

OCaml Hacks

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Preface

This is a book about hacking in ocaml. It's assumed that you already understand the underlying theory. Happy hacking Most parts are filled with code blocks, I will add some comments in the future. Still a book in progress. Don't distribute it.

☺

Acknowledgements

write
later

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Chapter 1

eco-system

1.1 ocamlbuild

The reason for ocamlbuild in OCaml is to solve the complex scheme to build camlp4. But it's very useful in other aspects

Your code is in the `_build` directory. `ocamlbuild` copies the **needed** source files and compiles them.

In `_build`, `_log` file logs detailed building process.

`ocamlbuild` automatically creates a symbol link to the executable it in the current directory

hygiene rules at start up (`.cmo`, `.cmi`, or `.o` should appear outside of the `_build`)
(`-no-hygiene`)

Important Compile Falgs

option	comment
-quiet	
-verbose <level>	
-documentation	show rules and flags for a specific <code>_tags</code> file
-clean	
-r	Traverse directories by default(true:traverse)
-I <path>	
-Is <path,...>	
-X <path>	ignore directory
-Xs <path,...>	
-lib <flag>	link to ocaml library
-libs <flag,...>	
-mod <module>	link to ocaml module
-mods	
-pkg <package>	link to ocaml findlib package
-pkgs <...>	
-lflag <flag>	ocamlc link flags
-lflags	
-cflag	ocamlc compe flags
-cflags	
-yacccflag	
-yacccflags	
-lexflag	
-lexflags	
-pp	preprocessing flagss
-tag <tag>	add to default tags
-tags	
-show-tags	<code>ocamlbuild -show-tags target</code>
-ignore <module,...>	
-no-hygiene	
-no-plugin	
-just-plugin	just build myocamlbuild.ml
-use-menhir	
-use-jocaml	
-use-ocamlfild	
-build-dir	set build directory (implies no-links)
-install-lib-dir <path>	
-install-bin-dir	
-ocamlc <command>	set the ocamlc command
-ocamlopt	
-ocamldoc	
-ocamlyacc	
-menhir	set the menhir tool (use it after -use-menhir)
-ocamllex	
-ocamlmktop	
-ocamlrun	
Simple Examples	supply arguments

1. `ocamlbuild -quiet xx.native -- args`
2. `ocamlbuild -quite -use-ocamlfind xx.native -- args`
3. pass flags to `ocamlc` at compile time.i.e. `-cflags -I,+lablgtk,-rectypes`
4. linking with **external** libraries. i.e. `-libs unix,num`. You may need add the options below to make it work if this not in OCaml's default search path

```
-cflags -I,/usr/local/lib/ocaml -lflags -I,/usr/local/lib/ocaml
```

5. mllib file

```
cat top_level.mllib
Dir_top_level_util
Dir_top_level
```

then you can `ocamlbuild top_level.cma`, then you can use `ocamlobjinfo` to see exactly which modules are compacted into it.

```
ocamlobjinfo _build/top_level.cma | grep Unit
Unit name: Dir_top_level_util
Unit name: Dir_top_level
```

6. mlpack file hierarchical packing



`_tags` File

Every source has a set of tags .

```
bash-3.2$ ocamlbuild -show-tags test.ml
Tags for "test.ml":
{. extension:ml, file:test.ml, ocaml, pkg_camlp4.macro,
  pkg_menhirLib,
  pkg_ulex, predefine_ulex.ml, quiet, syntax_camlp4o, traverse,
  use_menhir .}
bash-3.2$ ocamlbuild -show-tags test.byte
Tags for "test.byte":
{. byte, extension:byte, file:test.byte, ocaml, pkg_menhirLib,
  pkg_ulex,
  program, quiet, traverse, use_menhir .}
bash-3.2$ ocamlbuild -show-tags test.native
Tags for "test.native":
{. extension:native, file:test.native, native, ocaml,
  pkg_menhirLib,
  pkg_ulex, program, quiet, traverse, use_menhir .}
```

By preceding a tag with a minus sign, one may remove tags from one or more files.

The built-in `_tags` file

```

<*/*.ml>      or <*/*.mli> or <*/*.ml.depends> : ocaml
<*/*.byte> : ocaml, byte, program
<*/*.native>: ocaml, native, program
<*/*.cma>: ocaml, byte, library
<*/*.cmxa>: ocaml, native, library
<*/*.cmo>: ocaml, byte
<*/*.cmx>: ocaml, native

```

<*/*.ml> means that .ml files in *current dir or sub dir*. A special tag made from the path name of the file relative to the toplevel of the project is automatically defined for each file. Just as above `test.ml` will be tagged `file:test.ml` and also `extension:ml`

1. Including subdirectories include <foo> or <bar> or <baz> : include suppose you are calling `ocamlbuild foo/main.byte`, then use `Foo`, `Foo.Bar` and `Foo.Baz` in your code
2. grouping targets `foo.itarget`, `foo.otarget`

```

cat foo.itarget
main.native
main.byte
stuff.docdir/index.html

```

3. packing `foo.mlpack`

```

cat foo.mlpack
Bar
Baz

```

4. grouping `foo.mllib`
5. preprocessing either `-pp` or tags `pp(cmd ...)`
6. debuggin and profiling either `.d.byte`, `.p.native` or `true:debug`
7. documentation target

create a file called `foo.odocl`, then write the modules you want to document, then build the target `foo.docdir/index.html` when you use `-keep-code` flag

in myocamlbuild.ml, *only* document of exposed modules are kept, not very useful flag ["ocaml"; "doc"] & S[A"-keep-code"]; ocamldep seems to be **lightweight** ocamlbuild -ocamldoc 'ocamlfind ocamldoc -keep-code' foo.docdir/in
It's weird when you have mli file, -keep-code does not work

8. glob patterns

glob
pat-
terns

With lex yacc, ocamlfind

1. .mll .mly supported by default, {menhir (-use-menhir) or add a line true : use_menhir
2. add a line in tags file <*.ml> : pkg_sexplib.syntax, pkg_batteries.syntax, syntax_camlp4o
here syntax_camlp4o is translated by myocamlbuild.ml to -syntax camlp4o
to pass to ocamlfind pkg needs **ocamlbuild plugin** support.

Examples with Syntax extension

```
<*.ml>: package(lwt.unix), package(lwt.syntax), syntax(camlp4o) --
      only needs lwt.syntax when preprocessing
"prog.byte": package(lwt.unix)
```

```
<pa_*.r.{ml,cmo,byte}> : pkg_dynlink , pp(camlp4rf ), use_camlp4_full
```

```
<*_ulex.{byte,native}> : pkg_ulex
```

```
<*_ulex.ml> : syntax_camlp4o,pkg_ulex,pkg_camlp4.macro
```

```
<*_r.ml>:syntax_camlp4r,pkg_camlp4.quotations.r,pkg_camlp4.macro,pkg_camlp4.extend
```

```
pa_vector_r.ml:syntax_camlp4r,pkg_camlp4.quotations.r,pkg_camlp4.extend,pkg_sexplib
```

```
<pa_vector_r.{cmo,byte,native}>:pkg_dynlink,use_camlp4_full,pkg_sexplib
```

```
<*_o.ml> : syntax_camlp4o,pkg_sexplib.syntax
```

```
"map_filter_r.ml" : pp(camlp4r -filter map)
```

```
"wiki_r.ml" or "wiki2_r.ml" : pp(camlp4rf -filter meta), use_camlp4_full
```

```
"wiki2_r.mli" : use_camlp4_full
```

The .mli file also needs tags. For syntax extension, **order matters** , For more information, check out **camlp4/examples**. when you use pp flag, you need to specify the path to `pa_xx.cmo`, so symbol link may help. Since 3.12,, you can use `-use-ocamlfind` to activate. ocamlfind predicates can be activated with the `predicate(...)` tag.

```
<*.ml>: package(lwt.unix), package(lwt.syntax), syntax(camlp4o)
"prog.byte": package(lwt.unix)
```

Interaction with git

```
_log
_build
*.native
*.byte
*.d.native
*.p.byte
```

ocamlbuild cares white space, **take care when write tags file**

Rules

A rule is composed of triple (Tags, Targets => Dependencies).

Principal

ocamlbuild looks for all rules that are valid for this target. You can set `-verbose 10` to get the backtrace in case of a failure.

Plugins Plugin API

There are 3 stages,(hygiene, options(parsing the command line options), rules(adding the default rules to the system)). You can add hooks to what you want.

{Before|After}_{options|hygiene|rules} To change the options, simply refer to the Options module.

```

sub_modules "Ocamlbuild_plugin";;
module This_module_name_should_not_be_used :
  module Pathname :
    module Operators :
  module Tags :
    module Operators :
  module Command :
  module Outcome :
  module String :
  module List :
  module StringSet :
  module Options :
  module Arch :
  module Findlib :

```

Useful API,

Pathname.t,Tags.eltsstring List the tags of a file tags_of_pathname Tag a file
tag_file Untag a file tag_file "x.ml" ["-use_unix"] Arch.print_info

```

rule;;
- : string ->
  ?tags:string list ->
  ?prods:string list ->
  ?deps:string list ->
  ?prod:string ->
  ?dep:string ->
  ?stamp:string ->
  ?insert:[ 'after of string | 'before of string | 'bottom | 'top ] ->
  Ocamlbuild_plugin.action -> unit
= <fun>

```

The first arg is the name of the rule(unique required), ~dep is the dependency, ~prod

is the production. For example with `~dep:"%.ml" ~prod:"%.byte"`, you can produce “bla.byte” from “bal.ml”. There are some predefined commands such as Unix commands(`cp,mv,...`).

flag,dep

```
flag ["ocaml"; "compile"; "thread"'] (A "-thread")
```

It says tags `ocaml`, `compile`, `thread` should become `-thread`

```
type t =
  |Seq of t list
    (* A sequence of commands (like the ';' in shell) *)
  |Cmd of spec
    (* A command is made of command specifications (spec) *)
  |Echo of string list * pathname
    (* Write the given strings (w/ any formatting) to the given file *)
  |Nop
    (*The type t provides some basic combinators and command
      primitives. Other commands can be made of command specifications
      (spec).*)
type spec =
  |N (*No operation. *)
  |S of spec list (* A sequence. This gets flattened in the last stages*)
  |A of string (* An atom.*)
  |P of pathname (* A pathname.*)
  |Px of pathname
    (* A pathname, that will also be given to the call_with_target
      hook. *)
  |Sh of string
    (* A bit of raw shell code, that will not be escaped. *)
  |T of tags
    (* A set of tags, that describe properties and some semantics
      information about the command, afterward these tags will be replaced
```

```

    by command specs (flags for instance). *)
|V of string
(* A virtual command, that will be resolved at execution using
    resolve_virtuels *)
|Quote of spec
(* A string that should be quoted like a filename but isn't really
    one. *)

```

```

module Options

```

contains refs to be configured

```

module type OPTIONS = sig
  type command_spec

  val build_dir : string ref
  val include_dirs : string list ref
  val exclude_dirs : string list ref
  val nothing_should_be_rebuilt : bool ref
  val ocamlc : command_spec ref
  val ocamlpt : command_spec ref
  val ocamldep : command_spec ref
  val ocamlldoc : command_spec ref
  val ocaml yacc : command_spec ref
  val ocamllex : command_spec ref
  val ocamlrun : command_spec ref
  val ocamlmklib : command_spec ref
  val ocamlmktop : command_spec ref
  val hygiene : bool ref
  val sanitize : bool ref
  val sanitization_script : string ref
  val ignore_auto : bool ref
  val plugin : bool ref

```



```
val just_plugin : bool ref
val native_plugin : bool ref
val make_links : bool ref
val nostdlib : bool ref
val program_to_execute : bool ref
val must_clean : bool ref
val catch_errors : bool ref
val use_menhir : bool ref
val show_documentation : bool ref
val recursive : bool ref
val use_ocamlfind : bool ref

val targets : string list ref
val ocaml_libs : string list ref
val ocaml_mods : string list ref
val ocaml_pkgs : string list ref
val ocaml_cflags : string list ref
val ocaml_lflags : string list ref
val ocaml_ppflags : string list ref
val ocaml_yaccflags : string list ref
val ocaml_lexflags : string list ref
val program_args : string list ref
val ignore_list : string list ref
val tags : string list ref
val tag_lines : string list ref
val show_tags : string list ref

val ext_obj : string ref
val ext_lib : string ref
val ext_dll : string ref
val exe : string ref
```

```

    val add : string * Arg.spec * string -> unit
end

```

Some Examples

```

open Ocamlbuild_plugin;;
open Command;;

```

```

let alphaCaml = A"alphaCaml";;

```

```

dispatch begin function
  | After_rules ->
    rule "alphaCaml: mla -> ml & mli"
      ~prods:["%.ml"; "%.mli"]
      ~dep:"%.mla"
    begin fun env _build ->
      Cmd(S[alphaCaml; P(env "%.mla")])
    end
  | _ -> ()
end

```

```

(* Open the ocamlbuild world... *)

```

```

open Ocamlbuild_plugin;;

```

```

(* We work with commands so often... *)

```

```

open Command;;

```

```

(* This dispatch call allows to control the execution order of your
   directives. *)

```

```

dispatch begin function
  (* Add our rules after the standard ones. *)
  | After_rules ->

```

```

(* Add pa_openin.cmo to the ocaml pre-processor when use_opening is set *)
flag ["ocaml"; "pp"; "use_openin"] (A"pa_openin.cmo");

(* Running ocamldep on ocaml code that is tagged with use_openin will require
   Note that you only need this declaration when the syntax extension is pa
   sources to be compiled with ocamlbuild. *)
dep ["ocaml"; "ocamldep"; "use_openin"] ["pa_openin.cmo"];
| _ -> ()
end;;

```

```

"bar.ml": camlp4o, use_openin
<foo/*.ml> or <baz/**/*.ml>: camlp4r, use_openin
"pa_openin.ml": use_camlp4, camlp4o

```

```

open Ocamlbuild_plugin
open Unix

```

```

let version = "1.4.2+dev"

```

```

let time =
  let tm = Unix.gmtime (Unix.time ()) in
  Printf.sprintf "%02d/%02d/%04d %02d:%02d:%02d UTC"
    (tm.tm_mon + 1) tm.tm_mday (tm.tm_year + 1900)
    tm.tm_hour tm.tm_min tm.tm_sec

```

```

let make_version _ _ =
  let cmd =
    Printf.sprintf "let version = %S\n\
                    let compile_time = %S"
                    version time

```

```

in
  Cmd (S [ A "echo"; Quote (Sh cmd); Sh ">"; P "version.ml" ])

let () = dispatch begin function
  | After_rules ->
      rule "version.ml" ~prod: "version.ml" make_version
  | _ -> ()
end

open Ocamlbuild_plugin

let () =
  dispatch begin function
  | After_rules ->
      dep ["myfile"] ["other.ml"]
  | _ -> ()
end

```

1.2 godi

- godi_console
- useful paths

```
./build/distfiles/godi-batteries
```

```
~/SourceCode/ML/godi/build/distfiles/ocaml-3.12.0/toplevel/
```

```
godi_make makesum
```

```
godi_make install
```

```
godi_console info (godi_console list )
```

```
godi_add ~/SourceCode/ML/godi/build/packages/All/godi-calendar-2.03.tgz
```

```
god_i_console perform -build god_i-ocaml-graphics >.log 2 >1
perform (fetch, extract, patch, configure, build, install)
```

1.3 ocamlfind

findlib

- *ocamlfind browser -all*
- *ocamlfind browser -package batteries*

- syntax extension

```
ocamlfind ocamldep -package camlp4,xstrp4 -syntax camlp4r file1.ml file2.ml
```

ocamlfind can only handle flag camlp4r, flag camlp4o, so if you want to use other extensions, use -package camlp4,xstrp4, i.e. -package camlp4.macro

- META file (exmaple)

```
name="toplevel"
description = "toplevel_hacking"
requires = ""
archive(byte) = "dir_top_level.cmo"
archive(native) = "dir_top_level.cmx"
version = "0.1"
```

- simple Makefile for ocamlfind

```
all:
    @ocamlfind install toplevel META _build/*.cm[oxi]
clean:
    @ocamlfind remove toplevel
```

1.4 toplevel

1. #directory ‘‘_build’’ ;; #directory ‘‘+camlp4’’ ;; #load ‘‘...’’

2. trace
3. labels (ignore labels in function types)
4. warnings print_depth print_length
5. hacking Toploop

- re-direct

```

Toploop.execute_phrase (bool->formatter->Parsetree.toplevel_phrase->bool)
Toploop.read_interactive_input

- : (string -> string -> int -> int * bool) ref = (* topdirs.cmi *)

      Hashtbl.keys Toploop.directive_table;;

print_depth use principal untrace_all load list trace show directory u cd
Topdirs. (dir_load,dir_use,dir_install_printer,dir_trace,dir_untrace,dir_

- : (Format.formatter -> string -> unit) *
      (Format.formatter -> string -> unit) *
      (Format.formatter -> Longident.t -> unit) *
      (Format.formatter -> Longident.t -> unit) *
      (Format.formatter -> Longident.t -> unit) *
      (Format.formatter -> unit -> unit) *
      (Format.formatter -> string -> bool) * (unit -> unit) * (string -> u

```

- store env

```

let env = !Toploop.toplevel_env
... blabbla ...
Toploop.toplevel_env := env
Toploop.initialize_toplevel_env ()

```

- sample file for references in findlib

```

(* For Ocaml-3.03 and up, so you can do: #use "topfind" and get a
   * working findlib toplevel.

```

```

* First test whether findlib_top is already loaded. If not, load it now
* The test works by executing the toplevel phrase "Topfind.reset" and
* checking whether this causes an error.
*)

let exec_test s =
  let l = Lexing.from_string s in
  let ph = !Toploop.parse_toplevel_phrase l in
  let fmt = Format.make_formatter (fun _ _ _ -> ()) (fun _ -> ()) in
  try
    Toploop.execute_phrase false fmt ph
  with
    _ -> false
in
if not(exec_test "Topfind.reset;;") then (
  Topdirs.dir_load Format.err_formatter "/Users/bob/SourceCode/ML/godi/li
  Topdirs.dir_load Format.err_formatter "/Users/bob/SourceCode/ML/godi/li
);;

```

- topfind.ml

ideas : we can write **some utils** to check code later yeah. A poor man's code search tool (in the library `dir_top_level`)

```

se;;
- : ?ignore_module:bool -> (string -> bool) -> string -> string list =
se ~ignore_module:false (FILTER_* "char" space* "->" space* "bool") "String";;

```

```

module Dont_use_this_name_ever :
  val contains : string -> char -> bool
  val contains_from : string -> int -> char -> bool
  val rcontains_from : string -> int -> char -> bool
  val filter : (char -> bool) -> string -> string
  module IString : sig type t = String.t val compare : t
    -> t -> int end
  module NumString : sig type t = String.t val compare : t
    -> t -> int end

```

```

module Exceptionless :
module Cap :
  val filter : (char -> bool) -> [> 'Read ] t -> 'a t
  val contains : [> 'Read ] t -> char -> bool
  val contains_from : [> 'Read ] t -> int -> char ->
    bool
  val rcontains_from : [> 'Read ] t -> int -> char ->
    bool
  module Exceptionless :

```

```

Hashtbl.add
Toploop.directive_table
"require"
(Toploop.Directive_string
  (fun s ->
    protect load_deeply (Fl_split.in_words s)
  ))
;;
Hashtbl.add Toploop.directive_table "pwd"
(Toploop.Directive_none (fun _ ->
  print_endline (Sys.getcwd ()))));;
#pwd;;

/Users/bob/SourceCode/Notes

```

1.5 git

- ignore set
 _log _build *.native *.byte *.d.native *.p.byte

Chapter 2

lexing

2.1 lexing-ulex-ocamllex

Ulex support unicode, while ocamllex don't, the tags file is as follows

```
$ cat tags
<*_ulex.ml> : syntax_camlp4o, pkg_ulex
<*_ulex.{byte,native}> : pkg_ulex
```

Use default myocamlbuild.ml, like `ln -s ~/myocamlbuild.ml` and make a symbol link `pa_ulex.cma` to `camlp4` directory, this is actually not necessary but sometimes for debugging purpose, as follows, this is pretty easy

```
camlp4o pa_ulex.cma -printer OCaml test_ulex.ml -o test_ulex.ppo
```

Ulex does not support `as` syntax as ocamllex.

```
let regexp number = ['0'-'9'] +
let regexp line = [^'\n']* ('\\n' ?)
let u8l = Ulexing.utf8_lexeme
let rec lexer1 arg1 arg2 .. = lexer
  |regexp -> action |..
and lexer2 arg1 arg2 .. = lexer
  |regexp -> action |...
```

Roll back

Ulexing.rollback lexbuf, so for string lexing, you can rollback one char, and *plugin your string lexer*, but *not generally usefull*, ulex *does not support shortest mode yet*. Sometimes the semantics of rolling back is not what you want as recursive descent parser.

Abstraction with macro package

Since you need inline to do macro preprocessing, so use syntax extension macro to **inline** your code,

```
<*_ulex.ml> : syntax_camlp4o, pkg_ulex, pkg_camlp4_macro
<*_ulex.{byte,native}> : pkg_ulex
```

Attention! Since you use ocamlbuild to build, then you need to copy you include files to `_build` if you use relative path in **INCLUDE** macro, otherwise you should use absolute path.

You can predefine some regexps (copied from ocaml source code) `parsing/lexer.ml`.

```
let u8l = Ulexing.utf8_lexeme
let u8_string_of_int_array arr =
  Utf8.from_int_array arr 0 (Array.length arr)
let u8_string_of_int v =
  Utf8.from_int_array [|v|] 0 1

let report_error ?(msg="") lexbuf =
  let (a,b) = Ulexing.loc lexbuf in
  failwith ((Printf.sprintf "unexpected error (%d,%d) : " a b )^ msg)

(** copied from ocaml 3.12.1 source code *)
let regexp newline = ('\010' | '\013' | "\013\010")
let regexp blank = [' ' '\009' '\012']
let regexp lowercase = ['a'-'z' '\223'-'246' '\248'-'255' '_']
let regexp uppercase = ['A'-'Z' '\192'-'214' '\216'-'222']
```

```

let regexp identchar =
  ['A'-'Z' 'a'-'z' '_' '\192'-' \214' '\216'-' \246' '\248'-' \255' '\'' '0'-'9']

let regexp symbolchar =
  ['!' '$' '%' '&' '*' '+' '-' '.' '/' ':' '<' '=' '>' '?' '@' '^' '|' '~']

let regexp decimal_literal =
  ['0'-'9'] ['0'-'9' '_']*
let regexp hex_literal =
  '0' ['x' 'X'] ['0'-'9' 'A'-'F' 'a'-'f'] ['0'-'9' 'A'-'F' 'a'-'f' '_']*
let regexp oct_literal =
  '0' ['o' 'O'] ['0'-'7'] ['0'-'7' '_']*
let regexp bin_literal =
  '0' ['b' 'B'] ['0'-'1'] ['0'-'1' '_']*
let regexp int_literal =
  decimal_literal | hex_literal | oct_literal | bin_literal
let regexp float_literal =
  ['0'-'9'] ['0'-'9' '_']* (['.' ['0'-'9' '_']* ])? (['e' 'E'] ['+' '-']? ['0'-'9'])

let regexp blanks = blank +
let regexp whitespace = (blank | newline) ?
let regexp underscore = "_"
let regexp tilde = "~"

let regexp lident = lowercase identchar *

let regexp uidnet = uppercase identchar *

(** Handle string *)
let initial_string_buffer = Array.create 256 0

```

```

let string_buff = ref initial_string_buffer
let string_index = ref 0

let reset_string_buffer () =
  string_buff := initial_string_buffer;
  string_index := 0

(** store a char to the buffer *)
let store_string_char c =
  if !string_index >= Array.length (!string_buff) then begin
    let new_buff = Array.create (Array.length (!string_buff) * 2) 0 in
    Array.blit (!string_buff) 0 new_buff 0 (Array.length (!string_buff));
    string_buff := new_buff
  end;
  Array.unsafe_set (!string_buff) (!string_index) c;
  incr string_index

let get_stored_string () =
  let s = Array.sub (!string_buff) 0 (!string_index) in
  string_buff := initial_string_buffer;
  s

let char_for_backslash = function
  | 110 -> 10 (*'n' -> '\n'*)
  | 116 -> 9  (*'t' -> '\t' *)
  | 98  -> 8  (*'b' -> '\b'*)
  | 114 -> 13 (*'r' -> '\r' *)
  | c -> c
(** user should eat the first "\"*)
let char_literal = lexer

```

```

| newline "\"" ->
  (Ulexing.lexeme_char lexbuf 0)
| [^ '\\\ ' \010' \013'] "\"" ->
  (* here may return a unicode we use *)
  (Ulexing.lexeme_char lexbuf 0)
  (** here we have two quotient just to appeal the typesetting *)
| "\\\" ['\\\ ' \', 'n' 't' 'b' 'r' ' ']' "\"" ->
  (char_for_backslash (Ulexing.lexeme_char lexbuf 1 ))
| "\\\" ['0'-'9'] ['0'-'9'] ['0'-'9'] "\"" ->
  let arr = Ulexing.sub_lexeme lexbuf 1 3 in
  (** Char.code '0' = 48 *)
  100*(arr.(0)-48)+10*(arr.(1)-48)+arr.(2)-48
| "\\\" 'x' ['0'-'9' 'a'-'f' 'A'-'F'] ['0'-'9' 'a'-'f' 'A'-'F'] "\"" ->
  let arr = Ulexing.sub_lexeme lexbuf 2 2 in
  let v1 =
    if arr.(0) >= 97
    then (arr.(0)-87 ) * 16
    else if arr.(0) >= 65
    then (arr.(0)-55) * 16
    else (arr.(0) - 48) * 16 in
  let v2 =
    if arr.(1) >= 97
    then (arr.(1)-87 )
    else if arr.(1) >= 65
    then (arr.(1)-55)
    else (arr.(1) - 48) in
  (v1 + v2 )
| "\\\" _ ->
  let (a,b) = Ulexing.loc lexbuf in
  let l = Ulexing.sub_lexeme lexbuf 0 2 in
  failwith

```

```

(Printf.sprintf
  "expecting a char literal (%d,%d) while %d%d appeared" a b 1.(0) 1.(1))
| _ ->
  let (a,b) = Ulexing.loc lexbuf in
  let l = Ulexing.lexeme lexbuf in
  failwith
(Printf.sprintf
  "expecting a char literal (%d,%d) while %d appeared" a b 1.(0))

(** ocaml supports multiple line string "a b \
  b" => interpreted as "a b b"
  actually we are always operation on an int
  *))
let rec string = lexer
(** for typesetting, duplication is not necessary *)
| ['"' '"] -> () (* end *)

| '\\ newline ([' ' '\t' * ) ->
  string lexbuf
(** for typesetting, duplication is not necessary *)
| '\\ ['\\' '\'' '"' '\n' '\t' '\b' '\r' ' ' ] ->
  store_string_char(char_for_backslash (Ulexing.lexeme_char lexbuf 1));
  string lexbuf
| '\\ ['0'-'9' ] ['0'-'9' ] ['0'-'9' ] ->
  let arr = Ulexing.sub_lexeme lexbuf 1 3 in
  let code = 100*(arr.(0)-48)+10*(arr.(1)-48)+arr.(2)-48 in
  store_string_char code ;
  string lexbuf
| '\\ 'x' ['0'-'9' 'a'-'f' 'A'-'F' ] ['0'-'9' 'a'-'f' 'A'-'F' ] ->
  let arr = Ulexing.sub_lexeme lexbuf 2 2 in
  let v1 =

```

```

    if arr.(0) >= 97
    then (arr.(0)-87 ) * 16
    else if arr.(0) >= 65
    then (arr.(0)-55) * 16
    else (arr.(0) - 48) * 16 in
let v2 =
    if arr.(1) >= 97
    then (arr.(1)-87 )
    else if arr.(1) >= 65
    then (arr.(1)-55)
    else (arr.(1) - 48) in
let code = (v1 + v2 ) in
store_string_char code ;
string lexbuf
| '\\' _ ->
    let (a,b) = Ulexing.loc lexbuf in
    let l = Ulexing.sub_lexeme lexbuf 0 2 in
    failwith
    (Printf.sprintf
        "expecting a string literal (%d,%d) while %d%d appeared" a b l.(0) l.(1))
    let (a,b) = Ulexing.loc lexbuf in
    let l = Ulexing.lexeme lexbuf in
    failwith
    (Printf.sprintf
        "expecting a string literal (%d,%d) while %d appeared" a b
        l.(0))
| _ ->
    store_string_char (Ulexing.lexeme_char lexbuf 0);
    string lexbuf
(** you should provide ''' as entrance *)
let string_literal lexbuf =

```

```

reset_string_buffer();
string lexbuf;
get_stored_string()

```

Ulex interface

Roughly equivalent to the module Lexing, except that its lexbuffers handles Unicode code points OCaml type `int` in the range `0.. 0x10ffff` instead of bytes (OCaml-type `char`).

You can customize implementation for lex buffers, define a module `L` which implements *start*, *next*, *mark*, and *backtrack* and the *Error exception*. They need not work on a type named `lexbuf`, you can use the type name you want. Then, just do in your *ulex-processed* source, before the first lexer specification `module Ulexing = L`. If you inspect the processed output by `camlp4`, you can see that the generated code *introducing Ulexing very late* and actually use very limited functions, other functions are just provided for your convenience, and it did not have any type annotations, so you really can customize it. I think probably `ocamllex` can do the similar trick.

*(** Runtime support for lexers generated by [ulex].*

This module is roughly equivalent to the module Lexing from the OCaml standard library, except that its lexbuffers handles Unicode code points (OCaml type: [int] in the range [0..0x10ffff]) instead of bytes (OCaml type: [char]).

It is possible to have ulex-generated lexers work on a custom implementation for lex buffers. To do this, define a module [L] which implements the [start], [next], [mark] and [backtrack] functions (See the Internal Interface section below for a specification), and the [Error] exception.

They need not work on a type named [lexbuf]: you can use the type name you want. Then, just do in your ulex-processed source, before the first lexer specification:


```
[module Ulexing = L]
```

Of course, you'll probably want to define functions like [lexeme] to be used in the lexers semantic actions.

```
*)
```

```
type lexbuf
```

```
(** The type of lexer buffers. A lexer buffer is the argument passed to the scanning functions defined by the generated lexers. The lexer buffer holds the internal information for the scanners, including the code points of the token currently scanned, its position from the beginning of the input stream, and the current position of the lexer. *)
```

```
exception Error
```

```
(** Raised by a lexer when it cannot parse a token from the lexbuf. The functions [Ulexing.lexeme_start] (resp. [Ulexing.lexeme_end]) can be used to find to positions of the first code point of the current matched substring (resp. the first code point that yield the error). *)
```

```
exception InvalidCodepoint of int
```

```
(** Raised by some functions to signal that some code point is not compatible with a specified encoding. *)
```

```
(** {6 Clients interface} *)
```

```
val create: (int array -> int -> int -> int) -> lexbuf
```

```
(** Create a generic lexer buffer. When the lexer needs more characters, it will call the given function, giving it an array of integers [a], a position [pos] and a code point count [n]. The function should put [n] code points or less in [a], starting at
```

*position [pos], and return the number of characters provided. A return value of 0 means end of input. *)*

```
val from_stream: int Stream.t -> lexbuf
  (** Create a lexbuf from a stream of Unicode code points. *)

val from_int_array: int array -> lexbuf
  (** Create a lexbuf from an array of Unicode code points. *)

val from_latin1_stream: char Stream.t -> lexbuf
  (** Create a lexbuf from a Latin1 encoded stream (ie a stream
    of Unicode code points in the range [0..255]) *)

val from_latin1_channel: in_channel -> lexbuf
  (** Create a lexbuf from a Latin1 encoded input channel.
    The client is responsible for closing the channel. *)

val from_latin1_string: string -> lexbuf
  (** Create a lexbuf from a Latin1 encoded string. *)

val from_utf8_stream: char Stream.t -> lexbuf
  (** Create a lexbuf from a UTF-8 encoded stream. *)

val from_utf8_channel: in_channel -> lexbuf
  (** Create a lexbuf from a UTF-8 encoded input channel. *)

val from_utf8_string: string -> lexbuf
  (** Create a lexbuf from a UTF-8 encoded string. *)

type enc = Ascii | Latin1 | Utf8
val from_var_enc_stream: enc ref -> char Stream.t -> lexbuf
```

*(** Create a lexbuf from a stream whose encoding is subject to change during lexing. The reference can be changed at any point. Note that bytes that have been consumed by the lexer buffer are not re-interpreted with the new encoding.*

*In [Ascii] mode, non-ASCII bytes (ie [>127]) in the stream raise an [InvalidCodepoint] exception. *)*

```
val from_var_enc_string: enc ref -> string -> lexbuf
  (** Same as [Ulexing.from_var_enc_stream] with a string as input. *)

val from_var_enc_channel: enc ref -> in_channel -> lexbuf
  (** Same as [Ulexing.from_var_enc_stream] with a channel as input. *)
```

*(** {6 Interface for lexers semantic actions} *)*

*(** The following functions can be called from the semantic actions of lexer definitions. They give access to the character string matched by the regular expression associated with the semantic action. These functions must be applied to the argument [lexbuf], which, in the code generated by [ulex], is bound to the lexer buffer passed to the parsing function.*

*These functions can also be called when capturing a [Ulexing.Error] exception to retrieve the problematic string. *)*

```
val lexeme_start: lexbuf -> int
  (** [Ulexing.lexeme_start lexbuf] returns the offset in the input stream of the first code point of the matched string. The first code point of the stream has offset 0. *)
```

```
val lexeme_end: lexbuf -> int
(** [Ulexing.lexeme_end lexbuf] returns the offset in the input stream
    of the character following the last code point of the matched
    string. The first character of the stream has offset 0. *)

val loc: lexbuf -> int * int
(** [Ulexing.loc lexbuf] returns the pair
    [(Ulexing.lexeme_start lexbuf, Ulexing.lexeme_end lexbuf)]. *)

val lexeme_length: lexbuf -> int
(** [Ulexing.loc lexbuf] returns the difference
    [(Ulexing.lexeme_end lexbuf) - (Ulexing.lexeme_start lexbuf)],
    that is, the length (in code points) of the matched string. *)

val lexeme: lexbuf -> int array
(** [Ulexing.lexeme lexbuf] returns the string matched by
    the regular expression as an array of Unicode code point. *)

val get_buf: lexbuf -> int array
(** Direct access to the internal buffer. *)

val get_start: lexbuf -> int
(** Direct access to the starting position of the lexeme in the
    internal buffer. *)

val get_pos: lexbuf -> int
(** Direct access to the current position (end of lexeme) in the
    internal buffer. *)

val lexeme_char: lexbuf -> int -> int
(** [Ulexing.lexeme_char lexbuf pos] returns code point number [pos] in
    the matched string. *)
```

```
val sub_lexeme: lexbuf -> int -> int -> int array
(** [Ulexing.lexeme lexbuf pos len] returns a substring of the string
    matched by the regular expression as an array of Unicode code point. *)

val latin1_lexeme: lexbuf -> string
(** As [Ulexing.lexeme] with a result encoded in Latin1.
    This function throws an exception [InvalidCodepoint] if it is not possible
    to encode the result in Latin1. *)

val latin1_sub_lexeme: lexbuf -> int -> int -> string
(** As [Ulexing.sub_lexeme] with a result encoded in Latin1.
    This function throws an exception [InvalidCodepoint] if it is not possible
    to encode the result in Latin1. *)

val latin1_lexeme_char: lexbuf -> int -> char
(** As [Ulexing.lexeme_char] with a result encoded in Latin1.
    This function throws an exception [InvalidCodepoint] if it is not possible
    to encode the result in Latin1. *)

val utf8_lexeme: lexbuf -> string
(** As [Ulexing.lexeme] with a result encoded in UTF-8. *)

val utf8_sub_lexeme: lexbuf -> int -> int -> string
(** As [Ulexing.sub_lexeme] with a result encoded in UTF-8. *)

val rollback: lexbuf -> unit
(** [Ulexing.rollback lexbuf] puts [lexbuf] back in its configuration before
    the last lexeme was matched. It is then possible to use another
```

*lexer to parse the same characters again. The other functions above in this section should not be used in the semantic action after a call to [Ulexing.rollback]. *)*

*(** {6 Internal interface} *)*

*(** These functions are used internally by the lexers. They could be used to write lexers by hand, or with a lexer generator different from [ulex]. The lexer buffers have a unique internal slot that can store an integer. They also store a "backtrack" position.*

**)*

val start: lexbuf -> **unit**

*(** [Ulexing.start lexbuf] informs the lexer buffer that any code points until the current position can be discarded. The current position become the "start" position as returned by [Ulexing.lexeme_start]. Moreover, the internal slot is set to [-1] and the backtrack position is set to the current position.*

**)*

val next: lexbuf -> **int**

*(** [Ulexing.next lexbuf next] extracts the next code point from the lexer buffer and increments to current position. If the input stream is exhausted, the function returns [-1]. *)*

val mark: lexbuf -> **int** -> **unit**

*(** [Ulexing.mark lexbuf i] stores the integer [i] in the internal slot. The backtrack position is set to the current position. *)*

val backtrack: lexbuf -> **int**

*(** [Ulexing.backtrack lexbuf] returns the value stored in the*

*internal slot of the buffer, and performs backtracking
(the current position is set to the value of the backtrack position). *)*

Ulex does not handle line position, you have only global char position, but we are using emacs, not matter too much

ATTENTION

When you use ulex to generate the code, make sure to write the interface by yourself, the problem is that when you use the default interface, it will generate `__table__`, and different file may overlap this name, when you open the module, it will cause a disaster, so the best to do is write your `.mli` file.

