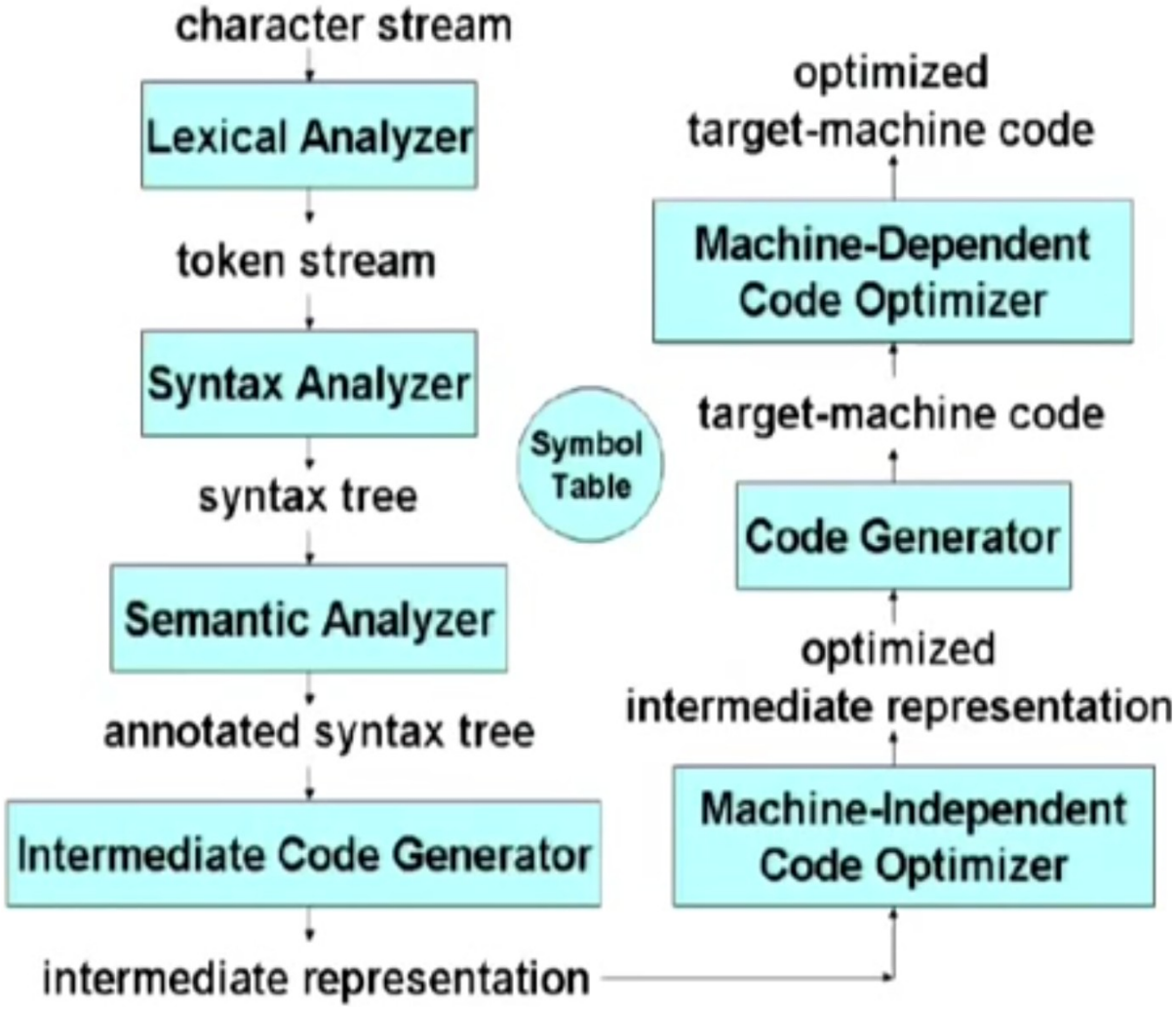
Lexical Analysis

CSE 415: Compiler Construction

Phases of a Compiler



What is Lexical Analysis

- The input is a high level language program, such as a 'C' program in the form of a sequence of characters
- The output is a sequence of *tokens* that is sent to the parser for syntax analysis
- Strips off blanks, tabs, newlines, and comments from the source program
- Keeps track of line numbers and associates error messages from various parts of a compiler with line numbers
- Performs some preprocessor functions such as `#define` and `#include` in 'C'

