dOvs Eksamens Noter

Hugh Benjamin Zachariae

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1 Compiler intro

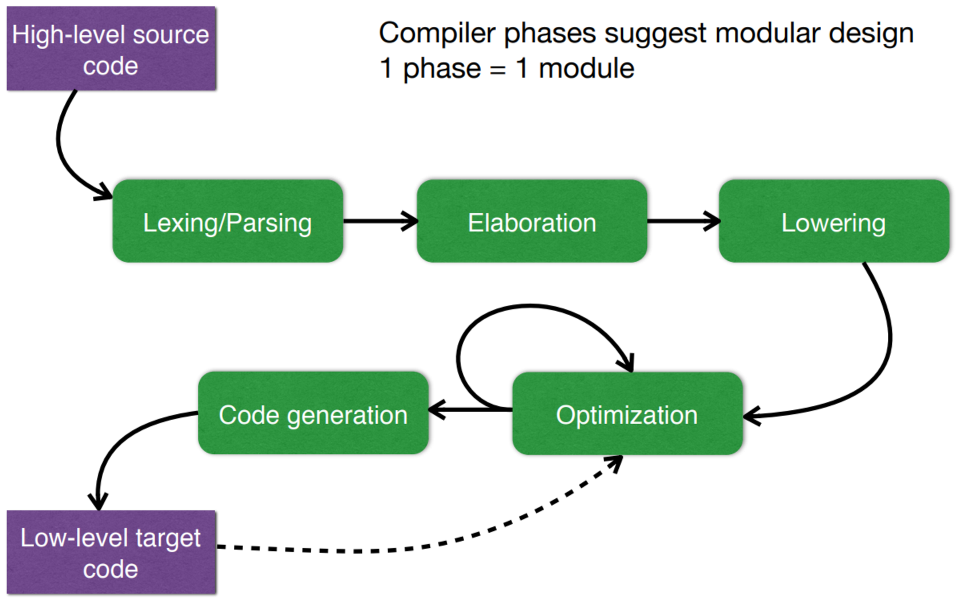


Figure 1: Compiler modular phases.

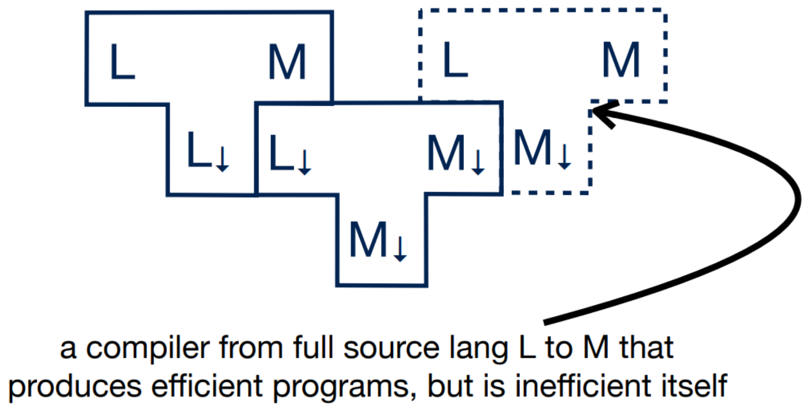


Figure 2: Bootstrap compiling

- **Lexing/Parsing**: String $\rightarrow_{lexing}$ Tokens $\rightarrow_{parsing}$ Abstract Syntax Tree (AST)
- **Elaboration**: *Resolving scope* and *Type checking*. Most errors found here.
- **Lowering**: High-level features to target-language like constructs (e.g. assembly-like). *Intermediate representation*, LLVM.
- **Optimization**: Detect and rewrite expensive operations. Lifting invariants out of loops, parallelization.
- **Code generation**: fx LLVM to X86 (registers, instruction etc.)

- **Bootstrapping compilers**: Compile your language in your own language.

