ASPIRE : Iterative Specification Synthesis for Security

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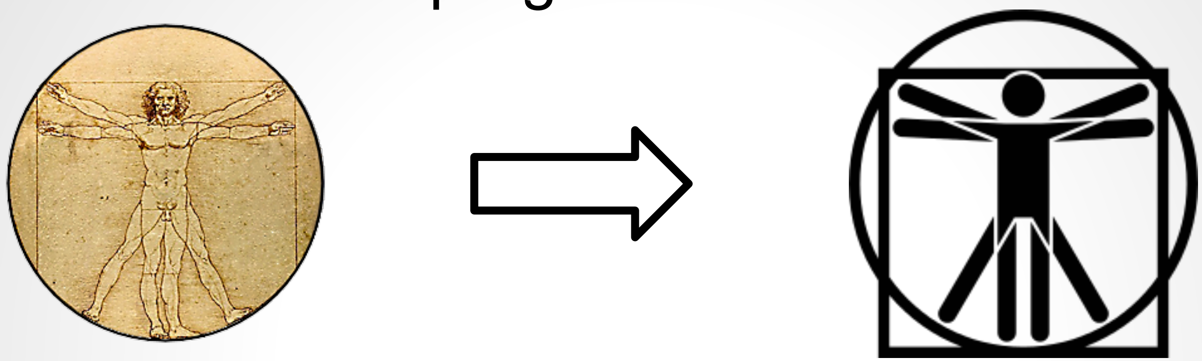
Security Analysis of Software Systems

- Abstract: From programs to **models**



- Check: **Security properties** on the models

Specifications =  + 

The Spectrum of Security Analyses

seL4

PROSECCO
PROGRAMMING SECURELY WITH CRYPTOGRAPHY

SLAM

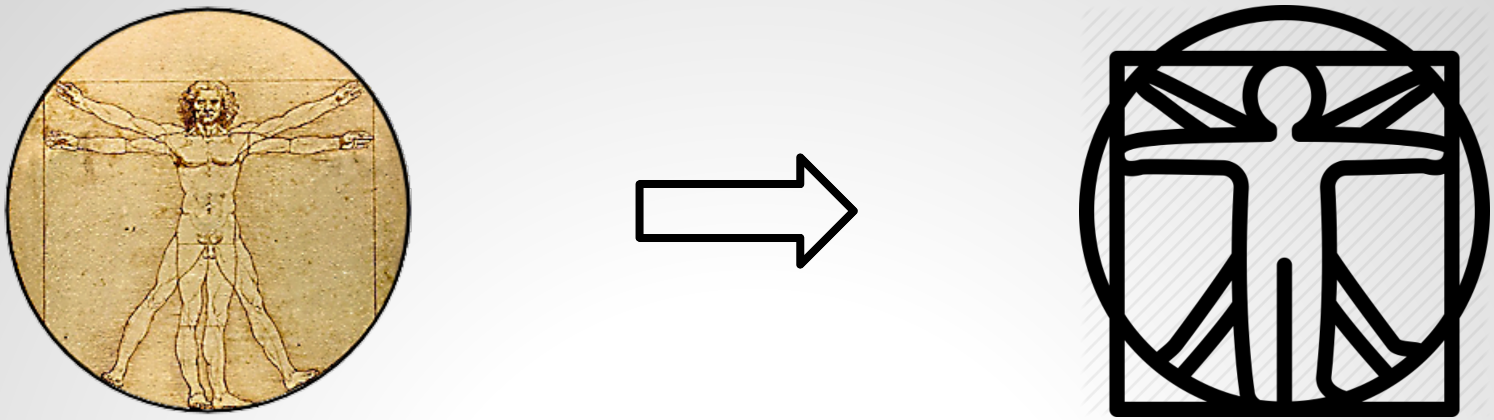
address-sanitizer

CompCert C

BitBlaze

Completely manual

Fully automatic



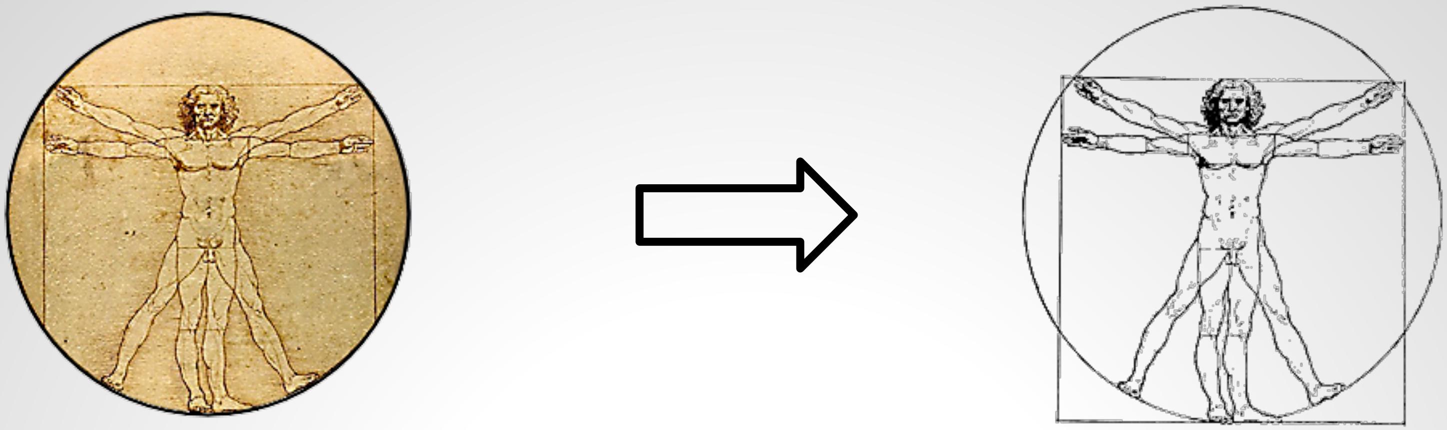
seL4

PROSECCO
PROGRAMMING SECURELY WITH CRYPTOGRAPHY

CompCert C

Manual Specification Creation

- Steep learning curve
- Model remains error prone
- Process has to be repeated for different applications



SLAM

address-sanitizer

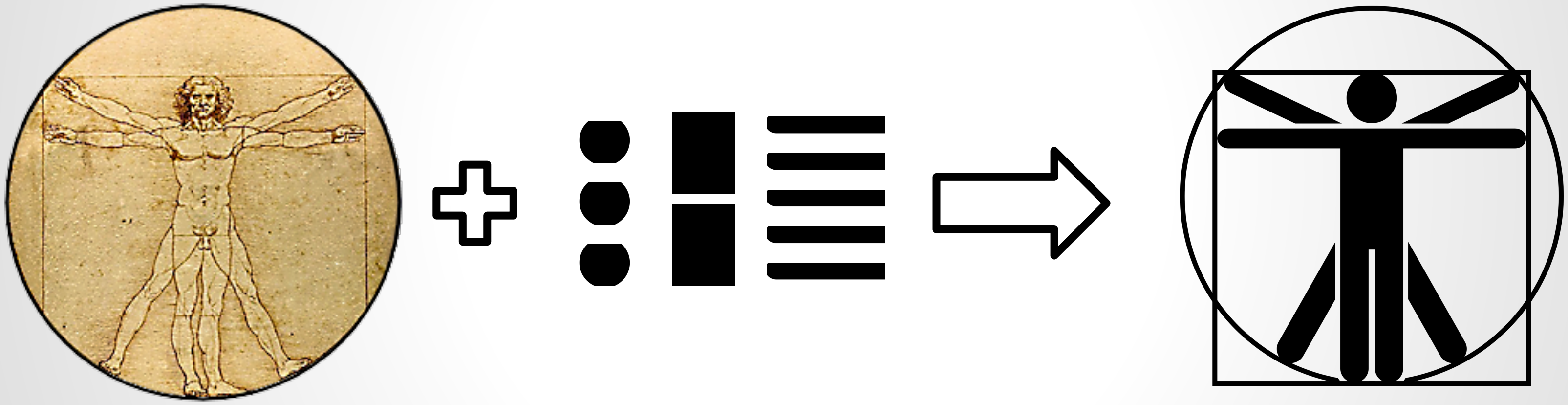
BitBlaze

Automatic Program Analysis (Bottom-up)

- Unable to efficiently recognize high-level semantics (“bad at throwing away details”)
- Typically requires full code visibility or complex environment models
- Properties often hard-coded into the analyzers

Is there a middle ground?

