Exame Recurso 2022

1

Problem 1. Run-Time Environments [10 points]
In the PASCAL language one can define functions and procedures that are local to other procedures, *i.e.,* they are only visible within the scope of that immediately enclosing procedure. This is analogous to the use of nested blocks in the C language. For example, in the code below procedure `f3` is only visible inside the code of procedure `f2`. But neither inside the code of `f1` nor inside the procedure `main`.

```
01:  procedure main
02:    integer a, b, c;
03:    procedure f1(a,b);
04:      integer a, b;
05:      call f2(0,b,a);
06:    end;
07:    procedure f2(x,y,z);
08:      integer x, y, z;
09:      procedure f3(m,n);
10:          integer m, n;
11:          ...
12:      end;
13:      procedure f4(m,n);
14:        integer m, n;
15:          ...
16:      end;
17:      call f3(y,z);
18:      call f4(c,x);
19:    end;
20:  ...
21:  call f1(a,b);
22:  end;
```

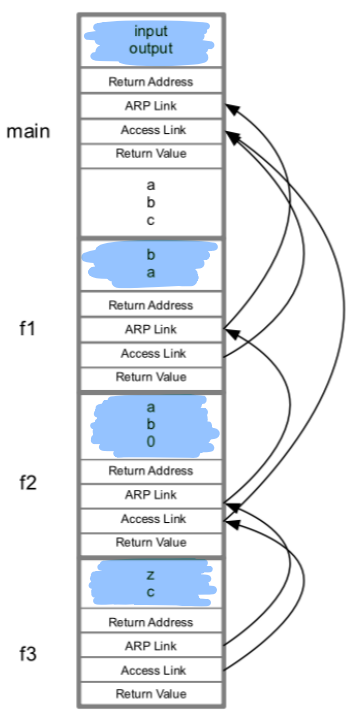
For this code answer the following questions:

a) On line `17` and `18`, which variables are used as the actual values of the parameters of both calls to `f3` and `f4` respectively.
b) Draw (using simplified Activation Records layout) when the control flow of the program reaches line `11` (i.e., inside procedure `f3`). Draw the links regarding the ARs and the Access Links used to access non-local variables. Explain how the compiler can generate code to access the local variable x of the procedure `f2` in the body of procedure `f3`.

a) - f3 Call uses y and z as parameters, and these two are local variables to f2.

- f4 call uses c and x as parameters. x is a local variable to f2 and c is a local variable to main.

b)



In line 11 of the program, we don't need to represent f4, because the program didn't reached his point yet.

Access Links point to the procedure that have local variables that we might want to access. f2 has the access link pointed to the main because the main is his generator.

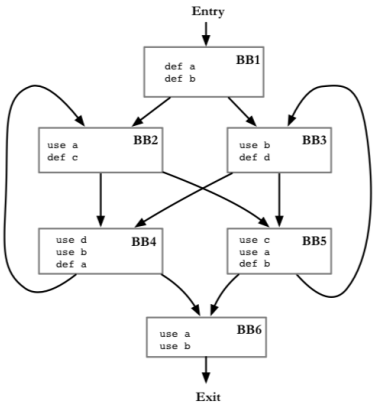
The parameters of each procedure are represented in the blue sections.

The ARP Links point to the ARP Links of their Caller's.

2

Problem 2. Control-Flow Analysis and Register Allocation [20 points]

Consider the CFG as shown below corresponding to a procedure with local variables a, b, c and d.



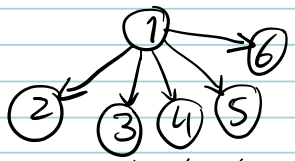
For this code determine the following:

a. [05 points] Dominator tree and the natural loops in this code (if any) along with the corresponding back edge(s).

b. [10 points] Determine the DU-chains and the corresponding webs for the variables a, b, c and d, as well as the corresponding interference graph.

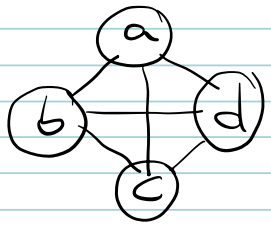
c. [05 points] Can you color the resulting interference graphs with 2 colors? If you cannot, suggest and present the rationale for a strategy that will reduce the connectivity of the corresponding interference graph so that it becomes 2-colorable.

a)



There are no back edges, so there are no natural loops.

b) a and b cover the entire CFG. For c and d, they encompass the basic blocks 2,3 and 4 for d and 2,3,5 for c.

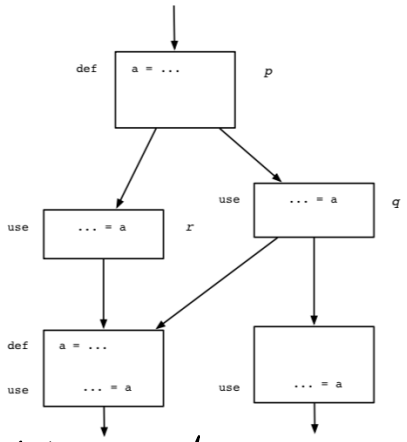


c) The interference graph is a clique of size 4, as a result, we need 4 colors to color this graph. One strategy to reduce the number of colors needed is not assign registers to the variables c and d as this variables have live ranges with minor lengths, having a number of references possibly smaller than a and b. This rationale is based on the first "global allocation algorithm" and if explicit memory references are inserted, then, ideally in terms of the dynamic execution of the code, the number of memory accesses is smaller than they would be if we were to choose variables a and b.

③

Problem 3: Iterative Data-Flow Analysis [20 points]

In class we discussed the Live-Variable Analysis problem, where one variable is said to be live at program point *p*, if its value is used along some control-flow path from *p*. In other word, the value of the variable at p can be used in another point *q* without being possibly redefined. In the example below, we say that the variable *a* is live at *p* because there is a control-flow path starting at *p* where the current value of *a* is still possibly used (in this case at *q*). Conversely, the same variable is dead at *r* since its value is no longer used beyond that point as the variable *a* is redefined in all the control-flow paths beyond *r*.



Regarding this data-flow analysis problem answer the following:

a. [05 points] What is the set of values in the corresponding lattice and the initial values?

b. [05 points] What is the direction of the problem, backwards or forward and why?

c. [05 points] What is the basic block transfer function for this data-flow problem, i.e., the GEN and KILL and the equations the iterative approach needs to solve?

d. [05 points] At control-flow merge points, what is the meet operator, and why?

a) Lattice values consist of unordered sets of variables. All blocks initialize their IN values to the empty set.

b) The direction of the problem is backwards, because we can formulate this problem defining the input values as a function of the output values of each basic block. The information that a variable is still alive can be propagated backwards in the control flow revealing that a given variable is still needed in the future. This need is eliminated at the point where the variable is defined. The variable is dead before that definition. On merge of control-flow paths (backwards) a variable is alive if at least in one of the paths the variable is alive, which suggests that the merge function is the union of the IN sets of the successors of a basic block.

c) As suggested in the description, the transfer function (basic block or instruction level) is defined by the following equations:

$OUT(B) = \cup\ IN(S)$, S being successor of B;

$IN(B) = Use(B) \cup (OUT(B) - Def(B))$

d) The merge is the Union, since the problem clearly states that a variable is alive if there is at least one path along which the value of a given definition of the variable can still be used. Notice, that by initializing the IN values to the empty sets and using the Union function, the solutions of the equations can only grow and are limited by the size of the universe set that includes all the variables in the program.