



LiquidHaskell

Usable Language-Based Verification

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Formal Verification

Prove Properties of Software

Formal Verification

Prove Properties of Real Software

Formal Verification

Prove Properties of Real Software



“A plane will not crash”

Formal Verification

Prove Properties of Real Software



“Your passwords are SAFE”

Formal Verification, in Practice

Prove Properties of ~~Real Software~~
in Verification Specific Tools

Verification Specific Tools

```
Lemma plus_Snm_nSm : forall n m, S n + m = n + S m.  
intros.  
simpl in |- *.  
rewrite (plus_comm n m).  
rewrite (plus_comm n (S m)).  
trivial with arith.  
Qed.
```



“Plus is indeed associative!”

Verification Specific Tools

Difficult to use for Real Programs

Difficult to install

Special Syntax

No Compiler Optimizations

No Parallelism

Very Few Users!

My goal:

Verification of Real Programs

Verification of Real Programs

My approach:

Turn a **Language** into a Verifier

Reuse language's syntax, runtime, and users!

Verification of Real Programs

My approach:

Turn a **Language** into a Verifier

Target Language: Haskell

Haskell

+

Refinement Types

=



LiquidHaskell

Haskell

take :: [a] -> Int -> [a]

```
> take [1,2,3] 2  
> [1,2]
```

Haskell

take :: [a] -> Int -> [a]

```
> take [1,2,3] 500  
> ???
```

Refinement Types

```
take :: xs:[a] -> {i:Int | i < len xs} -> [a]
```



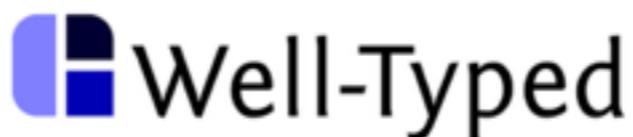
```
take :: xs:[a] -> {i:Int | i < len xs} -> [a]
```

```
> take [1,2,3] 500
> Refinement Type Error!
```



Use Haskell's syntax, runtime, and **users**!

Used in **Industry**: to speed up code



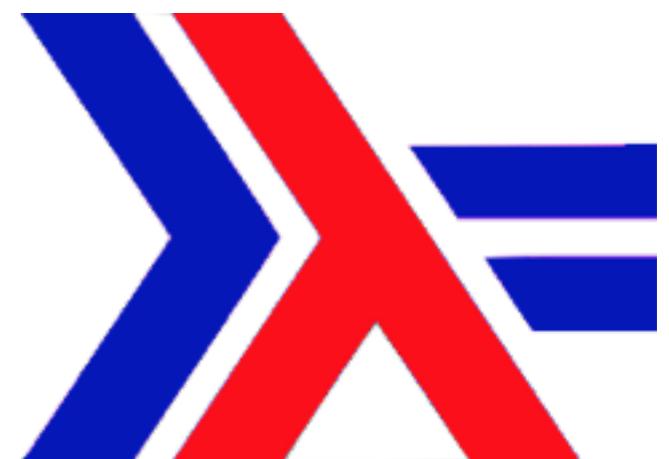
Used in **Education**: in Haskell courses!



Haskell

Functional Programming Language

Based on
Strong Typing + λ -calculus

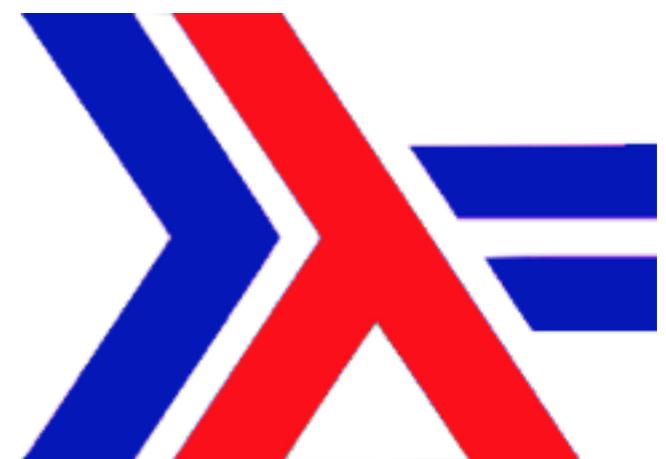


Haskell

Practical Programming Language

Fast Memory Manipulation with C wrappers

Allowing overread bugs



The Heartbleed Bug



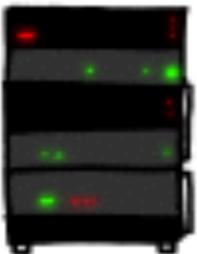
Buffer overread in OpenSSL. 2015

HOW THE HEARTBLEED BUG WORKS:

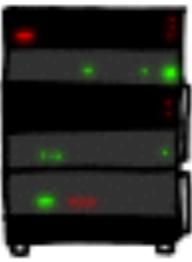
SERVER, ARE YOU STILL THERE?
IF SO, REPLY "POTATO" (6 LETTERS).



User Eric wants pages about "boats". User Erica requests secure connection using key "4538538374224". User Meg wants these 6 letters: POTATO. User Ada wants pages about "irl games". Unlocking secure records with master key 5130985733435. Macie (chrome user) sends this message: "H



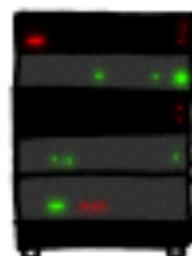
POTATO



SERVER, ARE YOU STILL THERE?
IF SO, REPLY "BIRD" (4 LETTERS).



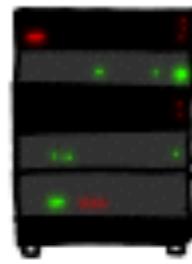
User Olivia from London wants pages about "new bees in car why". Note: Files for IP 375.381.283.17 are in /tmp/files-3843. User Meg wants these 4 letters: BIRD. There are currently 345 connections open. User Brendan uploaded the file selfie.jpg (contents: 834ba962e2ceb9ff89bd3bfff84)



HMM...



BIRD



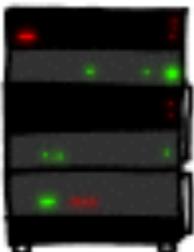
SERVER, ARE YOU STILL THERE?

a connection. Jake requested pictures of deer. User Meg wants these 500 letters: HAT. Lucas

SERVER, ARE YOU STILL THERE?
IF SO, REPLY "HAT" (500 LETTERS).

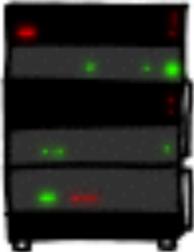


a connection. Jake requested pictures of deer.
User Meg wants these 500 letters: HAT. Lucas
requests the "missed connections" page. Eve
(administrator) wants to set server's master
key to "14835038534". Isabel wants pages about
"snakes but not too long". User Karen wants to
change account password to "CoHoBaSt". User



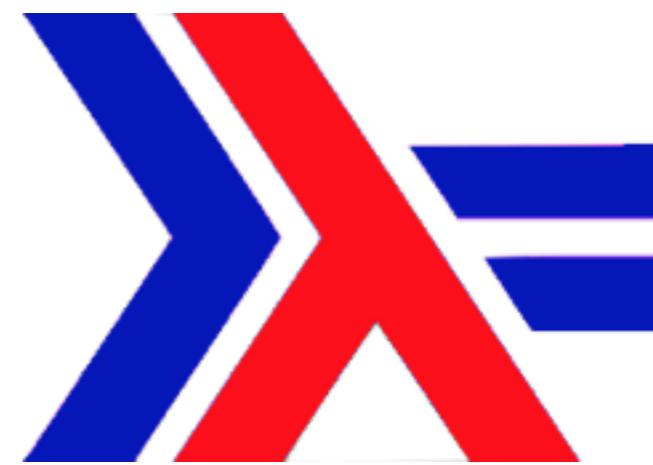
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(administrator) wants to set server's master
key to "14835038534". Isabel wants pages about
"snakes but not too long". User Karen wants to
change account password to "CoHoBaSt". User





in



```
module Data.Text where
take :: t:Text -> i:Int -> Text
```

```
> take "hat" 500
> *** Exception: Out Of Bounds!
```

Runtime Checks

```
take :: t:Text -> i:Int -> Text
take t i | i < len t
          = Unsafe.take t i
take t i
          = error "Out Of Bounds!"
```

Safe, but slow

No Checks

```
take :: t:Text -> i:Int -> Text
take t i | i < len t
          = Unsafe.take t i
take t i
error "Out Of Bounds!"
```

Fast, but unsafe!