Insight: Build from Common Blocks



Preliminary Results:

Security Analysis of Web Applications

Web Applications

- Hard to implement the protocols correctly
    - Customized APIs and undocumented behaviors
    - Subtleties of the web's security model
- Hard to check the protocol implementation
    - Hard to generate models
    - Hard to specify security properties
    - Don't have all parties' code

Problem Definition

Do the following:

a. construct a model that is consistent with the application behavior (i.e. the execution traces)
b. check the model against the security policy.

Given reasonable resources:

i. a web application consisting of multiple parties
ii. execution traces of the web application
iii. a security policy

The Security Policy

- Session integrity:
  - Any action that an honest server takes should not be directly/indirectly caused by a dishonest/untrusted party
  - e.g. A request caused by robber.com shouldn’t reduce money in my bank account
  - e.g. A request caused by sessionrider.com shouldn’t change my login status on facebook.com
- Information secrecy:
  - Secrets shared by the client and the server should not be learned or inferred by any unauthorized third-party

Modeling: Observations

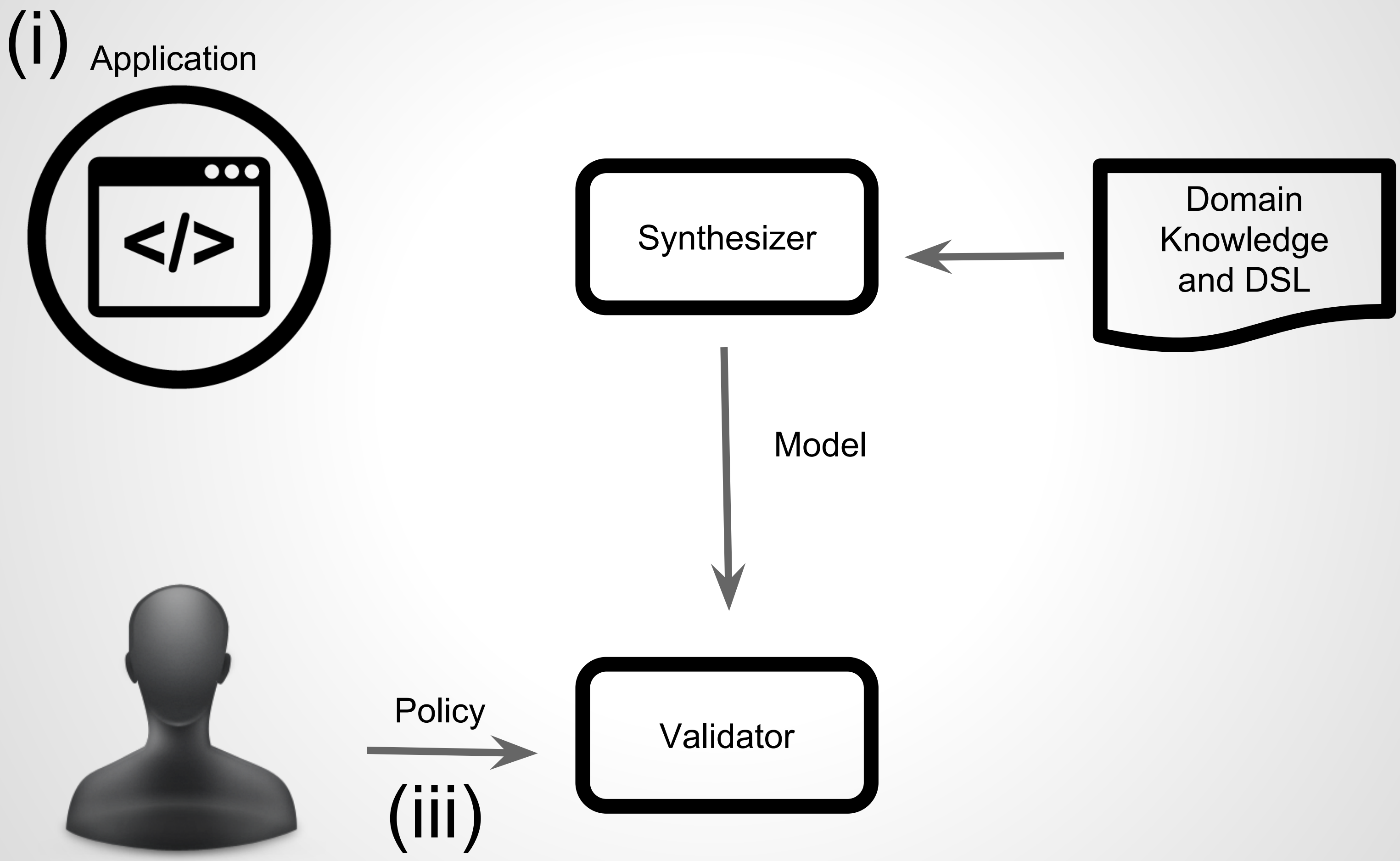
Common web application logics

- Web applications use similar mechanisms to maintain web sessions
- Single sign-on services use similar concepts regardless of the protocols (e.g Facebook Connect, Google Login, CAS Login, ...)
- E-commerce protocols user similar concepts and steps to process payments (e.g. Paypal, Amazon payment, …)

Modeling: Our approach

- Middle ground
  - Manually construct the basic blocks once
    - Application independent
  - Use these basic blocks to describe many protocols
    - Application dependent
- Representation:
  a domain specific language (DSL)
- Use DSL in program synthesis
  - programmatically search for program that passes test cases
  - high-level helps search efficiently

