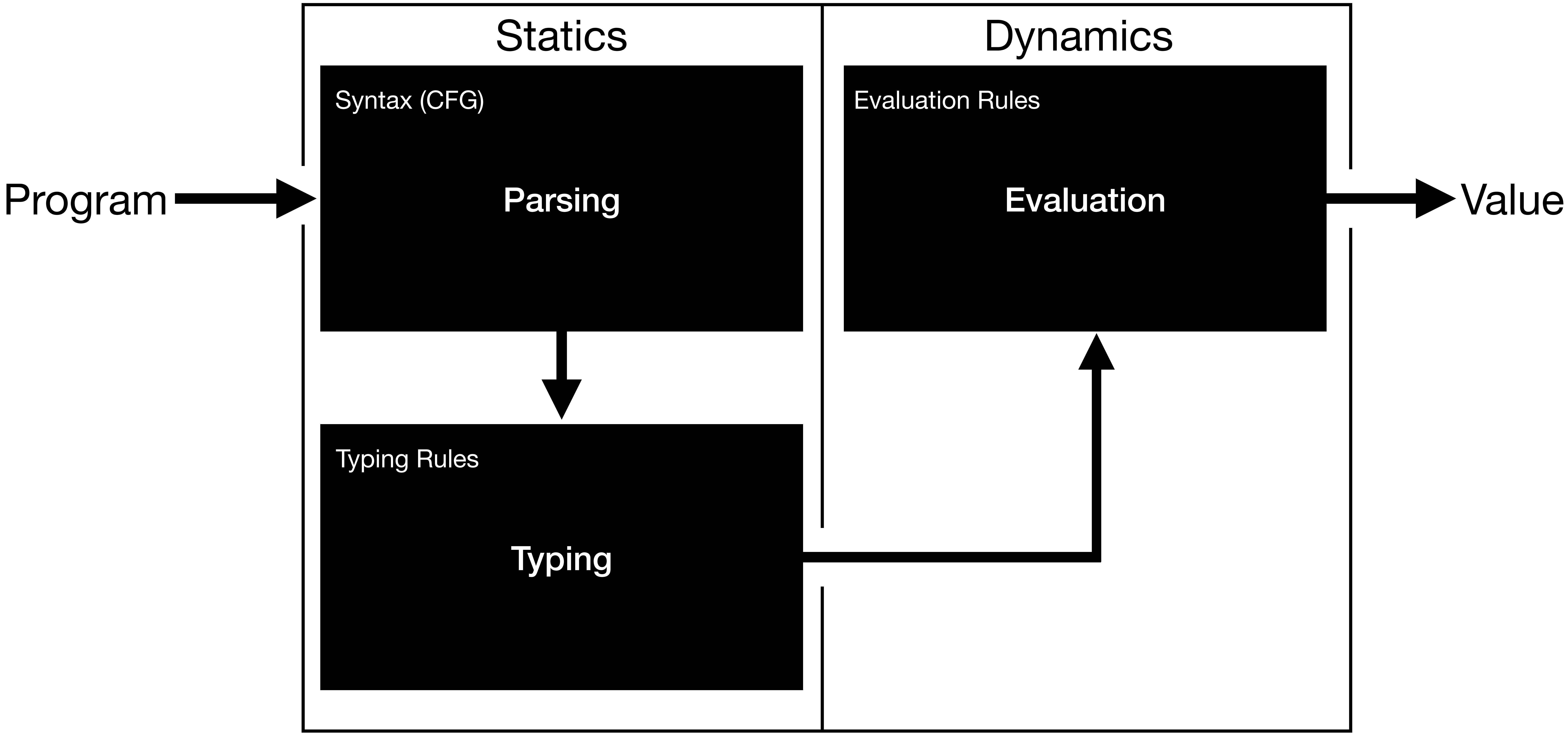
Object-Oriented Programming

Harley Eades III

Programming Language



Program

Statics

Syntax (CFG)

Parsing

Typing Rules

Typing

Dynamics

Evaluation Rules

Evaluation

Value

Part 1:Pairs

New Syntactic Forms: Adding Pairs

Terms

$t ::= \text{T}$
$\mid \text{F}$
$\mid \text{if } t_1 \text{ then } t_2 \text{ else } t_3$
$\mid x$
$\mid \text{fun } x : T \to \{t\}$
$\mid t_1\ t_2$
$\mid (t_1, t_2)$
$\mid t.1$
$\mid t.2$
$\mid \text{let } x = t_1 \text{ in } t_2$

