Xmonad in Coq:

Programming a window manager in a proof assistant

Wouter Swierstra

FP Dag 6/1/2012

Coq Extraction

- At its heart, Coq has a (simply) typed, total functional programming language *Gallina*.
- *Extraction* lets you turn Gallina programs into Caml, Haskell, or Scheme code.
- Extraction discards proofs, but may introduce ‘unsafe’ coercions.

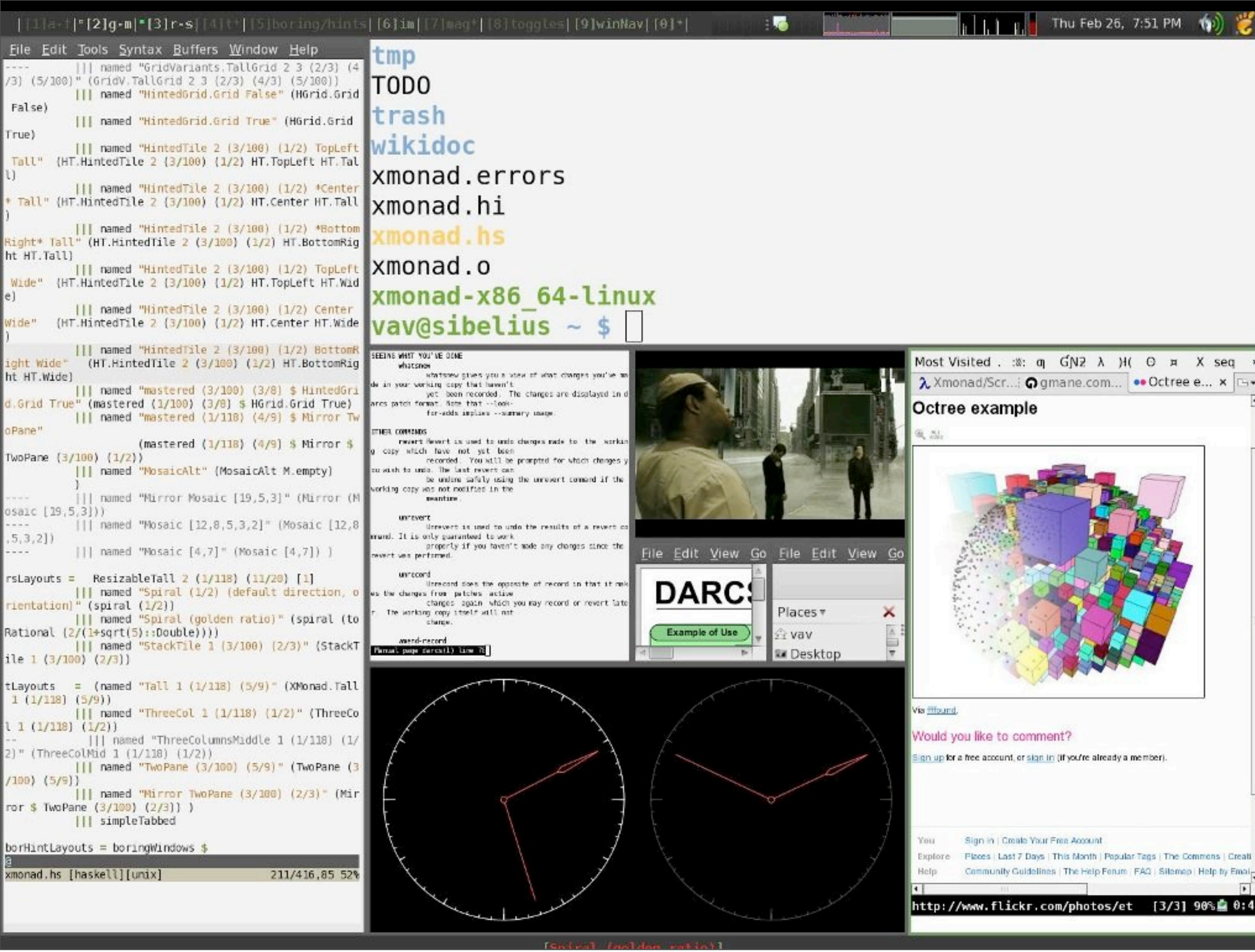
Extraction in action

- There are a only handful of ‘serious’ verified software developments using Coq and extracted code – CompCert being a notable example.
- Why isn’t it more widely used?

