COMPUTER SCIENCE TRIPOS Part II (General)
DIPLOMA IN COMPUTER SCIENCE

Monday 5 June 2006 1.30 to 4.30

PAPER 10 (PAPER 1 OF DIPLOMA IN COMPUTER SCIENCE)

*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 Coversheets
Tags

1 Foundations of Programming

(*a*) Explain the term *overloading* in the context of Java constructors and methods. [2 marks]

(*b*) Without describing the details of either, outline the relationship between the Java methods `System.out.printf()` and `String.format()`. [2 marks]

The ISO representation for the time of day is `hh:mm:ss` where (for the purposes of this question) `hh` is a two-digit integer in the range `00` to `23` and each of `mm` and `ss` is a two-digit integer in the range `00` to `59`.

The following Java test program exercises a proposed class `Time` which enables a time to be represented in ISO format and allows one time to be added to another:

```
public class TimeProg
 { public static void main(String[] args)
    { Time t1 = new Time(15,10,5);
      t1.add(5,10,15);
      t1.add(10,20);
      t1.add(5);
      System.out.printf("%s%n", t1);  // outputs 20:30:45
      Time t2 = new Time(60,70,80);
      System.out.printf("%s%n", t2);  // outputs 13:11:20
      t1.add(t2);
      System.out.printf("%s%n", t1);  // outputs 09:42:05
      Time t3 = new Time();
      System.out.printf("%s%n", t3);  // outputs 00:00:00
    }
 }
```

It may be assumed that only positive arguments are used but note that out-of-range values for minutes and seconds are treated sensibly (thus 80 seconds results in 1 being added to the number of minutes). An out-of-range value for hours is held modulo 24.

(*c*) Outline suitable specifications for the two versions of the constructor `Time()` and the four versions of the `add()` method. [6 marks]

(*d*) Write a class `Time` that would work with the test program above. [10 marks]

2 Foundations of Programming

(*a*) What is the difference between `MouseListener` and `MouseAdapter`? [3 marks]

(*b*) Via suitable HTML, the compiled version of the following Java code is presented to the `appletviewer` application:

```
import java.applet.Applet;
import java.awt.Graphics;
import java.awt.event.MouseAdapter;
import java.awt.event.MouseEvent;

public class MouseTest extends Applet
 { private String s = "Hello World";

   public void init()
    { this.addMouseListener(new ML());
    }

   public void paint(Graphics g)
    { g.drawRect(15, 15, 270, 70);
      g.drawString(this.s, 100, 60);
    }

   class ML extends MouseAdapter
    { public void mousePressed(MouseEvent e)
       { MouseTest.this.s = "Mouse Pressed";
       }
    }
}
```

Briefly explain what the code does and describe the initial appearance of the applet window. [6 marks]

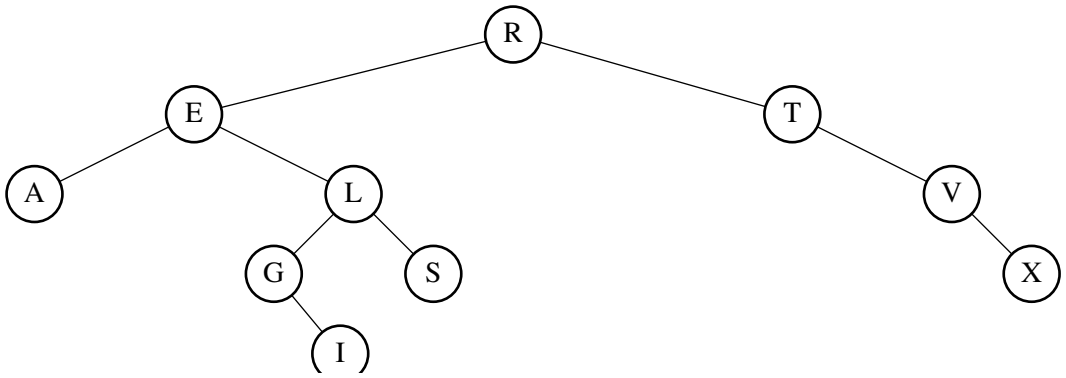
(*c*) The programmer moves the mouse pointer into the applet window, presses the mouse button and expects a new message to appear. Why doesn't it appear? Give *three* ways in which the expected result can be provoked without leaving `appletviewer`. [6 marks]

(*d*) The line `MouseTest.this.paint(MouseTest.this.getGraphics());` is added to the method `mousePressed()`. Describe the behaviour now if the mouse button is pressed when the pointer is in the applet. [3 marks]

(*e*) What would have been a more appropriate amendment to the method `mousePressed()`? Explain. [2 marks]

3 Data Structures and Algorithms

(*a*) Briefly explain what a binary search tree (BST) is, listing its properties. Is the following binary tree a BST or not, and why?



