CSC 372, Spring 2025

Lexing and SML Datatypes

Michelle Strout

THE UNIVERSITY OF ARIZONA

January 30, 2025

Plan

- **Announcements**
  - LA1 will be posted sometime tomorrow and due Friday Feb 14th
- **Last time**
  - Review previous quiz questions
  - SML intro continued and Types intro
  - Syntax and Semantics
- **Today**
  - Grammar clarification
  - Show Anki deck of PL concepts
  - Tokenization/Lexing as a part of syntactic analysis
  - Algebraic datatypes in SML

Grammar and Syntax Rules

- **What is a Grammar?**

- **A grammar defines a language by specifying:**
  - Tokens - The smallest units of a language (e.g., keywords, literals).
  - Rules - How tokens combine into valid statements.

- **Backus-Naur Form (BNF):**
  - Developed by John Backus and Peter Naur (~1960).
  - Defines structure using:
    - Terminals: Basic symbols (tokens).
    - Non-terminals: Higher-level constructs made from terminals.

Example formal grammar in BNF

- **Syntax rules in BNF for SML expressions**

```
<expr> ::= <value> | <expr> <op> <expr>
<value> ::= int | bool
<op> ::= + | * | and | or
```

- **Semantic rules**
  - Integers can be added or multiplied.
  - Booleans can be combined using logical operators.

- **Questions**
  - In the above grammar, how are the terminals denoted?
    - Int and bool are tokens with additional values associated with them, '+', …
  - Non-terminals? <expr>, <value>, …
  - What does the ::= mean?
  - What does the | mean?

Outline for today

- **Tokens exercise**
- **SML algebraic datatypes**
- **Regular expressions to specify tokens**
- **Complications with tokenization/lexing**
- **Simple tokenization for PA1**

Learning by doing in LA1 (show face.svg)

- Large assignment 1 is a compiler from shapes to svg

```
CIRCLE 120 150 60 white
```

