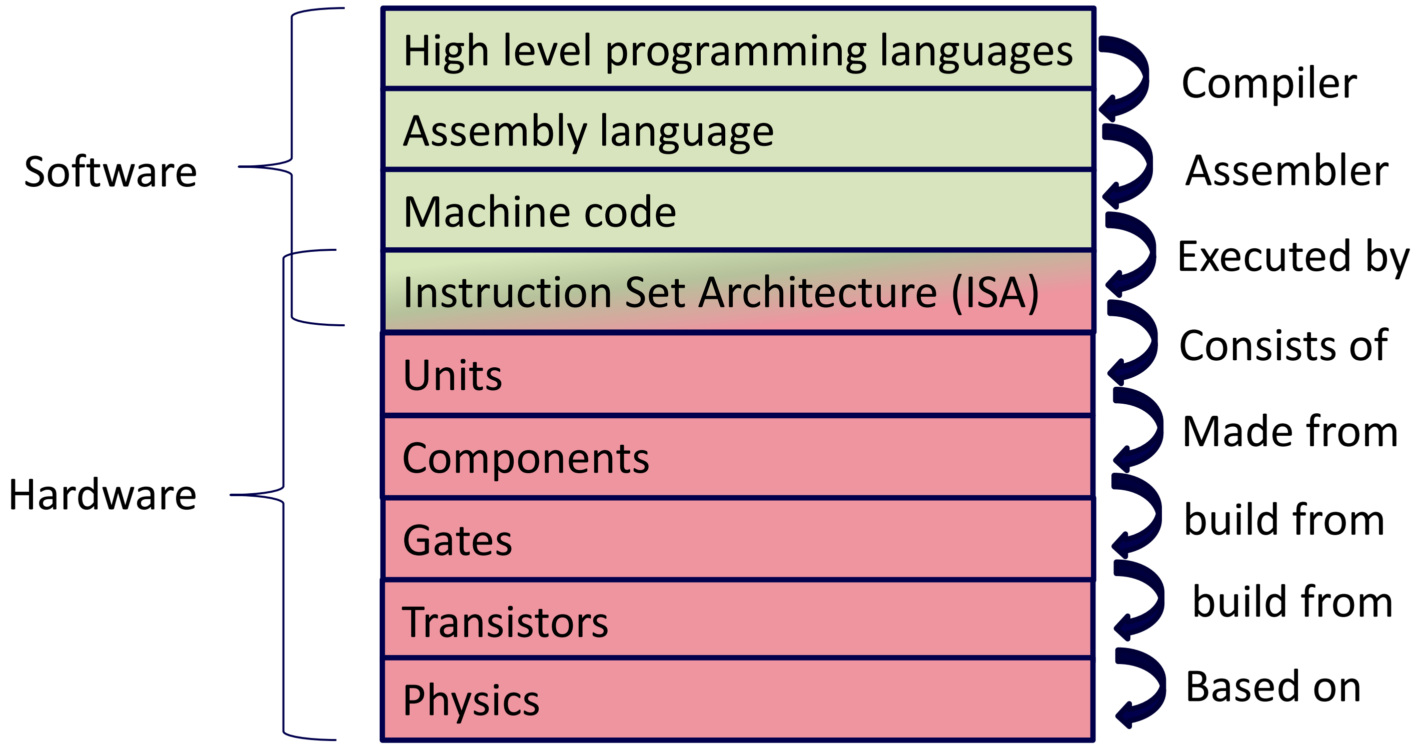
COMSM1302
Overview of Computer Architecture

Lecture 16

Compilers - 1

Layers



Software
Hardware
High level programming languages
Assembly language
Machine code
Instruction Set Architecture (ISA)
Units
Components
Gates
Transistors
Physics
Compiler
Assembler
Executed by
Consists of
Made from
build from
build from
Based on

Compiler phases

Lexer

Parser

Translator

Optimiser

Code generator

In this lecture

Lexer → Parser → Translator

- At the end of this lecture:
  - Learn how compilers read and understand programs.
  - How compliers can catch syntax and semantic errors.

