Decentralized Information Flow Control with the LIO library

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Stanford and Chalmers

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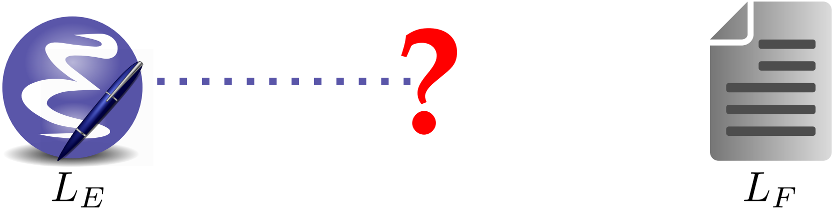
Project goal

Make it possible to hire median-quality programmers to build secure systems.

What is DIFC?



- IFC originated with military applications and classified data
- Every piece of data in the system has a label
- Every process/thread has a label
- Labels are partially ordered by $\sqsubseteq$ ("can flow to")
- Example: Emacs (labeled L_E) accesses file (labeled L_F)

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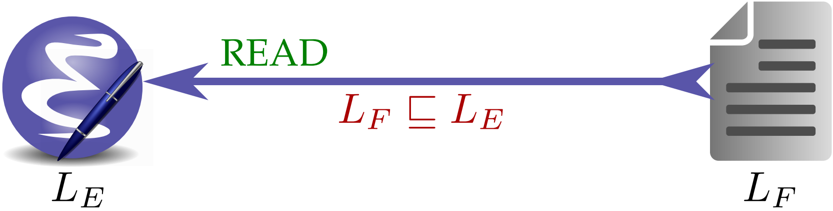

READ

$L_F \sqsubseteq L_E$

L_E

L_F

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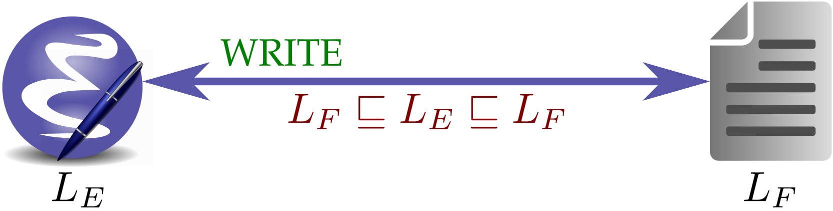
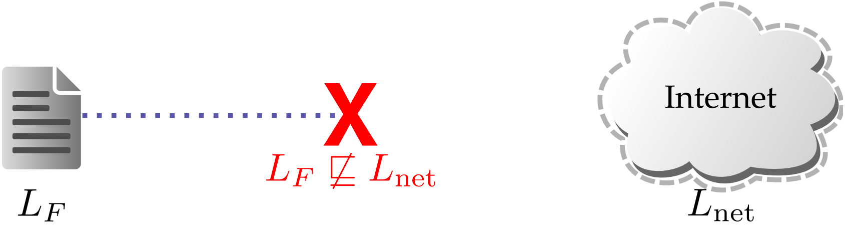


- **IFC originated with military applications and classified data**
- **Every piece of data in the system has a label**
- **Every process/thread has a label**
- **Labels are partially ordered by $\sqsubseteq$ ("can flow to")**
- **Example: Emacs (labeled L_E) accesses file (labeled L_F)**
  - File read? Information flows from file to emacs. System requires $L_F \sqsubseteq L_E$.
  - File write? Information flows in both directions. System enforces that $L_F \sqsubseteq L_E$ and $L_E \sqsubseteq L_F$.

Labels are transitive



- **$\sqsubseteq$ is a transitive relation**
  - Transitivity makes it easier to reason about security
- **Example: Label file so it cannot flow to Internet:** $L_F \not\sqsubseteq L_{\text{net}}$
  - Policy holds regardless of what other software does

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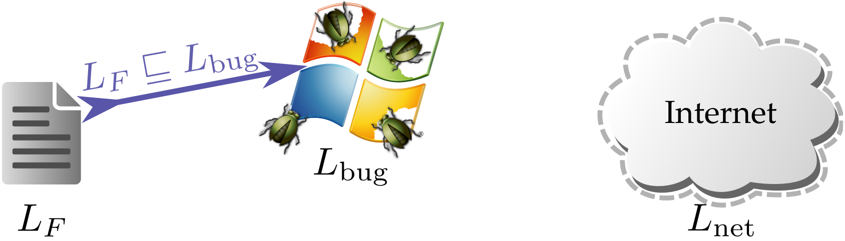