xmonad

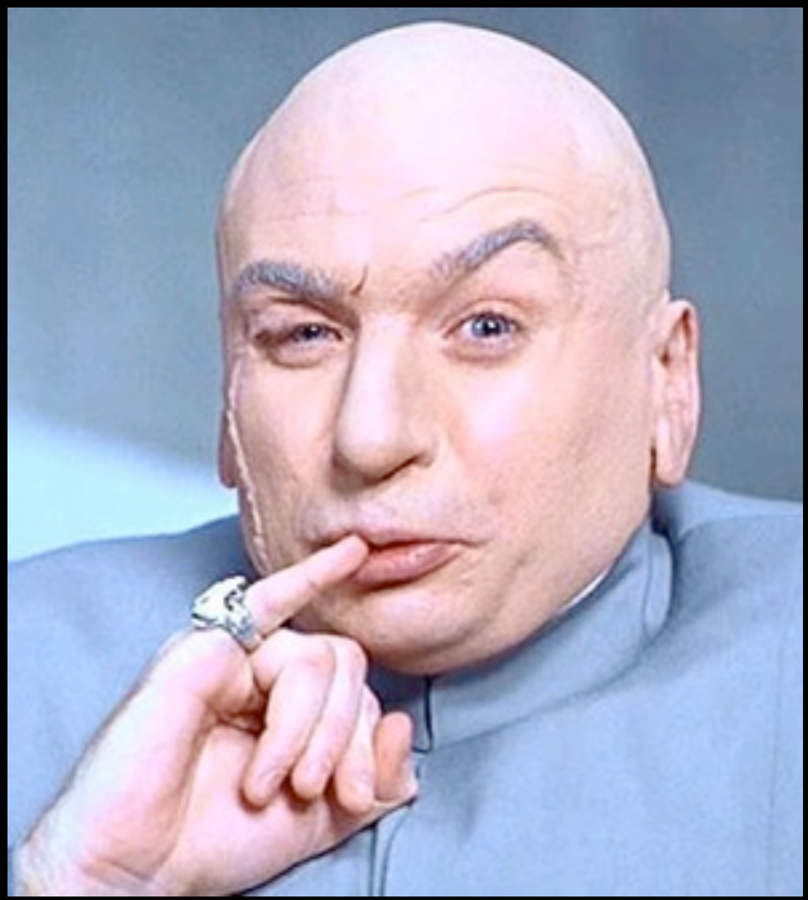
xmonad

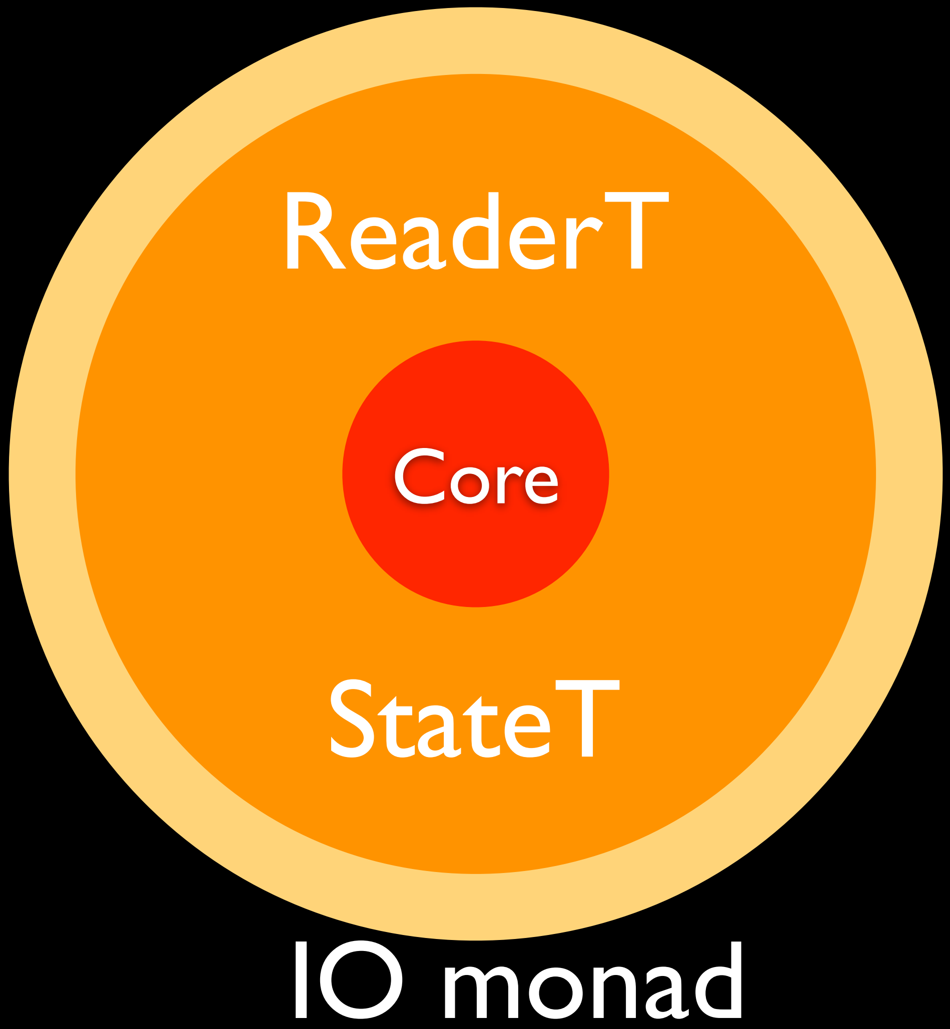
- A tiling window manager for X:
  - tiles windows over the whole screen;
  - automatically arranges windows;
  - written, configured, and extensible in Haskell;
  - has several tens of thousands of users.



Thu Feb 26, 7:51 PM
File Edit Tools Syntax Buffers Window Help
||| named "HintedGrid.Grid False" (HGrid.Grid False)
||| named "HintedGrid.Grid True" (HGrid.Grid True)
||| named "MosaicAlt" (MosaicAlt M.empty)
rsLayouts = ResizableTall 2 (1/118) (11/20) [1]
||| named "Spiral (1/2) (default direction, orientation)" (spiral (1/2))
||| named "Spiral (golden ratio)" (spiral (toRational (2/(1+sqrt(5)::Double))))
||| simpleTabbed
borHintLayouts = boringWindows $
xmonad.hs [haskell][unix] 211/416,85 52%
tmp
TODO
trash
wikidoc
xmonad.errors
xmonad.hi
xmonad.hs
xmonad.o
xmonad-x86_64-linux
vav@sibelius ~ $
SEEING WHAT YOU'VE DONE
whatsnew
OTHER COMMANDS
revert
unrevert
unrecord
amend-record
File Edit View Go
DARCS
Example of Use
Places
vav
Desktop
Most Visited
Octree example
Would you like to comment?
http://www.flickr.com/photos/et [3/3] 90%
[Spiral (golden ratio)]

xmonad: design principles





Design principles

- Keep the core **pure** and **functional**.
- Separate X server calls from internal data types and functions (Model-view-controller).
- Strive for highest quality code.