And when you write lexer, make sure you write the default branch, check the generated code, otherwise its behavior is weird.

`camlp4of -parser macro pa_ulex.cma test_calc.ml -printer o` **Example**

Here is the example of simple basic lexer

```
open Ulexing
open Batteries

let regexp op_ar = ['+' '-' '*' '/']
let regexp op_bool = ['!' '&' '|' ]
let regexp rel = ['=' '<' '>']

(** get string output, not int array *)
let lexeme = Ulexing.utf8_lexeme

let rec basic = lexer
  | [' ' ] -> basic lexbuf
  | op_ar | op_bool ->
    let ar = lexeme lexbuf in
    'Lsymbol ar
  | "<=" | ">=" | "<>" | rel ->
```

```

    'Lsymbol (lexeme lexbuf)
| ("REM" | "LET" | "PRINT"
   | "INPUT" | "IF" | "THEN") ->
    'Lsymbol (lexeme lexbuf)
| '-'?['0'-'9']+ ->
    'Lint (int_of_string (lexeme lexbuf))
| ['A'-'z']+ ->
    'Lident (lexeme lexbuf)
| ''' [^ '''] ''' ->
    'Lstring (let s = lexeme lexbuf in
              String.sub s 1 (String.length s - 2))
| eof -> raise End_of_file
| _ ->
    (print_endline (lexeme lexbuf ^ "unrecognized");
     basic lexbuf)

let token_of_string str =
  str
  |> Stream.of_string
  |> from_utf8_stream
  |> basic
let tokens_of_string str =
  let output = ref [] in
  let lexbuf = str |> Stream.of_string |> from_utf8_stream in
  (try
    while true do
      let token = basic lexbuf in
      output := token :: !output;
      print_endline (dump token)
    done
  with End_of_file -> ());

```



```

List.rev (!output)

let _ = tokens_of_string
    "a + b >= 3 > 3 < xx"

(**
  assert_failure, assert_equal, @?, assert_raises, skip_if, todo, cmp_float
  bracket
*)
let test_result = OUnit.(
  run_test_tt ("test-suite" >:::
    [
      "test2" >:: (fun _ -> ());
      "test1" >:: (fun _ -> "true" @? true)
    ]
  ))
;;

(**Remark
*)

ocamllex

1. module Lexing

```

```

se_str "from" "Lexing";;

val from_string : string -> lexbuf
val from_function : (string -> int -> int) -> lexbuf
val from_input : BatIO.input -> Lexing.lexbuf
val from_channel : BatIO.input -> Lexing.lexbuf

```

2. syntax

```

{header}
let ident = regexp ...
rule entrypoint [arg1 .. argn] =
  parse regexp {action}
  | ..
  | regexp {action}
and entrypoint [arg1 .. argn] =
  parse ..
and ...
{trailer}

```

The parse keyword can be replaced by shortest keyword.

Typically, the header section contains the *open* directives required by the actions

All identifiers starting with `__ocaml_lex` are reserved for use by **ocamllex**

3. example for me, best practice is put some test code in the trailer part, and use `ocamlbuild fc_lexer.byte` – to verify, or write a makefile. you can write several indifferent rule in a file using and.

```

(* verbatim translate *)
rule translate = parse
  | "current_directory" {print_string (Sys.getcwd ()); translate
    lexbuf}
  | _ as c {print_char c ; translate lexbuf}
  | eof {exit 0}

{
  let _ =

```

```

let chan = open_in "fc_lexer.mll" in begin
  translate (Lexing.from_channel chan );
  close_in chan
end
}

```

```

Legacy.Printexc.print;;
- : ('a -> 'b) -> 'a -> 'b = <fun>

```

4. caveat

the longest(shortest) win, then consider the order of each regexp later. Actions are evaluated after the *lexbuf* is bound to the current lexer buffer and the identifier following the keyword *as* to the matched string.

5. position

The lexing engine manages only the *pos_cnum* field of *lexbuf.lex_curr_p* with the number of chars read from the start of *lexbuf*. you are responsible for the other fields to be accurate. i.e.

```

let incr_lineno lexbuf = Lexing.(
  let pos = lexbuf.lex_curr_p in
  lexbuf.lex_curr_p <- { pos with
    pos_lnum = pos.pos_lnum + 1; (* line number *)
    pos_bol = pos.pos_cnum; (* the offset of the beginning of
      the
      line *)
  })

```

6. combine with ocaml yacc

normally just add *open Parse* in the header, and use the token defined in *Parse*

7. tips

- (a) keyword table

```

    {let keyword_table = Hashtbl.create 72
      let _ = ...
    }
    rule token = parse
    | ['A'-'z' 'a'-'z'] ['A'-'z' 'A'-'z' '0'-'9' '_' ] * as
      id
    {try Hashtbl.find keyword_table id with Not_found ->
      IDENT id}
    | ...

```

(b) for sharing **why ocamllex sucks**

some complex regexps are not easy to write, like string, but sharing is hard. To my knowledge, cpp preprocessor is fit for this task here. camlp4 is not fit, it will check other syntax, if you use ulex, camlp4 will do this job. So, my Makefile is part like this

```

lexer :
    cpp fc_lexer.mll.bak > fc_lexer.mll
    ocamlbuild -no-hygiene fc_lexer.byte --

```

even so, sharing is still very hard, since the built in compiler used another way to write string lexing. painful too sharing. so ulex wins in both aspects. sharing in ulex is much easier.

Chapter 3

parsing

3.1 ocaml yacc or menhir

We mainly cover menhir here.

A grammar is mainly composed of four elements (terminals, non-terminals, production rules, start symbol)

Syntax

```
% {header
% }
%%
Grammar rules
%%
trailer
```

A tiny example as follows (It has a subtle bug, readers should find it)

```
% {
  open Printf
  let parse_error s =
    print_endline "error\n";
    print_endline s ;
    flush stdout
  %}
```

```

%token <float> NUM
%token PLUS MINUS MULTIPLY DIVIDE CARET UMINUS
%token NEWLINE

%start input
%type <unit> input
%type <float> exp
%% /* rules and actions */

input: /* empty */ {}
      | input line {}
;

line: NEWLINE {}
      |exp NEWLINE {printf "\t%.10g\n" $1 ; flush stdout}
;

exp: NUM { $1 }
    |exp exp PLUS {$1 +. $2 }
    |exp exp MINUS {$1 -. $2 }
    |exp exp MULTIPLY {$1 *. $2 }
    |exp exp DIVIDE {$1 /. $2 }
    |exp exp CARET {$1 ** $2 }
    |exp UMINUS {- . $1 }
;

%%

```

Notice that start non-terminal can be given *several*, then you will have a different .mli file, notice that it's different from ocamllex, ocamlyacc will generate a .mli file, so here we get the output interface as follows:

```
%type <type> nonterminal ... nonterminal
%start symbol ... symbol
```

```
type token =
  | NUM of (float)
  | PLUS
  | MINUS
  | MULTIPLY
  | DIVIDE
  | CARET
  | UMINUS
  | NEWLINE
val input :
  (Lexing.lexbuf -> token) -> Lexing.lexbuf -> unit
val exp :
  (Lexing.lexbuf -> token) -> Lexing.lexbuf -> float
```

Notice that we may use character strings as implicit terminals as in

```
expr : expr "+" expr {}
      | expr "*" expr {}
      | ... ;
```

They are directly processed by the parser without passing through the lexer. But it breaks the uniformity

Contextual Grammar

```
open Batteries
```

```
(**
  Grammar
  L := w C w
  w := (A/B)*
```

```

*)
type token = A | B | C

let rec parser1 = parser
  | [< 'A ; l = parser1 >] -> (parser [< 'A>] -> "a") :: l
  | [< 'B ; l = parser1 >] -> (parser [< 'B>] -> "b") :: l
  | [<>] -> [] (* always succeed *)
let parser2 lst str =
  List.fold_left (fun s p -> p str ^ s) "" lst
let parser_L = parser
  | [< ls = parser1 ; 'C; r = parser2 ls >] ->
    r
let _ =
  [A;B;A;B;C;A;B;A;B]
|> Stream.of_list
|> parser_L
|> print_endline

```

First grammar

```

/* empty corresponds Ctrl-d.*/
input : /*empty*/ {} | input line {};

```

Notice here we **preferred left-recursive** in yacc. The underlying theory for LALR prefers LR. because all the elements must be shifted onto the stack *before* the rule can be applied even once.

```

exp : NUM | exp exp PLUS | exp exp MINUS ... ;

```

Here is our lexer

```

{
  open Rpcalc
  open Printf

```



```

    let first = ref true
  }
  let digit = ['0'-'9']
  rule token = parse
    | [' ' '\t' ] {token lexbuf}
    | '\n' {NEWLINE}
    | (digit+ | "." digit+ | digit+ "." digit*) as num
      {NUM (float_of_string num)}
    | '+' {PLUS}
    | '-' {MINUS}
    | '*' {MULTIPLY}
    | '/' {DIVIDE}
    | '^' {CARET}
    | 'n' {UMINUS}
    | _ as c {printf "unrecognized char %c" c ; token lexbuf}
  |eof {
    if !first then begin first := false; NEWLINE end
    else raise End_of_file }

{
  let main () =
    let file = Sys.argv.(1) in
    let chan = open_in file in
    try
      let lexbuf = Lexing.from_channel chan in
      while true do
        Rpcalc.input token lexbuf
      done
    with End_of_file -> close_in chan

  let _ = Printexc.print main ()

```

```
}
```

We write driver function in lexer for convenience, since lexer depends on yacc.
Printex.print

precedence associativity

Operator precedence is determined by the line ordering of the declarations;

%prec in the grammar section, the *%prec* simply instructs ocaml yacc that the rule */Minus exp* has the same precedence as *NEG %left,%right,%nonassoc*

1. The associativity of an operator *op* determines how repeated uses of the operator nest: whether *x op y op z* is parsed by grouping *x* with *y* or. *nonassoc* will consider it as an error
2. All the tokens declared in a single precedence declaration have equal precedence and nest together according to their associativity

```
%{
  open Printf
  open Lexing
  let parse_error s =
    print_endline "impossible happend! panic \n";
    print_endline s ;
    flush stdout
%}
```

```
%token NEWLINE
%token LPAREN RPAREN
%token <float> NUM
%token PLUS MINUS MULTIPLY DIVIDE CARET
```

```
%left PLUS MINUS MULTIPLY DIVIDE NEG
```

```

%right CARET

%start input
%start exp
%type <unit> input
%type <float> exp

%% /* rules and actions */

input: /* empty */ {}
      | input line {}
;

line: NEWLINE {}
     |exp NEWLINE {printf "\t%.10g\n" $1 ; flush stdout}
;

exp: NUM { $1 }
    | exp PLUS exp          { $1 +. $3 }
    | exp MINUS exp         { $1 -. $3 }
    | exp MULTIPLY exp      { $1 *. $3 }
    | exp DIVIDE exp        { $1 /. $3 }
    | MINUS exp %prec NEG   { -. $2 }
    | exp CARET exp         { $1 ** $3 }
    | LPAREN exp RPAREN     { $2 }
;

%%

```

Notice here the *NEG* is a place a holder, it takes the place, but it's not a token. since here we need *MINUS* has different levels. the interface file is as follows

```

type token =
  | NEWLINE
  | LPAREN
  | RPAREN
  | NUM of (float)
  | PLUS
  | MINUS
  | MULTIPLY
  | DIVIDE
  | CARET

val input :
  (Lexing.lexbuf -> token) -> Lexing.lexbuf -> unit
val exp :
  (Lexing.lexbuf -> token) -> Lexing.lexbuf -> float

```

Error Recovery

By default, the parser function raises exception after calling *parse_error*. The ocaml yacc reserved word *error*

```

line: NEWLINE | exp NEWLINE | error NEWLINE {}

```

If an expression that cannot be evaluated is read, the error will be recognized by the third rule for line, and parsing will continue (*parse_error* is still called). This form of error recovery deals with syntax errors. There are also other kinds of errors.

Location Tracking

It's very easy. First, remember to use *Lexing.new_line* to track your line number, then use *rhs_start_pos*, *rhs_end_pos* to track the symbol position. 1 is for the leftmost component.

```

Parsing.(
  let start_pos = rhs_start_pos 3 in
  let end_pos = rhs_end_pos 3 in

```

```

        printf "%d.%d --- %d.%d: dbz"
            start_pos.pos_lnum (start_pos.pos_cnum - start_pos.pos_bol)
            end_pos.pos_lnum (end_pos.pos_cnum - end_pos.pos_bol);
    1.0
)

```

For groupings, use the following function *symbol_start_pos*, *symbol_end_pos*. *symbol_start_pos* is set to the beginning of the leftmost component, and *symbol_end_pos* to the end of the rightmost component.

A complex Example

```

%{
    open Printf
    open Lexing
    let parse_error s =
        print_endline "impossible happend! panic \n";
        print_endline s ;
        flush stdout
    let var_table = Hashtbl.create 16
%}

```

```

%token NEWLINE
%token LPAREN RPAREN EQ
%token <float> NUM
%token PLUS MINUS MULTIPLY DIVIDE CARET
%token <string> VAR
%token <float->float>FNCT /* built in function */

%left PLUS MINUS
%left MULTIPLY DIVIDE
%left NEG

```

```

%right CARET
%start input
%start exp
%type <unit> input
%type <float> exp

%% /* rules and actions */

input: /* empty */ {}
      | input line {}
;

line: NEWLINE {}
     |exp NEWLINE {printf "\t%.10g\n" $1 ; flush stdout}
     |error NEWLINE {}
;

exp: NUM { $1 }
    | VAR
      {try Hashtbl.find var_table $1
       with Not_found ->
         printf "unbound value '%s'\n" $1;
         0.0
      }
    | VAR EQ exp
      {Hashtbl.replace var_table $1 $3; $3}
    | FNCT LPAREN exp RPAREN
      { $1 $3 }
    | exp PLUS exp          { $1 +. $3 }

```

```

| exp MINUS exp           { $1 -. $3 }
| exp MULTIPLY exp        { $1 *. $3 }
| exp DIVIDE exp
  { if $3 <> 0. then $1 /. $3
    else
      Parsing.(
        let start_pos = rhs_start_pos 3 in
        let end_pos = rhs_end_pos 3 in
        printf "%d.%d --- %d.%d: dbz"
          start_pos.pos_lnum (start_pos.pos_cnum - start_pos.pos_bol)
          end_pos.pos_lnum (end_pos.pos_cnum - end_pos.pos_bol);
        1.0
      )}
| MINUS exp %prec NEG      { -. $2 }
| exp CARET exp            { $1 ** $3 }
| LPAREN exp RPAREN        { $2 }
;

%%

(** lexer file *)
{
  open Rpcalc
  open Printf
  let first = ref true
}

let digit = ['0'-'9']

```

```

let id = ['a'-'z']+
rule token = parse
  | [' ' '\t' ] {token lexbuf}
  | '\n' {Lexing.new_line lexbuf ; NEWLINE}
  | (digit+ | "." digit+ | digit+ "." digit*) as num
    {NUM (float_of_string num)}
  | '+' {PLUS}
  | '-' {MINUS}
  | '*' {MULTIPLY}
  | '/' {DIVIDE}
  | '^' {CARET}
  | '(' {LPAREN}
  | ')' {RPAREN}
  | "sin" {FNCT(sin)}
  | "cos" {FNCT(cos) }
  | id as x {VAR x}
  | '=' {EQ}
  | _ as c {printf "unrecognized char %c" c ; token lexbuf}
  | eof {
    if !first then begin first := false; NEWLINE end
    else raise End_of_file }

{
let main () =
  let file = Sys.argv.(1) in
  let chan = open_in file in
  try
    let lexbuf = Lexing.from_channel chan in
    while true do
      Rpcalc.input token lexbuf

```



```

    done
  with End_of_file -> close_in chan

let _ = Printexc.print main ()

}

```

In my opinion, the best practice is first modify .mly file, then change .mll file later

SHIFT REDUCE

A very nice tutorial shift-reduce

```

%token ID COMMA COLON
%token BOGUS /* NEVER LEX */
%start def
%type <unit>def
%%

def:   param_spec return_spec COMMA {}
      ;

param_spec:  ty {}
            |  name_list COLON ty {}
            ;

/*
return_spec:
            ty {}
            |  name COLON ty {}

            |  ID BOGUS {}    // This rule is never used
            ;

*/

/* another way to fix the prob */

```

```

return_spec : ty {}
            | ID COLON ty {}

ty:         ID {}
            ;

name:       ID {}
            ;

name_list:
            name {}
            | name COMMA name_list {}
            ;

%{
%}

%token OPAREN CPAREN ID SEMIC DOT INT EQUAL

%start stmt
%type <int> stmt

%%

stmt: methodcall {0} | arrayasn {0}
    ;

/*
previous
methodcall: target OPAREN CPAREN SEMIC {0}
    ;

```

```
target:  ID DOT ID {0} | ID {0}
;
```

our strategy was **to** remove the "**extraneous**" non-terminal **in** the methodcall production, by moving one **of** the right-hand sides **of** target **to** the methodcall production

```
*/

methodcall: target OPAREN CPAREN SEMIC {0} | ID OPAREN CPAREN SEMIC {0}
;
target:  ID DOT ID {0}
;
arrayasn: ID OPAREN  INT CPAREN EQUAL INT SEMIC {0}
;

    %{
%}

%token RETURN ID SEMI EQ PLUS

%start methodbody
%type <unit> methodbody

%%

methodbody: stmtlist RETURN ID {}
;
/*
```

```

stmtlist: stmt stmtlist {} | stmt {}
;

the strategy here is simple, we use left-recursion instead of
right-recursion
*/

stmtlist: stmtlist stmt {} | stmt {}
;

stmt: RETURN ID SEMI {} | ID EQ ID PLUS ID {}
;

%{

%}

%token PLUS TIMES ID LPAREN RPAREN

%left PLUS
%left TIMES /* weird ocaml yacc can not detect typo TIMES */

/*
here we add associativity and precedence
*/

%start expr
%type <unit> expr

%%

```

```
expr: expr PLUS expr {}
    | expr TIMES expr {}
    | ID {}
    | LPAREN expr RPAREN {}
;

%{

%}

%token ID EQ LPAREN RPAREN IF ELSE THEN

%nonassoc THEN
%nonassoc ELSE

/*
here we used a nice trick to
handle such ambiguity. set precedence of THEN, ELSE
both needed
*/

%start stmt
%type <unit> stmt

%%

stmt: ID EQ ID {}
    | IF LPAREN ID RPAREN THEN stmt {}
    | IF LPAREN ID RPAREN THEN stmt ELSE stmt {}
```

```

;
/*
It's tricky here we modify the grammar an unambiguous one
*/

/*
stmt      : matched {}
           | unmatched {}
           ;

matched   : IF '(' ID ')' matched ELSE matched {}
           ;

unmatched : IF '(' ID ')' matched {}
           | IF '(' ID ')' unmatched {}
           | IF '(' ID ')' matched ELSE unmatched {}
           ;

*/
%%

```

The prec trick is covered not correctly in this tutorial.

The symbols are declared to associate to the left, right, nonassoc. The symbols are *usually* tokens, they can also be *dummy* nonterminals, for use with the %prec directive in the rule.

1. Tokens and rules have precedences. The precedence of a *rule* is the precedence of its *rightmost* terminal. you can override this default by using the %prec directive in the rule

2. A reduce/reduce conflict is resolved in favor of the first rule (in the order given by the source file)
3. A shift/reduce conflict is resolved by comparing the *precedence of the rule to be reduced* with the *precedence of the token to be shifted*. If the precedence of the rule is higher, then the rule will be reduced; if the precedence of the token is higher then token will be shifted.
4. A shift/reduce conflict between a rule and a token with the same precedence will be resolved using the associativity.
5. when a shift/reduce can not be resolved, a warning, and in favor of *shift*

MENHIR Related

1. Syntax

```

specification ::= declaration . . . declaration %% rule . . .
    rule [ %% Objective Caml code ]
    declaration ::= %{ Objective Caml code %}
                    % parameter < uid : Objective Caml
                        module type >
                    %token [ < Objective Caml type > ] uid
                        . . . uid
                    %nonassoc uid . . . uid
                    %left uid . . . uid
                    %right uid . . . uid
                    %type < Objective Caml type > lid . . .
                        lid
                    %start [ < Objective Caml type > ] lid
                        . . . lid
rule ::= [%public] [%inline] lid [( id, ..., id)] : [[] group |
    ... | group
group ::= production | . . . | production { Objective Caml code
    } [ %prec id ]
production ::= producer . . . producer [ %prec id ]
    producer ::= [ lid = ] actual
actual ::= id [( actual, ..., actual)] [ ? | + | * ]

\item parameter

    \begin{bluetext}
%parameter <uid: Objective module types>

```

This causes the entire parser to be parameterized over the module.

2. multiple files (private and public,tokens aside)
3. parameterized rules
4. inline
5. standard library

Name	Recognizes	Produces	Comment
option(X)	$\epsilon \mid X$	α option, if $X : \alpha$	inlined bool
ioption(X)			
boption(X)			
loption(X)	$\epsilon \mid X$	α list, if $X : \alpha$ list	
pair(X,Y)	$X \ Y$	$\alpha \times \beta$	
separated_pair(X,sep,Y)	$X \ \text{sep} \ Y$	$\alpha \times \beta$	
preceded(opening,X)	opening X	α , if $X : \alpha$	
terminated(X,closing)	X closing	α , if $X : \alpha$	
delimited(opening, X closing)	opening X closing	α , if $X : \alpha$	
list(X)			
nonempty_list(X)			
separated_list(sep,X)			
sepearted_nonempty_list(sep,X)			

6. combined with ulex

A typical tags file is as follows

```
true:use_menhir, pkg_ulex, pkg_pcre, pkg_menhirLib,
      pkg_batteries
<scanner.ml>: pkg_ulex, syntax_camlp4o
```

You have to use

Menhirlib.Convert

API, here


```

(** support ocamllex *)
type ('token, 'semantic_value) traditional =
  (Lexing.lexbuf -> 'token) -> Lexing.lexbuf -> 'semantic_value

(**
   This revised API is independent of any lexer generator. Here, the
   parser only requires access to the lexer, and the lexer takes no
   parameters. The tokens returned by the lexer may need to contain
   position information. *)

type ('token, 'semantic_value) revised =
  (unit -> 'token) -> 'semantic_value

(* A token of the revised lexer is essentially a triple of a token
   of the traditional lexer (or raw token), a start position, and
   and end position. The three [get] functions are accessors. *)

(* We do not require the type ['token] to actually be a triple type.
   This enables complex applications where it is a record type with
   more than three fields. It also enables simple applications where
   positions are of no interest, so ['token] is just ['raw_token]
   and [get_startp] and [get_endp] return dummy positions. *)

val traditional2revised:
  ('token -> 'raw_token) ->
  ('token -> Lexing.position) -> (* get a a start position *)
  ('token -> Lexing.position) -> (* get an end position *)
  ('raw_token, 'semantic_value) traditional ->
  ('token, 'semantic_value) revised

val revised2traditional:

```

```
( 'raw_token -> Lexing.position -> Lexing.position -> 'token) ->
( 'token, 'semantic_value) revised ->
( 'raw_token, 'semantic_value) traditional

(** concrete type used here *)
module Simplified : sig
  val traditional2revised:
    ( 'token, 'semantic_value) traditional ->
    ( 'token * Lexing.position * Lexing.position, 'semantic_value) revised
  val revised2traditional:
    ( 'token * Lexing.position * Lexing.position, 'semantic_value) revised ->
    ( 'token, 'semantic_value) traditional
end
```

7. example csss project

Chapter 4

camlp4

1. a brief intro to recursive descent parser

grammar transform

```
a : a x | b (x can be anything)
=>
a : b r
r : x r | e
----
exp : exp op exp | prim
=>
exp : prim expR
expR : op exp expR | e
```

2. tutorial

- (a) basics (camlp4 **command lines**)

```
bash-3.2$ camlp4 -where
/Users/bob/SourceCode/ML/godi/lib/ocaml/std-lib/camlp4
bash-3.2$ which camlp4
/Users/bob/SourceCode/ML/godi/bin/camlp4
```

```
find /Users/bob/SourceCode/ML/godi/bin -type f -perm -og+rx | grep camlp4
/Users/bob/SourceCode/ML/godi/bin/camlp4
/Users/bob/SourceCode/ML/godi/bin/camlp4boot
```

```

/Users/bob/SourceCode/ML/godi/bin/camlp4o
/Users/bob/SourceCode/ML/godi/bin/camlp4o.opt
/Users/bob/SourceCode/ML/godi/bin/camlp4of
/Users/bob/SourceCode/ML/godi/bin/camlp4of.opt
/Users/bob/SourceCode/ML/godi/bin/camlp4oof
/Users/bob/SourceCode/ML/godi/bin/camlp4oof.opt
/Users/bob/SourceCode/ML/godi/bin/camlp4orf
/Users/bob/SourceCode/ML/godi/bin/camlp4orf.opt
/Users/bob/SourceCode/ML/godi/bin/camlp4prof
/Users/bob/SourceCode/ML/godi/bin/camlp4r
/Users/bob/SourceCode/ML/godi/bin/camlp4r.opt
/Users/bob/SourceCode/ML/godi/bin/camlp4rf
/Users/bob/SourceCode/ML/godi/bin/camlp4rf.opt
/Users/bob/SourceCode/ML/godi/bin/mkcamlp4
/Users/bob/SourceCode/ML/godi/bin/safe_camlp4

```

so the tools at hand are `camlp4`, `camlp4o`, `camlp4of`, `camlp4oof`, `camlp4orf`, `camlp4r`, `camlp4rf`

```
camlp4 -h
```

```
Usage: camlp4 [load-options] [--] [other-options]
```

```
Options:
```

```
<file>.ml          Parse this implementation file
```

```
<file>.mli         Parse this interface file
```

```
<file>.(cmo|cma)  Load this module inside the Camlp4 core
```

```
-I <directory>    Add directory in search patch for object files.
```

```
-where            Print camlp4 library directory and exit.
```

```
-nolib           No automatic search for object files in library direct
```

```
-intf <file>      Parse <file> as an interface, whatever its extension.
```

```
-impl <file>      Parse <file> as an implementation, whatever its extens
```

```
-str <string>     Parse <string> as an implementation.
```

```
-unsafe          Generate unsafe accesses to array and strings.
```

<code>-noassert</code>	Obsolete, do not use this option.
<code>-verbose</code>	More verbose in parsing errors.
<code>-loc <name></code>	Name of the location variable (default: <code>_loc</code>).
<code>-QD <file></code>	Dump quotation expander result in case of syntax error
<code>-o <file></code>	Output on <file> instead of standard output.
<code>-v</code>	Print Camlp4 version and exit.
<code>-version</code>	Print Camlp4 version number and exit.
<code>-vnum</code>	Print Camlp4 version number and exit.
<code>-no_quot</code>	Don't parse quotations, allowing to use, e.g. "<:>" as
<code>-loaded-modules</code>	Print the list of loaded modules.
<code>-parser <name></code>	Load the parser <code>Camlp4Parsers/<name>.cm(o a xs)</code>
<code>-printer <name></code>	Load the printer <code>Camlp4Printers/<name>.cm(o a xs)</code>
<code>-filter <name></code>	Load the filter <code>Camlp4Filters/<name>.cm(o a xs)</code>
<code>-ignore</code>	ignore the next argument
<code>--</code>	Deprecated, does nothing

useful options `-str`, `-loaded-modules` `-parser <name>` load the parser `Camlp4Parsers/<name>.cm(o|a|xs)` `-printer <name>` load the printer `Camlp4Printers/<name>.cm(o|a|xs)`, `-filter <name>` load the filter `Camlp4Filters/<name>.cm(o|a|xs)`.

