CSC2/455 Software Analysis and Improvement
Available Expressions

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Outline

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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
- Iterative data flow analysis

Outline

Goals

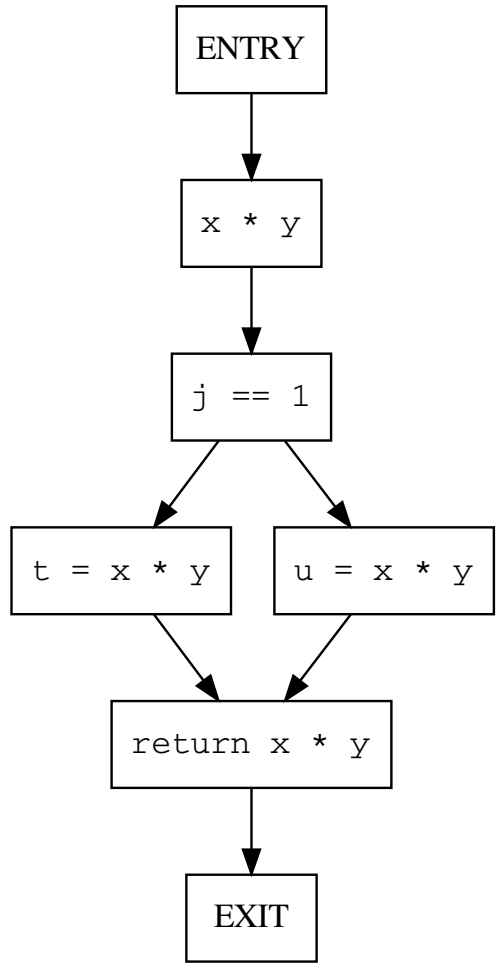
- Identify repeated calculations of the same expression
- Remove these repeated calculations (optimization)

Example 1

```
a = x * y;

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

return x * y;
```

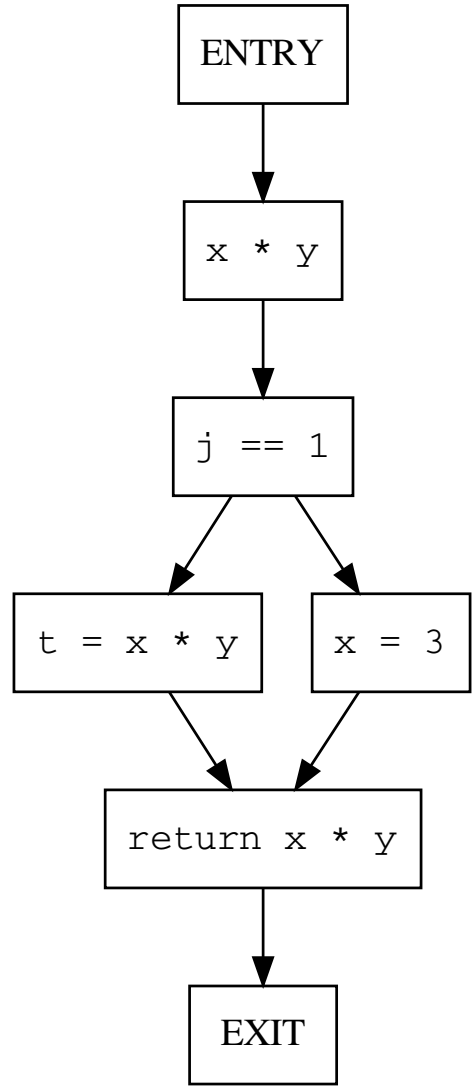


Example 2

```
a = x * y;

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

return x * y;
```



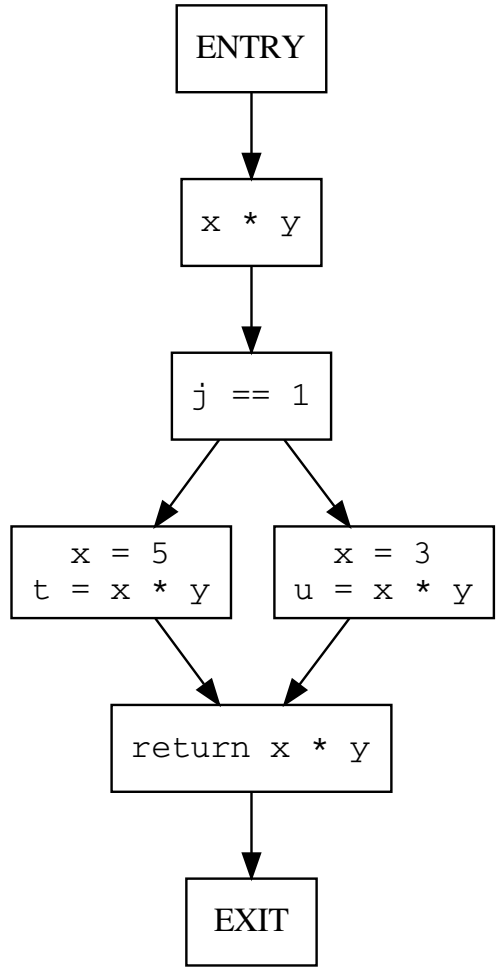
Example 3

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

- $\mathrm{GEN}(n)$
  - a block generates these expressions
- $\mathrm{KILL}(n)$
  - a block *kills* these expressions

Dataflow Equations: Incorporating Flow

- How does information flow for AVAIL?
- How do we "merge" information from multiple source blocks?

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

Dataflow Equations: Incorporating Flow

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

The Dataflow Equation

$$\text{AVAIL\_IN(n)} = \cap_{m \in \text{pred}(n)} \text{GEN}(m) \cup (\text{AVAIL\_IN}(m) - \text{KILL}(m))$$

Initialization

- $\text{AVAIL\_IN}(\mathit{ENTRY}) = \emptyset$
- $\text{AVAIL\_IN}(n) = \{\text{all expressions}\}$

Outline

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
  - 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)

Outline

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 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 set of dataflow facts?
  - The set of 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

Outline

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?

Definition

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

- it 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

Setting up the framework

- What is 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 set of dataflow facts?
  - The set of 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

Outline

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 (Avail)
  - Aho, Lam, Sethi and Ullman, Chapter 9, Section 9.2.4 (Reaching Definitions)