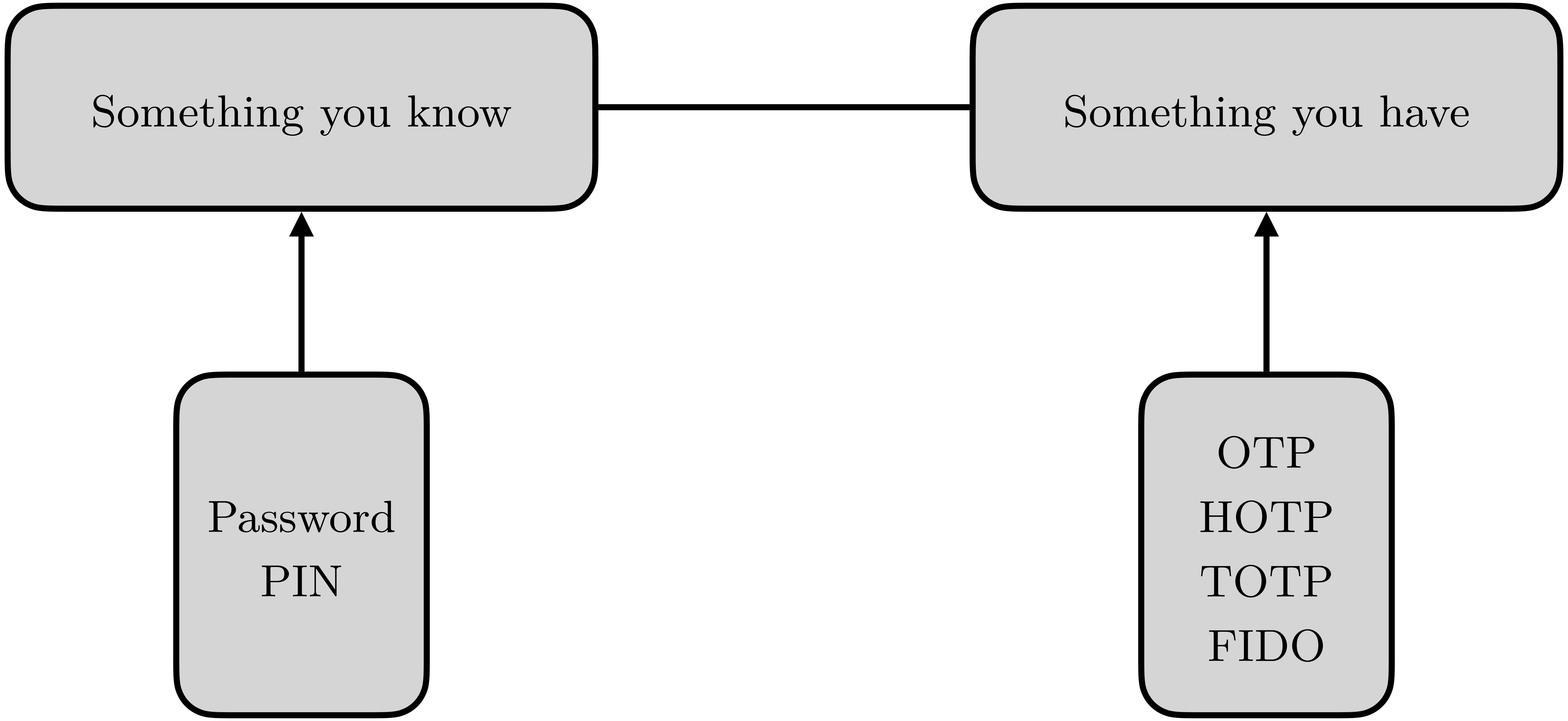
Multi-factor Authentication

(A crash-course)

Caleb Luzovich (*they/them*) — 2024

How does it work?