`-printer o` means print in original syntax these command line options are all handled in *Camlp4Bin.ml*

`camlp4o -h Options` added by loaded object files `-add_locations` Add locations as comment

`-no_comments|`

`-curry-constr` (Use curried constructors)

`-sep` Use this string between parsers

- (b) That reflective is true means when extending the syntax of the host language will also extend the embedded one

	host	embedded	reflective	3.09 equivalent
camlp4of	original	original	Yes	N/A
camlp4rf	revised	revised	Yes	N/A
camlp4r-parser rq	revised	revised	No	camlp4r q_MLast.cmo
camlp4orf	original	revised	No	camlp4o q_MLast.cmo
camlp4oof	original	original	No	N/A

(c) camlp4r

i. parser

RP, RPP(RevisedParserParser)

ii. printer

OCaml

(d) camlp4rf (extended from camlp4r)

i. parser

RP,RPP, GrammarP, ListComprehension, MacroP, QuotationExpander

ii. printer

OCaml

(e) camlp4o (extended from camlp4r)

i. parser

OP, OPP, RP,RPP

(f) camlp4of (extended from camlp4o)

i. parser

GrammarParser, ListComprehension, MacroP, QuotatuinExpander

ii. printer

(g) (without ocamlbuild, ocamlfind) **simple build and example**

ocamlc -pp camlp4o.opt error.ml

```

camlp4of -str "let a = [x| x <- [1.. 10] ] "
let a = [ 1..10 ]

```

```
camlp4o -str 'true && false'
true && false
```

```
camlp4of -str "let q = <:str_item< let f x = x >>"
```

```
let q =
```

```
  Ast.StSem (_loc,
```

```
    (Ast.StVal (_loc, Ast.ReNil,
```

```
      (Ast.BiEq (_loc,
```

```
        (Ast.PaId (_loc, (Ast.IdLid (_loc, "f"))))),
```

```
      (Ast.ExFun (_loc,
```

```
        (Ast.McArr
```

```
          (_loc,
```

```
            (Ast.PaId (_loc, (Ast.IdLid (_loc, "x"))))),
```

```
            (Ast.ExNil _loc), (Ast.ExId (_loc, (Ast.IdLid (_loc, "x"))
```

```
          (Ast.StNil _loc)))
```

3. Source Code

(a) directory structure

```
|<.>
|--<boot>
|--<build>
|--<Camlp4>
|----<Printers>
|----<Struct>      -- important
|-----<Grammar>
|--<Camlp4Filters> -- important
|--<Camlp4Parsers> -- important
|--<Camlp4Printers>
|--<Camlp4Top>
|--<examples>      -- important
|--<man>
```

```

|--<test>
|----<fixtures>
|--<unmaintained>  -- many useful extensions unmatained
|----<compile>
|----<etc>
|----<extfold>      -- fold extension
|----<format>
|----<lefteval>
|----<lib>
|----<ocamllex>
|----<ocpp>
|----<odyl>
|----<olabl>
|----<scheme>
|----<sml>

```

(b) Camlp4.PreCast (Camlp4/PreCast.ml)

Struct directory has module Loc, Dynloader Functor, Camlp4Ast.Make, Token.Make, Lexer.Make, Grammar.Static.Make, Quotation.Make
PreCast re-export such files

```

Struct/Loc.ml
Struct/Camlp4Ast.mlast
Struct/Token.ml
Struct/Grammar/Parser.ml
Struct/Grammar/Static.ml
Struct/Lexer.ml1
Struct/DynLoader.ml
Struct/Quotation.ml
Struct/AstFilters.ml
OCamlInitSyntax.ml
Printers/OCaml.ml
Printers/OCamlr.ml
Printers/Null.ml
Printers/DumpCamlp4Ast.ml
Printers/DumpOCamlAst.ml

```



```

module Id = struct
  value name = "Camlp4.PreCast";
  value version = Sys.ocaml_version;
end;
type camlp4_token = Sig.camlp4_token ==
  [ KEYWORD      of string
  | SYMBOL       of string          -- interesting
  | LIDENT       of string
  | UIDENT       of string
  | ESCAPED_IDENT of string          -- interesting
  | INT          of int and string
  | INT32        of int32 and string
  | INT64        of int64 and string
  | NATIVEINT    of nativeint and string
  | FLOAT        of float and string
  | CHAR         of char and string
  | STRING       of string and string
  | LABEL        of string
  | OPTLABEL     of string
  | QUOTATION    of Sig.quotation
  | ANTIQUOT     of string and string
  | COMMENT      of string          -- interesting
  | BLANKS       of string          -- interesting
  | NEWLINE      -- interesting
  | LINE_DIRECTIVE of int and option string -- interesting
  | EOI ];

module Loc = Struct.Loc;
module Ast = Struct.Camlp4Ast.Make Loc;
module Token = Struct.Token.Make Loc;

```

```

module Lexer = Struct.Lexer.Make Token;
module Gram = Struct.Grammar.Static.Make Lexer;
module DynLoader = Struct.DynLoader;
module Quotation = Struct.Quotation.Make Ast;

(** interesting, so you can make your own syntax totally
    but it's not easy to do this in toplevel, probably will crash..
    *)
module MakeSyntax (U : sig end) = OCamlInitSyntax.Make Ast Gram Quotation
module Syntax = MakeSyntax (struct end);
module AstFilters = Struct.AstFilters.Make Ast;
module MakeGram = Struct.Grammar.Static.Make;

module Printers = struct
  module OCaml = Printers.OCaml.Make Syntax;
  module OCamlr = Printers.OCamlr.Make Syntax;
  (* module OCamlrr = Printers.OCamlrr.Make Syntax; *)
  module DumpOCamlAst = Printers.DumpOCamlAst.Make Syntax;
  module DumpCamlp4Ast = Printers.DumpCamlp4Ast.Make Syntax;
  module Null = Printers.Null.Make Syntax;
end;

```

(c) Camlp4.OCamlInitSyntax

Given **Ast**, **Gram**, **Quotation**, we produce **Camlp4Syntax**

```

(** Ast -> Gram -> Quotation -> Camlp4Syntax *)
Make (Ast:Sig.Camlp4Ast) (Gram:  Sig.Grammar.Static
  with module Loc = Ast.Loc
  with type Token.t = Sig.camlp4_token)
(Quotation : Sig.Quotation
  with module Ast = Sig.Camlp4AstToAst Ast) :Sig.Camlp4Syntax
  with module Loc = Ast.Loc
    module Ast = Ast

```

```

    module Gram = Gram
    module Token = Gram.Token
    module Quotation = Quotation
= struct
    ... bla bla
value a_LIDENT = Gram.Entry.mk "bla bla"
    ...
EXTEND_Gram
top_phrase:
    [[ 'EOI -> None ]]
;
END;

module AntiQuoteSyntax = Struct
module LOC = Ast.Loc
module Ast = Sig.Camlp4AstToAst Ast ; (** intersting *)
(** Camlp4AstToAst the functor is a restriction
    functor. Takes a Camlp4Ast module and return it with some
    restrictions
    *)
module Gram = Gram ;
value antiquot_expr = Gram.Entry.mk "antiquot_expr";
value antiquot_patt = Gram.Entry.mk "antiquot_patt";
EXTEND_Gram
    antiquot_expr :
        [[ x = expr ; 'EOI -> x ]] ;
    antiquot_patt :
        [[ x = patt ; 'EOI -> x ]]
END;
value parse_expr loc str = Gram.parse_string antiquot_expr loc str ;
value parse_patt loc str = Gram.parse_string antiquot_patt loc str ;

```

```

end
module Quotation = Quotation ;
value parse_implem ...
value parse_interf ...
value print_interf ...
value print_implem ...
module Quotation = Quotation ;
end

```

Notice `Gram.Entry` is **dynamic, extensible**

- (d) `Camlp4.Sig.ml`
- (e) `Camlp4.Struct.Camlp4Ast.mlast` (`Camlp4.Camlp4Ast.parital.ml`)

```

Camlp4.Struct.Camlp4Ast.Make : Loc -> Sig.Camlp4Syntax
(** in the file we have *)
module Ast = struct
  include Sig.MakeCamlp4Ast Loc
end ;

```

interesting , it uses the **filter** itself

```

class map = Camlp4MapGenerator.generated;
class fold = Camlp4FoldGenerator.generated;

```

The filter *Camlp4MapGenerator* reads *OCaml* type definitions and generate a class that implements a map traversal. The generated class have a method per type you can override to implement a *map traversal*.

as follows, `Camlp4.Ast` has a corresponding map traversal object, which could be used by you: (the class was generated by our filter)

```

open Camlp4.PreCast
let simplify = object
  inherit Ast.map as super
  method expr e = match super#expr e with
    |<:expr< $x$ + 0 >> | <:expr< $x$ + 0 >> -> x

```

```

    | x -> x
end in AstFilters.register_str_item_filter simplify#str_item

```

To make life easier,

```

open Camlp4.PreCast
let simplify = Ast.map_expr begin function
    |<:expr< $x$ + 0 >> | <:expr< 0 + $x$ >> -> x
    | x -> x
end in AstFilters.register_str_item_filter simplify#str_item
(**
AstFilters.register_str_item_filter
register_sig_item_filter
register_topphrase_filter
*)

```

you can also generate map traversal for ocaml type. *put your type definition before you macro*, like this

```

type t1 = ...
and t2 = ...
and tn = ... ;
class map = Camlp4MapGenerator.generated;

tags : "map_filter_r.ml" : pp(camlp4r -filter map)

cat map_filter_r.ml

type a = [A of b | C ]
and b = [B of a | D ];
class map = Camlp4MapGenerator.generated;
(* output
type a = [ A of b | C ] and b = [ B of a | D ];
class map =
  object ((o : 'self_type))
    method b : b -> b = fun [ B _x -> let _x = o#a _x in B _x | D -> D ]

```

```

    method a : a -> a = fun [ A _x -> let _x = o#b _x in A _x / C -> C
    method unknown : ! 'a. 'a -> 'a = fun x -> x;
end;
*)

```

```
cat _build/map_filter_r.inferred.mli
```

```

type a = A of b | C
and b = B of a | D
class map :
  object method a : a -> a method b : b -> b method unknown : 'a -> 'a end

```

Camlp4 use the filter in `antiquot_expander`,
for example in `Camlp4Parsers/Camlp4QuotationCommon.ml`, in the definition of `add_quotation`, we have

```

value antiquot_expander = object
  inherit Ast.map as super ;
  method patt : patt -> patt ...
  method expr : expr -> expr ...
let expand_expr loc loc_name_opt s =
  let ast = parse_quot_string entry_eoi loc s in
  let () = MetaLoc.loc_name.val := loc_name_opt in
  let meta_ast = mexpr loc ast in
  let exp_ast = antiquot_expander#expr meta_ast in
  exp_ast in

```

Notice that it first invoked `parse_quot_string`, then do some transformation, **that's how quotation works !**, it will change to your customized quotation parser, and when it goes to antiquot syntax, it will go back to **host language parser**. Since the host language parser also support quotation syntax (due to **reflexivity**), so you **nest your quotation whatever you want**.

4. revised syntax

```

',\'
',\'

let x = 3
value x = 42 ; (str_item) (do't forget ;)
let x = 3 in x + 8
let x = 3 in x + 7 (expr)

-- signature
val x : int
value x : int ;

-- abstract module types
module type MT
module type MT = 'a

-- currying functor
type t = Set.Make(M).t
type t = (Set.Make M).t

--
e1;e2;e3
do{e1;e2;e3}

--
while e1 do e2 done
while e1 do {e2;e3 }
for i = e1 to e2 do e1;e2 done
for i = e1 to e2 do {e1;e2;e3}

--
() always needed

x::y
[x::y]
x::y::z
[x::[y::[z::t]]]
x::y::z::t
[x;y;z::t]

match e with
[p1 -> e1
|p2 -> e2];

fun x -> x
fun [x->x]

```

```

value rec fib = fun [
0|1 -> 1
|n -> fib (n-1) + fib (n-2)
];

fun x y (C z) -> t
fun x y -> fun [C z -> t]
-- the curried pattern matching can be done with "fun", but
-- only irrefutable

-- legall

fun []

match e with []

try e with []

-- pattern after "let" and "value" must be irrefutable

let f (x::y) = ...
let f = fun [ [x::y] -> ... ]

x.f <- y
x.f := y
x := !x + y
x.val := x.val + y

--
int list
list int

('a,bool) foo
foo 'a bool (*camlp4o -str "type t = ('a,bool) foo" -printer r -> type t = foo 'a bool*)

type 'a foo = 'a list list
type foo 'a = list (list a)

int * bool
(int * bool )

```



```

-- abstract type are represented by a unbound type variable
type 'a foo
type foo 'a = 'b

type t = A of i | B
type t = [A of i | B]

-- empty is legal
type foo = []

type t= C of t1 * t2
type t = [C of t1 and t2]

C (x,y)
C x y

type t = D of (t1*t2)
type t = [D of (t1 * t2)]

D (x,y)
D (x,y)

type t = {mutable x : t1 }
type t = {x : mutable t1}

if a then b
if a then b else ()

a or b & c
a || b && c

(+)
\+

(mod)
\mod

```

```

(* new syntax
   it's possible to group together several declarations
   either in an interface or in an implementation by enclosing
   them between "declare" and "end" *)

declare
  type foo = [Foo of int | Bar];
  value f : foo -> int ;
end ;

[<'1;'2;s;'3>]
[:'1; '2 ; s; '3 :]

parser [
  [: 'Foo :] -> e
  |[: p = f :] -> f ]

parser []
match e with parser []

-- support where syntax
value e = c
  where c = 3 ;

-- parser
value x = parser [
  [: '1; '2 :] -> 1
  |[: '1; '2 :] -> 2
];

-- object
class ['a,'b] point
class point ['a,'b]

class c = [int] color
class c = color [int]

-- signature
class c : int -> point

```

```

class c : [int] -> point

method private virtual
method virtual private

--

object val x = 3 end
object value x = 3; end

object constraint 'a = int end
object type 'a = int ; end

-- label type
module type X = sig val x : num:int -> bool end ;
module type X = sig value x : ~num:int -> bool ; end;

--
~num:int
?num:int

```

5. experimentation

(a) toplevel **via findlib**

```

ocaml
#camlp4r;
#load "camlp4rf.cma"

```

(b) using ocamlobjinfo to search modules

```

ocamlobjinfo 'camlp4 -where' /camlp4fulllib.cma | grep -i unit
Unit name: Camlp4_import
Unit name: Camlp4_config
Unit name: Camlp4
Unit name: Camlp4AstLoader
Unit name: Camlp4DebugParser
Unit name: Camlp4GrammarParser
Unit name: Camlp4ListComprehension

```

```

Unit name: Camlp4MacroParser
Unit name: Camlp4OCamlParser
Unit name: Camlp4OCamlRevisedParser
Unit name: Camlp4QuotationCommon
Unit name: Camlp4OCamlOriginalQuotationExpander
Unit name: Camlp4OCamlRevisedParserParser
Unit name: Camlp4OCamlParserParser
Unit name: Camlp4OCamlRevisedQuotationExpander
Unit name: Camlp4QuotationExpander
Unit name: Camlp4AstDumper
Unit name: Camlp4AutoPrinter
Unit name: Camlp4NullDumper
Unit name: Camlp4OCamlAstDumper
Unit name: Camlp4OCamlPrinter
Unit name: Camlp4OCamlRevisedPrinter
Unit name: Camlp4AstLifter
Unit name: Camlp4ExceptionTracer
Unit name: Camlp4FoldGenerator
Unit name: Camlp4LocationStripper
Unit name: Camlp4MapGenerator
Unit name: Camlp4MetaGenerator
Unit name: Camlp4Profiler
Unit name: Camlp4TrashRemover
Unit name: Camlp4Top

```

(c) using **script** (oco using original syntax is ok)

but when using ocr, it will have some problems, i.e. .ocamlinit, and other startup files including findlib. here I use .ocamlinitr (revised syntax) for ocr, but it still have some problem with findlib, (internal, hard to solve), but does not really matter.

```

bash-3.2$ cat /usr/local/bin//oco
ledit -x -h ~/.ocaml_history ocaml dynlink.cma camlp4of.cma -warn-error +a-4-6-27..29

```

```
cat 'which ocr'
ledit -x -h ~/.ocaml_history ocaml dynlink.cma camlp4rf.cma -init ~/.ocamlinitr -warn-error +a-4-6-27...29
```

6. parser extensible

(a) simple calc example

```
open Camlp4.PreCast;
value expression = Gram.Entry.mk "expression" ;
EXTEND Gram
  GLOBAL: expression ;
  expression : [
    "add" LEFTA
    [ x = SELF ; "+" ; y = SELF -> x + y
    | x = SELF ; "-" ; y = SELF -> x - y]
    | "mult" LEFTA
    [ x = SELF ; "*" ; y = SELF -> x * y
    | x = SELF ; "/" ; y = SELF -> x / y]
    | "pow" RIGHTA
    [ x = SELF ; "**" ; y = SELF -> int_of_float (float x ** float y) ]
    | "simple" NONA
    [ x = INT -> int_of_string x
    | "(" ; x = SELF ; ")" -> x ]
  ] ;
END;
value _ = Printf.printf "%d" (
  Gram.parse_string
    expression
    (Loc.mk "<string>" ) "3 + ((4 - 2) + 28 * 3 ** 2) + (4 / 2)" );
(* (read_line ()) ; *)
```

```
$cat _tags
<pa_*r.{ml,cmo,byte}> : pkg_dynlink , camlp4rf, use_camlp4_full
```

for `oco` in `toplevel` , extensible parser works **quite well in original syntax**, so if you don't do quasiquotation in `toplevel`, *feel free to use original syntax*. Original syntax works as follows

```
let expression = Gram.Entry.mk "expression" ;
EXTEND Gram
  GLOBAL : expression ;
  expression : [
    "add"
    [ x = SELF; "+"; y = SELF -> x + y
    | x = SELF; "-"; y = SELF -> x - y ]
    "mult"
    [ x = SELF; "*"; y = SELF -> x * y
    | x = SELF; "/"; y = SELF -> x / y]
    "pow" RIGHTA
    [ x = SELF ; "**"; y = SELF -> int_of_float (float x ** float y)]
    "simple" NONA
    [ x = INT -> int_of_string x
    | "(" ; x = SELF; ")" -> x]
  ] ;
END ;;
Gram.parse_string
  expression
  (Loc.mk "<string>")
  "3 + ((4 - 2) + 28 * 3 ** 2) + (4 / 2)"
```

(b) some keywords for parser

```
EXTEND END LIST0 LIST1 SEP TRY SELF OPT FIRST LAST LEVEL AFTER BE
```

`SELF` represents either the **current level**, the **next level** or the **first level** depending on the **associativity** and the **position** of the `SELF` in the rule .

The identifier `NEXT`, which is a call to the next level of the current entry.

(c) mechanism

there are four generally four phases

- 1 collection of new keywords, and update of the lexer associated to the grammar
- 2 representation of the grammar as a tree data structure
- 3 left-factoring of each precedence level

when there's a common prefix of symbols (a symbol is a keyword, token, or entry), the parser does not branch until the common parser has been parsed. **that's how grammars are implemented, first the corresponding tree is generated, then the parser is generated for the tree.** some tiny bits

(i) Greedy first

when one rule is a prefix of another. **a token or keyword is preferred over epsilon, the empty string (this also holds for other ways that a grammar can match epsilon)** factoring happens when the parser is built .

(ii) **explicit token or keyword trumps an entry** so you have two productions, with the same prefix, except the last one. one is another entry, and the other is a token, **the parser will first try the token, if it succeeds, it stops, otherwise they try the entry.** This sounds weird, but it is reasonable, after left-factorization, the parser pays no cost when it tries just a token, it's amazing that even more tokens, the token rule still wins, and **even the token rule fails after consuming some tokens, it can even transfer to the entry rule**, local try????? . **it seems that after factorization, the rule order may be changed .**

weird stuff

```
let m_expr = MGram.Entry.mk "m_expr";;
let _ =
```

```

EXTEND MGram GLOBAL: m_expr ;
  m_expr :
    [[ "foo"; f -> print_endline "first"
      | "foo" ; "bar"; "baz" -> print_endline "second"]
    ];
  f : [["bar"; "baz" ]]; END;;
MGram.parse_string m_expr (Loc.mk "<string>") "foo bar baz ";;
second
(** after factorization, it chooses the second one *)
(** DELETE_RULE expr: SELF; "+"; SELF END;; *)
let _ = MGram.Entry.clear m_expr;
EXTEND MGram GLOBAL: m_expr ;
  m_expr :
    [[ "foo"; f -> print_endline "first"
      | "foo" ; "bar"; "bax" -> print_endline "second"]
    ];
  f : [["bar"; "baz" ]]; END;
MGram.parse_string m_expr (Loc.mk "<string>") "foo bar baz ";;
first
let _ = MGram.Entry.clear m_expr;
EXTEND MGram GLOBAL: m_expr ;
  m_expr :
    [[ "foo"; f -> print_endline "first"
      | "foo" ; "bar"; f -> print_endline "second"]
    ];
  f : [["bar"; "baz" ]]; END;
MGram.parse_string m_expr (Loc.mk "<string>") "foo bar baz ";;
Exception: Loc.Exc_located (<abstr>,
  Stream.Error "[f] expected after \"bar\" (in [m_expr])").

```

The translated code is not too indicative, all the dispatch magic

hides in MGram.extend function (or Insert.extend function) */SourceCode/ML/go*
3.12.1/camlp4/Camlp4/Struct/Grammar/Insert.ml

```
value extend entry (position, rules) =
  let elev = levels_of_rules entry position rules in
  do {
    entry.edesc := Dlevels elev;
    entry.estimate :=
      fun lev strm ->
        let f = Parser.start_parser_of_entry entry in
        do { entry.estimate := f; f lev strm };
    entry.econtinue :=
      fun lev bp a strm ->
        let f = Parser.continue_parser_of_entry entry in
        do { entry.econtinue := f; f lev bp a strm }
  };
```

(iii) factoring only happens in the same level within a rule.

(iv) explicit backtracking

```
(**hand-coded entry MGram.Entry.of_parser *)
let test = MGram.Entry.of_parser "test"
  (fun strm -> match Stream.npeek 2 strm with
    [_ ; KEYWORD "xyzzy", _] -> raise Stream.Failure | _ -> ()) ;;
EXTEND MGram
  GLOBAL: m_expr ;
  g : [[ "plugh" ]] ; f1 : [[ g ; "quux" ]]; f2 : [[g ; "xyzzy"]] ;
  m_expr : [[test ; f1 -> print_endline "1" | f2 -> print_endline "2"]];
# MGram.parse_string m_expr (Loc.mk "<string>") "plugh xyzzy";;
```

4 the data structure representing the grammar is then passed as argument
 to a generic parser

(a) left factorization

take rules as follows as an example

```

"method"; "private"; "virtual"; l = label; ":"; t = poly_type
"method"; "virtual"; "private"; l = label; ":"; t = poly_type
"method"; "virtual"; l = label; ":"; t = poly_type
"method"; "private"; l = label; ":"; t = poly_type; "="; e = expr
"method"; "private"; l = label; sb = fun_binding
"method"; l = label; ":"; t = poly_type; "="; e = expr
"method"; l = label; sb = fun_binding

```

The rules are inserted in a tree and the result looks like:

```

"method"
|-- "private"
|   |-- "virtual"
|   |   |-- label
|   |   |-- ":"
|   |   |-- poly_type
|   |-- label
|   |-- ":"
|   |-- poly_type
|   |-- ":@"
|   |-- expr
|   |-- fun_binding
|-- "virtual"
|   |-- "private"
|   |   |-- label
|   |   |-- ":"
|   |   |-- poly_type
|   |-- label
|   |-- ":"
|   |-- poly_type
|-- label
|   |-- ":"

```

```

      |      |-- poly_type
      |      |      |-- "="
      |      |      |-- expr
      |-- fun_binding

```

This tree is built as long as rules are inserted.

(d) **start and continue** At each entry level, the rules are separated into **two trees**:

- (a) The tree of the rules not starting with neither the current entry name nor by “SELF”(start)
- (b) The tree of the rules starting with the current entry or by SELF, this symbol **itself not being included** in the tree

They determine two functions :

- i. The function named “**start**”, analyzing the first tree
- ii. The function named “**continue**”, taking, as parameter, a value previously parsed, and analyzing the second tree.

A call to an entry, correspond to a call to the “**start**” function of the “**first**” level of the entry.

For the “start”, it tries its tree, if it works, it calls the “continue” function of the same level, giving the result of “start” as parameter. If this “continue” fails, return itself. (continue may do some more interesting stuff). If the “start” function fails, the “start” of the next level is tested until it fails.

For the “continue”, it first tries the “continue” function of the **next** level. (here + give into *), if it fails or it’s the last level, it then tries itself, giving the result as parameter. If it still fails, return its extra parameter.

A special case for rules ending with SELF or the current entry name. For this last symbol, there’s a call to the “start” function of **the current level (RIGHTA) or the next level (OTHERWISE)**

When a SELF or the current entry name is encountered in the middle of the rule, there’s a call to the start of the **first level** of the current entry.

Each entry has a start and continue

```

(* list of symbols, possible empty *)
LIST0 : LIST0 rule | LIST0 [ <rule definition> -> <action> ]
(* with a separator *)
LIST0 : LIST0 rule SEP <symbol>
| LIST0 [<rule definition > -> <action>] SEP <symbol>
LIST1 rule
| LIST1 [<rule definition > -> <action > ]
| LIST1 rule SEP <symbol>
| LIST1 [<rule definition > -> <action >] SEP <symbol>
OPT <symbol>
SELF
TRY (* backtracking *)
FIRST LAST LEVEL level, AFTER level, BEFORE level

```

(e) stream parser

(a) stream parser

```

let rec p = parser [< '"foo"; 'x ; '"bar">] -> x | [< '"baz"; y = p >] -> y;;
val p : string Batteries.Stream.t -> string = <fun>

```

```

camlp4of -str "let rec p = parser [< '\"foo\""; 'x ; '\"bar\">] -> x
(* normal pattern : first peek, then junk it *)
let rec p (__strm : _ Stream.t) =
  match Stream.peek __strm with
  | Some "foo" ->
    (Stream.junk __strm;
    (match Stream.peek __strm with
    | Some x ->
      (Stream.junk __strm;
      (match Stream.peek __strm with
      | Some "bar" -> (Stream.junk __strm; x)
      | _ -> raise (Stream.Error ""))))

```

```

        | _ -> raise (Stream.Error "")))
| Some "baz" ->
    (Stream.junk __strm;
     (try p __strm with | Stream.Failure -> raise (Stream.Error ""))
    | _ -> raise Stream.Failure
camlp4of -str "let rec p = parser [< x = q >] -> x | [< '\\"bar\\">] ->
let rec p (__strm : _ Stream.t) =
  try q __strm
  with
  | Stream.Failure -> (* limited backtracking *)
    (match Stream.peek __strm with
     | Some "bar" -> (Stream.junk __strm; "bar")
     | _ -> raise Stream.Failure)

```

(b) Grammar

```

open Camlp4.PreCast
module MGram = MakeGram (Lexer)
let expr = MGram.Entry.mk "expr"
EXTEND MGram
  expr :
    [ [ "foo" ; x = LIDENT ; "bar" -> "foo-bar+" ^x ]
    | [ "bar" ; y = expr -> "baz+" ^ y ] ] ;
END
MGram.Entry.print Format.std_formatter expr
expr: [ LEFTA
  [ "foo"; LIDENT _; "bar" ]
| LEFTA
  [ "bar"; SELF ] ]
- : unit = ()

MGram.parse_string expr Loc.ghost "foo xx bar";;
- : string = "foo-bar+xx"
se (FILTER _* "Exc_located") "Loc" ;;

```

```
exception Exc_located of t * exn
se (FILTER _* "type" space+ "t") "Loc";;
type t = Camlp4.PreCast.Loc.t
```

we can re-raise the exception so it gets *printed* .

A literal string (like “foo”) indicates a **KEYWORD** token ; using it in a grammar **registers the keyword** with the lexer. When it is promoted as a key word, it will no longer be used as a **LIDENT**, so for example, the parser parser, will **break some valid programs** before, because **parser** is now a keyword. This is the convention, to make things simple, you can find other ways to overcome the problem, but it’s too complicated. you can also say (x= KEYWORD) or pattern match syntax (‘LIDENT x) to get the actual token constructor. The parser **ignores** extra tokens after a success.

- levels

they can be labeled following an entry, like (expr LEVEL "mul"). However, explicitly specifying a level when calling an entry defeats the start/continue mechanism.

- NEXT LIST0 SEP OPT TRY

NEXT refers to the entry being defined at the following level regardless of associativity or position. LIST0 elem SEP sep . Both LIST0 and OPT can match the epsilon, but its priority is lower. For TRY, non-local backtracking, a Stream.Error will be converted to a Stream.Failure.

```
expr : [[ TRY f1 -> "f1" | f2 -> "f2" ]]
```

- nested rule (only one level)

```
[x = expr ; ["+" | "plus" ]; y = expr -> x + y ]
```

- EXTEND is an expression (of type unit)

it can be evaluated at toplevel, but also inside a function, when the syntax extension takes place when the function is called.

- Translated sample code

```

open Camlp4.PreCast
module MGram = MakeGram(Lexer)
EXTEND MGram
  GLOBAL: m_expr ;
  m_expr :
    [[ "foo"; f -> print_endline "first"
      | "foo" ; "bar"; "bax" -> print_endline "second"]
    ];
  f : [["bar"; "baz" ]]; END;;

```

```

open Camlp4.PreCast
module MGram = MakeGram(Lexer)
let _ =
  let _ = (m_expr : 'm_expr MGram.Entry.t) in
  let grammar_entry_create = MGram.Entry.mk in
  let f : 'f MGram.Entry.t = grammar_entry_create "f"
  in
  (MGram.extend (m_expr : 'm_expr MGram.Entry.t)
    ((fun () ->
      (None,
       [ (None, None,
          [ ([ MGram.Skeyword "foo"; MGram.Skeyword "bar";
              MGram.Skeyword "bax" ],
             (MGram.Action.mk
              (fun _ _ _ (_loc : MGram.Loc.t) ->
                (print_endline "second" : 'm_expr)))));
          ([ MGram.Skeyword "foo";
              MGram.Snterm (MGram.Entry.obj (f : 'f MGram.Entry.t)
              (MGram.Action.mk
               (fun _ _ (_loc : MGram.Loc.t) ->
                 (print_endline "first" : 'm_expr)))))) ] ) ]))
    ))

```

```

    ());
MGram.extend (f : 'f MGram.Entry.t)
  ((fun () ->
    (None,
     [ (None, None,
        [ [ MGram.Skeyword "bar"; MGram.Skeyword "baz" ],
          (MGram.Action.mk
            (fun _ _ (_loc : MGram.Loc.t) -> (() : 'f))))
      ])))
  ()))

```

- if there are unexpected symbols after a correct expression, the trailing symbols are ignored.

```

let expr_eoi = Grammar.Entry.mk "expr_eoi" ;;
EXTEND expr_eoi : [[ e = expr ; EOI -> e]]; END ;;

```

The keywords are stored in a hashtable, so it can be updated dynamically.

- level

```

rule ::= list-of-symbols-seperated-by-semicolons ->
  action
level ::= optional-label optional-associativity
[list-of-rules-operated-by-bars]
entry-extension ::=
identifier : optional-position [ list-of-levels-
seperated-by-bars ]
optional-position ::= FIRST | LAST | BEFORE label |
  AFTER label |
LEVEL label

```

- insert

when you extend an entry, by default **the first level of the extension extends the first level of the entry**

for example you a grammar like this :

```

["add" LEFTA
 [SELF; "+" ; SELF | SELF; "-" ; SELF]

```



```

| "mult" RIGHTA
[SELF; "*" ; SELF | SELF; "/" ; SELF]
| "simple" NONA
[ "("; SELF; ")" | INT ] ]
EXTEND expr : [[ x = expr ; "plus1plus" ; y = expr -> x + 1 + y ]]
END ;;

```

This extends the first level “add”. you can double check by printing the result

```

MGram.Entry.print Format.std_formatter m_expr ;;
expr: [ "add" LEFTA
  [ SELF; "plus1plus"; SELF (** interesting *)
  | SELF; "+"; SELF
  | SELF; "-"; SELF ]
| "mult" RIGHTA
  [ SELF; "*" ; SELF
  | SELF; "/" ; SELF ]
| "simple" NONA
  [ "("; SELF; ")"
  | INT ((_)) ] ]

```

create a new level in the last position

```

EXTEND MGram m_expr: LAST [[x = SELF ; "plus1plus" ; y = SELF ]];
MGram.Entry.print Format.std_formatter m_expr ;;
expr: [ "add" LEFTA
  [ SELF; "plus1plus"; SELF
  | SELF; "+"; SELF
  | SELF; "-"; SELF ]
| "mult" RIGHTA
  [ SELF; "*" ; SELF
  | SELF; "/" ; SELF ]
| "simple" NONA

```

```

    [ "("; SELF; ")"
    | INT ((_)) ]
| LEFTA
[ SELF; "plus1plus"; SELF ] ] ;

```

insert in the level “mult” in the first position

```

EXTEND MGram m_expr: LEVEL "mult" [[x = SELF ; "plus1plus" ; y =
# MGram.Entry.print Format.std_formatter m_expr ;

```

```

expr: [ "add" LEFTA
    [ SELF; "plus1plus"; SELF
    | SELF; "+"; SELF
    | SELF; "-"; SELF ]
| "mult" RIGHTA
    [ SELF; "plus1plus"; SELF (* added entry*)
    | SELF; "*"; SELF
    | SELF; "/"; SELF ]
| "simple" NONA
    [ "("; SELF; ")"
    | INT ((_)) ]
| LEFTA
    [ SELF; "plus1plus"; SELF ] ]

```

insert a new level before “mult”

```

EXTEND MGram m_expr: BEFORE "mult" [[x = SELF ; "plus1plus" ; y =
# MGram.Entry.print Format.std_formatter m_expr ;

```

```

expr: [ "add" LEFTA
    [ SELF; "plus1plus"; SELF
    | SELF; "+"; SELF
    | SELF; "-"; SELF ]
| LEFTA
    [ SELF; "plus1plus"; SELF ]
| "mult" RIGHTA

```

```

    [ SELF; "plus1plus"; SELF
    | SELF; "*"; SELF
    | SELF; "/"; SELF ]
| "simple" NONA
  [ "("; SELF; ")"
  | INT ((_)) ]
| LEFTA
  [ SELF; "plus1plus"; SELF ] ]
se (FILTER _* "val" _* "expr" space+ ":" ) "Syntax" ;;

val loc_of_expr : expr -> loc
val loc_of_module_expr : module_expr -> loc
val loc_of_class_expr : class_expr -> loc
    val meta_loc_expr : loc -> loc -> expr
    val meta_loc_expr : loc -> loc -> expr
    val meta_loc_expr : loc -> 'a -> expr
    val meta_loc_expr : loc -> 'a -> expr
        val meta_class_expr : loc -> class_expr -> expr
        val meta_expr : loc -> expr -> expr
        val meta_module_expr : loc -> module_expr -> expr
        val meta_class_expr : loc -> class_expr -> patt
        val meta_expr : loc -> expr -> patt
        val meta_module_expr : loc -> module_expr -> patt
val map_expr : (expr -> expr) -> map
val ident_of_expr : expr -> ident
val list_of_expr : expr -> expr list -> expr list
val list_of_class_expr :
val list_of_module_expr :
    val loc_of_expr : expr -> loc
    val loc_of_module_expr : module_expr -> loc
    val loc_of_class_expr : class_expr -> loc
        val loc_of_expr : expr -> loc

```

```

    val loc_of_module_expr : module_expr -> loc
    val loc_of_class_expr : class_expr -> loc
    val parse_expr : Ast.loc -> string -> Ast.expr
    val class_expr : Ast.class_expr Gram.Entry.t
    val class_info_for_class_expr : Ast.class_expr Gram.Entry.t
    val comma_expr : Ast.expr Gram.Entry.t
    val eq_expr : (string -> Ast.patt -> Ast.patt) Gram.Entry.t
    val expr : Ast.expr Gram.Entry.t
    val field_expr : Ast.rec_binding Gram.Entry.t
    val label_expr : Ast.rec_binding Gram.Entry.t
    val module_expr : Ast.module_expr Gram.Entry.t
    val opt_expr : Ast.expr Gram.Entry.t
    val opt_when_expr : Ast.expr Gram.Entry.t
    val sem_expr : Ast.expr Gram.Entry.t

    Gram.Entry.print Format.std_formatter Syntax.expr;;

```

```

expr:
[ ";" LEFTA
  [ seq_expr ]
| "top" RIGHTA
  [ "RE_PCRE"; regexp
  | "REPLACE"; regexp; "->"; sequence
  | "SEARCH"; regexp; "->"; sequence
  | "MAP"; regexp; "->"; sequence
  | "COLLECT"; regexp; "->"; sequence
  | "COLLECTOBJ"; regexp
  | "SPLIT"; regexp
  | "REPLACE_FIRST"; regexp; "->"; sequence
  | "SEARCH_FIRST"; regexp; "->"; sequence
  | "MATCH"; regexp; "->"; sequence
  | "FILTER"; regexp
  | "CAPTURE"; regexp
  | "function"; OPT "|"; LIST1 regexp_match_case SEP
    "|"
  (* syntax extension by mikmatch*)

  | "parser"; OPT parser_ipatt; parser_case_list
  | "parser"; OPT parser_ipatt; parser_case_list

