This assignment is not required; you may do any or all of the following three programs for extra credit.

1. You are to redo Question 4 of Project #2 (lazy lists and the “Sieve of Erastosthenes”) in Java. Since Java is not polymorphic, you will implement lazy lists of type Object. Since Java does not support first-class functions, you’ll need to use the following trick to encapsulate a function within a class definition. Assume we wish to pass a function of type () -> LazyList. We first create an abstract class that contains only one member function, f:

   abstract class LazyListFct {
       abstract LazyList f();
   }

Subclasses of LazyListFct then simply redefine f to be one particular () -> LazyList function, e.g.

   class ExLazyListFct extends LazyListFct{
       LazyList f() { return seq(1,100); }
   }

Whenever a particular function must be passed as a value, an instance of a subclass of LazyListFct is used. The class you need to implement, LazyList, is structured as follows:

   class LazyList {
       boolean NullList; // Is this list null?
       Object head;     // Head of this list, if NullList is false
       LazyListFct tail; // Function to compute tail of this list,
                           // if NullList is false
       LazyList() { NullList = true;} // Creates a null LazyList
       LazyList(Object h, LazyListFct t) {
           NullList = false; // Creates a non-null LazyList
           head = h;
           tail = t;
       }
   static LazyList seq(int start, int finish){
       // Same def as in Question #4 of project 2
   }
To show that your lazy lists work compile and run class Test in ~cs538-1/public/java. You’ll see (again) that the sieve is slow. (Even slower than in ML!).

2. Once you have lazy lists working in Java, you can improve your implementation by using some of features of Pizza. In particular, you can make your lazy lists polymorphic, allowing, e.g., LazyList<int> or LazyList<boolean>.

Pizza also allows first-class functions, so you can improve your implementation by using a member function that is a function (e.g., () -> LazyList f( ) { return seq(1,100);}).

3. You are to redo Question 4 of Project #2 (lazy lists and the “Sieve of Erastosthenes”) in Python. Since Python is dynamically typed, you may represent null lazy lists as [] (just like ordinary Python lists). Moreover, a lazy list containing only one value may be represented as an ordinary list: [ val ]. Longer lazy lists will be represented as a list with two values: [val, fct]. val is the head of the list; it is an ordinary Python value. fct is a suspension function of no arguments; when called it will generate a lazy list representing the tail of the list.

In Python function literals (lambda terms) are represented as

lambda args: expression

You must be careful though; Python allows access to locals and globals but not direct access to intermediately scoped identifiers. You can use the following trick to allow access to intermediately scoped identifiers in a lambda term.

Python allows parameters with default values. If a parameter is not given a value at

```python
static LazyList infseq(int start){
    // Same def as in Question #4 of project 2
}
static LazyList boolseq(boolean start){
    // Creates an infinite LazyList containing the values
    // start, !start, start, !start, ...
}
static LazyList constList(int val){
    // Create an infinite LazyList containing val in
    // every position
}
static LazyList filter(LazyList control, LazyList data){
    // Same def as in Question #4 of project 2
}
static LazyList primes() {
    // Same def as in Question #4 of project 2
}
Object Nth(int n) {
    // Same def as in Question #4 of project 2,
    // EXCEPT that it throws a RuntimeException
    // if n-th element does not exist
}
void printN(int n) {
    // Like firstN except that values are printed
    // rather than formed into a list. After printing
    // current line is terminated (like a println).
}
```
the point of call, the default is used. The syntax (in a lambda term) is:

\[
\text{lambda } \ id_1=\text{val}_1, \ldots, \ id_n=\text{val}_n: \ expression
\]

If \( id_1 \) to \( id_n \) aren’t given values in a call, the values of \( \text{val}_1 \) to \( \text{val}_n \) will be available by using the names \( id_1 \) to \( id_n \), and the values of \( \text{val}_1 \) to \( \text{val}_n \) can be immediately scoped identifiers. Thus in

```python
def retFct(a):
    return lambda x=a:x
```

function \( \text{retFct} \) returns a function whose value, when called without parameters, is the value of \( a \). You can use a similar approach when you build suspensions for lazy lists.

In ML the function \( \text{Nth} \) returns \( \text{None} \) if the \( n \)-th element of a list does not exist. In Python you can use the special value \( \text{None} \) for the same purpose.

Since Python is interpreted, you may find that the call \( \text{Nth}(\text{primes}(), 20) \) takes too long. If so, try a simpler call like \( \text{Nth}(\text{primes}(), 19) \) or \( \text{Nth}(\text{primes}(), 18) \).

### What to Hand In

Submit your solution electronically by placing your files in your handin directory: ~cs538-1/public/handin/proj4/your-login. Each file should include a comment that contains

- your name, your login

Be sure to make clear which of the three programs you have decided to implement.