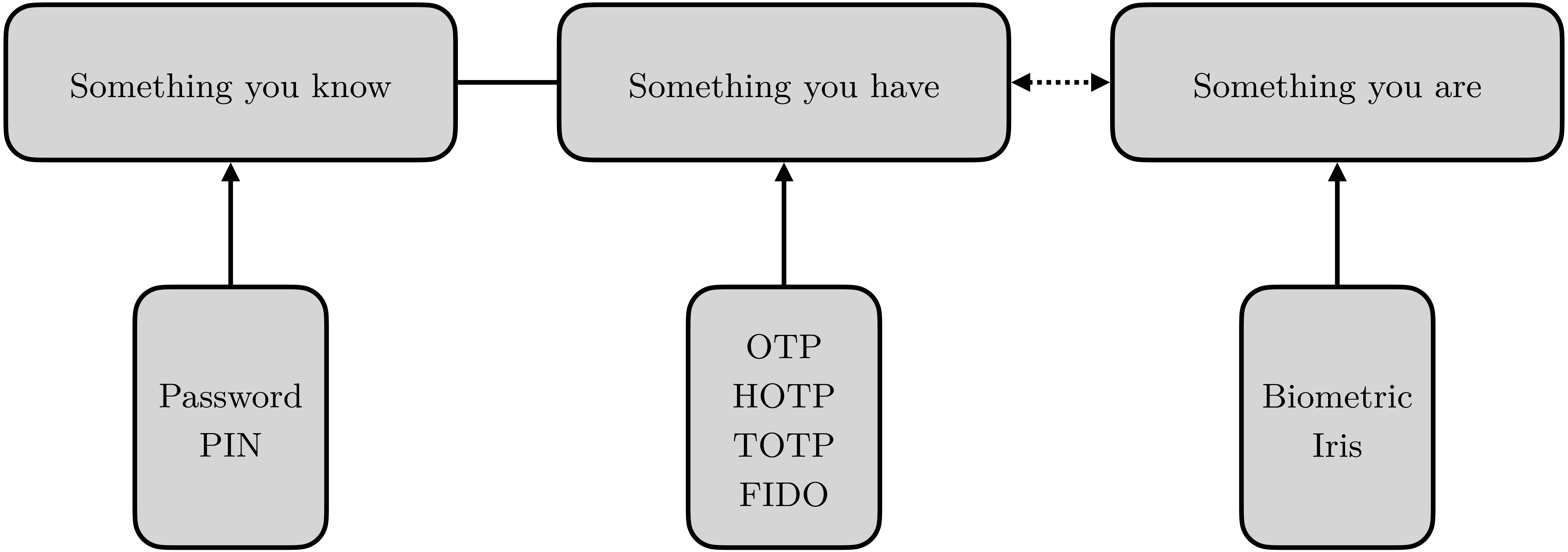
Something you know

Something you have

Password
PIN

OTP
HOTP
TOTP
FIDO

2FA



Something you know

Something you have

Something you are

Password
PIN

OTP
HOTP
TOTP
FIDO

Biometric
Iris

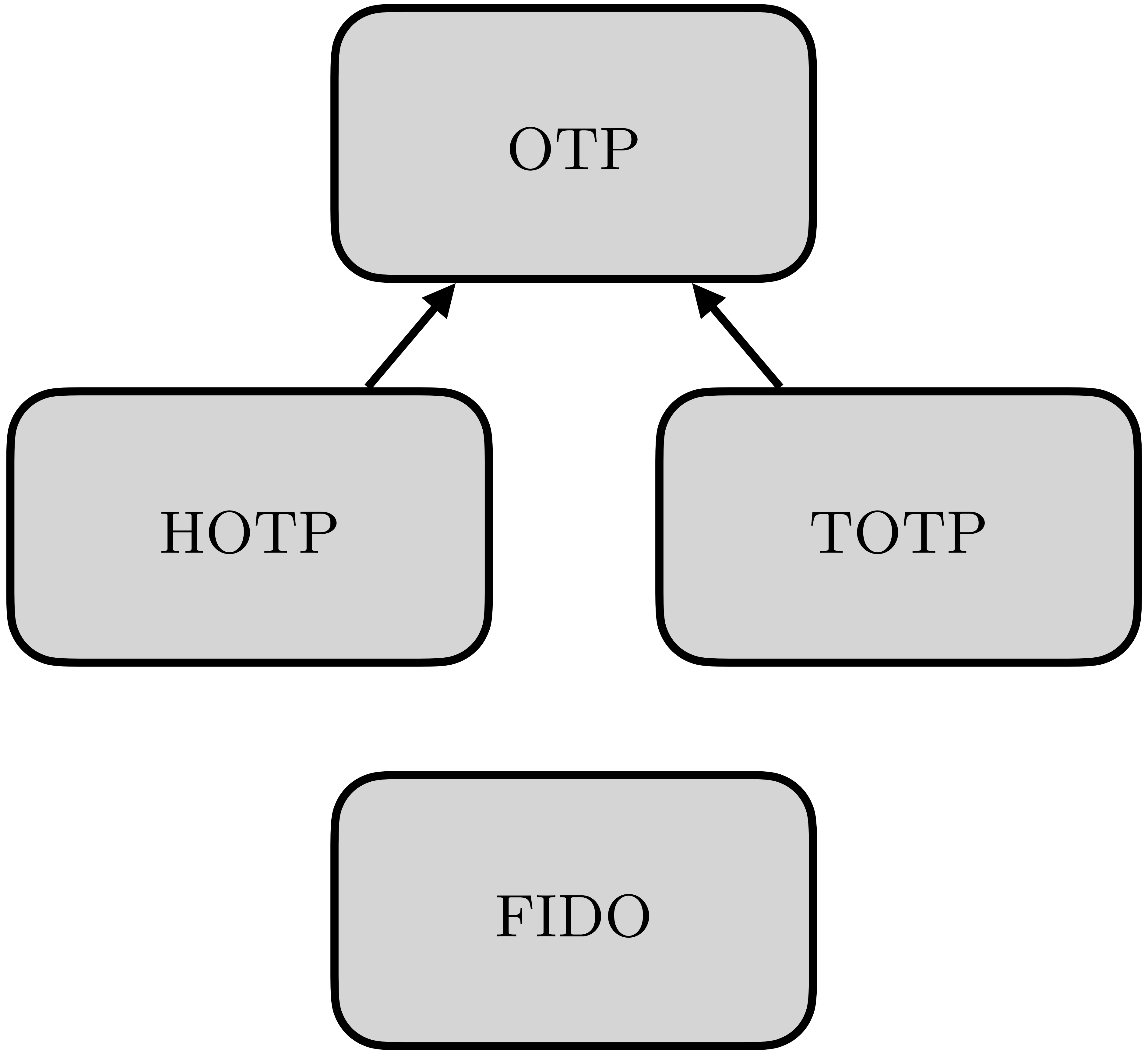
MFA

Something you know

- Password
- PIN (Personal Identification Number)

Something you have

- OTP (One-Time Password)
  - HOTP (Hash-based OTP)
  - TOTP (Time-based OTP)
- FIDO (Fast IDentity Online)
  - U2F (Universal 2nd Factor)
  - CTAP2 – (Client to Authenticator Protocol)



Something you have

One-Time Password

- Typically sent over SMS/Email/Voicemail
- Also umbrella term for HOTPs and TOTPs

