More Target Independent LLVM Bitcode

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- Target Dependent Properties
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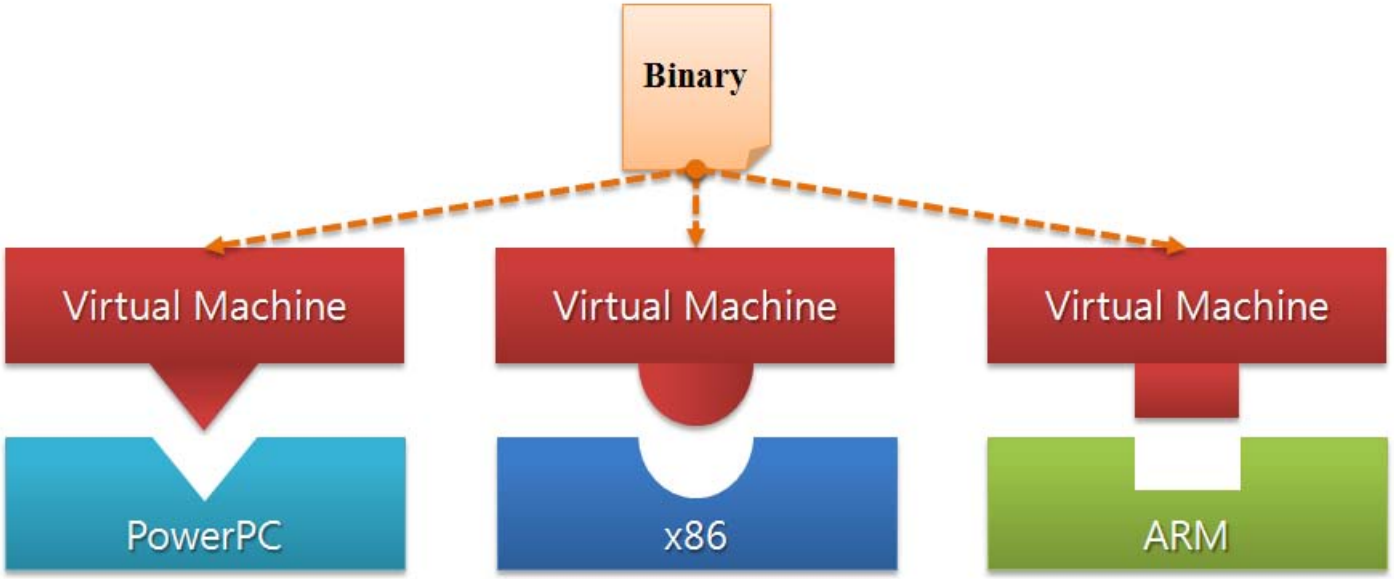
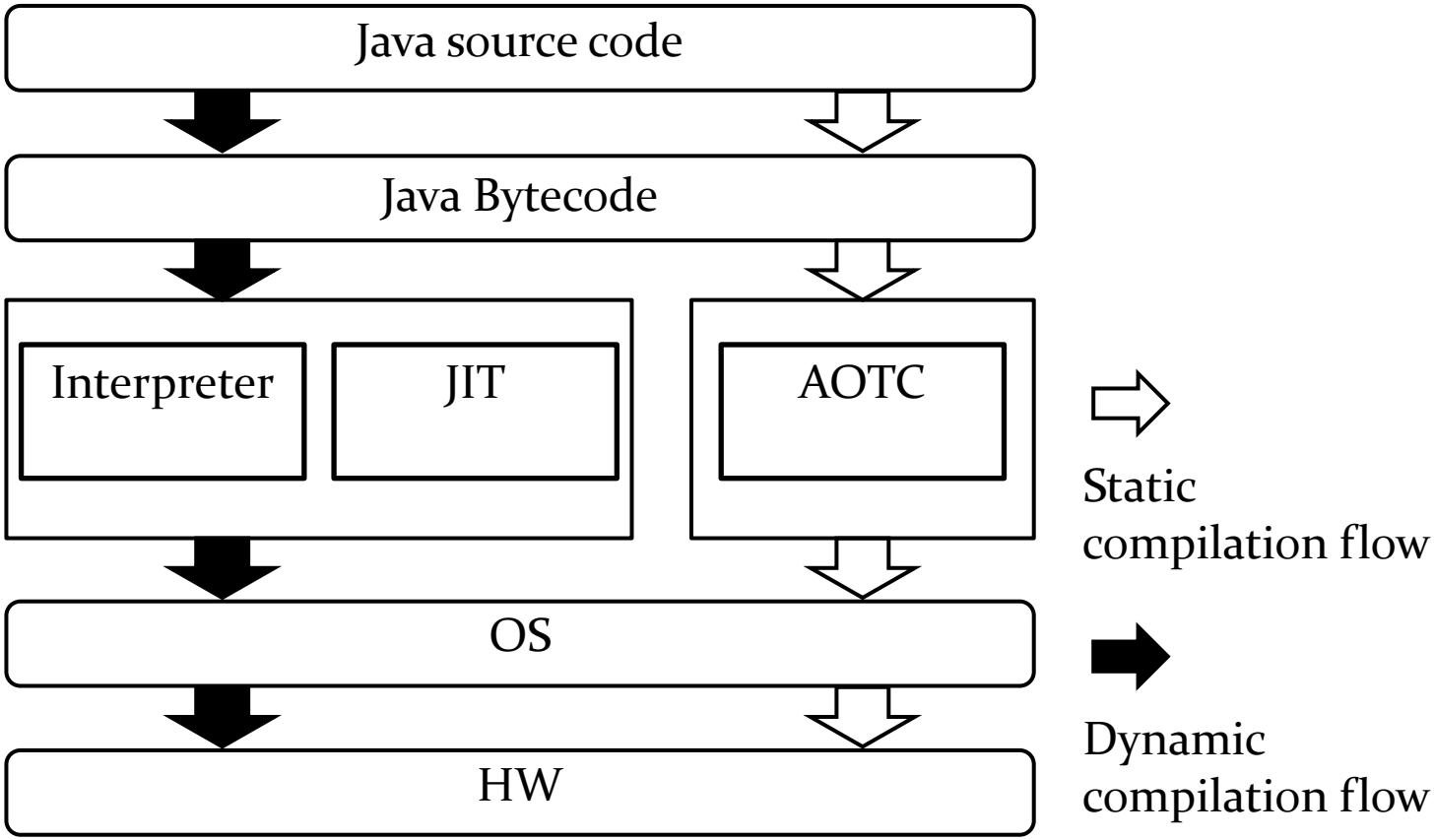
Motivation

- A compiled code can be executed identically on all of machines using virtual machine.
- Is it possibe to use LLVM Bitcode like Java Bytecode??

