Workshop on Essential Abstractions in GCC

Manipulating GIMPLE IR

GCC Resource Center
(www.cse.iitb.ac.in/grc)

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Outline

- An Overview of GIMPLE
- Using GIMPLE API in GCC-4.7.2
- Adding a GIMPLE Pass to GCC
Part 1

An Overview of GIMPLE
GIMPLE: A Recap

- Language independent three address code representation
  - Computation represented as a sequence of basic operations
  - Temporaries introduced to hold intermediate values
- Control construct explicated into conditional and unconditional jumps
Motivation Behind GIMPLE

- Previously, the only common IR was RTL (Register Transfer Language)

- Drawbacks of RTL for performing high-level optimizations
  - Low-level IR, more suitable for machine dependent optimizations (e.g., peephole optimization)
  - High level information is difficult to extract from RTL (e.g. array references, data types etc.)
  - Introduces stack too soon, even if later optimizations do not require it
Why Not Abstract Syntax Trees for Optimization?

- ASTs contain detailed function information but are not suitable for optimization because
  - **Lack of a common representation across languages**
    - No single AST shared by all front-ends
    - So each language would have to have a different implementation of the same optimizations
    - Difficult to maintain and upgrade so many optimization frameworks
  - **Structural Complexity**
    - Lots of complexity due to the syntactic constructs of each language
    - Hierarchical structure and not linear structure
      Control flow explication is required
Need for a High Level IR

- Earlier versions of GCC would build up trees for a single statement, and then lower them to RTL before moving on to the next statement.
- For higher level optimizations, entire function needs to be represented in trees in a language-independent way.
- Result of this effort - GENERIC and GIMPLE.
What is GENERIC?

What?

- Language independent IR for a complete function in the form of trees
- Obtained by removing language specific constructs from ASTs
- All tree codes defined in $(SOURCE)/gcc/tree.def$

Why?

- Each language frontend can have its own AST
- Once parsing is complete they must emit GENERIC
What is GIMPLE?

- GIMPLE is influenced by SIMPLE IR of McCat compiler
- But GIMPLE is not the same as SIMPLE (GIMPLE supports GOTO)
- It is a simplified subset of GENERIC
  - 3 address representation
  - Control flow lowering
  - Cleanups and simplification, restricted grammar
- Benefit: Optimizations become easier
The Goals of GIMPLE are

- Lower control flow
  Sequenced statements + conditional and unconditional jumps

- Simplify expressions
  Typically one operator and at most two operands

- Simplify scope
  Move local scope to block begin, including temporaries
Tuple Based GIMPLE Representation

- Earlier implementation of GIMPLE used trees as internal data structure.
- Tree data structure was much more general than was required for three address statements.
- Now a three address statement is implemented as a tuple.
- These tuples contain the following information:
  - Type of the statement
  - Result
  - Operator
  - Operands

The result and operands are still represented using trees.
Observing Internal Form of GIMPLE

test.c.004t.gimple
with compilation option
-fdump-tree-all

x = 10;
y = 5;
D.1954 = x * y;
a.0 = a;
x = D.1954 + a.0;
a.1 = a;
D.1957 = a.1 * x;
y = y - D.1957;

test.c.004t.gimple with compilation option
-fdump-tree-all-raw

gimple_assign <integer_cst, x, 10, NULL>
gimple_assign <integer_cst, y, 5, NULL>
gimple_assign <mult_expr, D.1954, x, y>
gimple_assign <var_decl, a.0, a, NULL>
gimple_assign <plus_expr, x, D.1954, a.0>
gimple_assign <var_decl, a.1, a, NULL>
gimple_assign <mult_expr, D.1957, a.1, x>
gimple_assign <minus_expr, y, y, D.1957>
test.c.004t.gimple
with compilation option
-fdump-tree-all

if (a < c)
goto <D.1953>;
else
goto <D.1954>;
<D.1953>:
a = b + c;
goto <D.1955>;
<D.1954>:
a = b - c;
<D.1955>:

test.c.004t.gimple with compilation option
-fdump-tree-all-raw

gimple_cond <lt_expr, a,c,<D.1953>, <D.1954>>
gimple_label <<D.1953>>
gimple_assign <plus_expr, a, b, c>
gimple_goto <<D.1955>>
gimple_label <<D.1954>>
gimple_assign <minus_expr, a, b, c>
gimple_label <<D.1955>>
Observing Internal Form of GIMPLE

test.c.004t.gimple
with compilation option
-fdump-tree-all

if (a < c)
goto <D.1953>;
else
  goto <D.1954>;

