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

Thursday 4 June 2020 1.30 to 4.30

COMPUTER SCIENCE 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.*

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) Consider a program in a simple language L which manipulates only two forms of values: 64-bit two's-complement integers and 64-bit IEEE floating-point values. L includes variables, integer and floating-point operators and constants, and conditional expressions, but no functions. It is considered a (hard) error if a bit-pattern representing a floating-point value is operated on as if it were an integer and vice versa. There are no implicit coercions, so `1 + 2.3` would be an error. The job of both static and dynamic type checkers is to stop such errors from happening.

(i) Explain the difference between static type checking and dynamic type checking, pointing out any compile-time or run-time costs and any differences in how variables are declared. [3 marks]

(ii) We can say that a static type system is *sound* if whenever we have two programs S and D, differing only in whether they use static or dynamic type checking, then S passing type checking implies D executes successfully. In a sound type system, does D executing successfully imply that S passes type checking? Justify your answer for L. [2 marks]

(b) Give three programs exemplifying failure of type soundness in existing languages. Two should involve distinct past-or-current programming languages and one should reflect the absence of checks performed by most linkers. [4 marks]

(c) To what extent does Java use static and/or dynamic typing? [2 marks]

(d) (i) A monad M can be seen as a type constructor for an abstract data type. Give the two operations which every monad must possess, along with their types. [3 marks]

(ii) Now consider the monad `E` and the functions `f` and `safediv`, given in SML syntax by:

```
datatype a E = return a | fail
fun (fail >>= f) = fail
 |  ((return v) >> f) = f v

fun f(w,x,y,z) = (w div x) div (y div z)
fun safediv(x,y) = if y<>0 then return(x div y) else fail
```

Re-code `f` as a function `g` which uses operations from monad `E` along with function `safediv` so that the only non-zero tests around division are within `safediv`. Remark on any difference between the types of `f` and `g`. [6 marks]

2 Economics, Law and Ethics

You have an idea for an innovative new type of application for self-directed teaching and learning. The *eTeacher* uses state-of-the-art natural language processing approaches to allow for text and speech interaction. Over time, it builds a profile of the user's most effective means of learning, and tailors the teaching style accordingly. The intended users are secondary school students and adults who wish to refresh their understanding of Mathematics, English, Geography, or History. You plan to monetise the application by way of advertisements and in-app purchases.

(*a*) You are seeking investors. Discuss the economic and legal considerations that might inform your business plan and persuade investors to fund your startup. For a convincing pitch, you should define the necessary terms and explain your reasoning. [7 marks]

(*b*) Explain how things might change if the economy goes into recession. [3 marks]

(*c*) Outline the principles of the General Data Protection Regulation (GDPR). How might you comply with the GDPR and allow individuals to exercise their rights? [10 marks]

3 Economics, Law and Ethics

(*a*) Define the following terms, providing examples to illustrate their meaning.

(*i*) Pareto improvement [2 marks]

(*ii*) Pareto efficient allocation [2 marks]

(*iii*) Utility [2 marks]

(*b*) Explain the theorems of welfare economics, comparing and contrasting classical utilitarian welfare and Rawlsian welfare.

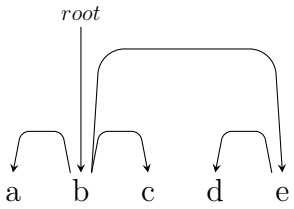
[8 marks]

(*c*) Do you expect the free market will solve the privacy problem?

[6 marks]

4 Formal Models of Language

The string 'a b c d e' has the following dependency parse:



The table shows the first two actions when deriving this parse using a modified shift-reduce parser which uses the actions: SHIFT, RIGHT-ARC and LEFT-ARC.

STACK	BUFFER	ACTION
	abcde	SHIFT
a	bcde	SHIFT
ab	cde	

(*a*) Describe the actions SHIFT, RIGHT-ARC and LEFT-ARC in terms of their effect on the stack and buffer. Also describe any arcs that are recorded when the actions are used. [5 marks]

(*b*) The parser also uses the action TERMINATE which links a lone item on the stack to *root*. Complete the parse action table such that the actions derive the parse shown at the top of the page. [6 marks]

(*c*) In Part (*b*) you have selected the parse actions by hand; explain how the sequence of parse actions is obtained from data in an automatic parser. [4 marks]

(*d*) The dependency parse for the string 'a b c d e' is homomorphic with the English language string 'Alice shook up the potion'. An alternative word order for this string is 'Alice shook the potion up'.

