

CS 152: *Programming Language Paradigms*



Modules, Structs, Hashes, and Operational Semantics

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Modules



Review Modules from HW 1

(in-class)

How do we organize code in Java?

- **Packages** provide units of code
- **Keywords** specify method access

In Java, keywords specify access

- **public**
- **protected**
- no keyword (package access)
- **private**

Organizing Code in Racket

- *Exports* specify public values:
(provide big-add)
- *Imports* specify code dependencies:
(require "big-num.rkt")

Structs and Hashes



Structs

- *Structures* allow us to create more sophisticated data structures:
`(struct name (field1 field2 ...))`
- Once we have a structure, we can *destructure* it with the **match** keyword to get at the contents.
- <Example in class>

Hashes

- Hashes are maps of key/value pairs.
- *Unlike* Java, hashes are immutable.
- <example in class>

Formal Semantics

Why do we need
formal semantics?


Everyone knows what an
if statement does, right?

```
if true then
```

```
    x = 1
```

```
else
```

```
    x = 0
```



At the end of this code
snippet, the value of x
will be 1

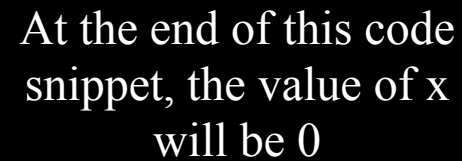
Everyone knows what an
if statement does, right?

```
if false then
```

```
    x = 1
```

```
else
```

```
    x = 0
```



At the end of this code
snippet, the value of x
will be 0

Everyone knows what an
if statement does, right?

```
if 0 then  
  x = 1
```

Will x be set to 0,
like in C/C++?

```
else  
  x = 0
```

Will x be set to 1,
like in Ruby?

Or will it be an
error, like in Java?

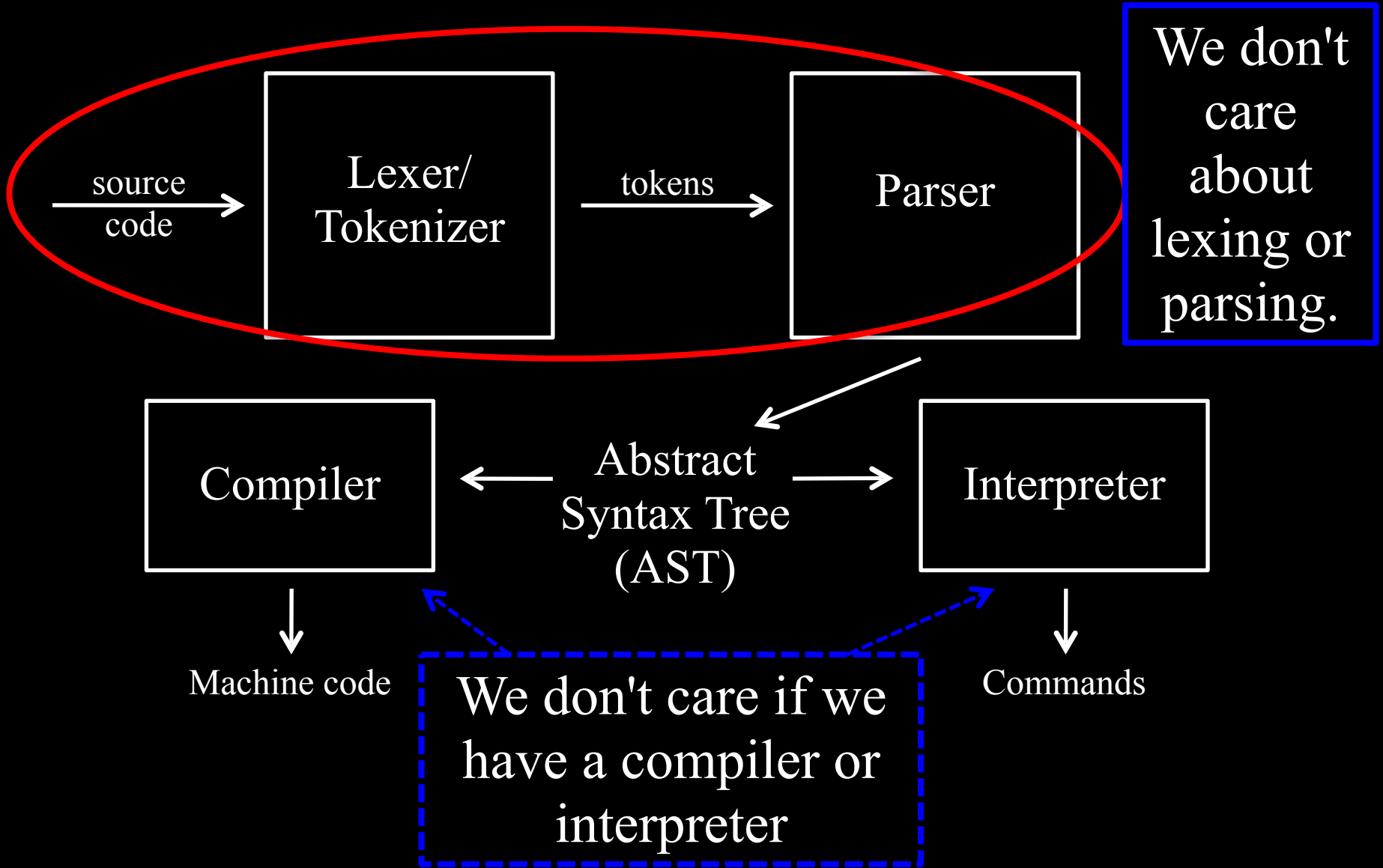
Everyone knows what an
if statement does, right?

```
x = if true  
    then 1  
    else 0
```

