COMPUTER SCIENCE TRIPOS Part IB 75%

Thursday 7 June 2018 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

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1 Concepts in Programming Languages

(*a*) Various languages provide a built-in '`eval`' operator which evaluates an expression passed as an argument. Discuss the extent to which this: (*i*) fits with existing language features, naming languages or classes of languages for which it is easy or hard to implement; (*ii*) easily deals with variable scoping; (*iii*) is a security risk. [4 marks]

(*b*) (*i*) Explain and justify what goes wrong when the following code is given to a Standard ML system:

```
fun id x = x;
val fnlist = ref [id];
fnlist := (fn x=>x+1) :: !fnlist;
fnlist := Math.sqrt :: !fnlist;
print (hd(!fnlist)(1))
```

(*ii*) Explain, giving an example, a related problem involving polymorphic exceptions.

[5 marks]

(*c*) (*i*) Explain the concept of a "value type" in an object-oriented language, including which, if any, primitive and non-primitive types in Java can be seen as value types.

(*ii*) Discuss to what extent a programmer can use `final` to create value types in Java, and whether this implementation gives the expected space and time usage. [*Hint:* You may find it useful to discuss arrays of complex numbers.]

[5 marks]

(*d*) An implementation of finite sets of natural numbers in Standard ML uses `int list` as its representation. However, certain client code has been found to be buggy, because it misuses `::` to add elements (creating duplicates) and `length` to obtain the number of elements (miscounting duplicates).

(*i*) Explain how ML modules might be helpful for addressing such bugs.

(*ii*) Use the ML modules language to create a type `natset` which uses `int list` internally but only exposes operations (*a*) to create an empty set, (*b*) to (functionally) insert one (non-negative) element into a set, (*c*) to sum the elements in a set, (*d*) to count the number of elements in a set. No other operation may create or manipulate an `natset` value.

[6 marks]

2 Economics, Law and Ethics

(*a*) Describe the possible market failures affecting anti-virus software firms in the late 1980s and early 1990s, when viruses were a new threat to computer systems and dozens of firms started up to offer anti-virus software. [5 marks]

(*b*) Describe how the incentives facing anti-virus software firms had changed 10 years later once the industry had consolidated into a handful of large firms. How might this affect attacker behaviour? [5 marks]

(*c*) How will the incentives have changed in recent years with the spread of online banking and crypto currencies? [5 marks]

(*d*) How do you expect the anti-virus industry to change as computing shifts from PCs and laptops to phones and tablets? What about the impact of systems embedded in durable consumer goods such as cars? [5 marks]

3 Formal Models of Language

Consider the following grammar:

$$
\begin{array}{rcl}
\text{S} & \rightarrow & \text{NP VP} \\
\text{NP} & \rightarrow & \text{N S} \\
\text{NP} & \rightarrow & \text{N} \\
\text{VP} & \rightarrow & \text{V N} \\
\text{VP} & \rightarrow & \text{V}
\end{array}
$$

$$
\begin{array}{rcl}
\text{N} & \rightarrow & \{\textit{Alice}, \textit{cats}\} \\
\text{V} & \rightarrow & \{\textit{saw}, \textit{grinned}\}
\end{array}
$$

(a) The grammar can be used to generate the following sentences:

(i) *Alice saw cats*

(ii) *Cats Alice saw grinned*

Draw derivation trees for both of these sentences. [2 marks]

(b) What is the longest sentence that can be generated by the grammar? Describe this sentence. [2 marks]

(c) Is the language generated by the grammar a regular language? Provide a proof for your answer. [8 marks]

(d) A psycho-linguistic experiment shows that, by the 2nd word in the sentence, Part (a)(ii) is harder to process than the sentence Part (a)(i). Yngve hypothesised that a speaker's short-term memory functions as a stack. Explain how this hypothesis might account for the experimental results by drawing the stack arising from a top-down parse of the two sentences. [4 marks]

(e) How might the sentence in Part (a)(ii) be altered so that it has the same meaning but is easier to process? Explain your reasoning. [4 marks]

4 Further Graphics

(*a*) Here are two methods for implementing a cube using signed distance fields:

```
float methodOne(vec3 p) {
  return max(max(abs(p.x), abs(p.y)), abs(p.z)) - 1;
}

float methodTwo(vec3 p) {
  vec3 d = abs(p) - vec3(1);
  return min(max(d.x, max(d.y, d.z)), 0.0)
      + length(max(d, 0.0));
}
```

One is preferable to the other for producing better images faster. Which one, and why? [4 marks]

(*b*) Complete the code below to implement the signed distance field function for a finite line segment with hemispherical end-caps (Figure 1) of arbitrary start point, end point, and radius. [4 marks]

```
float lineSegment(vec3 p, vec3 start, vec3 end, float radius) {
  // [YOUR CODE HERE]
}

float getSdf(vec3 p) {
  return lineSegment(
      p, vec3(-PI, 0, 0), vec3(PI, 0, 0), 0.5);
}
```

