COMPUTER SCIENCE TRIPOS Part IB

Monday 5 June 2017 1.30 to 4.30

COMPUTER SCIENCE Paper 3

*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 Programming in C and C++

(*a*) Consider the following program, written to test whether the representation of `int` on a particular architecture uses two's complement or not.

```
#include <limits.h>
#include <stdio.h>

int main(void) {
  printf("%d\n", (INT_MAX + 1) < 0);
  return 0;
}
```

Explain what this program is permitted to output, and why. [5 marks]

(*b*) Consider the following C function, intended to receive a string as an argument and return a reversed string as a result. (The `strlen` function returns the number of characters in the string.)

```
#include <string.h>
#include <stdlib.h>

char *reverse(char *input) {
  int len = strlen(input);
  char output[len];
  for (int i = 0; i < len; i++) {
     output[len - i - 1] = input[i];
  }
  return output;
}
```

(*i*) Identify three bugs in this function. [6 marks]

(*ii*) Write a correct version of this function. [9 marks]

2 Programming in C and C++

(*a*) In a C++ program, suppose there is a function with the following prototype.

```
void foo(MyClass x)
```

Suppose that this function is invoked in a call `foo(z)`.

(*i*) What does C++ do when `z` is passed as an argument to `foo`?

(*ii*) Explain briefly in English how the `MyClass` class can be modified to raise compile-time errors when objects of type `MyClass` are passed as arguments.

(*iii*) Why might you want to do this?

(*iv*) In response, how should the type of `foo` be declared instead? Give a new function prototype for `foo`.

[3 marks each]

(*b*) In C, it is typical for APIs to expose functions which create values (such as `fopen`) and then subsequently delete them (such as `fclose`). For example, a C program might use files with code like:

```
void bar(void) {
   FILE *fp = fopen("example.txt","r");
   baz(fp);
   fclose(fp);
}
```

(*i*) What makes this style of resource management problematic in C++? Your answer should explain what `baz` could do that creates resource-management hazards. [3 marks]

(*ii*) Describe the preferred alternative to handling this kind of resource management issue in modern C++. [2 marks]

(*iii*) Define a C++ class which wraps the C file API to support C++ style resource management. You only need to show how to wrap the resource management calls (`fopen` and `fclose`), and may ignore the rest of the file API. [3 marks]

3 Compiler Construction

(*a*) Explain why some programming languages require automatic memory management ("garbage collection") for program execution. [4 marks]

(*b*) At a given point in the execution of a program, what can be considered as garbage? How can garbage be located in memory? [4 marks]

(*c*) Suppose a programmer is implementing garbage collection using reference counting. Discuss whether or not they need to consider the possibility of a reference count overflowing when incremented. [4 marks]

(*d*) Suppose we are writing a compiler for an ML-like language. We want to employ the equation

```
(map f) o (map g) = map (f o g)
```

as a left-to-right rewrite rule for optimisation. The symbol `o` represents function composition — for any value `v` the expression `(f o g) v` evaluates to the value of `f(g v)`.

Discuss the merits of this idea. Is it always correct? [8 marks]

4 Compiler Construction

Consider the following simple evaluator for a language of expressions written in OCaml.

```
type expr =
   | Integer of int             (* integer                *)
   | Pair of expr * expr        (* pair                   *)
   | Apply of string * expr     (* apply a named function *)

type value =
     | INT of int
     | PAIR of value * value

(* eval : expr -> value *)
let rec eval = function
   | Integer n      -> INT n
   | Pair (e1, e2)  -> PAIR (eval e1, eval e2)
   | Apply (f, e)   -> eval_function(f, eval e)
```

In this code the function `eval_function` has type `string * value -> value` and is used to evaluate some "built in" functions. For example,

```
eval_function("add", PAIR(INT 10, INT 7))
```

could return the value `INT 17`.

(*a*) Rewrite the `eval` function in continuation passing style (CPS) to produce a function `eval_cps` so that the function

```
let eval_2 e = eval_cps (fun x -> x) e
```

will produce the same results as the function `eval`. [10 marks]

(*b*) Eliminate higher-order continuations from your `eval_cps` function. That is, introduce a data type `cnt` to represent continuations and write functions of type

```
eval_cps_dfn : cnt -> expr -> value
apply_cnt    : cnt * value -> value
eval_3       : expr -> value
```

using the technique of defunctionalisation. Note that functions `eval_cps_dfn` and `apply_cnt` will be mutually recursive. [10 marks]

5 Concepts in Programming Languages

(*a*) "Fortran, Algol and Lisp invented most programming language concepts 50 years ago; adding the concept of object-orientation suffices to explain all programming languages to date". To what extent is this statement true or false? Provide evidence for both, keeping in mind developments in hardware, large-scale system design, type systems and the like. [5 marks]

(*b*) "JavaScript is just Java with dynamic typing". Discuss. [3 marks]

(*c*) In Java and the JVM every value is either a primitive type or a heap-allocated object. However, Java 8 added ML-style functions-as-values. How is this achieved both at the value level and the type level, and does this addition increase the expressiveness of Java or merely provide more compact syntax? [4 marks]

