CSCI: 4500/6500 Programming Languages

Natural and Programming Languages

Syntactic Structures

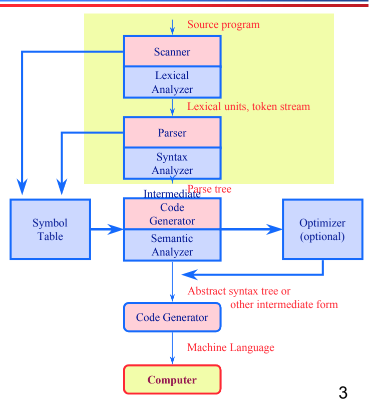
Portions of this lecture thanks to: Prof David Evans, U Virginia and Prof Spencer Rugaber, GTech

Review Last Time: Programming Language History

- **50s, 60s: Exciting Time**
  - » Invention of: assemblers, compilers, interpreters, first high-level languages, *structured programming*, abstraction, formal syntax, object-oriented programming, LISP, program verification
- **70s, 80s, 90s: Boring Time**
  - » Refinement of earlier ideas, better implementations, making theory more practical
  - » A few new/refined ideas: functional languages, data abstraction, concurrent languages, data flow, type theory, etc.
- **00+s: Party Time**
  - » New Environment: Internet, large scale distributed computing, the grid, Java, C#, Maria at UGA
- **Alan Kay: "The best way to predict the future is to invent it."**

This Week: Programming Language Implementation

- **This week and next we will talk about the first two phases of compilation, namely, scanning and parsing.**



Formal System & Language

Formal System:

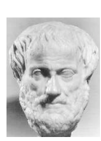
- **Set of symbols:**
  - » the primitives
- **Set of rules for manipulating symbols**
  - » Rules of production

What is a Language (theoretically)?:

- **Formal System + (mapping of sequence of symbols and their meaning)**

Linguist's Language

- **Description of pairs (S, M)**
  - » S is the "sound", or any kind of surface forms, and
  - » M is the meaning.
- **Language specifies properties of *sound* and *meaning* and how they relate (Aristotle characterize language as a system than links sound and meaning)**
  - **Aristotle: 384-322 B.C. Greek philosopher, father of deductive logic, Meta physics, "Physics", teacher of Alexander the Great.**



What are languages made of?

- **Primitives**
  - » The smallest units of meaning, or the *simplest surface forms* (pronunciation).
- **Means of Combination (all languages have these)**
  - » Like Rules of Production for Formal Systems
  - » Creates new surface forms from the ones you have
- **Means of Abstraction (all powerful languages have these)**
  - » Ways to use simple surface forms to represent complicated ones

What is longest word in the English language?

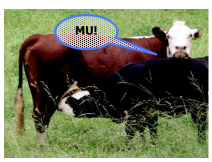
- ***Supercalifragilisticexpialidocious***
  - » Popularized by Mary Poppins
  - » Oxford English Dictionary, 34 letters
  - » Nonsense word meaning fantastic
- **Pneumonoultramicroscopicsilicovolcanoconiosis**
  - » Factious word to mean: 'a lung disease caused by the inhalation of very fine silica dust', 45 letters
  - » 207,000+ mitochondrial DNA
- **Floccinaucinihilipilification**
  - » The estimation of something as worthless (usage dated since 1741)
  - » 27 letters, longest non-technical word according first edition of Oxford English Dictionary (floccus - I don't care, I don't make wool, naucum - little value, nihilum - nothing, pilus - a bit or whit, something small and insignificant

Creating longer words

- **Floccinaucinihilipilification**
  - » The estimation of something as worthless, the act of estimating something as useless
- **Anti-floccinaucinihilipilification**
  - » The estimation of something as not worthless
- **Antifloccinaucinihilipilification-or**
  - » The one who does the act of not rendering useless
- **Anti- antifloccinaucinihilipilification**

Natural Languages

- Are there any non recursive languages?
- No, we would run out of things to say
- So, we only need to start with a few building blocks and from there we can create infite things



What are languages made of?

- **Primitives**
  - » The smallest units of meaning, the "*simplest" surface forms.* Lexemes lowest level of meaning.
- **Means of Combination** (all languages have these)
  - » Creates new surface forms from the ones you have
  - » Sentences and works on word parts too!
- **Means of Abstraction** (all powerful languages have these)
  - » Ways to use simple surface forms to represent more complicated ones
  - » Example: prounouns: "I in English; or Phom, Dichan is the polite way of saying I in Thai depending on gender (Dichan for females).