[3 marks]

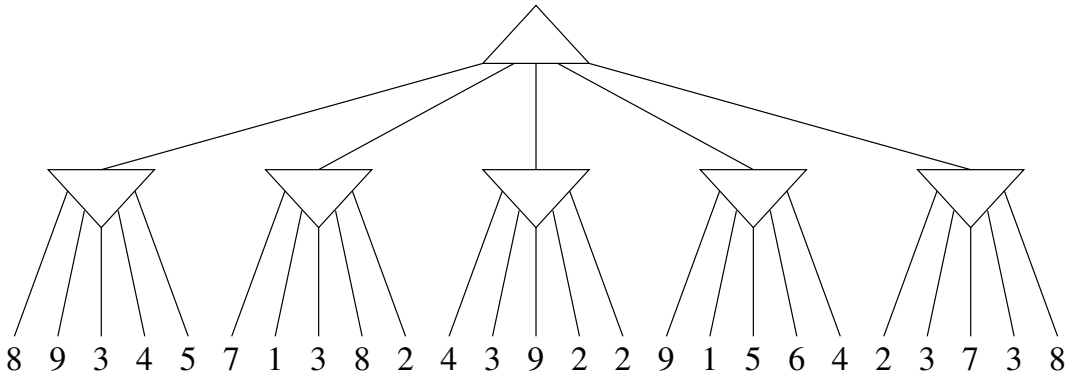
(*b*) Describe an optimally efficient algorithm to find the predecessor of a given node n in a BST and explain why it works. [6 marks]

(*c*) Describe an optimally efficient algorithm for deleting a node d from a BST when neither of d's subtrees is empty. Explain why it works and prove that what remains is still a BST. [5 marks]

(*d*) Assume that node l, whose key is k_l, is a leaf of a BST and that its parent is node p, with key k_p. Prove that, of all the keys in the BST, k_p is either the smallest key greater than k_l or the largest key smaller than k_l. [6 marks]

4 Artificial Intelligence I

(*a*) Give a detailed description of the *minimax algorithm* for two-player games, illustrating your answer using the following game tree.



[10 marks]

(*b*) Describe the modifications required to the minimax algorithm in order to apply it to realistic games. [5 marks]

(*c*) Give a detailed description of the technique of $\alpha - \beta$ pruning, again illustrating your answer using the game tree above. [5 marks]

5 Comparative Programming Languages

(*a*) In order to remove the overhead of a function call, a programmer decides to replace all calls to a function `f` with the macro `F`, where `f` and `F` are defined as follows:

```
int f(int x) { return x+x;}

#define F(X) (X)+(X)
```

(*i*) Give two valid C expressions involving `f` which produce different results when `F` is substituted for `f`. Justify your answer. [4 marks]

(*ii*) State the C language feature which can be used to correctly remove the overhead of a function call. [1 mark]

(*b*) Consider the following:

```
static struct link {
  int v;
  struct link *next;
} *head=0;

void convert(int a[], int len);
```

Write a function definition for `convert` which updates `head` to point to a linked-list containing the elements of `a` in the same order. You may assume `len` contains the number of elements in `a`. [5 marks]

(*c*) Consider the following C++ declaration:

```
template<int n> int SumSquares();
```

(*i*) Using function specialisation, provide an implementation of `SumSquares` so that, given an integer `N`, `SumSquares<N>()` returns:

$$\sum_{i=1}^{\mathtt{N}} i^2$$

[5 marks]

(*ii*) Compare and contrast the functionality of the C preprocessor and the C++ template system. Explain why it is not possible to write a C preprocessor macro to implement `SumSquares`. [5 marks]

6 Introduction to Functional Programming

(*a*) The *extension* of a list ℓ, denoted $\#\ell$, is the set of all its elements; that is, formally,

$$\#\texttt{[]} = \{\ \}$$
$$\#(h\texttt{::}t) = \{h\} \cup \#t$$

Thus, for instance, $\#\texttt{[0,1,2,3,1,2,3,2,3,3]} = \{\texttt{0}, \texttt{1}, \texttt{2}, \texttt{3}\}$.

You are asked to give four implementations of an (*extensional*) *remove* curried function

```
''a rm :  ''a -> ''a list -> ''a list
```

satisfying the following specification:

$$\#(\texttt{rm}\ x\ \ell) = (\#\ell) \setminus \{x\}$$

for all equality types α, and values x of type α and ℓ of type α `list`.

(*i*) The first implementation should use the ML built-in functional

```
'a filter :  ('a -> bool) -> 'a list -> 'a list
```

[2 marks]

(*ii*) The second implementation should use the ML built-in functionals

```
'a concat :  'a list list -> 'a list
('a, 'b) map :  ('a -> 'b) -> 'a list -> 'b list
```

[2 marks]

(*iii*) The third implementation should be a simple recursive function using only the `list` datatype constructors. [4 marks]

(*iv*) The fourth implementation should be a tail-recursive function using only the `list` datatype constructors. [6 marks]

(*b*) Rigorously argue for the correctness of either the third or the fourth of your implementations. [6 marks]

7 Operating System Foundations

(*a*) Describe the steps involved in resolving any component of a file pathname. [6 marks]

(*b*) (*i*) Describe the steps involved in

- creating a file;
- deleting a file. [8 marks]

(*ii*) Discuss the possible effects of a crash, causing loss of main memory, at various points during file creation and deletion. [6 marks]

8 Numerical Analysis I

(*a*) An IEEE Single Precision number is stored in 32 bits, of which 8 bits are reserved for the exponent. Explain the terms *normalised number* and *hidden bit*. How many bits are used to store the *significand*, and what is the *precision*? Show by means of a diagram how the bits are arranged in storage. [4 marks]

(*b*) How is the value of the exponent stored? What are the stored values of the exponents e_{min} and e_{max}? [3 marks]

(*c*) Which values are represented by the following bit patterns? [Show signs where appropriate.]

