# The Pythia PRF Service

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# Summary

**Passwords:** Ubiquitous, but vulnerable to offline attack



**New direction:** Complete architecture for password storage using a new cryptographic PRF service.

**Better:** no offline attacks, compromise recovery, key management, cryptographic erasure of stolen information


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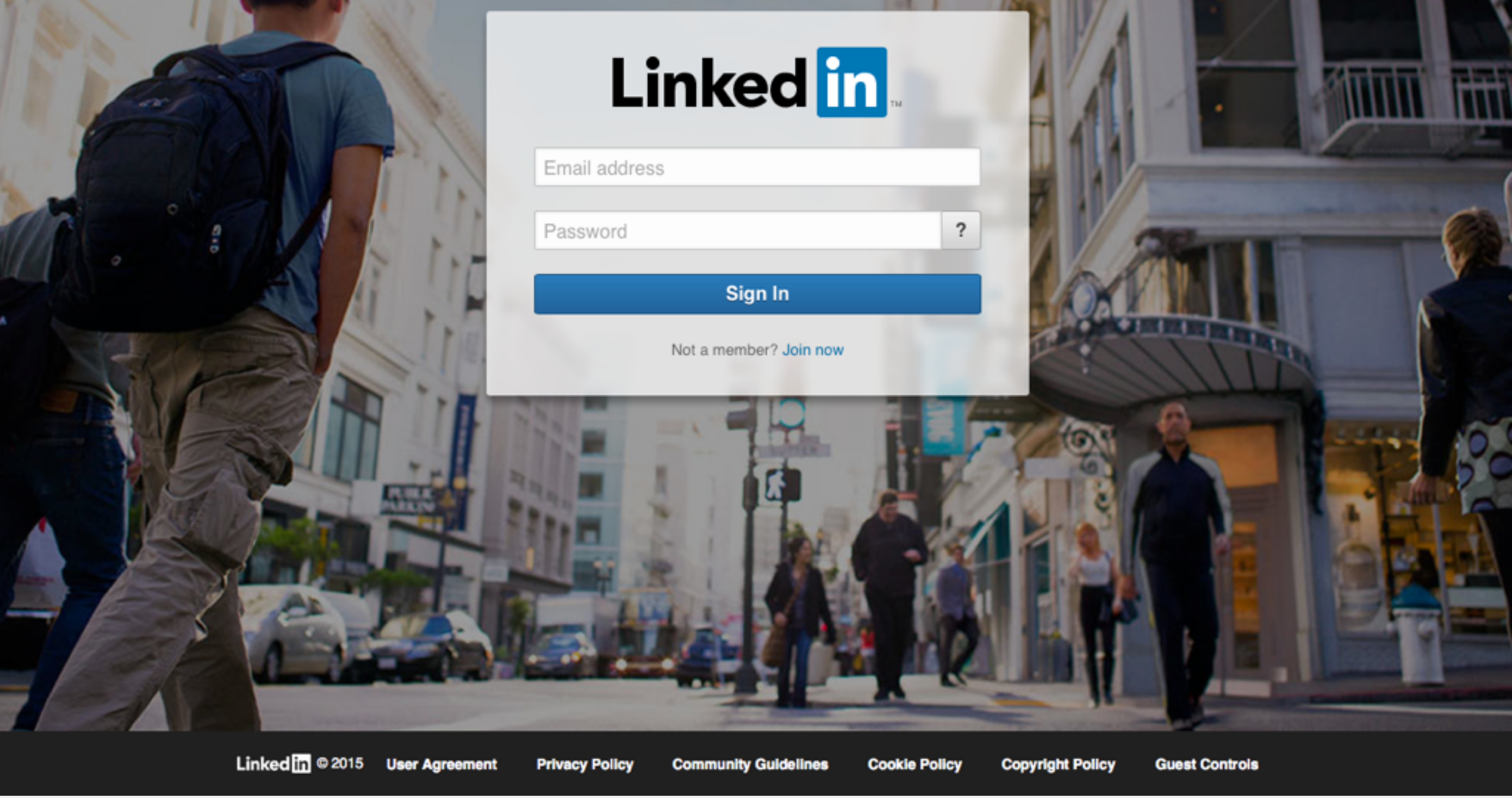


Website stores one of:

