A DEPENDENTLY TYPED LIBRARY FOR STATIC INFORMATION-FLOW CONTROL IN IDRIS

Simon Gregersen, Søren Eller Thomsen, and Aslan Askarov

AARHUS UNIVERSITY
DEPARTMENT OF COMPUTER SCIENCE

Hmm... I need a library!

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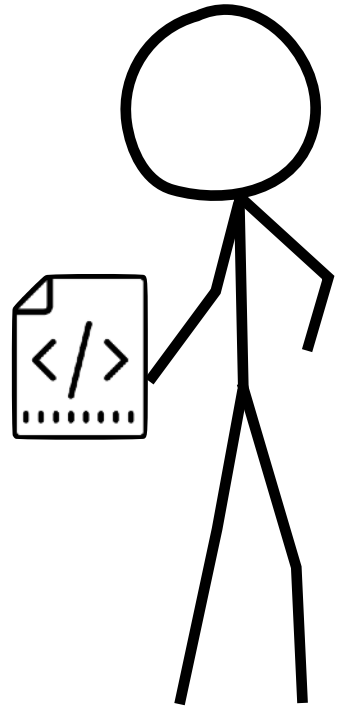

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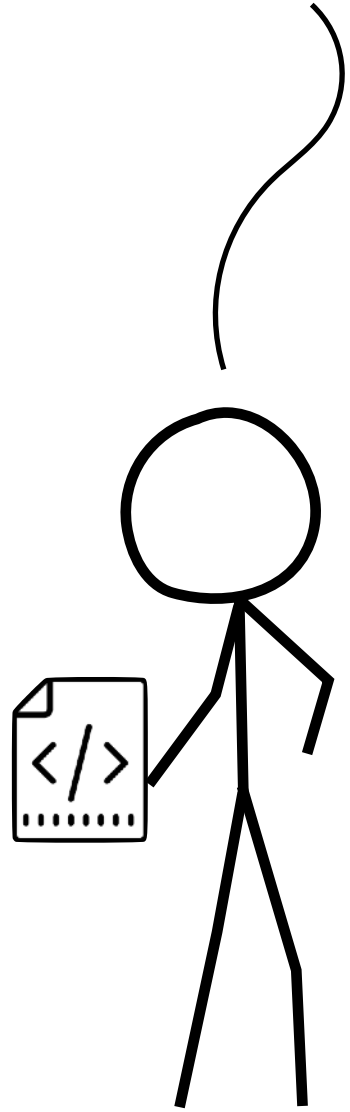

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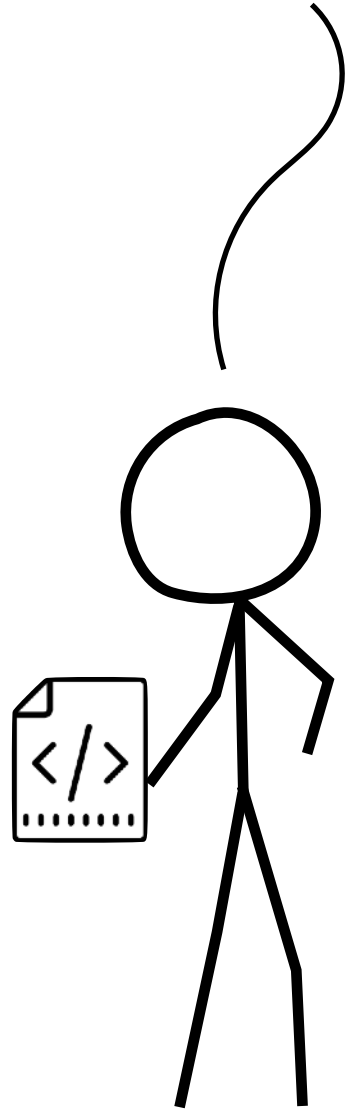

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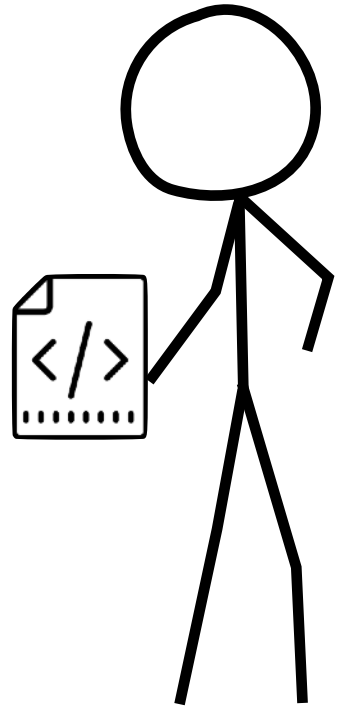
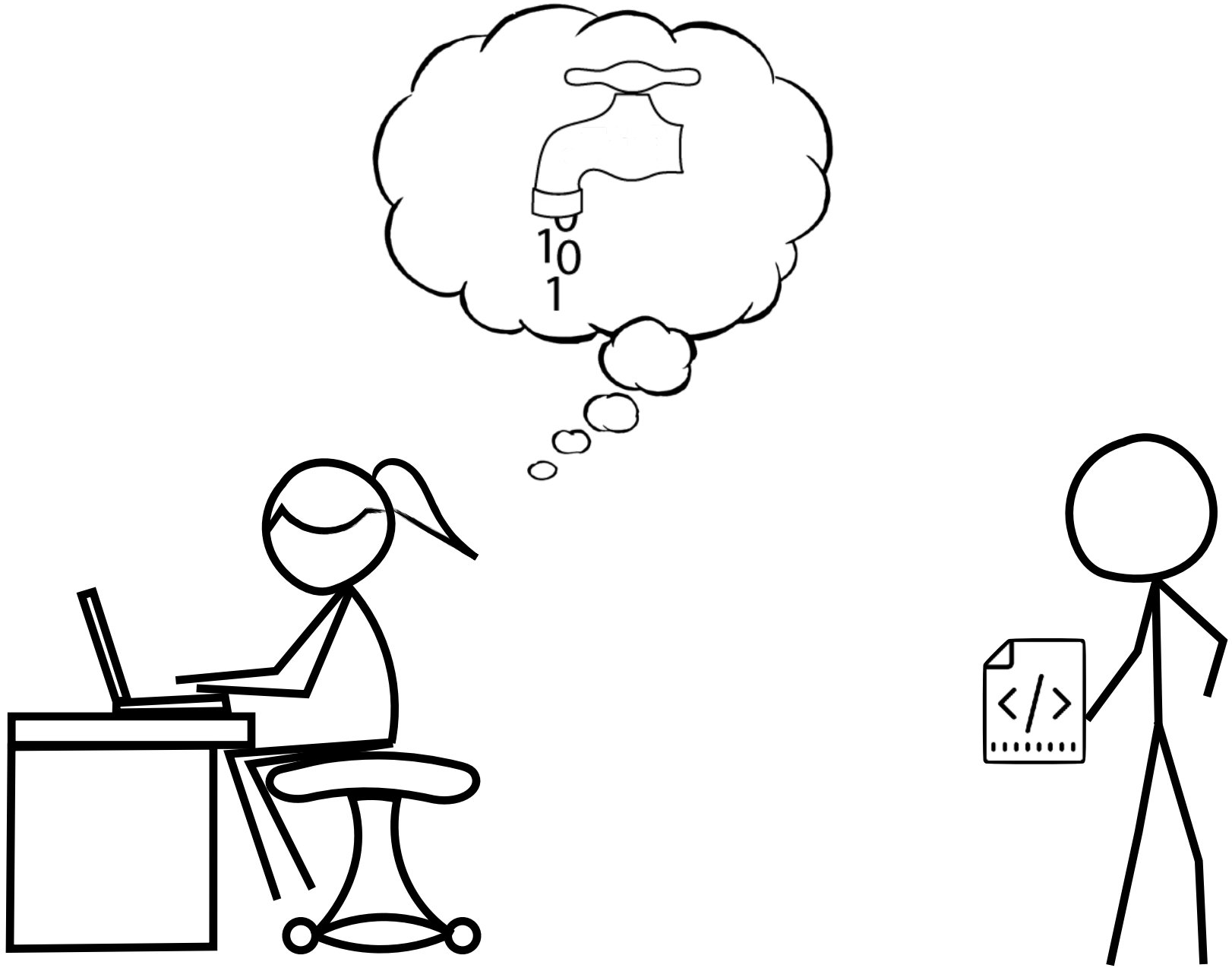
Of course!

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Paragon

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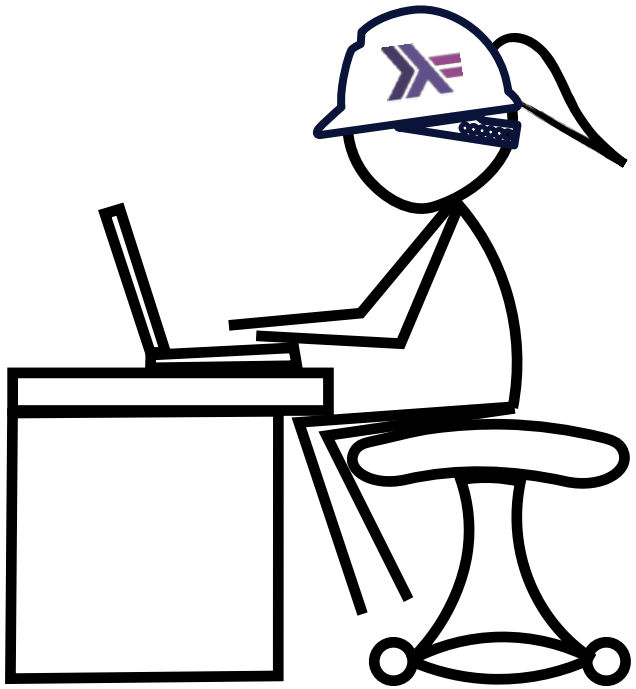
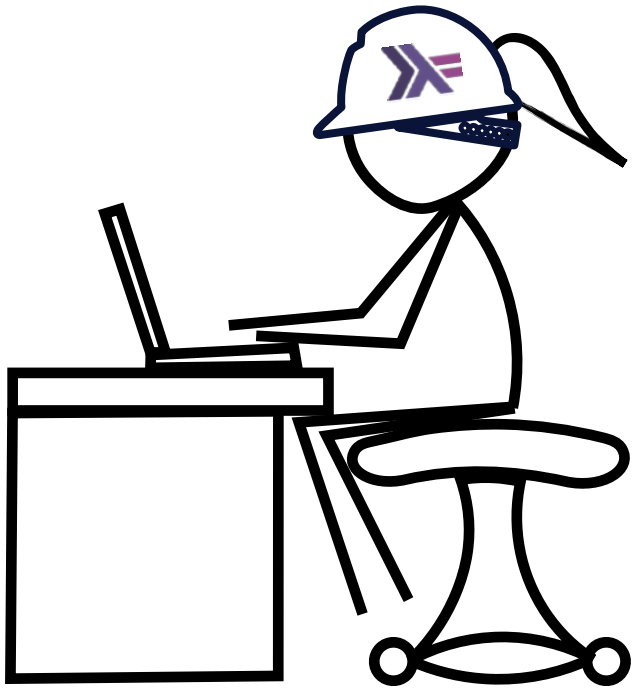
Flow Caml

That's a lot of work!



HASKELL LIBRARIES



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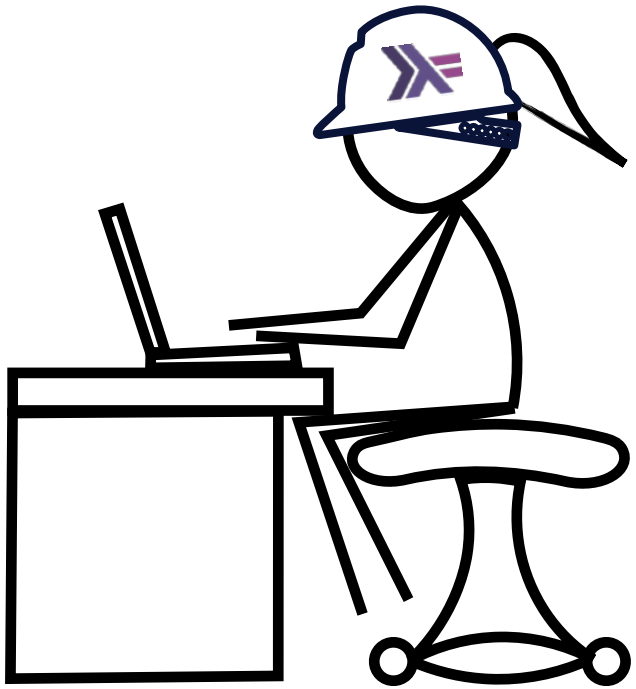

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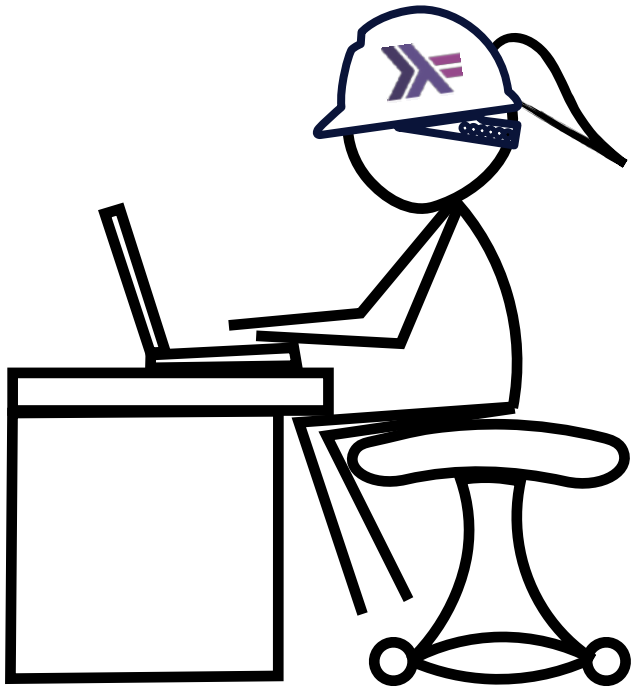

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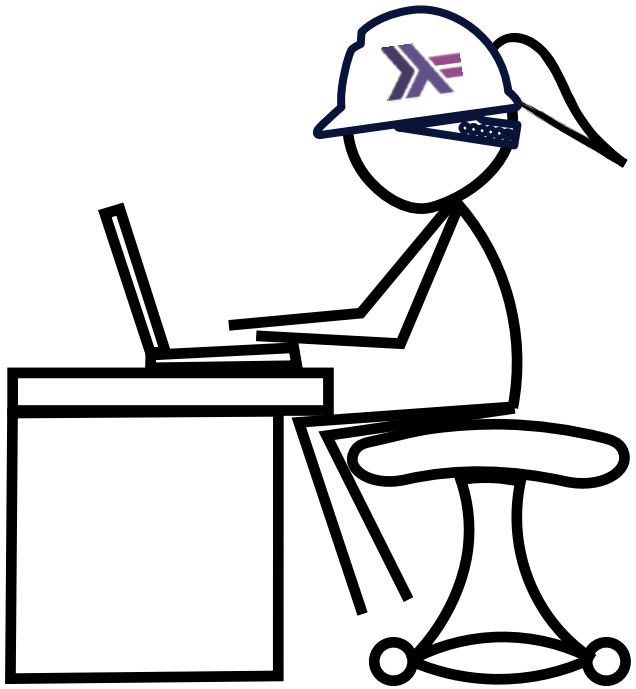

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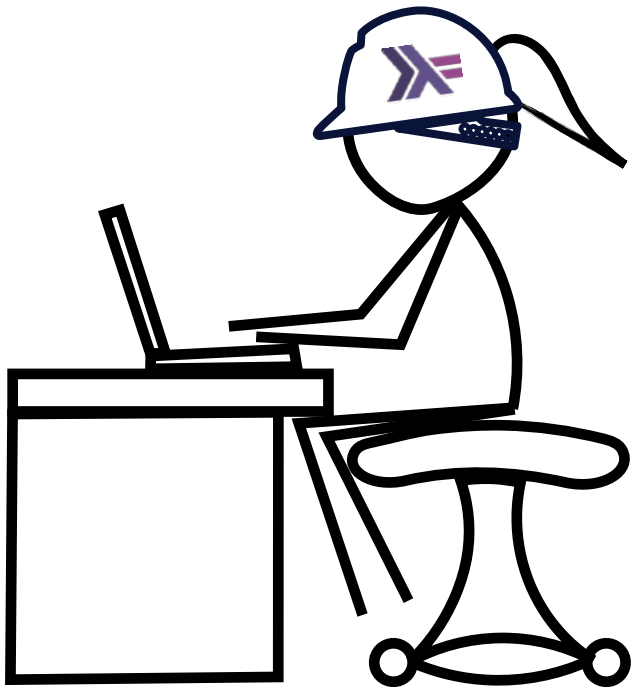
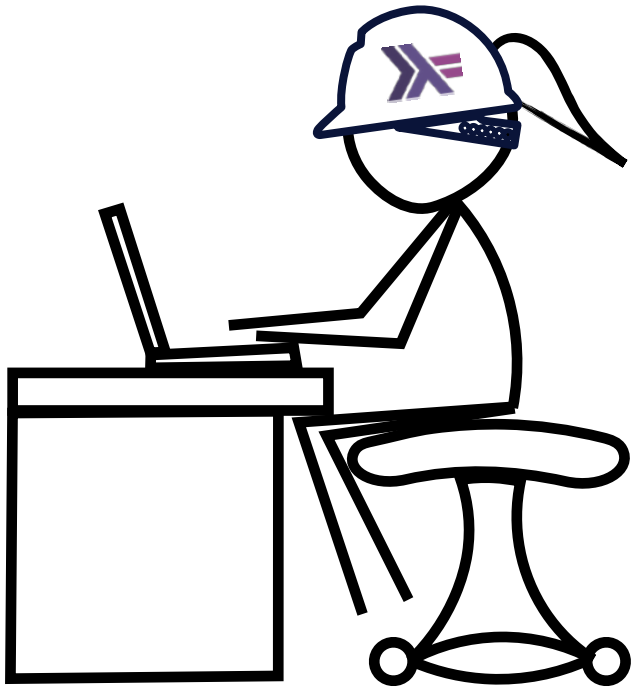


MAC (Russo, 2015)

- A lightweight library
- No run-time checks
- Illegal flows rejected at compile-time



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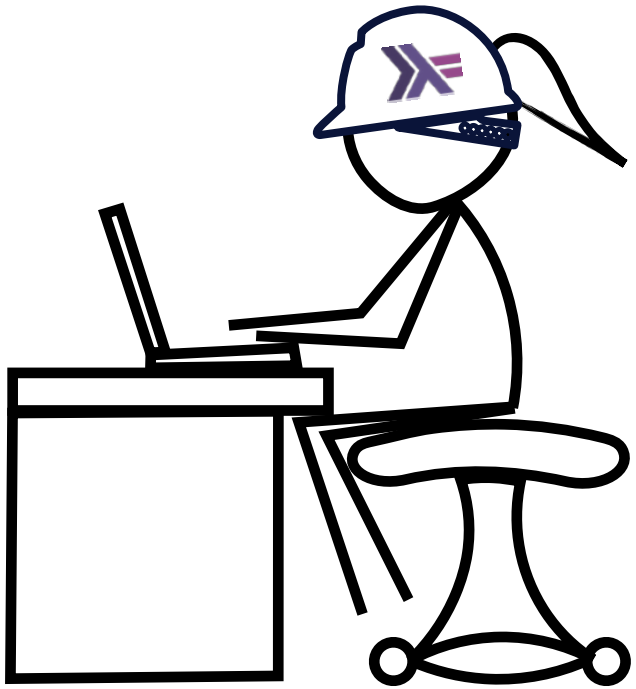
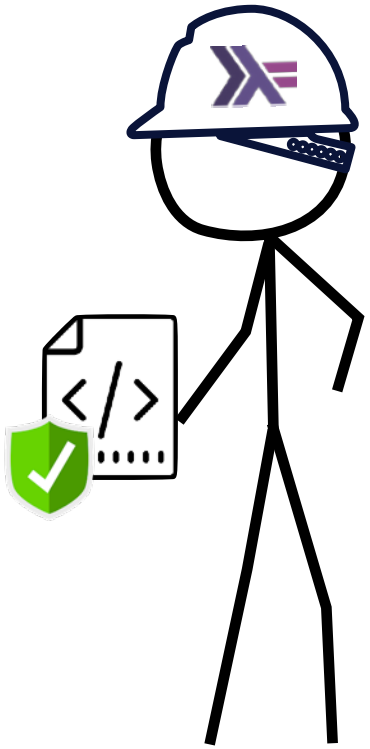
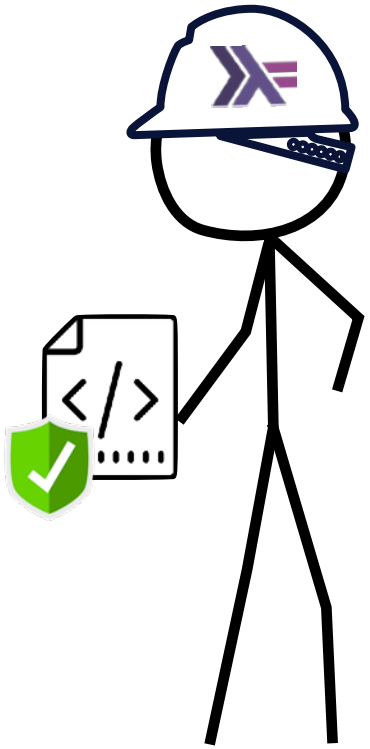




