COMPUTER SCIENCE TRIPOS Part II

Thursday 3 June 1993 1.30 to 4.30

Paper 9

Answer **five** *questions.*
No more than **two** *questions from any one section are to be answered.*
Submit the answers in five **separate** *bundles each with its own cover sheet.*
Write on **one** *side of the paper only.*

SECTION A

1 Digital Signal Processing

Describe in detail the use of the bilinear transformation

$$s \rightarrow \frac{2}{T}\,\frac{z-1}{z+1}$$

for the design of digital filters from analogue filters. Discuss the advantages and disadvantages of the method. [8 marks]

It is required to design a second order maximally flat digital low-pass filter having a 3dB cut-off frequency of $0.2f_s$ where f_s is the sampling frequency. The design is to be based on the analogue Butterworth filter defined by:

$$|H(j\omega)|^2 = \frac{1}{1 + \left(\dfrac{\omega}{\omega_c}\right)^{2N}}$$

where N is the filter order and ω_c is the 3dB cut-off frequency. It can be shown that the s-domain transfer function for the second order Butterworth filter is given by:

$$H(s) = \frac{1}{1 + \sqrt{2}\left(\dfrac{s}{\omega_c}\right) + \left(\dfrac{s}{\omega_c}\right)^2}$$

Calculate the coefficient values for the corresponding digital low-pass filter and draw its block diagram. [12 marks]

2 Digital Communication II

Describe the Asynchronous Transfer Mode (ATM). [5 marks]

What are the benefits and drawbacks of the choice of ATM over normal packet switching? [5 marks]

An ATM switch can be built with a set of buffering input and output ports and an unbuffered interconnection network. Describe with examples the desirable attributes of such a network. [10 marks]

3 Computer System Modelling

Consider a transaction system with 20 workstations and 4 fileservers, each with 2 discs. The system is monitored and it is found that, for each transaction, on average:

40 ms of workstation CPU is consumed

6 ms of fileserver CPU is consumed

10 ms of fileserver disc is consumed.

The system is arranged so that asymmetry in disc access is limited to 3 : 2 from highest to lowest, as is fileserver-usage asymmetry. Workstation usage is balanced.

Perform a bottleneck analysis of the system for throughput and response time. State any assumptions made. [10 marks]

Give an estimate of the response time when the system is handling

(*a*) 10

(*b*) 100

(*c*) 1000

transactions per second.

Note: a balanced system with K devices and N customers has a utilisation

$$U = \frac{N}{N + K - 1}$$

[10 marks]

4 Graphics II

Compare object-space and image-space visibility tests in synthesising an image for display. [12 marks]

Describe one visibility test in detail. [8 marks]

SECTION B

5 Designing Interactive Applications

Explain the term *user's conceptual model*. How is the user's conceptual model formed? [4 marks]

Describe Fitts' law and Hick's law and explain how each might influence the design of an information display. [4 marks]

The receptionist at a small research laboratory is required to field incoming messages and make sure that they reach the recipient in a timely manner. Some messages arrive by word of mouth, others by phone, courier, e-mail or FAX. There are about 100 recipients, most of whom are researchers. They spend a large proportion of their time in meetings of one sort or another, some of which are held in offices, the remainder in conference rooms. The receptionist endeavours to avoid interrupting important meetings unnecessarily.

It is proposed to build a system based upon Active Badge technology to improve message handling activities in the laboratory. Each member of staff wears an active badge. An existing Location Server provides client applications with up-to-date information about the location and movements of each active badge.

Imagine you have to develop a requirements specification that might reasonably arise from your own investigations. Write down three or four key requirements. [2 marks]

On *one* side of paper, draw up the screen layout for your proposed application and annotate it with the rationale for each key design decision. [10 marks]

6 Optimising Compilers

Consider a flowgraph, containing 3-address instructions, which represents a source-level routine. Let e be an expression (e may be considered to be a right-hand side 3-address instruction, i.e. either x or x **op** y where x and y are variables).

