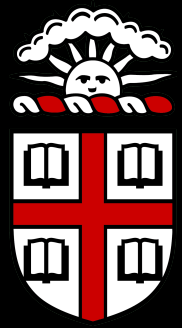
QUACK: Hindering Deserialization Attacks via Static Duck Typing

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?

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Ease-Of-Use Trumps Safety

Client

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

Analytics Server

```
class Event {
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Event()
->wrapped_obj=…

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Exploiting A Deserialization Vulnerability

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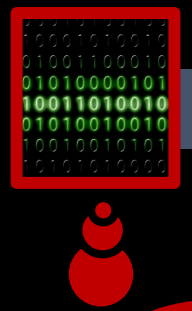

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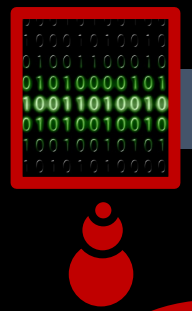

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LogginClass.MessageLogger

Exploiting A Deserialization Vulnerability

```
class MessageLogger {
   public function __wakeup() {
      unlink(this->logFile); }
}
```

```
MessageLogger()
   -> logfile = `.htaccess`
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Analytics Server

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LogginClass.MessageLogger

Exploiting A Deserialization Vulnerability

```
class MessageLogger {
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```

Invoked upon deserialization →
Subverted to an Exploit-Building Class

```
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LogginClass.MessageLogger

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Deserialization Attacks Affect Real-World Applications

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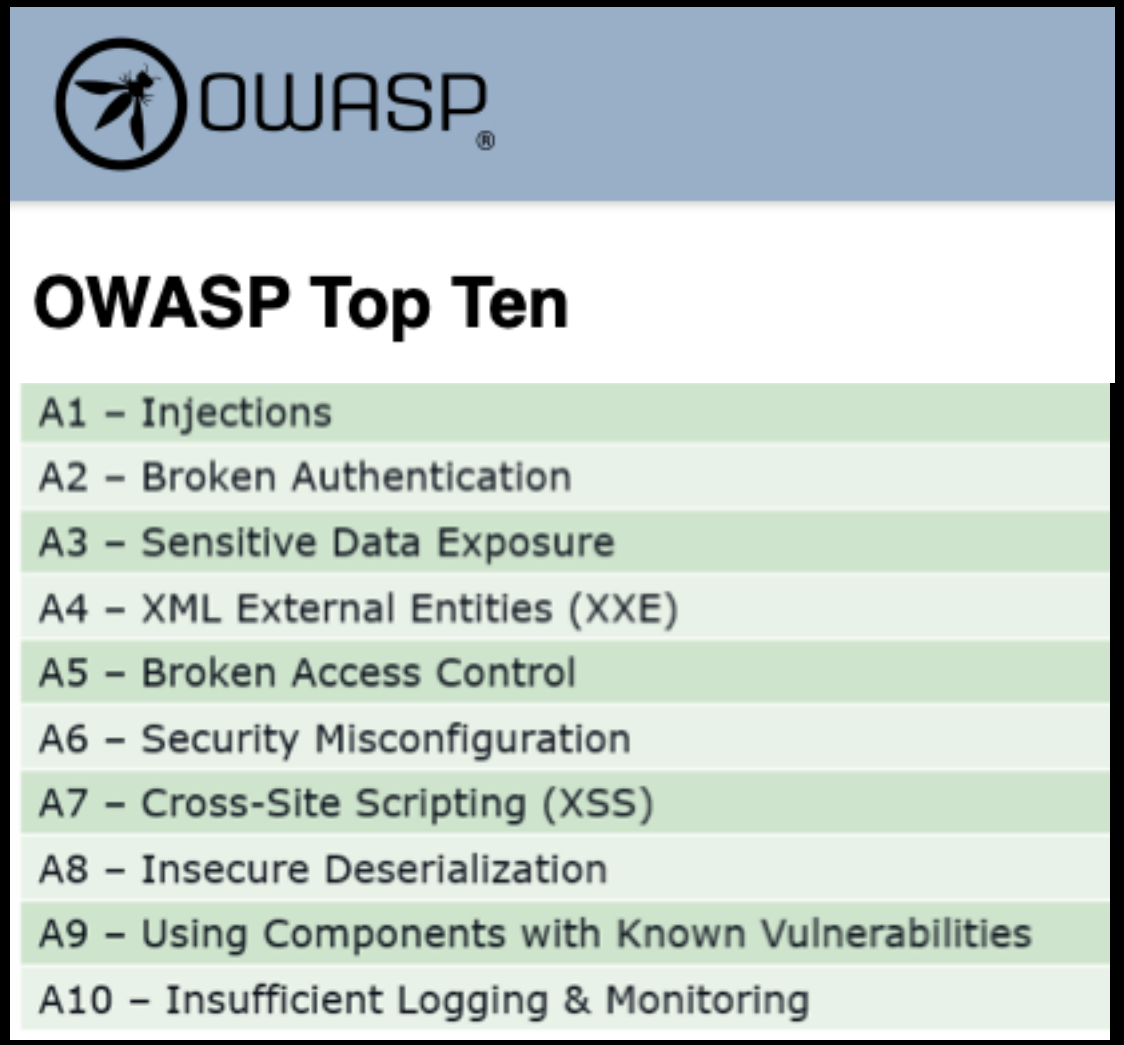

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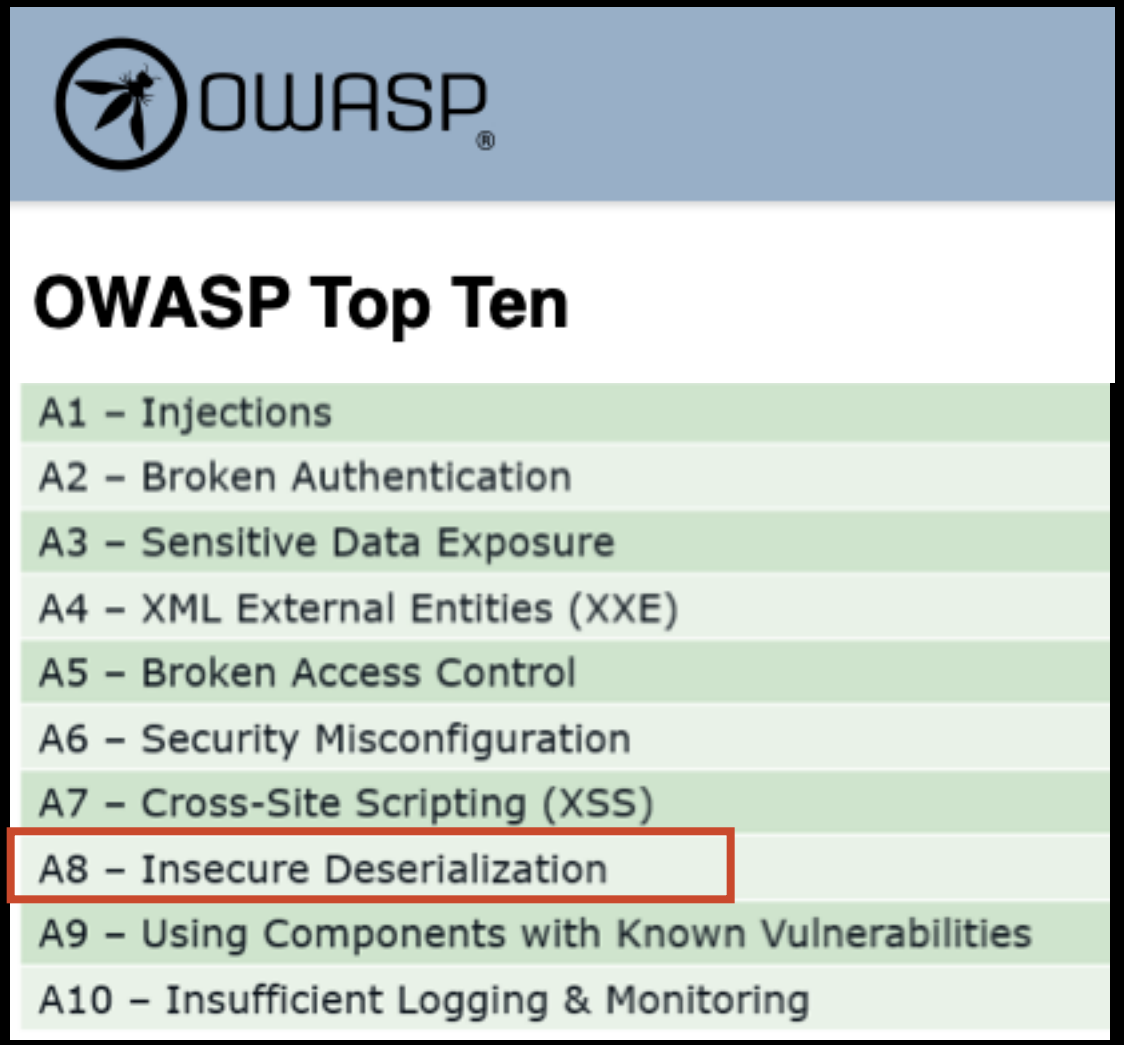