No Checks

```
take :: t:Text -> i:Int -> Text
take t i | i < len t
          = Unsafe.take t i
take t i
error "Out Of Bounds!"
```

Overread

```
> take "hat" 500
> "hat\58456\2594\SOH\NUL..."
```

Static Checks

```
take :: t:Text -> i:Int -> Text
take t i | i < len t
          = Unsafe.take t i
take t i
= error "Out Of Bounds!"
```

Static Checks

```
take :: t:Text -> i:{i < len t} -> Text
take t i | i < len t
  = Unsafe.take t i
take t i
  = error "Out Of Bounds!"
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Static Checks

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Static Checks

```
take :: t:Text -> i:{i < len t} -> Text
take t i
= Unsafe.take t i
```

Static Checks

```
take :: t:Text -> i:{i < len t} -> Text
take t i
= Unsafe.take t i
```

```
> take "hat" 500
```

Type Error



LiquidHaskell

Refinement Types



Checks valid arguments, under facts.

Checks valid arguments, under facts.

```
take :: t:Text -> {v | v < len t} -> Text
heartbleed = let x = "hat"
            in take x 500
```

len x = 3 => v = 500 => v < len x

Checks valid arguments, under facts.

```
take :: t:Text -> {v | v < len t} -> Text
heartbleed = let x = "hat"
            in take x 500
```

len x = 3 => v = 500 => v < len x

Checks valid arguments, under facts.

```
take :: t:Text -> {v | v < len t} -> Text
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```
heartbleed = let x = "hat"  
           in take x 500
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len x = 3 => v = 500 => v < len x

Checks valid arguments, under facts.

```
take :: t:Text -> {v | v < len t} -> Text
```

```
heartbleed = let x = "hat"  
           in take x 500
```

len x = 3 => $v = 500$ => $v < \text{len } x$

Checks valid arguments, under facts.

```
take :: t:Text -> {v | v < len t} -> Text  
heartbleed = let x = "hat"  
           in take x 500
```

len x = 3 => v = 500 => v < len x

Checks valid arguments, under facts.

```
take :: t:Text -> {v | v < len t} -> Text
heartbleed = let x = "hat"
             in take x 500
```

```
len x = 3 => v = 500 => v < len x
```

Checks valid arguments, under facts.

```
take :: t:Text -> {v | v < len t} -> Text
heartbleed = let x = "hat"
            in take x 500
```

SMT-
query

len x = 3 => v = 500 => v < len x

Checks valid arguments, under facts.

```
take :: t:Text -> {v | v < len t} -> Text
heartbleed = let x = "hat"
            in take x 500
```

SMT-
invalid

len x = 3 => v = 500 => v < len x

Checks valid arguments, under facts.

```
take :: t:Text -> {v | v < len t} -> Text
heartbleed = let x = "hat"
            in take x 500
```

Checker reports **Error**

len x = 3 => v = 500 => v < len x

Checks valid arguments, under facts.

```
take :: t:Text -> {v | v < len t} -> Text
```

```
heartbleed = let x = "hat"
```

```
in take x 500
```

Checker reports **Error**

len x = 3 => v = 500 => v < len x

Checks valid arguments, under facts.

```
take :: t:Text -> {v | v < len t} -> Text
```

```
heartbleed = let x = "hat"  
           in take x 2
```

Checker reports **OK**

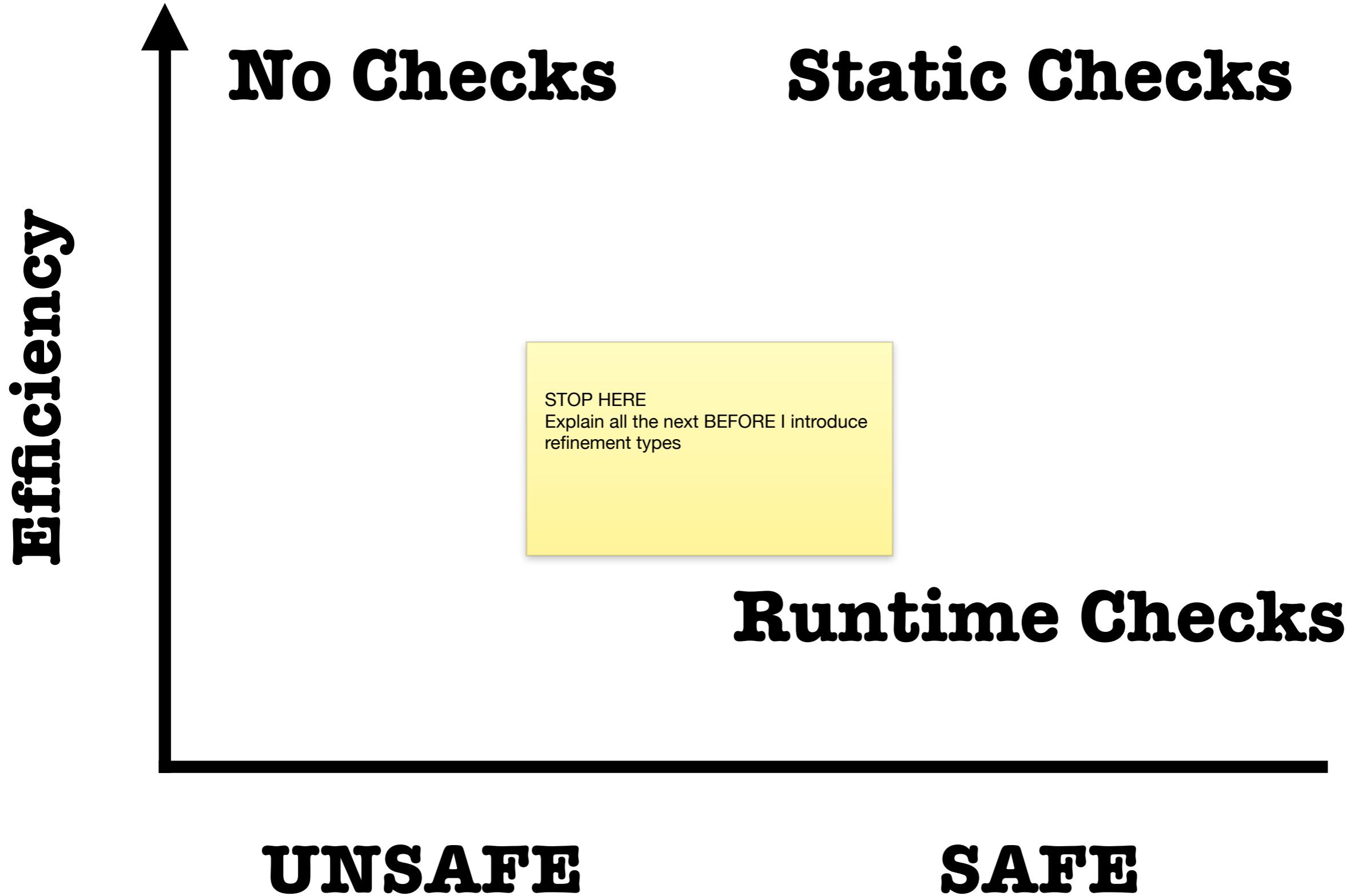
SMT-
valid

len x = 3 => v = 2 => v < len x



Checks valid arguments, under facts.

Static Checks





LiquidHaskell

Static Checks

Safe & Fast Code!

Static Checks

Safe & Fast Code!

Application: Speed up Parsing

Application: Speed up Parsing

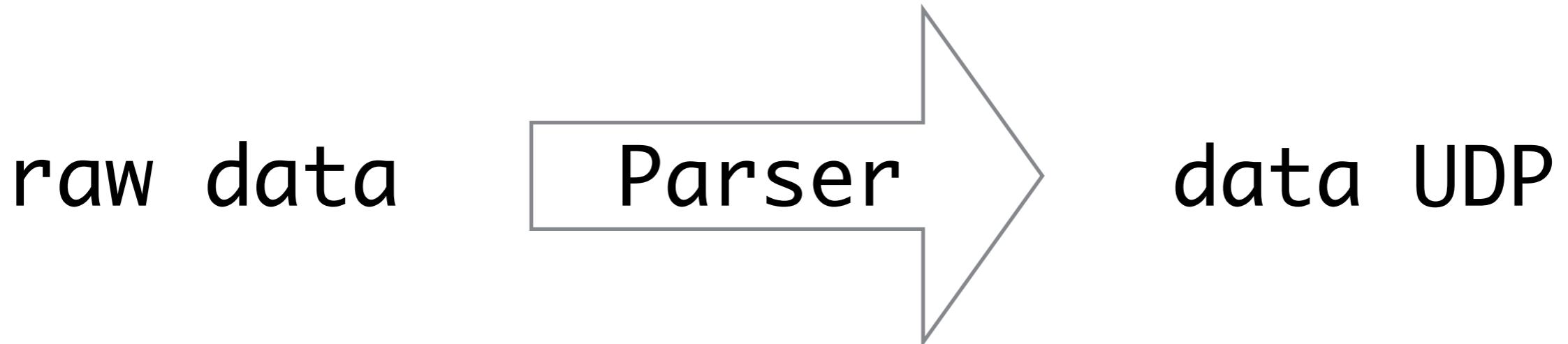
Simplified application of Liquid Haskell

by Gabriel Gonzalez



Application: Speed up Parsing

UDP: User Datagram Protocol



Application: Speed up Parsing

```
data UDP = UDP
  { udpSrcPort :: Text -- 2 chars
  , udpDestPort :: Text -- 2 chars
  , udpLength :: Text -- 2 chars
  , udpChecksum :: Text -- 2 chars
  }
```