```

```

| "let"; "try"; OPT "rec"; LIST1 let_binding SEP "
  and"; "in"; sequence;
  "with"; LIST1 lettry_case SEP "|"
(* syntax extension mikmatch
   let try a = raise Not_found in a with Not_found
   -> 24;; *)

| "let"; LIDENT "view"; UIDENT _; "="; SELF; "in";
  sequence
(* view patterns *)

| "let"; "module"; a_UIDENT; module_binding0; "in";
  expr LEVEL ";";
| "let"; "open"; module_longident; "in"; expr LEVEL
  ";";
| "let"; OPT "rec"; binding; "in"; sequence
| "if"; SELF; "then"; expr LEVEL "top"; "else";
  expr LEVEL "top"
| "if"; SELF; "then"; expr LEVEL "top"
| "fun"; fun_def
| "match"; sequence; "with"; "parser"; OPT
  parser_ipatt; parser_case_list
| "match"; sequence; "with"; "parser"; OPT
  parser_ipatt; parser_case_list
| "match"; sequence; "with"; OPT "|"; LIST1
  regexp_match_case SEP "|"
| "try"; SELF; "with"; OPT "|"; LIST1
  regexp_match_case SEP "|"
| "try"; sequence; "with"; match_case
| "for"; a_LIDENT; "="; sequence; direction_flag;
  sequence; "do";
  do_sequence
| "while"; sequence; "do"; do_sequence
| "object"; opt_class_self_patt; class_structure; "
  end" ]
| LEFTA
[ "EXTEND"; extend_body; "END"
  | "DELETE_RULE"; delete_rule_body; "END"
  | "GDELETE_RULE"
  | "GEXTEND" ]

(* operators *)
| "," LEFTA
[ SELF; ","; comma_expr ]

| ":@" NONA
[ SELF; ":@"; expr LEVEL "top"

```

```

| SELF; "<-" ; expr LEVEL "top" ]

| "||" RIGHTA
  [ SELF; infixop6; SELF ]

| "&&" RIGHTA
  [ SELF; infixop5; SELF ]

| "<" LEFTA
  [ SELF; infix operator (level 0) (comparison
    operators, and some others);
    SELF ]

| "^" RIGHTA
  [ SELF; infix operator (level 1) (start with '^', '
    @'); SELF ]

| "::" RIGHTA
  [ SELF; "::"; SELF ]

| "+" LEFTA
  [ SELF; infix operator (level 2) (start with '+',
    '-'); SELF ]

| "*" LEFTA
  [ SELF; "land"; SELF
  | SELF; "lor"; SELF
  | SELF; "lxor"; SELF
  | SELF; "mod"; SELF
  | SELF; infix operator (level 3) (start with '**',
    '/', '%'); SELF ]

| "***" RIGHTA
  [ SELF; "asr"; SELF
  | SELF; "lsl"; SELF
  | SELF; "lsr"; SELF
  | SELF; infix operator (level 4) (start with "***")
    (right assoc); SELF ]

| "unary␣minus" NONA
  [ "-"; SELF
  | "-."; SELF ]

(* apply *)
| "apply" LEFTA
  [ SELF; SELF
  | "assert"; SELF
  | "lazy"; SELF ]

| "label" NONA
  [ "~"; a_LIDENT
  | LABEL _; SELF
  | OPTLABEL _; SELF
  | "?"; a_LIDENT ]

```

```

| "." LEFTA
[ SELF; "."; "("; SELF; ")"
| SELF; "."; "["; SELF; "]"
| SELF; "."; "{"; comma_expr; "}"
| SELF; "."; SELF
| SELF; "#"; label ]
| "~-" NONA
[ "!" ; SELF
| prefix operator (start with '!', '?', '~'); SELF
]
| "simple" LEFTA
[ "false"
| "true"
| "{"; TRY [ label_expr_list; "]" ]
| "{"; TRY [ expr LEVEL "."; "with" ];
    label_expr_list; "}"
| "new"; class_longident
| QUOTATION _
| ANTIQUOT (("exp" | "" | "anti"), _)
| ANTIQUOT ("bool", _)
| ANTIQUOT ("tup", _)
| ANTIQUOT ("seq", _)
| "'"; a_ident
| "["; "]"
| "["; sem_expr_for_list; "]"
| "[|"; "|]"
| "[|"; sem_expr; "|]"
| "{<"; ">}"
| "{<"; field_expr_list; ">}"
| "begin"; "end"
| "begin"; sequence; "end"
| "("; ")"
| "("; "module"; module_expr; ")"
| "("; "module"; module_expr; ":"; package_type; ")"
| ""
| "("; SELF; ";"; ")"
| "("; SELF; ";"; sequence; ")"
| "("; SELF; ":"; ctyp; ")"
| "("; SELF; ":"; ctyp; ">"; ctyp; ")"
| "("; SELF; ">"; ctyp; ")"
| "("; SELF; ")"
| stream_begin; stream_end
| stream_begin; stream_expr_comp_list; stream_end
| stream_begin; stream_end
| stream_begin; stream_expr_comp_list; stream_end
| a_INT
| a_INT32
| a_INT64

```

```
| a_NATIVEINT
| a_FLOAT
| a_STRING
| a_CHAR
| TRY module_longident_dot_lparen; sequence; ")"
| TRY val_longident ] ]
```

```
let try a = 3 in true with Not_found -> false || false;;
true
```

first, it uses start parser to parse *let try a = 3 in true with Not_found*
-> false, then it calls the cont parser, and the next level cont parser,
 etc, and then it succeeds. This also applies to “apply” level.
 a tiny extension

```
let env = ref [] ;;
(** now in the toplevel, it has two environments, one
    is .., the other is envn
*)
```

EXTEND Gram

```
Syntax.expr: LEVEL "simple" [x = LIDENT -> List.assoc x !env
env := ["x",3];;
(** oh, no, it will be intercepted by our grammar
    env := ["x",3];;
Error: Camlp4: Uncaught exception: Not_found
*)
(** sucks, in the toplevel, it's really hard to roll back
    cause, all your programs following are affected
*)
```

```
DELETE_RULE Gram Syntax.expr: LIDENT END ;;
Exception: Not_found.
```

another example

```
DELETE_RULE Gram Syntax.expr: stream_begin ; stream_end END
~~~~~
```

```
Error: Unbound value stream_begin
```



```

    (* horrible *)
    (** does not supported any more for the operator ... *)
let add_infix lev op =
  EXTEND Gram
    Syntax.expr : LEVEL $lev$ [[ x = SELF ; $op$ ; y = SELF ->

```

- when two rules overlapping, the EXTEND statement replaces the old version by the new one and displays a warning.

```

se (FILTER _* "warning") "Syntax"
type warning = Loc.t -> string -> unit
val default_warning : warning
val current_warning : warning ref
val print_warning : warning

```

7. jake's blog

(a) part1

easy to experiment, using my previous `oco`, and type

```

oco
open Camlp4.PreCast ;;
let _loc = Loc.ghost ;;
(** An idea, how about writing another pretty printer, the printer is au

```

(b) part2

just ast transform, easy to experiment in toplevel

```

let cons = ["A"; "B"; "C"];;
let tys = Ast.tyOr_of_list (List.map (fun str -> <:ctyp< $uid:str$ >>) co
val tys : Camlp4.PreCast.Ast.ctyp =
  Camlp4.PreCast.Ast.TyOr (<abstr>,
    Camlp4.PreCast.Ast.TyId (<abstr>, Camlp4.PreCast.Ast.IdUid (<abstr>,
    Camlp4.PreCast.Ast.TyOr (<abstr>,
    Camlp4.PreCast.Ast.TyId (<abstr>,
    Camlp4.PreCast.Ast.IdUid (<abstr>, "B"))),

```

```

    Camlp4.PreCast.Ast.TyId (<abstr>,
        Camlp4.PreCast.Ast.IdUid (<abstr>, "C"))))

    (** here you can better understand what ctyp really means, a type
    expression, not a top-level struct, cool
    *)

let verify = <:ctyp< A | B | C>>;

val verify : Camlp4.PreCast.Ast.ctyp =
    Camlp4.PreCast.Ast.TyOr (<abstr>,
        Camlp4.PreCast.Ast.TyId (<abstr>, Camlp4.PreCast.Ast.IdUid (<abstr>,
            Camlp4.PreCast.Ast.TyOr (<abstr>,
                Camlp4.PreCast.Ast.TyId (<abstr>,
                    Camlp4.PreCast.Ast.IdUid (<abstr>, "B"))),
                Camlp4.PreCast.Ast.TyId (<abstr>,
                    Camlp4.PreCast.Ast.IdUid (<abstr>, "C")))))



---


verify = tys;;
- : bool = true (** amazing result! *)



---



let type_def = <:str_item< type t = $tys$>>;

val type_def : Camlp4.PreCast.Ast.str_item =
    Camlp4.PreCast.Ast.StSem (<abstr>,
        Camlp4.PreCast.Ast.StTyp (<abstr>,
            Camlp4.PreCast.Ast.TyDcl (<abstr>, "t", [],
                Camlp4.PreCast.Ast.TySum (<abstr>,
                    Camlp4.PreCast.Ast.TyOr (<abstr>,
                        Camlp4.PreCast.Ast.TyId (<abstr>,
                            Camlp4.PreCast.Ast.IdUid (<abstr>, "A"))),
                        Camlp4.PreCast.Ast.TyOr (<abstr>,
                            Camlp4.PreCast.Ast.TyId (<abstr>,
                                Camlp4.PreCast.Ast.IdUid (<abstr>, "B"))),
                            Camlp4.PreCast.Ast.TyId (<abstr>,
                                Camlp4.PreCast.Ast.IdUid (<abstr>, "C")))))

```

```

    [])),
    Camlp4.PreCast.Ast.StNil <abstr>)



---


Printers.OCaml.print_implem type_def ;;
type t = | A | B | C;;
let verify = <:str_item< type t = | A | B | C>>;



---


val verify : Camlp4.PreCast.Ast.str_item =
  Camlp4.PreCast.Ast.StSem (<abstr>,
    Camlp4.PreCast.Ast.StTyp (<abstr>,
      Camlp4.PreCast.Ast.TyDcl (<abstr>, "t", [],
        Camlp4.PreCast.Ast.TySum (<abstr>,
          Camlp4.PreCast.Ast.TyOr (<abstr>,
            Camlp4.PreCast.Ast.TyOr (<abstr>,
              Camlp4.PreCast.Ast.TyId (<abstr>,
                Camlp4.PreCast.Ast.IdUid (<abstr>, "A")),
              Camlp4.PreCast.Ast.TyId (<abstr>,
                Camlp4.PreCast.Ast.IdUid (<abstr>, "B")))),
            Camlp4.PreCast.Ast.TyId (<abstr>,
              Camlp4.PreCast.Ast.IdUid (<abstr>, "C")))),
          [])),
    Camlp4.PreCast.Ast.StNil <abstr>)



---


# verify = type_def;;
- : bool = false



---


let match_case = List.map (fun c -> <:match_case< $uid:c$ -> $('str:c$ >>)
let to_string = <:expr< function $match_case$ >>;;

val to_string : Camlp4.PreCast.Ast.expr =
  Camlp4.PreCast.Ast.ExFun (<abstr>,
    Camlp4.PreCast.Ast.McOr (<abstr>,
      Camlp4.PreCast.Ast.McArr (<abstr>,
        Camlp4.PreCast.Ast.PaId (<abstr>,
          Camlp4.PreCast.Ast.IdUid (<abstr>, "A")),

```

```

Camlp4.PreCast.Ast.ExNil <abstr>,
Camlp4.PreCast.Ast.ExStr (<abstr>, "A")),
Camlp4.PreCast.Ast.McOr (<abstr>,
Camlp4.PreCast.Ast.McArr (<abstr>,
Camlp4.PreCast.Ast.PaId (<abstr>,
Camlp4.PreCast.Ast.IdUid (<abstr>, "B")),
Camlp4.PreCast.Ast.ExNil <abstr>,
Camlp4.PreCast.Ast.ExStr (<abstr>, "B")),
Camlp4.PreCast.Ast.McArr (<abstr>,
Camlp4.PreCast.Ast.PaId (<abstr>,
Camlp4.PreCast.Ast.IdUid (<abstr>, "C")),
Camlp4.PreCast.Ast.ExNil <abstr>,
Camlp4.PreCast.Ast.ExStr (<abstr>, "C")))))

Printers.OCaml.print_implem <:str_item<let f = $to_string$ >>;
let f = function | A -> "A" | B -> "B" | C -> "C";;

let match_case2 = List.map (fun c -> <:match_case< $'str:c$ -> $uid:c$
>>) cons|> Ast.mcOr_of_list ;;

Printers.OCaml.print_implem <:str_item<let f = function $match_case2$ >>;
let f = function | "A" -> A | "B" -> B | "C" -> C;;
Printers.OCaml.print_implem <:str_item<let f = function $match_case2$ | _ -> invalid_arg "haha">>;
let f = function | "A" -> A | "B" -> B | "C" -> C | _ -> invalid_arg "haha";;

```

anyother way to verify? The output does not seem to guarantee its correctness.. **when you do antiquotation, in the cases of inserting an AST rather than a string, usually you do not need tags, when you inserting a string, probably you need it.**

(c) part3 : quotations in depth

```

[ 'QUOTATION x -> Quotation.expand _loc x Quotation.DynAst.
  expr_tag ]

```

The 'QUOTATION token contains a record including the body of the quotation and the tag. The record is passed off to the Quotation module to

be expanded. The expander parses the quotation string starting at some non-terminal(you specified), then runs the result through the antiquotation expander

```
| 'ANTIQUOT ('exp' | '' | 'anti' as n) s ->
<:expr< $anti:make_anti ~c:"expr" n s $>>
```

The antiquotation creates a special AST node to hold the body of the antiquotation, each type in the AST has a constructor (ExAnt, TyAnt, etc.) c here means context.

```
27 matches for "Ant" in buffer: Camlp4Ast.partial.ml
   5: | BAnt of string ]
   9: | ReAnt of string ]
  13: | DiAnt of string ]
  17: | MuAnt of string ]
  21: | PrAnt of string ]
  25: | ViAnt of string ]
  29: | OvAnt of string ]
  33: | RvAnt of string ]
  37: | OAnt of string ]
  41: | LAnt of string ]
  47: | IdAnt of loc and string (* $$$ *) ]
  87: | TyAnt of loc and string (* $$$ *)
  93: | PaAnt of loc and string (* $$$ *)
 124: | ExAnt of loc and string (* $$$ *)
 202: | MtAnt of loc and string (* $$$ *) ]
 231: | SgAnt of loc and string (* $$$ *) ]
 244: | WcAnt of loc and string (* $$$ *) ]
 251: | BiAnt of loc and string (* $$$ *) ]
 258: | RbAnt of loc and string (* $$$ *) ]
 267: | MbAnt of loc and string (* $$$ *) ]
 274: | McAnt of loc and string (* $$$ *) ]
 290: | MeAnt of loc and string (* $$$ *) ]
 321: | StAnt of loc and string (* $$$ *) ]
 337: | CtAnt of loc and string ]
 352: | CgAnt of loc and string (* $$$ *) ]
 372: | CeAnt of loc and string ]
 391: | CrAnt of loc and string (* $$$ *) ];
```

```
<:expr< $int: "4"$ >>;
```

```
- : Camlp4.PreCast.Ast.expr = Camlp4.PreCast.Ast.ExInt (<abstr>, "4")
```

```

<:expr< $('int: 4$ >>; (** the same result *)
- : Camlp4.PreCast.Ast.expr = Camlp4.PreCast.Ast.ExInt (<abstr>, "4")
<:expr< $('flo:4.1323243232$ >>;
- : Camlp4.PreCast.Ast.expr = Camlp4.PreCast.Ast.ExFlo (<abstr>, "4.1323243232")
# <:expr< $flo:"4.1323243232"$ >>;
- : Camlp4.PreCast.Ast.expr = Camlp4.PreCast.Ast.ExFlo (<abstr>, "4.1323243232")
(** maybe the same for flo *)

```

antiquotation example

```

match_case:
[ [ "["; l = LIST0 match_case0 SEP "|"; "]" -> Ast.
  mcOr_of_list l
  | p = ipatt; "->"; e = expr -> <:match_case< $p$ ->
    $e$ >> ] ]
;
match_case0:
[ [ 'ANTIQUOT ("match_case"|"list" as n) s ->
  <:match_case< $anti:mk_anti ~c:"match_case" n s$
    >>
  | 'ANTIQUOT ("|"anti" as n) s ->
  <:match_case< $anti:mk_anti ~c:"match_case" n s$
    >>
  | 'ANTIQUOT ("|"anti" as n) s; "->"; e = expr ->
  <:match_case< $anti:mk_anti ~c:"patt" n s$ ->
    $e$ >>
  | 'ANTIQUOT ("|"anti" as n) s; "when"; w = expr; "
  ->"; e = expr ->
  <:match_case< $anti:mk_anti ~c:"patt" n s$ when
    $w$ -> $e$ >>
  | p = patt_as_patt_opt; w = opt_when_expr; "->"; e =
    expr -> <:match_case< $p$ when $w$ -> $e$ >>
  ] ]

```

you can see that `match_case0`, if we use the list antiquotation, the first case in `match_case0` returns an antiquotation with tag `listmatch_case`, and we get the following expansion

```

value antiquot_expander = object
  inherit Ast.map as super;
  method patt = fun
    [ <:patt@_loc< $anti:s$ >> | <:patt@_loc< $str:s$ >>
      as p ->
      let mloc _loc = MetaLoc.meta_loc_patt _loc _loc in

```

```

handle_antiquot_in_string s p TheAntiquotSyntax.
  parse_patt _loc (fun n p ->
    match n with
    [ "antisig_item" -> <:patt< Ast.SgAnt $mloc
      _loc$ $p$ >>
    | "antistr_item" -> <:patt< Ast.StAnt $mloc
      _loc$ $p$ >>
    | "antictyp" -> <:patt< Ast.TyAnt $mloc _loc$
      $p$ >>
    | "antipatt" -> <:patt< Ast.PaAnt $mloc _loc$
      $p$ >>
    | "antiexpr" -> <:patt< Ast.ExAnt $mloc _loc$
      $p$ >>
    | "antimodule_type" -> <:patt< Ast.MtAnt $mloc
      _loc$ $p$ >>
    | "antimodule_expr" -> <:patt< Ast.MeAnt $mloc
      _loc$ $p$ >>
    | "anticlass_type" -> <:patt< Ast.CtAnt $mloc
      _loc$ $p$ >>
    | "anticlass_expr" -> <:patt< Ast.CeAnt $mloc
      _loc$ $p$ >>
    | "anticlass_sig_item" -> <:patt< Ast.CgAnt
      $mloc _loc$ $p$ >>
    | "anticlass_str_item" -> <:patt< Ast.CrAnt
      $mloc _loc$ $p$ >>
    | "antiwith_constr" -> <:patt< Ast.WcAnt $mloc
      _loc$ $p$ >>
    | "antibinding" -> <:patt< Ast.BiAnt $mloc _loc$
      $p$ >>
    | "antirec_binding" -> <:patt< Ast.RbAnt $mloc
      _loc$ $p$ >>
    | "antimatch_case" -> <:patt< Ast.McAnt $mloc
      _loc$ $p$ >>
    | "antimodule_binding" -> <:patt< Ast.MbAnt
      $mloc _loc$ $p$ >>
    | "antiident" -> <:patt< Ast.IdAnt $mloc _loc$
      $p$ >>
    | _ -> p ])
  | p -> super#patt p ];
method expr = fun
  [ <:expr@_loc< $anti:s$ >> | <:expr@_loc< $str:s$ >>
  as e ->
    let mloc _loc = MetaLoc.meta_loc_expr _loc _loc in
    handle_antiquot_in_string s e TheAntiquotSyntax.
      parse_expr _loc (fun n e ->
        match n with
        [ "'int" -> <:expr< string_of_int $e$ >>
        | "'int32" -> <:expr< Int32.to_string $e$ >>

```

```

| "int64" -> <:expr< Int64.to_string $$ >>
| "nativeint" -> <:expr< Nativeint.to_string
  $$ >>
| "flo" -> <:expr< Camlp4_import.Oprint.
  float_repres $$ >>
| "str" -> <:expr< Ast.safe_string_escaped $$
  >>
| "chr" -> <:expr< Char.escaped $$ >>
| "bool" -> <:expr< Ast.IdUid $mloc _loc$ (if
  $$ then "True" else "False") >>
| "liststr_item" -> <:expr< Ast.stSem_of_list
  $$ >>
| "listsig_item" -> <:expr< Ast.sgSem_of_list
  $$ >>
| "listclass_sig_item" -> <:expr< Ast.
  cgSem_of_list $$ >>
| "listclass_str_item" -> <:expr< Ast.
  crSem_of_list $$ >>
| "listmodule_expr" -> <:expr< Ast.meApp_of_list
  $$ >>
| "listmodule_type" -> <:expr< Ast.mtApp_of_list
  $$ >>
| "listmodule_binding" -> <:expr< Ast.
  mbAnd_of_list $$ >>
| "listbinding" -> <:expr< Ast.biAnd_of_list $$
  >>
| "listbinding;" -> <:expr< Ast.biSem_of_list
  $$ >>
| "listrec_binding" -> <:expr< Ast.rbSem_of_list
  $$ >>
| "listclass_type" -> <:expr< Ast.ctAnd_of_list
  $$ >>
| "listclass_expr" -> <:expr< Ast.ceAnd_of_list
  $$ >>
| "listident" -> <:expr< Ast.idAcc_of_list $$
  >>
| "listctypand" -> <:expr< Ast.tyAnd_of_list $$
  >>
| "listctyp;" -> <:expr< Ast.tySem_of_list $$
  >>
| "listctyp*" -> <:expr< Ast.tySta_of_list $$
  >>
| "listctyp|" -> <:expr< Ast.tyOr_of_list $$ >>
| "listctyp," -> <:expr< Ast.tyCom_of_list $$
  >>
| "listctyp&" -> <:expr< Ast.tyAmp_of_list $$
  >>

```



```

| "listwith_constr" -> <:expr< Ast.wcAnd_of_list
  $$ >>
| "listmatch_case" -> <:expr< Ast.mcOr_of_list
  $$ >>
| "listpatt," -> <:expr< Ast.paCom_of_list $$
  >>
| "listpatt;" -> <:expr< Ast.paSem_of_list $$
  >>
| "listexpr," -> <:expr< Ast.exCom_of_list $$
  >>
| "listexpr;" -> <:expr< Ast.exSem_of_list $$
  >>
| "antisig_item" -> <:expr< Ast.SgAnt $mloc
  _loc$ $$ >>
| "antistr_item" -> <:expr< Ast.StAnt $mloc
  _loc$ $$ >>
| "antictyp" -> <:expr< Ast.TyAnt $mloc _loc$
  $$ >>
| "antipatt" -> <:expr< Ast.PaAnt $mloc _loc$
  $$ >>
| "antiexpr" -> <:expr< Ast.ExAnt $mloc _loc$
  $$ >>
| "antimodule_type" -> <:expr< Ast.MtAnt $mloc
  _loc$ $$ >>
| "antimodule_expr" -> <:expr< Ast.MeAnt $mloc
  _loc$ $$ >>
| "anticlass_type" -> <:expr< Ast.CtAnt $mloc
  _loc$ $$ >>
| "anticlass_expr" -> <:expr< Ast.CeAnt $mloc
  _loc$ $$ >>
| "anticlass_sig_item" -> <:expr< Ast.CgAnt
  $mloc _loc$ $$ >>
| "anticlass_str_item" -> <:expr< Ast.CrAnt
  $mloc _loc$ $$ >>
| "antiwith_constr" -> <:expr< Ast.WcAnt $mloc
  _loc$ $$ >>
| "antibinding" -> <:expr< Ast.BiAnt $mloc _loc$
  $$ >>
| "antirec_binding" -> <:expr< Ast.RbAnt $mloc
  _loc$ $$ >>
| "antimatch_case" -> <:expr< Ast.McAnt $mloc
  _loc$ $$ >>
| "antimodule_binding" -> <:expr< Ast.MbAnt
  $mloc _loc$ $$ >>
| "antiident" -> <:expr< Ast.IdAnt $mloc _loc$
  $$ >>
| _ -> e ])
| e -> super#expr e ];

```

here we see the ambiguity of original syntax,

```
<< type t = [ $list:List.map (fun c -> <:ctyp< $uid:c$ >>)$ ]
    >>
```

in original syntax, it does not know it's variant context, or just type synonym. (you can add a constructor to make it clear)

(d) part4 parsing ocaml itself using camlp4

```
Camlp4.Register.loaded_modules;;

- : string list ref =
{Pervasives.contents =
  ["Camlp4ListComprehension"; "Camlp4MacroParser"; "Camlp4MacroParser";
   "Camlp4GrammarParser"; "Camlp4OCamlParserParser";
   "Camlp4OCamlRevisedParserParser"; "Camlp4OCamlParser";
   "Camlp4QuotationExpander"; "Camlp4OCamlRevisedParser"]} }
```

we have to use revised syntax here, because when using quasiquotation, it has ambiguity to get the needed part, revised syntax was designed to reduce the ambiguity here .

The following code is a greate file parsing ocaml itself. Do not use MakeSyntax below, since it will introduce unnecessary abstraction type, which makes sharing code very difficult

```
open Batteries_uni ;
open Camlp4.PreCast ;
module MySyntax = Camlp4.OCamlInitSyntax.Make Ast Gram Quotation ;
module M = Camlp4OCamlRevisedParser.Make MySyntax ; (* load r parser *)
(** in toplevel, I did not find a way to introduce such module
    because it will change the state
    *)
module N = Camlp4OCamlParser.Make MySyntax ; (* load o parser*)
value my_parser = MySyntax.parse_imlem;
value str_items_of_file file_name =
```

```

file_name
|> open_in
|> Stream.of_input
|> my_parser (Loc.mk file_name)
|> flip Ast.list_of_str_item [] ;

(** it has ambiguity in original syntax, so pattern match
    will be more natural in revised syntax
*)
value rec do_str_item str_item tags =
  match str_item with
  [ <:str_item< value $rec:_$ $binding$ >> ->
    let bindings = Ast.list_of_binding binding []
    in List.fold_right do_binding bindings tags
  | _ -> tags ]
and do_binding bi tags = match bi with
[ <:binding@loc< $lid:lid$ = $_$ >> ->
  let line = Loc.start_line loc in
  let off = Loc.start_off loc in
  let pre = "let " ^ lid in
  [(pre,lid,line,off) :: tags ]
| _ -> tags ];

value do_fn file_name =
  file_name
|> str_items_of_file
|> List.map (flip do_str_item [])
|> List.concat ;

(**use MSyntax.parse_imlem*)
value _ =

```

```

do_fn "/Users/bob/SourceCode/OCaml/Parsing/camlp4/otags_test.ml"
|> List.iter (fun (a, b, c, d) -> Printf.printf "%s-%s %d-%d \n" a b c d)
value do_fn_2 fn_2 = fn_2 ;

(**use my syntax *)
(* do_fn "/Users/bob/SourceCode/OCaml/Parsing/camlp4/otags.ml"; *)
(* Exception: Loc.Exc_located <abstr> (Stream.Error "entry [implem] is not found" *)
(* empty"). *)

(* - : list (string * string * int * int) = *)
(* [("let str_items_of_file", "str_items_of_file", 4, 9); *)
(* ("let do_str_item", "do_str_item", 15, 286); *)
(* ("let do_binding", "do_binding", 21, 519)] *)

(** tags *)
"otags.ml" : pp(camlp4rf )
<otags.{cmo,byte,native}> : pkg_dynlink , use_camlp4_full, pkg_batteries
(** be careful, when you use the parser to lift itself, you have to
provide a lot of parsers...
module M4 = Camlp4QuotationExpander.Make MySyntax ;
can make your parser parse itself, great!!
*)

se (FILTER _* "of_") "Stream" ;;

val of_list : 'a list -> 'a t
val of_string : string -> char t
val of_channel : in_channel -> char t
val of_enum : 'a BatEnum.t -> 'a Stream.t
val of_input : BatIO.input -> char Stream.t
val of_fun : (unit -> 'a) -> 'a Stream.t

```

(e) part5 structure item filters

because I use revised syntax, and take a reference of the documentation, my ast filter is much nicer than jaked's. the documentation of quasiquotation

from the wiki page is quite helpful

```

value (|>) x f = f x ;
module Make (AstFilters : Camlp4.Sig.AstFilters) = struct
  open AstFilters ;
  value code_of_con_names name cons _loc =
    let match_cases =
      cons |>
      List.map
        (fun str -> <:match_case< $uid:str$ -> $str:str$ >>)
        |> Ast.mCOr_of_list in
    let reverse_cases =
      cons |>
      List.map (fun con -> <:match_case< $str:con$ -> $uid:con$ >>)
        |> Ast.mCOr_of_list in
    <:str_item<
      value $lid:(name^"_to_string") $ =
        fun [ $match_cases$ ] ;
      value $lid:(name^"_of_string") $ =
        fun [ $reverse_cases$ | x -> invalid_arg x ] >> ;
    value rec filter str_item = match str_item with
      [ <:str_item@_loc< type $lid:tid$ = [ $t$ ] >> -> begin
        (* [ ] is necessary for revised syntax,
           otherwise, it will be weird, [] tells it in a list context
           *)
        try
          (** good, this can be got from Abstract_Syntax_Tree *)
          let ctys = Ast.list_of_ctyp t [] in
          let con_names =
            List.map (fun [ <:ctyp< $uid:c $ >> -> c
                          | x -> "FUCK" ]) ctys in
          let code = code_of_con_names tid con_names _loc in

```

```

    <:str_item< $str_item$ ; $code$ ; >>
  with
    [Exit -> begin
      print_endline "check " ;
      str_item end ]
  end
  |_ -> begin print_endline "not simple type " ; str_item end ];
  AstFilters.register_str_item_filter filter ;
end ;
module Id = struct
  value name = "filter_toy";
  value version = "0.1" ;
end ;
value _ =
  let module M = Camlp4.Register.AstFilter Id Make in
    () ;

```

```

"filter.ml" : pp(camlp4rf )
<filter.{cmo,byte,native}> : pkg_dynlink, use_camlp4_full,
  pkg_batteries
"filter_test.ml" : pp(camlp4of -parser filter.cmo)

```

the register mechanism should be remembered *let module M = Camlp4.Register.AstFilter Id Make in*

we can test our filter as follows

`camlp4of -parser _build/filter.cmo filter_test.ml -filter lift -printer o`
 by the **lift filter** you can see its **internal representation**, textual code does not guarantee its correctness, but the AST representation could guarantee its correctness. Built in filters as follows :

(a) fold map

```

class x = Camlp4MapGenerator.generated ;
class x = Camlp4FoldGenerator.generated ;

```

- (b) meta
 - lifting function from a type definition – these functions are what *Camlp4AstLifter* uses to lift the AST, and also how *quotations* are implemented
- (c) LocationStripper (replace location with Loc.ghost)
 - might be useful when you compare two asts? YES! idea? how to use lifter at toplevel, how to beautify our code, without the horribling output? (I mean, the qualified name is horrible)
- (d) Camlp4Profiler
 - inserts profiling code
- (e) Camlp4TrashRemover
- (f) Camlp4ExceptionTracer
- (f) part6 extensible parser (moved to extensible parser part)
- (g) part7 revised syntax
 - revised syntax provides more context in the form of extra brackets etc. so that antiquotation works more smoothly.
- (h) part8, 9 quotation

- (a) Quotation.add quotation_expander

```

se (FILTER _* "expand_fun") "Quotation";;

type 'a expand_fun = Ast.loc -> string option -> string -> 'a
val add : string -> 'a DynAst.tag -> 'a expand_fun -> unit
val find : string -> 'a DynAst.tag -> 'a expand_fun

```

other useful functions

```

type 'a expand_fun = Ast.loc -> string option -> string -> 'a
val add : string -> 'a DynAst.tag -> 'a expand_fun -> unit
val find : string -> 'a DynAst.tag -> 'a expand_fun
val default : string ref (* default quotations *)
val parse_quotation_result :
  (Ast.loc -> string -> 'a) ->

```

```

    Ast.loc -> Camlp4.Sig.quotation -> string -> string -> 'a
val translate : (string -> string) ref
val expand : Ast.loc -> Camlp4.Sig.quotation -> 'a DynAst.tag -> 'a
val dump_file : string option ref

```

in previous camlp4, Quotation provides a string to string transformation, then it default uses Syntax.expr or Syntax.patt to parse the returned string. following drawbacks

- needs a **more** parsing phase
- the resulting string may be syntactically incorrect, difficult to **debug**

(b) quotation expander

when without antiquotaions, a parser is enough, other things are quite mechanical

```

open Camlp4.PreCast
module Jq_ast = struct
  type float' = float
  type t =
    Jq_null
  | Jq_bool of bool
  | Jq_number of float'
  | Jq_string of string
  | Jq_array of t list
  | Jq_object of (string*t) list
end
include Jq_ast
module MetaExpr = struct
  (** the generator scans all the types defined in the current modul
      then generate code for the last-appearing recursive bundle
  *)
  let meta_float' _loc f = <:expr< $'flo:f$ >>
  include Camlp4Filters.MetaGeneratorExpr(Jq_ast)

```



```

    (* due to this can not run in toplevel *)
end
module MetaPatt = struct
  let meta_float' _loc f = <:patt< $'flo:f$ >>
  include Camlp4Filters.MetaGeneratorPatt(Jq_ast)
end
module MGram = MakeGram(Lexer)
let json_parser = MGram.Entry.mk "json"
  EXTEND MGram
  GLOBAL : json_parser ;
  json_parser :
    [ ["null" -> Jq_null
      | "true" -> Jq_bool true
      | "false" -> Jq_bool false
      | n = [x = INT -> x | y = FLOAT -> y ] -> Jq_number (float_of_s
      | s = STRING -> Jq_string s
      | "["; xs = LISTO SELF SEP "," ; "]" -> Jq_array xs
      | "{"; kvs = LISTO [s = STRING; ":"; v = json_parser -> (s,v)] SI
      | "}" -> Jq_object kvs
    ] ] ; END
let json_eoi = MGram.Entry.mk "json_eoi"
  EXTEND MGram
  GLOBAL: json_eoi ;
  json_eoi : [[x = json_parser ; EOI -> x ]] ; END
let test =
  MGram.parse_string json_eoi (Loc.mk "<string>")
    "[true,false]"

```

Mechanical installation to get a quotation expander

```

module Q = Syntax.Quotation
(* #directory "/Users/bob/SourceCode/OCaml/Parsing/camlp4/_build";;
(* camlp4of -filter meta json.ml -printer o *)

```

```

let (|>) x f = f x
let parse_quot_string _loc s =
  MGram.parse_string json_eoi _loc s
let expand_expr _loc _ s =
  s
  |> parse_quot_string _loc
  |> MetaExpr.meta_t _loc

(* to make it able to appear in the toplevel *)
let expand_str_item _loc _ s =
  (**insert an expression as str_item *)
  <:str_item@_loc< $exp: expand_expr _loc None s $ >>
let expand_patt _loc _ s =
  s
  |> parse_quot_string _loc
  |> MetaPatt.meta_t _loc

let _ =
  Q.add "json" Q.DynAst.expr_tag expand_expr ;
  Q.add "json" Q.DynAst.patt_tag expand_patt ;
  Q.add "json" Q.DynAst.str_item_tag expand_str_item ;
  Q.default := "json"

