Phases of a Compiler

scanner

- Compiler starts by seeing only characters

```
if (a < 4) {
   b := 5
}
```

scanner

- Compiler starts by seeing only text
  - Not very easy to read!

```
'i' 'f' '␣' '(' 'a' '<'
'4' ')' '␣' '{' '\n' '\t'
'b' ':' '=' '5' '\n' '}'
```

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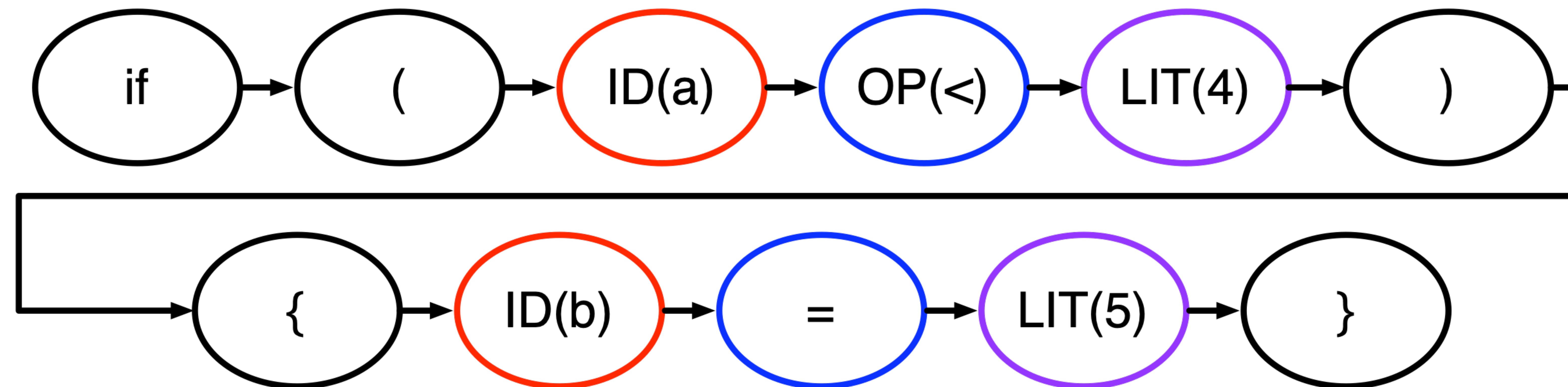
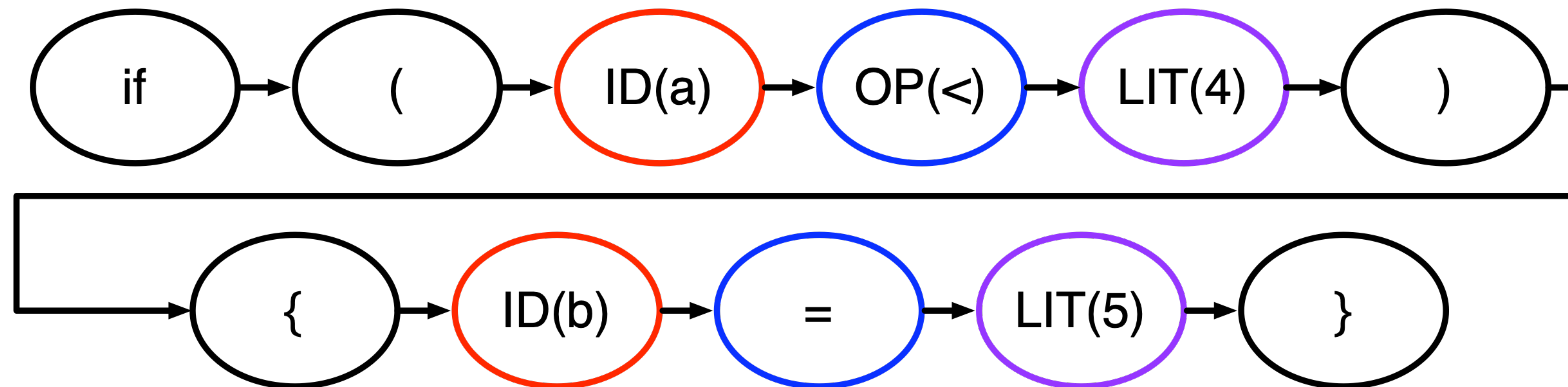
- Scanner converts this into a series of tokens
  - One item for each “word” in the program



