Lecture Outline

- Review of Diffie-Hellman key exchange
- Looking at Authentication from a number of perspectives
  - Today: authenticating users, services

Agreeing on Secret Keys *Without Prior Arrangement*

Diffie-Hellman Key Exchange

- While we have powerful symmetric-key technology, it requires Alice & Bob to agree on a secret key *ahead of time*
- What if instead they can somehow generate such a key *when needed*?
- Seems impossible in the presence of Eve observing all of their communication …
  - How can they exchange a key without her learning it?
- But: actually is possible using public-key technology
  - Requires that Alice & Bob **know** that their messages will reach one another without any meddling
  - So works for Eve-the-eavesdropper, but not Mallory-the-MITM
  - Protocol: *Diffie-Hellman Key Exchange* (DHE)

Diffie-Hellman Key Exchange

p, g

Eve

p, g

Alice

p, g

Bob

1. Everyone agrees in advance on a well-known (large) prime **p** and a corresponding **g**: $1 < g < p-1$

Diffie-Hellman Key Exchange

p, g

a? b?

Eve

p, g

a

Alice

p, g

b

Bob

2. Alice picks random secret '**a**': 1 < a < p-1

3. Bob picks random secret '**b**': 1 < b < p-1

Diffie-Hellman Key Exchange

p, g

A

B

a? b?

Eve

p, g

a

Alice

p, g

b

Bob

$A = g^a \bmod p$

$g^b \bmod p = B$

4. Alice sends $A = g^a \bmod p$ to Bob
5. Bob sends $B = g^b \bmod p$ to Alice

Diffie-Hellman Key Exchange

p, g

A

B

a? b?

Eve

p, g

a

K

Alice

p, g

b

K

Bob

$A = g^a \bmod p$

B

A

$g^b \bmod p = B$

6. Alice knows {a, A, B}, computes
   $K = B^a \bmod p = (g^b)^a = g^{ba} \bmod p$
7. Bob knows {b, A, B}, computes
   $K = A^b \bmod p = (g^a)^b = g^{ab} \bmod p$
8. K is now the shared secret key.

Diffie-Hellman Key Exchange

p, g

A

B

a? b?

K?

Eve

p, g

a

K

Alice

p, g

b

K

Bob

$A = g^a \bmod p$

B

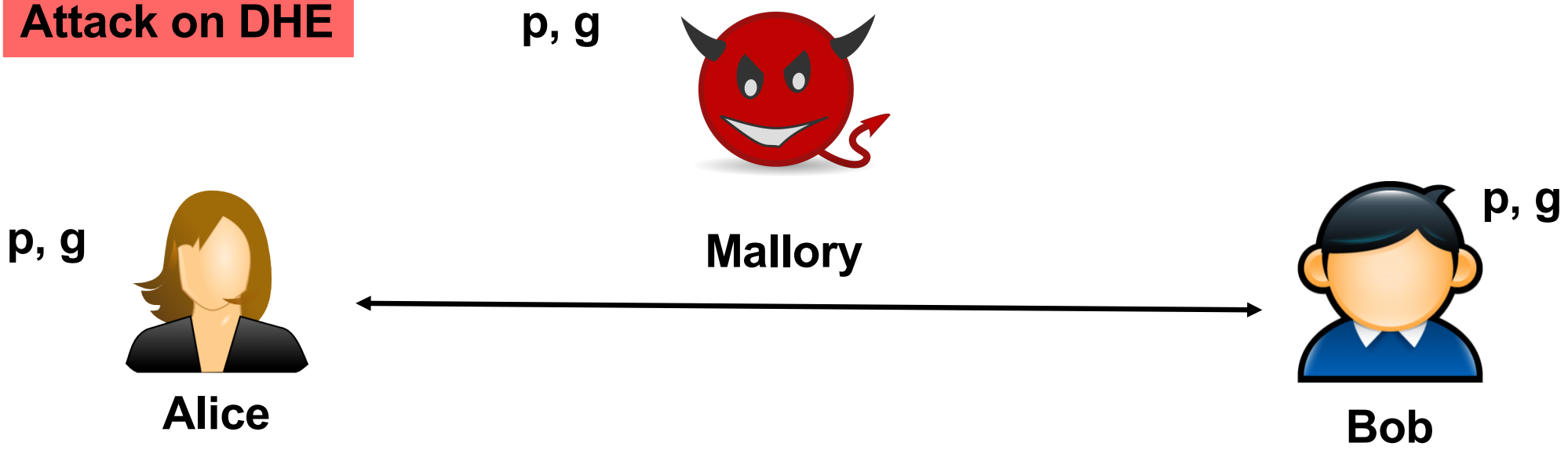
A

$g^b \bmod p = B$

While Eve knows {p, g, $g^a \bmod p$, $g^b \bmod p$}, believed to be ***computationally infeasible*** for her to then deduce K = $g^{ab} \bmod p$.

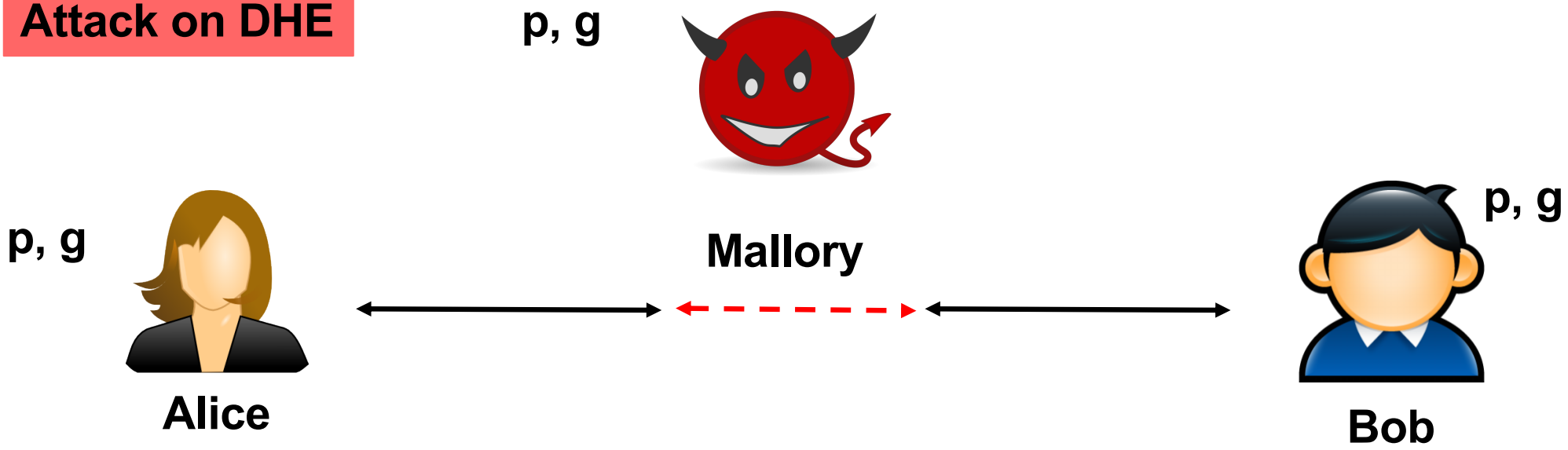
She can easily construct $A \cdot B = g^a \cdot g^b \bmod p = g^{a+b} \bmod p$.
But computing g^{ab} requires ability to take *discrete logarithms* mod p.

Attack on DHE



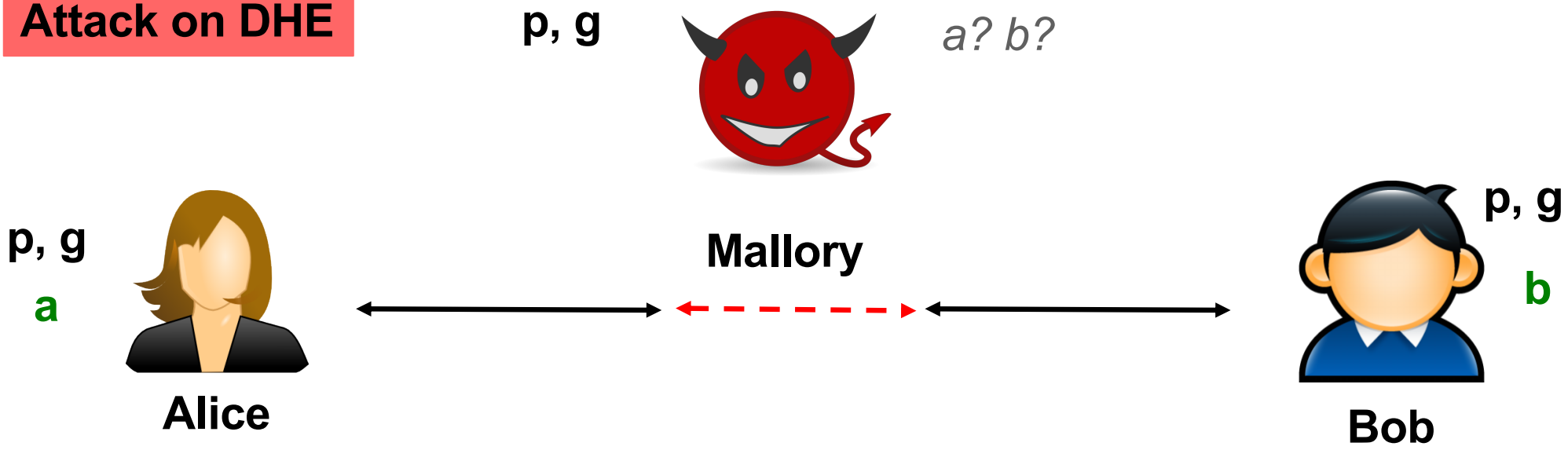
What happens if instead of Eve watching, Alice & Bob face the threat of a hidden Mallory (MITM)?

Attack on DHE



What happens if instead of Eve watching, Alice & Bob face the threat of a hidden Mallory (MITM)?

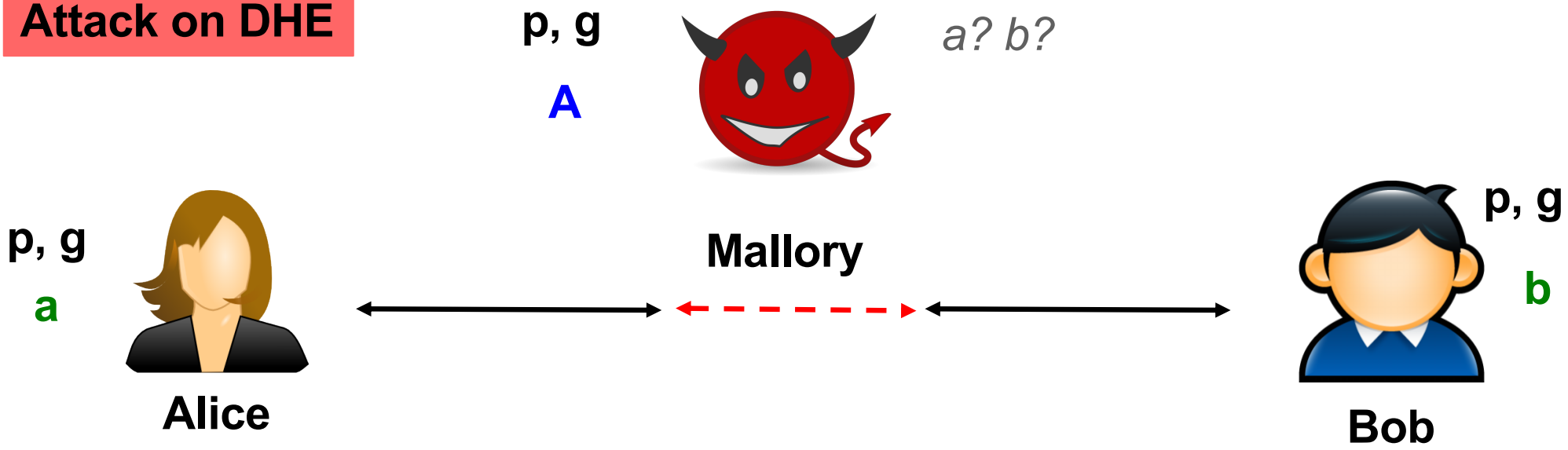
Attack on DHE



2. Alice picks random secret '**a**': 1 < a < p-1

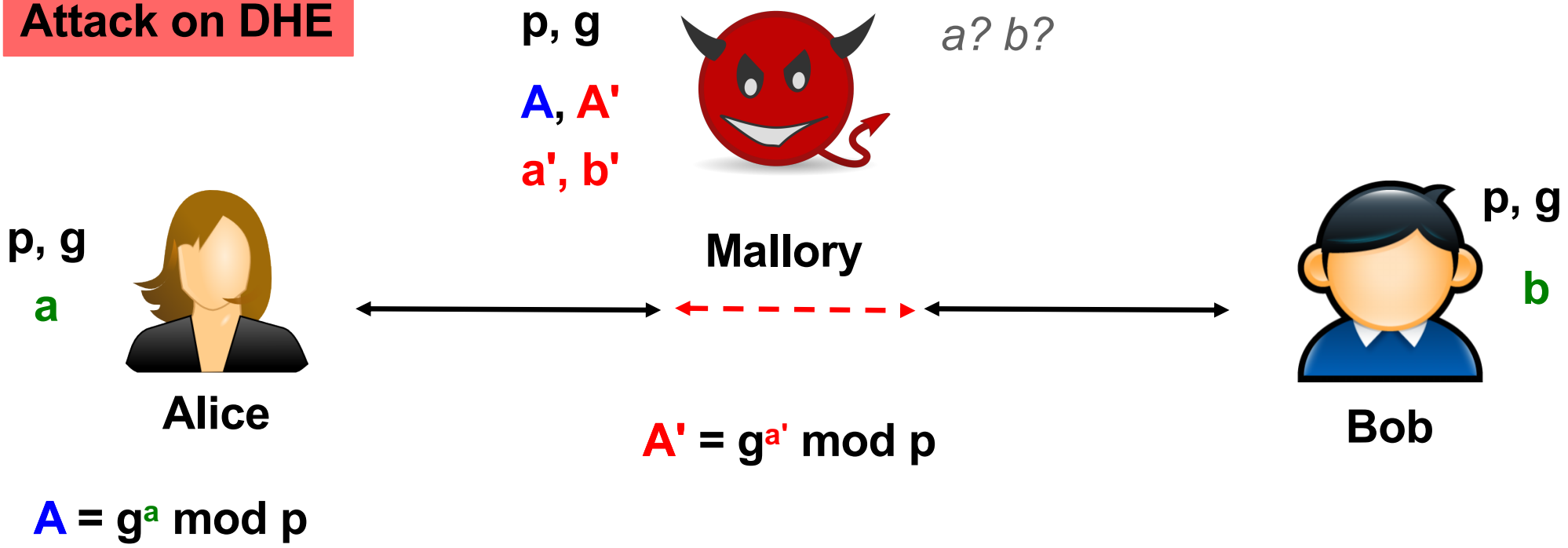
3. Bob picks random secret '**b**': 1 < b < p-1

Attack on DHE



4. Alice sends $A = g^a \bmod p$ to Bob
5. Mallory prevents Bob from receiving A

Attack on DHE



6. Mallory generates her own a', b'
7. Mallory sends $A' = g^{a'} \bmod p$ to Bob

Attack on DHE

p, g

A, A'

a', b'

a? b?

p, g

a

Alice

Mallory

p, g

b

Bob

$A' = g^{a'} \bmod p$

$A = g^{a} \bmod p$

A'

$g^{b} \bmod p = B$

8. The same happens for Bob and B/B'

Attack on DHE

p, g

A, B, A', B'

a', b'

a? b?

p, g

a

Alice

Mallory

p, g

b

Bob

$A = g^a \bmod p$

$A' = g^{a'} \bmod p$

$B' = g^{b'} \bmod p$

A'

$g^b \bmod p = B$

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Attack on DHE

p, g

A, B, A', B'

a', b'

a? b?

p, g

a

Alice

Mallory

p, g

b

Bob

$A = g^a \bmod p$

B'

$A' = g^{a'} \bmod p$

$B' = g^{b'} \bmod p$

$K'_1 = A^{b'} \bmod p = g^{ab'} \bmod p$

$K'_2 = B^{a'} \bmod p = g^{ba'} \bmod p$

A'

$g^b \bmod p = B$

$K'_1 = (B')^a \bmod p$
$= (g^{b'})^a = g^{b'a} \bmod p$

$K'_2 = (A')^b \bmod p$
$= (g^{a'})^b = g^{a'b} \bmod p$

9. Alice and Bob now compute keys they share with … Mallory!
10. Mallory can relay encrypted traffic between the two …

    10'. Modifying it or making stuff up *however she wishes*

Questions?

