**Name:**

# Midterm 2

CMSC 430
Introduction to Compilers
Fall 2015

November 11, 2015

## Instructions

**This exam contains 8 pages, including this one. Make sure you have all the pages. Write your name on the top of this page before starting the exam.**

Write your answers on the exam sheets. If you finish at least 15 minutes early, bring your exam to the front when you are finished; otherwise, wait until the end of the exam to turn it in. Please be as quiet as possible.

If you have a question, raise your hand. If you feel an exam question assumes something that is not written, write it down on your exam sheet. Barring some unforeseen error on the exam, however, you shouldn't need to do this at all, so be careful when making assumptions.

| Question | Score | Max |
|---|---|---|
| 1 | | 20 |
| 2 | | 30 |
| 3 | | 20 |
| 4 | | 30 |
| Total | | 100 |

**Question 1. Short Answer (20 points).**

**a. (5 points)** Briefly describe what a *basic block* is.

**b. (5 points)** Are the kinds of optimizations discussed in class guaranteed to make programs go faster? Explain briefly.

**c. (5 points)** List three distinct items that might be part of a function's *activation record* or *stack frame*.

**d. (5 points)** Briefly explain the relationship between an interpreter and a symbolic executor.

**Question 2. Code Generation (30 points).** Below is code from `06-codegen-2.ml`, showing the input expression language and part of the compiler. We've eliminated global variables since they're not needed for this problem.

```
type expr =
  | EInt of int
  | EAdd of expr * expr
  | EMul of expr * expr
  | ESeq of expr * expr
  | EIfZero of expr * expr * expr

type reg = [ `Reg of int ]
type src = [ `Int of int ]

type instr =
  | ILoad of reg * src          (* dst, src *)
  | IAdd of reg * reg * reg     (* dst, src1, src2 *)
  | IMul of reg * reg * reg     (* dst, src1, src2 *)
  | IIfZero of reg * int        (* guard, target *)
  | IJmp of int                 (* target *)
  | IMov of reg * reg           (* dst, src *)
```

```
let rec comp_expr = function
  | EInt n ->
      let r = next_reg () in
        (r, [ILoad (`L_Register r, `L_Int n)])
  | ...
  | EIfZero (e1, e2, e3) ->
      let (r1, p1) = comp_expr e1 in
      let (r2, p2) = comp_expr e2 in
      let (r3, p3) = comp_expr e3 in
      let r = next_reg () in
        (r, p1 @
            [IIfZero (`L_Register r1, (2 + (List.length p3)))] @
            p3 @
            [IMov (`L_Register r, `L_Register r3);
             IJmp (1 + (List.length p2))] @
            p2 @
            [IMov (`L_Register r, `L_Register r2)]
        )
```

**a. (10 points)** Suppose we add a construct `EDoWhile(e1, e2)` that executes `e1` while `e2` in non-zero and terminates, returning `0`, when `e2` becomes `0`. (Note this means `e1` will always be executed at least once.) Add a case to `comp_expr` for compiling `EDoWhile`.

```
let rec comp_expr = function
  ...
  | EDoWhile (e1, e2) ->
```

**b. (5 points)** Suppose we extend the language with *local variables*. We add `ELocRd(x)` to indicate a read of local variable `x`, where `x` is a string, and `ELocWr(x, e)` to indicate writing the value of expression `e` to local variable `x`.

