Section 4: CUP & LL

CSE 401/M501

Adapted from Autumn 2022

Administrivia

- Homework 2 is due tonight!
  - You have late days if you need them (2 max)
- Parser is due one week from today (also 2 late days)
  - Be sure to check your scanner feedback – out later this week
- HW3 will be out soon, due in 1.5 weeks on ***Monday, May 5th***
  - **Only one late day allowed** on this assignment so we can distribute solutions before the midterm at the end of that week.
  - More on hw3 in sections next week, but start before then if you can

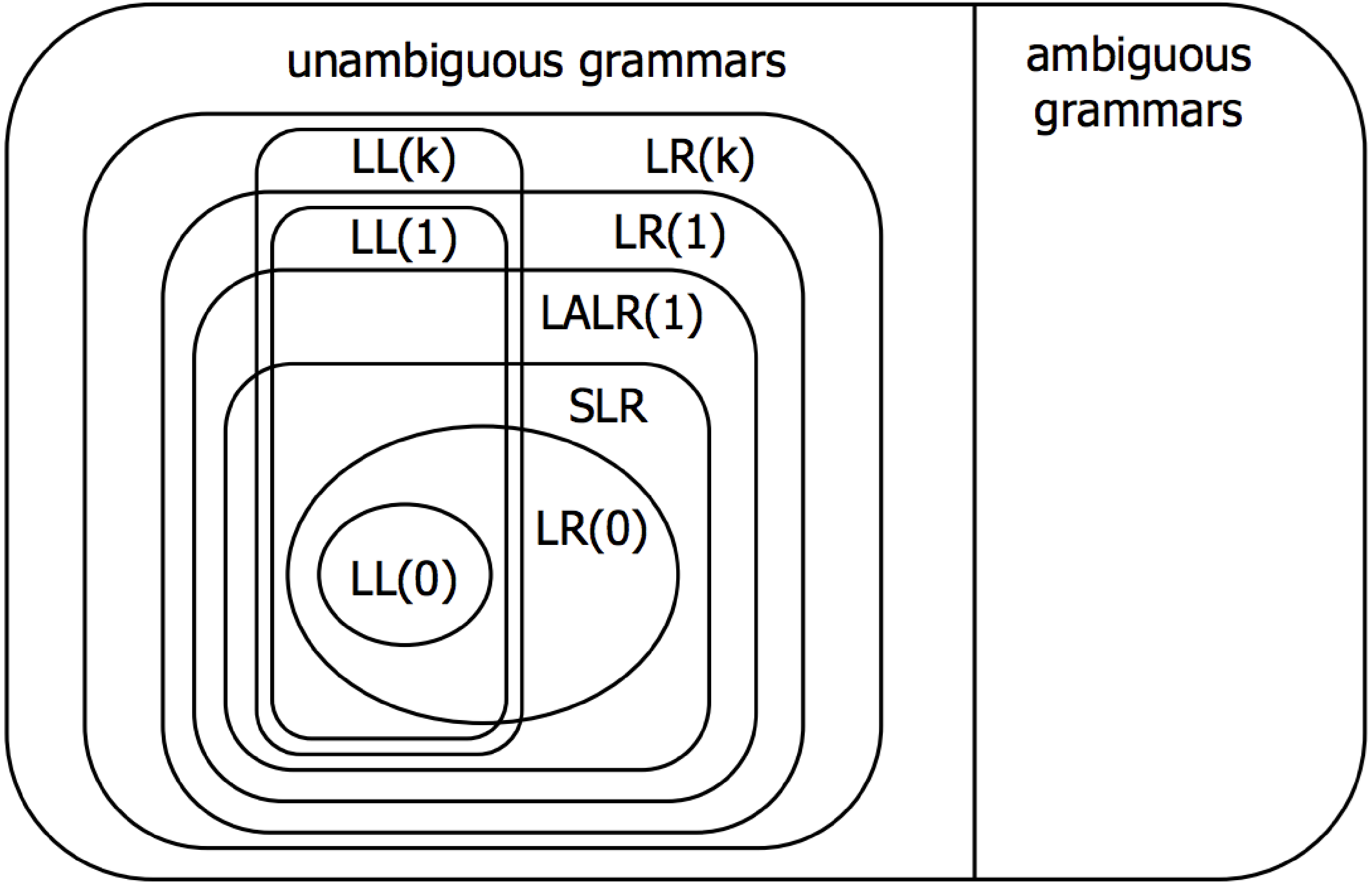
April:

WE ARE HERE

21	22	23	24	25
11:30-12:30 OH (Karen) CSE2 150	13:30-14:30 OH (Sriya) CSE2 152	11:30-12:30 OH (Karen) CSE2 150	Section *CUP parser generator, ASTs; LL parsing*	13:30-14:30 OH (Sriya) CSE2 152
13:00-14:00 OH (Bill) CSE 3rd floor breakout	14:30-15:30 OH (Eric) CSE2 152	13:00-14:00 OH (Bill) CSE 3rd floor breakout	15:30-16:30 OH (Eric) CSE2 152	14:30-15:20 Lecture CSE2 G10 *Intro to Checking (Semantics and Types) (4.1-4.2)*
14:30-15:20 Lecture CSE2 G10 *ASTs & visitors*		14:30-15:20 Lecture CSE2 G10 *LL Parsing & recursive descent (3.3)*	23:59 hw2 due (LR grammars)	

Parser Live Demo

Language Hierarchies



The CUP parser generator

- Uses LALR(1)
  - A little weaker (less selective), but many fewer states than LR(1) parsers
  - Handles most realistic programming language grammars
  - More selective than SLR (or LR(0)) about when to do reductions, so works for more languages

The CUP parser generator

- LALR(1) parser generator based on YACC and Bison
- CUP can resolve some ambiguities itself
  - Precedence for reduce/reduce conflicts
  - Associativity for shift/reduce conflicts
  - Useful for our project for things like arithmetic expressions (use exp+exp, exp*exp, etc. for fewer non-terminals, then add precedence and associativity declarations). ***Read the CUP docs!***

MiniJava Grammar -> AST Node

Use this to check your work *only after* your team has examined the grammar and AST code first.

```
Program       Goal ::= MainClass ( ClassDeclaration )* <EOF>
MainClass     MainClass ::= "class" Identifier "{" "public" "static" "void" "main" "(" "String" "[" "]" Identifier ")" "{" Statement "}" "}"
ClassDecl     ClassDeclaration ::= "class" Identifier ( "extends" Identifier )? "{" ( VarDeclaration )* ( MethodDeclaration )* "}"
VarDecl       VarDeclaration ::= Type Identifier ";"
MethodDecl    MethodDeclaration ::= "public" Type Identifier "(" ( Type Identifier ( "," Type Identifier )* )? ")" "{" ( VarDeclaration )* ( Statement )* "return" Expression ";" "}"
Type          Type ::= "int" "[" "]"
                     | "boolean"
                     | "int"
                     | Identifier
Statement     Statement ::= "{" ( Statement )* "}"
                     | "if" "(" Expression ")" Statement "else" Statement
                     | "while" "(" Expression ")" Statement
                     | "System.out.println" "(" Expression ")" ";"
                     | Identifier "=" Expression ";"
                     | Identifier "[" Expression "]" "=" Expression ";"
Exp           Expression ::= Expression ( "&&" | "<" | "+" | "-" | "*" ) Expression
                     | Expression "[" Expression "]"
                     | Expression "." "length"
                     | Expression "." Identifier "(" ( Expression ( "," Expression )* )? ")"
                     | <INTEGER_LITERAL>
                     | "true"
                     | "false"
                     | Identifier
                     | "this"
                     | "new" "int" "[" Expression "]"
                     | "new" Identifier "(" ")"
                     | "!" Expression
                     | "(" Expression ")"
Identifier    Identifier ::= <IDENTIFIER>
```

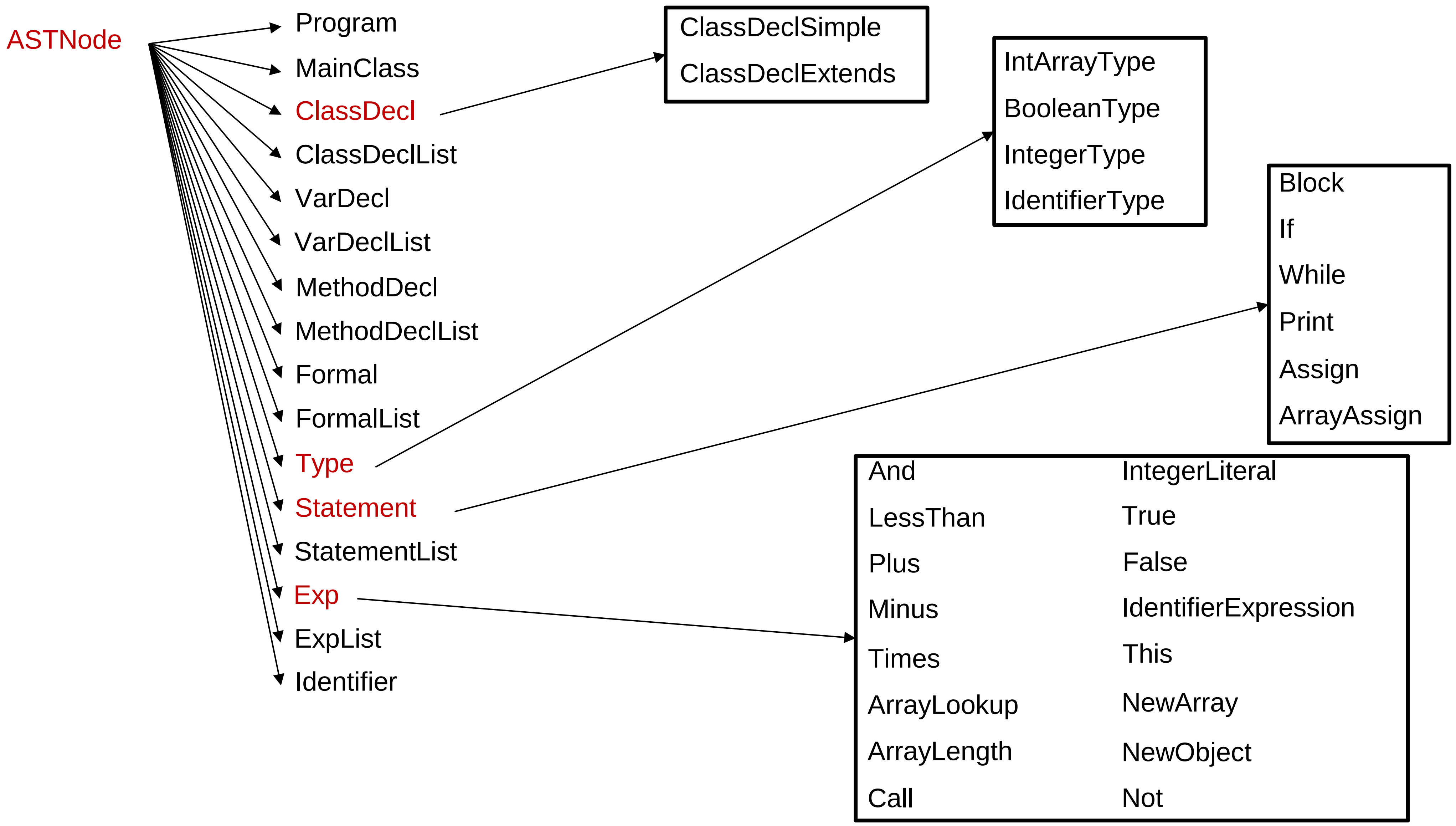
ClassDeclSimple

ClassDeclExtends (if there is “extends”)

