COMPUTER SCIENCE TRIPOS Part II

Tuesday 6 June 2000 1.30 to 4.30

Paper 7

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 Specification and Verification I

Explain why the Assignment Axiom of Floyd–Hoare logic is valid only for assignments whose right-hand sides have no side effects. [4 marks]

Illustrate your explanation with an example. [4 marks]

Suppose expressions of the form $(C;E)$ are allowed, where C is a command and E is an ordinary expression (E has no embedded commands). $(C;E)$ is evaluated by first executing the command C (with possible side-effects) and then returning the value of the expression E.

Discuss how Floyd–Hoare logic might be extended to handle such expressions.
[6 marks]

Illustrate your discussion by giving a proof in the extended logic of

$$\{Y \leqslant X\}$$
$$R := X \,;\, Q := 0;$$
$$\texttt{WHILE (BEGIN } R := R - Y \,;\, Q := Q + 1 \texttt{ END; } Y \leqslant R) \texttt{ DO SKIP}$$
$$\{X = R + (Y \times Q) \,\wedge\, R < Y\}$$
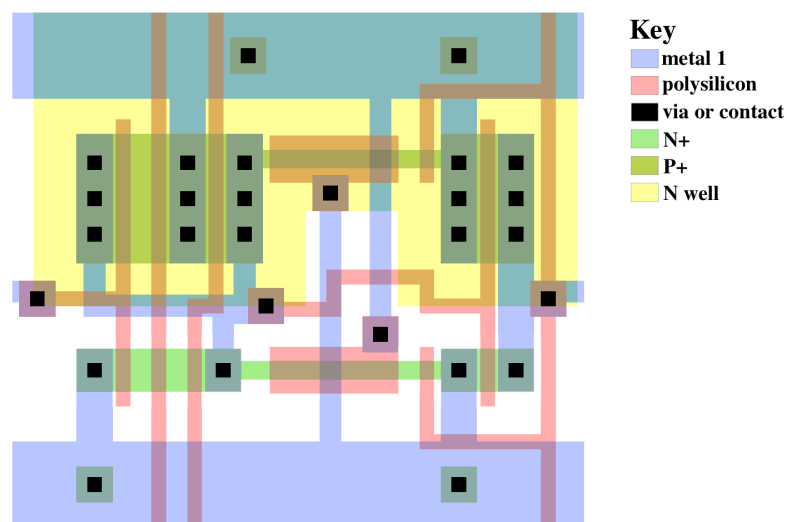
[6 marks]

1 **[TURN OVER**

2 VLSI Design

The colour picture below shows the layout of a standard cell designed as part of a library for implementing self-timed circuits in CMOS. The colours have the conventional interpretations: blue is metal-1, red is polysilicon, green is n-diffusion, cyan is p-diffusion, yellow is n-well and black denotes contact cuts.

Derive a stick diagram from the layout. [8 marks]

Derive a circuit diagram labelling the external connections and explain the purpose and operation of the cell. [6 + 6 marks]

Key
- metal 1
- polysilicon
- via or contact
- N+
- P+
- N well

3 Comparative Architectures

Describe the characteristic features of a VLIW (Very Long Instruction Word) processor architecture. [3 marks]

VLIW processors aim to achieve high execution throughput using a different strategy from that of out-of-order dynamic execution RISC implementations. Compare and contrast these different approaches, pointing out the advantages and disadvantages of each strategy in achieving this goal.

You may wish to consider the following issues:

- instruction issue logic

- cache sizes

- compiler code generation

- execution unit utilisation

[9 marks]

Why have VLIW architectures traditionally been used only for special-purpose applications such as Digital Signal Processors? [3 marks]

What techniques have been developed to make VLIW-like architectures more suitable for general-purpose use? [5 marks]

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4 Information Retrieval

You work for a large company where there are many meetings, both of internal staff and between staff and external clients. Meetings are recorded in formal minutes. The company's files of minutes are large, and the material has to be kept for many years since it may be necessary to check back on decisions taken early in large projects.

