Addressing Covert Termination and Timing Channels in Concurrent Information Flow Systems

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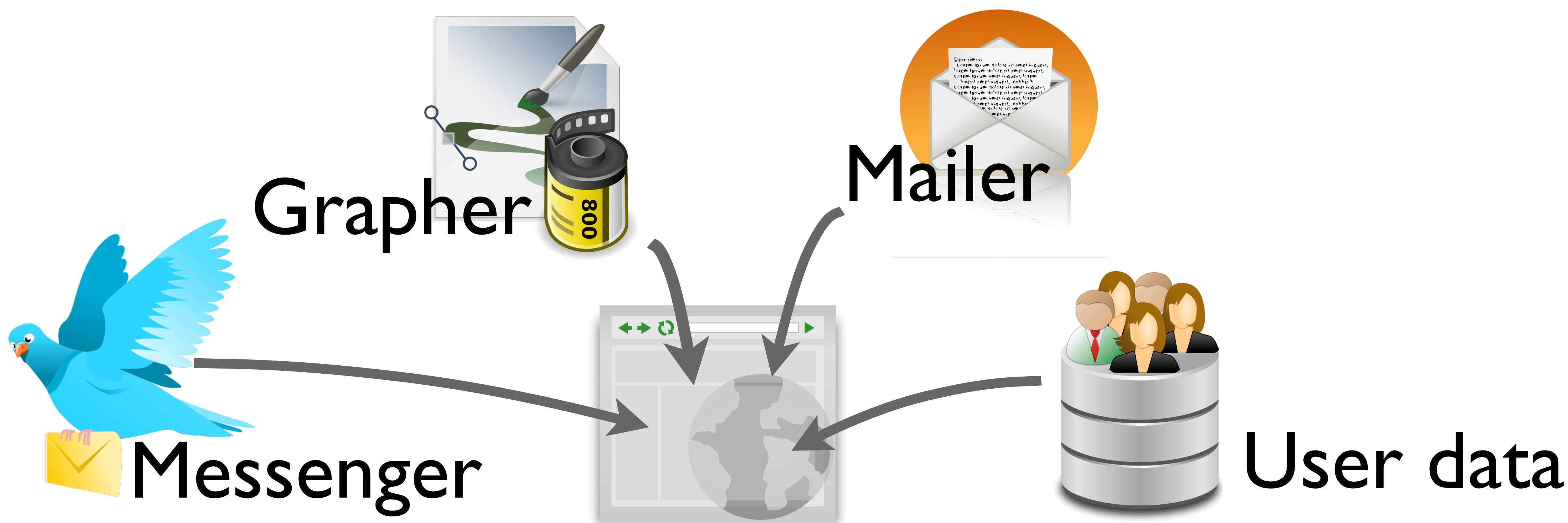
STANFORD UNIVERSITY

CHALMERS

Motivation

Web framework for integrating 3rd party apps



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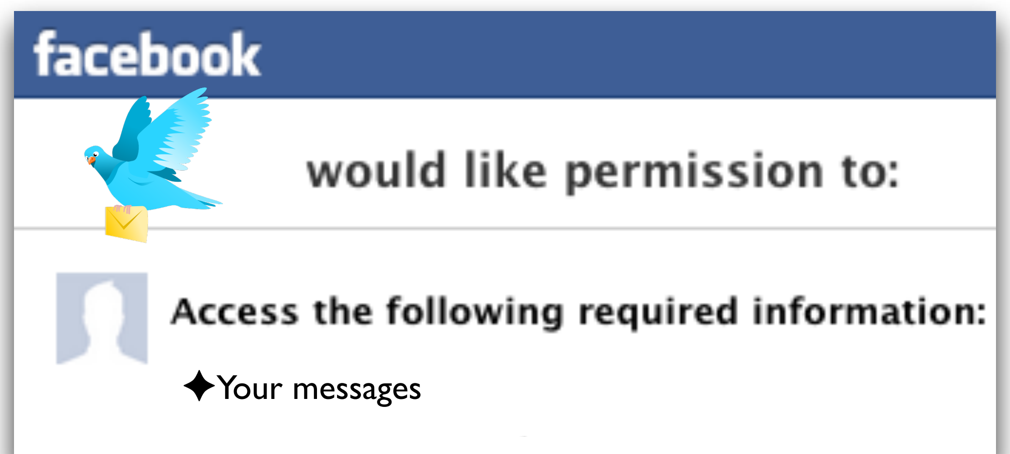

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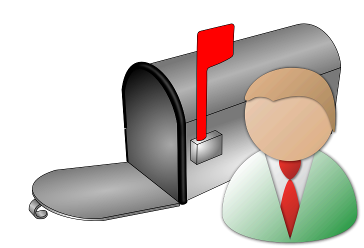

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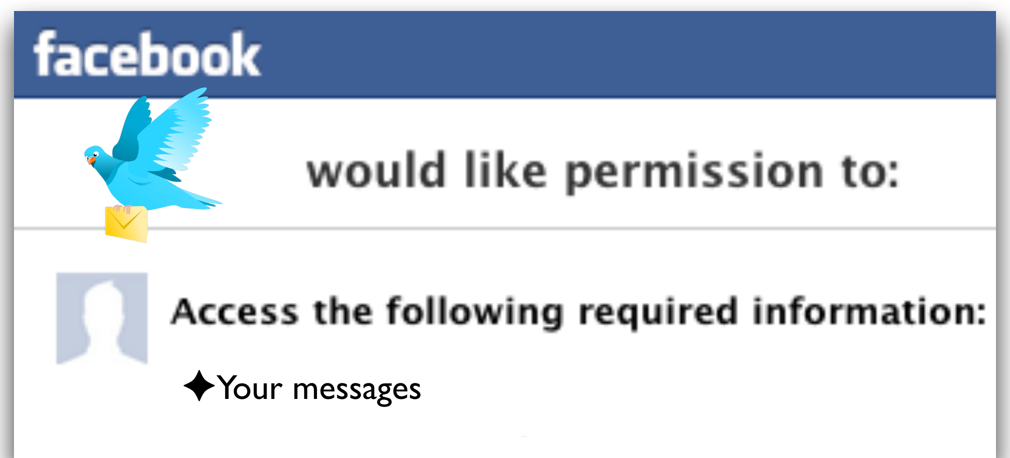

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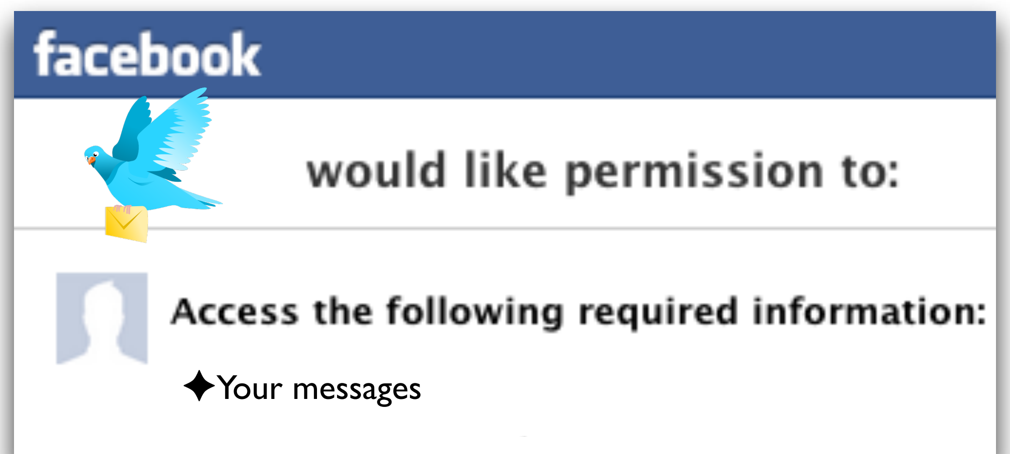

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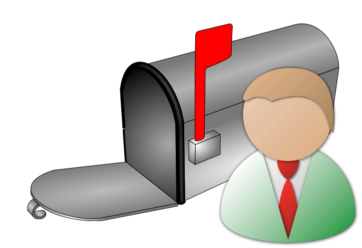

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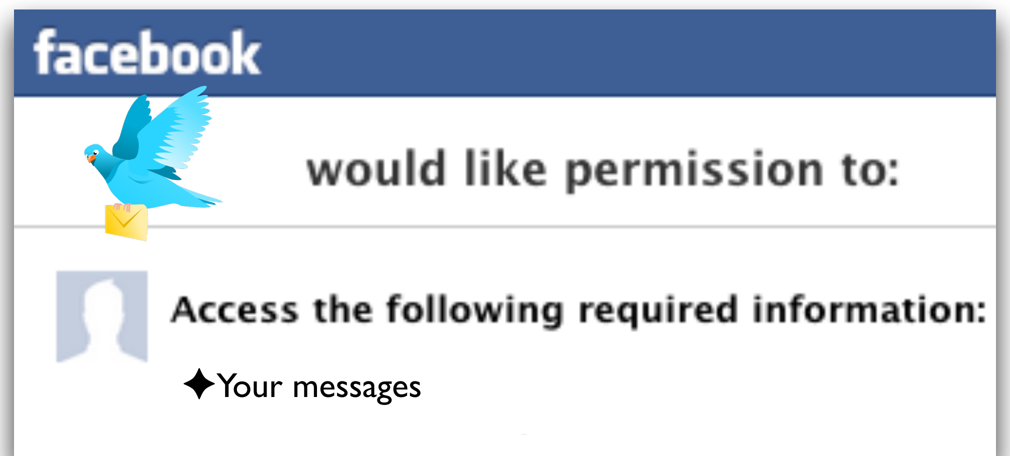

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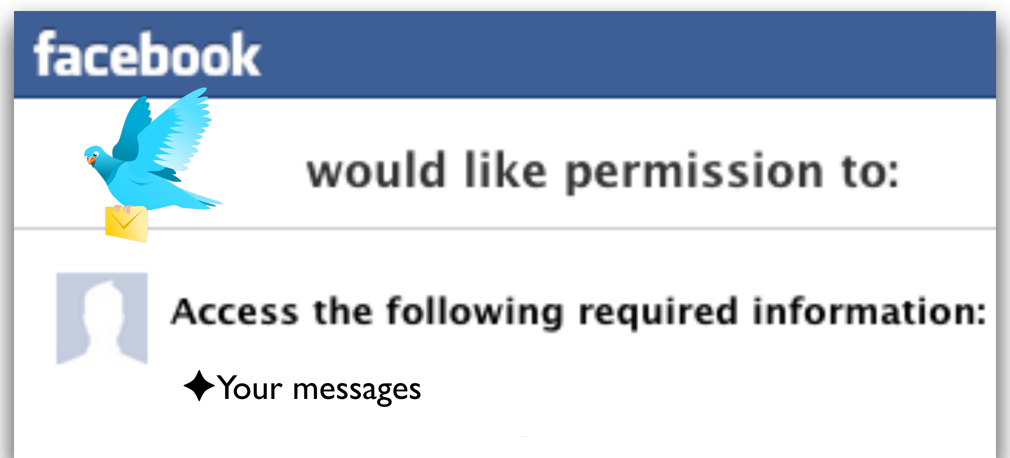

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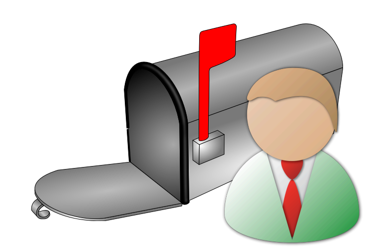

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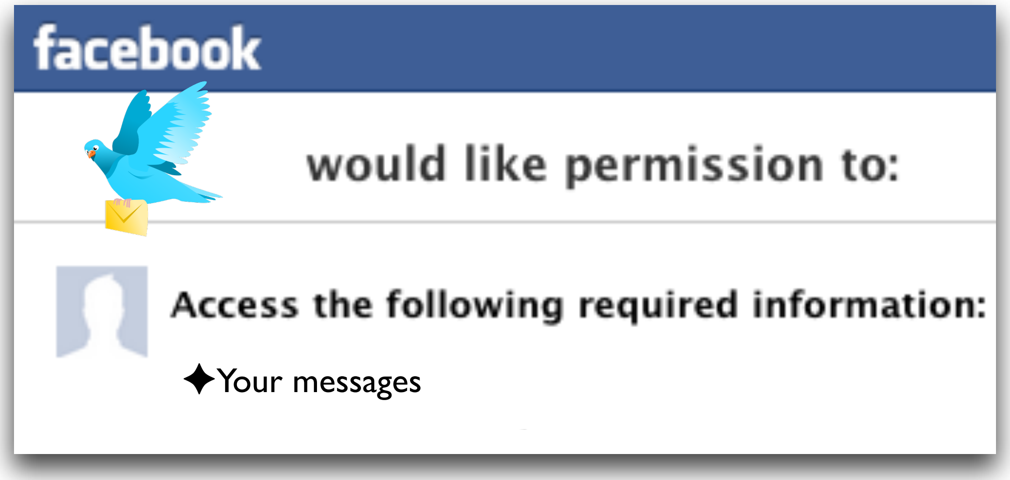

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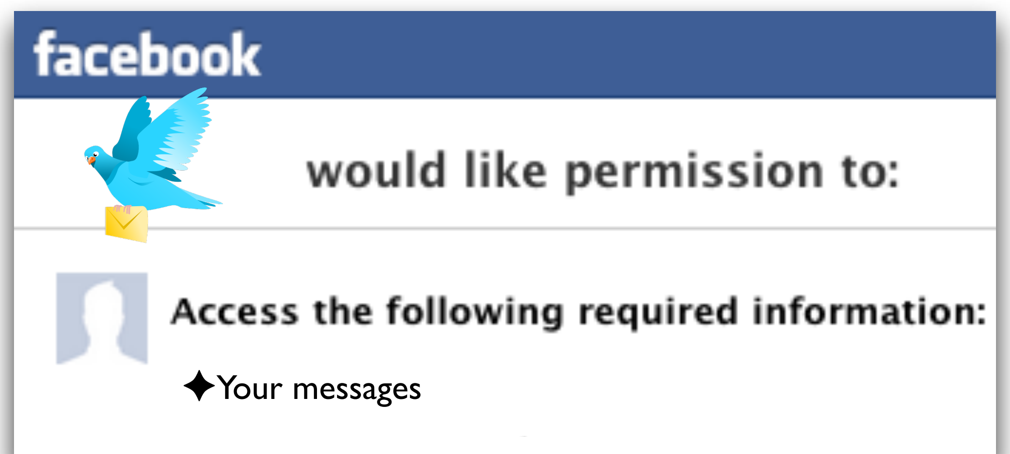

