CSE 390B, Winter 2023

Building Academic Success Through Bottom-Up Computing

Professional Networking & Compiler Phases

Professional Networking in College, Exploring the Compiler Phases, Project 7 Overview

Lecture Outline

- **Professional Networking in College**
  - **Benefits of Building Connections, Networking Strategies**
- Exploring the Compiler Phases
  - Scanner: Process of Tokenizing an Input File
  - Parser: Making Meaning From Tokens Through ASTs
  - Type Checking, Optimization, and Code Generation
- Project 7 Overview
  - Midterm Corrections, Professor Meeting Report

Benefits of Building Connections

- Reaching out to your professors, TAs, and peers can be a great way to discover opportunities
- Taking the time to connect with these people can open several doors and leverage your potential
- Excellent opportunity for new perspectives and ideas for those who have been in your shoes before
- Connecting with others helps you find inspiration and build your knowledge and experience

Strategies for Networking

- Get involved in communities on campus (e.g., RSOs, TAing, research, part-time campus job)
- Invest in building relationships with people and developing a presence in their lives
- Take time to reflect on how others can support you by bringing to them your interests and questions
- Not all networking efforts will be well-received, but don't be afraid to just go for it

Discussion on Building Connections

Take some time to think about these questions:

- In what ways do you already connection with others on a regular basis? How else can you build your connections?
- How can you benefit from building your community of people you can network with?
- What would you share with someone you recently made a connection with?

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The Compiler: Goal

```
public int fact(int n) {
  if (n == 0) {
    return 1;
  } else {
    return n * fact(n - 1);
  }
}
```

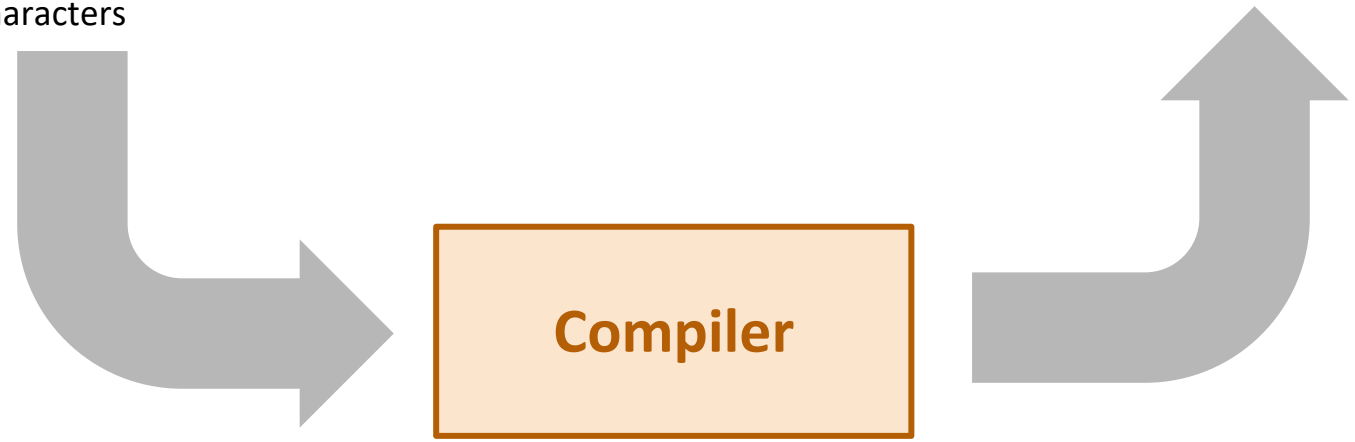
High-Level Language

Theory Definition: a string, from the set of strings making up a language

Practical Definition: a file containing a bunch of characters

```
(fact)
  @R0
  M=M+1
  @R1
  D=A
  @ifbranch
  D;JEQ
```

Assembly Language



The Compiler: Implementation

```
public int fact(int n) {
  if (n == 0) {
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High-Level Language

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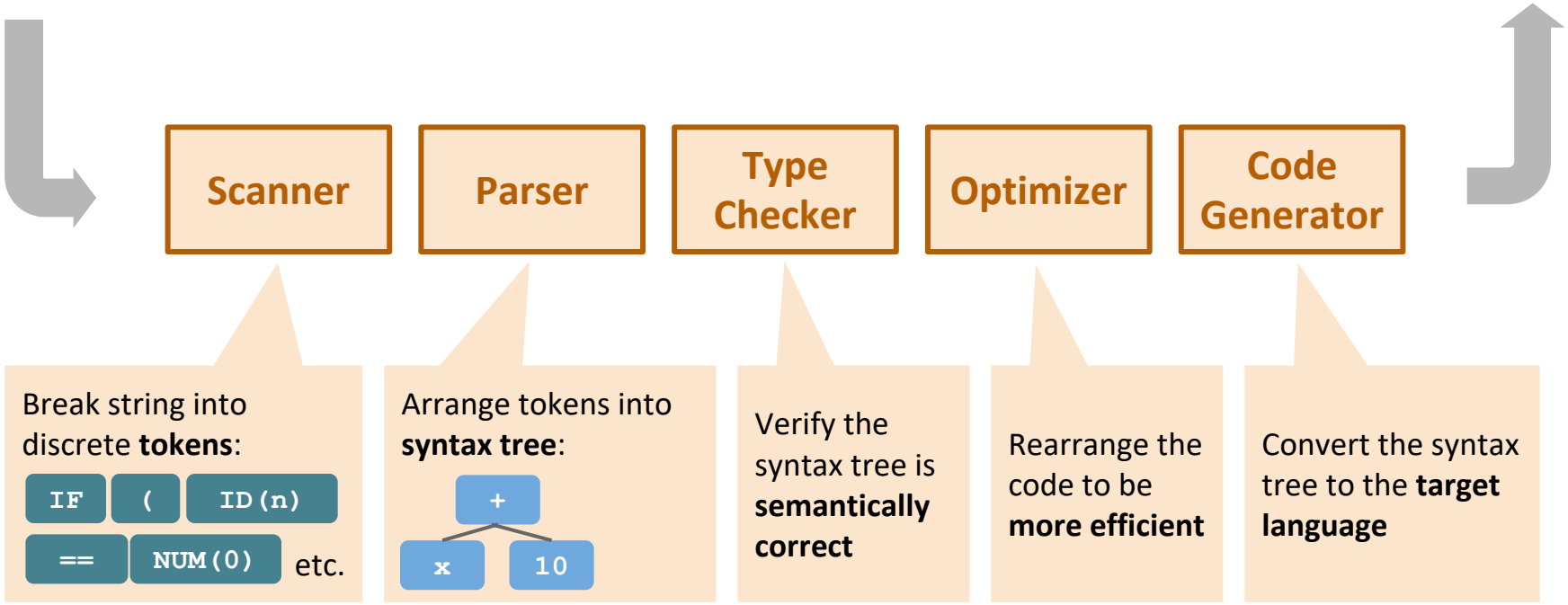
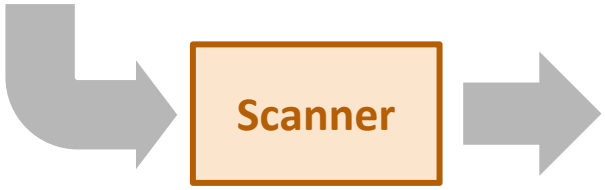
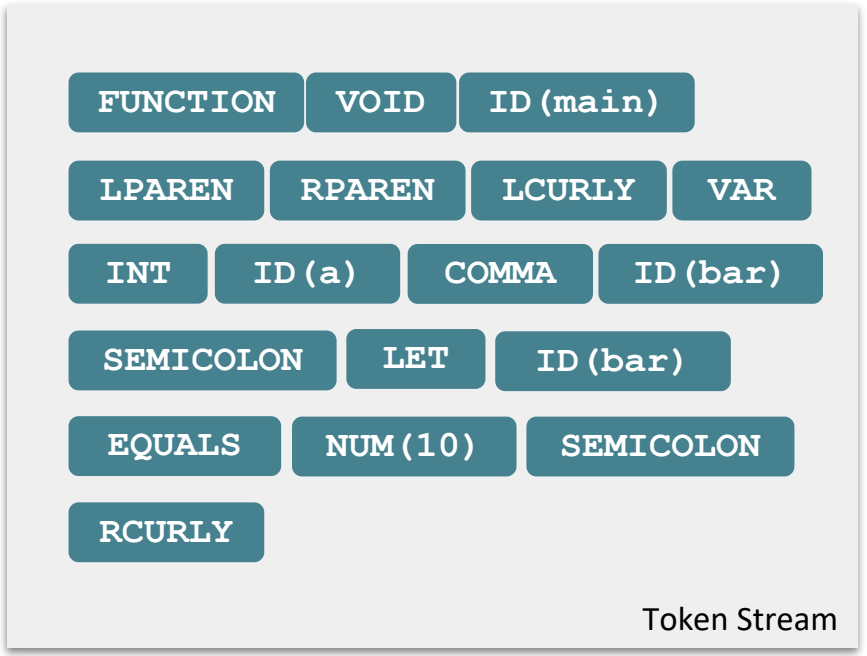


The Scanner

```
function void main() {
  var int a, bar;
  let bar=10; // init
}
```

Jack





- Reads a giant string, breaks down into tokens
  - Each token has a type: what role does this token play?
    - E.g., `LCURLY` is a type representing an occurrence of "{"
  - What types do we care about? The "building blocks" of our programming language:
    - Keywords (e.g., `FUNCTION`), operators (e.g., `EQUALS`), and punctuation (e.g., `SEMICOLON` or `COMMA`)

The Scanner

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  let bar=10; // init
}
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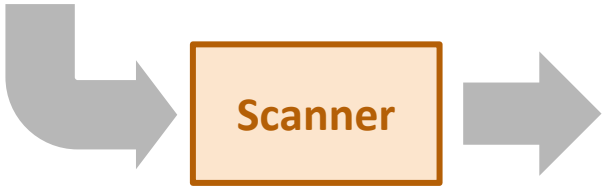


FUNCTION VOID ID(main)

LPAREN RPAREN LCURLY VAR

INT ID(a) COMMA ID(bar)

SEMICOLON LET ID(bar)

EQUALS NUM(10) SEMICOLON

RCURLY

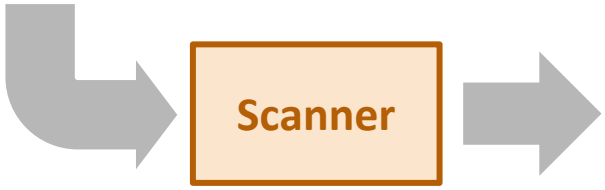
Token Stream

- In addition to a type, some tokens carry a value:
  - Identifiers (e.g., `ID(a)`)
  - Numbers (e.g., `NUM(10)`)
- Scanner should present a *clean* token stream
  - No whitespace or comments: the rest of the compiler only wants to consider things that change program meaning

The Scanner: How?