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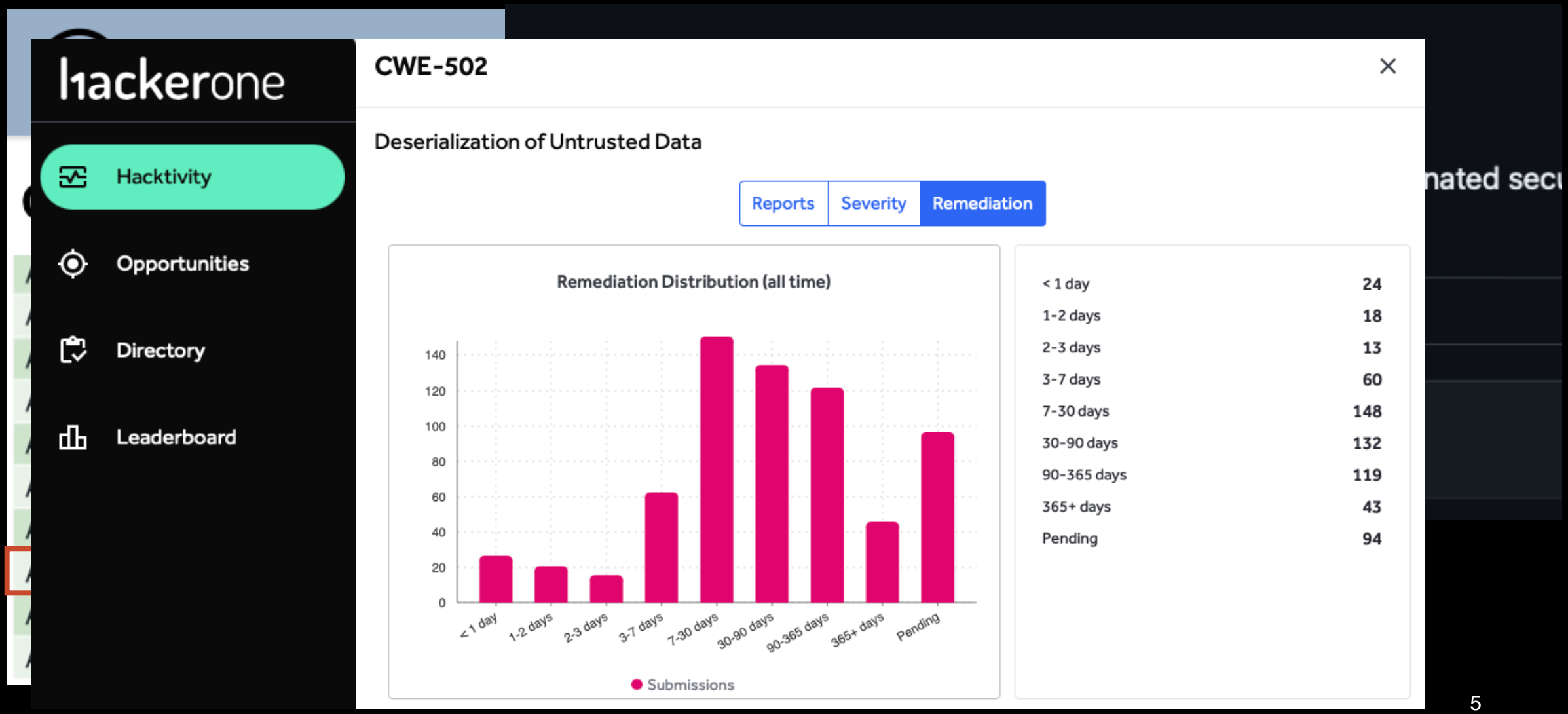

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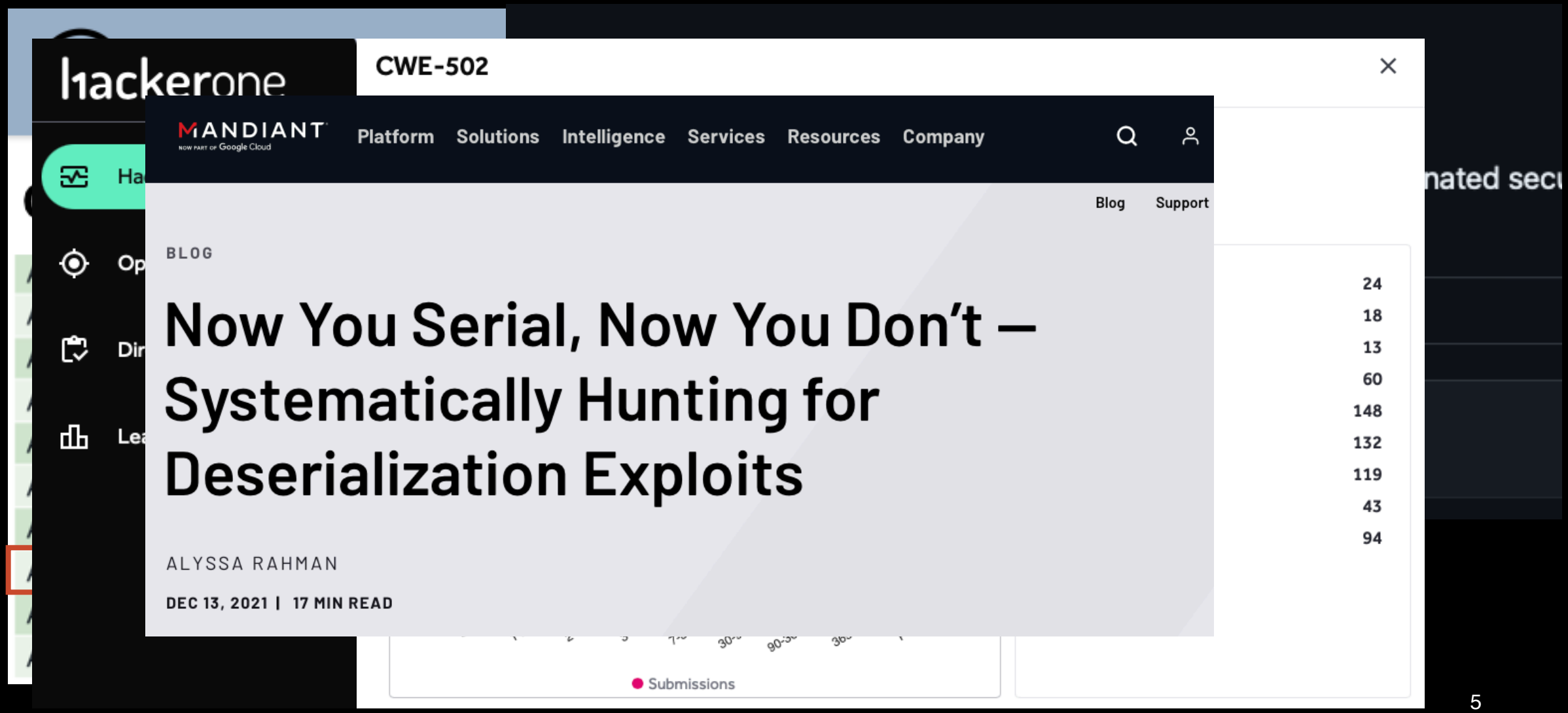

Exploit Generation Techniques Are Improving

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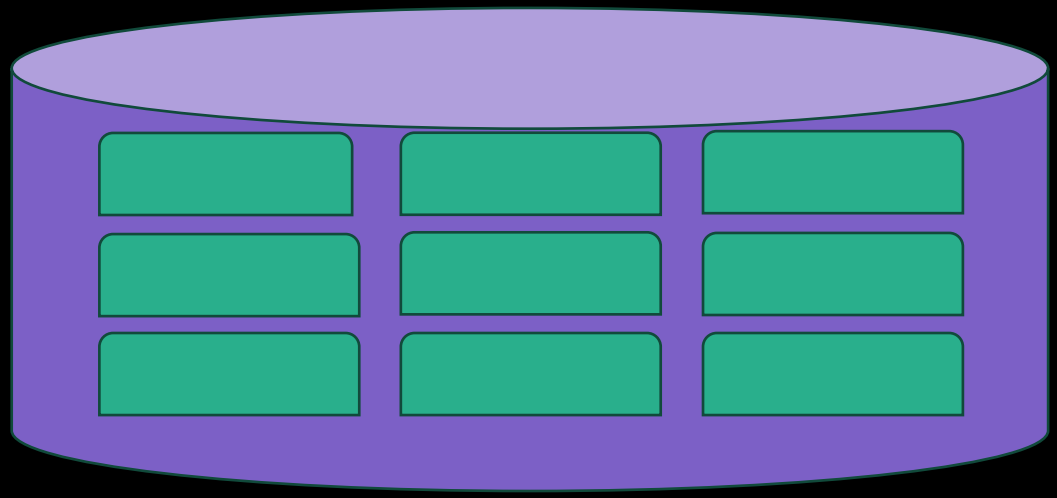

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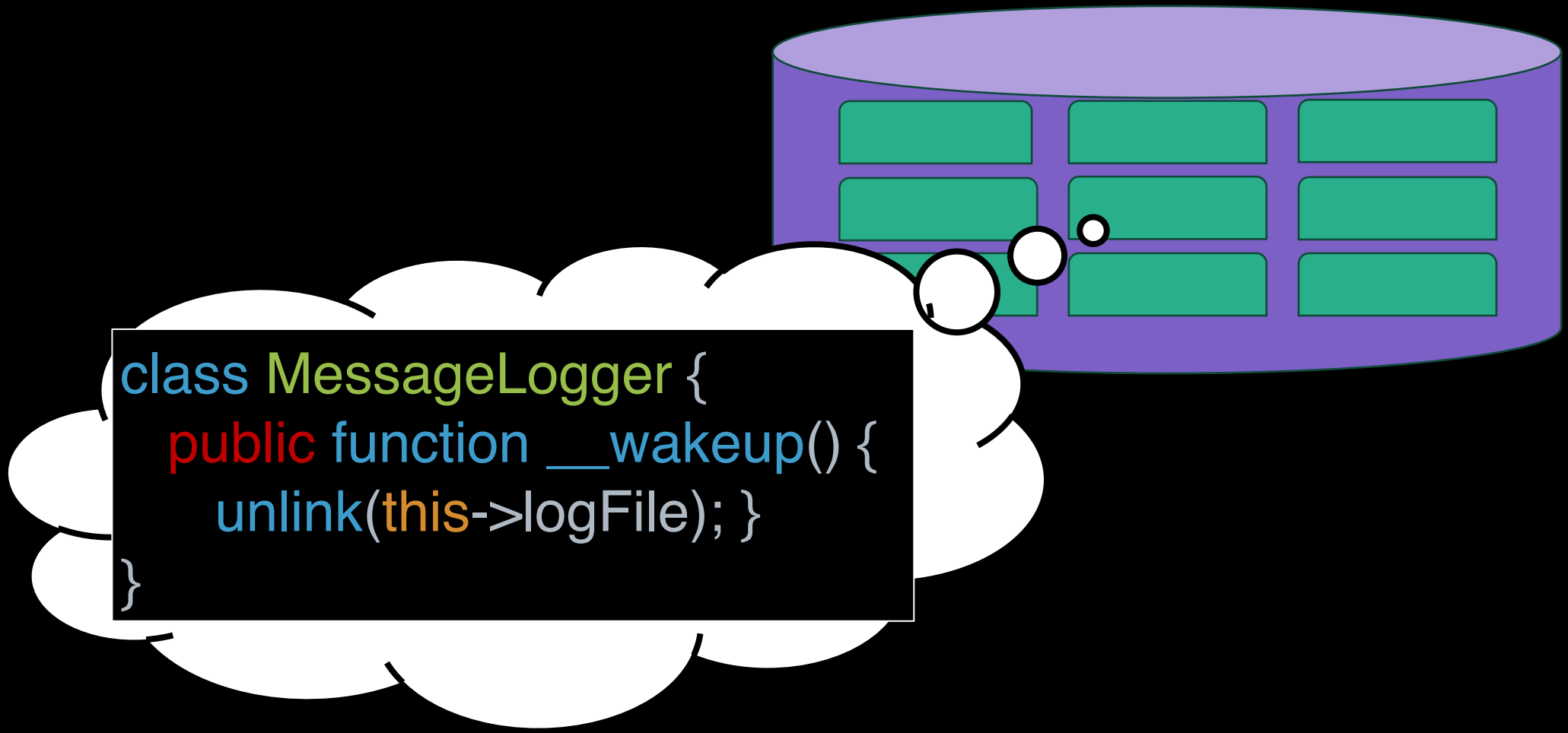

