LiquidHaskell

Usable Language-Based Verification

Niki Vazou
University of Maryland

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 :: t:Text -> {i:Int | i < len t} -> Text
```

LiquidHaskell

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

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

LiquidHaskell

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

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

AWAKE Well-Typed

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

UNIVERSITY OF MARYLAND 1856

COLLEG. BRYN MAWR. SIGILL. VERITATEM DILEXI

UNIVERSITY OF CALIFORNIA SAN DIEGO LET THERE BE LIGHT

Haskell

Functional Programing Language

Based on

Strong Typing + λ-calculus

Haskell

Practical Programing Language

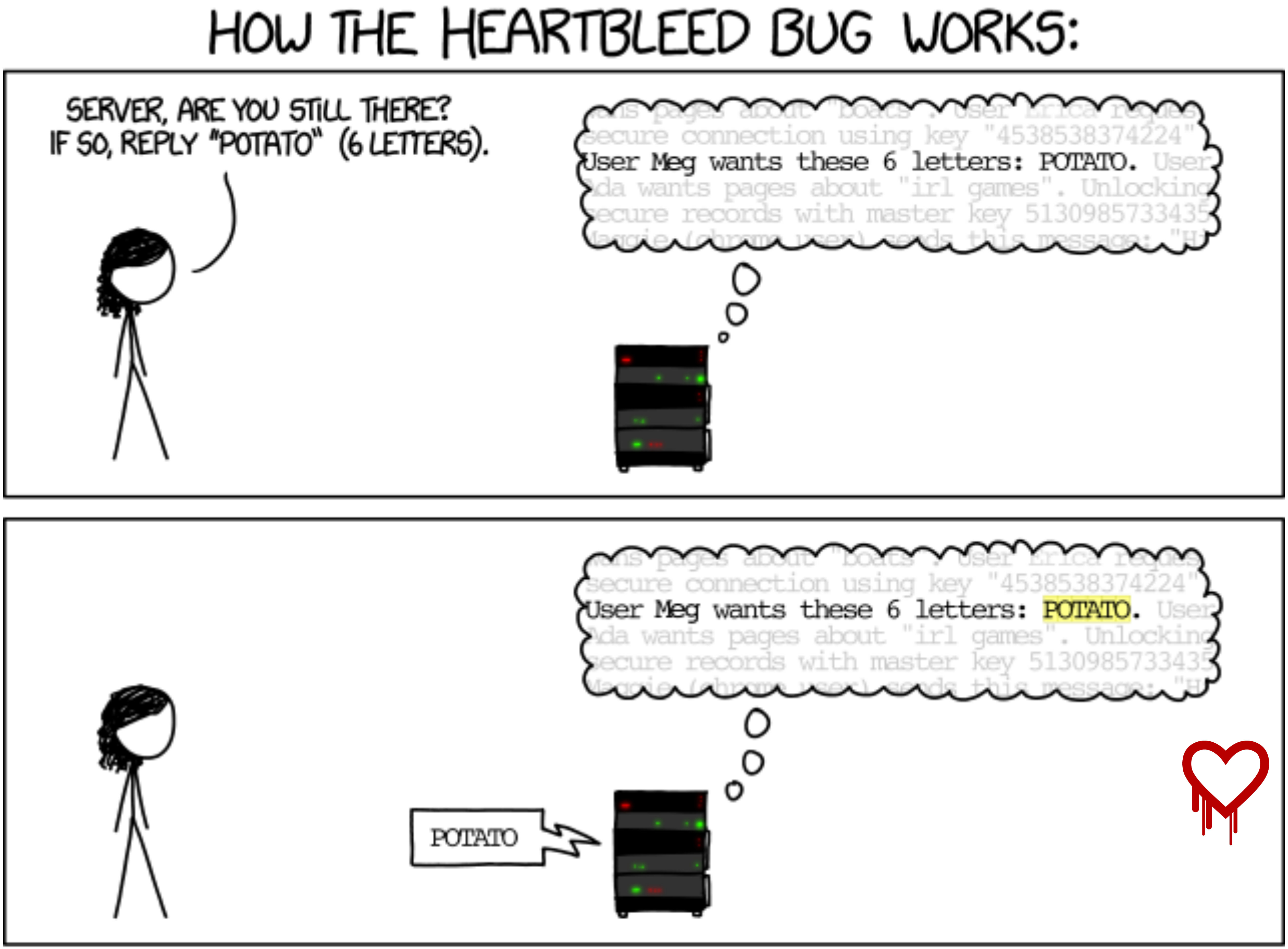
Fast Memory Manipulation

with C wrappers

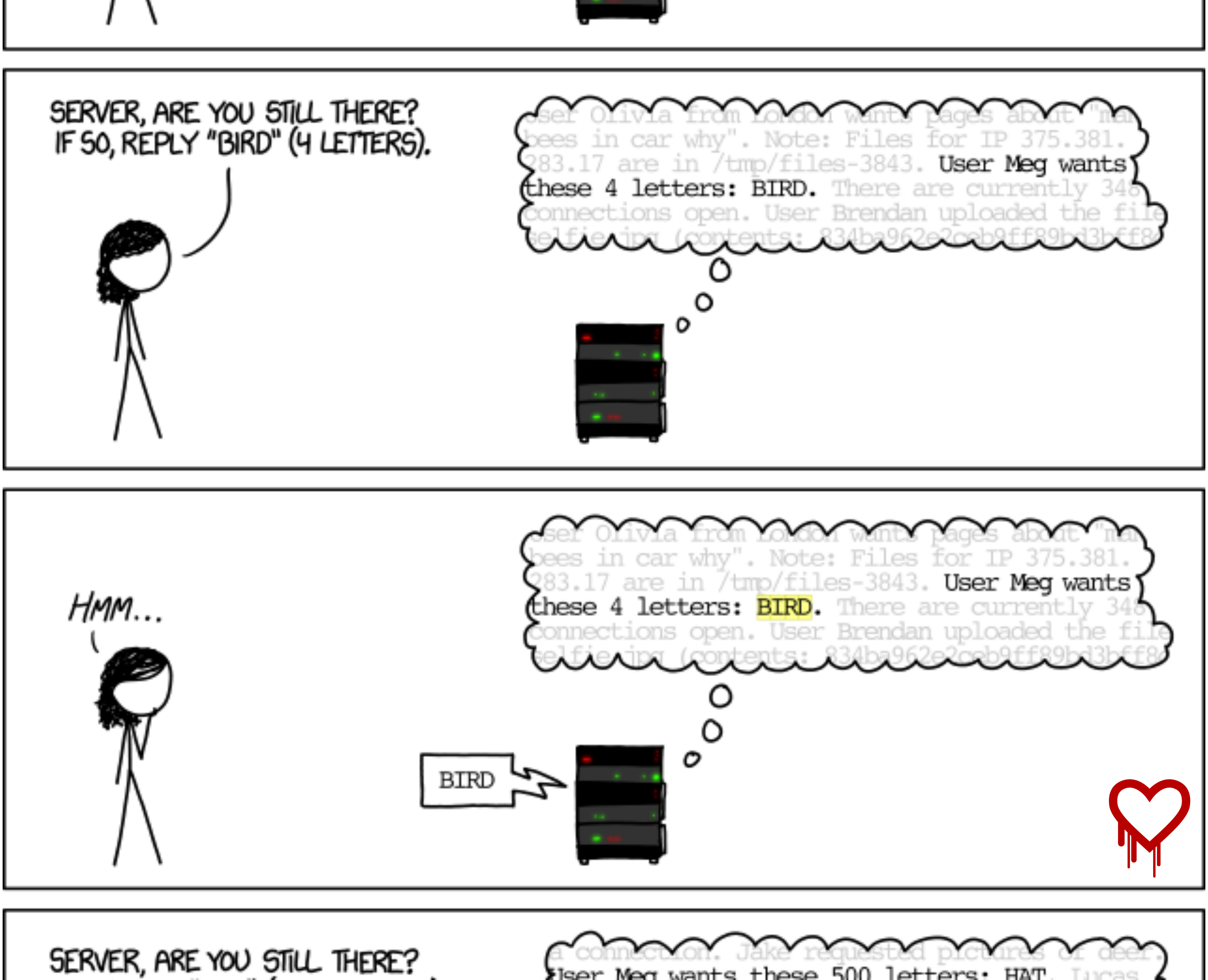
Allowing overread bugs

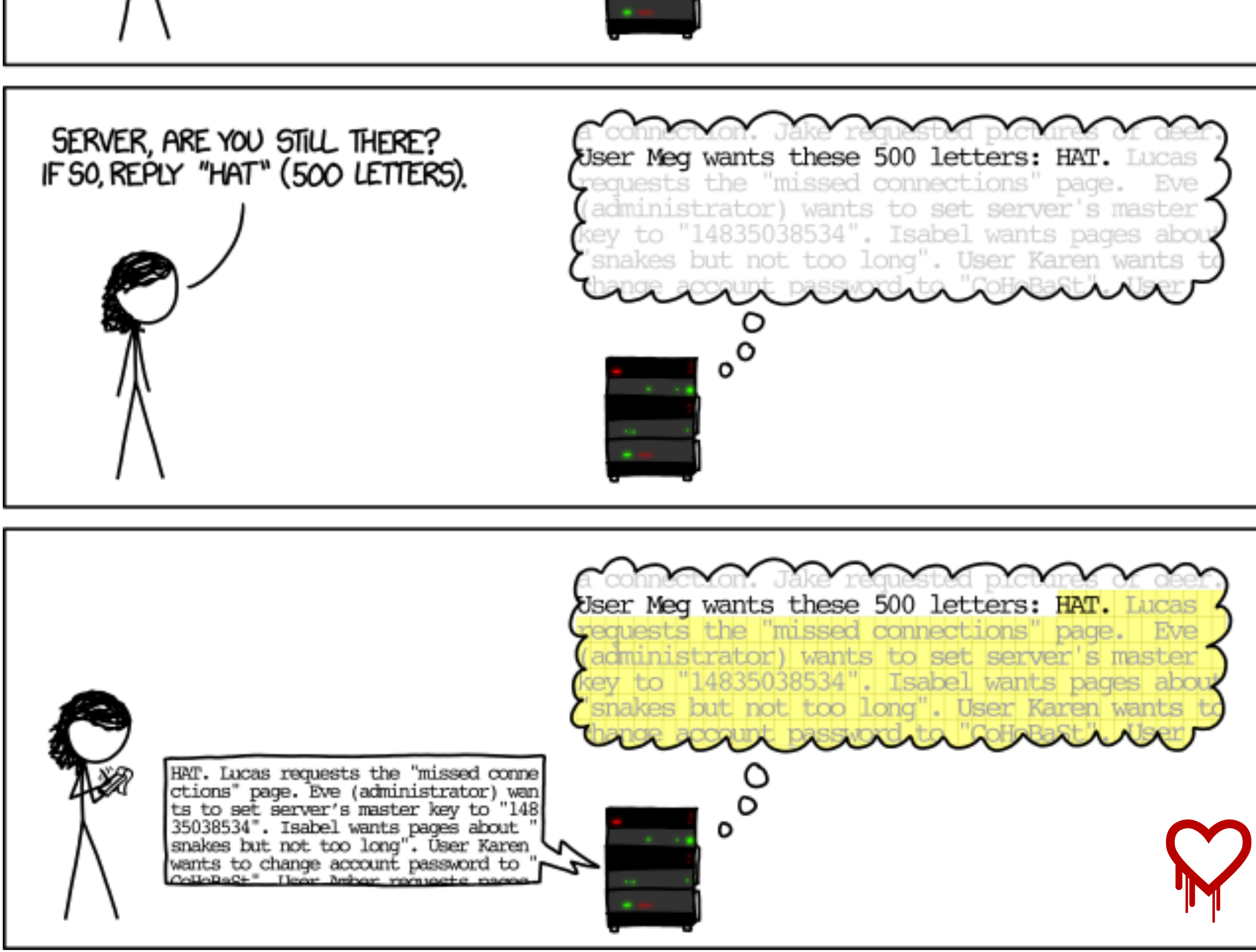
The Heartbleed Bug

Buffer overread in OpenSSL. 2015



HOW THE HEARTBLEED BUG WORKS:
SERVER, ARE YOU STILL THERE? IF SO, REPLY "POTATO" (6 LETTERS).
secure connection using key "4538538374224"
User Meg wants these 6 letters: POTATO. User
da wants pages about "irl games". Unlocking
secure records with master key 5130985733435
secure connection using key "4538538374224"
User Meg wants these 6 letters: POTATO. User
da wants pages about "irl games". Unlocking
secure records with master key 5130985733435
POTATO


SERVER, ARE YOU STILL THERE? IF SO, REPLY "BIRD" (4 LETTERS).
Olivia from London wants pages about
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
connections open. User Brendan uploaded the
HMM...
Olivia from London wants pages about
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
connections open. User Brendan uploaded the
BIRD
SERVER, ARE YOU STILL THERE?
connection. Jake requested pictures of deer.
Meg wants these 500 letters: HAT.


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
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
HAT. Lucas requests the "missed conne
ctions" page. Eve (administrator) wan
ts to set server's master key to "148
35038534". Isabel wants pages about "
snakes but not too long". User Karen
wants to change account password to "
CoHoBaSt". User Amber requests pages

in