<D.1953>:
  a = b + c;
  goto <D.1955>;

<D.1954>:
  a = b - c;

<D.1955>:

test.c.004t.gimple with compilation option
-fdump-tree-all-raw

gimple_cond <lt_expr, a,c,<D.1953>, <D.1954>>
gimple_label <<D.1953>>
gimple_assign <plus_expr, a, b, c>
gimple_goto <<D.1955>>
gimple_label <<D.1954>>
gimple_assign <minus_expr, a, b, c>
gimple_label <<D.1955>>
GIMPLE: An Overview of GIMPLE

Observing Internal Form of GIMPLE

test.c.004t.gimple with compilation option
-fdump-tree-all

if (a < c)
goto <D.1953>;
else
goto <D.1954>;

<D.1953>:
  a = b + c;
goto <D.1955>;

<D.1955>:

-Dump tree-all-raw

test.c.004t.gimple with compilation option
-fdump-tree-all-raw

gimple_cond <lt_expr, a,c,<D.1953>, <D.1954>>
gimple_label <<D.1953>>
gimple_assign <plus_expr, a, b, c>
gimple_goto <<D.1955>>
gimple_label <<D.1954>>
gimple_assign <minus_expr, a, b, c>
gimple_label <<D.1955>>
Observing Internal Form of GIMPLE

test.c.004t.gimple with compilation option
-fdump-tree-all

if (a < c)
goto <D.1953>;
else
goto <D.1954>;

<D.1953>:
  a = b + c;
goto <D.1955>;

<D.1954>:
  a = b - c;

<D.1955>:

test.c.004t.gimple with compilation option
-fdump-tree-all-raw

gimple_cond <lt_expr, a,c,<D.1953>, <D.1954>>
gimple_label <<D.1953>>
gimple_assign <plus_expr, a, b, c>
gimple_goto <<D.1955>>
gimple_label <<D.1954>>
gimple_assign <minus_expr, a, b, c>
gimple_label <<D.1955>>
Part 2

Manipulating GIMPLE
Iterating Over GIMPLE Statements

- A basic block contains a doubly linked-list of GIMPLE statements
- The statements are represented as GIMPLE tuples, and the operands are represented by tree data structure
- Processing of statements can be done through iterators
Iterating Over GIMPLE Statements

- A basic block contains a doubly linked-list of GIMPLE statements
- The statements are represented as GIMPLE tuples, and the operands are represented by tree data structure
- Processing of statements can be done through iterators

```c
basic_block bb;
gimple_stmt_iterator gsi;

FOR_EACH_BB (bb)
{
    for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi); %
         gsi_next (&gsi))
        find_pointer_assignments (gsi_stmt (gsi));
}
```
Iterating Over GIMPLE Statements

- A basic block contains a doubly linked-list of GIMPLE statements
- The statements are represented as GIMPLE tuples, and the operands are represented by tree data structure
- Processing of statements can be done through *iterators*

```c
basic_block bb;
gimple_stmt_iterator gsi;

FOR_EACH_BB (bb)
{
    for (gsi = gsi_start_bb (bb); !gsi_end_p (gsi); %
        gsi_next (&gsi))
        find_pointer_assignmentsgsi_stmt (gsi));
}
```

Basic block iterator
Iterating Over GIMPLE Statements

- A basic block contains a doubly linked-list of GIMPLE statements
- The statements are represented as GIMPLE tuples, and the operands are represented by tree data structure
- Processing of statements can be done through iterators

```c
basic_block bb;
gimple_stmt_iterator gsi;

FOR_EACH_BB (bb)
{
  for (gsi = gsi_start_bb (bb); !gsi_end_p (gsi); %
    gsi_next (&gsi))
    find_pointer_assignmentsgsi_stmt (gsi));
}
```

GIMPLE statement iterator
Iterating Over GIMPLE Statements

- A basic block contains a doubly linked-list of GIMPLE statements
- The statements are represented as GIMPLE tuples, and the operands are represented by tree data structure
- Processing of statements can be done through iterators

```c
basic_block bb;
gimple_stmt_iterator gsi;

FOR_EACH_BB (bb)
{
  %
  for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi); %
       gsi_next (&gsi))
    find_pointer_assignmentsgsi_stmt (gsi));
}
```

