Responding to the Trillion-Dollar Threat of Cybercrime

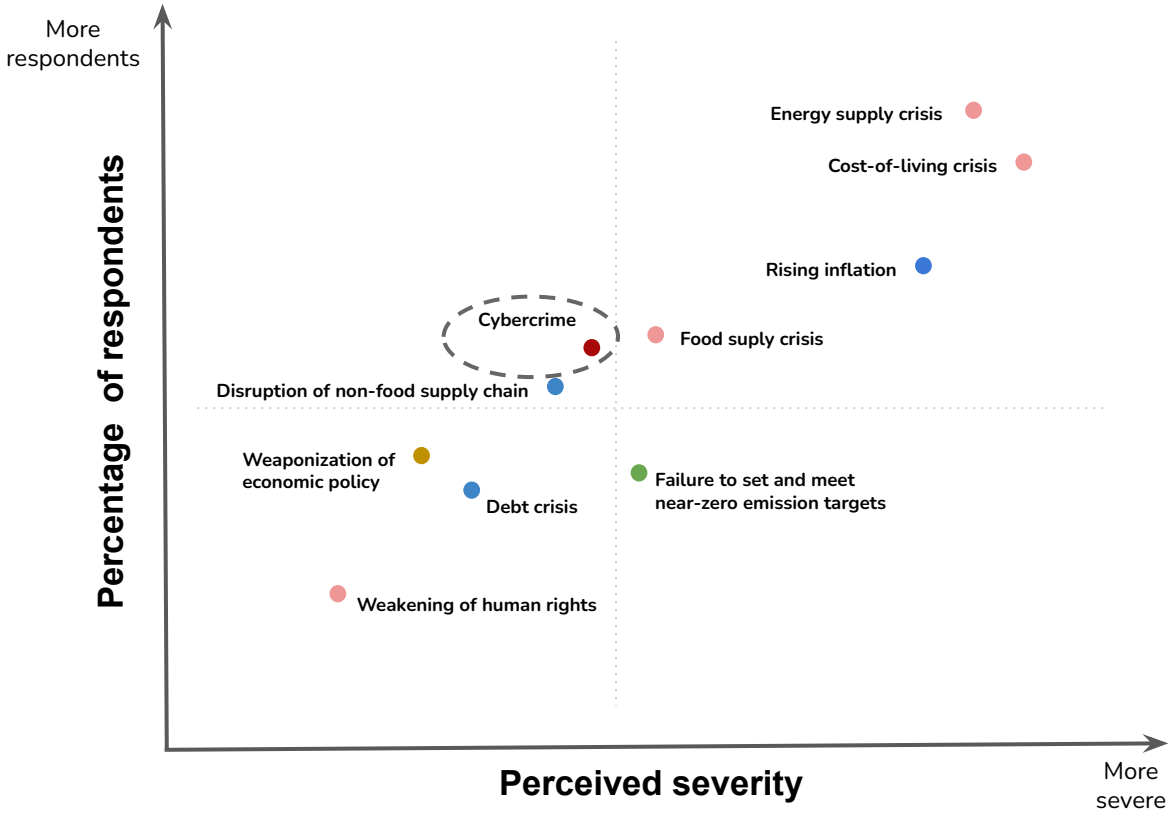
Vaggelis Atlidakis

BROWN

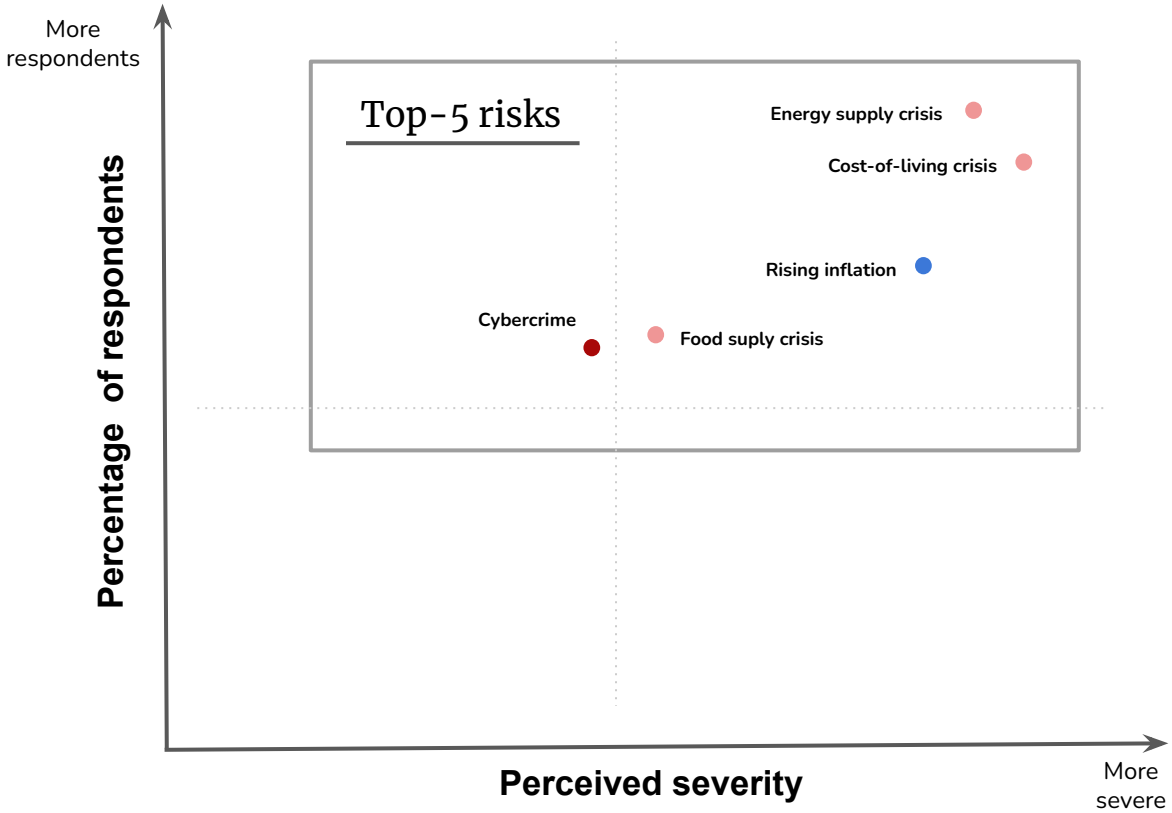
LACEWORK


WORLD
ECONOMIC
FORUM

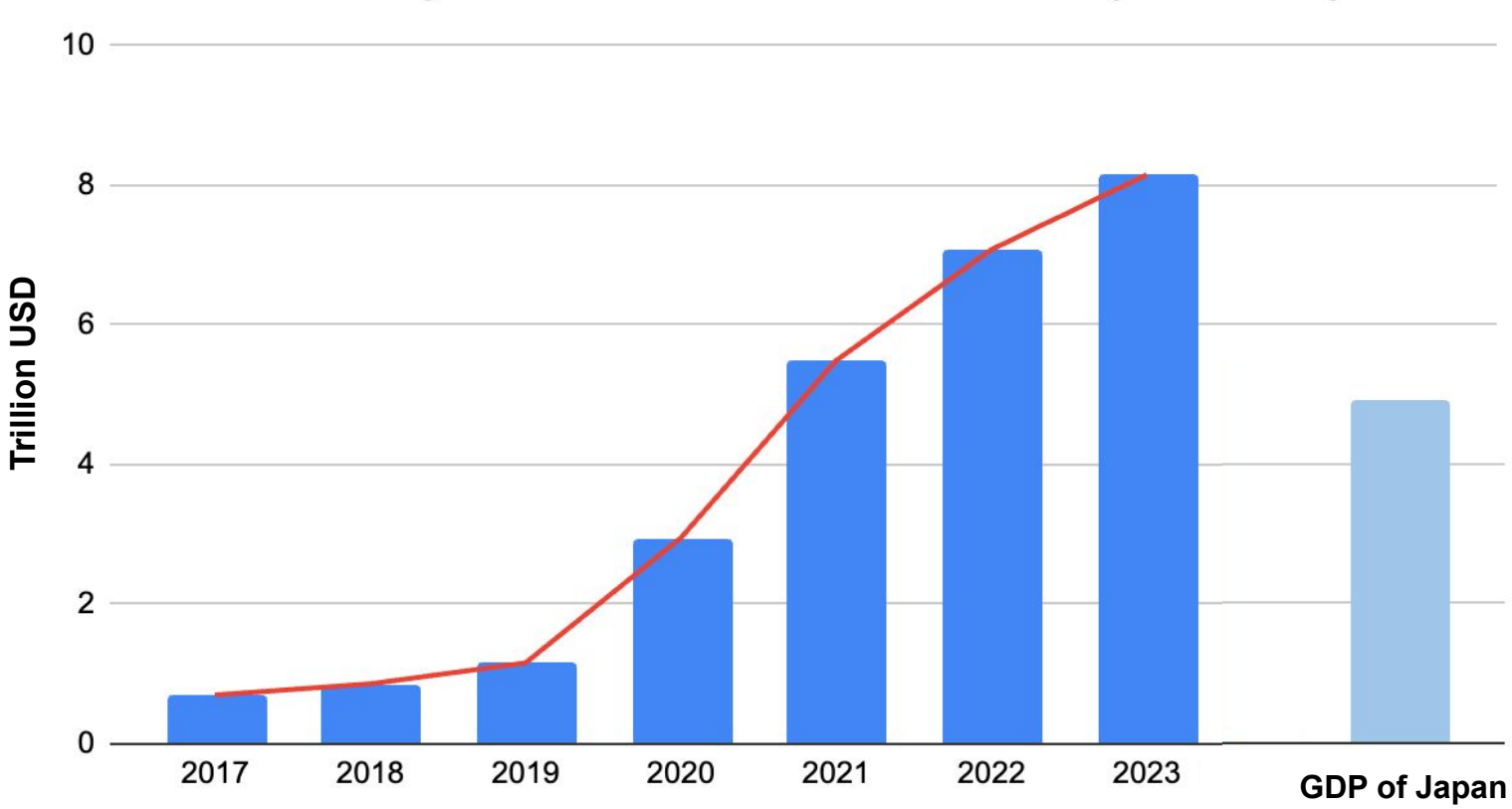
Global Manifesting Risks, World Economic Forum 2022-23



Global Manifesting Risks, World Economic Forum 2022-23



Estimated Cost of Cybercrime, Worldwide 2017-23 (Statistica)



What should we do?

