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
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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

```java
a = x * y;
if(j == 1) {
    t = x * y;
} else {
    x = 3;
}
return x * y;
```
Is \( x \times y \) available at the return statement?

\[
a = x \times y;
\]

\[
\text{if}(j == 1) \{ \\
\qquad x = 5; \\
\qquad t = x \times y; \\
\} \quad \text{else} \{ \\
\qquad x = 3; \\
\qquad u = x \times y; \\
\}
\]

\[
\text{return} \ x \times y;
\]
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

- $\text{GEN}(n)$
  - a block $n$ generates these expressions

- $\text{KILL}(n)$
  - 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?

$$\text{AVAIL\_IN}(n) = ?$$
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

\[ \text{AVAIL}_\text{IN}(n) = \bigcap_{m \in \text{pred}(n)} \text{GEN}(m) \cup (\text{AVAIL}_\text{IN}(m) - \text{KILL}(m)) \]
Initialization

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

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

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.
• 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
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?
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
• 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)