Thinking about Authentication

- Fundamental issue for networking:
  - Parties only connected by untrustworthy medium
- Broad & evolving topic
- Goal: develop a sense for authentication paradigms & issues
  - Including *weaker* forms
- Will include some review
- Will skip some (much) state-of-the-art

Thinking about Authentication, con't

- Spectrum:
  - Which user (human) am I dealing with?
  - Which server (institution) am I dealing with?
  - What attributes does this party have?
    - Affiliation, human-or-program, country, …
  - Is this the same entity as before?

- A springboard for discussion: Let's start with very basic circa 1990s web authentication …

C → S: **`GET http://mybank.com/`**

S → C: page, including a login form

C → S: **`POST http://mybank.com/login?`**
`u=`*USER*`&p=`***PASSWD***

[*server marks this session as authenticated*]

S → C: **`Set-Cookie: sessionid=`***NONCE*

(Cookie is an "authenticator" for session)

C → S: **`GET http://mybank.com/moneyxfer.cgi`**
`Cookie: sessionid=`*NONCE*

Threats?

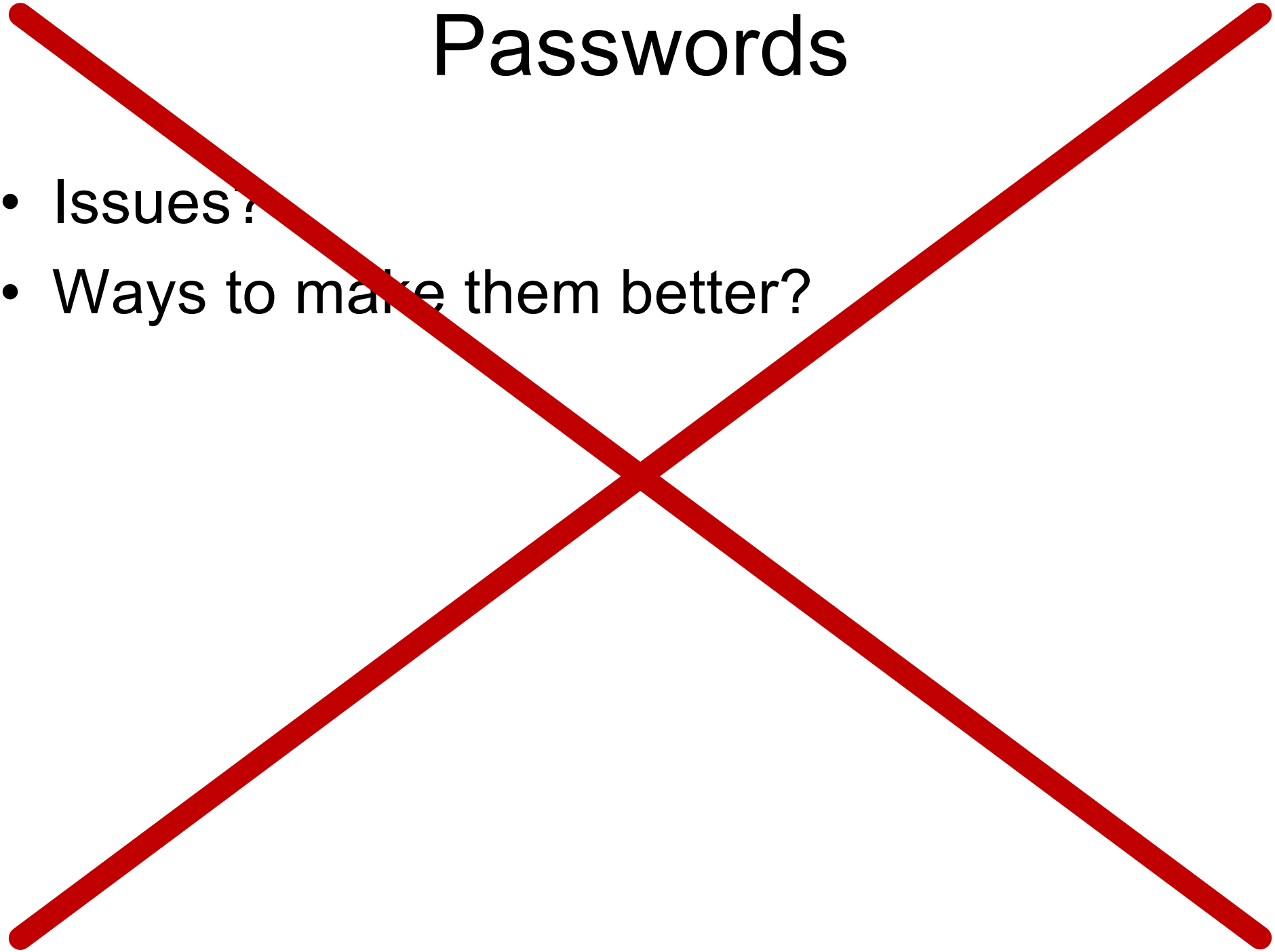
- No encryption: can know password, username, cookie
- MITM can manipulate cookies, migrate user associated with activity
- Weak passwords
- Reused passwords

Threats?

- Sniffing, MITM (network; app-level relay)
  ⇒ Theft of password and/or authenticator
- 3rd-party manipulation of automation
  - E.g. CSRF (browser fetching of images)
  - E.g. XSS (browser execution of JS replies)
- Password security
  - Blind guessing / bruteforcing
  - Reuse (breaches)
  - Phishing
- Compromised client: hijacking

Passwords

- Issues?
- Ways to make them better?



IEEE Symposium on Security & Privacy

The 2012 symposium will mark the 33rd annual meeting of this flagship conference. Since 1980, the IEEE Symposium on Security and Privacy has been the premier forum for presenting developments in computer security and electronic privacy, and for bringing together researchers and practitioners in the field. The symposium will be held in the San Francisco Bay Area, California.

10:30-11:45 Session 11: Passwords

Chair: William Enck

Guess again (and again and again): Measuring password strength by simulating password-cracking algorithms

Patrick Gage Kelley, Saranga Komanduri, Michelle L. Mazurek, Richard Shay, Tim Vidas, Lujo Bauer, Nicolas Christin, Lorrie Faith Cranor, and Julio Lopez (Carnegie Mellon University)

slides

SoK = *Systemization of Knowledge*

ized corpus of 70 million passwords

)

[SoK] The quest to replace passwords: A framework for comparative evaluation of web authentication schemes

Joseph Bonneau (University of Cambridge), Cormac Herley (Microsoft Research), Paul C. van Oorschot (Carleton U), and Frank Stajano (University of Cambridge)

The Quest to Replace Passwords: A Framework for Comparative Evaluation of Web Authentication Schemes*

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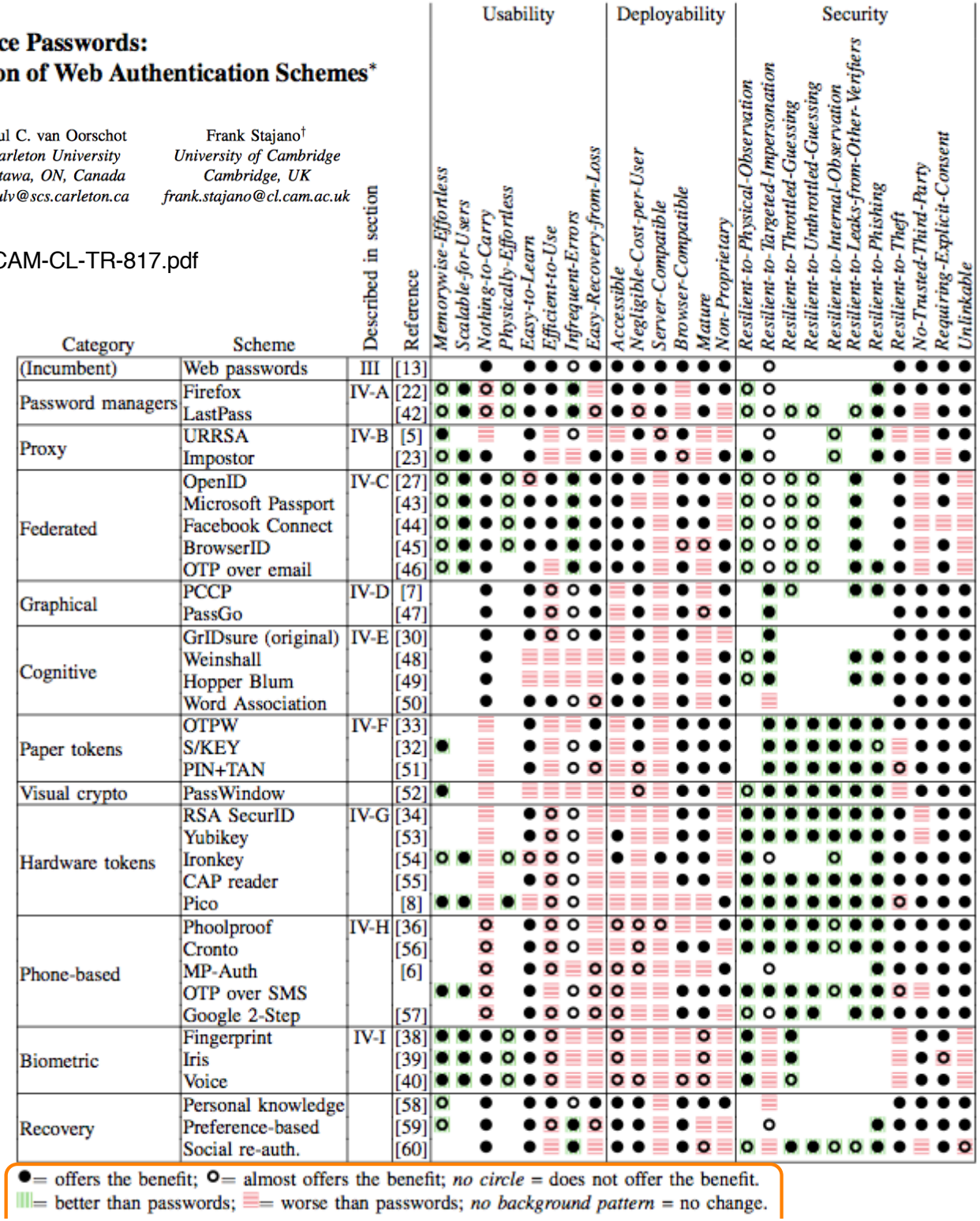

The Quest to Replace Passwords: A Framework for Comparative Evaluation of Web Authentication Schemes*

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Cormac Herley, *Microsoft Research, Redmond, WA, USA, cormac@microsoft.com*

Paul C. van Oorschot, *Carleton University, Ottawa, ON, Canada, paulv@scs.carleton.ca*

Frank Stajano†, *University of Cambridge, Cambridge, UK, frank.stajano@cl.cam.ac.uk*

https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-817.pdf

User doesn't have to memorize anything (weaker: just 1 secret)

				Usability								Deployability						Security										
Category	Scheme	Described in section	Reference	*Memorywise-Effortless*	*Scalable-for-Users*	*Nothing-to-Carry*	*Physically-Effortless*	*Easy-to-Lea*	*Efficient-to-*	*Infrequent-E*	*Easy-Recove*	*Accessible*	*Negligible-C*	*Server-Com*	*Browser-Co*	*Mature*	*Non-Proprie*	*Resilient-to-*	*Resilient-to-*	*Resilient-to-*	*Resilient-to-*	*Resilient-to-*	*Resilient-to-*	*Resilient-to-*	*Resilient-to-*	*No-Trusted-*	*Requiring-E*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○					●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●		●	●	●		●		○	○				●	●	●		●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●		●		○	○	○	○		○	●	●		●
Proxy	URRSA	IV-B	[5]	●				●		○			●	○	●				○			○	●	●		●
	Impostor		[23]	○	●	●		●				●		●	○		●	●	○			○	●	●		●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●		●	●	●	○	○	○	○	●		●			
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●			●	●		○	○	○	○	●		●		●	
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●		●	●		○	○	○	○	●		●			
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●		○	○	●	○	○	○	○	●		●		●	
	OTP over email		[46]	○	●	●		●		●	●	●	●		●		●	○	○	○	○	●	●	●		●	
Graphical	PCCP	IV-D	[7]			●		●	○	○	●		●		●		●		●	○		●	●	●		●	●
	PassGo		[47]			●		●	○	○	●		●		●	○	●		●					●		●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●		●		●		●		●					●		●	●
	Weinshall		[48]			●							●		●		●	○	●			●	●	●		●	●
	Hopper Blum		[49]			●						●	●		●		●	○	●			●	●	●		●	●
	Word Association		[50]			●		●	●	○	○	●	●		●		●							●		●	●
Paper tokens	OTPW	IV-F	[33]					●			●		●		●	●	●		●	●	●	●	●	●		●	●
	S/KEY		[32]	●				●		○	●		●		●	●	●		●	●	●	●	○			●	●
	PIN+TAN		[51]					●		○	○		○		●	●	●		●	●	●	●	●	○		●	●
Visual crypto	PassWindow		[52]	●									○		●	●		○	●	●	●	●	●			●	●
Hardware tokens	RSA SecurID	IV-G	[34]					●	○	○					●	●			●	●	●	●	●	●		●	●
	Yubikey		[53]					●	○	○		●			●	●			●	●	●	●	●	●		●	●
	Ironkey		[54]	○	●		○	○	○	○		●		●	●	●			○			○		●		●	●
	CAP reader		[55]					●	○	○					●	●			●	●	●	●	●	●		●	●
	Pico		[8]	●	●		●		○	○						●			●	●	●	●	●	○		●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○		○	○	○			●		●	●	●	○	●	●		●	●
	Cronto		[56]			○		●	○	○			○		●	●			●	●	●	○	●	●		●	●
	MP-Auth		[6]			○		●	○		○	○	○				●		○					●		●	●
	OTP over SMS			●	●	○		●		○	○	○			●	●	●		●	●	●	○	●	○		●	●
	Google 2-Step		[57]			○		●	○	○	○	○			●	●			○	○	●		●	●		●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○			○					○		●		●					●	
	Iris		[39]	●	●	●	○	●	○			○					○		●		●					●	○
	Voice		[40]	●	●	●	○	●	○			○	○		○	○	●		●		○					●	
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●		●	●										●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●		●				○					●		●	●
	Social re-auth.		[60]			●		●		●		●	●		●	○		○		●	●	○	●	●		●	○

●= offers the benefit; ○= almost offers the benefit; *no circle* = does not offer the benefit.
= better than passwords; = worse than passwords; *no background pattern* = no change.

