On the Security and Privacy of Modern Single Sign-On in the Web

(Not Only) Attacks on OAuth and OpenID Connect

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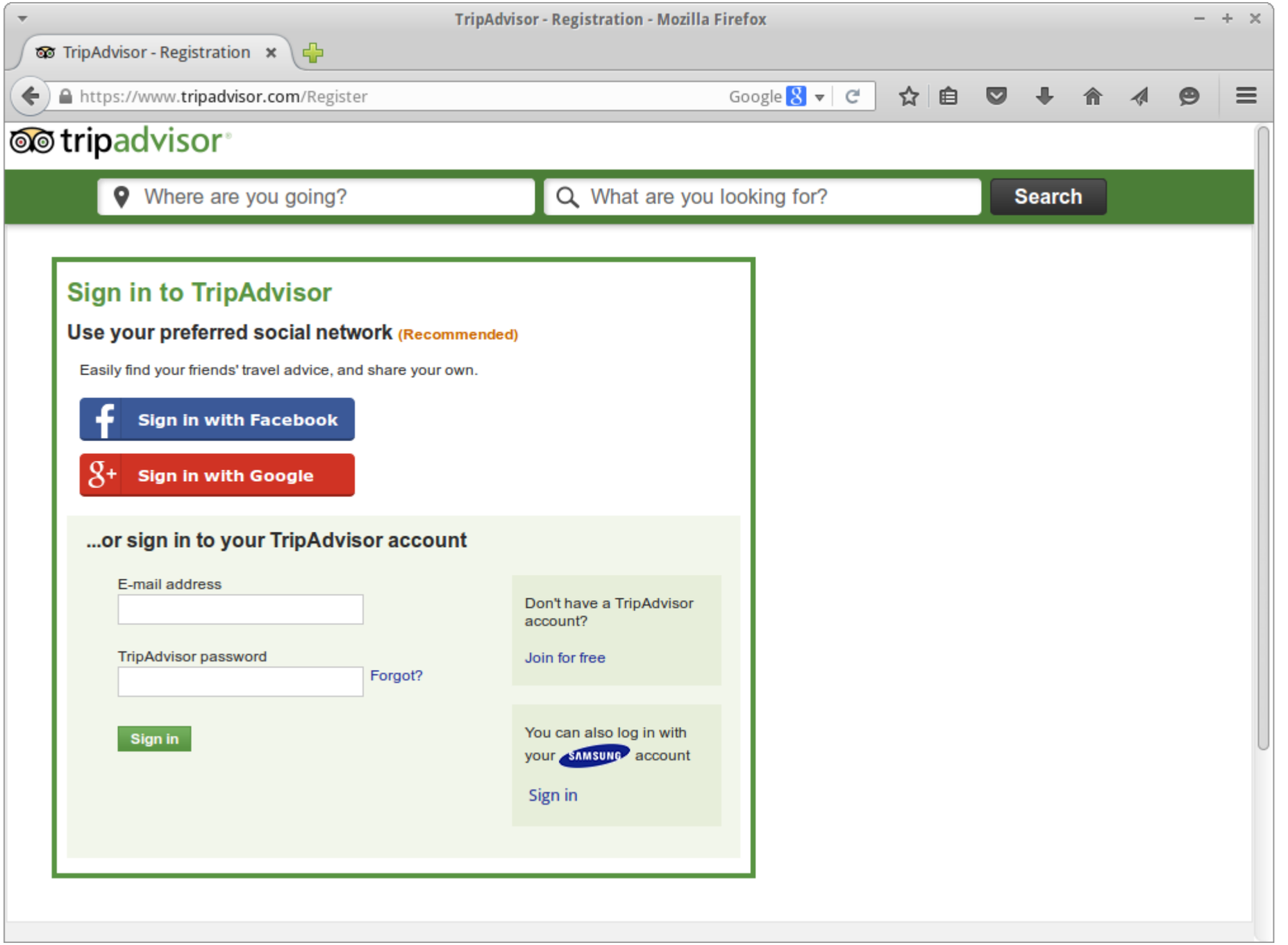
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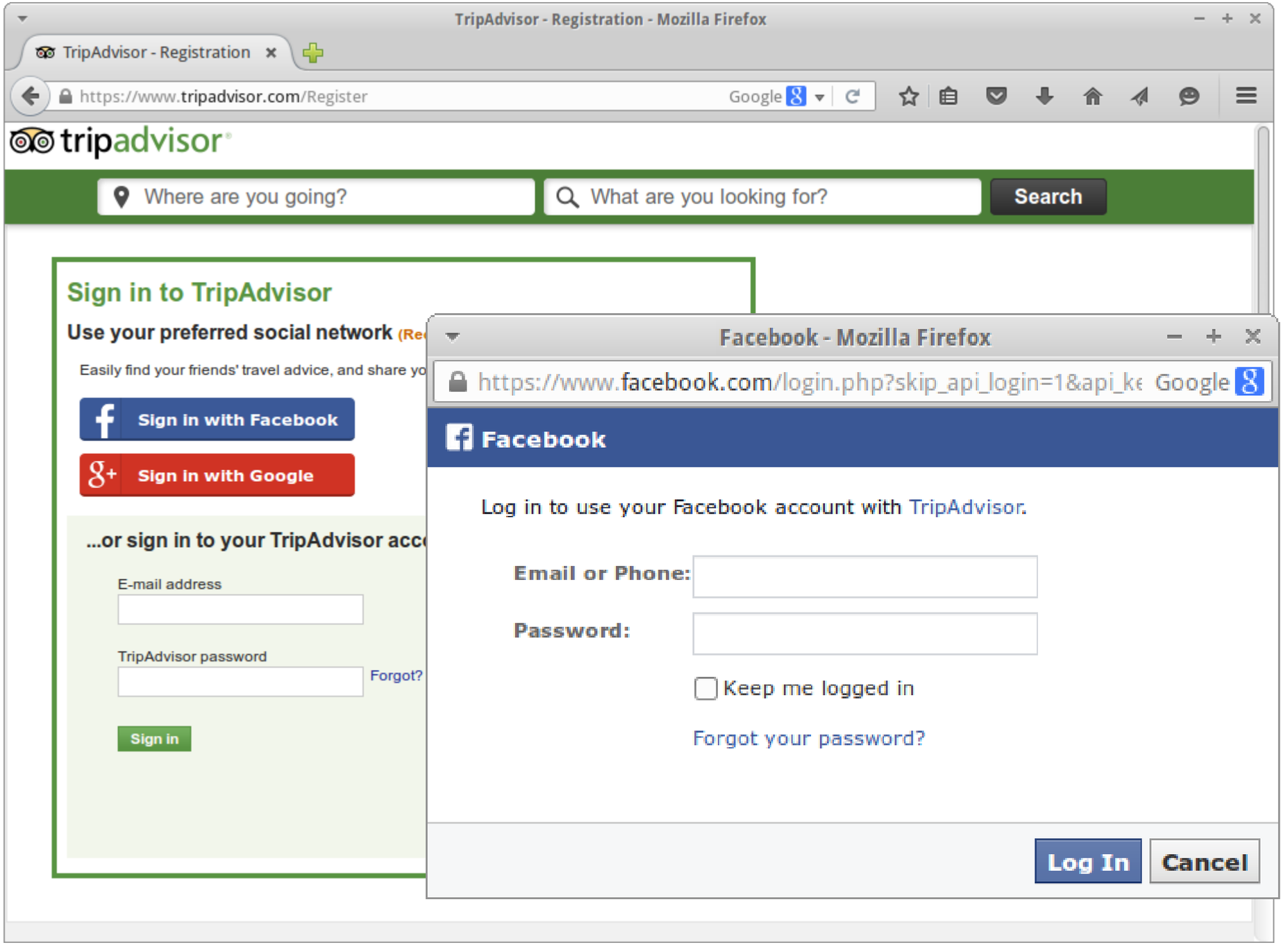
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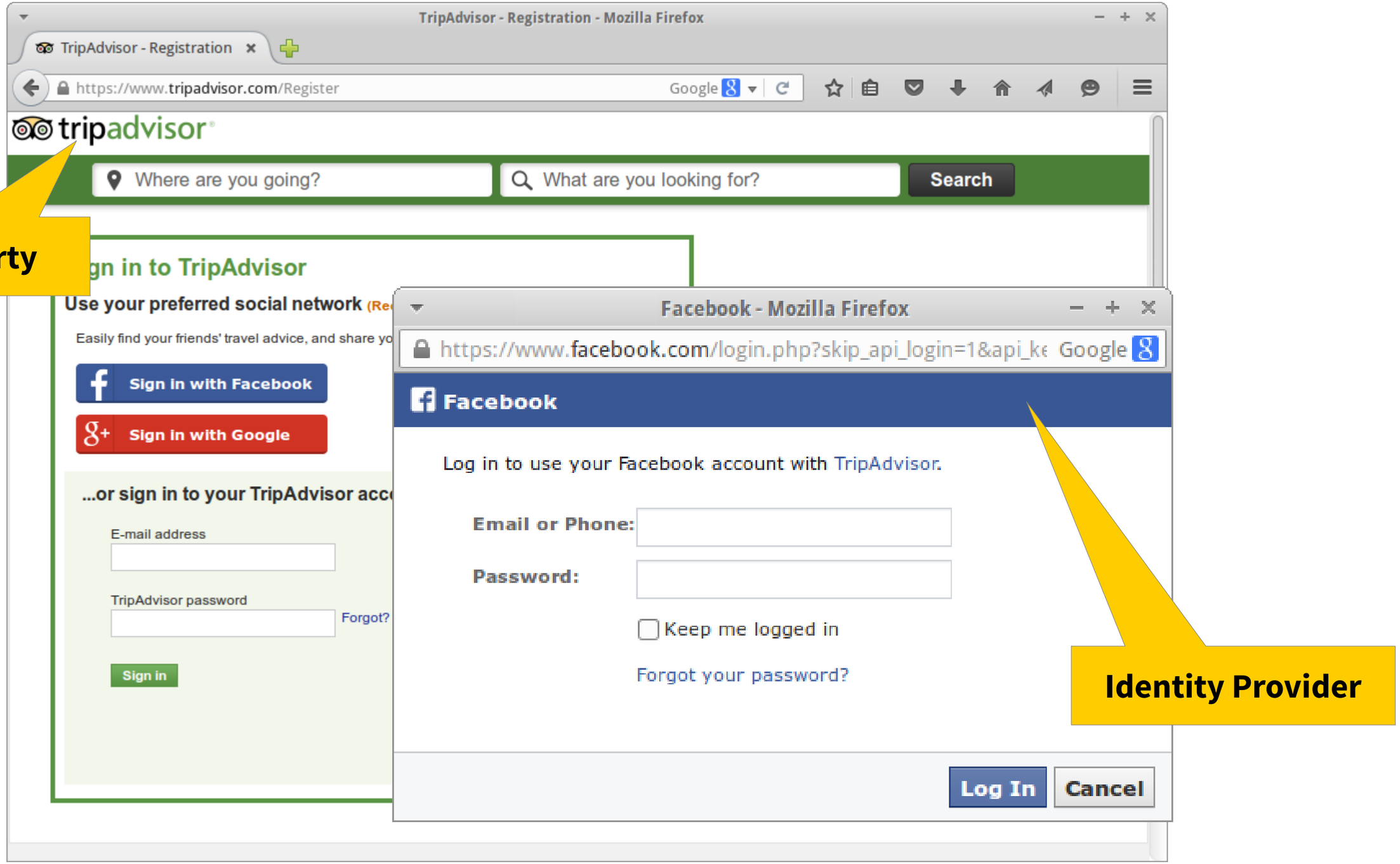
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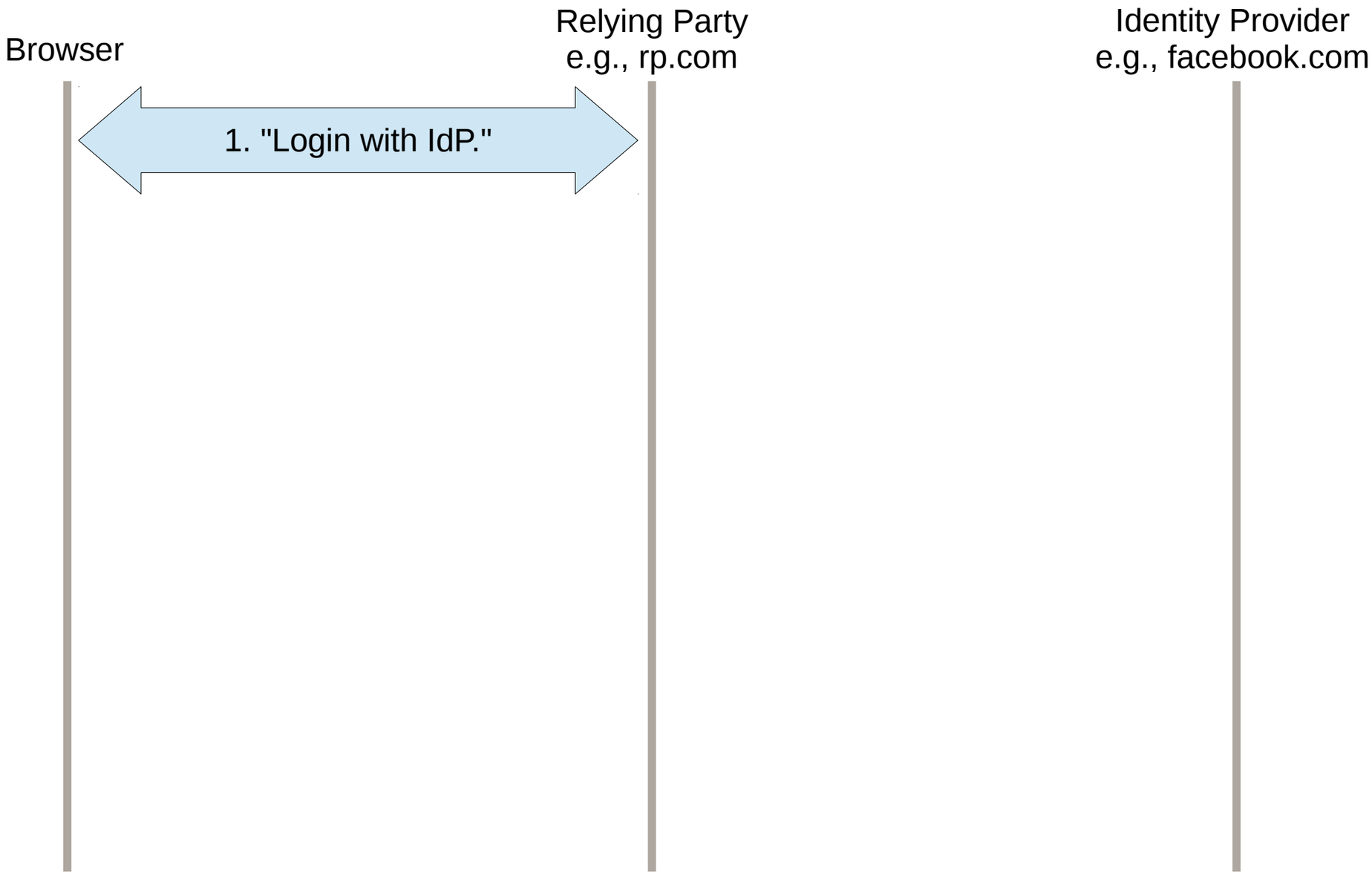
Forgot your password?
Log In
Cancel
Identity Provider

Web SSO: Basic Principle



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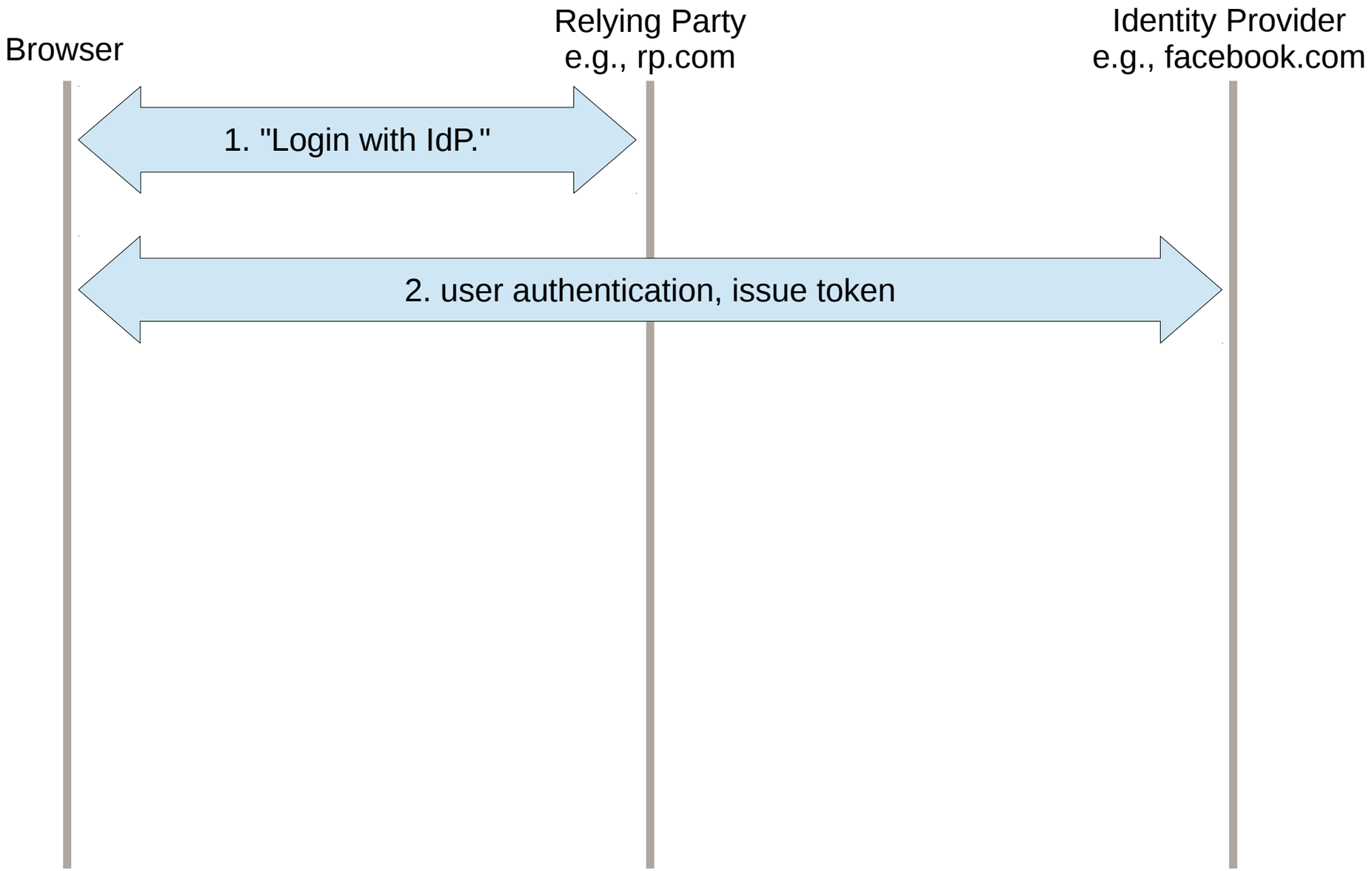

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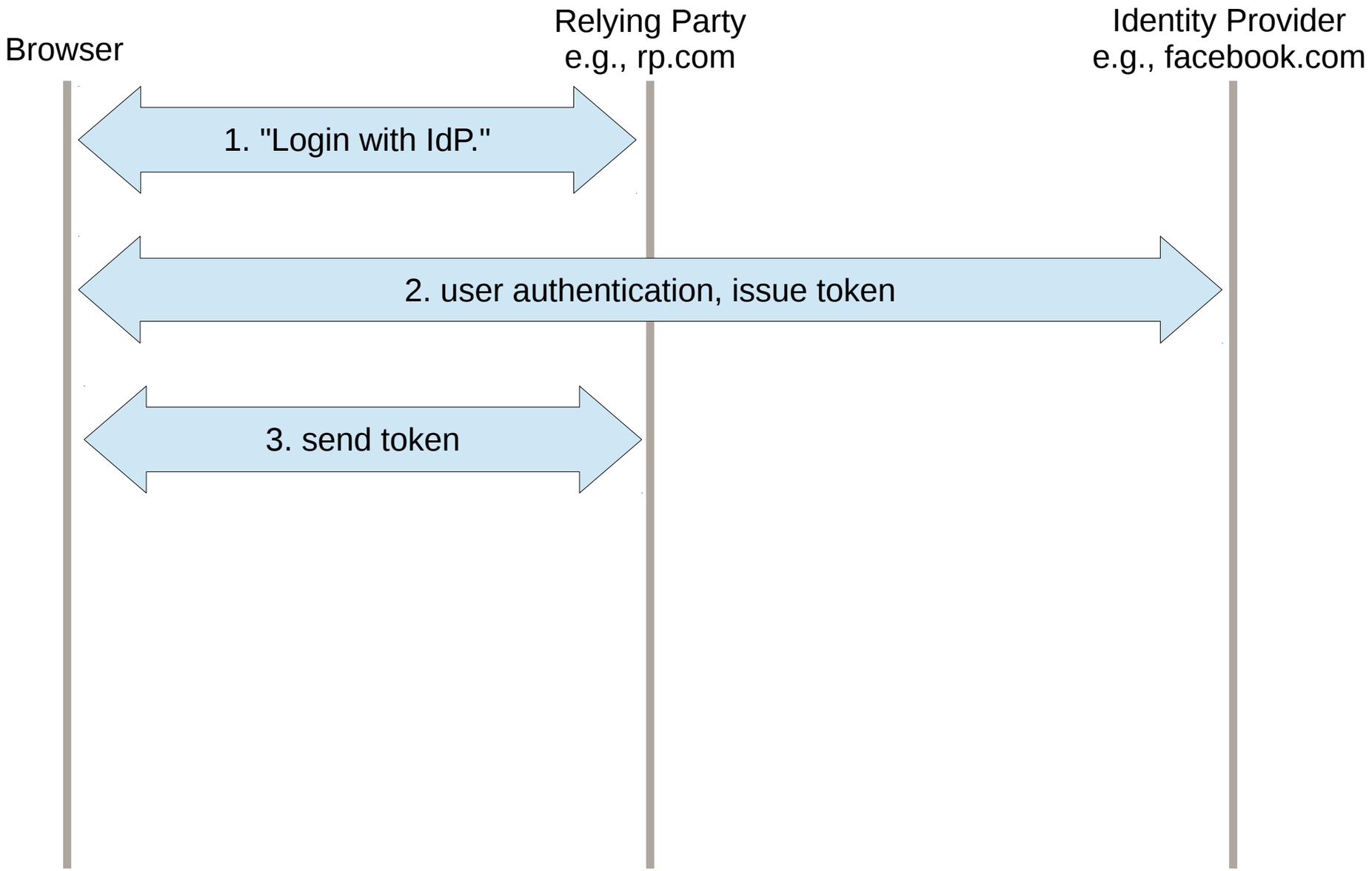

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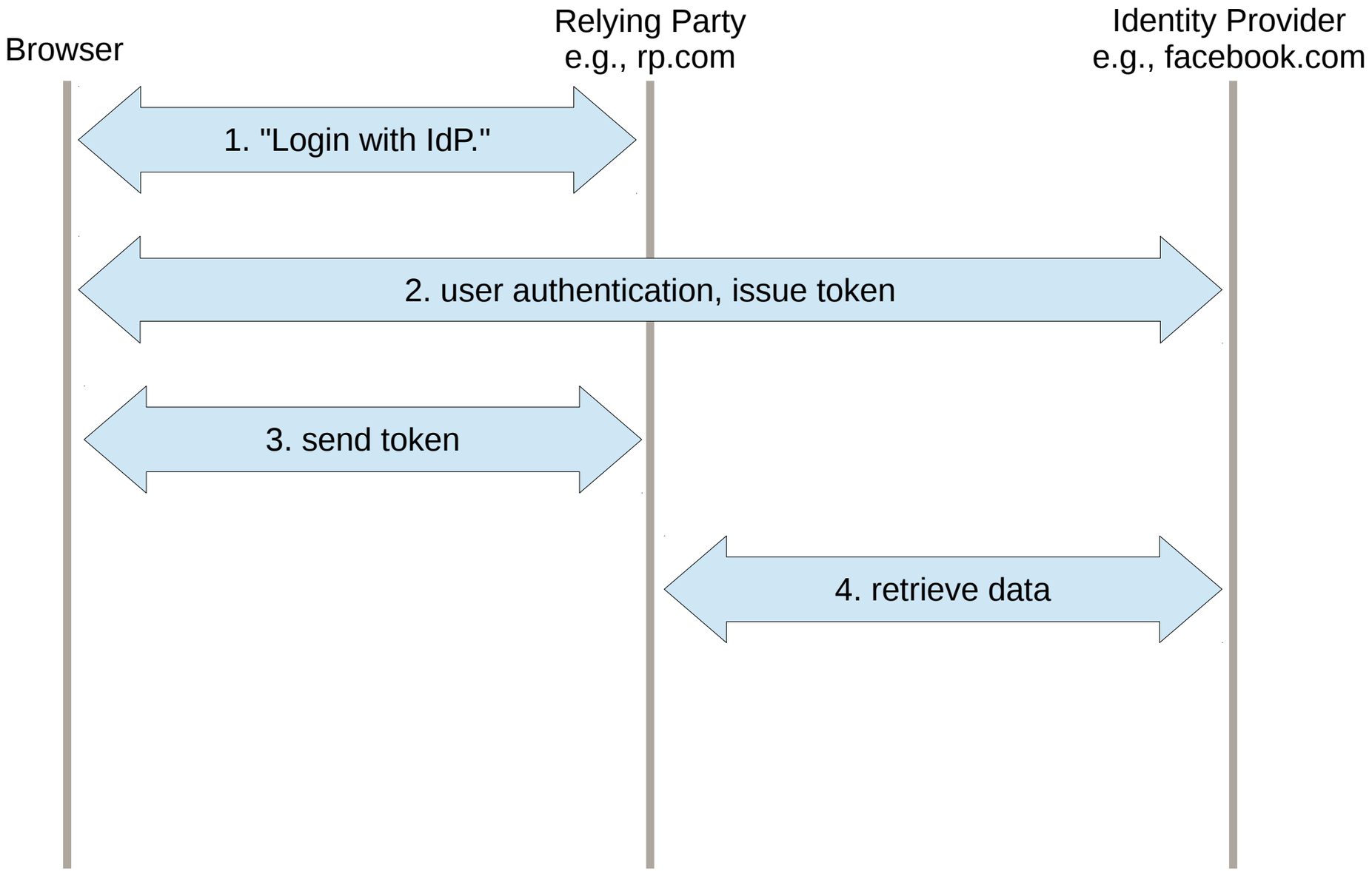

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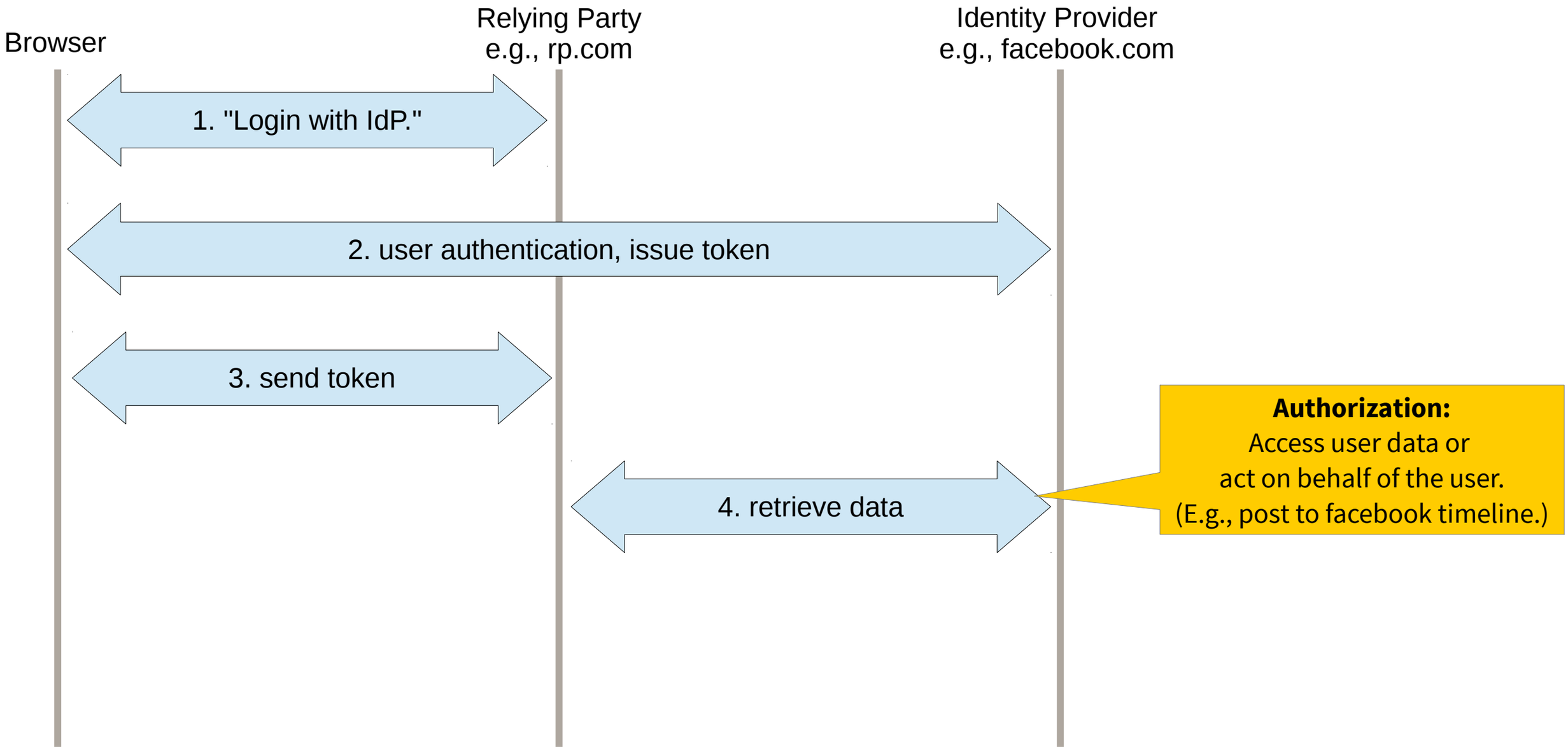

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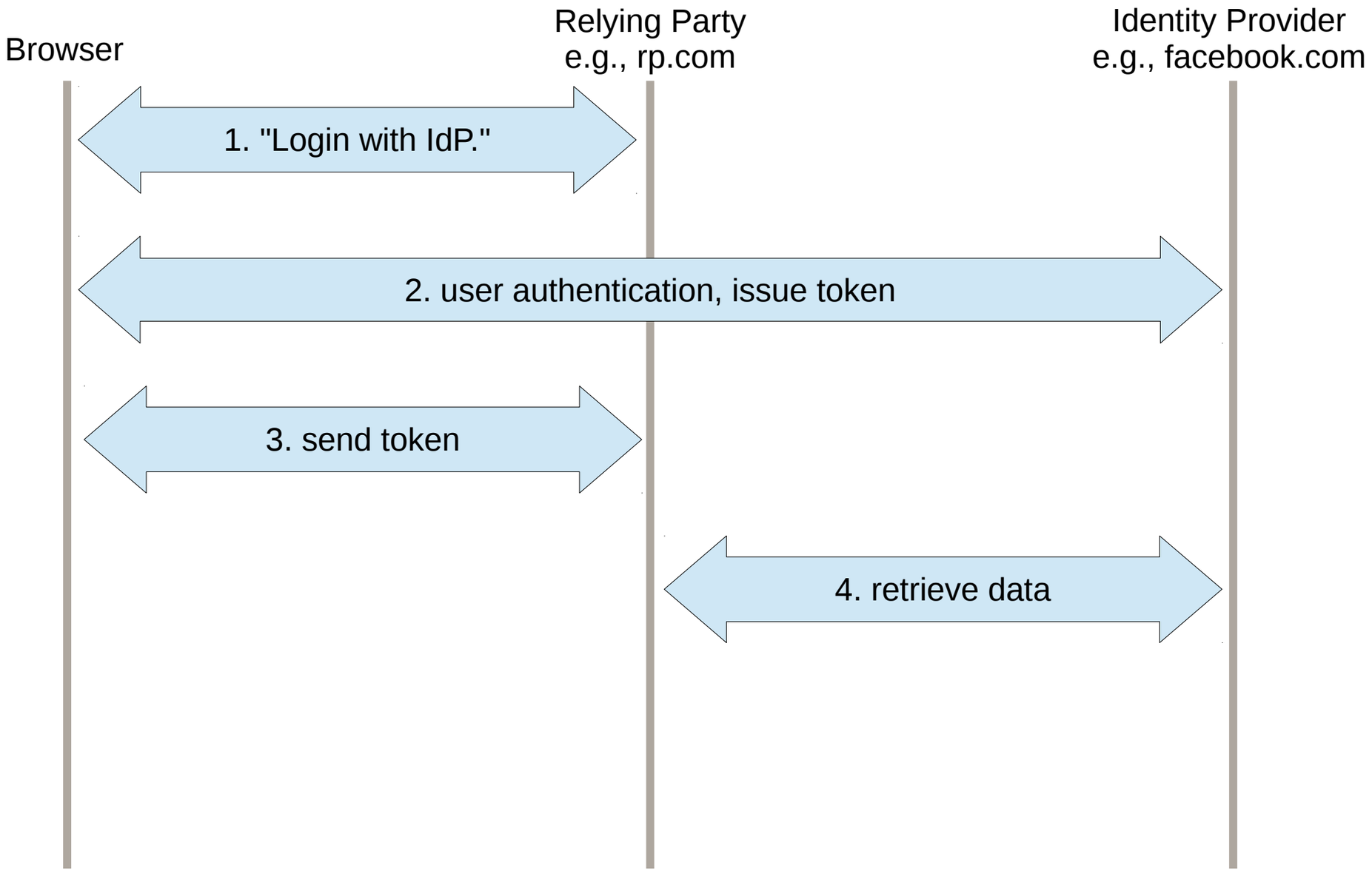

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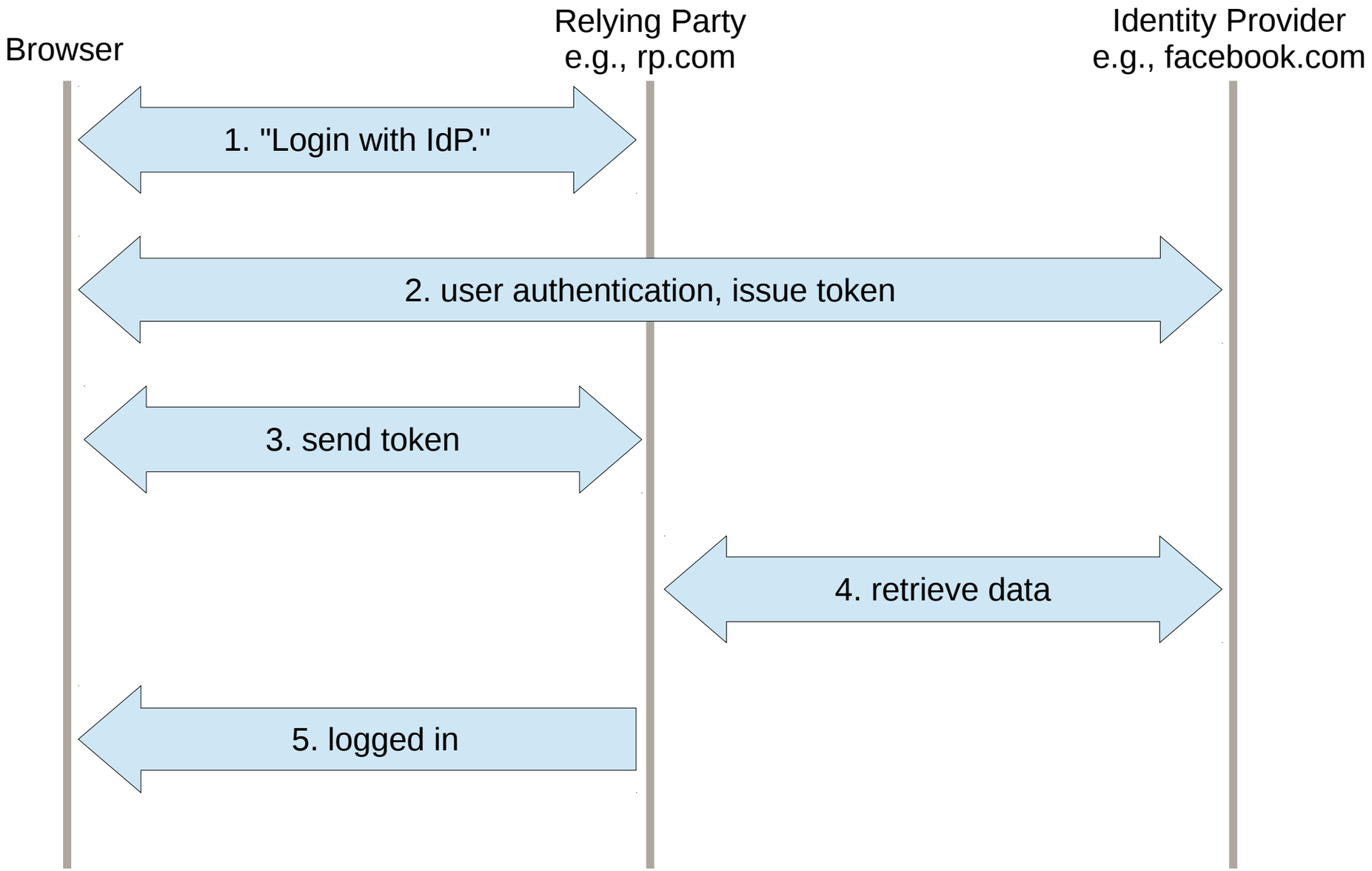

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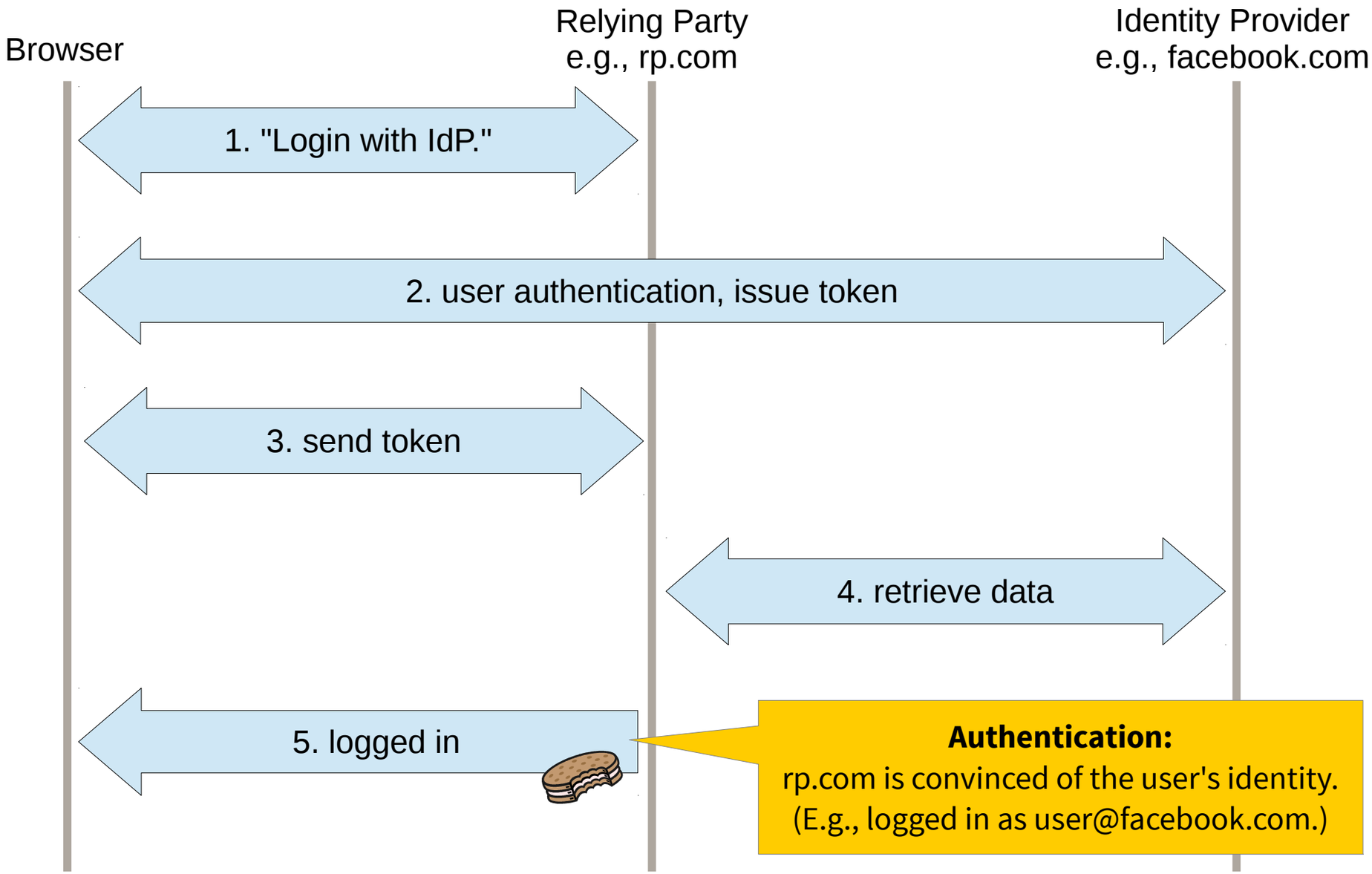

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For users

+ ease-of-use
+ harder to forget passwords

- lack of privacy
- IdP account is single point of failure

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For Identity Providers

+ more user data (for advertising, etc.)
+ service for users
- more user data
- implementation overhead

Not-so-Modern SSO Systems

OAuth 1.0

- Old! (2006)
- Many flaws
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- **Do not use!**

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OpenID

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- Not user-friendly
- Super-flexible (read: not developer-friendly)
- **Do not use!**

Modern Single-Sign On Systems

OAuth 2.0

- Modern (2011) authorization protocol
- **Completely incompatible to OAuth < 2.0**
- Bearer token approach, no crypto (except transport layer)
- Used everywhere (almost!)
- Not for authentication. *Repeat: Not for authentication!*

Quelle: Internet

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OpenID Connect

- Very modern (2014)!
- Authentication layer **on top of OAuth**
- **Completely incompatible to OpenID**
- IdP Discovery and dynamic RP Registration

Web SSO: The Chart of Confusion

Authorization

OAuth 1.0

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marketing predecessor of

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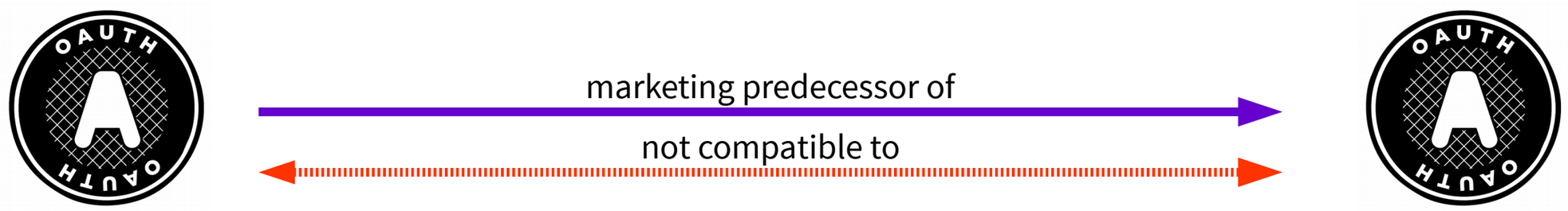

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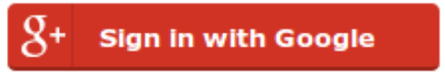

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OpenID Connect

Modern Single-Sign On Systems

Mozilla Persona
aka. BrowserID

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- **Privacy goal:** IdPs do not learn where you log in (see later)
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- Target: Integrate into browsers

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  ... which never happened.
- New target: Pure web implementation using HTML5 & stuff
  ... with "bridges" to OpenID and OAuth
- **Failed, but interesting approach!**

What else?

- SAML
- Shibboleth
- WebAuth
- CAS
- …

So what is this all about?

Our Goal

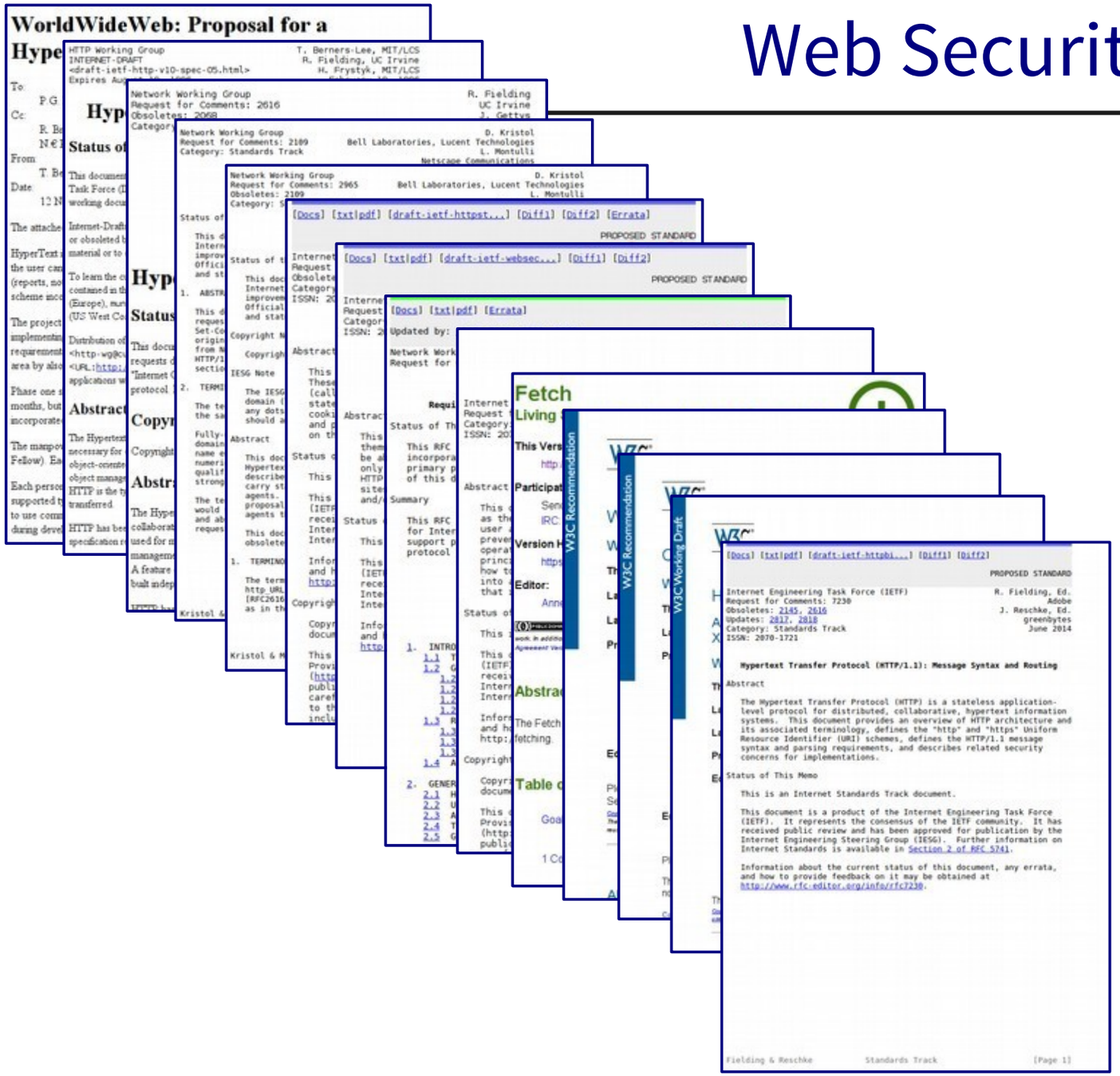
We analyze whether web mechanisms
(here: Web SSO protocols)
are secure
when implemented correctly
(i.e., following the standards and all best practices).

Our Goal

In other words:

Are the standards and protocols secure?

Web Security: State of the Art



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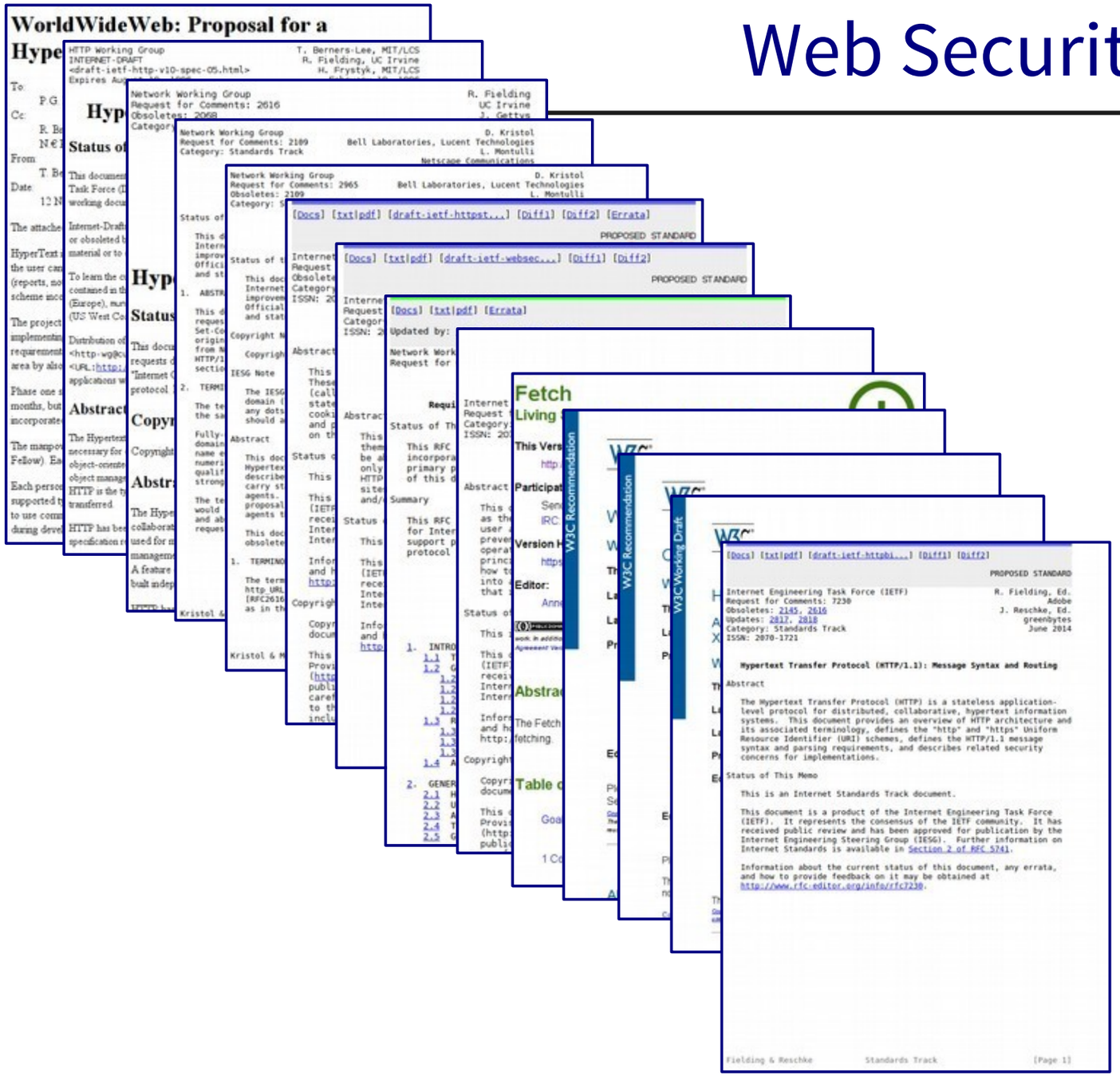

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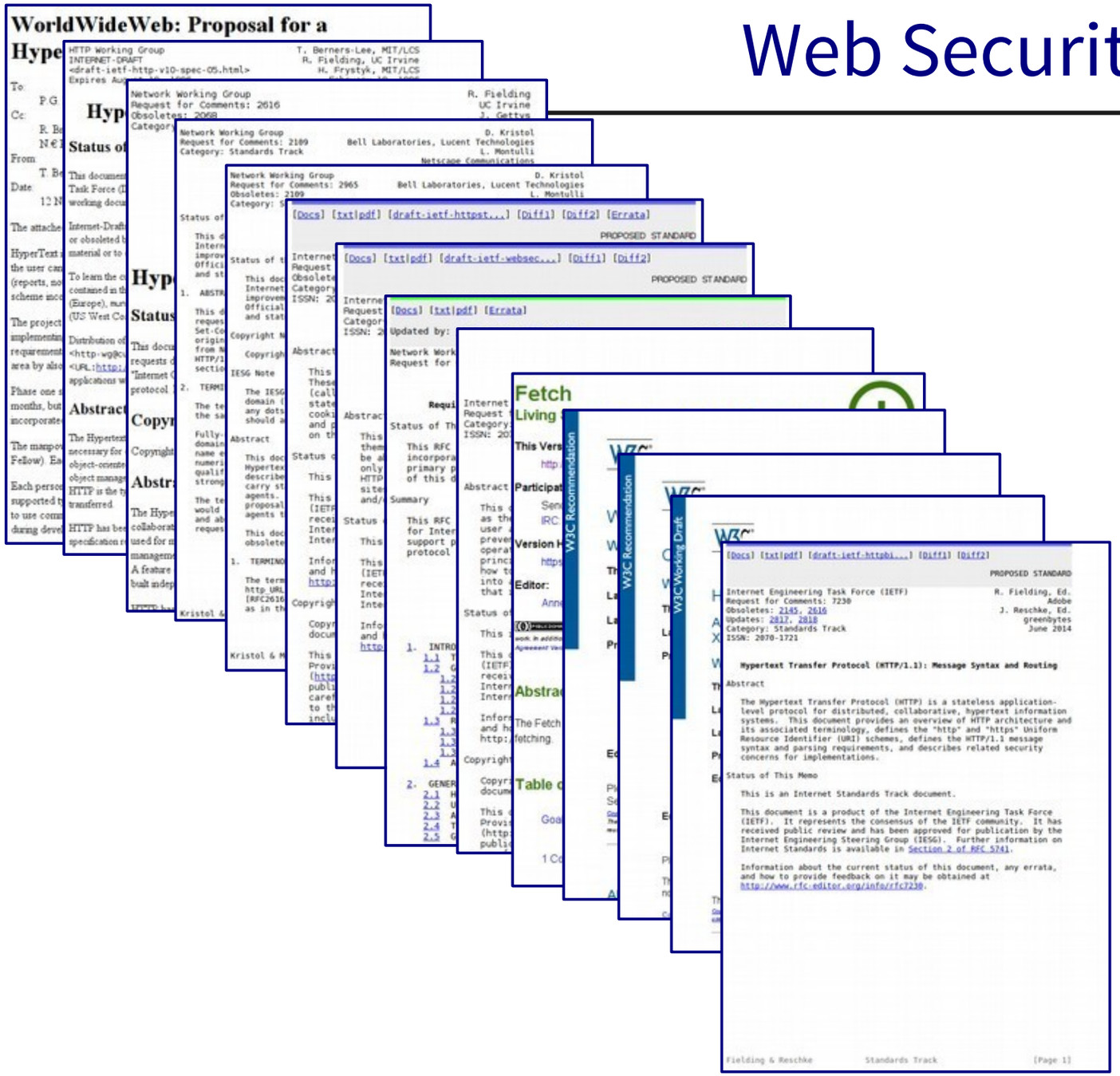

Looks fine
to me!

Our Approach: Formal Analysis

(part of our PhD research)

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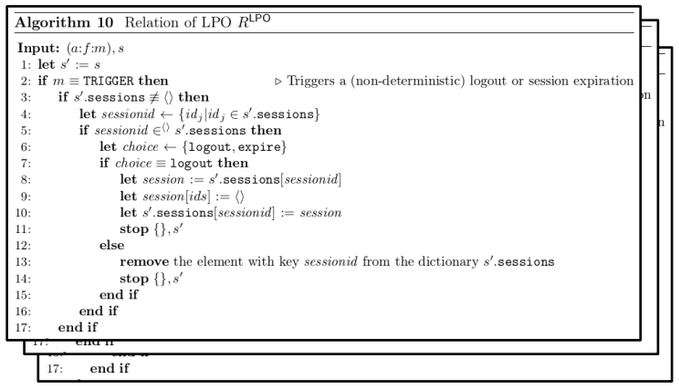
1. Create a Model of the Web Infrastructure and Web Applications



Algorithm 10 Relation of LPO R^{LPO}

Input: $(a{:}f{:}m), s$

1: **let** $s' := s$
2: **if** $m \equiv$ `TRIGGER` **then** ▷ Triggers a (non-deterministic) logout or session expiration
3: **if** $s'.\mathtt{sessions} \not\equiv \langle\rangle$ **then**
4: **let** *sessionid* $\leftarrow \{id_j | id_j \in s'.\mathtt{sessions}\}$
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6: **let** *choice* $\leftarrow$ {`logout`, `expire`}
7: **if** *choice* $\equiv$ `logout` **then**
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10: **let** $s'.\mathtt{sessions}[sessionid] :=$ *session*
11: **stop** $\{\}, s'$
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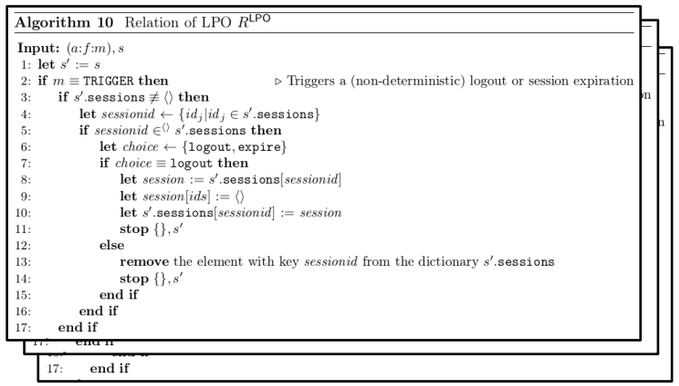

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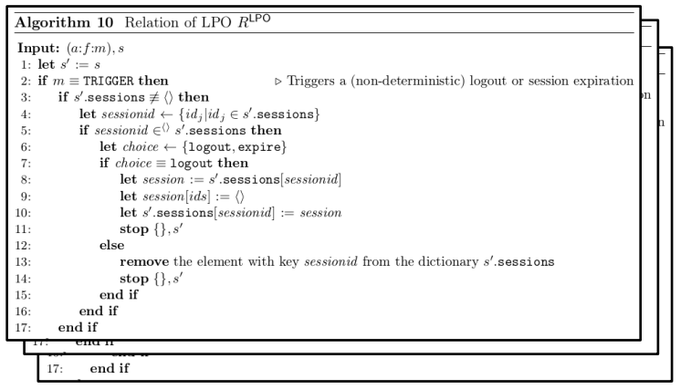

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(Models are incomplete by nature, but useful, see TLS 1.3)

2. ???

3. Proofs of Security!

$$A \Rightarrow \neg B$$

None of our business ...

- Phishing
- Clickjacking
- Stupid Users (cf. phishing)
- Compromised Browsers/OSs
- Compromised Databases, etc.

What is security? What is privacy?

Authentication Properties

(A) An attacker (having full control over the network) should not be able to use a service of a relying party as an honest user.

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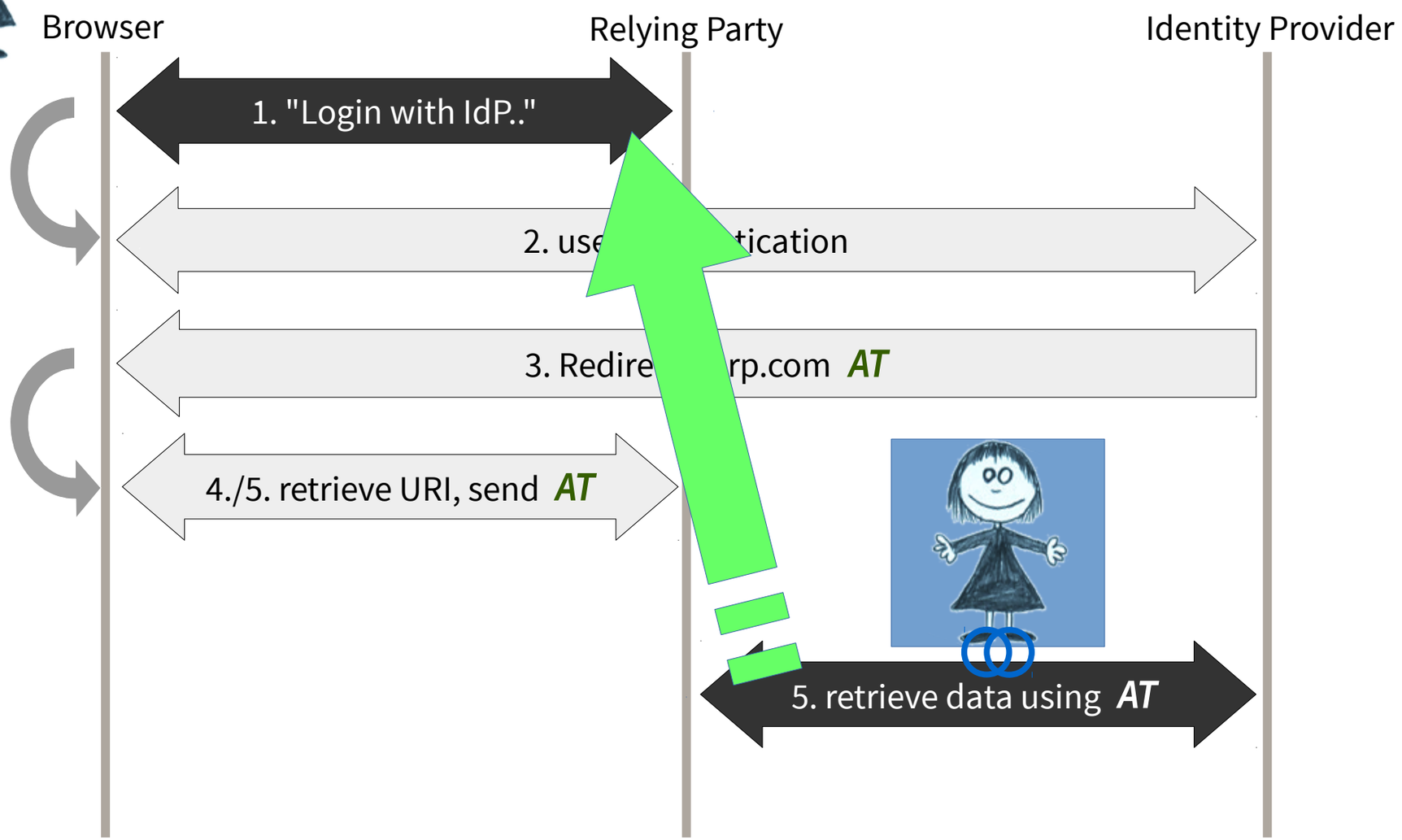
(A) An attacker (having full control over the network) should not be able to use a service of a relying party as an honest user.

(B) An attacker should not be able to authenticate an honest browser to a relying party as the attacker.

e.g., session fixation/swapping

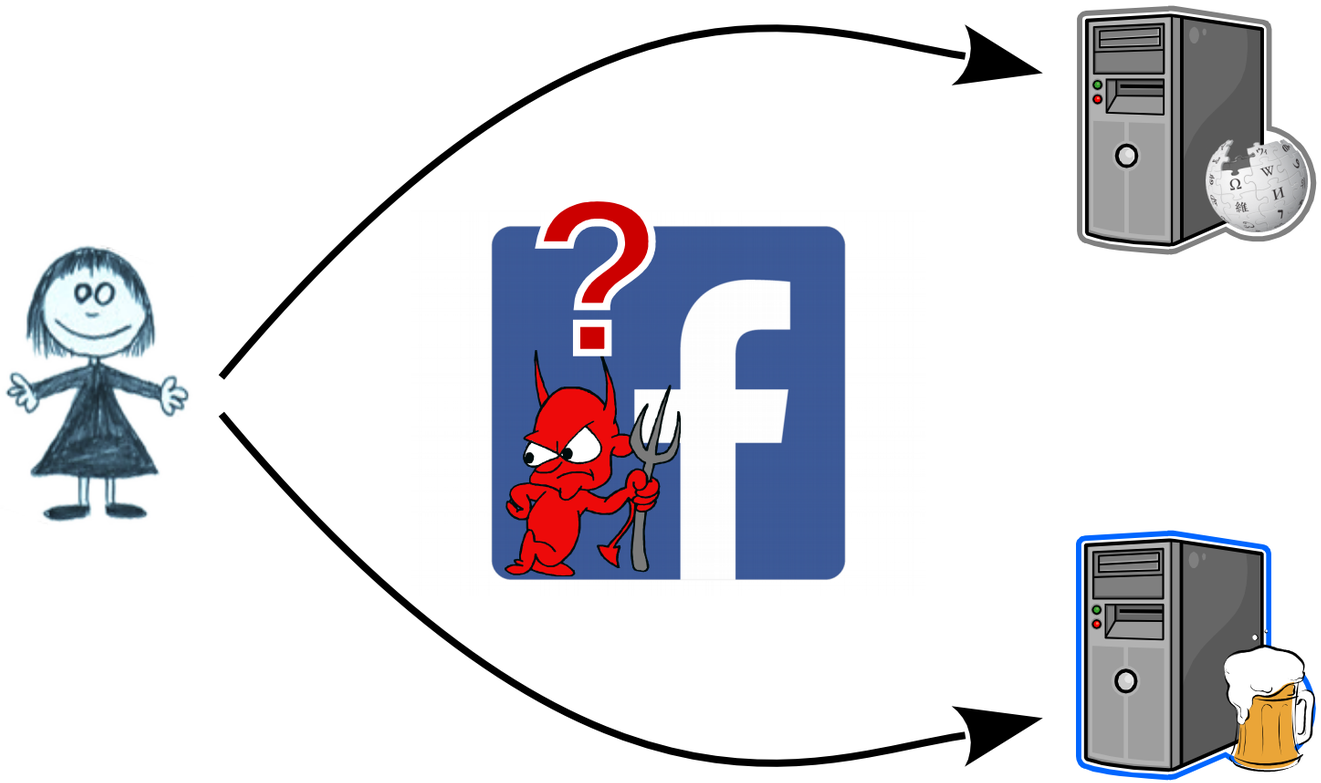
Session Integrity



Privacy

Privacy in Web SSO (IdP Privacy):

A malicious identity provider should not be able to distinguish whether Alice logs in at relying party A or B.



There are also other notions of Privacy for SSO!

Ok, let's start with OAuth (2.0!) ....

OAuth 2.0: RFC 6749 (and others)

Four modes of Interaction:

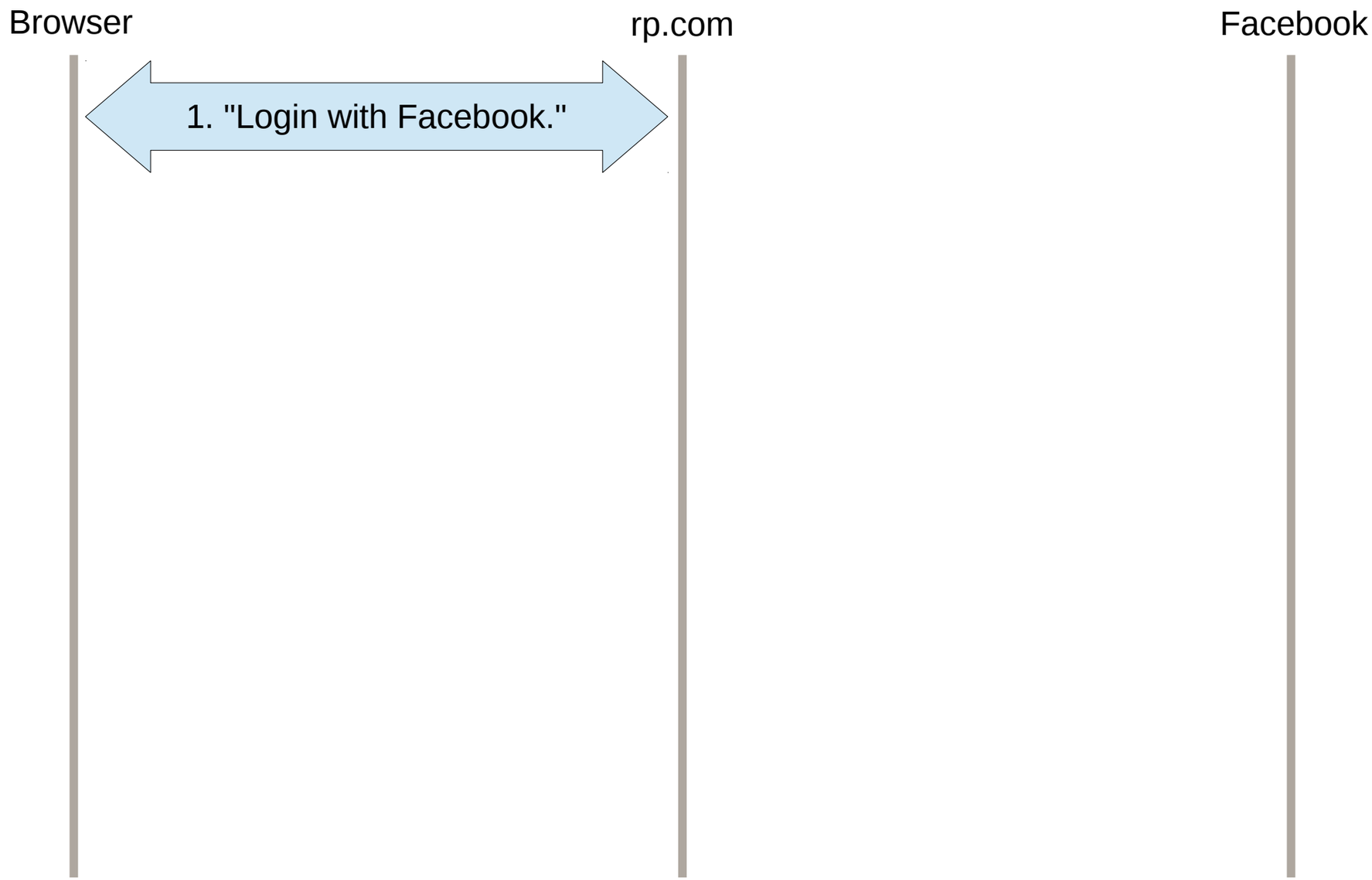
- **Implicit Mode**
- **Authorization Code Mode**

} most common

- Resource Owner Password Credentials Mode
- Client Credentials Mode

... and many other options.

