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Grammars

(Part 1)

Lecture 20-2
Day 22/31

CS 154
Formal Languages and Computability
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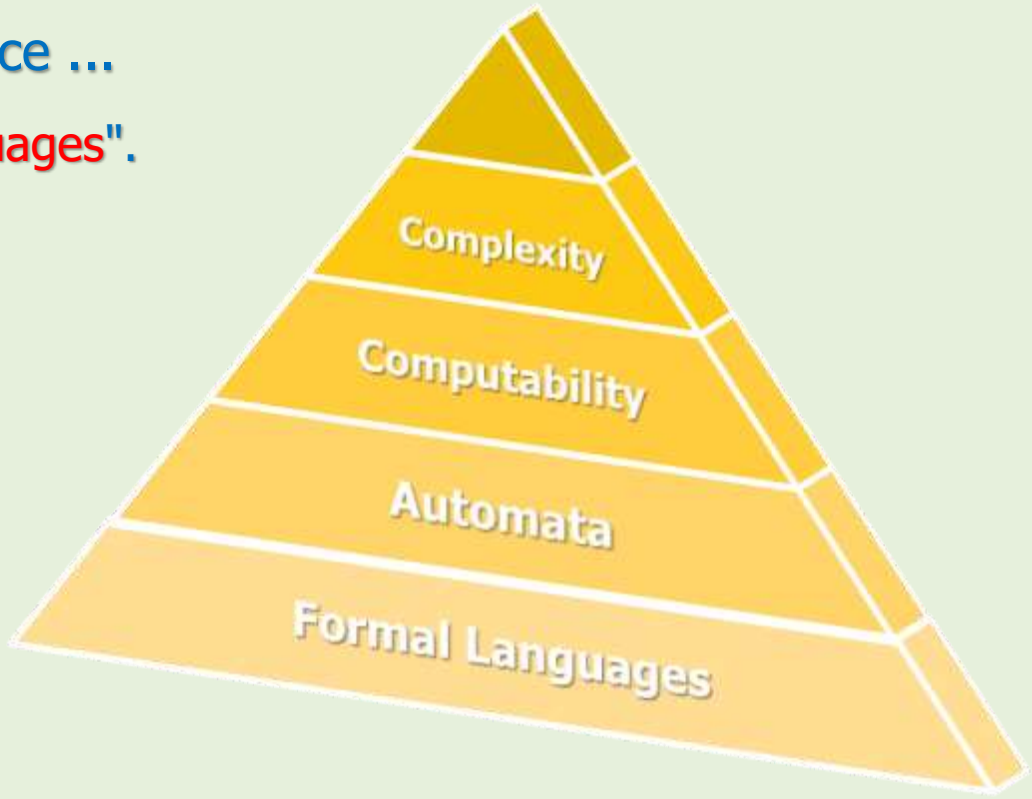
The Big Picture of the Course

Computer Science Foundation

- We started the semester with "Formal Languages" but we said:
  - we'd get back to it during the semester.
- So far, we've got back twice ...
  - Introduced "Regular Languages".
  - Introduced "REGEXs".
- ... and this is the 3rd time!



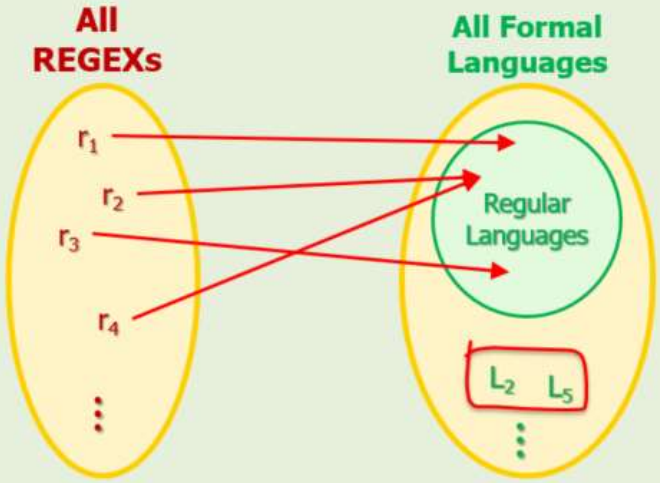
Motivation

- So far, we've represented formal languages by two mathematical tools:
  - Sets (set builder, roster method, Venn diagrams)
  - Regular Expressions (REGEXs)

What is the problem with them?

