CS 3210
Principles of PL

Lesson 02

Agenda (1st half)

- Review
- PL Abstraction Levels
- PL Evaluation

Agenda (2nd half)

- The Compilation Process
- The Linking Process
- The Interpretation Process
- The Hybrid Process
- Describing Syntax

PL Abstraction Levels

- Machine
- Assembly
- System
- High-level
- Visual

PL Evaluation

- What makes a good PL?

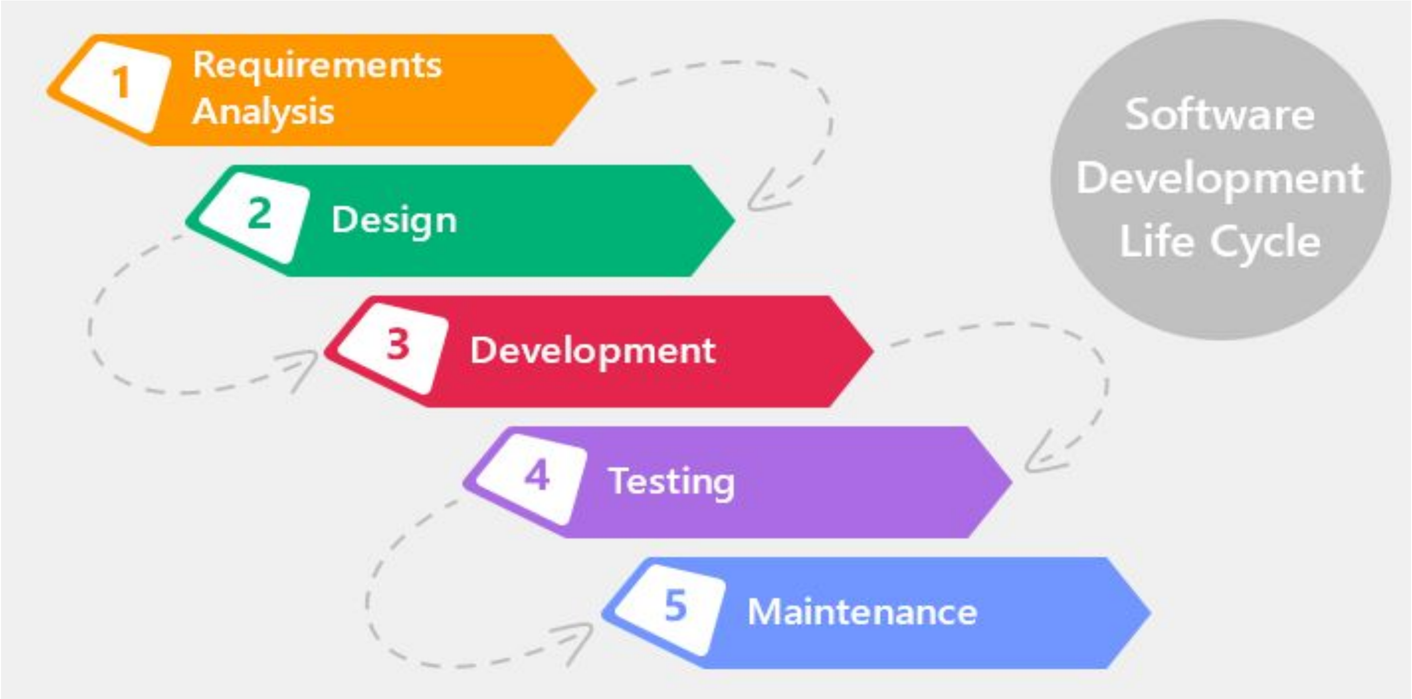
PL Evaluation

Table 1.1 Language evaluation criteria and the characteristics that affect them

Characteristic	CRITERIA: READABILITY	WRITABILITY	RELIABILITY
Simplicity	•	•	•
Orthogonality	•	•	•
Data types	•	•	•
Syntax design	•	•	•
Support for abstraction		•	•
Expressivity		•	•
Type checking			•
Exception handling			•
Restricted aliasing			•

PL Evaluation

- Readability and the software crisis of the 70s



PL Evaluation

- Writability:
  - measures how easy a PL can be used to create programs for a chosen problem domain

