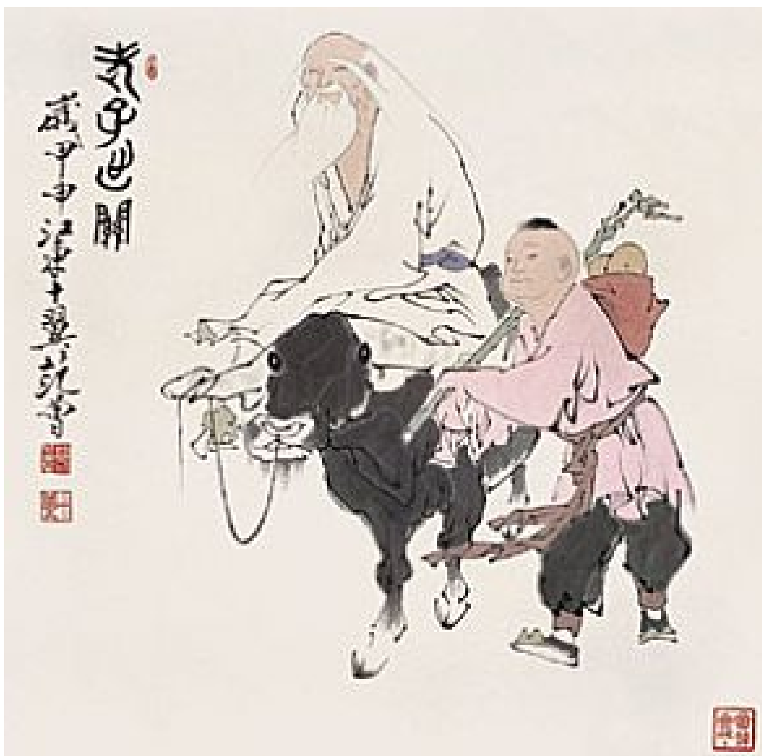
FUN OF PROGRAMMING

the tao produced one
one produced two
two produced three
three produced all things

by

hongbo zhang



University Of Pennsylvania

Work In Progress

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

Contents

Todo list

Chapter 1

Tool Chain

1.1 ocamlbuild

The reason for `ocamlbuild` in OCaml is to solve the complex scheme to when building camlp4. But it's very useful in other aspects as well.

Your code is in the `_build` directory. `ocamlbuild` copies the `needed` source files and compiles them. In `_build`, `_log` file contains 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 not appear outside of the `_build`). Sometimes when you want to mix c-stubs, you tag the .o object file `precious` or `-no-hygiene`

Important Compile Flags

option	comment
-quiet	
-verbose <level>	
-documentation	show rules and flags for a **specific** `_tags` 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 *.cma*
-libs <flag,...>	
-mod <module>	link to ocaml module
-mods	
-pkg <package>	link to *ocamlfind package*
-pkgs <...>	
-lflag <flag>	ocamlc link flags
-lflags	
-cflag	ocamlc comple flags
-cflags	
-yaccflag	Add to ocamlyacc flags, you can hack for `menhir`
-yaccflags	
-lexflag	
-lexflags	
-pp	preprocessing flagss
-tag <tag>	add to default tags
-tags	
-show-tags	for *debugging*,`ocamlbuild -show-tags target`
-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	
--	supply arguments

Simple Examples

```
ocamlbuild -quiet xx.native -- args
ocamlbuild -quite -use-ocamlfind xx.native -- args
```

You can pass flags to `ocamlc` at compile time. i.e, `-cflags -I,+lablgtk,-rectypes`

You can link 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`

You can also build a library with specicfic modules included using `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
```

mlpack file

You can alo use `mlpack` file to do hierachical packing

You can also make use of `_tags` file for convenience. Every source tree may have a `_tags` file, and each target may have 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 .}
```

You can digest the output to get a general idea of how tags file work. By preceding a tag with a minus sign, one can `remove` tags from one or more files.

The built-in `_tags` file as follows:

```
<**/*.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
```

You can do some experiment do verify it, create a empty directory, and make a dummy ml file, then type `ocamlbuild -show-tags test.ml`, you will get the output as follows

```
Tags for "test.ml": {. extension:ml, file:test.ml, ocaml, quiet .}
```

`<**/*.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`

Considering multiple directories:

Suppose our directory structure is as follows

```
   |---bar
   |---baz
   |---foo
```

Our tags file is

```
<bar> or <baz> : include
bash-3.2$ cat foo/main.ml
open Printf
let _ = begin
  print_int Barfile.i;
  print_int Bazfile.j;
end
```

Here module `Barfile` and `Bazfile` lies in directries `bar,baz`. So, after typing ocamlbuild in `toplevel directory`, then your directory structure is as follows

```
   |-_build
```

```
  |---bar
  |---baz
  |---foo
  |-bar
  |-baz
  |-foo
```

What `ocamlbuild` did is explicit if you read `_log`

```
bash-3.2$ cat _build/_log
### Starting build.
# Target: foo/main.ml.depends, tags: { extension:ml, file:foo/main.
   ml, ocaml, ocamldep, quiet, traverse }
/opt/godi/bin/ocamldep.opt -modules foo/main.ml > foo/main.ml.
   depends
# Target: bar/barfile.ml.depends, tags: { extension:ml, file:bar/
   barfile.ml, ocaml, ocamldep, quiet, traverse }
/opt/godi/bin/ocamldep.opt -modules bar/barfile.ml > bar/barfile.ml.
   depends
# Target: baz/bazfile.ml.depends, tags: { extension:ml, file:baz/
   bazfile.ml, ocaml, ocamldep, quiet, traverse }
/opt/godi/bin/ocamldep.opt -modules baz/bazfile.ml > baz/bazfile.ml.
   depends
# Target: bar/barfile.cmo, tags: { byte, compile, extension:cmo,
   extension:ml, file:bar/barfile.cmo, file:bar/barfile.ml, implem,
   ocaml, quiet, traverse }
/opt/godi/bin/ocamlc.opt -c -I bar -I baz -o bar/barfile.cmo bar/
   barfile.ml
# Target: baz/bazfile.cmo, tags: { byte, compile, extension:cmo,
   extension:ml, file:baz/bazfile.cmo, file:baz/bazfile.ml, implem,
   ocaml, quiet, traverse }
/opt/godi/bin/ocamlc.opt -c -I baz -I bar -o baz/bazfile.cmo baz/
   bazfile.ml
# Target: foo/main.cmo, tags: { byte, compile, extension:cmo,
   extension:ml, file:foo/main.cmo, file:foo/main.ml, implem, ocaml,
    quiet, traverse }
/opt/godi/bin/ocamlc.opt -c -I foo -I baz -I bar -o foo/main.cmo foo
   /main.ml
# Target: foo/main.byte, tags: { byte, dont_link_with, extension:
   byte, file:foo/main.byte, link, ocaml, program, quiet, traverse }
/opt/godi/bin/ocamlc.opt bar/barfile.cmo baz/bazfile.cmo foo/main.
   cmo -o foo/main.byte
# Compilation successful.
```

So, you can see that `-I` flags was added for each included directory and their source was copied to _build, `foo` was copied was due to our target `foo/main.byte`. They are still flat structure actually. Ocamlbuild still views each directory as source directory and do santity check. Each source tree should still be built using ocamlbuild, it's not easy to mix with other build tools. You can add `-I` flags by hand, but the relative path does not work. I did not find a perfect way to mix ocamlbuild with other build tools yet.

You can also group your targets `foo.itarget, foo.otarget`

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

Then you can say `ocamlbuild foo.otarget`

For preprocessing either `-pp` or tags `pp(cmd ...)`

For debugging and profiling either `.d.byte, .p.native` or `true:debug`

To build documentation, 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(1.1.3), *only* document of exposed modules are kept, not very useful. Add such a line in your `myocamlbuild.ml` plugin. `flag ["ocaml"; "doc"] & S[A"-keep-code"];` Or you can do it by hand `ocamlbuild -ocamldoc 'ocamlfind ocamldoc -keep-code' foo.docdir/index.html` `ocamldep` seems to be **lightweight**. It's weird when you have `mli` file, `-keep-code` does not work

Glob Patterns

With lex yacc, ocamlfind

`.mll .mly` supported by default, you can use menhir `-use-menhir` or add a line `true : use_menhir`

Add a line in tags file

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

Here `syntax_camlp4o` is translated by myocamlbuild.ml(1.1.3) 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 prepossessing
"prog.byte": package(lwt.unix)
```

There are two style to cooperate with syntax extension, one way is above, combined with ocamlfind, in most case it works, but it is not very well considering you want to build `.ml.ppo` and other stuff. The other way is to use `pp` directly, you could simlink your extension file to `camlp4 -where`. I found this way is more natural. There's another way which is used local(1.1.3), we will introduce it later.

We can see different styles here.

```
<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.syntax
<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** in the ocaml source tree. 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)
```

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

1.1.1 Principles

Rules

A rule is composed of triple (Tags, Targets → Dependencies). `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.

Plugin API Documentation

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 :
```

Here `sub_modules` is a helper function which will be introduced later(some ideas, combined with ocamlgraph and camlp4-parser to generate a graph?).

1.1.2 Practical bits

Useful API `Pathname.t,Tags.eltstring` 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 argument 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

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

It says when tags `ocaml, compile, thread` are met together, `-thread` option should be emitted.

```
(** module Command *)
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_virtuals *)
|Quote of spec
(* A string that should be quoted like a filename but isn't really
 one. *)
```

`module Options` contains refs to be configured

1.1.3 Plugin

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
(**

# This link should be created by your ./configure script
# The pointed directory contains the compiled files (.cmo, .cmi).
$ ln -s /path/to/your/alphaCaml/directory/ alphaLib

$ cat _tags
"alphaLib": include, precious

# it's very nice to make the whole directory precious, this is a way to mix
# different buiding unit.
*)
```

```ocaml
(* 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 the cmo.
       Note that you only need this declaration when the syntax extension is part of the
       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
```

Mixed with C stubs

My point is that tag your c code precious, then mv it into _build directory. Then link it by hand.

```
_tags:
<single_write.o> : precious

Makefile:
_build/single_write.o: single_write.o
  test -d $(LIB) || mkdir $(LIB)
  cp single_write.o $(LIB)
# tag single_write.o precious
write.cma:  _build/single_write.o write.cmo
  cd $(LIB); ocamlc -custom -a -o single_write.o write.cmo
```

Sometimes perfect solution does not exist, at least I don't find, write `myocamlbuild.ml` to drive the building process is not cost effective.

Another typical `myocamlbuild.ml` plugin.

```
open Ocamlbuild_plugin
open Command

let run_and_read      = Ocamlbuild_pack.My_unix.run_and_read
let blank_sep_strings = Ocamlbuild_pack.Lexers.blank_sep_strings
let find_packages () =
  blank_sep_strings &
    Lexing.from_string &
    run_and_read "ocamlfind list | cut -d' ' -f1"
(** ocamlfind can only handle these two flags *)
let find_syntaxes () = ["camlp4o"; "camlp4r"]

let trim_endline str =
  let len = String.length (str) in
  if len = 0 then str
  else if str.[len-1] = '\n'
  then String.sub str 0 (len-1)
  else str

(** list extensions, but not used here *)
let extensions () =
  let pas = List.filter
    (fun x ->
      String.contains_string x  0 "pa_" <> None) (find_packages ()) in
  let tbl = List.map
    (fun pkg ->
      let dir =
        trim_endline (run_and_read ("ocamlfind query " ^ pkg))in
      (pkg, dir)) pas in
  tbl

let debug = ref false

let site_lib () =
  trim_endline (run_and_read ("ocamlfind printconf destdir"))

let _ =
  if !debug then begin
    List.iter (fun (pkg,dir) -> Printf.printf "%s,%s\n" pkg dir)
      (extensions ());
    Printf.printf "%s\n" (site_lib())
  end
```

```
(* Menhir options *)
let menhir_opts = S
        [A"--dump";A"--explain"; A"--infer";]

let ocamlfind x = S[A"ocamlfind"; x]
module Default = struct
  let before_options () =
    Options.ocamlc     := ocamlfind & A"ocamlc";
    Options.ocamlopt   := ocamlfind & A"ocamlopt";
    Options.ocamldep   := ocamlfind & A"ocamldep";
    Options.ocamldoc   := ocamlfind & A"ocamldoc";
    Options.ocamlmktop := ocamlfind & A"ocamlmktop"
  let after_rules () =
  (*when one link an ocaml library/binary/package, should use -linkpkg*)
    flag ["ocaml"; "byte"; "link";"program"] & A"-linkpkg";
    flag ["ocaml"; "native"; "link";"program"] & A"-linkpkg";
    List.iter begin fun pkg ->
      flag ["ocaml"; "compile";  "pkg_"^pkg] & S[A"-package"; A pkg];
      flag ["ocaml"; "ocamldep"; "pkg_"^pkg] & S[A"-package"; A pkg];
      flag ["ocaml"; "doc";      "pkg_"^pkg] & S[A"-package"; A pkg];
      flag ["ocaml"; "link";     "pkg_"^pkg] & S[A"-package"; A pkg];
      flag ["ocaml"; "infer_interface"; "pkg_"^pkg] & S[A"-package"; A pkg];
      flag ["menhir"] menhir_opts; (* add support for menhir*)
    end (find_packages ());
  (* Like -package but for extensions syntax. Morover -syntax is
   * useless when linking. *)
    List.iter begin fun syntax ->
      flag ["ocaml"; "compile";  "syntax_"^syntax] & S[A"-syntax"; A syntax];
      flag ["ocaml"; "ocamldep"; "syntax_"^syntax] & S[A"-syntax"; A syntax];
      flag ["ocaml"; "doc";      "syntax_"^syntax] & S[A"-syntax"; A syntax];
      flag ["ocaml"; "infer_interface";  "syntax_"^syntax] & S[A"-syntax"; A syntax];
    end (find_syntaxes ());
  (* The default "thread" tag is not compatible with ocamlfind.
     Indeed, the default rules add the "threads.cma" or
     "threads.cmxa" options when using this tag. When using the
     "-linkpkg" option with ocamlfind, this module will then be
     added twice on the command line.
     To solve this, one approach is to add the "-thread" option when using
     the "threads" package using the previous plugin.
  *)
    flag ["ocaml"; "pkg_threads"; "compile"]  (S[A "-thread"]);
    flag ["ocaml"; "pkg_threads"; "link"]     (S[A "-thread"]);
    flag ["ocaml"; "pkg_threads"; "infer_interface"] (S[A "-thread"])
end
```

```ocaml
type actions =  (unit -> unit) list ref

let before_options : actions = ref []
and after_options : actions = ref []
and before_rules : actions = ref []
and after_rules : actions = ref []

let (+>) x l =
  l := x :: !l

let apply  plugin = begin
  Default.before_options +> before_options;
  Default.after_rules +> after_rules;
  (** for pa_ulex, you must create the symbol link by yourself*)
  (fun _ -> flag ["ocaml"; "pp"; "use_ulex"] (A"pa_ulex.cma")) +> after_rules;
  (fun _ -> flag ["ocaml"; "pp"; "use_bolt"] (A"bolt_pp.cmo")) +> after_rules;
  (fun _ ->
    flag ["ocaml"; "pp"; "use_bitstring"]
    (S[A"bitstring.cma"; A"bitstring_persistent.cma"; A"pa_bitstring.cmo"])) +> after_rules;
  (fun _ ->
    dep ["ocamldep"; "file:test/test_string.ml"]
      ["test/test_data/string.txt";
       "test/test_data/char.txt"]) +> after_rules;


  (* (fun _ -> *)
  (*   dep ["file:test/test_string.byte"] ["test/test_data/string.txt"]) +> after_rules; *)
  plugin ();
  dispatch begin function
    | Before_options -> begin
      List.iter (fun f -> f () ) !before_options;
    end
    | After_rules -> begin
      List.iter (fun f -> f ()) !after_rules;
    end
    | _ -> ()
  end ;
end


let _ =
  (** customize your plugin here *)
  let plugin = (fun _ -> ())  in
  apply plugin
```

```
(**
   customized local filter
*)
(* let _ = dispatch begin function *)
(*   |After_rules -> begin  *)
(*     flag ["ocaml"; "pp"; "use_filter"] (A"pa_filter.cma"); *)
(*     dep ["ocaml"; "ocamldep"; "use_filter"] ["pa_filter.cma"]; *)
(*   end  *)
(*   |_ -> () *)
(* end *)
```

Interaction with git (.gitignore)

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

1.2 godi

Godi is a convenient pkg-manager for ocaml libraries, not very friendly to Mac Users, however.

- `godi_console`
- Useful Paths

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

- Some Useful commands

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

1.3 ocamlfind

Link to findlib

Some Useful commands *ocamlfind browser -all* open documentation in ocamlbrowser *ocamlfind browser -package batteries*

Syntax extension support

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

ocamlfind can only handle flag `camlp4r`, `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

Some useful directories

```
#directory ''_build'' ;; #directory ''+camlp4'' ;; #load ''...''
```

You can also trace labels (ignore labels in function types), and do something about warnings, customize your printing function (`print_depth print_length`).

Here we mainly focus on how to Hack Toploop

Redirect

```
Toploop.execute_phrase
-: bool -> formatter -> Parsetree.toplevel_phrase -> bool
Toploop.read_interactive_input
- : (string -> string -> int -> int * bool) ref = (* topdirs.cmi *)
BatHashtbl.keys Toploop.directive_table |> BatEnum.iter (BatString.print stdout |- print_newline);;

(* print_depth use principal untrace_all load list trace show
directory u cd install_printer print_length labels remove_printer
camlp4o quit untrace thread camlp4r require warnings hide rectypes pwd
predicates warn_error *)

Topdirs.(dir_load,dir_use,dir_install_printer,dir_trace,dir_untrace,dir_untrace_all,load_file,dir_quit,dir_cd);;

- : (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 -> unit)
```

A snippet for redirect the output of toplevel

```
(** dynamic evaluate the phrase in toplevel and return the result
    as a string
*)
let eval s =
  let l = Lexing.from_string s in
  let ph = !Toploop.parse_toplevel_phrase l in
  let buf = Buffer.create 1000 in
  let fmt = Format.formatter_of_buffer buf in
  try
    let _ = Toploop.execute_phrase true fmt ph in
```

```
    Buffer.contents buf
  with
      _ -> invalid_arg ("eval: " ^ s )
```

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 toploop.
 * 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 "/path/to/findlib/findlib.cma";
  Topdirs.dir_load Format.err_formatter "/path/to/findlib/findlib_top.cma";
);;
```

topfind.ml

Ideas : we can write **some utils** to check code later, Yes, 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 ocamldoc

A special comment is associated to an element if it is placed before or after the element.

A special comment before an element is associated to this element if :

There is no blank line or another special comment between the special comment and the element. However, a regular comment can occur between the special comment and the element.

The special comment is not already associated to the previous element.

The special comment is not the first one of a toplevel module. A special comment after an element is associated to this element if there is no blank line or comment between the special comment and the element.

There are two exceptions: for type constructors and record fields in type definitions, the associated comment can only be placed after the constructor or field definition, without blank lines or other comments between them. The special comment for a type constructor with another type constructor following must be placed before the '|' character separating the two constructors.

Some elements support only a subset of all @-tags. Tags that are not relevant to the documented element are simply ignored. For instance, all tags are ignored when documenting type constructors, record fields, and class inheritance clauses. Similarly, a `@param` tag on a class instance variable is ignored

Markup language

```
text ::= (text_element)+
text_element ::=
| {[0-9]+ text}format text as a section header; the integer
   following
{ indicates the sectioning level.
  | {[0-9]+:label text} same, but also associate the name label to
     the
  current point. This point can be referenced by its fully-qualified
  label in a {! command, just like any other element.
    | {b text}set text in bold.
    | {i text}set text in italic.
    | {e text}emphasize text.
    | {C text}center text.
    | {L text}left align text.
```

```
    | {R text}right align text.
    | {ul list}build a list.
    | {ol list}build an enumerated list.
    | {{:string}text}put a link to the given address (given as a
    string) on the given text.
    | [string]set the given string in source code style.
    | {[string]}set the given string in preformatted source code
    style.
    | {v string v}set the given string in verbatim style.
    | {% string %}take the given string as raw LATEX code.
      | {!string}insert a reference to the element named
      string. string must be a fully qualified element name, for
      example Foo.Bar.t. The kind of the referenced element can be
      forced (useful when various elements have the same qualified
      name) with the following syntax: {!kind: Foo.Bar.t} where kind
      can be module, modtype, class, classtype, val, type, exception
         ,
      attribute, method or section.
      | {!modules: string string ...}insert an index table for the
      given module names. Used in HTML only.
      | {!indexlist}insert a table of links to the various indexes
      (types, values, modules, ...). Used in HTML only.
      | {^ text}set text in superscript.
      | {_ text}set text in subscript.
      | escaped_stringtypeset the given string as is; special
      characters ('{', '}', '[', ']' and '@') must beescaped by a
         '\'
      | blank_lineforce a new line.

list ::=
  | ({- text})+
  | ({li text})+
```

Predefined tags

The folowing table gives the list of predefined @-tags, with their syntax and meaning. @author stringThe author of the element. One author by @author tag. There may be several @author tags for the same element.

@deprecated textThe text should describe when the element was deprecated, what to use as a replacement, and possibly the reason for deprecation.

@param id textAssociate the given description (text) to the given parameter name id. This tag is used for functions, methods, classes and functors.

@raise Exc textExplain that the element may raise the exception Exc.

@return textDescribe the return value and its possible values. This tag is used for functions and methods.

@see <url> textAdd a reference to the URL between '<' and '>' with the given text as comment.

@see 'filename' textAdd a reference to the given file name (written between single quotes), with the given text as comment.

@see “document name” textAdd a reference to the given document name (written between double quotes), with the given text as comment.

@since stringIndicate when the element was introduced.

@before v textAssociate the given description (text) to the given version v in order to document compatibility issues.

@version string: The version number for the element.

1.6 git

- ignore set

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

Chapter 2

Lexing

2.1 Lexing

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.` So, you should do symbol link and write a very simple plugin like this

```
let _ =
  (** customize your plugin here *)
  let plugin = (fun _ -> begin
    (fun _ -> flag ["ocaml"; "pp"; "use_ulex"] (A"pa_ulex.cma")) +> after_rules;
  end
  )  in
  apply plugin
```

And your tags file should be like this

```
<test1.ml> : camlp4o, use_ulex
<test1.{cmo,byte,native}> : pkg_ulex
```

You can analyze the `_build/_log` to know how it works.

```
### Starting build.
# Target: test1.ml.depends, tags: { camlp4o, extension:ml,
# file:test1.ml, ocaml, ocamldep, quiet, traverse, use_ulex }
ocamlfind ocamldep -pp 'camlp4o pa_ulex.cma' -modules test1.ml >
# test1.ml.depends # cached
```

The nice thing is that you can `ocamlbuild test1.pp.ml` directly to view the source. A nice feature.

Ulex does not support `as` syntax as ocamllex. Its extended syntax is like this:

```
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 prepossessing, 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'] ['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 l.(0) l.(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 l.(0))

(** ocaml spuports 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))  | (newline  | eof )  ->
    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()
```

You can also use myocamlbuild plugin to write a dependency to avoid all these problems. But I am not sure which is one is better, copy paste or using `INCLUDE` macro. Maybe we are over-engineering.

