

Porting GCC Compiler

Part I : How GCC works?

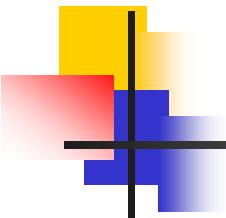


Choi, Hyung - Kyu

hectoct@altair.snu.ac.kr

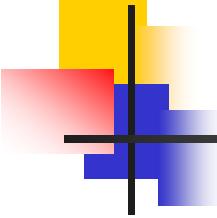
July 17, 2003

Microprocessor Architecture and System Software Laboratory



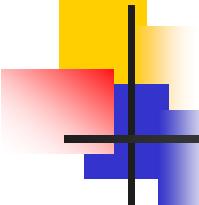
About this presentation material

- Basically this document is based on GCC 2.95.2
 - Some example are from Calm32(Samsung) port of GCC 2.95.2
- This document have been updated to follow up GCC 3.4.



Main Goal of GCC

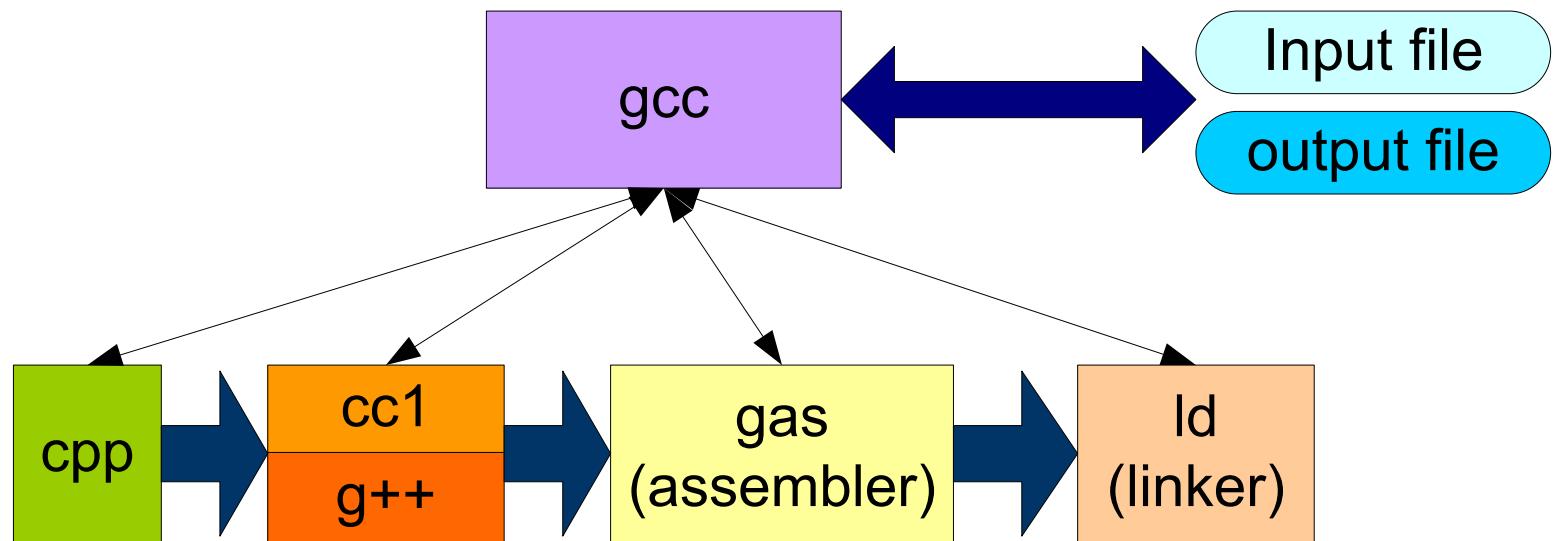
- Make a good, fast compiler
- for machines on which the GNU system aims to run including GNU/Linux variants
 - *int* is at least a 32-bit type
 - have several general registers
 - with a flat (non-segmented) byte addressed data address space (the code address space can be separate).
 - Target *ABI(application binary interface)*s may have 8, 16, 32 or 64-bit int type. char can be wider than 8 bits
- Elegance, theoretical power and simplicity are only secondary



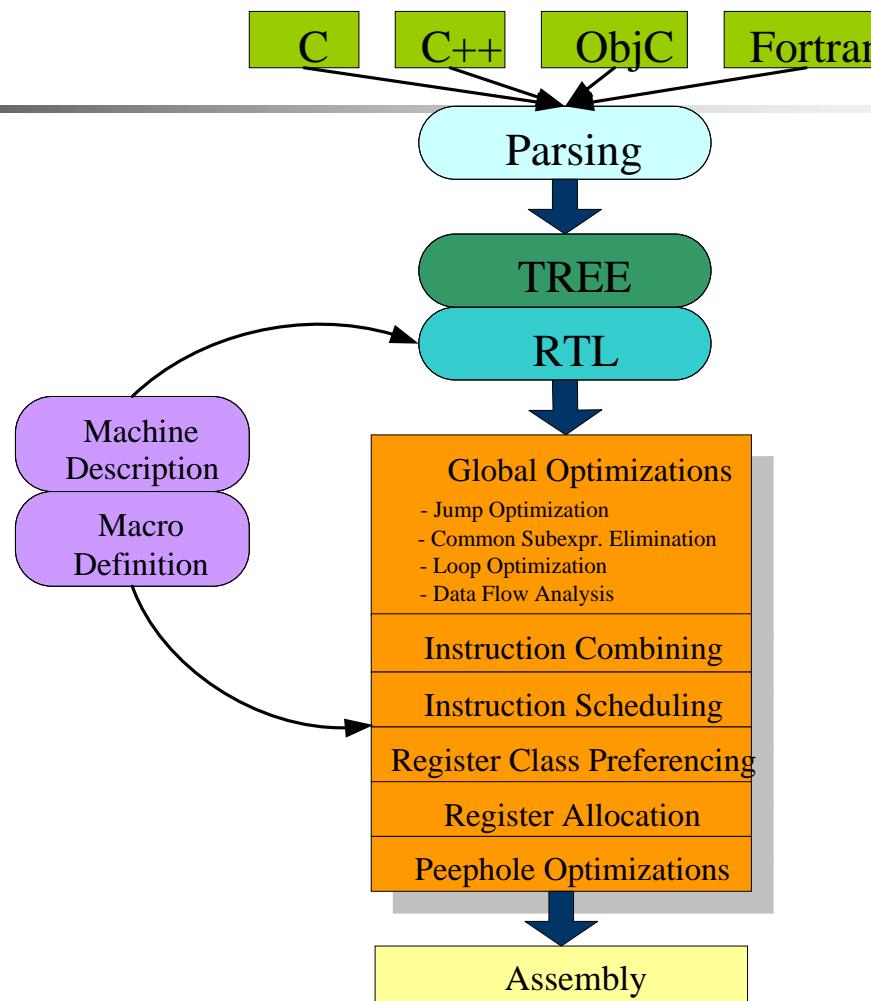
GCC Compilation System

- Compilation system includes the phases
 - Preprocessor
 - Compiler
 - Optimizer
 - Assembler
 - Linker
- *Compiler Driver* coordinates these phases.

