

*Workshop on Essential Abstractions in GCC*

## Manipulating GIMPLE and RTL IRs

GCC Resource Center

([www.cse.iitb.ac.in/grc](http://www.cse.iitb.ac.in/grc))

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# Outline

- An Overview of GIMPLE
- Using GIMPLE API in GCC-4.5.0
- Adding a GIMPLE Pass to GCC
- An Internal View of RTL
- Manipulating RTL IR
- An Overview of RTL



*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  
Program = sequenced statements + jump
- Simplify expressions  
Typically: two operand assignments!
- 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  
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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>>
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gimple_goto <<D.1955>>
gimple_label <<D.1954>>
gimple_assign <minus_expr, a, b, c>
gimple_label <<D.1955>>
```



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<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>
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```



# 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*

# *Using GIMPLE API in GCC-4.5.0*

## 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))  
        analyze_statement (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](#)

```
basic_block bb;  
gimple_stmt_iterator gsi;  
  
FOR_EACH_BB (bb)  
{  
    for (gsi = gsi_start_bb (bb); !gsi_end_p (gsi);  
         gsi_next (&gsi))  
        analyze_statement (gsi_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](#)

```
basic_block bb;  
gimple_stmt_iterator gsi;  
  
FOR_EACH_BB (bb)  
{  
    for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi);  
        gsi_next (&gsi))  
        analyze_statement (gsi_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))  
        analyze_statement (gsi_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](#)

```
basic_block bb;  
gimple_stmt_iterator gsi;  
  
FOR_EACH_BB (bb)  
{  
    for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi);  
        gsi_next (&gsi))  
        analyze_statement (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))  
        analyze_statement (gsi_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))  
        analyze_statement (gsi_stmt (gsi));  
}
```

Return the current statement



## Other Useful APIs for Manipulating GIMPLE

- `gimple_assign_lhs`: Extracting the left hand side
- `gimple_assign_rhs1`: Extracting the left operand of the right hand side
- `gimple_assign_rhs2`: Extracting the right operand of the right hand side
- `gimple_assign_rhs_code`: Code of the operator of the right hand side

A complete list can be found in the file `gimple.h`



## *Part 3*

# *Adding a GIMPLE Pass to GCC*

## Adding a GIMPLE Intraprocedural Pass in GCC-4.5.0

1. Add the following `gimple_opt_pass` struct instance to the file  
`struct gimple_opt_pass pass_intra_gimple_manipulation =`  
`{`

```
    {  
        GIMPLE_PASS,                /* optimization pass type */  
        "gm",                       /* name of the pass*/  
        gate_gimple_manipulation,    /* gate. */  
        intra_gimple_manipulation,  /* execute (driver function) */  
        NULL,                       /* sub passes to be run */  
        NULL,                       /* next pass to run */  
        0,                          /* static pass number */  
        0,                          /* timevar_id */  
        0,                          /* properties required */  
        0,                          /* properties provided */  
        0,                          /* properties destroyed */  
        0,                          /* todo_flags start */  
        0                           /* todo_flags end */  
    }  
};
```



## Adding a GIMPLE Intraprocedural Pass in GCC-4.5.0

2. Write the driver function in file `gimple-manipulation.c`

3. Declare your pass in file `tree-pass.h`:

```
extern struct gimple_opt_pass  
pass_intra_gimple_manipulation;
```

4. Add your pass to the intraprocedural pass list in

```
init_optimization_passes()
```

```
...
```

```
NEXT_PASS (pass_intra_gimple_manipulation);
```

```
NEXT_PASS (pass_lower_complex_00);
```

```
NEXT_PASS (pass_cleanup_eh);
```

```
...
```



## Adding a GIMPLE Intraprocedural Pass in GCC-4.5.0

5. In `$SOURCE/gcc/Makefile.in`, add `gimple-manipulate.o` to the list of language independent object files. Also, make specific changes to compile `gimple-manipulate.o` from `gimple-manipulate.c`
6. Configure and build gcc  
(For simplicity, we will make `cc1` only)
7. Debug `cc1` using `ddd/gdb` if need arises



## An Intraprocedural Analysis Application

Calculate the number of pointer statements in GIMPLE (i.e. result or an operand is a pointer variable)



## An Intraprocedural Analysis Application

Calculate the number of pointer statements in GIMPLE (i.e. result or an operand is a pointer variable)