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Cognitively practical for user having many accounts

				Usability								Deployability						Security									
Category	Scheme	Described in section	Reference	*Memorywise-Effortless*	*Scalable-for-Users*	*Nothing-to-Carry*	*Physically-Effortless*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-Errors*	*Easy-Recov*	*Accessible*	*Negligible-C*	*Server-Com*	*Browser-Co*	*Mature*	*Non-Propri*	*Resilient-to*	*Resilient-to*	*Resilient-to*	*Resilient-to*	*Resilient-to*	*Resilient-to*	*Resilient-to*	*Resilient-to*	*No-Trusted*	*Requiring-I*	*Unlinkable*
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Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○		○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○		○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○	●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○	●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○	●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○	●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○	●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○		●	●	●	●	●	●
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Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	●		●					●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●			●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●			●	●	●	●	●	●
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Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	○	▒	●	●	●
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Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒	●	●	●	●	●	●	●	▒	●	●
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	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	●	▒	●	●	●	●	●	●	○	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	○	●	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	●	●	●	●	○	●	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○			●	●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●	●	●	●	●	○	●	○	●	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	○	○	●	●		●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●				▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●				▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒	●	▒	○				▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒					●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○				●	●	●	●	●
	Social re-auth.		[60]			●		●	▒	▒	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○

●= offers the benefit; ○= almost offers the benefit; *no circle* = does not offer the benefit.
▒= better than passwords; ▒= worse than passwords; *no background pattern* = no change.

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https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-817.pdf

No physical object (weaker: you carry it anyway)

				Usability								Deployability					Security										
Category	Scheme	Described in section	Reference	*Memorywise-Effortless*	*Scalable-for-Users*	*Nothing-to-Carry*	*Physically-Effortless*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-Errors*	*Easy-Recov*	*Accessible*	*Negligible-C*	*Server-Com*	*Browser-Co*	*Mature*	*Non-Propri*	*Resilient-to*	*Resilient-to*	*Resilient-to*	*Resilient-to*	*Resilient-to*	*Resilient-to*	*Resilient-to*	*Resilient-to*	*No-Trusted*	*Requiring-I*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○				●	●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○			●	●	●	●	▒	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○	○	●	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○		○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○		○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○	●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○	●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○	●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○	●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○	●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○		●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●					●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●					●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●			●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●			●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒					●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒	●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒	●	○		○		●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	▒	●	●	●	●	●	●	●	○	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	○	●	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	●	●	●	●	○	●	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○			●	●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●	●	●	●	●	○	●	○	●	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	○	○	●	●		●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●				▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●				▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒	●	▒	○				▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒					●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○				●	●	●	●	●
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○

●= offers the benefit; ○= almost offers the benefit; *no circle* = does not offer the benefit.
▒= better than passwords; ▒= worse than passwords; *no background pattern* = no change.

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No user action required (weaker: user speaks)

Category	Scheme	Described in section	Reference	Memorywise-Effortless	Scalable-for-Users	Nothing-to-Carry	Physically-Effortless	Easy-to-Learn	Efficient-to-Use	Infrequent-Errors	Easy-Recovery-from-Lo	Accessible	Negligible-Cost-per-Us	Server-Compatible	Browser-Compatible	Mature	Non-Proprietary	Resilient-to-Physical-O	Resilient-to-Targeted-In	Resilient-to-Throttled-C	Resilient-to-Unthrottled	Resilient-to-Internal-Ob	Resilient-to-Leaks-from	Resilient-to-Phishing	Resilient-to-Theft	No-Trusted-Third-Party	Requiring-Explicit-Con	Unlinkable
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○						●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○					●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○		○	●	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒	●	○			○		●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	▒	●	●	●	●	●	●	●	○	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	●	○	●	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒	●	●	●	●	○	●	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○					●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●	●	●	●	●	○	●	●	○	▒	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	○	○	●	●		●	●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒	●	▒	○					▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒						●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○					●	●	●	●	●
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○

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(E.g.: not a do-crypto-in-your-head scheme)

Category	Scheme	Described in section	Reference	Memorywise-Effortless	Scalable-for-Users	Nothing-to-Carry	Physically-Effortless	Easy-to-Learn	Efficient-to-Use	Infrequent-Errors	Easy-Recovery-from-Lo	Accessible	Negligible-Cost-per-Us	Server-Compatible	Browser-Compatible	Mature	Non-Proprietary	Resilient-to-Physical-O	Resilient-to-Targeted-In	Resilient-to-Throttled-G	Resilient-to-Unthrottled	Resilient-to-Internal-Ob	Resilient-to-Leaks-from	Resilient-to-Phishing	Resilient-to-Theft	No-Trusted-Third-Party	Requiring-Explicit-Con	Unlinkable
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○						●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○					●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○		○	●	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒		●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒		●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒		●	○		○		●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒		●	●	●	●	●	●	●	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	▒	●		●	●	●	●	●	●	○	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●		●	●	●	●	○	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒		●	●	●	●	○	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○					●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●		●	●	●	●	○	●	○	▒	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒		○	○	●	●		●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○		●	▒	●				▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○		●	▒	●				▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	●		●	▒	○				▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒						●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○					●	●	●	●	●
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○

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The Quest to Replace Passwords:
A Framework for Comparative Evaluation of Web Authentica

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https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-817.pdf

Doesn't require much user time; new associations aren't burdensome

				Usability								Deployability					Security										
Category	Scheme	Described in section	Reference	*Memorywise-Effortless*	*Scalable-for-Users*	*Nothing-to-Carry*	*Physically-Effortless*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-Errors*	*Easy-Recovery-from-Lo*	*Accessible*	*Negligible-Cost-per-Us*	*Server-Compatible*	*Browser-Compatible*	*Mature*	*Non-Proprietary*	*Resilient-to-Physical-O*	*Resilient-to-Targeted-In*	*Resilient-to-Throttled-C*	*Resilient-to-Unthrottled*	*Resilient-to-Internal-On*	*Resilient-to-Leaks-from*	*Resilient-to-Phishing*	*Resilient-to-Theft*	*No-Trusted-Third-Party*	*Requiring-Explicit-Con*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○					●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○				●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○	○	●	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒	●	○			○		●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	▒	●	●	●	●	●	●	●	○	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	●	○	●	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	●	●	●	●	●	○	●	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○					●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●	●	●	●	●	○	●	●	○	●	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	○	○	●	●		●	●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●				▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●				▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒	●	▒	○				▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒						●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○					●	●	●	●
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○

●= offers the benefit; ○= almost offers the benefit; *no circle* = does not offer the benefit.
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Won't frustrate legit users

https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-817.pdf

				Usability							Deployability					Security											
Category	Scheme	Described in section	Reference	*Memorywise-Effortless*	*Scalable-for-Users*	*Nothing-to-Carry*	*Physically-Effortless*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-Errors*	*Easy-Recovery-from-L*	*Accessible*	*Negligible-Cost-per-U*	*Server-Compatible*	*Browser-Compatible*	*Mature*	*Non-Proprietary*	*Resilient-to-Physical-*	*Resilient-to-Targeted-*	*Resilient-to-Throttled-*	*Resilient-to-Unthrottl*	*Resilient-to-Internal-C*	*Resilient-to-Leaks-fro*	*Resilient-to-Phishing*	*Resilient-to-Theft*	*No-Trusted-Third-Party*	*Requiring-Explicit-Consent*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○					●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○					●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○		○	●	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	●	▒	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒	●	○			○		●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	▒	●	●	●	●	●	●	●	○	●	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	●	○	●	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	●	●	●	●	●	○	●	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○					●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●	●	●	●	●	○	●	●	○	●	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	○	○	●	●		●	●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒	●	▒	○					▒	●	●	▒
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	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○					●	●	●	●	●
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	○	●	▒	●	○

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https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-817.pdf

Recovery is quick, low-hassle, assured

				Usability								Deployability						Security														
Category	Scheme	Described in section	Reference	*Memorywise-Effortless*	*Scalable-for-Users*	*Nothing-to-Carry*	*Physically-Effortless*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-Errors*	*Easy-Recovery-from-Loss*	*Accessible*	*Negligible-Cost-per-User*	*Server-Compatible*	*Browser-Compatible*	*Mature*	*Non-Proprietary*	*Resilient-to-Physical-Observation*	*Resilient-to-Targeted-Impersonation*	*Resilient-to-Throttled-Guessing*	*Resilient-to-Unthrottled-Guessing*	*Resilient-to-Internal-Observation*	*Resilient-to-Leaks-from-Other-Verifiers*	*Resilient-to-Phishing*	*Resilient-to-Theft*	*No-Trusted-Third-Party*	*Requiring-Explicit-Consent*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○						●	●	●	●
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	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○		○	●	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●
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	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	▒	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	▒	●	▒	●	●	▒	●	●	●	●	●	●	●	▒	●	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	▒	●	▒	●	●	▒	●	○		○		●	●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	▒	●	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	●	▒	●	●	●	●	●	●	○	▒	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	●	○	●	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒	●	●	●	●	○	●	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○				●	●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●	●	●	●	●	○	●	●	○	▒	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	○	○	●	●		●	●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒	●	▒	○					▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒						●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○					●	●	●	●	●
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	○	●	●	▒	●	○

●= offers the benefit; ○= almost offers the benefit; *no circle* = does not offer the benefit.
▒= better than passwords; ▒= worse than passwords; *no background pattern* = no change.

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Works for users w/ physical disabilities/conditions

				Usability								Deployability					Security										
Category	Scheme	Described in section	Reference	*Memorywise-Effortless*	*Scalable-for-Users*	*Nothing-to-Carry*	*Physically-Effortless*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-Errors*	*Easy-Recovery-from-Loss*	*Accessible*	*Negligible-Cost-per-User*	*Server-Compatible*	*Browser-Compatible*	*Mature*	*Non-Proprietary*	*Resilient-to-Physical-Observation*	*Resilient-to-Targeted-Impersonation*	*Resilient-to-Throttled-Guessing*	*Resilient-to-Unthrottled-Guessing*	*Resilient-to-Internal-Observation*	*Resilient-to-Leaks-from-Other-Verifiers*	*Resilient-to-Phishing*	*Resilient-to-Theft*	*No-Trusted-Third-Party*	*Requiring-Explicit-Consent*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○					●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	≡	●	●	●	≡	●	●	○	○				●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	≡	●	≡	○	○	○	○	○	●	●	≡	●	●
Proxy	URRSA	IV-B	[5]	●		≡		●	≡	○	≡	≡	●	○	●	≡	≡		○			○		●	≡	●	●
	Impostor		[23]	○	●	●		●	≡	≡	●	●	≡	●	○	≡	●	●	○			○		●	●	≡	●	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	≡	●	●	●	○	○	○	○		●		●	≡	●	≡
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	≡	≡	●	●	≡	○	○	○	○		●		●	≡	●	≡
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	≡	●	●	≡	○	○	○	○		●		●	≡	≡	≡
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	≡	○	○	●	○	○	○	○		●		●	≡	●	≡
	OTP over email		[46]	○	●	●		●	≡	●	●	●	●	≡	●	≡	●	○	○	○	○		●	●	●	≡	●	≡
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	≡	●	≡	●	≡	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	≡	●	≡	●	○	●		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	≡	●	≡	●	≡	≡		●						●	●	●	●
	Weinshall		[48]			●		≡	≡	≡	≡	≡	●	≡	●	≡	●	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		≡	≡	≡	≡	●	●	≡	●	≡	●	○	●				●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	≡	●	≡	●		≡						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			≡		●	≡	≡	●	≡	●	≡	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		≡		●	≡	○	●	≡	●	≡	●	●	●		●	●	●	●	●	○	≡	●	●	●
	PIN+TAN		[51]			≡		●	≡	○	○	≡	○	≡	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		≡		≡	≡	≡	≡	≡	○	≡	●	●	≡	○	●	●	●	●	●	●	≡	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			≡		●	○	○	≡	≡	≡	≡	●	●	≡		●	●	●	●	●	●	●	≡	●	●
	Yubikey		[53]			≡		●	○	○	≡	●	≡	≡	●	●	≡		●	●	●	●	●	●	●	≡	●	●
	Ironkey		[54]	○	●	≡	○	○	○	○	≡	●	≡	●	●	●	≡		●	○		○		●	●	●	●	●
	CAP reader		[55]			≡		●	○	○	≡	≡	≡	≡	●	●	≡		●	●	●	●	●	●	●	≡	●	●
	Pico		[8]	●	●	≡	●	≡	○	○	≡	≡	≡	≡	≡	≡	●		●	●	●	●	●	●	○	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	≡	○	○	○	≡	≡	●		●	●	●	●	○	●	●	●	●	●
	Cronto		[56]			○		●	○	○	≡	≡	○	≡	●	●	≡		●	●	●	●	○	●	●	●	●	●
	MP-Auth		[6]			○		●	○	≡	○	○	○	≡	≡	≡	●		○					●	●	●	●	●
	OTP over SMS			●	●	○		●	≡	○	○	○	≡	≡	●	●	●		●	●	●	●	○	●	○	≡	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	≡	≡	●	●	≡		○	○	●	●		●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	≡	≡	○	≡	≡	≡	○	≡		●	≡	●				≡	●	●	≡
	Iris		[39]	●	●	●	○	●	○	≡	≡	○	≡	≡	≡	○	≡		●	≡	●				≡	●	○	≡
	Voice		[40]	●	●	●	○	●	○	≡	≡	○	○	≡	○	○	≡		●	≡	○				≡	●	●	≡
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	≡	●	●	●			≡					●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	≡	●	≡	≡			○				●	●	●	●	●
	Social re-auth.		[60]			●		●	≡	●	≡	●	●	≡	●	○	≡	○	≡	●	●	○	○	●	●	≡	●	○

●= offers the benefit; ○= almost offers the benefit; *no circle* = does not offer the benefit.
≡= better than passwords; ≡= worse than passwords; *no background pattern* = no change.