ASPIRE Workflow



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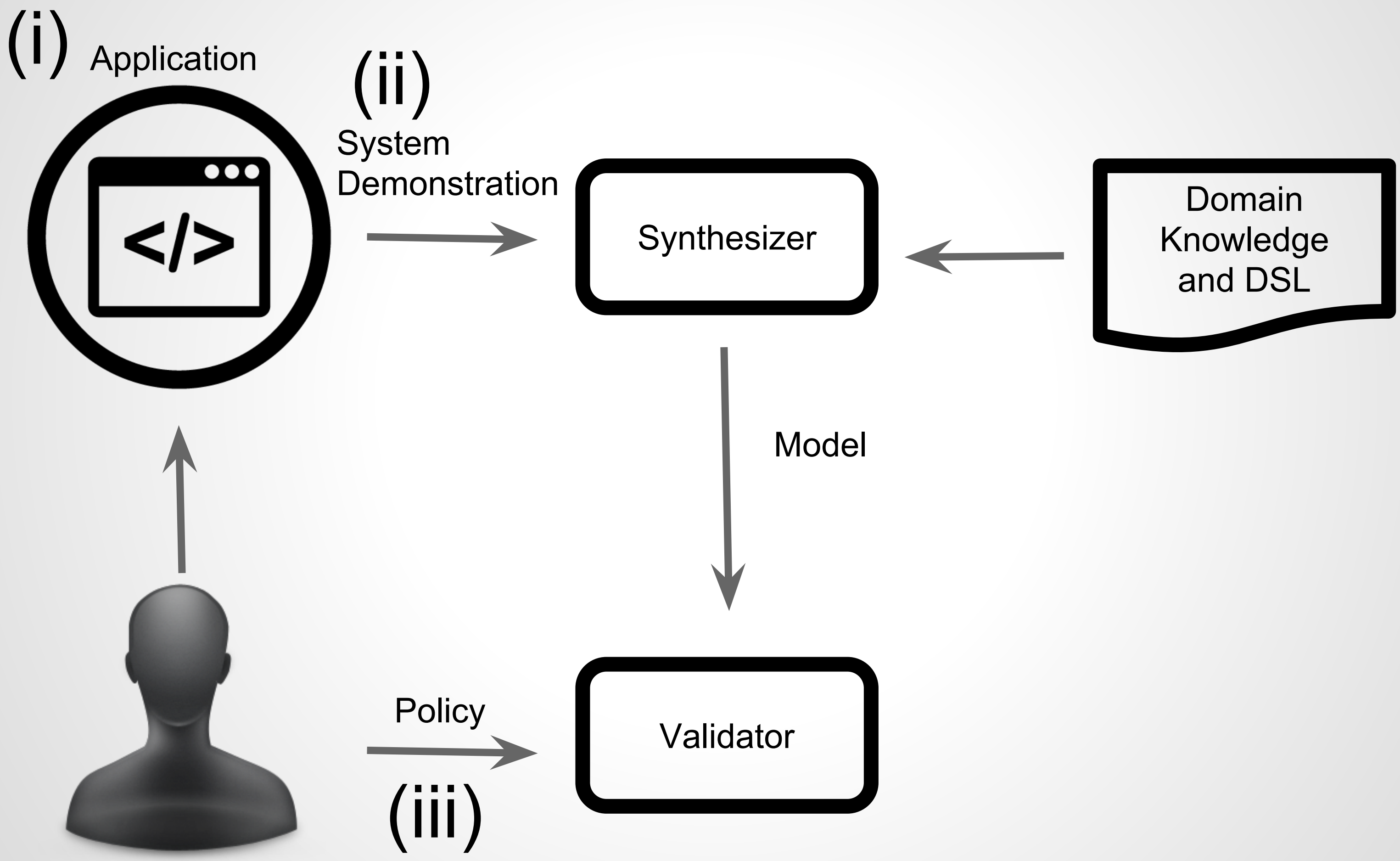

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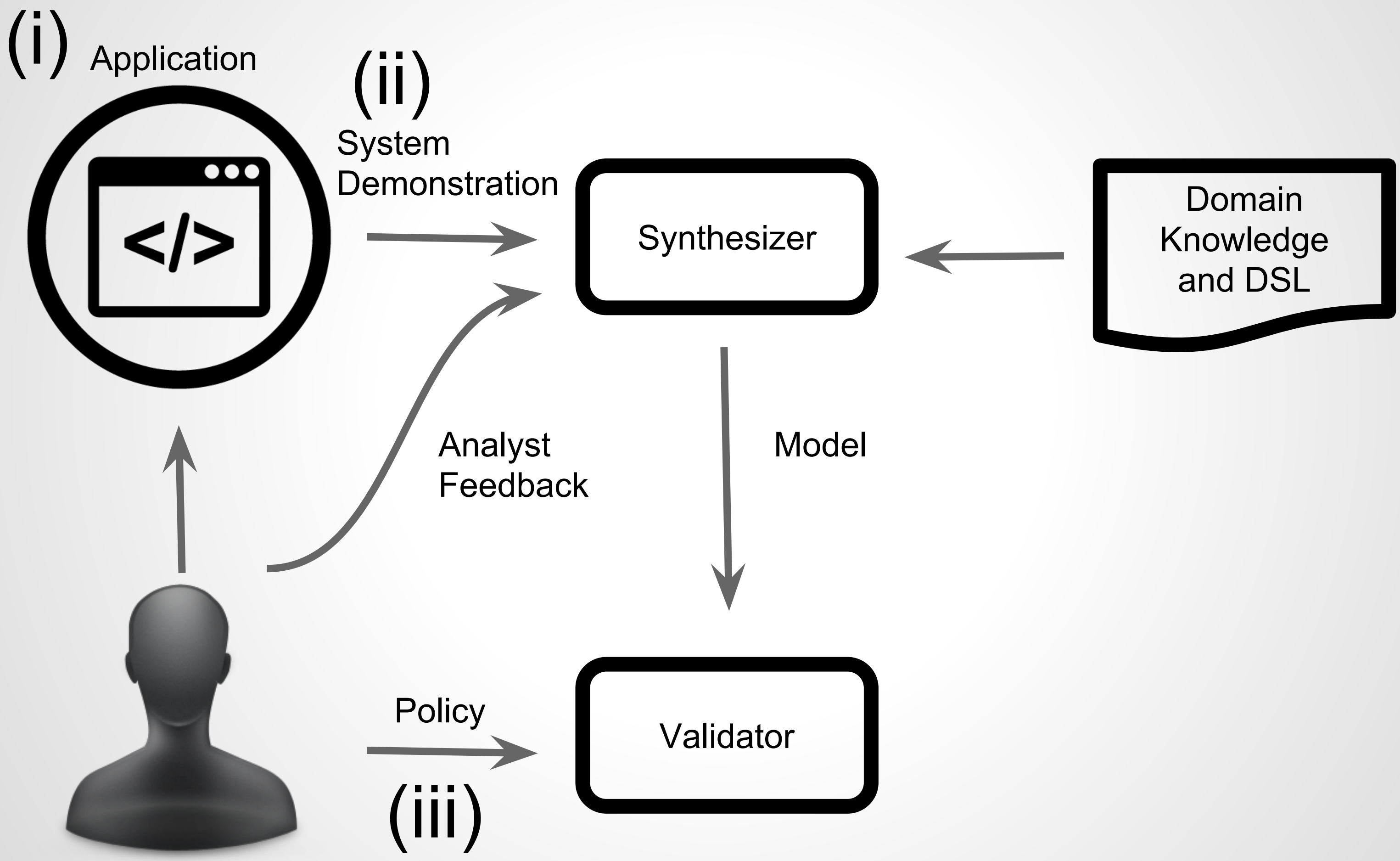

