Logistics

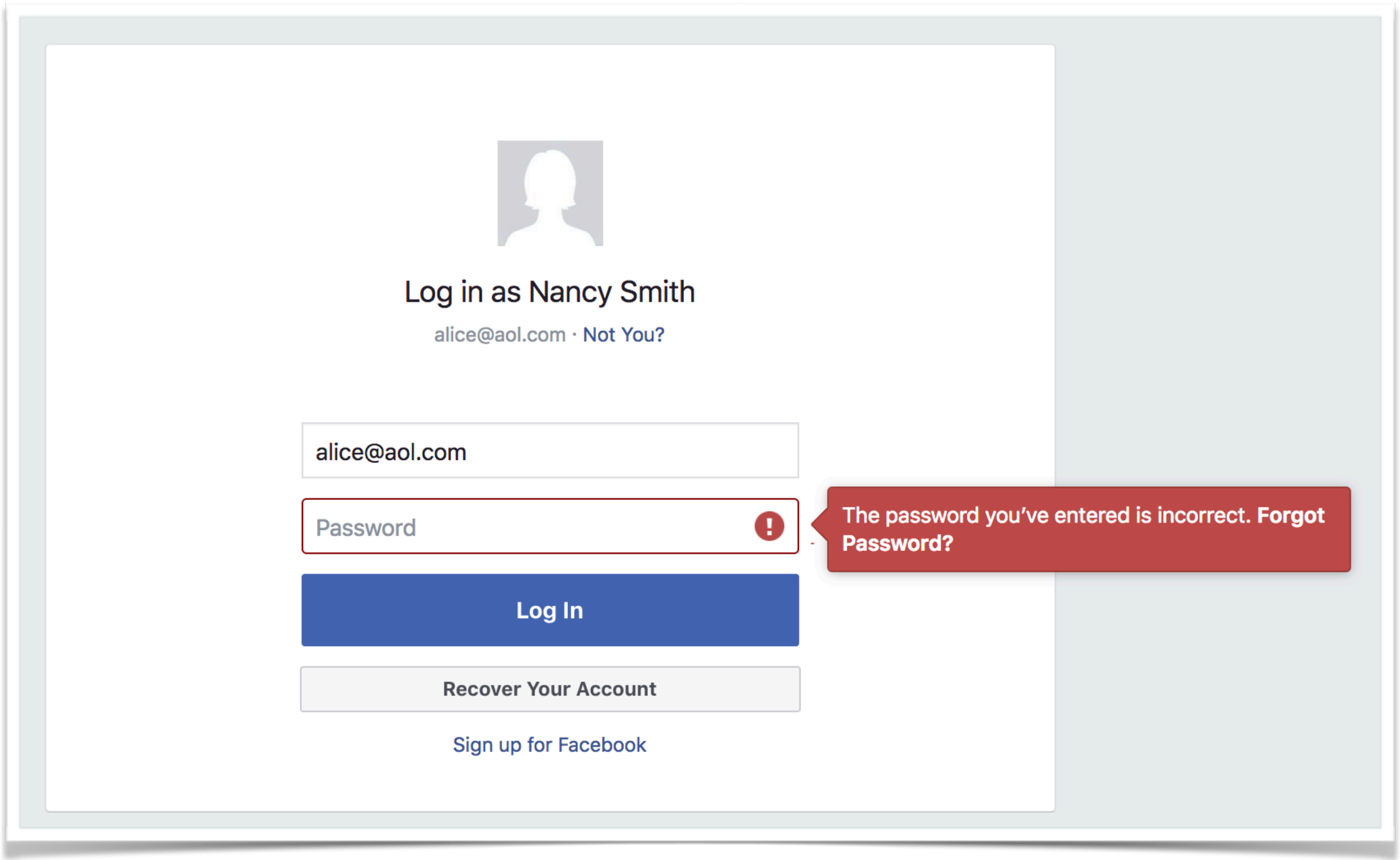
- Next week, my OH will be 10-11 vs 11-12
- HW6 (= writing + Monad.hs) counts!
  - You HW grade = max of 5 HWs
- CAPEs!