Get the first statement of bb
Iterating Over GIMPLE Statements

- A basic block contains a doubly linked-list of GIMPLE statements
- The statements are represented as GIMPLE tuples, and the operands are represented by tree data structure
- Processing of statements can be done through iterators

```c
basic_block bb;
gimple_stmt_iterator gsi;

FOR_EACH_BB (bb)
{
    for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi); %
         gsi_next (&gsi))
        find_pointer_assignments(gsi_stmt (gsi));
}
```

True if end reached
Iterating Over GIMPLE Statements

- A basic block contains a doubly linked-list of GIMPLE statements
- The statements are represented as GIMPLE tuples, and the operands are represented by tree data structure
- Processing of statements can be done through iterators

```c
basic_block bb;
gimple_stmt_iterator gsi;

FOR_EACH_BB (bb)
{
    for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi); %
        gsi_next (&gsi))
        find_pointer_assignmentsgsi_stmt (gsi));
}
```

Advance iterator to the next GIMPLE stmt
Iterating Over GIMPLE Statements

- A basic block contains a doubly linked-list of GIMPLE statements
- The statements are represented as GIMPLE tuples, and the operands are represented by tree data structure
- Processing of statements can be done through iterators

```c
basic_block bb;
gimple_stmt_iterator gsi;

FOR_EACH_BB (bb)
{
    for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi); %
        gsi_next (&gsi))
        find_pointer_assignmentsgsi_stmt (gsi));
}
```

Return the current statement
Printing Successors of a Basic Block

```c
edge e;
edge_iterator ei;
basic_block bb;

FOR_EACH_BB_FN (bb, cfun)
{
    fprintf(dump_file, "\n Successor(s) of basic block bb%d: ",
            bb->index);
    FOR_EACH_EDGE (e, ei, bb->succs)
    {
        basic_block succ_bb = e->dest;
        fprintf(dump_file, "bb%d\t",succ_bb->index);
    }
    fprintf(dump_file, "\n");
}
```
Printing Successors of a Basic Block

```c
edge e;
edge_iterator ei;
basic_block bb;

FOR_EACH_BB_FN (bb, cfun)
{
    fprintf(dump_file, "\n Successor(s) of basic block bb%d: ",
            bb->index);
    FOR_EACH_EDGE (e, ei, bb->succs)
    {
        basic_block succ_bb = e->dest;
        fprintf(dump_file, "bb%d\t", succ_bb->index);
    }
    fprintf(dump_file, "\n");
}
```

Basic block iterator for current function represented by cfun
Printing Successors of a Basic Block

```c
edge e;
edge_iterator ei;
basic_block bb;

FOR_EACH_BB_FN (bb, cfun)
{
    fprintf(dump_file, "\n Successor(s) of basic block bb%d: ", 
             bb->index);
    FOR_EACH_EDGE (e, ei, bb->succs)
    {
        basic_block succ_bb = e->dest;
        fprintf(dump_file, "bb%d\t ", succ_bb->index);
    }
    fprintf(dump_file, "\n");
}
```
Extracting parts of GIMPLE statements:

- `gimple_assign_lhs`: left hand side
- `gimpel_assign_rhs1`: left operand of the right hand side
- `gimple_assign_rhs2`: right operand of the right hand side
- `gimple_assign_rhs_code`: operator on the right hand side

A complete list can be found in the file `gimple.h`
Discovering More Information from GIMPLE

- Discovering local variables
- Discovering global variables
- Discovering pointer variables
- Discovering assignment statements involving pointers (i.e. either the result or an operand is a pointer variable)
static void gather_local_variables ()
{
    tree list;

    if (!dump_file)
        return;

    fprintf(dump_file,"\nLocal variables : ");
    FOR_EACH_LOCAL_DECL (cfun, u, list)
    {
        if (!DECL_ARTIFICIAL (list))
            fprintf(dump_file, "%s\n", get_name (list));
    }
}
static void gather_local_variables ()
{
    tree list;

    if (!dump_file)
        return;

    fprintf(dump_file,"\nLocal variables : ");
    FOR_EACH_LOCAL_DECL (cfun, u, list)
    {
        if (!DECL_ARTIFICIAL (list))
            fprintf(dump_file, "%s\n", get_name (list));
    }
}
static void gather_local_variables ()
{
    tree list;

    if (!dump_file)
        return;

    fprintf(dump_file,\
            "\nLocal variables : ");
    FOR_EACH_LOCALDECL (cfun, u, list)
    {
        if (!DECL_ARTIFICIAL (list))
            fprintf(dump_file, "\%s\n", get_name (list));
    }
}