Running Example: Synthesis

```
~GET /login HTTP/1.1
Host: bodgeitstore.com

HTTP/1.1 200 OK
Content-Type: text/html
Set-Cookie: session=7ffa4512
<form method="post" action="/login">
<input type="hidden" name="csrftoken" value="3eff8527">
<input type="text" name="username">
<input type="password" name="password">
<input type="submit" name="submit" value="login">
</form>

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Host: bodgeitstore.com
csrftoken=3eff8527&username=user1&password=secretpwd&submit=login

HTTP/1.1 200 OK
Content-Type: text/html
<b>Welcome!</b>
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init:
  bodgeit knows t1,t2;
  client knows t3,t4;
messages:
  request(server=bodgeit, type=req-helo),
  response(server=bodgeit, type=resp-helo,
    fields=(jsid in setcookie, csrf in body)),
  request(server=bodgeit, type=req-login,
    fields=(rcsrf in urlparam, rjsid in cookie,
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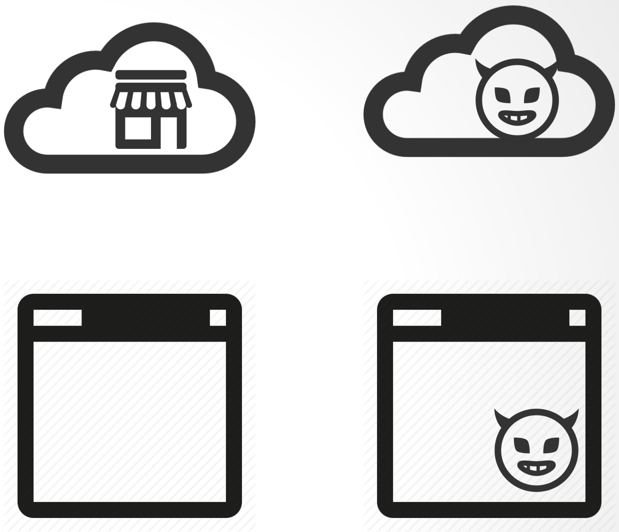
Running Example: Checking

CSRF:



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some (r.payload – r.cookies)
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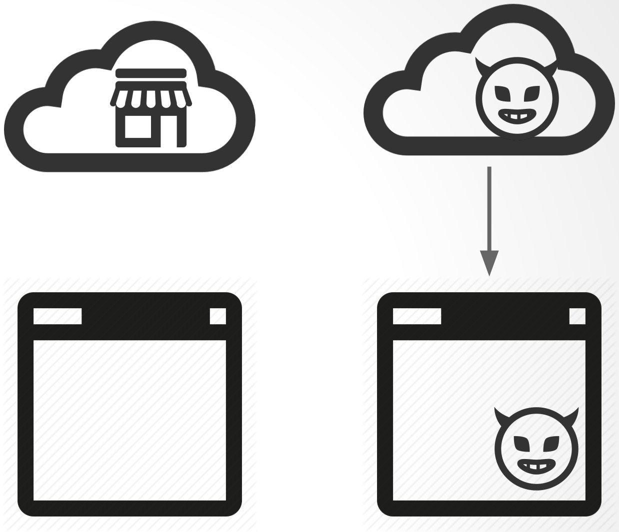
Running Example: Checking

CSRF:

1. Malicious server serves malicious web page to victim client



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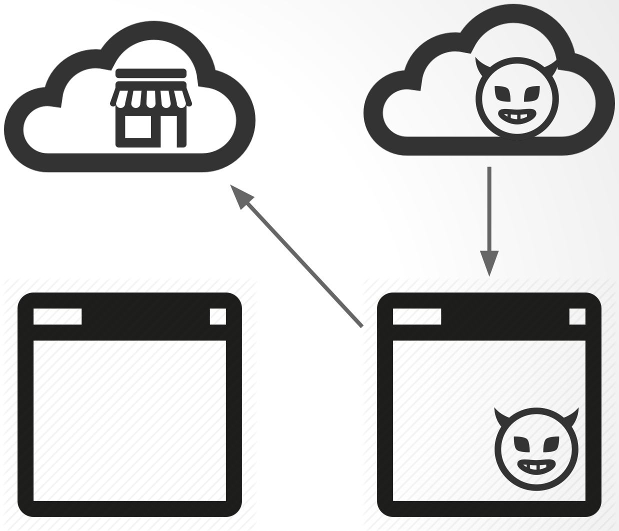
Running Example: Checking

CSRF:

1. Malicious server serves malicious web page to victim client
2. Malicious web page sends request to victim server
   - uses existing cookies
   - attacker controls the other parameters



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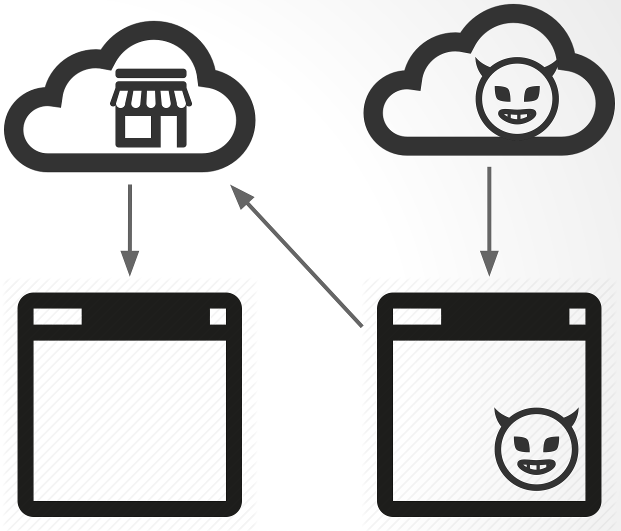
Running Example: Checking

CSRF:

1. Malicious server serves malicious web page to victim client
2. Malicious web page sends request to victim server
3. Victim server performs action and responds to victim client



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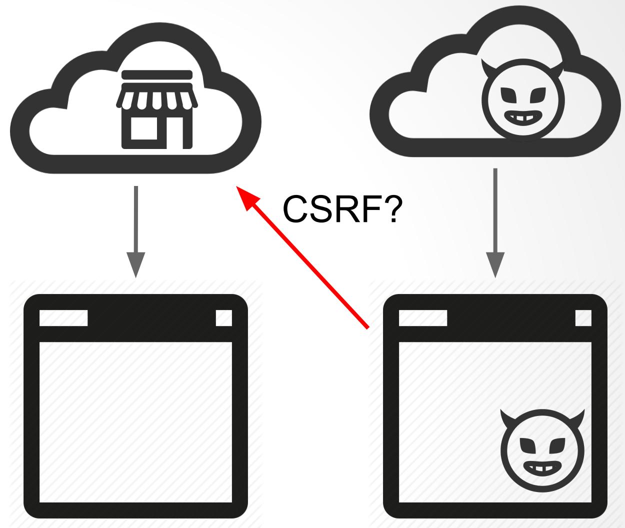

Rule encoding:

- Request caused by malicious page

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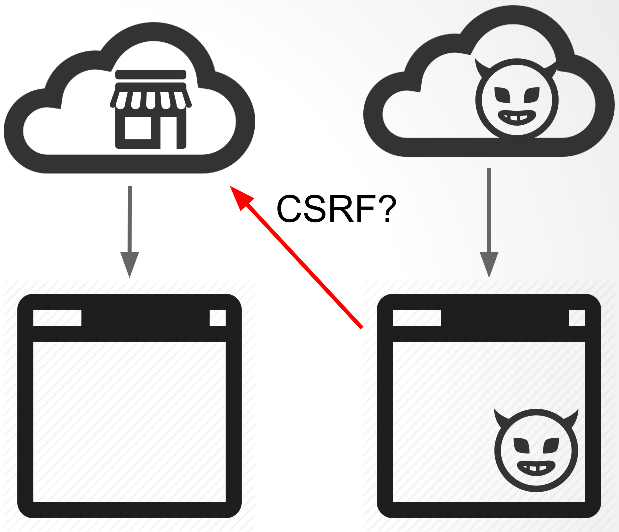

Rule encoding:

- Request caused by malicious page
- The victim client sent it to the victim server

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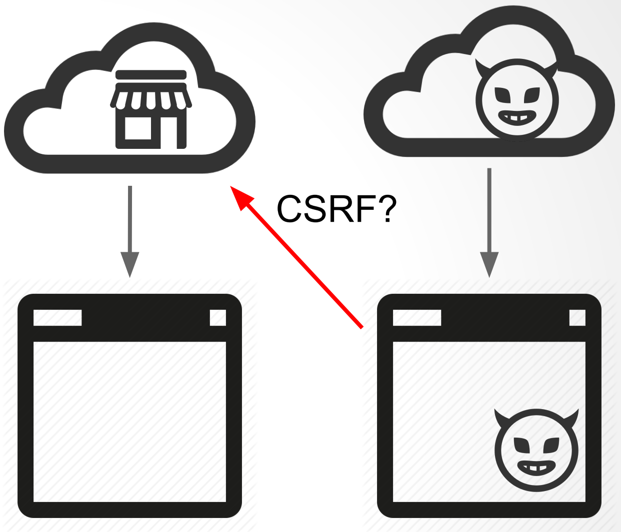

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Running Example: CSRF Token

UNSAT