Special-topic: constant-time programming

Today + Week 10

- What is constant-time programming?
- Constant-time programming in C
- Constant-time programming in FaCT

What’s wrong with this picture?



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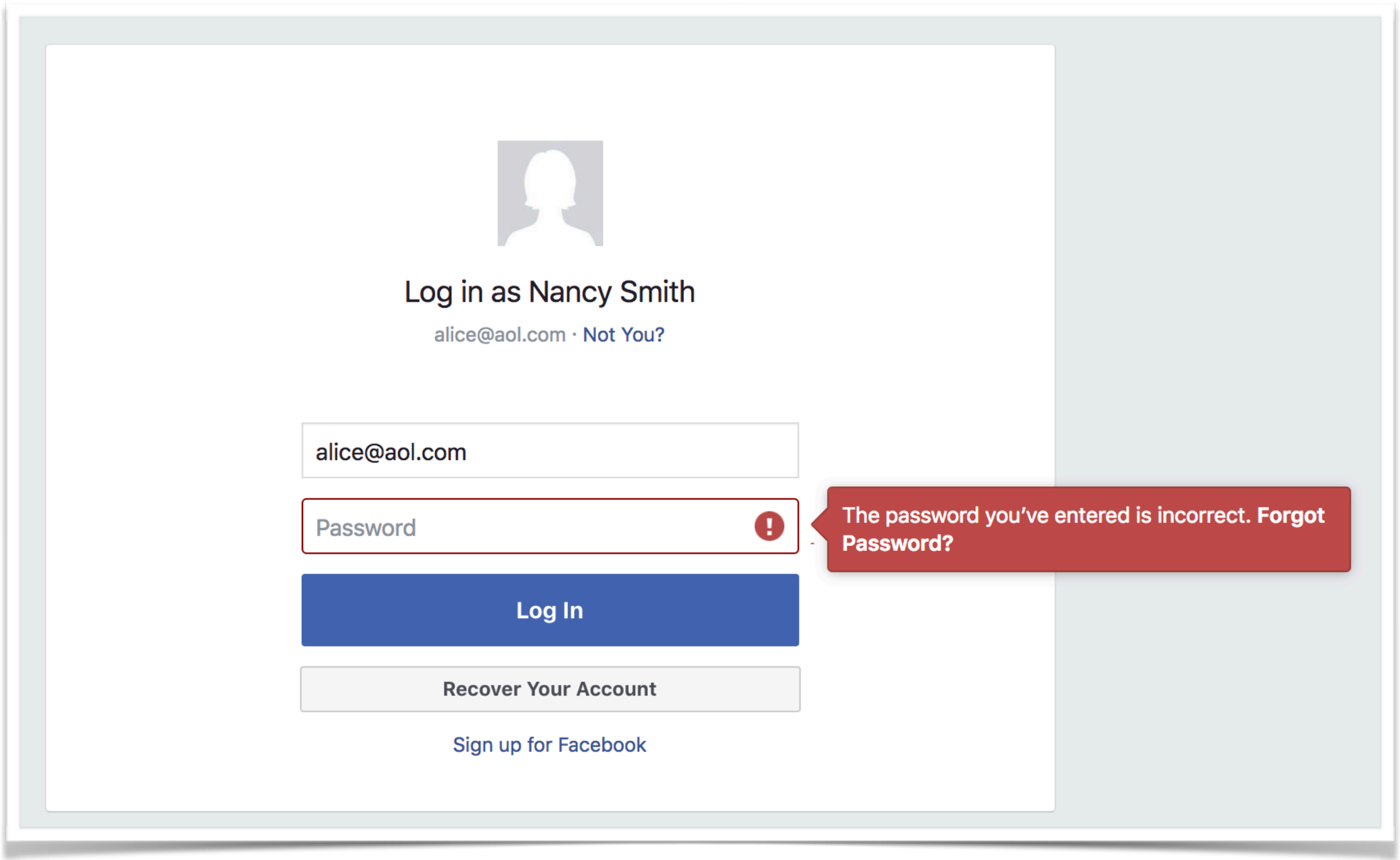

It’s leaking that alice@aol.com is a valid user on FB!