Compiler phases

- Lexer
- Parser
- Translator
- Optimiser
- Code generator

Lexer / Tokeniser

int add(int x, int y) {

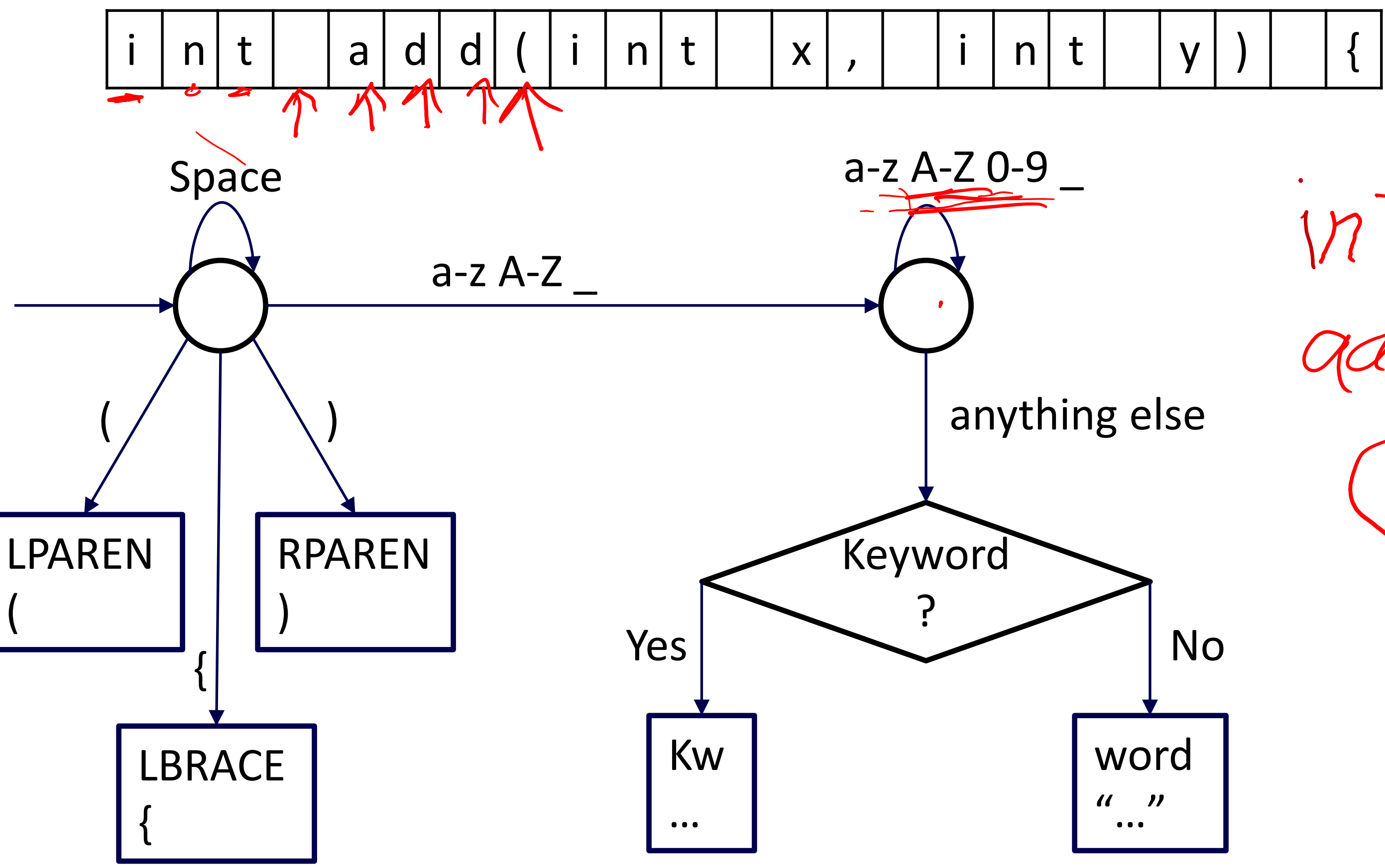
i	n	t		a	d	d	(	i	n	t		x	,		i	n	t		y	)		{

Kw	word	LPAREN	Kw	word	comma	Kw	word	RPAREN	LBRACE
int	“add”	(	int	“x”	,	int	“y”	)	{

Lexer

- Input: sequence of characters
- Output: sequence of tokens with
  - type (KEYWORD, WORD, LPAREN, RPAREN, ...)
  - value, eg. [WORD "main"], [LPAREN "("]
  - debugging info (file, line, position)
- Operation: recognise tokens with state machines.

