PIDE as front-end technology for Coq

Makarius Wenzel *

Univ. Paris-Sud, Laboratoire LRI, UMR8623, Orsay, F-91405, France
CNRS, Orsay, F-91405, France

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Abstract

Isabelle/PIDE is the current Prover IDE technology for Isabelle. It has been developed in ML and Scala in the past 4–5 years for this particular proof assistant, but with an open mind towards other systems. PIDE is based on an asynchronous document model, where the prover receives edits continuously and updates its internal state accordingly. The interpretation of edits and the policies for proof document processing are determined by the prover. The editor front-end merely takes care of visual rendering of formal document content.

Here we report on an experiment to connect Coq to the PIDE infrastructure of Isabelle. This requires to re-implement the core PIDE protocol layer of Isabelle/ML in OCaml. The payload for semantic processing of proof document content is restricted to lexical analysis in the sense of existing CoqIde functionality. This is sufficient as proof-of-concept for PIDE connectivity. Actual proof processing is then a matter of improving Coq towards timeless and stateless proof processing, independently of PIDE technicalities. The implementation worked out smoothly and required minimal changes to the refined PIDE architecture of Isabelle2013.

This experiment substantiates PIDE as general approach to prover interaction. It illustrates how other provers of the greater ITP family can participate by following similar reforms of the classic TTY loop as was done for Isabelle in the past few years.

1 Motivation

Is interactive theorem proving inherently tied to the command-line? Is the Proof General wrapper for that command-line the optimum of what can be achieved? Can we ever go beyond it conceptually and technologically?

The PIDE (Prover IDE) approach challenges the predominance of Proof General [2] and its many clones like CoqIde, Matita [1], Proofweb [4]. PIDE is centered around general principles of document-oriented asynchronous interaction, possibly with parallel processing on the prover side [7,8,10]. It has required several years to reach the first stable release of the Isabelle/jEdit Prover IDE in October 2011 [9]. Isabelle2013 (February 2013) includes the third stable release of Isabelle/jEdit, and is already the default instead of Proof General (even just for the pragmatic reason that it works more likely out-of-the-box).

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Can other provers join this movement? The present paper reports on an experiment called CoqPIDE that exchanges the back-end of Isabelle/jEdit to use Coq instead of Isabelle (see https://bitbucket.org/makarius/coq-pide/src/443d088a72e6/README.PIDE?at=v8.4 from January 2013).

The common language of the PIDE prover integration is Scala [5], but the prover needs to implement certain operations to support document-oriented interaction natively in its own language, which is OCaml for Coq.

Scala provides immediate access to existing Java IDE frameworks. Our standard application uses jEdit, but Eclipse, Netbeans, IntelliJ IDEA are in principle possible as well. The JVM is also a good platform for advanced web services.

In the past, OCaml was quite capable to integrate mainstream C libraries, such as GTK for GUI components, although that is now outdated. OCaml/GTK was used to implement CoqIde within Coq itself, but GTK does not yet provide a full-scaled IDE, not even an able text editor.

The Java platform in general, and jEdit in particular, are not free from technical problems, but Isabelle/jEdit shows how these raw industrial materials can be adopted for our provers. Scala is particularly helpful to make the JVM platform accessible to the higher-order functional culture of proof assistants.

The main results of the CoqPIDE experiment are as follows:

Universal. The requirements for the prover to implement the PIDE document model are easily met by porting existing SML implementations to OCaml. Note that PIDE defines only rather general principles of document editing, leaving most of the details to the prover.

Clarity. The minimal PIDE protocol implementation for OCaml/Coq helps to explain how PIDE actually works, without the additional layers of sophistication and performance tuning that have accumulated in Isabelle already.

Frugality. A meaningful application of PIDE to a different prover merely requires 40 kB of sources in OCaml (26 kB) and Scala (14 kB). Approx. 50% is for the implementation of PIDE datatypes and protocol operations, the other 50% Coq-specific “payload”. For more serious semantic processing on the prover side, the payload will grow beyond this initial PIDE configuration.

2 PIDE Document Operations

The PIDE document model maintains sources (produced by the editor) and resulting formal content (produced by the prover). Its programming interface consists of statically-typed Scala operations. Document.update(old_version, new_version, edits) applies source edits to turn one version non-destructively into another. Document.remove_versions(versions) indicates obsolete versions to allow garbage collection eventually.