2.1.1 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 (OCamltype : `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
or
ocamlbuild basic_ulex.pp.ml
```

A basic Example

Here is the example of simple basic lexer

```
open Ulexing
open BatPervasives
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"
```

Notice that `ocamlnet` provides a fast `Ulexing module`, probably you can change its interal representation.

parser-help to co-ordinate men-hir and ulex

I have written a helper package to make lexer more available

2.2 Ocamlllex

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_linenum 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 ocamlyacc

   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 Ocamlyacc

We mainly cover menhir here.

A grammar is mainly composed of four elements(terminals, non-terminals, production rulls, 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 gammar

```
/* 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 associatitvity

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

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

1. The associatitvity 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 associatitvity

```
%{
  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.

Error Recovery

By default, the parser function raises exception after calling *parse_error* The ocamlyacc 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 symbolposition. 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} | arrayasgn {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}
;
arrayasgn: 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 ocamlyacc can not detect typo TIMEs */

/*
here we add assiocaitivity 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 ruel(in the order given by the source file)

3. A shift/reduce conflict is resolved by comparing the *predecence of the rule to be reduced* with the *precedence of the token to be shifted*. If the predecence of the rule is higher, then the rule will be reducecd; if the predecence 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*

3.2 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)	ϵ | X	α option, if X : α	
ioption(X)			inlined
boption(X)			bool
loption(X)	ϵ |X	α list, if X : α list	
pair(X,Y)	X Y	$\alpha \times \beta$	
separated_pair(X,sep,Y)	X sep Y	$\alpha \times \beta$	
preceded(opening,X)	opening X	α, if X : α	
terminated(X,closing)	X closing	α, if X : α	
delimited(opening, X closing)	opening X closing	α, if X : α	
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. *)
```

```ocaml
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

Camlp4 stands for Preprocess-Pretty-Printer for `OCaml`, it's extremely powerful and hard to grasp as well.

4.1 Breif intro to parser

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
```

4.2 Basics Structure

4.2.1 Experimentation Environment

On Toplevel **via findlib**

```
ocaml
#camlp4r;
#load "camlp4rf.cma"
```

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
```

Using **script** (oco using original syntax is ok), but when using ocr(default revised syntax), it will have some problems, i.e. .ocamlinit, and other startup files including findlib, so you'd better not use revised syntax in the toplevel. here I use .ocamlinitr (revised syntax) for ocr, but it still have some problem with findlib, (internal, hard to solve), but it 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
```

4.2.2 Command Options

```
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
```

You can grep all executables relevant to camlp4 using a one-line bash as follows:

```
find $(dirname $(which ocaml)) -type f -perm -og+rx | grep camlp4 |
while read ss ; do echo $(basename $ss) ; done
```

```
camlp4
camlp4boot
camlp4o
camlp4o.opt
camlp4of
camlp4of.opt
camlp4oof
camlp4oof.opt
camlp4orf
camlp4orf.opt
camlp4prof
camlp4r
camlp4r.opt
camlp4rf
camlp4rf.opt
mkcamlp4
```

```
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
     directory.
  -intf <file>     Parse <file> as an interface, whatever its
     extension.
  -impl <file>     Parse <file> as an implementation, whatever its
     extension.
  -str <string>    Parse <string> as an implementation.
  -unsafe          Generate unsafe accesses to array and strings.
  -noassert        Obsolete, do not use this option.
  -verbose         More verbose in parsing errors.
  -loc <name>      Name of the location variable (default: _loc).
  -QD <file>       Dump quotation expander result in case of syntax
     error.
  -o <file>        Output on <file> instead of standard output.
  -v               Print Camlp4 version and exit.
  -version         Print Camlp4 version number and exit.
  -vnum            Print Camlp4 version number and exit.
  -no_quot         Don't parse quotations, allowing to use, e.g.
     "<:>" as token.
  -loaded-modules  Print the list of 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)
  -ignore          ignore the next argument
  --               Deprecated, does nothing
```

Useful options

`-str`

`-loaded-modules`

`-parser <name>` load the parser *Camlp4Parsers/<name>.cm(o|a|xs)*

`-printer <name>` load the printer *Camlp4Printerss/<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 lineoptions are all handled in /Camlp4Bin.ml |

`Camlp4o -h` There are options added by loaded object files

`-add_locations` Add locations as comment

`-no_comments`

`-curry-constr`

`-sep` Use this string between parsers

4.2.3 Module Components

	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

That reflective is true means when extending the syntax of the host language will **also extend the embedded one**

Camlp4r

1. parser
   RP, RPP(RevisedParserParser)

2. printer
   OCaml

Camlp4rf (extended from camlp4r)

1. parser
   RP,RPP, GrammarP, ListComprehension, MacroP, QuotationExpander

2. printer

   OCaml

Camlp4o (extended from camlp4r)

1. parser

   OP, OPP, RP,RPP

Camlp4of (extended from camlp4o)

1. parser

   GrammarParser, ListComprehension, MacroP, QuotatuinExpander

2. printer

4.2.4 Simple Experiment

Without `ocamlbuild`, `ocamlfind`, a simple build would be like this

```
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))
```

`camlp4of -p r -str 'you code'` is a good way to learn the corresponding revised syntax. You can also **customize** you options in your filter

```
let _ =  begin
  Camlp4.Options.add "-abstract" (Arg.Set abstract)
 "Use abstract types for semi opaque ones";
  Options.add "-concrete" (Arg.Clear abstract)
 "Use concrete types for semi opaque ones";
end
```

4.2.5 SourceCode Exploration

Now we begin to explore the structure of camlp4 Source Code. First let's have a look at the directory structure of `camlp4` directory.

```
|<.>
|--<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>
```

`Camlp4.PreCast (Camlp4/PreCast.ml)`

Struct directory has module *Loc, Dynloader Functor, Camlp4Ast.Make, Token.Make, Lexer.Make, Grammar.Static.Make, Quotation.Make*

File `Camlp4.PreCast` **Re-Export** such files

```
Struct/Loc.ml
Struct/Camlp4Ast.mlast
Struct/Token.ml
Struct/Grammar/Parser.ml
Struct/Grammar/Static.ml
Struct/Lexer.mll
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
```

```
(** Camlp4.PreCast.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 (* *, +, +++*%, %#@... *)
  | LIDENT        of string (* lower case identifier *)
  | UIDENT        of string (* upper case identifier *)
  | ESCAPED_IDENT of string (* ( * ), ( ++##> ), ( foo ) *)
  | INT           of int and string  (* `INT(i,is)  42, 0xa0, 0XffFFff, 0b1010101, 0O644, 0o644 *)
  | INT32         of int32 and string (* 42l, 0xa0l... *)
  | INT64         of int64 and string (* 42L, 0xa0L... *)
  | NATIVEINT     of nativeint and string (* 42n, 0xa0n... *)
  | FLOAT         of float and string (* 42.5, 1.0, 2.4e32 *)
  | CHAR          of char and string  (* with escaping *)
  | STRING        of string and string (* with escaping *)
  | LABEL         of string (* *)
  | OPTLABEL      of string
  | QUOTATION     of Sig.quotation (* << foo >> <:quot_name< bar >> <@loc_name<bar>>
     type quotation ={ q_name : string; q_loc : string;
     q_shift : int; q_contents : string; } *)
```

```
  | ANTIQUOT      of string and string    (* $foo$  $anti_name:foo$ $`anti_name:foo$ *)
  | COMMENT       of string
  | BLANKS        of string               (* some non newline blanks *)
  | NEWLINE                               (* interesting *)
  | LINE_DIRECTIVE of int and option string  (* #line 42, #foo "string" *)
  | 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;

(** intersting, so you can make your own syntax totally but it's not
    easy to do this in toplevel, probably will crash. We will give a
    nice solution later *)

module MakeSyntax (U : sig end) = OCamlInitSyntax.Make Ast Gram Quotation;
module Syntax = MakeSyntax (struct end);
module AstFilters = Struct.AstFilters.Make Ast; (** Functorize *)
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;
```

4.2.6 Fully Utilize Camlp4 Parser and Printers

If we want to define our special syntax, we could do it like this

```
(** The problem for the toplevel is that you can not find the library
    of the parser?  Even if you succeed, it may change the hook of toplevel,
    not encouraged yet.
*)
open Camlp4.PreCast;

(** Set to Original Parser *)
module MSyntax=
    (Camlp4OCamlParser.Make
```

```
    (Camlp4OCamlRevisedParser.Make
    (Camlp4.OCamlInitSyntax.Make Ast Gram Quotation)));

(** Two styles of printers *)
module OPrinters = Camlp4.Printers.OCaml.Make(MSyntax);
module RPrinters = Camlp4.Printers.OCamlr.Make(MSyntax);


value  parse_exp = MSyntax.Gram.parse_string MSyntax.expr
  (MSyntax.Loc.mk "<string>");

(** Object-oriented paradigm *)
value print_expo =  (new OPrinters.printer ())#expr Format.std_formatter;
value print_expr = (new RPrinters.printer ())#expr Format.std_formatter;
value (|>) x f = f x;

value parse_and_print str = str
  |> parse_exp
  |> (fun x -> begin
    print_expo x;
    Format.print_newline ();
    print_expr x ;
    Format.print_newline ();
  end );

begin
  List.iter parse_and_print
    ["let a = 3 in fun x -> x + 3  ";
     "fun x -> match x with Some  y -> y | None -> 0 ";
    ];
end ;

(**
   output
let a = 3 in fun x -> x + 3
let a = 3 in fun x -> x + 3
fun x -> match x with | Some y -> y | None -> 0
fun x -> match x with [ Some y -> y | None -> 0 ]
*)
```

Here we see we could get any parser, any printer we want, very convenient. Notice `Gram.Entry` is **dynamic, extensible**

4.2.7 OCamlInitSyntax

```
(** File Camlp4.OCamlInitSyntax.ml
    Ast -> Gram -> Quotation -> Camlp4Syntax
    Given Ast, Gram, Quotation, we produce Camlp4Syntax
 *)
module 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
                    and module Ast = Ast
                    and module Token = Gram.Token
                    and module Gram = Gram
                    and module Quotation = Quotation
= struct

  module Loc     = Ast.Loc;
  module Ast     = Ast;
  module Gram    = Gram;
  module Token   = Gram.Token;
  open Sig;

  (* Warnings *)
  type warning = Loc.t -> string -> unit;
  value default_warning loc txt = Format.eprintf "<W> %a: %s@." Loc.print loc txt;
  value current_warning = ref default_warning;
  value print_warning loc txt = current_warning.val loc txt;

  value a_CHAR = Gram.Entry.mk "a_CHAR";
  value a_FLOAT = Gram.Entry.mk "a_FLOAT";
  value a_INT = Gram.Entry.mk "a_INT";
  value a_INT32 = Gram.Entry.mk "a_INT32";
  value a_INT64 = Gram.Entry.mk "a_INT64";
  value a_LABEL = Gram.Entry.mk "a_LABEL";
  value a_LIDENT = Gram.Entry.mk "a_LIDENT";
  value a_NATIVEINT = Gram.Entry.mk "a_NATIVEINT";
  value a_OPTLABEL = Gram.Entry.mk "a_OPTLABEL";
  value a_STRING = Gram.Entry.mk "a_STRING";
  value a_UIDENT = Gram.Entry.mk "a_UIDENT";
  value a_ident = Gram.Entry.mk "a_ident";
  value amp_ctyp = Gram.Entry.mk "amp_ctyp";
  value and_ctyp = Gram.Entry.mk "and_ctyp";
  value match_case = Gram.Entry.mk "match_case";
  value match_case0 = Gram.Entry.mk "match_case0";
```

```
value binding = Gram.Entry.mk "binding";
value class_declaration = Gram.Entry.mk "class_declaration";
value class_description = Gram.Entry.mk "class_description";
value class_expr = Gram.Entry.mk "class_expr";
value class_fun_binding = Gram.Entry.mk "class_fun_binding";
value class_fun_def = Gram.Entry.mk "class_fun_def";
value class_info_for_class_expr = Gram.Entry.mk "class_info_for_class_expr";
value class_info_for_class_type = Gram.Entry.mk "class_info_for_class_type";
value class_longident = Gram.Entry.mk "class_longident";
value class_longident_and_param = Gram.Entry.mk "class_longident_and_param";
value class_name_and_param = Gram.Entry.mk "class_name_and_param";
value class_sig_item = Gram.Entry.mk "class_sig_item";
value class_signature = Gram.Entry.mk "class_signature";
value class_str_item = Gram.Entry.mk "class_str_item";
value class_structure = Gram.Entry.mk "class_structure";
value class_type = Gram.Entry.mk "class_type";
value class_type_declaration = Gram.Entry.mk "class_type_declaration";
value class_type_longident = Gram.Entry.mk "class_type_longident";
value class_type_longident_and_param = Gram.Entry.mk "class_type_longident_and_param";
value class_type_plus = Gram.Entry.mk "class_type_plus";
value comma_ctyp = Gram.Entry.mk "comma_ctyp";
value comma_expr = Gram.Entry.mk "comma_expr";
value comma_ipatt = Gram.Entry.mk "comma_ipatt";
value comma_patt = Gram.Entry.mk "comma_patt";
value comma_type_parameter = Gram.Entry.mk "comma_type_parameter";
value constrain = Gram.Entry.mk "constrain";
value constructor_arg_list = Gram.Entry.mk "constructor_arg_list";
value constructor_declaration = Gram.Entry.mk "constructor_declaration";
value constructor_declarations = Gram.Entry.mk "constructor_declarations";
value ctyp = Gram.Entry.mk "ctyp";
value cvalue_binding = Gram.Entry.mk "cvalue_binding";
value direction_flag = Gram.Entry.mk "direction_flag";
value direction_flag_quot = Gram.Entry.mk "direction_flag_quot";
value dummy = Gram.Entry.mk "dummy";
value entry_eoi = Gram.Entry.mk "entry_eoi";
value eq_expr = Gram.Entry.mk "eq_expr";
value expr = Gram.Entry.mk "expr";
value expr_eoi = Gram.Entry.mk "expr_eoi";
value field_expr = Gram.Entry.mk "field_expr";
value field_expr_list = Gram.Entry.mk "field_expr_list";
value fun_binding = Gram.Entry.mk "fun_binding";
value fun_def = Gram.Entry.mk "fun_def";
value ident = Gram.Entry.mk "ident";
value implem = Gram.Entry.mk "implem";
value interf = Gram.Entry.mk "interf";
value ipatt = Gram.Entry.mk "ipatt";
value ipatt_tcon = Gram.Entry.mk "ipatt_tcon";
```

```
value label = Gram.Entry.mk "label";
value label_declaration = Gram.Entry.mk "label_declaration";
value label_declaration_list = Gram.Entry.mk "label_declaration_list";
value label_expr = Gram.Entry.mk "label_expr";
value label_expr_list = Gram.Entry.mk "label_expr_list";
value label_ipatt = Gram.Entry.mk "label_ipatt";
value label_ipatt_list = Gram.Entry.mk "label_ipatt_list";
value label_longident = Gram.Entry.mk "label_longident";
value label_patt = Gram.Entry.mk "label_patt";
value label_patt_list = Gram.Entry.mk "label_patt_list";
value labeled_ipatt = Gram.Entry.mk "labeled_ipatt";
value let_binding = Gram.Entry.mk "let_binding";
value meth_list = Gram.Entry.mk "meth_list";
value meth_decl = Gram.Entry.mk "meth_decl";
value module_binding = Gram.Entry.mk "module_binding";
value module_binding0 = Gram.Entry.mk "module_binding0";
value module_declaration = Gram.Entry.mk "module_declaration";
value module_expr = Gram.Entry.mk "module_expr";
value module_longident = Gram.Entry.mk "module_longident";
value module_longident_with_app = Gram.Entry.mk "module_longident_with_app";
value module_rec_declaration = Gram.Entry.mk "module_rec_declaration";
value module_type = Gram.Entry.mk "module_type";
value package_type = Gram.Entry.mk "package_type";
value more_ctyp = Gram.Entry.mk "more_ctyp";
value name_tags = Gram.Entry.mk "name_tags";
value opt_as_lident = Gram.Entry.mk "opt_as_lident";
value opt_class_self_patt = Gram.Entry.mk "opt_class_self_patt";
value opt_class_self_type = Gram.Entry.mk "opt_class_self_type";
value opt_class_signature = Gram.Entry.mk "opt_class_signature";
value opt_class_structure = Gram.Entry.mk "opt_class_structure";
value opt_comma_ctyp = Gram.Entry.mk "opt_comma_ctyp";
value opt_dot_dot = Gram.Entry.mk "opt_dot_dot";
value row_var_flag_quot = Gram.Entry.mk "row_var_flag_quot";
value opt_eq_ctyp = Gram.Entry.mk "opt_eq_ctyp";
value opt_expr = Gram.Entry.mk "opt_expr";
value opt_meth_list = Gram.Entry.mk "opt_meth_list";
value opt_mutable = Gram.Entry.mk "opt_mutable";
value mutable_flag_quot = Gram.Entry.mk "mutable_flag_quot";
value opt_polyt = Gram.Entry.mk "opt_polyt";
value opt_private = Gram.Entry.mk "opt_private";
value private_flag_quot = Gram.Entry.mk "private_flag_quot";
value opt_rec = Gram.Entry.mk "opt_rec";
value rec_flag_quot = Gram.Entry.mk "rec_flag_quot";
value opt_sig_items = Gram.Entry.mk "opt_sig_items";
value opt_str_items = Gram.Entry.mk "opt_str_items";
value opt_virtual = Gram.Entry.mk "opt_virtual";
value virtual_flag_quot = Gram.Entry.mk "virtual_flag_quot";
```

```
value opt_override = Gram.Entry.mk "opt_override";
value override_flag_quot = Gram.Entry.mk "override_flag_quot";
value opt_when_expr = Gram.Entry.mk "opt_when_expr";
value patt = Gram.Entry.mk "patt";
value patt_as_patt_opt = Gram.Entry.mk "patt_as_patt_opt";
value patt_eoi = Gram.Entry.mk "patt_eoi";
value patt_tcon = Gram.Entry.mk "patt_tcon";
value phrase = Gram.Entry.mk "phrase";
value poly_type = Gram.Entry.mk "poly_type";
value row_field = Gram.Entry.mk "row_field";
value sem_expr = Gram.Entry.mk "sem_expr";
value sem_expr_for_list = Gram.Entry.mk "sem_expr_for_list";
value sem_patt = Gram.Entry.mk "sem_patt";
value sem_patt_for_list = Gram.Entry.mk "sem_patt_for_list";
value semi = Gram.Entry.mk "semi";
value sequence = Gram.Entry.mk "sequence";
value do_sequence = Gram.Entry.mk "do_sequence";
value sig_item = Gram.Entry.mk "sig_item";
value sig_items = Gram.Entry.mk "sig_items";
value star_ctyp = Gram.Entry.mk "star_ctyp";
value str_item = Gram.Entry.mk "str_item";
value str_items = Gram.Entry.mk "str_items";
value top_phrase = Gram.Entry.mk "top_phrase";
value type_constraint = Gram.Entry.mk "type_constraint";
value type_declaration = Gram.Entry.mk "type_declaration";
value type_ident_and_parameters = Gram.Entry.mk "type_ident_and_parameters";
value type_kind = Gram.Entry.mk "type_kind";
value type_longident = Gram.Entry.mk "type_longident";
value type_longident_and_parameters = Gram.Entry.mk "type_longident_and_parameters";
value type_parameter = Gram.Entry.mk "type_parameter";
value type_parameters = Gram.Entry.mk "type_parameters";
value typevars = Gram.Entry.mk "typevars";
value use_file = Gram.Entry.mk "use_file";
value val_longident = Gram.Entry.mk "val_longident";
value value_let = Gram.Entry.mk "value_let";
value value_val = Gram.Entry.mk "value_val";
value with_constr = Gram.Entry.mk "with_constr";
value expr_quot = Gram.Entry.mk "quotation of expression";
value patt_quot = Gram.Entry.mk "quotation of pattern";
value ctyp_quot = Gram.Entry.mk "quotation of type";
value str_item_quot = Gram.Entry.mk "quotation of structure item";
value sig_item_quot = Gram.Entry.mk "quotation of signature item";
value class_str_item_quot = Gram.Entry.mk "quotation of class structure item";
value class_sig_item_quot = Gram.Entry.mk "quotation of class signature item";
value module_expr_quot = Gram.Entry.mk "quotation of module expression";
value module_type_quot = Gram.Entry.mk "quotation of module type";
value class_type_quot = Gram.Entry.mk "quotation of class type";
```

```
value class_expr_quot = Gram.Entry.mk "quotation of class expression";
value with_constr_quot = Gram.Entry.mk "quotation of with constraint";
value binding_quot = Gram.Entry.mk "quotation of binding";
value rec_binding_quot = Gram.Entry.mk "quotation of record binding";
value match_case_quot = Gram.Entry.mk "quotation of match_case (try/match/function case)";
value module_binding_quot = Gram.Entry.mk "quotation of module rec binding";
value ident_quot = Gram.Entry.mk "quotation of identifier";
value prefixop = Gram.Entry.mk "prefix operator (start with '!', '?', '~')";
value infixop0 = Gram.Entry.mk "infix operator (level 0) (comparison operators, and some others)";
value infixop1 = Gram.Entry.mk "infix operator (level 1) (start with '^', '@')";
value infixop2 = Gram.Entry.mk "infix operator (level 2) (start with '+', '-')";
value infixop3 = Gram.Entry.mk "infix operator (level 3) (start with '*', '/', '%')";
value infixop4 = Gram.Entry.mk "infix operator (level 4) (start with \"**\") (right assoc)";

EXTEND Gram
  top_phrase:
    [ [ `EOI -> None ] ]
  ;
END;

module AntiquotSyntax = struct
  module Loc  = Ast.Loc;
  module Ast  = Sig.Camlp4AstToAst Ast;
  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 wrap directive_handler pa init_loc cs =
  let rec loop loc =
    let (pl, stopped_at_directive) = pa loc cs in
    match stopped_at_directive with
    [ Some new_loc ->
      let pl =
        match List.rev pl with
```

```
          [ [] -> assert False
          | [x :: xs] -> 
              match directive_handler x with
              [ None -> xs
              | Some x -> [x :: xs] ] ]
        in (List.rev pl) @ (loop new_loc)
      | None -> pl ]
    in loop init_loc;

  value parse_implem ?(directive_handler = fun _ -> None) _loc cs =
    let l = wrap directive_handler (Gram.parse implem) _loc cs in
    <:str_item< $list:l$ >>;

  value parse_interf ?(directive_handler = fun _ -> None) _loc cs =
    let l = wrap directive_handler (Gram.parse interf) _loc cs in
    <:sig_item< $list:l$ >>;

  value print_interf ?input_file:(_) ?output_file:(_) _ = failwith "No interface printer";
  value print_implem ?input_file:(_) ?output_file:(_) _ = failwith "No implementation printer";
end;
```

`OCamlInitSyntax` does not do too many things, first, it initialize all the entries needed later (they are all blank, to be extended by your functor), after initialization, it created a submodule `AntiquotSyntax`, and initialize two entries `antiquot_expr` and `antiquot_patt`, very easy.

4.2.8 Camlp4.Sig

`Camlp4.Sig.ml` All are signatures, there's even no `Camlp4.Sig.mli`.

4.2.9 Camlp4.Struct.Camlp4Ast.mlast

This file use macro`INCLUDE` to include `Camlp4.Camlp4Ast.parital.ml` for reuse.

4.2.10 AstFilters

Notice an interesting module `AstFilters`, is defined by `Struct.AstFilters.Make`, which we see in `Camlp4.PreCast.ml` It's very simple actually.

```
(**AstFilters.ml*)
module Make (Ast : Sig.Camlp4Ast)
```

```
: Sig.AstFilters with module Ast = Ast
= struct

  module Ast = Ast;

  type filter 'a = 'a -> 'a;

  value interf_filters = Queue.create ();
  value fold_interf_filters f i = Queue.fold f i interf_filters;
  value implem_filters = Queue.create ();
  value fold_implem_filters f i = Queue.fold f i implem_filters;
  value topphrase_filters = Queue.create ();
  value fold_topphrase_filters f i = Queue.fold f i topphrase_filters;

  value register_sig_item_filter f = Queue.add f interf_filters;
  value register_str_item_filter f = Queue.add f implem_filters;
  value register_topphrase_filter f = Queue.add f topphrase_filters;
end;

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

4.2.11 Camlp4.Register

Let's see what's in `Register` module

```
(**
   Camlp4.Register.ml
*)
module PP = Printers;
open PreCast;

type parser_fun 'a =
  ?directive_handler:('a -> option 'a) -> PreCast.Loc.t -> Stream.t char -> 'a;

type printer_fun 'a =
  ?input_file:string -> ?output_file:string -> 'a -> unit;

(** a lot of parsers to be modified *)
value sig_item_parser = ref (fun ?directive_handler:(_) _ _ -> failwith "No interface parser");
value str_item_parser = ref (fun ?directive_handler:(_) _ _ -> failwith "No implementation parser");
```

```
value sig_item_printer = ref (fun ?input_file:(_) ?output_file:(_) _ -> failwith "No interface printer");
value str_item_printer = ref (fun ?input_file:(_) ?output_file:(_) _ -> failwith "No implementation printer");

(** a queue of callbacks *)
value callbacks = Queue.create ();

value loaded_modules = ref [];

(** iterate each callback*)
value iter_and_take_callbacks f =
  let rec loop () = loop (f (Queue.take callbacks)) in
  try loop () with [ Queue.Empty -> () ];

(** register module, add to the Queue *)
value declare_dyn_module (m:string) (f:unit->unit) =
  begin
    (* let () = Format.eprintf "declare_dyn_module: %s@." m in *)
    loaded_modules.val := [ m :: loaded_modules.val ];
    Queue.add (m, f) callbacks;
  end;

value register_str_item_parser f = str_item_parser.val := f;
value register_sig_item_parser f = sig_item_parser.val := f;
value register_parser f g =
  do { str_item_parser.val := f; sig_item_parser.val := g };
value current_parser () = (str_item_parser.val, sig_item_parser.val);

value register_str_item_printer f = str_item_printer.val := f;
value register_sig_item_printer f = sig_item_printer.val := f;
value register_printer f g =
  do { str_item_printer.val := f; sig_item_printer.val := g };
value current_printer () = (str_item_printer.val, sig_item_printer.val);

module Plugin (Id : Sig.Id) (Maker : functor (Unit : sig end) -> sig end) = struct
  declare_dyn_module Id.name (fun _ -> let module M = Maker (struct end) in ());
end;

module SyntaxExtension (Id : Sig.Id) (Maker : Sig.SyntaxExtension) = struct
  declare_dyn_module Id.name (fun _ -> let module M = Maker Syntax in ());
end;

module OCamlSyntaxExtension
  (Id : Sig.Id) (Maker : functor (Syn : Sig.Camlp4Syntax) -> Sig.Camlp4Syntax) =
struct
  declare_dyn_module Id.name (fun _ -> let module M = Maker Syntax in ());
end;
```

