Compiling Loops

C/Java code:

```
while ( sum != 0 ) {
   <loop body>
}
```

Machine code:

```
loopTop:    cmpl   $0, %eax
            je     loopDone
              <loop body code>
            jmp    loopTop
loopDone:
```

- **How to compile other loops should be straightforward**
  - The only slightly tricky part is to be sure where the conditional branch occurs: top or bottom of the loop
- **How would for(i=0; i<100; i++) be implemented?**

"Do-While" Loop Example

C Code

```
int fact_do(int x)
{
  int result = 1;
  do {
    result *= x;
    x = x-1;
  } while (x > 1);
  return result;
}
```

Goto Version

```
int fact_goto(int x)
{
  int result = 1;
loop:
  result *= x;
  x = x-1;
  if (x > 1) goto loop;
  return result;
}
```

- Use backward branch to continue looping
- Only take branch when "while" condition holds

"Do-While" Loop Compilation

Goto Version

```
int
fact_goto(int x)
{
  int result = 1;


loop:
  result *= x;
  x = x-1;
  if (x > 1)
    goto loop;

  return result;
}
```

Assembly

```
fact_goto:
  pushl %ebp          # Setup
  movl %esp,%ebp      # Setup
  movl $1,%eax        # eax = 1
  movl 8(%ebp),%edx   # edx = x

.L11:
  imull %edx,%eax     # result *= x
  decl %edx           # x--
  cmpl $1,%edx        # Compare x : 1
  jg .L11             # if > goto loop

  movl %ebp,%esp      # Finish
  popl %ebp           # Finish
  ret                 # Finish
```

Registers:

%edx	x
%eax	result

General "Do-While" Translation

C Code

```
do
   Body
   while (Test);
```

Goto Version

```
loop:
   Body
   if (Test)
      goto loop
```

- *Body:*

```
{
    Statement1;
    Statement2;
       …
    Statementn;
}
```

- *Test* **returns integer**

  = 0 interpreted as false

  ≠ 0 interpreted as true

"While" Loop Translation

C Code

```
int fact_while(int x)
{
  int result = 1;
  while (x > 1) {
    result *= x;
    x = x-1;
  };
  return result;
}
```

Goto Version

```
int fact_while_goto(int x)
{
  int result = 1;
  goto middle;
loop:
  result *= x;
  x = x-1;
middle:
  if (x > 1)
    goto loop;
  return result;
}
```

- Used by GCC for both IA32 & x86-64
- First iteration jumps over body computation within loop straight to test

"While" Loop Example

```
int fact_while(int x)
{
  int result = 1;
  while (x > 1) {
    result *= x;
    x--;
  };
  return result;
}
```

```
# x in %edx, result in %eax
  jmp   .L34        #   goto Middle
.L35:               # Loop:
  imull %edx, %eax  #   result *= x
  decl  %edx        #   x--
.L34:               # Middle:
  cmpl  $1, %edx    #   x:1
  jg    .L35        #   if >, goto
                    #           Loop
```

"For" Loop Example: Square-and-Multiply

```
/* Compute x raised to nonnegative power p */
int ipwr_for(int x, unsigned int p)
{
   int result;
   for (result = 1; p != 0; p = p>>1) {
      if (p & 0x1)
         result *= x;
      x = x*x;
   }
   return result;
}
```

- **Algorithm**
  - Exploit bit representation: $p = p_0 + 2p_1 + 2^2p_2 + \ldots 2^{n-1}p_{n-1}$
  - Gives: $x^p = z_0 \cdot z_1^{\,2} \cdot (z_2^{\,2})^{\,2} \cdot \ldots \cdot \underbrace{(\ldots((z_{n-1}^{\,2})^{\,2})\ldots)^{\,2}}_{n-1 \text{ times}}$

    $z_i = 1$ when $p_i = 0$

    $z_i = x$ when $p_i = 1$
  - Complexity $O(\log p)$

Example

$3^{10} = 3^2 * 3^8$

$= 3^2 * ((3^2)^2)^2$

ipwr Computation

```
/* Compute x raised to nonnegative power p */
int ipwr_for(int x, unsigned int p)
{
   int result;
   for (result = 1; p != 0; p = p>>1) {
      if (p & 0x1)
         result *= x;
      x = x*x;
   }
   return result;
}
```

before iteration	result	x=3	p=10
1	1	3	$10=1010_2$
2	1	9	$5=\ 101_2$
3	9	81	$2=\ \ 10_2$
4	9	6561	$1=\ \ \ 1_2$
5	59049	43046721	0_2

"For" Loop Example

```
int result;
for (result = 1; p != 0; p = p>>1)
{
   if (p & 0x1)
      result *= x;
   x = x*x;
}
```

General Form

```
for (Init; Test; Update)
    Body
```

Init	*Test*	*Update*	*Body*
`result = 1`	`p != 0`	`p = p >> 1`	`{ if (p & 0x1) result *= x; x = x*x; }`

"For" → "While"

For Version

```
for (Init; Test; Update)
    Body
```


While Version

```
Init;
while (Test) {
    Body
    Update ;
}
```


Goto Version

```
   Init;
   goto middle;
loop:
   Body
   Update ;
middle:
   if (Test)
     goto loop;
done:
```

For-Loop: Compilation

For Version

```
for (Init; Test; Update)
    Body
```

```
for (result = 1; p != 0; p = p>>1)
{
  if (p & 0x1)
    result *= x;
  x = x*x;
}
```

Goto Version

```
  Init;
  goto middle;
loop:
  Body
  Update ;
middle:
  if (Test)
    goto loop;
done:
```

```
  result = 1;
goto middle;
loop:
  if (p & 0x1)
    result *= x;
  x = x*x;
  p = p >> 1;
middle:
  if (p != 0)
    goto loop;
done:
```