Workshop on Essential Abstractions in GCC

Gray Box Probing of GCC

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

Department of Computer Science and Engineering,
Indian Institute of Technology, Bombay

1 July 2012

Part 1

Preliminaries

Outline

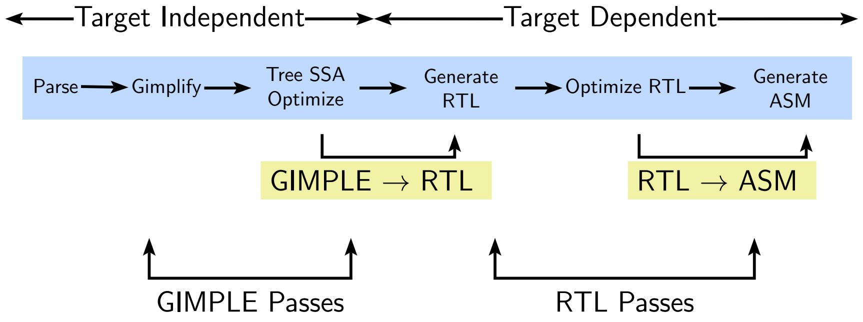
- Introduction to Graybox Probing of GCC
- Examining AST
- Examining GIMPLE Dumps
  - Translation of data accesses
  - Translation of intraprocedural control flow
  - Translation of interprocedural control flow
- Examining RTL Dumps
- Examining Assembly Dumps
- Examining GIMPLE Optimizations
- Conclusions

What is Gray Box Probing of GCC?

- Black Box probing:
  Examining only the input and output relationship of a system
- White Box probing:
  Examining internals of a system for a given set of inputs
- Gray Box probing:
  Examining input and output of various components/modules
  - Overview of translation sequence in GCC
  - Overview of intermediate representations
  - Intermediate representations of programs across important phases

Basic Transformations in GCC

Tranformation from a language to a *different* language



Transformation Passes in GCC 4.6.2

- A total of 207 unique pass names initialized in `${SOURCE}/gcc/passes.c`
  Total number of passes is 241.
  - Some passes are called multiple times in different contexts
    Conditional constant propagation and dead code elimination are called thrice
  - Some passes are enabled for specific architectures
  - Some passes have many variations (eg. special cases for loops)
    Common subexpression elimination, dead code elimination
- The pass sequence can be divided broadly in two parts
  - Passes on GIMPLE
  - Passes on RTL
- Some passes are organizational passes to group related passes

Passes On GIMPLE in GCC 4.6.2

Pass Group	Examples	Number of passes
Lowering	GIMPLE IR, CFG Construction	10
Simple Interprocedural Passes (Non-LTO)	Conditional Constant Propagation, Inlining, SSA Construction	38
Regular Interprocedural Passes (LTO)	Constant Propagation, Inlining, Pointer Analysis	10
LTO generation passes		02
Other Intraprocedural Optimizations	Constant Propagation, Dead Code Elimination, PRE Value Range Propagation, Rename SSA	65
Loop Optimizations	Vectorization, Parallelization, Copy Propagation, Dead Code Elimination	28
Generating RTL		01
Total number of passes on GIMPLE		154

Passes On RTL in GCC 4.6.2

Pass Group	Examples	Number of passes
Intraprocedural Optimizations	CSE, Jump Optimization, Dead Code Elimination, Jump Optimization	27
Loop Optimizations	Loop Invariant Movement, Peeling, Unswitching	07
Machine Dependent Optimizations	Register Allocation, Instruction Scheduling, Peephole Optimizations	50
Assembly Emission and Finishing		03
Total number of passes on RTL		87

Finding Out List of Optimizations

Along with the associated flags

- A complete list of optimizations with a brief description

  gcc -c --help=optimizers

- Optimizations enabled at level 2 (other levels are 0, 1, 3, and s)

  gcc -c -O2 --help=optimizers -Q

Producing the Output of GCC Passes

- Use the option -fdump-<ir>-<passname>

  <ir> could be
  - tree: Intraprocedural passes on GIMPLE
  - ipa: Interprocedural passes on GIMPLE
  - rtl: Intraprocedural passes on RTL
- Use all in place of <pass> to see all dumps

  Example: gcc -fdump-tree-all -fdump-rtl-all test.c
- Dumping more details:

  Suffix raw for tree passes and details or slim for RTL passes

  Individual passes may have more verbosity options (e.g. -fsched-verbose=5)
- Use -S to stop the compilation with assembly generation
- Use --verbose-asm to see more detailed assembly dump

Total Number of Dumps

Optimization Level	Number of Dumps	Goals
Default	47	Fast compilation
O1	138	
O2	164	
O3	174	
Os	175	Optimize for space

Selected Dumps for Our Example Program

GIMPLE dumps (t)

001t.tu
003t.original
004t.gimple
006t.vcg
009t.omplower
010t.lower
012t.eh
013t.cfg
017t.ssa
018t.veclower
019t.inline_param1
020t.einline
037t.release_ssa
038t.inline_param2
044i.whole-program
048i.inline
138t.cplxlower0
143t.optimized
224t.statistics

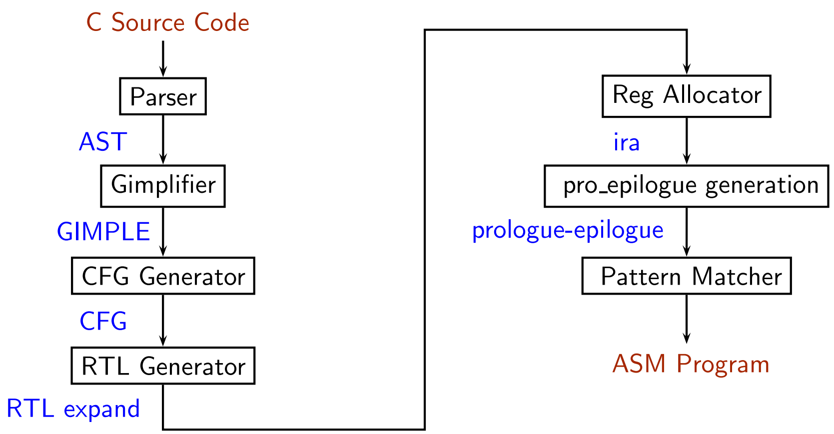
ipa dumps (i)

000i.cgraph
014i.visibility
015i.early_local_cleanups
044i.whole-program
048i.inline

rtl dumps (r)

144r.expand
145r.sibling
147r.initvals
148r.unshare
149r.vregs
150r.into_cfglayout
151r.jump
163r.reginfo
183r.outof_cfglayout
184r.split1
186r.dfinit
187r.mode_sw
188r.asmcons
191r.ira
194r.split2
198r.pro_and_epilogue
211r.stack
212r.alignments
215r.mach
216r.barriers
220r.shorten
221r.nothrow
222r.final
223r.dfinish
assembly

Passes for First Level Graybox Probing of GCC



Lowering of abstraction!

Part 2

Examining AST Dump

Generating Abstract Syntax Tree

```
$ gcc -fdump-tree-original-raw test.c
```


Abstract Syntax Tree

test.c

```
int a;
int main()
{
    a = 55;
}
```

test.c.003t.original

```
;; Function main (null)
;; enabled by -tree-original

@1      bind_expr        type: @2      body: @3
@2      void_type        name: @4      algn: 8
@3      modify_expr      type: @5      op 0: @6      op 1: @7
@4      type_decl        name: @8      type: @2
@5      integer_type     name: @9      size: @10     algn: 32
                         prec: 32      sign: signed  min : @11
                         max : @12
@6      var_decl         name: @13     type: @5      srcp: t1.c:1
                         size: @10     algn: 32      used: 1
@7      integer_cst      type: @5      low : 55
@8      identifier_node  strg: void    lngt: 4
@9      type_decl        name: @14     type: @5
@10     integer_cst      type: @15     low : 32
@11     integer_cst      type: @5      high: -1      low : -2147483648
@12     integer_cst      type: @5      low : 2147483647
@13     identifier_node  strg: a       lngt: 1
@14     identifier_node  strg: int     lngt: 3
@15     integer_type     name: @16     size: @17     algn: 64
                         prec: 64      sign: unsigned min : @18
                         max : @19
@16     identifier_node  strg: bit_size_type          lngt: 13
@17     integer_cst      type: @15     low : 64
@18     integer_cst      type: @15     low : 0
@19     integer_cst      type: @15     low : -1
```

Part 3

Examining GIMPLE Dumps

Gimplifier

- About GIMPLE
  - Three-address representation derived from GENERIC
    Computation represented as a sequence of basic operations
    Temporaries introduced to hold intermediate values
  - Control construct are explicated into conditional jumps
- Examining GIMPLE Dumps
  - Examining translation of data accesses
  - Examining translation of control flow
  - Examining translation of function calls

GIMPLE: Composite Expressions Involving Local and Global Variables

test.c

```
int a;

int main()
{
  int x = 10;
  int y = 5;

  x = a + x * y;
  y = y - a * x;

}
```

test.c.004t.gimple

```
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;
```

Global variables are treated as "memory locations" and local variables are treated as "registers"

GIMPLE: 1-D Array Accesses

test.c

```
int main()
{
  int a[3], x;
  a[1] = a[2] = 10;
  x = a[1] + a[2];
  a[0] = a[1] + a[1]*x;
}
```

test.c.004t.gimple

```
a[2] = 10;
D.1952 = a[2];
a[1] = D.1952;
D.1953 = a[1];
D.1954 = a[2];
x = D.1953 + D.1954;
D.1955 = x + 1;
D.1956 = a[1];
D.1957 = D.1955 * D.1956;
a[0] = D.1957;
```

