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

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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
- Iterative data flow analysis
- A brief look at quality of solutions
  - Path-based vs Iterative
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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;
```
Example 2

\[
a = x \times y;
\]

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

return x \times y;

ENTRY

a = x \times y

EXIT

j == 1

t = x \times y  x = 3

return x \times y

EXIT
Example 3

Is \( x \times y \) available at the return statement?

\[
\begin{align*}
    &a = x \times y; \\
    &\text{if}(j == 1) \quad \{
    &x = 5; \\
    &t = x \times y;
    \} \quad \text{else} \quad \{
    &x = 3; \\
    &u = x \times y;
    \}
    \\
    &\text{return} \; x \times y;
\end{align*}
\]
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
How does information flow for AVAIL?

How do we “merge” information from multiple source blocks?

\[ \text{AVAIL}_{\text{IN}}(n) = ? \]
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

- \text{AVAIL\_IN}(ENTRY) = \emptyset
- \text{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)
Example

(Note: The \#n notation identifies a definition)

\[
y#0 = 0;
x#0 = 1995;
\]

\[
\text{if}(y == 0) \{ \\
\quad x#1 = 2000;\\n\quad y#1 = 50; \\
\} \text{ else } \{ \\
\quad x#2 = 3000; \\
\} \\
\]
\[
a#0 = x + y;
\]

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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Postscript
Example

\[x = 10;\]
\[y = 20;\]
\[\text{if}(x > y) \{\]
\[\quad u = x + y;\]
\[\} \text{ else } \{\]
\[\quad t = x + y;\]
\[\}
\[\text{return } x + y;\]

- 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.
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)