Section 4: CUP & LL

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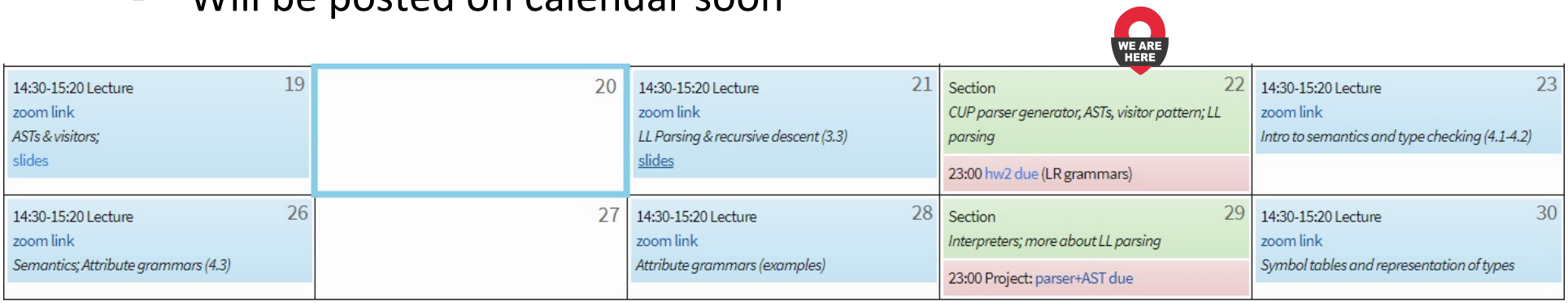
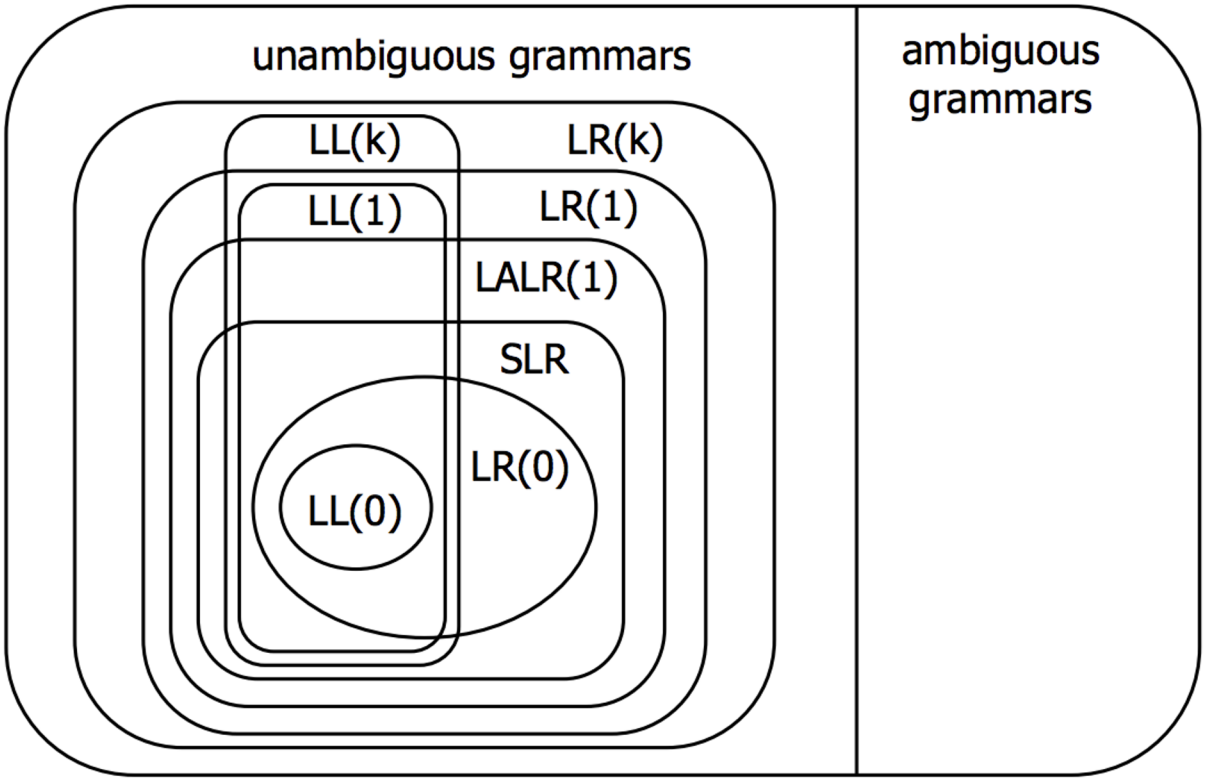
Adapted from Autumn 2020

Administrivia

- Homework 2 is due tonight!
  - You have late days if you need them
- Parser is due one week from today
  - Be sure to check your Scanner feedback
- Watch demo video on CUP & AST Hierarchies
  - Will be posted on calendar soon