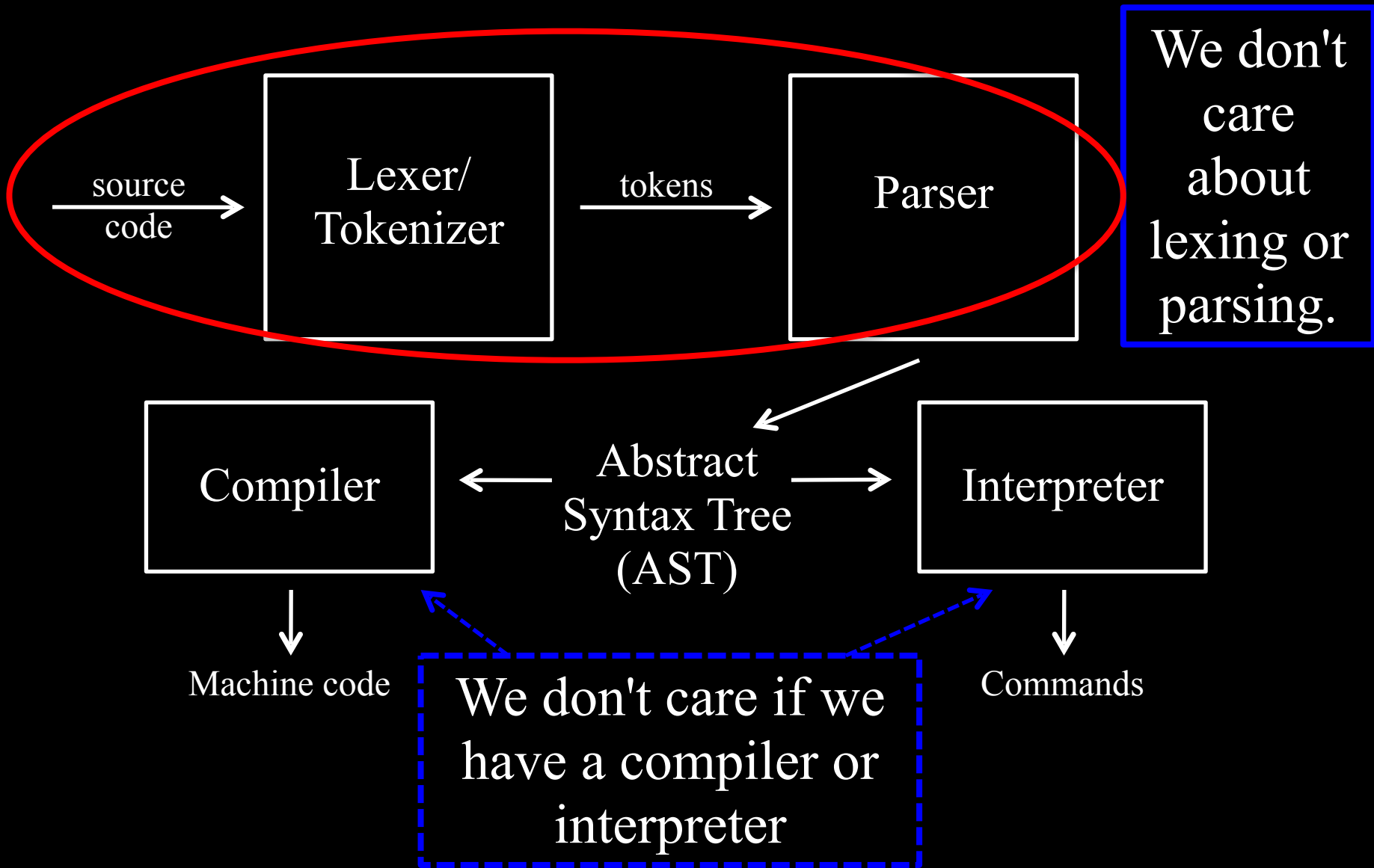
Is assignment valid
or an error?