Exclude variables that do not appear in the source
static void gather_local_variables ()
{
    tree list;

    if (!dump_file)
        return;

    fprintf(dump_file, "\nLocal variables : ");
    FOR_EACH_LOCAL_DECL (cfun, u, list)
    {
        if (!DECL_ARTIFICIAL (list))
            fprintf(dump_file, "%s\n", get_name (list));
    }
}
static void gather_global_variables ()
{
    struct varpool_node *node;

    if (!dump_file)
        return;

    fprintf(dump_file,"
Global variables : ");
    for (node = varpool_nodes; node; node = node->next)
    {
        tree var = node->decl;
        if (!DECL_ARTIFICIAL(var))
        {
            fprintf(dump_file, get_name(var));
            fprintf(dump_file,"
    ");
        }
    }
}
static void gather_global_variables ()
{
    struct varpool_node *node;

    if (!dump_file)
        return;

    fprintf(dump_file,"\nGlobal variables : ");
    for (node = varpool_nodes; node; node = node->next)
    {
        tree var = node->decl;
        if (!DECL_ARTIFICIAL(var))
        {
            fprintf(dump_file, get_name(var));
            fprintf(dump_file, "\n");
        }
    }
}

List of global variables of the current function
static void gather_global_variables ()
{
    struct varpool_node *node;

    if (!dump_file)
        return;

    fprintf(dump_file, "\nGlobal variables : ");
    for (node = varpool_nodes; node; node = node->next)
    {
        tree var = node->decl;
        if (!DECL_ARTIFICIAL(var))
            {
                fprintf(dump_file, get_name(var));
                fprintf(dump_file, "\n");
            }
    }
}

Exclude variables that do not appear in the source
static void gather_global_variables ()
{
    struct varpool_node *node;

    if (!dump_file)
        return;

    fprintf(dump_file, "\nGlobal variables : ");
    for (node = varpool_nodes; node; node = node->next) {
        
        tree var = node->decl;
        if (!DECL_ARTIFICIAL(var)) {
            
            fprintf(dump_file, get_name(var));
            fprintf(dump_file,"\n");
        }
    }
static void gather_global_variables ()
{
    struct varpool_node *node;

    if (!dump_file)
        return;

    fprintf(dump_file, "\nGlobal variables : ");
    for (node = varpool_nodes; node; node = node->next)
    {
        tree var = node->decl;
        if (!DECL_ARTIFICIAL(var))
        {
            fprintf(dump_file, get_name(var));
            fprintf(dump_file, "\n");
        }
    }
}
Assignment Statements Involving Pointers

int *p, *q;
void callme (int);
int main ()
{
    int a, b;
p = &b;
callme (a);
return 0;
}
void callme (int a)
{
    a = *(p + 3);
    q = &a;
}

main ()
{
    int D.1965;
    int a;
    int b;
p = &b;
callme (a);
D.1965 = 0;
return D.1965;
}
callme (int a)
{
    int * p.0;
    int a.1;
p.0 = p;
    a.1 = MEM[(int *)p.0 + 12B];
a = a.1;
    q = &a;
}
Discovering Pointers in GIMPLE IR

static bool
is_pointer_var (tree var)
{
    return is_pointer_type (TREE_TYPE (var));
}

static bool
is_pointer_type (tree type)
{
    if (POINTER_TYPE_P (type))
        return true;
    if (TREE_CODE (type) == ARRAY_TYPE)
        return is_pointer_var (TREE_TYPE (type));
    /* Return true if it is an aggregate type. */
    return AGGREGATE_TYPE_P (type);
}
static bool is_pointer_var (tree var)
{
    return is_pointer_type (TREE_TYPE (var));
}

static bool is_pointer_type (tree type)
{
    if (POINTER_TYPE_P (type))
        return true;
    if (TREE_CODE (type) == ARRAY_TYPE)
        return is_pointer_var (TREE_TYPE (type));
    /* Return true if it is an aggregate type. */
    return AGGREGATE_TYPE_P (type);
}
static bool
is_pointer_var (tree var)
{
    return is_pointer_type (TREETYPE (var));
}

static bool
is_pointer_type (tree type)
{
    if (POINTER_TYPE_P (type))
        return true;
    if (TREE_CODE (type) == ARRAY_TYPE)
        return is_pointer_var (TREETYPE (type));
    /* Return true if it is an aggregate type. */
    return AGGREGATE_TYPE_P (type);
}