(*i*) 00000000 00000000 00000000 00000000

(*ii*) 11111111 11111111 11111111 11111111

(*iii*) 00111111 10000000 00000000 00000000

(*iv*) 11000000 00000000 00000000 00000000

(*v*) 00000000 00000000 00000000 00000001

(*vi*) 01111111 10000000 00000000 00000000 [6 marks]

(*d*) Define *machine epsilon* ε_m. Estimate its value in IEEE Single Precision. [2 marks]

(*e*) What are the two sources of error in the formula

$$f'(x) \simeq \frac{f(x+h) - f(x)}{h}$$

and how does each type of error behave as h increases? Suggest a suitable value of h to use with this formula for IEEE Single Precision when $f(x) = O(1)$. [5 marks]

9 Mathematics for Computation Theory

(a) Let A, B C be sets. Define:

(i) the *Cartesian product* $(A \times B)$;

(ii) the set of relations R between A and B;

(iii) the identity relation Δ_A on the set A.

[3 marks]

(b) Suppose S, T are relations between A and B, and between B and C, respectively. Define the inverse relation S^{-1} and the product relation $S \circ T$.
[2 marks]

(c) Let f be a relation between A and B. Characterise the following conditions in terms of the algebra of relations:

(i) f is a partial function;

(ii) f is a total function;

(iii) (total) function f is a surjection (ONTO);

(iv) (total) function f is an injection $(1-1)$.

[4 marks]

(d) A total function that is both a surjection and an injection is called a *bijection*. Show that if f is a bijection between A and B, f^{-1} is also a bijection.
[2 marks]

(e) Consider the set of natural numbers $\mathbb{N} = \{0, 1, 2, \ldots\}$. Define relation $f = \{((x, y), z) \mid z = 2^x(2y + 1)\} \subseteq ((\mathbb{N} \times \mathbb{N}) \times \mathbb{N})$. Which of conditions ($i$)–($iv$) in part ($c$) does relation f between $(\mathbb{N} \times \mathbb{N})$ and $\mathbb{N}$ satisfy? [6 marks]

(f) Show how to modify f to establish a bijection $h : \mathbb{N} \to (\mathbb{N} \times \mathbb{N})$. [3 marks]

10 Computation Theory

(*a*) (*i*) Give a graphical representation of the following register machine program.

$$
\begin{aligned}
L0: &\quad Z^+ \to L1 \\
L1: &\quad L^- \to L2, L3 \\
L2: &\quad Z^+ \to L0 \\
L3: &\quad Z^- \to L4, L5 \\
L4: &\quad L^+ \to L3 \\
L5: &\quad X^- \to L1, L6 \\
L6: &\quad \text{HALT}
\end{aligned}
$$

[3 marks]

(*ii*) Assuming the contents of register Z is initially 0, when the program is run starting at instruction $L0$ what functions of the initial contents of registers X and L are computed in X and L when the machine halts? [5 marks]

(*b*) (*i*) What is meant by a *Turing machine*, its *configurations*, *transition relation* and the *computations* it carries out? What does it mean to say that a computation *halts*? [6 marks]

(*ii*) Given a Turing machine, is it decidable whether or not for all possible initial configurations the machine will not halt after 100 steps of transition? Justify your answer. [6 marks]

11 Computer Graphics and Image Processing

(*a*) Describe, in outline, each of the z-buffer, BSP tree, and painter's algorithm methods for rendering a set of 3D polygons. [4 marks each]

(*b*) Compare and contrast the three methods. [8 marks]

12 Introduction to Security

(*a*) Name *three* types of software vulnerability; give an example of each and a brief description of how each could be exploited. [9 marks]

(*b*) Alice wants to attack Bob's computer via the Internet, by sending IP packets to it, directly from her own computer. She does not want Bob to find out the IP address of her computer.

(*i*) Is this easier to achieve for Alice with TCP- or UDP-based application protocols? Explain why. [3 marks]

(*ii*) For the more difficult protocol, explain *one* technique that Alice could try to overcome this obstacle and *one* countermeasure that Bob could implement in his computer. [3 marks]

(*iii*) Name *three* functions that Alice's Internet service provider could implement to make it more difficult for Alice to achieve her goal? [3 marks]

(*c*) In what way are TCP/UDP port numbers below 1024 special? [2 marks]

END OF PAPER