GCC Execution

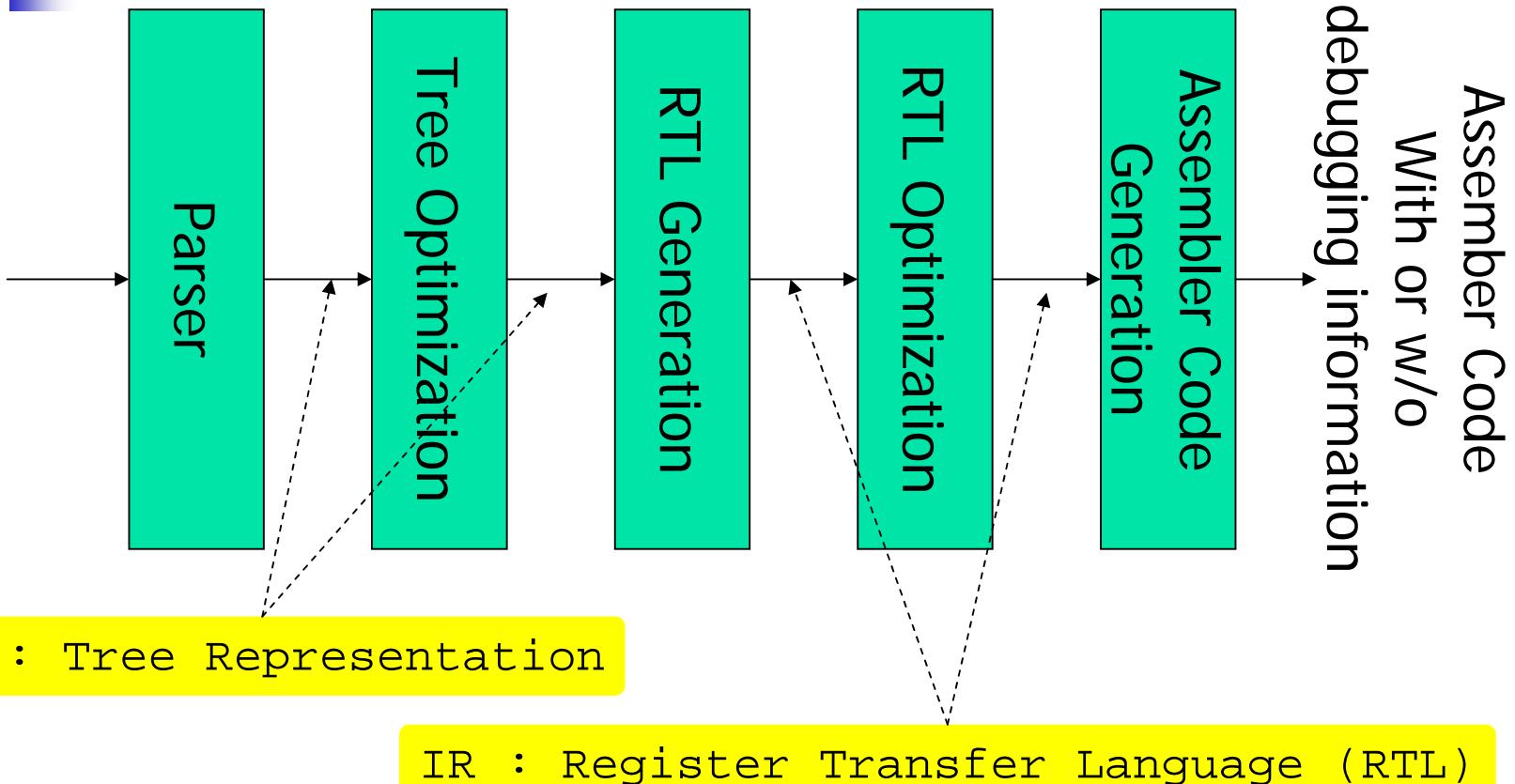


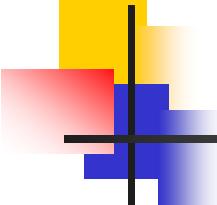
The Structure of GCC Compiler



GCC Compiler flow

For each function





Intermediate Language (1/2)

- RTL(Register Transfer Language)
- Used to describe *instructions* (instrucitons)
- Written in LISP - like form

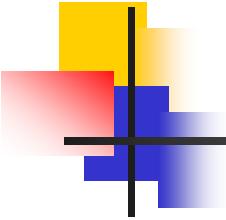
```
(set (mem:SI (reg: SI 54))  
      (reg:SI 53))
```

Above RTL statement means "*set memory pointed by register 54 with value in register 53*"

i.e. **st [r54], r53**

destination source



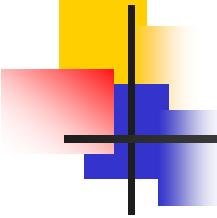


Intermediate Language (2/2)

- Example of RTL

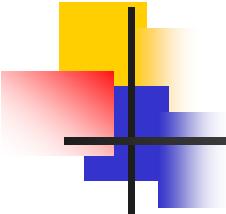
(plus:SI (reg:SI 55) (const_int -1))

- Adds two 4-byte integer (SImode) operands.
- First operand is register
 - Register is also 4-byte integer.
 - Register number is 55.
- Second operand is constant integer.
 - Value is "-1".
 - Mode is VOIDmode (not given).



Intermediate Language : machine mode

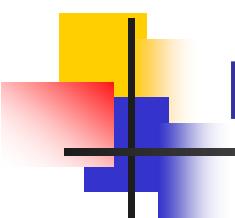
- BI mode
 - a single bit, for predicate registers
- [QI/HI/SI/DI/TI/OI] mode
 - Quarter-Integer(1bytes)
 - Half-Integer(2bytes)
 - Single Integer(4bytes)
 - Double Integer(8bytes)
 - Tetra Integer(16bytes)
 - Octa Integer(32bytes)
- PSImode
 - Partial single integer mode which occupies four bytes but doesn't really use all four. e.g. pointers on some machines
- And many other machine mode such as float-point mode, complex mode and etc.



Three Main Conversions in the compiler

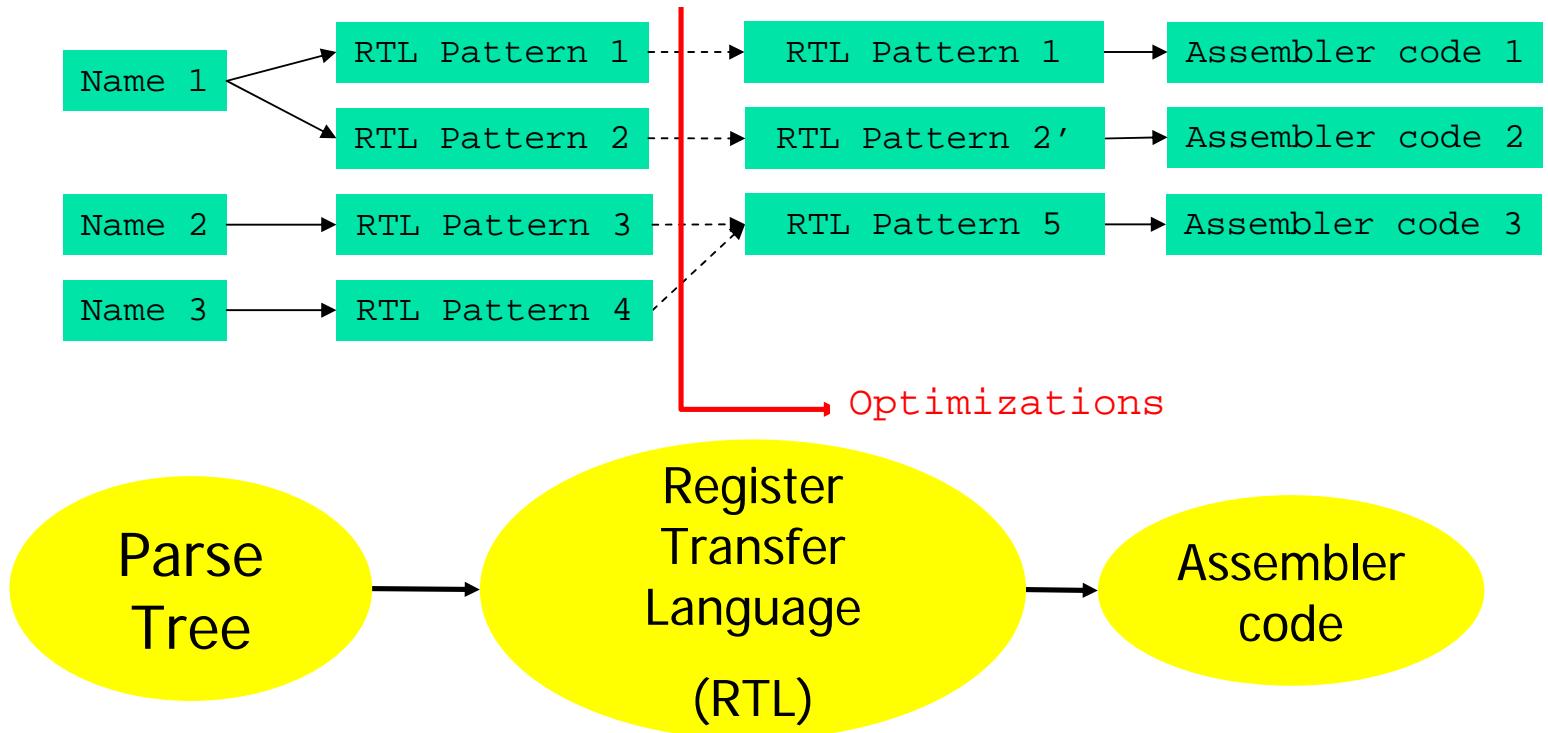
- The front end reads the source code and builds a *parse tree*.
- The *parse tree* is used to generate an RTL *insn* list based on *named instruction patterns*.
- The *insn* list is matched against the *RTL templates* to produce *assembler code*.

