编程语言的设计原理

Design Principles of Programming Languages

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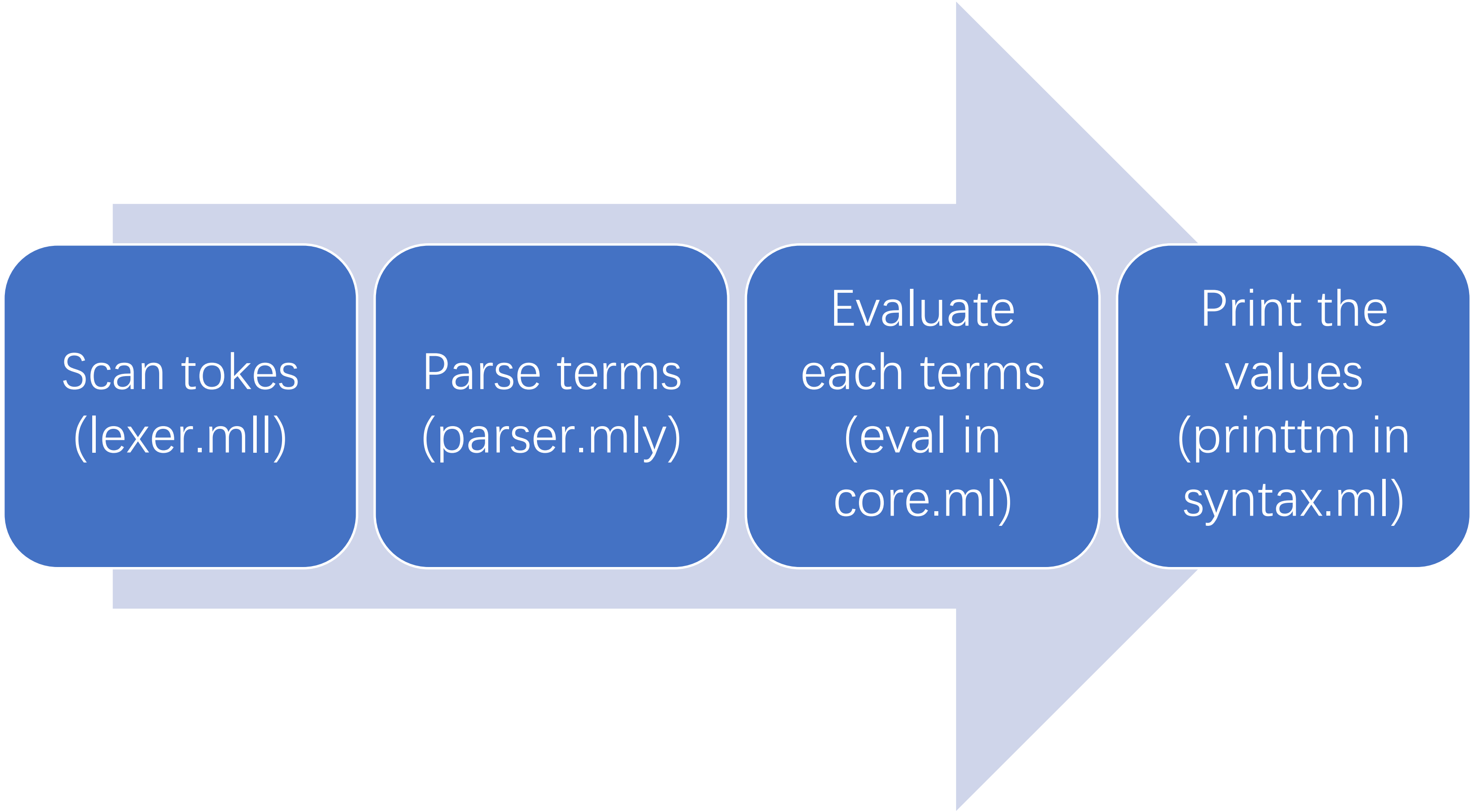
Practice in Class

arith, fullsimple, fullref

Structure of package

main.ml drives the whole process



Commands

- Each line of the source file is parsed *as a command*
  - type command = | Eval of info * term
  - New commands will be added later

- Main routine for each file

```
let process_file f =
    alreadyImported := f :: !alreadyImported;
    let cmds = parseFile f in
        let g c =
            open_hvbox 0;
            let results = process_command c in
      print_flush();
      results
in
  List.iter g cmds
```

