COMPUTER SCIENCE TRIPOS Part II (General)
DIPLOMA IN COMPUTER SCIENCE

Tuesday 4 June 1996 1.30 to 4.30

Paper 11 (Paper 2 of Diploma in Computer Science)

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 Software Engineering

Outline the software life cycle. Briefly describe each of the stages, its relation to other stages and its overall importance. [7 marks]

Describe how management can monitor the progress of a software project. In this respect, how does software differ from traditional engineering disciplines such as construction? [4 marks]

F.P. Brooks has listed *complexity*, *conformity*, *changeability* and *invisibility* as impediments to software development. What does he mean by these terms, and what independent evidence is available to support his analysis? [9 marks]

2 Modula-3

Explain the purposes of the Modula-3 reserved words `NIL`, `NULL`, `REFANY` and `TYPECASE` and describe how they are used in the following program.

```
MODULE Sub EXPORTS Main;

IMPORT IO, Fmt;

TYPE
  RefLink = REF Link;
  Link = RECORD val : CARDINAL; next : RefLink := NIL END;

PROCEDURE ToText (r : REFANY) : TEXT =
  BEGIN
    TYPECASE r OF
      NULL          => RETURN "NIL"
    | RefLink (r1) => RETURN Fmt.Int (r1^.val) & "::" &
                                                 ToText(r1^.next)
      ELSE
        RETURN "** Unknown Type **"
      END
    END ToText;

VAR
  jack : RefLink;
  jill := NEW (RefLink, val := 4);

BEGIN
  jill^.next := NEW (RefLink, val := 7,
                              next := NEW (RefLink, val := 11));
  IO.Put (ToText(jack) & "\n");
  IO.Put (ToText(jill) & "\n")
END Sub.
```

[6 marks]

What is output by the program? Explain how this comes about. [4 marks]

Explain the use of the Modula-3 functions `ISTYPE` and `NARROW`. [4 marks]

Suppose `TYPECASE` were missing from Modula-3. Rewrite the procedure `ToText` using `ISTYPE` instead. Explain the operation of the revised procedure. [6 marks]

3 Further Modula-3

What are `UNSAFE` interfaces and implementations in Modula-3 and what are they used for? [5 marks]

Write brief notes on the following Modula-3 keywords:

`UNTRACED`
`ADDRESS`
`ADR`
`LOOPHOLE`
`DISPOSE` [3 marks each]

4 Compiler Construction

Describe a structure that could be used to represent the abstract syntax tree of the following λ-expression:

$$(\lambda a.(\lambda f.fa)(\lambda n.n+1))3$$

Outline the definition of an evaluator function `eval(expr, env)` that could be used to evaluate a given expression `expr` represented in this way in the context of an environment given by `env`. Pay particular attention to the treatment of bound variables and the mechanism you use for function calls. [7 marks]

Is it possible with your implementation to give it a λ-expression which would cause `eval` to recurse to an unlimited depth? If so, give such a λ-expression; if not, explain why. [3 marks]

Is it possible with your implementation to give it a λ-expression that causes an environment chain of unlimited length to be created during the evaluation? If so, give a λ-expression that would cause this; if not, explain why it is not possible. [3 marks]

In an erroneous implementation of `eval` the value of

$$(\lambda x.body)$$

is an object that does not incorporate the contextual environment, and whose call evaluates *body* in an environment derived from the environment of the call. Explain why such an implementation is wrong, giving an example λ-expression that would yield different results when evaluated by this implementation and yours. [7 marks]

5 Data Structures and Algorithms

Show why comparison-based sorting of n items cannot take much less than $n \log n$ comparisons, being clear about your assumptions. Why can it take *any* less than $n \log n$? [10 marks]

If 1024 numbers are drawn randomly in the range 0–127 and sorted by binary insertion, about how many compares would you expect? A fairly rough estimate will do if your reasoning is clear. [10 marks]

6 Operating System Foundations

Give a detailed criticism of the following options for supporting interactions between processes in separate address spaces:

(a) pipes

(b) asynchronous message passing

(c) synchronous message passing

[20 marks]

7 Operating System Functions

What is meant by the term *demand paging* in a virtual memory management system, and how is it implemented? [5 marks]

Briefly describe five techniques which the operating system and/or hardware can implement to improve the efficiency of demand paging. [5 marks]

