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Self-Verifying Authentication – A Framework for Safer Integrations of Single-Sign-On Services

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Motivation

- SSO – the “front door” lock for tens of millio
  - E.g., Airbnb.com allows Facebook sign in.
- Many companies provide identity services
  - Provide SDKs (i.e., lock products) for different we
  - Step-by-step instructions to teach programmers
    - E.g., OpenID Connect 1.0 spec, Azure AD dev guid
- But most website programmers are not expe “locksmiths”
  - Imagine that you need to read an installation guide, drill holes, and install a lock cylinder, knobs and steel plates on your front door
  - Can every average homeowner do it securely?

Security-Critical Logic Bugs are Pervasive

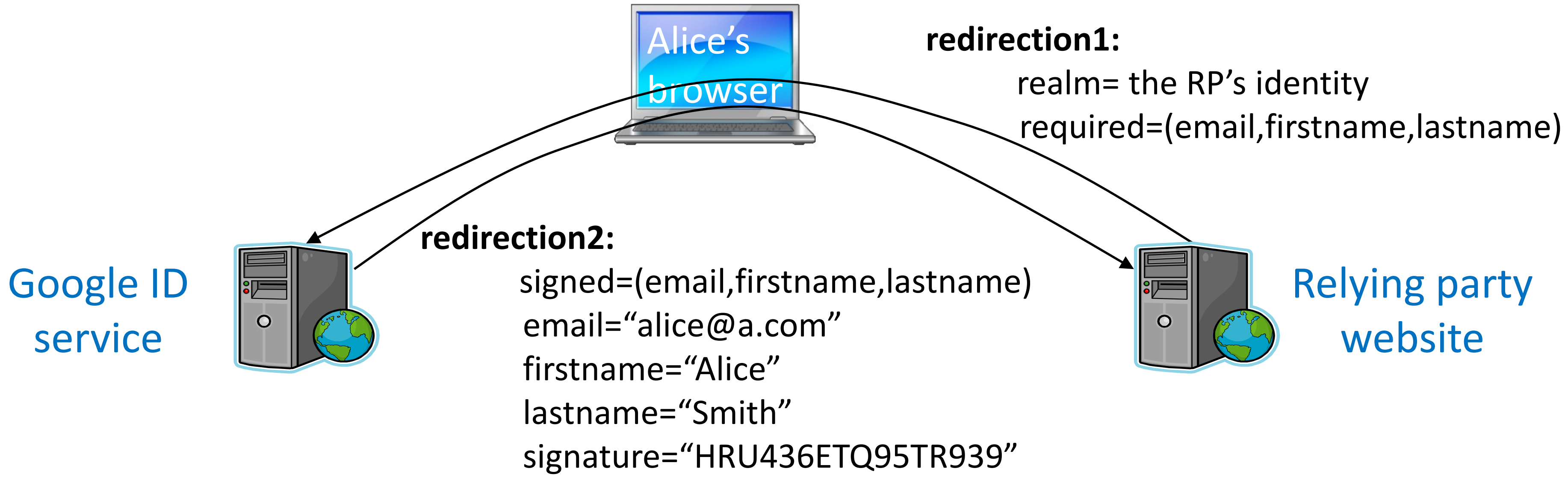
- Numerous studies have shown serious bugs
  - Papers in leading academic security conferences
  - Findings from the Black Hat community
    - E.g., in Black Hat USA 2016 and Black Hat Europe 2016
- Consequences:
  - An attacker can sign into a victim's account
  - An attacker can stealthily cause the victim to sign into the attacker's account (commonly known as *login request forgery*)
- Cloud-API integration bugs are the No.4 cloud security top threat
  - SSO logic flaws are the primary example of this bug category

