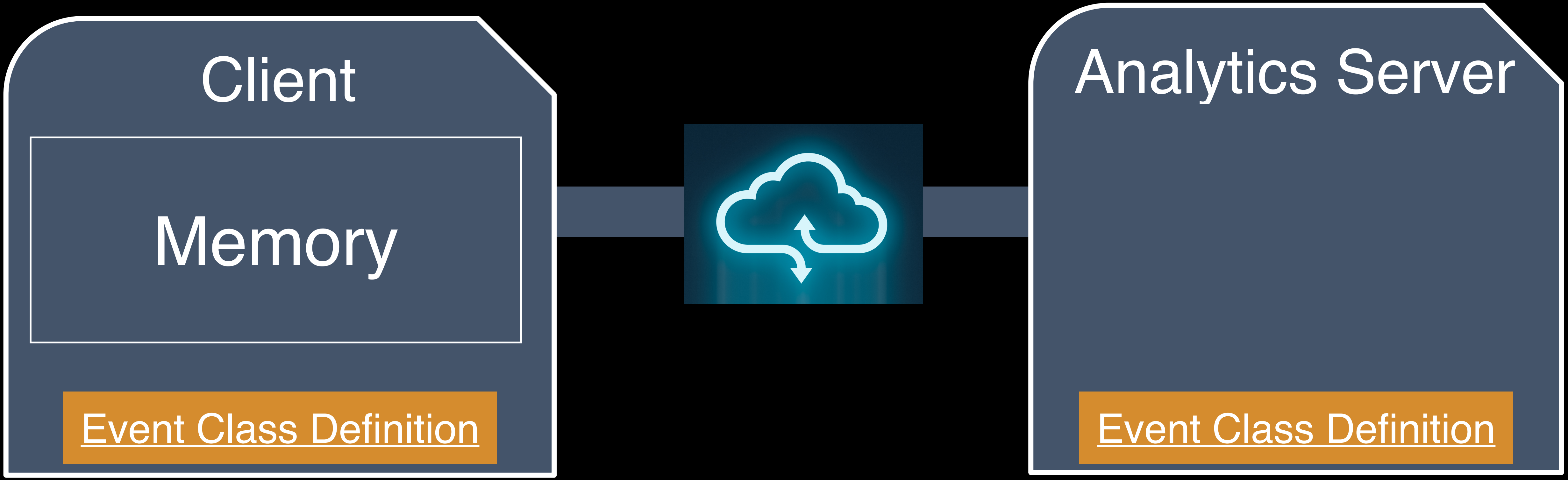
QUACK: Hindering Deserialization Attacks via Static Duck Typing

Yaniv David[1], Neophytos Christou[2], Andreas D. Kellas[1], Vasileios P. Kemerlis[2], Junfeng Yang[1]

[1]Columbia University [2]Brown University

Background: What’s the Deal With Serialization?



Client

Memory

Event Class Definition

Analytics Server

Event Class Definition

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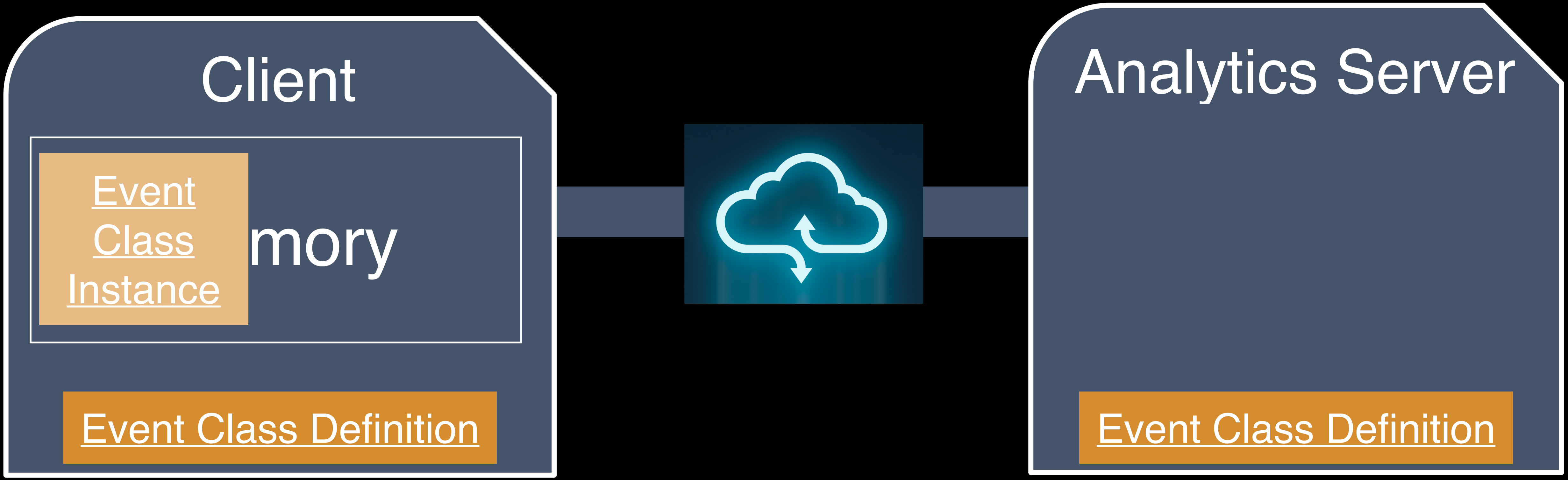

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Event Class Instance

mory

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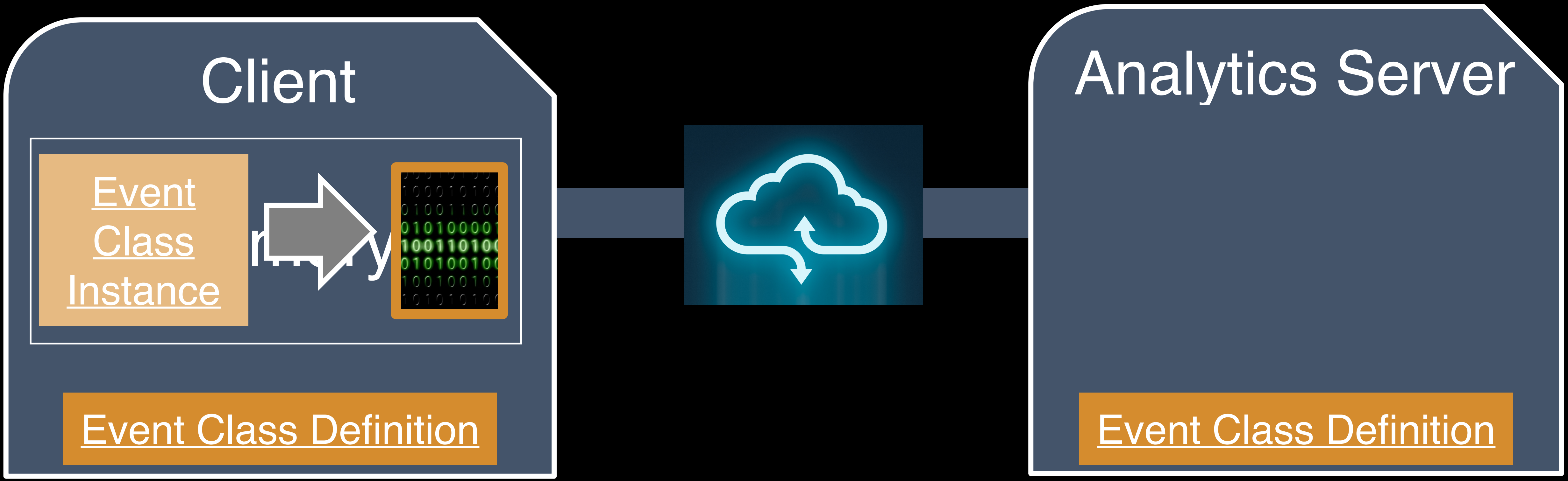

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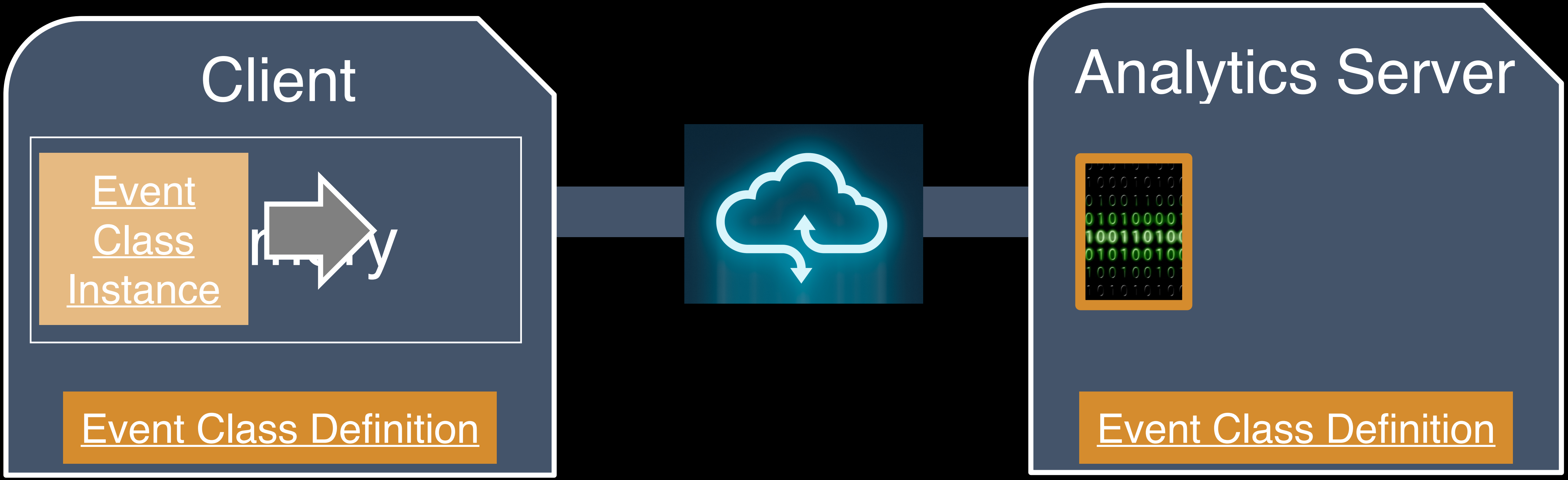

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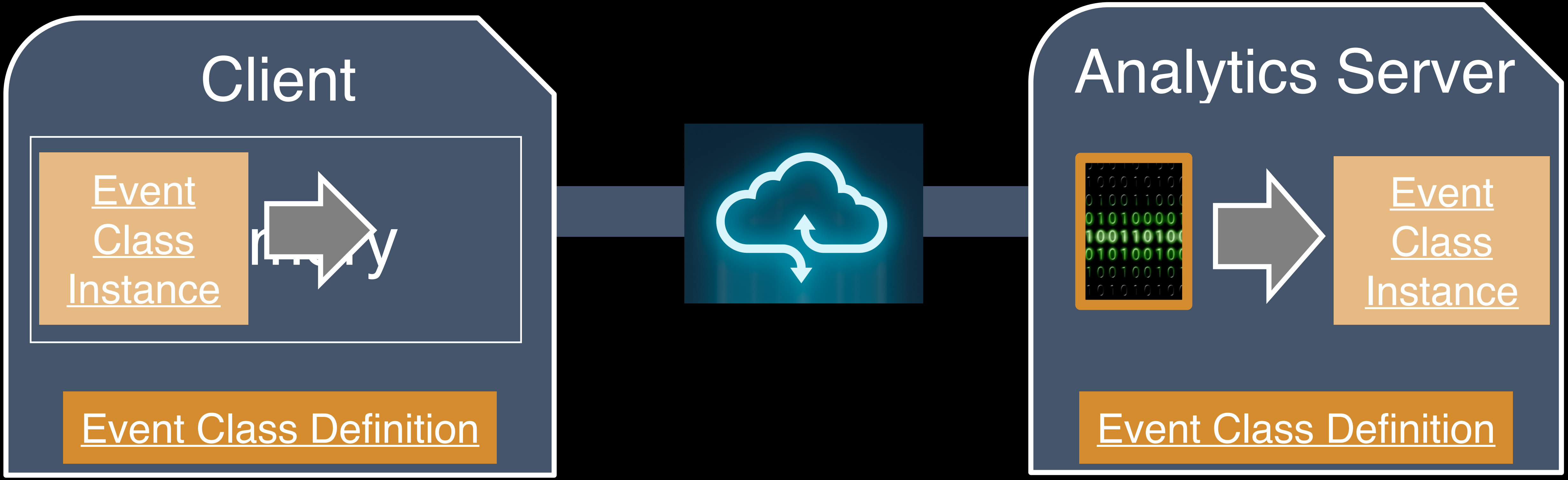

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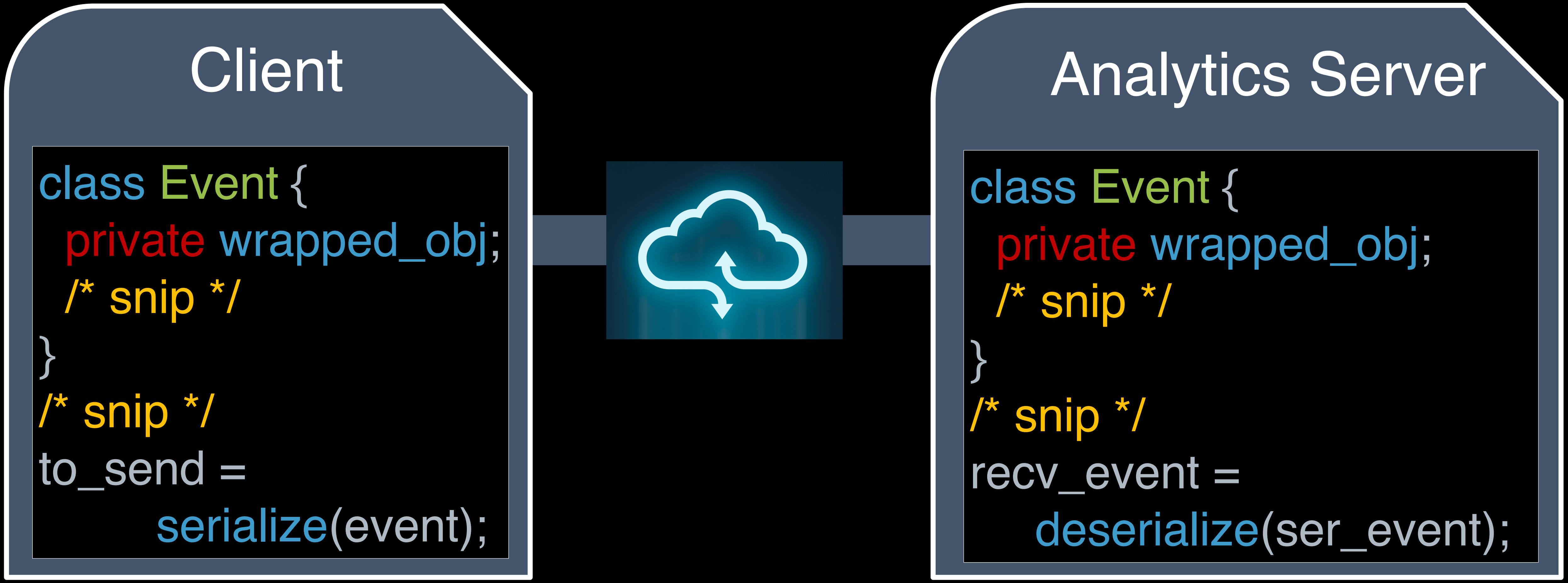
Ease-Of-Use Trumps Safety



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Analytics Server

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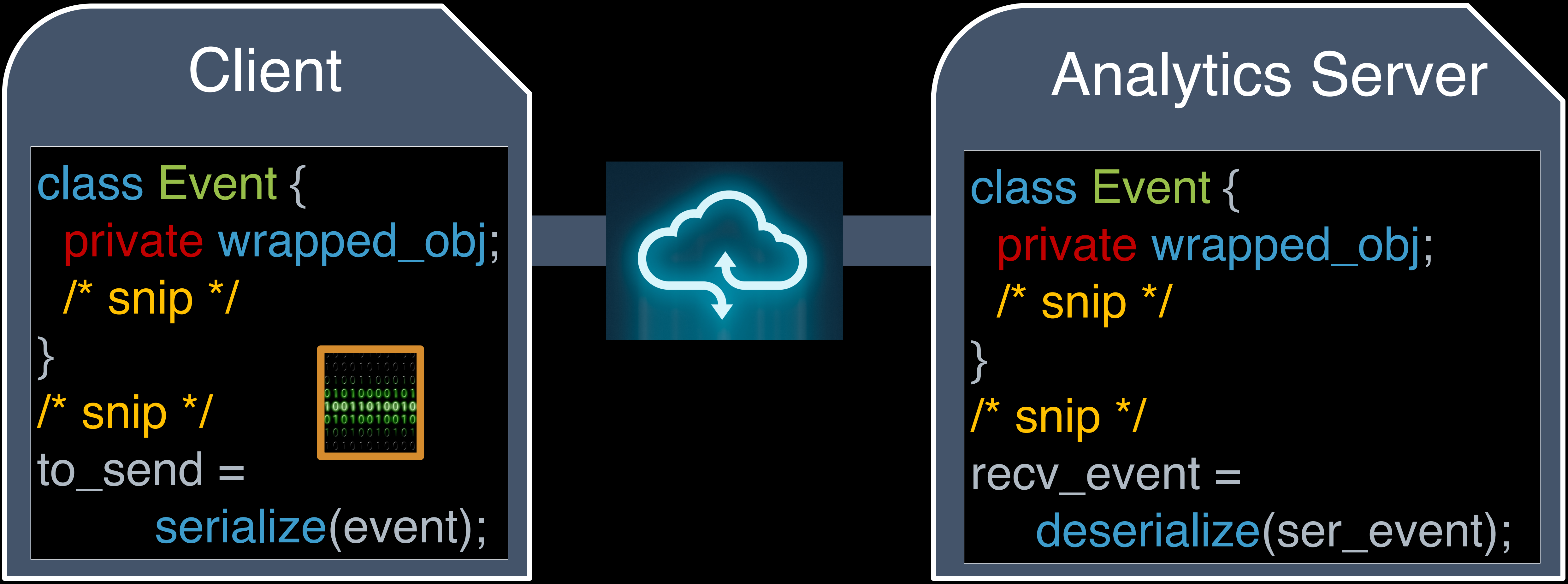