Document update is declarative: it specifies where to insert or remove parts of the source text, but its operational consequences are determined by the prover. Each document version is associated with an execution in ML to work out these
formal details, and report results back to the Scala side. PIDE provides operational hints to improve performance, like `Document.discontinue_execution()` and `Document.cancel_execution()` in certain situations of its editing pipeline. Cancellation should cause some physical interrupt within the prover, which is important for long-running proof checking, but the CoqPIDE ignores this for now.

Note that the PIDE model is inherently asynchronous: the front-end never waits for the back-end. Uninterruptible execution could mean (infinitely) long delay of the update of formal annotations seen in the editor buffer, but the Prover IDE does not block, nor lock text in the manner of Proof General.

3 PIDE Protocol Implementation (OCaml)

The PIDE protocol merely propagates tree-structured datatypes between Scala and ML, but various details need to be observed to make it robust, efficient, and portable. It is a bit like plumbing different kinds of metal: a leaden JVM with an aluminium ML system, using a copper pipe. The PIDE protocol stack has evolved over several years to the “proven technology” in Isabelle2013. For CoqPIDE, we re-implemented the ML side in OCaml, which turned out a simple programming exercise of a few days (including to learn some OCaml in the first place). The main protocol layers are as follows.

Bidirectional byte-channel. PIDE demands a bidirectional communication channel based on clean byte-streams, with block-buffering and high throughput. On Unix this can be implemented by a pair of fifos (named pipes), which are opened like a regular file on each side, in the correct order for rendezvous. PIDE on Windows uses TCP sockets instead, but they turn out slightly less efficient and less robust on some ML versions. For CoqPIDE we use fifos and thus restrict it to Unix for now, although OCaml sockets probably work as well.

Content sent over the byte-channel is partitioned into chunks with explicit length indication (encoded via ASCII digits followed by newline). This depends on the assumption that the channel is private to the protocol handler. Note that public stdout cannot be used, because it is subject to spurious output by parts of the ML process (runtime system, libraries) beyond our control. Classic Proof General [2] avoids this problem by using human-readable control commands and asking the user for manual repairs when the protocol loses synchronization. This no longer worked for the PGIP/XML protocol [3], so it was suffering from breakdown caused by unexpected diagnostic messages.

Text encoding and character positions. Text on the JVM consists of 16-bit characters, but requires one or two such characters to represent a single Unicode 6 codepoint according to UTF-16. ML usually prefers some extension of ASCII, formerly ISO-latin, now UTF-8 where multi-character encodings are commonplace. In any case, logical text addressing needs to agree on both sides to attach error messages or other formal markup precisely to source positions.

PIDE standardizes towards UTF-8 on the prover side and recodes text to UTF-16 for Scala/JVM. Physical text addressing works via byte offsets in ML, and character offsets on the JVM. Logical text positions are either translated explicitly by functions provided by the prover, or represented in a way that is invariant wrt. the encoding (like Isabelle symbols [5, §2.1]). For CoqPIDE we
have re-used `byte_offset_to_char_offset` from CoqIde, which works for the Basic Multilingual Plane where UTF-16 requires only one 16-bit character.

**YXML transfer syntax of untyped trees.** PIDE uses untyped XML trees for document markup (and arbitrary ML/Scala values), but ignores the complications of official XML syntax and various attempts at XML type-systems. Instead, the markup tree structure over the text is represented by two special control characters that are outside the text range of XML 1.0 and what provers normally use. In contrast to official XML syntax, this avoids quoting of the text and allows cumulative markup of text that might have been marked already.

Our XML transfer syntax is called YMXL (pronounced as “Why XML?”), see also [8, §2.3]. Efficient and robust YXML parsing is easily implemented in any programming language. What is also notable about YXML is that it is orthogonal to UTF-8 text encoding; the operations to decode text and to recover tree structure can be *commuted* by the PIDE infrastructure as required.

The OCaml version of YXML is a literal translation of the SML version from Isabelle, see also [https://bitbucket.org/makarius/yxml](https://bitbucket.org/makarius/yxml) and appendix A.1. Note that CoqIde uses some XML Light implementation instead, which suffers from typical problems with boundary cases of standard XML (e.g. incorrect treatment of white-space).