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One-Time Password

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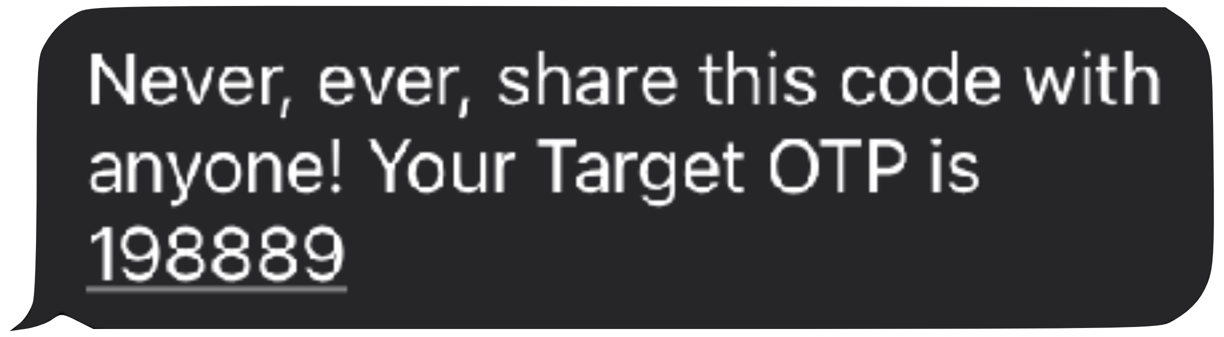
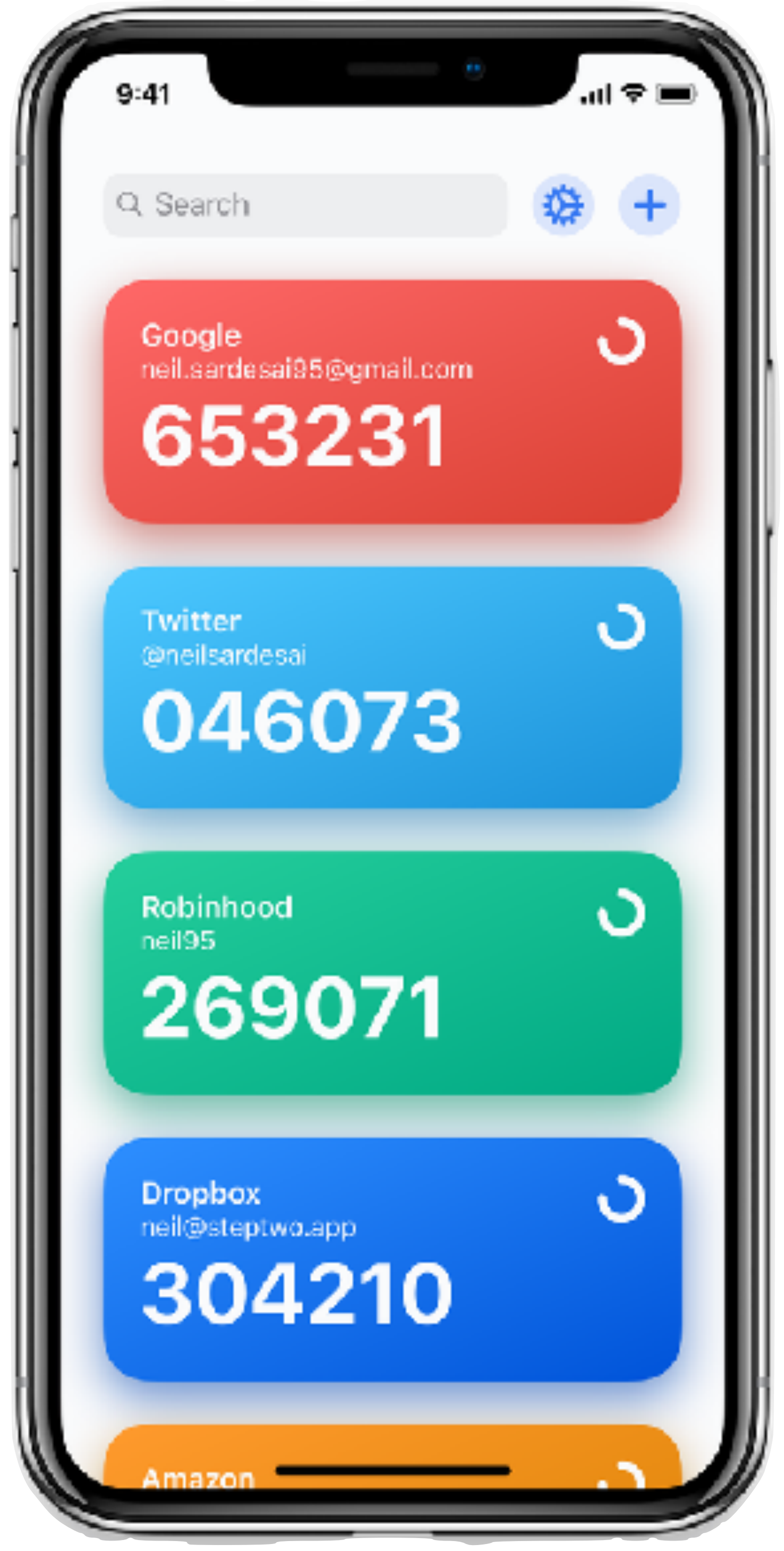


Never, ever, share this code with anyone! Your Target OTP is 198889

Something you have

One-Time Password

- Typically sent over SMS/Email/Voicemail
- Also umbrella term for HOTPs and TOTPs



Google
neil.sardesai95@gmail.com
653231

Twitter
@neilsardesai
046073

Robinhood
neil95
269071

Dropbox
neil@steptwo.app
304210

Amazon

Step Two App, https://neilsardesai.com/step-two

One-Time Password

HOTPs & TOTPs

- Use 3–4 variables in calculation
- Differ in how one of those variables are calculated

<table>
<tr><th>TOTP</th><th>HOTP</th></tr>
<tr><td colspan="2">Digit count (min of 6 is standard)</td></tr>
<tr><td colspan="2">Shared key</td></tr>
<tr><td>Time contingent</td><td>Counter contingent</td></tr>
</table>

One-Time Password
HOTPs & TOTPs

- Use 3–4 variables in calculation
- Differ in how one of those variables are calculated

TOTP	HOTP
Length(6) → “293 842” Length(8) → “0148 1928”	
Shared key	
Time contingent	Counter contingent

One-Time Password
HOTPs & TOTPs

- Use 3–4 variables in calculation
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TOTP	HOTP
Length(6) → “293 842” Length(8) → “0148 1928”	
Key_{x} → “339 790” Key_{y} → “082 918”	
Time contingent	Counter contingent

One-Time Password
HOTPs & TOTPs

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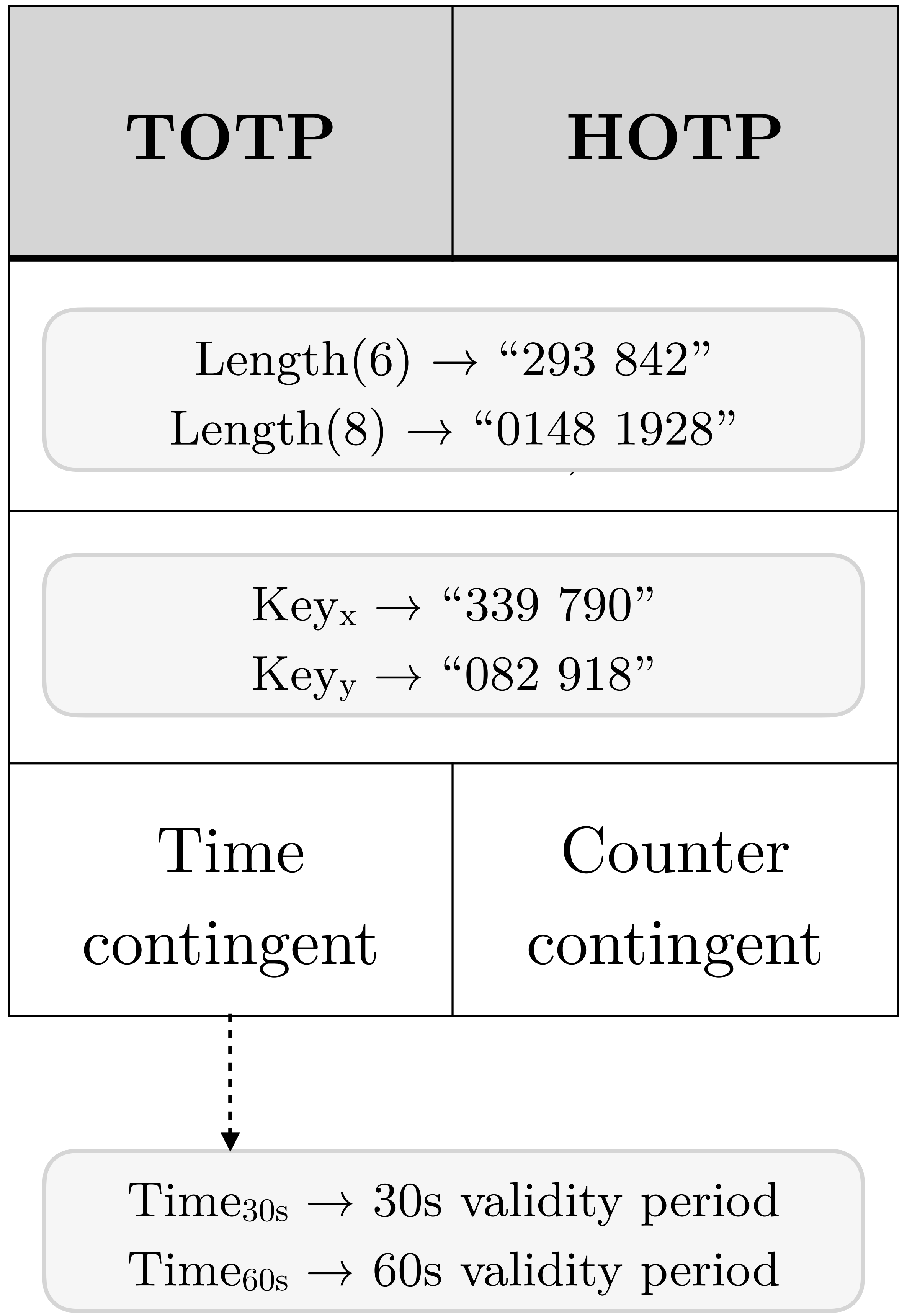