Structure of package: syntax

- syntax. ml defines the terms

```
type term =
    TmTrue of info
  | TmFalse of info
  | TmIf of info * term * term * term
  | TmZero of info
  | TmSucc of info * term
  | TmPred of info * term
  | TmIsZero of info * term
```

- Info: a data type recording *the position* of the term in the source file

Structure of package: evaluation

- eval in core.ml

```
let rec eval t =
  try let t' = eval1 t
      in eval t'
  with NoRuleApplies → t
```

- eval1: perform a *single step reduction*

Structure of package : evaluation

```
let rec isnumericval t = match t with
    TmZero(_)           → true
  | TmSucc(_, t1)       → isnumericval t1
  | _                   → false
```

Some abbreviations

- UCID = upper case identifier
- LCID = lower case identifier
- ty = type
- tm = term
- LCURLY = “{“
- RCURLY = “}”
- LPAREN = “(“
- RPAREN = “)“
- USCORE = “_”
- ……

Exercise arith.simple_use

- Using arith to write the following equation
  - Return five if two is not zero, otherwise return nine

  - Hint: read the code in *parser.mly*

Exercise arith.size

- Make the *evaluation* computes *the size of a term* (3.3.2) instead of reducing the term, and test it on the original test.f
  - Hint:
    - pr: string -> unit — prints a string to the screen
    - string_of_int : int -> string — converts an integer into a string
    - Remember to change both .ml and .mli files

Big-step vs small-step

- Big-step is usually easier to understand
  - called "*natural semantics*" in some articles
- Big-step often leads to *simpler proof*
- Big-step cannot describe computations that *do not produce a value*
  - Non-terminating computation
  - "Stuck" computation

Exercise arith.big-step

- Change the evaluation to use *big-step semantics*, and compute the following expressions:
  - true;
  - if false then true else false;
  - if 0 then 1 else 2;
  - if true then (succ false) else 2;
  - 0;
  - succ (pred 0);
  - iszero (pred (succ (succ 0)));

fullsimple

- Implementing all extensions in Chapter 11.
- Allow different types of command:
  - evaluation: type-checking and reducing a term
  - bindings
    - Variable binding: a: Int;
    - Type variable binding: T;
    - Term abbreviation binding: t = succ 0;
    - Type abbreviation binding: T = Nat -> Nat;
- Types can be used without declaration (uninterpreted types)

```
x:X
(lambda a:X. a) x
```

Review: nameless representation

- What is the nameless representation of the following term?

$$\lambda x.\ x\ (\lambda y.\ x\ y)$$

$$\lambda.\ 0\ (\lambda.\ 1\ 0)$$

Fullsimple, terms

```
type term =
      TmVar of info * int * int
    | TmAbs of info * string * ty * term
    | TmApp of info * term * term
    | …
```

- Using *nameless representation of terms*
- The *second int* for TmVar is used for debugging
  - = the number of items in the context
- The “*string*” in TmAbs is used for printing

Example: printing terms

```
and printtm_ATerm outer ctx t = match t with
    | TmVar(fi, x, n)  ->
        if ctxlength ctx = n then
            pr (index2name fi ctx x)
        else
            pr (“[bad index: ” ^  …… )
   | TmAbs(fi, x, tyT1, t2)  ->
        (let (ctx’, x') = (pickfreshname ctx x) in
            obox(); pr "lambda ";
             pr x'; pr ":"; printty_Type false ctx tyT1; pr "."; …
             printtm_Term outer ctx' t2; …
```

Review: context

- What contexts are used in our course?
  – Mapping names to integers in nameless representation
  – Σ: mapping variables to types
- Can be combined into one
- New contexts in the implementation
  – Type variable binding: marking type variables
  – Term abbreviation binding: Mapping variables to terms (and their types)
  – Type abbreviation binding: Mapping type variables to terms

```
type binding =
      NameBind
    | TyVarBind
    | VarBind of ty
    | TmAbbBind of term * (ty option)
    | TyAbbBind of ty

    type context = (string * binding) list
```

Auxiliary functions for nameless representation

- name2index

  info->context ->string->int

  return the index of a name

- index2name

  info->context ->int->string

  inverse of the above

- pickfreshname

  context->string ->(context, string)

  generate a fresh name using the second parameter as hint

```
type binding =
    ~~NameBind~~
    | TyVarBind
    | VarBind of ty
    | TmAbbBind of term * (ty option)
    | TyAbbBind of ty

    type context = (string * binding) list
```