```
module SyntaxPlugin (Id : Sig.Id) (Maker : functor (Syn : Sig.Syntax) -> sig end) = struct
  declare_dyn_module Id.name (fun _ -> let module M = Maker Syntax in ());
end;

module Printer
  (Id : Sig.Id) (Maker : functor (Syn : Sig.Syntax)
                                -> (Sig.Printer Syn.Ast).S) =
struct
  declare_dyn_module Id.name (fun _ ->
    let module M = Maker Syntax in
    register_printer M.print_implem M.print_interf);
end;

module OCamlPrinter
  (Id : Sig.Id) (Maker : functor (Syn : Sig.Camlp4Syntax)
                                -> (Sig.Printer Syn.Ast).S) =
struct
  declare_dyn_module Id.name (fun _ ->
    let module M = Maker Syntax in
    register_printer M.print_implem M.print_interf);
end;

module OCamlPreCastPrinter
  (Id : Sig.Id) (P : (Sig.Printer PreCast.Ast).S) =
struct
  declare_dyn_module Id.name (fun _ ->
    register_printer P.print_implem P.print_interf);
end;

module Parser
  (Id : Sig.Id) (Maker : functor (Ast : Sig.Ast)
                                -> (Sig.Parser Ast).S) =
struct
  declare_dyn_module Id.name (fun _ ->
    let module M = Maker PreCast.Ast in
    register_parser M.parse_implem M.parse_interf);
end;

module OCamlParser
  (Id : Sig.Id) (Maker : functor (Ast : Sig.Camlp4Ast)
                                -> (Sig.Parser Ast).S) =
struct
  declare_dyn_module Id.name (fun _ ->
    let module M = Maker PreCast.Ast in
    register_parser M.parse_implem M.parse_interf);
end;
```

```
module OCamlPreCastParser
  (Id : Sig.Id) (P : (Sig.Parser PreCast.Ast).S) =
struct
  declare_dyn_module Id.name (fun _ ->
    register_parser P.parse_implem P.parse_interf);
end;

module AstFilter
  (Id : Sig.Id) (Maker : functor (F : Sig.AstFilters) -> sig end) =
struct
  declare_dyn_module Id.name (fun _ -> let module M = Maker AstFilters in ());
end;

sig_item_parser.val := Syntax.parse_interf;
str_item_parser.val := Syntax.parse_implem;

module CurrentParser = struct
  module Ast = Ast;
  value parse_interf ?directive_handler loc strm =
    sig_item_parser.val ?directive_handler loc strm;
  value parse_implem ?directive_handler loc strm =
    str_item_parser.val ?directive_handler loc strm;
end;

module CurrentPrinter = struct
  module Ast = Ast;
  value print_interf ?input_file ?output_file ast =
    sig_item_printer.val ?input_file ?output_file ast;
  value print_implem ?input_file ?output_file ast =
    str_item_printer.val ?input_file ?output_file ast;
end;

value enable_ocaml_printer () =
  let module M = OCamlPrinter PP.OCaml.Id PP.OCaml.MakeMore in ();

value enable_ocamlr_printer () =
  let module M = OCamlPrinter PP.OCamlr.Id PP.OCamlr.MakeMore in ();

(* value enable_ocamlrr_printer () =
  let module M = OCamlPrinter PP.OCamlrr.Id PP.OCamlrr.MakeMore in ();    *)

value enable_dump_ocaml_ast_printer () =
  let module M = OCamlPrinter PP.DumpOCamlAst.Id PP.DumpOCamlAst.Make in ();

value enable_dump_camlp4_ast_printer () =
  let module M = Printer PP.DumpCamlp4Ast.Id PP.DumpCamlp4Ast.Make in ();
```

```
value enable_null_printer () =
  let module M = Printer PP.Null.Id PP.Null.Make in ();
```

Notice that functors Plugin, SyntaxExtension, OCamlSyntaxExtension, OCamlSyntaxExtension, SyntaxPlugin, they did the same thing essentially, they apply the second Funtor to Syntax(Camlp4.PreCast.Syntax).

Functors Printer, OCamlPrinter, OCamlPrinter, they did the same thing, apply the Make to Syntax, then register it.

Functors Parser, OCamlParser, did the same thing.

Functors AstFilter did nothing interesting.

It sticks to the toplevel

```
sig_item_parser.val := Syntax.parse_interf;
str_item_parser.val := Syntax.parse_implem;
```

.

It mainly hook some global variables, like `Camlp4.Register.loaded_modlules`, but there's no fresh meat in this file. To conclude, Register did nothing, except making your code more modular, or register your syntax extension.

As we said, another utility, you can inspect what modules you have loaded in toplevel:

```
Camlp4.Register.loaded_modules;;
- : string list ref =
{Pervasives.contents =
  ["Camlp4GrammarParser"; "Camlp4OCamlParserParser";
   "Camlp4OCamlRevisedParserParser"; "Camlp4OCamlParser";
   "Camlp4OCamlRevisedParser"]}
```

4.2.12 Camlp4Ast

```
(** CAMLP4AST RevisedSyntax *)
type loc = Loc.t
and meta_bool =
  [ BTrue
  | BFalse
  | BAnt of string ]
```

```
and rec_flag =
  [ ReRecursive
  | ReNil
  | ReAnt of string ]
and direction_flag =
  [ DiTo
  | DiDownto
  | DiAnt of string ]
and mutable_flag =
  [ MuMutable
  | MuNil
  | MuAnt of string ]
and private_flag =
  [ PrPrivate
  | PrNil
  | PrAnt of string ]
and virtual_flag =
  [ ViVirtual
  | ViNil
  | ViAnt of string ]
and override_flag =
  [ OvOverride
  | OvNil
  | OvAnt of string ]
and row_var_flag =
  [ RvRowVar
  | RvNil
  | RvAnt of string ]
and meta_option 'a =
  [ ONone
  | OSome of 'a
  | OAnt of string ]
and meta_list 'a =
  [ LNil
  | LCons of 'a and meta_list 'a
  | LAnt of string ]
```

```
and ident =
  [ IdAcc of loc and ident and ident (* i . i *)
(*  <:ident< a . b >>   Access in module
   IdAcc of Loc.t and ident and ident *)
  | IdApp of loc and ident and ident (* i i *)
```

```
(*  <:ident< a b >>
   Application
   IdApp of Loc.t and ident and ident *)
  | IdLid of loc and string (* foo *)
(* <:ident< $lid:i$ >>
   Lowercase identifier
   IdLid of Loc.t and string
*)
  | IdUid of loc and string (* Bar *)
(* <:ident< $uid:i$ >>
   Uppercase identifier
   IdUid of Loc.t and string
*)
  | IdAnt of loc and string (* $s$ *)
(* <:ident< $anti:s$ >>
   Antiquotation
   IdAnt of Loc.t and string
*)
 ]
(*  <:ident< $list:x$ >>
   list of accesses
   Ast.idAcc_of_list x  use IdAcc to accumulate to a list
 *)
and ctyp =
  [ TyNil of loc
  (*<:ctyp< >>  Empty typeTyNil of Loc.t *)
  | TyAli of loc and ctyp and ctyp (* t as t *)  (* list 'a as 'a *)
  (* <:ctyp< t as t >>  Type aliasing
     TyAli of Loc.t and ctyp and ctyp *)
  | TyAny of loc (* _ *)
  (*  <:ctyp< _ >> Wildcard TyAny of Loc.t *)
  | TyApp of loc and ctyp and ctyp (* t t *)  (* list 'a *)
  (* <:ctyp< t t >> Application TyApp of Loc.t and ctyp and ctyp *)
  | TyArr of loc and ctyp and ctyp (* t -> t *)  (* int -> string *)
  (* <:ctyp< t -> t >>Arrow TyArr of Loc.t and ctyp and ctyp       *)
  | TyCls of loc and ident (* #i *)  (* #point *)
  (* <:ctyp< #i >> Class type TyCls of Loc.t and ident     *)
  | TyLab of loc and string and ctyp (* ~s:t *)
  (* <:ctyp< ~s >>  Label type TyLab of Loc.t and string and ctyp    *)
  | TyId  of loc and ident (* i *)  (* Lazy.t *)
  (* <:ctyp< $id:i$ >>  Type identifier of TyId of Loc.t and ident *)
  (* <:ctyp< $lid:i$ >> TyId (_, IdLid (_, i)) *)
  (* <:ctyp< $uid:i$ >>  TyId (_, IdUid (_, i)) *)
  | TyMan of loc and ctyp and ctyp (* t == t *)  (* type t = [ A | B ] == Foo.t *)
  (* <:ctyp< t == t >>  Type manifest TyMan of Loc.t and ctyp and ctyp       *)

  (* type t 'a 'b 'c = t constraint t = t constraint t = t *)
```

```
| TyDcl of loc and string and list ctyp and ctyp and list (ctyp * ctyp)
(* <:ctyp< type t 'a 'b 'c = t constraint t = t constraint t = t >>
   Type declaration
   TyDcl of Loc.t and string and list ctyp and ctyp and list (ctyp * ctyp) *)

(* < (t)? (..)? > *) (* < move : int -> 'a .. > as 'a  *)
| TyObj of loc and ctyp and row_var_flag
(* <:ctyp< < (t)? (..)? > >> Object type TyObj of Loc.t and ctyp and meta_bool       *)

| TyOlb of loc and string and ctyp (* ?s:t *)
(* <:ctyp< ?s:t >>  Optional label type TyOlb of Loc.t and string and ctyp       *)
| TyPol of loc and ctyp and ctyp (* ! t . t *) (* ! 'a . list 'a -> 'a *)
(* <:ctyp< ! t . t >> = Polymorphic type TyPol of Loc.t and ctyp and ctyp       *)
| TyQuo of loc and string (* 's *)
(* <:ctyp< 's >>' TyQuo of Loc.t and string       *)
| TyQuP of loc and string (* +'s *)
(* <:ctyp< +'s >> TyQuP of Loc.t and string       *)
| TyQuM of loc and string (* -'s *)
(* <:ctyp< -'s >> TyQuM of Loc.t and string       *)
| TyVrn of loc and string (* `s *)
(* <:ctyp< `s >> Polymorphic variant of TyVrn of Loc.t and string       *)
| TyRec of loc and ctyp (* { t } *) (* { foo : int ; bar : mutable string } *)
(* <:ctyp< { t } >>  Record TyRec of Loc.t and ctyp *)

| TyCol of loc and ctyp and ctyp (* t : t *)
(* <:ctyp< t : t >>Field declarationTyCol of Loc.t and ctyp and ctyp       *)
| TySem of loc and ctyp and ctyp (* t; t *)
(* <:ctyp< t; t >>Semicolon-separated type listTySem of Loc.t and ctyp and ctyp       *)
| TyCom of loc and ctyp and ctyp (* t, t *)
(* <:ctyp< t, t >>Comma-separated type listTyCom of Loc.t and ctyp and ctyp *)
| TySum of loc and ctyp (* [ t ] *) (* [ A of int and string | B ] *)
(* <:ctyp< [ t ] >>Sum typeTySum of Loc.t and ctyp       *)
| TyOf  of loc and ctyp and ctyp (* t of t *) (* A of int *)
(* <:ctyp< t of t >>TyOf of Loc.t and ctyp and ctyp       *)
| TyAnd of loc and ctyp and ctyp (* t and t *)
(* <:ctyp< t and t >>TyAnd of Loc.t and ctyp and ctyp *)
| TyOr  of loc and ctyp and ctyp (* t | t *)
(* <:ctyp< t | t >>"Or" pattern between typesTyOr of Loc.t and ctyp and ctyp       *)
| TyPrv of loc and ctyp (* private t *)
(* <:ctyp< private t >>Private type TyPrv of Loc.t and ctyp       *)
| TyMut of loc and ctyp (* mutable t *)
(* <:ctyp< mutable t >>  Mutable type TyMut of Loc.t and ctyp       *)
| TyTup of loc and ctyp (* ( t ) *) (* (int * string) *)
(* <:ctyp< ( t ) >> or <:ctyp< $tup:t$ >>  Tuple of TyTup of Loc.t and ctyp       *)
| TySta of loc and ctyp and ctyp (* t * t *)
(* <:ctyp< t * t >> TySta of Loc.t and ctyp and ctyp       *)
| TyVrnEq of loc and ctyp (* [ = t ] *)
```

```
  (* <:ctyp< [ = t ] >>  TyVrnEq of Loc.t and ctyp       *)
  | TyVrnSup of loc and ctyp (* [ > t ] *)
  (* <:ctyp< [ > t ] >> open polymorphic variant type TyVrnSup of Loc.t and ctyp       *)
  | TyVrnInf of loc and ctyp (* [ < t ] *)
  (* <:ctyp< [ < t ] >>  closed polymorphic variant type with no known tags
      TyVrnInf of Loc.t and ctyp       *)
  | TyVrnInfSup of loc and ctyp and ctyp (* [ < t > t ] *)
  (*  <:ctyp< [ < t > t ] >> closed polymorphic variant type with some known tags
      TyVrnInfSup of Loc.t and ctyp and ctyp
  *)
  | TyAmp of loc and ctyp and ctyp (* t & t *)
  (* <:ctyp< t & t >>conjuntive type in polymorphic variants
     TyAmp of Loc.t and ctyp and ctyp   *)
  | TyOfAmp of loc and ctyp and ctyp (* t of & t *)
  (* <:ctyp< $t1$ of & $t2$ >>Special (impossible) constructor (t1)
     that has both no arguments and arguments compatible with t2 at the
     same time.TyOfAmp of Loc.t and ctyp and ctyp *)
  | TyPkg of loc and module_type (* (module S) *)
  (* <:ctyp<(module S) >>  TyPkg of loc and module_type    *)
  | TyAnt of loc and string (* $s$ *)
  (* <:ctyp< $anti:s$ >>AntiquotationTyAnt of Loc.t and string       *)
  (*<:ctyp< $list:x$ >>list of accumulated ctyps
  depending on context,
  Ast.tyAnd_of_list,
  Ast.tySem_of_list,
  Ast.tySta_of_list,
  Ast.tyOr_of_list,
  Ast.tyCom_of_list,
  Ast.tyAmp_of_list

  In a closed variant type <:ctyp< [ < $t1$ > $t2$ ] >> the type t2 must
    not be the empty type; use a TyVrnInf node in this case.

  Type conjuctions are stored in a TyAmp tree, use Camlp4Ast.list_of_ctyp and
  Camlp4Ast.tyAmp_of_list to convert from and to a list of types.

  Variant constructors with arguments and polymorphic variant
  constructors with arguments are both represented with a TyOf
  node. For variant types the first TyOf type is an uppercase
  identifier (TyId), for polymorphic variant types it is an TyVrn
  node.

  Constant variant constructors are simply represented as
  uppercase identifiers (TyId). Constant polymorphic variant
  constructors take a TyVrn node.  *)
]
and patt =
```

```
[ PaNil of loc
(* <:patt< >>Empty patternPaNil of Loc.t *)
| PaId  of loc and ident (* i *)
(* <:patt< $id:i$ >>IdentifierPaId of Loc.t and ident       *)
(* <:patt< $lid:i$ >>PaId (_, IdLid (_, i)) *)
(* <:patt< $uid:i$ >>PaId (_, IdUid (_, i)) *)
| PaAli of loc and patt and patt (* p as p *) (* (Node x y as n) *)
(* <:patt< ( p as p ) >>AliasPaAli of Loc.t and patt and patt       *)
| PaAnt of loc and string (* $s$ *)
(* <:patt< $anti:s$ >>AntiquotationPaAnt of Loc.t and string       *)
| PaAny of loc (* _ *)
(* <:patt< _ >>WildcardPaAny of Loc.t       *)
| PaApp of loc and patt and patt (* p p *) (* fun x y -> *)
(* <:patt< p p >>ApplicationPaApp of Loc.t and patt and patt       *)
| PaArr of loc and patt (* [| p |] *)
(* <:patt< [| p |] >>ArrayPaArr of Loc.t and patt       *)
| PaCom of loc and patt and patt (* p, p *)
(* <:patt< p, p >>Comma-separated pattern listPaCom of Loc.t and patt and patt       *)
| PaSem of loc and patt and patt (* p; p *)
(* <:patt< p; p >>Semicolon-separated pattern listPaSem of Loc.t and patt and patt       *)
| PaChr of loc and string (* c *) (* 'x' *)
(* <:patt< $chr:c$ >>CharacterPaChr of Loc.t and string       *)
| PaInt of loc and string
(* <:patt< $int:i$ >>IntegerPaInt of Loc.t and string       *)
| PaInt32 of loc and string
(* <:patt< $int32:i$ >>Int32PaInt32 of Loc.t and string       *)
| PaInt64 of loc and string
(* <:patt< $int64:i$ >>Int64PaInt64 of Loc.t and string       *)
| PaNativeInt of loc and string
(* <:patt< $nativeint:i$ >>NativeIntPaNativeInt of Loc.t and string       *)
| PaFlo of loc and string
(* <:patt< $flo:f$ >>FloatPaFlo of Loc.t and string       *)
| PaLab of loc and string and patt (* ~s or ~s:(p) *)
(* <:patt< ~s >> <:patt< s:(p) >>LabelPaLab of Loc.t and string and patt       *)

(* ?s or ?s:(p) *)
| PaOlb of loc and string and patt
(* <:patt< ?s >> <:patt< ?s:(p) >>Optional labelPaOlb of Loc.t and string and patt       *)

(* ?s:(p = e) or ?(p = e) *)
| PaOlbi of loc and string and patt and expr
(* <:patt< ?s:(p = e) >> <:patt< ?(p = e) >
   >Optional label with default valuePaOlbi of Loc.t and string and patt and expr       *)

| PaOrp of loc and patt and patt (* p | p *)
(* <:patt< p | p >>OrPaOrp of Loc.t and patt and patt       *)
| PaRng of loc and patt and patt (* p .. p *)
```

```
(* <:patt< p .. p >>Pattern rangePaRng of Loc.t and patt and patt *)
| PaRec of loc and patt (* { p } *)
(* <:patt< { p } >>RecordPaRec of Loc.t and patt *)
| PaEq  of loc and ident and patt (* i = p *)
(* <:patt< i = p >>EqualityPaEq of Loc.t and ident and patt       *)
| PaStr of loc and string (* s *)
(* <:patt< $str:s$ >>StringPaStr of Loc.t and string *)
| PaTup of loc and patt (* ( p ) *)
(* <:patt< ( $tup:p$ ) >>TuplePaTup of Loc.t and patt       *)
| PaTyc of loc and patt and ctyp (* (p : t) *)
(* <:patt< (p : t) >>Type constraintPaTyc of Loc.t and patt and ctyp       *)
| PaTyp of loc and ident (* #i *)
(* <:patt< #i >>PaTyp of Loc.t and ident
   used in polymorphic variants
*)
| PaVrn of loc and string (* `s *)
(* <:patt< `s >>Polymorphic variantPaVrn of Loc.t and string   *)
| PaLaz of loc and patt (* lazy p *)
(* <:patt< lazy x >> *)
]
(* <:patt< $list:x$ >>list of accumulated patts depending on context,
   Ast.paCom_of_list, Ast.paSem_of_list Tuple elements are wrapped in a
   PaCom tree. The utility functions Camlp4Ast.paCom_of_list and
   Camlp4Ast.list_of_patt convert from and to a list of tuple
   elements.  *)
and expr =
 [ ExNil of loc
    (* <:expr< >> *)
 | ExId  of loc and ident (* i *)
    (* <:expr< $id:i$ >> notice that antiquot id requires ident directly *)
    (* <:expr< $lid:i$ >> ExId(_,IdLid(_,i)) *)
    (* <:expr< $uid:i$ >> ExId(_, IdUid(_,i)) *)
 | ExAcc of loc and expr and expr (* e.e *)
    (* <:expr< $e1$.$e2$ >> Access in module ? *)
 | ExAnt of loc and string (* $s$ *)
    (* <:expr< $anti:s$ >> *)
 | ExApp of loc and expr and expr (* e e *)
    (* <:expr< $e1$ $e2$ >> Application *)
 | ExAre of loc and expr and expr (* e.(e) *)
    (* <:expr< $e$.($e$) >> Array access  *)
 | ExArr of loc and expr (* [| e |] *)
    (* <:expr< [|$e$| ] Array declaration *)
 | ExSem of loc and expr and expr (* e; e *)
    (* <:expr< $e$; $e$ >>  *)
 | ExAsf of loc (* assert False *)
    (* <:expr< assert False >> *)
 | ExAsr of loc and expr (* assert e *)
```

```
    (* <:expr< assert $e$ >>  *)
| ExAss of loc and expr and expr (* e := e *)
    (* <:expr< $e$ := $e$ >>  *)
| ExChr of loc and string (* 'c' *)
    (* <:exp< $`chr:s$ >> Character *)
| ExCoe of loc and expr and ctyp and ctyp (* (e : t) or (e : t :> t) *)
    (* <:expr< ($e$:> $t$) >> <:expr< ($e$ : $t1$ :> $t2$ ) >>
       The first ctyp is populated by TyNil
    *)
| ExFlo of loc and string (* 3.14 *)
    (* <:expr< $flo:f$ >> *)
    (* <:expr< $`flo:f$ >>  ExFlo(_,string_of_float f) *)

(* for s = e to/downto e do { e } *)
| ExFor of loc and string and expr and expr and direction_flag and expr
    (* <:expr< for $s$ = $e1$ to/downto $e2$ do { $e$  } >>  *)
| ExFun of loc and match_case (* fun [ mc ] *)
    (* <:expr< fun [ $a$ ] >>  *)
| ExIfe of loc and expr and expr and expr (* if e then e else e *)
    (* <:expr< if $e$ then $e$ else $e$ >>  *)
| ExInt of loc and string (* 42 *)
    (* <:expr< $int:i$ >> *)
    (* <:expr< $`int:i$ >> ExInt(_, string_of_int i) *)
| ExInt32 of loc and string
    (* <:expr< $int32:i$ >>
       <:expr< $`int32:i$ >>
    *)
| ExInt64 of loc and string
    (* <:expr< $int64:i$ >> *)
    (* <:expr< $`int64:i$ >>  *)
| ExNativeInt of loc and string
    (* <:expr< $nativeint:i$ >> <:expr< $`nativeint:i$ >>  *)
| ExLab of loc and string and expr (* ~s or ~s:e *)
    (* <:expr< ~ $s$ >> ExLab (_, s, ExNil) *)
    (* <:expr< ~ $s$ : $e$ >>  *)
| ExLaz of loc and expr (* lazy e *)
    (* <:expr< lazy $e$ >>  *)


| ExLet of loc and rec_flag and binding and expr
    (* <:expr< let $b$ in $e$ >> *)
    (* <:expr< let rec $b$ in $e$ >>    *)

| ExLmd of loc and string and module_expr and expr
    (* <:expr< let module $s$ = $me$ in $e$ >>  *)
```

```
| ExMat of loc and expr and match_case
    (* <:expr< match $e$ with [ $a$ ] >>  *)

(* new i *)
| ExNew of loc and ident
    (* <:expr< new $id:i$ >>  new object *)
    (* <:expr< new $lid:str$ >>  *)

(* object ((p))? (cst)? end *)
| ExObj of loc and patt and class_str_item
    (* <:expr< object ( ($p$))? ($cst$)? end >>  object declaration *)

(* ?s or ?s:e *)
| ExOlb of loc and string and expr
    (* <:expr< ? $s$ >>      Optional label  *)
    (* <:expr< ? $s$ : $e$ >>  *)

| ExOvr of loc and rec_binding
(* <:expr< {< $rb$  >} >>  *)

| ExRec of loc and rec_binding and expr
    (* <:expr< { $b$ } >> *)
    (* <:expr< {($e$ ) with $b$ } >>  *)
| ExSeq of loc and expr
    (* <:expr< do { $e$ } >> *)
    (* <:expr< $seq:e$ >> *)
    (* another way to help you figure out the type *)
    (* type let f e = <:expr< $seq:e$ >> in the toplevel            *)

| ExSnd of loc and expr and string
    (* <:expr< $e$ # $s$ >> METHOD call  *)

| ExSte of loc and expr and expr
    (* <:expr< $e$.[$e$] >> String access  *)

| ExStr of loc and string
    (* <:expr< $str:s$ >> "\n" -> "\n" *)
    (* <:expr< $`str:s$ >> "\n" -> "\\n" *)

| ExTry of loc and expr and match_case
    (* <:expr< try $e$ with [ $a$ ] >>  *)


| ExTup of loc and expr
    (* <:expr< ( $tup:e$ ) >>  *)

| ExCom of loc and expr and expr
```

```
    (* <:expr< $e$, $e$ >>  *)

