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).

```java
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:

```java
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]