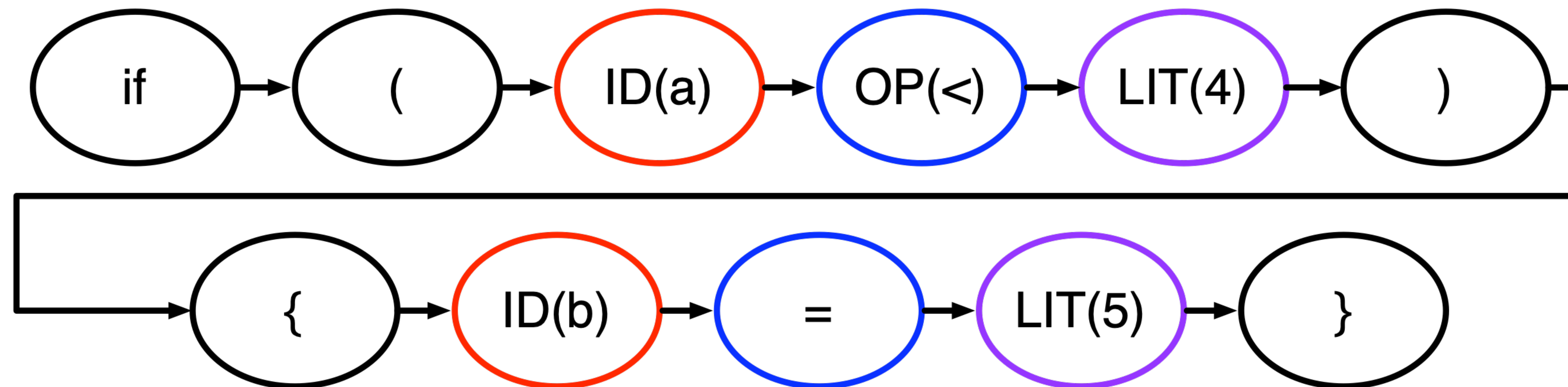
scanner

- Compiler starts by seeing only text
  - Not very easy to read!
- Scanner converts this into a series of tokens
  - One item for each "word" in the program
- But we still do not know what the *structure* of the program is