(* (e : t) *)
| ExTyc of loc and expr and ctyp
    (* <:expr< ($e$ : $t$ ) Type constraint  *)

| ExVrn of loc and string
    (* <:expr< `$s$ >>  *)

| ExWhi of loc and expr and expr
    (* <:expr< while $e$ do { $e$ } >>  *)

| ExOpI of loc and ident and expr
    (* <:expr< let open $id:i$ in $e$ >>  *)

| ExFUN of loc and string and expr
    (* <:expr< fun (type $s$ ) -> $e$  >> *)
    (* let f x (type t) y z = e *)

| ExPkg of loc and module_expr
   (* (module ME : S) which is represented as (module (ME : S)) *)
]
and module_type =
  (**
     mt ::=
     | (* empty *)
     | ident
     | functor (s : mt) -> mt
     | 's
     | sig sg end
     | mt with wc
     | $s$
  *)
  [ MtNil of loc

  | MtId  of loc and ident
  (* i *)  (* A.B.C *)
  (* <:module_type< $id:ident$ >> named module type  *)

  | MtFun of loc and string and module_type and module_type
  (* <:module_type< functor ($uid:s$ : $mtyp:mta$ ) -> $mtyp:mtr$ >> *)

  | MtQuo of loc and string
  (* 's *)

  | MtSig of loc and sig_item
  (* sig sg end *)
```

```
    (* <:module_type< sig $sigi:sig_items$ end >>  *)

    | MtWit of loc and module_type and with_constr
    (* mt with wc *)
    (* <:module_type< $mtyp:mt$ with $with_constr:with_contr$ >>  *)
    | MtOf of loc and module_expr
    (* module type of m *)

    | MtAnt of loc and string
    (* $s$ *)
]
  (** Several with-constraints are stored in an WcAnd tree. Use
      Ast.wcAnd_of_list and Ast.list_of_with_constr to convert from and to a
      list of with-constraints.  Several signature items are stored in an
      SgSem tree. Use Ast.sgSem_of_list and Ast.list_of_sig_item to convert
      from and to a list of signature items. *)
and sig_item =
    (*
       sig_item, sg ::=
   | (* empty *)
   | class cict
   | class type cict
   | sg ; sg
   | #s
   | #s e
   | exception t
   | external s : t = s ... s
   | include mt
   | module s : mt
   | module rec mb
   | module type s = mt
   | open i
   | type t
   | value s : t
   | $s$
   lacking documentation !!
    *)
  [ SgNil of loc

    (* class cict *)
    (* <:sig_item< class $s$ >>;; *)
    (* <:sig_item< class $typ:s$ >>;; *)
    | SgCls of loc and class_type

    (* class type cict *)
    (* <:sig_item< class type $s$ >>;; *)
    (* <:sig_item< class type $typ:s$ >>;;  *)
```

```
| SgClt of loc and class_type

(* sg ; sg *)
| SgSem of loc and sig_item and sig_item

(* # s or # s e ???  *)
(* Directive  *)
| SgDir of loc and string and expr

(* exception t *)
| SgExc of loc and ctyp

(* external s : t = s ... s *)
(*  <:sig_item< external $lid:id$ : $typ:type$ = $str_list:string_list$ >>
    another antiquot str_list
*)
| SgExt of loc and string and ctyp and meta_list string

(* include mt *)
| SgInc of loc and module_type

(* module s : mt *)
(* <:sig_item< module $uid:id$ : $mtyp:mod_type$ >>
   module Functor declaration
*)
(**
   <:sig_item< module $uid:mid$ ( $uid:arg$ : $mtyp:arg_type$ ) : $mtyp:res_type$ >>
   -->
   <:sig_item< module $uid:mid$ : functor ( $uid:arg$ : $mtyp:arg_type$ ) -> $mtyp:res_type$ >>
*)
| SgMod of loc and string and module_type

(* module rec mb *)
| SgRecMod of loc and module_binding

(* module type s = mt *)
(* <:sig_item< module type $uid:id$ = $mtyp:mod_type$ >>
   module type declaration
*)
(**
   <:sig_item< module type $uid:id$ >> abstract module type
   -->
   <:sig_item< module type $uid:id$ = $mtyp:<:module_type< >>$ >>
*)
| SgMty of loc and string and module_type

(* open i *)
```

```
 | SgOpn of loc and ident

  (* type t *)
  (* <:sig_item< type $typ:type$ >>  *)
 (** <:sig_item< type $lid:id$ $p1$ ... $pn$ = $t$ constraint $c1l$
    = $c1r$ ... constraint $cnl$ = $cnr$ >>

    type declaration
    SgTyp
    of Loc.t and (TyDcl of Loc.t and id and [p1;...;pn] and t and
    [(c1l, c1r); ... (cnl, cnr)]) *)
 | SgTyp of loc and ctyp

  (* value s : t *)
  (* <:sig_item< value $lid:id$ : $typ:type$ >>  *)
 | SgVal of loc and string and ctyp

 | SgAnt of loc and string (* $s$ *) ]
(** An exception is treated like a single type constructor. For
   exception declarations the type should be either a type
   identifier (TyId) or a type constructor (TyOf).

   Abstract module type declarations (i.e., module type
   declarations without equation) are represented with the empty
   module type.

   Mutually recursive type declarations (separated by
   and) are stored in a TyAnd tree. Use Ast.list_of_ctyp and
   Ast.tyAnd_of_list to convert to and from a list of type
   declarations.

   The quotation parser for types (<:ctyp< ... >>) does not parse
   type declarations. Type declarations must therefore be embedded
   in a sig_item or str_item quotation.

   There seems to be no antiquotation syntax for a list of type
   parameters and a list of constraints inside a type
   declaration. The existing form can only be used for a fixed
   number of type parameters and constraints.

   Complete class and class type declarations (including name and
   type parameters) are stored as class types.

   Several "and" separated class or class type declarations are
   stored in a CtAnd tree, use Ast.list_of_class_type and
   Ast.ctAnd_of_list to convert to and from a list of class
   types.  *)
```

```
and with_constr =
    (**
       with_constraint, with_constr, wc ::=
   | wc and wc
   | type t = t
   | module i = i
    *)
  [ WcNil of loc

    (* type t = t *)
    (* <:with_constr< type $typ:type_1$ = $typ:type_2$ >>  *)
    | WcTyp of loc and ctyp and ctyp

    (* module i = i *)
    (* <:with_constr< module $id:ident_1$ = $id:ident_2$ >>  *)
    | WcMod of loc and ident and ident

    (* type t := t *)
    | WcTyS of loc and ctyp and ctyp

    (* module i := i *)
    | WcMoS of loc and ident and ident

    (* wc and wc *)
    (* <:with_constr< $with_constr:wc1$ and $with_constr:wc2$ >> *)
    | WcAnd of loc and with_constr and with_constr

    | WcAnt of loc and string (* $s$ *)
]
  (** Several with-constraints are stored in an WcAnd tree. Use
      Ast.wcAnd_of_list and Ast.list_of_with_constr to convert from and
      to a list of with-constraints. *)
and binding =
  (**  binding, bi ::=
   | bi and bi
   | p = e *)
  [ BiNil of loc

    (* bi and bi *)  (* let a = 42 and c = 43 *)
    (* <:binding< $b1$ and $b2$ >>  *)
    | BiAnd of loc and binding and binding

    (* p = e *)  (* let patt = expr *)
    (* <:binding< $pat:pattern$ = $exp:expression$ >>
       <:binding< $p$ = $e$ >> ;; both are ok
    *)
    (**
```

```
        <:binding< $pat:f$ $pat:x$ = $exp:ex$ >>
        -->
        <:binding< $pat:f$ = fun $pat:x$ -> $exp:ex$ >>

        <:binding< $pat:p$ : $typ:type$ = $exp:ex$ >>
        typed binding -->
        <:binding< $pat:p$ = ( $exp:ex$ : $typ:type$ ) >>

        <:binding< $pat:p$ :> $typ:type$ = $exp:ex$ >>
        coercion binding -->
        <:binding< $pat:p$ = ( $exp:ex$ :> $typ:type$ ) >>
    *)
    | BiEq  of loc and patt and expr

    | BiAnt of loc and string (* $s$ *)
    (**
        The utility functions Camlp4Ast.biAnd_of_list and
        Camlp4Ast.list_of_bindings convert between the BiAnd tree of
        parallel bindings and a list of bindings.  The utility
        functions Camlp4Ast.binding_of_pel and pel_of_binding convert
        between the BiAnd tree and a pattern * expression lis
    *)  ]
and rec_binding =
    (** record bindings
         record_binding, rec_binding, rb ::=
         | rb ; rb
         | x = e
    *)
  [ RbNil of loc

    (* rb ; rb *)
    | RbSem of loc and rec_binding and rec_binding

    (* i = e
        very simple
    *)
    | RbEq  of loc and ident and expr

    | RbAnt of loc and string (* $s$ *)
    ]

  and module_binding =
    (**
        Recursive module bindings
        module_binding, mb ::=
        | (* empty *)
        | mb and mb
```

```
      | s : mt = me
      | s : mt
      | $s$
    *)
    [ MbNil of loc

    (* mb and mb *) (* module rec (s : mt) = me and (s : mt) = me *)
    | MbAnd of loc and module_binding and module_binding

    (* s : mt = me *)
    | MbColEq  of loc and string and module_type and module_expr

    (* s : mt *)
    | MbCol  of loc and string and module_type

    | MbAnt of loc and string (* $s$ *) ]

and match_case =
    (**
      match_case, mc ::=
      | (* empty *)
      | mc | mc
      | p when e -> e
      | p -> e
    (* a sugar for << p when e1 -> e2 >> where e1 is the empty expression *)
    <:match_case< $list:mcs$ >>list of or-separated match casesAst.mcOr_of_list
    *)
    [
      (* <:match_case< >>  *)
      McNil of loc

    (* a | a *)
    (* <:match_case< $mc1$ | $mc2$ >>            *)
    | McOr of loc and match_case and match_case

    (* p (when e)? -> e *)
    (* <:match_case< $p$ -> $e$ >>    *)
    (* <:match_case< $p$ when $e1$ or $e2$ >>    *)
    | McArr of loc and patt and expr and expr

    (* <:match_case< $anti:s$ >>    *)
    | McAnt of loc and string (* $s$ *) ]

and module_expr =
    (**
       module_expression, module_expr, me ::=
      | (* empty *)
```

```
   | ident
   | me me
   | functor (s : mt) -> me
   | struct st end
   | (me : mt)
   | $s$
   | (value pexpr : ptype)
*)
[
  (* <:module_expr< >>  *)
  MeNil of loc

(* i *)
(* <:module_expr< $id:mod_ident$ >>  *)
| MeId  of loc and ident

(* me me *)
(* <:module_expr< $mexp:me$ $mexp:me$ >>         Functor application *)
| MeApp of loc and module_expr and module_expr

(* functor (s : mt) -> me *)
(* <:module_expr< functor ($uid:id$ : $mtyp:mod_type$) -> $mexp:me$ >>  *)
| MeFun of loc and string and module_type and module_expr

(* struct st end *)
(* <:module_expr< struct $stri:str_item$ end >>  *)
| MeStr of loc and str_item

(* (me : mt) *)
(* <:module_expr< ($mexp:me$ : $mtyp:mod_type$ ) >>
   signature constraint
*)
| MeTyc of loc and module_expr and module_type

(* (value e) *)
(* (value e : S) which is represented as (value (e : S)) *)
(* <:module_expr< (value $exp:expression$ ) >>
   module extraction

   <:module_expr< (value $exp:expression$ : $mtyp:mod_type$ ) >>
   -->
   <:module_expr<
   ( value $exp: <:expr< ($exp:expression$ : (module $mtyp:mod_type$ ) ) >> $ )
   >>
*)
| MePkg of loc and expr
```

```
    (* <:module_expr< $anti:string$ >>          *)
    | MeAnt of loc and string (* $s$ *)

(** Inside a structure several structure items are packed into a StSem
    tree. Use Camlp4Ast.stSem_of_list and Camlp4Ast.list_of_str_item to
    convert from and to a list of structure items.

    The expression in a module extraction (MePkg) must be a type
    constraint with a package type. Internally the syntactic class of
    module types is used for package types.
*)
]
  and str_item =
    (**
        structure_item, str_item, st ::=
   | (* empty *)
   | class cice
   | class type cict
   | st ; st
   | #s
   | #s e
   | exception t or exception t = i
   | e
   | external s : t = s ... s
   | include me
   | module s = me
   | module rec mb
   | module type s = mt
   | open i
   | type t
   | value b or value rec bi
   | $s$
    *)
    [ StNil of loc

    (* class cice *)
    (* <:str_item< class $cdcl:class_expr$ >>  *)
    | StCls of loc and class_expr

    (* class type cict *)
    (**
      <:str_item< class type $typ:class_type$ >>
       --> class type definition
    *)
    | StClt of loc and class_type

    (* st ; st *)
```

```
(* <:str_item< $str_item_1$; $str_item_2$ >>  *)
| StSem of loc and str_item and str_item

(* # s or # s e *)
(* <:str_item< # $string$ $expr$ >>  *)
| StDir of loc and string and expr

(* exception t or exception t = i *)
(* <:str_item< exception $typ:type$ >>   -> None *)
(* <:str_item< exception $typ:type$ >> ->
   Exception alias -> Some ident
*)
| StExc of loc and ctyp and meta_option(*FIXME*) ident

(* e *)
(* <:str_item< $exp:expr$ >> toplevel expression          *)
| StExp of loc and expr

(* external s : t = s ... s *)
(* <:str_item< external $lid:id$ : $typ:type$ = $str_list:string_list$ >>  *)
| StExt of loc and string and ctyp and meta_list string

(* include me *)
(* <:str_item< include $mexp:mod_expr$ >>  *)
| StInc of loc and module_expr

(* module s = me *)
(* <:str_item< module $uid:id$ = $mexp:mod_expr$ >>  *)
| StMod of loc and string and module_expr

(* module rec mb *)
(* <:str_item< module rec $module_binding:module_binding$ >>  *)
| StRecMod of loc and module_binding

(* module type s = mt *)
(* <:str_item< module type $uid:id$ = $mtyp:mod_type$ >> *)
| StMty of loc and string and module_type

(* open i *)
(* <:str_item< open $id:ident$ >>  *)
| StOpn of loc and ident

(* type t *)
(* <:str_item< type $typ:type$ >>  *)
(**
   <:str_item< type $lid:id$ $p1$ ... $pn$ = $t$
   constraint $c1l$ = $c1r$ ... constraint $cnl$ = $cnr$ >>
```

```
      -->
      StTyp of Loc.t and
      (TyDcl of Loc.t and id and [p1;...;pn] and t and [(c1l, c1r); ... (cnl, cnr)])
    *)
    | StTyp of loc and ctyp

    (* value (rec)? bi *)
    (* <:str_item< value $rec:r$ $binding$ >>          *)
    (* <:str_item< value rec $binding$ >> *)
    (* <:str_item< value  $binding$ >> *)
    | StVal of loc and rec_flag and binding

    (* <:str_item< $anti:s$ >>          *)
    | StAnt of loc and string (* $s$ *)
(**
   <:str_item< module $uid:id$ ( $uid:p$ : $mtyp:mod_type$ ) = $mexp:mod_expr$ >>
   ---->
   <:str_item< module $uid:id$ =
   functor ( $uid:p$ : $mtyp:mod_type$ ) -> $mexp:mod_expr$ >>

   <:str_item< module $uid:id$ : $mtyp:mod_type = $mexp:mod_expr$ >>
   ---->
   <:str_item< module $uid:id$ = ($mexp:mod_expr$ : $mtyp:mod_type ) >>

   <:str_item< type t >>
   ---->
   <:str_item< type t = $<:ctyp< >>$ >>

   <:str_item< # $id$ >> (directive without arguments)
   ---->
   <:str_item< # $a$ $<:expr< >>$ >>


   A whole compilation unit or the contents of a structure is given as
   *one* structure item in the form of a StSem tree.

   The utility functions Camlp4Ast.stSem_of_list and
   Camlp4Ast.list_of_str_item convert from and to a list of structure
   items.

   An exception is treated like a single type constructor. For
   exception definitions the type should be either a type identifier
   (TyId) or a type constructor (TyOf). For execption aliases it
   should only be a type identifier (TyId).

   Abstract types are represented with the empty type.
```

```
   Mutually recursive type definitions (separated by and) are stored
   in a TyAnd tree. Use Ast.list_of_ctyp and Ast.tyAnd_of_list to
   convert to and from a list of type definitions.

   The quotation parser for types (<:ctyp< ... >>) does not parse type
   declarations. Type definitions must therefore be embedded in a
   sig_item or str_item quotation.

   There seems to be no antiquotation syntax for a list of type
   parameters and a list of constraints inside a type definition. The
   existing form can only be used for a fixed number of type
   parameters and constraints.

   Complete class type definitions (including name and type
   parameters) are stored as class types.

   Several "and" separated class type definitions are stored in a
   CtAnd tree, use Ast.list_of_class_type and Ast.ctAnd_of_list to
   convert to and from a list of class types.

   Several "and" separated classes are stored in a CeAnd tree, use
   Ast.list_of_class_exprand Ast.ceAnd_of_list to convert to and from
   a list of class expressions.

   Several "and" separated recursive modules are stored in a MbAnd
   tree, use Ast.list_of_module_binding and Ast.mbAnd_of_list to
   convert to and from a list of module bindings.

   Directives without argument are represented with the empty
   expression argument.  *)
]
and class_type =
  (** Besides class types, ast nodes of this type are used to
      describe *class type definitions*
      (in structures and signatures)
      and class declarations (in signatures).

      class_type, ct ::=
   | (* empty *)
   | (virtual)? i ([ t ])?
   | [t] -> ct
   | object (t) csg end
   | ct and ct
   | ct : ct
   | ct = ct
   | $s$
    *)
```

```
[ CtNil of loc

  (* (virtual)? i ([ t ])? *)
  (* <:class_type< $virtual:v$ $id:ident$ [$list:p$ ] >> *)
  (* instanciated class type/ left hand side of a class *)
  (* declaration or class type definition/declaration  *)
  | CtCon of loc and virtual_flag and ident and ctyp

  (* [t] -> ct *)
  (* <:class_type< [$typ:type$] -> $ctyp:ct$ >>
       class type valued function
  *)
  | CtFun of loc and ctyp and class_type

  (* object ((t))? (csg)? end *)
  (* <:class_type< object ($typ:self_type$) $csg:class_sig_item$ end >> *)
  (* class body type *)
  | CtSig of loc and ctyp and class_sig_item

  (* ct and ct *)
  (* <:class_type< $ct1$ and $ct2$ >> *)
  (* mutually recursive class types *)
  | CtAnd of loc and class_type and class_type

  (* ct : ct *)
  (* <:class_type< $decl$ : $ctyp:ct$ >> *)
  (* class  c : object .. end   class declaration as in
     "class c: object .. end " in a signature
  *)
  | CtCol of loc and class_type and class_type

  (* ct = ct *)
  (* <:class_type< $decl$ = $ctyp:ct$ >> *)
  (* class type declaration/definition as in "class type c = object .. end " *)
  | CtEq  of loc and class_type and class_type


  (* $s$ *)
  | CtAnt of loc and string
  (**
     <:class_type< $id:i$ [ $list:p$] >>
     --->
     <:class_type< $virtual:Ast.BFalse$ $id:i$ [ $list:p$] >>

     <:class_type< $virtual:v$ $id:i$ >>
     --->
     <:class_type< $virtual:v$ $id:i$ [ $<:ctyp< >>$ ] >>
```

```
      <:class_type< object $x$ end >>
      --->
      <:class_type< object ($<:ctyp< >>$) $x$ end >>
    *)
(** CtCon is used for possibly instanciated/parametrized class
    type identifiers. They appear on the left hand side of class
    declaration and class definitions or as reference to existing
    class types. In the latter case the virtual flag is probably
    irrelevant.


    Several type parameters/arguments are stored in a TyCom tree, use
    Ast.list_of_ctyp and Ast.tyCom to convert to and from list of
    parameters/arguments.

    An empty type parameter list and an empty type argument is
    represented with the empty type.

    The self binding in class body types is represented by a type
    expression. If the self binding is absent, the empty type
    expression (<:ctype< >>) is used.

    Several class signature items are stored in a CgSem tree, use
    Ast.list_of_class_sig_item and Ast.cgSem_of_list to convert to and
    from a list of class signature items

*)
]
  and class_sig_item =
    (**
      class_signature_item, class_sig_item, csg ::=
   | (* empty *)
   | type t = t
   | csg ; csg
   | inherit ct
   | method s : t or method private s : t
   | value (virtual)? (mutable)? s : t
   | method virtual (mutable)? s : t
   | $s$
    *)
    [

      (* <:class_sig_item< >>  *)
      CgNil of loc

    (* <:class_sig_item< constraint $typ:type1$ = $typ:type2$ >>
```

```
      type constraint  *)
  | CgCtr of loc and ctyp and ctyp

  (* csg ; csg *)
  | CgSem of loc and class_sig_item and class_sig_item

  (* inherit ct *)
  (* <:classs_sig_item< inherit $ctyp:class_type$ >>  *)
  | CgInh of loc and class_type

  (* method s : t or method private s : t *)
  (* <:class_sig_item< method $private:pf$ $lid:id$:$typ:type$ >>    *)
  | CgMth of loc and string and private_flag and ctyp

  (* value (virtual)? (mutable)? s : t *)
  (* <:class_sig_item< value $mutable:mf$ $virtual:vf$ $lid:id$ : $typ:type$ >>  *)
  | CgVal of loc and string and mutable_flag and virtual_flag and ctyp

  (* method virtual (private)? s : t *)
  (* <:class_sig_item< method virtual $private:pf$ $lid:id$ : $typ:type$ >>   *)
  | CgVir of loc and string and private_flag and ctyp

  (* <:class_sig_item< $anti:a$ >>    *)
  | CgAnt of loc and string (* $s$ *)

  (**
     <:class_sig_item< type $typ:type_1$ = $typ:type_2$
     --->
     <:class_sig_item< constraint $typ:type_1$ = $typ:type_2$ >>

     The empty class signature item is used as a placehodler in
     empty class body types (class type e = object end )
  *)
]
and class_expr =
  (** Ast nodes of this type are additionally used to describe whole
     (mutually recursive) class definitions.


     class_expression, class_expr, ce ::=
   | (* empty *)
   | ce e
   | (virtual)? i ([ t ])?
   | fun p -> ce
   | let (rec)? bi in ce
   | object (p) (cst) end
   | ce : ct
```

```
 | ce and ce
 | ce = ce
 | $s$
*)
[
  CeNil of loc

  (* ce e *)
  (*
    <:class_expr< $cexp:ce$ $exp:exp$ >>

    application
  *)
  | CeApp of loc and class_expr and expr

  (* (virtual)? i ([ t ])? *)
  (* <:class_expr< $virtual:vf$ $id:ident$
     [ $typ:type_param$ ] >>

     instanciated class/ left hand side of class
     definitions.

     CeCon of Loct.t and vf and ident and type_param
  *)
  | CeCon of loc and virtual_flag and ident and ctyp

  (* fun p -> ce *)
  (* <:class_expr< fun $pat:pattern$ -> $cexp:ce$ >>
     class valued funcion

     CeFun of Loc.t and pattern and ce
  *)
  | CeFun of loc and patt and class_expr

  (* let (rec)? bi in ce *)
  (* <:class_expr< let $rec:rf$ $binding:binding$ in $cexp:ce$ >>  *)
  | CeLet of loc and rec_flag and binding and class_expr

  (* object ((p))? (cst)? end *)
  (* <:class_expr< object ( $pat:self_binding$ ) $cst:class_str_items$ end >> *)
  | CeStr of loc and patt and class_str_item

  (* ce : ct
     type constraint
     <:class_expr< ($cexp:ce$ : $ctyp:class_type$) >>
  *)
  | CeTyc of loc and class_expr and class_type
```

```
    (* ce and ce
       mutually recursive class definitions
    *)
    | CeAnd of loc and class_expr and class_expr

    (**
       <:class_expr< $ci$ = $cexp:ce$ >>
       class definition as in class ci = object .. end
    *)
    | CeEq  of loc and class_expr and class_expr

    (* $s$ *)
    (** <:class_expr< $anti:s$ >> *)
    | CeAnt of loc and string
    (**
       <:class_expr< $id:id$ [$tp$] >>
       ----> non-virtual class/ instanciated class
       <:class_expr< $virtual:Ast.BFalse$ $id:id$ [$tp$ ] >>

       <:class_expr< $virtual:vf$ $id:id$ >>
       ---->
       <:class_expr< $virtual:vf$ $id:id$ [ $<:ctyp< >>$ ] >>

       <:class_expr< fun $pat:p1$ $pat:p2$ -> $cexp:ce$ >>
       ---->
       <:class_expr< fun $pat:p1$ -> fun $pat:p2$ -> $cexp:ce$ >>

       <:class_expr< let $binding:bi$ in $cexp:ce$ >>
       ---->
       <:class_expr< let $rec:Ast.BFalse$ $binding:bi$ in $cexp:ce$ >>

       <:class_expr< let $rec:Ast.BFalse$ $binding:bi$ in $cexp:ce$ >>
       ---->
       <:class_expr< object ( $<:patt< >>$ ) $cst:cst$ end >>
    *)
(** No type parameters or arguments in an instanciated class
    (CeCon) are represented with the empty type (TyNil).

    Several type parameters or arguments in an instanciated class
    (CeCon) are stored in a TyCom tree. Use Ast.list_of_ctyp and
    Ast.tyCom_of_list convert to and from a list of type parameters.

    There are three common cases for the self binding in a class
    structure: An absent self binding is represented by the
    empty pattern (PaNil).  An identifier (PaId) binds the
    object.  A typed pattern (PaTyc) consisting of an identifier
```

```
     and a type variable binds the object and the self type.