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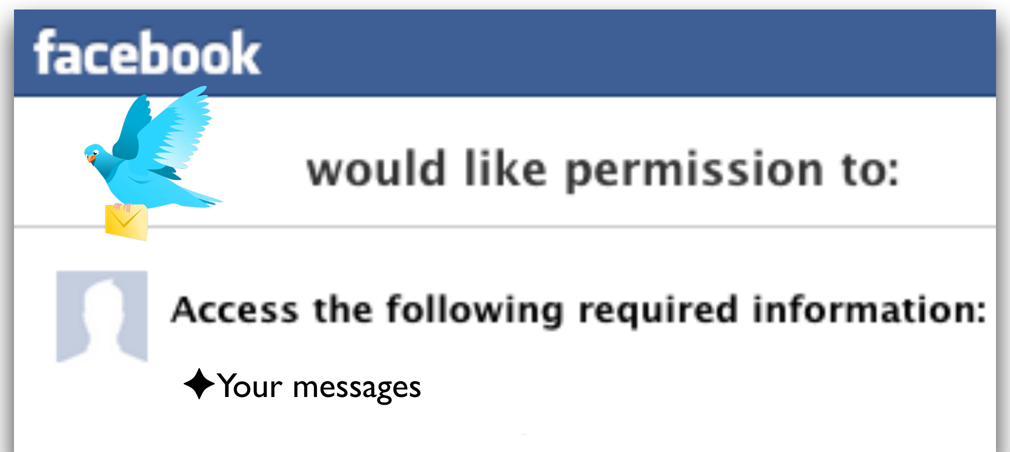

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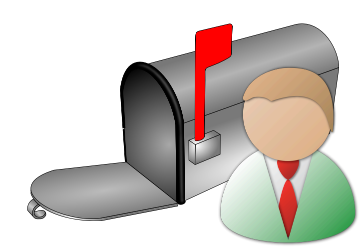

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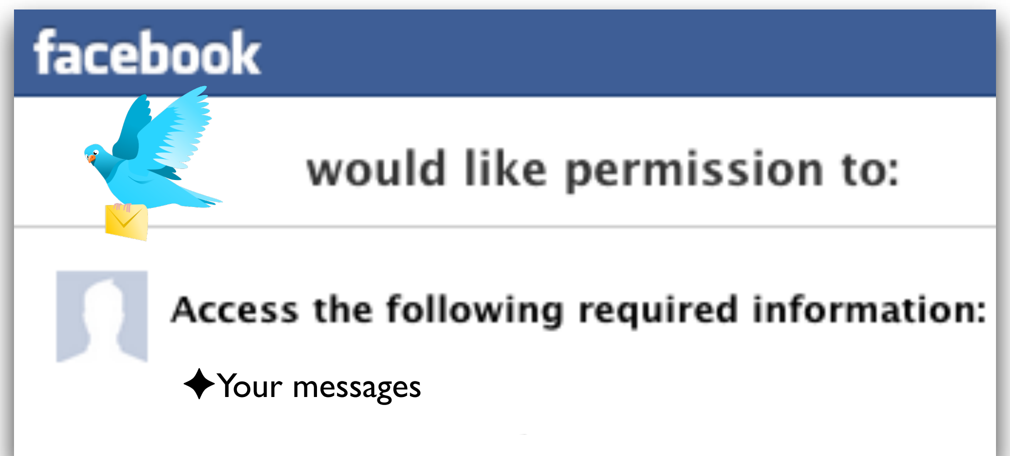

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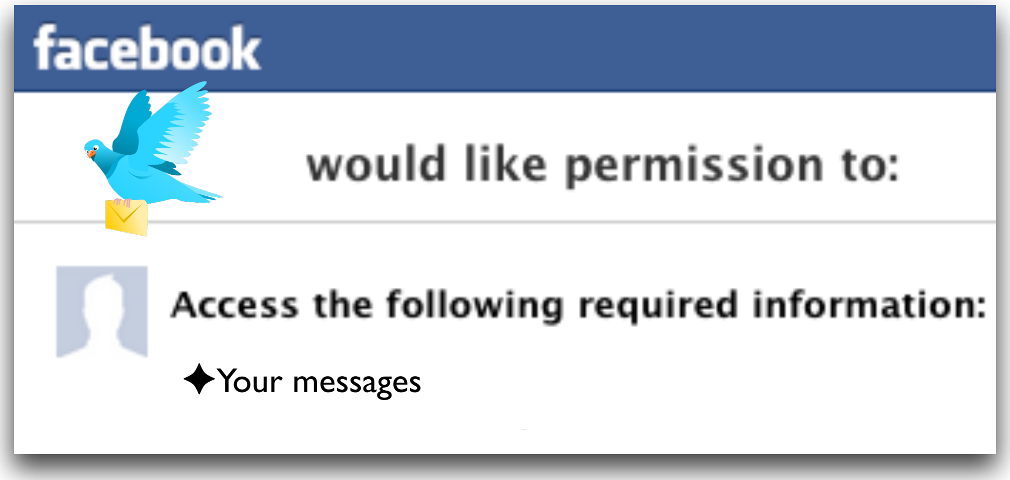

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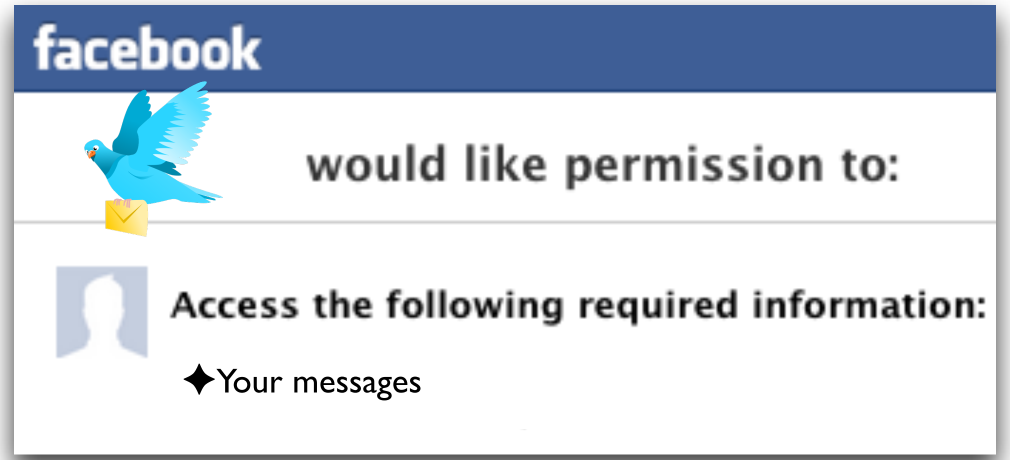

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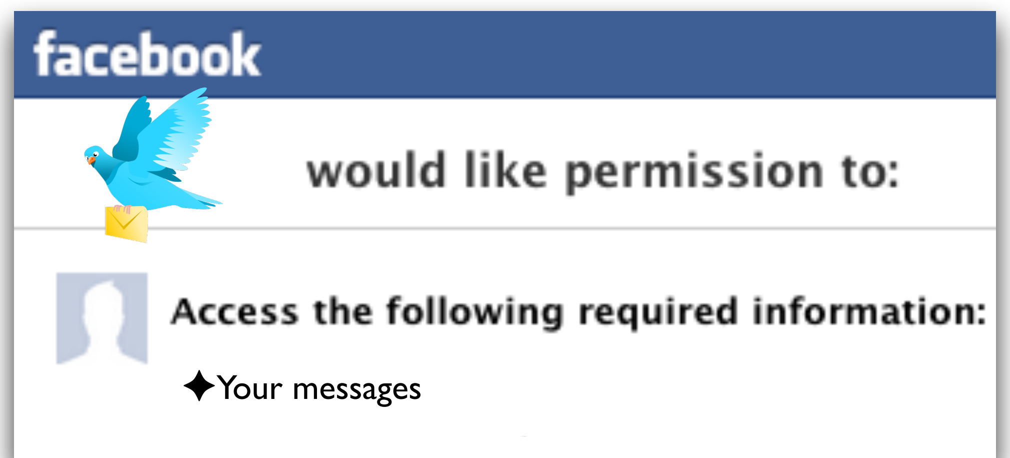

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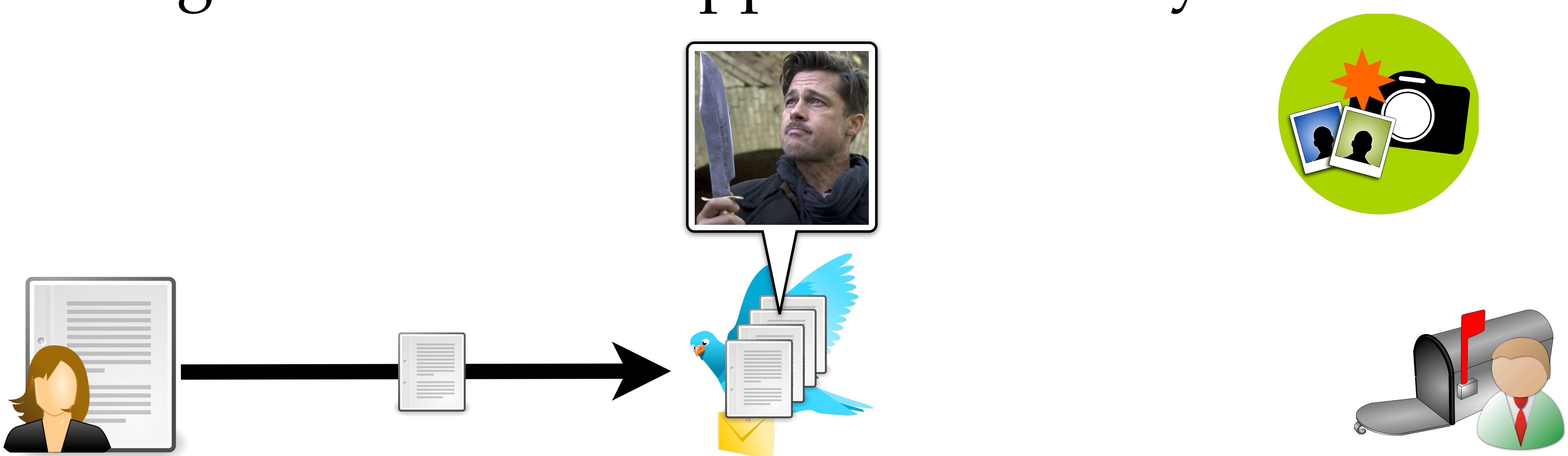

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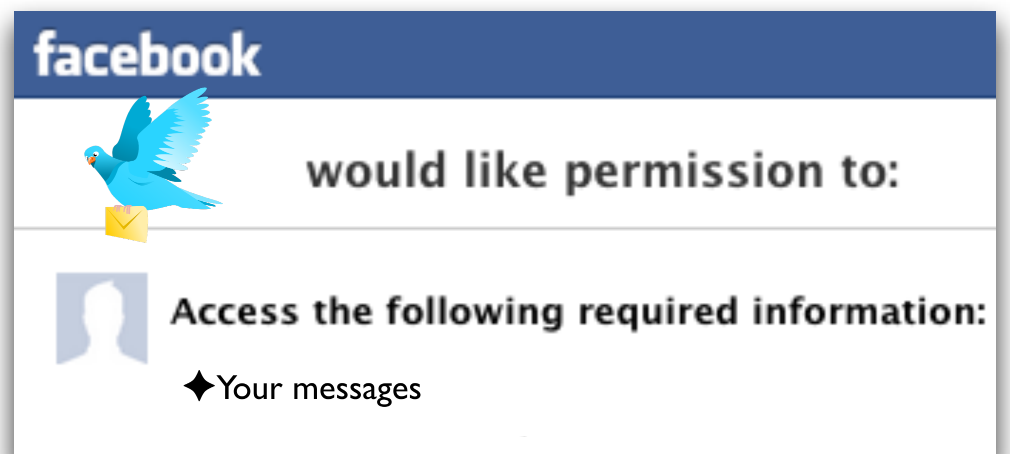

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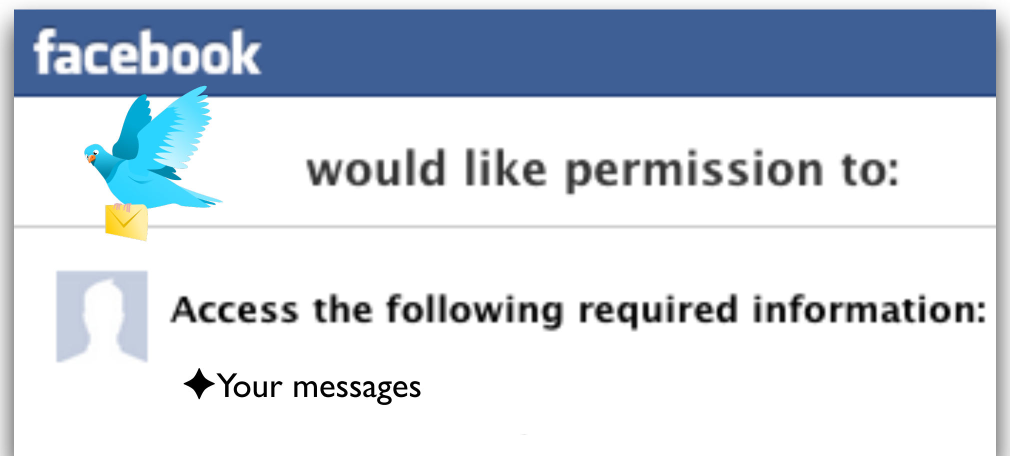

