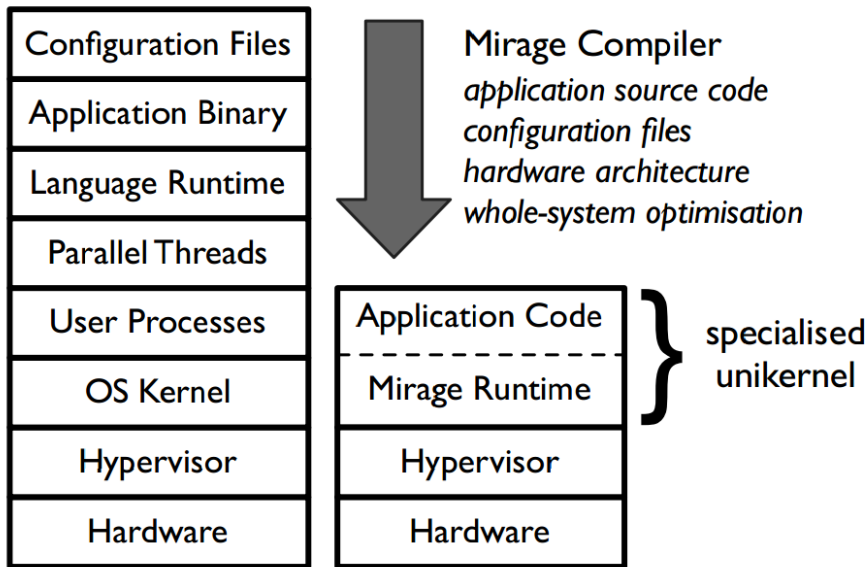


Modularity and Backpack

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MirageOS



MirageOS

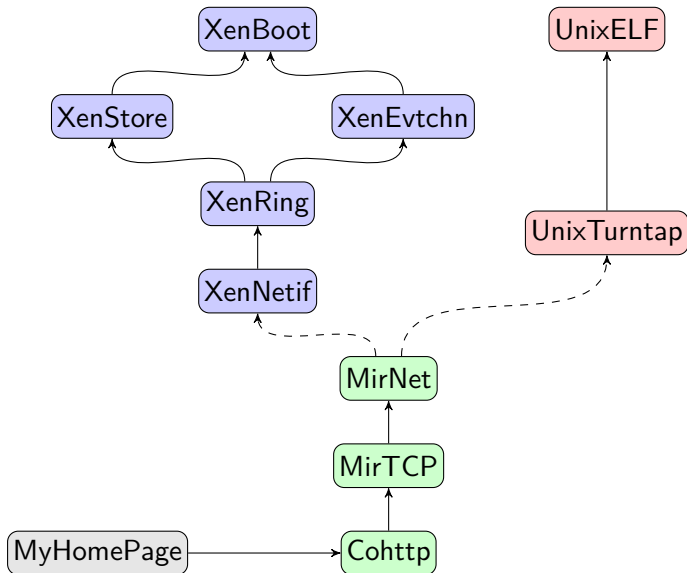


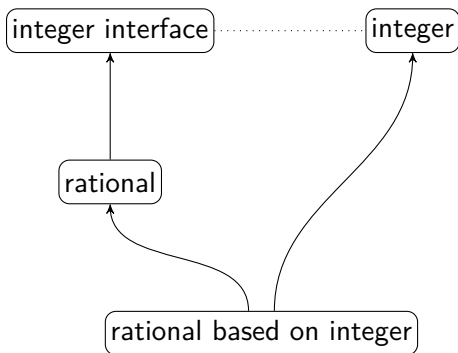
Exhibit 1

MirageOS

The compiler heavily emphasises static type checking, and the resulting binaries are fast native code with no runtime type information and the module system is among the most powerful in a general-purpose programming language in terms of permitting flexible and safe code reuse and refactoring.