Fix this by hiding users!

```
function login(req) {
  if (!isValid(req.user)) {
     // reply “Invalid user or password”
  } else {
     const pHash = findPass(req.user);
     if (pHash !== hash(req.password)) {
        // reply “Invalid user or password”
     } else {
        // succesfull login!
     }
  }
}
```

Is this secure? A: yes, B: no

```
function login(req) {
  if (!isValid(req.user)) {
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  }
}
```
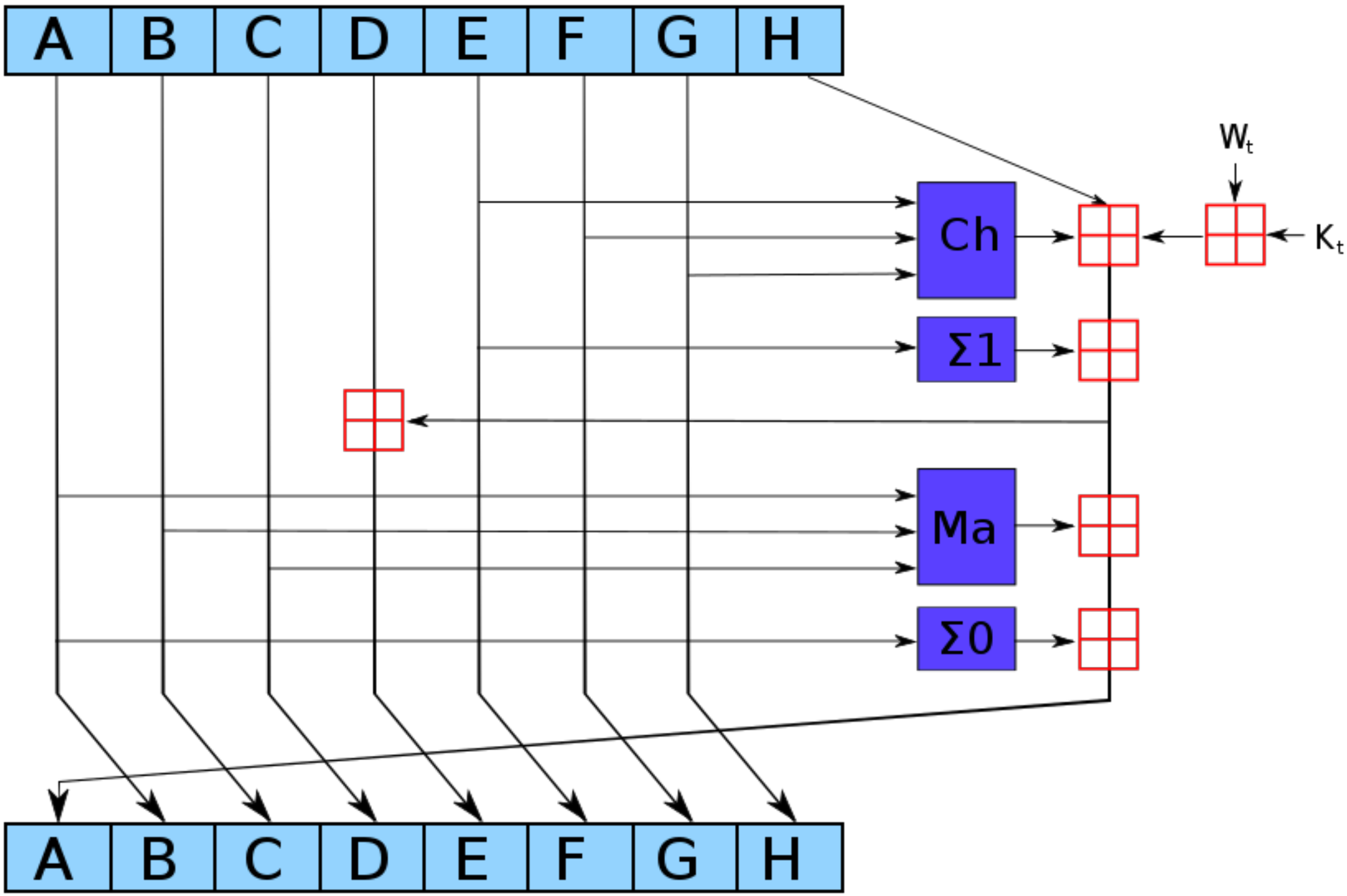

Need to always do the password hashing!