Lexer - state machines



int → kword

add → word

(

Tokens in gcc error messages

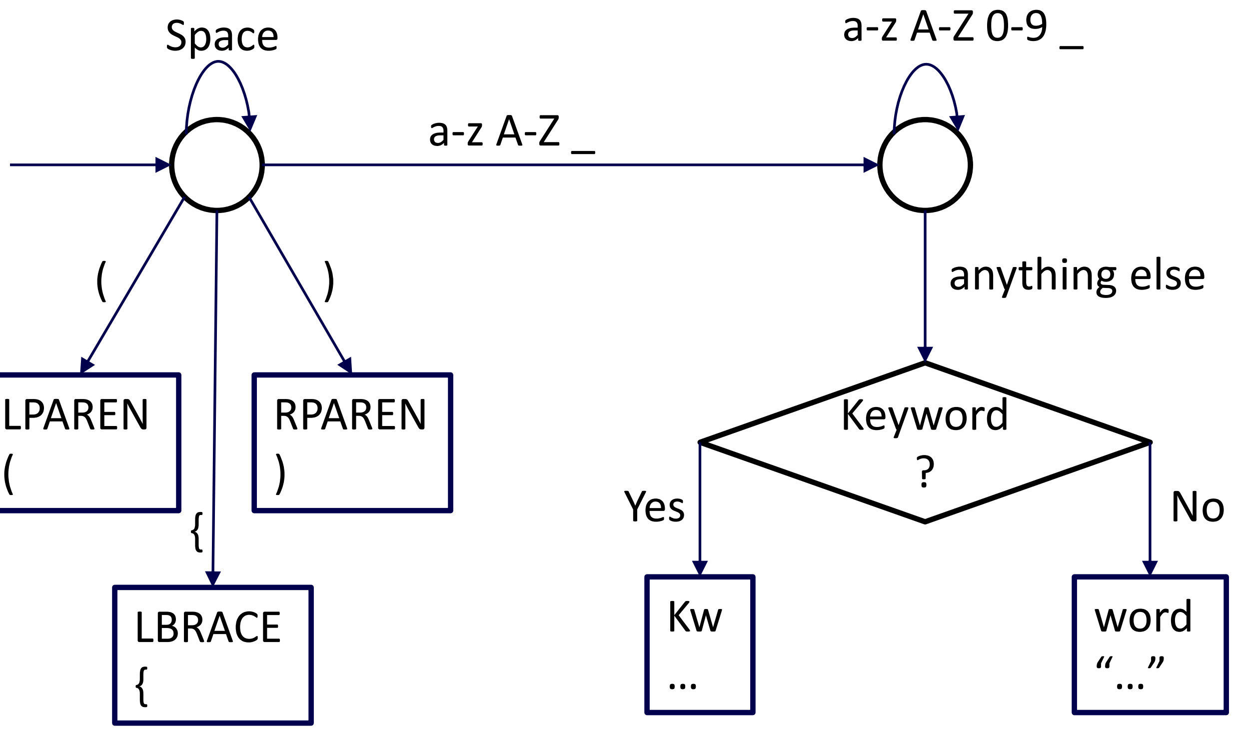
```
int main(void){
   int x;
   int y;
   x = 3;
   y = 4;
   x+ = 0;
   y += x;
return y
}
```

file.c: In function ‘**main**’:

file.c:6:5: error: expected expression before ‘**=**’ token

x+ = 0;

Lexer - examples



- Examples
  1. Int a
  2. Int) a

KW RPAREN

Word

Compiler phases

- Lexer
- Parser int) a ;
- Translator
- Optimiser
- Code generator

Parser's job

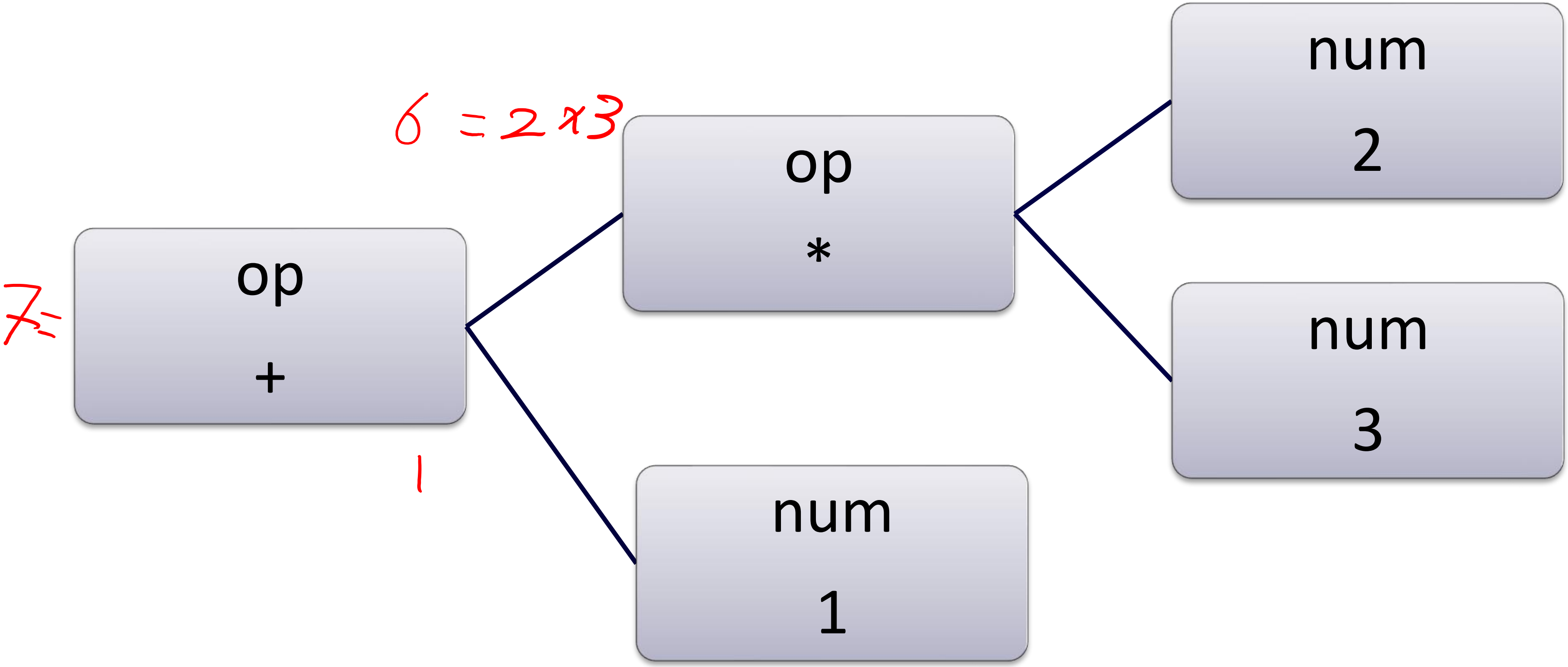
- valid c: int main(int argc, char x)
- not valid c: main int int))(
- To the lexer, both of these are just sequences of tokens.
- It's the parser's job to decide if a sequence of tokens is a valid program.