Values

$v ::= \text{T}$
$\mid \text{F}$
$\mid \text{fun } x : T \to \{t\}$
$\mid (v_1, v_2)$

Types

$T ::= \text{Bool}$
$\mid (T_1, T_2)$
$\mid T_1 \to T_2$

Example Programs

$$\begin{aligned}&\text{let twist} = \text{fun}\, p : (\text{Bool}, \text{Bool}) \to \{(p.2,p.1)\}\\ &\qquad\qquad \text{in twist}\,(\text{T}, \text{F})\end{aligned}$$

$$\begin{aligned}&\text{let second} = \text{fun}\, p : (\text{Bool} \to \text{Bool}, \text{Bool}) \to \{\text{if}\; p.2 \;\text{then}\; p.1\;\text{T else F}\}\\ &\qquad\qquad\quad \text{in second}\,(\text{fun}\, x : \text{Bool} \to \{\text{if}\; x \;\text{then F else T}\}, \text{T})\end{aligned}$$

Statics: Bools

$$\frac{\Gamma \vdash t_1 : \mathsf{Bool} \qquad \Gamma \vdash t_2 : T \qquad \Gamma \vdash t_3 : T}{\Gamma \vdash \mathsf{if}\ t_1\ \mathsf{then}\ t_2\ \mathsf{else}\ t_3 : T}\ \mathsf{If}$$

$$\frac{}{\Gamma \vdash \mathsf{T} : \mathsf{Bool}}\ \mathsf{T}$$

$$\frac{}{\Gamma \vdash \mathsf{F} : \mathsf{Bool}}\ \mathsf{F}$$

Statics: Functions

$$\frac{}{\Gamma_1, x : T, \Gamma_2 \vdash x : T}\ \text{Var}$$

$$\frac{\Gamma, x : T_1 \vdash t : T_2}{\Gamma \vdash \mathsf{fun}\, x : T_1 \to \{t\} : T_1 \to T_2}\ \text{Fun}$$

$$\frac{\Gamma \vdash t_1 : T_1 \to T_2 \qquad \Gamma \vdash t_2 : T_1}{\Gamma \vdash t_1\, t_2 : T_2}\ \text{App}$$

$$\frac{\Gamma \vdash t_1 : T_1 \qquad \Gamma, x : T_1 \vdash t_2 : T_2}{\Gamma \vdash \mathsf{let}\, x = t_1\, \mathsf{in}\, t_2 : T_2}\ \text{Let}$$

Statics: Pairs

$$\frac{\Gamma \vdash t_1 : T_1 \quad \Gamma \vdash t_2 : T_2}{\Gamma \vdash (t_1, t_2) : (T_1, T_2)}\ \text{Pair}$$

$$\frac{\Gamma \vdash t : (T_1, T_2)}{\Gamma \vdash t.1 : T_1}\ \text{First}$$

$$\frac{\Gamma \vdash t : (T_1, T_2)}{\Gamma \vdash t.2 : T_2}\ \text{Second}$$

Call-by-Value Dynamics: Bools

$$\frac{t_1 \rightsquigarrow t_1'}{\textsf{if}\ t_1\ \textsf{then}\ t_2\ \textsf{else}\ t_3 \rightsquigarrow \textsf{if}\ t_1'\ \textsf{then}\ t_2\ \textsf{else}\ t_3}\ \textsf{If}$$

$$\frac{}{\textsf{if T then}\ t_2\ \textsf{else}\ t_3 \rightsquigarrow t_2}\ \textsf{IfT}$$

$$\frac{}{\textsf{if F then}\ t_2\ \textsf{else}\ t_3 \rightsquigarrow t_3}\ \textsf{IfF}$$

Call-by-Value Dynamics: Functions

$$\frac{t_1 \rightsquigarrow t_1'}{t_1\, t_2 \rightsquigarrow t_1'\, t_2}\ \text{App1}$$

$$\frac{}{\mathsf{let}\ x = v\ \mathsf{in}\ t \rightsquigarrow [v/x]t}\ \text{Let}\beta$$

$$\frac{t_2 \rightsquigarrow t_2'}{v_1\, t_2 \rightsquigarrow v_1\, t_2'}\ \text{App2}$$

$$\frac{}{(\mathsf{fun}\, x : T \rightarrow \{t\})\, v \rightsquigarrow [v/x]t}\ \beta$$