Language Hierarchies



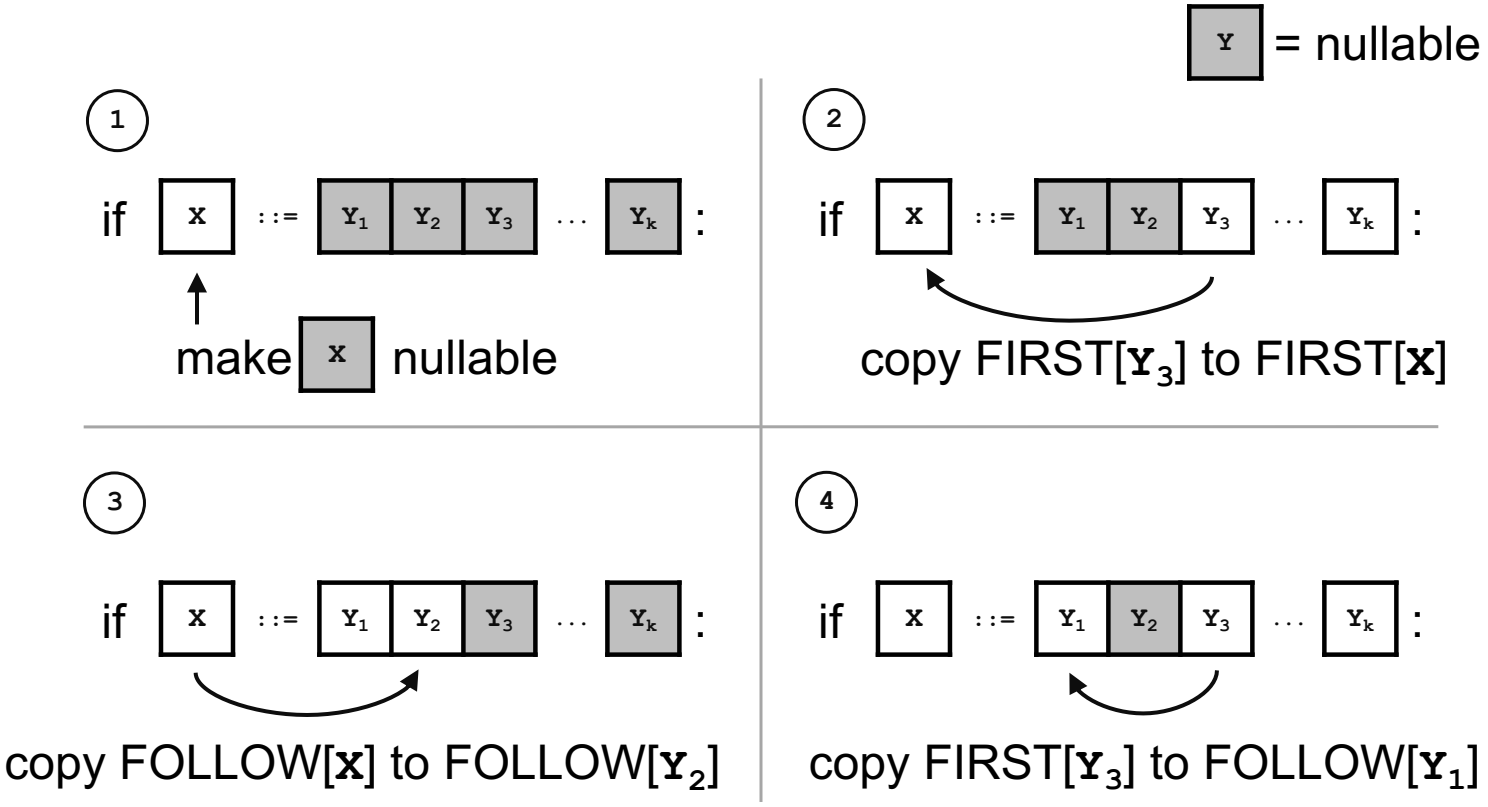
The CUP parser generator

- 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

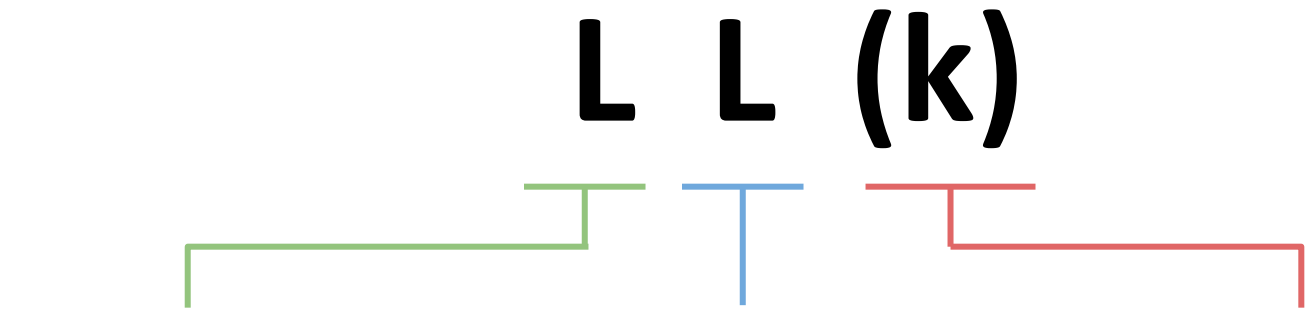
- Based on LALR(1)
- CUP can resolve some ambiguities itself
  - Precedence for reduce/reduce conflicts
  - Associativity for shift/reduce conflicts
  - Useful for our project for things like arithmetic expressions (exp+exp, exp*exp for fewer non-terminals, then add precedence and associativity declarations).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

Computing FIRST, FOLLOW, & nullable (3)



Computing FIRST, FOLLOW, and nullable

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



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

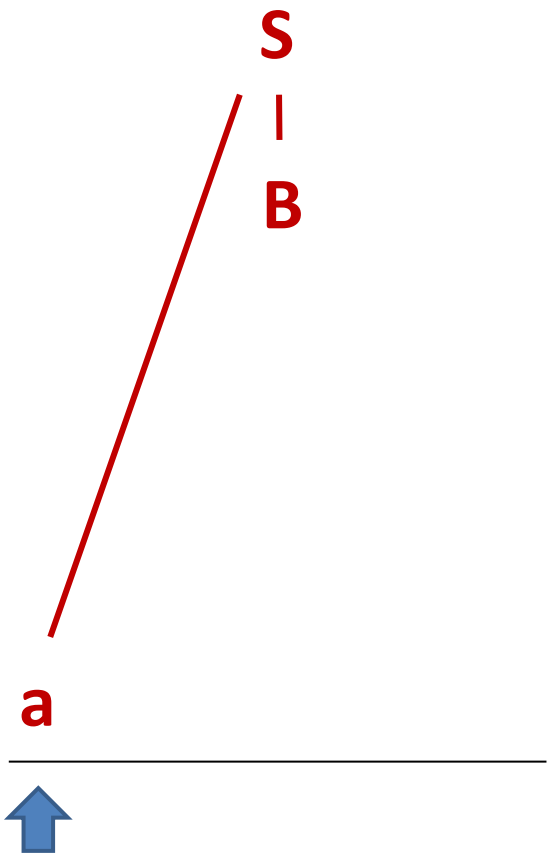
- The LL condition enable the parser to choose productions correctly with 1 symbol of look-ahead
- We can often transform a grammar to satisfy this if needed

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”

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Lookahead	Remaining
a	z x

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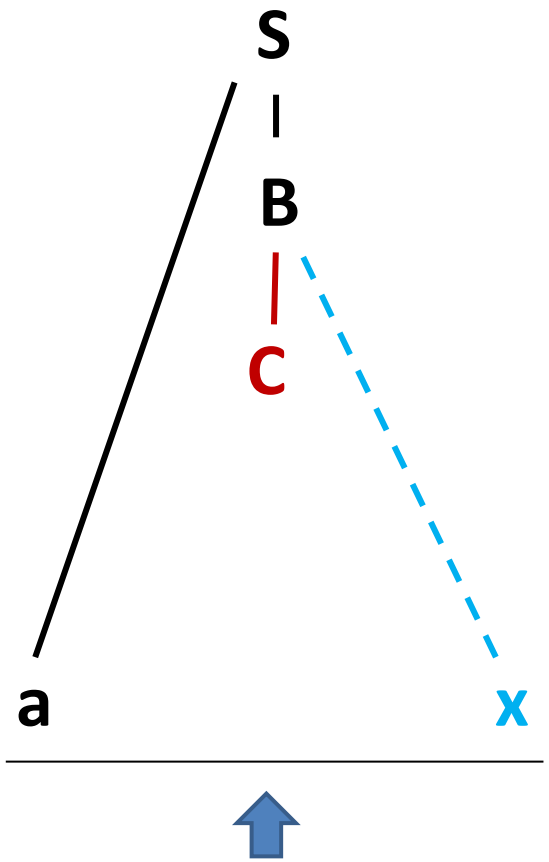
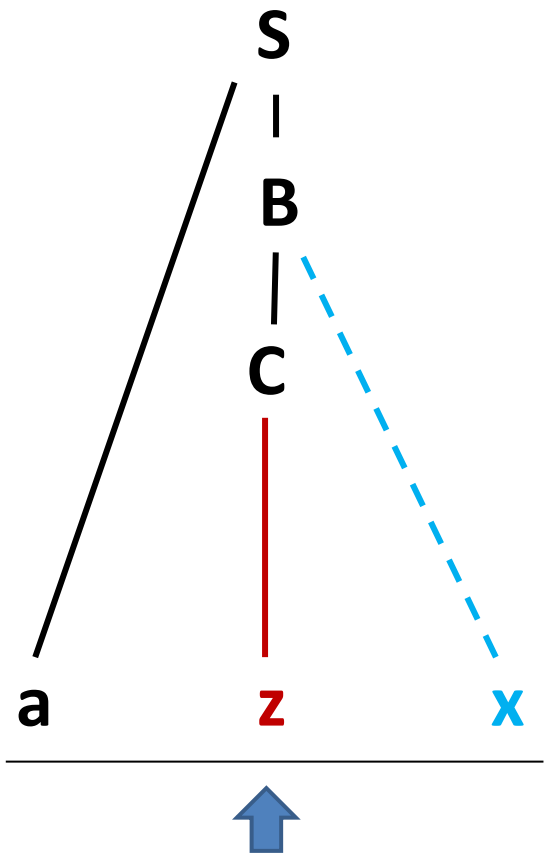



```
0. S ::= a B
1. B ::= C x | y
2. C ::= ε | z
```