We say that e is *very busy* at a node n if all paths from n compute the expression e at least once *and* each such computation yields the same value as evaluating e at n would (i.e. no modification of its variables occurs between n and the first occurrence of e on any path from n).

Let $VB(n)$ be the set of very busy expressions at n.

(a) Give data flow equations for $VB(n)$. [4 marks]

(b) Give the relationship, if any, to the set $Avail(n)$ of expressions available at n including the direction (forwards/backwards) of the analyses. Indicate whether either inclusion $VB(n) \subseteq Avail(n)$ or $Avail(n) \subseteq VB(n)$ holds. [4 marks]

(c) Sketch an algorithm to compute $VB(n)$, briefly commenting on any initialisation. [4 marks]

Suppose now that we compile a program in a call-by-need functional language into 3-address code using closures (i.e. $\lambda().e'$) to represent laziness. Given a functional definition $f(x, y, z) = e$ we have notions of f being strict in, or needing, its second parameter y.

Point out similarities and differences between these notions and that of y (or $y()$) being very busy at some, to be determined, point in the 3-address code form of e. [8 marks]

Hint: you may find it helpful to consider separately

(a) a case where e uses only the conditional function and strict primitive functions such as $+$

(b) a case such as $f(x, y) = g(x, y + 1)$

7 Artificial Intelligence II

Discuss any *two* methods for computing information about the three-dimensional layout of surfaces in a scene, given one or more images of the scene. Illustrate your answer with appropriate mathematical relationships and fragments of computer programs. [20 marks]

8 Database Topics

Describe the differences between navigational and algebraic data manipulation. [6 marks]

What problems would arise when incorporating an algebraic style of data manipulation into a persistent programming language such as PS-ALGOL? How might they be solved? [14 marks]

SECTION C

9 Natural Language Processing

Write on *four* of the following topics, describing the problems they raise and their significance for natural language processing. [5 marks each]

(*a*) *Worst-case* (exponential) syntactic ambiguity

(*b*) Semantic interpretation of *embedded* propositions (such as *John thinks the prime minister is a grey man*)

(*c*) Focus and anaphoric reference

(*d*) Unification as a technique for expressing syntactic rules

(*e*) Defeasible reasoning for interpreting utterances

(*f*) Natural prosody for speech synthesis from text

10 Semantics

Explain what is a *well-founded* binary relation, and state the principle of well-founded induction. [3 marks]

Show that the binary relation $\lhd$ on the integers which is given by

$$m \lhd n \qquad \text{if and only if} \qquad n < m \leqslant 100$$

is well-founded. [2 marks]

Consider the ML declarations

$$\begin{array}{ll} \mathsf{fun} & f(x) = \ \mathsf{if}\ x > 100\ \mathsf{then}\ (x-10)\ \mathsf{else}\ f(f(x+11)); \\ \mathsf{fun} & g(x) = \ \mathsf{if}\ x > 100\ \mathsf{then}\ (x-10)\ \mathsf{else}\ 91; \end{array}$$

Prove, by induction on the well-founded relation $\lhd$, that f and g determine equal integer-valued functions.

Hint: for the induction step you may find it helpful to consider separately the cases $x > 100$, $x = 100$, $90 \leqslant x < 100$ and $x < 90$. [15 marks]

11 Types

Describe the relation of *β-reduction* between expressions in the second order lambda calculus $\lambda 2$. Explain the *Church–Rosser* and *strong normalisation* properties of this relation. How do they lead to a procedure for deciding whether two closed, typable $\lambda 2$ expressions are β-convertible? [8 marks]

If α is a type variable and σ is a $\lambda 2$ type, the 'existential type' $\exists\alpha.\sigma$ is defined to be $\forall\beta.((\forall\alpha.\sigma\to\beta)\to\beta)$, where β is a new type variable not occurring in σ. Show that there is a closed $\lambda 2$ expression, *Pair*, of type $\forall\alpha.(\sigma\to\exists\alpha.\sigma)$. [5 marks]

