

## 2009 Paper 9 Question 10

### Optimising Compilers

Given a flowgraph  $G$  representing a function  $f$  having parameters  $(x_1, \dots, x_k)$ , we are interested in when and how its parameters are used, in particular when we can guarantee that one or more of its variables are read during its execution. You may assume  $G$  has conditionals, assignment and arithmetic operators but no function calls.

(a) Representing dataflow properties as the set of variables that must inevitably be read when execution starts at node  $n$ , give dataflow equations for the sets  $mustuse(n)$ . [4 marks]

(b) Now, supposing this analysis is not precise enough for our needs, we refine the dataflow properties to be  $mustuseoneof(n)$ —the set of sets of variables so that, for example,  $\{\{v_1, v_2\}, \{v_3\}\}$  means that “every path starting at  $n$  must either read  $v_3$  or read both  $v_1$  and  $v_2$ ; no other possibility exists”. Give dataflow equations for  $mustuseoneof(n)$ . [Hint: you may need to generalise the traditional  $(\dots \setminus kill_n \cup gen_n)$  to e.g.  $gen_n(kill_n(\dots))$ .] [4 marks]

(c) Assuming that  $n_0$  is the entry node of  $G$  and that the values of its arguments have already been stored in its parameters  $(x_1, \dots, x_k)$ , relate  $mustuseoneof(n_0)$  to the strictness function  $f^\#$  corresponding to  $f$ . For this purpose you may now assume  $G$  to be appropriately restricted for a lazy functional language (e.g. assignments only corresponding to initialisations). Your answer should include

(i) a map from sets of sets of variables to Boolean functions, discussing whether this is injective;

(ii) the difference between  $\{\}$  and  $\{\{\}\}$  ;

(iii) remarking on any way in which the correspondence is not perfect.

[8 marks]

(d) Now suppose we add function calls, each summarised by a  $mustuseoneof$  set, how might we deal with the dataflow of (say)  $z = h(x-1, y+1)$  assuming lazy semantics? Suppose  $f$  now has a recursive call, for example

$$f(x, y) = \text{if } x=0 \text{ then } y \text{ else } f(x-1, y+1)$$

explain what you expect the  $mustuseoneof$  set for the body of  $f$  to be and how this might be achieved by iterating from a given initial set. [4 marks]