DOM-XSS Detection via Webpage Interaction Fuzzing and URL Component Synthesis

Nuno Sabino, Darion Cassel, Rui Abreu, Pedro Adão, Lujo Bauer and Limin Jia

Carnegie Mellon University

TÉCNICO LISBOA

U. PORTO
FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

DOM-based Cross-Site Scripting (DOM-XSS)

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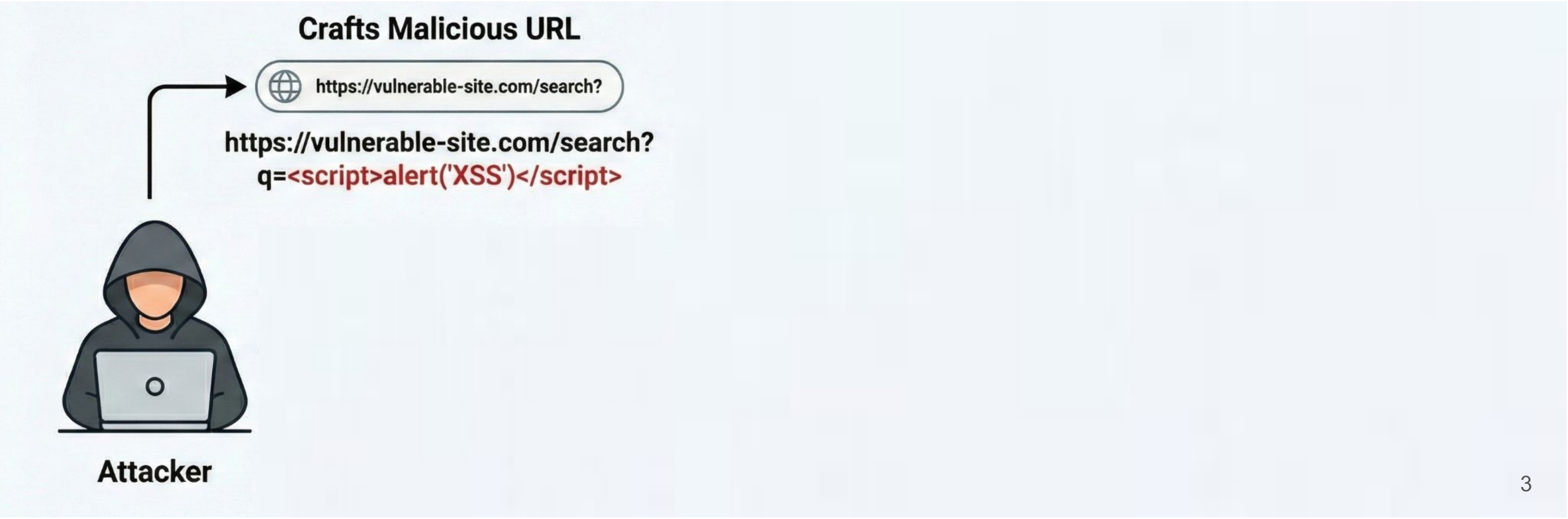

```
https://vulnerable-site.com/search?
q=<script>alert('XSS')</script>
```