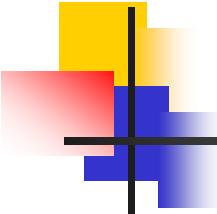




Name, RTL pattern and Assembler code

- Tree has pre-defined standard names.



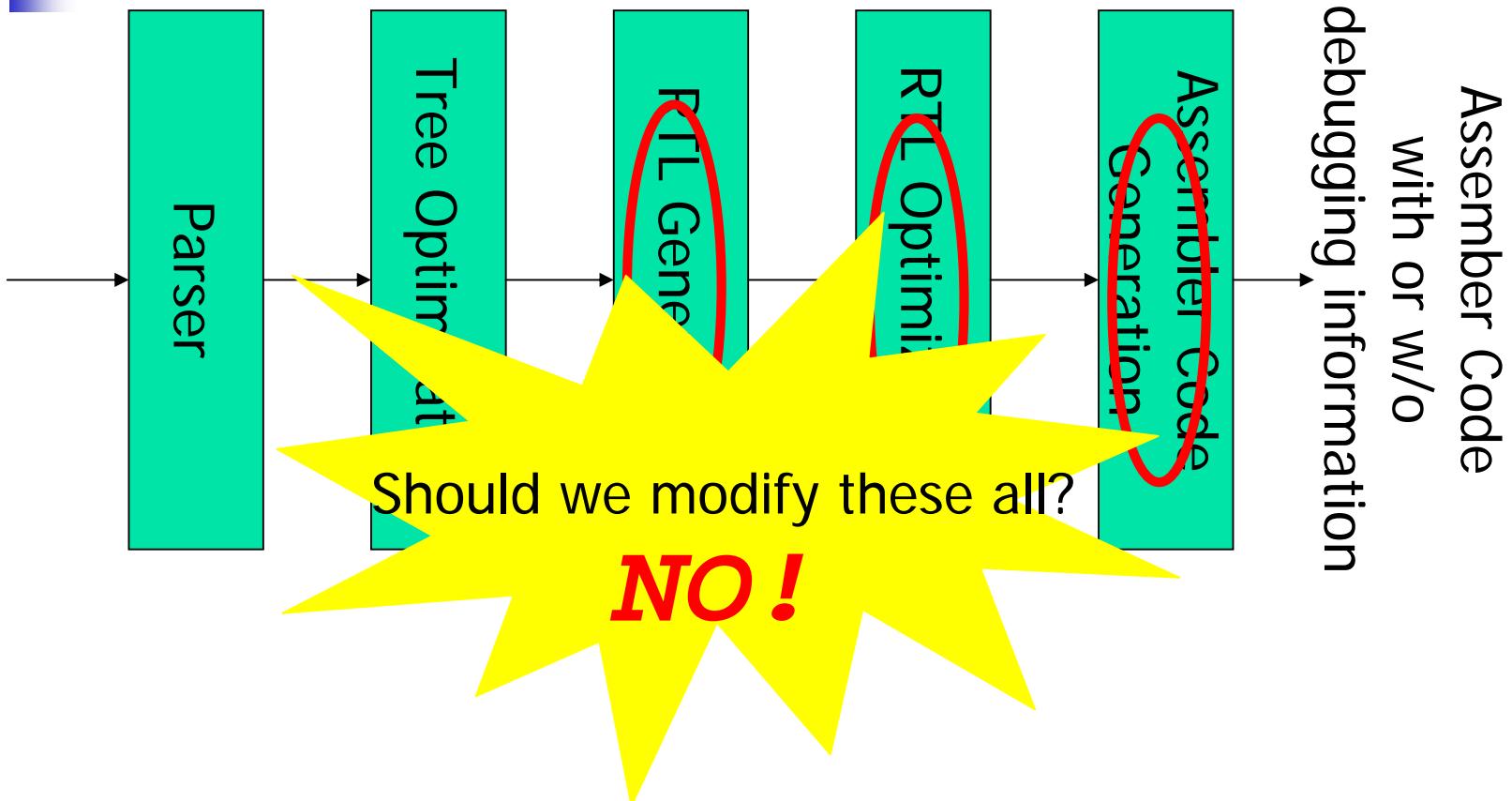


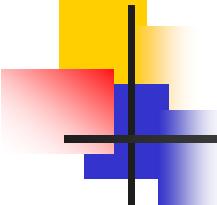
Optimizations

- Tree optimization
 - tree based inlining
 - constant folding
 - some arithmetic simplification
- RTL optimization
 - performs many well known optimizations
 - e.g. jump optimization, common subexpression elimination (CSE), loop optimization, if-conversion, instruction scheduling, register allocation and etc

How to port ?

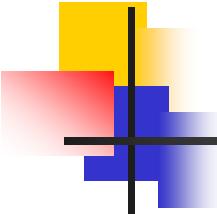
For each function





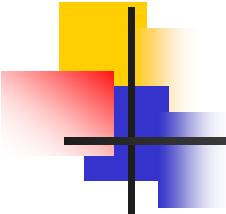
Then how ? (1/2)

- Just write below 3 files in
`<gcc_root>/gcc/config/machine/`
 - `machine.md` : *machine description*
 - `machine.h` : *target description macros*
 - `machine.c` : user-defined functions
used in `machine.md` and `machine.h`
 - e.g. SPARC
 - in `<gcc_root>/gcc/config/sparc/`
 - `sparc.md`, `sparc.h`, `sparc.c`

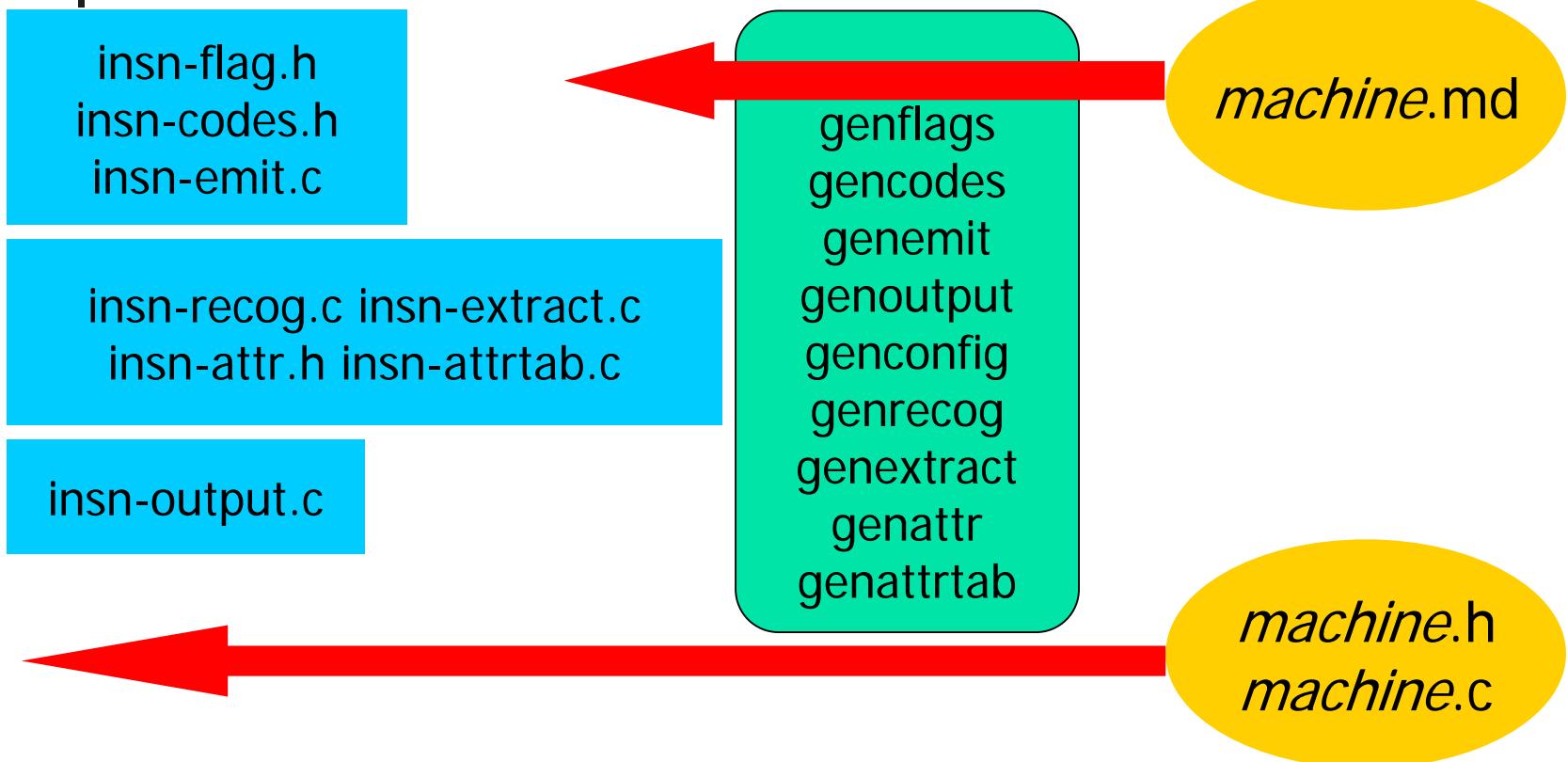


Then how ? (2/2)