What is the *working set* of a program, and how can an operating system use it in the management of virtual memory? [3 marks]

Describe the clock (second chance) algorithm for selecting a VM page for replacement when a page fault occurs. How is the performance of this algorithm affected by the memory size of the computer system, and how may this be avoided? [7 marks]

8 Mathematics for Computation Theory

Let E be an event over S that is accepted by the deterministic finite automaton $M \equiv (Q, S, \iota, f, A)$, where $|\,Q\,| = N$. Suppose that $z \in E$ is a word such that $\ell(z) \geqslant N$: show that we may write $z = uvw$ where

(*i*) $\ell(uv) \leqslant N$

(*ii*) $\ell(v) \geqslant 1$

(*iii*) for all $n \geqslant 0$, $uv^n w \in E$ [12 marks]

State whether each of the following languages over $S = \{a, b\}$ is regular, giving your reasons.

(*a*) $L_1 = \{ww \mid w \in S^*\}$ [6 marks]

(*b*) $L_2 = \{wzw \mid w, z \in S^*\}$ [2 marks]

[Note: $|\,Q\,|$ indicates the number of elements in set Q, and $\ell(w)$ the number of characters in word w.]

9 Computation Theory

A *bag* B of natural numbers is a total function $f_B : \mathbb{N} \to \mathbb{N}$ giving for each natural number x the count $f_B(x)$ of occurrences of x in B. If each $f_B(x) = 0$ or 1, then f_B is the characteristic function χ_s of a set S: every set can thus be regarded as a bag.

(*a*) A bag B is *recursive* if the function f_B is computable. Suppose that the sequence of bags $\{B_n \mid n \in \mathbb{N}\}$ is recursively enumerated by the computable function $e(n, x) = f_n(x)$, which gives the count of x in each bag B_n. Show that there is a recursive set S that is different from each bag B_n. [7 marks]

Hence prove that the set of all recursive bags cannot be recursively enumerated. [3 marks]

(*b*) A bag B is *finite* if there is $X \in \mathbb{N}$ such that $f_B(x) = 0$ for all $x \geqslant X$. Show that the set of all finite bags is recursively enumerable. [10 marks]

10 Numerical Analysis I

Let x^* be the floating-point representation of a number x. Define the *absolute error* and *relative error* in representing x by x^*. How are these errors related? [3 marks]

Let x_1, x_2 be two numbers. Find expressions for

(a) the *absolute error* in representing $x_1 + x_2$

(b) the *relative error* in representing $x_1.x_2$ (where "." denotes multiplication) [4 marks]

Assume that the numbers 1 and 2 are represented exactly. Find an expression for the absolute error in calculating $2x + 1$. [2 marks]

In an iterative calculation the number y is an improved value of x, derived from the assignments

$$p := x/2 + 1$$
$$q := x - 2$$
$$y := p + 1/q$$

If ε_x is the absolute error in representing x, find an expression for the *absolute error* ε_y in representing y. [6 marks]

What is the approximate *relative error* δ_y in representing y when $x = 2.01$? [5 marks]

11 Graphics

Describe a quad-tree encoding method for greyscale images. [6 marks]

Given the following greyscale image, draw a diagram showing how it would be encoded using your method from the previous part.

33	39	43	72
34	54	64	81
42	54	71	83
60	64	77	89

[4 marks]

An image processing package allows the user to design 3×3 convolution filters. Design 3×3 filters to perform the following tasks:

(a) blurring [2 marks]

(b) edge detection of vertical edges [2 marks]

Choose one of the two filters (a) or (b) from the previous part. Explain how it works, using the following image as an example (you may round off any calculated values to the nearest integer).

100	100	100	0	0	0
100	100	100	0	0	0
100	100	100	0	0	0
100	100	100	100	100	100
100	100	100	100	100	100
100	100	100	100	100	100

[6 marks]

12 Digital Electronics

Design a synchronous sequential circuit with one input and one output which produces an output $X = 1$ whenever any of the following input sequences occur: 1100, 1010 or 1001. The circuit resets to its initial state after a 1 output has been generated.

(a) Draw a state diagram and provide a transition table. [10 marks]

(b) Choose an assignment and show the control factors for JK flip flops. [10 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]