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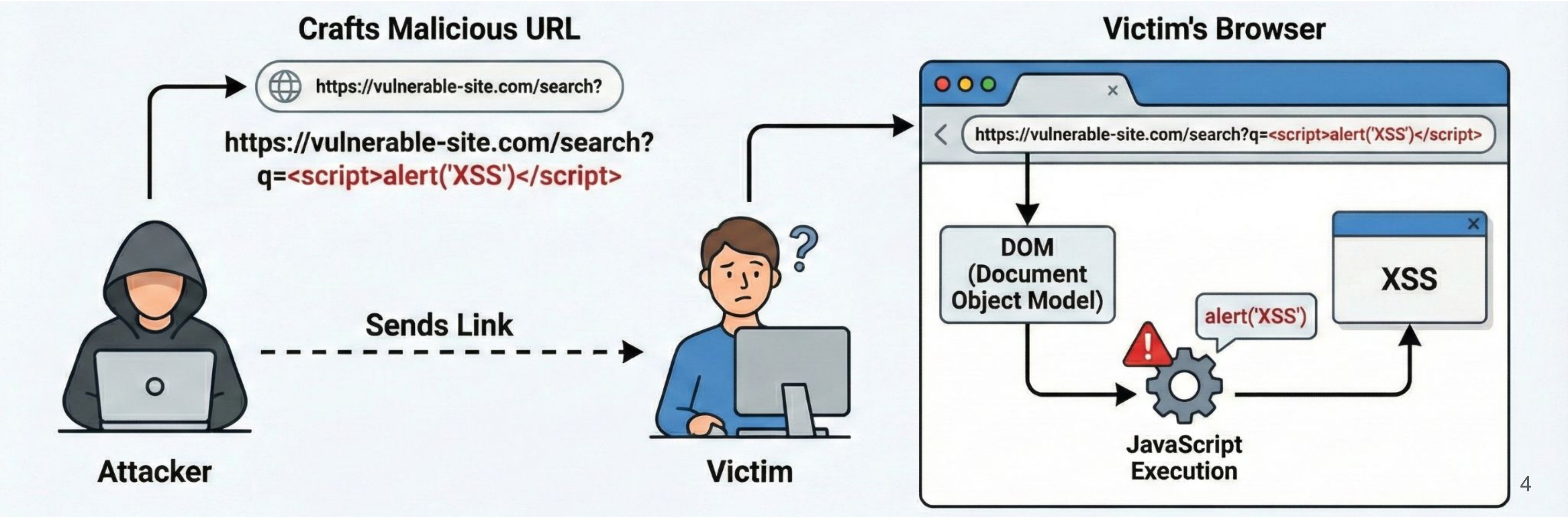
Crafts Malicious URL
https://vulnerable-site.com/search?
https://vulnerable-site.com/search?
q=<script>alert('XSS')</script>
Sends Link
Attacker
Victim
Victim's Browser
https://vulnerable-site.com/search?q=<script>alert('XSS')</script>
DOM (Document Object Model)
alert('XSS')
XSS
JavaScript Execution

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- Trusted Types sanitizers are hard to implement correctly
- Web application firewalls are easily bypassable

DOM-XSS studied over the years

Dynamic taint approaches can automatically and scalably analyse pages

- **25mflows (2013)**[1]→ 8,163 DOM-XSS flows after analyzing 504,275 pages

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- **DOMsday (2017)**[2] → 3,219 DOM-XSS flows after analysing 44,722 pages

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- **DOMsday (2017)**[2] → 3,219 DOM-XSS flows after analysing 44,722 pages
- **TalkGen (2020)**[3] → 7,199 DOM-XSS flows after analysing 390,092 pages

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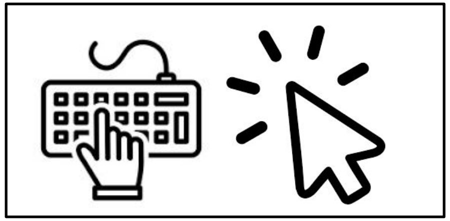

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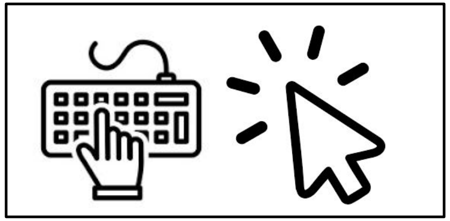

  - ↪ Parts of the URL, e.g., **GET parameters** and **fragment values**

https://www.example.com/calc?x=2&y=3#blue

Presentation overview

- ➢ Analysis and vulnerability confirmation methodology (shared with prior work)

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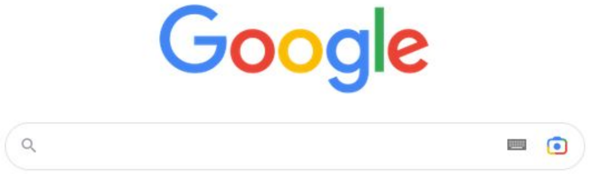
- ➢ Large scale evaluation results

Pipeline to detect DOM-XSS shared by prior work[1,2,3]