You are asked to design a retrieval system so that company staff can locate minutes on a particular topic. Because of the legal implications that past discussions and decisions may have, the company is particularly concerned that the new retrieval system will be reliable and effective.

Outline the design of your system, indicating the particular features it will have that are intended to meet the company's requirements (you can assume that minutes are always clearly dated and have explicit lists of participants).   [10 marks]

The company is willing to allow the installation of a pilot system so your approach can be evaluated under realistic conditions.

Describe, in detail, your design for the evaluation: what data, operational conditions and aspects of your system would you consider, and why? What performance measures would you apply, and why?   [10 marks]

5 Security

"Robert Morris Senior was responsible for Unix security, Robert Morris Junior for the Internet worm. The father did much more damage to Internet security than the son" (Whitfield Diffie).   Discuss.   [20 marks]

6   Neural Computing

Explain the key ideas of a Hopfield artificial neural network for content-addressable, associative memory. In explaining how memories are stored and retrieved, be sure to define the notions of:

- configuration space

- connectivity matrix

- stable attractor

- basin of attraction

- network capacity, and its dependence on the number of "neurones"

[10 marks]

Marshall as many lines of evidence as you can to support the view that in human vision "what you see is your own 'graphics', rather than the retinal image as faithfully recorded by photoreceptors in the eye". Explain the significance of this observation for vision theory and for machine vision.   [8 marks]

Suppose you were trying to design a machine vision system based as closely as possible upon human vision. Would you aim to design in the visual illusions that nearly all people "see" as well? (These include the distortions of geometrical form, angle and relative length illusions, etc.) If such properties emerged as unintended consequences of your vision design, would you consider them to be features, or bugs?   [2 marks]

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7 Natural Language Processing

The following context-free grammar and lexicon generates the examples below it with multiple derivations and therefore multiple associated interpretations.

(a) S → NP VP

(b) NP → Det N

(c) NP → NP PP

(d) N → N N

(e) VP → V NP

(f) VP → V NP PP

(g) VP → VP PP

(h) PP → P NP

N → car | park | tree | boy | toy | morning | . . .
V → hit | . . .
P → in | with | . . .
Det → a | the | . . .

a car hit the tree in the park
the boy hit the toy car park with a toy car in the morning

Describe how a probabilistic version of the context-free grammar (PCFG) can be created, defining the constraints which must hold for the resulting PCFG to be interpretable as a stochastic language model. [8 marks]

How accurate would the resulting PCFG be at assigning the semantically appropriate derivations the highest probability for the examples and other structurally similar sentences? [6 marks]

Define an improved probabilistic model for discriminating alternative derivations. What problems would arise in the implementation of this model? [6 marks]

8 Computer System Modelling

What is meant by the term *memoryless* as used in describing a Markov chain?

[3 marks]

What limitation does this place on using Markov chains to model real systems?

[3 marks]

"As systems become saturated their response time becomes unpredictable."
Why is this? Illustrate your answer using an M/M/1 queueing system.   [10 marks]

Show, by drawing the state transition diagram of a Markov chain, how arrival processes with inter-arrival times that are not exponentially distributed can be modelled. [4 marks]

9 Specification and Verification II

Define a predicate Rise such that Rise $clk\ t$ is true if and only if there is a rising edge on clk at time t. [2 marks]

Consider the following definition of the behaviour of a register in higher order logic:

$$\mathsf{DFF}(q, d, clk, ce, ar, spare) =$$
$$(q\ 0\ =\ \mathsf{F})\ \wedge$$
$$\forall t.$$

   (`if` Rise $clk\ t\ \vee$ Rise $ar\ t$

    `then` (`if` $ar(t{+}1)$

         `then` $q(t{+}1)\ =\ \mathsf{F}$

         `else` (`if` $ce(t{+}1)$ `then` $q(t{+}1)\ =\ d\ t$ `else` $q(t{+}1) = q\ t$))

    `else` $q(t{+}1) = q\ t)$

Describe in detail the behaviour of $\mathsf{DFF}(q, d, clk, ce, ar, spare)$. [6 marks]