```
function void main() {
  var int a, bar;
  let bar=10; // init
}
```

Jack



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RCURLY

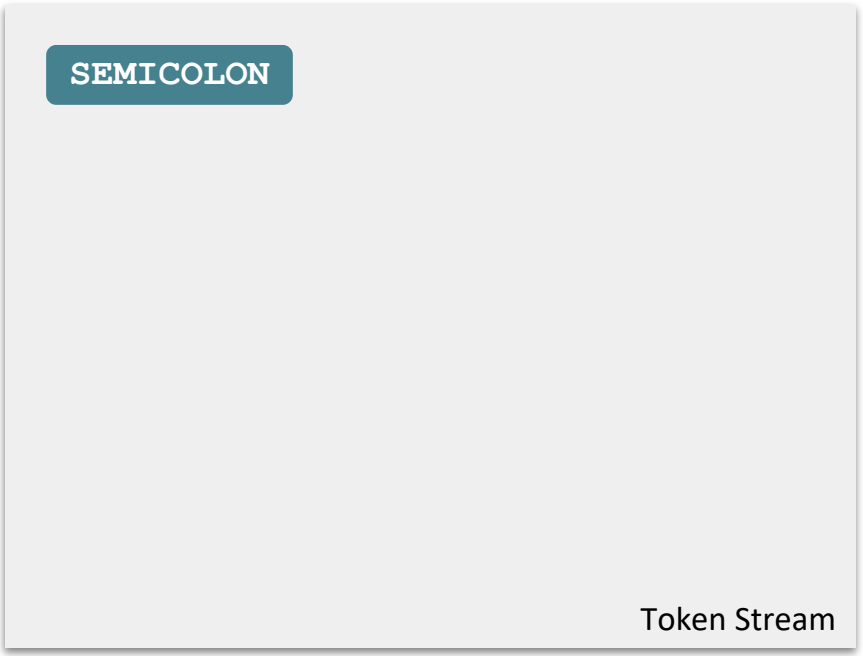
Token Stream

- What if we split the input program on whitespace, and match each segment to a token type? (E.g., "{" → LCURLY)
- Tempting, but we would end up with "a," "bar;" "bar=10;"
  - Whitespace is tricky: generally, we want to ignore it, but we can't count on it being there

The Scanner: How?

- How can we take a line of code in Jack and convert this into a token stream?
  - Keep cursor on current char
  - Break off a token when we complete one
  - If the next char could be part of this token, accumulate it

The Scanner: How?



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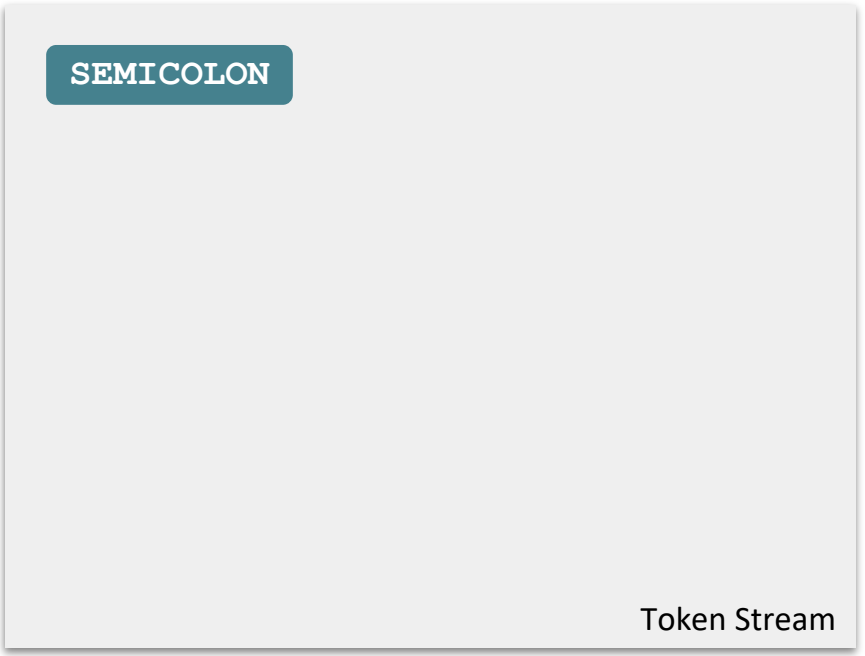

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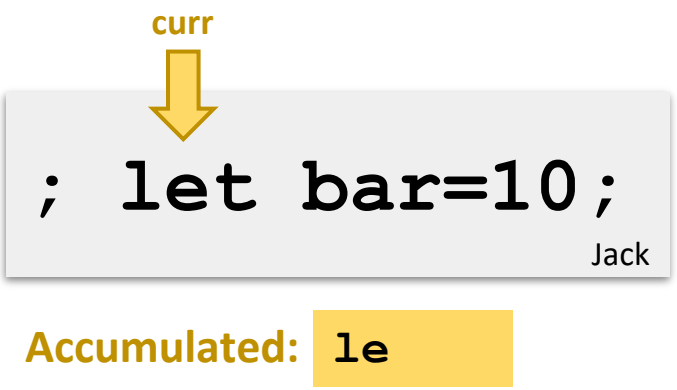

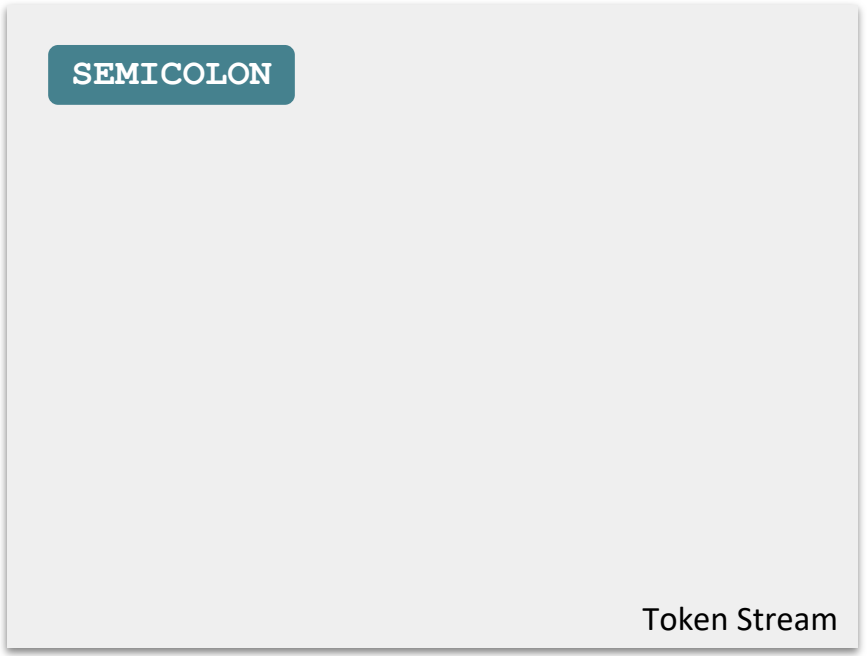

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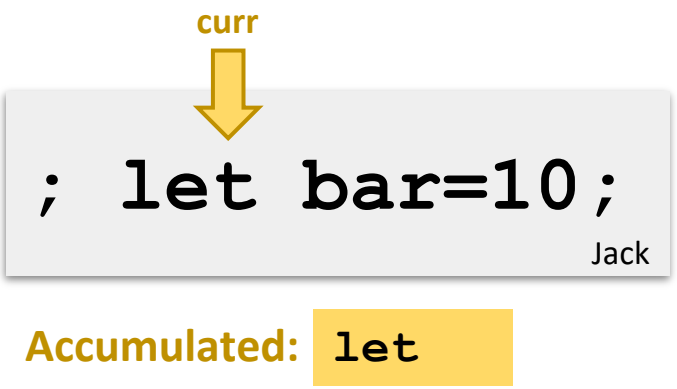

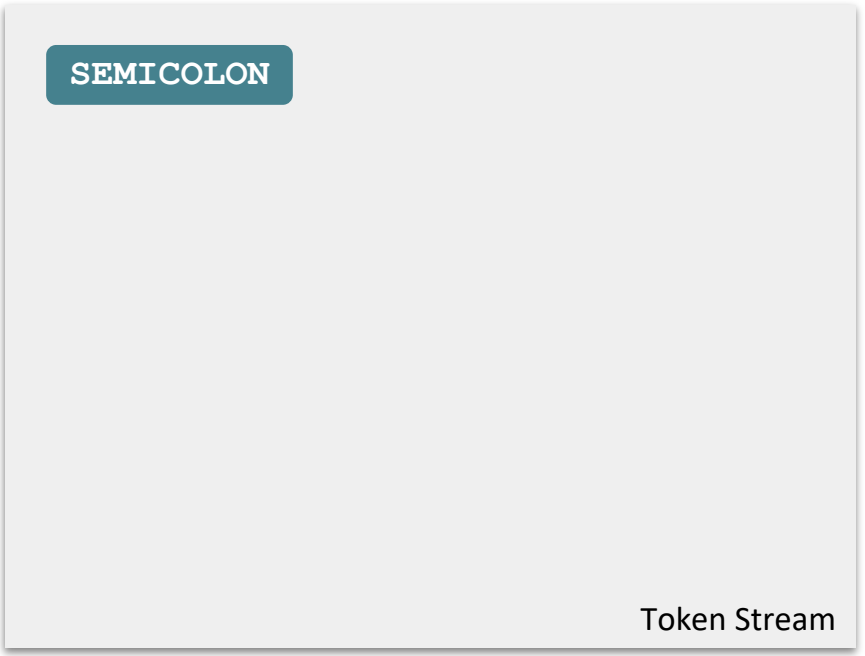

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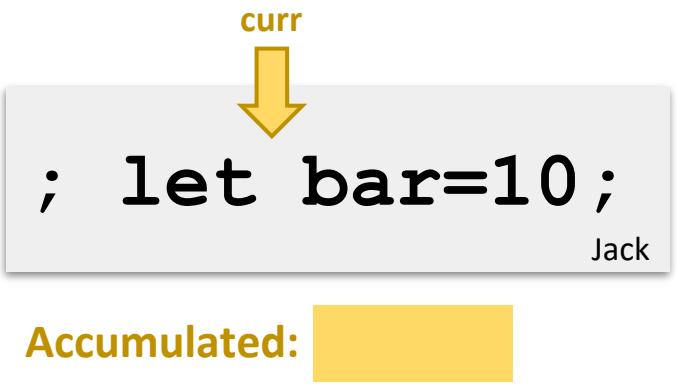