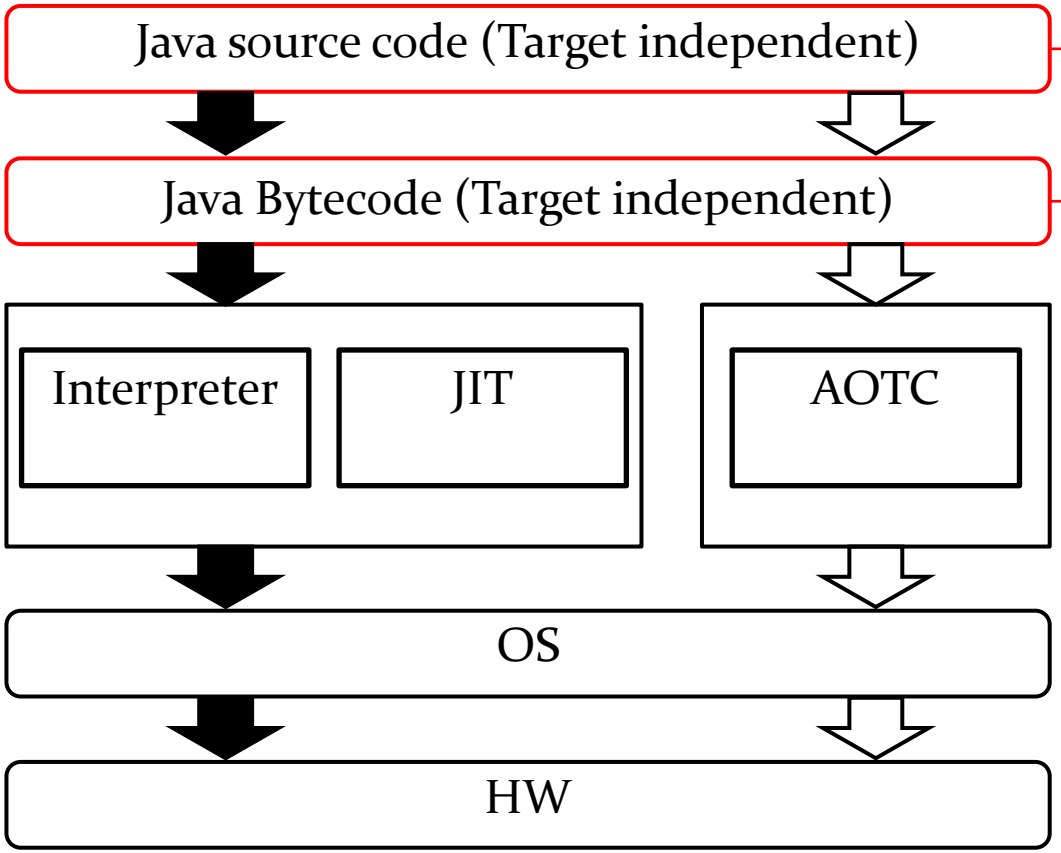


Java Compilation Flow



Java Compilation Flow

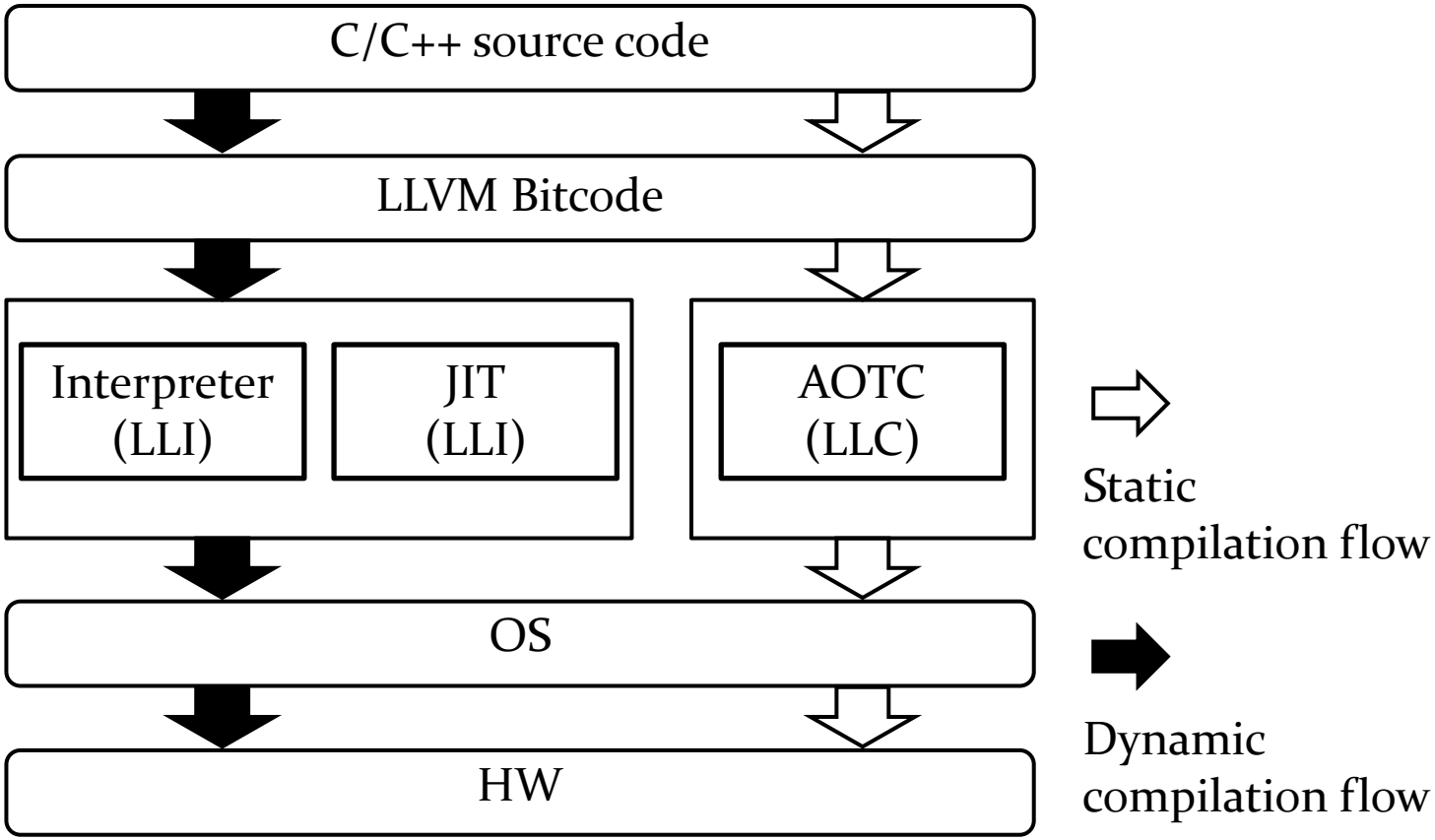
Java language is not affetcted by specific machine.
Java bytecode is same among machines.



Static compilation flow

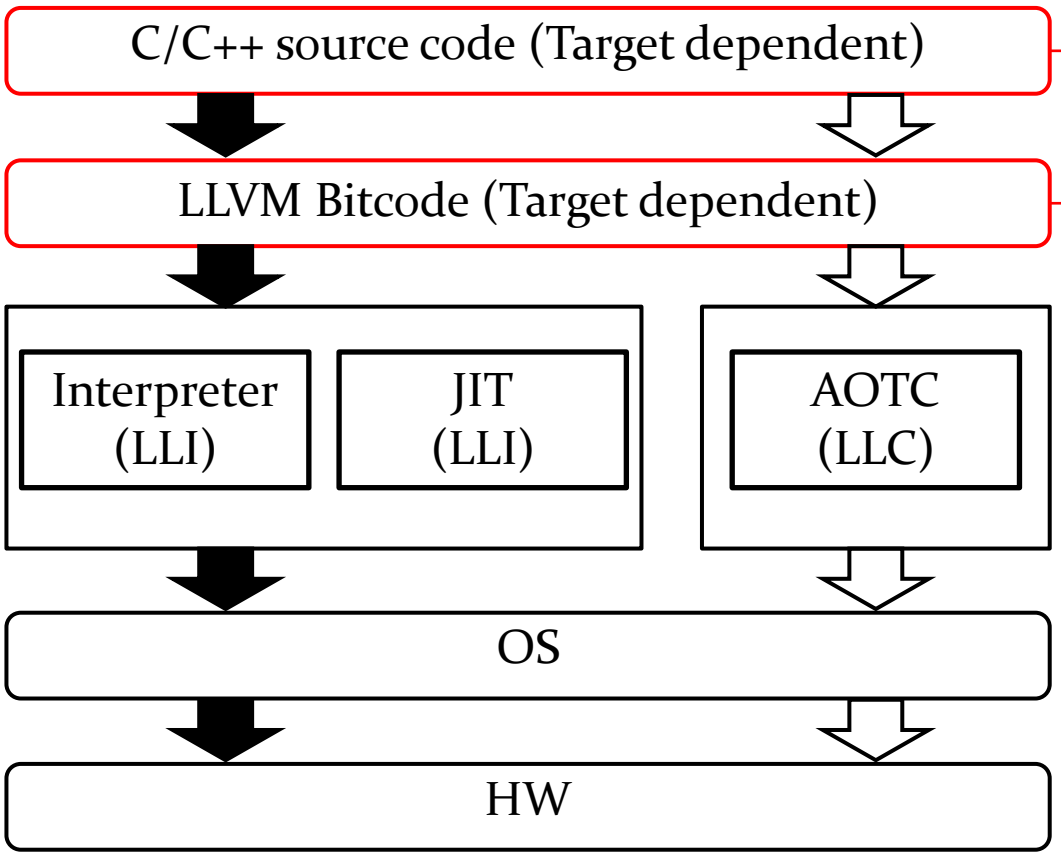
Dynamic compilation flow

LLVM Compilation Flow



LLVM Compilation Flow

C/C++ language is affetcted by specific machine.
LLVM bitcode is not same among machines.