URL of target



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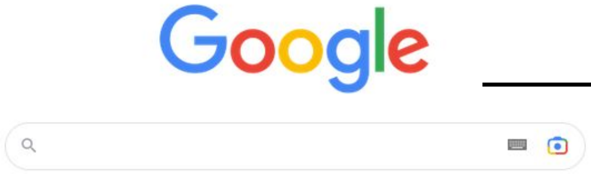

Browser implementing Dynamic Taint Analysis

document.write(location.search)

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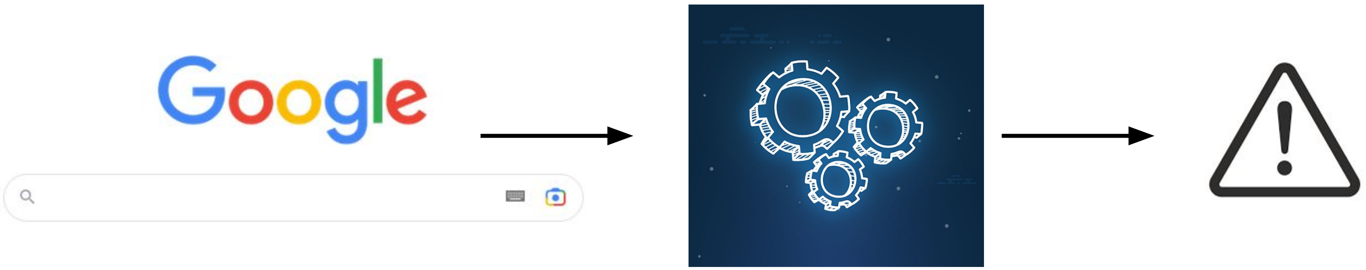
URL of target **Browser implementing Dynamic Taint Analysis** **Potential flows**



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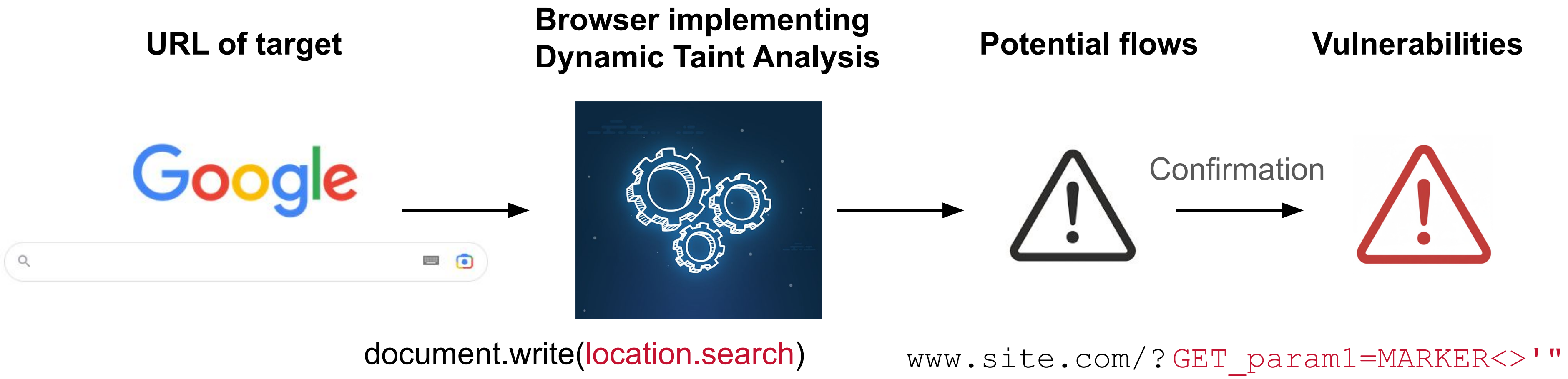

