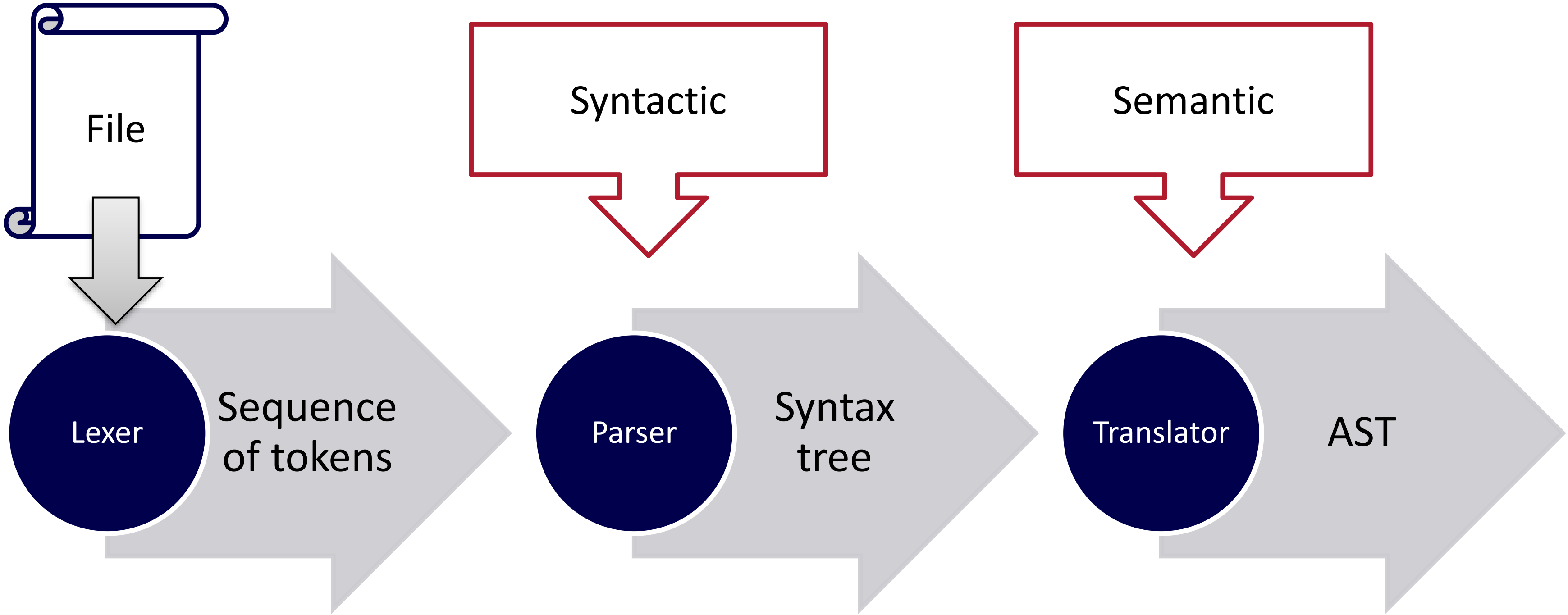
COMSM1302
Overview of Computer Architecture

