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

Tuesday 2 June 1998 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. 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 Software Engineering I

Discuss the lessons learned from the London Ambulance Service disaster under the following headings:

(*a*) capturing user requirements

(*b*) project management

(*c*) quality assurance

(*d*) testing [16 marks]

What in your view would be the single most important measure to take in developing a mission-critical system in order to reduce the likelihood of such a disaster? [4 marks]

2 Modula-3

The first half-dozen or so lines are missing from the program below. They include an `IMPORT` directive, a `TYPE` declaration and a `VAR` declaration. Suggest what the missing lines might be. [5 marks]

Describe how the program works, and give its resulting output. [15 marks]

```
PROCEDURE upk() =
  BEGIN
    k := k + 10
  END upk;

PROCEDURE jill() =
  BEGIN
    upk();
    k := k + 200
  END jill;

PROCEDURE jack (pr : MyProc; n : CARDINAL) =
  VAR
    a : CARDINAL;
  BEGIN
    a := 10*n;
    pr();
    IF n > 1000  THEN
      k  := k + 1;
      jack (jill, n-1000);
      a := a + n
    END;
    k := k + a
  END jack;

BEGIN
  k := 0;
  jack (upk, 3000);
  IO.Put ("k = " & Fmt.Int(k) & "\n")
END UpkEtc.
```

3 Programming in Java

Describe briefly the facilities provided in Java for synchronising concurrent threads. [6 marks]

An alternative scheme would be to model the system used in some shops where a machine issues numbered tickets to customers, and customers are served in numeric order. A ticket machine holds an integer, initially zero, and has a single atomic operation:

`turn()`	increments the integer and returns its previous value

A scheduler also holds an integer, initially zero, and has two atomic operations:

`next()`	increments the integer count
`queue(value)`	suspends the calling thread until the count is at least as large as the value given as an argument

Given a ticket machine, `m`, and a scheduler, `s`, a critical region could then be coded as follows:

```
number = m.turn();
s.queue(number);
    .
    .       protected code
    .
s.next();
```

Write Java classes `TicketMachine`, with a `turn` method, and `Scheduler`, with `next` and `queue` methods. [8 marks]

Show how a synchronised buffer holding a single value could be implemented using this new scheme. [6 marks]

4 Compiler Construction

Sketch parsers based on

(*a*) recursive descent, and [8 marks]

(*b*) a table-driven method of your choice (e.g. SLR(1)) [12 marks]

suitable for parsing the following grammar:

```
S  ->  E eof
E  ->  E + T | E - T | T
T  ->  P ^ T | P
P  ->  ( E ) | n
```

with `S` as the start symbol. The table-driven parser should include the associated algorithm which interprets the table. The parsers do not need to produce a parse tree, merely to report whether the input string is generated by the above grammar. You may assume there is a routine `lex()` which when called places the next symbol (`+`, `-`, `^`, `(`, `)`, `n`, `eof`) in variable `token`.

5 Data Structures and Algorithms

Describe and justify Dijkstra's algorithm for finding the shortest path between two vertices in a directed graph with non-negative lengths associated with its edges.
[8 marks]

For the case where the nodes represent towns and the costs C_{uv} represent distances by road, Hart, Nilsson & Raphael proposed a variation where the next node to be considered is based on minimising

$$D(a) + H(a, \text{destination})$$

instead of the usual $D(a)$. $H(u, v)$ is a heuristic function which here should be taken as some constant (k, say) multiplied by the Euclidean distance between towns u and v.

Explain what benefits such a modification might bring and investigate how the correctness and speed of the modified algorithm changes with the value of k.

Can such a variation help in finding the shortest routes to all nodes from a given starting node? Justify your answer. [12 marks]

6 Operating System Foundations

A barber provides a hair-cutting service. He has a shop with two doors: an entrance and an exit. He spends his time serving customers one at a time. When none are in the shop, the barber sleeps in the barber's chair. When a customer arrives and finds the barber sleeping, the customer awakens the barber and sits in the barber's chair to receive his haircut. After the cut is done, the barber sees the customer out through the exit door. If the barber is busy when a customer arrives, the customer waits in one of the chairs provided for the purpose. If all the chairs are full he goes away. After serving a customer the barber looks to see whether any are waiting and if so proceeds to serve one of them. Otherwise, he sleeps again in his chair.

In this question we represent the barber and his customers as synchronising processes.