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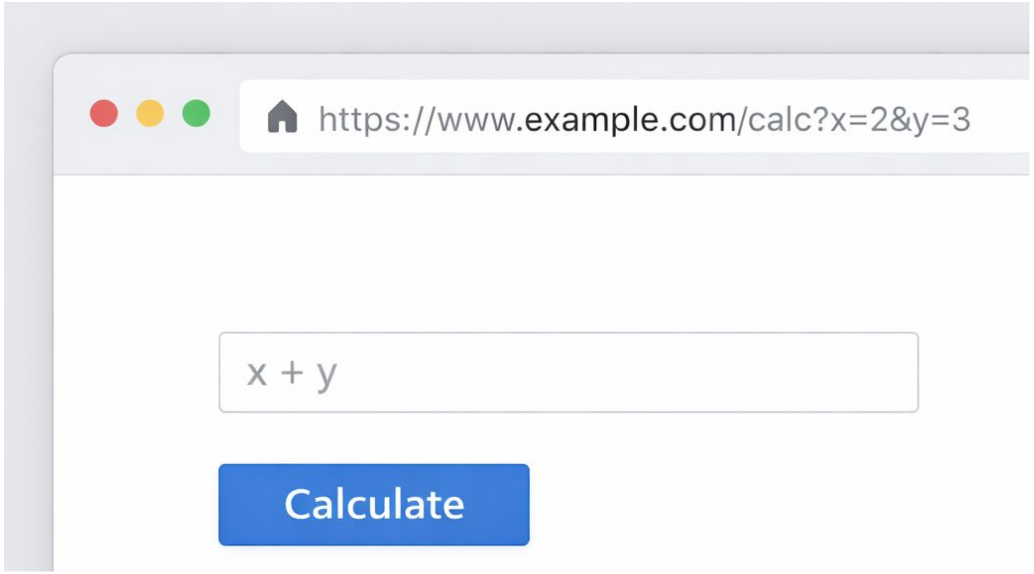

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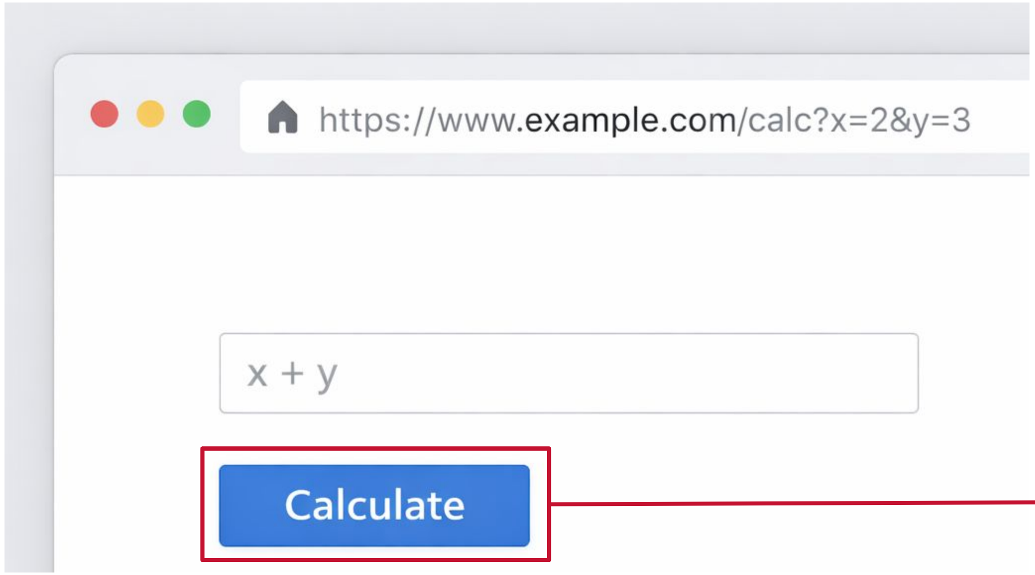