Application: Speed up Parsing

```
udpP :: Text -> UDP
udpP bs =
  let (udp1, bs1) = splitAt 2 bs
  let (udp2, bs2) = splitAt 2 bs1
  let (udp3, bs3) = splitAt 2 bs2
  let (udp4, bs4) = splitAt 2 bs3
in UDP (udp1 upd2 udp3 upd4)
```

Safe but Slow (4 runtime checks)

Solution: Merge checks

Application: Speed up Parsing

```
udpP :: Text -> Maybe UDP
udpP bs =
  if length bs >= 8 then
    let (udp1, bs1) = US.splitAt 2 bs
    let (udp2, bs2) = US.splitAt 2 bs1
    let (udp3, bs3) = US.splitAt 2 bs2
    let (udp4, bs4) = US.splitAt 2 bs3
    in Just (UDP udp1 udp2 udp3 udp4)
  else Nothing
```

Safe and Fast (1 runtime check!)

Application: Speed up Parsing

```
udpP :: Text -> Maybe UDP
udpP bs =
  if length bs >= 8 then
    let (udp1, bs1) = US.splitAt 2 bs
    let (udp2, bs2) = US.splitAt 2 bs1
    let (udp3, bs3) = US.splitAt 4 bs2
    let (udp4, bs4) = US.splitAt 2 bs3
    in Just (UDP udp1 udp2 udp3 udp4)
  else Nothing
```

Safe and Fast, but error prone

Application: Speed up Parsing

```
udpP :: Text -> Maybe UDP
udpP bs =
  if length bs >= 8 then
    let (udp1, bs1) = US.splitAt 2 bs
      in Just (UDP udp1 upd2 upd3 upd4)
  else Nothing

splitAt :: i:Int -> t:{i < len t} ->
(tl:{i = len tl}, tr:{len tr = len t - i})
```

Enforce Static Checks!

Application: Speed up Parsing

```
udpP :: Text -> Maybe UDP
```

```
udpP bs =  
  if length bs >= 8 then  
    let (udp1, bs1) = US.splitAt 2 bs0  
    let (udp2, bs2) = US.splitAt 2 bs1  
    let (udp3, bs3) = US.splitAt 4 bs2  
    let (udp4, bs4) = US.splitAt 2 bs3  
    in Just (UDP udp1 upd2 upd3 upd4)  
  else Nothing
```

Error

Enforce Static Checks!

Application: Speed up Parsing

OK

```
udpP :: Text -> Maybe UDP
udpP bs =
  if length bs >= 8 then
    let (udp1, bs1) = US.splitAt 2 bs
    let (udp2, bs2) = US.splitAt 2 bs
    let (udp3, bs3) = US.splitAt 2 bs
    let (udp4, bs4) = US.splitAt 2 bs
    in Just (UDP udp1 upd2 upd3 upd4)
  else Nothing
```

Haskell code!
- syntax
- compiler

No proofs!
- SMT automated!

Provably Correct & Faster (x6) Code!

Application: Speed up Parsing

```
udpP :: Text -> Maybe UDP
udpP bs =
  if length bs >= 8 then
    let (udp1, bs1) = US.splitAt 2 bs
    let (udp2, bs2) = US.splitAt 2 bs1
    let (udp3, bs3) = US.splitAt 2 bs2
    let (udp4, bs4) = US.splitAt 2 bs3
    in Just (UDP udp1 upd2 upd3 upd4)
  else Nothing
```

Provably Correct & Faster (x6) Code!
Haskell Code: Verification with SMT



Provably Correct & Faster (x6) Code!

Haskell Code: Verification with SMT



Verification with SMT

If p is safe indexing

```
{t:Text | i < len t }
```

Verification with SMT

If p from decidable theories

$$\{t : a \mid p\}$$

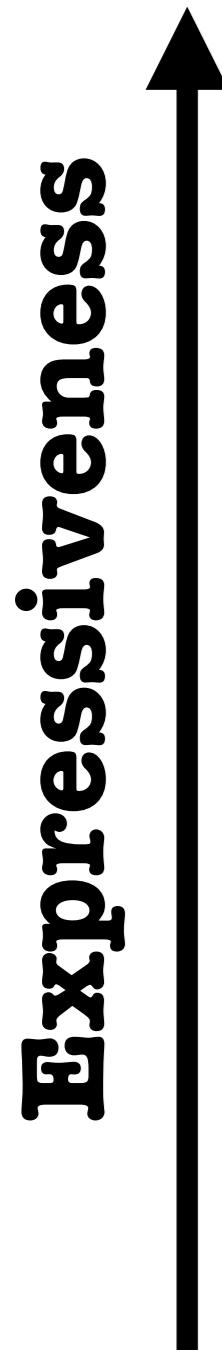
Boolean Logic

(QF) Linear Arithmetic

Uninterpreted Functions ...

What other properties can we express?

Verification with SMT



Critical Properties (Goal):

“The plane will not crash!”

Math Theorems (POPL’18):

“If $f(x) < f(x+1)$, then f is monotonic”

Safe Indexing (Haskell’14):

“Your passwords are safe!”

Verification with SMT

Refinement Reflection, POPL'18

for Theorem Proving in Haskell!

“If $f(x) < f(x+1)$, then f is monotonic”

Fibonacci in Haskell

```
fib :: i:{Int | 0≤i} -> {v:Int | 0<v ∧ i≤v}
fib i
| i≤1          = 1
| otherwise     = fib (i-1) + fib (i-2)
```

Fibonacci in Haskell

```
fib :: i:{Int | 0≤i} -> {v:Int | 0<v ∧ i≤v}
fib i
| i≤1          = 1
| otherwise     = fib (i-1) + fib (i-2)
```

How to express **theorems** about functions?

\forall i. $0 \leq i \Rightarrow \text{fib } i \leq \text{fib } (i+1)$

How to express **theorems** about functions?

Step 1: Definition

In SMT **fib** is “Uninterpreted Function”

\forall i j. i = j => fib i = fib j

How to connect logic **fib** with Haskell **fib**?

How to connect logic fib with Haskell fib?

```
fib :: i:{Int | 0≤i} -> {v:Int | 0<v∧i≤v}
fib i
| i≤1          = 1
| otherwise    = fib (i-1) + fib (i-2)
```

Not Decidable!

SMT Axiom

\forall i.

if $i \leq 1$ then $\text{fib } i = 1$
else $\text{fib } i = \text{fib } (i-1) + \text{fib } (i-2)$

How to connect logic fib with Haskell fib?

```
fib :: i:{Int | 0≤i} -> {v:Int | 0<v ∧ i≤v}
fib i
| i≤1          = 1
| otherwise     = fib (i-1) + fib (i-2)
```

Refinement Reflection

```
fib :: i:{Int | 0≤i} -> {v:Int | v=fib i ∧
    if i≤1 then fib i = 1
    else fib i = fib (i-1) + fib (i-2)
}
```

Refinement Reflection

Step 1: Definition

Step 2: Reflection

```
fib :: i:{Int | 0≤i} -> {v:Int | v=fib i ∧
    if i≤1 then fib i = 1
    else fib i = fib (i-1) + fib (i-2)
}
```

Refinement Reflection

Step 1: Definition

Step 2: Reflection

```
fib :: i:{Int | 0≤i} -> {v:Int | v=fib i ∧  
    if i≤1 then fib i = 1  
    else fib i = fib (i-1) + fib (i-2)  
}
```

Step 3: Application

```
fib 0 :: {v:Int | v=fib 0 ∧ fib 0 = 1}
```

Application is Type Level Computation

fib 0

fib 0 = 1

Application Type Level Computation

fib 0

fib 0 = 1

fib 1

fib 1 = 1

fib 2

fib 2 = fib 1 + fib 0

fib i

?