MAC (Russo, 2015)

- A lightweight library
- No run-time checks
- Illegal flows rejected at compile-time
- **Limitation:** statically defined security compartments



EXAMPLE: AUCTION

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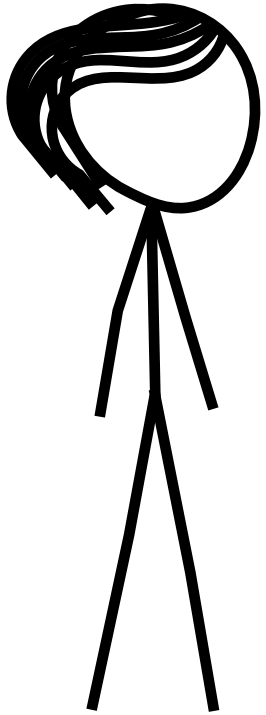
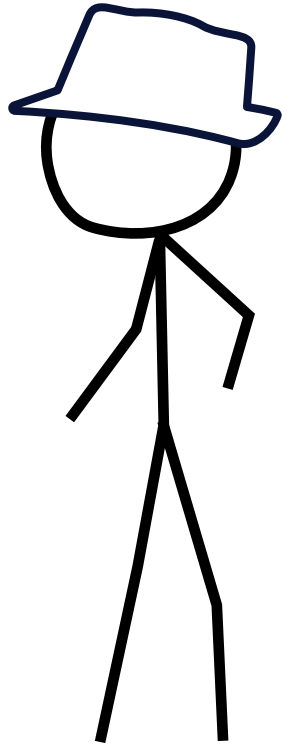


Dan



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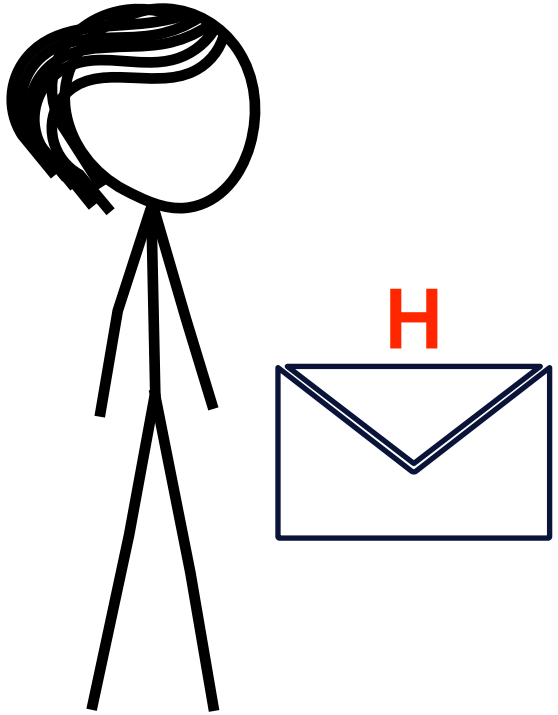

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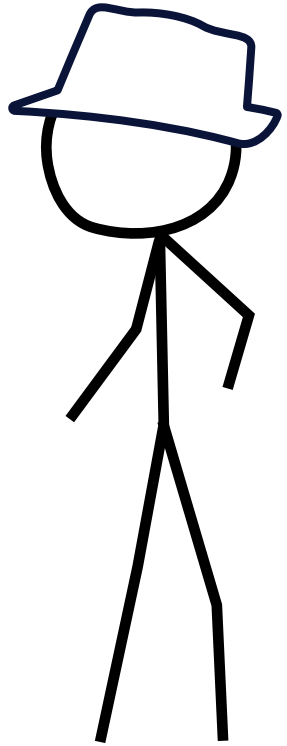

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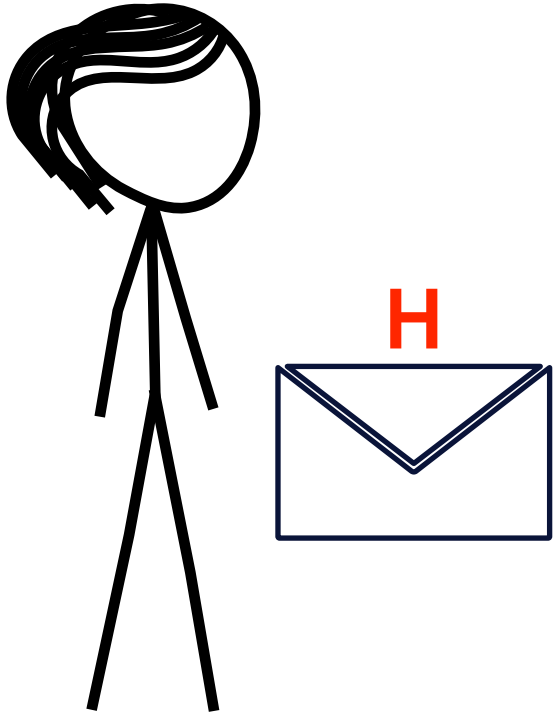

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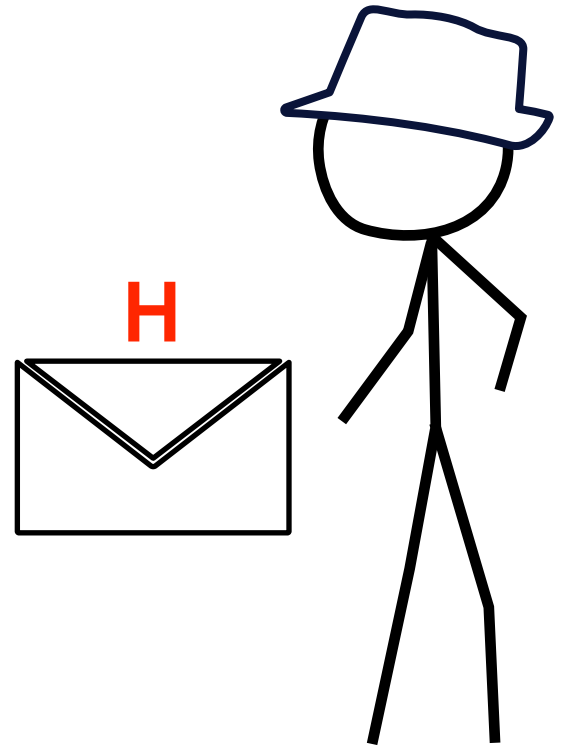

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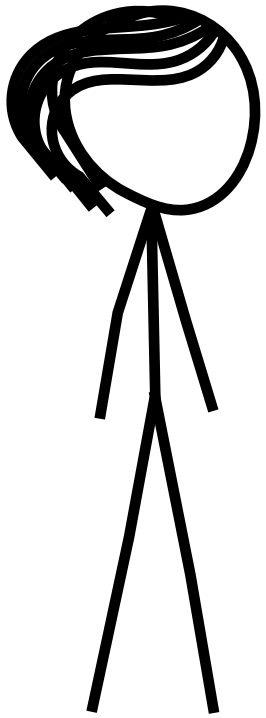

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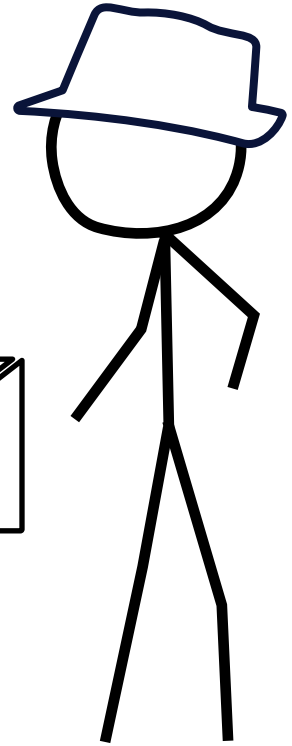

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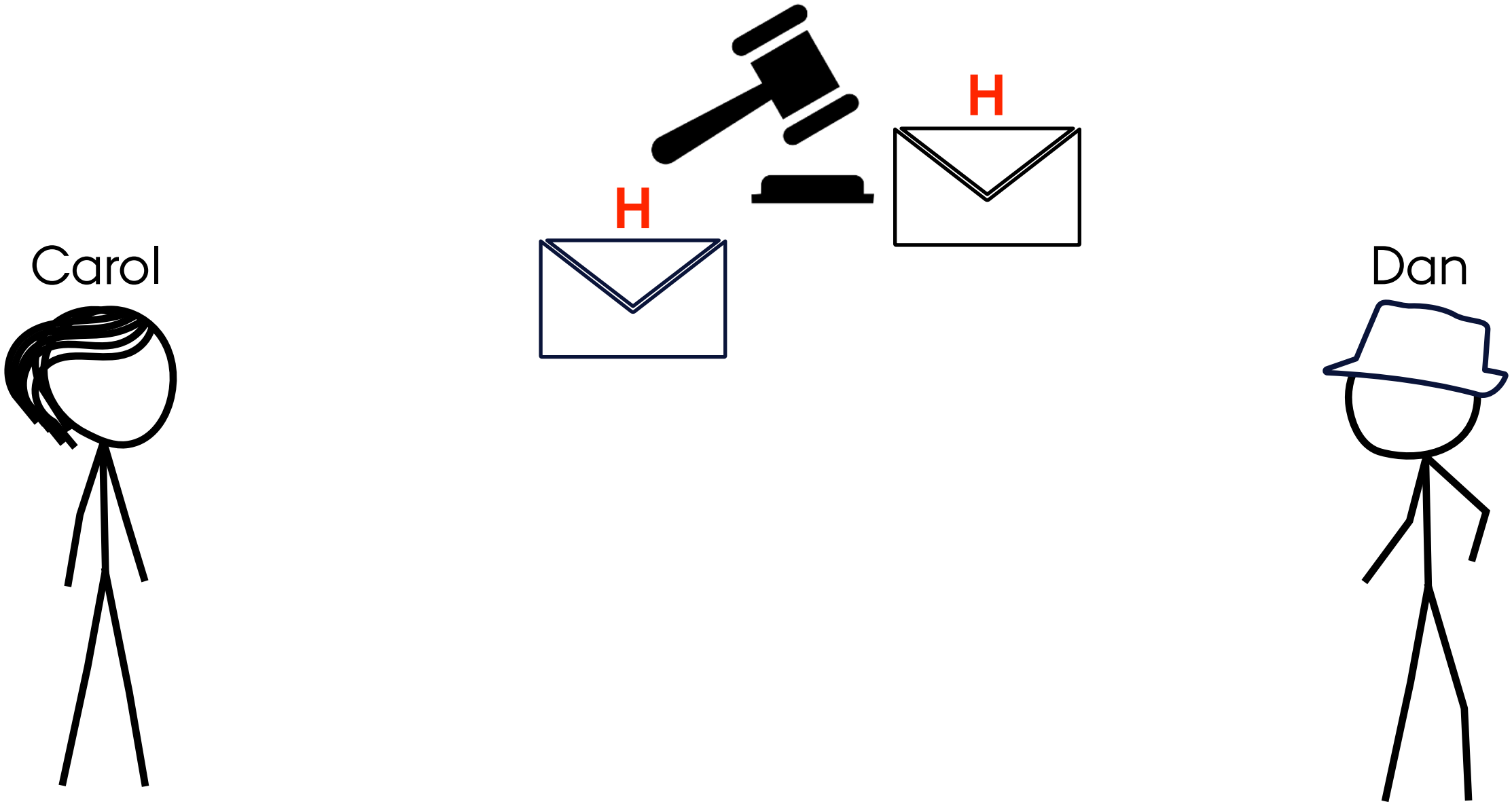

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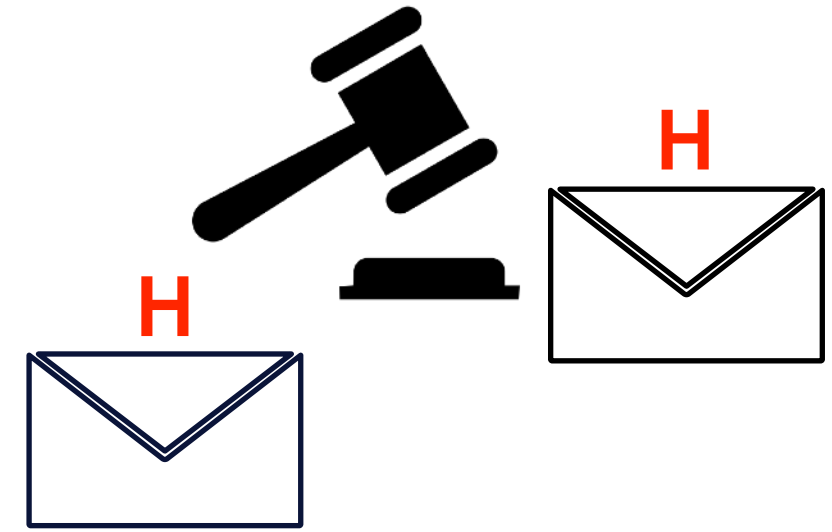
$H \not\subseteq L$



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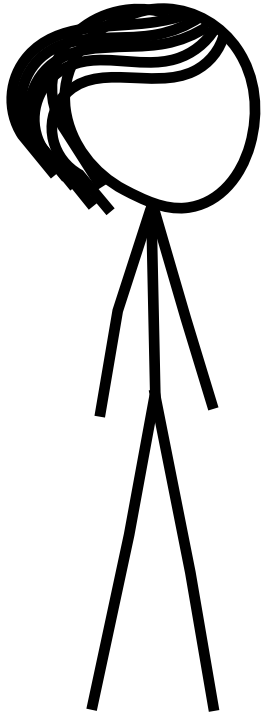

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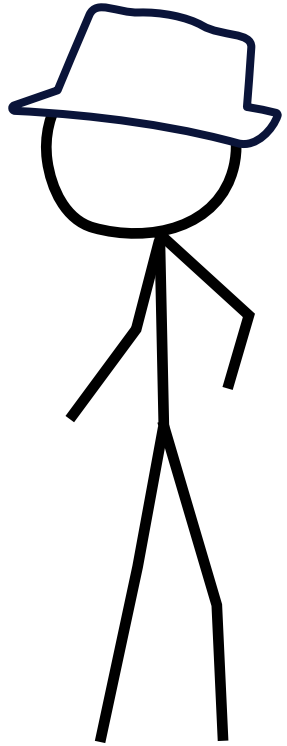

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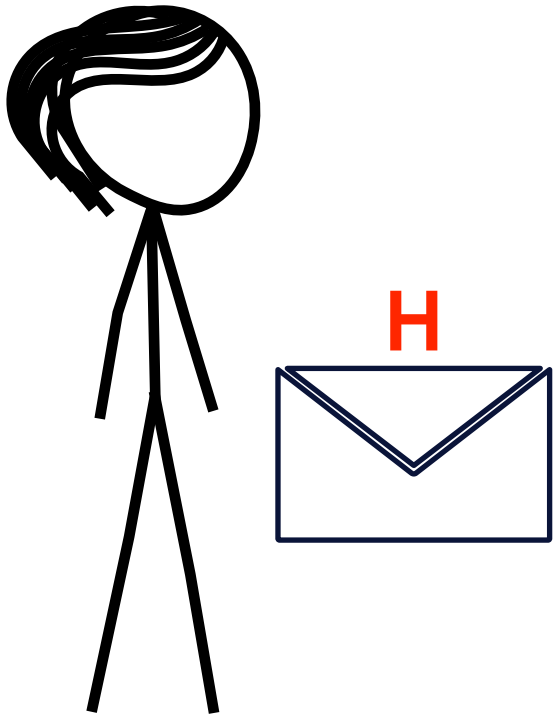

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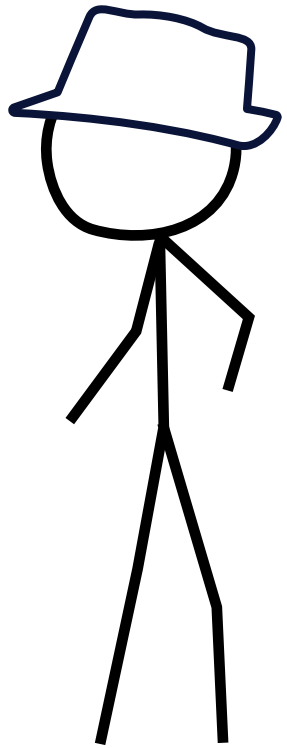

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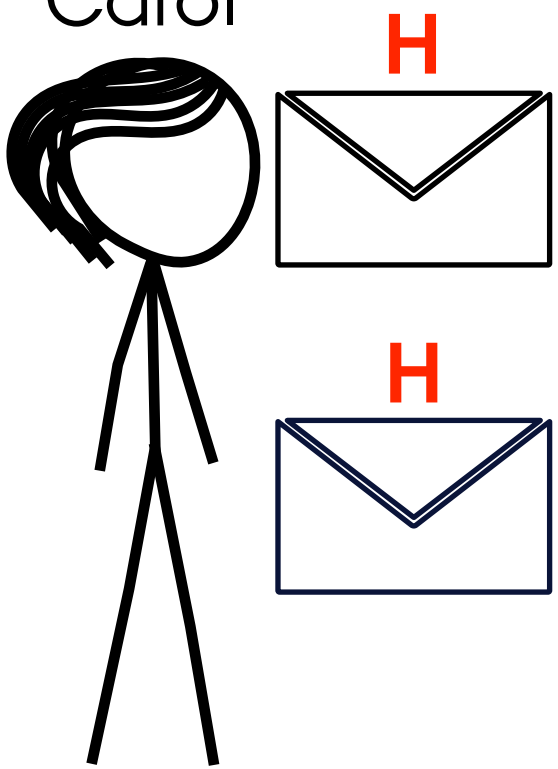

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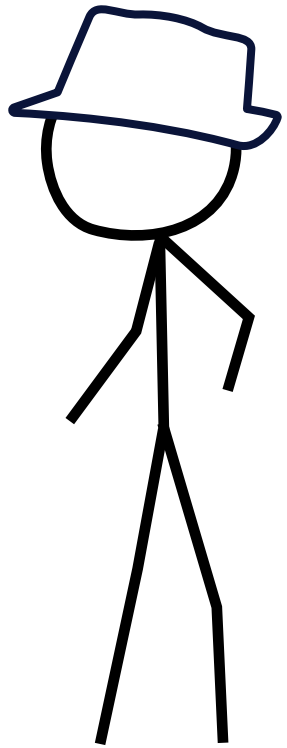

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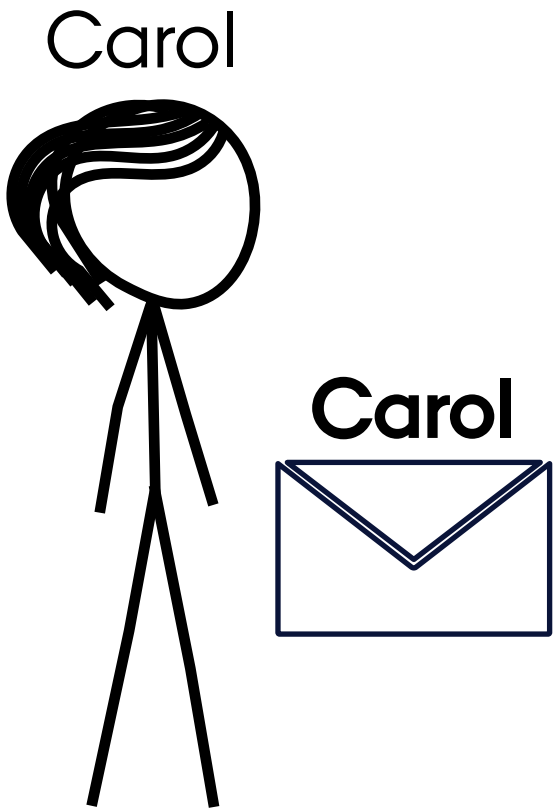