What is Lexical Analysis

- Stream of characters is grouped into tokens
- Examples of tokens are identifiers, reserved words, integers, doubles or floats, delimiters, operators and special symbols

```
int a;
a = a + 2;
```

int	reserved word
a	identifier
;	special symbol
a	identifier
=	operator
a	identifier
+	operator
2	integer constant
;	special symbol

Tokens, Patterns and Lexemes

- Running example: *float abs_zero_Kelvin = -273;*
- Token (also called *word*)
  - A string of characters which logically belong together
  - **float**, **identifier**, **equal**, **minus**, **intnum**, **semicolon**
  - Tokens are treated as terminal symbols of the grammar specifying the source language
- Pattern
  - The set of strings for which the *same* token is produced
  - The pattern is said to *match* each string in the set
  - *float*, *l(l+d+_)**, *=*, *-*, *d+*, *;*
- Lexeme
  - The sequence of characters matched by a pattern to form the corresponding token
  - "float", "abs_zero_Kelvin", "=", "-", "273", ";"

Tokens in Programming Languages

- Keywords, operators, identifiers (names), constants, literal strings, punctuation symbols such as parentheses, brackets, commas, semicolons, and colons, etc.
- A unique integer representing the token is passed by LA to the parser
- Attributes for tokens (apart from the integer representing the token)
  - *identifier*: the lexeme of the token, or a pointer into the symbol table where the lexeme is stored by the LA
  - *intnum*: the value of the integer (similarly for *floatnum*, etc.)
  - *string*: the string itself
  - The exact set of attributes are dependent on the compiler designer

Difficulties in Lexical Analysis

- Certain languages do not have any reserved words, *e.g.*, **while, do, if, else**, etc., are reserved in 'C', but not in PL/1
- In FORTRAN, some keywords are context-dependent
  - In the statement, *DO 10 I = 10.86*, **DO10I** is an identifier, and **DO** is not a keyword
  - But in the statement, *DO 10 I = 10, 86*, **DO** is a keyword
  - Such features require substantial *look ahead* for resolution
- Blanks are not significant in FORTRAN and can appear in the midst of identifiers, but not so in 'C'
- LA cannot catch any significant errors except for simple errors such as, illegal symbols, etc.
- In such cases, LA skips characters in the input until a well-formed token is found

Specification and Recognition of Tokens

- Regular definitions, a mechansm based on *regular expressions* are very popular for specification of tokens
  - Has been implemented in the lexical analyzer generator tool, LEX
  - We study regular expressions first, and then, token specification using LEX
- Transition diagrams, a variant of finite state automata, are used to implement regular definitions and to recognize tokens
  - Transition diagrams are usually used to model LA before translating them to programs by hand
  - LEX automatically generates optimized FSA from regular definitions
  - We study FSA and their generation from regular expressions in order to understand transition diagrams and LEX

Languages

- **String**: A finite sequence of juxtaposed symbols
  - **abcb, caba** are strings over the symbols *a*,*b*, and *c*
  - $|w|$ is the length of the string *w*, and is the #symbols in it
  - ϵ is the empty string and is of length 0
- **Alphabet**: A *finite* set of symbols
- **Language**: A set of strings of symbols from some alphabet
  - Φ and $\{\epsilon\}$ are languages
  - The set of palindromes over {0,1} is an infinite language
  - The set of strings, {01, 10, 111} over {0,1} is a finite language
- If Σ is an alphabet, Σ^* is the set of all strings over Σ

Language Representations

- **Regular expressions** (type-3 or regular languages), **context-free grammars** (type-2 or context-free languages), **context-sensitive grammars** (type-1 or context-sensitive languages), and **type-0 grammars** are finite representations of respective languages
- RL $<<$ CFL $<<$ CSL $<<$ type-0 languages

Examples of Languages

Let $\Sigma = \{a, b, c\}$

- $L_1 = \{a^m b^n | m, n \geq 0\}$ is regular
- $L_2 = \{a^n b^n | n \geq 0\}$ is context-free but not regular
- $L_3 = \{a^n b^n c^n | n \geq 0\}$ is context-sensitive but neither regular nor context-free
- Showing a language that is type-0, but none of CSL, CFL, or RL is very intricate and is omitted