2 Lexical

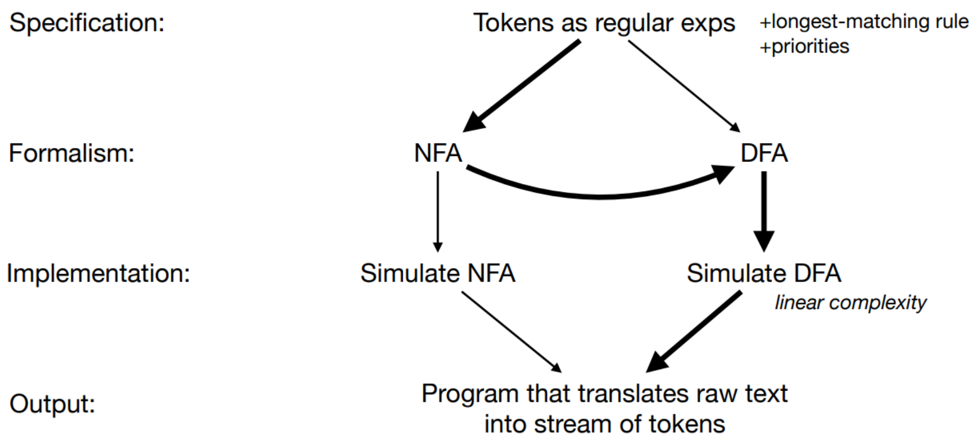


Figure 3: REG to NFA to DFA

- Tokens: E.g. ID("a"), INT, IF etc. Some tokens include metadata like names in ID.
- Non-tokens: comments, whitespace etc.
- REG → NFA → (closures) DFA → Minimized DFA (more effective)
- REG: Handle priorities and longest matching string token wins.
- Ocamllex: Lexer generator

3 Parsing

A context-free grammar (CFG) is a 4-tuple $G = (V, \Sigma, S, P)$

- V is a finite set of *nonterminal* symbols
- Σ is an alphabet of *terminal* symbols and $V \cap \Sigma = \emptyset$
- $S \in V$ is a *start* symbol
- P is a finite set of *productions* of the form $A \to \alpha$, where
  - $A \in V$, i.e., A is a nonterminal, and
  - $\alpha \in (V \cup \Sigma)^*$, i.e., α is possibly empty string of nonterminals or terminals

Figure 4: CFG Definition

$S \to$ if E then S else S
$S \to$ begin S L
$S \to$ print E
$L \to$ end
$L \to$; S L
$E \to$ num = num

- FIRST (α) : set of terminals that begin strings derived from α
- FOLLOW(X): set of terminals a that can appear immediately to the right of X in some derivable string, e.g., $S \Rightarrow^* \alpha X a \beta$
- Let nullable(X) be true when X can derive empty string ε

Nonterminal	Nullable?	First set	Follow set
S		if, begin, print	else, end, ;, $
L		end, ;	else, end, ;, $
E		num	then, else, end, ; $

Figure 5: Top-down parsing table. You do not want more than one possibility in a cell.

- Abstract Syntax Tree (AST):
- Context-Free Grammars (CFG):
  - *Terminals $\to$ production rules*
  - Terminals are leafs in the tree (e.g. x, y).
  - Non-Terminals are links in the tree (e.g. BinExp)
  - Definition see figure 4.
  - Ambiguity: You don't want ambiguity, you want determinism. *Associativity* (right/left) and *precedence* (e.g. times before plus).
- Top-down/Bottom-up parsing:
  - Top-down is predictive parsing:

    * leftmost derivation
    * "see whats coming"
    * Breaks down at for example: $S \rightarrow S + x \mid S - x \mid x$. Here you don't know what to do when you see an $x \ldots$
    * See figure 5 for parsing table.
  - Bottom-up: **LR parsing** is rightmost reduction.
    * Rightmost reduction
    * Includes EOF "$" symbol.

3.1 LR parsing

Bottom-up:

- Rightmost reduction
- Includes EOF "$" symbol.

Terms:

- An **Item** is a hypothesis about sub-derivations: N is hypothesis, α is confirmed to be parsed, β is to be confirmed, $N \rightarrow \alpha.\beta$. Notice that it looks like a production rule, but with a dot somewhere in it.
- Item is reducible if β is empty. The right side of the dot is empty.
- ϵ-closure of an item set: add new hypothesis to set if expecting a non-terminal. Accessible steps while doing lambda steps.
- Stack based: stack of alternating items sets and derivation trees.
- Conflicts: shift/reduce, reduce/reduce. You don't know what to do from one state, when seeing an input symbol.