Formal

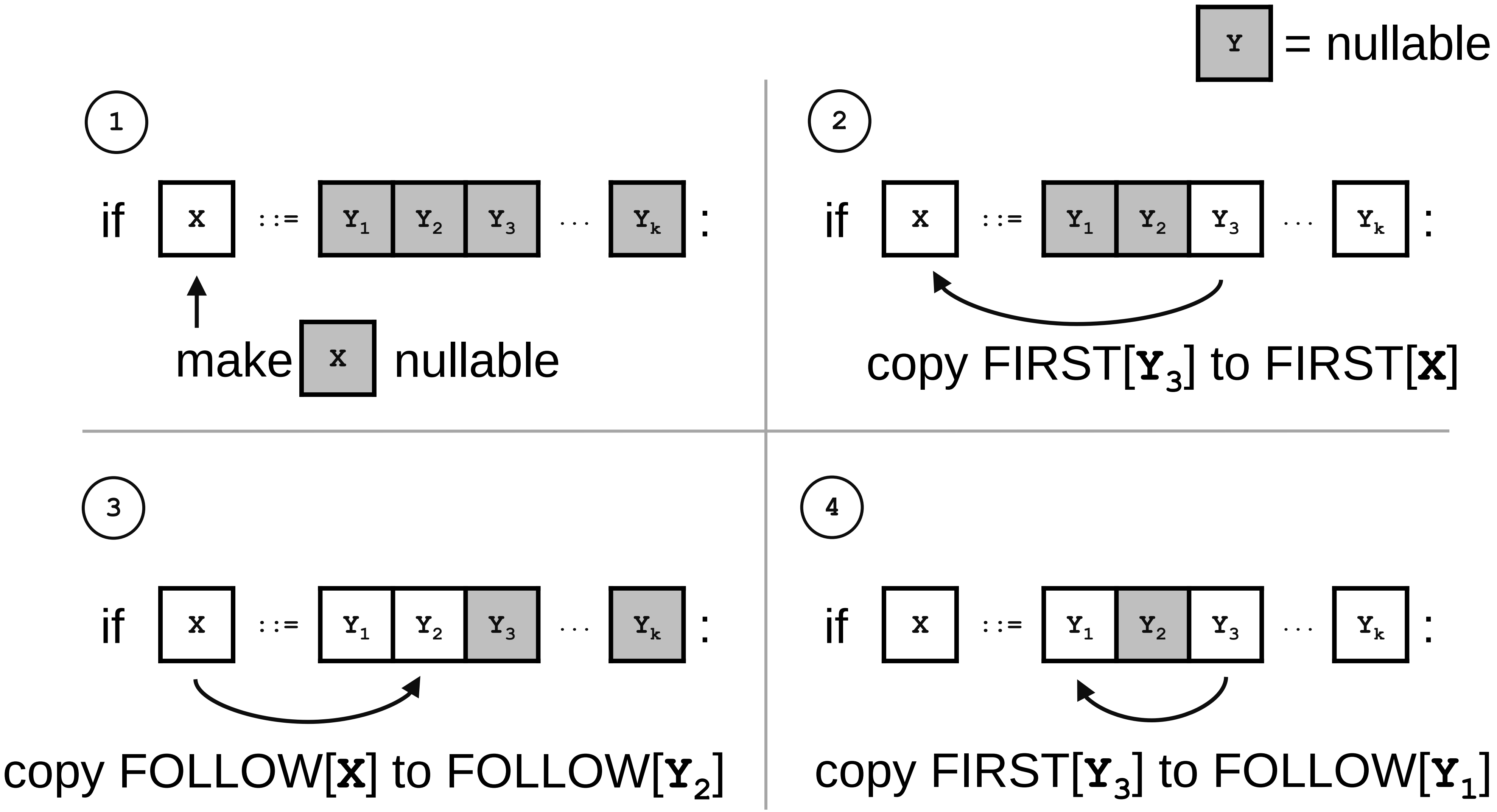
Block

Abstract Syntax Tree Class Hierarchy



LL Parsing

Computing FIRST, FOLLOW, & nullable (3)



Computing FIRST, FOLLOW, and nullable

```
repeat
    for each production X := Y_1 Y_2 … Y_k
        if Y_1 … Y_k are all nullable (or if k = 0)
          set nullable[X] = true
        for each i  from 1 to k and each j  from i +1 to k
          if Y_1 … Y_{i-1} are all nullable (or if i = 1)
                add FIRST[Y_i ] to FIRST[X]
          if Y_{i+1} … Y_k are all nullable (or if i = k )
                add FOLLOW[X] to FOLLOW[Y_i]
          if Y_{i+1} … Y_{j-1} are all nullable (or if i+1=j)
                add FIRST[Y_j] to FOLLOW[Y_i]
Until FIRST, FOLLOW, and nullable do not change
```

L L (k)

Left-to-Right

Only takes one pass, performed from the left

Leftmost

At each point, finds the derivation for the leftmost handle **(top-down)**

k Terminal Lookahead

Must determine derivation from the next unparsed terminal in the string

Typically k = 1, just like LR

LL(k) parsing

- LL(*k*) scans left-to-right, builds leftmost derivation, and looks ahead *k* symbols

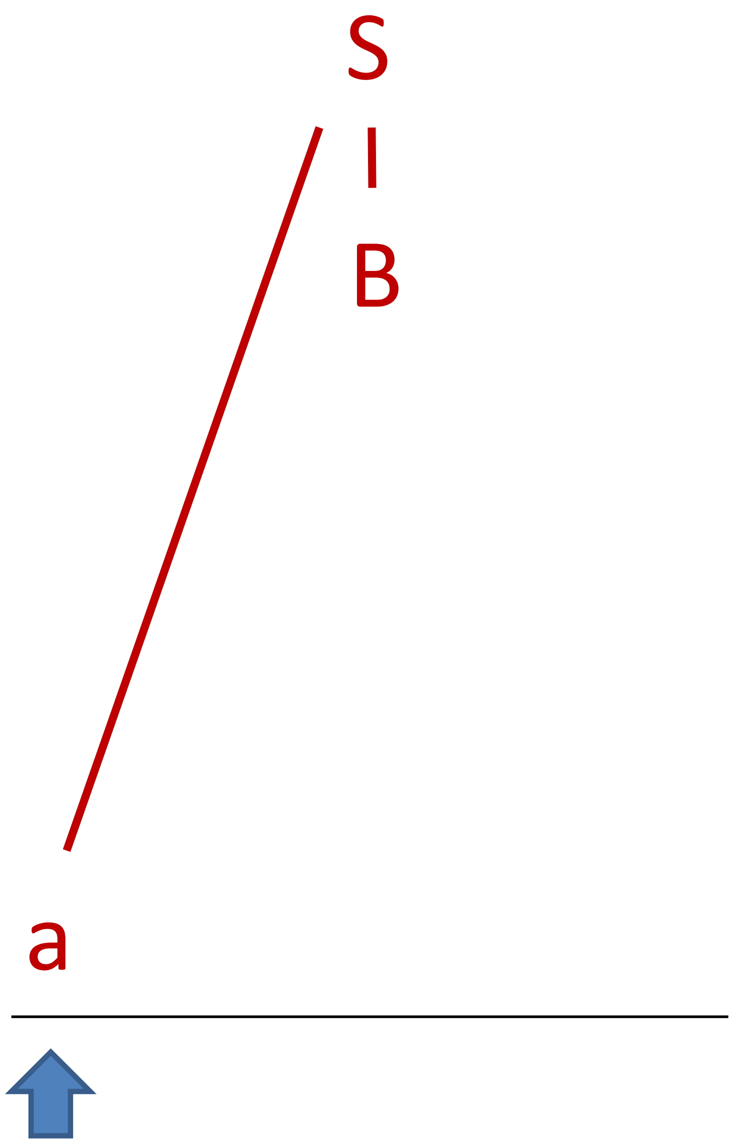
- The LL condition enables the parser to choose productions correctly with 1 symbol of look-ahead
- We can often transform a grammar to satisfy this if needed

LL(1) parsing: An example top-down derivation of “a z x”

```
0. S ::= a B
1. B ::= C x | y
2. C ::= ε | z
```

Lookahead	Remaining
a	z x

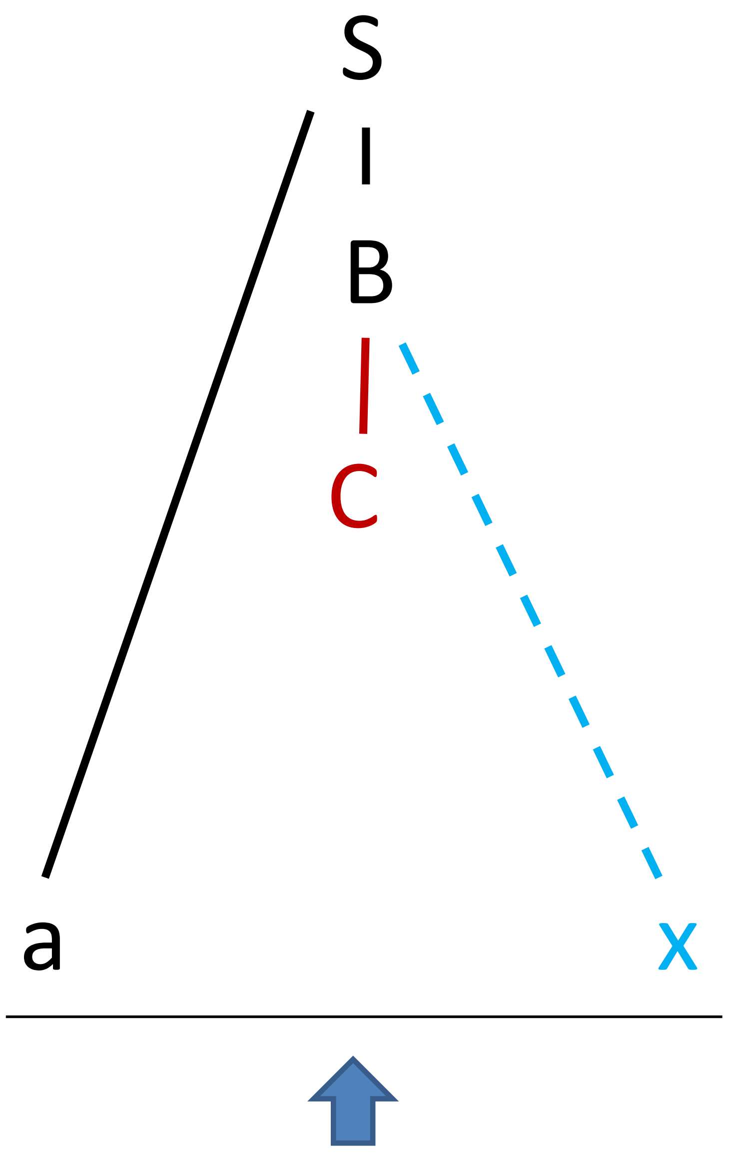
Top-Down Derivation of “a z x”




```
0. S ::= a B
1. B ::= C x | y
2. C ::= ε | z
```

Lookahead	Remaining
a	z x

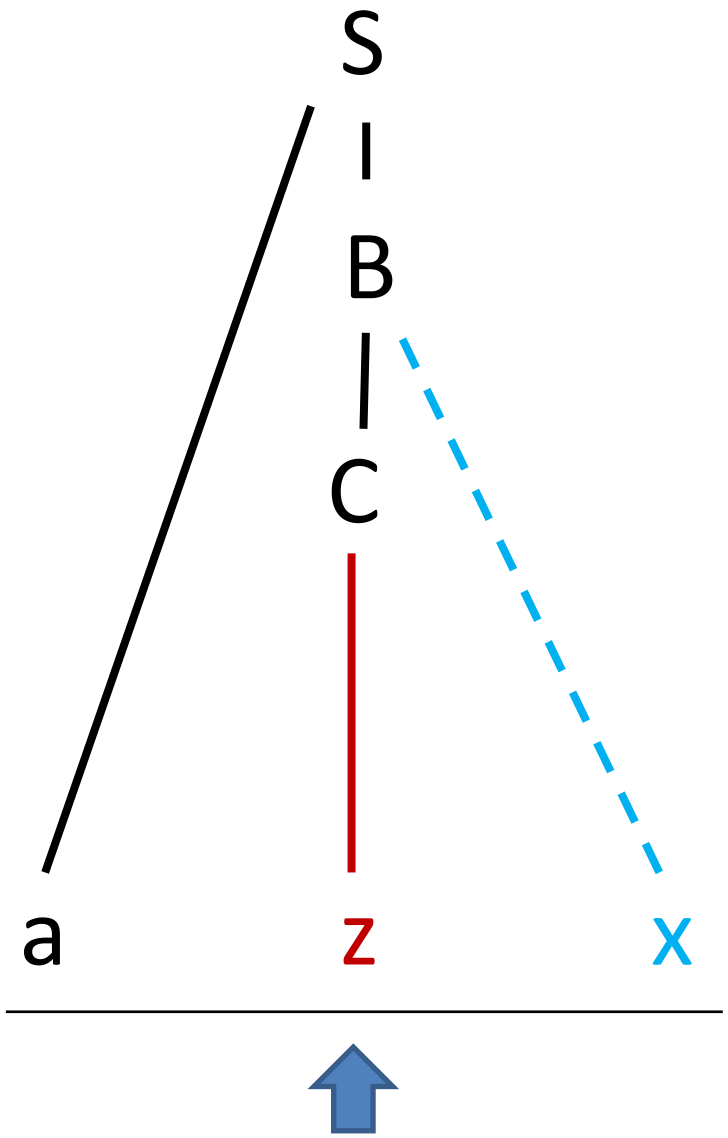
Top-Down Derivation of “a z x”




```
0. S ::= a B
1. B ::= C x | y
2. C ::= ε | z
```