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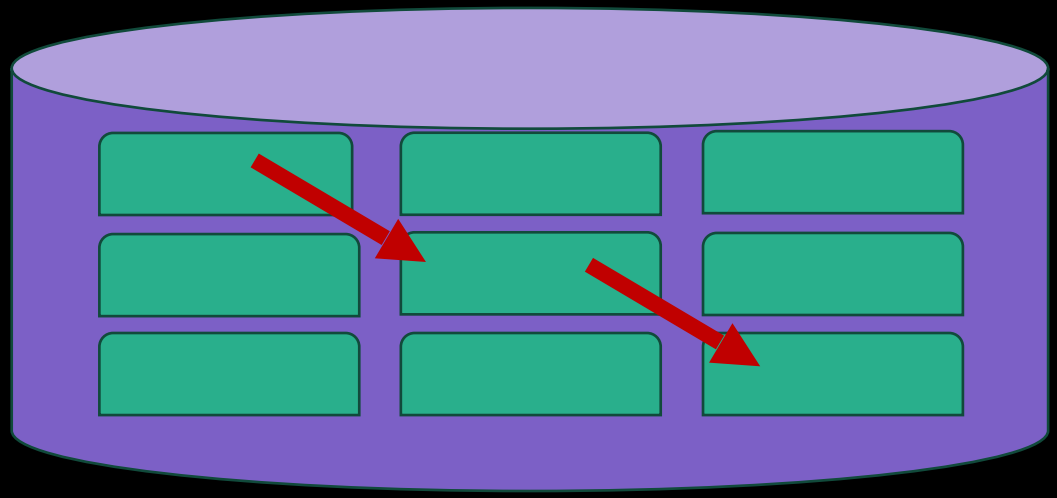
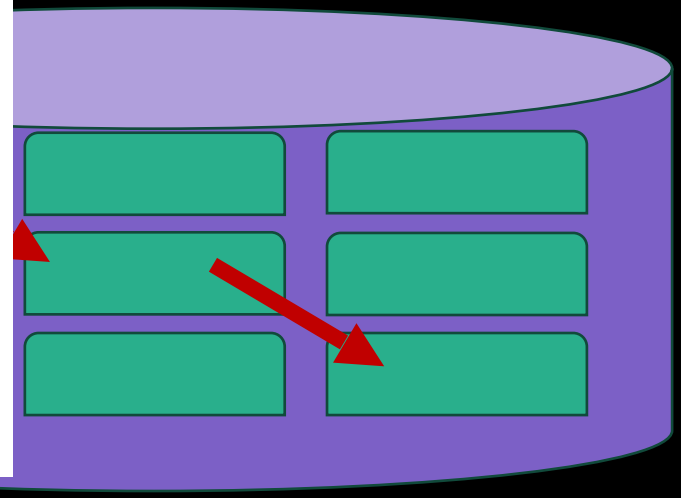


Exploit Generation Techniques Are Improving

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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Code Reuse Attacks in PHP: Automated POP Chain Generation

Johanne

FUGIO: Automatic Exploit Generation for PHP Object Injection Vulnerabilities

Sunnyeo Park* *KAIST*

Daejun Kim* *KAIST*

Suman Jana *Columbia University*

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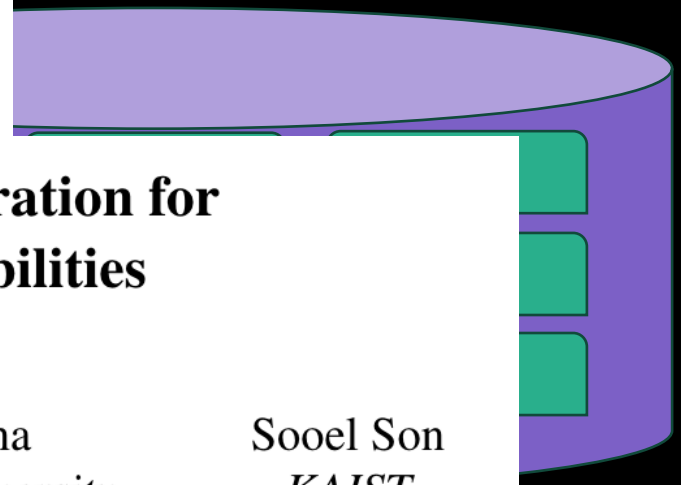

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Improving Java Deserialization Gadget Chain Mining via Overriding-Guided Object Generation

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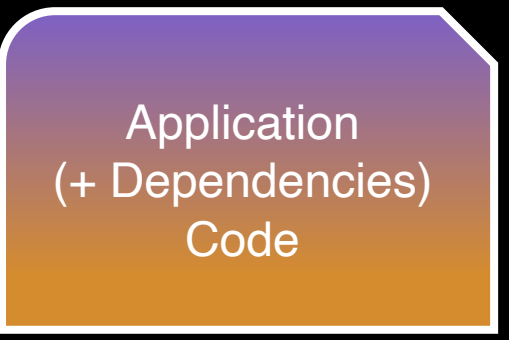

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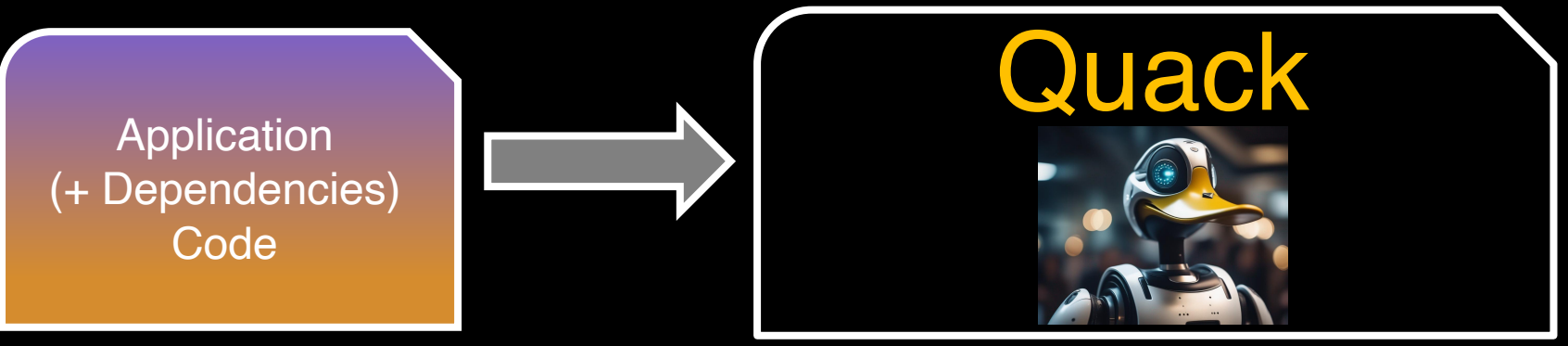

Image Source: Stable Diffusion @ stablediffusionweb.com

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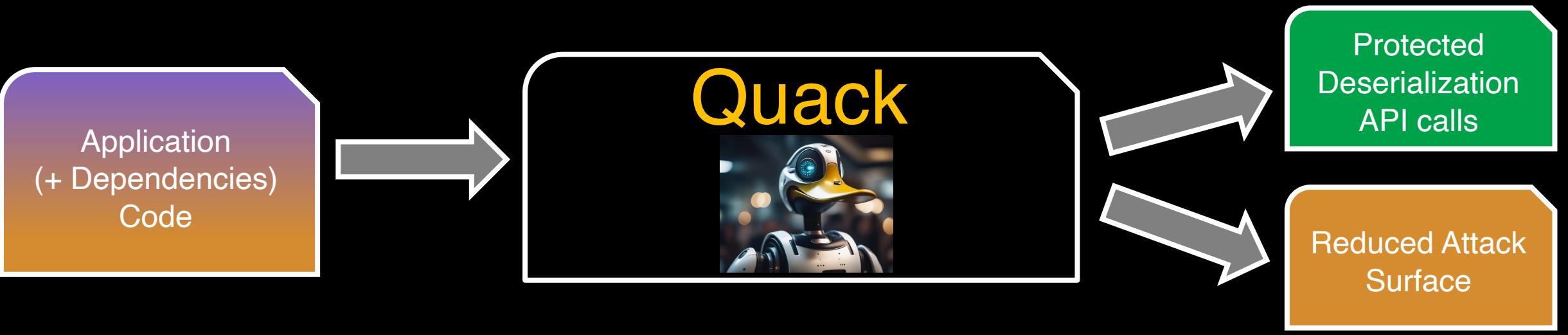