(*i*) Draw the dependency parse for the alternative string. [1 mark]

(*ii*) Compare capturing natural language alternations using a context-free grammar as opposed to a dependency grammar. [4 marks]

5 Formal Models of Language

c, d, e are melodic elements. A birdsong is composed of a sequence of these elements as follows:

$c\ c\ d\ c\ c\ e\ c\ c\ d\ c\ c\ d\ c\ c\ e$

(a) (i) Using byte pair encoding induce a context-free grammar for this sequence of birdsong. Show your workings and state what you have decided to do in the case of a tie. [6 marks]

(ii) Draw the derivation tree that parses the birdsong using your induced grammar. [1 mark]

(iii) What are the shortcomings of this method of grammar induction for natural languages? [3 marks]

(b) Assuming that c, d and e are the only melodic elements available in the birdsong, and that the excerpt we are given is probabilistically representative of the birdsong in the wild, what is the average information produced per element? Provide relevant equations. [3 marks]

(c) In Part (b) we assumed a 1st-order model of the birdsong. What assumption does this make about the sequence of elements? [1 mark]

(d) Consider a 2nd-order model of the birdsong and calculate the conditional entropy. Provide relevant equations. [4 marks]

(e) How can we calculate the entropy rate of birdsong? Provide relevant equations. [2 marks]

6 Further Graphics

(*a*) Consider the b-spline curve $P(t)$ with knot vector [0, 1, 2, 3, 3, 3] and $k = 3$.

(*i*) In a single sentence, explain the effect on $P(t)$ of repeating a knot value k times. [1 mark]

(*ii*) State the equations that define $P(t)$. [3 marks]

(*iii*) State the equation and sketch the graph for each of the three quadratic basis functions $N_{i,3}(t)$ of $P(t)$. [8 marks]

(*iv*) Plot the path of $P(t)$ for control points $P_0 = (0, 0)$, $P_1 = (4, 0)$, $P_2 = (4, 4)$. [4 marks]

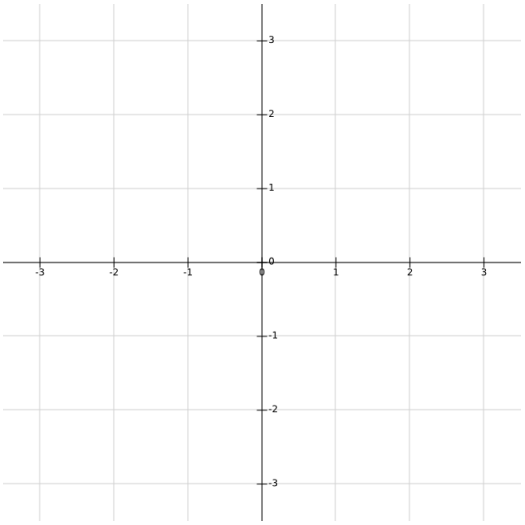
(*b*) Consider an embedded closed manifold surface with 48 vertices, 48 faces, and 100 edges.

(*i*) What is the genus of this surface, and what is the formula to find it? [2 marks]

(*ii*) What is the total angle deficit of this surface, and what is the formula to find it? [2 marks]

7 Further Graphics

(a) Consider the set $\mathbf{C}$ of 2D control points:
$\mathbf{C} = \{\ (0,0),\ (0,2),\ (2,1),\ (2,-1),\ (-2,-1),\ (-2,1)\ \}$



On 3 separate 2D graph plots, each ranging from $(-3,-3)$ to $(3,3)$,

(i) Draw the *Voronoi diagram* of $\mathbf{C}$ [2 marks]

(ii) Draw the *Delaunay triangulation* of $\mathbf{C}$ [2 marks]

(iii) Draw the *empty circles* of the *Voronoi points* of $\mathbf{C}$ [2 marks]

(iv) What is the first value in the *equiangularity* of $\mathbf{C}$? [3 marks]

(v) What is the (X,Y) position of the Voronoi point of $\mathbf{C}$ with the most negative Y coordinate? [3 marks]

(b) Using pseudocode, give an algorithm for finding the Delaunay triangulation of a set of 2D points $\mathbf{S}$. [4 marks]

(c) Explain why the empty circles around the Voronoi points of a Voronoi diagram are, in fact, empty. [4 marks]

8 Further HCI

The design of conversational agents such as Echo or Siri has become very conventional with an activation phrase (e.g. 'hey assistant') and an action phrase (e.g. 'play encouraging music'). You're acting as the HCI researcher for a startup intending to disrupt the market by producing a radically different interaction design for the assistant you're developing.

(*a*) What is a usability problem with conversational agents? [1 mark]

(*b*) Why is iterative design important? What are the convergent and divergent phases of a design process? [3 marks]

(*c*) How would you go about performing the divergent phases on this project? What would you expect the output to be? [4 marks]

(*d*) How would you go about performing the convergent phases on this project? What would you expect the output to be? [4 marks]

(*e*) After following this process you have a candidate design. What are two properties that the design should have? [2 marks]

(*f*) For *each* property, (i) name the underlying theory, (ii) what approach you would take to testing whether the design has that property, and (iii) a limitation of your method. [6 marks]

9 Further HCI

You are designing a new syntax for a programming language like Java, with the intention of making it more approachable to students by using English words instead of punctuation symbols.