- Sets are NOT practical in computer science!

- REGEXs are limited to regular languages.



Objective of This Lecture

- We need a more powerful and practical tool to represent NONREGULAR languages!

That is Grammar!

- Our target is to represent all formal languages!
- But like any other tools, grammars have their own limitations.

- We'll be talking about grammars for 3 sessions!

Grammars

Introduction

- What would be your reaction if you encounter the following English sentences:
  - dog the runs.
  - dog runs the.
  - runs dog the.

- Even though all words are correct English words but the combinations are meaningless.
- The words' positions are not as they should be!

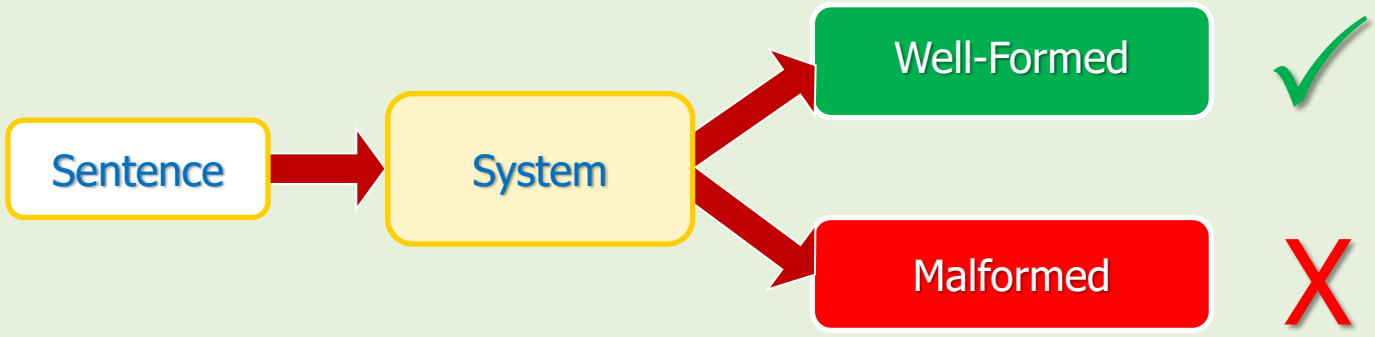
- In computer science and linguistic terminology:

  These sentences are not "well-formed".

What Are We Looking For?

- We need a system (or tool) to distinguish between:

  "well-formed" and "malformed" sentences



- Let's start with a simple example from a natural language like English.
- Then we'll generalize the idea to formal languages.

A Simple English Grammar

- A simple rule for constructing an English "sentence" is:

  <sentence> → <noun-phrase> <predicate>

  - Read "→" as: "is defined as"

- This rule is called "production rule".
  - Because we can produce an English sentence by this rule.

- The problem is ...
- We defined a sentence but we introduced two new "variables":

  <noun-phrase> and <predicate>!

- So, we need to define them before going further.

A Simple English Grammar

<sentence> → <noun-phrase> <predicate>

- We might define these new variables by the following production rules:

<noun-phrase> → <article> <noun>

<predicate> → <verb>

- Again, we introduced new variables <article>, <noun>, and <verb> that should be defined.

- So, we need to keep going ...

A Simple English Grammar

<sentence> → <noun-phrase> <predicate>

<noun-phrase> → <article> <noun>

<predicate> → <verb>

- We might define these new variables by the following production rules:

<article> → a

<article> → the

<noun> → dog

<noun> → boy

<verb> → runs

<verb> → walks

No variables left!

A Simple English Grammar: Notes & Definitions

- Variables are defined either by other variables,
- Or they are assigned "values" (aka terminals),
- Or mix of both (we'll see in the next slides)

Rough Definition of Grammar

- A set of production rules is called "grammar".
  - Later, we define it formally.
- Every grammar has a "starting variable".
  - In this example, we define <sentence> as the starting variable.