Implicit Mode



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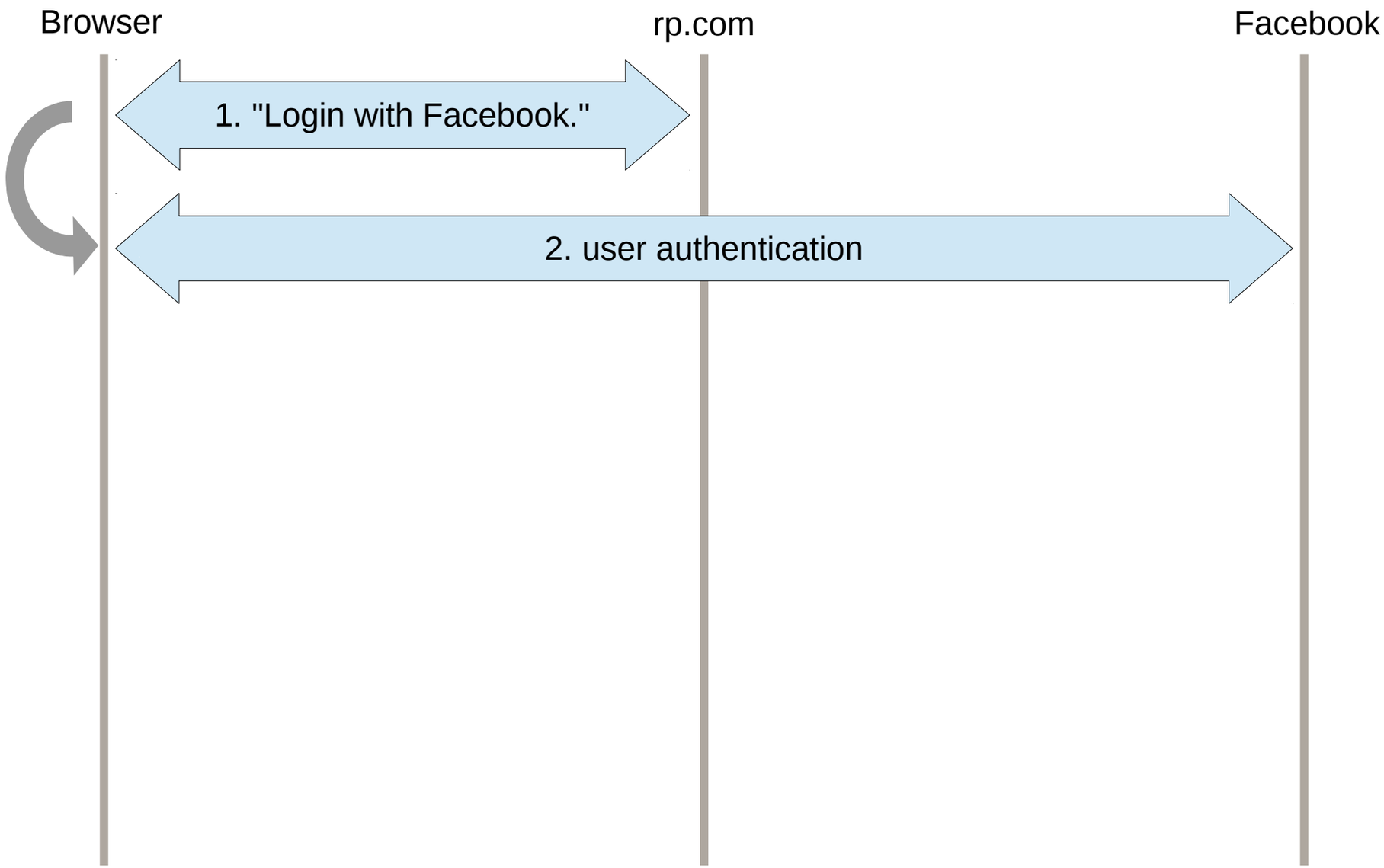

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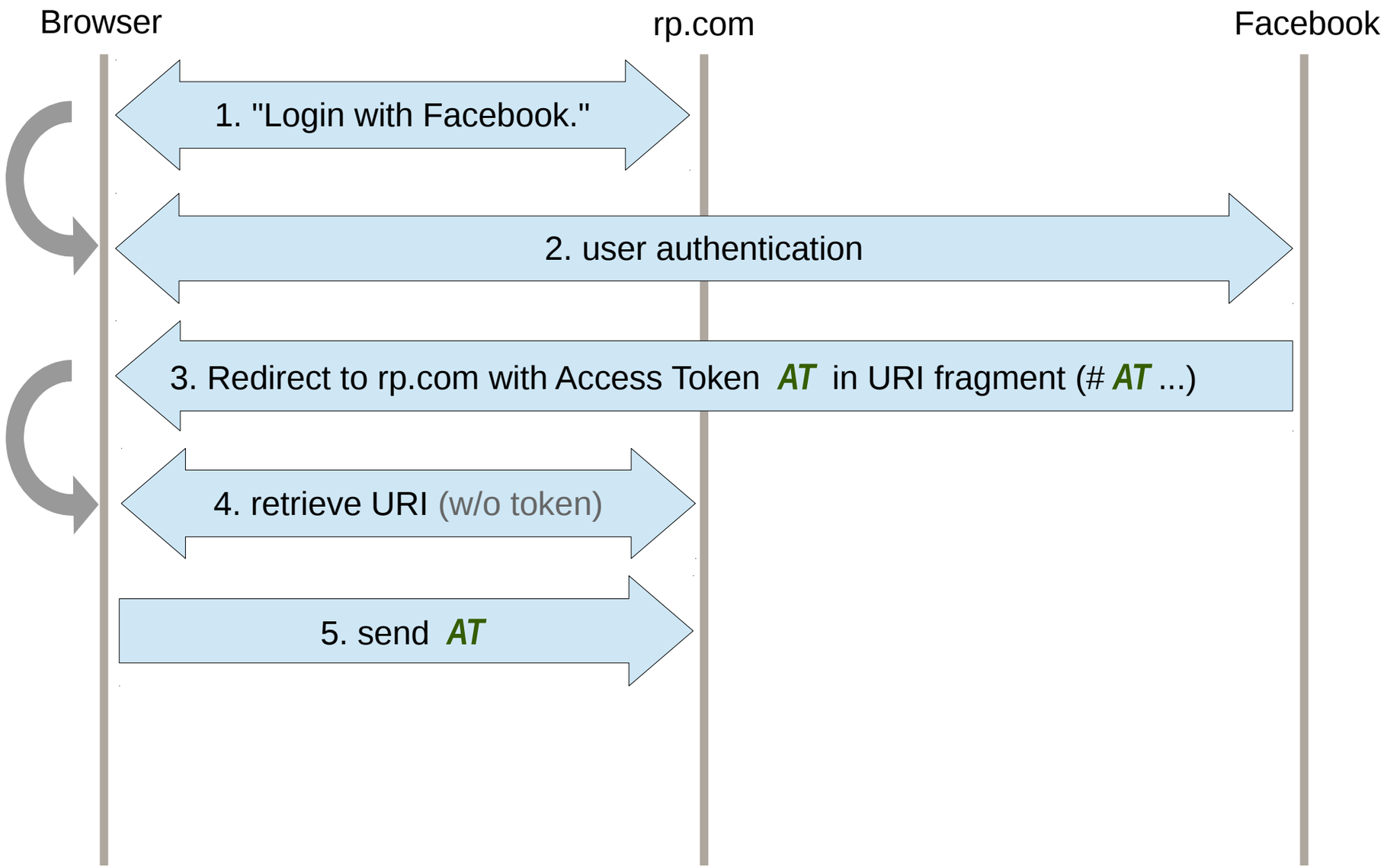

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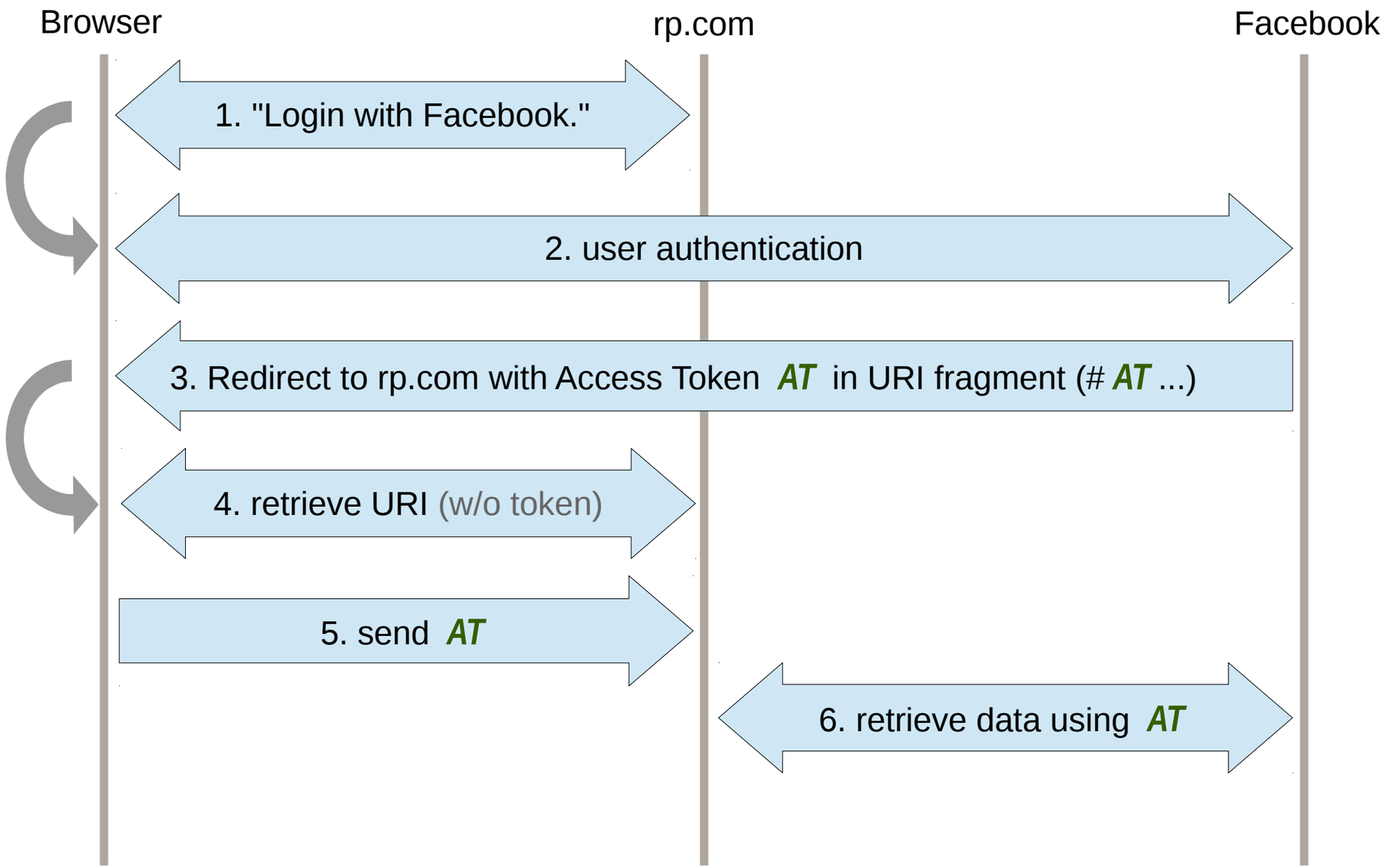

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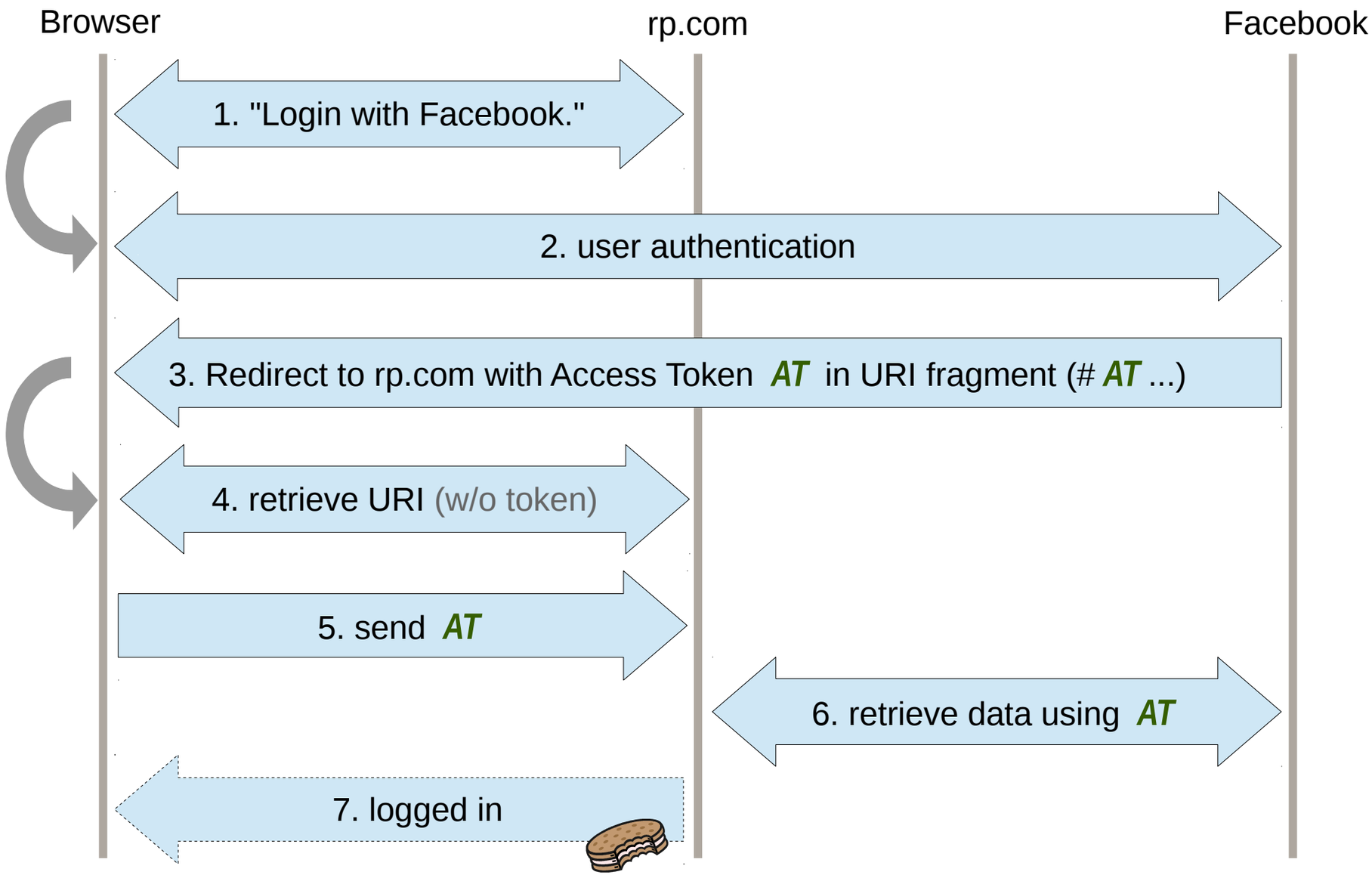

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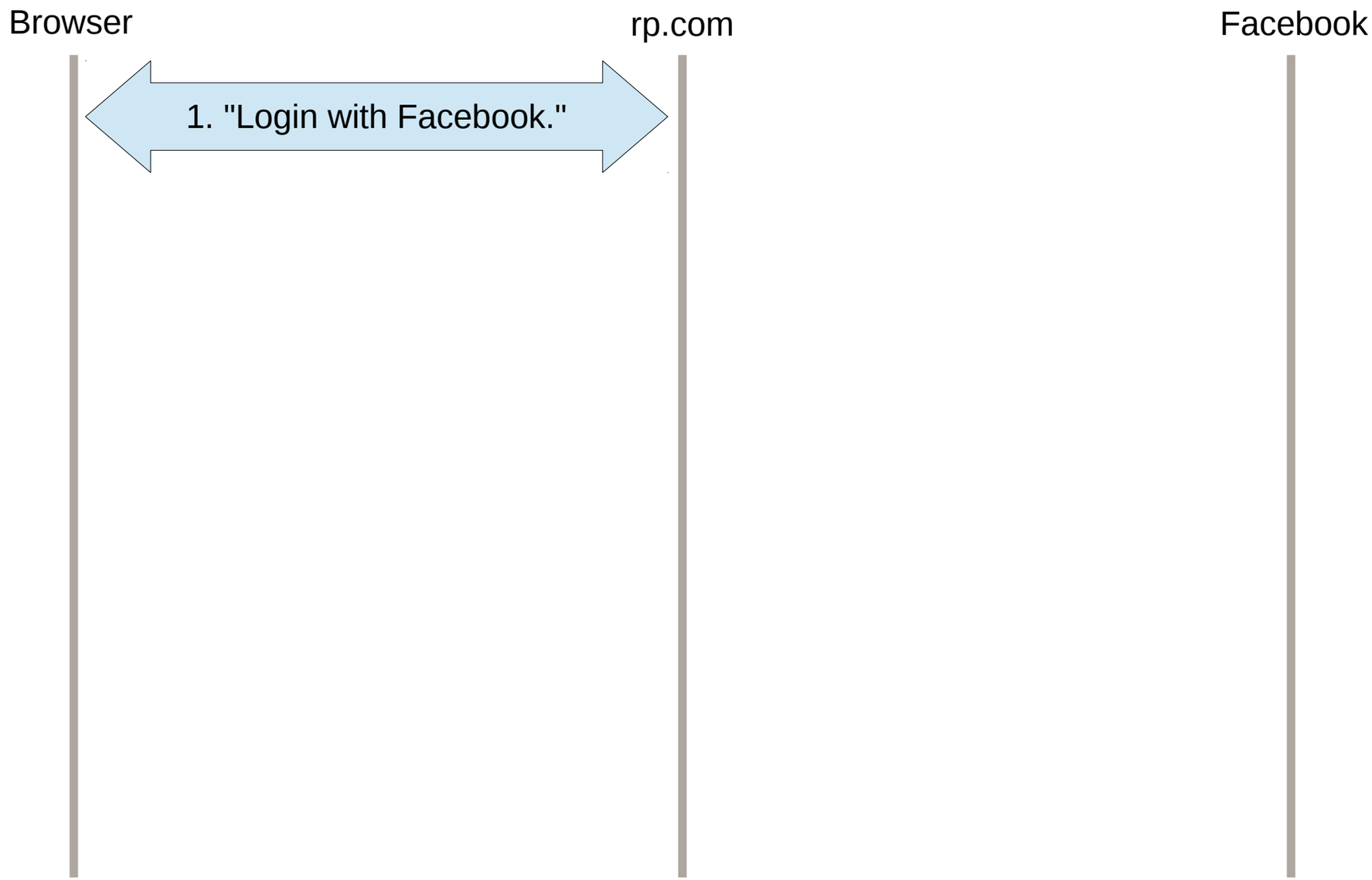

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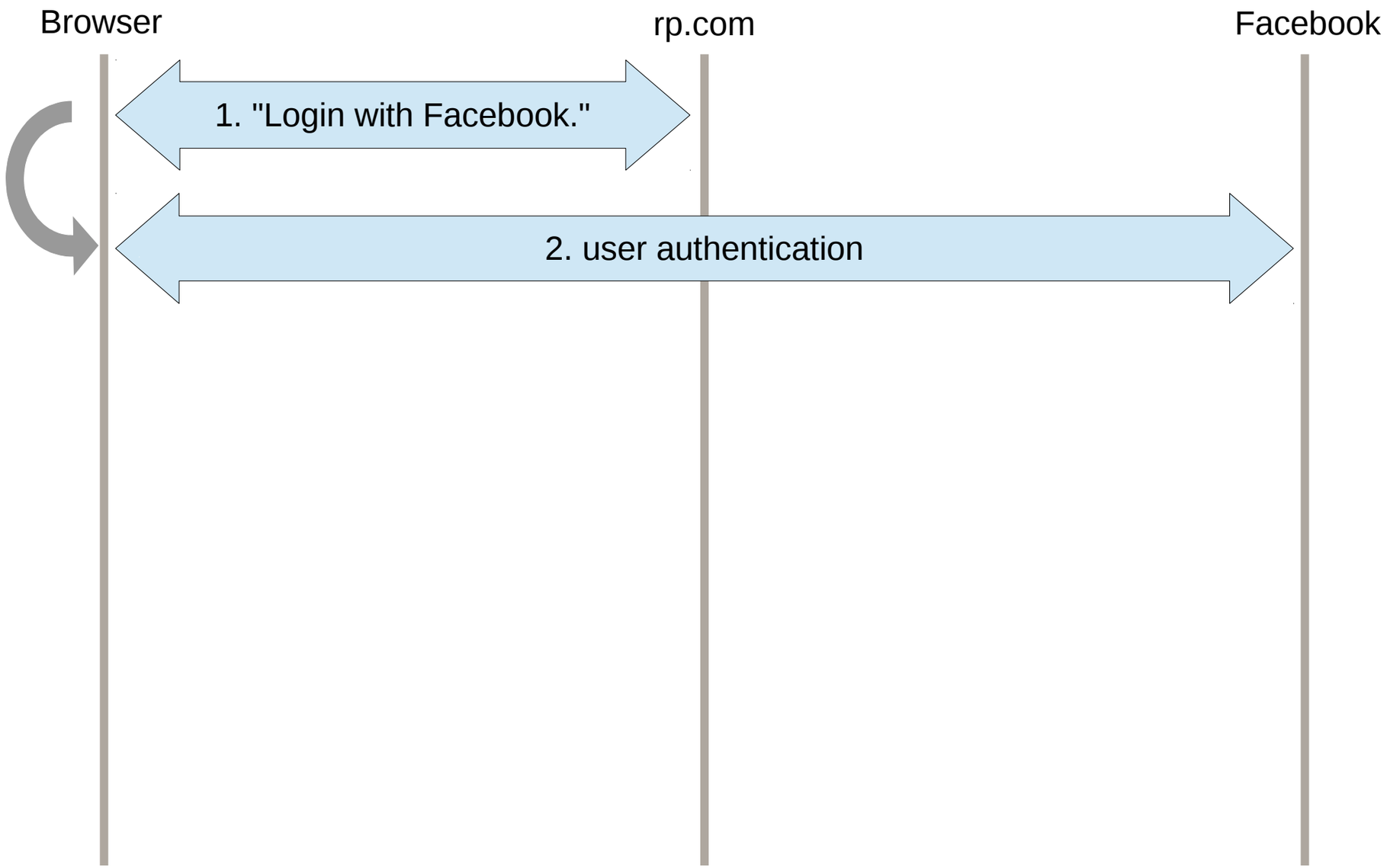

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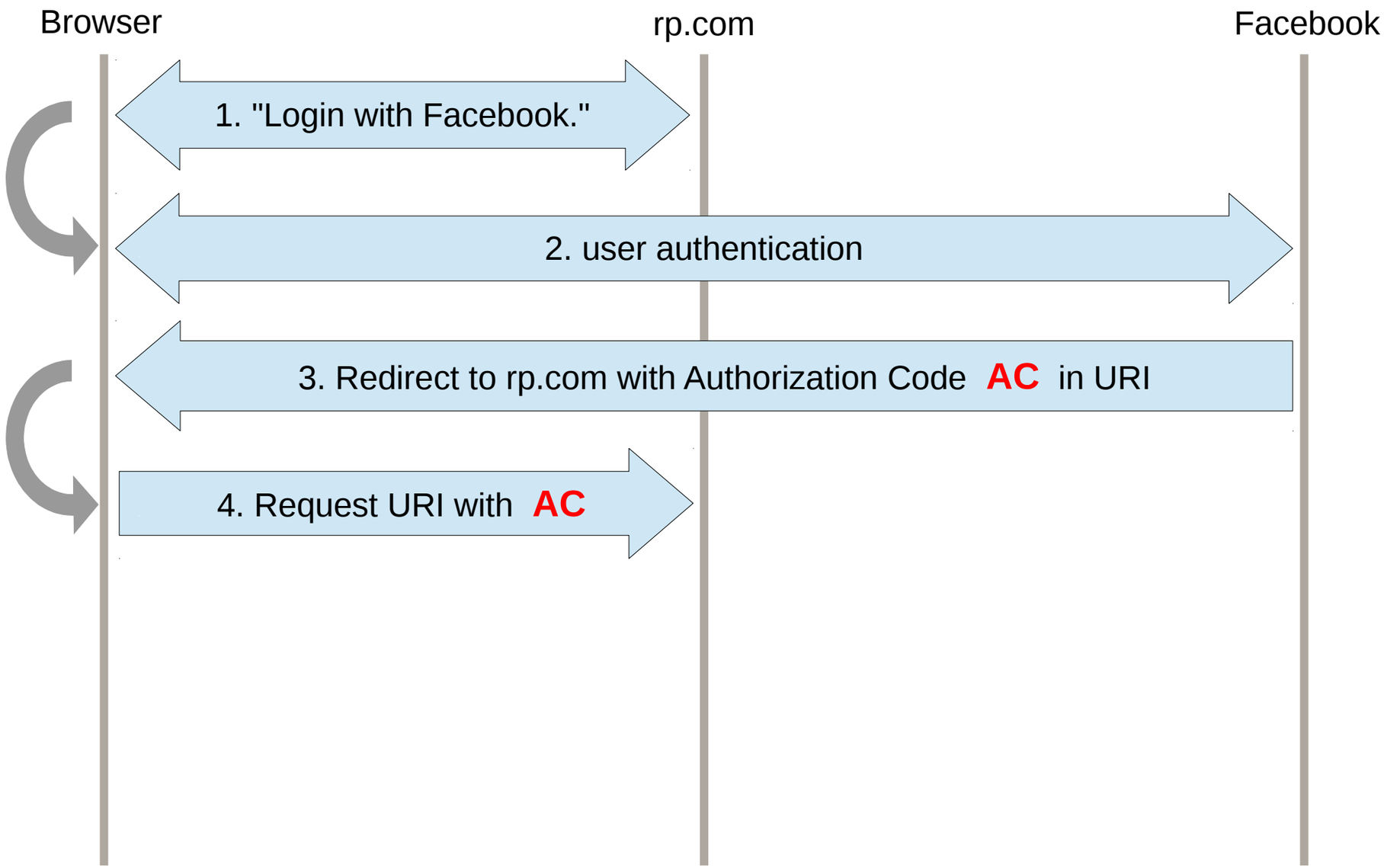

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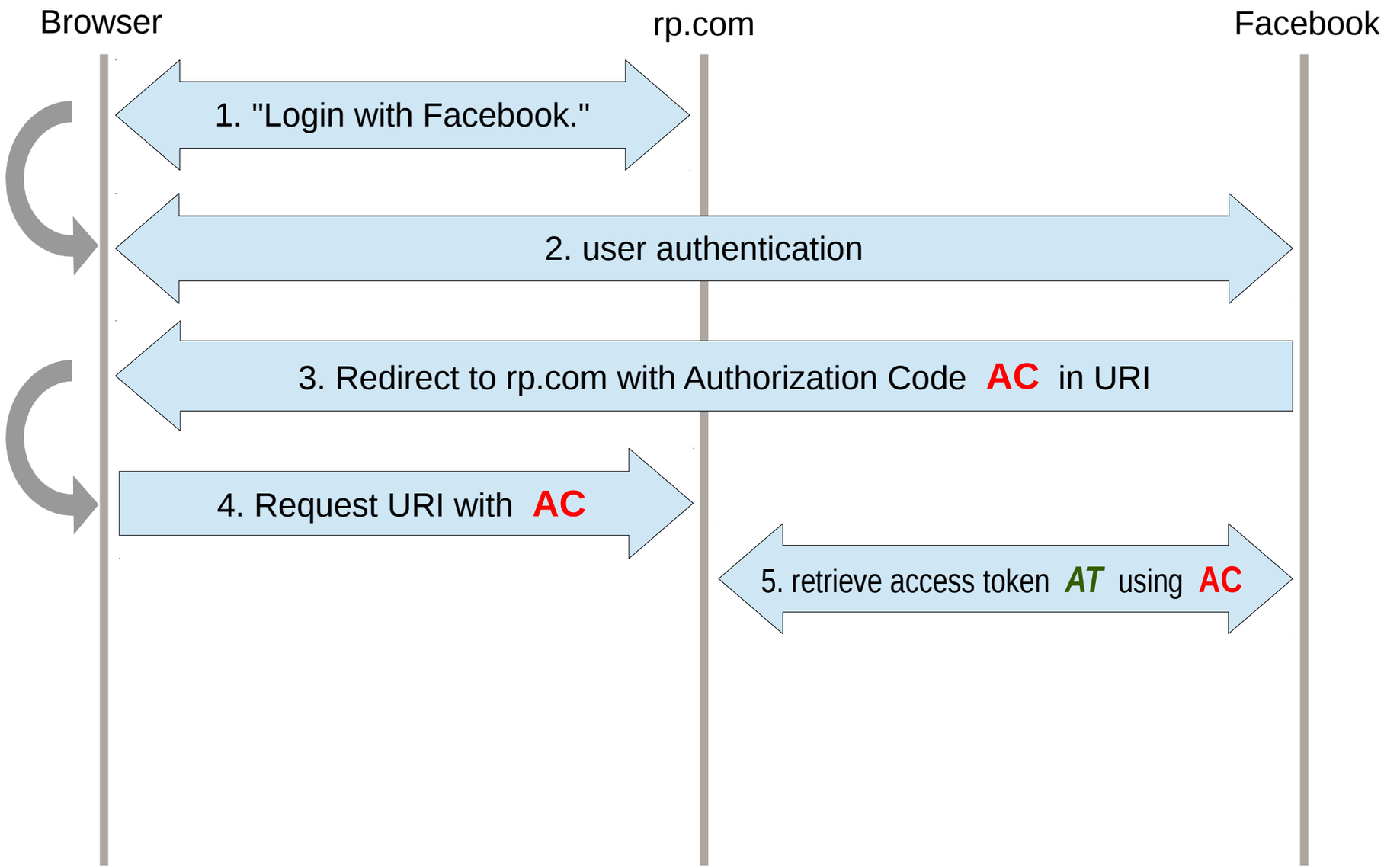

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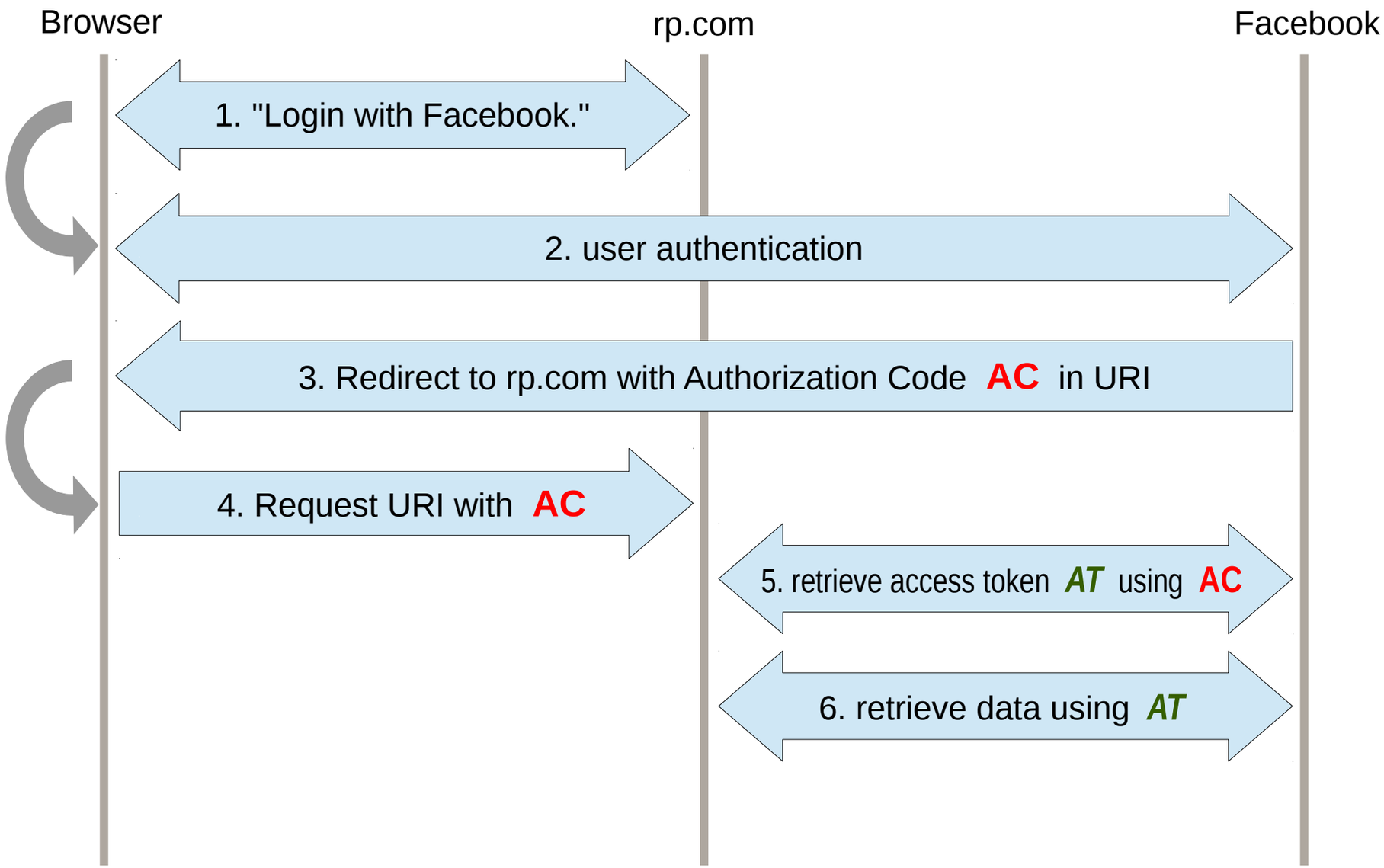
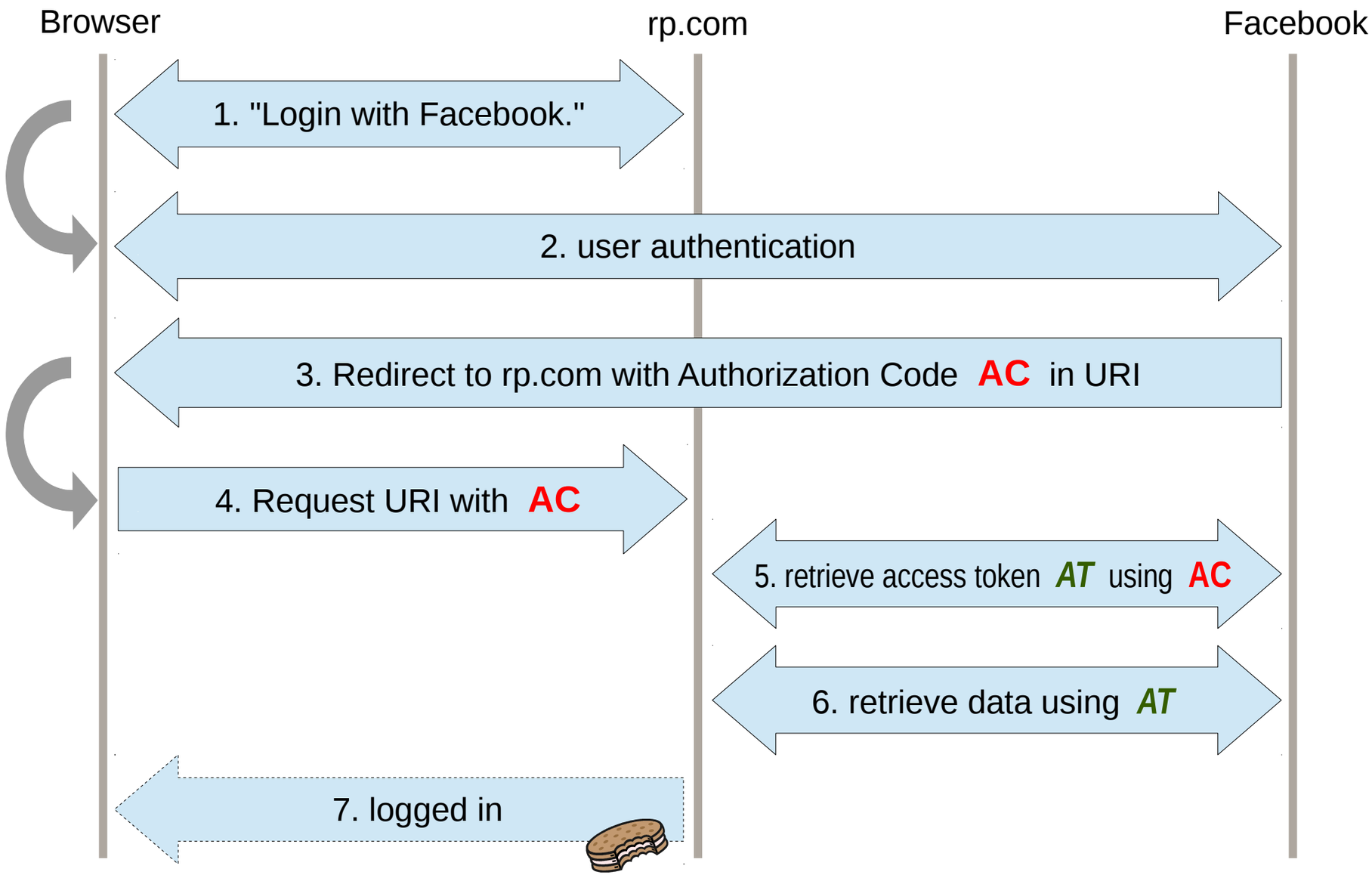


Authorization Code Mode



(Selected) Attacks on OAuth 2.0

Known Attacks...

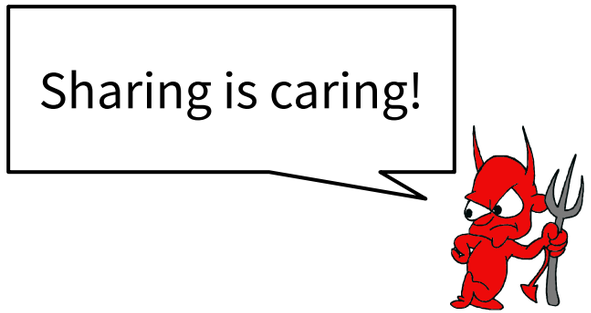
Known Attacks...

- Cut‘n‘paste attack

Known Attacks...

- Cut‘n‘paste attack

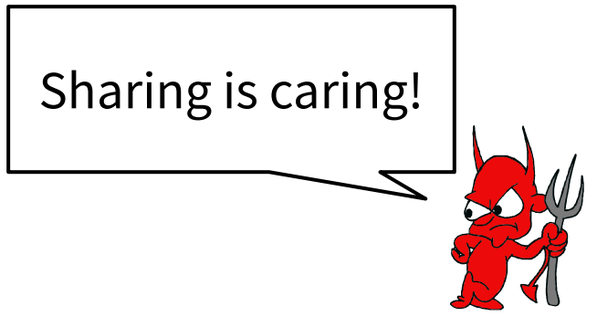
- Lack of HTTPS



Known Attacks...

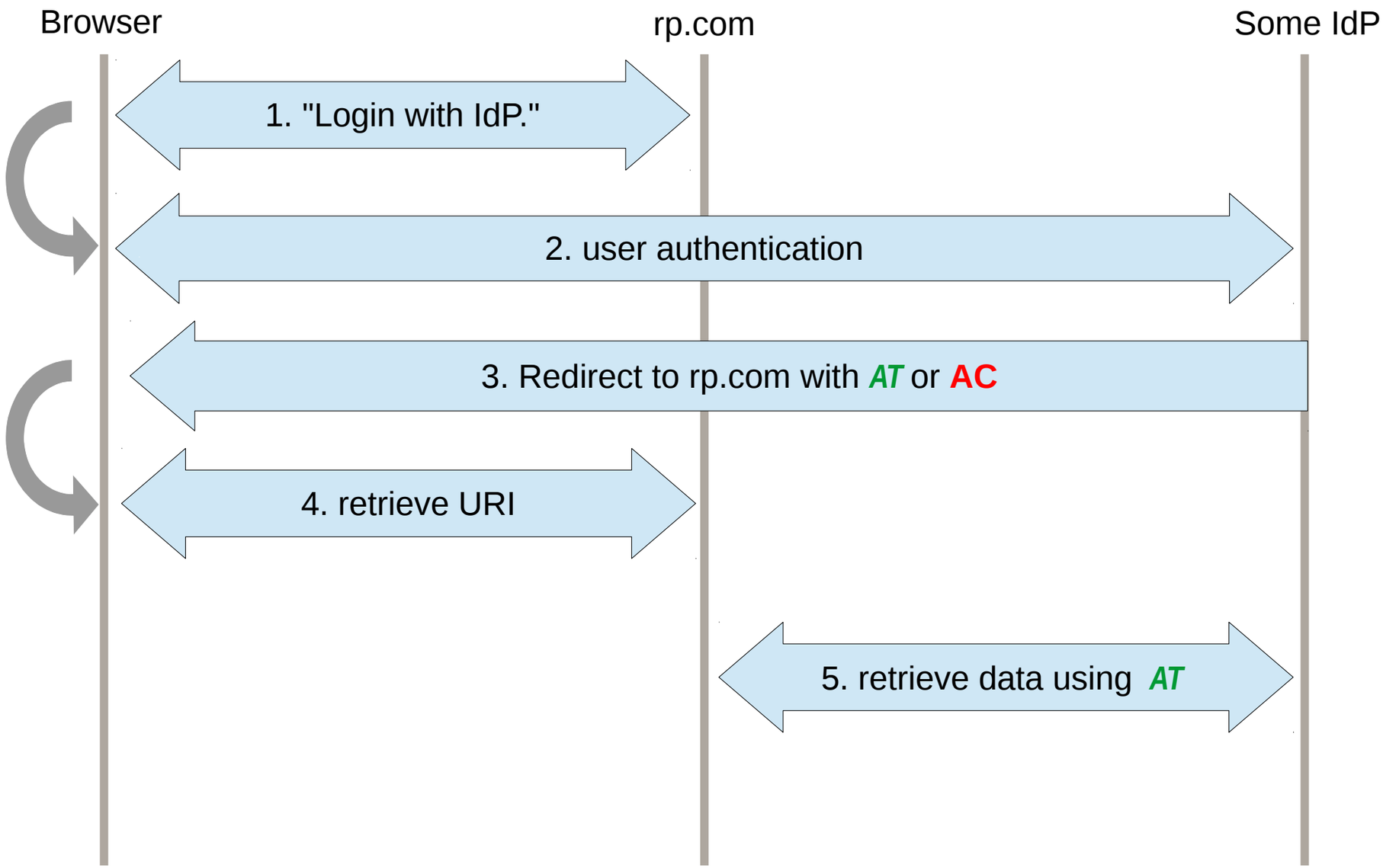
- Cut‘n‘paste attack

- Lack of HTTPS

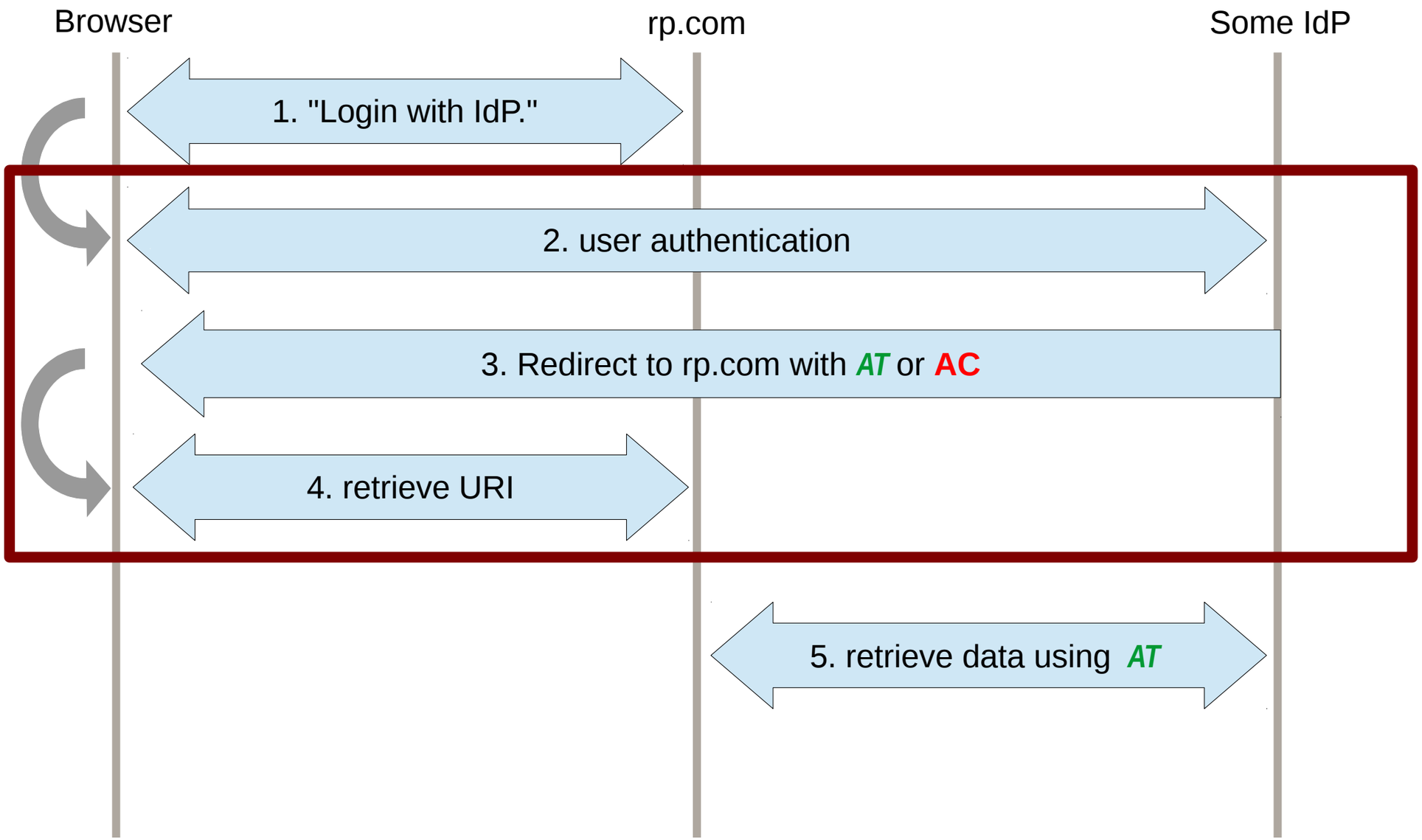


- Setting Cookies via HTTP

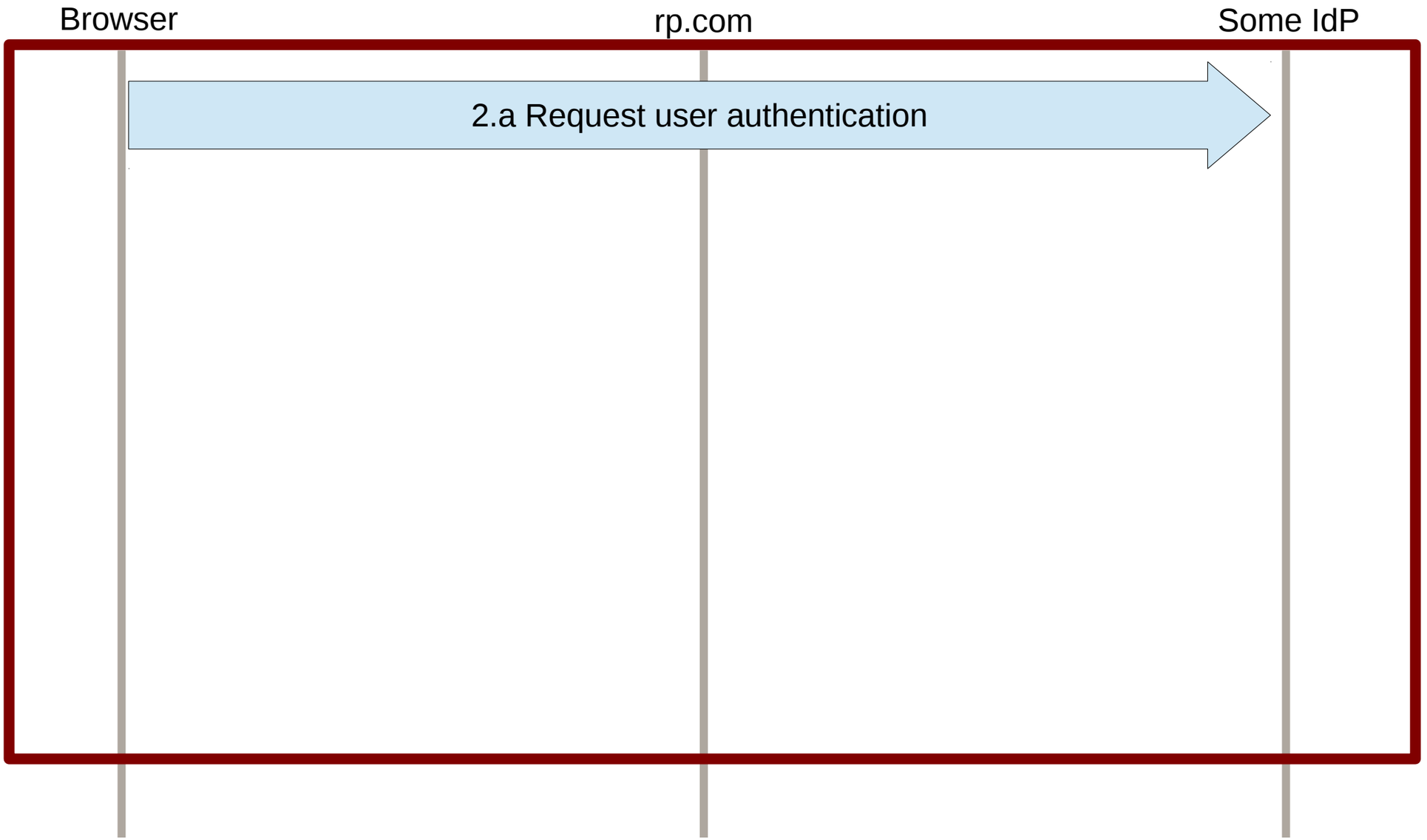
307 Redirect Attack



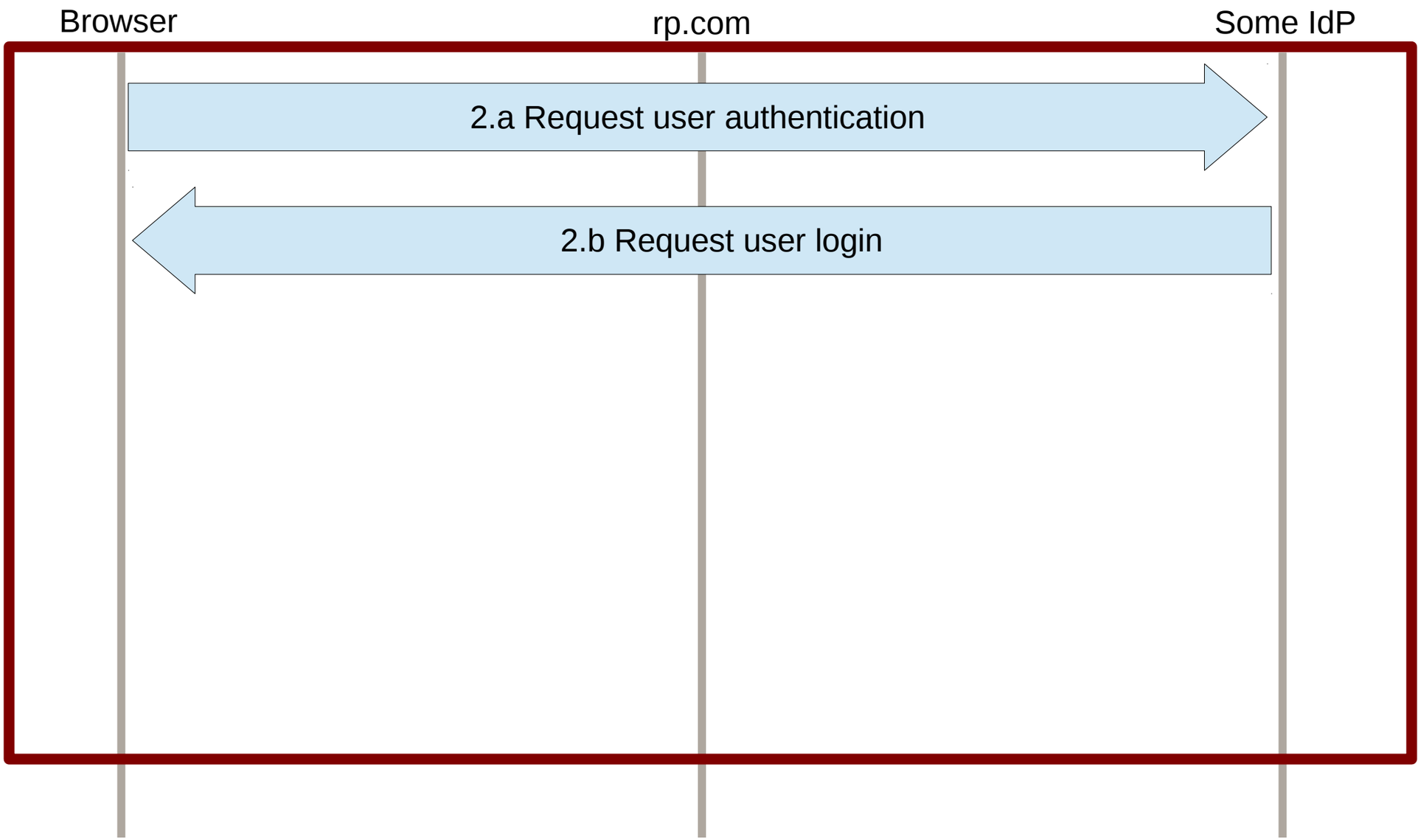
307 Redirect Attack



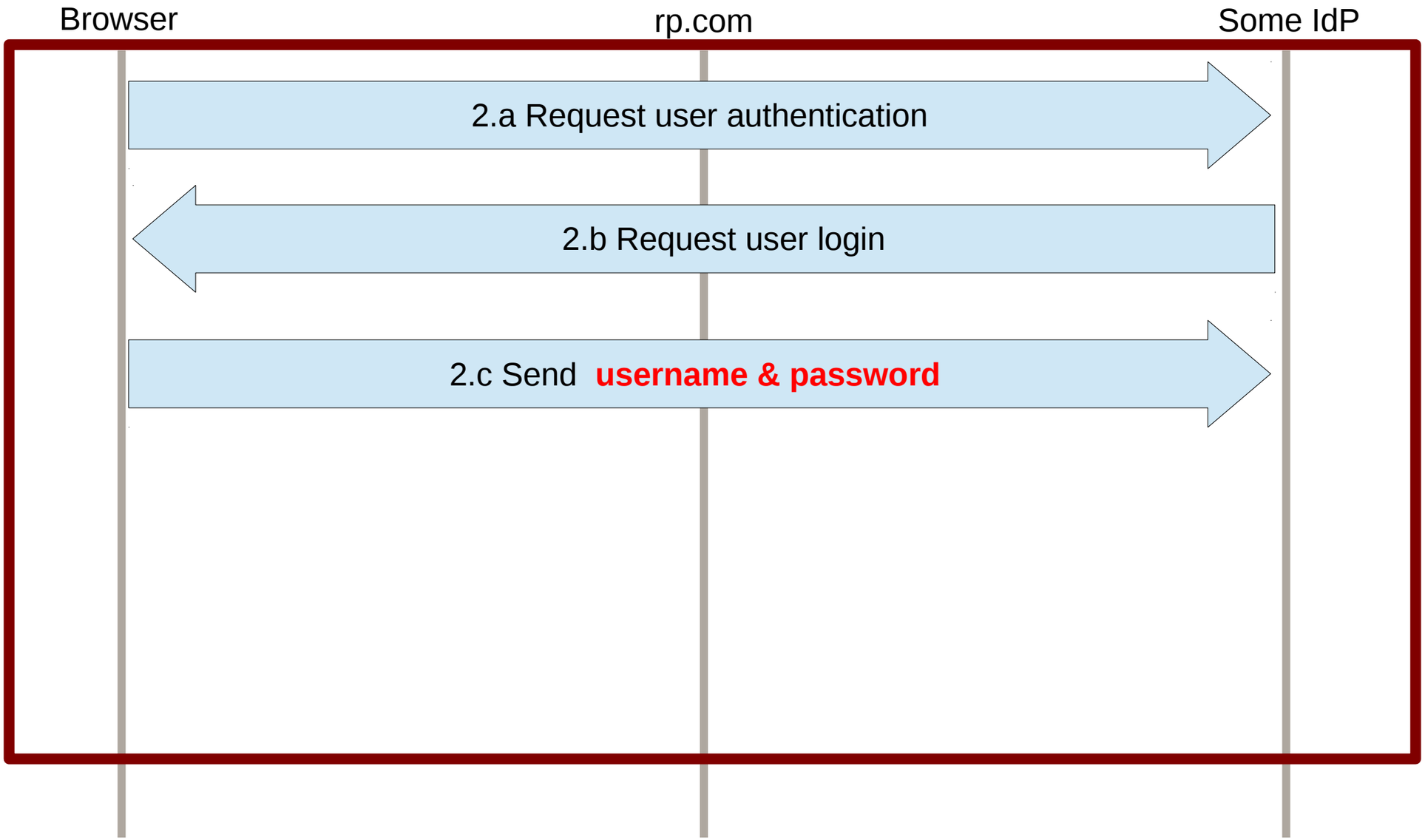
307 Redirect Attack



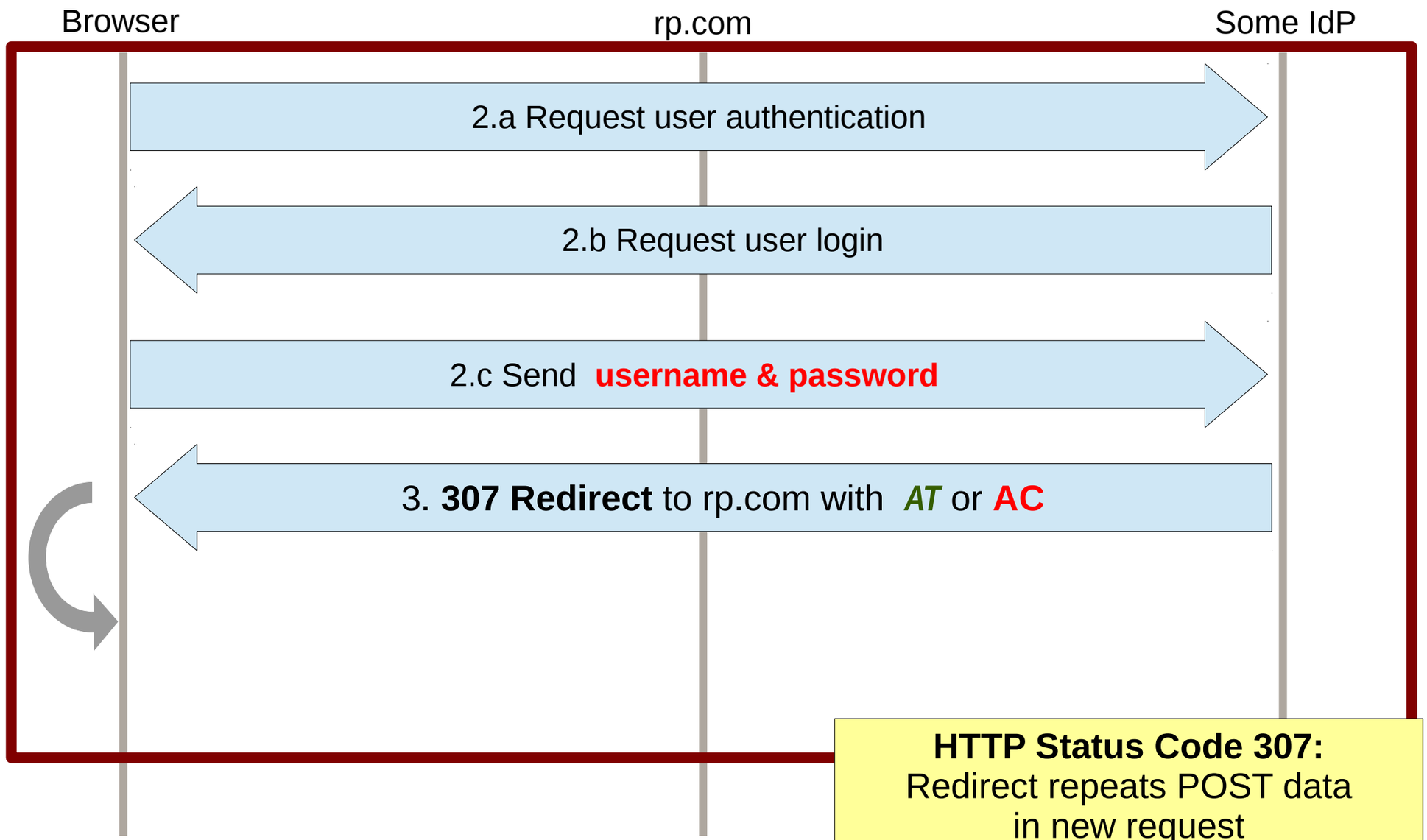
307 Redirect Attack



307 Redirect Attack

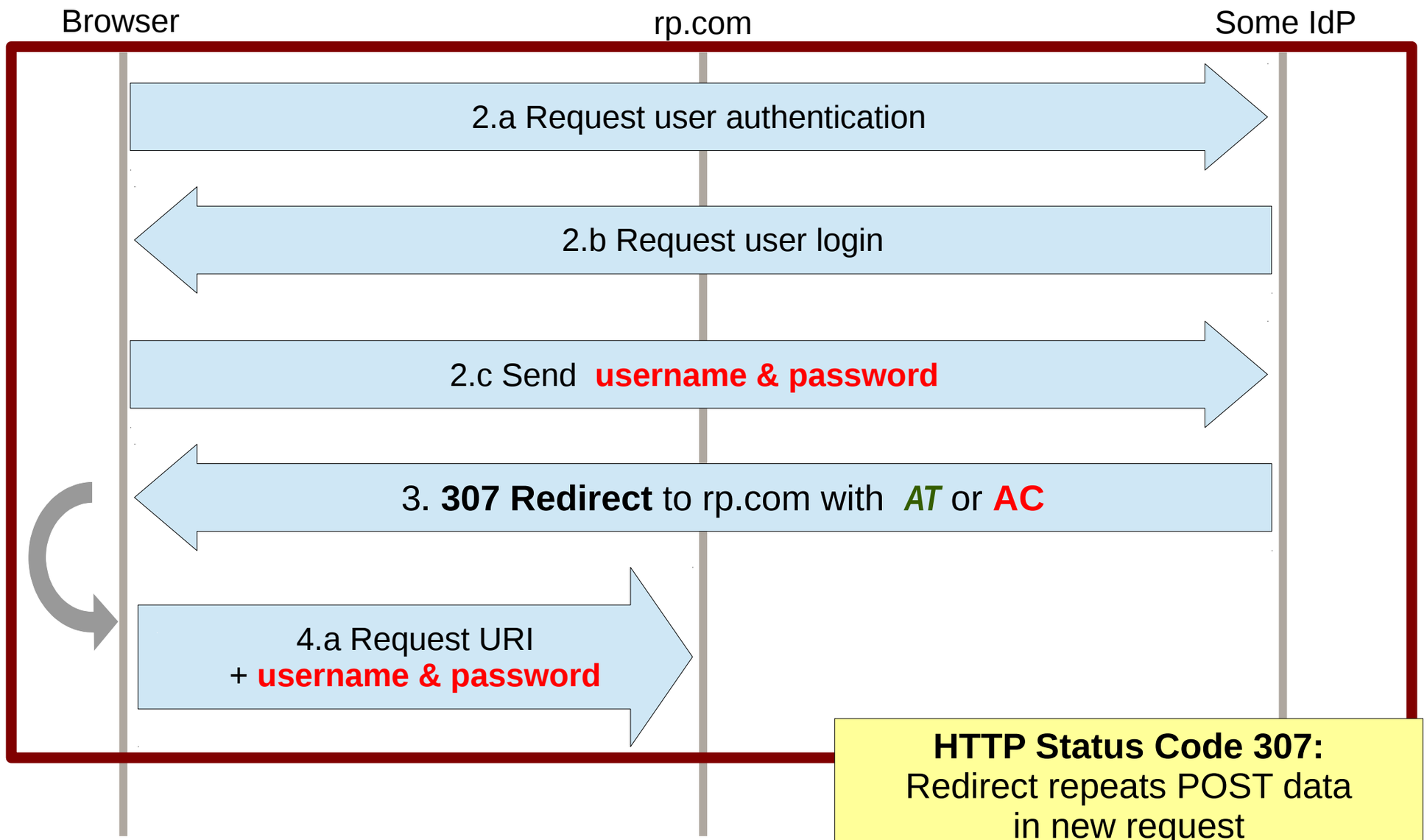


307 Redirect Attack



HTTP Status Code 307:
Redirect repeats POST data
in new request

307 Redirect Attack



HTTP Status Code 307:
Redirect repeats POST data
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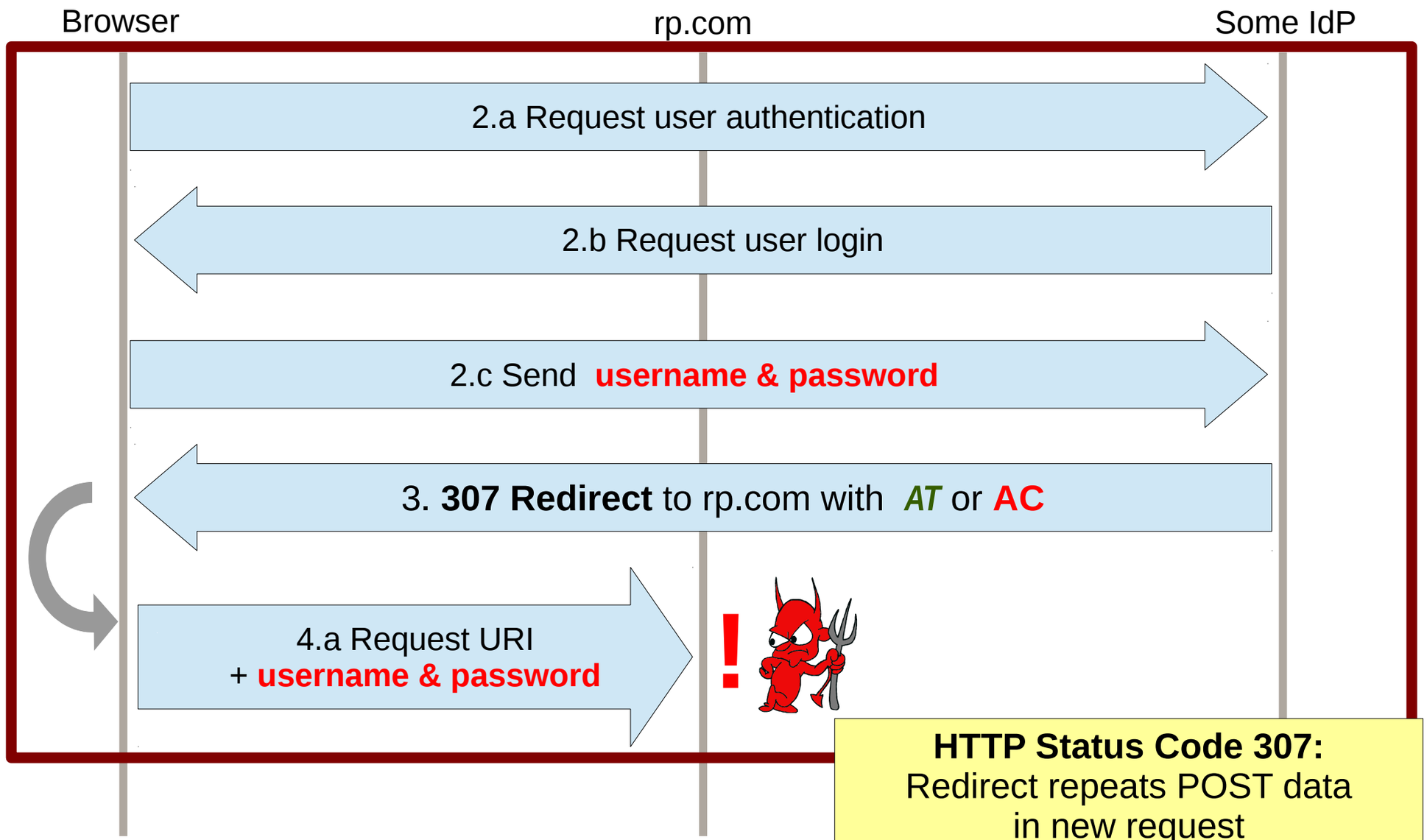
307 Redirect Attack



HTTP Status Code 307:
Redirect repeats POST data
in new request

307 Redirect Attack

OAuth standard says:

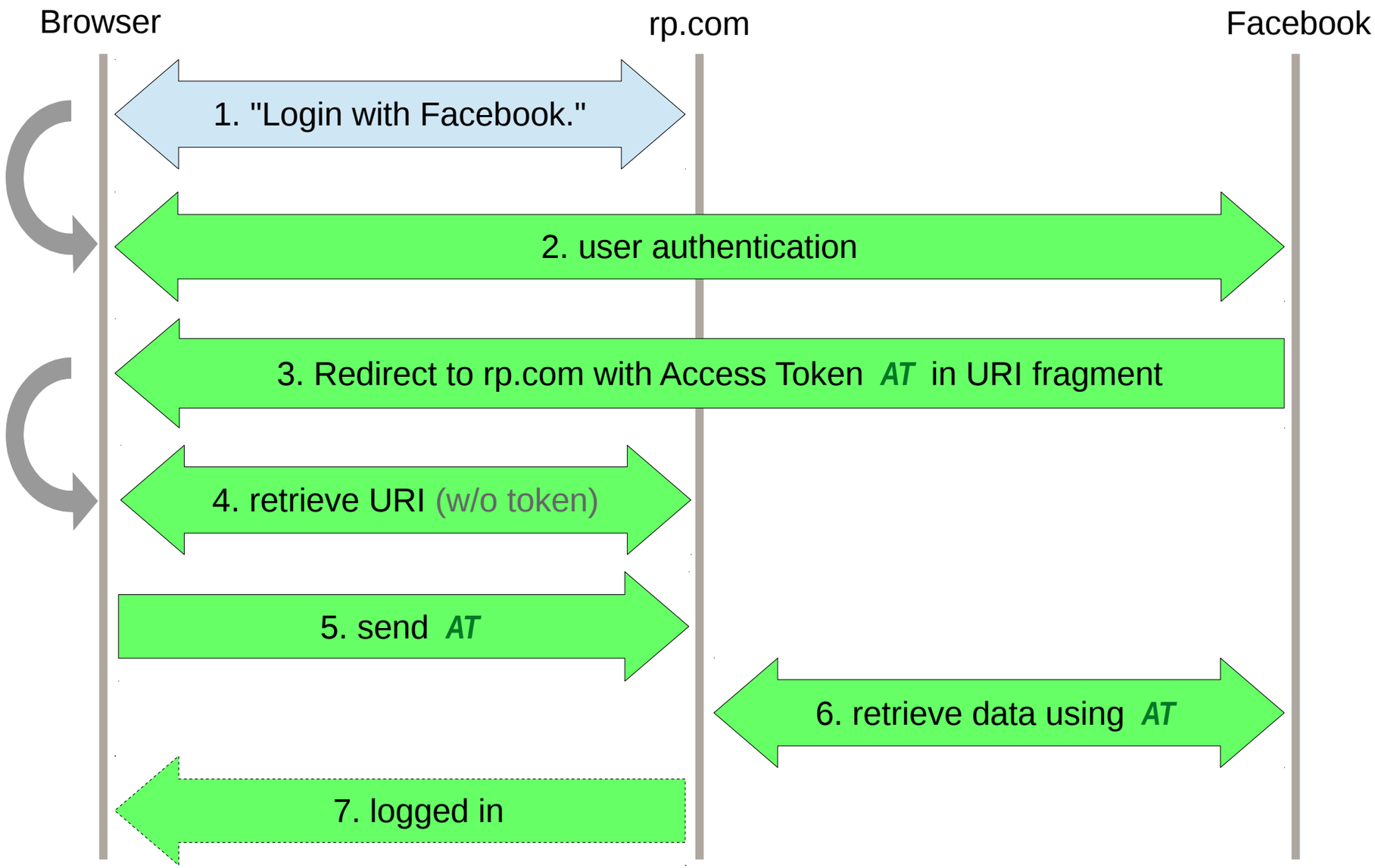
1.7. HTTP Redirections

This specification makes extensive use of HTTP redirections, in which the client or the authorization server directs the resource owner's user-agent to another destination. While the examples in this specification show the use of the HTTP 302 status code, any other method available via the user-agent to accomplish this redirection is allowed and is considered to be an implementation detail.

Mitigation:

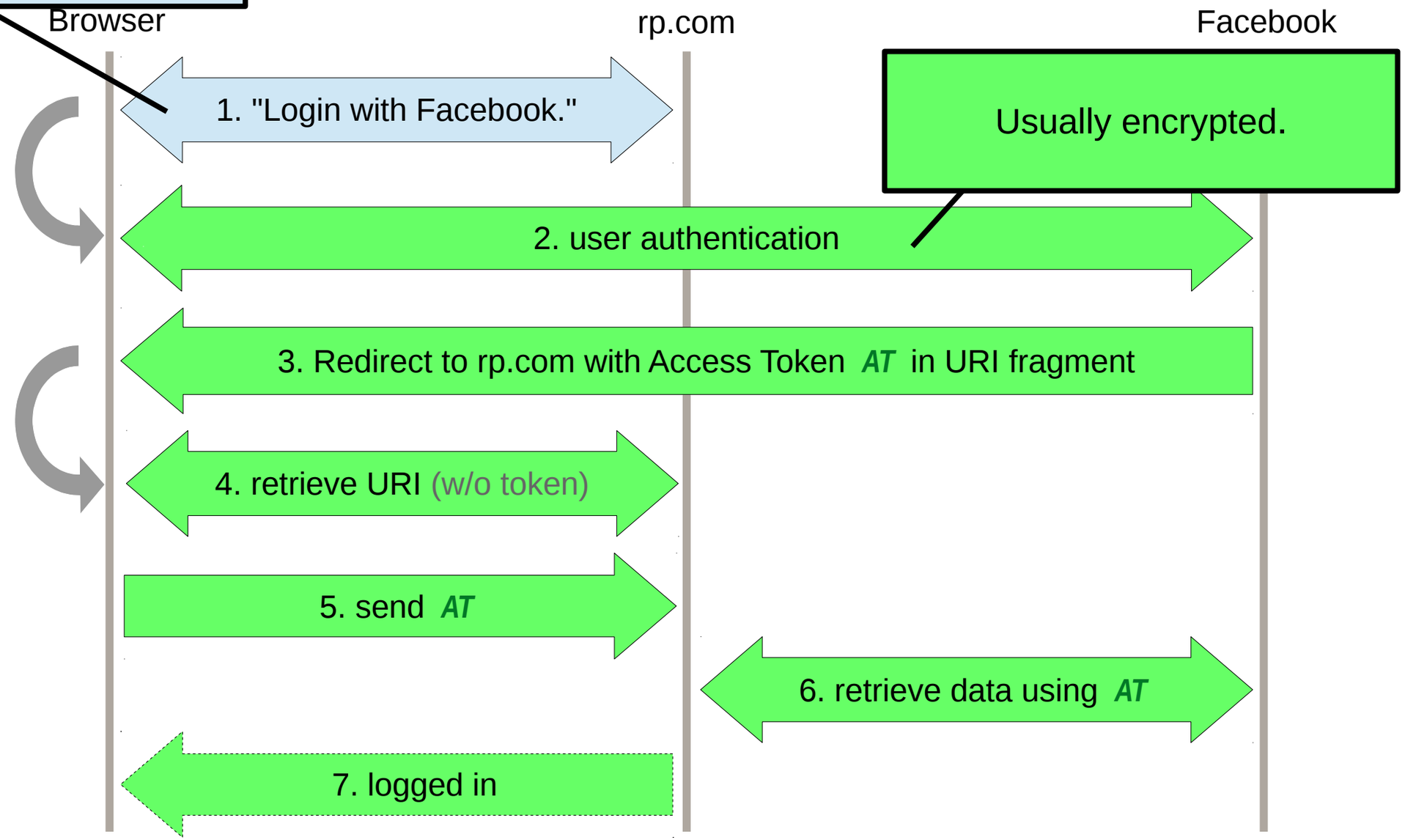
Make 303 or any other method that does not forward POST data.

IdP Mix-Up Attack in Implicit Mode

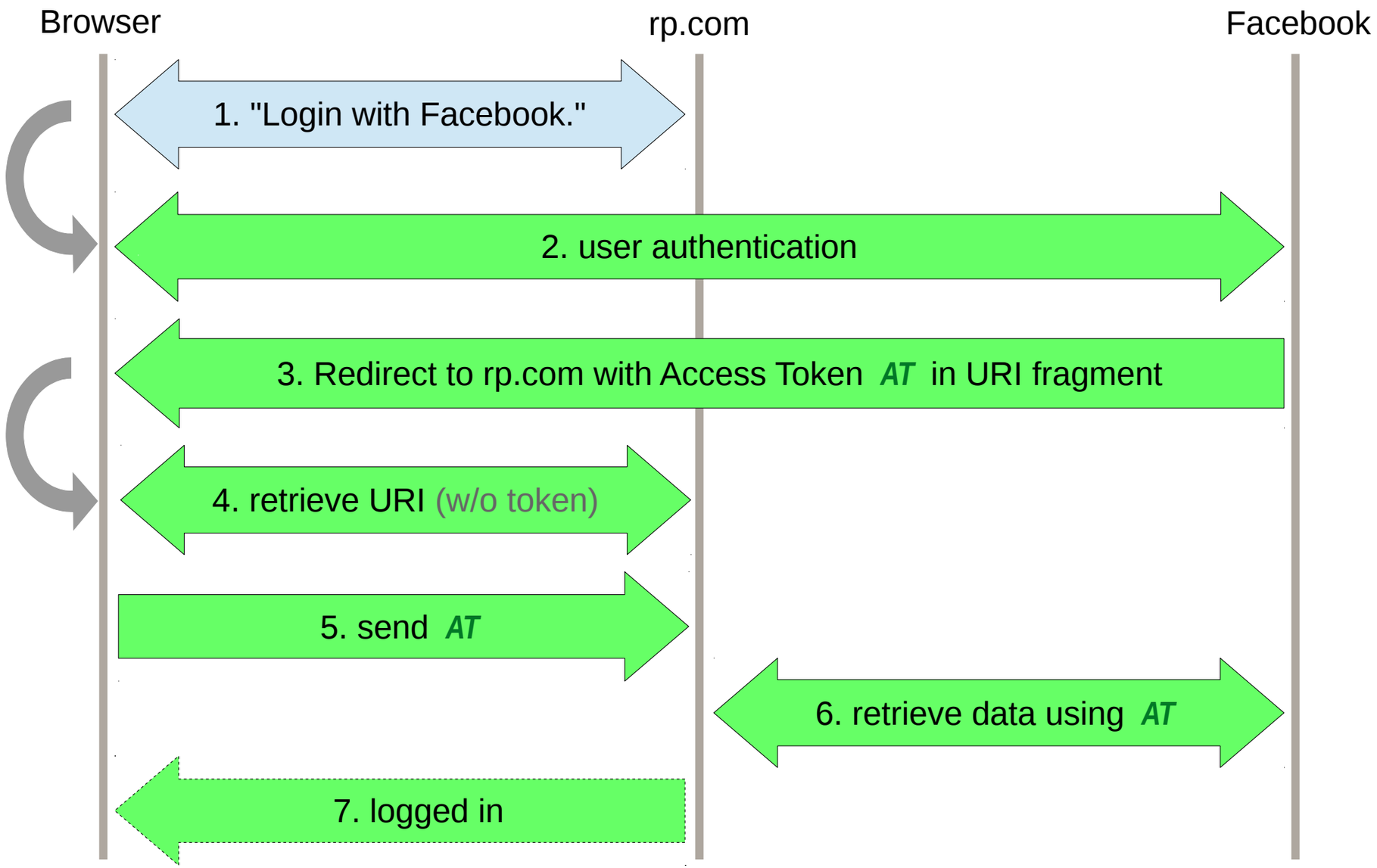


IdP Mix-Up Attack in Implicit Mode

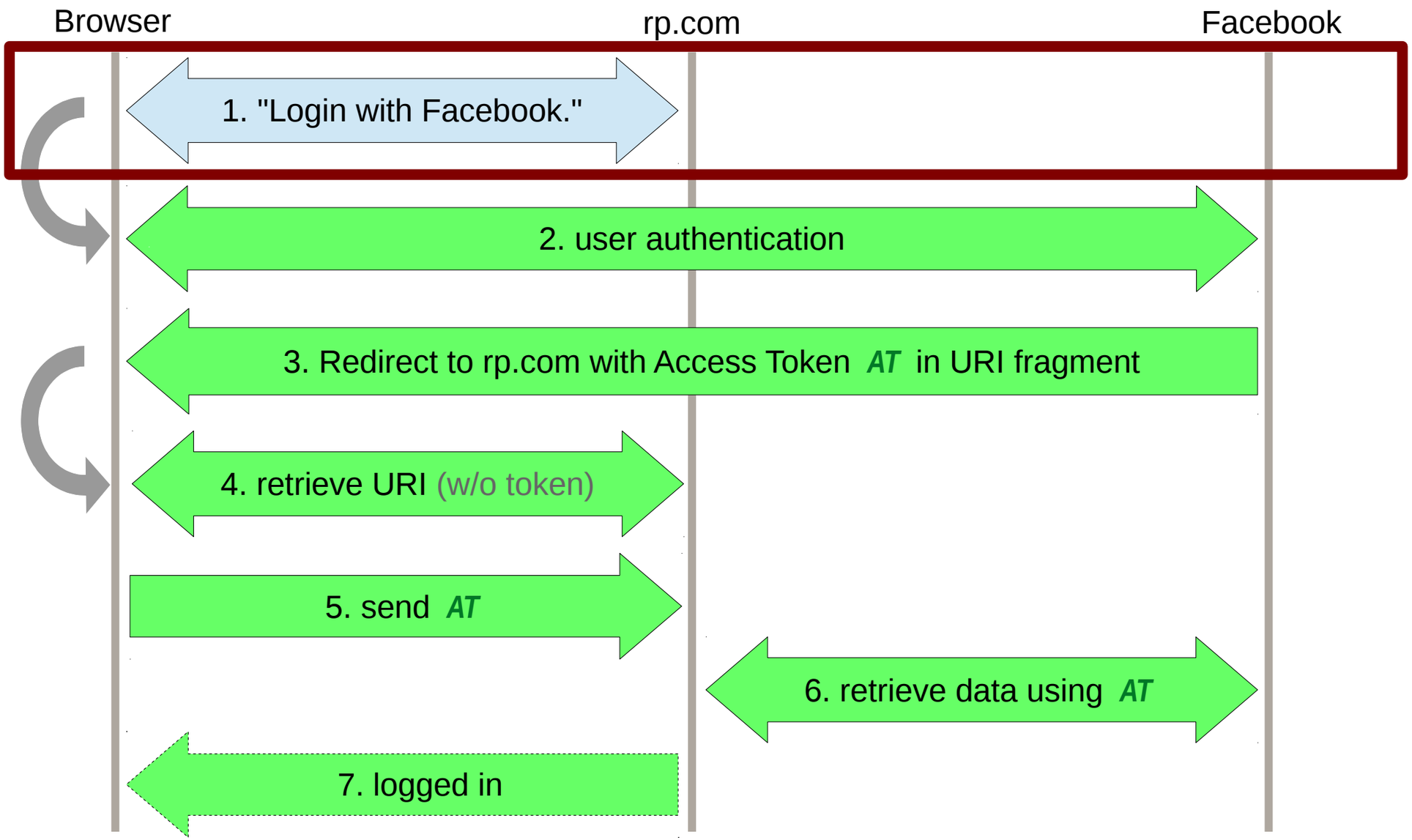
Often unencrypted or vulnerable to TLS stripping since **no confidential data** is transfered.