Lookahead	Remaining
z	x

Top-Down Derivation of “a z x”




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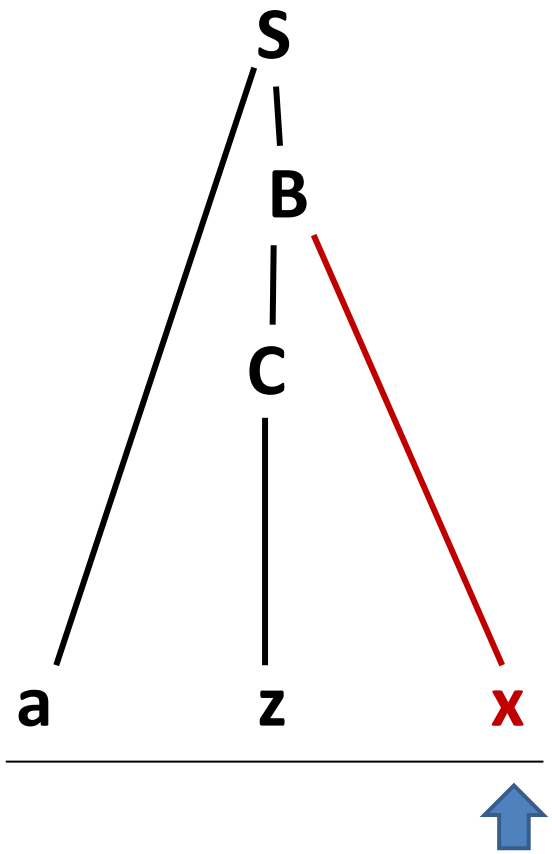

Lookahead	Remaining
z	x

Top-Down Derivation of “a z x”

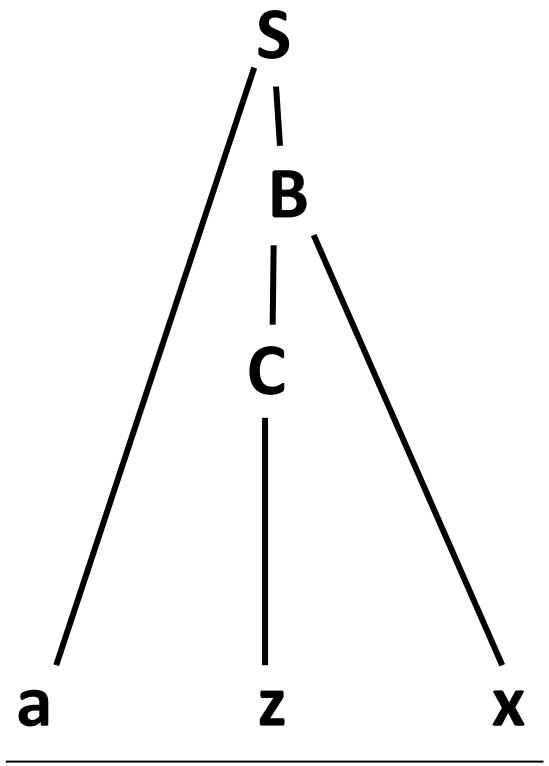



```
0. S ::= a B
1. B ::= C x | y
2. C ::= ε | z
```