```
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 ()
{
    p = &b;
    callme (a);
    D.1965 = 0;
    return D.1965;
}
callme (int a)
{
    p.0 = p;
    D.1963 = p.0 + 12;
    a.1 = *D.1963;
    a = a.1;
    q = &a;
}
```





## An Intraprocedural Analysis Application

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

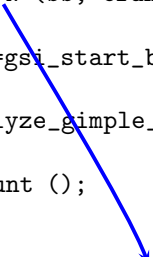
    initialize_var_count ();
    FOR_EACH_BB_FN (bb, cfun)
    {
        for (gsi=gsi_start_bb (bb); !gsi_end_p (gsi);
              gsi_next (&gsi))
            analyze_gimple_stmt (gsi_stmt (gsi));
    }
    print_var_count ();
    return 0;
}
```



## An Intraprocedural Analysis Application

```
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))
            analyze_gimple_stmt (gsi_stmt (gsi));
    }
    print_var_count ();
    return 0;
}
```



Basic block iterator parameterized with function



## An Intraprocedural Analysis Application

```
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))
            analyze_gimple_stmt (gsi_stmt (gsi));
    }
    print_var_count ();
    return 0;
}
```

Current function (i.e. function being compiled)



## An Intraprocedural Analysis Application

```
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))
            analyze_gimple_stmt (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;
    D.1963 = p.0 + 12;
    a.1 = *D.1963;
    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;
    D.1963 = p.0 + 12;
    a.1 = *D.1963;
    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;
    D.1963 = p.0 + 12;
    a.1 = *D.1963;
    a = a.1;
    q = &a;
}
```

Information collected by intraprocedural Analysis pass

- For main: 1
- For callme: 3



## Intraprocedural Analysis Results

```
main ()
{
    p = &b;
    callme (a);
    D.1965 = 0;
    return D.1965;
}
callme (int a)
{
    p.0 = p;
    D.1963 = p.0 + 12;
    a.1 = *D.1963;
    a = a.1;
    q = &a;
}
```

Information collected by intraprocedural Analysis pass

- For main: 1
- For callme: 3

Perform interprocedural analysis to get collective information





## Adding a GIMPLE Interprocedural Pass in GCC-4.5.0

1. Add the following `gimple_opt_pass` struct instance to the file  
`struct simple_ipa_opt_pass pass_inter_gimple_manipulation =`  
`{`

```
    {
        SIMPLE_IPA_PASS,           /* optimization pass type */
        "gm",                      /* name of the pass*/
        gate_gimple_manipulation,  /* gate. */
        inter_gimple_manipulation, /* execute (driver function) */
        NULL,                      /* sub passes to be run */
        NULL,                      /* next pass to run */
        0,                        /* static pass number */
        0,                        /* timevar_id */
        0,                        /* properties required */
        0,                        /* properties provided */
        0,                        /* properties destroyed */
        0,                        /* todo_flags start */
        0                          /* todo_flags end */
    }
};
```



## Adding a GIMPLE Interprocedural Pass in GCC-4.5.0

2. Write the driver function in file `gimple-manipulation.c`

3. Declare your pass in file `tree-pass.h`:

```
extern struct simple_ipa_opt_pass  
    pass_inter_gimple_manipulation;
```

4. Add your pass to the interprocedural pass list in

```
init_optimization_passes()  
  
...  
p = &all_regular_ipa_passes;  
NEXT_PASS (pass_ipa_whole_program_visibility);  
NEXT_PASS (pass_inter_gimple_manipulation);  
NEXT_PASS (pass_ipa_cp);  
...
```



## Adding a GIMPLE Interprocedural Pass in GCC-4.5.0

5. In `$SOURCE/gcc/Makefile.in`, add `gimple-manipulate.o` to the list of language independent object files. Also, make specific changes to compile `gimple-manipulate.o` from `gimple-manipulate.c`
6. Configure and build gcc for `cc1`
7. Debug using `ddd/gdb` if a need arises



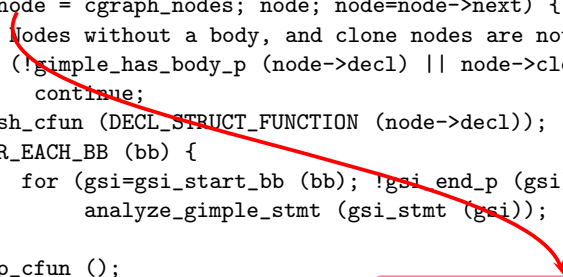
## An Interprocedural Analysis Application

```
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))
                analyze_gimple_stmt (gsi_stmt (gsi));
        }
        pop_cfun ();
    }
    print_var_count ();
    return 0;
}
```