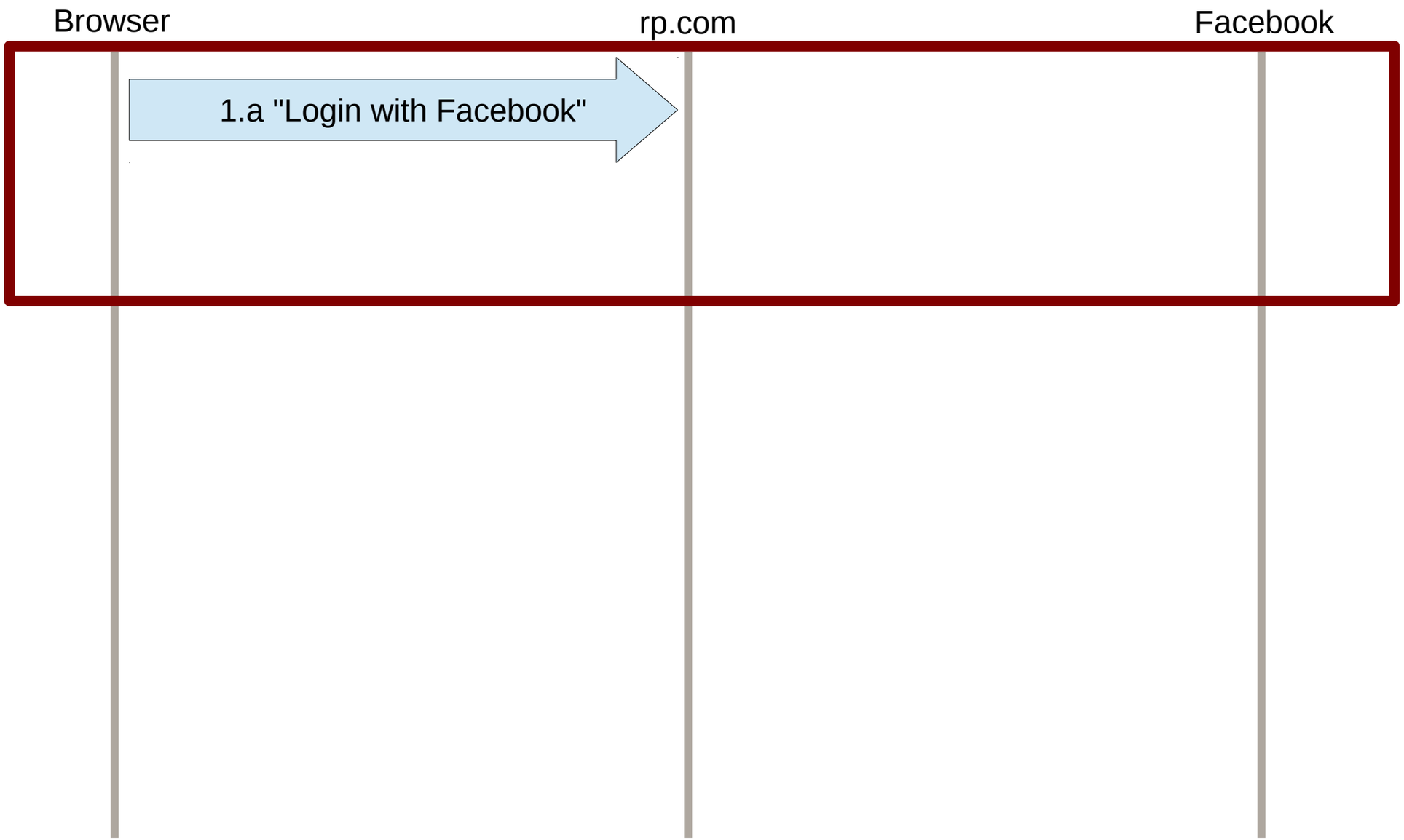
IdP Mix-Up Attack in Implicit Mode



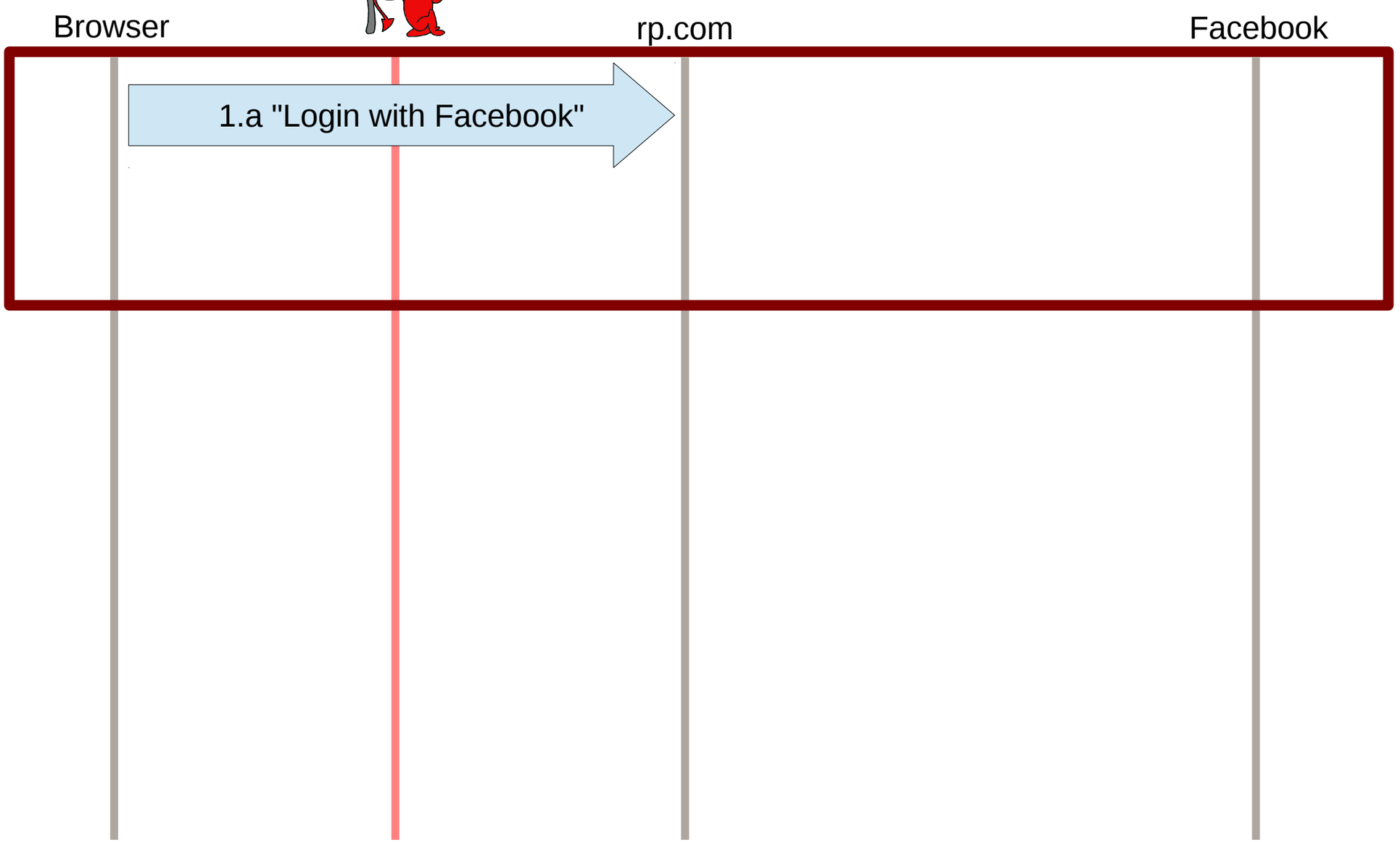
IdP Mix-Up Attack in Implicit Mode



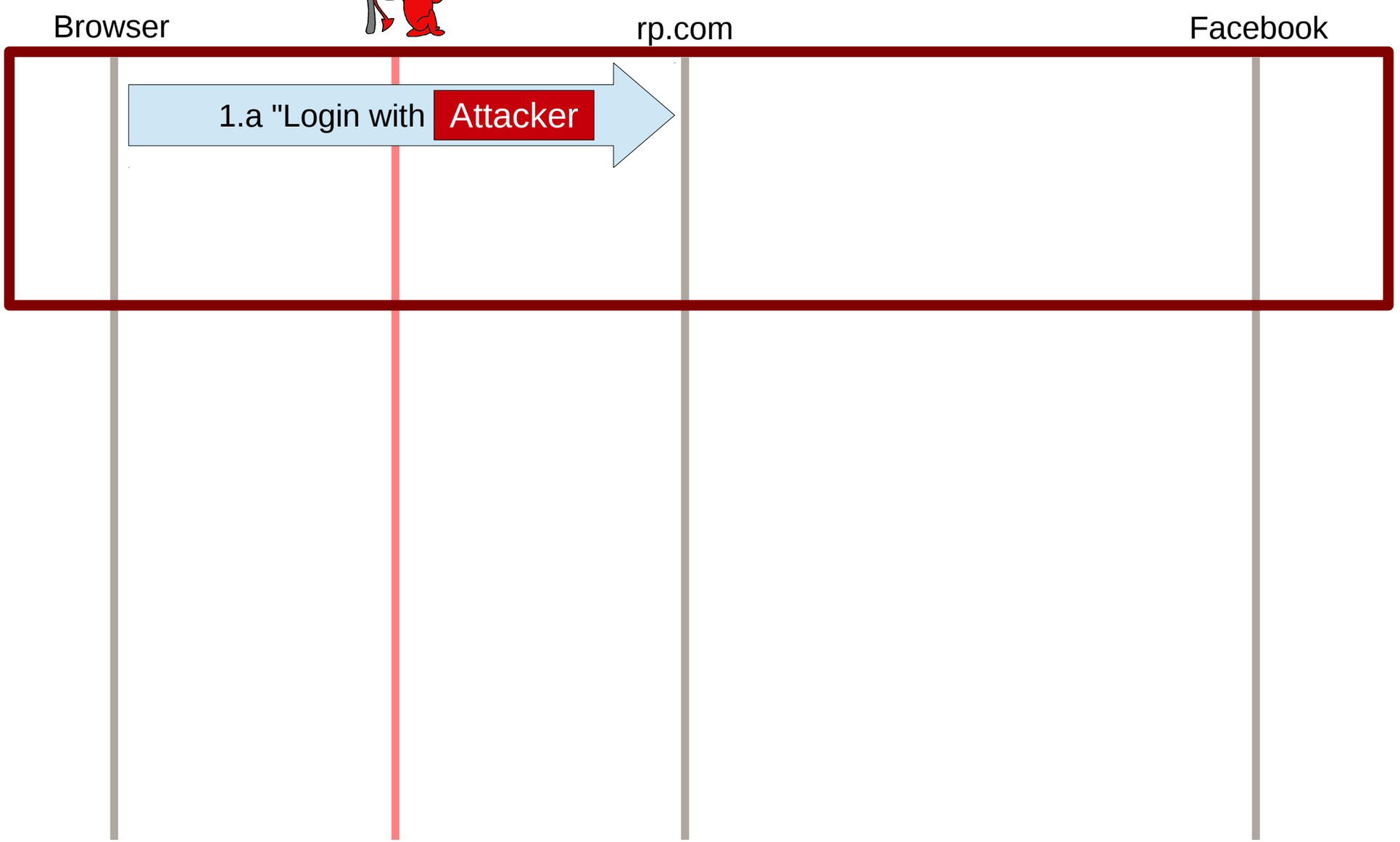
IdP Mix-Up Attack in Implicit Mode



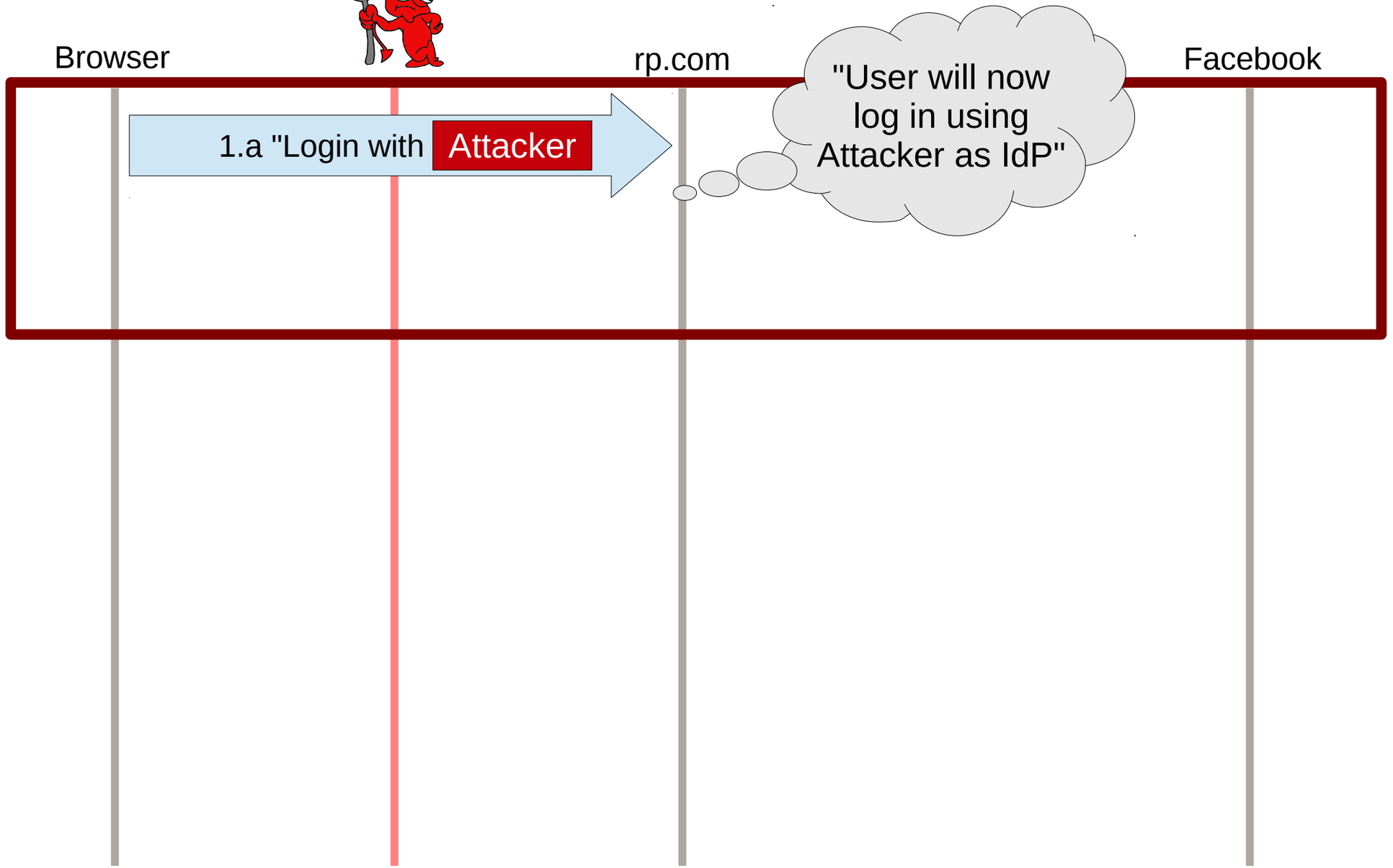
IdP Mix-Up Attack in Implicit Mode



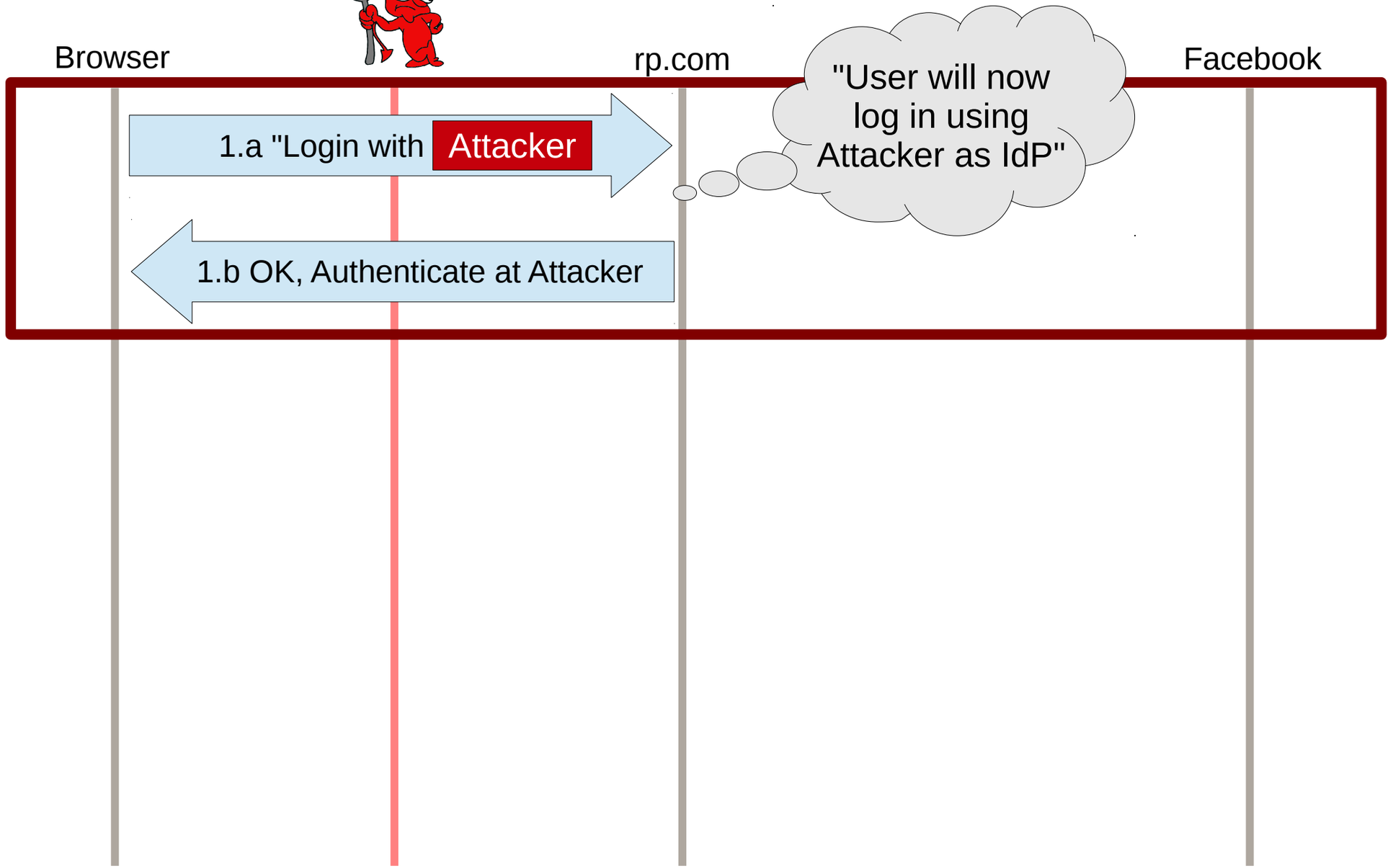
IdP Mix-Up Attack in Implicit Mode



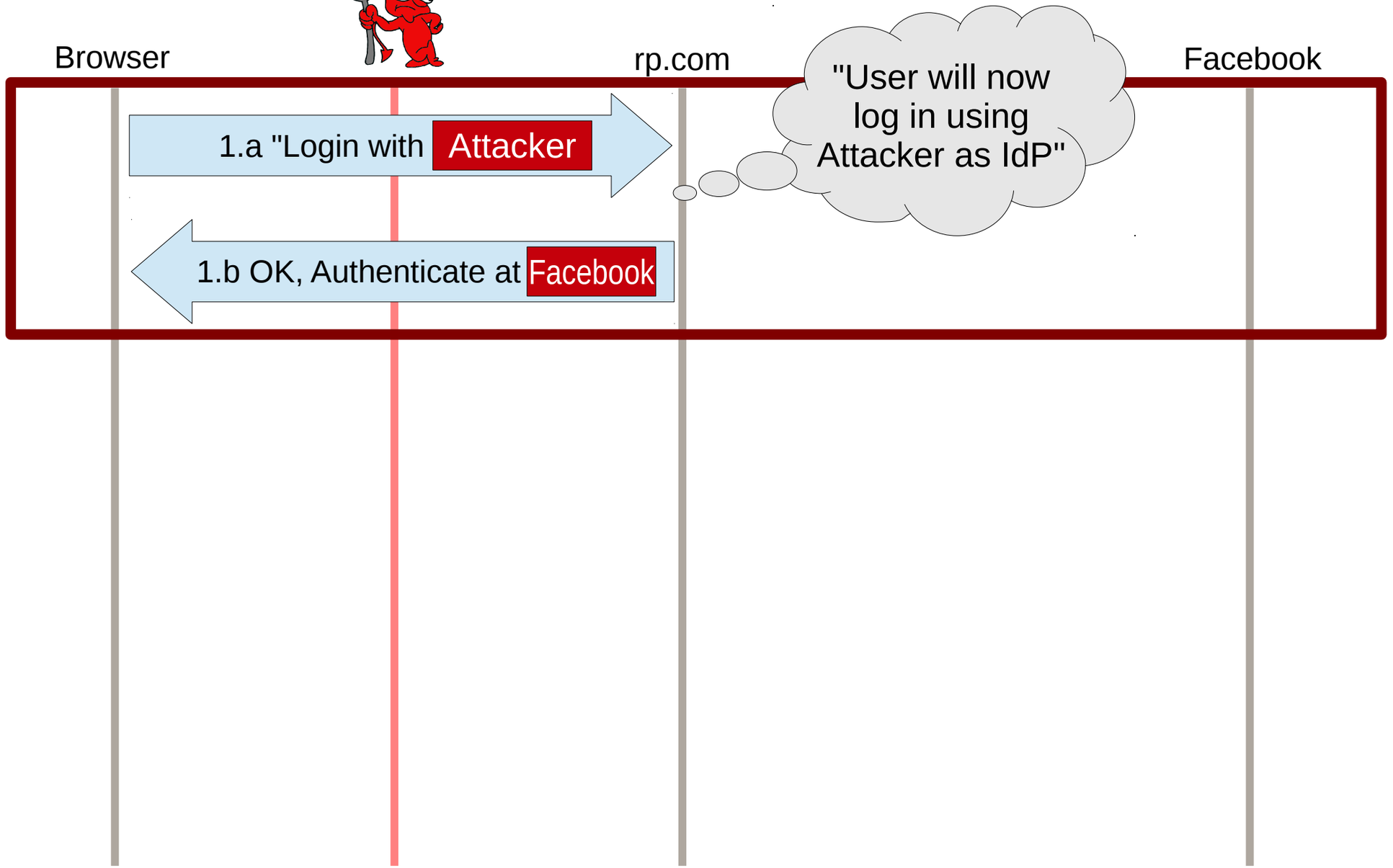
IdP Mix-Up Attack in Implicit Mode



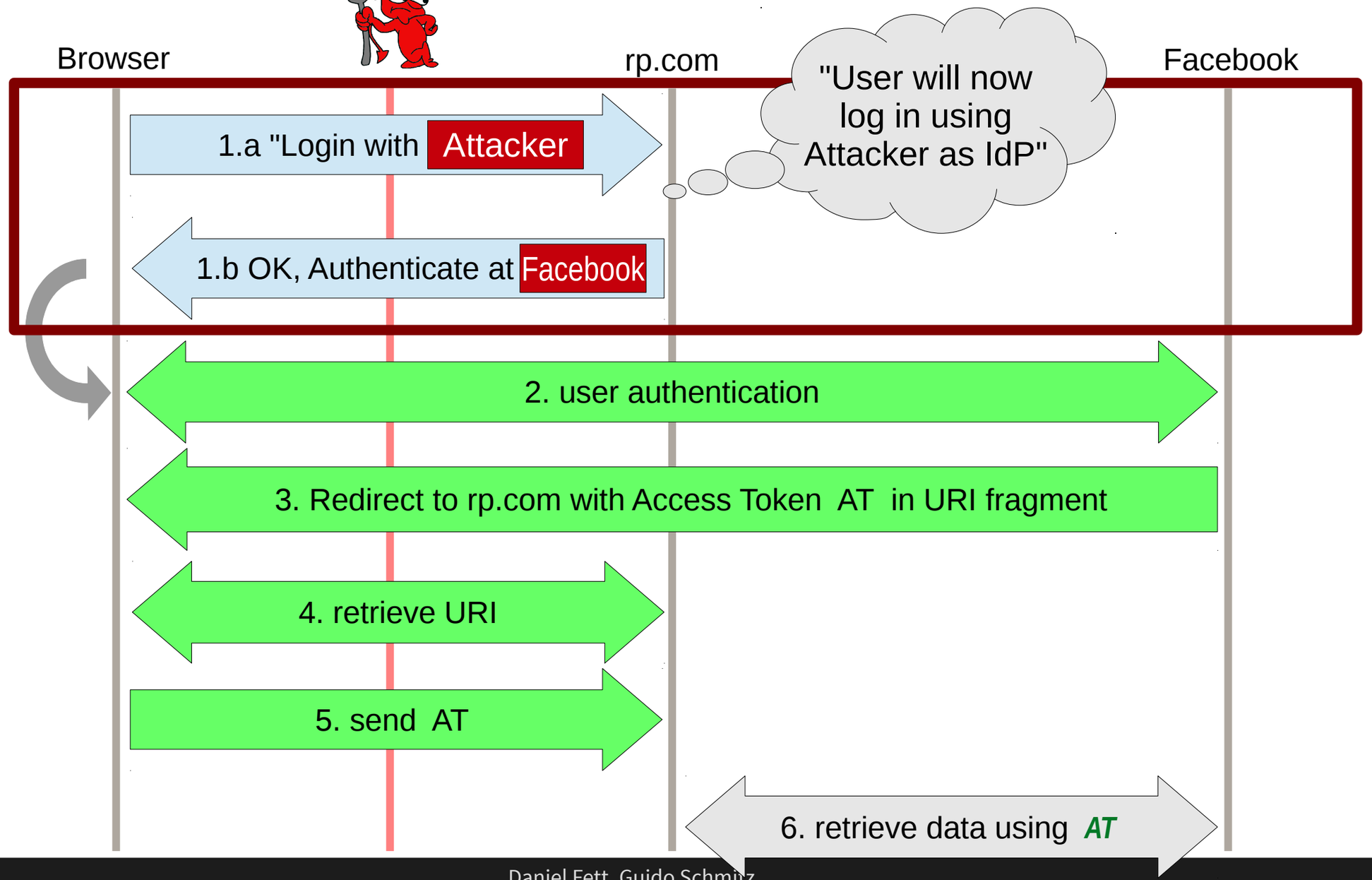
IdP Mix-Up Attack in Implicit Mode



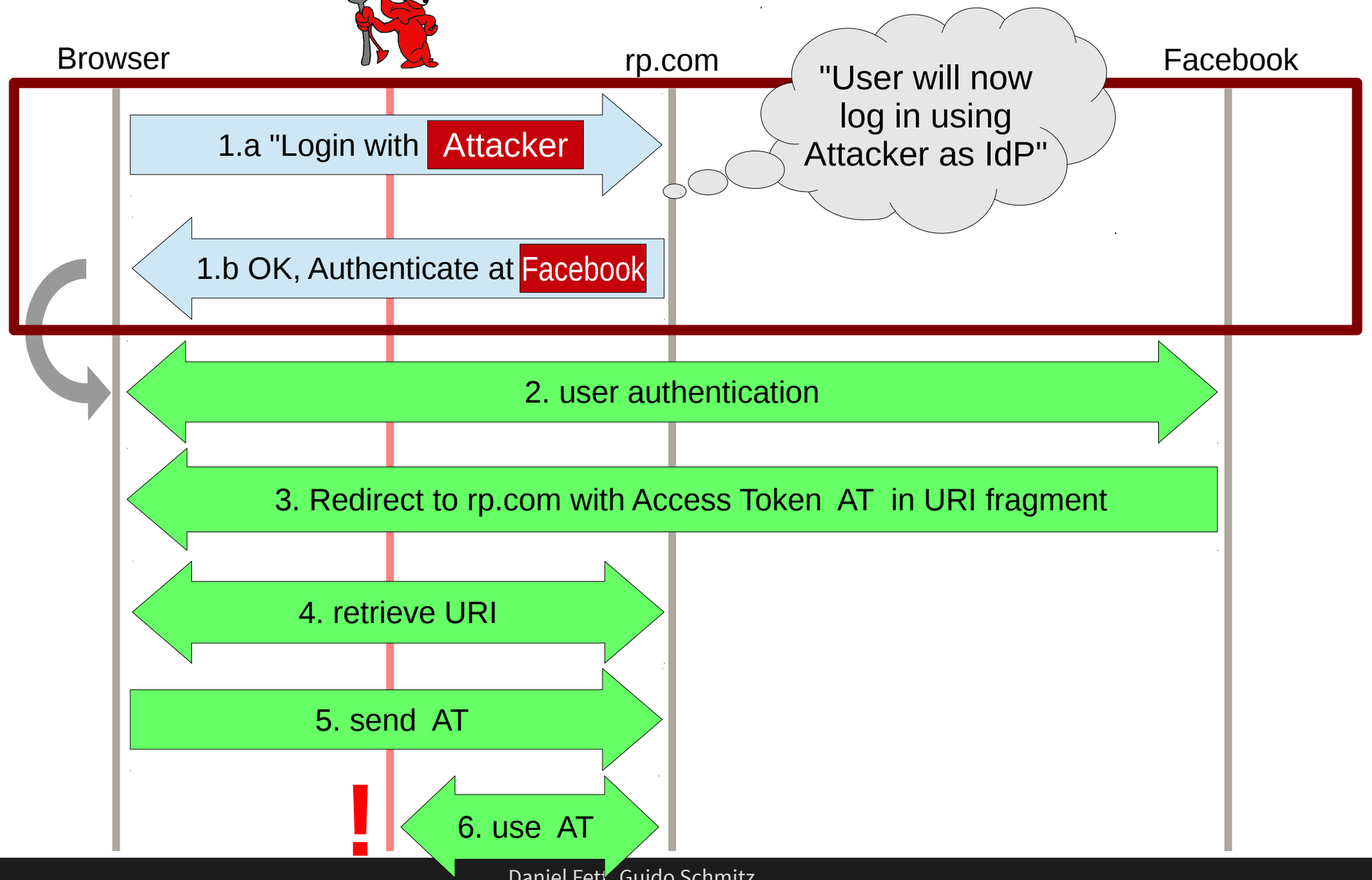
IdP Mix-Up Attack in Implicit Mode



IdP Mix-Up Attack in Implicit Mode



IdP Mix-Up Attack in Implicit Mode



IdP Mix-Up Attack

+ Variants

More details have to be taken care of:

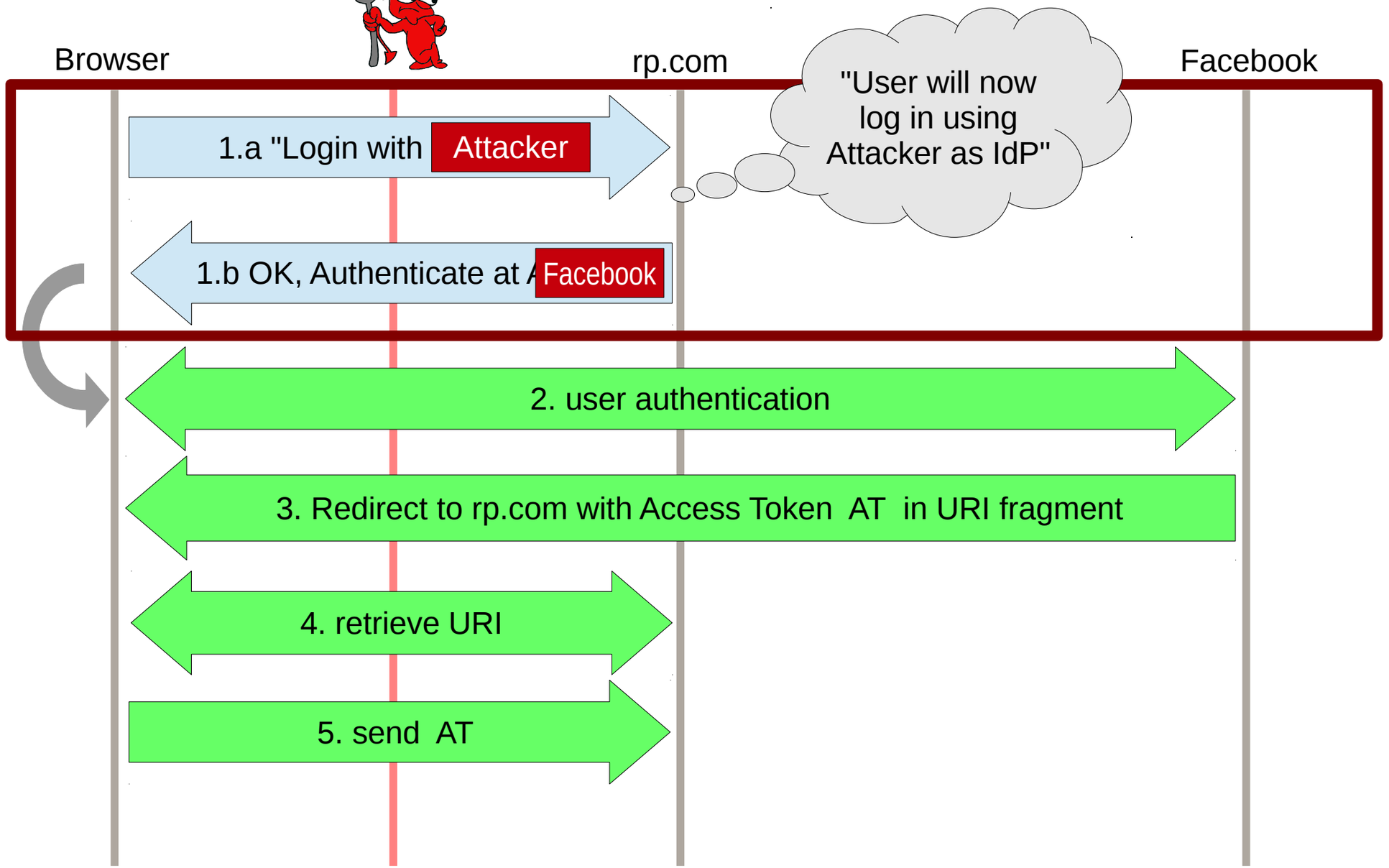
- Breaking authentication instead of authorization (some additional steps)
- Client Identifiers (i.e., RPs identify themselves to IdPs)
- Client Credentials (i.e., RPs authenticate to IdPs)
- In OpenID Connect: Message signing, "ID Token", endpoint discovery, etc.

→ **Sucessfully attacked real-world implementation.**

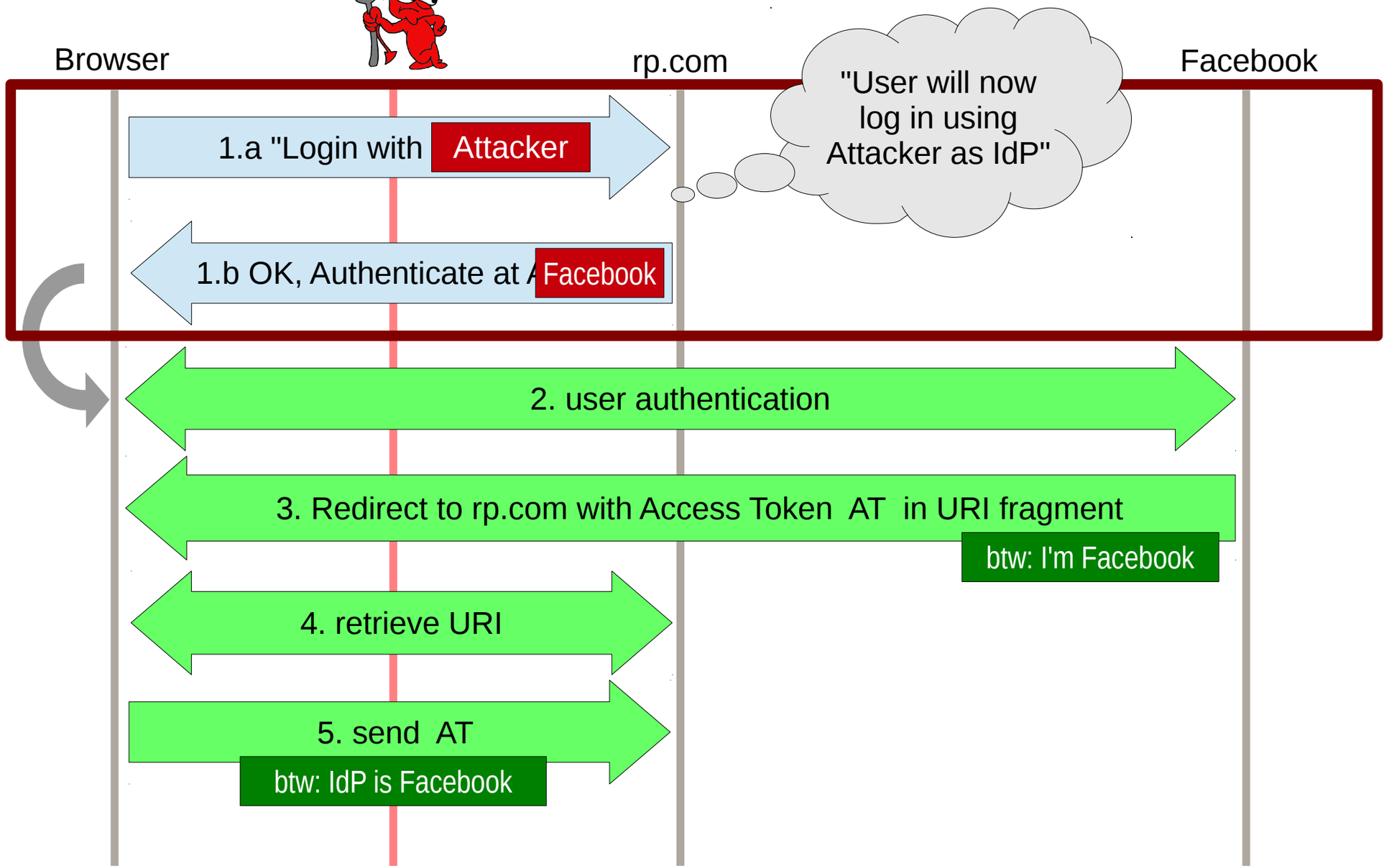
Multiple/malicious IdPs.
Related problems:

[Bansal et al. 2012]
[Mladenov et al. 2015]

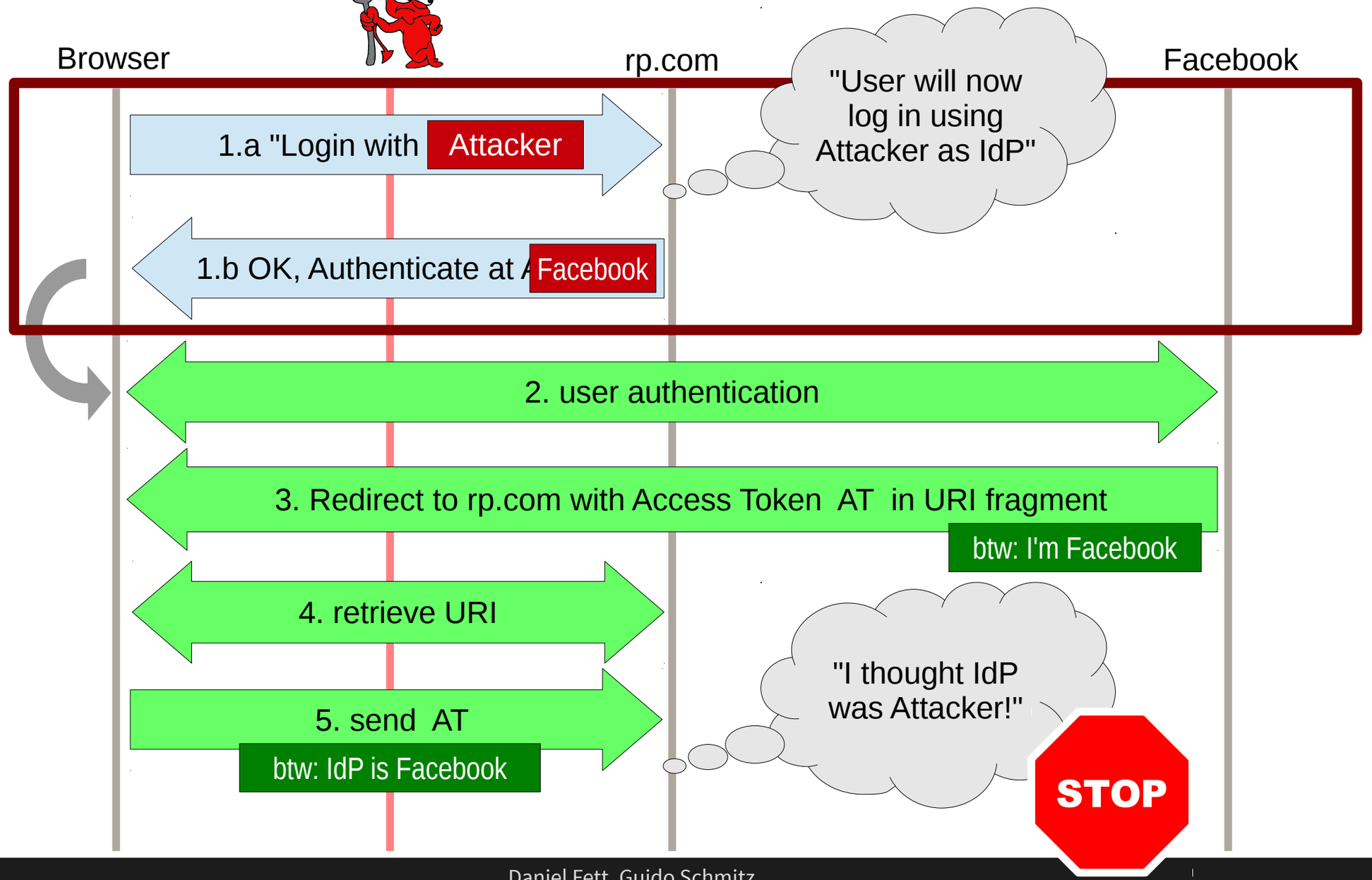
IdP Mix-Up Attack: Mitigation



IdP Mix-Up Attack: Mitigation



IdP Mix-Up Attack: Mitigation



Impact

- Emergency meeting of the IETF OAuth Working Group
- Public disclosure of the attacks
- Triggered OAuth Security Workshop
- New RFC in preparation
- Interest in formal analysis

OAuth 2.0

Security	**attacks + fix** **formally proven** 
Privacy	**NONE**

First Attempt with Privacy Feature:
BrowserID a.k.a. Mozilla Persona

BrowserID (a.k.a. Mozilla Persona)

- Web-based Single Sign-On system

- Design goals:
  - No central authority
  - Better privacy

BrowserID Overview

alice@mailprovider.com

Phase 1: Provisioning

BrowserID Overview

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BrowserID Overview

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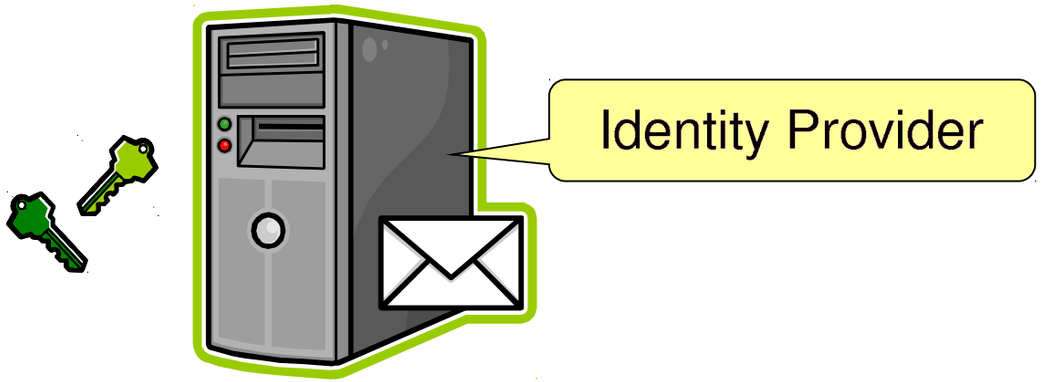

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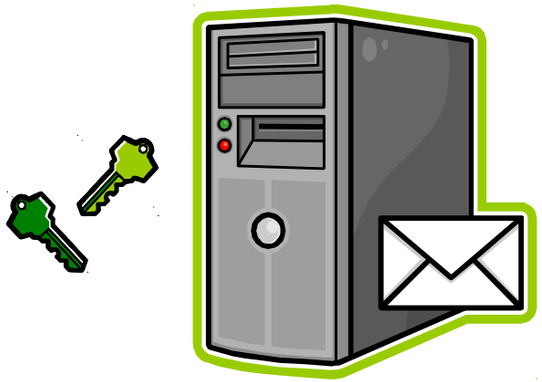

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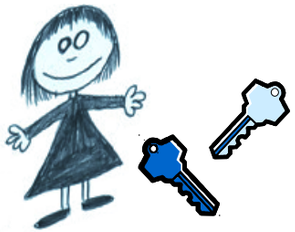
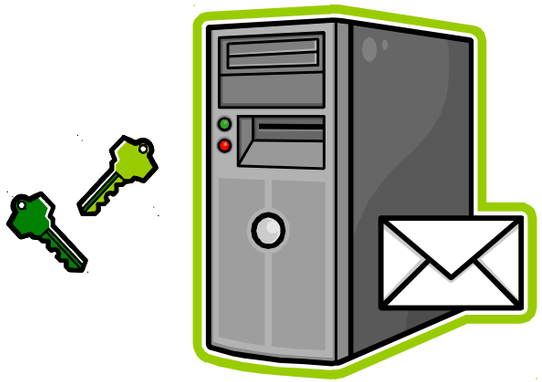


alice@mailprovider.com



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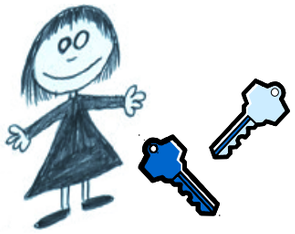

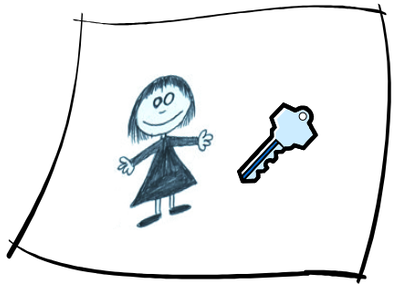

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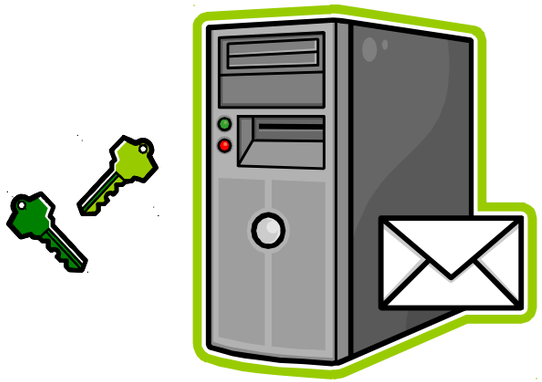

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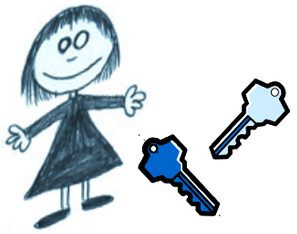

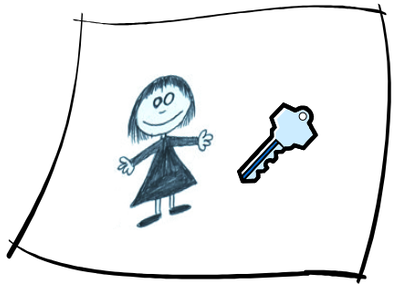

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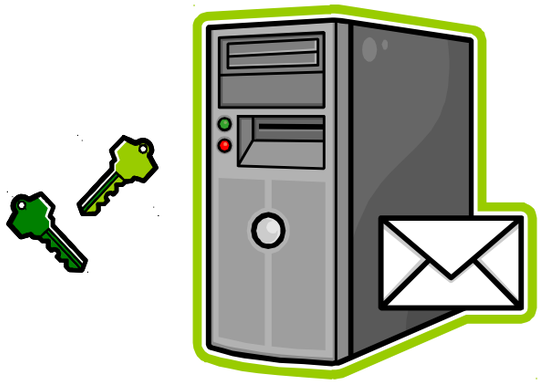

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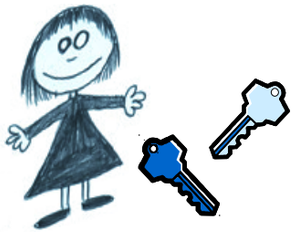

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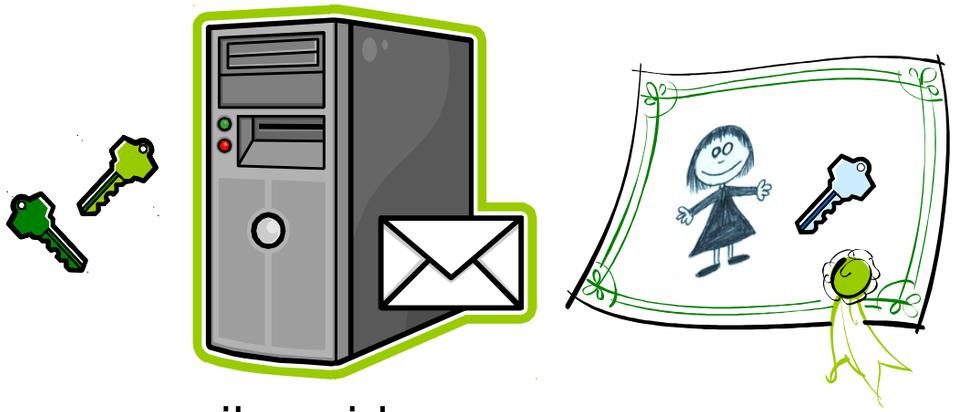

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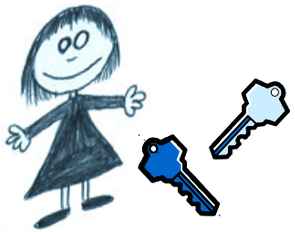

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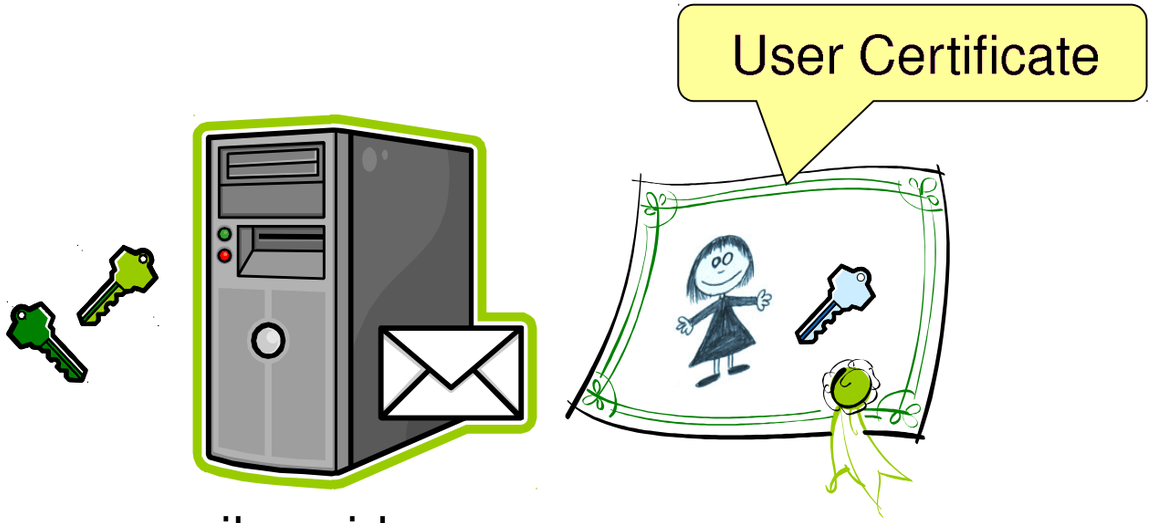

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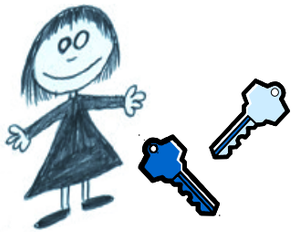

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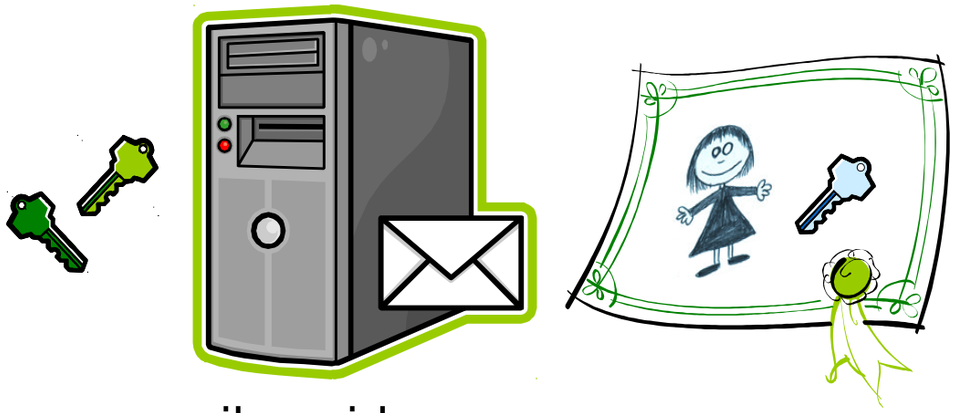

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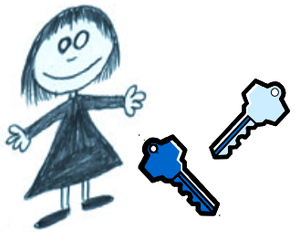
BrowserID Overview



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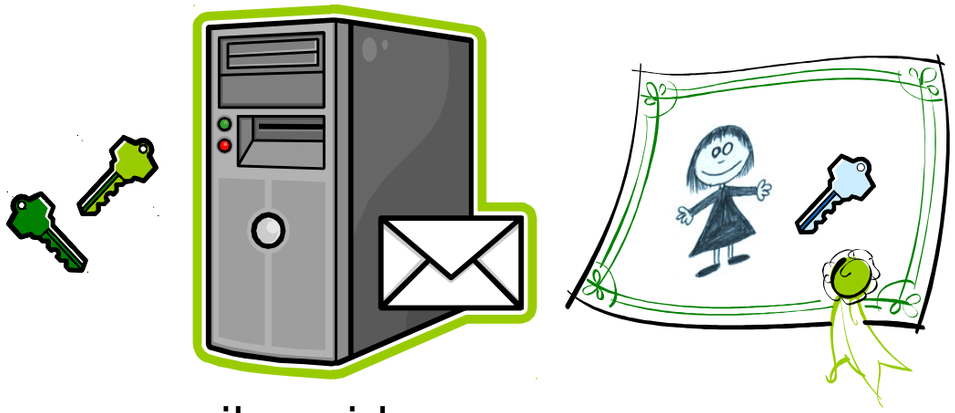

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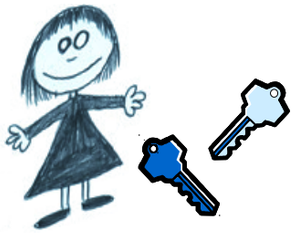
BrowserID Overview



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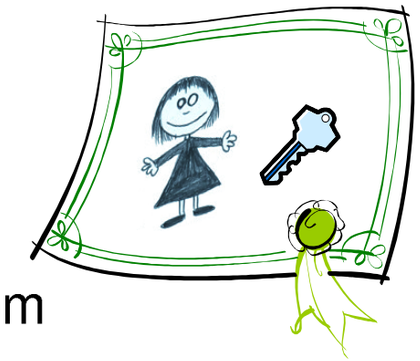
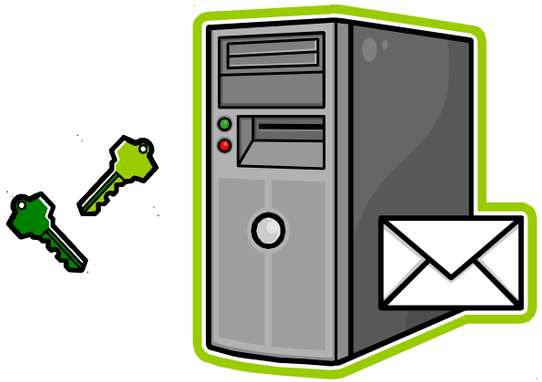


Phase 2: Authentication



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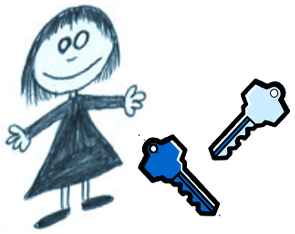

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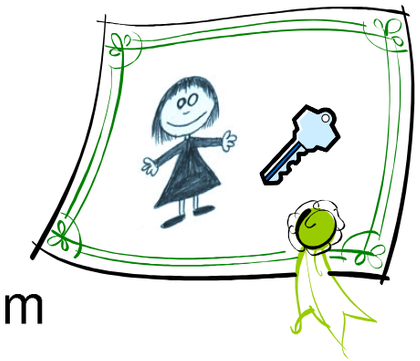

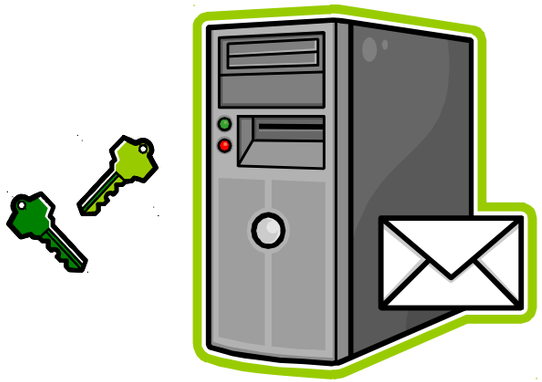

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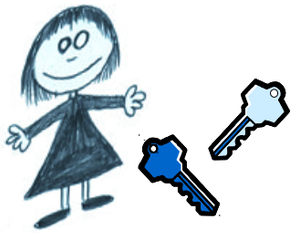

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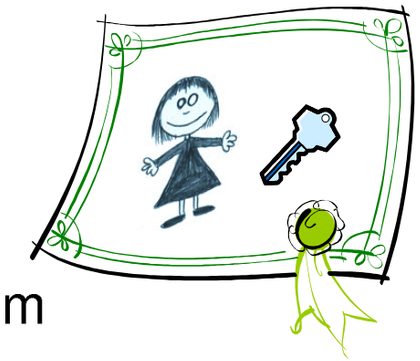

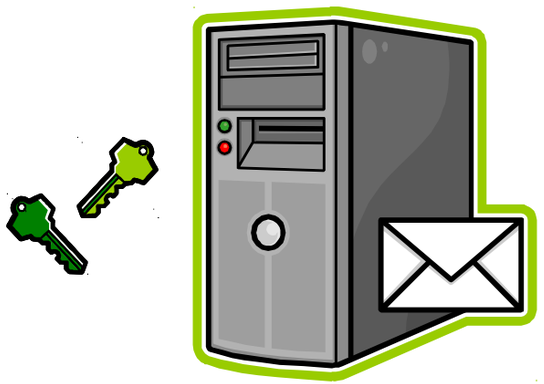

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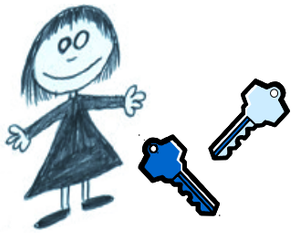
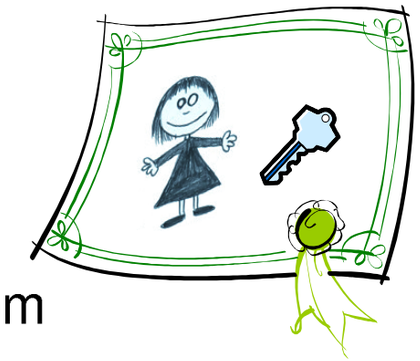
Relying Party

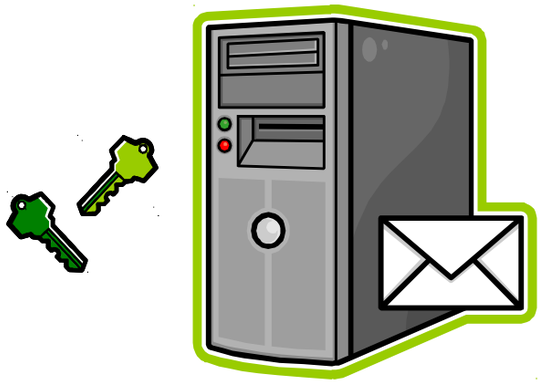
wikipedia.org

BrowserID Overview



alice@mailprovider.com

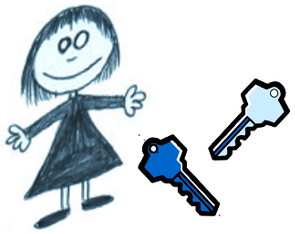




mailprovider.com

wikipedia.org

BrowserID Overview



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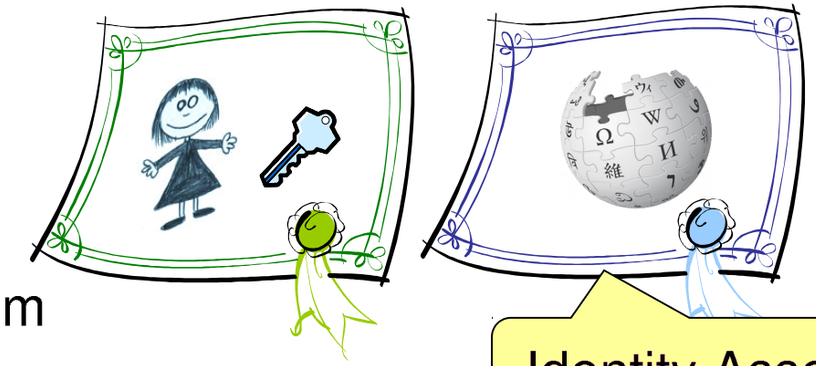
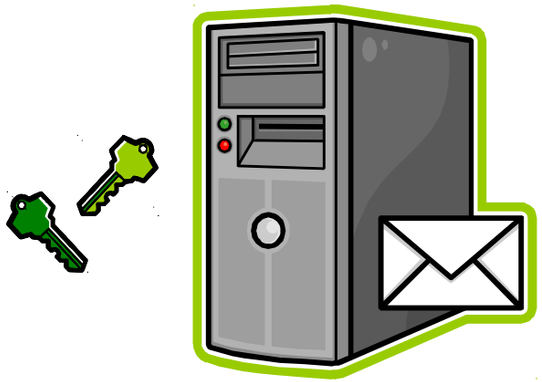


Identity Assertion



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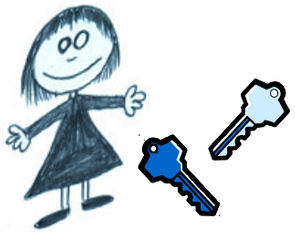
BrowserID Overview



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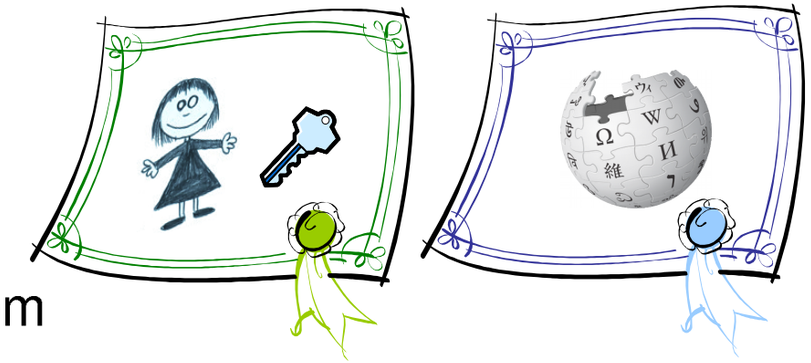

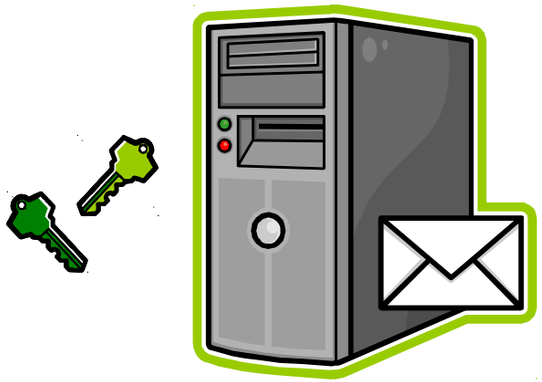

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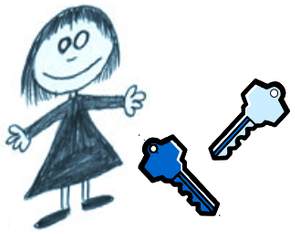
wikipedia.org

BrowserID Overview



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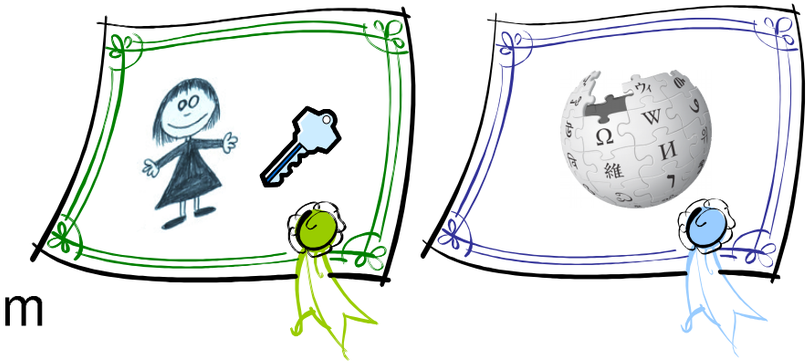

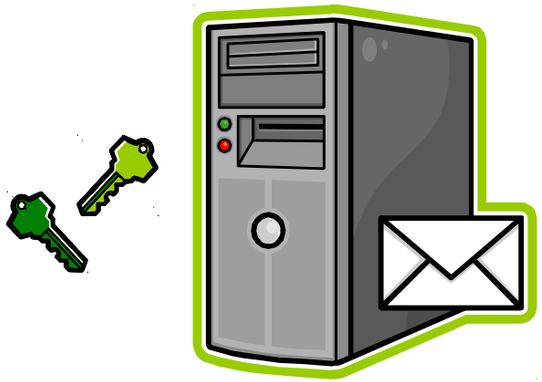

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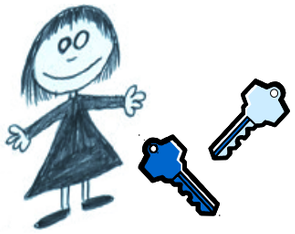
wikipedia.org

BrowserID Overview



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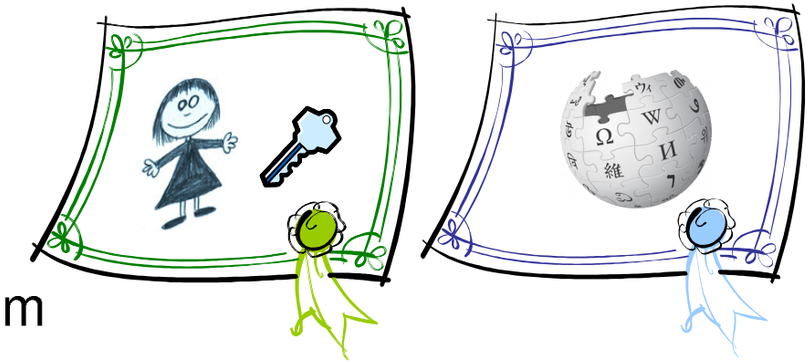

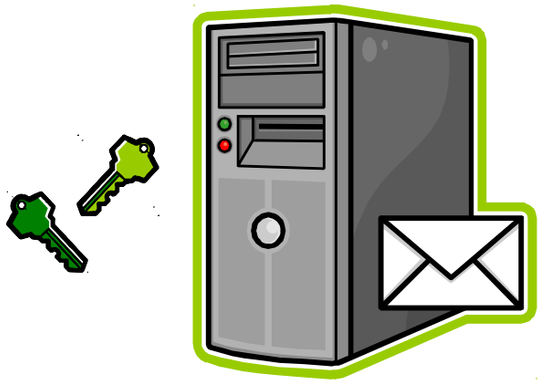

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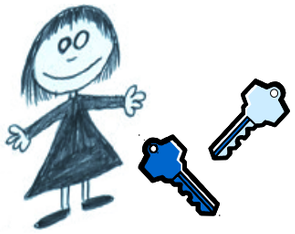
BrowserID Overview



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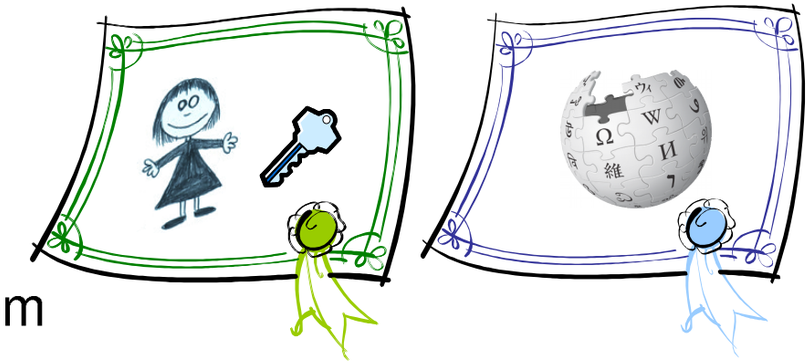

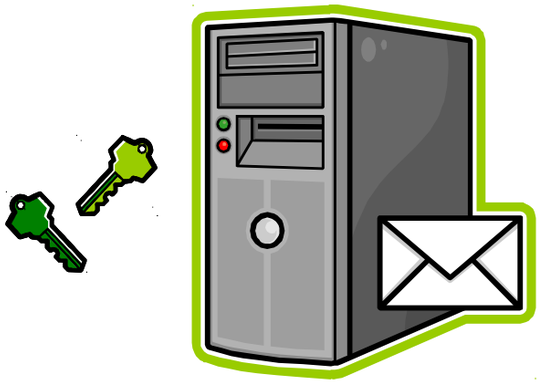

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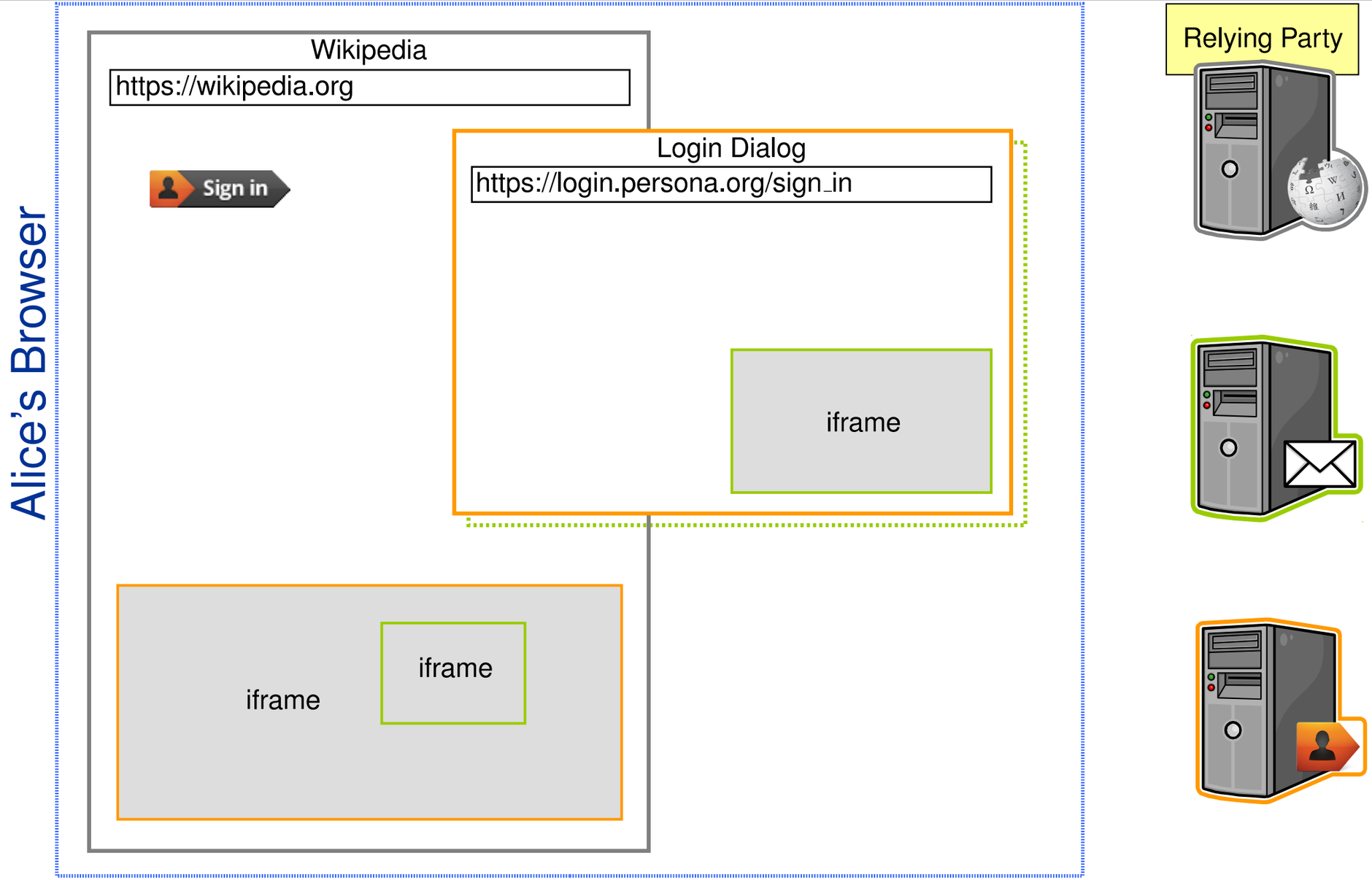
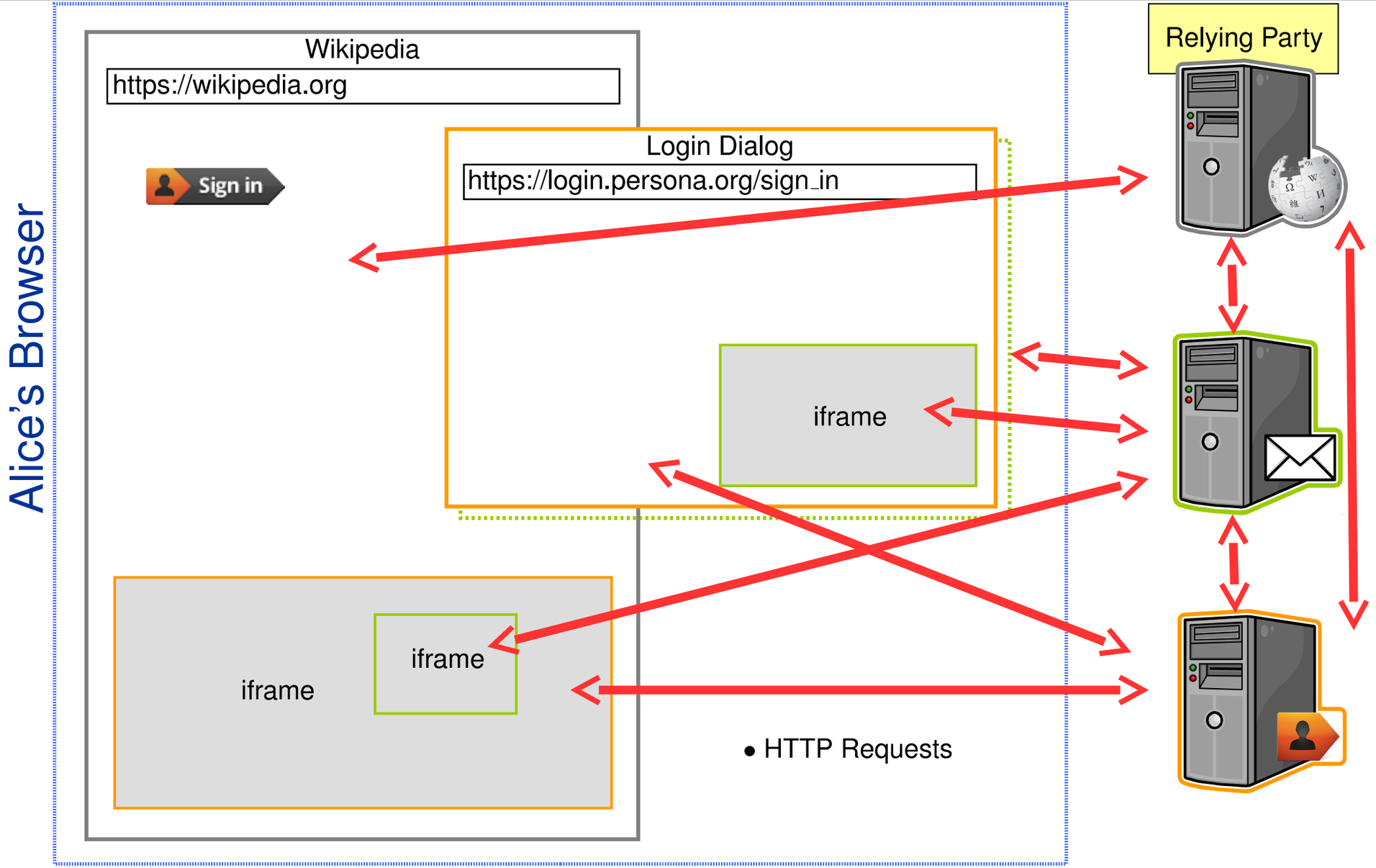
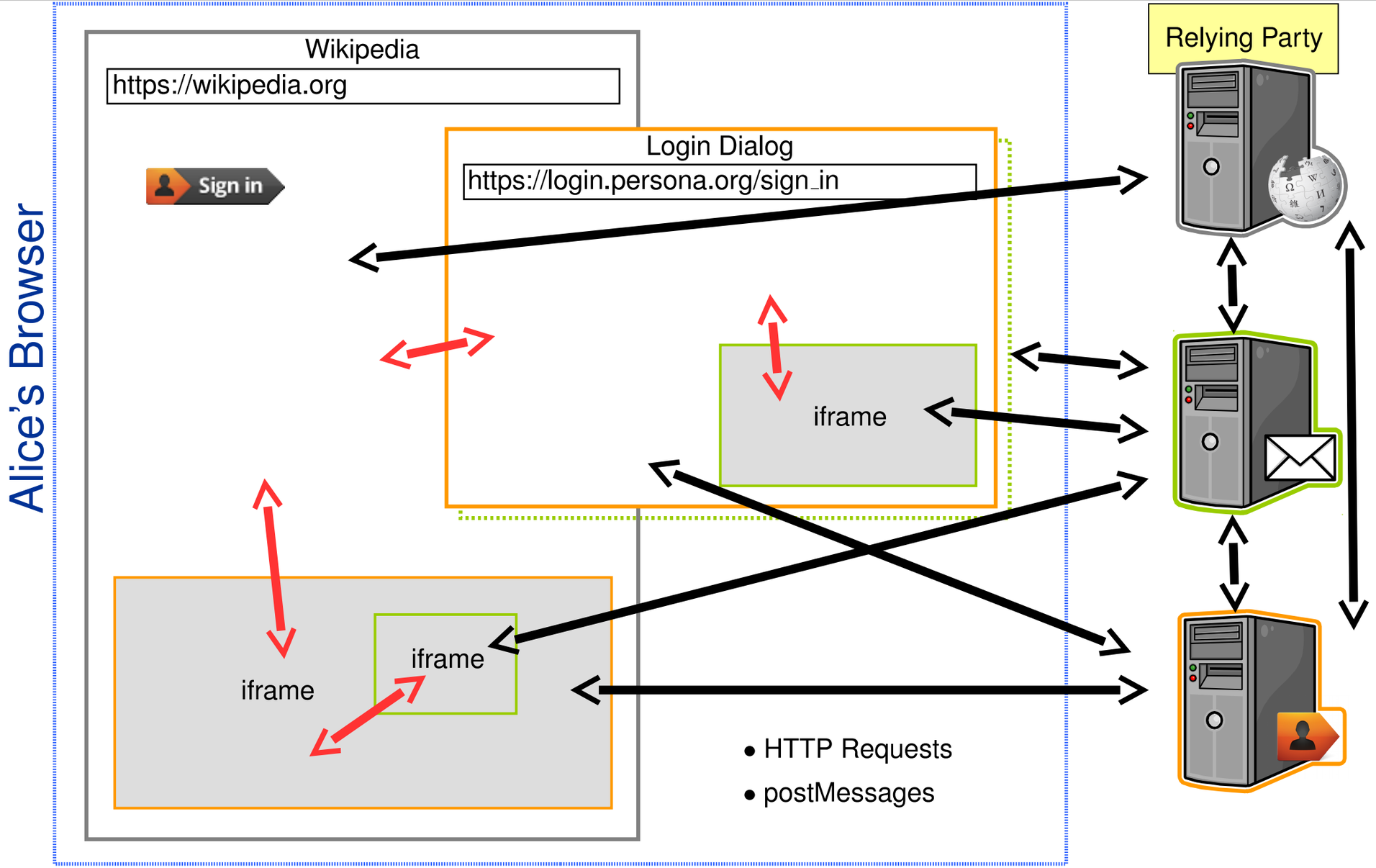
BrowserID Implementation



BrowserID Implementation



BrowserID Implementation



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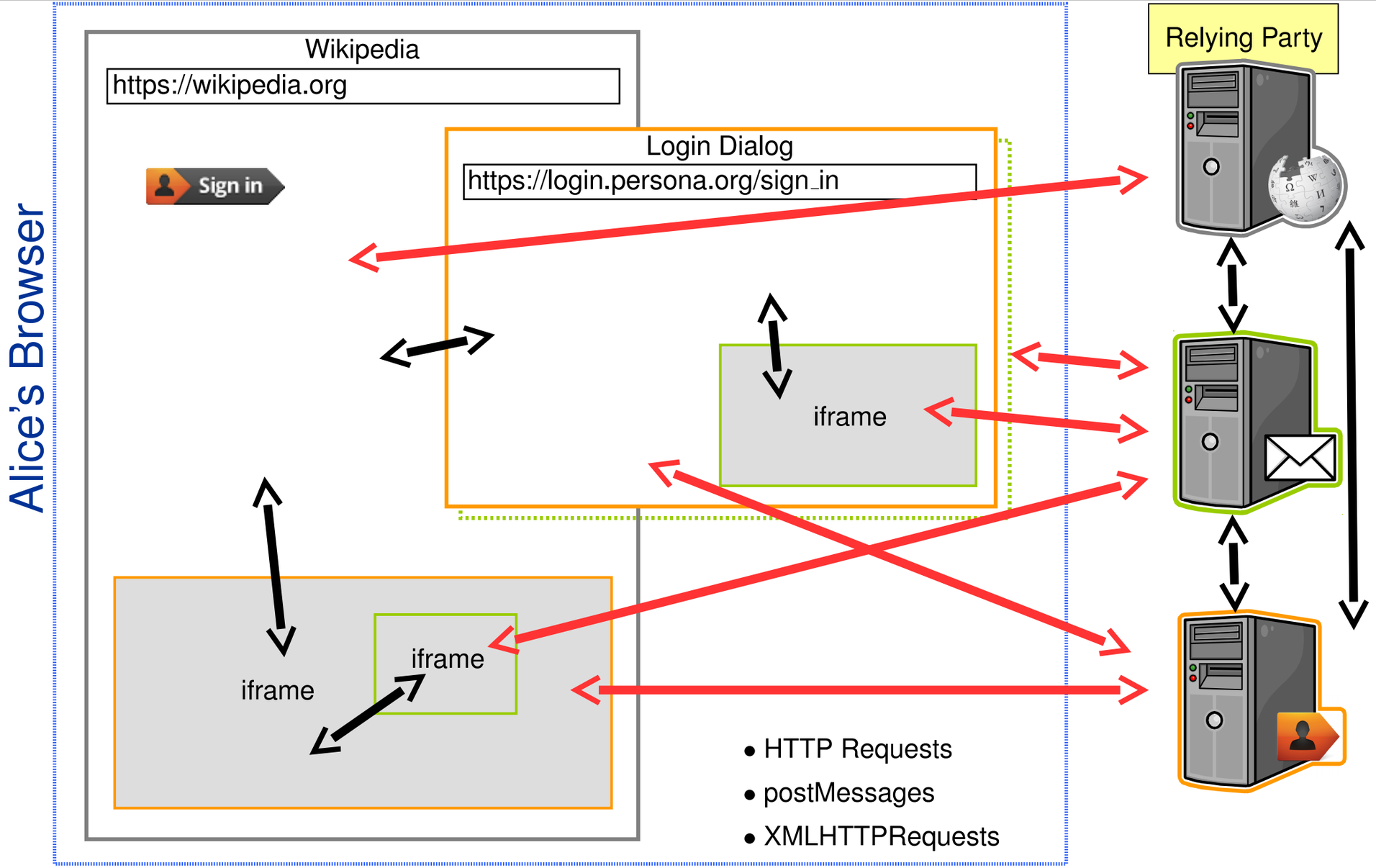

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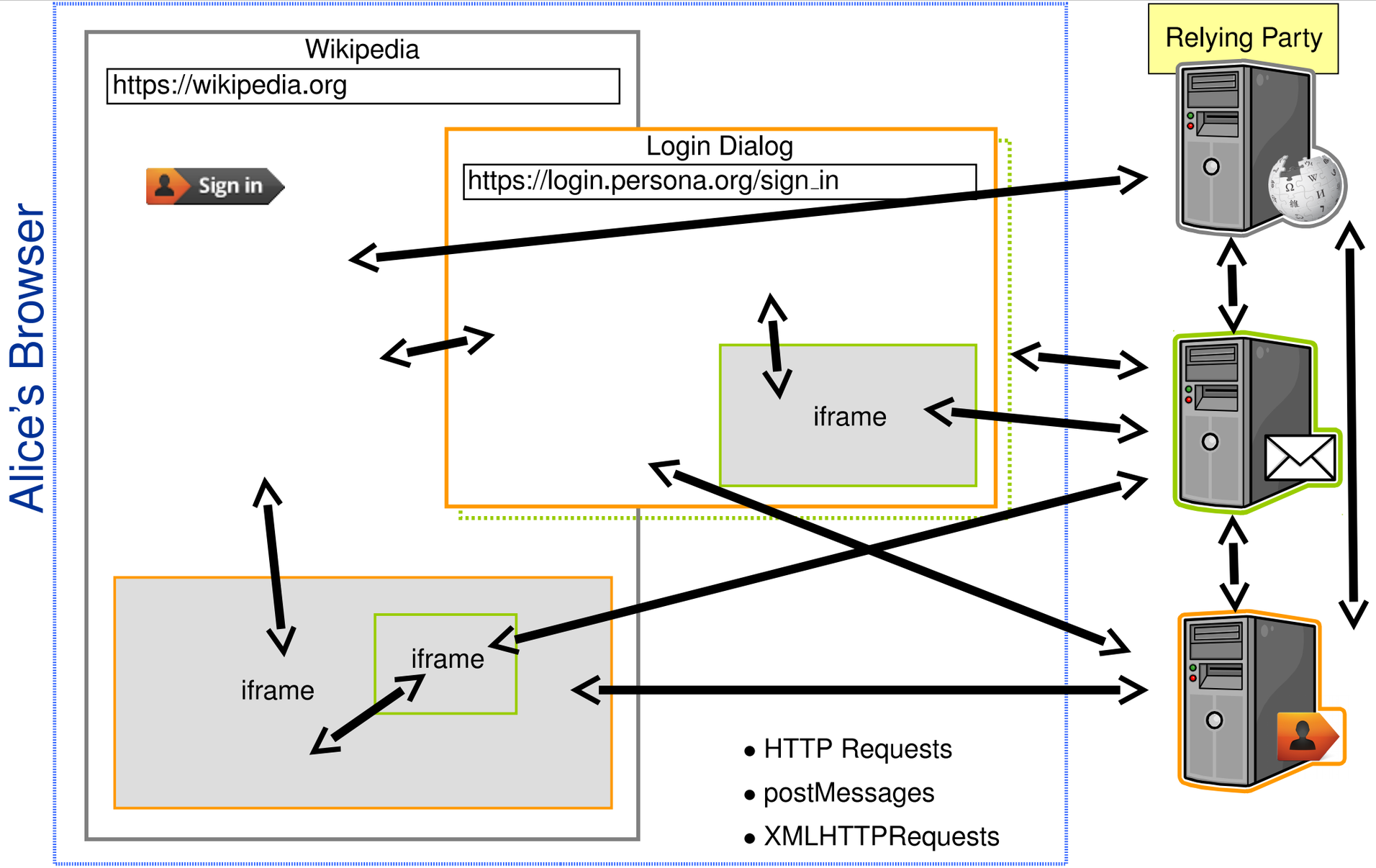
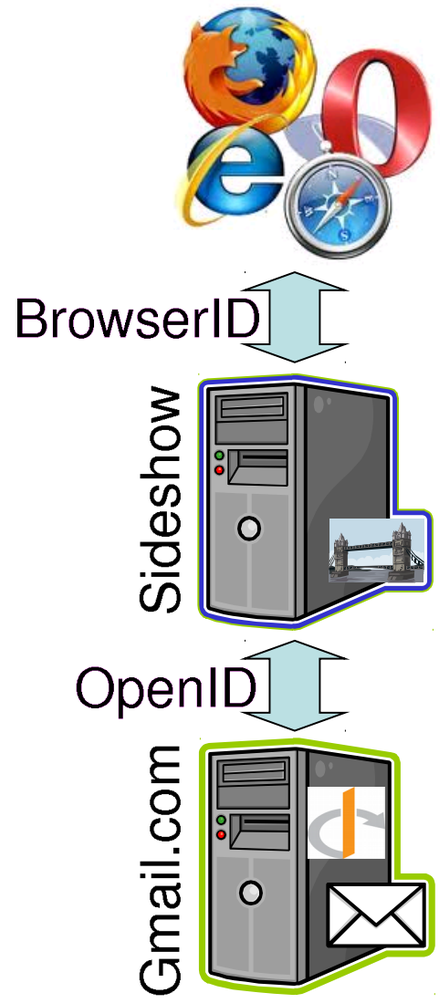


Identity Bridge

- Gmail.com / Yahoo.com (used to) support OpenID authentication (only)
- New party: Bridging Server
  - Sideshow (for Gmail.com)
  - BigTent (for Yahoo.com)
- User authenticates to bridging server via OpenID
- Bridging server provides BrowserID interface
- Problem: OpenID identities are not email addresses
  Solution: additional email attribute (OpenID AX)



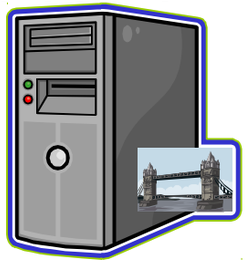
Identity Bridge

Alice's Browser

https://sideshow/...