Parser

- Input: sequence of tokens
- Output: syntax tree
- Operation: depends on the kind of language

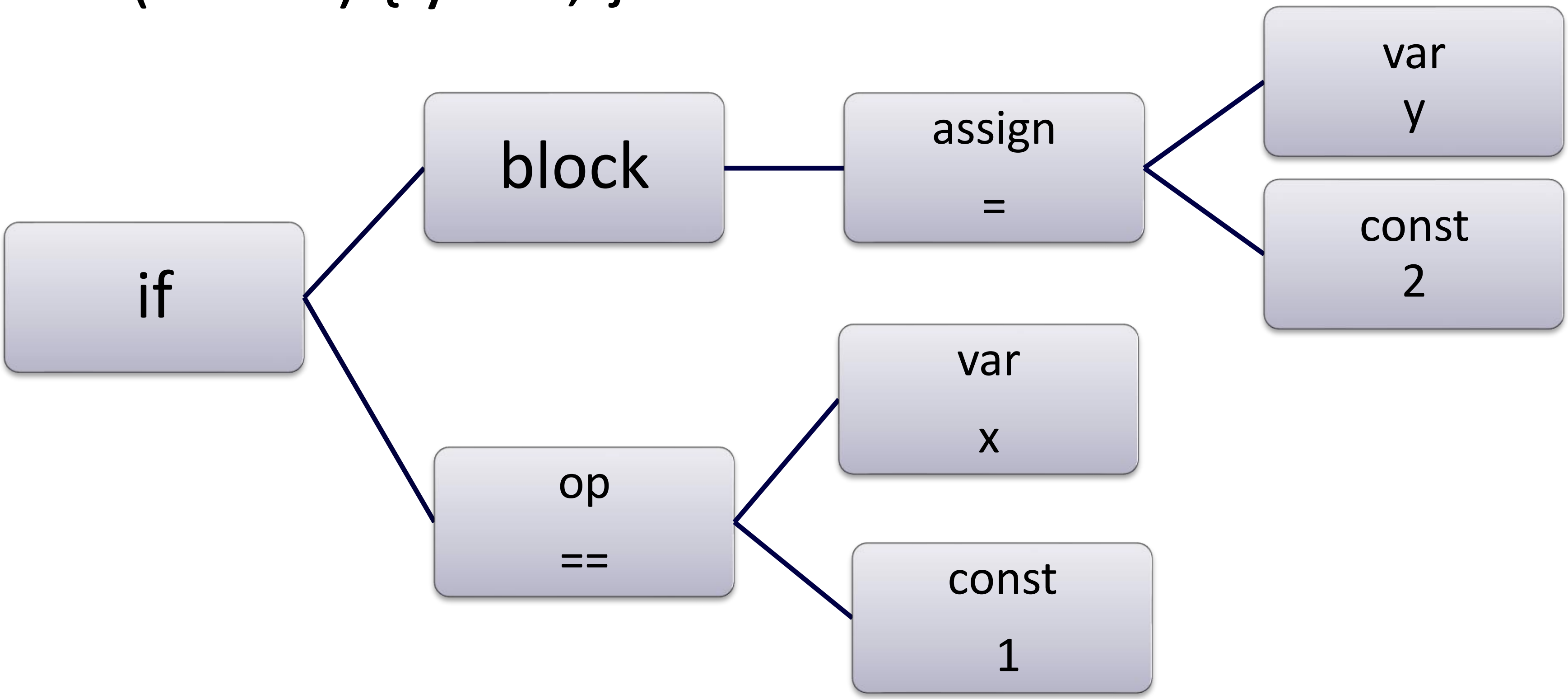
Syntax trees – example 1

- 1 + 2 * 3



Syntax trees – example 2

- if (x == 1) { y = 2; }



Grammars

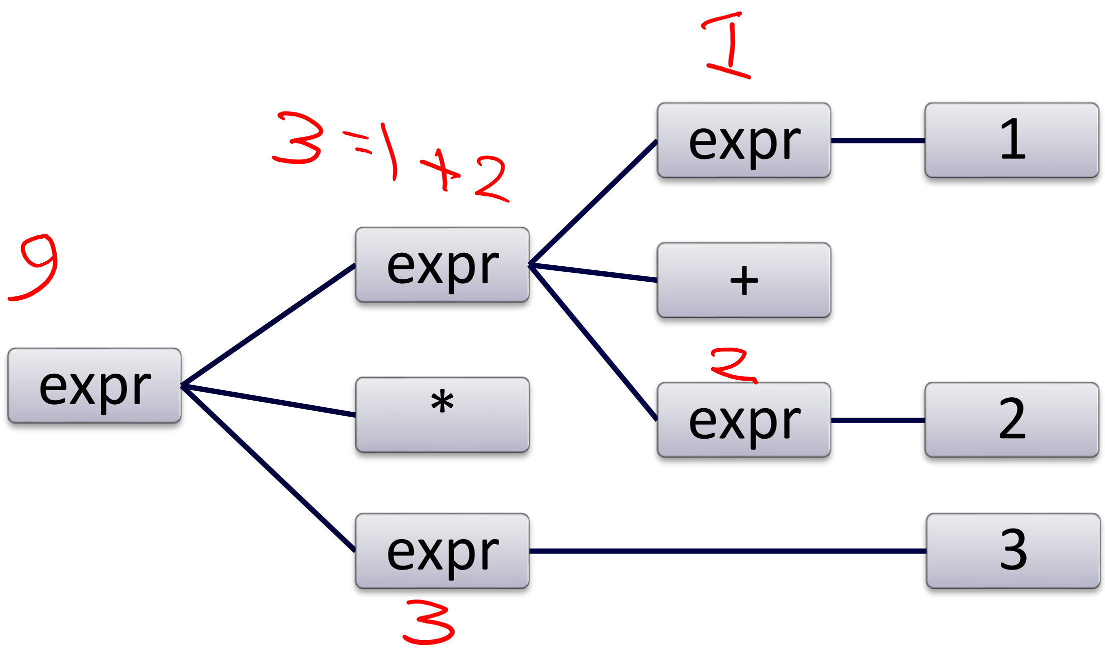
- 1 + 2 *3
- How can we parse this?
- How can we evaluate this?
- There are infinitely many possible mathematical expressions with just numbers, + and * (and infinitely many things that are not valid expressions, like * 1 *).