- pw
- Hash(pw)
- salt, Hash(salt, pw)
- salt, $\text{Hash}^{4096}$(salt, pw)

6.5M hashes leaked

**90%**

recovered 2 weeks

# Password Database Compromises


**Password DB breaches are common**

# Facebook’s Password Onion

```
$cur  = ‘password’
$cur  = md5($cur)
$salt = randbytes(20)
$cur  = hmac_sha1($cur, $salt)
$cur  = remote_hmac_sha256($cur, $secret)
$cur  = scrypt($cur, $salt)
$cur  = hmac_sha256($cur, $salt)
```

**Archeological record of FB’s struggles with password security.**

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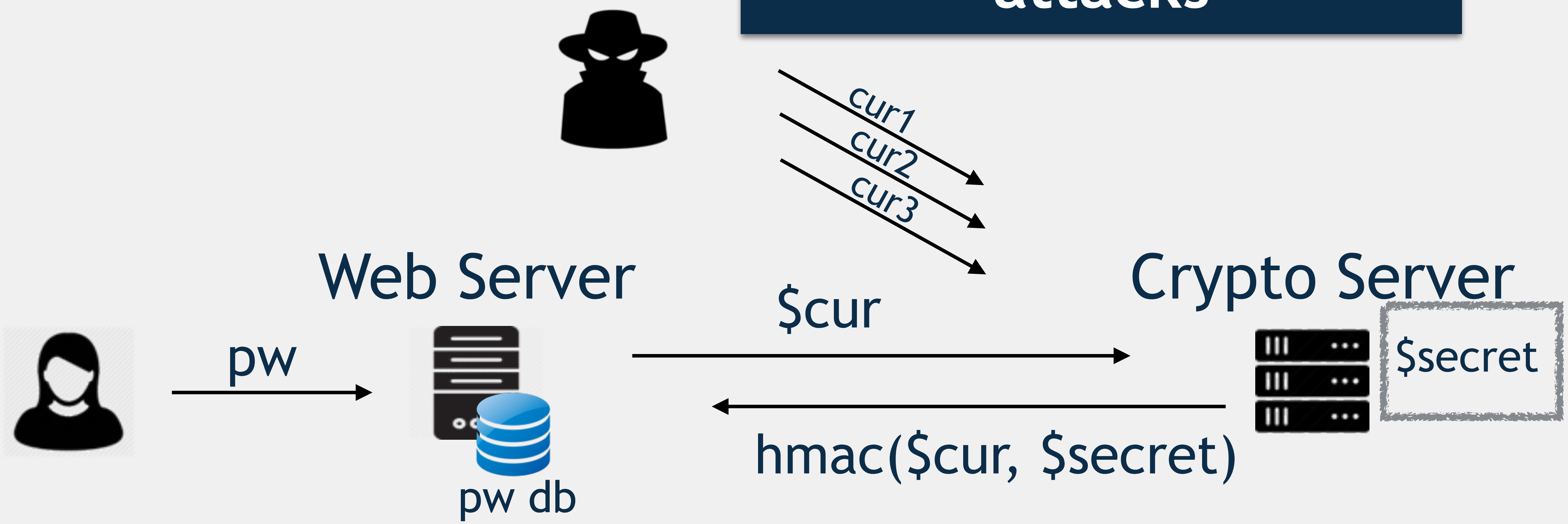
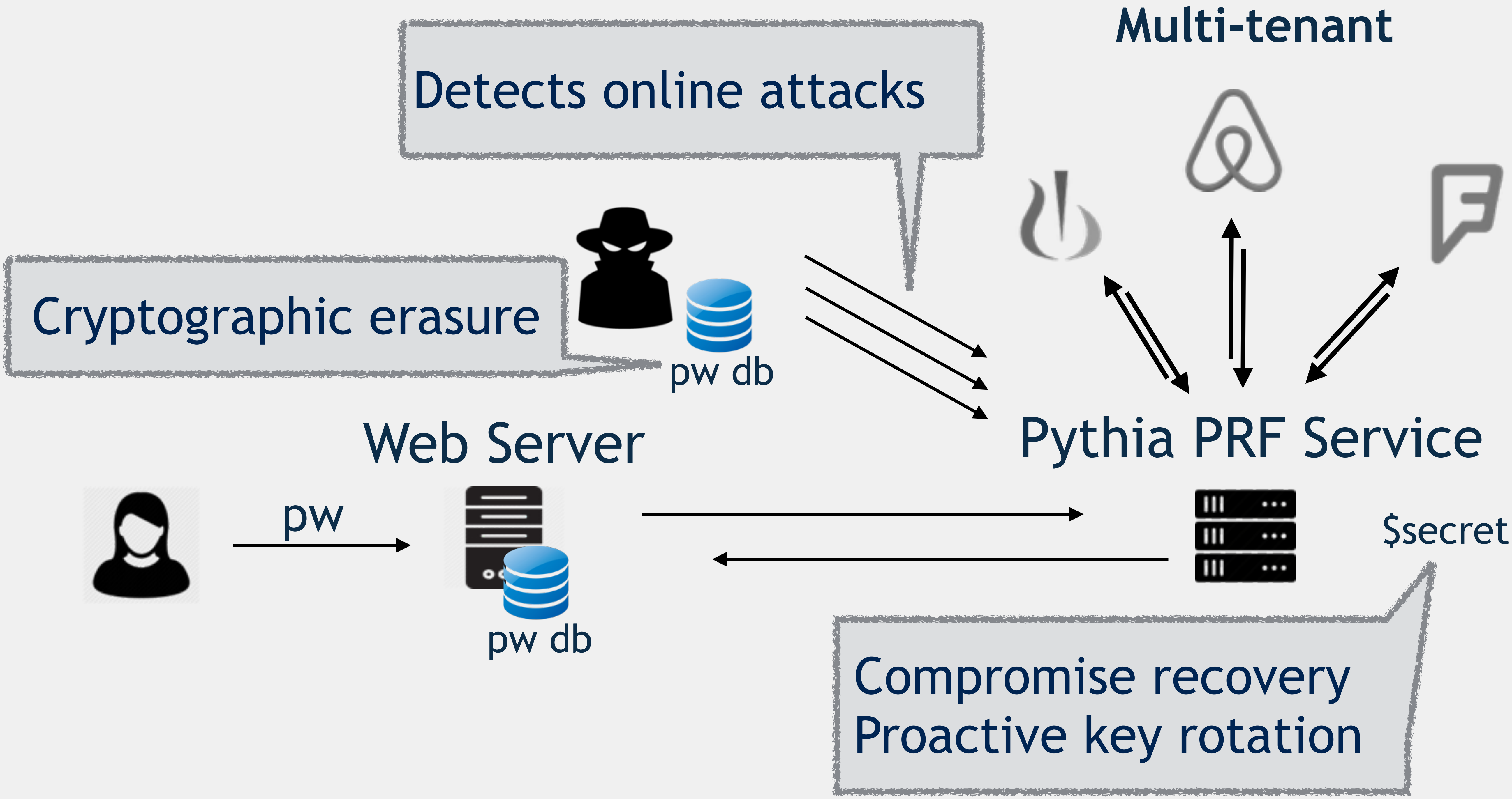
# Remote HMAC Distributes Trust