TOTP | HOTP

Length(6) → “293 842”
Length(8) → “0148 1928”

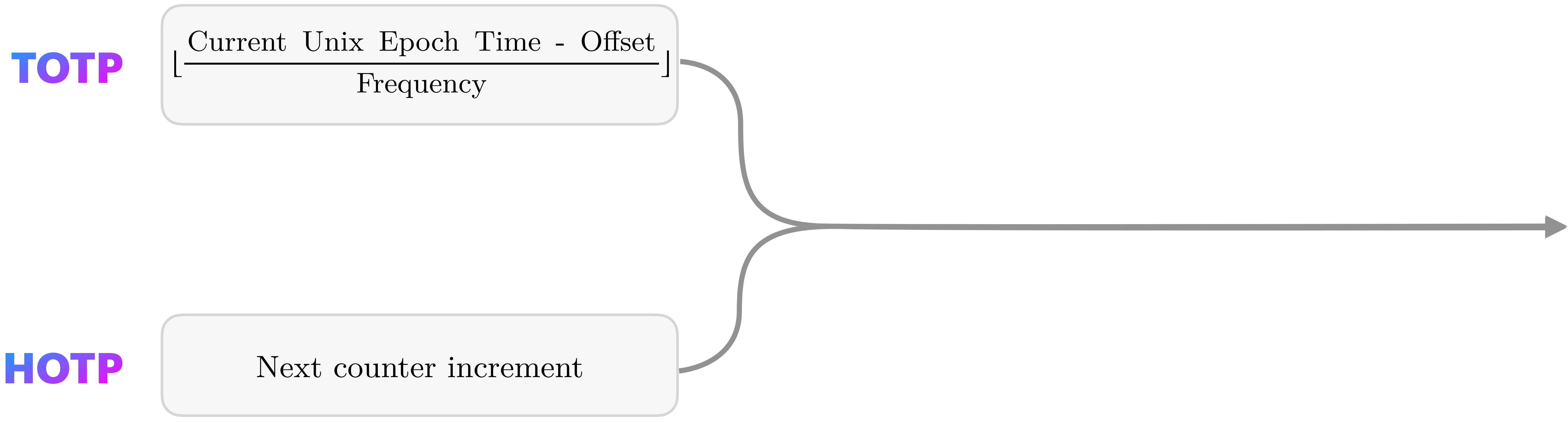
Key_x → “339 790”
Key_y → “082 918”

Time contingent | Counter contingent

Time_{30s} → 30s validity period
Time_{60s} → 60s validity period

HOTPs & TOTPs

Calculation



TOTP

$$\left\lfloor \frac{\text{Current Unix Epoch Time - Offset}}{\text{Frequency}} \right\rfloor$$

HOTP

Next counter increment

Step 1 — Getting the Counter

HOTPs & TOTPs

Calculation

Base 32:

