Written Assignment 11
Due May 9, 2006

This assignment asks you to prepare written answers to questions on higher-order functions and garbage collection. Each of the questions has a short answer. You may discuss this assignment with other students and work on the problems together. However, your write-up should be your own individual work. *Please write the name of the account you are using for CS164* **and your section time** *on your homework.* Remember that written assignments are to be turned in either in class or in the CS164 homework box in 283 Soda by 12:30 PM on the due date.

1. Compute the following least upper bounds. Write undefined if undefined. (Note: $Int \leq Object$ and $String \leq Object$)
   (a) $Int \rightarrow Object \sqcup Object \rightarrow Int$
   (b) $Int \rightarrow String \sqcup String \rightarrow Int$
   (c) $Int \rightarrow String \sqcup Object \rightarrow Int$
   (d) $(Object \rightarrow Object) \rightarrow String \sqcup Object \rightarrow Int$
   (e) $(String \rightarrow Int) \rightarrow (Object \rightarrow Int) \sqcup (Int \rightarrow Object) \rightarrow (Int \rightarrow String)$
2. Prove the following statement: for any T, the set of upper bounds of T, i.e., $\{T' \mid T \leq T'\}$, is finite. (Recall that the syntax of types is $T ::= C \mid T \rightarrow T$ where C is a class appearing in the program.)
3. Consider the following simple model for estimating the cost of garbage collection (GC). We divide running time into time spent actually running the user's program (which is useful work), and time spent in GC (which is overhead).
   - The number of cycles required for a single GC is equal to the number of different memory words that GC references. That is, even if a GC touches a particular word of memory more than once, we only charge 1 cycle.
   - The *survival rate* is the amount of the live data after a GC, expressed as a fraction of the total heap size. For example, if garbage collecting a 10MB heap leaves 1MB of live data, then the survival rate is 0.1.
   - A user program allocates 1 word of heap for every 10 cycles of time the user program is running (i.e., not doing GC).

   Given a survival rate s and a total heap size n (measured in words), give formulas for the fraction of total execution time spent in garbage collection for Stop-and-Copy and for Mark-and-Sweep. Assume the program runs for a long time—that is, we are interested in steady-state performance.