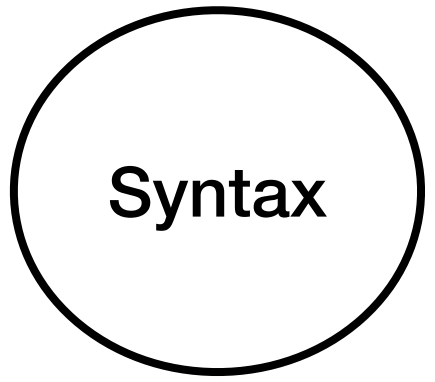
$$\frac{t_1 \rightsquigarrow t_1'}{\mathsf{let}\ x = t_1\ \mathsf{in}\ t_2 \rightsquigarrow \mathsf{let}\ x = t_1'\ \mathsf{in}\ t_2}\ \text{Let}$$

Call-by-Value Dynamics: Pairs

$$\frac{t_1 \leadsto t_1'}{(t_1, t_2) \leadsto (t_1', t_2)}\ \text{Pair1} \qquad \frac{t \leadsto t'}{t.1 \leadsto t'.1}\ \text{Proj1} \qquad \frac{}{(v_1, v_2).1 \leadsto v_1}\ \text{Pair}\beta_1$$

$$\frac{t_2 \leadsto t_2'}{(v_1, t_2) \leadsto (v_1, t_2')}\ \text{Pair2} \qquad \frac{t \leadsto t'}{t.2 \leadsto t'.2}\ \text{Proj2} \qquad \frac{}{(v_1, v_2).2 \leadsto v_2}\ \text{Pair}\beta_2$$

Core Design Concepts:



Syntax

Part 2:Unit

New Syntactic Forms: Adding Unit

Terms

$$
\begin{aligned}
t ::=\ & \mathsf{T} \\
\mid\ & \mathsf{F} \\
\mid\ & \text{if } t_1 \text{ then } t_2 \text{ else } t_3 \\
\mid\ & x \\
\mid\ & \text{fun } x : T \to \{t\} \\
\mid\ & t_1\ t_2 \\
\mid\ & () \\
\mid\ & \text{match } t_1 \{ () \to t_2 \} \\
\mid\ & (t_1, t_2) \\
\mid\ & t.1 \\
\mid\ & t.2 \\
\mid\ & \text{let } x = t_1 \text{ in } t_2
\end{aligned}
$$

Values

$$
\begin{aligned}
v ::=\ & \mathsf{T} \\
\mid\ & \mathsf{F} \\
\mid\ & \text{fun } x : T \to \{t\} \\
\mid\ & (v_1, v_2) \\
\mid\ & ()
\end{aligned}
$$

Types

$$
\begin{aligned}
T ::=\ & \text{Bool} \\
\mid\ & () \\
\mid\ & (T_1, T_2) \\
\mid\ & T_1 \to T_2
\end{aligned}
$$

Example: Sequence

$$t_1; t_2 = (\mathsf{let}\, x = t_1 \,\mathsf{in}\, t_2)$$

$$\frac{\Gamma \vdash t_1 : T_1 \qquad \Gamma \vdash t_2 : ()}{\Gamma \vdash t_1; t_2 : ()}\ \text{Seq}$$

$$\mathsf{let}\, x = t_1; t_2 = (\mathsf{let}\, x = t_1 \,\mathsf{in}\, t_2)$$

$$\frac{\Gamma \vdash t_1 : T_1 \qquad \Gamma, x : T_1 \vdash t_2 : ()}{\Gamma \vdash \mathsf{let}\, x = t_1; t_2 : ()}\ \text{Define}$$

Example: Sequencing Programs

$$\frac{\Gamma \vdash t : \text{String}}{\Gamma \vdash \text{print}\, t : ()}\ \text{Print}$$

$$\text{let twist} = \text{fun}\, p : (\text{Bool}, \text{Bool}) \rightarrow \{(p.2, p.1\};$$
$$\text{let second} = \text{fun}\, p : (\text{Bool} \rightarrow \text{Bool}, \text{Bool}) \rightarrow \{\text{if}\, p.2\ \text{then}\ p.1\ \text{T else F}\};$$
$$\text{if (second (fun}\, x : \text{Bool} \rightarrow \{x\}, \text{T})) \text{ then } \underline{\text{print "True"}} \text{ else } \underline{\text{print"False"}}$$