Hashing takes take

- What is a cryptographic hash function?
  - Pre-image resistant: Given output, cannot find input such that output=hash(input)
  - Second pre-image resistant: Given $input_1$, cannot find $input_2$ such that $hash(input_1) = hash(input_2)$
  - Collision resistant: Cannot find $input_1$, $input_2$ such that $hash(input_1) = hash(input_2)$
- How are hash functions implemented?
  - Lots of bit mixing

E.g., SHA2, 60-80x:



Don’t use hash functions for passwords

- In practice you should NOT hash passwords
- You should use algorithms like bcrypt and scrypt
  - Internally use hash functions
  - Designed to be resistant to brute-force attacks that try to guess passwords even w/ Moore’s law

Let’s always compute hash!

```
function login(req) {
  const uHash = hash(req.password);
  if (!isValid(req.user)) {
    // reply “Invalid user or password”
  } else {
     const pHash = findPass(req.user);
     if (pHash !== uHash) {
        // reply “Invalid user or password”
     } else {
        // succesfull login!
     }
  }
}
```

Let’s always compute hash!

```
function login(req) {
  const uHash = hash(req.password);
  if (!isValid(req.user)) {
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  } else {
     const pHash = findPass(req.user);
     if (pHash !== uHash) {
        // reply “Invalid user or password”
     } else {
        // succesfull login!
     }
  }
}
```

Are we done? A: yes, B: no

Always run isValid & findPass

```
function login(req) {
  const user  = findUser(req.user);
  const uHash = hash(req.password);

  if (!user || uHash !== user.pHash) {
    // reply “Invalid user or password”
  } else {
    // succesfull login!
  }
}
```

Always run isValid & findPass

```
function login(req) {
  const user  = findUser(req.user);
  const uHash = hash(req.password);

  if (!user || uHash !== user.pHash) {
    // reply “Invalid user or password”
  } else {
    // succesfull login!
  }
}
```

Finally, are we done? A: yes, B: no

Short circuit operators

- How do we evaluate exp_1 || exp_2 ?
  - $exp_1 \rightarrow \cdots \rightarrow value$
  - if $value_1$ = true
    then true else $exp_2 \rightarrow \cdots \rightarrow value_2$
- How do we evaluate exp_1 && exp_2 ?
  - $exp_1 \rightarrow \cdots \rightarrow value$
  - if $value_1$ = false
    then false else $exp_2 \rightarrow \cdots \rightarrow value_2$

Don’t use short-circuiting operators

```
b2i :: Bool -> Int
i2b :: Int -> Bool
```

```
function login(req) {
  const user  = findUser(req.user);
  const uHash = hash(req.password);

  if (i2b(b2i(!user) | b2i(uHash !== user.pHash))) {
    // reply “Invalid user or password”
  } else {
    // succesfull login!
  }
}
```

Don’t use short-circuiting operators

```
b2i :: Bool -> Int
i2b :: Int -> Bool
```

```
function login(req) {
  const user  = findUser(req.user);
  const uHash = hash(req.password);

  if (i2b(b2i(!user) | b2i(uHash !== user.pHash))) {
    // reply “Invalid user or password”
  } else {
    // succesfull login!
  }
}
```

OMG, now are we done? A: yes, B: no

```
uHash !== user.pHash
```

May be leaking information about the stored password!

String comparison is dangerous

- What is !== doing internally when comparing strings?
  - Probably using C's strcmp
- How does strcmp work?