Grammars- first attempt

expr: num | expr '+' expr | expr '*' expr

- 1+2*3

1 + 6 = 7

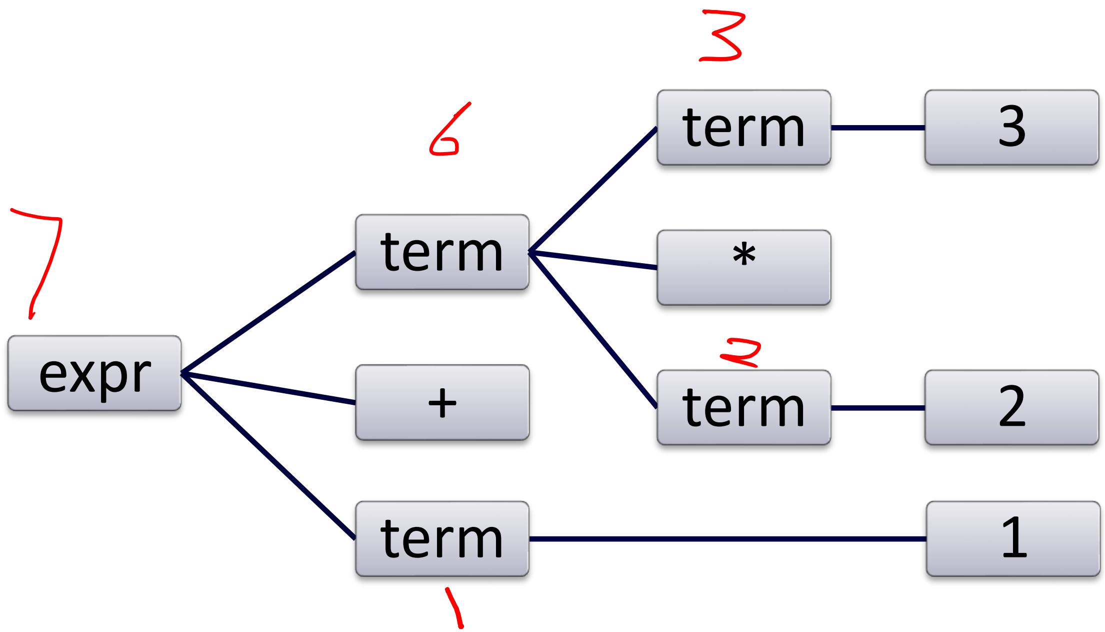


Grammars - second attempt

expr: term '+' term

term: num | term '*' term

1+2*3 = 7

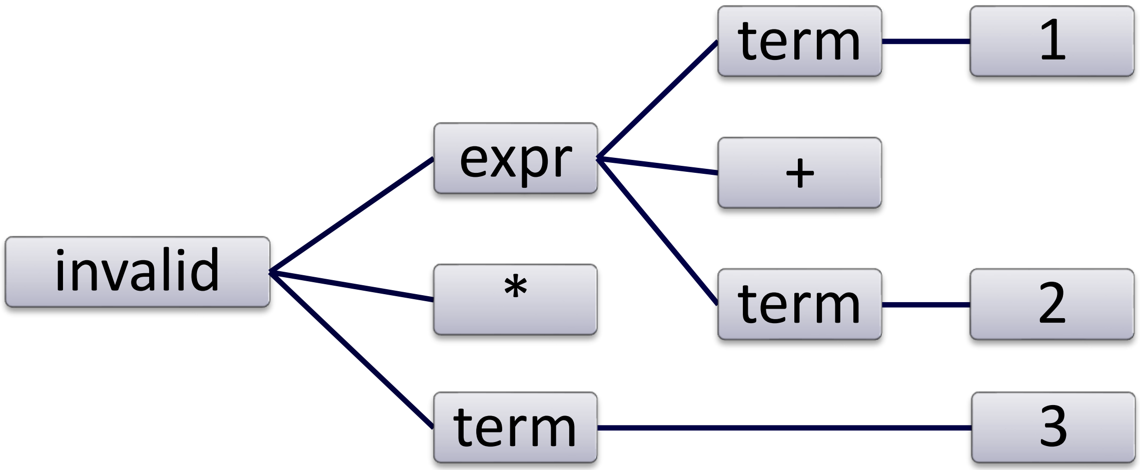


Grammars – invalid example

expr: term '+' term

term: num | term '*' term

1+2*3



C grammar

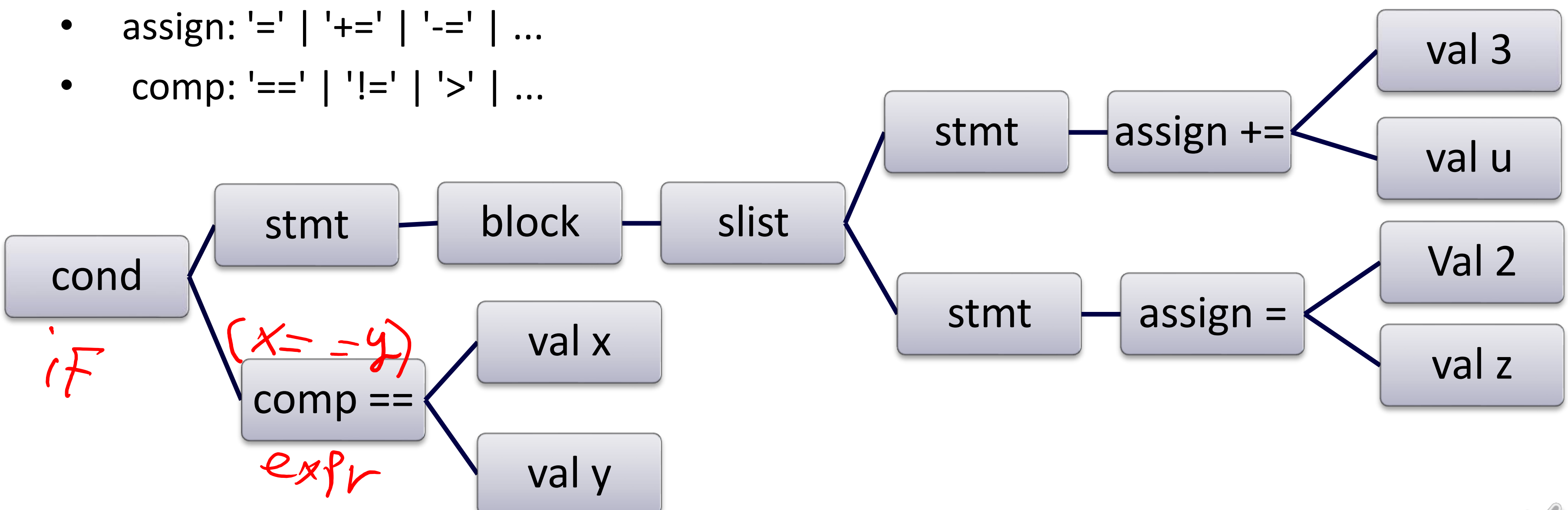
- stmt: expr ';' | cond | block ...
- cond: IF '(' expr ')' stmt
- block: '{' slist '}'
- slist: stmt | slist stmt
- expr: expr assign expr | expr comp expr | val
- assign: '=' | '+=' | '-=' | ...
- comp: '==' | '!=' | '>' | ...

```
if (x == y)
{ z = 2; u += 3; }
```

C grammar and syntax tree

- stmt: expr ';' | cond | block ...
- cond: IF '(' expr ')' stmt
- block: '{' slist '}'
- slist: stmt | slist stmt
- expr: expr assign expr | expr comp expr | val
- assign: '=' | '+=' | '-=' | ...
- comp: '==' | '!=' | '>' | ...

if (x == y){ z = 2; u += 3; }



Error handling

- If something goes wrong building the syntax tree: display an error message.
- As long as each token has file/line/column info attached, there's a chance of a useful error message.