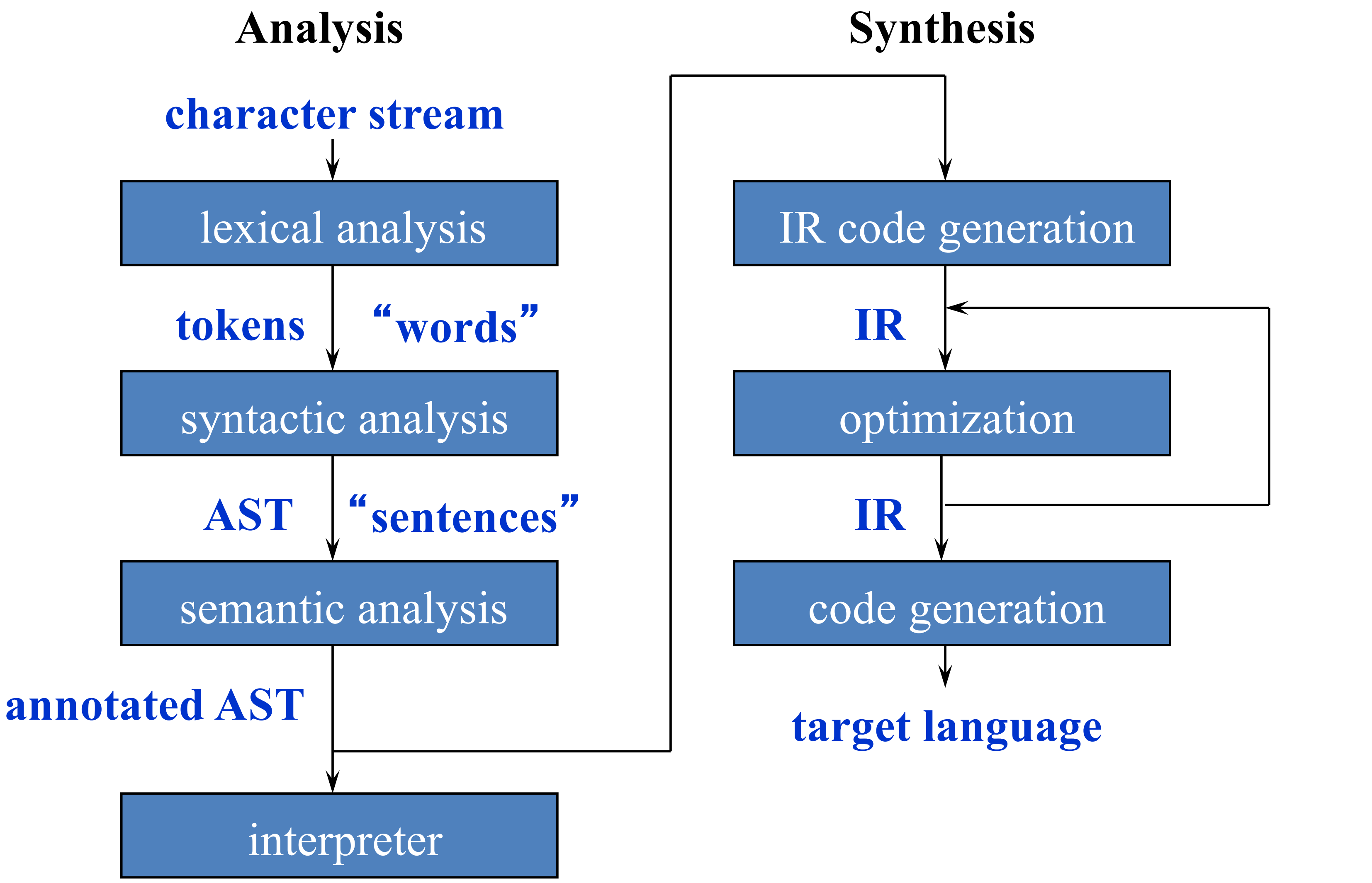
```
<circle cx="120" cy="150" r="60" fill="white" />
```

- Going to specify the input with a context free grammar and tokens with regular expressions

- Going to implement a lexer/tokenization, parser, AST (abstract syntax tree), and “codegen” in SVG

Structure of a Typical Compiler

THE UNIVERSITY OF ARIZONA
Computer Science



Tokens and tokenization

THE UNIVERSITY OF ARIZONA
Computer Science

- We can define a token as the smallest unit in a language that has meaning.
- The process of taking a string of input and dividing it up into tokens is called tokenization.
- It's not just about determining what the tokens are–we also want to categorize them into kinds of tokens so that we can then use them to determine legal structures.

Identifying Tokens Exercises

- **At your tables, list out the different tokens in the below "shapes" file using the provided SML datatype**

```
CIRCLE 120 150 60 white
LINE 0 0 300 300 black
RECTANGLE 30 20 300 250 blue
```

```
(* Token datatype *)
datatype token =
    TokenCIRCLE
  | TokenLINE
  | TokenRECTANGLE
  | TokenNUM of int
  | TokenCOLOR of string
```

Foundation: Data/Values in SML

- **Base types: int, real, bool, char, string**
- **Functions**
- **Constructed data**
  - Tuples: pairs, triples, etc.
  - (Records with named fields)
  - Lists and other algebraic data types

Slide Content Credits for slides 10-15: Tufts Comp105
by Norman Ramsey and Kathleen Fisher

Algebraic Datatypes in SML

- **Enumerated types**
  - Datatypes can define an enumerated type and associated values

```
datatype suit = heart | diamond | spade | club
```

- **"suit" is the name of a new type**

- **Data constructors heart, diamond, space, and club are values of that type**

- **Data constructors are separated by vertical bars**

Algebraic Datatypes

- **Pattern matching**
  - Datatypes are deconstructed using pattern matching

```
fun toString heart = "heart"
  | toString diamond = "diamond"
  | toString spade = "spade"
  | toString club = "club"

val suitName = toString heart
```