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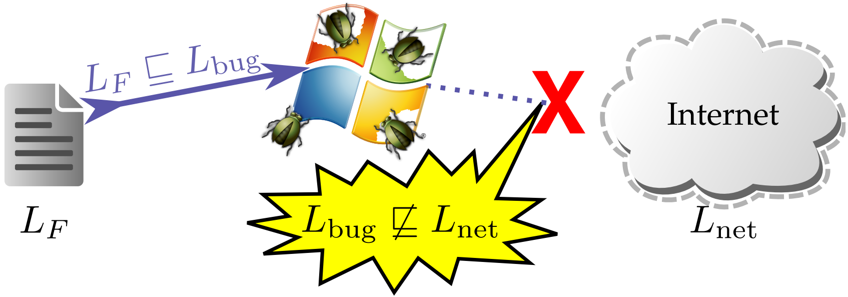
$L_F \sqsubseteq L_{\text{bug}}$
L_F
X
$L_{\text{bug}} \not\sqsubseteq L_{\text{net}}$
Internet
L_{net}

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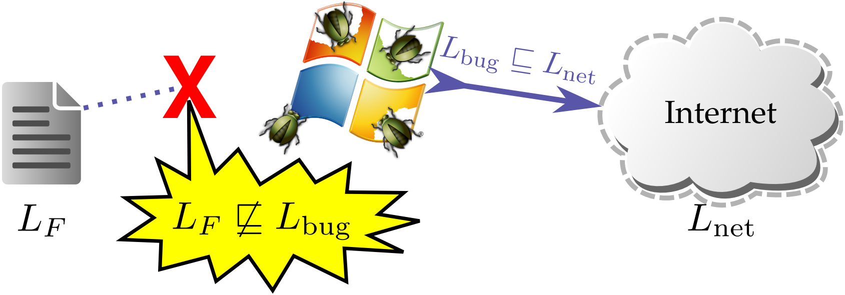
  - Process labeled L_{bug} reads file, so must have $L_F \sqsubseteq L_{\text{bug}}$
  - But since $L_F \not\sqsubseteq L_{\text{net}}$, it must be the case that $L_F \sqsubseteq L_{\text{bug}} \not\sqsubseteq L_{\text{net}}$

Labels are transitive



L_F
$L_F \not\sqsubseteq L_{\mathrm{bug}}$
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Internet
L_{net}

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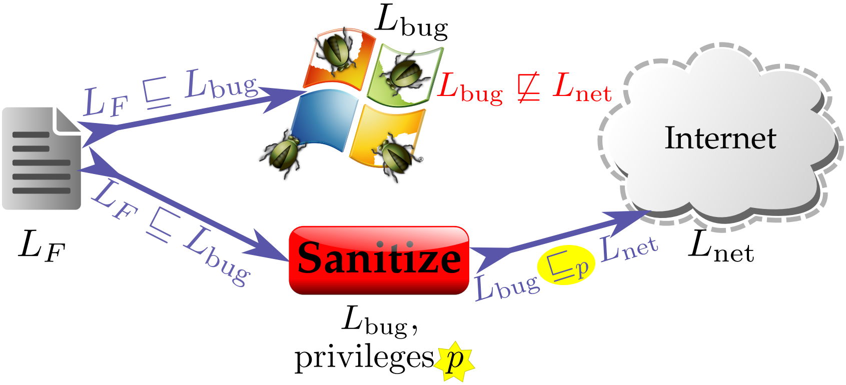
- **Conversely, if app write to network have** $L_F \not\sqsubseteq L_{\mathrm{bug}} \sqsubseteq L_{\mathrm{net}}$

Labels form a lattice

$$\begin{tikzcd}
 & L_{\mathrm{AB}} & \\
L_{\mathrm{A}} \arrow[ur, "\sqsubseteq"] & & L_{\mathrm{B}} \arrow[ul, "\sqsubseteq"'] \\
 & L_{\emptyset} \arrow[ul, "\sqsubseteq"'] \arrow[ur, "\sqsubseteq"] &
\end{tikzcd}$$

- **Consider two users, A and B**
  - Label public data $L_{\emptyset}$, A's private data L_A, B's private data L_B
- **What if you mix A's and B's private data in a single document?**
  - Both A and B should be concerned about the release of such a document
  - Need a label at least as restrictive as both L_A and L_B
  - Use the least upper bound (a.k.a. *lub* or *join*) of L_A and L_B, written $L_A \sqcup L_B$