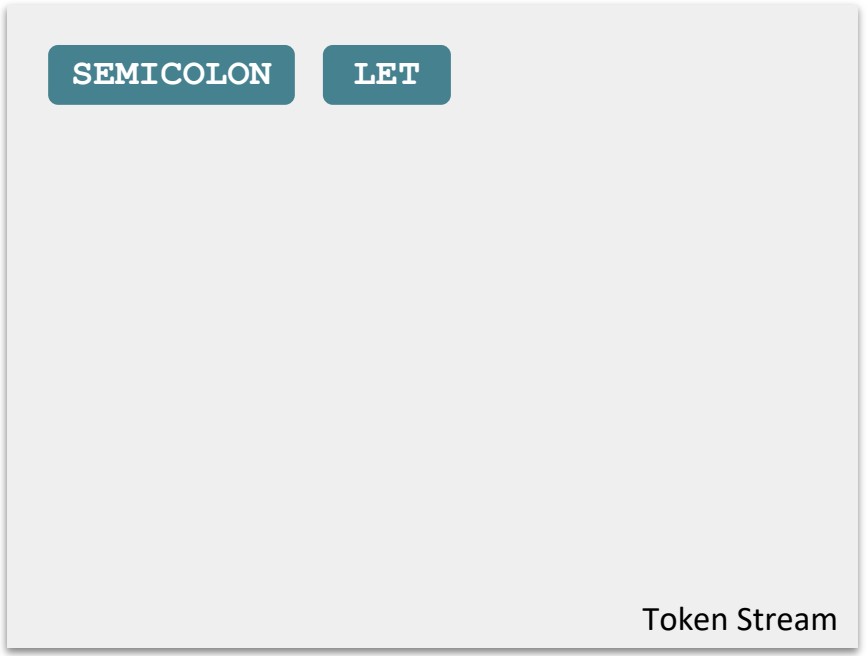

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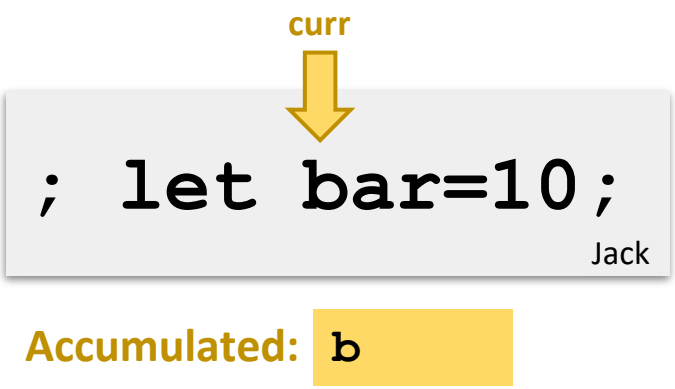

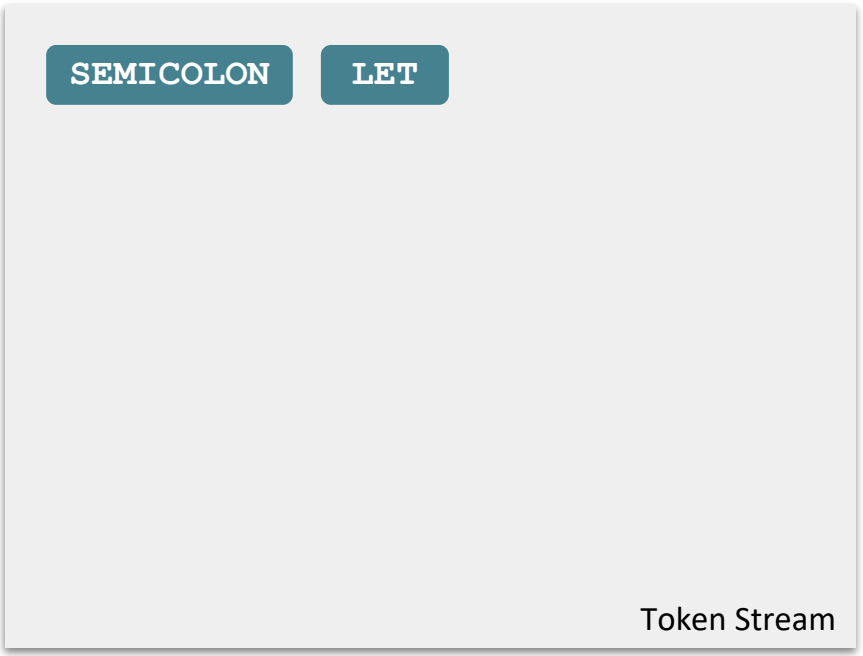

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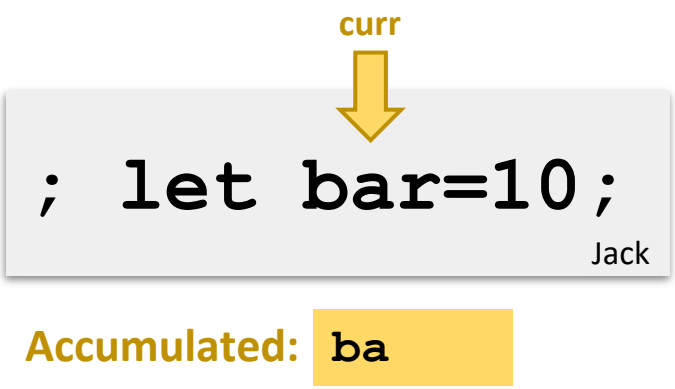

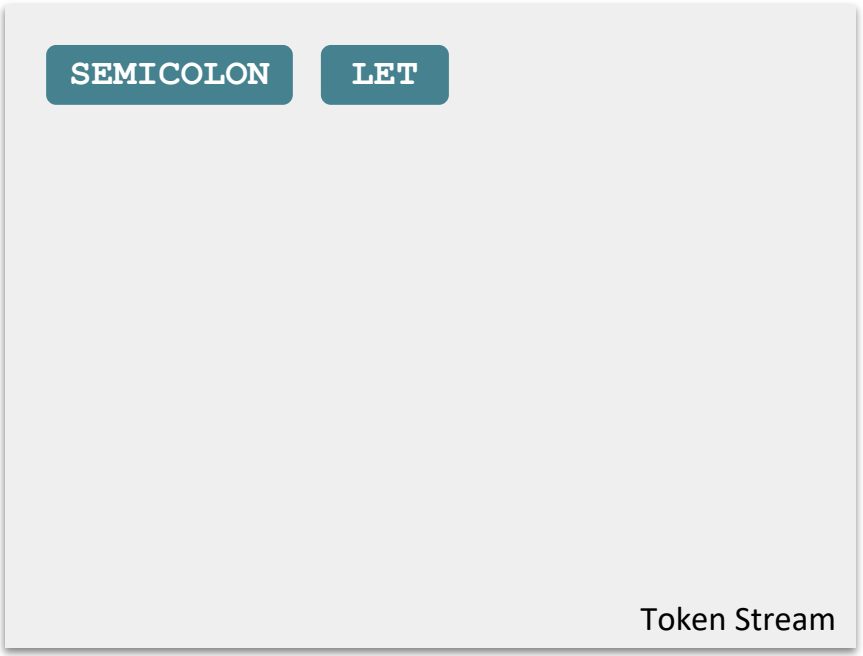

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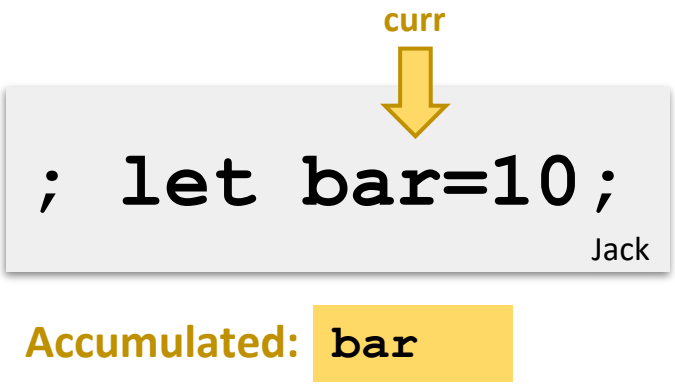

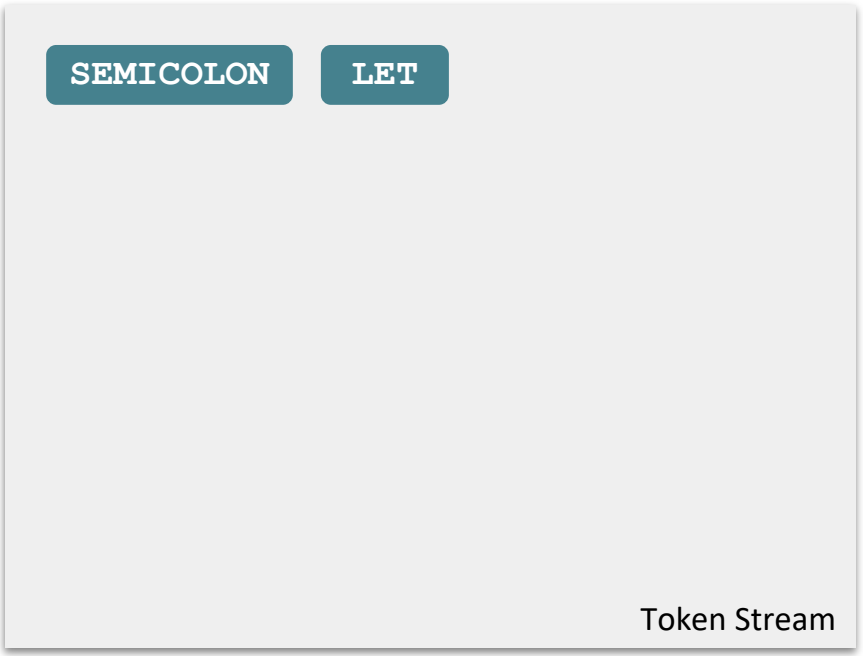

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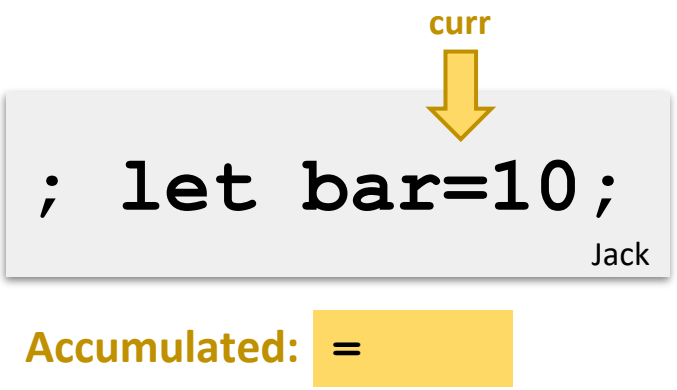

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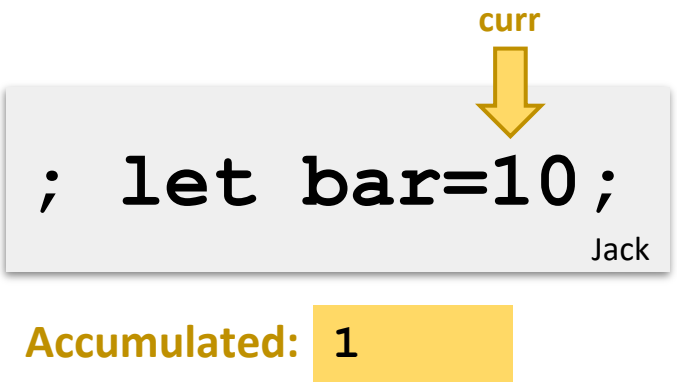

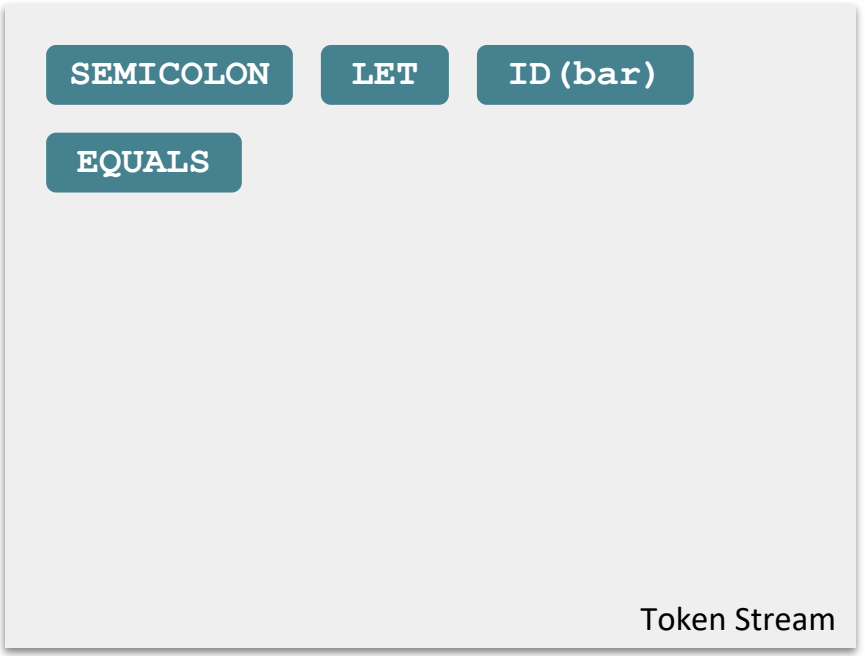

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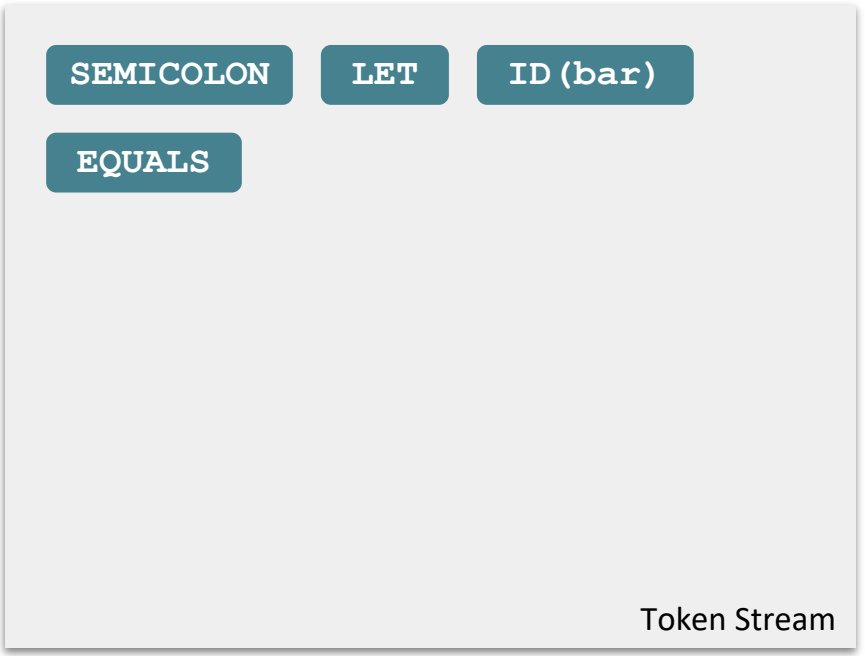

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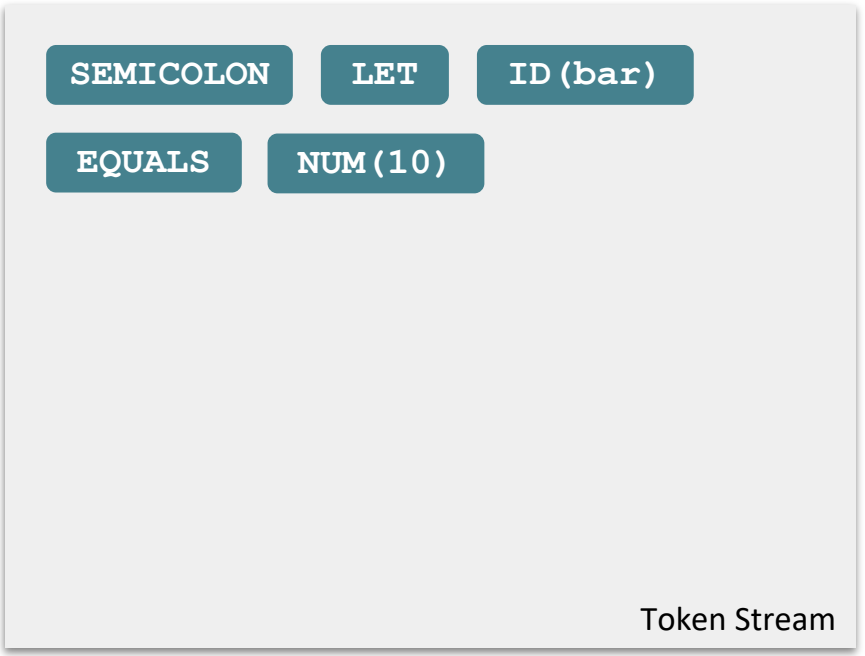

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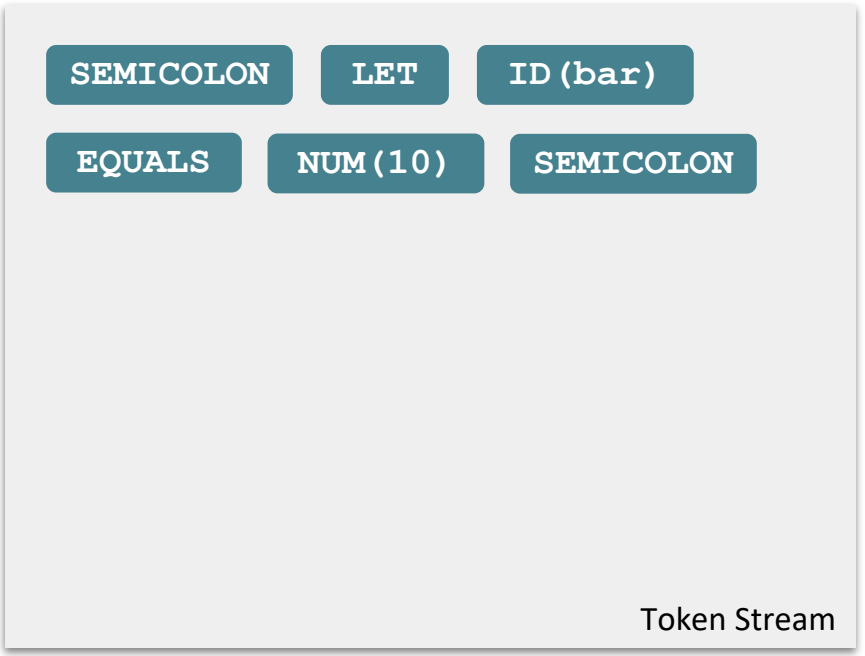

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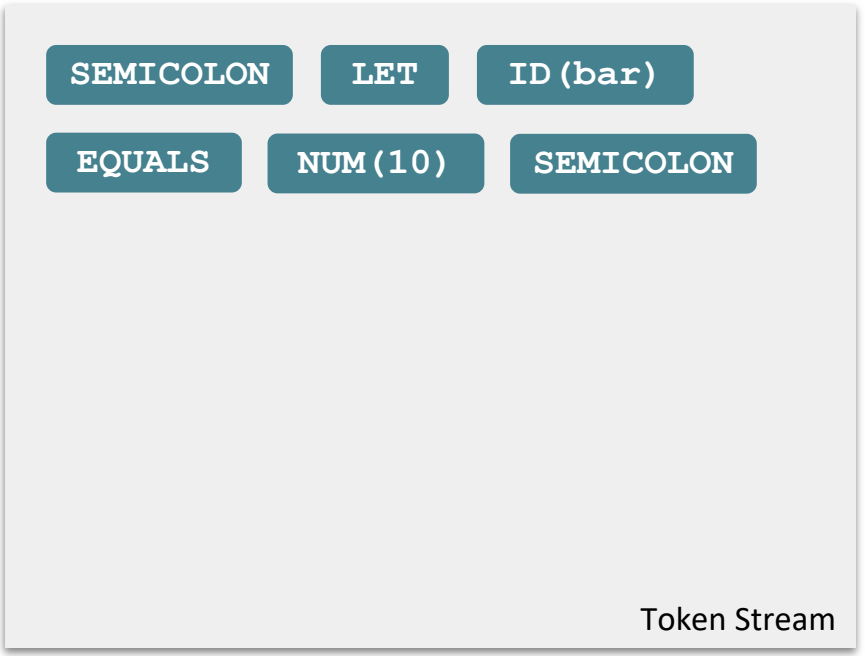

- How to distinguish built-in keywords (e.g., “let”) from identifiers (e.g., “bar”)?
  - When token is done, check against list of keywords

The Scanner: Why?