Attack demos

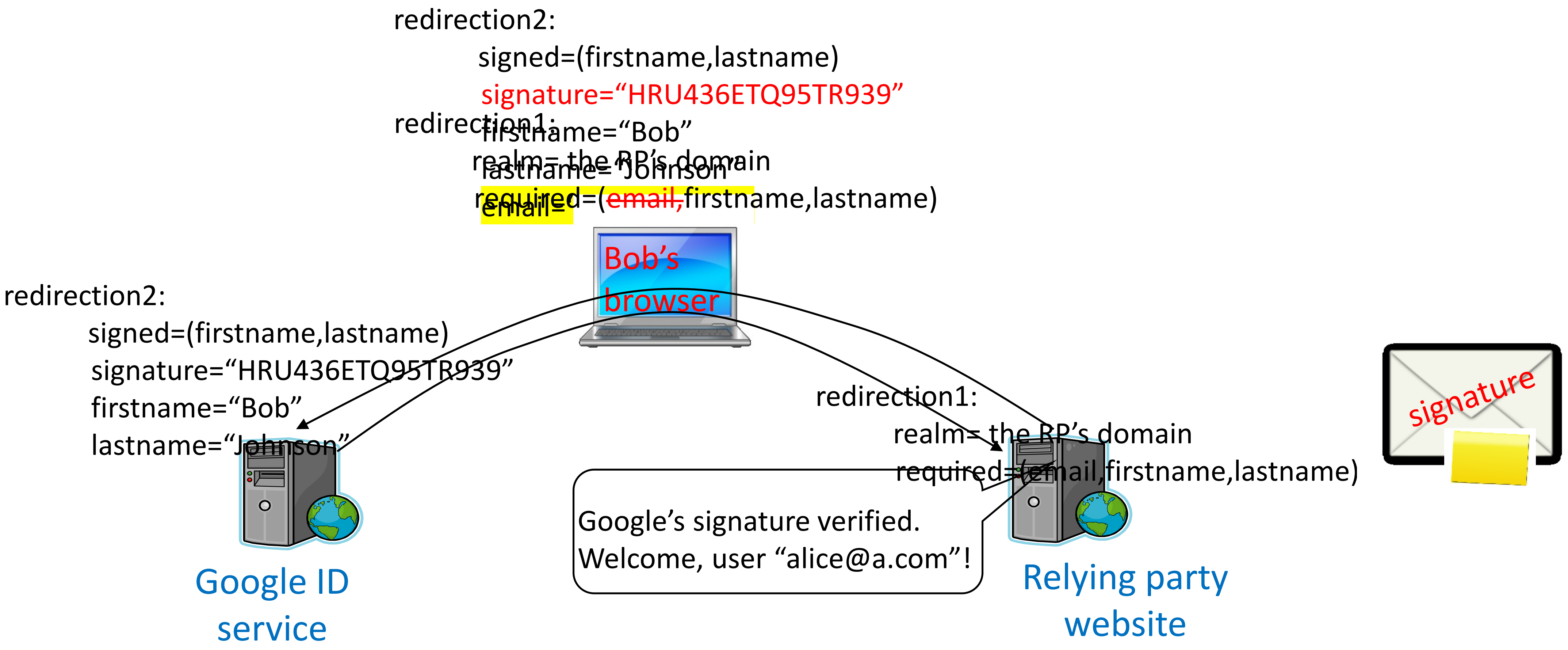
- Demo 1:
  - Microsoft Azure AD library for Node.JS
  - Attacker logs into any victim's account
  - Video
- Demo 2:
  - https://web.skype.com
  - Login request forgery: victim unknowingly login into the attacker's account
  - Video1 video2
- We have reported many SSO issues to various identity providers and websites.
  - Companies, big or small, make these mistakes.

Example: an SSO bug due to insufficient logic checks using Google ID

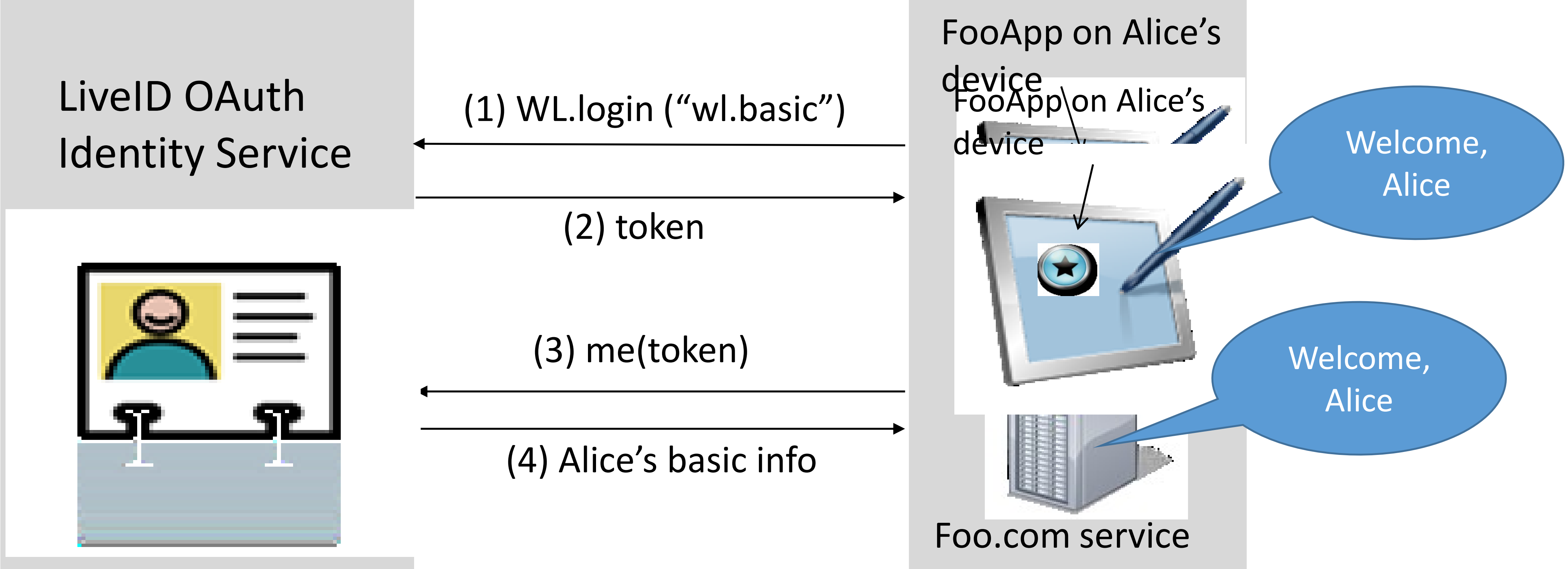
- A simplified illustration of the Google ID protocol
  - In 2012, it was based on Open ID 2.0