```haskell
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!”
```

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!”~~

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

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
```

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

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
```

$$\boxed{len\ x = 3 \Rightarrow v = 500 \Rightarrow v < len\ x}$$

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.

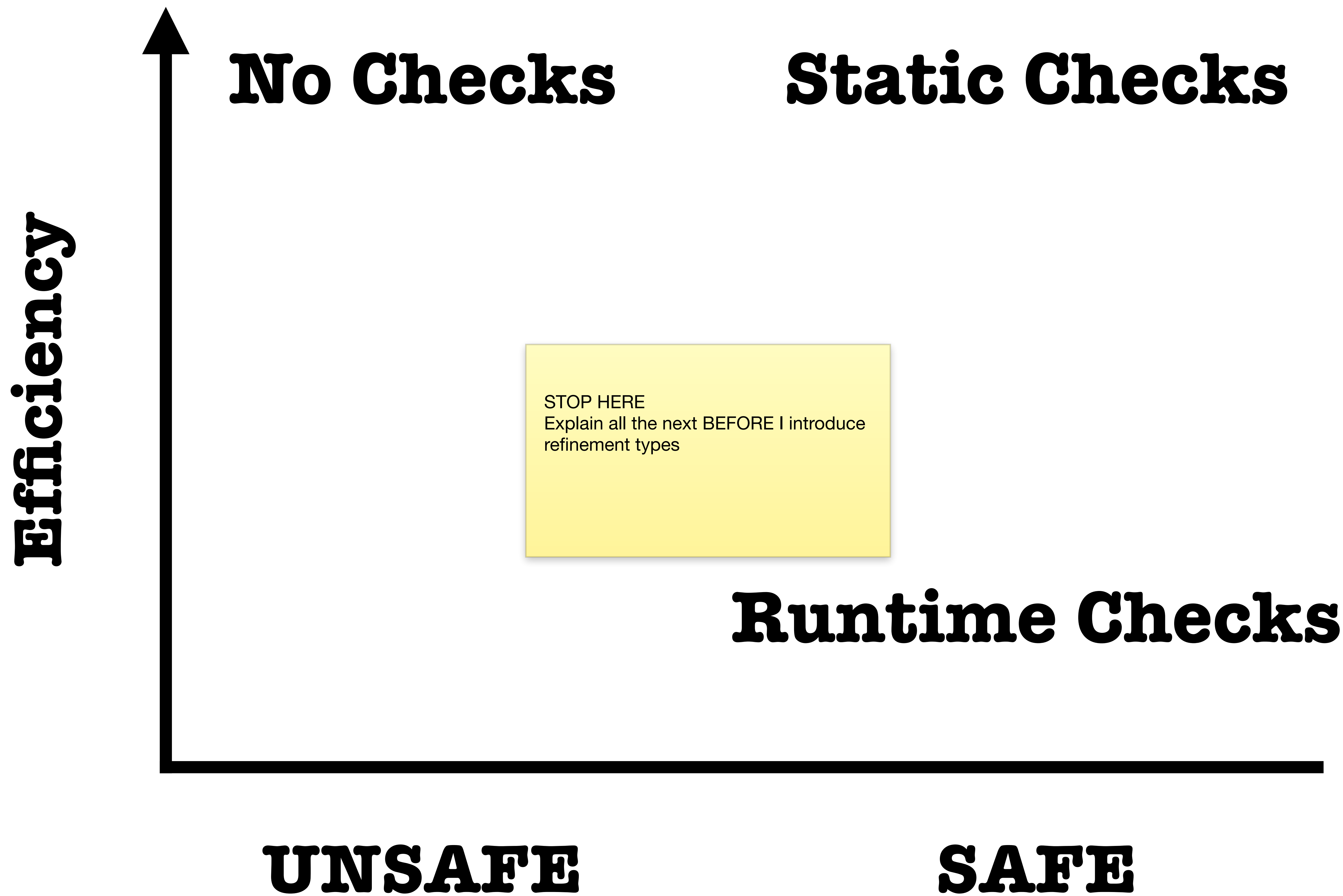
```
take :: t:Text->{v|v < len t}->Text
heartbleed = let x = "hat"
                 in  take x  2
```

Checker reports **OK** **SMT-valid**

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

Checks valid arguments, under facts.

Static Checks



STOP HERE
Explain all the next BEFORE I introduce refinement types

LiquidHaskell

Static Checks

Safe & Fast Code!

Static Checks

Safe & Fast Code!

Application: Speedup Parsing

Application: Speedup Parsing

Simplified application of Liquid Haskell

by Gabriel Gonzalez

AWAKE

Application: Speedup Parsing

UDP:User Datagram Protocol

raw data $\rightarrow$ Parser $\rightarrow$ data UDP

Application: Speedup Parsing

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

Application: Speedup 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: Speedup 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 udp3 upd4)
 else Nothing
```