GIMPLE: 2-D Array Accesses

test.c

```
int main()
{
  int a[3][3], x, y;
  a[0][0] = 7;
  a[1][1] = 8;
  a[2][2] = 9;
  x = a[0][0] / a[1][1];
  y = a[1][1] % a[2][2];
}
```

test.c.004t.gimple

```
a[0][0] = 7;
a[1][1] = 8;
a[2][2] = 9;
D.1953 = a[0][0];
D.1954 = a[1][1];
x = D.1953 / D.1954;
D.1955 = a[1][1];
D.1956 = a[2][2];
y = D.1955 % D.1956;
```

- No notion of "addressable memory" in GIMPLE.
- Array reference is a single operation in GIMPLE and is linearized in RTL during expansion

GIMPLE: Use of Pointers

test.c

```
int main()
{
  int **a,*b,c;
  b = &c;
  a = &b;
  **a = 10;   /* c = 10 */
}
~
```

test.c.004t.gimple

```
main ()
{
  int * D.1953;
  int * * a;
  int * b;
  int c;

  b = &c;
  a = &b;
  D.1953 = *a;
  *D.1953 = 10;
}
```


GIMPLE: Use of Structures

test.c

```
typedef struct address
{ char *name;
} ad;

typedef struct student
{ int roll;
  ad *ct;
} st;

int main()
{ st *s;
  s = malloc(sizeof(st));
  s->roll = 1;
  s->ct=malloc(sizeof(ad));
  s->ct->name = "Mumbai";
}
```

test.c.004t.gimple

```
main ()
{
  void * D.1957;
  struct ad * D.1958;
  struct st * s;
  extern void * malloc (unsigned int);

  s = malloc (8);
  s->roll = 1;
  D.1957 = malloc (4);
  s->ct = D.1957;
  D.1958 = s->ct;
  D.1958->name = "Mumbai";
}
```


GIMPLE: Pointer to Array

test.c

```
int main()
{
  int *p_a, a[3];

  p_a = &a[0];

  *p_a = 10;
  *(p_a+1) = 20;
  *(p_a+2) = 30;
}
```

test.c.004t.gimple

```
main ()
{
  int * D.2048;
  int * D.2049;
  int * p_a;
  int a[3];

  p_a = &a[0];
  *p_a = 10;
  D.2048 = p_a + 4;
  *D.2048 = 20;
  D.2049 = p_a + 8;
  *D.2049 = 30;
}
```

GIMPLE: Translation of Conditional Statements

test.c

```
int main()
{
    int a=2, b=3, c=4;
    while (a<=7)
    {
        a = a+1;
    }
    if (a<=12)
        a = a+b+c;

}
```

test.c.004t.gimple

```
if (a <= 12) goto <D.1200>;
else  goto <D.1201>;
<D.1200>:
D.1199 = a + b;
a = D.1199 + c;
<D.1201>:
```


GIMPLE: Translation of Loops

test.c

```
int main()
{
    int a=2, b=3, c=4;
     while (a<=7)
     {
         a = a+1;
     }
    if (a<=12)
        a = a+b+c;
}
```

test.c.004t.gimple

```
goto <D.1197>;
<D.1196>:
a = a + 1;
<D.1197>:
if (a <= 7) goto <D.1196>;
else goto <D.1198>;
<D.1198>:
```


Control Flow Graph: Textual View

test.c.004t.gimple

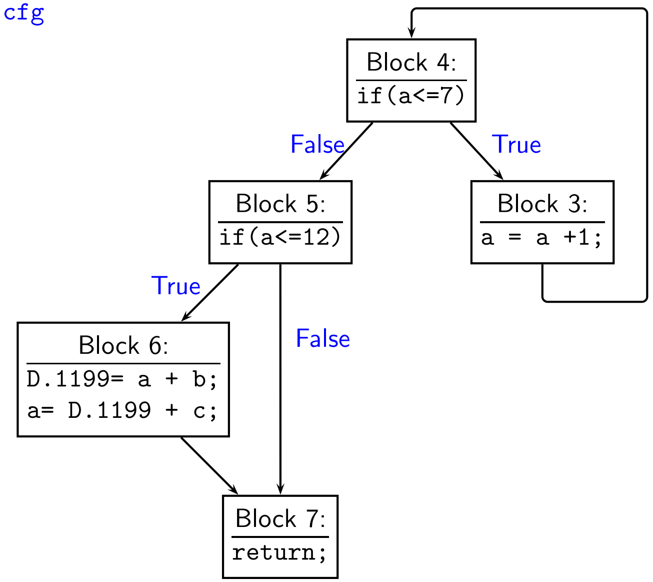
```
if (a <= 12) goto <D.1200>;
else  goto <D.1201>;
<D.1200>:
D.1199 = a + b;
a = D.1199 + c;
<D.1201>:
```

test.c.013t.cfg

```
<bb 5>:
  if (a <= 12)
    goto <bb 6>;
  else
    goto <bb 7>;

<bb 6>:
  D.1199 = a + b;
  a = D.1199 + c;

<bb 7>:
  return;
```

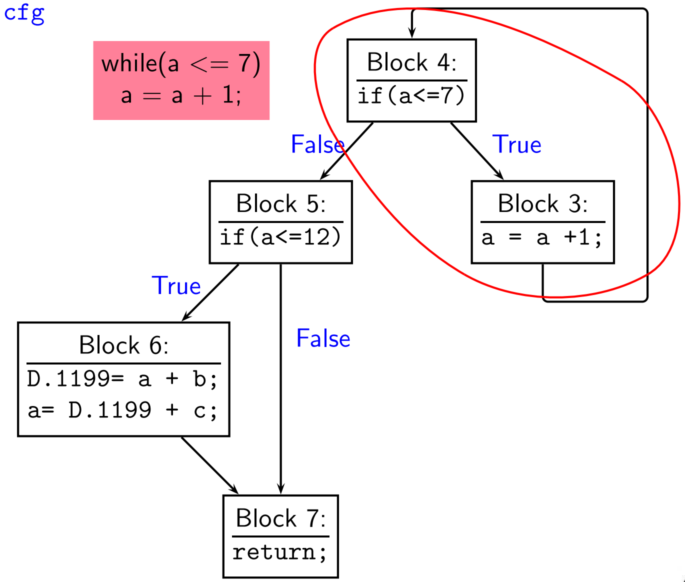

Control Flow Graph: Pictorial View

test.c.013t.cfg



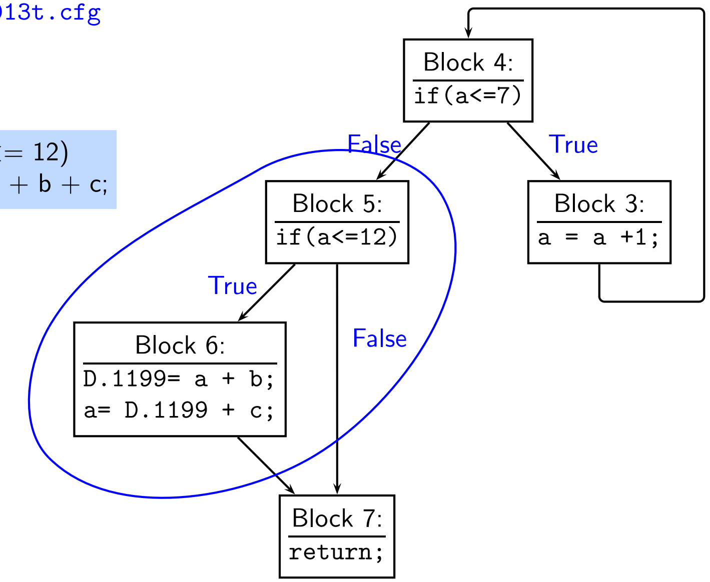
Control Flow Graph: Pictorial View

test.c.013t.cfg



Control Flow Graph: Pictorial View

test.c.013t.cfg



GIMPLE: Function Calls and Call Graph

test.c

```
extern int divide(int, int);
int multiply(int a, int b)
{
   return a*b;
}

int main()
{ int x,y;
  x = divide(20,5);
  y = multiply(x,2);
  printf("%d\n", y);
}
```

test.c.000i.cgraph

```
printf/3(-1)  @0xb73c7ac8 availability:not_availa
  called by: main/1  (1.00 per call)
  calls:
divide/2(-1)  @0xb73c7a10 availability:not_availa
  called by: main/1  (1.00 per call)
  calls:
main/1(1)  @0xb73c7958 availability:available 38
  called by:
  calls: printf/3  (1.00 per call)
         multiply/0 (1.00 per call)
         divide/2 (1.00 per call)
multiply/0(0)  @0xb73c78a0 vailability:available
  called by: main/1  (1.00 per call)
  calls:
```


