Can’t keep secrets? Use Haskell!

An introduction to Information Flow Libraries

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Utrecht
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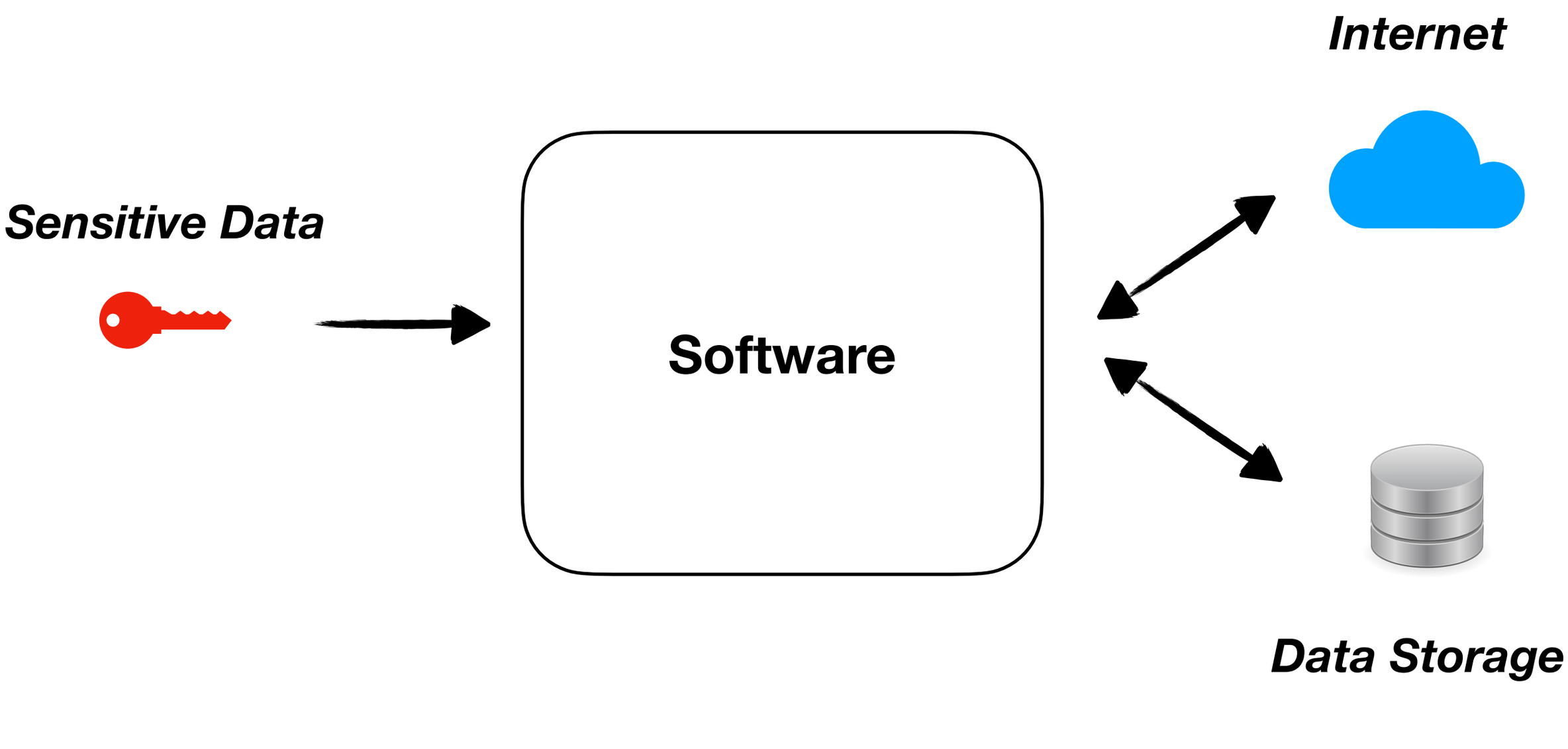
Privacy concerns in software systems



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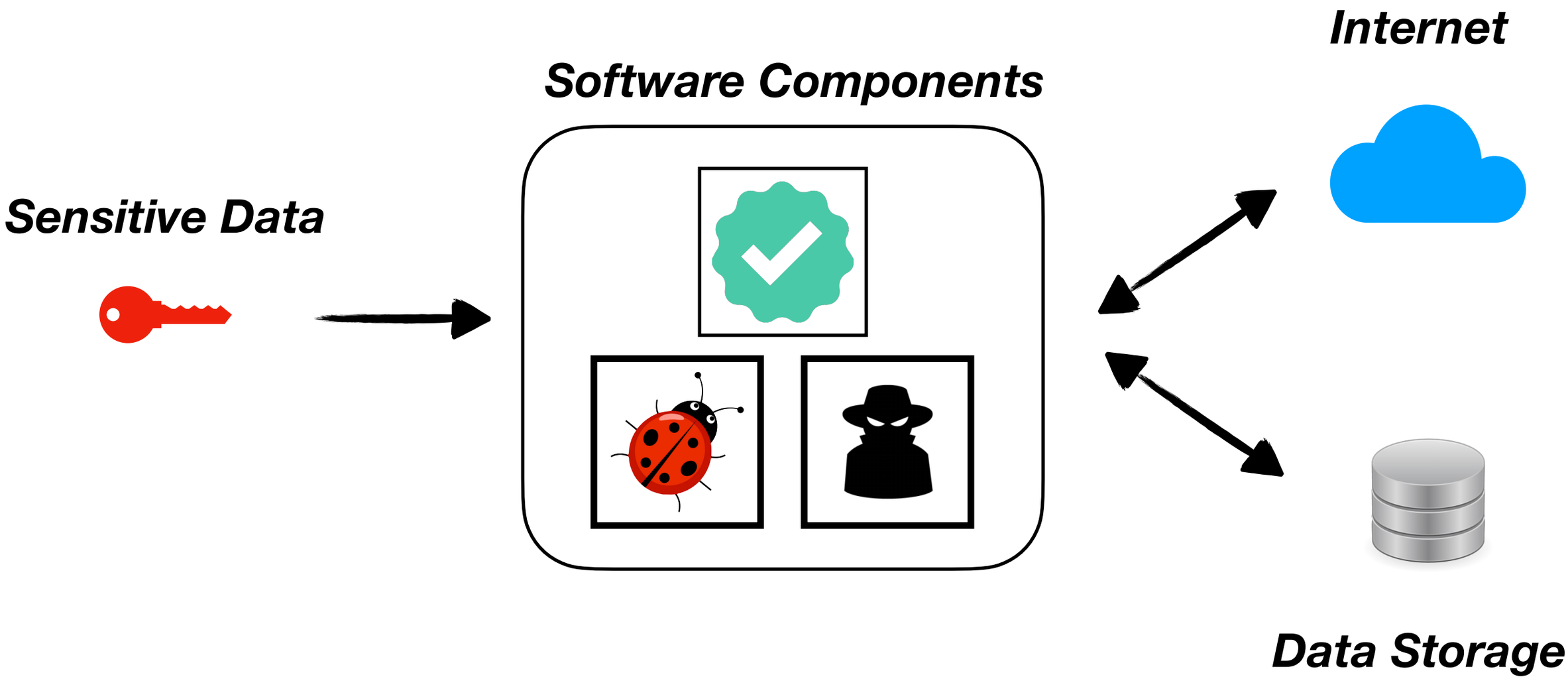