- ? if $i \leq 1$ then fib i = 1
- ? else fib i = fib (i-1) + fib (i-2)

Application Type Level Computation

fib 0

fib 0 = 1

fib 1

fib 1 = 1

fib 2

fib 2 = fib 1 + fib 0

if $1 < i$ then

fib i

fib i = fib (i-1) + fib (i-2)

if $i \leq 1$ then fib i = 1

else fib i = fib (i-1) + fib (i-2)

Application Type Level Computation

fib 0

fib 0 = 1

fib 1

fib 1 = 1

fib 2

fib 2 = fib 1 + fib 0

if 1 < i then

fib i

fib i = fib (i-1) + fib (i-2)

fib (i+1)

fib (i+1) = fib i + fib (i-1)

Theorem Proving

```
fibUp :: i:Nat -> {fib i ≤ fib (i+1)}
fibUp i
| i == 0
= fib 0 <. fib 1
*** QED
| i == 1
= fib 1 <=. fib 1 + fib 0 <= fib 2
*** QED
| otherwise
= fib i
<=. fib i + fib (i-1)
<=. fib (i+1)
*** QED
```

Reflection for Theorem Proving

Theorems are refinement types.

Proofs are functions.

Check that functions prove theorems.

Proofs are functions.

`fibUp :: i:Nat -> {fib i ≤ fib (i+1)}`

Proofs are functions.

`fibUp :: i:Nat -> {fib i ≤ fib (i+1)}`

Let's call them!

`fibUp 4 :: {fib 4 ≤ fib 5}`

`fibUp i :: {fib i ≤ fib (i+1)}`

`fibUp (j-1) :: {fib (j-1) ≤ fib j}`

Proofs are functions. Let's call them!

```
fibMono :: i:Nat -> j:{Nat | i < j}  
         -> {fib i ≤ fib j}
```

```
fibMono i j  
| i + 1 == j  
= fib i  
<=. fib (i+1) ? fibUp i  
==. fib j  
*** QED  
| otherwise  
= fib i  
<=. fib (j-1) ? fibMono i (j-1)  
<=. fib j     ? fibUp (j-1)  
*** QED
```

Proofs are functions. Let's call them!

```
fibMono :: i:Nat -> j:{Nat | i < j}  
         -> {fib i ≤ fib j}
```

```
fibMono i j  
| i + 1 == j  
= fib i  
<=. fib (i+1) ? fibUp i  
==. fib j  
*** QED  
| otherwise  
= fib i  
<=. fib (j-1) ? fibMono i (j-1)  
<=. fib j      ? fibUp (j-1)  
*** QED
```

Proofs are functions. Let's abstract them!

```
fibMono :: i:Nat -> j:{Nat | i < j}
          -> fib:(Nat -> Int)
          -> (k:Nat -> {fib k ≤ fib (k+1)})
          -> {fib i ≤ fib j}
```

```
fibMono i j fib fibUp
| i + 1 == j
= fib i
<=. fib (i+1) ? fibUp i
==. fib j
*** QED
| otherwise
= fib i
<=. fib (j-1) ? fibMono i (j-1)
<=. fib j      ? fibUp (j-1)
*** QED
```



Refinement Reflection for **Expressiveness**

 Liquid Haskell

Refinement Reflection for **Expressiveness**

Application (Haskell'17):
String Matching Parallelization

Refinement Reflection for **Expressiveness**

Idea:

Encode HO specs in FO SMT decidable logic

Metatheory:

THEOREM 4.1. [Soundness of λ^R]

- **Denotations** If $\Gamma; R \vdash p : \tau$ then $\forall \theta \in [\![\Gamma]\!]. \theta \cdot p \in [\![\theta \cdot \tau]\!]$.
- **Preservation** If $\emptyset; \emptyset \vdash p : \tau$ and $p \hookrightarrow^* w$, then $\emptyset; \emptyset \vdash w : \tau$.

E PROOF OF SOUNDNESS

We prove Theorem 4.1 of § D by reduction to Soundness of λ^U [Vazou et al. 2014a].

THEOREM E.1. [Denotations] If $\Gamma \vdash p : \tau$ then $\forall \theta \in [\Gamma]. \theta \cdot p \in [\theta \cdot \tau]$.

PROOF. We use the proof from [Vazou et al. 2014b] and specifically Lemma 4 that is identical to the statement we need to prove. Since the proof proceeds by induction in the type derivation, we need to ensure that all the modified rules satisfy the statement.

- T-EXACT Assume $\Gamma \vdash e : \{v : B \mid \{r\} \wedge v = e\}$. By inversion $\Gamma \vdash e : \{v : B \mid \{r\}\}$ (1). By (1) and IH we get $\forall \theta \in [\Gamma]. \theta \cdot e \in [\theta \cdot \{v : B \mid \{r\}\}]$. We fix a $\theta \in [\Gamma]$. We get that if $\theta \cdot e \hookrightarrow^* w$, then $\theta \cdot \{r\} \hookrightarrow^* \text{True}$. By the Definition of $=$ we get that $w = w \hookrightarrow^*$ True. Since $\theta \cdot (v = e) \vdash v = e$, we get $\theta \cdot e \in [\theta \cdot \{v : B \mid \{r\} \wedge v = e\}]$.
- T-LET Assume $\Gamma \vdash \text{let } rec \; r \; (2)$, and $\Gamma \vdash r \; (3)$. By IH $\forall \theta \in [\Gamma]. \theta \cdot r \in [\theta \cdot \{r\}]$ (2'). By (1') and by the type rule (3) $\forall \theta \in [\Gamma]. \theta \cdot p[\text{fix } x \; e]$.
- T-REFL Assume $\Gamma \vdash \text{refl } e \; in \; p : \tau$. By IH, $\forall \theta \in [\Gamma]$ terms in p are closed under evaluation.
- T-FIX In Theorem 8.3 from [Wadler and Paolini 2004]) we prove

$\Gamma \vdash e \rightsquigarrow p$

sort Fun $s_x s_y$,
action of sort

Refinement Reflection, POPL'18

by **Vazou**, Tondwalkar, Choudhury, Scott,
Newton, Wadler, and Jhala

THEOREM E.2. [Preservation] If $\emptyset \vdash p : \tau$ and $p \hookrightarrow^* w$ then $\emptyset \vdash w : \tau$.

PROOF. In [Vazou et al. 2014b] proof proceeds by iterative application of Type Preservation Lemma 7. Thus, it suffices to ensure Type Preservation in λ^R , which is true by the following Lemma. \square

LEMMA E.3. If $\emptyset \vdash p : \tau$ and $p \hookrightarrow p'$ then $\emptyset \vdash p' : \tau$.

PROOF. Since Type Preservation in λ^U is proved by induction on the type derivation tree, we need to ensure that all the modified rules satisfy the statement.

- T-EXACT Assume $\emptyset \vdash p : \{v : B \mid \{r\} \wedge v = p\}$. By inversion $\emptyset \vdash p : \{v : B \mid \{r\}\}$. By IH we get $\emptyset \vdash p' : \{v : B \mid \{r\}\}$. By rule T-EXACT we get $\emptyset \vdash p' : \{v : B \mid \{r\} \wedge v = p'\}$. Since subtyping is closed under evaluation, we get $\emptyset \vdash \{v : B \mid \{r\} \wedge v = p'\} \leq \{v : B \mid \{r\} \wedge v = p\}$. By rule T-SUB we get $\emptyset \vdash p' : \{v : B \mid \{r\} \wedge v = p\}$.

By 25, the above set is not empty, and hence τ is valid under d . \square

Example: Fibonacci is increasing In § 2 we verified that under a definition d that includes fib, the term fibUp proves

$$n : \text{Nat} \rightarrow \{\text{fib } n \leq \text{fib } (n + 1)\}$$

Thus, by Theorem D.3 we get

$$\forall n. 0 \leq n \hookrightarrow^* \text{True} \Rightarrow \text{fib } n \leq \text{fib } (n + 1) \hookrightarrow^* \text{True}$$

for all assignments $\sigma \models p$.

Embedding Functions As λ^P is a first-order logic, we embed λ -abstraction and application using the uninterpreted functions lam and app. We embed λ -abstractions using lam as shown in

COROLLARY E.5. If $i \vdash e : \text{Bool}$, e reduces to a value and $i \vdash e \rightsquigarrow p$, then for every $\theta \in [\Gamma]$ and every $\sigma \in \theta^\perp$, $\theta^\perp \cdot e \hookrightarrow^* \text{True}$ iff $\sigma^\beta \models p$.

referring to the proofs in [Vazou et al. 2014b].



