Compilation and Program Analysis (#5) : Syntax-Directed Code Generation

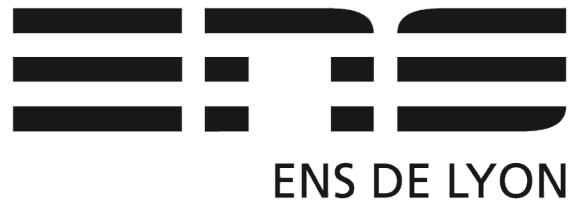
Laure Gonnord

http://laure.gonnord.org/pro/teaching/capM1.html

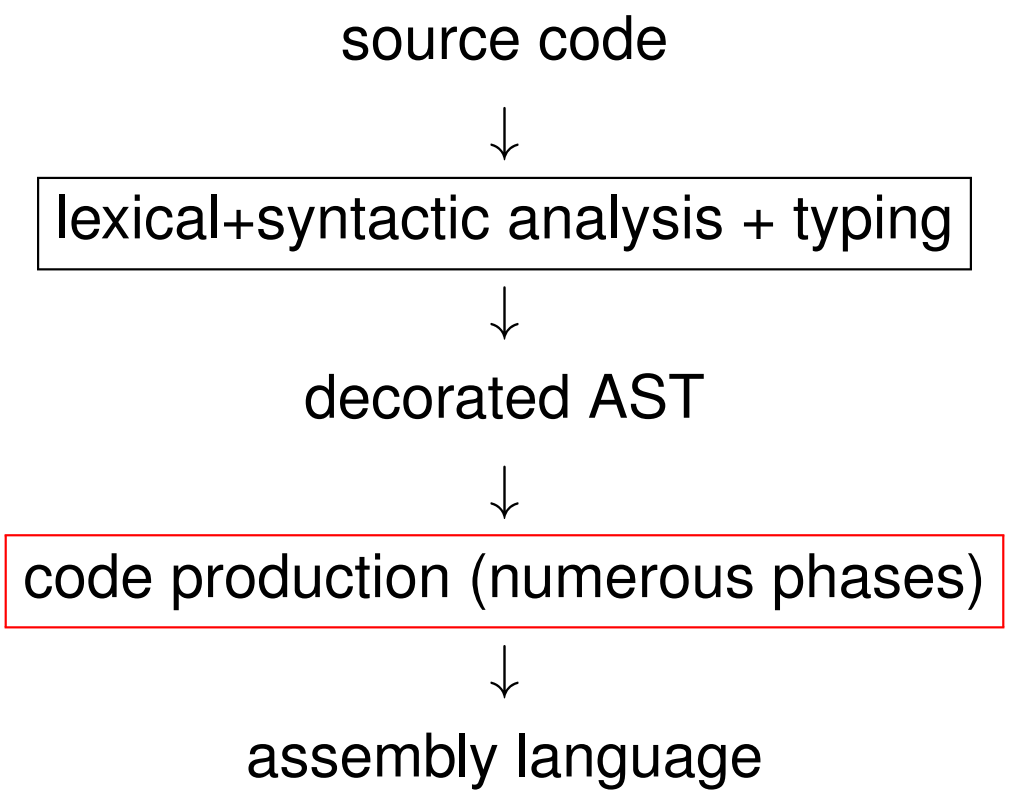
Laure.Gonnord@ens-lyon.fr

Master 1, ENS de Lyon

oct 2016



Big picture


source code
lexical+syntactic analysis + typing
decorated AST
code production (numerous phases)
assembly language

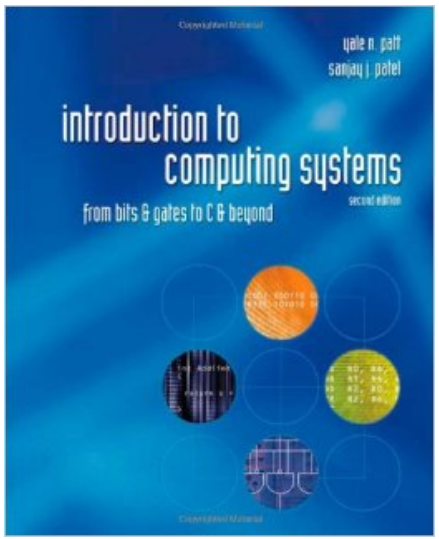
Rules of the Game here

For this code generation :

- Still no functions and no non-basic types. (mini-while)
- Syntax-directed : one grammar rule $\rightarrow$ a set of instructions.
  - Code redundancy.
- No register reuse : everything will be stored on the stack.

