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

Thursday 5 June 1997 1.30 to 4.30

Paper 13 (Paper 4 of Diploma in Computer Science)

Answer **five** *questions.*
Submit the answers in five **separate** *bundles, each with its own cover sheet. On each cover sheet, write the numbers of* **all** *attempted questions, and circle the number of the question attached.*
Write on **one** *side of the paper only.*

1 Distributed Systems

Discuss the tradeoffs that can be made between *consistency* and *availability* of replicated data in a distributed system. Your discussion should cover (*a*) the requirements of different applications and (*b*) the algorithms and protocols that can be used to implement the required policies. [20 marks]

2 Computer Architecture

What is the *PCI Local Bus* and when is it used? [5 marks]

What types of signals are defined in its specification? [5 marks]

Characterise operation of buses such as the PCI Local Bus in terms of basic read, basic write, and basic arbitration operations. [10 marks]

3 Digital Communication I

Explain the terms *ARQ protocol* and *window* of an ARQ protocol. [5 marks]

An ARQ protocol uses a window of 1 kbyte. The protocol is used over a link whose capacity is 1 Mbps. In the absence of transmission errors (or any other loss) determine (*a*) for a link delay of 100 μs, and (*b*) for a link delay of 250 ms, the time required to transfer each of the following amounts of information over the link:

1 kbyte, 1 Mbyte and 1 Gbyte [12 marks]

State and explain in which of these cases moving to a larger window size will not significantly improve the transfer time. [3 marks]

4 Computer Graphics and Image Processing

It is convenient to be able to specify colours in terms of a three-dimensional coordinate system. Three such coordinate systems are: RGB, HLS, L*a*b*.

Choose *two* of these three coordinate systems and for *each* of your chosen two:

(*a*) describe what each of the three coordinates represents [2 marks each]

(*b*) describe why the coordinate system is a useful representation of colour [2 marks each]

Draw *either* the first eight one-dimensional Haar basis functions *or* the first eight one-dimensional Walsh–Hadamard basis functions. [4 marks]

Calculate the coefficients of your chosen eight basis functions for the following one-dimensional image data:

12 16 20 24 24 16 8 8 [4 marks]

Explain why, in general, the Haar or Walsh–Hadamard encoded version of an image is preferable to the original image for storage or transmission. [4 marks]

5 Business Studies

Describe the rôles and relationships of the members of a Chief Programmer team. [5 marks]

Describe Maslow's *Hierarchy of Needs.* [5 marks]

Discuss stages of group formation. How does belonging to a group satisfy some of the needs described by Maslow? [5 marks]

"The problems of co-ordination mean that there is a limit on the size of any software system that can be successfully built." Discuss. [5 marks]

6 Programming in C and C++

Write a declaration of a C++ class that might be used to implement a binary tree with each node able to hold an integer. Your implementation (i.e. the class itself and those bodies which conveniently fit within it) should make it impossible for casual programmers to access the pointer fields that link parts of the tree together except through cleanly specified access functions. Show how you would overload the "+" operator in C++ to provide a neat notation for adding a new item into such a tree. [20 marks]

7 Compiler Construction

Investigate whether the following grammar for regular expressions is SLR(1) by attempting to construct its Action and Goto matrices.

```
S -> R eof

R -> F | R + F

F -> P | F P

P -> x | ( R ) | P *
```

Find all the conflicts, if any, in the two matrices. [20 marks]

8 Prolog for Artificial Intelligence

A binary tree is constructed from binary compound terms $\mathtt{n}(a, b)$ called *nodes*, where components a and b are either nodes or integers. Suppose integer components are restricted to the values 0 and 1.

Write a Prolog program to return a list of all the 0's and a list of all the 1's in a given tree. For example, the goal `enum(n(n(0,1),1),X,Y)` should instantiate `X` to `[0]` and `Y` to `[1,1]`. The program is required to use difference lists. [20 marks]

9 Databases

What particular strengths of the relational model have led to the pre-eminent position that it holds today as a vehicle for database management? [8 marks]

Identify any weaknesses in the model, illustrating your answer by examples. [6 marks]

How might these weaknesses be remedied while retaining the advantages of the model? [6 marks]

10 Introduction to Functional Programming

Consider the following Standard ML type `expression` intended to represent integer arithmetic expressions built up from named variables using addition and multiplication:

```
datatype expression = Var of string
                    | Sum of expression * expression
                    | Product of expression * expression;
```

[In the CAML dialect of ML `datatype` is written `type`.]

For example, the expression $((a + b)c)(d + e)$ would be represented by:

```
Product(Product(Sum(Var "a", Var "b"), Var "c"),
        Sum(Var "d", Var "e"))
```

Write an ML function `freevars` (using any dialect of ML) which takes an argument, `e`, of type `expression` and returns a value of type `string list` containing all the variables in `e`. This list may contain repeated instances of variables. [10 marks]

Write a second ML function `eval` (again using any dialect of ML) which takes two arguments. The first argument is of type `expression` and the second is an association list of type `(string * int) list` giving a value for each variable, for example:

```
[("a",1), ("b",0), ("c",2), ("d",4), ("e",1)]
```

[In the CAML dialect of ML semicolons are used as list separators.]

When `eval` is applied to the above examples it returns 10. [10 marks]

11 Computer Vision

Discuss the rôle of non-linear operators in vision for the extraction of motion information, texture information, colour information, and stereo information. What are the limitations of linear operators (such as filters) compared with non-linear ones? What is a quadrature pair, and what is a Hilbert pair? What is a Hilbert Transform, and what is a natural way to build a useful non-linear operator from it? [20 marks]

12 Complexity Theory

Suppose you had a conventional sequential computer with a special coprocessor which could multiply two n-bit numbers in time proportional to $\log(n)$, even for very large n. Explain how you would implement a fast integer square root program on this system. Comment on the performance you could expect to achieve.

[20 marks]

13 Numerical Analysis II

Explain the term *positive semi-definite.* [1 mark]

Let $\mathbf{A}$ be a square matrix. State *Schwarz's inequality* for the product $\mathbf{Ax}$. What are the *singular values* of $\mathbf{A}$, and how are they related to the ℓ_2 norm of $\mathbf{A}$?

[4 marks]

Describe briefly the *singular value decomposition* of the matrix $\mathbf{A}$, and how it may be used to solve the linear equations $\mathbf{Ax} = \mathbf{b}$. [4 marks]

Let $\hat{\mathbf{x}}$ be an approximate solution of $\mathbf{Ax} = \mathbf{b}$, and write $\mathbf{r} = \mathbf{b} - \mathbf{A}\hat{\mathbf{x}}$, $\mathbf{e} = \mathbf{x} - \hat{\mathbf{x}}$. Find an expression for the relative error $\|\mathbf{e}\|/\|\mathbf{x}\|$ in terms of computable quantities. Show how your formula is related to the *singular values* of $\mathbf{A}$. [8 marks]

How may this formula be used if some *singular values* are very small? [3 marks]