Exercise fullsimple.nameless

- Construct a term *t* that is evaluated a term *t'* in fullsimple, where *t'* is different from *t* via only alpha-renaming (i.e., no beta-reduction)

Exercise fullsimple.match

- Add pattern matching for *tuples*, and test on the following expressions
  - let {x, y, z} = {true, 1, {2}} in z;
  - let {x, y, z} = {true, 1, {2}} in (lambda x:Nat. x) y;
  - let {x, y, z} = let x = 1 in {true, x, {2}} in z;
  - lambda x:Nat. let {x, y} = {true, 1} in x;
  - let x = 0 in let {y, z} = {1, 2} in x;
  - let {y, z} = {1, 2} in let y = 3 in y;
- Part of the code is already provided to you in the following two pages

Partial code for fullsimple.match

- Adding the following line to “type term =” in syntax.ml
  – | TmPLet of info * string list * term * term
- Adding the following lines after line 235 in parser.mly
  – | LET Pattern EQ Term IN Term

    { fun ctx -> TmPLet($1, $2, $4 ctx, $6 (List.fold_left (fun x y -> addname x y) ctx $2)) }

  – Pattern :

    LCURLY MetaVars RCURLY

    { $2 }

    | LCURLY RCURLY

    { [] }
- Add the following line to tminfo in syntax.ml
  – | TmPLet(fi,_,_,_) -> fi

Partial code for fullsimple.match

- Adding the following lines to “printtm_Term” in syntax.ml

```
| TmPLet(fi, xs, t1, t2) ->
obox0();
 pr "let {";
 let rec print xs =
 match xs with
       x::x'::rest -> pr x; pr ","; print (x'::rest);
       | x::[] -> pr x;
       | [] -> pr ""; in
 print xs;
 pr "} = ";
 printtm_Term false ctx t1;
 print_space(); pr "in"; print_space();
 let ctx' = List.fold_left (fun ctx x -> addname ctx x) ctx xs in
 printtm_Term false ctx' t2;
 cbox()
```

Key to fullsimple.match

- Add the following lines to eval1

```
 | TmPLet(fi,p,v1,t2)
       when (isval ctx v1) && (is_matched p v1) ->
     let m = terms v1 in
     List.fold_left (fun term v -> termSubstTop v term) t2 (List.rev m)
```

- And add the following two functions

```
let is_matched patterns tmrecord = match tmrecord with
  | TmRecord(fi, fields) ->
     List.length fields = List.length patterns
  | _ -> false
let terms tmrecord = match tmrecord with
    TmRecord(_, fields) -> List.map (fun (_, t) -> t) fields
  | _ -> []
```

Key to fullsimple.match

- Add the following lines to typeof

```
| TmPLet(fi,p,t1,t2) ->
    (match typeof ctx t1 with
    | TyRecord(fields) when List.length fields = List.length p ->
        let (ctx', _) = List.fold_left (
          fun (ctx, xs) (_, tyT1) ->
          let ctx' = addbinding ctx (List.hd xs) (VarBind(tyT1)) in
          (ctx', List.tl xs)
        ) (ctx, p) fields in
        typeShift (- List.length fields) (typeof ctx' t2)
    | _ -> error fi "pattern mismatch")
```

- Add the following line to tmmap in syntax.ml

```
| TmPLet(fi,p,t1,t2) -> TmPLet(fi,p,walk c t1,walk (c+(List.length p)) t2)
```

Exercise fullsimple.natlist

- Try the following term in fullsimple and explain why it cannot be typed

```
NatList = <nil:Unit, cons:{Nat,NatList} >;
nil =  <nil=unit>  as NatList;
cons = lambda n:Nat. lambda l:NatList. <cons={n, l}> as NatList;
```

Exercise fullsimple.let

- Do exercise 11.5.1 letexercise

Exercise for fullsimple.rec_fix

- Define plus using fix and test the following expressions
  - plus 10 105;
  - plus 0 1;
  - plus 0 0;
  - plus 2 0;

Exercise fullref.rec_no_fix

- Write plus without using fix or letrec in fullref

Homework

- Please use the associated code to finish the exercises
- If an exercise asks for a program in the defined language, submit the program.
- If an exercise asks for modifying the interpreter
  - Submit all code
  - Your submission should contain file test.f that contains the expressions required by the exercise
  - TA will perform the following two commands to verify your submission:
    - make
    - ./f test.f
- Please submit a compressed file where each problem in a separate folder