Goal

- Attack surface reduction

Our Arsenal

- Software Testing: *Investigate whether a piece of software manifests undesirable behavior (bugs)*
- Software Hardening: *Enforce the principle of least privilege*
- Risk Management: *Decide what vulnerabilities to focus on (patch) first*

Goal

- Attack surface reduction

Outline

- Software Testing
  - Fairtest [Euro S&P '17]
  - RESTler [ICSE ’19, ICST '20]
  - Cynthia [ICSE ’21]
  - IvySyn [USENIX SEC '23]
- Software Hardening
  - PixelDP [S&P '19]
  - EPF [USENIX ATC '23]
  - FineIBT [RAID '23]
  - Sysxchg [CCS '23]
- Risk Management
  - Lacework

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What

- Cloud services with REST APIs
- Find ``500 Internal Server Errors''

Why

- Past approaches were not automated
- Testing one API request each time

How: *Stateful REST API Fuzzing*

- Generate *stateful* sequences of API requests

Example

A Gitlab test

1. Create a gitlab project
2. Create a file
3. Delete the file

➢ “500 Internal Server Error”

producer of: project-id

```
curl --request POST --header "PRIVATE-TOKEN: <your-token>" \
     --header "Content-Type: application/json" --data '{
        "name": "new_project", "description": "New Project", "path": "new_project",
        "namespace_id": "42", "initialize_with_readme": "true"}' \
     --url "https://gitlab.example.com/api/v4/projects/"
```

project-id: 13083

consumer of: project-id

producer of: file-name

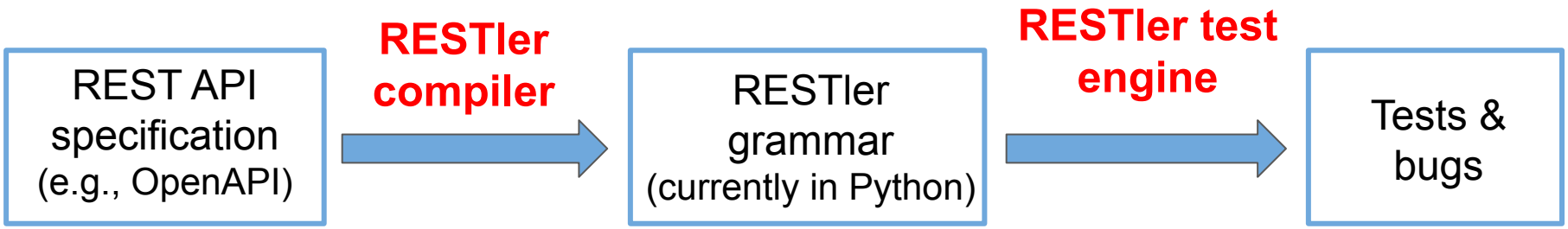
```
curl --request POST --header 'PRIVATE-TOKEN: <your_access_token>' \
     --header "Content-Type: application/json" \
     --data '{"branch": "main", "author_email": "author@example.com", "author_name": "Firstname Lastname",
              "content": "some content", "commit_message": "create a new file"}' \
     "https://gitlab.example.com/api/v4/projects/13083/repository/files/app%2Fproject%2Erb"
```

consumer of: project-id, file-name

file-name: app/project.rb

```
curl --request DELETE --header 'PRIVATE-TOKEN: <your_access_token>' \
     --header "Content-Type: application/json" \
     --data '{"branch": "main", "author_email": "author@example.com", "author_name": "Firstname Lastname",
       "commit_message": "          "}' \
     "https://gitlab.example.com/api/v4/projects/13083/repository/files/app%2Fproject%2Erb"
```

Overview



- Identify producer-consumer relationships
- Generate code to parse responses

- Generate tests (state-space exploration)
- Drop invalid requests

Selected evaluation results

- Q1: Do RESTler tests help increase code coverage?
- Q2: Sample bugs?

Study subject: Gitlab

Deeper service exploration (Q1)

API Family	Total API Requests	Seq. Len.	Code Coverage (lines of code)	Tests
Gitlab	15 (*11)	1	598	1
Commits		2	1108	7
		3	1196	250
		4	1760	2220
		…	…	…

Testing APIs with RESTler (5h per API family)

- Longer sequences increase service-side code coverage

Deeper service exploration (Q1)

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Testing APIs with RESTler (5h per API family)

- ❖ Longer sequences increase service-side code coverage
- ❖ Progress in large search space

Example: Testing for 5 hours

- ➢ **Brute-force**: 741 million sequences
- ➢ **RESTler:** 2220 total test sequences
  - ✓ Producer-consumer request dependencies
  - ✓ Dynamic service feedback

Bugs found with RESTler (Q2)

Gitlab Bug [#50268]

1. Create a gitlab project
2. Create a file with a proper commit message
3. Delete the file with an empty commit message

➢ “500 Internal Server Error”

➢ Found 28 confirmed such bugs in Gitlab

➢ …and more in production Azure cloud services

Checking Security Properties of RESTful Cloud Services

What

- Find errors that don't cause ``500 Internal Server Errors''

Why

- Not everything is visible from response status codes
- Security-relevant issues may be going unnoticed

How: *Augment Stateful REST API Fuzzing*

- Introduce security rules and check for violations

Selected security rules

- Use-after-free rule
  1. Delete /api/projects/1
  - ➢ Access /api/projects/1 **MUST FAIL**

- Resource-hierarchy rule
  1. Create /api/projects/1 and /api/projects/2
  2. Create /api/projects/1/branches/1
  - ➢ Access /api/projects/2/branches/1 **MUST FAIL**

- Resource-leakage rule
  1. Create /api/projects/1 and receive error code (e.g., 404 or 500 HTTP status)
  - ➢ Access /api/projects/1 **MUST FAIL**

Selected security rules

- Use-after-free rule
  1. Delete /api/projects/1
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We've just augmented stateful REST API fuzzing with active property checking!