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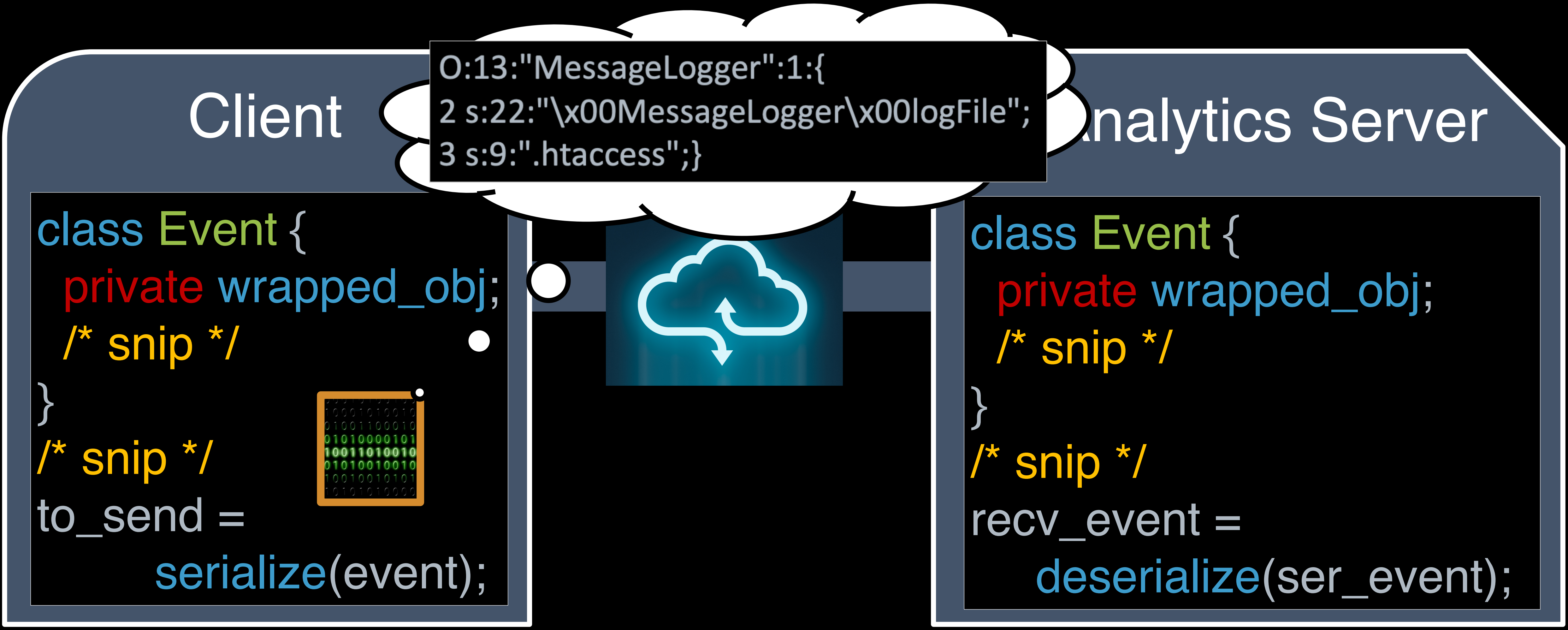