GIMPLE: Function Calls and Call Graph

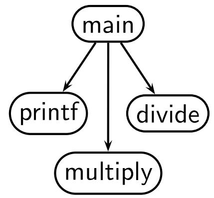
test.c

```
extern int divide(int, int);
int multiply(int a, int b)
{
   return a*b;
}

int main()
{ int x,y;
  x = divide(20,5);
  y = multiply(x,2);
  printf("%d\n", y);
}
```

test.c.000i.cgraph

```
printf/3(-1)
  called by: main/1
  calls:
divide/2(-1)
  called by: main/1
  calls:
main/1(1)
  called by:
  calls: printf/3
         multiply/0
         divide/2
multiply/0(0)
  called by: main/1
  calls:
```

call graph



visible

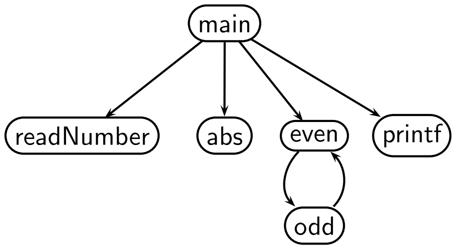
visibl

GIMPLE: Call Graphs for Recursive Functions

test.c

```
int even(int n)
{  if (n == 0) return 1;
   else return (!odd(n-1));
}

int odd(int n)
{  if (n == 1) return 1;
   else return (!even(n-1));
}

main()
{ int n;

  n = abs(readNumber());
  if (even(n))
    printf ("n is even\n");
  else printf ("n is odd\n");
}
```

call graph



Inspect GIMPLE When in Doubt (1)

```
int x=2,y=3;
x = y++ + ++x + ++y;
```

What are the values of x and y?
x = 10 , y =5

x	3
y	3
$(y+x)$	6
$(y+x)+y$	

Inspect GIMPLE When in Doubt (1)

```
int x=2,y=3;
x = y++ + ++x + ++y;
```

What are the values of x and y?
x = 10 , y =5

x	3
y	4
$(y+x)$	6
$(y+x)+y$	

Inspect GIMPLE When in Doubt (1)

```
int x=2,y=3;
x = y++ + ++x + ++y;
```

What are the values of x and y?
x = 10 , y =5

x	3
y	5
$(y+x)$	6
$(y+x)+y$	

Inspect GIMPLE When in Doubt (1)

```
int x=2,y=3;
x = y++ + ++x + ++y;
```

What are the values of x and y?
x = 10 , y =5

x	3
y	5
$(y+x)$	6
$(y+x)+y$	11

1 July 2012 Graybox Probing: Examining GIMPLE Dumps 28/56

Inspect GIMPLE When in Doubt (1)

int x=2,y=3;
x = y++ + ++x + ++y;

What are the values of x and y?
x = 10 , y =5

x	3
y	5
$(y+x)$	6
$(y+x)+y$	11

```
x = 2;
y = 3;
x = x + 1; /* 3 */
D.1572 = y + x;  /* 6 */
y = y + 1;  /* 4 */
x = D.1572 + y;  /* 10 */
y = y + 1;  /* 5 */
```

Essential Abstractions in GCC GCC Resource Center, IIT Bombay

Inspect GIMPLE When in Doubt (2)

- How is `a[i] = i++` handled?
  This is an undefined behaviour as per C standards.
- What is the order of parameter evaluation?
  For a call `f(getX(),getY())`, is the order left to right? arbitrary?
  Is the evaluation order in GCC consistent?
- Understanding complicated declarations in C can be difficult
  What does the following declaration mean :

```
int * (* (*MYVAR) (int) ) [10];
```

Hint: Use `-fdump-tree-original-raw-verbose` option. The dump to see is `003t.original`

Part 4

Examining RTL Dumps

RTL for i386: Arithmetic Operations (1)

Translation of $a = a + 1$

Dump file: `test.c.144r.expand`

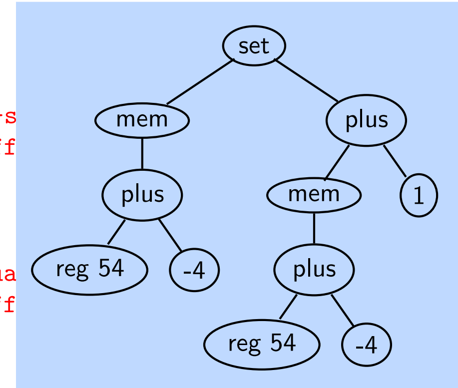
```
(insn 12 11 13 4 (parallel [
   ( set (mem/c/i:SI
           (plus:SI
              (reg/f:SI 54 virtual-stack-vars)
              (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
        (plus:SI
           (mem/c/i:SI
              (plus:SI
                 (reg/f:SI 54 virtual-stack-vars)
                 (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```


RTL for i386: Arithmetic Operations (1)

Translation of $a = a + 1$

Dump file: `test.c.144r.expand`

```
(insn 12 11 13 4 (parallel [
   ( set (mem/c/i:SI
           (plus:SI
              (reg/f:SI 54 virtual-s
              (const_int -4 [0xfffff
        (plus:SI
           (mem/c/i:SI
              (plus:SI
                 (reg/f:SI 54 virtua
                 (const_int -4 [0xff
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```

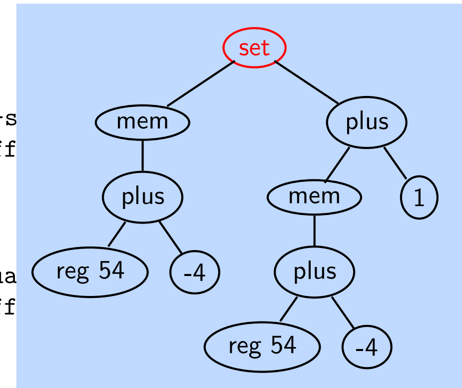


RTL for i386: Arithmetic Operations (1)

Translation of $a = a + 1$

Dump file: `test.c.144r.expand`

```
(insn 12 11 13 4 (parallel [
   ( set (mem/c/i:SI
           (plus:SI
              (reg/f:SI 54 virtual-s
              (const_int -4 [0xfffff
        (plus:SI
           (mem/c/i:SI
              (plus:SI
                 (reg/f:SI 54 virtua
                 (const_int -4 [0xff
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```



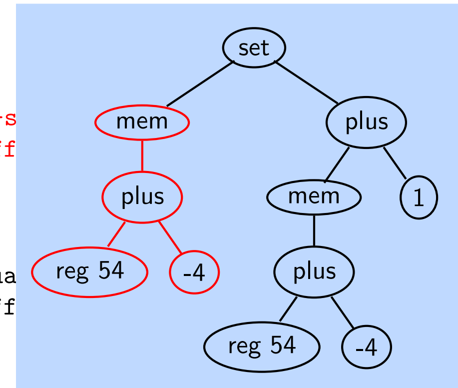
RTL for i386: Arithmetic Operations (1)

Translation of $a = a + 1$

Dump file: `test.c.144r.expand`

a is a local variable allocated on stack

```
(insn 12 11 13 4 (parallel [
   ( set (mem/c/i:SI
           (plus:SI
              (reg/f:SI 54 virtual-s
              (const_int -4 [0xfffff
        (plus:SI
           (mem/c/i:SI
              (plus:SI
                 (reg/f:SI 54 virtua
                 (const_int -4 [0xff
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```



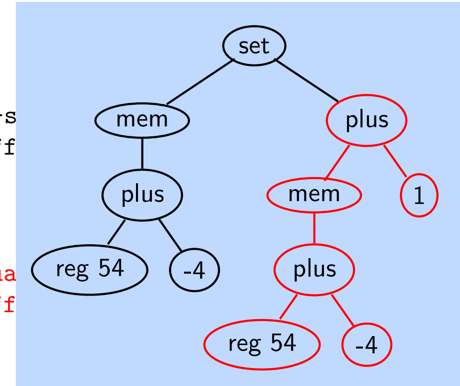
RTL for i386: Arithmetic Operations (1)

Translation of $a = a + 1$

Dump file: `test.c.144r.expand`

a is a local variable allocated on stack

```
(insn 12 11 13 4 (parallel [
   ( set (mem/c/i:SI
         (plus:SI
            (reg/f:SI 54 virtual-s
            (const_int -4 [0xfffff
      (plus:SI
         (mem/c/i:SI
            (plus:SI
               (reg/f:SI 54 virtua
               (const_int -4 [0xff
         (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```



1 July 2012 Graybox Probing: Examining RTL Dumps 30/56

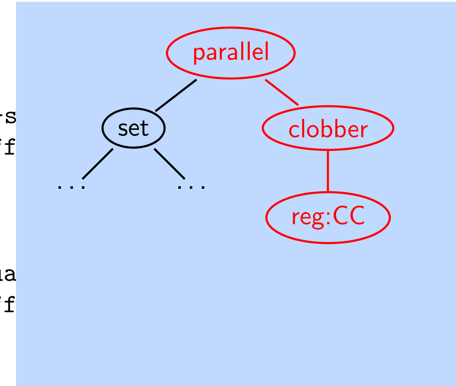
RTL for i386: Arithmetic Operations (1)

Translation of $a = a + 1$

Dump file: `test.c.144r.expand`

side-effect of plus may modify condition code register non-deterministically

```
(insn 12 11 13 4 (parallel [
   ( set (mem/c/i:SI
         (plus:SI
            (reg/f:SI 54 virtual-s
            (const_int -4 [0xfffff
      (plus:SI
         (mem/c/i:SI
            (plus:SI
               (reg/f:SI 54 virtua
               (const_int -4 [0xff
         (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```



1 July 2012 Graybox Probing: Examining RTL Dumps 30/56

RTL for i386: Arithmetic Operations (1)

Translation of $a = a + 1$

Dump file: `test.c.144r.exp`

Output with `slim` suffix

```
{[r54:SI-0x4]=[r54:SI-0x4]+0x1;
   clobber flags:CC;
}
```

```
(insn 12 11 13 4 (parallel
   ( set (mem/c/i:SI
         (plus:SI
            (reg/f:SI 54 virtual-stack-vars)
            (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
      (plus:SI
         (mem/c/i:SI
            (plus:SI
               (reg/f:SI 54 virtual-stack-vars)
               (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
         (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```


Additional Information in RTL

```
(insn 12 11 13 4 (parallel [
   (set (mem/c/i:SI
           (plus:SI
              (reg/f:SI 54 virtual-stack-vars)
              (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
        (plus:SI
           (mem/c/i:SI
              (plus:SI
                 (reg/f:SI 54 virtual-stack-vars)
                 (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```