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What

- Memory safety errors in Deep Learning (DL) frameworks

Why

- Core of DL frameworks is implemented in C/C++
- Past approaches required manual effort and domain knowledge

How: A bottom-up approach

- Find a crash in the native part
- Synthesize python code reproducing the crash

Example

Native (*kernel*) implementation

```
class EditDistanceOp : public OpKernel {
  void Compute(OpKernelContext* ctx) override {
  // ...
  if (g_truth == g_hypothesis) {
  auto loc = std::inner_product(g_truth.begin(),
     g_truth.end(), output_strides.begin(),
     int64_t{0});
  OP_REQUIRES(
      loc < output_elements,
      errors::Internal("..."))
  output_t(loc) =
      gtl::LevenshteinDistance<T>(truth_seq,
        hypothesis_seq, cmp);
  // ...
```

Triggers a crash

from public python APIs

Proof-of-Vulnerability (PoV)

```
hypothesis_indices = tf.constant(-125099896764,
                     shape=[3,3], dtype=tf.int64)
hypothesis_values  = tf.constant(0,
                     shape=[3], dtype=tf.int64)
hypothesis_shape   = tf.constant(0,
                     shape=[3], dtype=tf.int64)
truth_indices      = tf.constant(0,
                     shape=[2,3], dtype=tf.int64)
truth_values       = tf.constant(-1879048192,
                     shape=[2], dtype=tf.int64)
truth_shape        = tf.constant(2,
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tf.raw_ops.EditDistance(
    hypothesis_indices = hypothesis_indices,
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    hypothesis_shape   = hypothesis_shape,
    truth_indices      = truth_indices,
    truth_values       = truth_values,
    truth_shape        = truth_shape)
```

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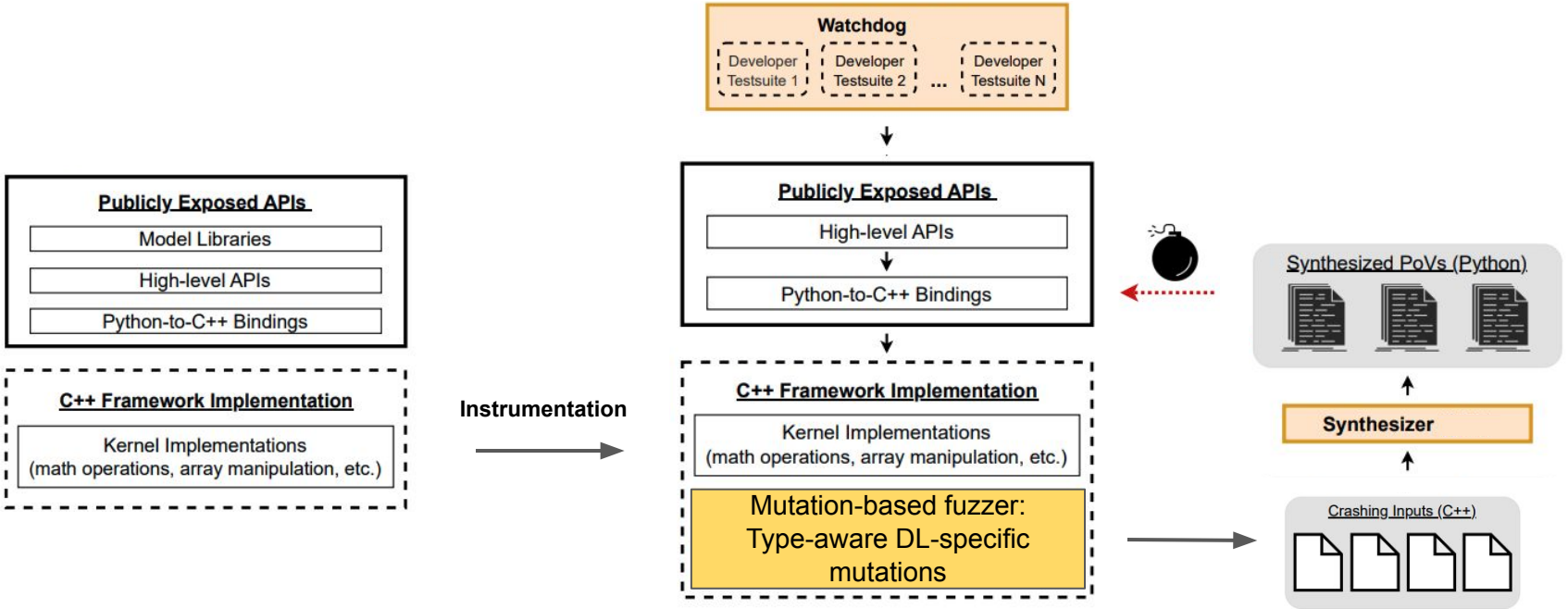
Watchdog
Developer Testsuite 1
Developer Testsuite 2
...
Developer Testsuite N
Publicly Exposed APIs
Model Libraries
High-level APIs
Python-to-C++ Bindings
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Instrumentation
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Kernel Implementations (math operations, array manipulation, etc.)
Mutation-based fuzzer: Type-aware DL-specific mutations
Synthesized PoVs (Python)
Synthesizer
Crashing Inputs (C++)

