You shall not password !

An extensive analysis of multi-factor authentication protocols

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Introduction

Our goal

Secure Authentication:

Every accepted login by the server and coming from some computer has been initiated on the very same computer by the user.

Common solution: login / password

Passwords are bad

Passwords are compromised:

- Database leaks
- Phishing
- Keyloggers

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"1234", "password", "qwerty"

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"123456!", "p@ssword1", "Qwerty"

Second Factor authentication

The current solution

Use a second factor to confirm login, either a smartphone or a dedicated token.

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Protocols we studied:

- Google 2 Step (Verification code, One Tap, Double Tap)
- FIDO's U2F (Google, Facebook, Github, Dropbox,...)

Main ideas

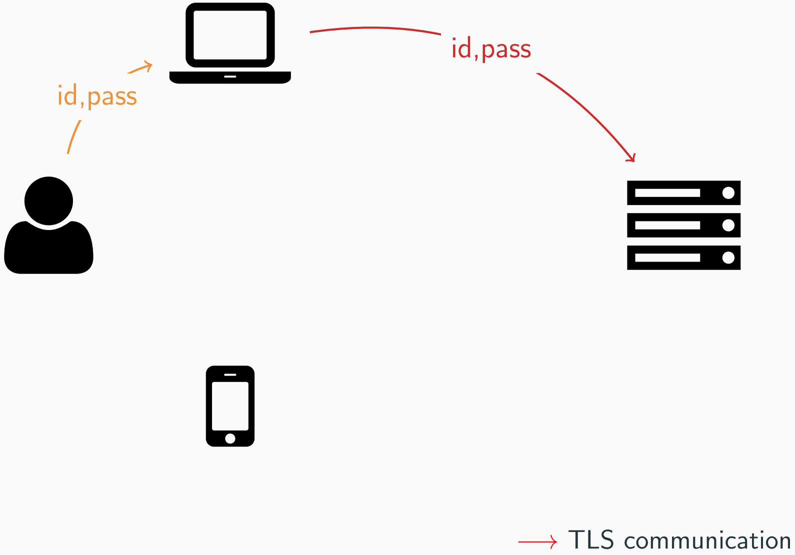
A case study of Google 2 Step and FIDO's U2F

- Many different threat models (malwares, phishing, human errors...)
- Automated analysis of all scenarios

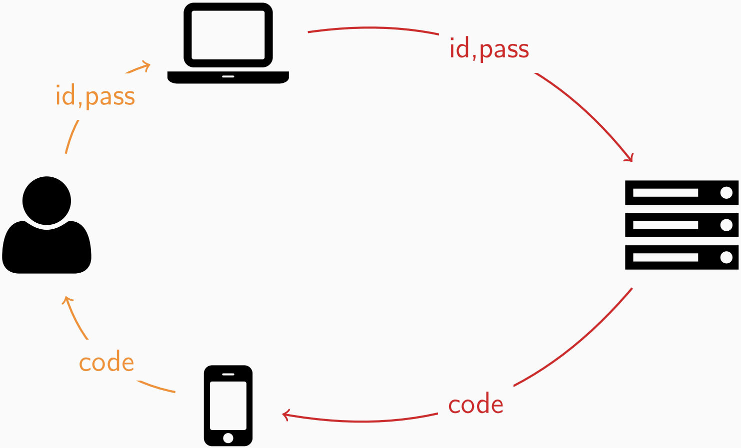
$\rightarrow$ 6 172 (non-redundant) scenarios analysed by PROVERIF in 8 minutes