Liquid Haskell on papers

↑
Expressiveness

Refinement Reflection, POPL'18

by **Vazou**, Tondwalkar, Choudhury, Scott,
Newton, Wadler, and Jhala

Refinement Types for Haskell, ICFP'14

by **Vazou**, Seidel, Jhala, Vytiniotis, and Peyton-Jones



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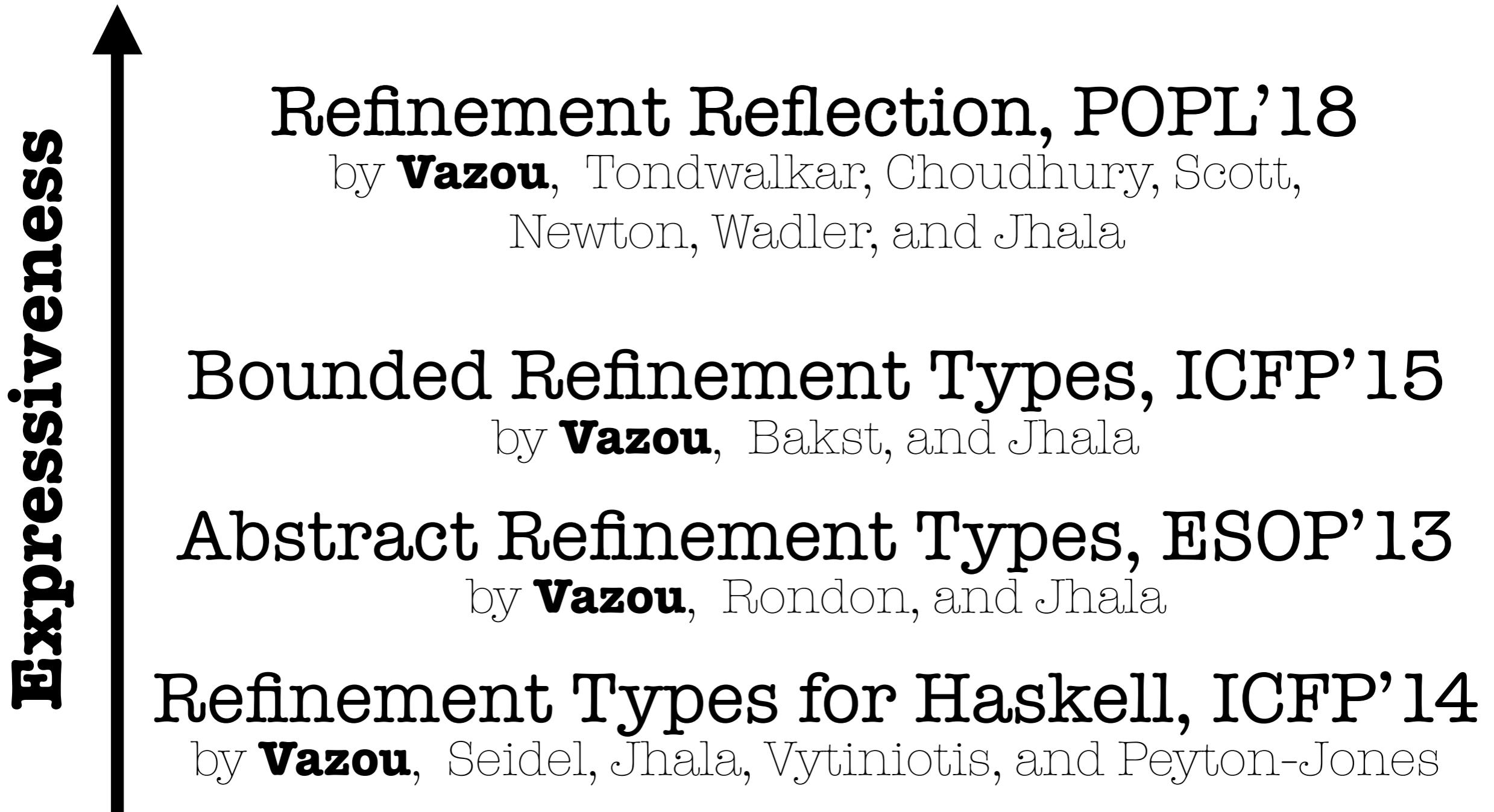
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Liquid Haskell on papers



Liquid Haskell on github

ucsd-progsys / liquidhaskell

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Liquid Types For Haskell Edit

Add topics

8,382 commits 94 branches 19 releases 38 contributors

Branch: develop New pull request Create new file Upload files Find file Clone or download

nikivazou Merge pull request #1223 from ucsd-progsys/HaskellFunInRefs ... Latest commit 82f5baa 5 days ago

benchmarks move tests into pos a month ago

devel Fix travis error 6 days ago

Liquid Haskell on github

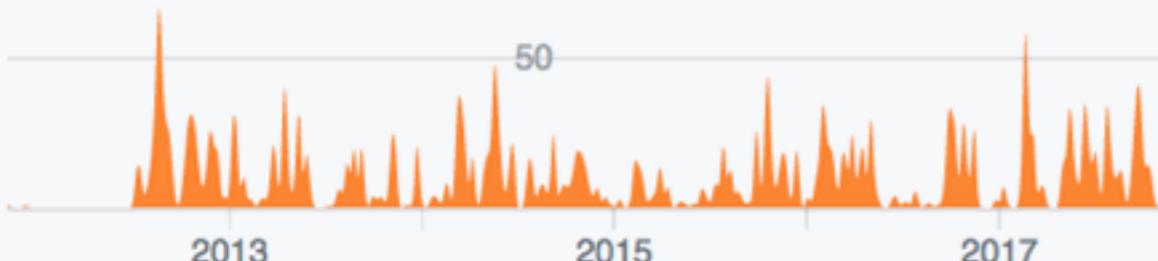
Jan 15, 2012 – Jan 25, 2018

Contributions: Commits ▾



ranjitjhala

3,093 commits 474,271 ++ 304,536 --

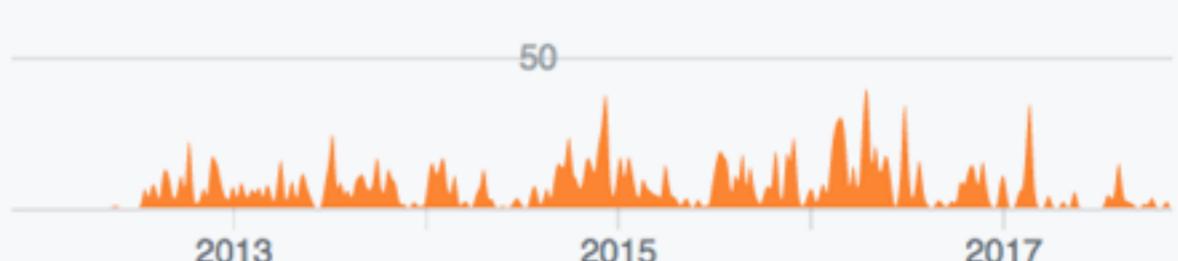


#1



nikivazou

2,113 commits 358,364 ++ 294,962 --



#2



gridaphobe

814 commits 114,731 ++ 79,008 --

#3

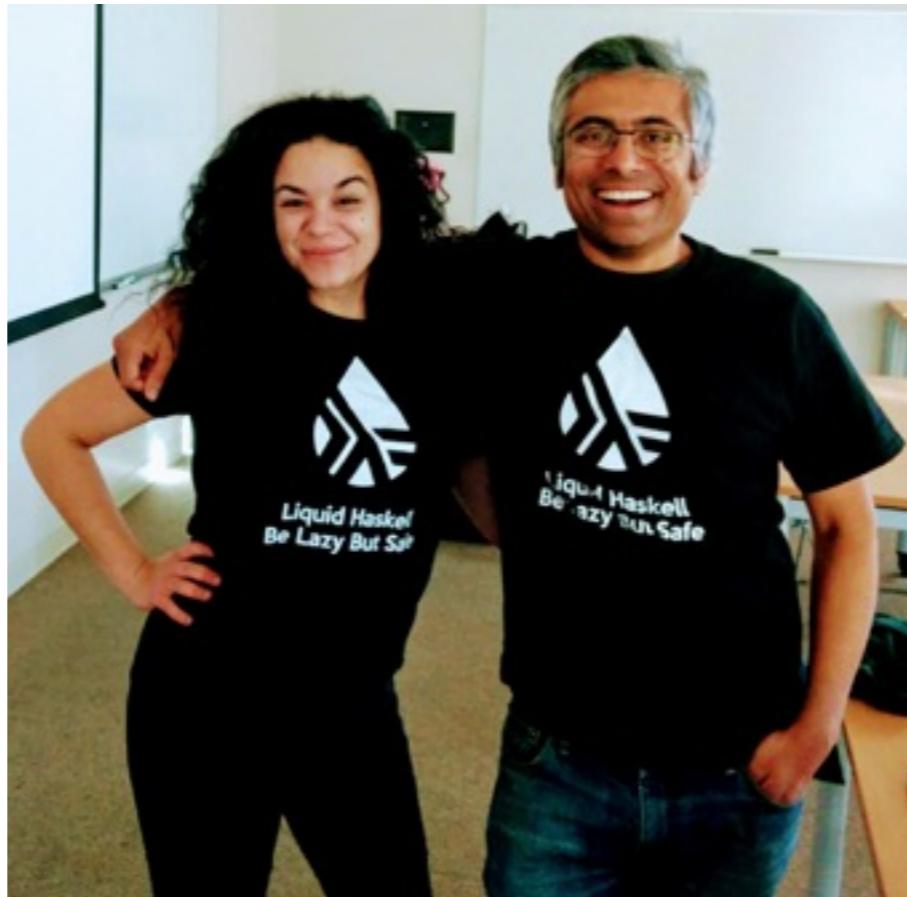


spinda

155 commits 7,430 ++ 5,350 --

#4

Liquid Haskell dev team



Niki Vazou & Ranjt Jhala,
Liquid Haskell dev team

Liquid Haskell in the real world

Education



Will Kunkel,
undergrad @UMD



Rachel Xu & Xinyue Zhang,
undergrads @Bryn Mawr College



Niki Vazou & Ranjt Jhala,
Liquid Haskell dev team

Industry



Gabriel Gonzalez
Awake Security



Edsko de Vries
Well-Typed

Liquid Haskell in Education

This is Will Kunkel.