Tokens in gcc error messages

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

expr : expr assign expr

expr : val

file.c: In function ‘**main**’:

file.c:6:5: error: expected expression before ‘**=**’ token

x+ = 0;

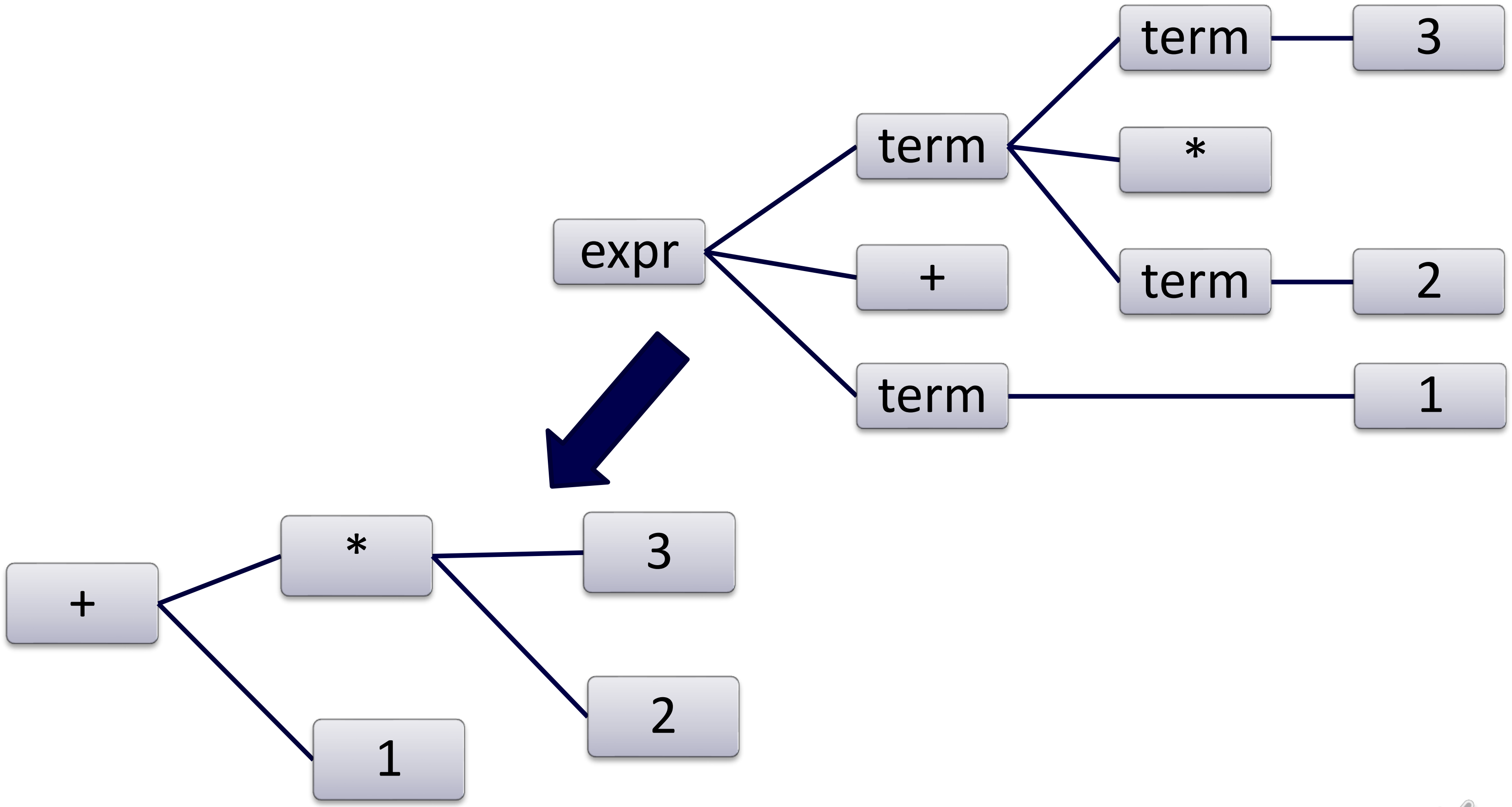
Compiler phases

- Lexer
- Parser
- Translator
- Optimiser
- Code generator

Translation

- Input: syntax tree.
  Output: independent representation (IR).
- Operations: tree transformations , symbol tables, semantic analysis.

Tree transformation

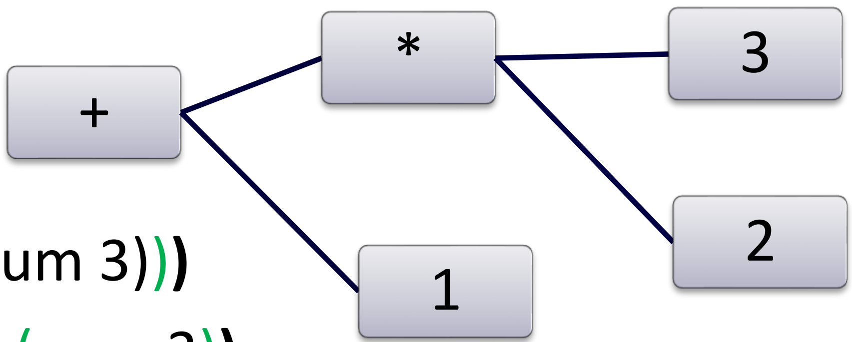


Evaluation / semantics

- Eval (n) = n
- Eval (+) = eval(a) + eval(b)

  a b
- Eval (*) = (eval(a) * eval(b))

  a b



- eval(add (num 1) (mul (num 2) (num 3)))
- = eval(num 1) + eval(mul (num 2) (num 3))
- = 1 + (eval(num 2) * eval(num 3)) = 1 + (2 * 3)

Syntax and semantics

- **syntax**: structure
- **semantics**: meaning

- "The circle square." is a syntax error.
- "The circle is square." is a semantic error.

