Inductive Definitions

Languages,

Grammars,

Parsing

Motivation: Parsing

- Parsing is the act of turning text into meaningful information.
- Example:
  - **Programming language**: Parsing makes the language into an executable machine language program.
  - **Calculator**: Parsing interprets the symbols to carry out the calculation being represented.

    345 + 62.7*84.9

    doesn't have a "magical" meaning; we have to give it one.

Grammars, and Induction

- Grammars provide a **plan** for parsing; they define the **syntax** of a language.

- Grammars are an instance of a more general concept: **Inductive Definitions**.

- rex rules are often inductive definitions; but grammars may be **non-deterministic** for a reason.

Inductive Definitions

- Inductive definitions are the main "constructive" way to define **infinite sets**.

- We will need infinite sets in much of what follows.

Inductive Definitions

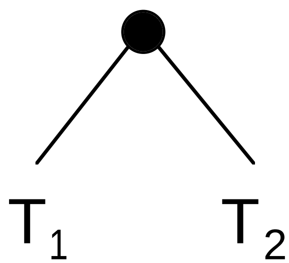
- Elements of an inductive definition of a set S.
  - Basis
  - Induction rule(s)
  - Extremal clause

Inductive Definitions

- Elements of an inductive definition of a set S:
  - **Basis**: Defines a few items to be in S.
  - **Induction rule**(s): Introduce new items in S based on existence of other, usually simpler, items.
  - **Extremal clause**: Says that the only items in S are those derivable by the previous two elements, applied any finite numer of times.

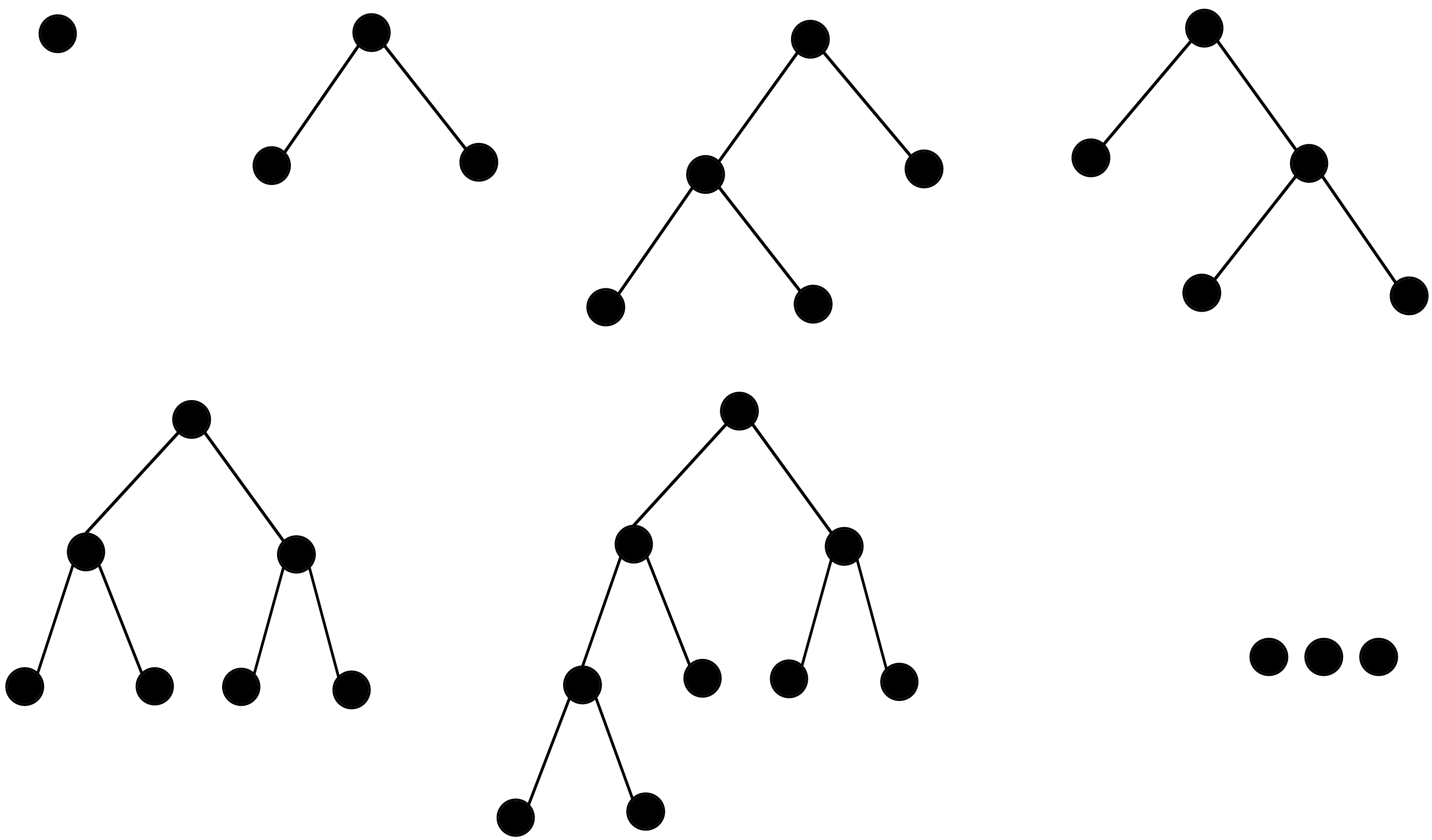
Example of ID: Binary Trees

- ● is a binary tree.
- If T_1 and T_2 are binary trees, then so is:



- Extremal clause: The only binary trees are those constructible by a finite number of applications of the above rules.