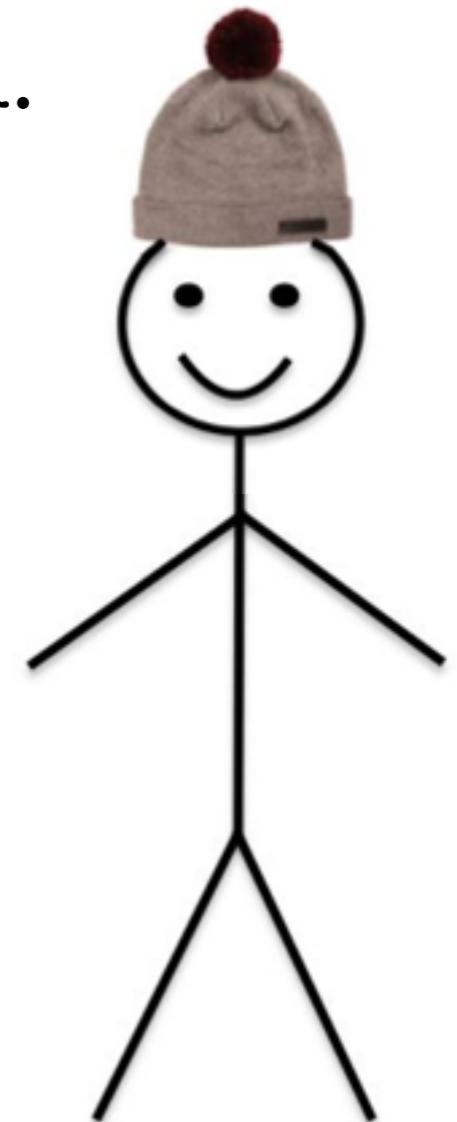
Will took my undergrad course on Haskell.

Will learnt Liquid Haskell in 2 weeks.

Will was **3rd** in POPL'18 **Student Research Competition** with his project “Comparing Liquid Haskell and Coq”

Will is smart.

Be like Will.



Liquid Haskell in Education

Two winners in POPL'18 Student Research Competition



“Comparing Liquid Haskell and Coq”



Will Kunkel,
undergrad @UMD



“Comparing Dependent Haskell,
Liquid Haskell and F*”



Rachel Xu & Xinyue Zhang,
undergrads @Bryn Mawr College

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Liquid Haskell in the real world

Education



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undergrad @UMD



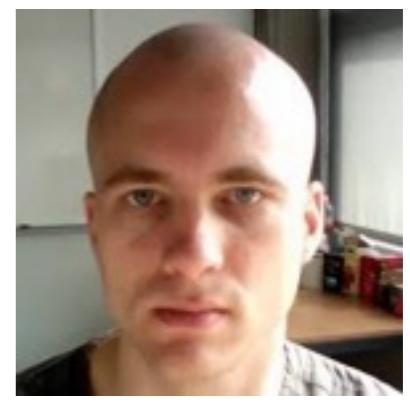
Rachel Xu & Xinyue Zhang,
undergrads @Bryn Mawr College



Niki Vazou & Ranjt Jhala,
Liquid Haskell dev team



Gabriel Gonzalez
Awake Security



Edsko de Vries
Well-Typed



Liquid Haskell in Industry

Gabriel Gonzalez



Static checks during parsing.

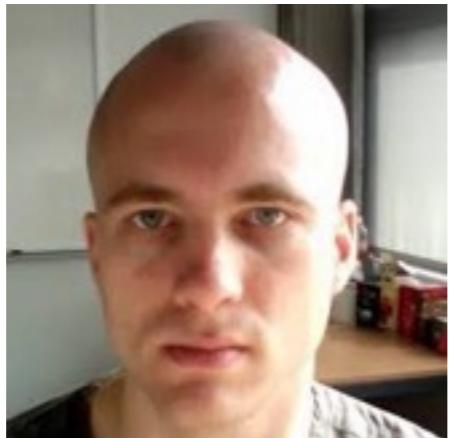
Provably Correct & Faster (x6) Code!

Huge speedup for internet traffic parsing.

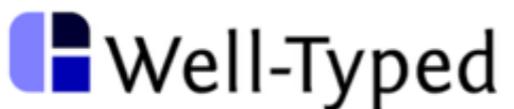


Liquid Haskell in Industry

Gabriel Gonzalez

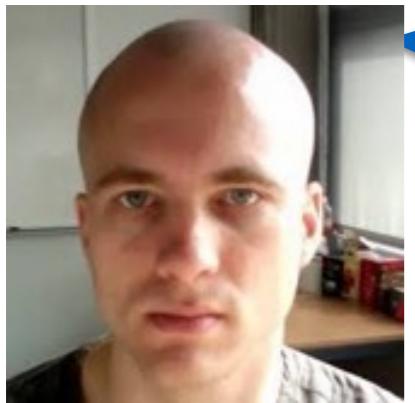


Edsko de Vries





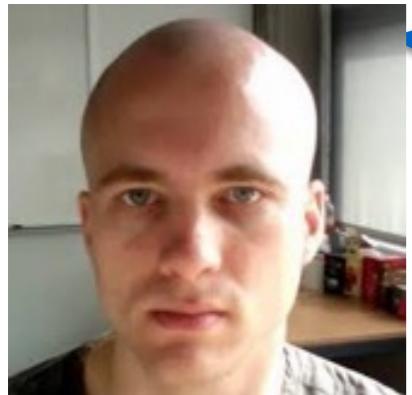
I am a Haskell consultant at a
cryptocurrency/blockchain company.
We have a blockchain algorithm written
in paper & a Haskell implementation.
We want Liquid Haskell to connect them.



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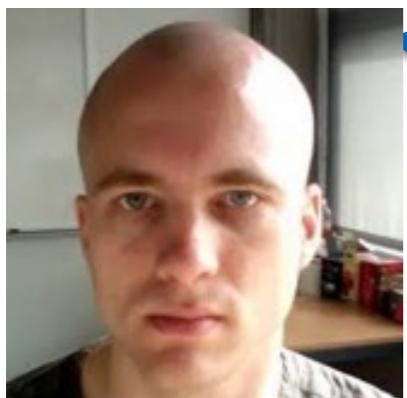
Awesome! Lmk if you need anything!





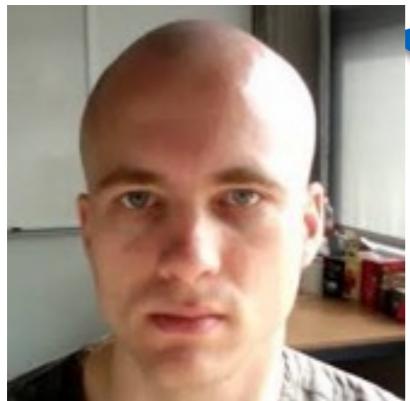
I am a Haskell consultant at a
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I want **interactive proof generation**!

More user suggestions



Edsko de Vries
industrial rep.

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Richard Eisenberg
ghc devs rep.

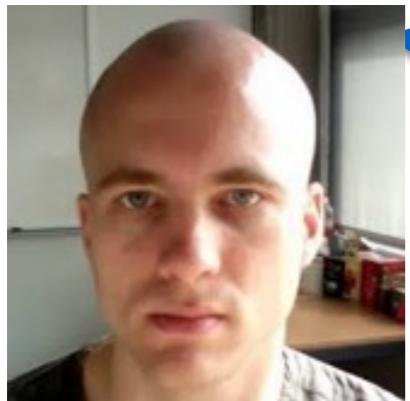
Can we use Liquid Haskell proofs for
compiler optimizations?



Leo Lambropoulos
Coq rep.