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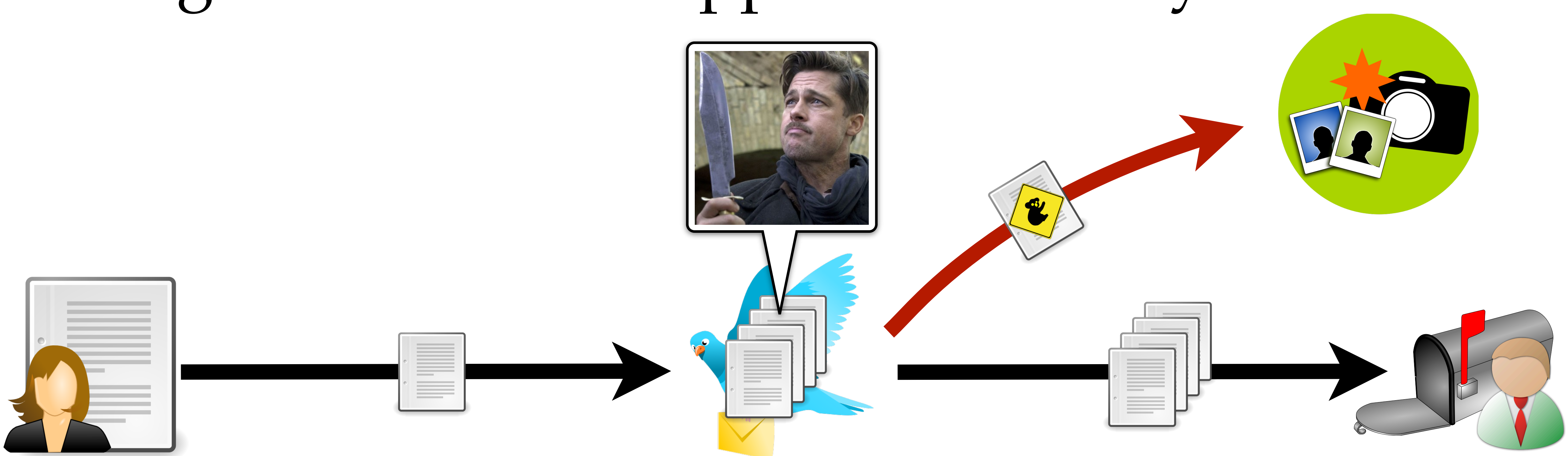


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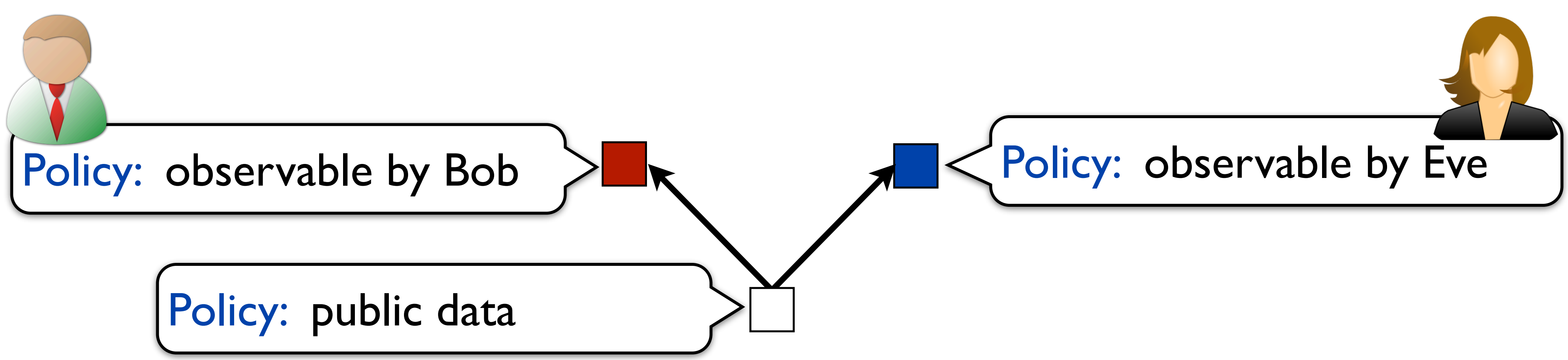
Fundamental Problem

- Problem:
  - Read sensitive data with **`getUserMessages`**
  - Wrote to remote host with **`alertPaparazzi`**
- Solution:
  - Restrict who the app can communicate with depending on what data it has read

Alternative Approach

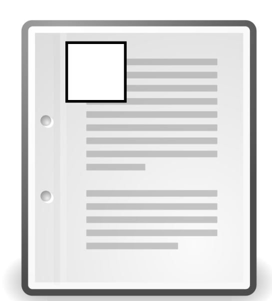
Information Flow Control with LIO

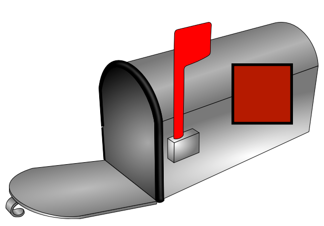
- Label every object with a security level/policy
  - *Label protects data by specifying who can read/write*
- Example security label lattice:



LIO Monad

- Execute computations in **`LIO`** monad
  - Records context "current" label
  - I.e., tracks taint of computation
  - Restricts side-effects an app can perform
- Example (sending Bob a message):





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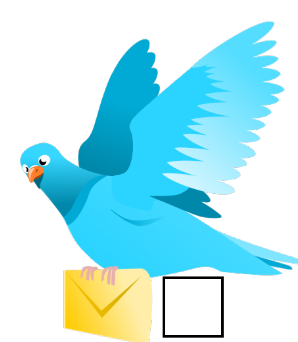

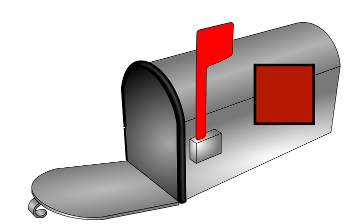

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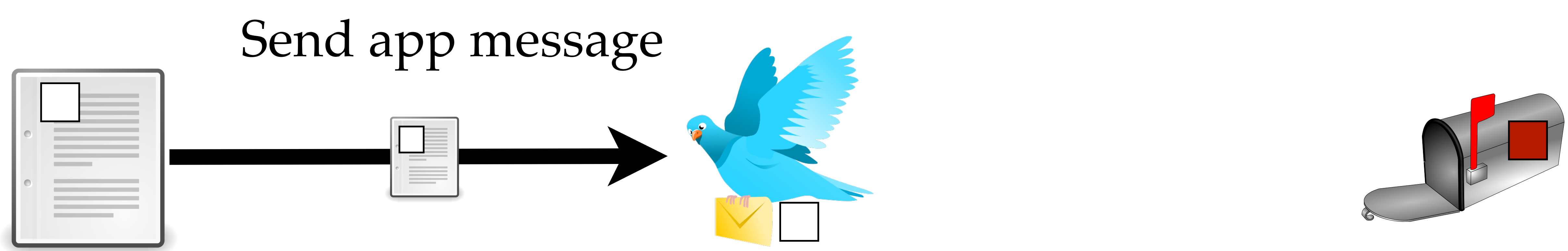

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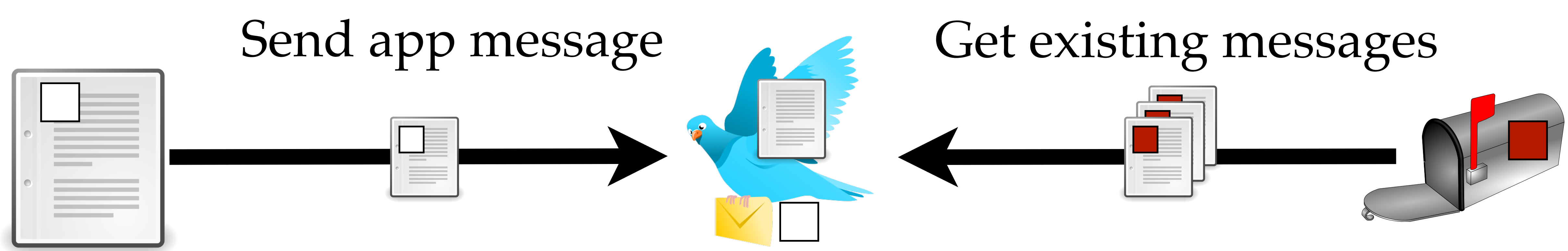

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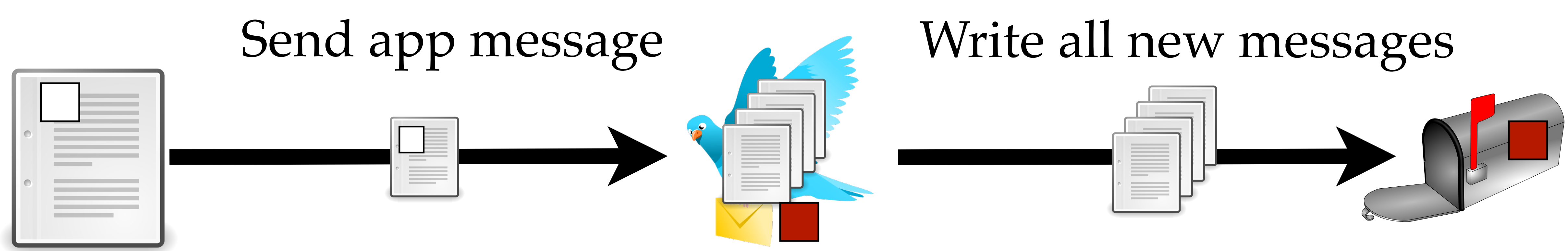

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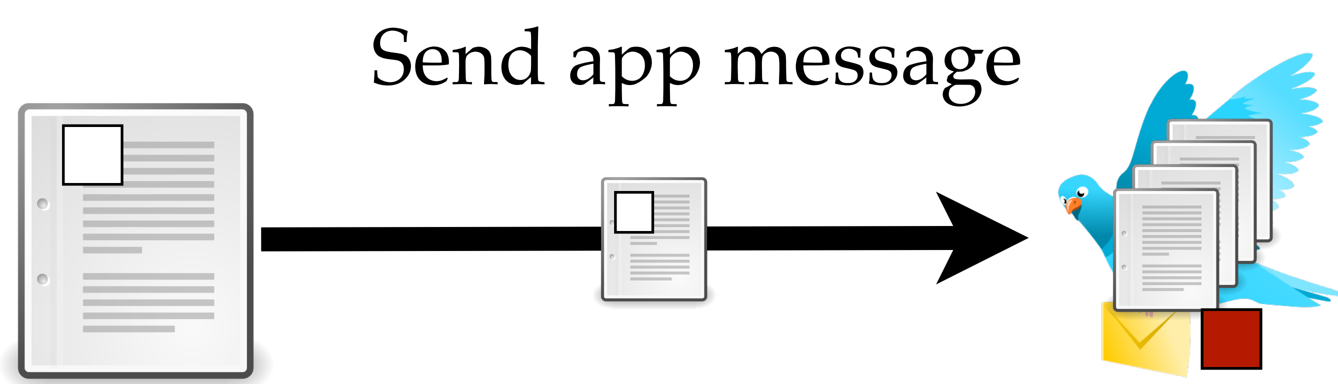

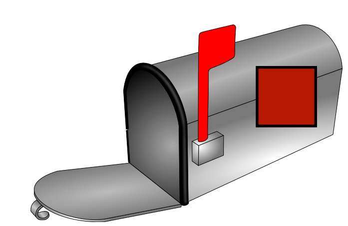

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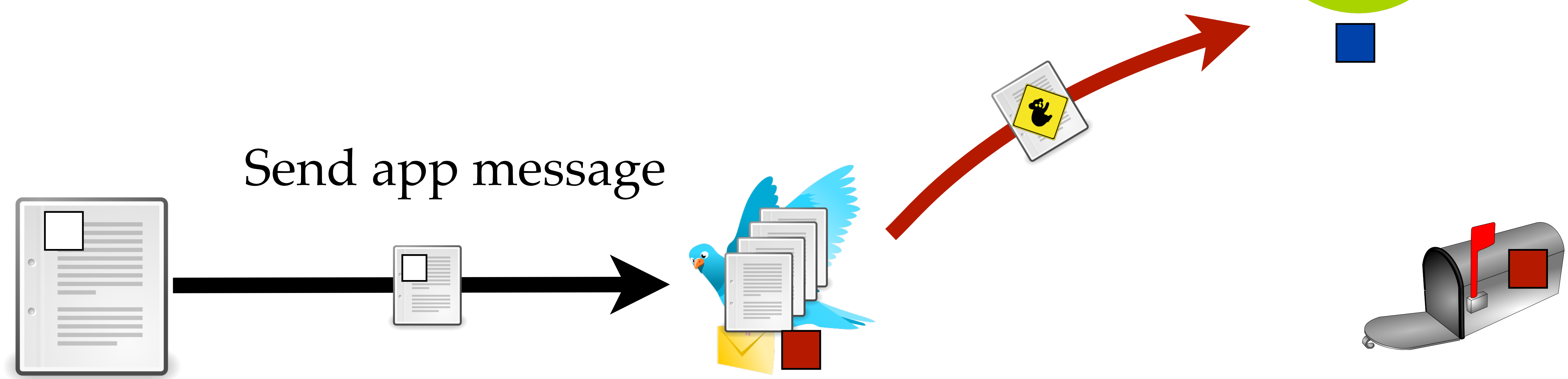

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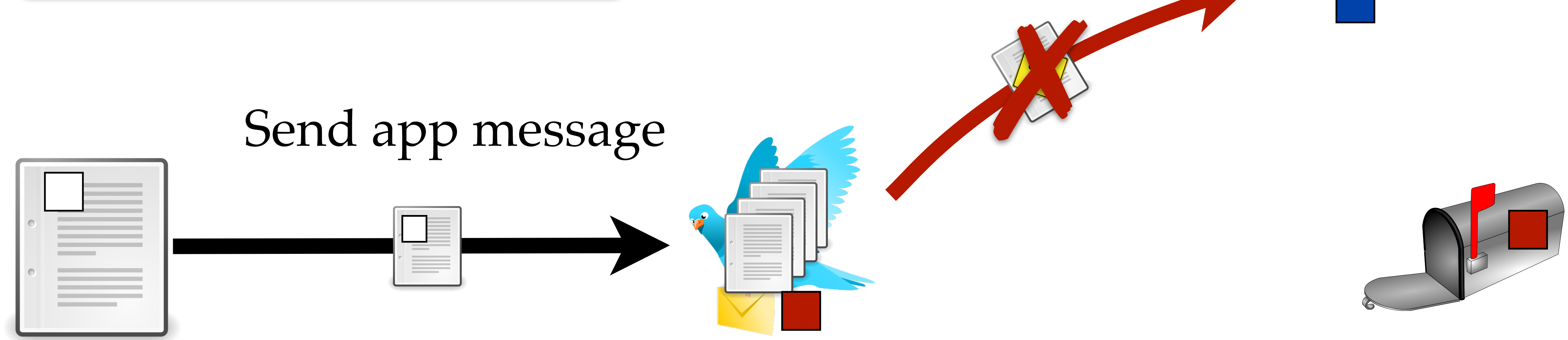
App receives exception:
Trying to leak sensitive data.