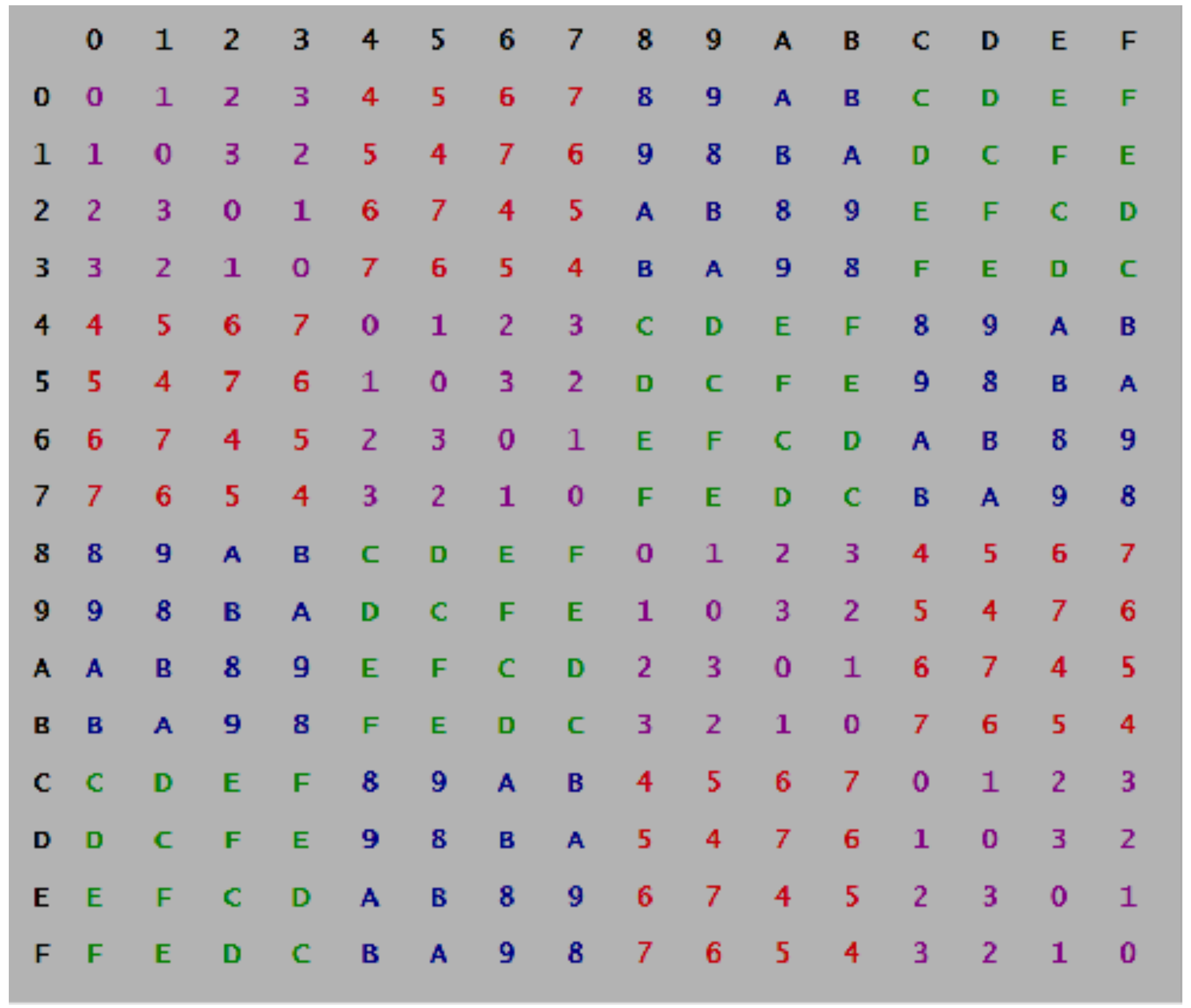
GEZDGNBVGY3TQOJQGEZDGNBVGY3TQOJQ

Base 10:

12345678901234567890

Step 2 — Decode secret from Base 32 (if needed)

HOTPs & TOTPs
Calculation



	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
1	1	0	3	2	5	4	7	6	9	8	B	A	D	C	F	E
2	2	3	0	1	6	7	4	5	A	B	8	9	E	F	C	D
3	3	2	1	0	7	6	5	4	B	A	9	8	F	E	D	C
4	4	5	6	7	0	1	2	3	C	D	E	F	8	9	A	B
5	5	4	7	6	1	0	3	2	D	C	F	E	9	8	B	A
6	6	7	4	5	2	3	0	1	E	F	C	D	A	B	8	9
7	7	6	5	4	3	2	1	0	F	E	D	C	B	A	9	8
8	8	9	A	B	C	D	E	F	0	1	2	3	4	5	6	7
9	9	8	B	A	D	C	F	E	1	0	3	2	5	4	7	6
A	A	B	8	9	E	F	C	D	2	3	0	1	6	7	4	5
B	B	A	9	8	F	E	D	C	3	2	1	0	7	6	5	4
C	C	D	E	F	8	9	A	B	4	5	6	7	0	1	2	3
D	D	C	F	E	9	8	B	A	5	4	7	6	1	0	3	2
E	E	F	C	D	A	B	8	9	6	7	4	5	2	3	0	1
F	F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0

XOR Table for Hex, https://crypto.stackexchange.com/questions/43200/how-to-xor-two-hexa-numbers-by-hand-fast

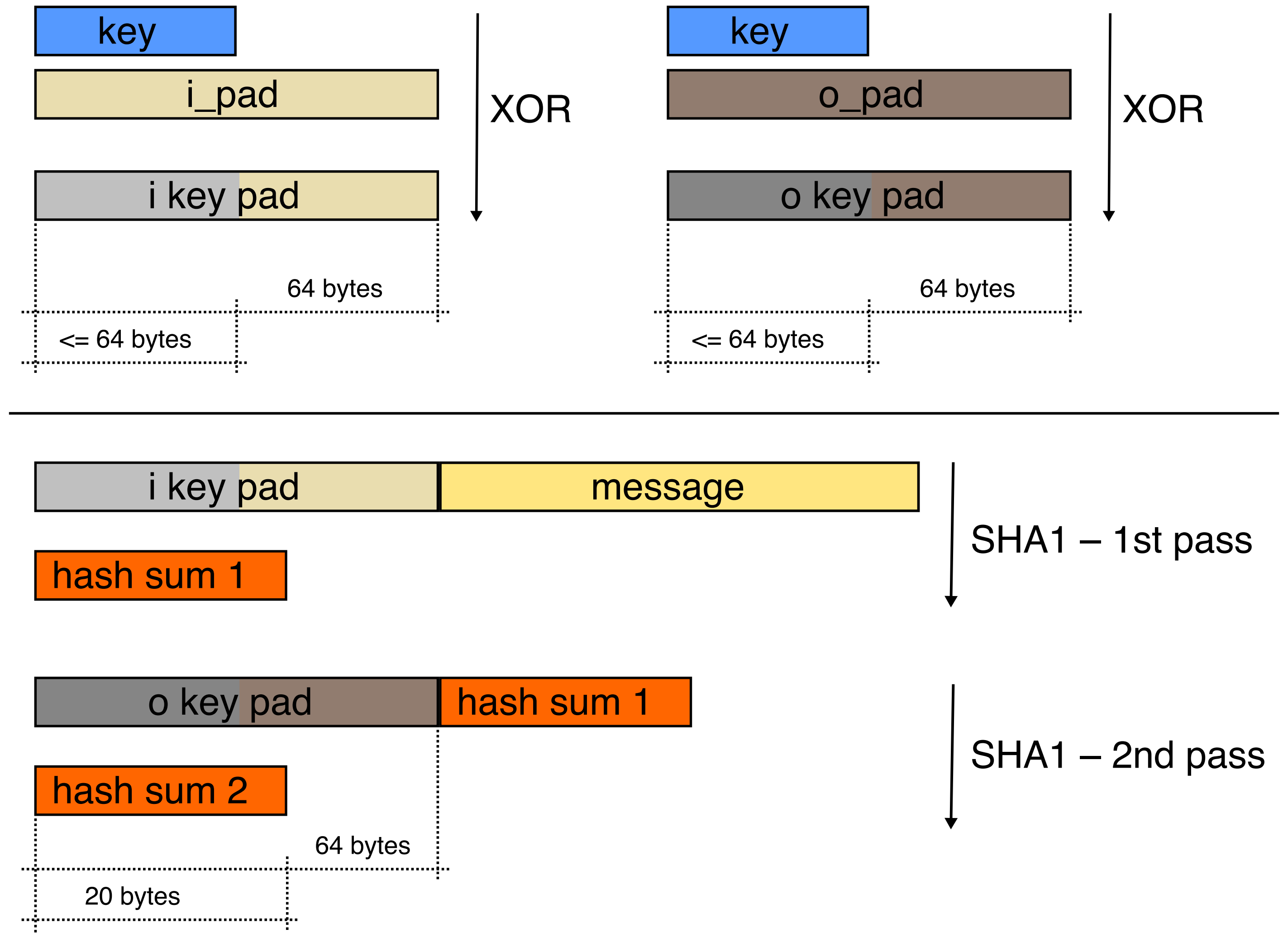
$$\mathrm{HMAC}(K, m) = \mathrm{H}\Big(\big(K' \oplus opad\big) \parallel \mathrm{H}\big(\big(K' \oplus ipad\big) \parallel m\big)\Big)$$

$$K' = \begin{cases} \mathrm{H}\,(K)\text{if } K \text{ is larger than block size} \\ K \qquad \text{otherwise} \end{cases}$$