I do not trust it! Liquid Haskell should
generate **proof certificates!**

More user suggestions



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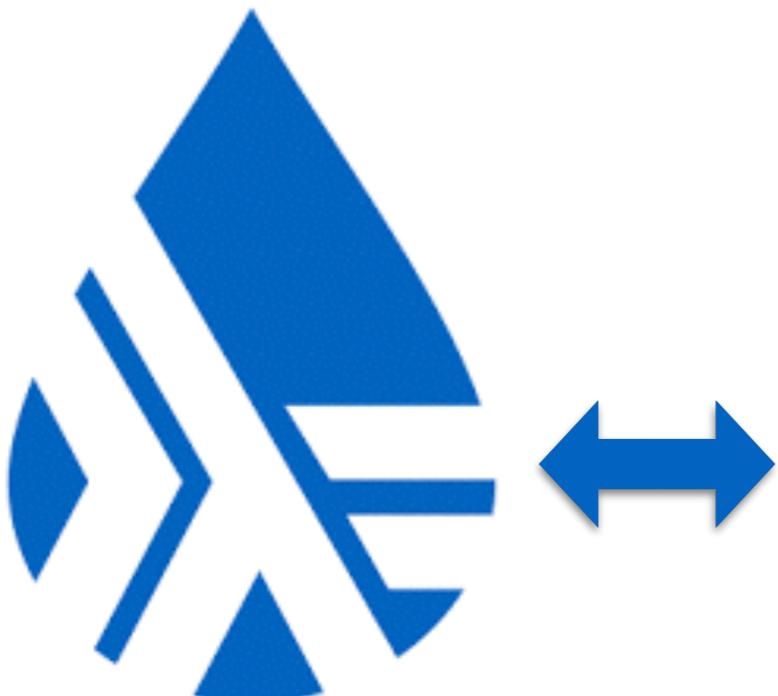
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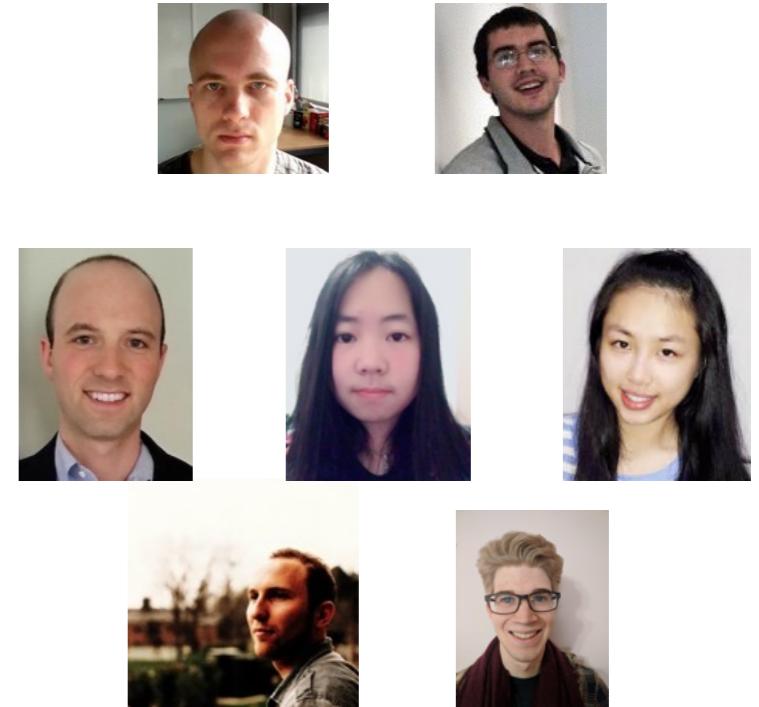


Liquid Haskell has many users

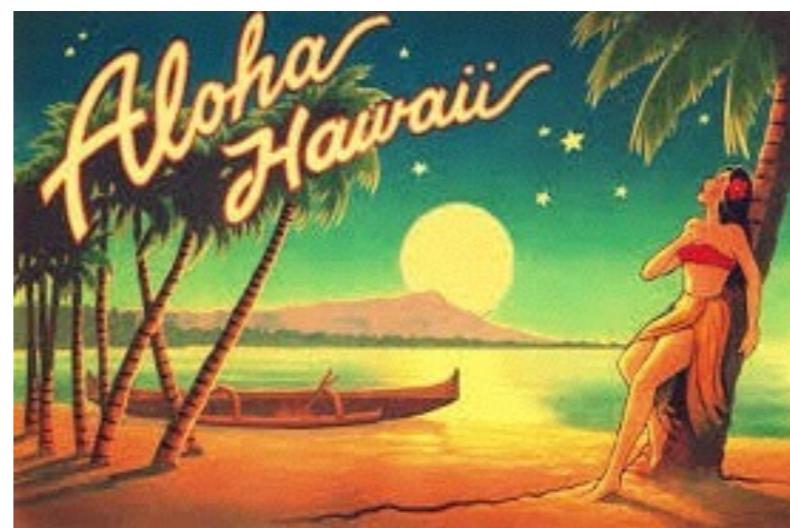
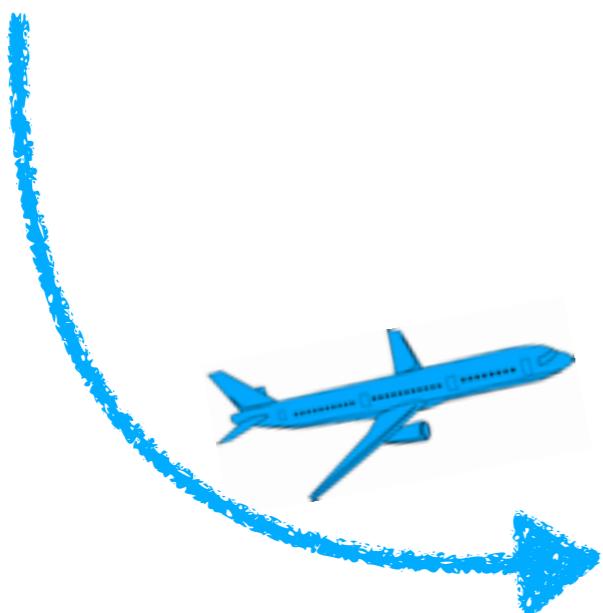
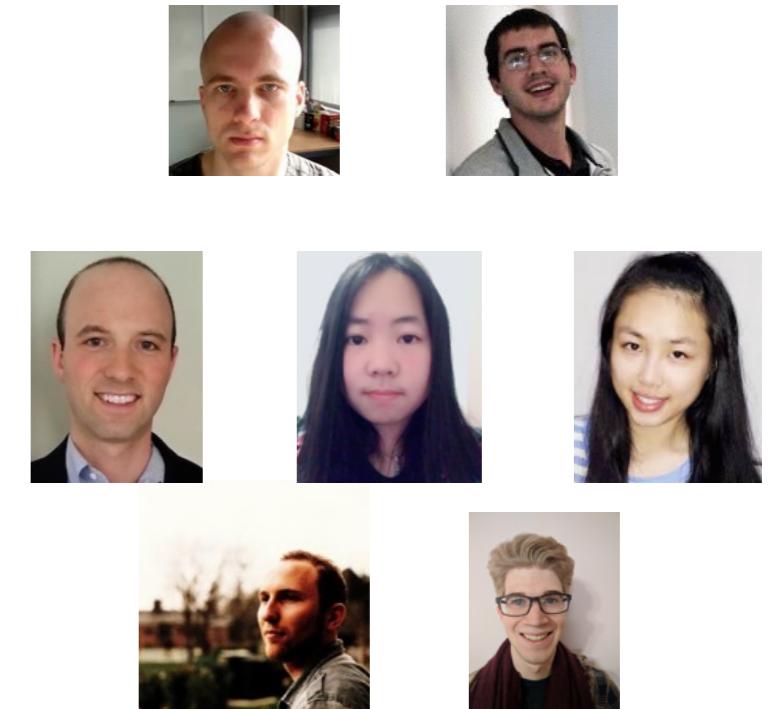
7,765 downloads