`onclick` event handler:
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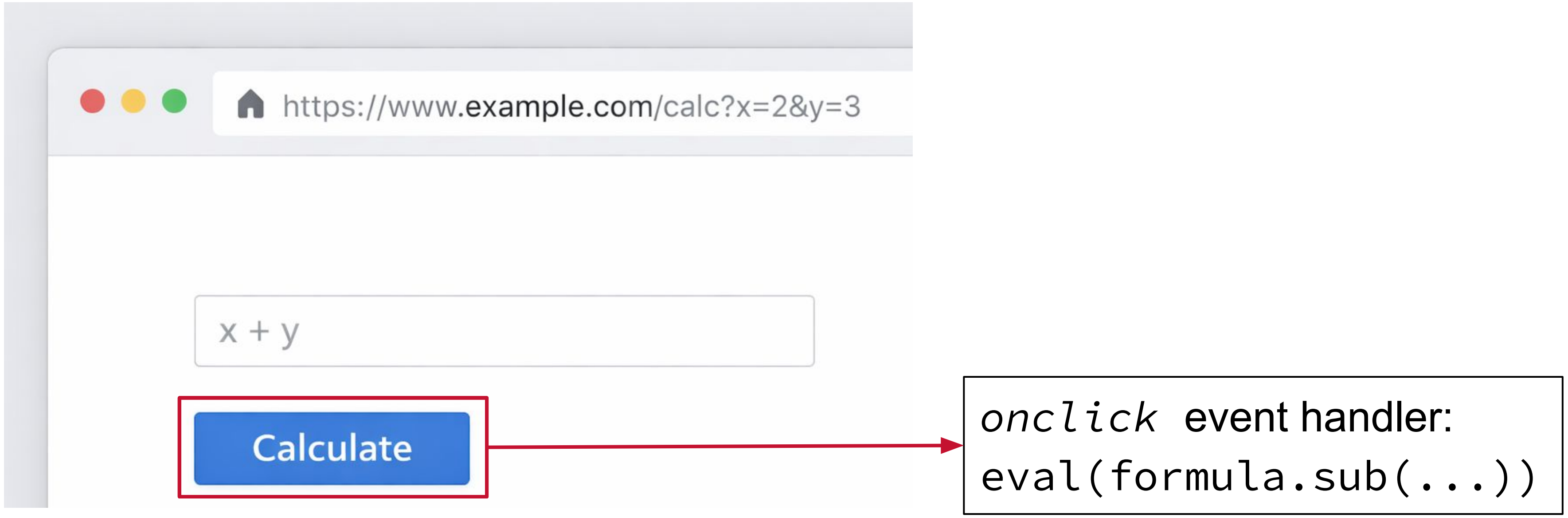

onclick event handler:

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Our proposal: Fuzzing user interactions to trigger event handlers

Automatic methods to simulate user actions exist, but…

- Only support mouse, keyboard events and forms[1,2,4,5,6]

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Automatic methods to simulate user actions exist, but…

- Only support mouse, keyboard events and forms[1,2,4,5,6]
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- Computationally heavy [4,6]

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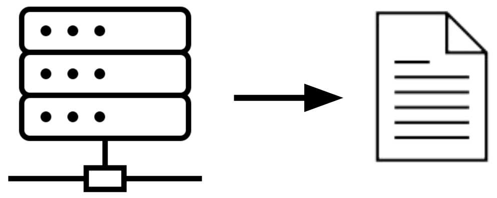
Fuzzing user interactions to execute event handlers



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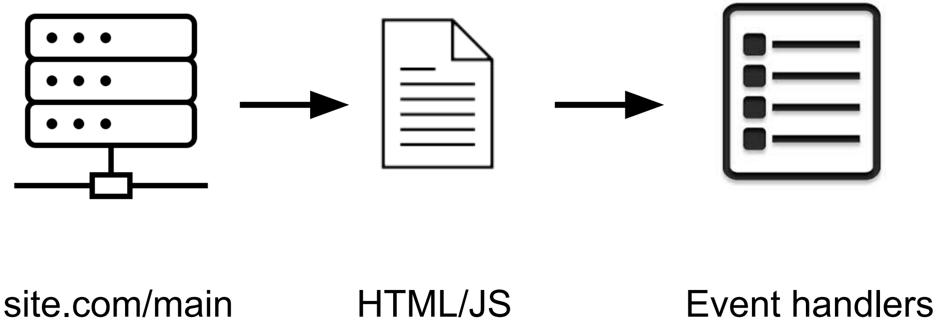