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E.g.: plausible for startups to use

				Usability							Deployability					Security									
Category	Scheme	Described in section	Reference	*Memorywise-Effortless*	*Scalable-for-Users*	*Nothing-to-Carry*	*Physically-Effortless*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-Errors*	*Easy-Recovery-from-Loss*	*Accessible*	*Negligible-Cost-per-User*	*Server-Compatible*	*Browser-Compatible*	*Mature*	*Non-Proprietary*	*Resilient-to-Physica*	*Resilient-to-Targete*	*Resilient-to-Throttle*	*Resilient-to-Unthrot*	*Resilient-to-Interna*	*Resilient-to-Leaks-f*	*Resilient-to-Phishin*	*Resilient-to-Theft*	*No-Trusted-Third-P*	*Requiring-Explicit-C*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○					●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○				●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○		○	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒	●	○			○		●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	▒	●	●	●	●	●	●	●	○	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	●	○	●	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒	●	●	●	●	○	●	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○					●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●	●	●	●	●	○	●	●	○	▒	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	○	○	●	●		●	●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒	●	▒	○					▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒						●	●	●
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	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○

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Can look like "incumbent" to servers

Category	Scheme	Described in section	Reference	Usability: *Memorywise-Effortless*	*Scalable-for-Users*	*Nothing-to-Carry*	*Physically-Effortless*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-Errors*	*Easy-Recovery-from-Loss*	Deployability: *Accessible*	*Negligible-Cost-per-User*	*Server-Compatible*	*Browser-Compatible*	*Mature*	*Non-Pro*	Security: *Resilien*	*Resilien*	*Resilien*	*Resilien*	*Resilien*	*Resilien*	*Resilien*	*No-Trus*	*Requirin*	*Unlinka*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○					●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○				●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○	○	●	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		▒	●	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●				●	●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●					●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●			●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●			●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒					●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒		●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒		●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒		●	○		○		●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒		●	●	●	●	●	●	●	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	●	▒		●	●	●	●	●	●	○	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●		●	●	●	●	○	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	●		●	●	●	●	○	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○				●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●		●	●	●	○	●	○	▒	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒		○	○	●	●		●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○		●	▒	●			▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○		●	▒	●			▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒		●	▒	○			▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●			▒					●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○					●	●	●	●
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○

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Just requires HTML5/JS; weaker: very common plugins

https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-817.pdf

				Usability									Deployability				Security														
Category	Scheme	Described	Reference	*Memorywise-effortless*	*Scalable-for-users*	*Nothing-to-carry*	*Physically-effortless*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-errors*	*Easy-recovery-from-loss*	*Accessible*	*Negligible-cost-per-user*	*Server-Compatible*	*Browser-Compatible*	*Mature*	*Non-Proprietary*	*Resilient-to-Physical-Observation*	*Resilient-to-Targeted-Impersonation*	*Resilient-to-Throttled-Guessing*	*Resilient-to-Unthrottled-Guessing*	*Resilient-to-Internal-Observation*	*Resilient-to-Leaks-from-Other-Verifiers*	*Resilient-to-Phishing*	*Resilient-to-Theft*	*No-Trusted-Third-Party*	*Requiring-Explicit-Consent*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○						●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○					●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○		○	●	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒	●	○			○		●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	▒	●	●	●	●	●	●	●	○	●	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	●	○	●	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒	●	●	●	●	○	●	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○					●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●	●	●	●	●	○	●	●	○	▒	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	○	○	●	●		●	●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	○	▒	●	▒	●					▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	○	▒	●	▒	●					▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒	●	▒	○					▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒						●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○					●	●	●	●	●
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○

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Not just a research prototype/toy

https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-817.pdf

				Usability								Deployability					Security												
Category	Scheme	Described	Reference	Memorywise-	Scalable-for-	Nothing-to-	Physically-	Easy-to-Le	Efficient-to-	Infrequent-	Easy-Recov	Accessible	Negligible-	Server-Cor	Browser-C	Mature	Resilient-to-	Resilient-to-	Resilient-to-	Resilient-to-	Resilient-to-Internal-Observation	Resilient-to-Leaks-from-Other-Verifiers	Resilient-to-Phishing	Resilient-to-Theft	No-Trusted-Third-Party	Requiring-Explicit-Consent	Unlinkable
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●		○					●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	○	○				●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	○	○	○	○	○	●	●	●	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒	○			○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	○			○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	○	○	○	○		●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	○	●				●	●	●	●	●	●
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Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	○	●	●	●	●	●	●	▒	●	●	●
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	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●		●	●	●	●	●	●	●	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	●		●	●	●	●	●	●	○	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	○	●	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●		●	●	●	○	●	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	●		○					●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●		●	●	●	○	●	●	○	▒	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●		○	○	●	●		●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	○		●	▒	●				▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	○		●	▒	●				▒	●	○	▒
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	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	○	▒	●	●	○	○		●	▒	●	○

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Category	Scheme	Described in section	Reference	*Memorywise-Effortless*	*Scalable-for-Users*	*Nothing-to-Carry*	*Physically-Effortless*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-Errors*	*Easy-Recovery-from-Loss*	*Accessible*	*Negligible-Cost-per-User*	*Server-Compatible*	*Browser-Compatible*	*Non-Proprietary*	*Resilient-to-Physical-Observ*	*Resilient-to-Targeted-Imper*	*Resilient-to-Throttled-Guess*	*Resilient-to-Unthrottled-Gu*	*Resilient-to-Internal-Observ*	*Resilient-to-Leaks-from-Oth*	*Resilient-to-Phishing*	*Resilient-to-Theft*	*No-Trusted-Third-Party*	*Requiring-Explicit-Consent*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●		○					●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	○	○				●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	○	○	○	○		○	●	●	▒	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒		○			○		●	▒	▒	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	○			○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	○	○	○	○		●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	○	●				●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒		▒						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	○	●	●	●	●	●	●	▒	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	▒		●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	▒		●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	▒		●	○		○		●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	▒		●	●	●	●	●	●	●	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	●		●	●	●	●	●	●	○	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒		●	●	●	●	○	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	▒		●	●	●	●	○	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	●		○					●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●		●	●	●	○	●	●	○	●	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	▒		○	○	●			●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	○		●	▒	●				▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	○		●	▒	●				▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○		●	▒	○				▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●		▒						●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒		○					●	●	●	●	●
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	○	▒	●	●	○	○	○	●	●	▒	●	○

●= offers the benefit; ○= almost offers the benefit; *no circle* = does not offer the benefit.
▒= better than passwords; ▒= worse than passwords; *no background pattern* = no change.

The Quest to Replace Passwords: A Framework for Comparative Evaluation of Web Authentication Schemes*

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Requires a bunch (> 10-20) of sessions for local attacker to subvert (even using sneaky techniques)

				Usability							Deployability					Security											
Category	Scheme	Desc	Refs	*Mem*	*Scal*	*Noth*	*Phys*	*Easy*	*Effic*	*Infre*	*Easy*	*Acce*	*Negl*	*Serv*	*Brow*	*Mature*	*Non-Proprietary*	*Resilient-to-Physical-Observation*	*Resilient-to-Targeted-Impersonation*	*Resilient-to-Throttled-Guessing*	*Resilient-to-Unthrottled-Guessing*	*Resilient-to-Internal-Observation*	*Resilient-to-Leaks-from-Other-Verifiers*	*Resilient-to-Phishing*	*Resilient-to-Theft*	*No-Trusted-Third-Party*	*Requiring-Explicit-Consent*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○						●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○					●	●	▒	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○		○	●	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	▒	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒		●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒		●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒		●	○			○		●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒		●	●	●	●	●	●	●	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	●	▒		●	●	●	●	●	●	○	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●		●	●	●	●	○	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒		●	●	●	●	○	●	●	▒	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○					●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●		●	●	●	●	○	●	○	●	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒		○	○	●	●		●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○		●	▒	●				▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○		●	▒	●				▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒		●	▒	○				▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒						●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○					●	●	●	●	●
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○		●	▒	●	○

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The Quest to Replace Passwords:
A Framework for Comparativ

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Possessing personal knowledge doesn't help attacker; weaker: user must exercise discipline in choices

				Usability										Deployability					Security												
Category	Scheme	De	Re	*Memorywise-Effortless*	*Scalable-for-Users*	*Nothing-to-Carry*	*Physically-Effortless*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-Errors*	*Easy-Recovery-from-Loss*	*Accessible*	*Negligible-Cost-per-User*	*Server-Compatible*	*Browser-Compatible*	*Mature*	*Non-Proprietary*	*Resilient-to-Physical-Observation*	*Resilient-to-Targeted-Impersonation*	*Resilient-to-Throttled-Guessing*	*Resilient-to-Unthrottled-Guessing*	*Resilient-to-Internal-Observation*	*Resilient-to-Leaks-from-Other-Verifiers*	*Resilient-to-Phishing*	*Resilient-to-Theft*	*No-Trusted-Third-Party*	*Requiring-Explicit-Consent*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○					●	●	●	●	
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○				●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○	○	●	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○		○		●	●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○		○		●	●	▒	▒	●	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	▒	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●				●		●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒	●	○		○		●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	●	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	▒	●	●	●	●	●	●	●	○	●	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	●	○	●	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒	●	●	●	●	○	●	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○				●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●	●	●	●	●	○	●	●	○	▒	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	○	○	●	●		●	●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	○	●	▒	○					▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒						●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○					●	●	●	●	●
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○

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It takes a *lot* of guesses

https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-817.pdf

				Usability								Deployability					Security											
Category	Scheme	Described in sect.	Reference	*Memorywise-Effo*	*Scalable-for-User*	*Nothing-to-Carry*	*Physically-Effortl*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-Errors*	*Easy-Recovery-fr*	*Accessible*	*Negligible-Cost-p*	*Server-Compatibl*	*Browser-Compati*	*Mature*	*Non-Proprietary*	*Resilient-to-Physical-Observation*	*Resilient-to-Targeted-Impersonation*	*Resilient-to-Throttled-Guessing*	*Resilient-to-Unthrottled-Guessing*	*Resilient-to-Internal-Observation*	*Resilient-to-Leaks-from-Other-Verifiers*	*Resilient-to-Phishing*	*Resilient-to-Theft*	*No-Trusted-Third-Party*	*Requiring-Explicit-Consent*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○					●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○				●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○	○	●	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○		○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○		○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒	●	○		○		●	●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	▒	●	●	●	●	●	●	●	●	○	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	●	○	●	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒	●	●	●	●	○	●	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○					●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●	●	●	●	●	○	●	●	○	▒	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	○	○	●	●		●	●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	○	▒	●	▒	●				▒	●	●	▒	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	○	▒	●	▒	●				▒	●	○	▒	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒	●	▒	○				▒	●	●	▒	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒					●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○					●	●	●	▒
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○

●= offers the benefit; ○= almost offers the benefit; *no circle* = does not offer the benefit.
▒= better than passwords; ▒= worse than passwords; *no background pattern* = no change.

The Quest to Replace Passwords: A Framework for Comparative Evaluation of Web Authentication Schemes*

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https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-

It's *infeasible* to guess (e.g. requires 2^{64} tries)

				Usability										Deployability					Security												
Category	Scheme	Described	Reference	*Memorywo*	*Scalable-*	*Nothing-t*	*Physically*	*Easy-to-L*	*Efficient-t*	*Infrequen*	*Easy-Rec*	*Accessible*	*Negligible*	*Server-Co*	*Browser-C*	*Mature*	*Non-Prop*	*Resilient-to-Physical-Observation*	*Resilient-to-Targeted-Impersonation*	*Resilient-to-Throttled-Guessing*	*Resilient-to-Unthrottled-Guessing*	*Resilient-to-Internal-Observation*	*Resilient-to-Leaks-from-Other-Verifiers*	*Resilient-to-Phishing*	*Resilient-to-Theft*	*No-Trusted-Third-Party*	*Requiring-Explicit-Consent*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○						●	●	●	●	
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	▒	○	○					●	●	▒	●	●	
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○		○	●	●	▒	●	●	
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	▒	●	●	
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●	
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒	
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒	
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	▒	▒	
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒	
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	●	▒	●	▒	
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●	
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●	
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●	
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●				●	●	●	●	●	●	
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●	
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●	
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●	
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●	
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●	
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●	
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●	
	Yubikey		[53]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●	
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒	●	○			○		●	●	▒	●	●	
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●	
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	●	▒	●	●	●	●	●	●	●	○	●	●	●	
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	●	○	●	●	●	●	●	●	
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒	●	●	●	●	○	●	●	●	●	●	●	
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○					●	●	●	●	●	
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●	●	●	●	●	○	●	●	○	▒	●	●	
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	○	○	●	●		●	●	●	●	●	●	
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	●	▒	
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	○	▒	
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒	●	▒	○					▒	●	●	▒	
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒						●	●	●	●	
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○					●	●	●	●	●	
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○		●	▒	●	○	