Current Instruction

Additional Information in RTL

```
(insn 12 11 13 4 (parallel [
   (set (mem/c/i:SI
           (plus:SI
              (reg/f:SI 54 virtual-stack-vars)
              (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
        (plus:SI
           (mem/c/i:SI
              (plus:SI
                 (reg/f:SI 54 virtual-stack-vars)
                 (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```

Previous Instruction

Additional Information in RTL

```
(insn 12 11 13 4 (parallel [
   (set (mem/c/i:SI
           (plus:SI
              (reg/f:SI 54 virtual-stack-vars)
              (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
        (plus:SI
           (mem/c/i:SI
              (plus:SI
                 (reg/f:SI 54 virtual-stack-vars)
                 (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```

Next Instruction

Additional Information in RTL

```
(insn 12 11 13 4 (parallel [
   (set (mem/c/i:SI
           (plus:SI
              (reg/f:SI 54 virtual-stack-vars)
              (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
        (plus:SI
           (mem/c/i:SI
              (plus:SI
                 (reg/f:SI 54 virtual-stack-vars)
                 (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```

Basic Block

Additional Information in RTL

```
(insn 12 11 13 4 (parallel [
   (set (mem/c/i:SI
           (plus:SI
              (reg/f:SI 54 virtual-stack-vars)
              (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
        (plus:SI
           (mem/c/i:SI
              (plus:SI
                 (reg/f:SI 54 virtual-stack-vars)
                 (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```

File name: Line number

Additional Information in RTL

```
(insn 12 11 13 4 (parallel [
   (set (mem/c/i:SI
           (plus:SI
              (reg/f:SI 54 virtual-stack-vars)
              (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
        (plus:SI
           (mem/c/i:SI
              (plus:SI
                 (reg/f:SI 54 virtual-stack-vars)
                 (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```

memory reference that does not trap

Additional Information in RTL

```
(insn 12 11 13 4 (parallel [
   (set (mem/c/i:SI
           (plus:SI
              (reg/f:SI 54 virtual-stack-vars)
              (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
        (plus:SI
           (mem/c/i:SI
              (plus:SI
                 (reg/f:SI 54 virtual-stack-vars)
                 (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```

scalar that is not a part of an aggregate

Additional Information in RTL

```
(insn 12 11 13 4 (parallel [
   (set (mem/c/i:SI
           (plus:SI
              (reg/f:SI 54 virtual-stack-vars)
              (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
        (plus:SI
           (mem/c/i:SI
              (plus:SI
                 (reg/f:SI 54 virtual-stack-vars)
                 (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```

register that holds a pointer

Additional Information in RTL

```
(insn 12 11 13 4 (parallel [
   (set (mem/c/i:SI
           (plus:SI
              (reg/f:SI 54 virtual-stack-vars)
              (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
        (plus:SI
           (mem/c/i:SI
              (plus:SI
                 (reg/f:SI 54 virtual-stack-vars)
                 (const_int -4 [0xfffffffc])) [0 a+0 S4 A32])
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t.c:24 -1 (nil))
```

single integer

RTL for i386: Arithmetic Operations (2)

Translation of $a = a + 1$ when a is a global variable

Dump file: `test.c.144r.expand`

```
(insn 11 10 12 4 (set
   (reg:SI 64 [ a.0 ])
   (mem/c/i:SI (symbol_ref:SI ("a")
         <var_decl 0xb7d8d000 a>) [0 a+0 S4 A32])) t.c:26 -1 (nil))

(insn 12 11 13 4 (parallel [
   (set (reg:SI 63 [ a.1 ])
        (plus:SI (reg:SI 64 [ a.0 ])
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
 ]) t.c:26 -1 (nil))

(insn 13 12 14 4 (set
   (mem/c/i:SI (symbol_ref:SI ("a")
        <var_decl 0xb7d8d000 a>) [0 a+0 S4 A32])
   (reg:SI 63 [ a.1 ])) t.c:26 -1 (nil))
```


1 July 2012 Graybox Probing: Examining RTL Dumps 32/56

RTL for i386: Arithmetic Operations (2)

Translation of $a = a + 1$ when a is a global variable

Dump file: `test.c.144r.expand`

```
(insn 11 10 12 4 (set
   (reg:SI 64 [ a.0 ])
   (mem/c/i:SI (symbol_ref:SI ("a")
         <var_decl 0xb7d8d000 a>) [0 a+                    )

(insn 12 11 13 4 (parallel [
   (set (reg:SI 63 [ a.1 ])
        (plus:SI (reg:SI 64 [ a.0 ])
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
 ]) t.c:26 -1 (nil))

(insn 13 12 14 4 (set
   (mem/c/i:SI (symbol_ref:SI ("a")
        <var_decl 0xb7d8d000 a>) [0 a+0 S4 A32])
   (reg:SI 63 [ a.1 ])) t.c:26 -1 (nil))
```

Load a into reg64

Essential Abstractions in GCC GCC Resource Center, IIT Bombay

1 July 2012 Graybox Probing: Examining RTL Dumps 32/56

RTL for i386: Arithmetic Operations (2)

Translation of $a = a + 1$ when a is a global variable

Dump file: `test.c.144r.expand`

```
(insn 11 10 12 4 (set
   (reg:SI 64 [ a.0 ])
   (mem/c/i:SI (symbol_ref:SI ("a")
         <var_decl 0xb7d8d000 a>) [0 a+                    )

(insn 12 11 13 4 (parallel [
   (set (reg:SI 63 [ a.1 ])
        (plus:SI (reg:SI 64 [ a.0 ])
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
 ]) t.c:26 -1 (nil))

(insn 13 12 14 4 (set
   (mem/c/i:SI (symbol_ref:SI ("a")
        <var_decl 0xb7d8d000 a>) [0 a+0 S4 A32])
   (reg:SI 63 [ a.1 ])) t.c:26 -1 (nil))
```

Load a into reg64

reg63 = reg64 + 1

Essential Abstractions in GCC GCC Resource Center, IIT Bombay

1 July 2012 Graybox Probing: Examining RTL Dumps 32/56

RTL for i386: Arithmetic Operations (2)

Translation of $a = a + 1$ when a is a global variable

Dump file: `test.c.144r.expand`

```
(insn 11 10 12 4 (set
   (reg:SI 64 [ a.0 ])
   (mem/c/i:SI (symbol_ref:SI ("a")
         <var_decl 0xb7d8d000 a>) [0 a+                    )

(insn 12 11 13 4 (parallel [
   (set (reg:SI 63 [ a.1 ])
        (plus:SI (reg:SI 64 [ a.0 ])
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
 ]) t.c:26 -1 (nil))

(insn 13 12 14 4 (set
   (mem/c/i:SI (symbol_ref:SI ("a")
        <var_decl 0xb7d8d000 a>) [0 a+0 S4 A32])
   (reg:SI 63 [ a.1 ])) t.c:26 -1 (nil))
```

Load a into reg64

reg63 = reg64 + 1

store reg63 into a

Essential Abstractions in GCC GCC Resource Center, IIT Bombay

RTL for i386: Arithmetic Operations (2)

Translation of $a = a + 1$ when a is a global variable
Dump file: `test.c.144r.expand`

```
(insn 11 10 12 4 (set
   (reg:SI 64 [ a.0 ])
   (mem/c/i:SI (symbol_ref:SI ("a")
         <var_decl 0xb7d8d000 a>) [0 a+                    )

(insn 12 11 13 4 (parallel [
   (set (reg:SI 63 [ a.1 ])
        (plus:SI (reg:SI 64 [ a.0 ])
           (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
 ]) t.c:26 -1 (nil))

(insn 13 12 14 4 (set
   (mem/c/i:SI (symbol_ref:SI ("a")
        <var_decl 0xb7d8d000 a>) [0 a+0 S4 A32])
   (reg:SI 63 [ a.1 ])) t.c:26 -1 (nil))
```

Load a into reg64
reg63 = reg64 + 1
store reg63 into a

Output with `slim` suffix

```
r64:SI=[‘a’]
{r63:SI=r64:SI+0x1;
   clobber flags:CC;
}
[‘a’]=r63:SI
```


RTL for i386: Arithmetic Operations (3)

Translation of $a = a + 1$ when a is a formal parameter
Dump file: `test.c.144r.expand`

```
(insn 10 9 11 4 (parallel [
   (set
      (mem/c/i:SI
         (reg/f:SI 53 virtual-incoming-args) [0 a+0 S4 A32])
      (plus:SI
         (mem/c/i:SI
            (reg/f:SI 53 virtual-incoming-args) [0 a+0 S4 A32])
               (const_int 1 [0x1])))
  (clobber (reg:CC 17 flags))
 ]) t1.c:25 -1 (nil))
```


RTL for i386: Arithmetic Operations (3)

Translation of $a = a + 1$ when a is a formal parameter
Dump file: `test.c.144r.expand`

```
(insn 10 9 11 4 (parallel [
   (set
      (mem/c/i:SI
         (reg/f:SI 53 virtual-incoming-
      (plus:SI
         (mem/c/i:SI
            (reg/f:SI 53 virtual-incomi
               (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t1.c:25 -1 (nil))
```

Access through argument pointer register instead of frame pointer register

No offset required?

RTL for i386: Arithmetic Operations (3)

Translation of $a = a + 1$ when a is a formal parameter
Dump file: `test.c.144r.expand`

```
(insn 10 9 11 4 (parallel [
   (set
      (mem/c/i:SI
         (reg/f:SI 53 virtual-incoming-
      (plus:SI
         (mem/c/i:SI
            (reg/f:SI 53 virtual-incomi
               (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
  ]) t1.c:25 -1 (nil))
```

Access through argument pointer register instead of frame pointer register

No offset required?

Output with `slim` suffix