     More than one class structure item are stored in a CrSem
     tree. Use Ast.list_of_class_str_item and Ast.crSem_of_list to
     convert to and from a list of class items.
*)
]
and class_str_item =
     (**
        class_structure_item, class_str_item, cst ::=
   | (* empty *)
   | cst ; cst
   | type t = t
   | inherit(!)? ce (as s)?
   | initializer e
   | method(!)? (private)? s : t = e or method (private)? s = e
   | value(!)? (mutable)? s = e
   | method virtual (private)? s : t
   | value virtual (private)? s : t
   | $s$
     *)
  [
    CrNil of loc

     (* cst ; cst *)
     | CrSem of loc and class_str_item and class_str_item

     (* type t = t *)
     (* <:class_str_item< constraint $typ:type_1$ = $typ:type_2$ >>
        type constraint
     *)
     | CrCtr of loc and ctyp and ctyp

     (* inherit(!)? ce (as s)? *)
     (* <:class_str_item< inherit $!:override$ $cexp:class_cexp$ as $lid:id$ >>  *)
     | CrInh of loc and override_flag and class_expr and string

     (* initializer e *)
     (* <:class_str_item< initializer $exp:expr$ >>  *)
     | CrIni of loc and expr

     (** method(!)? (private)? s : t = e or method(!)? (private)? s = e *)
     (** <:class_str_item< method $!override$ $private:pf$ $lid:id$: $typ:poly_type$ =
         $exp:expr$ >>
     *)
     | CrMth of loc and string and override_flag and private_flag and expr and ctyp
```

```
    (* value(!)? (mutable)? s = e *)
    (** <:class_str_item< value $!:override$ $mutable:mf$ $lid:id$ = $exp:expr$ >>
       instance variable
    *)
    | CrVal of loc and string and override_flag and mutable_flag and expr

    (** method virtual (private)? s : t *)
    (** <:class_str_item< method virtual $private:pf$ $lid:id$ : $typ:poly_type$ >>
       virtual method
    *)
    | CrVir of loc and string and private_flag and ctyp

    (* value virtual (mutable)? s : t *)
    (* <:class_str_item< value virtual $mutable:mf$ $lid:id$ : $typ:type$ >> *)
    (* virtual instance variable  *)
    | CrVvr of loc and string and mutable_flag and ctyp

    | CrAnt of loc and string (* $s$ *)

(**
   << constraint $typ:type_1$ = $typ:type_2$ >>
   ----> type constraint
   << type $typ:type1$ = $typ:type2$ >>

   << inherit $!:override$ $cexp:class_exp$ >>
   ---> superclass without binding
   << inherit $!:override$ $cexp:class_exp$ as $lid:""$ >>

   <<inherit $cexp:class_exp$ as $lid:id$ >>
   ---> superclass without override
   <<inherit $!:Ast.OvNil$ $cexp:class_exp$ as $lid:id$ >>

   <:class_str_item< method $private:pf$ $lid:id$ : $typ:poly_type$ = $exp:expr$ >>
   non-overriding method
   <:class_str_item< method $!:Ast.OvNil$
   $private:pf$ $lid:id$ : $typ:poly_type$ = $exp:expr$ >>

   <:class_str_item< method $private:pf$ $lid:id$ = $exp:expr$ >>
   monomorphic method
   <:class_str_item< method $private:pf$ $lid:id$ : $typ:<:ctyp< >>$ = $exp:expr$ >>

   <:class_str_item< method $lid:id$ : $typ:poly_type$ = $exp:expr$ >>
   public method
   <:class_str_item< method $private:Ast.PrNil$ $lid:id$ : $typ:poly_type$ = $exp:expr$ >>

   <:class_str_item< method $private:pf$ $lid:id$ :
   $typ:poly_type$ $pat:pattern$ = $exp:expr$ >>
```

```
method arguments
<:class_str_item< method $private:pf$ $lid:id$ :
$typ:poly_type$ = fun $pat:pattern$ -> $exp:expr$ >>

<:class_str_item< method $private:pf$ $lid:id$ :
$typ:poly_type$ : $typ:res_type$ = $exp:expr$ >>
return type constraint
<:class_str_item< method $private:pf$ $lid:id$ :
$typ:poly_type$ = ($exp:expr$ : $typ:res_type$) >>

<:class_str_item< method $private:pf$ $lid:id$ :
$typ:poly_type$ :> $typ:res_type$ = $exp:expr$ >>
return type coercion
<:class_str_item< method $private:pf$ $lid:id$ :
$typ:poly_type$ = ($exp:expr$ :> $typ:res_type$ ) >>

<:class_str_item< value $mutable:mu$ $lid:id$ = $exp:expr$ >>
non-overriding instance variable
<:class_str_item< value $!:Ast.OvNil$ $mutable:mf$ $lid:id$ = $exp:expr$ >>

<:class_str_item< value $!:override$ $lid:id$ = $exp:expr$ >>
immutable instance variable
<:class_str_item< value $!:override$ $mutable:Ast.MuNil$ $lid:id$ = $exp:expr$ >>

<:class_str_item< value $!:override$ $mutable:mf$ $lid:id$ :
$typ:res_type$ = $exp:expr$ >>
type restriction<:class_str_item
< value $!:override$ $mutable:mf$ $lid:id$ =
($exp:expr$ : $typ:res_type$) >>

<:class_str_item< value $!:override$ $mutable:mf$ $lid:id$ :>
$typ:res_type$ = $exp:expr$ >>
simple value coercion
<:class_str_item< value $!:override$ $mutable:mf$ $lid:id$ =
($exp:expr$ :> $typ:res_type$) >>

<:class_str_item< value $!:override$ $mutable:mf$ $lid:id$ :
$typ:expr_type$ :> $typ:res_type$ = $exp:expr$ >>
complete value coercion
<:class_str_item< value $!:override$ $mutable:mf$ $lid:id$ =
($exp:expr$ : $typ:expr_type$ :> $typ:res_type$) >>

<:class_str_item< method virtual $lid:id$ : $typ:poly_type$ >>
public virtual method
<:class_str_item< method $private:Ast.PrNil$ virtual $lid:id$ : $typ:poly_type$ >>

<:class_str_item< value $!:override$ virtual $lid:id$ : $typ:type$ >>
```

```
   immutable virtual value
   <:class_str_item< value $!:override$ virtual $mutable:Ast.MuNil$ $lid:id$
   : $typ:type$ >>

   A missing superclass binding is represented with the empty string
   as identifier.  Normal methods and explicitly polymophically typed
   methods are represented with the same ast node (CrMth). For a normal
   method the poly_type field holds the empty type (TyNil).
*)
];
```

4.3 Extensible Parser

Camlp4's extensible parser is deeply combined with its own lexer, use menhir if it is very complex and not ocaml-oriented. It is very hard to debug in itself. So I suggest it is used to do simple ocaml-oriented parsing.

4.3.1 Examples

First example (a simple calculation)

```
open Camlp4.PreCast

let expression = Gram.Entry.mk "expression"

let _ =
  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

let  _ =
  Printf.printf "%d" (
    Gram.parse_string
      expression
      (Loc.mk "<string>" ) "3 +  ((4 - 2) + 28 * 3 ** 2) + (4 / 2)" );
    (* (read_line ()) ;  *)
```

The tags file is

```
<simple_calc.ml> : pp(camlp4of)
<simple_calc.{cmo,byte,native}> : use_dynlink, use_camlp4_full
```

For oco in **toplevel** , extensible parser works **quite well in original syntax**, so if you don't do quasiquoation in toplevel, *feel free to use original syntax*.

Some keywords for extensible paser

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

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.

4.3.2 Mechanism

A brief introduction to its 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 perfix of symblos(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 prductions, 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** .

(iii) the data structure representing the grammar is then passed as argument to a generic parser

It's really hard to understand how it really works. Here are some experiments I did, but did not know how to explain

```
(** #require "camlp4.gramlib"*)
open Camlp4.PreCast

module MGram = MakeGram(Lexer)

let m_expr = MGram.Entry.mk "m_expr";;
let pr = MGram.Entry.print
let _ =
  EXTEND MGram
    GLOBAL: m_expr ;
    m_expr :
      [[ "foo"; f  -> print_endline "first"
       | "foo" ; "bar"; "baz" -> print_endline "second"]
      ];
    f : [["bar"; "baz" ]];  END;;

let _ = pr Format.std_formatter m_expr
let _ = MGram.parse_string m_expr (Loc.mk "<string>") "foo bar baz ";;

(** output
    m_expr: [ LEFTA
    [ "foo"; "bar"; "baz"
    | "foo"; f ] ]
    second
*)


(** DELETE_RULE expr: SELF; "+"; SELF END;; *)
let _ = begin
```

```
  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;
  pr Format.std_formatter m_expr ;
  MGram.parse_string m_expr (Loc.mk "<string>") "foo bar baz "
end
(** output:
   m_expr: [ LEFTA
    [ "foo"; "bar"; "bax"
    | "foo"; f ] ]
  first
*)

let _ = begin
  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;
  pr Format.std_formatter m_expr;
  MGram.parse_string m_expr (Loc.mk "<string>") "foo bar baz "
end
(**
   m_expr: [ LEFTA
   [ "foo"; "bar"; f
   | "foo"; f ] ]
   Exception:
   Loc.Exc_located (<abstr>,
   Stream.Error "[f] expected after \"bar\" (in [m_expr])").
*)
```

We see that `MGram.Entry.print` is a good utility.

The processed code is not too indicative, all the dispatch magic hides in `MGram.extend` function (or |Insert.extend| function) *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.estart :=
    fun lev strm ->
      let f = Parser.start_parser_of_entry entry in
      do { entry.estart := 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 }
};
```

Factoring only happens in the same level within a rule.

You can do explicit backtracking by hand (npeek trick)

```
(**hand-coded entry  MGram.Entry.of_parser *)
open Camlp4.PreCast
module MGram = MakeGram(Lexer)
let pr = MGram.Entry.print
let test = MGram.Entry.of_parser "test"
  (fun strm -> match Stream.npeek 2 strm with
      [_ ; KEYWORD "xyzzy", _ ] -> raise Stream.Failure
    | _ -> ())
let m_expr = MGram.Entry.mk "m_expr"

let _ = begin
  EXTEND MGram GLOBAL: m_expr ;
  g : [[ "plugh" ]] ;
  f1 : [[ g ; "quux" ]];
  f2 : [[g ; "xyzzy"]] ;
  m_expr : [[test ; f1 -> print_endline "1" | f2 -> print_endline "2" ]] ;
  END ;
  pr Format.std_formatter m_expr;
  MGram.parse_string m_expr (Loc.mk "<string>") "plugh xyzzy"
end

(**
   m_expr: [ LEFTA
   [ test; f1
   | f2 ] ]
   2
*)
```

(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.

(b) **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 :

(a) The function named “start”, analyzing the first tree

(b) 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
```

4.3.3 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 | [< '\"baz\"; y = p >] -> y;;"
(** output
   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\">] -> \"bar\""
(** output  *)
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)
```

4.3.4 Grammar

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

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

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 (‘LINDENT x) to get the actual token constructor. The parser **ignores** extra tokens after a success.

1. LEVELS

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

2. NEXT LIST0 SEP OPT TRY

   NEXT refers to the entry being defined at the following level regardless of assocaitivity 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" ]]
   ```

3. nested rule (only one level)

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

4. 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.

5. 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;;
```

The processed code is as follows:

```
(** translated code output *)
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)))) ]) ]))
          ()))
```

6. 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 hashtbl**, so it can be updated `dynamically`.

7. 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
```

8. Grammar modification

   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 :

```
(* #require "camlp4.gramlib";; *)

open Camlp4.PreCast
module MGram = MakeGram(Lexer)

let test = MGram.Entry.mk "test"
let p = MGram.Entry.print


let _ = begin
  MGram.Entry.clear test;
  EXTEND MGram GLOBAL: test;
  test:
    ["add" LEFTA
        [SELF; "+" ; SELF | SELF; "-" ; SELF]
    | "mult" RIGHTA
        [SELF; "*" ; SELF | SELF; "/" ; SELF]
    | "simple" NONA
        [ "("; SELF; ")"  | INT ] ];
  END;
```

```
  p Format.std_formatter test;
end

(** output
 test: [ "add" LEFTA
        [ SELF; "+"; SELF
        | SELF; "-"; SELF ]
      | "mult" RIGHTA
        [ SELF; "*"; SELF
        | SELF; "/"; SELF ]
      | "simple" NONA
        [ "("; SELF; ")"
        | INT ((_)) ] ]

*)
```

```
let _ = begin
  EXTEND MGram GLOBAL: test;
    test: [[ x = SELF ; "plus1plus" ; y = SELF ]];
  END ;
  p Format.std_formatter test
end
(** output
test: [ "add" LEFTA
    [ SELF; "plus1plus"; SELF
  | SELF; "+"; SELF
  | SELF; "-"; SELF ]
| "mult" RIGHTA
  [ SELF; "*"; SELF
  | SELF; "/"; SELF ]
| "simple" NONA
  [ "("; SELF; ")"
  | INT ((_)) ] ]
*)
```

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

When you want to create a new level in the last position

```
let _ = begin
  EXTEND MGram  test: LAST
    [[x = SELF ; "plus1plus" ; y = SELF ]];
```

```
  END;
  p Format.std_formatter test
end
(** output
              test: [ "add" LEFTA
  [ SELF; "plus1plus"; SELF
  | SELF; "+"; SELF
  | SELF; "-"; SELF ]
| "mult" RIGHTA
  [ SELF; "*"; SELF
  | SELF; "/"; SELF ]
| "simple" NONA
  [ "("; SELF; ")"
  | INT ((_)) ]
| LEFTA
  [ SELF; "plus1plus"; SELF ] ]
*)
```

When you want to insert in the level "mult" in the first position

```
let _ = begin
  EXTEND MGram  test: LEVEL "mult" [[x = SELF ; "plus1plus" ; y = SELF ]]; END ;
  p Format.std_formatter test;
end
(** output
      test: [ "add" LEFTA
  [ SELF; "plus1plus"; SELF
  | SELF; "+"; SELF
  | SELF; "-"; SELF ]
| "mult" RIGHTA
  [ SELF; "plus1plus"; SELF
  | SELF; "*"; SELF
  | SELF; "/"; SELF ]
| "simple" NONA
  [ "("; SELF; ")"
  | INT ((_)) ]
| LEFTA
  [ SELF; "plus1plus"; SELF ] ]
*)
```

When you want to insert a new level before "mult"

```
let _ = begin
```

```
  EXTEND MGram  test: BEFORE "mult" [[x = SELF ; "plus1plus" ; y = SELF ]];
  END ;
  p Format.std_formatter test;
end
(** output
        test: [ "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 ] ]
*)
```

9. Grammar example You can do some search in the toplevel as follows

```
se (FILTER _* "val" _* "expr" space+ ":" ) "Syntax" ;;

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

Code listed below is the expr parse tree

```
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 ] ]
```

A syntax extension of `let try`

```
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(you modify the Camlp4.PreCast.Gram, it will be reflected on the fly)

```
open Camlp4.PreCast
let env = ref []
(** Toploop.toplevel_env *)
(** sucks, in the toplevel, it's really hard to roll back cause, all
    your programs following are affected , horrible *)
let _ = begin
  let _loc = Loc.ghost in
  EXTEND Gram Syntax.expr:
    LEVEL "simple" [[x = LIDENT -> List.assoc x !env ]] ; END ;
  env := ["x", <:expr< 3 >> ]
end

let y = 4 in let a = x + y in a;;

(** Error: Camlp4: Uncaught exception: Not_found
   first y,a  is pat
   second y results in an exception
*)
(** DELETE_RULE Gram Syntax.expr: LIDENT    END ;; *)


(** NOT supported yet
let add_infix lev op =
    EXTEND Gram
      Syntax.expr :
      LEVEL $lev$
      [[ x = SELF ;  $op$ ; y = SELF ->
      <:expr< $lid:op$ $x$ $y$ >>]]; END  ;;
*)
```

10. 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
```

4.4 Rewrite of Jake's blog

Jake's blog is a very comprehensive tutorial for camlp4 introduction.

4.4.1 Part1

Easy to experiment in the toplevel, using my previous **oco**,

```
open Camlp4.PreCast ;;
let _loc = Loc.ghost ;;
(**
   blabla...
   An idea, how about writing another pretty printer,
   the printer is awful*)
```

4.4.2 Part2

Just ast transform, easy to experiment in toplevel as well.

```
(* #require "camlp4.gramlib";; *)
open Camlp4.PreCast
open BatPervasives
let cons = ["A"; "B";"C"] and _loc = Loc.ghost ;;
let tys = Ast.tyOr_of_list
  (List.map (fun str -> <:ctyp< $uid:str$ >>) cons);;

(*
val tys : Camlp4.PreCast.Ast.ctyp =
  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"))))
*)
(** here you can better understand what ctyp really means, a type
expression, not a top-level struct, cool
*)
let verify = <:ctyp< A |B |C>>;;

let _ = begin
  print_bool (verify = tys);
end
```

```
(*
  true
*)

let type_def = <:str_item< type t = $tys$ >>
(*
val type_def : Camlp4.PreCast.Ast.str_item =
  Camlp4.PreCast.Ast.StTyp (<abstr>,
   Camlp4.PreCast.Ast.TyDcl (<abstr>, "t", [],
    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")))),
    []))
*)

let _ =  begin
  Printers.OCaml.print_implem type_def ;
end
(*
  type t = A | B | C
*)


(** always ambiguous when manipulating ast using original syntax
    recommend using revised syntx
*)
let verify2 = <:str_item< type t =  [ A | B | C ] >>;;
(*
val verify2 : Camlp4.PreCast.Ast.str_item =
  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")))),
    []))
```

```
*)
let _ = begin
  print_bool (verify2 = type_def);
  Printers.OCaml.print_implem verify2
end

(*
  false
  type t = | A | B | C;;
*)

let match_case =
  List.map
    (fun c -> <:match_case< $uid:c$ -> $`str:c$ >>) cons
    |> Ast.mcOr_of_list ;;
(*
  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"))))
*)
let to_string = <:expr< fun [ $match_case$ ] >>;;
(*
    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")))))
*)

let pim = Printers.OCaml.print_implem

let _ = begin
  pim <:str_item< let a = $to_string$ in a >>;
end
(*
  let a = function | A -> "A" | B -> "B" | C -> "C" in a;;
*)

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


let _ = begin
  pim  <:str_item<let f = fun [ $match_case2$ ] in f  >>;
  pim <:str_item<let f = fun [ $match_case2$ | _ -> invalid_arg "haha" ] in f >>;
end

(*

let f = function | "A" -> A | "B" -> B | "C" -> C in f;;
let f = function | "A" -> A | "B" -> B | "C" -> C | _ -> invalid_arg "haha"
in f;;

*)
```

Anyother way to verify? The output of printers 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*.

4.4.3 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` means context here.

Here we grep `Ant`, and the output is as follows

```
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 (* $s$ *) ]
    87:     | TyAnt of loc and string (* $s$ *)
    93:     | PaAnt of loc and string (* $s$ *)
   124:     | ExAnt of loc and string (* $s$ *)
   202:     | MtAnt of loc and string (* $s$ *) ]
   231:     | SgAnt of loc and string (* $s$ *) ]
   244:     | WcAnt of loc and string (* $s$ *) ]
   251:     | BiAnt of loc and string (* $s$ *) ]
   258:     | RbAnt of loc and string (* $s$ *) ]
   267:     | MbAnt of loc and string (* $s$ *) ]
   274:     | McAnt of loc and string (* $s$ *) ]
   290:     | MeAnt of loc and string (* $s$ *) ]
   321:     | StAnt of loc and string (* $s$ *) ]
   337:     | CtAnt of loc and string ]
   352:     | CgAnt of loc and string (* $s$ *) ]
   372:     | CeAnt of loc and string ]
   391:     | CrAnt of loc and string (* $s$ *) ];
```

ANTIQUOTATION example

```
<: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 *)
```

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

```
      | "listctyp|" -> <:expr< Ast.tyOr_of_list $e$ >>
      | "listctyp," -> <:expr< Ast.tyCom_of_list $e$ >>
      | "listctyp&" -> <:expr< Ast.tyAmp_of_list $e$ >>
      | "listwith_constr" -> <:expr< Ast.wcAnd_of_list $e$ >>
      (* interesting bits *)
      | "listmatch_case" -> <:expr< Ast.mcOr_of_list $e$ >>
      | "listpatt," -> <:expr< Ast.paCom_of_list $e$ >>
      | "listpatt;" -> <:expr< Ast.paSem_of_list $e$ >>
      | "listexpr," -> <:expr< Ast.exCom_of_list $e$ >>
      | "listexpr;" -> <:expr< Ast.exSem_of_list $e$ >>
      | "antisig_item" -> <:expr< Ast.SgAnt $mloc _loc$ $e$ >>
      | "antistr_item" -> <:expr< Ast.StAnt $mloc _loc$ $e$ >>
      | "antictyp" -> <:expr< Ast.TyAnt $mloc _loc$ $e$ >>
      | "antipatt" -> <:expr< Ast.PaAnt $mloc _loc$ $e$ >>
      | "antiexpr" -> <:expr< Ast.ExAnt $mloc _loc$ $e$ >>
      | "antimodule_type" -> <:expr< Ast.MtAnt $mloc _loc$ $e$ >>
      | "antimodule_expr" -> <:expr< Ast.MeAnt $mloc _loc$ $e$ >>
      | "anticlass_type" -> <:expr< Ast.CtAnt $mloc _loc$ $e$ >>
      | "anticlass_expr" -> <:expr< Ast.CeAnt $mloc _loc$ $e$ >>
      | "anticlass_sig_item" -> <:expr< Ast.CgAnt $mloc _loc$ $e$ >>
      | "anticlass_str_item" -> <:expr< Ast.CrAnt $mloc _loc$ $e$ >>
      | "antiwith_constr" -> <:expr< Ast.WcAnt $mloc _loc$ $e$ >>
      | "antibinding" -> <:expr< Ast.BiAnt $mloc _loc$ $e$ >>
      | "antirec_binding" -> <:expr< Ast.RbAnt $mloc _loc$ $e$ >>
      | "antimatch_case" -> <:expr< Ast.McAnt $mloc _loc$ $e$ >>
      | "antimodule_binding" -> <:expr< Ast.MbAnt $mloc _loc$ $e$ >>
      | "antiident" -> <:expr< Ast.IdAnt $mloc _loc$ $e$ >>
      | _ -> 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 synonm. (you can add a constructor to make it clear)

4.4.4 Part4 Parsing Ocaml Itself Using Camlp4

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.

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 Camlp4.PreCast ;
open BatPervasives ;
(** My own syntax *)
module MySyntax = Camlp4.OCamlInitSyntax.Make Ast Gram Quotation ;

(** load r parser *)
module M = Camlp4OCamlRevisedParser.Make MySyntax ;

(** load quotation parser *)
module M4 = Camlp4QuotationExpander.Make MySyntax ;


(** 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_implem;
value str_items_of_file file_name =
  file_name
  |> open_in
  |> BatStream.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_implem*)
value _ =
  do_fn "otags.ml"
  |> List.iter (fun (a, b, c, d) -> Printf.printf "%s-%s %d-%d \n" a b c d)  ;


(* output
  let my_parser-my_parser 22-469
  let str_items_of_file-str_items_of_file 23-510
  let do_str_item-do_str_item 33-779
  let do_binding-do_binding 39-1012
  let do_fn-do_fn 48-1256
*)


let sig =
  let str = eval "module X = Camlp4.PreCast ;;"
  and _loc = Loc.ghost in
  Stream.of_string str |> Syntax.parse_interf  _loc ;;

open Camlp4.PreCast.Syntax.Ast

(* output
SgMod (<abstr>, "X",
 MtSig (<abstr>,
  SgSem (<abstr>,
   SgSem (<abstr>,
    SgTyp (<abstr>,
     TyDcl (<abstr>, "camlp4_token", [],
      TyMan (<abstr>,
       TyId (<abstr>,
        IdAcc (<abstr>,
         IdAcc (<abstr>, IdUid (<abstr>, "Camlp4"), IdUid (<abstr>, "Sig")),
         IdLid (<abstr>, "camlp4_token"))),
       TySum (<abstr>,
        TyOr (<abstr>,
         TyOr (<abstr>,
          TyOr (<abstr>,
           TyOr (<abstr>,
```

```
TyOr (<abstr>,
 TyOr (<abstr>,
  TyOr (<abstr>,
   TyOr (<abstr>,
    TyOr (<abstr>,
     TyOr (<abstr>,
      TyOr (<abstr>,
       TyOr (<abstr>,
        TyOr (<abstr>,
         TyOr (<abstr>,
          TyOr (<abstr>,
           TyOr (<abstr>,
            TyOr (<abstr>,
             TyOr (<abstr>,
              TyOr (<abstr>,
               TyOr (<abstr>,
                TyOf (<abstr>,
                 TyId (<abstr>, IdUid (<abstr>, "KEYWORD")),
                 TyId (<abstr>, IdLid (<abstr>, "string"))),
                TyOf (<abstr>,
                 TyId (<abstr>, IdUid (<abstr>, "SYMBOL")),
                 TyId (<abstr>, IdLid (<abstr>, "string")))),
               TyOf (<abstr>,
                TyId (<abstr>, IdUid (<abstr>, "LIDENT")),
                TyId (<abstr>, IdLid (<abstr>, "string")))),
              TyOf (<abstr>,
               TyId (<abstr>, IdUid (<abstr>, "UIDENT")),
               TyId (<abstr>, IdLid (<abstr>, "string")))),
             TyOf (<abstr>,
              TyId (<abstr>, IdUid (<abstr>, "ESCAPED_IDENT")),
              TyId (<abstr>, IdLid (<abstr>, "string")))),
            TyOf (<abstr>,
             TyId (<abstr>, IdUid (<abstr>, "INT")),
             TyAnd (<abstr>,
              TyId (<abstr>, IdLid (<abstr>, "int")),
              TyId (<abstr>, IdLid (<abstr>, "string"))))),
           TyOf (<abstr>,
            TyId (<abstr>, IdUid (<abstr>, "INT32")), ...)),
          ...),
         ...),
        ...),
       ...),
      ...),
     ...),
    ...),
   ...),
  ...),
```

```
            ...),
           ...),
          ...),
         ...),
        ...))),
     ...)),
   ...),
  ...)))
*)
```

4.4.5 Part5 Structure Item Filters

Because I use revised syntax, and take a reference of the documenation, my ast filter is much nicer than jaked's. the documentation of quasiquotation from the wiki page is quite helpful

```
(* open BatPervasives; *)

open Camlp4.PreCast;
open Printf;
(* open Batteries; *)
(* value pim = Printers.OCaml.print_implem ; *)
open Util;

(* 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 [ $list:match_cases$ ]
      ;
      value $lid:(name^"_of_string") $ =
          fun [ $list:reverse_cases$ | x -> invalid_arg x ]
      ; >>;
```

```
 (** idea, view patterns are fit here, try it later *)
 value rec filter str_item = match str_item with
     [
       <:str_item@_loc< type $lid:tid$ = [ $t$ ]>> -> begin
         try
           let ctys = Ast.list_of_ctyp t [] in
           let con_names =
             List.map (fun [ <:ctyp< $uid:c$>> -> c
                           | x -> raise Not_found ]) ctys in
           let code = code_of_con_names tid con_names _loc in
           begin
             prerr_string "generating code right now";
             <:str_item< $str_item$; $code$>>
           end
         with
             [exn -> begin
               prerr_string (sprintf "%s\n : error \n" tid);
               raise Not_found;
             end ]
       end
     | x -> begin
       x
     end
     ] ;
   AstFilters.register_str_item_filter filter;
end ;

module Id = struct
  value name = "pa_filter";
  value version = "0.1";
end ;

value _ =
  let module M = Camlp4.Register.AstFilter Id Make in
  ();
```

For locally used syntax extension, I found write some tiny bits ocamlbuild code pretty convenient. In `myocamlbuild.ml`, only needs to append some code like this

```
let apply  plugin = begin
  Default.before_options +> before_options;
  Default.after_rules +> after_rules;
  plugin ();
  dispatch begin function
```

```
| Before_options -> begin
  List.iter (fun f -> f () ) !before_options;
end
| After_rules -> begin
  List.iter (fun f -> f ()) !after_rules;
end
```

The tags file then will be like this

```
<pa_filter.{ml}> : pp(camlp4rf)
<pa_filter.{cmo}> : use_camlp4
<test_filter.ml> : camlp4o, use_filter
```

Using Register Filter has some limitations, like it first parse the whole file, and then transform each `structure item` one by one, so the previously generated code will `not have` an effect on the later code. This is probably what not you want.

