COMPUTER SCIENCE TRIPOS Part II

Tuesday 4 June 1996 1.30 to 4.30

Paper 7

Answer **five** *questions.*
Submit the answers in five **separate** *bundles each with its own cover sheet.*
Write on **one** *side of the paper only.*

1 Specification and Verification I

Write a paragraph on *each* of the following:

(*a*) the relationship between Floyd–Hoare logic and verification conditions [5 marks]

(*b*) partial correctness *versus* total correctness [5 marks]

(*c*) reasoning about arrays [5 marks]

(*d*) soundness and completeness of Floyd–Hoare logic [5 marks]

2 VLSI

Describe the VLSI structures used in the design of a typical state-of-the-art CPU chip. [8 marks]

What major architectural components would you expect to find on the critical path? [4 marks]

What techniques are available to the VLSI designer to maximize performance of these components? [8 marks]

3 Comparative Architectures

Discuss *five* of the following in 100–150 words:

(*a*) delayed loads

(*b*) delayed branches and annulment

(*c*) subword (for example byte) memory access

(*d*) unaligned memory access

(*e*) variable length instructions

(*f*) multi-cycle (for example division) instructions

(*g*) multiple functional units and multiple issue

You may find it useful to discuss these issues with respect to two architectures which differ in the aspect concerned. [4 marks each]

4 ECAD Topics

Write brief notes on *each* of the following:

(*a*) structural hardware description language [4 marks]

(*b*) behavioural hardware description language [4 marks]

(*c*) event-driven simulation [4 marks]

(*d*) circuit simulation [4 marks]

(*e*) fault simulation [4 marks]

5 Philosophy

Either Explain and briefly discuss *each* of the following:

(*a*) fallacy of equivocation [4 marks]

(*b*) the type–token distinction [4 marks]

(*c*) the use–mention distinction [4 marks]

(*d*) relations-in-intension and relations-in-extension [4 marks]

(*e*) self-refuting sentences [4 marks]

or "You will be hanged at 9 a.m. one day this week but will not know when." Can this prediction be made good? [20 marks]

6 Artificial Intelligence

Devise a semantic network capable of representing propositions of the following kinds:

John loves Mary more than she loves him.
John thinks that Mary does not love him.
John thinks that Mary does not love him, but she does love him.

It will not be necessary for you to address linguistic issues such as pronoun resolution. [6 marks]

Identify some ontological and epistemological commitments of your representation. [4 marks]

Demonstrate some inferences that can be made from such a network. [4 marks]

How can you distinguish between statements that are represented by the network and statements that are implied by the network? [3 marks]

Explain how your network can be represented by data structures. [3 marks]

7 Computational Neuroscience

List five critical respects in which the operating principles that are apparent in biological nervous tissue differ from those that apply in current computers, and in each case comment upon how these might explain key differences in performance such as adaptability, speed, fault-tolerance, and ability to solve ill-conditioned problems. [20 marks]

8 Database Topics

Explain what is meant by saying that *persistence* of data is an orthogonal property in a programming language. [3 marks]

What additional concepts not usually found must be introduced into a programming language before it becomes suitable for database use? [5 marks]

How are database applications supported in the language PS-ALGOL? [12 marks]

9 Security

Describe the Clark–Wilson security policy model, and discuss how it might typically be applied. [12 marks]

It is suggested that, in order to control the spread of computer viruses, a company implement a Clark–Wilson policy in which the constrained data items are all the executable files on its computers. In what ways might this be inadequate and how, if at all, might these inadequacies be remedied? [8 marks]

10 Types

Explain the term *minimal type* and discuss its importance in typechecking algorithms for type systems with subtyping. What is the difference between a minimal type and a principal typing? [6 marks]

Write subtyping and typing algorithms (*either* as syntax-directed systems of inference rules *or* as pseudo-code) for the following "core" of the simply typed lambda-calculus with subtyping.

$$\begin{array}{rcl} e & ::= & x \\ & & fun(x \in T)e \\ & & e_1\ e_2 \end{array}$$

$$\begin{array}{rcl} T & ::= & T_1 \to T_2 \\ & & Top \end{array}$$

Your algorithms need not handle records or booleans. [6 marks]

Suppose that we add to this calculus a type $Box(T)$ for each type T, and the expression constructors

$$\begin{array}{rcl} e & ::= & \ldots \\ & & box\ e \\ & & contents\ e \\ & & e_1 \leftarrow e_2 \end{array}$$

with the following evaluation rules:

$$\frac{e \Downarrow r}{box\ e \Downarrow box\ r}$$

$$\frac{e \Downarrow box\ r}{contents\ e \Downarrow r}$$

$$\frac{e_1 \Downarrow box\ r_1 \qquad e_2 \Downarrow r_2}{e_1 \leftarrow e_2 \Downarrow box\ r_2}$$