Current best practices

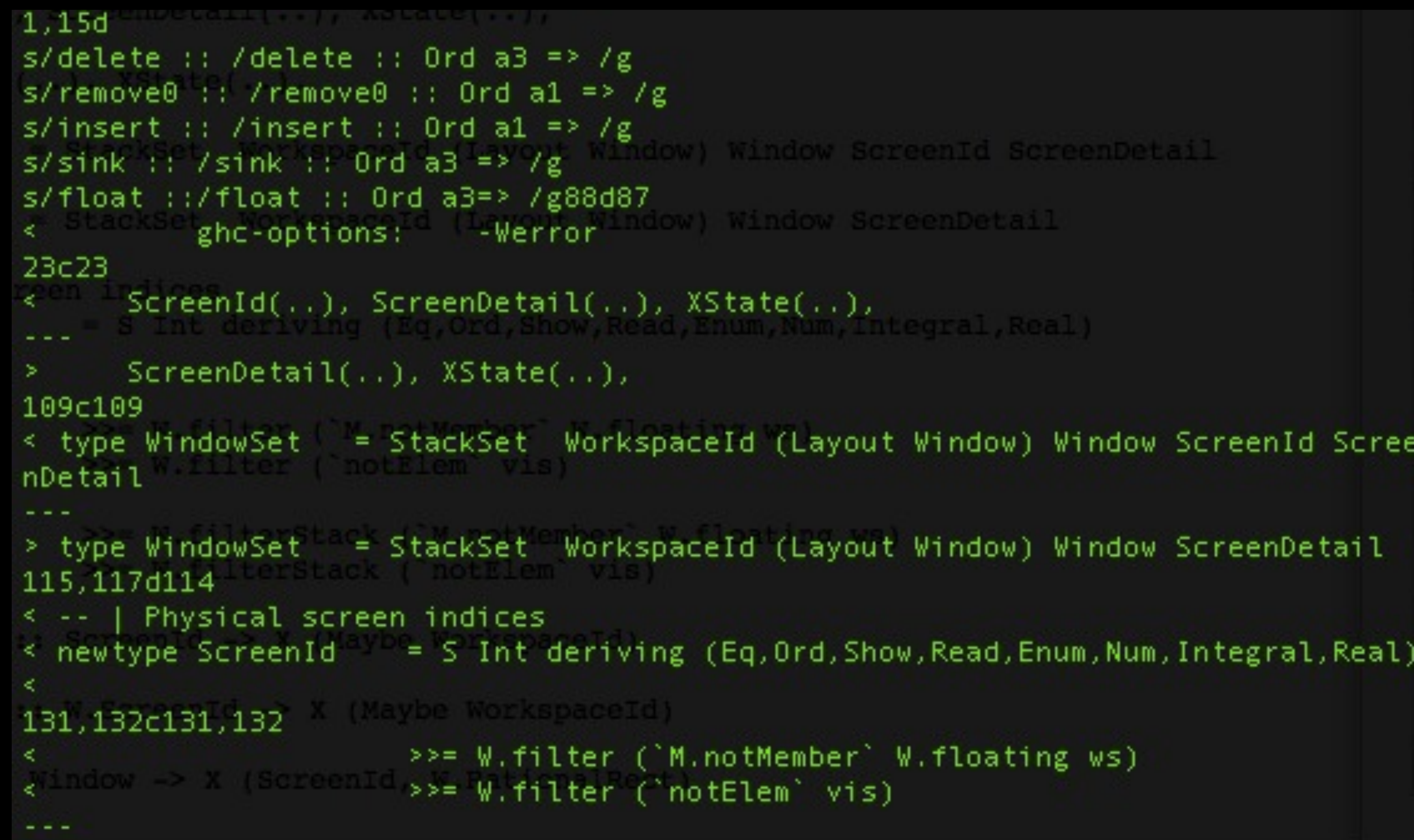
- Combining QuickCheck and HPC:
  - Write tests;
  - Find untested code;
  - Repeat.

Can we do better?

- Re-implement core xmonad data types and functions in Coq,
- and ensure that the ‘extracted’ code is a drop-in replacement for the existing Haskell module,
- and formally prove (some of) the QuickCheck properties in Coq.

Blood

Sweat



Shell script

What happens in the functional core?

