COMPUTER SCIENCE TRIPOS Part Ib

Tuesday 1 June 1993 1.30 to 4.30

Paper 4

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 Further Modula-3

Describe the facilities in Modula-3 for defining generic interfaces and modules. [5 marks]

Illustrate your answer by sketching a generic interface and implementation for a `Bag`, that is, a collection of items of the same type (possibly including duplicates), implemented as an opaque object with `insert` and `remove` methods. [10 marks]

The default `Bag` should be implemented as a stack, using a last-in first-out policy. Describe briefly alternative implementations providing specialisations of `Bag` to give a `Queue` (first-in first-out) and `Set` (ignoring duplicates). [5 marks]

2 Common Lisp

You are asked by your manager to write a Lisp macro, `itercall`. Evaluating `(itercall` F E`)` evaluates E, which is expected to yield a non-negative integer n. It then executes the function calls `(`F `1)`, ..., `(`F n`)` in succession, and returns `nil`.

(a) Your first version of the macro expands to a loop, which uses the symbol `i` as an index variable and the symbol `n` to store the initial value of E. Present the code for this version. [5 marks]

(b) Your manager complains that the function

```
(defun test1 (i) (itercall (lambda (x) (print (cons x i))) 10))
```

does not work as expected. Explain the problem and suggest how to fix it by modifying the macro. [4 marks]

(c) Your manager requests a final modification: `(itercall` F E`)` should generate straight-line code instead of a loop provided E is an integer constant less than twenty. Present the code for this version. Will it run faster than the previous versions? [11 marks]

Note: `(integerp` x`)` tests whether x is an integer. Each time `(gensym)` is called, it returns a new symbol not previously used in the Lisp system.

3 Software Engineering

Give a brief description of the main constructs used in a VDM specification. [7 marks]

Discuss to what extent the notation used in VDM is significantly different from that used in a conventional programming language. [6 marks]

Use VDM to specify a function that will find the difference between the largest and the smallest values held in an integer array. [7 marks]

4 Prolog

The following Prolog clauses define the procedure named `reverse`. The goal `reverse(X,Y)` succeeds for the list `X`, instantiating `Y` to the reverse of the list `X`. For example, evaluating the goal `reverse([a,b,c],Q)` instantiates `Q` to `[c,b,a]`.

```
reverse(X,Y) :- rev(X,[],Y).

rev([],L,L).
rev([H|T],R,Y) :- rev(T,[H|R],Y).
```

Explain how this procedure works, using a small example. [10 marks]

What is the outcome of the goal `reverse(L,[a,b,c])`? Explain your answer carefully. [10 marks]

5 Programming Language Compilation

Give a brief description of the main features of Lex and Yacc. [5+5 marks]

Illustrate their use by outlining how you would construct a parser for expressions composed of identifiers, integers, function calls and the operators `*`, `/`, `+` and `-`. [10 marks]

6 UNIX Case Study

Show how race conditions can arise:

(a) among processes over access to shared data [4 marks]

(b) between processes and interrupt-driven routines [4 marks]

Discuss why the UNIX kernel cannot be run on a shared-memory multiprocessor. [7 marks]

Outline how the UNIX kernel could be modified to run on a shared-memory multiprocessor. [3 marks]

Describe briefly an alternative approach. [2 marks]

7 Operating System Functions

In relation to virtual memory, describe the terms *segment*, *page* and *translation lookaside buffer* (TLB). [6 marks]

The operating system for a microprocessor supports a virtual memory model which implements both segmentation and paging. The only hardware assistance for the virtual memory system in the microprocessor is an on-chip TLB.

Outline the data structures held by the operating system. [5 marks]

Describe the actions of the operating system in response to an address exception due to not matching the address issued by the processor in the TLB. [5 marks]

How can the operating system use access permissions to aid its page replacement policy? [4 marks]

8 Data Structures and Algorithms

A directed graph of n nodes numbered $1, 2, \ldots, n$ can be represented by an $n \times n$ adjacency matrix G_1, where $G_1[i, j]$ is true if there is an edge connecting node i to node j, and $G_1[i, j]$ is false otherwise.

By extension, define G_k to be that matrix such that $G_k[i, j]$ is true if there is a path of length $\leqslant k$ connecting node i to node j, and $G_k[i, j]$ is false otherwise.

Describe an algorithm to generate G_2 from G_1. [12 marks]

How could this algorithm be used to generate the transitive closure of a graph given its adjacency matrix? [5 marks]

What is the cost of this transitive closure algorithm in terms of n and m, where m is the maximum path length in the transitive closure? [3 marks]

9 Graphics II

When scan-converting items for display, a Z-buffer is sometimes used to avoid some sorting. Outline its operation and limitations. [12 marks]

The use of an A-buffer will improve matters. Explain why. [8 marks]

10 Numerical Analysis I

What is meant by the term *loss of significance*? What is the essential difference between the terms *condition* and *stability* in numerical analysis? Define the term *machine epsilon* and explain why it is an important parameter. [6 marks]

Use the recurrence formula

$$\cos[(k+1)\theta] = 2\cos\theta\cos[k\theta] - \cos[(k-1)\theta]$$

with starting values $\cos 0 = 1$, $\cos\theta = \frac{1}{\sqrt{2}} + \varepsilon$ to evaluate $\cos 2\theta$ and show that loss of significance occurs. [4 marks]

Evaluate $\cos 3\theta$ and $\cos 4\theta$, ignoring terms $O(\varepsilon^3)$. On this evidence, comment on the stability of the formula. [8 marks]

Is the computed value of $\cos 2\theta$ acceptable? Explain your answer. [2 marks]