Primitives/Tokens

- Described by regular expressions
  - » First phase of compilation process converts strings/lexemes of the programming language to tokens (a representation of the lexeme in the computer)
    - – Example: letter (letter | digit) *
- Regular expression (over some given alphabet)
  - » 3 operations:
    - – Concatenation
    - – Repetition
    - – Alternation (Choice)
- Corresponds to type-3 grammars in Chomsky hierarchy and is the most restrictive A -> a, A-> aB or A -> Ba
- Many utilities exist that use regular expressions
  - » grep (global regular expression print)
  - » Lex/flex, turn a regular expression of tokens into a scanner, so they are generators

Means of Combination

- Allow us to say infinitely many things with a finite set of primitives
- We can create *sentences* using primitives
  - » In English "words" are really not the primitives since we can create longer words
- How can we describe "means of combinations" the syntax of a language?
  - » Computer Scientists:
    - – Backus-Normal-Form -> Backus-*Naur*-Form (BNF)
  - » We will talk about semantics later

BNF Example

```
Sentence ::= Noun-Phrase  Verb-Phrase
Noun-Phrase ::= Maria | Microsoft
Verb-Phrase := Rocks |  Jumps
```

- **What are the terminals?**
  - » **Maria, Microsoft, Rocks, Jumps**
- **How many different things can we express with this language?**
  - » **4**
  - » **… but only 1 is true**

BNF Example

Sentence ::= Noun-Phrase Verb-Phrase Non-Phrase
Noun-Phrase ::= Noun | Adjective Noun-Phrase
Noun := Maria | Microsoft | Home | Feet
Adjective := Yellow | Smelly
Verb-Phrase := Skips | Runs | Rocks

- **Now we can express infinitely many things with this little language…**

Definition of Languages

- **Recognizers**
  - » **Reads input string and accepts or rejects if the string is in the language**
- **Generators**
  - » **Generate sentences of a language**
  - » **Example: Grammars are language generators**

BNF and Context Free Grammars

- **Context Free Grammars**
  - » **Developed by Noam Chomsky in the 1950s**
  - » **Define a class of languages called context-free languages (type 2)**
- **Backus Naur Form**
  - » **Equivalent to context-free grammars**
  - » **BNF is a meta-language used to describe antother language**

BNF Basics

A BNF grammar consists of four parts:

- ***Tokens:* tokens of the language, the terminals**
- ***Non-terminal symbols:* BNF abstractions in <> brackets**
- ***A start symbol***
- **Grammar: The set of *productions or rules***

BNF details

- **The tokens are the smallest units of syntax**
  - » **Strings of one or more characters of program text**
  - » **They are atomic: not treated as being composed from smaller parts**
- **The non-terminal symbols stand for larger pieces of syntax**
  - » **They are strings enclosed in angle brackets, as in <NP>**
  - » **They are not strings that occur literally in program text**
  - » **The grammar says how they can be expanded into strings of tokens**
- **The start symbol is the particular non-terminal that forms the root of any parse tree for the grammar**

BNF Productions (Grammar)

- The productions are the tree-building rules
- Each one has a left-hand side, the separator ::=, and a right-hand side
  - » The left-hand side is a single non-terminal
  - » The right-hand side is a sequence of one or more things, each of which can be either a token or a non-terminal
- A production gives one possible way of building a parse tree: it permits the non-terminal symbol on the left-hand side to have the things on the right-hand side, in order, as its children in a parse tree

Alternatives

- The BNF grammar can give the left-hand side, the separator ::=, and then a list of possible right-hand sides separated by the special symbol |

Example

<exp> ::= *<exp>* **+** *<exp>* | *<exp>* ***** *<exp>* | **(** *<exp>* **)**
| **a** | **b** | **c**

- Equivalent to six productions:

<exp> ::= *<exp>* **+** *<exp>*
<exp> ::= *<exp>* ***** *<exp>*
<exp> ::= **(** *<exp>* **)**
<exp> ::= **a**
<exp> ::= **b**
<exp> ::= **c**

Extensions to BNF - EBNF

- BNF is sufficient to describe context free languages
- Various extensions and modifications have been made to ease the expression of programming language grammars
  - » The extensions can be bee describe in the original BNF
  - » Collectively these are called EBNF extended BNF

