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 \( \text{IO} \) monad as including two operations \( \text{readint} \) and \( \text{writeint} \) which respectively read integers from \( \text{stdin} \) and write integers to \( \text{stdout} \). Give the types of these operators. [2 marks]

(c) Assume \texttt{MLreadint} and \texttt{MLwriteint} are primitives with side effects for input-output and consider the ML expression \texttt{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 \texttt{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 \texttt{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).

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

[4 marks]

(e) Consider the Java code:

\[
\text{Object n = new Integer(42);}
\text{ArrayList<? extends Object> v1;}
\text{ArrayList<Object> v2;}
\text{ArrayList<Integer> w = new ArrayList<>(10);}
\]

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]