DIFC is Decentralized



L_{bug}
$L_F \sqsubseteq L_{\text{bug}}$
$L_{\text{bug}} \not\sqsubseteq L_{\text{net}}$
Internet
L_F
$L_F \sqsubseteq L_{\text{bug}}$
Sanitize
$L_{\text{bug}} \sqsubseteq_p L_{\text{net}}$
L_{net}
L_{bug},
privileges p

- **Different software has access to different privileges**
- **Exercising privilege p changes label requirements**
    - $\sqsubseteq_p$ ("can flow under privileges p") is more permissive than $\sqsubseteq$
    - $L_F \sqsubseteq_p L_{\text{proc}}$ to read, and additionally $L_{\text{proc}} \sqsubseteq_p L_F$ to write file
- **Idea: Set labels so you know who has relevant privs**

Example privileges

$$\begin{tikzcd}
 & L_{\mathrm{AB}} & \\
L_{\mathrm{A}} \arrow[ur, "\sqsubseteq", sloped] & & L_{\mathrm{B}} \arrow[ul, "\sqsubseteq"', sloped] \\
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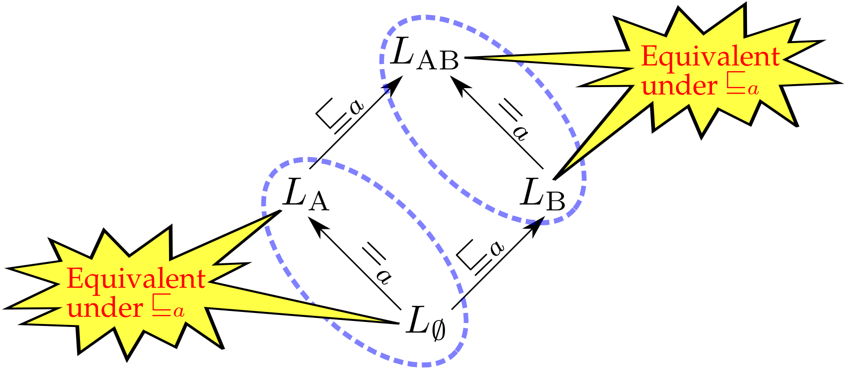
\end{tikzcd}$$

- **Consider again simple two user lattice**
- **Let a be user A's privileges, b be user B's privileges**
- **Clearly $L_A \sqsubseteq_a L_\emptyset$ and $L_B \sqsubseteq_b L_\emptyset$**
  - Users should be able to make public or *declassify* their own private data
- **Users should also be able to *partially declassify* data**
  - I.e., $L_{AB} \sqsubseteq_a L_B$ and $L_{AB} \sqsubseteq_b L_A$

Example privileges



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Labels in Haskell

- **Represent as type class to accommodate various lattices**

```
class (Eq l, Show l, Typeable l) => Label l where
  lub :: l -> l -> l            -- Least upper bound
  glb :: l -> l -> l            -- Greatest lower bound
  canFlowTo :: l -> l -> Bool -- "Can flow to" partial order
(⊑) = canFlowTo
```

- **We use *DC labels*, pairs of CNF formulas over principals**

$$\overbrace{\textit{reader-condition}}^{\text{secrecy component}} \;\%\%\; \overbrace{\textit{writer-condition}}^{\text{integrity component}}$$

  - Example: `("A" \/ "B") %% "X" /\ ("A" \/ "B")`
    A or B can read; one of A's or B's permissions *plus* X's required to write
  - Mixing data increases secrecy, decreases integrity

$$(S_1 \,\%\%\, I_1) \sqcup (S_2 \,\%\%\, I_2) = (S_1 \wedge S_2 \,\%\%\, I_1 \vee I_2)$$

  - Data can only flow to less secrecy or more integrity ($\Rightarrow$ is "implies")

$$(S_1 \,\%\%\, I_1) \sqsubseteq (S_2 \,\%\%\, I_2) \quad \textbf{iff} \quad (S_1 \Rightarrow S_2) \wedge (I_2 \Rightarrow I_1)$$