Safe and Fast (1 runtime check!)

Application: Speedup 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 upd2 udp3 upd4)
 else Nothing
```

Safe and Fast, bur error prone

Application: Speedup Parsing

```
udpP :: Text -> Maybe UDP
udpP bs =
  if length bs >= 8 then
    let (udp1, bs1) = US.splitAt 2 bs
```

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

```
    in Just (UDP udp1 upd2 udp3 upd4)
 else Nothing
```

Enforce Static Checks!

Application: Speedup Parsing

Error

```
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 udp3 upd4)
 else Nothing
```

Enforce Static Checks!

Application: Speedup 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 udp3 upd4)
 else Nothing
```

Haskell code!
- syntax
- compiler

No proofs!
- SMT automated!

Provably Correct & Faster (x6) Code!

Application: Speedup 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 udp3 upd4)
 else Nothing
```

Provably Correct & Faster (x6) Code!

Haskell Code: Verification with SMT

LiquidHaskell

Provably Correct & Faster (x6) Code!

Haskell Code: Verification with SMT

AWAKE

Verification with SMT

For Safe Indexing

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

Expressed with decidable theories of

Boolean Logic
(QF) Linear Arithmetic
Uninterpreted Functions

Verification with SMT

For Safe Indexing

What other properties can we express?

Verification with SMT

Expressiveness

Critical Properties:

"The plane will not crash!"

Math Theorems:

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

Safe Indexing:

"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 ≤ i => fib i ≤ 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 target fib?

How to connect logic fib with target fib?

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

$\boxed{\text{Not Decidable}}$

SMT Axiom

```
\forall i.
   if i≤1 then fib i = 1
   else fib i = fib (i-1) + fib (i-2)
```

How to connect logic fib with target 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

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≤1 then fib i = 1
else fib i = fib (i-1) + fib (i-2)
```