Lookahead	Remaining
z	x

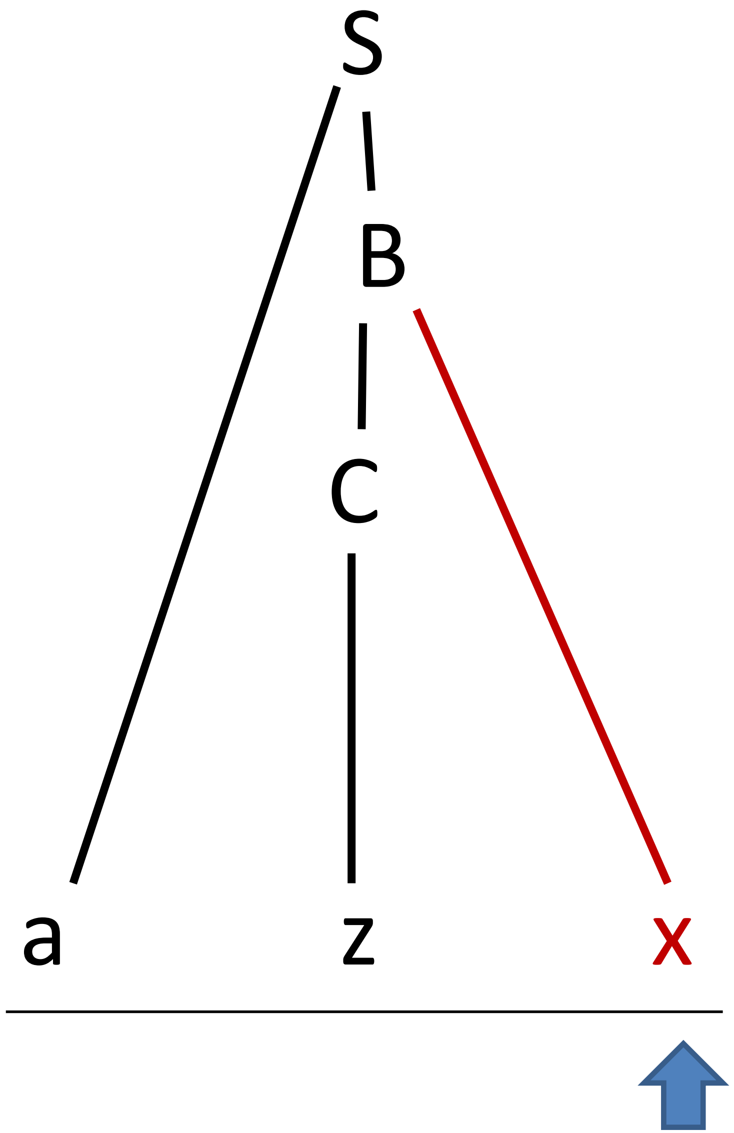
Top-Down Derivation of “a z x”




```
0. S ::= a B
1. B ::= C x | y
2. C ::= ε | z
```

Lookahead	Remaining
z	x

Top-Down Derivation of “a z x”

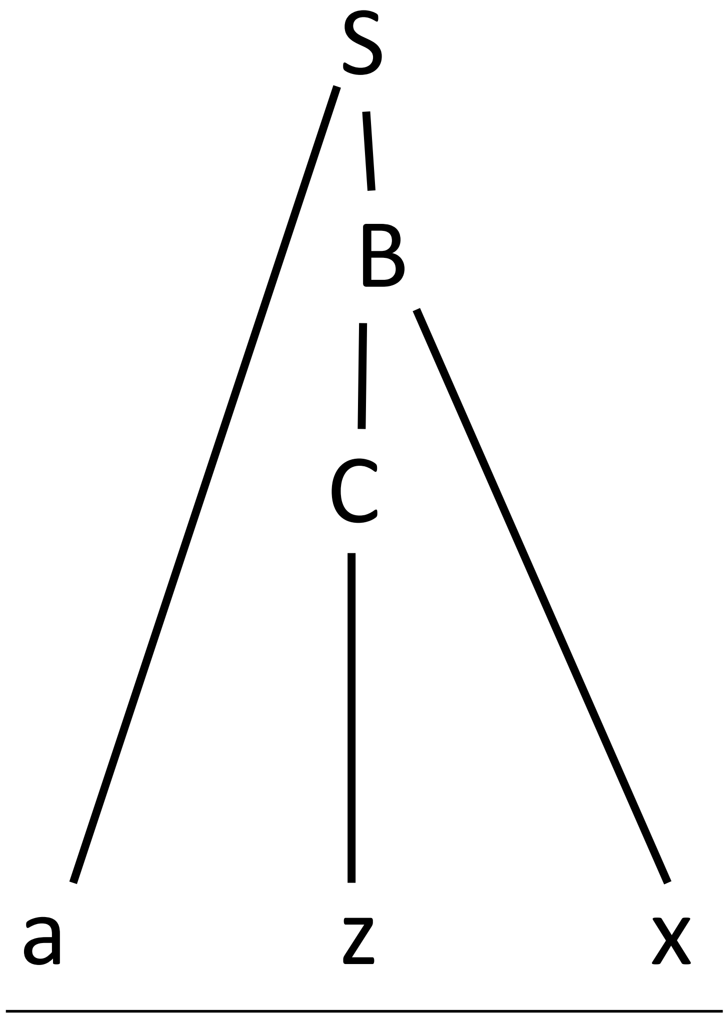



```
0. S ::= a B
1. B ::= C x | y
2. C ::= ε | z
```

Lookahead | Remaining

x

Top-Down Derivation of “a z x”




```
0. S ::= a B
1. B ::= C x | y
2. C ::= ε | z
```

Successful parse!

LL Condition

For each nonterminal in the grammar:

– Its *productions* must have disjoint FIRST sets

✗
```
A ::= x | B
B ::= x
```

✓
```
A ::= x | B
B ::= y
```

– If it is *nullable*, the FIRST sets of its productions must be disjoint from its FOLLOW set

✗
```
S ::= A x
A ::= ε | x
```

✓
```
S ::= A y
A ::= ε | x
```

**We can often transform a grammar to satisfy this if needed

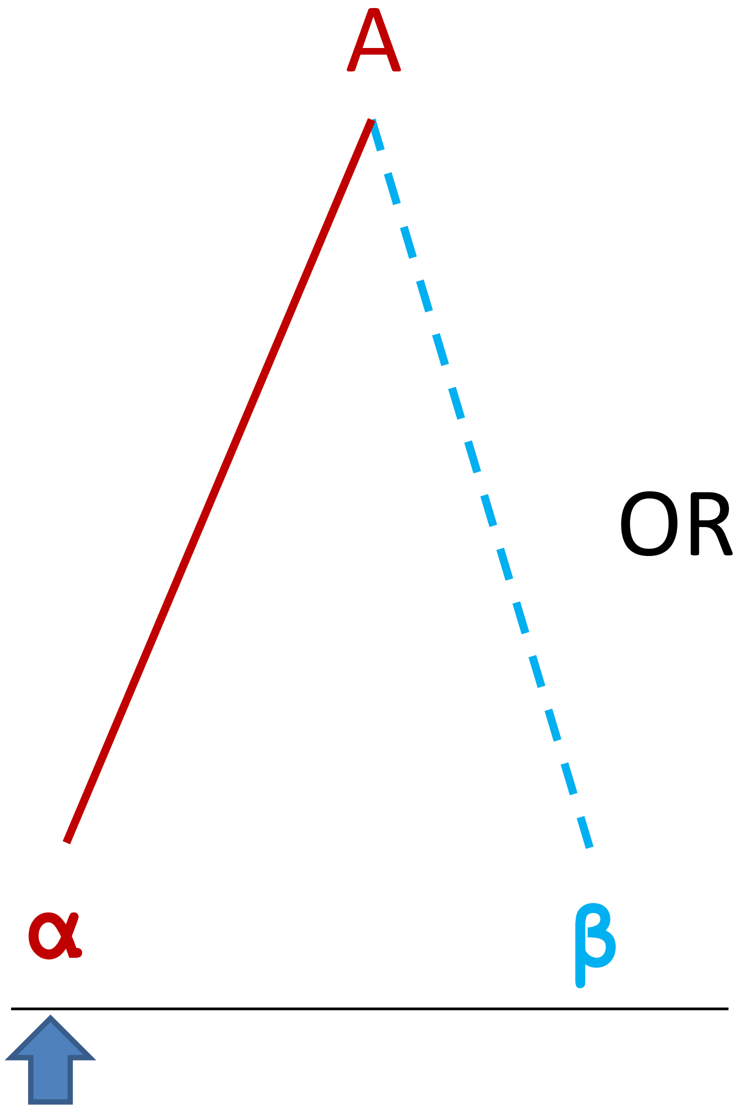
Canonical FIRST Conflict

Problem

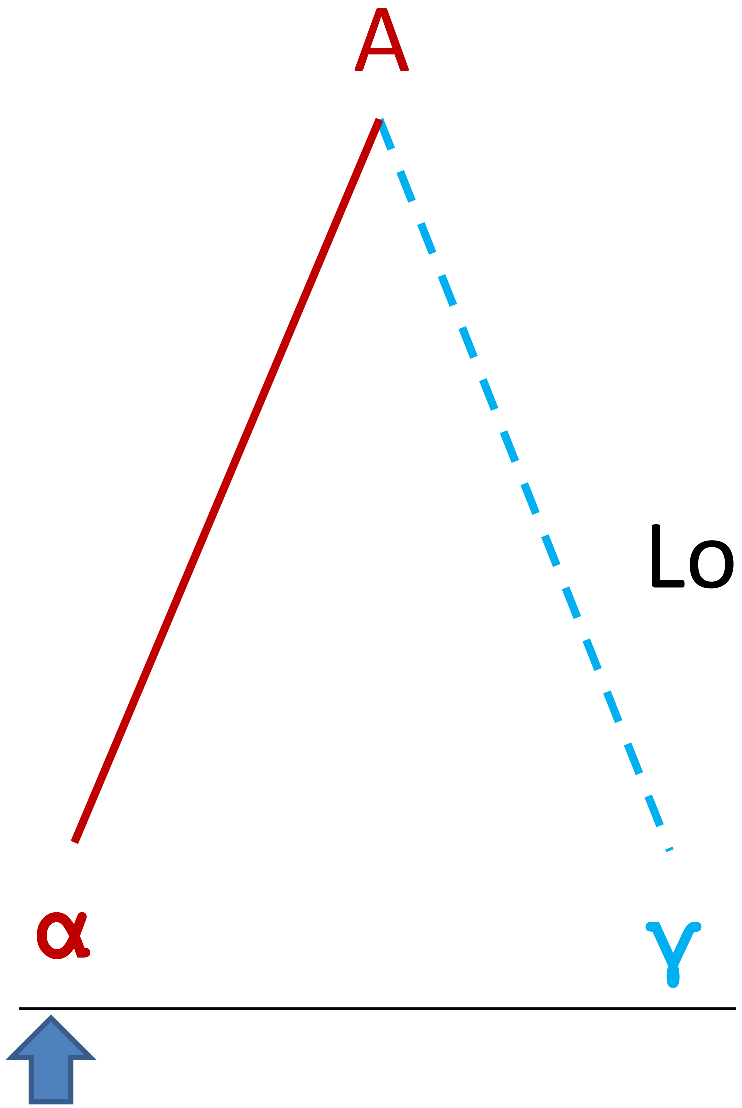
0. A ::= $\alpha\beta$ **|** $\alpha\gamma$

The FIRST sets of the right-hand sides for the SAME NON-TERMINAL must be disjoint!