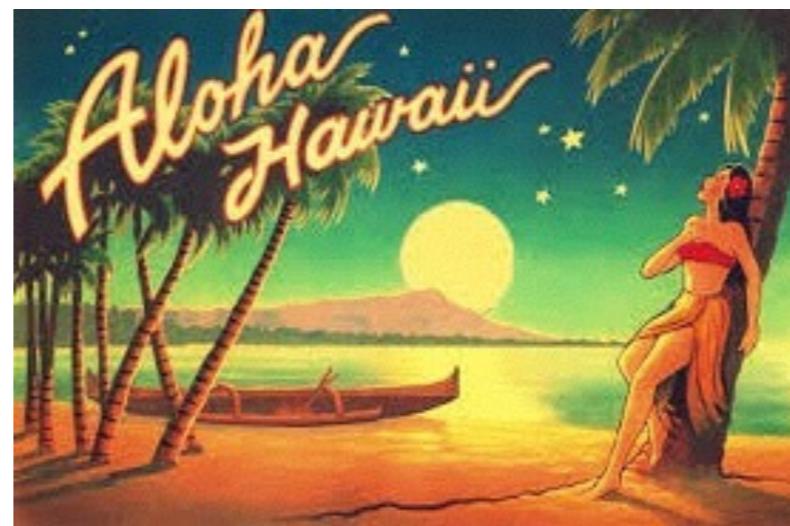
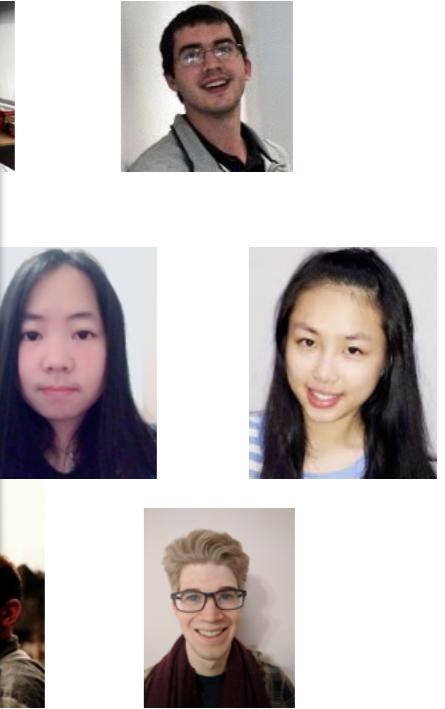
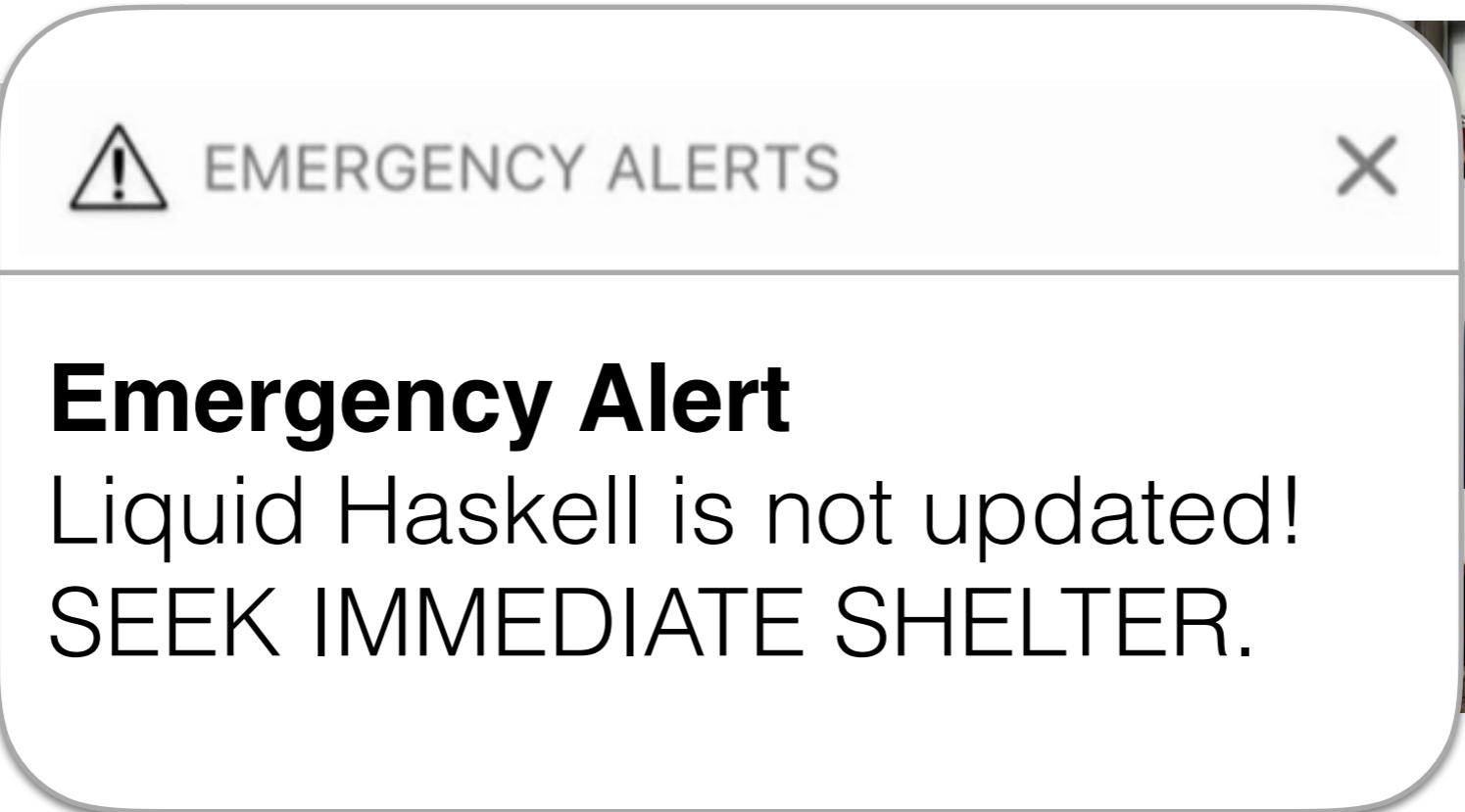
many users, but two main devs



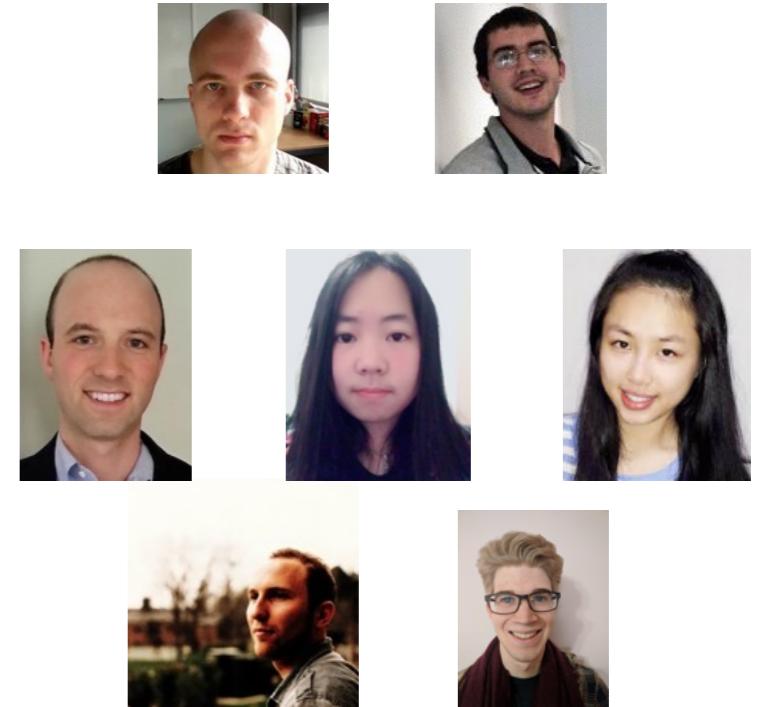
many users, but two main devs



many users, but two main devs



many users, but two main devs



Goal: Expand the Liquid Haskell Team

Future work in Liquid Haskell

I. Proof Assistance

II. Compiler Interaction

III. Real-world applications

I. Proof Assistance

Goal: Coq-like IDE

for case splitting, sub-goal detection

I. Proof Assistance

Idea: Proofs are Haskell programs

Program Synthesis for Proof Generation

Error Reporting for Failure Diagnosis

I. Proof Assistance

Idea: Proofs are Haskell programs

Program Synthesis for Proof Generation

Error Reporting for Failure Diagnosis

II. Compiler Integration

Goals:

more precise error messages
compiler optimizations

II. Compiler Integration

Idea:

Translate Refinement to Dependent Types

Challenge:

Dependent Types require explicit proofs

III. Real-World Applications

Web Programming (Yesod)

e.g., taint analysis

Distributed Programming (Haxl)

e.g., eventual consistency

III. Real-World Applications

Current Work:
Information Control Flow (LIO)
for non-interference

Future work in Liquid Haskell

I. Proof Assistance

II. Compiler Integration

III. Real-World Applications

Vision:

Embed verification in Haskell programming

Vision: **Embed verification in Haskell programming**

Specs are just comments **inside** the languages, ...
thus, learning effort is small.

Semi-**automatically** machine checked, via SMTs.
For runtime **optimizations**, by the user or the **compiler**.

Vision: Embed verification in ~~Haskell~~-programming mainstream

Ruby, JavaScript, Scala, ...

Refinement Types for Ruby

Refinement Types for TypeScript

SMT-Based Checking of Predicate-Qualified Types for Scala

Georg Stefan Schmid Viktor Kuncak

EPFL, Switzerland

{firstname.lastname}@epfl.ch

Univ



LiquidHaskell

Embed verification in Haskell programming

Fast & Safe Code
Static Checks

Theorem Proving
Refinement Reflection

Applications
Education & Industry

Thanks!