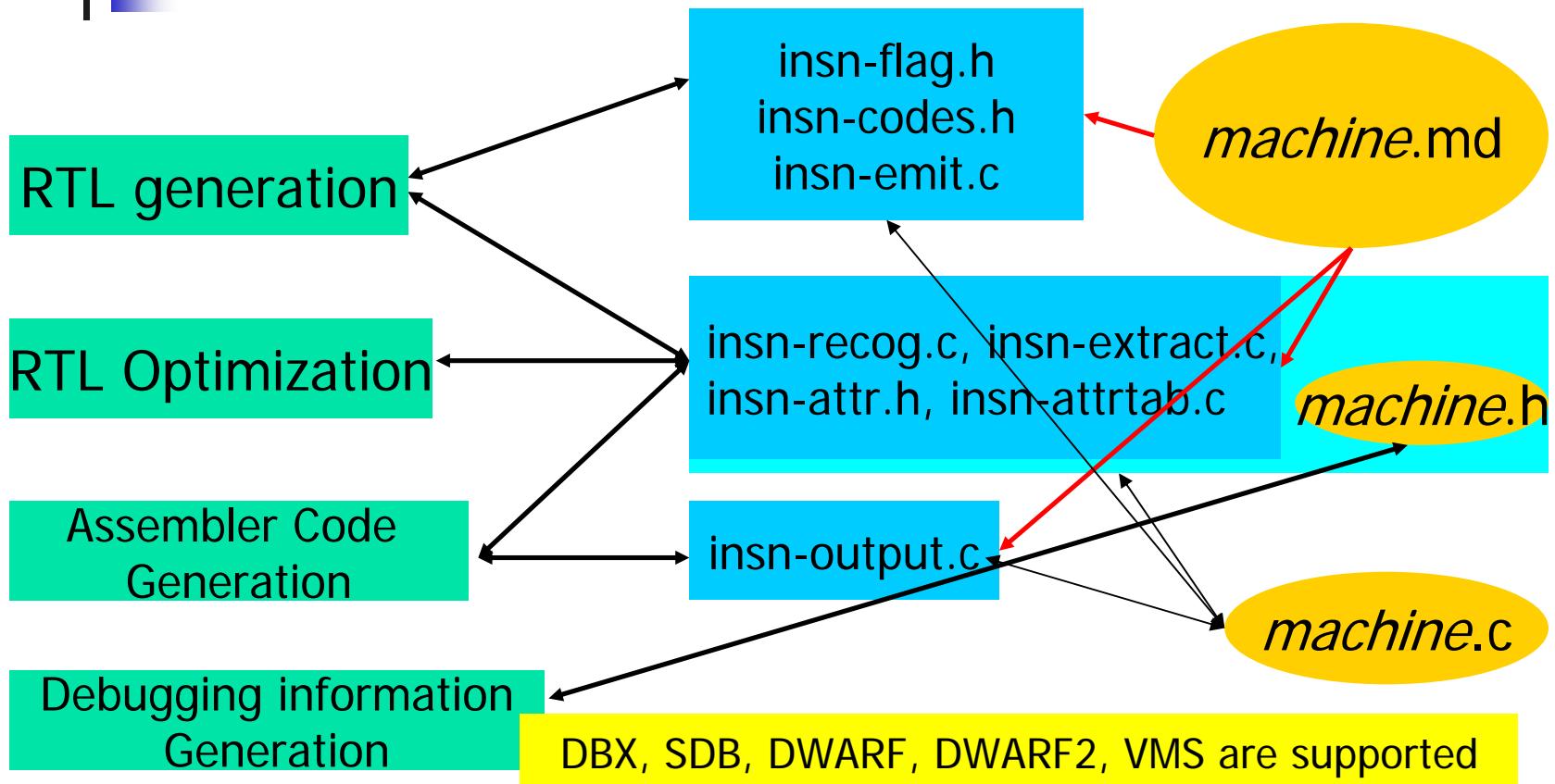
- Then let Makefile does below two jobs
 - Generate some .c and .h files from machine description(*machine.md*) file
 - Then actually compile .c and .h files including generated files.

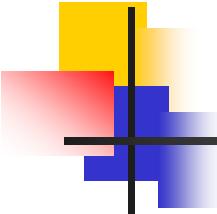


Build process (1/2)



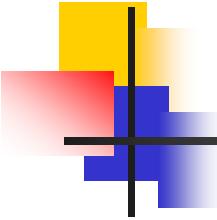
Build process (2/2)





Machine Description

- *machine.md* contains machine description
- Machine Description
 - CPU description
 - Functional Units, Latency and etc
 - RTL Patterns
 - Used when convert Tree into RTL
 - All kind of RTL Patterns which can be generated
 - Assembler mnemonic
 - etc.



Target Description Macro

- *machine.h* contains target description macros
- Target Description Macro
 - Storage layout
 - alignment, endian, structure padding and etc
 - ABI(Application Binary Interface)
 - calling convention, stack layout and etc
 - Register usage
 - allocation strategy, how value fit in registers and etc
 - Defining output assembler language
 - Controlling Debugging Information Format
 - Library supports
 - etc.