Static compilation flow

Dynamic compilation flow

Target Dependent Properties

- LLVM frontend
  - LLVM frontend generates some target dependent bitcodes with common LLVM IR.
    - Function type
    - Sizeof() keyword
- LLVM IR
  - Bitcode does not support common IR in some cases.
    - Long double type
    - Struct type with bitfield
- Source language
  - Inline assembly
  - Target dependent source codes

Target Dependent Properties

- LLVM frontend
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Function Type

- Function Type
  - ABI compatibility

```
 1 struct operands {
 2   int a;
 3   char b;
 4 };
 5
 6 int add(struct operands ops) {
 7   return ops.a + ops.b;
 8 }
 9
10 int main(void) {
11   int c;
12   struct operands ops;
13
14   ops.a = 1;
15   ops.b = 2;
16   c = add(ops);
17
18   return 0;
19 }
```

Function Type

x86

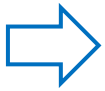
```
28 define i32 @main() nounwind {
29 entry:
30   %retval = alloca i32                               ; <i32*> [#uses=2]
31   %ops = alloca %struct.operands                     ; <%struct.operands*> [#uses=3]
32   %c = alloca i32                                    ; <i32*> [#uses=1]
33   %0 = alloca i32                                    ; <i32*> [#uses=2]
34   %"alloca point" = bitcast i32 0 to i32             ; <i32> [#uses=0]
35   %1 = getelementptr inbounds %struct.operands* %ops, i32 0, i32 0 ; <i32*> [#uses=1]
36   store i32 1, i32* %1, align 4
37   %2 = getelementptr inbounds %struct.operands* %ops, i32 0, i32 1 ; <i8*> [#uses=1]
38   store i8 2, i8* %2, align 4
39   %3 = call i32 @add(%struct.operands* byval align 4 %ops) nounwind ; <i32> [#uses=1]
```

ARM

```
36 define arm_aapcscc i32 @main() nounwind {
37 entry:
38   %retval = alloca i32                               ; <i32*> [#uses=2]
39   %ops = alloca %struct.operands                     ; <%struct.operands*> [#uses=3]
40   %c = alloca i32                                    ; <i32*> [#uses=1]
41   %0 = alloca i32                                    ; <i32*> [#uses=2]
42   %"alloca point" = bitcast i32 0 to i32             ; <i32> [#uses=0]
43   %1 = getelementptr inbounds %struct.operands* %ops, i32 0, i32 0 ; <i32*> [#uses=1]
44   store i32 1, i32* %1, align 4
45   %2 = getelementptr inbounds %struct.operands* %ops, i32 0, i32 1 ; <i8*> [#uses=1]
46   store i8 2, i8* %2, align 4
47   %3 = bitcast %struct.operands* %ops to %0*         ; <%0*> [#uses=1]
48   %elt = getelementptr inbounds %0* %3, i32 0, i32 0 ; <[2 x i32]*> [#uses=2]
49   %elt1 = getelementptr inbounds [2 x i32]* %elt, i32 0, i32 0 ; <i32*> [#uses=1]
50   %val = load i32* %elt1                             ; <i32> [#uses=1]
51   %elt2 = getelementptr inbounds [2 x i32]* %elt, i32 0, i32 1 ; <i32*> [#uses=1]
52   %val3 = load i32* %elt2                            ; <i32> [#uses=1]
53   %4 = call arm_aapcscc  i32 @add(i32 %val, i32 %val3) nounwind ; <i32> [#uses=1]
```

Sizeof() keyword

```
1 int main(void) {
2   int a = sizeof(long double);
3
4   return 0;
5 }
```



x86

```
3 target triple = "i386-pc-linux-gnu"
4
5 define i32 @main() nounwind {
6 entry:
7   %retval = alloca i32
8   %a = alloca i32
9   %0 = alloca i32
10  %"alloca point" = bitcast i32 0 to i32
11  store i32 12, i32* %a, align 4
12  store i32 0, i32* %0, align 4
13  %1 = load i32* %0, align 4
14  store i32 %1, i32* %retval, align 4
15  br label %return
```

ARM

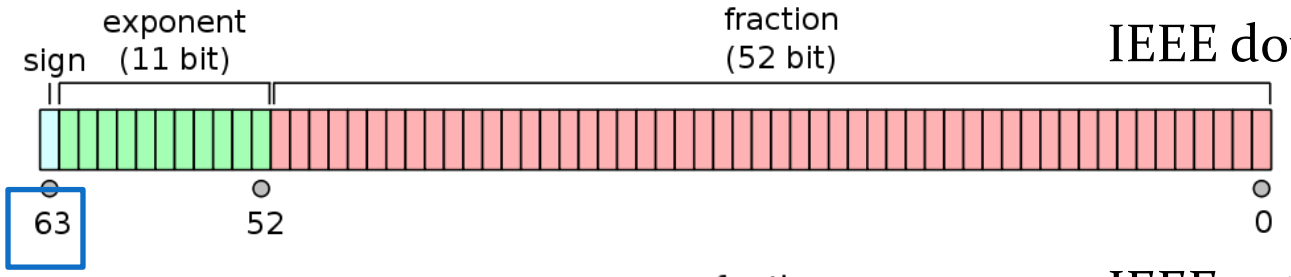
```
3 target triple = "armv5-none-linux-gnueabi"
4
5 define arm_aapcscc i32 @main() nounwind {
6 entry:
7   %retval = alloca i32
8   %a = alloca i32
9   %0 = alloca i32
10  %"alloca point" = bitcast i32 0 to i32
11  store i32 8, i32* %a, align 4
12  store i32 0, i32* %0, align 4
13  %1 = load i32* %0, align 4
14  store i32 %1, i32* %retval, align 4
15  br label %return
```

Target Dependent Properties

- LLVM frontend
  - LLVM frontend generates some target dependent bitcodes with common LLVM IR.
    - Function type
    - Sizeof() keyword
- LLVM IR
  - LLVM does not support common IR in some cases.
    - Long double type
    - Struct type with bitfield
- Source language
  - Inline assembly
  - Target dependent source codes

