COMPUTER SCIENCE TRIPOS Part IB 75%, Part II 50%

Thursday 6 June 2019 1.30 to 4.30

COMPUTER SCIENCE Paper 7

*Answer **five** questions.*

Question 11 (DSP) can only be attempted by Part II 50% candidates.

*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.*

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

STATIONERY REQUIREMENTS
Script paper
Blue cover sheets
Tags

SPECIAL REQUIREMENTS
Approved calculator permitted

1 Concepts in Programming Languages

(a) Algol-60 provided two parameter-passing mechanisms: call-by-value and call-by-name.

(i) Explain these mechanisms. [2 marks]

(ii) Justify or criticise the statement that "the former is expensive for arrays and the latter interacts badly with side effects". [2 marks]

(iii) What parameter-passing mechanism(s) do C and Java use, and how do such languages deal with an array being passed as a parameter? [2 marks]

(b) A side-effect-free call-by-value language has its ML-like syntax of expressions e extended to be able to model call-by-name and (LISP-like) call-by-text:

$$e ::= \ldots \mid \texttt{suspend}\ e \mid \texttt{force}\ e \quad \text{(call-by-name)}$$
$$e ::= \ldots \mid \texttt{quote}\ e \mid \texttt{eval}\ e \quad \text{(call-by-text)}$$

Both `suspend` e and `quote` e yield an unevaluated representation of e as a value for later evaluation by `force` and `eval` respectively. Sketch two programs (differing only in whether they use `suspend` and `force` or `quote` and `eval`) which give different results. [*Note:* Answers using side-effecting operators can only gain partial marks.]

[4 marks]

(c) A library defines a generic class `Foo<T>` in a Java-like language. A user's program declares a class `C` and subclasses it as class `D`, creating variables `fc` and `fd` of types `Foo<C>` and `Foo<D>` respectively.

(i) Construct a declaration of `Foo<T>` along with a program of the above form containing the assignment `fc=fd` which, if this statement were legal, would be the cause of a later run-time error when executed. [5 marks]

(ii) How might the language syntax be changed to optionally express that the above assignment is to be allowed, indicating any compensating restrictions required for the declaration of `Foo<T>` or `fc` to avoid run-time errors. [3 marks]

(iii) How do Java arrays of type `T[]` fit in with your answer to Part (c)(i)? [2 marks]

2 Economics, Law and Ethics

(*a*) Describe five different types of auctions. [5 marks]

(*b*) If you were in the business of selling advertisements, what would be an efficient way to price them? [5 marks]

(*c*) How might one political candidate achieve a better price per advertisement than their opponents? [5 marks]

(*d*) What are bidding rings and what might game theory tell us about them? [5 marks]

3 Economics, Law and Ethics

(*a*) What do sections 1, 2 and 3 of the Computer Misuse Act 1990 prohibit? [6 marks]

(*b*) Eve is operating a DDoS-for-hire service and has recruited 100,000 CCTV cameras into a botnet. If Mallory pays Eve $2 to take down a gaming teamspeak server for five minutes, what offences, if any, are being committed by Eve and Mallory? [8 marks]

(*c*) How might the Wimbledon case (*R v. Lennon 2005*) apply to this case? [6 marks]

4 Formal Models of Language

This question relates to an information source that produces symbols from an alphabet.

(a) X is an information source, which produces symbols from the set $\{a, b, c, d, S\}$

(i) If we assume X produces symbols with equal probability, what is the entropy of X? [1 mark]

(ii) In fact, X produces symbols with non-equal probabilities. What do you know about the entropy of X compared to your previous answer? [1 mark]

(iii) X produces symbols with probability distribution:

$$p(a) = 0.4,\ p(b) = 0.2,\ p(c) = 0.2,\ p(d) = 0.1,\ p(S) = 0.1$$

Give an expression for the entropy of information source X. [2 marks]

(b) The symbol sequence produced by X represents consecutive words of a language, where S indicates whitespace.

(i) Describe and provide an equation for the entropy of the language produced by the symbol sequence. [2 marks]

(ii) A student observes that when a word in the language contains c it is always followed by b. Explain how this redundancy helps communication over a channel that tends to swap b with d. [2 marks]

(c) Define a noisy channel and describe how it could be interpreted with respect to human language communication. [6 marks]

(d) Computational Linguists have hypothesised that natural languages have evolved to be both efficient and robust to noise. Do you agree? Justify your answer by referring to information theory and giving appropriate examples. [6 marks]

5 Formal Models of Language

This question concerns lexical grammars.