Selected evaluation results

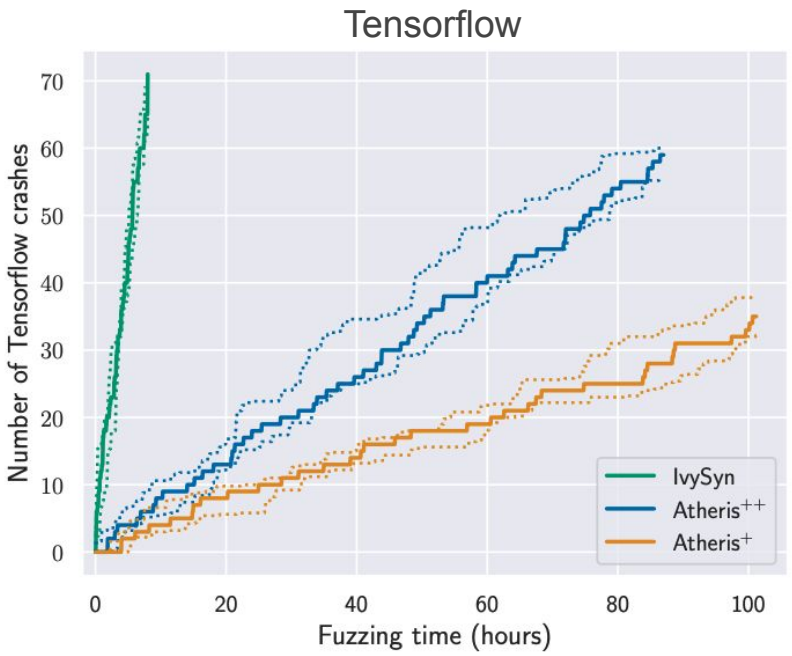
- Q1: How quickly can IvySyn find crashes?
- Q2: How effective is IvySyn in synthesizing PoVs?

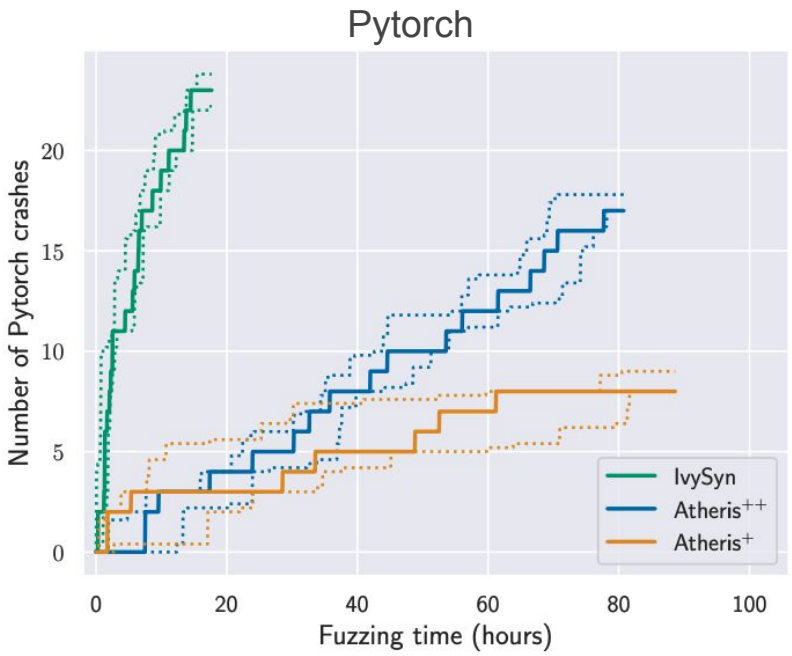
Target Frameworks: Tensorflow and Pytorch

Against *Atheris*: https://github.com/google/atheris

- ***Atheris*+**: Default *Atheris* + automation
- **Atheris++**: Default *Atheris* + automation + type-aware
- **IvySyn:** Type-aware + DL-specific mutations

Efficiency in finding crashing inputs (Q1)