```
{[r53:SI]=[r53:SI]+0x1;
clobber flags:CC;
}
```

RTL for i386: Arithmetic Operation (4)

Translation of $a = a + 1$ when a is the second formal parameter

Dump file: `test.c.144r.expand`

```
(insn 10 9 11 4 (parallel [
   (set
      (mem/c/i:SI
         (plus:SI
            (reg/f:SI 53 virtual-incoming-args)
            (const_int 4 [0x4])) [0 a+0 S4 A32])
      (plus:SI
         (mem/c/i:SI
            (plus:SI
               (reg/f:SI 53 virtual-incoming-args)
               (const_int 4 [0x4])) [0 a+0 S4 A32])
         (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
 ]) t1.c:25 -1 (nil))
```


1 July 2012 Graybox Probing: Examining RTL Dumps 34/56

RTL for i386: Arithmetic Operation (4)

Translation of $a = a + 1$ when a is the second formal parameter

Dump file: `test.c.144r.expand`

```
(insn 10 9 11 4 (parallel [
   (set
      (mem/c/i:SI
         (plus:SI
            (reg/f:SI 53 virtual-
            (const_int 4 [0x4]))
      (plus:SI
         (mem/c/i:SI
            (plus:SI
               (reg/f:SI 53 virtu
               (const_int 4 [0x4]
         (const_int 1 [0x1])))
   (clobber (reg:CC 17 flags))
 ]) t1.c:25 -1 (nil))
```


Offset 4 added to the argument pointer register

When a is the first parameter, its offset is 0!

Output with `slim` suffix

```
{[r53:SI+0x4]=[r53:SI+0x4]+0x1;
 clobber flags:CC;
}
```


RTL for spim: Arithmetic Operations

Translation of $a = a + 1$ when a is a local variable

Dump file: `test.c.144r.expand`

r39=stack($fp - 4)
r40=r39+1
stack($fp - 4)=r40

```
(insn 7 6 8 4 (set (reg:SI 39)
      (mem/c/i:SI (plus:SI (reg/f:SI 33 virtual-stack-vars)
            (const_int -4 [...])) [...])) -1 (nil))
(insn 8 7 9 4 test.c:6 (set (reg:SI 40)
      (plus:SI (reg:SI 39)
           (const_int 1 [...]))) -1 (nil))
(insn 9 8 10 4 test.c:6 (set
      (mem/c/i:SI (plus:SI (reg/f:SI 33 virtual-stack-vars)
           (const_int -4 [...])) [...])
      (reg:SI 40)) test.c:6 -1 (nil))
```

In spim, a variable is loaded into register to perform any instruction, hence three instructions are generated

RTL for i386: Control Flow

What does this represent?

```
(jump_insn 15 14 16 4 (set (pc)
      (if_then_else (lt (reg:CCGC 17 flags)
            (const_int 0 [0x0]))
          (label_ref 12)
          (pc))) p1.c:6 -1 (nil)
      (nil)
    -> 12)
```

pc = r17 <0 ? label(12) : pc

RTL for i386: Control Flow

Translation of `if (a > b) { /* something */ }`

Dump file: `test.c.144r.expand`

```
(insn 8 7 9 (set (reg:SI 61)
   (mem/c/i:SI (plus:SI (reg/f:SI 54 virtual-stack-vars)
   (const_int -8 [0xfffffff8])) [0 a+0 S4 A32])) test.c:7 -1 (nil))
(insn 9 8 10 (set (reg:CCGC 17 flags)
   (compare:CCGC (reg:SI 61)
      (mem/c/i:SI (plus:SI (reg/f:SI 54 virtual-stack-vars)
      (const_int -4 [0xfffffffc])) [0 b+0 S4 A32]))) test.c:7 -1 (nil))
(jump_insn 10 9 0 (set (pc)
    (if_then_else (le (reg:CCGC 17 flags)
        (const_int 0 [0x0]))
        (label_ref 13)
        (pc))) test.c:7 -1 (nil))
      -> 13)
```


Part 5

Examining Assembly Dumps

i386 Assembly

Dump file: `test.s`

```
      jmp   .L2
.L3:
      addl  $1, -4(%ebp)
.L2:
      cmpl  $7, -4(%ebp)
      jle   .L3
      cmpl  $12, -4(%ebp)
      jg    .L6
      movl  -8(%ebp), %edx
      movl  -4(%ebp), %eax
      addl  %edx, %eax
      addl  -12(%ebp), %eax
      movl  %eax, -4(%ebp)
.L6:
```

```
while (a <= 7)
{
    a = a+1;
}
if (a <= 12)
{
    a = a+b+c;
}
```


i386 Assembly

Dump file: `test.s`

```
      jmp   .L2
.L3:
      addl  $1, -4(%ebp)
.L2:
      cmpl  $7, -4(%ebp)
      jle   .L3
      cmpl  $12, -4(%ebp)
      jg    .L6
      movl  -8(%ebp), %edx
      movl  -4(%ebp), %eax
      addl  %edx, %eax
      addl  -12(%ebp), %eax
      movl  %eax, -4(%ebp)
.L6:
```

```
while (a <= 7)
{
    a = a+1;
}
if (a <= 12)
{
    a = a+b+c;
}
```

i386 Assembly

Dump file: `test.s`

```
      jmp   .L2
.L3:
      addl  $1, -4(%ebp)
.L2:
      cmpl  $7, -4(%ebp)
      jle   .L3
      cmpl  $12, -4(%ebp)
      jg    .L6
      movl  -8(%ebp), %edx
      movl  -4(%ebp), %eax
      addl  %edx, %eax
      addl  -12(%ebp), %eax
      movl  %eax, -4(%ebp)
.L6:
```

```
while (a <= 7)
{
    a = a+1;
}
if (a <= 12)
{
    a = a+b+c;
}
```


i386 Assembly

Dump file: `test.s`

```
      jmp   .L2
.L3:
      addl  $1, -4(%ebp)
.L2:
      cmpl  $7, -4(%ebp)
      jle   .L3
      cmpl  $12, -4(%ebp)
      jg    .L6
      movl  -8(%ebp), %edx
      movl  -4(%ebp), %eax
      addl  %edx, %eax
      addl  -12(%ebp), %eax
      movl  %eax, -4(%ebp)
.L6:
```

```
while (a <= 7)
{
    a = a+1;
}
if (a <= 12)
{
    a = a+b+c;
}
```


Part 6

Examining GIMPLE Optimization

Example Program for Observing Optimizations

```
int main()
{ int a, b, c, n;

  a = 1;
  b = 2;
  c = 3;
  n = c*2;
  while (a <= n)
  {
    a = a+1;
  }
  if (a < 12)
    a = a+b+c;
  return a;
}
```

- What does this program return?
- 12
- We use this program to illustrate various shades of the following optimizations:

  Constant propagation, Copy propagation, Loop unrolling, Dead code elimination

Compilation Command

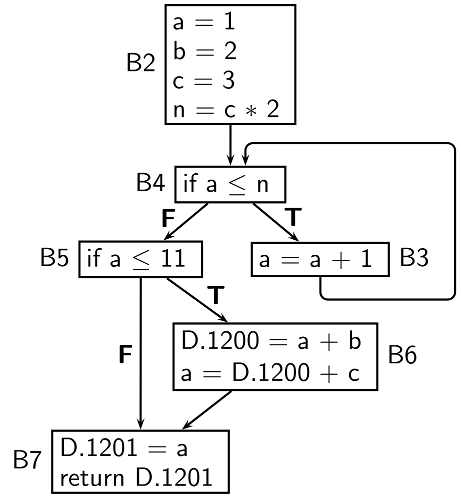
```
$gcc -fdump-tree-all  -O2 ccp.c
```


Example Program 1

Program ccp.c

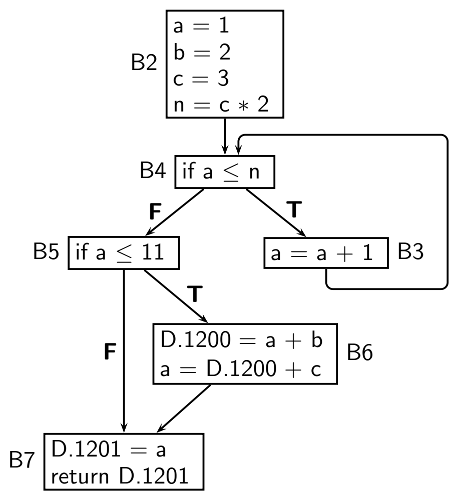
```
int main()
{ int a, b, c, n;

  a = 1;
  b = 2;
  c = 3;
  n = c*2;
  while (a <= n)
  {
    a = a+1;
  }
  if (a < 12)
    a = a+b+c;
  return a;
}
```

Control flow graph



Control Flow Graph: Pictorial and Textual View

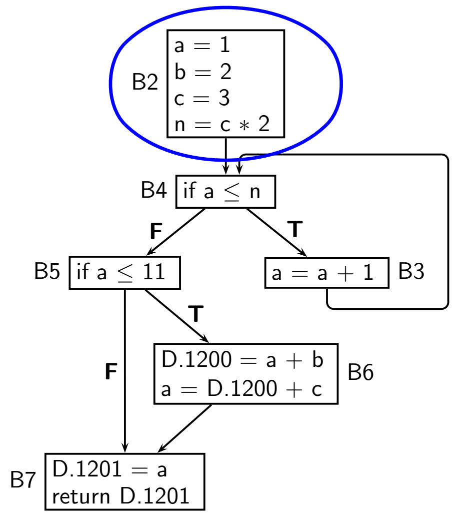
Control flow graph



Dump file ccp.c.013t.cfg

Control Flow Graph: Pictorial and Textual View

Control flow graph

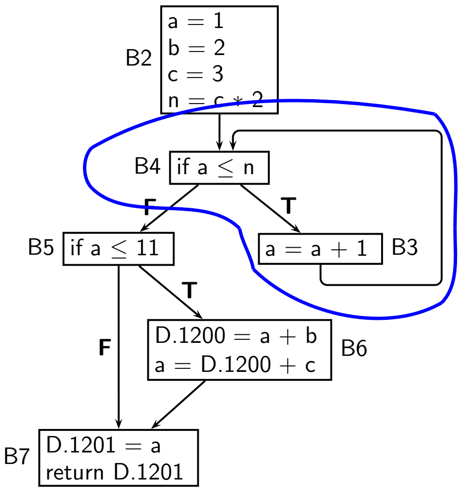


Dump file ccp.c.013t.cfg