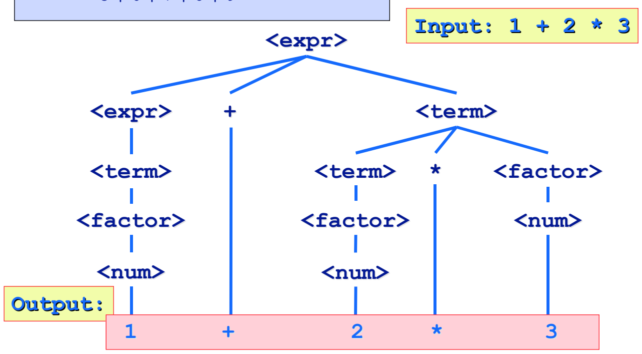
Example EBNF extensions

- Remove brackets for non-terminal
- Replace ::= with →
- Replace vertical bars with spaces
- \+ for one or more occurrences
  - » EBNF: A → X (Y)$^+$
  - » BNF: A := XB
    - – B := Y | YB
- * for zero or more occurrences

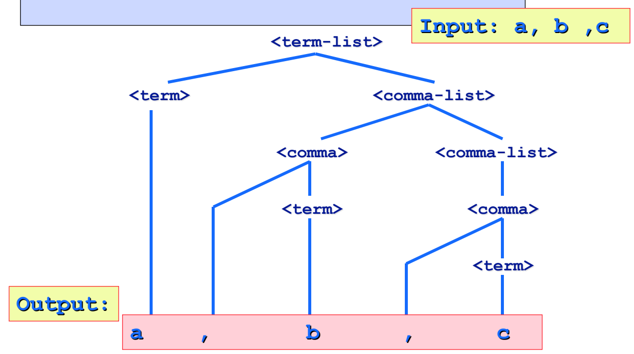
Concrete Syntax

- To build a parse tree, put the start symbol at the root
- Add children to every non-terminal, following any one of the productions for that non-terminal in the grammar
- Done when all the leaves are tokens
- Read off leaves from left to right—that is the string derived by the tree

```
<expr> ::= <expr> + <term> | <term>
<term> ::= <term> * <factor> | <factor>
<factor> ::= '(' <expr ')' | <num>
<num> ::= 0 | 1 | 2 | 3 | 4 |
          5 | 6 | 7 | 8 | 9
```



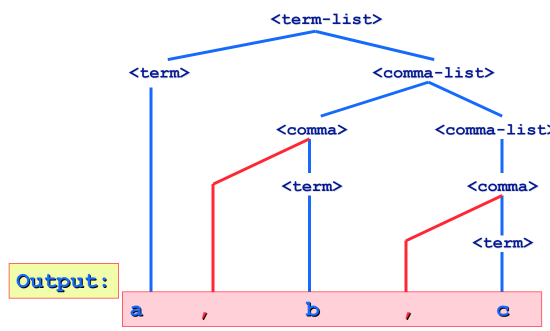

```
<term-list> ::= <term> | <term> <comma-list>
<comma-list> ::= <comma-term> | <comma-term> <comma-list>
<comma-term> ::= ',' <term>
<term> ::= a | b | c | d | e | f
```



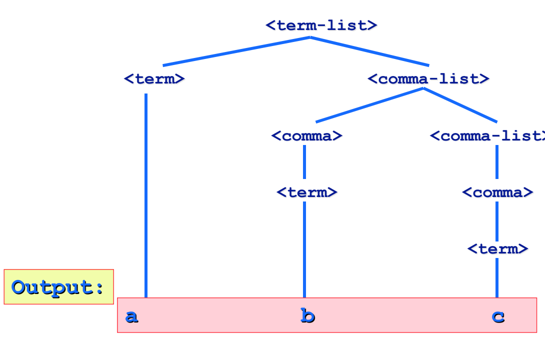
Abstract Syntax Tree

- An abstract syntax tree (AST) describes the elements of a program stripped down to the essentials.
  - Remove unnecessary components
  - Some symbols are there not to be interpreted, e.g. punctuations with really no meaning
    - Example: "," are there only to tell parser how to build tree
  - Convert tree from a narrow tree to flat tree
  - Remove non-essential intermediate non-terminals