(** make quotation from a parser *)
let install_quotation my_parser (me,mp) name =
  let module Q = Syntax.Quotation in
  let expand_expr _loc _ s = s |> my_parser _loc |> me _loc in
  let expand_str_item _loc _ s = <:str_item@_loc< $exp: expand_expr
    _loc None s $>> in
  let expand_patt _loc _ s = s |> my_parser _loc |> mp _loc in
  Q.add name Q.DynAst.expr_tag expand_expr ;

```

```
Q.add "json" Q.DynAst.patt_tag expand_patt ;
Q.add "json" Q.DynAst.str_item_tag expand_str_item
```

```
val install_quotation :
  (Camlp4.PreCast.Ast.loc -> string -> 'a) ->
  (Camlp4.PreCast.Ast.loc -> 'a -> Camlp4.PreCast.Ast.
    expr) *
  (Camlp4.PreCast.Ast.loc -> 'a -> Camlp4.PreCast.Ast.
    patt) -> string -> unit =
  <fun>
```

```
"json.ml" : pp(camlp4of -filter meta)
```

```
<json.{cmo,byte,native}> : pkg_dynlink, use_camlp4_full
```

so in the toplevel

```
#directory "/Users/bob/SourceCode/OCaml/Parsing/camlp4/_build";;
```

```
#load "json.cmo" ;
```

```
open Json; (* for Jq_ast module, you can find other ways to work
around this *)
```

```
<< [ 3 ,4 ]>>;;
```

```
- : Json.Jq_ast.t = Json.Jq_ast.Jq_array [Json.Jq_ast.Jq_number 3.; Json.Jq_ast.Jq_number
4.]
```

(c) antiquotation expander

the meta filter treat any other constructor **ending in Ant** specially instead of

```
| Jq_Ant(loc,s) -> <:expr< Jq_Ant ($meta_loc loc$, $meta_string s$) >
```

they have

```
| Jq_Ant(loc,s) -> ExAnt(loc,s)
```

Instead of lifting the constructor, they translate it directly to ExAnt or PaAnt.

Attention, there is no semi or comma required in GLOBAL list, GLOBAL: json_eoi json ; (just whitespace)

```

open Camlp4.PreCast
module Jq_ast = struct
  type float' = float
  type t =
    Jq_null
  | Jq_bool of bool
  | Jq_number of float'
  | Jq_string of string

  | Jq_array of t
  | Jq_object of t
  | Jq_colon of t * t  (* to make an object *)
  | Jq_comma of t * t  (* to make an array *)
  | Jq_Ant of Loc.t * string
  | Jq_nil (* similiar to StNil *)
  let rec t_of_list lst = match lst with
    | [] -> Jq_nil
    | b::bs -> Jq_comma (b, t_of_list bs)
  end

include Jq_ast

module MGram = MakeGram(Lexer)

let json  = MGram.Entry.mk "json"
let json_eoi = MGram.Entry.mk "json_eoi"

EXTEND MGram
GLOBAL: json_eoi json ;
json_eoi : [[ x = json ; EOI -> x ]];

```

```

json :
  [[ "null" -> Jq_null
    | "true" -> Jq_bool true
    | "false" -> Jq_bool false

    | 'ANTIQUOT ("|" "bool"|"int"|"floo"|"str"|"list"|"alist" as n , s
      Jq_Ant(_loc, n ^ ":" ^ s )

    | n = [ x = INT-> x | x = FLOAT -> x ] -> Jq_number (float_of_s
    | "["; es = SELF ; "]" -> Jq_array es
    | "{"; kvs = SELF ;"}" -> Jq_object kvs

    | k= SELF; ":" ; v = SELF -> Jq_colon (k, v)
    | a = SELF; "," ; b = SELF -> Jq_comma (a, b)
    | -> Jq_nil  (* camlp4 parser epsilon has a lower priority *)

  ]];

END ;;

module AQ = Syntax.AntiquotSyntax
module Q = Syntax.Quotation
let destruct_aq s =
  let pos = String.index s ':' in
  let len = String.length s in
  let name = String.sub s 0 pos in
  let code = String.sub s (pos+1) (len-pos-1) in
  name, code

(** alternative*)
let destruct_aq2 = function (RE (_* Lazy as name) ":" (_* as conten

```

```

let /(_* Lazy as x) ":" (_* as rest ) / = "ghsoghos:ghsogh: ghsoghgo";;
val rest : string = "ghsogh: ghsoghgo"

```

```

val x : string = "ghsoghos"

```

```

let try /(_* Lazy as x) ":" (_* as rest ) / = "ghsoghosghsog ghsoghgo"
in (x,rest)
with Match_failure _ -> ("","");;

```

notice that Syntax.AntiquotSyntax.(parse_expr,parse_patt) Syntax.(parse_implem,
parse_interf)

```

        val parse_expr : Ast.loc -> string -> Ast.expr
        val parse_patt : Ast.loc -> string -> Ast.patt
    val parse_implem :
    val parse_interf :

let aq_expander = object
  inherit Ast.map as super
  method expr = function
    | Ast.ExAnt(_loc, s) ->
      let n, c = destruct_aq s in
      (** first round*)
      let e = AQ.parse_expr _loc c in
      begin match n with
      | "bool" -> <:expr< Jq_ast.Jq_bool $e$ >> (* interesting *)
      | "int" -> <:expr< Jq_ast.Jq_number (float $e$ ) >>
      | "flo" -> <:expr< Jq_ast.Jq_number $e$ >>
      | "str" -> <:expr< Jq_ast.Jq_string $e$ >>
      | "list" -> <:expr< Jq_ast.t_of_list $e$ >>
      | "alist" ->
        <:expr<
          Jq_ast.t_of_list
          (List.map (fun (k,v) -> Jq_ast.Jq_colon (Jq_ast.Jq_string
            $e$ )

```

```

        >>
        | _ -> e
    end
    | e -> super#expr e
method patt = function
| Ast.PaAnt(_loc,s) ->
    let n,c = destruct_aq s in
    AQ.parse_patt _loc c  (* ignore the tag *)
| p -> super#patt p
end
module MetaExpr = struct
    (** the generator scans all the types defined in the current modul
        then generate code for the last-appearing recursive bundle
        *)
    let meta_float' _loc f = <:expr< $'flo:f$ >>
    include Camlp4Filters.MetaGeneratorExpr(Jq_ast)
end
module MetaPatt = struct
    let meta_float' _loc f = <:patt< $'flo:f$ >>
    include Camlp4Filters.MetaGeneratorPatt(Jq_ast)
end
let (|>) x f = f x
let parse_quot_string _loc s =
    let q = !Camlp4_config.antiquotations in
    (** checked by the lexer to allow antiquotation
        the flag is initially set to false, so antiquotations
        appearing outside a quotation won't be parsed
        *)
    Camlp4_config.antiquotations := true ;
let res = MGram.parse_string json_eoi _loc s in
    Camlp4_config.antiquotations := q ;

```

```

res
let expand_expr _loc _ s =
  s
  |> parse_quot_string _loc
  |> MetaExpr.meta_t _loc
  |> aq_expander#expr
(* so it can appear in the toplevel *)
let expand_str_item _loc _ s =
  (**insert an expression as str_item *)
  <:str_item@_loc< $exp: expand_expr _loc None s $ >>
let expand_patt _loc _ s =
  s
  |> parse_quot_string _loc
  |> MetaPatt.meta_t _loc
  |> aq_expander#patt
let _ =
  Q.add "json" Q.DynAst.expr_tag expand_expr ;
  Q.add "json" Q.DynAst.patt_tag expand_patt ;
  Q.add "json" Q.DynAst.str_item_tag expand_str_item ;
  Q.default := "json"

MGram.parse_string json_eoi Loc.ghost "[1,2]";;
- : t = Jq_array (Jq_comma (Jq_number 1., Jq_number 2.))
MGram.parse_string json_eoi Loc.ghost "[1,2,]";;
- : t = Jq_array (Jq_comma (Jq_comma (Jq_number 1., Jq_number 2.), Jq_nil))
MGram.parse_string json_eoi Loc.ghost "1,2";;
- : t = Jq_comma (Jq_number 1., Jq_number 2.)
let alist = ["haha", <<1>>;"bob",<<3>>] in <:json< [1 , $alist:alist$ ]>>;

- : Json_anti.Jq_ast.t =
Json_anti.Jq_ast.Jq_array
(Json_anti.Jq_ast.Jq_comma (Json_anti.Jq_ast.Jq_number 1.,
  Json_anti.Jq_ast.Jq_comma
    (Json_anti.Jq_ast.Jq_colon (Json_anti.Jq_ast.Jq_string "haha",

```



```

        Json_anti.Jq_ast.Jq_number 1.),
    Json_anti.Jq_ast.Jq_comma
    (Json_anti.Jq_ast.Jq_colon (Json_anti.Jq_ast.Jq_string "bob",
        Json_anti.Jq_ast.Jq_number 3.),
    Json_anti.Jq_ast.Jq_nil))))

let b = << $ << 1 >> $ >> = << 1 >>;;
val b : bool = true

```

```

<< $ << 1 >> $ >> --> parsing (my parser)
Jq_Ant(_loc, "<<1>>") --> lifting (mechanical)
Ex_Ant(_loc, "<<1>>") --> parsing (the host parser )
<:expr< Jq_number 1. >> --> antiquot_expand (my
    anti_expander )
<:expr < Jq_number 1. >>
*)
"json_anti.ml" : pp(camlp4of -filter meta)
<json_anti.{cmo,byte,native}> : pkg_dynlink,
    use_camlp4_full

```

(i) part 10 lexer

Just follow the signature of module type `Lexer` is enough. generally you have to provide module `Loc`, `Token`, `Filter`, `Error`, and `mk` is essential

```
val mk : unit -> Loc.t -> char Stream.t -> (Token.t * Loc.t ) Stream.t
```

the verbose part lies in that you have to use the `Camlp4.Sig.Loc`, usually you have to maintain a mutable context, so when you lex a token, you can query the context to get `Loc.t`. you can refer Jake's `jq_lexer.ml` for more details. How about using lexer, parser all by myself? The work need to be done lies in you have to supply a plugin of type `expand_fun`, which is type `'a expand_fun = Ast.loc -> string option -> string -> 'a` so if you dont use `ocamllexer`, why bother the grammar module, just use `lex yacc` will make life easier, and you code will run faster .

```

type pos = {
  line : int;
  bol   : int;

```

```

    off  : int
};

type t = {
  file_name : string;
  start      : pos;
  stop       : pos;
  ghost      : bool
};

open Camlp4.PreCast
module Loc = Camlp4.PreCast.Loc
module Error : sig
  type t
  exception E of t
  val to_string : t -> string
  val print : Format.formatter -> t -> unit
end = struct
  type t = string
  exception E of string
  let print = Format.pp_print_string (* weird, need flush *)
  let to_string x = x
end
let _ =
  let module M = Camlp4.ErrorHandler.Register (Error) in ()
let (|>) x f = f x
module Token : sig
  module Loc : Camlp4.Sig.Loc
  type t
  val to_string : t -> string
  val print : Format.formatter -> t -> unit
  val match_keyword : string -> t -> bool
  val extract_string : t -> string

```

```

module Filter : sig
  (* here t refers to the Token.t *)
  type token_filter = (t, Loc.t) Camlp4.Sig.stream_filter
  type t
  val mk : (string->bool)-> t
  val define_filter : t -> (token_filter -> token_filter) -> unit
  val filter : t -> token_filter
  val keyword_added : t -> string -> bool -> unit
  val keyword_removed : t -> string -> unit
end

module Error : Camlp4.Sig.Error
end = struct
  (** the token need not to be a variant with arms with KEYWORD
      EOI, etc, although conventional
  *)
  type t =
    | KEYWORD of string
    | NUMBER of string
    | STRING of string
    | ANTIQUOT of string * string
    | EOI
  let to_string t =
    let p = Printf.sprintf in
    match t with
    | KEYWORD s -> p "KEYWORD %S" s
    | NUMBER s -> p "NUMBER %S" s
    | STRING s -> p "STRING %S" s
    | ANTIQUOT (n,s) -> p "ANTIQUOT %S: %S" n s
    | EOI -> p "EOI"
  let print fmt x = x |> to_string |> Format.pp_print_string fmt
  let match_keyword kwd = function

```

```

|KEYWORD k when kwd = k -> true
|_ -> false

let extract_string = function
|KEYWORD s | NUMBER s | STRING s -> s
|tok -> invalid_arg ("can not extract a string from this token : "
                    ^ to_string tok)

module Loc = Camlp4.PreCast.Loc
module Error = Error
module Filter = struct
  type token_filter = (t * Loc.t ) Stream.t -> (t * Loc.t) Stream.t

  (** stub out *)
  (** interesting *)
  type t = unit

  (** the argument to mk is a function indicating whether
      a string should be treated as a keyword, and the default
      lexer uses it to filter the token stream to convert identifiers
      into keywords. if we want our parser to be extensible, we should
      take this into account
  *)
  let mk _ = ()
  let filter _ x = x
  let define_filter _ _ = ()
  let keyword_added _ _ _ = ()
  let keyword_removed _ _ = ()
end
end
module L = Ulexing

```

```
INCLUDE "/Users/bob/predefine_ulex.ml"

(* let rec token c = lexer *)
(*   / eof -> EOI *)
(*   / newline -> token *)
(** TOKEN ERROR LOC
    mk : unit -> Loc.t -> char Stream.t -> (Token.t * Loc.t) Stream.t

    Loc.of_tuple :
    string * int * int * int * int * int * int * bool ->
    Loc.t

*)
```

8. useful links [Abstract_Syntax_Tree](#)

[elehack](#)

[meta-guide](#)

[camlp4](#)

Chapter 5

practical parts

5.1 batteries

syntax extension Not of too much use , **Never use it in the toplevel**

- comprehension (M.filter, concat, map, filter_map, enum, of_enum)
since it's at preprocessed stage, you can use some trick
`let module Enum = List in` will change the semantics
`let open Enum in` doesn't make sense, since it uses qualified name inside

5.1.1 Dev

- make changes in both .ml and .mli files

5.1.2 BOLT

5.2 Mikmatch

Directly supported in toplevel Regular expression *share* their own namespace.

1. compile

```
"test.ml" : pp(camlp4o -parser pa_mikmatch_pcre.cma)
<test.{cmo,byte,native}> : pkg_mikmatch_pcre
-- myocamlbuild.ml use default
```

2. toplevel

```
ocaml
#camlp4o ;;
#require "mikmatch_pcre" ;; (* make sure to follow the order strictly *)
```

3. debug

```
camlp4of -parser pa_mikmatch_pcre.cma -printer o test.ml
(* -no_comments does not work *)
```

4. structure

regular expressions can be used to match strings, it must be preceded by the RE keyword, or placed between slashes (/./).

```
match ... with pattern -> ...
function pattern -> ...
try ... with pattern -> ...
let /regexp/ = expr in expr
let try (rec) let-bindings in expr with pattern-match
(only handles exception raised by let-bindings)
MACRO-NAME regexp -> expr ((FILTER | SPLIT) regexp)
```

```
let x = (function (RE digit+) -> true | _ -> false) "13232";;
val x : bool = true
# let x = (function (RE digit+) -> true | _ -> false) "1323a2";;
val x : bool = true
# let x = (function (RE digit+) -> true | _ -> false) "x1323a2";;
val x : bool = false
```

```

let get_option () = match Sys.argv with
  [| _ |] -> None
  [| _ ; RE (lower+ as key) "=" (_* as data) |] -> Some(key,data)
  |_ -> failwith "Usage: myprog [key=val]";;
val get_option : unit -> (string * string) option = <fun>

```

```

let option = try get_option () with Failure (RE "usage~") -> None ;;
val option : (string * string) option = None

```

5. sample regex built in regexes

```

lower, upper, alpha(lower|upper), digit, alnum, punct
graph(alnum|punct), blank, cntrl, xdigit, space
int, float
bol(beginning of line)
eol
any(except newline)
bos, eos

```

```

let f = (function (RE int as x : int) -> x ) "132";;
val f : int = 132
let f = (function (RE float as x : float) -> x ) "132.012";;
val f : float = 132.012
let f = (function (RE lower as x ) -> x ) "a";;
val f : string = "a"
let src = RE_PCRE int ;;
val src : string * 'a list = ("[\-\?0(?:[Xx][0-9A-Fa-f]+|(?:[0o][0-7]+|[Bb][01]+))|[0-9]+)", [])
let x = (function (RE _* bol "haha") -> true | _ -> false) "x\nhaha";;
val x : bool = true

```

```

RE hello = "Hello!"
RE octal  = ['0'-'7']
RE octal1 = ["01234567"]
RE octal2 = ['0' '1' '2' '3' '4' '5' '6' '7']
RE octal3 = ['0'-'4' '5'-'7']
RE octal4 = digit # ['8' '9']  (* digit is a predefined set of characters *)
RE octal5 = "0" | ['1'-'7']

```



```

RE octal6 = ['0'-'4'] | ['5'-'7']
RE not_octal = [ ^ '0'-'7' ] (* this matches any character but an octal digit *)
RE not_octal' = [ ^ octal ]  (* another way to write it *)

RE paren' = "(" _* Lazy ")"
(* _ is wild pattern, paren is built in *)
let p = function (RE (paren' as x )) -> x ;;



---


p "(xx)";;
- : string = "(xx)"
# p "(x)x)";;
- : string = "(x)"


---



RE anything  = _*          (* any string, as long as possible *)
RE anything' = _* Lazy    (* any string, as short as possible *)
RE opt_hello  = "hello"?   (* matches hello if possible, or nothing *)
RE opt_hello' = "hello"? Lazy (* matches nothing if possible, or hello *)
RE num = digit+           (* a non-empty sequence of digits, as long as possible *)
                          (* shortcut for: digit digit* *)
RE lazy_junk = _+ Lazy    (* match one character then match any sequence
                          of characters and give up as early as possible *)

RE at_least_one_digit = digit{1+}      (* same as digit+ *)
RE at_least_three_digits = digit{3+}
RE three_digits = digit{3}
RE three_to_five_digits = digit{3-5}
RE lazy_three_to_five_digits = digit{3-5} Lazy

let test s = match s with
  RE "hello" -> true
| _ -> false

```

It's important to know that matching process will try *any* possible combination until the pattern is matched. However the combinations are tried from left

to right, and repeats are either greedy or lazy. (greedy is default). laziness triggered by the presence of the Lazy keyword.

6. fancy features of regex

(a) normal

```
let x = match "hello world" with
  RE "world" -> true
  | _ -> false;;

val x : bool = false
```

(b) pattern match syntax (the let constructs can be used directly with a regexp pattern, but **let RE ... = ...** does not look nice, the sandwich notation (/.../) has been introduced)

```
Sys.ocaml_version;;
- : string = "3.12.1"
# RE num = digit + ;;
```

```
RE num = digit + ;;

let /(num as major : int ) "." (num as minor : int)

( "." (num as patchlevel := fun s -> Some (int_of_string s))
  | (" " as patchlevel := fun s -> None ))

( "+" (_* as additional_info := fun s -> Some s )
  | (" " as additional_info := fun s -> None )) eos

/ = Sys.ocaml_version ;;
```

we always use **as** to extract the information.

```
val additional_info : string option = None
val major : int = 3
```

```

val minor : int = 12
val patchlevel : int option = Some 1

```

(c) File processing (Mikmatch.Text)

```

val iter_lines_of_channel : (string -> unit) -> in_channel -> unit
val iter_lines_of_file : (string -> unit) -> string -> unit
val lines_of_channel : in_channel -> string list
val lines_of_file : string -> string list
val channel_contents : in_channel -> string
val file_contents : ?bin:bool -> string -> string
val save : string -> string -> unit
val save_lines : string -> string list -> unit
exception Skip
val map : ('a -> 'b) -> 'a list -> 'b list
val rev_map : ('a -> 'b) -> 'a list -> 'b list
val fold_left : ('a -> 'b -> 'a) -> 'a -> 'b list -> 'a
val fold_right : ('a -> 'b -> 'b) -> 'a list -> 'b -> 'b
val map_lines_of_channel : (string -> 'a) -> in_channel -> 'a list
val map_lines_of_file : (string -> 'a) -> string -> 'a list

```

(d) Mikmatch.Glob (pretty useful)

```

val scan :
  ?absolute:bool ->
  ?path:bool ->
  ?root:string ->
  ?nofollow:bool -> (string -> unit) -> (string -> bool) list -> unit
val lscan :
  ?rev:bool ->
  ?absolute:bool ->
  ?path:bool ->
  ?root:string list ->
  ?nofollow:bool ->

```

```

    (string list -> unit) -> (string -> bool) list -> unit
val list :
  ?absolute:bool ->
  ?path:bool ->
  ?root:string ->
  ?nofollow:bool -> ?sort:bool -> (string -> bool) list -> string list
val llist :
  ?rev:bool ->
  ?absolute:bool ->
  ?path:bool ->
  ?root:string list ->
  ?nofollow:bool ->
  ?sort:bool -> (string -> bool) list -> string list list

```

here we want to get ~/.*/*.conf file X.list (predicates corresponding to each layer .

```

let xs = let module X = Mikmatch.Glob in X.list ~root:"/Users/bob" [FILTER "." ; FILTER _* ".conf" eos ] ;;
val xs : string list = [".libfetiion/libfetiion.conf"]

```

```

let xs =
  let module X = Mikmatch.Glob in
    X.list ~root:"/Users/bob" [const true; FILTER _* ".pdf" eos ]
  in print_int (List.length xs) ;;

```

455

(e) Lazy or Greedy

```

match "acbde (result), blabla... " with
RE _* "(" (_* as x) ")" -> print_endline x | _ -> print_endline "Failed";;

result

match "acbde (result),(bla)bla... " with
RE _* Lazy "(" (_* as x) ")" -> print_endline x | _ -> print_endline "Failed";;

result),(bla

```

```
let / "a"? ("b" | "abc" ) as x / = "abc" ;; (* or patterns, the same as before*)
val x : string = "ab"
# let / "a"? Lazy ("b" | "abc" ) as x / = "abc" ;;
val x : string = "abc"
```

In place conversions of the substrings can be performed, using either the predefined converters *int*, *float*, or custom converters

```
let z = match "123/456" with RE (digit+ as x : int ) "/" (digit+ as y : int) -> x ,y ;;
val z : int * int = (123, 456)
```

Mixed pattern

```
let z = match 123,45, "6789" with i,_, (RE digit+ as j : int) | j,i,_ -> i * j + 1;;
val z : int = 835048
```

(f) Backreferences

Previously matched substrings can be matched again using backreferences.

```
let z = match "abcbabc" with RE _* as x !x -> x ;;
val z : string = "abc"
```

(g) Possessiveness prevent backtracking

```
let x = match "abc" with RE _* Possessive _ -> true | _ -> false;;
val x : bool = false
```

(h) macros

i. FILTER macro

```
let f = FILTER int eos;;
val f : ?share:bool -> ?pos:int -> string -> bool = <fun>
# f "32";;
- : bool = true
# f "32a";;
- : bool = false
```

ii. REPLACE macro

```
let remove_comments = REPLACE "#" _* Lazy eol -> "" ;;
val remove_comments : ?pos:int -> string -> string = <fun>
# remove_comments "Hello #comment \n world #another comment" ;;
```

```
- : string = "Hello \n world "
let x = (REPLACE "," -> ";;" ) "a,b,c";;
val x : string = "a;;b;;c"
```

iii. REPLACE__FIRST macro

iv. SEARCH(__FIRST) COLLECT COLLECTOBJ MACRO

```
let search_float = SEARCH_FIRST float as x : float -> x ;;
val search_float : ?share:bool -> ?pos:int -> string -> float = <fun>
search_float "bla bla -1.234e12 bla";;
- : float = -1.234e+12
let get_numbers = COLLECT float as x : float -> x ;;
val get_numbers : ?pos:int -> string -> float list = <fun>
get_numbers "1.2 83 nan -inf 5e-10";;
- : float list = [1.2; 83.; nan; neg_infinity; 5e-10]
let read_file = Mikmatch.Text.map_lines_of_file (COLLECT float as x : float -> x );;
val read_file : string -> float list list = <fun>

(** Negative assertions *)
let get_only_numbers = COLLECT < Not alnum . > (float as x : float) < . Not alnum > -> x

let list_words = COLLECT (upper | lower)+ as x -> x ;;
val list_words : ?pos:int -> string -> string list = <fun>
# list_words "gshogh sghos sgho ";;
- : string list = ["gshogh"; "sghos"; "sgho"]
RE pair = "(" space* (digit+ as x : int) space* "," space* ( digit + as y : int ) space* ")";;
# let get_objlist = COLLECTOBJ pair;;
val get_objlist : ?pos:int -> string -> < x : int; y : int > list =
```

v. SPLIT macro

```
let ys = (SPLIT space* [",;"] space* ) "a,b,c, d, zz";;
val ys : string list = ["a"; "b"; "c"; "d"; "zz"]
let f = SPLIT space* [",;"] space* ;;
val f : ?full:bool -> ?pos:int -> string -> string list = <fun>
```

Full is false by default. When true, it considers the regexp as a separator between substrings even if the first or the last one is empty. will add some whitespace trailins

```
f ~full:true "a,b,c,d;" ;;
- : string list = ["a"; "b"; "c"; "d"; ""]
```

vi. MAP macro (a weak lexer) (MAP regexp -> expr)

splits the given string into fragments: the fragments that do not match

the pattern are returned as *Text* *s*. Fragments that match the pattern are replaced by the result of *expr*

```
let f = MAP ( "+" as x = 'Plus ) -> x ;;
val f : ?pos:int -> ?full:bool -> string -> [> 'Plus | 'Text of string ] list =
let x = (MAP ', ' -> 'Sep ) "a,b,c";;
val x : [> 'Sep | 'Text of string ] list = ['Text "a"; 'Sep; 'Text "b"; 'Sep; 'Text "c"]
```

```
let f = MAP ( "+" as x = 'Plus ) | ("-" as x = 'Minus) | ("/" as x = '
| ("*" as x = 'Mul) | (digit+ as x := fun s -> 'Int (int_of_string s
| (alpha [alpha digit] + as x := fun s -> 'Ident s) -> x ;;
```

```
val f :
  ?pos:int ->
  ?full:bool ->
  string ->
  [> 'Div
    | 'Ident of string
    | 'Int of int
    | 'Minus
    | 'Mul
    | 'Plus
    | 'Text of string ]
list = <fun>
# f "+-*/";;
- : [> 'Div
    | 'Ident of string
    | 'Int of int
    | 'Minus
    | 'Mul
    | 'Plus
    | 'Text of string ]
list
=
```

```

[‘Text ""; ‘Plus; ‘Text ""; ‘Minus; ‘Text ""; ‘Mul; ‘Text ""; ‘Div; ‘T
let xs = Mikmatch.Text.map (function ‘Text (RE space* eos) -> raise Mi
val xs :
  [> ‘Div
    | ‘Ident of string
    | ‘Int of int
    | ‘Minus
    | ‘Mul
    | ‘Plus
    | ‘Text of string ]
list = [‘Plus; ‘Minus; ‘Mul; ‘Div]

```

vii. lexer (ulex is faster and more elegant)

```

let get_tokens = f |- Mikmatch.Text.map (function ‘Text (RE space* eos
-> raise Mikmatch.Text.Skip | ‘Text x -> invalid_arg x | x
-> x) ;;

```

```

val get_tokens :
  string ->
  [> ‘Div
    | ‘Ident of string
    | ‘Int of int
    | ‘Minus
    | ‘Mul
    | ‘Plus
    | ‘Text of string ]
list = <fun>

```

```

get_tokens "a1+b3/45";;

```

```

- : [> ‘Div
    | ‘Ident of string
    | ‘Int of int

```



```

| 'Minus
| 'Mul
| 'Plus
| 'Text of string ]

list
= ['Ident "a1"; 'Plus; 'Ident "b3"; 'Div; 'Int 45]

```

viii. SEARCH macro (location)

```

let locate_arrows = SEARCH %pos1 "->" %pos2 -> Printf.printf "(%i-%i)" pos1 (pos2-1);;
val locate_arrows : ?pos:int -> string -> unit = <fun>
# locate_arrows "gshogho->ghso";;
(7-8)- : unit = ()
let locate_tags = SEARCH "<" "/"? %tag_start (* Lazy as tag_contents) %tag_end ">" -> Printf.printf "

```

(i) debug

```

let src = RE_PCRE <Not alnum . > (float as x : float ) < . Not alnum > in print_endline (fst src);;
(?<![0-9A-Za-z])([+\-]?(?:?:[0-9]+(?:\.[0-9]*)?|\.[0-9]+)(?:[Ee][+\-]?[0-9]+)?(?:?:[Nn][Aa][Nn]|[Ii][Nn][Ff]

```

(j) ignore the case

```

match "OCaml" with RE "0" "caml"~ -> print_endline "success";;
success

```

(k) zero-width assertions

```

RE word = < Not alpha . > alpha+ < . Not alpha>
RE word' = < Not alpha . > alpha+ < Not alpha >

RE triplet = <alpha{3} as x>
let print_triplets_of_letters = SEARCH triplet -> print_endline x
print_triplets_of_letters "helhgoshogho";;

hel
elh
lhg
hgo
gos
osh

```

```

sho
hog
ogh
gho
- : unit = ()

(SEARCH alpha{3} as x -> print_endline x ) "hello world";;

hel
wor

(SEARCH <alpha{3} as x> -> print_endline x ) "hello world";;

hel
ell
llo
wor
orl
rld

(SEARCH alpha{3} as x -> print_endline x ) ~pos:2 "hello world";;

llo
wor

```

(l) dynamic regexp

```

let get_fild x = SEARCH_FIRST @x "=" (alnum* as y) -> y;;
val get_fild : string -> ?share:bool -> ?pos:int -> string -> string = <fun>
# get_fild "age" "age=29 ghos";;
- : string = "29"

```

(m) reuse

using macro INCLUDE

(n) view patterns

```

let view XY = fun obj -> try Some (obj#x, obj#y) with _ -> None ;;
val view_XY : < x : 'a; y : 'b; .. > -> ('a * 'b) option = <fun>
# let test_orign = function

```

```

    %XY (0,0) :: _ -> true
  | _ -> false
;;

    val test_orign : < x : int; y : int; .. > list -> bool = <fun>

let view Positive = fun x -> x > 0
let view Negative = fun x -> x <= 0

let test_positive_coords = function
  %XY ( %Positive, %Positive ) -> true
  | _ -> false

    (** lazy pattern is already supported in OCaml *)
let test x = match x with
  lazy v -> v

type 'a lazy_list = Empty | Cons of ('a * 'a lazy_list lazy_t)

let f = fun (Cons ( _ , lazy (Cons ( _ , lazy (Empty)) ) )) -> true ;;
let f = fun %Cons (x1, %Cons (x2 %Empty)) -> true (* simpler *)

```

implementation let view X = f is translated into: let view_X = f

Similarly, we have local views: let view X = f in ...

Given the nature of camlp4, this is the simplest solution that allows us to make views available to other modules, since they are just functions, with a standard name. When a view X is encountered in a pattern, it uses the view_X function. The compiler will complain if doesn't have the right type, but not the preprocessor.

About inline views: since views are simple functions, we could insert functions directly in patterns. I believe it would make the pattern really difficult

to read, especially since views are expected to be most useful in already complex patterns.

About completeness checking: our definition of views doesn't allow the compiler to warn against incomplete or redundant pattern-matching. We have the same situation with regexps. What we define here are incomplete or overlapping views, which have a broader spectrum of applications than views which are defined as sum types.

(o) tiny use

```

se (FILTER _* "map_lines_of_file" ) "Mikmatch";;
val map_lines_of_file : (string -> 'a) -> string -> 'a list

```

```

let _ = Mikmatch.map_lines_of_file
  (function x ->
    match x with
    | RE "\xbegin{bluecode}" -> "\n" ^ x
    | RE "\xend{bluecode}" -> x ^ '\n'
    | _ -> x )
  "/Users/bob/SourceCode/Notes/ocaml-hacker.tex"
|> List.enum
|> File.write_lines "/Users/bob/SourceCode/Notes/ocaml-hacker-back-up.tex"

```

5.3 pcre

pcre is more flexible and dynamic compared with using mikmatch, but more verbose however.

1. Backreferences

```

Pcre.(Pmatch ~flags: [] ~pat:"('\\w)(\\s*)->(\\s*)\\1" " 'a -> 'a"));;

bool = true

```

5.4 objsize

5.5 pa-do

- delimited overloading

5.6 caml-inspect

It's mainly used to debug programs or presentation. [blog](#)

1. usage

```
#require "inspect";;  
open Inspect ;;  
  
Sexpr.(dump (test_data ()))  
Sexpr.(dump dump) (** can dump any value, including closure *)  
Dot.(dump_osx dump_osx)
```

2. *module Dot*

```
dump  
dump_to_file  
dump_with_formatter  
dump_osx
```

3. *module Sexpr*

```
dump  
dump_to_file  
dump_with_formatter
```

4. principle

OCaml values all share a *common low-level* representation. The basic building block that is used by the runtime-system (which is written in the C programming

language) to represent any value in the OCaml universe is the value type. Values are always *word-sized*. A word is either 32 or 64 bits wide(*Sys.word_size*)

A value can either be a pointer to a block of values in the OCaml heap, a pointer to an object outside of the heap, or an unboxed integer. Naturally, blocks in the heap are garbage-collected.

To distinguish between unboxed integers and pointers, the system uses the least-significant bit of the value as a flag. If the LSB is set, the value is unboxed. If the LSB is cleared, the value is a pointer to some other region of memory. This encoding also explains why the `int` type in OCaml is only 31 bits wide (63 bits wide on 64 bit platforms).

Since blocks in the heap are garbage-collected, they have strict structure constraints. Information like the tag of a block and its size(in words) is encoded in the header of each block.

There are two categories of blocks with respect to the garbage collector:

(a) Structured blocks

May only contain well-formed values, as they are recursively traversed by the garbage collector.

(b) Raw blocks

are not scanned by the garbage collector, and can thus contain arbitrary values.

Structured blocks have tag values lower than *Obj.no_scan_tag*, while raw blocks have tags equal or greater than *Obj.no_scan_tag*.

The type of a block is its tag, which is stored in the block header.(*Obj.tag*)

```
Obj.([let f ()= repr |- tag in no_scan_tag, f () 0, f () [|1.;2.|], f
() (1,2) ,f () [|1,2|]);;
```