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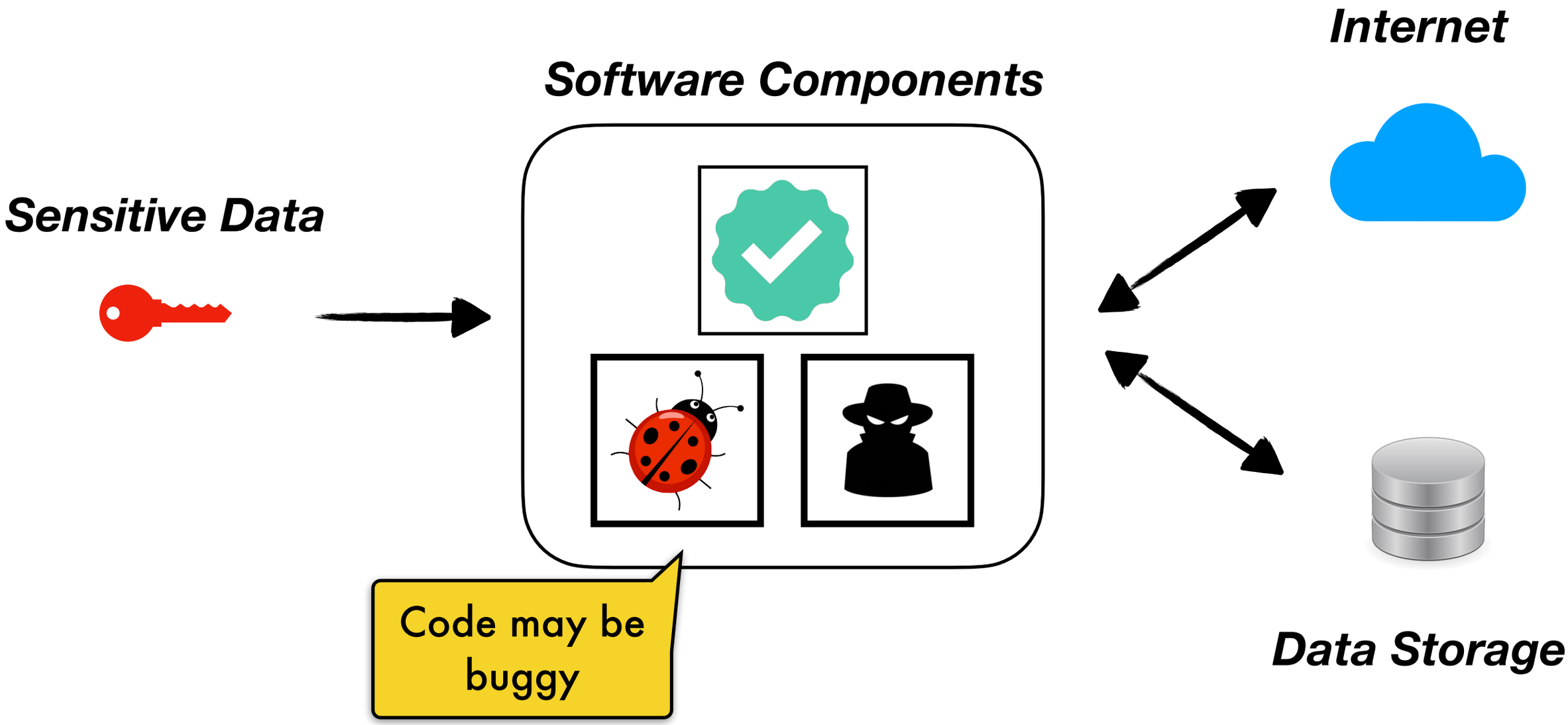

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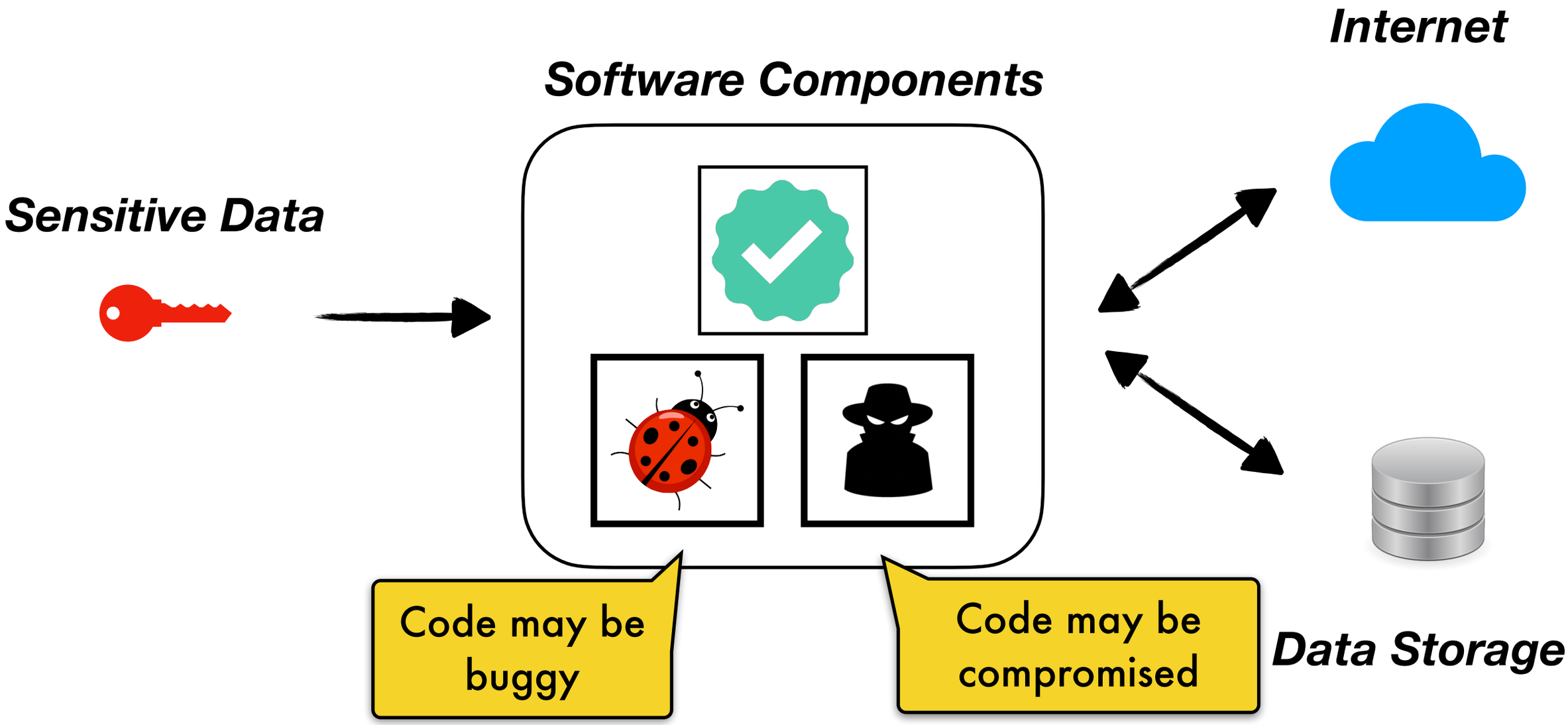

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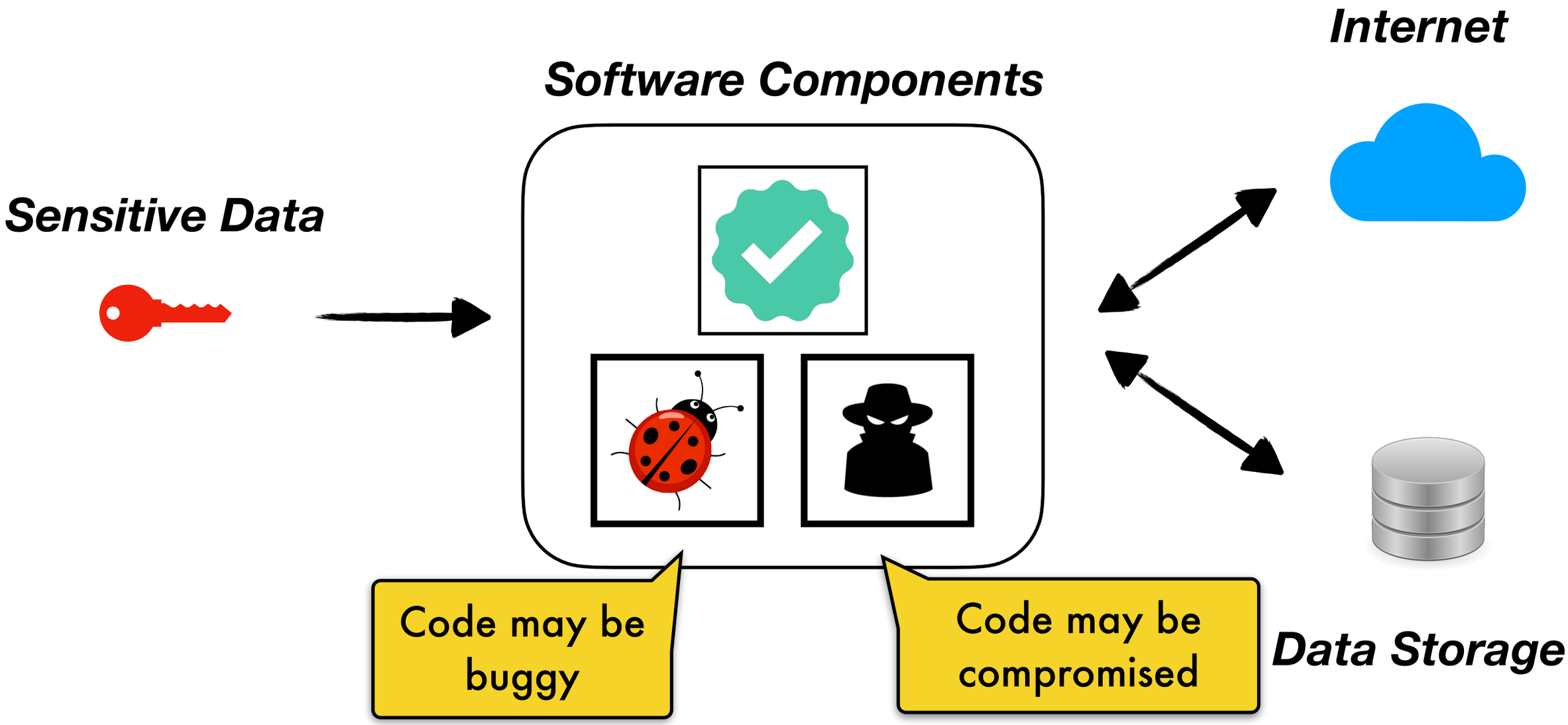