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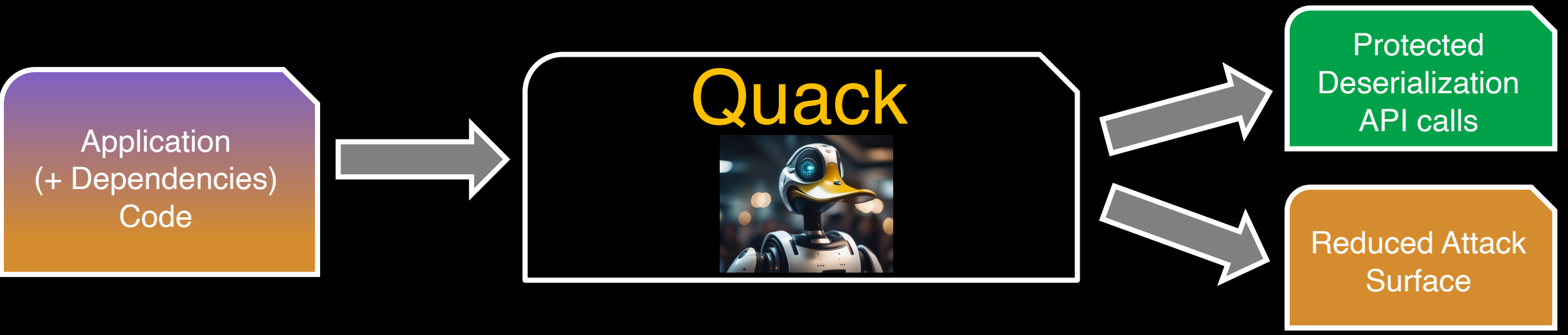

Built Quack-php and evaluated on diverse set of real applications against SOTA exploit-generation-tool

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Quack: Hindering Deserialization Attacks

Built Quack-php and eva eal applications
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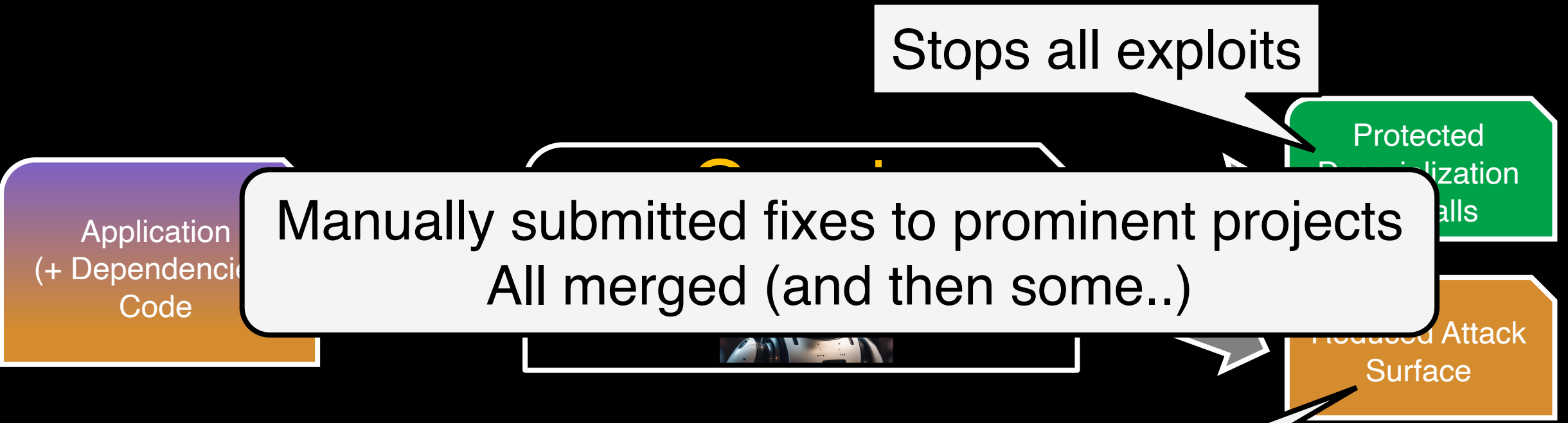

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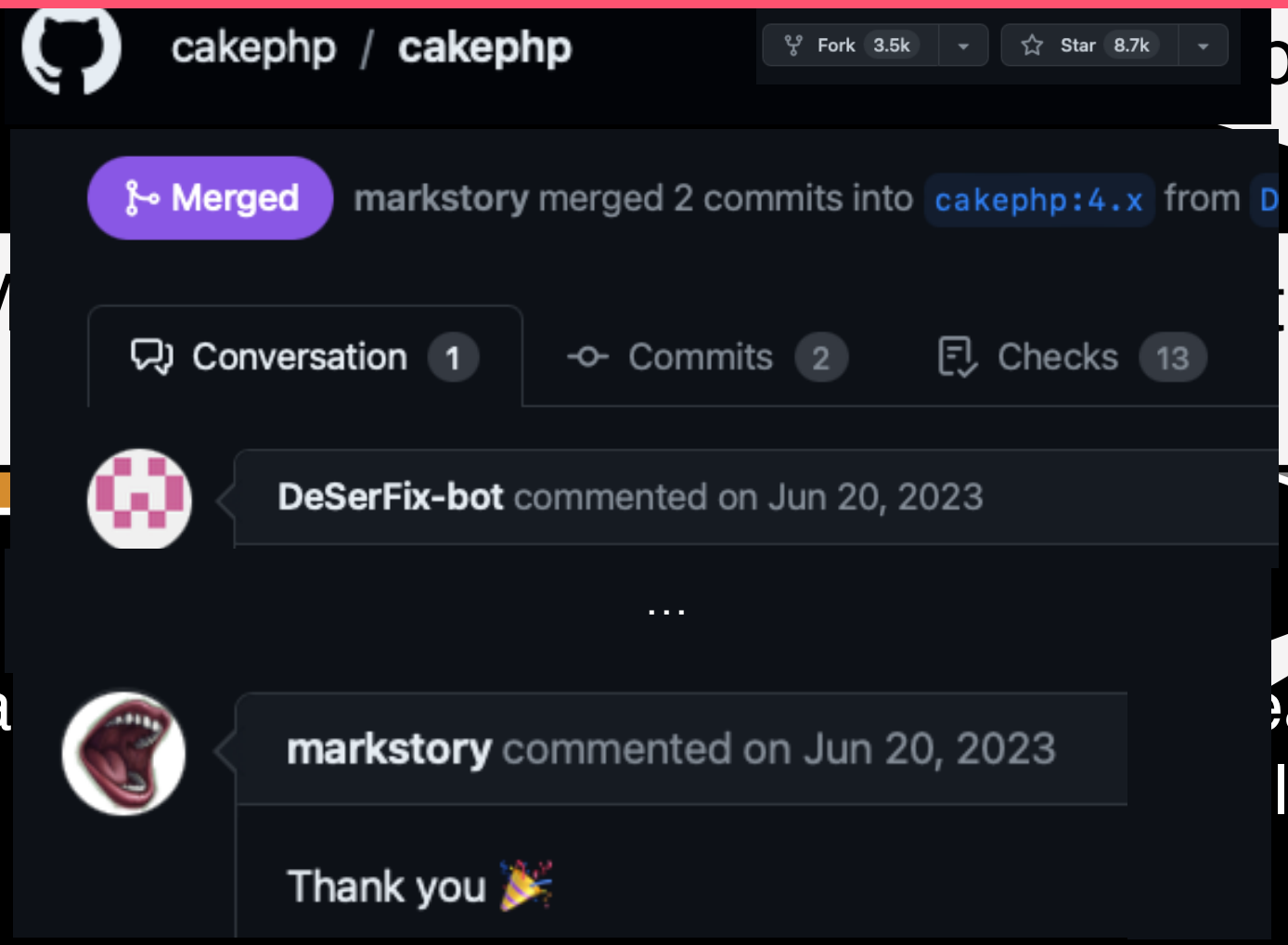

Application (+ Dependenci Code

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Protected
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Attack Surface

Built Qua

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Quack: Hindering Deserialization Attacks

Stops all exploits

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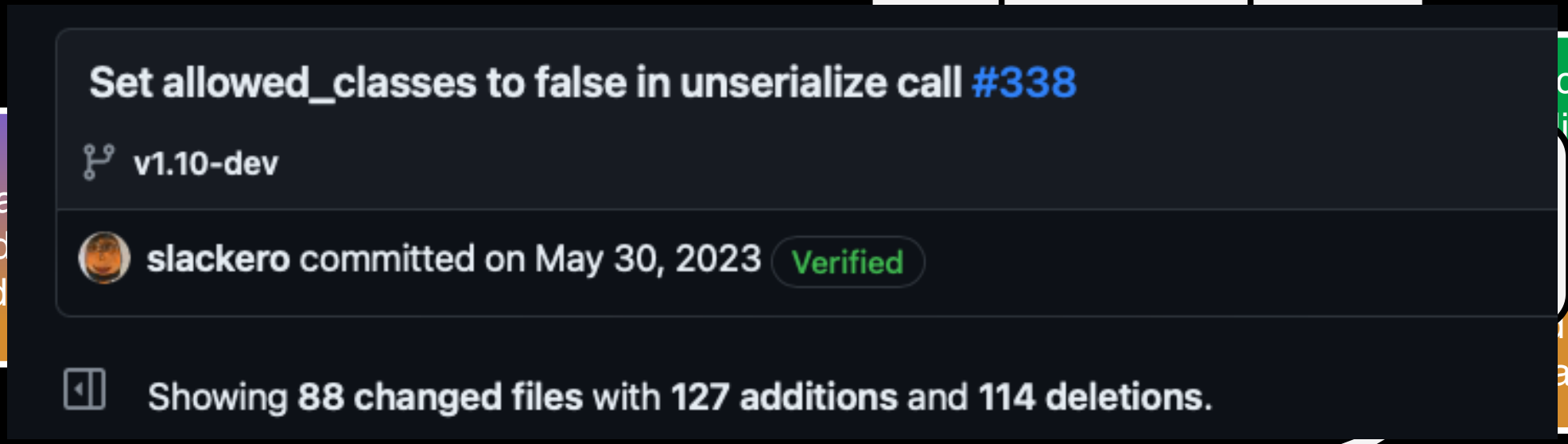