PL Evaluation

- Reliability:
  - a program is said to be reliable if it performs to its specifications under different conditions (e.g., different platforms, inputs, etc.)
  - the easier a program is to write, the more likely it is to be correct
  - programs that are difficult to read are difficult both to write and modify

PL Evaluation

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Restricted aliasing			•

PL Evaluation

- Simplicity:
  - # of constructs
    - Large PLs often end up having overlooked features
      - Example:
        - Java’s “Double Brace Initialization” is a feature that allows writing expressions to create and initialize collections

PL Evaluation

```
@Test
public void whenInitializeSetWithDoubleBraces_containsElements() {
    Set<String> countries = new HashSet<String>() {
        {
            add("India");
            add("USSR");
            add("USA");
        }
    };

    assertTrue(countries.contains("India"));
}
```

PL Evaluation

- Simplicity:
  - # of constructs
    - Large PLs often end up having overlooked features
      - Example:
        - Naming slices in Python

```python
a = [0, 1, 2, 3, 4, 5]
last3 = slice(-3, None)
print(a[last3])
```


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PL Evaluation

- Simplicity:
  - Feature Multiplicity
    - having more than one way to accomplish a particular operation

```
count = count + 1
count += 1
count++
++count
```

PL Evaluation

- Simplicity:
  - Operator Overloading
    - When a single operator has more than one meaning
    - Example:

      “+” being used for both addition and concatenation

PL Evaluation

- Simplicity:
  - Operator Overloading
    - How “+” works in Python when operands are lists?
    - How about when one operand is a list and the other is a scalar value?

```python
a = [0, 1, 2]
b = [3, 4, 5]
c = a + b
print(c)

d = a + 1
print(d)
```

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PL Evaluation

- Simplicity:
  - Simple languages are easier to learn
  - It should not be understood as less powerful
  - Be careful not to carry the concept too far
  - Example:
    - Most forms of assembly language are very simple and hard to read at the same time

PL Evaluation

- Orthogonality:
  - a language is orthogonal if its features are built upon a small, mutually independent set of primitive operations
  - in other words, language features can be used in any combinations <u>that make sense</u>
  - orthogonal languages are conceptually simple, having fewer exceptional rules

PL Evaluation

- Orthogonality:
  - Examples of lack of orthogonality in C:
    - **arrays** and **structs** are the only two structured data types available in C
    - **structs** can be returned from functions
    - **arrays** cannot

PL Evaluation

- Orthogonality:
  - Examples of lack of orthogonality in C:
    - **void** is a type in C but you cannot use **void** in all contexts like the other types
    - for example, you cannot define a pointer to **void** or use **void** to define a field in a **struct**

PL Evaluation

- Orthogonality:
  - Examples of lack of orthogonality in C:
    - **array** variables cannot be assigned to other **array** variables

PL Evaluation

- Orthogonality:
  - Examples of lack of orthogonality in Java:
    - there are two type categories in Java: *primitive* and *user-defined* (class types)
    - there is no mechanism that allow the creation of primitive types

PL Evaluation

- Orthogonality:
  - Most of the times PL designers trade-off orthogonality for efficiency
  - Also, too much orthogonality can negatively influence writability if unforeseen combinations of constructs lead to code absurdities hard to be detected by the compiler

PL Evaluation

- Data Types:
  - As mentioned before, a data type defines a collection of data values and a set of predefined operations on those values
  - Lack of types for commonly used values certainly impacts a PL readability, writability, and reliability

PL Evaluation

- Syntax Design:
  - syntax is the form while semantic is the meaning
  - in a well designed PL, semantics should follow directly from syntax

PL Evaluation

- Syntax Design:
  - Example:
    - **static** in C has different semantics depending on the context of its appearance
      - if used inside a function it means that a variable is to be defined at compile time (in contrast with **auto** variables)
      - if used outside all functions it means that a variable shall not be exported from the file where it was created

PL Evaluation

- Syntax Design:
  - the words chosen to be included in a PL grammar directly affect its readability
  - for example, most PL use the same set of words to represent common statements, such as **if**, **while**, **for**, etc.