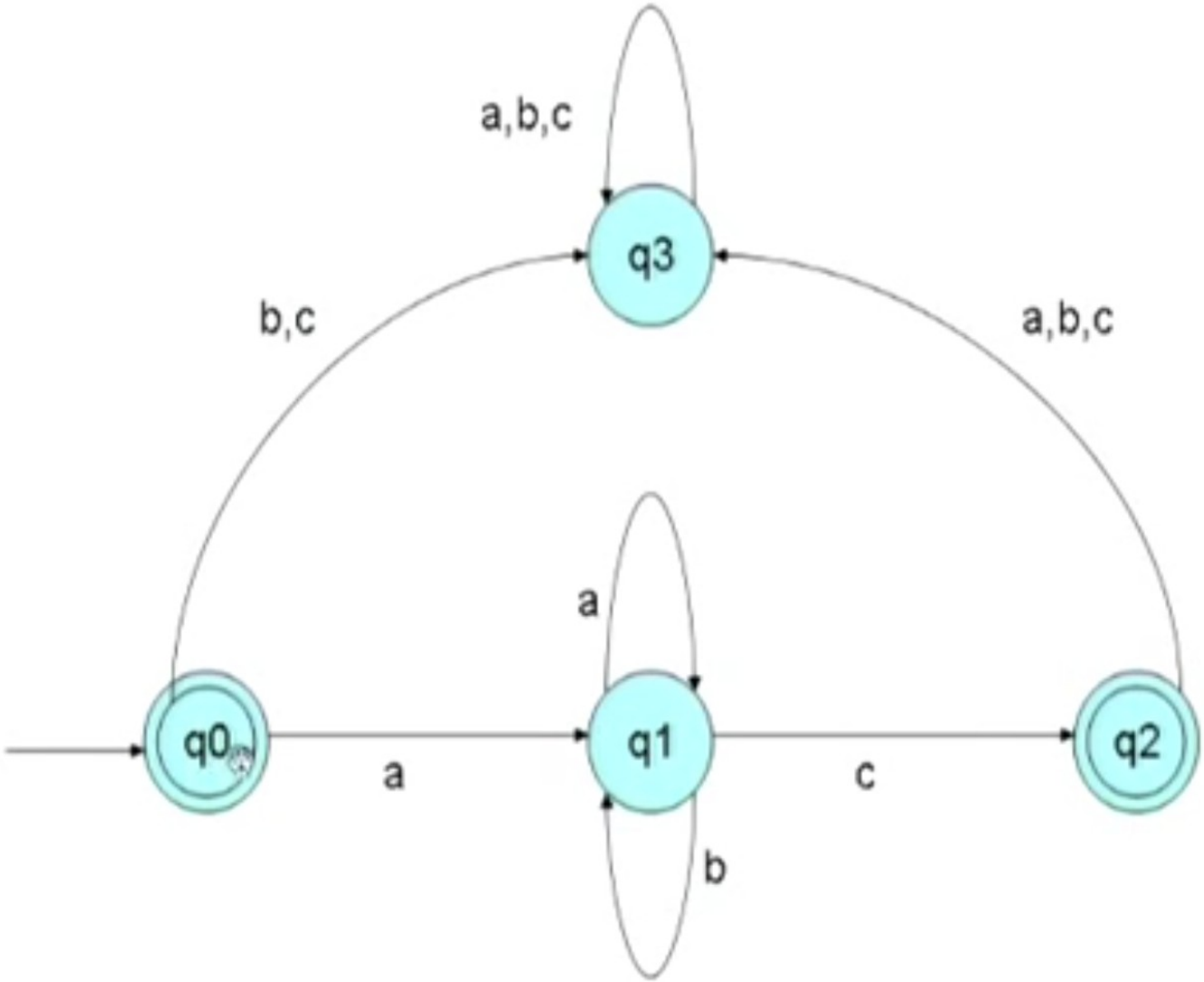
Automata

- Automata are machines that accept languages
  - Finite State Automata accept RLs (corresponding to REs)
  - Pushdown Automata accept CFLs (corresponding to CFGs)
  - Linear Bounded Automata accept CSLs (corresponding to CSGs)
  - Turing Machines accept type-0 languages (corresponding to type-0 grammars)
- Applications of Automata
  - Switching circuit design
  - Lexical analyzer in a compiler
  - String processing (*grep*, *awk*), etc.
  - State charts used in object-oriented design
  - Modelling control applications, e.g., elevator operation
  - Parsers of all types
  - Compilers

