The Power of Functional Programming and Static Type Systems in Server-Side Web Applications

Oskar Wickström
https://wickstrom.tech

Kats Conf 2, Dublin, Feb 2017

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- Welcome to my talk with a very long title
- The Power of Functional Programming and Static Type Systems in Server-Side Web Applications

Elegant Weapons for a More Civilized Page

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- This was my original title, but I did not dare apply with it

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- I live and work in Malmo in Sweden
- I started out in music
- Wrote my first band site in PHP
- Luckily I was saved by functional programming not long after
- Worked on Oden
- I am currently working on CodeScene, mostly in Clojure

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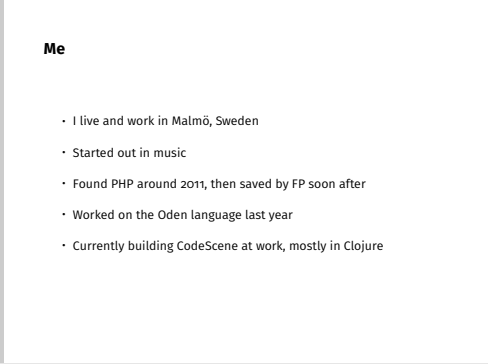

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- First: general overview of ...
- Then look closer at server-side rendering
- and some examples of static typing for server-side web, next level
- then we will dive into Hyper
  - Design
  - Type-Level Routing
  - XHR Clients
  - Future Work

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Overview: Functional Programming and Web Applications

- Let’s get going

Functional Programming Influence

- Functional programming influences Javascript
- ECMAScript
- Underscore, Rambda, Fantasy Land
- React is functional ...
- FRP has made its way into ...
- Still, main focus of efforts...

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Single-Page Applications

- Single page apps work more like traditional desktop apps
- Lot of JS frameworks, many just minor flavours of previous ones
- Some of the big ones are...
- And usually, without Javascript execution, you get nothing
  - Does this matter? Yes.
  - Disabled, flaky network, low-budget devices
- SPAs tends to reinvent things already present in web browers, like routing and forms

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What about Server-Side Rendering?

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- What about ...
- Do we need to make a binary choice?
- No. One approach is Progressive Enhancement...

Progressive Enhancement

- Progressive enhancement is about defining the lower bound of support
- Then gradually make things nicer for more capable clients
- Everyone above that threshold gets something, even if it’s rough

80/20

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- Let’s say all of your code and functionality is not equally important
- A smaller part provides the core value of your business
- You have lots of supporting code as well
- Login forms, settings pages, payment, integrations, documentation
- Do they really needs Javascript to be able to work?
- I would claim most would work fine with links and forms
- Let’s write client-side code where it provides value
- Unless you enjoy reinventing the web browser over and over

“Isomorphic” Web Applications

- I want to mention the hype around *isomorphic* web apps
- Goal:...
- One executes in the browser locally
- The other transfers state over the network through links and forms
- Are we really talking about initial rendering ...?

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- It progressively enhances a server-side app with low effort
- *explain steps...*
- Maybe this is a bit rough...

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- I do not know if this is the case...
- Let’s use good languages and make use of ... (change slide)

Static Typing for Server-Side Web

- Static typing for server-side web

Static Typing for Server-Side Web

- We have seen a lot of dynamically typed languages in web development, PHP, Ruby...
- Also the mainstream object-oriented like Java and C#, perhaps with MVC frameworks
- When programs grow big, and teams grow big, static typing is our friend
- We should be able to safely build abstractions and compose things
- Be confident that the pieces work together
- We should be able to maintain code, refactor it, change it, delete it
- Again, I think we need a good developer experience
- Not only making stuff shiny, but by using solid theory and research

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- For Haskell, two alternatives are ...
- Not that I know much about Scala, but I found these...
- And, as we are going to talk about PureScript, I want to mention...
- (10 MINUTES?)