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

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

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

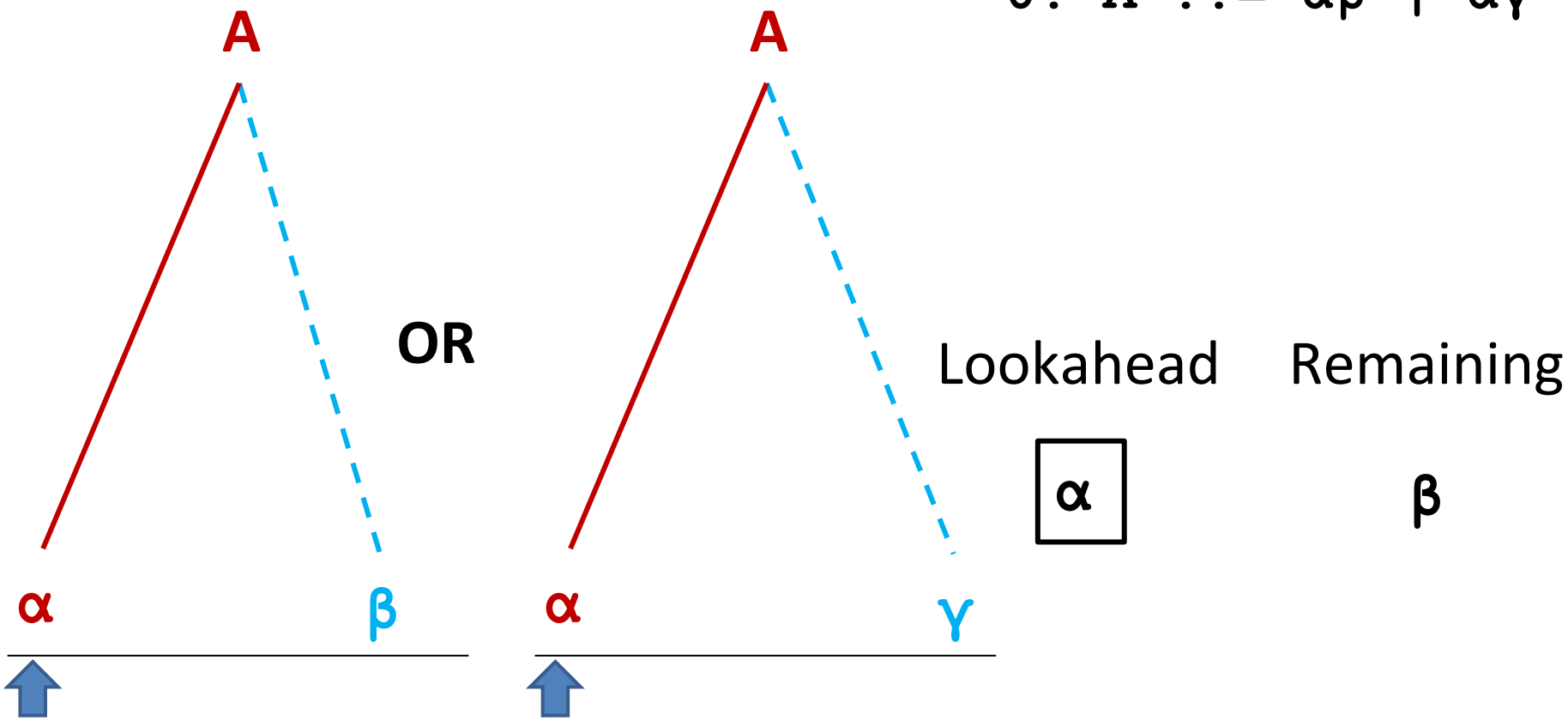
Canonical FIRST Conflict

Problem

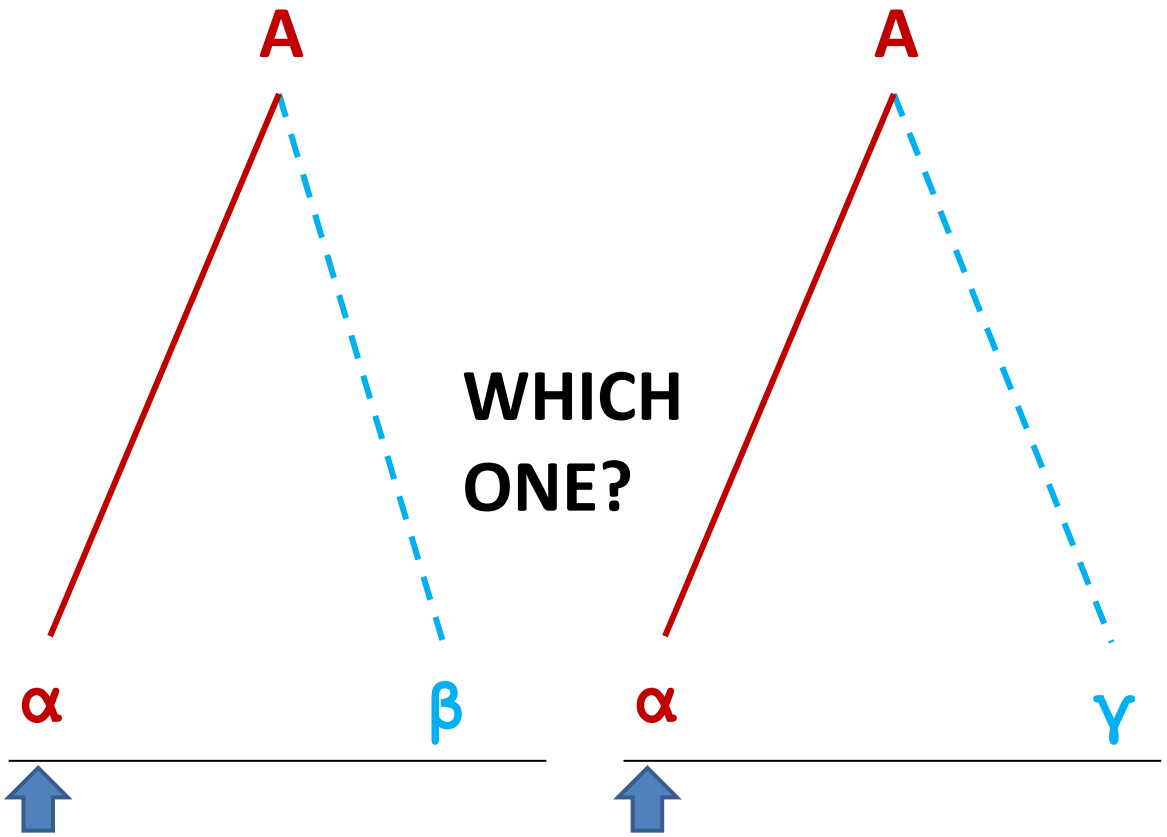
```
0. A ::= αβ | αγ
```

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



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

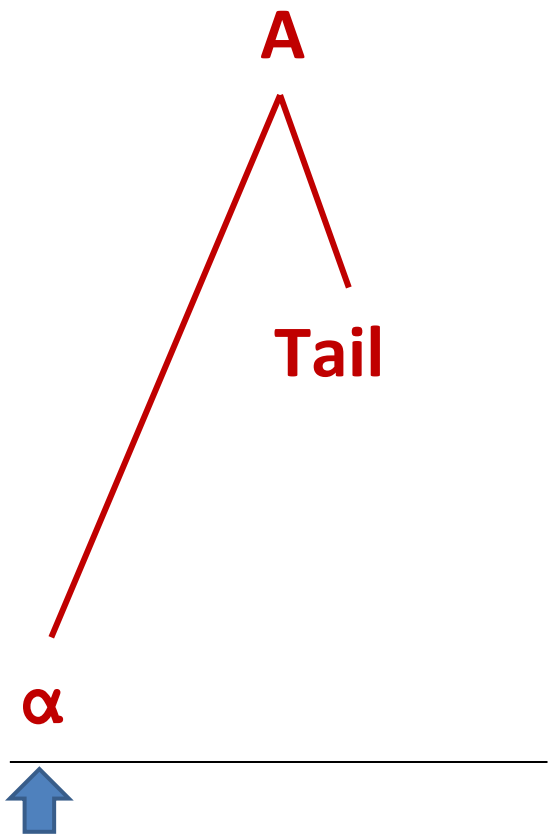
```
0. A ::= αβ | αγ
```

```
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"

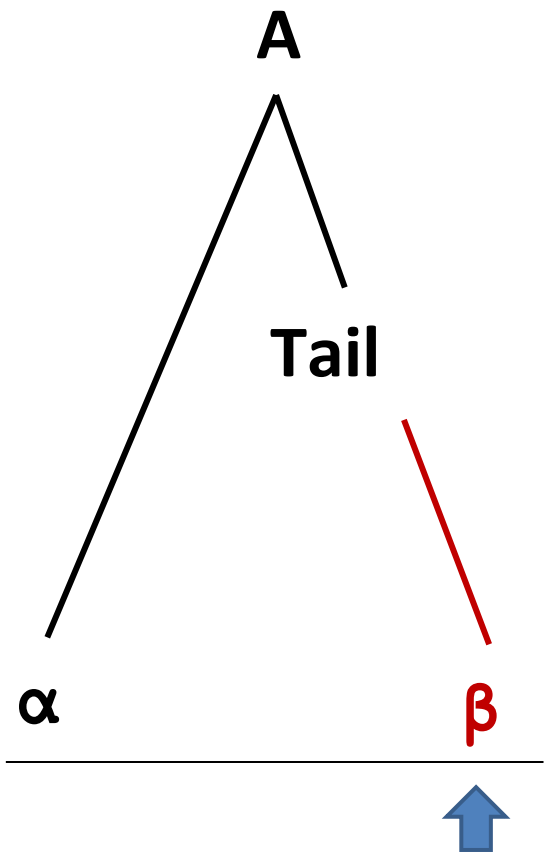



```
0. A ::= α Tail
1. Tail ::= β | γ
```

Lookahead Remaining

α β

Top-Down Derivation of "αβ"

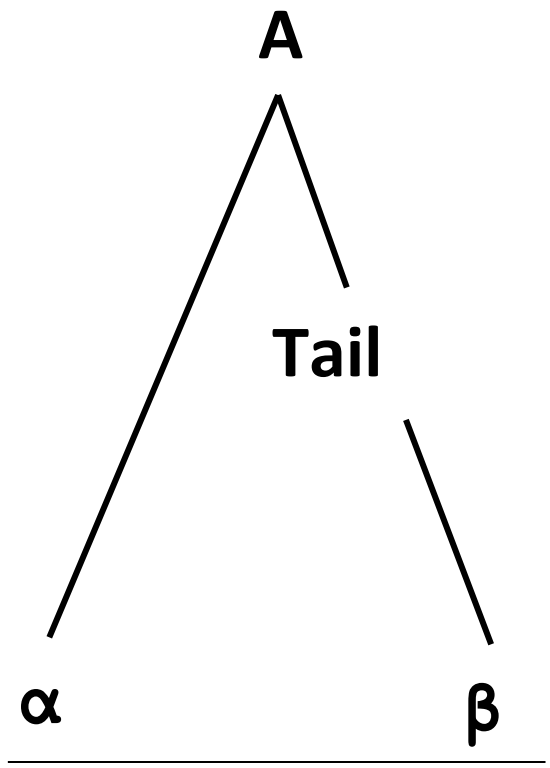