Application | Type Level Computation

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≤1 then fib i = 1
else fib i = fib (i-1) + fib (i-2)
```

Application   Type Level Computation

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

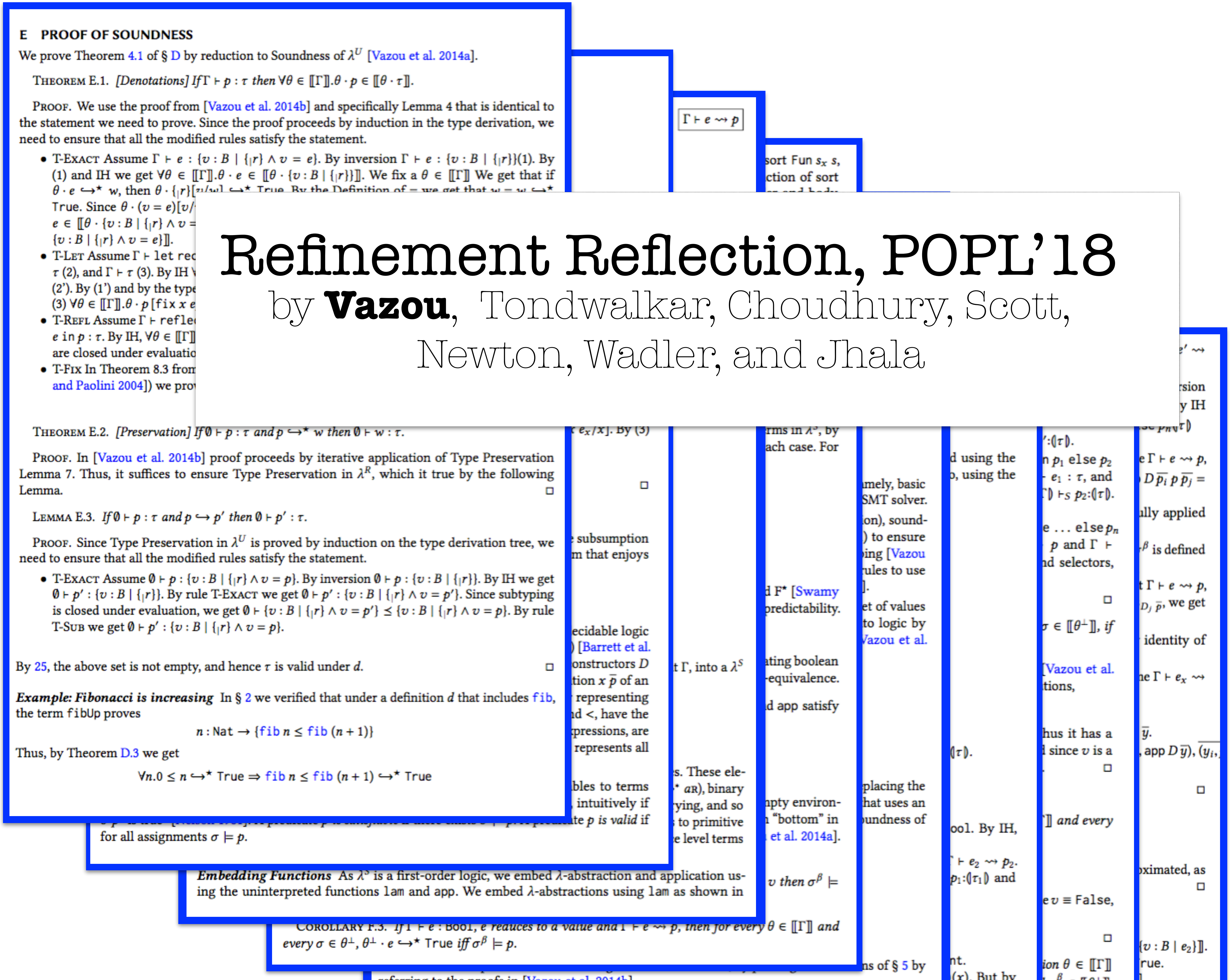
Metatheory:

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* $p \hookrightarrow^\star w$, *then* $\emptyset; \emptyset \vdash w : \tau$.

Refinement Reflection, POPL'18

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



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 $\theta \cdot \{|r\}[v/w] \hookrightarrow^*$ True. By the Definition of $=$ we get that $w = w \hookrightarrow^*$ True. Since $\theta \cdot (v = e)[v/$ … $e \in [\![\theta \cdot \{v : B \mid \{|r\} \wedge v =$ … $\{v : B \mid \{|r\} \wedge v = e\}]\!]$.
- T-LET Assume $\Gamma \vdash$ let rec … τ (2), and $\Gamma \vdash \tau$ (3). By IH … (2'). By (1') and by the type … (3) $\forall \theta \in [\![\Gamma]\!].\theta \cdot p$[fix x e …
- T-REFL Assume $\Gamma \vdash$ refle… e in $p : \tau$. By IH, $\forall \theta \in [\![\Gamma]\!]$ … are closed under evaluatio…
- T-FIX In Theorem 8.3 from … and Paolini 2004]) we pro…

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 it true by the following Lemma. □

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 $\emptyset \vdash \{v : B \mid \{|r\} \wedge v = p'\} \preceq \{v : B \mid \{|r\} \wedge v = p\}$. 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. □