Let's try a top-down derivation of αβ



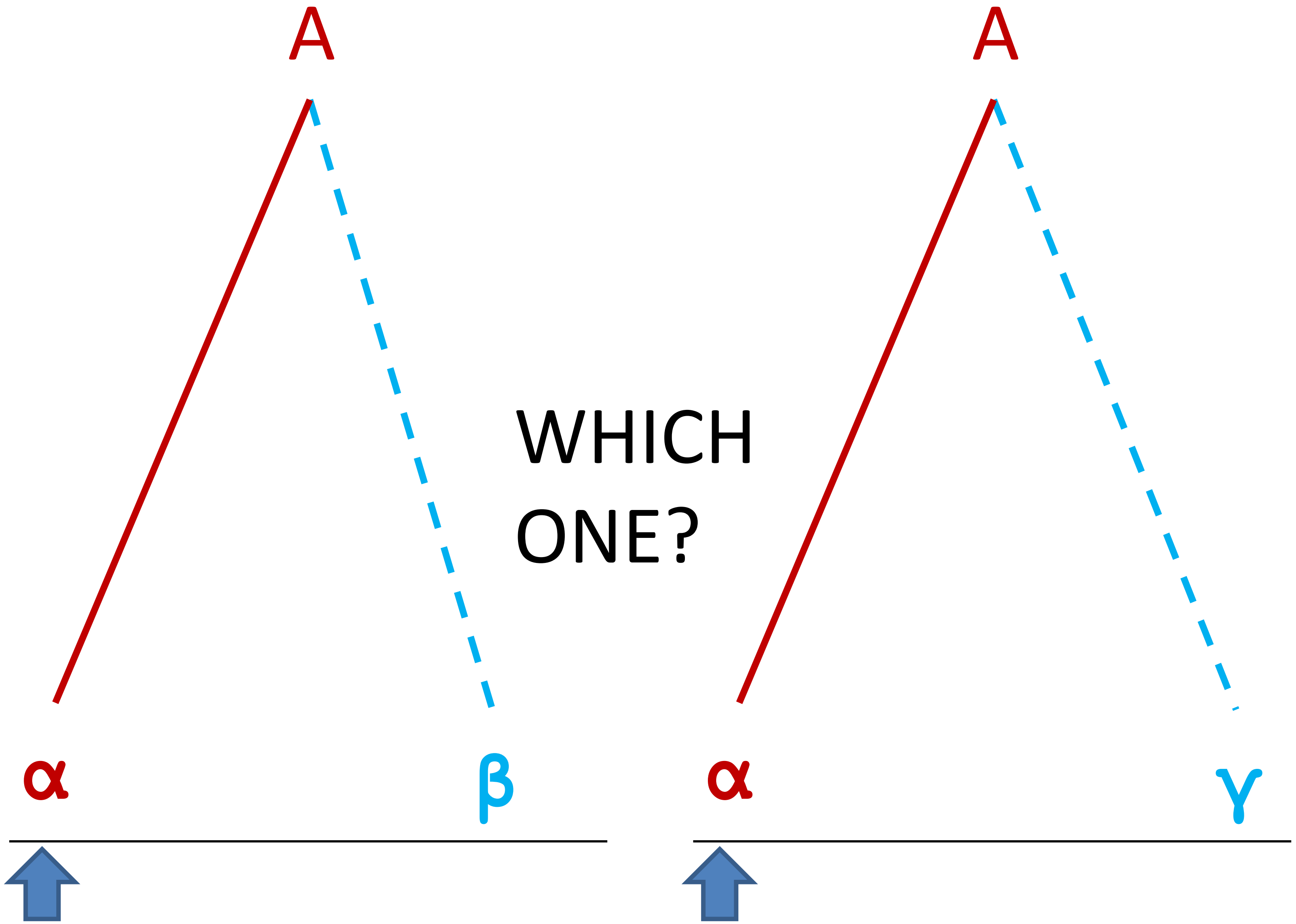
OR




```
0. A ::= αβ | αγ
```

Lookahead	Remaining
α	β

Let's try a top-down derivation of αβ




```
0. A ::= αβ | αγ
```

We don't know!

We are using an LL(1) parser, we can't see more than **α**!

Canonical FIRST Conflict Solution

Solution

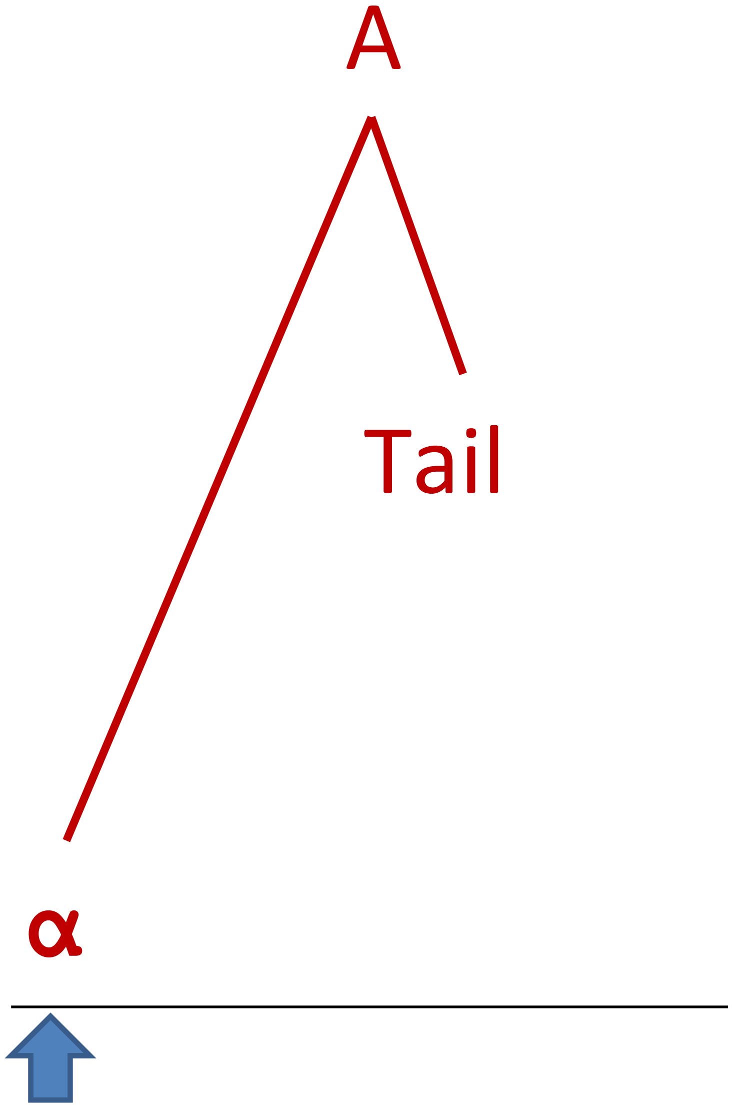
```
0. A ::= αβ | αγ

0. A ::= α Tail
1. Tail ::= β | γ
```

Factor out the common prefix

When multiple productions of a nonterminal share a common prefix, turn the different suffixes into a new nonterminal.

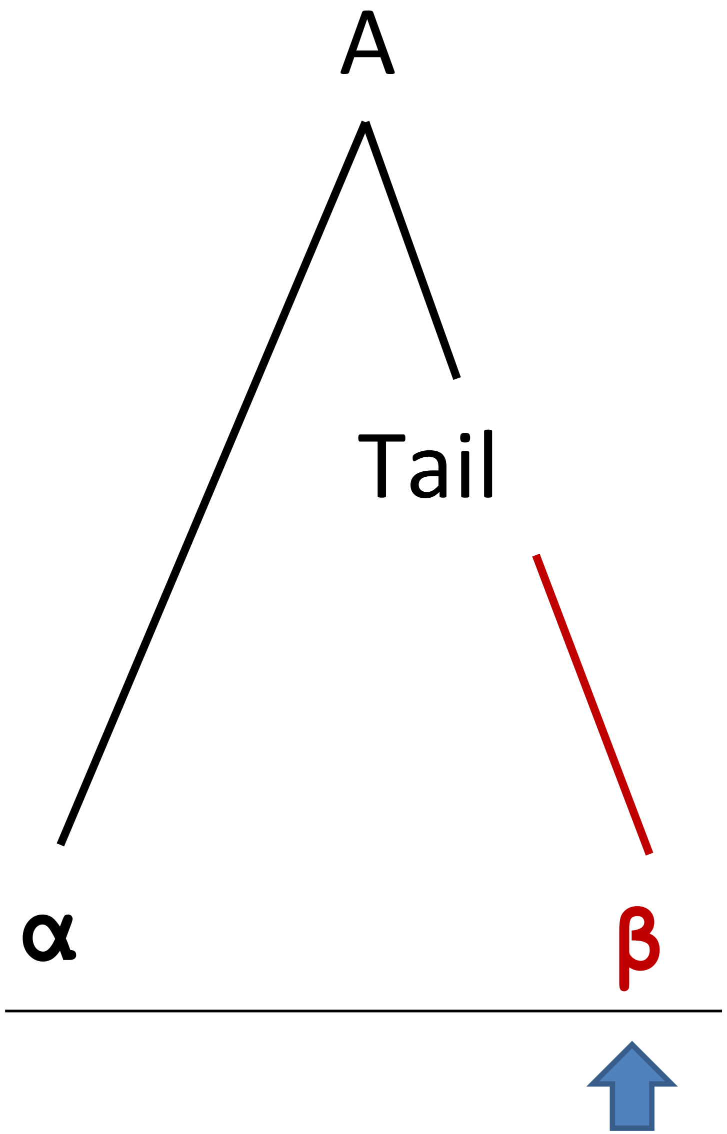
Top-Down Derivation of “αβ”




```
0. A ::= α Tail
1. Tail ::= β | γ
```

Lookahead	Remaining
α	β

Top-Down Derivation of “αβ”

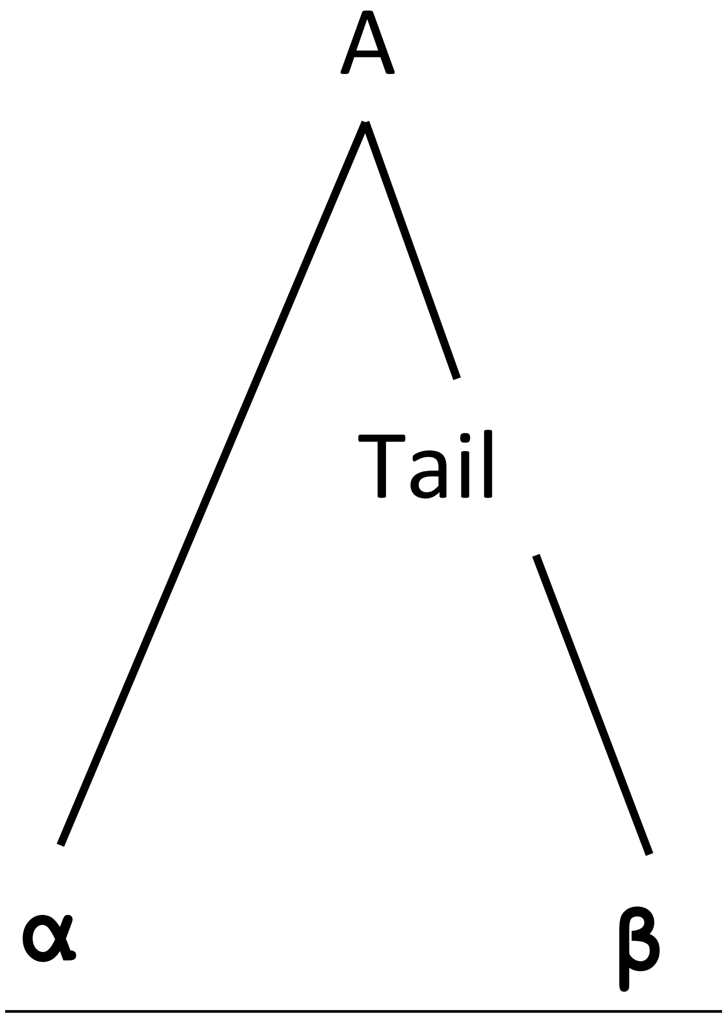



```
0. A ::= α Tail
1. Tail ::= β | γ
```

Lookahead Remaining

β

Top-Down Derivation of "αβ"




```
0. A ::= α Tail
1. Tail ::= β | γ
```

Successful parse!