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))
```

message = "Hello"

massage = "Hi"

print(message).

→ Hello

str message;

message = "H"

→ massage = "x"

Asymmetric

- In math:
  - $a = b + 1 \Leftrightarrow b + 1 = a$
- In programming:
  - $a = b + 1; \not\Leftrightarrow b + 1 = a;$

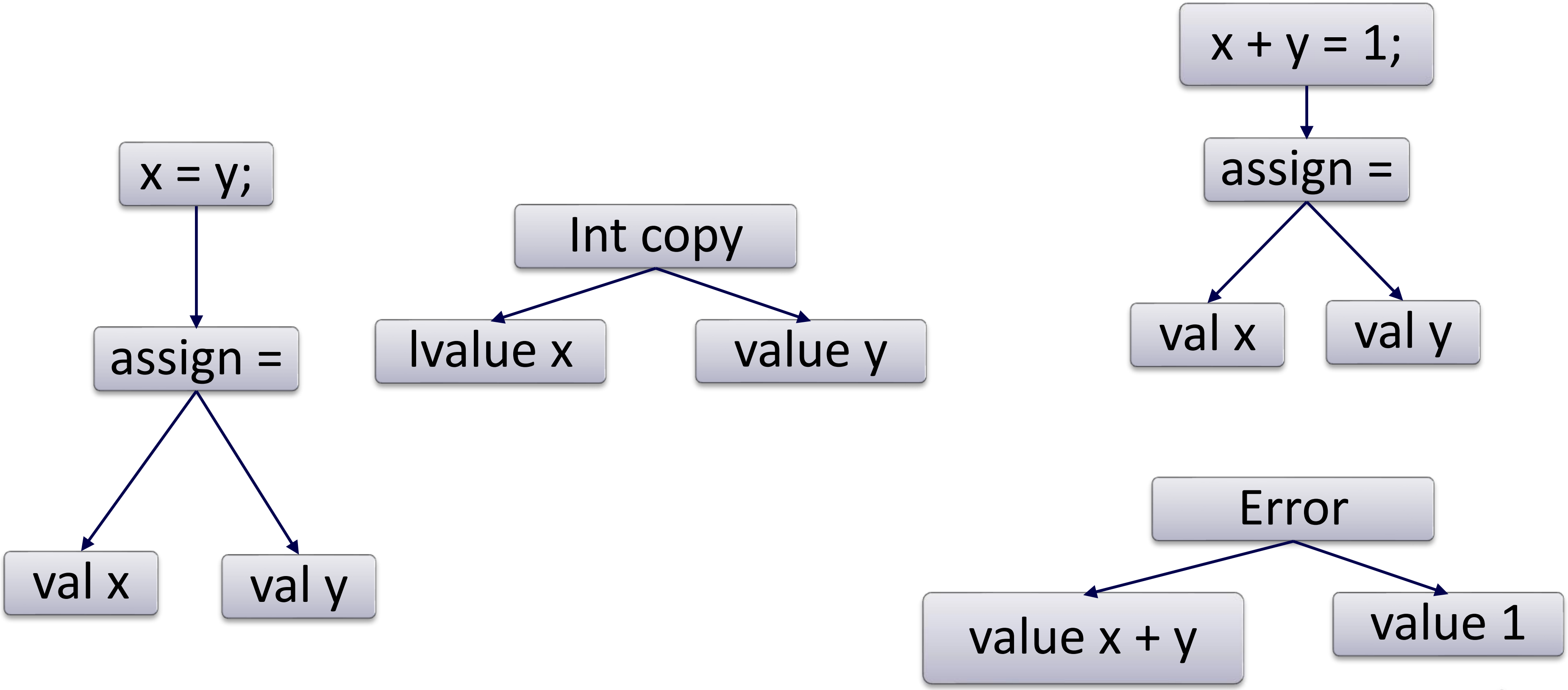
Lvalues

- 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 = 5; ?
x = y = 3;	x+y = 5; ?
x+ = 4	x++ = 6; ?

Translator

- Translator: turn one syntax tree into another.



Translator – error

KW W

```
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

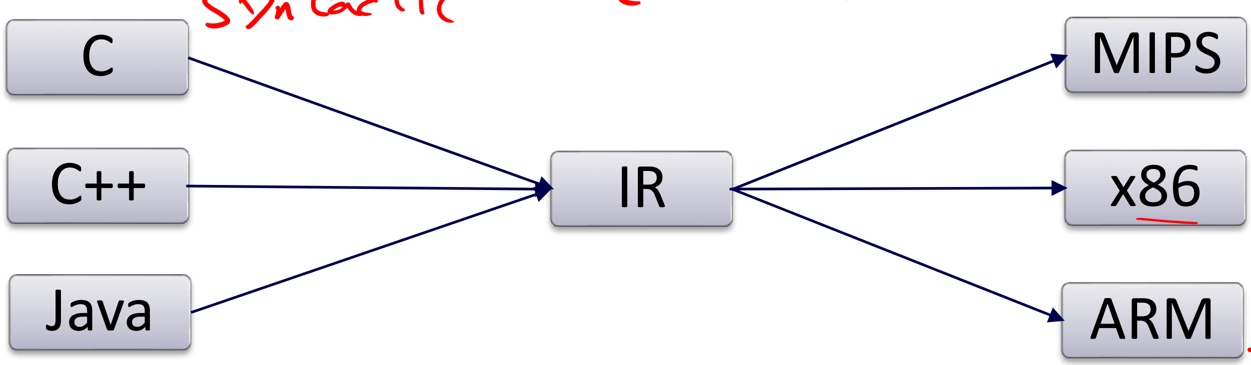
- Compilers use language- and platform-independent IR in which programs are abstract syntax trees.

Lexer → Parser → Tarnslator → AST → optimiser

Parser ↓ syntactic

Tarnslator ↓ semantic

optimiser ↓ code gerator ↓ machine code



Intermediate representation

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

Translator

- Transform syntax tree
- Create Symbol Table
  - Deal with scopes
  - Deal with types
- 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.