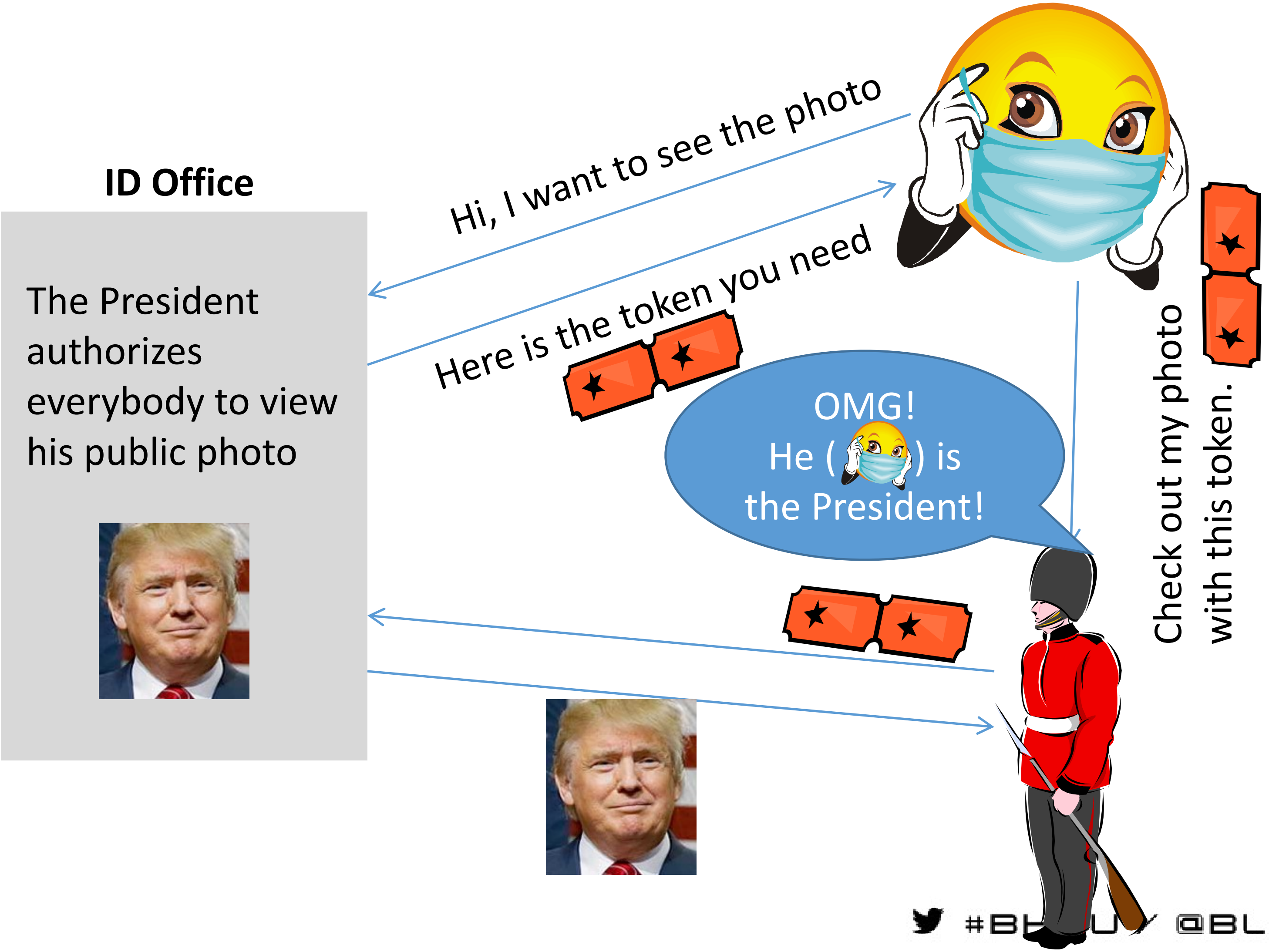
Vulnerability and attack



Example: unintended usage of OAuth 2.0 access token



Confusion about authentication and authorization



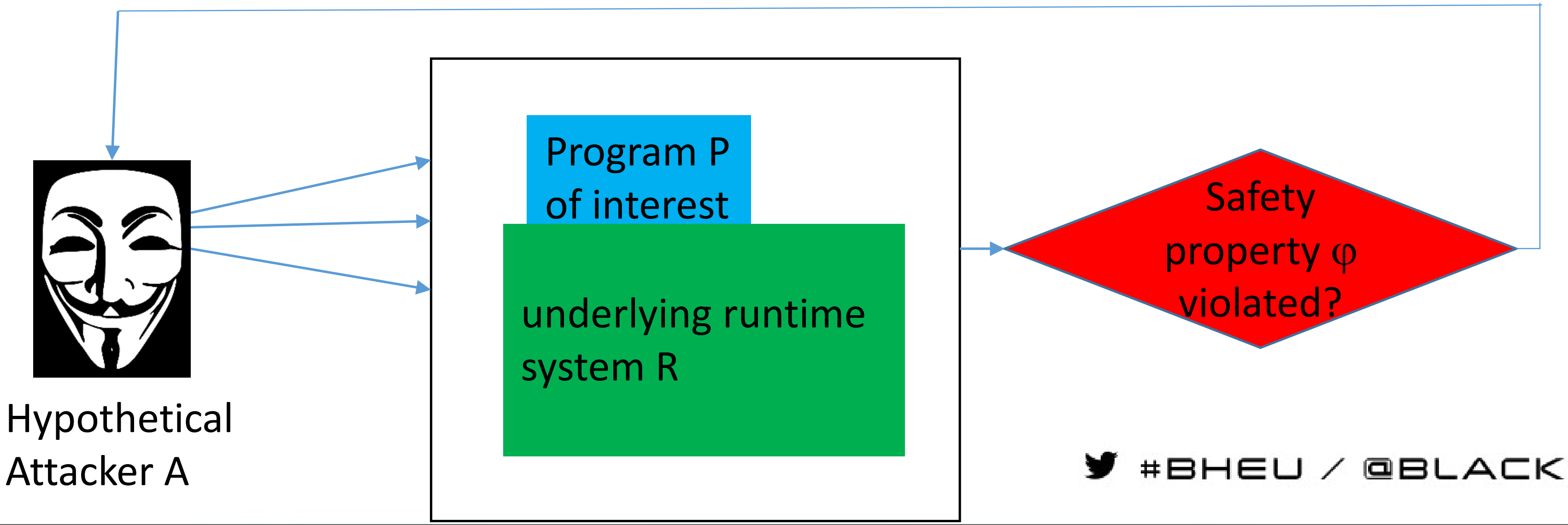
demo

Program verification to prevent logic bugs in SSO

Our verification technology: self-verifying execution (SVX)

Hurdles of traditional verification approaches

- Why can't I feed my source code P and a property φ into a program verifier, and expect bugs to be found automatically?
- Because program verification is a very challenging task
  - Need to model the runtime system R – hard to be precise
  - Need to model the unknown attacker A – hard to be exhaustive
  - Theorem to prove: if attacker A calls P for infinitely many times, and each time has multiple public APIs, can φ ever be violated?
  - Need to prove by induction (because of the infinite possibilities of executions) – hard to automate.



Basic idea of SVX

- Every actual execution is responsible for collecting its own executed code, and proving that it satisfies φ.

- No need to model the attacker
  - Because every execution is driven by a real user.
- No need to model the runtime platform
  - Because execution happens on the actual platform
- No need for inductive proof
  - Because it only proves “this execution satisfies φ”, not “all possible executions satisfy φ”.

Example: comparing integer constants among three websites

Alice.com

```
const int Value=10;
Message grab (Message m1)
```

Message

Untrusted client

Safety property φ:

Whenever conclude(m2) is reached, m2 must represent the website holding the biggest int.