A solution for the barber using only semaphores is:

```
waiting : integer         := 0;  % customers waiting to be cut
guard : semaphore         := 1;  % delimits a critical region to protect waiting
customers : semaphore     := 0;  % counting semaphore of customers
barber : semaphore        := 0;  % barber waiting for a customer (1) or not (0)?
```

The barber executes the following program:

```
WAIT (customers);              % sleeps if there are none
WAIT (guard);
   waiting := waiting −1;      % otherwise changes waiting under exclusion
   SIGNAL (barber);            % and indicates his readiness to cut hair
SIGNAL (guard);
cut hair;
```

(*a*) Give the corresponding code for a customer. [6 marks]

(*b*) Give the corresponding solution using a monitor. [10 marks]

(*c*) To what extent are the difficulties of semaphore programming alleviated by the provision of monitors? [4 marks]

7 Operating System Functions

What is a *translation lookaside buffer* (TLB)? Describe its operation with the aid of a diagram. How is the TLB affected by processor context switches for (*i*) threads and (*ii*) processes? [10 marks]

A process has four page frames allocated to it. (All of the following numbers are decimal, and all numbers start from zero.) The time of the last loading of a page into each page frame, the time of last access to the page, the virtual page number in each frame and the Referenced (R) and Modified (M) bits for each page frame are shown in the table below. Times are in clock ticks from the process start time at time 0.

Virtual Page #	Frame #	Time Loaded	Time Referenced	M	R
2	0	60	161	0	1
1	1	130	160	0	0
0	2	26	162	1	0
3	3	20	163	1	1

A page fault to virtual page 4 has occurred. Which page frame will have its contents replaced under each of the following replacement algorithms? Briefly explain why in each case.

(*a*) FIFO

(*b*) LRU

(*c*) Second Chance (Clock)

(*d*) Enhanced Second Chance

[6 marks]

Given the above state of memory before the fault, and the reference string of virtual page numbers: (4, 0, 0, 0, 2, 4, 2, 1, 0, 3, 2), calculate how many page faults would occur under the LRU policy if a working set with a window size of 4 were used instead of a fixed allocation of 4 frames. Show clearly when each page fault would occur. [4 marks]

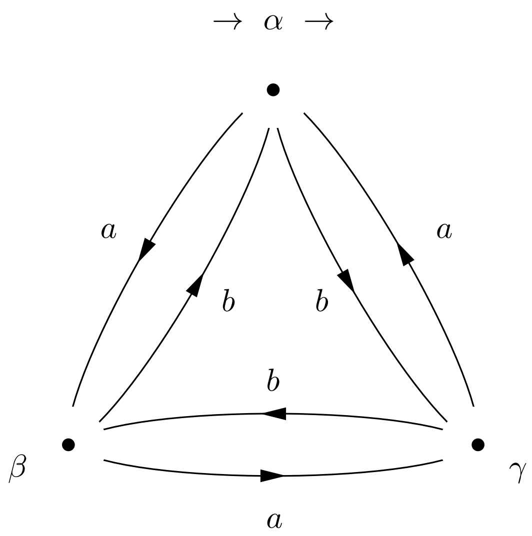
8 Mathematics for Computation Theory

Let $M = \begin{pmatrix} A & B \\ C & D \end{pmatrix}$ be an $(m+n) \times (m+n)$ event matrix partitioned so that A, D are square $(m \times m), (n \times n)$ matrices respectively. Let

$$E = (A + BD^*C)^* \qquad F = A^*B(D + CA^*B)^*$$
$$G = D^*C(A + BD^*C)^* \qquad H = (D + CA^*B)^*.$$

Show that $X = \begin{pmatrix} E & F \\ G & H \end{pmatrix}$ satisfies the event matrix equation $X = I + MX$, where I is the identity $(m+n) \times (m+n)$ matrix. [7 marks]

Consider the following deterministic finite automaton:



Here α is the initial state, and the sole accepting state. Show that the event recognised by the automaton may be described by the regular expression

$$\left\{a(ab)^*b + a^2(ba)^*a + b^2(ab)^*b + b(ba)^*a\right\}^*$$

Explain how each of the summands in the brackets arises. [13 marks]

[You may assume that if $M = \begin{pmatrix} A & B \\ C & D \end{pmatrix}$ is an event transition matrix partitioned so that A and D are square, then $M^* = \begin{pmatrix} E & F \\ G & H \end{pmatrix}$ takes the form stated above.]

9 Computation Theory

Explain *Church's Thesis*, making clear its connection with computability.

[3 marks]

Define precisely what is meant by the set of all *Primitive Recursive* (*PR*) functions.

[4 marks]

Outline steps that would enable you to recursively enumerate the set of all PR functions, showing how to determine the arity of each function generated (little detail is required). [7 marks]

Suppose that $V(n, x)$ is a recursive enumeration of all the PR functions of arity 1. By considering the function $v(x) = S\big(V(x, x)\big)$ or otherwise, show that

(a) the enumerating function $V(n, x)$ cannot itself be Primitive Recursive;

[4 marks]

(b) there are Total Recursive functions that are not Primitive Recursive.

[2 marks]

10 Numerical Analysis I

What are the three basic operations used in *Gaussian Elimination with partial pivoting*? [3 marks]

Consider the equations

$$\begin{pmatrix} 5 & 5 & 9 \\ 1 & 0.99 & 100 \\ 1 & 2 & 3.8 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} 0.5 \\ 100 \\ 2.1 \end{pmatrix}$$

Perform only the operations described below. Be careful to ensure that results and all intermediate values are rounded to **only 2 significant decimal digits**. [A calculator may be used, but is not essential.]