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

$$n : \mathsf{Nat} \to \{\mathsf{fib}\ n \leq \mathsf{fib}\ (n+1)\}$$

Thus, by Theorem D.3 we get

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

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

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

Liquid Haskell on papers

Expressiveness

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Expressiveness

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Bounded Refinement Types, ICFP'15
by **Vazou**, Bakst, and Jhala

Abstract Refinement Types, ESOP'13
by **Vazou**, Rondon, and Jhala

Refinement Types for Haskell, ICFP'14
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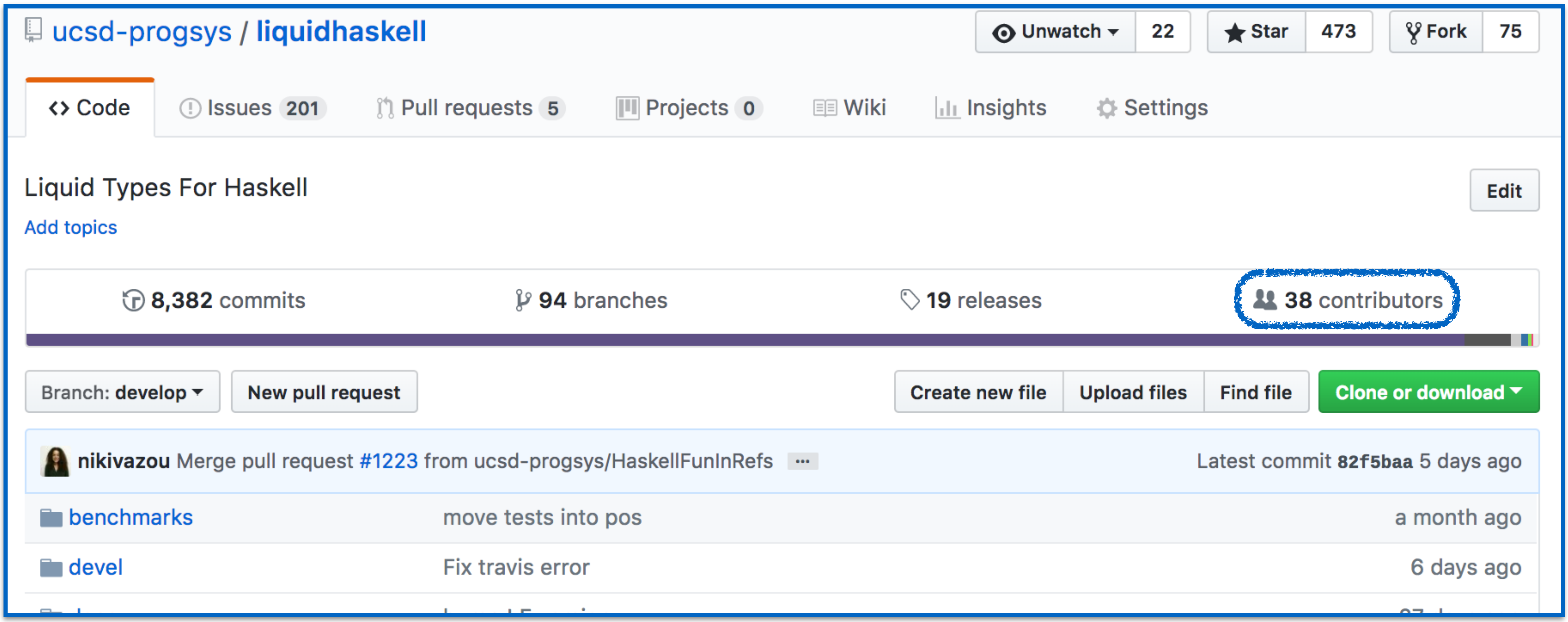
Liquid Haskell on github



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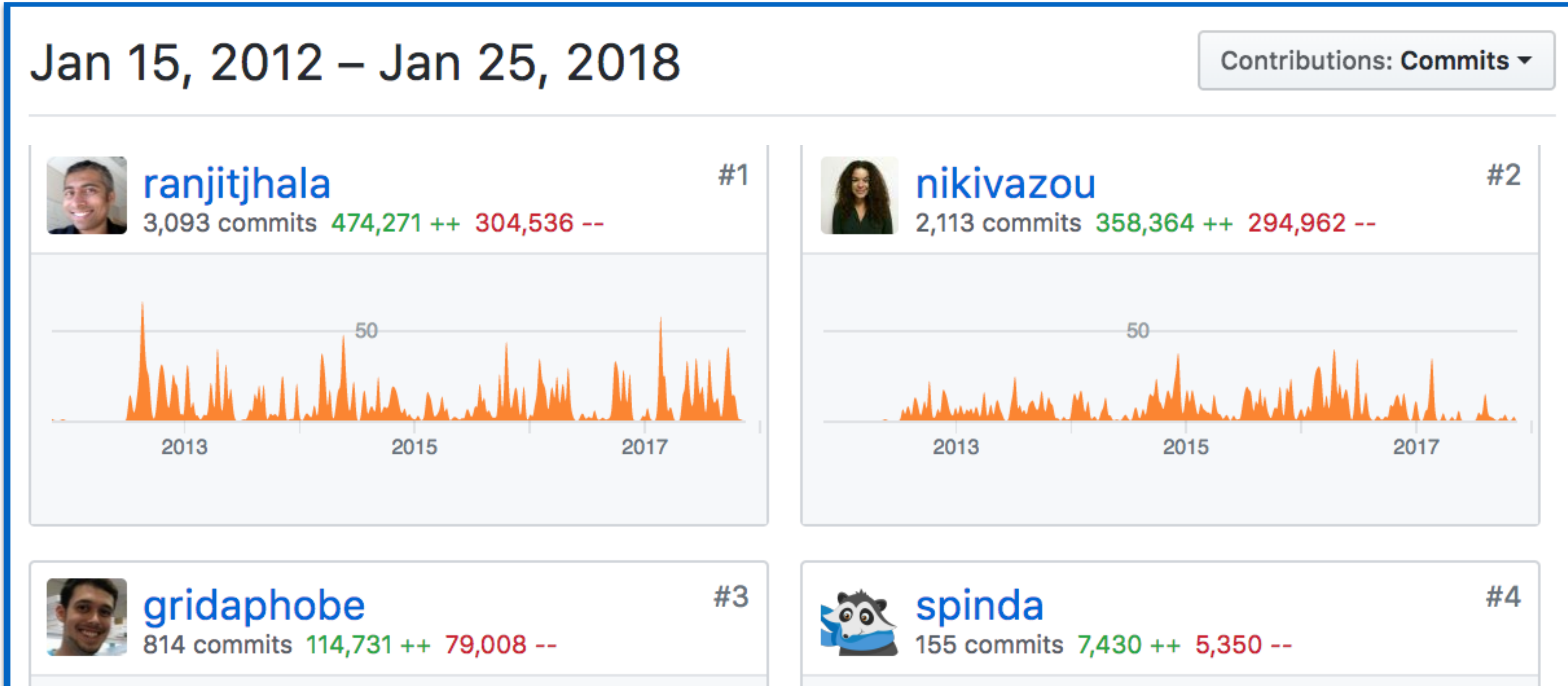


Liquid Haskell dev team

Niki Vazou & Ranjt Jhala,
Liquid Haskell dev team

Liquid Haskell in the real world

Education

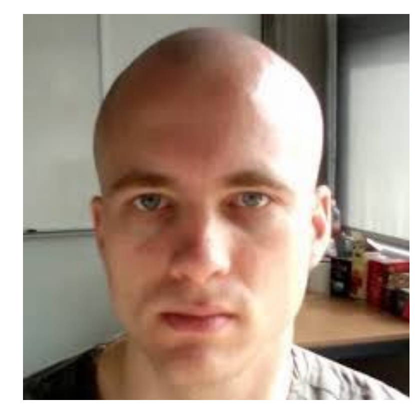
Will Kunkel,
undergrad @UMD

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.

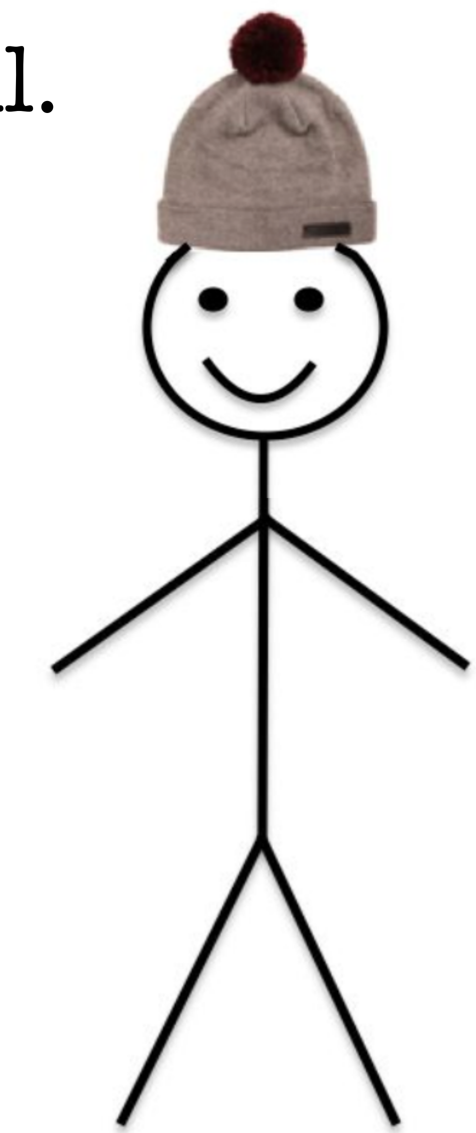
Will took my undergrad course on Haskell.

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

Liquid Haskell in the real world

Education