- Fundamentally: The compiler can't reason about a massive string, so we need to boil it down to its meaning
  - A great place to start is grouping characters that form a "word"

- Engineering-wise: Separation of concerns
  - A stream of tokens is an important abstraction for many file-processing tasks, not just compiling
  - Cleaning away whitespace and comments makes rest of compiler simpler

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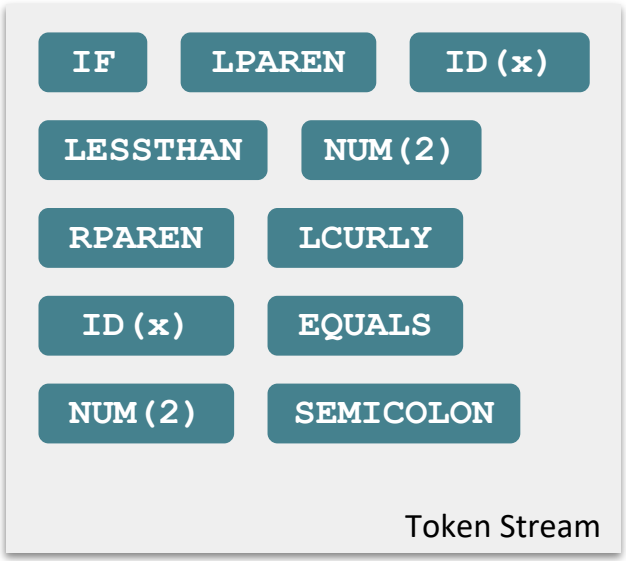
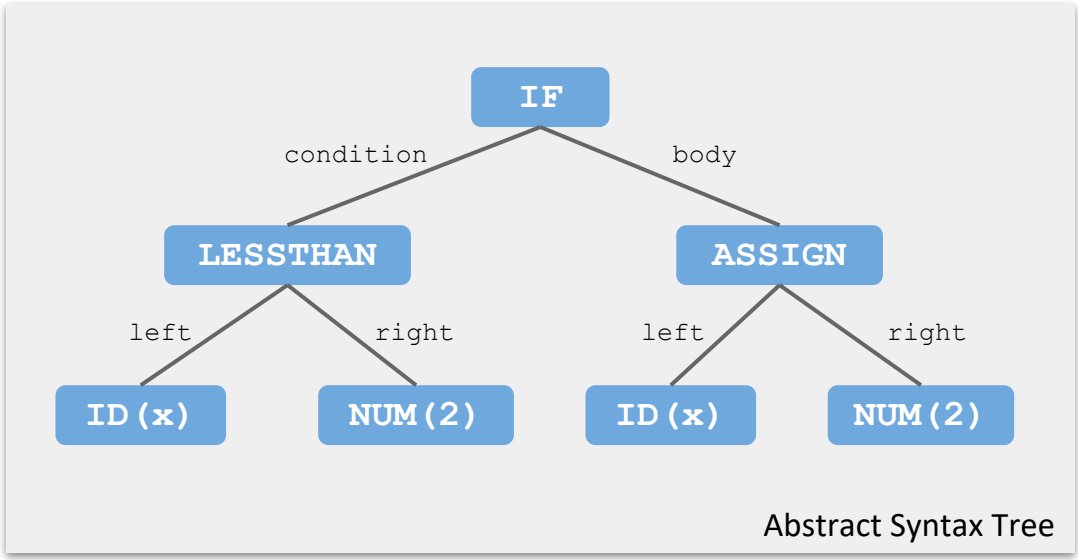
The Parser





- Takes in the *flat* token stream and outputs a *structured* tree representation of program constructs
- Result: an **Abstract Syntax Tree**
  - Captures the structural features of the program
  - **Important distinction**: cares about big-picture syntax (E.g., entire `if` statement) rather than nitty-gritty syntax (E.g., semicolons, parentheses, even word "if" used to write that `if` statement)

Describing a Programming Language

- Many ways to define programming languages, some formal
  - We won't cover language definition in depth
  - See CSE 341, CSE 401, CSE 402

- Example: Statements vs. Expressions

Statements
Perform an action

- Assignment Statement