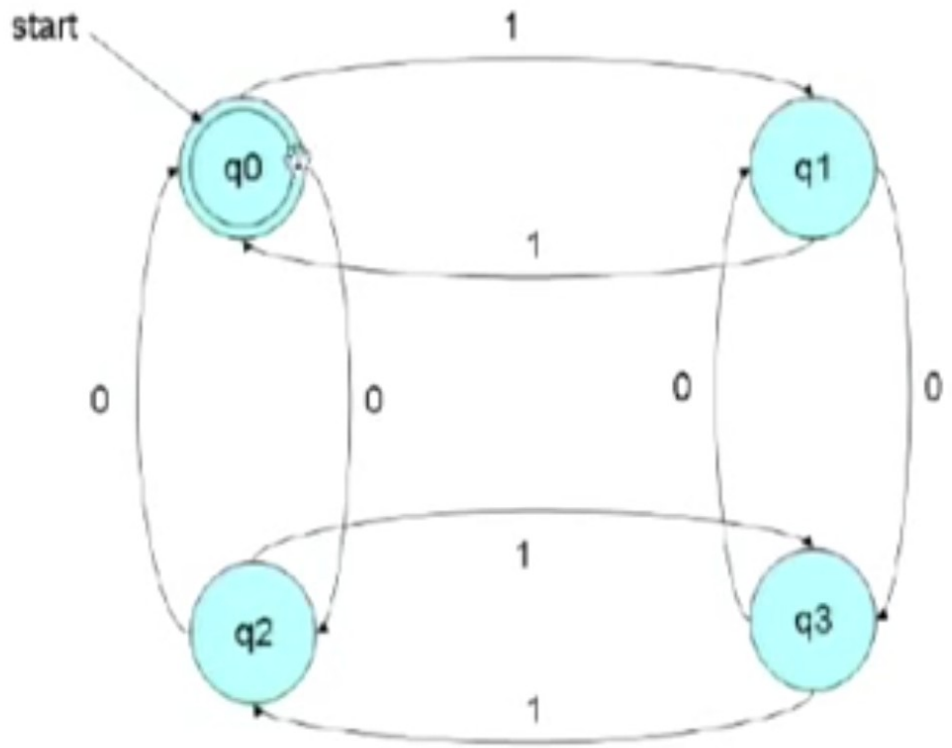
Finite State Automaton (FSA)

- An FSA is an **acceptor** or **recognizer** of regular languages
- An FSA is a 5-tuple, $(Q, \Sigma, \delta, q_0, F)$, where
  - Q is a finite set of states
  - Σ is the input alphabet
  - δ is the transition function, $\delta : Q \times \Sigma \rightarrow Q$
    That is, $\delta(q, a)$ is a state for each state q and input symbol a
  - q_0 is the start state
  - F is the set of *final* or *accepting* states
- In one move from some state q, an FSA reads an input symbol, changes the state based on δ, and gets ready to read the next input symbol
- An FSA **accepts** its input string, if starting from q_0, it consumes the entire input string, and reaches a final state
- If the last state reached is not a final state, then the input string is rejected

FSA Example



FSA Example



- $Q = \{q_0, q_1, q_2, q_3\}$, q_0 is the start state
- $F = \{q_0\}$, δ is as in the figure
- Language accepted is the set of all strings of 0's and 1's, in which the no. of 0's and the no. of 1's are even numbers

