1 Digital Electronics and Computer Design

A sequential machine with two input wires and a single output has a behaviour specified in the following transition table:

<table>
<thead>
<tr>
<th>Initial state</th>
<th>Input</th>
<th>Next state</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>00</td>
<td>00</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>01</td>
<td>01</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>a</td>
<td></td>
<td>c</td>
<td>b</td>
</tr>
<tr>
<td>b</td>
<td></td>
<td>d</td>
<td>b</td>
</tr>
<tr>
<td>c</td>
<td></td>
<td>e</td>
<td>d</td>
</tr>
<tr>
<td>d</td>
<td></td>
<td>b</td>
<td>d</td>
</tr>
<tr>
<td>e</td>
<td></td>
<td>a</td>
<td>d</td>
</tr>
</tbody>
</table>

Demonstrate that this behaviour could be exhibited by a machine with fewer states. [12 marks]

Draw the state diagram for the reduced machine. [8 marks]

2 Computer Structures

What are the parameters which characterise the operation of a cache? [8 marks]

Describe three methods of mapping memory blocks to cache blocks. [7 marks]

Would the cache be a help or a hindrance if the CPU were used to handle continuously changing data such as video? [5 marks]
3 Digital Communication I

Define the term *circuit* as used in “circuit switching”. [4 marks]

Sketch the design of the in-band switching function of a circuit switch which switches $4 \times 2$ Mbps trunks each supporting $32 \times 64$ Kbps channels. [8 marks]

Describe how you would augment this design to allow the set up and clearing of connections. You should invent your own simple protocol for this purpose. [8 marks]

4 Graphics

Discuss sampling artifacts and their effect on image quality on a raster display. [10 marks]

What can be done to reduce or eliminate them? [10 marks]

5 Programming in C

Write a program in C which, given two integer inputs $J$ and $K$, will output the combinations of $J$ things partitioned into $K$ groups. For example, if $J = 5$ and $K = 3$, the output would be:

$\begin{align*}
5,0,0 \\
4,1,0 \\
3,2,0 \\
3,1,1 \\
2,2,1
\end{align*}$

[20 marks]
6 Programming Language Compilation

Suggest how you would represent Lambda-expressions in a form suitable for a simple Lambda-evaluator in which the environment is represented as a linked list of name-value pairs. [5 marks]

Outline the design of the evaluator, paying particular attention to the treatment of bound variables, abstractions and applications. [5 marks]

Augment your evaluator to cope with sufficient expression operators, including a built-in version of the Y operator so that when the evaluator is given the abstract syntax tree for

\[ Y \ (\lambda f. \lambda n. \text{n=0} \rightarrow 1, \text{n} \ast f(\text{n}-1)) \ 5 \]

it will yield 120. [10 marks]

7 Artificial Intelligence I

Compare and contrast heuristic search and exhaustive search. [6 marks]

Which compromises are accepted by the heuristic approach? [8 marks]

Illustrate your answer with examples of heuristics. [6 marks]

8 Databases

What are the primitives in terms of which a network data model is presented? [4 marks]

Explain how such a data model is specified in the CODASYL Schema Data Definition Language. [6 marks]

How does an application programmer in COBOL gain access to a CODASYL database? [3 marks]

Describe the COBOL programmer’s model of the database, illustrating your answer with suitable data manipulation commands. [7 marks]
9 Specification and Verification of Hardware

Briefly discuss each of the following topics:

(a) the representation of schematic diagrams in predicate calculus

(b) the use of primitive recursion in hardware specification

(c) modelling combinational and sequential circuits

(d) temporal abstraction

10 Complexity

What is a Hamiltonian Circuit? What is the Boolean Satisfiability Problem “3-SAT”?

In 50 to 100 words each, sketch

(a) how an efficient solution to 3-SAT would allow you to construct an efficient solution to the Hamiltonian Circuit problem

(b) how an efficient solution to the Hamiltonian Circuit problem would allow you to solve 3-SAT

(c) what is meant by “efficient” in this context

You are not expected to include technical details of any constructions you need in deriving one algorithm from another: a clear statement of what can be done will suffice.
11 Computation Theory

*The Halting Problem for register machines is unsolvable.* State, without proof, a precise form of this result. [3 marks]

Let the computation by program $p$ on data $d$ be represented by the natural number $k$ that codes the pair $(p, d)$. By considering the set $H(k)$ of the HALTing computations represented by codes $k' \leq k$, show that there is an increasing total function $h(k)$ which grows too fast to be computable. [6 marks]

Given $h : \mathbb{N} \to \mathbb{N}$ with the above property

\[
\text{let } f(k) = h(k) + k \\
\text{and } g(x) = \sup\{k : f(k) \leq x\}.
\]

Then $f : \mathbb{N} \to \mathbb{N}$ is strictly increasing, and $g : \mathbb{N} \to \mathbb{N}$ satisfies

\[
g(f(k)) = k, \quad g(x) < k \quad \text{for all } x < f(k).
\]

Show that $g$ grows too slowly to be computable in the following sense...

given $G : \mathbb{N} \to \mathbb{N}$ such that

(a) \{G(n) : n \in \mathbb{N}\} is unbounded

(b) $G(n) \leq g(n)$ for all $n \in \mathbb{N}$

then $G(n)$ is not computable. [11 marks]

12 Software Engineering

Discuss the reasons why substantial software systems often take longer to implement than planned and do not perform as well as expected. [10 marks]

If you were in charge of a large team implementing such a system, how would you ensure that the product was both reliable and finished on time? [10 marks]