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```
O:13:"MessageLogger":1:{
s:22:"\x00MessageLogger\x00logFile";
s:9:".htaccess";}
```

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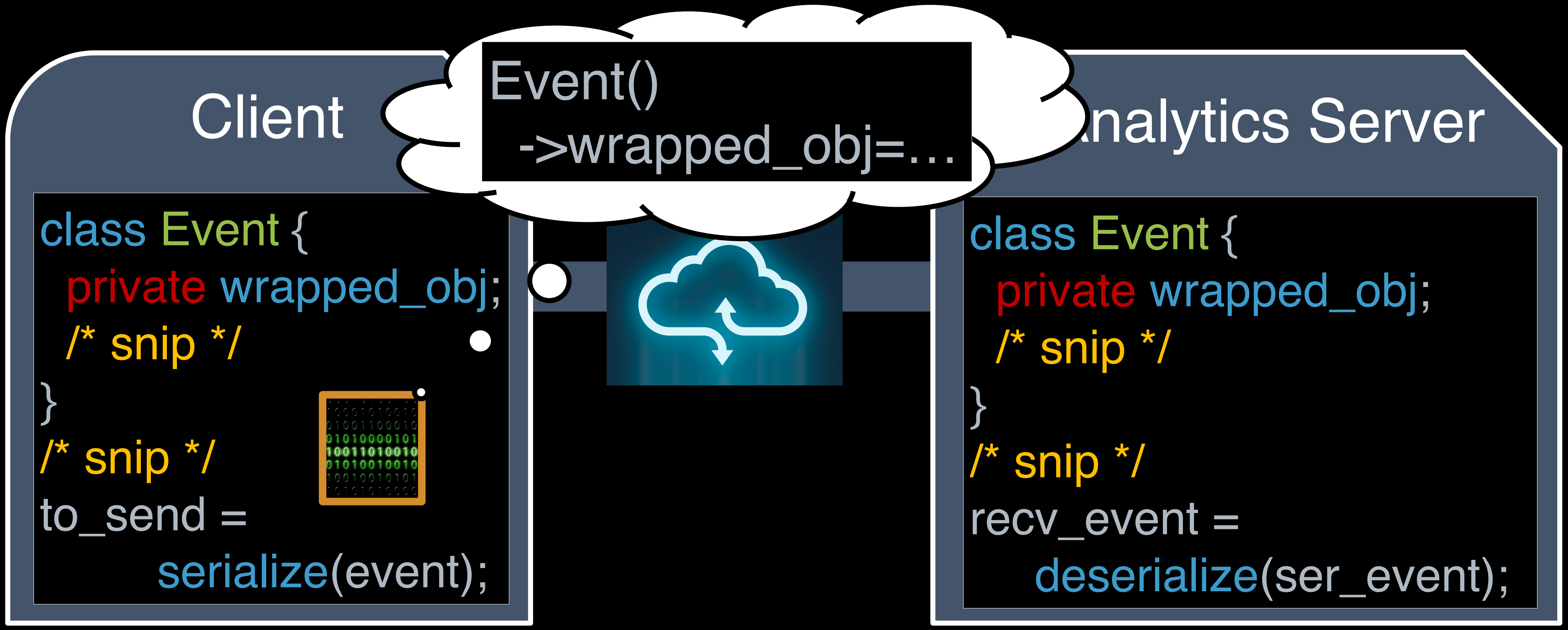

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```
Event()
  ->wrapped_obj=…
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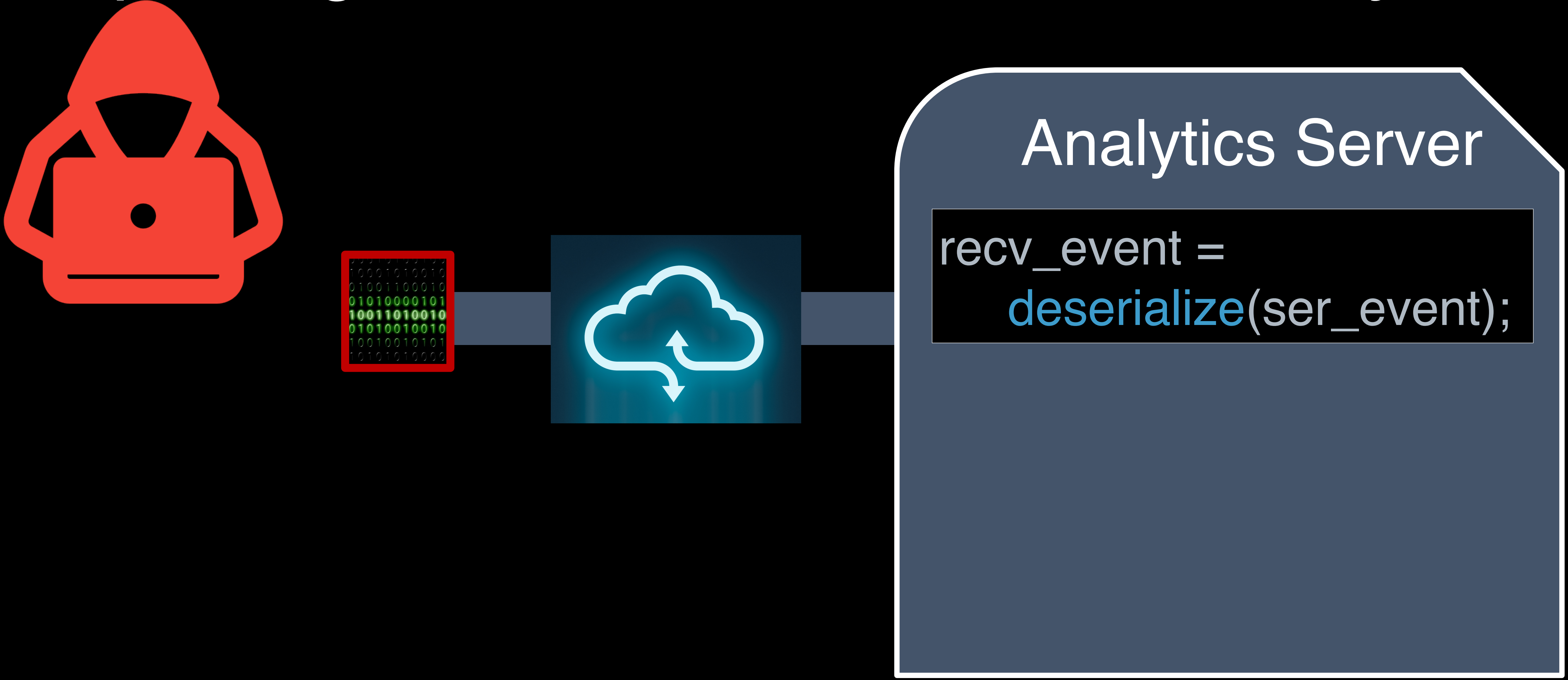
Exploiting A Deserialization Vulnerability



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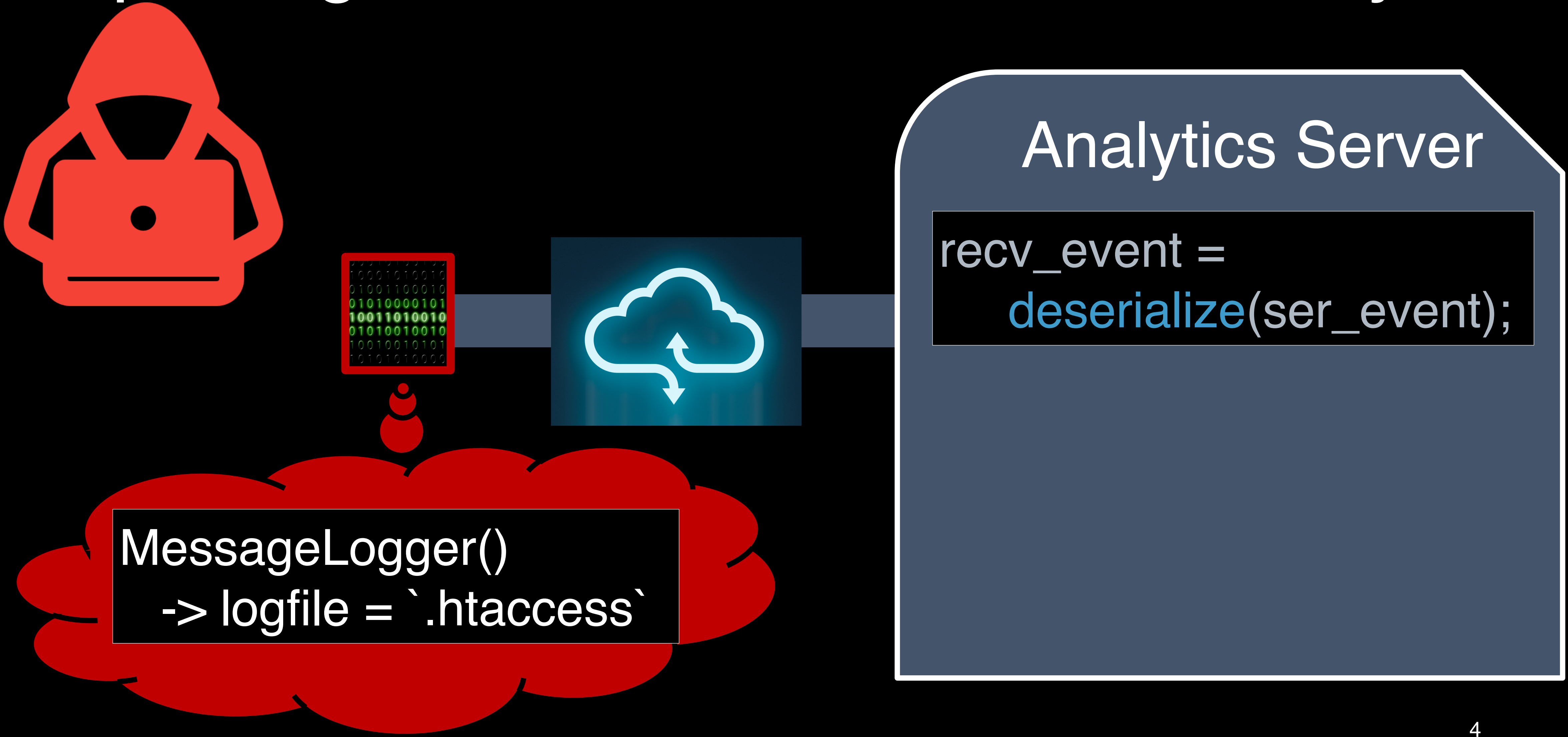

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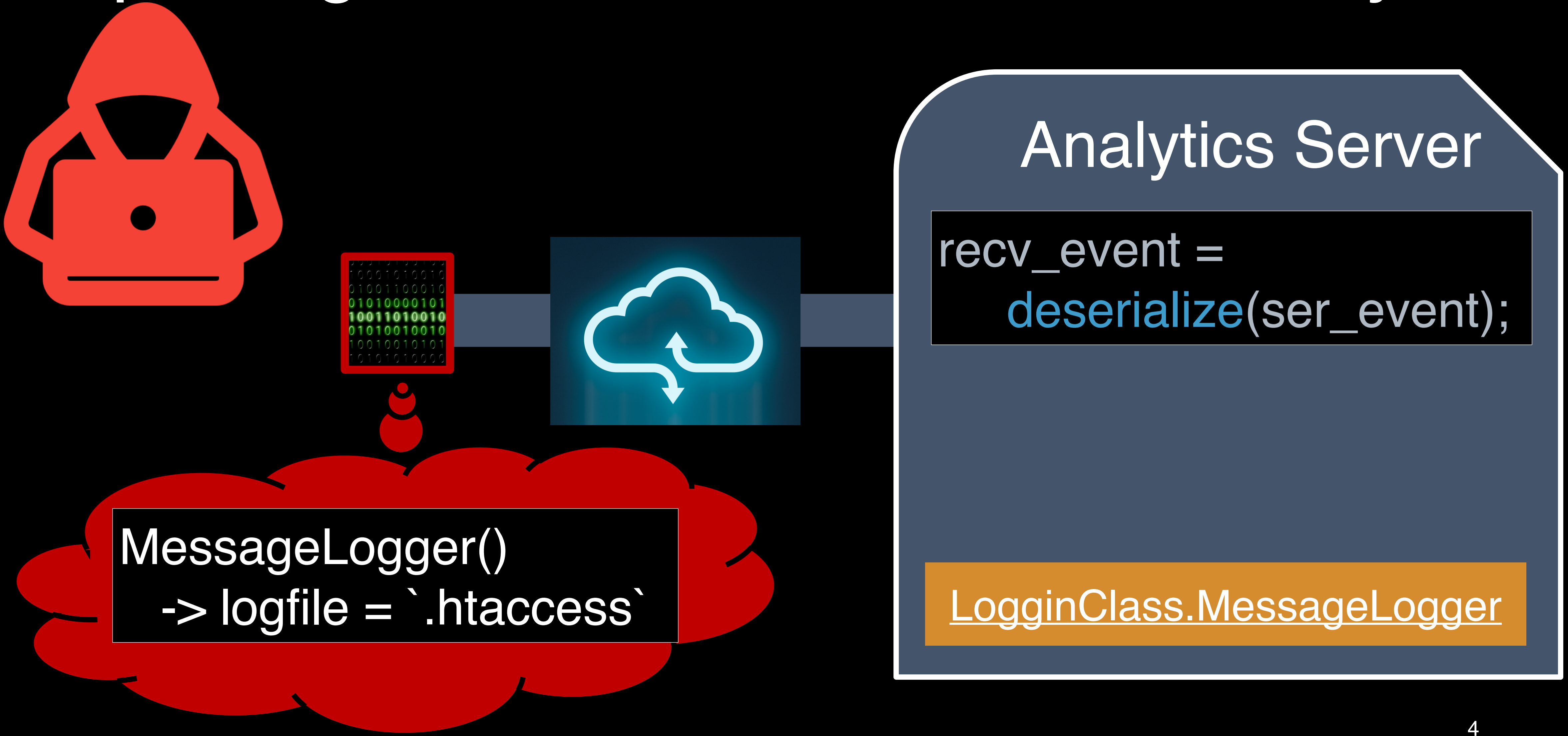

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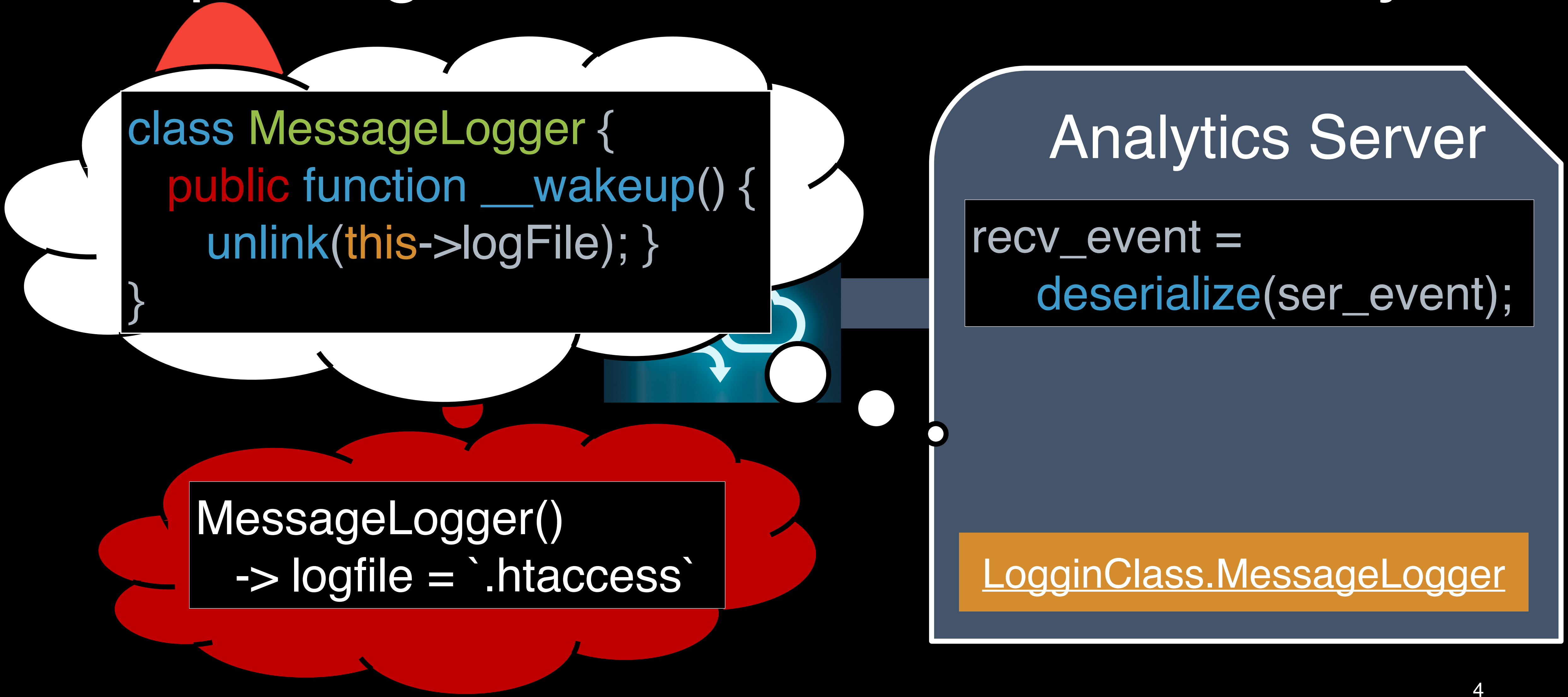

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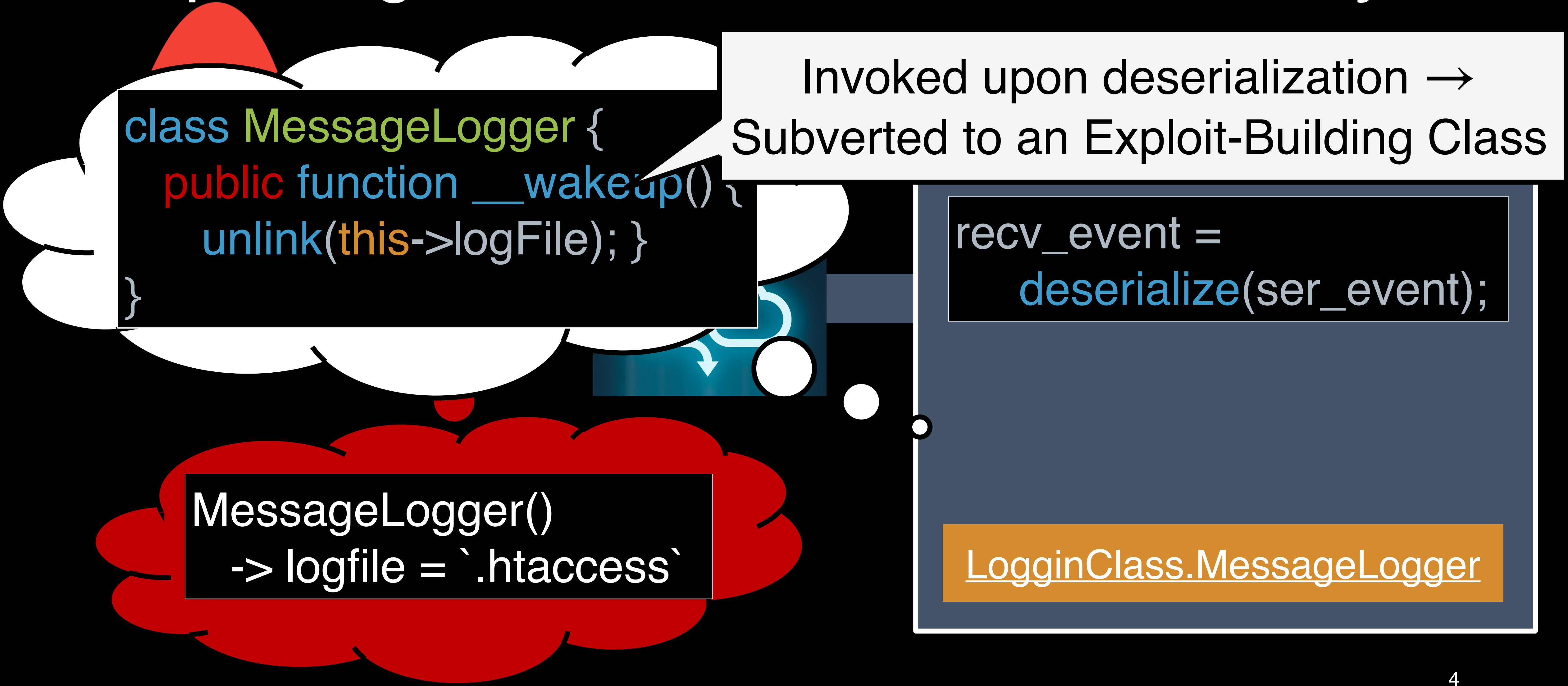

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Invoked upon deserialization →
Subverted to an Exploit-Building Class

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Deserialization Attacks Affect Real-World Applications

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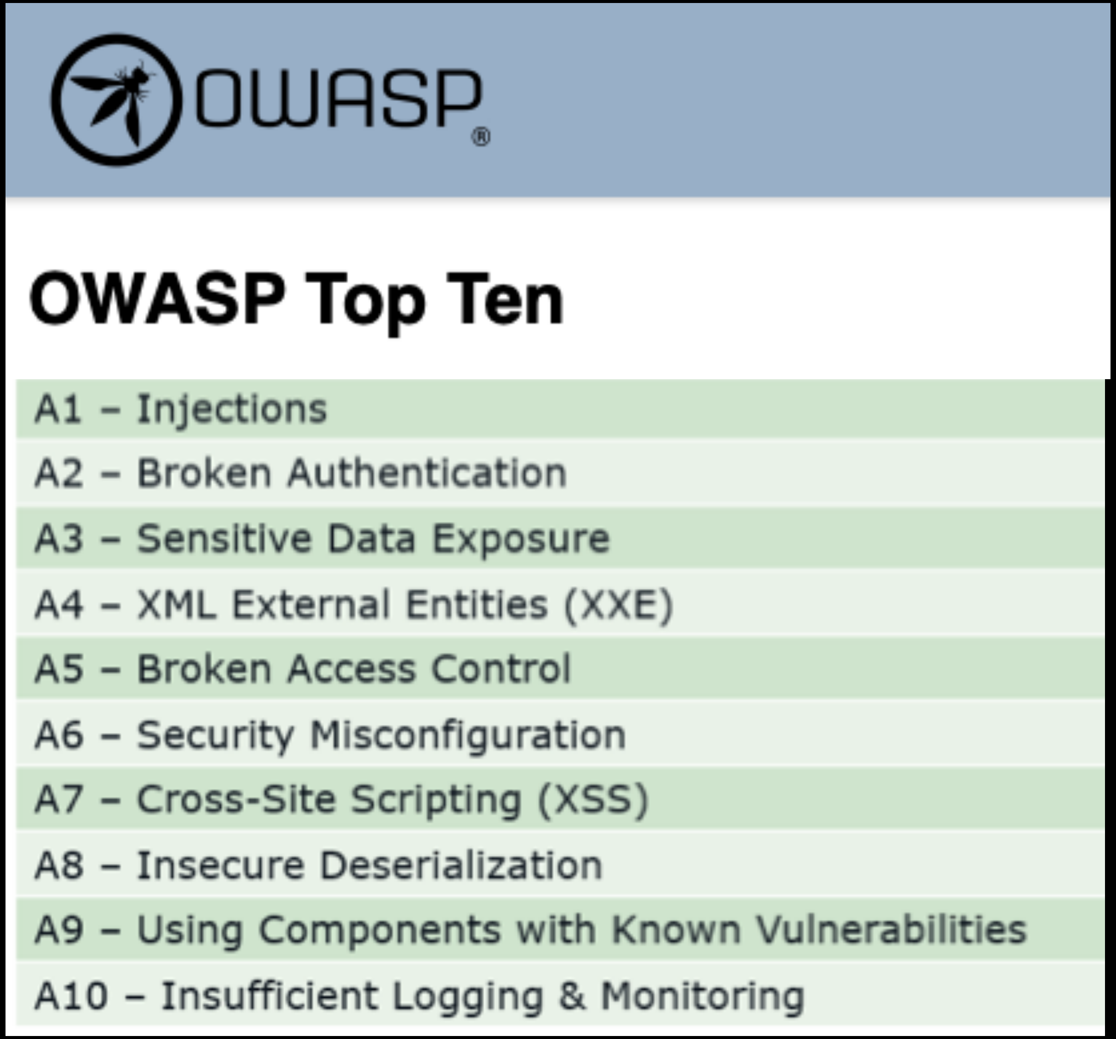

OWASP Top Ten

- A1 – Injections
- A2 – Broken Authentication
- A3 – Sensitive Data Exposure
- A4 – XML External Entities (XXE)
- A5 – Broken Access Control
- A6 – Security Misconfiguration
- A7 – Cross-Site Scripting (XSS)
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- A9 – Using Components with Known Vulnerabilities
- A10 – Insufficient Logging & Monitoring

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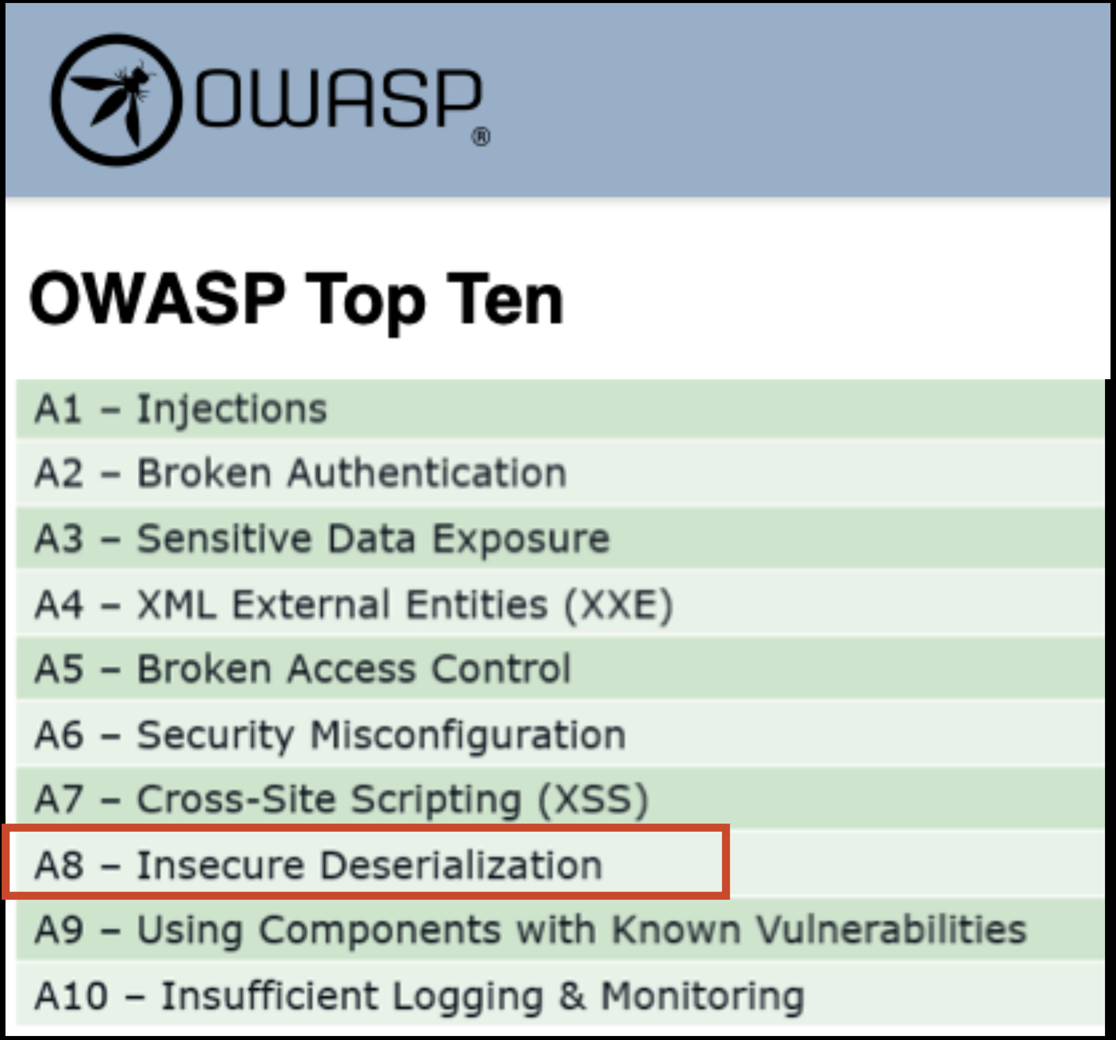

OWASP®

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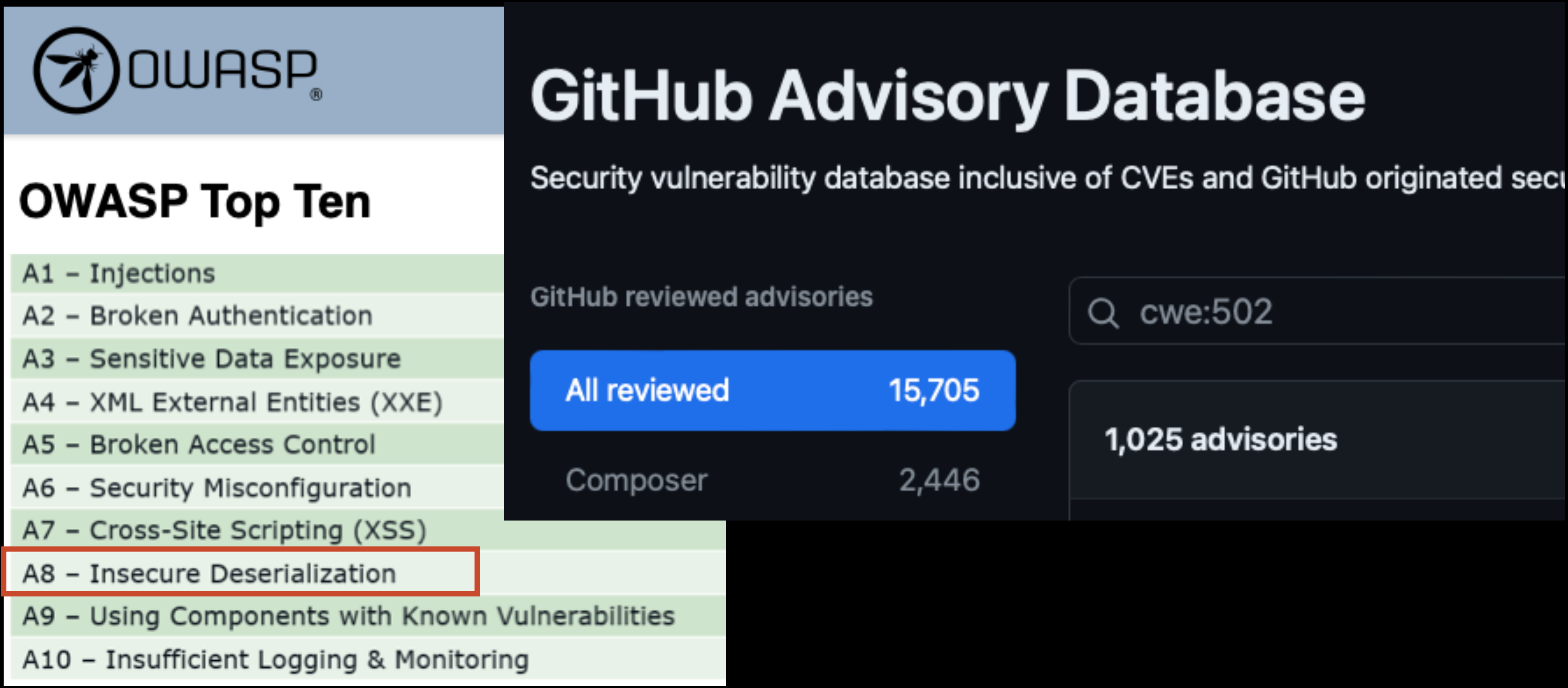

OWASP®

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GitHub Advisory Database

Security vulnerability database inclusive of CVEs and GitHub originated secu

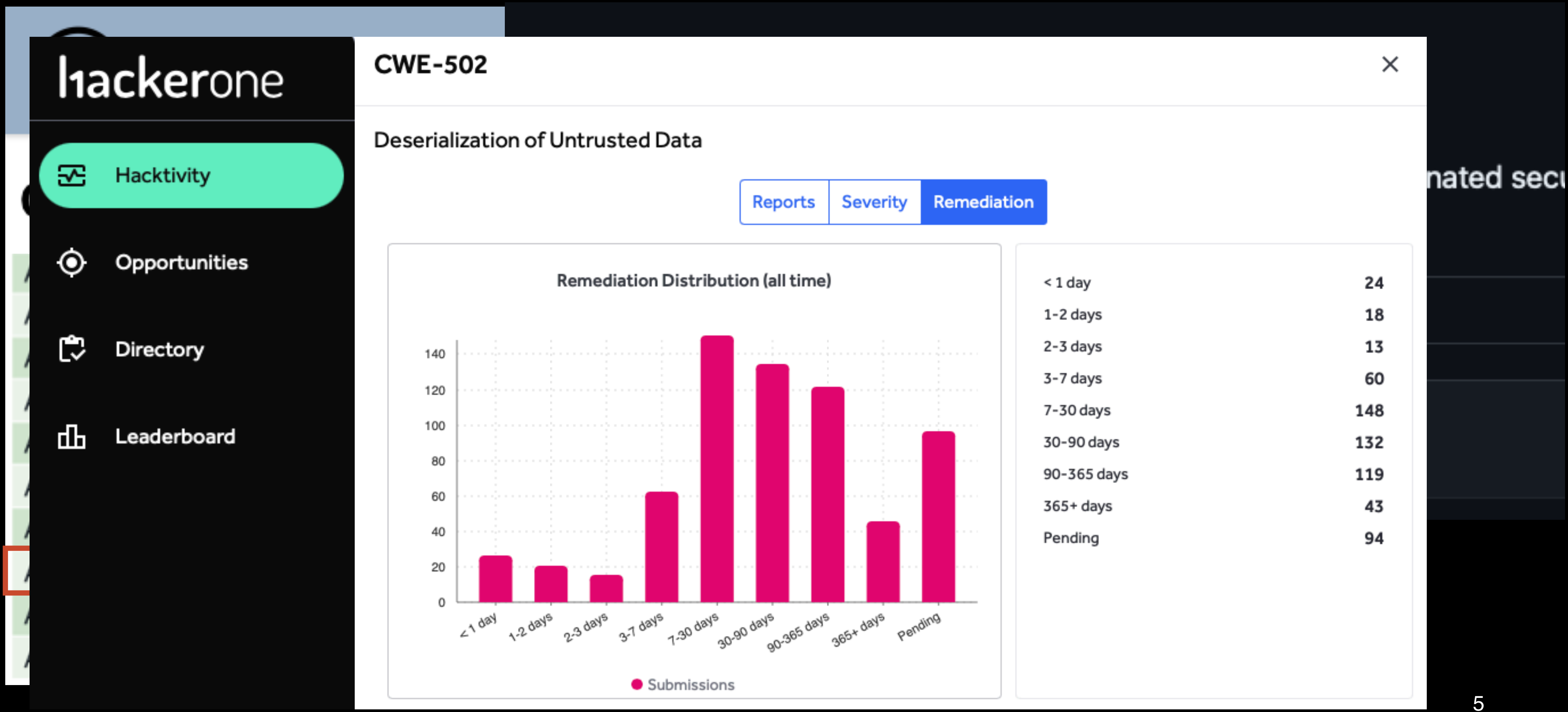
GitHub reviewed advisories

All reviewed	15,705
Composer	2,446

cwe:502

1,025 advisories

Deserialization Attacks Affect Real-World Applications



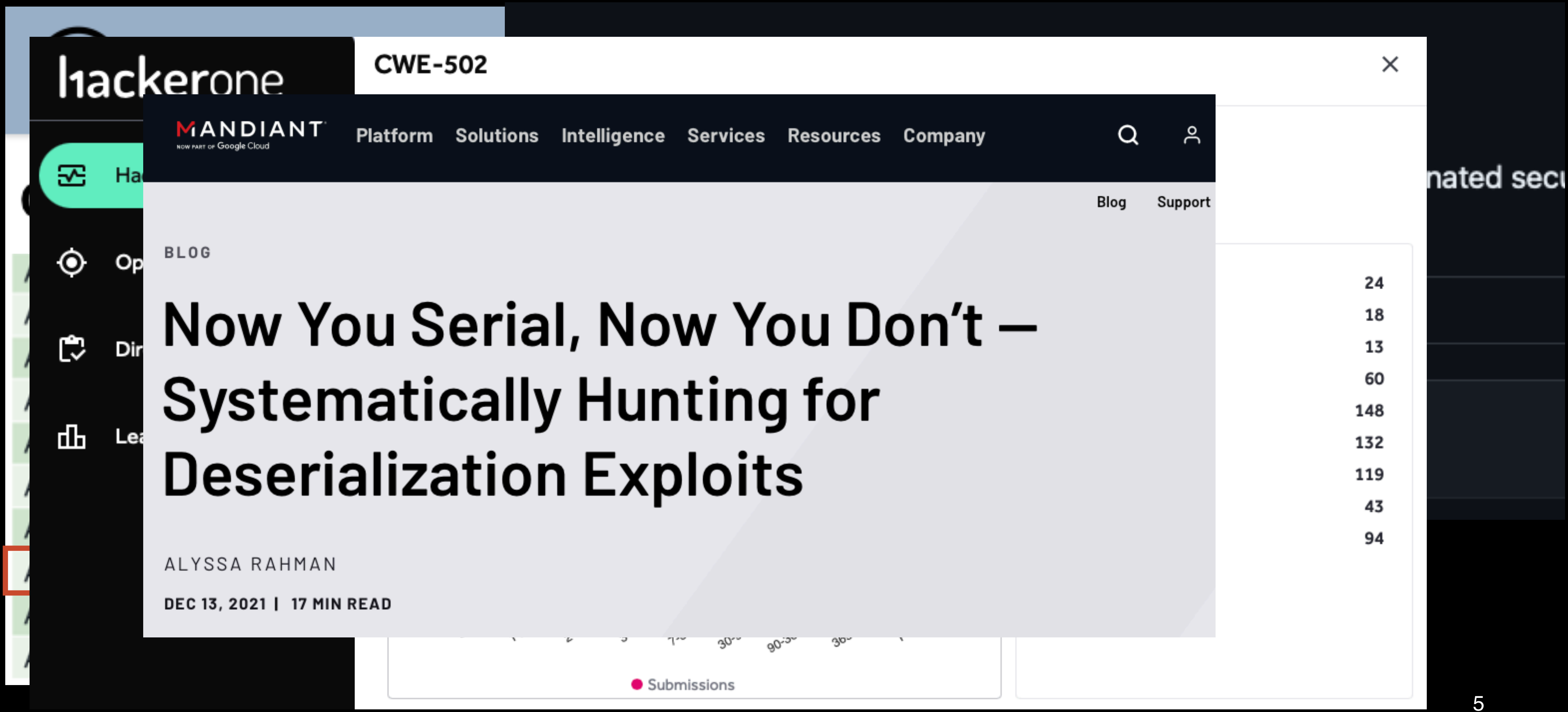
CWE-502

Deserialization of Untrusted Data