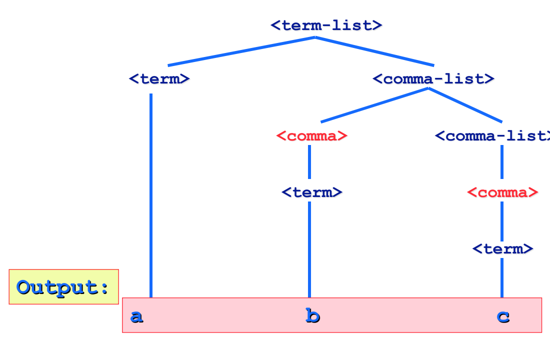
Remove Commas



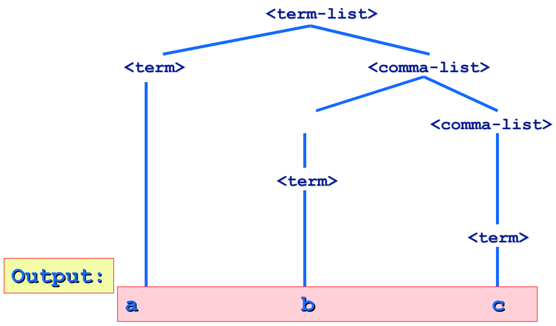
Remove Commas



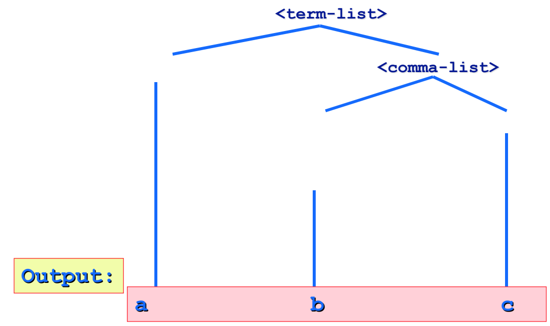
Remove intermediate non-terminals



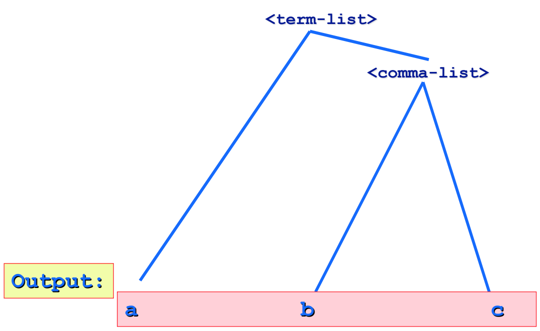
Remove intermediate non-terminals



Remove intermediate non-terminals



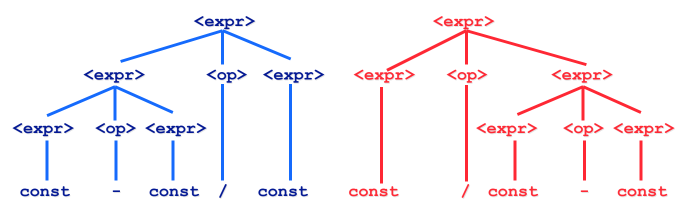
Remove intermediate non-terminals



Ambiguity in Grammars

- Some grammars have more than 1 parse tree for a given string
- Example:

```
<expr> ::= <expr> <op> <expr> | const
<op> ::=  / | -
```



Ambiguity

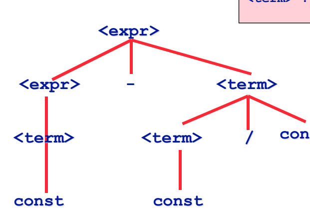
- Compiler often base the semantic on a phrase's parse tree
  - » More than one cannot determine the meaning
  - » Unless there are some additional non-grammatical information
- Precedence and associatively can be defined outside the grammar
- Can include it in the grammar to facilitate the compiler to evaluate from the parse tree

Unambiguous Expression Grammar

- If we use the parse tree to indicate precedence levels of operators we cannot have ambiguity

```
<expr> ::= <expr> <op> <expr> | const
<op> ::=  / | -
```

```
<expr> ::= <expr> - <term> | <term>
<term> ::=  <term> / const | const
```

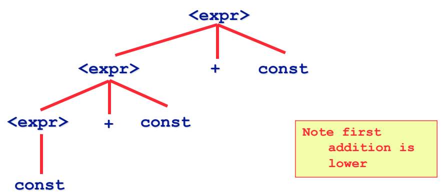


Hint: Higher precedence operators are lower in tree, here "/" has higher precedence than "-"

Associativity

- Operator associativity can also be indicated by a grammar
- Left Associative: 9+5+2 is equivalent to (9 +5) + 2

```
<expr> -> <expr> + <expr> |  const  (ambiguous)
<expr> -> <expr> + const  |  const  (unambiguous)
```



- Project 1 is posted due 2 weeks from today
- No floccipoccinihilipilification please!