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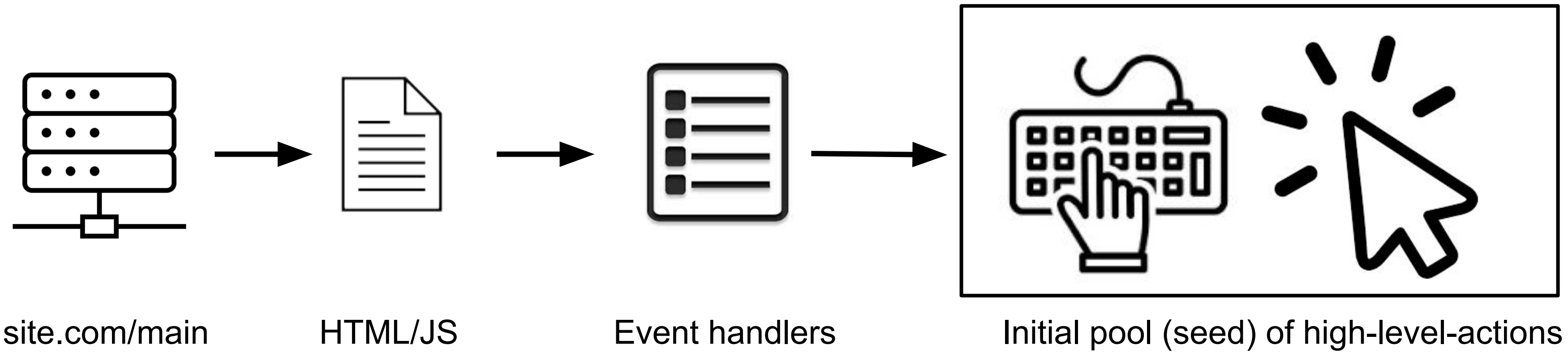
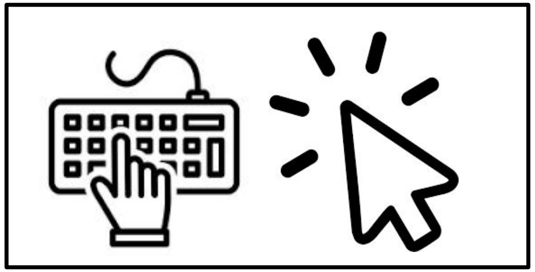


High level action: A specific interaction with the page

onkeydown → { `focus(element); generateKeyPress(key=random)` }

Interactions are combined to improve event handler execution

```
{ReleaseMouse(), Drag(position), Click(element)}
```



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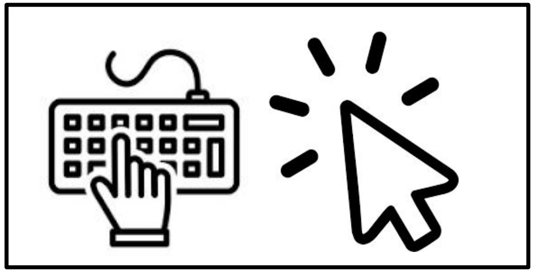
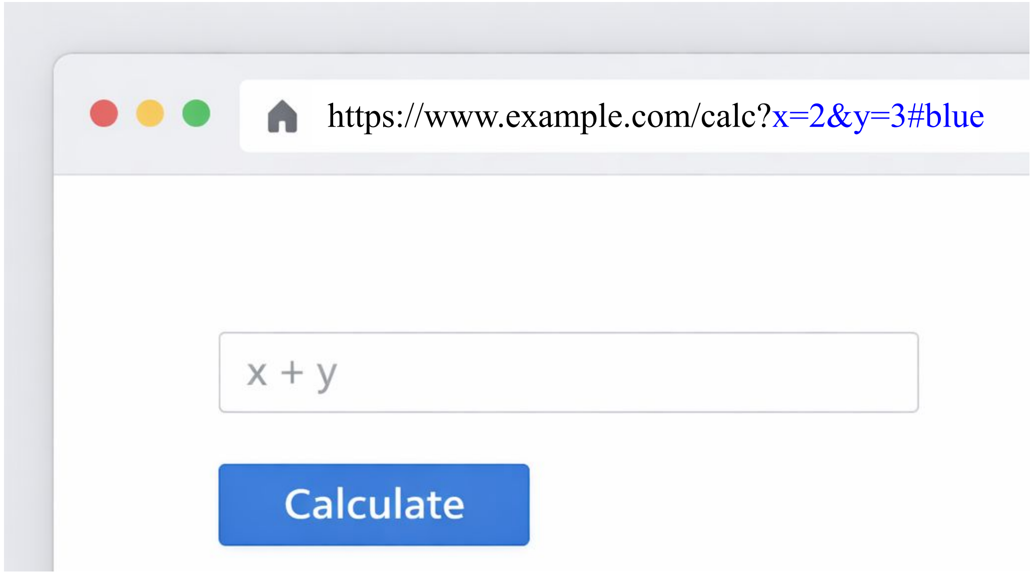