Remediation Distribution (all time)

< 1 day	24
1-2 days	18
2-3 days	13
3-7 days	60
7-30 days	148
30-90 days	132
90-365 days	119
365+ days	43
Pending	94

Deserialization Attacks Affect Real-World Applications



BLOG

Now You Serial, Now You Don’t — Systematically Hunting for Deserialization Exploits

ALYSSA RAHMAN

DEC 13, 2021 | 17 MIN READ

Exploit Generation Techniques Are Improving

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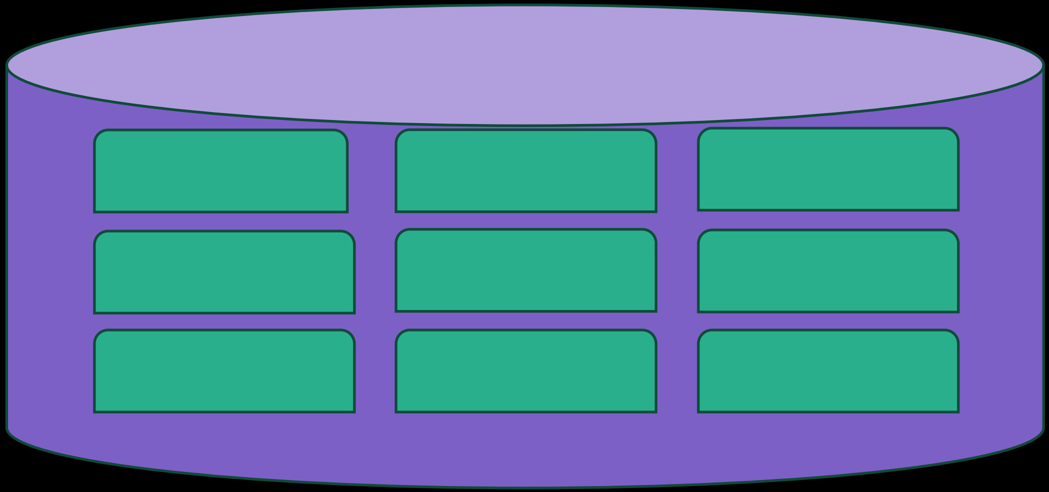

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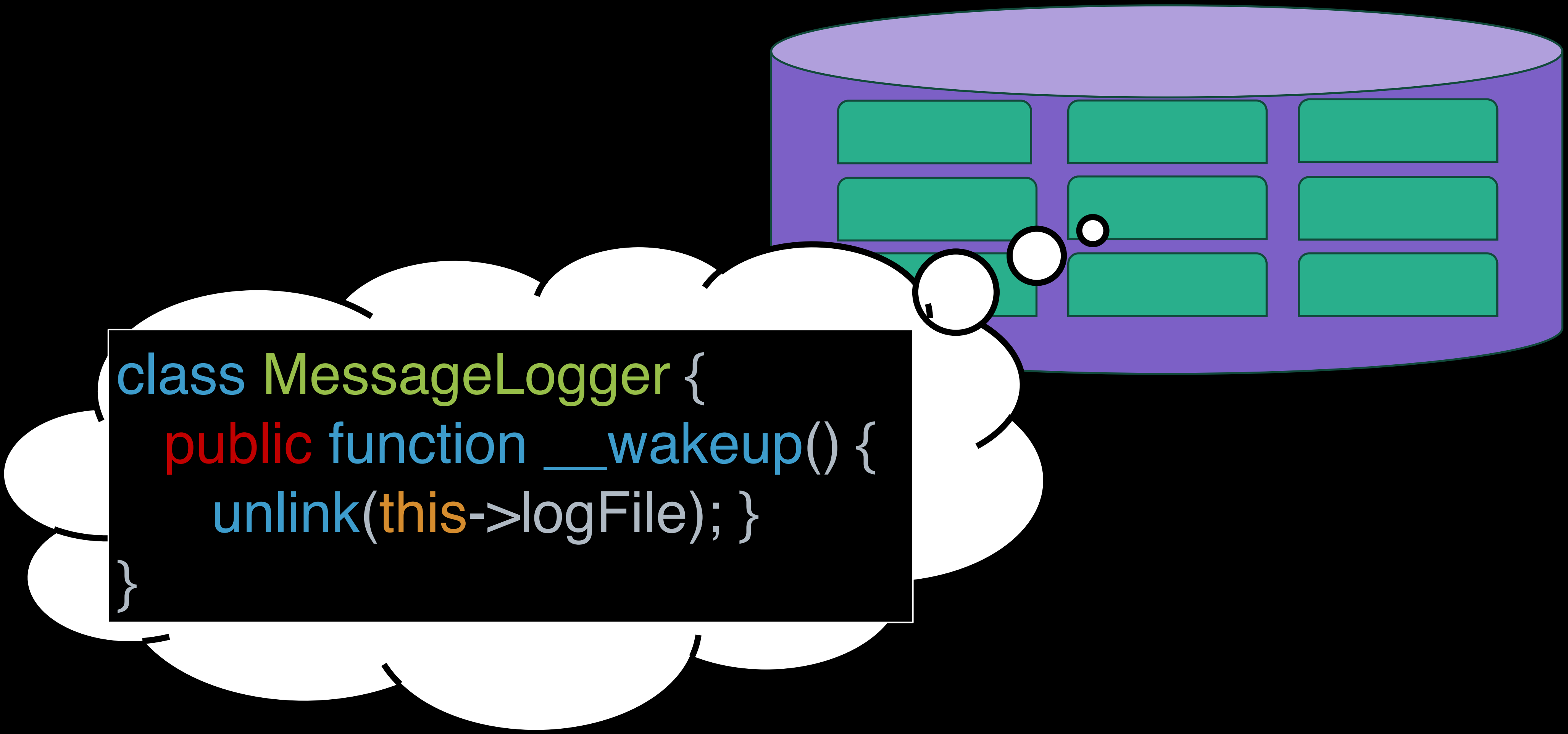

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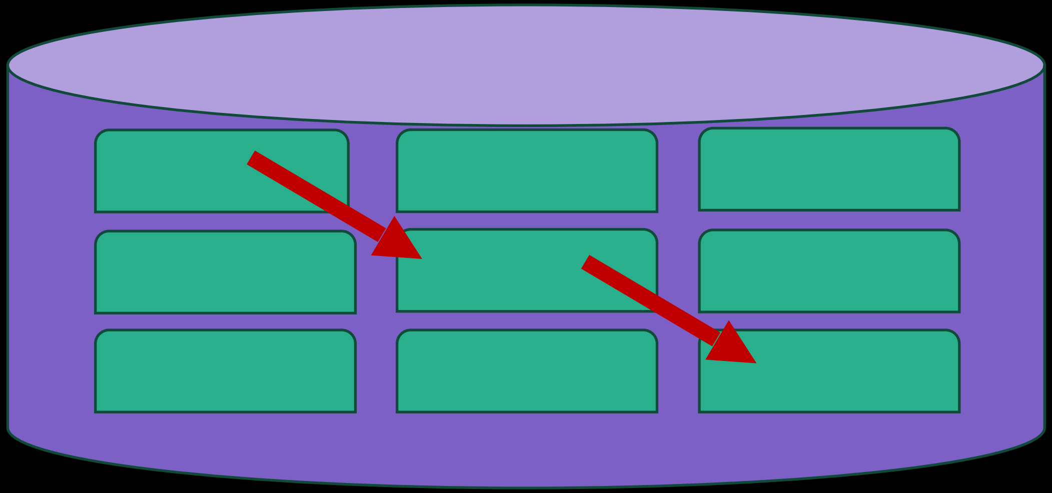

Exploit Generation Techniques Are Improving

Code Reuse Attacks in PHP: Automated POP Chain Generation

Johannes Dahse, Nikolai Krein, and Thorsten Holz
Horst Görtz Institute for IT-Security (HGI)
Ruhr-University Bochum, Germany
{firstname.lastname}@rub.de

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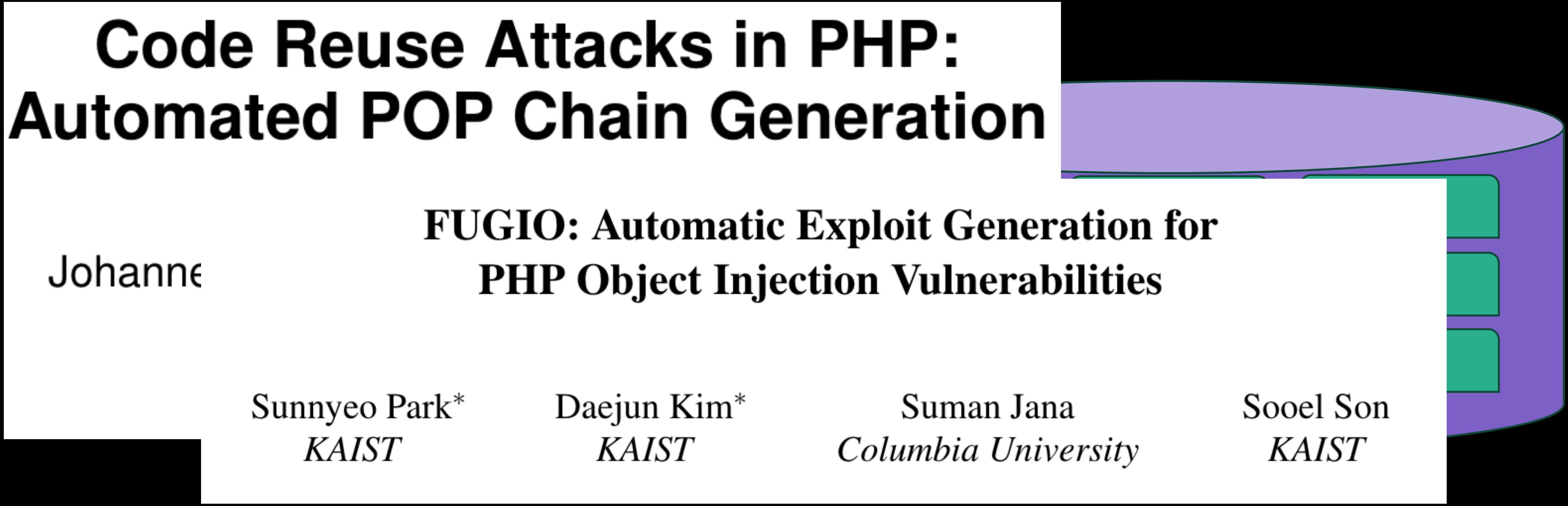

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FUGIO: Automatic Exploit Generation for PHP Object Injection Vulnerabilities

Sunnyeo Park*
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Daejun Kim*
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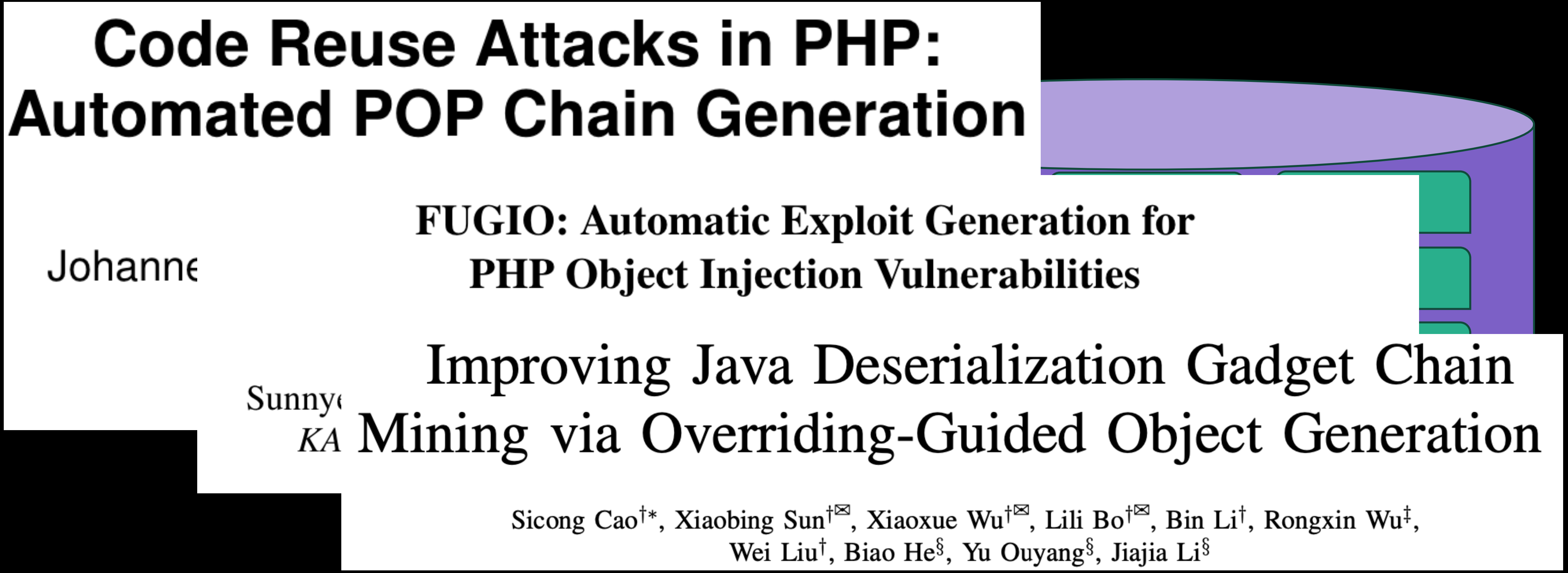

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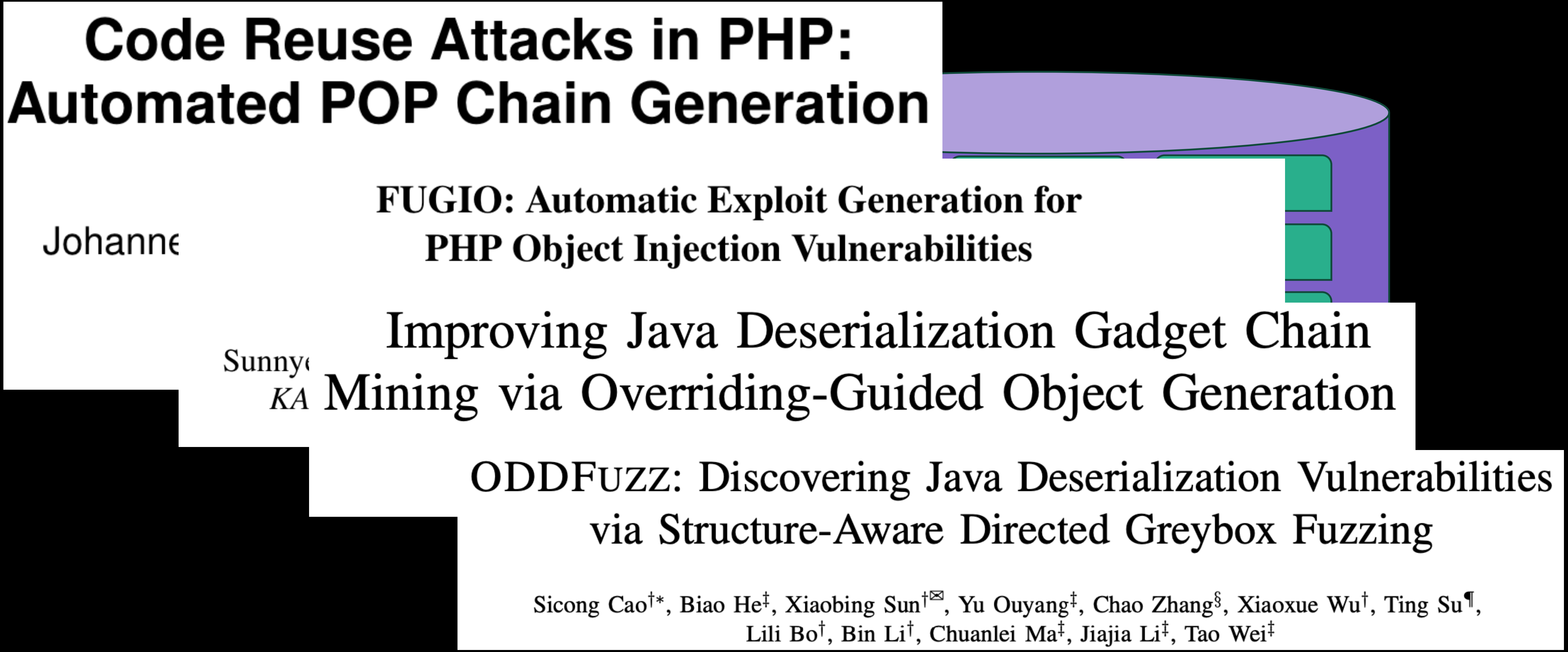

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David et. al., Hindering Deserialization Attacks via Static Duck Typing **[NDSS ‘24]**

Application
(+ Dependencies)
Code

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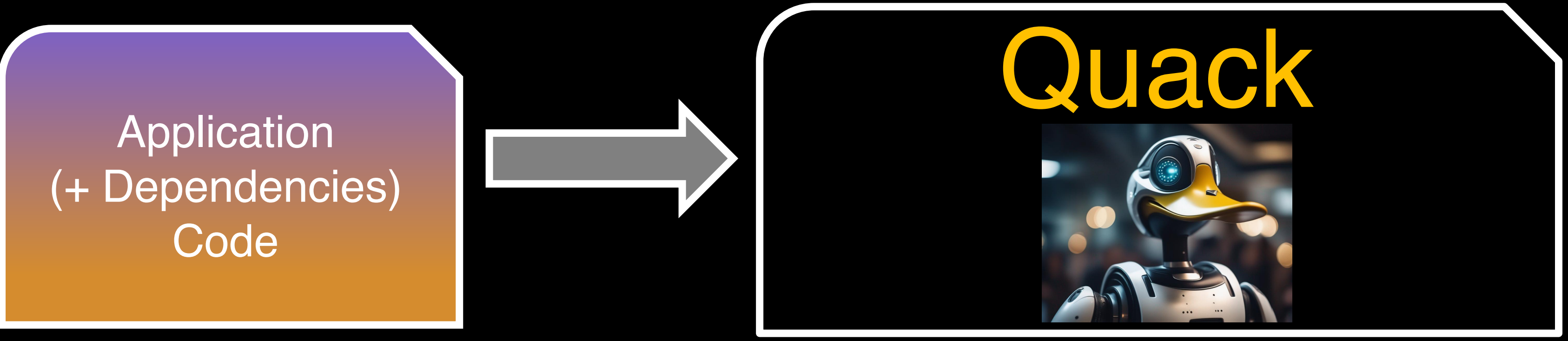

Application (+ Dependencies) Code

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Image Source: Stable Diffusion @ stablediffusionweb.com

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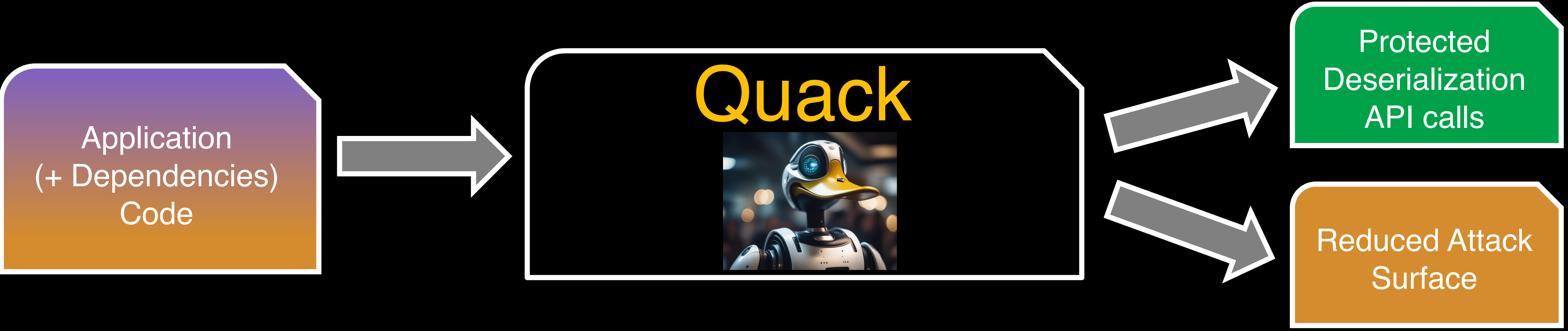

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Protected Deserialization API calls

Reduced Attack Surface

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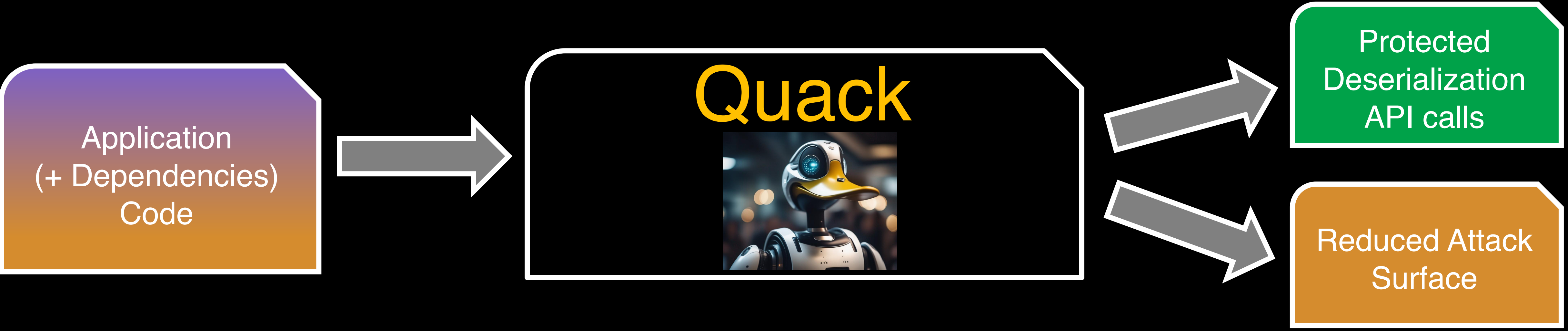