Built Quack-php and eva
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97% blocked exploit-building classes

eal applications
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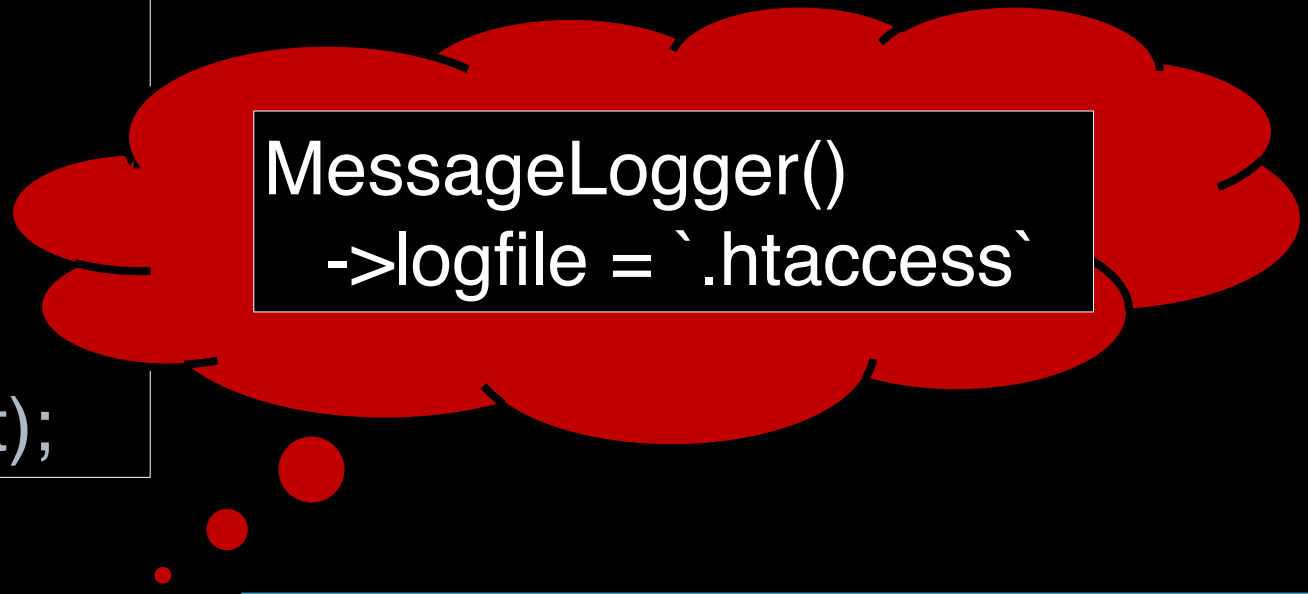


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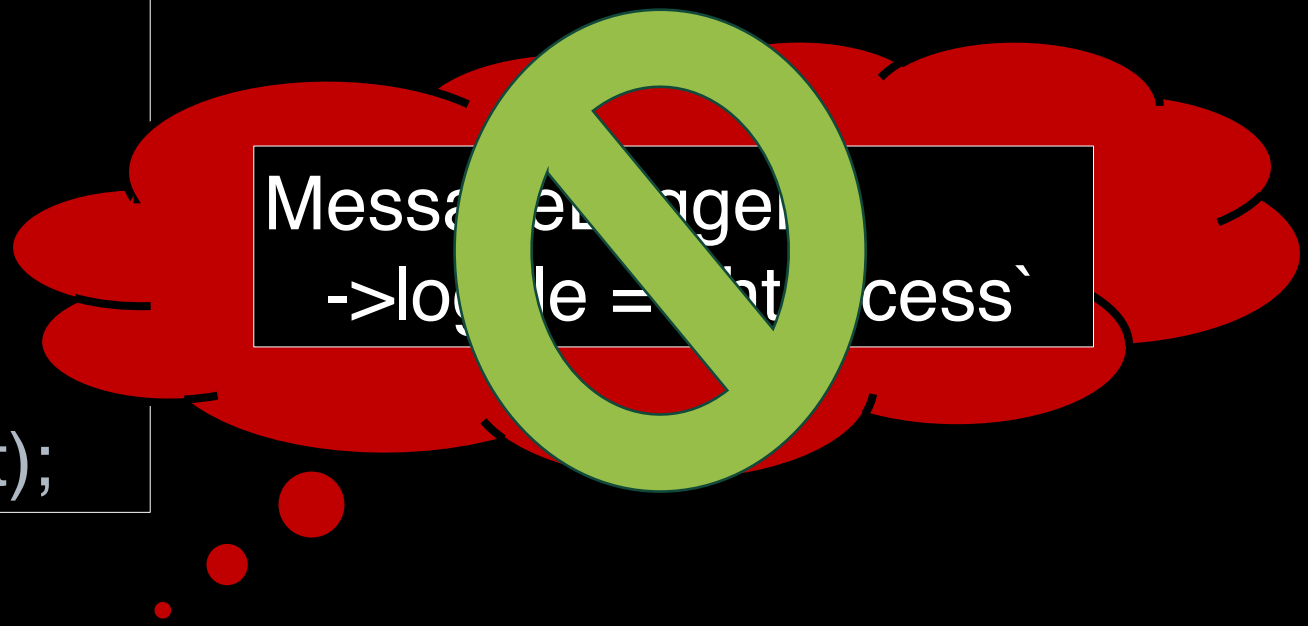

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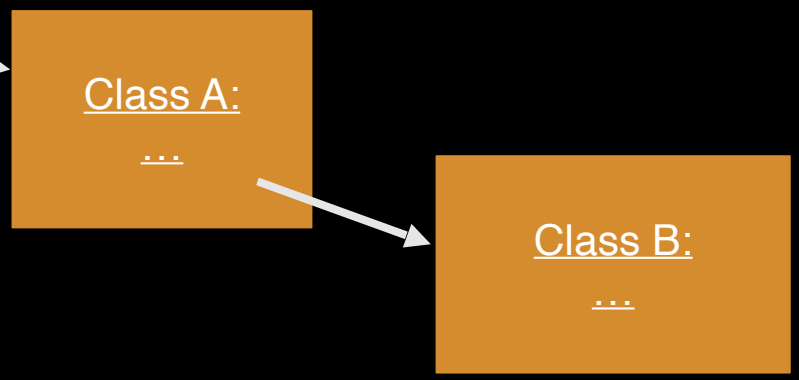


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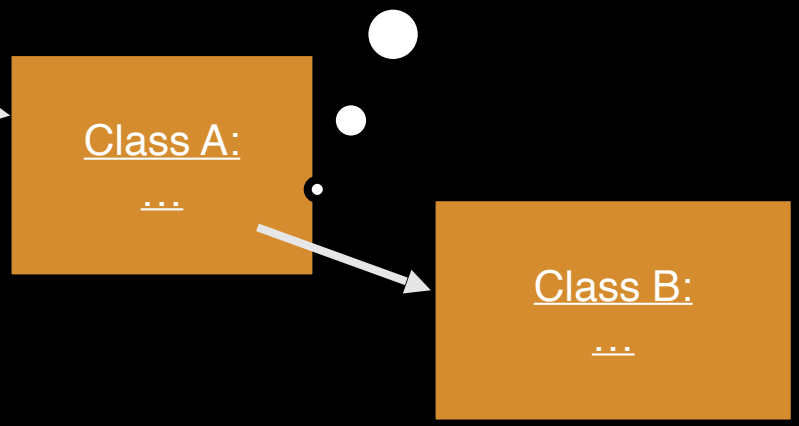


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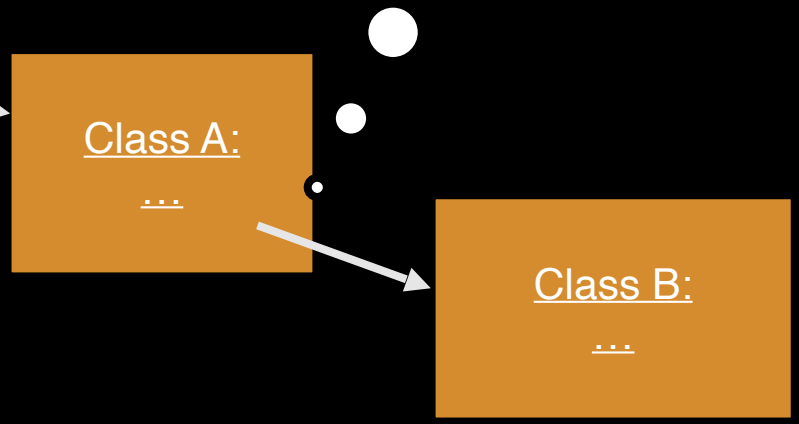


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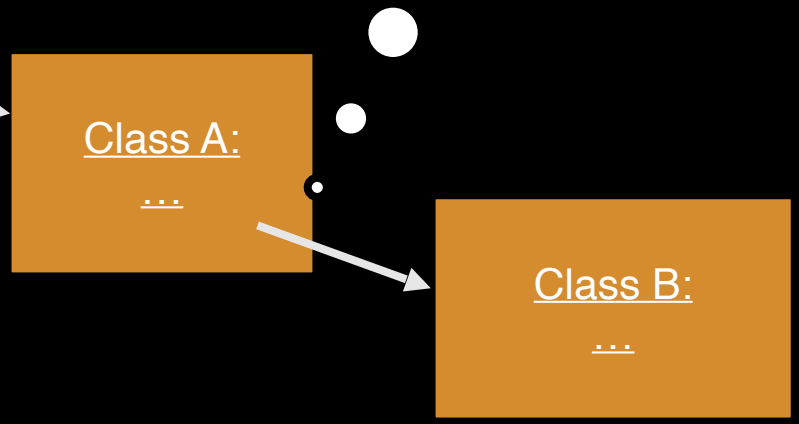


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Key Challenge in Protecting Deserialization API calls

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Type checkers are not geared for this

