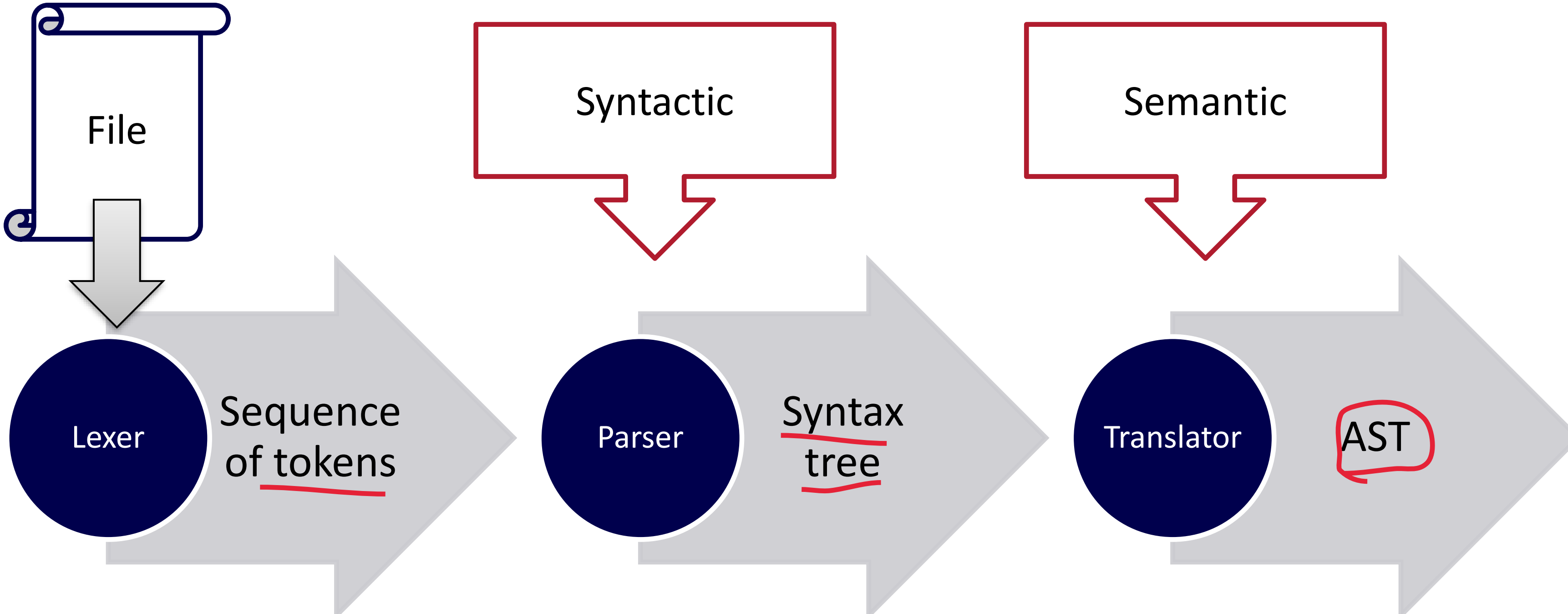
COMSM1302
Overview of Computer Architecture

Lecture 17

Compilers - 2

In the previous lecture



- Symbol table
- Scoping

In this lecture

Translator → Optimiser → Code generator

- At the end of this lecture:
  - Learn how compilers can handle different programing languages and different target platforms.
  - How you can use compliers to generate optimise assembly codes.

Compiler phases

- Lexer
- Parser
- Translator
- Optimiser
- Code generator

Typing

- In C, x++ means:
  - if x is an integer: add 1 to x
  - if x is a struct ... : an error
- x+y needs different instructions for char/int/long etc.
- So, for each active variable we need to track its **type** in the symbol table.

Different types of typing

- **Static typing**: variable types are established at compile time.
- **Dynamic typing**: the type of a variable can change (and needs to be checked) at runtime.