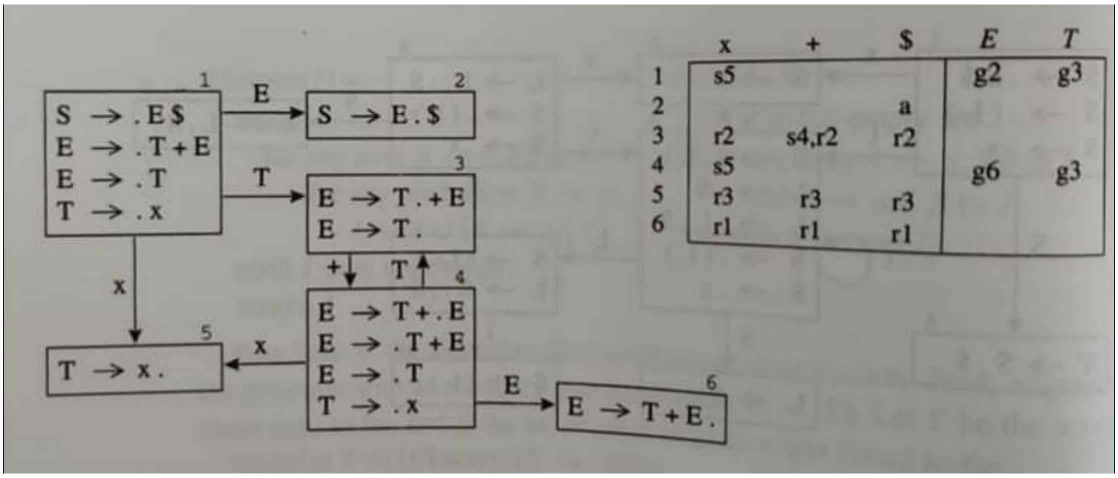
Operations: Look up stack state, and input symbol to get action

- Reduce k: Pop stack as many times as the number of symbols on the right-hand side of rule k. Choose a grammar rule $X \rightarrow A\ B\ C$; pop C, B, A from the top of the stack, and push X onto the stack. If dot is found on the right side of all symbols.
- Shift: Advance input one token; push token to stack. Go from one state to another after seeing a terminal input. Move dot one spot.
- Goto: Add hypethesis to stack - which sub-derivations we can go to. Goto state (move across edge). Go from one state to another after seeing a non-terminal. Move dot one spot.

Goto and shift must preserve the structure of the stack (item set > derivation).

Examples: All LR parsing examples

You can create a DFA by calculating first, the starting state and its closure. Then calculate the closures (dot in front of non-terminal) developed by shifting each terminal and non-terminal from that state (moving the dot after the shifted input symbol). Afterwards, you can develop a parsing table, *state* by terminal/non-terminal. See figure 6 for parsing table, DFA for shift reduce grammar.



	x	+	$	E	T
1	s5			g2	g3
2			a		
3	r2	s4,r2	r2		
4	s5			g6	g3
5	r3	r3	r3		
6	r1	r1	r1		

Figure 6: LR(0) shift/reduce conflict, parsing table and state DFA, sn: shift to state n

Reduction based on k lookahead. The higher k, the less conflicts. However, more than 1 is not used for compilation, as the parsing table would be huge.

Since LR(0) needs no lookahead, we require one action for each state. With shift and reduce, we get a shift/reduce conflict.

LR(1) items consists of a *grammar production*, a *right-hand-side position* and a *lookahead symbol.* Choose whether or not to reduce based on stack and one lookahead on input.

Lookaheads are calculated by: Any state that contains an item of the form $A \to x.By\ \{t\}$, where x and y are arbitrary strings of terminals and nonterminals and B is a nonterminal, you add an item of the form $B \to .w\ \{s\}$ for every production $B \to w$ and for every terminal in the set $s = FIRST(yt)$.

3.2 Scoping rules

Rules of programming language to regulate how names and ID's are resolved.

Problems:

- Nesting: Same name for variable in nested scopes. What value should we return?
- Forward reference: Using something before it is declared. E.g. mutual recursion.

Scoping terms:

- Scope of declaration: Part of the program where the declaration can be referred to.
- **Static nested scopes (SML style)**: Identifier scope is the smallest block (begin/end, function, or procedure body) containing the identifier's declaration. This means that an identifier declared in some block is only accessible within that block and from procedures declared within it.
  - Nearest visible: Return value of nearest declaration in the code.
  - Stack-like behavior

- JS function-level lexical scoping: Inner functions contain the scope of parent functions even if the parent function has returned.

- **Static scoping**: Inner functions can access identifiers in outer scope. Can be deduced in compile time (C).
- **Dynamic scoping**: A function p which prints x. Two functions, $d1$ and $d2$,that declare x as 1 and 2 and then calls p. $d1$ will print 1 and $d2$ will print 2. I.e. the scope depends on the call stack and chain of function calls.

Namespace: Different declaration identifiers can reside in different syntactic namespaces. E.g. in Tiger: *var/function* are in the same namespace, but *type* is in another.
Tiger scoping and namespaces:

- Global: base types (`int`, `string`) and built-in functions (e.g. `print`).