```
<bb 2>:
a = 1;
b = 2;
c = 3;
n = c * 2;
goto <bb 4>;
```

Control Flow Graph: Pictorial and Textual View

Control flow graph

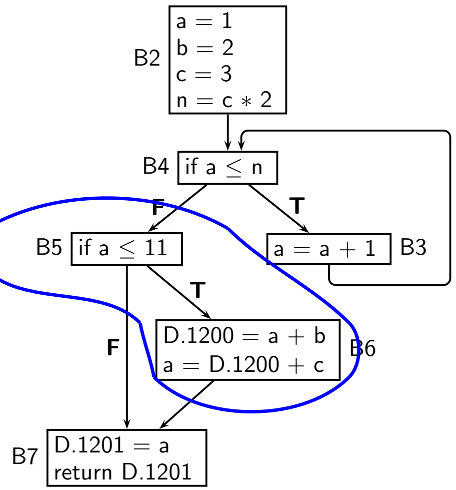


Dump file ccp.c.013t.cfg

```
<bb 3>:
a = a + 1;

<bb 4>:
if (a <= n)
   goto <bb 3>;
else
   goto <bb 5>;
```


Control Flow Graph: Pictorial and Textual View

Control flow graph

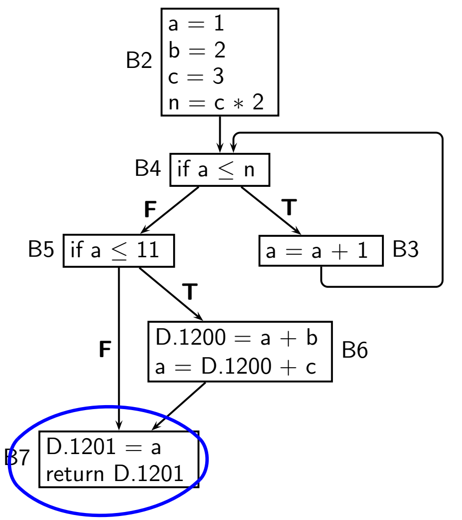


Dump file ccp.c.013t.cfg

```
<bb 5>:
if (a <= 11)
    goto <bb 6>;
else
    goto <bb 7>;

<bb 6>:
D.1200 = a + b;
a = D.1200 + c;
```


Control Flow Graph: Pictorial and Textual View

Control flow graph

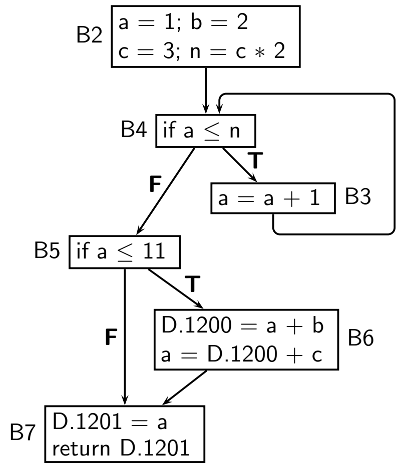


Dump file ccp.c.013t.cfg

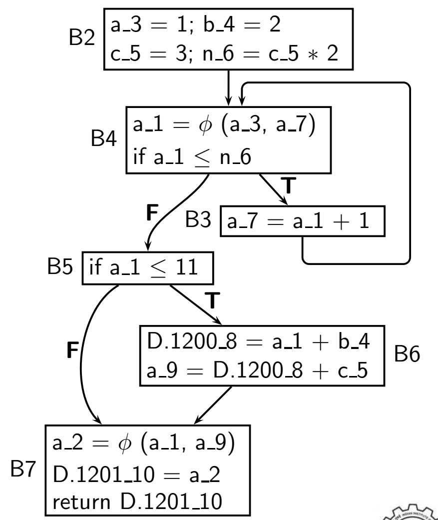
```
<bb 7>:
D.1201 = a;
return D.1201;
```


Single Static Assignment (SSA) Form

Control flow graph

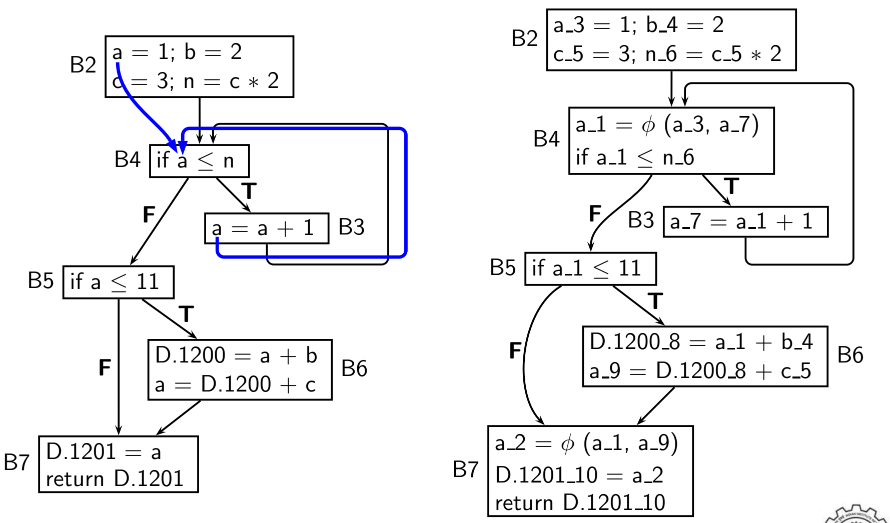


SSA Form



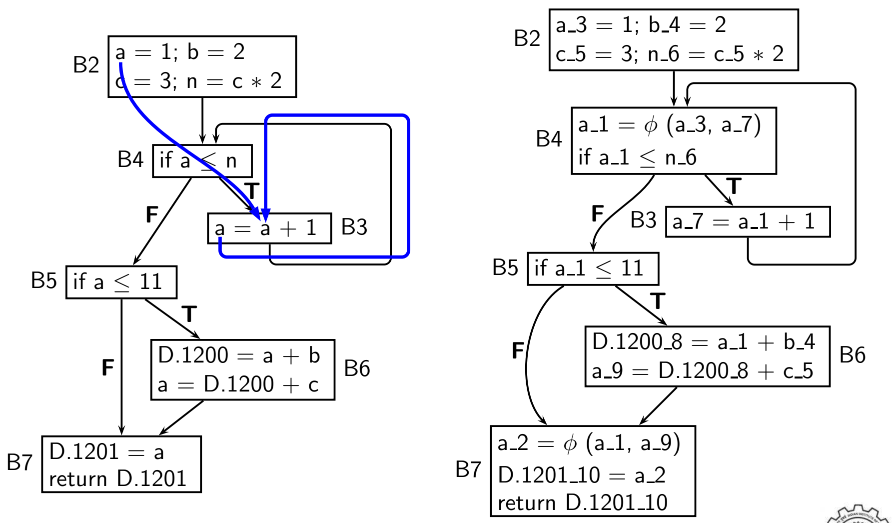
Single Static Assignment (SSA) Form

Control flow graph | SSA Form



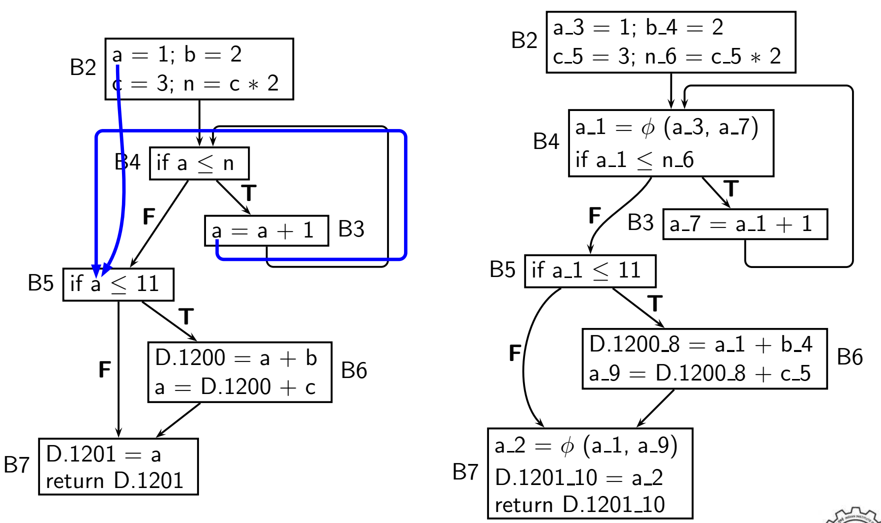
Single Static Assignment (SSA) Form

Control flow graph | SSA Form



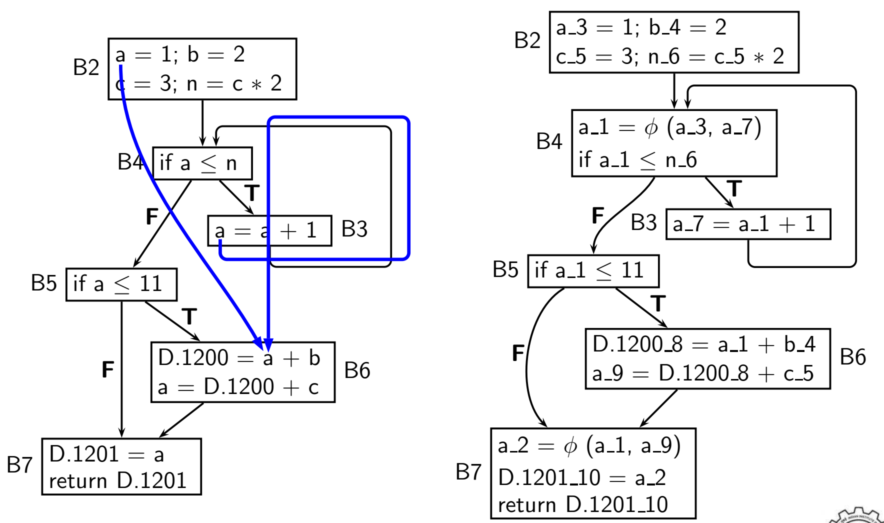
Single Static Assignment (SSA) Form

Control flow graph | SSA Form



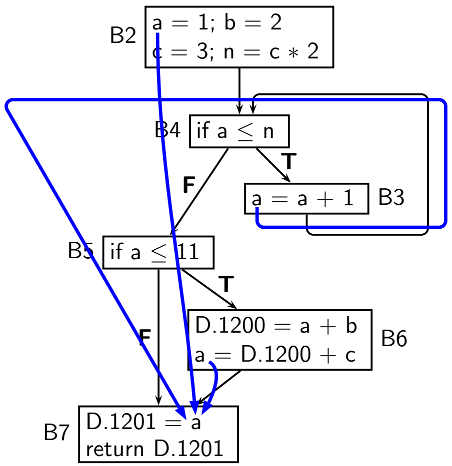
Single Static Assignment (SSA) Form

Control flow graph | SSA Form

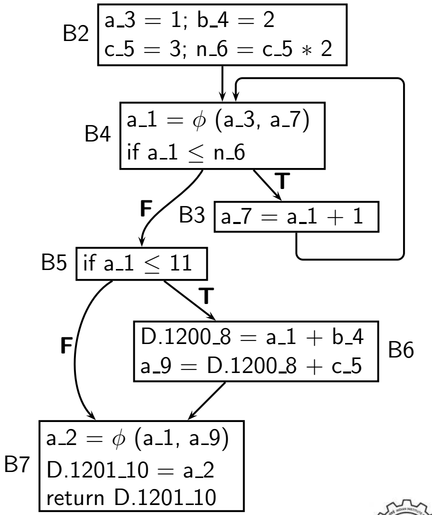


Single Static Assignment (SSA) Form

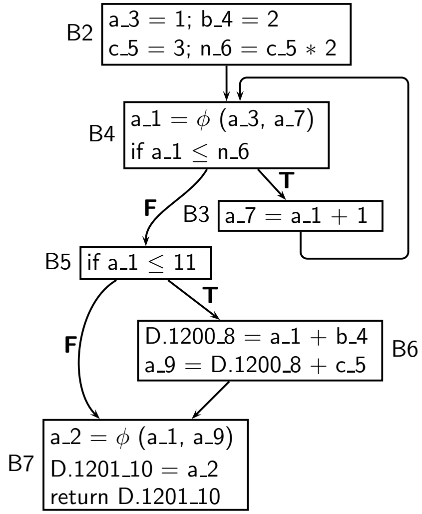
Control flow graph



SSA Form



Properties of SSA Form

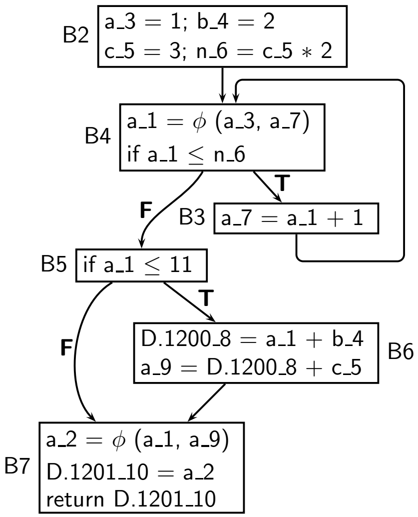


- A ϕ function is a multiplexer or a selection function
- Every use of a variable corresponds to a unique definition of the variable
- For every use, the definition is guaranteed to appear on every path leading to the use

SSA construction algorithm is expected to insert as few ϕ functions as possible to ensure the above properties

SSA Form: Pictorial and Textual View

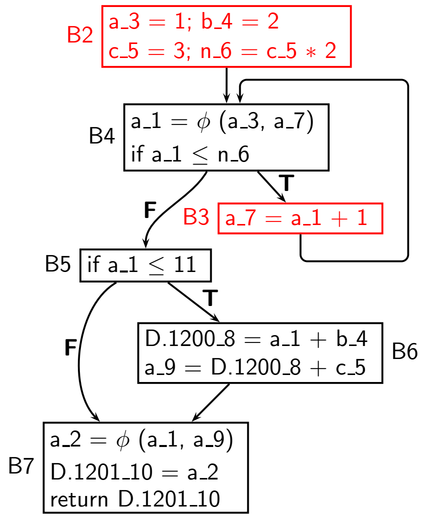
CFG in SSA form



Dump file ccp.c.017t.ssa

SSA Form: Pictorial and Textual View

CFG in SSA form

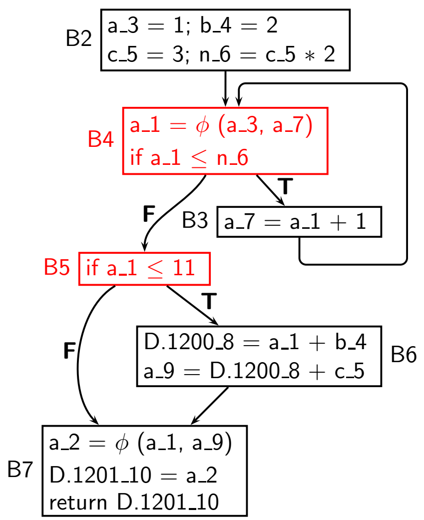


Dump file ccp.c.017t.ssa