Simple English Grammar

1. <sentence> → <noun-phrase> <predicate>
2. <noun-phrase> → <article> <noun>
3. <predicate> → <verb>
4. <article> → a
5. <article> → the
6. <noun> → dog
7. <noun> → boy
8. <verb> → runs
9. <verb> → walks

Repeated

A Simple English Grammar: Examples

Example 1

- Is this a "well-formed" sentence?

the dog runs

Solution

- A sentence is well-formed if we can "derive" it from the production rules.
- We start from the "starting variable":

<sentence> ⇒ <noun-phrase> <predicate>

⇒ <article> <noun> <verb>

⇒ the <noun> <verb>

⇒ the dog <verb>

⇒ the dog runs

Simple English Grammar

1. <sentence> → <noun-phrase> <predicate>
2. <noun-phrase> → <article> <noun>
3. <predicate> → <verb>
4. <article> → a
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6. <noun> → dog
7. <noun> → boy
8. <verb> → runs
9. <verb> → walks

Repeated

A Simple English Grammar: Examples

Example 1 (cont'd)

- We derived the sentence "the dog runs" from the set of production rules (grammar), so, IT IS WELL-FORMED.

- We used "⇒" notation for "derivation".
  - Read "⇒" as: "derives"
- We can also represent the whole process as:

$$\text{<sentence>} \overset{*}{\Rightarrow} \text{the dog runs}$$

to represent "multiple derivations" when we want to summarize the whole process.

- Now, let's take a failure example.

A Simple English Grammar: Examples

Example 2

- Is this a "well-formed" sentence?

  the runs dog

Solution

- <sentence> ⇒ <noun-phrase> <predicate>

  ⇒ <article> <noun> <verb>

  ⇒ the <noun> <verb>

- "runs" is NOT a "noun"!
- It fails, so, the sentence IS MALFORMED.
- What else can we derive from this grammar?

Simple English Grammar

1. <sentence> → <noun-phrase> <predicate>
2. <noun-phrase> → <article> <noun>
3. <predicate> → <verb>
4. <article> → a
5. <article> → the
6. <noun> → dog
7. <noun> → boy
8. <verb> → runs
9. <verb> → walks

Repeated

A Simple English Grammar: Examples

Example 3

- The set of all sentences derivable from this grammar is:

{ a dog runs,

a dog walks,

a boy runs,

a boy walks,

the dog runs,

the dog walks,

the boy runs,

the boy walks }

- What can we call this set of strings?