```
x = y;
```

- If Statement

```
if (x == 0) {
  x = y;
}
```

Expressions
Evaluate to a result

- Operators

```
x == 0;
```

- Variable

```
x
```

- Constant

```
24
```

Describing a Programming Language

- These broad categories lend themselves well to recursive definitions
  - Easily express all possible configurations of the language constructs

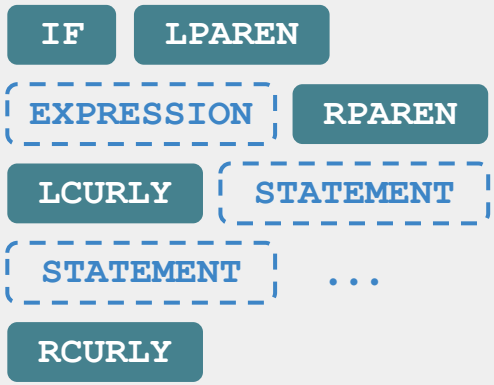
Symbolic Example

```
if (x == 0) {
  x = y;
}
```

General Definition of an `if` Statement

```
if ( EXPRESSION )
{
  STATEMENT
  STATEMENT
    ...
}
```

Token Stream Definition



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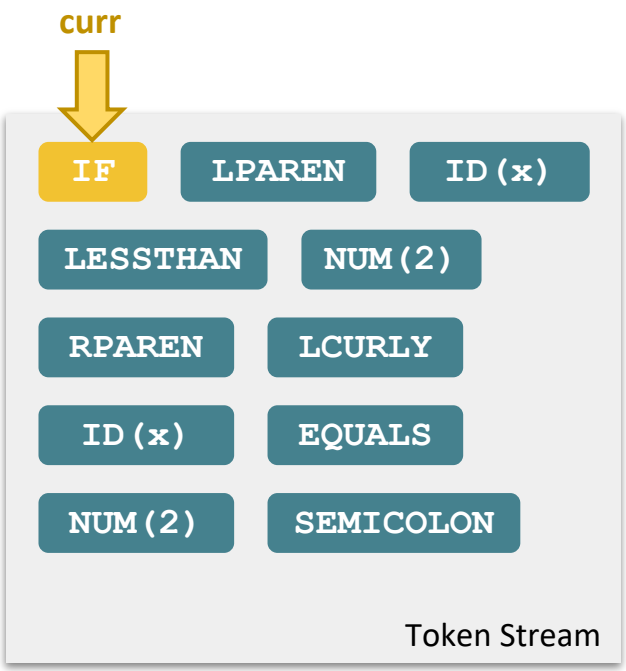
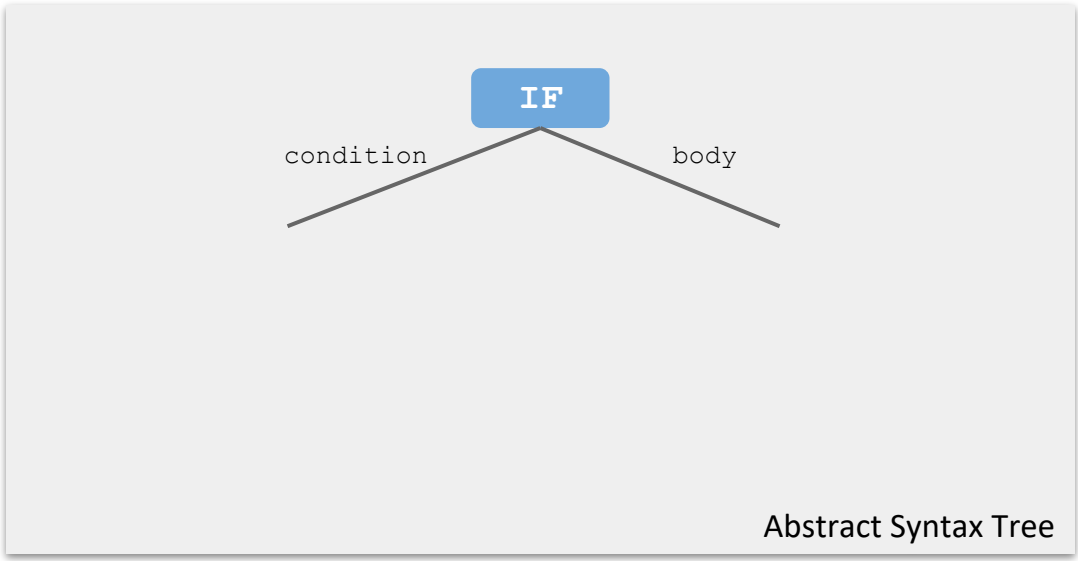
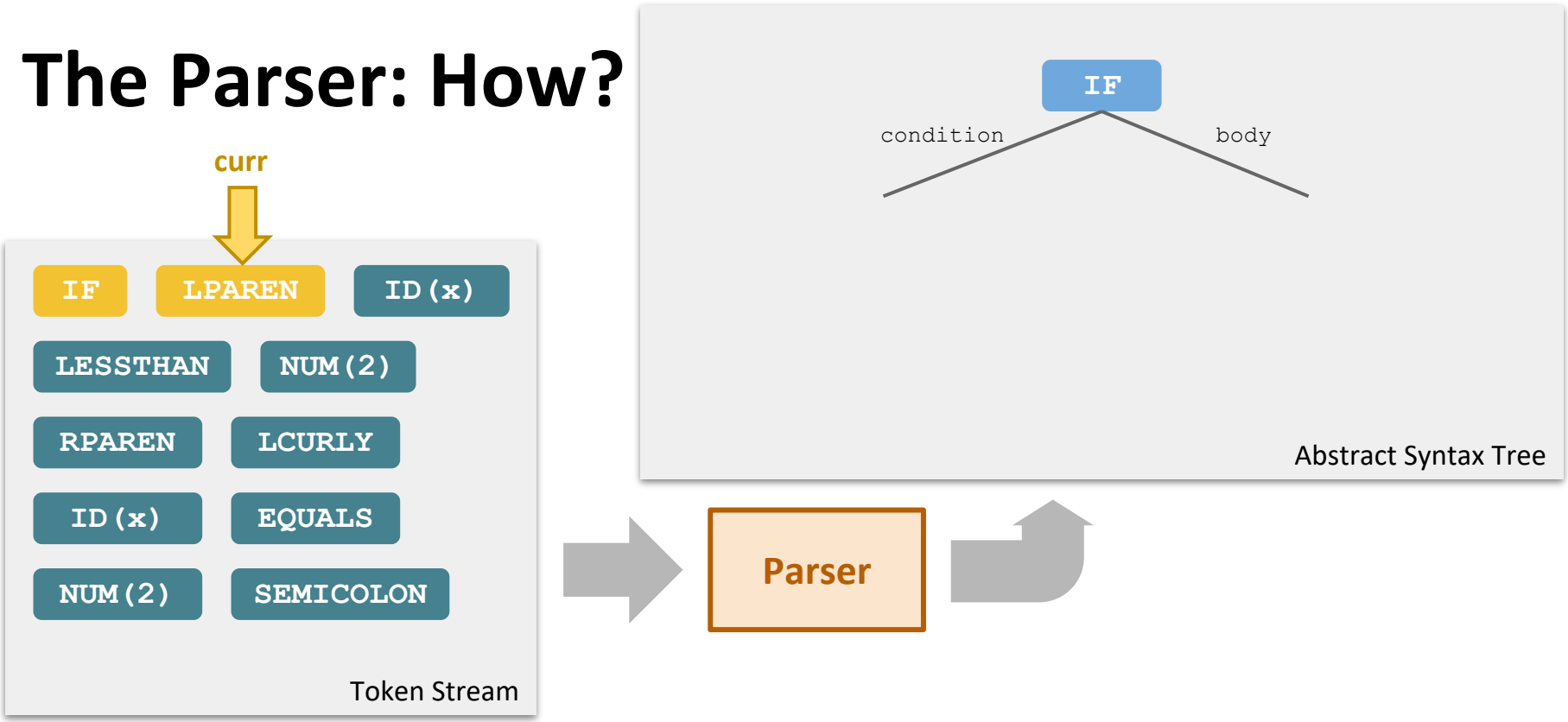