(*c*) Implement a version of `getSdf()` that doubles the height of your line segment and translates it by -0.5 along the Z axis, to be centred at $(0, 0, -0.5)$ (Figure 2). [4 marks]

(*d*) Implement a version of `getSdf()` that warps the original line segment into a sine wave $sin(X)$ (Figure 3). [4 marks]

(*e*) Modify `getSdf()` to render the sine wave model subtracted from the taller model (Figure 4). [4 marks]

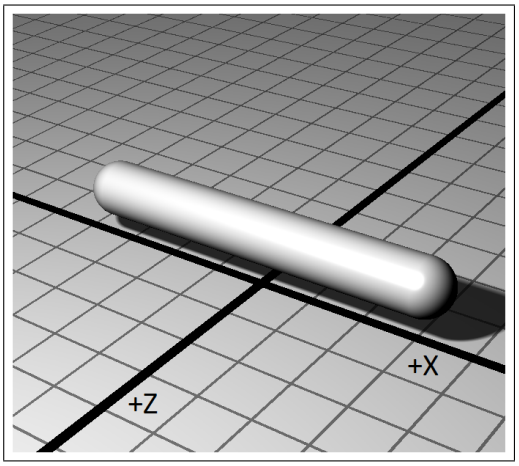


Figure 1

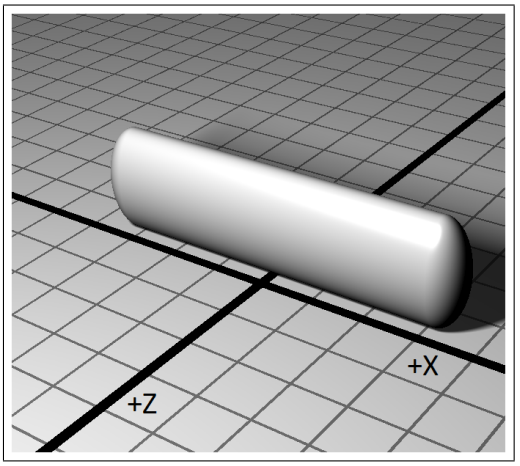


Figure 2

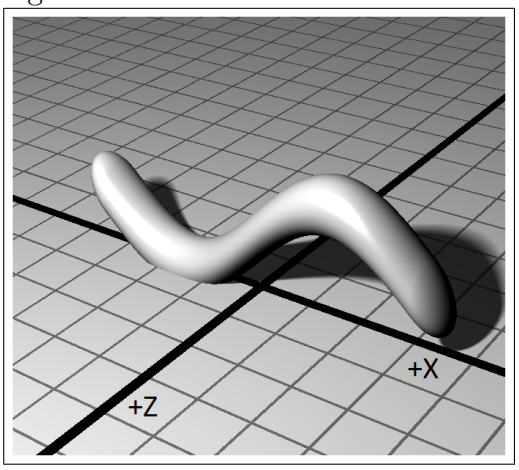


Figure 3

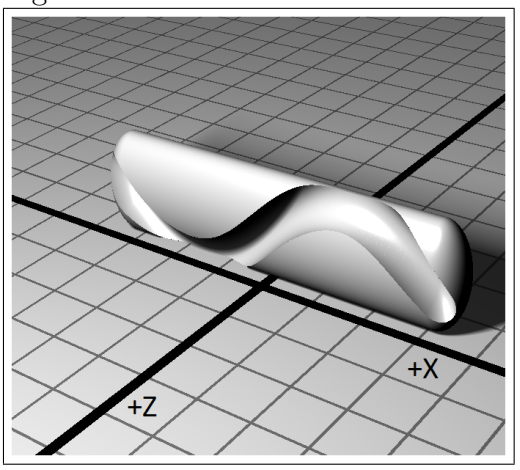


Figure 4

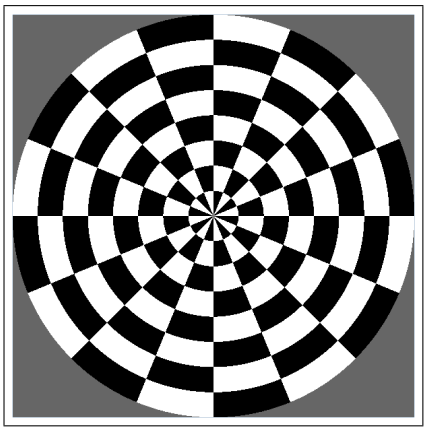
Figure 1: A finite cylinder of radius 0.5 centred at $(0, 0, 0)$ with hemispherical end-caps, starting at $(-\pi, 0, 0)$ and ending at $(\pi, 0, 0)$.
Figure 2: The original finite cylinder has been enlarged to double its height on the Y axis and has been translated in Z so that it is now centred at $(0, 0, -0.5)$.
Figure 3: The original finite cylinder has been warped with a sine wave. Its centre remains at $(0, 0, 0)$ and its endpoints remain centred around $(+/-\pi, 0, 0)$, but in between its central axis falls to $Y = -1$ and rises to $Y = 1$.
Figure 4: The sine wave has been subtracted from the double-height cylinder.