You syntax extension may depends on other modules, make sure your `pa_xx.cma` contains all the modules statically. You can write a `pa_xx.mllib`, or link the module to `cma` file by hand.

For instance, you `pa_filter.cma` depends on `Util`, then you will

`ocalmc -a pa_filter.cmo util.cmo -o pa_filer.cma`

then you could use `camlp4o -parser pa_filter.cma`, it works.

If you write `pa_xx.mllib` file, it would be something like

```
pa_filter
util
```

If you want to use other libraries to write syntax extension, make sure you link **all** libraries, including recursive dependency, i.e, the require field of batteries.

```
ocamlc -a  -I +num -I `ocamlfind query batteries` nums.cma unix.cma
bigarray.cma str.cma batteries.cma pa_filter.cma -o x.cma
```

You must link all the libraries *recursively*, even you don't need it at all. This is the defect of the OCaml compiler. `-linkall` here links submodules, recursive linking needs you say it clearly, you can find some help in the META file.

We can also test our filter seriously as follows `camlp4of -parser _build/filter.cmo filter_test.ml`

By the **lift filter** you can see its **internal representation**, textual code does not gurantee its correctness, but the AST representation could gurantee its correctness.

Built in filters could be referred in 4.6.1.

4.4.6 Part6 Extensible Parser (moved to extensible parser part)

4.4.7 Part7 Revised Syntax

Revised syntax provides more context in the form of extra brackets etc. so that antiquotation works more smoothly. Simple ideas, this is acutally a part of the job `view patterns`, `F#` makes use of view patterns extensively in terms of quotations, can we borrow some ideas?

4.4.8 Part8, 9 Quotation

(a) Quotation module

```
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 enought, other things are quite mechanical

A comprehensive Example Suppose we have already defined an AST, and did the parser, meta part(4.6.1). The parser part is simple, as follows

```
module MGram = MakeGram(Lexer)
let json_parser = MGram.Entry.mk "json"
let json_eoi = MGram.Entry.mk "json_eoi"
let _ =   let open Jq_ast in begin
  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_string n )
     | s = STRING -> Jq_string s
     | "["; xs = LIST0 SELF SEP "," ; "]" -> Jq_array xs
     | "{"; kvs = LIST0 [s = STRING; ":"; v = json_parser -> (s,v)] SEP ",";
     "}" -> Jq_object kvs
     ]] ; END ;
  EXTEND MGram  GLOBAL: json_eoi ;
  json_eoi : [[x = json_parser ; EOI -> x ]] ;
  END ;
  MGram.parse_string json_eoi (Loc.mk "<string>") "[true,false]"
end
```

Now we do a mechanical installation to get a quotation expander All need is as follows:

```
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 =
   (** exp antiquotation 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 _  = let open Syntax.Quotation in begin
  add "json" DynAst.expr_tag expand_expr ;
  add "json" DynAst.patt_tag expand_patt ;
  add "json" DynAst.str_item_tag expand_str_item ;
  default := "json";
end
```

You could also refactor you code as follows:

```
(** make quotation from a parser *)
let install_quotation my_parser (me,mp) name =
  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
  let open Syntax.Quotation in begin
    add name DynAst.expr_tag expand_expr ;
    add "json" DynAst.patt_tag expand_patt ;
    add "json" DynAst.str_item_tag expand_str_item;
  end
```

So in the toplevel

```
#directory "/_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.]
```

To build, just add a plugin to your `myocamlbuild.ml` as follows:

```
let _ =
  let plugin =
    (fun _ -> begin
      (fun _ -> begin
        flag ["ocaml";"pp";"use_filter"] (A"pa_filter.cma");
        dep ["ocaml"; "ocamldep"; "use_filter"] ["pa_filter.cma"];
      end ) +> after_rules;

      (fun _ -> begin
        flag ["ocaml";"pp"; "use_json"] (A"json.cmo");
        dep ["ocaml";"ocamldep";"use_json"] ["json.cmo"];
      end ) +> after_rules;
    end ) in
  apply plugin
```

And tags file is as follows

```
<test_json.ml> : camlp4o , use_json
<test_json.byte> : pkg_dynlink ,use_camlp4
```

```
(**
   here we open Json, introduces the dependence on camlp4
   when you build a byte.
*)
open Json
let a =
  << [true, false ] >>
```

It's quite annoying since our type definition was bundled with `Camlp4.PreCast`, when linking, we introduce unnecessary dependency on camlp4. You can find some way to walk around it, but still anonying.

(c) Antiquotation Expander

The meta filter treat any other constructor **ending in Ant** specially.

Instead of handling this way:

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

They have:

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

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)

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

Notice that `Syntax.AntiquotSyntax.(parse_expr,parse_patt)` `Syntax.(parse_implem, pa` provides the parser as a host language. The normal part is as follows:

And also, `Syntax.AntiquotSyntax` only provides `parse_expr,parse_patt` corresponding to two postions where quotations happen.

```
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
let (|>) x f = f x

module MetaExpr = struct
  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
```

Here we define the AST in a special way for the convenience of inserting code. The parser is modified:

```
module MGram = MakeGram(Lexer)
let json  = MGram.Entry.mk "json"
let json_eoi = MGram.Entry.mk "json_eoi"

let _ = let open Jq_ast in begin
  EXTEND  MGram  GLOBAL: json_eoi  json ;
  json_eoi : [[ x = json ; EOI -> x ]];
  json :
    [[ "null" -> Jq_null
     |"true" -> Jq_bool true
     |"false" -> Jq_bool false
     (** register special tags for anti-quotation*)
     | `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_string n)
     | "["; 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 ;
end
```

```
let destruct_aq s  =
  let try  /(_* Lazy as  name ) ":" (_* as content)/ = s
  in  name,content
  with Match_failure _ -> invalid_arg (s  ^ "in destruct_aq")

let aq_expander = object
  inherit Ast.map as super
  method expr = function
    |Ast.ExAnt(_loc, s) ->
      let n, c = destruct_aq s in
      (** use host syntax to parse the string  *)
```

```ocaml
      let e = Syntax.AntiquotSyntax.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 k, v))
            $e$ )
          >>
        |_ -> e
      end
    |e -> super#expr e
  method patt = function
    | Ast.PaAnt(_loc,s) ->
      let n,c = destruct_aq s in
      Syntax.AntiquotSyntax.parse_patt _loc c  (* ignore the tag *)
    | p -> super#patt p
end


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 inserted here *)
  |> aq_expander#expr

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 inserted here *)
  |> aq_expander#patt
let _  = let open Syntax.Quotation in  begin
  add "json" DynAst.expr_tag expand_expr ;
  add "json" DynAst.patt_tag expand_patt ;
  add "json" DynAst.str_item_tag expand_str_item ;
  default := "json";
end
```

```
#load "json_ant.cmo";;
open Json_ant;;
# let a =  << [true,false]>>;;
val a : Json_ant.Jq_ast.t =
  Json_ant.Jq_ast.Jq_array
   (Json_ant.Jq_ast.Jq_comma (Json_ant.Jq_ast.Jq_bool true,
     Json_ant.Jq_ast.Jq_bool false))
# let b = << [true, $a$, false ]>>;;
val b : Json_ant.Jq_ast.t =
  Json_ant.Jq_ast.Jq_array
   (Json_ant.Jq_ast.Jq_comma
     (Json_ant.Jq_ast.Jq_comma (Json_ant.Jq_ast.Jq_bool true,
       Json_ant.Jq_ast.Jq_array
        (Json_ant.Jq_ast.Jq_comma (Json_ant.Jq_ast.Jq_bool true,
          Json_ant.Jq_ast.Jq_bool false))),
     Json_ant.Jq_ast.Jq_bool false))

# << $ << 1 >> $ >>;;
- : Json_ant.Jq_ast.t = Json_ant.Jq_ast.Jq_number 1.
```

The procedure is as follows:

```
<< $ << 1 >> $>>  (* parsing (my parser) *)
Jq_Ant(_loc, "<< 1 >> ") (* lifting  (mechnical) *)
Ex_Ant(_loc, "<< 1 >>") (* parsing  (the host parser *)
<:expr< Jq_number 1. >>   (* antiquot_expand (my anti_expander ) *)
<:expr < Jq_number 1. >>
```

4.4.9 Part 10 Lexer

This part is deprecated. Camlp4 is not vanilla, it's inappropriate for not ocaml-oriented programming, since you have to do too much by hand. Just follow the signature of module type Lexer is enough. generally you have to provide module Loc, Token, Filter, Error, and mk 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
*)
```

4.5 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
```

Inside a << do { ... } >> you can use << let var = expr1; expr2 >> like << let var = expr1 in expr2>> .

The main goal is to facilitate imperative coding inside a « do »:

```
do {
 let x = 42;
 do_that_on x;
 let y = x + 2;
 play_with y;
}
```

That's nice but undocumented **Without** such a syntax the regular one will make you nest `do { ... }` notations.

```
do {
 foo 1;
 let x = 43 in do {
    bar x;
 };
```

```
  (* x should be out of the scope *)
}
```

Alas `<< let ... in >>` and `<< let ... ; >>` have the same semantics inside a `<< do { ... } >>` what I regret because `<< let ... in >>` is not local anymore.

In plain OCaml it's different since `<< ; >>` is a binary operator so you must see `<< let a = () in a; a >>` like `<< let a = () in (a; a) >>`.

Another utility to learn some revised syntax

```
camlp4o -printer r -str '{ s with foo = bar }'
{(s) with foo = bar;};

camlp4o -printer r -str 'type t = [`A | `B ]'

type t = [= `A | `B ];
```

4.6 Built in syntax extension in camlp4

4.6.1 Map Filter

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*. It needs to read the `definition` of the type.

Camlp4 uses the **filter** iteself to bootstrap.

```
(** file Camlp4Ast.mlast *)
class map = Camlp4MapGenerator.generated;
class fold = Camlp4FoldGenerator.generated;
```

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

```
let b = new Camlp4.PreCast.Ast.map ;;
val b : Camlp4.PreCast.Ast.map = <obj>
```

4.6.2 Case study-Filter example

```
(** a simple ast transform *)
open Camlp4.PreCast
let simplify = object
  inherit Ast.map as super
  method expr e = match super#expr e with
   | <:expr< $x$ + 0 >> | <:expr< 0 + $x$  >> ->  x
   | x -> x
end in AstFilters.register_str_item_filter simplify#str_item
```

you can write it without sytax extension(very tedious),

```
(** the same as above without syntax extension, you can get with
    camlp4of ast_add_zero.ml -printer o *)
let _ =
  let simplify =
object
  inherit Ast.map as super
  method expr =
    fun e ->
```

```
      match super#expr e with
        | Ast.ExApp (_,
                     (Ast.ExApp (_, (Ast.ExId (_, (Ast.IdLid (_, "+")))), x)),
                     (Ast.ExInt (_, "0"))) |
          Ast.ExApp (_,
                      (Ast.ExApp (_, (Ast.ExId (_, (Ast.IdLid (_, "+")))),
                                  (Ast.ExInt (_, "0")))),
                      x)
          -> x
        | x -> x
end
  in AstFilters.register_str_item_filter simplify#str_item
```

To make life easier, you can write like this

```
let _ =
  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
```

In the module `Camlp4.PreCast.AstFilters`, which is generated by `Camlp4.Struct.AstFilters` there are some utiliies to do filter over the ast. It's actually very simple. (4.2.10)

```
type 'a filter = 'a -> 'a
val register_sig_item_filter : Ast.sig_item filter -> unit
val register_str_item_filter : Ast.str_item filter -> unit
val register_topphrase_filter : Ast.str_item filter -> unit
val fold_interf_filters : ('a -> Ast.sig_item filter -> 'a) -> 'a -> 'a
val fold_implem_filters : ('a -> Ast.str_item filter -> 'a) -> 'a -> 'a
val fold_topphrase_filters :
  ('a -> Ast.str_item filter -> 'a) -> 'a -> 'a
```

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

```
type a =
  | A of b
  | C
and b =
  | B of a
  | D
```

```
class map = Camlp4MapGenerator.generated

let _ =
  let v = object
    inherit map as super
    method! b x = match super#b x with
      | D -> B C
      | x -> x
  end in
  assert (v#b D = B (C))
```

Without filter, you would write the transformer by hand like this

```
(** The processed output of ast_map *)
type a = | A of b | C and b = | B of a | D

class map =
  object ((o : 'self_type))
    method b : b -> b = function | B _x -> let _x = o#a _x in B _x | D -> D
    method a : a -> a = function | A _x -> let _x = o#b _x in A _x | C -> C
    method unknown : 'a. 'a -> 'a = fun x -> x
  end

let _ =
  let v =
    object
      inherit map as super
      method! b = fun x -> match super#b x with | D -> B C | x -> x
    end
  in assert ((v#b D) = (B C))
```

4.6.3 Bootstrap

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 ; (** inherited from Ast.map *)
  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 be changed 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.**

There are other transformers as well.

4.6.4 Fold filter

```
  class x = Camlp4FoldGenerator.generated ;
```

4.6.5 Meta filter

Meta filter needs a module name, however, it also needs the source of the definition of the module. (Since OCaml does not have type reflection). There are some problems here, first you want to separate the type definition in another file, this could be achieved while using macro `INCLUDE`, and `Camlp4Trash`, however, you also want to make your type definition to using another syntax extension, i.e, `sexplib`, `deriving`, `deriving` will generate a bunch of modules and types, which conflicts with our `Meta filter`. So, be careful here.

However, the problem can not be solved for meta filter, it can be solved for `map, fold` filter, for the meta filter, it will introduce the name of `Camlp4Trash` into the source, so you can not really trash the module. The only way to do it is to write your own `TrashModule` ast filter.

```
(**
   camlp4of -filter map -filter fold -filter trash  -filter meta -parser Pa_type_conv.cma pa_sexp_conv.cma pa_json_ast.m
*)
```

```
open Sexplib.Std

type float' = float
and 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
with sexp
```

```
open Camlp4.PreCast
open Json_ast

module Camlp4TrashX = struct
    INCLUDE "json_ast.ml"
end

open Camlp4TrashX

class map = Camlp4MapGenerator.generated

class fold = Camlp4FoldGenerator.generated
```

```
module MetaExpr = struct
  let meta_float' _loc f =
    <:expr< $`flo:f$ >>
  include Camlp4Filters.MetaGeneratorExpr(Camlp4TrashX)
end

module MetaPatt  = struct
  let meta_float' _loc f =
    <:patt< $`flo:f$ >>
  include Camlp4Filters.MetaGeneratorPatt(Camlp4TrashX)
end
```

Notice that we have `Camlp4TrashX`, you can not trash it, due to the fact that the generated code needs it.

4.6.6 Lift filter

These functions are what *Camlp4AstLifter uses* to lift the AST, and also how *quotations are implemented* A example of meta filter could be found here . Here we do a interesting experiment, lift a ast for serveral times

```
camlp4o -filter lift -filter lift  test_lift.ml -printer o >
   test_lift_1.ml
camlp4o -filter lift -filter lift  test_lift_1.ml -printer o >
   test_lift_2.ml
```

```
type t =
    A | B

let loc = Loc.ghost
in
  Ast.StTyp (loc,
    (Ast.TyDcl (loc, "t", [],
       (Ast.TySum (loc,
          (Ast.TyOr (loc, (Ast.TyId (loc, (Ast.IdUid (loc, "A")))),
             (Ast.TyId (loc, (Ast.IdUid (loc, "B")))))))),
       [])))

let loc = Loc.ghost
in
  Ast.StExp (loc,
    (Ast.ExLet (loc, Ast.ReNil,
       (Ast.BiEq (loc, (Ast.PaId (loc, (Ast.IdLid (loc, "loc")))),
          (Ast.ExId (loc,
             (Ast.IdAcc (loc, (Ast.IdUid (loc, "Loc")),
                (Ast.IdLid (loc, "ghost")))))))),
       (Ast.ExApp (loc,
          (Ast.ExApp (loc,
             (Ast.ExId (loc,
                (Ast.IdAcc (loc, (Ast.IdUid (loc, "Ast")),
                   (Ast.IdUid (loc, "StTyp")))))),
             (Ast.ExId (loc, (Ast.IdLid (loc, "loc")))))),
          (Ast.ExApp (loc,
             (Ast.ExApp (loc,
                (Ast.ExApp (loc,
                   (Ast.ExApp (loc,
                      (Ast.ExApp (loc,
                         (Ast.ExId (loc,
                            (Ast.IdAcc (loc, (Ast.IdUid (loc, "Ast")),
```

```
                  (Ast.IdUid (loc, "TyDcl")))))),
              (Ast.ExId (loc, (Ast.IdLid (loc, "loc")))))),
            (Ast.ExStr (loc, "t")))),
          (Ast.ExId (loc, (Ast.IdUid (loc, "[]")))))),
        (Ast.ExApp (loc,
          (Ast.ExApp (loc,
            (Ast.ExId (loc,
              (Ast.IdAcc (loc, (Ast.IdUid (loc, "Ast")),
                (Ast.IdUid (loc, "TySum")))))),
            (Ast.ExId (loc, (Ast.IdLid (loc, "loc")))))),
          (Ast.ExApp (loc,
            (Ast.ExApp (loc,
              (Ast.ExApp (loc,
                (Ast.ExId (loc,
                  (Ast.IdAcc (loc, (Ast.IdUid (loc, "Ast")),
                    (Ast.IdUid (loc, "TyOr")))))),
                (Ast.ExId (loc, (Ast.IdLid (loc, "loc")))))),
              (Ast.ExApp (loc,
                (Ast.ExApp (loc,
                  (Ast.ExId (loc,
                    (Ast.IdAcc (loc, (Ast.IdUid (loc, "Ast")),
                      (Ast.IdUid (loc, "TyId")))))),
                  (Ast.ExId (loc, (Ast.IdLid (loc, "loc")))))),
                (Ast.ExApp (loc,
                  (Ast.ExApp (loc,
                    (Ast.ExId (loc,
                      (Ast.IdAcc (loc,
                        (Ast.IdUid (loc, "Ast")),
                        (Ast.IdUid (loc, "IdUid")))))),
                    (Ast.ExId (loc, (Ast.IdLid (loc, "loc")))))),
                  (Ast.ExStr (loc, "A")))))))),
            (Ast.ExApp (loc,
              (Ast.ExApp (loc,
                (Ast.ExId (loc,
                  (Ast.IdAcc (loc, (Ast.IdUid (loc, "Ast")),
                    (Ast.IdUid (loc, "TyId")))))),
                (Ast.ExId (loc, (Ast.IdLid (loc, "loc")))))),
              (Ast.ExApp (loc,
                (Ast.ExApp (loc,
                  (Ast.ExId (loc,
                    (Ast.IdAcc (loc, (Ast.IdUid (loc, "Ast")),
                      (Ast.IdUid (loc, "IdUid")))))),
                  (Ast.ExId (loc, (Ast.IdLid (loc, "loc")))))),
                (Ast.ExStr (loc, "B"))))))))))),
    (Ast.ExId (loc, (Ast.IdUid (loc, "[]"))))))))))
```

4.6.7 Location Strip filter

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, but you can solve it by open the Module)

4.6.8 Camlp4Profiler

Inserts profiling code

4.6.9 Camlp4TrashRemover

```
open Camlp4;

module Id = struct
  value name    = "Camlp4TrashRemover";
  value version = Sys.ocaml_version;
end;

module Make (AstFilters : Camlp4.Sig.AstFilters) = struct
  open AstFilters;
  open Ast;

  register_str_item_filter
    (Ast.map_str_item
      (fun
       [ <:str_item@_loc< module Camlp4Trash = $_$ >> ->
            <:str_item<>>
       | st -> st ]))#str_item;

end;

let module M = Camlp4.Register.AstFilter Id Make in ();
```

4.6.10 Camlp4ExceptionTracer

4.7 Examples

4.7.1 Pa_python

```
(* Author: bobzhang1988@seas215.wlan.seas.upenn.edu        *)
(* Version: $Id: test.ml,v 0.0 2012/02/12 19:48:30 bobzhang1988 Exp $ *)
(* open BatPervasives *)

(* ocamlbuild -lflags -linkall translate.cma *)
(* camlp4o -I _build translate.cma -impl test.py -printer o *)
open Printf
open Camlp4.PreCast

open Camlp4

(**
   1. Define your own ast
      There's need to add location to your ast.
      This can locate the error position during type-check time
      If you only care syntax-error location, then it's not necessary
   2. Parse to your ast
   3. Translate yor ast to ocaml ast
      two ways to translate
      a. meta-expr
         mechanical, but not very useful, just make your concrete syntax
         a little easy
      b. do some transformation
         semantics changed
   4. define quotation syntax for your syntax tree
      not necessary but make your life easier
*)

(**
   concrete_syntax
   stmt:
      def id = expr
      print exprs
   expr:
      string-literal
      id

   exprs: expr list
*)


(* module MGram = MakeGram(Lexer) *)
```

```
module MGram = Gram

type  stmt =
    Def of Loc.t *  id * expr
  | Print of Loc.t * expr list
and  expr =
  | Var of Loc.t * id
  | String of Loc.t * string
and id = string
and prog =
  | Prog of Loc.t * stmt list

let pys = MGram.Entry.mk "pys"
let pys_eoi = MGram.Entry.mk "pys_eoi"

let _ = begin
  MGram.Entry.clear pys;
  MGram.Entry.clear pys_eoi;
  EXTEND MGram GLOBAL: pys_eoi;
  pys_eoi:
    [ [ prog= pys ; EOI -> prog ]];
  END;
  EXTEND MGram GLOBAL:pys;
    pexpr: [
      [ s = STRING -> String(_loc, s)
        (** here we want  "\n" be comprehended as "\n", so we don't
            escape.
            *)
      | id = LIDENT -> Var(_loc, id)
      ]
    ];
    pys:
      [ [ stmts = LIST0 [ p = py ;  ";" -> p  ]  -> Prog(_loc, stmts)] ];
    py:
      [
        [ "def"; id=LIDENT; "="; e = pexpr -> begin
          (* prerr_endline "def"; *)
          Def (_loc, id, e);
        end
        | "print"; es = LIST1 pexpr SEP "," ->
           Print(_loc, es)
        ]
      ];
  END;
end

let pys_parser  str =
```

```
  MGram.parse_string pys_eoi (Loc.mk "<string>") str

let a =
  pys_parser "def a = \"3\"; def b =  \"4\"; def c =  \"5 \"; print a,b,c; "

(** Parser is ok now.  Now Ast Transformer, if we defined quotation
    for our own syntax. That would be easier *)
```

Now we transform the ast to the semantics what we want, we write Ast transformation using revised syntax(robust, and disambiguous) .