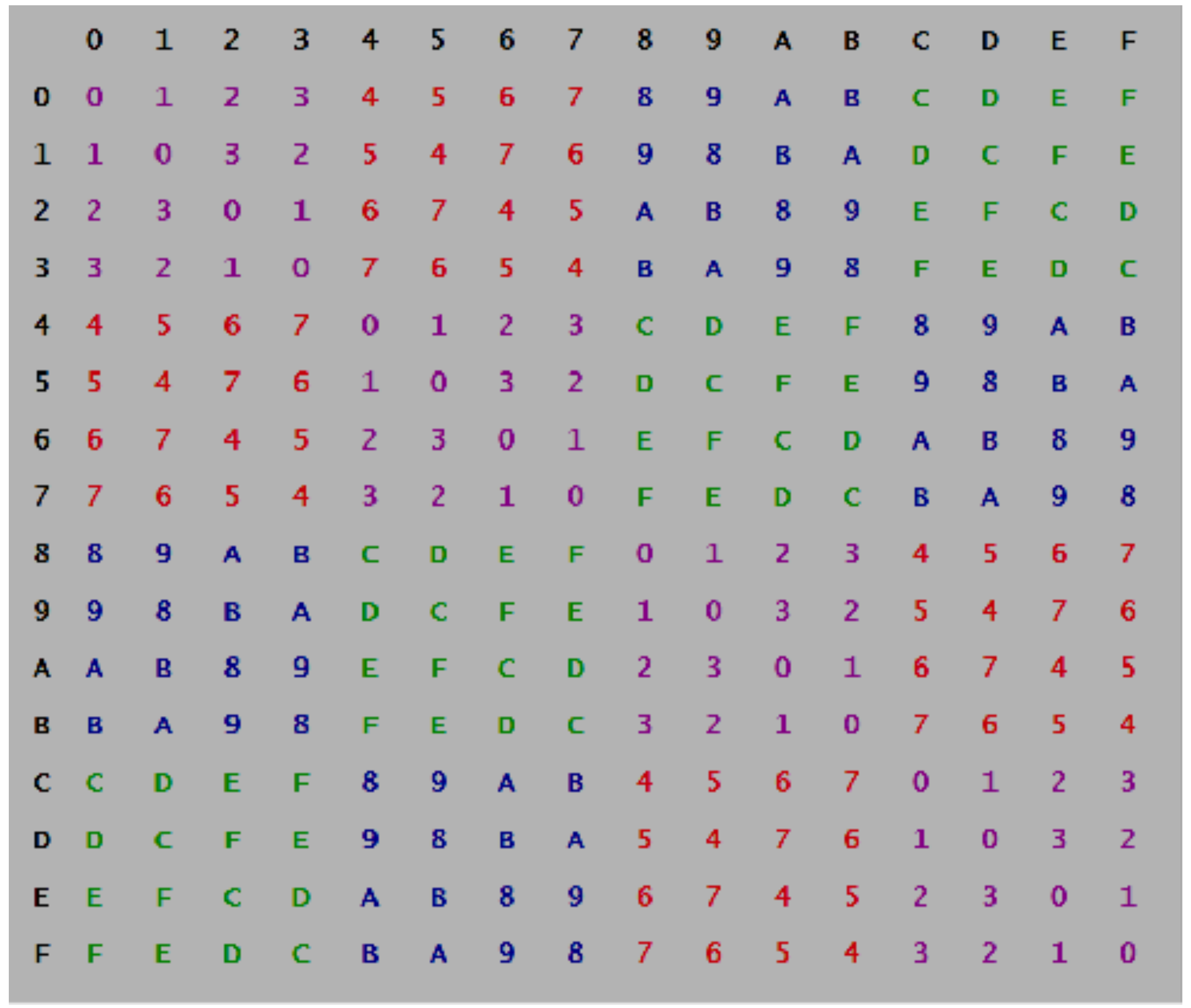
Step 3 — Calculate SHA1 HMAC (Hash-based Message Authentication Code)

HOTPs & TOTPs

Calculation



By Gdrooid - Own work, CC0, https://commons.wikimedia.org/w/index.php?curid=34446189



	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
1	1	0	3	2	5	4	7	6	9	8	B	A	D	C	F	E
2	2	3	0	1	6	7	4	5	A	B	8	9	E	F	C	D
3	3	2	1	0	7	6	5	4	B	A	9	8	F	E	D	C
4	4	5	6	7	0	1	2	3	C	D	E	F	8	9	A	B
5	5	4	7	6	1	0	3	2	D	C	F	E	9	8	B	A
6	6	7	4	5	2	3	0	1	E	F	C	D	A	B	8	9
7	7	6	5	4	3	2	1	0	F	E	D	C	B	A	9	8
8	8	9	A	B	C	D	E	F	0	1	2	3	4	5	6	7
9	9	8	B	A	D	C	F	E	1	0	3	2	5	4	7	6
A	A	B	8	9	E	F	C	D	2	3	0	1	6	7	4	5
B	B	A	9	8	F	E	D	C	3	2	1	0	7	6	5	4
C	C	D	E	F	8	9	A	B	4	5	6	7	0	1	2	3
D	D	C	F	E	9	8	B	A	5	4	7	6	1	0	3	2
E	E	F	C	D	A	B	8	9	6	7	4	5	2	3	0	1
F	F	E	D	C	B	A	9	8	7	6	5	4	3	2	1	0

XOR Table for Hex, https://crypto.stackexchange.com/questions/43200/how-to-xor-two-hexa-numbers-by-hand-fast

Step 3 — Calculate SHA1 HMAC (Hash-based Message Authentication Code)

HOTPs & TOTPs

Calculation

cc 93 cf 18 50 8d 94 93 4c 64 b6 5d 8b a7 66 7f b7 cd e4 b0

cc	93	cf	18	50	8d	94	93	4c	64	b6	5d	8b	a7	66	7f	b7	cd	e4	b0
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

Step 4 — Dynamically truncate result using last byte

HOTPs & TOTPs

Calculation

cc 93 cf 18 50 8d 94 93 4c 64 b6 5d 8b a7 66 7f b7 cd e4 bf

cc	93	cf	18	50	8d	94	93	4c	64	b6	5d	8b	a7	66	7f	b7	cd	e4	bf
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

Step 4 — Dynamically truncate result using last byte

HOTPs & TOTPs

Calculation

cc 93 cf 18

a	b	c	d	e	f
2	3	4	5	6	7

4c 93 cf 18

Step 5 — Clear top of selection (if necessary)

HOTPs & TOTPs

Calculation

Hexadecimal (Base 16):
4c 93 cf 18

Base 10:
1284755224

Step 6 — Convert to Base 10

HOTPs & TOTPs
Calculation

Code	1	2	8	4	7	5	5	2	2	4
Length	10	9	8	7	6	5	4	3	2	1

We’re done!