**Hard to detect online attacks**




**How do we rotate $secret?**

# Our Approach: Pythia PRF



# PRF Query — New User

User | Web Server | Pythia Server

user,pw

```
t:=random()
x:=blind(pw)
```

Web Server ID

Blinded PW

query: w,t,x

User ID

```
k := keytable[w]
```
y := $F_k$(t,x)

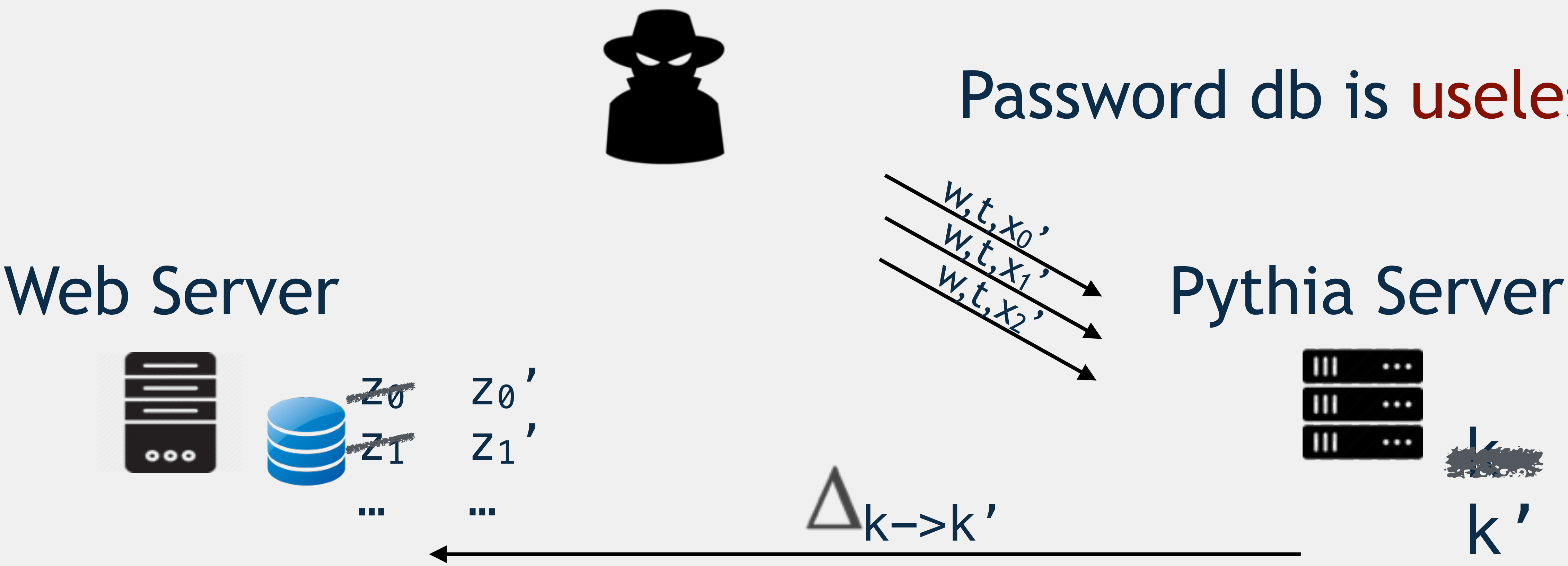
y

Protected PW

```
z := unblind(y)
store: (user,t,z)
```

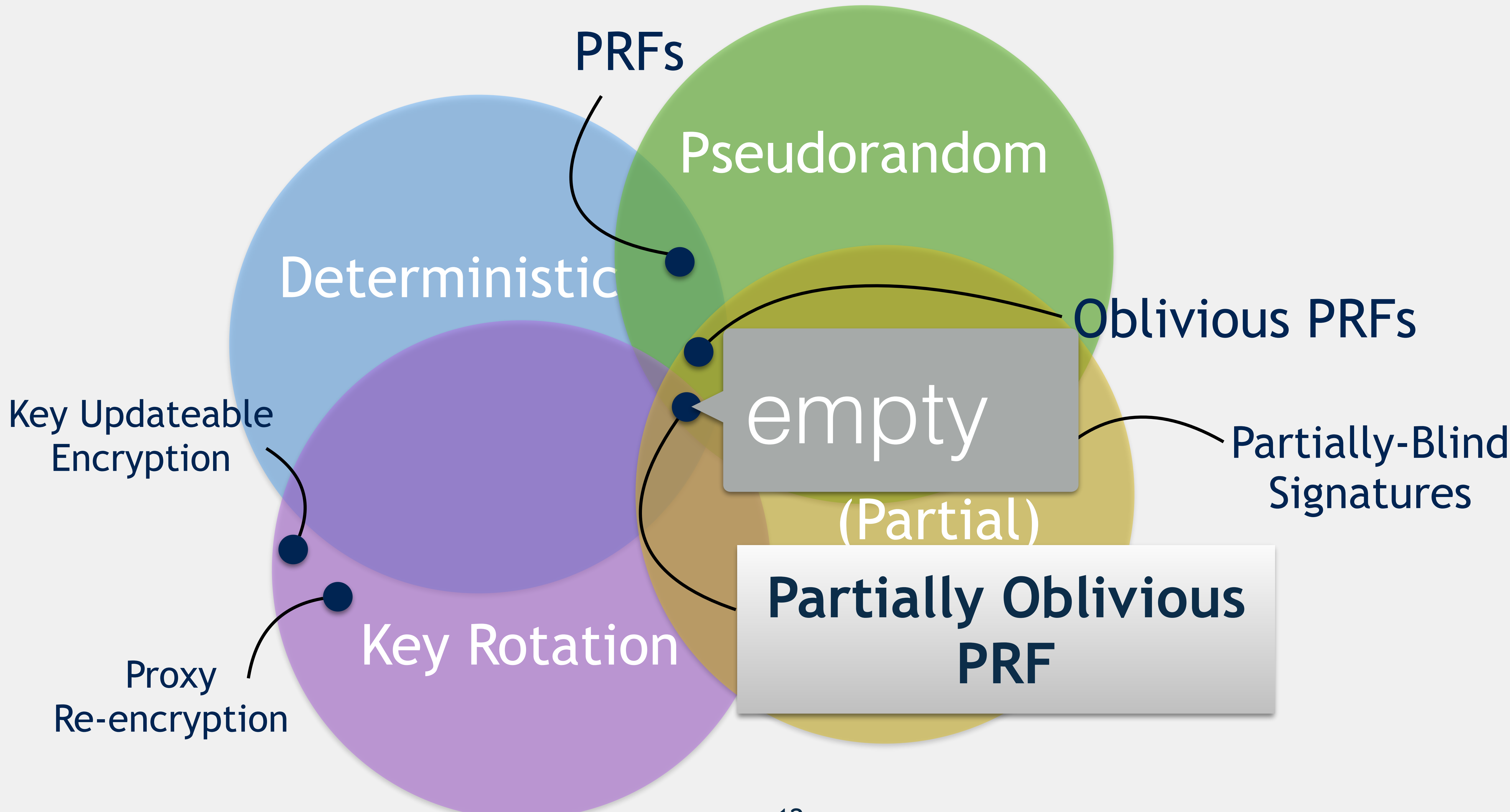
# Compromise Recovery

Password db is useless




Doesn’t require original password
User password remains unchanged

# Existing Crypto Primitives are Insufficient



# Partially Obl. PRF Construction

Bilinear Pairing $e: G_1 x G_2 \rightarrow G_T$

$$e(a^x, b^y) = e(a,b)^{xy}$$

Web Server

**PRF Query**

Pythia Server

$x := H(pw)^r$

blind()

$w,t,x \longrightarrow$

$k := keytable[w]$

$\longleftarrow y := e(H(t), x)^k$

$F_k(t,x)$

$z := y^{1/r} = e(H(t), H(pw))^{k*r*1/r} = \boxed{e(H(t), H(pw))^k}$

unblind()

Similar use of pairings: [Sakai, Ohgishi, Kasahara] [Boneh,Waters]

