

The Environment Model Semantics

```
env :: n || n
env :: e1 + e2 || n
      if env :: e1 || n1 and
env :: e2 || n2
      and n is the result of
applying
      primitive operation +
to n1 and n2
env :: (e1, e2) || (v1, v2)
      if env :: e1 || v1 and
env :: e2 || v2
env :: fst e || v1
      if env :: e || (v1,v2)
env :: Left e || Left v
      if env :: e || v
env :: match e with Left x -> e1
      | Right y -> e2 ||
v1
      if env :: e || Left v and
      env +{x=v} :: e1 || v1
env :: let x = e1 in e2 || v2
      if env :: e1 || v1 and
      env +{x=v1} :: e2 || v2
env :: (fun x -> e) || <<fun x ->
e, env>>
env :: e1 e2 || v
      if env :: e1 || <<fun x ->
e, env'>>
      and env :: e2 || v2
      and env' + {x=v2} :: e || v
env :: let rec f x = e1 in e2 ||
v
      if env + {f = <<f, fun x ->
e1, env>>}
      :: e2 || v
env :: e1 e2 || v
      if env :: e1 || <<f, fun x ->
e, env'>>
```

The Environment Model Semantics (cont)

```
> and env :: e2 || v2
and env' + {x=v2,f=<<f, fun x -> e, env'>>}
:: e || v
```

Environment Model Semantics Rule with Lexical Scoping

Technique to Generalize Folding

1. Write a recursive fold function that takes in one argument for each variant of the datatype.
2. That fold function matches against the datatype variants, calling itself recursively on any instance of the datatype that it encounters.
3. When a variant carries data of a type other than the datatype being folded, use the appropriate argument to fold to incorporate that data.
4. When a variant carries no data, use the appropriate argument to fold to produce an accumulator.

```
let rec fold_left (f : 'a -> 'b -> 'a) (acc : 'a) (lst : 'b list): 'a =
  match lst with
  [] -> acc
  | x :: xs -> fold_left f (f acc x) xs
fold_left : 'a -> 'b -> 'a -> 'a -> 'b list -> 'a
let rec fold_right (f : 'a -> 'b -> 'b) (l : 'a list) (acc : 'b) : 'b =
  match l with
  [] -> acc
  | x :: xs -> f x (List.fold_right f xs acc)
fold_right: 'a -> 'b -> 'b -> 'a list -> 'b -> 'b
```

Technique to Generalize Folding (cont)

```
> Example of Generalized fold:
type
'a exprTree =
| Val of 'a
| Unop of ('a -> 'a) * 'a exprTree
| Binop of ('a -> 'a -> 'a) 'a exprTree 'a
exprTree
let rec exprTree_fold (foldVal) (foldUnop)
(foldBinop) = function
  | Val x -> foldVal x
  | Unop (f, t) -> foldUnop f (exprTree_fold foldVal foldUnop foldBinop t) | Binop (f, t1, t2) -> foldBinop f (exprTree_fold foldVal foldUnop foldBinop t1) (exprTree_fold foldVal foldUnop foldBinop t2)
;;
```

Generalized fold and List folding functions

Function Type Inference

Infer the type of functions from operations nested within the function. Start off by labeling all of the bindings and parameters with a random type Tn. And, then find out the type for each of them. Use patterns like the branches of an if and else statements are the same type and same goes for match statements.

Function Type Inference (cont)

Points to note are that the failure ("blah") and Exception Not_found have type 'a (just something random), so they can be restricted to whatever the other type is in a match expression. Also, let rec f x= f x in f has type 'a -> 'b

Documenting Abstractions

A specification is a contract between an implementer of an abstraction and a client of an abstraction. An implementation satisfies a specification if it provides the described behavior.

Locality: abstraction can be understood without needing to examine implementation

Modifiability: abstraction can be reimplemented without changing implementation of other abstractions

Good Specs:

Sufficiently restrictive: rule out implementations that wouldn't be useful to clients

Sufficiently general: do not rule out implementations that would be useful to clients

Sufficiently clear: easy for clients to understand behavior

Documenting Abstractions (cont)

Abstraction function (AF) captures designer's intent in choosing a particular representation of a data abstraction. Not actually OCaml function but an abstract function. Maps concrete values to abstract values. Think about Set example, where implementer sees Set as 'a list [1;2] but user sees it as {1,2}.

Many-to-one: many values of concrete type can map to same value of abstract type.

[1;2] & [2;1] both map to {1,2}

Partial: some values of concrete type do not map to any value of abstract type

[1;1;2] because no duplicates

$opA(AF(c)) = AF(opC(c))$. AF commutes with op!