- Like a scanner: pass token stream, building up as we go
- Intuition: If we see `IF` and `LPAREN`, we are entering an if statement and next we must see a complete expression
  - Keep reading until we have a complete expression (recursively parse that) and attach on the condition side of the `IF`

The Parser: How?



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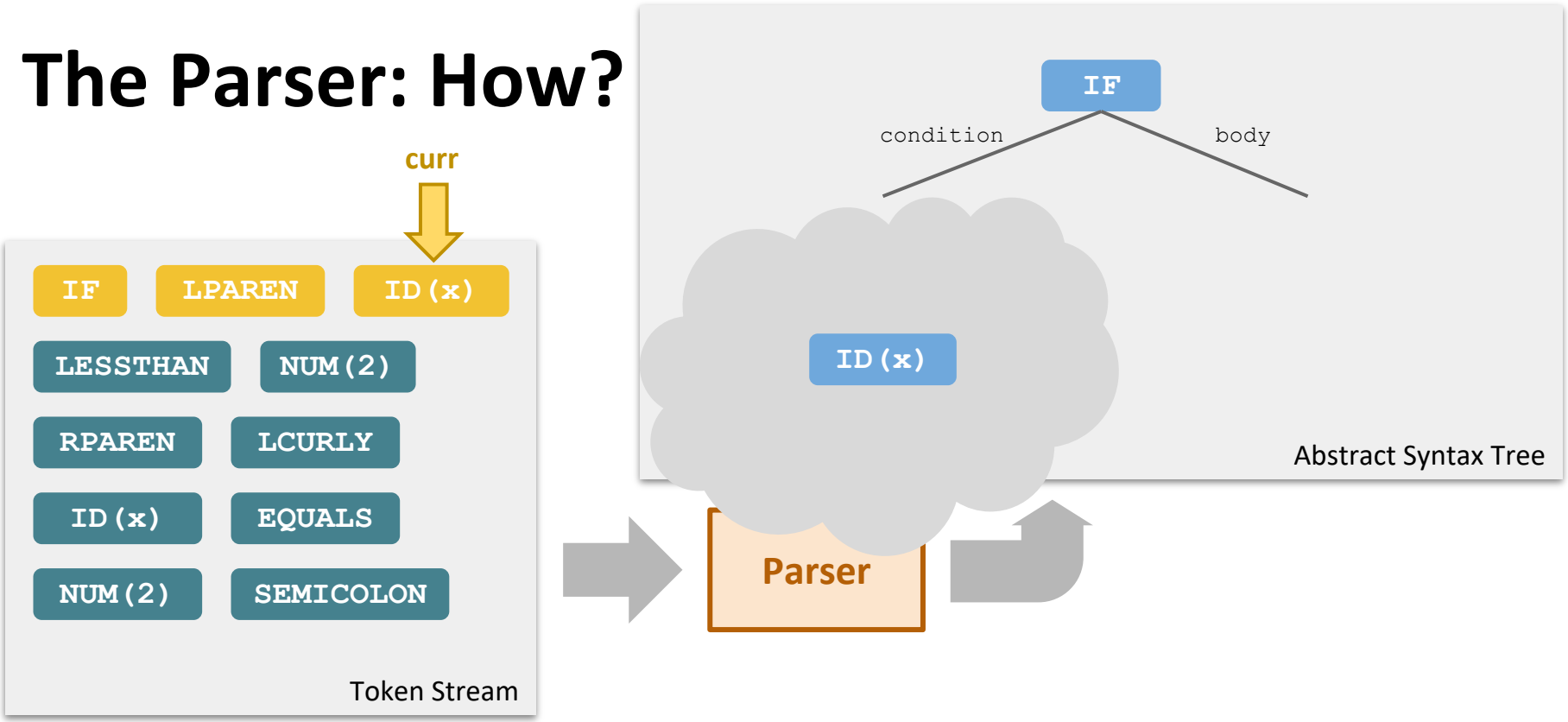

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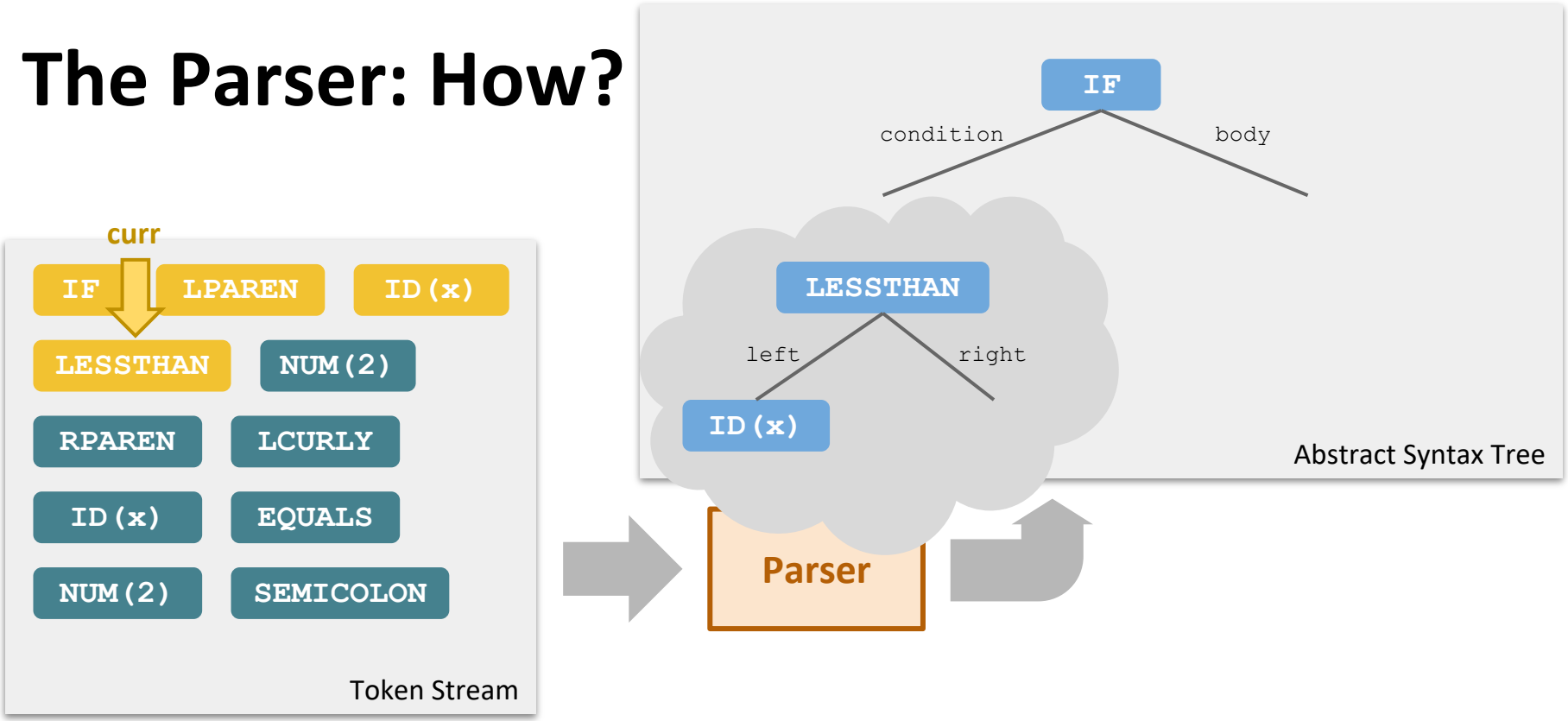

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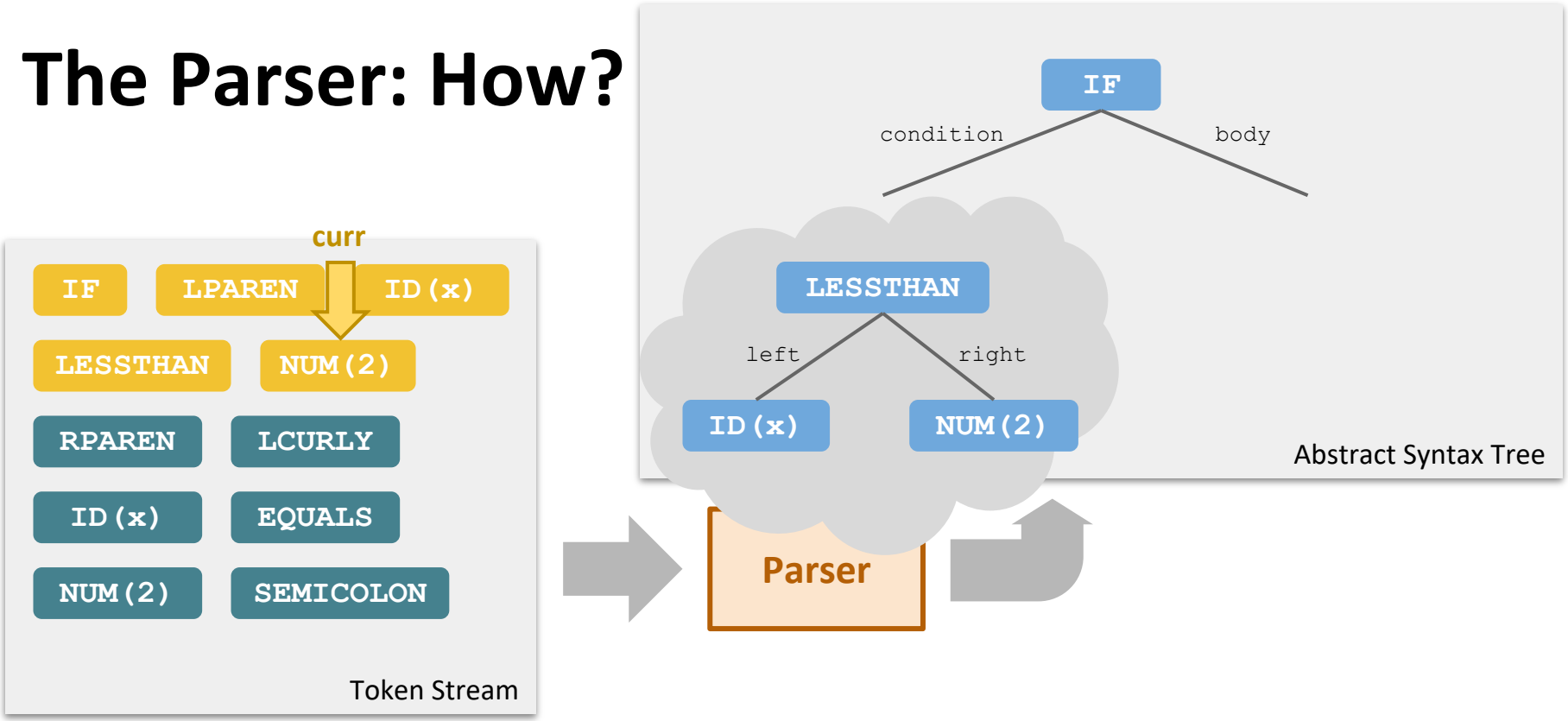

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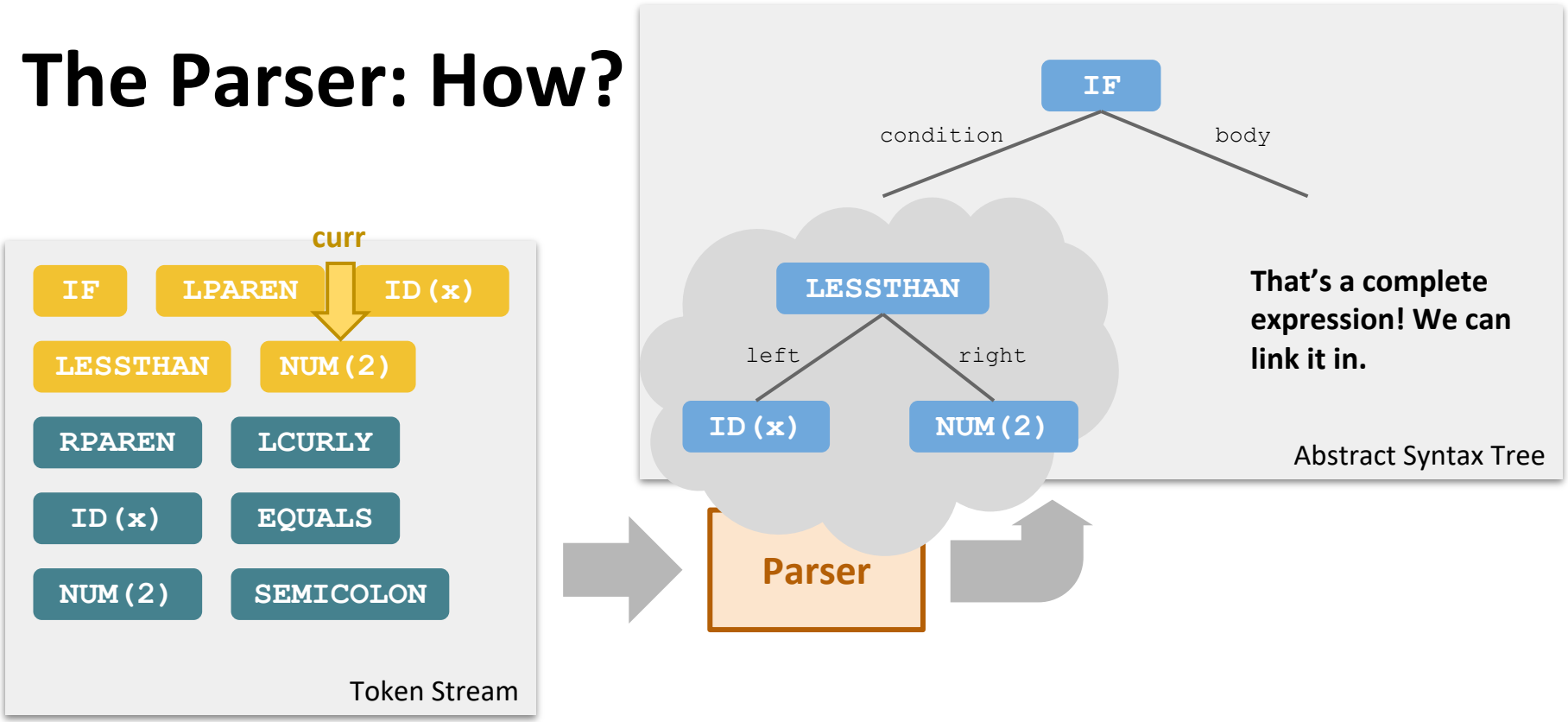

- Like a scanner: pass token stream, building up as we go