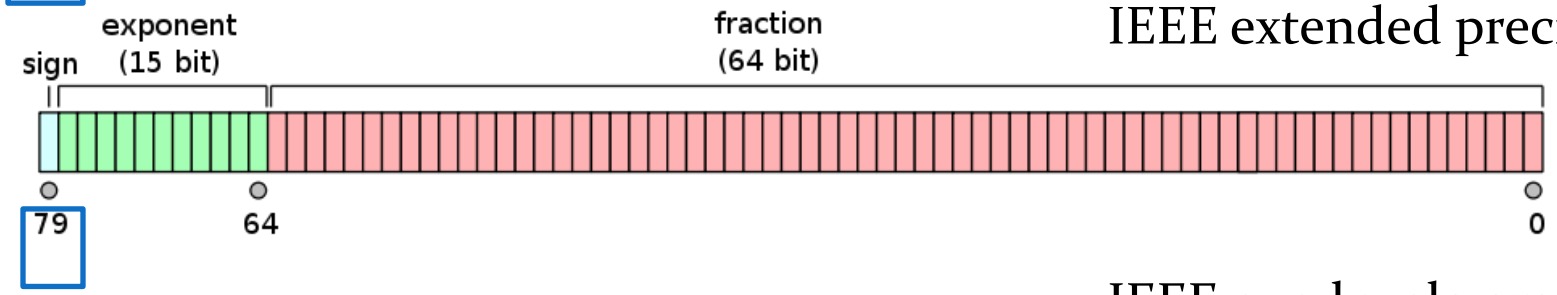
Target Dependent Properties

- long double type
  - Various encoding formats



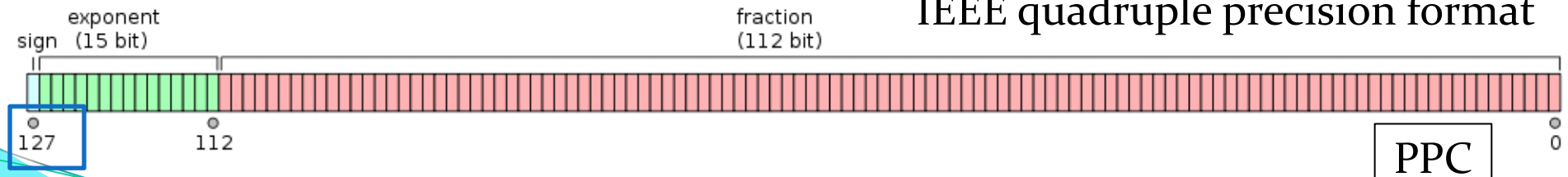
IEEE double precision format

ARM



IEEE extended precision format

X86



IEEE quadruple precision format

PPC

Target Dependent Properties

```
 1 #include <stdio.h>
 2
 3 int main(void)
 4 {
 5   long double a = 3.14;
 6   long double b = 2.2;
 7   long double c;
 8
 9   c = a + b;
10
11   printf("c=%Lf\n", c);
12
13   return 0;
14 }
```

LLVM does not support common IR type for long double type.

```
%"alloca point" = bitcast i32 0 to i32
store x86_fp80 0xK4000C8F5C28F5C28F800, x86_fp80* %a, align 4
store x86_fp80 0xK40008CCCCCCCCCCCD000, x86_fp80* %b, align 4
%1 = load x86_fp80* %a, align 4
%2 = load x86_fp80* %b, align 4
%3 = fadd x86_fp80 %1, %2                                ;
```

LLVM Bitcode For X86

```
%"alloca point" = bitcast i32 0 to i32
store double 3.140000e+00, double* %a, align 8
store double 2.200000e+00, double* %b, align 8
%1 = load double* %a, align 8
%2 = load double* %b, align 8
%3 = fadd double %1, %2
```

LLVM Bitcode for ARM

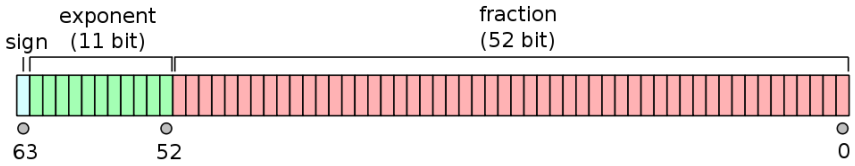
Target Dependent Properties

```
1  #include <stdio.h>
2
3  int main(void)
4  {
5    long double a = 3.14;
6    long double b = 2.2;
7    long double c;
8
9    c = a + b;
10
11   printf("c=%Lf\n", c);
12
13   return 0;
14 }
```

Application

Source for ARM

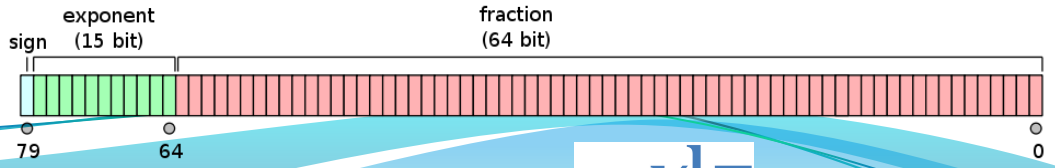
IEEE_double format encoding
variable “c”
as parameter for printf function



Library

System X86

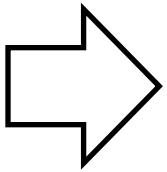
Printf function waits
X86_fp80 format encoding
Variable for “%Lf”
on X86 architecture



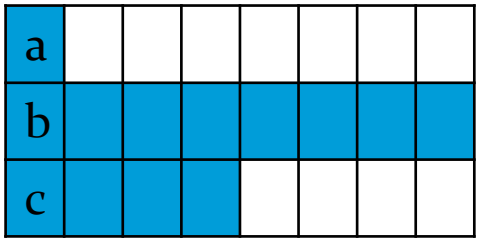
Target Dependent Properties

- Strcut type with bitfield

```
struct foo
{
    char a:4;
    long long b:61;
    int c:30;
};
```