Key Challenge in Protecting Deserialization API calls

- Infer all types for root objects + fields and collections

Type inference is too conservative

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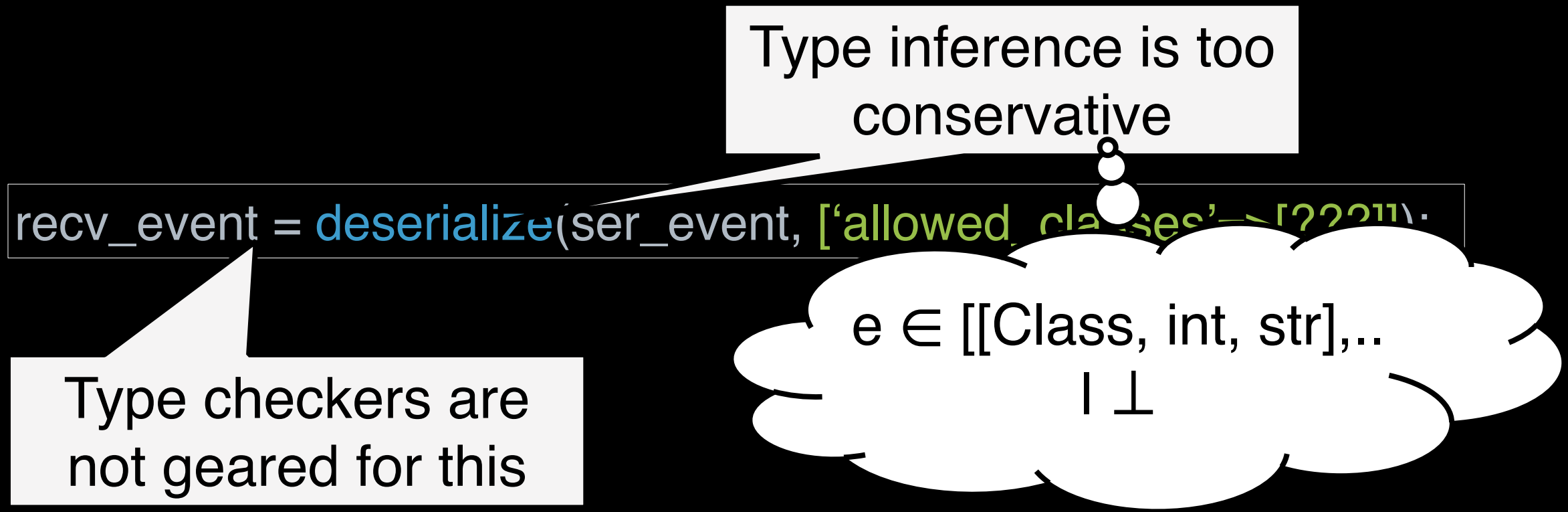