Code must not leak sensitive data to the internet!

*Bugs that leak sensitive data are **everywhere!***

Zocdoc says 'programming errors' exposed access to patients' data

[TechCrunch.com, May 2021]

Twitter advising all 330 million users to change passwords after bug exposed them in plain text

[The Verge, May 2018]

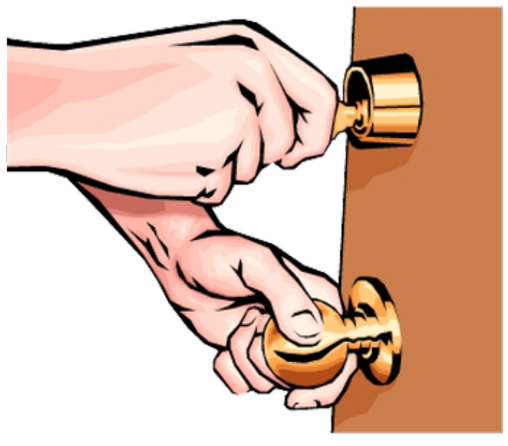
A New Facebook Bug Exposes Millions of Email Addresses

A recently discovered vulnerability discloses user email addresses even when they're set to private.

[Wired, April 2021]

How can we prevent data leaks?

Restrict access to data



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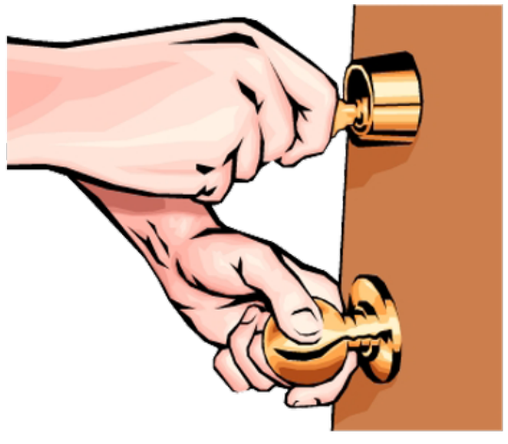

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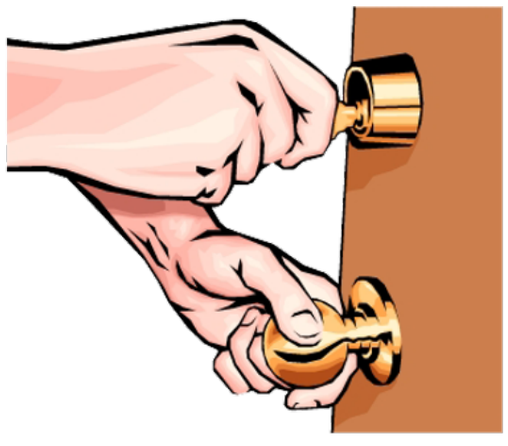

Discretionary Access Control

Restrict data propagation

Mandatory Access Control

Information Flow Control

What is Information-Flow Control?

IFC is a **principled approach** to **data confidentiality:**

- **Specify** how information may propagate in the system:

"Sensitive inputs may not flow to the internet"

- **Track data flows** across program components
- **Detect & suppress** data leaks

Building IFC systems is hard!

- How do you track data flows?
  - **Develop** special **compilers**
  - **Redesign web browsers**
  - **Modify operating systems**
- **Custom systems** are hard to develop, maintain, and adopt!

Building IFC systems is hard!

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Researchers have built IFC systems for Java, Javascript, Ocaml, Firefox, Chrome, Unix, …

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Building IFC systems in Haskell is easier!

- **Haskell "pure" abstractions** can directly express IFC anaylses

- Embed IFC analyses into **Haskell library interface**

- Build IFC systems on top of **IFC libraries**

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APIs prevent leaks by construction!

Haskell IFC Libraries

Library	*Enforcement*
MAC	**Static**
HLIO	**Hybrid**
LIO	**Dynamic**

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They all apply similar principles

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Access external resources (eg files, network, databases)

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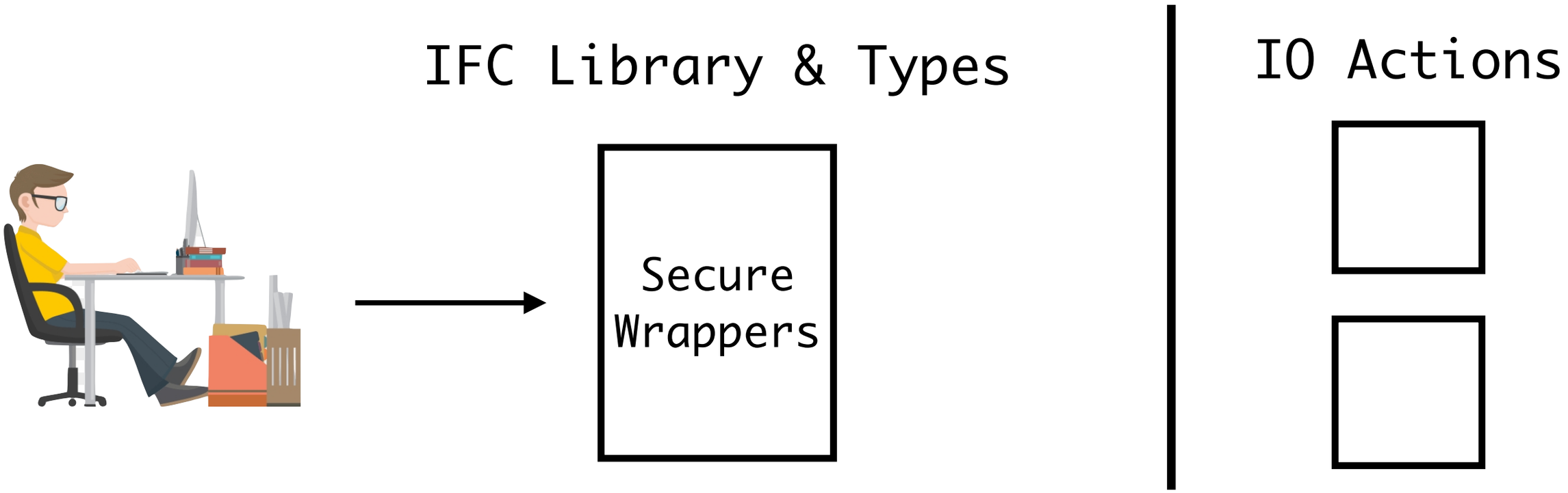
```
String
 Bool
  Int
  ...
```

No IO: data is confined!