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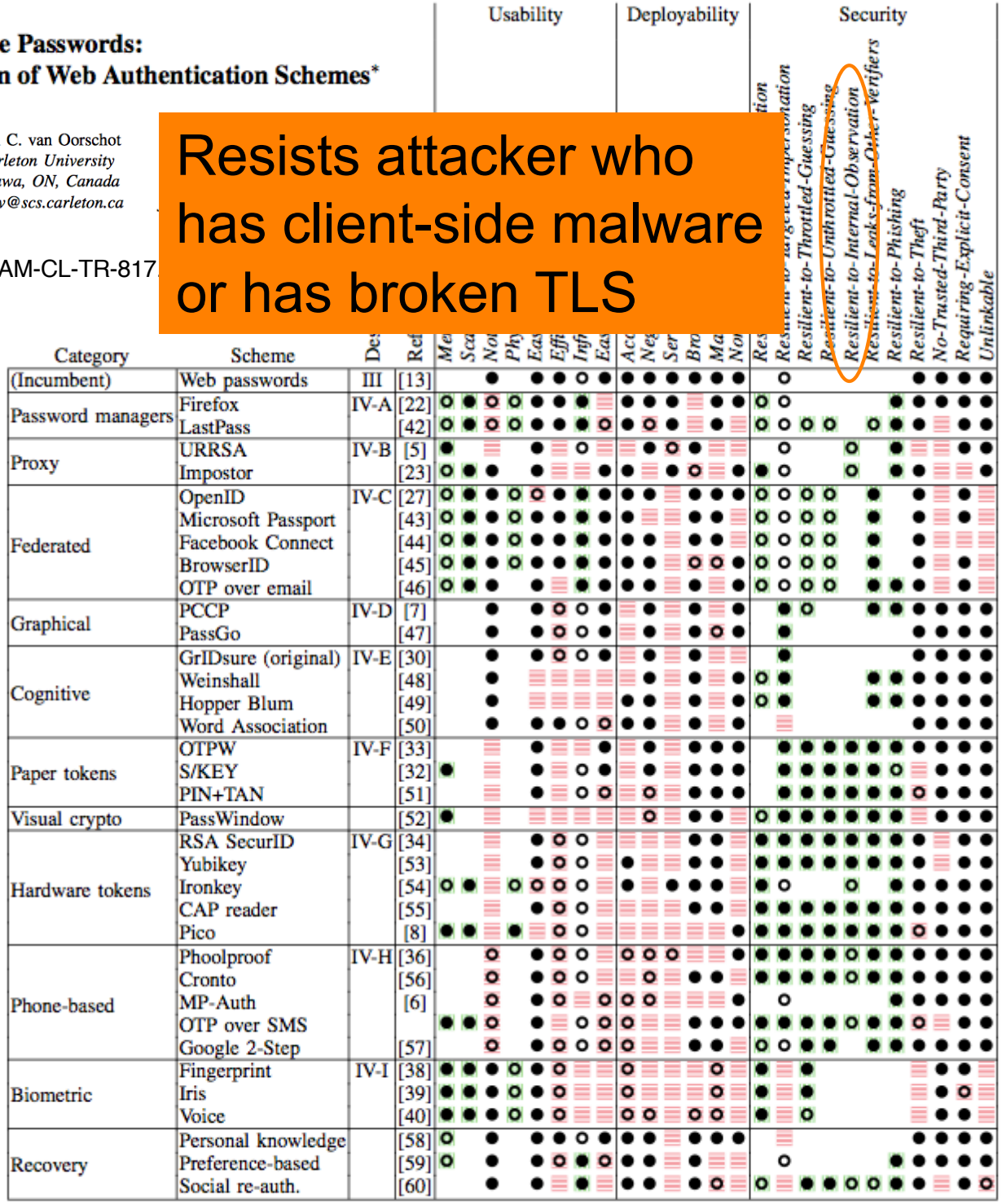
https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-817

Resists attacker who has client-side malware or has broken TLS



Category	Scheme	Des.	Ref.	Usability										Deployability								Security											
				Memorywise-Effortless	*Scalable-for-Users*	*Nothing-to-Carry*	*Physically-Effortless*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-Errors*	*Easy-Recovery-from-Loss*	*Accessible*	*Negligible-Cost-per-User*	*Server-Compatible*	*Browser-Compatible*	*Mature*	*Non-Proprietary*	*Resilient-to-Physical-Observation*	*Resilient-to-Targeted-Impersonation*	*Resilient-to-Throttled-Guessing*	*Resilient-to-Unthrottled-Guessing*	*Resilient-to-Internal-Observation*	*Resilient-to-Leaks-from-Other-Verifiers*	*Resilient-to-Phishing*	*Resilient-to-Theft*	*No-Trusted-Third-Party*	*Requiring-Explicit-Consent*	*Unlinkable*						
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Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●		●	●	●		●	●	○	○					●	●								
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●		●		○	○	○	○		○	●	●								
Proxy	URRSA	IV-B	[5]	●				●		○			●	○	●				○			○		●			●	●					
	Impostor		[23]	○	●	●		●			●	●		●	○			●	○			○		●	●			●					
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●		●	●	●	○	○	○	○		●		●		●						
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●			●	●		○	○	○	○		●		●		●						
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●		●	●		○	○	○	○		●		●		●						
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●		○	○		○	○	○	○		●		●		●						
	OTP over email		[46]	○	●	●		●		●	●	●	●		●			○	○	○	○		●	●	●		●						
Graphical	PCCP	IV-D	[7]			●		●	○	○	●		●		●		●		●	○			●	●	●	●	●						
	PassGo		[47]			●		●	○	○	●		●		●	○	●		●						●	●	●						
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●		●		●		●		●						●	●	●						
	Weinshall		[48]			●					●		●		●		●	○	●				●	●	●	●	●						
	Hopper Blum		[49]			●					●		●		●		●	○	●				●	●	●	●	●						
	Word Association		[50]			●		●	●	○	○		●		●		●								●	●	●						
Paper tokens	OTPW	IV-F	[33]					●			●		●		●		●		●	●	●	●	●	●	●	●	●						
	S/KEY		[32]	●				●		○	●		●		●		●		●	●	●	●	○	●	●	●	●						
	PIN+TAN		[51]					●		○	○		○		●		●		●	●	●	●	●	○	●	●	●						
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	Yubikey		[53]					●	○	○			●		●		●		●	●	●	●	●	●	●	●	●						
	Ironkey		[54]	○	●		○	○	○	○			●		●		●		●	○		○		●	●	●	●						
	CAP reader		[55]					●	○	○					●		●		●	●	●	●	●	●	●	●	●						
	Pico		[8]	●	●		●		○	○					●		●		●	●	●	●	●	●	○	●	●						
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○		○	○	○			●		●	●	●	○	●	●	●	●	●						
	Cronto		[56]			○		●	○	○			○		●		●		●	●	●	○	●	●	●	●	●						
	MP-Auth		[6]			○		●	○		○	○	○				●		○					●	●	●	●						
	OTP over SMS			●	●	○		●		○	○	○			●		●		●	●	●	○	●	●	○	●	●						
	Google 2-Step		[57]			○		●	○	○	○	○			●		●		○	○	●	●	●	●	●	●	●						
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○			○				○			●		●				○	●	●						
	Iris		[39]	●	●	●	○	●	○			○				○			●		●				○	●	○						
	Voice		[40]	●	●	●	○	●	○			○	○			○	○		●		○				○	●	●						
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●		●	●	●								●	●	●						
	Preference-based		[59]	○		●		●	○	●	○	●	●		●				○						●	●	●						
	Social re-auth.		[60]			●		●		●		●	●		●	○		○		●	●	○	●	●	●		○						

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A problem at one site doesn't endanger other sites

https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-817.pdf

				Usability									Deployability					Security												
Category	Scheme	Described in	Reference	*Memorywise-*	*Scalable-for-*	*Nothing-to-*	*Physically-*	*Easy-to-Le-*	*Efficient-to-*	*Infrequent-*	*Easy-Recov-*	*Accessible*	*Negligible-C-*	*Server-Com-*	*Browser-Co-*	*Mature*	*Non-Propri-*	*Resilient-to-*	*Resilient-to-*	*Resilient-to-*	*Resilient-to-Unthrottled-Guessing*	*Resilient-to-Internal-Observation*	*Resilient-to-Leaks-from-Other-Verifiers*	*Resilient-to-Phishing*	*Resilient-to-Theft*	*No-Trusted-Third-Party*	*Requiring-Explicit-Consent*	*Unlinkable*			
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○						●	●	●	●			
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○					●	●	▒	●	●			
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○		○	●	●	▒	●	●			
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	▒	●	●			
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●			
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒			
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒			
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	▒	▒			
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒			
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	●	▒	●	▒			
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●			
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●			
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●			
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●				●	●	●	●	●	●			
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●			
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●			
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●			
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●			
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●			
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●			
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●			
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●			
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒	●	○			○		●	●	▒	●	●			
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●			
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	▒	●	●	●	●	●	●	●	●	○	●	●	●			
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	●	○	●	●	●	●	●	●			
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒	●	●	●	●	○	●	●	●	●	●	●			
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○					●	●	●	●	●			
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	▒	●	●	●	●	●	●	○	●	○	●	●	●	●			
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	●	○	○	●		●	●	●	●	●	●			
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	●	▒			
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	○	▒			
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒	●	▒	○					▒	●	●	▒			
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒						●	●	●	●			
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○					●	●	●	●	●			
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○			

●= offers the benefit; ○= almost offers the benefit; *no circle* = does not offer the benefit.
▒= better than passwords; ▒= worse than passwords; *no background pattern* = no change.

The Quest to Replace Passwords: A Framework for Comparative Evaluation of Web Authentication Schemes*

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https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-817.pdf

Resists off-line phishing

				Usability							Deployability						Security										
Category	Scheme	Described in section	Reference	*Memorywise-Effortless*	*Scalable-for-Users*	*Nothing-to-Carry*	*Physically-Effortless*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-Errors*	*Easy-Recovery-from-Loss*	*Accessible*	*Negligible-Cost-per-User*	*Server-Compatible*	*Browser-Compatible*	*Mature*	*Non-Proprietary*	*Resilient-to-Physical-Obse*	*Resilient-to-Targeted-Impe*	*Resilient-to-Throttled-Gue*	*Resilient-to-Unthrottled-G*	*Resilient-to-Internal-Obse*	*Resilient-to-Leaks from-Ot*	*Resilient-to-Phishing*	*Resilient-to-Theft*	*No-Trusted-Third-Party*	*Requiring-Explicit-Consen*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○						●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○					●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○		○	●	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒	●	○			○		●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	▒	●	●	●	●	●	●	●	○	●	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	●	○	●	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒	●	●	●	●	○	●	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○					●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●	●	●	●	●	○	●	●	○	▒	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	○	○	●	●		●	●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●				▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●				▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒	●	▒	○				▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒						●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○					●	●	●	●	▒
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○

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A Framework for Comparative Evaluation of Web Authentication Schemes*

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Pau
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Otta
pau

https://www.cl.cam.ac.uk/techreports/UC

Attacker can't benefit by stealing physical object;
weaker: it's protected (e.g., PIN)

				Usability								Deployability					Security											
Category	Scheme	Des	Ref	Memorywise-Effortless	Scalable-for-Users	Nothing-to-Carry	Physically-Effortless	Easy-to-Learn	Efficient-to-Use	Infrequent-Errors	Easy-Recovery-from-Loss	Accessible	Negligible-Cost-per-User	Server-Compatible	Browser-Compatible	Mature	Non-Proprietary	Resilient-to-Physical-Observation	Resilient-to-Targeted-Impersonation	Resilient-to-Throttled-Guessing	Resilient-to-Unthrottled-Guessing	Resilient-to-Internal-Observation	Resilient-to-Leaks-from-Other-Verifiers	Resilient-to-Phishing	Resilient-to-Theft	No-Trusted-Third-Party	Requiring-Explicit-Consent	Unlinkable
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○							●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○					●	●	▒	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○		○	●	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	▒	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	▒	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	▒	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒	●	●	●	●	●	●	●	▒	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒	●	○			○		●	●	▒	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	▒	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	●	▒	●	●	●	●	●	●	●	○	▒	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	●	○	●	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒	●	●	●	●	○	●	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○					●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●	●	●	●	●	○	●	●	○	▒	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	○	○	●	●		●	●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●					▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒	●	▒	○					▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒						●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○					●	●	●	●	●
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○

●= offers the benefit; ○= almost offers the benefit; *no circle* = does not offer the benefit.
▒= better than passwords; ▒= worse than passwords; *no background pattern* = no change.

The Quest to Replace Passwords:
A Framework for Comparative Evaluation of Web Authentication Sch

Trust localized to user/service

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https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-817.pdf

				Usability							Deployability						Security										
Category	Scheme	Described in section	Reference	*Memorywise-Effortless*	*Scalable-for-Users*	*Nothing-to-Carry*	*Physically-Effortless*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-Errors*	*Easy-Recovery-from-Loss*	*Accessible*	*Negligible-Cost-per-User*	*Server-Compatible*	*Browser-Compatible*	*Mature*	*Non-Proprietary*	*Resilient-to-Physical-Observ*	*Resilient-to-Targeted-Impers*	*Resilient-to-Throttled-Guess*	*Resilient-to-Unthrottled-Gue*	*Resilient-to-Internal-Observ*	*Resilient-to-Leaks-from-Oth*	*Resilient-to-Phishing*	*Resilient-to-Theft*	*No-Trusted-Third-Party*	*Requires-Explicit-Consent*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○						●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○				●	●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○	○	●	●	▒	●	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒	●	○			○		●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	▒	●	●	●	●	●	●	●	○	●	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	●	○	●	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒	●	●	●	●	○	●	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○					●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●	●	●	●	●	○	●	●	○	●	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	○	○	●	●		●	●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●				▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○	●	▒	●				▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒	●	▒	○				▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒						●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○					●	●	●	●	●
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○

●= offers the benefit; ○= almost offers the benefit; *no circle* = does not offer the benefit.
▒= better than passwords; ▒= worse than passwords; *no background pattern* = no change.