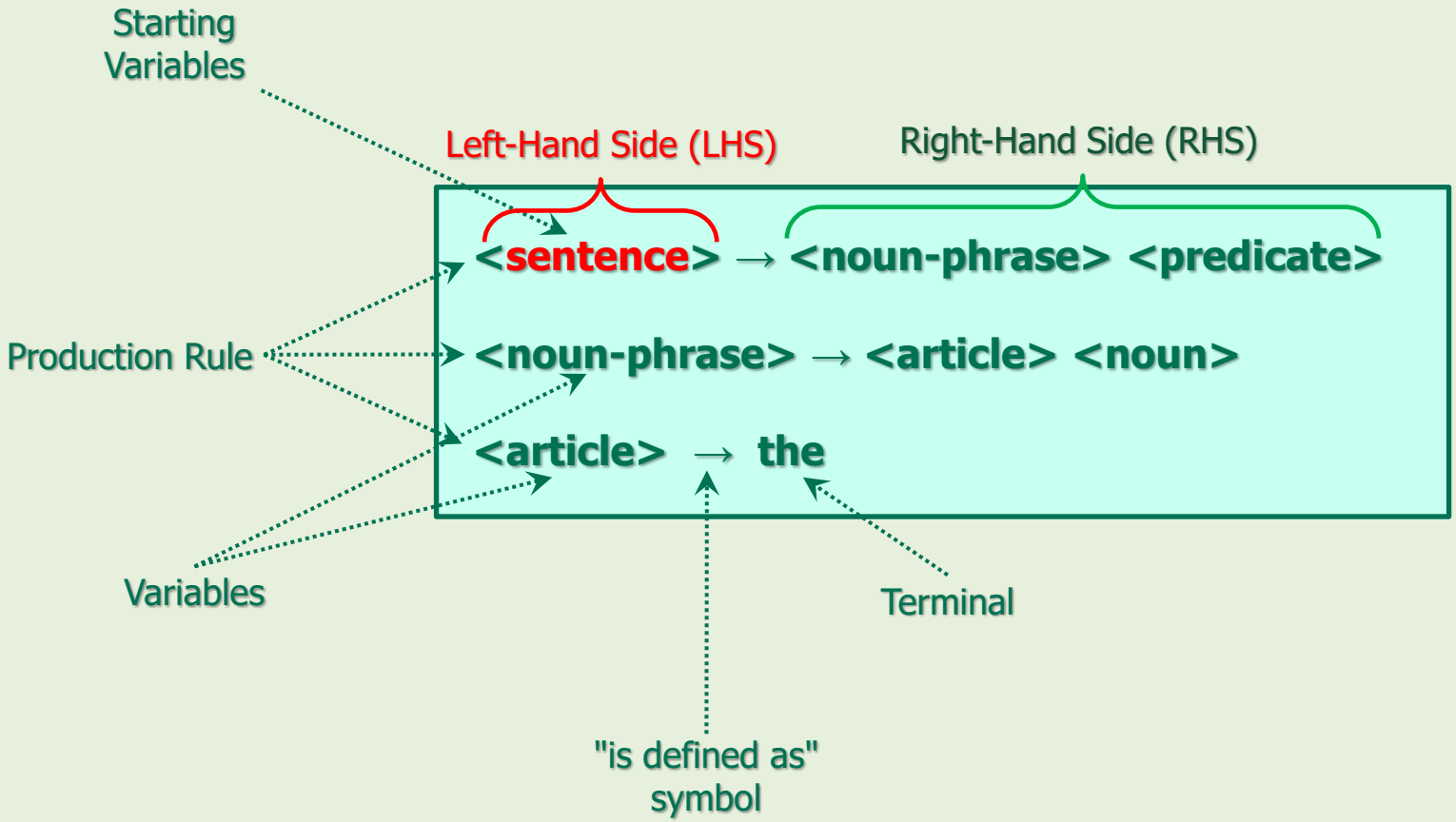
The language generated by the grammar

Simple English Grammar

1. <sentence> → <noun-phrase> <predicate>
2. <noun-phrase> → <article> <noun>
3. <predicate> → <verb>
4. <article> → a
5. <article> → the
6. <noun> → dog
7. <noun> → boy
8. <verb> → runs
9. <verb> → walks

Repeated

Grammar Terminologies



A Side Note About Natural Languages

- Unfortunately, natural languages were not developed by mathematicians.
- That's why, there are thousands of exceptions in their definition!
- So, learning them perfectly as second languages is very hard!

- The only successful language that was developed by a scientist is ...

  Esperanto!

- For more info, please look at the appendix A at the end of this lecture note.
- It is just for your information and is NOT part of this course.

References

1. Linz, Peter, "An Introduction to Formal Languages and Automata, 5th ed.," Jones & Bartlett Learning, LLC, Canada, 2012
2. Michael Sipser, "Introduction to the Theory of Computation, 3rd ed.," CENGAGE Learning, United States, 2013
   ISBN-13: 978-1133187790
3. The ELLCC Embedded Compiler Collection, available at: http://ellcc.org/

Appendix A

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Esperanto

A World Without War!

Esperanto Creator's Motivation

- Constructed in 1873 by Polish medical doctor, inventor, and writer, Ludwik L. Zamenhof (1859-1917).

- He had the dream of "a world without war".
- He believed this language can help international people to communicate easily.
- And the communications could prevent wars!