Insight: Infer Classes Using Object's Usage

```
recv_event = deserialize(ser_event, ['allowed_classes'=>??]);
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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();
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Deserialized objects must contain "my_call" and "my_field"

Insight: Infer Classes Using Object's Usage

Decision Point

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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

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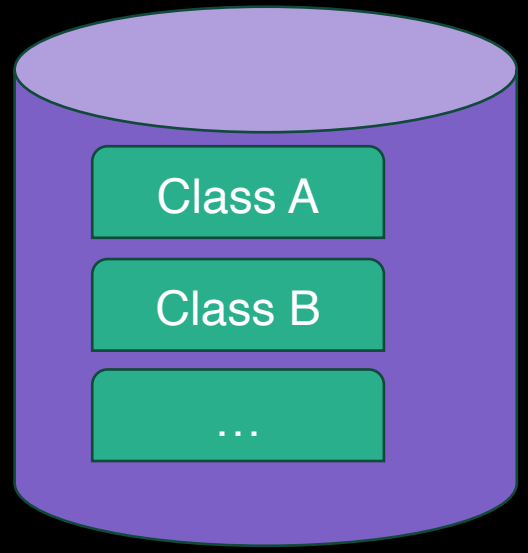

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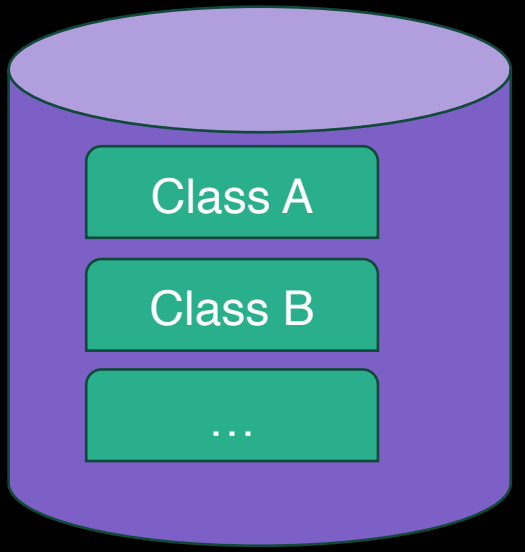

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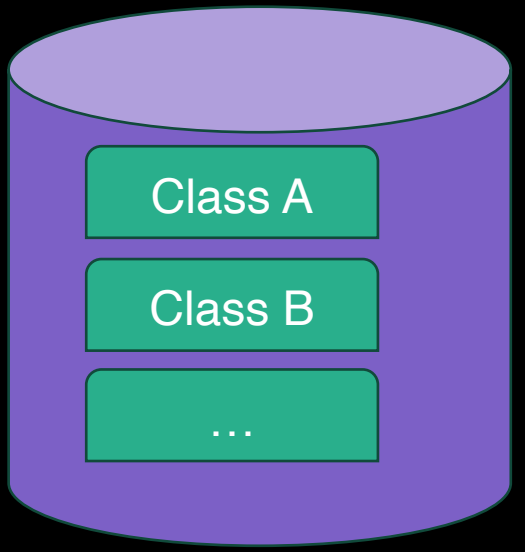

Follow

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eventDispatch.php

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}
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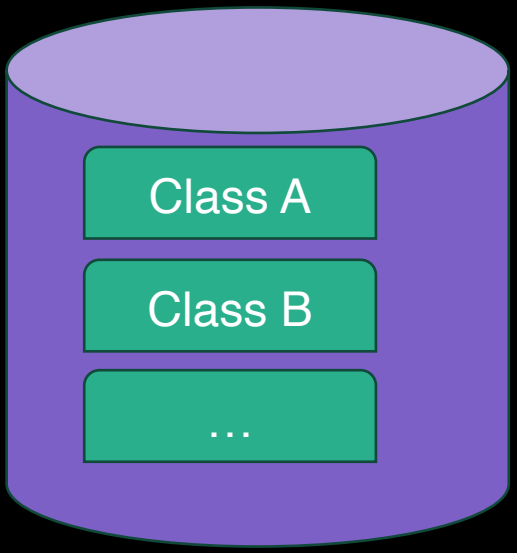

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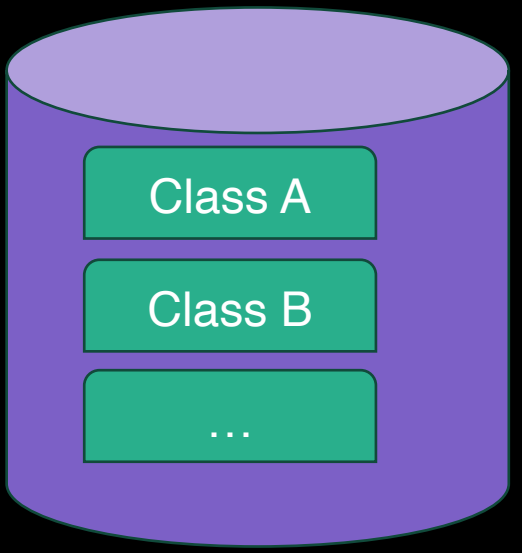
No Type Hint



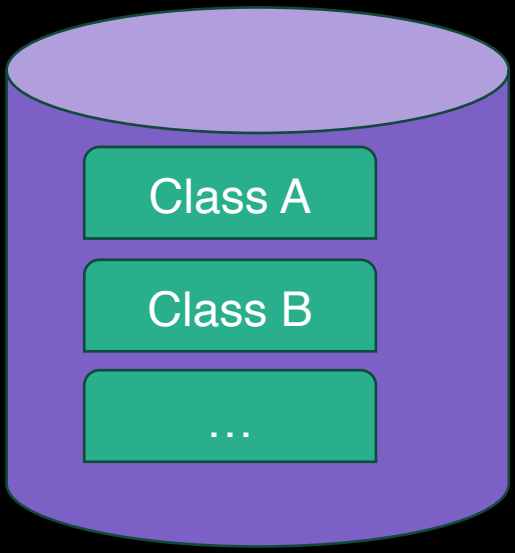
Analyzing Our Motivating Example

eventDispatch.php

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

No Type Hint

Has method with this name



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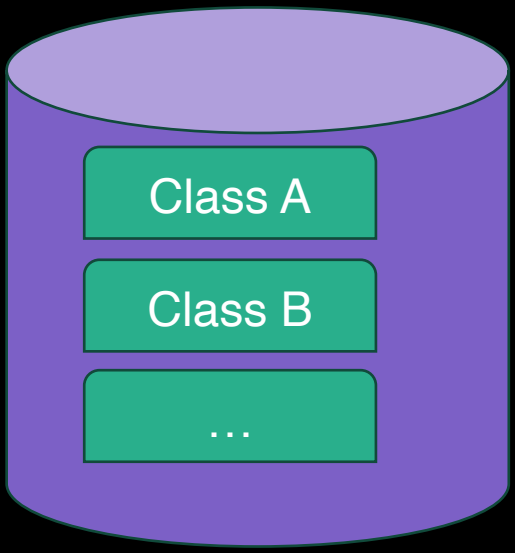

No Type Hint

Has method with this name

Returns *string* or *no-return-type*

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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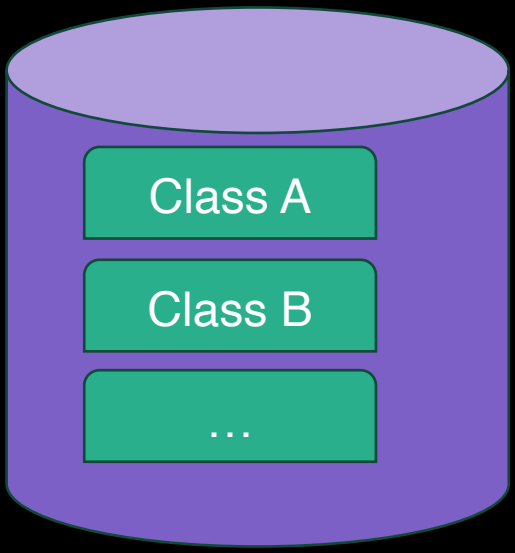

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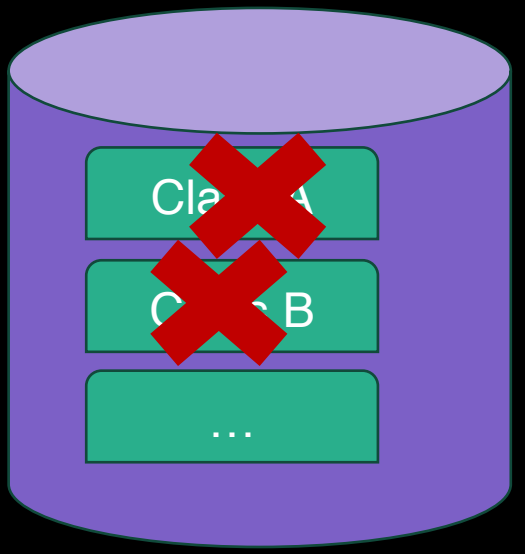

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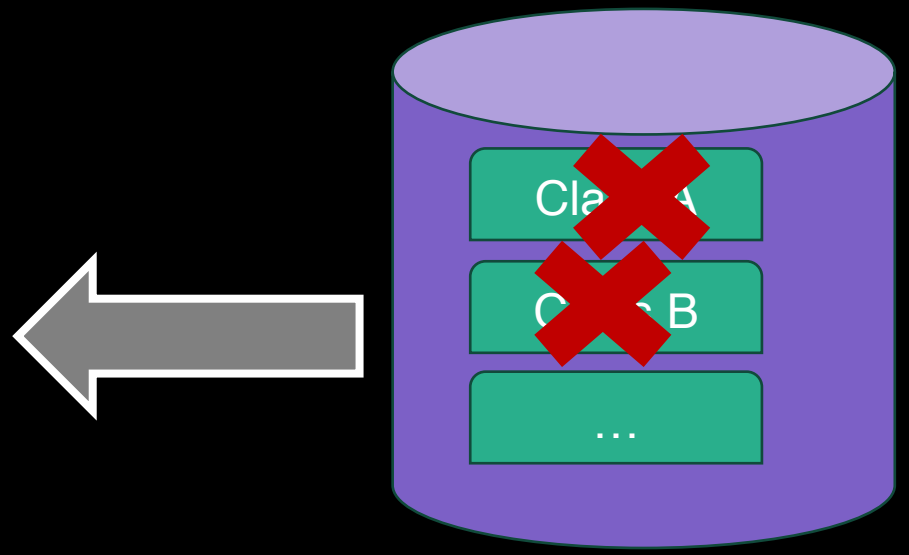

Analyzing Our Motivating Example

event.php

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class owa_event {
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```

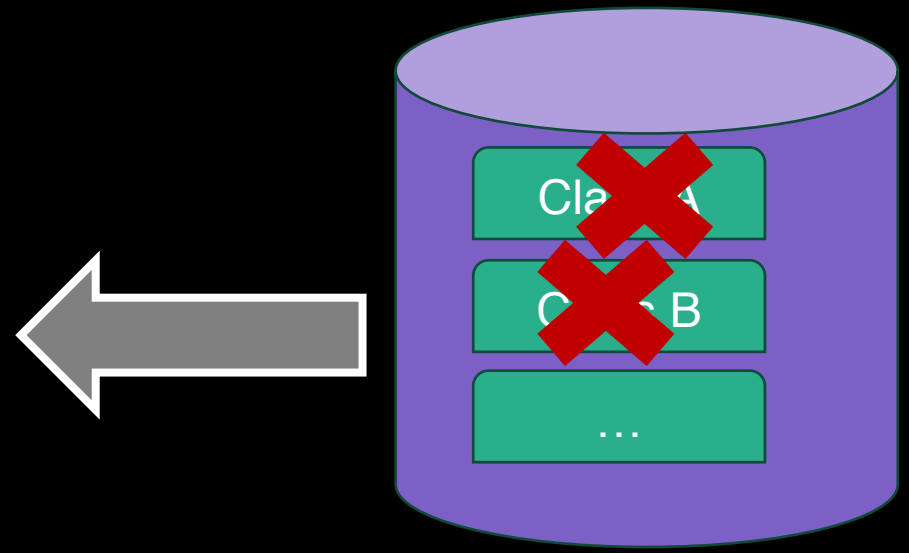

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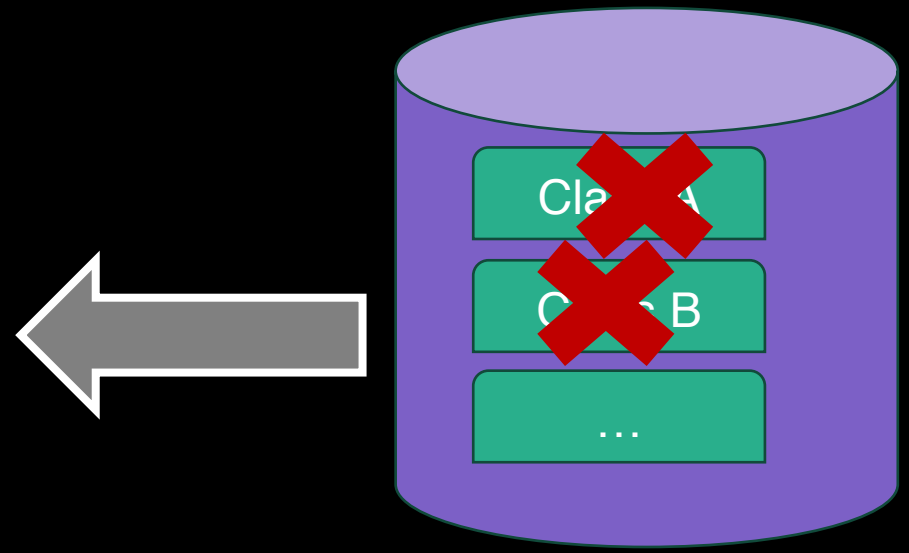

Analyzing Our Motivating Example