Examples of Binary Trees



Example of ID: **Natural Numbers ω**

- **Basis**: 0 is in ω.
- **Induction**: If n is in ω, so is the successor of n (variously denoted n', S(n), or n+1).
- **Extremal**: The only elements in ω are those derivable by applications of the above rules.
- Examples: 0, 0', 0'', 0''', 0'''', ... are all elements of ω.

Notes

- ω is an **infinite** set.
- ω's members are all **finite**.
- ω does *not* contain infinity (∞) as an element.

Interpretations of Successor (')

- What are 0', 0'', 0''', ... really?
  - Strings of symbols, **or**
  - Things that can be constructed from **sets**, a more primitive concept.
    - Two variations:
      - 0 is { }, the empty set; X' is the set {X}, **or**
      - 0 is { }, the empty set; X' is the set $X \cup \{X\}$.
    - In the second example: 0 is {}, 0' is {{}}, 0'' is {{}, {{}}}, 0''' is {{}, {{}}, {{}, {{}}}}, ...
    - Advantage: $0^{n\,\text{'s}}$ is a set **with n distinct members**.

Decimal Numerals

- We can agree by convention that
  - 1 stands for 0',
  - 2 stands for 0'',
  - ...
  - 9 stands for 0'''''''''.
  - Beyond that, give an algorithm for generating additional numerals:

    10, 11, 12, 13, ...

Decimal Numbering Rule

- The successor of x0 (concatenation) is x1, the successor of x1 is x2, ..., and the successor of x8 is x9.
- The successor of x9 is y0 where y is the successor of x.
- Example: 0, 1, ..., 9, 10, 11, ..., 19, 20, 21, ..., 99, 100, ...

1-adic Numerals

- The only digit is 1.
- The empty string (denoted λ so it is readable) stands for 0.
- 1X (1 followed by X) stands for X'.
- The numerals are:

  λ, 1, 11, 111, 1111, 1111, ...

- Could also use lists: [ ], [1], [1, 1], [1, 1, 1], ...

2-adic Numerals

- The digits are 1 and 2.
- The empty string (denoted λ so it is visible) stands for 0.
- The numerals are:

  λ, 1, 2, 11, 12, 21, 22, 111, 112, ...
- Unlike binary numerals, there is **no redundancy** (1, 01, 001, 0001, ... all mean the same thing in binary).

Roman Numerals

- The digits are I, V, X, L, C, D, M.
- There is no string for 0.
- The successor of I is s(I) = II, s(II) = III, s(III) = IV, etc.

Numerals vs. Numbers

- **Numbers** are abstract.

- **Numerals** are a concrete *representation* of numbers.

Strings over an alphabet Σ

- The set of *all* finite strings over an alphabet Σ is denoted Σ^*.
- Example:
  - $\{a, b\}^* =$
    $\{\lambda, a, b, aa, ab, ba, bb, aaa, aab, aba, \ldots\}$

Strings over an alphabet Σ

- Basis: λ is in Σ^*.
- Inductive rule: If $x \in \Sigma^*$ and $\sigma \in \Sigma$, then σx (σ followed by x) is in Σ^*.
- Extremal clause.

Languages

- A language over Σ is any subset of Σ^*.

- Examples, where $\Sigma = \{a, b\}$
  - $\{a, b\}^*$ itself
  - $\{\ \}$ the empty language
  - {ba, baba} maybe your first language
  - $\{\lambda$, aa, aaaa, aaaa, aaaaaa, ...$\}$ the language of an even number of a's.

More Languages

- Examples, where $\Sigma = \{a, b\}$
  - $\{\lambda$, ab, ba, aabb, abab, baab, bbaa, aaabbb, aababb, ...} the language in which the number of a's equals the number of b's.
  - {a, b, aa, bb, aab, aba, baa, abb, bab, bba, ...} the language in which the number of a's is *not* equal to the number of b's.
  - {ab, abab, aabb, aababb, ...} a language you might recognize.

Languages

- There are lots of languages, some very weird.
- To be of computational interest, a language needs to be defined **inductively**.
- We need a way of telling whether a given string is in the language or not (called ***parsing*** the string).

Non-Trivial Language Defined Inductively

- L = {ab, abab, aabb, aababb, ...}
- Basis: ab is in L.
- Inductive rules:
  - If x is in L, so is axb.
  - If x_1 and x_2 are in L, so is x_1x_2.

Grammars: A Shorthand

- Spelling everything out with these inductive definitions is laborious.
- We need a shorthand, especially for more complex languages.
- The idea comes from linguistics and early work on computer languages.

Grammatical Definition

- There is a "start symbol", or "root", say S, *not* in the alphabet of the language itself.
- $\rightarrow$ is a symbol meaning "can be rewritten as".
- Grammar rules:
  - S $\rightarrow$ ab
  - S $\rightarrow$ aSb
  - S $\rightarrow$ SS
- Application of rules is by "free choice".
- A sequence of applications is called a **derivation**.
- The strings in the language are those that **don't** include S.