Formal semantics define how a language works *concisely and with minimal ambiguity.*

A Review of Compilers



A Review of Compilers



Abstract Syntax Tree (AST)

ASTs are the
key to
understanding
a language

Bool* Language

$e ::=$

true

| false

| if e

then e

else e

expressions:

constant true

constant false

conditional

Despite appearances,
these are really ASTs

Values in Bool*

$\forall ::=$ *values:*
true constant true
| false constant false

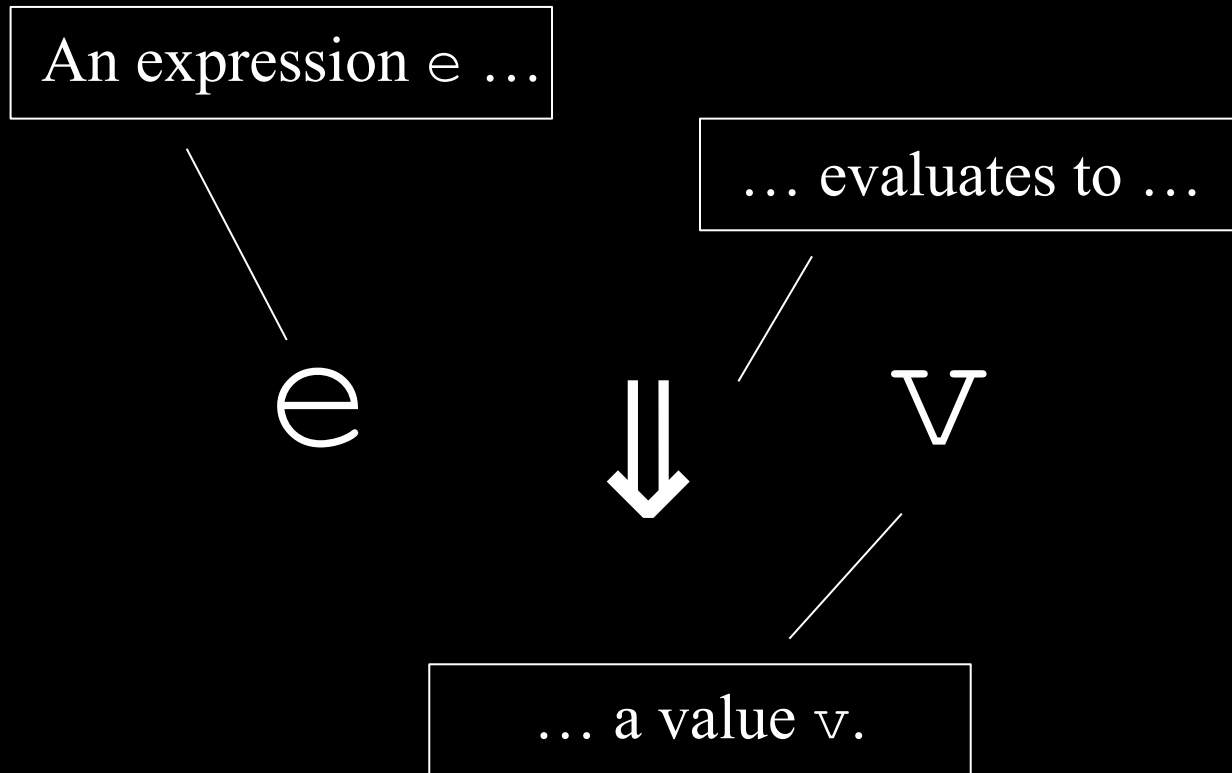
Formal Semantic Styles

- Operational semantics
 - Big-step (or "natural")
 - Small-step (or "structural")
- Axiomatic semantics
- Denotational semantics

Formal Semantic Styles

- **Operational semantics**
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- **Axiomatic semantics**
- **Denotational semantics**

Big-Step Evaluation Relation



Big-Step Evaluation Relation

limits when the
rule applies

Preconditions /

e



v

Big-step semantics for Bool*

B-IfTrue

$$\frac{e1 \Downarrow \text{true} \quad e2 \Downarrow v}{\text{if } e1 \text{ then } e2 \text{ else } e3 \Downarrow v}$$

B-IfFalse

$$\frac{e1 \Downarrow \text{false} \quad e3 \Downarrow v}{\text{if } e1 \text{ then } e2 \text{ else } e3 \Downarrow v}$$

B-Value

$$\frac{}{v \Downarrow v}$$

Converting our rules into code

(in-class)

Bool* extension: numbers

Users demand a new feature – numbers!

We will add 3 new features:

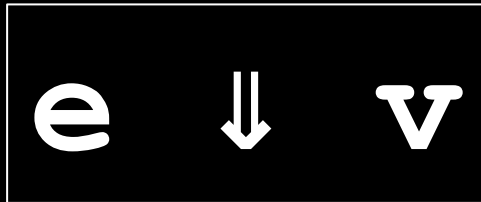
- Numbers, represented by `n`