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queue.php

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/* snip */
raw_event =    >getLast('event');
event = deserialize(raw_event,
++                  ['allowed_classes' => ['owa_event']]);
owa::getEventDispatcher()->notify(event);
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Stops 14 different exploit chains

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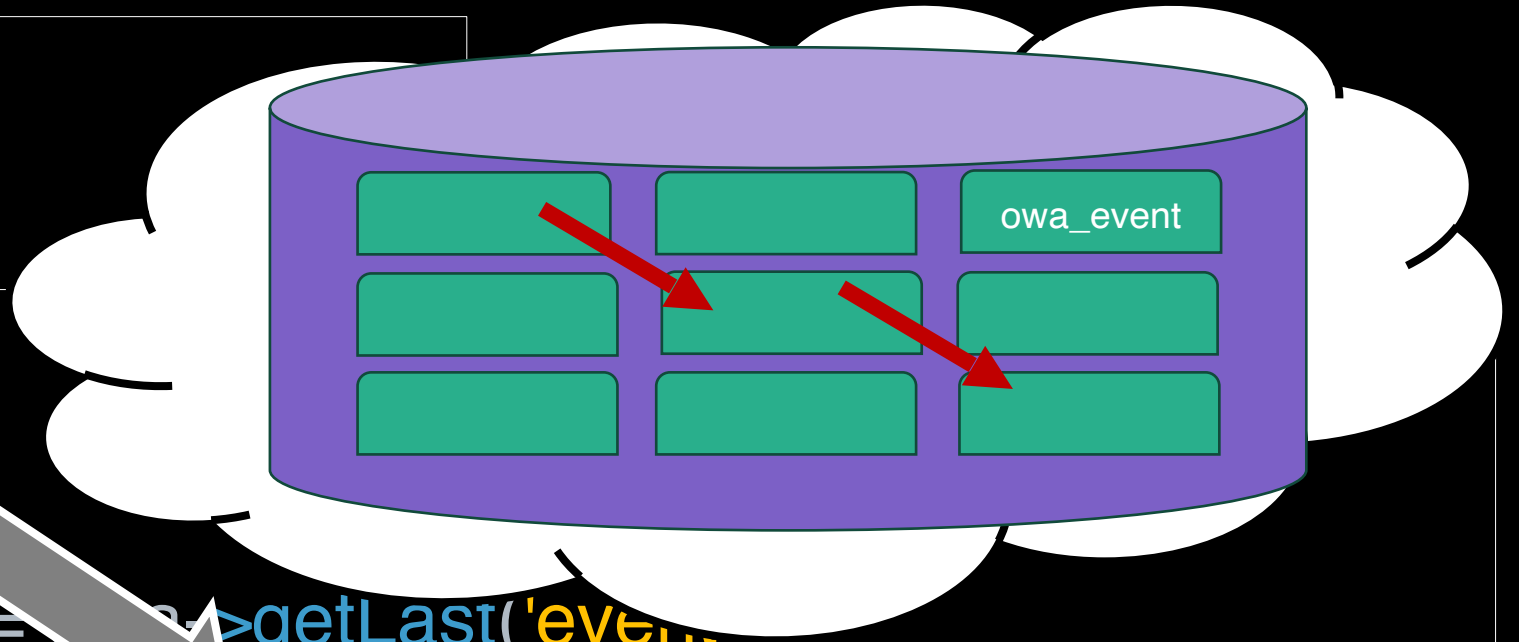


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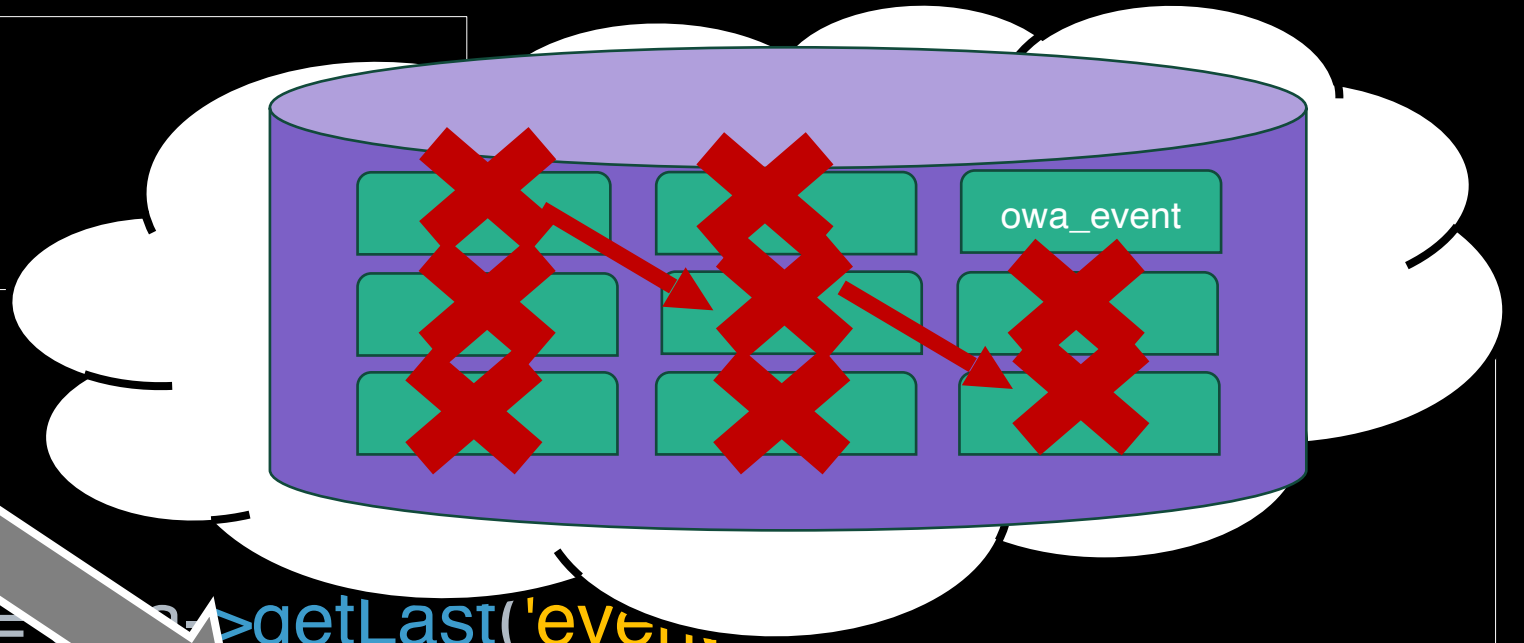

Stops 14 different exploit chains

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	5	79 (55)	100%
VULN202x	10	194(114)	95(8)%

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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	
Piwik 0.4.5	CVE-2009-4137	1	
Joomla-3.0.2	CVE-2013-1453	2	
CubeCart 5.2.0	CVE-2013-1465	1	
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
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Joomla-3.0.2	CVE-2013-1453	2	0
CubeCart 5.2.0	CVE-2013-1465	1	0
Contao CMS 3.2.4	CVE-2014-1860	5	0
Open Web Analytics	CVE-2014-2294	14	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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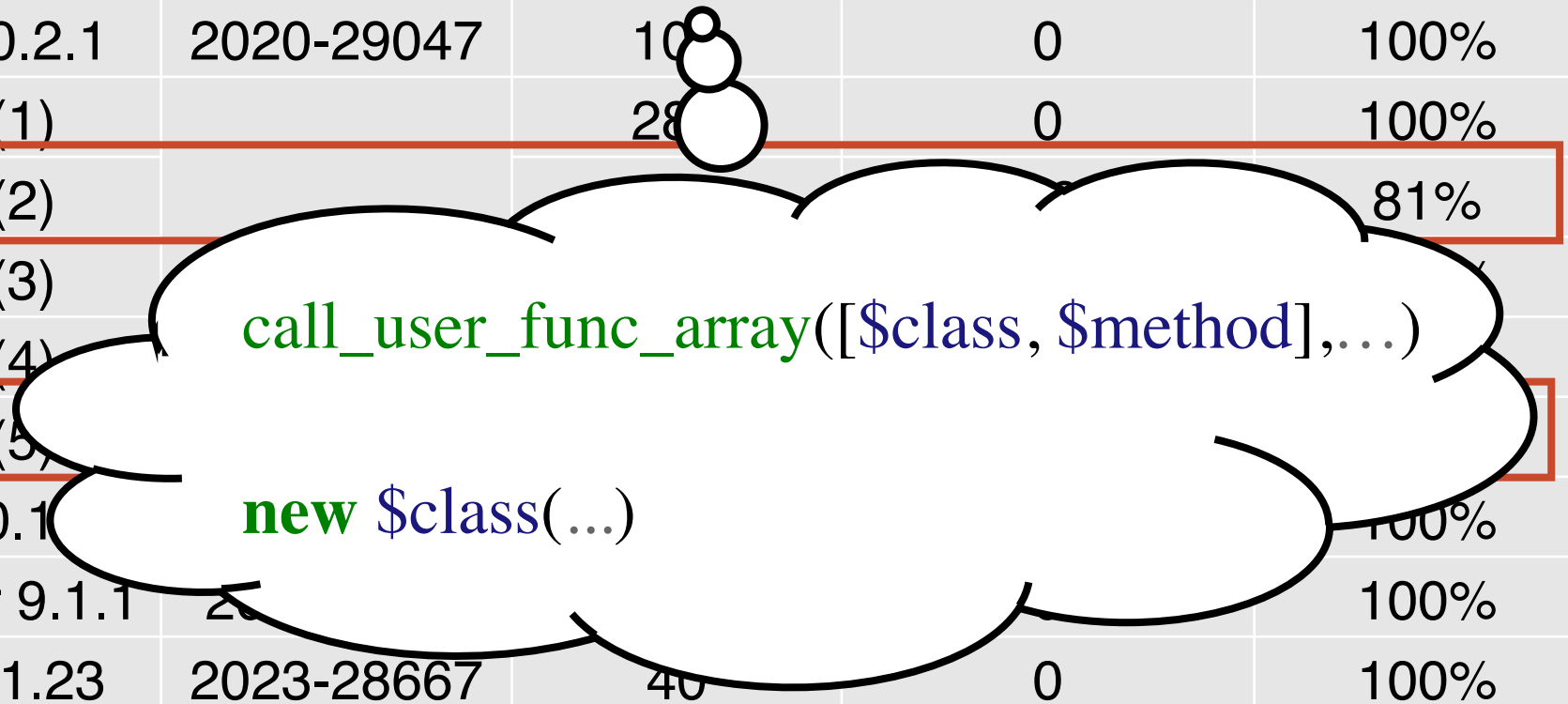

Performance and Safety

Dataset	#CVEs	Exploit-Building Classes [AVG(STD)]	
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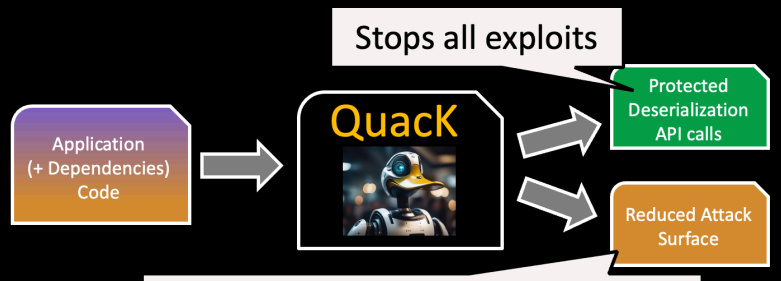
- Favor soundness → **no Negatives**
- Offline project scan: **< 7 minutes**
- Enforcement incurs **negligible overheads**

https://github.com/columbia/quack

Artifact Evaluated
NDSS SYMPOSIUM
Available
Functional
Reproduced

Quack: Securing Applications Against Deserialization Attacks



Stopping Deserialization Exploits

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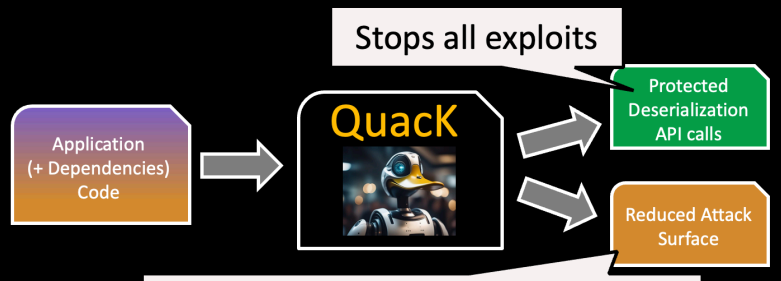

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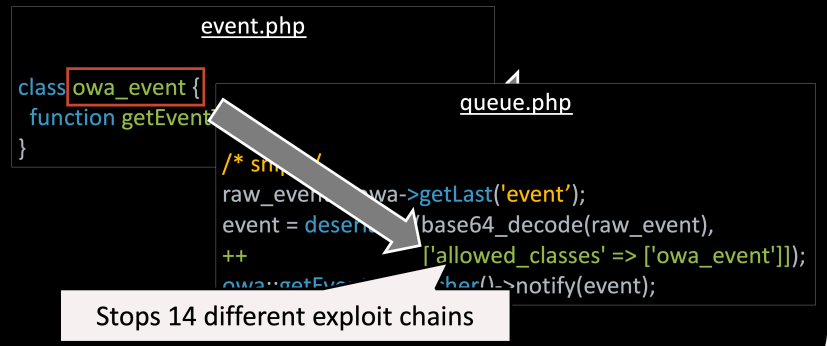

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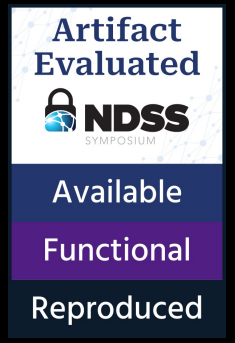
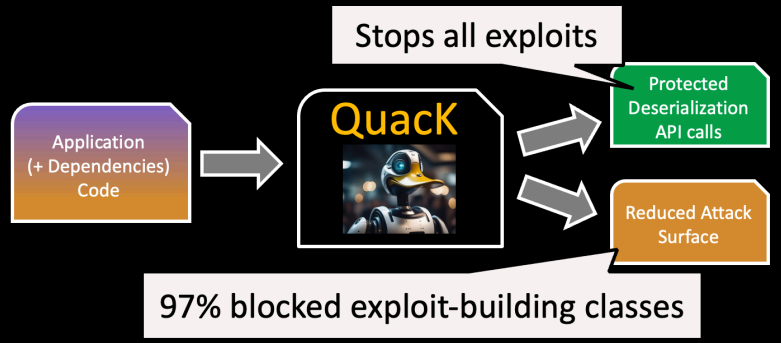


Quack: Securing Applications Against Deserialization Attacks



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