Data types

```
data Zipper a = Zipper
  { left :: [a]
  , focus :: !a
  , right :: [a]
  }
```

Example - I

```
focusLeft :: Zipper a -> Zipper a
focusLeft (Zipper (l:ls) x rs) =
  Zipper ls l (x : rs)
focusLeft (Zipper [] x rs) =
  let (y : ys) = reverse (x : rs)
  in Zipper ys y []
```

Example - II

```
reverse :: Zipper a -> Zipper a
reverse (Zipper ls x rs) =
  Zipper rs x ls

focusRight :: Zipper a -> Zipper a
focusRight =
  reverse . focusLeft . reverse
```

Did I change the program?

Too general types

- The core data types are as polymorphic as possible: `Zipper a` not `Zipper Window`.
- This is usually, but not always a good thing.
- For example, each window is tagged with a 'polymorphic' type that must be in Haskell's `Integral` class.
- But these are only ever instantiated to `Int`.

Totality

- This project is feasible because most of the functions are structurally recursive.
- But there's still work to do. Why is this function total?

```
focusLeft (Zipper [] x rs) =
  let (y : ys) = reverse (x : rs)
  in Zipper [] y ys
```

More totality

- One case which required more work.
- One function finds a window with a given id, and then move left *until* it is in focus.
- Changed to compute the number of moves necessary and move that many steps.

Extraction problems

- The basic extracted code is a bit rubbish:
  - uses unsafeCoerce (too much);
  - uses Peano numbers, extracted Coq booleans, etc.
  - uses extracted Coq data types for zippers;
  - generates 'non-idiomatic' Haskell.

Customizing extraction

- There are various hooks to customize the extracted code:
  - inlining functions;
  - using Haskell data types;
  - realizing axioms.

Danger!

- Using $(a = b) \vee (a \neq b)$ is much more informative than Bool.
- But we'd like to use 'real' Haskell booleans:

```
Extract Inductive sumbool =>
"Bool" [ "True" "False" ].
```

- Plenty of opportunity to shoot yourself in the foot!

User defined data types

- Coq generated data types do not have the same names as the Haskell original.
- The extracted file exports ‘too much’.
- Solution:
  - Customize extraction.
  - Write a sed script that splices in a new module header & data types.

Interfacing with Haskell

- I'd like to use Haskell's data structures for finite maps and dictionaries.
- Re-implementing them in Coq is not an option.
- Add the API as Axioms to Coq...
- ... but also need to postulate properties.
- **Diagnosis: axiom addiction!**

Type classes

- Haskell's function to check if an element occurs in a list:

```
elem :: Eq a => a -> [a] -> Bool.
```

- A Coq version might look like:

```
Variable a : Set.
Variable cmp : forall (x y : a),
  {x = y} + {x <> y}.
Definition elem : a -> list a -> ...
```

Extracted code

- Extracting this Coq code generates functions of type:

```
_elem :: (a -> a -> Bool) ->
  a -> [a] -> bool.
```

- Need a manual 'wrapper function'

```
elem :: Eq a => a -> [a] -> Bool
elem = _elem (==)
```

More type class headaches

- We need to assume the existence of Haskell's finite maps:

```
Axiom FMap : Set -> Set -> Set.

Axiom insert : forall (k a : Set),

  k -> a -> FMap k a -> FMap k a.
```

- In reality, these functions have additional type class constraints...

Another dirty fix

- Need another sed script to patch the types that Coq generates:

```
s/insert :: /insert :: Ord a1 => /g
```

- Not pretty...
- **Lesson:** Gallina is not the same as Haskell.

And now...

- Extraction & post-processing yields a drop-in replacement for the original Haskell module.
- That passes the xmonad test suite.

Verification

- So far, this gives us totality (under certain conditions).
- I've proven a few QuickCheck properties in Coq.
- Some properties are trivial; some are more work. But this we know how to do!

Conclusions

- Formal verification can complement, but not replace a good test suite.
- Extraction can introduce bugs!
- If you want to do formal verification, but need `sed` to ‘fix’ your code, something is wrong...

Looking ahead

- There is plenty of work to be done on tighter integration between proof assistants and programming languages.
- You don't want to write *all* your code in Coq; but interacting with another programming language all happens through extraction.
- What are the alternatives?