```
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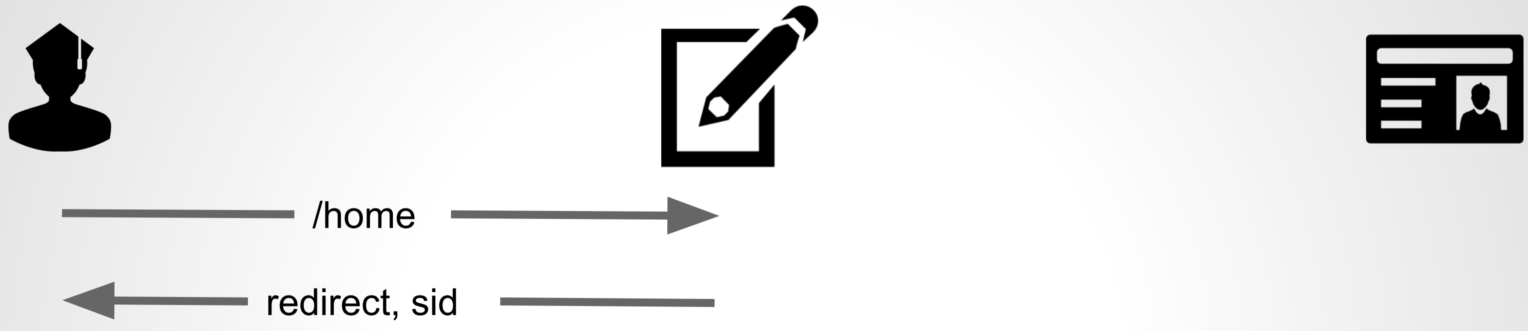
Case Study: the CAS Protocol

User

Services
(Relying party)

Identity
Provider

The Synthesized Model



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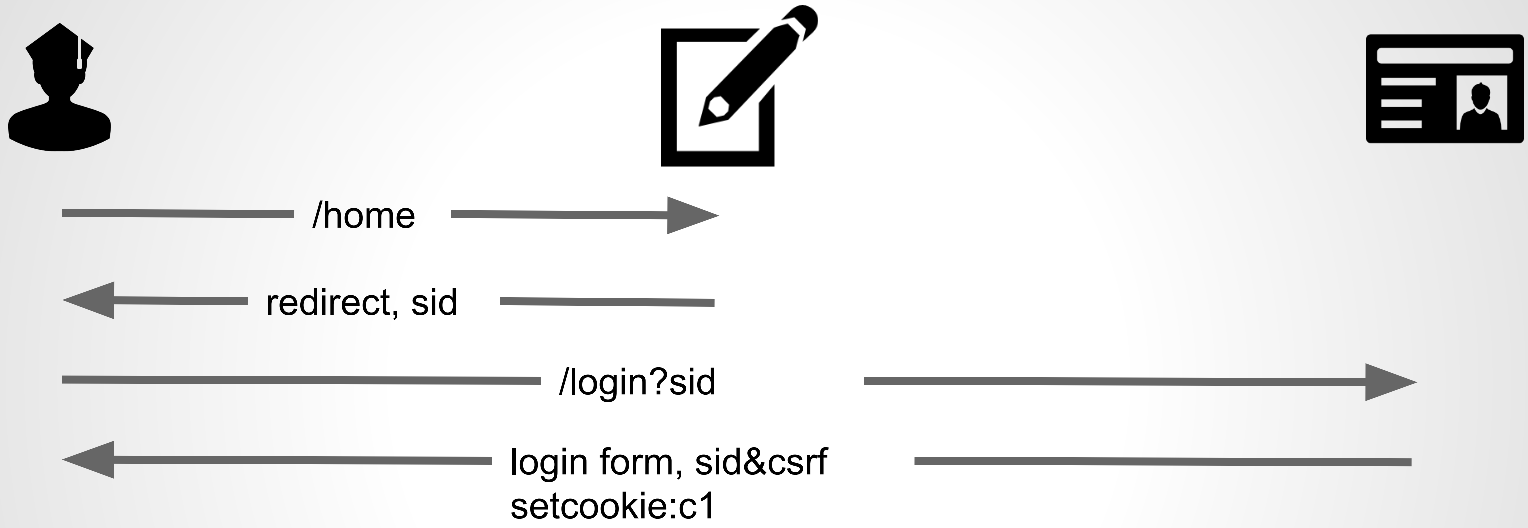

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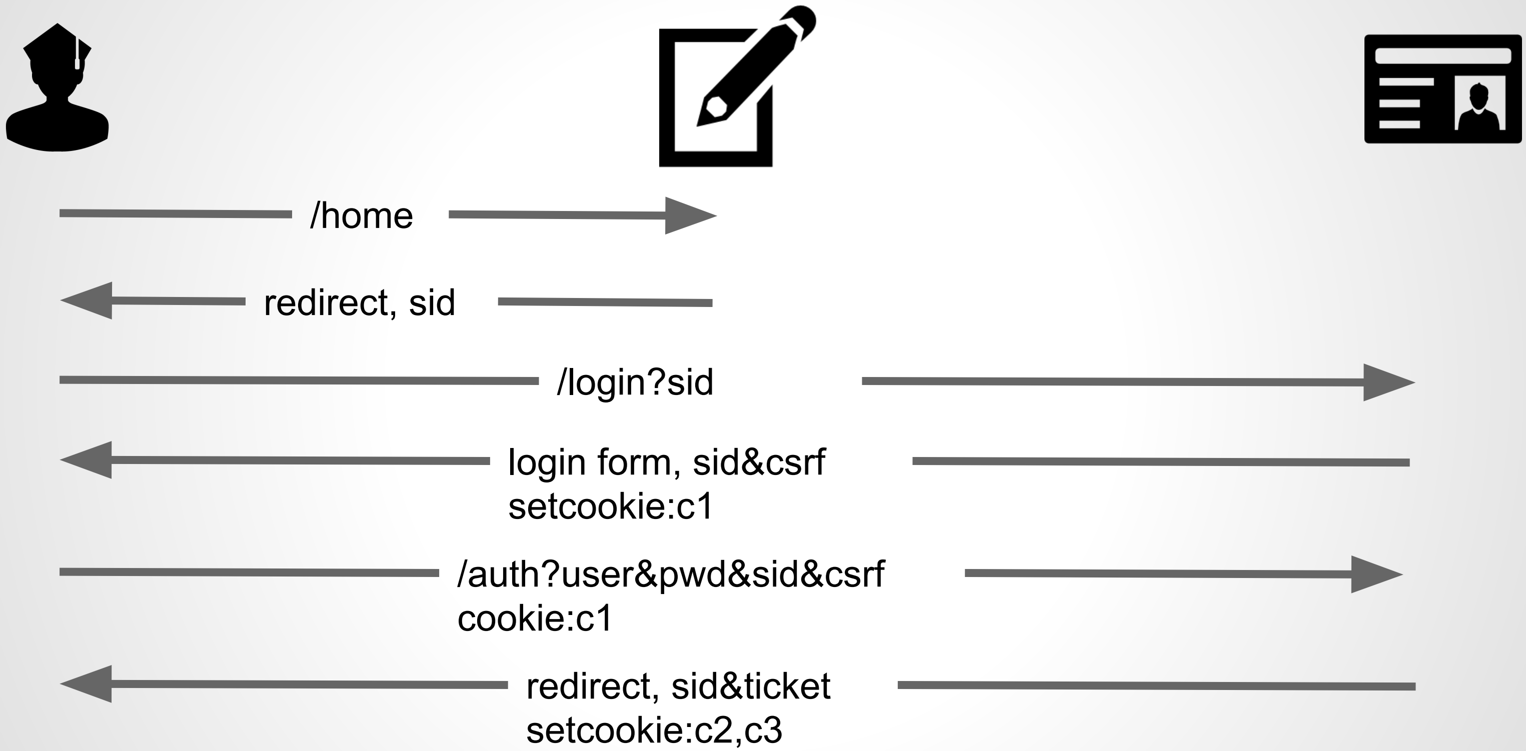