How do IFC libraries prevent leaks?

- Untrusted code may perform **IO only through IFC library**
- IFC libraries wrap **IO actions** with **security types**
- Security types **restrict IO actions to prevent leaks**



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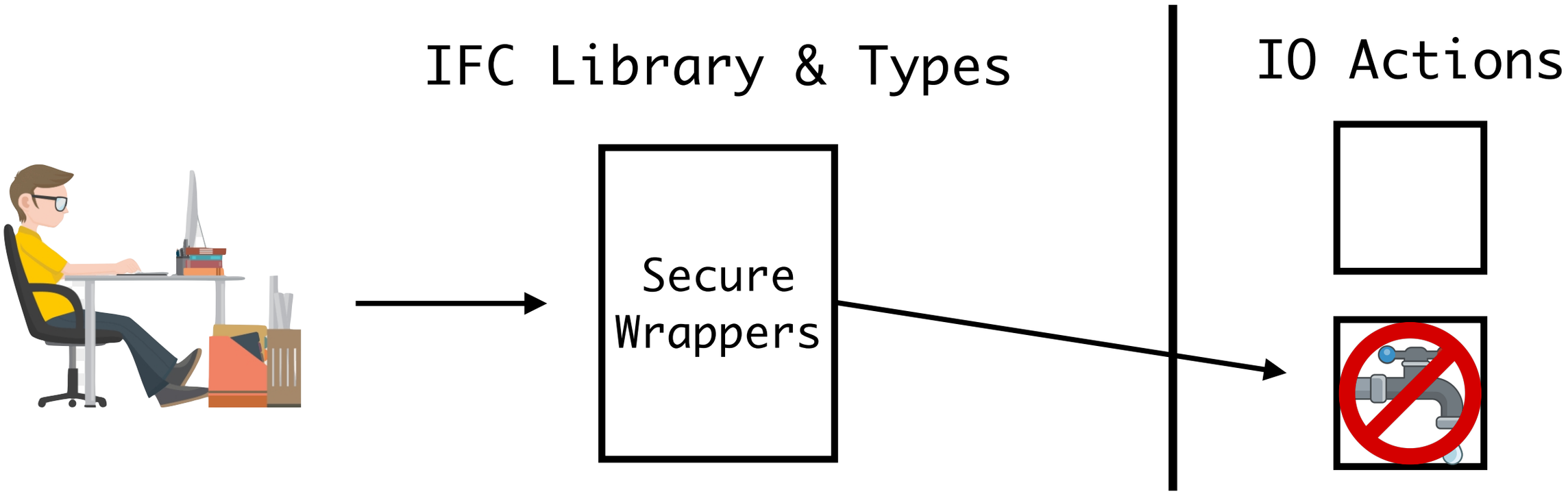

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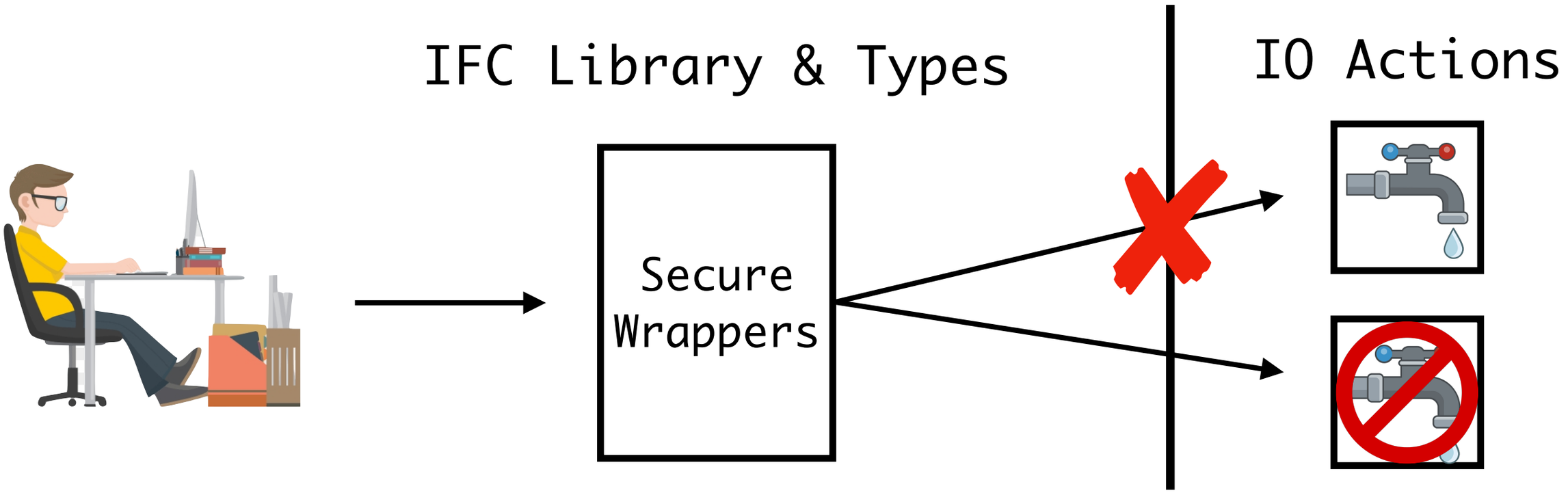
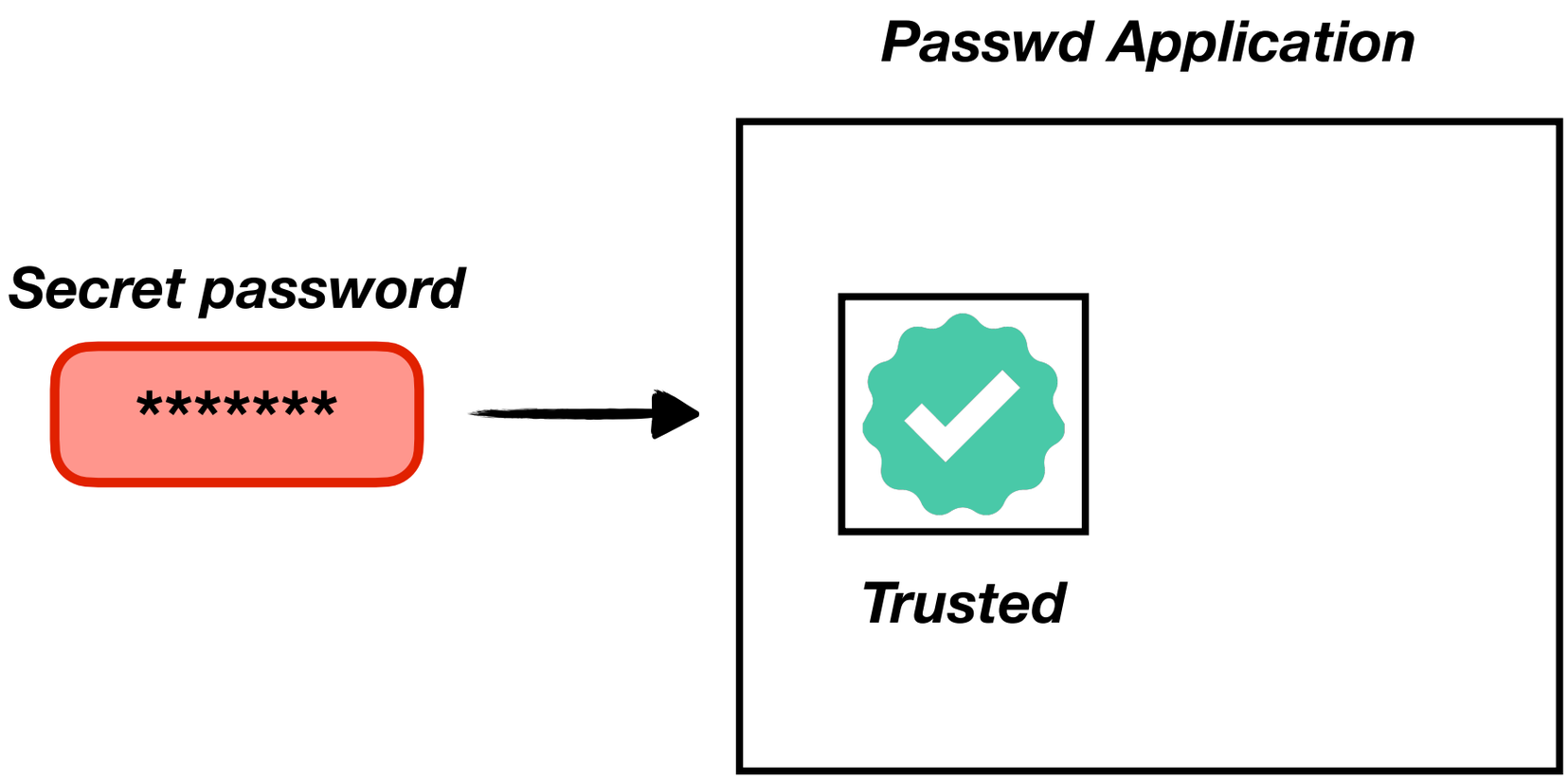