- Technical Background of MirageOS

Toy Problem



ML Modules

Structures

```
structure IntInteger =  
  struct  
    type integer = int  
    val zero = 0  
    fun succ n = n + 1  
    fun add a b = a + b  
    fun mul a b = a * b  
  end
```

ML Modules

Signatures

```
signature INTEGER =  
  sig  
    type integer  
    val zero: integer  
    val succ: integer -> integer  
    val add: integer -> integer -> integer  
    val mul: integer -> integer -> integer  
  end
```

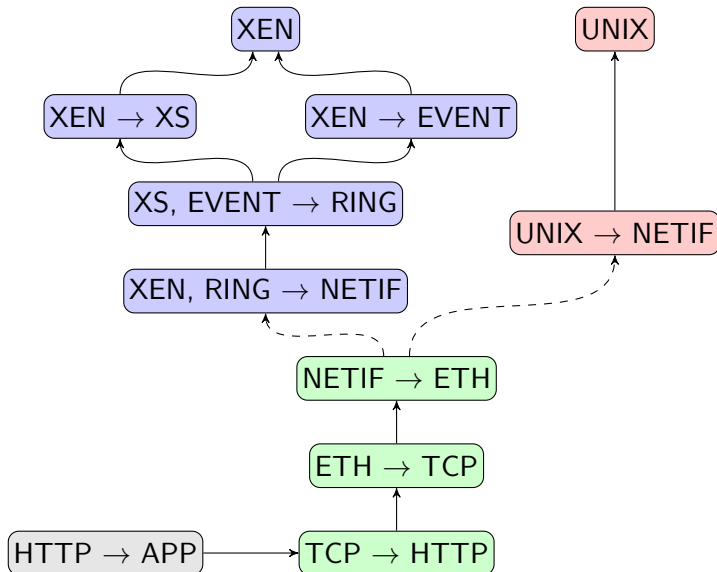
ML Modules

Functors

```
functor RationalFun(l: INTEGER) =  
  struct  
    type rational = l.integer * l.integer  
    fun nom (n, _) = n  
    fun denom (_, d) = d  
    fun add (n1, d1) (n2, d2) =  
      (l.add (l.mul n1 d2) (l.mul n2 d1),  
       l.mul d1 d2)  
  end
```

```
structure IntRational = RationalFun(IntInteger)
```


ML Modules



Scala

trait ~ signature

```
trait IntegerSig {  
  type Integer  
}
```

object ~ structure

```
object IntInteger extends IntegerSig {  
  type Integer = Int  
}
```

class ~ functor

```
class RationalFun[I <: IntegerSig](i: I) {  
  type Rational = (I#Integer, I#Integer)  
}
```

Exhibit 2

tagstream-conduit

```
data Dec builder string = Dec
{ decToS      :: builder -> string
, decBreak    :: (Char -> Bool) -> string ->
                  (string, string)
, decBuilder  :: string -> builder
, decDrop     :: Int -> string -> string
, decEntity   :: string -> Maybe string
, decUncons   :: string -> Maybe (Char, string)
}
```

Exhibit 3

tagsoup

```
class (Typeable a, Eq a) => StringLike a where  
  empty      :: a  
  cons       :: Char -> a -> a  
  uncons     :: a -> Maybe (Char, a)  
  toString   :: a -> String  
  fromString :: String -> a  
  — [...] ]
```

Backpack

Modules

```
module IntegerInt where
```

```
type Integer = Int
```

```
zero = 0
```

```
succ = (+1)
```

```
add = (+)
```

```
mul = (*)
```

Backpack

Signatures

```
module IntegerSig where  
  
data Integer  
  
zero  :: Integer  
succ  :: Integer  
add   :: Integer -> Integer -> Integer  
mul   :: Integer -> Integer -> Integer
```

Backpack

Modules

```
module Rational where  
  
import qualified IntegerSig as I  
  
data Rational = R I.Integer I.Integer  
  
nom (R n _) = n  
denom (R _ d) = d  
add (R n1 d1) (R n2 d2) =  
  R (I.add (I.mul n1 d2) (I.mul n2 d1))  
    (I.mul d1 d2)
```