– x = 5;
– if (x == 0) { x = y; }

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

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

→ x = x + 0

→ y = y + x

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
x = x + 0;        str  r3, [fp, #-12]
x += 0; y += x;
y = y + x         ldr  r2, [fp, #-12]
                  ldr  r3, [fp, #-8]
                  add  r3, r2, r3
                  str  r3, [fp, #-12]
```

```
return 0;      mov  r3, #0
}
               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;

y

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

y = y + x

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;
}
```

y = x+y

r x y

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

Compiler phases

- Lexer
- Parser
- Translator
- Optimiser
- Code generator

Code generator

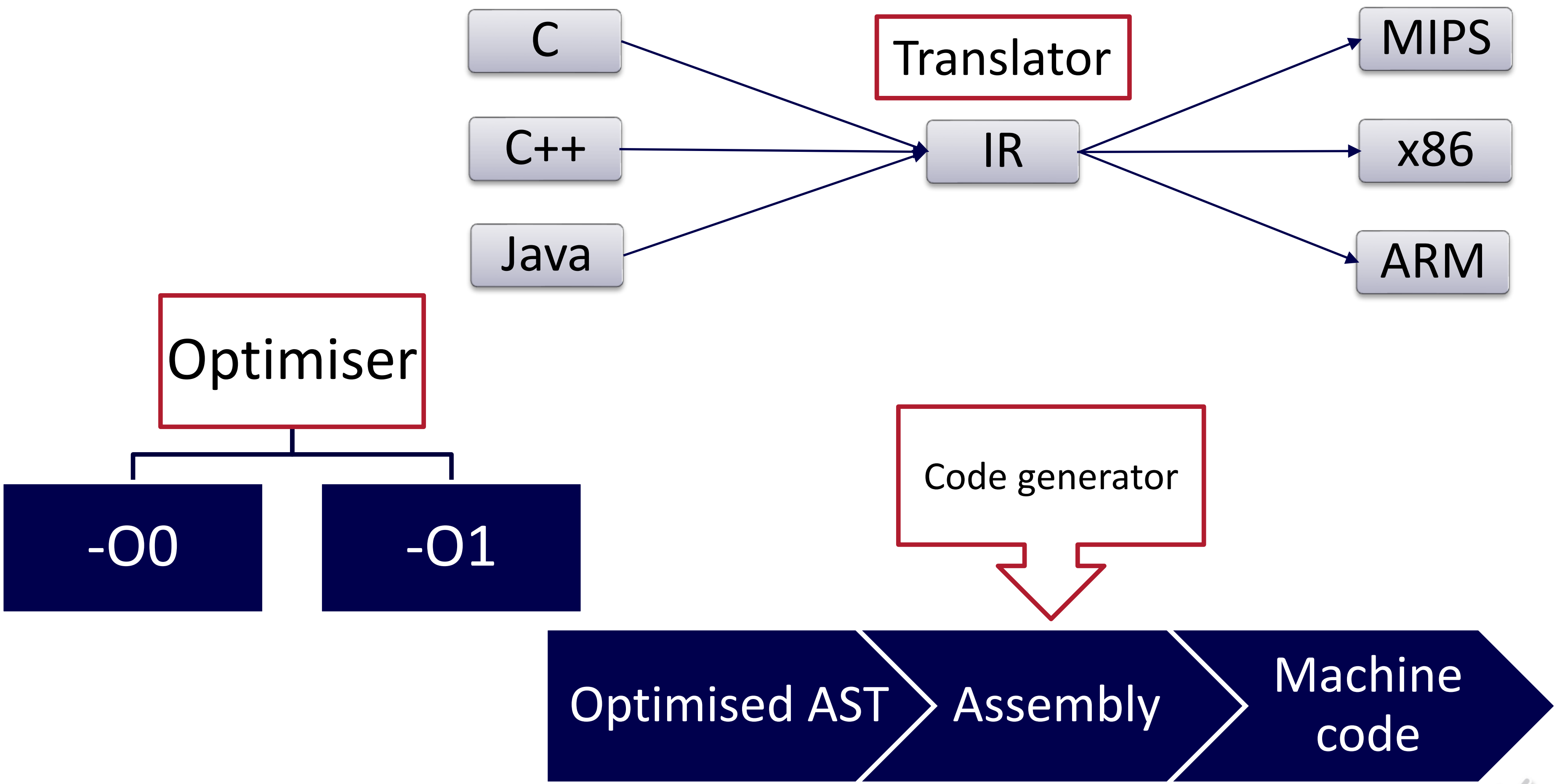
- Input: optimised AST
- Output: machine code / executable file
- often in 2 phases:
  - AST → assembly
  - assembly → machine code

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