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- Looking at other frameworks, like connect and Plug...
- In Java Servlets it's called filters
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```
java.lang.NullPointerException
        at compojure.core$routing$fn__18027.invoke(core.clj:151)
        at clojure.core$some.invokeStatic(core.clj:2592)
        at clojure.core$some.invoke(core.clj:2583)
        at compojure.core$routing.invokeStatic(core.clj:151)
        at compojure.core$routing.doInvoke(core.clj:148)
        at clojure.lang.RestFn.applyTo(RestFn.java:139)
        at clojure.core$apply.invokeStatic(core.clj:648)
        at clojure.core$apply.invoke(core.clj:641)
        at compojure.core$routes$fn__18031.invoke(core.clj:156)
        at clojure.lang.Var.invoke(Var.java:379)
        at compojure.core$wrap_routes$fn__18115.invoke(core.clj:279)
        at compojure.core$routing$fn__18027.invoke(core.clj:151)
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        at compojure.core$routes$fn__18031.invoke(core.clj:156)
        at ring.middleware.reload$wrap_reload$fn__12009.invoke(reload.clj:38)
        at selmer.middleware$wrap_error_page$fn__12022.invoke(middleware.clj:9)
        at prone.middleware$wrap_exceptions$fn__12220.invoke(middleware.clj:126)
        at codescene_cloud_web.layout$wrap_pjax_request$fn__7992.invoke(layout.clj:39)
        at buddy.auth.middleware$wrap_authentication$fn__3988.invoke(middleware.clj:42)
        at buddy.auth.middleware$wrap_authorization$fn__3996.invoke(middleware.clj:94)
        at ring.middleware.flash$wrap_flash$fn__8070.invoke(flash.clj:35)
        at ring.middleware.session$wrap_session$fn__8328.invoke(session.clj:103)
        at ring.middleware.keyword_params$wrap_keyword_params$fn__8364.invoke(keyword_params.clj:35)
        at ring.middleware.nested_params$wrap_nested_params$fn__8416.invoke(nested_params.clj:86)
        at ring.middleware.multipart_params$wrap_multipart_params$fn__8515.invoke(multipart_params.clj:133)
        at ring.middleware.params$wrap_params$fn__8543.invoke(params.clj:64)
        at ring.middleware.cookies$wrap_cookies$fn__8203.invoke(cookies.clj:161)
        at ring.middleware.absolute_redirects$wrap_absolute_redirects$fn__8720.invoke(absolute_redirects.clj:38)
        at ring.middleware.resource$wrap_resource$fn__8565.invoke(resource.clj:28)
        at ring.middleware.content_type$wrap_content_type$fn__8631.invoke(content_type.clj:38)
        at ring.middleware.default_charset$wrap_default_charset$fn__8666.invoke(default_charset.clj:28)
        at ring.middleware.not_modified$wrap_not_modified$fn__8687.invoke(not_modified.clj:61)
        at ring.middleware.x_headers$wrap_x_headers$fn__8904.invoke(x_headers.clj:51)
```

Let’s use extensible records in PureScript!

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- After a talk by Edwin Brady on Idris and session types, I got this idea...
- How about using extensible records ...

!!YPER

Type-safe, statically checked composition of HTTP servers

!!YPER

Type-safe, statically checked composition of HTTP servers

- And that's where Hyper started
- (20 MINUTES?)

Goals

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- The goals are...
- A safe HTTP middleware architecture
- Make the effects of applying middleware explicit in types
- Ensure correct composition
- Interoperability with NodeJS and other backends
- Different web servers, Erlang backend, purescript-native
- Also: no magic. No preprocessing or code generation.

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- Track middleware effects in type system...
- Leverage extensible records in PureScript
- Provide a common API for middleware
- Write backend-agnostic middleware
- Integrate with existing NodeJS libraries

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Design

- I will go through the core design first

Conn

```
type Conn req res components =
  { request :: req
  , response :: res
  , components :: components
  }
```


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- Conn, short for Connection
- Models the entirety of an HTTP connection
- Design adapted from Plug in Elixir
- It has a request and response, maybe not surprising
- But also components, which is an extension point for middleware
- I'm not so sure about components yet, it may go away

Middleware (Old Design)