```
0. A ::= α Tail
1. Tail ::= β | γ
```

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**

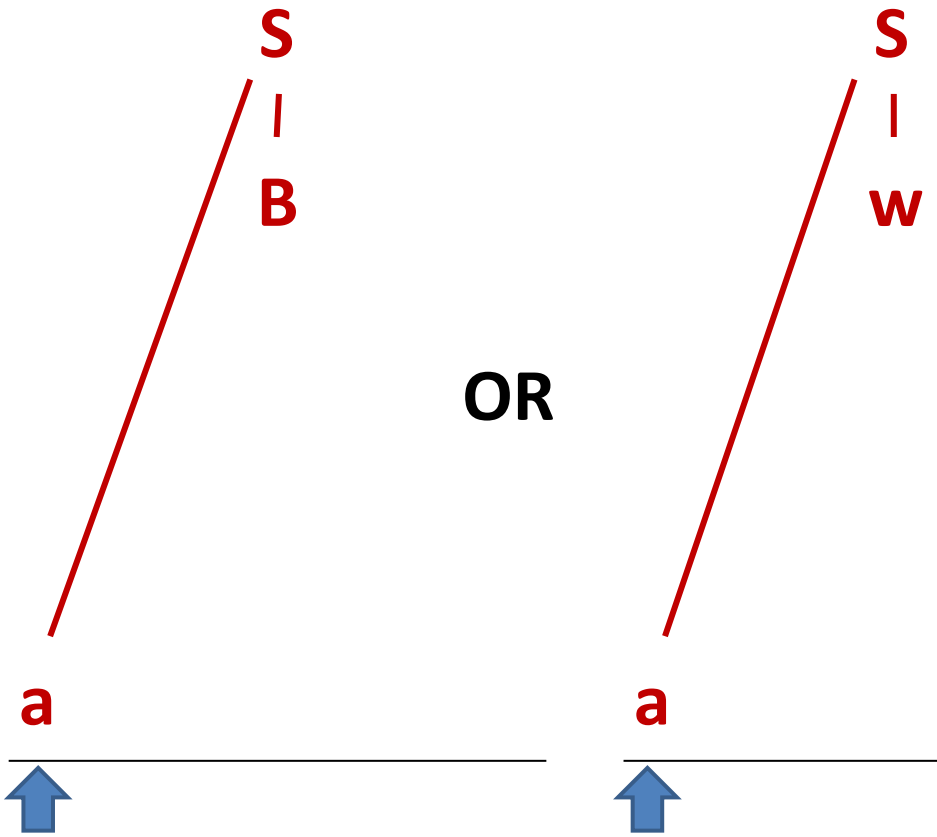
What's the issue?

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

There's a FIRST Conflict!

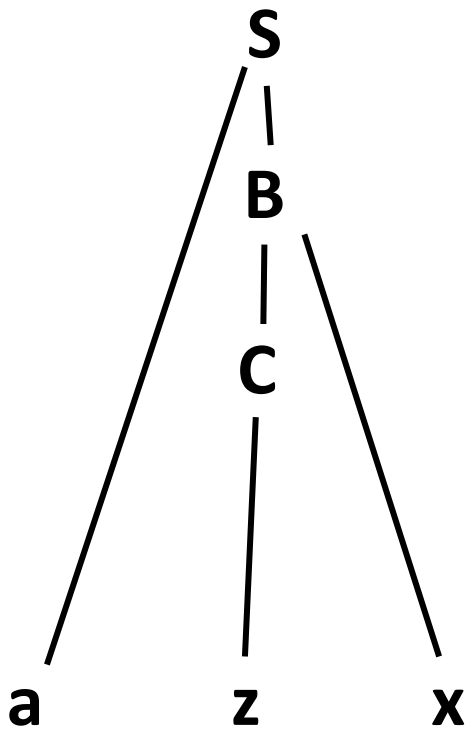
Top-Down Derivation of “a z x”: LL(1) can’t

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



Lookahead	Remaining
a	z x

Parse Tree without changing Grammar

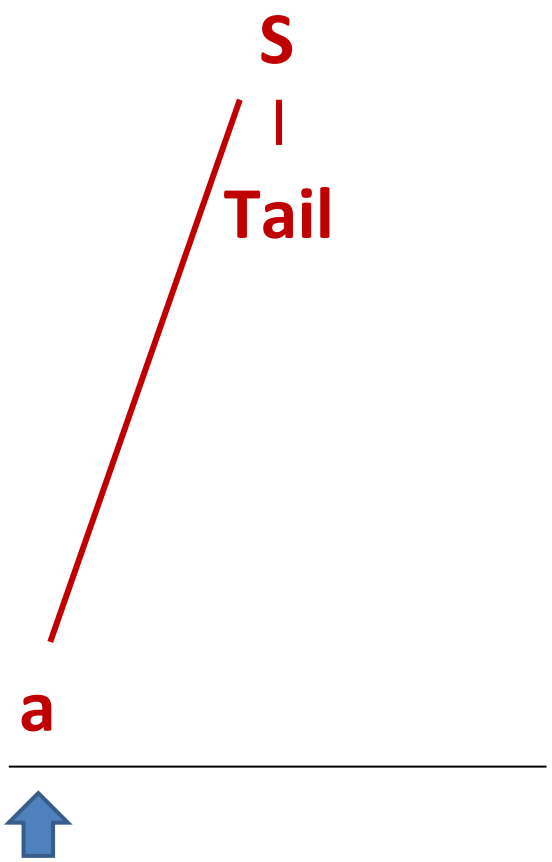



```
0. S ::= a B | a w
1. B ::= C x | y
2. C ::= ε | z
```

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”




```
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1. Tail ::= B | w
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```
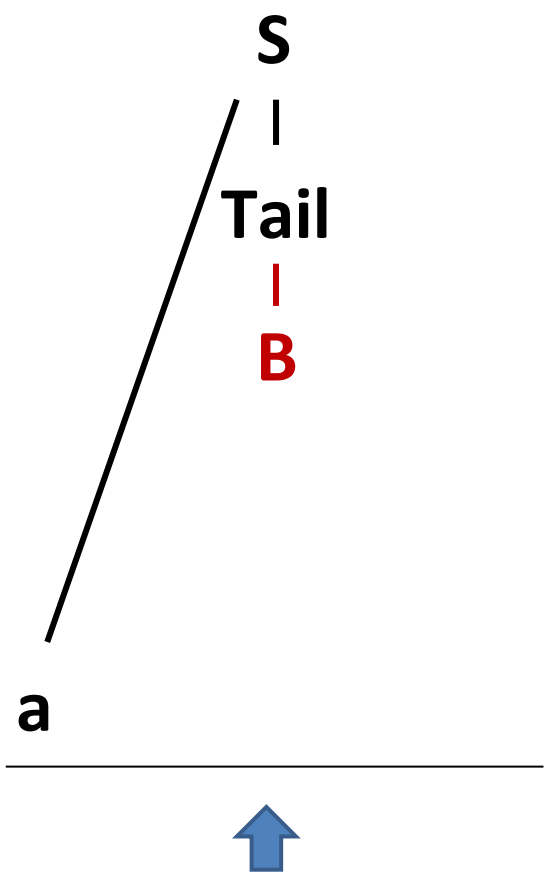