Given valid $\lambda 2$ type assertions

$$\begin{aligned} \Gamma &\vdash E : \exists\alpha.\sigma \\ \Gamma, x : \sigma &\vdash N : \sigma' \end{aligned}$$

where α and β do not occur free in Γ or σ', show how to construct a $\lambda 2$ expression $\mathit{Case}(E, \alpha, x, N)$ such that

(*a*) $\Gamma \vdash \mathit{Case}(E, \alpha, x, N) : \sigma'$, and

(*b*) if $\Gamma \vdash M : (\alpha \mapsto \tau)\sigma$ where τ is a type not containing free occurrences of β, then

$$\mathit{Case}(\mathit{Pair}_\tau M, \alpha, x, N) \quad \beta\text{-reduces to} \quad (x \mapsto M)(\alpha \mapsto \tau)N.$$

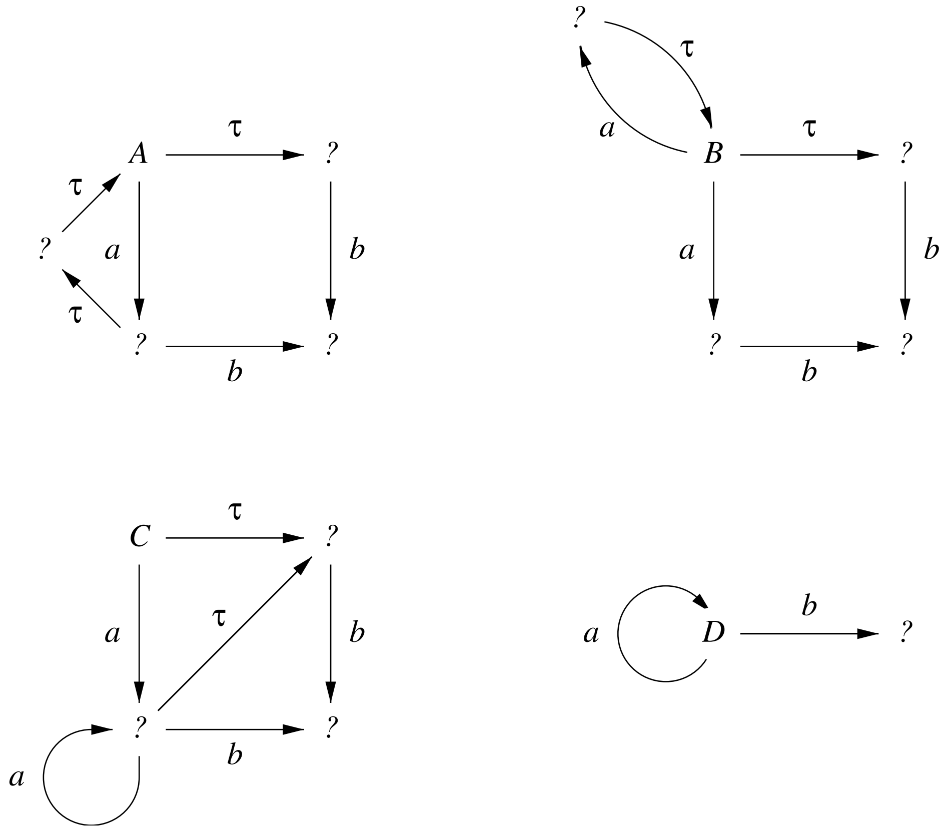
(Here $(\alpha \mapsto \tau)$ denotes the operation of substituting τ for the type variable α and $(x \mapsto M)$ denotes the operation of substituting the expression M for the identifier x.)

[7 marks]

12 Concurrency

Define the notion of *observation equivalence* ($\approx$) for CCS agents. [5 marks]

Find definitions of CCS agents A, B, C and D with the following transition graphs.



[5 marks]

For each pair (P, Q) of these four agents A, B, C, D, determine whether or not P is observation equivalent to Q. (You may use the fact that $\approx$ is an equivalence relation.) [10 marks]