Porting GCC Compiler

Part II : In details



Choi, Hyung-Kyu

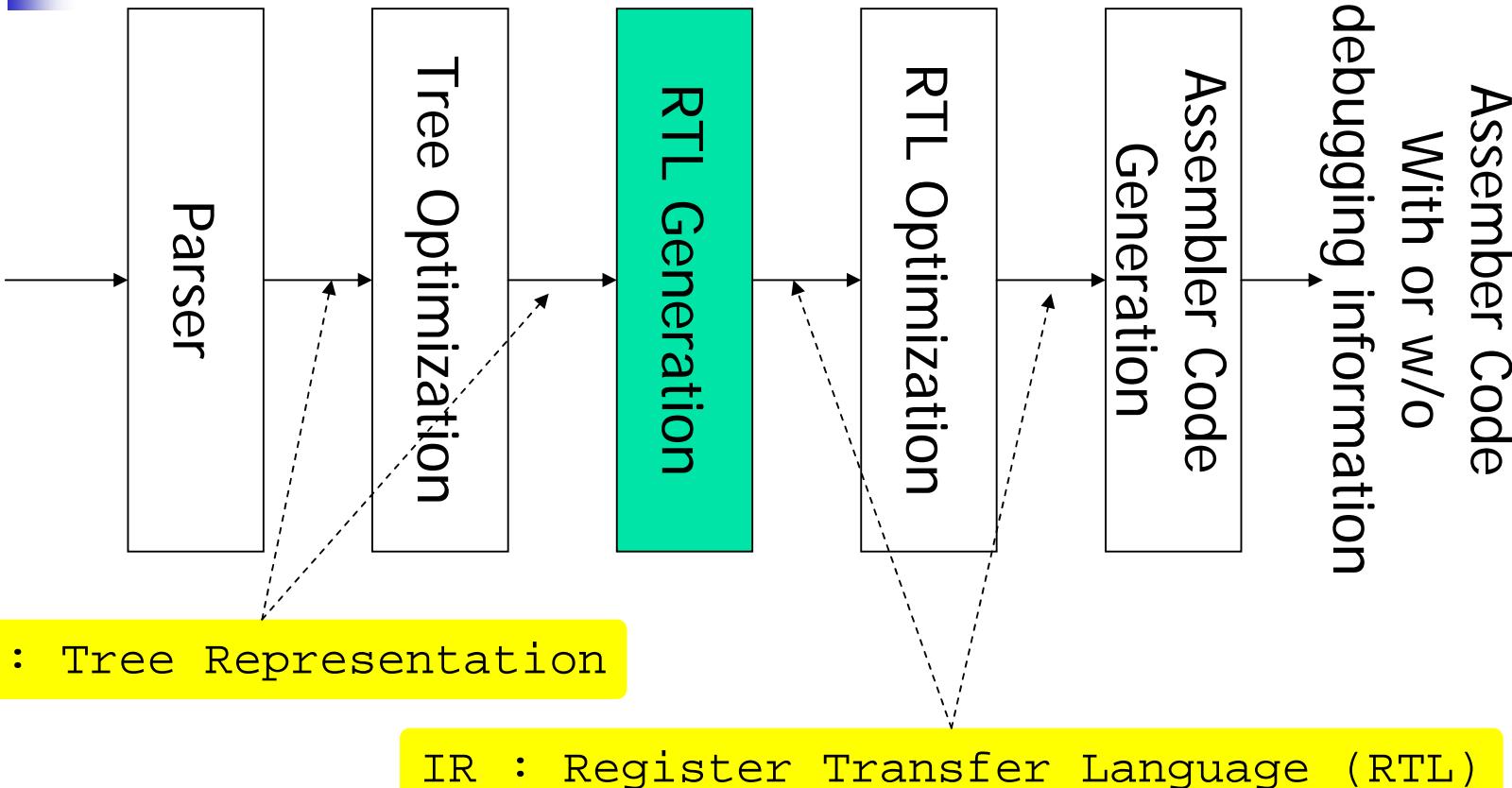
hectoct@altair.snu.ac.kr

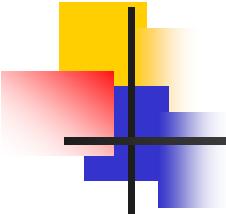
July 17, 2003

Microprocessor Architecture and System Software Laboratory

GCC Compiler flow

For each function





RTL Generation

- Convert parse tree into RTL *insn* list based on *named instruction patterns*
- How?
 - Tree has pre-defined standard pattern names
 - e.g. “addsi3”, “movsi” and etc.
 - Example of standard pattern name
 - “addsi3” : which means “add *op2* and *op1*, and storing result in *op0*, where all operands have SImode”
 - For each standard pattern name, generate RTL *insn* list defined in *machine.md*

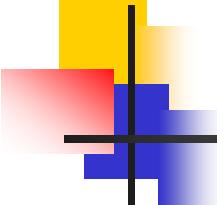
RTL Generation Example 1

Machine description : define_insn

```
(define_insn "addc"
  [(set (match_operand:SI 0 "arith_reg_operand" "=r")
        (plus:SI (plus:SI (match_operand:SI
1 "arith_reg_operand" "0")
                    (match_operand:SI
2 "arith_reg_operand" "r")))
        (reg:SI 18)))
   (set (reg:SI 18)
        (ltu:SI (plus:SI (match_dup 1) (match_dup 2))
        (match_dup 1)))]
  ""
  "ADC\t%0,%2"
  [(set_attr "type" "arith")])
```

The diagram illustrates the structure of the machine description. The code is divided into several colored sections:

- Name:** The identifier "addc" is highlighted with a red oval.
- RTL Template:** The assembly-like code within the first set of brackets.
- Condition (optional):** The empty string "" following the first bracket.
- Output Template:** The string "ADC\t%0,%2" following the second bracket.
- Attributes:** The final set of brackets containing the "set_attr" command.



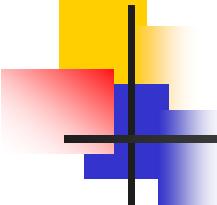
RTL Generation Example 1a

■ Standard name in Tree

In addsi3.c

```
int i;  
int  
main()  
{  
    i = i + 1;  
}
```

```
movsi ; r54 < #i  
movsi ; r55 < #i  
movsi ; r56 < mem(r55)  
addsi3 ; r57 < r56 + 1  
movsi ; mem(r54) < r57
```



RTL Generation Example 1b

- Find RTL pattern by name defined in .md

In `machine.md`

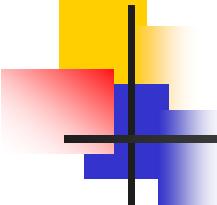
```
(define_insn "addsi3"
  [(set (match_operand:SI 0
    "arith_reg_operand" "=r,r")
        (plus:SI (match_operand:SI 1
          "arith_operand" "%0,0")
          (match_operand:SI 2
            "arith_operand" "r,I")))
      (clobber (reg:SI 18))])
```

.. w

.. .

In `insn-emit.c`

```
rtx
gen_addsi3 (operand0, operand1, operand2)
  rtx operand0; rtx operand1; rtx operand2;
{
  return gen_rtx_PARALLEL (VOIDmode,
    gen_rtvec (2,
      gen_rtx_SET (VOIDmode, operand0,
        gen_rtx_PLUS (SImode, operand1, operand2)),
      gen_rtx_CLOBBER (VOIDmode,
        gen_rtx_REG (SImode,
          18))));
```



RTL Generation Example 1c

- Generate RTL from Tree

```
movsi ; r54 ← #i  
movsi ; r55 ← #i  
movsi ; r56 ← mem(r55)  
addsi3 ; r57 ← r56 + 1  
movsi ; mem(r54) ←r57
```

In **addsi3.c.rtl**

```
(insn 14 13 16 (parallel[  
  (set (reg:SI 57)  
    (plus:SI (reg:SI 56)  
      (const_int 1  
        [0x1])))  
  (clobber (reg:SI 18 t))  
]) -1 (nil)  
(nil))
```

RTL Generation Example 2

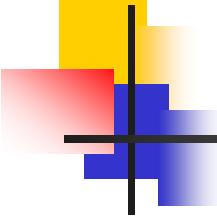
- Machine description : define_expand

```
(define_expand "zero_extendhi2" [ (set (match_operand:SI 0 "register_operand" "")  
          (and:SI (subreg:SI  
                    (match_operand:HI 1 "register_operand" "")  
                    0)  
                  (match_dup 2))))]  
  ""  
  "operands[2]=force_reg(SImode,GEN_INT(65535));")
```

The diagram illustrates the structure of an RTL expansion macro. It is divided into four horizontal sections by colored bars:

- Name:** The first section, highlighted in red, contains the macro name "zero_extendhi2".
- RTL Template:** The second section, highlighted in yellow, contains the RTL template code.
- Condition (optional):** The third section, highlighted in green, contains the condition "0".
- Preparation statement:** The fourth section, highlighted in blue, contains the preparation statement "operands[2]=force_reg(SImode,GEN_INT(65535));".

Curly braces on the right side group the sections into pairs: {RTL Template, Condition} and {Name, Preparation statement}.



RTL Generation Example 2a

- We can generate RTL sequences from standard name while generating RTL patterns.
 - by using “*define_expand*” instead of “*define_insn*”

Before RTL generation

```
 . . .
zero_extendhi32: r54<-r52
. . .
```

After RTL generation

```
(insn 23 22 24 0x0 (set (reg:SI 55)
  (const_int 65535 [0xffff])) -1 (nil)
  (nil))

(insn 24 23 25 0x0 (set (reg:SI 54)
  (and:SI (subreg:SI (reg:SI 52) 0)
    (reg:SI 55))) -1 (nil)
  (nil))
```

RTL Generation Example 3

■ Machine description : define_split

```
(define_split
```

```
  [(set(match_operand:DI 0 "arith_reg_operand" "=r" )  
        (plus:DI(match_operand:DI 1 "arith_reg_operand" "%0" )  
                (match_operand:DI 2 "arith_reg_operand" "r" )))  
   (clobber (reg:SI 18))]
```

```
  "reload_completed"
```

```
  [ . . . ]
```

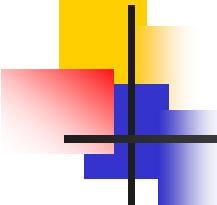
```
  { . . .  
    DONE; } "
```

} insn pattern

Condition

new insn patterns

preparation
statements



RTL Generation Example 3a

- We can also split generated insn pattern into new insn patterns.
 - by using “*define_split*” instead of “*define_insn*”