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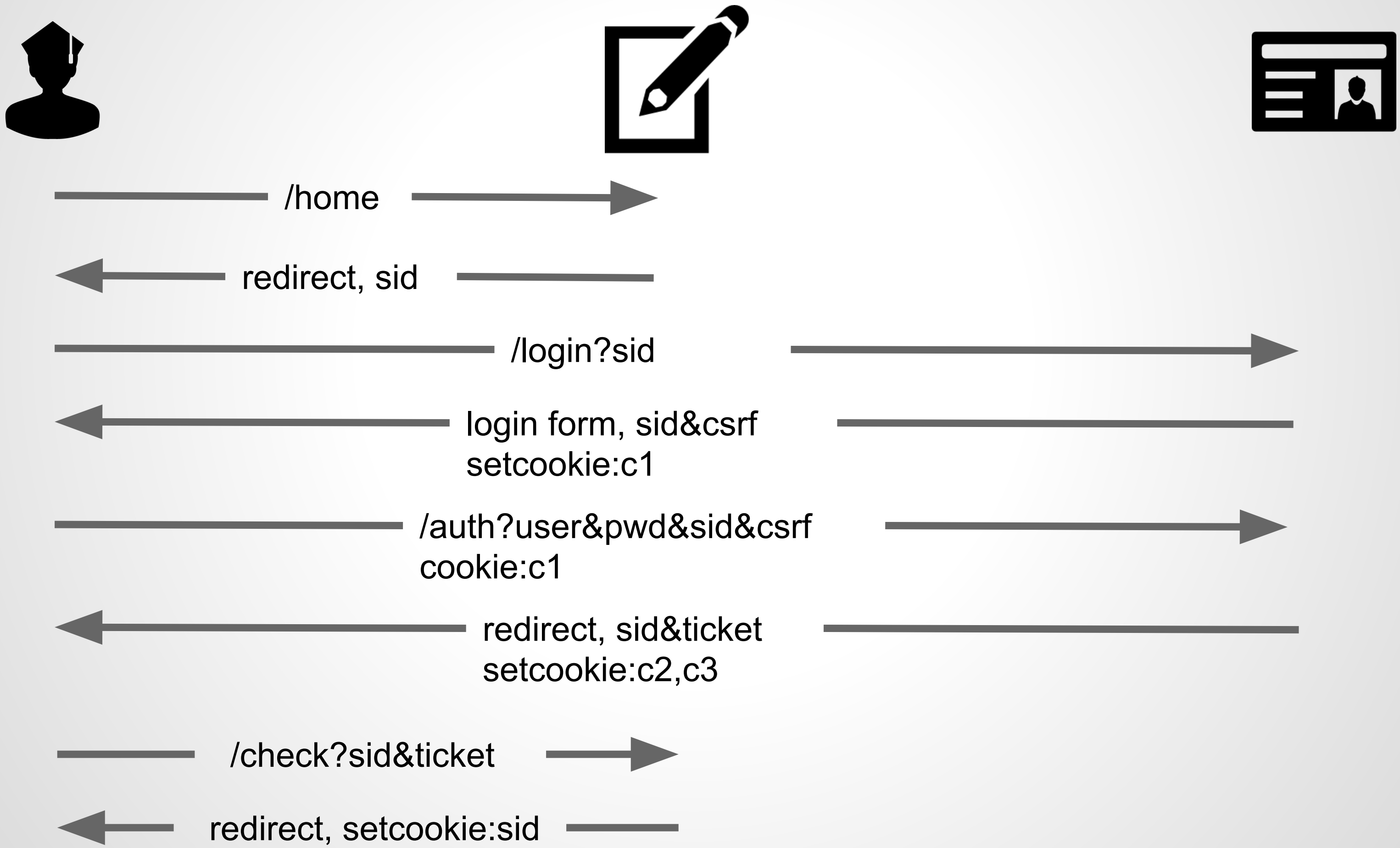
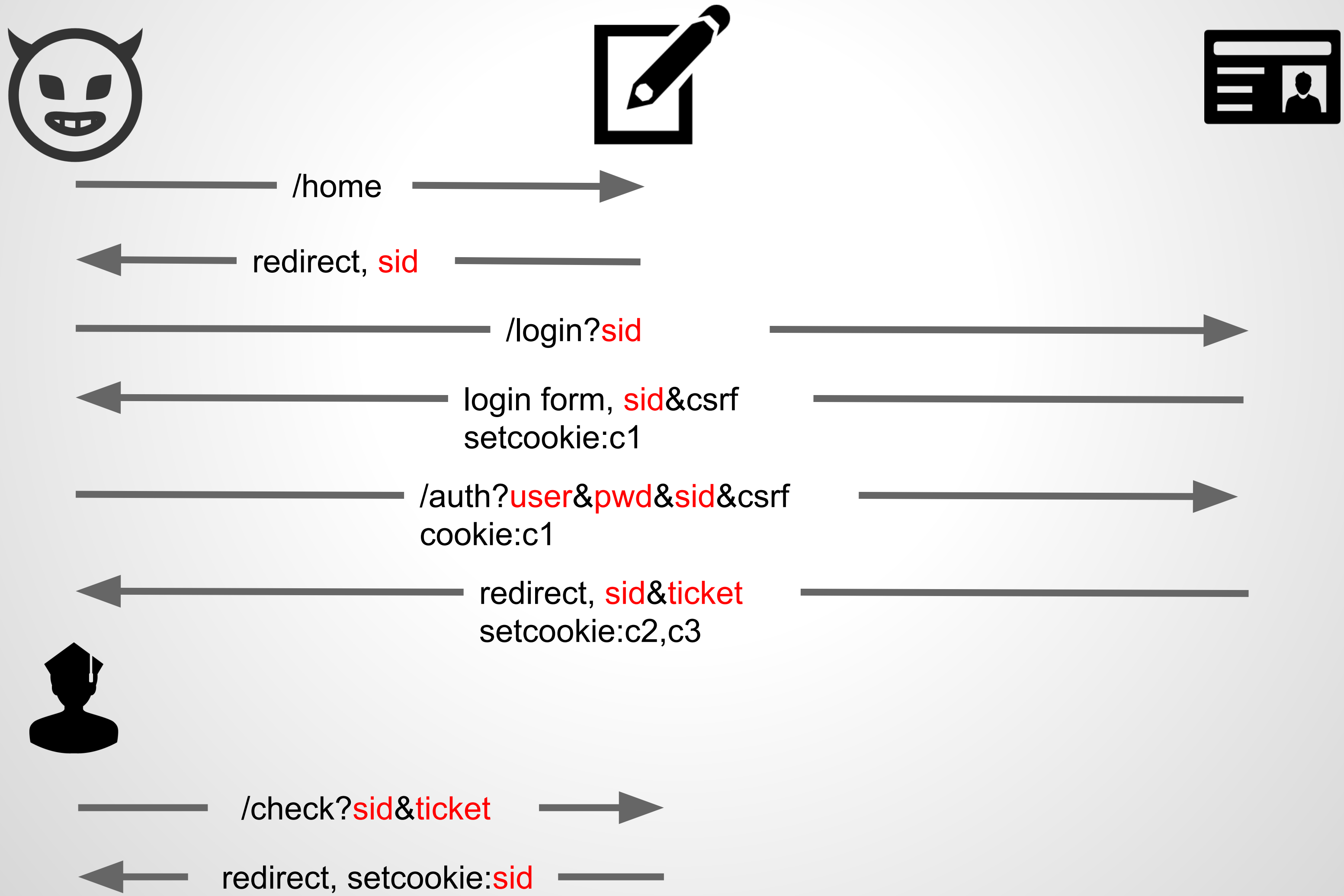