The Target Machine : LC3 (course #1)

[*Introduction to Computing Systems : From Bits and Gates to C and Beyond*, McGraw-Hill, 2004].



See also :

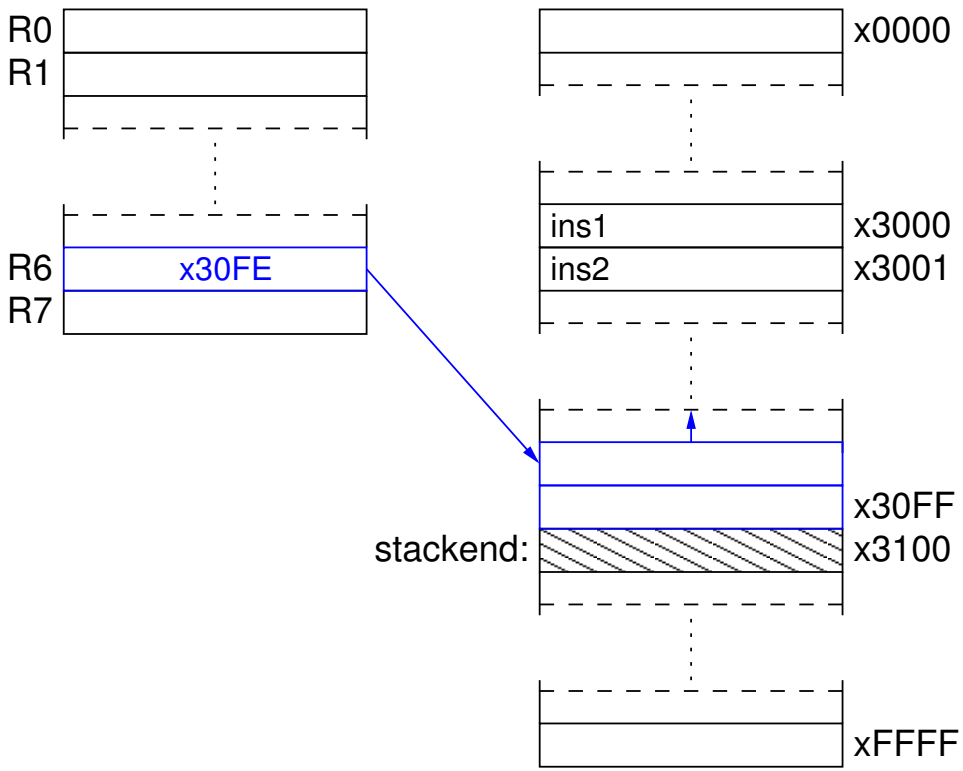
`http://highered.mcgraw-hill.com/sites/0072467509/`

A stack, why ?

- Store constants, strings, ...
- Provide an easy way to communicate arguments values (see later)
- Give place to store intermediate values (here)

LC3 stack emulation - from the archi course

- R6 is initialised to a “end of stack” address (stackend)
- R6 always stores the address of the last value stored in the stack.
- The stack grows in the dir. of **decreasing addresses !**



LC3 stack emulation : concretely 1/2

```
            .ORIG x3000
; Main program
main:       LD R6,spinit   ; stack pointer init
            ...
            HALT

; Stack management
spinit:     .FILL stackend
            .BLKW #15      ; this stack is rather small
stackend:   .BLKW #1       ; end of stack address
            .END
```

LC3 stack emulation : concretely 2/2

Push the content of Ri :

```
ADD R6,R6,-1   ; move head of stack
STR Ri,R6,0    ; store the value
```