Mutate / combine actions

```
{Click(element);Drag(position);ReleaseMouse(), ... }
```

GET parameters can influence page behavior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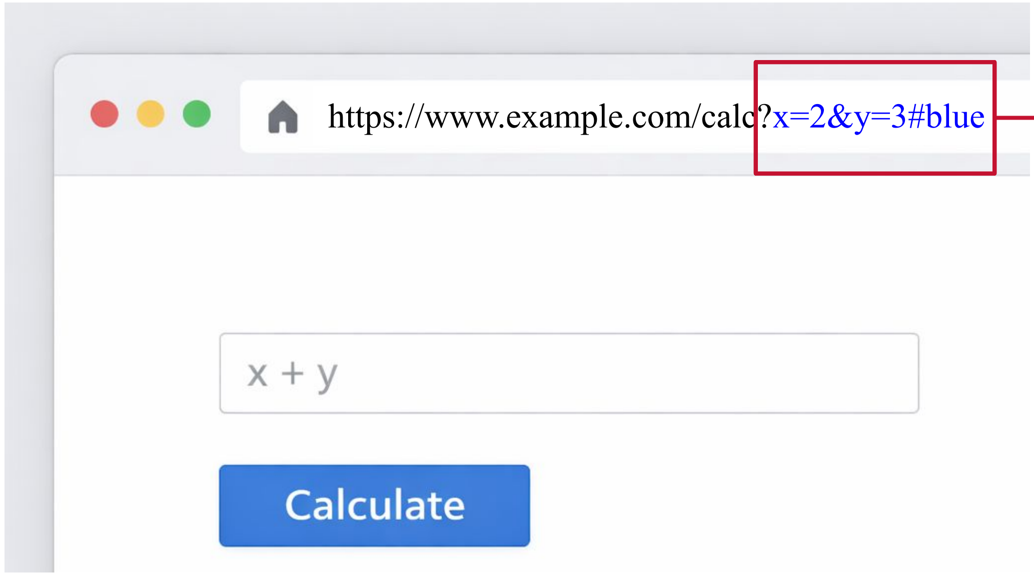
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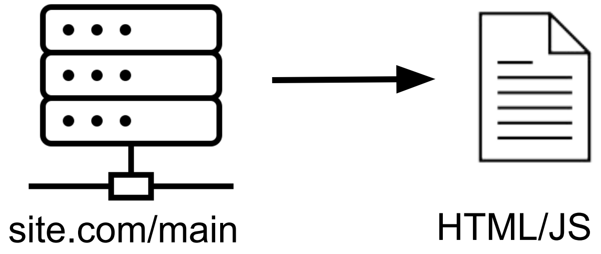
What happens with different values?

Instrumenting pages to track symbolic constraints



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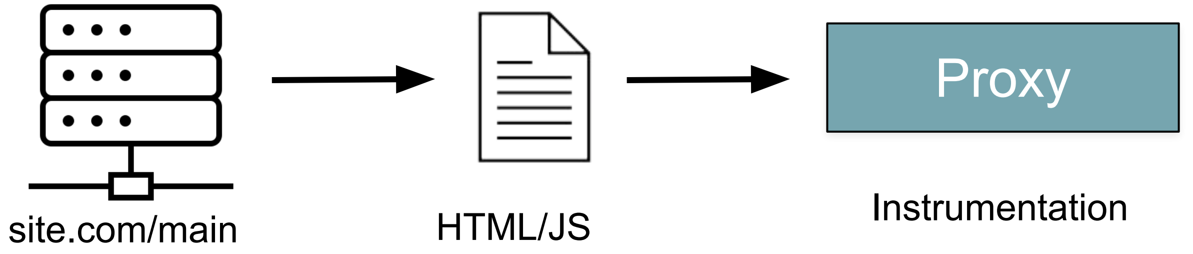