ARM

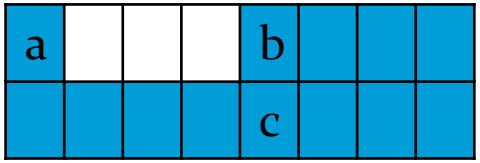


Memory

<{ i8, [7 x i8], i64, i32, [4 x i8]}>

LLVM IR

x86



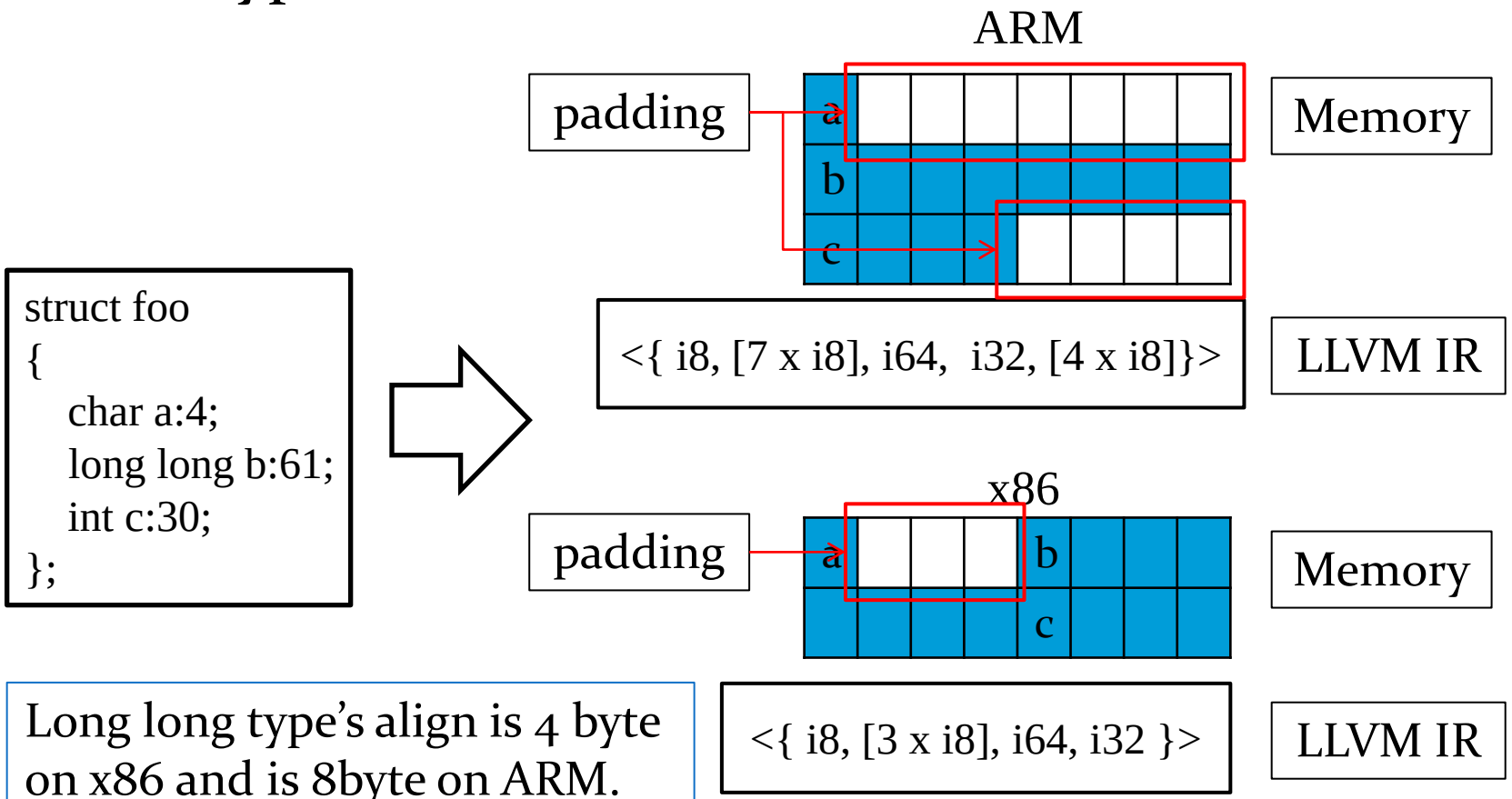
Memory

<{ i8, [3 x i8], i64, i32 }>

LLVM IR

Target Dependent Properties

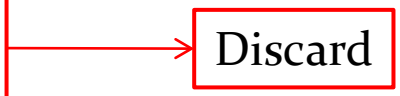
- Strcut type with bitfield



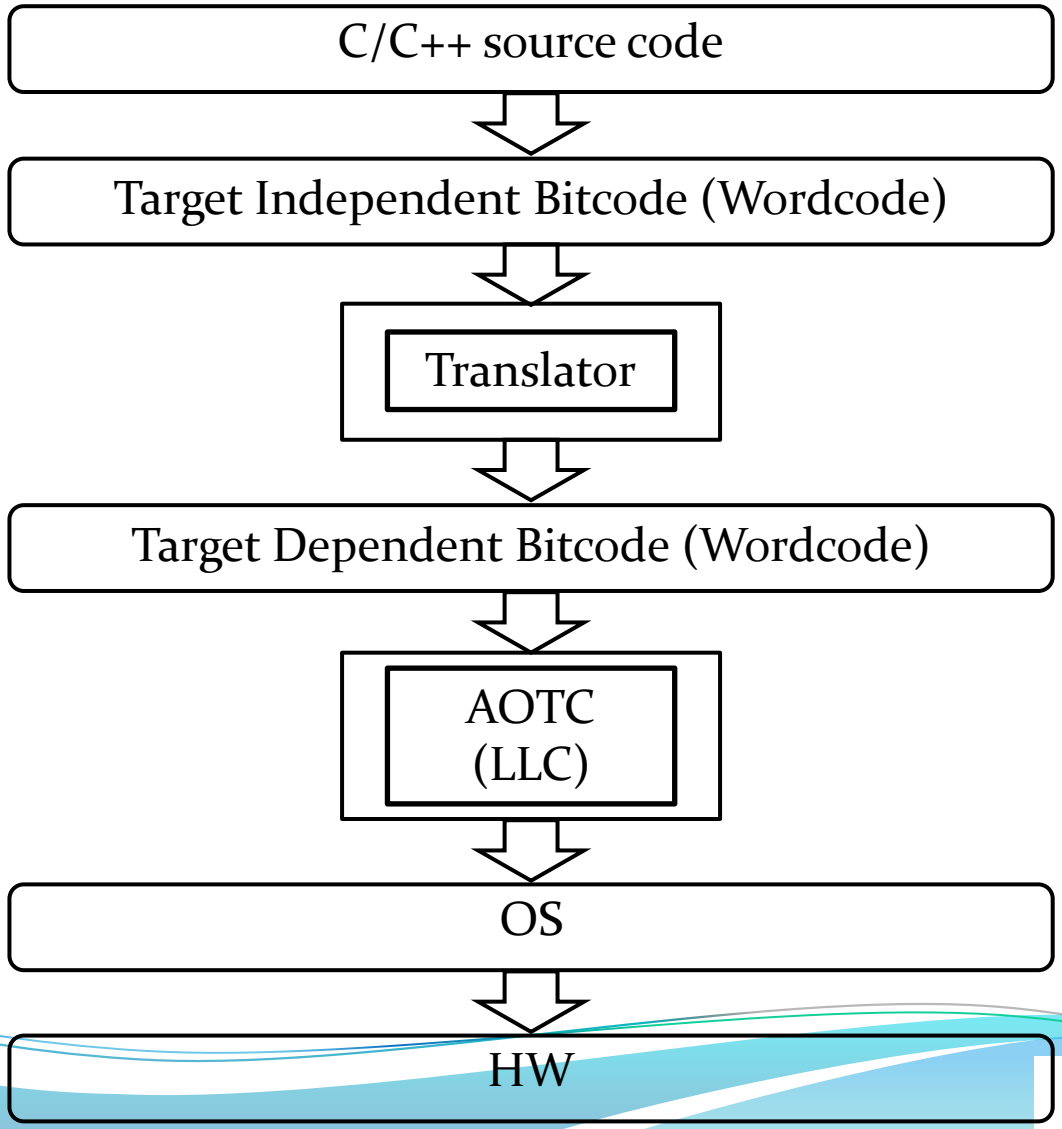
Long long type's align is 4 byte on x86 and is 8byte on ARM. Struct type's align is biggest field's align.

Target Dependent Properties

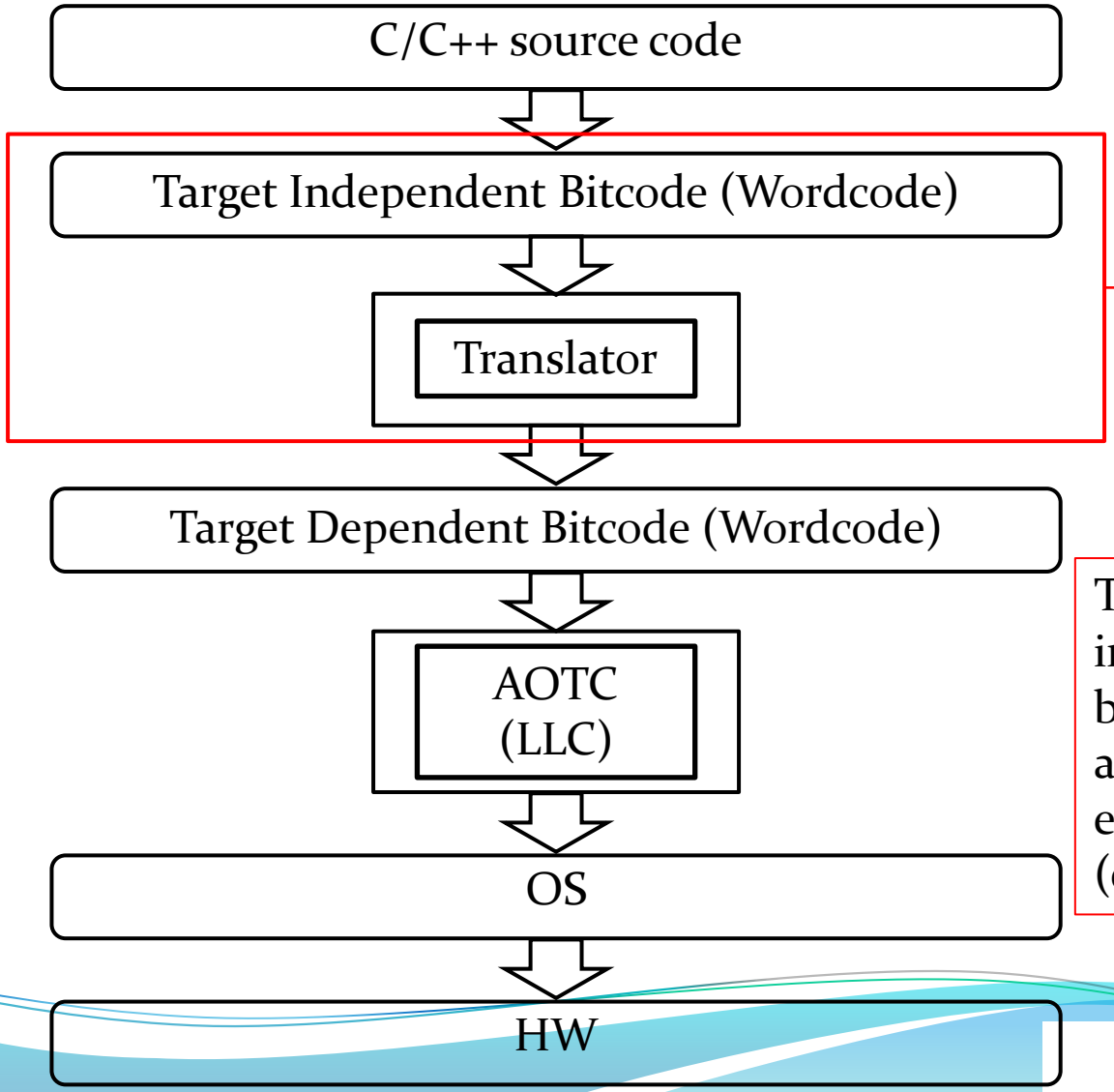
- LLVM frontend
  - LLVM frontend generates some target dependent bitcodes with common LLVM IR.
    - Function type → ABI compatibility
    - Sizeof() keyword
- LLVM IR
  - Bitcode does not support common IR in some cases.
    - Long double type
    - Struct type with bitfield
- Source language
  - Inline assembly
  - Target dependent source codes