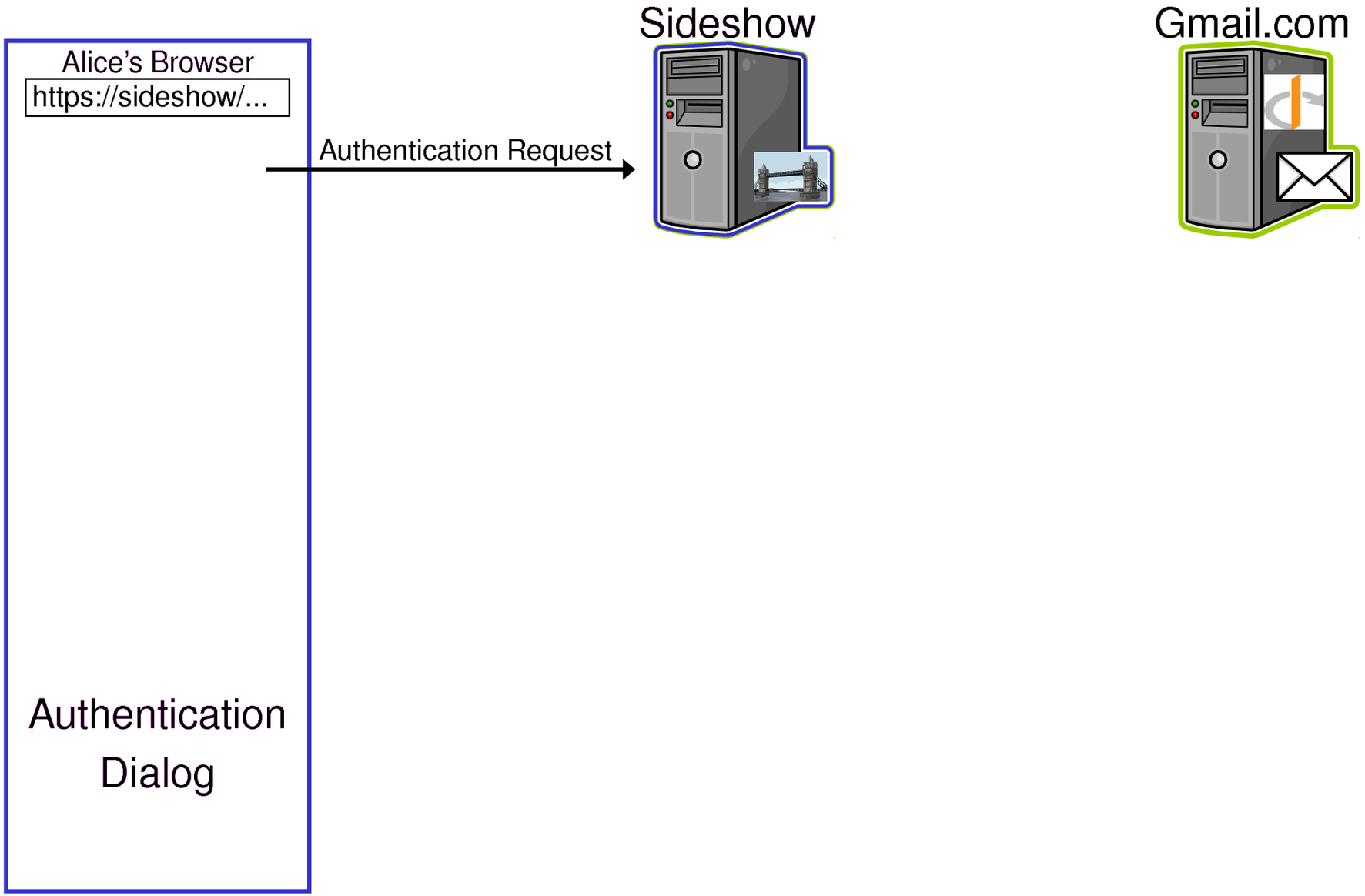
Authentication Dialog

Sideshow



Gmail.com

Identity Bridge



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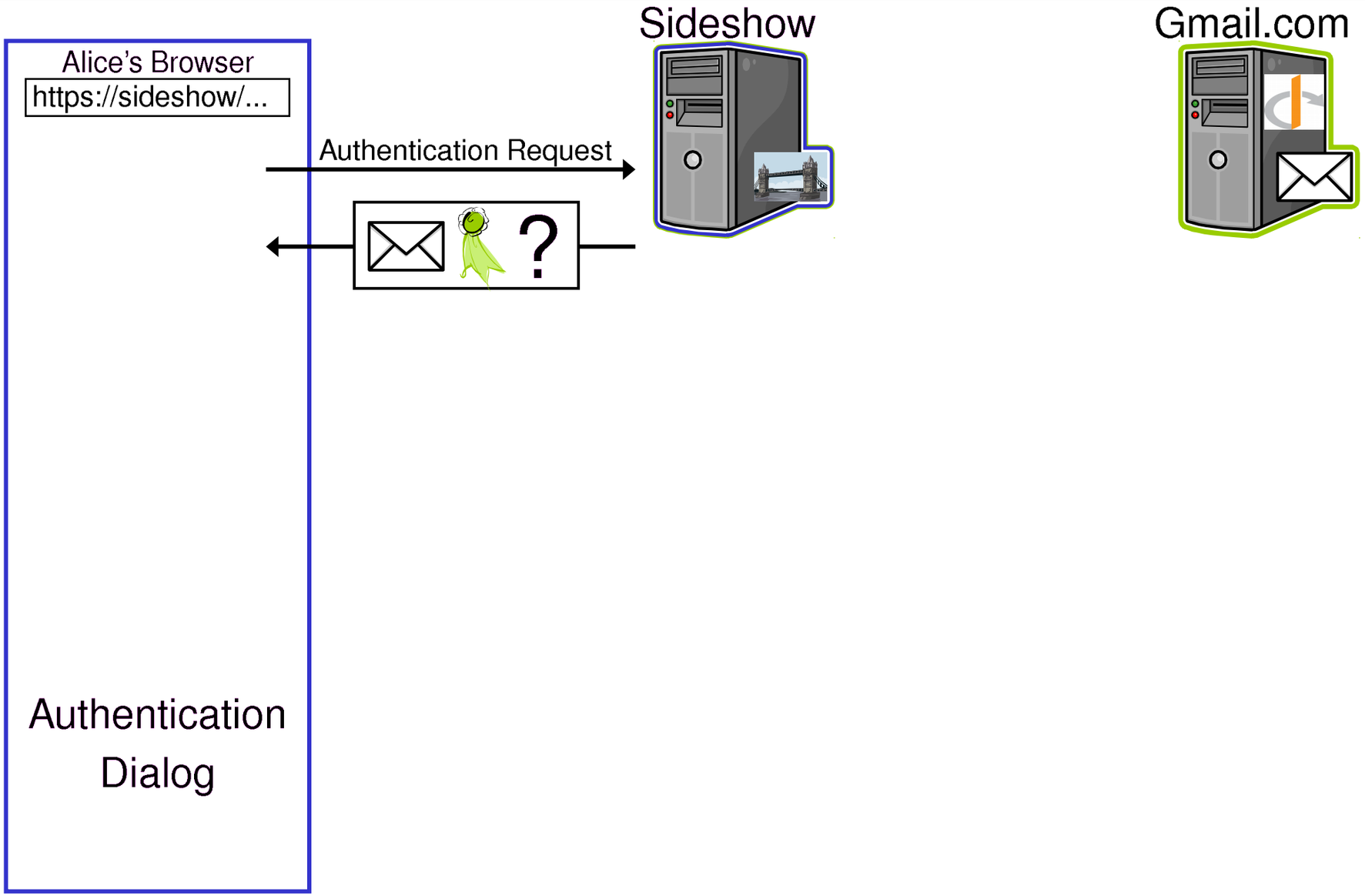

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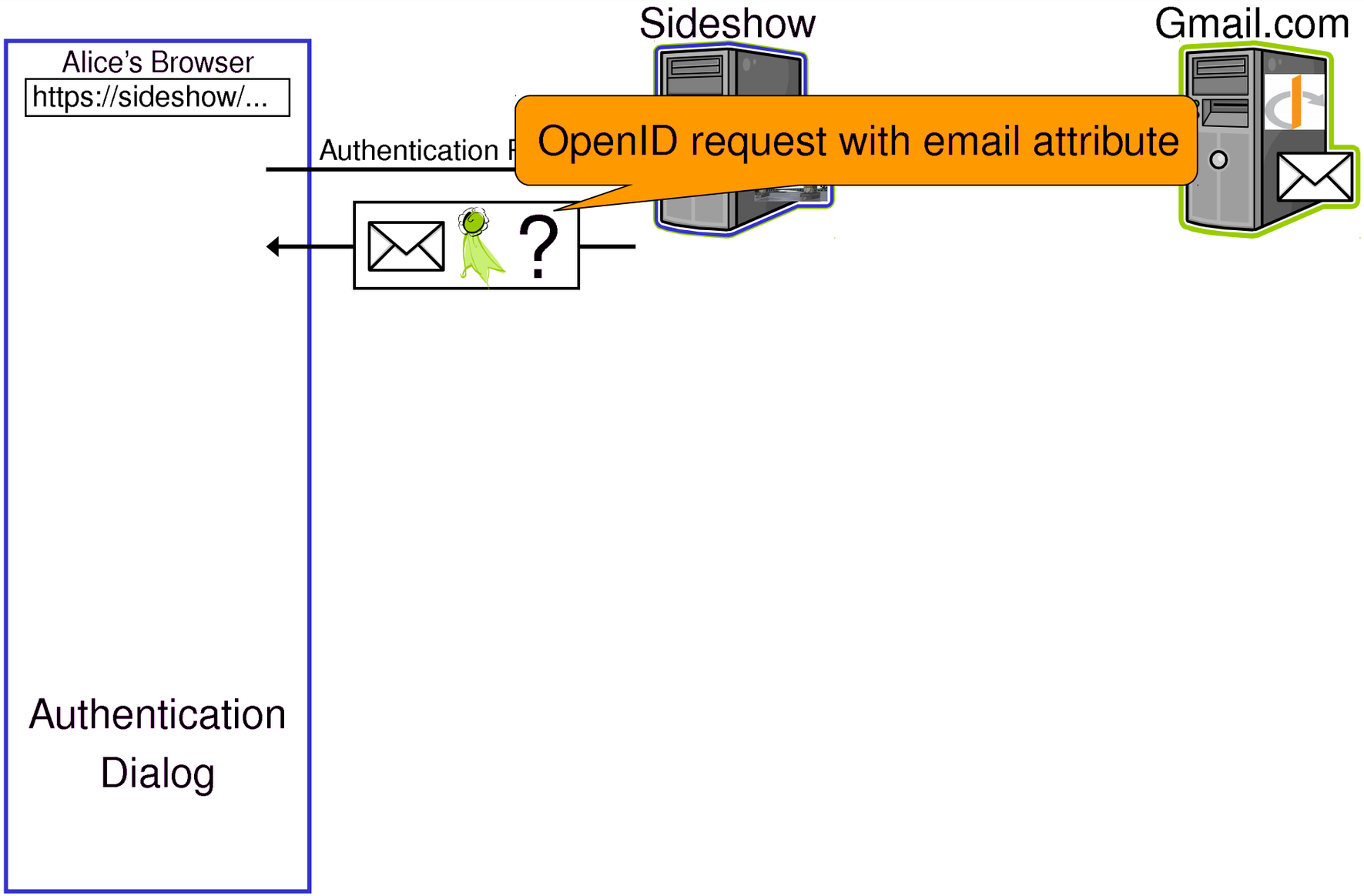

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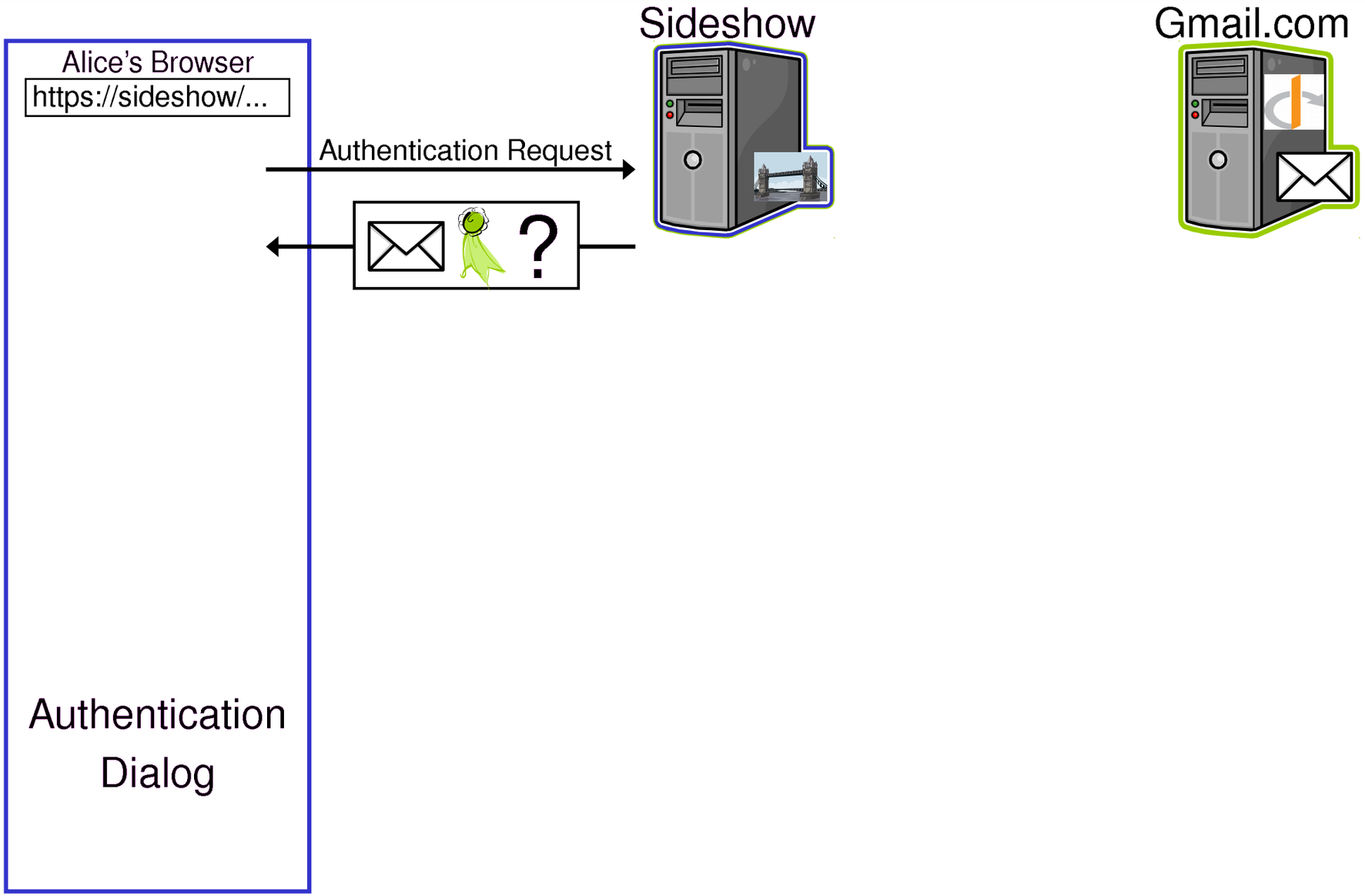

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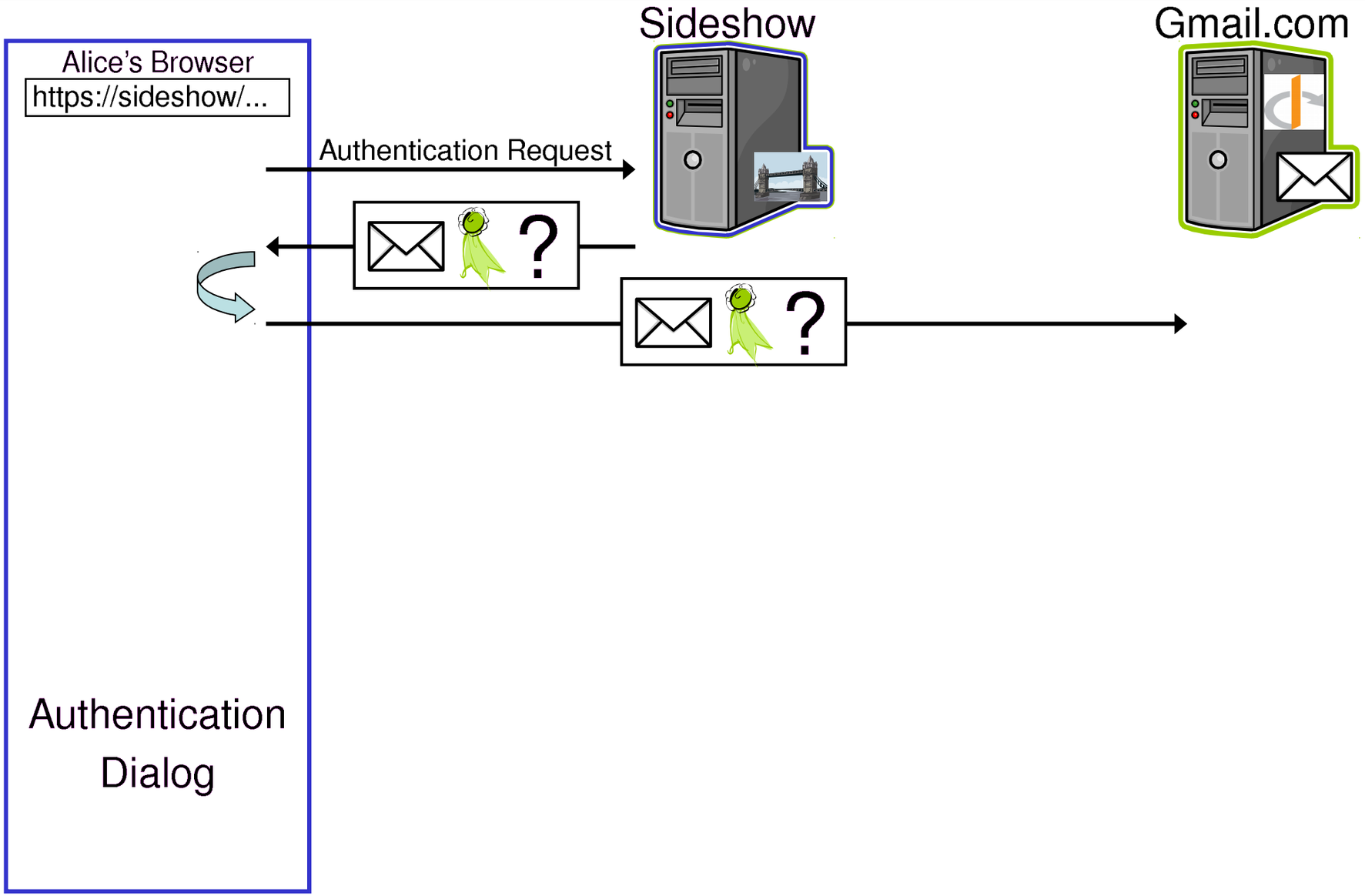

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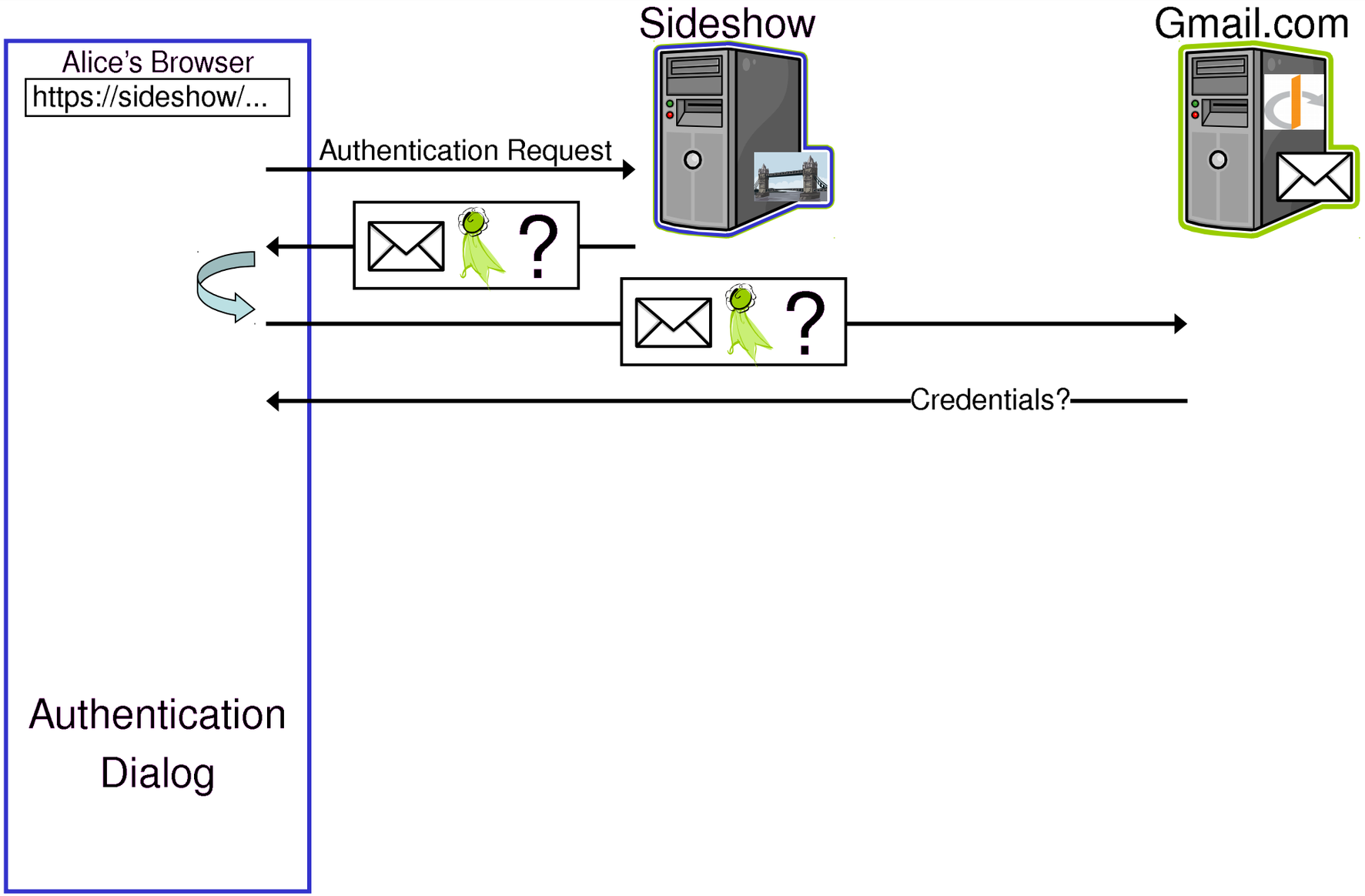

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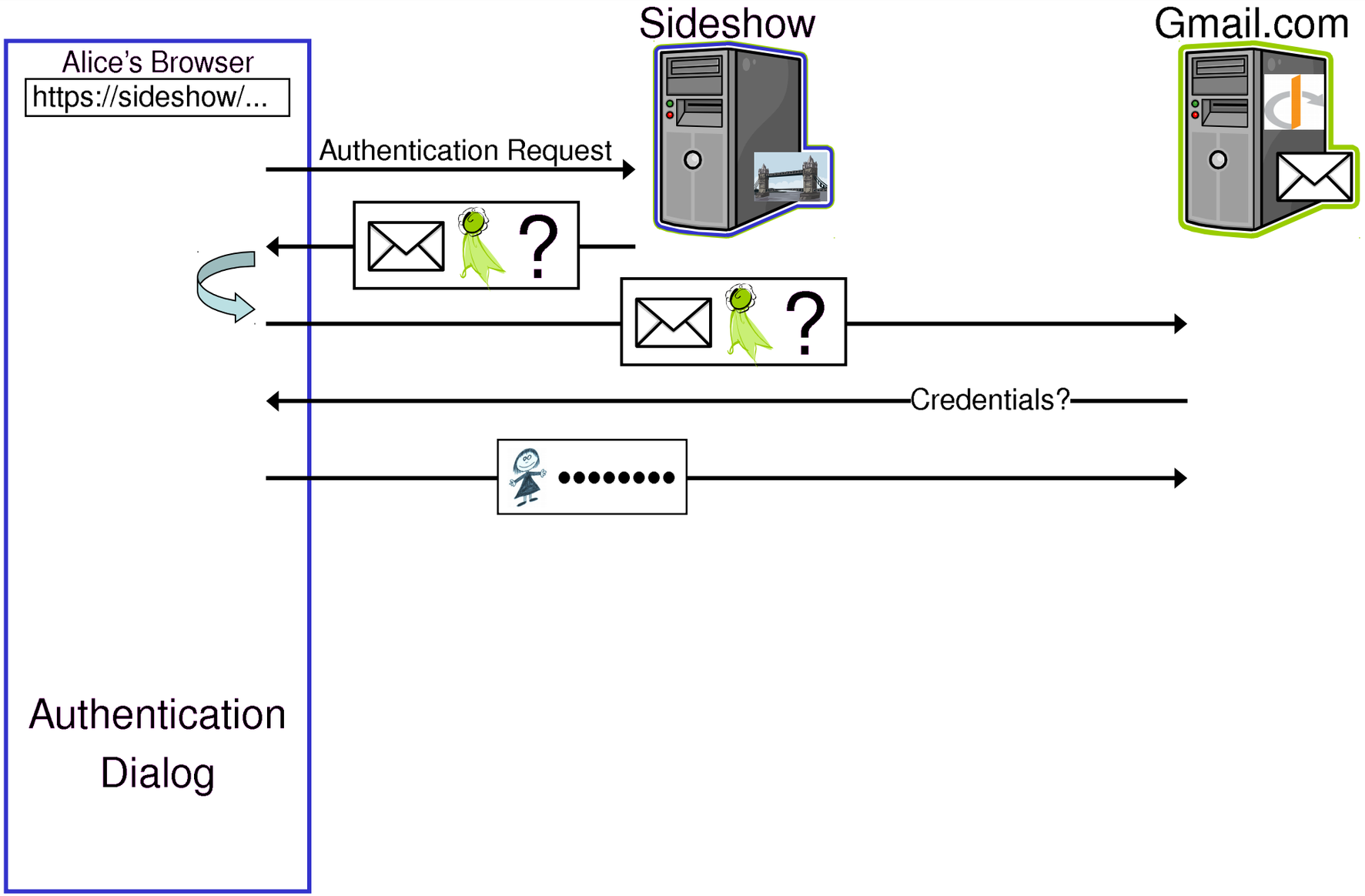

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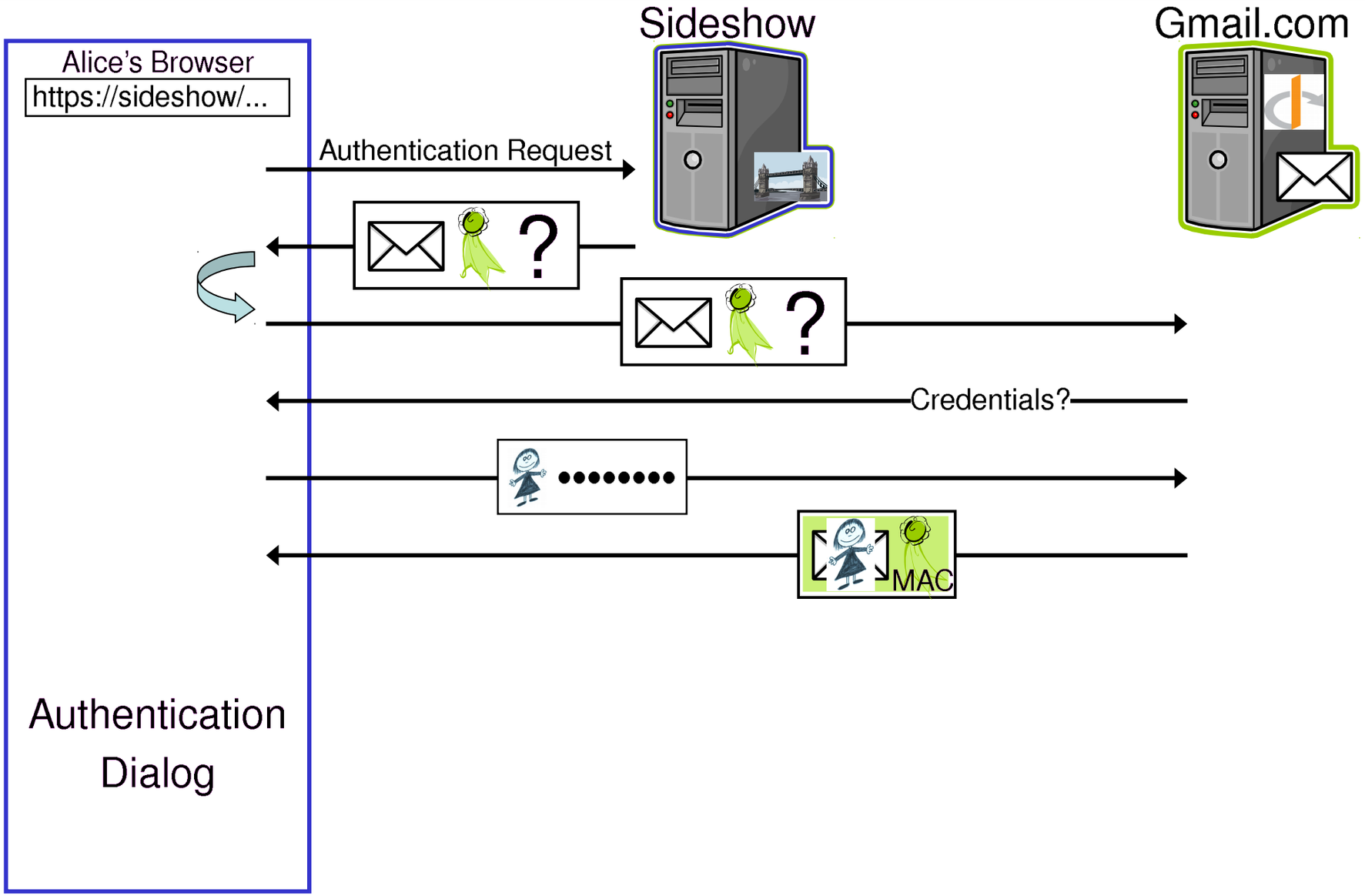

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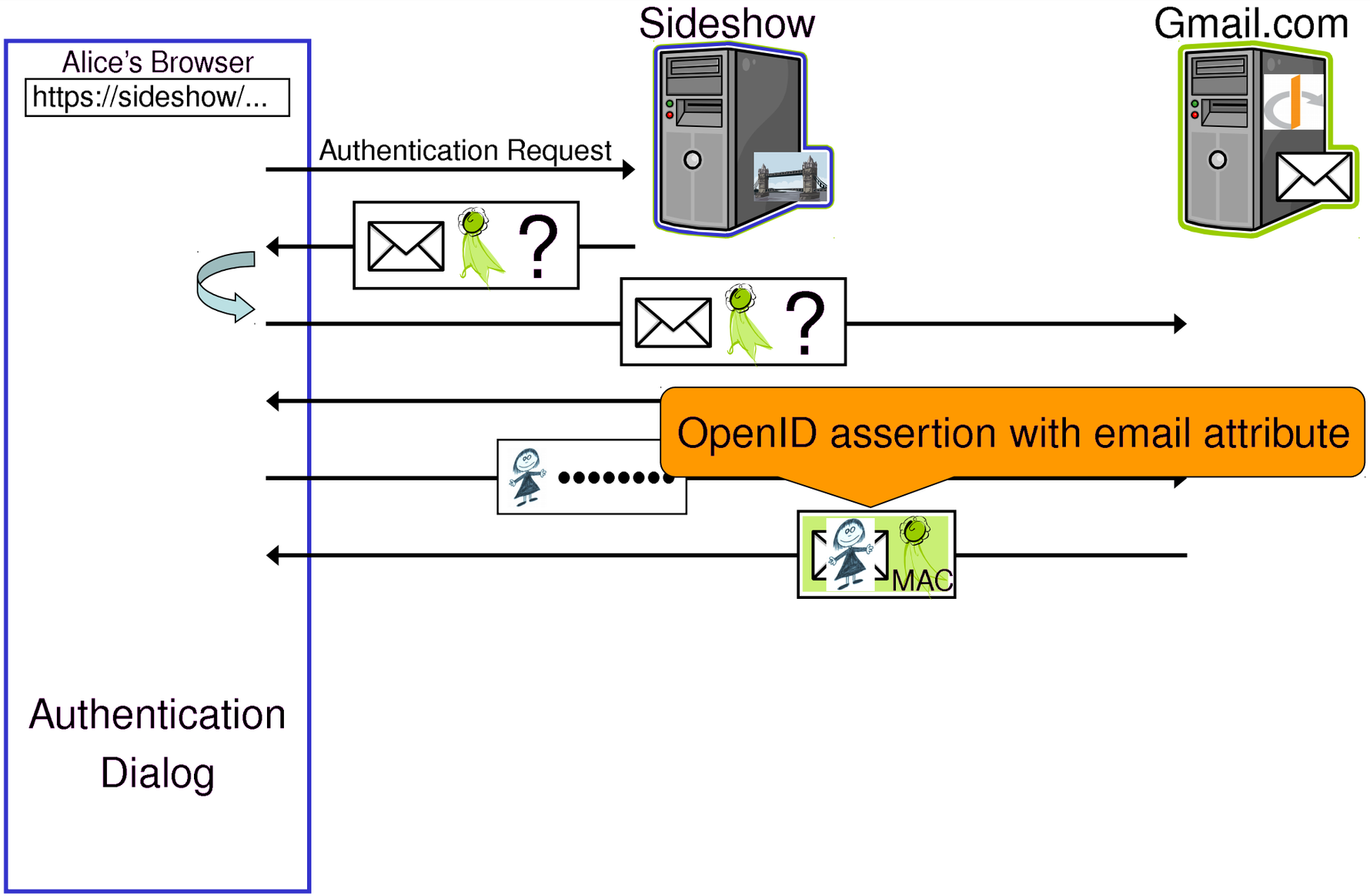

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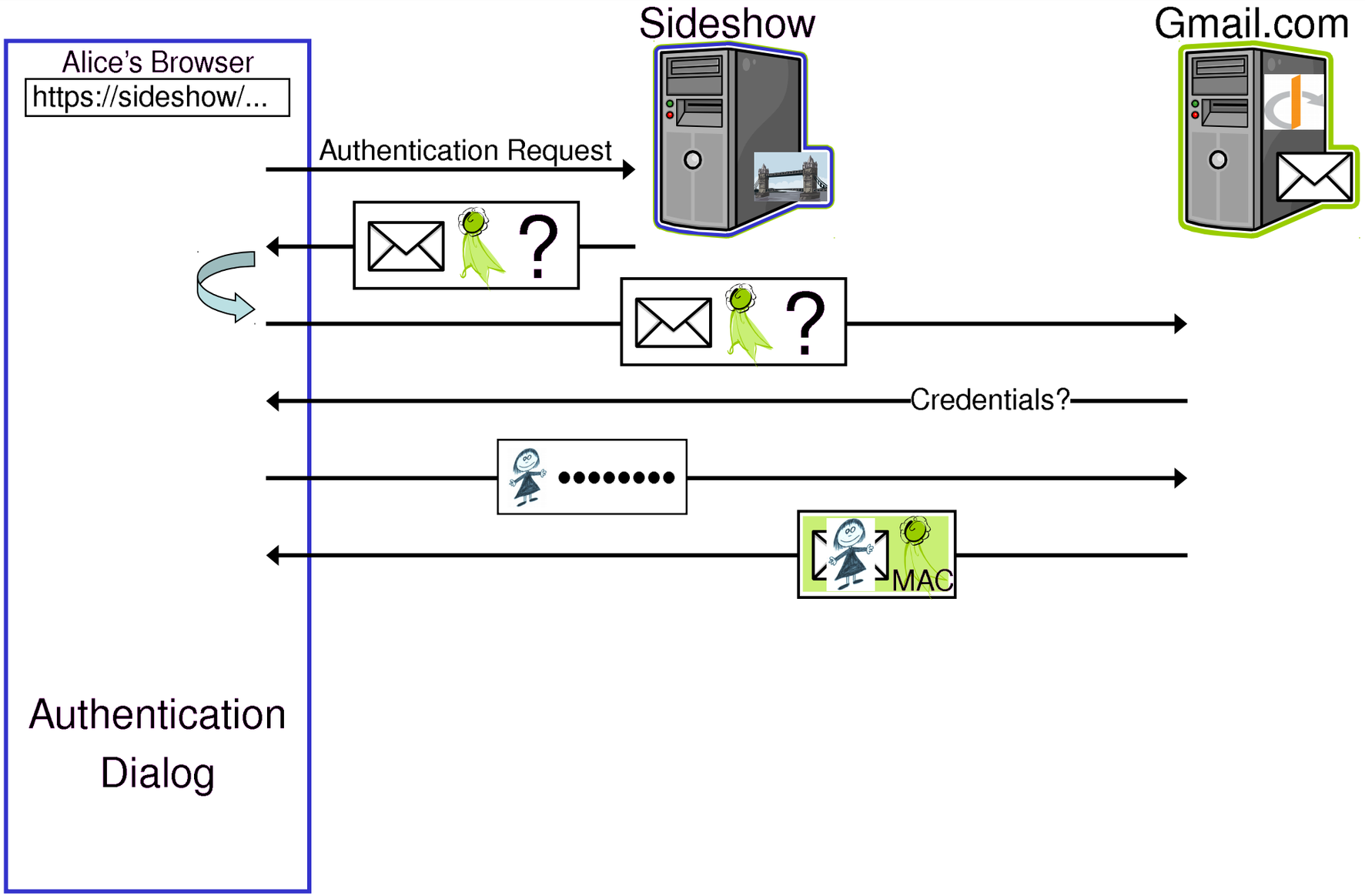

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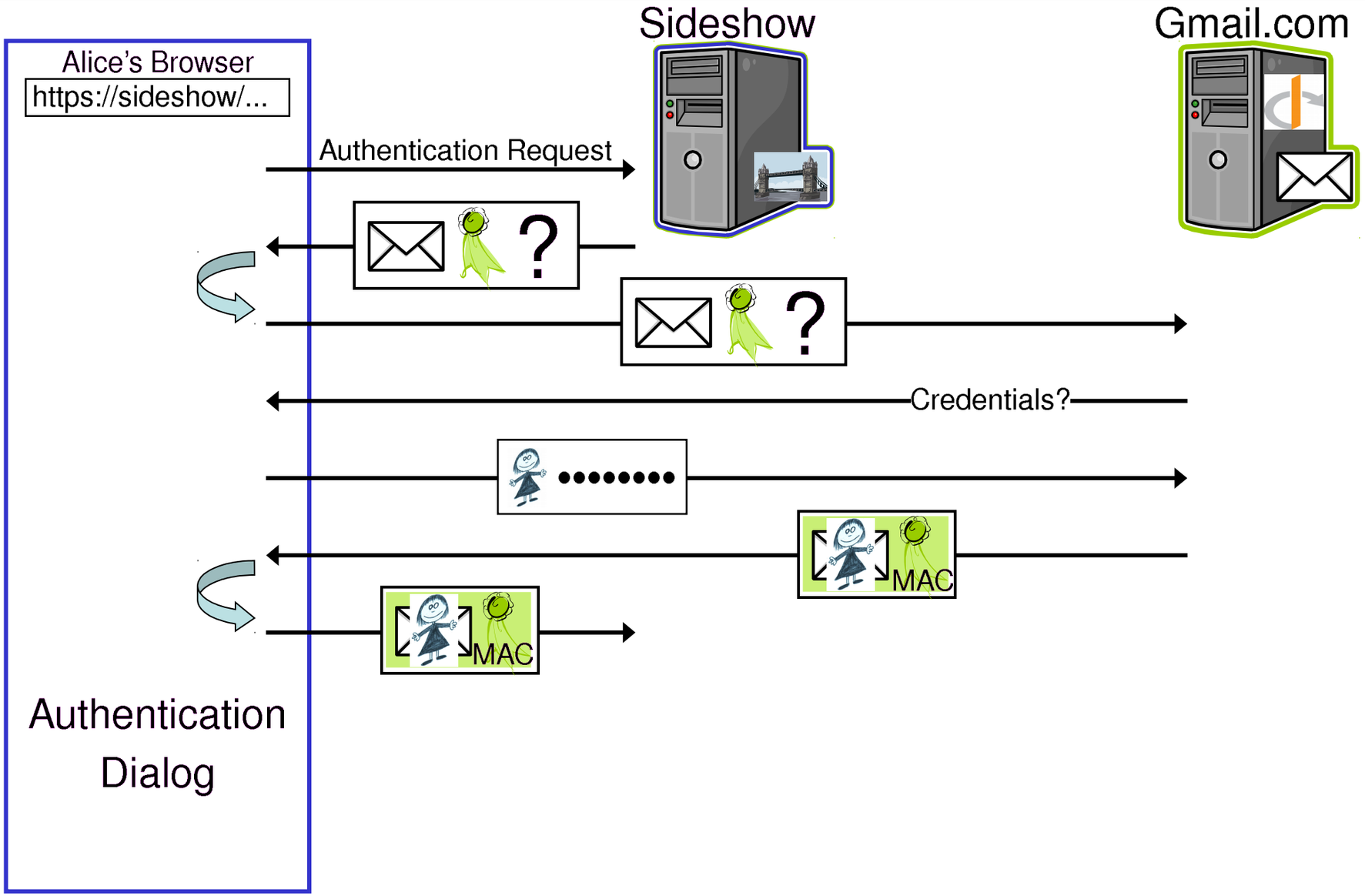

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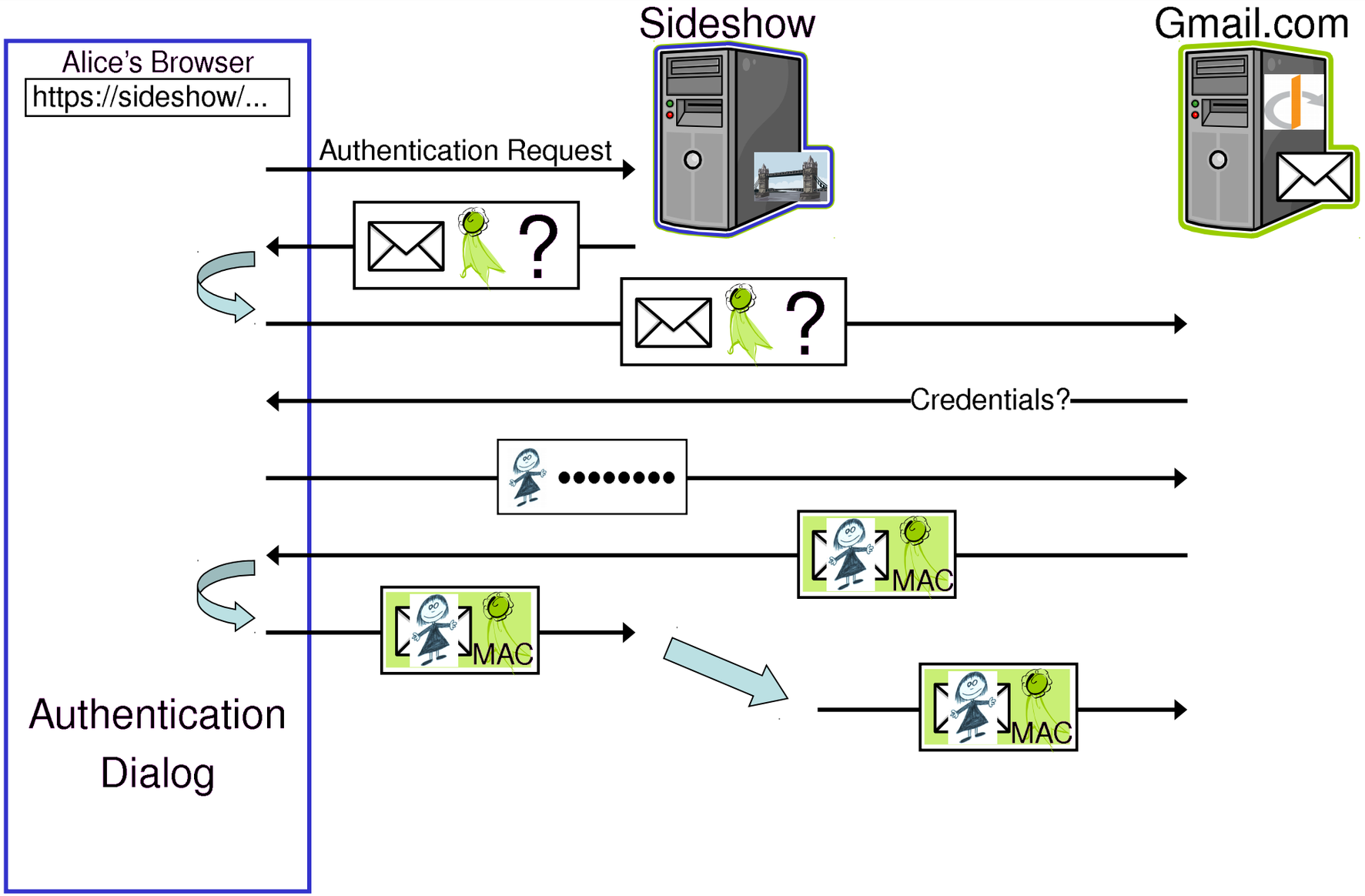

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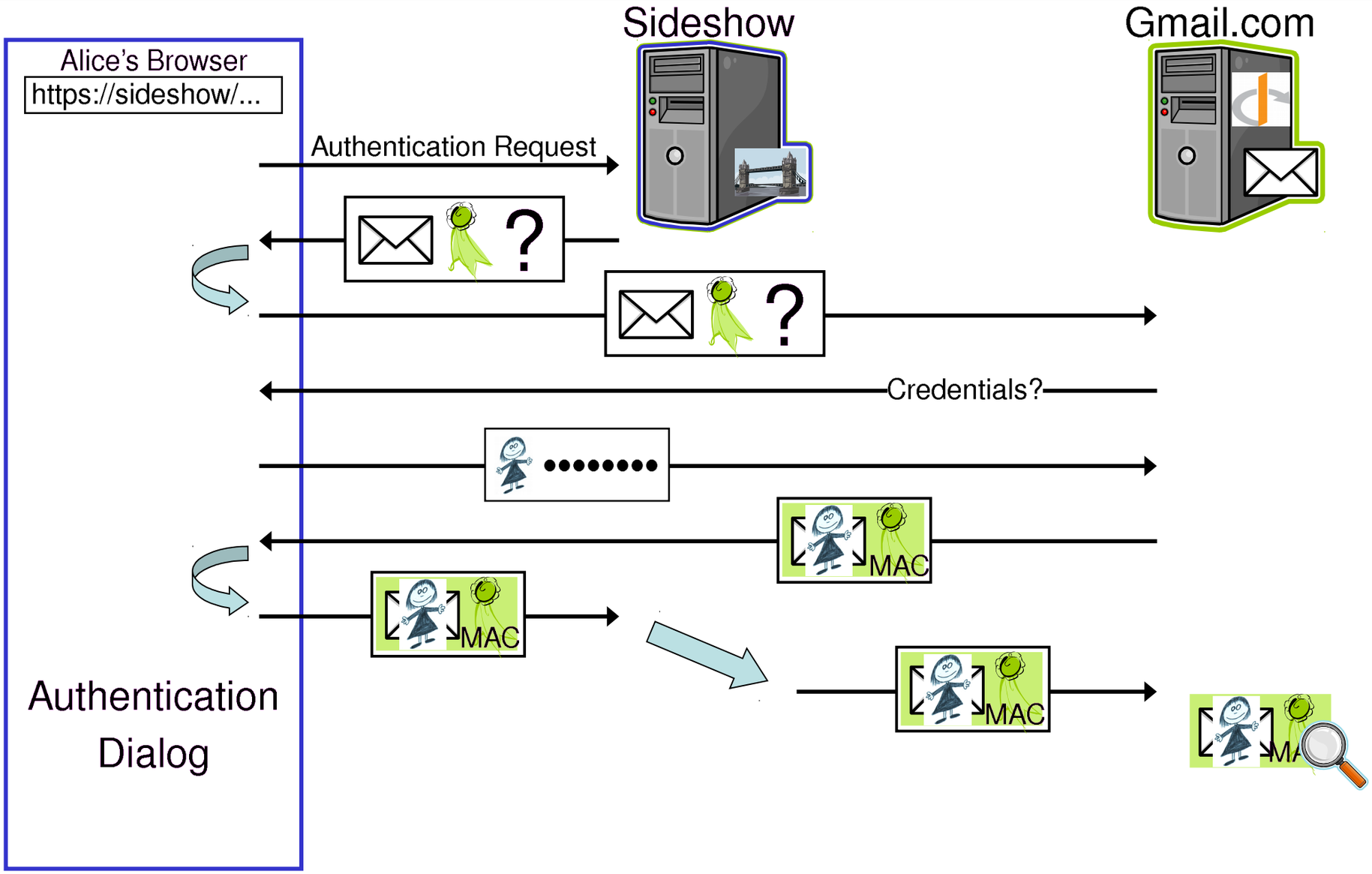

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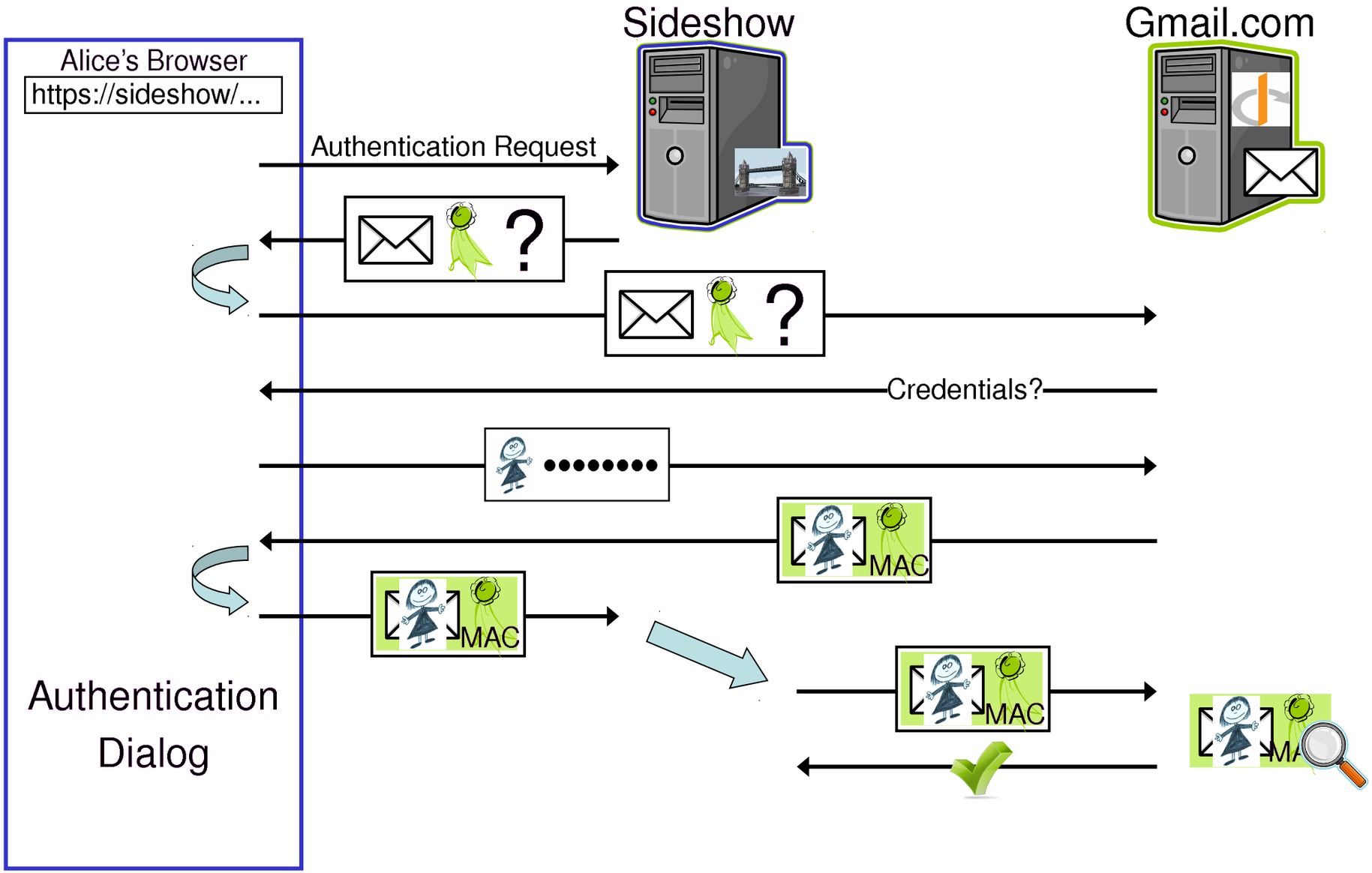

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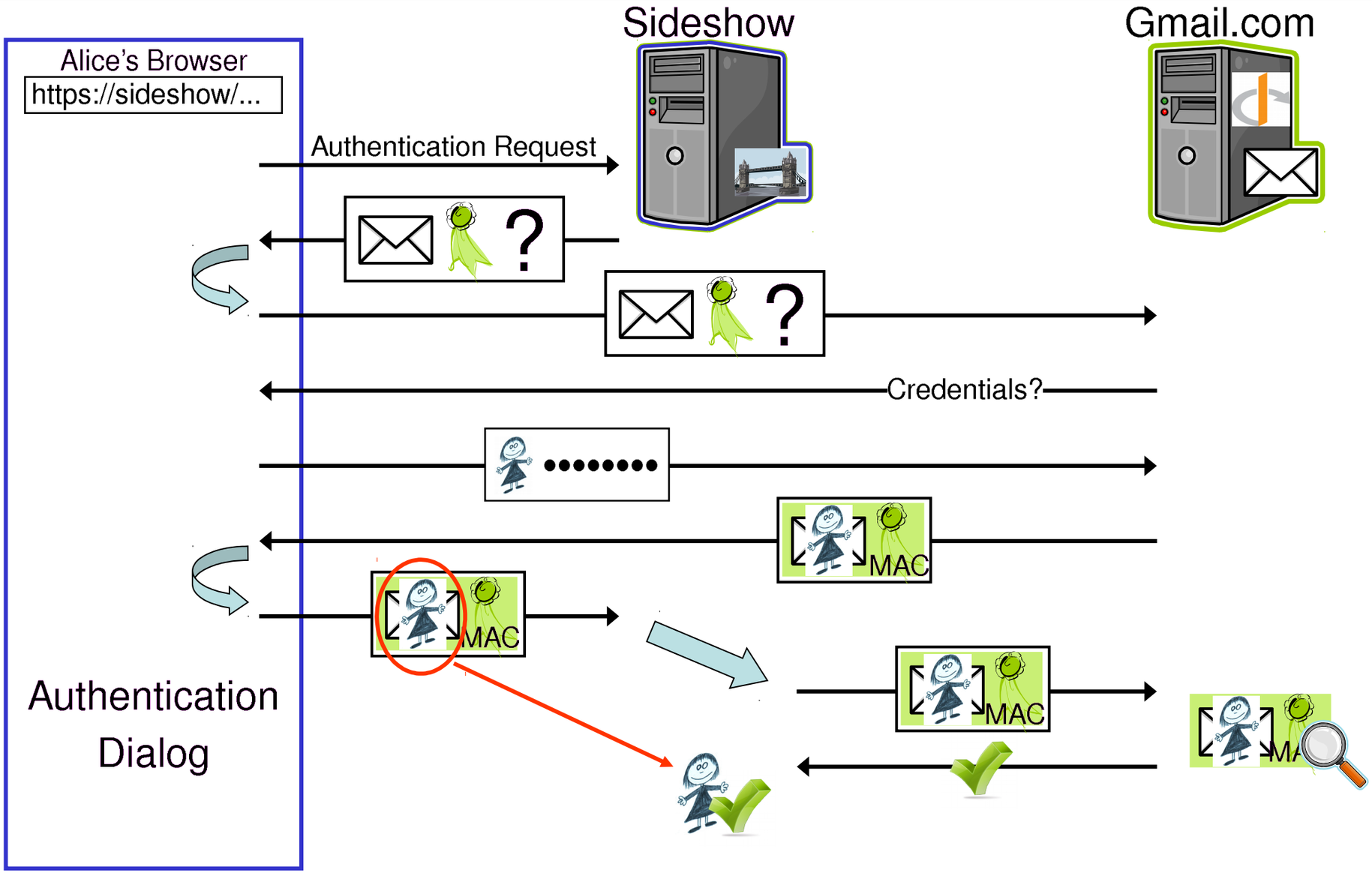

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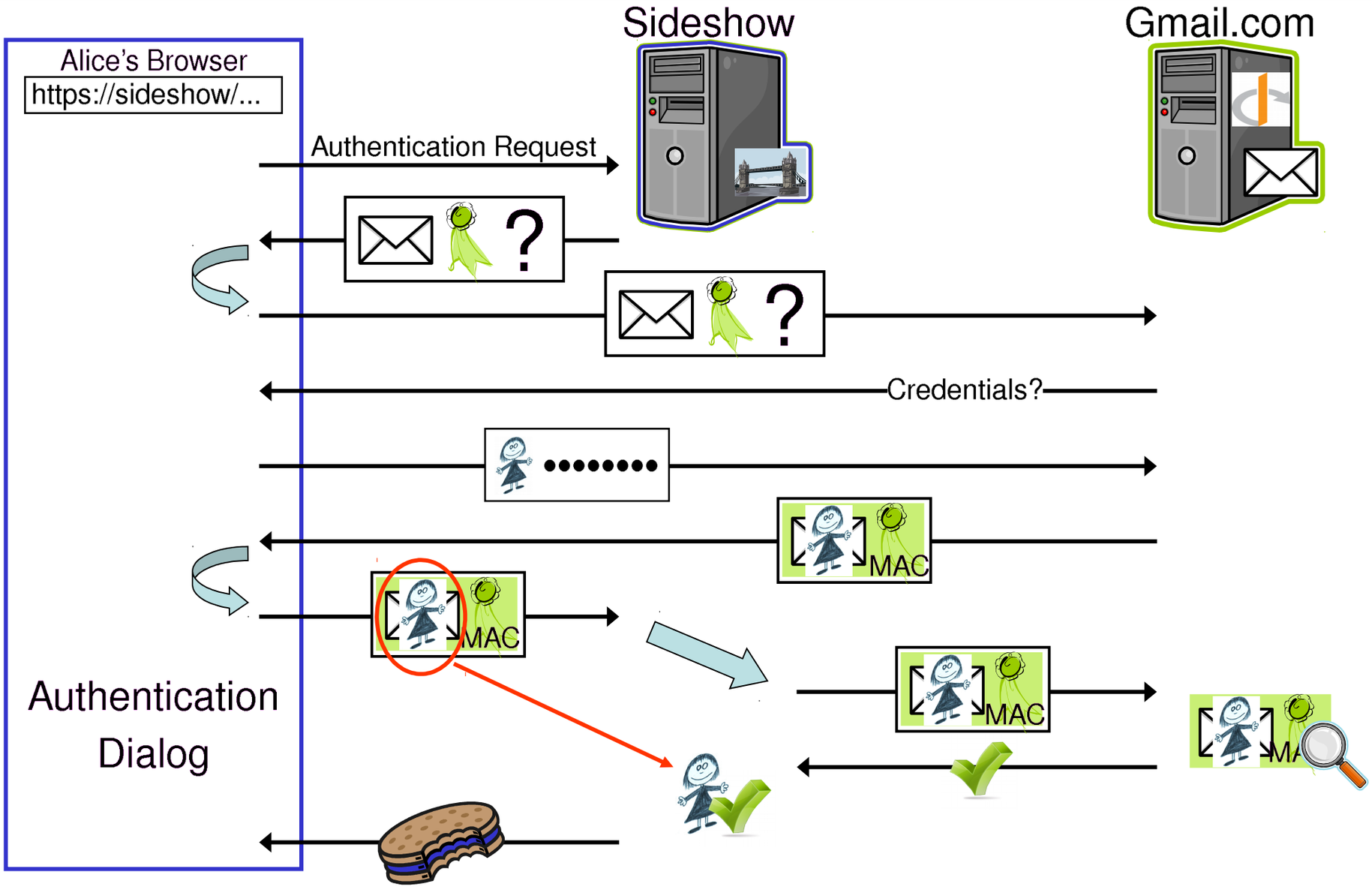

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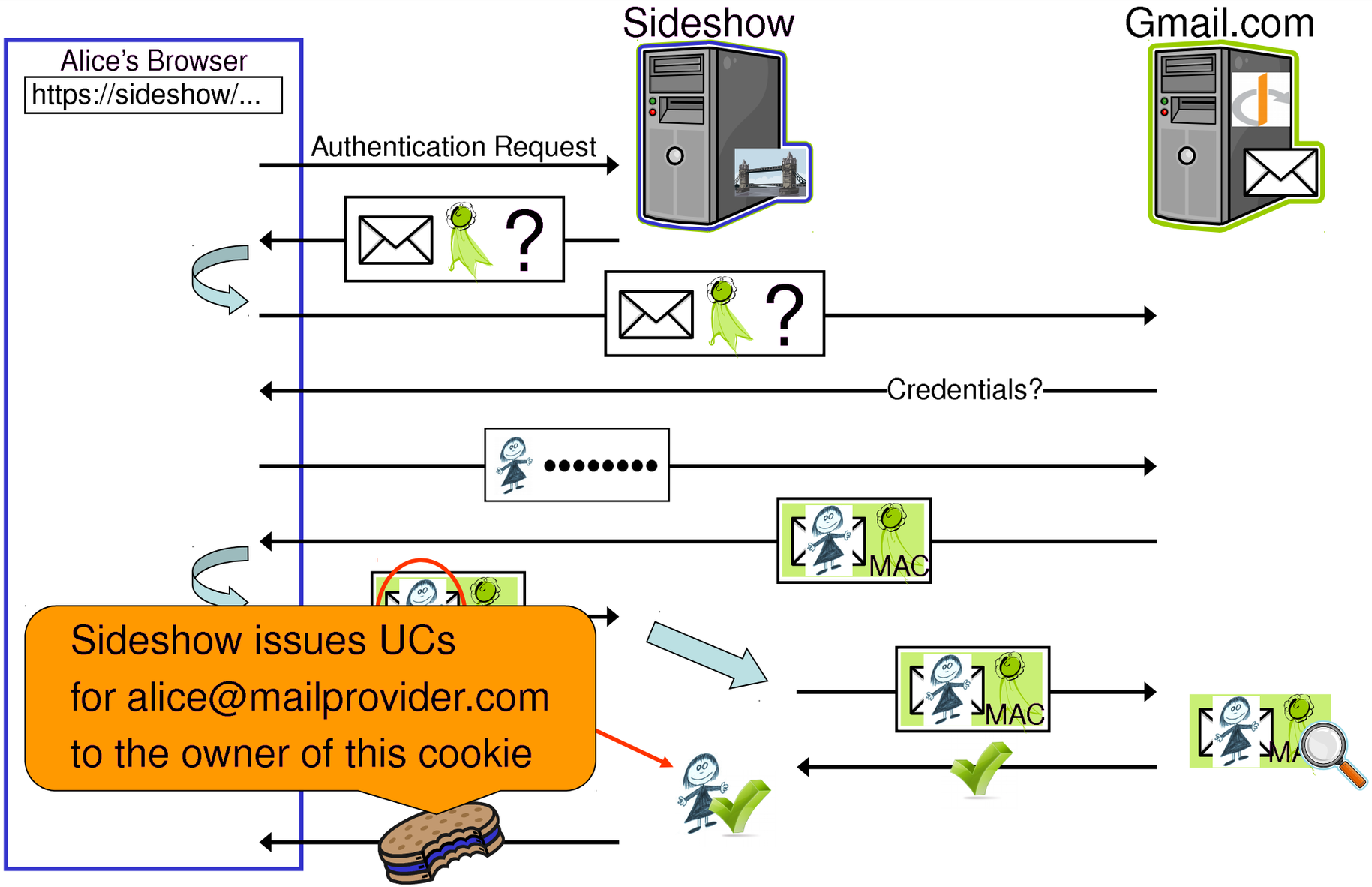


Selected Attacks on BrowserID a.k.a. Mozilla Persona

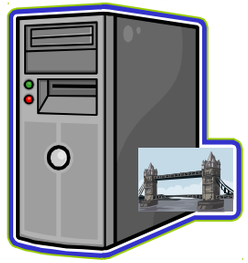
Identity Forgery (I)

Attacker's Browser

https://sideshow/...

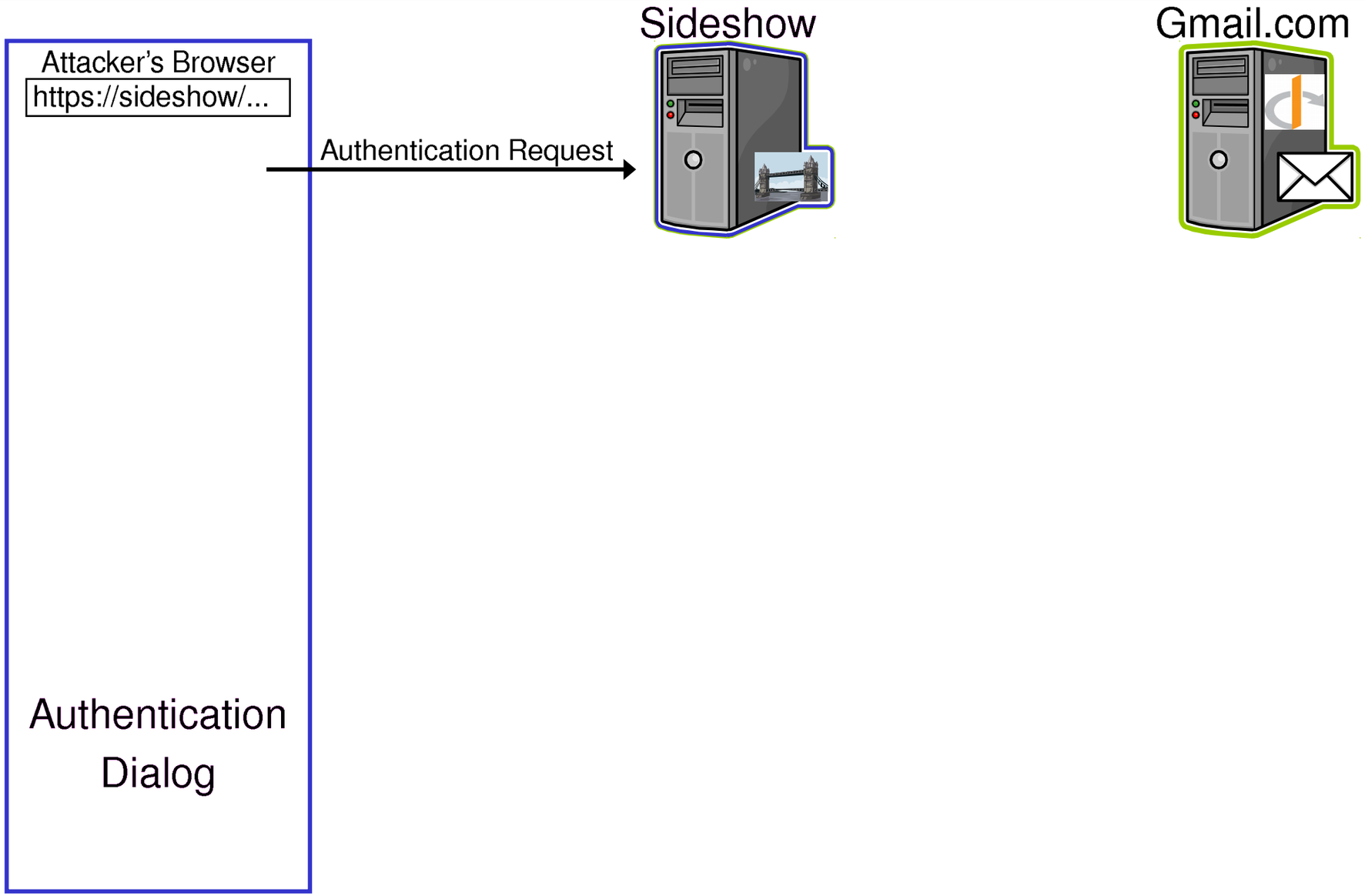
Authentication Dialog

Sideshow



Gmail.com

Identity Forgery (I)



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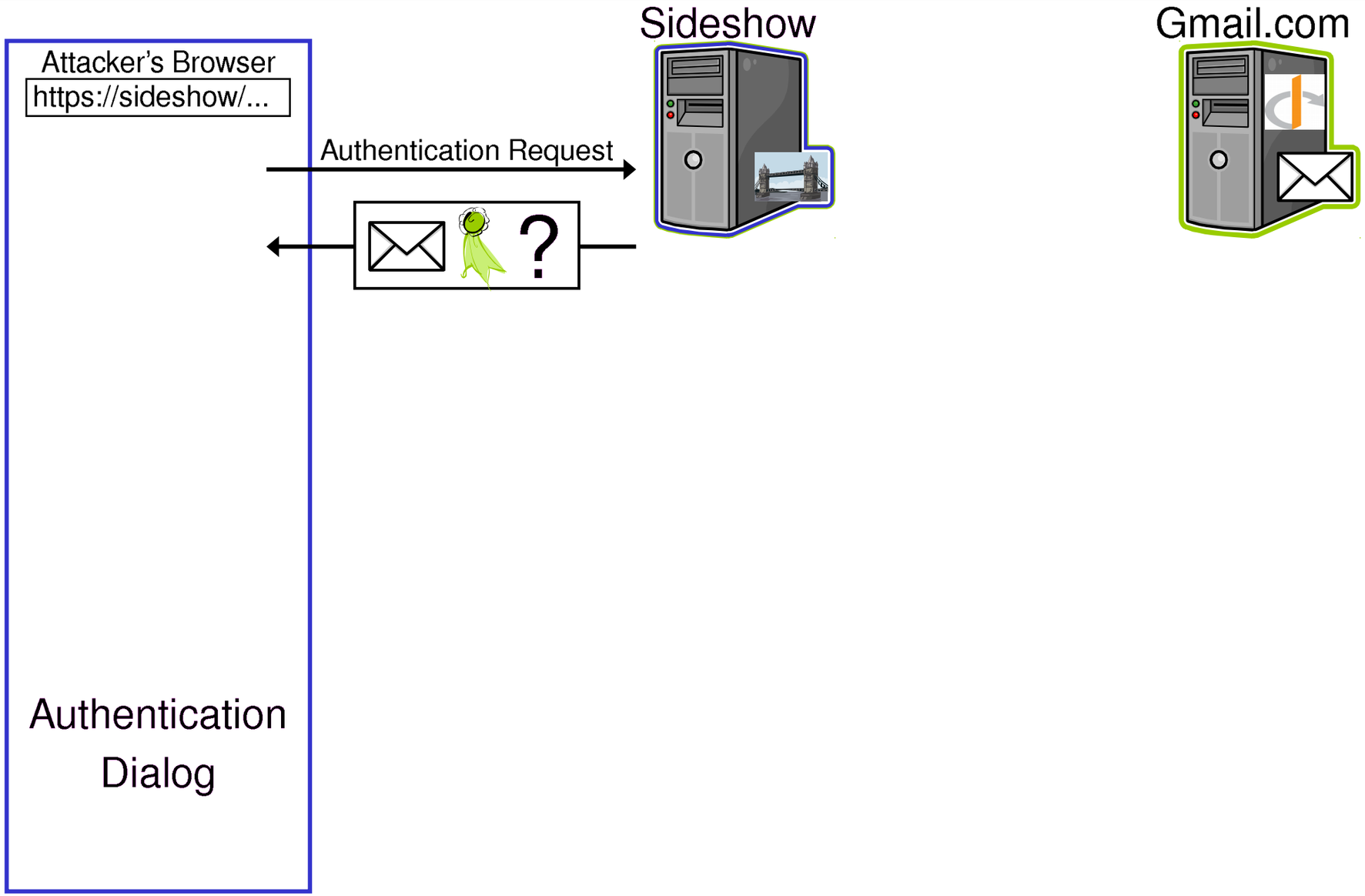

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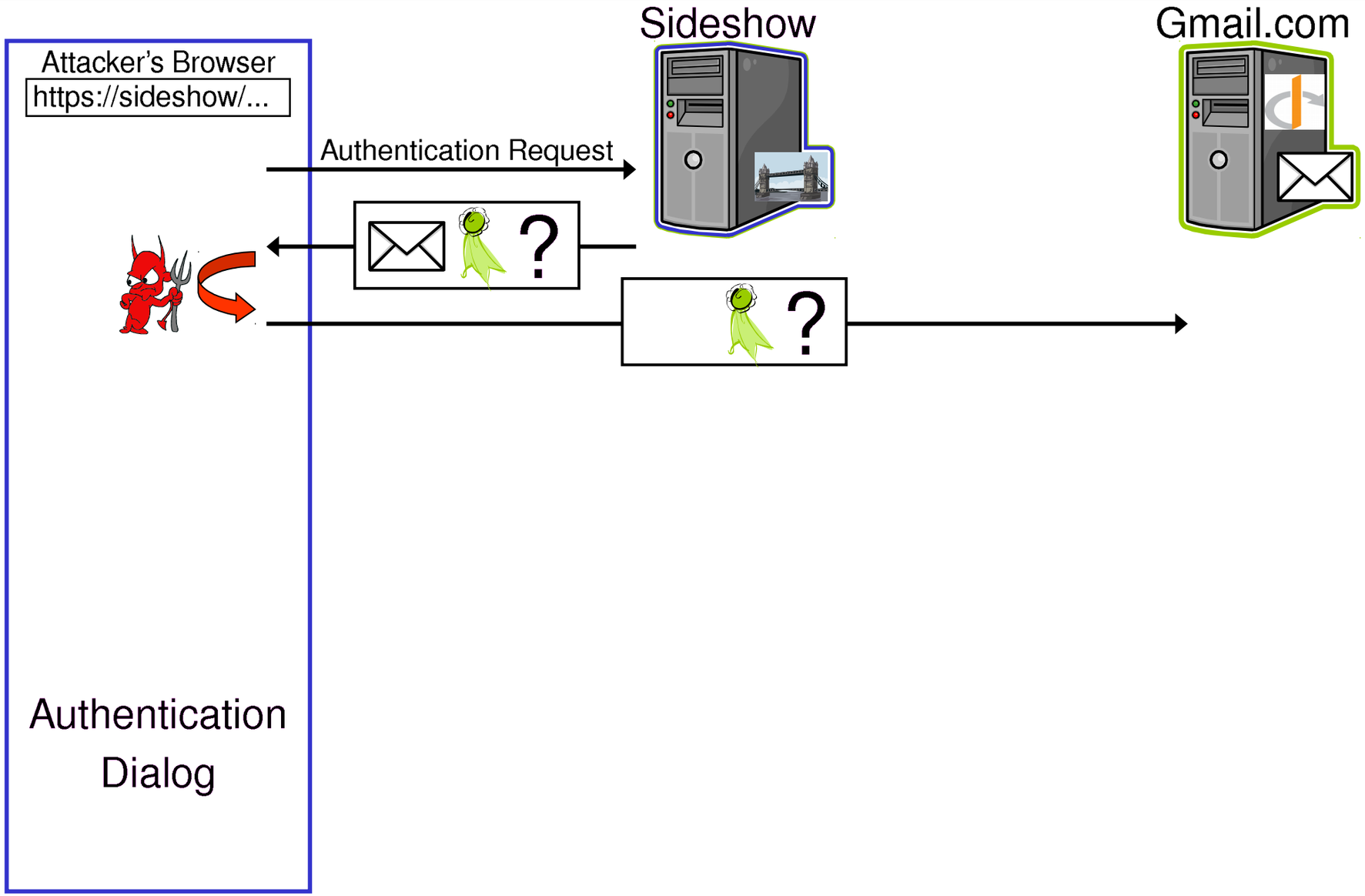

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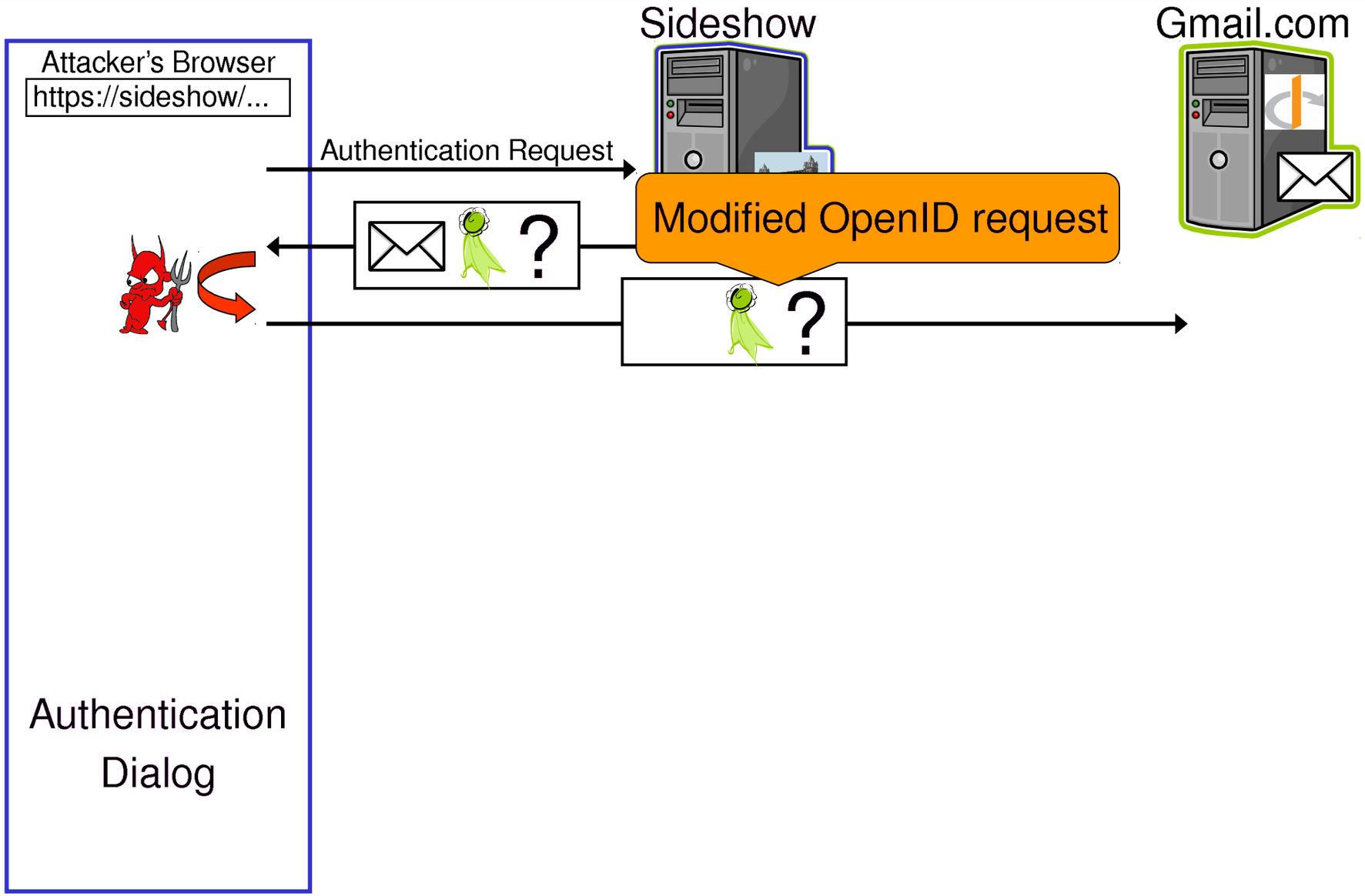