Presentation of the protocols

Google 2 Step - Verification Code



Google 2 Step - Verification Code



$\longrightarrow$ TLS communication

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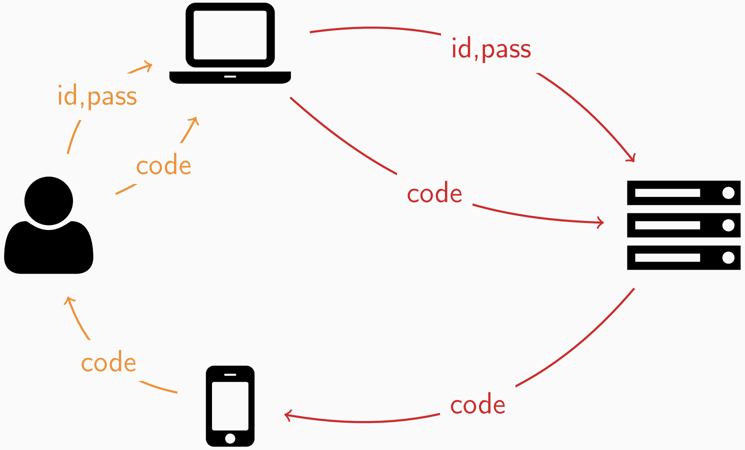
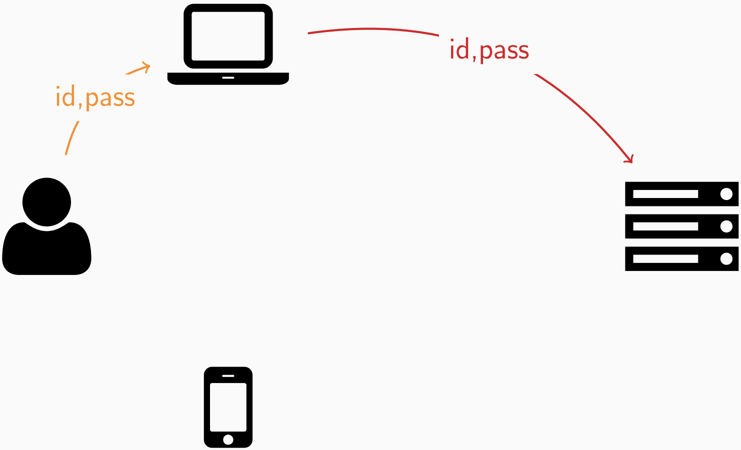
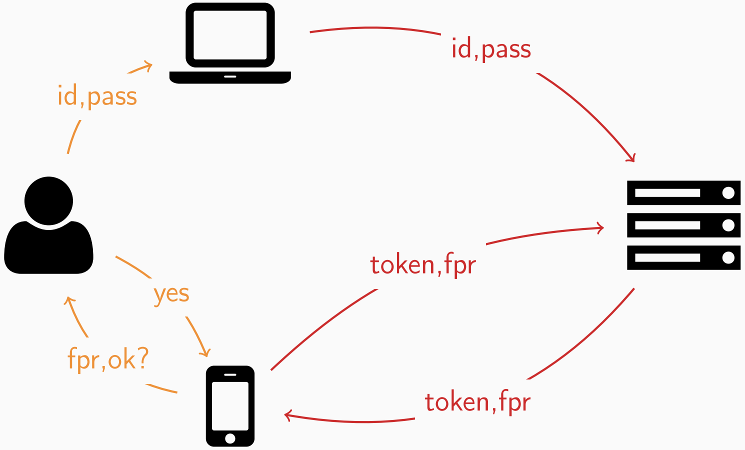


Google 2 Step - One Tap

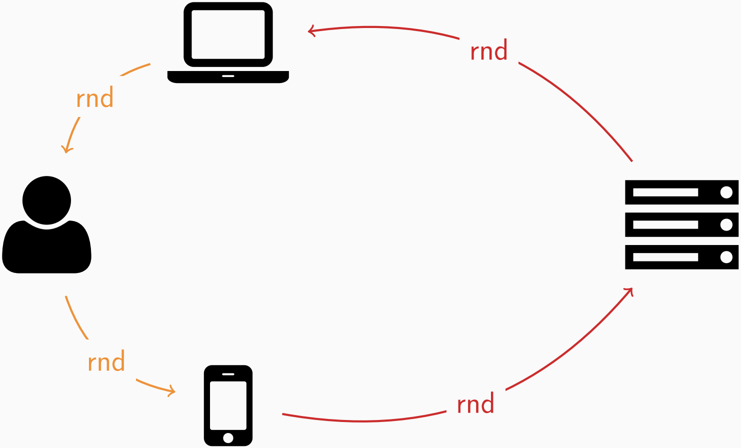


Google 2 Step - One Tap



fpr : IP,location, OS,...

Google 2 Step - Double Tap



FIDO

A token with cryptographic capabilities

- A public key is registered server side.
- On login, a challenge containing a random nonce, the origin and the TLS sid is signed.

I trust this computer

An option provided by major companies (Google, Facebook,...):

I trust this computer = disable second factor

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It must be taken into account in the analysis

Threat model

Goals

First hypothesis

The user password has been compromised

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Goal

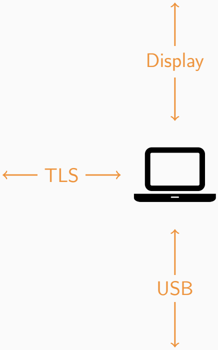
Consider many different scenarios :

- Malware on the computer
- Malware on the phone
- Human erros (Phishing, No Compare)
- Fingerprint Spoofing

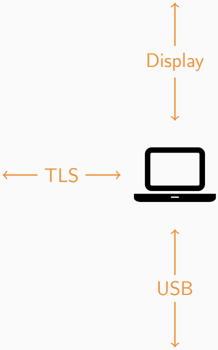
What guarantees from different protocols under different threats?