Write a toString function for token datatype

- At your tables, write a string function on the whiteboards

```
datatype token =
    TokenCIRCLE
  | TokenLINE
  | TokenRECTANGLE
  | TokenNUM of int
  | TokenCOLOR of string
```

Data constructors can take arguments!

```
datatype IntTree = Leaf | Node of int * IntTree * IntTree
```

- **What is the name of the new type?**
  - IntTree
- **What data constructors are in the above?**
  - Leaf, Node (, ,)
- **What is the parameter to the Node data constructor?**
  - The 3-tuple
- **What are some example values made with the data constructors?**
  - Node (4, Leaf, Leaf), Node (4, Node (3, Leaf, Leaf), Leaf)
- **What are the type(s) of those values?**
  - IntTree

Tree Example

```
val tempty = Leaf
val t1 = Node (1, tempty, tempty)
val t2 = Node (2, t1, t1)
val t3 = Node (3, t2, t2)
```

- ➔ Tree diagram

- Questions
  - What is the in-order traversal of t3?
    - 1,2,1,3,1,2,1
  - What is the pre-order traversal of t3?
    - 3,2,1,1,2,1,1

Deconstruct values with pattern matching

```
fun inOrder Leaf = []
  | inOrder (Node (v, left, right)) =
        (inOrder left) @ [v] @ (inOrder right)
val il3 = inOrder t3

fun preOrder Leaf = []
  | preOrder (Node (v, left, right)) =
         v :: (preOrder left) @ (preOrder right)
val pl3 = preOrder t3
```

- **Notes**
  - IntTree is monomorphic because it has a single type
  - Note though that the inOrder and preOrder functions only care about the structure of the tree, not the payload value
- **Questions**
  - What does @ do?
  - How would we implement postOrder? (postOrder left) @ (postOrder right) @ [v]

Outline for today

THE UNIVERSITY OF ARIZONA
Computer Science

- Tokens exercise
- SML algebraic datatypes
- Regular expressions to specify tokens
- Complications with tokenization/lexing
- Simple tokenization for PA1

Languages

A language is a set of strings
(sometimes called sentences)

String: A finite sequence of letters

Examples: "cat", "dog", "house", …

Defined over a fixed alphabet:

$$\Sigma = \{a, b, c, \ldots, z\}$$

Empty String

A string with no letters: ε (sometimes λ is used)

Observations: $|\varepsilon| = 0$

$$\varepsilon w = w\varepsilon = w$$

$$\varepsilon abba = abba\varepsilon = abba$$

Regular Expressions

Regular expressions describe regular languages

You have probably seen them in OSs / editors

Example: $(a \mid (b)(c))^*$

describes the language

$$L((a \mid (b)(c))^*) = \{\varepsilon, a, bc, aa, abc, bca, \ldots\}$$

Recursive Definition for Specifying Regular Expressions

Primitive regular expressions: $\emptyset, \quad \varepsilon, \quad \alpha$

where $\alpha \in \Sigma$, *some alphabet*

Given regular expressions r_1 and r_2

$$\left.\begin{array}{l} r_1 \mid r_2 \\ r_1 \; r_2 \\ r_1 \, * \\ (r_1) \end{array}\right\} \text{Are regular expressions}$$

Regular operators

choice:	**A | B**	**a string from L(A) or from L(B)**
concatenation:	**A B**	**a string from L(A) followed by a string from L(B)**
repetition:	**A***	**0 or more concatenations of strings from L(A)**
	A^+	**1 or more**
grouping:	**(A)**	

Concatenation has precedence over choice: A|B C vs. (A|B)C

More syntactic sugar, used in scanner generators:

- **[abc] means a or b or c**
- **[\t\n] means tab, newline, or space**
- **[a-z] means a,b,c, …, or z**