```
type Middleware m c c’ = c -> m c’
```


Middleware (Old Design)

type Middleware m c c’ = c -> m c’

- A function transformed a Conn to another Conn, in some type *m*
- The *m* was usually an Applicative or a Monad
- A type synonym for a regular function
- This signature might remind you of Bind

Middleware (Old Design)

```
authenticateUser >=> parseForm >=> saveTodo
```


Middleware (Old Design)

authenticateUser >=> parseForm >=> saveTodo

- Middleware could therefore be composed using regular Kleisli composition
- Here we see three middleware, composed from left to right
- The connection goes into the first one, it gives back a new one, goes into the second, and so on
- All good? Not really.

Whoops, Not Safe

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badMiddleware conn = do
  _ <- respond "First response" conn
  respond "Second response, crash!" conn
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- We define a middleware called *badMiddleware*
- It takes a conn and passes it to the first respond middleware
- It ignores that resulting conn, passes the argument again
- Had we passed the result, or used Kleisli, we would have a type error
- The problem: Our safety is in the Conn values, and we can discard them
- The solution: The monad has to carry the Conn type

Middleware (Revised)

```
newtype Middleware m i o a =
  Middleware (i -> m (Tuple a o))
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Middleware (Revised)


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- The new middleware is an indexed monad
- Works as a state monad, with state type changes in its parameters
- You cannot run an effectful middleware without the types matching
- Let's see how this can solve the double-respond problem from before
- We will begin by looking at Response State Transitions

Response State Transitions

Response State Transitions

- Hyper tracks the state of response writing
- Guarantees correctness in response side effects, preventing common programming errors
- Abstractions can be built on top safely
- Response-writing middleware can be backend-agnostic

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- Takes Conn with Response writer in the **from** state
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- Go through them one by one

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  writeHeader
    :: Header
    -> ResponseStateTransition m rw HeadersOpen HeadersOpen

  closeHeaders
    :: ResponseStateTransition m rw HeadersOpen BodyOpen

  send
    :: b
    -> ResponseStateTransition m rw BodyOpen BodyOpen

  end
    :: ResponseStateTransition m rw BodyOpen ResponseEnded
```


ResponseWriter

```
class ResponseWriter rw m b | rw -> b where
  writeStatus
    :: Status
    -> ResponseStateTransition m rw StatusLineOpen HeadersOpen

  writeHeader
    :: Header
    -> ResponseStateTransition m rw HeadersOpen HeadersOpen

  closeHeaders
    :: ResponseStateTransition m rw HeadersOpen BodyOpen

  send
    :: b
    -> ResponseStateTransition m rw BodyOpen BodyOpen

  end
    :: ResponseStateTransition m rw BodyOpen ResponseEnded
```

- ResponseWriter encodes the possible state transitions
- Go through them one by one

What if we do it wrong?

```
          v
20        writeStatus statusOK
21        :*> respond "Hello, Hyper!"
22        :*> closeHeaders
                      ^

Could not match type

  BodyOpen

with type

  HeadersOpen
```


What if we do it wrong?

```
          v
20        writeStatus statusOK
21        :*> respond "Hello, Hyper!"
22        :*> closeHeaders
                      ^

Could not match type

  BodyOpen

with type

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```

- And if we write responses incorrectly, we get a compile-time error
- With this safety, we can without fear build new things on top

Writing Headers

```
headers
```


Writing Headers

```
headers
```

- The *headers* function is a minimal example of abstraction
- It writes all specified headers, then closes headers
- The implementation? Pretty simple.
- Now for a much higher-level abstraction on top of Hyper, namely *type-level routing*
- (30 MINUTES?)