```
- : int * int * int * int * int = (251, 1000, 254, 0, 0)
```

```
se_str "_tag" "Obj";;
```

```

external tag : t -> int = "caml_obj_tag"
external set_tag : t -> int -> unit = "caml_obj_set_tag"
val lazy_tag : int
val closure_tag : int
val object_tag : int
val infix_tag : int
val forward_tag : int
val no_scan_tag : int
val abstract_tag : int
val string_tag : int
val double_tag : int
val double_array_tag : int
val custom_tag : int
val final_tag : int
val int_tag : int
val out_of_heap_tag : int
val unaligned_tag : int

```

- (a) *0 to Obj.no_scan_tag-1* A structured block (an array of Caml objects). Each field is a value.
- (b) *Obj.closure_tag*: A closure representing a functional value. The first word is a pointer to a piece of code, the remaining words are values containing the environment.
- (c) *Obj.string_tag*: A character string.
- (d) *Obj.double_tag*: A double-precision floating-point number.
- (e) *Obj.double_array_tag*: An array or record of double-precision floating-point numbers.
- (f) *Obj.abstract_tag*: A block representing an abstract datatype.
- (g) *Obj.custom_tag*: A block representing an abstract datatype with user-defined finalization, comparison, hashing, serialization and deserialization

functions attached

- (h) *Obj.object_tag*: A structured block representing an object. The first field is a value that describes the class of the object. The second field is a unique object id (see *Oo.id*). The rest of the block represents the variables of the object.
- (i) *Obj.lazy_tag*, *Obj.forward_tag*: These two block types are used by the runtime-system to implement lazy-evaluation.
- (j) *Obj.infix_tag*: A special block contained within a closure block

5. representation

For atomic types

- (a) int, char (ascii code) : Unboxed integer values
- (b) float : Blocks with tag *Obj.double_tag*
- (c) string : Blocks with tag *Obj.string_tag*
- (d) int32, int64, nativeint : Blocks with *Obj.custom_tag*

For Tuples and records: Blocks with tag 0

```
Obj.((1,2) |> repr |> tag);;
- : int = 0
```

For normal array(except float array), Blocks with tag 0

For Arrays and records of floats: Block with tag *Obj.double_array_tag*

For concrete types,

- (a) Constant ctor : Represented by unboxed integers(0,1,...).
- (b) Non-Constant ctor: Block with a tag lower than *Obj.no_scan_tag* that encodes the constructor, numbered in order of declaration, starting at 0.

For objects: Blocks with tag *Obj.object_tag*. The first field refers to the class of the object and its associated method suite. The second field contains a unique object ID. The remaining fields are the instance variables of the object.

For polymorphic variants: Variants are similar to constructed terms. There are a few differences

- (a) Variant constructors are identified by their hash value
- (b) Non-constant variant constructors are not flattened. They are always block of size 2, where the first field is the hash. The second field can either contain a single value or a pointer to another structured block(just like a tuple)

5.7 ocamlgraph

ocamlgraph is a sex library which deserve well-documentation.

1. simple usage in the module *Graph.Pack.Digraph*

```
se_str "label" "PDig.V";;

type label = int
val create : label -> t
val label : t -> label
```

Follow this file, you could know how to build a graph, A nice trick, to bind open command to use graphviz to open the file, then it will do the sync automatically and you can `#u "open *.dot"`, so nice

```
module PDig = Graph.Pack.Digraph
let g = PDig.Rand.graph ~v:10 ~e:20 ()
(* get dot output file *)
let _ = PDig.dot_output g "g.dot"
(* use gnu/gv to show *)
let show_g = PDig.display_with_gv;;
```

```

let g_closure = PDig.transitive_closure ~reflexive:true g
(** get a transitive closure *)
let _ = PDig.dot_output g_closure "g_closure.dot"

let g_mirror = PDig.mirror g
let _ = PDig.dot_output g_mirror "g_mirror.dot"

let g1 = PDig.create ()
let g2 = PDig.create ()

let [v1;v2;v3;v4;v5;v6;v7 ] = List.map PDig.V.create [1;2;3;4;5;6;7]

let _ = PDig.(
  begin
    add_edge g1 v1 v2;
    add_edge g1 v2 v1;
    add_edge g1 v1 v3;
    add_edge g1 v2 v3;
    add_edge g1 v5 v3;
    add_edge g1 v6 v6;
    add_vertex g1 v4
  end
)

let _ = PDig.(
  begin
    add_edge g2 v1 v2;
    add_edge g2 v2 v3;
    add_edge g2 v1 v4;
    add_edge g2 v3 v6;
    add_vertex g2 v7
  end
)

```

```

end
)

let g_intersect = PDig.intersect g1 g2
let g_union = PDig.union g1 g2

let _ =
  PDig.(
    let f = dot_output in begin
      f g1 "g1.dot";
      f g2 "g2.dot";
      f g_intersect "g_intersect.dot";
      f g_union "g_union.dot"
    end
  )

module PDig = Graph.Pack.Digraph
sub_modules "PDig";;

  module V :
  module E :
  module Mark :
  module Dfs :
  module Bfs :
  module Marking : sig val dfs : t -> unit val has_cycle : t -> bool end
  module Classic :
  module Rand :
  module Components :
  module PathCheck :
  module Topological :

```

Different modules have corresponding algorithms

2. hierachical

```
sub_modules "Graph" (** output too big *)
```

idea. can we draw a tree graph for this??

Graph.Pack requires its label being integer

```
sub_modules "Graph.Pack"
```

```

module Digraph :
  module V :
  module E :
  module Mark :
  module Dfs :
  module Bfs :
  module Marking :
  module Classic :
  module Rand :
  module Components :
  module PathCheck :
  module Topological :
module Graph :
  module V :
  module E :
  module Mark :
  module Dfs :
  module Bfs :
  module Marking :
  module Classic :
  module Rand :
  module Components :
  module PathCheck :
  module Topological :
```

3. hierachical for undirected graph

```

Graph.Pack.(Di)Graph
Undirected imperative graphs with edges and vertices labeled with integer.
Graph.Imperative.Matrix.(Di)Graph
Imperative Undirected Graphs implemented with adjacency matrices, of course integer(Matrix)

Graph.Imperative.(Di)Graph
Imperative Undirected Graphs.
Graph.Persistent.(Di)Graph
Persistent Undirected Graphs.

```

Here we have functor *Graph.Imperative.Graph.Concrete*, *Graph.Imperative.Graph.Abstract*, *Graph.Imperative.Graph.ConcreteLabeled*, *Graph.Imperative.Graph.AbstractLabeled* we see that

```

module Abstract:
functor (V : Sig.ANY_TYPE) -> Sig.IM with type V.label = V.t
and type E.label = unit

module AbstractLabeled:
functor (V : Sig.ANY_TYPE) ->
functor (E : Sig.ORDERED_TYPE_DFT) -> Sig.IM with type V.label
= V.t and type E.label = E.t

module Concrete:
functor (V : Sig.COMPARABLE) -> Sig.I with type V.t = V.t and
type V.label = V.t and type E.t = V.t * V.t
and type E.label = unit

module ConcreteBidirectional:
functor (V : Sig.COMPARABLE) -> Sig.I with type V.t = V.t and
type V.label = V.t and type E.t = V.t * V.t
and type E.label = unit

module ConcreteBidirectionalLabeled:
functor (V : Sig.COMPARABLE) ->
functor (E : Sig.ORDERED_TYPE_DFT) -> Sig.I with type V.t = V.t
and type V.label = V.t
and type E.t = V.t * E.t * V.t and type E.label = E.t

module ConcreteLabeled:
functor (V : Sig.COMPARABLE) ->

```

```

functor (E : Sig.ORDERED_TYPE_DFT) -> Sig.I with type V.t = V.t
  and type V.label = V.t
  and type E.t = V.t * E.t * V.t and type E.label = E.t

```

so, as soon as you want to label your vertices with strings and your edges with floats, you should use functor. Take ConcreteLabeled as an example

```

module V = struct
  type t = string
  let compare = Pervasives.compare
  let hash = Hashtbl.hash
  let equal = (=)
end
module E = struct
  type t = float
  let compare = Pervasives.compare
  let default = 0.0
end
module X = Graph.Imperative.Graph.ConcreteLabeled (V) (E);;
module Y = Graph.Imperative.Digraph.ConcreteLabeled (V) (E);;

(**
  val add_edge : t -> vertex -> vertex -> unit
  val add_edge_e : t -> edge -> unit
  val remove_edge : t -> vertex -> vertex -> unit
  val remove_edge_e : t -> edge -> unit

  Not only that, but the V and E structure will work for
  persistent and directed graphs that are concretelabeled,
  and you can switch by replacing Imperative with Persistent
  , and Graph with Digraph.
*)

module W = struct
  type label = float
  type t = float
  let weight x = x (* edge label -> weight *)
  let compare = Pervasives.compare
  let add = (+.)
  let zero = 0.0
end

module Dijkstra = Graph.Path.Dijkstra (X) (W);;

```

4. another example (edge unlabeled, directed graph)

```

open Graph
module V = struct
  type t = string
  let compare = Pervasives.compare
  let hash = Hashtbl.hash
  let equal = (=)
end
module G = Imperative.Digraph.Concrete (V)
let g = G.create ()
let _ = G.(begin
  add_edge g "a" "b";
  add_edge g "a" "c";
  add_edge g "b" "d";
  add_edge g "b" "d"
end )
module Display = struct
  include G
  let vertex_name v = (V.label v)
  let graph_attributes _ = []
  let default_vertex_attributes _ = []
  let vertex_attributes _ = []
  let default_edge_attributes _ = []
  let edge_attributes _ = []
  let get_subgraph _ = None
end
module Dot_ = Graphviz.Dot(Display)
let _ =
  let out = open_out "g.dot" in
  finally (fun _ -> close_out out) (fun g ->
    let fmt =
      (out |> Format.formatter_of_output) in

```

```
Dot_.fprintf_graph fmt g ) g
```

It seems that Graphviz.Dot is used to display directed graph, Graphviz.Neato is used to display undirected graph.

here is a useful example to visualize the output generated by ocamldep.

```
open Batteries_uni
open Graph
module V = struct
  type t = string
  let compare = Pervasives.compare
  let hash = Hashtbl.hash
  let equal = (=)
end
module StringDigraph = Imperative.Digraph.Concrete (V)
module Display = struct
  include StringDigraph
  open StringDigraph
  let vertex_name v = (V.label v)
  let graph_attributes _ = []
  let default_vertex_attributes _ = []
  let vertex_attributes _ = []
  let default_edge_attributes _ = []
  let edge_attributes _ = []
  let get_subgraph _ = None
end

module DisplayG = Graphviz.Dot(Display)

let dot_output g file =
  let out = open_out file in
```



```

finally (fun _ -> close_out out) (fun g ->
  let fmt =
    (out |> Format.formatter_of_output) in
  DisplayG.fprint_graph fmt g ) g

let g_of_edges edges = StringDigraph.(
  let g = create () in
  let _ = Stream.iter (fun (a,b) -> add_edge g a b) edges in
  g
)

let line = "path.ml: Hashtbl Heap List Queue Sig Util"

let edges_of_line line =
  try
    let (a::b::res) =
      Pcre.split ~pat:".ml:" ~max:3 line in
    let v_a =
      let _ = a.[0]<- Char.uppercase a.[0] in
      a in
    let v_bs =
      (Pcre.split ~pat:"\\s+" b ) |> List.filter (fun x -> x <> "") in
    let edges = List.map (fun v_b -> v_b, v_a ) v_bs in
    edges
  with exn -> invalid_arg ("edges_of_line : " ^ line)

let lines_stream_of_channel chan = Stream.from (fun _ ->
  try Some (input_line chan) with End_of_file -> None );;

let edges_of_channel chan = Stream.(

```

```

    let lines = lines_stream_of_channel chan in
    let edges = lines |> map (edges_of_line |- of_list) |> concat in
    edges
  )

```

```

let graph_of_channel = edges_of_channel |- g_of_edges

```

```

let _ =
  let stdin = open_in Sys.argv.(1) in
  let g = graph_of_channel stdin in begin
    Printf.printf "writing to dump.dot\n";
    dot_output g "dump.dot";
    Printf.printf "finished\n"
  end

```

5.8 Modules

- BatEnum

- utilities

```

range ~until:20 3
filter, concat, map, filter_map
(--), (--^) (|>) (@/) (/@)
No_more_elements (*interface for dev to raise (in Enum.make next)*)
icons, lcons, cons

```

- don't play effects with enum

- idea??? how about divide enum to two; one is just for iterator the other is for lazy evaluation. (iterator is lazy???)

- Set (*one comparison, one container*)

```

Set.IntSet
Set.CharSet
Set.RopeSet
Set.NumStringSet

```

for polymorphic set

```

split
union
empty
add

```

why polymorphic set is dangerous? Because in Haskell, $Eq\ a \Rightarrow$ is implicitly you want to make your comparison method is unique, otherwise you union two sets, how to make sure they use the same comparison, here we use abstraction types, one comparison, one container we can not override polymorphic = behavior, polymorphic = is pretty bad practice for complex data structure, mostly not you want, so write compare by yourself

As follows, compare is the right semantics.

```

# Set.IntSet.(compare (of_enum (1--5)) (of_enum (List.enum [5;3;4;2;1])));;
- : int = 0
# Set.IntSet.(of_enum (1--5) = of_enum (List.enum [5;3;4;2;1]));;
- : bool = false

```

- caveat

- module syntax

```

module Enum = struct
  include Enum include Labels include Exceptionless
end

```

floating nested modules up (Enum.include, etc) include Enum, will expose all Enum have to the following context, so Enum.Labels is as Labels, so

you can now include Labels, but *Labels.v* will override *Enum.v*, maybe you want it, and *module Enum* still has *Enum.Labels.v*, we just duplicated the nested module into toplevel

5.9 pa-monad

1. debug
tags file

```
"monad_test.ml" : pp(camlp4o -parser pa_monad.cmo)
camlp4o -parser pa_monad.cmo monad_test.ml -printer o

(** filter *)

let a = perform let b = 3 in b
let bind x f = f x
let c = perform c <-- 3 ; c
(* output
let a = let b = 3 in b
let bind x f = f x
let c = bind 3 (fun c -> c)
*)

let bind x f = List.concat (List.map f x)
let return x = [x]
let bind2 x f = List.concat (List.map f x)

let c = perform
  x <-- [1;2;3;4];
  y <-- [3;4;4;5];
  return (x+y)

let d = perform with bind2 in
  x <-- [1;2;3;4];
  y <-- [3;4;4;5];
  return (x+y)

let _ = List.iter print_int c
let _ = List.iter print_int d

(*
```

```

let bind x f = List.concat (List.map f x)
let return x = [ x ]
let bind2 x f = List.concat (List.map f x)
let c =
  bind [ 1; 2; 3; 4 ]
    (fun x -> bind [ 3; 4; 4; 5 ] (fun y -> return (x + y)))
let d =
  bind2 [ 1; 2; 3; 4 ]
    (fun x -> bind2 [ 3; 4; 4; 5 ] (fun y -> return (x + y)))
let _ = List.iter print_int c
let _ = List.iter print_int d
*)

```

2. translation rule

it's simple. **perform** or **perform with bind in** then it will translate all phrases ending with `;; x <- me;` will be translated into `me »= (fun x ->); me;` will be translated into `me »= (fun _ -> ...)` you should refer `pa_monad.ml` for more details *perform with exp1 and exp2 in exp3* uses the first given expression as bind and the second as match-failure function. *perform with module Mod in exp* use the function named bind from module Mod. In addition uses the module's failwith in refutable patterns

```

let a = perform with (flip Option.bind) in a <-- Some 3; b<-- Some 32; Some (a+ b) ;;
val a : int option = Some 35

```

it will be translated into

```

let a =
  flip Option.bind (Some 3)
    (fun a -> flip Option.bind (Some 32) (fun b -> Some (a + b))
    )

```

3. ParameterizedMonad

```

class ParameterizedMonad m where
  return :: a -> m s s a

```

```
(>>=) :: m s1 s2 t -> (t -> m s2 s3 a) -> m s1 s3 a
```

```
data Writer cat s1 s2 a = Writer {runWriter :: (a, cat s1 s2)}
```

```
instance (Category cat) => ParameterizedMonad (Writer cat) where
  return a = Writer (a,id)
  m >>= k = Writer $ let
    (a,w) = runWriter
    (b,w') = runWriter (k a)
  in (b, w' . w)
```

```
module State : sig
  type ('a,'s) t = 's -> ('a * 's)
  val return : 'a -> ('a,'s) t
  val bind : ('a,'s) t -> ('a -> ('b,'s) t) -> ('b,'s) t
  val put : 's -> (unit,'s) t
  val get : ('s,'s) t
end = struct
  type ('a,'s) t = ('s -> ('a * 's))
  let return v = fun s -> (v,s)
  let bind (v : ('a,'s) t) (f : 'a -> ('b,'s) t) : ('b,'s) t =
    fun s ->
      let a,s' = v s in
      let a',s'' = f a s' in
      (a',s'')
  let put s = fun _ -> (), s
  let get = fun s -> s,s
end

module PState : sig
  type ('a, 'b, 'c) t = 'b -> 'a * 'c
  val return : 'a -> ('a,'b,'b) t
  val bind : ('b,'a,'c) t -> ('b -> ('d,'c, 'e) t) -> ('d,'a,'e)
    t
  val put : 's -> (unit,'b,'s) t
  val get : ('s,'s,'s) t
end = struct
  type ('a,'s1,'s2) t = 's1 -> ('a * 's2)
  let return v = fun s -> (v,s)
  let bind v f = fun s ->
```

```

    let a,s' = v s in
    let a',s'' = f a s' in
    (a',s'')
  let put s = fun _ -> (), s
  let get = fun s -> s,s
end

```

```

let v = State.([perform x <-- return 1 ; y <-- return 2 ; let _ =
print_int (x+y) in return (x+y) ));

```

```

val v : (int, '_a) State.t = <fun>

```

```

let v = State.([perform x <-- return 1 ; y <-- return 2 ; z <-- get ; put (x+
z<-- get ; let _ = print_int z in return (x+y+z))));

```

```

val v : (int, int) State.t = <fun>

```

```

v 3;;
6- : int * int = (9, 6)

```

```

let v = PState.([perform x <-- return 1 ; y <-- return 2 ; z <-- get ; put (x
z<-- get ; let _ = print_int z in return (x+y+z))));

```

```

val v : (int, int, int) PState.t = <fun>

```

```

v 3 ;;
6- : int * int = (9, 6)

```

```

let v = PState.([perform x <-- return 1 ; y <-- return 2 ; z <-- get ;
put (string_of_int (x+y+z)) ; return z ));

```

```

val v : (int, int, string) PState.t = <fun>

```

```

# v 3;;
v 3;;
- : int * string = (3, "6")

```

5.10 delimited continuations

Continuations A conditional branch selects a continuation from the two possible futures; raising an exception discards. Traditional way to handle continuations explicitly in a program is to transform a program into cps style. Continuation captured by `call/cc` is the **whole** continuation that includes all the future computation.. In practice, most of the continuations that we want to manipulate are only a part of computation. Such continuations are called **delimited continuations** or **partial continuations**.

1. cps transform

there are multiple ways to do cps transform, here are two.

```

-----
[x] --> x
[\x. M] --> \k . k (\x . [M])
[M N] --> \k. [M] (\m . m [N] k)
-----

-----
[x] --> \k . k x
[\x. M] --> \k. k (\x.[M])
[M N] --> \k. [M] (\m . [N] (\n. m n k))
-----

[callcc (\k. body)] = \outk. (\k. [body] outk) (\v localk. outk
v)

```

2. experiment

```

#load "delimcc.cma";;

Delimcc.shift;;

- : 'a Delimcc.prompt -> (('b -> 'a) -> 'a) -> 'b = <fun>

reset (fun () -> M ) --> push_prompt p (fun () -> M )
shift (fun k -> M) --> shift p (fun k -> M )

```


in racket you should have *(require racket/control)* and then *(reset expr ...+)*
(shift id expr ...+)

```
module D = Delimcc
(** set the prompt *)
let p = D.new_prompt ()
let (reset,shift),abort = D.(push_prompt &&& shift &&& abort ) p;;
let foo x = reset (fun () -> shift (fun cont -> if x = 1 then cont 10 else 20
```

```
foo 1 ;;
- : int = 110
foo 2 ;;
- : int = 20
5 * reset (fun () -> shift (fun k -> 2 * 3 ) + 3 * 4 );;
- : int = 30
reset (fun () -> 3 + shift (fun k -> 5 * 2 ) ) - 1 ;;
- : int = 9
```

```
val p : '_a D.prompt = <abstr>
val reset : (unit -> '_a) -> '_a = <fun>
val shift : (('a -> '_b) -> '_b) -> '_a = <fun>
val abort : '_a -> 'b = <fun>
```

```
let p = D.new_prompt ()
let (reset,shift),abort = D.(push_prompt &&& shift &&& abort ) p;;
```

```
reset (fun () -> if (shift (fun k -> k(2 = 3))) then "hello" else "hi ") ^ "world";;
- : string = "hi world"
reset (fun () -> if (shift (fun k -> "laji")) then "hello" else "hi ") ^ "world";;
- : string = "lajiworl"
reset (fun _ -> "hah");;
- : string = "hah"
```

```
let make_operator () =
  let p = D.new_prompt () in
  let (reset,shift),abort = D.(push_prompt &&& shift &&& abort) p in
  p,reset,shift,abort
```

Delimited continuations seems not able to handle answer type polymorphism.

```
exception Str of ['Found of int | 'NotFound]
```

```
let times lst =
  let rec times_aux lst = match lst with
    | [] -> 1
    | 0 :: xs -> shift (fun _ -> 0 )
    | x :: xs -> begin
        (* printf "entering %d\n" x ; *)
        let v = x * times_aux xs in
        (* printf "exiting %d\n" x ; *)
        v
      end in
  reset (fun () -> times_aux lst )
```

Store the continuation, the type system is not friendly to the continuations, but fortunately we have *side effects* at hand, we can store it. (This is pretty hard in Haskell)

```
let p,reset,shift,abort = make_operator() in
  let c = ref None in
  begin
    reset (fun () -> 3 + shift (fun k -> c:= Some k ; 0) - 1) ;
    Option.get (!c) 20
  end ;;

  Characters 81-139:

  reset (fun () -> 3 + shift (fun k -> c:= Some k ; 0) - 1) ;
  ~~~~~

  Warning 10: this expression should have type unit.
```

```
- : int = 22
```

```

let cont =
  let p,reset,shift,abort = make_operator() in
  let c = ref None in
  let rec id lst = match lst with
    | [] -> shift (fun k -> c:=Some k ; [] )
    | x :: xs -> x :: id xs in
  let xs = reset (fun () -> id [1;2;3;4]) in
  xs, Option.get (!c);;

val cont : int list * (int list -> int list) = ([], <fun>)

```

```

# let a,b = cont ;;
val a : int list = []

val b : int list -> int list = <fun>
# b [];;
- : int list = [1; 2; 3; 4]

```

```

type tree = Empty | Node of tree * int * tree
let walk_tree =
  let cont = ref None in
  let p,reset,shift,abort = make_operator() in
  let yield n = shift (fun k -> cont := Some k; print_int n ) in
  let rec walk2 tree = match tree with
    | Empty -> ()
    | Node (l,v,r) ->
      walk2 l ;
      yield v ;
      walk2 r in
  fun tree -> (reset (fun _ -> walk2 tree ), cont);;

val walk_tree : tree_t -> unit * ('_a -> unit) option Batteries.ref =

```

```

# let _, cont = walk_tree tree1 ;;
1val cont : ('_a -> unit) option Batteries.ref = {contents = Some <fun>}

```

```
# Option.get !cont ();;
2- : unit = ()
# Option.get !cont ();;
3- : unit = ()
# Option.get !cont ();;
- : unit = ()
# Option.get !cont ();;
- : unit = ()
```

It's quite straightforward to implement yield using delimited continuation, since each time shifting will escape the control, and you store the continuation, later it can be resumed.

```
(** defer the continuation *)
shift (fun k -> fun () -> k "hello")
```

By wrapping continuations, we can **access the information outside** of the enclosing reset while staying within reset lexically.

suppose this type check

```
let f x = reset (fun () -> shift (fun k -> fun () -> k "hello") ^ "world" ) x
f : unit -> string
```

3. Answer type modification (serious) in the following context, `reset (fun () -> [...] ^ "world")` the value returned by reset appears to be a string. An answer type is a type of the enclosing *reset*.

4. reorder delimited continuations

if we apply a continuation at the tail position, the captured computation is simply resumed. If we apply a continuation at the non-tail position, we can perform additional computation after resumed computation finishes.

Put differently, we can switch the execution order of the surrounding context.

```
let p,reset,shift,abort = make_operator () in
  reset (fun () -> 1 + (shift (fun k -> 2 * k 3 )));;
```

```
- : int = 8

let p,reset,shift,abort = make_operator () in
  let either a b = shift (fun k -> k a ; k b ) in
  reset (fun () ->
    let x = either 0 1 in
    print_int x ; print_newline ());;

0
1
```

5. useful links

[sea side](#)

[shift and reset tutorial](#)

[shift reset tutorial](#)

[racket control operators](#)

[caml-shift-paper.pdf](#)

[caml-shift-talk](#)

Chapter 6

Runtime

1. values

integer-like *int, char, true, false, [], (), and some variants* (batteries dump) *pointer*
(word-aligned, the bottom 2 bits of every pointer always 00, 3 bits 000 for 64-bit)

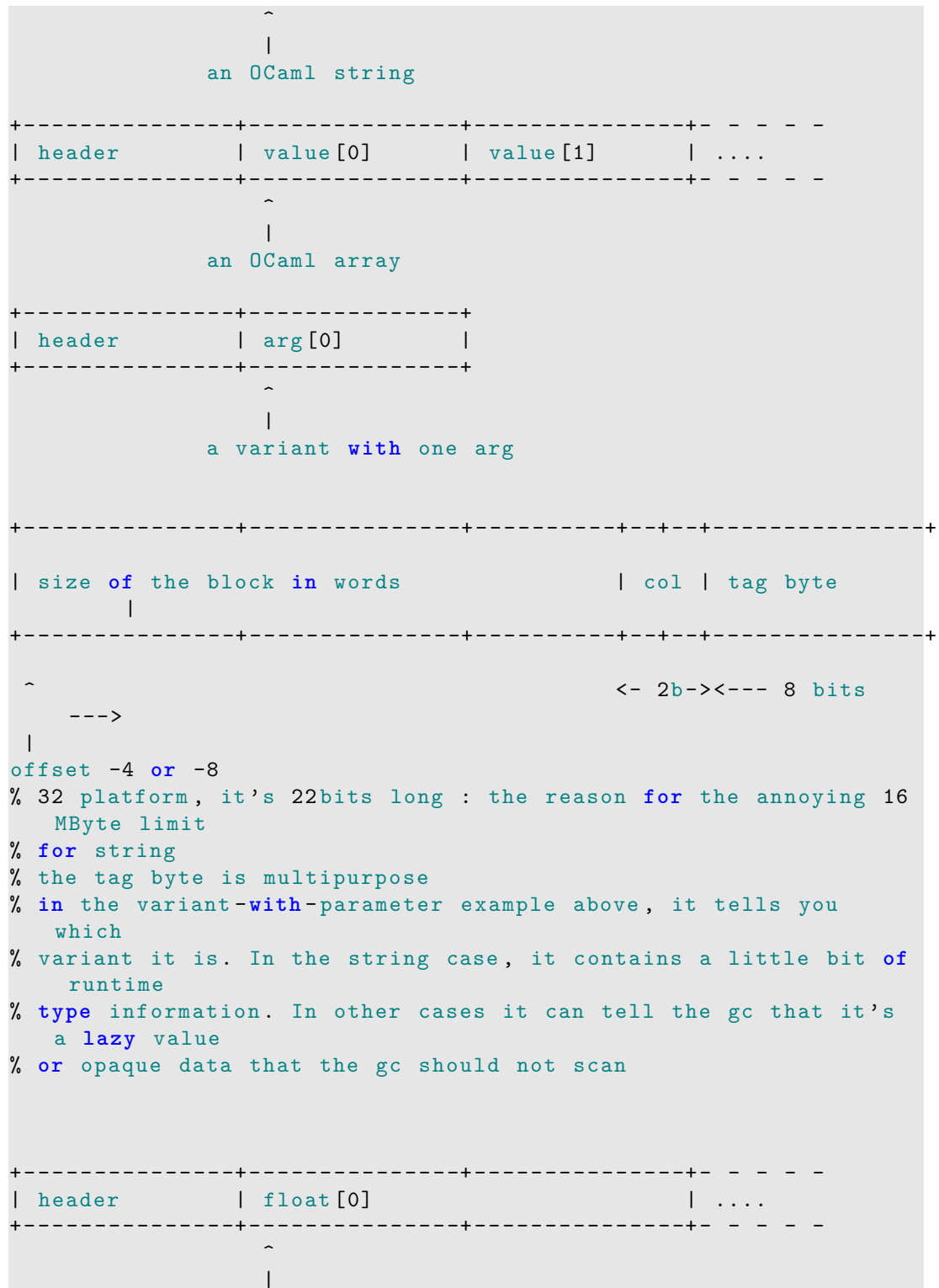
```
% 32 bit
+-----+-----+-----+
| pointer                                     | 0 | 0 |
+-----+-----+-----+

+-----+-----+-----+
| integer (31 or 63 bits)                    | 1 |
+-----+-----+-----+

% why ?
% GC needs this information
% if the algorithm uses arrays of 32/64bit numbers,
% then you can use a Bigarray

+-----+-----+-----+-----+
| header          | word[0]          | word[1]          | ....
+-----+-----+-----+-----+
                        ^
                        |
                    pointer (a value)

+-----+-----+-----+-----+
| header          | 'a' 'b' 'c' 'd' 'e' 'f' '\0' '\1' |
+-----+-----+-----+-----+
```



```
an OCaml float array  
% in the file <byterun/mlvalues.h>
```

any int, char	stored directly as a value, shifted left by 1 bit, with LSB=1
(), [], false	stored as OCaml int 0 (native 1)
true	stored as OCaml int 1
variant type t = Foo Bar Baz (no parameters)	stored as OCaml int 0,1,2
variant type t = Foo Bar of int	the variant with no parameters are stored as OCaml int 0,1,2, etc. counting just the variants that have no parameters. The variants with parameters are stored as blocks, counting just the variants with parameters. The parameters are stored as words in the block itself. Note there is a limit around 240 variants with parameters that applies to each type , but no limit on the number of variants without parameters you can have. this limit arises because of the size of the tag byte and the fact that some of high numbered tags are reserved
list [1;2;3]	This is represented as 1::2::3::[] where [] is a value in OCaml int 0, and h::t is a block with tag 0 and two parameters. This representation is exactly the same as if list was a variant
tuples, struct and array	These are all represented identically, as a simple array of values, the tag is 0. The only difference is that an array can be allocated with variable size, but structs and tuples always have a fixed size.
struct or array where every ele- ments is a float	These are treated as a special case. The tag has special value <code>Dyn_array_tag</code> (254) so that the GC knows how to deal with these. Note this exception does not apply to tuples that contains floats, beware anyone who would declare a vector as (1.0,2.0).
any string	strings are byte arrays in OCaml, but they have quite a clever representation to make it very efficient to get their length, and at the same time make them directly compatible with C strings. The tag is <code>String_tag</code> (252).

here we see the module Obj

```
Obj.("gshogh" |> repr |> tag);;
- : int = 252
```

```
let a = [|1;2;3|] in Obj.(a|>repr|>tag);;
- : int = 0
Obj.(a |> repr |> size);;
- : int = 3
```

string has a clever algorithm

```
Obj.("ghsoghshgoshgoshgoshogh"|> repr |> size);;
- : int = 4 (4*8 = 32 )
"ghsoghshgoshgoshgoshogh" |> String.length;;
24 (padding 8 bits)
```

like all heap blocks, strings contain a header defining the size of the string in machine words.

```
("aaaaaaaaaaaaaaaa"|>String.length);;
- : int = 16
# Obj.("aaaaaaaaaaaaaaaa"|>repr |> size);;
- : int = 3
```

padding will tell you how many words are padded actually

```
number_of_words_in_block * sizeof(word) + last_byte_of_block - 1
```

The null-termination comes handy when passing a string to C, but is not relied upon to compute the length (in Caml), allowing the string to contain nulls.

```
repr : 'a -> t (id)
obj  : t -> 'a (id)
magic : 'a -> 'b (id)

is_block : t -> bool = "caml_obj_is_block"
is_int   : t -> bool = "%obj_is_int"

tag : t -> int = "caml_obj_tag" % get the tag field
```

```
set_tag : t -> int -> unit = "caml_obj_set_tag"

size : t -> int = "%obj_size" % get the size field

field : t -> int -> t = "%obj_field" % handle the array part
set_field : t -> int -> t -> unit = "%obj_set_field"

double_field : t -> int -> float
set_double_field : t -> int -> float -> unit

new_block : int -> int -> t = "caml_obj_block"

dup : t -> t = "caml_obj_dup"

truncate : t -> int -> unit = "caml_obj_truncate"
add_offset : t -> Int32.t -> t = "caml_obj_add_offset"

marshal : t -> string
```

```
Obj.(None |> repr |> is_int);;
- : bool = true
Obj.("ghsogho" |> repr |> is_block);;
- : bool = true
Obj.(let f x = x |> repr |> is_block in (f Bar, f (Baz 3)));;
- : bool * bool = (false, true)
```

Chapter 7

GC

1. heap

Most OCaml blocks are created in the minor(young) heap.

- (a) minor heap (*32K words for 32 bit, 64K for 64 bit by default*) in my mac, i use “`ledit ocaml -init x`” to avoid loading startup scripts, then

```
Gc.stat ()
```

```
{Gc.minor_words = 104194.; Gc.promoted_words = 0.; Gc.major_words = 43979.
  Gc.minor_collections = 0; Gc.major_collections = 0; Gc.heap_words = 12697
  Gc.heap_chunks = 1; Gc.live_words = 43979; Gc.live_blocks = 8446;
  Gc.free_words = 82997; Gc.free_blocks = 1; Gc.largest_free = 82997;
  Gc.fragments = 0; Gc.compactions = 0; Gc.top_heap_words = 126976;
  Gc.stack_size = 52}
```

```
78188 lsr 16 ;;
- : int = 1
```

The diagram illustrates the layout of the OCaml heap. It is divided into two main sections: an 'unallocated' section on the left and an 'allocated part' on the right, separated by a dashed line. The 'unallocated' section is bounded by a caret (^) at the top and a vertical line labeled 'caml_young_limit' at the bottom. The 'allocated part' is bounded by a caret (^) at the top and a vertical line labeled 'caml_young_ptr' at the bottom. Below 'caml_young_ptr', a dashed arrow points left with the text 'allocation proceeds', indicating that memory allocation grows downwards from the current pointer position.