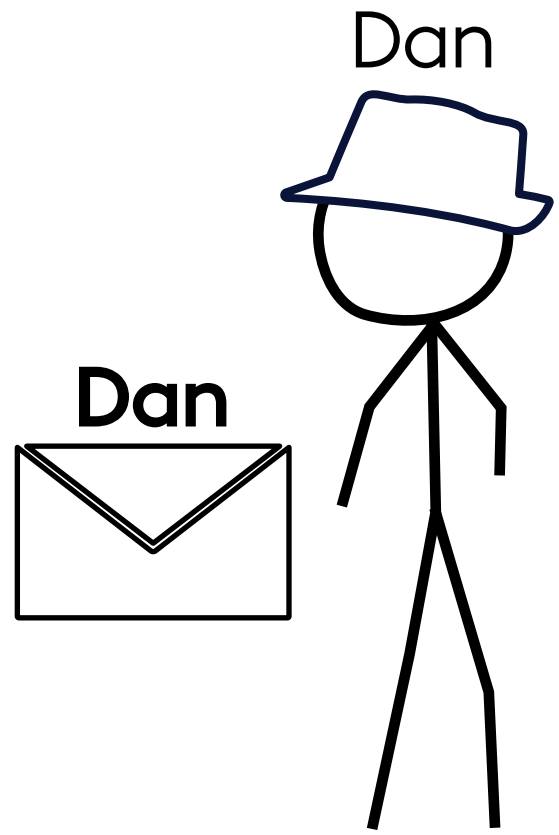

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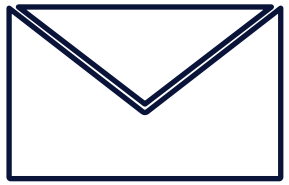

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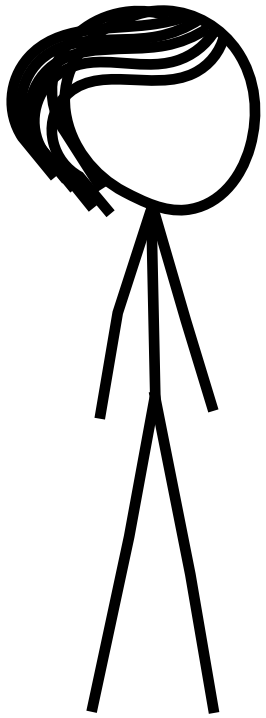

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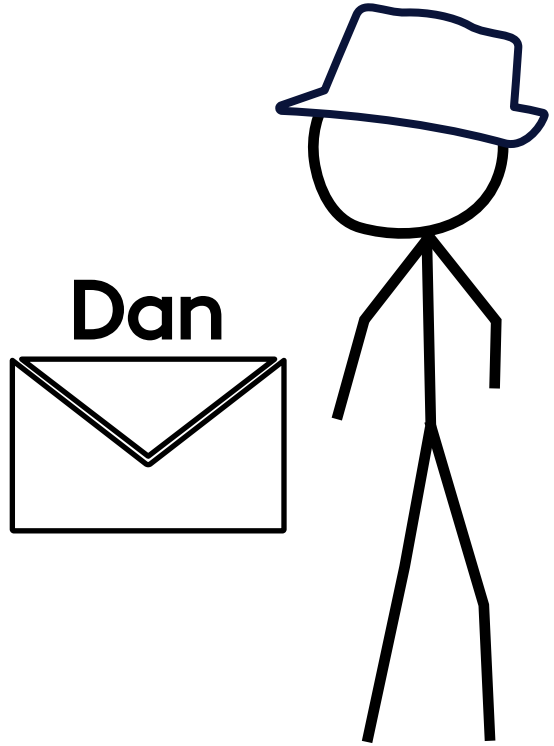

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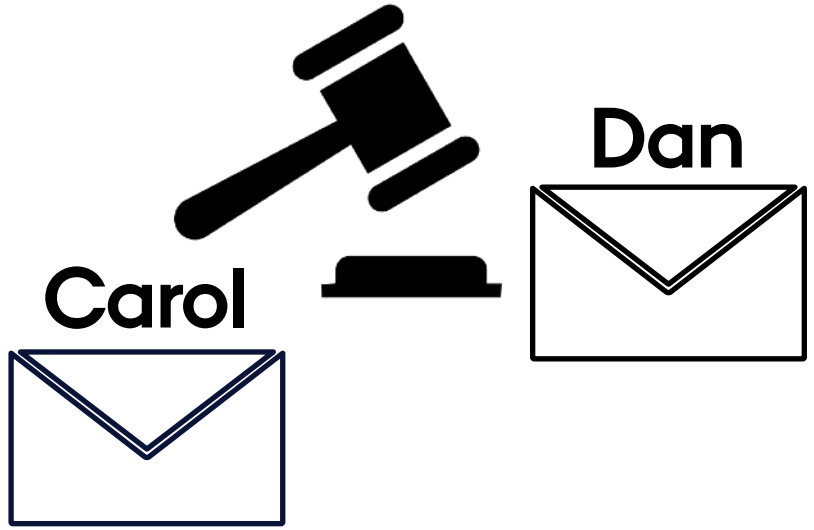

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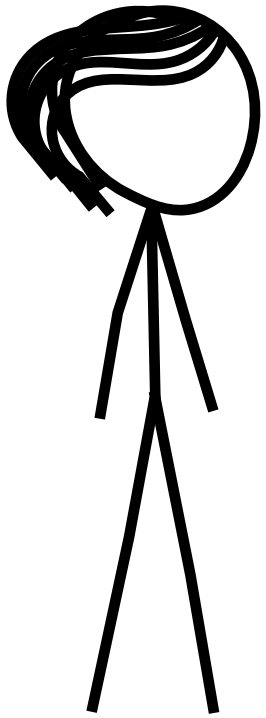

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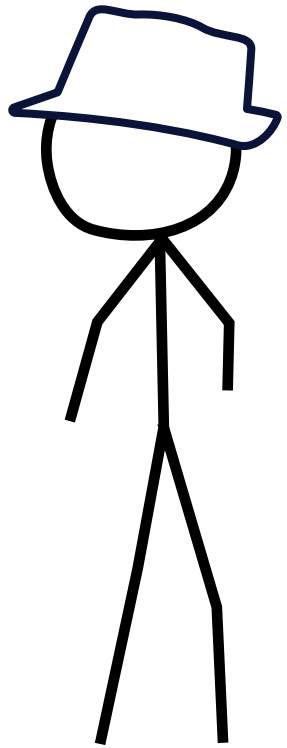

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Carol $\not\subseteq$ **Dan**

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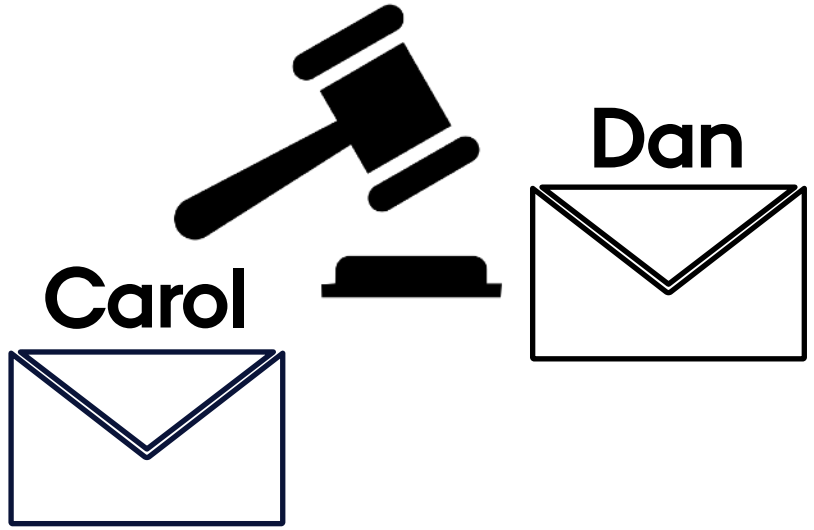

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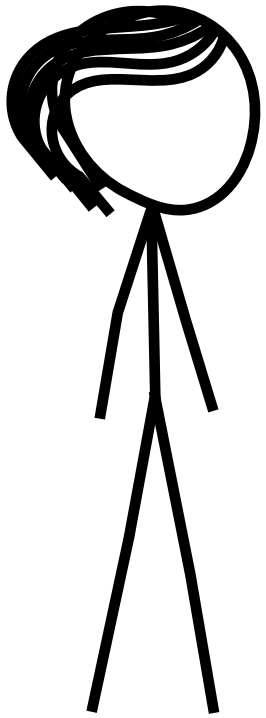

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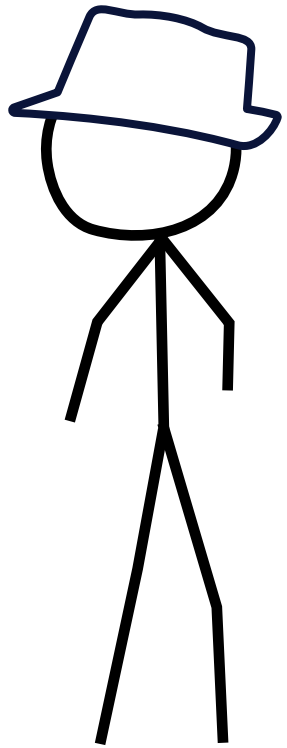

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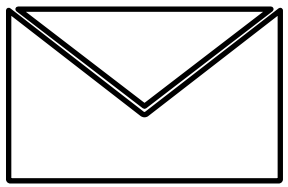

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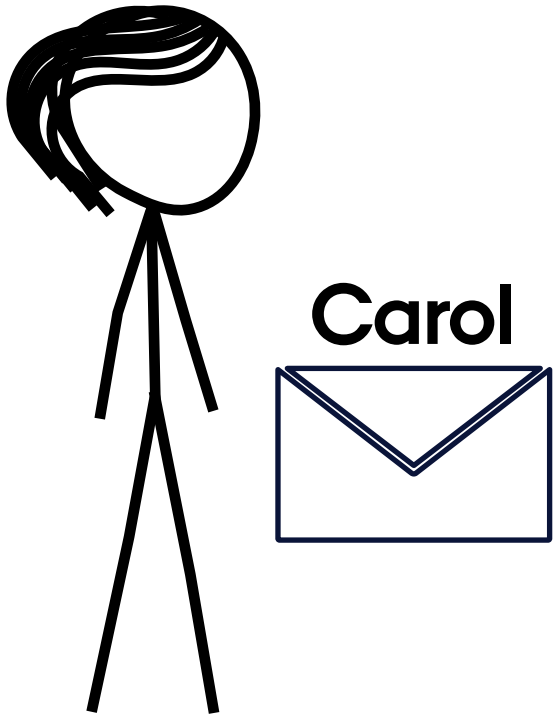

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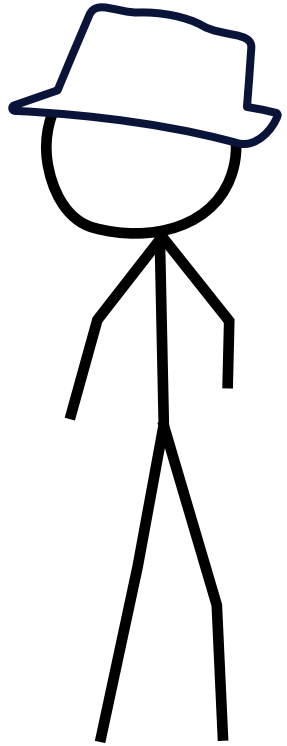

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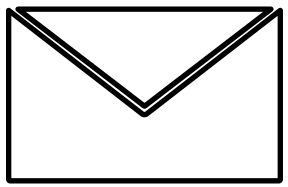

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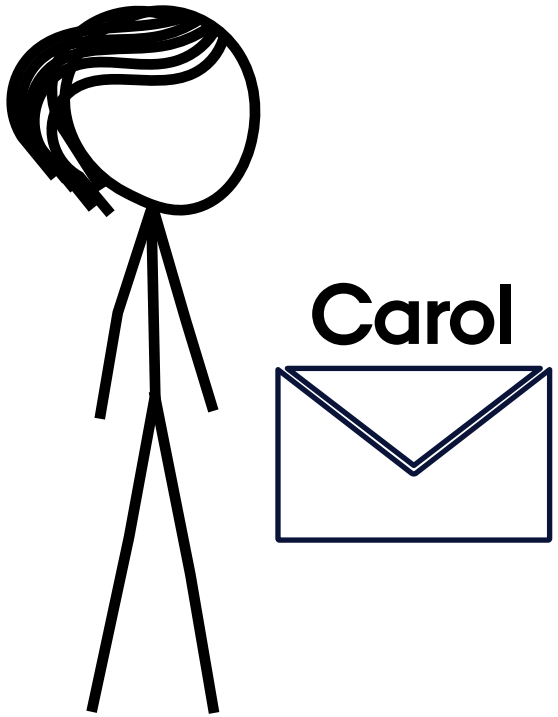

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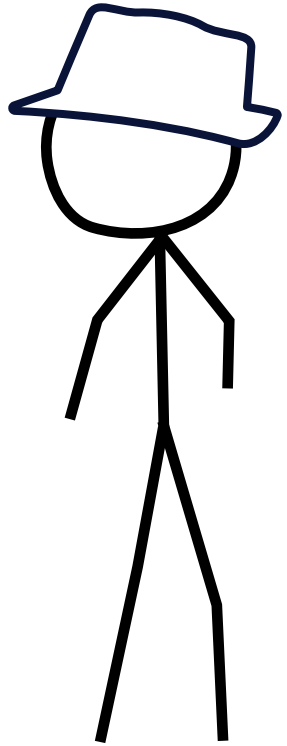

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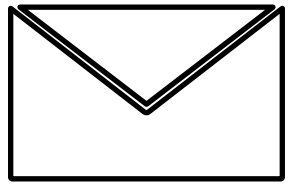

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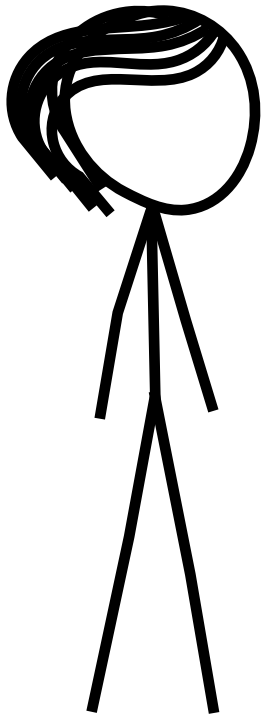

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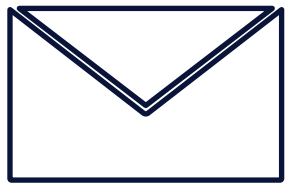

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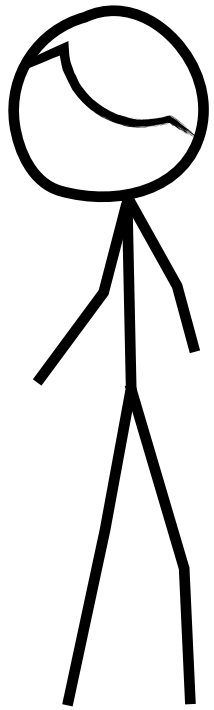

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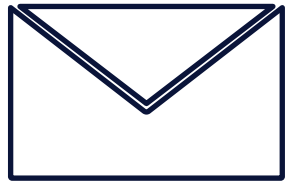

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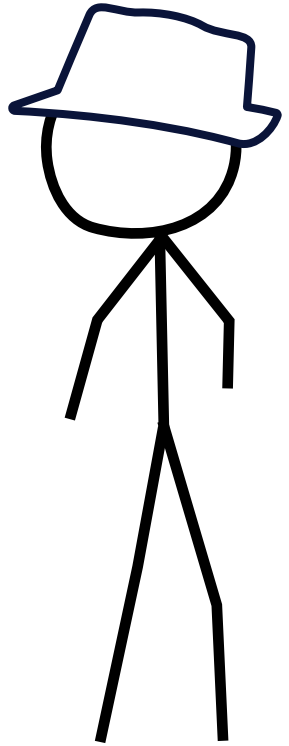


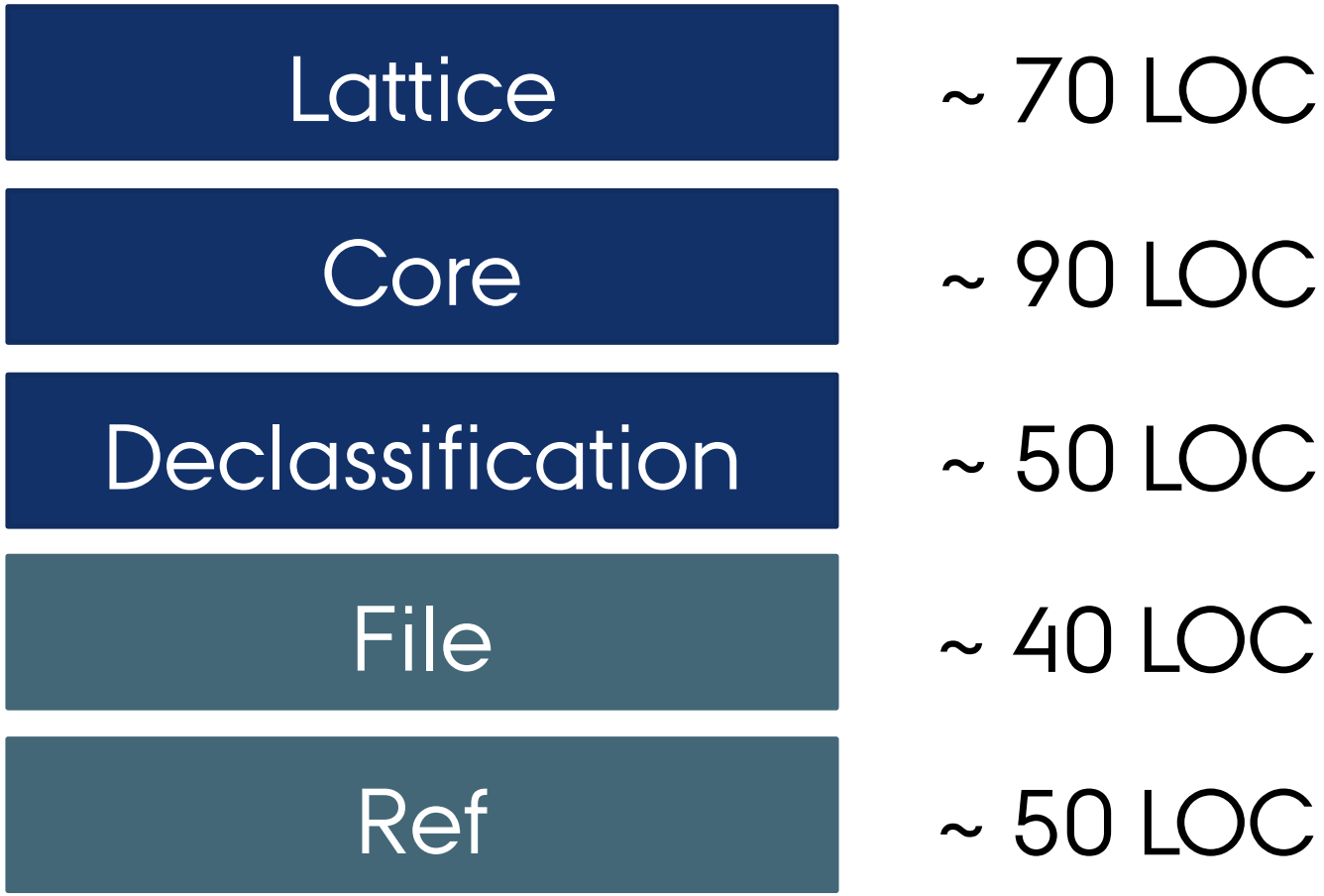
THIS WORK

- **DEPSEC**: a static information-flow control (IFC) library for Idris
- Showcases how dependent types increase the expressiveness of state-of-the-art IFC libraries
- Novel and powerful means for statically-enforced declassification using dependent types