Syntax error example

```
int main (void){
a = 3;
int a
int b = 1;
return -1
}
```

Semantic error example

```
int main (void){
a = 3;
int a;
int b = 1;
return -1;
}
```

Syntax and semantic - example

```
int main (void){
int a;
a = 3;
int b = 1;
return -1;
}
```

Symbol tables

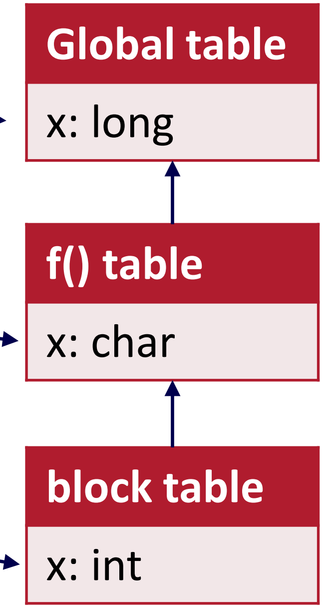
- C requires you to declare names (functions, variables etc.) before you use them.
- int x; // a declaration – goes in the symbol table
- x = 1; // a definition – produces machine code
- int x = 1; // both in one go.
- If no table contains the variable, you get an "x is not defined" error

Scoping -example

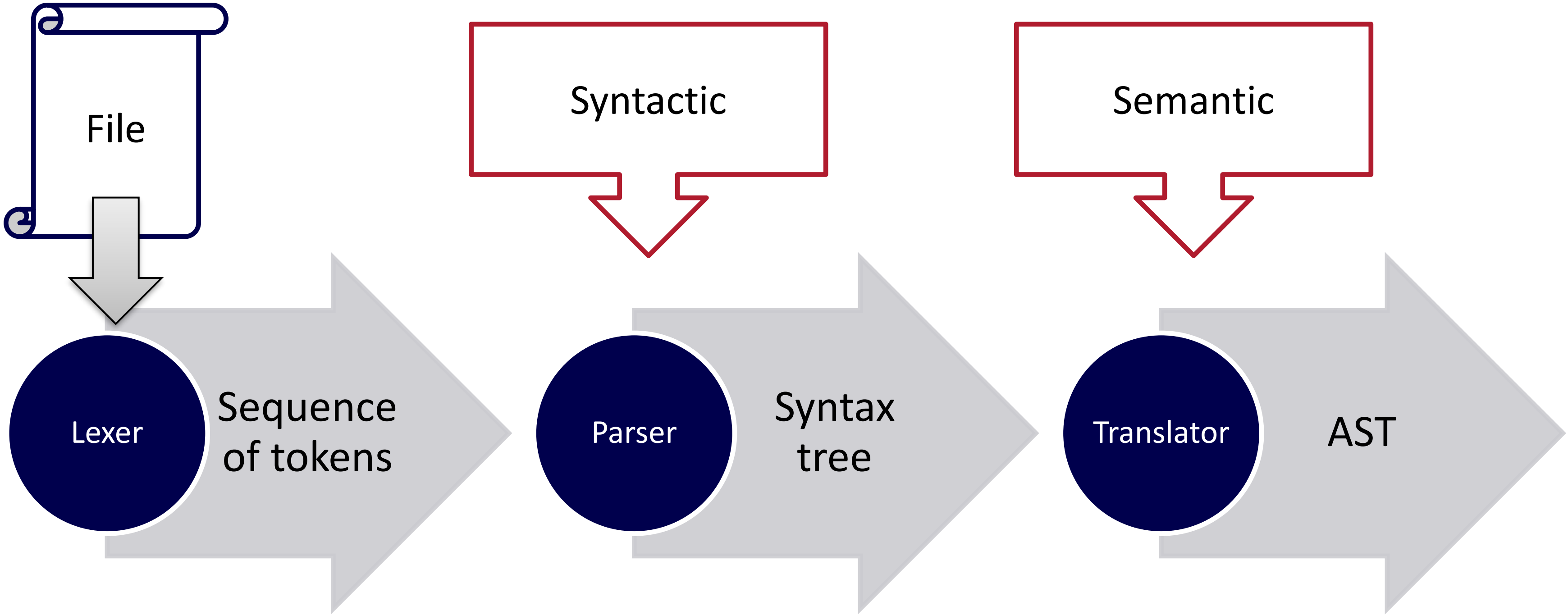
```c
long x = 1;
void f (){
	char x = 2;
	if (x){
		int x = 3;
		printf("%d/n" , x);
		}
}
```

Scoping

```
long x = 1;
void f (){

    char x = 2;
    if (x){

        int x = 3;
        printf("%d/n" , x);

    }

}
```



Summary



- Symbol table
- Scoping