In adddi3.c

```
long long i;  
  
int  
main()  
{  
    i = i+1;  
}
```

While RTL generation

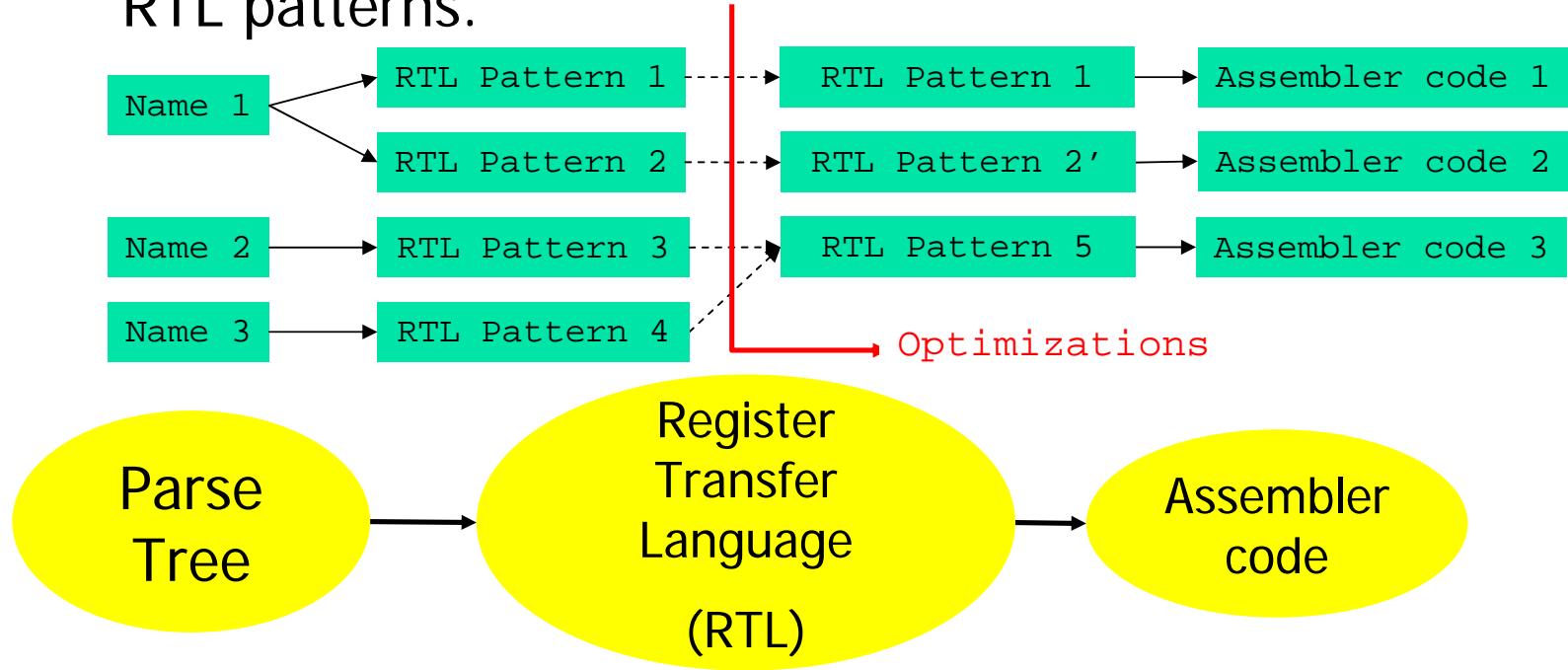
```
movdi ; r54 ← #i  
movdi ; r55 ← #I  
movdi ; r56 ← mem(r55)  
movdi ; r57 ← const 1  
adddi3 ; let's split  
movdi ; mem(r54) ← r58
```

After splitting standard name

```
movdi ; r54 ← #i  
movdi ; r55 ← #I  
movdi ; r56 ← mem(r55)  
movdi ; r57 ← const 1  
adddi3 ;  
addc ;  
movdi ; mem(r54) ← r58
```

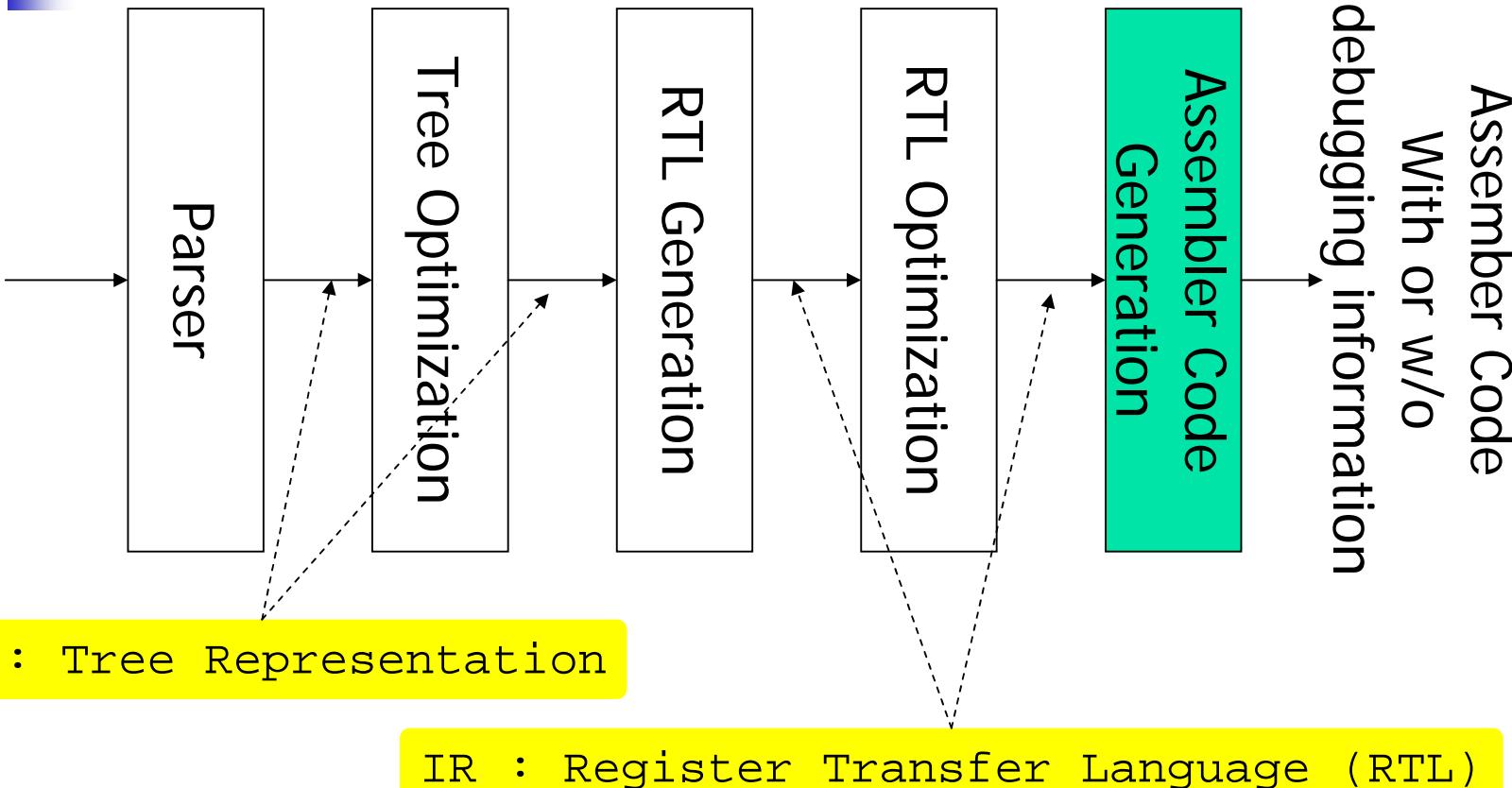
Name, RTL pattern and Assembler code

- There can be only **one** name (standard or not) for **one unique** RTL pattern. But one name can have multiple RTL patterns.



GCC Compiler flow

For each function



Assembly code Generation

Example 1a

- Let's think previous example

In adddi3.c

```
long long i;  
  
int  
main()  
{  
    i = i+1;  
}
```

After splitting standard name

(and just before Assembly code generation)

```
movdi ;  
movdi ;  
movdi ;  
movdi ;  
addsi3 ; r2 ← r2 + r4  
addc ; r1 ← r1 + r3  
movdi ;
```

Assembly code Generation

Example 1b

- Find asm output by RTL pattern matching

In `machine.md`

```
(define_insn "addc"
  [(set (match_operand:SI 0 "arith_reg_operand" "=r")
        (plus:SI (plus:SI (match_operand:SI
1 "arith_reg_operand" "0")
                    (match_operand:SI
2 "arith_reg_operand" "r")))
        (reg:SI 18)))
  (set (reg:SI 18)
    (ltu:SI (plus:SI (match_dup 1) (match_dup 2))
  (match_dup 1)))]
  ""
  "ADC\t%0,%2"
  [(set_attr "type" "arith")])
```

In `insn-output.c`

```
const char * const
insn_template[] = {
  . . .
  "ADC\t%0,%2",
  . . .
};
```

Assembly code Generation

Example 1c

- Find asm output by RTL pattern matching

After splitting standard name

(and just before Assembler code generation)

...

addsi3 ; r2 \leftarrow r2 + r4

addc ; r1 \leftarrow r1 + r3

...