PL Evaluation

- Syntax Design:
  - another important PL design choice refers to the mechanisms used to define compound statements
  - some PLs use matching pair of special words or symbols to form groups
  - others use braces (Java) or tabs (python)

PL Evaluation

- Expressivity:
  - computations can be expressed using powerful operators
  - it measures how simple it is to express an idea (write a program) using a PL

PL Evaluation

- Expressivity:

Java

```java
public class Main {
  public static void main(String[] args) {
      System.out.println("hello world");
    }
}
```

Python

```python
print("hello world");
```

PL Evaluation

- Type Checking:
  - testing for type errors in a given program, either by the compiler or during program execution

PL Evaluation

- Type Checking:
  - Example:
    - early versions of the original C language didn’t require parameters to functions to be type checked
    - for example, an `int` could be passed to a function that expected a `float`, with unpredictable results (see Ariane 5 explosion)

PL Evaluation

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PL Evaluation

- Exception Handling:
  - the ability of a program to intercept run-time errors and take corrective measures
  - this features is common in most languages today, but older languages, such as C, don't provide explicit mechanism for exception handling

PL Evaluation

- Aliasing:
  - the ability to use distinct names to refer to the same memory location
  - it can be dangerous because it can lead to errors difficult to trace, making the PL less reliable
  - Example: > 1 reference to an object

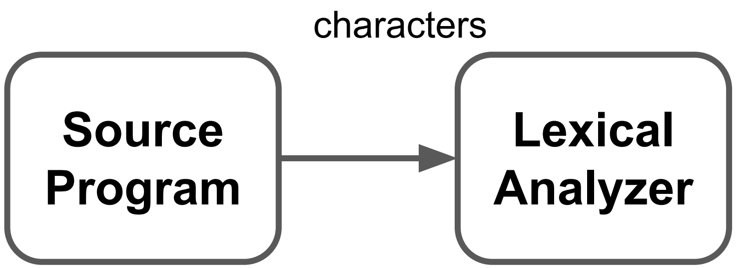
Agenda (2nd half)

- The Compilation Process
- The Linking Process
- The Interpretation Process
- The Hybrid Process
- Describing Syntax

