

CSC2/455 Software Analysis and Improvement

Dead Code Elimination

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URCS

Outline

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The Perils of DCE

Postscript

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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?

Aside: Converting Control Dependence to Data Dependence

Allen, Kennedy, Porterfield, Warren, “Conversion of Control Dependence to Data Dependence”, POPL (1983) *

- Required reading for 455

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

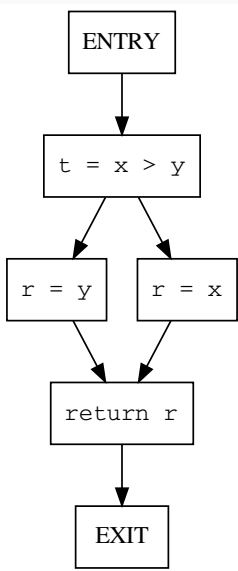
    r = y;
    goto L2;

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

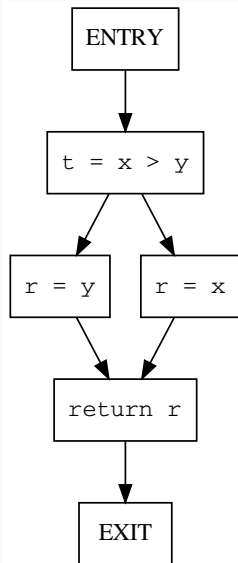


Control Dependence: Formal Definition

- 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 $i \rightarrow j_0 \rightarrow j_1 \rightarrow \dots \rightarrow k$, k postdominates all j_x
 - k does not strictly postdominate i

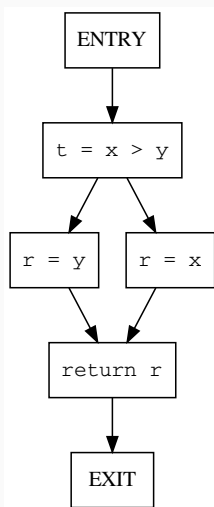
Control Dependence: Example #1

- Consider k : $r = y$
- Is it control dependent on i :
 $t = x > y$?
- Only one path $i \rightarrow k$
 - $r = y$ post-dominates $r = y$
 - $r = y$ does not strictly postdominate i
 - Because it is not a post-dominator of i , and $k \neq i$
- So k is control-dependent on i



Control Dependence: Example #2

- Now, consider k : return r
 - i is still $t = x > y$
- Two paths, first path
 $i \rightarrow j_0 \rightarrow k$
 - j_0 is $r = y$
 - return r post-dominates $r = y$ and itself
 - return r strictly postdominates i
 - Because it is a post-dominator of i , and $k \neq i$
- So k is *not* control-dependent on i

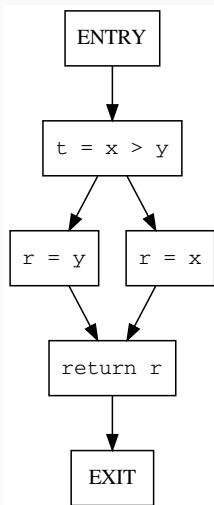


Path #2 of Example #2

- Second path is $i \rightarrow j_1 \rightarrow k$
 - j_1 is $x = x$
- Similar arguments show that k is not control-dependent on i

Using Reverse Dominance Frontiers (RDF)

- Given that return r is useful, so are $r = x$ and $r = y$
- We can see that $t = x > y$ is in the *reverse dominance frontier* (*RDF*) of $r = x$ and $r = y$
 - *RDF* is *DF* on edge-reversed CFG.
- Indeed, *RDFs* identify control dependences



Marking conditional 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 conditional branches in k 's *reverse dominance frontier* $RDF(k)$ 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 conditional 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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The NULL pointer in Kernel Code

```
static unsigned int tun_chr_poll(struct file *file, poll_table * wa
{
    struct tun_file *tfile = file->private_data;
    struct tun_struct *tun = __tun_get(tfile);
    struct sock *sk = tun->sk;
    unsigned int mask = 0;

    if (!tun)
        return POLLERR;
```

Details here: Jonathan Corbet, Fun with NULL pointers, part 1

The BIND issue

Beginning with GCC 4.9.0, code optimization in GCC now includes (by default) an optimization which is intended to eliminate unnecessary null pointer comparisons in compiled code.

Unfortunately, this optimization removes checks which are necessary in BIND and the demonstrated effect is to cause unpredictable assertion failures during execution of named, resulting in termination of the server process.

Source: <https://kb.isc.org/docs/aa-01167>

The gory details:

https://gcc.gnu.org/bugzilla/show_bug.cgi?id=61236

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References

- Chapter 10 of Torczon and Cooper
 - Section 10.2