer:

1.2 Briefly explain how you may differentiate between a safety or liveness property for a model, by examining their counter-examples.

Answer:

1.3 Two systems are described by `S1 = P || Q;` and `S2 = P ||| Q;` One of the processes `S1,S2` could have a smaller statespace than the other. Which one, and why?

Answer:

Q1 (Short Answer Questions) (Continued)

1.4 If a process P has 4 states, and a process Q has 3 states, what is the lower bound on the number of states for $P \,||\, Q$, the parallel composition of P and Q? Justify your answer.

Answer:

1.5 Write a CSP#/PAT assertion for a process P that expresses the idea "It is always the case that if a button b is pressed, then missile m will be launched".

Answer:

1.6 Briefly explain the principle differences between a computing grid and a compute cluster.

Answer:

Q2 (Process algebra) (7 marks)

2.1 Prove that in the process definitions below, R always reaches deadlock. (4 marks)

$$\begin{aligned} P &= a \rightarrow d \rightarrow c \rightarrow P \\ Q &= b \rightarrow c \rightarrow d \rightarrow Q \\ R &= P \| Q \end{aligned}$$

You should use laws of process algebra (attached to the end of this exam), making it clear which laws you are using for each step of your proof.

Answer:

Q2 (Process algebra) (Continued)

2.2 Briefly explain how a CSP# process can be used to express a property, and for that property to be checked in a model checker. (2 marks)

In your answer you should give a small example of a property P, for a model M, expressed as a CSP# process. You should then show the assertion used to check the property.

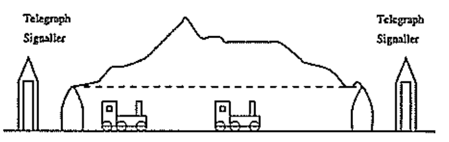
Answer:

2.3 Give one language element found in CSP# (in PAT) that is not found in CSP. (1 mark)

Answer:

Q3 (Modelling) (12 marks)

3.1 In class we saw the Clayton Tunnel protocol failure after 21 years continuous operation:



Clayton Tunnel - August 1861

The system's function was to ensure that only one train could be in the Clayton Tunnel at a time. At each end of the tunnel was a signal box, a signaller, and signalling equipment involving a three-way switch and an indicator. The signaller could indicate any of three situations to the other signaller: (i) nothing at all, (ii) Train in Tunnel, and (iii) Tunnel Clear.

The signallers had a red flag which they would place by the track to alert the train drivers to stop, and if they saw a train (entering or leaving the tunnel) they would signal to the other end of the tunnel (Train-in-tunnel or Tunnel-clear). Both signallers could then set or clear the red warning flag. If a train driver saw a red flag, they would stop and not enter the tunnel. A flaw in a protocol led to two trains colliding - inside the tunnel - one going forward and one in reverse.

Assume you are going to model this system in CSP, including the notion that two trains could be in the tunnel at the same time (which would be bad). Give the names and brief (one-line) descriptions of the processes, and shared actions you would define. (3 marks)

Answer:

Q3 (Modelling) (Continued)

3.2 For question 3.1 give the CSP for your processes. (4 marks)

Answer:

Q3 (Modelling) (Continued)

3.3 For your model give a CSP/PAT safety assertion that asserts that only one train is in the tunnel at any one time. Briefly explain how it is supposed to work. (2 marks)

Answer:

3.4 Consider the following CSP/PAT model. Draw the Labelled Transition System (LTS) for Test(). (3 marks)

```
Test() =   hi -> Skip()
        [] lo -> Stop()
        [] lilo -> Test();
```

Answer:

Q4 (Java programming) (7 marks)

4.1 The following Java class is used by two different Java threads, the first one of which calls `put`, setting `x` to `42`, and then setting `valid` to be `true`. No thread changes `x` or `valid` after this. The other thread calls `get`, checking for `valid` to be `true` and then uses the value of `x`, which should now be 42. However, in Java, it is possible for `x` to have the value 0 when we want to use it in the method `get`. This is due to a particular property of the Java memory model. Briefly explain what causes the effect. (3 marks)

```
class Tricky {
   int x=0;
   boolean valid=false;
   public void put() {
      x = 42;
      valid = true;
   }
   void get() {
      if (valid == true) {
         ... use x here - should be 42 right?
      }
   }
}
```

Answer:

4.2 Give two different techniques to fix the code. (4 marks)

Briefly describe each of your techniques, showing how you would change the code.