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Built Quack-php and evaluated on diverse set of real applications against SOTA exploit-generation-tool

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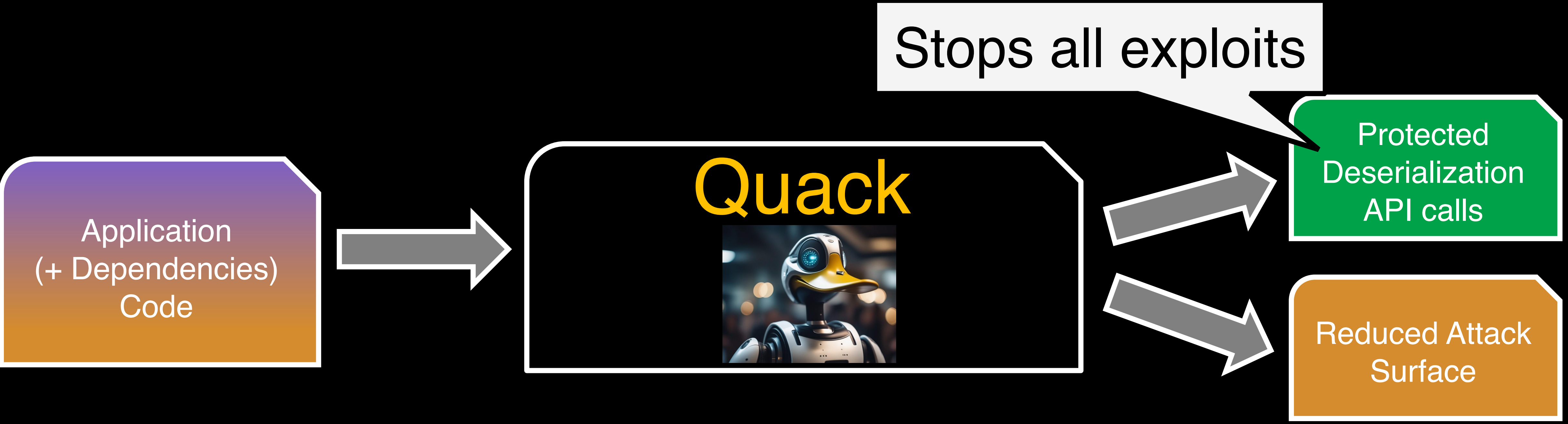

Stops all exploits

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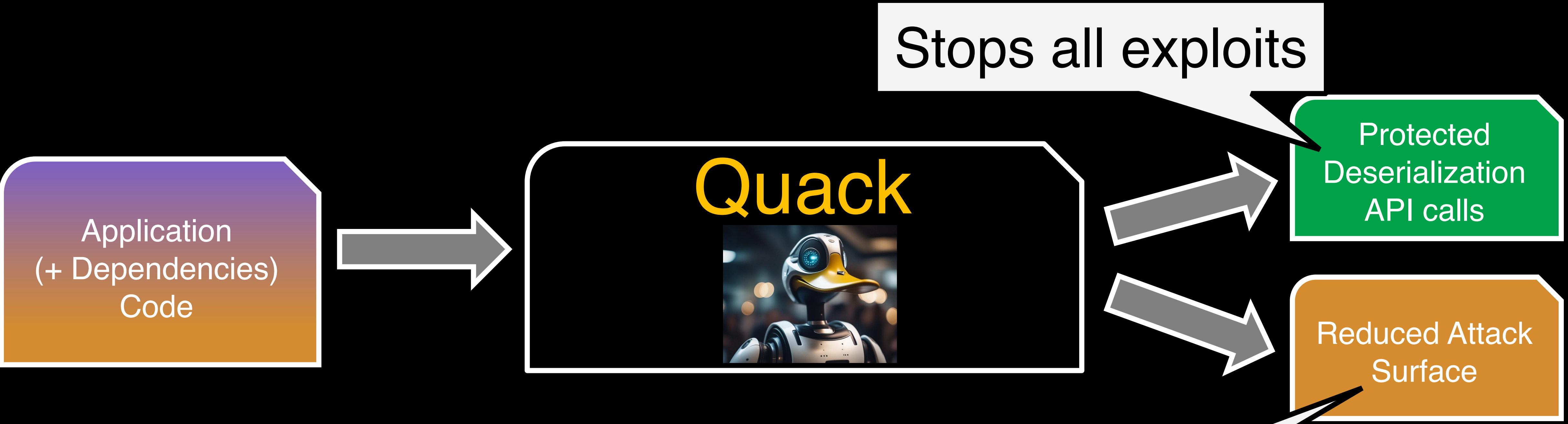

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Built Quack-php and eva eal applications against SC l

97% blocked exploit-building classes

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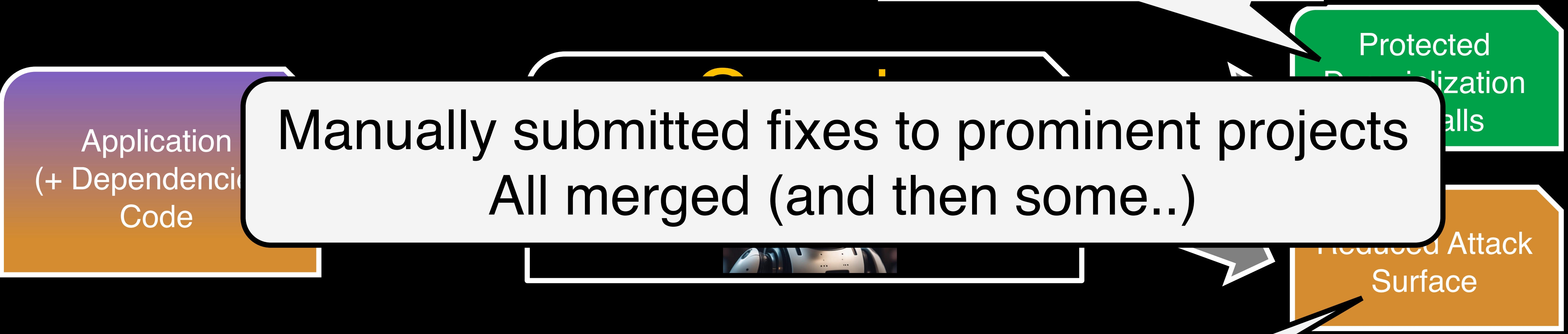

Manually submitted fixes to prominent projects
All merged (and then some..)

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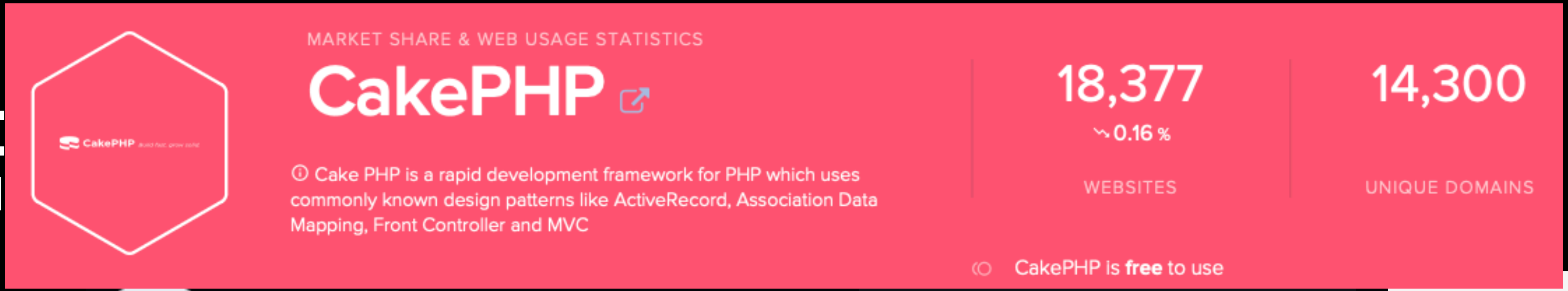
Image Source: Stable Diffusion @ stablediffusionweb.com

Quack:

David et. al



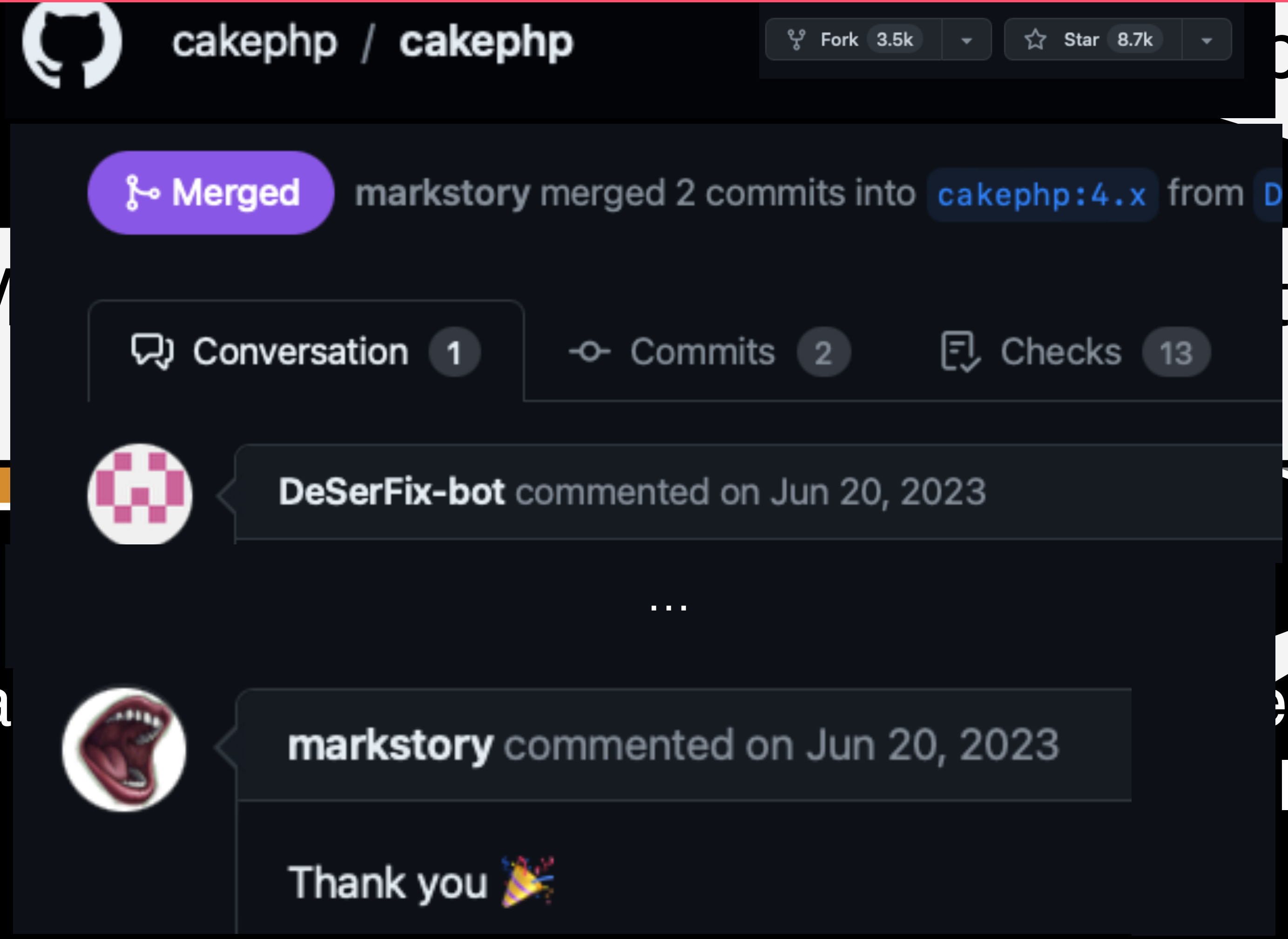
MARKET SHARE & WEB USAGE STATISTICS

CakePHP

ⓘ Cake PHP is a rapid development framework for PHP which uses commonly known design patterns like ActiveRecord, Association Data Mapping, Front Controller and MVC

18,377	14,300
↘0.16 %	
WEBSITES	UNIQUE DOMAINS

CakePHP is **free** to use



cakephp / **cakephp**

Merged markstory merged 2 commits into `cakephp:4.x` from D

DeSerFix-bot commented on Jun 20, 2023

...

markstory commented on Jun 20, 2023

Thank you 🎉

Application
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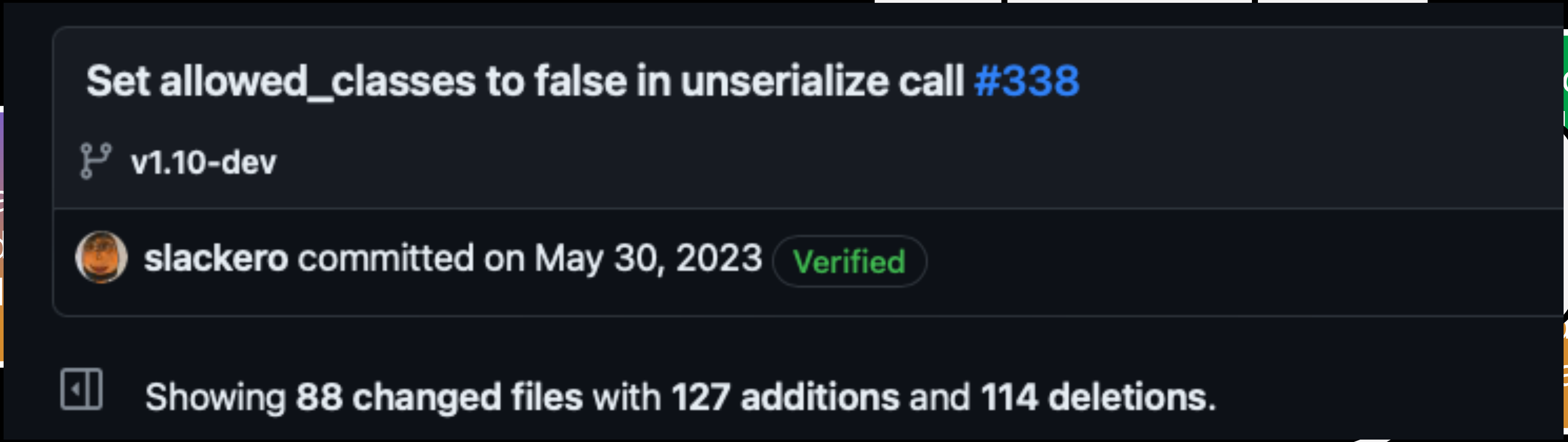

Set allowed_classes to false in unserialize call #338

v1.10-dev

slackero committed on May 30, 2023 Verified

Showing **88 changed files** with **127 additions** and **114 deletions.**

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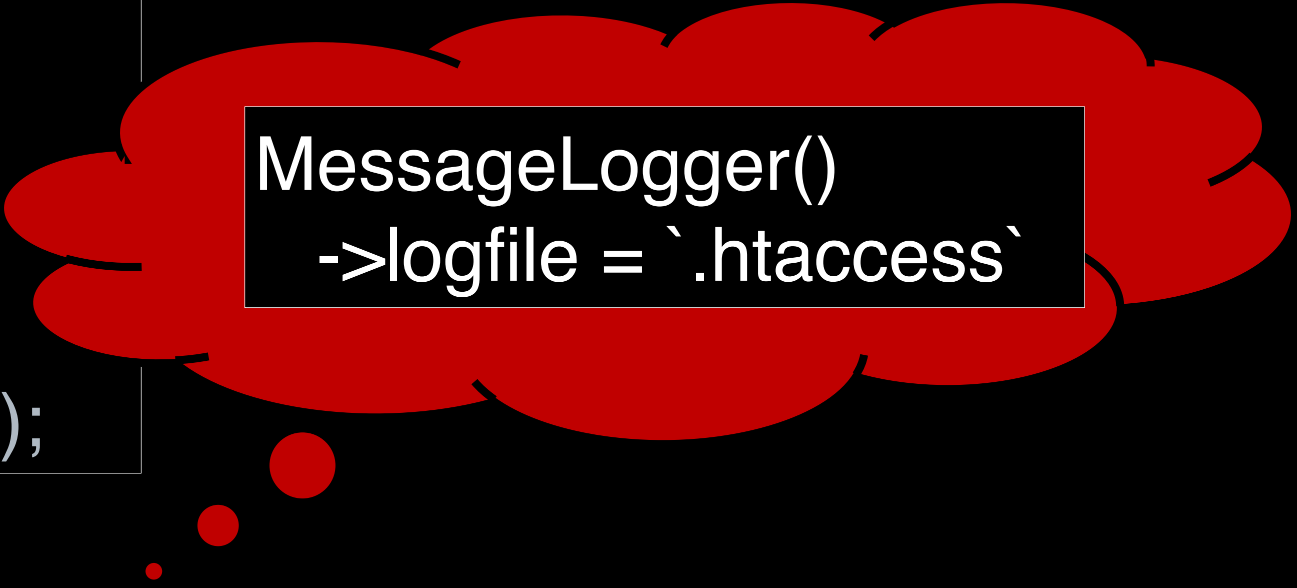

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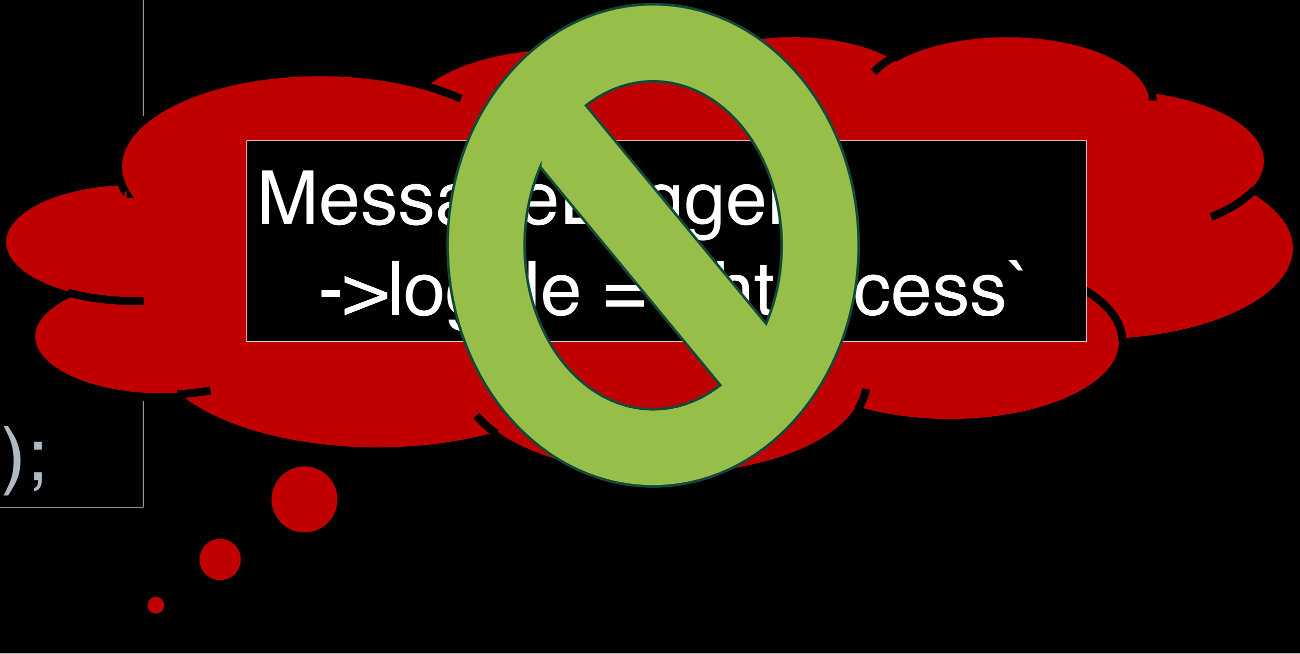

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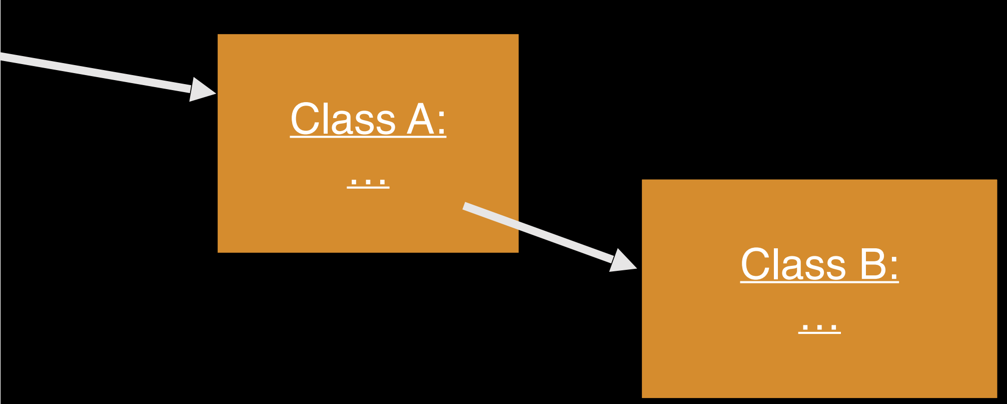

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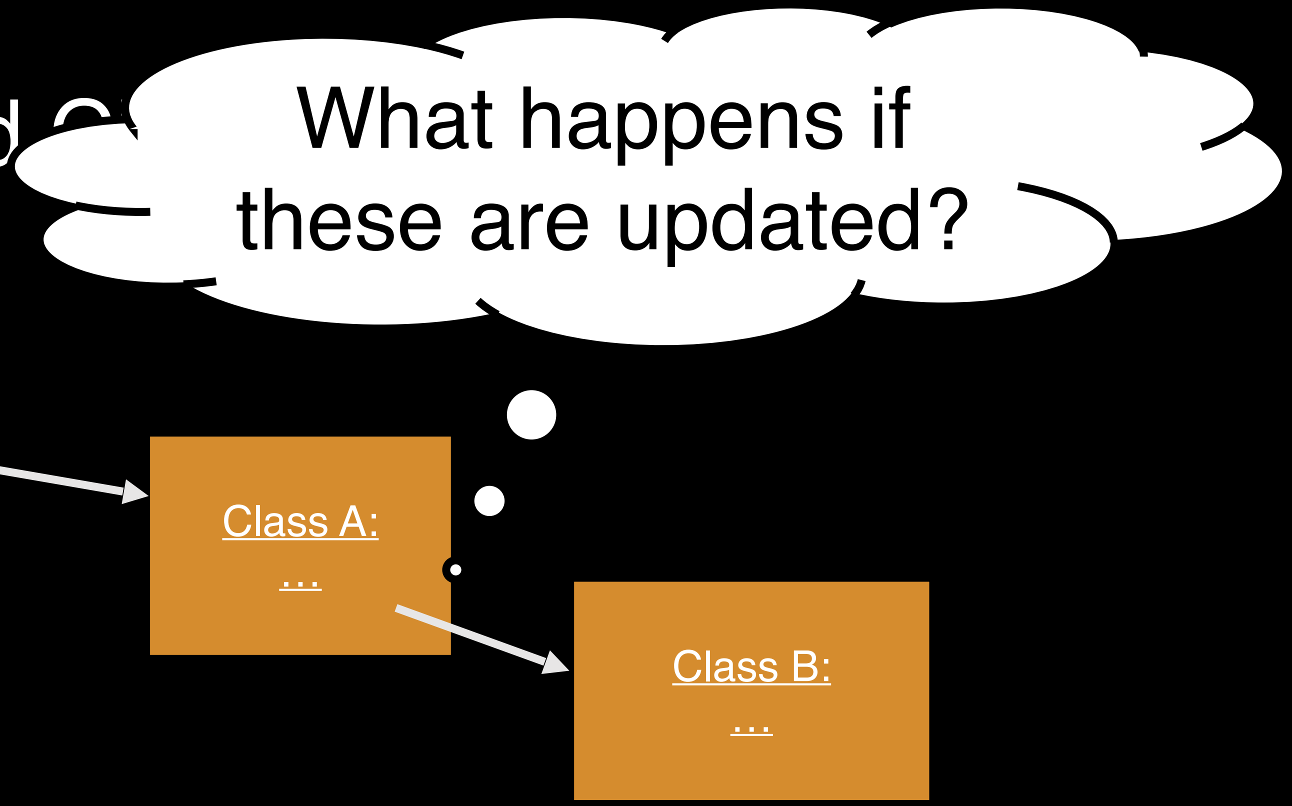

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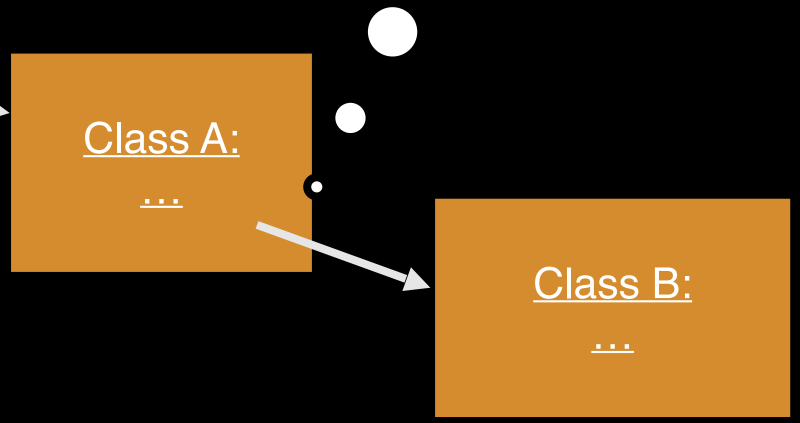
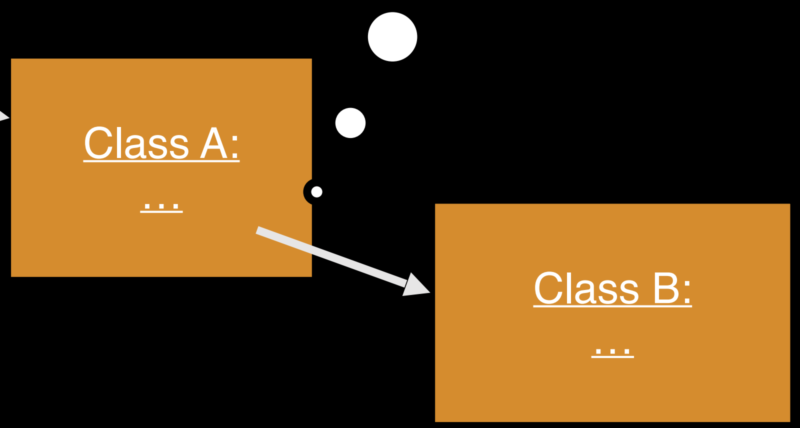