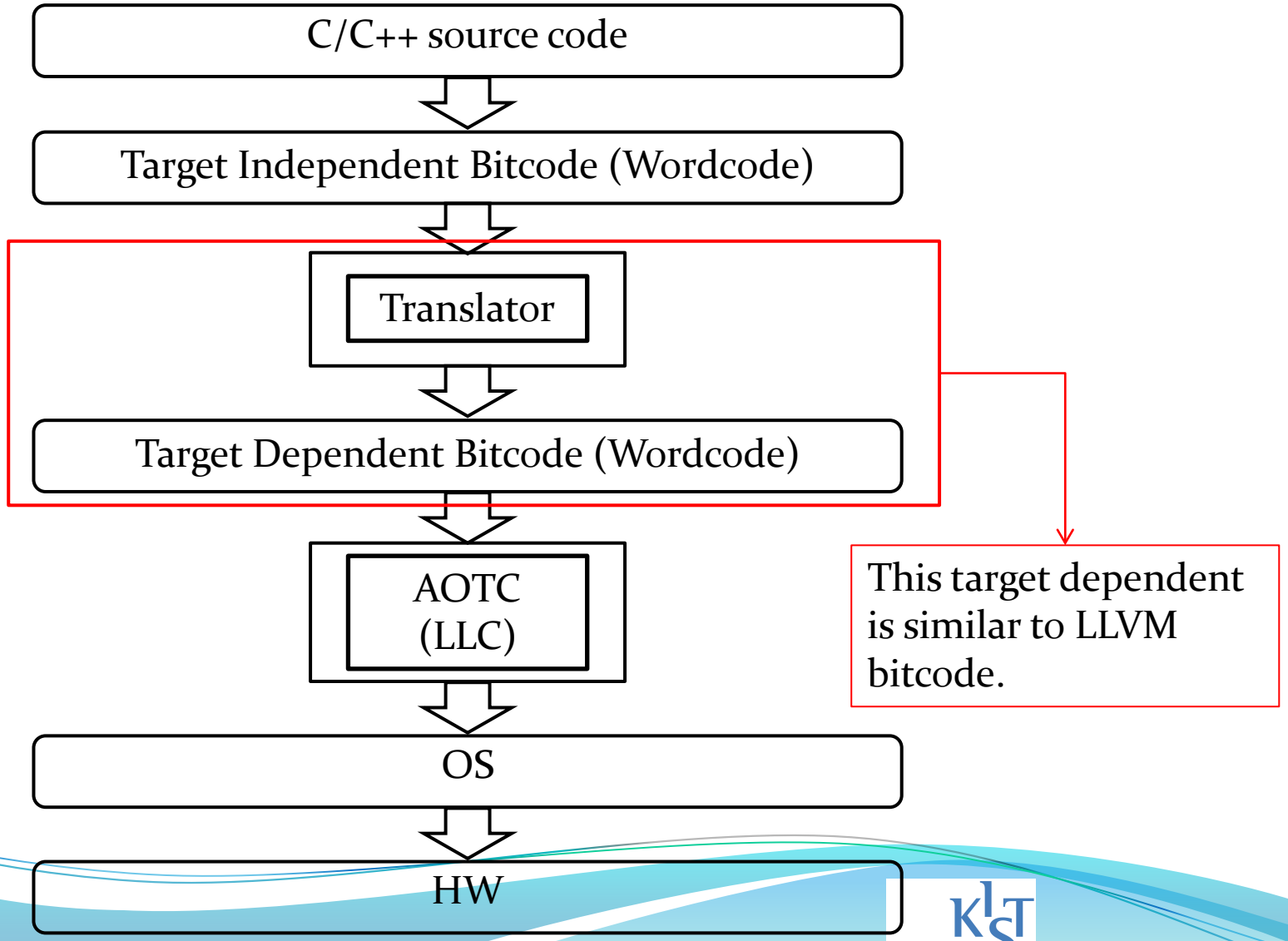
New Compilation Strategy



New Compilation Strategy



New Compilation Strategy



Wordcode

- Wordcode can be target dependent or target independent.
  - Target independent Wordcode
    - IntegerTypes with align information from source code
    - StructType with bitfield
    - Long double type
    - Etc…
  - Target dependent Wordcode
    - It is similar to LLVM bitcode.
- Wordcode is applied to almost passes on LLVM.

Wordcode

```
1 int main (void) {
2   char a;
3   short b;
4   int c;
5   long d;
6   long long e;
7   float f;
8   double g;
9
10  return 0;
11 }
```

Target independent Wordcode

```
1  ; ModuleID = 'a.c'
2  target datalayout = "e-p:32:32:32-i1:8:8-i8:8:8-
   -v64:64:64-v128:128:128-a0:0:64-f192:32:32"
3  target triple = "ovm-none-linux"
4
5  define i32(int) @main() nounwind {
6  entry:
7    %retval = alloca i32(int)
8    %g = alloca double
9    %f = alloca float
10   %e = alloca i64(longlong)
11   %d = alloca i32(long)
12   %c = alloca i32(int)
13   %b = alloca i16(short)
14   %a = alloca i8(char)
15   %0 = alloca i32(int)
16   %"alloca point" = bitcast i32() 0 to i32()
17   store i32(int) 0, i32(int)* %0, align 4
18   %1 = load i32(int)* %0, align 4
19   store i32(int) %1, i32(int)* %retval, align 4
20   br label %return
21
22 return:
23   %retval1 = load i32(int)* %retval
24   ret i32(int) %retval1
25 }
```

Wordcode

Target independent Wordcode

```
1  ; ModuleID = 'a.c'
2  target datalayout = "e-p:32:32:32-i1:8:8-i8:8:8-
   -v64:64:64-v128:128:128-a0:0:64-f192:32:32"
3  target triple = "ovm-none-linux"
4
5  define i32(int) @main() nounwind {
6  entry:
7    %retval = alloca i32(int)
8    %g = alloca double
9    %f = alloca float
10   %e = alloca i64(longlong)
11   %d = alloca i32(long)
12   %c = alloca i32(int)
13   %b = alloca i16(short)
14   %a = alloca i8(char)
15   %0 = alloca i32(int)
16   %"alloca point" = bitcast i32() 0 to i32()
17   store i32(int) 0, i32(int)* %0, align 4
18   %1 = load i32(int)* %0, align 4
19   store i32(int) %1, i32(int)* %retval, align 4
20   br label %return
21
22 return:
23   %retval1 = load i32(int)* %retval
24   ret i32(int) %retval1
25 }
```