Changing original grammar a little (Grammar 1)

```
0. S ::= a B | a w
1. B ::= C x | y
2. C ::= ε | z
```

Lookahead	Remaining
a	z x

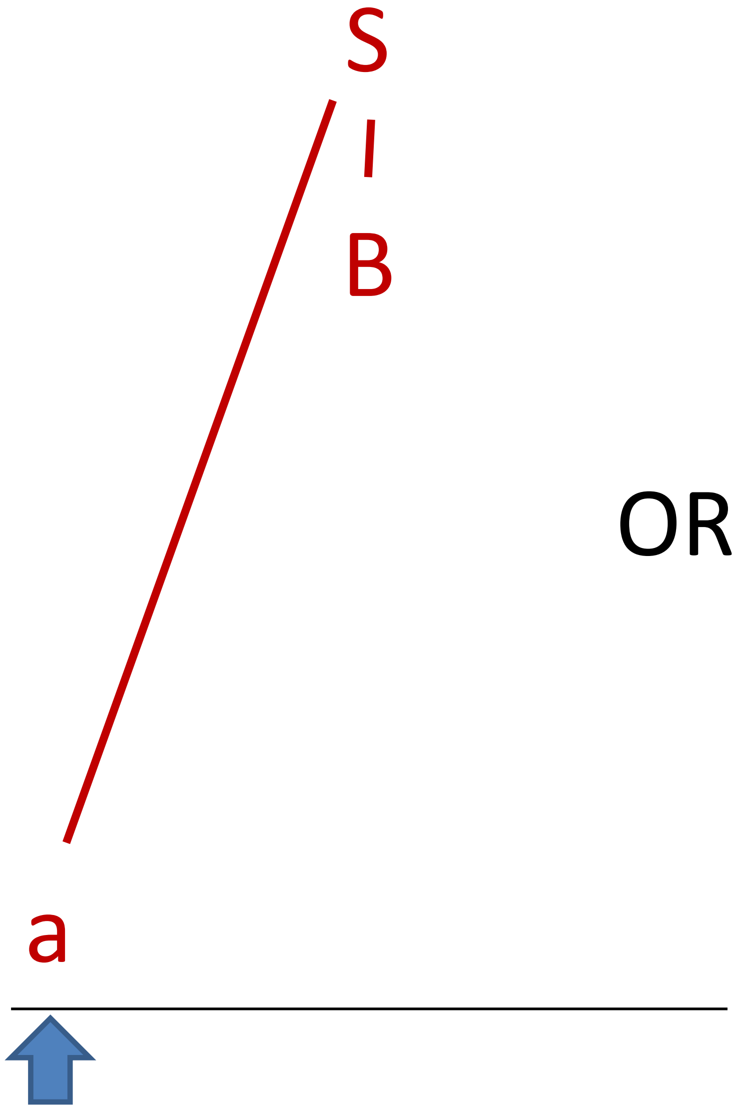
What's the issue?

```
0. S ::= a B | a w
1. B ::= C x | y
2. C ::= ε | z
```

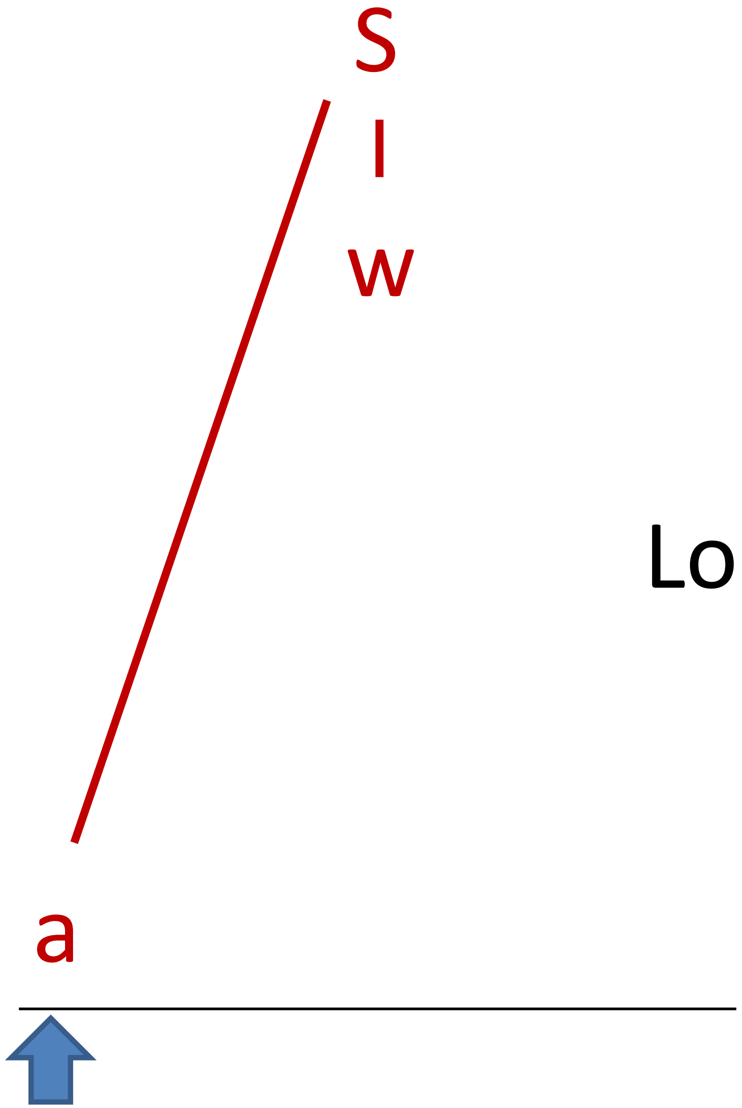
There's a FIRST Conflict!

Top-Down Derivation of “a z x”: LL(1) can’t parse

```
0. S ::= a B | a w
1. B ::= C x | y
2. C ::= ε | z
```

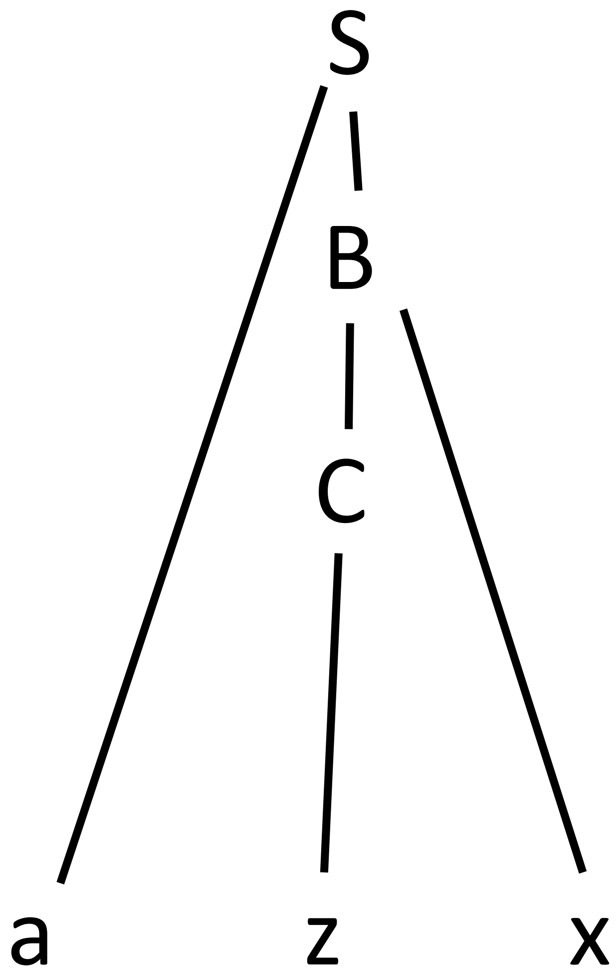


OR



Lookahead	Remaining
a	z x

Parse Tree without changing Grammar

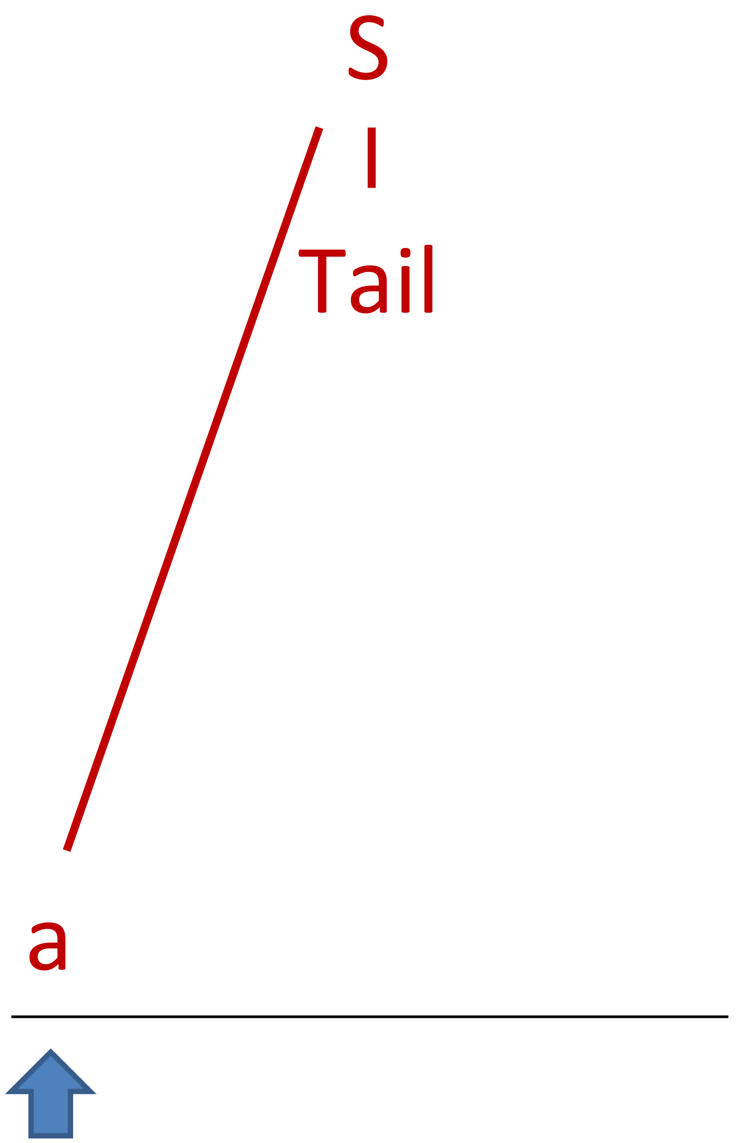



```
0. S ::= a B | a w
1. B ::= C x | y
2. C ::= ε | z
```

Applying the Fix: Factor out the Common Prefix

```
0. S ::= a Tail
1. Tail ::= B | w
2. B ::= C x | y
3. C ::= ε | z
```

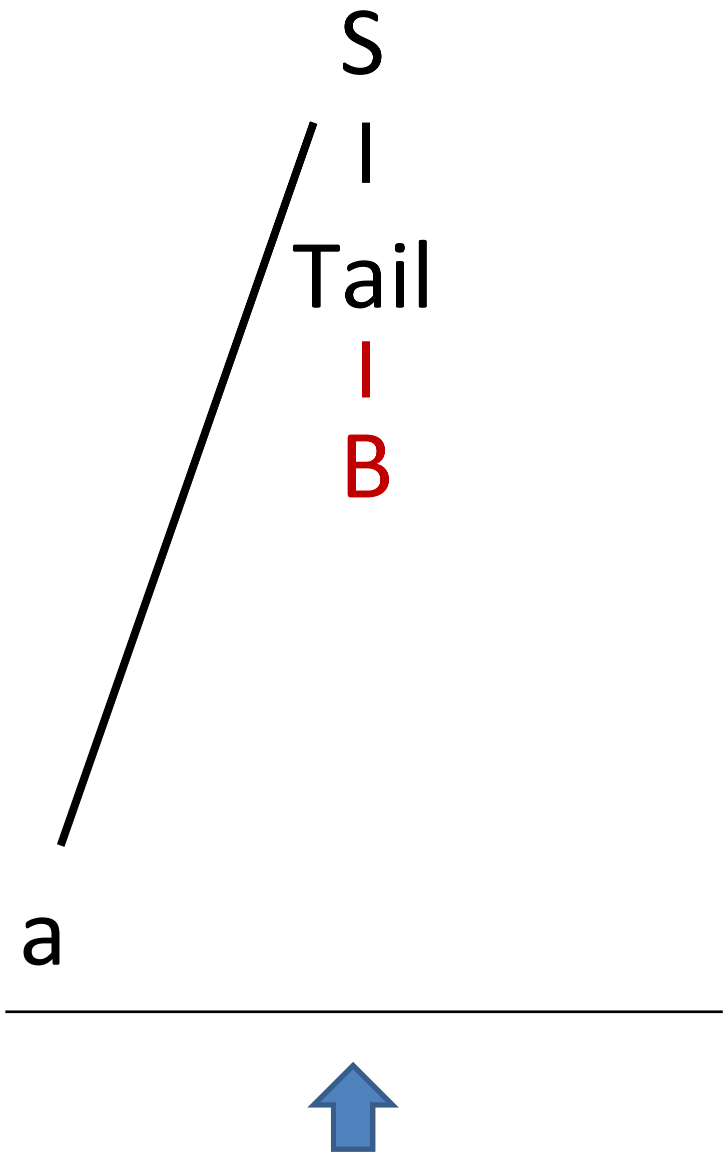
Top-Down Derivation of “a z x”




```
0. S ::= a Tail
1. Tail ::= B | w
2. B ::= C x | y
3. C ::= ε | z
```