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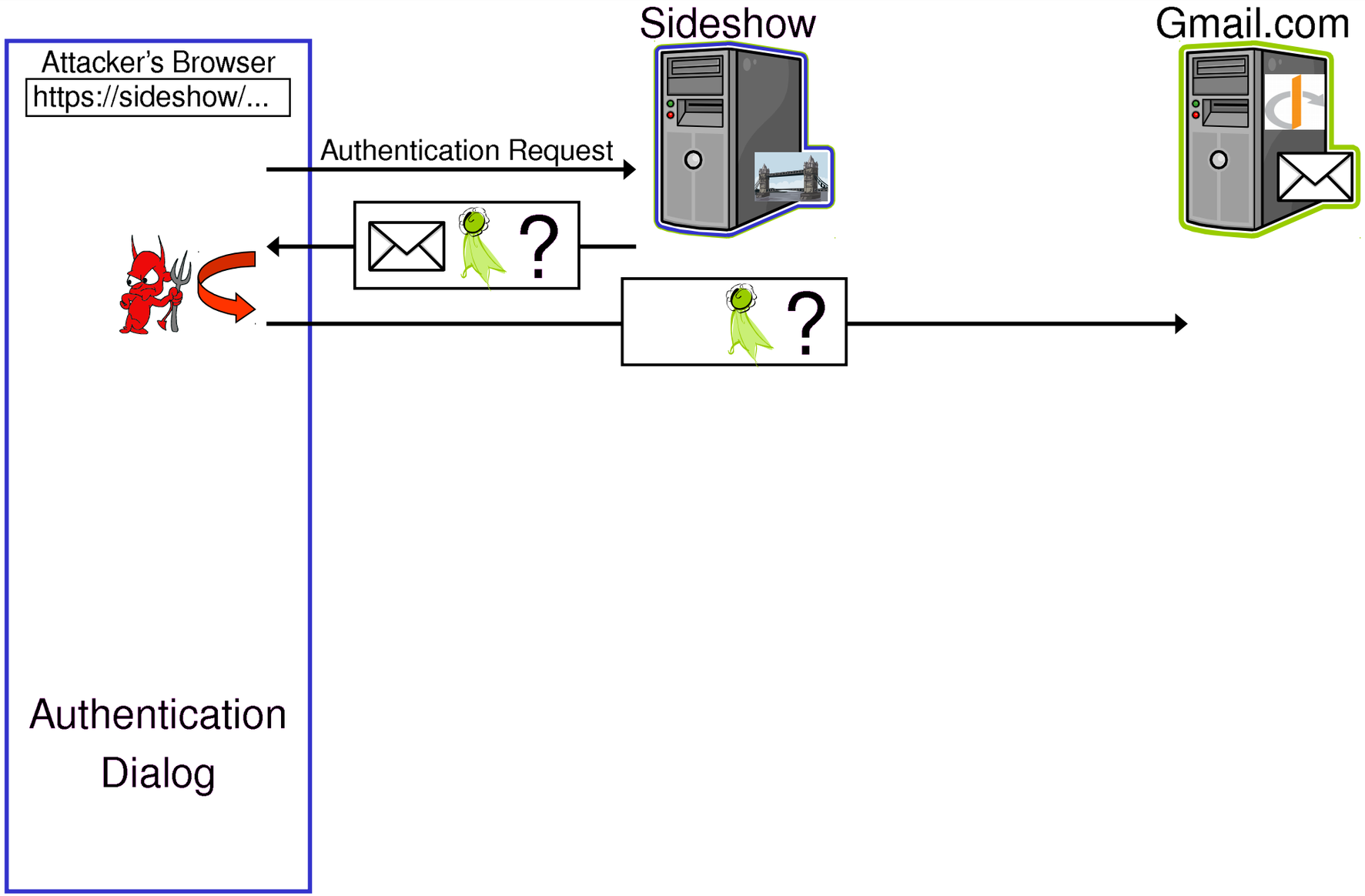

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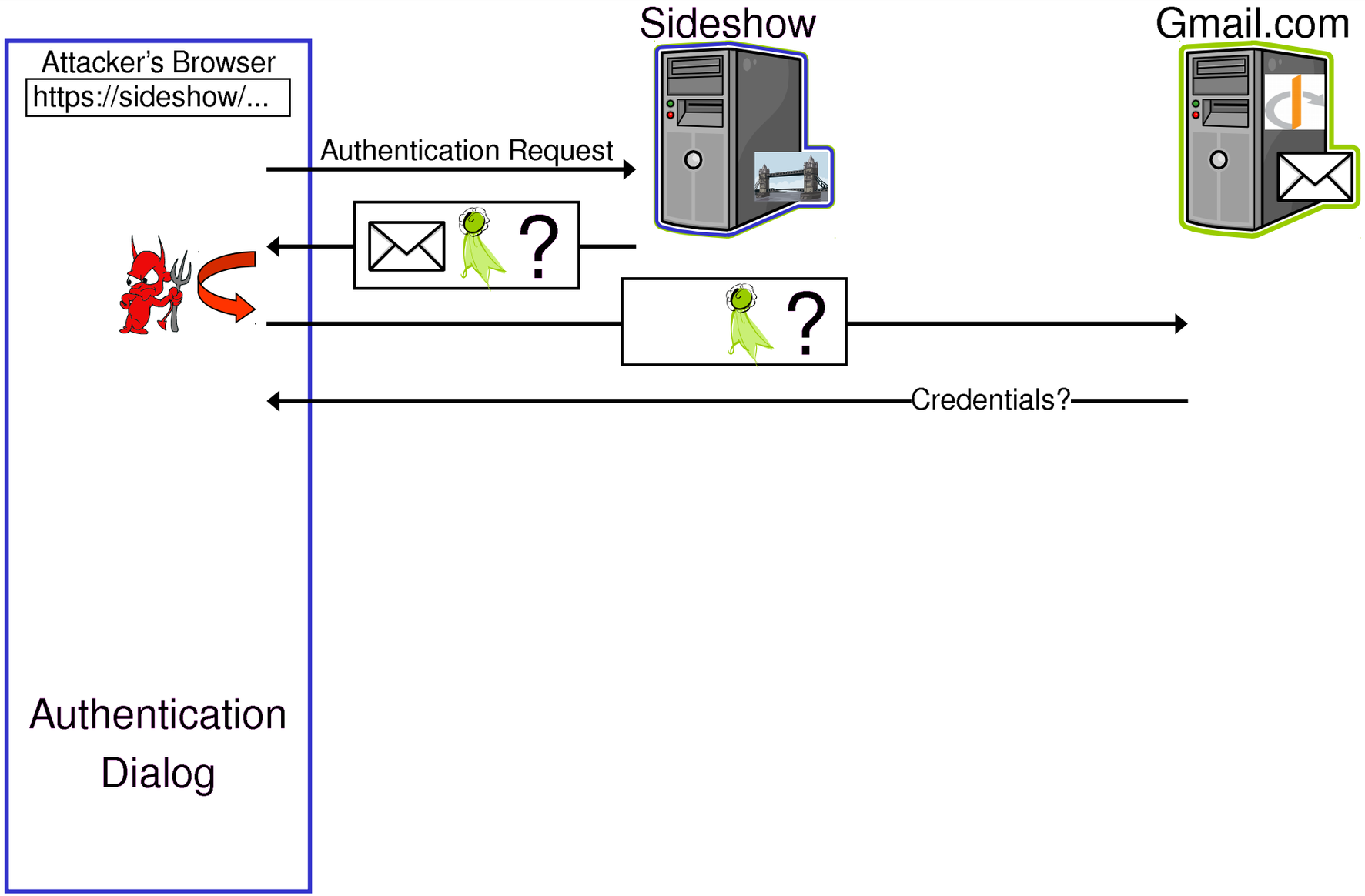

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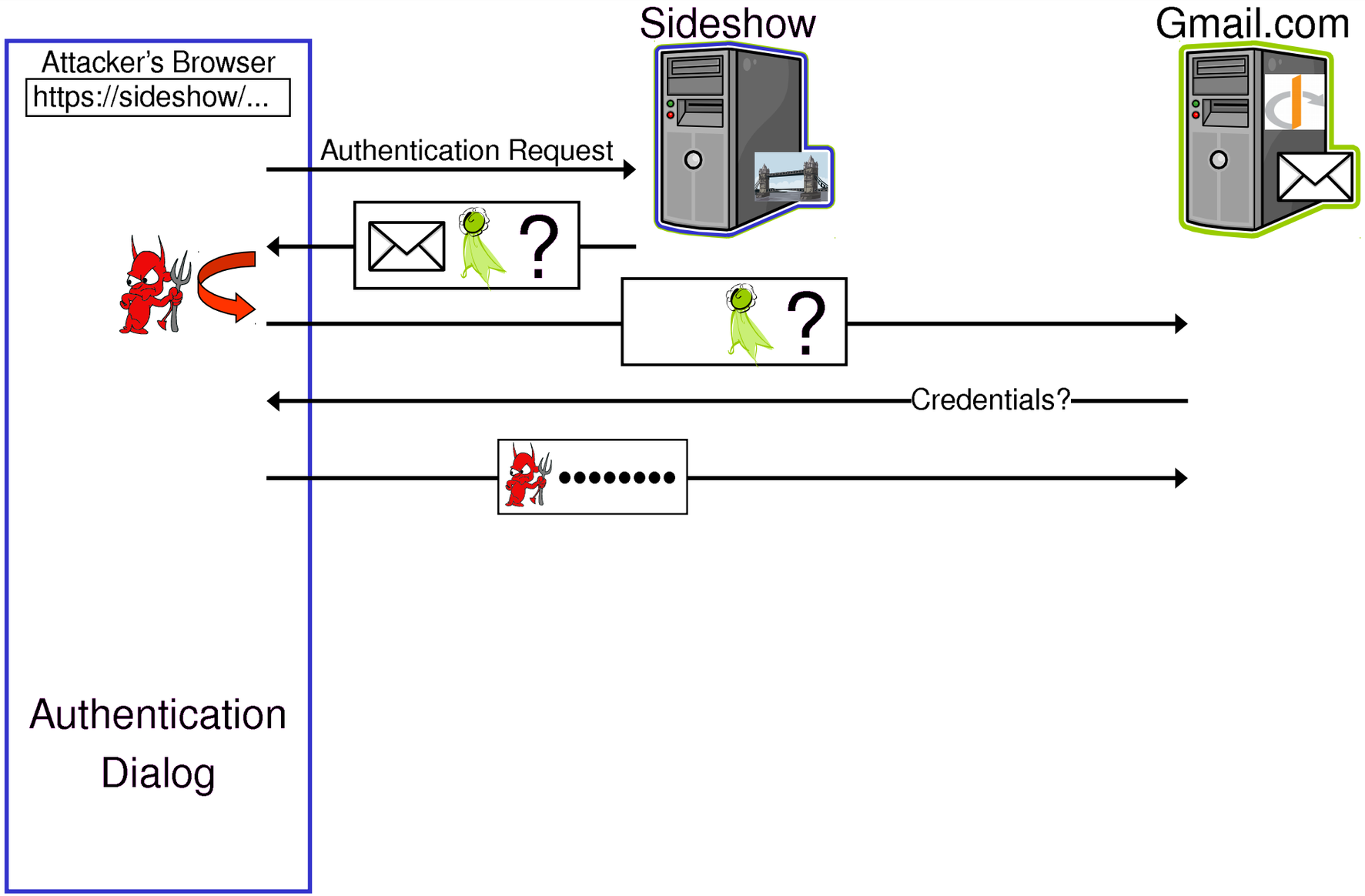

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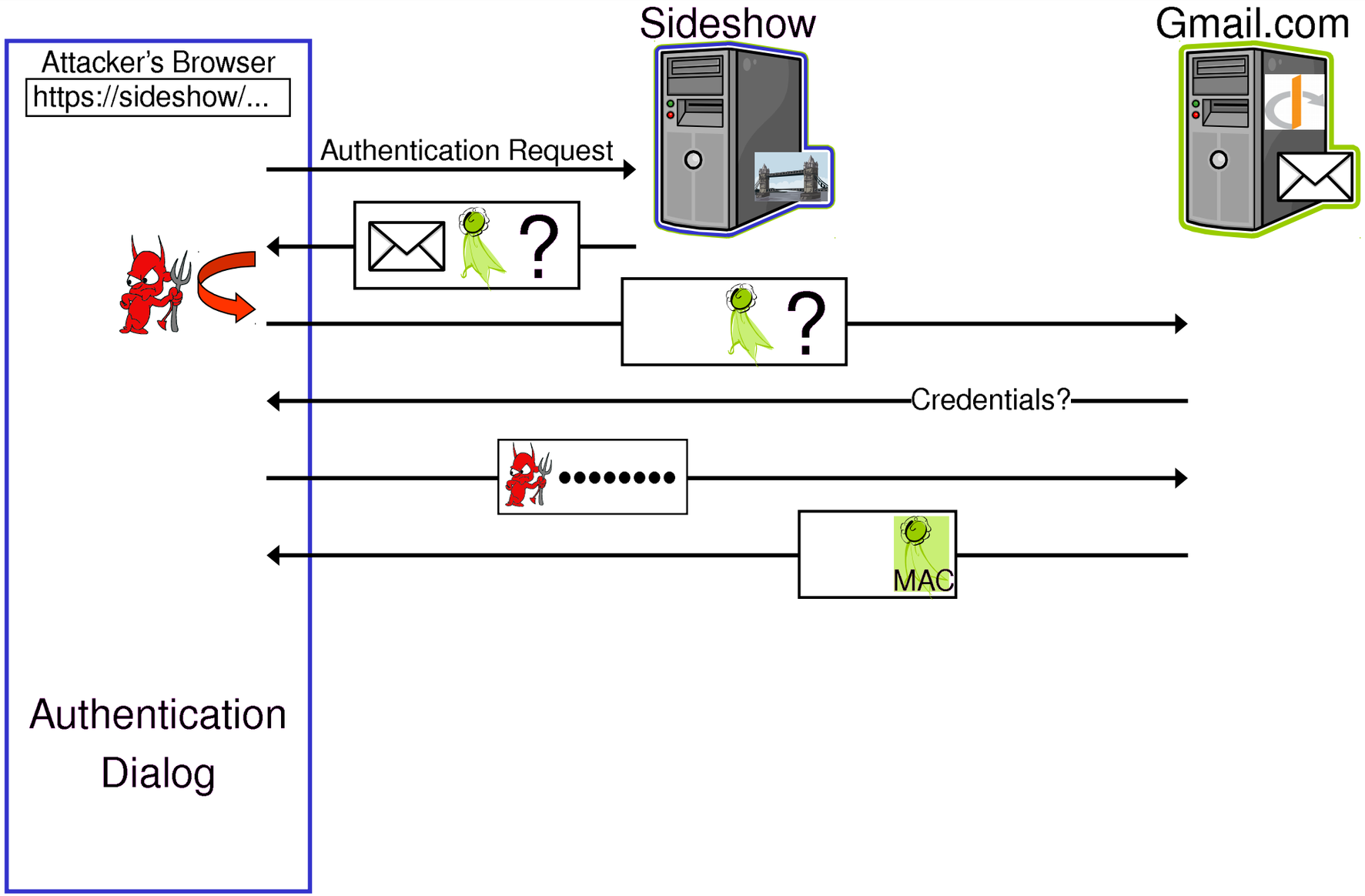

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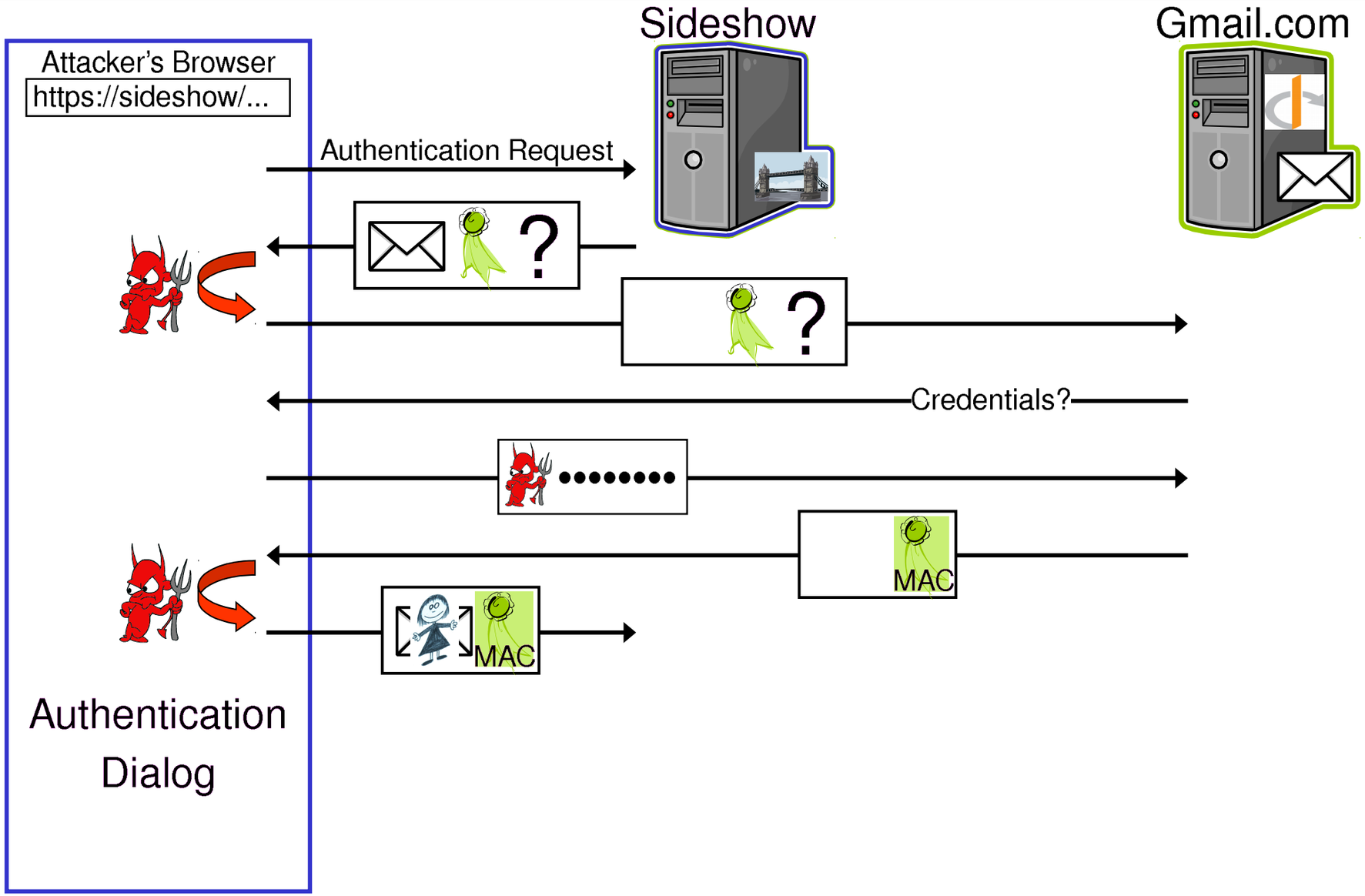

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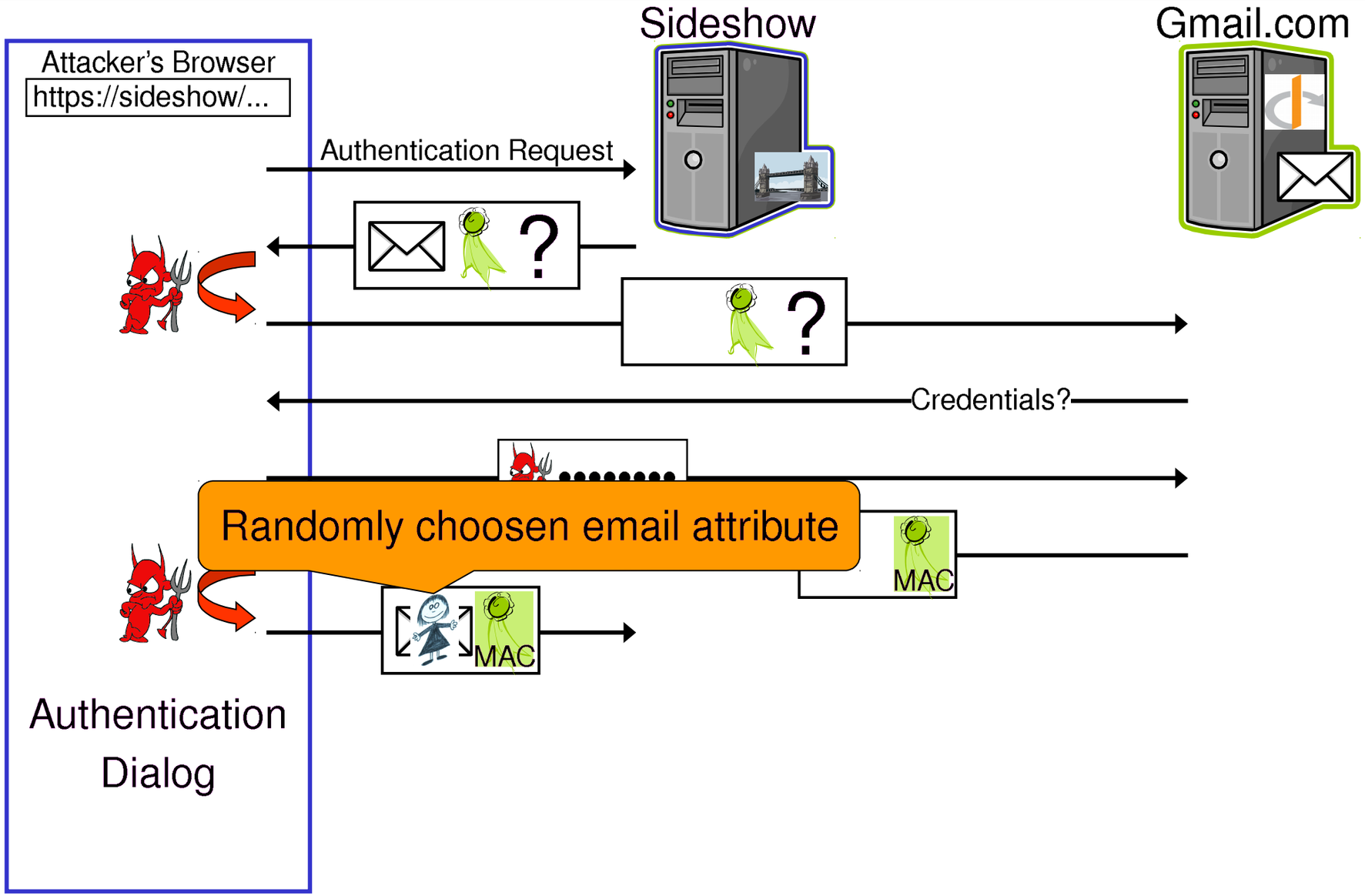

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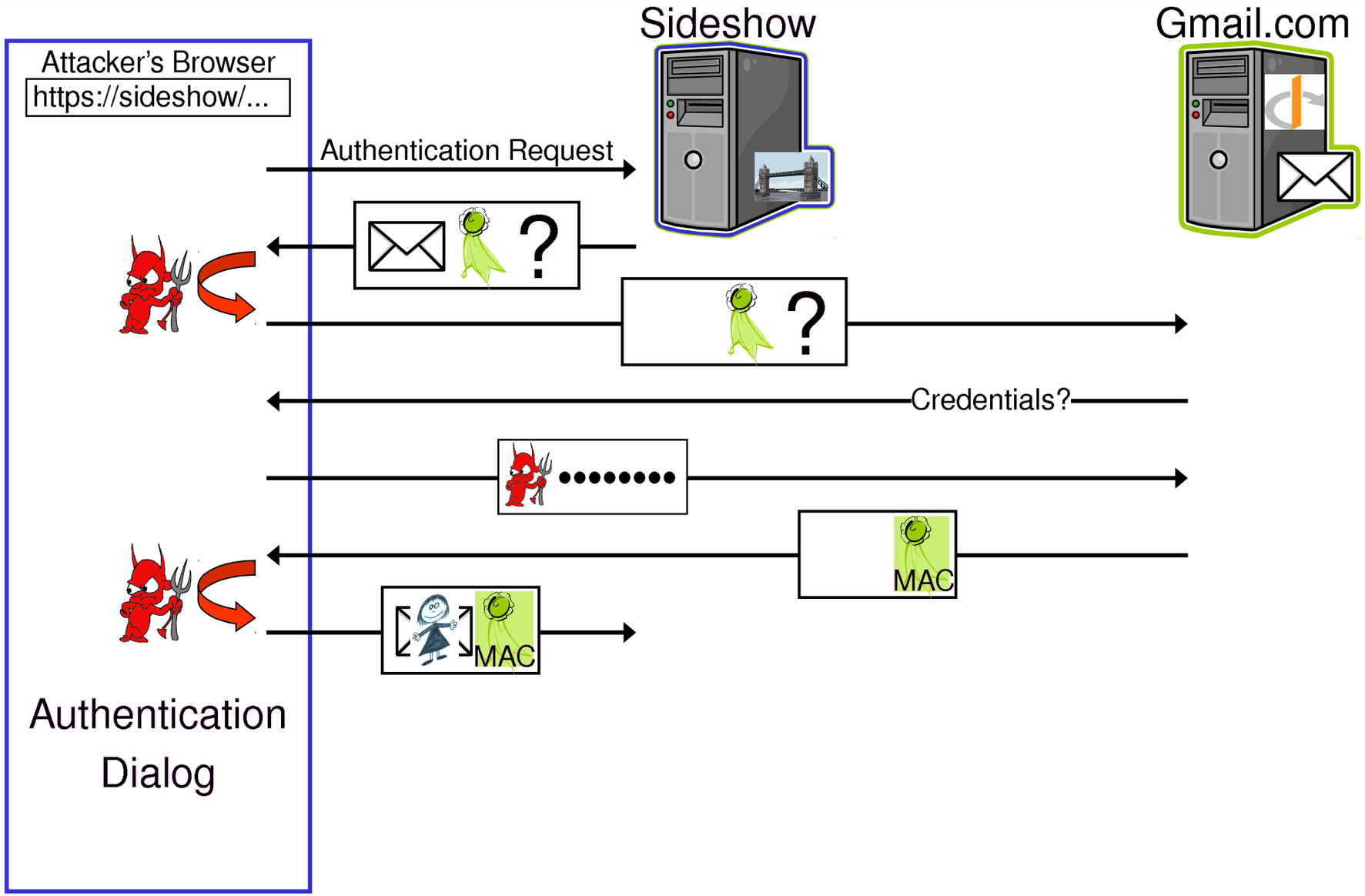

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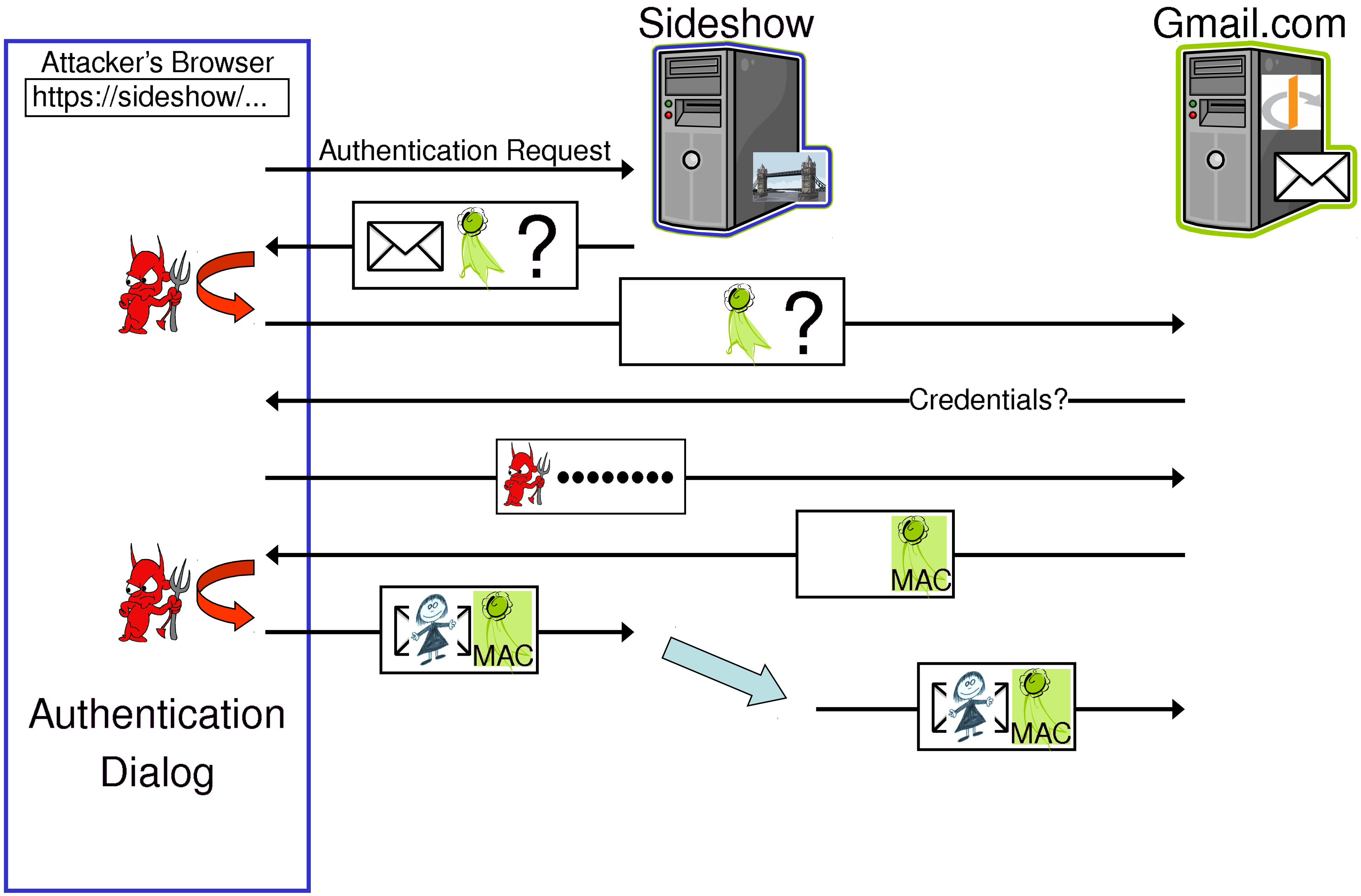

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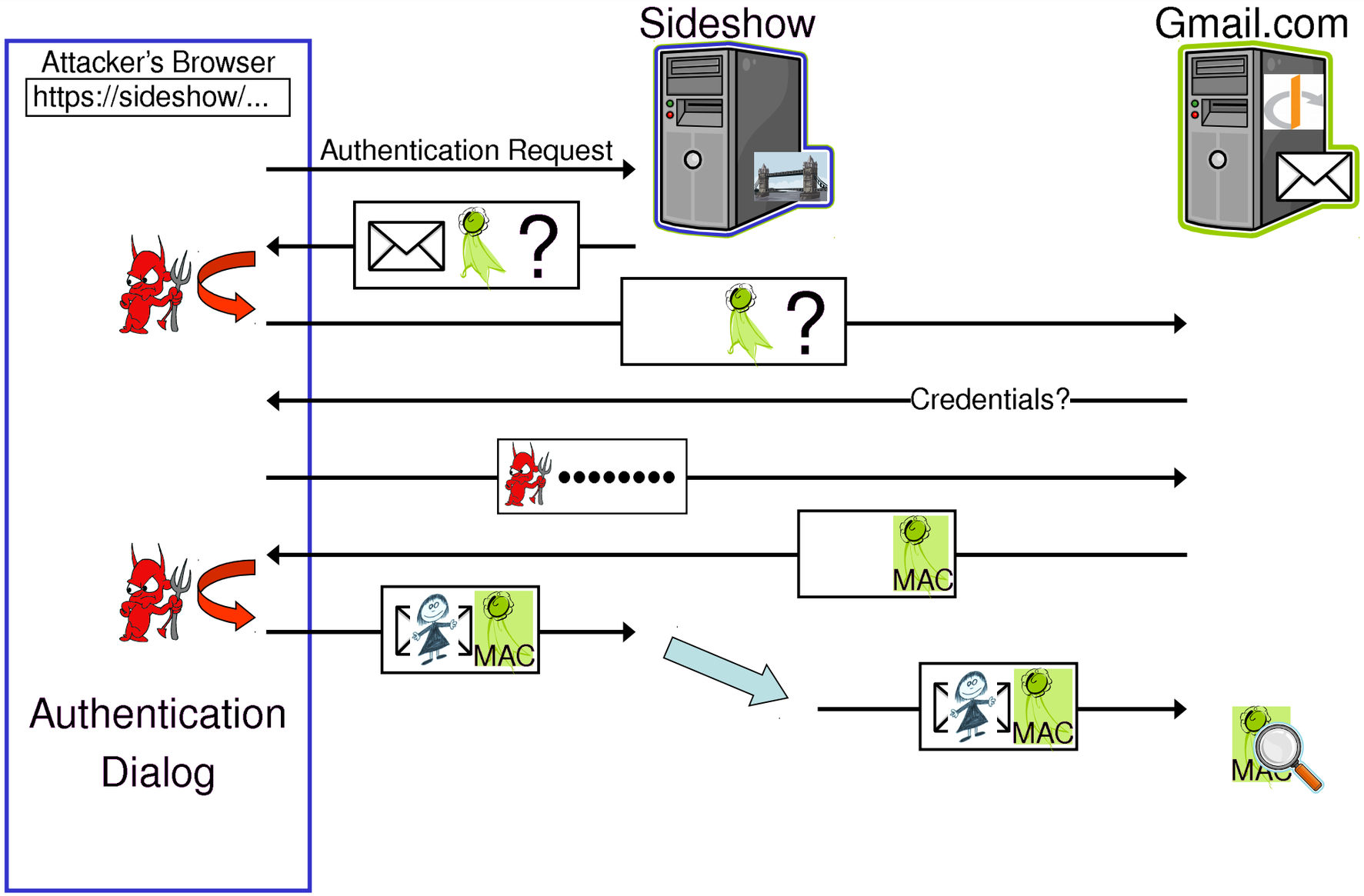

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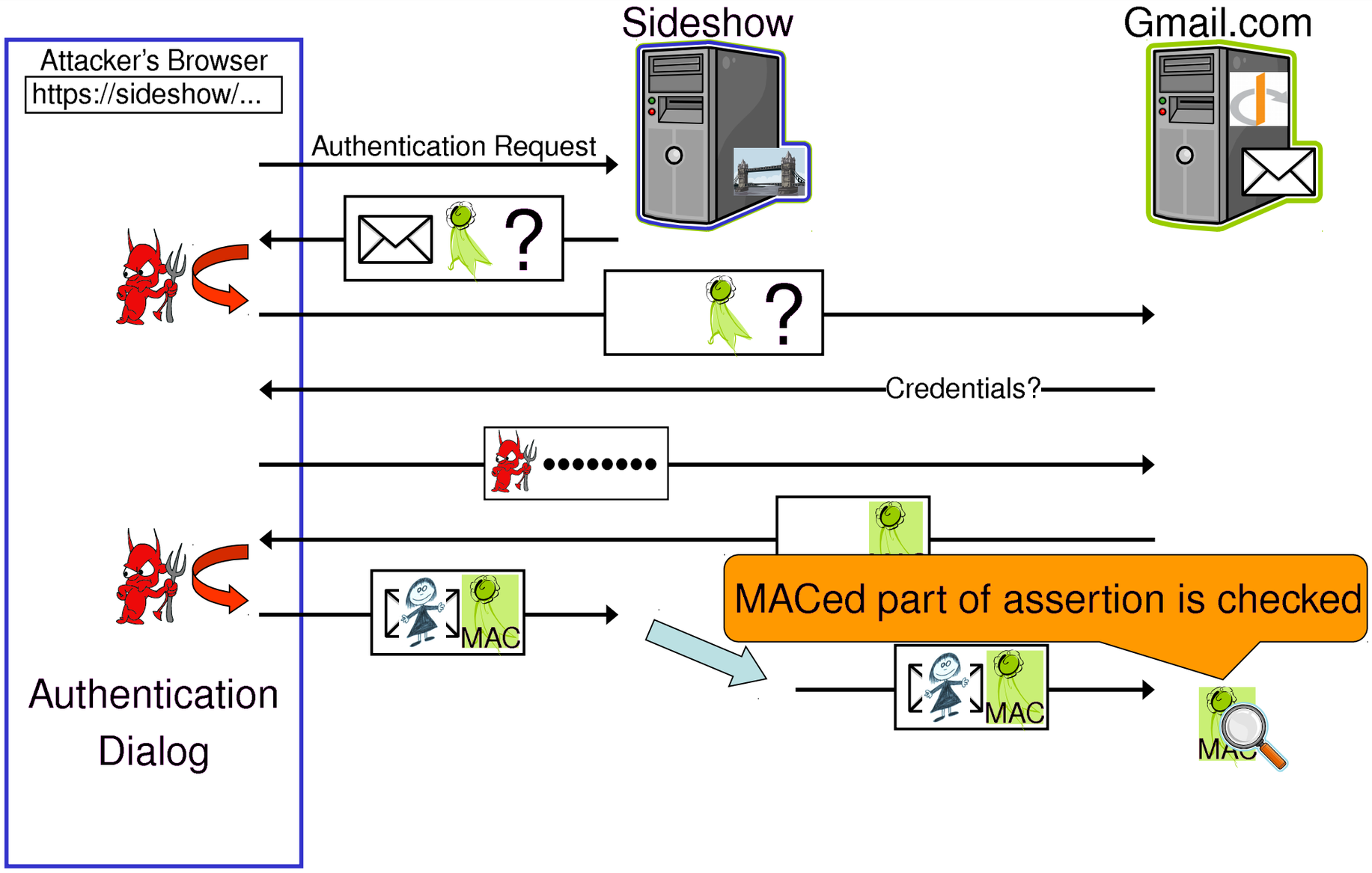

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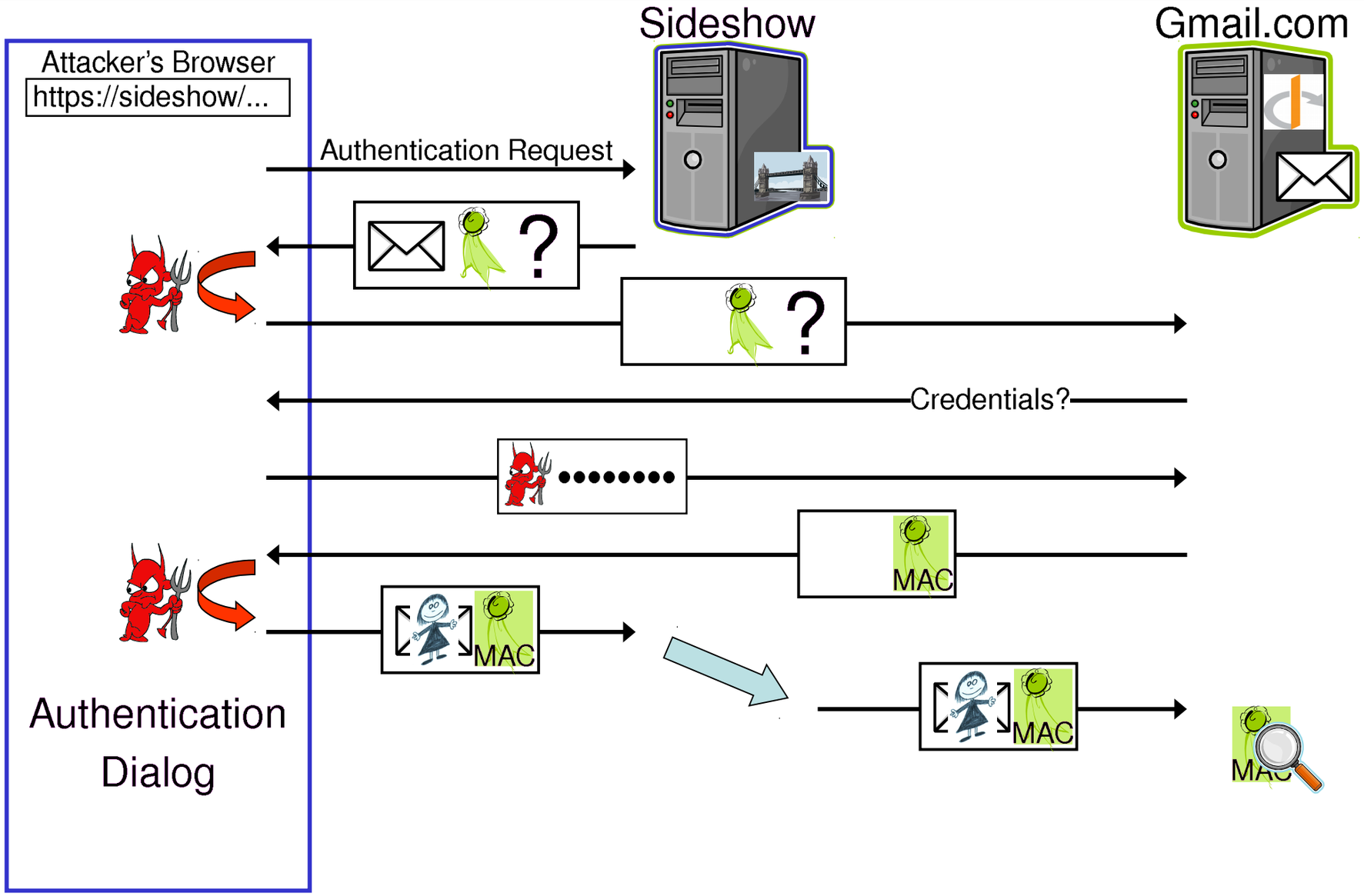
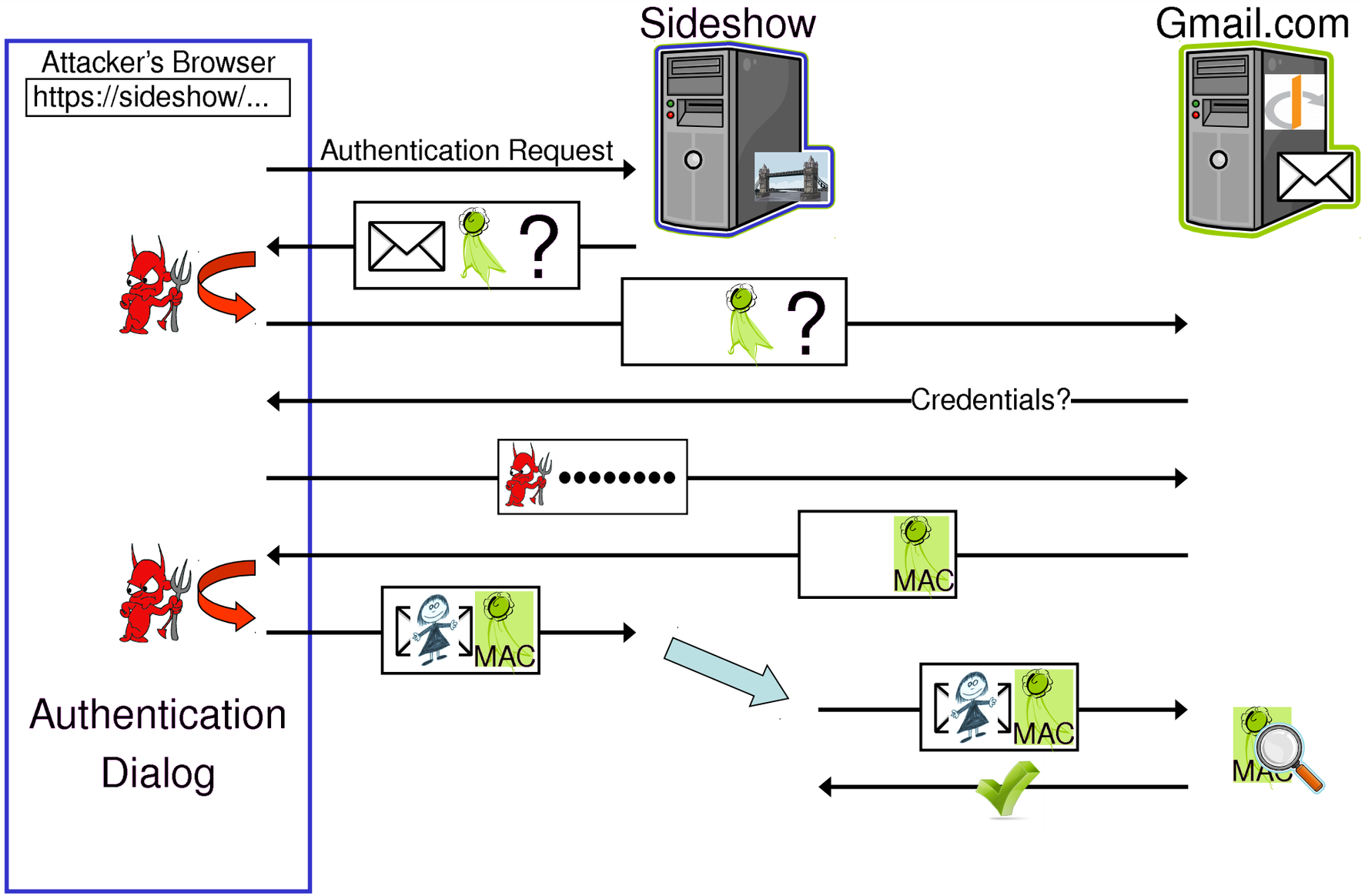


Identity Forgery (I)



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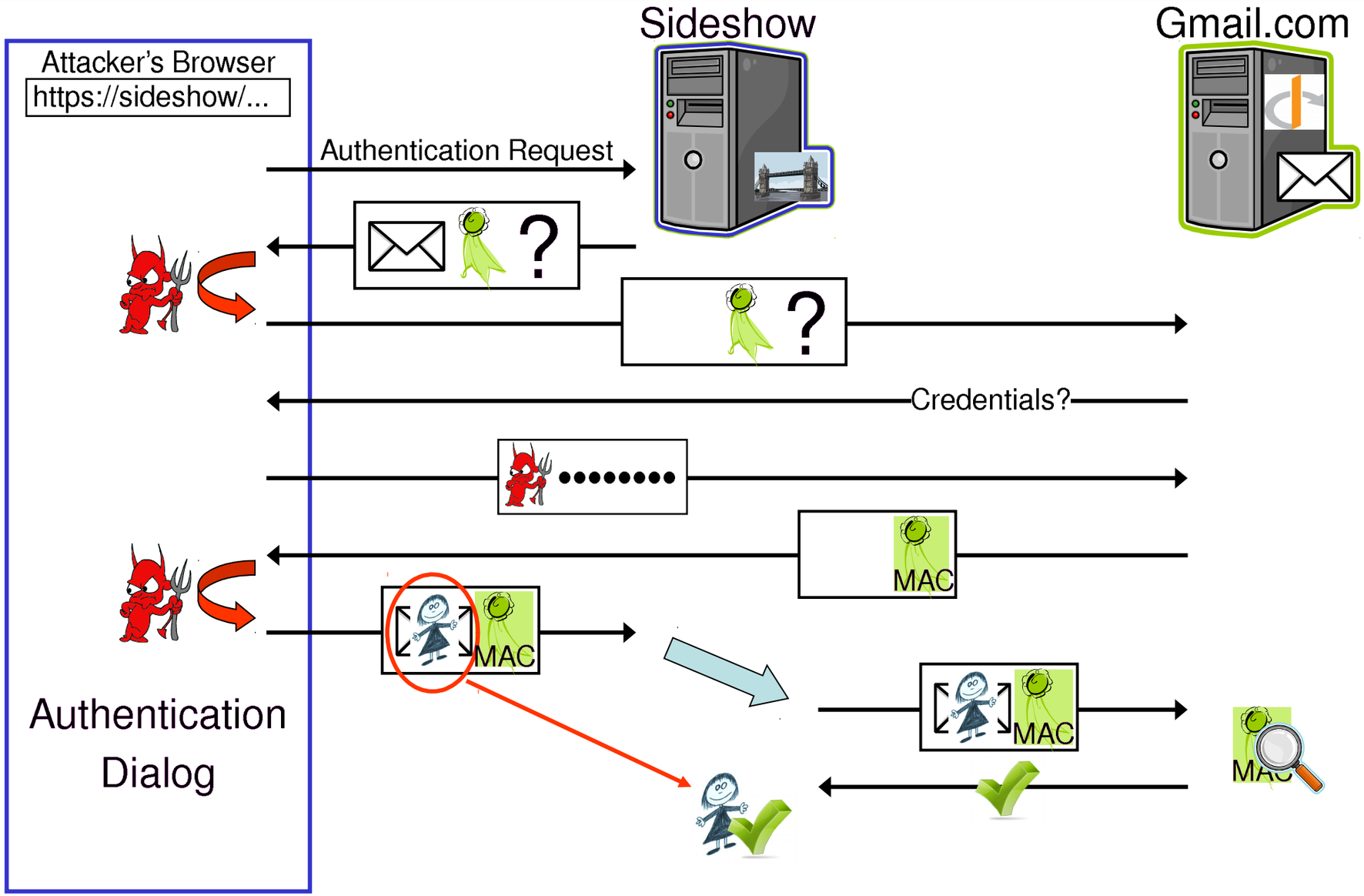

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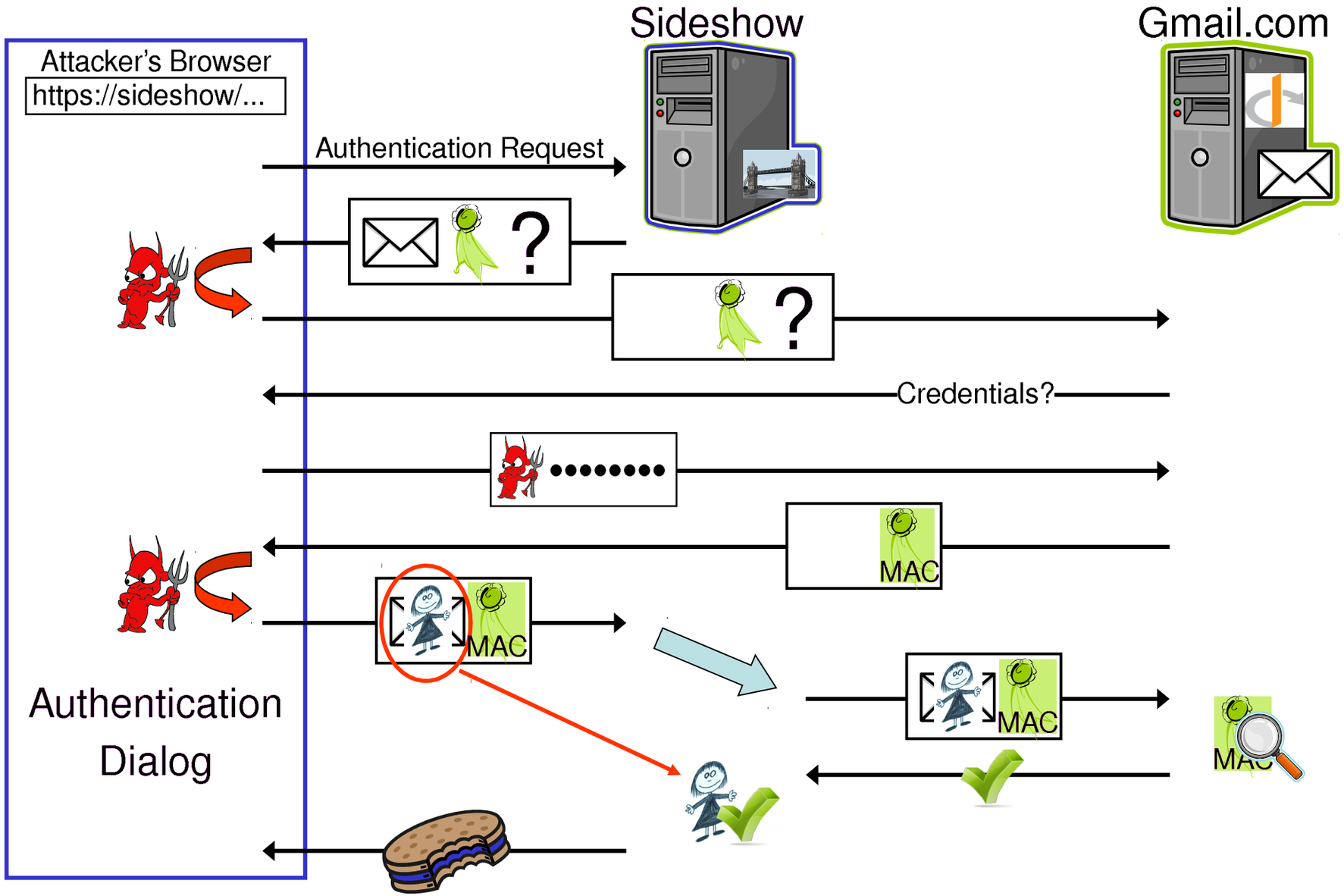

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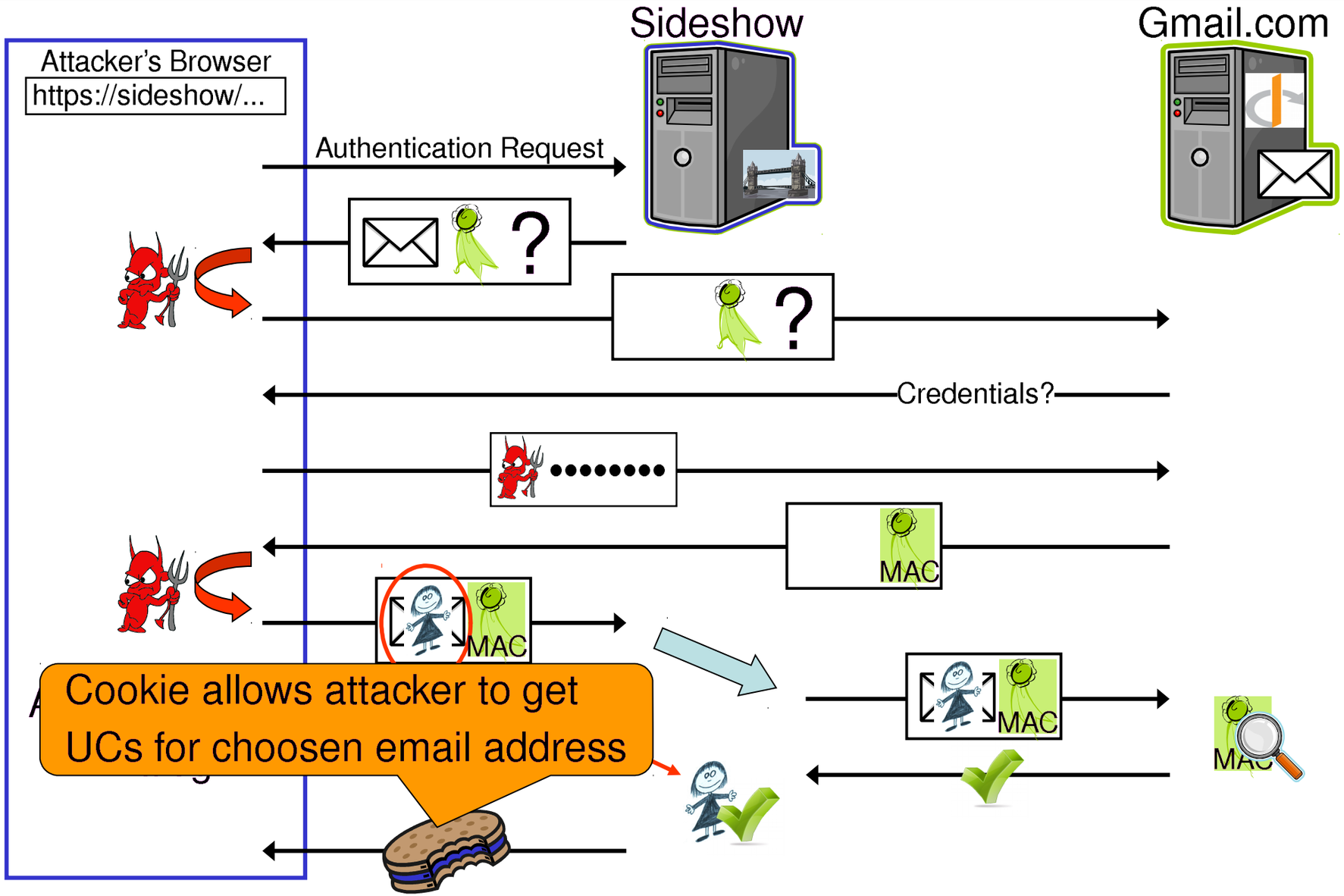


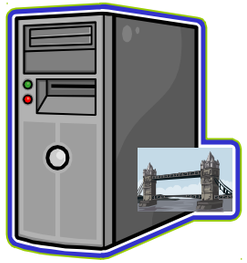
Identity Forgery (II)

Attacker's Browser

https://sideshow/...

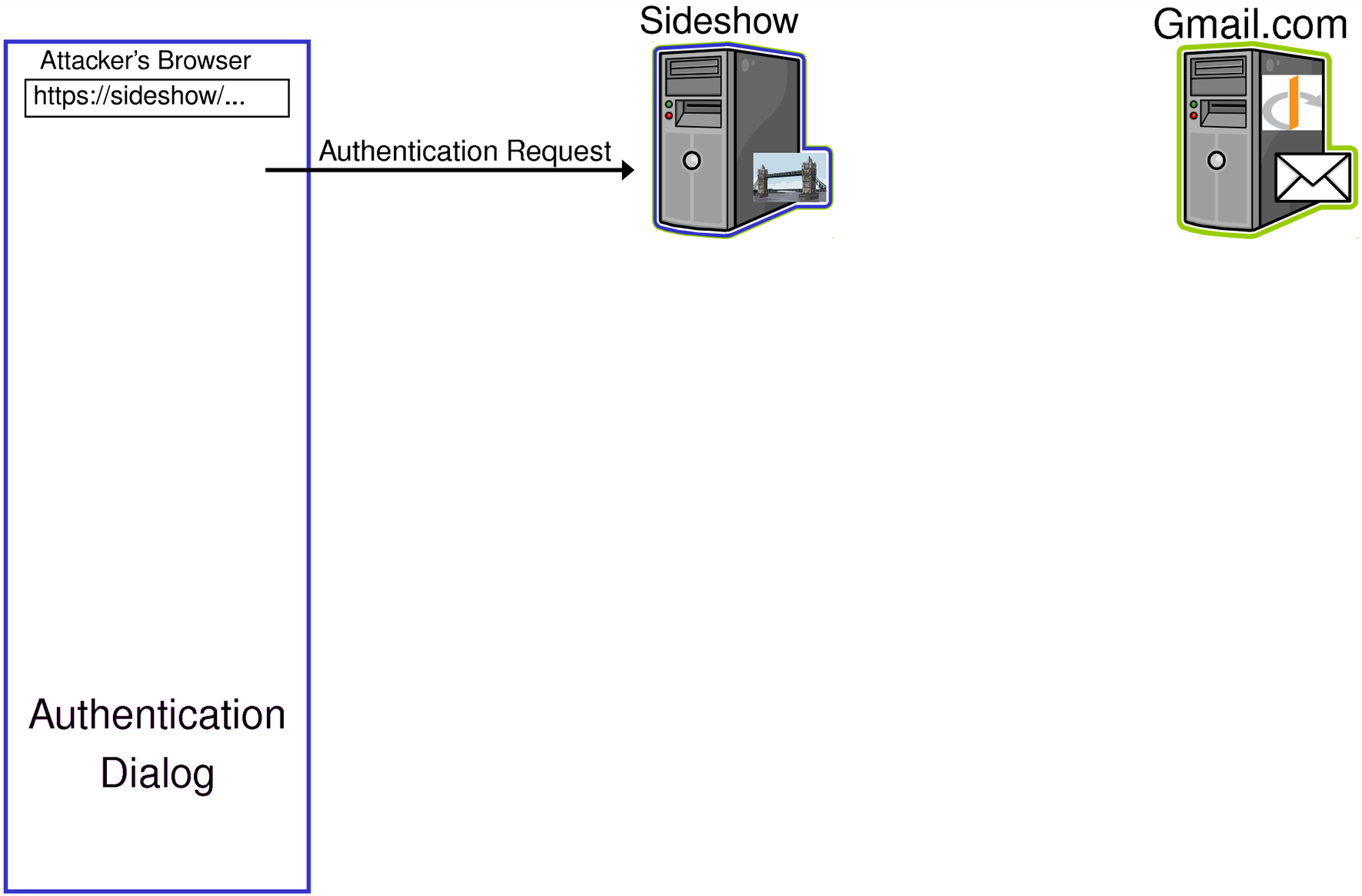
Authentication Dialog

Sideshow



Gmail.com

Identity Forgery (II)



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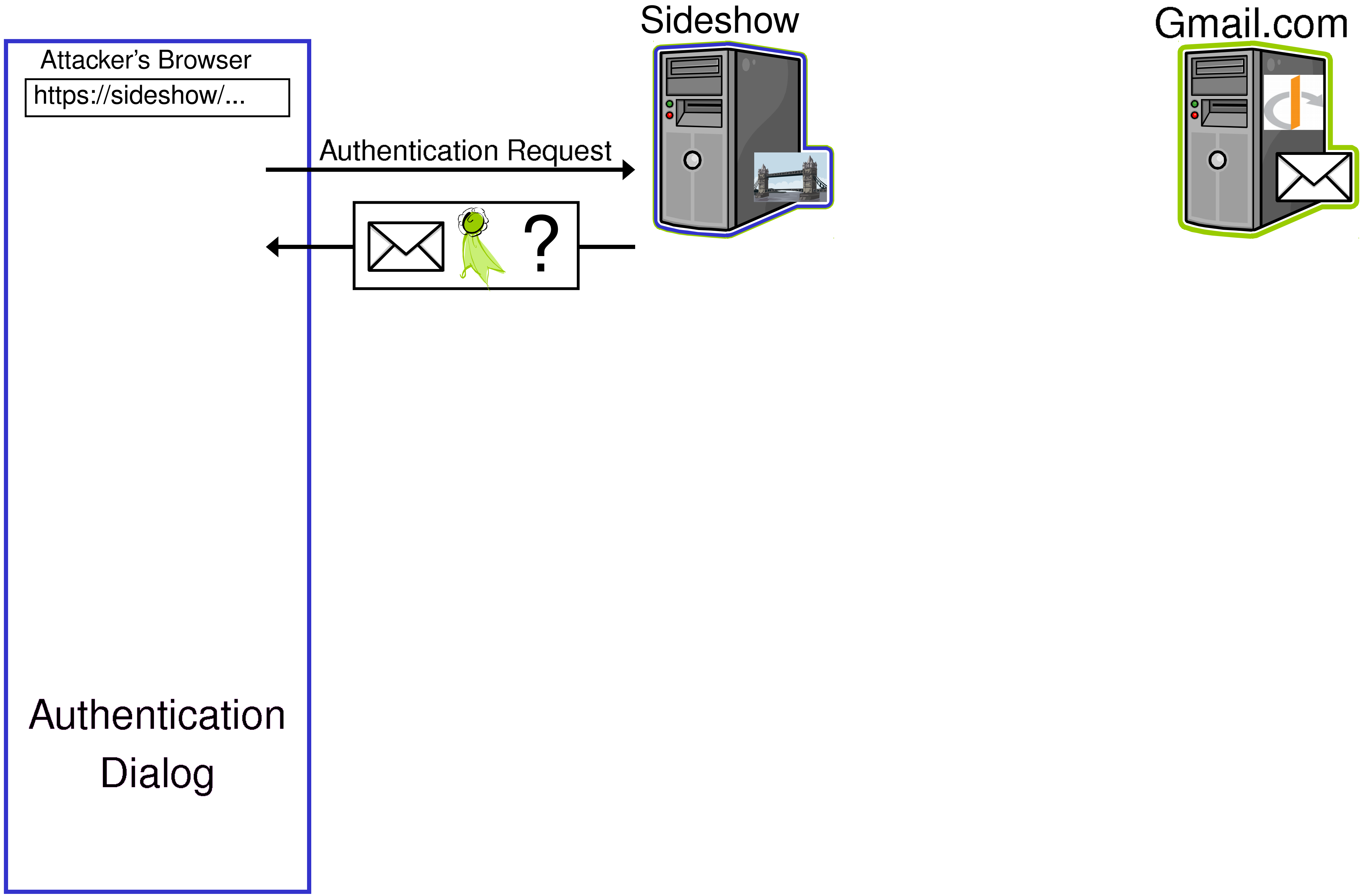

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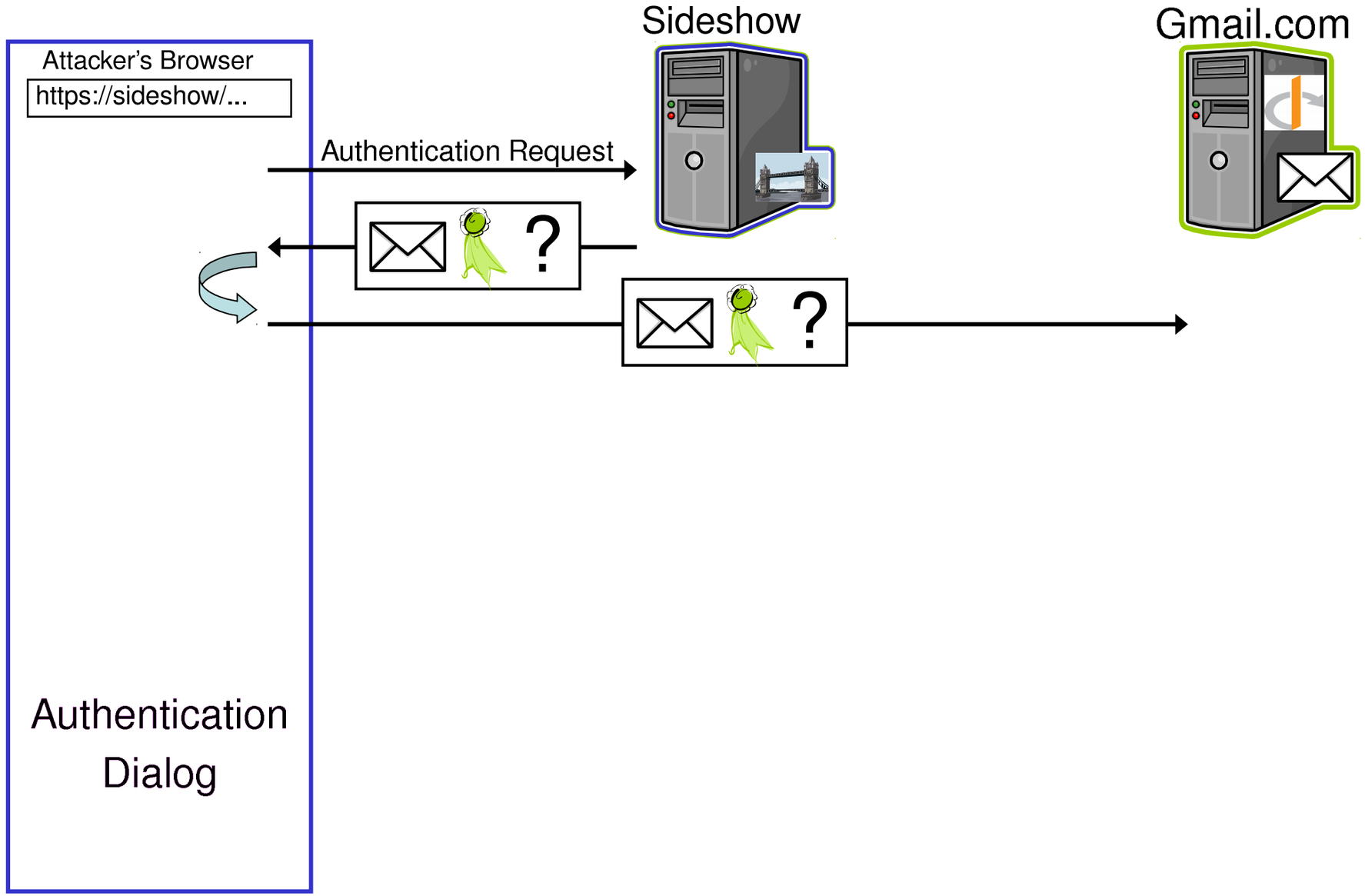

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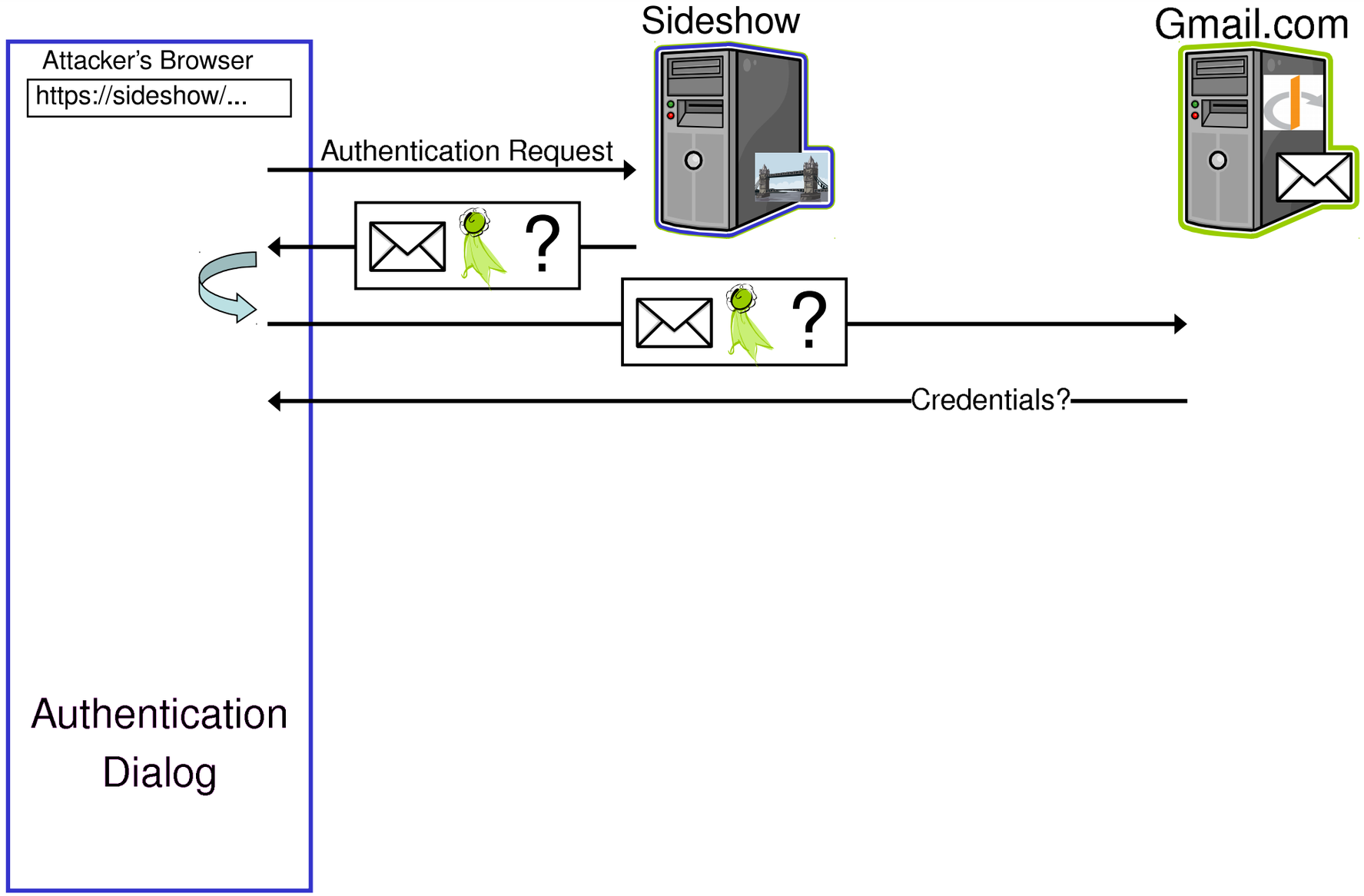

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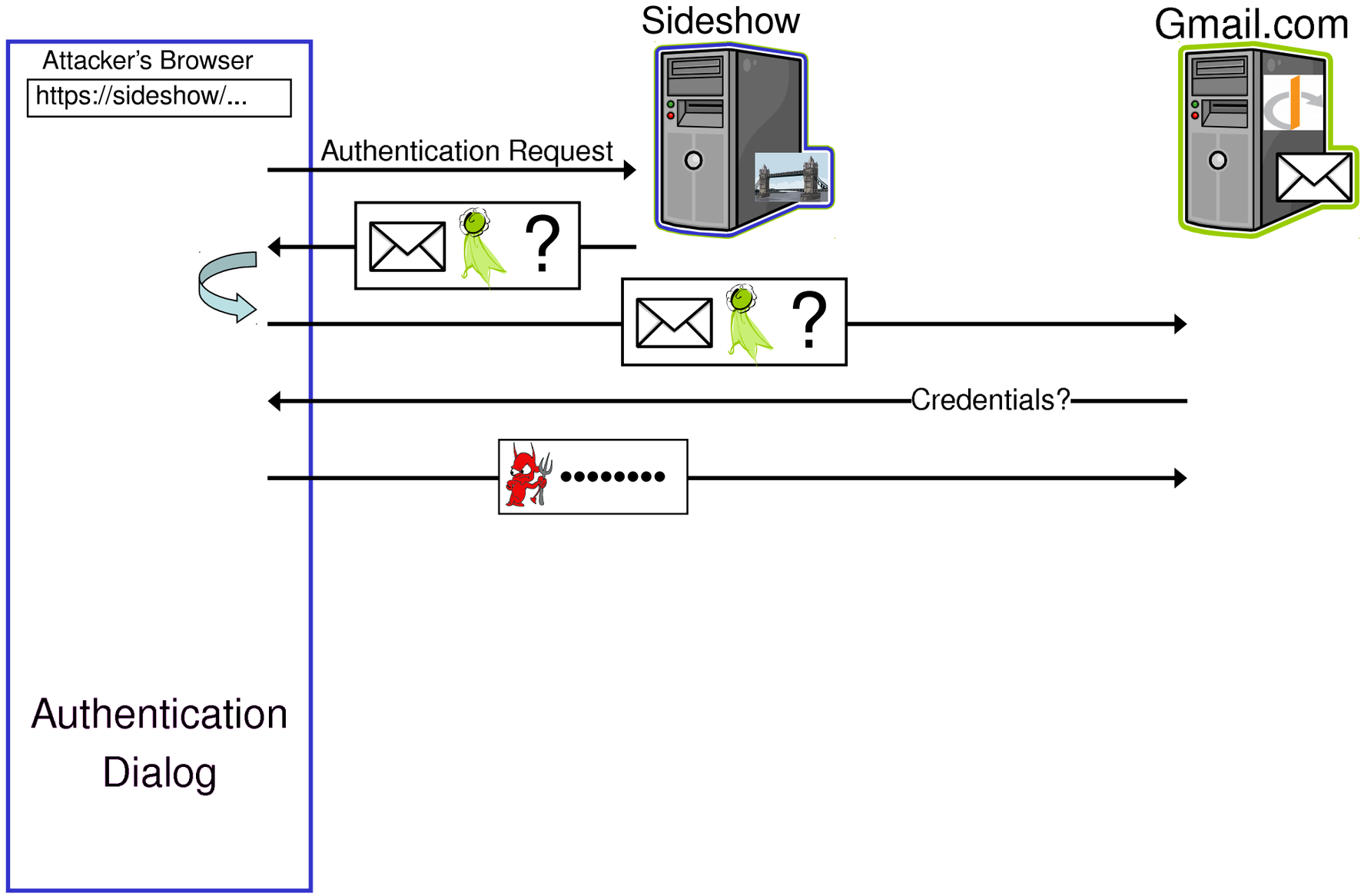

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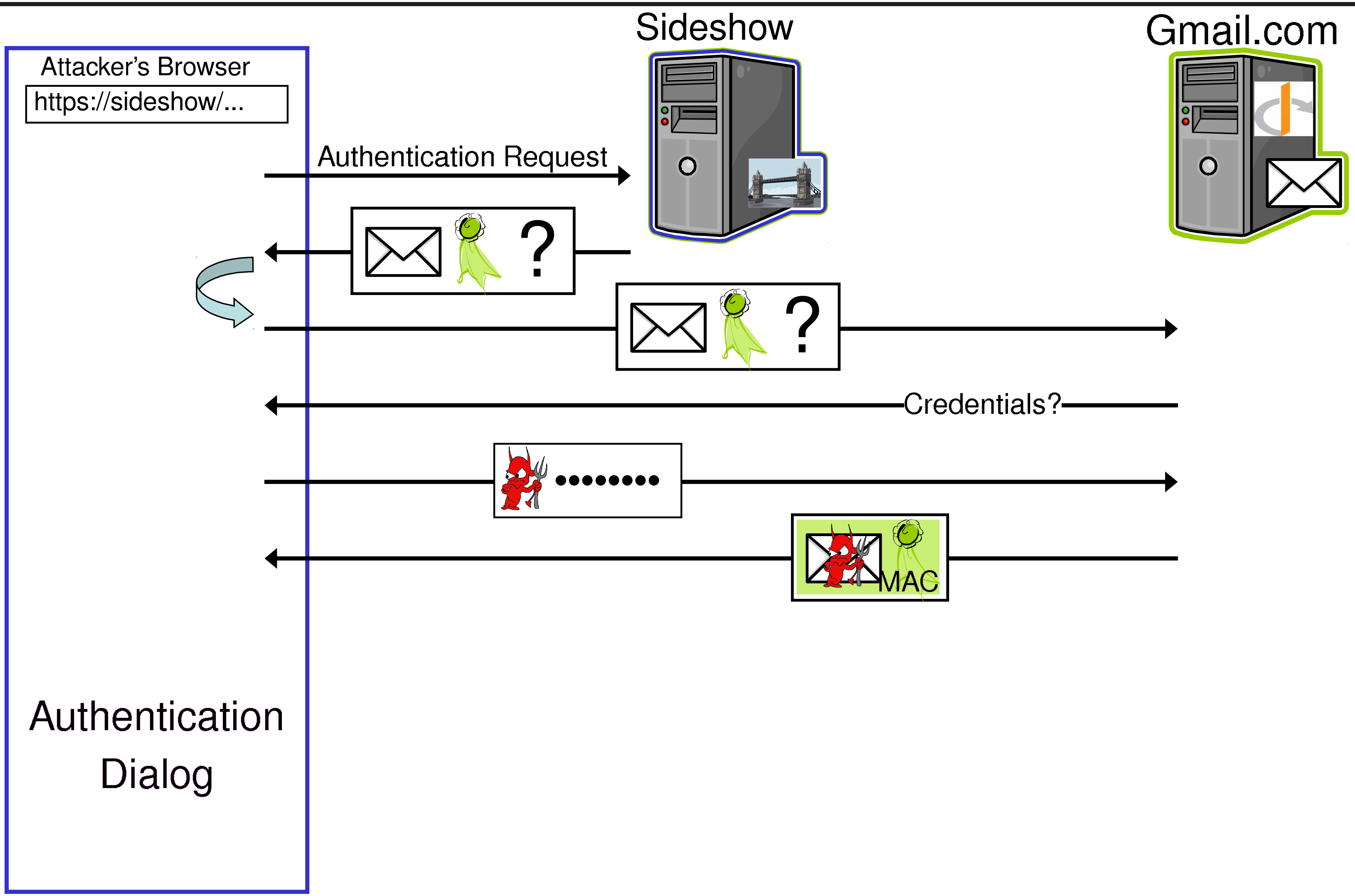