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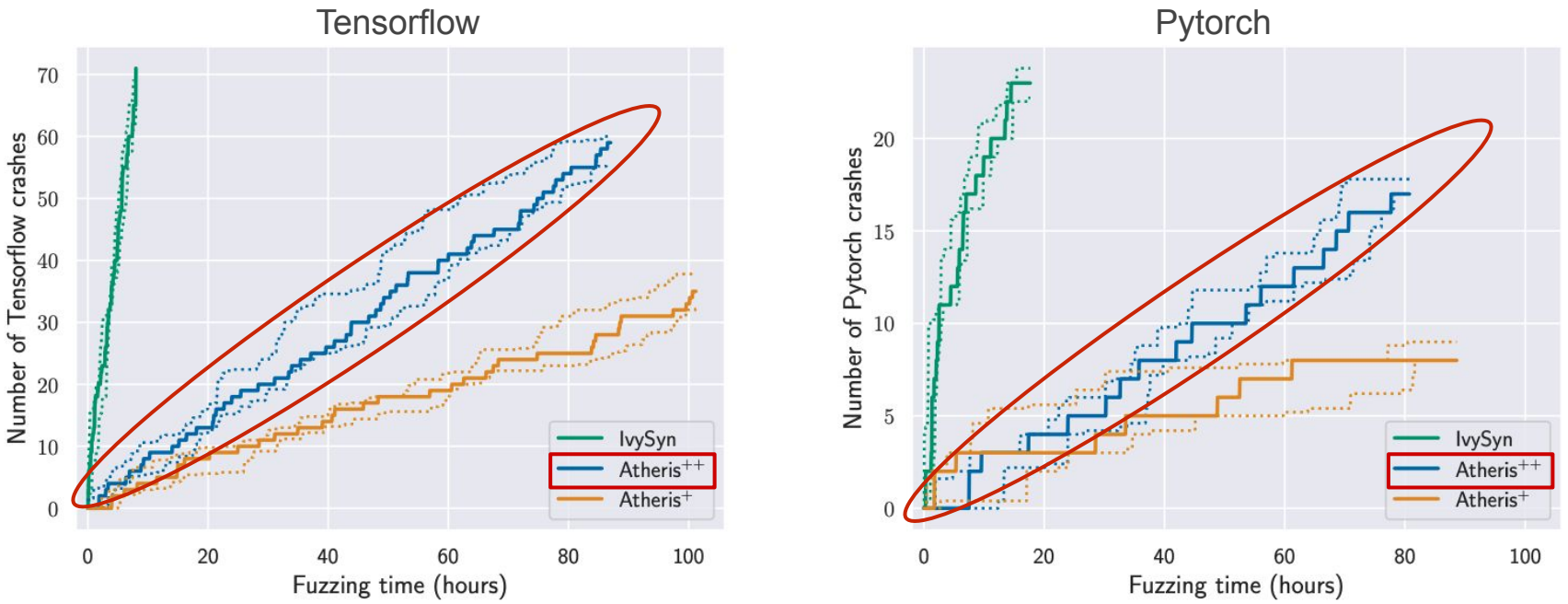
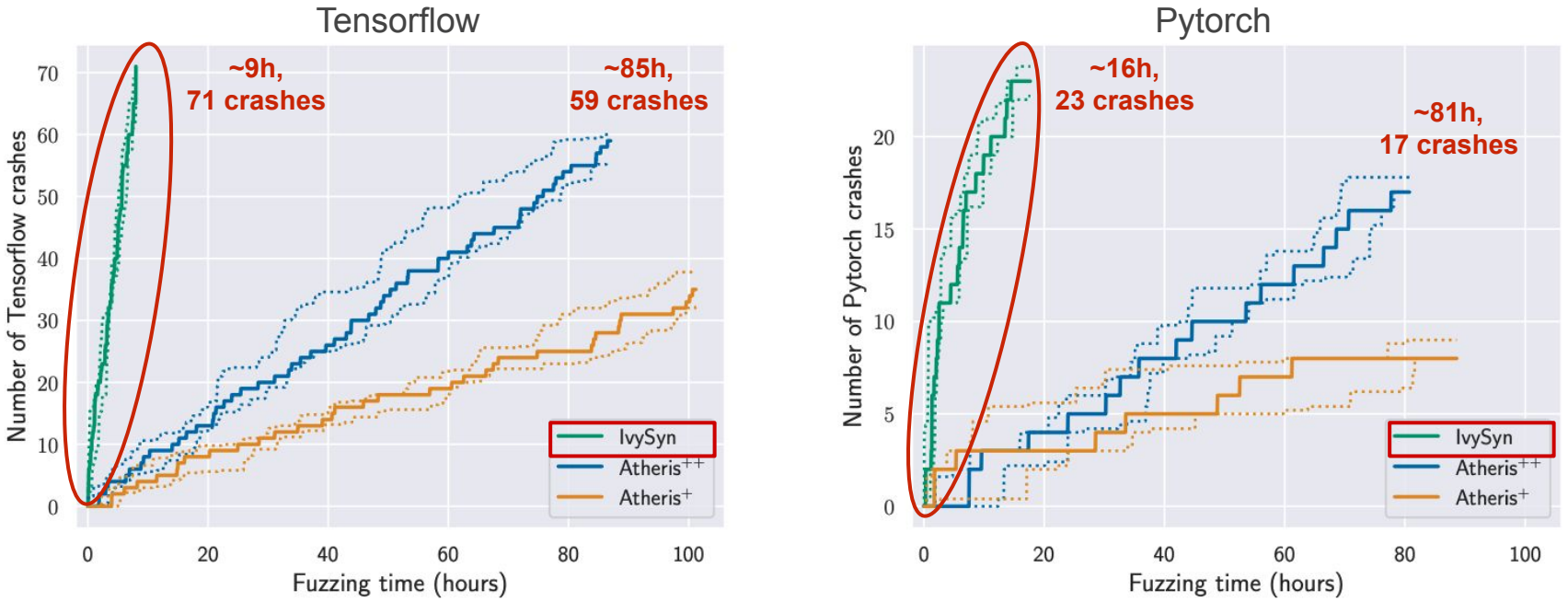


Efficiency in finding crashing inputs (Q1)



Effectiveness in synthesizing PoVs (Q2)

Framework	Fuzzed Kernels	Unique Crashes	Synthesized PoVs
Tensorflow	412	103	86 / 103 (83%)
Pytorch	747	81	49 / 81 (60%)
All	1159	184	135 / 184 (73%)

