CSC2/455 Software Analysis and Improvement
Dead Code Elimination

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Outline

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So far

- Source code
- Three-address form
- Control-flow graphs
- SSA form
- Data flow analyses

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Definitions

- Dead code
  - *Useless operation*: Not externally visible
  - *Unreachable code*: Cannot be executed
- *Critical operation*: (Direct) "Useful operation"
  - Operation that computes return value
  - Operation that stores to memory (i.e. is externally visible)
  - Operation that performs I/O
  - ...

Two Steps: Step 1

- Find all directly useful operations and mark them
- Find all indirectly useful operations and mark them
  - I.e. those that feed into directly useful operations
- Iterate until all operations that ultimately feed into directly useful operations have been found and marked

Two Steps: Step 2

- Remove all operations that remain unmarked

Example #1

```
void swap(int *x, int *y) {
  int t;

  t = *x;
  *x = *y;
  *y = t;
}
```

Example #2

```
int min(int x, int y) {
  int r;

  if (x > y) {
    r = y;
  } else {
    r = x;
  }

  return r;
}
```

Example #2: 3AC

```
int min(int x, int y) {
  int r;
  int t;

  t = x > y;
  if(t == 0) goto L1;

  r = y;
  goto L2;

L1:
  r = x;

L2:
  return r;
}
```

Example #2: With useless operations removed

```
int min(int x, int y) {
  int r;

  r = y;
  r = x;

  return r;
}
```

- Marking and removing useless operations uses only dataflow information
- Must also preserve control flow (i.e. control dependences)
  - How to identify useful branches?

Handling Control Flow

- Assume all "jumps" (unconditional branches) are useful
  - i.e. `goto Lx`
- What about conditional branches?

Conditional Branches: Example

```
int first_N_sum(int N) {
    int s = 0;

    for(int i = 1; i <= N; i++)
        s = s + i;

    return N * (N + 1) / 2;
}
```

3AC code for conditional branches

```
int first_N_sum(int N) {
    int s = 0;
    int i, t;

    i = 1;
L1:
    t = i <= N;
    if(t == 0) goto L2;

    s = s + i;
    i++;
    goto L1;

L2:
    return N * (N + 1) / 2;
}
```

How do we recognize that the conditional branch is useless in this case?

GCC 8.2 for x86-64 (-O0)

```
first_N_sum(int):
        push    rbp
        mov     rbp, rsp
        mov     DWORD PTR [rbp-20], edi
        mov     DWORD PTR [rbp-4], 0        ; s = 0
        mov     DWORD PTR [rbp-8], 1        ; i = 1

.L3:
        mov     eax, DWORD PTR [rbp-8]
        cmp     eax, DWORD PTR [rbp-20]
        jg      .L2
        ; s = s + i
        mov     eax, DWORD PTR [rbp-8]
        add     DWORD PTR [rbp-4], eax
        add     DWORD PTR [rbp-8], 1
        jmp     .L3
.L2:
        mov     eax, DWORD PTR [rbp-20]
        add     eax, 1
        imul    eax, DWORD PTR [rbp-20]
        mov     edx, eax
        shr     edx, 31
        add     eax, edx
        sar     eax
        pop     rbp
        ret
```

GCC 8.2 for x86-64 (-O1)

```
first_N_sum(int):
        test    edi, edi
        jle     .L2
        lea     edx, [rdi+1]
        mov     eax, 1          ; i = 1
 .L3:
        add     eax, 1          ; i = i + 1
        cmp     eax, edx
        jne     .L3
 .L2:
        lea     eax, [rdi+1]
        imul    edi, eax
        mov     eax, edi
        shr     eax, 31
        add     eax, edi
        sar     eax
        ret
```

GCC 8.2 for x86-64 (-O2)

```
first_N_sum(int):
        lea     eax, [rdi+1]
        imul    edi, eax
        mov     eax, edi
        shr     eax, 31
        add     eax, edi
        sar     eax
        ret
```

All compiler output examples obtained using the Compiler Explorer.

Conditional Branches

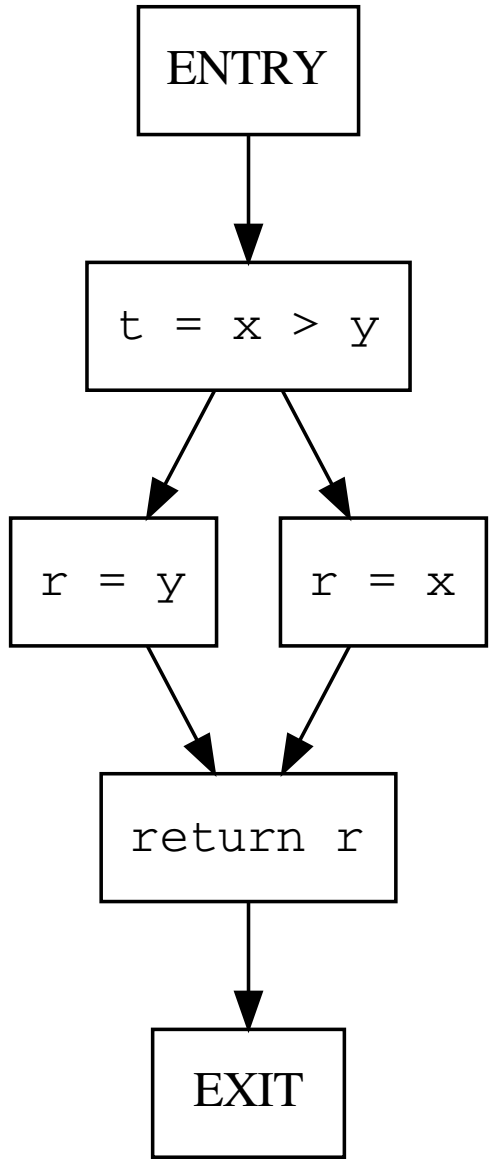
- A conditional branch is useful only if:
  - A useful operation depends on it
- Control dependence
  - (informal) an operation O is dependent on a branch B if the direction of the branch B affects if O is executed
  - CFG property

Example of control dependence

```
t = x > y
if(t == 0) goto L1

   r = y;
   goto L2;

L1:
   r = x;

L2:
   return r;
```

The assignments to `r` are dependent on `if(t == 0)`, but `return r` is not

Control dependence in the CFG



Control Dependence: Formal Definition

- Postdominance
  - A node n postdominates m if it occurs on all paths from m to EXIT
- A node k is control dependent on i if:
  - For a path $i \rightarrow j_0 \rightarrow j_1 \rightarrow ... \rightarrow k$, k postdominates all j_x
  - k does not strictly postdominate i

Marking unconditional branches useful

- If node k contains useful operations,
- And if k is control-dependent on node i,
- Then the (conditional) branch in i is useful.
- Operationalized as:
  - If block k contains useful operations
  - Mark all branches in k's *reverse dominance frontier* $\mathrm{RDF}(k)$ as useful
  - RDF computed as DF on *edge-reversed* CFG

Dead Code Elimination: High-level algorithm

- Mark all directly useful operations
- Repeat until convergence
  - Mark all indirectly useful operations
  - Mark all unconditional branches in RDFs of useful operations as useful
- Remove all unmarked operations
- Remove empty nodes in CFG / remove all useless control flow

See algorithms in Figure 10.1 and 10.2 in Turczon and Cooper.

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References

- Chapter 10 of Torczon and Cooper
  - Section 10.2