Dynamic typing – Python example

```
x = 2
print(type(x))

x = 'Hello'
print(type(x))
```

Asymmetric

- In math:
  - $a = b + 1 \Leftrightarrow b + 1 = a$
- In programming:
  - `a = b + 1;` $\nLeftrightarrow$ `b + 1 = a;`

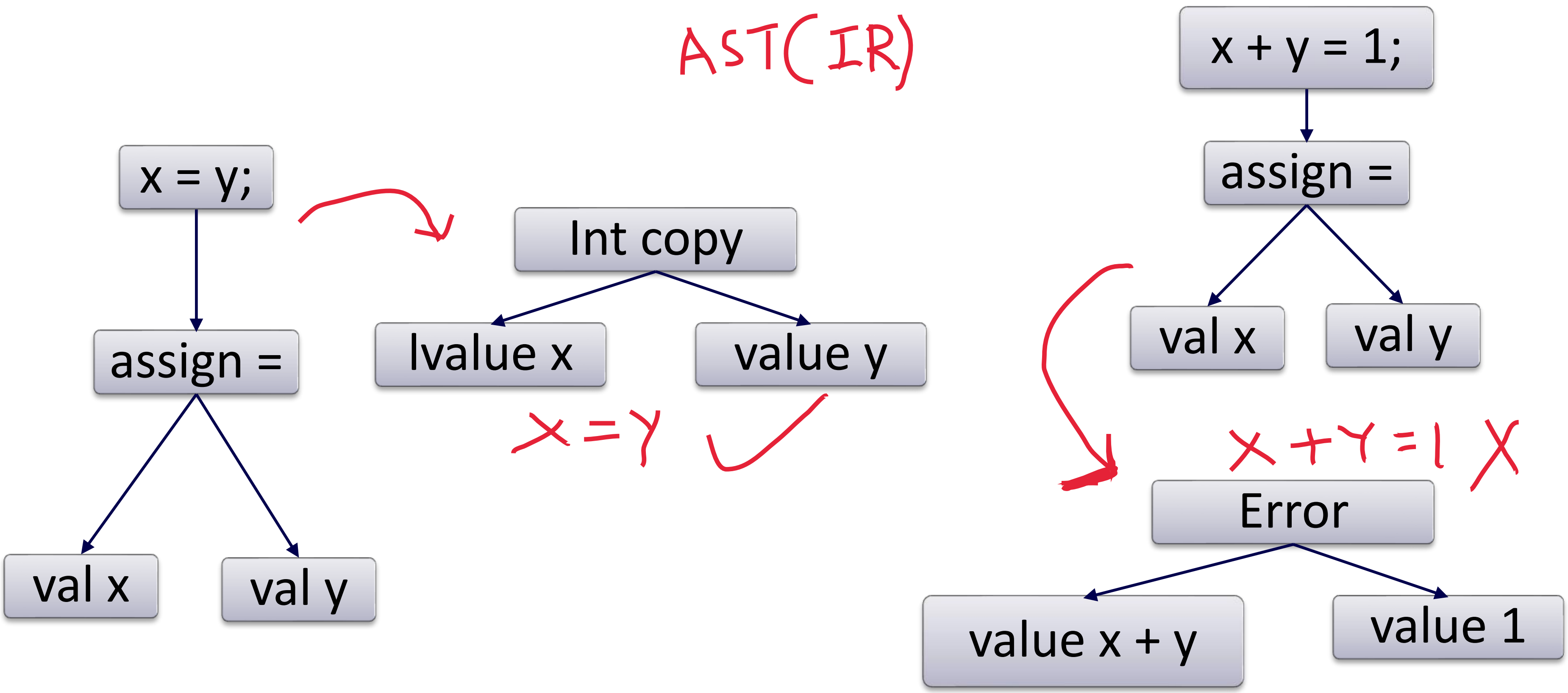
Lvalues

- L-values ("left values") are "things that you can assign to". During translation, we can catch illegal assignments.

L-values in C:	Not L-values in C:
x	2
x = y	x+y
x+	x++

Translator

- Translator: turn one syntax tree into another.



Translator – error

```c
int main(void){
 int x;
 int y;
 x + y = 1;
return 0;
}
```

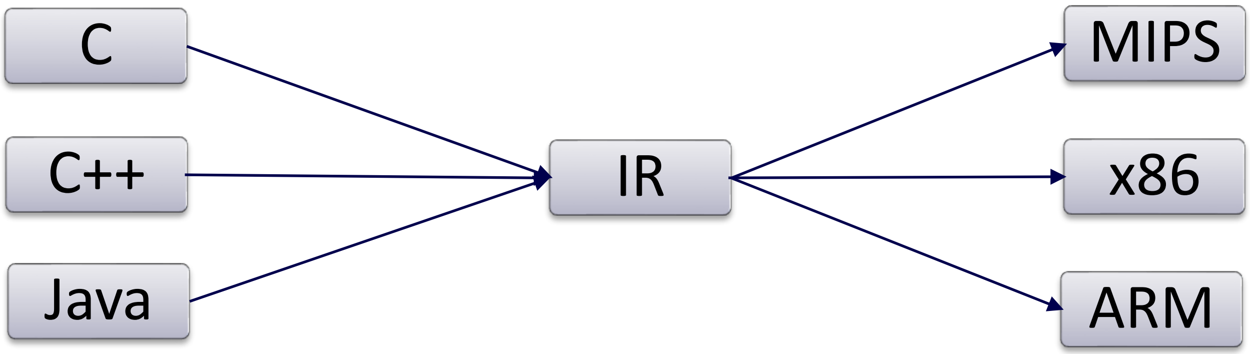
file.c:5:8: error: lvalue required as left operand of assignment

