1. This question is about concurrent programming with threads.

The following Java is from a class written to represent a person’s name. Some of the code is to be used in concurrent programming.

```java
// Class to represent a person’s name, made up of their first name and last name.
public class FullName {
    private String first = "";
    private String last = "";

    // Operation to copy the contents of one fullname into another
    public static void copy(FullName p, FullName q) {
        q.first = p.first;
        q.last = p.last;
    }

    // Wrapper around the copy operation
    public static void safe_copy(FullName p, FullName q) {
        synchronized(p){  // Claim first fullname p
            synchronized(q){  // Claim second fullname q
                copy(p,q);    // Copy across contents
            }
        }
    }

    // Remainder of class omitted
}
```

(a) Describe what it means for methods in Java to be thread safe. \[1 \text{ mark}\]

(b) The `copy` method is not thread safe. Explain why, showing fragments of code and their execution to demonstrate how this can be a problem in practice. \[6 \text{ marks}\]

(c) The method `safe_copy` is a wrapper around `copy` that is intended to be thread safe. However, it is still problematic for use in concurrent code, as it may cause deadlock.

(i) Describe what it means for threaded concurrent code to deadlock. \[2 \text{ marks}\]

(ii) Explain why `safe_copy` may cause deadlock, and give code fragments demonstrating how this can be a problem in practice. \[6 \text{ marks}\]
2. This question is about types and type systems.

(a) The following are three variations on the idea of polymorphism in programming languages.
   (i) Subtype polymorphism.
   (ii) Parametric polymorphism.
   (iii) Ad-hoc polymorphism.

For each of these give a brief explanation of what it is, and give an example. [6 marks]

Note: Each example can be in any programming language — Haskell, Java, Scala, or whatever you think appropriate — but you must say which language it is. You can use different languages for each example if you think that will help your explanations.

(b) Suppose we have a dependently-typed lambda calculus which includes types $\text{Int}$ of integers, $\text{Num}$ of non-negative integers, and $\text{Matrix} \ n \ m$ of integer matrices with $n$ rows and $m$ columns, for $n, m : \text{Num}$. One possible operation in the language is to generate an identity matrix:

   $$\text{identity} : \forall n : \text{Num}. \text{Matrix} \ n \ n .$$

   (i) Give a suitable dependent type for the operation of matrix addition $\text{add}$.
   (ii) Give a suitable dependent type for matrix multiplication $\text{mult}$.
   (iii) Use some or all of $\text{identity}$, $\text{add}$, and $\text{mult}$ to write out a term that computes the $5 \times 5$ matrix that has leading diagonal elements all 2 and zero elsewhere (i.e. double the identity matrix). [5 marks]