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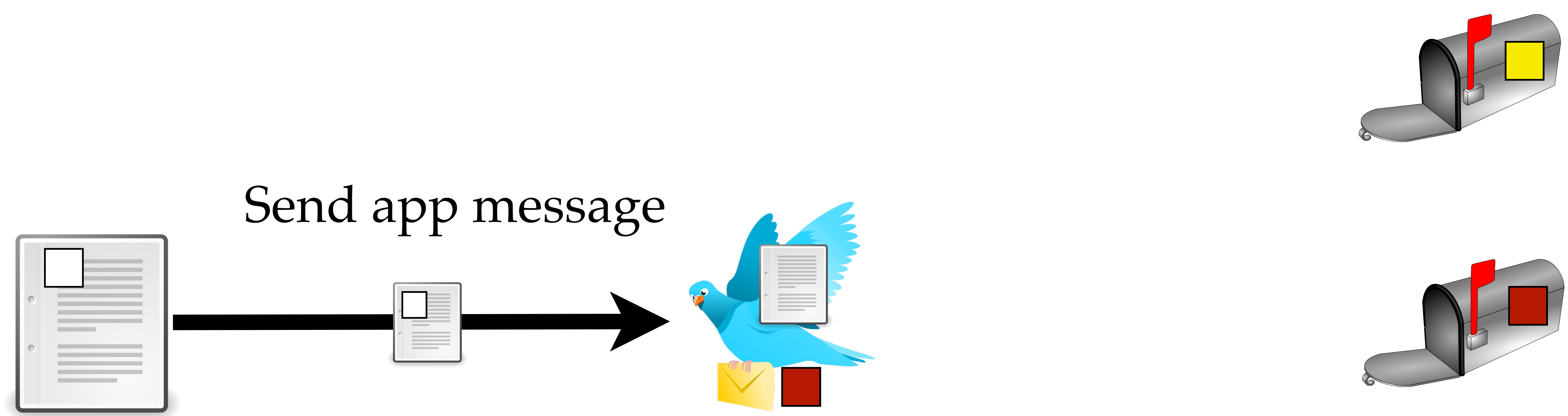

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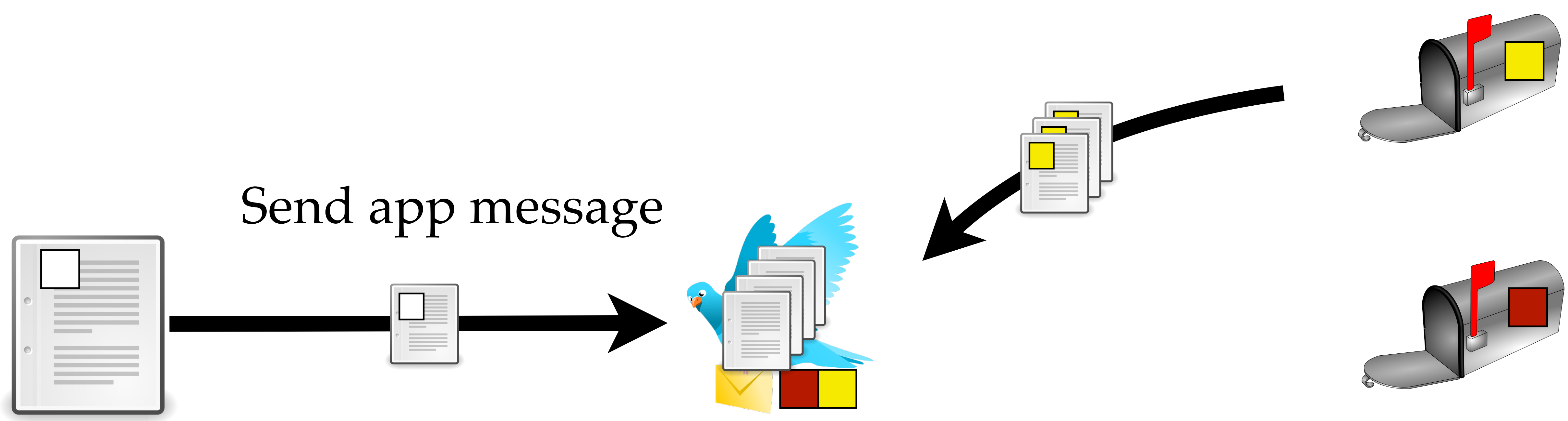

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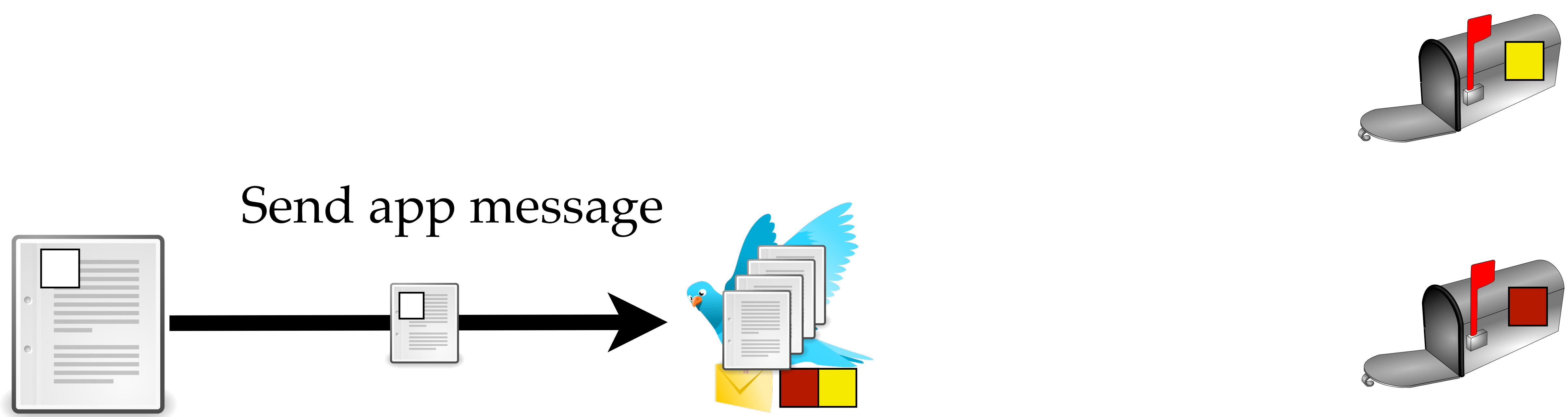

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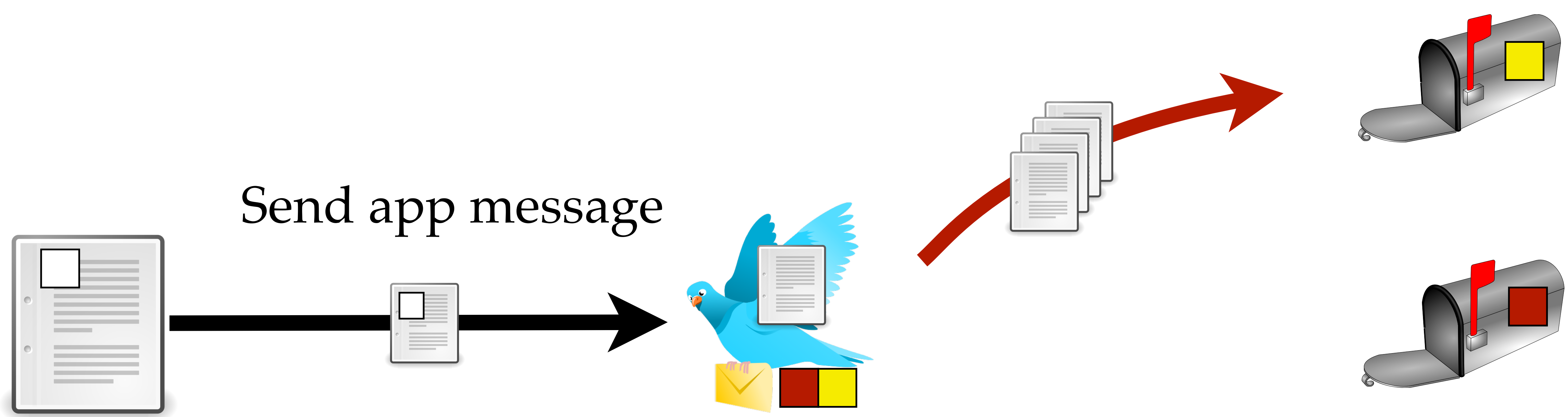

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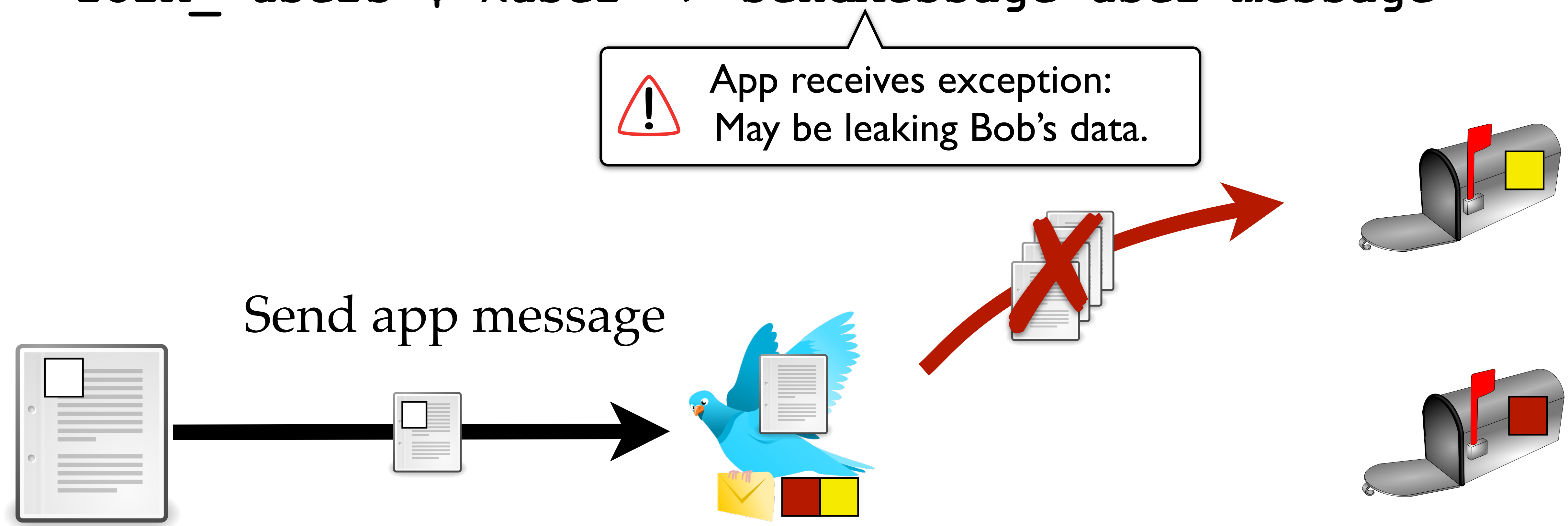

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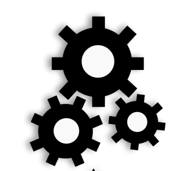