Modelling Malwares

Device = set of interfaces



Device = set of interfaces



Access levels

Read Only or Read Write

$$\begin{tikzcd}
 & \text{Out RW} \arrow[dl] \arrow[dr] & \\
\text{In RW} \arrow[dr] & & \text{Out RO} \arrow[dl] \\
 & \text{In RO} \arrow[d] & \\
 & \text{NA} &
\end{tikzcd}$$

Scenarios

Notations

- Malware : $\mathcal{M}^{\text{interf}}_{\text{in}:acc1,out:acc2}$
- Phising : PH
- Fingerprint Spoofing : FS
- No Compare : NC

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Examples

- Keylogger : $\mathcal{M}^{\text{usb}}_{\text{in}:\mathcal{RO}}$
- Wifi Hotspot : FS PH
- Broken TLS encryption : $\mathcal{M}^{\text{tls}}_{\text{io}:\mathcal{RW}}$

Modeling in Proverif

TLS modeling

- A set of identities : id_{server}, $id_{user's\ computer}$, ...
- A private function symbol tls

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TLS :=

Asynchronous communications over channel $tls(id_{client}, id_{server})$

If id_{client} or id_{server} is compromised, we give $tls(id_{client}, id_{server})$ to the attacker

Malwares

Read only access to some channel ch :

$$\mathbf{in}(ch, x).P \rightarrow \mathbf{in}(ch, x).\mathbf{out}(a, x).P$$

or

$$\mathbf{out}(ch, x).P \rightarrow \mathbf{out}(a, x).\mathbf{out}(ch, x).P$$

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or

$$\mathbf{out}(ch, x).P \to \mathbf{out}(a, x).\mathbf{out}(ch, x).P$$

Read write access to ch :

$$P \to \mathbf{out}(a, ch).P$$

Human errors

No compare

Remove some checks

Phishing

The server's url (id_{server}) is chosen by the attacker.
$\rightarrow$ The human may check or not that it is indeed the server he wishes to contact.

Fingerprint Spoofing

Fingerprint

A function symbol $fpr(id)$

$\rightarrow$ a server may obtain $fpr(id_{client})$ from $tls(id_{client}, id_{server})$

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Spoofing

$$\mathtt{fpr}(\mathtt{spoof}_{\mathtt{fpr}}(\mathtt{fpr}(c))) = \mathtt{fpr}(c)$$

Analysis

Properties

Three types of login

- *untrusted login* login on an untrusted computer
- *trusted login* login on a trusted computer; sets "trust this computer" option
- *cookie login* login after "trust this computer" option enabled

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Three properties

$$accept_x(id) \Longrightarrow_{\text{inj}} request_x(id) \qquad x \in \{u, t, c\}$$

Every accepted login was preceded by a distinct login request by the human.

One file = one protocol with all scenarios

```
let Device =
    in(d_in,(token));
      #if defined(D_I_RO) && !defined(D_I_RW)
      out(a,(token));
      #endif
    out(d_out,(token))
    |
        (
          ...
```

Methodology

A bash script

- takes a combination of attacker capabilities as input
- generates the proverif file

A python script

- runs proverif for all pertinent combinations of scenarios
- generate the result table

Analysis of Google 2 step protocols

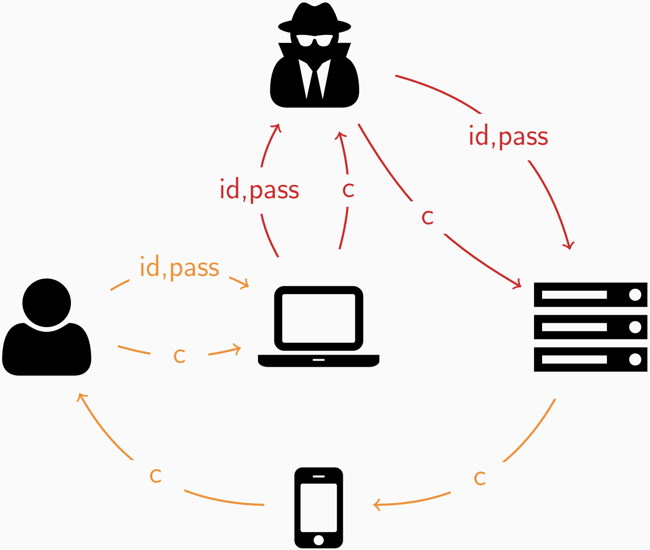
Threat Scenarios	g2V	g2OT	g2OT$^{\mathsf{fpr}}$
	✔	✖	✔
PH	✖	✖	✔
NC	✔	✖	✖
FS	✔	✖	✖
PH NC	✖	✖	✖
PH FS	✖	✖	✖
$\mathcal{M}^{\mathsf{dev}}_{\mathsf{in}:\mathcal{RO}}$	✖	✖	✔
$\mathcal{M}^{\mathsf{t-dis}}_{\mathsf{io}:\mathcal{RO}}$	✔	✖	✔
$\mathcal{M}^{\mathsf{t-tls}}_{\mathsf{io}:\mathcal{RO}}$	✖	✖	✔
$\mathcal{M}^{\mathsf{t-usb}}_{\mathsf{in}:\mathcal{RO}}$	✖	✖	✔
$\mathcal{M}^{\mathsf{dev}}_{\mathsf{in}:\mathcal{RW}}$	✖	✖	✖
$\mathcal{M}^{\mathsf{t-tls}}_{\mathsf{io}:\mathcal{RW}}$	✖	✖	✗✓✗
$\mathcal{M}^{\mathsf{t-usb}}_{\mathsf{in}:\mathcal{RW}}$	✖	✖	✓✓✗