Using the Grammar Rules

- Grammar rules:
  - $S \rightarrow ab$
  - $S \rightarrow aSb$
  - $S \rightarrow SS$
- Example derivations of strings in the language:
  - $S \Rightarrow ab$
  - $S \Rightarrow aSb \Rightarrow aabb$
  - $S \Rightarrow aSb \Rightarrow aaSbb \Rightarrow aaabbb$
  - $S \Rightarrow SS \Rightarrow abS \Rightarrow abab$
  - $S \Rightarrow SS \Rightarrow SSS \Rightarrow ababab$
  - $S \Rightarrow SS \Rightarrow aSbS \Rightarrow aabbS \Rightarrow aabbaSb \Rightarrow aabbaabb$

Generalizing Grammar Rules

- Instead of just S, allow multiple symbols, called **auxiliaries**, none of which are in the alphabet of the language.
- A distinguished auxiliary is called the **root** or "**start symbol**".
- The symbols in the alphabet of the language are called **terminals**.
- The rules are known as **productions**.

Example:
Grammar for Additive Arithmetic Expressions

- The root is A.
- The terminals are {a, b, c, +}.
- The productions are:
  - $A \to V$
  - $A \to V + A$
  - $V \to a$
  - $V \to b$
  - $V \to c$

Example Derivations

- The productions are:
  - $A \rightarrow V$
  - $A \rightarrow V + A$
  - $V \rightarrow a$
  - $V \rightarrow b$
  - $V \rightarrow c$
- Sample derivations:
  - $A \Rightarrow V \Rightarrow a$
  - $A \Rightarrow V \Rightarrow c$
  - $A \Rightarrow V + A \Rightarrow c + A \Rightarrow c + V \Rightarrow c + a$
  - $A \Rightarrow V + A \Rightarrow c + A \Rightarrow c + V + A \Rightarrow c + b + A \Rightarrow c + b + V \Rightarrow c + b + a$

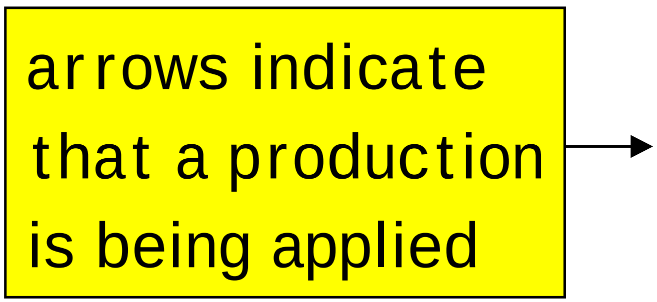
Shorthands on top of Shorthands

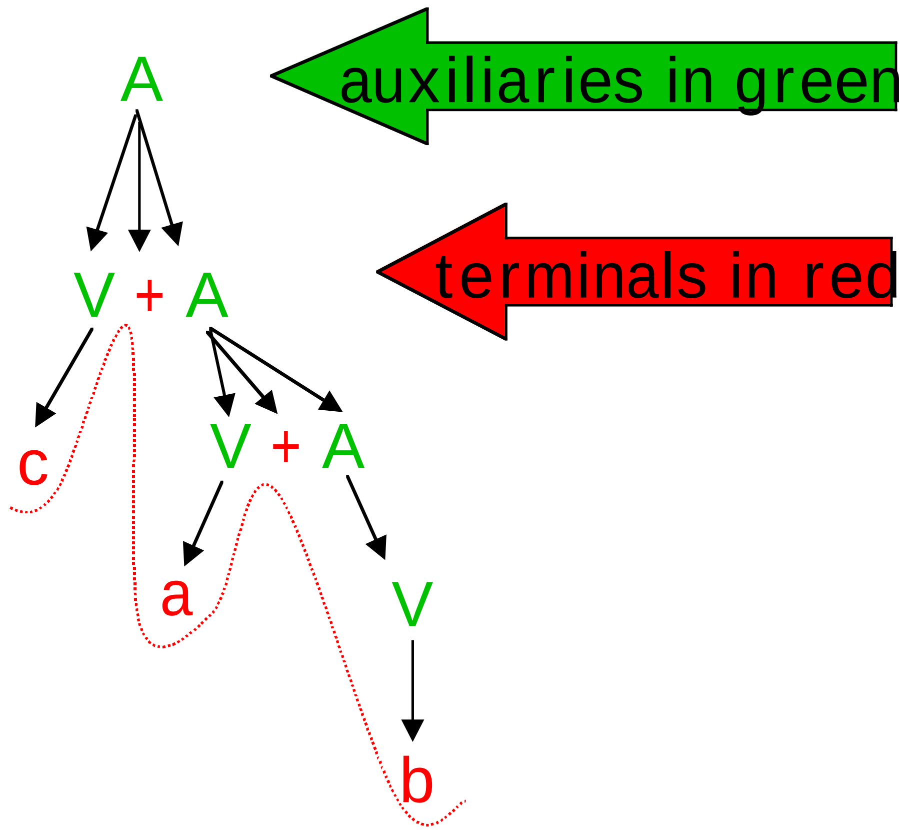
- The productions are:
  - $A \rightarrow V$
  - $A \rightarrow V + A$
  - $V \rightarrow a$
  - $V \rightarrow b$
  - $V \rightarrow c$
- Group by common left-hand sides
- Use | (read "or") to represent alternatives:
  - $A \rightarrow V \mid V + A$
  - $V \rightarrow a \mid b \mid c$
- Note: | "binds more loosely" than other symbols.
- Same grammar, just a briefer notation.