Write sound typing and subtyping rules for these constructs. [5 marks]

Now suppose that we add to this calculus the type variables and bounded universal quantification of System $F_{\leqslant}$. Indicate how your typing and/or subtyping rules must change (while remaining sound!) so that the expression

$$fun(X \leqslant Box(Top \to Top))\ fun(x \in X)\ x \leftarrow (fun(y \in Top)\ y)$$

has the type

$$All(X \leqslant Box(Top \to Top))\ X \to X$$

[3 marks]

11 Specification and Verification II

Explain how a register can be modelled either as a unit-delay, or with an explicit clock input. [4 marks]

Describe the relationship between the two models. [4 marks]

Design a device with input i and output o that outputs on o the sum of the inputs present at i at the preceding two clock edges. [4 marks]

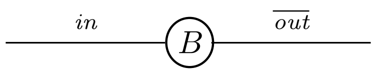
Give two specifications of the device: (a) as an abstract sequential machine and (b) with an explicit clock input. [4 marks]

State a logical relationship between the two specifications. [4 marks]

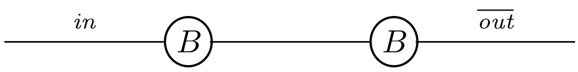
12 Communicating Automata

Define the notion of *weak bisimulation* over a labelled transition system. [3 marks]

A one-cell buffer B can be defined by $B \stackrel{\text{def}}{=} in.B'$, $B' \stackrel{\text{def}}{=} \overline{out}.B$ (the content of messages being ignored).



Define the linking operator $\frown$, in terms of basic operators, so that $B \frown B$ represents two buffer cells in sequence.



[3 marks]

Derive $B \frown B \xrightarrow{in} B' \frown B$ from the basic transition rules, and draw the complete transition graph of $B \frown B$. [3 marks]

A lossy buffer cell L (like B except that it may lose messages) can be defined by $L \stackrel{\text{def}}{=} in.L'$, $L' \stackrel{\text{def}}{=} \overline{out}.L + \tau.L$. Draw the complete transition graphs of both $B \frown L$ and $L \frown B$. [4 marks]

Show that $B \frown L \not\approx L \frown B$, by considering the state $L \frown B'$ (accessible from $L \frown B$) and showing that no appropriate state of $B \frown L$ can be observation equivalent to $L \frown B'$. [4 marks]

Is $L \frown L \approx B \frown L$ true? Outline an argument to prove or disprove it. [3 marks]

13 Designing Interactive Applications

When a new patient applies to join a doctor's practice, personal and medical-history details must be obtained. Usually the patient (or the patient's parent in the case of young children) must fill in a form of two pages or more for inclusion in the patient's records. With the computerization of one particular doctor's practice, P1, a means is needed for entering the new patient's details. Two approaches are considered:

(A) the doctor interviews the patient at the start of the initial consultation, and enters the details as they are elicited;

(B) upon application, the patient or parent sits down at a computer and enters the details.

Write one-sentence problem statements for each design problem. Then, drawing on your knowledge of the work of the doctor, discuss the pros and cons of the two approaches. [12 marks]

Suppose two practices, P1 and P2, adopt approaches A and B respectively. Each is dissatisfied with the results. Practice P1 therefore decides to switch to approach B, installing a computer in a booth adjoining its waiting room, running the system designed for the doctor (modified only to prevent access to existing records), so that patients and parents can enter their details. Meanwhile practice P2 decides to change to approach A, loading the patient data entry program, unchanged, onto the doctor's PC so that he or she can enter the details during consultations.

If you were asked to advise practices P1 and P2 on these moves, what outcomes would you predict? What analytical method would you use, in each case, to back up your predictions, and why? [8 marks]

14 Additional Topics

What is the principle of operation of the Global Positioning System (GPS)? [10 marks]

Write short notes on *four* appplications which are made possible by information supplied by this system. [10 marks]

15 Additional Topics

Explain the concept of *environment* as used in Natural Semantics. In particular, explain its use in the delivery judgements which describe the *evaluation* of phrases in Standard ML. What are the main kinds of *result* which such an evaluation may deliver, for different kinds of phrase? [6 marks]

The following Standard ML program has three top-level phrases:

```
val step = 5;
fun sum(0) = 0 | sum(n) = step*n + sum(n-1);
sum(3);
```

What are the components of the three environments in which these three phrases are evaluated? During the evaluation of `sum(3)`, the expression `sum(n-1)` is evaluated several times; in which environments do these evaluations take place? [7 marks]

Give two examples of theorems which one may be able to prove about the delivery judgements for evaluation, and explain the practical relevance of these theorems. [7 marks]