Running example: Password Manager



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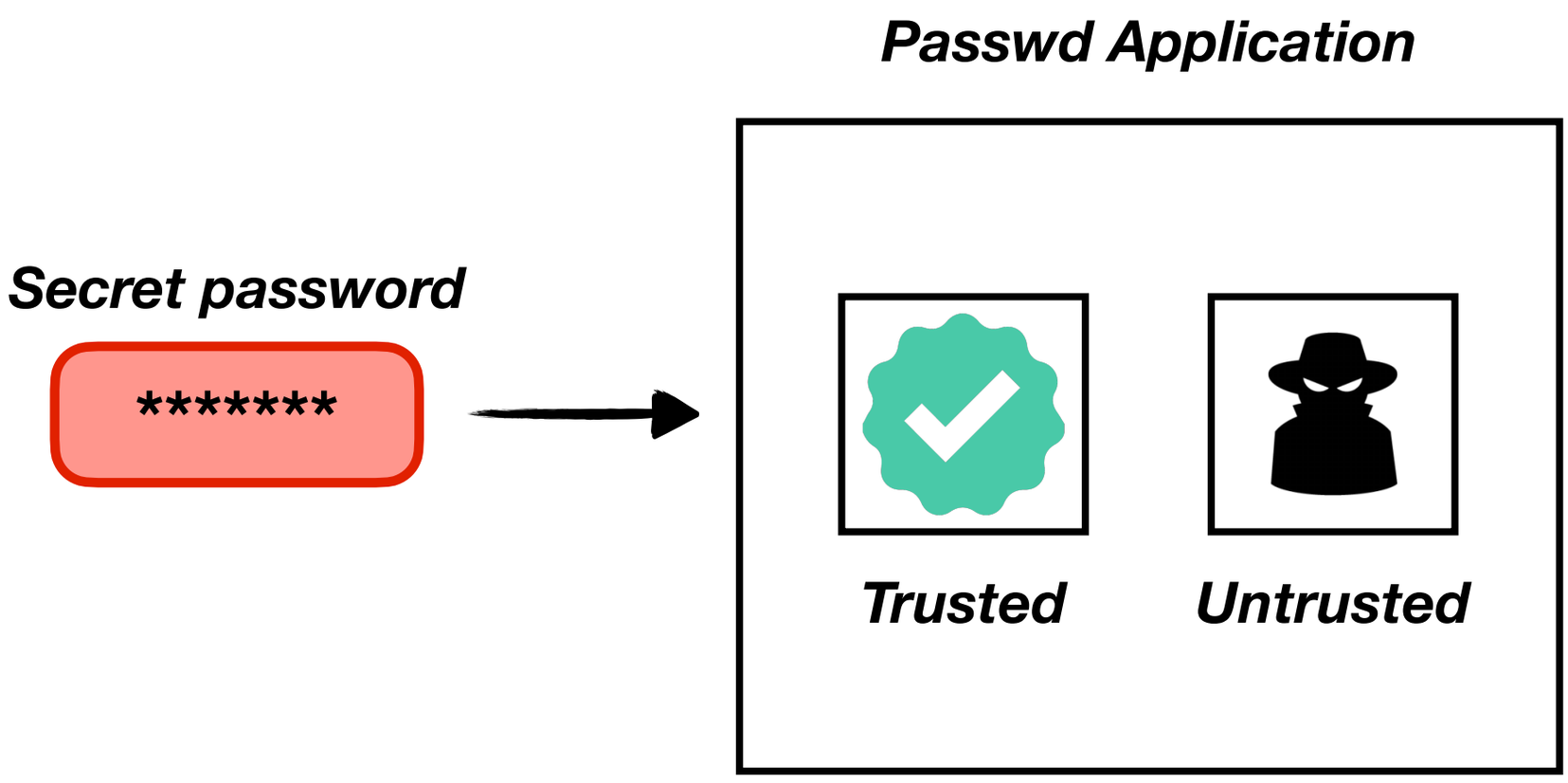

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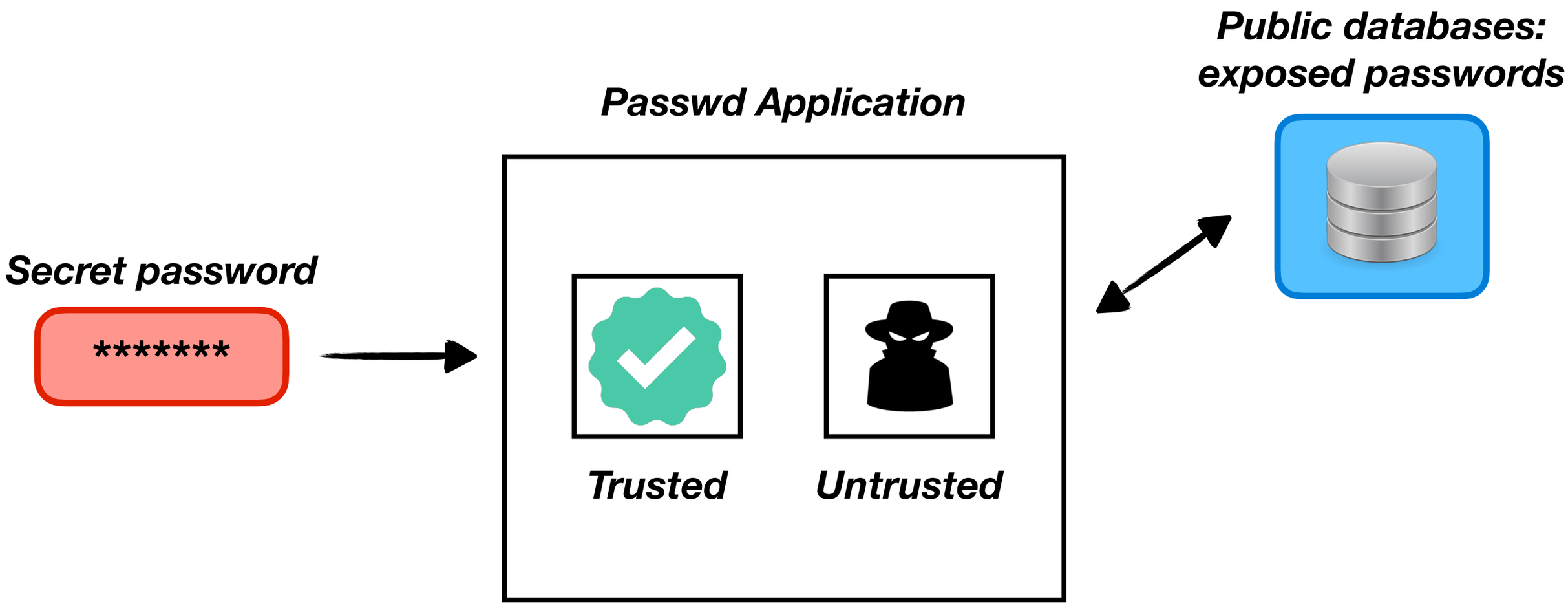