Step 7 — Grab selection by code length

Something you have
FIDO — CTAP1 / U2F

- Primarily seen in “security keys”
- Only two major flows: Registration & Authentication
- Highly resistant to phishing because of ID matching
- Stems into FIDO2; CTAP2; WebAuthn; “Passkeys”

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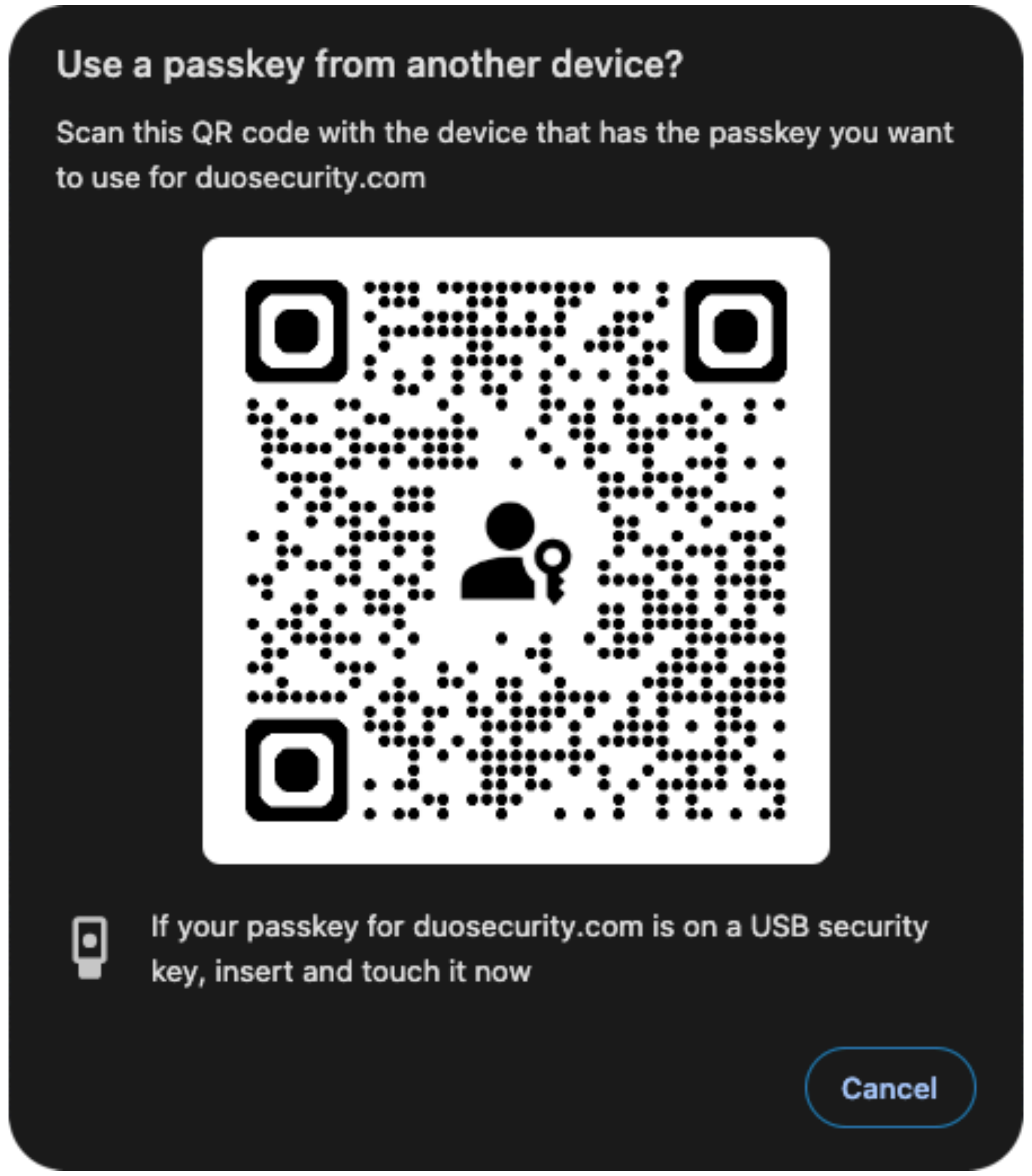
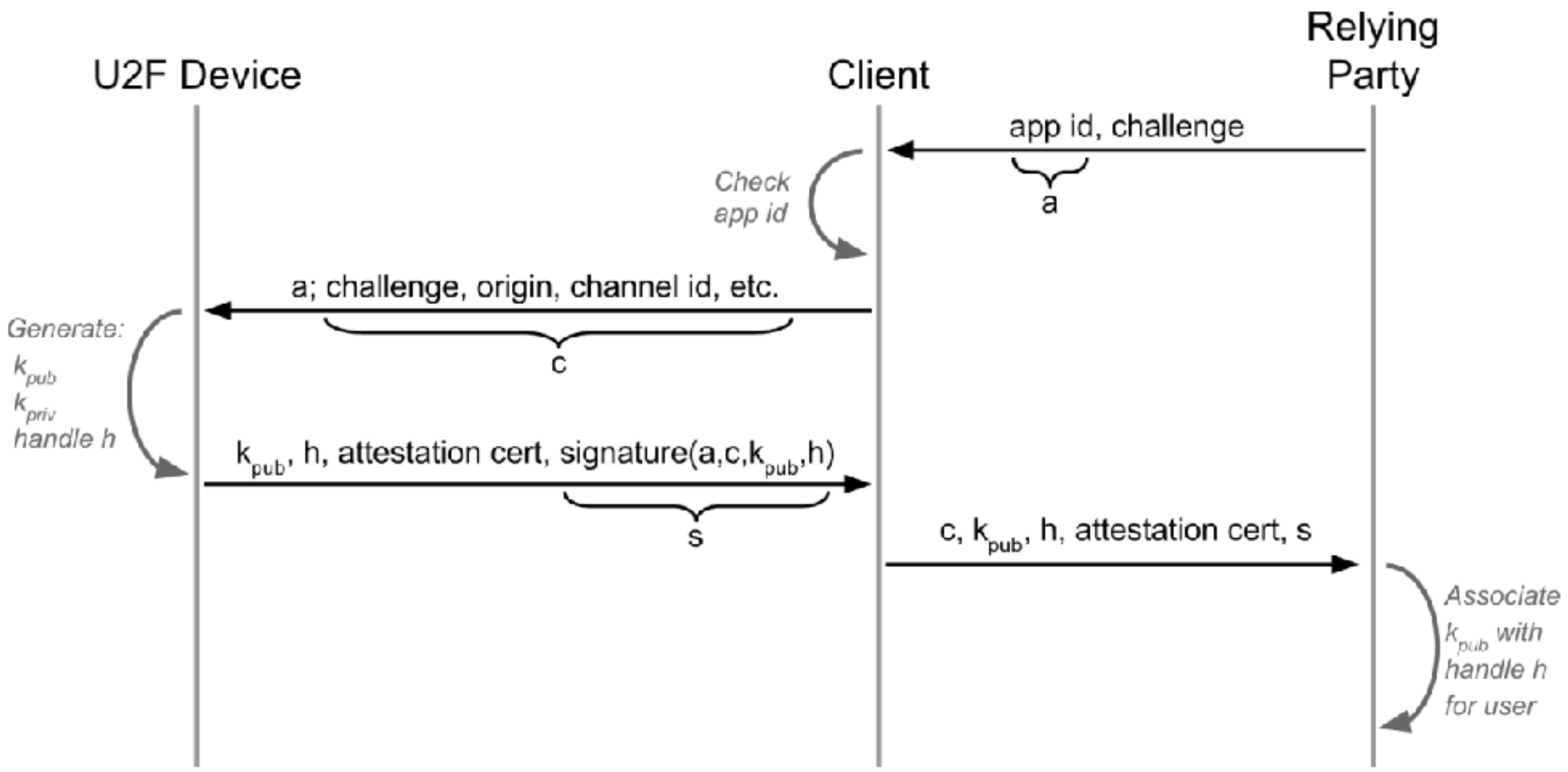