Lookahead	Remaining
a	z x

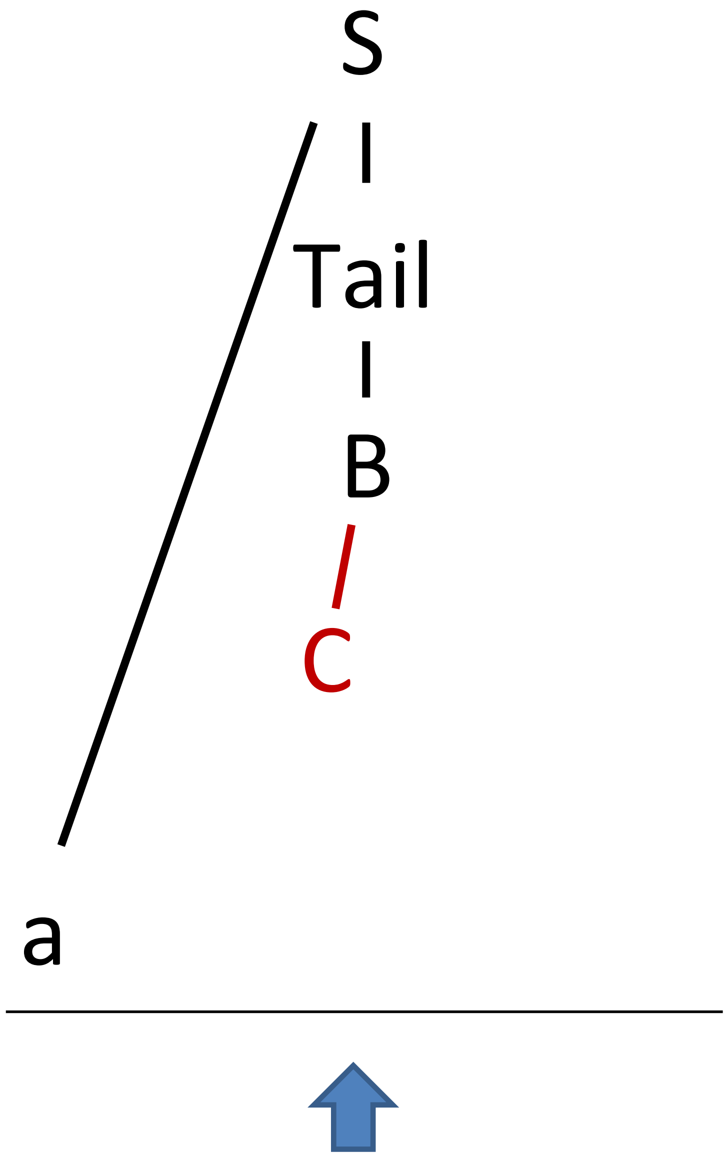
Top-Down Derivation of “a z x”




```
0. S ::= a Tail
1. Tail ::= B | w
2. B ::= C x | y
3. C ::= ε | z
```

Lookahead	Remaining
z	x

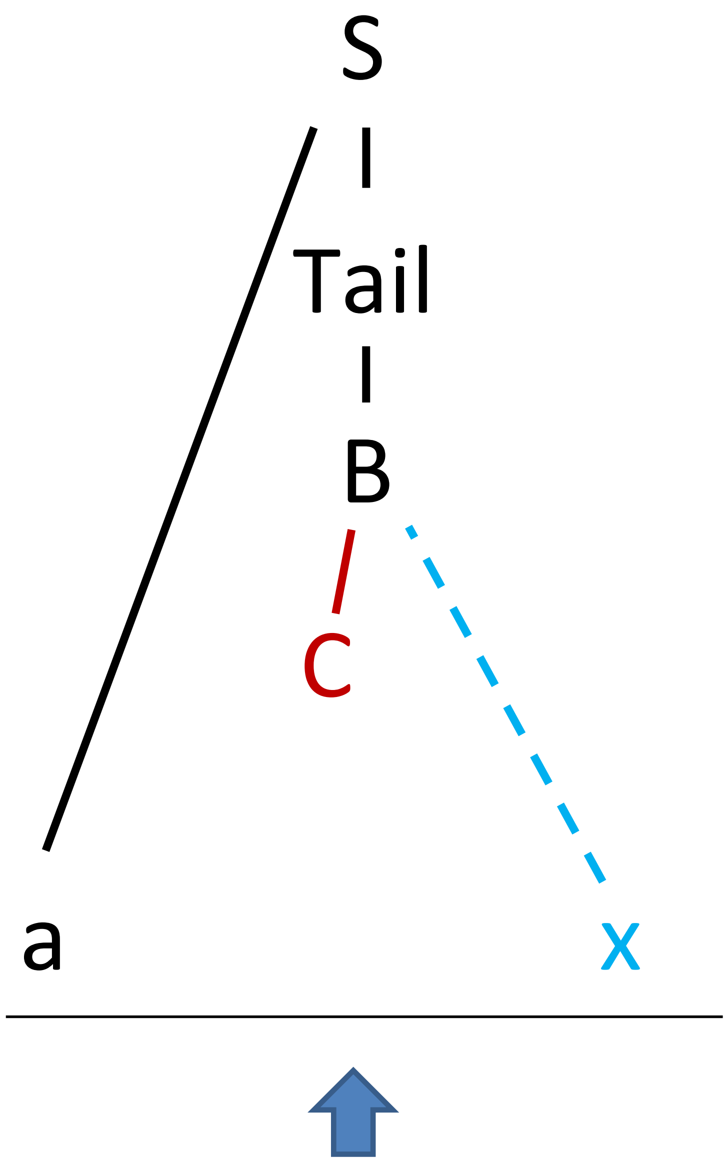
Top-Down Derivation of “a z x”




```
0. S ::= a Tail
1. Tail ::= B | w
2. B ::= C x | y
3. C ::= ε | z
```

Lookahead	Remaining
z	x

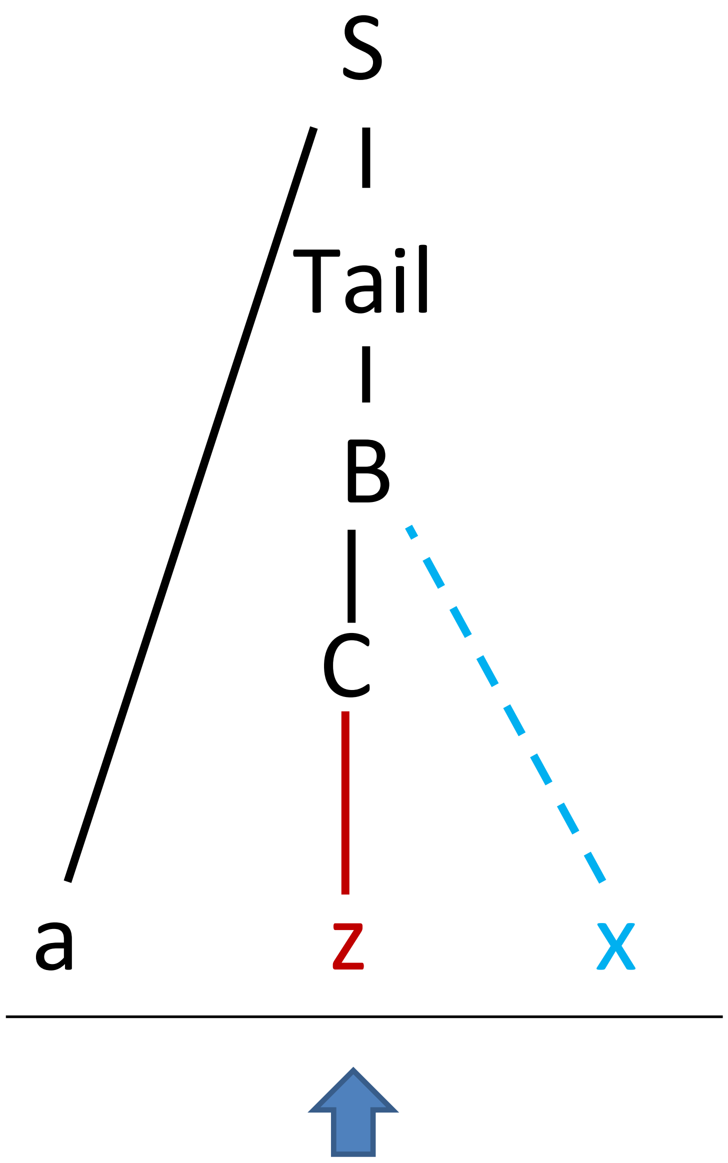
Top-Down Derivation of "a z x"




```
0. S ::= a Tail
1. Tail ::= B | w
2. B ::= C x | y
3. C ::= ε | z
```

Lookahead	Remaining
z	x

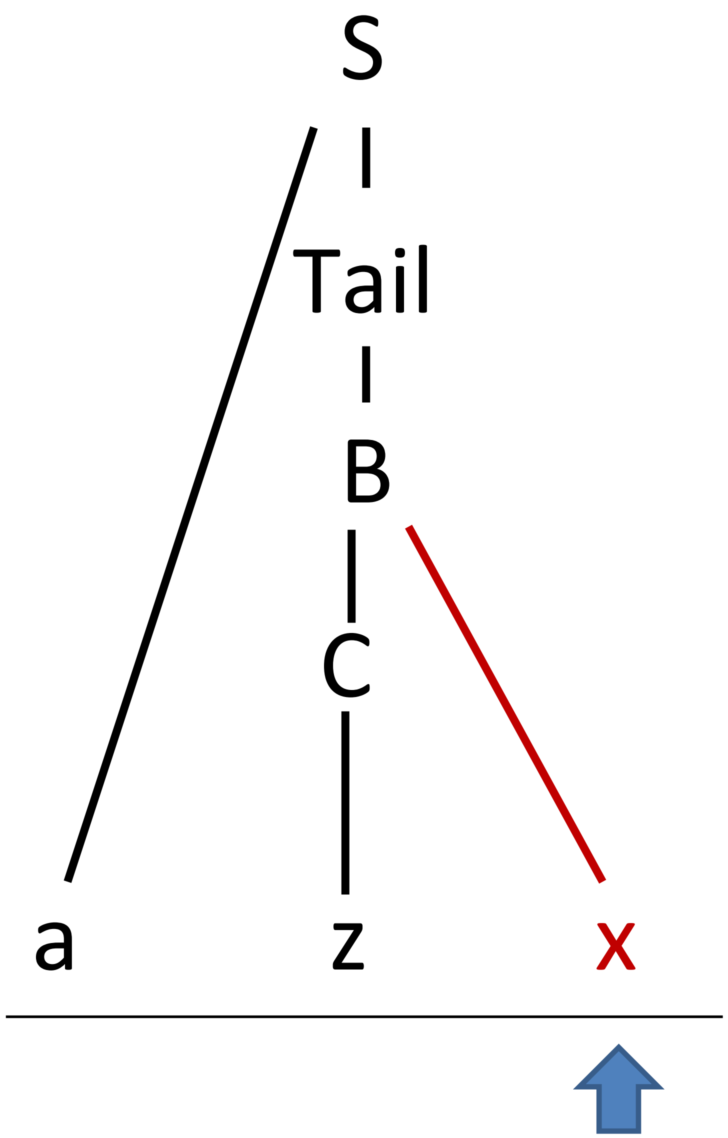
Top-Down Derivation of “a z x”




```
0. S ::= a Tail
1. Tail ::= B | w
2. B ::= C x | y
3. C ::= ε | z
```

Lookahead	Remaining
z	x

Top-Down Derivation of “a z x”