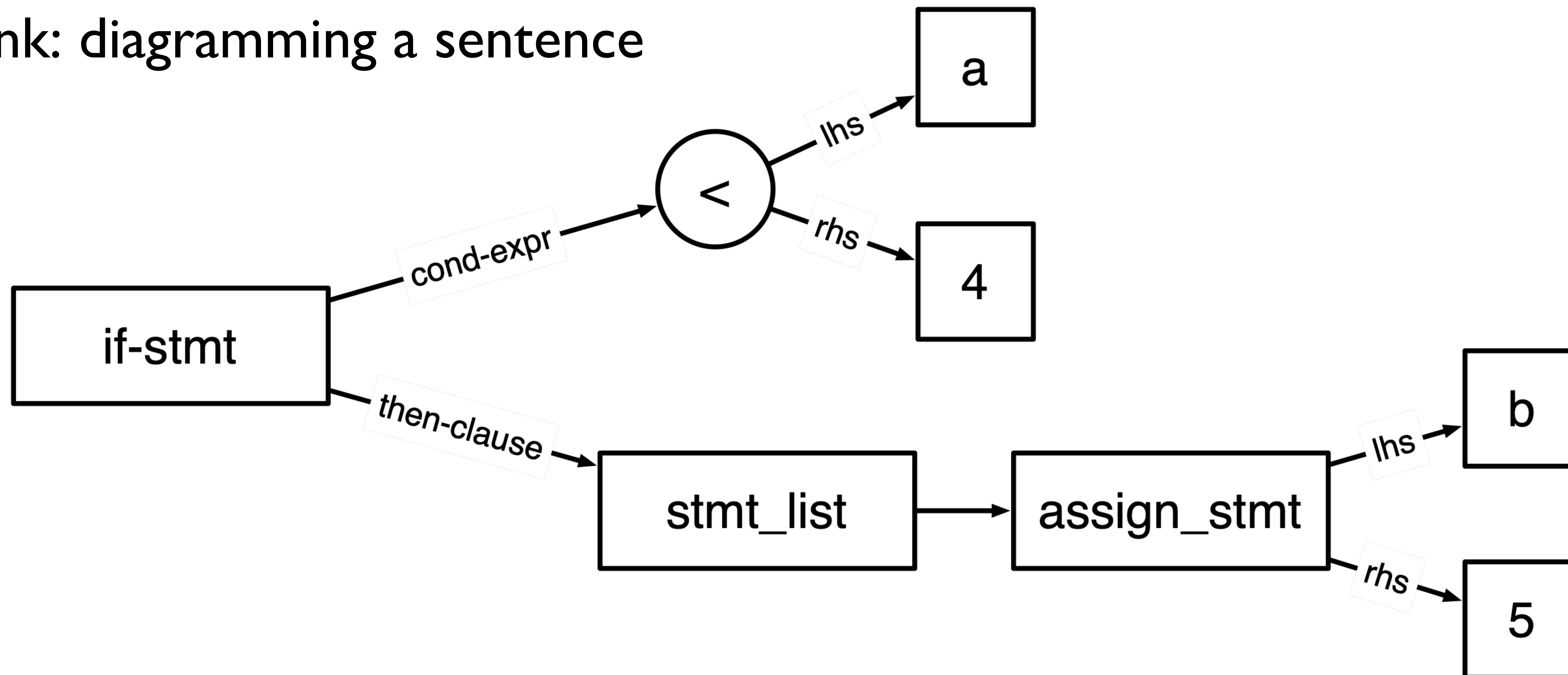
parser

- Converts string of tokens into a parse tree or an abstract syntax tree.
- Captures syntactic structure of code (i.e., "this is an if statement, with a then-block")



parser

- Converts string of tokens into a parse tree or an abstract syntax tree.
- Captures syntactic structure of code (i.e., “this is an if statement, with a then-block”)
  - Think: diagramming a sentence



semantic actions

- Interpret the semantics of syntactic constructs
  - Note that up until now we have only been concerned with what the syntax of the code is
  - What’s the difference?

syntax vs semantics

- Syntax: “grammatical” structure of language
  - What symbols, in what order, are a legal part of the language?
  - What is a valid “sentence”?
- But something that is syntactically correct may mean nothing!
  - “colorless green ideas sleep furiously”
- Semantics: meaning of language
  - What does a particular set of symbols, in a particular order, mean?
  - What does it mean to be an if statement?
  - “evaluate the conditional, if the conditional is true, execute the then clause, otherwise execute the else clause”

a note on semantics

- How do you define semantics?
  - Static semantics: properties of programs
    - All variables must have a type
    - Expressions must use consistent types
    - Can define using *attribute grammars*
  - Dynamic semantics: how does a program execute?
    - Documentation
    - Can define an *operational* or *denotational semantics* for a language
      - Well beyond the scope of this class!
- For many languages, "the compiler is the specification"

semantic actions

- Actions taken by compiler based on the semantics of program statements
  - Building a *symbol table*
  - Generating *intermediate representations*

symbol tables

- A list of every declaration in a program
  - Variables, functions, types, etc.
- Keeps track of key information about a symbol
  - Variables: scope, type, location (for global variables)
  - Structure definitions: names of fields, types of fields, layout of structure
  - Functions: return type, argument types and names
  - …

intermediate representation

- Also called *IR*
- A (relatively) low level representation of the program
- But not machine-specific!
- One example: three address code

```
       bge a, 4, done
       mov 5, b
done:  //done!
```

- Each instruction can take at most three operands (variables, literals, or labels)
  - Note: no registers!

optimizer

- Transforms code to make it more efficient
- Different kinds, operating at different levels
  - High-level optimizations
    - Loop interchange, parallelization
    - Operates at level of AST, or even source code
  - Scalar optimizations
    - Dead code elimination, common sub-expression elimination
    - Operates on IR
  - Peephole optimizations
    - Strength reduction, constant folding
    - Operates on small sequences of instructions

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C++ source #1

A Save/Load + Add new... Vim CppInsights Quick-bench C++

```cpp
bool collatz(unsigned __int128 x) {
    while (true) {
        if (x <= 1)
            return true;

        if (x % 2)
            x >>= 1;
        else
            x = 3*x + 1;
    }
}
```

x86-64 clang (trunk) (C++, Editor #1, Compiler #1)

x86-64 clang (trunk) -O3

A Output... Filter... Libraries + Add new... Add tool...

```asm
collatz(unsigned __int128): # @collatz(unsigned __int128)
  mov al, 1
  ret
```

https://gcc.godbolt.org/z/Wrfeo18of

code generation

- Generate assembly from intermediate representation
  - Select which instructions to use
  - Schedule instructions
  - Decide which registers to use

```
      bge a, 4, done
      mov 5, b
done: //done!
```

```
     lw r1 a
     li r2 4
     bge r1 r2 done
     li r3 5
     sw r3 b
done:
```

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```
       bge a, 4, done
       mov 5, b
done:  //done!
```

```
     li r1 4
     lw r2 a
     blt r1 r2 done
     li r1 5
     sw r1 b
done:
```

next: putting it all together

Or: How do these phases interact?