~	~	
		Tags in the range 0..245 are used for variants
~	~	
245		
+-----+		
246		Lazy (before being forced)
+-----+		
247		Closure
+-----+		
248		Object
+-----+		
		contains
249		Used to implement closures
		which the
+-----+		
		scan
250		Used to implement lazy values
+-----+		
251		Abstract data
+-----+		
		contains
252		String
		data
+-----+		
		must
253		Double
+-----+		
254		Array of doubles
+-----+		
255		Custom block
+-----+		

so, in the normal course of events, a small, long-lived object will start on the minor heap and be copied into the major heap. **Large objects go straight to the major heap** But there is another important structure used in the major heap, called the **page table**. The garbage collector must at all times know which pieces of memory belong to the major heap, and which pieces of memory do not, and it uses the page table to track this. One reason **why we always want to know where the major heap lies** is so we can avoid scanning pointers which point to C structs outside the OCaml heap. The GC will not stray beyond its own heap, and treats all pointers outside as opaque (it doesn't touch them or follow them). In

OCaml 3.10 the page table was implemented as a simple bitmap, with 1 bit per page of virtual memory (major heap chunks are always page-aligned). This was unsustainable for 64 bit address spaces where memory allocations can be very very **far apart**, so in OCaml 3.11 this was changed to a sparse hash table. Because of the page table, C pointers can be stored directly as values, which saves time and space. (However, if your C pointer later gets freed, you must NULL the value-the reason is that the same memory address might later get malloced for the OCaml major heap, thus *suddenly* becoming a *valid* address again. THIS usually results in crash). In a functional language **which does not allow any mutable references**, there's one guarantee you can make which is there could **never be a pointer going from the major heap to something in the minor heap**, so when an object in an immutable language graduates from the minor heap to the major heap, it is fixed forever(until it becomes unreachable), and can not point back to the minor heap. But ocaml is impure, so if the minor heap collection worked exactly as previous, then the outcome wouldn't be good, maybe some object is not pointed at **by any local root**, so it would be *unreachable* and would *disappear*, leaving a **dangling pointer**. **one solution would be to check the major heap, but that would be massively time-consuming: minor-collections are supposed to be very quick** What OCaml does instead is to have a separate *refs* list. This contains a list of pointers that point **from the major heap to the minor heap**. During a minor heap collection, the refs list is consulted for additional roots(and after the minor heap collection, the refs list can be started anew).

The refs list however has to be updated, and it gets **updated potentially every time we modify a mutable field in a struct**. The code calls the c function **caml_modify** which both mutates the struct and decides whether this is a major→minor pointer to be added to the refs list.

If you use mutable fields then this is **much slower** than a simple assignment. However, **mutable integers** are ok, and don't trigger the extra

call. You can also **mutate fields** yourself, eg. from c functions or using Obj, **provided you can guarantee that this won't generate a pointer between the major and minor heaps.**

The OCaml gc does not collect the major heap in one go. It spreads the work over small **slices**, and splices are grouped into whole *phases* of work. A *slice* is just a defined amount of work.

The phases are mark and sweep, and some additional sub-passes dealing with weak pointers and finalization.

Finally there is *a compaction phase* which is triggered when there is no other work to do and the estimate of free space in the heap has reached some threshold. This is tunable. You can schedule when to compact the heap – while waiting for a key-press or between frames in a live simulation. There is also a penalty for doing a slice of the major heap – for example if the minor heap is exhausted, then some activity in the major heap is unavoidable. However if you make the **minor heap large enough**, you can completely control when GC work is done. You can also move *large structures out of the major heap entirely*,

2. module Gc

```
Gc.compact () ;;
let checkpoint p = Gc.compact () ; prerr_endline ("checkpoint_at
              _position_" ^ p )
```

The checkpoint function does two things: *Gc.compact ()* does a full major round of garbage collection and compacts the heap. This is the most aggressive form of Gc available, and it's highly likely to *segfault* if the heap is corrupted. *prerr_endline* prints a message to stderr and crucially also flushes stderr, so you will see the message printed immediately.

you **should** grep for `caml_heap_check` in byterun for details

```
void caml_compact_heap (void)
{
```



```

    char *ch, *chend;

                                Assert (caml_gc_phase == Phase_idle)

    caml_gc_message (0x10, "Compacting heap...\n", 0);

#ifdef DEBUG
    caml_heap_check ();
#endif

#ifdef DEBUG
void caml_heap_check (void)
{
    heap_stats (0);
}
#endif

#ifdef DEBUG
    ++ major_gc_counter;
    caml_heap_check ();
#endif

```

3. tune

problems can arise when you're building up ephemeral data structures which are larger than the minor heap. The data structure won't stay around overly long, but it is a bit too large. Triggering major GC slices more often can cause static data to be walked and re-walked more often than is necessary. tuning sample

```

let _ =
  let gc = Gc.get () in
    gc.Gc.max_overhead <- 1000000;

```

```
gc.Gc.space_overhead <- 500;  
gc.Gc.major_heap_increment <- 10_000_000;  
gc.Gc.minor_heap_size <- 10_000_000;  
Gc.set gc
```

7.1 ocamlrun

- ocamlrun
the ocamlrun command comprises three main parts: the bytecode interpreter, the memory allocator and garbage collector, and a set of c functions that implement primitive operations such as input/output.

Chapter 8

Object-oriented

Write
later

Chapter 9

complex language features

9.1 stream expression

streams

1. stream expression

```
let rec walk dir =
  let items = try
    Array.map (fun fn -> let path = Filename.concat dir fn in
      try if Sys.is_directory path then 'Dir path else 'File path
      with e -> 'Error(path,e) ) (Sys.readdir dir)
  with e -> [| 'Error (dir,e) |] in
  Array.fold_right
    (fun item rest -> match item with
      | 'Dir path -> [< 'item ; walk path; rest >]
      | _ -> [< 'item; rest >]) items [< >];;

val walk :
  string ->
  [> 'Dir of string | 'Error of string * exn | 'File of string ]
  Batteries.Stream.t = <fun>
```

```

(** alternative without syntax extension *)
let rec walk dir =
  let items =
    try
      Array.map
        (fun fn ->
          let path = Filename.concat dir fn in
          try if Sys.is_directory path
            then 'Dir path
            else 'File path
          with | e -> 'Error (path, e))
        (Sys.readdir dir)
    with | e -> [| 'Error (dir, e) |]
  in
    Array.fold_right
      (fun item rest ->
        match item with
        | 'Dir path ->
            Stream.icons item (Stream.lapp (fun _ -> walk path) rest)
        | _ -> Stream.icons item rest)
      items Stream.empty

val walk :
  string ->
  [> 'Dir of string | 'Error of string * exn | 'File of string ]
  Batteries.Stream.t = <fun>

Stream.(
  walk "/Users/bobzhang1988"
  |> take 10 |> iter
  (

```

```

(function 'Dir s -> "dir :" ^ s
  | 'File s -> "file: " ^ s
  | 'Error (s,e) -> "error: " ^ s ^ " " ^ Printexc.to_string e
  ) |- print_string |- print_newline)
);;

file: /Users/bobzhang1988/#test.el#
file: /Users/bobzhang1988/.bash_history
file: /Users/bobzhang1988/.bashrc
file: /Users/bobzhang1988/.CFUserTextEncoding
file: /Users/bobzhang1988/.DS_Store
file: /Users/bobzhang1988/.emacs
dir :/Users/bobzhang1988/.emacs.d
file: /Users/bobzhang1988/.emacs.d/.emacs
dir :/Users/bobzhang1988/.emacs.d/.git
dir :/Users/bobzhang1988/.emacs.d/.git/branches

```

2. module Stream

```

Stream.npeek;;
- : int -> 'a Batteries.Stream.t -> 'a list = <fun>
Stream.next;;
- : 'a Stream.t -> 'a = <fun>

```

```

let lines_stream_of_channel chan = Stream.from (fun _ ->
  try Some (input_line chan) with End_of_file -> None );;

val lines_stream_of_channel : BatIO.input -> string Batteries.Stream.t =

it raises Stream.Failure on an empty stream, i.e. Stream.next

let line_stream_of_string string =
  Stream.of_list (Str.[ ]split (regexp "\n") string))

```

3. Constructing streams

```
Stream.from
Stream.of_list
Stream.of_string (* char t *)
Stream.of_channel (* char t *)
```

4. Consuming streams

```
Stream.peek
Stream.junk
```

```
let paragraph lines =
  let rec next para_lines i =
    match Stream.peek lines, para_lines with
    | None, [] -> None
    | Some "", [] ->
      Stream.junk lines (* still a white paragraph *)
      next para_lines i
    | Some "", _ | None, _ ->
      Some (String.concat "\n" (List.rev para_lines)) (* a new paragraph *)
    | Some line, _ ->
      Stream.junk lines ;
      next (line :: para_line ) i in
  Stream.from (next [])

let stream_fold f stream init =
  let result = ref init in
  Stream.iter (fun x -> result := f x !result) stream; !result;;

val stream_fold : ('a -> 'b -> 'b) -> 'a Batteries.Stream.t -> 'b -> 'b =
  <fun>
```

```

let stream_concat streams =
  let current_stream = ref None in
  let rec next i =
    try
      let stream = match !current_stream with
        | Some stream -> stream
        | None ->
          let stream = Stream.next streams in
          current_stream := Some stream ;
          stream in
      try Some (Stream.next stream)
      with Stream.Failure -> (current_stream := None ; next i)
    with Stream.Failure -> None in
  Stream.from next

```

5. *copying or sharing* streams
 this was called *dup* in Enum

```

(** create 2 buffers to store some pre-fetched value *)
let stream_tee stream =
  let next self other i =
    try
      if Queue.is_empty self
      then
        let value = Stream.next stream in
        Queue.add value other ;
        Some value
      else
        Some (Queue.take self)
    with Stream.Failure -> None in
  let q1,q2 = Queue.create (), Queue.create () in
  (Stream.from (next q1 q2), Stream.from (next q2 q1))

```


6. convert arbitrary data types to streams

if the datatype defines an *iter* function, and you don't mind using threads, you can use a *producer-consumer* arrangement to invert control.

```
let elements iter coll =
  let channel = Event.new_channel () in
  let producer () =
    let _ = iter (fun x -> Event.([ sync (send channel (Some x ))])) coll in
    Event.([ sync (send channel None)]) in
  let consumer i =
    Event.([ sync (receive channel)]) in
  ignore (Thread.create producer ()) ;
  Stream.from consumer

val elements : (('a -> unit) -> 'b -> 'c) -> 'b -> 'a Batteries.Stream.t =
```

Keep in mind that these techniques spawn producer threads which carry a few risks: they only terminate when they have finished iterating, and any change to the original data structure while iterating may produce unexpected results.

9.2 The module Language

9.3 The module Language

Chapter 10

subtle bugs

1. reload duplicate modules

this is fragile when you load some modules like syntax extension, or toploop modules. use *ocamlobjinfo* to see which modules are loaded exactly

Chapter 11

interoperating with C

Write
later

Chapter 12

Book

12.0.1 Developing Applications with Objective Caml

1. caveat

(a) $+$ (modulo the boundary, *will not be checked*)

(b) $1.0/0.0 \rightarrow \infty$

(c) $+, -, *, ./, **, \text{mod}, \text{ceil}, \text{floor}, \text{sqrt}, \text{exp}, \text{log}, \text{log10}, \text{cos}, \text{sin}, \text{tan}, \text{acos}, \text{asin}, \text{atan}$

(d) $\text{asin}3.14 \rightarrow \text{nan}$

(e) `char_of_int 255` \rightarrow `'\255'` (can not display)

(f) `char_of_int int_of_char string_of_int int_of_string string_of_int 2551` \rightarrow

(g) `string` (length $\leq 2^{24} - 6$)

(h) `==` (*physical equal*) (`=`, `!=`, `<`, `>`)

```
true == true;;
- : bool = true
# 3 == 3;;
- : bool = true
# 1. == 1.;;
- : bool = false
```

(i) `int * int * int` is different from `(int * int) * int`

(j) unreasonable parametric equality `(=)` : `'a -> 'a -> bool`

Warning 8: this pattern-matching is not exhaustive.

Here is an example of a value that is not matched:

```
'f'
```

```
val test : char -> bool = <fun>
```

(m) records

```
type complex = {re:float;img:float};;
type complex = { re : float; img : float; }
# let add {re; img} {re; img} = 3;;
val add : complex -> complex -> int = <fun>
# let add {re; img} {re; img} = {re = re +. re; img = img +. img};;
val add : complex -> complex -> complex = <fun>
```

(n) *redefinition marsks the previous one, while values of the masked types still exist, but it now turns to be an abstract type*

(o) exception

i. Match_failure Division_by_zero Failure

ii. exception Name of t – monomorphic , extensible sum Type

when pattern match your exception, its type should be fixed

iii. control flow

(p) **disagree over interface**

when toplevel loads the same module (only the name is the same), it will check the interface is equal, this sucks since ocaml has flat namespace for module

2. sharing

for structured values, it will be sharing , however, *vectors of floats don't share*

```
let a = Array.create 3 0.;;
val a : float array = [|0.; 0.; 0.|]
# a.(0)==a.(1);;
- : bool = false
```

3. weak type variables

```

let b = ref []
(* b should 'a list ref, since b is not pure, cannot be shared *)
let a = []
(* a : 'a list *)
let a = None
(* a : 'a option *)n
let a = Array.create 3 None
(* 'a option array *)
# type ('a,'b) t = {ch1 : 'a list; mutable ch2 : 'b list};;
type ('a, 'b) t = { ch1 : 'a list; mutable ch2 : 'b list; }
# let v = {ch1=[];ch2=[]};;
val v : ('a, 'b) t = {ch1 = []; ch2 = []}

```

mutable sharing conflicts with polymorphism

4. library

(a) List

```

@ length hd tl nth rev append rev_append concat flatten
iter map rev_map left_fold fold_right iter2 map2 rev_map2
fold_left2 fold_right2 for_all exists for_all2 exists2
mem memq find filter partition assoc assq remove_assoc remove_assq
split combine sort stable_sort fast_sort merge

```

```

# List.assq 3 [3,4;1,2];;
- : int = 4
# List.assq 3. [3.,4;1.,2];;
Exception: Not_found.

```

(b) Array

Array.create_matrix creates Non-Rectangular matrices

```

length get set make create init -- when you don't want to initialize
make_matrix (int->int->'a -> 'a array array) create_matrix;
append concat sub copy fill ('a array -> int -> int -> 'a -> int)
blit (Array.Labels.blit), to_list, of_list map iteri mapi fold_left
fold_right sort stable_sort fast_sort unsafe_get unsafe_set copy

```

(c) IO

```

open_in open_out close_in close_out input_line
input : Batteries.Legacy.in_channel -> string -> int -> int -> int = <fun
output: Batteries.Legacy.out_channel -> string -> int -> int -> unit =<f
read_line print_string print_newline print_endline

```

(d) stack (imperative data structure actually)

```

exceptin Empty
create
type 'a t = { mutable c : 'a list }
(* mutable to delay initialization *)
push pop top clear copy is_empty length iter enum copy
of_enum print
module Exceptionless
  top : 'a t -> 'a option, pop

```

(e) stream imperative

```

'a t
exception Failure
exception Error of string
from
of_list of_string of_channel iter empty peek junk count npeek
iapp icons ising lapp lcons lsing
sempty slazy dump npeek

syntax extension (for my experience, use it in shell, but not in tuareg
toplevel)

let concat_stream a b = [<a;b>]

val concat_stream :
  'a Batteries.Stream.t -> 'a Batteries.Stream.t -> 'a Batteries.Stream.

```


expression not preceded by an `!` considered to be sub-stream destructive
 pattern matching (camlp5 or extended parser can merge) consumed (error),
 failure

(f) Array List String Hashtbl Buffer Queue

(g) Sort

```
module X = Sort ;;

module X :
  sig
    val list : ('a -> 'a -> bool) -> 'a list -> 'a list
    val array : ('a -> 'a -> bool) -> 'a array -> unit
    val merge : ('a -> 'a -> bool) -> 'a list -> 'a list -> 'a list
  end
```

(h) Weak (vector of weak pointers) abstract type

```
sig
  type 'a t = 'a Weak.t
end
```

(i) Printf

```
%t -> (output->unit)
%t%s -> (output->unit)->string->unit
```

they all should be processed at **compile time**

(j) Digest

hash functions return a fingerprint of their entry (reversible)

```
val string : string -> t -- fingerprint of a string
val file : string -> t -- fingerprint of a file
```

(k) Marshal estimate data size

```
type external_flag = No_sharing | Closures

let size x = x |> flip Marshal.to_string [] |> flip Marshal.data_size 0;;
```

```

val size : 'a -> int = <fun>
# size 3;;
- : int = 1
# size 3.;;
- : int = 9
# size "ghsogho";;
- : int = 8
# size "ghsogho1";;
- : int = 9
# size "ghsogho1ah";;
- : int = 11
# size 111;;
- : int = 2

```

(l) Sys

```

os_type interactive word_size max_string_length
max_array_length time argv getenv command file_exists
remove rename chdir getcwd

```

```

# float (Sys.max_string_length ) /. (2. ** 57.);;
- : float = 0.999999999999999889

```

(m) Arg Filename Printexc

(n) Printexc

```

# module P = Printexc;;
module P :
  sig
    val to_string : exn -> string
    val catch : ('a -> 'b) -> 'a -> 'b
    val get_backtrace : unit -> string
    val record_backtrace : bool -> unit
    val backtrace_status : unit -> bool
    val register_printer : (exn -> string option) -> unit
    val pass : ('a -> 'b) -> 'a -> 'b
    val print : 'a BatInnerIO.output -> exn -> unit
    val print_backtrace : 'a BatInnerIO.output -> unit
  end

```

(o) Num

(p) Arith_status

```
# module X = Arith_status;;

module X :
  sig
    val arith_status : unit -> unit
    val get_error_when_null_denominator : unit -> bool
    val set_error_when_null_denominator : bool -> unit
    val get_normalize_ratio : unit -> bool
    val set_normalize_ratio : bool -> unit
    val get_normalize_ratio_when_printing : unit -> bool
    val set_normalize_ratio_when_printing : bool -> unit
    val get_approx_printing : unit -> bool
    val set_approx_printing : bool -> unit
    val get_floating_precision : unit -> int
    val set_floating_precision : int -> unit
  end
```

(q) Dynlink

choice at execution time, load a new module and hide the code code (hot-patch) actually (`#load` is kinda hot-patch), however to write it in programs *more flexible* than `#load`, `load` requires its name are fixed, and `load` will check .mli file, Dynlink **does not** do this check, while when you want to do X.blabla, it still checks, so still don't work, only side effects will work.

```
#direcotry "+dynlink";;
#load "dynlink.cma";;
Dynlink.loadfile "test.cmo";;
```

5. syntaxes

6. expr

```

exp      ::=value-path  -- value-name or module-path.value-name
| constant
| ( expr )
| begin expr end
| ( expr : typexpr )
| expr ,  expr { , expr } -- tuple
| constr expr -- constructor
| 'tag-name expr -- polymorphic variant
| expr :: expr -- list
| [ expr { ; expr } ]
| [| expr { ; expr } |]
| { field = expr { ; field = expr } }
| { expr with field = expr { ; field = expr } }
| expr { argument }+ -- application
| prefix-symbol expr -- prefix operator
| expr infix-op expr
| expr . field
| expr . field <- expr -- still an expression
| expr .( expr )
| expr .( expr ) <- expr
| expr .[ expr ]
| expr .[ expr ] <- expr
| if expr then expr [ else expr ]
| while expr do expr done
| for ident = expr ( to | downto ) expr do expr done
| expr ; expr
| match expr with pattern-matching
| function pattern-matching
| fun multiple-matching -- multiple parameters matching
| try expr with pattern-matching
| let [rec] let-binding { and let-binding } in expr

```

```

| new class-path
| object class-body end
| expr # method-name
| inst-var-name
| inst-var-name <- expr
| ( expr :> typexpr )
| ( expr : typexpr :> typexpr )
| {< inst-var-name = expr { ; inst-var-name = expr } >}
| assert expr
| lazy expr

```

argument::=expr

```

| ~ label-name
| ~ label-name : expr
| ? label-name
| ? label-name : expr

```

pattern-matching::=

```

[[] pattern [when expr]-> expr { |pattern [when expr] -> expr }

```

multiple-matching::= { parameter }+ [when expr]-> expr

let-binding::=pattern = expr

```

| value-name { parameter } [: typexpr] = expr

```

parameter::=pattern

```

| ~ label-name
| ~ ( label-name [: typexpr] )
| ~ label-name : pattern
| ? label-name
| ? ( label-name [: typexpr] [= expr] )

```

```

| ? label-name : pattern
| ? label-name : ( pattern [: typexpr] [= expr] )

```

```

let f ?test:(Some x ) y = x + y;;
~~~~~

```

Warning 8: this pattern-matching is not exhaustive.

Here is an example **of** a value that is not matched:

None

```

val f : ?test:int -> int -> int = <fun>

```

7. pattern

```

pattern      ::=      value-name
| _
| constant
| pattern as value-name
| ( pattern )
| ( pattern : typexpr )
| pattern | pattern
| constr pattern
| 'tag-name pattern
| #typeconstr-name -- object ?
| pattern { , pattern }
| { field = pattern { ; field = pattern } }
| [ pattern { ; pattern } ]
| pattern :: pattern
| [| pattern { ; pattern } |]
| lazy pattern

```

8. toplevel-phrase

```

toplevel-input ::= { toplevel-phrase } ;;

```

```

toplevel-phrase ::= definition
    | expr
    | #ident directive-argument

directive-argument ::= epsilon
    | string-literal
    | integer-literal
    | value-path

definition ::= let [rec] let-binding {and let-binding}
    | external value-name : typexpr = external-declaration
    | type-definition
    | exception-definition
    | class-definition
    | classtype-definition
    | module module-name {(module-name : module-type)} [:module-type] = module-type
    | module type module-name = module-type
    | open module-path
    | include module-expr

```

9. type-definition

```

type-definition      ::= type typedef { and typedef }

typedef              ::= [type-params] typeconstr-name [type-information]

type-information ::=
    [type-equation] [type-representation]{ type-constraint }

type-equation ::= = typexpr

type-representation ::=
    = constr-decl { | constr-decl }
    | = { field-decl { ; field-decl } }

```

```

type-params ::= type-param
               | ( type-param { , type-param } )

type-param ::= ' ident
               | + ' ident
               | - ' ident

constr-decl ::= constr-name
               | constr-name of typexpr { * typexpr }

field-decl ::= field-name : poly-typexpr
               | mutable field-name : poly-typexpr
type-constraint ::= constraint ' ident = typexpr

```

```

# type t;;
type t

```

10. interoperating with C

Difficulties

(a) Machine representation of data

(b) GC

calling a c function from ocaml must not modify the memory in ways incompatible with ocaml gc.

(c) Exceptions

C does not support exceptions, different mechanisms for aborting computations, this complicates ocaml's exception handling

(d) sharing common resources

input-output. each language maintains its own input-output buffers.

Communications

(a) external declarations

it associates a c function definition with an ocaml name, while giving the type of the latter.

```
external caml_name : type = "C_name"
val caml_name : type
```

both works, but in the latter case, calls to the c function *first go* through the general function application mechanism of ocaml. This is slightly less efficient, but hides the implementation of the function as a c function.

(b) external functions with more than five arguments

```
external caml_name : type = "C_name_bytecode" "
    C_name_native"
```

chap7 Development Tools

1. Command names

ocaml	toplevel top
ocamlrun	bytecode interpreter
ocamlc	bytecode batch compiler
ocamlopt	native code batch compiler
ocamlc.opt	<i>optimized</i> bytecode batch compiler
ocamlopt.opt	<i>optimized</i> native code batch compiler
ocamlmktop	new <i>toplevel</i> constructor

The optimized compilers are themselves compiled with the Objective Caml native compiler. They compile *faster* but are otherwise *identical* to their unoptimized counterparts.

2. compilation unit

For the interactive system, the unit of compilation corresponds to a phrase of

the language. For the batch compiler, the unit of compilation is two files: the source file, and the interface file

extension	meaning
.ml	source
.mli	interface
.cmi	compiled interface
.cmo	object file (byte)
.cma	library object file(bytecode)
.cmx	object file (native)
.cmxa	library object file(native)
.c	c source
.o	c object file (native)
.a	c library object file (native)

The *compiled interface* is used for both the bytecode and native code compiler.

3. ocamlc

-a	construct a runtime library
-c	compile <i>without</i> linking
-o name_of_executable	specify the name of the executable
-linkall	link with <i>all</i> libraries used
-i	<i>display all</i> compiled global declarations
-pp command	preprocessor
-unsafe	turn off index checking
-v	display version
-w list	choose among the list the level of warning message
-impl file	indicate that <i>file</i> is a caml source(.ml)
-intf file	as a caml interface(.mli)
-I dir	add directory in the list of directories
-thread	light process
-g, -noassert	linking
-custom, -cclib, -ccopt, -cc	standalone executable
-make-runtime, -use-runtime	runtime
-output-obj	c interface

warning messages.

A/a	enable/disable all messages	the compiler chooses the
F/f	partial application in a sequence	
P/p	incomplete pattern matching	
U/u	missing cases in pattern matching	
X/x	enable/disable all other messages	
M/m and V/v	for hidden object	

(A) by default. turn off some warnings sometimes is helpful, for example

```
ocamlbuild -cflags -w,aPF top_level.cma
```

4. ocamlpt

	-compact	optimize the produced code for space
	-S	keeps the assembly code in a file
	-inline level	set the aggressiveness of inlining
5. Toplevel	-I dir	adds the directory
	-unsafe	no bounds checking

6. ocamlmktop

it's often used for pulling native object code libraries (typically written in C) into a new toplevel. `-cclib libname, -ccopt optioin, -custom, -I dir -o exectuable`

```
ocamlmktop -custom -o mytoplevel graphics.cma \
-cclib -I/usr/X11/lib -cclib -lX11
```

This *standalone* exe(-custom) will be *linked* to the library X11(libX11.a) which in turn will be looked up in the path `/usr/X11/lib`

A standalone exe is a program that *does not* depend on OCaml installation to run. The OCaml native compiler produces standalone executables by default. But without `-custom` option, the bytecode compiler produces an executable which requires the *bytecode interpreter ocamlrun*

```
ocamlc test.ml -o a
```

```
ocamlc -custom test.ml -o b
```

```
-rwxr-xr-x  1 bob  staff    12225 Dec 23 16:31 a
-rwxr-xr-x  1 bob  staff   198804 Dec 23 16:31 b
```

```
bash-3.2$ cat a | head -n 1
#!/Users/bob/SourceCode/ML/godi/bin/ocamlrun
```

without `-custom`, it depends on *ocamlrun*. With `-custom`, it contains the *Zinc* interpreter as well as the program bytecode, this file can be executed directly or copied to another machine (using the same CPU/Operating System).

Still, the inclusion of machine code means that stand-alone executables are not portable to other systems or other architectures.

7. optimization

It is necessary to not create *intermediate closures* in the case of application on several arguments. For example, when the function *add* is applied with two integers, it is not useful to create the first closure corresponding to the function of applying *add* to the first argument. It is necessary to note that the creation of a closure would *allocate* certain memory space for the environment and would require the recovery of that memory space in the future. *Automatic memory recovery* is the second major performance concern, along with environment.

8. chap10 Program Analysis Tool

(a) ocamldep

-I	add dir
-impl,-intf	
-ml(i)-synonym <e>	consider <e> as a synonym of .ml(i) extension
-modules	Print module dependencies in raw form(not suitable for make)
-native	generate dependencies for a pure native-code project
-slash	for windows & unix

```
ocamldep -modules *.ml
```

```
ta.ml: Array Printf
```

```
tb.ml: Array Ta
```

```
\begin{bluecode}
```

```
\begin{redcode}
```

```
ocamldep *.ml
```

```
\end{redcode}
```

```
\begin{bluecode}
```

```
ta.cmo:
```

```
ta.cmx:
```

```
tb.cmo: ta.cmo
```

```
tb.cmx: ta.cmx
```

other examples

```
ocamlfind ocamldep -modules dir_top_level_util.ml >
  dir_top_level_util.ml.depends
ocamlfind ocamldep -pp 'camlp4of -parser pa_mikmatch_pcre.
  cma' -modules dir_top_level.ml > dir_top_level.ml.
  depends
```

(b) debug

`##(un)trace command ,##untrace_all.`

```
let verify_div a b q r = a = b * q + r ;;
val verify_div : int -> int -> int -> int -> bool = <fun>
# #trace verif_div ;;
Unbound value verif_div.
# #trace verify_div ;;
verify_div is now traced.
```

```
verify_div 11 5 2 1 ;;
```

```
verify_div <-- 11
```

```
verify_div --> <fun>
```

```
verify_div* <-- 5
```

```
verify_div* --> <fun>
```

```
verify_div** <-- 2
```

```
verify_div** --> <fun>
```

```
verify_div*** <-- 1
```

```
verify_div*** --> true
```

```
- : bool = true
```

```

let rec belongs_to (e:int) = function
  | [] -> false
  | t :: q -> (e=t) || belongs_to e q;;
  val belongs_to : int -> int list -> bool = <fun>
# #trace belongs_to;;
belongs_to is now traced.
# belongs_to 4 [3;5;7;4];;
belongs_to <-- 4
belongs_to --> <fun>
belongs_to* <-- [3; 5; 7; 4]
belongs_to <-- 4
belongs_to --> <fun>
belongs_to* <-- [5; 7; 4]
belongs_to <-- 4
belongs_to --> <fun>
belongs_to* <-- [7; 4]
belongs_to <-- 4
belongs_to --> <fun>
belongs_to* <-- [4]
belongs_to* --> true
belongs_to* --> true
belongs_to* --> true
belongs_to* --> true
- : bool = true

```

```

# let rec belongs to (e : int) = function
[] -> false
| t :: q -> belongs to e q || (e = t) ; ;
val belongs_to : int -> int list -> bool = <fun> # #trace
  belongs to ;;
belongs_to is now traced.
# belongs to 3 [3;5;7] ;;
belongs_to <-- 3
belongs_to --> <fun>
belongs_to* <-- [3; 5; 7]
belongs_to <-- 3
belongs_to --> <fun>
belongs_to* <-- [5; 7]
belongs_to <-- 3
belongs_to --> <fun>
belongs_to* <-- [7]
belongs_to <-- 3
belongs_to --> <fun>
belongs_to* <-- []
belongs_to* --> false
belongs_to* --> false

```

```

belongs_to* --> false
belongs_to* --> true
- : bool = true

```

Trace providing a mechanism for the efficiency analysis of recursive functions, not that friendly, however, no indented output. To make things worse, trace *does not show the value corresponding to an argument of a parameterized type*. The toplevel can show only monomorphic types.

Moreover, it only keeps the inferred types of *global declarations*. Therefore after compilation of the expression, the toplevel in fact *no longer* processes any further type information about the expression.

Only global type declarations are kept in the environment of the toplevel loop, *local functions* can not be traced for the same reasons as above

```

let rec belongs_to e = function
  | [] -> false
  | t :: q -> (e=t) || belongs_to e q;;
  val belongs_to : 'a -> 'a list -> bool = <fun>
# belongs_to 4 [3;5;7;4];;
- : bool = true
# #trace belongs_to;;
belongs_to is now traced.
# belongs_to 4 [3;5;7;4];;
belongs_to <-- <poly>
belongs_to --> <fun>
belongs_to* <-- [<poly>; <poly>; <poly>; <poly>]
belongs_to <-- <poly>
belongs_to --> <fun>
belongs_to* <-- [<poly>; <poly>; <poly>]
belongs_to <-- <poly>
belongs_to --> <fun>
belongs_to* <-- [<poly>; <poly>]
belongs_to <-- <poly>
belongs_to --> <fun>
belongs_to* <-- [<poly>]
belongs_to* --> true
belongs_to* --> true
belongs_to* --> true
belongs_to* --> true
- : bool = true

```

(c) ocamldbg

The `-g` option produces a `.cmo` file with the debugging information. (byte-code only)

12.0.2 Ocaml for scientists

- caveat

– string char 'a' = '\097' "Hello world".[4]

```
[1;2;3].(1)
2
```

– objects

```
(* it's a type class type *)
class type number = object
  method im:float
  method re:float
end

class complex x y = object
  val x = x
  val y = y
  method re:float = x
  method im:float = y
end ;;

let b : number = new complex 3. 4.

