

Workshop on Essential Abstractions in GCC

Manipulating GIMPLE and RTL IRs

GCC Resource Center

(www.cse.iitb.ac.in/grc)

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Outline

- An Overview of GIMPLE
- Using GIMPLE API in GCC-4.6.0
- Adding a GIMPLE Pass to GCC
- An Internal View of RTL
- Manipulating RTL IR



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 New 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 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



GIMPLE Goals

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>
```



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>>
```



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>  
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gimple_assign <minus_expr, a, b, c>  
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Observing Internal Form of GIMPLE

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    if (a < c)
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<D.1953>:
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    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  
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```

```
  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](#)

```
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));
}
```



Iterating Over GIMPLE Statements

- A basic block contains a doubly linked-list of GIMPLE statements
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- Processing of statements can be done through [iterators](#)

```
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));  
}
```



Basic block iterator



Iterating Over GIMPLE Statements

- A basic block contains a doubly linked-list of GIMPLE statements
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```
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](#)

```
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
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- Processing of statements can be done through [iterators](#)

```
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](#)

```
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](#)

```
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



Other Useful APIs for Manipulating GIMPLE

Extracting parts of GIMPLE statements:

- `gimple_assign_lhs`: left hand side
- `gimple_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)



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)

The first two are relevant to your lab assignment

The other two constitute an example of a complete pass



Discovering Local Variables in GIMPLE IR

```
static void gather_local_variables ()
{
    tree list = cfun->local_decls;

    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));
        list = TREE_CHAIN (list);
    }
}
```



Discovering Local Variables in GIMPLE IR

```
static void gather_local_variables ()
{
    tree list = cfun->local_decls;

    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));
        list = TREE_CHAIN (list);
    }
}
```

List of local variables of the current function



Discovering Local Variables in GIMPLE IR

```
static void gather_local_variables ()
{
    tree list = cfun->local_decls;

    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));
        list = TREE_CHAIN (list);
    }
}
```



Local variable iterator



Discovering Local Variables in GIMPLE IR

```
static void gather_local_variables ()
{
    tree list = cfun->local_decls;

    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));
        list = TREE_CHAIN (list);
    }
}
```

Exclude variables that do not appear in the source



Discovering Local Variables in GIMPLE IR

```
static void gather_local_variables ()
{
    tree list = cfun->local_decls;

    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));
        list = TREE_CHAIN (list);
    }
}
```

Find the name from the TREE node



Discovering Local Variables in GIMPLE IR

```
static void gather_local_variables ()
{
    tree list = cfun->local_decls;

    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));
        list = TREE_CHAIN (list);
    }
}
```

Go to the next item in the list



Discovering Global Variables in GIMPLE IR

```
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");
        }
    }
}
```

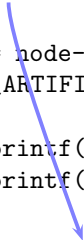


Discovering Global Variables in GIMPLE IR

```
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



Discovering Global Variables in GIMPLE IR

```
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



Discovering Global Variables in GIMPLE IR

```
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");
        }
    }
}
```

Find the name from the TREE node

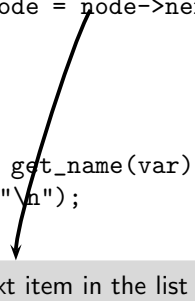


Discovering Global Variables in GIMPLE IR

```
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");
        }
    }
}
```



Go to the next item in the list



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));
}

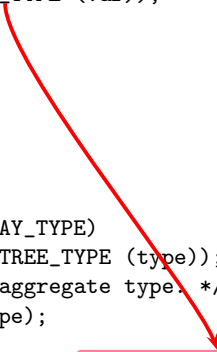
static bool
is_pointer_type (tree type)
{
    if (POINTER_TYPE_P (type))
        return true;
    if (TREE_CODE (type) == ARRAY_TYPE)
        return is_pointer_var (TREE_TYPE (type));
    /* Return true if it is an aggregate type. */
    return AGGREGATE_TYPE_P (type);
}
```



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);
}
```



Data type of the expression



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);
}
```

Defines what kind of node it is



Discovering Assignment Statements Involving Pointers

```
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++;
    }
  }
}
```



Discovering Assignment Statements Involving Pointers

```
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++;
    }
  }
}
```

Extract the LHS of the assignment statement



Discovering Assignment Statements Involving Pointers

```
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++;
    }
  }
}
```

Extract the first operand of the RHS



Discovering Assignment Statements Involving Pointers

```
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++;
    }
  }
}
```

Extract the second operand of the RHS



Discovering Assignment Statements Involving Pointers

```
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++;
    }
  }
}
```

Pretty print the GIMPLE statement



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;
}
```



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;
}
```

Basic block iterator parameterized with function



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;
}
```

Current function (i.e. function being compiled)



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;
}
```

GIMPLE statement iterator



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



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?