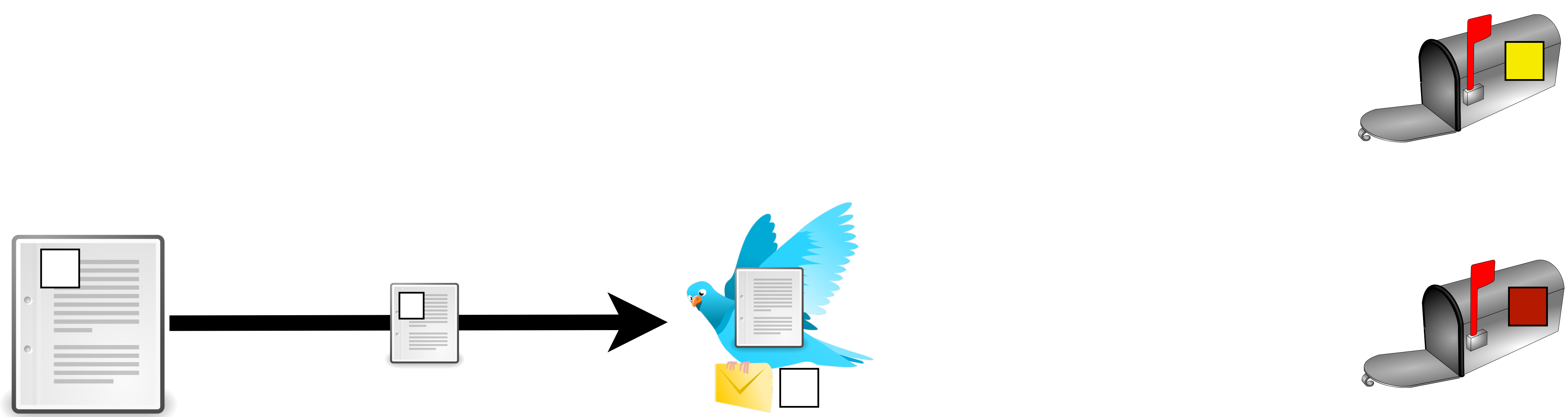

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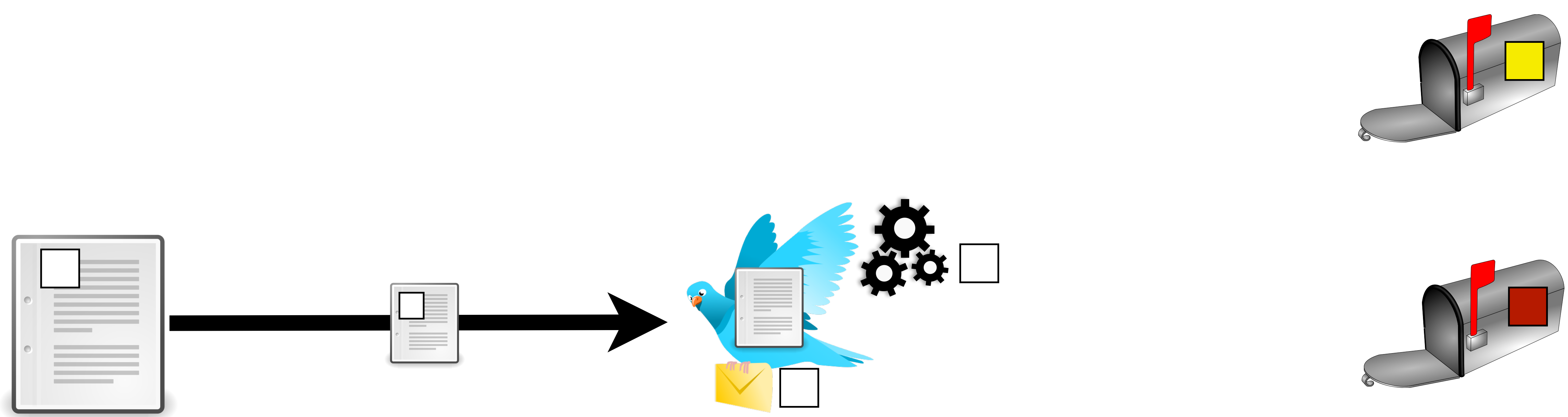

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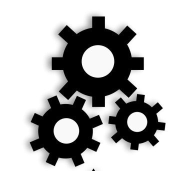

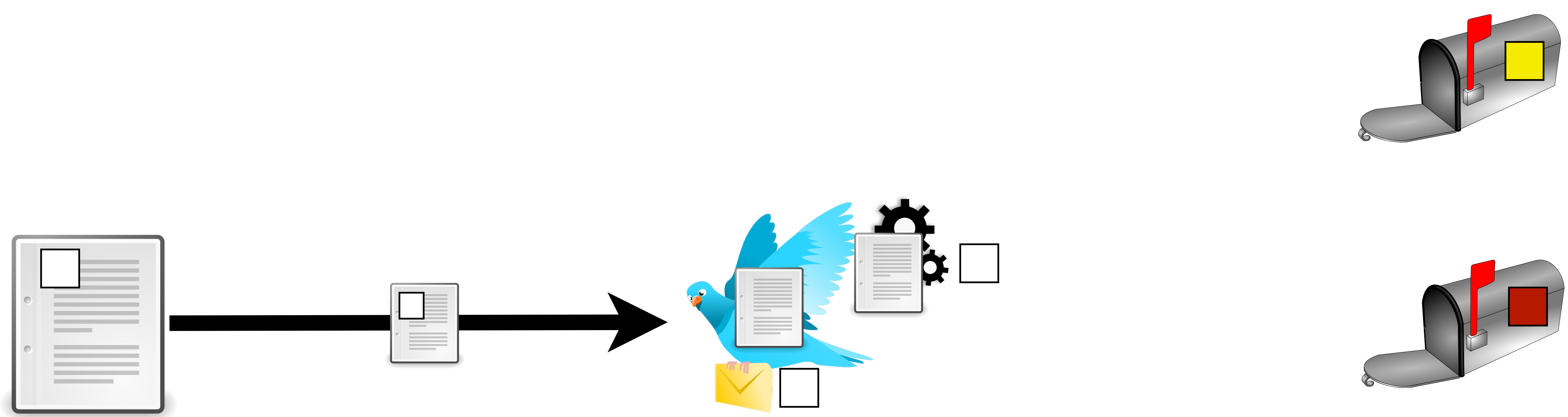

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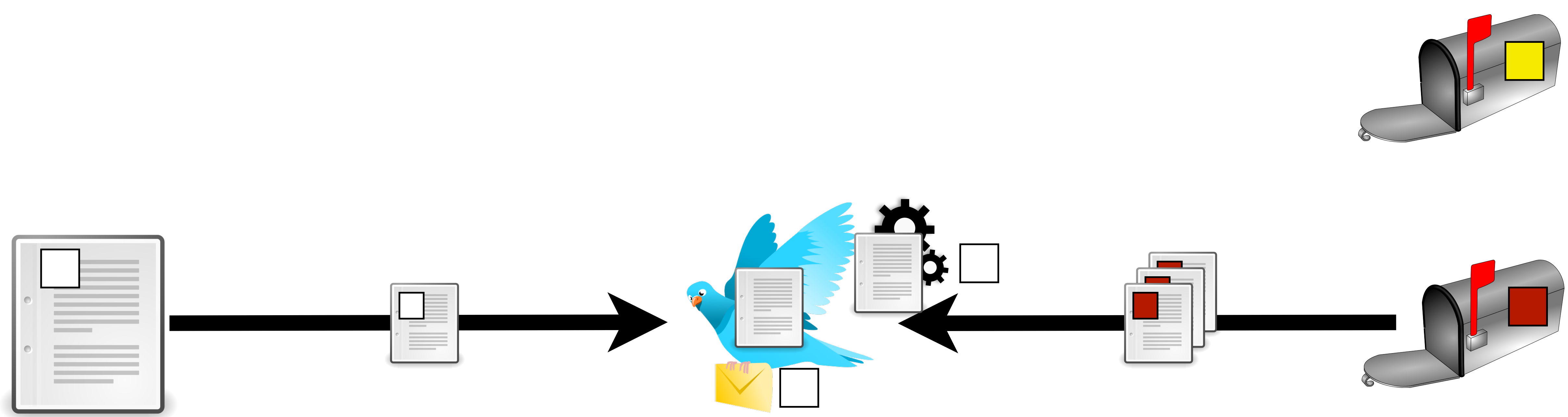

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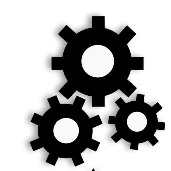

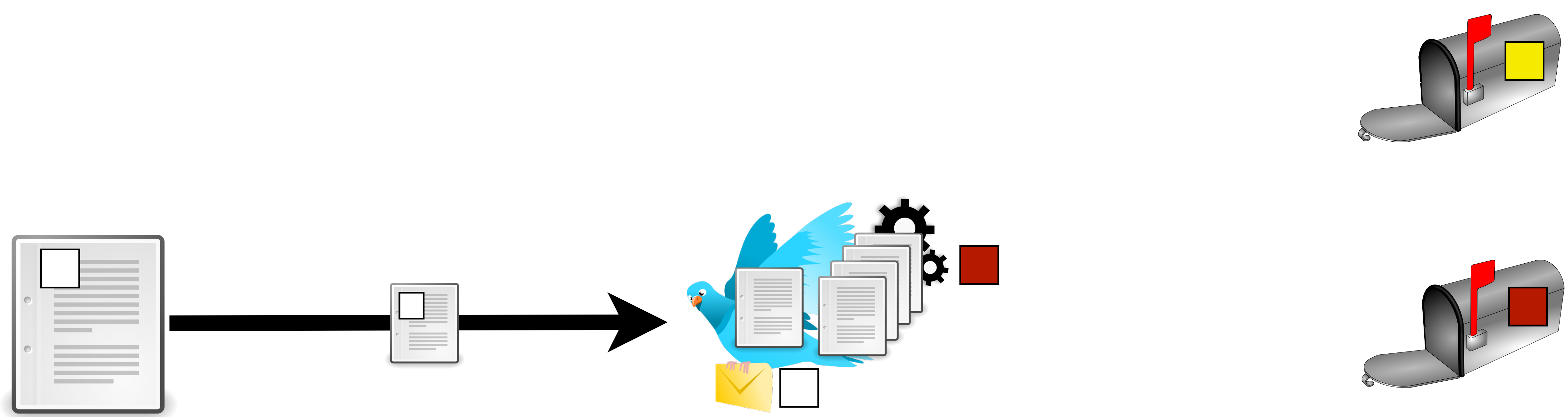

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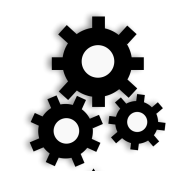

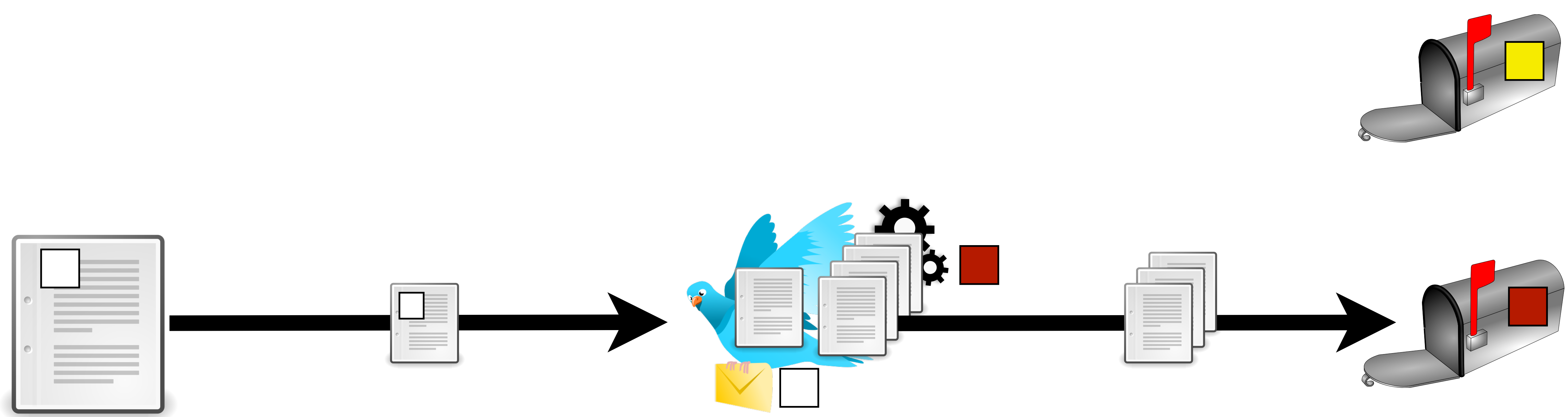

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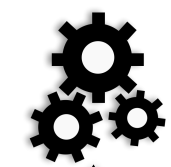

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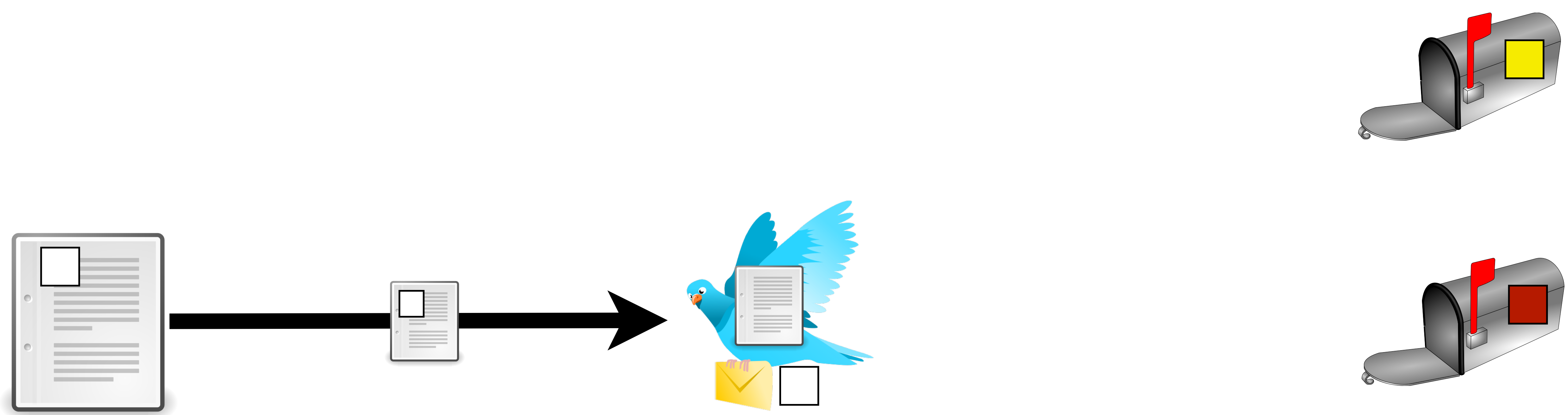