Target dependent Wordcode (ARM)

```
1  ; ModuleID = 'a.mod.opt.arm.bc'
2  target datalayout = "e-p:32:32:32-i1:8:8-i8:
   -v64:64:64-v128:128:128-a0:0:64"
3  target triple = "armv5-none-linux-gnueabi"
4
5  define i32() @main() nounwind {
6  entry:
7    %retval = alloca i32()
8    %g = alloca double
9    %f = alloca float
10   %e = alloca i64()
11   %d = alloca i32()
12   %c = alloca i32()
13   %b = alloca i16()
14   %a = alloca i8()
15   %0 = alloca i32()
16   %"alloca point" = bitcast i32() 0 to i32()
17   store i32() 0, i32()* %0, align 4
18   %1 = load i32()* %0, align 4
19   store i32() %1, i32()* %retval, align 4
20   br label %return
21
22 return:
23   %retval1 = load i32()* %retval
24   ret i32() %retval1
25 }
```

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Long Double Type

Input

Long Double Type

Target Independent Wordcode

Intermediate Representation

Target Dependent Wordcode

X86_fp80

IEEE_double

IEEE_quad

```c
#include <stdio.h>

int main(void) {
  long double a = 3.14;
  long double b = 2.2;
  long double c;

  c = a + b;

  printf("c=%Lf\n", c);
  return 0;
}
```

Long Double Type

Target independent Wordcode

```
 7 define i32(int) @main() nounwind {
 8 entry:
 9   %retval = alloca i32(int)                       ; <i32(int)*> [#uses=2]
10   %c = alloca long_double                         ; <long_double*> [#uses=2]
11   %b = alloca long_double                         ; <long_double*> [#uses=2]
12   %a = alloca long_double                         ; <long_double*> [#uses=2]
13   %0 = alloca i32(int)                            ; <i32(int)*> [#uses=2]
14   %"alloca point" = bitcast i32() 0 to i32()      ; <i32()> [#uses=0]
15   store long_double 0xL0000000000000081000000000000000C8F5C28F5C28F800, long_double* %a, align 8
16   store long_double 0xL0000000000000081000000000000000CCCCCCCCCCCD000, long_double* %b, align 8
17   %1 = load long_double* %a, align 8              ; <long_double> [#uses=1]
18   %2 = load long_double* %b, align 8              ; <long_double> [#uses=1]
19   %3 = fadd long_double %1, %2                    ; <long_double> [#uses=1]
20   store long_double %3, long_double* %c, align 8
21   %4 = load long_double* %c, align 8              ; <long_double> [#uses=1]
22   %5 = call i32(int) (i8(char)*, ...)* @printf(i8(char)* noalias getelementptr inbounds ([7 x i8(
   char)]* @.str, i32(int) 0, i32(int) 0), long_double %4) nounwind ; <i32(int)> [#uses=0]
23   store i32(int) 0, i32(int)* %0, align 4
24   %6 = load i32(int)* %0, align 4                 ; <i32(int)> [#uses=1]
25   store i32(int) %6, i32(int)* %retval, align 4
26   br label %return
```

Long Double Type

Target dependent Wordcode (x86)

```
 7 define i32() @main() nounwind {
 8 entry:
 9   %retval = alloca i32()                          ; <i32()*> [#uses=2]
10   %c = alloca x86_fp80                            ; <x86_fp80*> [#uses=2]
11   %b = alloca x86_fp80                            ; <x86_fp80*> [#uses=2]
12   %a = alloca x86_fp80                            ; <x86_fp80*> [#uses=2]
13   %0 = alloca i32()                               ; <i32()*> [#uses=2]
14   %"alloca point" = bitcast i32() 0 to i32()      ; <i32()> [#uses=0]
15   store x86_fp80 0xK4000C8F5C28F5C28F800, x86_fp80* %a, align 4
16   store x86_fp80 0xK40008CCCCCCCCCCCD000, x86_fp80* %b, align 4
17   %1 = load x86_fp80* %a, align 4                 ; <x86_fp80> [#uses=1]
18   %2 = load x86_fp80* %b, align 4                 ; <x86_fp80> [#uses=1]
19   %3 = fadd x86_fp80 %1, %2                       ; <x86_fp80> [#uses=1]
20   store x86_fp80 %3, x86_fp80* %c, align 4
21   %4 = load x86_fp80* %c, align 4                 ; <x86_fp80> [#uses=1]
22   %5 = call i32() (i8()*, ...)* @printf(i8()* noalias getelementptr inbounds ([7 x i8()]* @.str,
   i32() 0, i32() 0), x86_fp80 %4) nounwind ; <i32()> [#uses=0]
```

Result

```
jaykang10:~/test$ ./b.org.x86
c=5.340000
jaykang10:~/test$ ./b.mod.opt.x86
c=5.340000
```

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Long Double Type

Target dependent Wordcode (ARM)

```
 7 define i32() @main() nounwind {
 8 entry:
 9   %retval = alloca i32()                          ; <i32()*> [#uses=2]
10   %c = alloca double                              ; <double*> [#uses=2]
11   %b = alloca double                              ; <double*> [#uses=2]
12   %a = alloca double                              ; <double*> [#uses=2]
13   %0 = alloca i32()                               ; <i32()*> [#uses=2]
14   %"alloca point" = bitcast i32() 0 to i32()      ; <i32()> [#uses=0]
15   store double 3.140000e+00, double* %a, align 8
16   store double 2.200000e+00, double* %b, align 8
17   %1 = load double* %a, align 8                   ; <double> [#uses=1]
18   %2 = load double* %b, align 8                   ; <double> [#uses=1]
19   %3 = fadd double %1, %2                         ; <double> [#uses=1]
20   store double %3, double* %c, align 8
21   %4 = load double* %c, align 8                   ; <double> [#uses=1]
22   %5 = call i32() (i8()*, ...)* @printf(i8()* noalias getelementptr inbounds ([7 x i8()]* @.str,
   i32() 0, i32() 0), double %4) nounwind ; <i32()> [#uses=0]
```

Result

```
[sbox-FREMANTLE_ARMEL: ~] > ./b.org.arm
c=5.340000
[sbox-FREMANTLE_ARMEL: ~] > ./b.mod.opt.arm
c=5.340000
```

Struct Type with Bitfield

Input

```
struct foo
{
   char a:4;
   long long b:61;
   int c:30;
};
```

Target Independent Wordcode

{ i4(char), i61(longlong), i30(int) }

Target Dependent Wordcode

ARM

<{ i8, [7 x i8], i64, i32, [4 x i8]}>

x86

<{ i8, [3 x i8], i64, i32 }>

```c
#include <stdio.h>

struct foo {
char a:4;
long long b:61;
int c:30;
};

struct foo var = {1, 2, 3};

int main(void) {
  printf("var.c = %d\n", var.c);

  return 0;
}
```

Struct Type with Bitfield

Target independent Wordcode

```
1  ; ModuleID = 'c.c'
2  target datalayout = "e-p:32:32:32-i1:8:8-i8:8:8-i16:16:16-i32:32:32-i64:64:64-f32:32:32-f64:64:64
   -v64:64:64-v128:128:128-a0:0:64-f192:32:32"
3  target triple = "ovm-none-linux"
4
5  %struct.foo = type { i4(char), i61(longlong), i30(int) }
6
7  @var = global %struct.foo { i4(char) 1, i61(longlong) 2, i30(int) 3 } ; <%struct.foo*> [#uses=1]
8  @.str = private constant [12 x i8(char)] [i8(char) 118, i8(char) 97, i8(char) 114, i8(char) 46, i
   8(char) 99, i8(char) 32, i8(char) 61, i8(char) 32, i8(char) 37, i8(char) 100, i8(char) 10, i8(cha
   r) 0], align 1 ; <[12 x i8(char)]*> [#uses=1]
9
10 define i32(int) @main() nounwind {
11 entry:
12   %retval = alloca i32(int)                        ; <i32(int)*> [#uses=1]
13   %"alloca point" = bitcast i32() 0 to i32()       ; <i32()> [#uses=0]
14   %0 = ovmresolving load i30(int)* getelementptr inbounds (%struct.foo* @var, i32() 0, i32() 2),
   align 8 ; <i30(int)> [#uses=1]
15   %1 = sext i30(int) %0 to i32(int)                ; <i32(int)> [#uses=1]
16   %2 = call i32(int) (i8(char)*, ...)* @printf(i8(char)* noalias getelementptr inbounds ([12 x i8
   (char)]* @.str, i32(int) 0, i32(int) 0), i32(int) %1) nounwind ; <i32(int)> [#uses=0]
17   br label %return
18
19 return:                                           ; preds = %entry
20   %retval1 = load i32(int)* %retval                ; <i32(int)> [#uses=1]
21   ret i32(int) %retval1
22 }
```