Statics: Bools

$$\frac{\Gamma \vdash t_1 : \textsf{Bool} \qquad \Gamma \vdash t_2 : T \qquad \Gamma \vdash t_3 : T}{\Gamma \vdash \textsf{if}\ t_1\ \textsf{then}\ t_2\ \textsf{else}\ t_3 : T}\ \textsf{If}$$

$$\frac{}{\Gamma \vdash \textsf{T} : \textsf{Bool}}\ \textsf{T}$$

$$\frac{}{\Gamma \vdash \textsf{F} : \textsf{Bool}}\ \textsf{F}$$

Statics: Functions

$$\frac{}{\Gamma_1, x : T, \Gamma_2 \vdash x : T}\ \text{Var}$$

$$\frac{\Gamma, x : T_1 \vdash t : T_2}{\Gamma \vdash \mathsf{fun}\, x : T_1 \to \{t\} : T_1 \to T_2}\ \text{Fun}$$

$$\frac{\Gamma \vdash t_1 : T_1 \to T_2 \qquad \Gamma \vdash t_2 : T}{\Gamma \vdash t_1\, t_2 : T_2}\ \text{App}$$

$$\frac{\Gamma \vdash t_1 : T_1 \qquad \Gamma, x : T_1 \vdash t : T_2}{\Gamma \vdash \mathsf{let}\, x = t_1\, \mathsf{in}\, t_2 : T}\ \text{Let}$$

Statics: Pairs

$$\frac{\Gamma \vdash t_1 : T_1 \quad \Gamma \vdash t_2 : T_2}{\Gamma \vdash (t_1, t_2) : (T_1, T_2)}\ \text{Pair}$$

$$\frac{\Gamma \vdash t : (T_1, T_2)}{\Gamma \vdash t.1 : T_1}\ \text{First}$$

$$\frac{\Gamma \vdash t : (T_1, T_2)}{\Gamma \vdash t.2 : T_2}\ \text{Second}$$

Statics: Unit

$$\frac{}{\Gamma \vdash () : ()}\ \text{Unit}$$

$$\frac{\Gamma \vdash t_1 : () \qquad \Gamma \vdash t_2 : T}{\Gamma \vdash \mathsf{match}\ t_1 \{() \to t_2\} : T}\ \text{Match}$$

Call-by-Value Dynamics: Bools

$$\frac{t_1 \rightsquigarrow t_1'}{\text{if } t_1 \text{ then } t_2 \text{ else } t_3 \rightsquigarrow \text{if } t_1' \text{ then } t_2 \text{ else } t_3}\ \text{If}$$

$$\frac{}{\text{if T then } t_2 \text{ else } t_3 \rightsquigarrow t_2}\ \text{IfT}$$

$$\frac{}{\text{if F then } t_2 \text{ else } t_3 \rightsquigarrow t_3}\ \text{IfF}$$

Call-by-Value Dynamics: Functions

$$\frac{t_1 \rightsquigarrow t_1'}{t_1\, t_2 \rightsquigarrow t_1'\, t_2}\ \text{App1}$$

$$\frac{t_2 \rightsquigarrow t_2'}{v_1\, t_2 \rightsquigarrow v_1\, t_2'}\ \text{App2}$$

$$\frac{t_1 \rightsquigarrow t_1'}{\mathsf{let}\, x = t_1\, \mathsf{in}\, t_2 \rightsquigarrow \mathsf{let}\, x = t_1'\, \mathsf{in}\, t_2}\ \text{Let}$$

$$\frac{}{\mathsf{let}\, x = v\, \mathsf{in}\, t \rightsquigarrow [v/x]t}\ \text{Let}\beta$$

$$\frac{}{(\mathsf{fun}\, x : T \rightarrow \{t\})\, v \rightsquigarrow [v/x]t}\ \beta$$

Call-by-Value Dynamics: Pairs

$$\frac{t_1 \rightsquigarrow t_1'}{(t_1, t_2) \rightsquigarrow (t_1', t_2)}\ \text{Pair1} \qquad \frac{t \rightsquigarrow t'}{t.1 \rightsquigarrow t'.1}\ \text{Proj1} \qquad \frac{}{(v_1, v_2).1 \rightsquigarrow v_1}\ \text{Pair}\beta_1$$

$$\frac{t_2 \rightsquigarrow t_2'}{(v_1, t_2) \rightsquigarrow (v_1, t_2')}\ \text{Pair2} \qquad \frac{t \rightsquigarrow t'}{t.2 \rightsquigarrow t'.2}\ \text{Proj2} \qquad \frac{}{(v_1, v_2).2 \rightsquigarrow v_2}\ \text{Pair}\beta_2$$