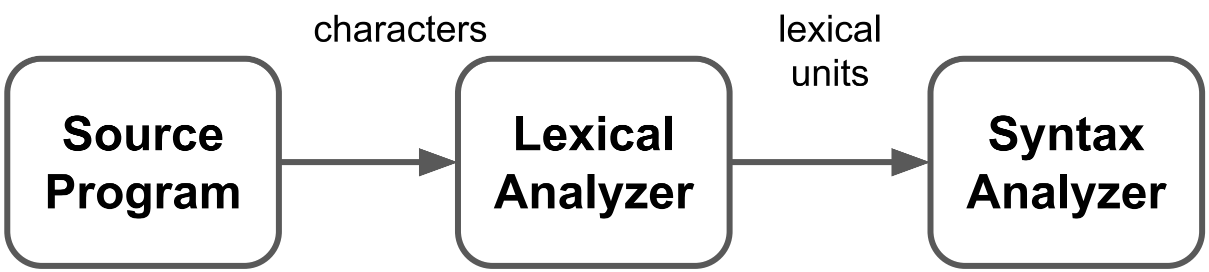
The Compilation Process

Source Program

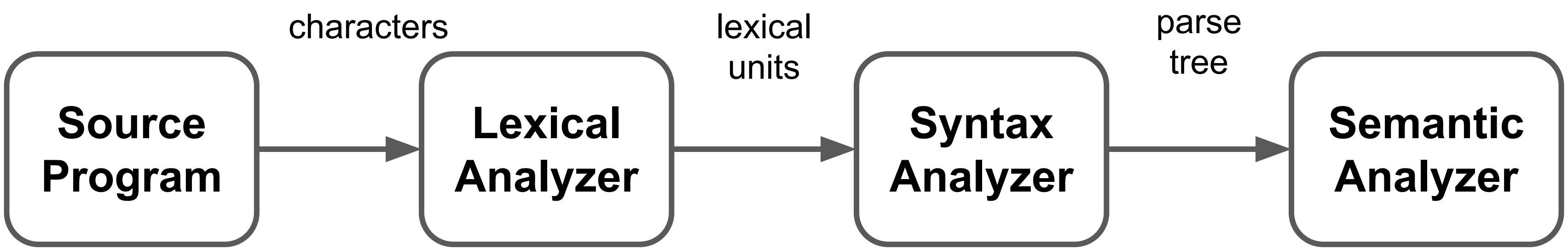
The Compilation Process



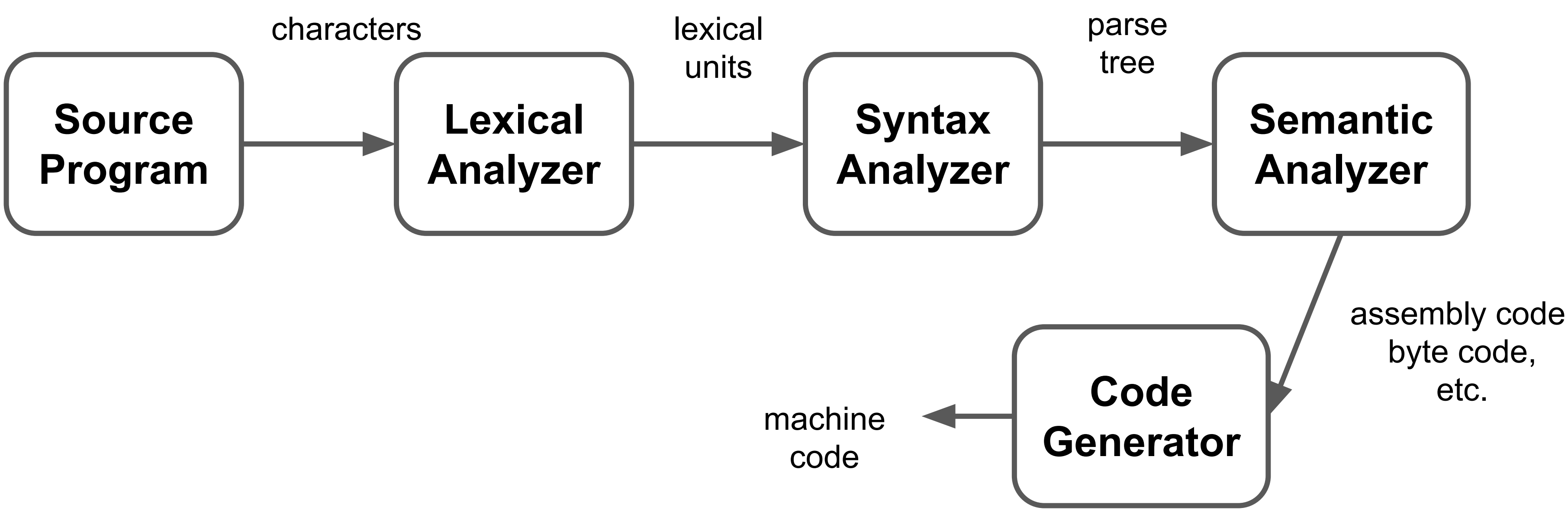
The Compilation Process



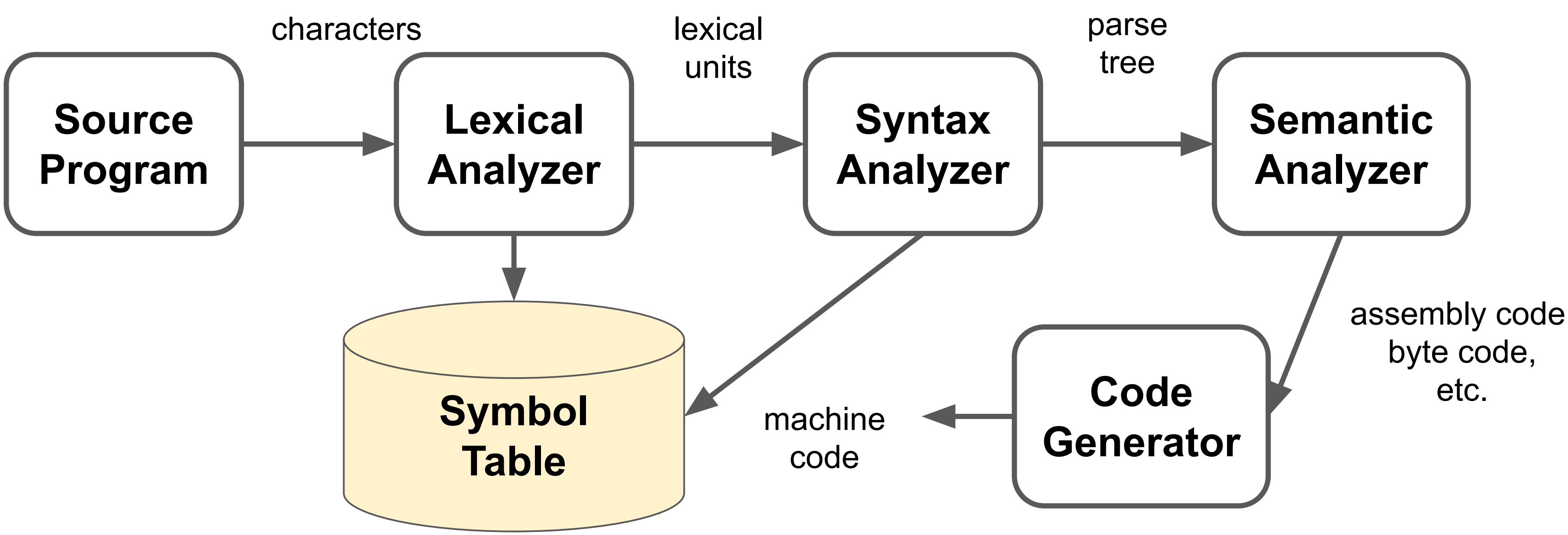
The Compilation Process



The Compilation Process



The Compilation Process



The Linking Process

- Programs depend heavily on low-level system calls
- They also require other external programs from supporting libraries
- Those extra pieces of code need to be linked to the user program

