Look-up rules
How we resolve various “symbols” is a key part of language definition.

- In many ways, FP boils down to first-class functions, *lexical scope*,
  and immutability.

In Smalltalk, we *syntactically distinguish* variables (which resolve to
objects), messages (which determine what method is called), and a
few special names (true, false, nil, self, super)

- Java makes the same distinction

- Messages are *second-class*

Name Resolution
To resolve a variable (e.g., \( x \)):

- Like in ML or Scheme, if a use of \( x \) is in the lexical scope of
code-block variable (\( \{ x \ x \ \ldots \} \)) or local method variable or
  parameter, we resolve \( x \) using the environment in which the
code-block or method-body was defined.
  - Smalltalk implementation must build closures (those pairs of
    code and environment you built last week)

- Else if a use of \( x \) is in a method \( m \) of class \( A \) (because \( A \) or a
  transitive superclass of \( A \) defines \( m \)) and \( x \) is an instance or class
  variable of \( A \) (because \( A \) or a transitive superclass of \( A \) defines \( x \)),
  then \( x \) resolves to a field of the object \( \texttt{self} \) resolves to.

- Else if \( x \) is a global (e.g., a class object), then \( x \) resolves to that.

Note: Ignoring pool dictionaries.
Now messages

To resolve a message (e.g., \( m \)):

- A message is sent to an object (e.g., \( e \) \( m \)), so first evaluate \( e \) to an object \( \text{obj} \).
- Get the class of \( \text{obj} \) (every object has a class).
- If \( m \) is defined in \( \Lambda \), invoke that method, else recur with superclass of \( \Lambda \).

What about self?

As always, evaluation takes place in an environment.

In every environment, \texttt{self} is always bound to some object. (This determines message resolution for \texttt{self} and \texttt{super}.)

Key principles of OOP:

- Inheritance and override (last slide)
- Private fields (just abstraction)
- The semantics of message send

To send \( m \) to \( \text{obj} \) means evaluate the body of the method \( m \) resolves to for \( \text{obj} \) in an environment with argument names mapped to actual arguments and \texttt{self} bound to \( \text{obj} \).

That last phrase is exactly what “late-binding”, “dynamic dispatch”, and “virtual function call” mean. It is why code defined in superclasses can invoke code defined in subclasses.

Some Perspective on Late-Binding

Later we will discuss design considerations for when late-binding is a good or bad thing. For now, here are some opinions:

- Late-binding makes a more complicated semantics
  - Smalltalk without \texttt{self} is easier to define and reason about
  - It takes months in 142/143 to get to where we can explain it
  - It makes it harder to reason about programs
- But late-binding is often an elegant pattern for reuse
  - Smalltalk without \texttt{self} is not Smalltalk
  - Late-binding fits well with the “object analogy”
  - Late-binding can make it easier to localize specialized code even when other code wasn’t expecting specialization

A Lower-Level View

Smalltalk clearly encourages late-binding with its message-send semantics.

But a definition in one language is often a pattern in another...

We can simulate late-binding in Scheme easily enough

And sketch how compilers/interpreters implement objects

- A naive but accurate view of implementation can give an alternate way to reason about programs
The Key Idea

The key to implementing late-binding is extending all the methods to take an extra argument (for `self`).

So an object is implemented as a record holding methods and fields, where methods are passed self explicitly.

And message-resolution always uses `self`.

What about classes and performance?

This approach, while a fine pattern, has some problems:

- It doesn’t model Smalltalk, where methods can be added/removed from classes dynamically and an object’s class determines behavior.
- It is space-inefficient: all objects of a class have the same methods.
- It is time-inefficient: message-send should be constant-time, not list traversals.

We fix the first two by adding a level of indirection: put a single class field in an object and have a global class-table.

We fix the third with better data structures and various tricks.

Nonetheless: Without dynamic class changes, the “method slot” approach and “class field” approach are equivalent.

Really Implementing Late-Binding

- We have seen late-binding as a Scheme pattern
- In reality, we have learned roughly how OO implementations do it, without appealing to assembly code (where it really happens)

- Using ML instead of Scheme would have been a pain:
  - The ML type system is “unfriendly” for `self`.
  - We would have roughly taken the “embed Scheme in ML” approach, giving every object the same ML type.
  - But to be fair, most OO languages are “unfriendly” to ML datatypes, first-class functions, and parametric polymorphism.
  - Another day we’ll show closures as a pattern in OOP