Describe how circuit structures can be represented in logic. Explain how internal lines are modelled. [6 marks]

Consider a device $\mathsf{D}(q, d, clk)$ with inputs clk and d and output q that is implemented using a DFF by connecting the ce line to power and the ar line to ground. Draw a diagram of this circuit and write down the corresponding logical formula. Derive a simplified formula for $\mathsf{D}(q, d, clk)$. [6 marks]

10 Advanced Graphics and HCI

The screen excerpts in the illustration below show two possible methods by which a user can start numbering the pages of a Microsoft Word document from page zero rather than page one. Use the cognitive walkthrough method to assess the usability of these two alternatives. List any assumptions that you make in this analysis.   [12 marks]

How could Fitts' law be used to predict the time users take to carry out these alternatives? For what kind of users would this data be most relevant?   [4 marks]

What techniques could be used to design an alternative method for defining page numbers with improved usability? What specific improvements might result?

[4 marks]
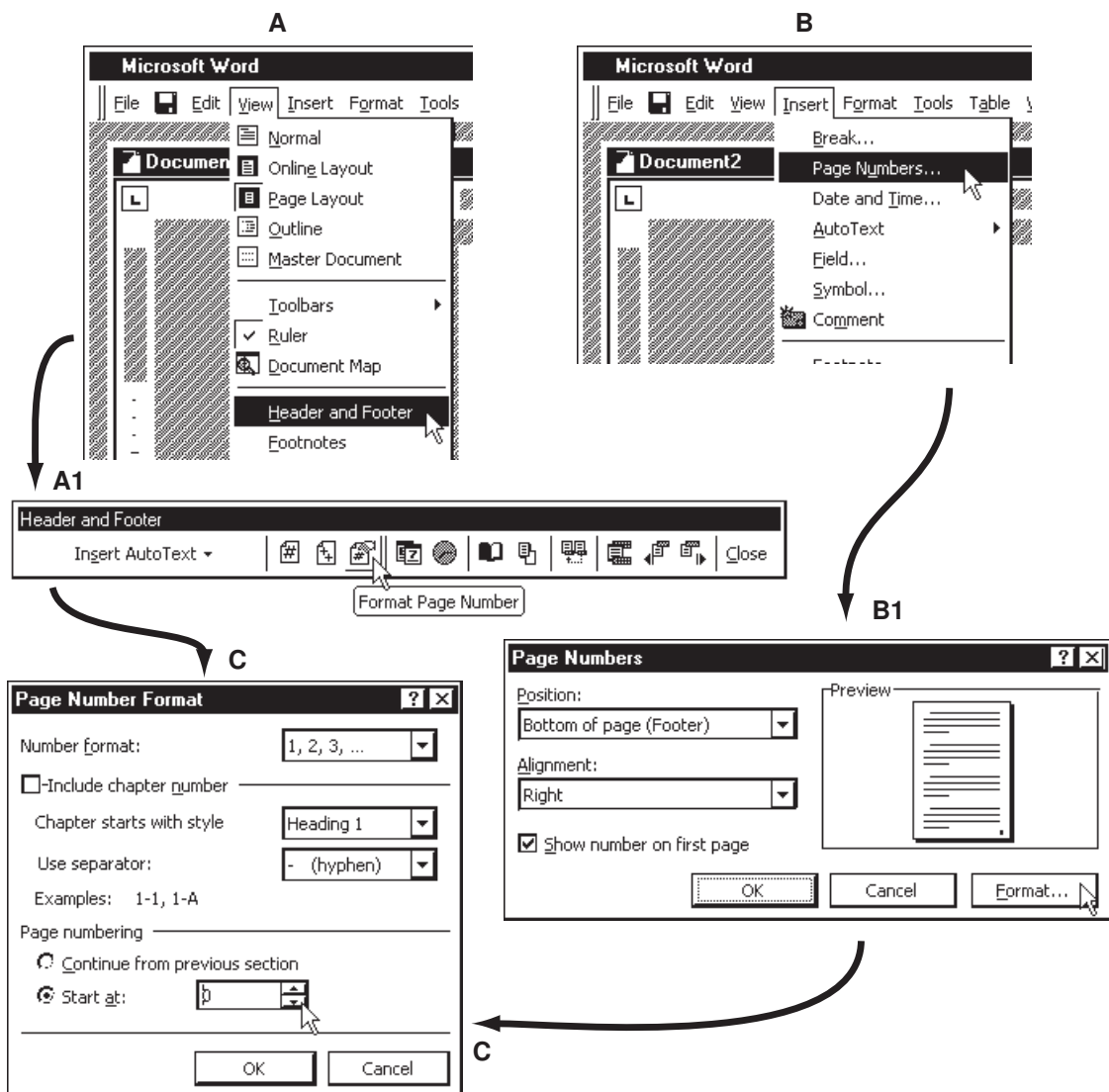
11 Types

The terms of the untyped lambda calculus, $M ::= x \mid \lambda x(M) \mid M\,M$, are to be assigned types of the form $\tau ::= \alpha \mid \tau \to \tau$, where α ranges over an infinite set of type variables. Give an inductive definition of a typing judgement of the form $A, \Delta \vdash M : \tau$, where Δ is a finite function from variables to types whose domain of definition contains the free variables of M, and where A is a finite set of type variables containing the type variables occurring in τ and Δ.   [3 marks]

Write $\mathrm{Typ}(A)$ for the set of types involving only type variables in the set A. Let A, A', A'' be finite sets of type variables; S be a function from A to $\mathrm{Typ}(A')$ and T a function from A' to $\mathrm{Typ}(A'')$; τ_1, τ_2 be types in $\mathrm{Typ}(A)$; and τ' be a type in $\mathrm{Typ}(A')$. Give definitions of the following concepts:

(a) The type $S(\tau_1)$ resulting from simultaneously substituting the type $S(\alpha)$ for occurrences of α in τ_1, as α ranges over A.   [2 marks]

(b) The composition $TS : A \to \mathrm{Typ}(A'')$ of the type substitutions S and T.