# let b = new complex 3. 4.;;
val b : complex = <obj>
# let b : number = new complex 3. 4.;;
val b : number = <obj>
```

```
# let make_z x y = object
  val x : float = x
  val y : float = y
  method re = x
```

```

    method im = y
  end;;

val make_z : float -> float -> < im : float; re : float > = <fun>

class type is kinda interface

# let abs_number (z:number) =
    let sqr x = x *. x in
    sqrt (sqr z#re +. sqr z#im);;

think class as a module

- asr (arith) (**) lsr
- elements

```

```

[1;2;3;4] |> Set.of_list |> Set.elements;;
- : int list = [1; 2; 3; 4]

```

- convention
- GMP (GNU library for arbitrary precision arithmetic)

```

module type INT_RANGE = sig
  type t
  val make : int -> int -> t
end

```

- Hashtbl(create, Make) Hashing is another form of structural comparison and should not be applied to **abstract types** *Semantically equivalent sets are likely to produce different hashes* notice *Map.empty* is polymorphic, *Hashtbl.empty* is monomorphic

12.0.3 caltech ocaml book

(a) oo

- immediate object

```

let poly = object
  val vertices = [|0,0;1,1;2,2|]
  method draw = "test"
end

```

- dynamic lookup

obj#method, the actual method that gets called is determined at *runtime*

```

# let draw_list items = List.iter (fun item->item#draw) items;;
val draw_list : < draw : unit; .. > list -> unit = <fun>

```

- type annotation (very common in oo)

- .. ellipse – row variable

{<>} represents a **functional update** (only fields), which produces a new object

```

# type 'a blob = <draw : unit; ..> as 'a ;;
type 'a blob = 'a constraint 'a = < draw : unit; .. >

```

```

let transform =
  object
    val matrix = (1.,0.,0.,0.,1.,0.)
    method new_scale sx sy =
      {<matrix= (sx,0.,0.,0.,sy,0.)>}
    method new_rotate theta =
      let s,c=sin theta, cos theta in
      {<matrix=(c,-.s,0.,s,c,0.)>}
    method new_translate dx dy=
      {<matrix=(1.,0.,dx,0.,1.,dy)>}
    method transform (x,y) =
      let (m11,m12,m13,m21,m22,m23)=matrix in
      (m11 *. x +. m12 *. y +. m13,
       m21 *. x +. m22 *. y +. m23)
  end ;;

```

```

val transform :
< new_rotate : float -> 'a; new_scale : float -> float -> 'a;
  new_translate : float -> float -> 'a;
  transform : float * float -> float * float >
as 'a = <obj>

#   let new_collection () =
    object
      val mutable items = []
      method add item = items <- item::items
      method transform mat =
        {<items = List.map (fun item -> item#transform mat) items>}
    end ;;

val new_collection :
unit ->
(< add : (< transform : 'c -> 'b; .. > as 'b) -> unit;
  transform : 'c -> 'a >
  as 'a) =
<fun>

```

- caveat

- field expression **could not** refer to other fields, nor to itself
- after you get the object you can have initializer
the object *does not exist* when the field values are be computed For the
initializer, you can call `self#blabla`

```

#   object
    val x = 1
    val mutable x_plus_1 = 0
    initializer
      x_plus_1 <- x + 1
  end ;;

- : < > = <obj>

```

– method private

– subtyping

supports *width and depth subtyping*, *contravariant and covariant* for subtyping of recursive object types, *first assume it is right* then prove it using such assumption

`e : t1 :> t2`

sometimes, type annotation and coercion both needed, when `t2` is recursive or `t2` has polymorphic structure

– narrowing

(opposite to subtyping) (**not permitted** in Ocaml) but you can simulate it. do runtime type testing

```
type animal = < eat : unit; v : exn >
type dog = < bark : unit; eat : unit; v : exn >
type cat = < eat : unit; meow : unit; v : exn >
exception Dog of dog
exception Cat of cat
let fido : dog = object(self) method v=Dog self method eat = () method
let miao : cat = object(self) method v = Cat self method eat = () meth
```

then you dispatch on `animal#v`, you can also encode using *polymorphic variant* sometimes ocaml's type annotation does not require its polymorphic is also a feature, you just **hint**, and let it guess, this is unlike haskell, always **universal quantifier** required.

```
type 'a animal = <eat:unit; tag : [>] as 'a >;
(** now we let the compiler to guess the type of 'a *)
let fido : 'a animal = object method eat = () method tag = 'Dog 3 end;;
val fido : [> 'Dog of int ] animal = <obj>

(**
# let fido : [< 'Dog of int] animal = object method eat = () method tag = 'Dog 3 end;;
val fido : [ 'Dog of int ] animal = <obj>
*)

let miao : [> 'Cat of int] animal = object method eat = () method tag = 'Cat 2 end;;
val miao : [> 'Cat of int ] animal = <obj>
```

```
# [fido;miao];;
- : [> 'Cat of int | 'Dog of int ] animal list = [<obj>; <obj>]

List.map (fun v -> match v#tag with 'Cat a -> a | 'Dog a -> a) [fido;miao];;
- : int list = [3; 2]
```

– modules vs objects

- (1) objects (data entirely hidden)
- (2) now both are first class (both can be used as arguments)
- (3) objects can bind type variable easier, especially when **self recursive** **recursive** is so natural in objects (isomorphic-like equivalence is free in oo) when we build an object of recursive type, but we don't care which type it is (maybe called existential type), so coding existential types is easier in OO

```
module type PolySig = sig
  type poly
  val create : (float*float) array -> poly
  val draw : poly -> unit
  val transform : poly -> poly
end

module Poly :PolySig =
  type poly = (float * float) array
  let create vertices = vertices
  let draw vertices = ()
  let transform matrix = matrix
end
```

Here module Poly is more natural to model it as an object

```
# class type poly = object
  method create : (float*float) array -> poly
  method draw : poly -> unit
  method transform : poly->poly
end
```

```
;;

class type poly =
  object
    method create : (float * float) array -> poly
    method draw : poly -> unit
    method transform : poly -> poly
  end

class poly = object (self:'self)
method test (x:'self) = x end;;

class poly : object ('a) method test : 'a -> 'a end
# let v = new poly;;

type blob = <draw:unit-> unit; transform:unit-> blob>;
type blob = < draw : unit -> unit; transform : unit -> blob >
type blob = {draw:unit-> unit; transform:unit-> blob};;
```

- parameterized class
template shows how to build an object
- polymorphic class

```
class ['a] cell(x:'a) = object
  method get = x
end ;;
class ['a] cell : 'a -> object method get : 'a end
```

(b) polymorphic variants

(a) simple example

```
let string_of_number = function 'Integer i -> i;;
val string_of_number : [< 'Integer of 'a ] -> 'a = <fun>
```

```
# let string_of_number = function
  | 'Integer i -> i
  | _ -> invalid_arg "string_of_number";;

val string_of_number : [> 'Integer of 'a ] -> 'a = <fun>
```

```

let test0 = function
  | 'Int i -> i

let test1 = function
  | 'Int i -> i
  | _ -> invalid_arg "invalid arg in test1"

let test2 = function
  | x -> test0 x

let test3 = function
  | x -> test1 x

(* let test4 : [> 'Real of 'a | 'Int of 'a ] -> 'a = function
   / 'Real x -> x *)
  | x -> test0 (x:> [< 'Int of 'a]) *)

let test5 = function
  | 'Real x -> x
  | x -> test1 x

val test0 : [< 'Int of 'a ] -> 'a = <fun>
val test1 : [> 'Int of 'a ] -> 'a = <fun>
val test2 : [< 'Int of 'a ] -> 'a = <fun>
val test3 : [> 'Int of 'a ] -> 'a = <fun>
val test5 : [> 'Int of 'a | 'Real of 'a ] -> 'a = <fun>

```

for open union, it's easy to reuse, but **unsafe**, for closed union, hard to use, since the type checker is conservative

```

test1 'Test;;
Exception: Invalid_argument "invalid arg in test1".

test0 'Test;;

```


Characters 6-11:

```
test0 'Test;;
```

```
~~~~~
```

```
Error: This expression has type [> 'Test ]
      but an expression was expected of type [< 'Int of 'a ]
      The second variant type does not allow tag(s) 'Test
```

(b) define polymorphic variant type

```
type number = [> 'Integer of int | 'Real of float ];;
```

```
~~~~~
```

```
Error: A type variable is unbound in this type declaration.
In type [> 'Integer of int | 'Real of float ] as 'a
the variable 'a is unbound
```

```
type 'a number = 'a constraint 'a = [>'Integer of int | 'Real of float]
```

```
let zero : 'a number = 'Zero;;
```

```
val zero : [> 'Integer of int | 'Real of float | 'Zero ] number = 'Zero
```

```
type number = [< 'Integer of int | 'Real of float ];;
```

```
~~~~~
```

```
Error: A type variable is unbound in this type declaration.
In type [< 'Integer of int | 'Real of float ] as 'a
the variable 'a is unbound
```

```
# type number = [ 'Integer of int | 'Real of float ];;
```

```
type number = [ 'Integer of int | 'Real of float ]
```

(c) sub-typing for polymorphic variants

```
[ 'A ] :> [ 'A | 'B ]
```

since you know how to handle A and B, then you know how to handle A

```
let f x = (x:[ 'A ] :> [ 'A | 'B ]);;
```

```
val f : [ 'A ] -> [ 'A | 'B ] = <fun>
```

ocaml does has width and depth subtyping if $t1 :> t1'$ and $t2 :> t2'$ then $(t1, t2) :> (t1', t2')$

```
let f x = (x:[ 'A ] * [ 'B ] :> [ 'A | 'C ] * [ 'B | 'D ]);;
```

```
val f : [ 'A ] * [ 'B ] -> [ 'A | 'C ] * [ 'B | 'D ] = <fun>
```

```
let f x = (x : [ 'A | 'B ] -> [ 'C ] :> [ 'A ] -> [ 'C | 'D ]);;
val f : ([ 'A | 'B ] -> [ 'C ]) -> [ 'A ] -> [ 'C | 'D ] = <fun>
```

(d) variance notation

if you don't write the $+$ and $-$, ocaml will **infer** them for you , but when you write abstract type in module type signatures, it makes sense. variance annotations **allow you to expose the subtyping properties** of your type in an interface, without exposing the representation.

```
type (+'a, +'b) t = 'a * 'b
type (-'a, +'b) t = 'a -> 'b
module M : sig
  type (+'a, +'b) t
end = struct
  type ('a, 'b) t = 'a * 'b
end
```

ocaml did the check when you define it, so you can not define it arbitrarily

(e) **co-variant** helps polymorphism

```
module M : sig
  type +'a t
  val embed : 'a -> 'a t
end = struct
  type 'a t = 'a
  let embed x = x
end ;;
M.embed [] ;;
- : 'a list M.t = <abstr>
```

(f) example

```
type suit = [ 'Club | 'Diamond | 'Heart | 'Spade ]

let winner = function 'Heart -> true | #suit -> false;;
val winner : [< suit ] -> bool = <fun>
let winner2 = function 'Unknown -> true | #suit -> false;;
val winner2 : [< 'Club | 'Diamond | 'Heart | 'Spade | 'Unknown ] -> bool =
```

```

    <fun>

    (* the variant tag does not belong to a particular type *)

    let winner3 : (suit -> bool) = function 'Unknown -> true | #suit -> false;;
                                     ~~~~~~

Warning 11: this match case is unused.
val winner3 : suit -> bool = <fun>

```

12.0.4 The functional approach to programming

12.0.5 practical ocaml

1. chap30

```
external functions_can_be_defined: unit -> unit = "int_c_code"
```

12.0.6 hol-light

- hol-light

12.1 UNIX system programming in ocaml

12.1.1 chap1

1. Modules Sys and Unix

Sys contains those functions common to Unix and Windows. **Unix** contains everything specific to Unix.

The *Sys* and *Unix* modules can override certain functions of the *Pervasives* module

```

Unix.stdin;;
- : Batteries.Unix.file_descr = <abstr>

```

```
Pervasives.stdin;;
- : in_channel = <abstr>
```

```
<prog.{native,byte}> : use_unix
ocamlmktop -o ocamlunix unix.cma
```

When running a program from a shell, the shell passes **arguments** and **environment** to the program. When a program terminates prematurely because *an exception was raised but not caught*, it makes an implicit call to *exit 2*. For *at_exit*, the last function to be registered is called first, and it can not be unregistered. However, we can walk around it using global variables.

```
Sys.argv, Sys.getenv , Unix.environment,
Pervasives.exit, Pervasives.at_exit, Unix.handle_unix_error
```

```
Sys.argv;;
```

```
- : string array =
[| "/Users/bob/SourceCode/ML/godi/bin/ocaml"; "dynlink.cma";
"camlp4of.cma"; "-warn-error"; "+a-4-6-27..29"| ]
```

```
Unix.environment ();;
```

```
- : string array =
[| "TERM=dumb"; "SHELL=/bin/bash";
"TMPDIR=/var/folders/R4/R4awSXDIH6GpuuMmaVeCzU+++TI/-Tmp-/" ;
"LIBRARY_PATH=/opt/local/lib/";
"EMACSDATA=/Applications/Aquamacs.app/Contents/Resources/etc";
"Apple_PubSub_Socket_Render=/tmp/launch-mcHkKo/Render";
"EMACSPATH=/Applications/Aquamacs.app/Contents/MacOS/bin";
"INCLUDE_PATH=/opt/local/include/"; "EMACS=t"; "USER=bob";
"LD_LIBRARY_PATH=/opt/local/lib/"; "COMMAND_MODE=unix2003"; "TERMCAP=";
"SSH_AUTH_SOCK=/tmp/launch-g9AcyQ/Listeners";
```

```

__CF_USER_TEXT_ENCODING=0x1F5:0:0"; "COLUMNS=68";
"PATH=/opt/local/sbin:/usr/local/sbin:/usr/local/lib:/Applications/MATLAB
"=/usr/local/bin/ledit"; "C_INCLUDE_PATH=/opt/local/include/";
"PWD=/Users/bob/SourceCode/Notes/ocaml-book";
"TEXINPUTS=./Applications/Aquamacs.app/Contents/Resources/lisp/aquamacs/ed
"EMACSLOADPATH=/Applications/Aquamacs.app/Contents/Resources/lisp:/Applicat
"SHLVL=3"; "HOME=/Users/bob"; "LOGNAME=bob";
"CAML4_EXAMPLE=/Users/bob/SourceCode/ML/godi/build/distfiles/ocaml-3.12.0/
"DISPLAY=/tmp/launch-sXEeNT/org.x:0"; "INSIDE_EMACS=23.3.50.1,comint";
"EMACSDOC=/Applications/Aquamacs.app/Contents/Resources/etc";
"SECURITYSESSIONID=616cd3"|]

```

2. ERROR handling

```

exception Unix_error of error * string * string
type error = E2BIG | ... | EUNKNOWERR of int

```

The second arg of *Unix_error* is the name of the system call that raised the error, the third, if possible, identifies the object on which the error occurred (i.e. file name). *Unix.handle_unix_error*, if this raises the exception *Unix_error*, displays the message, and *exit 2*

```

let handle_unix_error2 f arg = let open Unix in
  try
    f arg
  with Unix_error(err, fun_name, arg) ->
    prerr_string Sys.argv.(0);
    prerr_string ": \"";
    prerr_string fun_name;
    prerr_string "\" failed";
    if String.length arg > 0 then begin
      prerr_string " on \"";

```

```

prerr_string arg;
prerr_string "\"\" end;
prerr_string ": ";
prerr_endline (error_message err);
exit 2;;

```

```

val handle_unix_error2 : ('a -> 'b) -> 'a -> 'b = <fun>

```

```

let rec restart_on_EINTR f x =
try f x with Unix_error (EINTR, _, _) -> restart_on_EINTR f x

```

```

finally;;
- : (unit -> unit) -> ('a -> 'b) -> 'a -> 'b = <fun>
finally (fun _ -> print_endline "finally") (fun _ -> failwith "haha") ();;

```

finally

Exception: Failure "haha".

In case the program fails, i.e. raises an exception, *the finalizer is run and the exception `ex` is raised again*. If **both** the main function and the finalizer fail, the finalizer's exception is raised.

12.1.2 chap2

1. Files

File covers *standard files, directories, symbolic links, special files(devices), named pipes, sockets*

2. Filename module

makes filename cross platform

```

val current_dir_name : string
val parent_dir_name : string
val dir_sep : string

```

```

val concat : string -> string -> string
val is_relative : string -> bool
val is_implicit : string -> bool
val check_suffix : string -> string -> bool
val chop_suffix : string -> string -> string
val chop_extension : string -> string
val basename : string -> string
val dirname : string -> string
val temp_file : ?temp_dir:string -> string -> string ->
    string
val open_temp_file :
    ?mode:open_flag list ->
    ?temp_dir:string -> string -> string -> string *
    out_channel
val temp_dir_name : string
val quote : string -> string

```

non-directory files can have **many parents**(we say that they have many **hard links**). There are also *symbolic links* which can be seen as *non-directory* files containing a path, conceptually, this path can be obtained by reading the contents of the symbolic link like an ordinary file. Whenever a symbolic link occurs in the **middle** of a path, we have to follow its path transparently.

```

p/s/q -> l/q (l is absolute)
p/s/q -> p/l/q (l is relative)

```

```

Sys.getcwd, Sys.chdir, Unix.chroot

```

Unix.chroot p makes the node *p*, which should be a directory, the root of the *restricted* view of the hierarchy. Absolute paths are then interpreted according to this new root *p* (and *..* at the new root is itself). Due to hard links, a file can have many different names.

Unix.(link, unlink,symlink,rename);;

```

- : (string -> string -> unit) * (string -> unit) *
    (string -> string -> unit) * (string -> string -> unit)

```

unlink f is like *rm -f f*, *link f1 f2* is like *ln f1 f2*, *symlink f1 f2* is like *ln -s f1 f2*,
rename f1 f2 is like *mv f1 f2*

A file descriptor represents a pointer to a file along with other information like the current read/write position in the file, the access rights, etc. `file_descr`

```
Unix.([stdin,stdout,stderr]);;
```

```
- : Batteries.Unix.file_descr * Batteries.Unix.file_descr *  
  Batteries.Unix.file_descr
```

without redirections, the three descriptors refer to the terminal.

```
cmd > f ; cmd 2 > f
```

3. Meta attributes, types and permissions

```
Unix.(stat,lstat,fstat);;
```

```
(string -> Batteries.Unix.stats) *  
(string -> Batteries.Unix.stats) *  
(Batteries.Unix.file_descr -> Batteries.Unix.stats)
```

`lstat` returns information about the symbolic link itself, while `stat` returns information about the file that link points to.

```
Unix.(lstat &&& stat) "/usr/bin/al";;
```

```
({Batteries.Unix.st_dev = 234881026; Batteries.Unix.st_ino = 843893;  
  Batteries.Unix.st_kind = Batteries.Unix.S_LNK; (* link *)  
  Batteries.Unix.st_perm = 493; Batteries.Unix.st_nlink = 1;  
  Batteries.Unix.st_uid = 0; Batteries.Unix.st_gid = 0;  
  Batteries.Unix.st_rdev = 0; Batteries.Unix.st_size = 46;  
  (* pretty small as a link *)  
  Batteries.Unix.st_atime = 1273804908.;
```



```

Batteries.Unix.st_mtime = 1273804908.;
Batteries.Unix.st_ctime = 1273804908.},

{Batteries.Unix.st_dev = 234881026; Batteries.Unix.st_ino = 840746;
 Batteries.Unix.st_kind = Batteries.Unix.S_REG; (* regular file *)
 Batteries.Unix.st_perm = 493; Batteries.Unix.st_nlink = 1;
 Batteries.Unix.st_uid = 0; Batteries.Unix.st_gid = 80;
 Batteries.Unix.st_rdev = 0; Batteries.Unix.st_size = 163;
 (* maybe bigger *)
 Batteries.Unix.st_atime = 1323997427.;
 Batteries.Unix.st_mtime = 1271968805.;
 Batteries.Unix.st_ctime = 1273804911.})

```

A file is uniquely identified by the pair made of its device number (typically the disk partition where it is located) `st_dev` and its inode number `st_ino`

All the users and groups on the machine are usually described in the `/etc/passwd`, `/etc/groups` files.

```

st_uid
st_gid
getpwnam, getgrnam, (by name, get passwd_entry, group_entry)
getpwuid, getgrgid (by id)
getlogin, getgroups
chown, fchown

```

```
Unix.getlogin () |> Unix.getpwnam;;
```

```

{Batteries.Unix.pw_name = "bob"; Batteries.Unix.pw_passwd = "*****";
 Batteries.Unix.pw_uid = 501; Batteries.Unix.pw_gid = 20;
 Batteries.Unix.pw_gecos = "bobzhang"; Batteries.Unix.pw_dir = "/Users/bob";
 Batteries.Unix.pw_shell = "/bin/bash"}

```

for access rights, executable, writable, readable by the user owner, group owner, other users. For a directory, the executable permission means the right to enter

it, and read permission the right to list its contents. The special bits do not have meaning unless the **x** bit is set. The bit *t* allows sub-directories to inherit the permissions of the parent directory. On a directory, the bit *s* allows the use of the directory's *uid* or *gid* rather than the user's to create directories. For an executable file, the bit *s* allows the changing at execution time of the user's effective identity or group with the system calls *setuid* and *setgid*

```
Unix.(setuid, getuid);;
- : (int -> unit) * (unit -> int) = (<fun>, <fun>)
```

4. operations on directories

only the kernel can write in directories(when files are created). Opening a directory in write mode is *prohibited*.

```
Unix.(opendir, readdir, rewinddir, closedir);;
```

```
- : (string -> Batteries.Unix.dir_handle) *
    (Batteries.Unix.dir_handle -> string) *
    (Batteries.Unix.dir_handle -> unit) * (Batteries.Unix.dir_handle -> unit)
```

rewinddir repositions the descriptor at the **beginning** of the directory.

`mkdir, rmdir`

We can only remove a directory that is **already empty**. It is thus necessary to first recursively empty the contents of the directory and then remove the directory.

```
exception Hidden of exn
(** add a tag to exn *)
let hide_exn f x = try f x with exn -> raise (Hidden exn)
(** strip the tag of exn *)
let reveal_exn f x = try f x with Hidden exn -> raise exn
```

5. File manipulation

```
Unix.openfile;;
```

```
- : string ->
    Batteries.Unix.open_flag list ->
    Batteries.Unix.file_perm -> Batteries.Unix.file_descr
```

Most programs use *0o666* means *rw-rw-rw-*. with the default creation mask of *0o022*, the file is thus created with the permission *rw-r--r--*. With a more lenient mask of *0o002*, the file is created with the permissions *rw-rw-r--*. The third argument can be anything as *O_CREATE* is not specified. And to write to an empty file without caring any previous content, we use

```
Unix.openfile filename [O_WRONLY; O_TRUNC; O_CREAT] 0o666
```

If the file is scripts, we create it with execution permission:

```
Unix.openfile filename [O_WRONLY; O_TRUNC; O_CREAT] 0o777
```

If we want it to be confidential,

```
Unix.openfile filename [O_WRONLY; O_TRUNC; O_CREAT] 0o600
```

The *O_NONBLOCK* flag guarantees that if the file is a named pipe or a special file then the file opening and subsequent reads and writes will be non-blocking. The *O_NOCTTY* flag guarantees that if the file is a control terminal, it won't become the controlling terminal of the calling process.

```
Unix.(read,single_write);;
```

```
- : (Batteries.Unix.file_descr -> string -> int -> int -> int) *
    (Batteries.Unix.file_descr -> string -> int -> int -> int)
```

The *string* hold the read bytes or the bytes to write. The 3rd argument is the start, the forth is the number.

For writes, the number of bytes actually written is usually the number of bytes requested, with two exceptions (i) not possible to write (i.e. disk is full) (ii) the descriptor is a pipe or a socket open in non-blocking mode(async) (iii) due to OCaml, too large.

The reason for (iii) is that internally OCaml uses auxiliary buffer whose size is bounded by a maximal value.

OCaml also provides *Unix.write* which iterates the writes until all the data is written or an error occurs. The problem is that in case of error there's no way to know the number of bytes that were *actually written*. *single_write* preserves the atomicity of writes.

For reads, when the current position is at the end of file, read returns zero. The convention *zero equals end of file* also holds for special files, *i.e. pipes and sockets*. For example, read on a terminal returns zero if we issue a *Ctrl-D* on the input.

But you may consider the blocking-mode in case.

```
Unix.close : file_descr -> unit
```

In contrast to Pervasives' channels, a file descriptor does not need to be closed to ensure that all pending writes have been performed as write requests are *immediately* transmitted to the kernel. On the other hand, the number of descriptors allocated by a process is limited by the kernel (several hundreds to thousands).

```
let buffer_size = 8192
let buffer = String.create buffer_size
```

```
(** this is unsatisfactory, if we copy an executable file, we would
like the copy to be also executable. *)
```

```

let file_copy input output = Unix.(
  let fd_in = openfile input [O_RDONLY] 0 in
  let fd_out = openfile output [O_WRONLY; O_CREAT; O_TRUNC] 0o666 in
  let rec copy_loop () = match read fd_in buffer 0 buffer_size with
    | 0 -> ()
    | r -> write fd_out buffer 0 r |> ignore; copy_loop () in
  copy_loop ();
  close fd_in ;
  close fd_out
)

let copy () =
  if Array.length Sys.argv = 3 then begin
    file_copy Sys.argv.(1) Sys.argv.(2)
  end
  else begin
    prerr_endline
      ("Usage: " ^ Sys.argv.(0) ^ "<input_file> <output_file>");
    exit 1
  end

let _ = Unix.handle_unix_error copy ()

```

```
ocamlbuild find.byte -- find.ml find.xxxx
```

```

ocamlbuild find.byte -- find.ml find.xxxx
_build/find.byte: "open" failed on "find.ml": No such file or directory

```

6. system call

For a system call, even if it does very little work, cost dearly – much more than

a normal function call. So we need buffer to reduce the number of system call. For ocaml, the *Pervasives* module adds another layer *in_channel*, *out_channel*.

7. positioning and operations specific to certain file types

```
Unix.lseek;;
- : Batteries.Unix.file_descr -> int -> Batteries.Unix.seek_command -> int =
```

File descriptors provide a uniform and media-independent interface for data communication. However this uniformity breaks when we need to access all the features provided by a given media.

For normal files, specific API

```
Unix.(truncate, ftruncate);;
- : (string -> int -> unit) * (Batteries.Unix.file_descr -> int -> unit) =
```

For symbolic links

```
Unix.(symlink, readlink);;
- : (string -> string -> unit) * (string -> string) = (<fun>, <fun>)
```

special files

- (a) /dev/null black hole. (useful for ignoring the result)
- (b) /dev/tty* control terminals
- (c) /dev/pty* pseudo-terminals
- (d) /dev/hd* disks
- (e) /proc Under linux, system parameters organized as a file system.

many special files ignore *lseek*

8. terminals

```
Unix.(tcgetattr, tcsetattr);;
```

```
(Batteries.Unix.file_descr -> Batteries.Unix.terminal_io) *
(Batteries.Unix.file_descr ->
  Batteries.Unix.setattr_when -> Batteries.Unix.terminal_io -> unit)

Unix.(tcgetattr stdout);;
```

```
{Batteries.Unix.c_ignbrk = false; Batteries.Unix.c_brkint = true;
  Batteries.Unix.c_ignpar = false; Batteries.Unix.c_parmrk = false;
  Batteries.Unix.c_inpck = false; Batteries.Unix.c_istrip = false;
  Batteries.Unix.c_inlcr = false; Batteries.Unix.c_igncr = false;
  Batteries.Unix.c_icrnl = true; Batteries.Unix.c_ixon = false;
  Batteries.Unix.c_ixoff = false; Batteries.Unix.c_opost = true;
  Batteries.Unix.c_obaud = 9600; Batteries.Unix.c_ibaud = 9600;
  Batteries.Unix.c_csize = 8; Batteries.Unix.c_cstopb = 1;
  Batteries.Unix.c_cread = true; Batteries.Unix.c_parenb = false;
  Batteries.Unix.c_parodd = false; Batteries.Unix.c_hupcl = true;
  Batteries.Unix.c_clocal = false; Batteries.Unix.c_isig = false;
  Batteries.Unix.c_icanon = false; Batteries.Unix.c_noflsh = false;
  Batteries.Unix.c_echo = false; Batteries.Unix.c_echoe = true;
  Batteries.Unix.c_echok = false; Batteries.Unix.c_echonl = false;
  Batteries.Unix.c_vintr = '\003'; Batteries.Unix.c_vquit = '\028';
  Batteries.Unix.c_verase = '\255'; Batteries.Unix.c_vkill = '\255';
  Batteries.Unix.c_veof = '\004'; Batteries.Unix.c_veol = '\255';
  Batteries.Unix.c_vmin = 1; Batteries.Unix.c_vtime = 0;
  Batteries.Unix.c_vstart = '\017'; Batteries.Unix.c_vstop = '\019'}
```

it seems that `ledit` will change your input, and you can not get `Unix.(tcgetattr stdin)` work.

The code below works in real terminal, but does not work in pseudo-terminals (like Emacs)

```
let read_passwd message = Unix.(
```

```

match
  try
    let default = tcgetattr stdin in
    let silent = {default with c_echo = false; c_echoe = false ;
                      c_echok = false; c_echonl = false ; } in
    Some (default, silent)
  with _ -> None
with
|None -> Legacy.input_line Pervasives.stdin
|Some (default, silent) ->
  print_string message ;
  Legacy.flush Pervasives.stdout ;
  tcsetattr stdin TCSANOW silent ;
  try
    let s = Legacy.input_line Pervasives.stdin in
    tcsetattr stdin TCSANOW default; s
  with x ->      tcsetattr stdin TCSANOW default; raise x

);;

```

Sometimes a program needs to start another and connect its standard input to a terminal (or pseudo-terminal). To achieve that, we must manually look among the pseudo-terminals(`/dev/tty[a-z][a-f0-9]`) and find one that is not already open. We can open this file and start the program with this file on its standard input.

The function *tcsendbreak* sends an interrupt to the peripheral. The second argument is the duration of the interrupt.

```
tcdrain, tcflush, tcflow, setsid
```

9. locks on files


```

Unix.lockf;;
- : Batteries.Unix.file_descr -> Batteries.Unix.lock_command ->
  int -> unit =

```

ocaml-expect

```

let p = X.spawn "ocaml" [|];;
val p : X.t = <abstr>
X.expect p ~fmatches:[(fun s -> Some s)] [] "";;
- : string = "          Objective Caml version 3.12.1"
X.send p "3;;\n";;
- : unit = ()
X.expect p ~fmatches:[(fun s -> Some s)] [] "";;
- : string = "- : int = 3"

```

not very powerful

12.1.3 chap3

12.1.4 practical ocaml

1. chap30

```

external functions_can_be_defined: unit -> unit = "int_c_code"

```

12.1.5 tricks

- ocamlobjinfo
analyzing ocaml obj info

```

ocamlobjinfo ./_build/src/batEnum.cmo
File ./_build/src/batEnum.cmo
Unit name: BatEnum
Interfaces imported:
  720848e0b508273805ef38d884a57618  Array
  c91c0bbb9f7670b10cdc0f2dcc57c5f9  Int32

```

```

42fecddd710bb96856120e550f33050d  BatEnum
d1bb48f7b061c10756e8a5823ef6d2eb  BatInterfaces
81da2f450287aeff11718936b0cb4546  BatValue_printer
6fdd8205a679c3020487ba2f941930bb  BatInnerIO
40bf652f22a33a7cfa05ee1dd5e0d7e4  Buffer
c02313bdd8cc849d89fa24b024366726  BatConcurrent
3dee29b414dd26a1cfca3bbdf20e7dfc  Char
db723a1798b122e08919a2bfed062514  Pervasives
227fb38c6dfc5c0f1b050ee46651eebe  CamlinternalLazy
9c85fb419d52a8fd876c84784374e0cf  List
79fd3a55345b718296e878c0e7bed10e  Queue
9cf8941f15489d84ebd11297f6b92182  Camlinternal00
b64305dcc933950725d3137468a0e434  ArrayLabels
64339e3c28b4a17a8ec728e5f20a3cf6  BatRef
3aeb33d11433c95bb62053c65665eb76  Obj
3b0ed254d84078b0f21da765b10741e3  BatMonad
aaa46201460de222b812caf2f6636244  Lazy
Uses unsafe features: YES
Primitives declared in this module:

ocamlobjinfo /Users/bob/SourceCode/ML/godi/lib/ocaml/std-lib/
    camlp4/camlp4lib.cma |grep Unit
Unit name: Camlp4_import
Unit name: Camlp4_config
Unit name: Camlp4

```

obj has many Units, each Unit itself also import some interfaces. ideas: you can parse the result to get an dependent graph.

- operator associativity

the **first** char decides @ → right ; ^ → right

```

# let (^|) a b = a - b;;
val ( ^| ) : int -> int -> int = <fun>
# 3 ^| 2 ^| 1;;
- : int = 2

```

- literals

30l => int32

30L => int64

30n => nativeint

- `{re ;_}` some labels were intentionally omitted
this is a new feature in recent ocaml, it will emit an warning otherwise
- Emacs
there are some many tricks I can only enum a few
 - capture the shell command `C-u M-!` to capture the shell-command `M-/`
shell-command-on-region
- **dirty** compiling

```
# let ic = Unix.open_process_in "ocamlc test.ml 2>&1";;
val ic : in_channel = <abstr>
# input_line ic;;
- : string = "File \"test.ml\", line 1, characters 0-1:"
# input_line ic;;
- : string = "Error: I/O error: test.ml: No such file or directory"
# input_line ic;;
Exception: End_of_file.
```

- `toplevel.lib.cma` (`toplevel/toploop.mli`)
- memory profiling
You can override a little ocaml-benchmark to measure the allocation rate of the GC. This gives you a pretty good understanding on the fact you are allocating too much or not.

```
(** Benchmark extension    @author Sylvain Le Gall
*)
```

```
open Benchmark;;
type t =
  {
    benchmark: Benchmark.t;
    memory_used: float;
  }
```

```

;;

let gc_wrap f x =
  (* Extend sample to add GC stat *)
  let add_gc_stat memory_used samples =
    List.map
      (fun (name, lst) ->
        name,
        List.map
          (fun bt ->
            {
              benchmark = bt;
              memory_used = memory_used;
            }
          )
        lst
      )
    samples
  in
  (* Call throughput1 and add GC stat *)
  let () =
    print_string "Cleaning memory before benchmark"; print_newline ();
    Gc.full_major ()
  in
  let allocated_before =
    Gc.allocated_bytes ()
  in
  let samples =
    f x
  in
  let () =

```

```

    print_string "Cleaning memory after benchmark"; print_newline ();
    Gc.full_major ()
in
let memory_used =
    ((Gc.allocated_bytes ()) -. allocated_before)
in
    add_gc_stat memory_used samples
;;

let throughput1
    ?min_count ?style
    ?fwidth    ?fdigits
    ?repeat    ?name
    seconds
    f x =

    (* Benchmark throughput1 as it should be called *)
    gc_wrap
    (throughput1
        ?min_count ?style
        ?fwidth    ?fdigits
        ?repeat    ?name
        seconds f) x
;;

let throughputN
    ?min_count ?style
    ?fwidth    ?fdigits
    ?repeat
    seconds name_f_args =
    List.flatten

```

```

(List.map
  (fun (name, f, args) ->
    throughput1
      ?min_count ?style
      ?fwidth    ?fdigits
      ?repeat    ~name:name
      seconds f args)
    name_f_args)
;;

let latency1
  ?min_cpu ?style
  ?fwidth  ?fdigits
  ?repeat  n
  ?name    f x =
gc_wrap
  (latency1
    ?min_cpu ?style
    ?fwidth  ?fdigits
    ?repeat  n
    ?name    f) x
;;

let latencyN
  ?min_cpu ?style
  ?fwidth  ?fdigits
  ?repeat
  n name_f_args =
List.flatten
(List.map
  (fun (name, f, args) ->
    latency1

```

```
        ?min_cpu    ?style
        ?fwidth     ?fdigits
        ?repeat     ~name:name
        n           f args)
    name_f_args)
;;
```

12.1.6 ocaml blogs

ygrek
michal
eigenclass
syntax
jambon
Xavier Clerc
Zheng li
xleroy/teaching
alaska
erratique
duthier
David Teller
john harisson
Mike Gordon
Robert Keller
alexott
Yoann Padioleau