Lookahead	Remaining
a	z x

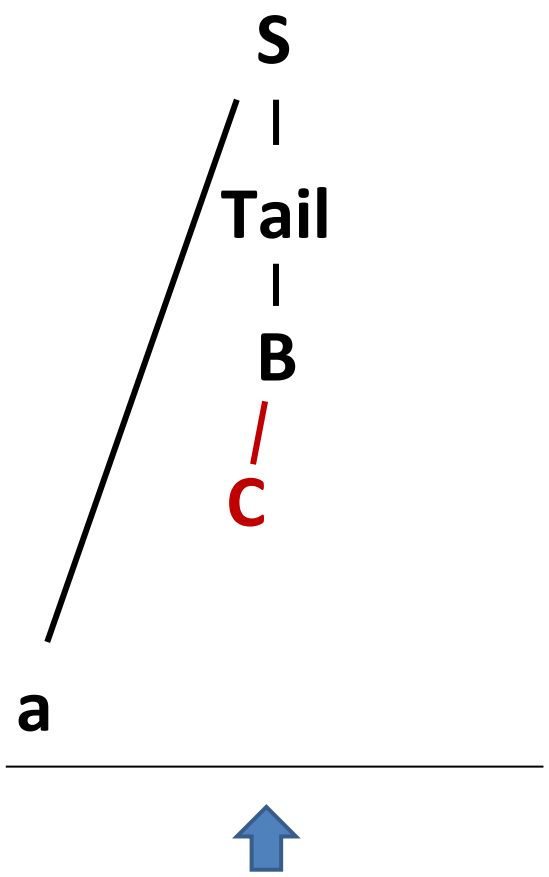
Top-Down Derivation of “a z x”




```
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”

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0. S ::= a Tail
1. Tail ::= B | w
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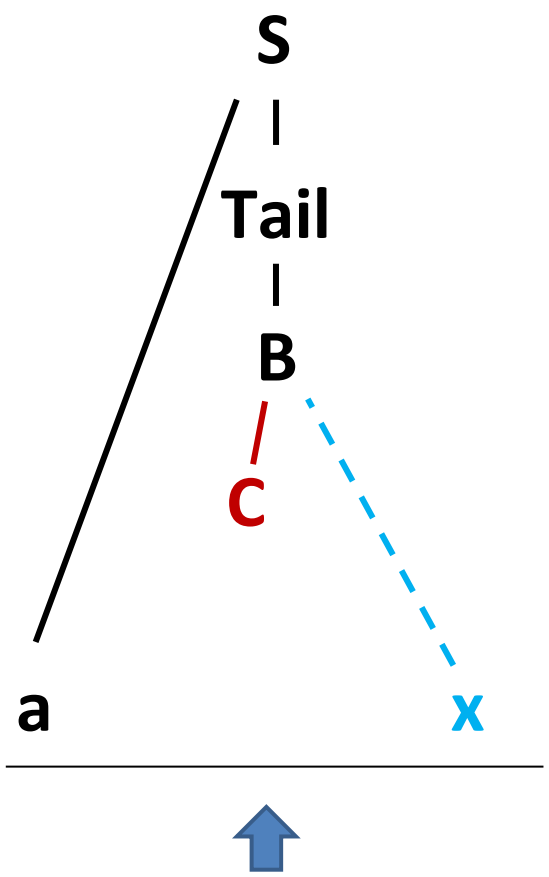
```

Lookahead	Remaining
z	x

Top-Down Derivation of “a z x”

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2. B ::= C x | y
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Lookahead	Remaining
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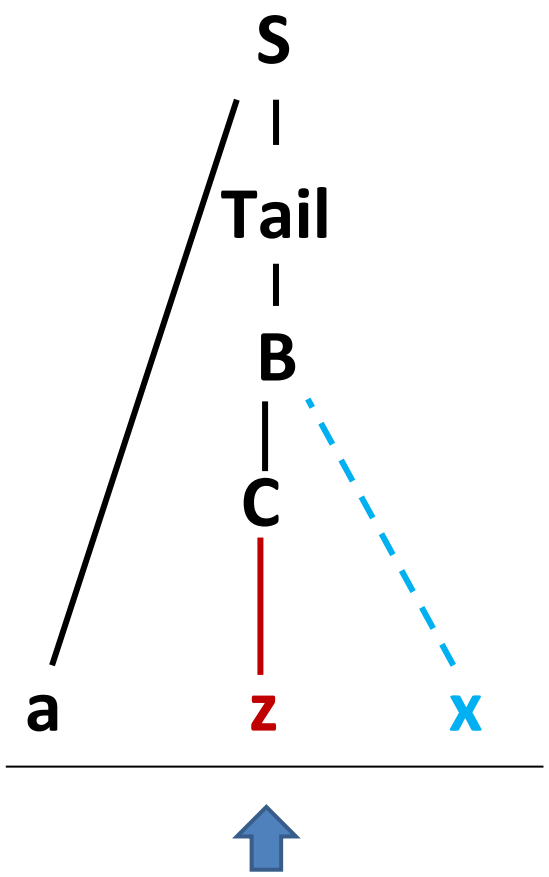
Top-Down Derivation of “a z x”

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```

Lookahead	Remaining
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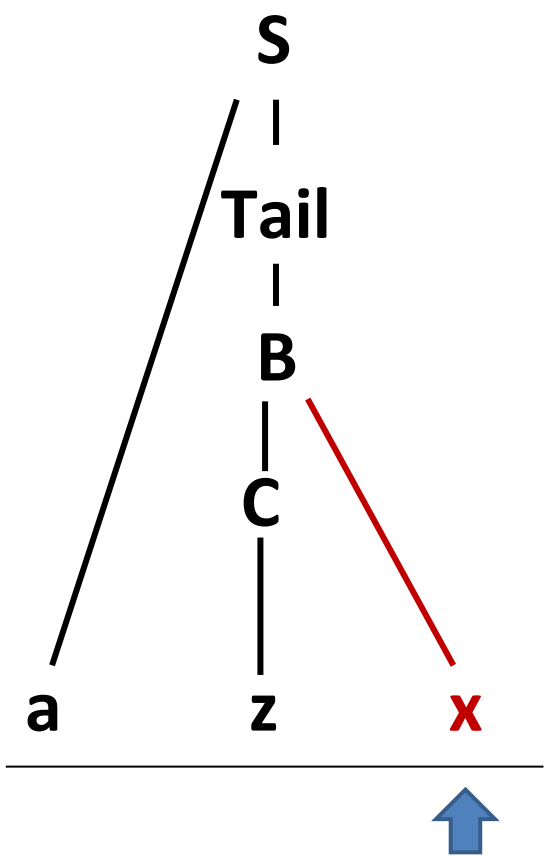
Top-Down Derivation of “a z x”




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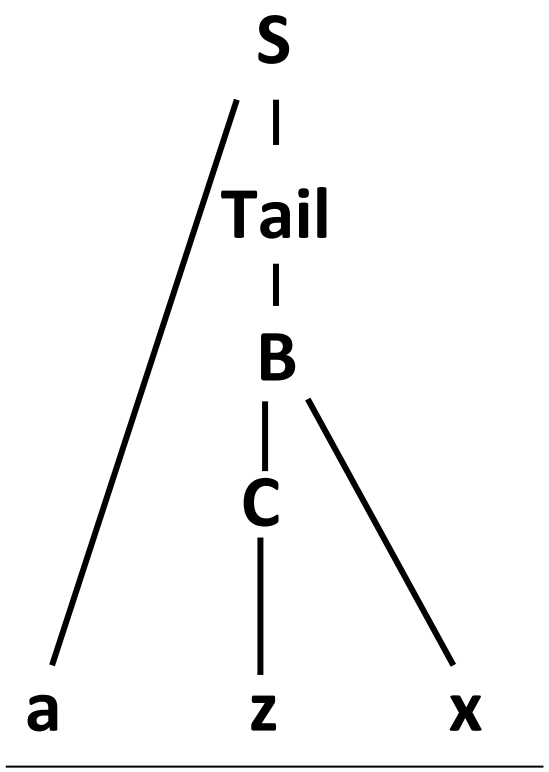