(*a*) Using the first equation as pivot, obtain two equations in x_2 and x_3. [4 marks]

(*b*) Solve the remaining two equations *without* interchanging equations. Obtain a value for x_3. [2 marks]

(*c*) Solve the same two equations again *with* interchange of equations. Show that the same value of x_3 is obtained to 2 significant digits. [2 marks]

(*d*) Use the method of *back substitution* twice to obtain a pair of solutions $\{x_1, x_2, x_3\}$ corresponding to steps (*b*) and (*c*). [4 marks]

(*e*) By substituting your results into the original equations, compute vectors of residual errors. Using any suitable norm, determine which of the pair of solutions is more accurate. [5 marks]

[TURN OVER

11 Computer Graphics and Image Processing

In ray tracing, *ambient*, *diffuse* and *Phong's specular* shading can be used to define the colour at a point on a surface. Explain what each of the three terms refers to, and what real effect each is trying to model. [3 marks each]

The diagram below represents a scene being ray traced. The circles may be taken to represent the cross-sections of spheres.

In answering the remaining parts of this question you may use the single sheet supplied with the examination paper. Ensure that you attach it to the rest of your answer.

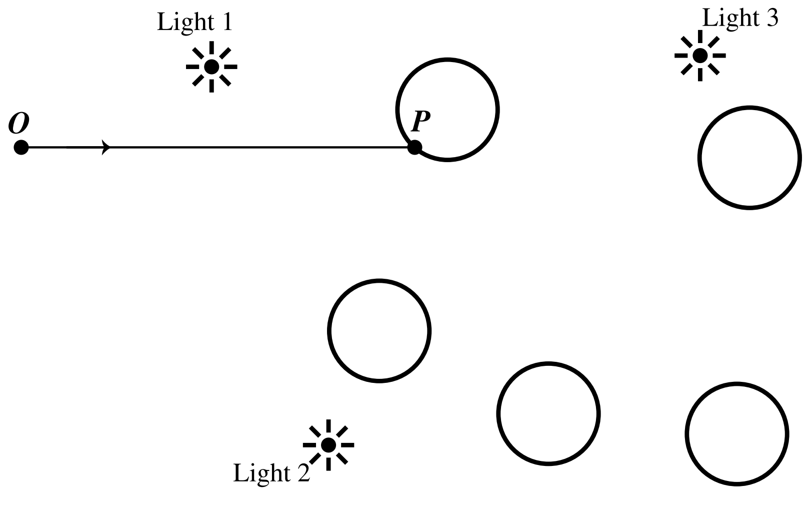
A particular ray from the eyepoint O has been found to have its closest intersection with an object at point P. Show, on a diagram, all subsequent rays and vectors which must be found in order to calculate the shading at point P. Explain the purpose of each one.

Assume that:

- each object has ambient, diffuse and specular reflections, but is *not* a perfect reflector
- each object is opaque
- all rays and vectors lie in the plane of the paper
- we are *not* using distributed ray tracing

[8 marks]

Assume now that all of the objects are perfect reflectors (in addition to having ambient, diffuse and specular reflection). Show, on a separate diagram, the extra rays which need to be calculated and explain the purpose of each one. [3 marks]



12 Digital Electronics

A controller is required for a traffic light at a four-way intersection. The lights follow the usual UK red, red–amber, green, amber sequence. The lights facing North and South are always identical, as are the lights facing East and West. There are four detectors which indicate if there is traffic approaching the lights from any direction.

(*a*) Describe all inputs and outputs of the control circuit. [3 marks]

(*b*) Provide a state diagram for the controller. You should indicate state duration (for example, a red–amber state might last 2 seconds). [7 marks]

(*c*) Describe how a programmable counter might be used to provide the state duration requirement. [3 marks]

(*d*) Give a design for a programmable counter which can be made to count for either four or eight clock ticks. [Hint: consider the inputs and outputs of the counter first.] You need not provide a circuit design. [7 marks]

13 Natural Language Processing

Write about *three* of the following problems, describing the issues they raise for natural language processing and possible techniques for dealing with them.

(*a*) The morphological decomposition and semantic interpretation of the following words:

reuse versus *react*
thinker versus *washer* versus *beggar*
decentralisation

(*b*) The syntactic ambiguity introduced by rules such as N $\rightarrow$ N N for noun compounds.

(*c*) The resolution of the potential ambiguity in *List the Frenchman among the programmers who understand*(*s*) *English* through the use of agreement features.

(*d*) The representation and recovery of the semantic interpretation of *Every company gave its representative a car* and the resolution of quantifier scope ambiguity.

(*e*) The representation and recovery of the anaphoric and referential links in the following discourse:

John saw a house he liked. The windows were large and the door was varnished. He wanted to go inside it.

[20 marks]