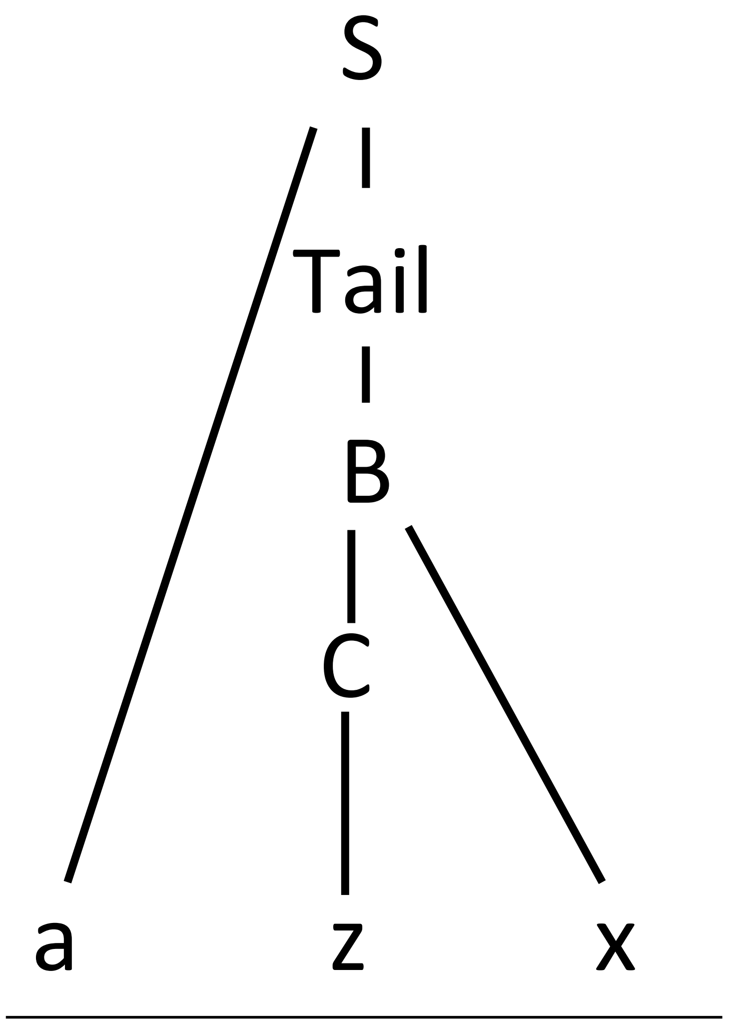



```
0. S ::= a Tail
1. Tail ::= B | w
2. B ::= C x | y
3. C ::= ε | z
```

Lookahead Remaining

x

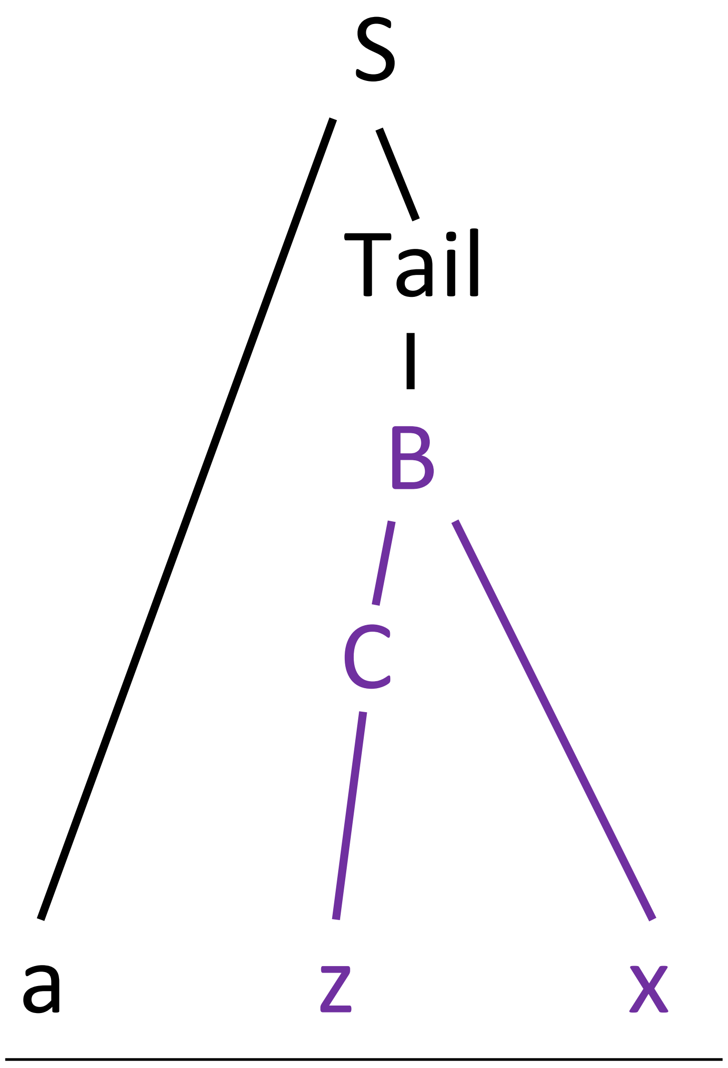
Top-Down Derivation of “a z x”



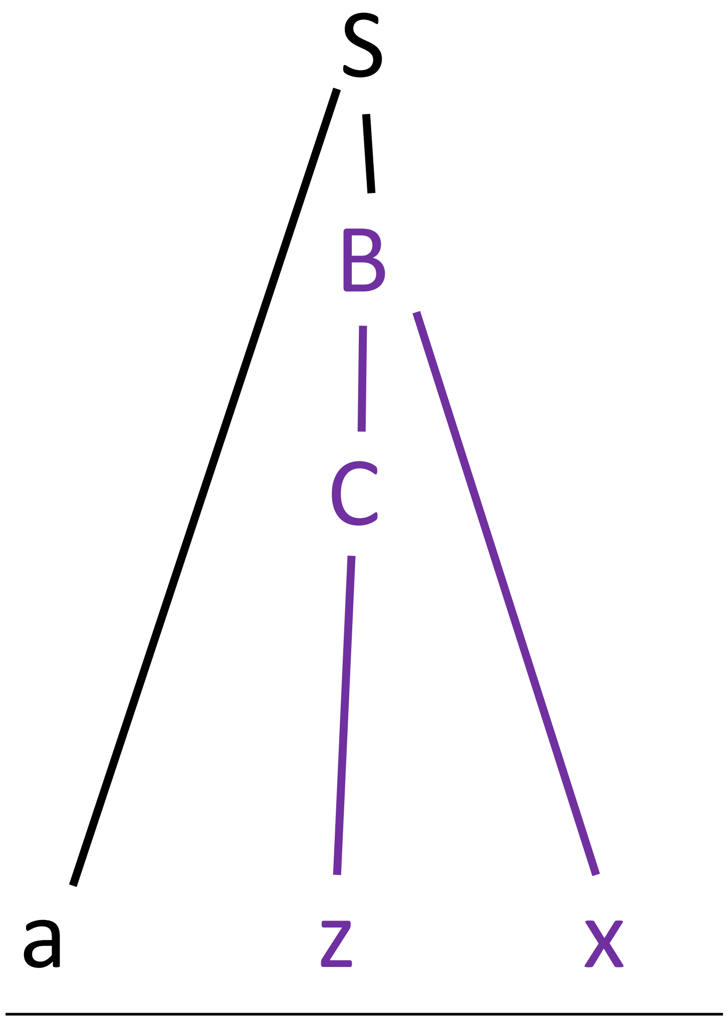

```
0. S ::= a Tail
1. Tail ::= B | w
2. B ::= C x | y
3. C ::= ε | z
```

Success!

Comparing Parse Trees



Purple trees
are the same!



LL Condition

For each nonterminal in the grammar:

– Its *productions* must have disjoint FIRST sets

✗
```
A ::= x | B
B ::= x
```

✓
```
A ::= x | B
B ::= y
```

– If it is *nullable*, the FIRST sets of its productions must be disjoint from its FOLLOW set

✗
```
S ::= A x
A ::= ε | x
```

✓
```
S ::= A y
A ::= ε | x
```

**We can often transform a grammar to satisfy this if needed

Canonical FIRST FOLLOW Conflict

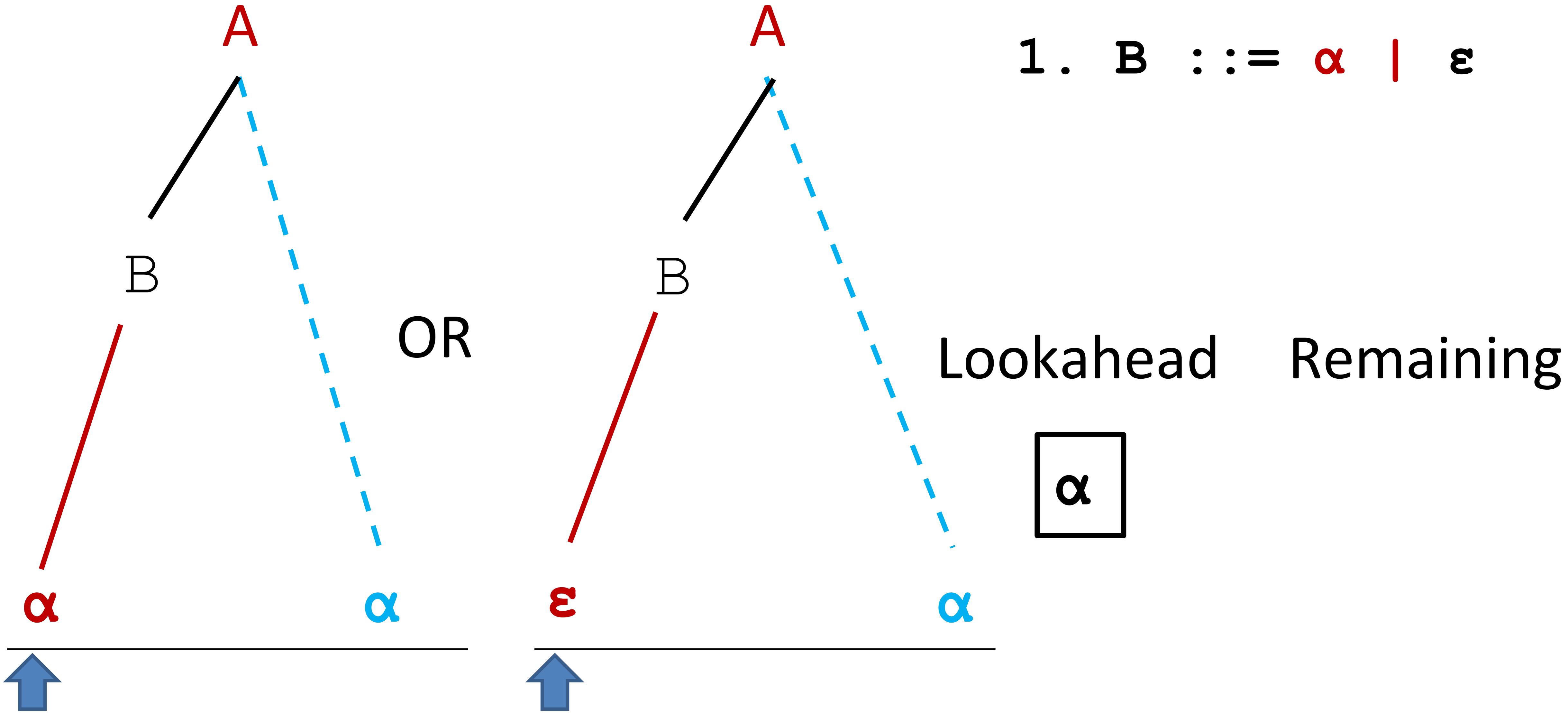
Problem

```
0. A ::= B α
1. B ::= α | ε
```

Because B is nullable, its FOLLOW set must be disjoint from the FIRST sets of its right-hand sides!

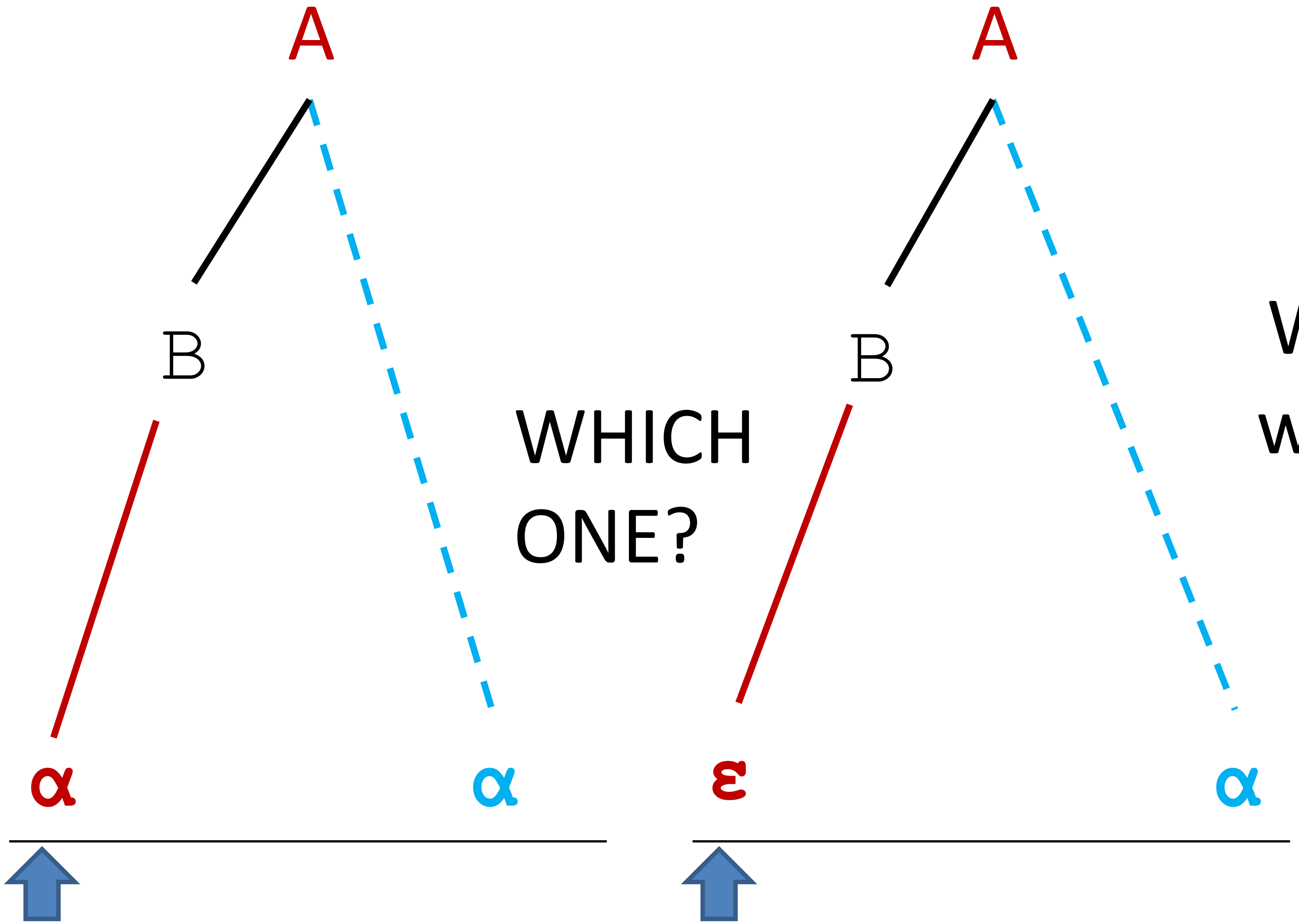
Let's try a top-down derivation of "α"

```
0. A ::= B α
1. B ::= α | ε
```