Alphabet (5 Vowels + 23 Consonants)

Letter	English Example
a	father
b	
c	cats
ĉ	chip
d	
e	bet
f	
g	go
ĝ	gem

Letter	English Example
h	
ĥ	kh in Persian
i	see
j	yes
ĵ	measure
k	
l	
m	
n	

Letter	English Example
o	so
p	
r	rolled "R"
s	
ŝ	share
t	
u	soon
ŭ	cow
v	
z	

Vowels & Consonants

- 5 Vowels: A, E, I, O, U
- 23 Consonants: the rest of alphabets

- Name the vowels by their pronunciation
- Name the consonants by: letter + o
- For example, we call "b" as "bo".

- The number of syllables of a word is the number of vowels.
- For example, "domo" (means house) has two syllables.

- The accented syllable is the second to the last syllable.

Rules

- All "nouns" are ended with 'o'.
- For example, "domo" means house.

- All "adjectives" are ended with 'a'.
- For example, "doma" means domestic.

- Adjectives can be placed before or after nouns.
- For example, "dolĉa pomo" or "pomo dolĉa" means "sweet apple".

- To make a negative adjective, just prefix it with "mal".
- For example, "bona" means "good" and "malbona" means "bad".

Rules

- All "adverbs" are ended with 'e'.
- For example, "rapide" means "quickly".

- Adverbs can be placed before or after the verb they modify.
- For example, "Ĝi flugas rapide" means "it flies quickly".
- Or we can say, "Ĝi rapide flugas".

- To make "plural", add 'j' at the end of the nouns and adjectives.
- For example, "seĝoj" means chairs.
- Example for plural, "rapidaj aŭtoj" means fast cars.
- Note that both adjective and noun should be plural.

Rules

- There is only one "definite article" "la" in Esperanto.
- For example, "la domo" means "the house".

- There is no indefinite article in Esperanto.
- So, if you don't use "la", it means the article is indefinite.

Rules

- To make "possessive personal pronoun", just add 'a' to the end of personal pronoun.
- For example, "mi" means "I", "mia" means "my".
- "vi" means "you", "via" means "your".

- To make a verb negative, just add "ne" before it.
- For example, "Ŝi estas alta." means "She is tall".
- "Ŝi ne estas alta." means "She is not tall".

Tenses

- Infinitives are ended with 'i'.
- For example, "flugi" means "to fly".

- Present tense is ended with "as".
- For example, "Mi flugas" means "I fly".

- Past tense is ended with "is".
- For example, "Mi flugis" means "I flied".

- Future tense is ended with "os".
- For example, "Mi flugos" means "I will fly".

Tenses

- Progressive Present is ended with "anta" but needs "estas" as well.
- For example, "Mi estas fluganta" means "I am flying".

Miscellaneous

- To make a question, add "Ĉu" at the beginning of the sentences.
- For example, "Mi flugas" means "I fly".
- "Ĉu mi flugas" means "Do I fly".
- It doesn't matter what tense the sentence has.

- Over all, Esperanto has 16 constants rules.
- These were some of them, I selected for your information.

General Info About Esperanto

- "Esperanto" means "one who hopes".
- The flag of Esperanto ...

- It is the most successful constructed language in the world.
- Almost two million people speak in Esperanto.
- The first World Congress of Esperanto was organized in 1905 in France.
- Esperanto was recognized as a language by UNESCO in 1954.
  - It was recommended as international non-governmental organizations language in 1985.
- In 2012, Google Translate added Esperanto into its list.
- Language codes in computer: ISO 639-1, ISO 639-2, ISO 639-3

Did You Know That ...

- Learning Esperanto as the second language will speed up learning 3rd and more languages.
- 8 Nobel laureates have been Esperantists
- Esperantists make up the largest non-political grouping in the British parliament.
- Leo Tolstoy helped found the Esperantist Vegetarian Association in 1908.
- In 1993, more than 4900 people (mainly non-Esperantists) visited the International Esperanto Museum in Vienna.
- Esperantists have continually suffered oppression from totalitarian governments!

Reference: http://esperanto.org/us/USEJ/world/index.html

References

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3. Esperanto lessons: https://www.youtube.com/watch?v=bLx5hLag6WQ