**XML/ML data representation.** The algebraic datatypes that PIDE transfers between Scala and ML may consist of base types like `bool`, `int`, `string` (for text in the above sense), product types (tuples or records), variant types (disjoint sums), and recursion over the same. Imitating the canonical memory layout of ML values in untyped memory, we provide ML functions and combinators for each of these type constructions wrt. raw XML trees:

```ocaml
type 'a Encode.t = 'a -> XML.tree list
Encode.string: string Encode.t
Encode.pair: 'a Encode.t -> 'b Encode.t -> ('a * 'b) Encode.t
Encode.list: 'a Encode.t -> 'a list Encode.t
```

Etc., also with symmetric versions for Decode. The modules XML.Encode and XML.Decode are available on the Scala side as well. The implementation is mostly trivial, consisting of a few lines for each combinator. Note that it is important to work recursively with XML.tree list and cope with its “mixed content” of alternating XML.Elem and XML.Text nodes. See also [https://bitbucket.org/makarius/yxml](https://bitbucket.org/makarius/yxml) and appendix A.2.

Each PIDE protocol function is wrapped into a combinator expression over XML.Encode and XML.Decode that is isomorphic to the corresponding datatype definitions of its arguments. This slight redundancy is isolated in a single place in Scala and ML, respectively. Public interfaces on each side are statically typed.

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4 **Coq-specific PIDE Modules (OCaml and Scala)**

After studying the Coq sources for a few days, to see what is already there to serve our purpose, we have chosen lexical syntax processing of CoqIde: it is used for syntax highlighting in its GTK text widget.
The result looks like in the given screenshot, but that is already CoqPIDE imitating the look-and-feel of CoqIde! This minimal PIDE application has required the following additional modules.

**Coq document structure.** CoqPIDE implements the main PIDE document operations using a very simple document model in OCaml: an association list of named nodes (.v files), each consisting on a list of entries (like command spans in Proof General). The Scala-side of CoqPIDE does not even exploit the full structure yet: it merely turns each file into one monolithic command span. This is sufficient to work efficiently with files of 10–100 kB size. Editing larger sources requires to use more sub-structure as is done routinely in Isabelle/PIDE.

**Coq markup and rendering.** PIDE allows the prover to annotate source text by arbitrary formal content, which is represented by untyped and uninterpreted XML trees. The prover may define its own vocabulary of markup elements, together with an interpretation that is called rendering. The rendering module provides functions to turn XML trees that are associated with given text ranges into GUI elements: colors, boxes, squiggles, icons, tooltips, hyperlinks etc.

CoqPIDE defines markup elements for the main lexical categories of Coq, with rendering that uses the original CoqIde colors. There are two tiny additions: the dot as proof-script terminator is painted red, and quoted strings are rendered with transparency (alpha channel) which is now common-place in Isabelle/PIDE — it helps to combine multiple layers of prover markup systematically.

**Coq theory syntax.** PIDE allows the prover to define aspects of its syntax directly on the editor side, e.g. to tell which files are special (.v for Coq) and how files are loaded for the prover (sources are managed by the front-end). CoqPIDE only provides the bare minimum to make the system work. Extra efforts would be required to imitate Isabelle/PIDE, which allows to augment theory syntax while editing, and resolve file dependencies automatically. The latter is important for applications consisting of several modules that are edited simultaneously. Note that neither CoqIde nor Proof General allow multiple “active” buffers.

Of course we could have augmented jEdit directly by a small Coq lexer in Scala to get plain syntax highlighting. Since CoqPIDE follows the architecture
of PIDE, with its asynchronous exchange of edits that are interpreted by the
prover, it may serve as a starting point for actual proof processing. Some of the
required reforms to the Coq toplevel have been explored already \[6\]. Eventually
we shall see these movements converge to more serious PIDE/Coq integration.

Isabelle shares the roots of TTY-based command-line interaction with Coq
and other members of the LCF family, but managed to reform itself towards
full-scale Prover IDE support within a few years. It should be feasible to transfer
more of what has been achieved here to other provers, unless the command-line
really turns out as part of the very essence of interactive theorem proving.

A  OCaml sources of the YXML library

A.1  YXML transfer syntax

(*
Efficient text representation of XML trees using extra characters X
and Y -- no escaping, may nest marked text verbatim. Suitable for
direct inlining into plain text.