Writing Headers

```
headers
  :: forall t m req res rw b c.
     (Traversable t, Monad m, ResponseWriter rw m b) =>
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Writing Headers

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headers
  :: forall t m req res rw b c.
     (Traversable t, Monad m, ResponseWriter rw m b) =>
     t Header
  -> Middleware
     m
     (Conn req { writer :: rw HeadersOpen | res } c)
     (Conn req { writer :: rw BodyOpen | res } c)
     Unit
```


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headers hs =
  traverse_ writeHeader hs
  :*> closeHeaders
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Type-Level Routing

- This is very much inspired by Servant, for Haskell
- I can really recommend Servant
- This version for Hyper, being written in PureScript, has some benefits
- I'll get to that later

A Routing Type

```
data Home = Home

type Site1 = Get HTML Home
```


A Routing Type

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```

- We first define a resource data type
- Then we define a routing type
- Note that the routing type has no value-level representation defined

Handler

```
home :: forall m. Monad m
     => ExceptT RoutingError m Home
home = pure Home
```


Handler

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- We also need a handler
- The handler is a function applied when a route is matched
- It returns a response for a request
- Argument types and return type can be our custom data types
- But how does one respond with HTML, or JSON

HTMLEncode

```
instance encodeHTMLHome :: EncodeHTML Home where
  encodeHTML Home =
    p [] [ text "Welcome to my site!" ]
```


HTMLEncode


```
instance encodeHTMLHome :: EncodeHTML Home where
  encodeHTML Home =
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```


- We need an instance of MimeEncoder
- By defining an instance for EncodeHTML, we get the MimeEncoder automatically
- Hyper includes a small HTML DSL for now
- It will probably use an existing one called *smolder* instead
- Remember how our routing type had no value-level representation?
- We need to pass it to the router, but how?

Proxy

The Proxy type and values are for situations where type information is required for an input to determine the type of an output, but where it is not possible or convenient to provide a value for the input.

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- We use the PureScript Proxy type

Site Proxy

```
site1 :: Proxy Site1
site1 = Proxy
```


Site Proxy

```
site1 :: Proxy Site1
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```

- Here we create a proxy for our routing type

Site Router

```
onRoutingError status msg =
  writeStatus status
  :*> contentType textHTML
  :*> closeHeaders
  :*> respond (maybe "" id msg)

site1Router = router site1 home onRoutingError
```


Site Router

```
onRoutingError status msg =
  writeStatus status
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  :*> closeHeaders
  :*> respond (maybe "" id msg)

site1Router = router site1 home onRoutingError
```

- We define an HTTP error handler
- And our router, by passing the proxy and our home handler

Main Entrypoint

```
main =
  runServer defaultOptions
            onListening
            onRequestError
            {}
            site1Router
  where
    onListening (Port port) =
      log ("Listening on http://localhost:" <> show port)

    onRequestError err =
      log ("Request failed: " <> show err)
```


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    onListening (Port port) =
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```

- Lastly, we define our main function that starts the server

More Routes!

- Having only one route seems lame. Let’s add some more

Multiple Endpoints with Captures

```haskell
data Home = Home

data AllUsers = AllUsers (Array User)

newtype User = User { id :: Int, name :: String }

type Site2 =
  Get HTML Home
  :<|> "users" :/ Get HTML AllUsers
  :<|> "users" :/ Capture "user-id" Int :> Get HTML User
```


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- (explain code)

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- Our home handler looks like before
- allUsers is simply wrapping the array of user values
- getUser performs a lookup, possibly throws Not Found error
- Now that we have multiple routes, how do we link between them?

Multiple Handlers

```
home :: forall m. Monad m => ExceptT RoutingError m Home
home = pure Home

allUsers :: forall m. Monad m => ExceptT RoutingError m AllUsers
allUsers = AllUsers <$> getUsers
```


Multiple Handlers

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home = pure Home

allUsers :: forall m. Monad m => ExceptT RoutingError m AllUsers
allUsers = AllUsers <$> getUsers

getUser :: forall m. Monad m => Int -> ExceptT RoutingError m User
getUser id' =
  find userWithId <$> getUsers >>=
  case _ of
    Just user -> pure user
    Nothing ->
      throwError (HTTPError { status: statusNotFound
                            , message: Just "User not found."
                            })
  where
    userWithId (User u) = u.id == id'
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  encodeHTML (AllUsers users) =
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- In our HTML encoder, we want to produce anchor tags
- As we have routing types, we get type-safe links for free