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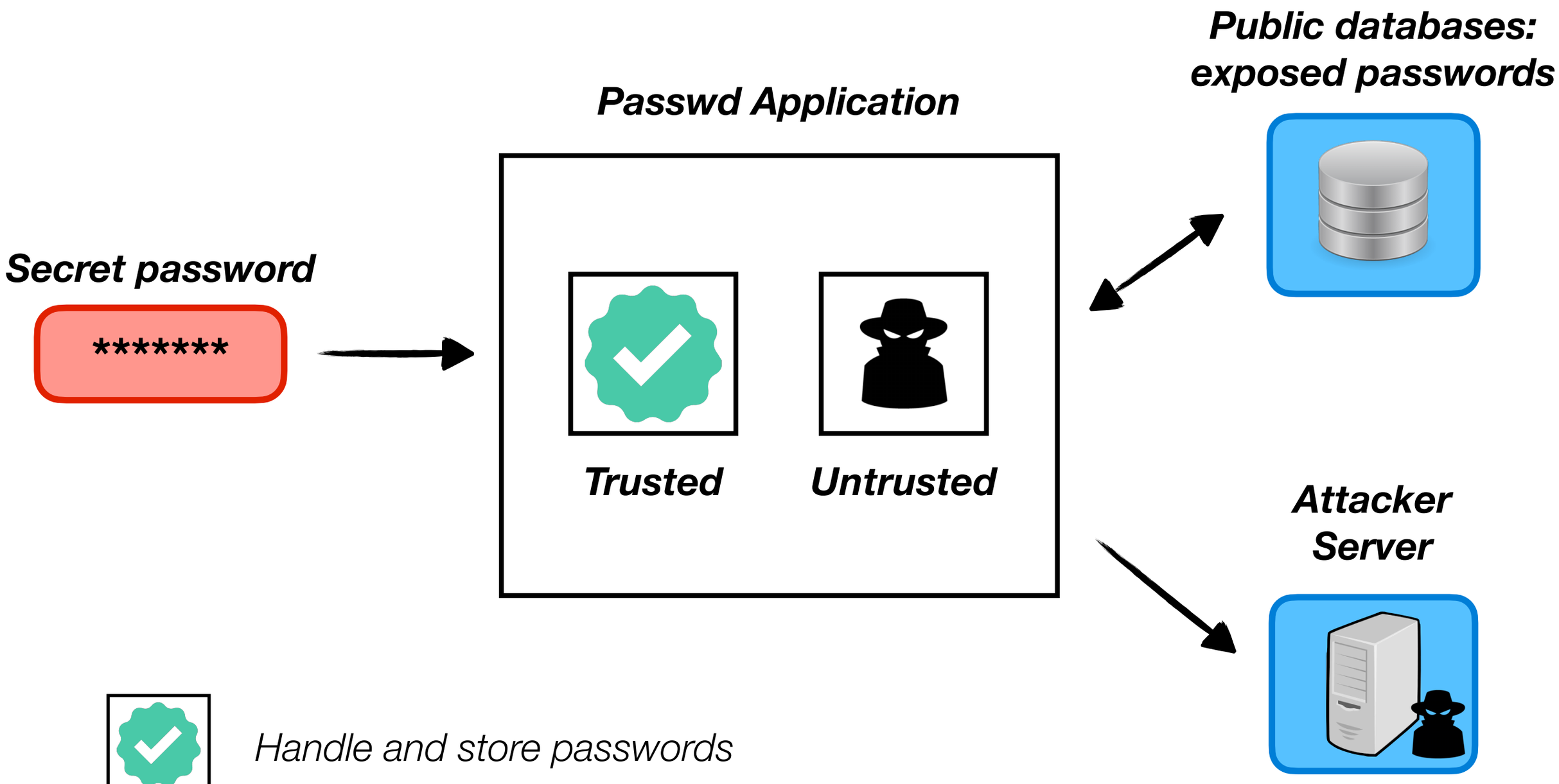

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DB access require input/output!

Trusted code for password manager

```
module Passwd where
import qualified Untrusted
choosePwd :: IO String
choosePwd = do
  putStr "Please, select your password:"
  pwd <- getLine
  b <- Untrusted.isWeakPwd pwd
  if b then
    do putStrLn "Your password is weak!”
       choosePwd
  else return pwd
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Public (observable) **outputs** can **leak secret password**!

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module Untrusted where

import Network.HTTP.Wget

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IFC libraries **disallow public outputs when secret data is in scope**!

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- "*Functional Pearl: Two Can Keep a Secret, If One of Them Uses Haskell", by A. Russo, ICFP 2015*

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- Define **abstract data type** for **labeled data**:

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- Only **trusted code can run secure computations**:

```
runMAC :: MAC l a -> IO a
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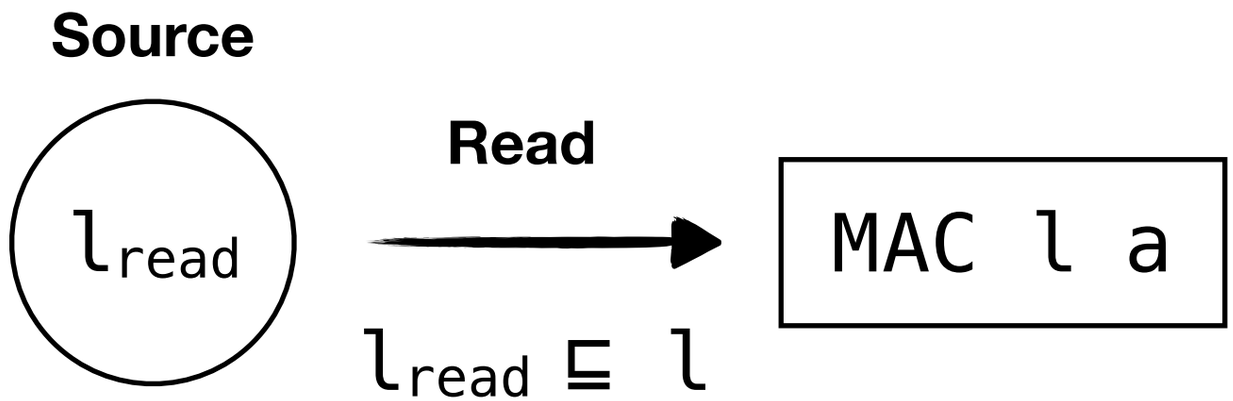

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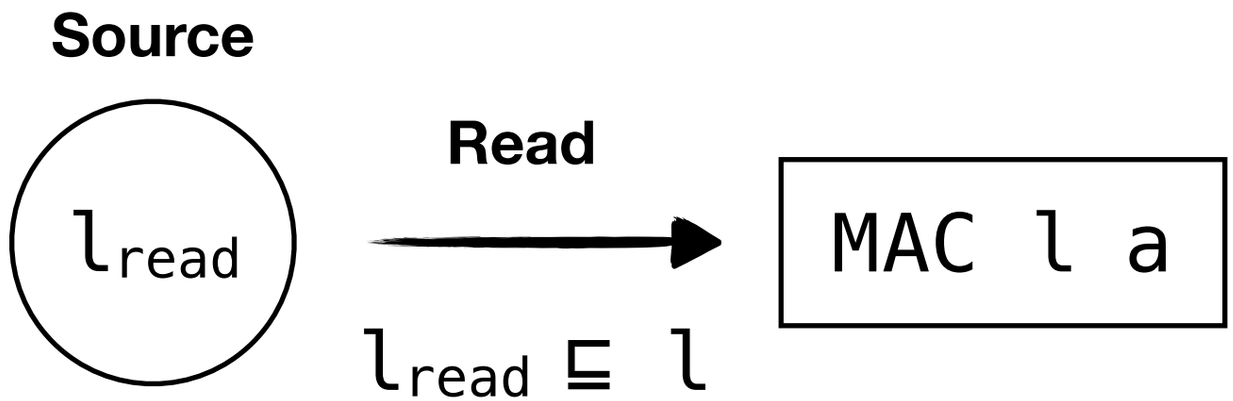