Defines what kind of node it is
static void
find_pointer_assignments (gimple stmt)
{
    if (is_gimple_assign (stmt))
    {
        tree lhsop = gimple_assign_lhs (stmt);
        tree rhsop1 = gimple_assign_rhs1 (stmt);
        tree rhsop2 = gimple_assign_rhs2 (stmt);
        /* Check if either LHS, RHS1 or RHS2 operands can be pointers. */
        if ((lhsop && is_pointer_var (lhsop)) ||
            (rhsop1 && is_pointer_var (rhsop1)) ||
            (rhsop2 && is_pointer_var (rhsop2))
        {
            if (dump_file)
                fprintf (dump_file, "Pointer Statement :");
            print_gimple_stmt (dump_file, stmt, 0, 0);
            num_ptr_stmts++;
        }
    }
}
static void
find_pointer_assignments (gimple stmt)
{
  if (is_gimple_assign (stmt))
  {
    tree lhsop = gimple_assign_lhs (stmt);
    tree rhsop1 = gimple_assign_rhs1 (stmt);
    tree rhsop2 = gimple_assign_rhs2 (stmt);
    /* Check if either LHS, RHS1 or RHS2 operands
       can be pointers. */
    if (((lhsop && is_pointer_var (lhsop)) ||
          (rhsop1 && is_pointer_var (rhsop1)) ||
          (rhsop2 && is_pointer_var (rhsop2)))
    
    { if (dump_file)
      
        fprintf (dump_file, "Pointer Statement : ");
        print_gimple_stmt (dump_file, stmt, 0, 0);
        num_ptr_stmts++;
        
      }
    }
  
  }
}
static void
find_pointer_assignments (gimple stmt)
{
  if (is_gimple_assign (stmt))
  {
    tree lhsop = gimple_assign_lhs (stmt);
    tree rhsop1 = gimple_assign_rhs1 (stmt);
    tree rhsop2 = gimple_assign_rhs2 (stmt);
    /* Check if either LHS, RHS1 or RHS2 operands
       can be pointers. */
    if ((lhsop && is_pointer_var (lhsop)) ||
        (rhsop1 && is_pointer_var (rhsop1)) ||
        (rhsop2 && is_pointer_var (rhsop2)))
    {
      if (dump_file)
        fprintf (dump_file, "Pointer Statement :");
      print_gimple_stmt (dump_file, stmt, 0, 0);
      num_ptr_stmts++;
    }
  }
}
static void
find_pointer_assignments (gimple stmt)
{
    if (is_gimple_assign (stmt))
    {
        tree lhsop = gimple_assign_lhs (stmt);
        tree rhsop1 = gimple_assign_rhs1 (stmt);
        tree rhsop2 = gimple_assign_rhs2 (stmt);
        /* Check if either LHS, RHS1 or RHS2 operands
         * can be pointers. */
        if ((lhsop && is_pointer_var (lhsop)) ||
            (rhsop1 && is_pointer_var (rhsop1)) ||
            (rhsop2 && is_pointer_var (rhsop2)))
        {
            if (dump_file)
                fprintf (dump_file, "Pointer Statement :");
            print_gimple_stmt (dump_file, stmt, 0, 0);
            num_ptr_stmts++;
        }
    }
}
static void
find_pointer_assignments (gimple stmt)
{
    if (is_gimple_assign (stmt))
    {
        tree lhsop = gimple_assign_lhs (stmt);
        tree rhsop1 = gimple_assign_rhs1 (stmt);
        tree rhsop2 = gimple_assign_rhs2 (stmt);
        /* Check if either LHS, RHS1 or RHS2 operands
         * can be pointers. */
        if ((lhsop && is_pointer_var (lhsop)) ||
            (rhsop1 && is_pointer_var (rhsop1)) ||
            (rhsop2 && is_pointer_var (rhsop2)))
            if (dump_file)
                fprintf (dump_file, "Pointer Statement : ");
            print_gimple_stmt (dump_file, stmt, 0, 0);
            num_ptr_stmts++;
    }
}
static unsigned int
intra_gimple_manipulation (void)
{
    basic_block bb;
gimpleStmtIterator gsi;