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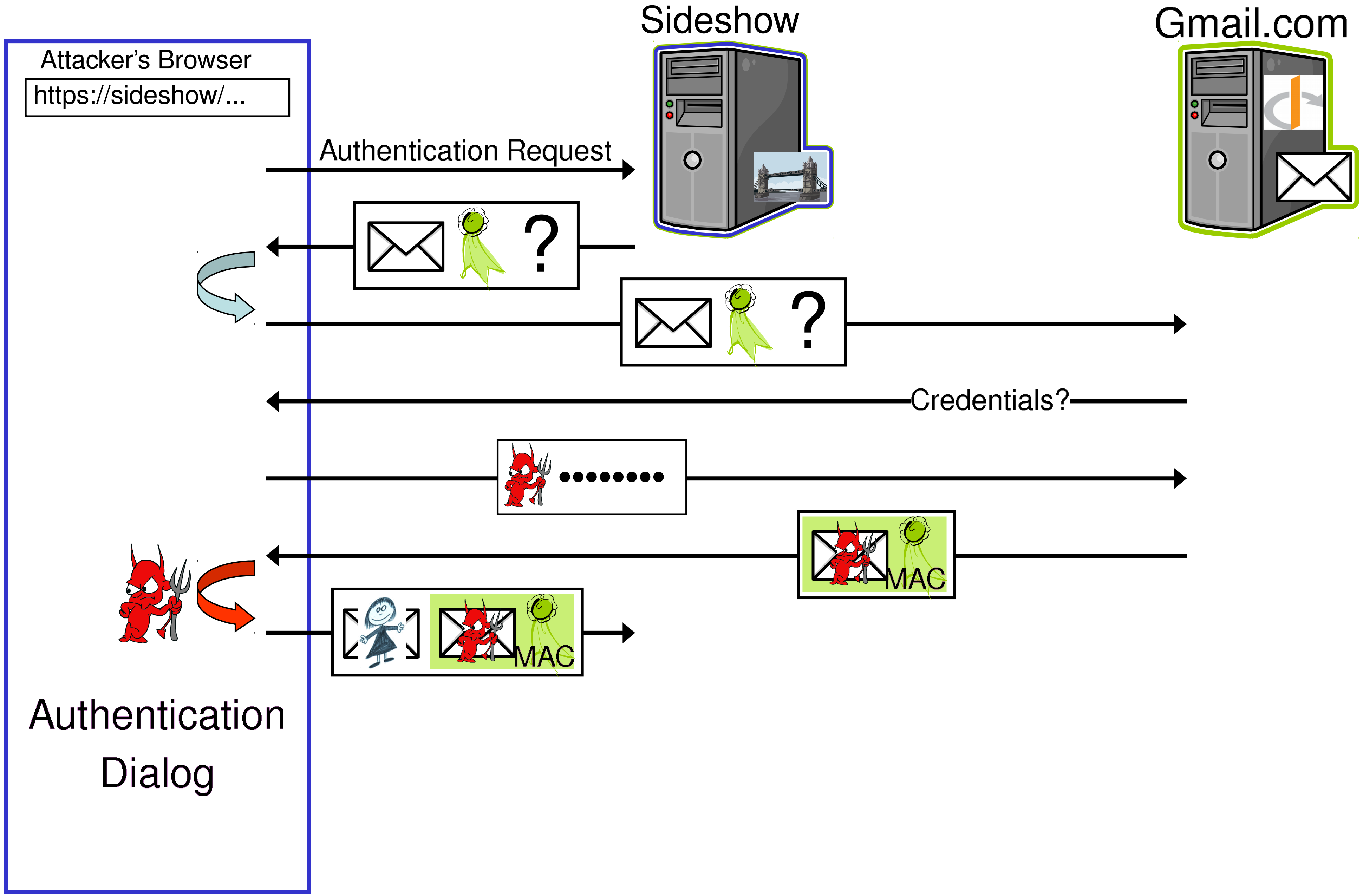

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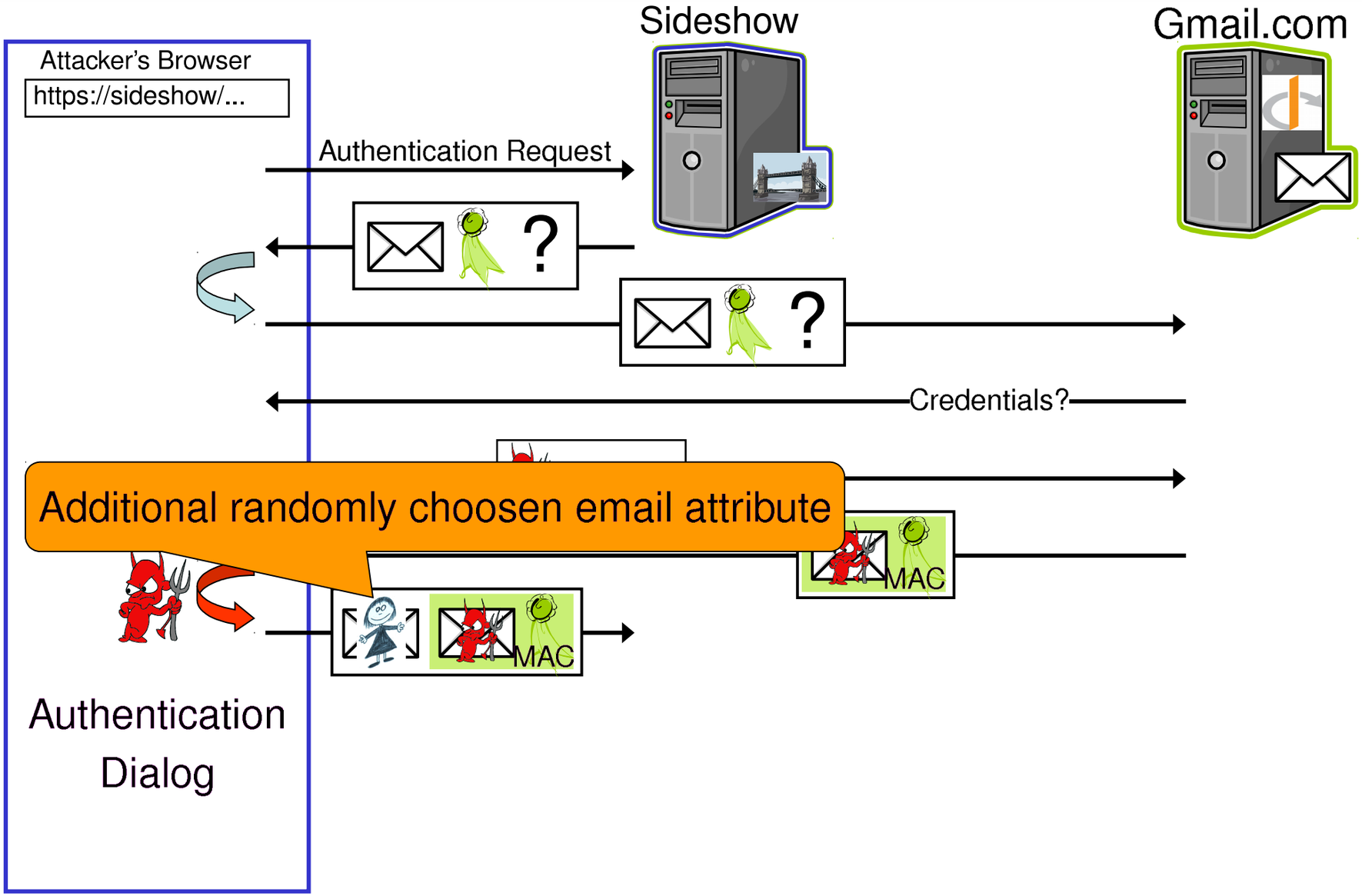

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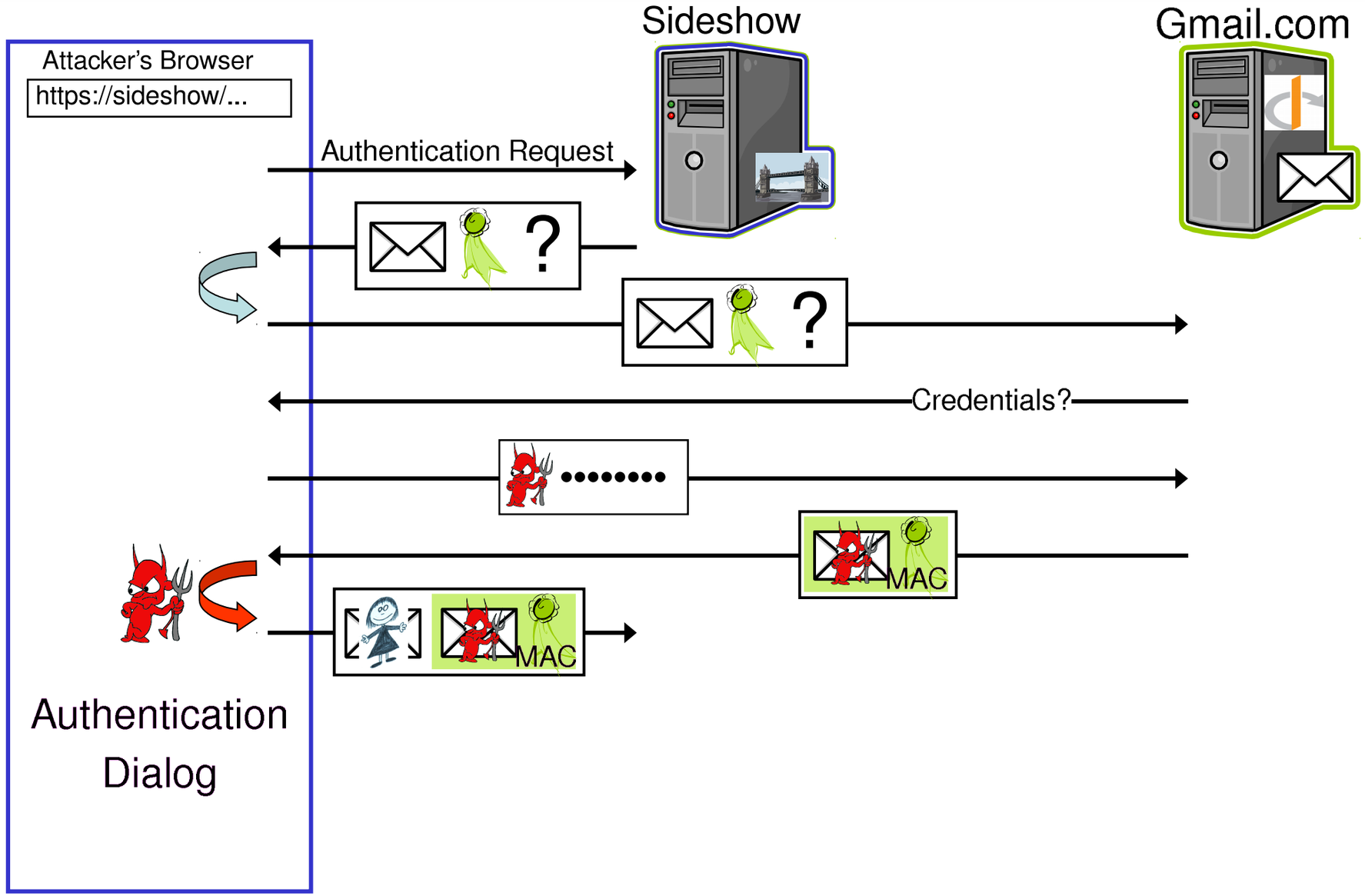

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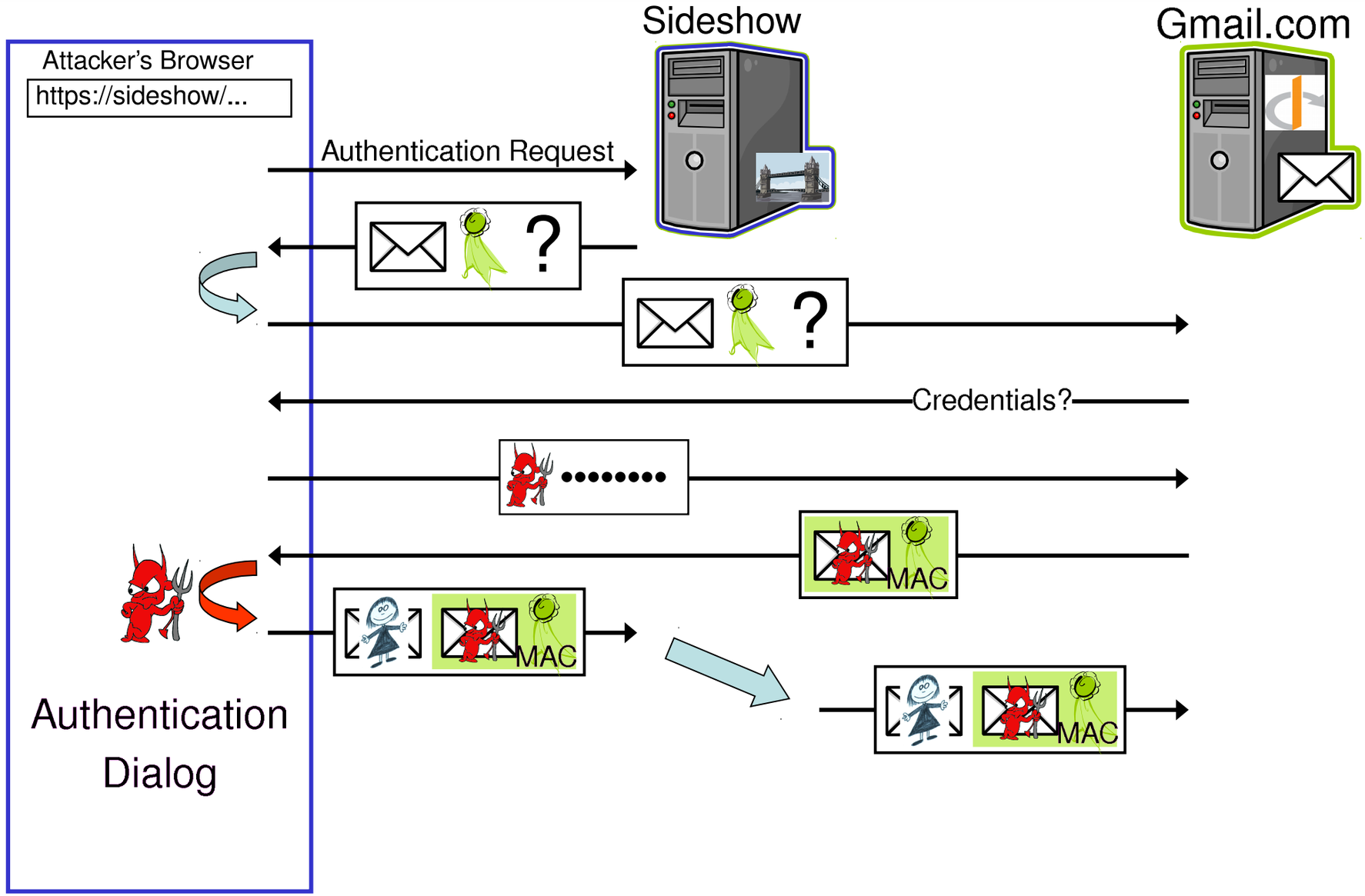

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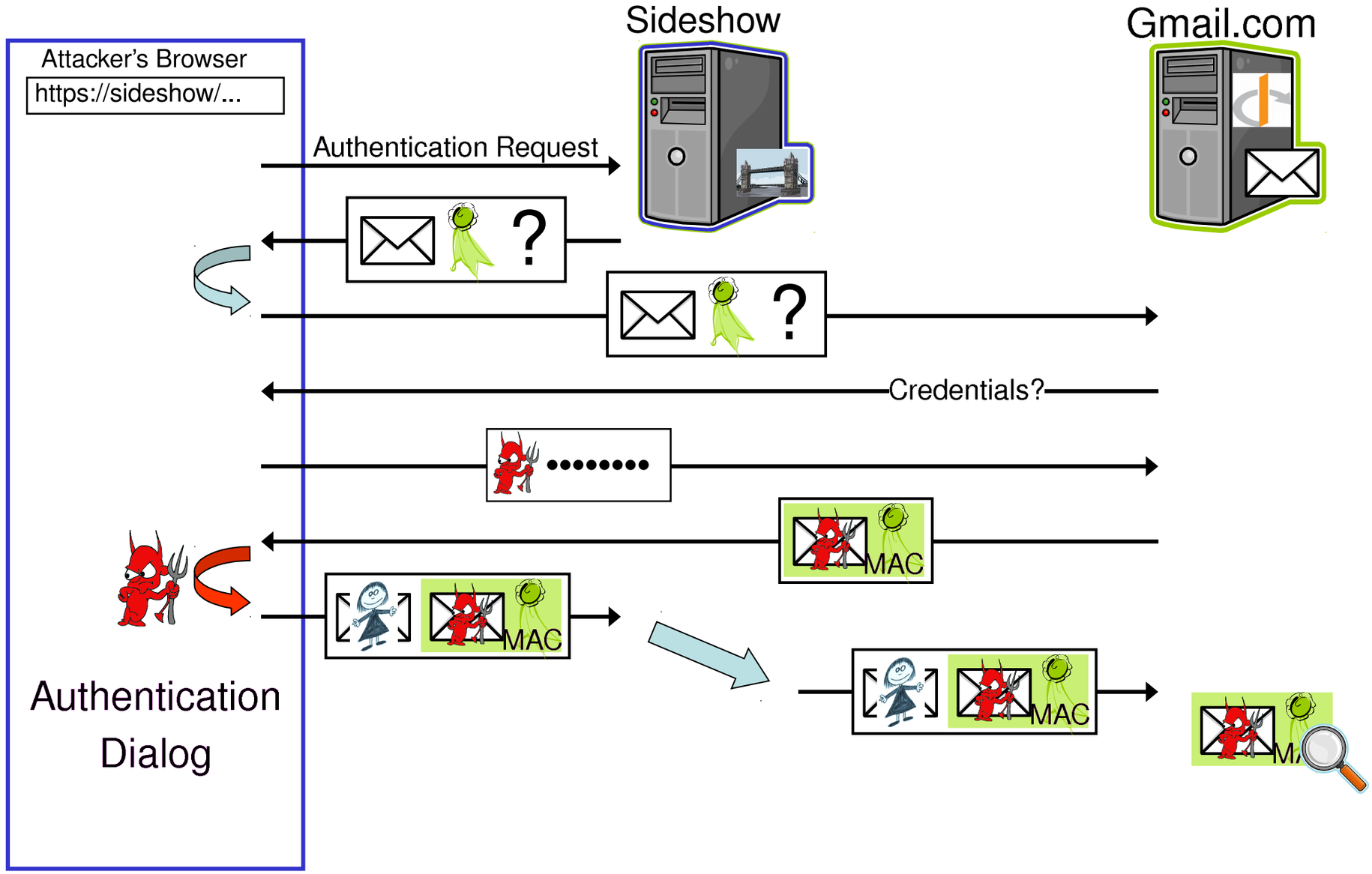

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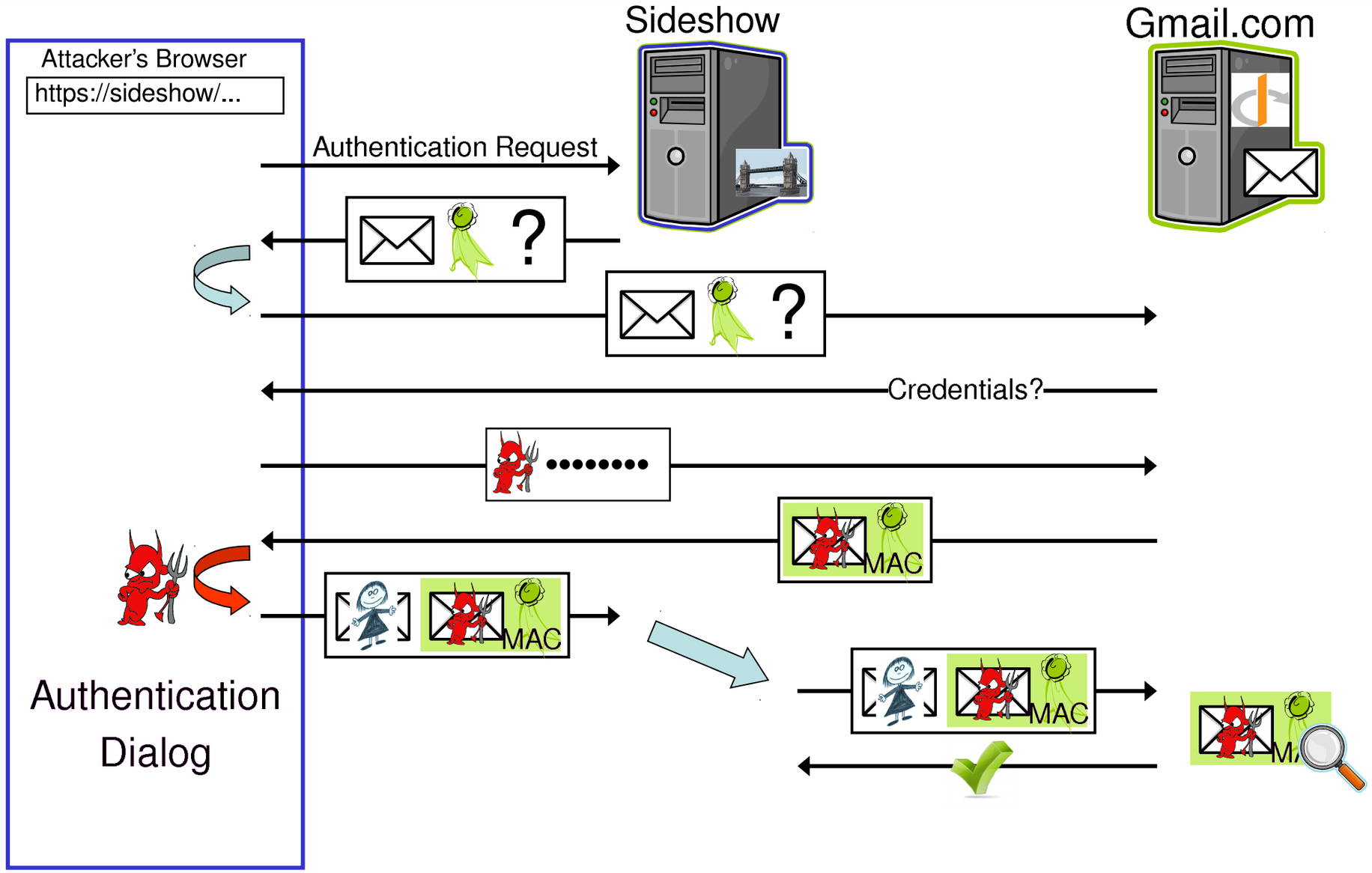

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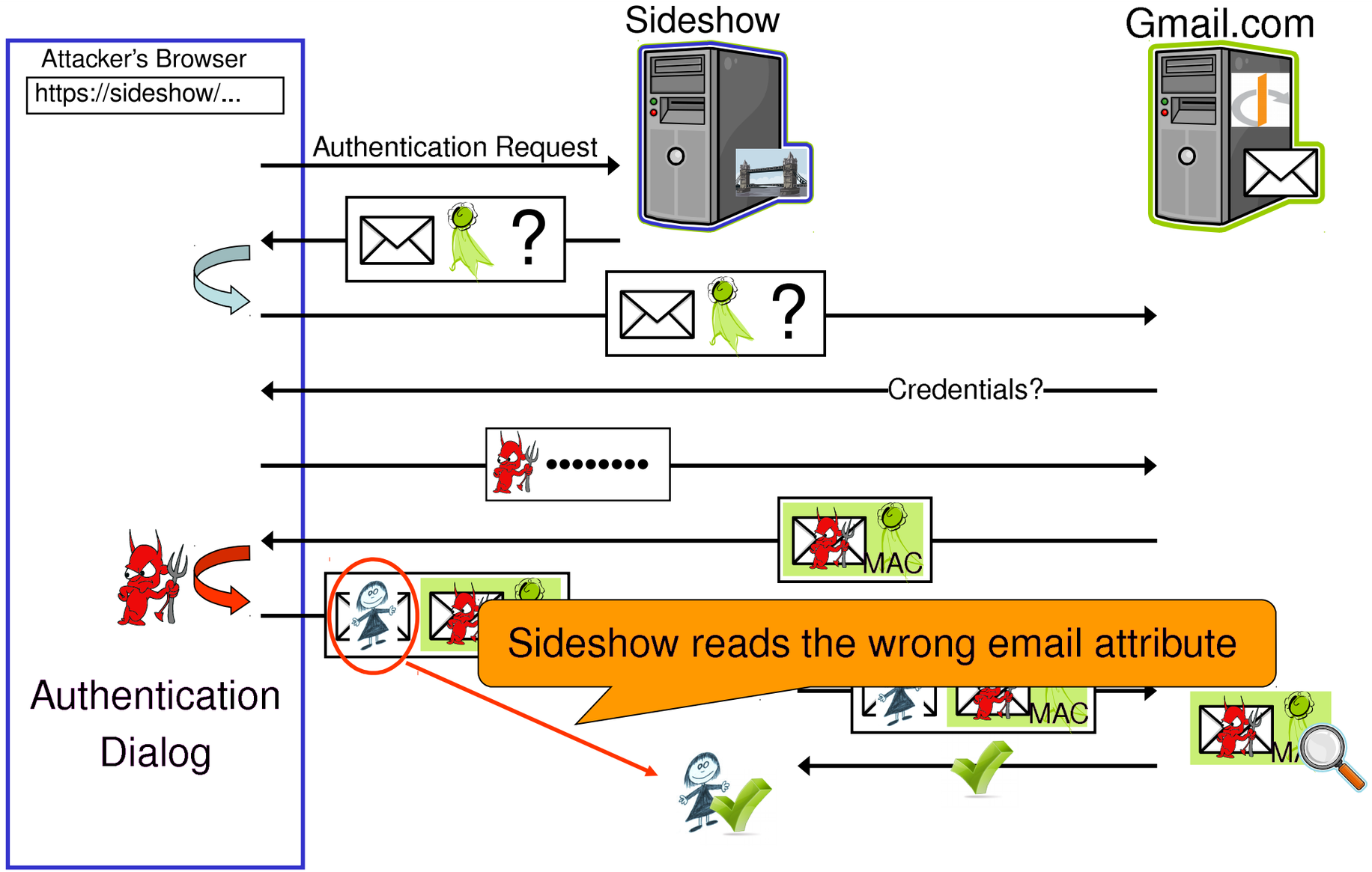

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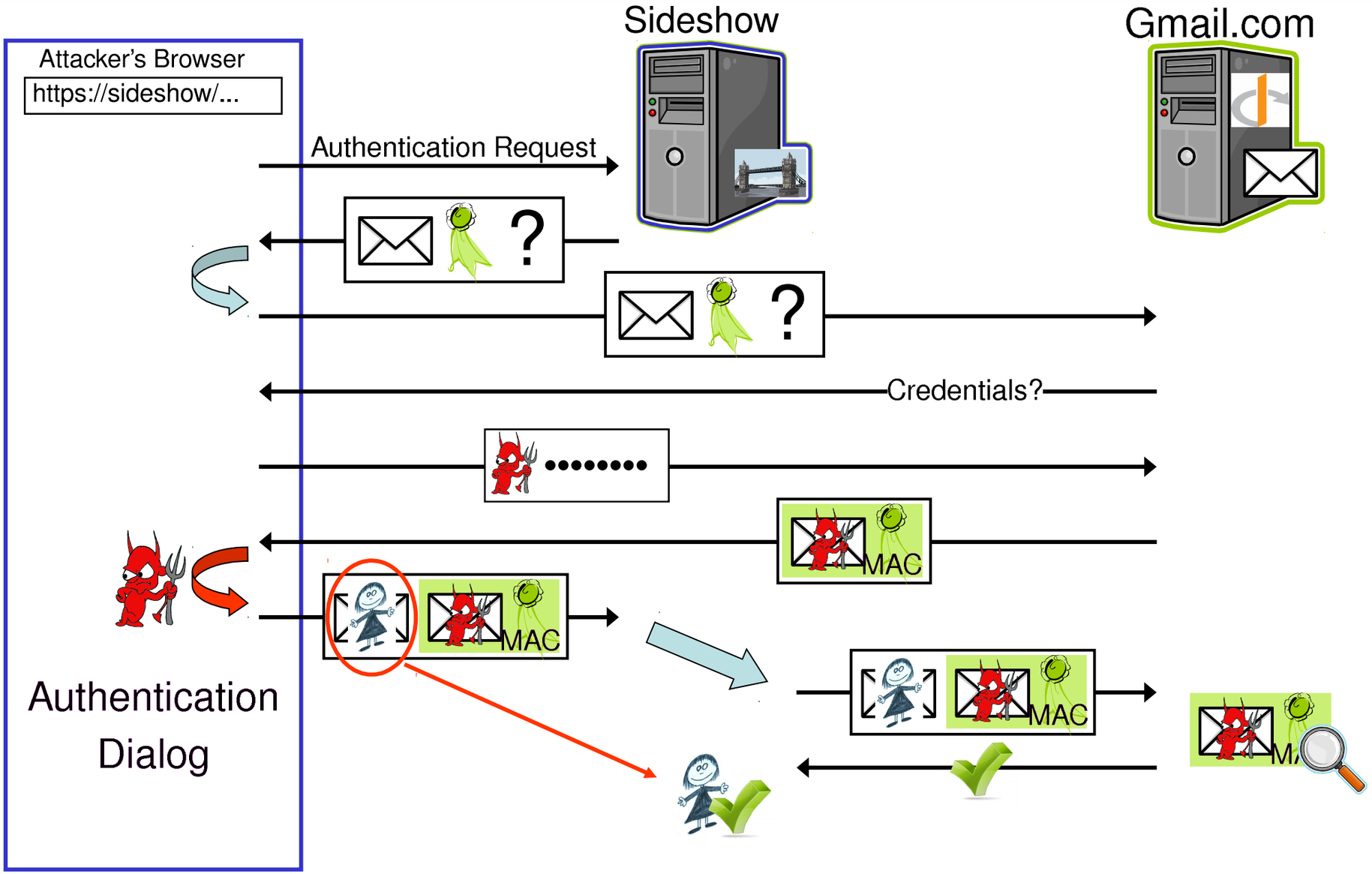

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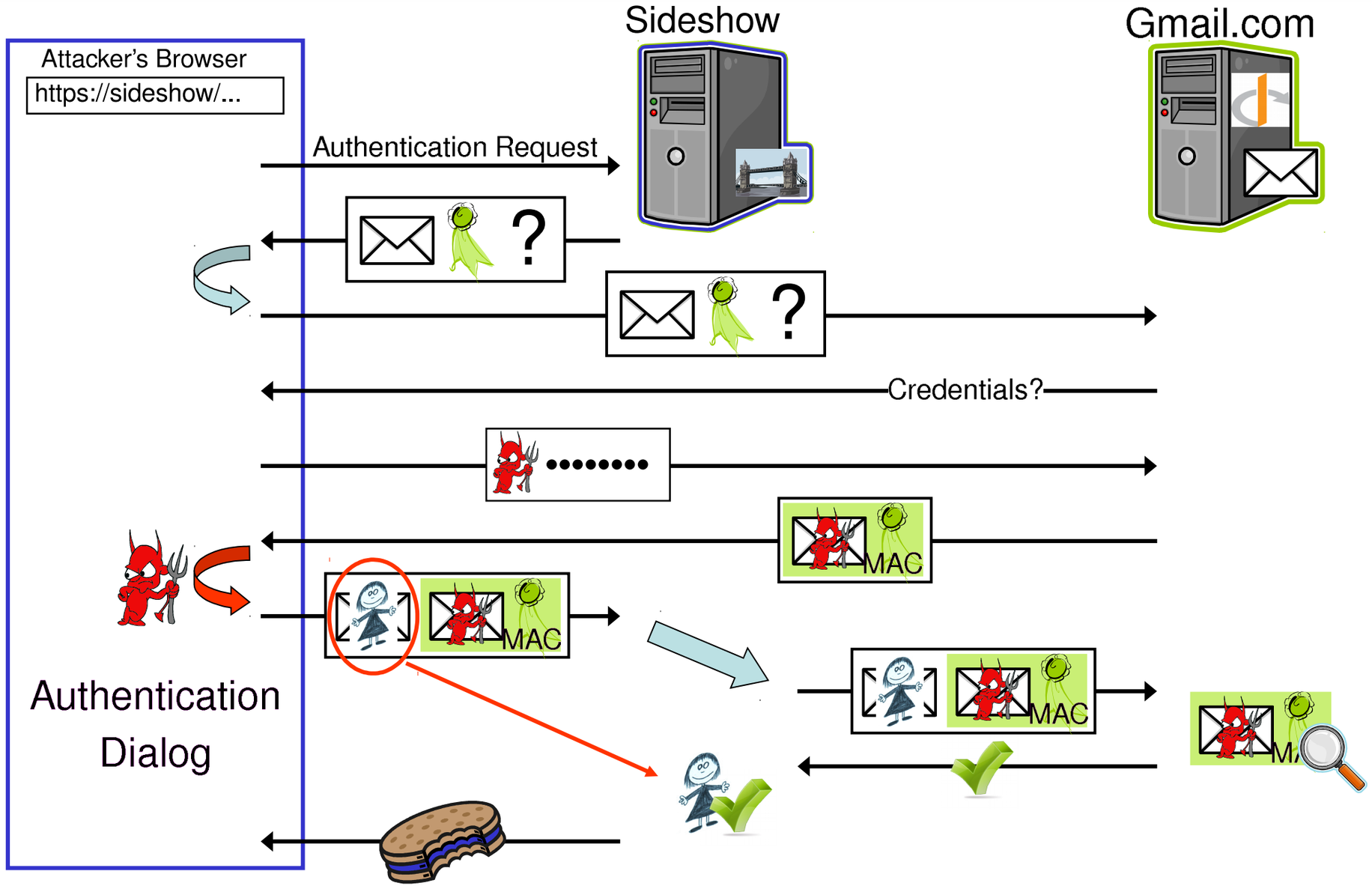
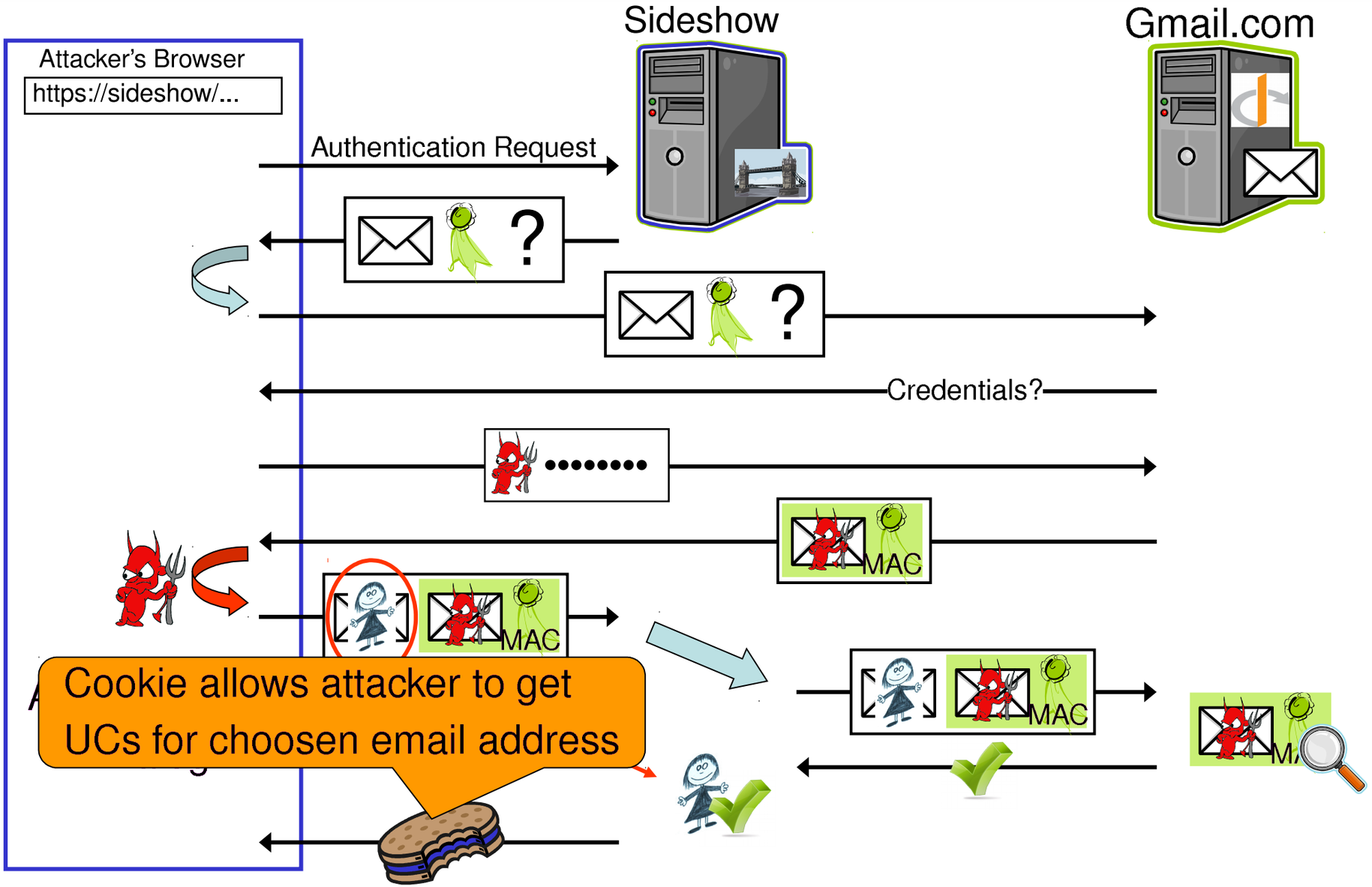


Identity Forgery (II)



Privacy

Unique claim:

"… the BrowserID protocol **never leaks** tracking information back **to the Identity Provider**." - Mozilla Persona FAQ

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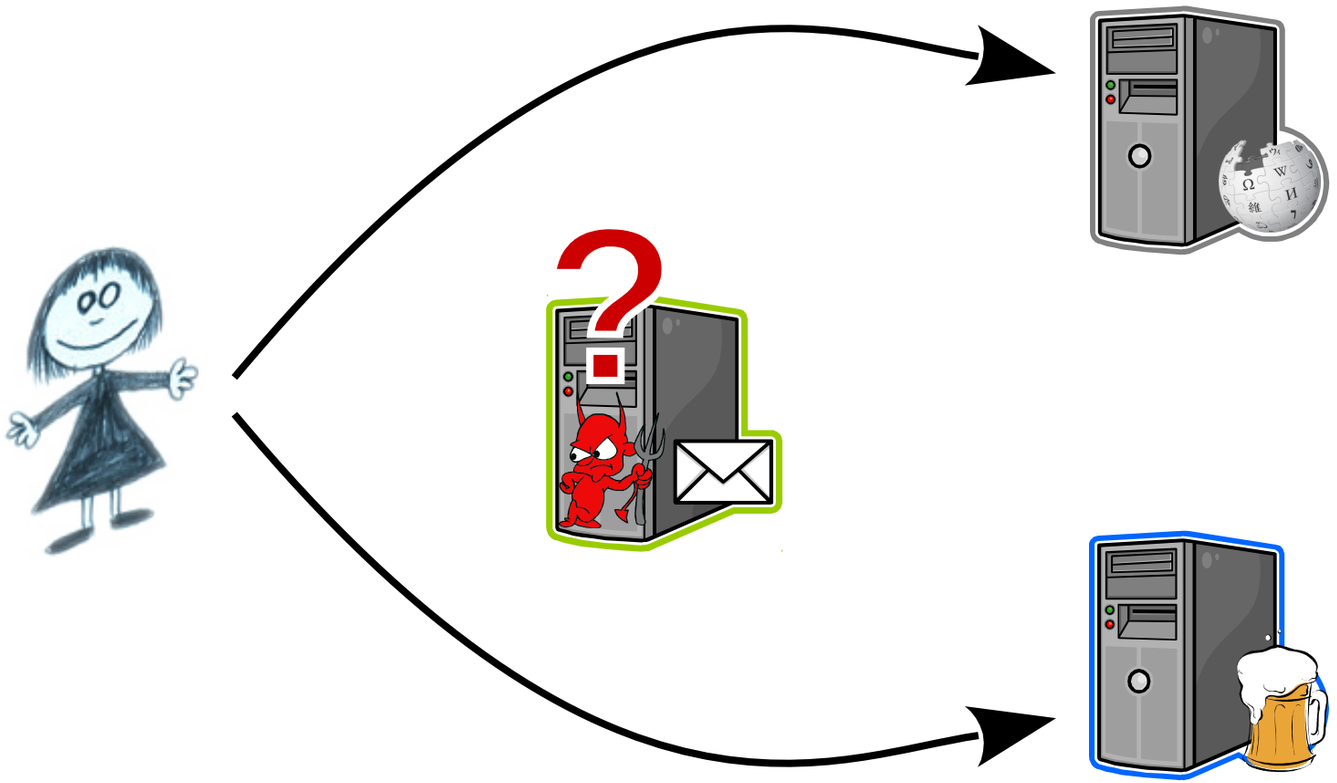

Privacy

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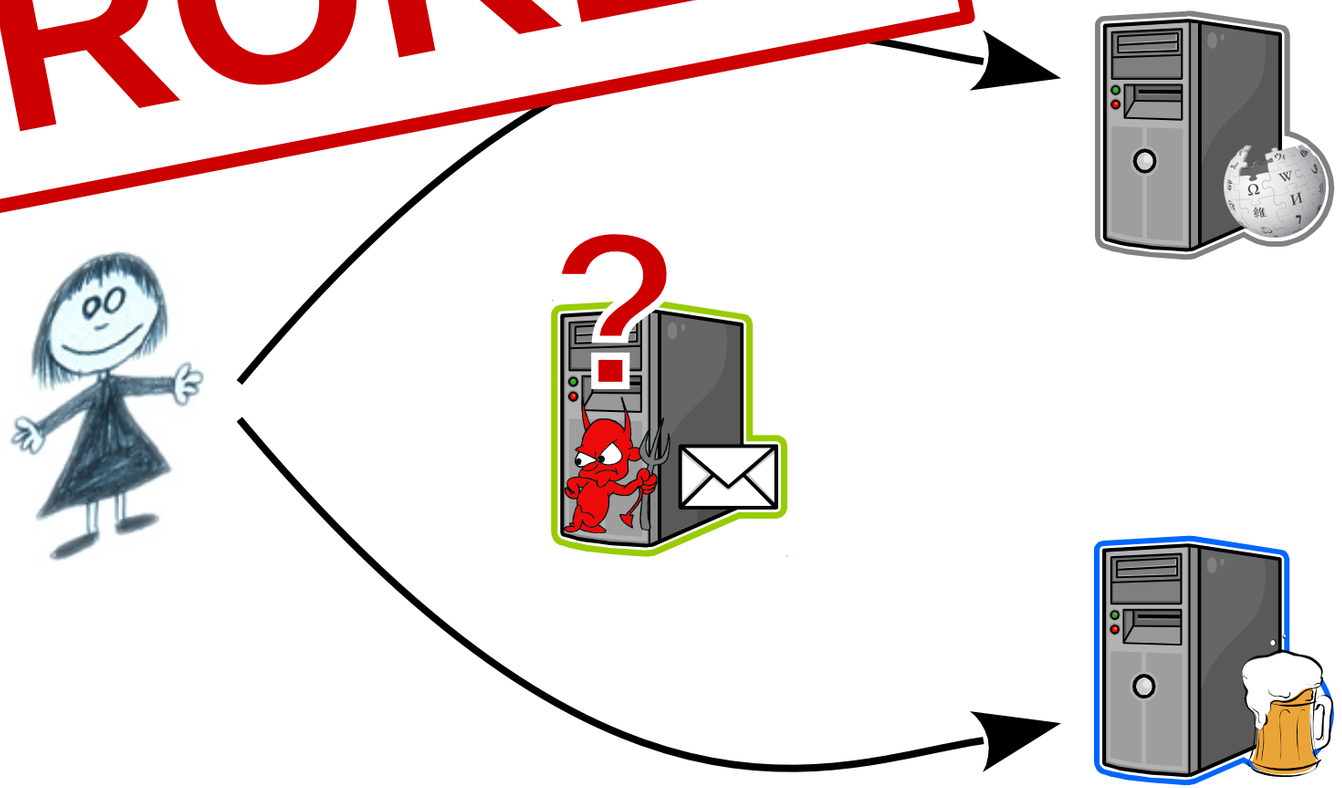
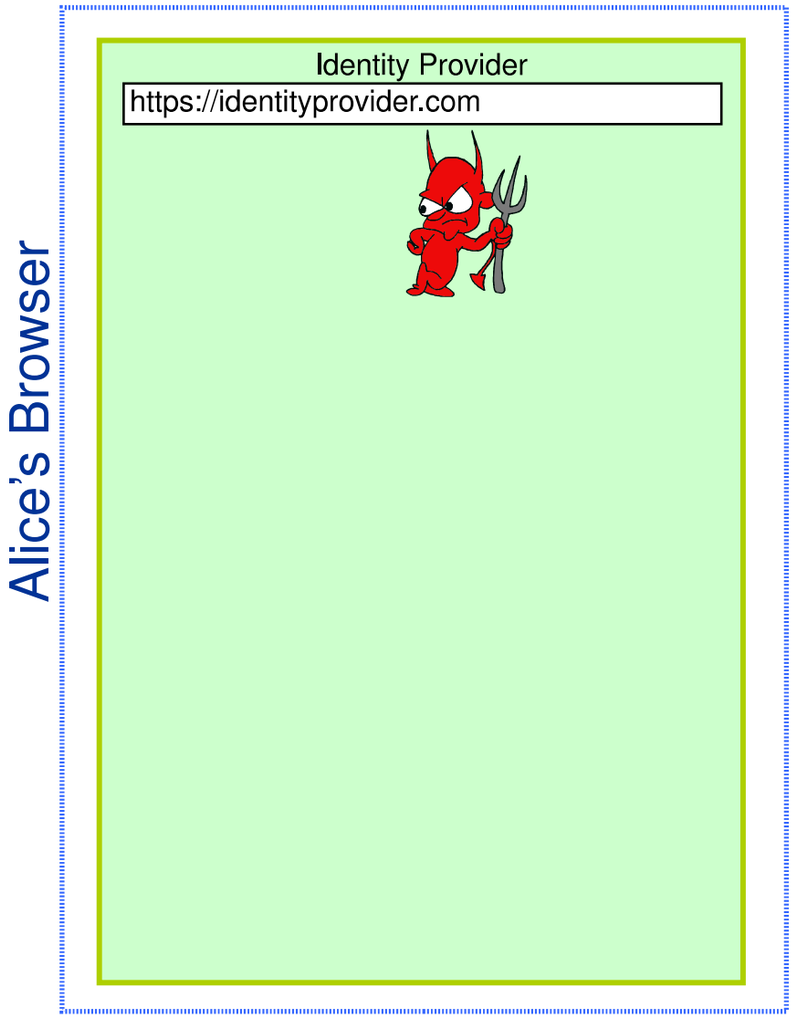
BROKEN



Privacy Attacks

Information is leaked by the **window structure** in the user's browser:



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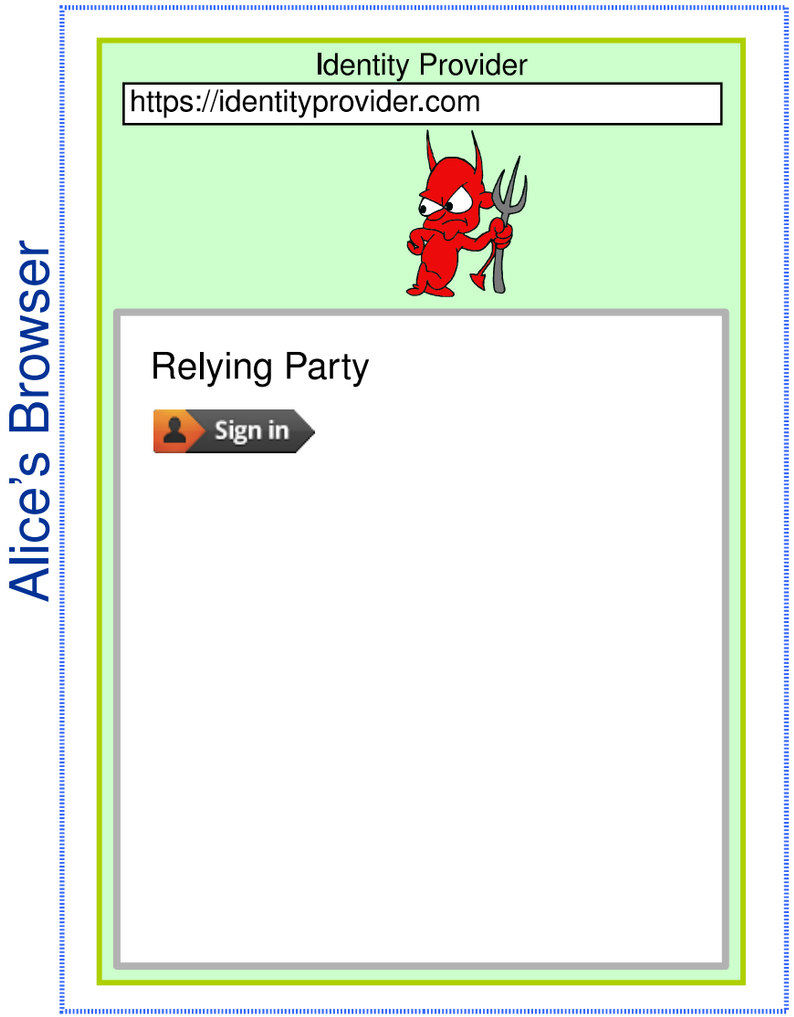

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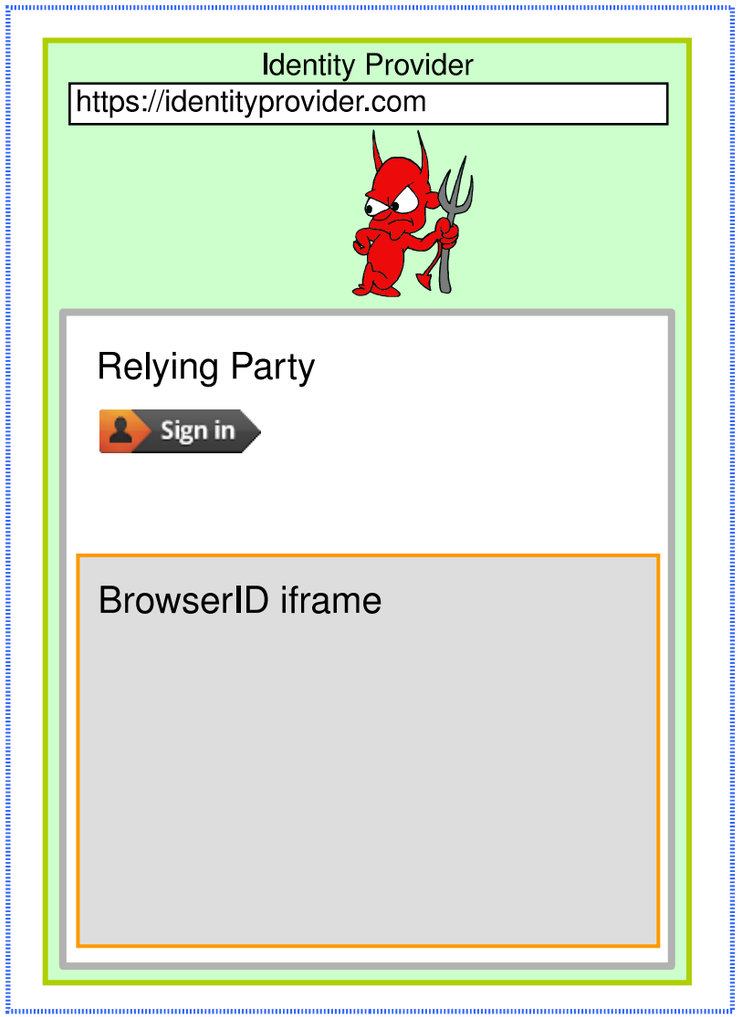

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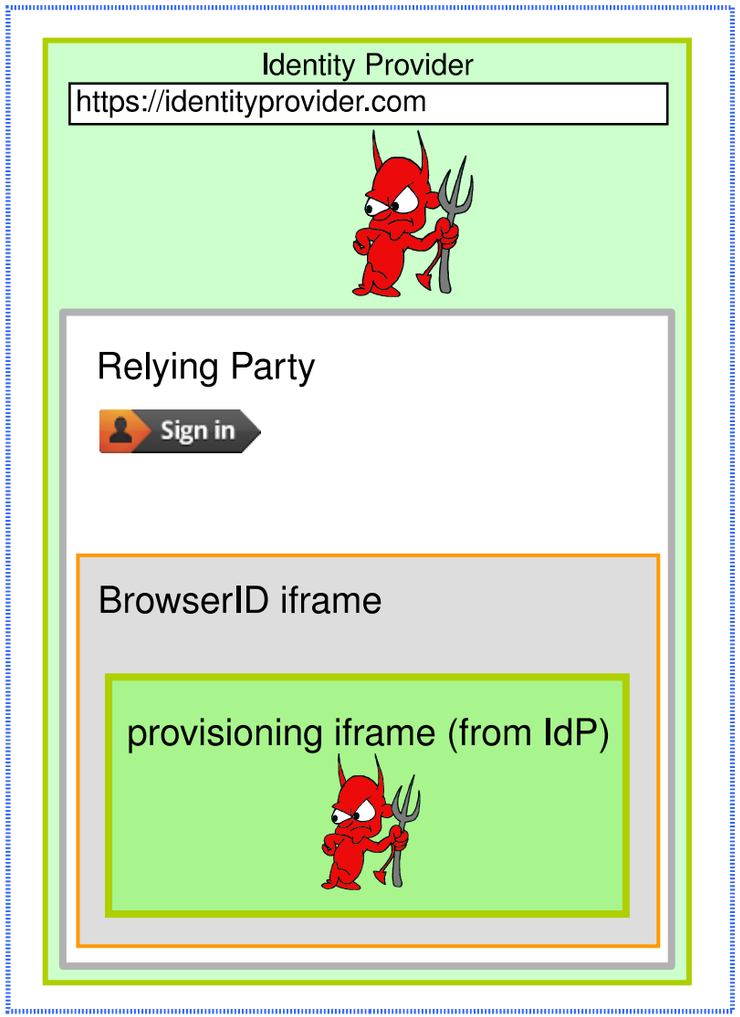

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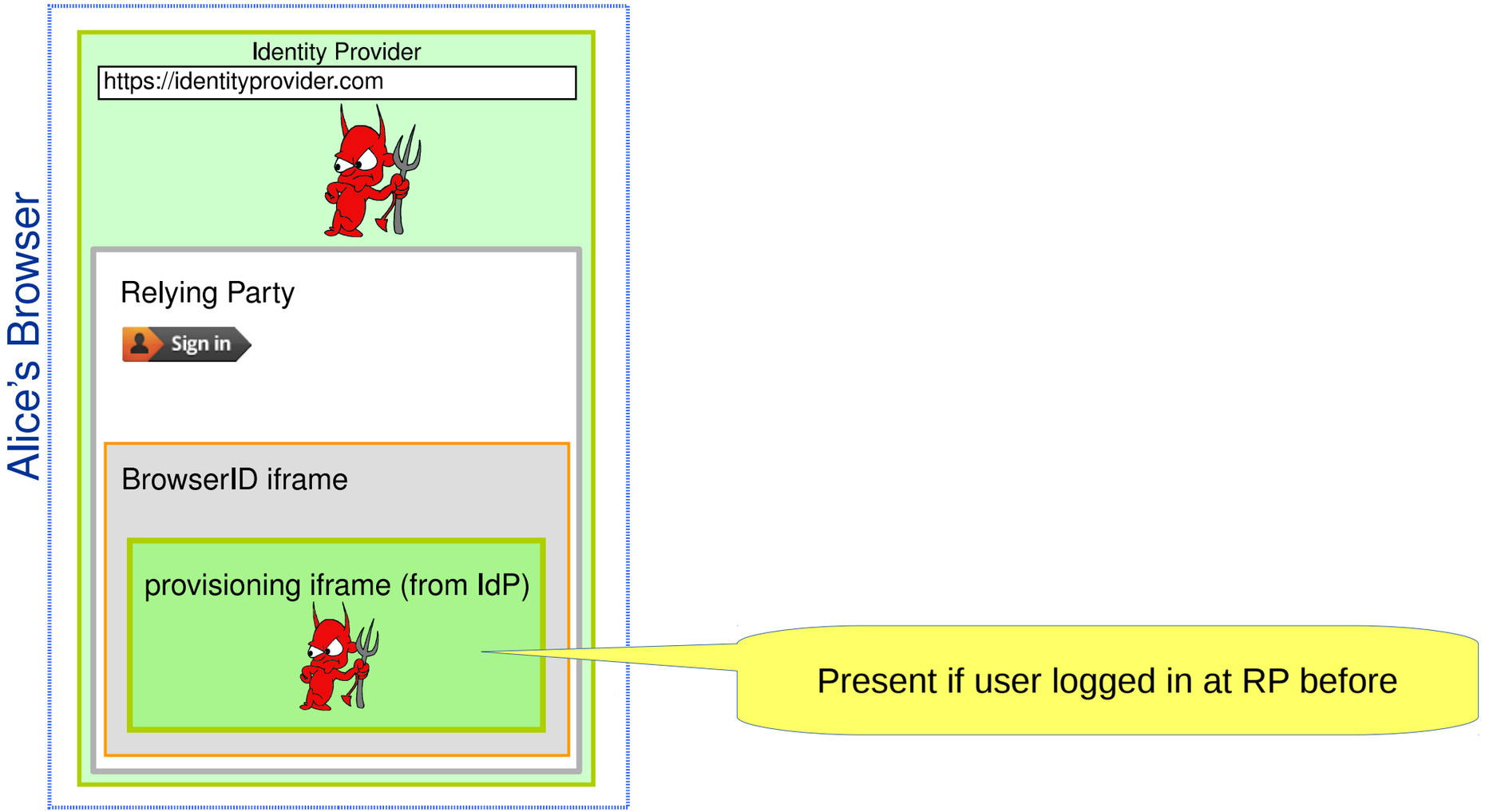

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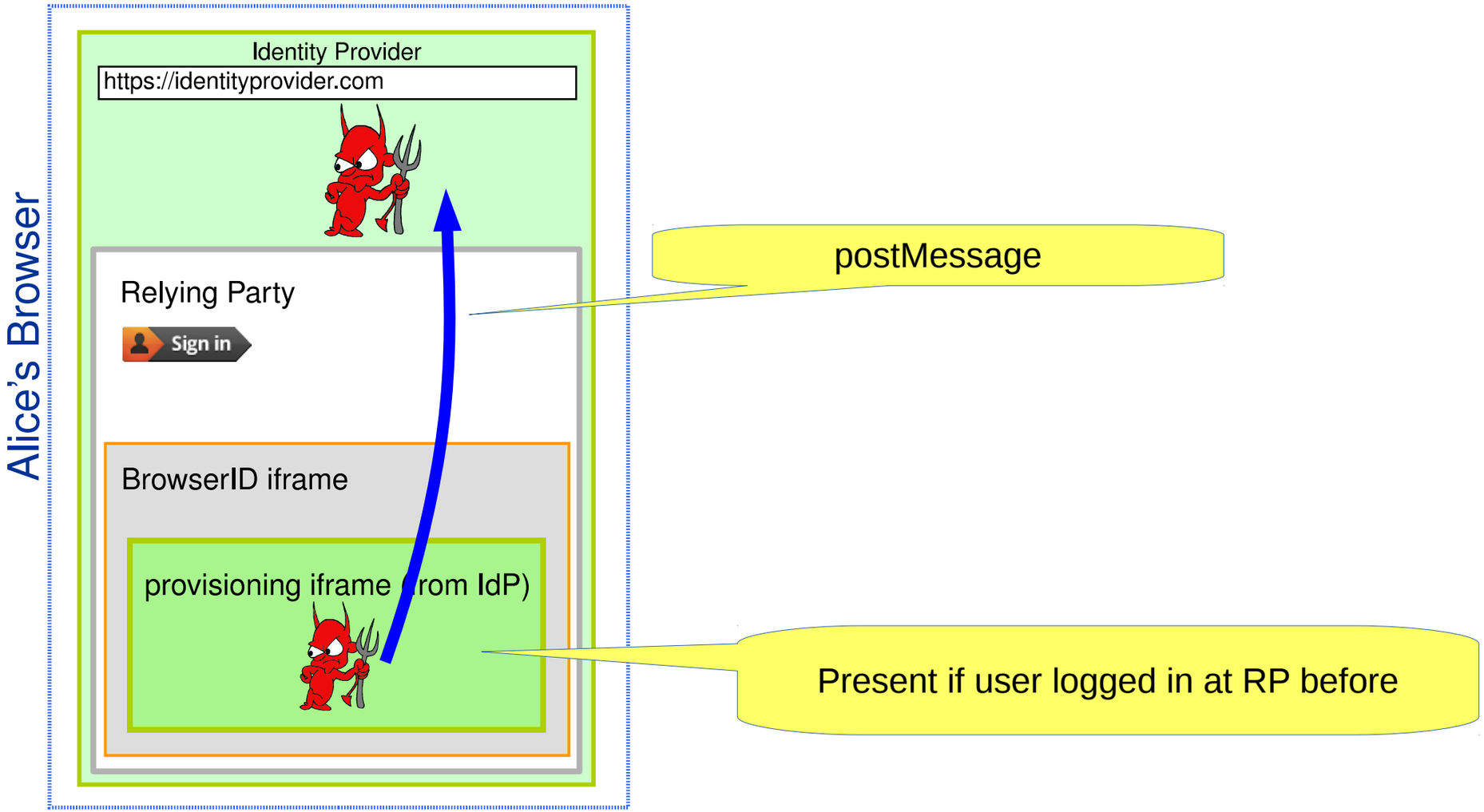

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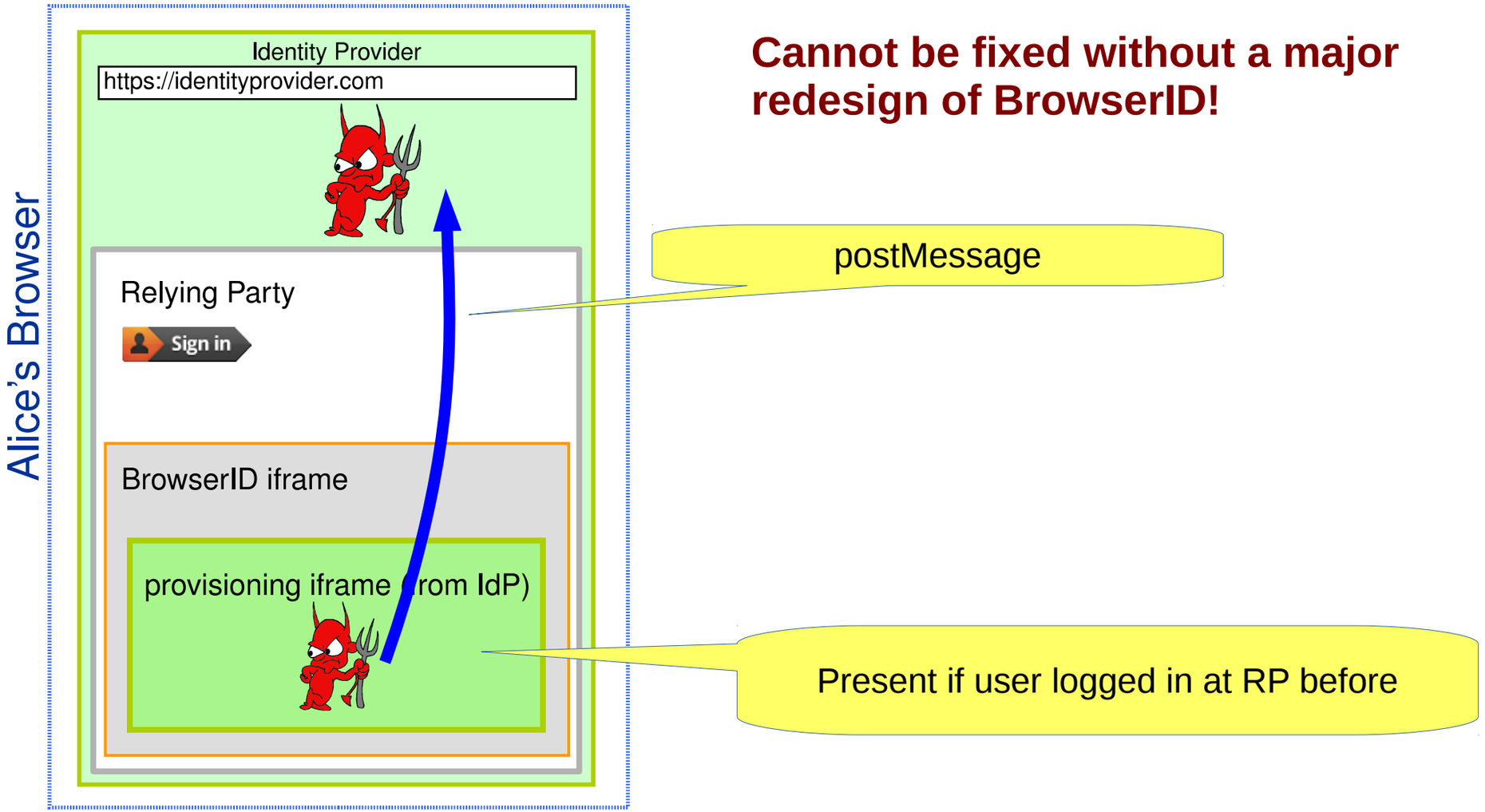

Cannot be fixed without a major redesign of BrowserID!

Privacy Attacks

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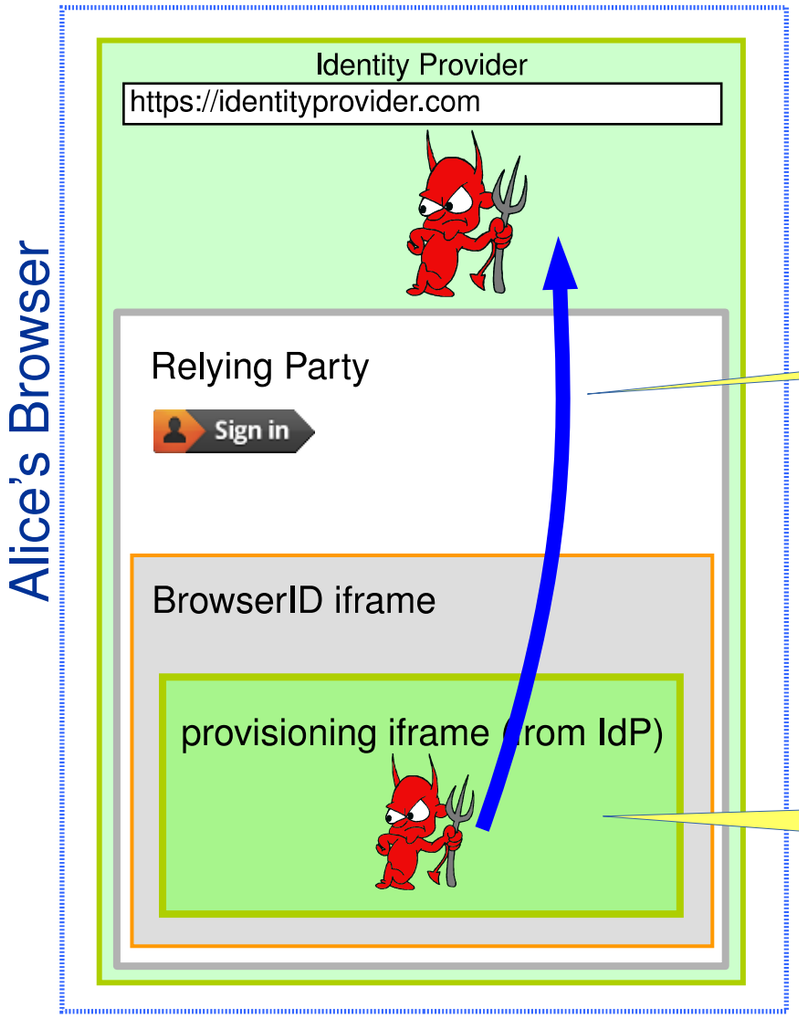


Cannot be fixed without a major redesign of BrowserID!

postMessage

Present if user logged in at RP before

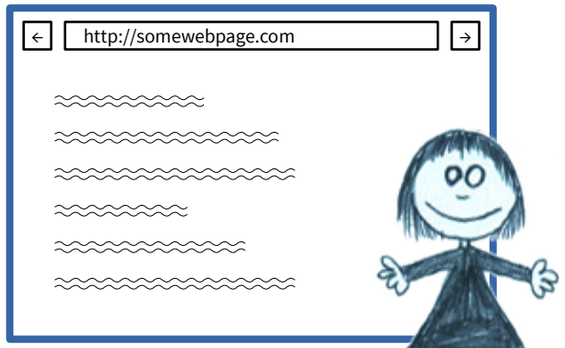
+ Variants

BrowserID

Security	**attack + fix** **formally proven** 
Privacy	

Can we build an SSO that provides security and privacy?

SPRESSO: Basic Principle

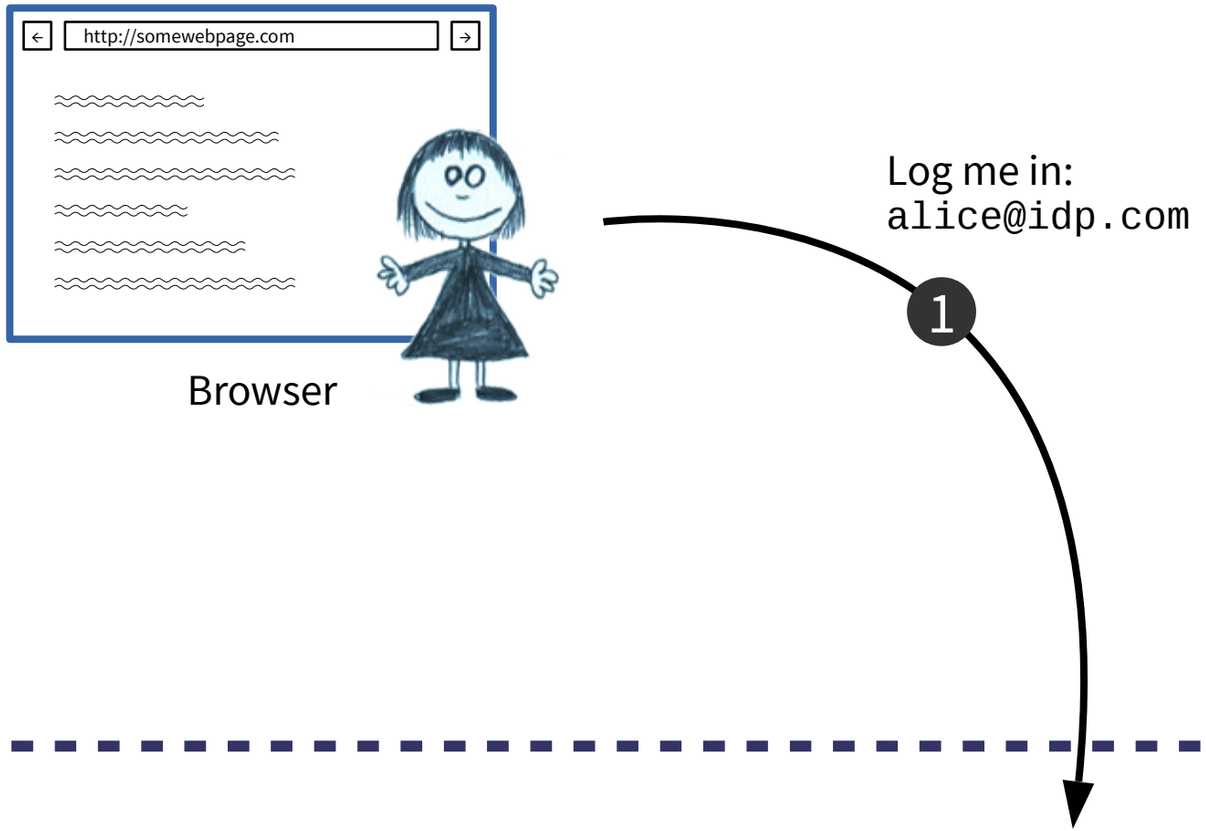


Browser

Identity Provider (idp.com)

Relying Party

SPRESSO: Basic Principle



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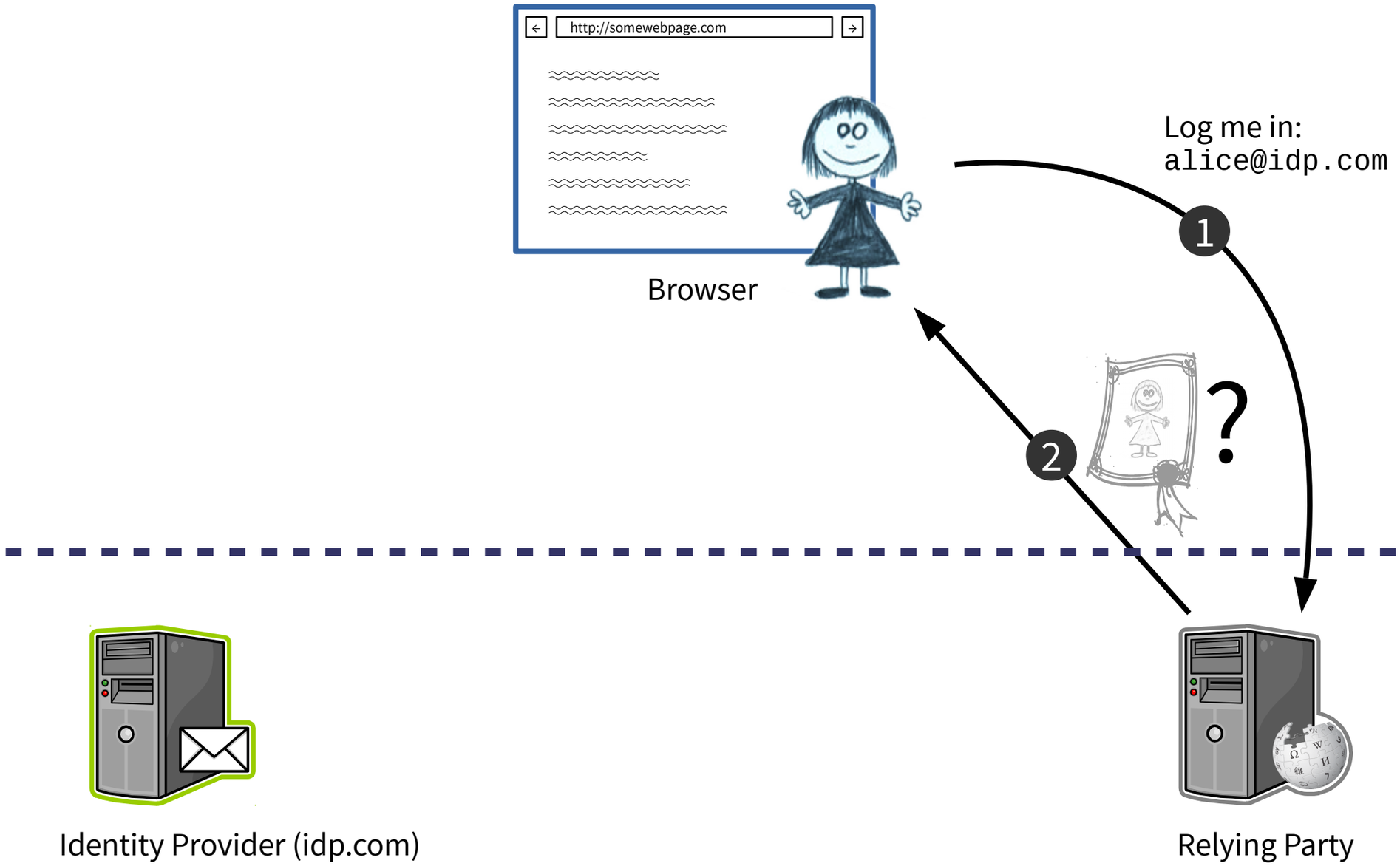

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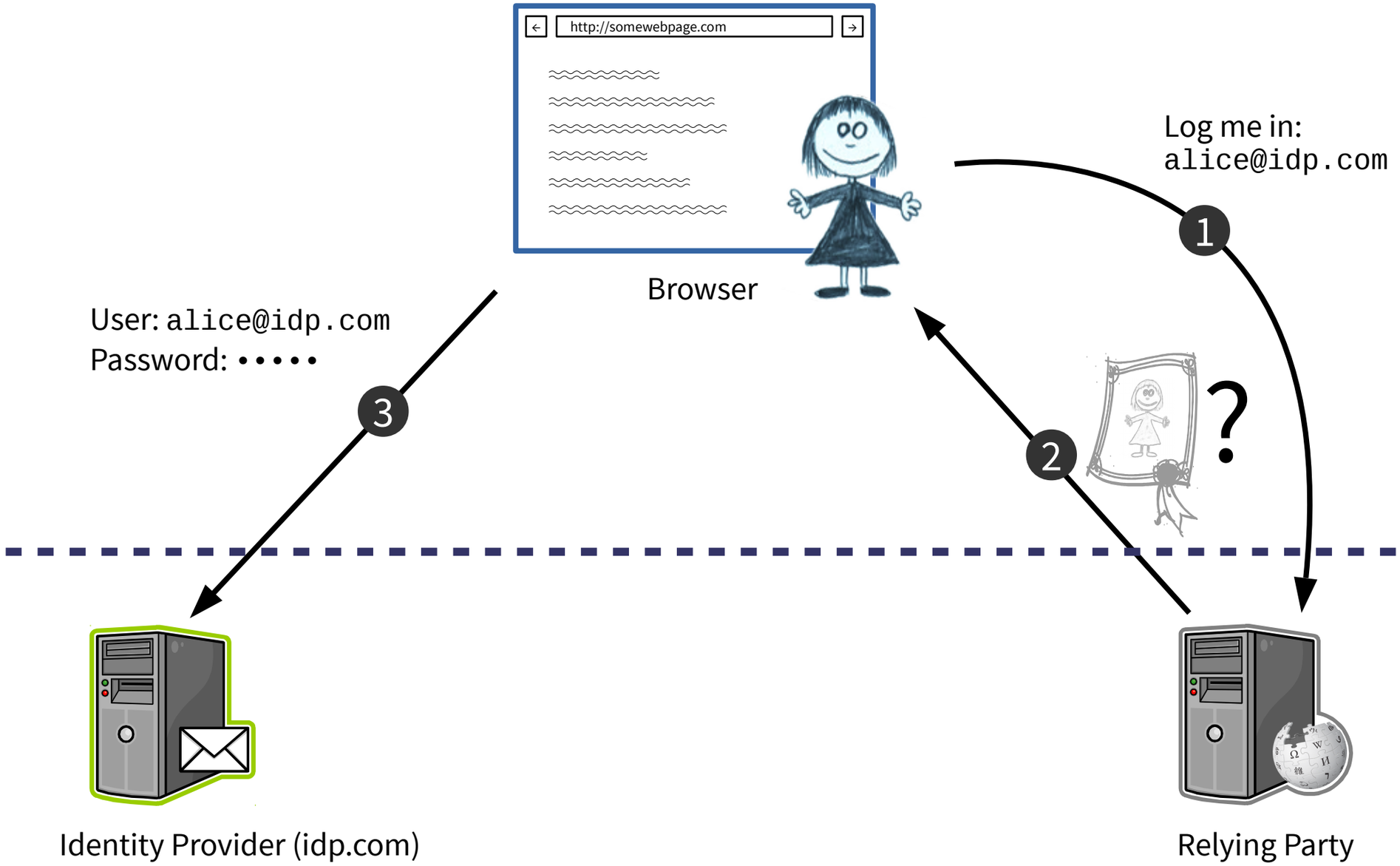

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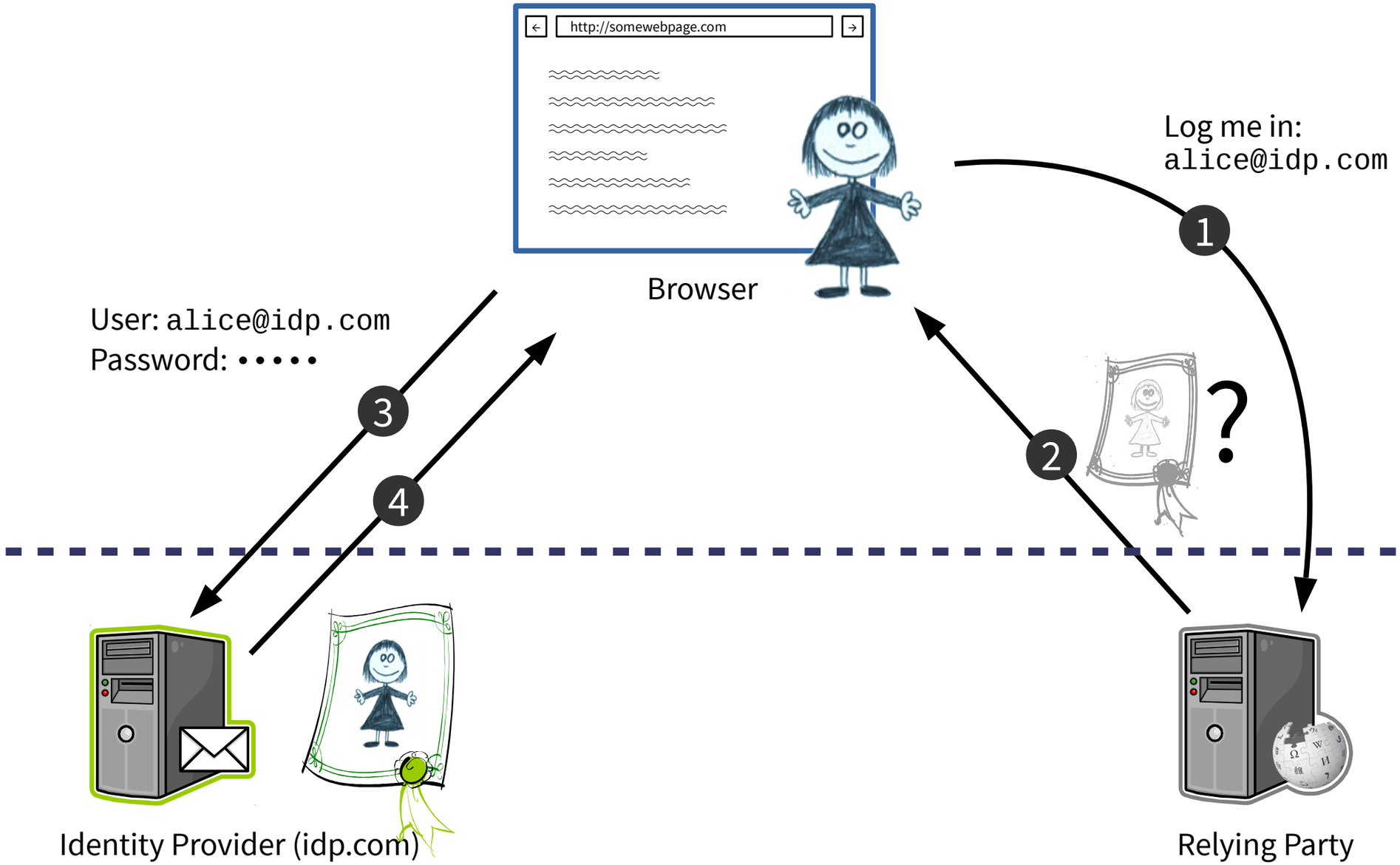