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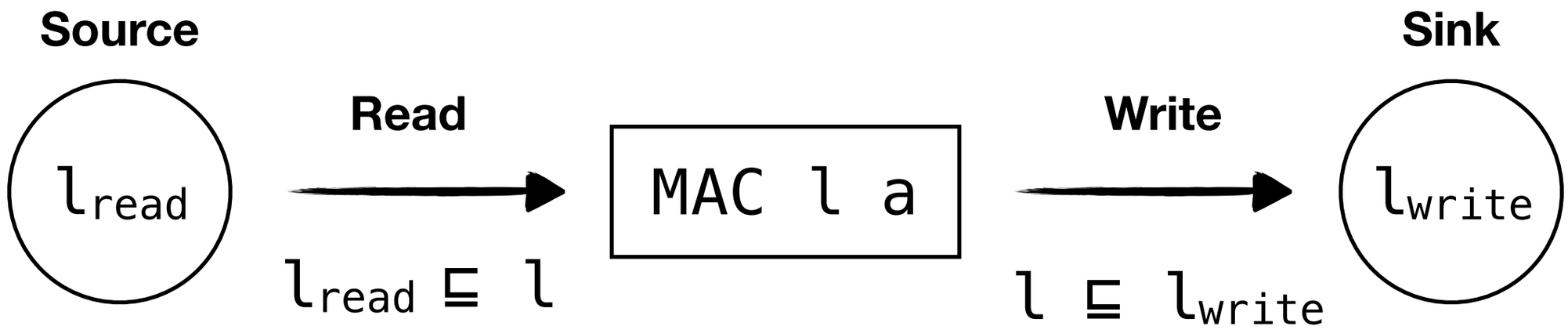

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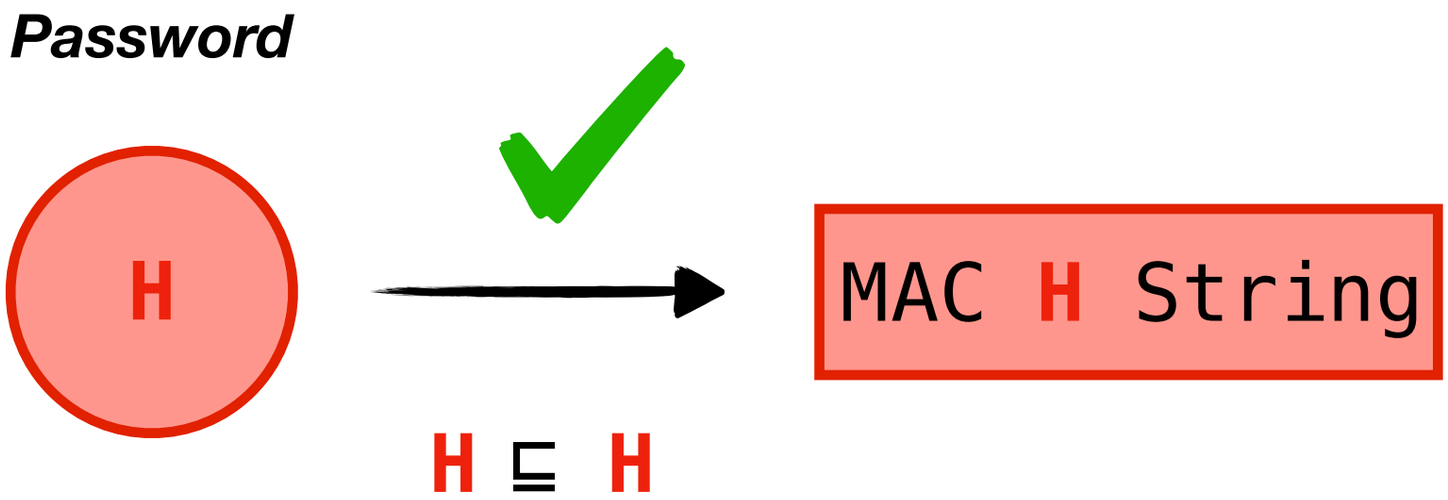

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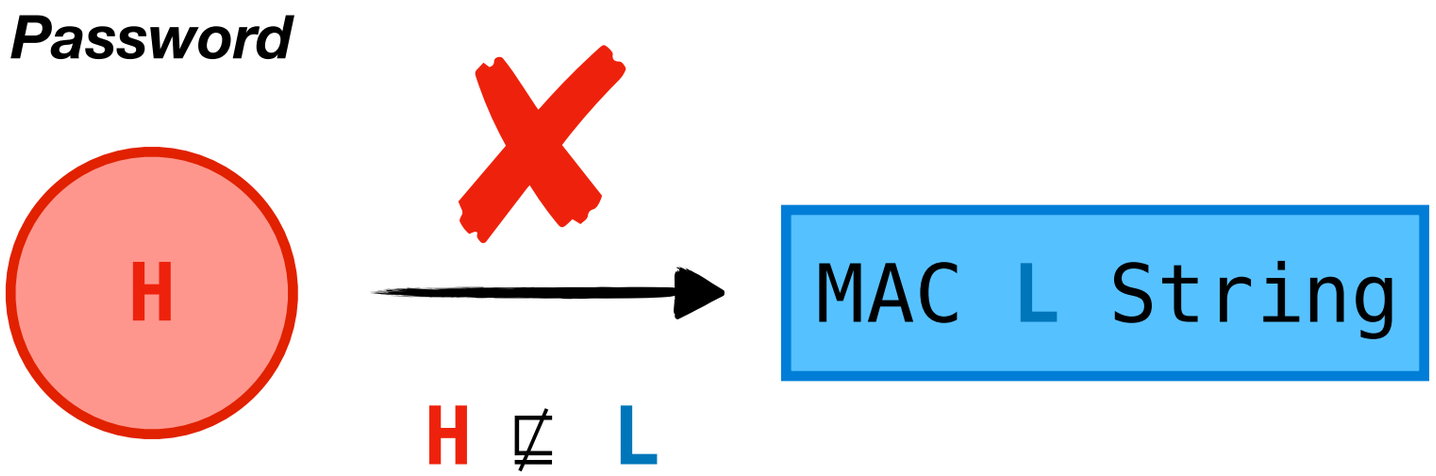

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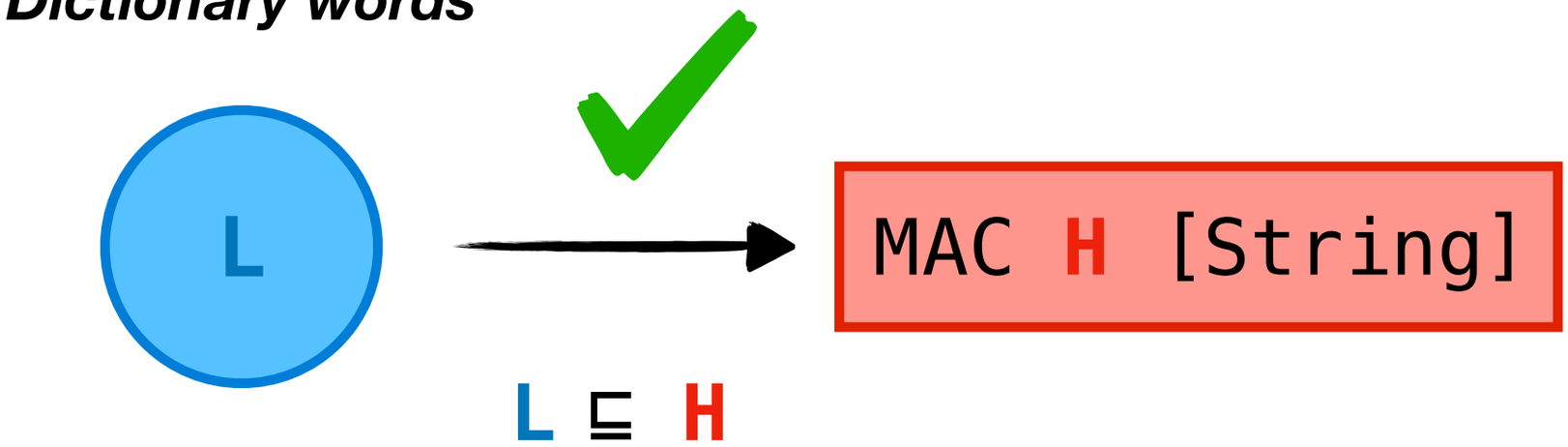

