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
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
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Postscript
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?

```java
a = x * y;

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

return x * y;
```
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?
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
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?

\[ \text{AVAIL\_IN}(n) = ? \]
• Information flows *forwards*

• Only expressions common to *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

- $\text{AVAIL_IN}(ENTRY) = \emptyset$
- $\text{AVAIL_IN}(n) = \{\text{all expressions}\}$
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)
(Note: The \#n notation identifies a definition)

\[
\begin{align*}
  y\#0 &= 0; \\
  x\#0 &= 1995; \\
  \text{if}(y == 0) \{ \\
    &\quad x\#1 = 2000; \\
    &\quad y\#1 = 50; \\
  \} \quad \text{else} \{ \\
    &\quad x\#2 = 3000; \\
  \} \\
  a\#0 &= x + y;
\end{align*}
\]

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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Postscript
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)