```
recv_event = deserialize(ser_event, [‘allowed_classes’=>[‘E  nt’]]);
```

Why Not Limit Deserialized C

What happens if these are updated?

```
class Event {
  private wrapped_obj;
  /* snip */
}
/* snip */
to_send = serialize(event);
```



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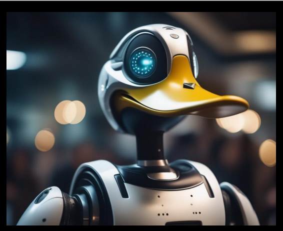

Key Challenge in Protecting Deserialization API calls

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- Infer all types for root objects + fields and collections

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Type inference is too conservative

```
recv_event = deserialize(ser_event, [‘allowed_classes’=>[???]]);
```

Type checkers are not geared for this

e ∈ [[Class, int, str],..

| ⊥

Insight: Infer Classes Using Object’s Usage

```
recv_event = deserialize(ser_event, [‘allowed_classes’=>??]);
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Insight: Infer Classes Using Object’s Usage

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```

Type class components ≠ full type
(for security, not optimization)

Insight: Infer Classes Using Object’s Usage

```
recv_event = deserialize(ser_event, [‘allowed_classes’=>??]);
recv_event->my_call();
something = recv_event->my_field
```

Insight: Infer Classes Using Object’s Usage

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recv_event = deserialize(ser_event, [‘allowed_classes’=>??]);
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Deserialized objects must contain “my_call” and “my_field”

Insight: Infer Classes Using Object’s Usage

Decision Point

```
recv_event = deserialize(ser_event, [‘allowed_classes’=>??]);
recv_event->my_call();
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Deserialized objects must contain “my_call” and “my_field”

Key Idea: Targeted On-Demand Class Identity Inference

- Start with the deserializable classes set
    - Conservatively handle dynamic class-loading patterns
- Gather objects (and fields, recursively) usage evidence
    - Over-approximate or know when to stop
- Use collected evidence to filter class set

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Inferring structure for input objects is useful for many tasks

Analyzing Our Motivating Example

queue.php