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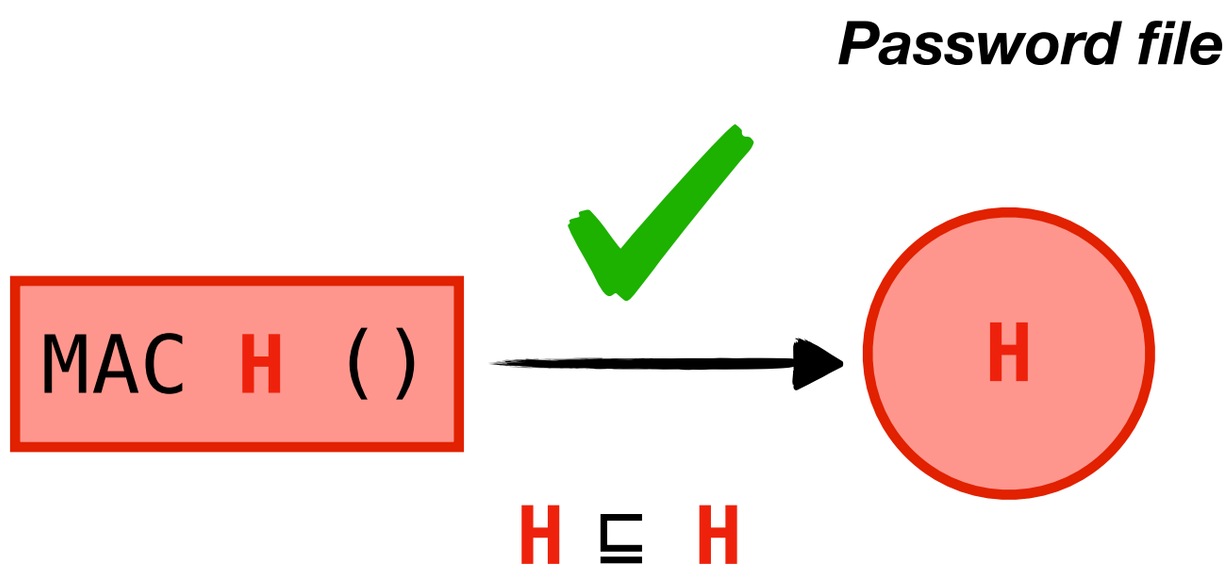

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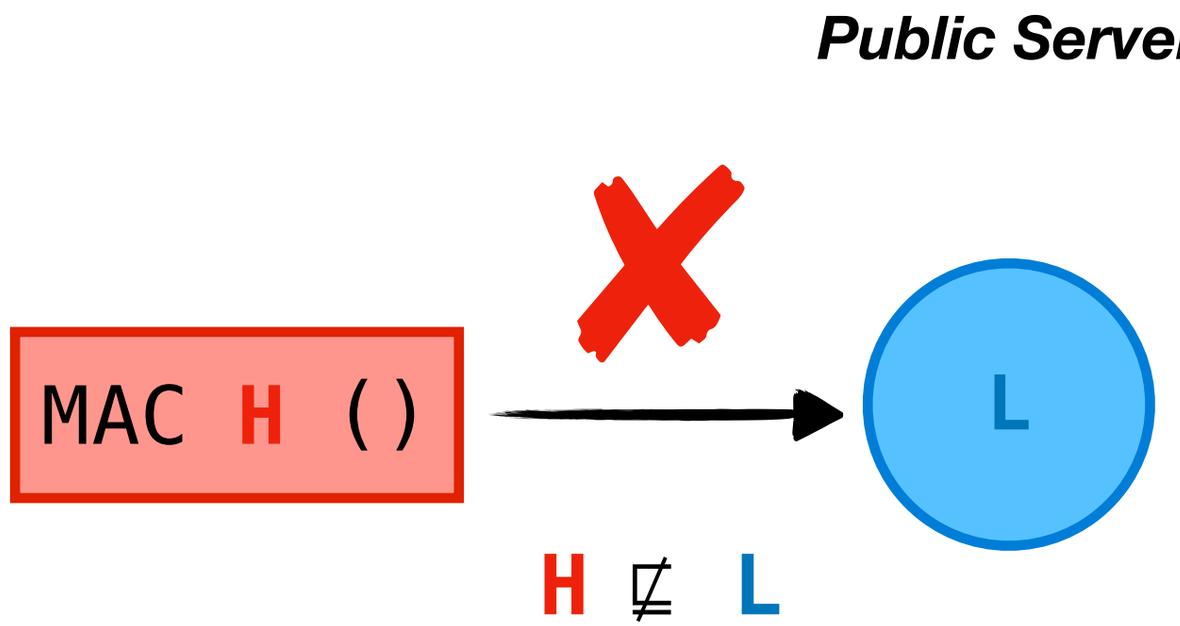

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unlabel :: l ⊑ h => Labeled l a -> MAC h a
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extract = read:
apply no read-up rule!

```
module Untrusted where

import MAC

isWeakPwd :: Labeled H String -> MAC L (MAC H Bool)
isWeakPwd lpwd = do
body <- wgetMAC “https://haveibeenpwned.com/Passwords”
ws <- ... // Parse body into list of passwords
return (

     do pwd <- unlabel lpwd
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Secure Password Manager

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module Passwd where

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choosePwd :: IO String
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  pwd <- getLine
  mac_H <- runMAC $ do
    lpwd <- label pwd :: MAC L (Labeled H String)
    Untrusted.isWeakPwd lpwd
  isWeak <- runMAC mac_H
  ...
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Why are MAC computations nested?

Alternatives are ill-typed or incomplete:

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isWeakPwd’ :: Labeled H String -> MAC L Bool
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isWeakPwd'' :: Labeled H String -> MAC H Bool
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No read-up: Cannot unlabel password

```
isWeakPwd'' :: Labeled H String -> MAC H Bool
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No write-down: Cannot fetch public databases

Why are MAC computations nested?

Alternatives are ill-typed or incomplete:

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Nested computations with many security levels are unmanageble!

$$\texttt{MAC } \mathbf{l_1} \texttt{ (MAC } \mathbf{l_2} \texttt{ (... (MAC } \mathbf{l_N} \texttt{ a) ...))}$$

How does MAC avoid nested computations?

- MAC provides a special operator:

```
toLabeled :: l ⊑ h => MAC h a -> MAC l (Labeled h a)
```

  - Embed MAC **h** actions into MAC **l** computation
  - Run nested MAC **h** computation
  - Return result labeled with **h** to outer MAC **l**

```
isWeakPwd :: Labeled H String -> MAC L (Labeled H Bool)
isWeakPwd lpwd = do
  ws <- getExposedPasswords
  toLabeled $ do
    pwd <- unlabel lpwd
    return (pwd `elem` ws)
```

toLabeled evaluates nested computation & returns labeled result

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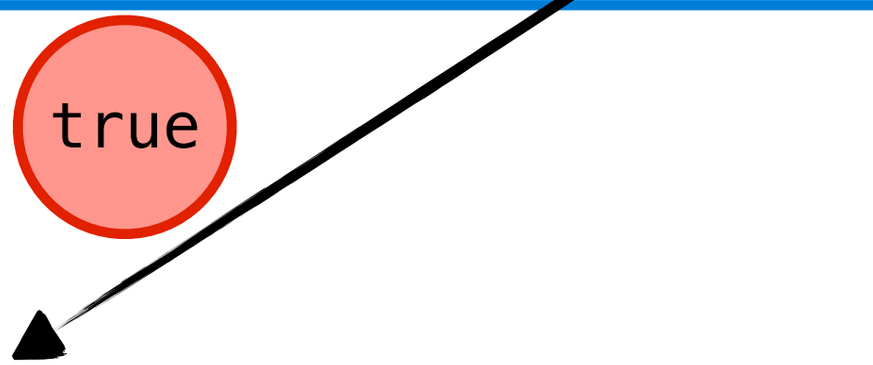

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toLabeled evaluates nested computation & returns labeled result

true

```
lbool <- runMAC $ do
      lpwd <- label pwd :: MAC L (Labeled H String)
      Untrusted.isWeakPwd lpwd
```

Summary: Core MAC API

```
newtype MAC l a = MAC (IO a)

newtype Labeled l a = Labeled a

 label :: l ⊑ h =>  a -> MAC l (Labeled h a)

 unlabel :: l ⊑ h => Labeled l a -> MAC h a

toLabeled :: l ⊑ h => MAC h a -> MAC l (Labeled h a)
```

What did we learn today?

- Haskell **pure abstractions** enable lightweight IFC analyses
- Fundamental principles behind Haskell IFC libraries
- An introduction to **MAC static IFC library**