Derivation Tree Visualization

$A \rightarrow V \mid V + A$

$V \rightarrow a \mid b \mid c$

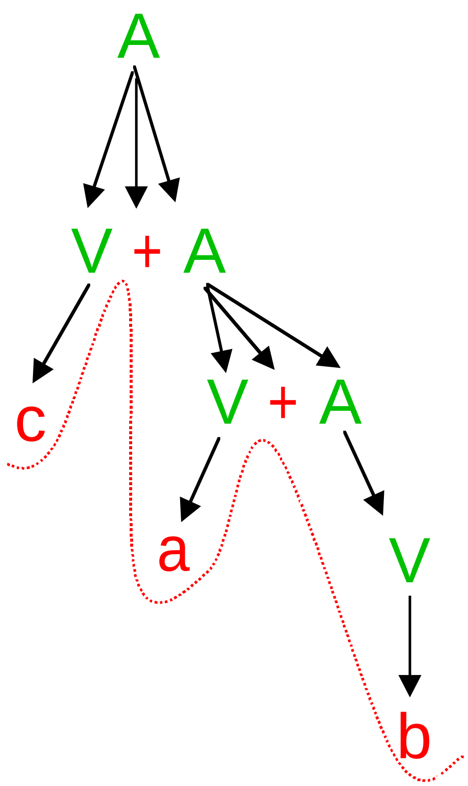




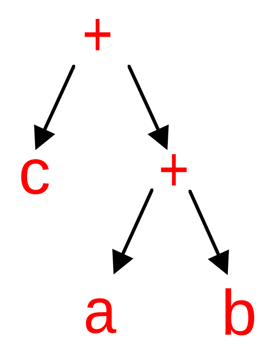
Terminal string = red “fringe” of tree = “c + a + b”

Syntax Tree (!= Derivation Tree)
Shows Implied "**Interpretation"** of String

Derivation Tree



Syntax Tree



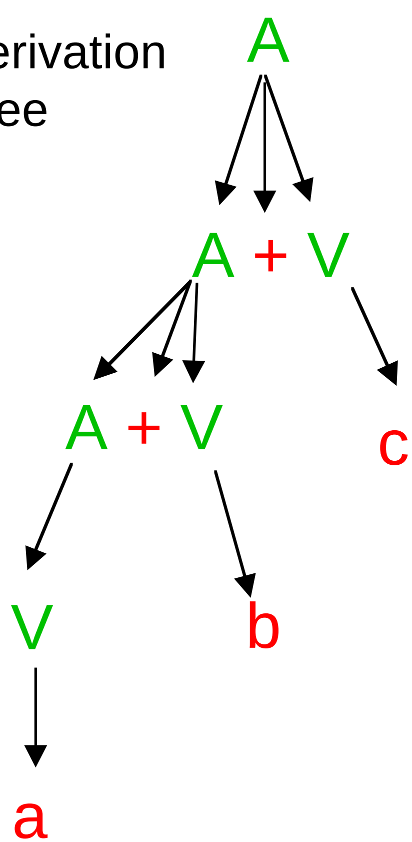
Right Grouping (used so far) vs. Left Grouping Productions

Left-grouping production

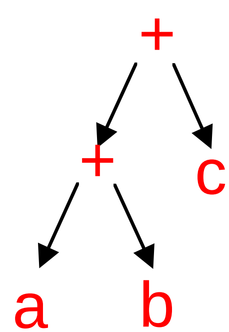
$A \rightarrow A + V \mid V$

$V \rightarrow a \mid b \mid c$

Derivation Tree



Syntax Tree

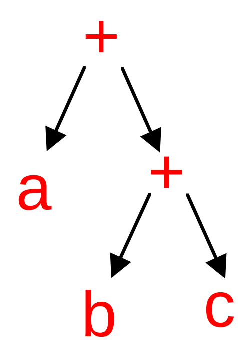


Right-grouping production

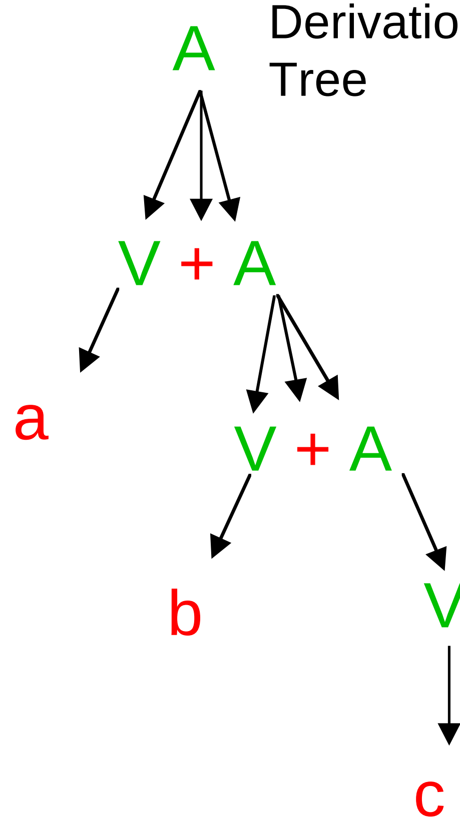
$A \rightarrow V + A \mid V$

$V \rightarrow a \mid b \mid c$

Syntax Tree



Derivation Tree



Does Grouping Matter?

- Mathematically, + is an associative operator:

  (a + b) + c == a + (b + c)

- However:
  - There **are** non-associative operators, such as -, where it does matter.
    - (a - b) - c ?= a - (b - c)
  - On computers, for floating point addition, associativity does not always hold.