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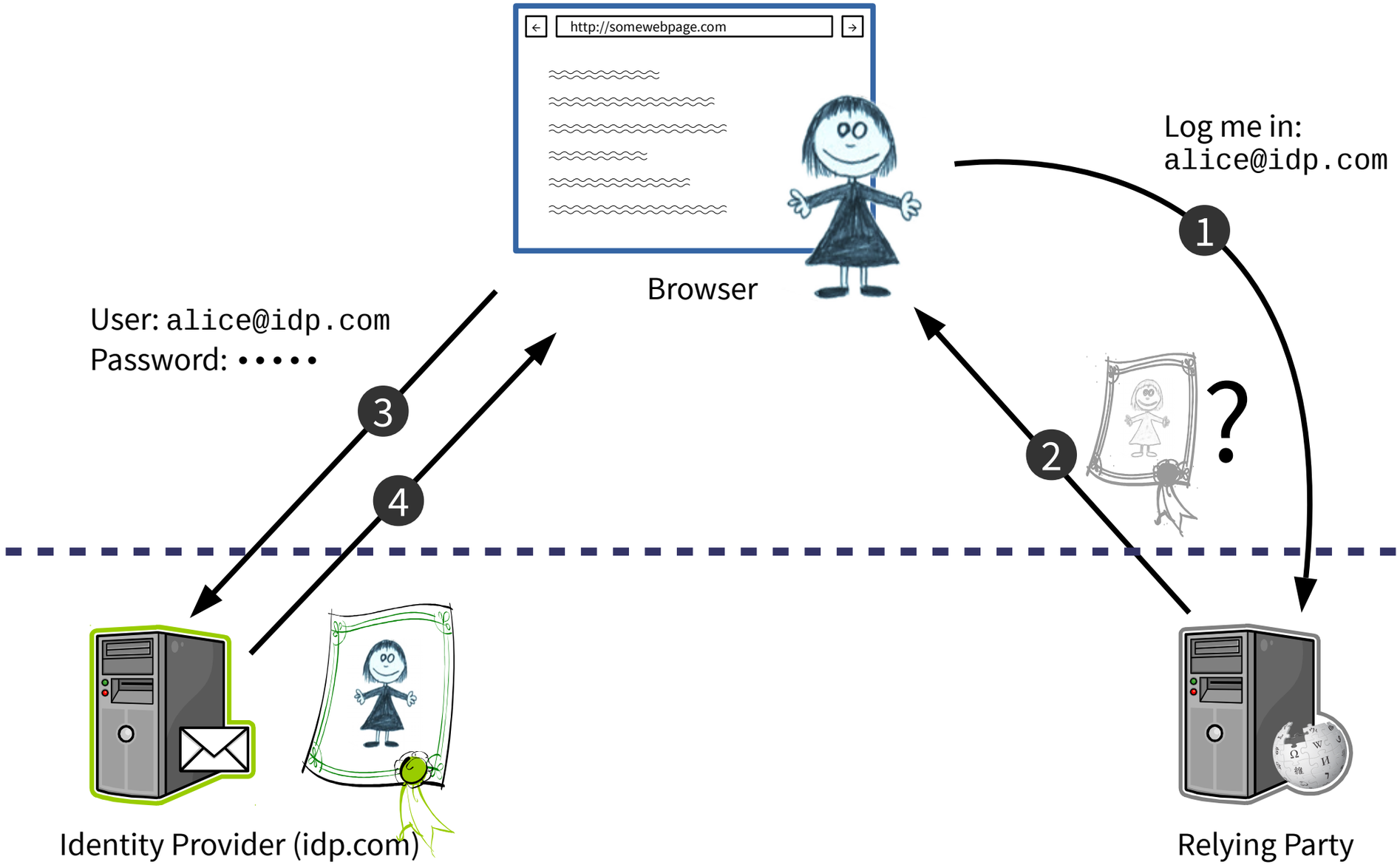

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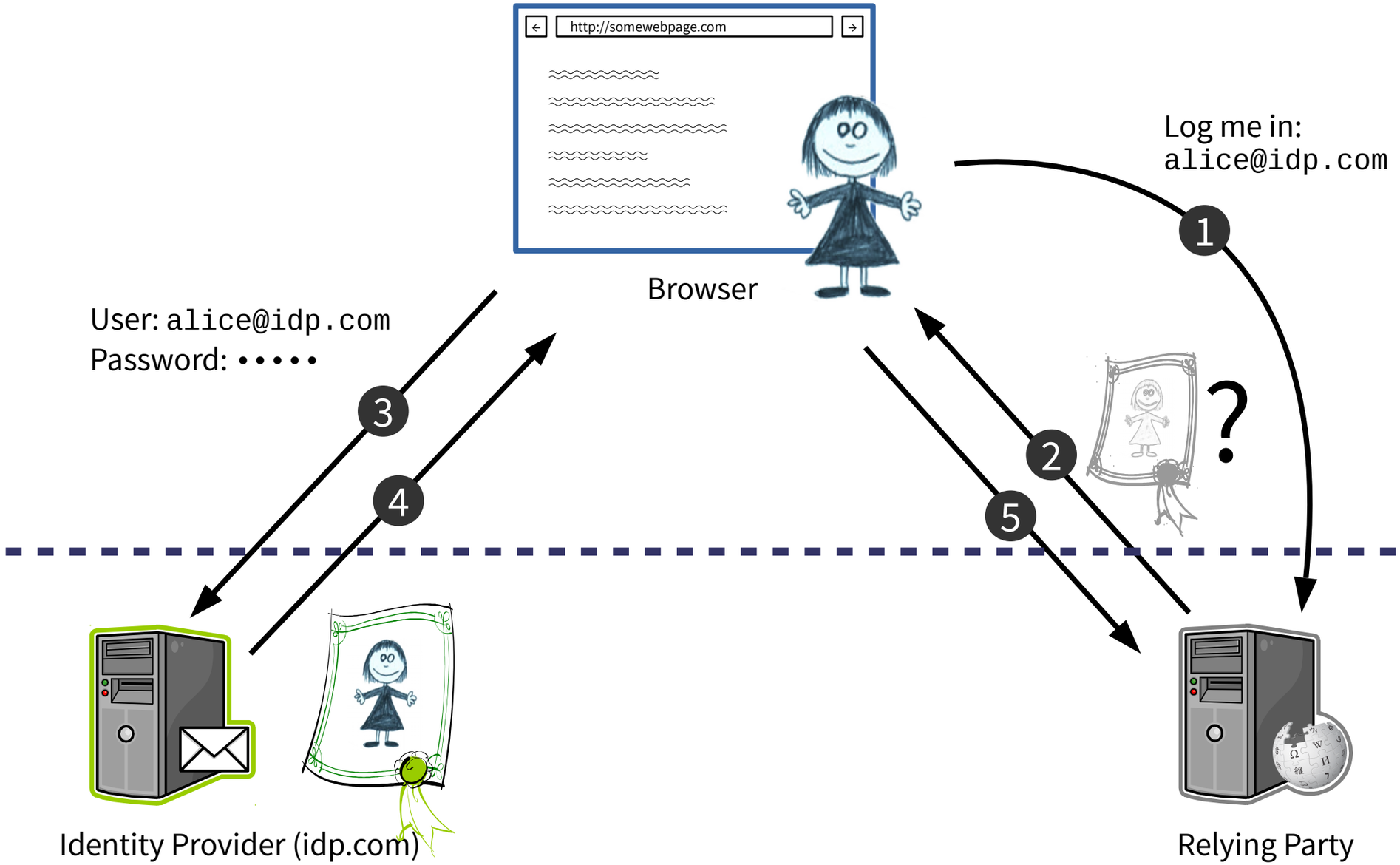

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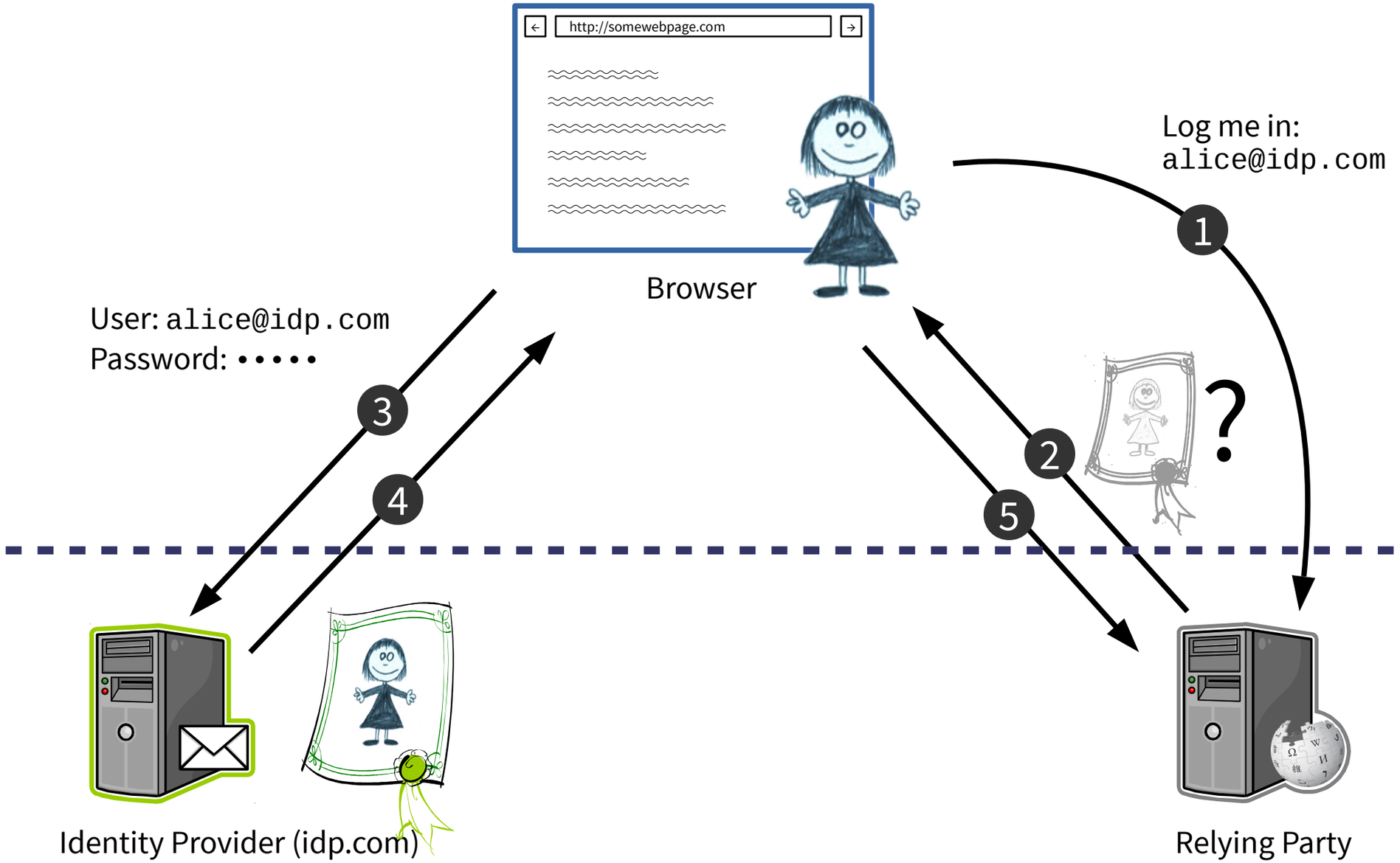

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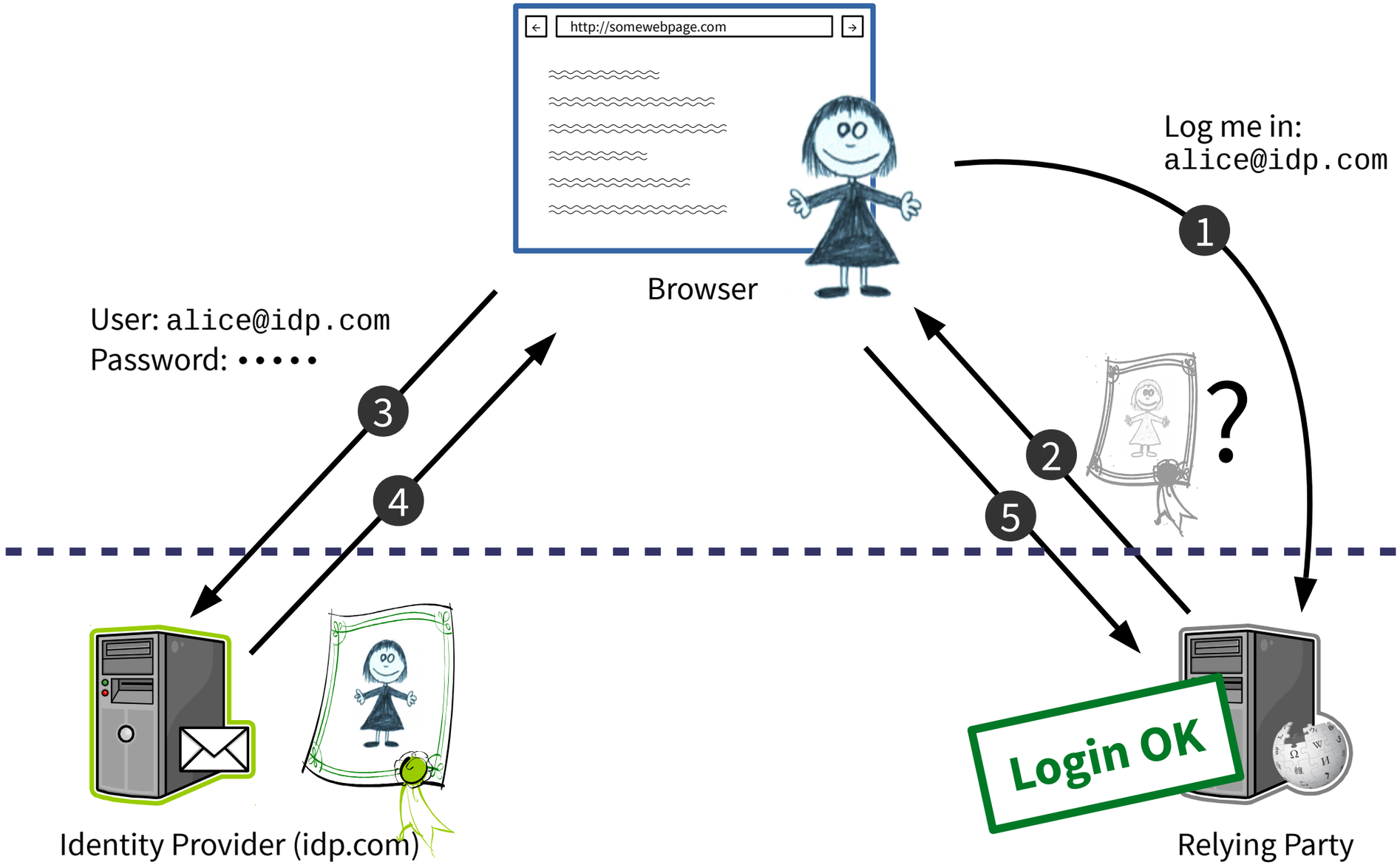
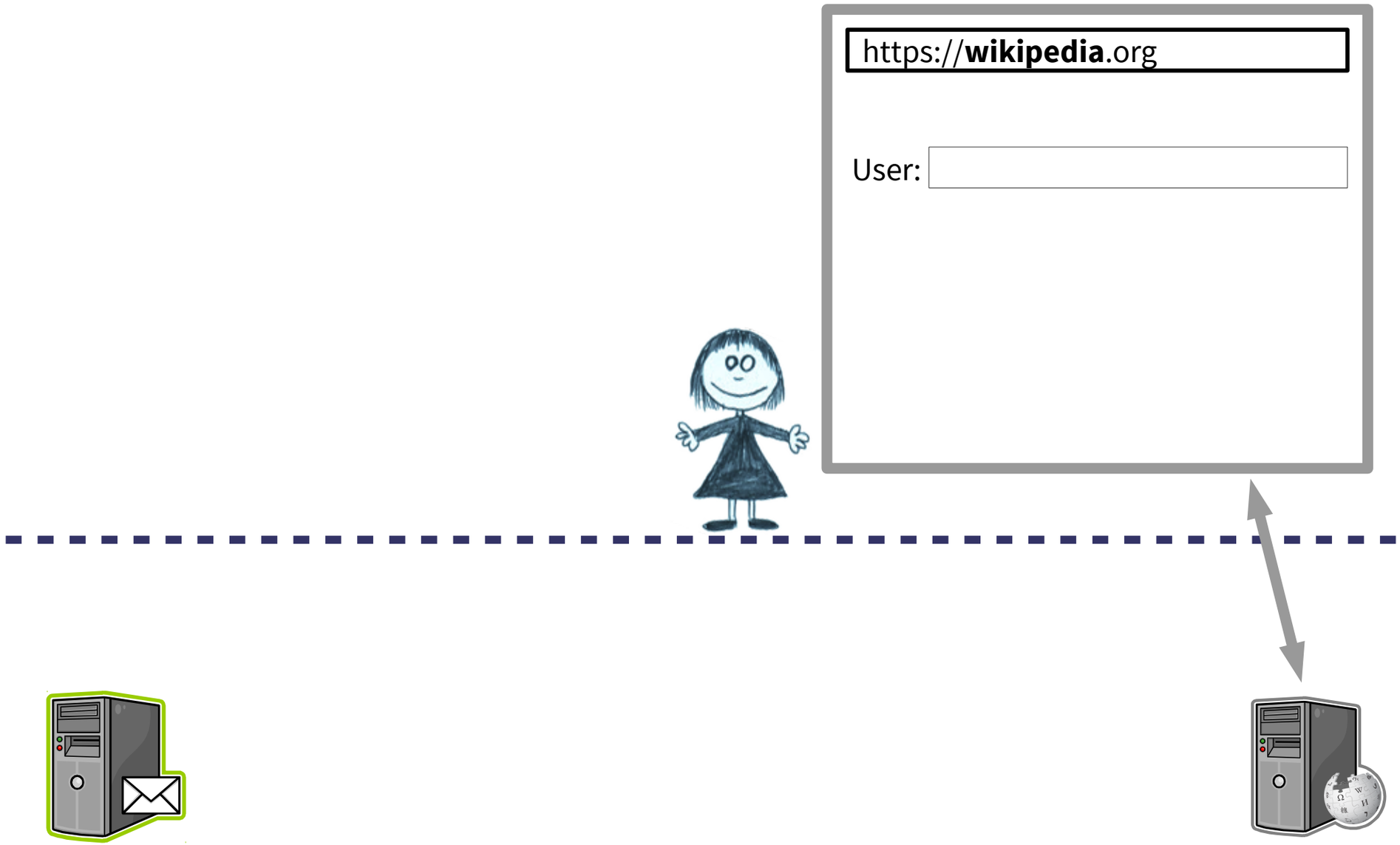


SPRESSO: Closer Look



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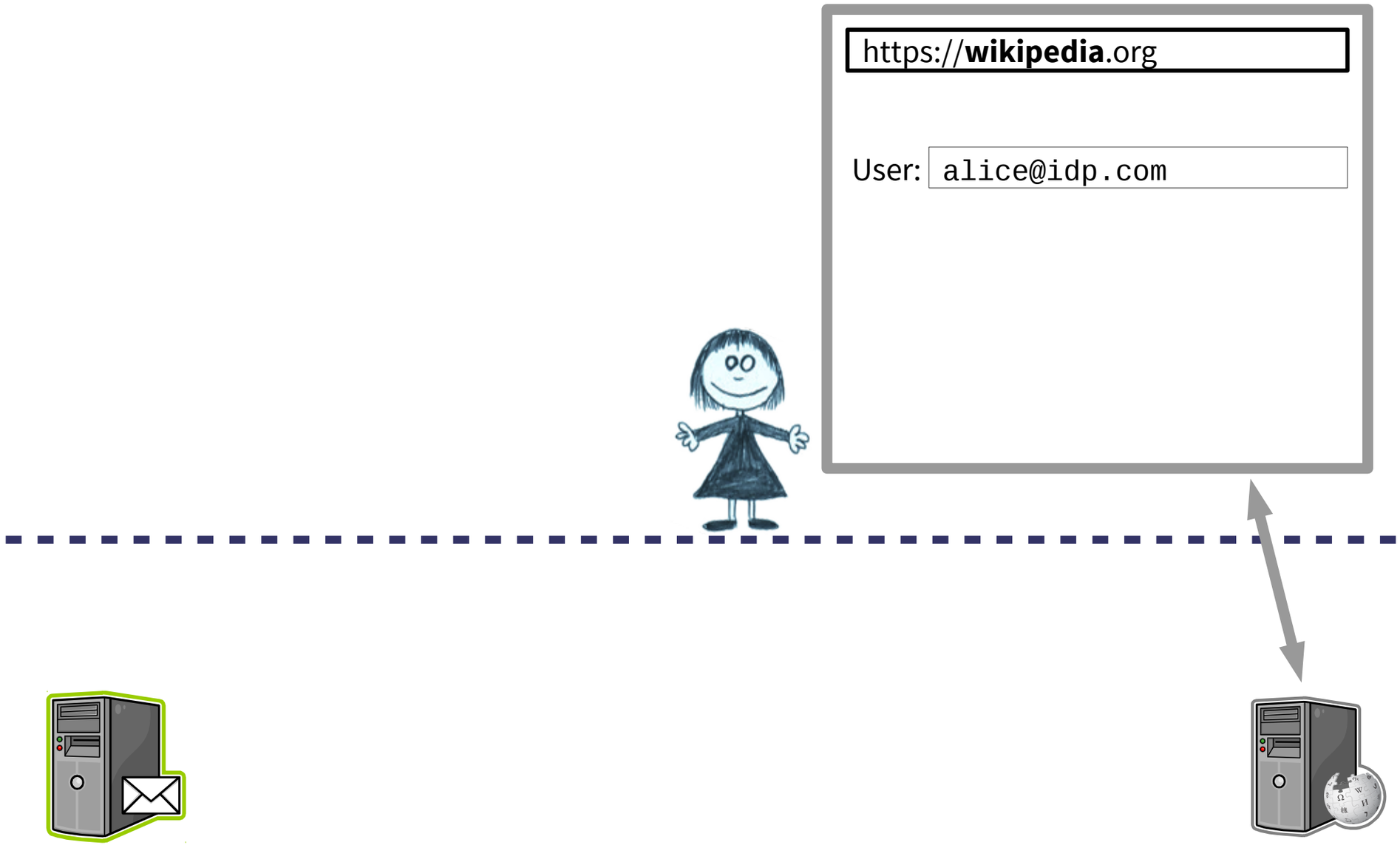

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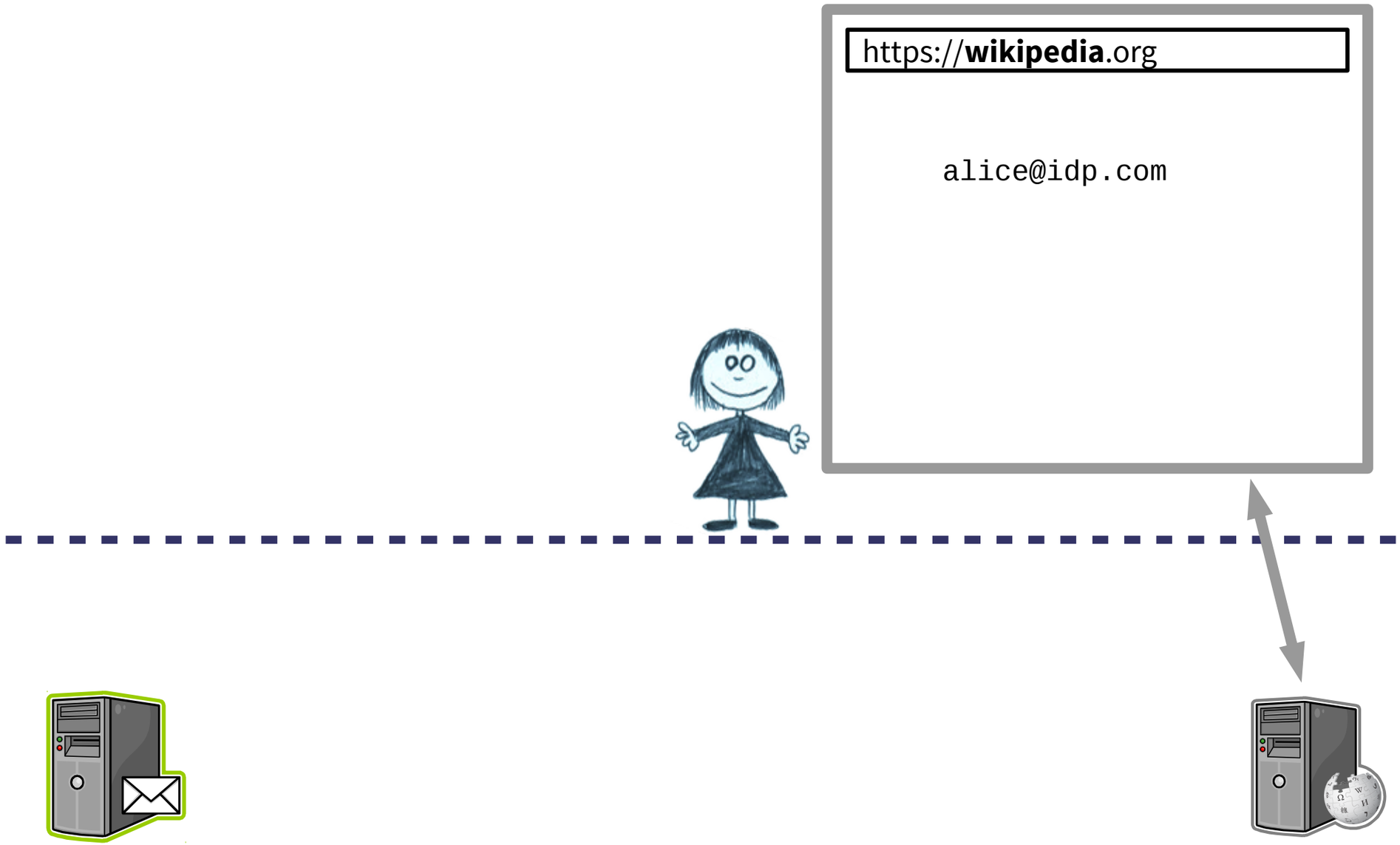

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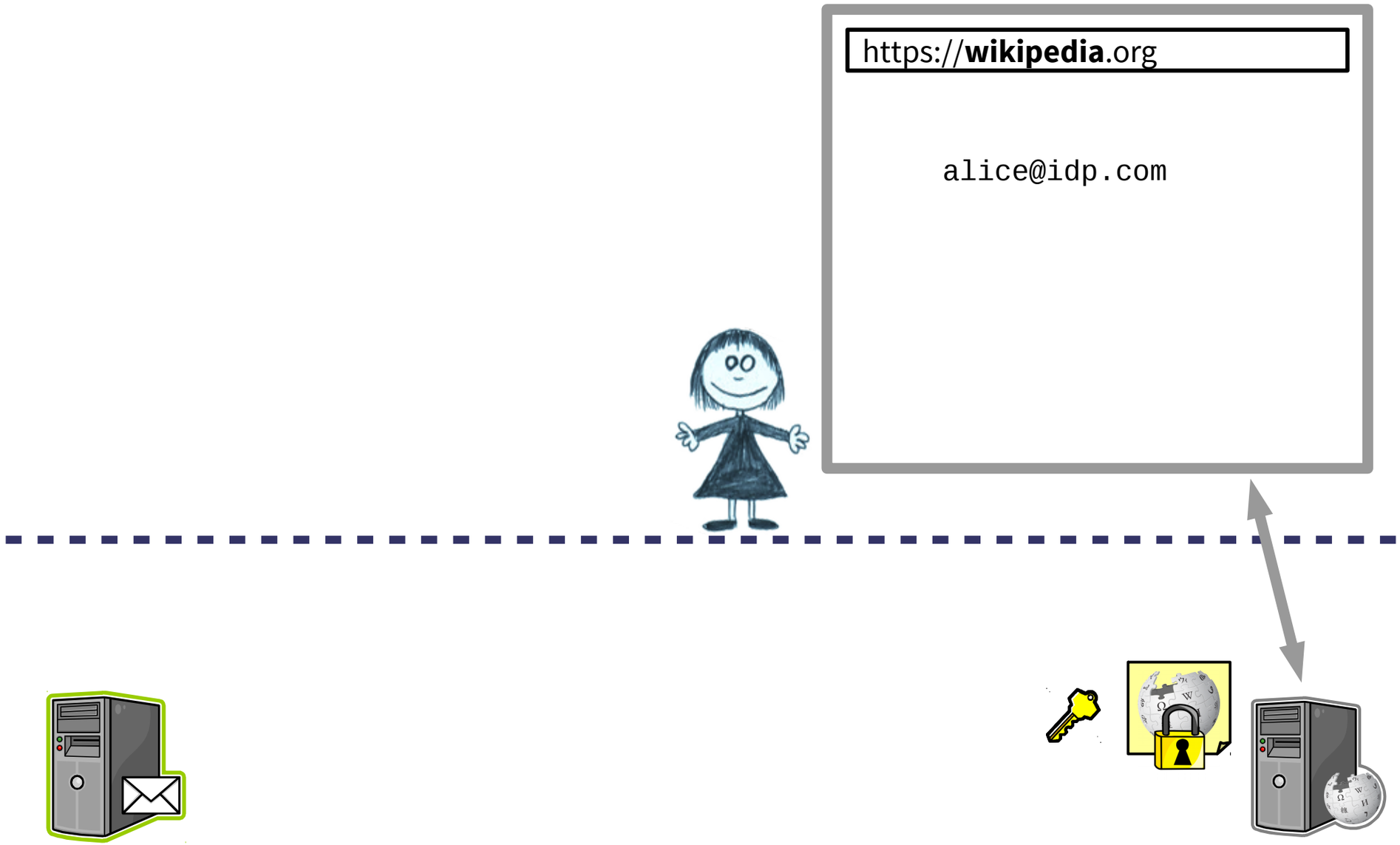

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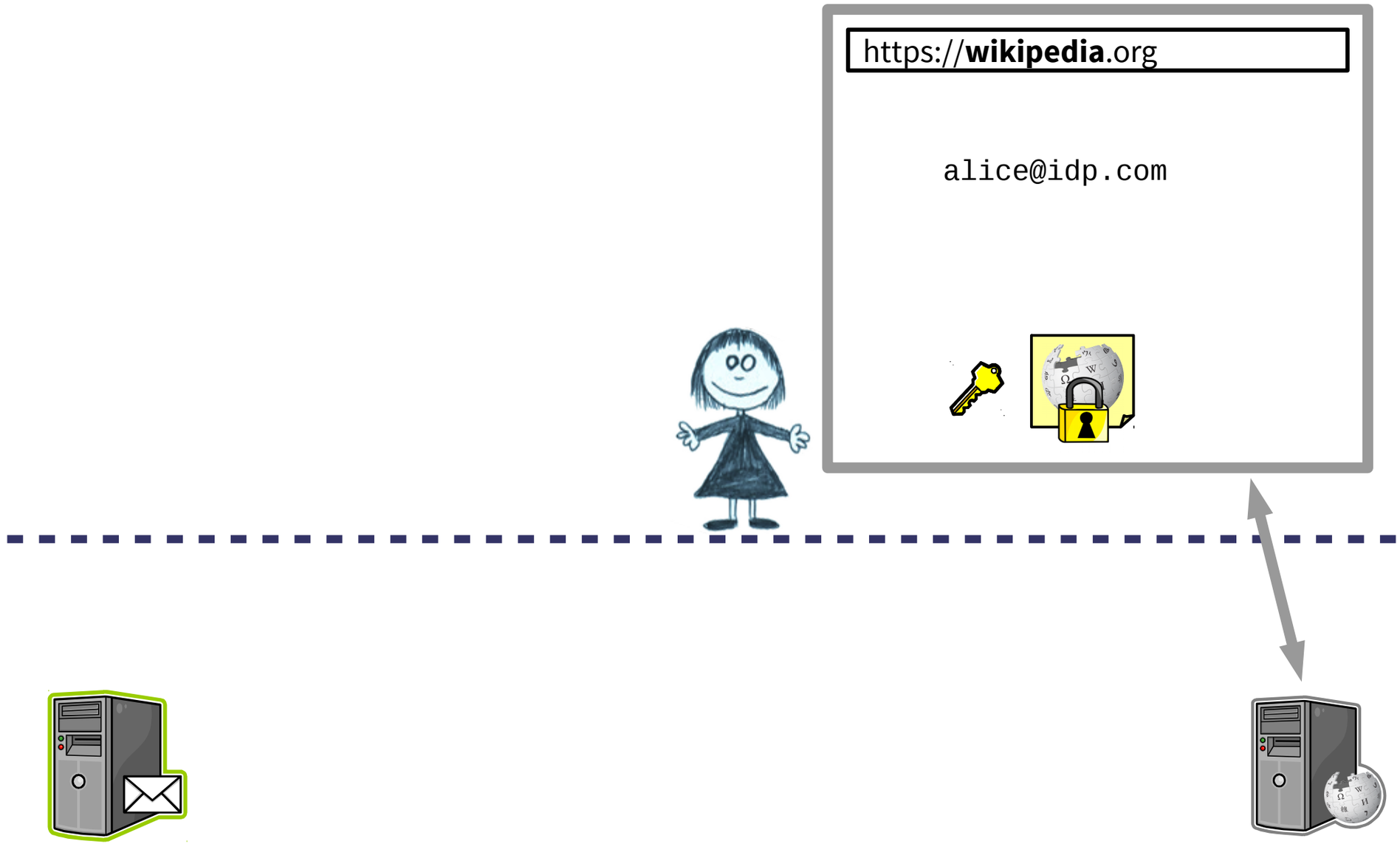

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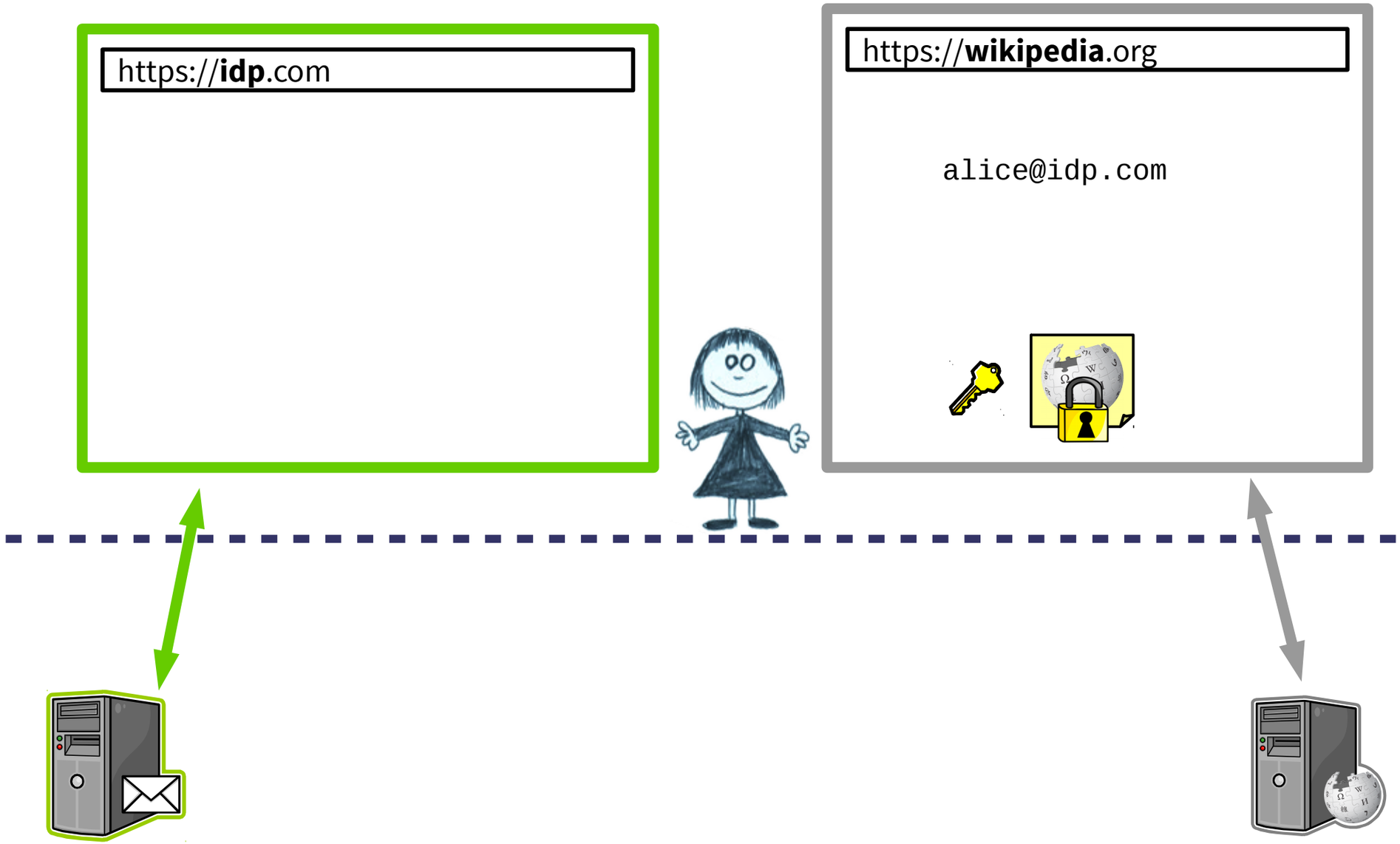

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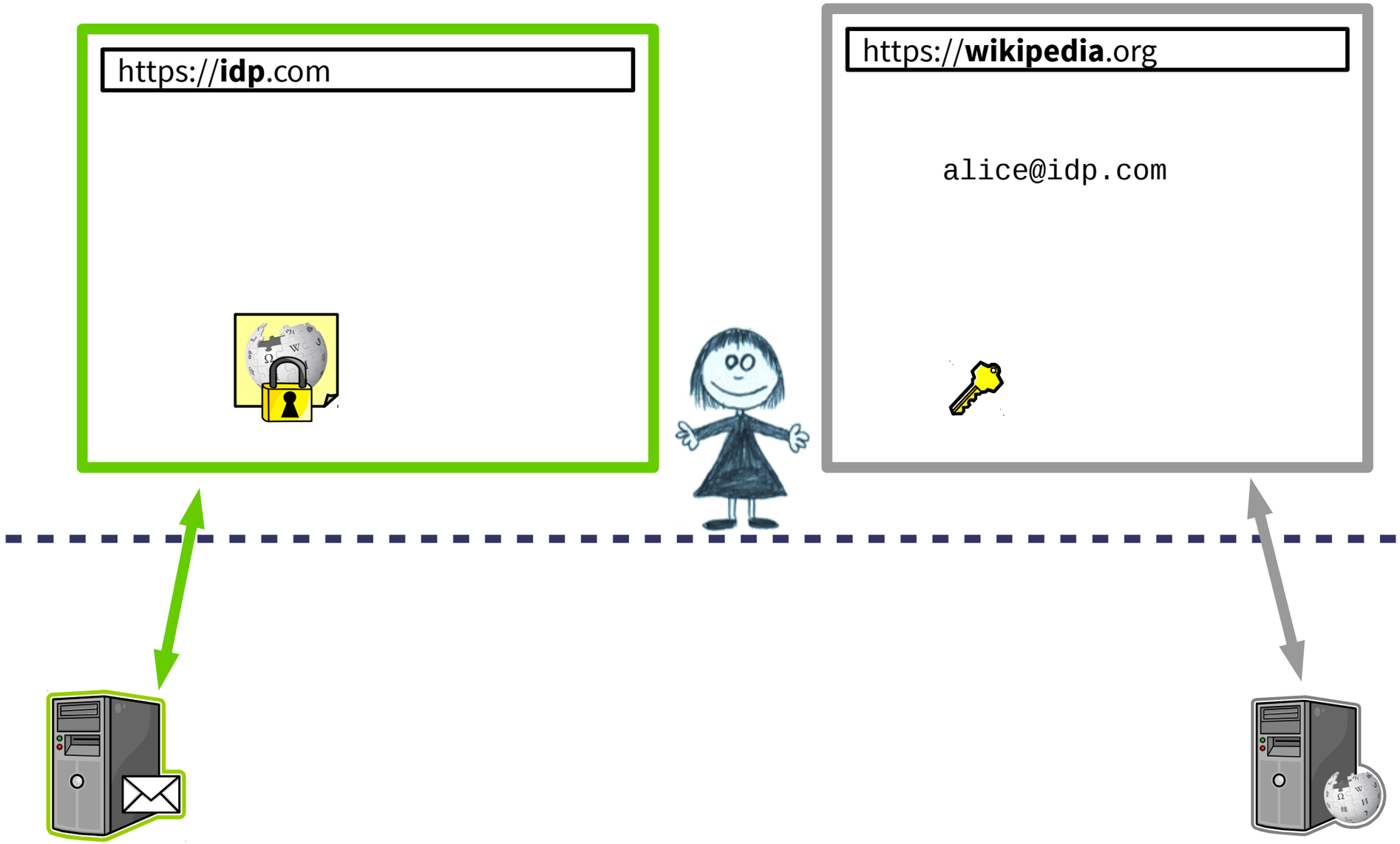

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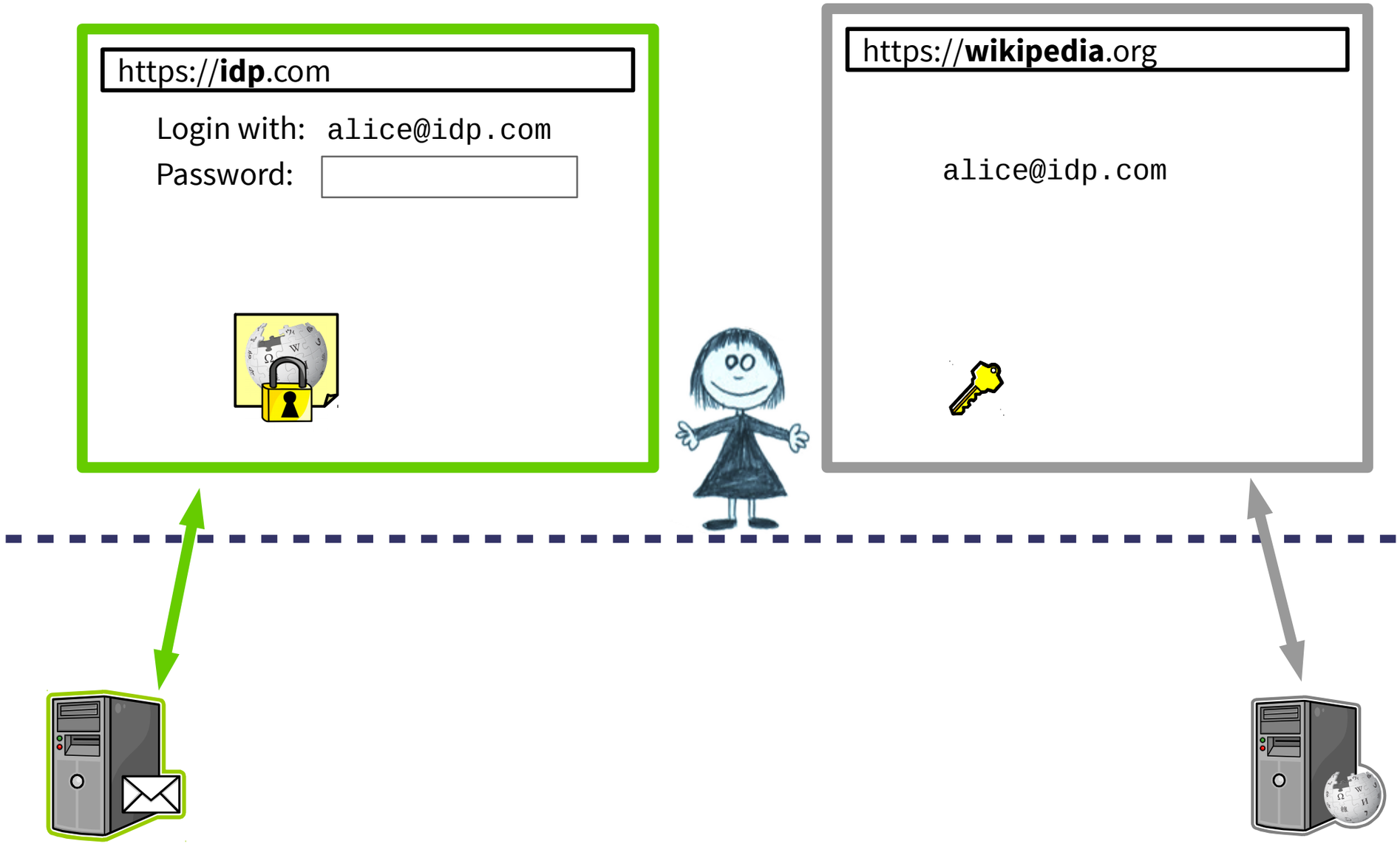

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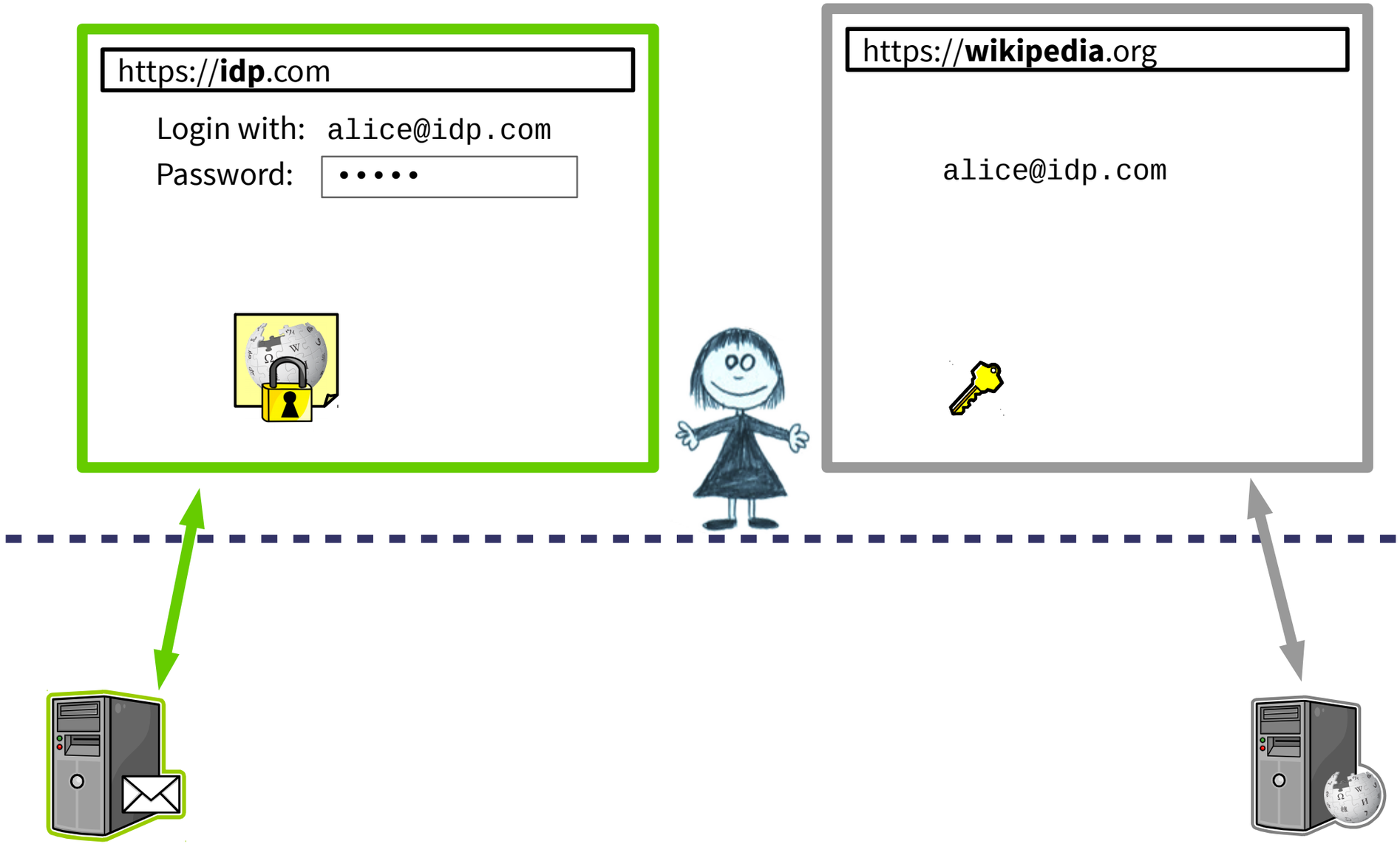

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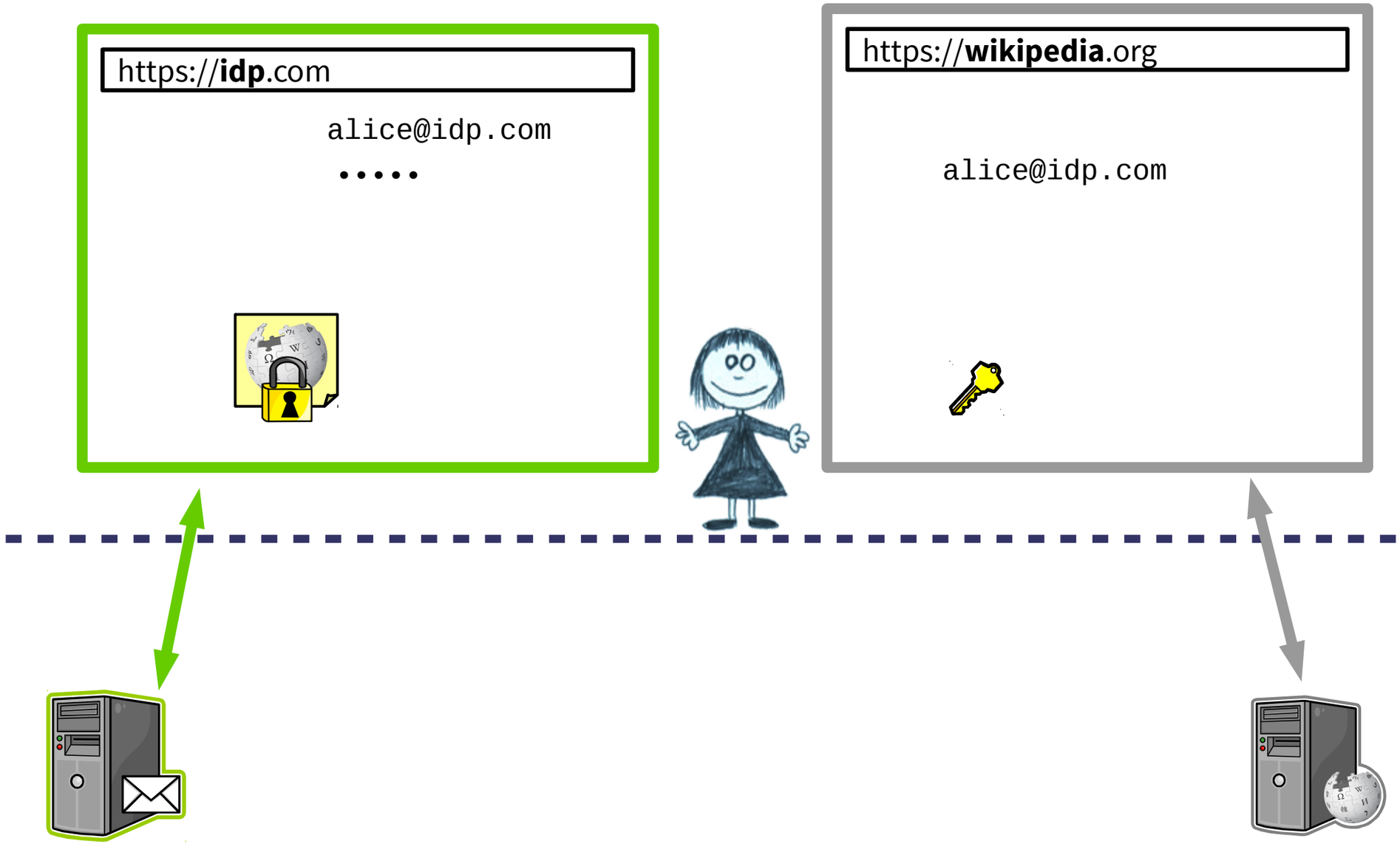

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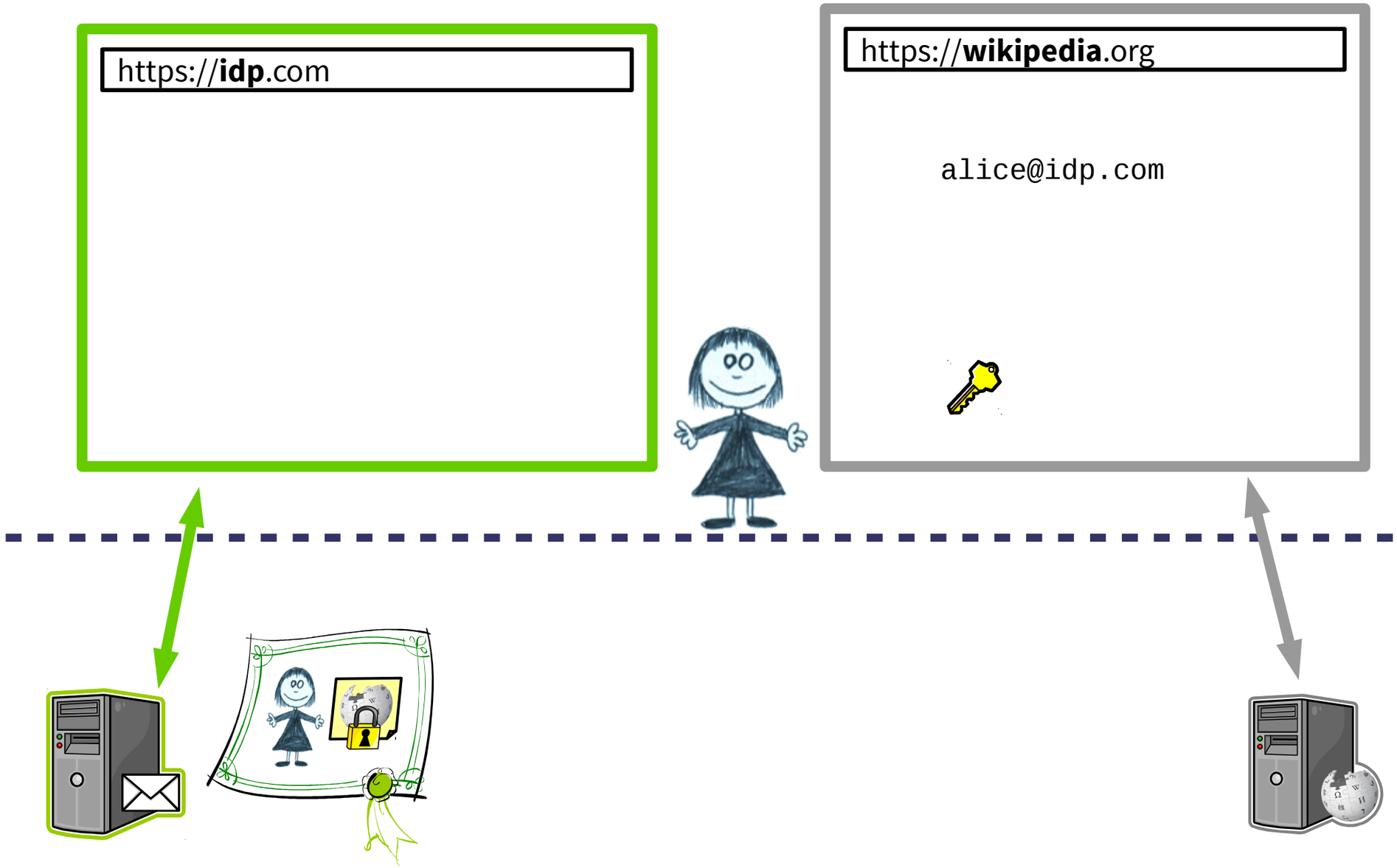

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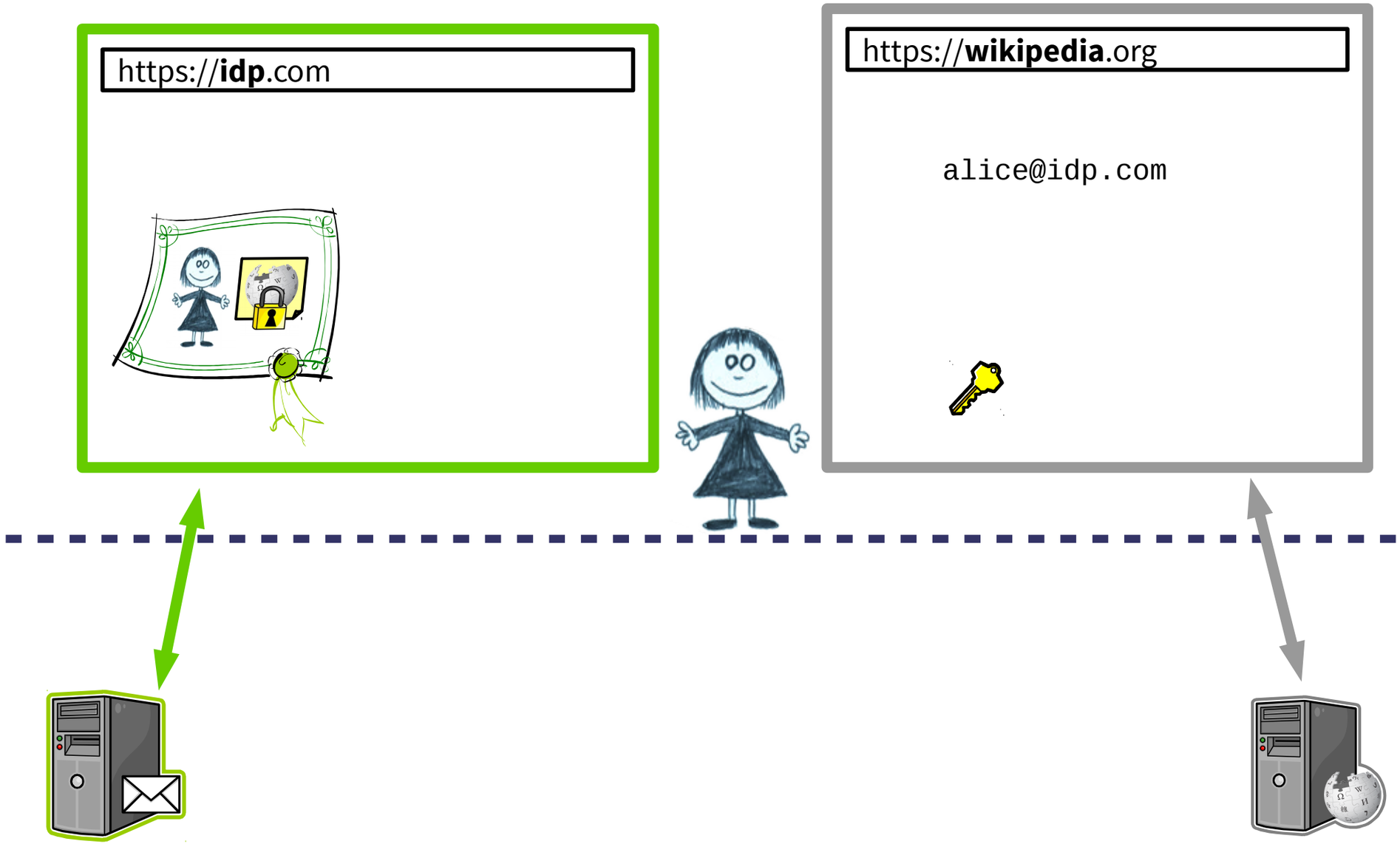

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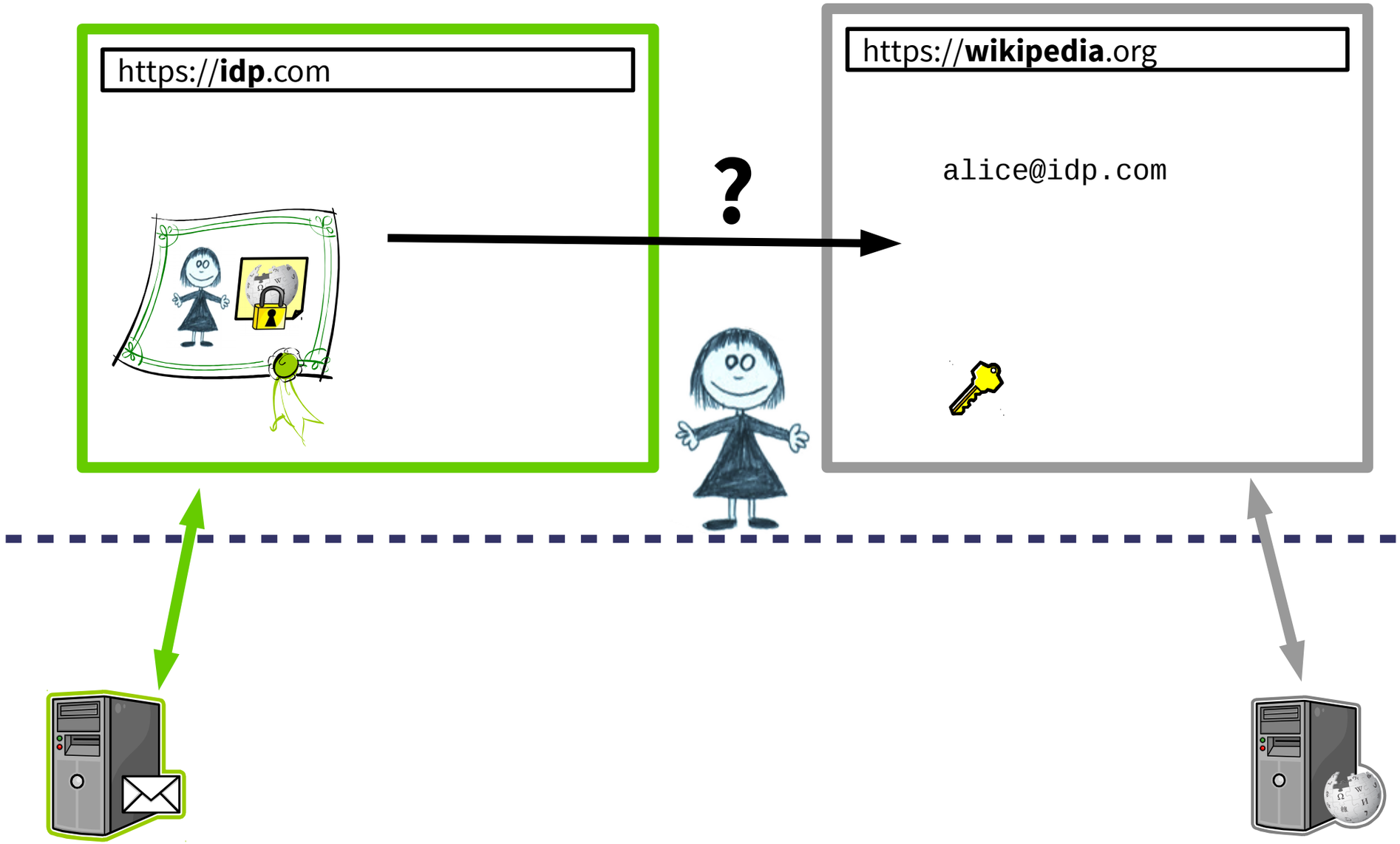

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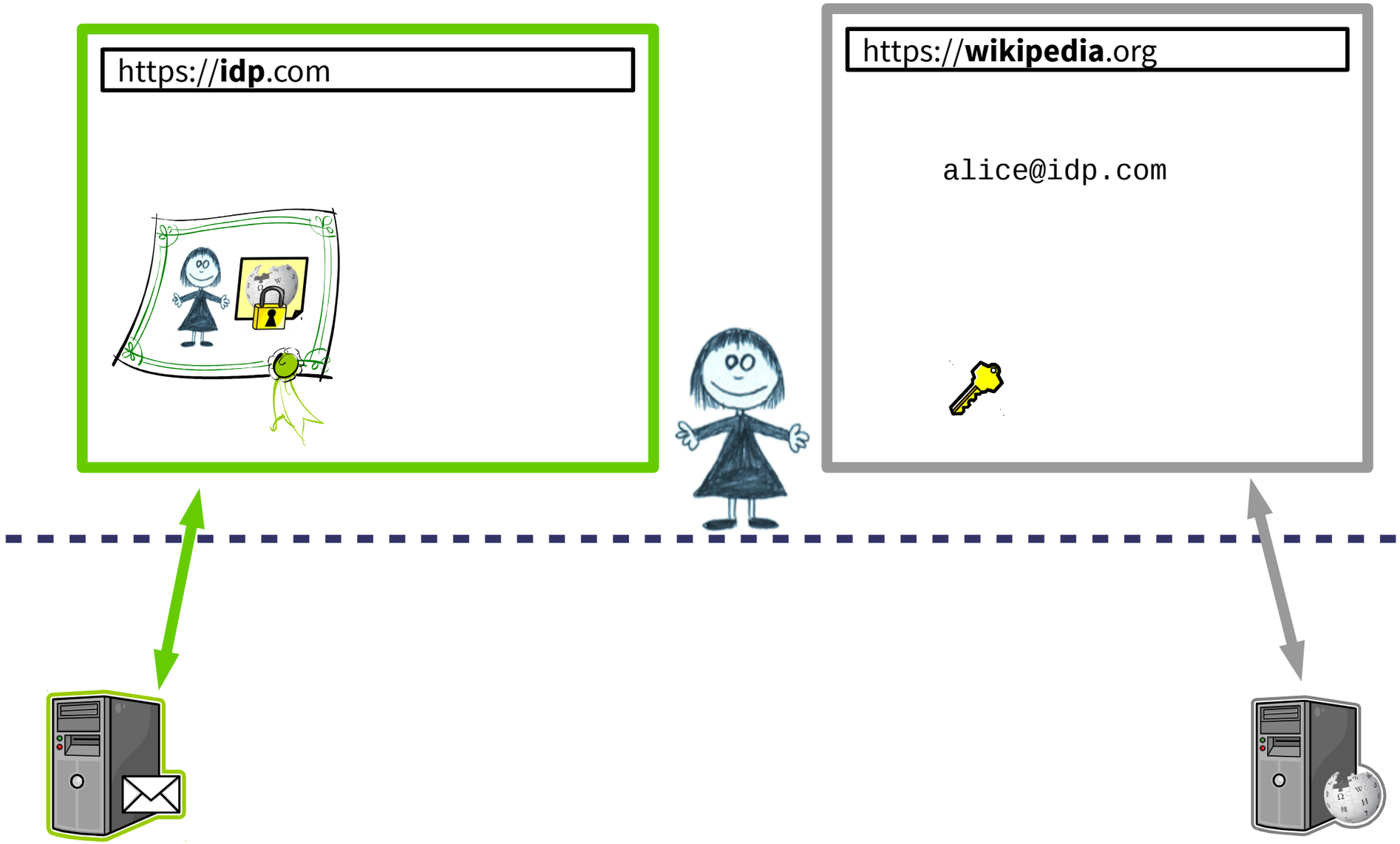

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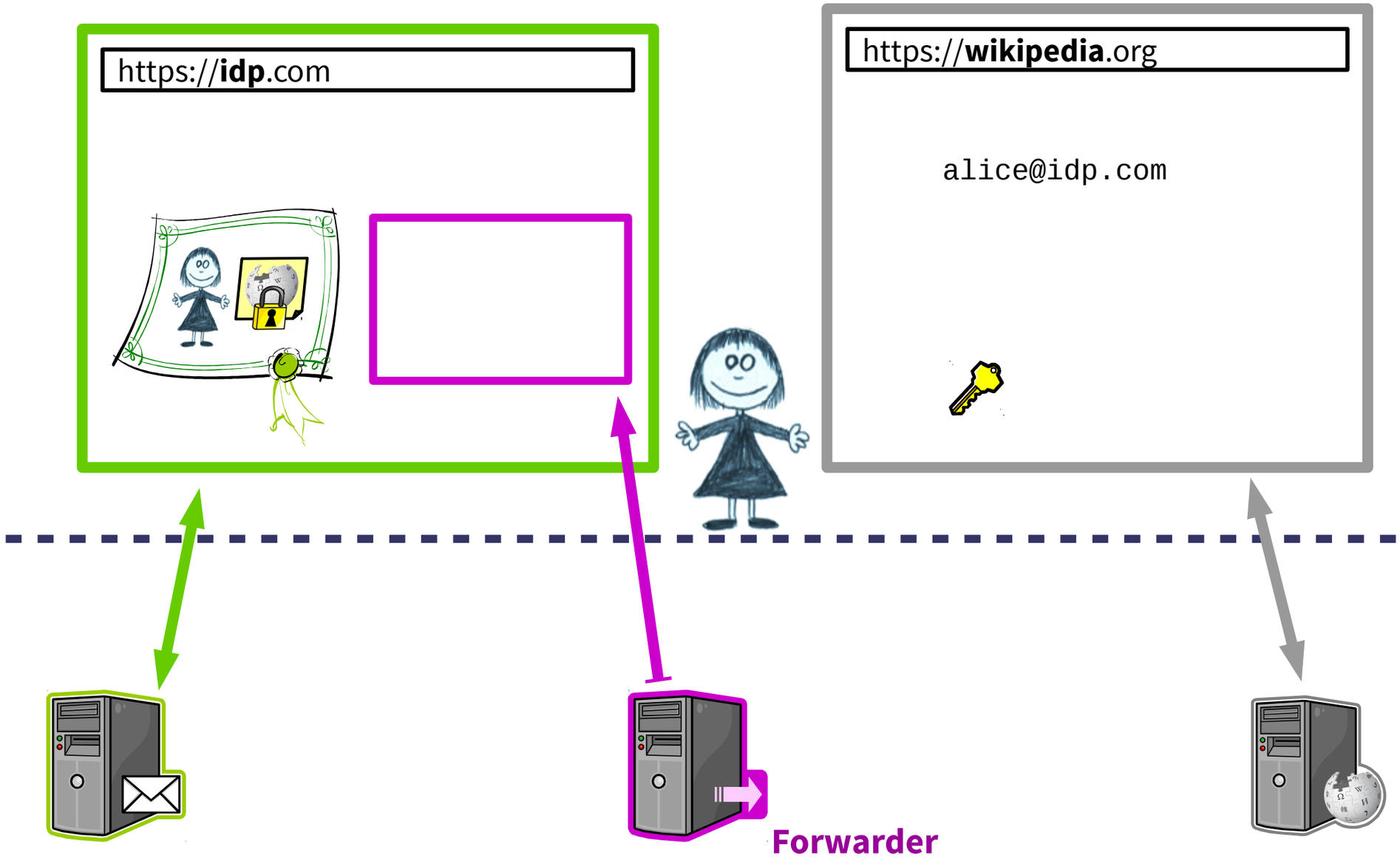

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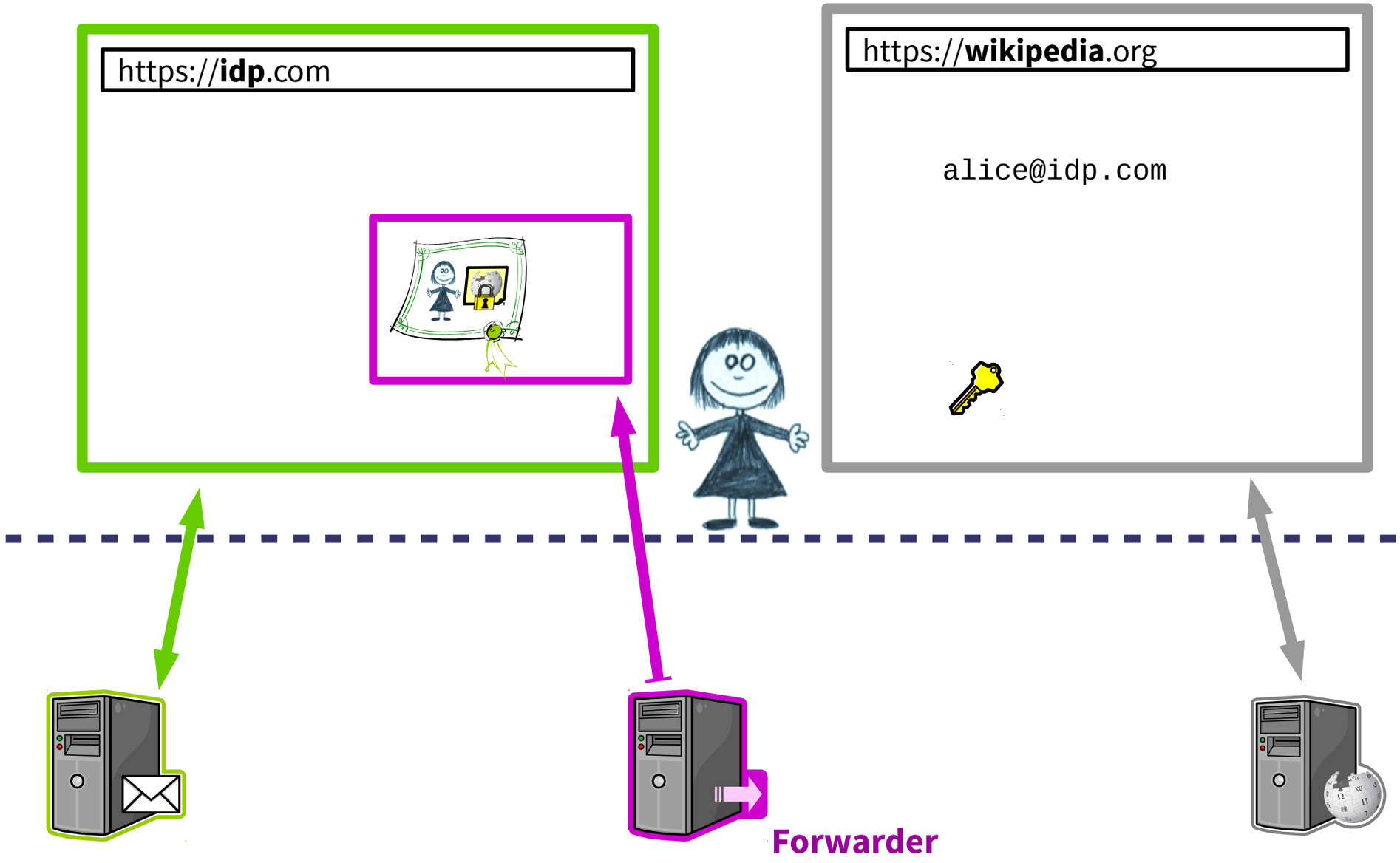
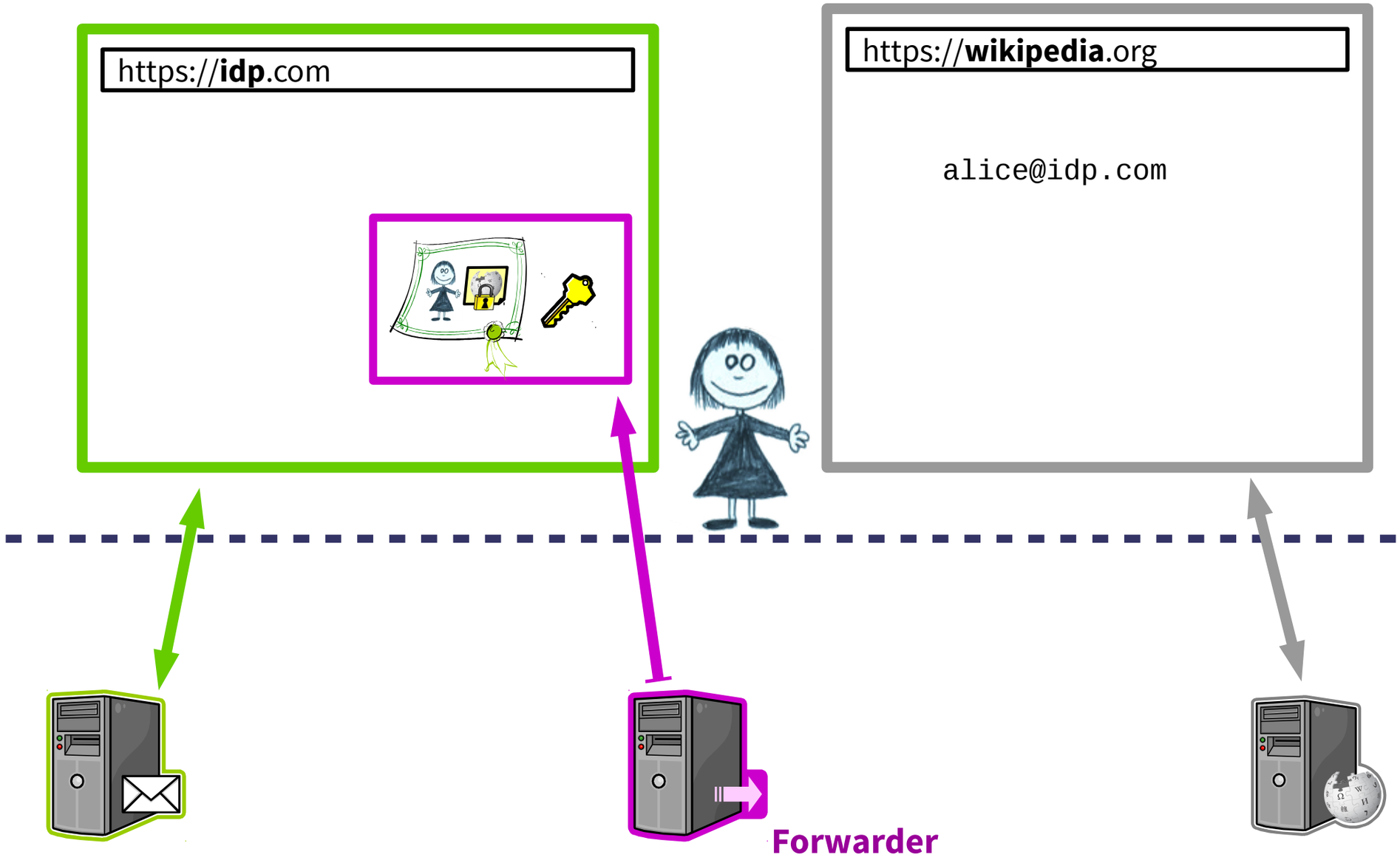


SPRESSO: Closer Look



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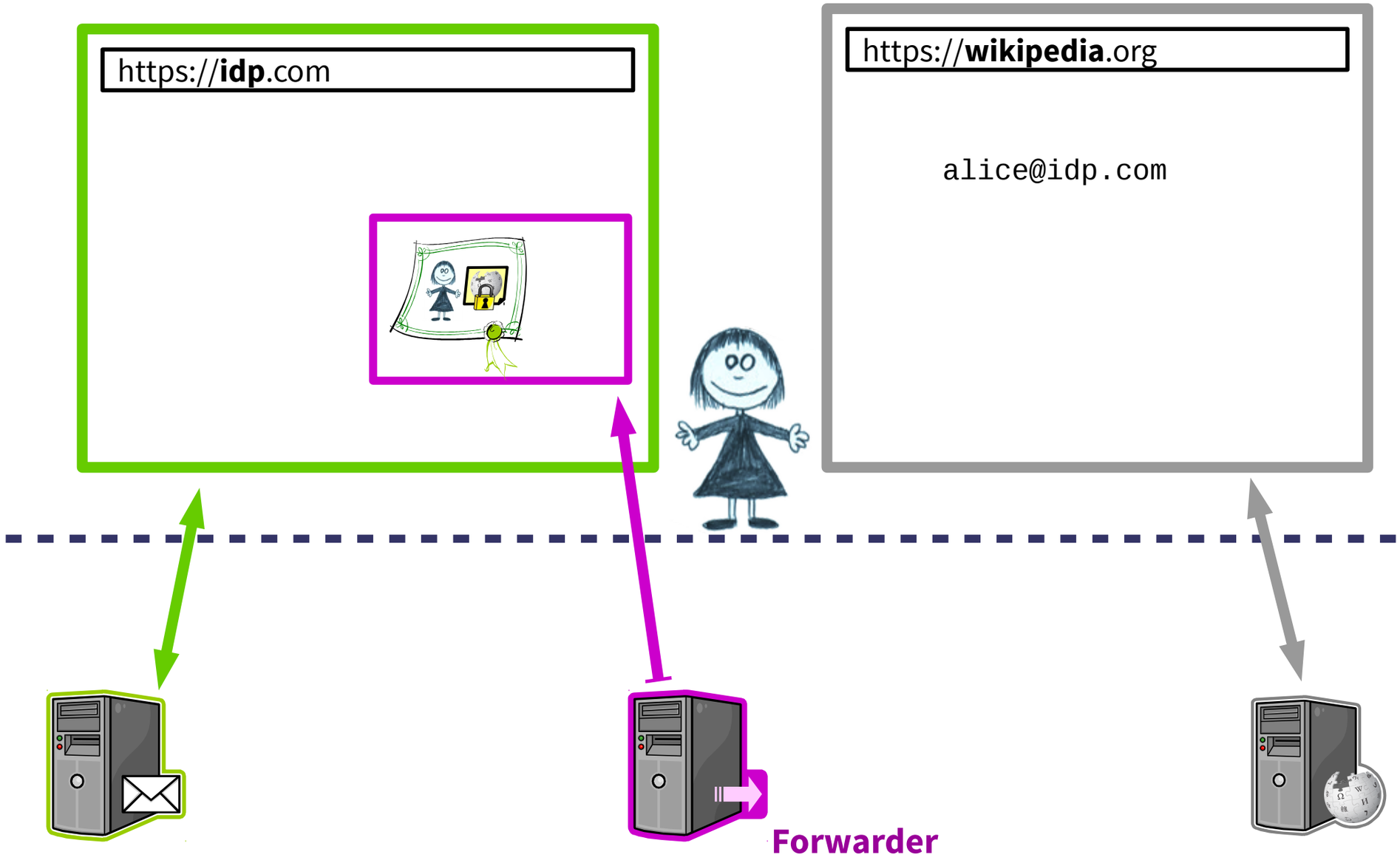