Don’t use strcmp

```
cmp :: String -> String -> Bool
```

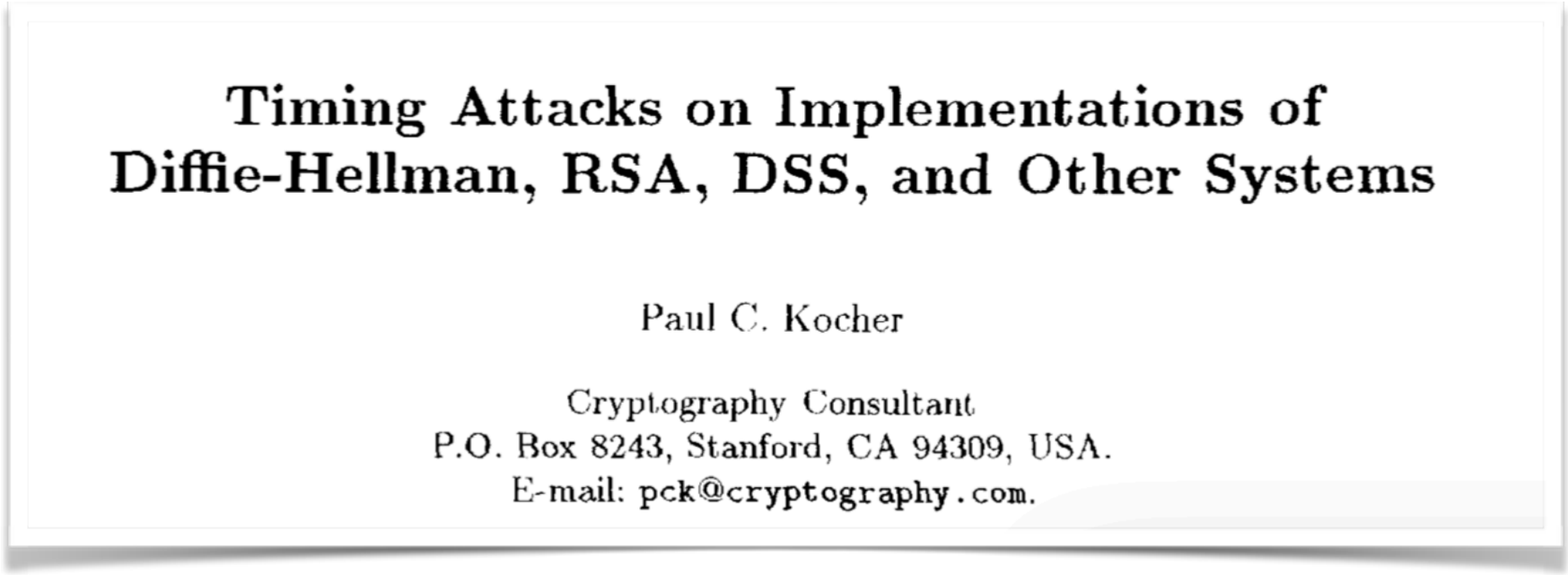
```
function login(req) {
  const user  = findUser(req.user);
  const uHash = hash(req.password);

  if (i2b(b2i(!user) | b2i(cmp(uHash, user.pHash)))) {
    // reply “Invalid user or password”
  } else {
    // succesfull login!
  }
}
```

cmp doesn’t terminate early, it loops to end of list

This is a lot of work..

do we really need to do this?



Timing Attacks on Implementations of Diffie-Hellman, RSA, DSS, and Other Systems

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- Implementing RSA algorithm by the book is unsafe

  - Attacker can learn secret keys via timing:

```
t0 ← getTime
rsa.decrypt(...)
t1 ← getTime
```

Crypto at the heart of SSL/TLS

- Secure Socket Layer/Transport Layer Security
  - Protocol used to provide secure pipe between networked computers
  - What does secure mean here?

Remote Timing Attacks are Practical

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- Can extract secret keys across the network
  - Is this still relevant today?
- Can extract secret keys across process
  - Where is this relevant today?
- Can extract secret keys across VMs
  - Where is this relevant today?

How can we avoid leaks?

- Randomization, randomization, randomization!
  - Every time server responds, delay by some random amount
  - Every time you do operation on integer, mask it with some random integer
- Challenges with this?

Constant-time

- Implement algorithms to run in constant-time
  - I.e., make sure that `t1-t0 = c`

```
t0 ← getTime
rsa.decrypt(...)
t1 ← getTime
```

  - Does this mean we can't use operators like && or ||?
    - A: yes, B: no

Constant-time (in secrets)

- Only parts of computations that deal with secrets need to run in constant-time
  - Don’t care about public parts!

How do we write constant-time code?

- We're going to look at two ways:
  - In a general-purpose language, C
  - In a domain-specific language, FaCT