Floating Point is Not Associative

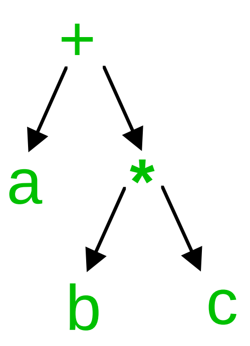
- Try this:
  - `sumup(m, n)   = m > n ? 0 : 1./m + sumup(m+1, n);`
  - `sumdown(m, n) = m > n ? 0 : 1./n + sumdown(m, n-1);`
  - `test(n) = sumup(1, n) == sumdown(1, n);`
  - `map(test, range(1, 100));`
  - ```
    [1, 1, 1, 1, 1, 0, 1, 1, 0, 1, 1, 1, 1, 0, 0, 0, 0, 1, 0, 1,
     1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 0, 1, 0, 0, 1,
     1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
     0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 1, 0, 0, 1, 1, 1, 1, 1, 0,
     1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 1, 0]
    ```
- Grouping sensitivity is due to round-off error.
    ```

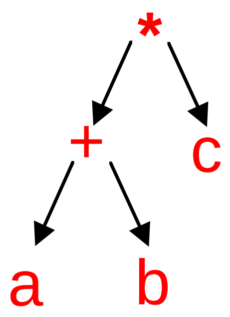
Precedence Issue
(multiple operator symbols)

- How do we ensure that the syntax tree of

$$a + b*c$$

looks like this: and not this:



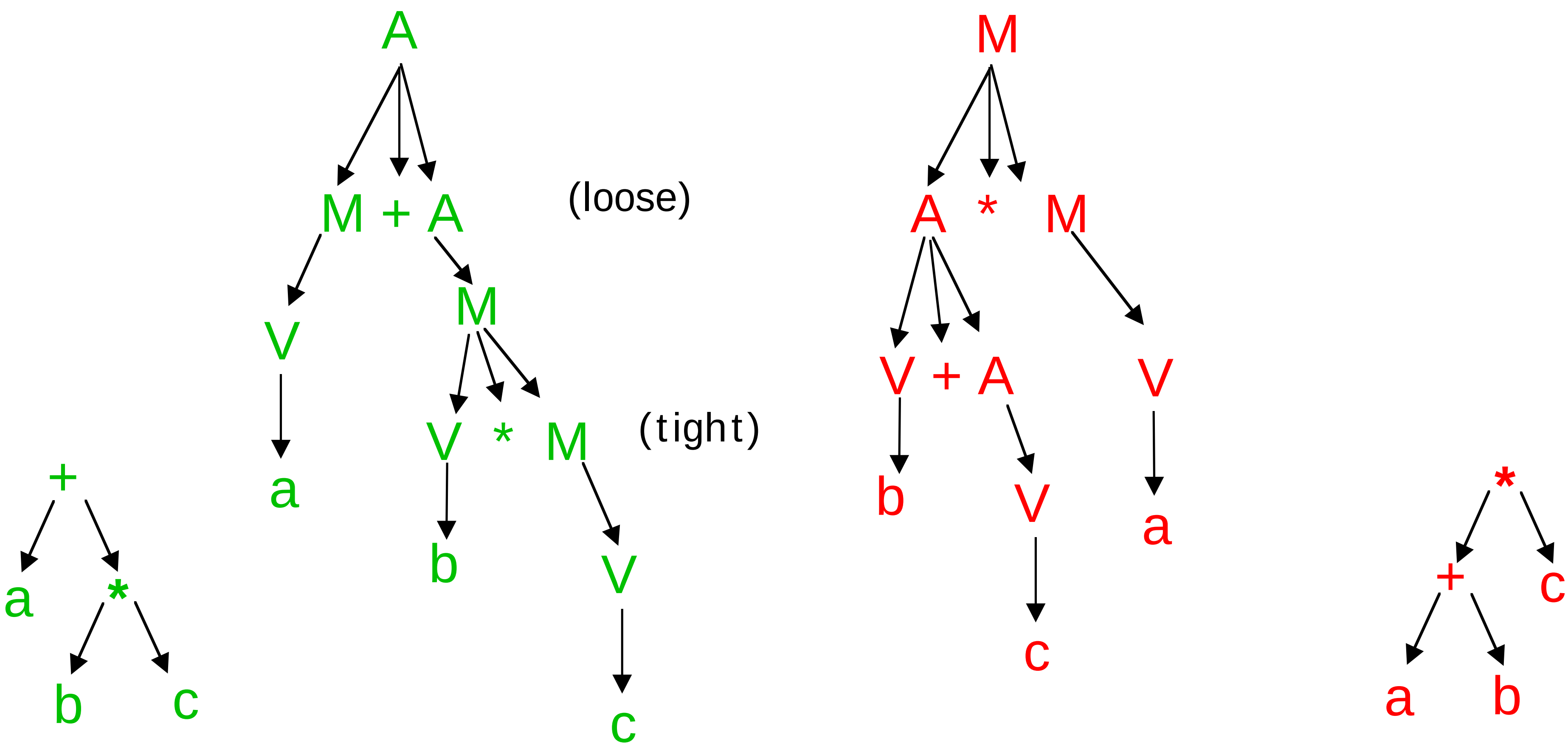


Multiple Auxiliaries

- We want * to “ bind more tightly” than +.
- Use a different auxiliary symbol for each level of precedence.
- Arrange it so that expansions from the tighter binding auxiliary symbol can only be done **after** those of the looser binding auxiliary.

Precedence Issue

- We must ensure that the **derivation** tree for a+b*c looks like this: and not this:



Example: Grammar for Additive **& Multiplicative** Arithmetic Expressions

- The root is A.
- The terminals are {a, b, c, +, *}.
- The productions are:
  - $A \rightarrow M + A \ | \ M$
  - $M \rightarrow V * M \ | \ V$
  - $V \rightarrow a \ | \ b \ | \ c$
- Intuitive rule: Operator “farther from the root” binds more tightly

Syntactic Categories

- The various auxiliary symbols typically represent syntactic categories: sets of sub-expressions having a certain type of meaning.
- Categories:
  - $A \rightarrow M + A \;|\; M$ S is a "sum"
  - $M \rightarrow V * M \;|\; V$ P is a "product"
  - $V \rightarrow a \;|\; b \;|\; c$ V is a "variable"

Example Derivations

- The productions are:
  - $A \rightarrow M + A \ | \ M$
  - $M \rightarrow V * M \ | \ V$
  - $V \rightarrow a \ | \ b \ | \ c$
- Sample derivations (A is the syntactic category):
  - $A \Rightarrow M \Rightarrow V \Rightarrow a$
  - $A \Rightarrow M + A \Rightarrow V + A \Rightarrow a + A \Rightarrow a + M \Rightarrow a + V \Rightarrow a + b$
  - $A \Rightarrow M + A \Rightarrow V + A \Rightarrow a + A \Rightarrow a + M \Rightarrow a + V*M$
    $\Rightarrow a + b * M \Rightarrow a + b * c$
  - $A \Rightarrow M + A \Rightarrow V*M + A \Rightarrow a *M + A \Rightarrow a *V + A$
    $\Rightarrow a *b + A \Rightarrow a *b + M \Rightarrow a *b + V \Rightarrow a *b + c$

Example Syntactic Categories

- The productions are:
  - $A \rightarrow M + A \mid M$
  - $M \rightarrow V * M \mid V$
  - $V \rightarrow a \mid b \mid c$
- Sample sub-derivations:
  - **Derivations from M**:
    - $M \Rightarrow V \Rightarrow a$
    - $M \Rightarrow V{*}M \Rightarrow a{*}M \Rightarrow a{*}V \Rightarrow a{*}b$
    - $M \Rightarrow V{*}M \Rightarrow a{*}M \Rightarrow a{*}V{*}M \Rightarrow a{*}b{*}M \Rightarrow a{*}b{*}V \Rightarrow a{*}b{*}a$
  - Observation: Derivations from M don’t include any +’s.

Exercise: Include ^ (power)

- ^ binds the most tightly
- * is next
- + is the weakest

How to handle ‘(’ ‘)’

- Parentheses means
  “handle inside as a single unit”

- Parallel level to a single **variable**
  - Sometimes called “primaries”

Two Main Language Problems

- Recognition problem:

  Is a given string in the language?

- Meaning problem:

  What is the meaning of a string if it *is* in the language?

Naïve Solution to the Recognition Problem

- To determine whether string x is in the language generated by a grammar:
  - Start with the start symbol.