Idris (Brady, 2013)

- **General-purpose**, pure functional language
- Features full dependent types
- Heavily inspired by Haskell

DepSec - Overview



DepSec - Overview

Lattice ~ 70 LOC

Core ~ 90 LOC

DepSec - Lattice

```
interface JoinSemilattice a where
  join        : a -> a -> a
  commutative : (x, y : a) -> x `join` y = y `join` x
  -- ...

interface Poset a where
  leq         : a -> a -> Type
  -- ...

implementation JoinSemilattice a => Poset a where
  leq x y = (x `join` y = y)
  -- ...

interface JoinSemilattice a => BoundedJoinSemilattice a where
  Bottom : a
  -- ...
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DepSec - CORE

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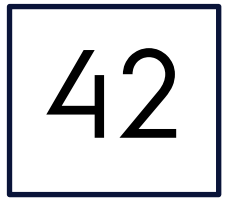


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DepSec - CORE

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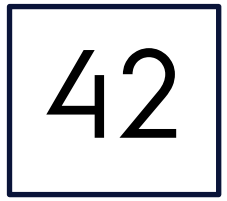

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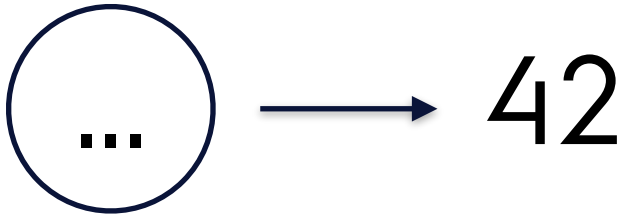

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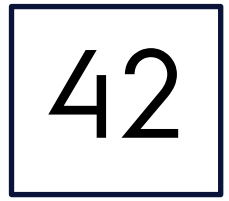

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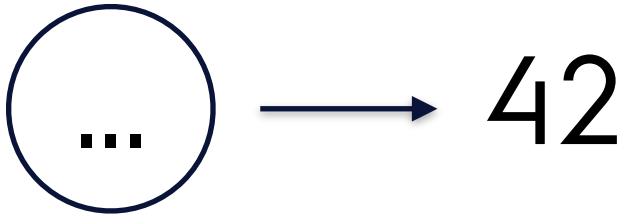

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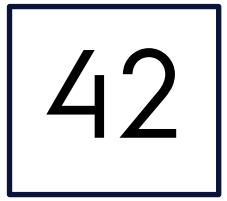

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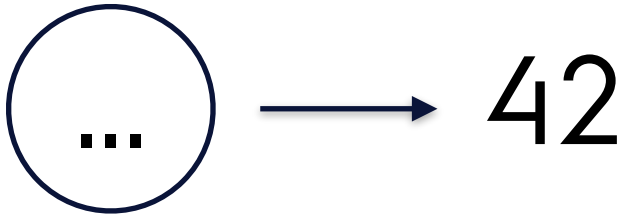

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```
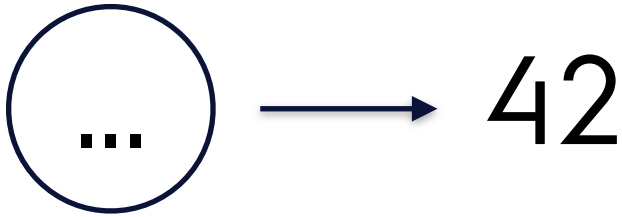

implicit parameter

context search

42

Labeled H Int



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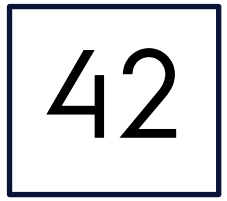

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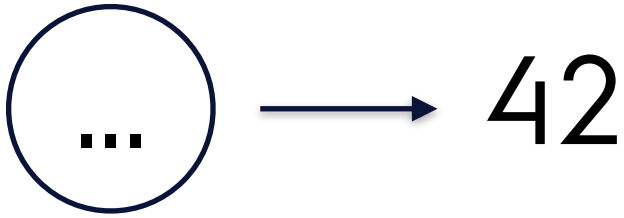

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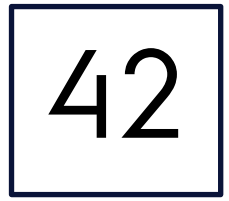

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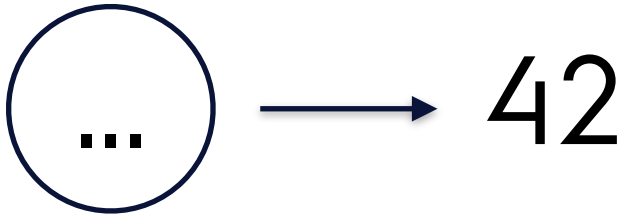

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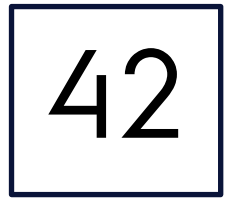

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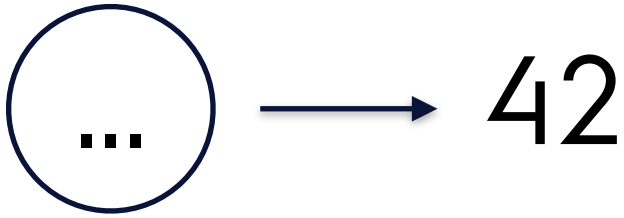

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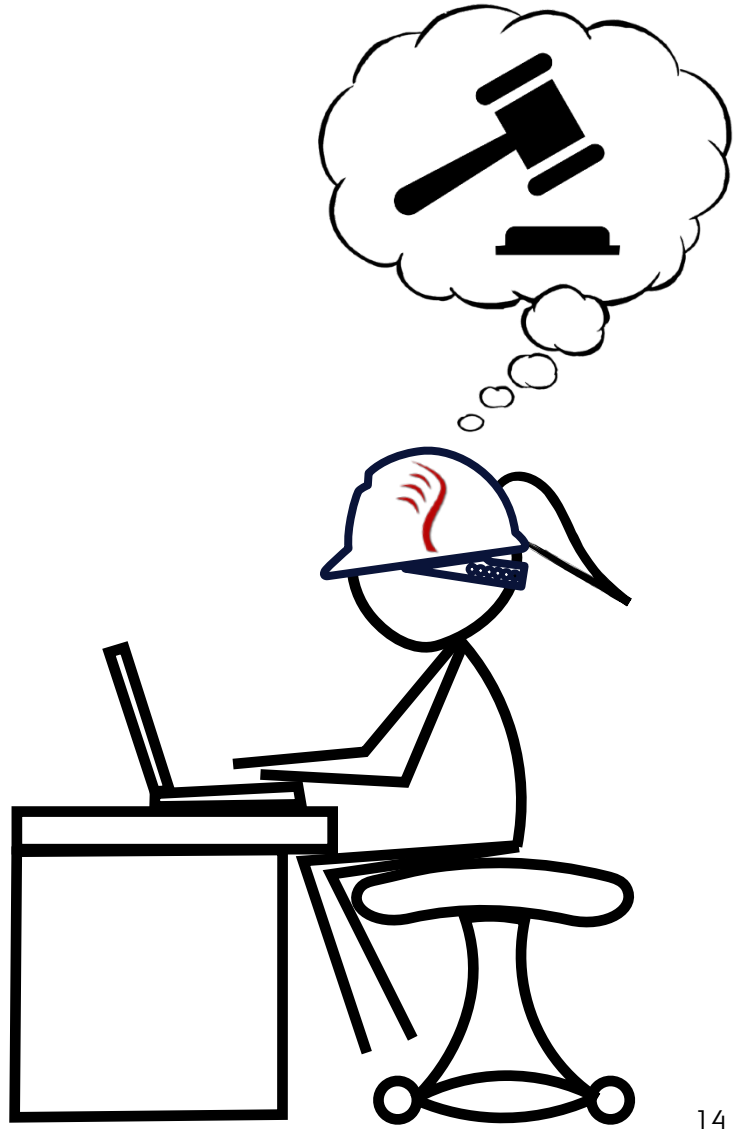
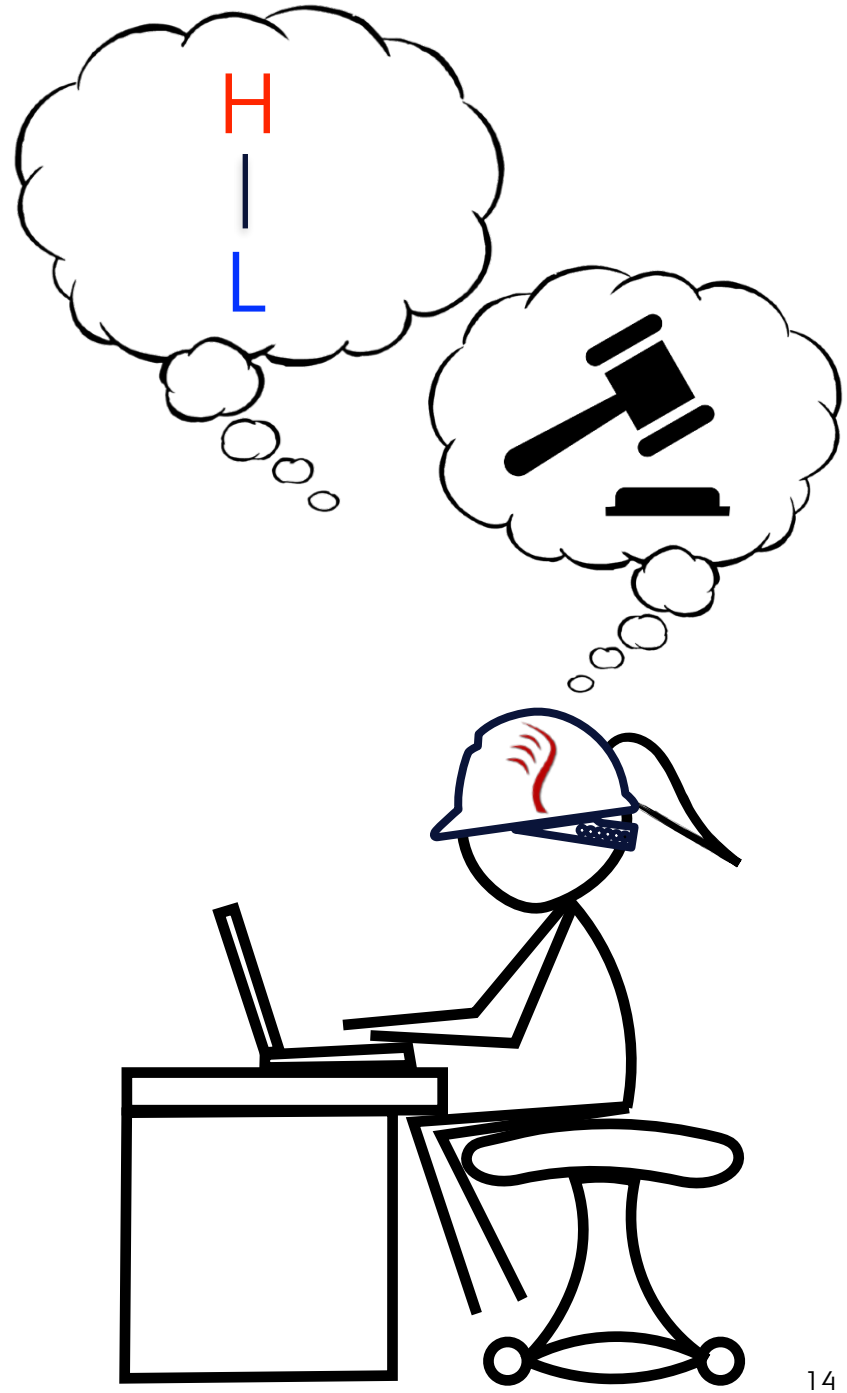
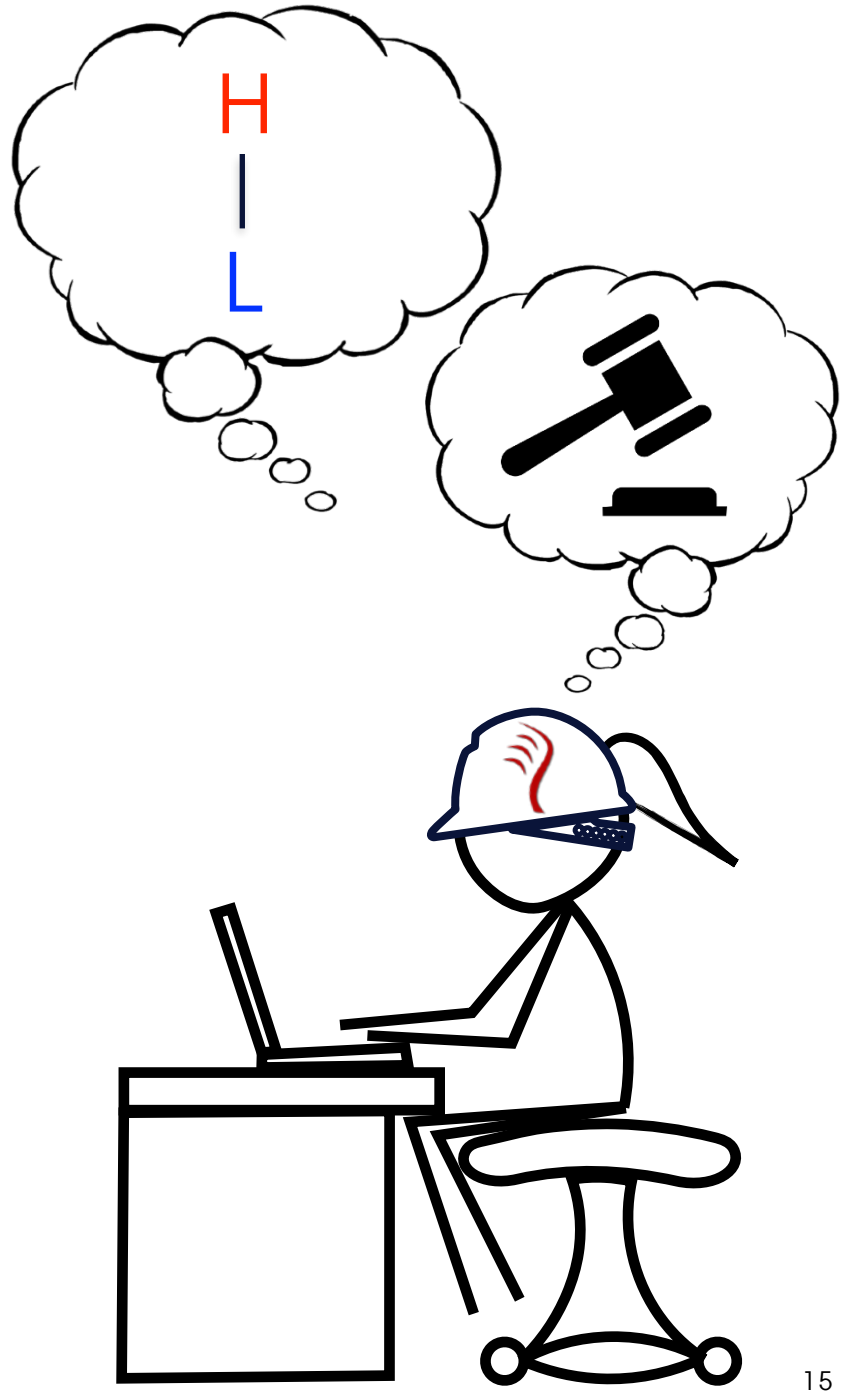
       -> Labeled l a
       -> Labeled l' a
```




H
I
L

AUCTION REQUIREMENTS

- Bids should be confidential
- Only winning bid should be disclosed
- Alice will put as little effort as possible into this project



AUCTION I - SETUP

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```
data TwoPoint = H | L

implementation JoinSemilattice TwoPoint where
  -- ...
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User = Nat

Bid : Type
Bid = (User, Nat)
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BidLog : Nat -> Type
BidLog n = Vect n (Labeled H Bid)
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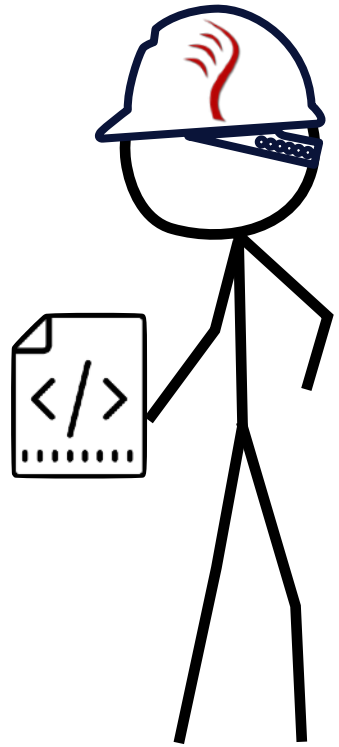
AUCTION I



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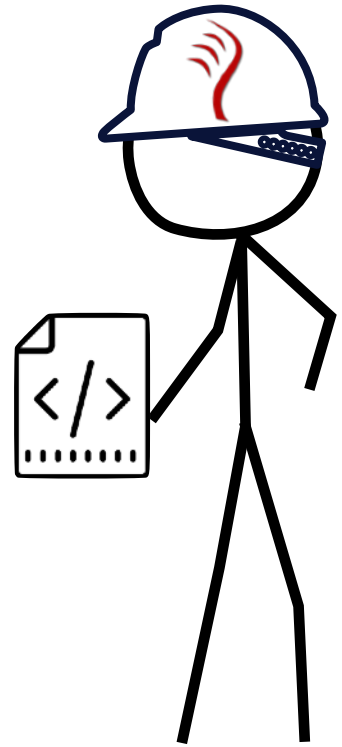

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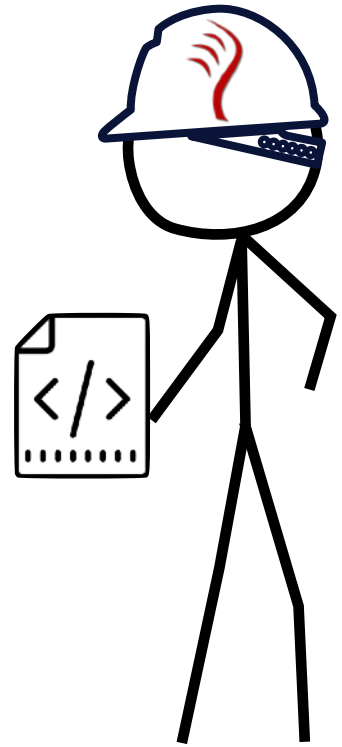

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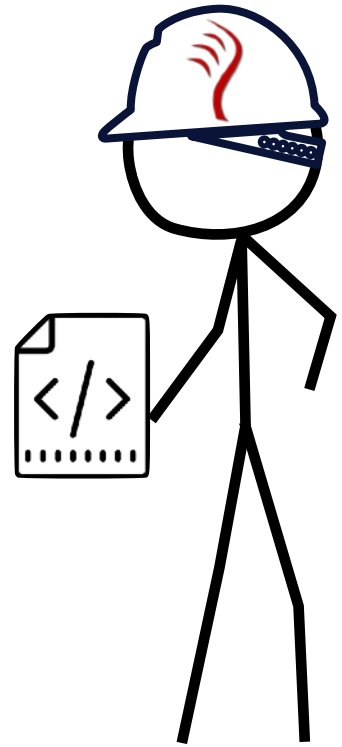

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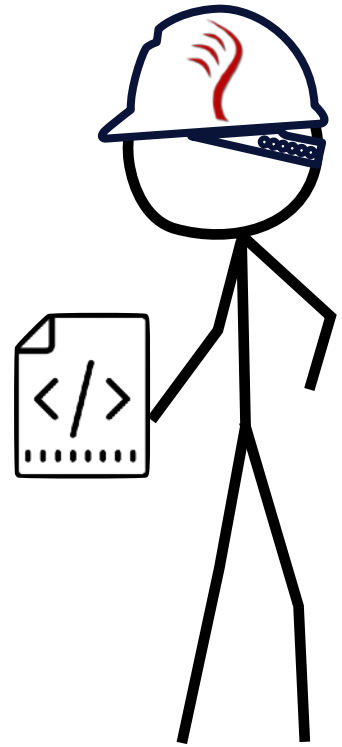