    initialize_var_count ();
    FOR_EACH_BB_FN (bb, cfun) 
    {
        for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi);
            gsi_next (&gsi))
            find_pointer_assignments (gsi_stmt (gsi));
    }
    print_var_count ();
    return 0;
}
static unsigned int 
intra_gimple_manipulation (void) 
{
    basic_block bb;
gimple_stmt_iterator gsi;

    initialize_var_count ();
    FOR_EACH_BB_FN (bb, cfun) 
    {
        for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi); 
            gsi_next (&gsi))
            find_pointer_assignments (gsi_stmt (gsi));
    }
    print_var_count ();
    return 0;
}
Putting it Together at the Intraprocedural Level

static unsigned int
intra_gimple_manipulation (void)
{
    basic_block bb;
    gimple_stmt_iterator gsi;

    initialize_var_count ();
    FOR_EACH_BB_FN (bb, cfun) {
        for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi);
            gsi_next (&gsi))
            find_pointer_assignments (gsi_stmt (gsi));
    }
    print_var_count ();
    return 0;
}
static unsigned int
intra_gimple_manipulation (void)
{
    basic_block bb;
    gimple_stmt_iterator gsi;

    initialize_var_count ();
    FOR_EACH_BB_FN (bb, cfun)
    {
        for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi);
             gsi_next (&gsi))
            find_pointer_assignments (gsi_stmt (gsi));
    }
    print_var_count ();
    return 0;
}
main ()
{
    ...
    p = &b;
    callme (a);
    D.1965 = 0;
    return D.1965;
}

Information collected by intraprocedural Analysis pass

callme (int a)
{
    ...
    p.0 = p;
    a.1 = MEM[(int *)p.0 + 12B];
    a = a.1;
    q = &a;
}
Intraprocedural Analysis Results

main ()
{
    ... 
    p = &b;
    callme (a);
    D.1965 = 0;
    return D.1965;
}
callme (int a)
{
    ... 
    p.0 = p;
    a.1 = MEM[(int *)p.0 + 12B];
    a = a.1;
    q = &a;
}

Information collected by intraprocedural Analysis pass

- For main: 1
Intraprocedural Analysis Results

main ()
{
    ...
    p = &b;
callme (a);
    D.1965 = 0;
    return D.1965;
}
callme (int a)
{
    ...
    p.0 = p;
a.1 = MEM[(int *)p.0 + 12B];
a = a.1;
    q = &a;
}

Information collected by intraprocedural Analysis pass

- For main: 1
- For callme: 2
Intraprocedural Analysis Results

main ()
{ ... 
  p = &b;
  callme (a);
  D.1965 = 0;
  return D.1965;
}
callme (int a)
{ ... 
  p.0 = p;
  a.1 = MEM[(int *)p.0 + 12B];
  a = a.1;
  q = &a;
}

Information collected by intraprocedural Analysis pass

- For main: 1
- For callme: 2

Why is the pointer in the red statement being missed?
Intraprocedural Analysis Results

main ()
{
    ...
    p = &b;
callme (a);
D.1965 = 0;
return D.1965;
}
callme (int a)
{
    ...
    p.0 = p;
a.1 = MEM[(int *)p.0 + 12B];
a = a.1;
q = &a;
}