Pop the content of the stack in Ri :

```
LDR Ri,R6,0    ; pop the value
ADD R6,R6,1    ; head of stack restauration
```

A first example (1/4)

How do we translate :

```
x=4;
y=12+x;
```

- Compute 4
- Store somewhere `place0`, then link $x \mapsto place0$
- Compute $12 + x$: 12 in `place1`, x in `place2`, then addition, store in `place3`, then link $x \mapsto place3$

▶ the code generator will use a place generator called `newtmp()`

A first example : 3@code (2/4)

"Compute 4 and store in x" :

```
AND temp1 temp1 0
ADD temp1 temp1 4
```

And $x \mapsto temp1$.

- This is called **three-adress code generation**

A first example : from 3@ code to valid LC-3 (3/4)

But this is not valid LC3 code !

We should use registers, but as they are only 8, we use the stack to store temporaries. Here **store R1 on the stack !**

```
AND R1 R1 0
ADD R1 R1 4
ADD R6 R6 -1 #here also store x -> R6 somewhere
STR R1 R6 0  #now R1 can be recycled
```

A first example : prelude/postlude 4/4

The rest of the code generation :

```
.ORIG X3000
LEA R6 data
[...]
stop: BR stop
data: .BLKW 42
.END
```

- This is valid LC-3 code that can be assembled and executed in Pennsim.

Objective of the rest of the course

3-address LC-3 **Code Generation** for the Mini-While language :

- All variables are int/bool.
- All variables are global.
- No functions

with syntax-directed translation. Implementation in Lab #5.

Code generation utility functions

We will use :

- A new (fresh) temporary can be created with a `newtemp()` function.
- A new fresh label can be created with a `newlabel()` function.

Abstract Syntax

Here numerical expressions.

$$
\begin{array}{rcll}
e & ::= & c & \textit{constant} \\
 & | & x & \textit{variable} \\
 & | & e + e & \textit{addition} \\
 & | & e \times e & \textit{multiplication} \\
 & | & \ldots &
\end{array}
$$

- forget about the multiplication (could be a lib function).

Code generation for expressions (semantic rules) 1/2

e ::= c	`#not valid if c is too big`
	`dr <-newTemp()`
	`code.add(InstructionAND(dr, dr, 0))`
	`code.add(InstructionAND(dr, dr, c))`
	`return dr`

e ::= x	`#get the place associated to x.`
	`regval=getTemp(x)`
	`return regval`

Code generation for numexpressions 2/2

e ::= e_1+e_2	`t1 <- genCode(e_1)`
	`t2 <- genCode(e_2)`
	`dr <- newTemp()`
	`code.add(InstructionADD(dr, t1, t2))`
	`return dr`

e ::= e_1-e_2	

e ::= true	`dr <-newTemp()`
	`code.add(InstructionAND(dr, dr, 0))`
	`code.add(InstructionAND(dr, dr, 1))`
	`return dr`

e ::= $e_1 < e_2$	

Abstract Syntax

$S(Smt)$	$::=$	$x := expr$	assign
	$\mid$	$skip$	do nothing
	$\mid$	$S_1; S_2$	sequence
	$\mid$	`if` b `then` S_1 `else` S_2	test
	$\mid$	`while` b `do` S `done`	loop

Code generation for commands (semantic rules) 1/2

x := e	`dr <- CodeGenExpr(e)`
	`#a code to compute e has been generated`
	`if x has a location loc:`
	`  code.add(instructionADD(loc,dr,0))`
	`else:`
	`  storeLocation(x,dr)`

S1 ; S2	`#concat codes`
	`CodeGenCommands(S1)`
	`CodeGenCommands(S2)`

Code generation for commands (semantic rules) 2/2

`if` b `then` $S1$ `else` $S2$	
`while` b `do` S `done`	

Drawbacks of the former translation

Drawbacks :

- redundancies (constants recomputations, . . .)
- memory intensive loads and stores.

▶ we need a more efficient data structure to reason on : **the control flow graph (CFG)**. (see next course)