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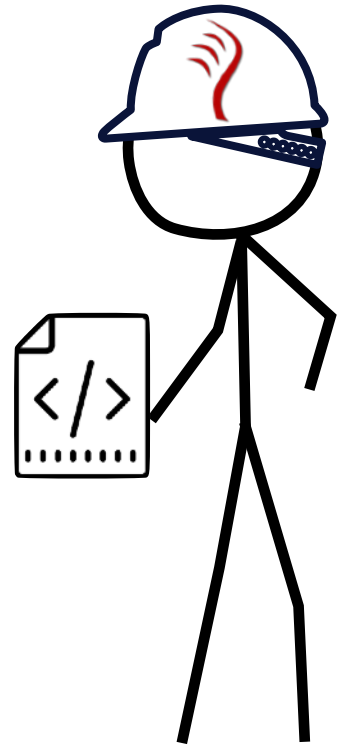

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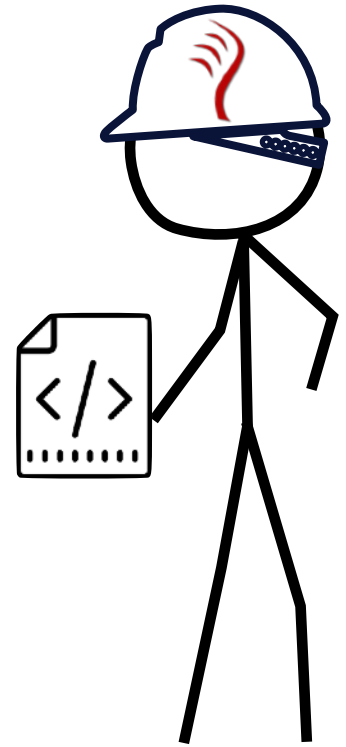

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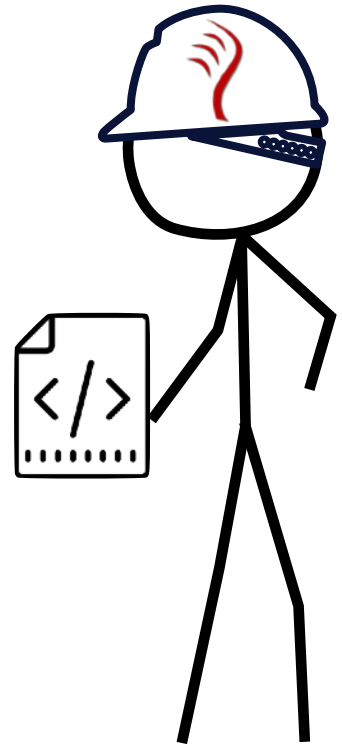

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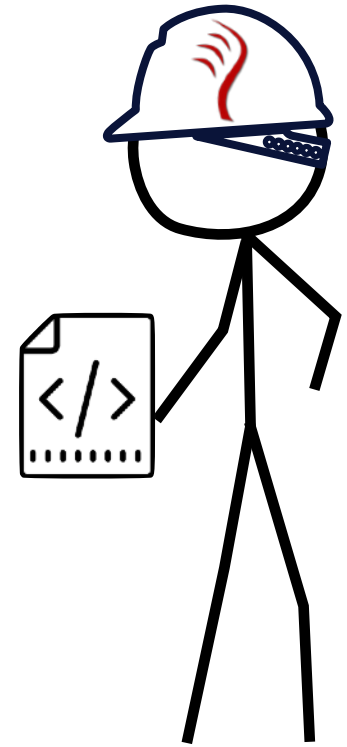

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getWinner : BidLog (S n) -> DIO L (Labeled H Bid)
getWinner log = plug $ computeMaxBid log
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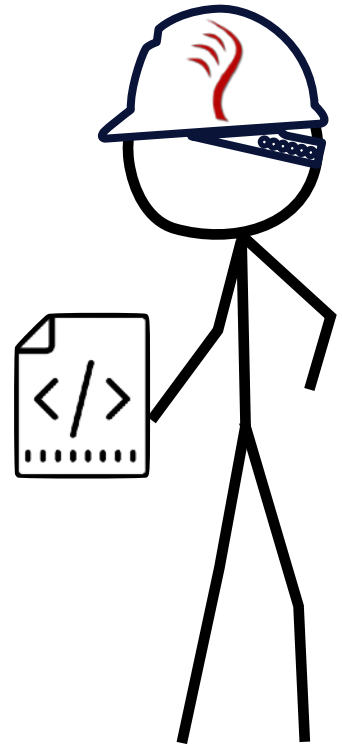

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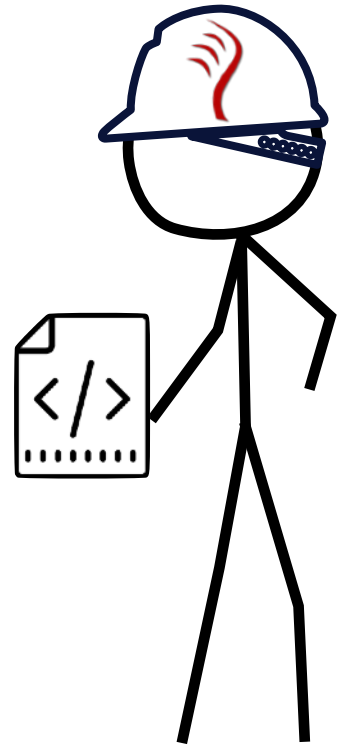

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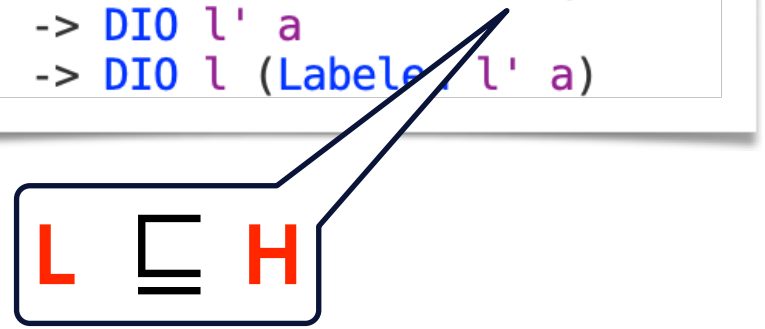


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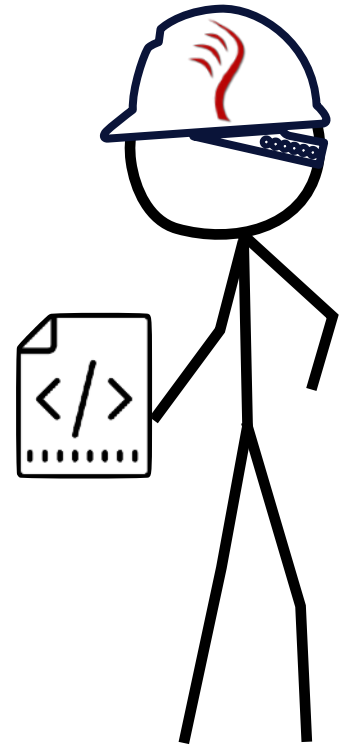

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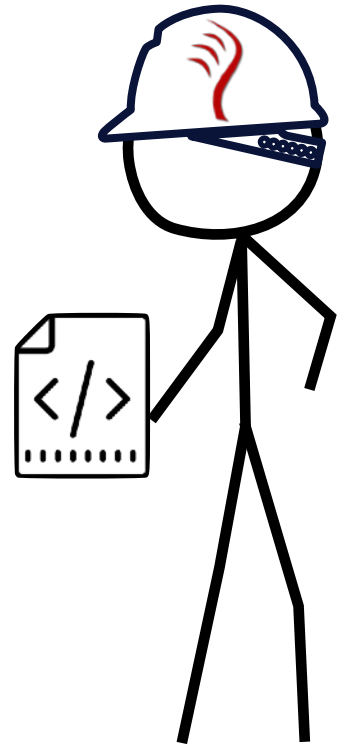

AUCTION I

```
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main =
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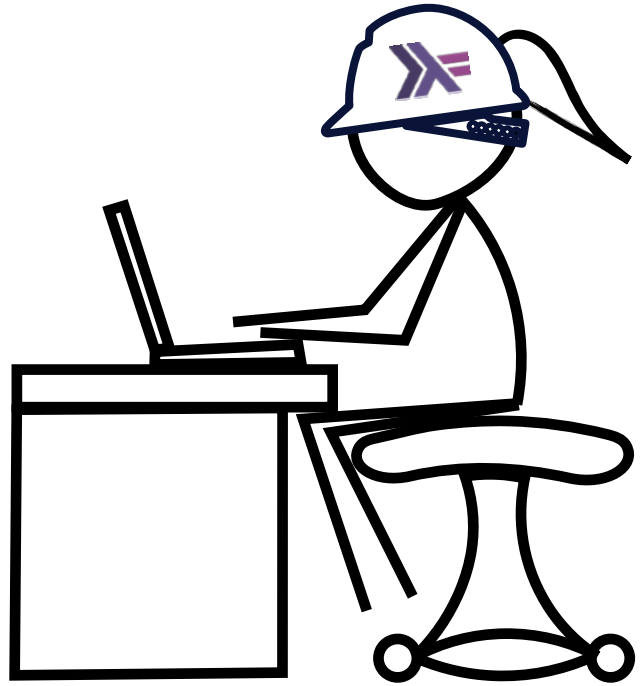

AUCTION II - SETUP

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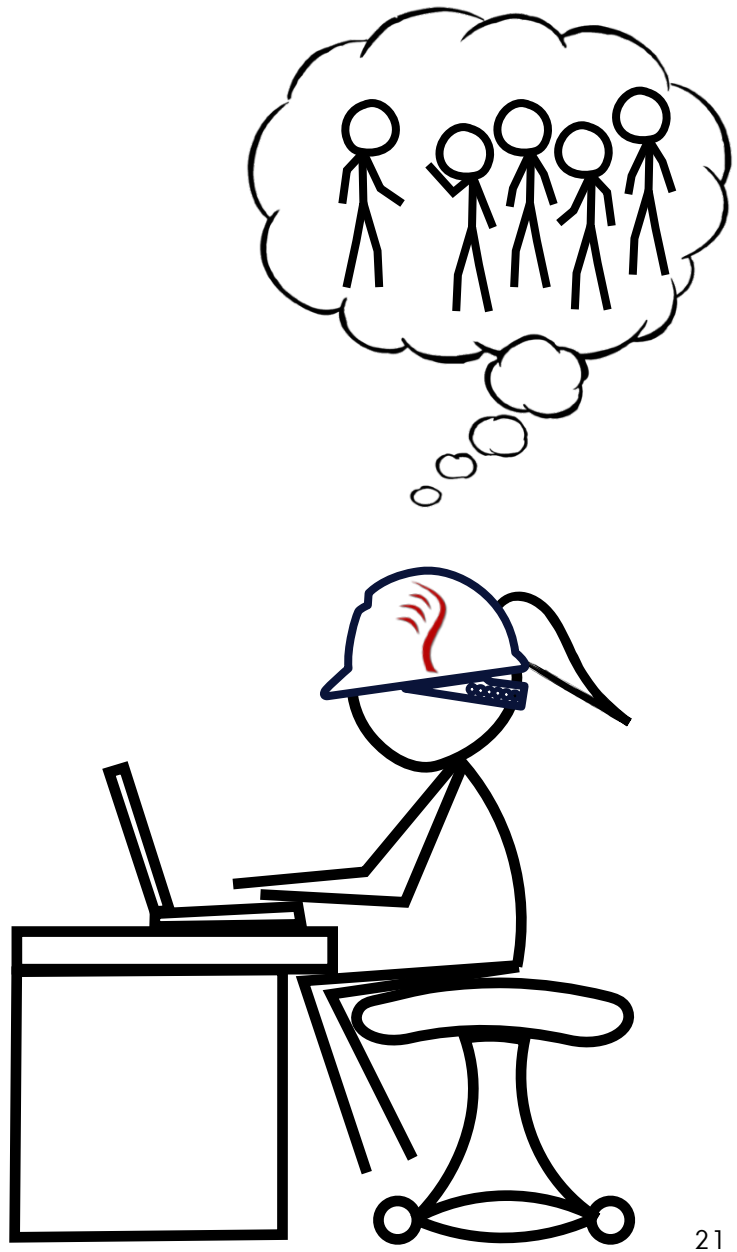

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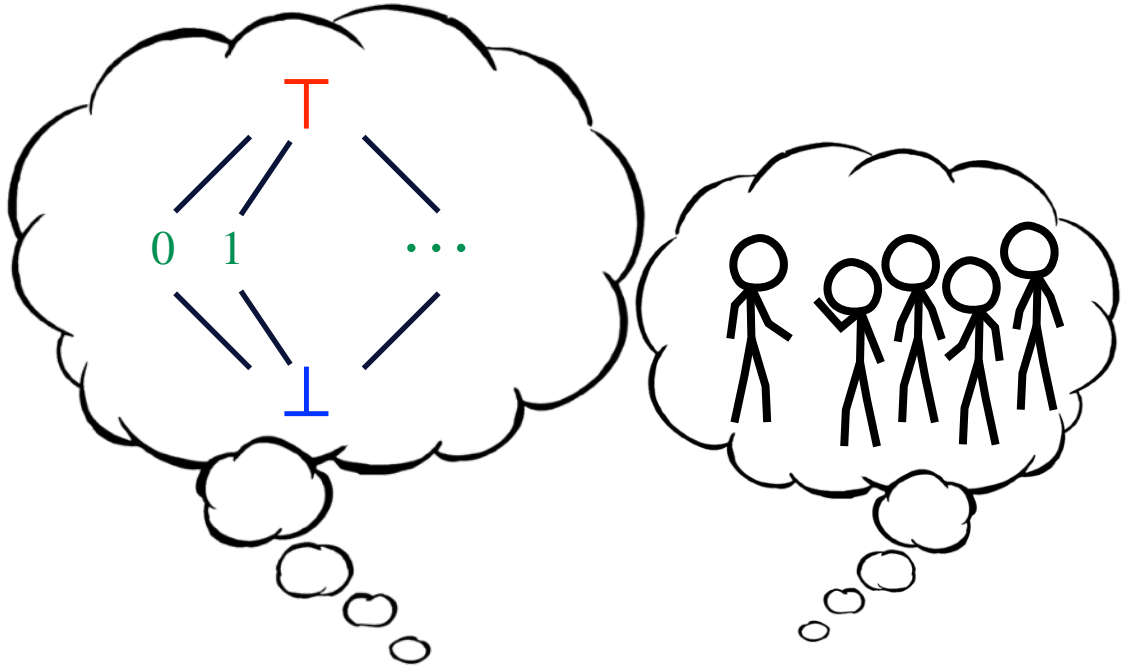

AUCTION II - SETUP

```
data Label : Type where
  Top  : Label
  U    : Nat -> Label
  Bot  : Label

implementation JoinSemilattice Label where
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implementation BoundedJoinSemilattice Label where
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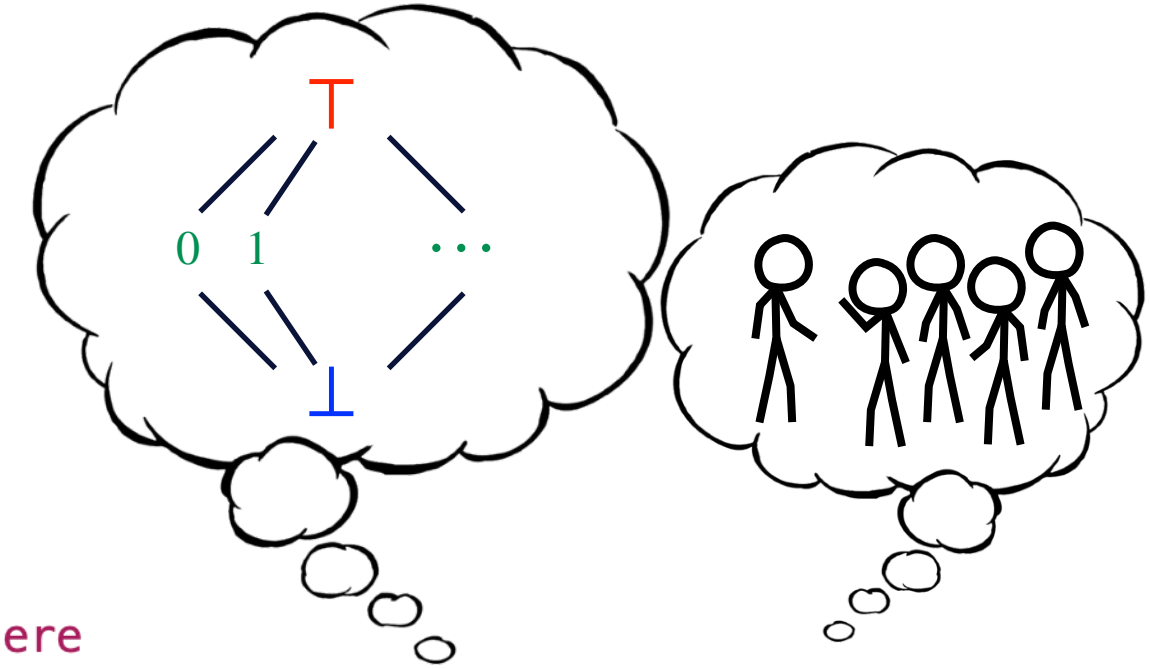

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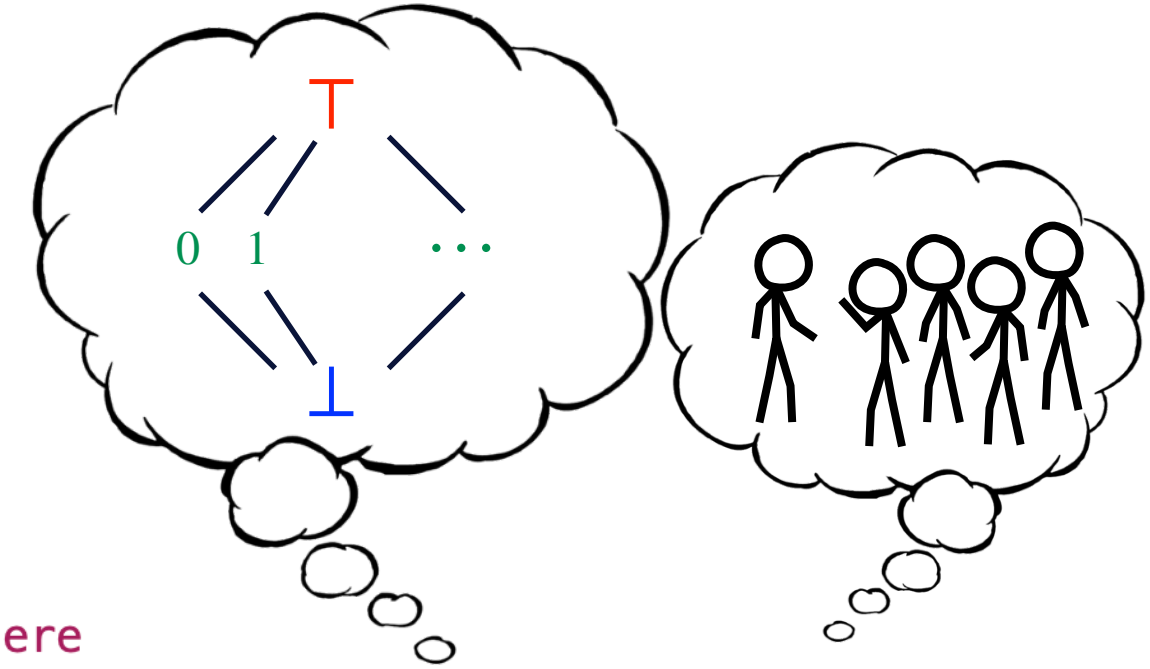
LabeledBid : Type
LabeledBid = (l : Label ** Labeled l Bid)