- Synthesized 135 PoVs
- Identified 61 previously-unknown vulnerabilities
- Assigned with 39 unique CVEs

https://gitlab.com/brown-ssl/ivysyn

```
import tensorflow as tf
hypothesis_indices = tf.constant(-125099896764,
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  void Compute(OpKernelContext* ctx) override {
  // ...
  if (g_truth == g_hypothesis) {
  auto loc = std::inner_product(g_truth.begin(),
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  OP_REQUIRES(
      ctx,
      0 <= loc &&
      loc < output_elements,
      errors::Internal("..."))
  output_t(loc) =
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  // ...
```

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↓ Top down (start from the APIs)

↑ Bottom up (start from native implementations)

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What

- A process must not have access to more syscalls than it needs

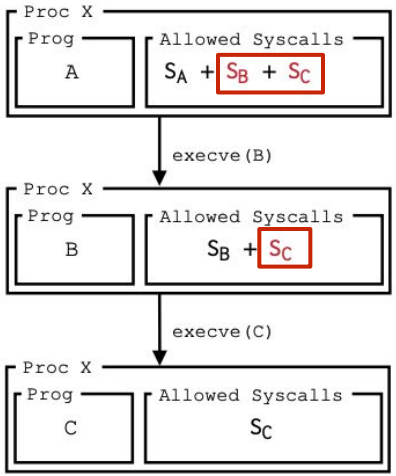
Why

- Linux kernel v6.0.8 provides ~400 sycalls
- Seccomp-BPF approaches: parent overpriviledge

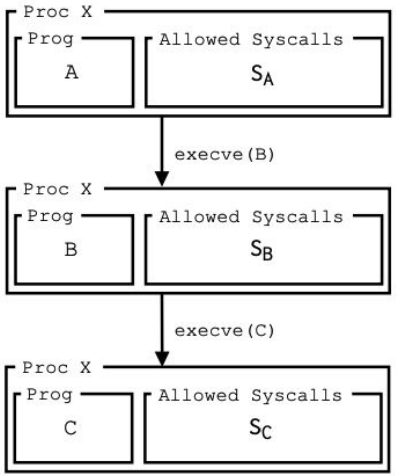
How: Process-specific syscall filters

Overview

Inherited filters

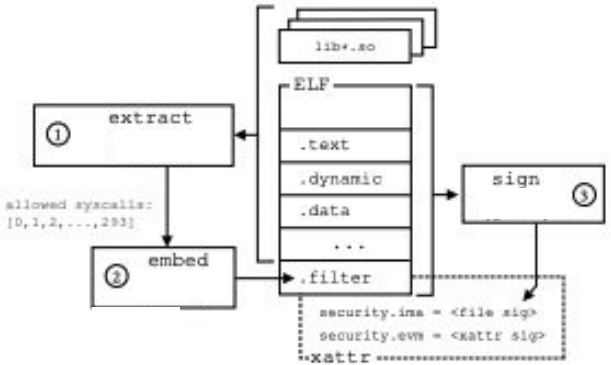


Adaptive *exec* filters

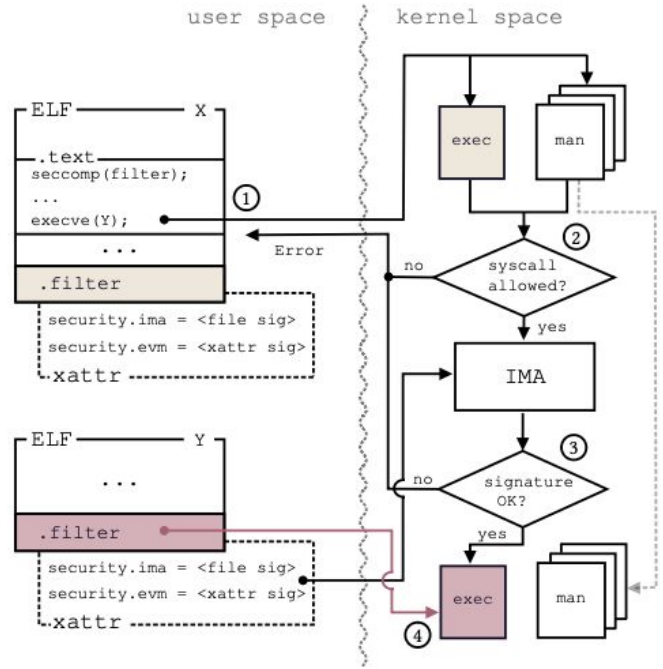


SysXCHG components

Offline phase



Online phase



https://gitlab.com/brown-ssl/sysxchg (Linux kernel v6.0.8, ≈ 600 LOC in C)

Selected results on the PaSh benchmark

Benchmarks	No of children	*Inhertance* model	*SysXCHG* model	Overpriviledge reduction	Unnecessary funct. (examples)	Critical
bi-grams	11	122	84	45%	{c,d,r}path chown	✓
shortest-scripts	8	108	84	28%	fattr id proc	✓
…	…	…	…	…	…	…
→	1	60	51	17%	{c,tmp}path proc	✓
AUR Package Compilation	69	176	84	109%	protexec vminfo …	✓
….	…	…	…	…	…	…
→	3	123	74	66%	{c,d,r,w}path chown …	✓
Wikipedia Web Indexing	16	146	84	73%	chown fattr protexec	✓

*PaSh: Light-touch Data-Parallel Shell Processing [Vasilakis et al., EuroSys '21]

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➢ CPU overhead is ~1.7%

*PaSh: Light-touch Data-Parallel Shell Processing [Vasilakis et al., EuroSys '21]

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- ➢ Vulnerability Risk Management