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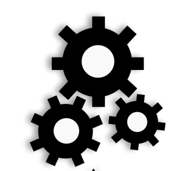
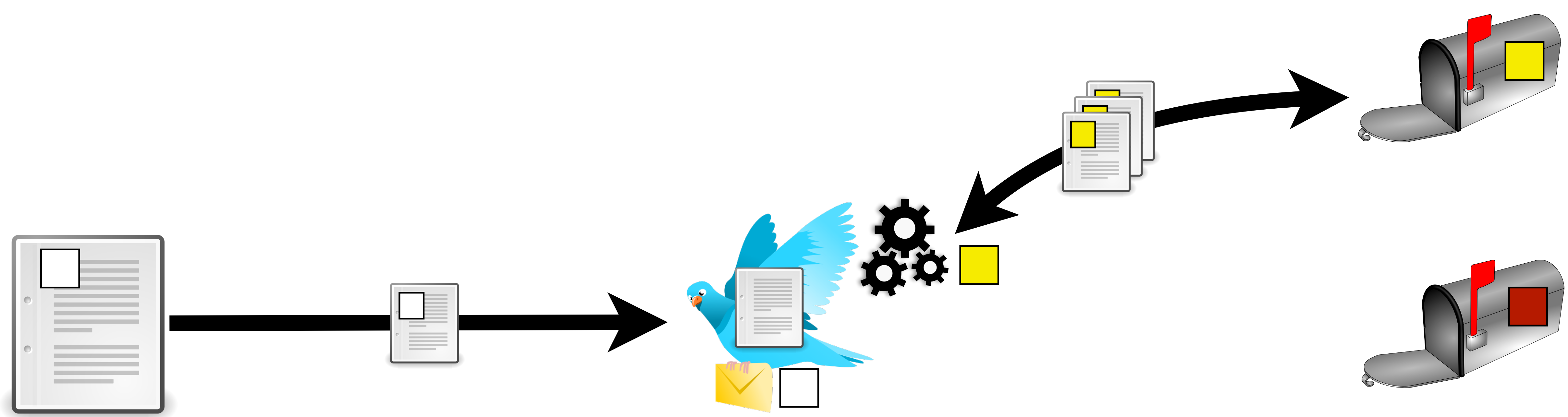




… `discard` *covertly leaks termination information.*

Termination Attack

- Leak secret bit through non-termination

```
isOfInterest :: User -> Int -> LIO ()
isOfInterest victim n = do
  discard $ do
    messages <- getUserMessages victim
    let user = recipient (message!!n)
    when (user == “Brad Pitt”) ⊥
  writeToPublicChannel “boring”
```

➤ If user matches: diverge in **`discard`** block

Else: write “boring” to public channel

Termination Attack

- Address at the framework/system level
- Use different attacker model
  - Termination-insensitive non-interference: *if a program terminates, then confidentiality and integrity of data is preserved*
- Don't address: very low bandwidth channel
  - Leaks 1 bit per run

Adding Fire

- Threads are crucial to modern web frameworks
  - Need to concurrently serve requests
- Viability of covert channel attacks
  - Termination attack leaks 1 bit per thread
  - Can leak data within same program
  - Permits attacks relying on internal timing

Internal Timing Attack

- Leak secret bit by affecting output ordering

```
isOfInterest :: User -> Int -> LIO ()
isOfInterest victim n = do
  fork $ do delay 100
            writeToPublicChannel "y"
  fork $ do
    discard $ do
      messages <- getUserMessages victim
       let user = msgDestination (message!!n)
       when (user == "Brad Pitt")$ delay 500
    writeToPublicChannel "es"
```

Write race to public channel

  - ➤ If user matches: write "y" first, then "es"
    Else: write "es" then "y"

- Analyze output: "yes" ➠ contact with Brad Pitt

Solution: Threads

Fighting fire with fire

- Decoupling **`discard`** computations
  - ➤ Spawn new thread to execute sub-computation
  - ➤ Immediately return a labeled future to thread
- Making LIO safe:
  - − **`discard`**
  - + **`lFork`**: spawn new, labeled threads
  - + **`lWait`**: force thread evaluation, first "raising" context label to read result and termination

~~Termination Attack~~

- Cannot leak bits through non-termination

```
isOfInterest :: User -> Int -> LIO ()
isOfInterest victim n = do
  discard lFork $ do
    messages <- getUserMessages victim
    let user = recipient (message!!n)
    when (user == “Brad Pitt”) ⊥
  writeToPublicChannel “clean”
```

- ➤ If user matches: diverge in **`discard`** block
- ➤ Always write “clean” to public channel

~~Internal Timing Attack~~

- Cannot affect output ordering

```
isOfInterest :: User -> Int -> LIO ()
isOfInterest victim n = do
  discard lFork $ do delay 100
                     writeToPublicChannel "y"
  discard lFork $ do
    lFork $ do
      messages <- getUserMessages victim
      let user = msgDestination (message!!n)
      when (user == "Brad Pitt")$ delay 500
    writeToPublicChannel "es"
```

NO race to public channel

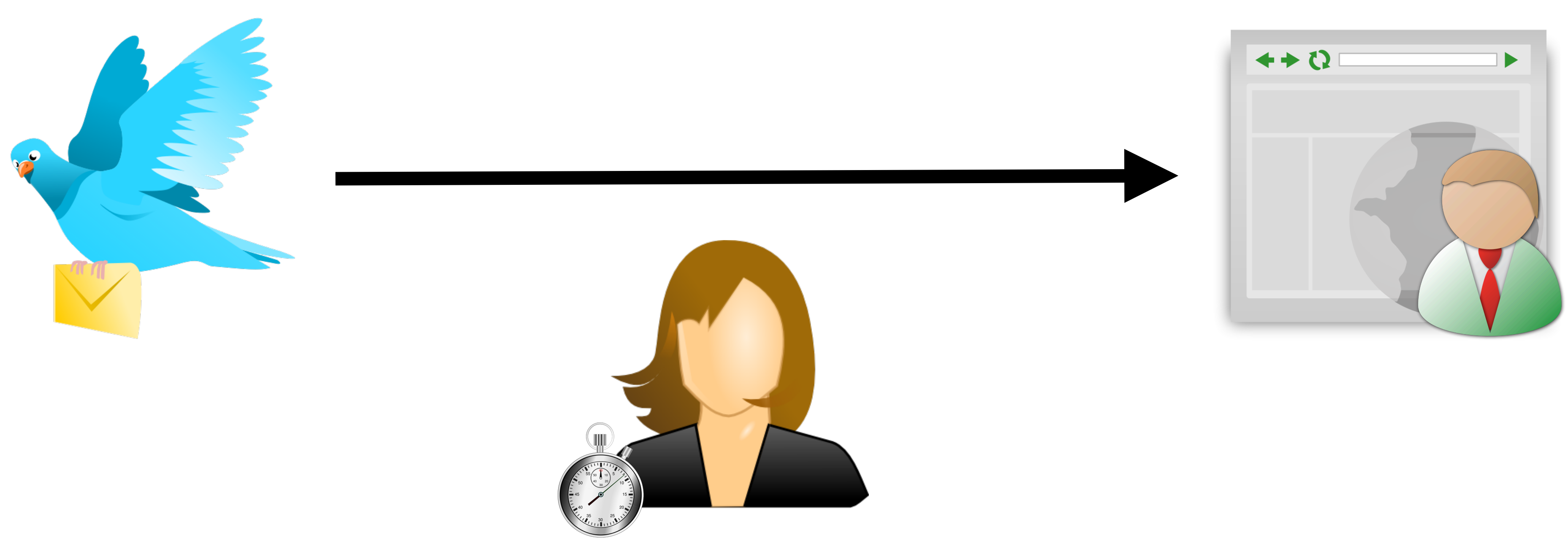
➤ Always write "es" first, then "y"

Status of LIO

- Used in production system
- Formalized as call-by-name λ-calculus
  - Support for thread spawning and joining with **`lFork`** and **`lWait`**
  - Support for mutable single-place channels
- Theorem: Termination-sensitive non-interference
  - Informally: *Confidentiality and integrity of data is preserved even if threads diverge.*

A Practical Perspective

- Covert channels closed by LIO
  - *Termination*
  - *Internal timing*
- What about external timing channel?



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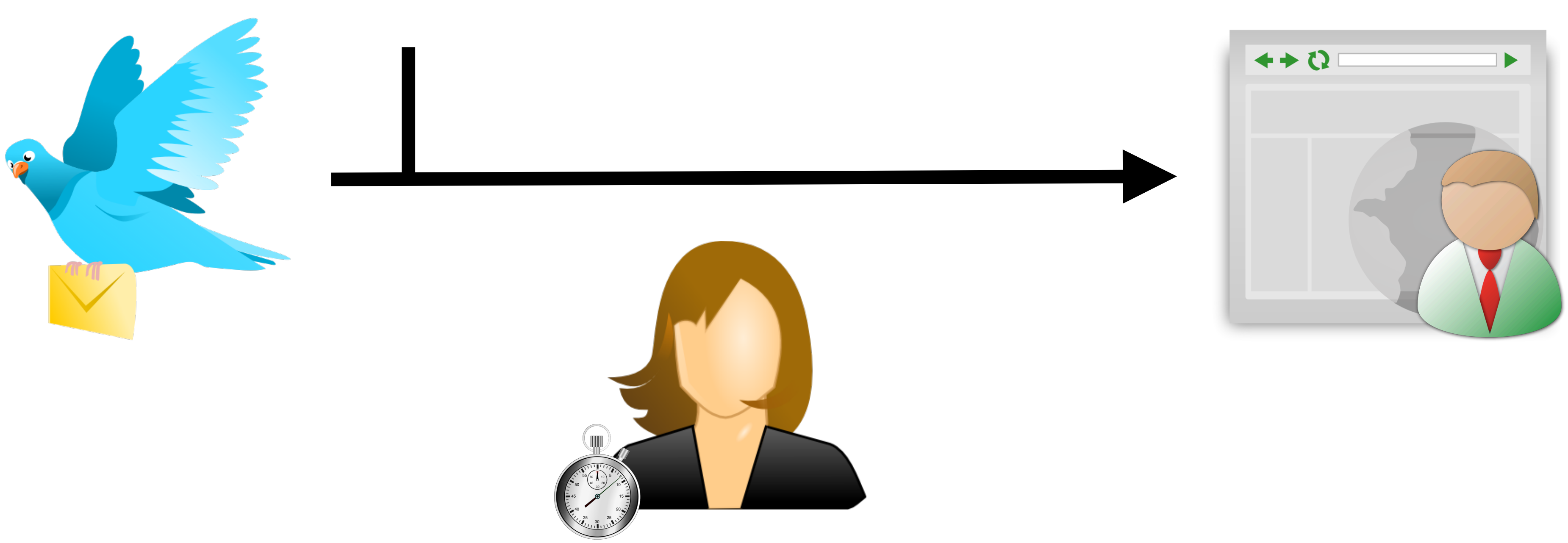

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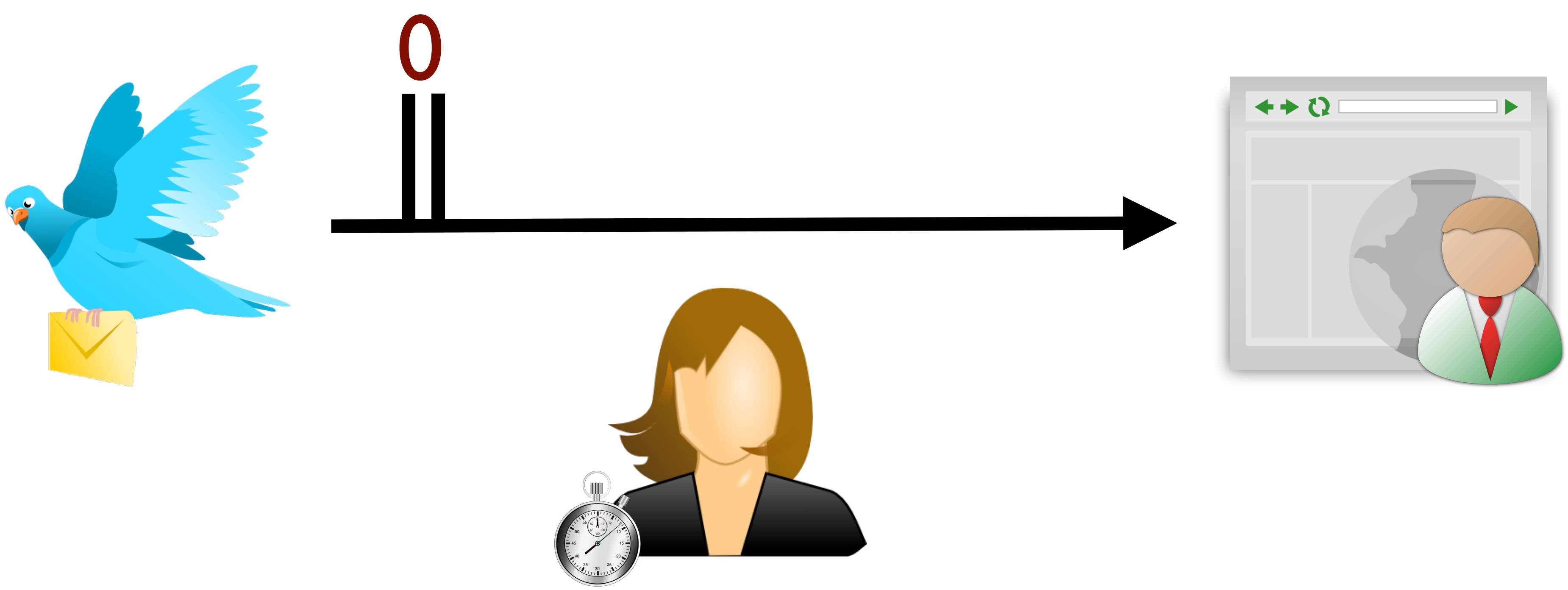