...

Analysis of Google 2 step - Verification code

- It is secure if the attacker only knows the password
- in any other cases...

Attack under Keylogger or Phishing or Malware



Analysis of Google 2 step - One Tap

- Without fingerprint, never secure : one can easily validate an attacker session

Adding the display

Recommendation:

Display (via SMS or on the smartphone screen) additional info:

- fingerprint (IP,locations, computer model).
- the type of login desired.

Benefits:

- avoids attacks changing the login type (e.g. replacing an untrusted, by trusted login)
- avoids attacks where attacker is able to spoof a fingerprint

Adding the display

Threat Scenarios				$g2V^{fpr}$	$g2V^{dis}$	$g2OT^{dis}$	$g2DT^{dis}$
PH				✔	✔	✔	✔
PH	FS			✖	✗✓✓	✖	✗✓✓
PH	FS	$\mathcal{M}^{\mathbf{t-tls}}_{\mathbf{io}:\mathcal{RO}}$		✖	✖	✖	✗✓✗
PH	FS	$\mathcal{M}^{\mathbf{t-usb}}_{\mathbf{in}:\mathcal{RO}}$		✖	✖	✖	✗✓✓
PH	FS	$\mathcal{M}^{\mathbf{t-dis}}_{\mathbf{io}:\mathcal{RW}}$		✖	✗✓✓	✖	✖
		$\mathcal{M}^{\mathbf{t-tls}}_{\mathbf{io}:\mathcal{RO}}$		✔	✔	✓✓✓	✔
		$\mathcal{M}^{\mathbf{t-usb}}_{\mathbf{in}:\mathcal{RO}}$		✔	✔	✓✓✓	✔
		$\mathcal{M}^{\mathbf{t-tls}}_{\mathbf{io}:\mathcal{RW}}$		✗✓✗	✓✓✗	✓✓✗	✓✓✗
		$\mathcal{M}^{\mathbf{t-usb}}_{\mathbf{in}:\mathcal{RW}}$		✓✓✗	✓✓✗	✓✓✗	✓✓✗
		$\mathcal{M}^{\mathbf{t-usb}}_{\mathbf{in}:\mathcal{RW}}$	$\mathcal{M}^{\mathbf{t-tls}}_{\mathbf{io}:\mathcal{RO}}$	✓✓✗	✓✓✗	✓✓✗	✓✓✗
	FS	$\mathcal{M}^{\mathbf{t-tls}}_{\mathbf{io}:\mathcal{RO}}$		✖	✓✗✗	✖	✓✓✗
	FS	$\mathcal{M}^{\mathbf{t-usb}}_{\mathbf{in}:\mathcal{RO}}$		✖	✓✗✗	✖	✔
	FS	$\mathcal{M}^{\mathbf{t-dis}}_{\mathbf{io}:\mathcal{RW}}$		✔	✔	✖	✓✗✗
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	FS	$\mathcal{M}^{\mathbf{t-usb}}_{\mathbf{in}:\mathcal{RW}}$	$\mathcal{M}^{\mathbf{t-tls}}_{\mathbf{io}:\mathcal{RO}}$	✖	✓✗✗	✖	✓✗✗
		$\mathcal{M}^{\mathbf{u-tls}}_{\mathbf{io}:\mathcal{RO}}$		✔	✔	✓✓✓	✔
		$\mathcal{M}^{\mathbf{u-usb}}_{\mathbf{in}:\mathcal{RO}}$		✔	✔	✓✓✓	✔
		$\mathcal{M}^{\mathbf{u-tls}}_{\mathbf{io}:\mathcal{RW}}$		✓✗✗	✔	✓✓✓	✓✓✓

...

U2F vs g2DT^{dis}

Pros of U2F

- a possibility of privacy
- strong protection against phishing

Cons of U2F

- no feedback
- not independent from the computer

Conclusions

- Detailed threat model for multi-factor authentication protocols
- Analysis of the full system
- Complete automation using PROVERIF and scripts
- Simple, small modifications (adding info to display) that enhance security