(*a*) Tree Adjoining Grammars contain two types of elementary tree.

(*i*) What are these trees called? [1 mark]

(*ii*) If one were building a grammar for English which aspects of language do the two tree types model? [2 marks]

(*b*) Provide a Tree Adjoining Grammar that can parse the string: *students enjoy easy exams* [5 marks]

(*c*) Show how a parse for this string is constructed. Explain the operations. [5 marks]

(*d*) Provide a Categorial Grammar that can parse the same sentence. [4 marks]

(*e*) When children learn their first language they usually acquire nouns before verbs before modifiers. They also usually produce single word strings before moving on to longer strings. With reference to Tree Adjoining Grammars and/or Categorial Grammars propose some hypotheses for this. Justify your proposals. [3 marks]

6 Further Graphics

(*a*) The challenge of simulation sickness (sim sickness) in Virtual Reality is a crucial hurdle in creating engaging virtual content.

(*i*) When it comes to avoiding sim sickness, what is the cardinal rule of VR? [1 mark]

(*ii*) Succinctly explain the triggers and effects of sim sickness. [2 marks]

(*iii*) List the constraints that sim sickness imposes on user interface design in VR. For each constraint give a one-sentence explanation of how developers must adapt to compensate. [5 marks]

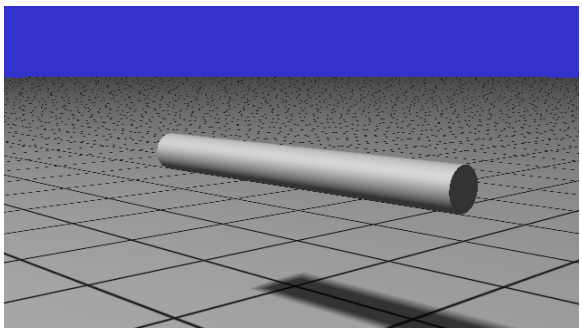
(*b*) A mathematician tells you that a mystery shape is composed of polygons forming a closed, connected, manifold mesh without border. They claim that the mesh has 832 vertices, 1,648 edges, and 600 faces. The mathematician wants to know if it is possible that there is a loop of connected polygon edges in the mesh which, if all of those edges were cut apart, would *not* split the mesh into disconnected parts.

(*i*)
- If you say no, they will want to know why.
- If you say that you cannot answer, they will want to know why not.
- If you say yes, they will ask you why; and then they will ask you to find the greatest possible number of such loops that could simultaneously be cut in the mesh.

What do you tell them? [5 marks]

(*ii*) If the mathematician had instead said that the mesh had 832 vertices, 1,648 edges, and 900 faces, would your answer to their question have been different? If so, how? [2 marks]

(*c*) Implement a Signed Distance Field method `cylinder()` which returns the signed distance from point p to a finite cylinder segment. The cylinder should go from point a to point b with flat ends and radius r.



```
float cylinder(vec3 p, vec3 a, vec3 b, float r) {
   // ...
}
```

[5 marks]

7 Further Graphics

(*a*) List at least five different visual cues which our brains use to infer depth. Give a one-sentence explanation of each. [5 marks]

(*b*) Consider the following signed distance field function:

```
#define min3(a, b, c) min(a, min(b, c))
#define max3(a, b, c) max(a, max(b, c))

float getSdf(vec3 p) {
  vec3 q = vec3(abs(p.x), abs(p.y), abs(p.z));
  return min3(
      max3(q.x / 3.0, q.y, q.z),
      max3(q.x, q.y / 3.0, q.z),
      max3(q.x, q.y, q.z / 3.0)) - 1.0;
}
```

(*i*) Draw the surface, including its dimensions [4 marks]

(*ii*) What is the Gaussian curvature of this surface at $(3, 0, 0)$? [1 mark]

(*iii*) What is the Gaussian curvature of this surface at $(1, 1, 1)$? [1 mark]

(*iv*) What is the total angle deficit of this surface? [2 marks]

(*v*) What is the angle deficit of this surface at $(1, 1, 1)$? [2 marks]

(*vi*) What is the normal of this surface at $(1, 1, 1)$? [2 marks]

(*vii*) By inserting a single line of code, how would you modify `getSdf()` so that the figure is repeated infinitely along the X axis, with each repetition exactly touching the previous instance? [3 marks]

8 Further HCI

In this question you will be asked to reflect on a project you have been involved in or observed, in which a design evolved, or could have evolved, through applying a theory of user behaviour. You may refer to a Part IB group project, practical work from Part IA/IB Interaction Design, or a project outside the Computer Science Tripos. You are advised to read the whole question before choosing a project to describe.