The Quest to Replace Passwords: A Framework for Comparative Evaluation of Web Authentication Schemes*

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User has to (knowingly) consent to authentication occurring

https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-817.pdf

				Usability								Deployability						Security													
Category	Scheme	Described	Reference	Memorywise-	Scalable-for-	Nothing-to-	Physically-	Easy-to-Le	Efficient-to-	Infrequent-	Easy-Recov	Accessible	Negligible-	Server-Cor	Browser-C	Mature	Non-Propri	Resilient-to-	Resilient-to-	Resilient-to-	Resilient-to-	Resilient-to-	Resilient-to-	Resilient-to-	Resilient-to-Theft	No-Trusted-Third-Party	Requiring-Explicit-Consent	Unlinkable
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○					●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○				●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○	●	●	▒	●	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○		○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○		○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	●		●						●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●			●	●		●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●			●	●		●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒	●	○		○		●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	▒	●	●	●	●	●	●	●	○	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●	●	●	●	○	●	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒	●	●	●	○	●	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○				●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●	●	●	●	●	○	●	○	●	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒	○	○	●	●		●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	○	▒	●	▒	●				▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	○	▒	●	▒	●				▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒	●	▒	○				▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●		▒					●	●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒		○				●	●	●	●	●
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○

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The Quest to Replace Passwords
A Framework for Comparative Evaluation of Web Au

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Two verifiers who collude can't link user across them based on authenticaticator alone

https://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-817.pdf

				Usability									Deployability					Security										
Category	Scheme	Described in	Reference	*Memorywise*	*Scalable-for*	*Nothing-to-C*	*Physically-E*	*Easy-to-Lea*	*Efficient-to-*	*Infrequent-E*	*Easy-Recove*	*Accessible*	*Negligible-C*	*Server-Comp*	*Browser-Co*	*Mature*	*Non-Proprie*	*Resilient-to-*	*Resilient-to-*	*Resilient-to-*	*Resilient-to-*	*Resilient-to-*	*Resilient-to-*	*Resilient-to-*	*Resilient-to-*	*No-Trusted-*	*Requires-Explicit-Consent*	*Unlinkable*
(Incumbent)	Web passwords	III	[13]			●		●	●	○	●	●	●	●	●	●	●		○					●	●	●	●
Password managers	Firefox	IV-A	[22]	○	●	○	○	●	●	●	▒	●	●	●	▒	●	●	○	○				●	●	●	●	●
	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○		○	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●			●	●		●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●			●	●		●	●	●	●
	Word Association		[50]			●		●	●	○	○	●	●	▒	●	▒	●		▒						●	●	●	●
Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●
Hardware tokens	RSA SecurID	IV-G	[34]			▒		●	○	○	▒	▒	▒	▒	●	●	▒		●	●	●	●	●	●	●	▒	●	●
	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒		●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒		●	○		○		●	●	▒	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒		●	●	●	●	●	●	●	▒	●	●
	Pico		[8]	●	●	▒	●	▒	○	○	▒	▒	▒	▒	▒	●	▒		●	●	●	●	●	●	○	●	●	●
Phone-based	Phoolproof	IV-H	[36]			○		●	○	○	▒	○	○	○	▒	▒	●		●	●	●	●	○	●	●	●	●	●
	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒		●	●	●	●	○	●	●	●	●	●
	MP-Auth		[6]			○		●	○	▒	○	○	○	▒	▒	▒	●		○					●	●	●	●	●
	OTP over SMS			●	●	○		●	▒	○	○	○	▒	▒	●	●	●		●	●	●	●	○	●	○	▒	●	●
	Google 2-Step		[57]			○		●	○	○	○	○	▒	▒	●	●	▒		○	○	●	●		●	●	●	●	●
Biometric	Fingerprint	IV-I	[38]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○		●	▒	●				▒	●	●	▒
	Iris		[39]	●	●	●	○	●	○	▒	▒	○	▒	▒	▒	▒	○		●	▒	●				▒	●	○	▒
	Voice		[40]	●	●	●	○	●	○	▒	▒	○	○	▒	○	○	▒		●	▒	○				▒	●	●	▒
Recovery	Personal knowledge		[58]	○		●		●	●	○	●	●	●	▒	●	●	●			▒					●	●	●
	Preference-based		[59]	○		●		●	○	●	○	●	●	▒	●	▒	▒			○				●	●	●	●
	Social re-auth.		[60]			●		●	▒	●	▒	●	●	▒	●	○	▒	○	▒	●	●	○	○	●	●	▒	●	○

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				Usability							Deployability					Security									
Category	Scheme	Described in section	Reference	*Memorywise-Effortless*	*Scalable-for-Users*	*Nothing-to-Carry*	*Physically-Effortless*	*Easy-to-Learn*	*Efficient-to-Use*	*Infrequent-Errors*	*Easy-Recovery-from-Loss*	*Accessible*	*Negligible-Cost-per-User*	*Server-Compatible*	*Browser-Compatible*	*Mature*	*Non-Proprietary*	*Resilient-to-Physical-Observation*	*Resilient-to-Targeted-Impersonation*	*Resilient-to-Throttled-Guessing*	*Resilient-to-Unthrottled-Guessing*	*Resilient-to-Internal-Observation*	*Resilient-to-Leaks-from-Other-Verifiers*	*Resilient-to-Phishing*	*Resilient-to-Theft*	*No-Trusted-Third-Party*	*Requiring-Explicit-Consent*	*Unlinkable*
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	LastPass		[42]	○	●	○	○	●	●	●	○	●	○	●	▒	●	▒	○	○	○	○	○	●	●	▒	●	●
Proxy	URRSA	IV-B	[5]	●		▒		●	▒	○	▒	▒	●	○	●	▒	▒		○			○		●	▒	▒	●	●
	Impostor		[23]	○	●	●		●	▒	▒	●	●	▒	●	○	▒	●	●	○			○		●	●	▒	▒	●
Federated	OpenID	IV-C	[27]	○	●	●	○	○	●	●	●	●	●	▒	●	●	●	○	○	○	○		●		●	▒	●	▒
	Microsoft Passport		[43]	○	●	●	○	●	●	●	●	●	▒	▒	●	●	▒	○	○	○	○		●		●	▒	●	▒
	Facebook Connect		[44]	○	●	●	○	●	●	●	●	●	●	▒	●	●	▒	○	○	○	○		●		●	▒	▒	▒
	BrowserID		[45]	○	●	●	○	●	●	●	●	●	●	▒	○	○	●	○	○	○	○		●		●	▒	●	▒
	OTP over email		[46]	○	●	●		●	▒	●	●	●	●	▒	●	▒	●	○	○	○	○		●	●	●	▒	●	▒
Graphical	PCCP	IV-D	[7]			●		●	○	○	●	▒	●	▒	●	▒	●		●	○			●	●	●	●	●	●
	PassGo		[47]			●		●	○	○	●	▒	●	▒	●	○	●		●						●	●	●	●
Cognitive	GrIDsure (original)	IV-E	[30]			●		●	○	○	●	▒	●	▒	●	▒	▒		●						●	●	●	●
	Weinshall		[48]			●		▒	▒	▒	▒	▒	●	▒	●	▒	●	○	●				●	●	●	●	●	●
	Hopper Blum		[49]			●		▒	▒	▒	▒	●	●	▒	●	▒	●	○	●				●	●	●	●	●	●
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Paper tokens	OTPW	IV-F	[33]			▒		●	▒	▒	●	▒	●	▒	●	●	●		●	●	●	●	●	●	●	●	●	●
	S/KEY		[32]	●		▒		●	▒	○	●	▒	●	▒	●	●	●		●	●	●	●	●	○	▒	●	●	●
	PIN+TAN		[51]			▒		●	▒	○	○	▒	○	▒	●	●	●		●	●	●	●	●	●	○	●	●	●
Visual crypto	PassWindow		[52]	●		▒		▒	▒	▒	▒	▒	○	▒	●	●	▒	○	●	●	●	●	●	●	▒	●	●	●
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	Yubikey		[53]			▒		●	○	○	▒	●	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
	Ironkey		[54]	○	●	▒	○	○	○	○	▒	●	▒	●	●	●	▒	●	○			○		●	●	●	●	●
	CAP reader		[55]			▒		●	○	○	▒	▒	▒	▒	●	●	▒	●	●	●	●	●	●	●	●	▒	●	●
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	Cronto		[56]			○		●	○	○	▒	▒	○	▒	●	●	▒	●	●	●	●	○	●	●	●	●	●	●
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Issues w/ Biometrics?

- Theft of artifact
  - High-res cameras + gummi bears
- Theft of digitization (replay)
  - Need challenge/response protocol
- Impairment
  - (Face recognition based on skull geometry)
- Irrevocable
  - More like a username than a password

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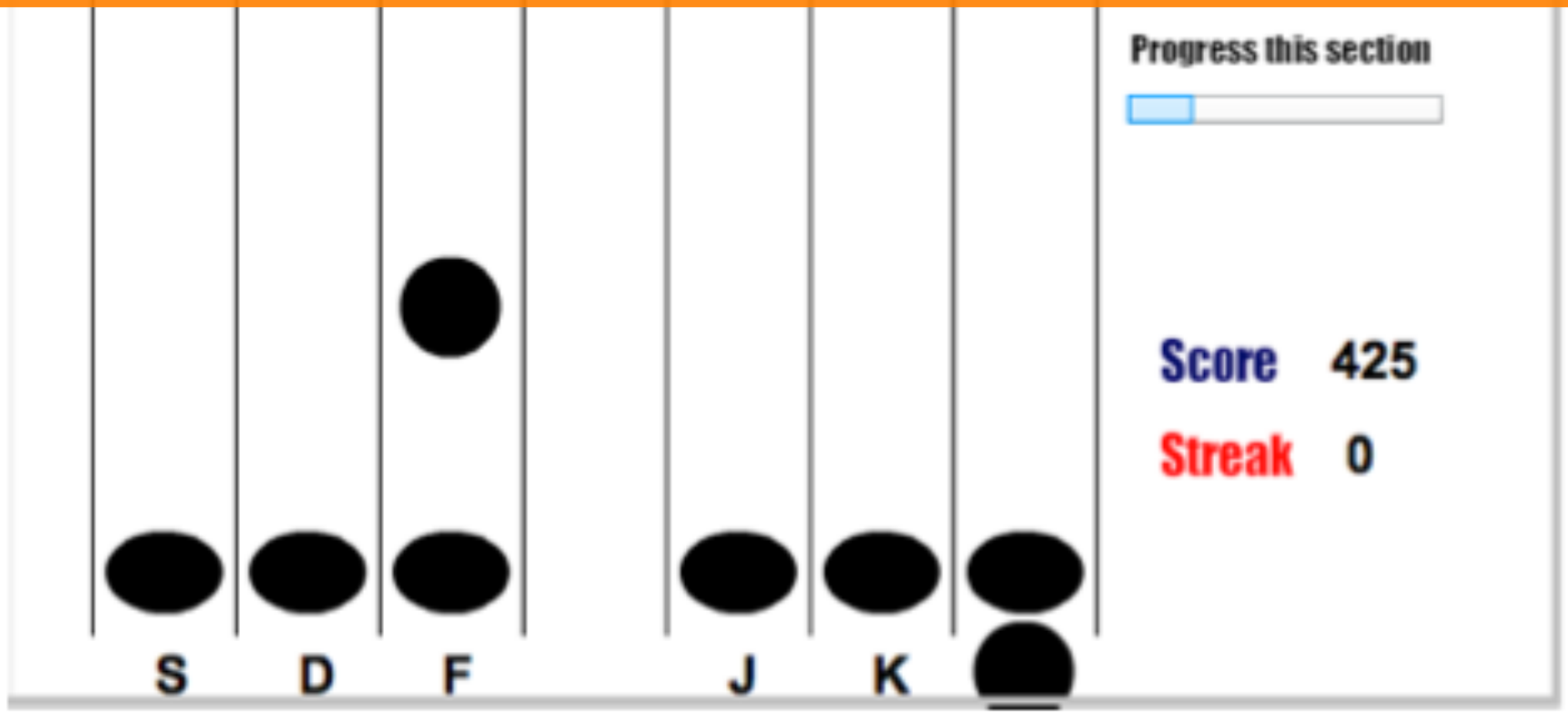
- Impairment
  - (Face recognition based on skull geometry)
- Irrevocable?
  - What if sites could *implant* a biometric?

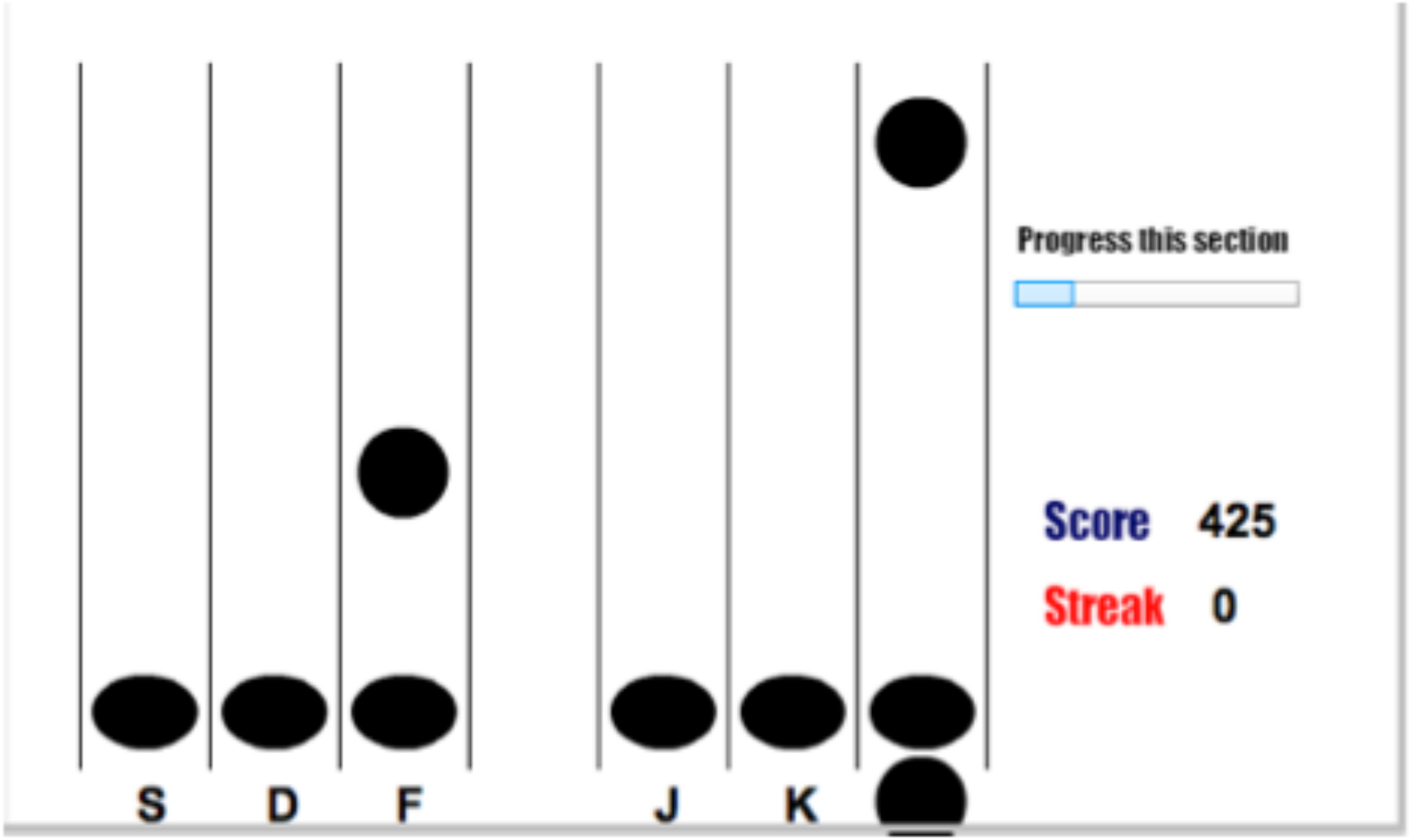
Implantable Biometrics

- Threat model: "*rubber hose cryptography*"
  - Any defenses?
- Consider scenario where authentication highly important
  - Can afford **lengthy** setup, validation sequences
- Abstract idea:
  - In setup phase, implant biometric password in *muscle memory*
  - Validation: probe muscle-memory response
- If user threatened, *they don't consciously know their password* ⇒ can't reveal it