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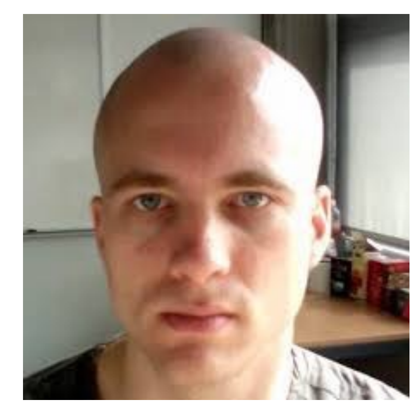


Edsko de Vries
Well-Typed

Liquid Haskell in Industry

Gabriel Gonzalez

AWAKE

Static checks during parsing.

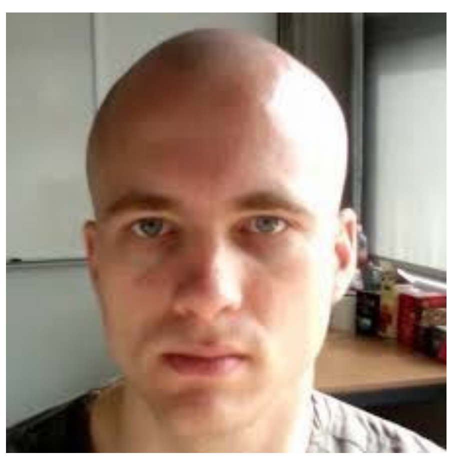
Provably Correct & Faster (x6) Code!

Huge speedup for internet traffic parsing.

Liquid Haskell in Industry

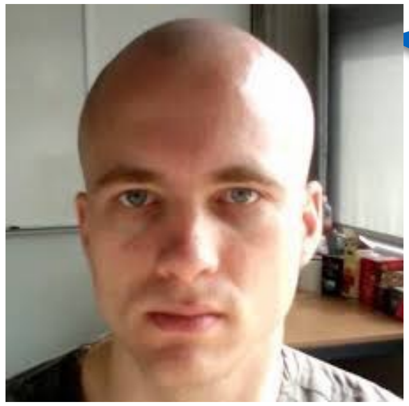
Gabriel Gonzalez

AWAKE

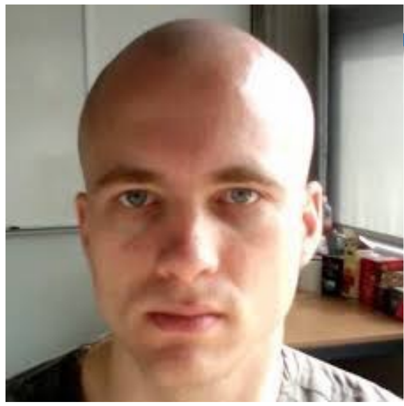


Well-Typed

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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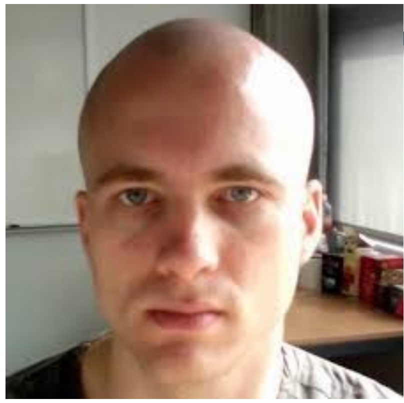

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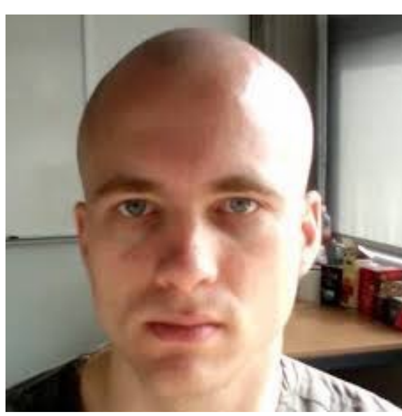
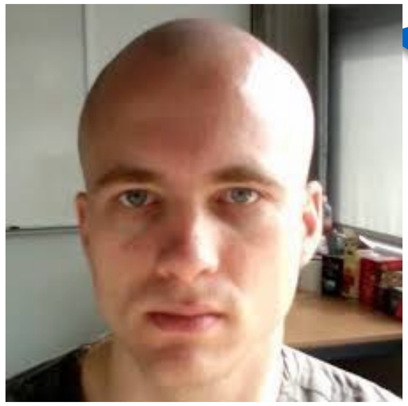


I want **interactive proof generation**!

More user suggestions



Edsko de Vries
industrial rep.

I want **interactive proof generation**!

Richard Eisenberg
ghc devs rep.

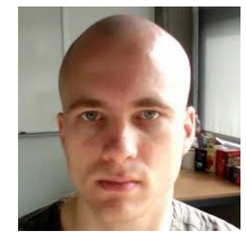
Can we use Liquid Haskell proofs for **compiler optimizations**?

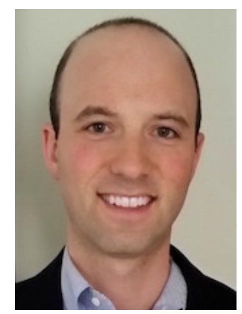
Leo Lambropoulos
Coq rep.

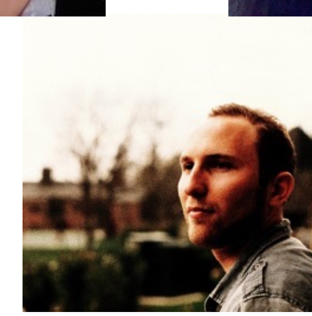
I do not trust it! Liquid Haskell should generate **proof certificates**!

Liquid Haskell has many users

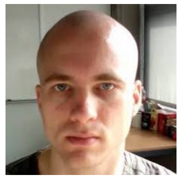
7,765 downloads

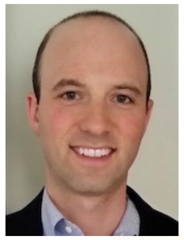





many users, but two main devs