```
/* snip */
raw_event = owa->getLast('event');
event = deserialize(raw_event);

owa::getEventDispatcher()->notify(event);
```

Open Web Analytics v1.5.6 containing the deserialization vulnerability CVE-2014-2294

Analyzing Our Motivating Example

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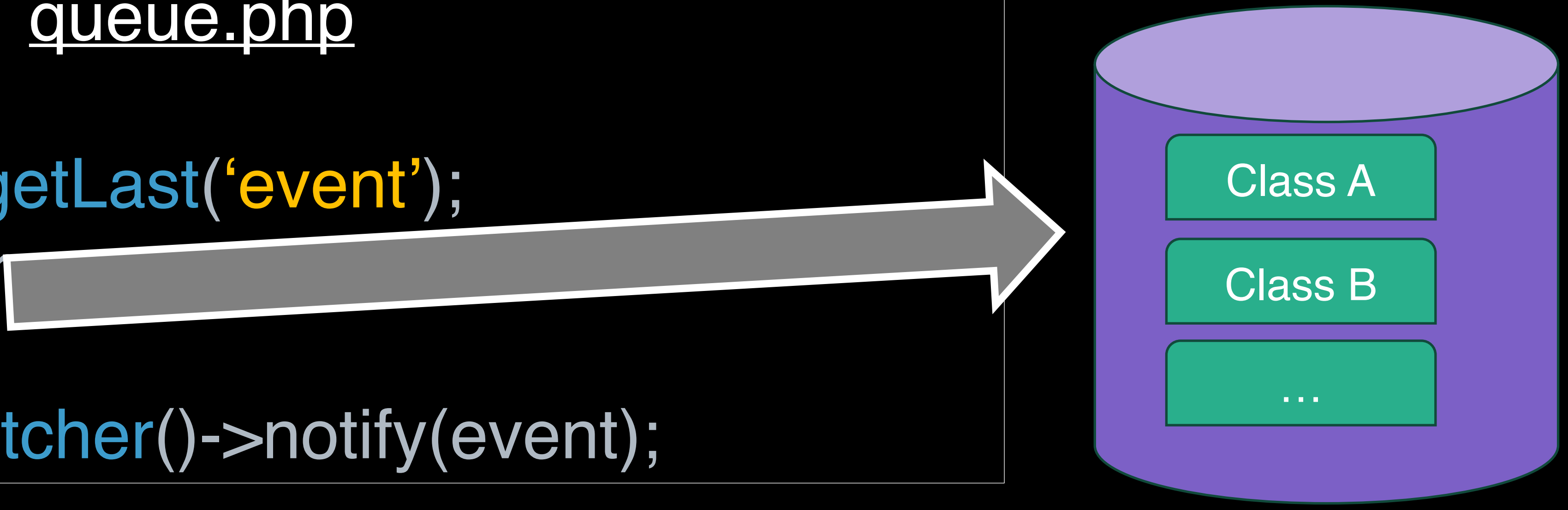

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Analyzing Our Motivating Example

Root Object

queue.php

```
/* sni
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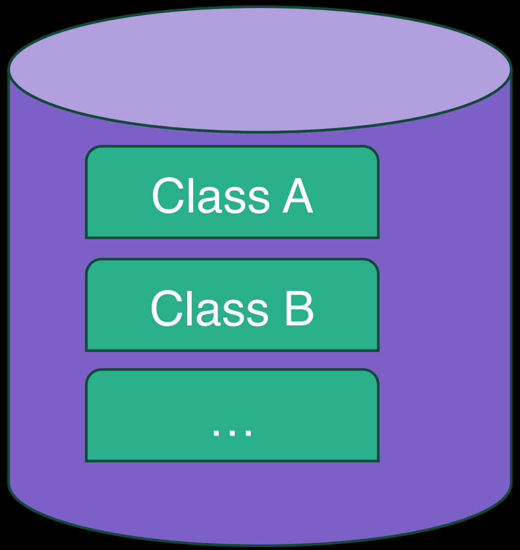

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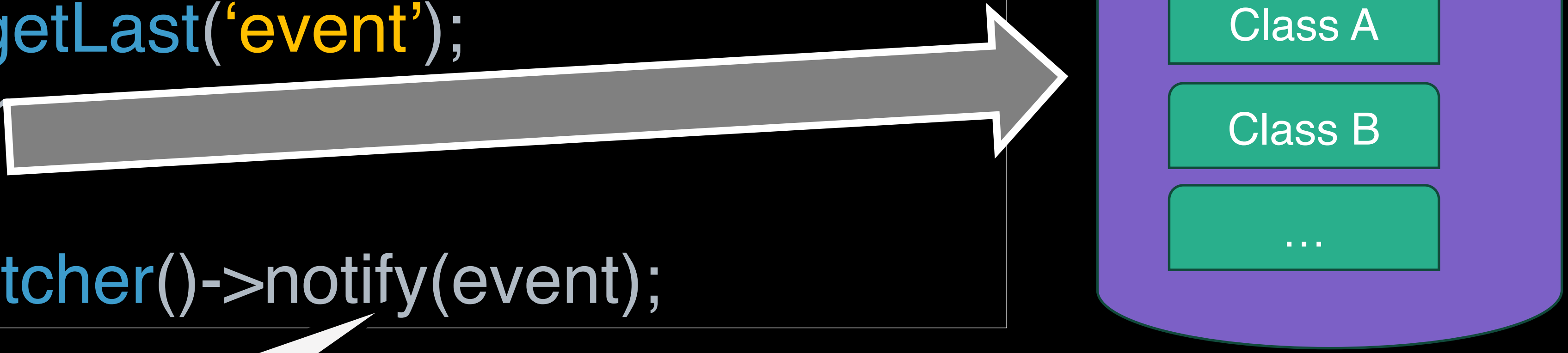

Follow

Open Web Ana containing the deserialization vulnerability CVE-2014-2294

Analyzing Our Motivating Example

eventDispatch.php

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class owa_eventDispatcher {
 function notify(event) {
       owa_coreAPI::debug("Notifying listeners of"
                                    + event->getEventType());
 }
}
```

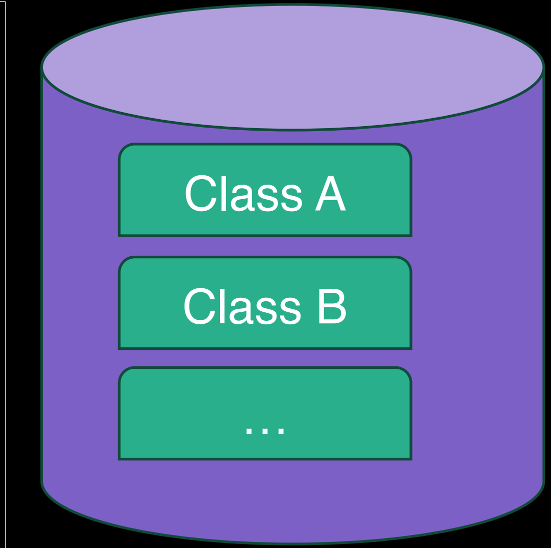

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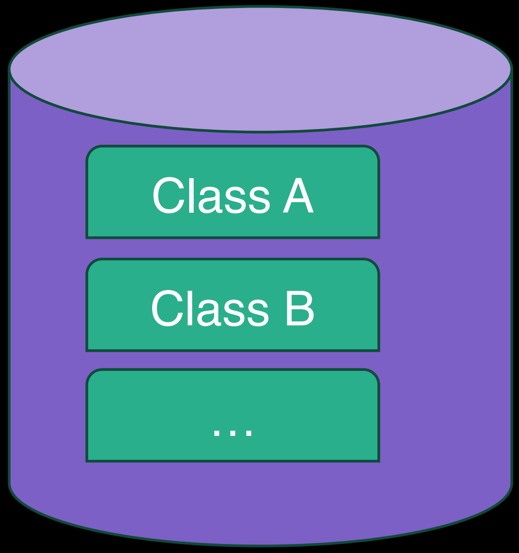

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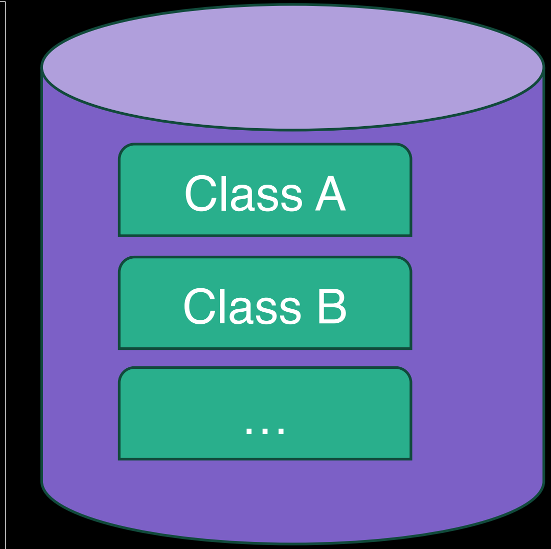

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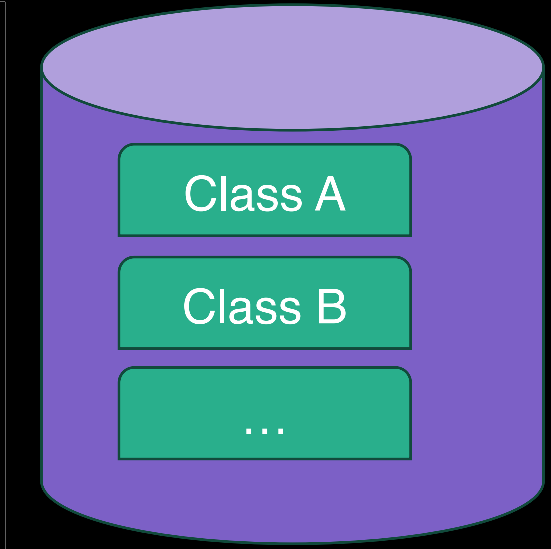

Analyzing Our Motivating Example

Rule Type	Partial Statement Matching Rule	Possible Classes
Exact	FunctionX (arg1, argi-1, t, argi+1, ...)	TypeOf(FunctionX's arg;)
	ClassXInstance MethodX (arg1, argi-1, t, argi+1, ...)	TypeOf(ClassX → MethodX's argi)
	(TypeName) t	TypeName
	Expr ? t: a (or symmetric case)	TypeOf(a)
Duck Typing	t->MethodX (...)	Classes with a method named 'MethodX'
	t.Fieldx	Classes with a field named 'FieldX'
	t <BinaryOp>a	Types allowing < BinaryOp>(e.g., "+" or ">=") with TypeOf(a)
	tOp> (or symmetric case)	Types allowing Op (e.g., "++")
	t[offset or key]	Types compatible with slicing
	a <AssignOp> t	Types allowing <AssignOp>(e.g., +=) with TypeOf(a)
	switch (t): case (a)	Types allowing equality check against TypeOf(a)

Analyzing Our Motivating Example

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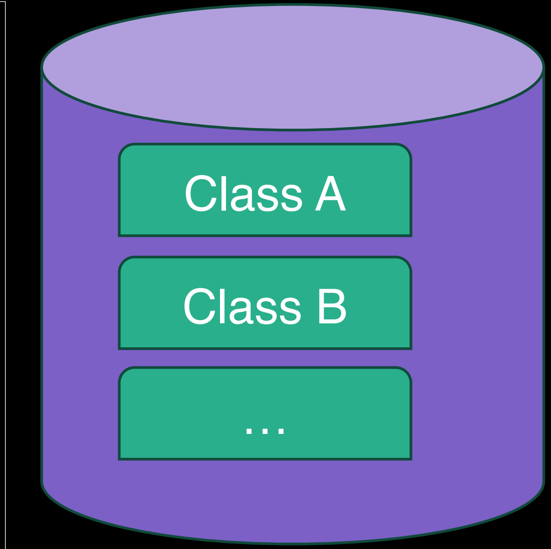

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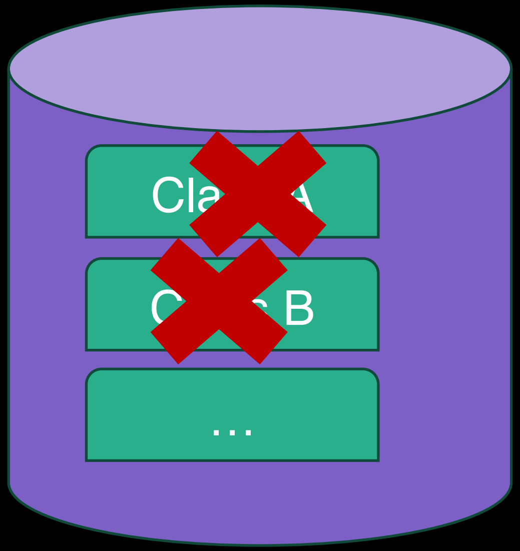

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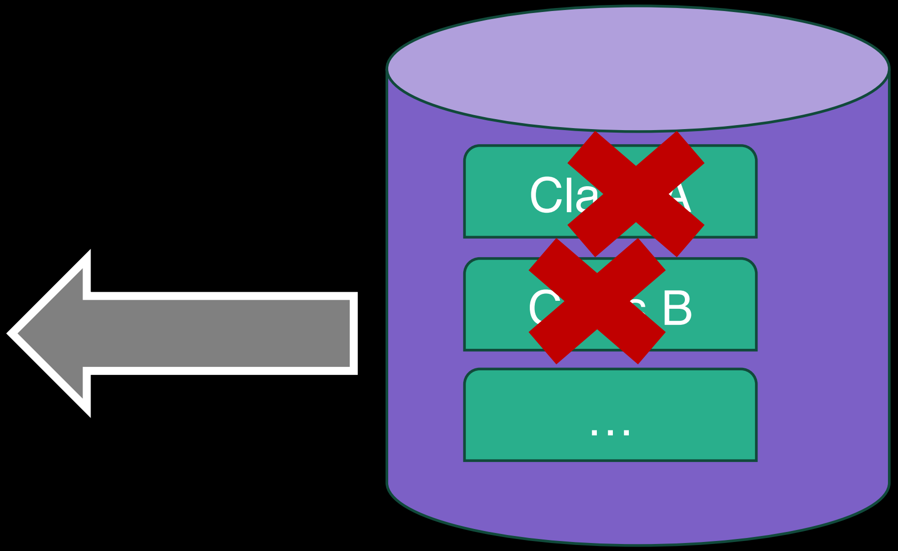

Analyzing Our Motivating Example

event.php

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class owa_event {
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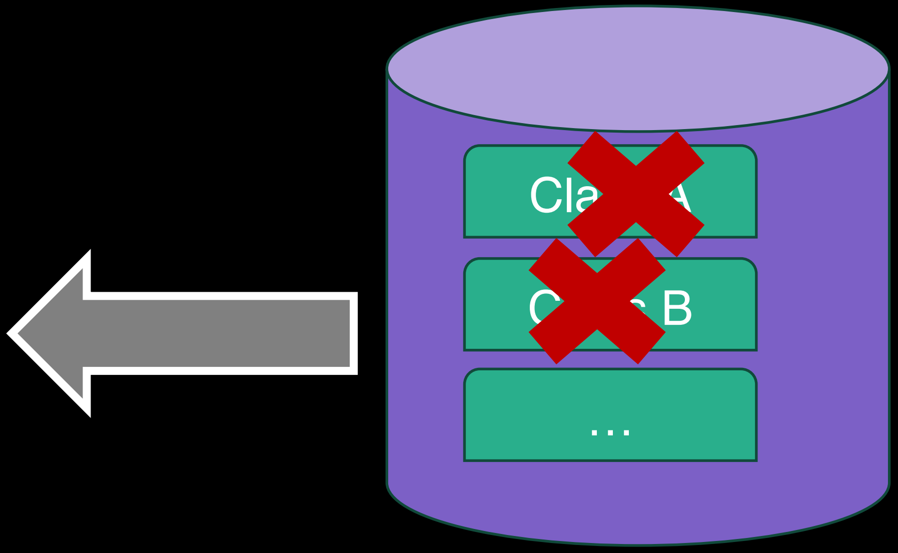

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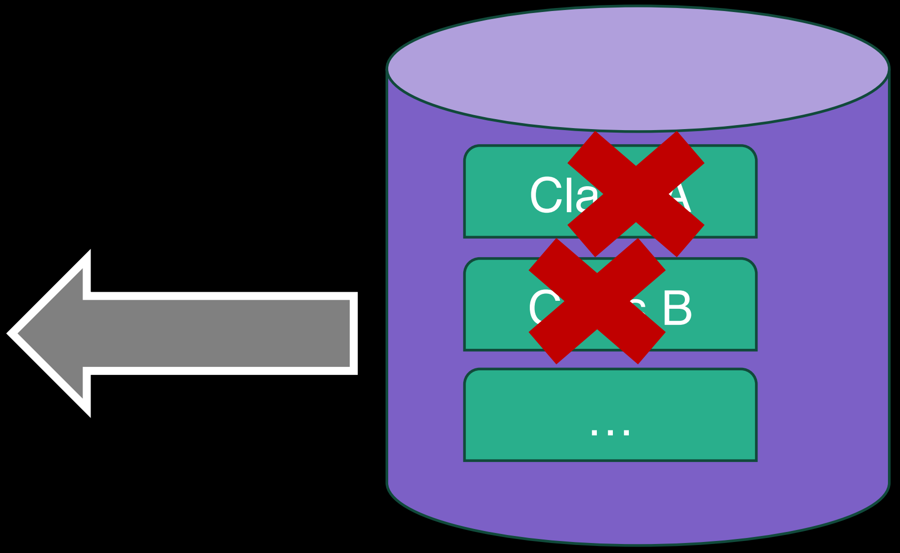

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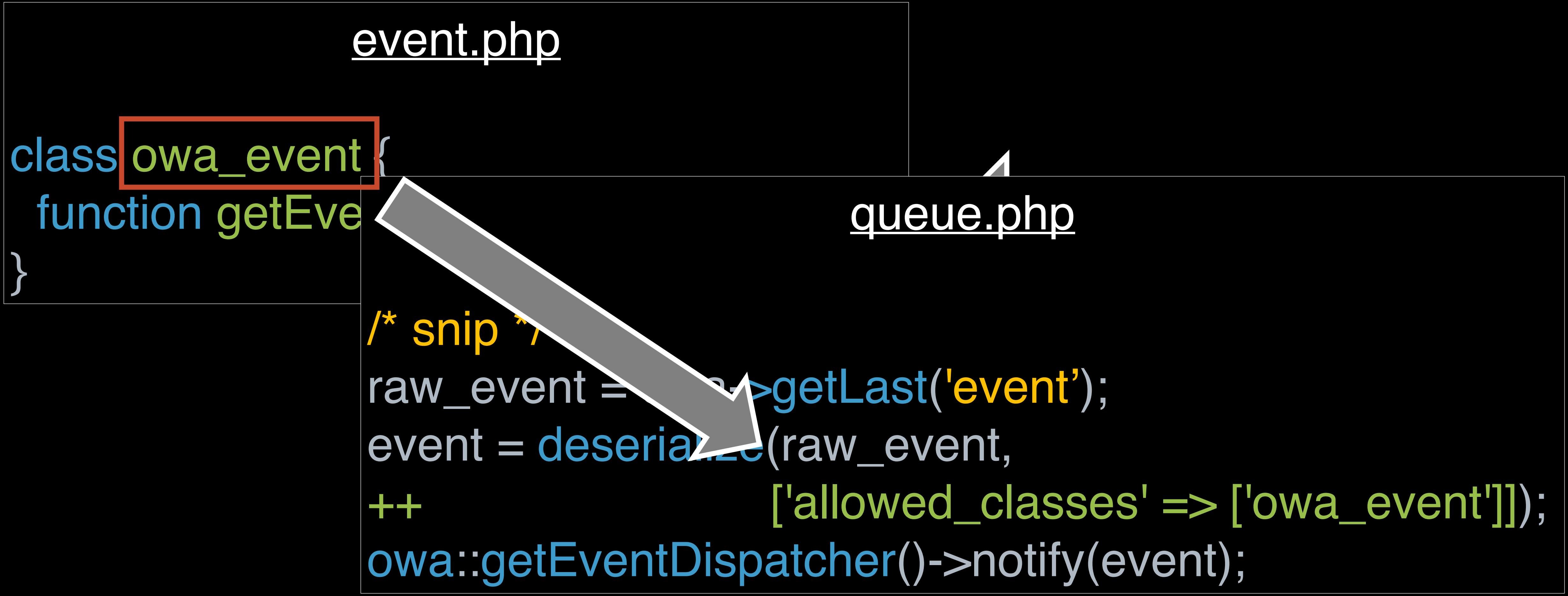

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Stops 14 different exploit chains

Analyzing Our Motivating Example

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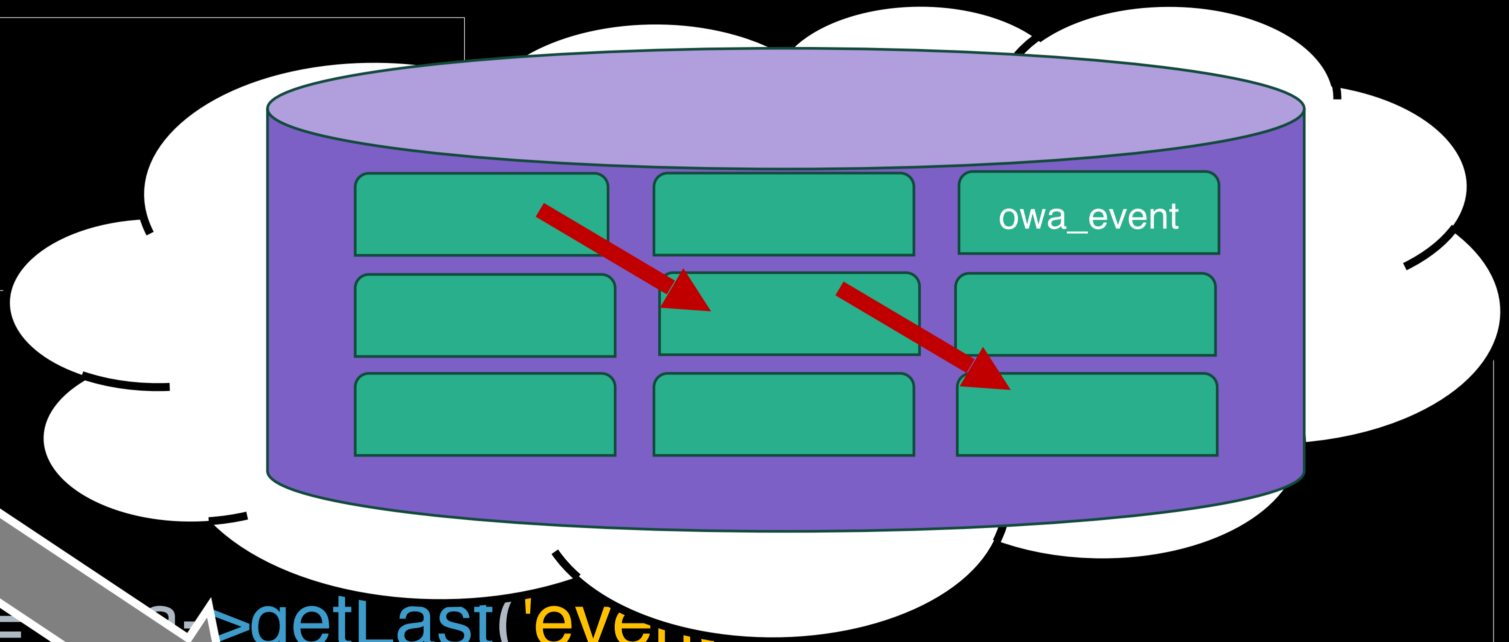

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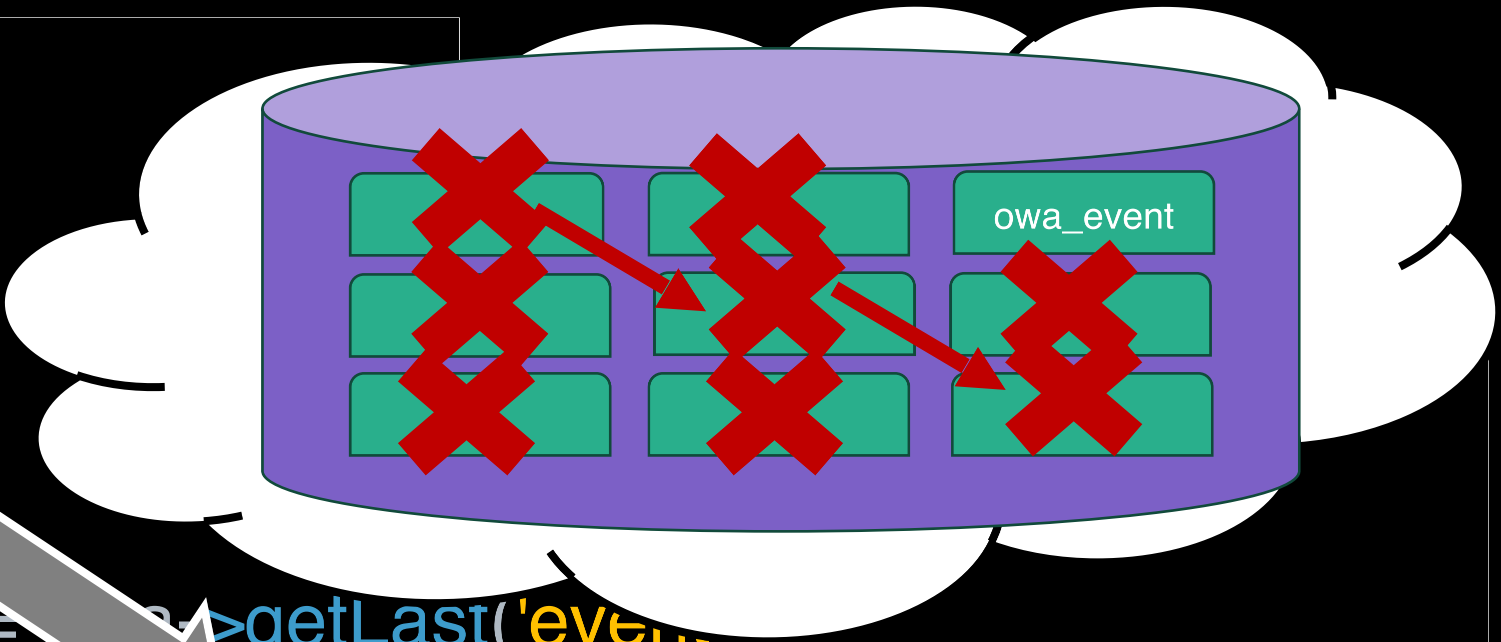

Stops 14 different exploit chains

Evaluation

- Compare against **FUGIO**, SOTA automatic exploit generation tool
  - Dynamically collect available classes and composes them into a gadget-chain

- Vulnerability Datasets
  - **FUGIO** – all vulnerable php applications used by previous papers
  - **VULN202X** – A sample of PHP deserialization vulnerabilities published at/after 2020

- Measure:
  - Exploit-building classes blocked (“Positive”)
  - Classes wrongfully excluded (“Negative”)

Quack Automatically Stops Or Hinders Attacks

Dataset	#CVEs	Exploit-Building Classes [AVG(STD)]	
		Initial Count	% Blocked
FUGIO	7	79 (55)	100%
VULN202x	10	194(114)	97(7)%

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Protecting Applications Against FUGIO

Application	CVE	# FUGIO-Generated Exploits	
Piwik 0.4.5	CVE-2009-4137		
Joomla-3.0.2	CVE-2013-1453		
CubeCart 5.2.0	CVE-2013-1465		
Contao CMS 3.2.4	CVE-2014-1860		
Open Web Analytics	CVE-2014-2294		

Protecting Applications Against FUGIO

Application	CVE	# FUGIO-Generated Exploits
		Original Version
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Joomla-3.0.2	CVE-2013-1453	2
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Contao CMS 3.2.4	CVE-2014-1860	5
Open Web Analytics	CVE-2014-2294	14

Protecting Applications Against FUGIO

Application	CVE	# FUGIO-Generated Exploits	
		Original Version	Quack-Protected Version
Piwik 0.4.5	CVE-2009-4137	1	0
Joomla-3.0.2	CVE-2013-1453	2	0
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Protecting Against Recent CVEs

Application	CVE	Exploit-Building Classes		
		#Blocked	#Remaining	%Blocked
ForkCMS 5.8.3	2020-24036	221	23	91%
WP-hotel-booking 10.2.1	2020-29047	103	0	100%
OpenCATS-0.9.5 (1)	2021-25294	288	0	100%
OpenCATS-0.9.5 (2)		232	56	81%
OpenCATS-0.9.5 (3)		288	0	100%
OpenCATS-0.9.5 (4)		288	0	100%
OpenCATS-0.9.5 (5)		232	56	81%
WP-AIOSEO 4.1.0.1	2021-24307	23	0	100%
WP-booking-calendar 9.1.1	2022-1463	96	0	100%
WP-lead-generated 1.23	2023-28667	40	0	100%

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```
call_user_func_array([$class, $method],...)

new $class(...)
```