```
<bb 2>:
a_3 = 1;
b_4 = 2;
c_5 = 3;
n_6 = c_5 * 2;
goto <bb 4>;

<bb 3>:
  a_7 = a_1 + 1;
```

SSA Form: Pictorial and Textual View

CFG in SSA form

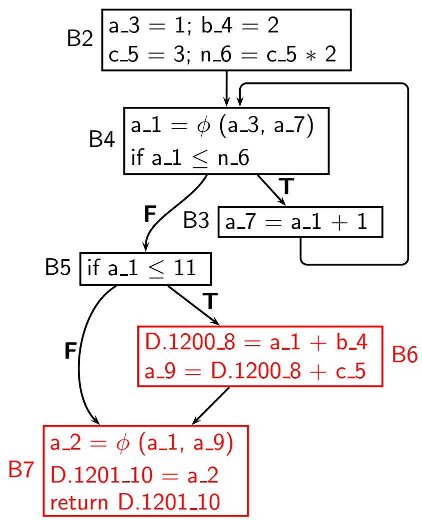


Dump file ccp.c.017t.ssa

```
<bb 4>:
  # a_1 = PHI <a_3(2), a_7(3)>
  if (a_1 <= n_6)
    goto <bb 3>;
  else
    goto <bb 5>;

<bb 5>:
  if (a_1 <= 11)
    goto <bb 6>;
  else
    goto <bb 7>;
```


SSA Form: Pictorial and Textual View

CFG in SSA form



Dump file ccp.c.017t.ssa

```
<bb 6>:
  D.1200_8 = a_1 + b_4;
  a_9 = D.1200_8 + c_5;

<bb 7>:
  # a_2 = PHI <a_1(5), a_9(6)>
  D.1201_10 = a_2;
  return D.1201_10;
```


A Comparison of CFG and SSA Dumps

Dump file ccp.c.013t.cfg

```
<bb 2>:
  a = 1;
  b = 2;
  c = 3;
  n = c * 2;
  goto <bb 4>;

<bb 3>:
  a = a + 1;
```

Dump file ccp.c.017t.ssa

```
<bb 2>:
  a_3 = 1;
  b_4 = 2;
  c_5 = 3;
  n_6 = c_5 * 2;
  goto <bb 4>;

<bb 3>:
  a_7 = a_1 + 1;
```


A Comparison of CFG and SSA Dumps

Dump file ccp.c.013t.cfg

```
<bb 4>:
  if (a <= n)
     goto <bb 3>;
  else
     goto <bb 5>;

<bb 5>:
  if (a <= 11)
      goto <bb 6>;
  else
      goto <bb 7>;
```

Dump file ccp.c.017t.ssa

```
<bb 4>:
  # a_1 = PHI <a_3(2), a_7(3)>
  if (a_1 <= n_6)
    goto <bb 3>;
  else
    goto <bb 5>;

<bb 5>:
  if (a_1 <= 11)
    goto <bb 6>;
  else
    goto <bb 7>;
```

A Comparison of CFG and SSA Dumps

Dump file ccp.c.013t.cfg

```
<bb 6>:
D.1200 = a + b;
a = D.1200 + c;

<bb 7>:
D.1201 = a;
return D.1201;
```

Dump file ccp.c.017t.ssa

```
<bb 6>:
  D.1200_8 = a_1 + b_4;
  a_9 = D.1200_8 + c_5;

<bb 7>:
  # a_2 = PHI <a_1(5), a_9(6)>
  D.1201_10 = a_2;
  return D.1201_10;
```


Copy Renamimg

Input dump: ccp.c.017t.ssa