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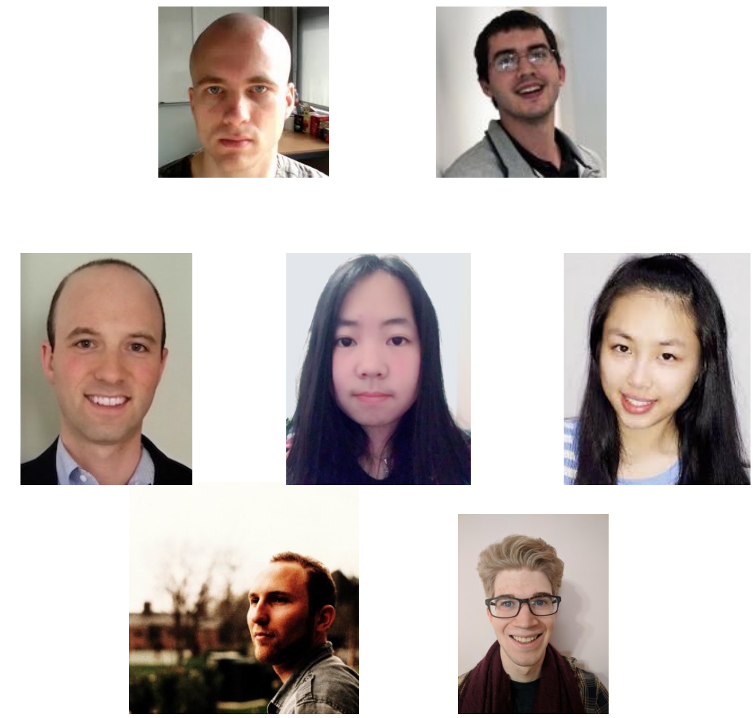

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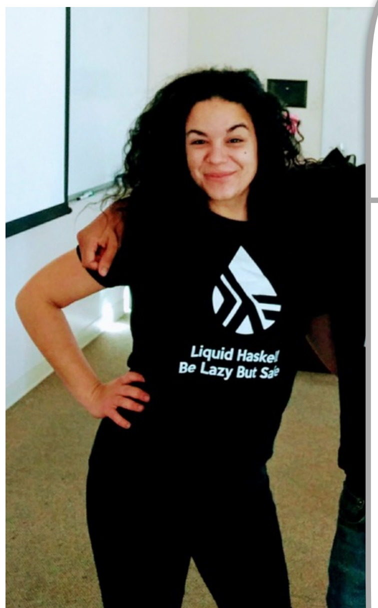
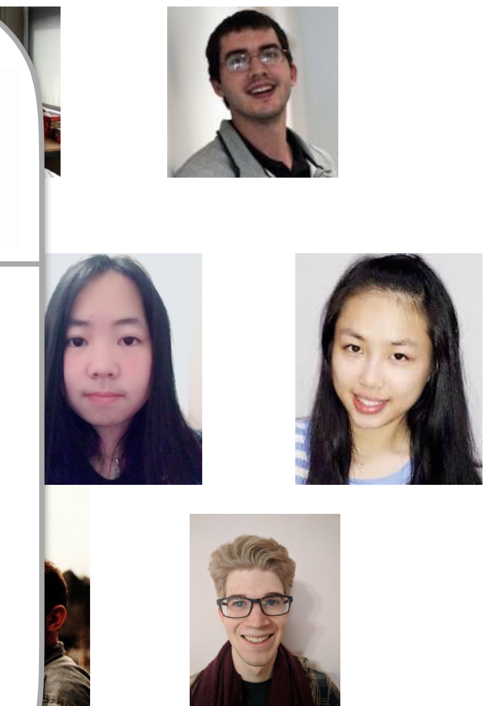


EMERGENCY ALERTS

Emergency Alert

Liquid Haskell is not updated!

SEEK IMMEDIATE SHELTER.



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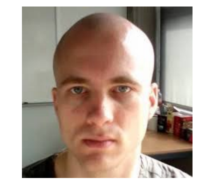

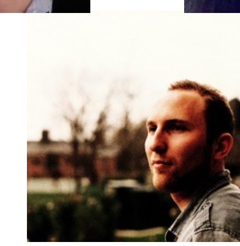

Goal: Expand the Liquid Haskell Team

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 Interaction

Goals:

more precise error messages

compiler optimizations

II. Compiler Interaction

Idea:

Translate Liquid to Dependent Types

Problem:

Dependent Types require explicit proofs

Future work in Liquid Haskell

I. Proof Assistance

II. Compiler Interaction

III. Real-world applications

Vision:
Embed verification in Haskell programming

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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

Univ

SMT-Based Checking of Predicate-Qualified Types for Scala

Georg Stefan Schmid   Viktor Kuncak
EPFL, Switzerland
{firstname.lastname}@epfl.ch

LiquidHaskell

Embed verification in Haskell programming

Fast & Safe Code
Static Checks

Theorem Proving
Refinement Reflection

Applications
Education & Industry

Thanks!

LiquidHaskell

Embed verification in Haskell programming