Lookahead Remaining

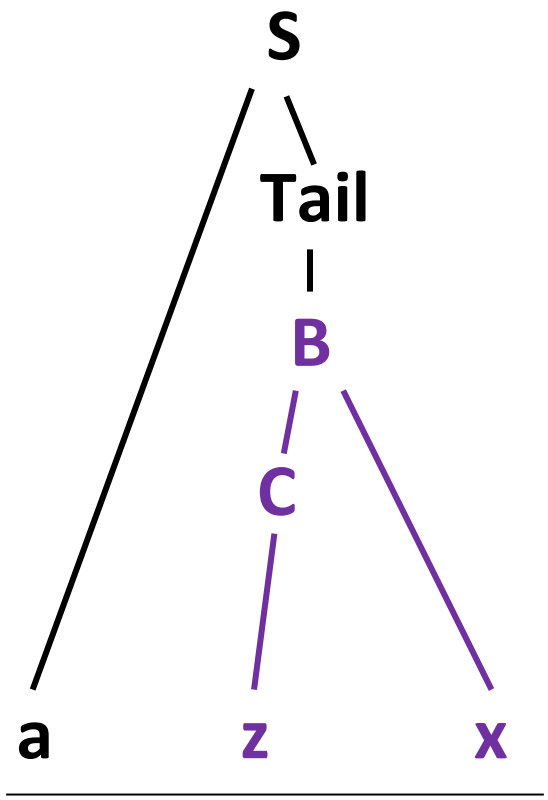
Top-Down Derivation of “a z x”



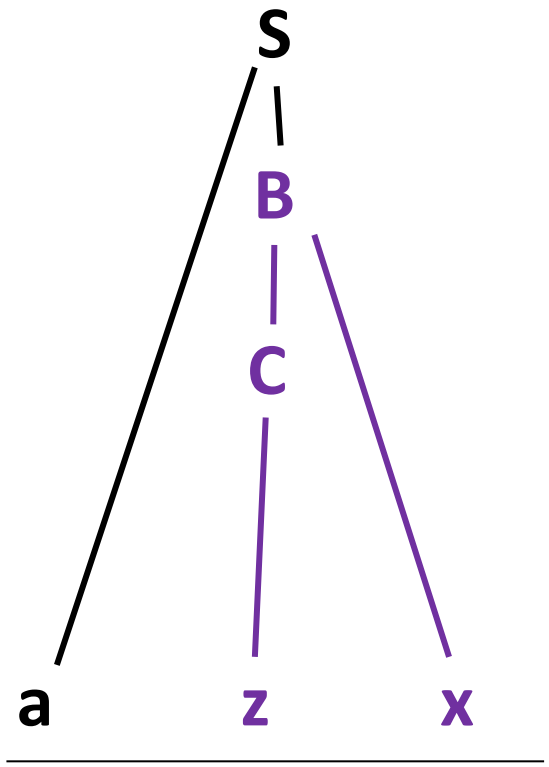
0. **S ::= a Tail**
1. **Tail ::= B | w**
2. B ::= C x | y
3. C ::= ε | z

Success!

Comparing Parse Trees



Purple trees are the same!



LL Condition

For each nonterminal in the grammar:

- Its *productions* must have disjoint FIRST sets

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

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

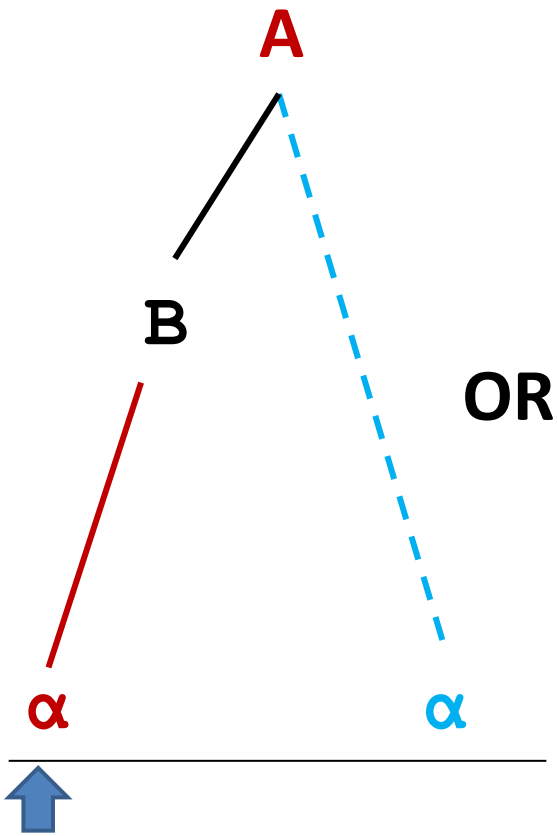
Canonical FIRST FOLLOW Conflict

Problem

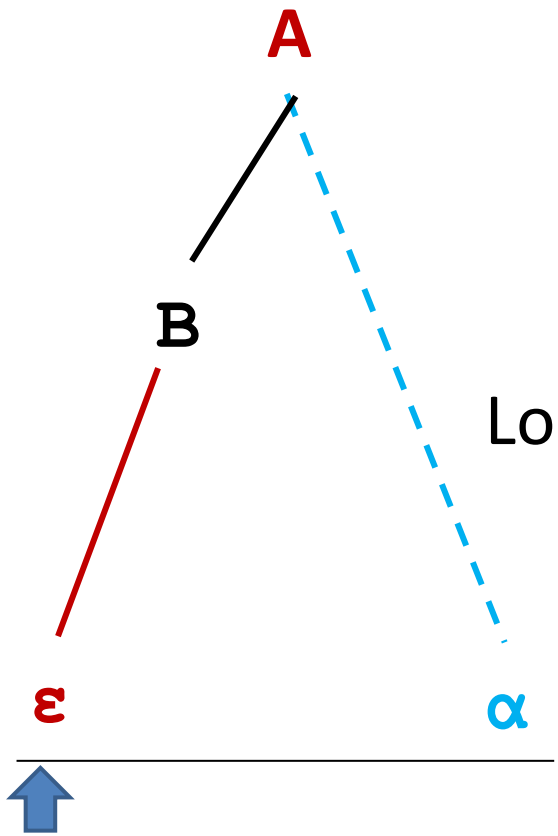
```
0. A ::= B α
1. B ::= α | ε
```

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"