The Vulnerability



Preliminary Results

Name	#Servers	New Hints	#Msgs	Verif. Time (s)	Vuln.?
CAS	2	None Ignore msg. (-) None	12 12 12	7.17 41.71 >7200	Y (New) Y (Known) N
NeedMy Password.com	1	None Ignore msg. (-) Input value (+)	8 8 8	7.20 9.53 8.16	Y (New) N Y (Known)
Govtrak.us	2	None Ignore URLs (-) Ignore msg. (-)	48 24 24	>7200 699.91 2399.77	N Y (New) Y (New)

ASPIRE's Architecture

- Core: the encoding of the domain knowledge for a class of applications
- The analyst starts by using examples to demonstrate how the application works
- The synthesizer generates one or more candidate models that
  - conform to the DSL syntax
  - conform to the examples
- The specifications will be inspected and the results will feedback to the synthesizer

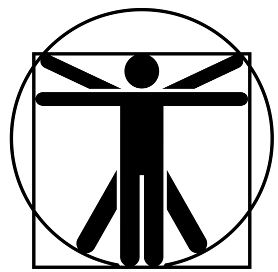
Conclusion

- Synthesize models of applications from high-level building blocks
  - Constructing the build blocks: manually from observation of common patterns
  - Constructing the model: automatically using synthesizers
- Key elements
  - The input: execution traces and feedback
  - The representation: domain specific languages
  - The algorithm: specification synthesis

End of presentation.
Backup slides and graphical resources follow.