Use a passkey from another device?

Scan this QR code with the device that has the passkey you want to use for duosecurity.com

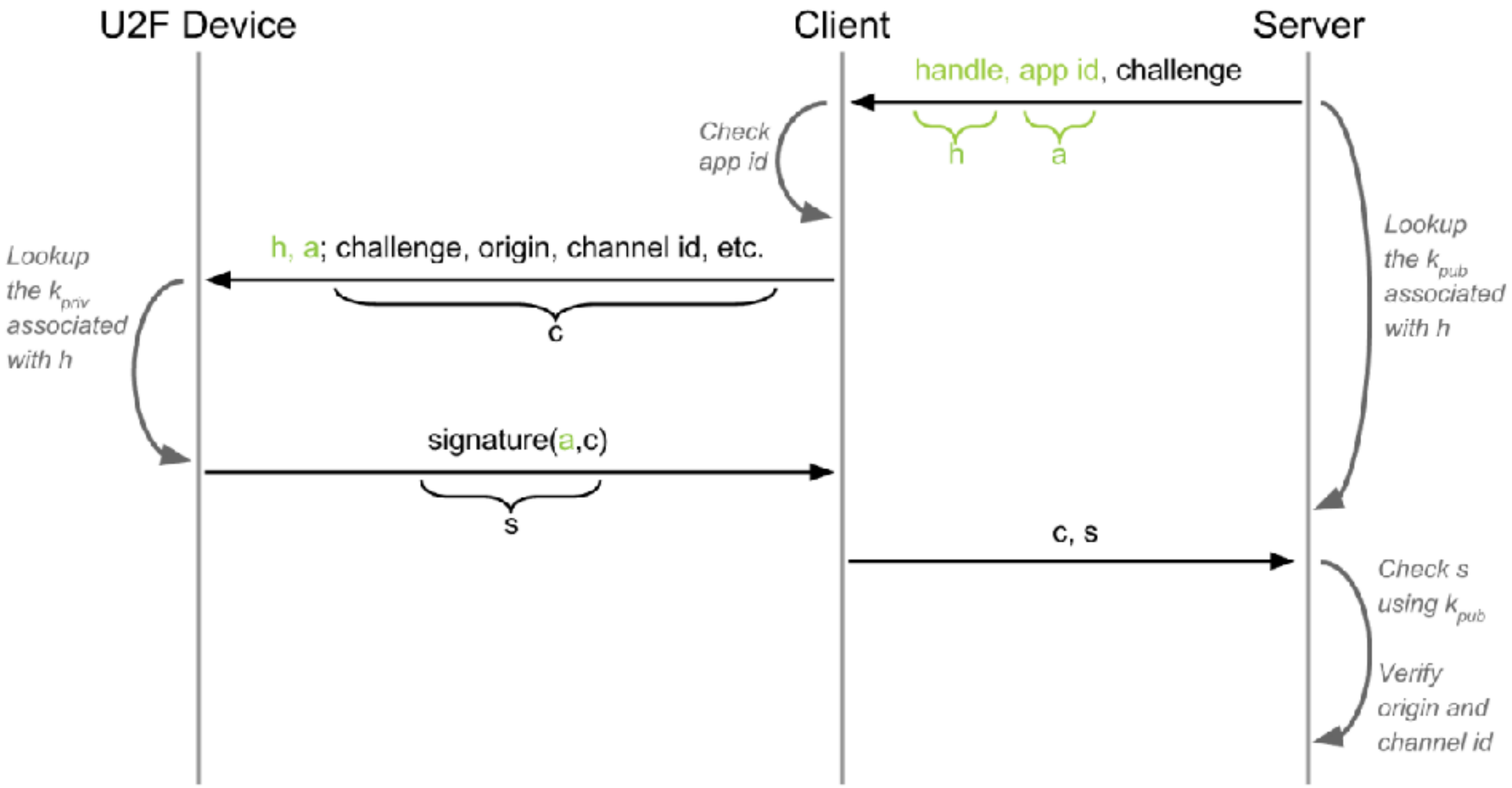
If your passkey for duosecurity.com is on a USB security key, insert and touch it now

FIDO — CTAP1 / U2F
Registration


U2F Device
Client
Relying Party
app id, challenge
a
Check app id
a; challenge, origin, channel id, etc.
c
Generate: k_{pub} k_{priv} handle h
k_{pub}, h, attestation cert, signature(a,c,k_{pub},h)
s
c, k_{pub}, h, attestation cert, s
Associate k_{pub} with handle h for user

CTAP1/U2F Registration Flow, https://engineering.tumblr.com/post/145560228370/u2f-with-yubikeys

FIDO — CTAP1 / U2F
Authentication


U2F Device
Client
Server
handle, app id, challenge
h
a
Check app id
Lookup the k_{pub} associated with h
h, a; challenge, origin, channel id, etc.
c
Lookup the k_{priv} associated with h
signature(a,c)
s
c, s
Check s using k_{pub}
Verify origin and channel id

CTAP1/U2F Authentication Flow, https://engineering.tumblr.com/post/145560228370/u2f-with-yubikeys

Security Considerations

- OTP
- HOTP
- TOTP
- FIDO

References

OTP, TOTP, HOTP

- https://mikecat.github.io/sbs_totp/
- https://jacob.jkrall.net/totp
- RFC 6238 — TOTP
- RFC 4648 — Base16, Base32, and Base64 Encodings
- RFC 4225 — HOTP
- RFC 2104 — HMAC

FIDO U2F/CTAP1

- https://docs.yubico.com/yesdk/users-manual/application-u2f/how-u2f-works.html
- https://fidoalliance.org/specs/fido-v2.0-ps-20190130/fido-client-to-authenticator-protocol-v2.0-ps-20190130.html
- https://webauthn.io/
- https://webauthn.guide/
- https://webauthn.me/