Backpack

Cabal packages

Integer implementation package

name: integer-int
exposed-modules: IntegerInt

Backpack

Cabal packages

Integer signature package

name:	integer-sig
version:	1.0
indefinite:	True
exposed-signatures:	IntegerSig

Backpack

Cabal packages

Rational “functor” package

name:	rational
indefinite:	True
build-depends:	integer-sig-1.0
exposed-modules:	Rational

Backpack

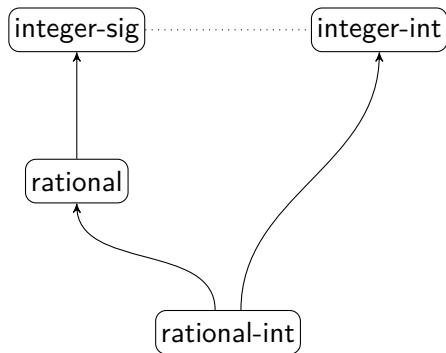
Mixing in

Rationals based on Integers

```
name: rational-int
build-depends:
  integer (IntegerInt as IntegerSig),
  rational
reexported-modules: Rational as RationalInt
```

Backpack

Package hierarchy



Instantiation Semantics

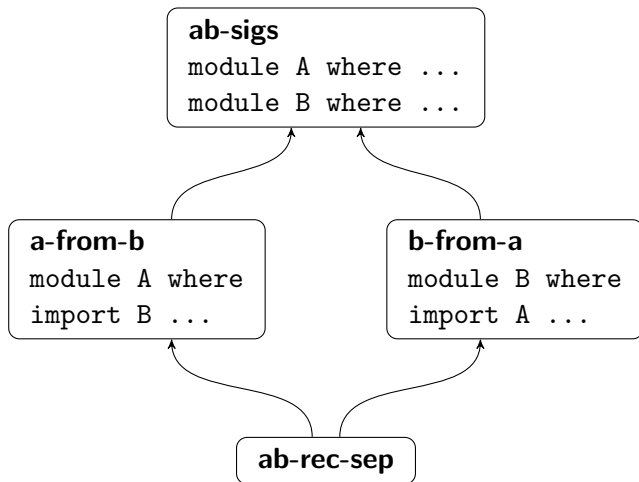
```
functor RationalFunD (I: INTEGER) =  
  struct  
    datatype rational =  
      R of I.integer * I.integer  
    val zero = R (I.zero, I.succ I.zero)  
  end  
structure R1 = RationalFunD (IntInteger)  
structure R2 = RationalFunD (IntInteger)
```

Is R1.rational the same type as R2.rational?

- ▶ *generative*: no
- ▶ *applicative*: yes

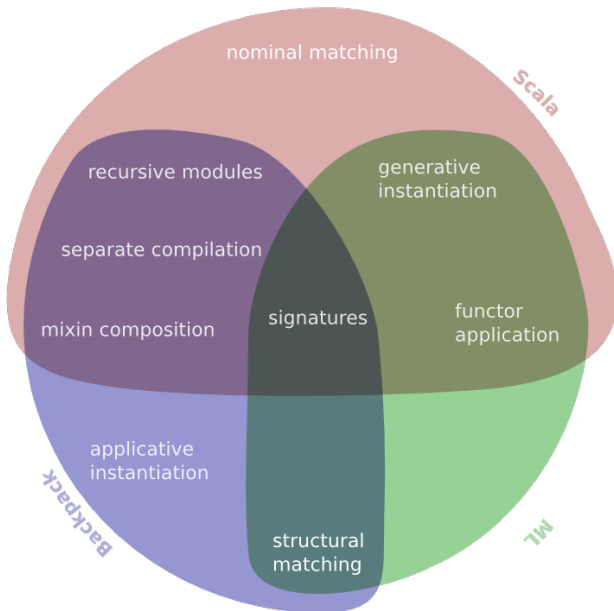
Backpack

Recursive linking



Module Systems

Features



More

- ▶ blog.ezyang.com (including comments)
- ▶ Edward Yang's *Haskell Implementor's Workshop* talk
- ▶ The Backpack paper
- ▶ papers by Derek Dreyer (e.g. MixML)