  - Generate strings successively by applying productions.
  - Eventually either:
    - The string x is generated, or
    - The new strings being generated all exceed x in length.
  - So we can tell whether or not x is *ever* generated.

Parsing

- Parsing seeks to solve both problems:
  - Recognition
  - Meaning
- In addition, it tries to do recognition much more efficiently than the naïve solution.

Recursive Descent Parsing

- Simplest reasonably general form of parsing.
- Works for many, but not all grammars.
- Sometimes a grammar can be transformed to enable recursive descent.
- Recall that each each auxiliary symbol in the grammar can be identified with a **syntactic category**, the set of strings that can be generated from that symbol (possibly with the help of other symbols). The meaning will derive from this idea.

Recursive Descent

- It's called "recursive" because in general grammar productions can "call" themselves or each other.

- It's called "descent" because parsing starts at the **root** of a "derivation tree" and proceeds toward the leaves.

Parse Methods

- For each auxiliary symbol in the grammar, construct a **parse method**
- Each parse method's responsibility is to recognize the longest string in the corresponding syntactic category in the remainder of the input, from the current point onward:

$$\underbrace{a\ +}_{\text{passed}}\ \underbrace{b\ *\ c}_{\text{remaining}}$$

Example

- Consider the grammar with start symbol S:
  - $S \rightarrow V + S \mid V$
  - $V \rightarrow a \mid b \mid c$
- The parse begins by trying to identify the entire input string as being in syntactic category S.
- Clearly it must find a V to start.
  - To find a V, it checks to see whether the next symbol is one of those listed.
- Having found a V, it checks to see if the next symbol is +.
  - If so, it recurses, trying to find another S.
  - If not it stops.
- After the top call to S returns, it checks to see whether there are any spurious remaining characters in the input.
  - If there are, the input is not accepted.
  - If not, the input is accepted.

Example: Success

$S \to V + S \mid V$
$V \to a \mid b \mid c$

- Suppose the input string is "a + b + c".
- Subscripts will indicate the particular instance of the method and the "argument" will indicate the unparsed remainder of the input.
- The parser calls S_1("a + b + c").
- S_1 calls V_1("a + b + c").
- V_1 identifies a, returns success and unparsed input "+ b + c".
- S_1 checks for + and finds it; therefore S_1 calls S_2("b + c").
- S_2 calls V_2("b + c").
- V_2 identifies b, returns success and unparsed input "+ c".
- S_2 checks for + and finds it; therefore S_2 calls S_3("c").
- S_3 calls V_3("c").
- V_3 identifies c, returns success and unparsed input "".
- S_3 checks for + and does not find it; therefore S_3 returns success with "".
- S_2 returns success with "".
- S_1 returns success with "". **The string is accepted.**

Example: Failure

$S \to V + S \mid V$
$V \to a \mid b \mid c$

- Suppose the input string is "a b + c".
- The parser calls S_1("a b + c").
- S_1 calls V_1("a b + c").
- V_1 identifies a, returns success and unparsed input "b + c".
- S_1 checks for + and does not find it; therefore S_1 returns success, with "b + c".
- **Since the top-level call to S_1 has returned, but there is residual input, the string is not accepted.**

A rex version of parsing

- Each syntactic category will be a rex function.
- There is one argument:
  - the unparsed input, a **list** of characters.
- There are two results:
  - success or failure indicator
    - for success: the Syntax Tree
    - for failure: FAILURE (some special value, not a syntax tree)
  - the unparsed input.

A rex version of parsing (1)