In addi3.s

...

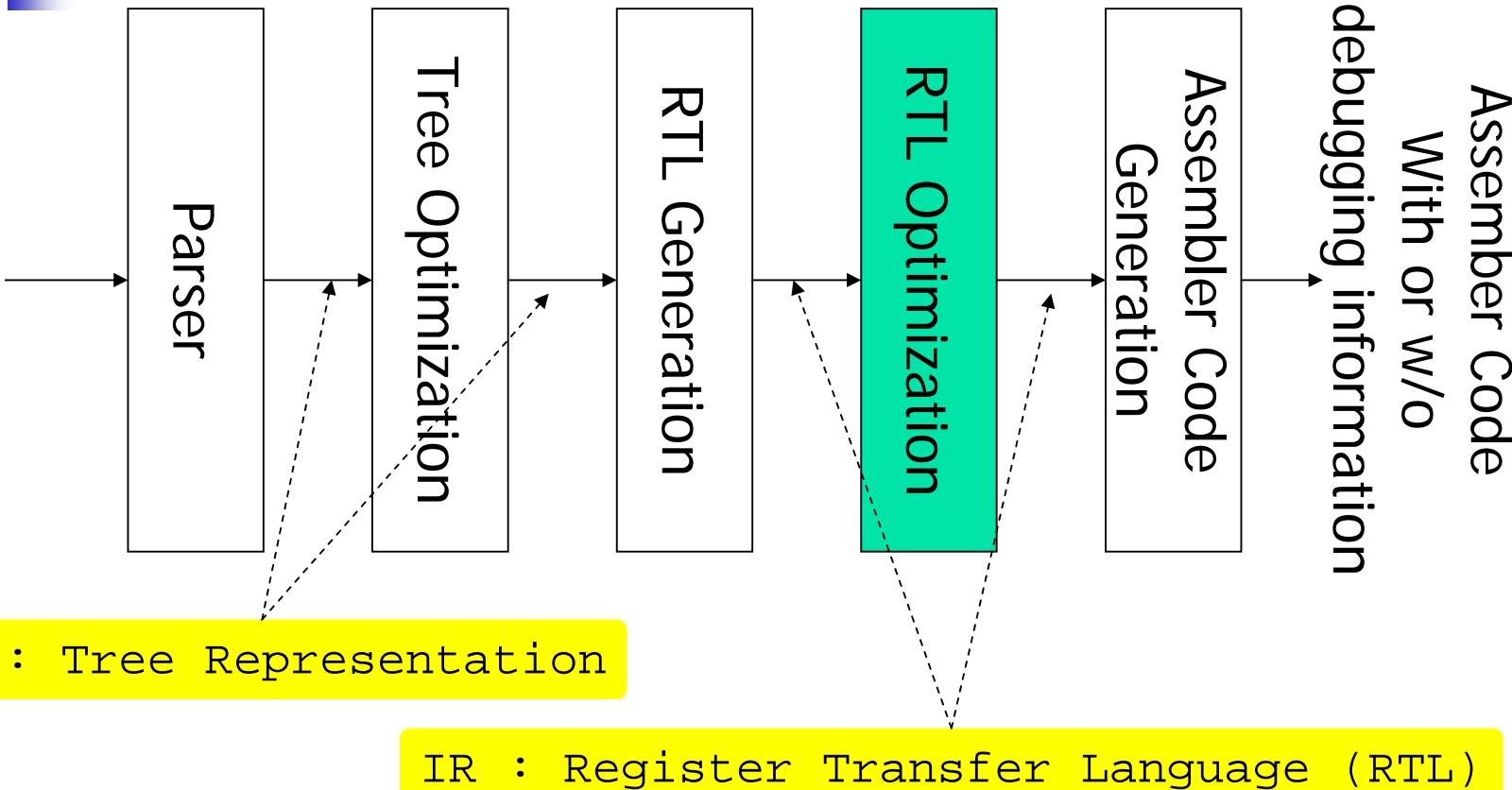
ADD r2,r4

ADC r1,r3

...

GCC Compiler flow

For each function



Optimization and RTL

Example 1a

- Let's think about two different RTL for one standard name

```
(define_insn "addsi3"
  [(set (match_operand:SI 0 "arith_reg_operand" "=r,r")
        (plus:SI (match_operand:SI 1 "arith_operand" "%0,0")
                  (match_operand:SI 2 "arith_operand" "r,I")))
   (clobber (reg:SI 18))]

  "w"
  .
  .
  )

  
```

Optimization and RTL

Example 1b

- For same example as before

Before optimization

```
. . .
addsi3
addc
movesi
movesi
. . .
```

In RTL form

```
[ (set (match_operand:SI 0 "arith_reg_operand" "=r,r")
      (plus:SI (match_operand:SI 1 "arith_operand" "%0,0")
                (match_operand:SI 2 "arith_operand" "r,I")))
  (clobber (reg:SI 18))]           ← Define register 18
[ (set (match_operand:SI 0 "arith_reg_operand" "=r")
      (plus:SI (plus:SI (match_operand:SI 1 "arith_reg_operand" "0")
                        (match_operand:SI 2 "arith_reg_operand" "r"))
                (reg:SI 18)))           ← Use register 18
  (set (reg:SI 18)
    (ltu:SI (plus:SI (match_dup 1) (match_dup 2)) (match_dup 1))))]
```

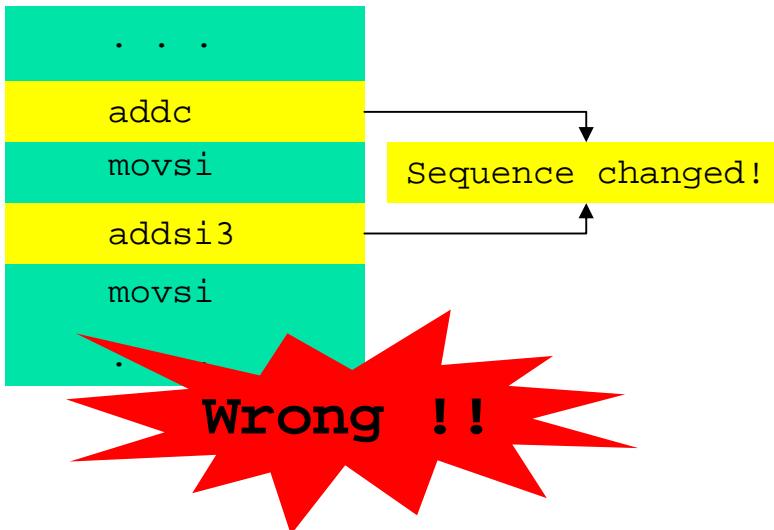
Optimization and RTL

Example 1b

- For same example as before

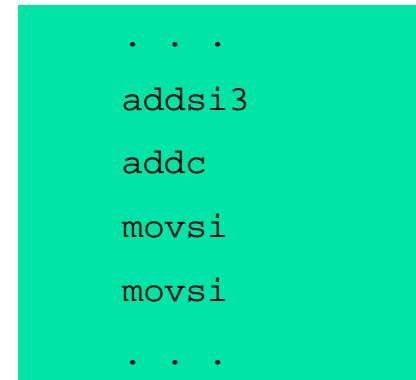
After instruction scheduling

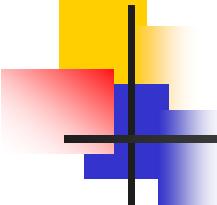
Without (clobber 18 t)



After instruction scheduling

With (clobber 18 t)





Optimization and attributes 2a

- You can introduce attributes by using "*define_attr*"
- You can assign multiple attributes for each RTL pattern

In `machine.md`

```
(define_attr "needs_delay_slot" "yes,no" (const_string "no"))
```

```
(define_attr "in_delay_slot" "yes,no"
  (cond [(eq_attr "type" "arith") (const_string "no")]
        (const_string "no")))
```

```
(define_insn "return"
  [ . . . ]
  " . . . "
  "JMPD\\tR14%#"
  [(set_attr "type" "return")
   (set_attr "needs_delay_slot" "yes")])
```

```
(define_insn "addc"
  [ . . . ]
  ""
  "ADC\\t%0,%2"
  [(set_attr "type" "arith")])
```

Optimization

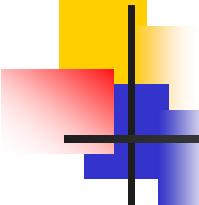
Set "in_delay_slot" attribute of "addc" to be "no"

