CS 553 Compiler Construction	**Final Examination**
Fall 2006	**December 14, 2006**

Name:

Please put your name on every sheet. The total number of possible points is 100. **Please think before you write,** so that your answers can be brief and fit in the space provided.

Total points: 100, 25% of course grade, Good luck!

1. [10 points] Data-Flow Analysis. Questions associated with the following program are on the next page.

	LIVEIN	**LIVEOUT**
`y = ...`		
`t = ...`		
`a = 3 + t`		
`b = a`		
`c = a`		
`x = 40`		
`if (y<x) goto L1`		
`z = y + c`		
`x = b + 30`		
`goto L2`		
`L1:`		
`z = y + 30`		
`L2:`		
`t = z + x`		

(a) Draw the control-flow graph for the problem 1 program superimposed over the existing statements. Put each statement in its own node.

(b) Perform live variable analysis on the problem 1 program. Indicate the LIVEIN and LIVEOUT set for each statement. Use the following data-flow equations:

$$LIVEOUT[n] = \cup_{s \in succ[n]} LIVEIN[s]$$
$$LIVEIN[n] = gen[n] \cup (LIVEOUT[n] - kill[n])$$

(c) In your own words, what are the $succ[n]$, $gen[n]$ and $kill[n]$ sets?

2. [20 points] Alias Analysis

FSCS **FICS**

```
    int g;

    main() {
      int **a, **b, *c, *d, e, f, *r, *s;

S1    c = &e;

S2    d = &f;

S3    a = &c;

S4    b = &d;

S5    r = bar( a );

S6    s = bar( &d );

    }


    int* bar(int **z) {
      int  *q;

S7    q = *z;

S8    q = &g;

S9    return q;
    }
```

For the above program, perform flow-sensitive, context-sensitive alias analysis (FSCS) and flow-insensitive, context-sensitive alias analysis (FICS). Showing you work will help in the assignment of partial credit.

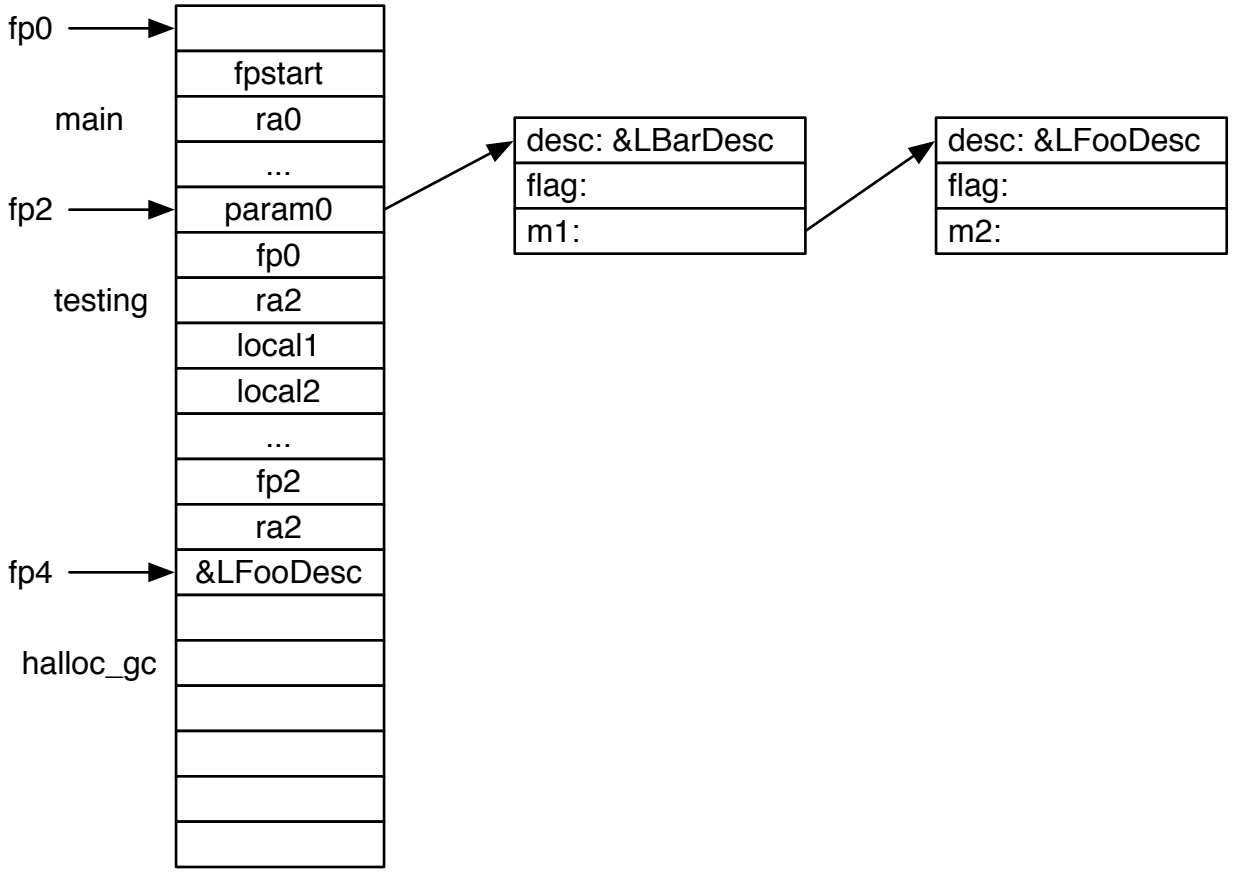
(a) For FSCS, what is the points-to set for variables `r` and `s` after statement S6?