Enforcing IFC

- **Supply a "Labeled IO" monad `LIO` to be used in place of `IO`**

```
{-# LANGUAGE Unsafe #-}
data LIOState l = LIOState { lioLabel, lioClearance :: !l }

newtype LIO l a = LIOTCB (IORef (LIOState l) -> IO a)
instance Monad (LIO l) where
  return = LIOTCB . const . return
  (LIOTCB ma) >>= k = LIOTCB $ \s -> do
    a <- ma s
    case k a of LIOTCB mb -> mb s

ioTCB :: IO a -> LIO l a -- back door for privileged code
ioTCB = LIOTCB . const    -- to execute arbitrary IO actions
```

- **Note: constructor `LIOTCB` *not* exported to safe code**
  - Idea: Start with no side effects possible in safe `LIO` code
  - Build up library of label-respecting side effects in trustworthy code
  - By convention, all privileged, unsafe symbols end . . . `TCB`

Adjusting and checking labels

- **Privileged code must check labels before impure actions**
- **Before reading object** obj**, must ensure** $L_{\text{obj}} \sqsubseteq L_{\text{thread}}$

```
taint :: Label l => l -> LIO l ()
taint lobj = do
  LIOState { lioLabel = l, lioClearance = c } <- getLIOStateTCB
  let l’ = l ⊔ lobj
  unless (l’ ⊑ c) $ labelError "taint" [lobj]
  modifyLIOStateTCB $ \s -> s { lioLabel = l’ }
```

- **Before writing, must check** $L_{\text{thread}} \sqsubseteq L_{\text{obj}} \sqsubseteq C_{\text{thread}}$

```
guardWrite :: Label l => l -> LIO l ()
guardWrite lobj = do
  LIOState { lioLabel = l, lioClearance = c } <- getLIOStateTCB
  unless (l ⊑ lobj) $ labelError "guardWrite" [newl]
  taint lobj
```

Representing privileges

- **Privilege type `p` describes pre-orders $\sqsubseteq_p$ on labels of type `l`**

```
class (Label l) => PrivDesc l p where
  downgradeP :: p -> l -> l -- get least equivalent label under ⊑p
  canFlowToP :: p -> l -> l -> Bool
  canFlowToP p l1 l2 = downgradeP p l1 ⊑ l2
```

- **DC label privileges are just CNF formulas, so that**

$$(S_1 \mathbin{\%\%} I_1) \sqsubseteq_p (S_2 \mathbin{\%\%} I_2) \quad \textbf{iff} \quad (p \wedge S_1 \Rightarrow S_2) \wedge (p \wedge I_2 \Rightarrow I_1)$$

- **Note a `PrivDesc` instance merely *describes* privileges**
  - To *exercise* them, must wrap them in type `Priv`

```
newtype Priv p = PrivTCB p
```

  - Safe code cannot import unsafe `PrivTCB` symbol
  - But can bootstrap privileges in `IO` monad before entering `LIO`

```
privInit :: p -> IO (Priv p)
privInit p = return $ PrivTCB p
```

Using `Priv` objects

- **For convenience, `Priv`s are also `PrivDesc`s**

```
instance (PrivDesc l p) => PrivDesc l (Priv p) where
  downgradeP (PrivTCB p) = downgradeP p
  canFlowToP (PrivTCB p) = canFlowToP p
```

- **Most functions have `...P` variants taking a `Priv` argument, e.g.:**

```
taintP :: PrivDesc l p => Priv p -> l -> LIO l ()
taintP p lobj_high = do
  ... Same basic body as taint ...
  where lobj = downgradeP p lobj_high
        (⊑)= canFlowToP p
```

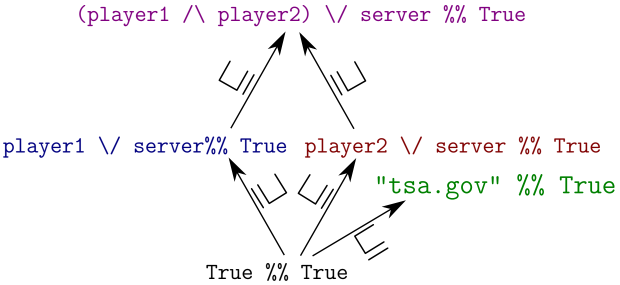
- **Can use one `Priv` object to obtain weaker ones it *speaks for***

```
delegate :: (SpeaksFor p) => Priv p -> p -> Priv p
delegate start_privs wanted_privs = ...
```