In *machine.md*

```
(define_attr "needs_delay_slot" "yes,no" (cond  
  [ (const_string "no") ]  
  [ (eq_attr "type" "arith") (const_string "no") ]  
  [ (const_string "no") ])
```

```
(define_insn "return"  
  [ . . . ]  
  " . . . "  
  "JMPD\\tR14%#"  
  [(set_attr "type" "return")  
   (set_attr "needs_delay_slot" "yes")])
```

```
(define_insn "addc"  
  [ . . . ]  
  "  
  "ADC\\t%0,%2"  
  (set_attr "type" "arith"))
```



Optimization and attributes 2c

- Finally you can specify delay slot scheduling policy by “`define_delay`”
- e.g. “`addc`” can not be in delay slot of “`return`”

In `machine.md`

```
(define_delay
  (eq_attr "needs_delay_slot" "yes")
  [(eq_attr "in_delay_slot" "yes") (nil) (nil)])
(define_delay
  (eq_attr "type" "return")
  . . .)
```

```
(define_insn "addc"
  . .
  [(set_attr "type" "arith")])
```

```
(define_insn "return"
  . .
  [(set_attr "type" "return")
   (set_attr "needs_delay_slot" "yes")])
```

Porting GCC Compiler

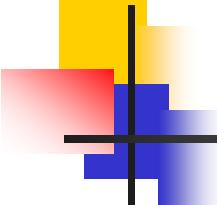
Part III : Other things

Choi, Hyung-Kyu

hectoct@altair.snu.ac.kr

July 17, 2003

Microprocessor Architecture and System Software Laboratory

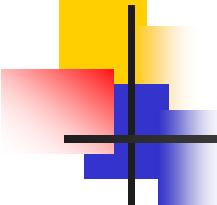


Not explained here 1a

- When generate RTL from Tree
 - Find RTL template by name?
 - No, also check machine mode and predicate for operand

```
(define_insn "addsi3"
  [(set (match_operand:SI 0 "arith_reg_operand" "=r,r")
        (plus:SI (match_operand:SI 1 "arith_operand" "%0,0")
                  (match_operand:SI 2 "arith_operand" "r,I"))))]
  ...
)
```

- How and where should we define predicate?



Not explained here 1b

- Predicate is C function with 2 arguments defined in *machine.c*

In *machine.c*

```
/* Returns 1 if OP is a valid source operand for an arithmetic insn.  
 */  
  
int arith_operand (rtx op, enum machine_mode mode)  
{  
    if (arith_reg_operand (op, mode))  
        return 1;  
  
    if (GET_CODE (op) == CONST_INT && CONST_OK_FOR_I (INTVAL (op)))  
        return 1;  
  
    return 0;  
}
```

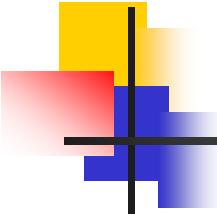
Not explained here 1c

- What happen, if there is no matching RTL template?
 - Automatically convert operand's machine mode by generating “**movm**” pattern to generate RTL
 - If fails, just abort!
 - e.g. If “addsi3” accepts only *register* and *immediate* operands

```
int i;  
int  
main()  
{  
    i = i + 1;  
}
```

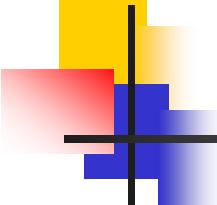
Generated automatically by GCC

```
movsi ; r54 ← #i  
movsi ; r55 ← #i  
movsi ; r56 ← mem(r55)  
addsi3 ; r57 ← r56 + 1  
movsi ; mem(r54) ← r57
```



Not explained here 2

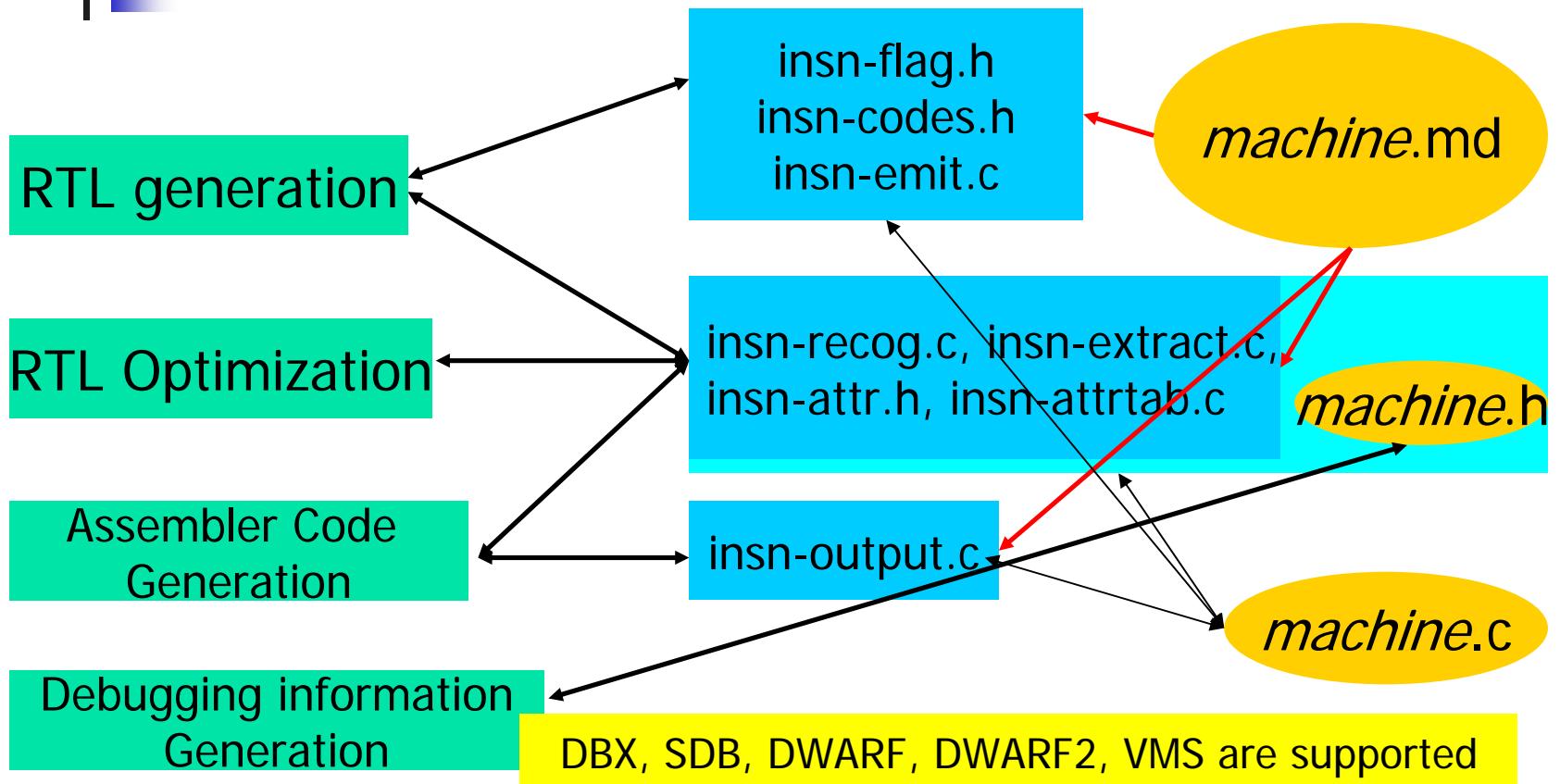
- In this presentation, only flow of GCC Compiler is explained.
- No implementation detail
 - RTL syntax
 - Target Macros in *machine.h*
 - Machine descriptions in *machine.md*
 - etc

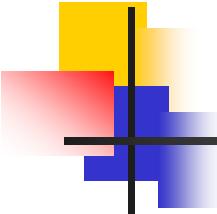


Limitation of GCC

- When new architecture feature is introduced, we can't porting by this method explained before.
 - You should modify core part of GCC Compiler.
 - e.g. There was no support for “register window”, “delay slot” in old version.
 - e.g. There was no support for 1bit-register before, such as predicate register in Itanium
- You don't have to consider optimization every time. But sometimes you should consider!

Summary





References

- GCC Internals Manual
 - <http://gcc.gnu.org/onlinedocs/>
 - Especially Ch.7 ~ Ch.11
- GCC home page
 - <http://gcc.gnu.org>
- crossgcc (mailing list)
 - archives : <http://sources.redhat.com/ml/crossgcc/>