Fill in the missing code of the following function `vars_of : expr -> string list` so it returns a list of the variables used in an expression. Assume you have a function `uniq : string list -> string list` that returns its input list with duplicates removed.

```
let rec vars_of' = function

| EInt _ ->

| EAdd (e1, e2) | ESub (e1, e2) | EMul (e1, e2)

| ESeq (e1, e2) | EDoWhile (e1, e2) ->

| ELocRd x ->

| ELocWr (x, e) ->

| EIfZero (e1, e2, e3) ->


let vars_of e =
```

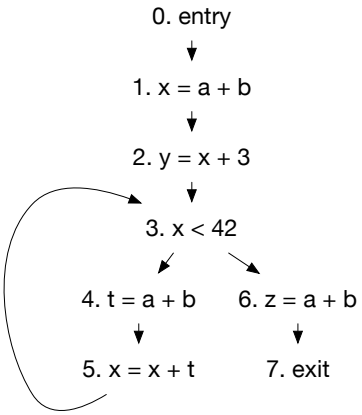
**c. (15 points)** Using `vars_of`, write a new function `comp : expr -> instr list` that builds a symbol table for the expression and then calls `comp_expr` to compile it using that symbol table. (Note this may be a slightly different approach for locals than you took in Project 4.) Also modify the signature of `comp_expr` appropriately and write down the cases for `ELocRd` and `ELocWr` in `comp_expr`. (You don't need to modify the other cases of `comp_expr` to match the new signature.)

**Question 3. De-Optimization (20 points).** Each RubeVM program on the left has had one (and only one) optimization applied to it, as indicated. Write a corresponding program on the right that shows the program *before* the optimization was applied.

| Optimized | De-optimized (original) code |
|---|---|
| Common subexpression elimination<br><br>`const r0, 42`<br>`const r1, 13`<br>`add r2, r0, r1`<br>`mov r3, r2` | |
| Copy propagation<br><br>`const r0, 42`<br>`add r1, r0, r0`<br>`mov r2, r1`<br>`add r3, r1, r1`<br>`mov r4, r1` | |
| Constant Folding<br><br>`const r0, 42`<br>`mk_tab r1`<br>`const r2, 84`<br>`wr_tab r1, r0, r2` | |
| Dead code elimination<br><br>`mk_tab r0`<br>`const r1, "a"`<br>`const r3, 1`<br>`wr_tab r0, r1, r3` | |
| Loop invariant code motion<br><br>`const r0, 5`<br>`const r1, 10`<br>`if_zero r0, 2`<br>`sub r0, r0, r1`<br>`jmp -3` | |

**Question 4. Data Flow Analysis (30 points).**

**a. (20 points)** In the following table, show each iteration of *available expressions* for the control-flow graph on the right. For each iteration, list the statement taken from the worklist in that step, the value of *out* computed for that statement, and the new worklist at the end of the iteration. You may or may not need all the iterations; you may also add more iterations if needed. Assume `x<42` is *not* a possible available expression, and do not add the exit node to the worklist.




Use $\emptyset$ for the set of no expressions, and $\top$ for the set of all expressions. What is $\top$?

$\top =$ [ ]

What are the initial *out*'s for each statement?

| **Stmt** | **0** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|---|
| Initial *out* | | | | | | | |

| **Iteration** | **0** | **1** | **2** | **3** | **4** |
|---|---|---|---|---|---|
| Stmt taken from worklist | N/A | 1 | | | |
| *Out* of taken stmt | N/A | a+b | | | |
| New worklist | 1,2,3,4,5,6 | 2,3,4,5,6 | | | |

| **Iteration** | **5** | **6** | **7** | **8** | **9** |
|---|---|---|---|---|---|
| Stmt taken from worklist | | | | | |
| *Out* of taken stmt | | | | | |
| New worklist | | | | | |

| **Iteration** | **10** | **11** | **12** | **13** | **14** |
|---|---|---|---|---|---|
| Stmt taken from worklist | | | | | |
| *Out* of taken stmt | | | | | |
| New worklist | | | | | |

**b. (10 points)** Write the gen and kill sets for the two analyses and statements shown below. Assume the set of expressions is {x+y, x+1, a+1, b+1}, and the set of variables is {a, b, x, y}. Write $\emptyset$ for an empty gen or kill set.

| | Live vars | | Very busy exprs | |
|---|---|---|---|---|
| stmt | gen | kill | gen | kill |
| a := x + y | | | | |
| a := b | | | | |
| x := x + 1 | | | | |