# Partially Obl. PRF Construction

Web Server

**Compromise Recovery**

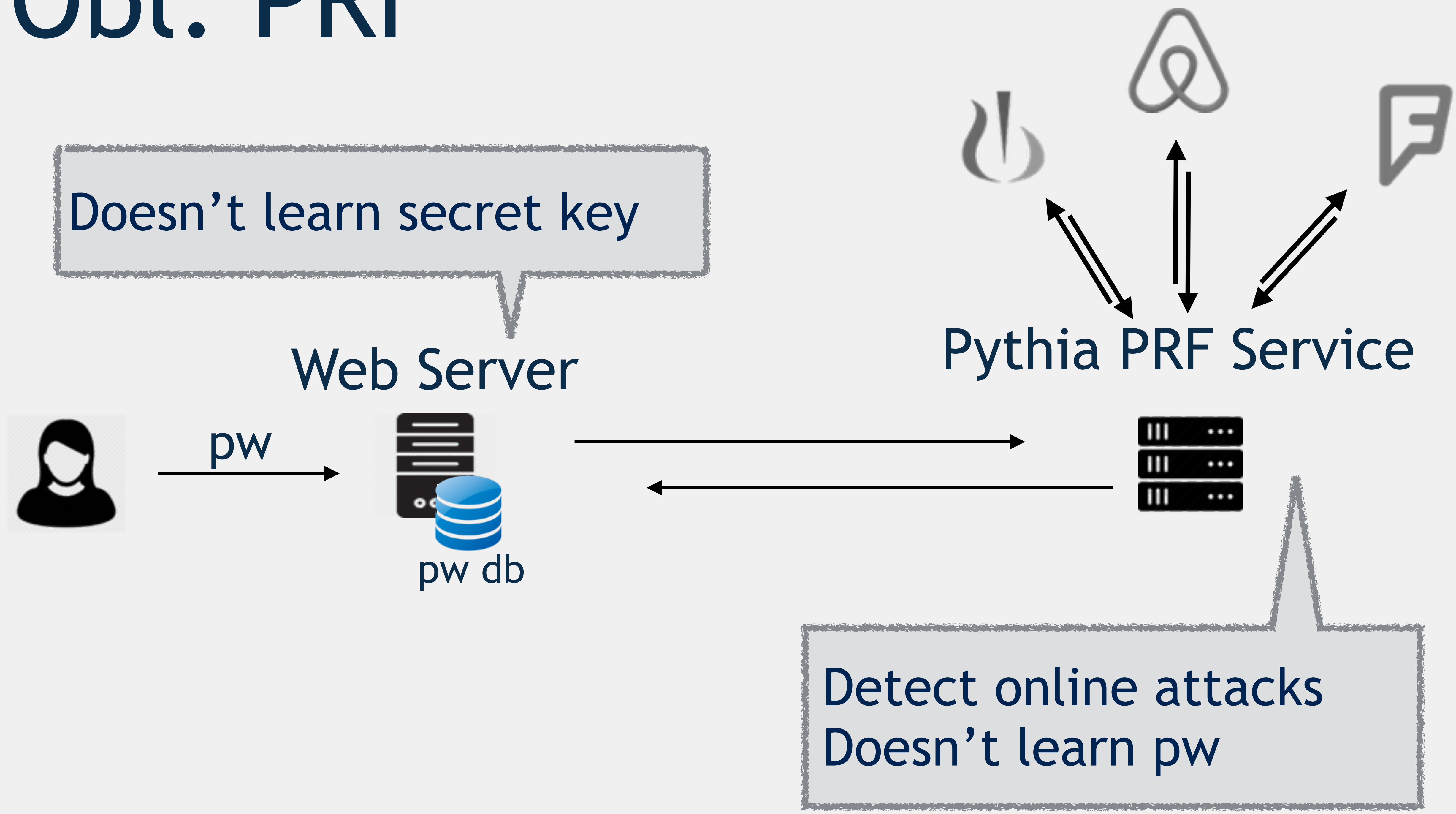
Pythia Server

$$\xleftarrow{\quad k'/k \quad}$$

$$z' := z^{k'/k} = e(H(t),\ H(pw))^{k*k'/k} = \boxed{e(H(t),\ H(pw))^{k'}}$$

update()

# Advantages of Partially Obl. PRF



# Easy to Deploy

```
def verify(username, pass):
  (salt,check) = authTableLookup(username)
  digest = hashpass(salt, pass)
  ppass = pythia.query(server, w, t, pass)
  digest = pythia.combine(ppass, digest)
  return digest == check
```

**Small change to code base**
**No impact on user experience**

# Parallel Password Onion

Web Server

Pythia Server

$a = H^{4096}(pw, t)$ `x:=blind(pw)` $\xrightarrow{\texttt{w,t,x}}$

`z:=unblind(pw)` $\xleftarrow{\texttt{y}}$

`result :=` $z^{a}$

No performance penalty

Strictly better security — Defense in depth

# Pythia Open Source Implementation

nginx

MongoDB

Source code on GitHub

Find links and information at:
https://pages.cs.wisc.edu/~ace

Test + Development server: remote-crypto.io

# Fast, Scalable PRF Service

| | |
|---|---|
| **PRF Query:** | 11.8ms (LAN) 96ms (WAN) |
| **Throughput:** | 1350 connections/sec (8-core EC2 instance)<br>Within factor of 2 of a TLS query |
| **Storage:** | O(1) per web server<br>Supports arbitrary number of users for each web server |
| **100M Web Server:** | 18.6 GB (keytable) |

# Beyond Web Servers

**File Encryption with remote erasure**

**Bitcoin Brainwallet**

**Message-locked Encryption**

# Conclusion

Password storage is broken: too easy to crack with offline attacks


**Pythia PRF:**

- prevents offline attacks, detects online attacks
- enables compromise recovery via key rotation, and crypto erasure via deletion
- democratizes access with a service architecture