 x + y = 1;

Intermediate representation

- Compilers use language- and platform-independent IR in which programs are abstract syntax trees.

IR can be generated from various languages and can be applied to various platforms.



Intermediate representation

- An IR typically targets a virtual machine with
  - an unlimited number of registers
  - an unlimited amount of memory max
  - a very rich (semantic) instruction set

Translator

1 • Transform syntax tree

2 • Create Symbol Table

  – Deal with scopes

  – Deal with types

3 • Normally outputs an intermediate hardware independent representation

  – Abstract Syntax Tree (AST)

Compiler phases

- Lexer
- Parser
- Translator
- **Optimiser**
- Code generator

Optimiser

- Input: AST
- Output: optimised AST
  - eliminate dead code
  - eliminate repeated register assignments
  - many passes (gcc has over 150)
  - The optimiser can do both general and processor-specific optimisations.

Optimisation levels

- **-O0** Most optimisations are disabled. The aim of the compiler is to reduce the compilation cost.

- **-O1** The compiler tries to reduce code size and execution time, without performing any optimizations that take a great deal of compilation time.

GCC optimisation options

- https://gcc.gnu.org/onlinedocs/gcc/Optimize-Options.html

Optimisation – example 1

```c
int main(void){
    int x;
    int y;
    x = 3;
    y = 4;
    x += 0;
    y += x;
return 0;
}
```

```
arm-none-eabi-gcc -g -O0 -c optimise-1.c
arm-none-eabi-objdump -S optimise-1.o > optimise-1.s
```

Example 1 -O0 optimisation

int main(void){

```
str fp, [sp, #-4]!
add fp, sp, #0
sub sp, sp, #12
```

int x; int y; x = 3;

```
mov     r3, #3
str     r3, [fp, #-8]
```

y = 4;

```
mov     r3, #4
str     r3, [fp, #-12]
```

x += 0; y += x;

```
ldr     r2, [fp, #-12]
ldr     r3, [fp, #-8]
add     r3, r2, r3
str     r3, [fp, #-12]
```

return 0;
}

```
mov     r3, #0
```

return register r0

```
mov     r0, r3
add     sp, fp, #0
ldr     fp, [sp], #4
bx      lr
```

= mov pc, lr

Example 1 -O1 optimisation

```
x = 3;
 y = 4;
 x += 0;
 y += x;
return 0;
}
            mov     r0, #0
            bx   lr
```

Optimisation – example 2

```
int main(void){
    int x;
    int y;
    x = 3;
    y = 4;
    x += 0;
    y += x;
return y;
}
```

Example 2 -O0 optimisation

```
int main(void){      str fp, [sp,#-4]!
                     add fp, sp, #0
                     sub sp, sp, #12
int x; int y; x = 3;
                     mov     r3, #3
                     str  r3, [fp, #-8]
y = 4;               mov     r3, #4
                     str  r3, [fp, #-12]
x += 0; y += x;
                     ldr  r2, [fp, #-12]   y
                     ldr  r3, [fp, #-8]    x
                     add r3, r2, r3
                     str  r3, [fp, #-12]

return y;            ldr  r3, [fp, #-12]
}
                     mov     r0, r3
                     add sp, fp, #0
                     ldr fp, [sp], #4
                     bx  lr
```

Example 2 -O1 optimisation

```
x = 3;
 y = 4;
 x += 0;
 y += x;
return y;
}
```

```
mov     r0, #7
bx   lr
```

Optimisation example 3

```
int main(int x, int y){
    x += 0;
    y += x;
return y;
}
```

Example 3 –O1 optimisation

```
int main(int x, int y){
 x += 0;
 y += x;
return y;
}
```

```
add r0, r0, r1
bx  lr
```