```
(* Author: bobzhang1988@seas215.wlan.seas.upenn.edu        *)
(* Version: $Id: translate.ml,v 0.0 2012/02/12 20:28:50 bobzhang1988 Exp $ *)


(** Revised Syntax *)

(* open BatPervasives; *)
open Printf;
open Test;
open Camlp4;
open Camlp4.PreCast;


value rec concat  (asts : list Ast.expr) : Ast.expr  =
    match asts with
   [ [] -> assert False
   | [h] -> h
   | [h::t ] ->
     let _loc = Ast.loc_of_expr h in
     <:expr< $h$ ^ $concat t$  >>
   ]
;

value rec translate (p: prog ) :Ast.str_item =
  match p with
      [ Prog(_loc,stmts) ->
        <:str_item< $list: List.map translate_stmt stmts $ >>
      ]
and translate_stmt (st:stmt) =
    match st with
    [ Def (_loc, id, expr) ->
      <:str_item< value $lid:id$ = $translate_expr expr$ ;>>
    | Print (_loc, exprs) ->
      <:str_item< print_endline $concat  (List.map translate_expr exprs) $;
        >>
```

```
    ]
and translate_expr (e:expr) =
    match e with
    [ Var (_loc, id) -> <:expr<$lid:id$ >>
    | String (_loc,s) -> <:expr<$str:s$ >>    (* Check whether needs escaped later*)
    ]
;

begin
  Gram.Entry.clear Syntax.str_item ;
  let open Syntax in begin
  EXTEND Gram GLOBAL:str_item;
    str_item : [ [ s = pys_eoi -> translate s ] ];
  END ;
  (* Gram.Entry.print Format.std_formatter expr; *)
  end ;
end;
```

```
(* module Pa_python (Syntax:Sig.Camlp4Syntax) = struct *)
(*   (\* open Syntax; *\) *)
(*   prerr_endline "why is it not invoked"; *)
(*   open Camlp4.PreCast.Syntax; *)
(*   Gram.Entry.clear str_item ; *)
(*   EXTEND Gram *)
(*     str_item : [ [ s = pys_eoi -> *)
(*       begin *)
(*         prerr_endline "here"; *)
(*         translate s; *)
(*       end ] ]; *)
(*   END ; *)
(*   include Syntax ; *)
(* end ; *)
```

```
(* prerr_endline "weird"; *)
(* let module M = Camlp4.Register.OCamlSyntaxExtension Id Pa_python in (); *)

(** Here we use MGram, they are _actually_ the same, but
    Syntax.Gram.Entry.t is not the same as
    Test.Prog Test.MGram.Entry.t
*)

(* Without functors *)
(* This is the most straightforward. We complete our code from above as follows: *)
```

Notice, we could either modify using functor interface(tedious, maybe robust, but it does not gurantee anything)

Test file is like this

```
def a = "3";
def b = "4";
def c = "5\n";

print a, b, c;
```

And out put

```
let a = "3"

let b = "4"

let c = "5\n"

let _ = print_endline (a ^ (b ^ c))
```

Everything seems pretty easy, but be careful! When you use camlp4 extensions, use ocamlobjinfo to examine which modules are exactly linked, normally you only need to link your own module file, don't try to link other modules, otherwise you will get trouble.

ocamlbuild is not that smart, use `ocamlbuild -clean` to keep your source tree clean.

The myocamlbuild.ml file now seems rather trival to write

```
  (fun _ -> begin
    flag ["ocaml"; "pp"; "use_python"]
      (S[A"test.cmo"; A"translate.cmo"]);
```

```
    flag ["ocaml"; "pp"; "use_list"]
      (S[A"pa_list.cmo"]);
  end ) +> after_rules;
  (fun _ -> begin
    dep ["ocamldep";  "use_python"] ["test.cmo"; "translate.cmo"];
    dep ["ocamldep";  "use_list"] ["pa_list.cmo"];
    Options.ocaml_lflags := "-linkall" :: !Options.ocaml_lflags;

   end ) +> after_rules;
```

Make sure you know which module you linked.

4.7.2 Pa_list

Notice that here for `pa_list.cmo`, we did not need to link `batteries`, since at executation time, it did not bother `Batteries` at all. Read the commented output, you see at this phase, that `Nil` was acutally translated into `"Nil"`. So actually you don't bother Batteries at all. Even you said `open Batteries`, ocaml compiler was not that stupid to link it.

The test file is also interesting.

This extension illustrates an example to tell us how to extend your parser. Remember, Camlp4 is a source to source level pretty-printer. So you don't need to be responsible for which library will be linked at the time of writing syntax extension. The user may make sure such module or value really exist.'

4.7.3 Pa_abstract

This example shows how to customize your options for your syntax extension.

4.7.4 Pa_apply

This is a dirty way to write a filter plugin, you may write a formal way which uses the interface of `Camlp4.Register`.

4.7.5 Pa_ctyp

This example shows how to make use of the existing parser or printer of camlp4.

4.7.6 Pa_exception_wrapper

4.7.7 Pa_exception_tracer

4.7.8 Pa_freevars

4.7.9 Pa_freevars_filter

4.7.10 Pa_global_handler

4.7.11 Pa_holes

4.7.12 Pa_minimm

4.7.13 Pa_plus

4.7.14 Pa_zero

4.7.15 Parse_arith

4.7.16 Pa_estring

4.7.17 Pa_holes

4.8 Useful links

Abstract_Syntax_Tree

elehack

meta-guide

camlp4

zheng.li

pa-do

Wiki

yutaka

Chapter 5

Libraries

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 preproccessed 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]+|(?:[Oo][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 = [".libfetion/libfetion.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 "abcabc" 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 = `Div)
  | ("*" 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; `Text ""]
```

```
let xs = Mikmatch.Text.map (function `Text (RE space* eos) -> raise Mikmatch.Text.Skip | token -> token
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 "%s %i-%i'
```

(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])))(?![0
```

(j) ignore the case

```
match "OCaml" with RE "O" "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 redundants 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{ocamlcode}" -> "\n" ^ x
      | RE "\xend{ocamlcode}" -> 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 pa-do

5.4 num

- delimited overloading

5.5 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 languag) 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.dobule_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)

5.6 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
)

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_.fprint_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
```

```ocaml
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
```

5.7 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 ues 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+y+z) ;
  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+y+z) ;
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")
```

5.8 bigarray

This implementation allows efficient sharing of large numerical arrays between Caml code and C or Fortran numerical libraries. Your are encouraged to `open Bigarray`. Big arrays support the ad-hoc polymorphic operations (comparison, hashing,marshall)

Element kinds

The abstract type `type ('a,'b) kind` captures type 'a for values read or written in the array, while 'b which represents the actual content of the big array.

Array layouts

5.9 sexplib

Basic Usage

```
#require "sexplib.top";;
```

```
open Sexplib
open Std
type t = A of int list | B with sexp;;
module S = Sexp;;
module C = Conv;;
```

```
 sub_modules "Sexplib";;
module This_module_name_should_not_be_used :
    module Type :
    module Parser :
    module Lexer :
    module Pre_sexp :
        module Annot :
        module Parse_pos :
        module Annotated :
        module Of_string_conv_exn :
    module Sexp_intf :
        module type S =
            module Parse_pos :
            module Annotated :
            module Of_string_conv_exn :
    module Sexp :
        module Parse_pos :
        module Annotated :
        module Of_string_conv_exn :
    module Path :
    module Conv :
        module Exn_converter :
    module Conv_error :
    module Exn_magic :
    module Std :
        module Hashtbl :
            module type HashedType =
            module type S =
            module Make :
        module Big_int :
        module Nat :
        module Num :
        module Ratio :
```

```
module Lazy :
```

build with sex-plib

Build
Debug

```
camlp4o -parser Pa_type_conv.cma pa_sexp_conv.cma   sexp.ml -printer
   o
```

Modules

`Sexp` Contains all I/O-functions for Sexp, module `Conv` helper functions converting OCaml-valus of `standard-types` to Sexp. Moduel `Path` supports sub-expression extraction and substitution.

Sexp

```
type t = Sexplib.Type.t = Atom of string | List of t list
```

Syntax

`with sexp` or `with sexp_of` or `with of_sexp`. `signatures` are also well supported. When packed, you should use `TYPE_CONV_PATH` to make the location right. Common utilities are exported by `Std`.

we hope `sexp_of_t |- t_of_sexp` to be an `id` function

```
let f = exp_of_int |- int_of_exp
Enum.( let a = range ~until:max_int min_int in
       fold2 (fun l r a -> a & (l=r)) true a (map f a) );;
```

5.10 bin-prot

5.11 fieldslib

5.12 variantslib

5.13 delimited continuations

Continuatioins A conditional banch selects a continuation from the two possible futures; rasing 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 ) + 100 )
```

```
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 = "lajiworld"
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 continutations, 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 () -> [...] ^ "word" )` 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

5.14 shcaml

A shell library. (you can refer `Shell` module of shell package)

All modules in the system are submodules of the `Shcaml` module, except ofr the module `Shtop`

5.15 deriving

Build

For debuging

```
cd `camlp4 -where`
ln -s `ocamlfind query deriving-ocsigen`/pa_deriving.cma
```

So you could type `camlp4o -parser pa_deriving.cma test.ml`

Toplevel `#require "deriving-ocsigen.syntax";;`
For building, a typical tags file is as follows.

```
true : pkg_deriving-ocsigen
<test.ml> : syntax_camlp4o, pkg_deriving-ocsigen.syntax
```

```
type 'a tree =
  | Leaf of 'a
  | Node of 'a * 'a tree * 'a tree
deriving (Show,Eq,Typeable, Functor)

let _ = begin
  print_string (Show.show<int tree> (Node (3, Leaf 4, Leaf 5)));
end
```

5.16 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 =>* 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

Chapter 6

Runtime

Should be re- written later

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 string

+---------------+---------------+---------------+- - - -
| header        | value[0]      | value[1]      | ....
+---------------+---------------+---------------+- - - -
                  ^
                  |
              an OCaml array

+---------------+---------------+
| header        | arg[0]        |
+---------------+---------------+
                  ^
                  |
              a variant with one arg
```

```
+--------------+-------------+---------+--+--+--------------+
| size of the block in words              | col | tag byte
       |
+--------------+-------------+---------+--+--+--------------+
 ^                                          <- 2b-><--- 8 bits
    --->
 |
offset -4 or -8
% 32 platform, it's 22bits long : the reason for the annoying 16
   MByte limit
% for string
% the tag byte is multipurpose
% in the variant-with-parameter example above, it tells you
   which
% variant it is. In the string case, it contains a little bit of
    runtime
% type information. In other cases it can tell the gc that it's
   a lazy value
% or opaque data that the gc should not scan



+--------------+-------------+-------------+- - - - -
| header       | float[0]                 | ....
+--------------+-------------+-------------+- - - - -
                 ^
                 |
              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 varient 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 elements is a float	These are treated as a special case. The tag has special value `Dyn_array_tag` (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 `String_tag` (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.("ghsoghoshgoshgoshgoshogh"|> repr |> size);;
- : int = 4 (4*8 = 32 )
"ghsoghoshgoshgoshgoshogh" |> 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

Should be re-written later

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 = 126976;
 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
```

```
+-----------------------------------------------------------+
| unallocated                         |///allocated part/////////|
+-----------------------------------------------------------+
 ^                                     ^
 |                                     |
caml_young_limit                  caml_young_ptr
                              <------ allocation proceeds
                                     in this direction
```

   Consider *the array of two elements*, the total size of this object *will be 3 words (header + 2 words)*, so 24 bytes for 64-bit , so the fast path for allocation is subtract size from caml_young_ptr. If caml_young_ptr < caml_young_limit, then take the slow path through the garbage collector. The fast path just **five machine instructions and no branches**. But even five instructions are costly in inner loops, be careful.

   (b) major heap

   when the minor heap runs out, it triggers a **minor collection**. The minor collection starts at all the local roots and *oldifies* them, basically copies them by reallocating those objects (recursively) **to the major heap**. After this, any object left in the minor heap **are unreachable**, so the minor heap can be reused by resetting **caml_young_ptr** .

```
           reachable         reachable
+----------+---------+-------+----+----+-----------------+
|          |/////////|       |///-->///|                 |
+----------+---------+-------+----+----+-----------------+
           ^                 ^
           |                 |
        local root        local root
```

At runtime the garbage collector *always* knows what is a pointer, and what is an int or opaque data (like a string). Pointers get scanned so the GC can find unreachable blocks. Ints and opaque data must not be scanned. *This is the reason for having a tag bit for integer-like values*, and one of the uses of the tag byte in the header.

```
                  "Tag byte space"
+-----------+
| 0         | Array, tuple, etc.
+-----------+
| 1         |
+-----------+
| 2         |
~           ~
|           | Tags in the range 0..245 are used for variants
~           ~
| 245       |
+-----------+
| 246       | Lazy (before being forced)
+-----------+
| 247       | Closure
+-----------+
| 248       | Object                              ^
+-----------+                                     |  Block
   contains
| 249       | Used to implement closures          |  values
   which the
+-----------+                                     |  GC should
   scan
| 250       | Used to implement lazy values       |
+-----------+ <----------------------------  No_scan_tag
| 251       | Abstract data                       |
+-----------+                                     |  Block
   contains
| 252       | String                              |  opaque
   data
```

```
+----------+                                                    |   which GC
   must
| 253      | Double                                             V   not scan
+----------+
| 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 a nd 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, **provied 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
    poisition " ^ 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
```

Chapter 8

Object-oriented

8.1 Simple Object Concepts

```
let poly = object
  val vertices = [|0,0;1,1;2,2|]
  method draw = "test"
end
(**
   val poly : < draw : string > = <obj>
*)
```

obj#method, the actual method gets called is determined at runtime.

```
let draw_list  =   List.iter (fun x -> x#draw)
(**
   val draw_list : < draw : unit; _.. > list -> unit = <fun>
*)
```

.. is a row variable

```
type 'a blob = <draw : unit;  ..> as 'a
(* type 'a blob = 'a constraint 'a = < draw : unit; .. >   *)
```

{<>} represents a **functional update** (only fields), which produces a new object

Some other examples

```
type 'a blob = 'a constraint 'a = < draw : unit > ;;
(* type 'a blob = 'a constraint 'a = < draw : unit >   *)

type 'a blob = 'a constraint 'a = < draw : unit ; .. > ;;
(* 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>
*)

let test_init =object
```

Something to Notice

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`

```
let test_init =object
```

```
    val x = 1
    val mutable x_plus_1 = 0
    initializer begin
      print_endline "hello ";
      x_plus_1 <- x + 1;
    end
end ;;

(**
hello
val test_init : <  > = <obj>
*)
```

Private method

```
let test_private = object
  val x = 1
  method private print =
    print_int x
end ;;
(* val test_private : <  > = <obj> *)
```

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. Sometimes, type annotation and coersion both needed, when t2 is recursive or t2 has polymorphic structure.

```
  e : t1 :> t2
```

Simulate narrowing(downcast)

```
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 bark = ()
```

```
end;;

let miao : cat = object(self)
  method v = Cat self
  method eat = ()
  method meow = ()
end;;

let _ = begin
  let test o = match o#v with
    | Dog o' -> print_endline "Dog"
    | Cat o' -> print_endline "Cat"
    | _ -> print_endline "not handled"
  in
  test fido;
  test miao;
end
(**
   Dog
   Cat
*)
```

It's doable, since `exn` is open and its tag is global, and you can store the tag information uniformly. But onething to notice is that you can not write safe code, since exn is extensible, you can not guarantee that you match is exhuastive.

You can also implement using polymorphic variants, this is essentially the same thing, since `Polymorphic Variants` is also global and extensible.

```
type 'a animal = <eat:unit; tag : 'a >;;


let fido : [< `Dog of int] animal = object method eat = () method tag = `Dog 3 end;;
(* val fido : [ `Dog of int ] animal = <obj> *)


let fido : 'a 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> *)
```

```
let aims =  [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] *)
```

8.2 Modules vs Objects

1. Objects (data entirely hidden)

2. Self recursive type is so natural in objects, isomorphic-like equivalence is free in oo.

3. Example

   ```
   let list_obj initial = object
     val content = initial
     method cons x = {< content = x :: content >}
   end


   (** module style *)
   module type PolySig = sig
     type poly
     val create : (float*float) array -> poly
     val draw : poly -> unit
     val transform : poly -> poly
   end
   ;;

   module Poly :PolySig = struct
     type poly = (float * float) array
     let create vertices = vertices
     let draw vertices = ()
     let transform matrix = matrix
   end;;


   (** class style *)
   class type poly  = object
    method create : (float*float) array -> poly
    method draw :  unit
   ```

```
 method transform : poly
end;;

class poly_class  = object (self:'self)
  val mutable vertices : (float * float ) array = [||]
  method create vs = {< vertices = vs >}
  method draw = ()
  method transform = {< vertices = vertices >}
end;;

(** makes the type not that horrible. First class objects, but not
    first class classes
*)
let a_obj : poly = new poly_class


(** oo-style *)
type blob = < draw : unit -> unit; transform : unit -> blob >;;

(** functional style *)
type blob2 = {draw:unit-> unit; transform:unit-> blob2};;
```

8.3 More about class

Write
later

Chapter 9

Language Features

9.1 Stream Expression

Link to streams

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 ] Stream.t

ocamlbuild test_stream.pp.ml

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.sempty
*)
open Batteries
```

```
let _ =
  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)
  );;
```

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))
```

Constructing streams

```
Stream.from
Stream.of_list
Stream.of_string (* char t *)
Stream.of_channel (* char t *)
```

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) stre  am; !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
```

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))
```

Convert arbitray data types to streams

If the datat type 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 GADT

```
type _ expr =
  | Int : int -> int expr
  | Add : (int -> int -> int) expr
  | App : ('a -> 'b ) expr * 'a expr -> 'b expr


let rec eval : type t . t expr -> t = function
  | Int n -> n
  | Add -> (+)
  | App (f,x) -> eval f (eval x)


(** tagless data structure *)
type _ ty =
  | Tint : int ty
  | Tbool : bool ty
  | Tpair : 'a ty * 'b ty -> ('a * 'b) ty

(** inside pattern matching, type inference progresses from left to
    right, allowing subsequent patterns to benift from type equations
    generated in the previous ones.
    This implies that d has type int on the first line,...
*)
let rec print : type a . a ty -> a -> string = fun t d ->
  match t, d with
    |Tint, n -> string_of_int n
    |Tbool,true -> "true"
    |Tbool,false -> "false"
    |Tpair (ta,tb), (a,b) ->
      "(" ^ print ta a ^ ", " ^ print tb b ^ ")"

let f = print (Tpair (Tint,Tbool))
```

read ml 2011 workshop paper

9.3 First Class Module

First class mdoule

```
module type ID = sig val id : 'a -> 'a end

let f m =
    let module Id = (val m : ID) in
    (Id.id 1, Id.id true);;

(* val f : (module ID) -> int * bool = <fun>   *)

f (module struct let id x = print_endline "ID!"; x end : ID);;
(*
  ID!
  ID!
*)
```

Here the argument `m` is a module. This is already possible with objects and records, but now modules are also allowed. We introduce three syntaxes

```
(your_module : Sig) (*packing*)
```

```
(val def : Sig) (*unpacking*)
```

```
(module Sig) (*type*)
```

Runtime choices, Type-safe plugins

Parametric algorithms

Read the slides by Jacques Garrigue

```
module type Number = sig
  type t
  val int : int -> t
  val (+) : t -> t -> t
  val (/) : t -> t -> t
end

let average (type t) number arr =
  let module N = (val number : Number with type t = t) in
  N.(
    let r = ref (int 0) and len = Array.length arr in
    for i = 0 to Pervasives.( len - 1) do
      r := !r + arr.(i)
```

```
    done;
    !r / int (Array.length arr)
  )

(* val average : (module Number with type t = 'a) -> 'a array -> 'a = <fun>     *)

let f =
  average
    (module struct
      type t = int
      let (+) = (+)
      let (/) = (/)
      let int = fun x -> x
    end : Number with type t = int);;
(* val f : int array -> int = <fun> *)
```

Notice `with type t = int` is necessary here.

The next is a fancy example to illustrate lebiniz equivalence, readers should try to digest it. Something to reminder, now the simple type may be a very complex module type.

```
type ('a, 'b) eq = (module EqTC with type a = 'a and type b = 'b)))

(** First class module to encode *)
module type TyCon = sig
  type 'a tc
end


module type WeakEQ =
sig
  type ('a, 'b) eq
  val refl : unit -> ('a, 'a) eq
  val symm : ('a, 'b) eq -> ('b, 'a) eq
  val trans : ('a, 'b) eq -> ('b, 'c) eq -> ('a, 'c) eq
  val cast : ('a, 'b) eq -> 'a -> 'b
end

module WeakEq : WeakEQ =
struct
  type ('a, 'b) eq = ('a -> 'b) * ('b -> 'a)
  let refl () = (fun x -> x), (fun x -> x)
  let symm  (f, g)        = (g, f)
  let trans (f, g) (j, k) = (fun x -> j (f x)), (fun x -> g (k x))
  let cast  (f, g)        = f
end
```

```
module type EQ =
sig
  type ('a, 'b) eq
  val refl : unit -> ('a, 'a) eq

  module Subst (TC : TyCon) :  sig
    val subst : ('a, 'b) eq -> ('a TC.tc, 'b TC.tc) eq
  end
  val cast : ('a, 'b) eq -> 'a -> 'b
end

module Eq : EQ = struct

  (** EqTC can be seen as a high-order kind, parameterized by two type
      variables a b. This is the limitation of ocaml, since type
      variable as a parameter can only appear in [type 'a t], the type
      variable will be *universally quantified* when it appears in
      other places *)
  module type EqTC =  sig
    type a
    type b
    (** You see the definition of [TC], it could be parameterized
        here *)
    module Cast : functor (TC : TyCon) ->  sig
      val cast : a TC.tc -> b TC.tc
    end
  end

  type ('a, 'b) eq = (module EqTC with type a = 'a and type b = 'b)

  let refl (type t) () =  (module struct
    type a = t
    type b = t
    module Cast (TC : TyCon) =
    struct
      let cast v = v
    end
  end : EqTC with type a = t and type b = t)

  let cast (type s) (type t) s_eq_t =
    let module S_eqtc = (val s_eq_t : EqTC with type a = s and type b = t) in
    let module C = S_eqtc.Cast(struct type 'a tc = 'a end) in
    C.cast

  module Subst (TC : TyCon) =  struct
    (** We have (s,t) eq, now we want to construct a proof of (s TC.t,
```

```
        t Tc.t) eq .
        i.e, a Sc.t -> b Sc.t, s Tc.t Sc.t -> t Tc.t Sc.t *)
    let subst (type s) (type t) s_eq_t =
      (module
       struct
         type a = s TC.tc
         type b = t TC.tc
         module S_eqtc = (val s_eq_t : EqTC with type a = s and type b = t)
         module Cast (SC : TyCon) =
         struct
           module C = S_eqtc.Cast(struct type 'a tc = 'a TC.tc SC.tc end)
           let cast = C.cast
         end
       end : EqTC with type a = s TC.tc and type b = t TC.tc)
  end
end

include Eq

let symm : 'a 'b. ('a, 'b) eq -> ('b, 'a) eq =
  fun (type a) (type b) a_eq_b ->
    let module S = Subst (struct type 'a tc = ('a, a) eq end) in
    cast (S.subst a_eq_b) (refl ())


let trans : 'a 'b 'c. ('a, 'b) eq -> ('b, 'c) eq -> ('a, 'c) eq =
  fun (type a) (type b) (type c) a_eq_b b_eq_c ->
    let module S = Subst(struct type 'a tc = (a, 'a) eq end) in
    cast (S.subst b_eq_c) a_eq_b

(** Our implementation of equality seems sufficient for the common
    examples, but has one apparent limitation, described below.  A few
    examples seem to require an inverse of Leibniz's law.  For
    injectivty type constructors t, we would like to have ('a t, 'b t)
    eq -> ('a, 'b) eq For example, given a proof that two function
    types are equal, we would like to extract proofs that the domain
    and codomain types are equal: ('a -> 'b, 'c -> 'd) eq -> ('a, 'c)
    eq * ('b, 'd) eq GADTs themselves support type decomposition in
    this way.  Unfortunately, injectivity is supported only for
    WeakEq.eq.  We may always get WeakEq.eq from EQ.eq.
*)
let degrade : 'r 's. ('r, 's) eq -> ('r, 's) WeakEq.eq =
  fun (type r) (type s) r_eq_s ->
    let module M = Eq.Subst(struct type 'a tc = ('a, r) WeakEq.eq end) in
    WeakEq.symm (cast (M.subst r_eq_s) (WeakEq.refl ()))
```

9.4 Pahantom Types

A simple example

```
module type S = sig
  type 'a expr
  val int : int -> int expr
  val bool : bool -> bool expr
  val add : int expr -> int expr -> int expr
  val app : ('a -> 'b ) expr -> ('a expr -> 'b expr)
  val lam : ('a expr -> 'b expr ) -> ('a -> 'b) expr
end
```