          [2 marks]

(c) S *unifies* τ_1 and τ_2.   [2 marks]

(d) S is the *most general unifier* of τ_1 and τ_2.   [2 marks]

(e) (S, τ') is a *typing* for a partial typing judgement $A, \Delta \vdash M : ?$.   [2 marks]

(f) (S, τ') is a *principal typing* for a partial typing judgement $A, \Delta \vdash M : ?$.
          [2 marks]

Give examples, with proof, of closed lambda terms M_1 and M_2 for which $\emptyset, \emptyset \vdash M_1 : ?$ has a typing and $\emptyset, \emptyset \vdash M_2 : ?$ does not.   [4 marks]

If a partial typing judgement has a typing, does it necessarily have a principal one?
          [1 mark]

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12 Additional Topics

The Active Bat is an ultrasonic tag, which forms part of an indoor location system. Describe the operation of this location system in terms of

(*a*) the basic method used to locate Active Bats   [6 marks]

(*b*) synchronisation of Active Bats with the fixed ultrasonic receivers   [6 marks]

(*c*) system resource allocation to Active Bats that are moving   [4 marks]

(*d*) methods of obtaining orientation information for tagged objects   [4 marks]

13 Additional Topics

Name *three* of the diagrammatic models included in the Unified Modeling Language (UML). For *each one* of the three models, repeat the following steps:

(*a*) Describe some benefit that this model can bring to a particular stage of a specification and design project.

(*b*) Describe how information in this model would be obtained (it may come from another UML model).

(*c*) Draw a simple example diagram illustrating the most important features of this model. Your example diagrams can illustrate a familiar system such as an automatic teller machine or vending machine. A complete design is not necessary.

[10 marks]

Describe *two* attributes of an object-oriented design that can be used to assess its quality for purposes of maintenance and software reuse. Describe how you would recognise UML diagrams (or make rough sketches to show what they would look like), contrasting a good design with a bad design for each attribute.   [6 marks]

Give an example of a typical programming problem in C++ that can be anticipated at the design stage with the assistance of behavioural models.   [4 marks]

END OF PAPER