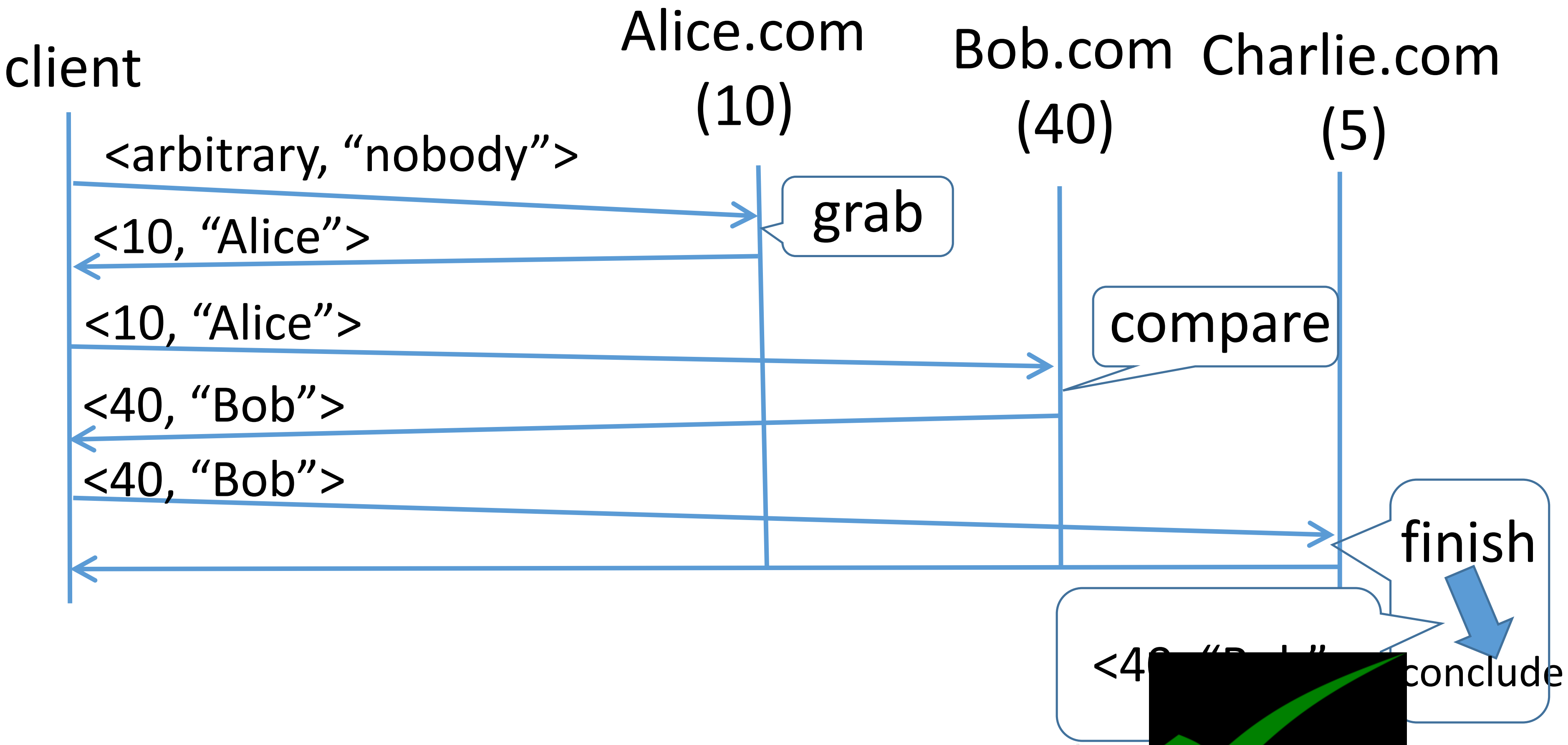
Bob.com

```
const int Value=40;
Message compare (Message m1)
{   ValidateSignature(m1);
    Message m2;
    m2 = <Value, “Bob”>;
    m2 = max(m1,m2);
    m2.SignBy(“Bob.com”);
    return m2;
}
```

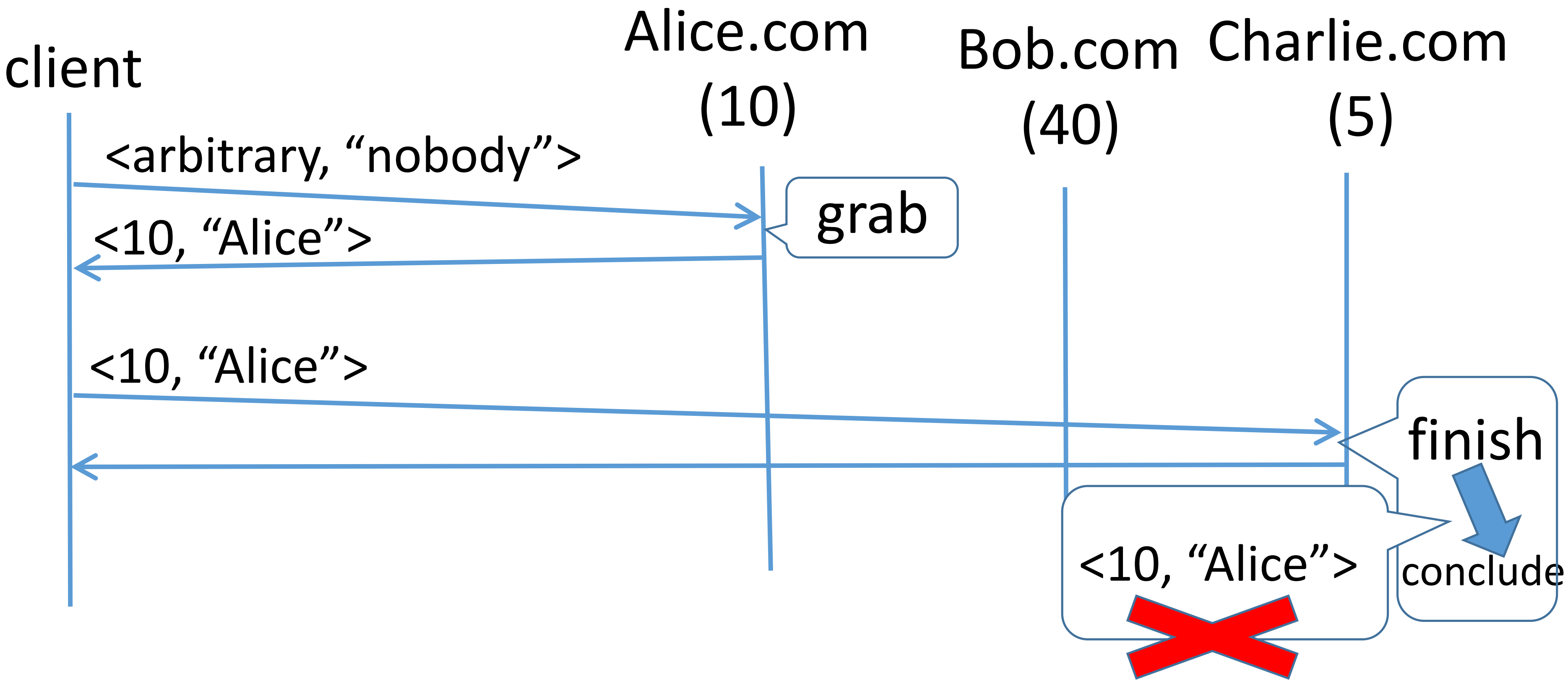
Charlie.com

```
const int Value=5;
Message finish (Message m1)
{   ValidateSignature(m1);
    Message m2;
    m2 = <Value, “Charlie”>;
    m2 = max(m1,m2);
    conclude(m2);
    return m2;
}
```