```
module M : S= struct
  type term =
      Int of int
    | Bool of bool
    | Add of term * term
    | App of term * term
    | Lam of (term -> term)

  type 'a expr =  term (* The phantom type *)
  let int : int -> int expr = fun i ->  (Int i)
  let bool : bool -> bool expr = fun b ->  (Bool b)

  let add : int expr -> int expr -> int expr =
    fun ( e1) ( e2) ->  (Add(e1,e2))

  let app : ('a -> 'b) expr -> ('a expr -> 'b expr) =
    fun ( e1) ( e2) ->  (App(e1,e2))

  let lam : ('a expr -> 'b expr) -> ('a -> 'b) expr =
    fun f ->  (Lam(fun x -> let ( b) = f ( x) in b))
end
```

```
open M

(*
  lam (fun x -> app x x );;
                      ^
Error: This expression has type ('a -> 'b) M.expr
       but an expression was expected of type 'a M.expr
*)
```

```
module Length : sig
  type 'a t = private float
  val meters : float -> [`Meters] t
  val feet : float -> [`Feet] t
  val (+.) : 'a t -> 'a t -> 'a t
  val to_float : 'a t -> float
end = struct
  type 'a t = float
  external meters : float -> [`Meters] t = "%identity"
  external feet : float -> [`Feet] t = "%identity"
  let (+.) = (+.)
  external to_float : 'a t -> float = "%identity"
end
```

```
let meters, feet = Length.( meters,feet)
let m1 = meters 10.
let m2 = meters 20.
open Printf

let _ =
  printf "10m + 20m = %g\n" Length.(( (m1 +. m2 ) :> float ))

let f1 = feet 40.
let f2 = feet 50.

let _ =   printf "40ft + 50ft = %g\n" (Length.( ((f1 +. f2) :> float )))

  (*printf "10m + 50ft = %g\n" (to_float (m1 +. f2)) (* error *) *)


module Connection : sig
  type 'a t

  (** we return a closed Readonly type *)
  val connect_readonly : unit -> [`Readonly] t

  (** we reeturn  a closed ReadWrite both type *)
  val connect : unit -> [`Readonly|`Readwrite] t

  (** read only or greater *)
  val status : [>`Readonly] t -> int

  val destroy : [>`Readwrite] t -> unit
end = struct
```

```
  type 'a t = int
  let count = ref 0
  let connect_readonly () = incr count; !count
  let connect () = incr count; !count
  let status c = c
  let destroy c = ()
end

module C = String.Cap


(** closed type here when you want it to be read only *)
let read : [ `Read] C.t = C.of_string "aghsogho"

(**
   error
   let _ = C.set s 0 'a'  ; s
*)

let a =
  C.set read 0 'b' ;
  C.get read 0


(** open for write and read *)
let write : [> `Write] C.t    = C.of_string "aghso"

let _ =
  C.set write 0 'a';
  print_char (C.get write 0);
  C.to_string write

(** now
write;;
- : [ `Read | `Write ] C.t = <abstr>
*)

module type S = sig
  type 'a perms
  type 'a t
  val read_only : [`Readable] perms
  val write_only : [`Writable] perms
  val read_write : [> `Readable | `Writable] perms
  (** interesting 'a perms -> 'a t, both perms and t are phantom
      types *)
  val map_file : string -> 'a perms -> int -> 'a t
  val get : [>`Readable] t -> int -> char
```

```
  val set : [>`Writable] t -> int -> char -> unit
end

(**
   Array1.map_file;;
   - : Unix.file_descr ->
   ?pos:int64 ->
   ('a, 'b) Batteries.Bigarray.kind ->
   'c Batteries.Bigarray.layout ->
   bool -> int -> ('a, 'b, 'c) Batteries.Bigarray.Array1.t

   Array1.get;;
   - : ('a, 'b, 'c) Batteries.Bigarray.Array1.t -> int -> 'a = <fun>p

   Array1.set;;
   - : ('a, 'b, 'c) Batteries.Bigarray.Array1.t -> int -> 'a -> unit = <fun>

*)
module M : S= struct
  open Unix
  open Bigarray
  type bytes = (int,int8_unsigned_elt,c_layout) Bigarray.Array1.t
  type 'a perms = int
  type 'a t = bytes
  let read_only = 1
  let write_only = 2
  let read_write = 3
  let openflags_of_perms n = match n with
    | 1 -> O_RDONLY, 0o400
    | 2 -> O_WRONLY, 0o200
    | 3 -> O_RDWR, 0o600
    | _ -> invalid_arg "access_of_openflags"
  let access_of_openflags  = function
    | O_RDONLY -> [R_OK;F_OK]
    | O_WRONLY -> [W_OK; F_OK]
    | O_RDWR -> [R_OK; W_OK;F_OK]
    | _ -> invalid_arg "access_of_openflags"

  let map_file filename perms sz =
    let oflags,fperm = openflags_of_perms perms in
    try
      access filename (access_of_openflags oflags);
      let fd = openfile filename [oflags;O_CREAT] fperm in
      Array1.map_file fd int8_unsigned c_layout false sz
    with
        _ ->
          invalid_arg "map_file: not even a valid permission"
```

```
  let  get a i = Char.chr (Array1.get a i)
  let set a i c = Array1.set a i (Char.code c)

end
```

A fancy example.

```
(** several tricks used in this file *)
module DimArray : sig
  type dec   (* = private unit *)
  type 'a d0 (* =  private unit *)
  and 'a d1  (* = private unit *)
  and 'a d2 (* = private unit *)
  and 'a d3 (* = private unit *)
  and 'a d4 (* = private unit *)
  and 'a d5 (* = private unit *)
  and 'a d6 (* = private unit *)
  and 'a d7 (* = private unit *)
  and 'a d8 (* = private unit *)
  and 'a d9 (* = private unit *)
  type zero (* = private unit  *)
  and nonzero (* = private unit*)
  type ('a, 'z) dim0 (* = private int*)
  type 'a dim = ('a, nonzero) dim0
  type ('t, 'd) dim_array = private ('t array)

  val dec :            ((dec, zero) dim0 -> 'b) -> 'b
  val d0 : 'a dim        -> ('a d0 dim -> 'b) -> 'b
  val d1 : ('a, 'z) dim0 -> ('a d1 dim -> 'b) -> 'b
  val d2 : ('a, 'z) dim0 -> ('a d2 dim -> 'b) -> 'b
  val d3 : ('a, 'z) dim0 -> ('a d3 dim -> 'b) -> 'b
  val d4 : ('a, 'z) dim0 -> ('a d4 dim -> 'b) -> 'b
  val d5 : ('a, 'z) dim0 -> ('a d5 dim -> 'b) -> 'b
  val d6 : ('a, 'z) dim0 -> ('a d6 dim -> 'b) -> 'b
  val d7 : ('a, 'z) dim0 -> ('a d7 dim -> 'b) -> 'b
  val d8 : ('a, 'z) dim0 -> ('a d8 dim -> 'b) -> 'b
  val d9 : ('a, 'z) dim0 -> ('a d9 dim -> 'b) -> 'b
  val dim : ('a, 'z) dim0 -> ('a, 'z) dim0
  val to_int : ('a, 'z) dim0 -> int
  (* arrays with static dimensions *)

  val make : 'd dim -> 't -> ('t, 'd) dim_array
  val init : 'd dim -> (int -> 'a) -> ('a, 'd) dim_array
  val copy : ('a, 'd) dim_array -> ('a, 'd) dim_array
  (* other array operations go here ... *)
  val get : ('a, 'd) dim_array -> int -> 'a
```

```
  val set : ('a, 'd) dim_array -> int -> 'a -> unit
  val combine :
    ('a, 'd) dim_array -> ('b, 'd) dim_array -> ('a -> 'b -> 'c) ->
    ('c, 'd) dim_array
  val length : ('a, 'd) dim_array -> int
  val update : ('a, 'd) dim_array -> int -> 'a -> ('a, 'd) dim_array
  val iter : f:('a -> unit) -> ('a, 'd) dim_array -> unit
  val map : f:('a -> 'b) -> ('a, 'd) dim_array -> ('b, 'd) dim_array
  val iteri : f:(int -> 'a -> unit) -> ('a, 'd) dim_array -> unit
  val mapi : f:(int -> 'a -> 'b) -> ('a, 'd) dim_array ->
    ('b, 'd) dim_array
  val fold_left : f:('a -> 'b -> 'a) -> init:'a -> ('b,'d) dim_array -> 'a
  val fold_right : f:('b -> 'a -> 'a) -> ('b, 'd) dim_array -> init:'a ->
    'a
  val iter2 :
    f:('a -> 'b -> unit) -> ('a,'d) dim_array -> ('b, 'd) dim_array ->
    unit
  val map2 :
    f:('a -> 'b -> 'c) -> ('a, 'd) dim_array -> ('b, 'd) dim_array ->
    ('c, 'd) dim_array
  val iteri2 :
    f:(int -> 'a -> 'b -> unit) -> ('a,'d) dim_array -> ('b, 'd)
    dim_array ->
    unit
  val mapi2 :
    f:(int -> 'a -> 'b -> 'c) -> ('a, 'd) dim_array -> ('b, 'd)
    dim_array ->
    ('c, 'd) dim_array
  val to_array : ('a, 'd) dim_array -> 'a array
end = struct
  include Array
  include Array.Labels
  (** some functions should be overriden later *)
  type dec = unit
  type 'a d0 = unit
  type 'a d1 = unit
  type 'a d2 = unit
  type 'a d3 = unit
  type 'a d4 = unit
  type 'a d5 = unit
  type 'a d6 = unit
  type 'a d7 = unit
  type 'a d8 = unit
  type 'a d9 = unit
  type zero = unit
  type nonzero = unit
```

```
type ('a, 'z) dim0 = int (* Phantom type *)
type 'a dim = ('a, nonzero) dim0

let dec k = k 0

let d0 d k = k (10 * d + 0)
let d1 d k = k (10 * d + 1)
let d2 d k = k (10 * d + 2)
let d3 d k = k (10 * d + 3)
let d4 d k = k (10 * d + 4)
let d5 d k = k (10 * d + 5)
let d6 d k = k (10 * d + 6)
let d7 d k = k (10 * d + 7)
let d8 d k = k (10 * d + 8)
let d9 d k = k (10 * d + 9)

let dim d = d

let to_int d = d

type ('t, 'd) dim_array = 't array

let make d x = Array.make (to_int d) x
let init d f = Array.init (to_int d) f
let copy x = Array.copy  x
(* other array operations go here ... *)
let get : ('a, 'd) dim_array -> int -> 'a = fun a d ->
  Array.get a d

let set : ('a, 'd) dim_array -> int -> 'a -> unit = fun a d v ->
  Array.set a d v

let unsafe_get : ('a, 'd) dim_array -> int -> 'a = fun a d ->
  Array.unsafe_get a d

let unsafe_set : ('a, 'd) dim_array -> int -> 'a -> unit = fun a d v ->
  Array.unsafe_set a d v

let combine :
    ('a, 'd) dim_array -> ('b, 'd) dim_array -> ('a -> 'b -> 'c) -> ('c,
'd) dim_array =
      fun a b f ->
        Array.init (Array.length a) (fun i -> f a.(i) b.(i))

let length : ('a, 'd) dim_array -> int = fun a -> Array.length a

let update : ('a, 'd) dim_array -> int -> 'a -> ('a, 'd) dim_array =
```

```
    fun a d v -> let result = Array.copy a in (Array.set result d v;
result)


  let rec iteri2 ~f a1 a2 =
    for i = 0 to length a1 - 1 do
      f i (unsafe_get a1 i) (unsafe_get a2 i)
    done
  let map2 ~f = map2 f
  let mapi2 ~f a1 a2 =
    let l = length a1 in
    if l = 0 then [||] else
    (let r = Array.make l (f 0 (unsafe_get a1 0) (unsafe_get a2 0)) in
     for i = 1 to l - 1 do
       unsafe_set r i (f i (unsafe_get a1 i) (unsafe_get a2 i))
     done;
     r)

  let to_array : ('a, 'd) dim_array -> 'a array = fun d -> d

end;;

open DimArray
let d10 = dec d1   d0 dim
let a = make d10 0.
let b = make d10 1.


module S : sig
  type 'a t = private ('a array)
  val of_float_array : 'a array -> 'a t
end = struct
  type 'a t = 'a array
  let of_float_array = fun x -> x
end
```

9.4.1 Useful links

jones

- jambo
- caml
- jane

9.5 Positive types

jane

write later with sub-typing

9.6 Private Types

Private types

Private type stand between abstract type and concrete types. You can coerce your private type back to the concrete type (zero-performance), but backward is **not allowed**.

For ordinary private type, you can still do pattern match, print the result in toplevel, and debugger. A big advantage for private type abbreviation is that for parameterized type(like container) coercion, you can still do the coercion pretty fast(optimization), and some parameterized types(not containers) can still do such coercions while abstract types can not do. Since ocaml does not provide ad-hoc polymorphism, or type functions like Haskell, this is pretty straight-forward.

```
module Int = struct
  type t = int
  let of_int x = x
  let to_int  x = x
end

module Priv : sig
  type t = private int
  val of_int : int -> t
  val to_int : t -> int
end = Int


module Abstr : sig
  type t
  val of_int : int -> t
  val to_int : t -> int
end = Int

let _ =
  print_int (Priv.of_int 3 :> int)

let _ =
  List.iter (print_int|-print_newline)
    ([Priv.of_int 1; Priv.of_int 3] :> int list)

(** non-container type *)
type 'a f =
  |A of (int -> 'a)
```

```
  |B

(** this is is hard to do when abstract types *)
let  a =
  ((A (fun x -> Priv.of_int x )) :> int f)
```

9.7 Subtyping

9.8 Explicit Nameing Of Type Variables

The type constructor it introduces can be used in places where a type variable is `not allowed`.

```
let f (type t) () =
    let module M = struct exception E of t end in
    (fun x -> M.E x ), (function M.E x -> Some x | _ -> None);;
val f : unit -> ('a -> exn) * (exn -> 'a option) = <fun>
```

The exception defined in local module can not be captured by other exception handler except wild catch.

Another example:

```
let sort_uniq (type s) (cmp : s -> s -> int) =
    let module S = Set.Make(struct type t = s let compare = cmp end) in
    fun l -> S.elements (List.fold_right S.add l S.empty);;
val sort_uniq : ('a -> 'a -> int) -> 'a list -> 'a list = <fun>
```

The functor needs a type constructor(type variable is not allowed)

9.9 The module Language

write later

Chapter 10

subtle bugs

10.1 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

Polymorphic comparisons

polymorphic comparison

jane

Chapter 11

Interoperating With C

Write later

Chapter 12

Pearls

12.1 Write Printf-Like Function With Ksprintf

```
let failwithf format = ksprintf failwith format
(*  val failwithf : ('a, unit, string, 'b) format4 -> 'a = <fun> *)
```

12.2 Optimization

`let a,b = ...` allocates a tuple `(a,b)` before discarding it, rewriting as `let a= ... and b = ... in .` ocaml does not support moving pointer Optimization, for example, `fib.(i)` will be translated to `fib + i * sizeof (int)`, quite expensive, try to avoid it, even `ref` is faster.

12.3 Weak Hashtbl

Weak Hash Weak pointer is like an ordinary pointer, but it doesn't "count" towards garbage collection. In other words if a value on the heap is only pointed at by weak pointers, then the garbage collector may free that value as if nothing was pointing to it'

A weak hash table uses weak pointers to avoid the garbage collection problem above. Instead of storing a permanent pointer to the keys or values, a weak hash table stores only a weak pointer, allowing the garbage collector to free nodes as normal

It probably isn't immediately obvious, but there are 3 variants of the weak hash table, to do with whether the key, the value or both are weak. (The fourth "variant", where both key and value are strong, is just an ordinary Hashtbl). Thus the OCaml standard library "weak hash table" has only weak values. The Hweak library has weak keys and values. And the WeakMetadata library (weakMetadata.ml, weakMetadata.mli) is a version of Hweak modified by me which has only weak keys.

12.4 Bitmatch

12.5 Interesting Notes

Ocsigen can load the code dynamically (both bytecode and native code) without having to restart the application (in fact, this is the default: static linking is a recent addition). You can use omake -P to have OMake monitor the filesystem and rebuild as you edit, in the background. Also, with a rule to the tell ocsigen to reload your application code (via the command FIFO), you can be running the new code the second you save it.

12.6 Polymorphic Variant

```ocaml
(* Author: bobzhang1988@seas215.wlan.seas.upenn.edu        *)
(* Version: $Id: pv.ml,v 0.0 2012/02/12 03:59:37 bobzhang1988 Exp $ *)
open BatPervasives
open Printf

let classify_chars s =
  let rec classify_chars_at p =
    if p < String.length s then
      let c = s.[p] in
      let cls =
        match c with
          | '0' .. '9' -> `Digit c
          | 'A' .. 'Z' | 'a' .. 'z' -> `Letter c
          | _ -> `Other c in
      cls :: classify_chars_at (p+1)
    else []
  in
  classify_chars_at 0
(* val classify_chars :
  string -> [> `Digit of char | `Letter of char | `Other of char ] list
*)


let recognize_numbers l =
  let rec recognize_at m acc =
    match m with
      | `Digit d :: m' ->
        let d_v = Char.code d - Char.code '0' in
        let acc' =
          match acc with
            | Some v -> Some(10*v + d_v)
            | None -> Some d_v in
        recognize_at m' acc'
      (** here makes the input and output the same time *)
      | x :: m' ->
        ( match acc with
          | None -> x :: recognize_at m' None
          | Some v -> (`Number v) :: x :: recognize_at m' None
        )
      | [] ->
        ( match acc with
          | None -> []
          | Some v -> (`Number v) :: []
        )
  in
```

```
  recognize_at l None
(** val recognize_numbers :
    ([> ‘Digit of char | ‘Number of int ] as ’a ) list -> ’a list

    Note that the type of the recognize_numbers
    function does not reflect all what we could know about the
    function. We can be sure that the function will never return a
    ‘Digit tag, but this is not expressed in the function type. We have
    run into one of the cases where the O’Caml type system is not
    powerful enough to find this out, or even to write this knowledge
    down. In practice, this is no real limitation - the types are
    usually a bit weaker than necessary, but it is unlikely that weaker
    types cause problems.’
*)


let analysis = classify_chars |- recognize_numbers
(**
   val analysis:
     string ->
     [> ‘Digit of char | ‘Letter of char | ‘Number of int | ‘Other of char ]  list

   It is no problem that classify_chars emits tags that are completely
   unknown to recognize_numbers. And both functions can use the same
   tag, ‘Digit, without having to declare in some way that they are
   meaning the same. It is sufficient that the tag is the same, and
   that the attached value has the same type.
*)


let number_value1 t =
  match t with
    | ‘Number n -> n
    | ‘Digit d -> Char.code d - Char.code ’0’

let number_value2 t =
  match t with
    | ‘Number n -> n
    | ‘Digit d -> Char.code d - Char.code ’0’
    | _ -> failwith "This is not a number"

(**
   val number_value1 : [< ‘Digit of char | ‘Number of int ] -> int = <fun>
   val number_value2 : [> ‘Digit of char | ‘Number of int ] -> int = <fun>
*)

type classified_char =
```

```
  [ `Digit of char | `Letter of char | `Other of char ]

type number_token =
  [ `Digit of char | `Number of int ]

(**
   Note that there is no ">" or "<" sign in such definitions - it
   would not make sense to say something about whether more or less
   tags are possible than given, because the context is missing.
*)

type classified_number_token = [classified_char  | number_token ]
(**
   type classified_number_token =
    [ `Digit of char | `Letter of char | `Number of int | `Other of char ]
*)

let rec sum l =
  match l with
    | x :: l' ->
      ( match x with
        | `Digit _ | `Number _ ->
              number_value1 x + sum l'
        | _ ->
              sum l' )
    | [] ->
      0
(**
   Warning 11: this match case is unused.
   val sum : [ `Digit of char | `Number of int ] list -> int = <fun>
*)

let rec sum2 l =
  match l with
    | x :: l' ->
      ( match x with
        | (`Digit _ | `Number _) as y ->
              number_value1 y + sum2 l'
        | _ ->
              sum2 l'
      )
    | [] ->
      0
(**
val sum2 : [> `Digit of char | `Number of int ] list -> int = <fun>
*)
let rec sum3 l =
```

```
  match l with
    | #number_token as y :: l' ->
      number_value1 y + sum3 l'
    | _ :: l' -> sum3 l'
    | [] -> 0

(**
 val sum3 : [> number_token ] list -> int = <fun>
*)

(** Internally, the tags are represented by hash values of the names
    of the tags. So the tags are simply reduced to integers at
    runtime. Compared with the normal variant types, there is some
    additional overhead for tags with values. In particular, for
    storing `X value one extra word is needed in comparison with the
    normal variant X value.  *)
```

Chapter 13

Book

13.0.1 Developing Applications with Objective Caml

1. caveat

   (a) + (modulo the boundary, *will not be checked*)

   (b) $1.0/0.0 \rightarrow \infty$

   (c) $+. - . * ./. **$ mod ceil floor sqrt exp log log10 cos sin tan acos asin atan

   (d) $asin 3.14 \rightarrow nan$

   (e) `char_of_int 255` → `'\255'` (can not display)

   (f) `char_of_int int_of_char string_of_int int_of_string string_of_int 2551 -> ''2551`

   (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`

   (k) recursive declaration

   ```
   let rec ones = 1 :: ones;;
   ```

   ```
   val ones : int list =
     [1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1;
      1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1;
      1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1;
      1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1;
      1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1;
      1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1;
      1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1;
      1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1;
      1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1;
      1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1;
      1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1;
      1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1; 1;
      ...]
   ```

```
let special_size l =
   let rec size_aux prev = function
     |[] -> 0
     |_ :: l1  -> if List.memq l1 prev then 1 else 1 + size_aux (l1::prev) l1 in size_aux [l]  l;;

 val special_size : 'a list -> int = <fun>
```

```
# special_size ones;;
- : int = 1
# let rec twos = 1 :: 2 :: twos in special_size twos;;
- : int = 2
# special_size [];;
- : int = 0
```

(l) combine patterns

p1 | .. | pn (all name is forbidden within these patterns) 'a' .. 'e'

```
let test 'a' .. 'e' = true;;
^^^^^^^^^^^^^^^^^
```

```
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 statble_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 =<fun>
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.t =
```

expression not preceded by an c̀onsidered 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
defition ::= let [rec] let-binding {and let-binding}
        | external value-name : typexpr = external-declartion
        | type-definition
        | exception-defition
        | class-definition
```

```
| classtype-definition
| module module-name {(module-name : module-type)} [:module-type] = module-expr
| 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

Difficutilies

(a) Machine reperesentation 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 workds, 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	*optimized* bytecode batch compiler
ocamlopt.opt	*optimized* native code batch compiler
ocamlmktop	new *toplevel* 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 *without* linking
-o name_of_executable	specify the name of the executable
-linkall	link with *all* libraries used
-i	*display all* 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 *file* 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. ocamlopt

-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 ofen 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) wil 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 machien(using the same CPU/Operating System).

Still, the inclusion of machine code means that stand-alone executalbes are not protable 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>	cosider <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
```

```
ocamldep *.ml
```

```
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 idented output. To make things worse, trace *does not show the value corresponding to an argument of a parameterized type*. The toploop 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 furthuer 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)

13.0.2 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) Hahsing 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*

13.0.3 caltech ocaml book

polymorphic variants

1. 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
```

2. **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 ]
```

3. **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>
```

4. 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

5. **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>
```

6. 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>
```

13.0.4 The functional approach to programming

13.0.5 practical ocaml

1. chap30

```
external functions_can_be_defined: unit -> unit = "int_c_code"
```

13.0.6 hol-light

- hol-light

13.1 UNIX system programming in ocaml

Unix library was in `otherlibs/unix/` directory. The meat is in `unix/unix.ml`

13.1.1 chap1

1. Modules Sys and Unix

   Sys containts 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/smlnj/bin:/usr/local/lib:/Applications/MATLAB_R2010b.app/bin:~/SourceCode/scala/scala-
  "_=/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/edit-modes/auctex/latex:";
  "EMACSLOADPATH=/Applications/Aquamacs.app/Contents/Resources/lisp:/Applications/Aquamacs.app/Contents/Resources/leim";
  "SHLVL=3"; "HOME=/Users/bob"; "LOGNAME=bob";
  "CAMLP4_EXAMPLE=/Users/bob/SourceCode/ML/godi/build/distfiles/ocaml-3.12.0/camlp4/examples/";
  "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 occured (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.

13.1.2 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 chaning at executation 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 directries

   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 wil be non-blocking. The *O_NOCTYY* 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 descript 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.mlx find.xxxx
_build/find.byte: "open" failed on "find.mlx": 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 communicatioin. 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

13.1.3 chap3

13.1.4 practical ocaml

1. chap30

```
external functions_can_be_defined: unit -> unit = "int_c_code"
```

13.1.5 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  CamlinternalOO
  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 @ $\rightarrow$ right ; ^ $\rightarrow$ 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.
```

- toplevellib.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.

```ocaml
(** 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)
;;
```

```
.ml.mli:
  rm -f $@
  $(OB) $(basename $@).inferred.mli
  cp _build/$(basename $@).inferred.mli $@
```

13.1.6 ocaml blogs

ygrek

michal

eigenclass

syntax

jambon

Xavier Clerc

Zheng li

xleroy/teaching

alaska

erratique

duther

David Teller

john harisson

Mike Gordon

Robert Keller

alexott

Yoann Padioleau

garrigue

jun

llvm

incubaid

heniz

memcheck

danmey

yutaka

Lindig