Type-Safe Links

```
instance encodeHTMLAllUsers :: EncodeHTML AllUsers where
  encodeHTML (AllUsers users) =
    element_ "div" [ h1 [] [ text "Users" ]
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```


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Multiple Endpoint Router

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site2Router =
  router site2 (home :<|> allUsers :<|> getUser) onRoutingError
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Multiple Endpoint Router

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- We combine our handlers with a structure matching the routing type
- Matching the type incorrectly would result in a type error
- OK, so that is nice.
- But I talked about progressive enhancement before? How about that?

Automatically Derived XHR Clients

- Instead of sprinkling Javascript or jQuery scripts all over the place
- with no type safety or guarantees they are in sync with routes
- Let’s automatically dervice safe XHR clients

Shared Routing Type

```
type TaskId = Int

data Task = Task TaskId String
```


Shared Routing Type

```
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data Task = Task TaskId String
```

- We define a type Task

Shared Routing Type

```
derive instance genericTask :: Generic Task

instance showTask :: Show Task where
  show = gShow

instance encodeJsonTask :: EncodeJson Task where
  encodeJson = gEncodeJson

instance decodeJsonTask :: DecodeJson Task where
  decodeJson = gDecodeJson
```


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```

- Provide some encoding and decoding instances for JSON

Shared Routing Type

```
type Site =
  "tasks" :/ (Get Json (Array Task)
              :<|> Capture "id" TaskId :> Get Json Task)
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- Define the routing type
- and our Proxy value
- We write our handlers and a server just like before
- Finally, we use it in a client-side application

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- This is a snippet from a PureScript Pux app
- The code in bold is where we generate AJAX clients for our site
- We pattern match on the structure to get a specific client
- I think this is a very strong case for Hyper

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Other Possibilites/Future Work

- So, what more can we do here?
- I'd like type safe form posts
- PJAX, the hyper way
- Mocked servers with Arbitrary
- Ring-like abstraction for response maps
- Other backends
- And in general, continue the quest for type-safe web!

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Summary

- Server-side or SPA is not a binary choice
- We can make the middleground much nicer, building better tools
- Good programming languages and type systems are our allies

Thank You!

Thank You!

- Thank you
- Here are some links to things I've mentioned...

Useful References I

- Gustaf Nilsson Kotte. *6 Reasons Isomorphic Web Apps is not the Silver Bullet You're Looking For.* URL: https://blog.jayway.com/2016/05/23/6-reasons-isomorphic-web-apps-not-silver-bullet-youre-looking/.
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- *Servant: A Type-Level Web DSL.* URL: https://haskell-servant.github.io/.

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- *Servant: A Type-Level Web DSL.* URL: https://haskell-servant.github.io/.

Useful References II

- *Play: The High Velocity Web Framework For Java and Scala.* URL: https://www.playframework.com/.
- *Rho: A DSL for building HTTP services with http4s.* URL: https://github.com/http4s/rho.
- *purescript-express: Purescript wrapper around Node.js Express web-framework.* URL: https://github.com/dancingrobot84/purescript-express.
- *purescript-rest: A toolkit for creating REST services with Node and PureScript.* URL: https://github.com/dicomgrid/purescript-rest.

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Useful References III

- *Hyper: Type-safe, statically checked composition of HTTP servers.*

  URL: https://owickstrom.github.io/hyper/.

- *purescript-proxy: Value proxy for type inputs.* URL:

  https://pursuit.purescript.org/packages/purescript-proxy/1.0.0.

- *Ring: Clojure HTTP server abstraction.* URL:

  https://github.com/ring-clojure.

- *Automatically derived XHR clients for Hyper routing types.* URL:

  https://github.com/owickstrom/purescript-hyper-routing-xhr.

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- *Hyper: Type-safe, statically checked composition of HTTP servers.* URL: https://owickstrom.github.io/hyper/.
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- Questions?