

CSC2/455 Software Analysis and Improvement

Available Expressions, Reaching Definitions, Very Busy Expressions

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January 30, 2023

URCS

Outline

Review

Available Expressions Analysis

The Data Flow Analysis Framework

Reaching Definitions Analysis

Very Busy Expressions (Anticipable expressions)

Postscript

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Data flow Analysis so far

- Live variable analysis
 - “Is there a read of this variable along any path?”
- Data flow equations
 - DEF and USE (or UE)
- Iterative data flow analysis
- A brief look at quality of solutions
 - Path-based vs Iterative

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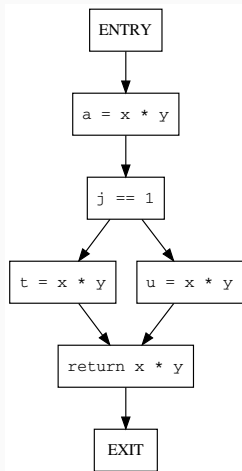
Postscript

Goals

- Identify repeated calculations of the same expression (analysis)
- Remove these repeated calculations (optimization)

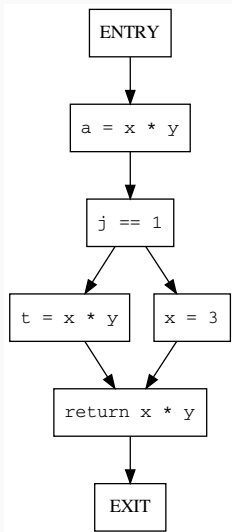
Example 1

```
a = x * y;  
  
if(j == 1) {  
    t = x * y;  
} else {  
    u = x * y;  
}  
  
return x * y;
```



Example 2

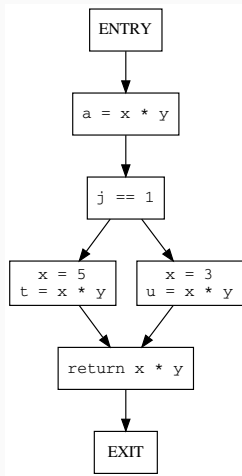
```
a = x * y;  
  
if(j == 1) {  
    t = x * y;  
} else {  
    x = 3;  
}  
  
return x * y;
```



Example 3

Is $x * y$ available at the return statement?

```
a = x * y;
if(j == 1) {
  x = 5;
  t = x * y;
} else {
  x = 3;
  u = x * y;
}
return x * y;
```



Definition

An expression e is available at a program point p iff:

- it has been calculated previously
 - these can be distinct calculations
- *all* paths from ENTRY to p contain the calculation
- no subexpression of e has been modified along these paths

Informally: Can we reuse the value computed previously by an expression instead of recalculating it?

Differences from LIVE

- What are the similarities from LIVE variable analysis?
- What are the differences from LIVE variable analysis?

Dataflow Equations: Basic Block

- $GEN(n)$
 - a block n generates these expressions
- $KILL(n)$
 - a block n *kills* these expressions

Dataflow Equations: Incorporating Flow

- How does information flow for AVAIL?
 - Does a basic block incorporate information from its predecessors?
 - Or its successors?
- How do we “merge” information from multiple source blocks?

$$\text{AVAIL_IN}(n) = ?$$

Dataflow Equations: Incorporating Flow

- Information flows *forwards*
- Only expressions common to all *all* paths are available
 - Note: Live variables needed *any* path

The Dataflow Equation

$$\text{AVAIL_IN}(n) = \bigcap_{m \in \text{pred}(n)} \text{GEN}(m) \cup (\text{AVAIL_IN}(m) - \text{KILL}(m))$$

Initialization

- $AVAIL_IN(ENTRY) = \emptyset$
- $AVAIL_IN(n) = \{\text{all expressions}\}$

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Building Blocks

- How to generate basic block facts
 - GEN (facts generated by this basic block)
 - KILL (facts killed by this basic block)
- How to merge facts across basic blocks
 - Use a control-flow graph to abstract control flow
 - Direction: forwards/backwards
 - Path requirement: “may” (any) or “must” (all)
 - Determines whether you obtain facts from predecessors or successors, and whether you use union or intersection
 - End goal: a data flow equation for each basic block that needs to be solved
- How to determine initial values
 - Usually analysis specific
- How to solve: iteration until fix point is reached
 - Other methods possible (later in course)

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Example

(Note: The #n notation identifies a definition)

```
y#0 = 0;
x#0 = 1995;

if(y == 0) {
    x#1 = 2000;
    y#1 = 50;
} else {
    x#2 = 3000;
}
a#0 = x + y;
```

Here, the value of y in the last line comes from $y\#0$ or $y\#1$, while the value of x comes from $x\#1$ or $x\#2$.

Definition

A definition of variable x at a point p reaches the use of x at a point q iff: there is a path from p to q along which x is not redefined.

Setting up the framework

- What is the domain of the set of dataflow facts?
- What are the basic block facts (i.e. GEN and KILL)?
- How does information flow?
- How is information merged?

Setting up the framework

- What is the domain of the set of dataflow facts?
 - The definitions
- What are the basic block facts (i.e. GEN and KILL)?
 - GEN is the set of definitions
 - KILL is the set of definitions
- How does information flow?
 - From a block's predecessors to it
- How is information merged?
 - Union

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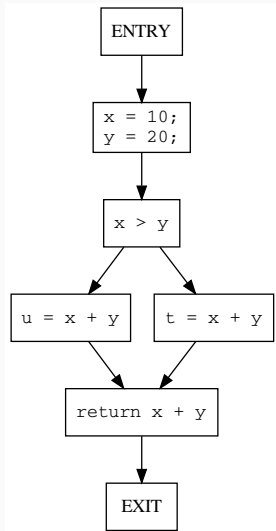
Example

```
x = 10;
y = 20;

if(x > y) {
    u = x + y;
} else {
    t = x + y;
}

return x + y;
```

- Can you move $x + y$ out of the `if` to (say) reduce code size?
- Where would you move it?
- What would AVAIL do here?



Definition

An expression e is *very busy* at the end of a basic block b iff:

- e is calculated on every path out of b ,
- e could be calculated in b without changing the results of calculating e in succeeding blocks

Note: e may not be currently calculated in b . Informally, we're trying to compute an expression earlier than it appears in the code *without* performing a redundant computation.

Setting up the framework

- What is the domain of the set of dataflow facts?
- What are the basic block facts (i.e. GEN and KILL)?
- How does information flow?
- How is information merged?

Setting up the framework

- What is the domain of the set of dataflow facts?
 - Expressions
- What are the basic block facts (i.e. GEN and KILL)?
 - GEN is the expressions evaluated in this block
 - KILL is the expressions redefined by this block
- How does information flow?
 - From the block's successors to it
- How is information merged?
 - Intersection

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References

- Chapter 9 of Cooper and Turczon
 - Section 9.2.4
- Also recommended (more detailed coverage here):
 - Aho, Lam, Sethi and Ullman, Chapter 9, Section 9.2.6 (Available Expressions)
 - Aho, Lam, Sethi and Ullman, Chapter 9, Section 9.2.4 (Reaching Definitions)