Markup <elem att="val" ...>...body...</elem> is encoded as:

```
X Y name Y att=val ... X
...
body
...
X Y X
*)

module type YXML =
sig
  val char_X: char
  val char_Y: char
  val no_output: string * string
  val output_markup: string * XML.attributes -> string * string
  val string_of_body: XML.body -> string
  val string_of: XML.tree -> string
  val parse_body: string -> XML.body
  val parse: string -> XML.tree
end

module YXML: YXML =
struct

  (* markers *)

  let char_X = '\005'
  let char_Y = '\006'

  let str_X = String.make 1 char_X
  let str_Y = String.make 1 char_Y

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let str_XY = str_X ^ str_Y
let str_XYX = str_XY ^ str_X

let detect s = String.contains s char_X || String.contains s char_Y

(* ML basics *)
let (|>) x f = f x
let (@>) f g x = g (f x)

let rec fold f list y =
  match list with
  [] -> y
  | x :: xs -> fold f xs (f x y)

(* output *)
let implode = String.concat ""
let content xs = implode (List.rev xs)
let add x xs = if x = "" then xs else x :: xs

let no_output = ("", "")

let output_markup (name, atts) =
  if name = "" then no_output
  else
    (str_XY ^ name ^
     implode (List.map (fun (a, x) -> str_Y ^ a ^ "=" ^ x) atts) ^ str_X,
     str_XYX)

let string_of_body body =
  let attrib (a, x) = add str_Y @> add a @> add "=" @> add x in
  let rec tree = function
    | XML.Elem ((name, atts), ts) ->
      add str_XY @> add name @> fold attrib atts @> add str_X @>
      trees ts @>
      add str_XY
    | XML.Text s -> add s
    and trees ts = fold tree ts
  in content (trees body [])

  string_of tree = string_of_body [tree]

(** parsing *)

(* split *)

let split fields sep str =
  let cons i n result =
if i = 0 && n = String.length str && n > 0 then str :: result
else if n > 0 then String.sub str i n :: result
else if fields then "" :: result
else result
in
let rec explode i result =
  let j = try String.index_from str i sep with Not_found -> -1 in
  if j >= 0 then explode (j + 1) (cons i (j - i) result)
  else List.rev (cons i (String.length str - i) result)
in explode 0 []

(* parse *)

let err msg = raise (Failure ("Malformed YXML: " ^ msg))
let err_attribute () = err "bad attribute"
let err_element () = err "bad element"
let err_unbalanced name =
  if name = "" then err "unbalanced element"
  else err ("unbalanced element \"" ^ name ^ "\"")

let parse_attrib s =
  try
    let i = String.index s '=' in
    let _ = if i = 0 then err_attribute () in
    let j = i + 1 in
    (String.sub s 0 i, String.sub s j (String.length s - j))
  with Not_found -> err_attribute ()

let parse_body source =

(* stack operations *)

let add x ((elem, body) :: pending) = (elem, x :: body) :: pending
in

let push name atts pending =
  if name = "" then err_element ()
  else ((name, atts), []) :: pending
in

let pop (((name, _) as markup, body) :: pending) =
  if name = "" then err_unbalanced ""
  else add (XML.Elem (markup, List.rev body)) pending
in

(* parse chunks *)

let chunks = split false char_X source |> List.map (split true char_Y) in

let parse_chunk = function
  | ['"'; ';''] -> pop
  | ('"' :: name :: atts) -> push name (List.map parse_attrib atts)
  | txts -> fold (fun s -> add (XML.Text s)) txts

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in
match fold parse_chunk chunks [(["", []], [])] with
| [(["", _], result)] -> List.rev result
| ((name, _), _) :: _ -> err_unbalanced name

let parse source =
match parse_body source with
| [result] -> result
| [] -> XML.Text ""
| _ -> err "multiple results"
end

A.2 Untyped XML trees and typed representation of ML values

module type XML_Data_Ops =
sig
  type 'a a
  type 'a t
  type 'a v
  val int_atom: int a
  val bool_atom: bool a
  val unit_atom: unit a
  val properties: (string * string) list t
  val string: string t
  val int: int t
  val bool: bool t
  val unit: unit t
  val pair: 'a t -> 'b t -> ('a * 'b) t