The expected protocol flow

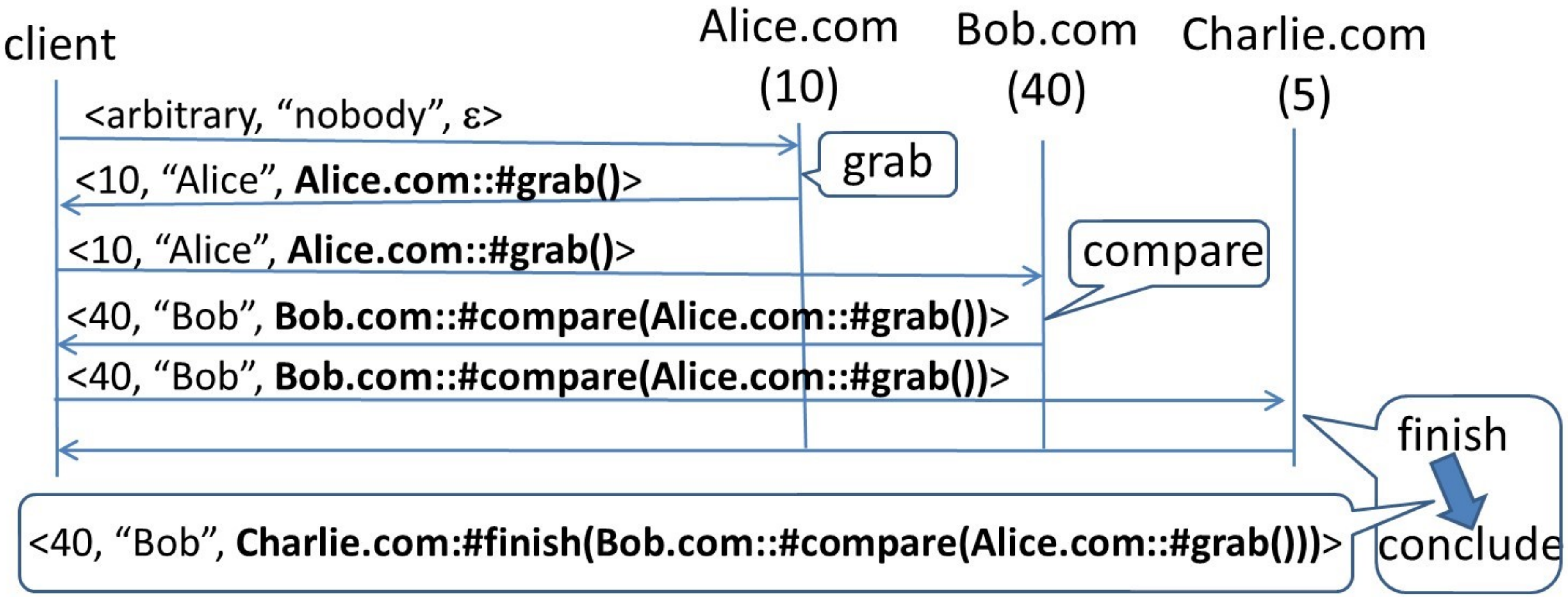


The system is vulnerable!



How SVX works

- Attach a field, namely *SymT (Symbolic Transaction)* onto every message.
- #grab, #compare and #finish are a compact representation of the executed code of these methods.