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

```
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;
}
```

Iterating over all the callgraph nodes



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;
}
```

Setting the current function in the context



Extending our Pass to Interprocedural Level

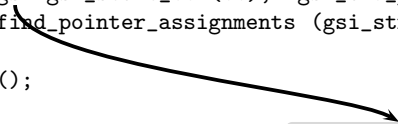
```
static unsigned int
inter_gimple_manipulation (void)
{
    struct cgraph_node *node;
    basic_block bb;
    gimple_stmt_iterator gsi;
    initialize_var_count ();
    for (node = cgraph_nodes; node; node=node->next) {
        /* Nodes without a body, and clone nodes are not interesting. */
        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;
}
```

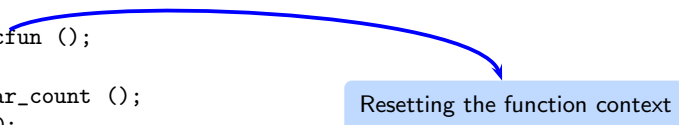


GIMPLE Statement Iterator



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;
}
```



Interprocedural Results

Number of Pointer Statements = 3



Interprocedural Results

Number of Pointer Statements = 3

Observation:

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



Part 3

An Overview of RTL

What is RTL ?

RTL = Register Transfer Language

Assembly language for an abstract machine with infinite registers



Why RTL?

A lot of work in the back-end depends on RTL. Like,

- Low level optimizations like loop optimization, loop dependence, common subexpression elimination, etc
- Instruction scheduling
- Register Allocation
- Register Movement



Why RTL?

For tasks such as those, RTL supports many low level features, like,

- Register classes
- Memory addressing modes
- Word sizes and types
- Compare and branch instructions
- Calling Conventions
- Bitfield operations



The Dual Role of RTL

- For specifying machine descriptions

Machine description constructs:

- ▶ `define_insn`, `define_expand`, `match_operand`

- For representing program during compilation

IR constructs

- ▶ `insn`, `jump_insn`, `code_label`, `note`, `barrier`



The Dual Role of RTL

- For specifying machine descriptions

Machine description constructs:

- ▶ `define_insn`, `define_expand`, `match_operand`

- For representing program during compilation

IR constructs

- ▶ `insn`, `jump_insn`, `code_label`, `note`, `barrier`

This lecture focusses on RTL as an IR



Part 4

An Internal View of RTL

RTL Objects

- Types of RTL Objects
 - ▶ Expressions
 - ▶ Integers
 - ▶ Wide Integers
 - ▶ Strings
 - ▶ Vectors

- Internal representation of RTL Expressions
 - ▶ Expressions in RTX are represented as trees
 - ▶ A pointer to the C data structure for RTL is called `rtx`



RTL Codes

RTL Expressions are classified into RTL codes :

- Expression codes are [names](#) defined in [rtl.def](#)
- RTL codes are C enumeration constants
- Expression codes and their meanings are [machine-independent](#)
- Extract the code of a RTL with the macro `GET_CODE(x)`



RTL Classes

RTL expressions are divided into few classes, like:

- RTX_UNARY : NEG, NOT, ABS
- RTX_BIN_ARITH : MINUS, DIV
- RTX_COMM_ARITH : PLUS, MULT
- RTX_OBJ : REG, MEM, SYMBOL_REF
- RTX_COMPARE : GE, LT
- RTX_TERNARY : IF_THEN_ELSE
- RTX_INSN : INSN, JUMP_INSN, CALL_INSN
- RTX_EXTRA : SET, USE



RTL Codes

The RTL codes are defined in `rtl.def` using cpp macro call `DEF_RTL_EXPR`, like :

- `DEF_RTL_EXPR(INSN, "insn", "iuuBieie", RTX_INSN)`
- `DEF_RTL_EXPR(SET, "set", "ee", RTX_EXTRA)`
- `DEF_RTL_EXPR(PLUS, "plus", "ee", RTX_COMM_ARITH)`
- `DEF_RTL_EXPR(IF_THEN_ELSE, "if_then_else", "eee", RTX_TERNARY)`

The operands of the macro are :

- Internal name of the rtx used in C source. It's a tag in enumeration `enum rtx_code`
- name of the rtx in the external ASCII format
- Format string of the rtx, defined in `rtl_format []`
- Class of the rtx



RTL Formats

```
DEF_RTL_EXPR(INSN, "insn", "iuuBieie", RTX_INSN)
```

- i : Integer
- u : Integer representing a pointer
- B : Pointer to basic block
- e : Expression



RTL statements

- RTL statements are instances of type `rtx`
- RTL insns contain embedded links
- Types of RTL insns :
 - ▶ `INSN` : Normal non-jumping instruction
 - ▶ `JUMP_INSN` : Conditional and unconditional jumps
 - ▶ `CALL_INSN` : Function calls
 - ▶ `CODE_LABEL`: Target label for `JUMP_INSN`
 - ▶ `BARRIER` : End of control Flow
 - ▶ `NOTE` : Debugging information