  ⇒ ~~**Lacework**~~

Disclaimer: This work is a Lacework product, led by Patrice Godefroid and Geremy Condra, and was started before I joined Lacework.

https://www.lacework.com/blog/why-active-vulnerability-detection-is-a-game-changer-for-vulnerability-risk-management/

What

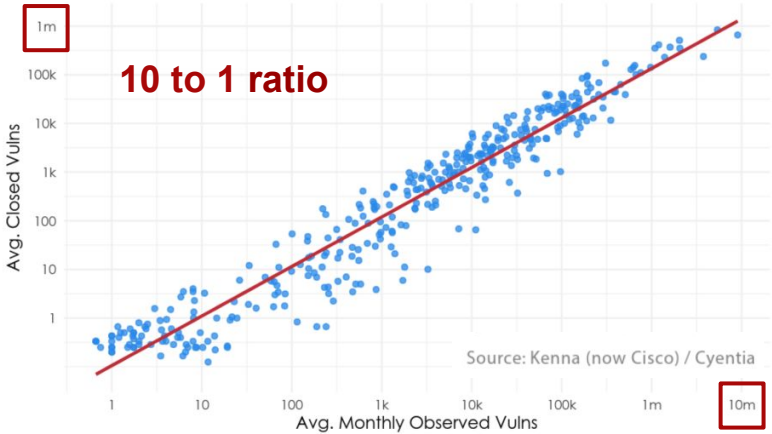
- Select what vulnerabilities to patch first

Why

- We cannot patch everything

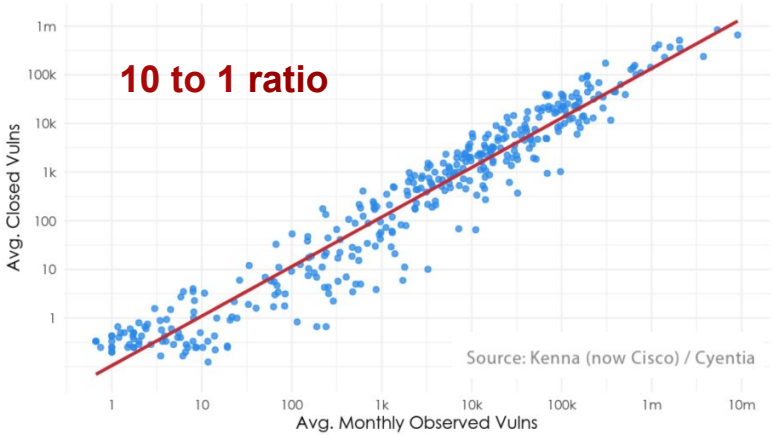
The drama of unpatched vulnerabilities

Accumulation velocity

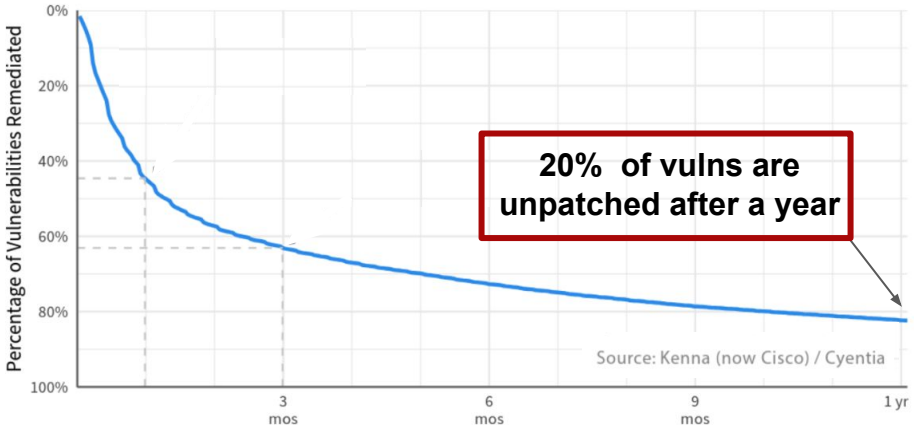


The drama of unpatched vulnerabilities

Accumulation velocity



Remediation velocity



What

- Select what vulnerabilities to patch first

Why

- We cannot patch everything

How: *Active Vulnerability Management*

Results on package (in) activity

➢ **Study Subject:** ~2.5K host machines over 2 weeks

❖ Unique host packages: 1361
  I. Vulnerable: **478**
  II. Active: 235
  III. Vulnerable & Active: **98**

❖ Active vulnerability management: From 478 to 98 there is a **79%** reduction
  ➢ Monitor package activity in production

https://www.lacework.com/blog/why-active-vulnerability-detection-is-a-game-changer-for-vulnerability-risk-management/

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- ➢ Vulnerability Risk Management
  - ✓ **Lacework**

- Software Testing
  - ✓ Fairtest [Euro S&P '17]
  - ✓ **RESTler [ICSE '19, ICST '20]**
  - ✓ Cynthia [ICSE '21]
  - ✓ **IvySyn [USENIX SEC '23]**
- Software Hardening
  - ✓ PixelDP [S&P '19]
  - ✓ EPF [USENIX ATC '23]
  - ✓ FineIBT [RAID '23]
  - ✓ **Sysxchg [CCS '23]**
- Vulnerability Risk Management
  - ✓ **Lacework**

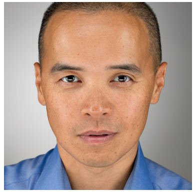
Goal

- Attack surface reduction

Thanks to all of them !!!




















金迪