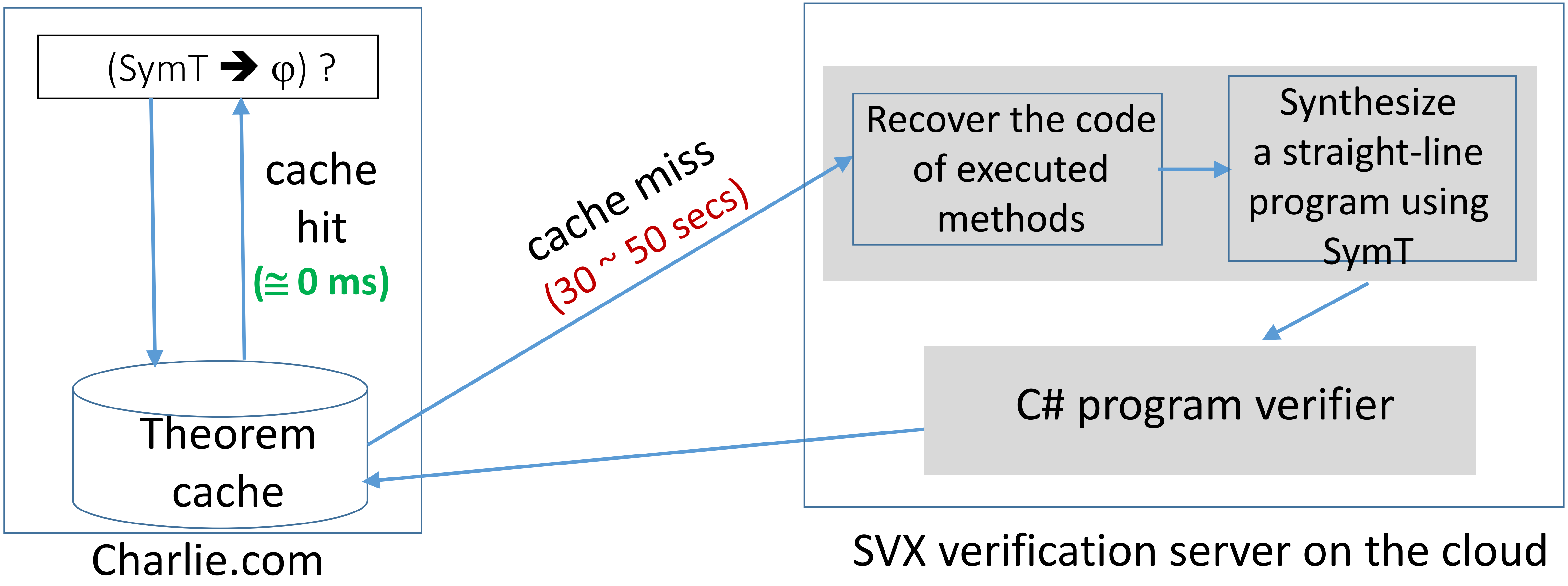
Verifying an execution

- Method conclude() calls a program verifier to prove:
  The final SymT $\rightarrow \varphi$
  - Charlie.com:#finish(Bo[redacted]#compare(Alice.com::#grab())) $\rightarrow \varphi$, the execution is accepted.
  - Charlie.com:#finish(Alice.com::#grab()) $\nrightarrow \varphi$, the execution is rejected.

- Note that the program verification is symbolic (only about code). The concrete values are ignored.
  - A middle ground between offline symbolic verification and runtime concrete checking.

- SVX's performance overhead is near-zero
  - Because the theorems can be cached.
  - All normal executions should hit the cache.