(*d*) What is the difference between internal and external iteration? Explain the key differences between the `Collection` and `Stream` interfaces in Java 8, commenting on any association with internal and external iteration. [4 marks]

(*e*) The `Stream` interface to Java provides the `parallel()` method to cause the elements of a Stream to be processed in parallel. Comment, fixing any problems you find, on the following program fragment (forming part of a top-level class) which has recently been adjusted by a new employee "to work faster" by the insertion of the call to `parallel()`.

```
int nin, nout;
Stream<String> shortstrings(Stream<String> s) {
  return s.parallel().filter(w ->
       { nin++;
         if (w.length() < 4) { nout++; return true;}
         return false;
       });
}
```

[4 marks]

6 Further Java

Your task is to implement a trusted timestamp service. The service should accept TCP connections from clients on port 2510, read in ASCII characters from clients up until the first newline character, cryptographically sign and date the characters read, and return the digital signature to the client before closing the connection. You may assume the existence of a class `Util` with a static method `String sign(String document)` which, given a string `document`, will generate a digital signature suitable for sending to the client.

(*a*) Write a single-threaded implementation of the trusted timestamp service. You may use any features of the Java standard library. [6 marks]

(*b*) Write an implementation of a queue as a class `ConcurrentBlockingQueue<T>`, with public methods `void put(T)` and `T get()`. Your implementation should be thread-safe and calls to `get` should block until an item is available for return to the caller. You should not use any features of the Java standard library except for `java.util.ArrayList`. [6 marks]

(*c*) Write a multi-threaded implementation of the trusted timestamp service which uses a static set of ten worker threads, created when the program starts, to service requests from clients. You may use any features of the Java standard library and you may assume an implementation of `ConcurrentBlockingQueue<T>` described in part (*b*). [5 marks]

(*d*) When will your multi-threaded implementation achieve lower-latency responses to clients than the single-threaded implementation? Why? [3 marks]

7 Prolog

(*a*) Define `and/3` to model an AND gate, using `0` and `1` to mean "false" and "true" respectively. [2 marks]

(*b*) A definition of `or/3` is shown on the left, and a query's result on the right:

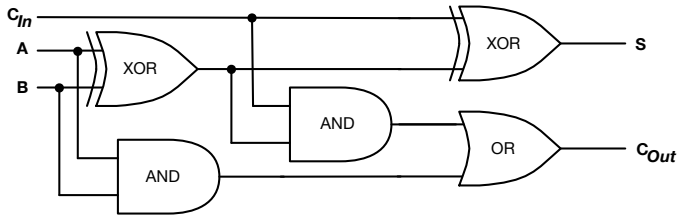
```
or(0,0,0).
or(_,_,1).
```

```
?- or(0,0,Result).
Result = 0 ;
Result = 1.
```

Explain this output, and correct `or/3` without increasing the number of clauses. [3 marks]

(*c*) Define `xor/3` using two rules. [2 marks]

(*d*) Define `full_adder(A, B, CIn, COut, S)` to implement the following circuit.



[5 marks]

(*e*) Define `zip(InList1, InList2, OutList)` such that if `InList1` is [1,3,...] and `InList2` is [2,4,...] then `OutList` must be [[1,2],[3,4],...]. [2 marks]

(*f*) Define `ripple_carry_adder(N, Inputs, CIn, COut, Result)` to cascade `N` calls to `full_adder/5`. Assume that we obtain parameter `Inputs` through `zip(`X`, `Y`, Inputs)` to add two `N`-bit values X and Y. In your answer take the most significant bit to be on the *right*. Thus you should expect to see:

```
?- ripple_carry_adder(2, [[1,1], [0,0]], 0, Cout, S).
Cout = 0, S = [0, 1].
?- ripple_carry_adder(2, [[0,0], [1,0]], 0, Cout, S).
Cout = 0, S = [0, 1].
?- ripple_carry_adder(2, [[0,0], [1,1]], 0, Cout, S).
Cout = 1, S = [0, 0].
```

[2 marks]

(*g*) Define the predicate `test(X,Y,N)` which tests `ripple_carry_adder/5` against Prolog's built-in addition function for up to `N` bits of precision, that is, fixed width `test(X,Y,N)` fails if overflow occurs (i.e., the carry bit is set). You may assume you are given predicates `dec2bin(Dec,BinList)` and `bin2dec(BinList,Dec)` for converting between integers and lists of bits, and `length(List,N)` which relates lists with their lengths. [4 marks]

8 Software Engineering

(*a*) Describe the main processes in a modern software development environment, and the tools used to support them. [6 marks]

(*b*) If the software were safety-critical, such as the control software for a car's anti-lock braking system (ABS), which other processes might be added? [4 marks]

(*c*) You are developing control software for a car whose latest model will have a network connection. Software upgrades will be delivered over the air rather than at service visits, so that any security vulnerabilities can be patched quickly. This in turn means that you will have to provide patches, to deal with both security and safety issues for the next 25 years. Discuss how this is likely to affect your development process, and the implications it will have for costs. [10 marks]

END OF PAPER