- `succ`, which takes a number and returns the next highest number.
- `pred`, which takes a number and returns the next lowest number.

Extended Bool* Language

```
e ::= true
    | false
    | if e then e else e
    | n
    | succ e
    | pred e
```

Let's extend our semantics to handle these new language constructs

Pop Quiz: Write operational semantics



```
e ::= e and e
    | e or e
    | not e
    | true
    | false
```

```
v ::= true
    | false
```

Lab: Write a Bool* Interpreter

- Starter code is available on the course website
- Extend Bool* with numbers, succ, and pred

Adding State to Semantics

SpartanLang

<code>e ::= !x</code>	dereferencing
<code> v</code>	values
<code> x := e</code>	assignment
<code> e ; e</code>	sequence
<code> e op e</code>	binary operations
<code> if e then e</code> <code> else e end</code>	conditionals
<code> while e do e end</code>	while loops

SpartanLang (continued)

$v ::= i$ integers
| b booleans

$op ::= +$ | $-$ binary operators
| \backslash | $*$
| $<$ | $>$
| $<=$ | $>=$

Bool* vs. SpartanLang evaluation

Bool* relation:

$e \Downarrow \top$

SpartanLang relation:

$e, \sigma \Downarrow \top, \sigma'$

A "store", represented by
the Greek letter sigma

The Store

- A mapping of references to values
- Roughly analogous to the heap in Java

Key store operations

- $\sigma (x)$
 - get the value for reference x .
- $\sigma [x := v]$
 - create a copy of store σ , except ...
 - reference x has value v .

HW 2: Write an Interpreter for SpartanLang.

Details in Canvas