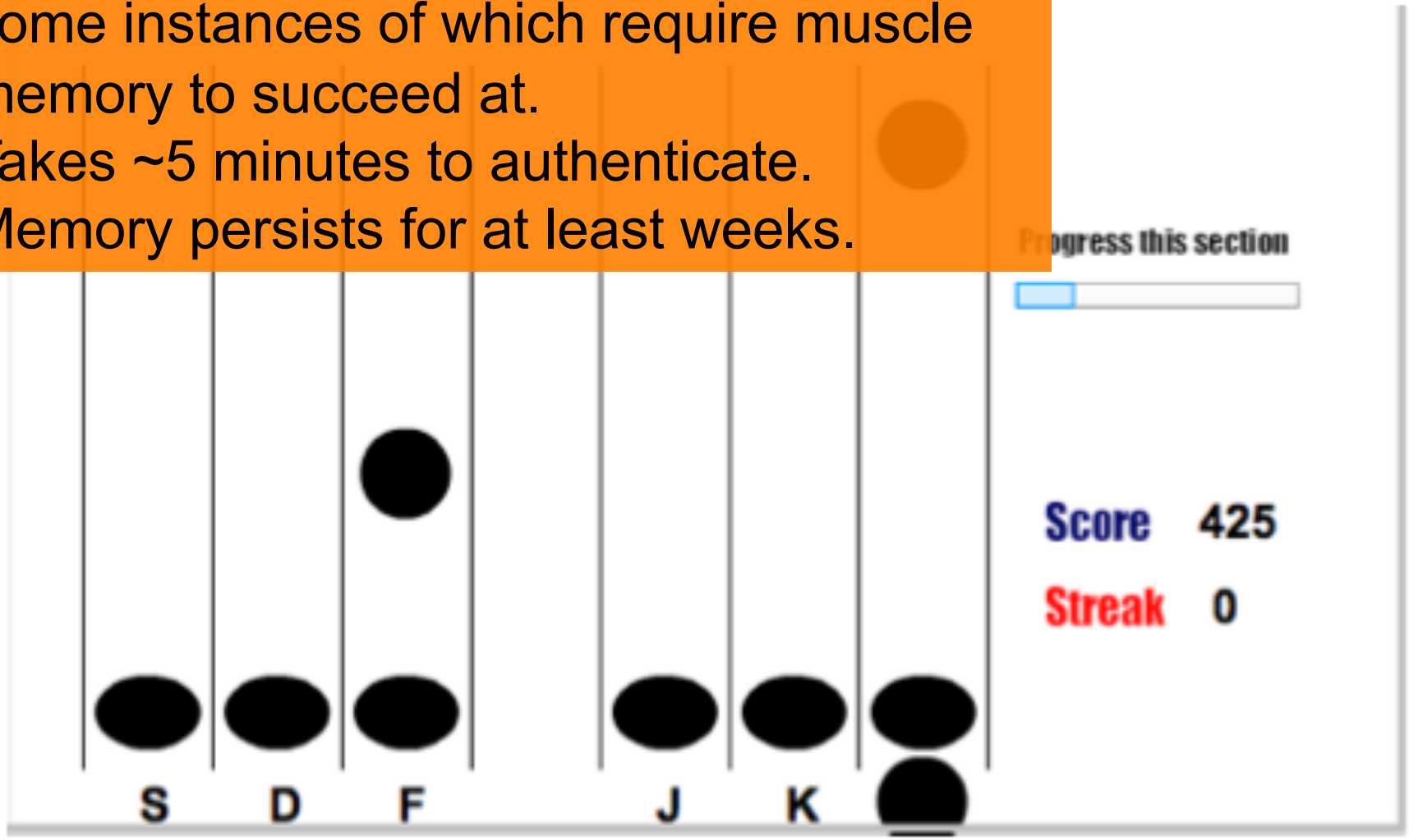
Authentication based on a game similar to *Guitar Hero*.
User presses a key corresponding to falling circles.
Game rachets up speed until user has a ~30% failure rate.
Embeds password in 80% of game instances.



30-45 minutes training: ~38 bits of entropy



Authentication: make user play game, some instances of which require muscle memory to succeed at.
Takes ~5 minutes to authenticate.
Memory persists for at least weeks.



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Issues w/ Recovery?

- Knowledge-based recovery is vulnerable to targeting attacker
- Opens up phishing opportunities
- May compound mental burden
- Overall security = min(orig. sec., rec. sec.)

Issues w/ Recovery?

- Can reduce security to that of *simpler mode*
  - E.g. iOS fingerprint/faceprint reduced to PIN
- Gets especially iffy when recovery relies on *email* and uses varying, non-robust second factors
  - Real-life example from 2012 …

(1) Get victim's email & home (billing) address
(2) Call Amazon, say you're the victim & want to
add a credit card #
(2') Add bogus card
(3) Call Amazon: "I've lost access to my email account"
Provide name, billing addr, new credit card #
(3') Add new email account
(4) Go to Amazon web site, send password reset to new acct
(5) This provides access to last four digits of account CCs
(6) Go to Apple. Provide billing addr. & last 4 digits ...
(6') ... receive temporary iCloud password
(7) Go to *N* services: password resets emailed to iCloud acct.
(8) Brick victim's devices & PROFIT

Thinking about Authentication, con't

- Spectrum:
  - Which user (human) am I dealing with?
  - Which server (institution) am I dealing with?
  - What attributes does this party have?
    - Affiliation, human-or-program, country, …
  - Is this the same entity as before?

Phishing

- Involves two key fake-outs:
  - Fool user into thinking attacker is really desired site
  - Fool site into thinking attacker is really desired user
- Can we rely on user to judge whether a site is genuine?

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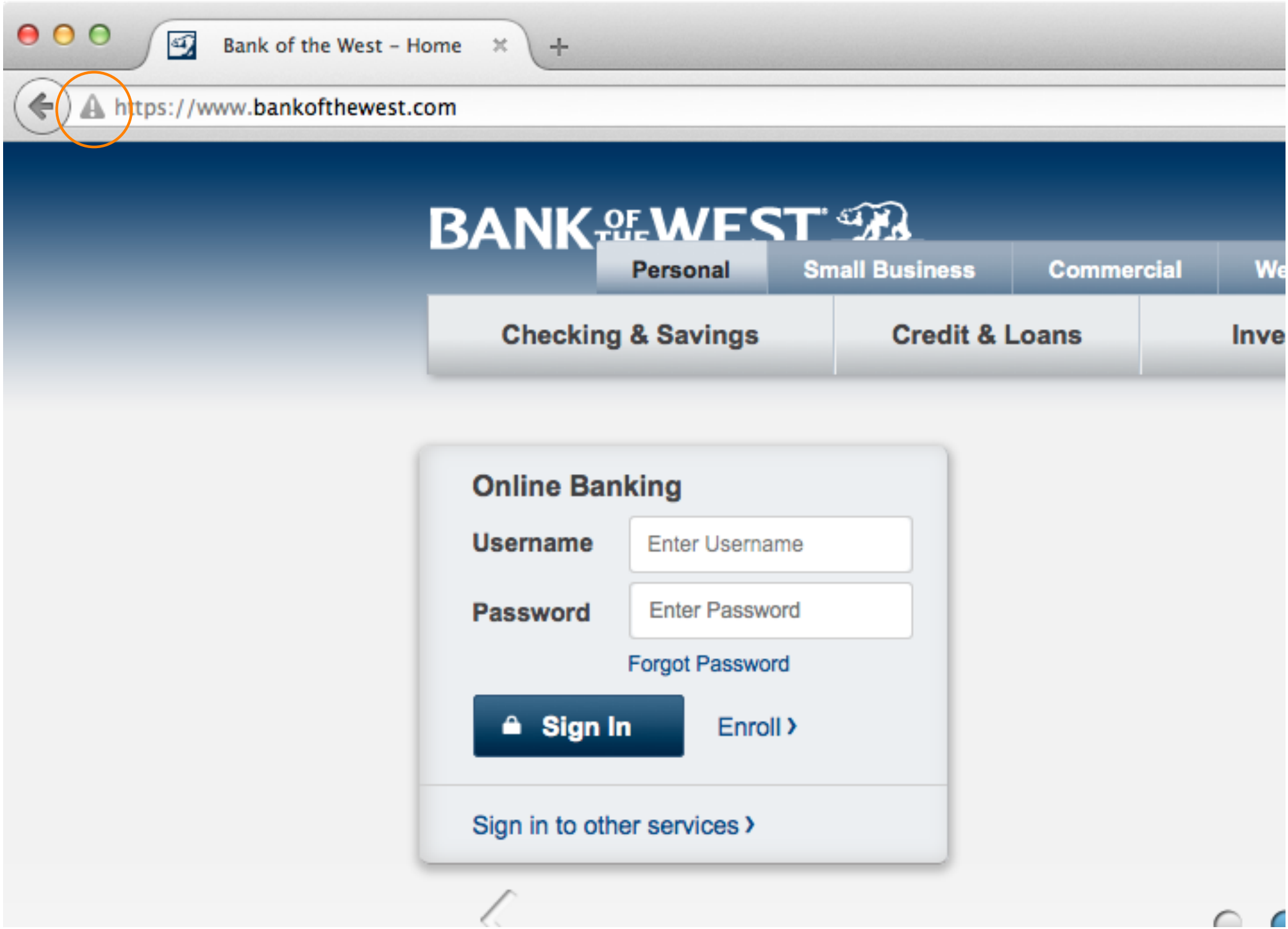
Are financial hardships making your mortgage payments difficult to afford?

A Commitment to Community

We have committed $75 billion in loans, investments and charitable contributions to the neighborhoods we serve.