```
// parse function for auxiliary A, rules A -> V | V + A

A(input) =
    Vresult = V(input),                                    // try for V
    [tree1, residue1] = Vresult,
    residue1 == [] ? Vresult                               // use A -> V

  : failed(tree1) ? Vresult                                // failure

  : first(residue1) == '+' ?

      ( [tree2, residue2] = A(rest(residue1)),             // try A -> V + A
        failed(tree2) ?
          Vresult                                          // use A -> V only
        : [mkTree('+', tree1, tree2), residue2]            // use A -> V + A
      )

  : Vresult;                                               // use A -> V
```

Test cases

```
test(A(explode("a")), ['a', []]);

test(A(explode("a+b")), [['+', 'a', 'b'], []]);

test(A(explode("a+b+c")), [['+', 'a', ['+', 'b', 'c']], []]);

test(A(explode("a+b+c+a")), [['+', 'a', ['+', 'b', ['+', 'c', 'a']]], []]);

test(A(explode("")), [FAILURE, []]);

test(A(explode("+")), [FAILURE, ['+']]);

test(A(explode("ab")), ['a', ['b']]);

test(A(explode("a+b+")), [['+', 'a', 'b'], ['+']]);

test(A(explode("a+b+c+")), [['+', 'a', ['+', 'b', 'c']], ['+']]);

test(A(explode("ab+c")), ['a', ['b', '+', 'c']]);

test(A(explode("a+b+")), [['+', 'a', 'b'], ['+']]);
```

A rex version of parsing (2)

```
// parse function for auxiliary V, rules V -> a | b | c

V([]) => [FAILURE, []];                                    // no input

V([c | chars]) => isVar(c) ? [mkTree(c), chars];           // variable

V([c | chars]) => [FAILURE, [c | chars]];                  // not a variable


// auxiliary functions

FAILURE = "failure";
VARS = ['a', 'b', 'c'];

isVar(char) = member(char, VARS);

failed(result) = result == FAILURE;

mkTree(Var) = Var;
mkTree(Op, Tree1, Tree2) = [Op, Tree1, Tree2];

parse(string) = A(explode(string));
```

Operators + and * with * having higher precedence

- Rules:
  - $A \rightarrow M + A \ | \ M$
  - $M \rightarrow V * M \ | \ V$
  - $V \rightarrow a \ | \ b \ | \ c$
- Note that * is *analogous* to +.
  - A is to M and + as
    M is to V and *
- Therefore the *same* rule **pattern** applies to both.

rex parsing for +, * (A)

```
A(input) =
    Mresult = M(input),                                      // try for M
    [tree1, residue1] = Mresult,
    residue1 == [] ? Mresult                                 // use A -> M

  : failed(tree1) ? Mresult                                  // failure

  : first(residue1) == '+' ?

      ( [tree2, residue2] = A(rest(residue1)),               // try A -> M + A
        failed(tree2) ?
          Mresult                                            // use A -> M only
        : [mkTree('+', tree1, tree2), residue2]              // use A -> M + A
      )

  : Mresult;                                                 // use A -> M
```

rex parsing for +, * (M)

```
M(input) =
    Vresult = V(input),                                    // try for V
    [tree1, residue1] = Vresult,
    residue1 == [] ? Vresult                               // use M -> V

  : failed(tree1) ? Vresult                                // failure

  : first(residue1) == '*' ?

      ( [tree2, residue2] = M(rest(residue1)),             // try M -> V * M
        failed(tree2) ?
          Vresult                                          // use M -> V only
        : [mkTree('*', tree1, tree2), residue2]            // use M -> V + M
      )

  : Vresult;                                               // use M -> V
```

Parsing Methods in Java

- In the Java version, we will “not need to” return the unparsed input as a value.
- We can side-effect the input stream to achieve a similar result, “using up” characters as we go.
- We can store the input stream in the parse object, rather than pass it as an argument.

Parsing Methods in Java

```
/**
 * ParseFromString is the base class for parsing from a String,
 * such as a single input line.
 */

class ParseFromString
{
ParseFromString(String input) // constructor

char nextChar()

boolean nextCharIs(char c)

char peek()

boolean skipWhitespace()
}
```

various utility methods

Additive Grammar

$$A \rightarrow V \mid V + A$$

$$V \rightarrow a|b|c|d|e|f|g|h|i|j|k|l|m \\ |n|o|p|q|r|s|t|u|v|w|x|y|z$$

Corresponding to the grammar above, there will be two parse methods:

```
A()
V()
```

Each parses from the current point in the input.

Runnable Examples

```
parse/addRecursive/Additive.java

parse/add/Additive.java

parse/addMult/AddMult.java

parse/simpleCalc/SimpleCalc.java
```

V() method

```
/**
 * PARSE METHOD for V → a|b|c|d|e|f|g|h|i|j|k|l|m|n|o|p
 *                      |q|r|s|t|u|v|w|x|y|z
 */

Object V()
  {
  skipWhitespace();

  if( isVar(peek()) )
    {
    return makeString(nextChar());
    }
  return failure;
  }
```

makeString(char c)