You might write:

– Abstraction Function: comment – AF: comment

– comment

Representation invariant characterizes which concrete values are valid and which are invalid.

-Valid concrete values will be mapped by AF to abstract values

-Invalid concrete value will not be mapped by AF to abstract values

Substitution Model of Evaluation

```
e1 + e2 --> e1' + e2
      if e1 --> e1'
v1 + e2 --> v1 + e2'
      if e2 --> e2'
n1 + n2 --> n3
      where n3 is the result
of applying primitive operation
+
to n1 and n2
(e1, e2) --> (e1', e2)
      if e1 --> e1'
(v1, e2) --> (v1, e2')
      if e2 --> e2'
fst (v1,v2) --> v1
Left e --> Left e'
      if e --> e'
match e with Left x -> e1 |
Right y -> e2
--> match e' with Left x -> e1 |
Right y -> e2
      if e --> e'
match Left v with Left x -> e1 |
Right y -> e2
--> e1{v/x}
match Right v with Left x -> e1
| Right y -> e2
--> e2{v/y}
let x = e1 in e2 --> let x = e1'
in e2
      if e1 --> e1'
let x = v in e2 --> e2{v/x}
e1 e2 --> e1' e2
      if e1 --> e1'
v e2 --> v e2'
```

Substitution Model of Evaluation (cont)

```
> if e2 -> e2'
Capture Avoiding Substitution
(fun x -> e) v2 -> e{v2/x}
(Left e'){e/x} = Left e'{e/x}
(Right e'){e/x} = Right e'{e/x}
(match e' with Left y -> e1 | Right z -> e2)
{e/x}
= match e'{e/x} with Left y -> e1{e/x} | Right
z -> e2{e/x}
(match e' with Left x -> e1 | Right z -> e2)
{e/x}
= match e'{e/x} with Left x -> e1 | Right z ->
e2{e/x}
(match e' with Left y -> e1 | Right x -> e2)
{e/x}
= match e'{e/x} with Left y -> e1{e/x} | Right
x -> e2
(match e' with Left x -> e1 | Right x -> e2)
{e/x}
= match e'{e/x} with Left x -> e1 | Right x ->
e2
(let x = e1 in e2){v/x} = let x = e1{v/x} in e2
(let y = e1 in e2){v/x} = let y = e1{v/x} in
e2{v/x}
(e1,e2){e/x} = (e1{e/x}, e2{e/x})
(fst e'){e/x} = fst e'{e/x}
```

Substitution Model Evaluation- Capture-avoiding substitution

Example Module & Functor example

Start off with this functor for Intervals.

```
module Make_interval :
  functor (Endpoint : Comparable) ->
    sig
      type t = Interval of
        Endpoint.t * Endpoint.t | Empty
      val create :
        Endpoint.t -> Endpoint.t -> t
      val is_empty : t ->
        bool
      val contains : t ->
        Endpoint.t -> bool
      val intersect : t ->
        t -> t
    end
```

Now, the functor does not have an abstract type. Because, the user can see the type in the functor. So, we have to hide that type through implementation. There's a problem with `Make_interval`. The invariant is enforced by the `create` function, but because `Interval.t` is not abstract, we can bypass the `create` function. So you do something like this with sharing constraints:

```
module Make_interval_rval (Endpoint : Comparable) :
  Interval_intf with type
    endpoint = int struct
      type endpoint =
        Endpoint.t
      type t = | Interval of
        Endpoint.t * Endpoint.t
        | Empty
```

Modules Signatures, Structures and Functors

Basically, signature is the interface that we must follow for a certain module. The Structure of a module is the implementation of the given signature of the module. Furthermore, the functors go ahead and parameterize modules: that is, they will take in a module or multiple modules as inputs and return a new module that is parameterized with the input module. So, suppose you have a given Set module and you want this module to be applicable to all types not only ints. So, you will need the notion of equality in your module, but this notion of equality is different between Ints and Strings, so you can parameterize by having a functor that has a type signature of `EQUAL` as its input. With functors remember to do the sharing constraints..

Matching Mechanics & Type Declarations

A type synonym is a new kind of declaration. The type and the name are interchangeable in every way.

Matching: Given a pattern `p` and a value `v`, decide

– Does pattern match value?

– If so, what variable bindings are introduced?

If `p` is a variable `x`, the match succeeds and `x` is bound to `v`.

If `p` is `_`, the match succeeds and no bindings are introduced

Matching Mechanics & Type Declarations (cont)

If p is a constant c , the match succeeds if v is c . No bindings are introduced

If p is $C\ p_1$, the match succeeds if v is $C\ v_1$ (i.e., the same constructor) and p_1 matches v_1 . The bindings are the bindings from the sub-match.