Information collected by intraprocedural Analysis pass

- For main: 1
- For callme: 2

Why is the pointer in the red statement being missed?
Because it is deeper in the tree and our program does not search deeper in the tree
Extending our Pass to Interprocedural Level

static unsigned int
inter_gimple_manipulation (void)
{
    struct cgraph_node *node;
    basic_block bb;
    gimple_stmt_iterator gsi;
    initialize_var_count ();
    for (node = cgraph_nodes; node; node=node->next) {
        /* Nodes without a body, and clone nodes are not interesting. */
        if (!gimple_has_body_p (node->decl) || node->clone_of)
            continue;
        push_cfun (DECL_STRUCT_FUNCTION (node->decl));
        FOR_EACH_BB (bb) {
            for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi); gsi_next (&gsi))
                find_pointer_assignments (gsi_stmt (gsi));
        }
        pop_cfun ();
    }
    print_var_count ();
    return 0;
}
static unsigned int
inter_gimple_manipulation (void)
{
    struct cgraph_node *node;
    basic_block bb;
    gimple_stmt_iterator gsi;
    initialize_var_count ();

    for (node = cgraph_nodes; node; node=node->next) {
        /* Nodes without a body, and clone nodes are not interesting. */
        if (!gimple_has_body_p (node->decl) || node->clone_of)
            continue;

        push_cfun (DECL_STRUCT_FUNCTION (node->decl));
        FOR_EACH_BB (bb) {
            for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi); gsi_next (&gsi))
                find_pointer_assignments (gsi_stmt (gsi));
        }
        pop_cfun ();
    }

    print_var_count ();
    return 0;
}
Extending our Pass to Interprocedural Level

```c
static unsigned int
inter_gimple_manipulation (void)
{
    struct cgraph_node *node;
    basic_block bb;
    gimple_stmt_iterator gsi;
    initialize_var_count ();
    for (node = cgraph_nodes; node; node=node->next) {
        /* Nodes without a body, and clone nodes are not interesting. */
        if (!gimple_has_body_p (node->decl) || node->clone_of)
            continue;
        push_cfun (DECL_STRUCT_FUNCTION (node->decl));
        FOR_EACH_BB (bb) {
            for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi); gsi_next (&gsi))
                find_pointer_assignments (gsi_stmt (gsi));
        }
        pop_cfun ();
    }
    print_var_count ();
    return 0;
}
```

Setting the current function in the context
Extending our Pass to Interprocedural Level

static unsigned int inter_gimple_manipulation (void)
{
    struct cgraph_node *node;
    basic_block bb;
    gimple_stmt_iterator gsi;
    initialize_var_count ();
    for (node = cgraph_nodes; node; node=node->next) {
        /* Nodes without a body, and clone nodes are not interesting. */
        if (!gimple_has_body_p (node->decl) || node->clone_of)
            continue;
        push_cfun (DECL_STRUCT_FUNCTION (node->decl));
        FOR_EACH_BB (bb) {
            for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi); gsi_next (&gsi))
                find_pointer_assignments (gsi_stmt (gsi));
        }
        pop_cfun ();
    }
    print_var_count ()
    return 0;
}

Basic Block Iterator
Extending our Pass to Interprocedural Level

```
static unsigned int
inter_gimple_manipulation (void)
{
    struct cgraph_node *node;
    basic_block bb;
    gimple_stmt_iterator gsi;
    initialize_var_count ()
    for (node = cgraph_nodes; node; node=node->next) {
        /* Nodes without a body, and clone nodes are not interesting. */
        if (!gimple_has_body_p (node->decl) || node->clone_of)
            continue;
        push_cfun (DECL_STRUCT_FUNCTION (node->decl));
        FOR_EACH_BB (bb) {
            for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi); gsi_next (&gsi))
                find_pointer_assignments (gsi_stmt (gsi));
        }
        pop_cfun ();
    }
    print_var_count ();
    return 0;
}
```
Extending our Pass to Interprocedural Level

```c
static unsigned int
inter_gimple_manipulation (void)
{
    struct cgraph_node *node;
    basic_block bb;
    gimple_stmt_iterator gsi;
    initialize_var_count ();
    for (node = cgraph_nodes; node; node=node->next) {
        /* Nodes without a body, and clone nodes are not interesting. */
        if (!gimple_has_body_p (node->decl) || node->clone_of)
            continue;
        push_cfun (DECL_STRUCT_FUNCTION (node->decl));
        FOR_EACH_BB (bb) {
            for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi); gsi_next (&gsi))
                find_pointer_assignments (gsi_stmt (gsi));
        }
        pop_cfun ();
    }
    print_var_count ();
    return 0;
}
```

Resetting the function context
Interprocedural Results

Number of Pointer Statements = 3
Number of Pointer Statements = 3

Observation:

- Information can be collected for all the functions in a single pass
- Better scope for optimizations