CSC2/455 Software Analysis and Improvement
Available Expressions, Reaching Definitions, Very Busy Expressions

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URCS
Outline

Review

Available Expressions Analysis

The Data Flow Analysis Framework

Reaching Definitions Analysis

Very Busy Expressions (Anticipable expressions)

Postscript
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Postscript
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
Goals

- Identify repeated calculations of the same expression (analysis)
- Remove these repeated calculations (optimization)
Example 1

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

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

return x * y;
Is $x \times y$ available at the return statement?

```plaintext
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?

$$AVAIL_{IN}(n) = ?$$
- Information flows *forwards*
- Only expressions common to all *all* paths are available
  - Note: Live variables needed *any* path
The Dataflow Equation

\[
AVAIL\_IN(n) = \bigcap_{m \in \text{pred}(n)} \text{GEN}(m) \cup (AVAIL\_IN(m) - \text{KILL}(m))
\]
• $\text{AVAIL}_\text{IN}(ENTRY) = \emptyset$
• $\text{AVAIL}_\text{IN}(n) = \{\text{all expressions}\}$
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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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Postscript
(Note: The #\text{n} notation identifies a definition)

\begin{verbatim}
y#0 = 0;
x#0 = 1995;

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

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 \( x#2 \).
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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Postscript
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?
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)