- Intuition: If we see `IF` and `LPAREN`, we are entering an if statement and next we must see a complete expression
  - Keep reading until we have a complete expression (recursively parse that) and attach on the condition side of the `IF`

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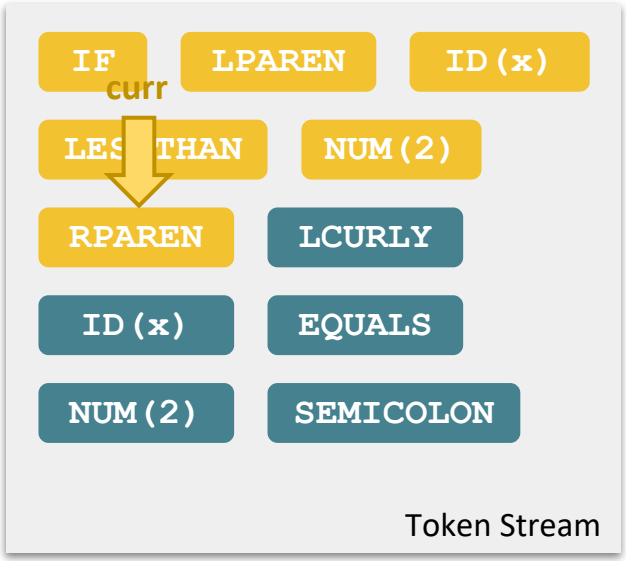

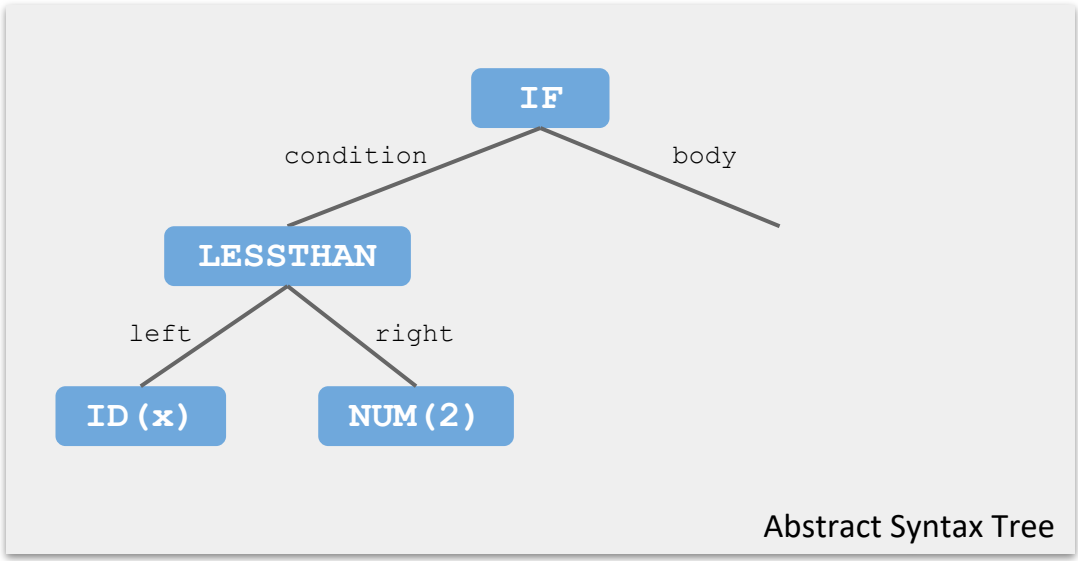

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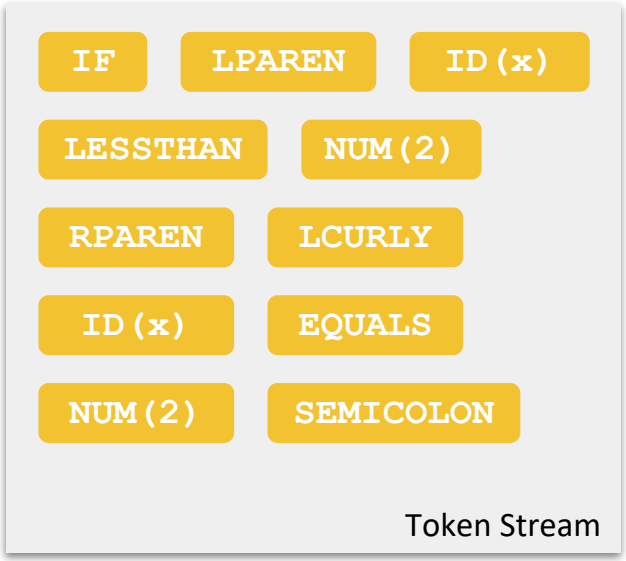

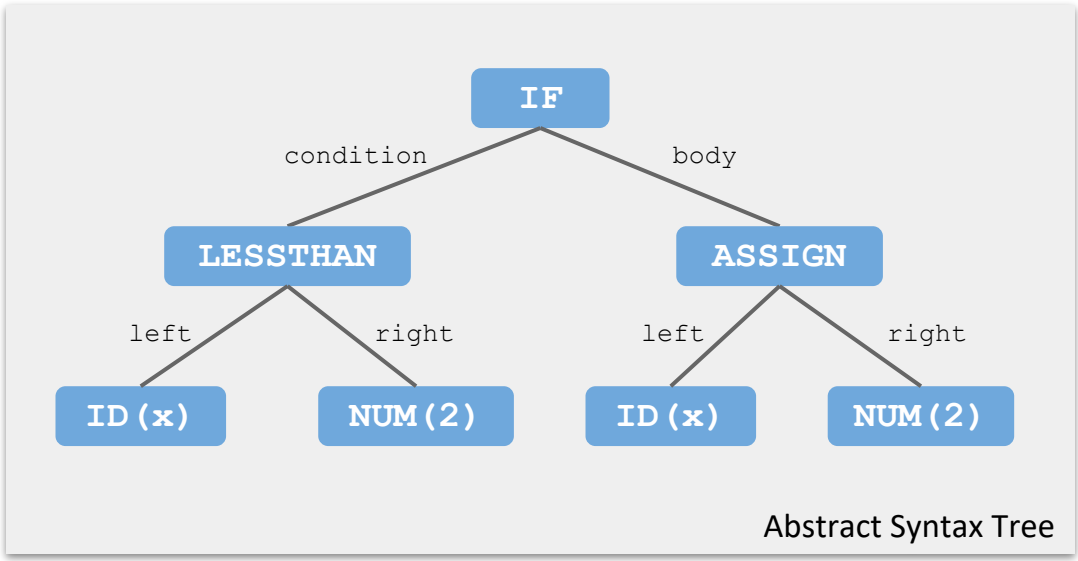

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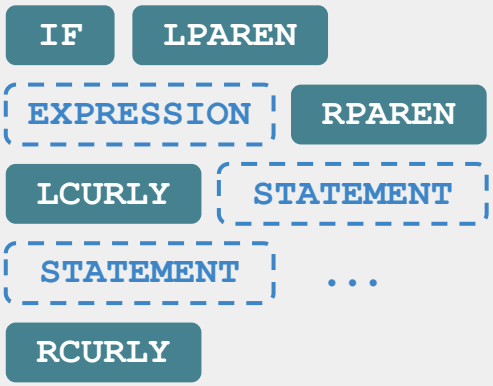
The Parser: How?

- Implementing the Parser is essentially encoding the token stream definition, which can be recursive

Token Stream Definition