(Note: Ground plane shown at $Y = -1$ for illustration purposes only)

5 Further Graphics

(*a*) Write a GLSL function `dartboard()` which takes as input a texture co-ordinate `texCoord` which ranges from $(0, 0) \rightarrow (1, 1)$, and returns the colours of the procedural texture for a black-and-white dartboard pattern of 16 squares around and 8 squares in radius (see figure below). The background behind the dartboard is gray.

```
vec3 dartboard(vec2 texCoord) {
  // [YOUR CODE HERE]
}
```



[6 marks]

(*b*) What is ...

(*i*) the formula for the *face angle* $\alpha(F, v_i)$ of face F at vertex v_i of a closed manifold? [2 marks]

(*ii*) the formula for the *angle deficit* $AD(v)$ of vertex v and its surrounding set of faces $\{F\}$? [2 marks]

(*iii*) the formula for the *Poincaré Formula* of a surface with genus g and Euler characteristic χ? [2 marks]

(*iv*) the formula for *Descartes' Theorem of Total Angle Deficit*? [2 marks]

(*c*) Consider a closed manifold surface with total angle deficit -4π.

(*i*) If your hypothetical surface has 20 vertices and 20 faces then how many edges must it have? [2 marks]

(*ii*) Sketch a picture of your surface. [4 marks]

6 Further HCI

(*a*) Explain in general how the actions that a user takes are related to the user's goals. Your answer should make reference to the function of perception, and to the nature of the cognitive processing that must occur. [8 marks]

(*b*) Describe a class of problems for which it is not possible to formulate goals. Give a specific example of a problem in this class, and with reference to that example, explain how it illustrates *two* significant attributes of the class. [6 marks]

(*c*) If an interactive system has several alternative models to describe the user's goal, how can Bayes' theorem be used to improve the system usability? [6 marks]

7 Further HCI

Imagine that you have been asked to implement a radical new design of your college website. The Senior Tutor has decided that, to make the college seem friendlier, the home page and navigation should be implemented using a group photograph of all members of the college that was taken last summer. Your task is to design graphical content that will be overlaid onto the photograph to provide all necessary information and navigation.

(*a*) Draw a sketch showing the main graphical features of your proposed design. (A few stick figures will be adequate to represent the original photograph. No additional marks will be given for realistic depictions of members of your college.) [4 marks]

(*b*) Explain how the display plane of the photograph has been segmented in your proposed design, including explanation of any visual marks that were used to achieve this segmentation. [6 marks]

(*c*) Choose *five* specific visual aspects of your proposed design, and for *each* of these five:

(*i*) Describe the graphical property used to implement this aspect (by reference to your sketch); and

(*ii*) Explain the mode of correspondence between this graphical property and the meaning that is intended in this aspect of your design.

[10 marks]

8 Prolog

In this question you should ensure that your predicates behave appropriately with backtracking. You **may not** make use of extra-logical built-in predicates such as `findAll`. Use of the cut operator is permitted unless specified otherwise. You may ignore the possibility of overflow or division by zero.

(*a*) A term can either be an *atom*, *variable* or a *compound term*. Define each of these. [3 marks]

(*b*) Euclid's algorithm for computing the greatest common divisor of two integers can be implemented in ML as:

```
fun gcd(a,0) = a
 |  gcd(a,b) = gcd(b, a mod b);
```

Provide an implementation in Prolog without using the cut operator. [4 marks]

(*c*) We can represent fractions using the compound term `div/2`. For example `div(1,3)` represents $\frac{1}{3}$.

Implement a predicate `simplify` which transforms a fraction into its smallest exact representation. For example, `simplify(div(8,4),B)` should unify `B` with `2`, and `simplify(div(4,8),A)` should unify `A` with `div(1,2)`. Your predicate should avoid unnecessary computation. [5 marks]

(*d*) We can also represent arithmetic expressions involving addition, subtraction, multiplication and division. For example, the expression $3\frac{5}{2-1}+4$ is represented as `add(mul(3,div(5,sub(2,1))),4)`.

Implement a predicate `reduce` which reduces an arithmetic expression to its smallest exact representation e.g. `reduce(add(div(1,2),div(1,4)),A)` should unify `A` with `div(3,4)`. [8 marks]

END OF PAPER