COMMITMENT

[–] Feedback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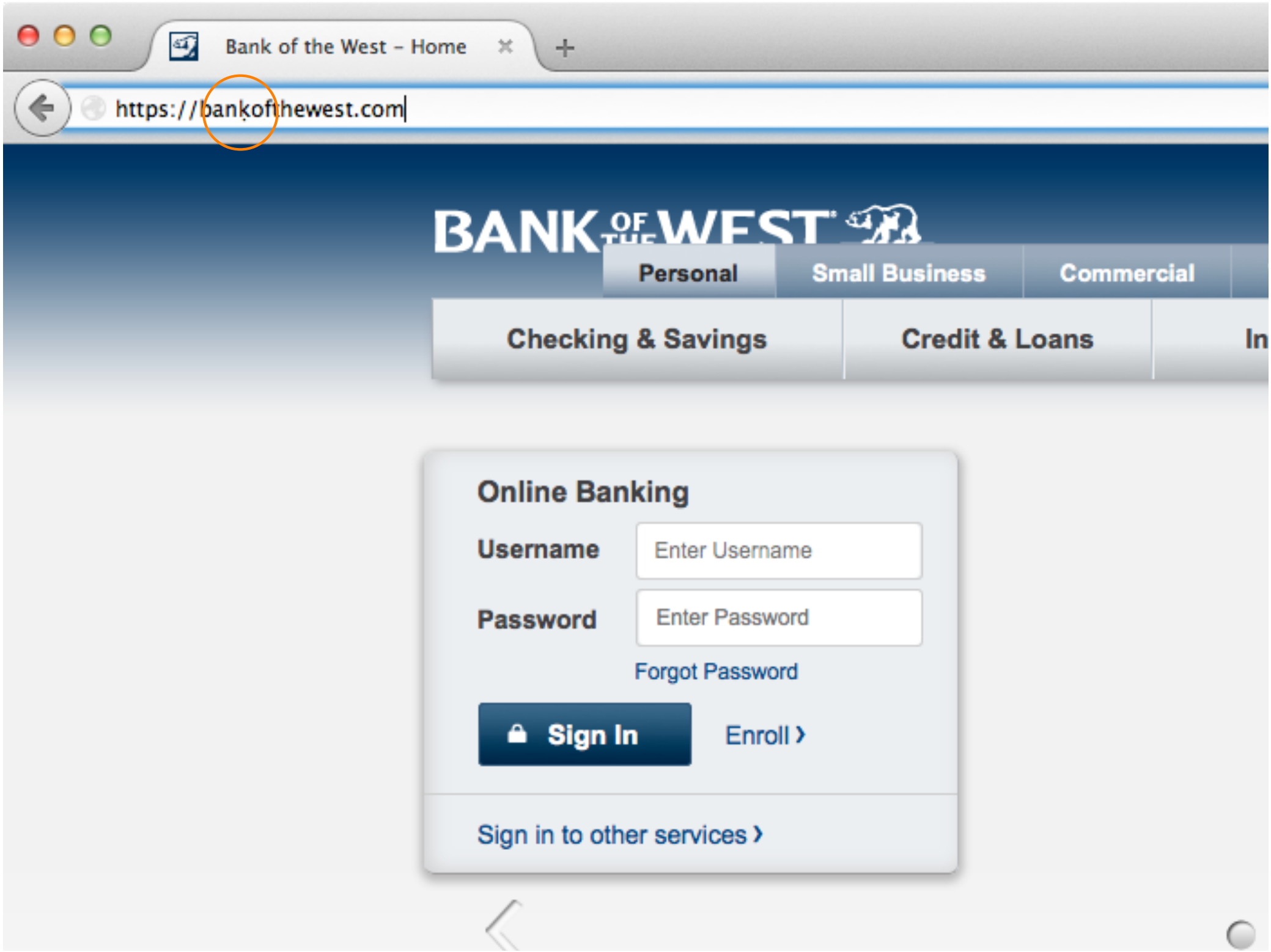
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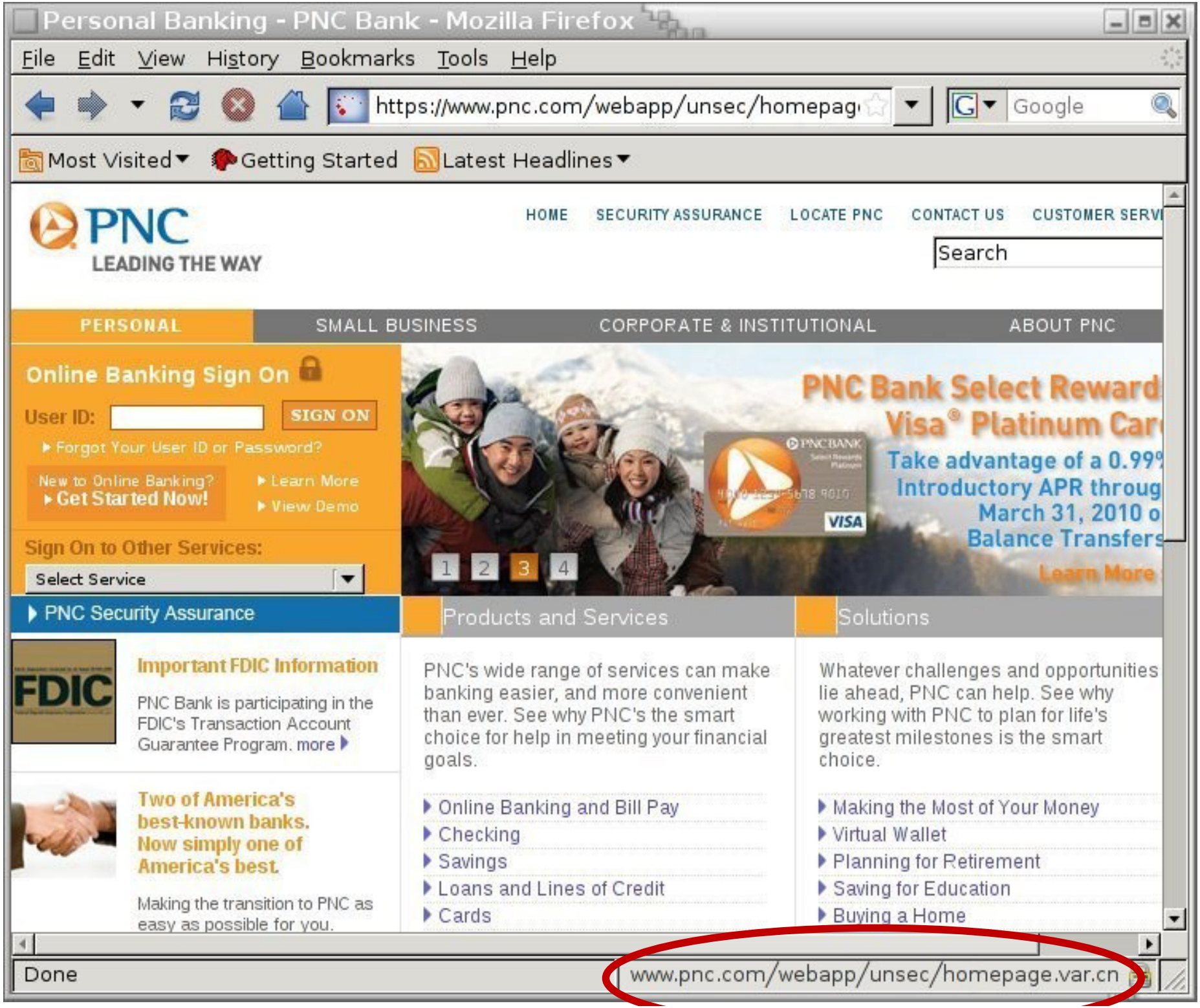
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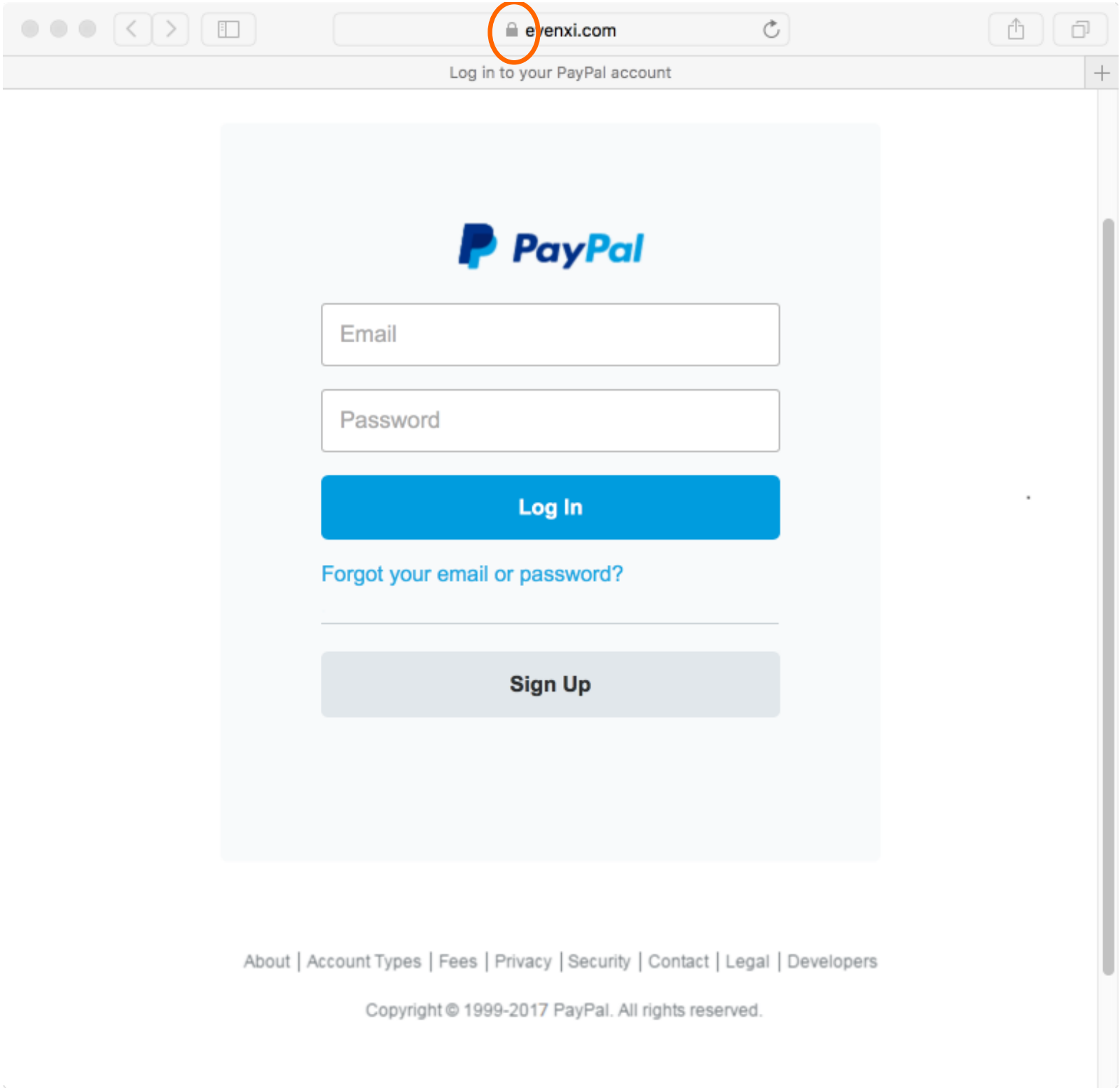
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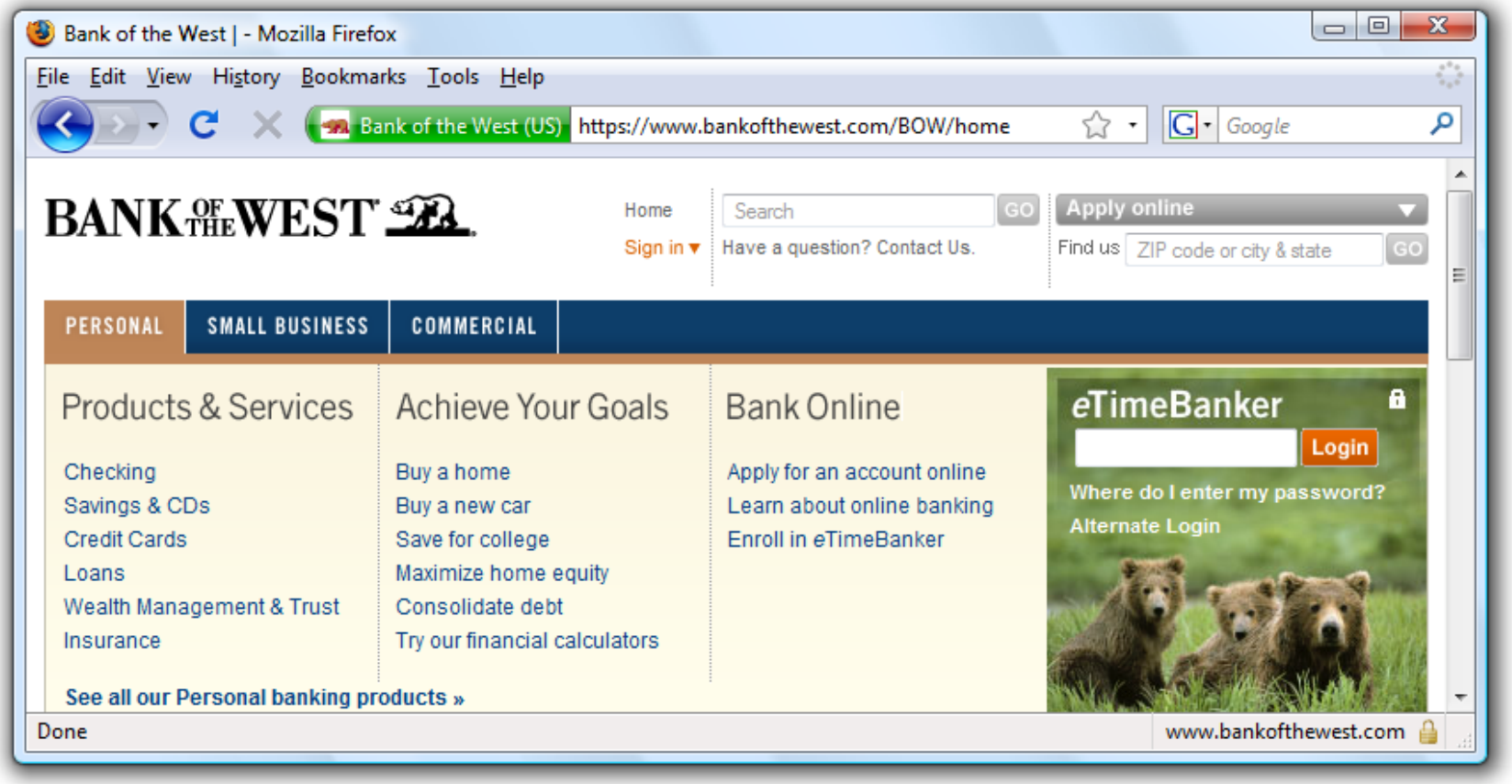

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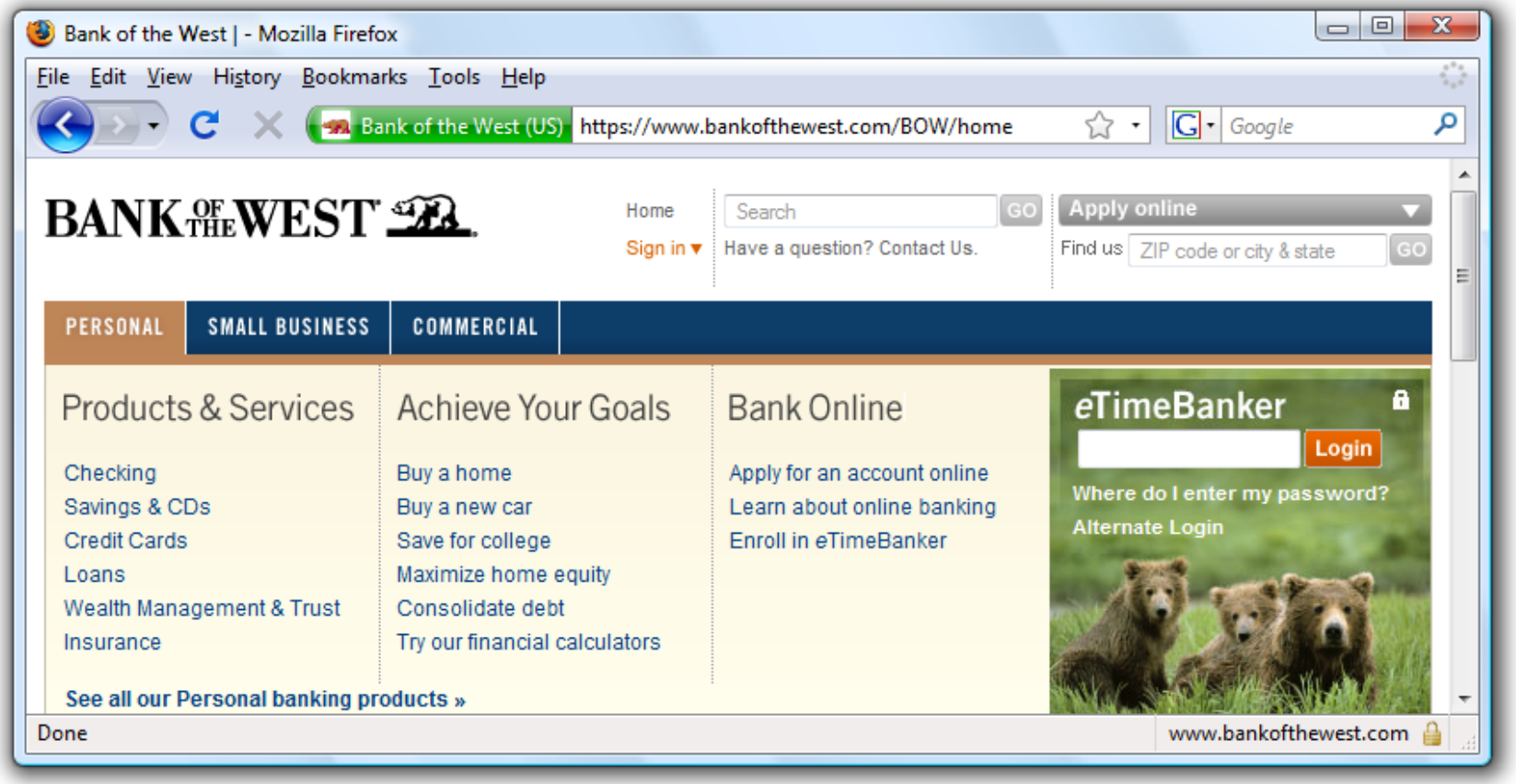

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