## An Interprocedural Analysis Application

```
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))
                analyze_gimple_stmt (gsi_stmt (gsi));
        }
        pop_cfun ();
    }
    print_var_count ();
    return 0;
}
```

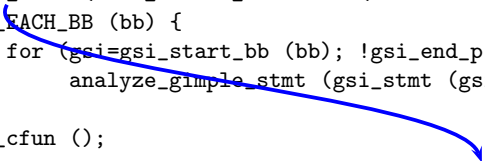


Iterating over all the callgraph nodes



## An Interprocedural Analysis Application

```
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))
                analyze_gimple_stmt (gsi_stmt (gsi));
        }
        pop_cfun ();
    }
    print_var_count ();
    return 0;
}
```

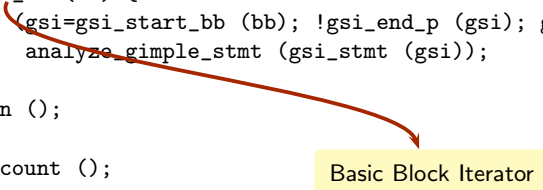


Setting the current function in context



## An Interprocedural Analysis Application

```
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))
                analyze_gimple_stmt (gsi_stmt (gsi));
        }
        pop_cfun ();
    }
    print_var_count ();
    return 0;
}
```

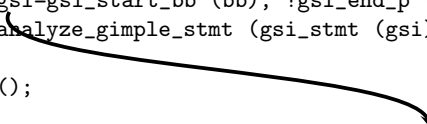


Basic Block Iterator



## An Interprocedural Analysis Application

```
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))
                analyze_gimple_stmt (gsi_stmt (gsi));
        }
        pop_cfun ();
    }
    print_var_count ();
    return 0;
}
```




GIMPLE Statement Iterator





## An Interprocedural Analysis Application

```
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))
                analyze_gimple_stmt (gsi_stmt (gsi));
        }
        pop_cfun ();
    }
    print_var_count ();
    return 0;
}
```



Resetting the function context



## An Interprocedural Analysis Application

```
static void
analyze_gimple_stmt (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++;
        }
    }
}
```



## An Interprocedural Analysis Application

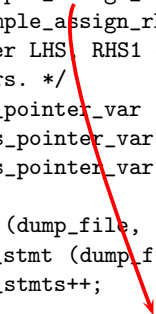
```
static void
analyze_gimple_stmt (gimple stmt)
{
    if (is_gimple_assign (stmt))
    {
        tree lhsop = gimple_assign_lhs (stmt);
        tree rhsop1 = gimple_assign_rhs1 (stmt);
        tree rhsop2 = gimple_assign_rhs2 (stmt);
        /* Check if either LHS, RHS1 or RHS2 operands
           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++;
        }
    }
}
```

Returns LHS of assignment statement



## An Interprocedural Analysis Application

```
static void
analyze_gimple_stmt (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++;
        }
    }
}
```



Returns first operand of RHS



## An Interprocedural Analysis Application

```
static void
analyze_gimple_stmt (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++;
        }
    }
}
```

Returns second operand of RHS



## An Interprocedural Analysis Application

```
static void
analyze_gimple_stmt (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



## An Interprocedural Analysis Application

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

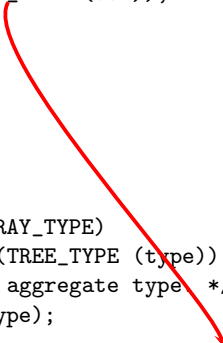
static bool
is_pointer_type (tree type)
{
    if (POINTER_TYPE_P (type))
        return true;
    if (TREE_CODE (type) == ARRAY_TYPE)
        return is_pointer_var (TREE_TYPE (type));
    /* Return true if it is an aggregate type. */
    return AGGREGATE_TYPE_P (type);
}
```



## An Interprocedural Analysis Application

```
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





## An Interprocedural Analysis Application

```
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



## Interprocedural Results

Number of Pointer Statements = 4



## Interprocedural Results

Number of Pointer Statements = 4

### Observation:

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



*Part 4*

# *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 5*

# *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`



## RTX Codes

RTL Expressions are classified into RTX codes :

- Expression codes are **names** defined in **rtl.def**
- RTX codes are C enumeration constants
- Expression codes and their meanings are **machine-independent**
- Extract the code of a RTX 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 6*

# *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;
  }
}
```