```
/**
 * make a String from a char
 */

static String makeString(char c)
  {
  return (new StringBuffer(1).append(c)).toString();
  }
```

isVar()

```
/**
 * predicate defining whether its argument is a variable
 */

boolean isVar(char c)
  {
  switch( c )
    {
    case 'a': case 'b': case 'c': case 'd': case 'e': case 'f': case 'g':
    case 'h': case 'i': case 'j': case 'k': case 'l': case 'm': case 'n':
    case 'o': case 'p': case 'q': case 'r': case 's': case 't': case 'u':
    case 'v': case 'w': case 'x': case 'y': case 'z':
      return true;

    default:
      return false;
    }
  }
```

Do *not* use **arithmetic** on integer codes for this purpose.

Recursive A() method

```
/**
 * PARSE METHOD for A -> V { '+' V }
 */

Object A()
  {
  Object result;
  Object V1 = V();
  if( isFailure(V1) ) return failure;

  if( skipWhitespace() && nextCharIs('+') )
    {
    Object A2 = A();
    if( isFailure(A2) ) return failure;
    return OpenList.list("+", V1, A2);
    }
  else
    {
    return V1;
    }
  }
```

Replacing some Recursion with Iteration

"Inverse McCarthy Transformation" for Grammars with **left**-grouping

{ } is a meta-symbol meaning **"0 or more of what's inside"**

- Recursion → Iteration
- Works in some cases, not all
- Use for convenience and readability

Recursive Form	**Iterative Form**
$A \rightarrow V \mid A + V$	$A \rightarrow V$ **{** $+ V$ **}**
$V \rightarrow a \mid b \mid c$	$V \rightarrow a \mid b \mid c$

both forms are "left grouping" in this example

A() method, iterative version

```
/** PARSE METHOD for A -> V { '+' V } **/

Object A()
  {
  Object result;
  Object V1 = V();
  if( isFailure(V1) ) return failure;

  result = V1;

  while( skipWhitespace() && nextCharIs('+') )
    {
    Object V2 = V();
    if( isFailure(V2) ) return failure;
    result = OpenList.list("+", result, V2);
    }
  return result;
  }
```

The Additive/Multiplicative Grammar

Additive

```
A -> V { '+' V }

V -> a|b|c|d|e|f|g|h|i|j|k|l|m
      |n|o|p|q|r|s|t|u|v|w|x|y|z
```

Additive and Multiplicative

```
A -> P  { ‘+’ P }
P -> V  { ‘*’ V }
V -> a|b|c|d|e|f|g|h|i|j|k|l|m
      |n|o|p|q|r|s|t|u|v|w|x|y|z
```

Construct methods by analogy.

Remembering Precedence Rules

- Tighter-binding operators are introduce **further** away from the root of the grammar:

root

$$A \rightarrow P \ \{ \text{'+'} \ P \}$$

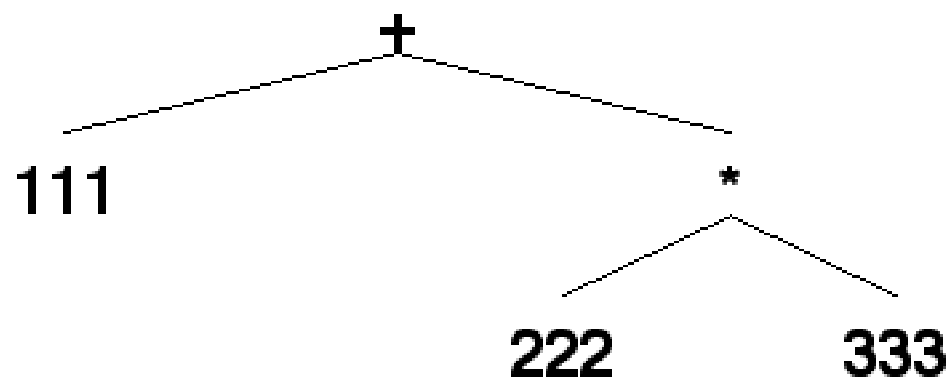
$$P \rightarrow V \ \{ \text{'*'} \ V \}$$

* binds more tightly than +

Syntax Tree Applet

Input numeric expression for syntax analysis:

111 + 222 * 333



http://www.cs.hmc.edu/courses/current/examples/java/parse/syntaxTree/SyntaxTree.html

Example: SimpleCalc

- Parses numeric expressions with +, *, ()
- Computes the *numeric* answer
- Same grammar as SyntaxTree applet

```
/**
 * SimpleCalc Parse method for A -> P { '+' P }
 **/

Object A()
  {
  Object result = P();                               // get first addend
  if( isFailure(result) ) return failure;

  while( skipWhitespace() && nextCharIs('+') )
    {
    Object P2 = P();                                 // get next addend
    if( isFailure(P2) ) return failure;
    try
      {
      result = Arith.add(result, P2);           // accumulate result
      }
    catch( IllegalArgumentException e )
      {
      System.err.println("error: IllegalArgumentException caught");
      }
    }
  return result;
  }
```

Grammar for Unicalc

- Example
  - 3.5 meters^2 / (watt hour)
- Operators
  - ^
  - /
  - juxtaposition (implied multiplication)
- Units (meter, second, etc.)
- Numbers (floating point allowed: 1.23e-45)
- Parentheses

Result of Parsing Unicalc

- A Unicalc quantity:
  Object with 3 components:
  - numeric multiplier
  - numerator
  - denominator
- The parser may perform some “algebra”:
  - ^ gets converted to multiplication
  - / and juxtaposition use Unicalc divide and multiply