Compiler phases

- Lexer
- Parser
- Translator
- Optimiser
- Code generator

Code generator

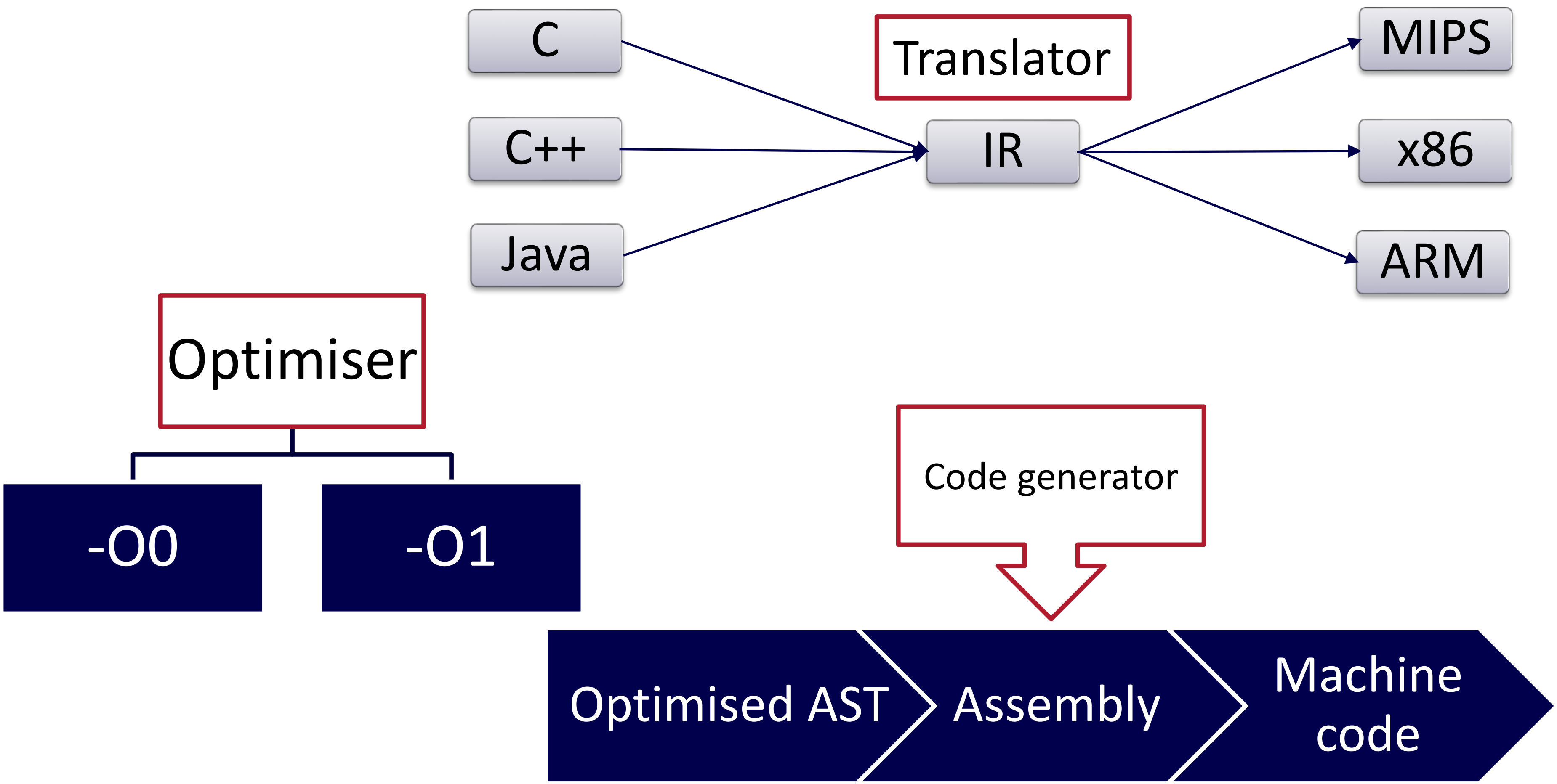
- Input: optimised AST
- Output: machine code / executable file
- often in 2 phases:
  1 – AST → assembly
  2 – assembly → machine code

Cross compilers

- The compiler does not have to run on the same architecture as the architecture targeted by the given program.

- Cross-compiling is compiling on a different platform to the target one.

Summary


C
C++
Java
Translator
IR
MIPS
x86
ARM
Optimiser
-O0
-O1
Code generator
Optimised AST
Assembly
Machine code