```
parseStatement() {
   ...
   if (currToken() == IF) {
         next() //consume "if"
         next() //consume "("

         // consumes tokens in expr
         e = parseExpression()

         next() // consume ")"
         next() // consume "{"

         // consumes tokens in stmt
         s = parseStatement()
         ...
             return new If(e, s)
   }
   ...
}
```

Lecture Outline

- Professional Networking in College
  - Benefits of Building Connections, Networking Strategies
- **Exploring the Compiler Phases**
  - Scanner: Process of Tokenizing an Input File
  - Parser: Making Meaning From Tokens Through ASTs
  - **Type Checking, Optimization, and Code Generation**
- Project 7 Overview
  - Midterm Corrections, Professor Meeting Report

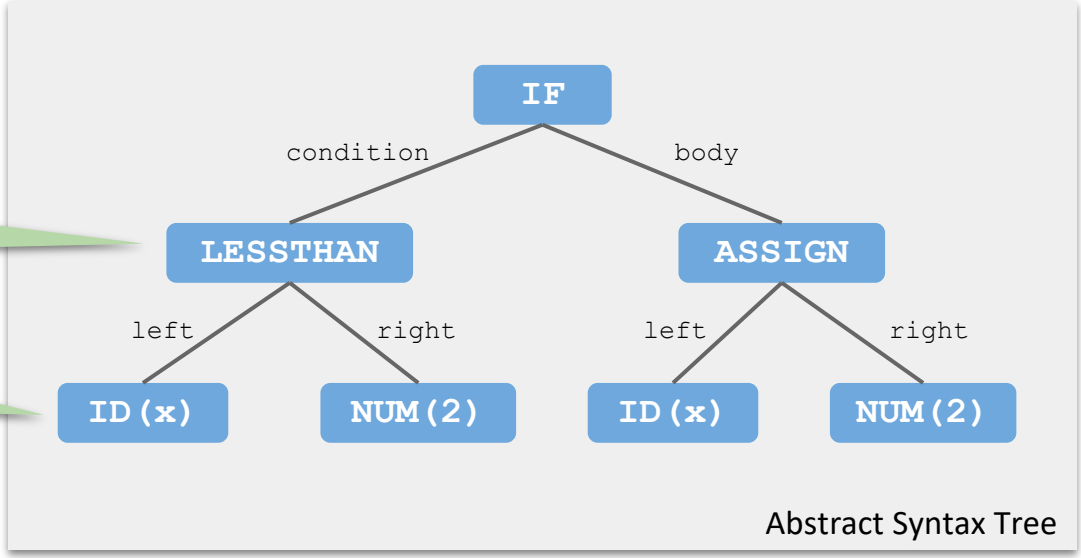
Type Checking (Semantic Analysis)

- Given the abstract syntax tree, run checks over it to ensure that it fits within constraints of the language
  - Do the types match up?

- Collect additional info for code generation, such as number and the type of arguments in each function

Does this expression evaluate to a Boolean?

Is the variable "x" defined at this point?



Optimization

- Code improvement: change correct code into semantically equivalent but "better" code

- Example: If something is computed every iteration of a while loop, the compiler could yank that computation out and compute it just once before entering the loop
  - Here, "better" means faster

- But requires caution: what if the value changes on each iteration of the loop?
  - "Semantically equivalent" means user sees same outcome

Code Generation

- One way to think of compiler is converting from string in source language to → its actual, abstract "meaning"
- Code generation is converting that "meaning" into a string in the destination language
- At its core, all that the code generation phase does is read through the Abstract Syntax Tree and print a set of statements depending on the AST node

Lecture Outline

- Professional Networking in College
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- Introduction to Compilers
  - Scanner: Process of Tokenizing an Input File
  - Parser: Making Meaning From Tokens Through ASTs
  - Type Checking, Optimization, and Code Generation
- **Project 7 Overview**
  - **Midterm Corrections, Professor Meeting Report**

Project 7 Overview

- Part I: Midterm Corrections
  - Due next Thursday (2/23) at 11:59pm (**no late days** can be used on midterm corrections)
  - Open-notes, open-tools
  - Only need to redo the problems that you missed
  - 50% of the points you earn back from midterm corrections will be added to your original midterm score
  - You can calculate your new midterm score using this formula:

$$Original\ Midterm\ Score + \frac{New\ Midterm\ Score - Original\ Midterm\ Score}{2}$$

- Part II: Professor Meeting Report
  - Due in two weeks on 3/2 at 11:59pm
  - Schedule the meeting as early as possible

Project 7, Part I: Midterm Corrections

- Review feedback from the course staff, celebrate the questions you got right, reflect on which areas you can continue to grow in

- If you think a problem was graded incorrectly, feel free to submit a regrade request on Gradescope
  - Don't be afraid to challenge our grading
  - This is a great learning opportunity for us all

- You can earn up to 50% of the points back that you missed on the midterm

Professor Meeting Report Discussion

In groups, spend 4-6 minutes discussing these questions:

- Which professors are you thinking about reaching out to? Why do you choose them?
- What questions would you ask to your professor? Why did you choose those questions?
- How can you apply the skill of meeting with professors in different contexts to help you succeed as a UW student? In your career?

Post-Lecture 14 Reminders

- **Project 6: Mock Exam Problem & Building a Computer due tonight (2/16) at 11:59pm**
- Project 7, Part I: Midterm Corrections due next Thursday (2/23) at 11:59pm
- Eric has office hours after class in CSE2 153
  - Feel free to post your questions on the Ed board as well