Let’s try a top-down derivation of “α”

```
0. A ::= B α
1. B ::= α | ε
```



We don’t know! Again, we can’t see more than α!

Canonical FIRST FOLLOW Conflict Solution

Solution

```
0. A ::= B α
1. B ::= α | ε
```

Substitute the common prefix

```
0. A ::= αα | α
```

Factor out the tail

```
0. A ::= α Tail
1. Tail ::= α | ε
```

Watch out for Nullability! (Grammar 2)

Changing the grammar again…

```
0. S ::= a B
1. B ::= C x | y
2. C ::= ε | x
```

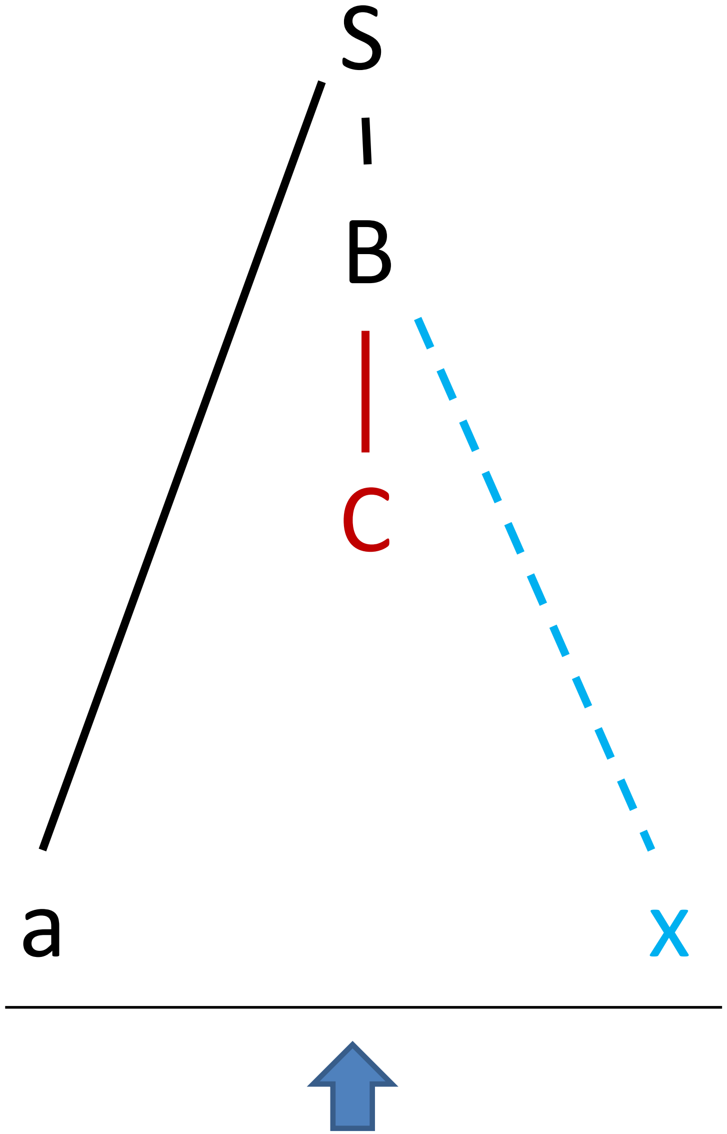
Lookahead	Remaining
a	x

What’s the issue?

```
0. S ::= a B
1. B ::= C x | y
2. C ::= ε | x
```

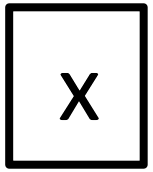
FIRST FOLLOW Conflict

Top down derivation of "ax"



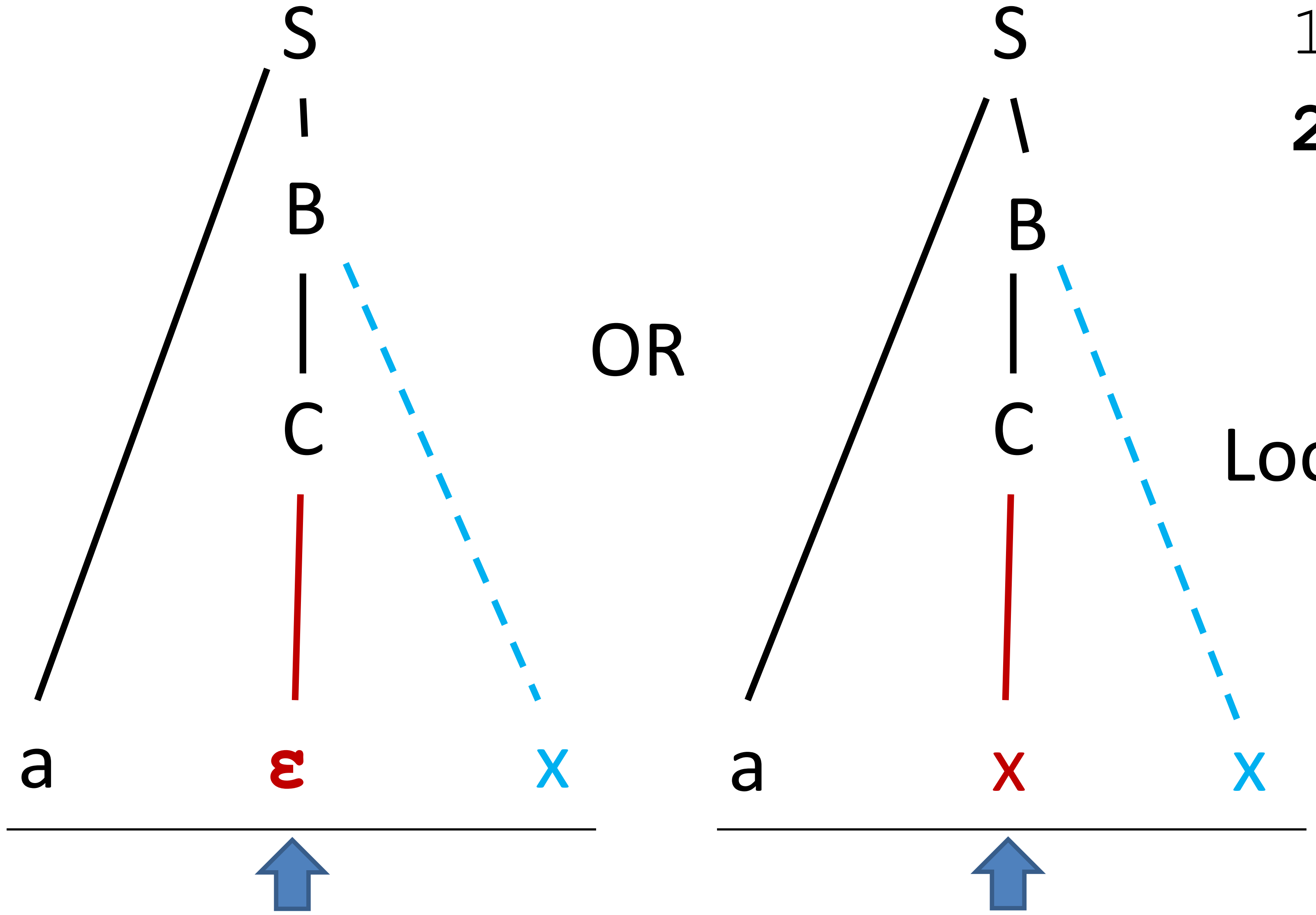

```
0. S ::= a B
1. B ::= C x | y
2. C ::= ε | x
```

Lookahead   Remaining

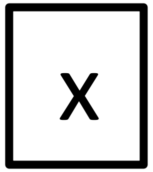


Top down derivation of “ax”

```
0. S ::= a B
1. B ::= C x | y
2. C ::= ε | x
```



Lookahead Remaining



Applying the Fix: Substitute the Common Prefix,

1

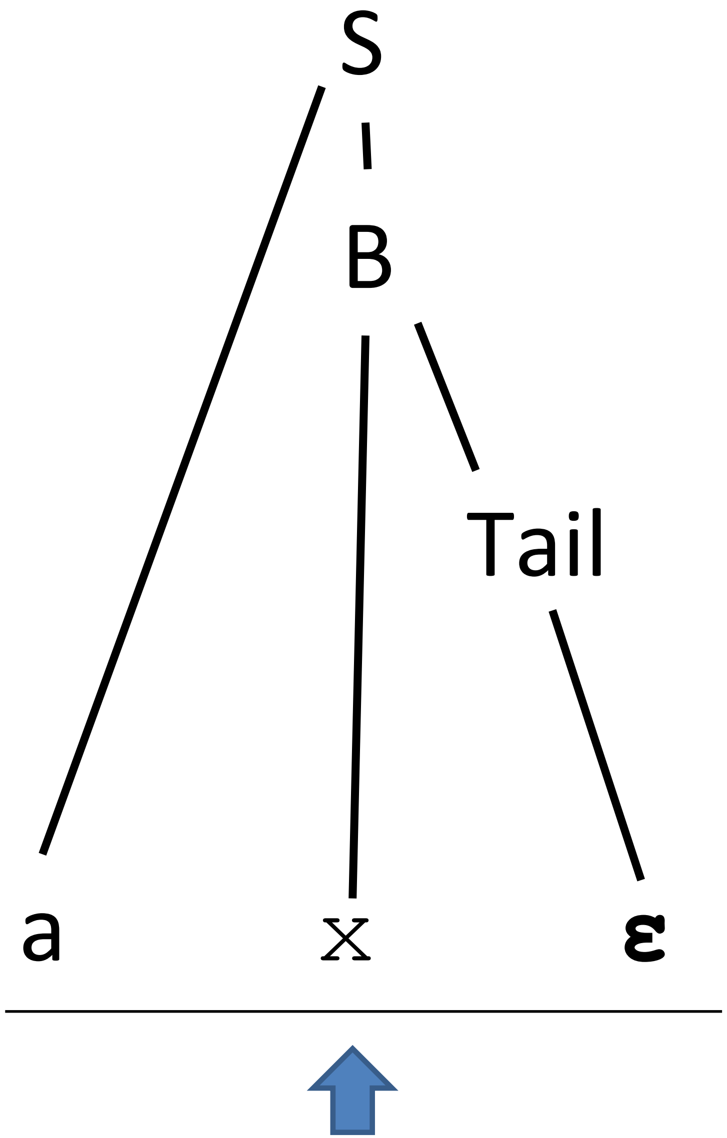
```
0. S ::= a B
1. B ::= x | xx | y
```

~~2. C ::= ε | x~~

2

```
0. S ::= a B
1. B ::= x Tail | y
2. Tail ::= x | ε
```

Top down derivation of “ax”




```
0. S ::= a B
1. B ::= x Tail | y
2. Tail ::= x | ε
```

Lookahead Remaining

x