Answer:

Q5 (Parallel computing) (10 marks)

5.1 You are to compute the solution of a problem for each element of a 1-dimensional array of size n. Each element is dependant on all the other elements. On a single processor, each computation for each element takes one second, and with no communication overhead, the total time is thus n seconds, an $\mathcal{O}(n)$ solution. Splitting the problem onto (say) p separate processors with $p = n$, will reduce the computation time to one second (an $\mathcal{O}(1)$ solution), but unfortunately, in the algorithm each processor will have to access the data elements in every other processor, as each element is dependant on all other elements. Assume that p divides n, the communication network is a shared bus, and communicating one element takes time t. Calculate the communication overhead in terms of t, p and n, explaining your answer. (2 marks)

5.2 Calculate the total time in terms of t, p and n, explaining your answer. (2 marks)

Q5 (Parallel computing) (Continued)

5.3 In Q5.1, the total time may be reduced on a different communication network; for example a ring. Briefly explain the underlying reason why the total time would be reduced on a ring, and quantify the improvement (perhaps by re-working your total time calculation. Explain your answer, stating any assumptions you may have made. (4 marks)

5.4 If each communication link in a 4D hypercube takes unit time, what is the maximum communication time between any two nodes? Explain your answer. (2 marks)

Q6 (MPI) (8 marks)

6.1 A problem in parallel computing requires work on an $n \times n$ 2-D array. In your implementation of a parallel solution, you use $p = n^2$ processes, assigning one process to each element of the array. In the algorithm, each element has a local computation, and then has to share the element values with all other processes in the row. After that there is some more computation in each process before sharing the element values with all other processes in the column. This cycle repeats (row, column, row...) for a long time - perhaps for t complete row-column cycles. The communication dominates the computation, so we are mostly concerned with how the processes communicate. Outline an MPI communication solution to the problem. (3 marks)

Answer:

6.2 For your MPI solution in question 6.1, explain what sort of hardware architecture might map best to the solution. (1 mark)

Answer:

Q6 (MPI) (Continued)

6.3 Sketch the C/MPI code for your solution to 6.1: (4 marks)

Answer:

=== END OF PAPER ===

Laws of process algebra...

Parallel Composition:

$P \| Q$	$=$	$Q \| P$	(symmetric)	$L1_{\|}$
$P \| (Q \| R)$	$=$	$(P \| Q) \| R$	(associative)	$L2_{\|}$
$P \| \text{Stop}$	$=$	Stop		$L3A_{\|}$
$(c \to P) \| (c \to Q)$	$=$	$c \to (P \| Q)$		$L4A_{\|}$
$(c \to P) \| (d \to Q)$	$=$	Stop if $c \neq d$		$L4B_{\|}$
$(a \to P) \| (c \to Q)$	$=$	$a \to (P \| (c \to Q))$		$L5A_{\|}$
$(c \to P) \| (b \to Q)$	$=$	$b \to ((c \to P) \| Q)$		$L5B_{\|}$
$(a \to P) \| (b \to Q)$	$=$	$a \to (P \| (b \to Q)) [] b \to ((a \to P) \| Q)$		$L6_{\|}$

Non-deterministic choice:

$P \langle\rangle P$	$=$	P	(idempotent)	$L1_{\langle\rangle}$
$P \langle\rangle Q$	$=$	$Q \langle\rangle P$	(symmetric)	$L2_{\langle\rangle}$
$P \langle\rangle (Q \langle\rangle R)$	$=$	$(P \langle\rangle Q) \langle\rangle R$	(associative)	$L3_{\langle\rangle}$
$x \to (P \langle\rangle Q)$	$=$	$(x \to P) \langle\rangle (x \to Q)$	(prefix distributes)	$L4_{\langle\rangle}$
$x : B \to (P \langle\rangle Q)$	$=$	$(x : B \to P) \langle\rangle (x : B \to Q)$		$L5_{\langle\rangle}$
$P \| (Q \langle\rangle R)$	$=$	$(P \| Q) \langle\rangle (P \| R)$		$L6_{\langle\rangle}$
$(P \langle\rangle Q) \| R$	$=$	$(P \| R) \langle\rangle (Q \| R)$		$L7_{\langle\rangle}$
$f(P \langle\rangle Q)$	$=$	$f(P) \langle\rangle f(Q)$		$L8_{\langle\rangle}$

General choice:

$P [] P$	$=$	P	(idempotent)	$L1_{[]}$
$P [] Q$	$=$	$Q [] P$	(symmetric)	$L2_{[]}$
$P [] (Q [] R)$	$=$	$(P [] Q) [] R$	(associative)	$L3_{[]}$
$P [] \text{Stop}$	$=$	P		$L4_{[]}$
$P [] (Q \langle\rangle R)$	$=$	$(P [] Q) \langle\rangle (P [] R)$		$L6_{[]}$
$P \langle\rangle (Q [] R)$	$=$	$(P \langle\rangle Q) [] (P \langle\rangle R)$		$L7_{[]}$

If P engages alone in a, Q engages alone in b, but c and d require simultaneous participation of both P and Q.