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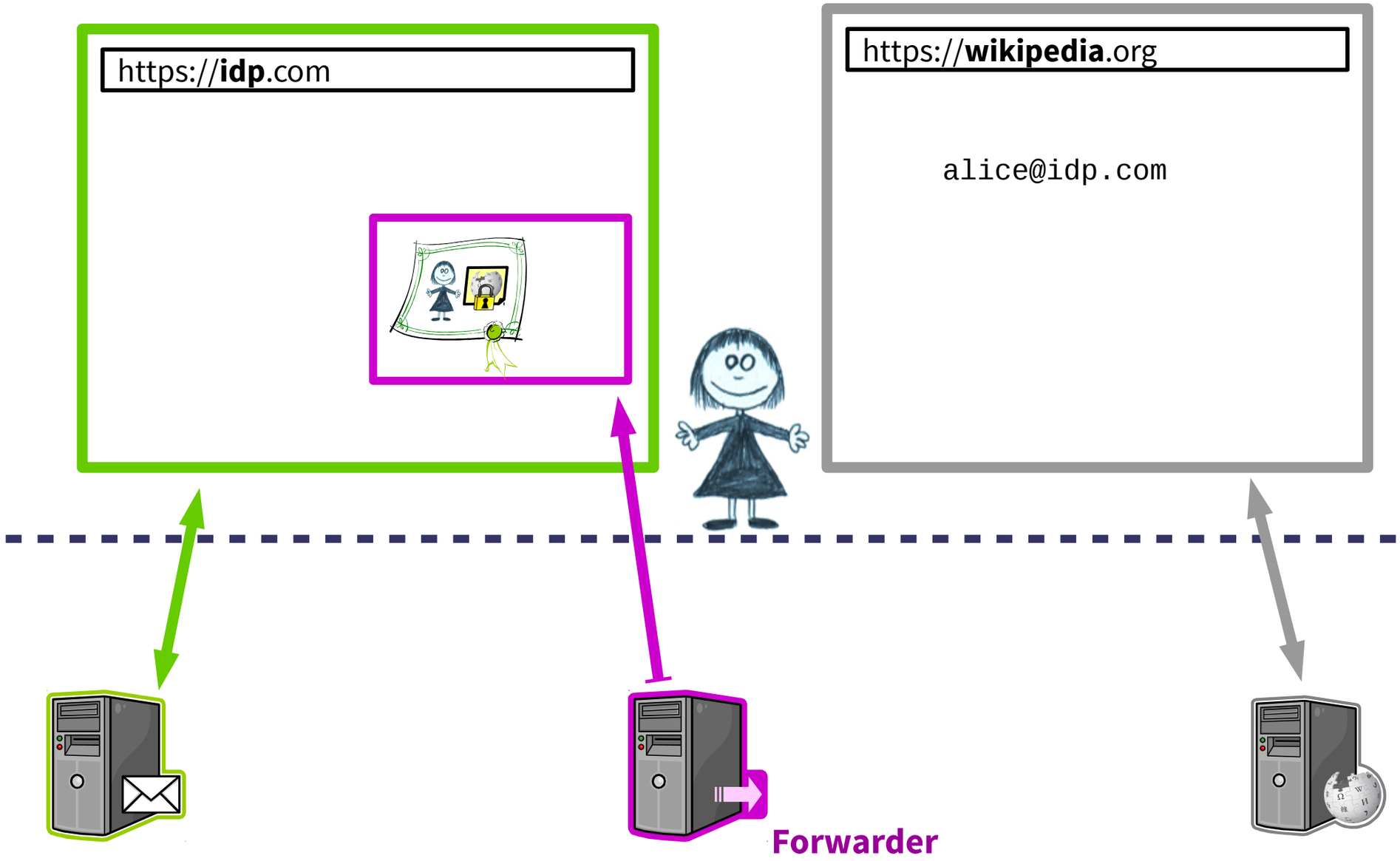

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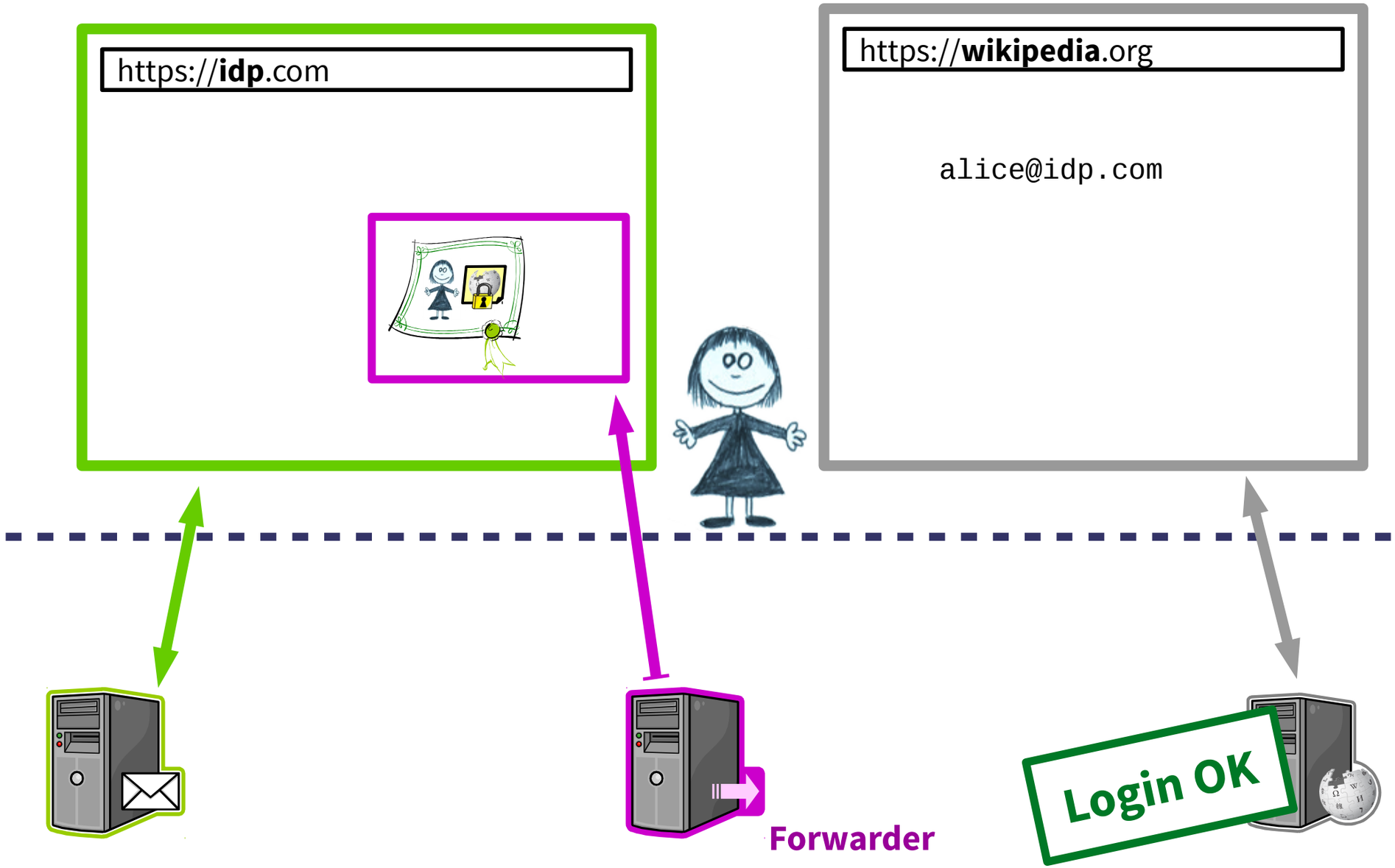

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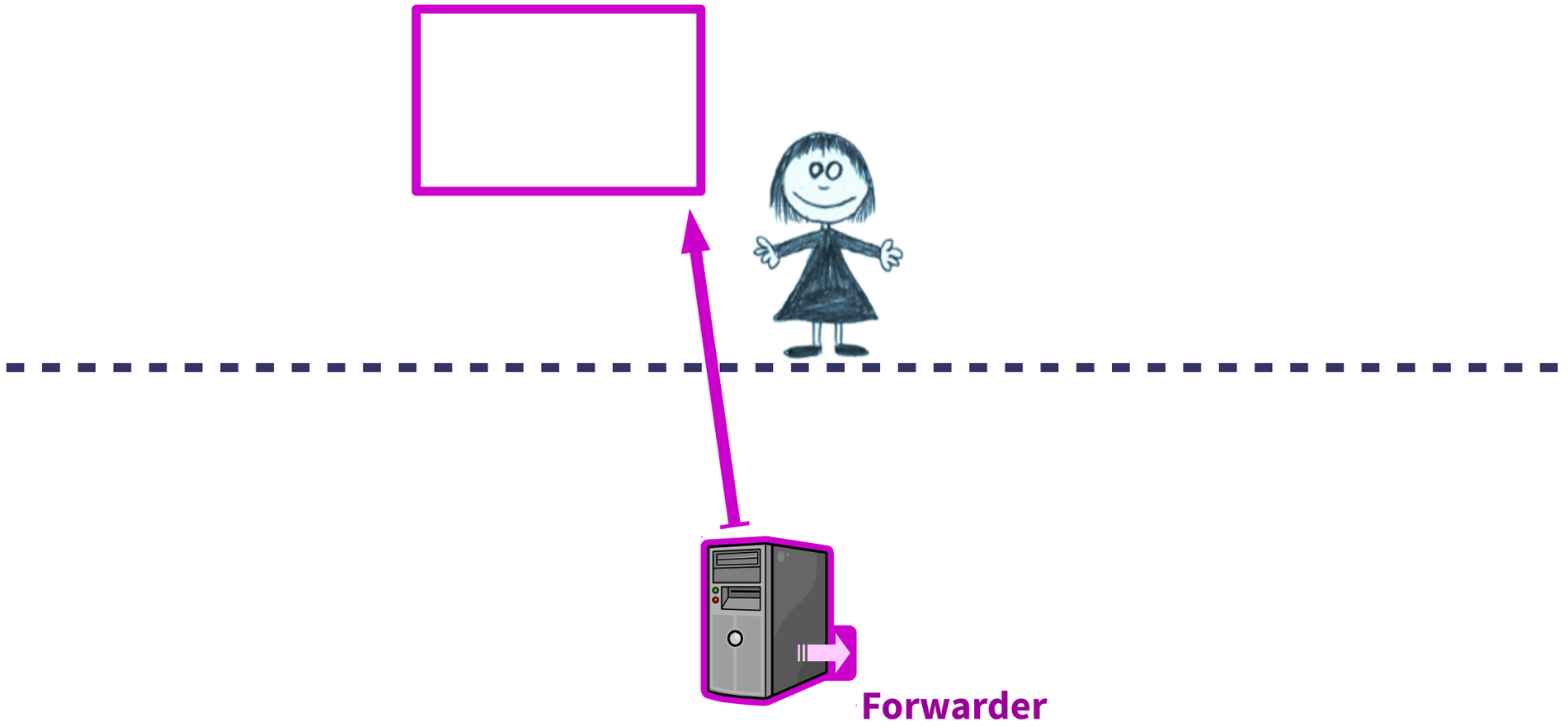

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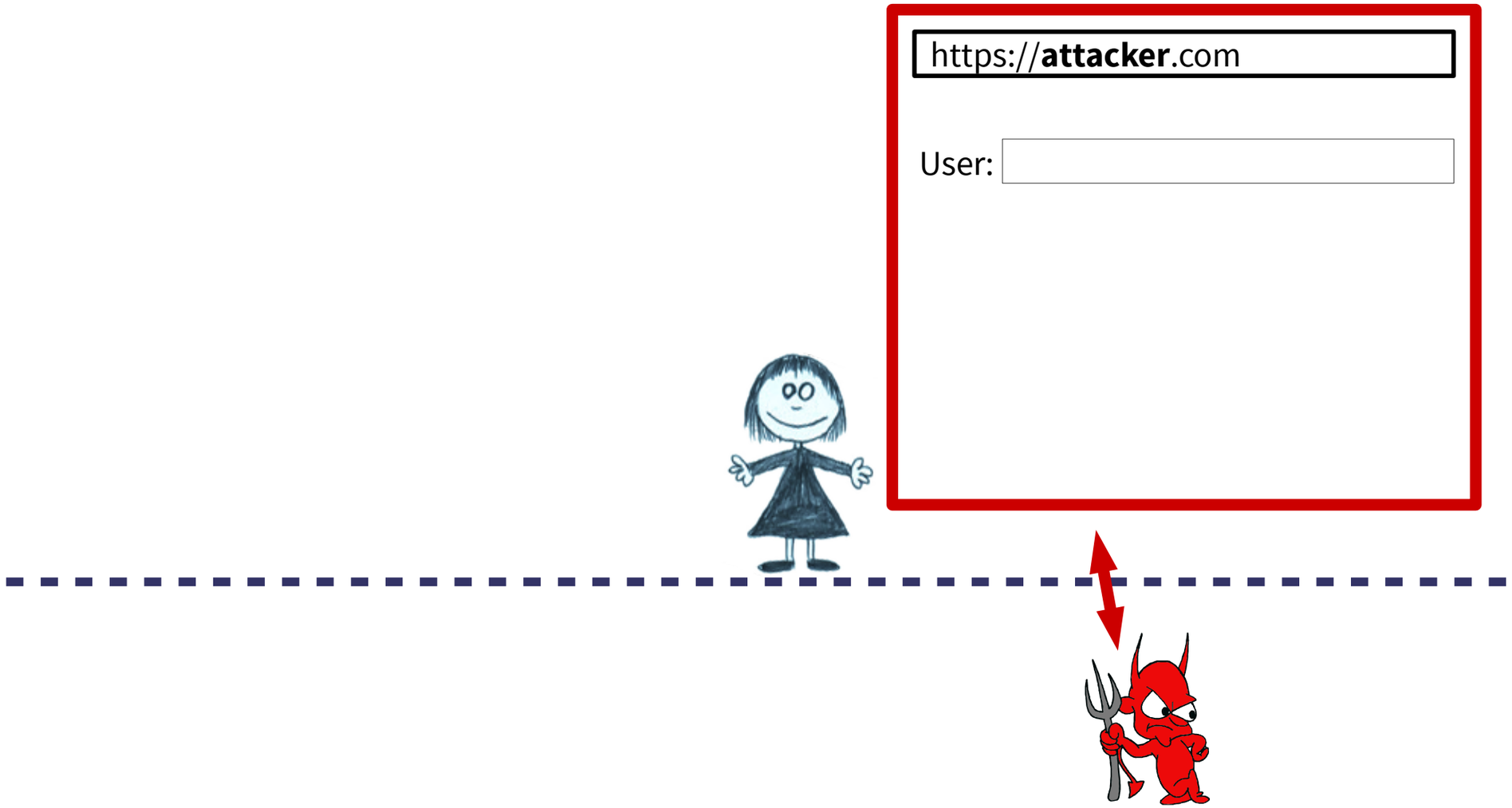

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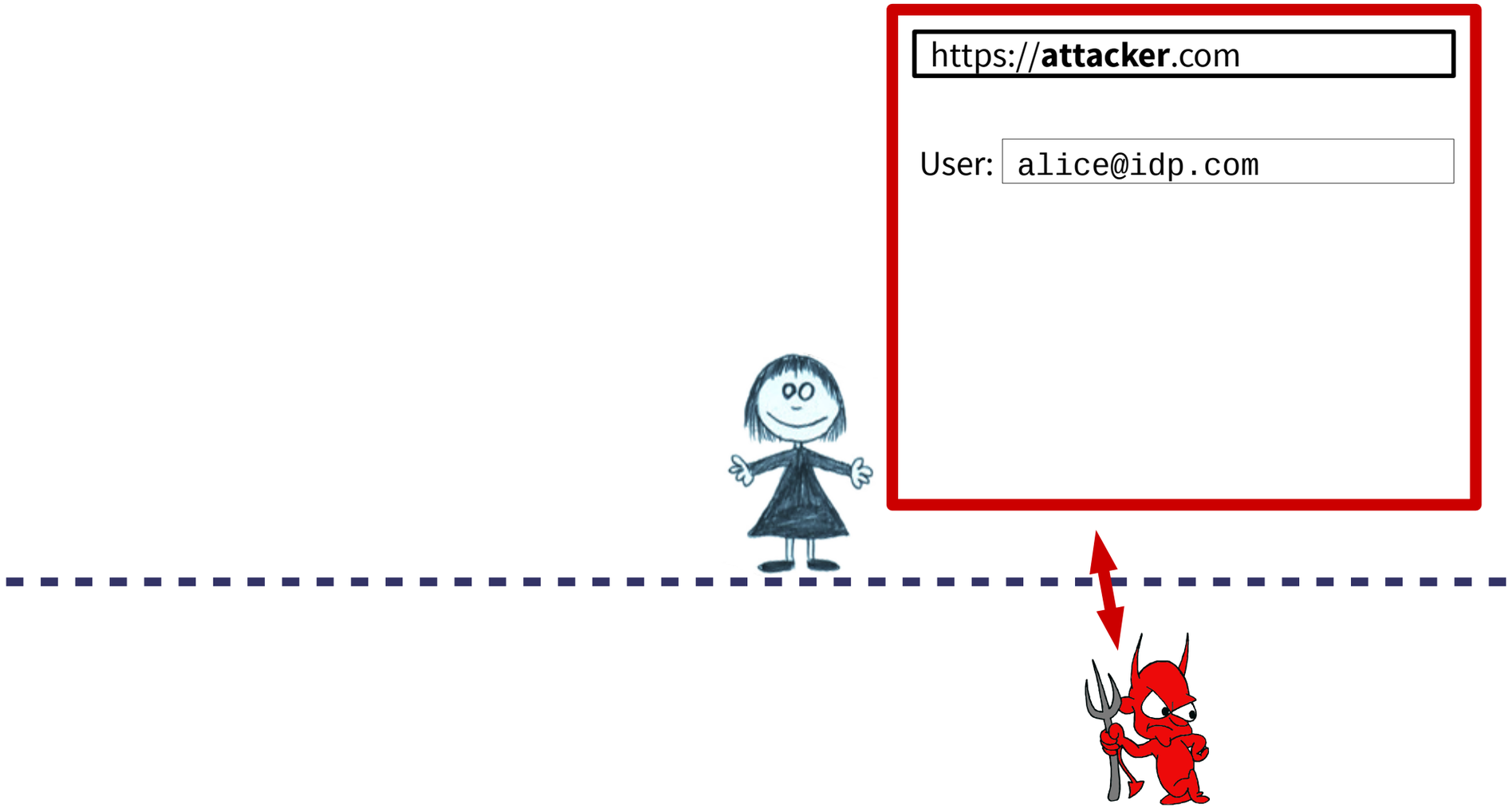

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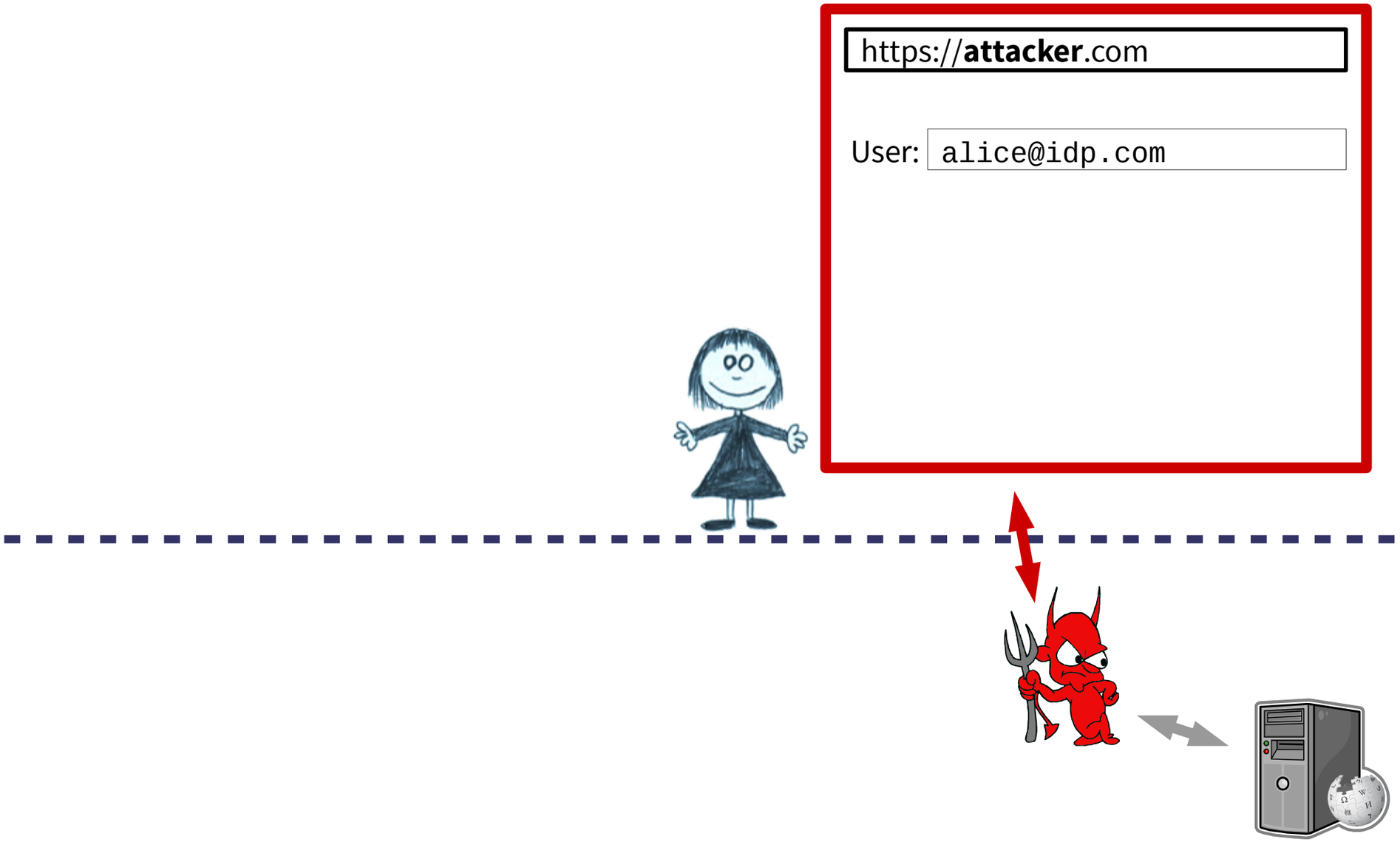

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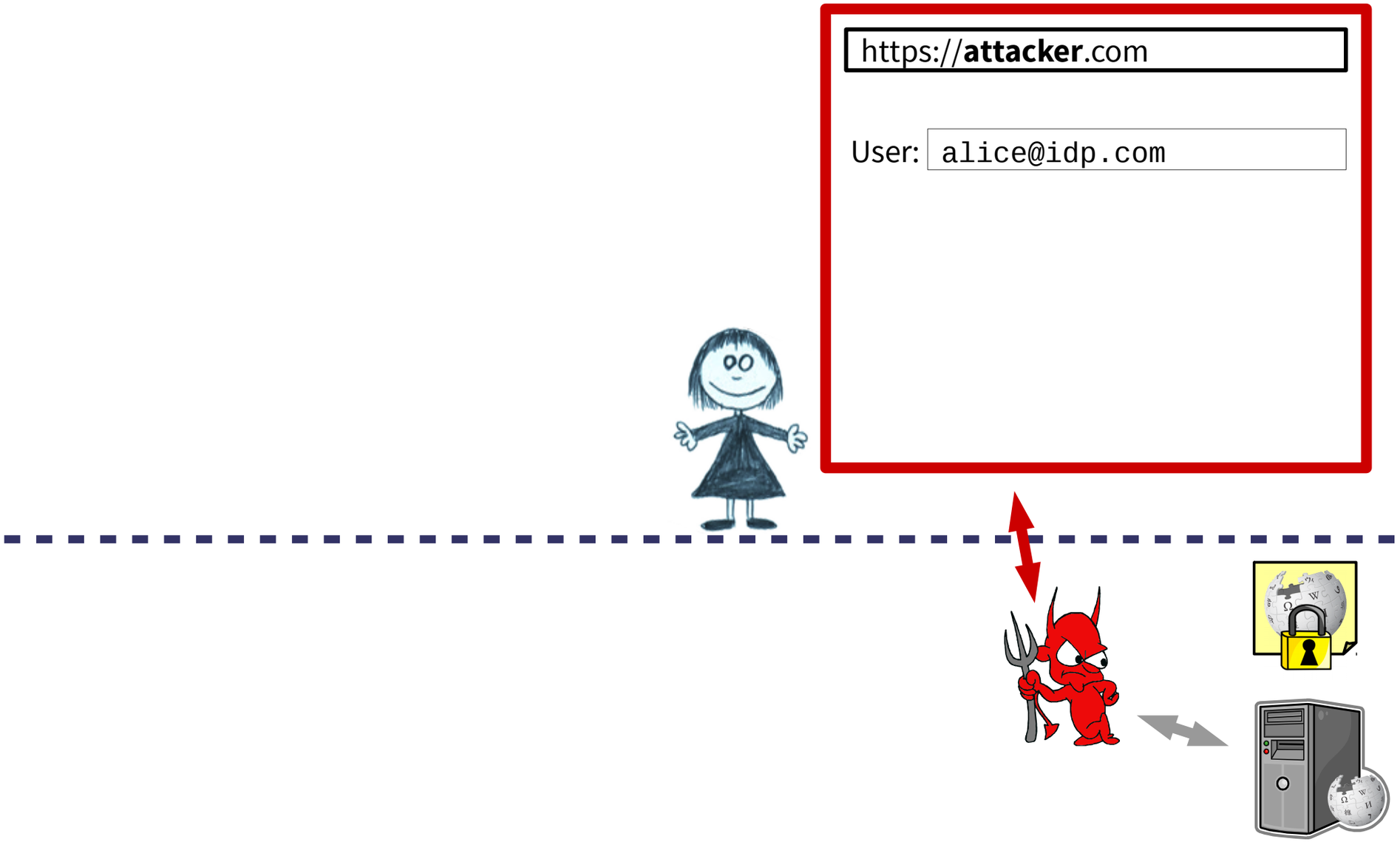

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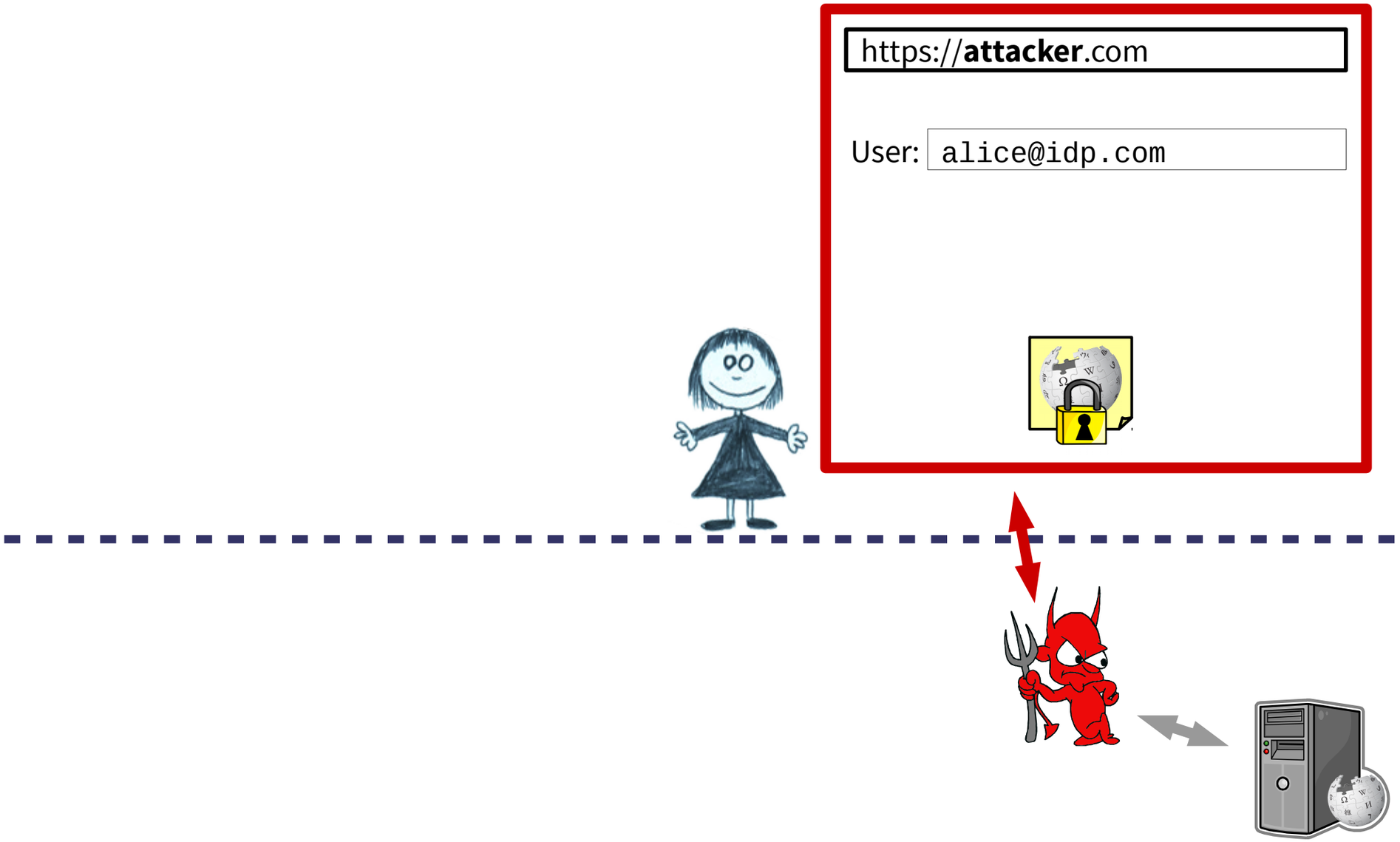

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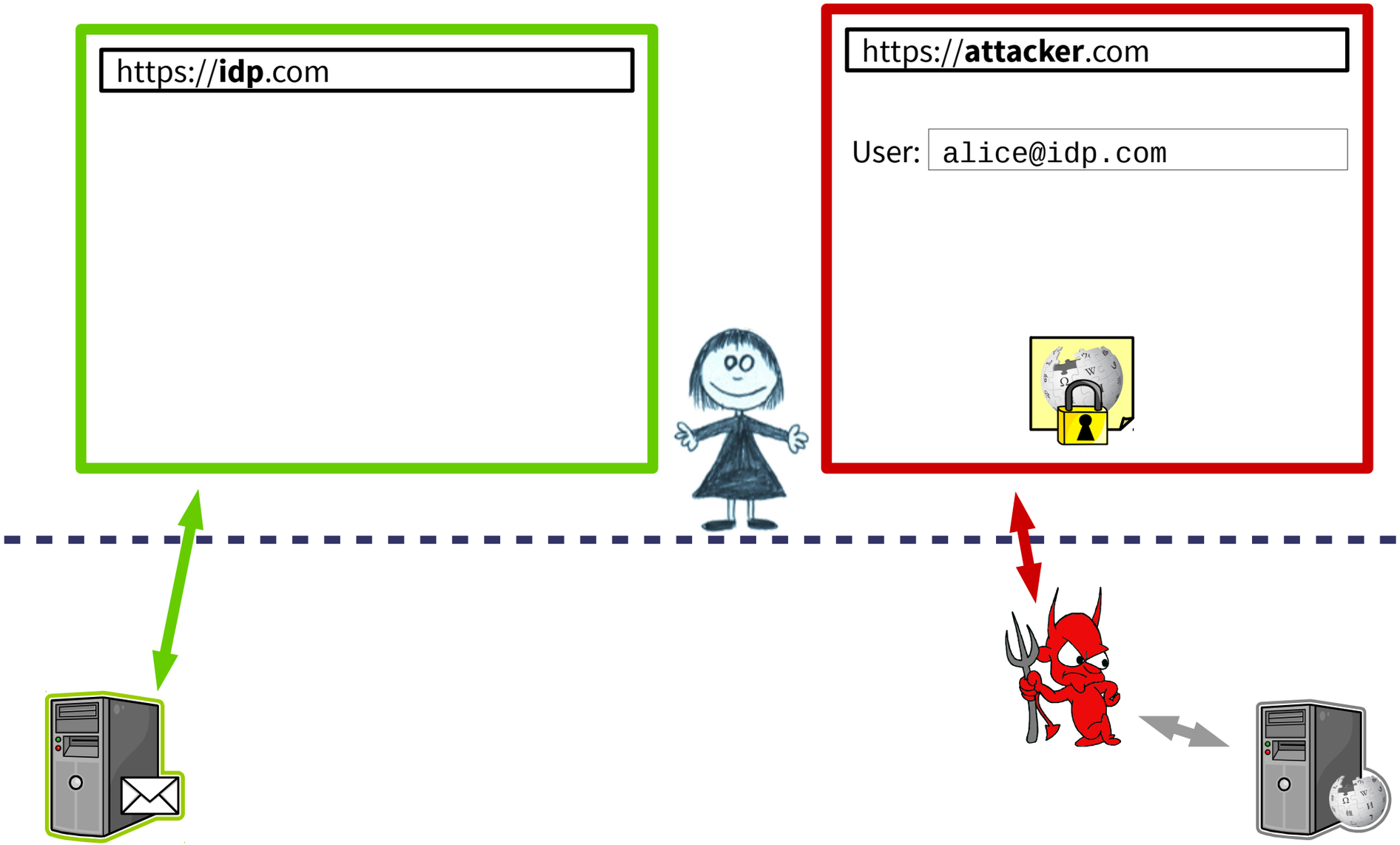

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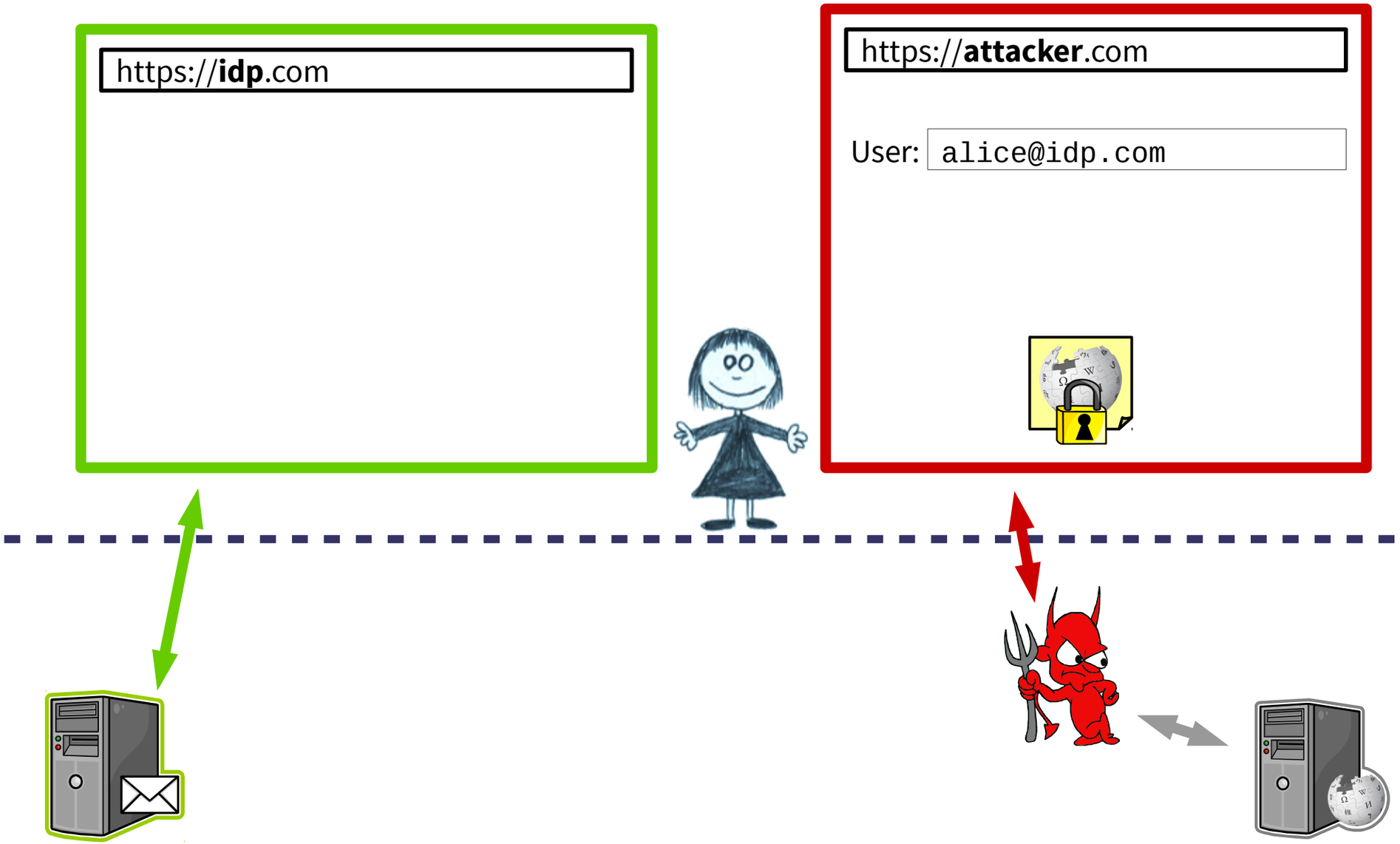

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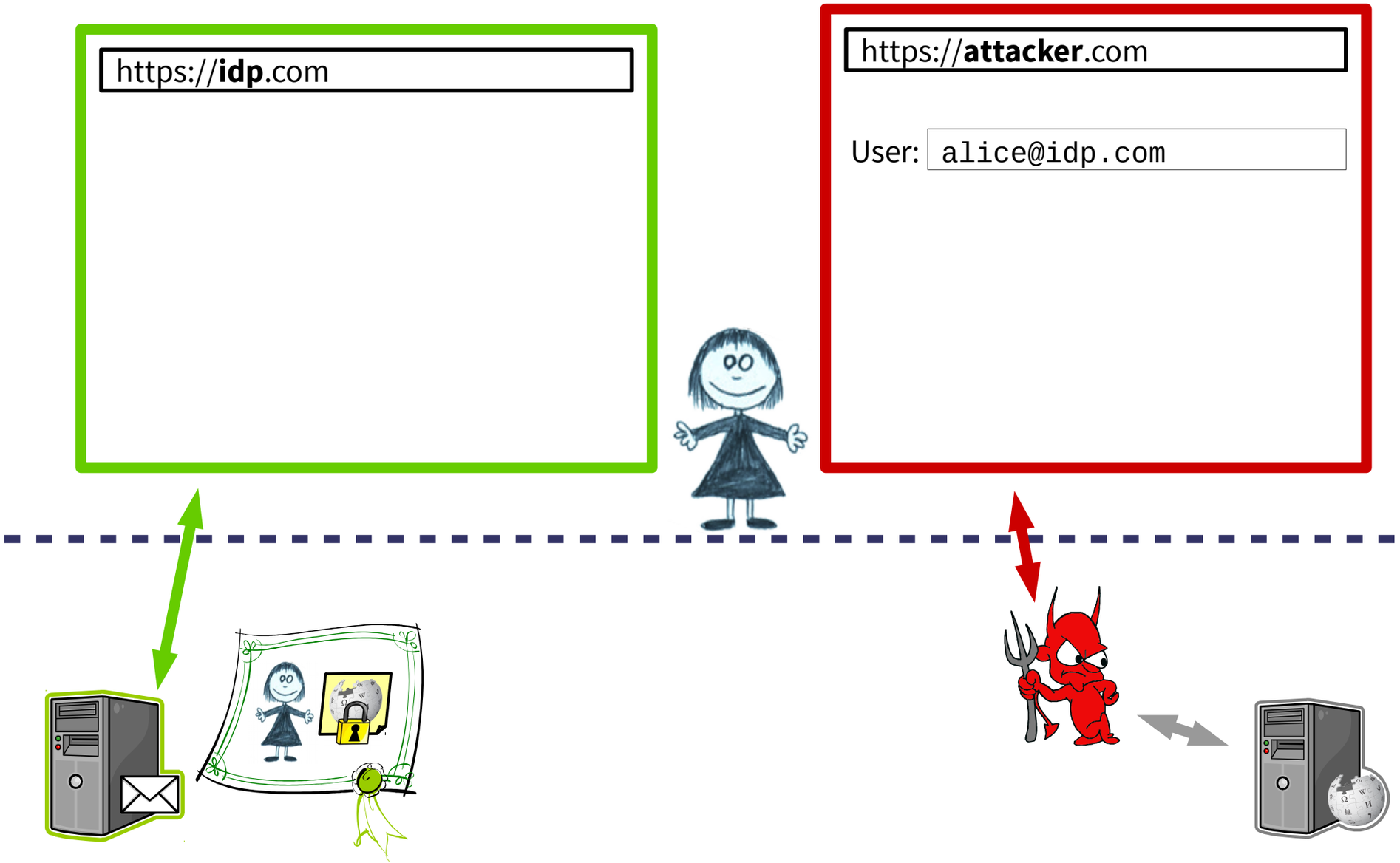

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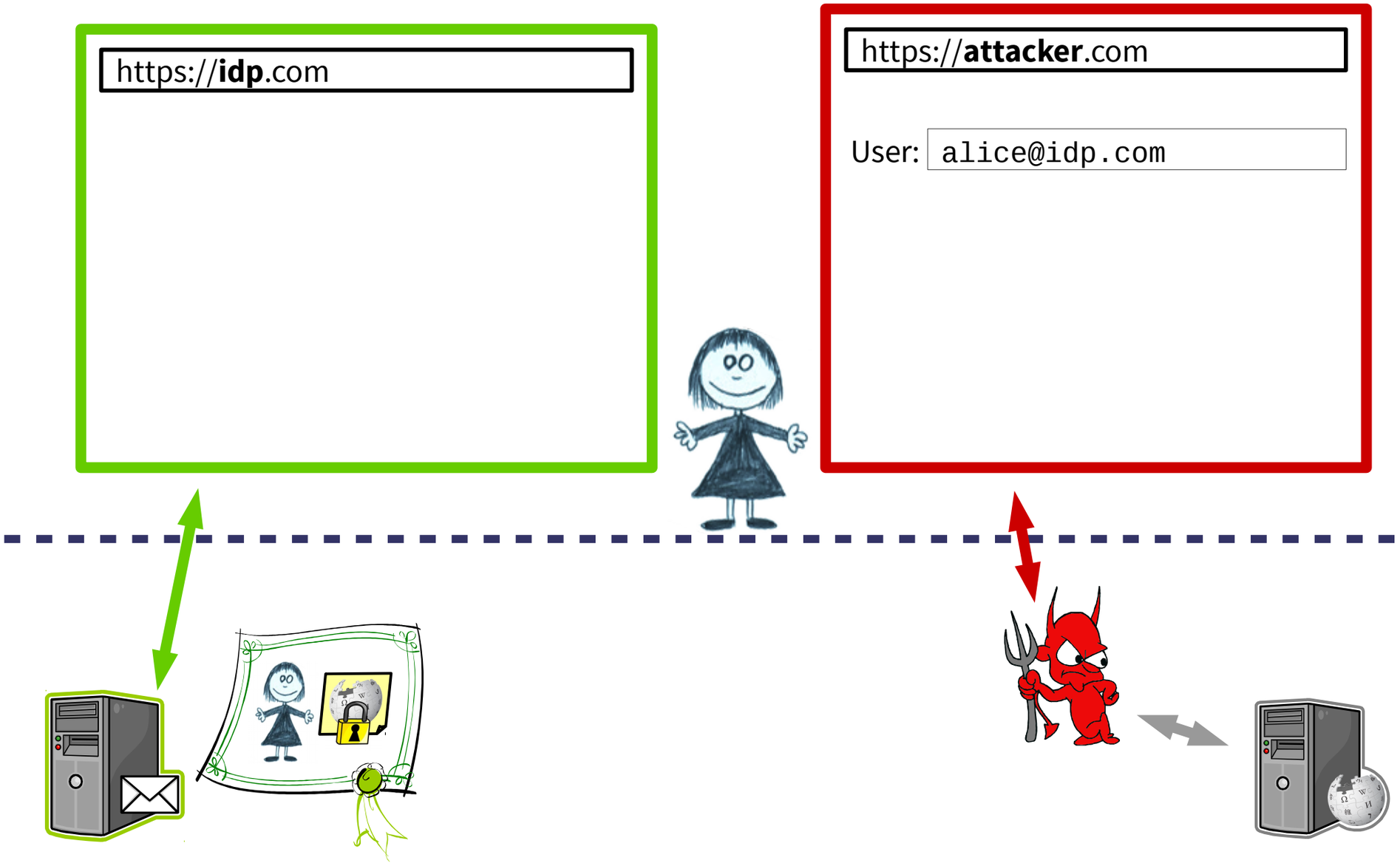

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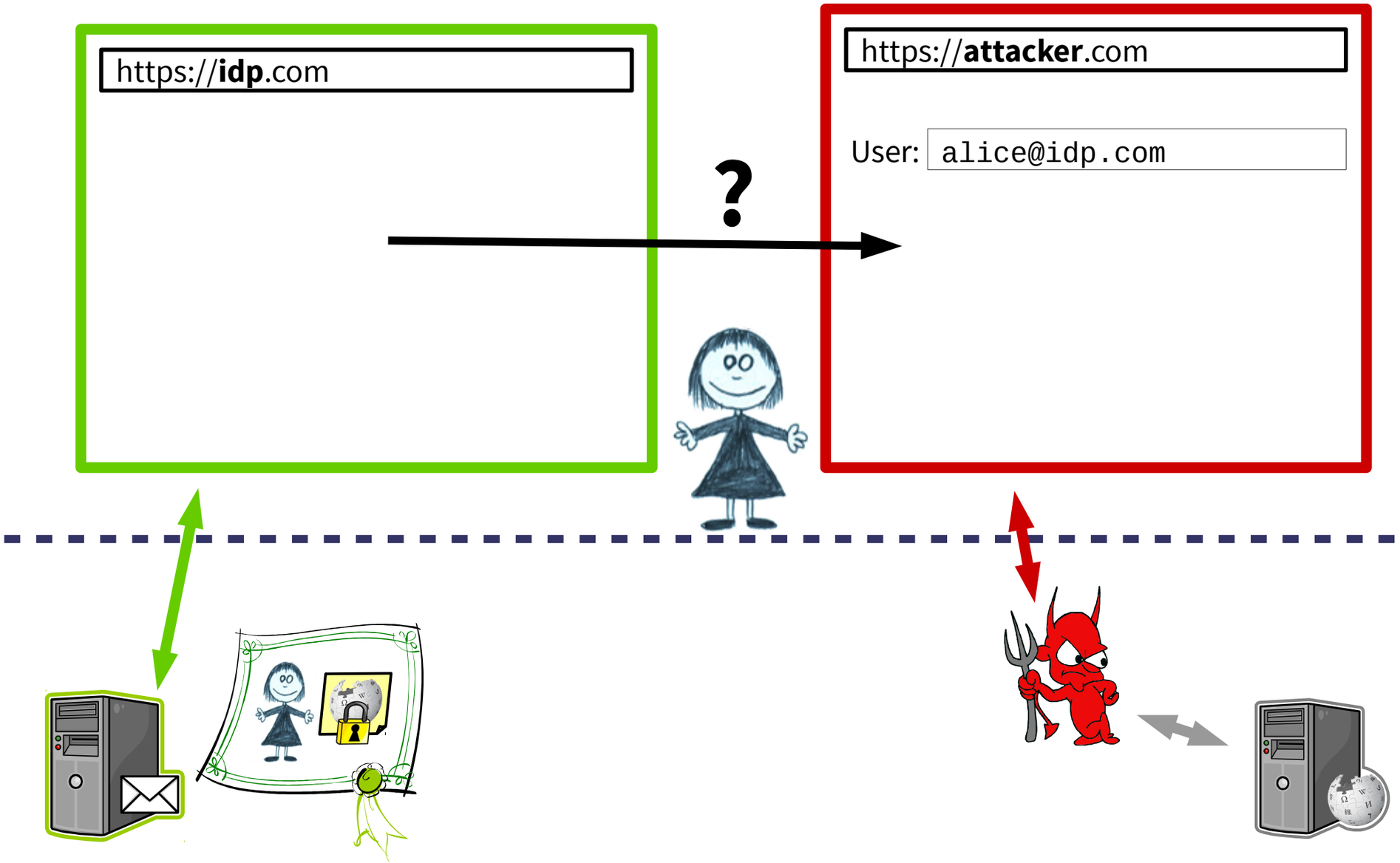

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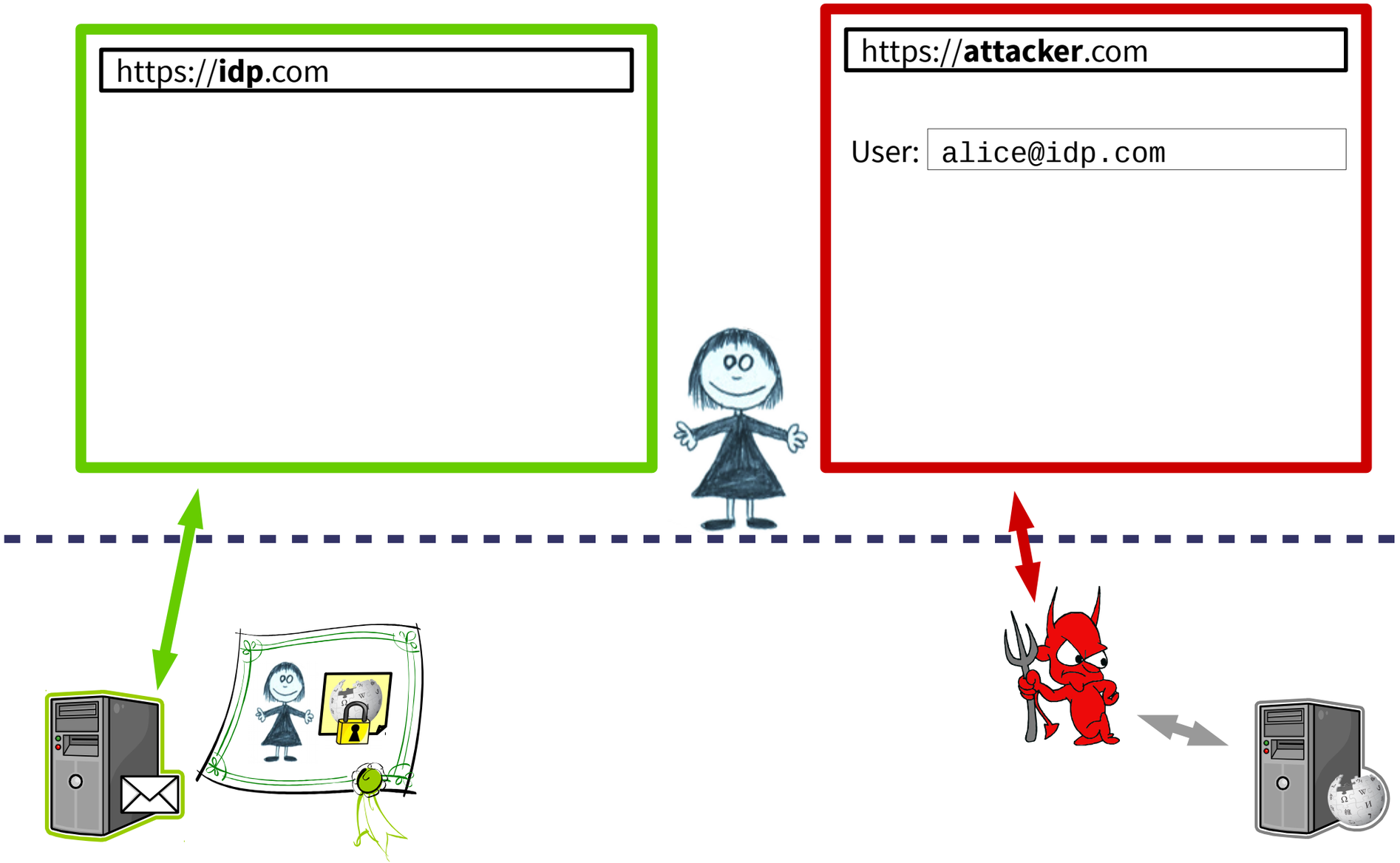

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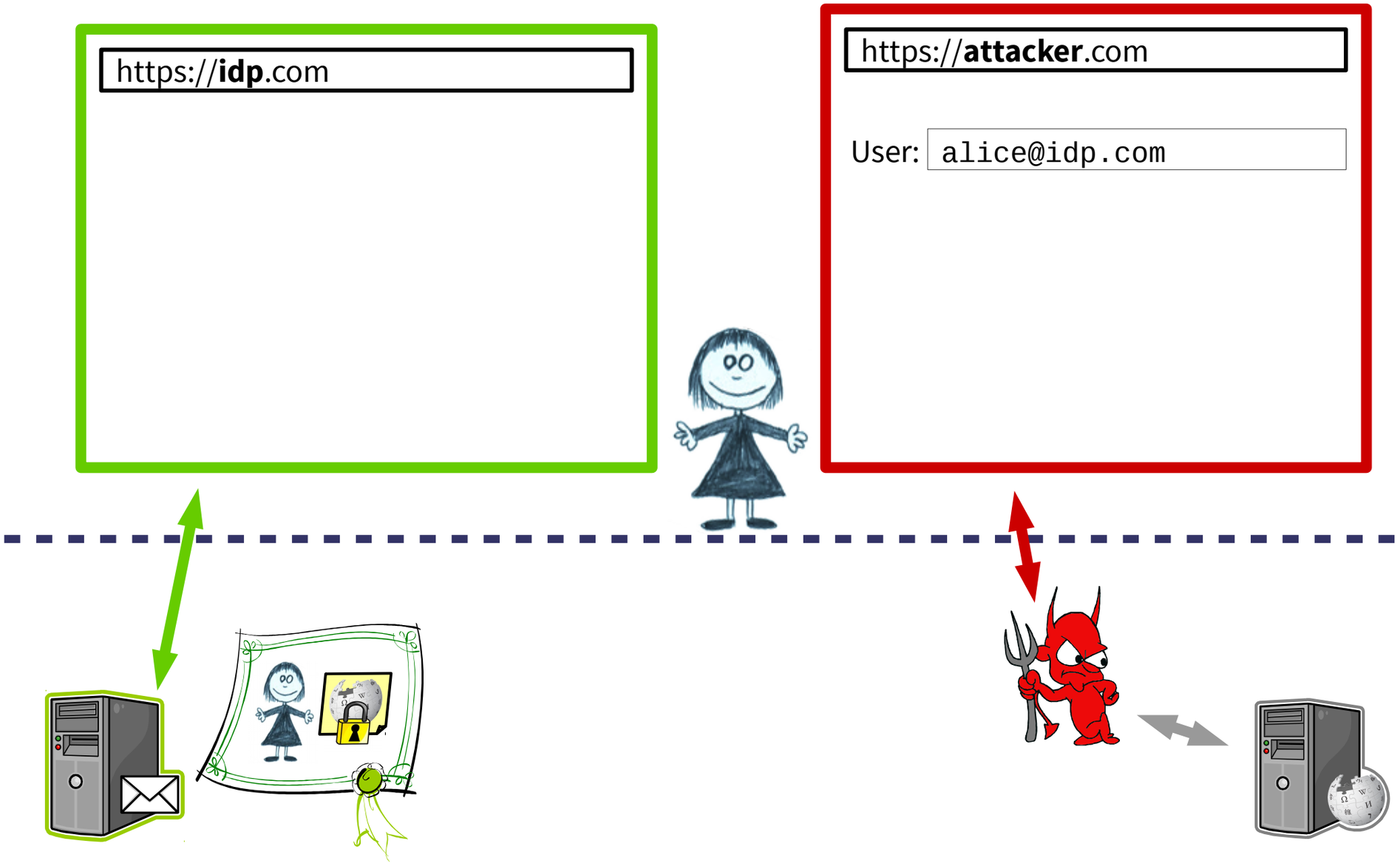

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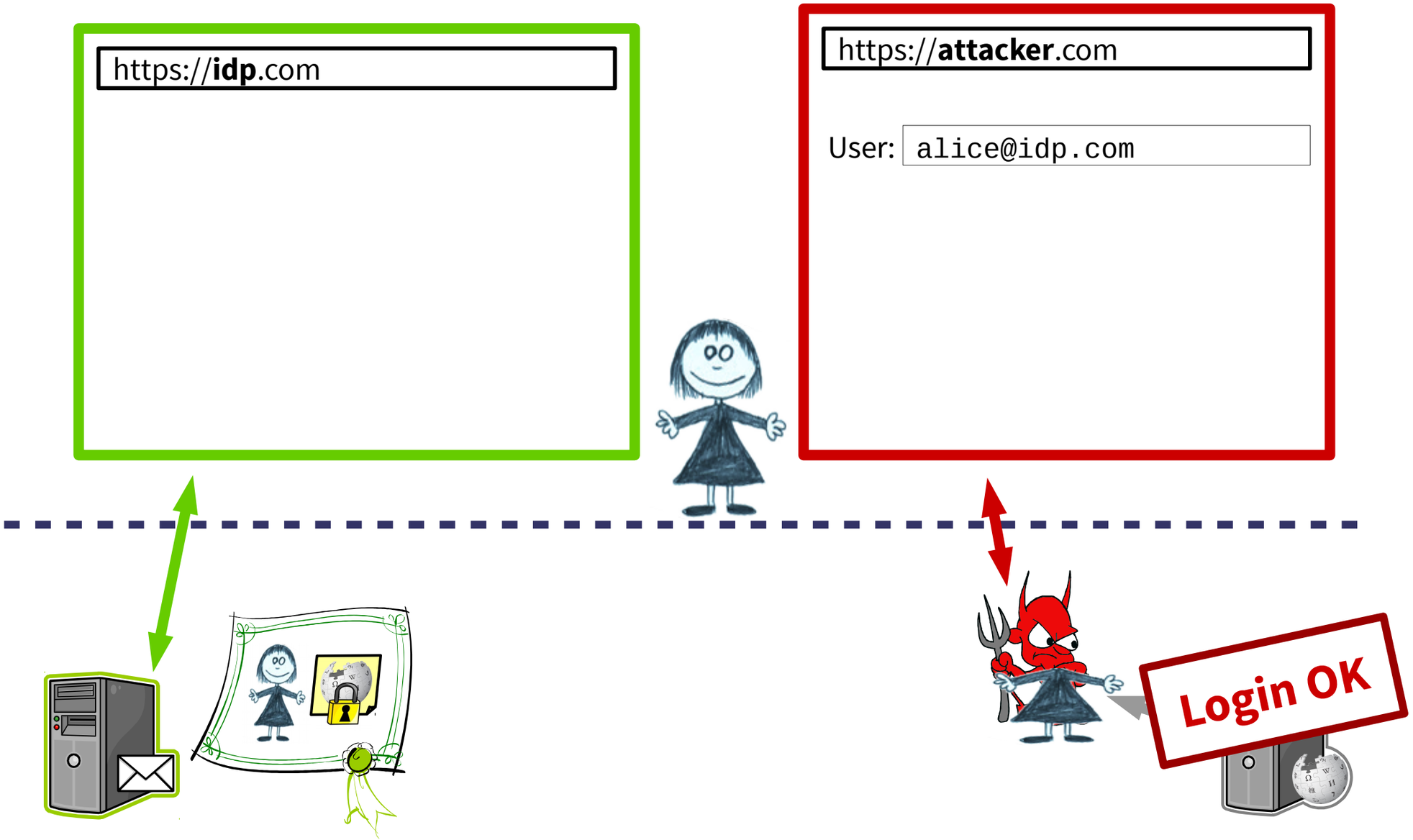

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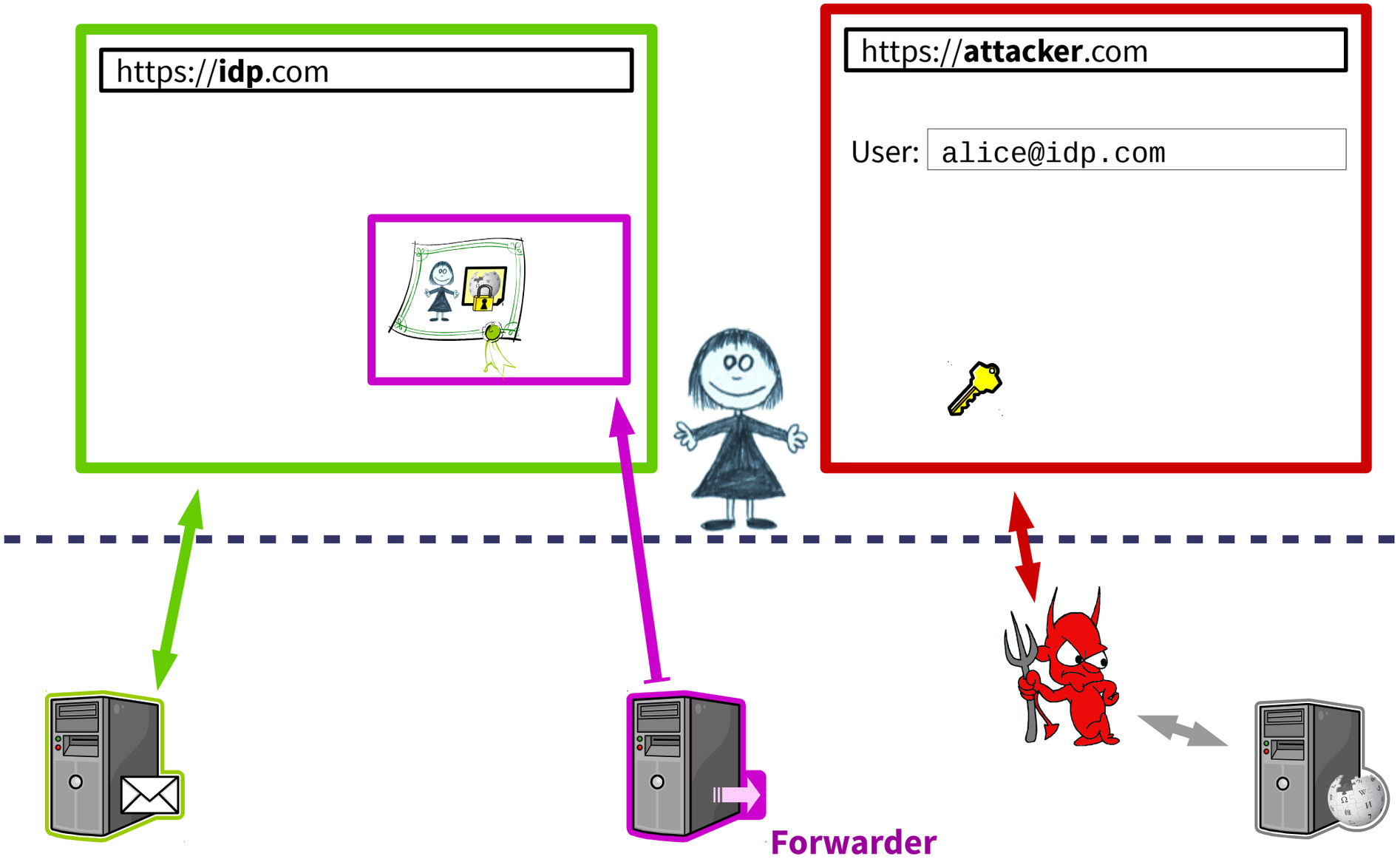

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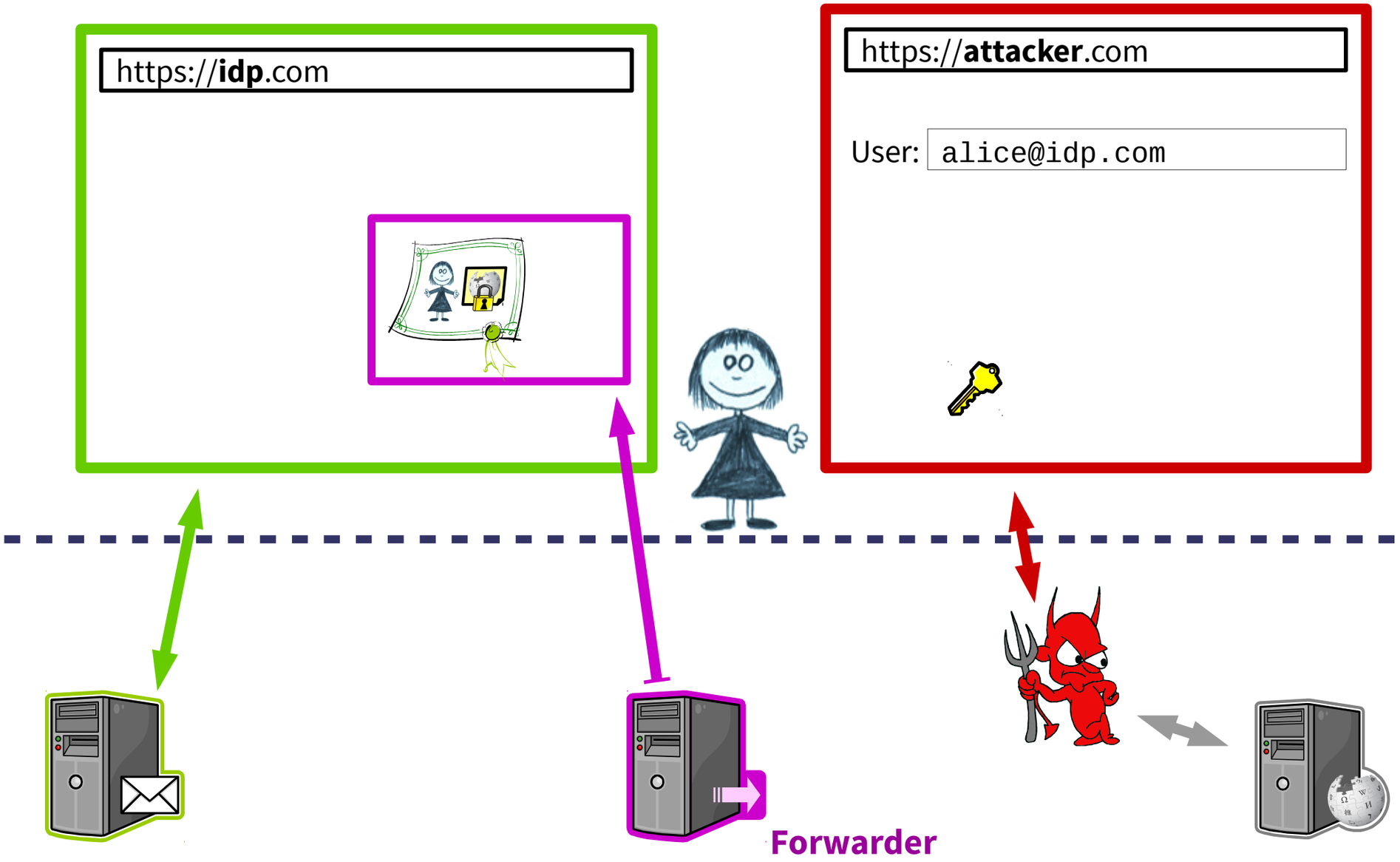

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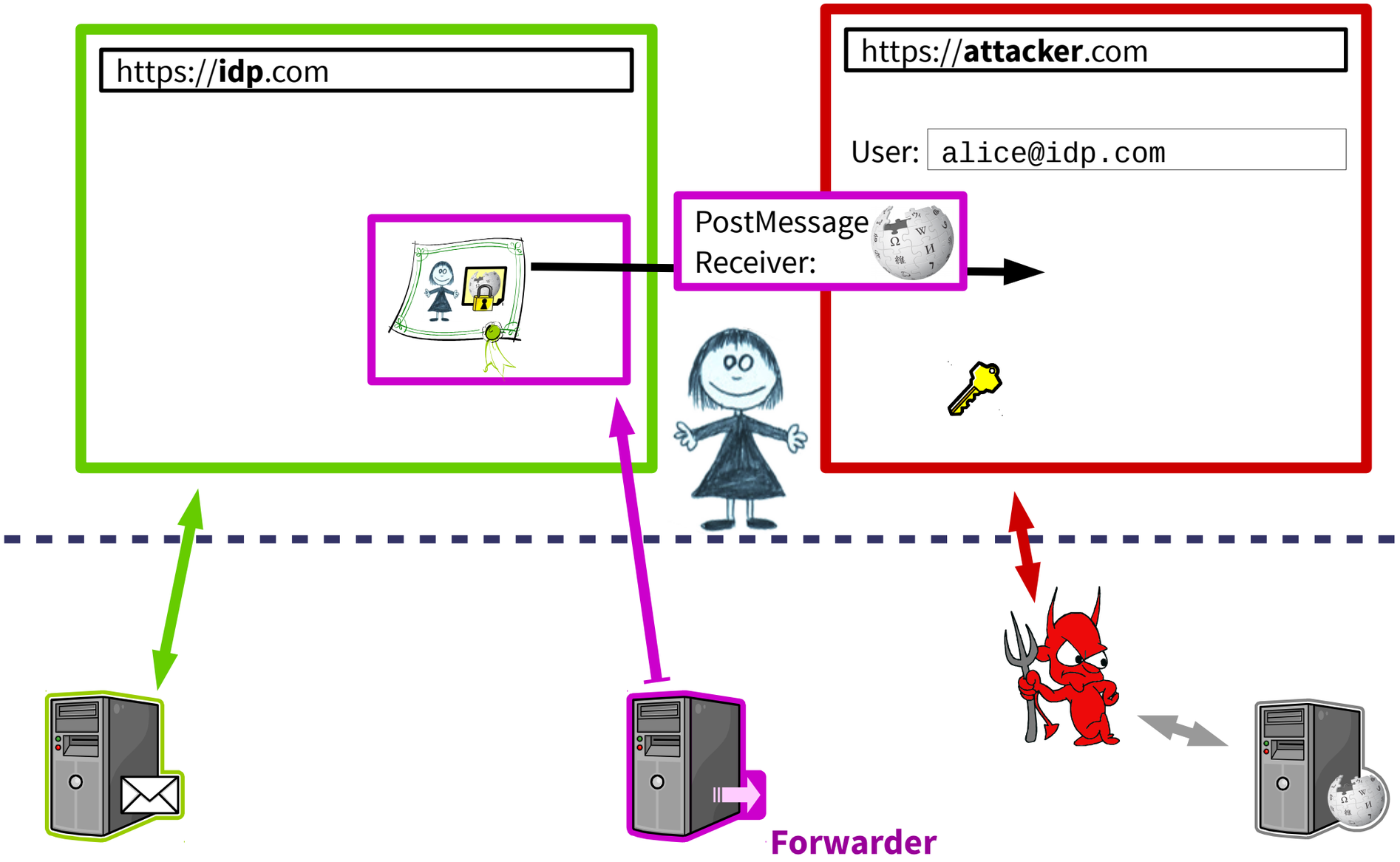

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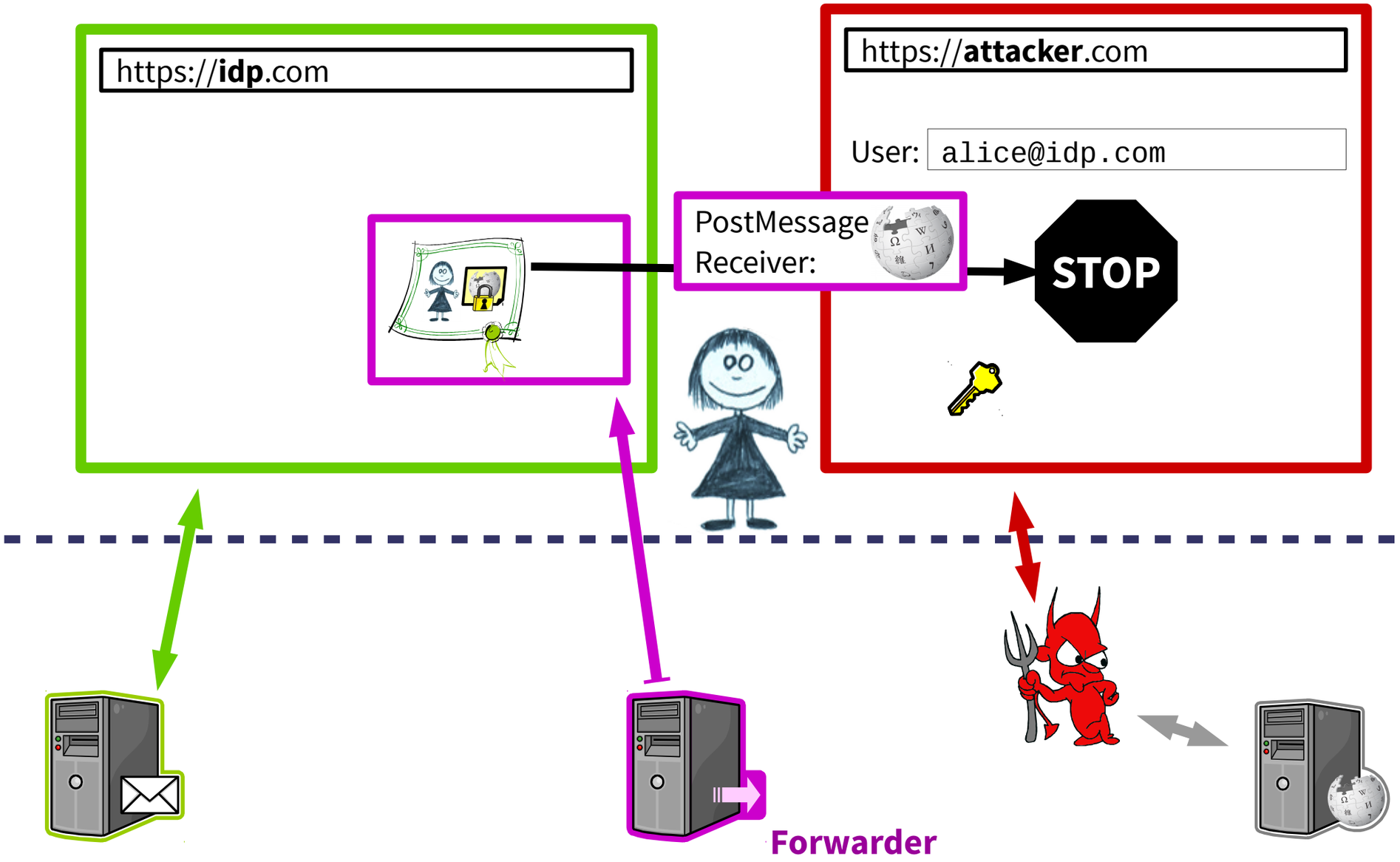

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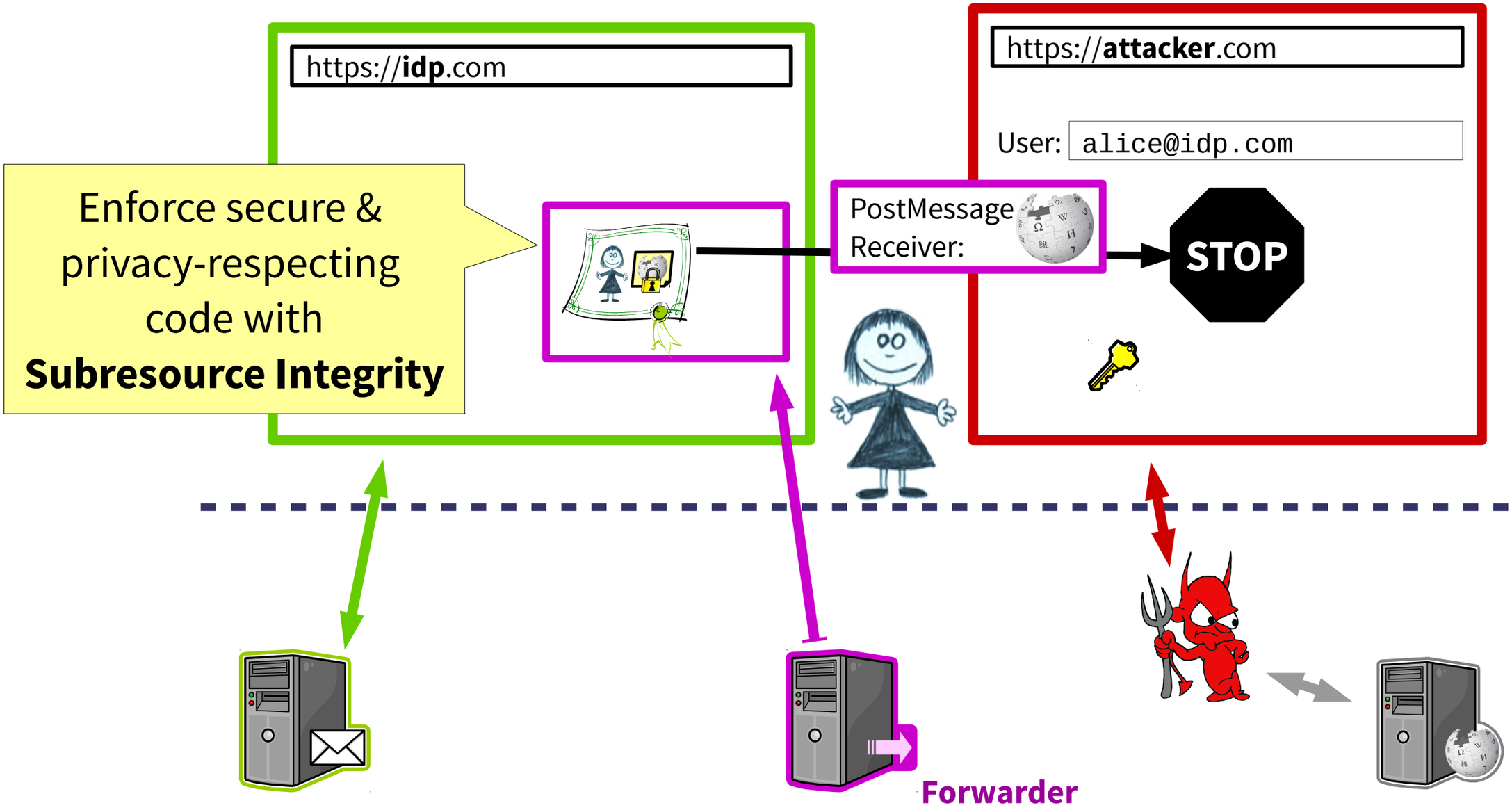


SPRESSO

Secure, Privacy-Respecting Single Sign-On

Features:

- Strong privacy
- Strong authentication
- Open and decentralized
- Web standards compliant, native HTML5 

Formal proofs:

Privacy and authentication

→ https://spresso.me

What's the takeaway?

Various SSO Sytems

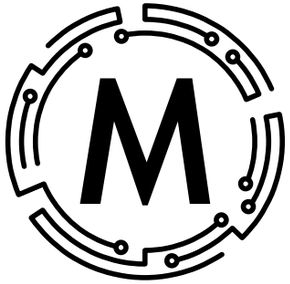
- OAuth 2.0 + OpenID Connect:
  - Formally proven
  - OK, if implemented correctly and *no privacy* works for you
- OAuth 1.0, OpenID: don‘t use
- BrowserID / Mozilla Persona: dead, broken privacy
- SPRESSO:
  - Formally proven
  - Currently just a Proof-of-Concept

Developers, Developers, Developers:

- Use libraries (e.g., pyoidc)
- never implement your own OAuth/etc.
- RFCs hard to read, information spread across several documents, not written clearly, not always up to date
  - yet still important reference

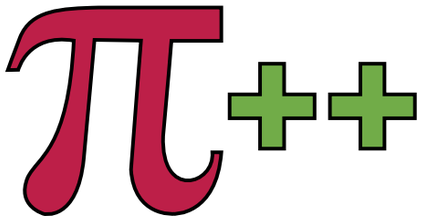
Thank You!

Find us at the **Maschinendeck** assembly in Hall 3 …



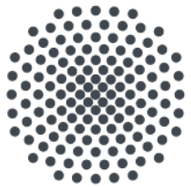
Maschinendeck.org

… or at the next **Pi and More,** January 14, in Krefeld …



PiAndMore.de

… or at the **University of Stuttgart** (starting January)



Universität Stuttgart