BidLog : Nat -> Type
BidLog n = Vect n LabeledBid
```



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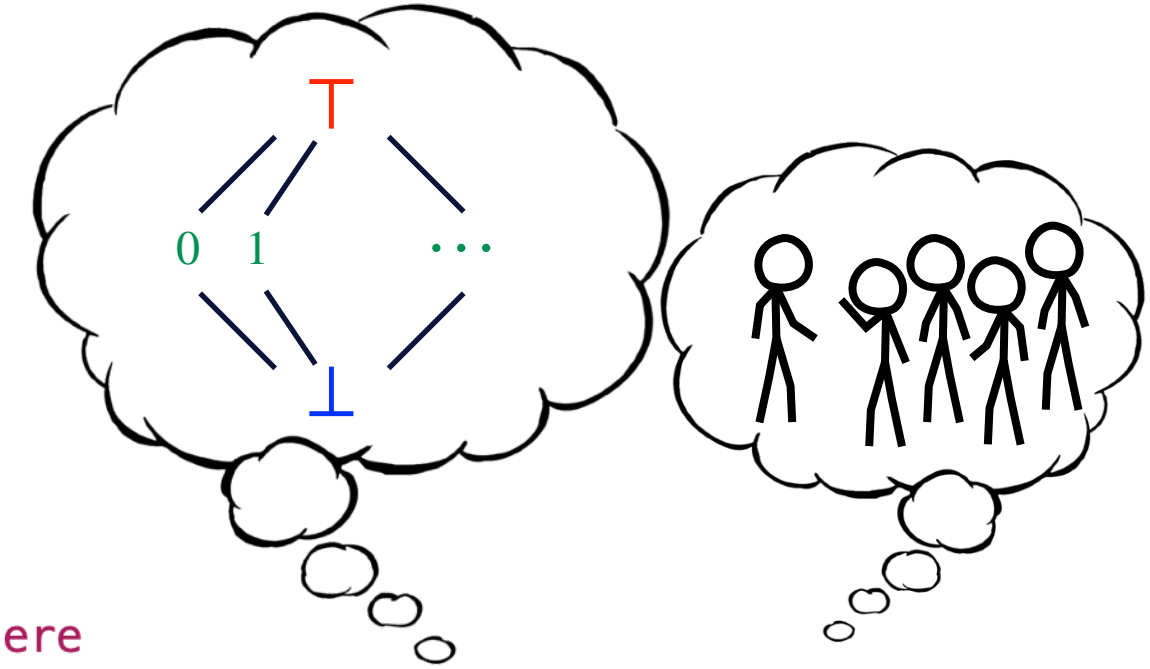
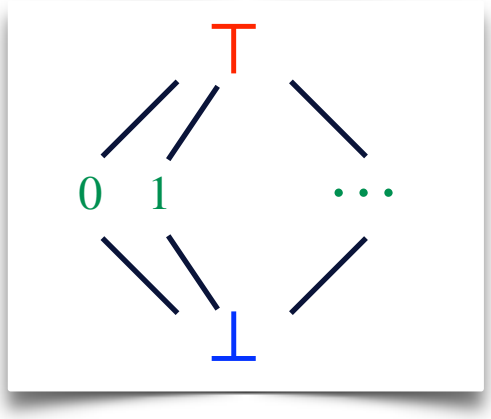
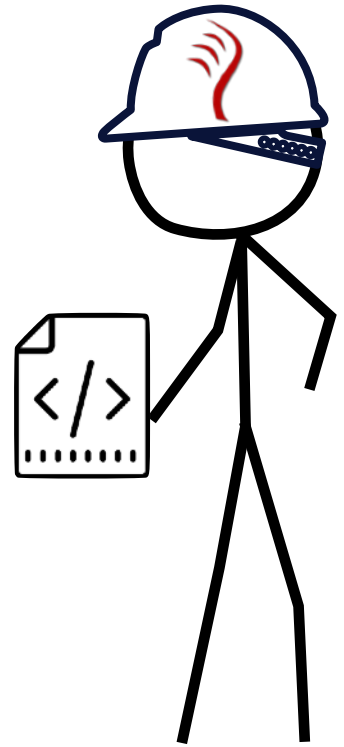
$\exists l$: Label . Labeled l Bid



AUCTION II





AUCTION II

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     plug $ maxLabeledBid bid' tail'
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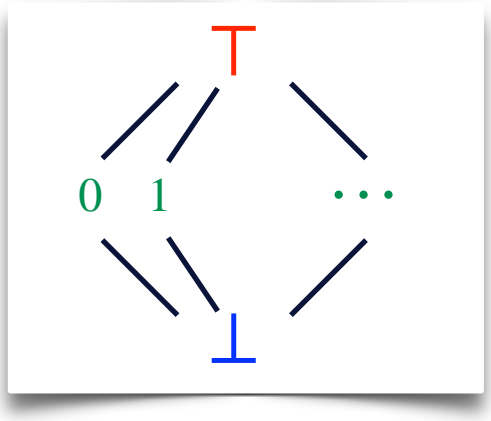

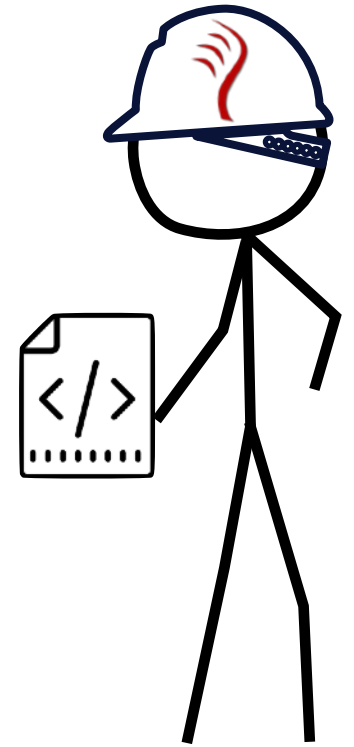

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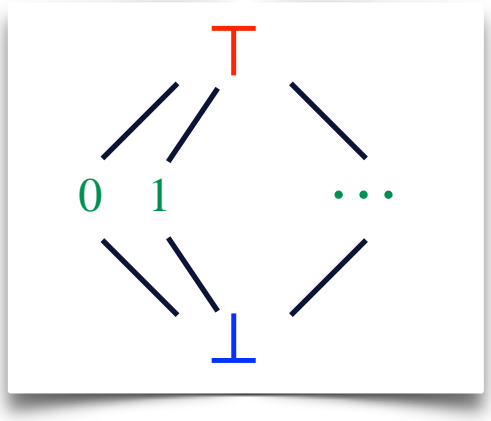

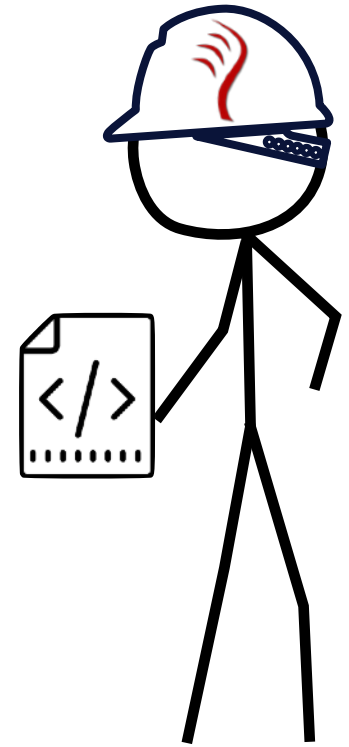

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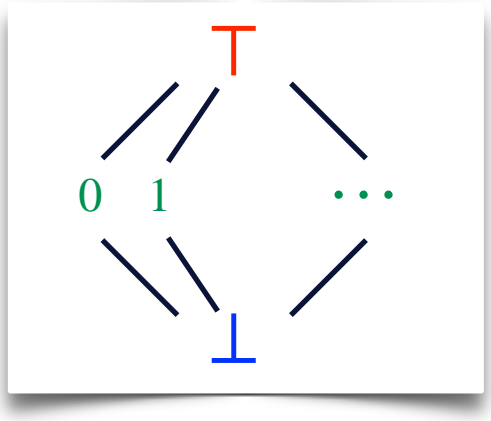

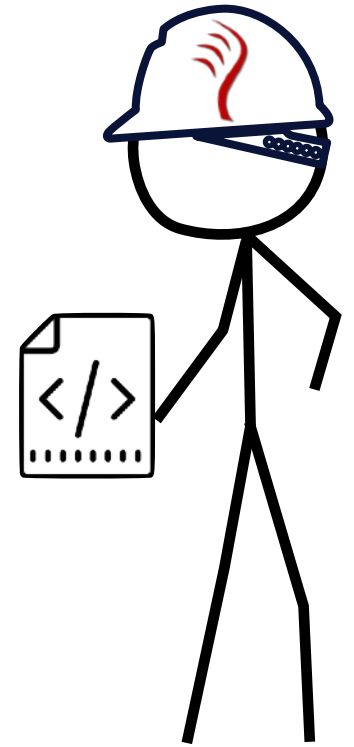

AUCTION II

```
relabel : Poset labelType
       => {l, l' : labelType}
       -> {auto flow : l `leq` l'}
       -> Labeled l a
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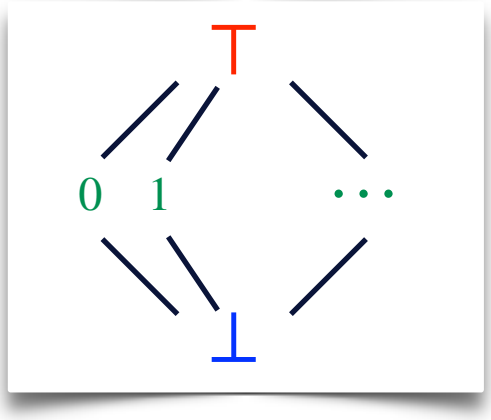

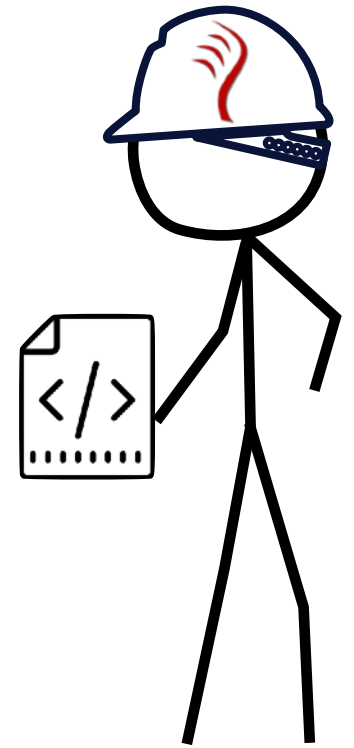

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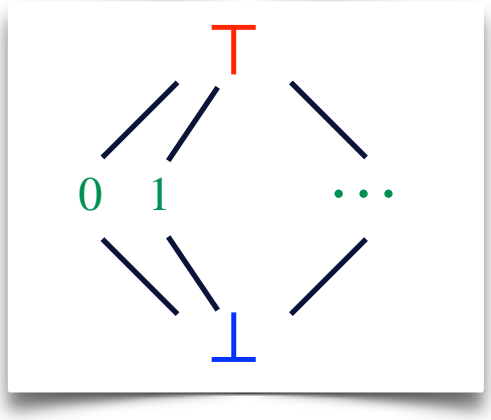

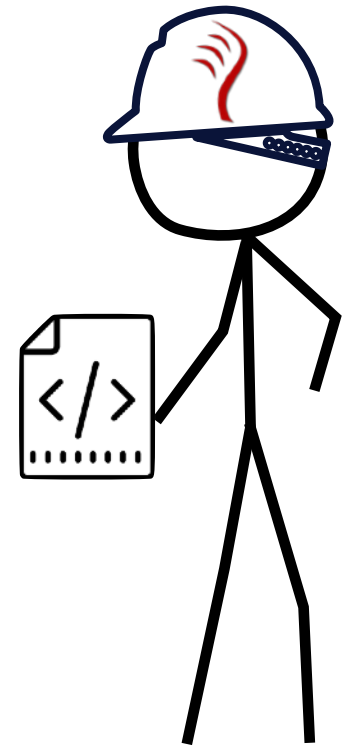

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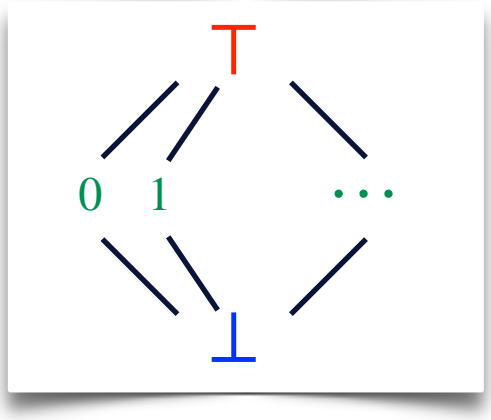

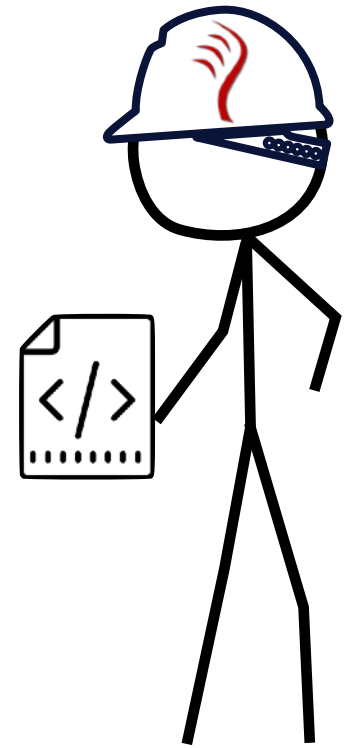

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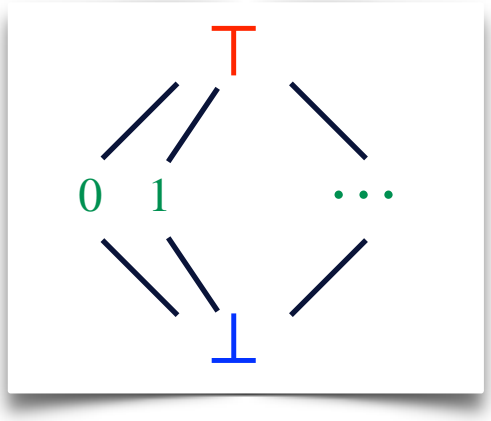
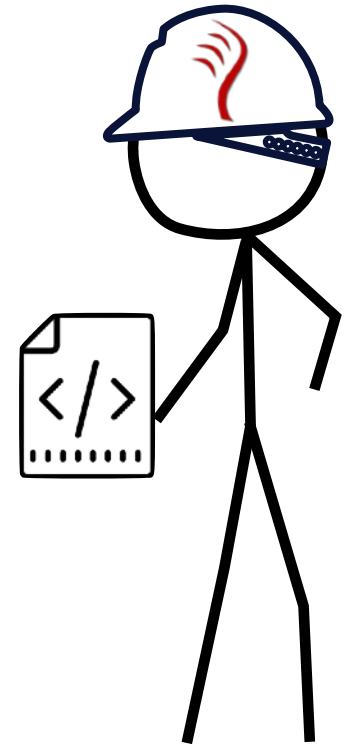
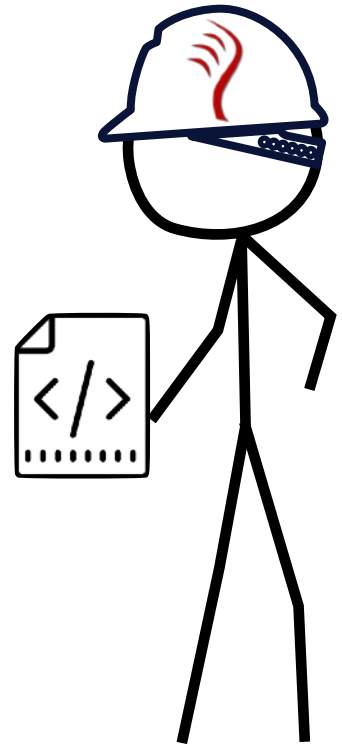




AUCTION II CONT'D

```
joinLabels : BoundedJoinSemilattice lt
          => Vect n (l : lt ** Labeled l a)
          -> lt
joinLabels [] = Bottom
joinLabels ((l ** _) :: xs) = join l $ joinLabels xs
```



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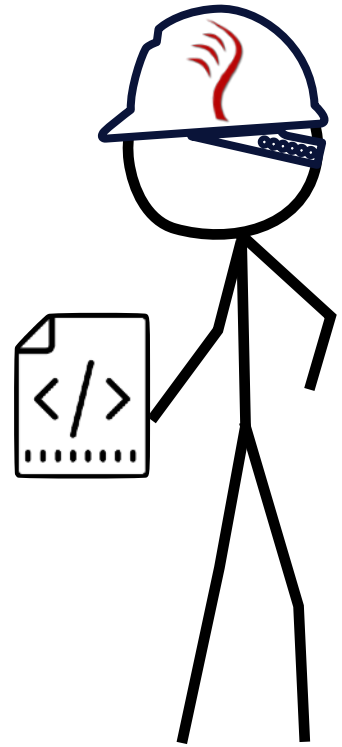
          -> lt
joinLabels [] = Bottom
joinLabels ((l ** _) :: xs) = join l $ joinLabels xs



getWinner' : (log : BidLog (S n))
          -> DIO Bot (Labeled (joinLabels log) Bid)
-- ...
```



AUCTION II CONT'D

