CSE401: Analysis

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Analysis and transformation

- Each optimization is one or more analyses followed by a transformation
- Analyze CFG and/or DFG by propagating information forward or backward along CFG and/or DFG edges
  - Merges in graph require combining information
  - Loops in graph require iterative approximation
- Perform improving transformations based on information computed
  - Have to wait until any iterative approximation has converged
- Analysis must be conservative, so that transformations preserve program behavior

A simple analysis

- Let's start with a simple analysis that can help us determine which assignments can be eliminated from a basic block
- The example is unreasonable as source, but perhaps not as intermediate code

```
proc foo(j, k, l:int):int
begin
  int a, b, c, n, x;
  a := 17 * j;
  b := k * k;
  c := a + b;
  a := k * 7;
  return c;
end
```


Liveness analysis

- This analysis is a form of liveness analysis
  - It can help identify assignments to remove
  - It can also form the basis for memory and register optimizations
- The goal is to identify which variables are *live* and which are *dead* at given program points
- The analysis is usually performed backwards
  - When a variable is used, it becomes lives in that statement and code before it
  - When a variable is assigned to, it becomes dead for all code before it
- Note the relationship to def-use, as we saw in the data flow graph

Work backwards

	Live	Dead
`proc foo(j, k, l:int):int`		
`begin`		
`int a, b, c, n, x;`		
`a := 17 * j;`	?	?
`b := k * k;`	?	?
`c := a + b;`	{k,l,a,b,c}	{j,n,x}
`a := k * 7;`	{k,l,c}	{j,n,x,a,b}
`return c;`	{c}	{j,k,l,n, x,a,b}
`end`		

So?

- This analysis shows we can eliminate the last assignment to `a`, which is no surprise
- Technically, assignments to a dead variable can be removed
  - The value isn't needed below, so why do the assignment?
- Furthermore, you could show for this example that the declarations for `n` and `x` aren't needed, since `n` nor `x` is ever live

Then…

- After eliminating the last assignment (and these two declarations), you can redo the analysis
- This analysis now shows that `l` is dead everywhere in the block, and it can be removed as a parameter
- The stack can be reduced because of this
- And the caller could, in principle, be further optimized

Well, that was easy

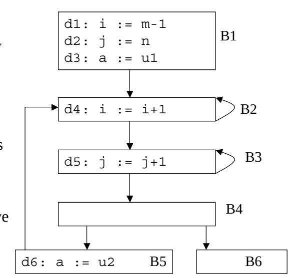
- But that's for basic blocks
- Once we have control flow, it's much harder to do because we don't know the order in which the basic blocks will execute
- We need to ensure (for optimization) that every possible path is accounted for, since we must make conservative assumptions to guarantee that the optimized code always works

Global data flow analysis

- We're going to need something called global data flow analysis
- The form we're interested in for live variable analysis (across basic blocks) is *any-path* analysis
  - An any-path property is true is there exists some path through the control flow graph such that the given property holds
    - For example, a variable is live if there is some path leading to it being accessed
    - For example, a variable is uninitialized if there is some path that does not initialize it
- All-path is the other major form of analysis

Example (Dragon, p. 609)

- Let's now consider this analysis over a control flow graph
  - Basic blocks connected by edges showing possible control flow
  - We will omit the conditionals and labels on edges, since that's fine for any-path analysis
  - This is extremely conservative (safe)



Some more terminology

- A *definition* of a variable `x` is a statement that assigns a value to `x`
  - (The book discussed unambiguous vs. ambiguous definitions, but we'll ignore this)
- A definition `d` reaches a program point `p` if
  - There is a path from the point immediately following `d` to `p`
  - And `d` is not killed along that path
- We're now really giving formal definitions to these terms, but we've used them before

Examples

- `d1`, `d2`, `d5` reach the beginning of B2
- `d2` does not reach B4, B5, or B6
- Note: this is a conservative analysis, since it may determine that a definition reaches a point even if it might not in practice

But how to compute in general?

- We'd like to be able to compute all reaching definitions (for example)
- Let's consider a simple language
  - It turns out to be very material
  - Complex languages impose really serious demands on data flow analysis
- S ::= **id :=** E | S **;** S | **if** E **then** S **else** S | **do** S **while** E
  E ::= **id + id** | **id**

Data flow equations

- We're now going to define a set of equations that represent the flow through different constructs in the language
- For example
  - out[S] = gen[S] ∪ (in[S] – kill[S])
  - "The information at the end of S is either generated within the statement (gen(S)) or enters at the beginning of the statement (in(S)) and is not killed by the statement (-kill(S))"

Example: d: `a := b+c`

- gen[S] = {d}
- kill[S] = D_a – {d}
- out[S] = gen[S] ∪ (in[S] – kill[S])

- D_a is the set of all definitions in the program for variable a

Example: S1 ; S2

- gen[S] = gen[S2] ∪ (gen[S1] – kill[S2])
- kill[S] = kill[S2] ∪ (kill[S1] – gen[S2])
- in[S1] = in[S]
- in[S2] = out[S1]
- out[S] = out[S2]

Example: if E then S1 else S2 fi

- gen[S] = gen[S1] ∪ gen[S2]
- kill[S] = kill[S1] ∩ kill[S2]
- in[S1] = in[S]
- in[S2] = in[S]
- out[S] = out[S1] ∪ out[S2]

Example: while E do S1

- gen[S] = gen[S1]
- kill[S] = kill[S1]
- in[S1] = in[S] ∪ gen[S1]
- out[S] = out[S1]

Then what?

- In essence, this defines a set of rules by which we can write down the relationships for gen/kill and in/out for a whole (structured) program
- This defines a set of equations that then need to be solved
- This solution can be complicated
  - We don't know if/when branches are taken
  - Loops introduce complications
  - Merges introduce complications
- Approaches to solutions: next lecture