```
<bb 7>:
  # a_2 = PHI <a_1(5), a_9(6)>
  D.1201_10 = a_2;
  return D.1201_10;
```

Output dump: ccp.c.022t.copyrename1

```
<bb 7>:
  # a_2 = PHI <a_1(5), a_9(6)>
  a_10 = a_2;
  return a_10;
```


First Level Constant and Copy Propagation

Input dump: ccp.c.022t.copyrename1

```
<bb 2>:
  a_3 = 1;
  b_4 = 2;
  c_5 = 3;
  n_6 = c_5 * 2;
  goto <bb 4>;

<bb 3>:
  a_7 = a_1 + 1;

<bb 4>:
  # a_1 = PHI < a_3(2), a_7(3)>
  if (a_1 <= n_6)
    goto <bb 3>;
  else
    goto <bb 5>;
```

Output dump: ccp.c.023t.ccp1

```
<bb 2>:
  a_3 = 1;
  b_4 = 2;
  c_5 = 3;
  n_6 = 6;
  goto <bb 4>;

<bb 3>:
  a_7 = a_1 + 1;

<bb 4>:
  # a_1 = PHI < 1(2), a_7(3)>
  if (a_1 <= 6)
    goto <bb 3>;
  else
    goto <bb 5>;
```


First Level Constant and Copy Propagation

Input dump: ccp.c.022t.copyrename1

```
<bb 2>:
  a_3 = 1;
  b_4 = 2;
  c_5 = 3;
  n_6 = 6;
  goto <bb 4>;

...

<bb 6>:
  D.1200_8 = a_1 + b_4;
  a_9 = D.1200_8 + c_5;
```

Output dump: ccp.c.023t.ccp1

```
<bb 2>:
  a_3 = 1;
  b_4 = 2;
  c_5 = 3;
  n_6 = 6;
  goto <bb 4>;

...

<bb 6>:
  D.1200_8 = a_1 + 2;
  a_9 = D.1200_8 + 3;
```

Second Level Copy Propagation

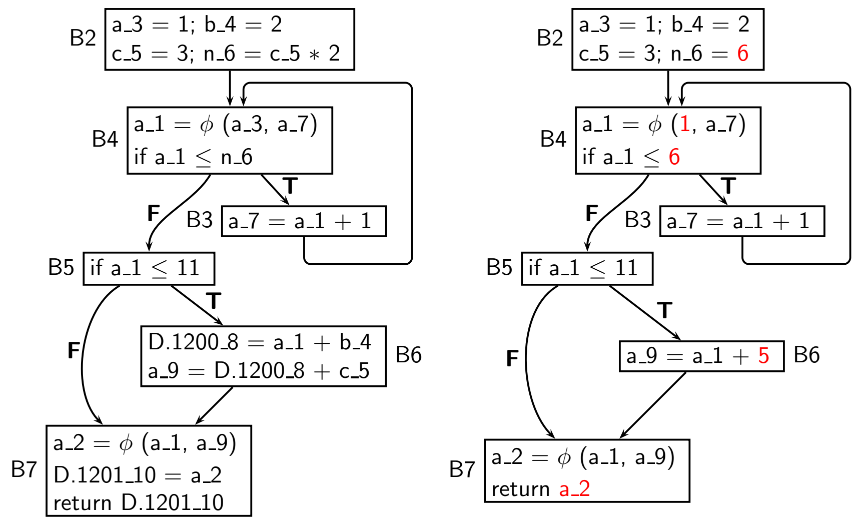
Input dump: ccp.c.023t.ccp1

```
<bb 6>:
  D.1200_8 = a_1 + 2;
  a_9 = D.1200_8 + 3;

<bb 7>:
  # a_2 = PHI <a_1(5), a_9(6)>
  a_10 = a_2;
  return a_10;
```

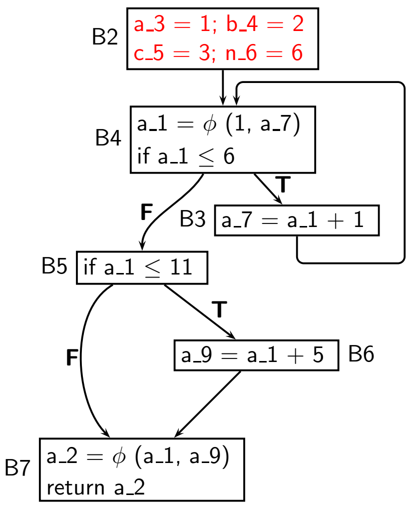
Output dump: ccp.c.027t.copyprop1

```
<bb 6>:
  a_9 = a_1 + 5;

<bb 7>:
  # a_2 = PHI <a_1(5), a_9(6)>
  return a_2;
```


The Result of Copy Propagation and Renaming

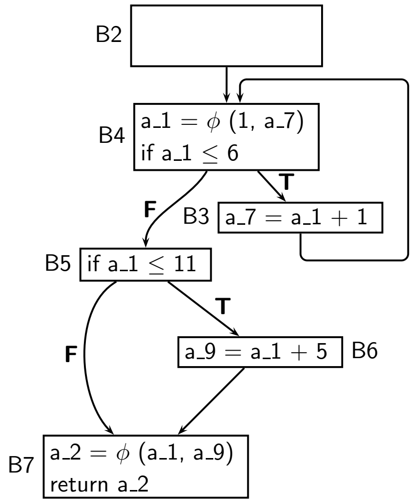


The Result of Copy Propagation and Renaming



- No uses for variables a_3, b_4, c_5, and n_6
- Assignments to these variables can be deleted

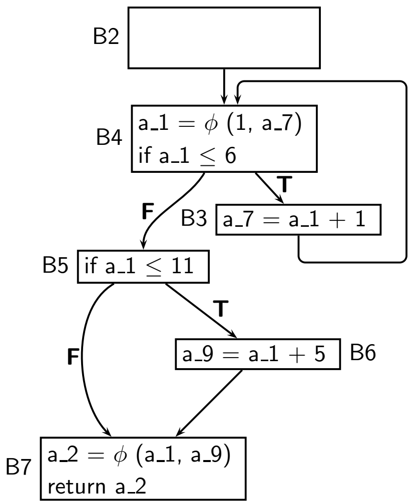
Dead Code Elimination Using Control Dependence

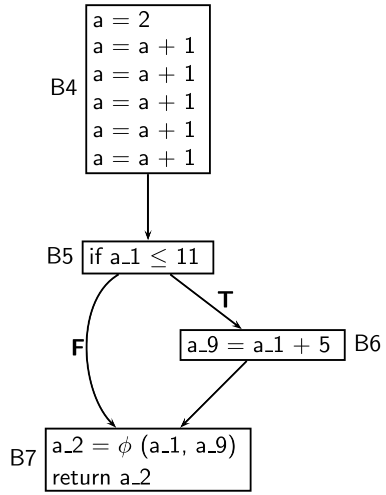


Dump file ccp.c.029t.cddce1

```
<bb 2>:
  goto <bb 4>;
<bb 3>:
  a_7 = a_1 + 1;
<bb 4>:
  # a_1 = PHI <1(2), a_7(3)>
  if (a_1 <= 6) goto <bb 3>;
  else goto <bb 5>;
<bb 5>:
  if (a_1 <= 11) goto <bb 6>;
  else goto <bb 7>;
<bb 6>:
  a_9 = a_1 + 5;
<bb 7>:
  # a_2 = PHI <a_1(5), a_9(6)>
  return a_2;
```

Loop Unrolling

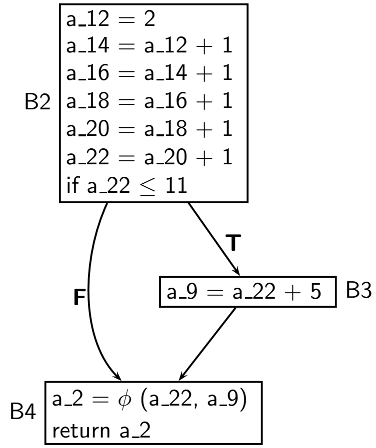




Complete Unrolling of Inner Loops

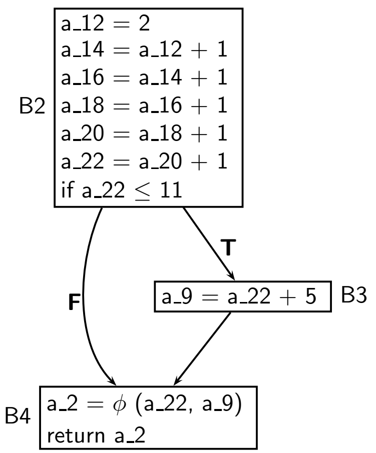
Dump file: ccp.c.058t.cunrolli

```
<bb 2>:
  a_12 = 2;
  a_14 = a_12 + 1;
  a_16 = a_14 + 1;
  a_18 = a_16 + 1;
  a_20 = a_18 + 1;
  a_22 = a_20 + 1;
  if (a_22 <= 11) goto <bb 3>;
  else goto <bb 4>;

<bb 3>:
  a_9 = a_22 + 5;

<bb 4>:
  # a_2 = PHI <a_22(2), a_9(3)>
  return a_2;
```



Another Round of Constant Propagation

Input



Dump file: ccp.c.059t.ccp2

```
main ()
{
  <bb 2>:
    return 12;

}
```


Part 7

Conclusions

Gray Box Probing of GCC: Conclusions

- Source code is transformed into assembly by lowering the abstraction level step by step to bring it close to the machine
- This transformation can be understood to a large extent by observing inputs and output of the different steps in the transformation
- It is easy to prepare interesting test cases and observe the effect of transformations
- One optimization often leads to another
  Hence GCC performs many optimizations repeatedly
  (eg. copy propagation, dead code elimination)