```
getWinner'' : BoundedJoinSemilattice a
           => (log : Vect (S n) (l : a ** Labeled l Bid))
           -> DIO (Bottom {a}) (Labeled (joinLabels log) Bid)
-- ...
  where
    maxLabeledBid : Poset a
                 => {z : a}
                 -> Labeled z Bid
                 -> Labeled z Bid
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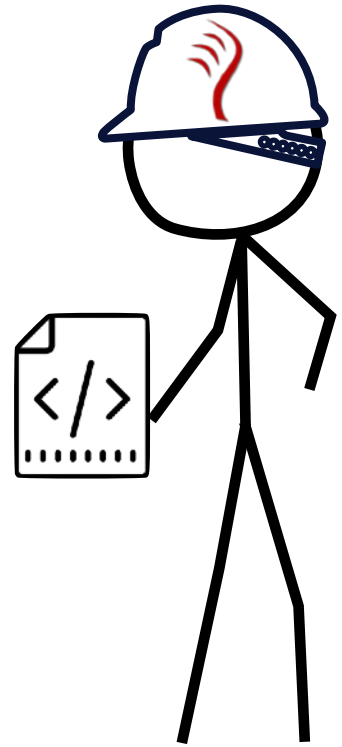
```



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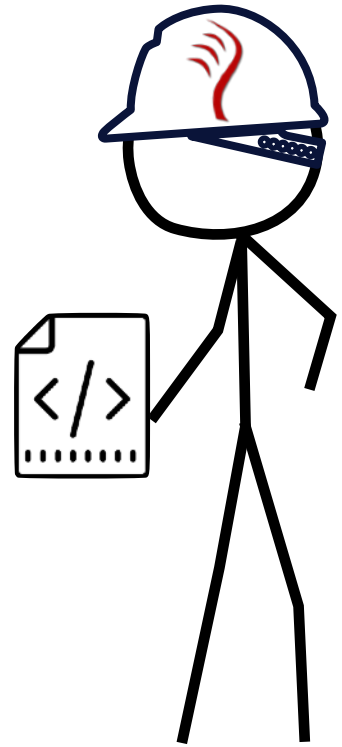

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```
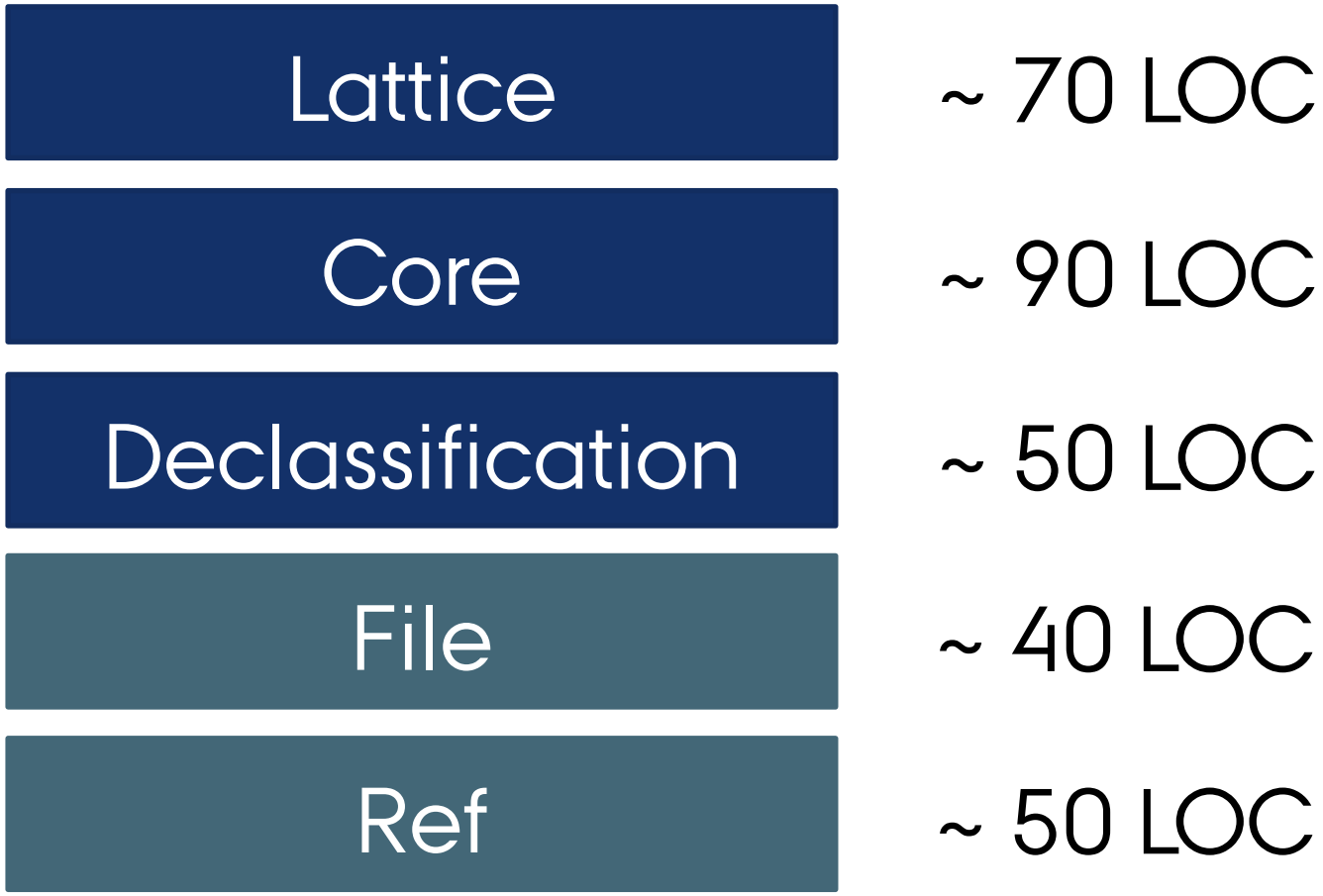

DECLASSIFICATION

- Can’t give full declassification powers to Bob
- Only the winning bid should be declassified
- How to address **what** is declassified?

DepSec - Overview

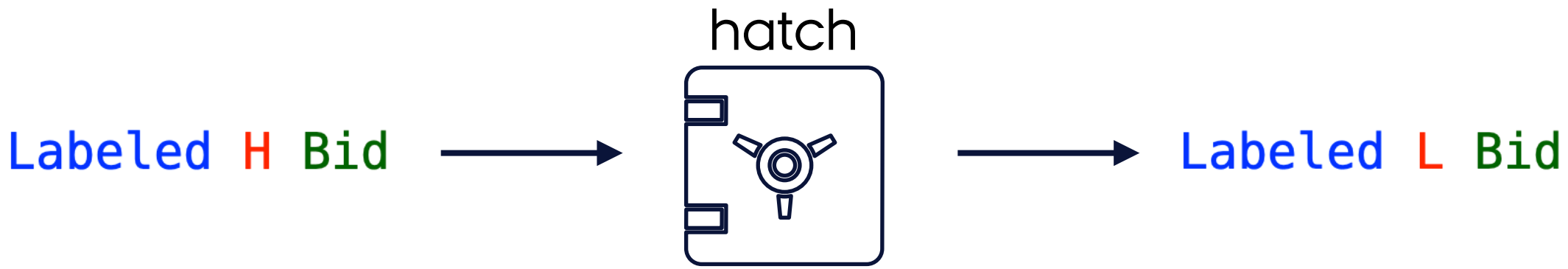


DEPSEC - OVERVIEW

Declassification

~ 50 LOC

ESCAPE HATCHES (Sabelfeld and Myers, 2003)



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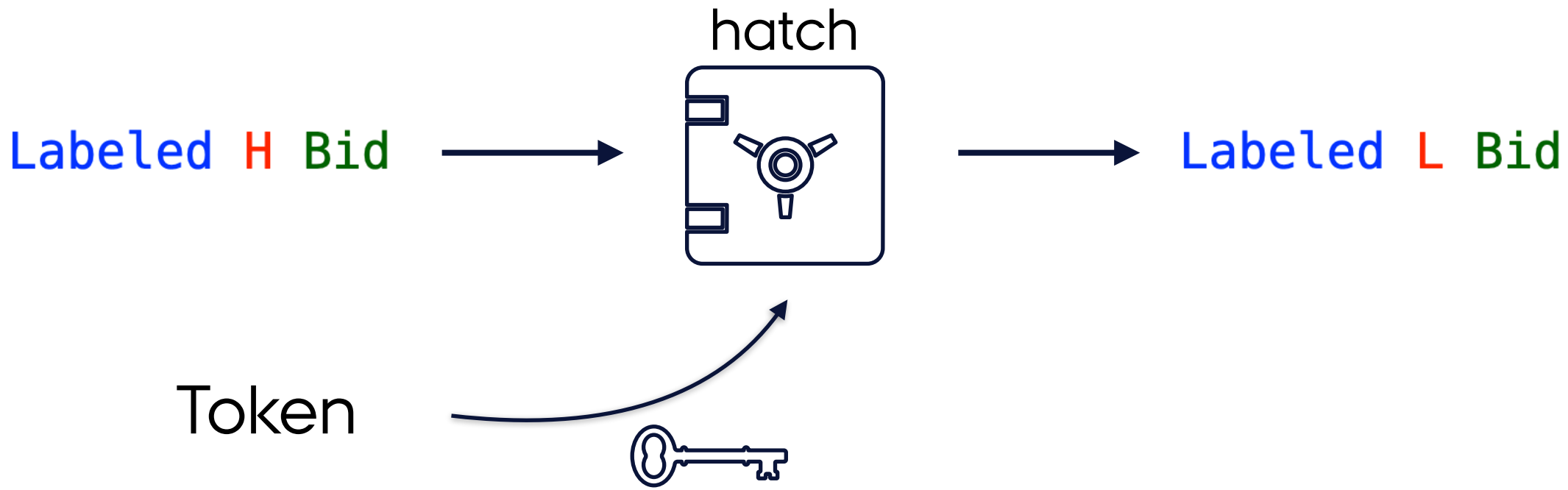

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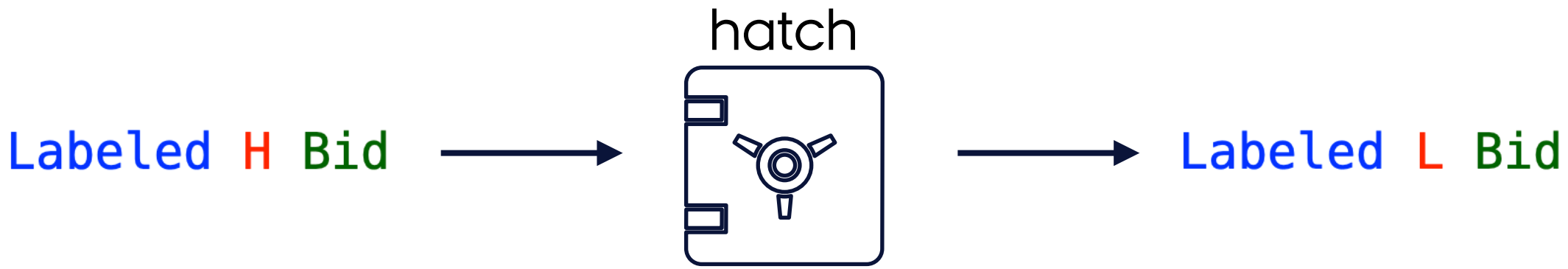

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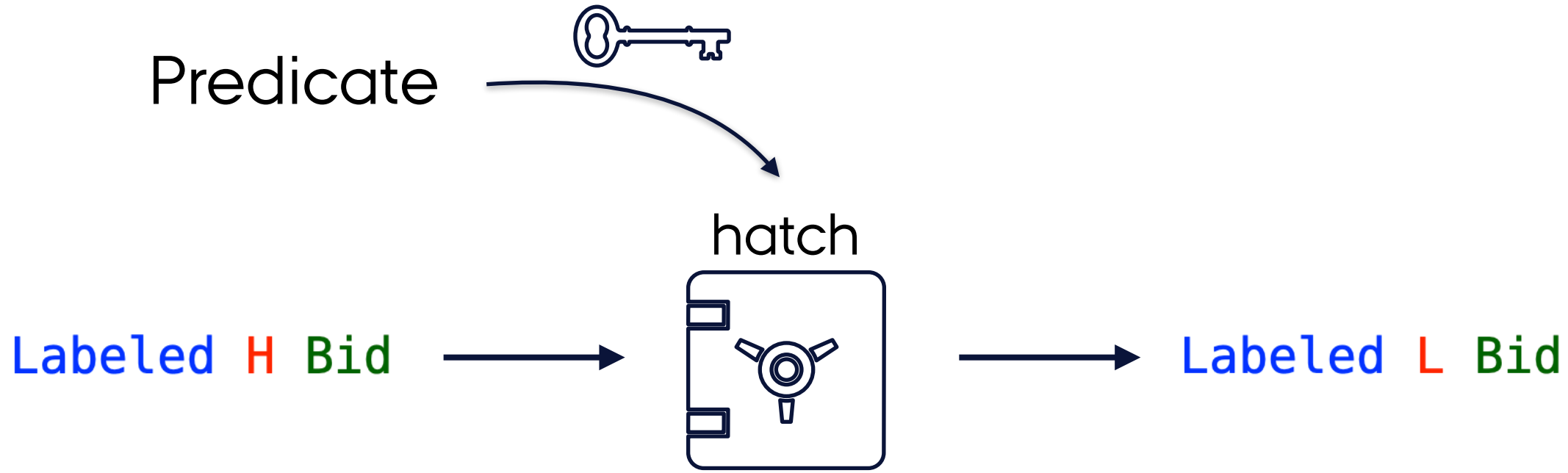

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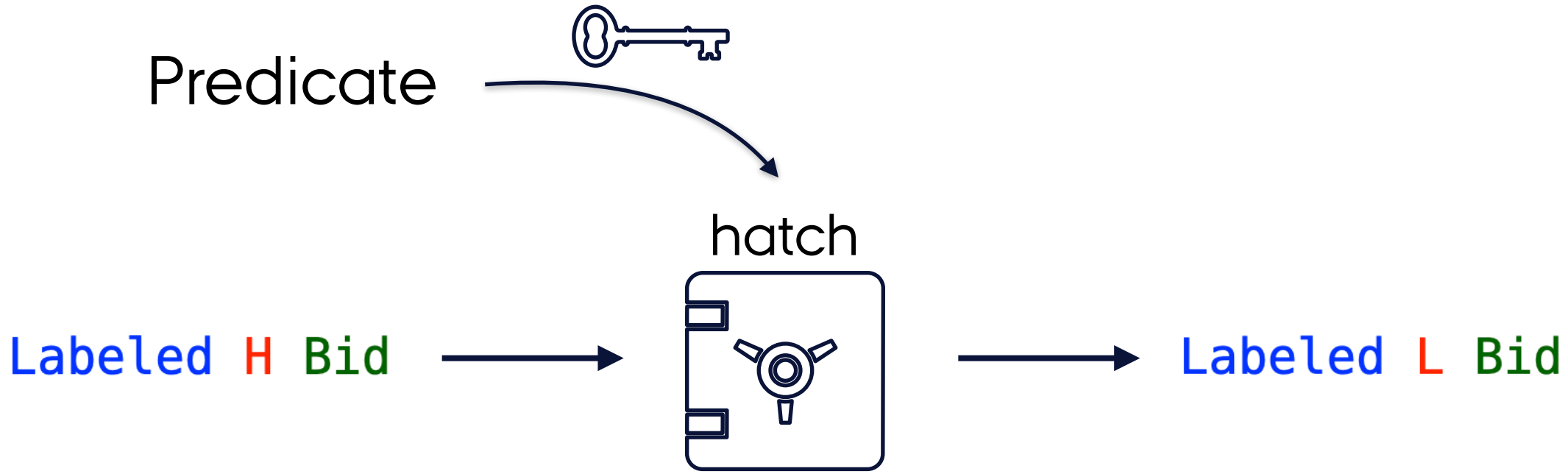


```
Labeled H (b : Bid ** HighestBid rec b) -> Labeled L Bid
```

AUCTION III - SETUP

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```
data Geq : Bid -> Labeled H Bid -> Type where
  -- ...

data MaxBid : Bid -> BidLog n -> Type where
  -- ...
```

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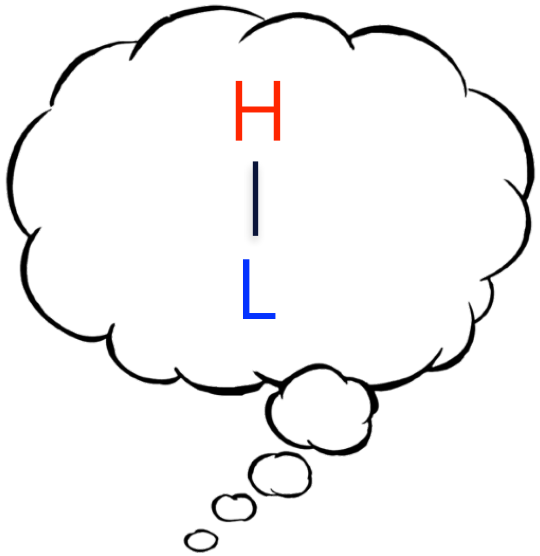
HighestBid : BidLog _ -> Bid -> Type
HighestBid log b = (Elem (label b) log, MaxBid b log)
```



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```

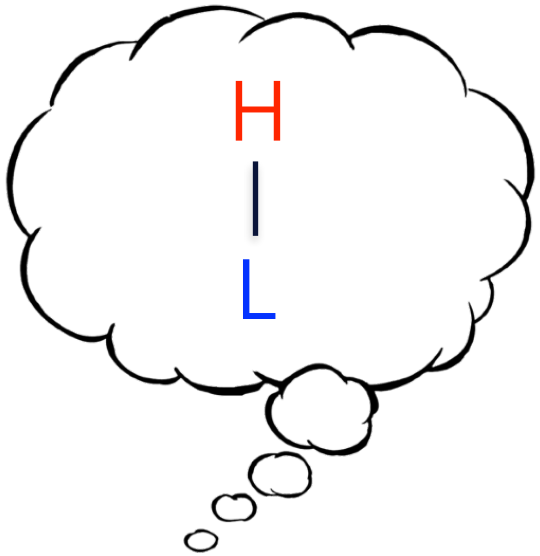

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data MaxBid : Bid -> BidLog n -> Type where
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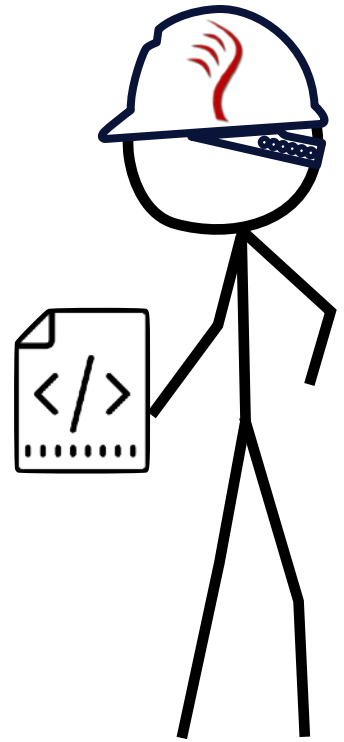
HighestBid : BidLog _ -> Bid -> Type
HighestBid log b = (Elem (label b) log, MaxBid b log)

HighestBidHatch : BidLog _ -> Type
HighestBidHatch log =
  Labeled H (b : Bid ** HighestBid log b) -> Labeled L Bid

printBid : Labeled L Bid -> DIO L ()
```

AUCTION III

```
auction : (log : BidLog (S n) ** HighestBidHatch log) -> DIO L ()
auction (bids ** hatch) =
     do max <- plug $ getMaxBid bids
        let max' : Labeled L Bid = hatch max
        printBid max'
  where
    getMaxBid : (r : BidLog (S n))
             -> DIO H (b : Bid ** HighestBid r b)
```



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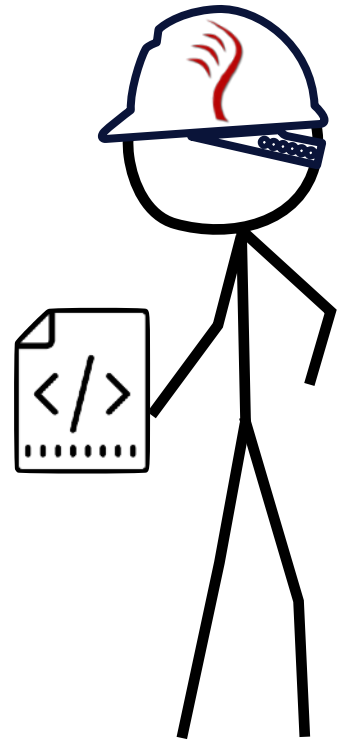

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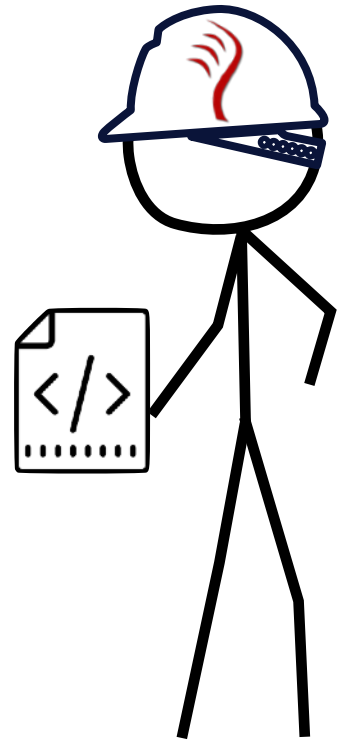

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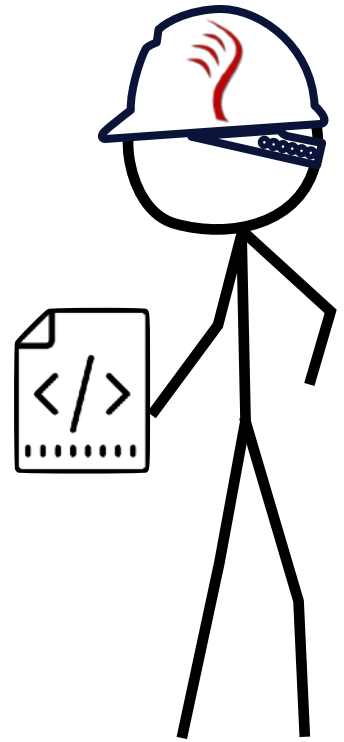

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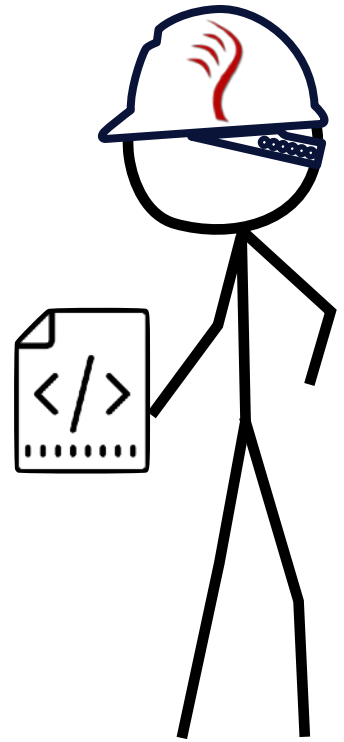