Performance and Safety

Dataset	#CVEs	Exploit-Building Classes [AVG(STD)]	
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VULN202x	10	212(106)	97(7)%

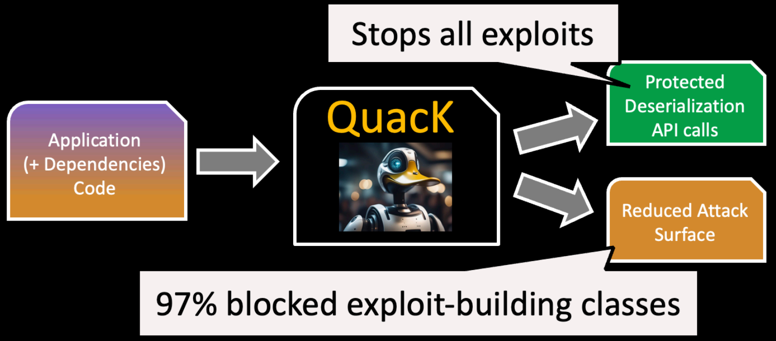
- Favor soundness → **no Negatives**
- Offline project scan: **< 7 minutes**
- Enforcement incurs **negligible overheads**

https://github.com/columbia/quack

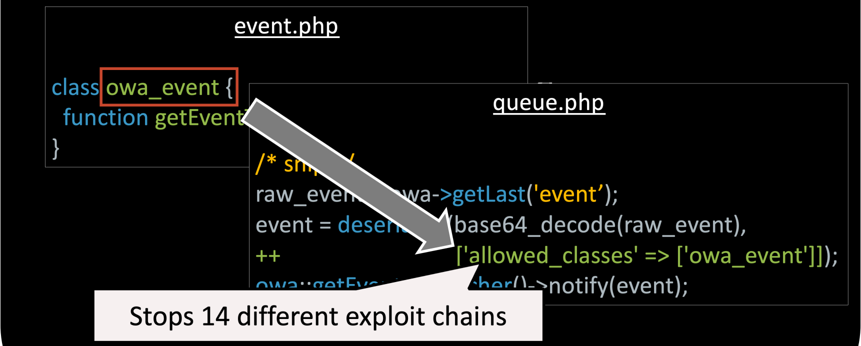
Artifact Evaluated
NDSS SYMPOSIUM
Available
Functional
Reproduced

Thank You!
Questions?

Quack: Securing Applications Against Deserialization Attacks


Stops all exploits
Application (+ Dependencies) Code
QuacK
Protected Deserialization API calls
Reduced Attack Surface
97% blocked exploit-building classes

Stopping Deserialization Exploits



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Stops 14 different exploit chains

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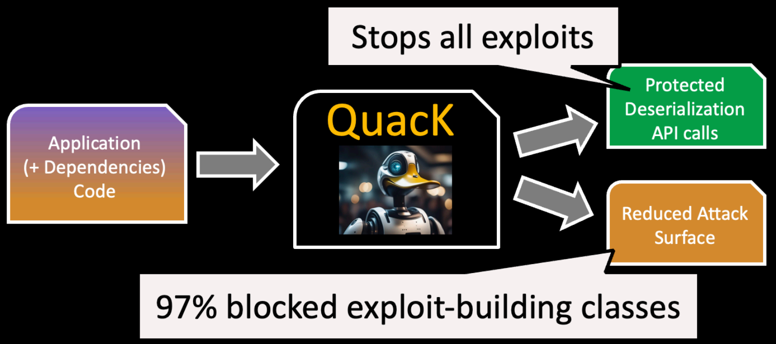

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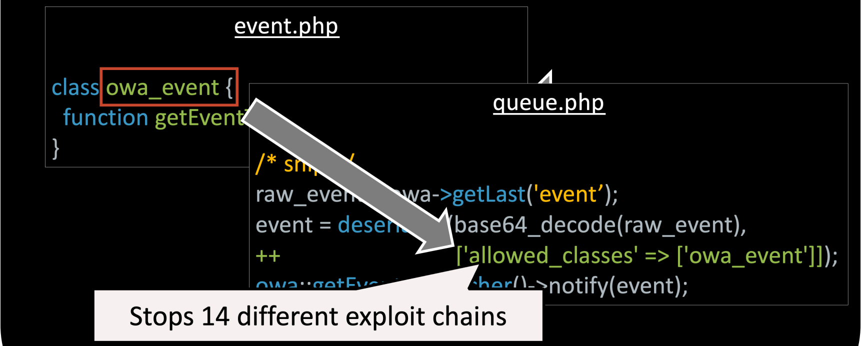
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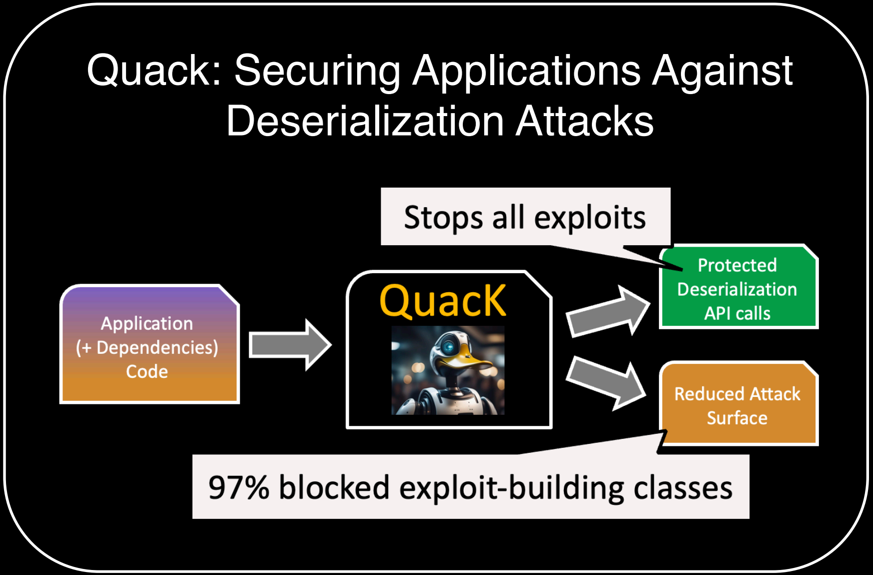

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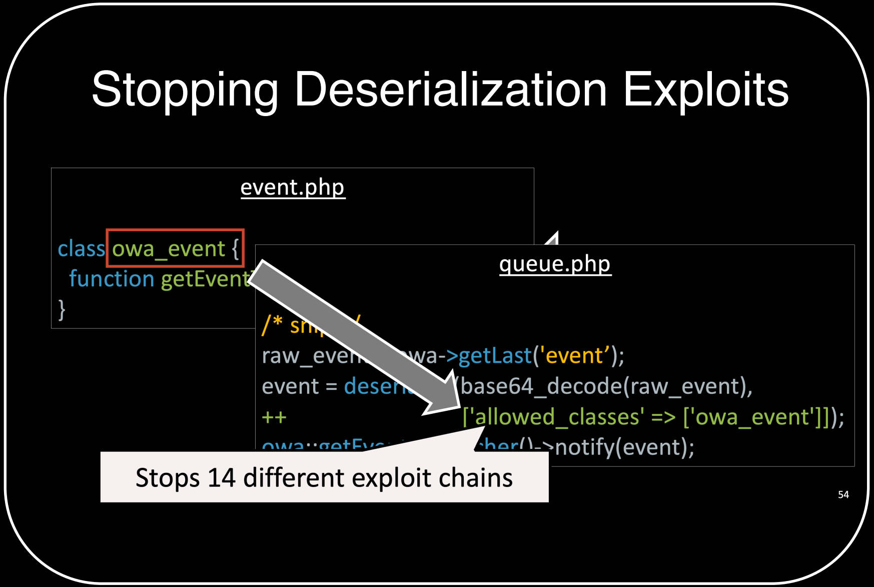

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54