  - With DC labels: p_1 speaks for p_2 **iff** $p_1 \Rightarrow p_2$

Example: Rock-Paper-Scissors server

- **Allow untrusted third parties to improve/translate game**
- **Third-party code should *not* be able to cheat (look at opponent's move before playing) or report scissors to `tsa.gov`**
- **Approach:**
  - Give privileges "`server`" to main server loop
  - Delegates sub-privileges to each player, e.g., "`(player1 \/ server)`", ...
  - Use appropriately labeled MVars to record each player's move
- **Lattice:**



`(player1 /\ player2) \/ server %% True`

`player1 \/ server%% True`

`player2 \/ server %% True`

`"tsa.gov" %% True`

`True %% True`

Demo time

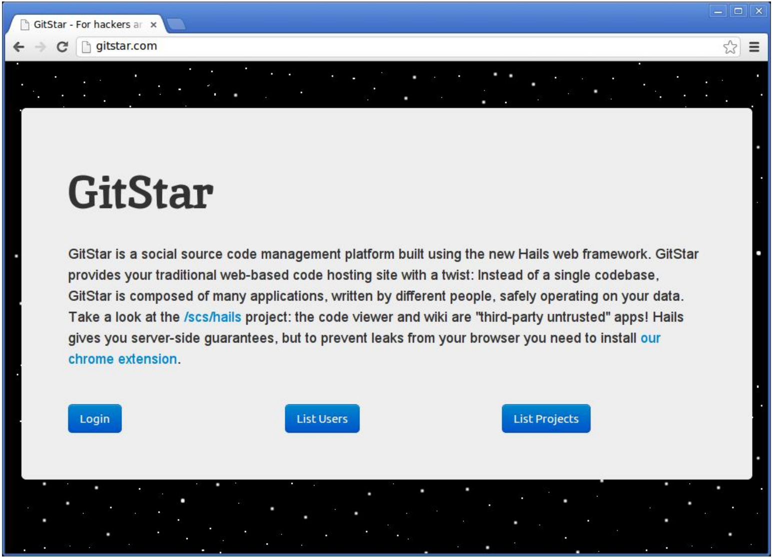
Get the code!

```
git clone http://tinyurl.com/liorock-git
cabal install --haddock-hyperlink-source lio
```

Hails: An LIO web framework

- **Introduces Model-Policy-View-Controller paradigm**
- **A Hails server comprises two types of software packages**
  - *VCs* contain view and controller logic
  - *MPs* contain model and policy logic
- **Policies enforced using LIO**
  - Also isolate spawned programs with Linux namespaces
- **Used for several web sites…**

GitStar

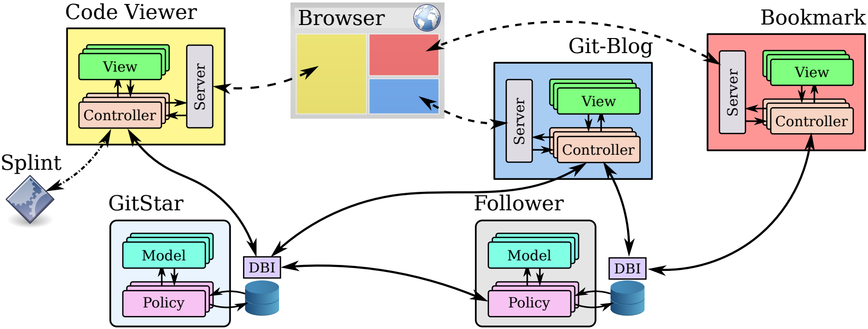


GitStar

GitStar is a social source code management platform built using the new Hails web framework. GitStar provides your traditional web-based code hosting site with a twist: Instead of a single codebase, GitStar is composed of many applications, written by different people, safely operating on your data. Take a look at the /scs/hails project: the code viewer and wiki are "third-party untrusted" apps! Hails gives you server-side guarantees, but to prevent leaks from your browser you need to install our chrome extension.