Call-by-Value Dynamics: Unit

$$\frac{t_1 \rightsquigarrow t_1'}{\mathsf{match}\; t_1 \{ () \to t_2 \} \rightsquigarrow \mathsf{match}\; t_1' \{ () \to t_2 \}}\;\text{Match}$$

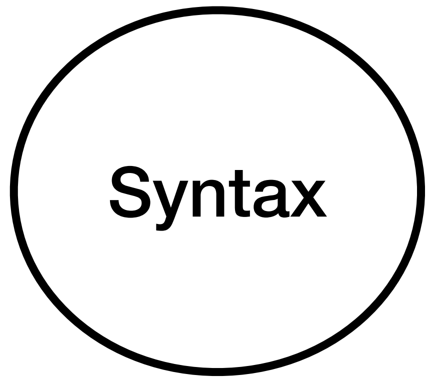
$$\frac{}{\mathsf{match}\; () \{ () \to t_2 \} \rightsquigarrow t_2}\;\text{Unit}\beta$$

Core Design Concepts:

Syntax

Part 3:Tuples

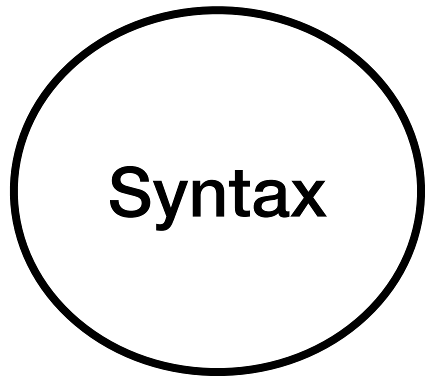
Core Design Concepts:



Syntax

Part 3:Records

Core Design Concepts:

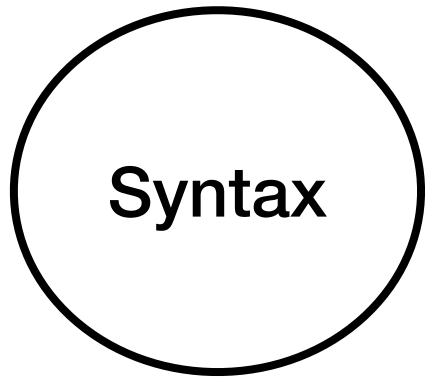


Syntax

Part ?: OOP in OCaml

What is OCaml?

Core Design Concepts:

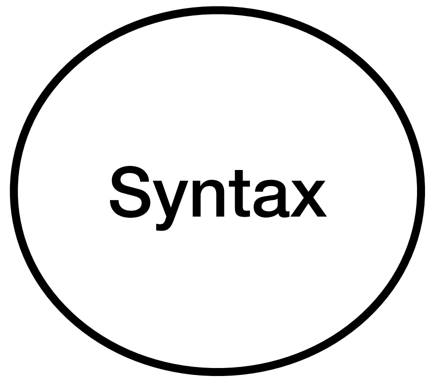


Syntax

An object oriented, imperative, functional programming language.

What is OCaml?

Core Design Concepts:



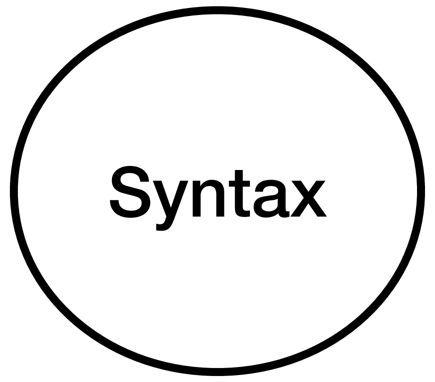
Syntax

An object oriented, imperative, functional programming language.

OCaml mixes all of these paradigms together.

What is OCaml?