Basic RTL APIs

- XEXP, XINT, XWINT, XSTR
 - ▶ Example: XINT(x,2) accesses the 2nd operand of rtx x as an integer
 - ▶ Example: XEXP(x,2) accesses the same operand as an expression
- Any operand can be accessed as any type of RTX object
 - ▶ So operand accessor to be chosen based on the format string of the containing expression
- Special macros are available for Vector operands
 - ▶ XVEC(exp,idx) : Access the vector-pointer which is operand number idx in exp
 - ▶ XVECLEN (exp, idx) : Access the length (number of elements) in the vector which is in operand number idx in exp. This value is an int
 - ▶ XVECEXP (exp, idx, eltnum) : Access element number "eltnum" in the vector which is in operand number idx in exp. This value is an RTX



RTL Insns

- A function's code is a doubly linked chain of INSN objects
- Insns are rtxs with special code
- Each insn contains atleast 3 extra fields :
 - ▶ Unique id of the insn , accessed by `INSN_UID(i)`
 - ▶ `PREV_INSN(i)` accesses the chain pointer to the INSN preceeding `i`
 - ▶ `NEXT_INSN(i)` accesses the chain pointer to the INSN succeeding `i`
- The first insn is accessed by using `get_insns()`
- The last insn is accessed by using `get_last_insn()`



Part 5

Manipulating RTL IR

Adding an RTL Pass

Similar to adding GIMPLE intraprocudural pass except for the following

- Use the data structure `struct rtl_opt_pass`
- Replace the first field `GIMPLE_PASS` by `RTL_PASS`



Sample Demo Program

Problem statement : Counting the number of SET objects in a basic block by adding a new RTL pass

- Add your new pass after `pass_expand`
- `new_rtl_pass_main` is the main function of the pass
- Iterate through different instructions in the doubly linked list of instructions and for each expression, call `eval_rtx(insn)` for that expression which recurse in the expression tree to find the set statements



Sample Demo Program

```
int new_rtl_pass_main(void){
    basic_block bb;
    rtx last,insn,opd1,opd2;
    int bbno,code,type;
    count = 0;
    for (insn=get_insns(), last=get_last_insn(),
        last=NEXT_INSN(last); insn!=last; insn=NEXT_INSN(insn))
    {
        int is_insn;
        is_insn = INSN_P (insn);
        if(flag_dump_new_rtl_pass)
            print_rtl_single(dump_file,insn);
        code = GET_CODE(insn);
        if(code==NOTE){ ... }
        if(is_insn)
        {
            rtx subexp = XEXP(insn,5);
            eval_rtx(subexp);
        }
    }
    ...
}
```



Sample Demo Program

```
int new_rtl_pass_main(void){
    basic_block bb;
    rtx last,insn,opd1,opd2;
    int bbno,code,type;
    count = 0;
    for (insn=get_insns(), last=get_last_insn(),
        last=NEXT_INSN(last); insn!=last; insn=NEXT_INSN(insn))
    {
        int is_insn;
        is_insn = INSN_P (insn);
        if(flag_dump_new_rtl_pass)
            print_rtl_single(dump_file,insn);
        code = GET_CODE(insn);
        if(code==NOTE){ ... }
        if(is_insn)
        {
            rtx subexp = XEXP(insn,5);
            eval_rtx(subexp);
        }
    }
    ...
}
```



Sample Demo Program

```
void eval_rtx(rtx exp)
{ rtx temp;
  int veclen,i,
  int rt_code = GET_CODE(exp);
  switch(rt_code)
  {   case SET:
      if(flag_dump_new_rtl_pass){
          fprintf(dump_file,"\nSet statement %d : \t",count+1);
          print_rtl_single(dump_file,exp);}
      count++; break;
  case PARALLEL:
      veclen = XVECLEN(exp, 0);
      for(i = 0; i < veclen; i++)
      {   temp = XVECEXP(exp, 0, i);
          eval_rtx(temp);
      }
      break;
  default: break;
  }
}
```



Sample Demo Program

```
void eval_rtx(rtx exp)
{ rtx temp;
  int veclen,i,
  int rt_code = GET_CODE(exp);
  switch(rt_code)
  {   case SET:
      if(flag_dump_new_rtl_pass){
          fprintf(dump_file,"\nSet statement %d : \t",count+1);
          print_rtl_single(dump_file,exp);}
      count++; break;
    case PARALLEL:
      veclen = XVECLEN(exp, 0);
      for(i = 0; i < veclen; i++)
      {   temp = XVECEXP(exp, 0, i);
          eval_rtx(temp);
      }
      break;
    default: break;
  }
}
```



Sample Demo Program

```
void eval_rtx(rtx exp)
{ rtx temp;
  int veclen,i,
  int rt_code = GET_CODE(exp);
  switch(rt_code)
  {   case SET:
      if(flag_dump_new_rtl_pass){
          fprintf(dump_file,"\nSet statement %d : \t",count+1);
          print_rtl_single(dump_file,exp);}
      count++; break;
    case PARALLEL:
      veclen = XVECLEN(exp, 0);
      for(i = 0; i < veclen; i++)
      {   temp = XVECEXP(exp, 0, i);
          eval_rtx(temp);
      }
      break;
    default: break;
  }
}
```