- **Public GitHub-like service supporting private projects**

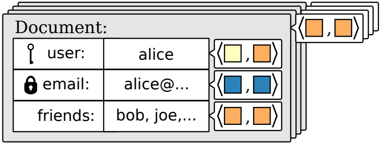
Simplified GitStar architecture



- **Two MPs: *GitStar* hosts git repos, *Follower* stores a relationship between users**
- **Three different VC apps make use of these MPs**
  - VCs can be written after the fact w/o permission of MP author
  - `LIO` ensures they cannot mis-use data

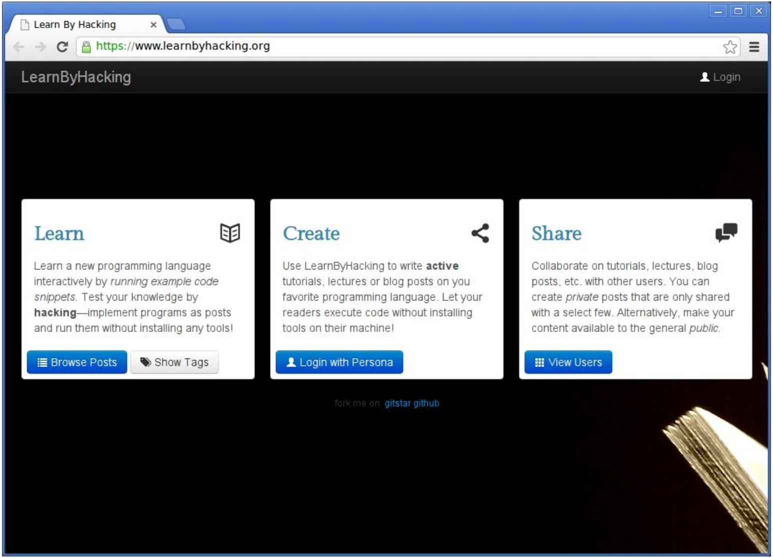
What policy looks like

```
-- Set policy for "users" collection:
collection "users" $ do
  -- Set collection label:
  access $ do
    readers ==> anybody
    writers ==> anybody
  -- Declare user field as a key:
  field "user" key
  -- Set document label, given document doc:
  document $ \doc -> do
    readers ==> anybody
    writers ==> ("user" ‘from‘ doc) \/ _Follower
  -- Set email field label, given document doc:
  field "email" $ labeled $ \doc -> do
    readers ==> ("user" ‘from‘ doc)
                \/ fromList ("friends" ‘from‘ doc)
                \/ _Follower
    writers ==> anybody
```



Labeled by: 🟨 Collection 🟧 Document 🟦 Field

LearnByHacking



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fork me on: gitstar github

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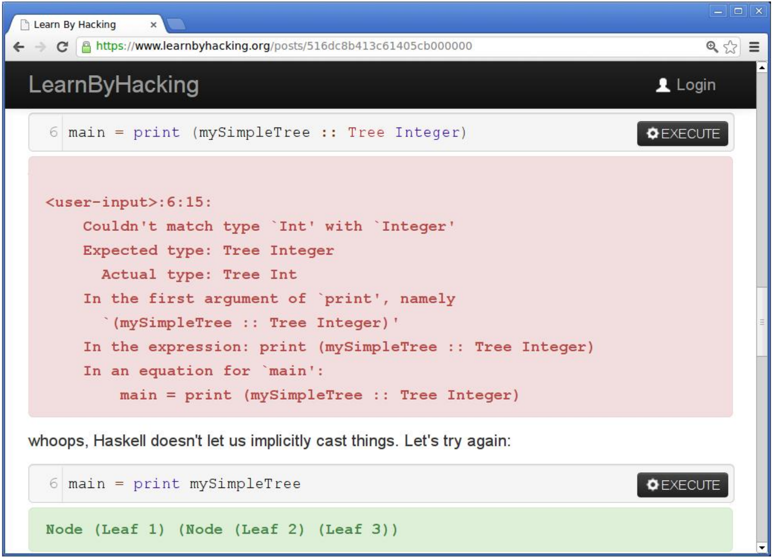

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EXECUTE

```
main = print (mySimpleTree :: Tree Integer)
```

```
<user-input>:6:15:
    Couldn't match type `Int' with `Integer'
    Expected type: Tree Integer
      Actual type: Tree Int
    In the first argument of `print', namely
      `(mySimpleTree :: Tree Integer)'
    In the expression: print (mySimpleTree :: Tree Integer)
    In an equation for `main':
        main = print (mySimpleTree :: Tree Integer)
```

whoops, Haskell doesn't let us implicitly cast things. Let's try again:

```
main = print mySimpleTree
```

```
Node (Leaf 1) (Node (Leaf 2) (Leaf 3))
```

Questions

Secure
Computer
Systems

```
http://www.scs.stanford.edu/
git clone http://tinyurl.com/liorock-git
```