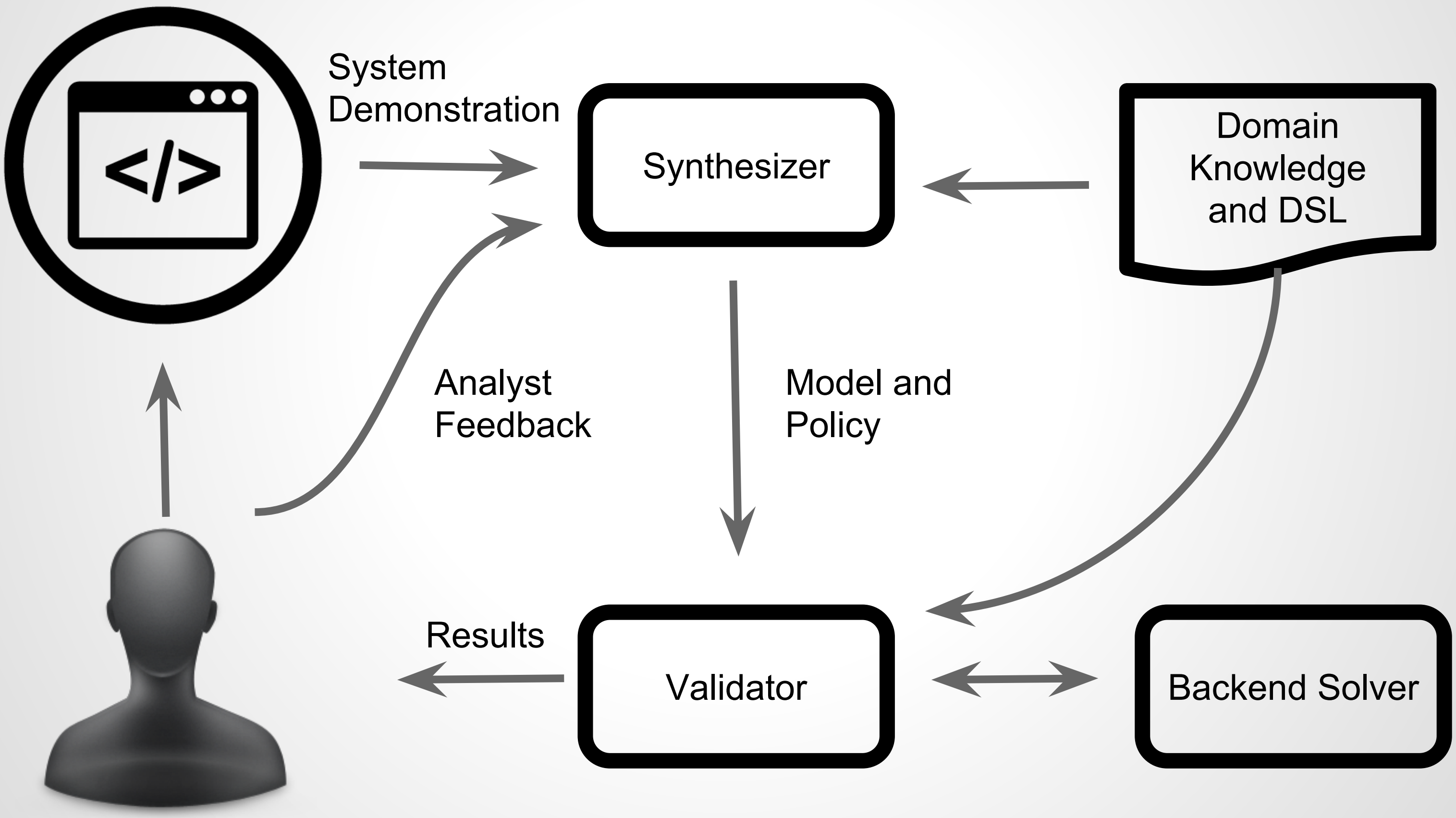
Security Policy + Model

∀😈,

security_policy( , 😈) = True

- Session integrity
- Information secrecy

ASPIRE Workflow



Use cases for the generated spec

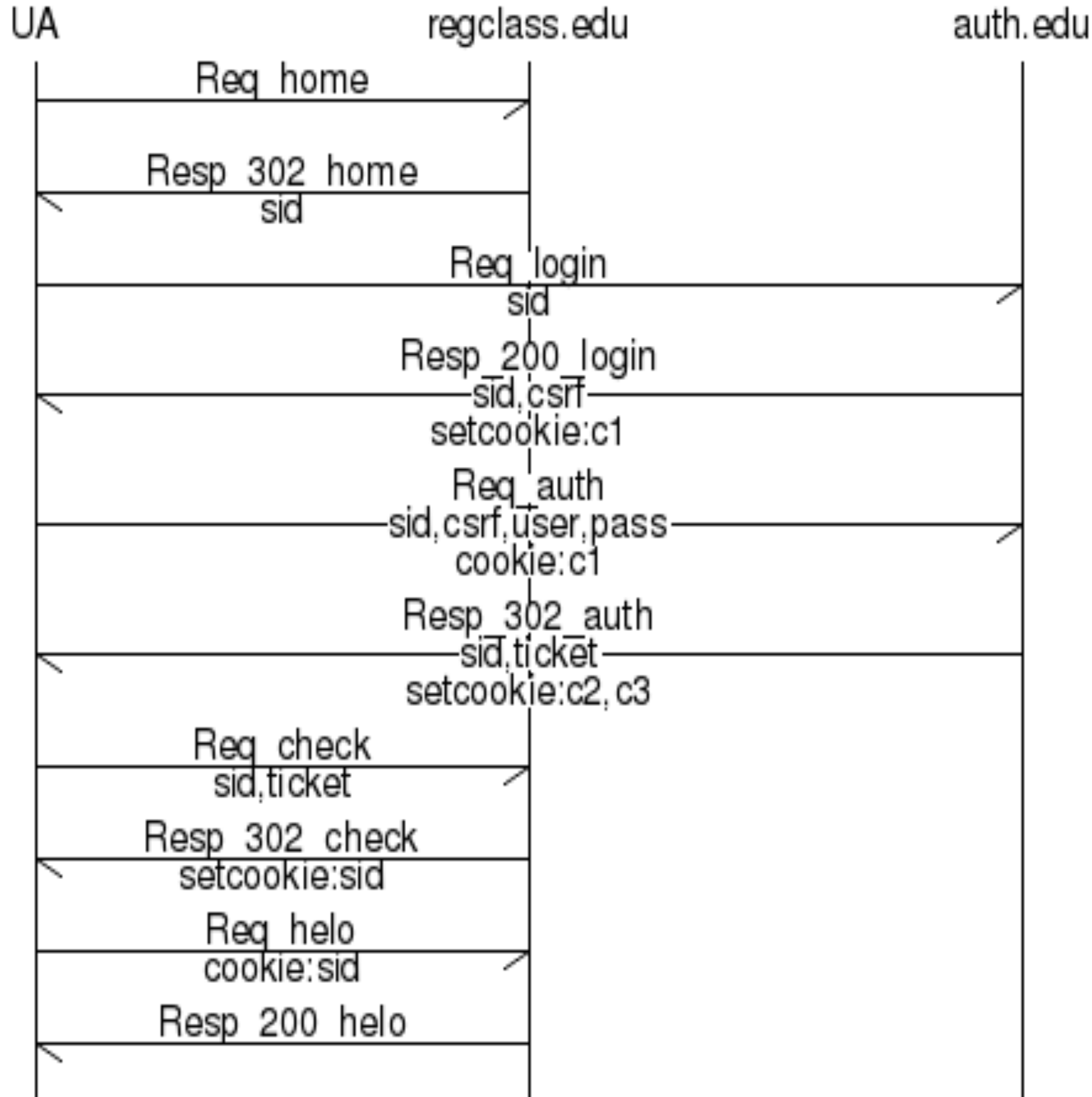
- Run classic analysis and verification tools
- Translate spec to implementation
- Help better understand the existing systems

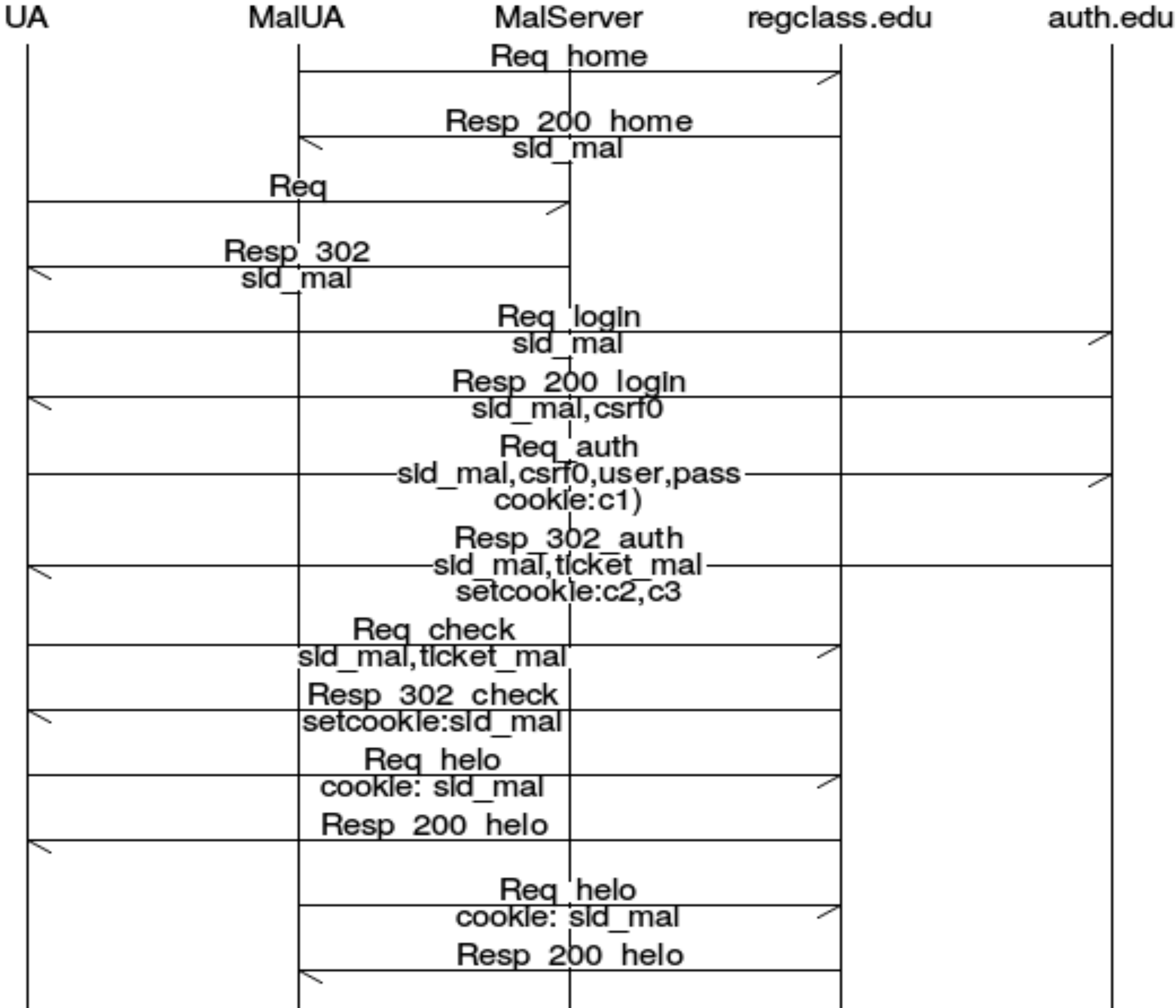
ASPIRE for the Web

- Given a multiparty web application and its execution traces
- Generate the specification of the web protocol used by the servers and the client
- Check for session integrity (CSRF) vulnerabilities on the specification
- Return attack traces or refine the specification to reduce false positives and false negatives

Components

- The DSL
- The synthesizer
- The validator


UA
regclass.edu
auth.edu
Req_home
Resp_302_home
sid
Req_login
sid
Resp_200_login
sid,csrf
setcookie:c1
Req_auth
sid,csrf,user,pass
cookie:c1
Resp_302_auth
sid,ticket
setcookie:c2,c3
Req_check
sid,ticket
Resp_302_check
setcookie:sid
Req_helo
cookie:sid
Resp_200_helo


UA
MalUA
MalServer
regclass.edu
auth.edu
Req_home
Resp_200_home
sid_mal
Req
Resp_302
sid_mal
Req_login
sid_mal
Resp_200_login
sid_mal,csrf0
Req_auth
sid_mal,csrf0,user,pass
cookie:c1)
Resp_302_auth
sid_mal,ticket_mal
setcookie:c2,c3
Req_check
sid_mal,ticket_mal
Resp_302_check
setcookie:sid_mal
Req_helo
cookie: sid_mal
Resp_200_helo
Req_helo
cookie: sid_mal
Resp_200_helo