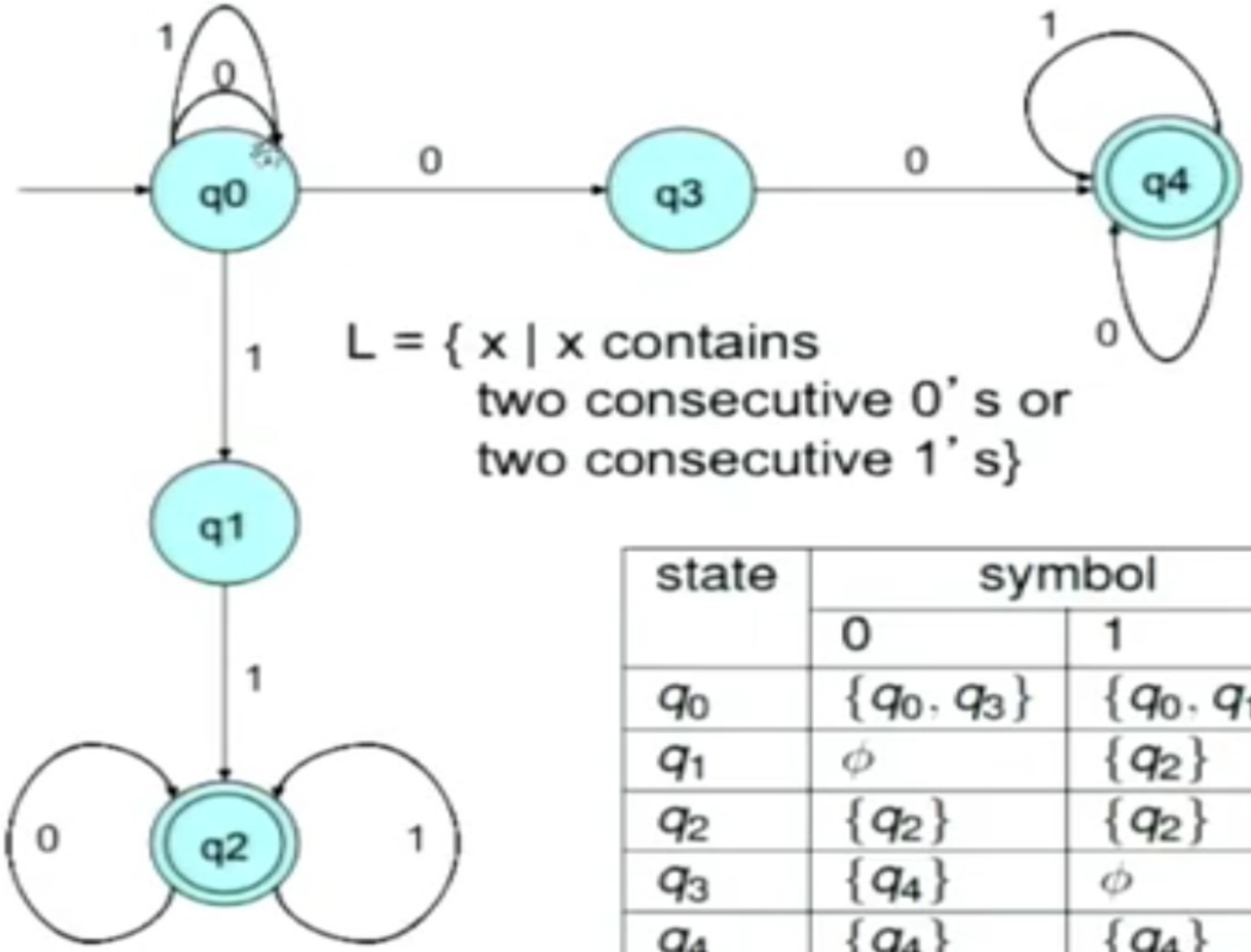
Regular Languages

- The language **accepted** by an FSA is the set of all strings accepted by it, i.e., $\delta(q_0, x) \epsilon F$
- This is a **regular language** or a **regular set**
- Later we will define **regular expressions** and **regular grammars** which are **generators** of regular languages
- It can be shown that for every regular expression, an FSA can be constructed and vice-versa

Non-deterministic FSA

- NFAs are FSA which allow 0, 1, or more transitions from a state on a given input symbol
- An NFA is a 5-tuple as before, but the transition function δ is different
- $\delta(q, a)$ = the set of all states p, such that there is a transition labelled a from q to p
- $\delta : Q \times \Sigma \rightarrow 2^Q$
- A string is accepted by an NFA if there *exists* a sequence of transitions corresponding to the string, that leads from the start state to some final state
- Every NFA can be converted to an equivalent DFA that accepts the same language

Non-deterministic FSA



state	symbol	
	0	1
q_0	$\{q_0, q_3\}$	$\{q_0, q_1\}$
q_1	ϕ	$\{q_2\}$
q_2	$\{q_2\}$	$\{q_2\}$
q_3	$\{q_4\}$	ϕ
q_4	$\{q_4\}$	$\{q_4\}$