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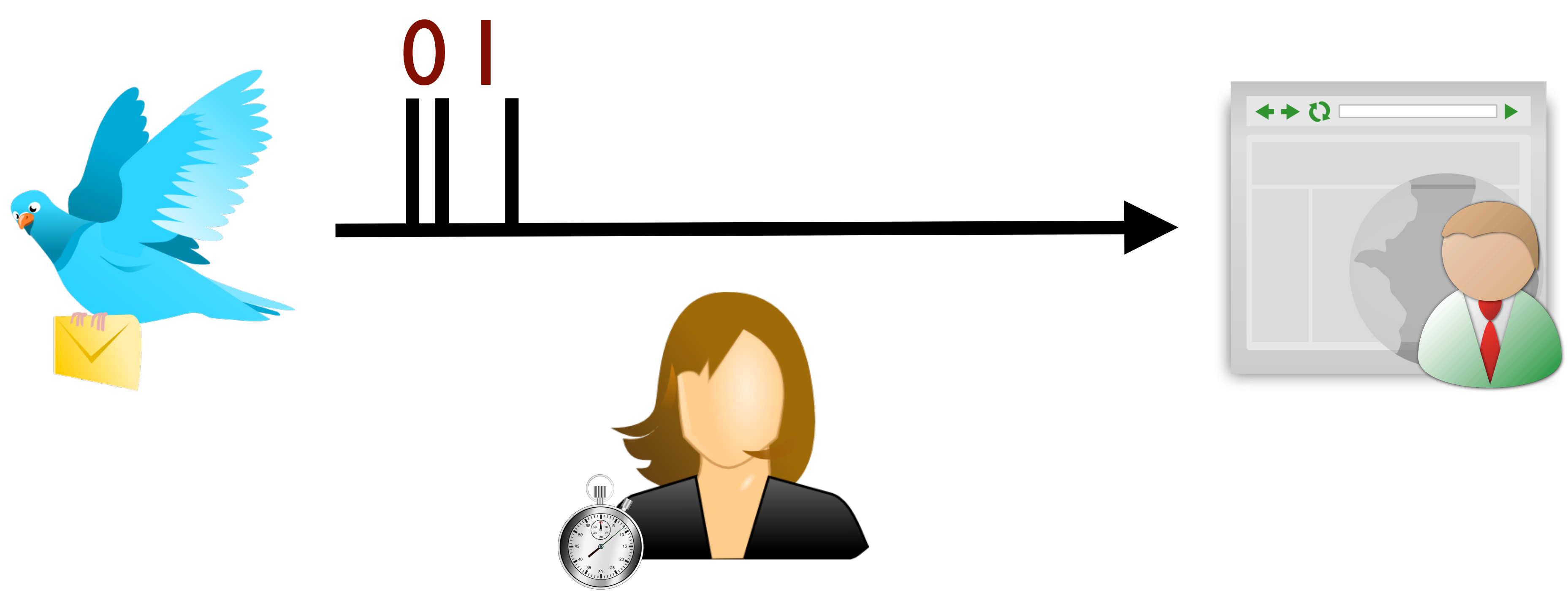

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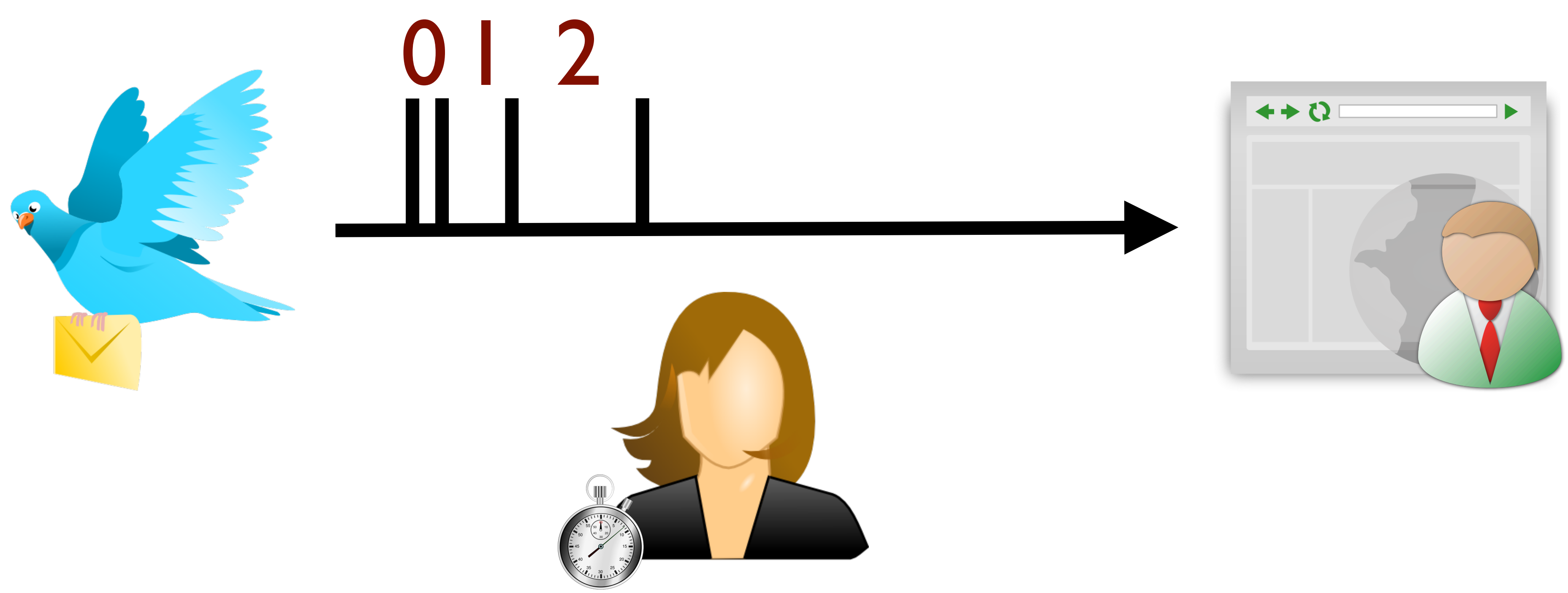

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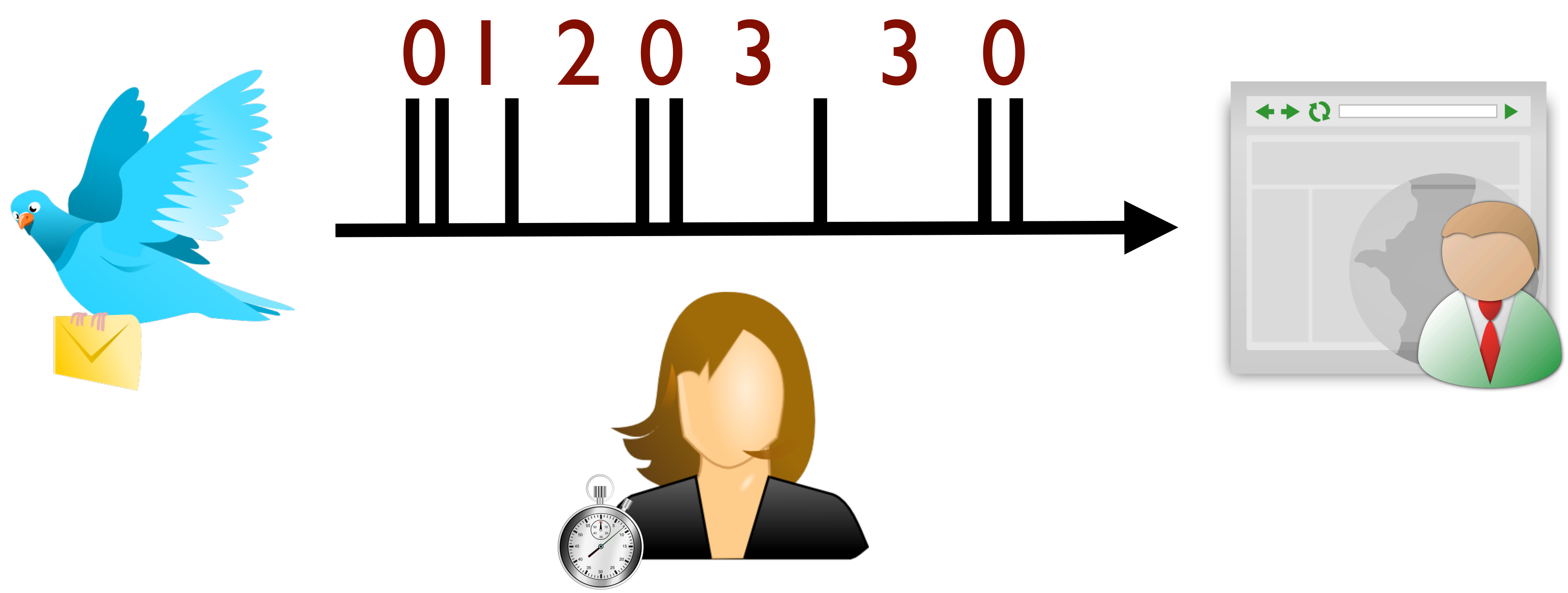

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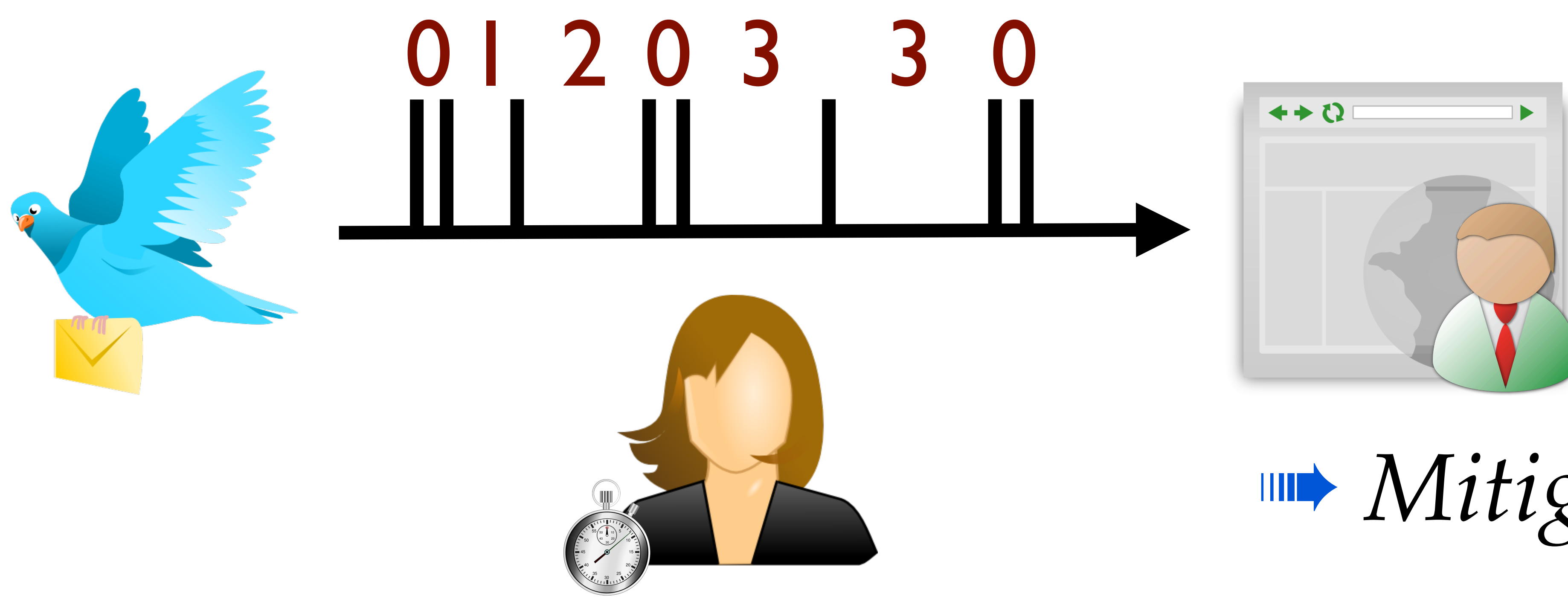


➠ *Mitigation*

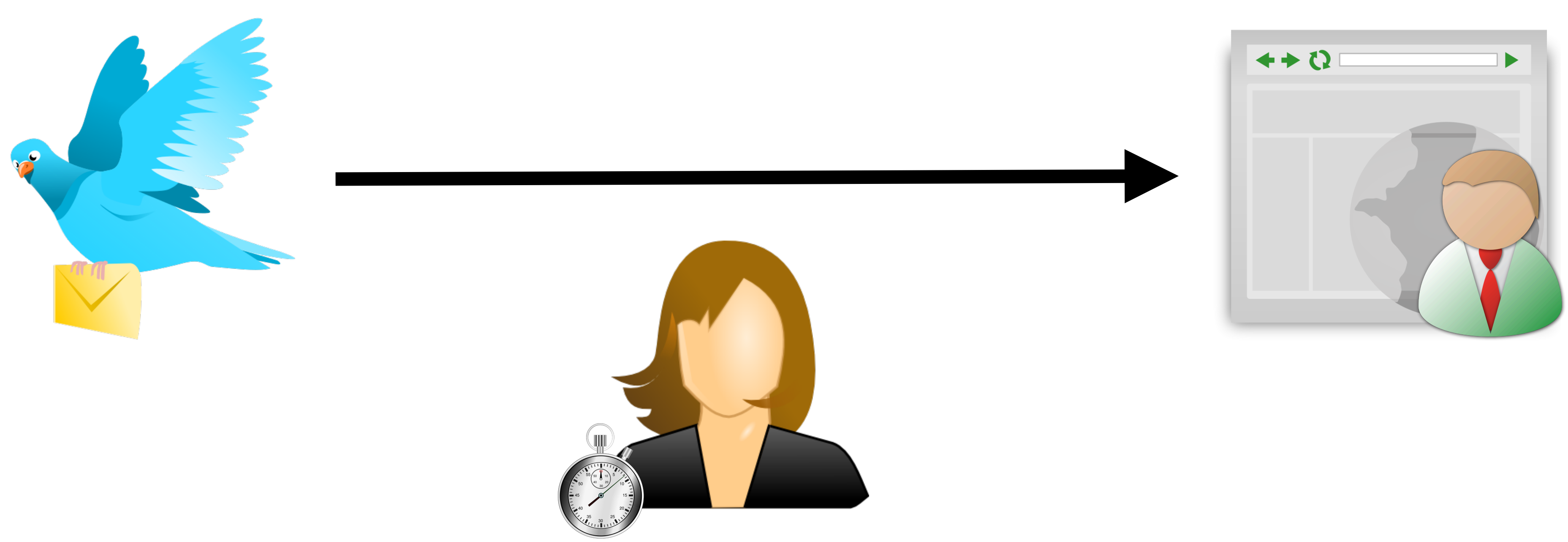
Thank you

`cabal install lio`

`http://gitstar.com/scs/lio`

Mitigation

- Predicative mitigation (Zhang, Askarov, Myers)
  - *Black-box approach ➠ monad transformers!*
  - *Predict output schedule for app*
  - *Misprediction leaks 1 bit, total bounded in log-time*