AUCTION III

```
plug : Poset labelType
    => {l,l' : labelType}
    -> {auto flow : l `leq` l'}
    -> DIO l' a
    -> DIO l (Labeled l' a)
```

```
auction : (log : BidLog (S n) ** HighestBidHatch log) -> DIO L ()
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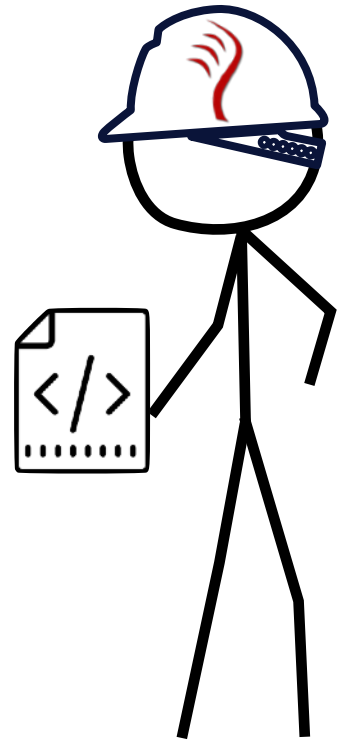

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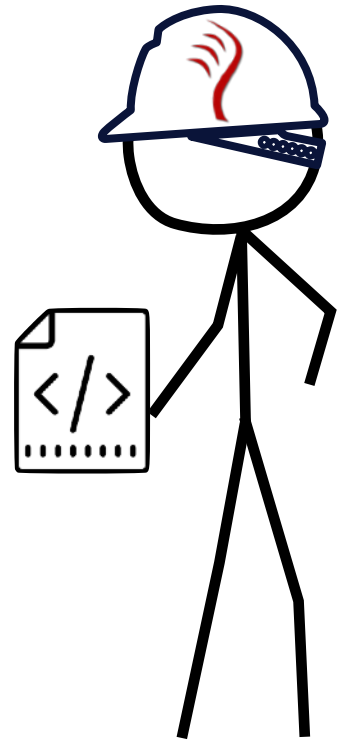

AUCTION III

```
HighestBidHatch : BidLog _ -> Type
HighestBidHatch log =
  Labeled H (b : Bid ** HighestBid log b) -> Labeled L Bid
```

```
auction : (log : BidLog (S n) ** HighestBidHatch log) -> DIO L ()
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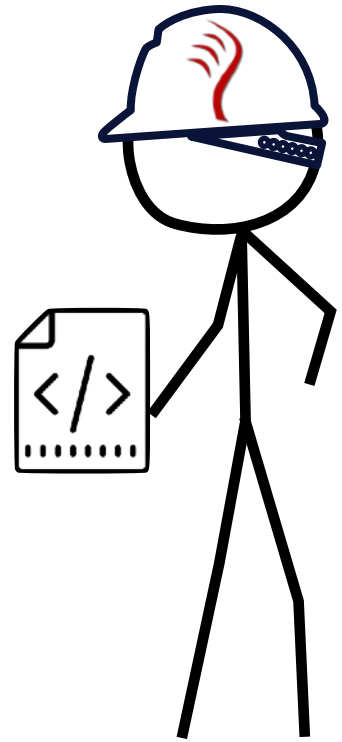

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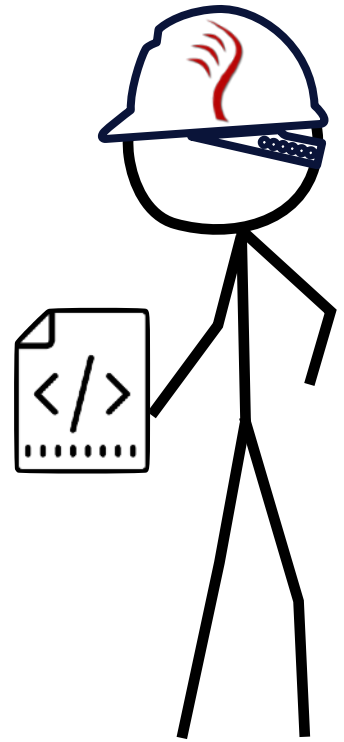


AUCTION III

```
main : IO ()
main =
  do putStrLn "##### Welcome to the auction! #####"
     putStrLn "Taking bids:"
     let log : BidLog _ = [!getBid, !getBid]
     run $ auction (predicateHatch log HighestBid)
     putStrLn "##### Bye bye! #####"
```

MORE EXAMPLES

- Time-based hatches
- Authority-based hatches
- Limiting hatch usage

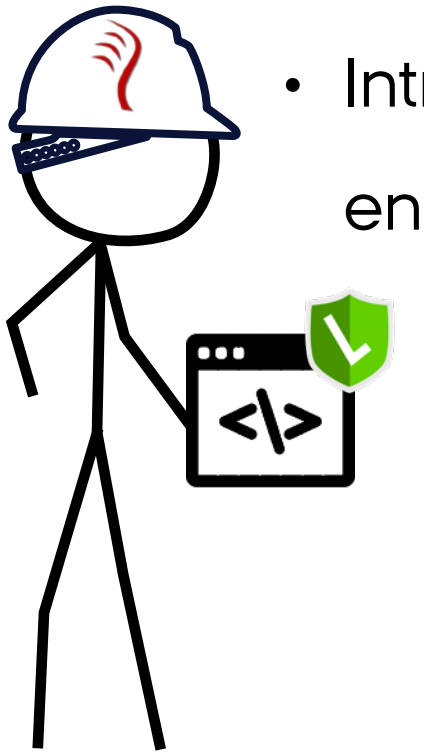
```
pwCheck : Labeled H Int
       -> DIO' L () [attempts ::: Attempts (3 + n) :-> Attempts n]
pwCheck secret =
  do x1 <- hatch secret 1
     x2 <- hatch secret 2
     x3 <- hatch secret 3
     x4 <- hatch secret 4 -- type error!
     pure ()
```

SECURITY GUARANTEES

Theorem 1 (PINI). *If* $c_1 \approx_{\ell_A} c_2$, $c_1 \Downarrow c_1'$, *and* $c_2 \Downarrow c_2'$ *then* $c_1' \approx_{\ell_A} c_2'$.

CONCLUSION

- **DEPSEC**: a static information-flow control library for Idris
- Showcased how dependent types increase the expressiveness of state-of-the-art information-flow control libraries
- Introduced predicate (and token) hatches for statically enforced declassification



AUCTION IV

- Bids are secret when the auction is ongoing
- When the auction is done, all bids are public
- How to address **when** bids are declassified?

AUCTION IV - SETUP

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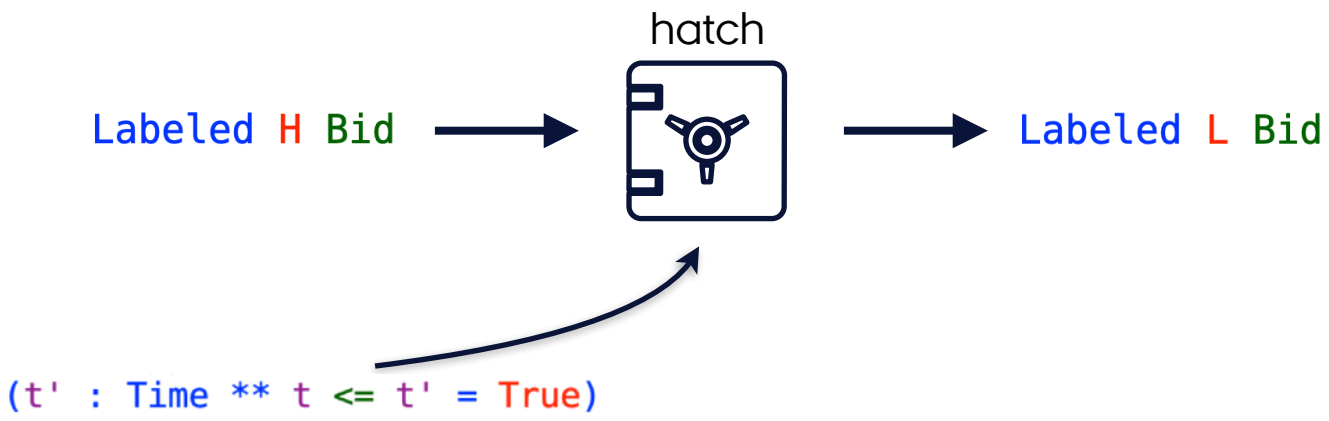
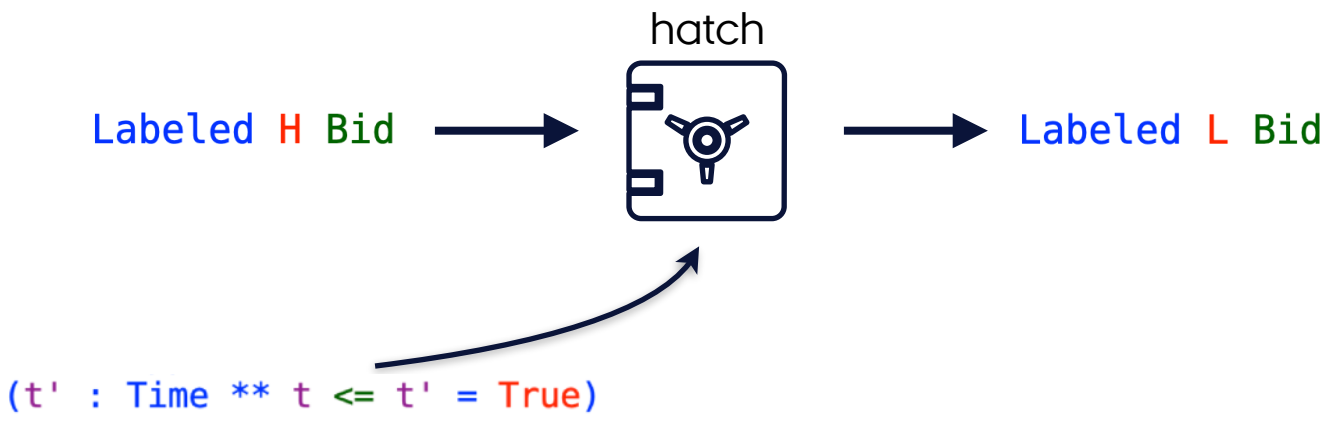


AUCTION IV - SETUP

```
data Time : Type where
  MkTime : (t : Integer) -> Time -- TCB
```



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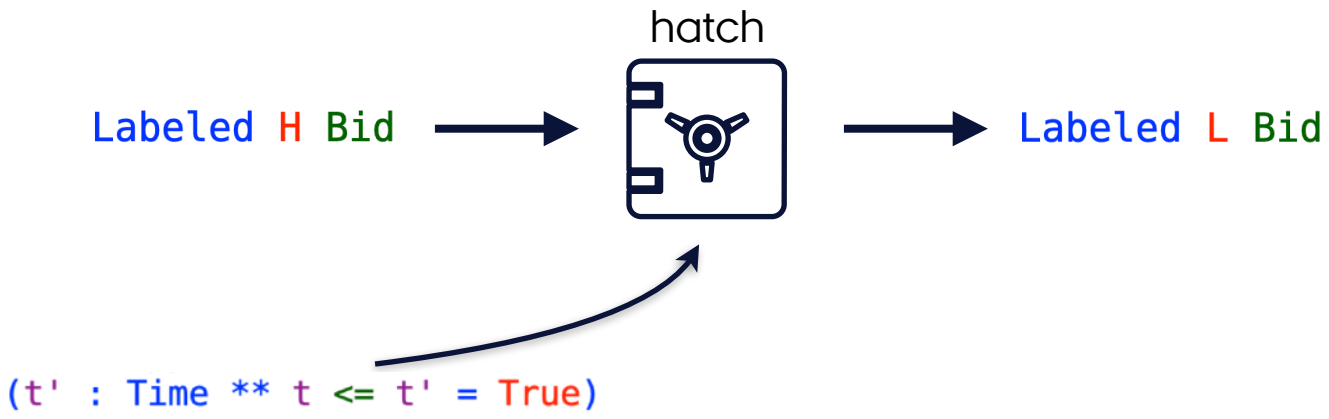

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TimeHatch : Time -> Type
TimeHatch t = (t' : Time ** t <= t' = True) -> Labeled H Bid -> Labeled L Bid
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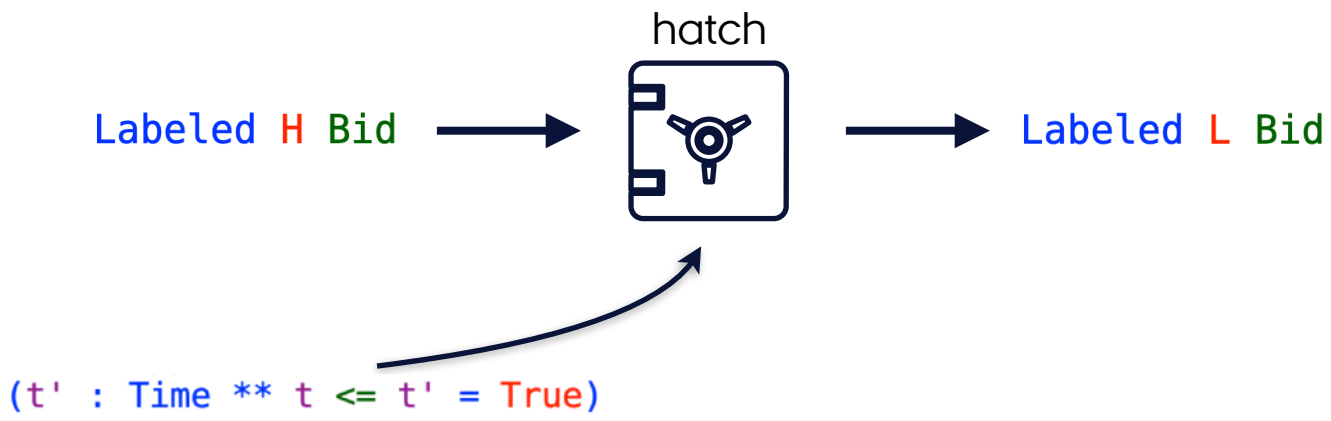

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getWinner : BidLog (S n) -> TimeHatch t -> DIO L ()
getWinner log {t} hatch =
  do winner <- plug $ getMaxBid log
     time <- tick
     case decEq (t <= time) True of
       Yes prf =>
         let declassified : Labeled L Bid = hatch (time ** prf) winner
         in printBid declassified
       No _ => pure () -- auction is not over yet
```

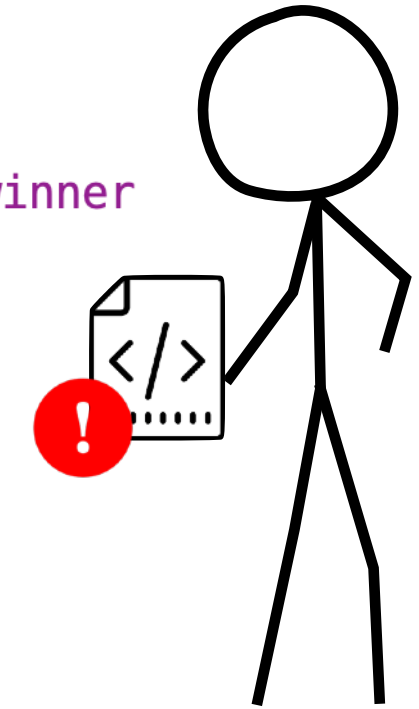

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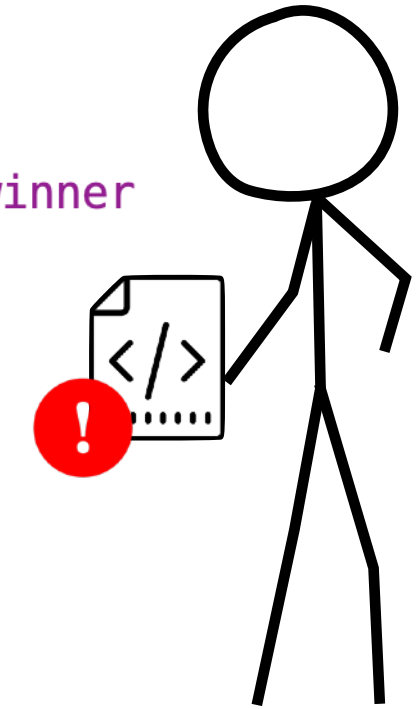

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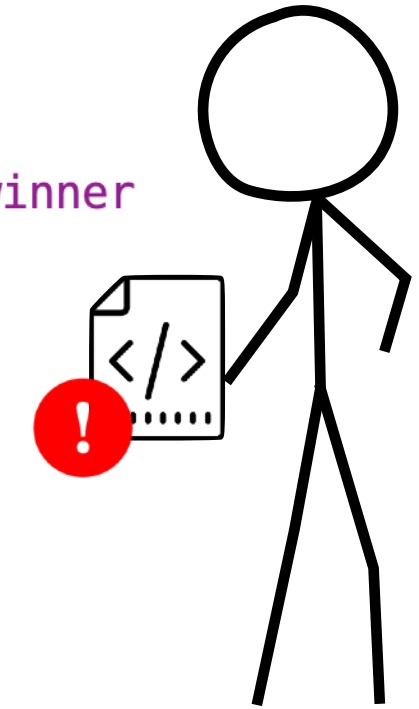

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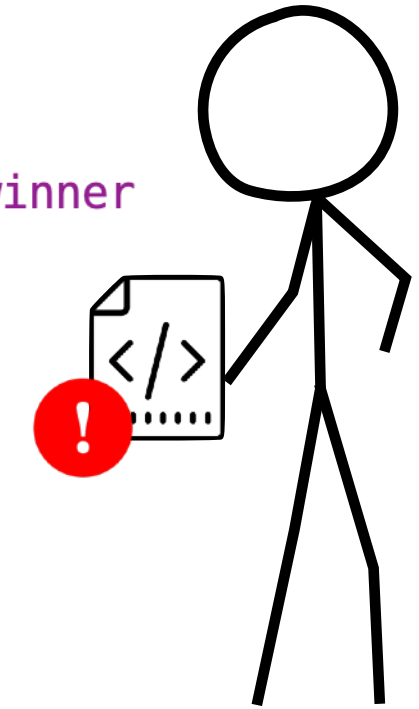

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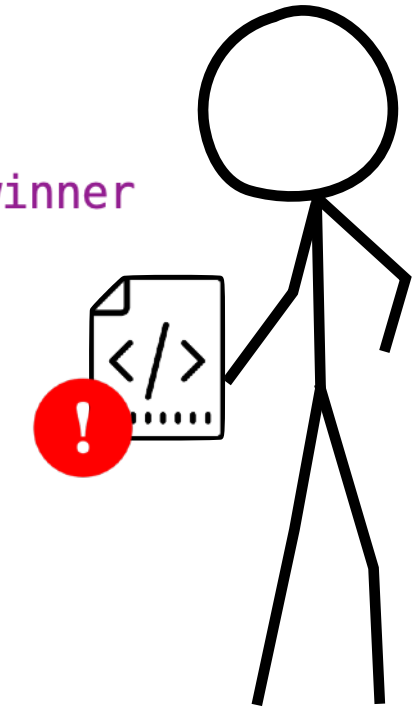

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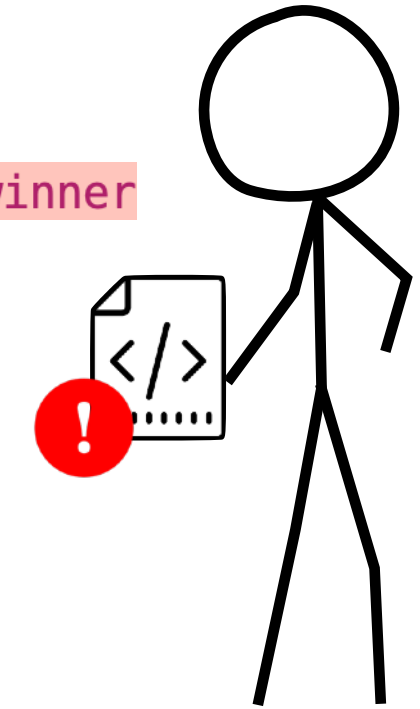

HATCH BUILDERS

```
predicateHatch : Poset labelType
              => {l, l' : labelType}
              -> {D, E : Type}
              -> (d : D)
              -> (P : D -> E -> Type)
              -> (d : D ** Labeled l (e : E ** P d e) -> Labeled l' E)


tokenHatch : Poset labelType
          => {l, l' : labelType}
          -> {E, S : Type}
          -> (Q : S -> Type)
          -> (s : S ** Q s) -> Labeled l E -> Labeled l' E
```

LATTICE

```
interface JoinSemilattice a where
  join        : a -> a -> a
  commutative : (x, y : a) -> x `join` y = y `join` x
  associative : (x, y, z : a) -> x `join` (y `join` z) = (x `join` y) `join` z
  idempotent  : (x : a)       -> x `join` x = x

interface Poset a where
  leq           : a -> a -> Type
  reflexive     : (x : a) -> x `leq` x
  antisymmetric : (x, y : a) -> x `leq` y -> y `leq` x -> x = y
  transitive    : (x, y, z : a) -> x `leq` y -> y `leq` z -> x `leq` z
```