  val triple: 'a t -> 'b t -> 'c t -> ('a * 'b * 'c) t
  val list: 'a t -> 'a list t
  val option: 'a t -> 'a option t
  val variant: 'a v list -> 'a t
end

module type XML =
sig
  type attributes = (string * string) list
  type tree = Elem of ((string * attributes) * tree list) | Text of string
  type body = tree list
  exception XML_Atom of string
  exception XML_Body of tree list
  module Encode: XML_Data_Ops with
    type 'a a = 'a -> string and
    type 'a t = 'a -> body and
    type 'a v = 'a -> string list * body
  module Decode: XML_Data_Ops with
    type 'a a = string -> 'a and
    type 'a t = body -> 'a and
    type 'a v = string list * body -> 'a
end

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module XML: 

struct

  type attributes = (string * string) list
  type tree = Elem of ((string * attributes) * tree list) | Text of string
  type body = tree list

let map_index f =
  let rec mapp _ = function
    | [] -> []
    | x :: xs -> f (i, x) :: mapp (i + 1) xs
  in mapp 0

exception XML_Atom of string
exception XML_Body of tree list

module Encode =

struct

  type 'a a = 'a -> string
  type 'a t = 'a -> body
  type 'a v = 'a -> string list * body

  (* atomic values *)
  let int_atom = string_of_int
  let bool_atom = function false -> "0" | true -> "1"
  let unit_atom () = ""

  (* structural nodes *)
  let node ts = Elem (("="; [], []), ts)
  let vector = map_index (fun (i, x) -> (int_atom i, x))
  let tagged (tag, (xs, ts)) = Elem ((int_atom tag, vector xs), ts)

  (* representation of standard types *)
  let properties props = [Elem (("="; props), [])]
  let string = function "" -> [] | s -> [Text s]
  let int i = string (int_atom i)
  let bool b = string (bool_atom b)

let unit () = string (unit_atom ())

let pair f g (x, y) = [node (f x); node (g y)]

let triple f g h (x, y, z) = [node (f x); node (g y); node (h z)]

let list f xs = List.map (fun x -> node (f x)) xs

let option f = function None -> [] | Some x -> [node (f x)]

let variant fns x = 
    let rec get_index i = function
      | [] -> raise (Failure "XML.Encode.variant")
      | f :: fs -> try (i, f x) with Match_failure _ -> get_index (i + 1) fs
    in [tagged (get_index 0 fns)]
end

module Decode = 
struct
    type 'a a = string -> 'a
    type 'a t = body -> 'a
    type 'a v = string list * body -> 'a

    (* atomic values *)
    let int_atom s = 
        try int_of_string s
        with Invalid_argument _ -> raise (XML_Atom s)

    let bool_atom = function
        | "0" -> false
        | "1" -> true
        | s -> raise (XML_Atom s)

    let unit_atom s =
        if s = "" then () else raise (XML_Atom s)

    (* structural nodes *)
    let node = function
        | Elem ((":", []), ts) -> ts
        | t -> raise (XML_Body [t])

    let vector =
        map_index (function (i, (a, x)) ->
            if int_atom a = i then x else raise (XML_Atom a))

    let tagged = function
        | Elem ((name, atts), ts) -> (int_atom name, (vector atts, ts))
let properties = function
  | [Elem ("="; props), []] -> props
  | ts -> raise (XML_Body ts)

let string = function
  | [] -> ""
  | [Text s] -> s
  | ts -> raise (XML_Body ts)

let int ts = int_atom (string ts)

let bool ts = bool_atom (string ts)

let unit ts = unit_atom (string ts)

let pair f g = function
  | [t1; t2] -> (f (node t1), g (node t2))
  | ts -> raise (XML_Body ts)

let triple f g h = function
  | [t1; t2; t3] -> (f (node t1), g (node t2), h (node t3))
  | ts -> raise (XML_Body ts)

let list f = List.map (fun t -> f (node t))

let option f = function
  | [] -> None
  | [t] -> Some (f (node t))
  | ts -> raise (XML_Body ts)

let variant fs = function
  | [t] ->
    let (tag, (xs, ts)) = tagged t in
    let f = try List.nth fs tag
      with Invalid_argument _ -> raise (XML_Body [t]) in
    f (xs, ts)
  | ts -> raise (XML_Body ts)

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