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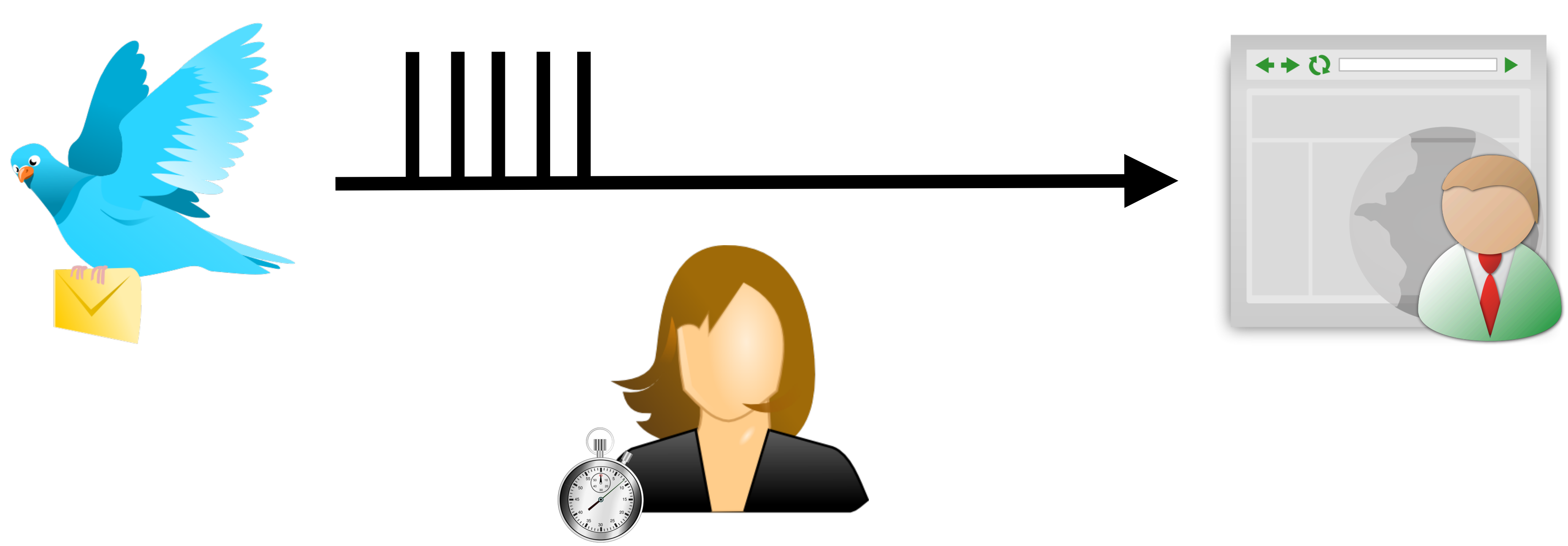

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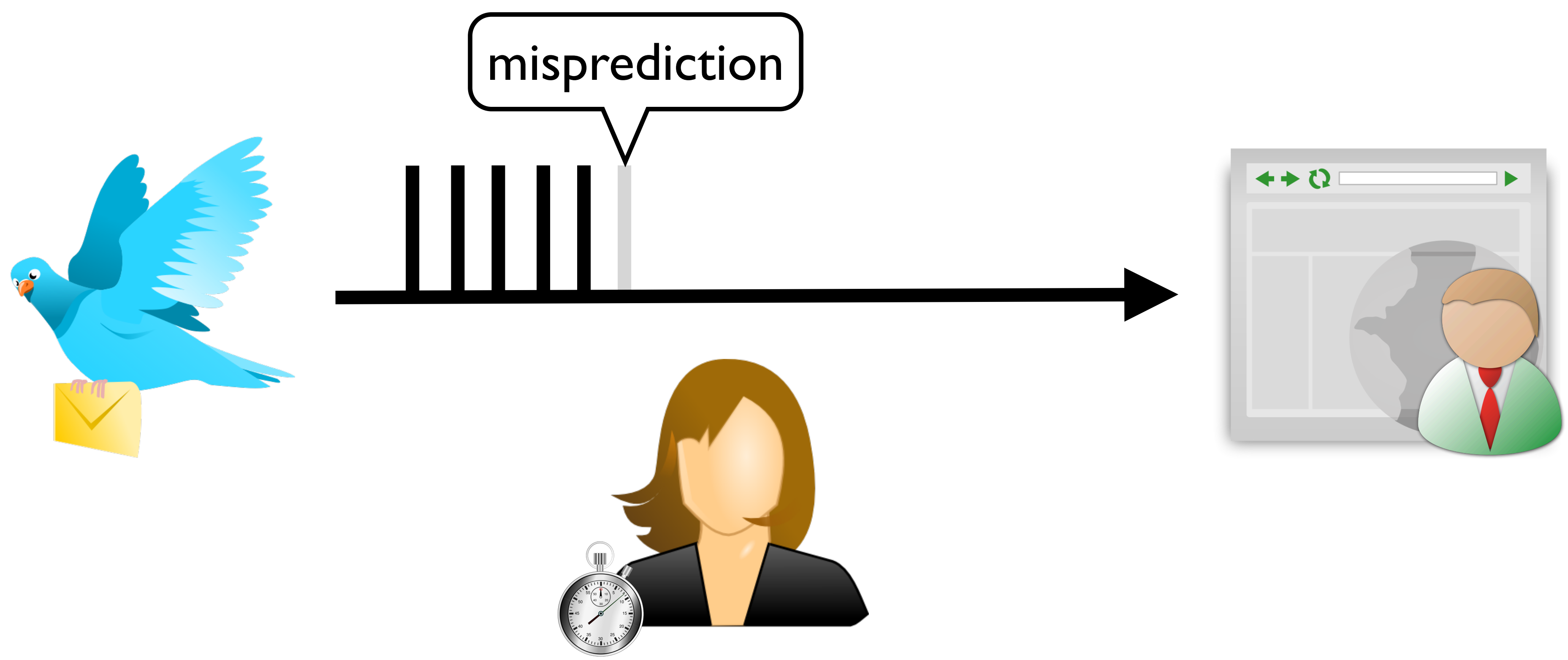

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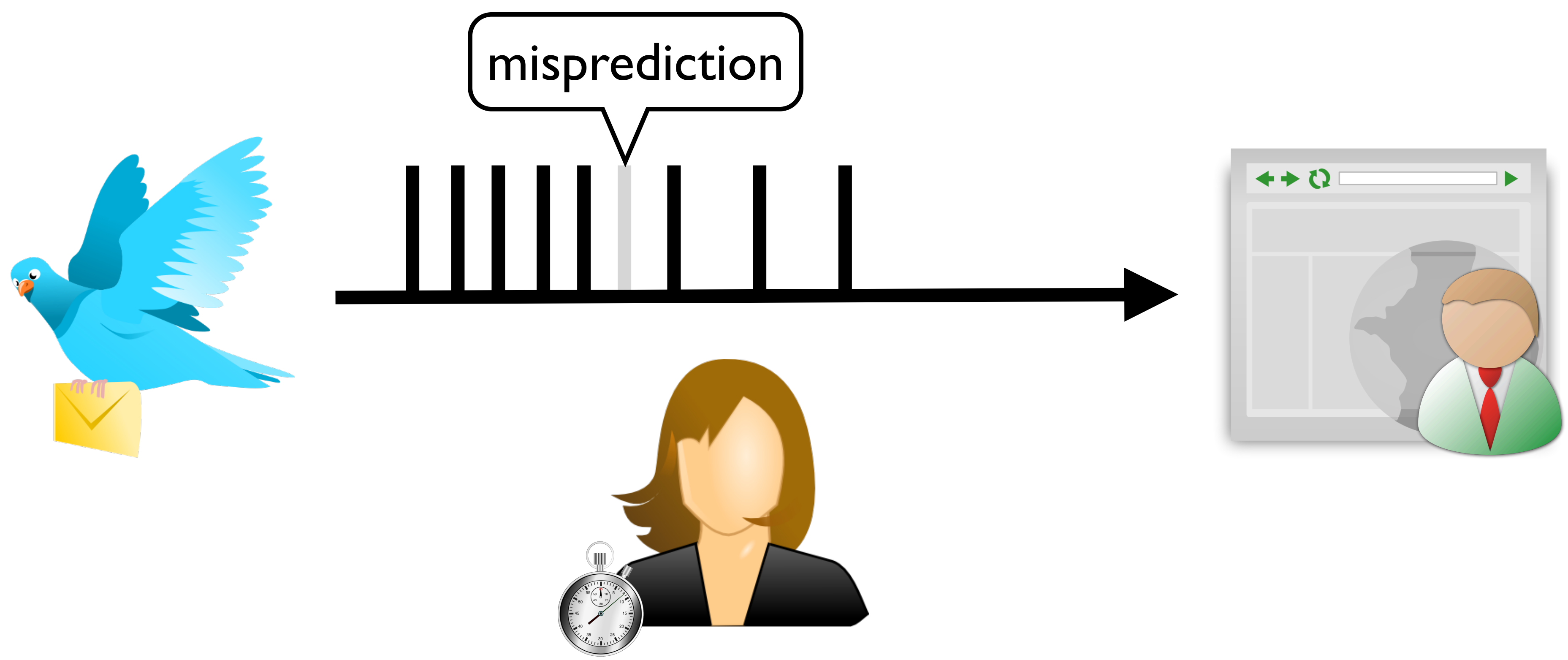

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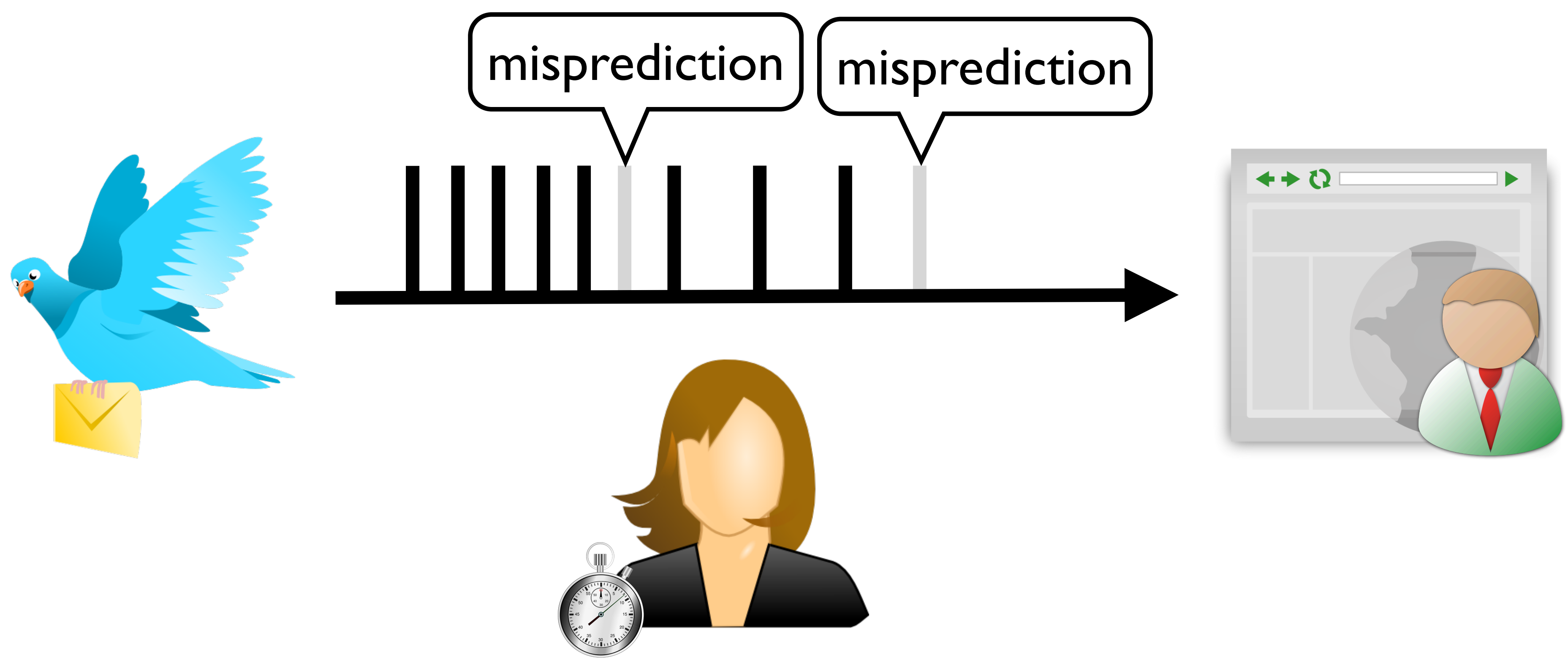

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