If p is (p_1, \dots, p_n) and v is (v_1, \dots, v_n) , the match succeeds if p_1 matches v_1 , and ..., and p_n matches v_n . The bindings are the union of all bindings from the sub-matches.

1. If Expressions are just pattern matches
2. Lists and options are just datatypes
3. Let expressions are also pattern matches.
4. A function argument can also be a pattern.

Type Checking Rules

Syntax:

$e_1 + e_2$

Type-c heck king:

If e_1 and e_2 have type int , then $e_1 + e_2$ has type int

Syntax: $e_1 < e_2$

Type-c heck king: if e_1 has type int and e_2 has type int then $e_1 < e_2$ has type bool

Syntax: if e_1 then e_2 else e_3

Type-c heck king: if e_1 has type bool and, for some type t , both e_2 and e_3 have type t , then if e_1 then e_2 else e_3 has type t

Simplified syntax:

let $x = e_1$ in e_2

Type Checking Rules (cont)

> Type-checking:

If $e_1:t_1$, and if $e_2:t_2$ under the assumption that $x:t_1$, then let $x = e_1$ in $e_2 : t_2$

Syntax: $e_0 (e_1, \dots, e_n)$

Type-checking:

If: e_0 has some type $(t_1 \dots t_n) \rightarrow t$ and e_1 has type t_1 , ..., e_n has type t_n

Then $e_0 (e_1, \dots, e_n)$ has type t

Syntax: $\{f_1=e_1; \dots; f_n=e_n\}$

Type-checking:

If $e_1:t_1$ and $e_2:t_2$ and ... $e_n:t_n$, and if t is a declared type of the form $\{f_1:t_1, \dots, f_n:t_n\}$, then $\{f_1 = e_1; \dots; f_n = e_n\}:t$

Syntax: $e.f$

Type-checking:

If $e:t_1$ and if t_1 is a declared type of the form $\{f:t_2, \dots\}$, then $e.f: t_2$

None has type 'a option

– much like $[]$ has type 'a list – None is a value

Some $e:t$ option if $e:t$

– much like $e::[]$ has type t list if $e:t$ – If $e \rightarrow v$ then Some $e \rightarrow$ Some v

Note- Datatype VS Records Table

Type Checking Rules part of Semantics

Key Points about Modules

Other key points with modules:

1. Difference between include and open is that include just sort of extends a module/ signature when its called. In general, opening a module adds the contents of that module to the environment that the compiler looks at to find the definition of various identifiers. While opening a module affects the environment used to search for identifiers, including a module is a way of actually adding new identifiers to a module proper. The difference between include and open is that we've done more than change how identifiers are searched for: we've changed what's in the module. Opening modules is usually not a good thing in top level as you are getting rid of the advantage of a new namespace and if you want to do it, do it locally..
2. Don't expose the type of module especially in the signature, it is smart to hid from your user as they may abuse your invariant and don't have any idea on the implementation. So, you can also change the implementation without them knowing.

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Key Points about Modules (cont)

3. We can also use sharing constraints in the context of a functor. The most common use case is where you want to expose that some of the types of the module being generated by the functor are related to the types in the module fed to the functor

Data Types VS Record VS Tuple

	Declare	Build/Construct	Access/Destruct
DataType	type	Constructor name	Pattern matching with match
Record	type	Record expression with {...}	Pattern matching with let OR field selection with dot operator
Tuple	N/A	Tuple expression with (...)	Pattern matching with let OR fst or snd

Records are used to store this AND that. Datatypes represent this OR that. Also, a tuple is just a record with its fields referred to by position, where as with records it is by name.

Algebraic Datatypes of form <Datatype: Name Student> of String

Dynamic VS Lexical Scoping

Rule of dynamic scope: The body of a function is evaluated in the current dynamic environment at the time the function is called, not the old dynamic environment that existed at the time the function was defined.

Dynamic VS Lexical Scoping (cont)

Rule of lexical scope: The body of a function is evaluated in the old dynamic environment that existed at the time the function was defined, not the current environment when the function is called.

Functions as First Class Citizens

Functions are values
 Can use them anywhere we use values
 First-class citizens of language, afforded all the "rights" of any other values
 – Functions can take functions as arguments – Functions can return functions as results
 ...functions can be higher-order
 Map: let rec map f xs = match xs with
 [] -> []
 | x::xs' -> (f x)::(map f xs')
 map: ('a->'b)->'alist->'blist
 Filter, Map, folds are iterators basically.
 They can iterate through structures just like normal loops can.