(*a*) Describe the project in one or two sentences. [2 marks]

(*b*) Describe the intended users of this system, and the benefits that they would obtain through using the system. [2 marks]

(*c*) Describe a theory of user behaviour that is relevant to the project, explaining why it is relevant. [3 marks]

(*d*) Would application of this theory be formative or summative? Explain why. [2 marks]

(*e*) How are the opportunities for design evolution different, when either summative or formative evaluation methods are applied? Your answer should refer to the roles of divergence and convergence in a design process. [4 marks]

(*f*) Explain what kind of evidence would be required when applying this theory in your project, and how you would obtain it, noting whether this evidence would involve qualitative or quantitative data. [3 marks]

(*g*) Describe how your project team applied, or could have applied, a method that would improve the reliability of *quantitative* data. [2 marks]

(*h*) Describe how your project team applied, or could have applied, a method that would improve the reliability of *qualitative* data. [2 marks]

9 Further HCI

(*a*) If HCI methods were applied to the design of a programming language and tools, what research questions might be explored, according to the concerns of first wave, second wave, and third wave HCI respectively? [6 marks]

(*b*) What empirical methods might be appropriate for studying programming activity, from the perspective of each of these three waves? [3 marks]

(*c*) Consider a programming language that has been proposed for the specification of firework displays. Suggest an analytical method that would be appropriate for evaluating and refining the usability of this language and associated tools. [1 mark]

(*d*) In terms of the analytical method proposed in Part (*c*), define the target user, the nature of their task, and several specific usability requirements that would result from that task. [5 marks]

(*e*) Choose one requirement identified in Part (*d*), and describe in detail an empirical approach that you would take to evaluating whether this requirement has been met. [5 marks]

10 Prolog

When answering this question you should ensure that each of your predicates has a comment giving a declarative reading of its behaviour and you should avoid unnecessary use of cut. Your solutions should not use any extra-logical predicates (such as `assertz`).

A map can be used to represent a polynomial where the keys are the exponents and the values are the corresponding coefficients. For example the polynomial $1+3x^2+9x^5$ could be encoded by a map $0\rightarrow 1, 2\rightarrow 3, 5\rightarrow 9$.

(*a*) Describe a Prolog datastructure you could use to represent a map. Clearly identify your use of atoms and compound terms. [3 marks]

(*b*) Implement a predicate `put` which associates a given value with a given key, replacing any existing value for that key. [4 marks]

(*c*) Show how you would use `put` to build a map representing the polynomial $1 + 3x^2 + 9x^5$. [1 mark]

(*d*) Implement a predicate `lookup` which finds the value associated with a given key in the map. If the key is not present then the result of the `lookup` should be `0`.

[5 marks]

(*e*) Using `put` and `lookup` or otherwise, implement a predicate `polyadd` which adds two polynomials together. Your predicate should be amenable to Last Call Optimisation. [7 marks]

11 Digital Signal Processing

This question can only be attempted by Part II 50% candidates.

(*a*) Name one advantage and one disadvantage of Finite-Impulse-Response (FIR) filters over Infinite-Impulse-Response (IIR) filters. [2 marks]

(*b*) For each of the following discrete systems $\{y_n\} = T\{x_n\}$, either show that T is equivalent to a convolution operation, by providing an impulse response $\{h_n\}$ such that

$$y_n = \sum_{i=-\infty}^{\infty} h_i x_{n-i}$$

or explain why the system cannot be described through convolution.

(*i*) $y_n = \frac{1}{2}(x_{2n} + x_{2n+1})$ [2 marks]

(*ii*) $y_n = x_{n+4}$ [2 marks]

(*iii*) $y_n = \frac{3}{2}x_{n-1} - \frac{1}{2}y_{n-2}$ [4 marks]

(*c*) What is the z-transform of the impulse response of the system in Part (*b*)(*iii*)? [4 marks]

(*d*) Consider a digital filter where the z-transform of the impulse response is

$$H(z) = \frac{z^2 - 1}{z^2 + \frac{49}{64}}.$$

(*i*) Draw the location of poles and zeros of $H(z)$ in the z-plane. [2 marks]

(*ii*) What is this kind of filter called? [1 mark]

(*iii*) A test signal $x(t) = \cos(2\pi f t)$ is sampled into $x_n = x(n/f_s)$, with rate $f_s = 4$ kHz, and then passed through this filter. For what values of f will the root-mean-square level at the filter output be maximal? [3 marks]

END OF PAPER