Struct Type with Bitfield

Target dependent Wordcode (x86)

```
 3 target triple = "i386-pc-linux-gnu"
 4
 5 %0 = type { i8(), i8(), i8(), i8(), i8(), i8(), i8(), i8(), i8(), i8(), i8(), i8(), i8(), i8(), i
   8(), i8() }
 6 %struct.foo = type <{ i8(), [3 x i8()], i64(), i32() }>
 7
 8 @var = global %0 { i8() 1, i8() 0, i8() 0, i8() 0, i8() 2, i8() 0, i8() 0, i8() 0, i8() 0, i8() 0
   , i8() 0, i8() 0, i8() 3, i8() 0, i8() 0, i8() 0 } ; <%0*> [#uses=1]
 9 @.str = private constant [12 x i8()] c"var.c = %d\0A\00", align 1 ; <[12 x i8()]*> [#uses=1]
10
11 define i32() @main() nounwind {
12 entry:
13   %retval = alloca i32()                          ; <i32()*> [#uses=1]
14   %"alloca point" = bitcast i32() 0 to i32()      ; <i32()> [#uses=0]
15   %0 = load i32()* getelementptr inbounds (%struct.foo* bitcast (%0* @var to %struct.foo*), i32()
   0, i32() 3), align 1 ; <i32()> [#uses=1]
16   %1 = shl i32() %0, 2                            ; <i32()> [#uses=1]
17   %2 = ashr i32() %1, 2                           ; <i32()> [#uses=1]
18   %3 = trunc i32() %2 to i30()                    ; <i30()> [#uses=1]
19   %4 = sext i30() %3 to i32()                     ; <i32()> [#uses=1]
20   %5 = call i32() (i8()*, ...)* @printf(i8()* noalias getelementptr inbounds ([12 x i8()]* @.str,
   i32() 0, i32() 0), i32() %4) nounwind ; <i32()> [#uses=0]
```

Result

```
jaykang10:~/test$ ./c.org.x86
var.c = 3
jaykang10:~/test$ ./c.mod.opt.x86
var.c = 3
```

Struct Type with Bitfield

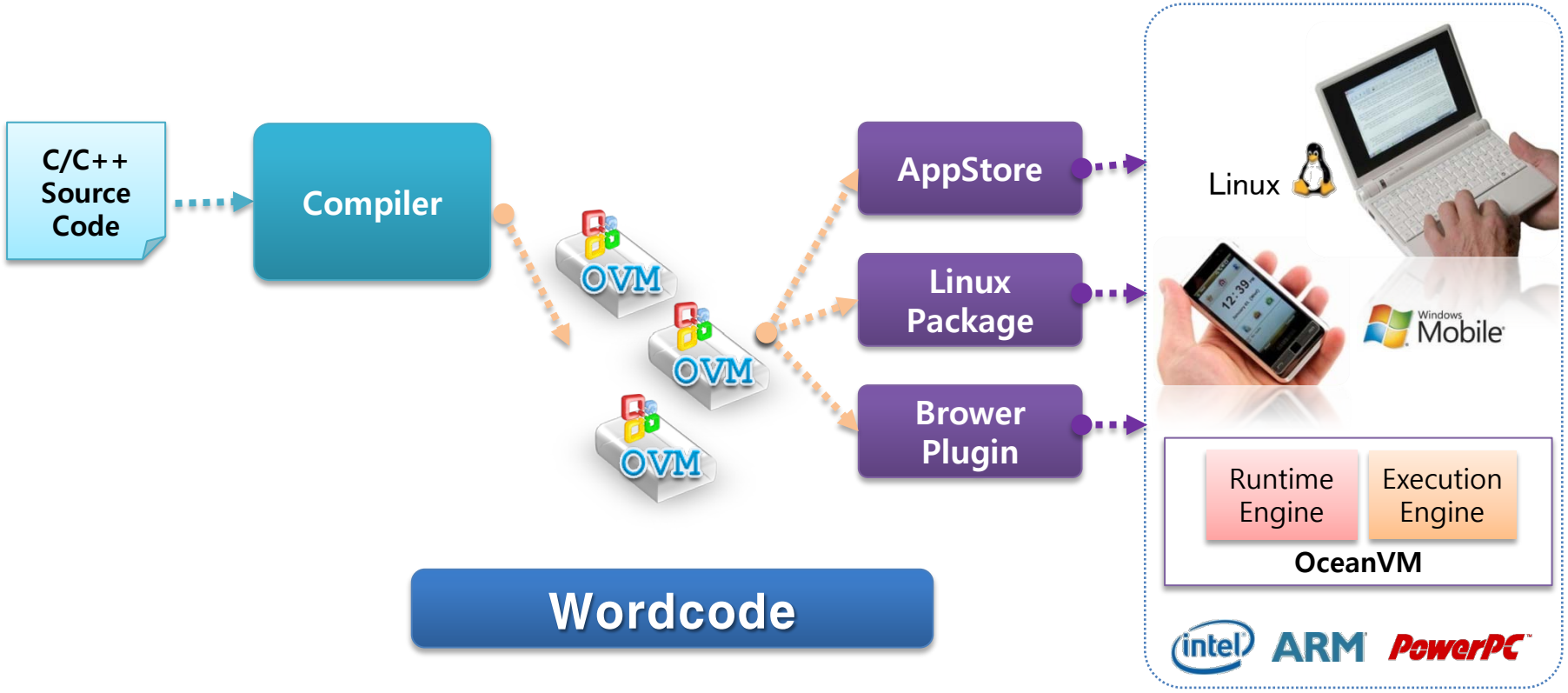
Target dependent Wordcode (ARM)

```
3  target triple = "armv5-none-linux-gnueabi"
4
5  %0 = type { i8(), i8(), i8(), i8(), i8(), i8(), i8(), i8(), i8(), i8(), i8(), i8(), i8(), i8(), i
   8(), i8(), i8(), i8(), i8(), [4 x i8()] }
6  %struct.foo = type <{ i8(), [7 x i8()], i64(), i32(), [4 x i8()] }>
7
8  @var = global %0 { i8() 1, i8() 0, i8() 0, i8() 0, i8() 0, i8() 0, i8() 0, i8() 0, i8() 2, i8() 0
   , i8() 0, i8() 0, i8() 0, i8() 0, i8() 0, i8() 0, i8() 3, i8() 0, i8() 0, i8() 0, [4 x i8()] zero
   initializer } ; <%0*> [#uses=1]
9  @.str = private constant [12 x i8()] c"var.c = %d\0A\00", align 1 ; <[12 x i8()]*> [#uses=1]
10
11 define i32() @main() nounwind {
12 entry:
13   %retval = alloca i32()                          ; <i32()*> [#uses=1]
14   %"alloca point" = bitcast i32() 0 to i32()      ; <i32()> [#uses=0]
15   %0 = load i32()* getelementptr inbounds (%struct.foo* bitcast (%0* @var to %struct.foo*), i32()
   0, i32() 3), align 1 ; <i32()> [#uses=1]
16   %1 = shl i32() %0, 2                            ; <i32()> [#uses=1]
17   %2 = ashr i32() %1, 2                           ; <i32()> [#uses=1]
18   %3 = trunc i32() %2 to i30()                    ; <i30()> [#uses=1]
19   %4 = sext i30() %3 to i32()                     ; <i32()> [#uses=1]
20   %5 = call i32() (i8()*, ...)* @printf(i8()* noalias getelementptr inbounds ([12 x i8()]* @.str,
   i32() 0, i32() 0), i32() %4) nounwind ; <i32()> [#uses=0]
```

Result

```
[sbox-FREMANTLE_ARMEL: ~] > ./c.org.arm
var.c = 3
[sbox-FREMANTLE_ARMEL: ~] > ./c.mod.opt.arm
var.c = 3
```

Application



Happy Hacking!