OR

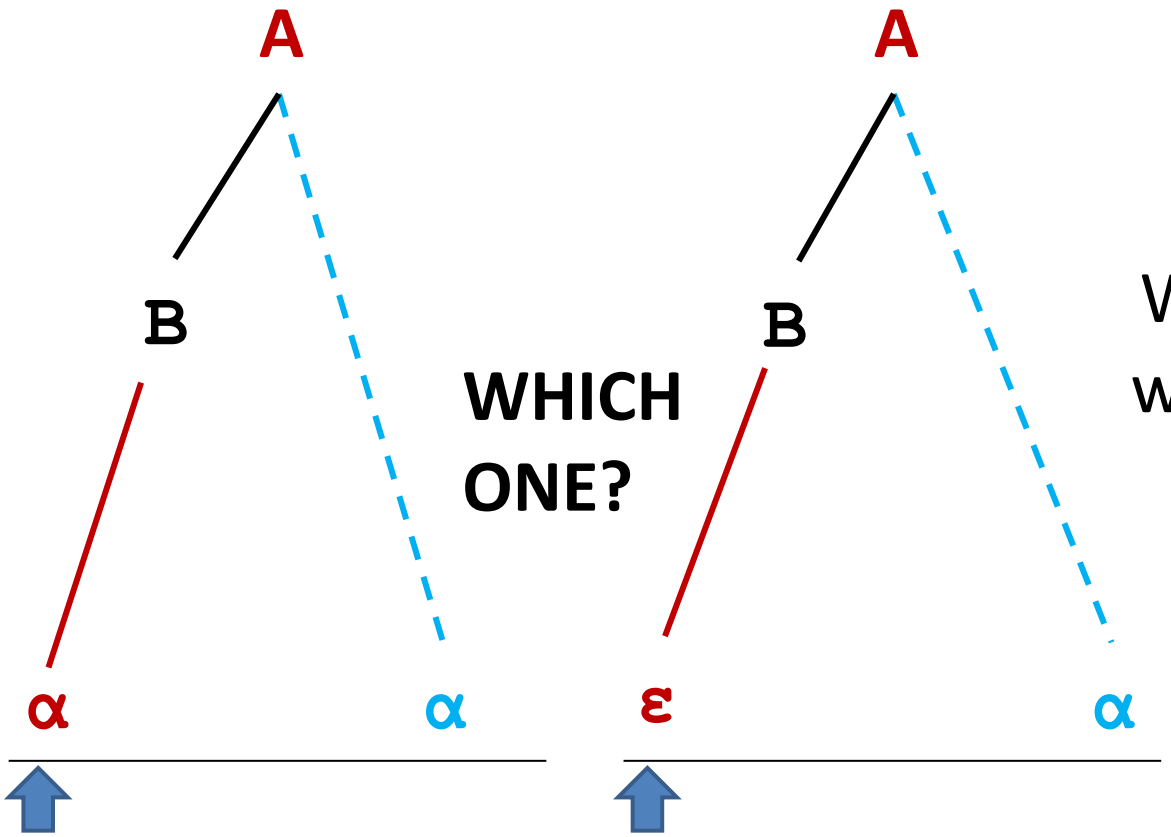



```
0. A ::= B α
1. B ::= α | ε
```

Lookahead Remaining

α

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
```

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

Factor out the tail

Watch out for Nullability! (Grammar 2)

Changing the grammar again…

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

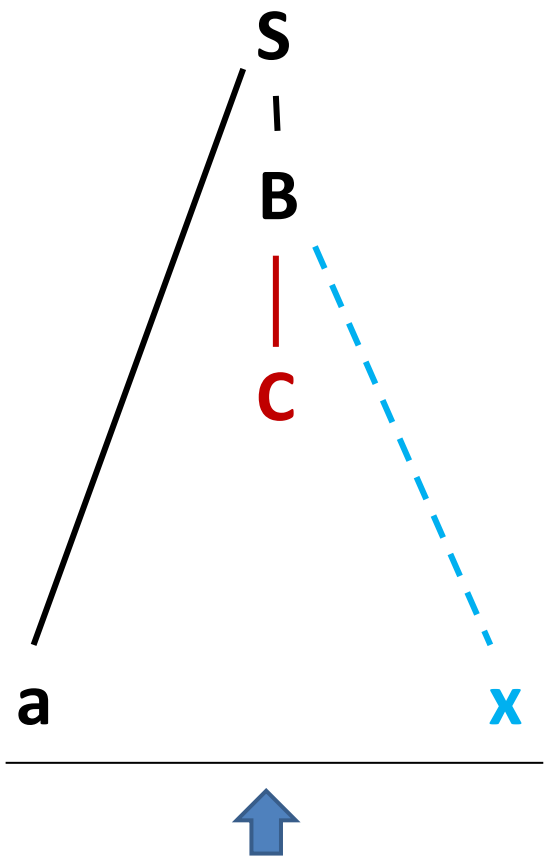
Lookahead	Remaining
a	x

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

x

Top down derivation of “ax”

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

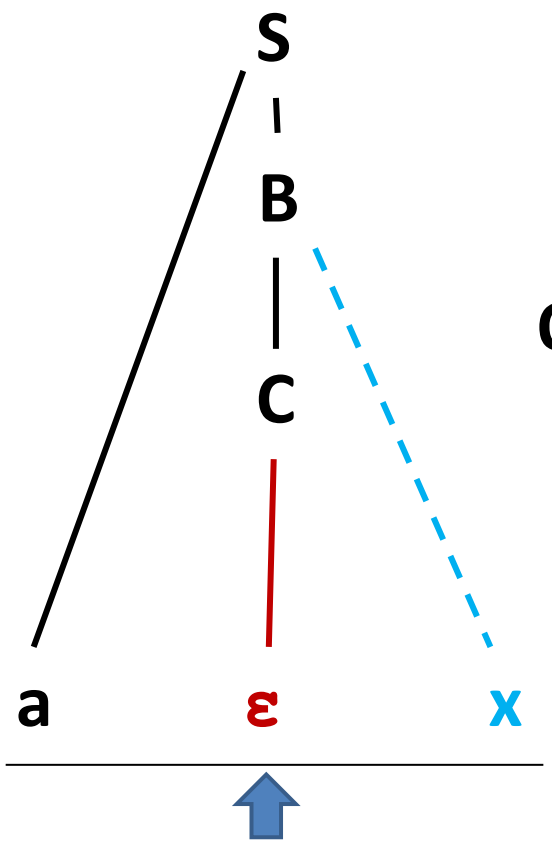

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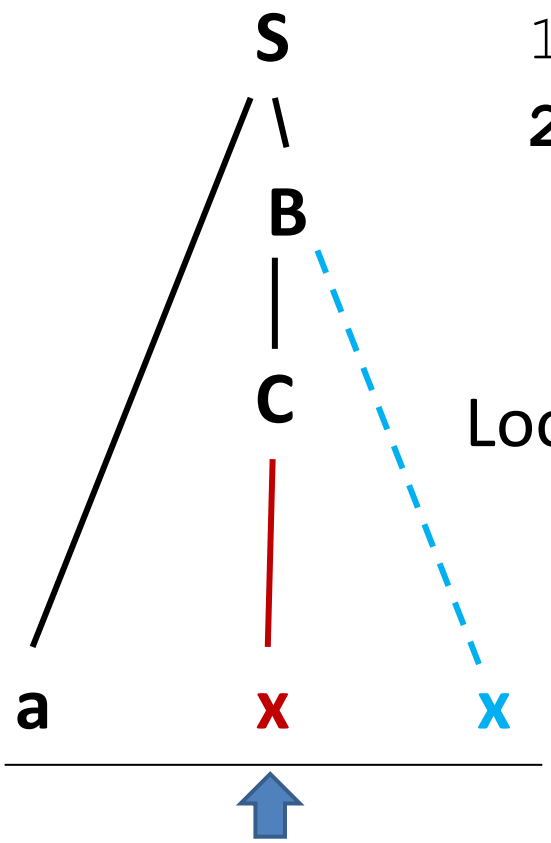


Lookahead	Remaining
x	

Applying the Fix: Substitute the Common Prefix,

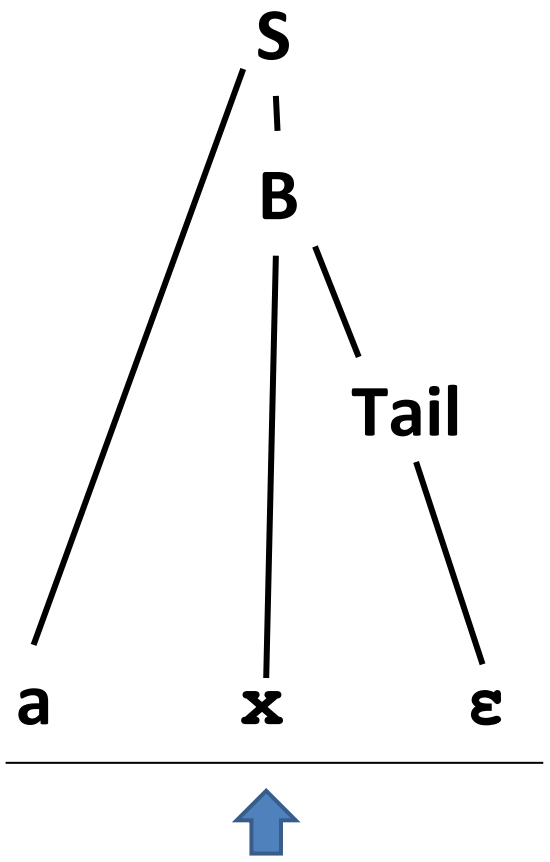
1

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