5 Concepts in Programming Languages (AM)

(a) Explain what is meant by a monad in a programming language, giving the two fundamental operations of a monad along with their types. [3 marks]

(b) Consider the use of a monad for input-output. For the purposes of this question, take the IO monad as including two operations readint and writeint which respectively read integers from stdin and write integers to stdout. Give the types of these operators. [2 marks]

(c) Assume MLreadint and MLwriteint are primitives with side effects for input-output and consider the ML expression add1 of type int:

\[
\text{let val x = MLreadint() in MLwriteint(x+1); x end}
\]

(i) Give an equivalent expression which uses the IO monad instead of side-effects, and state its type. [3 marks]

(ii) Give a function run2diff which can be applied to your answer to part (c)(i). When so applied it should give a value in the IO monad which corresponds to ML code that runs add1 twice and returns the difference between the values read. [4 marks]

(d) State what happens when attempting to compile and execute the following Java fragment (explaining the origin of any error messages or exceptions which might arise).

Object n = new Integer(42), o = new String("Whoops");
Object [] v;
Integer [] w = new Integer[10];
v = w;
v[4] = n;
v[5] = o; [4 marks]

(e) Consider the Java code:

Object n = new Integer(42);
ArrayList<? extends Object> v1;
ArrayList<Object> v2;
ArrayList<Integer> w = new ArrayList<>(10);

Explain any differences in behaviour between assignments v1 = w and v2 = w and also between method calls v1.set(4,n) and v2.set(4,n). [4 marks]