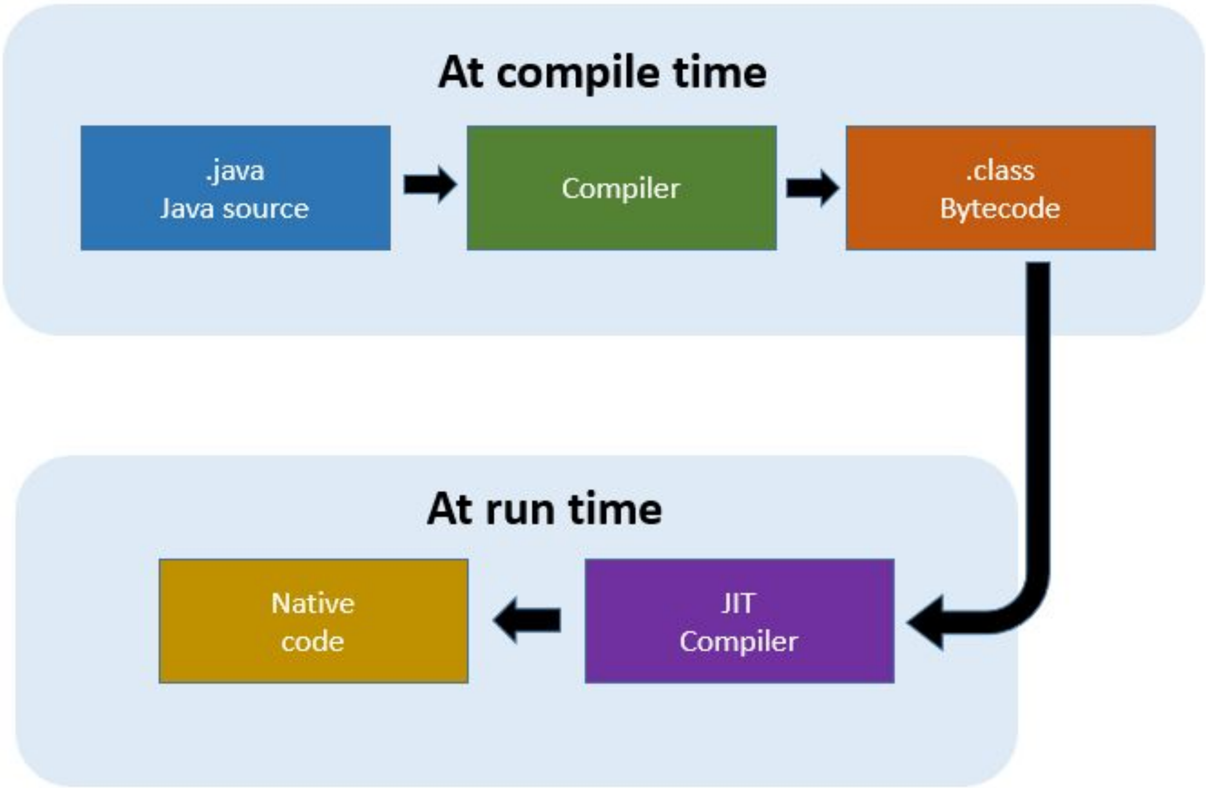
The Interpretation Process

- Each statement is decoded while the program runs
- The interpreter acts like a virtual machine
- It runs 10 to 100 times slower compared to compilation

The Hybrid Process

- The intermediate code (not the source code) is interpreted
- In other words, the source code is partially compiled
- The code generator is replaced by an interpreter
- Examples: Perl, Java, Python, and others

The Hybrid Process



Describing Syntax

- Alphabet:
  - A finite set of symbols
  - We like to use ∑ to represent alphabets
- Word:
  - A finite sequence of symbols from a given alphabet
  - If w is a word, |w| denotes its length
  - ε denotes the empty symbol

Describing Syntax

- Example:

$\sum = \{a, b\}$

a is a word from $\sum$ and $|a| = 1$

ab is another word from $\sum$ and $|ab| = 2$

bbbb is another word from $\sum$ and $|bbbb| = 4$

Describing Syntax

- Formal Language:
  - A set of words from an alphabet
  - Example:

$\sum = \{a, b\}$

L = {a, ab, bbbb} is a formal language from $\sum$

Describing Syntax

- Grammar:
  - G = (V, T, P, S), where:
    - V is a finite set of variables
    - T is a finite set of terminal symbols
    - P is a finite set of production rules
    - S is the start variable

Describing Syntax

- Example:

$G = (V, T, P, S)$

$V = \{S, D\}$

$T = \{0, 1, 2, \ldots, 9\}$

$P = \{S \rightarrow D, S \rightarrow DS, D \rightarrow 0|1|\ldots|9\}$

Describing Syntax

- Generated Language:
  - Given a grammar G, the generated language from G, denoted as L(G), is the set of all words that can be derived from S (start symbol) using only G's productions

Describing Syntax

- Example:

$G = (V, T, P, S)$

$V = \{S, D\}$

$T = \{0, 1, 2, \ldots, 9\}$

$P = \{S \rightarrow D, S \rightarrow DS, D \rightarrow 0|1|\ldots|9\}$

$L(G) = \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, \ldots\}$

Describing Syntax

- Left Linear Grammar:
  - G = (V, T, P, S)
  - A ϵ V, B ϵ V
  - w ϵ T*
  - G is left linear if all productions P have the form:
    - A → Bw | w

Describing Syntax

- Example:

$G = (V, T, P, S)$

$V = \{S, A\}$

$T = \{a, b\}$

$P = \{S \rightarrow Aaa \mid Abb,\ A \rightarrow Aa \mid Ab \mid \varepsilon\}$

Describing Syntax

- Right Linear Grammar:
  - $G = (V, T, P, S)$
  - $A \in V$, $B \in V$
  - $w \in T^*$
  - G is right linear if all productions P have the form:
    - $A \rightarrow wB \mid w$

Describing Syntax

- Example:

$G = (V, T, P, S)$

$V = \{S, A\}$

$T = \{a, b\}$

$P = \{S \rightarrow aS \mid bS \mid A, A \rightarrow aa \mid bb\}$

Describing Syntax

- Regular Grammar:
  - A left (or right) linear Grammar
  - If G is regular then we say that L(G) is regular

For Next Class

- Finish reading chapter 1
- Do Homework 1