COMPUTER SCIENCE TRIPOS Part IB

Monday 3 June 1996 1.30 to 4.30

Paper 3

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 Concurrent Systems

For a transaction model based on objects:

(*a*) Define how conflict may be specified in terms of object operation semantics. Give an example of conflicting operations. Give an example of non-conflicting operations that would conflict with read–write semantics. [3 marks]

(*b*) Define the necessary and sufficient condition for two transactions to be serializable. Give an example of a non-serializable pair of transactions. [2 marks]

(*c*) Define the necessary and sufficient condition for a concurrent execution schedule of a number of transactions to be serializable. Give an example of a serialization graph for four transactions that are non-serializable. [2 marks]

(*d*) Discuss how the three general approaches to providing concurrency control for transaction systems are designed to enforce the property you have defined in (*c*) above. [13 marks]

2 Further Modula-3

A Modula-3 library module is required to provide a buffered stream of characters between two threads, with appropriate synchronization.

Write a `Buffer` interface defining an opaque object type, `T`, with the following methods:

> `init`: taking an argument specifying the buffer size and returning a suitably initialized object
>
> `put`: inserting a single character into the buffer
>
> `get`: extracting a single character from the buffer

[4 marks]

Sketch a corresponding implementation giving

(*a*) the concrete revelation of the types [4 marks]

(*b*) the three default methods [4 marks each]

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3 Continuous Mathematics

We compute the representation of some continuous function $f(t)$ in a space spanned by an orthonormal family $\{\Psi_j(t)\}$ of continuous basis functions by projecting $f(t)$ onto them. We express these projections in bracket notation $<f(t), \Psi_j(t)>$ denoting $\int_{-\infty}^{\infty} f(t)\Psi_j(t)dt$, and $f(t)$ is assumed to be square-integrable.

(a) Give an expression for computing $f(t)$ if we know its projections $< f(t), \Psi_j(t) >$ onto this set of basis functions $\{\Psi_j(t)\}$. Explain what is happening. [5 marks]

(b) Now give an expression for computing $f^{(n)}(t)$, the nth derivative of $f(t)$ with respect to t, in terms of the same projections and continuous basis set. (You may assume the existence of all derivatives.) Explain your answer. [5 marks]

(c) Now consider a linear, time-invariant system with impulse-response function $h(t)$, having time-varying input $s(t)$ and time-varying output $r(t)$:

$$s(t) \longrightarrow \boxed{h(t)} \longrightarrow r(t)$$

In the case that the input is the complex exponential $s(t) = \exp(i\mu_j t)$ (where $i = \sqrt{-1}$ and μ_j is a constant), what can you say about the output $r(t)$ of such a system? [5 marks]

(d) If the input $s(t)$ has been represented in terms of a set of complex exponentials $\Psi_j(t) = \exp(i\mu_j t)$ as described at the beginning of this question, is it possible for *different* complex exponentials (not included in this set) to appear in the output $r(t)$ when it too is represented in terms of complex exponentials? Justify your answer. [5 marks]

4 Compiler Construction

Describe what is meant by a *phrase structured grammar* and a *context free grammar*. [3 marks]

Describe an algorithm to calculate the set $L_T(P)$ of all terminal symbols that can start a string derived from the non-terminal P using one or more productions of a given context free grammar. Illustrate your answer by calculating L_T sets for the following grammar:

```
S -> U V

V -> + U V | ϵ

U -> X W

W -> * X W | ϵ

X -> ( S ) | n
```

[6 marks]

Describe an algorithm to calculate the set `FOLLOW(P)` of terminal and non-terminal symbols for a given context free grammar, where

$$\texttt{FOLLOW(P) = \{ X | S} \overset{*}{\Rightarrow} \texttt{... P X ... \}}$$

i.e. all symbols that can follow `P` in a sentential form derived from the sentence symbol `S`. Illustrate your answer by calculating the `FOLLOW` sets for the grammar given above. [6 marks]

Outline possible ways in which the space used by the Action and Goto matrices of an SLR(1) parser can be reduced. [5 marks]

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]

How can this algorithm be extended to consider graphs with some negative lengths? [6 marks]

By considering the graph on $\{A, B, C\}$ with $A \to B$ having length -2, $B \to A$ having length 1 and $A \to C$ having length 1, or otherwise, show that the "shortest path" is not always well defined if there are negative lengths. When is it well defined? [6 marks]

6 Data Structures and Algorithms

Describe and justify the Graham scan algorithm for finding the convex hull of a set of points in the plane. [8 marks]

How does its cost depend on the number of points? [4 marks]

Give a technique for heuristically eliminating a number of points before doing the scan. In what circumstances can the heuristic fail to help and what would you do about it? [8 marks]

7 Structured Hardware Design

A design is required for a novelty LED flasher that is to be small, battery operated and mounted inside a compact disc box as a promotional gimmick. The device has one LED only, and this produces bright pulses at approximately one Hertz. Instead of being entirely regular, the pulses are to be perceptibly irregular, in a way which grabs the attention of the careful observer. There will be a single production run of 18 million units.

Discuss aspects of the design process, including the circuitry, whether to include a microprocessor, what, if any, ASIC technology to use, how many prototypes to generate and how they will be evaluated, and testing of the product. [15 marks]

The design specification is now changed, so that now a meaning is attached to the slight deviations from a regular pulsing pattern. In particular, the pattern must slowly and repeatedly convey a built-in secret message of about 100 characters. It is acceptable that the decoding operation would be hard for the man in the street, but possible by an intelligent alien or computer scientist. How does this influence the design approach and cost? [5 marks]

8 Operating System Functions

A computer with a 32-bit virtual addressing scheme uses pages of size 4 Kbyte. Describe, with the aid of diagrams, two practical schemes for managing its virtual address space, comparing them with regard to speed of access, efficiency (of space), and ease of memory sharing between processes. [10 marks]

A Winchester-style disc has its head currently located at track 100, and the head is moving towards track 0. Given the reference string (27, 129, 110, 186, 147, 41, 10, 64, 120, 11, 8, 10) representing the (ordered) sequence of requests for disc tracks, give the sequence of disc addresses visited by the disc head under the SSTF, SCAN and C-SCAN disc scheduling algorithms. In each case briefly describe the algorithm, and compute the average cost of a disc access in terms of the mean number of tracks traversed per access.

In what way is each of these algorithms biased in its service of disc requests? Describe an algorithm which reduces the bias. [10 marks]

9 Computation Theory

Show how to code the program and initial data for an n-register machine into natural numbers p and d. In what sense do the codes p and d determine a unique computation? [9 marks]

Using your codes establish a precise statement of the Halting Problem for Register Machines. [3 marks]

Assume that the Halting Problem is in general undecidable. Prove that it cannot be decided whether a general program p terminates when the initial data is zero in every register. [8 marks]

10 Numerical Analysis I

Explain how the 32 bits are arranged to store the *sign*, *exponent*, and *significand* in a single precision number under the IEEE binary floating-point standard (IEEE 754). How is the exponent stored? [2 marks]

Explain the terms e_{max}, e_{min}, *normalized number*, *denormal number*, *hidden bit*, NaN. [5 marks]

In terms of the stored bit-pattern, how can each of the following be recognized: ± 0, $\pm\infty$, *normalized number*, *denormal number*, NaN? [5 marks]

Suppose the principles of IEEE arithmetic are applied to a floating-point representation with only 6 stored bits. If the precision p is 3 (including the hidden bit) and e_{min} is -2, what is e_{max}? [2 marks]

List the 16 bit-patterns which do not represent normalized numbers, and identify what each represents. [6 marks]