Core Design Concepts:



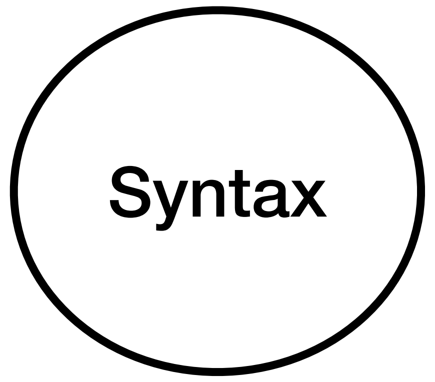
Syntax

An object oriented, imperative, functional programming language.

OCaml mixes all of these paradigms together.

What is OCaml?

Core Design Concepts:



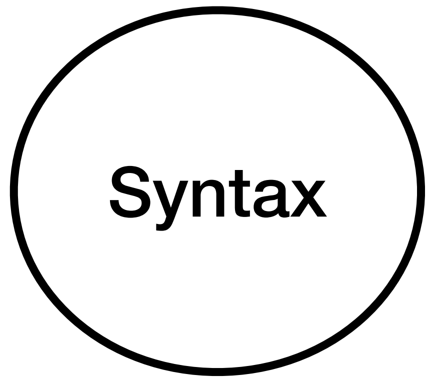
Syntax

An object oriented, imperative, functional programming language.

OCaml mixes all of these paradigms together.

What is OCaml?

Core Design Concepts:



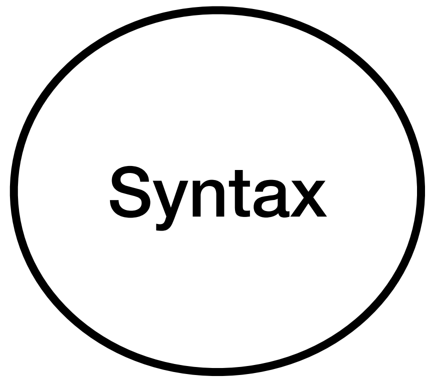
Syntax

An object oriented, imperative, functional programming language.

OCaml mixes all of these paradigms together.

What is OCaml?

Core Design Concepts:



Syntax

An object oriented, imperative, functional programming language.

OCaml mixes all of these paradigms together.

Class Definitions

Core Design Concepts:

Syntax

```
class name = object (self) … end
```

Class Definitions

Core Design Concepts:

Syntax

```
class stack_of_ints =

  object (self)

    val mutable the_list = ([] : int list)

     …

  end;;
```

Class Definitions

Core Design Concepts:

Syntax

```
class stack_of_ints =
  object (self)
    val mutable the_list = ([] : int list)
    method push x = …
    method pop = …
    method peek = …
    method size = …
  end;;
```

Class Definitions

Core Design Concepts:

Syntax

```
class stack_of_ints =
  object (self)
    val mutable the_list = ([] : int list)
    method push x = the_list <- Cons(x, the_list)
    method pop = …
    method peek = …
    method size = …
  end;;
```

Class Definitions

Core Design Concepts:

Syntax

```
class stack_of_ints =
  object (self)
    val mutable the_list = ([] : int list)
    method pop =
      let result = head the_list in
      the_list <- tail the_list;
      result
    method push x = …
    method peek = …
    method size = …
  end;;
```

Class Definitions

Core Design Concepts:

Syntax

```
class stack_of_ints =
  object (self)
    val mutable the_list = ([] : int list)
    method push x = …
    method pop = …
    method peek = head the_list
    method size = …
  end;;
```

Class Definitions

Core Design Concepts:

Syntax

```
class stack_of_ints =
  object (self)
    val mutable the_list = ([] : int list)
    method push x = …
    method pop = …
    method peek = …
    method size = length the_list
  end;;
```

Class Definitions

Core Design Concepts:

Syntax

```
class stack_of_ints =
  object (self) …
end;;
class stack_of_ints :
  object
    val mutable the_list : int list
    method peek : int
    method pop : int
    method push : int -> unit
    method size : int
  end
```

Accessing fields and methods

Core Design Concepts:

Syntax

```
# let s = new stack_of_ints;;
val s : stack_of_ints = <obj>
```

Accessing fields and methods

Core Design Concepts:

Syntax

```
s#fieldName

s#methodName
```

Accessing fields and methods

Core Design Concepts:

Syntax

```
# for i = 1 to 10 do
    s#push i
  done;;
- : unit = ()
# while s#size > 0 do
    Printf.printf "Popped %d off the stack.\n" s#pop
  done;;
…
Popped 10 off the stack.
Popped 9 off the stack.
Popped 8 off the stack.
- : unit = ()
```