Theorem cache and verification server

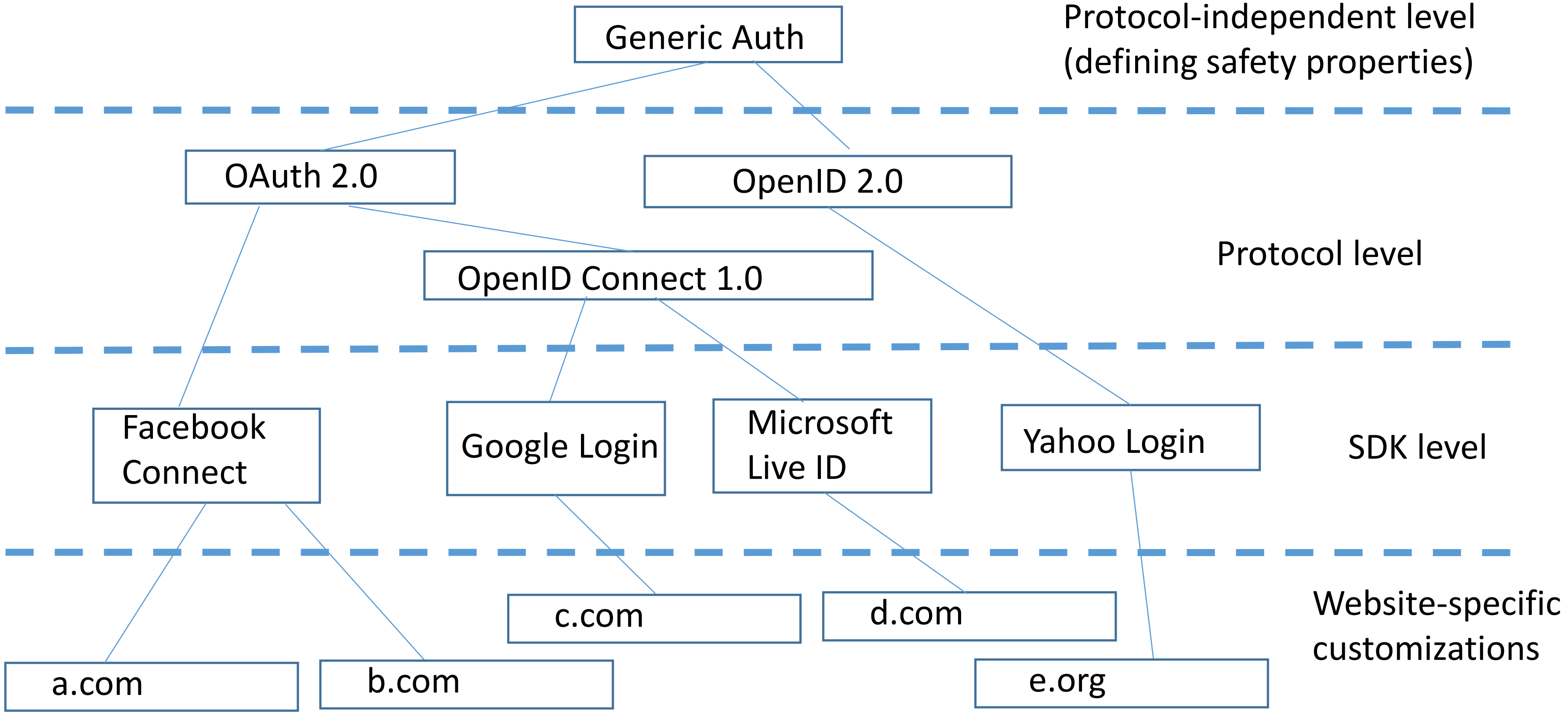


Our open-source project: SVAuth

Safer SSO integration solutions based on SVX

The SVAuth framework: SVX with OO

- Defines “login safety” and “login intent” properties at the base class level.
- Every concrete implementations are guaranteed to satisfy the base class level properties!



A decades-old problem in verification

- Liskov Substitution Principle (LSP) tries to ensure that
  - If a property is true for the base class, then it holds for all derived classes.

```
class Rectangle {
   int height, width;
   virtual int GetHeight() {return height;}
   virtual int GetWidth() {return width;}
   virtual void SetHeight(int x) {height=x;}
   virtual void SetWidth(int x) {width=x;}
}
```

```
class Square: Rectangle {
   override void SetHeight(int x)
        { height=x;
          width=x;  }
   override void SetWidth(int x)
        { height=x;
          width=x;  }
}
```

```
void foo(Rectangle r) {
      int w=r.GetWidth();
      r.SetHeight(3);
      Assert(w==r.GetWidth());
}
```

For SVX, there is not confusion

```
Rectangle r = new Rectan
Assert(foo(r));
```

```
Rectangle r = new Square();
Assert(foo(r));
```

Adopting SVAuth on your website -- extremely simple

- SVAuth consists of an agent and an adapter
  - Agent: public agent, organizational agent or localhost agent
  - Website developer picks an agent, and sets its endpoint in the SVAuth config file
  - Copy the adapter folder onto the website
- Assuming website *foo.com* is in PHP, and wants to do Facebook SSO
  - Simply redirect to "***http://foo.com/SVAuth/adaptors/php/start.php?provider=Facebook***"
  - Magically, the user's identity information is available in these session variables

    Session["SVAuth_UserID"]=108376550318508459185
    Session["SVAuth_FullName"]=John Doe
    Session["SVAuth_Email"]=johndoe@gmail.com
    Session["SVAuth_Authority"]=Google.com
  - Website programmers don't need to know anything about SSO protocols.

Our experience

- Current status
  - Support 7 SSO services and 3 languages (ASP.NET, PHP and Python)
  - Will support more.

- Integration with real-world applications
  - MediaWiki (8 lines of code changes)
    - Used by a Microsoft Research internal website.
  - HotCRP (21 lines of code changes)
  - CMT (10 lines of code changes)

- Open source, available on GitHub
  - Project repository: https://github.com/cs0317/SVAuth

SVAuth demo

Demos

- Buggy code
  - Remove cache entries
  - Comment out the line stateGenerator.Verify in Facebook.cs
  - *Login Intent* won't pass.
- Correct code, first execution
  - Program verification is triggered
  - Both *Login Safety* and *Login Intent* pass the verification.
- Correct code, second execution
  - Theorems hit the cache, near-zero runtime overhead

Black Hat Sound Bytes

- Most website programmers are not experienced "locksmiths"
  - Installing an SSO lock securely on a website is not easy.
  - SSO security bugs are pervasive. Even big companies make mistakes.
  - The problem is well known in the security community.
- Self-verifying execution (SVX)
  - It is a "locksmith" built into a lock product.
  - The locksmith watches how the lock is opened, and asserts if it is logically sound.
- SVAuth – Open-source SSO framework based on SVX
  - Please adopt SVAuth on your websites
  - Or, join the project to improve the code.
  - Let's fundamentally address the SSO security bugs.