(b) For FICS, what is the points-to set for variables `r` and `s` in the `main` function?

3. [20 points] Garbage Collection

```
class GC2 {
    public static void main(String[] a) {
        System.out.println(new Bar().testing()); }}  // call 1, call 2, call3

    class Bar {
        Foo m1;
        public int testing() {
            Bar local1;
            Foo local2;

            m1 = new Foo;    // call 4

            m1.m2 = this;

            local1 = new Bar;    // call 5

            local2 = new Foo;    // call 6
    }

    class Foo {
      Bar m2;
    }

##### Some of the generated MIPS
    .data
LptrmapC1:
    .word 0
    .word LretC1
    .word 0
    .word 0
LptrmapC2:
    .word LptrmapC1
    .word LretC2
    .word 0
    .word 0
LptrmapC3:
    .word LptrmapC2
    .word LretC3
    .word 0
    .word 0
LptrmapC4:
    .word LptrmapC3
    .word LretC4
```

```
    .word 3
    .word LptrmapC4data
LptrmapC4data:
    .word 1     # parameter 0 is a ptr
    .word 1     # local1 is a ptr
    .word 1     # local2 is a ptr
LptrmapC5:
    .word LptrmapC4
    .word LretC5
    .word 3
    .word LptrmapC5data
LptrmapC5data:
    .word 1     # parameter 0 is a ptr
    .word 1     # local1 is a ptr
    .word 1     # local2 is a ptr
LptrmapC6:
    .word LptrmapC5
    .word LretC6
    .word 3
    .word LptrmapC6data
LptrmapC6data:
    .word 1     # parameter 0 is a ptr
    .word 1     # local1 is a ptr
    .word 1     # local2 is a ptr


LFooDesc:
    .word 1
    .word LFooDescData
LFooDescData:
    .word 1
LBarDesc:
    .word 1
    .word LBarDescData
LBarDescData:
    .word 1
```



(a) What is the root set for garbage collection? Describe it in general and indicate the root set for the stack shown. The given stack shows the state at the end of call 4.

(b) All class instances require a 4 byte descriptor pointer and 4 byte flag field in addition to any member variables. Assuming a heap size of 30 bytes, which call site in the problem 3 program will result in the garbage collector being called?

(c) Will the garbage collection be successful? In other words, will there be any locations put on the free list? Why or why not?

4. [25 points] Data dependence analysis and unimodular transformations

```
for (i=0; i<N; i++) {
  for (j=0; j<M; j++) {
    A[i] = B[ j+3][ i-2 ] - 99;
    B[ j+1][ i ]  = x + y * i;
  }
}
```

(a) For the above program, what is direction vector for the output dependence? (Hint: Recall that $(*, <), (*, =)$, and $(*, >)$ are not legal dependence vectors.)

(b) For the above program, what is the distance vector for the flow dependence?

(c) What is the unimodular transformation matrix that specifies a permutation of the `i` and `j` loops in the program for problem 4?

(d) Is the problem 4 loop fully permutable? Why or why not?

5. [15 points] Loop Fission and the Kelly and Pugh Transformation Framework

(a) Show whether loop fission is legal or illegal for the following program using the K&P transformation framework.

```
for (i=0; i<N; i++) {
    A[ i ] = ... ;
    ... = A[ i - 1 ];
}
```

(b) Show whether loop fission is legal or illegal for the following program using the K&P transformation framework.

```
for (i=0; i<N; i++) {
    A[ i ] = ... ;
    ... = A[ i + 2 ];
}
```

6. [10 points] Tiling

(a) For this loop,

```
for (i=0; i<N; i++) {
  for (j=0; j<i; j++) {
    A[ i ][ j ] = ... ;
    ... = A[ i - 1 ][ j+1 ];
  }
}
```

is the following tiling transformation legal? (Hint: You don't have to use the K&P framework to show tiling legality for this example.)

$$\{[1, i, 1, j, 1] \rightarrow [1, ii', 1, jj', 1, i', 1, j', 1] \mid (ii' = i/3) \wedge (jj' = j/4) \wedge (i' = i) \wedge (j' = j)\}$$
$$\cup\{[1, i, 1, j, 2] \rightarrow [1, ii', 1, jj', 1, i', 1, j', 2] \mid (ii' = i/3) \wedge (jj' = j/4) \wedge (i' = i) \wedge (j' = j)\}$$

Why or why not?

(b) For this loop,

```
for (i=0; i<N; i++) {
  for (j=0; j<i; j++) {
    A[ i ][ j ] = ... ;
    ... = A[ i - 1 ][ j-2 ];
  }
}
```

is the following tiling transformation legal? (Hint: You don't have to use the K&P framework to show tiling legality for this example.)

$$\{[1, i, 1, j, 1] \rightarrow [1, ii', 1, jj', 1, i', 1, j', 1] \mid (ii' = i/3) \wedge (jj' = j/4) \wedge (i' = i) \wedge (j' = j)\}$$
$$\cup\{[1, i, 1, j, 2] \rightarrow [1, ii', 1, jj', 1, i', 1, j', 2] \mid (ii' = i/3) \wedge (jj' = j/4) \wedge (i' = i) \wedge (j' = j)\}$$

Why or why not?

7. [5 points extra credit] Suggest a project for next year's CS 553 that is different from the projects you were assigned or asked about in the homeworks.

   (a) Describe the project in one paragraph.

   (b) What concept will the students learn in more depth by doing the project?

   (c) What experimental results should be presented in the project report?