(*a*) How does an HCI designer use a theory of human behaviour in their design practice? [2 marks]

(*b*) What is an empirical method? Give an example and short description of that method. [3 marks]

(*c*) Describe in terms of the Cognitive Dimensions two trade-offs involved between the existing Java syntax and the new proposed syntax. [8 marks]

(*d*) How does the programming environment relate to this analysis? [2 marks]

(*e*) A manager makes a proposal to try different permutations of syntaxes and measure students' performance using each permutation. How would you measure and compare the students' performance? [2 marks]

(*f*) What are the likely strengths and weaknesses of the approach in Part (*e*)? [3 marks]

10 Prolog

In this question we will write a program to assign guests to seats around a dinner table. The table is rectangular with the same number of seats along both of the long sides. There are no seats along the short sides. Two guests sit *near* each other if they occupy adjacent seats on the same side of the table, or sit directly opposite one another. Each guest at the dinner table may express a preference to sit near to one or more other guests.

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) and you should not assume the existence of any library predicates.

(*a*) Define the concept of *generate and test* using this problem as an example. [2 marks]

(*b*) Describe a suitable approach for representing guests, their places at the table and their preferences. [2 marks]

(*c*) Implement a predicate `nextTo(A,B,Assigned)` which is true if guest `A` is sitting adjacent-to or directly opposite guest `B` in the seating assignment `Assigned`. [4 marks]

(*d*) Implement a predicate `satisfied(Assigned,Prefs)` which is true if `Assigned` is a seating assignment which meets all the preferences specified in `Prefs`. [3 marks]

(*e*) Implement a predicate `assign(N,Prefs,Assigned)` which succeeds if `Assigned` is a valid seating assignment for `N` guests with preferences `Prefs`. Your predicate should be able to generate the assignment and should fail if an odd number of guests are requested. [6 marks]

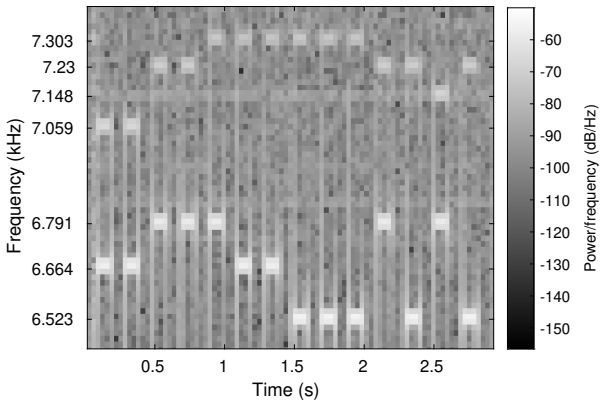
(*f*) What technique could you use to find the best assignment in those cases where it is not possible to meet the preferences of all the guests? Explain in words how you would alter your solution to do this. [3 marks]

11 Digital Signal Processing

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

You are the new CTO of *Missampled Ltd*, a consulting company specializing in fixing digital-signal-recording accidents. These are the first customers seeking your help:

(*a*) A police officer has recorded a conversation between suspects on an analog phone line. The recording $\{x_n\}$ has sampling frequency $f_s = 16$ kHz. But the officer had accidentally activated a "scramble" switch on the recorder, and as a result the recording now sounds high-pitched and is unintelligible.



The manual of the recorder does not explain what the "scramble" switch does. Using a spectrogram (above), you spot at the start of the recording a sequence of 14 tone pairs.

(*i*) What six computational steps are typically involved in producing such a spectrogram from a sequence of real-valued samples? [6 marks]

(*ii*) The spectrogram reminds you of DTMF-encoded touch-tone digits, but the frequencies are clearly not the standard ones at 697, 770, 852, 941, 1209, 1336, and 1477 Hz. What appears to have happened to the frequencies in this recording, how can this transformation be explained as a simple time-domain operation on its samples, and how can you then restore it such that the officer can hear the original voices again? [6 marks]

(*b*) A TV producer discovered that during the recording of a stage production, one of the microphones accidentally had activated the following digital FIR filter (where $\{x_n\}$ is the desired audio signal and $\{y_n\}$ is the available recorded sequence):

$$y_n = 0.4 \times \left(x_n + x_{n-1} + \frac{1}{2} x_{n-2} \right)$$

(*i*) What is the z-transform $H(z)$ of the impulse response of this filter? [2 marks]

(*ii*) What is the z-transform of the impulse response of a filter G that, if applied to the recorded samples $\{y_n\}$, converts them back into the original waveform $\{x_n\}$? [2 marks]

(*iii*) Draw a Direct Form I representation of G. [4 marks]

END OF PAPER