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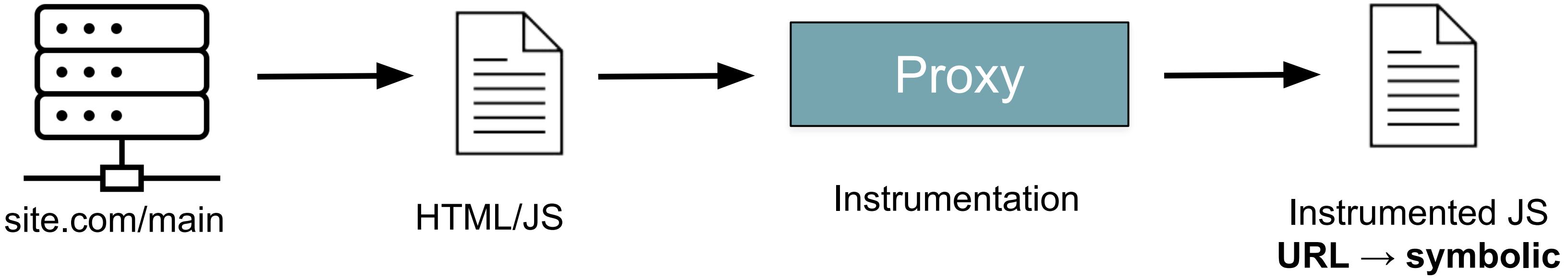

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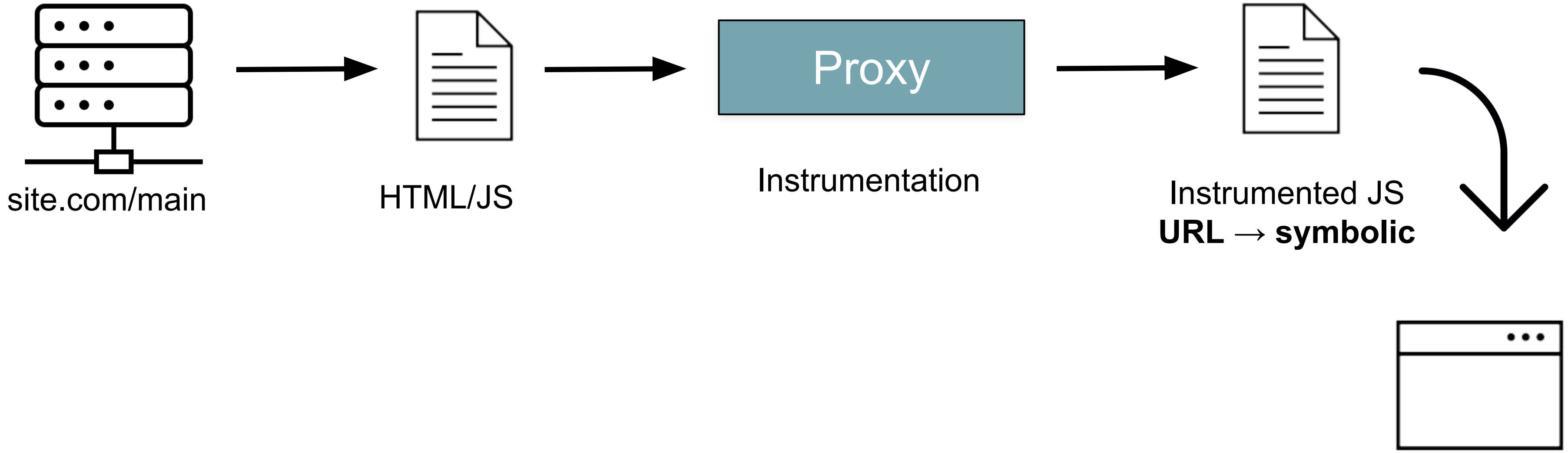

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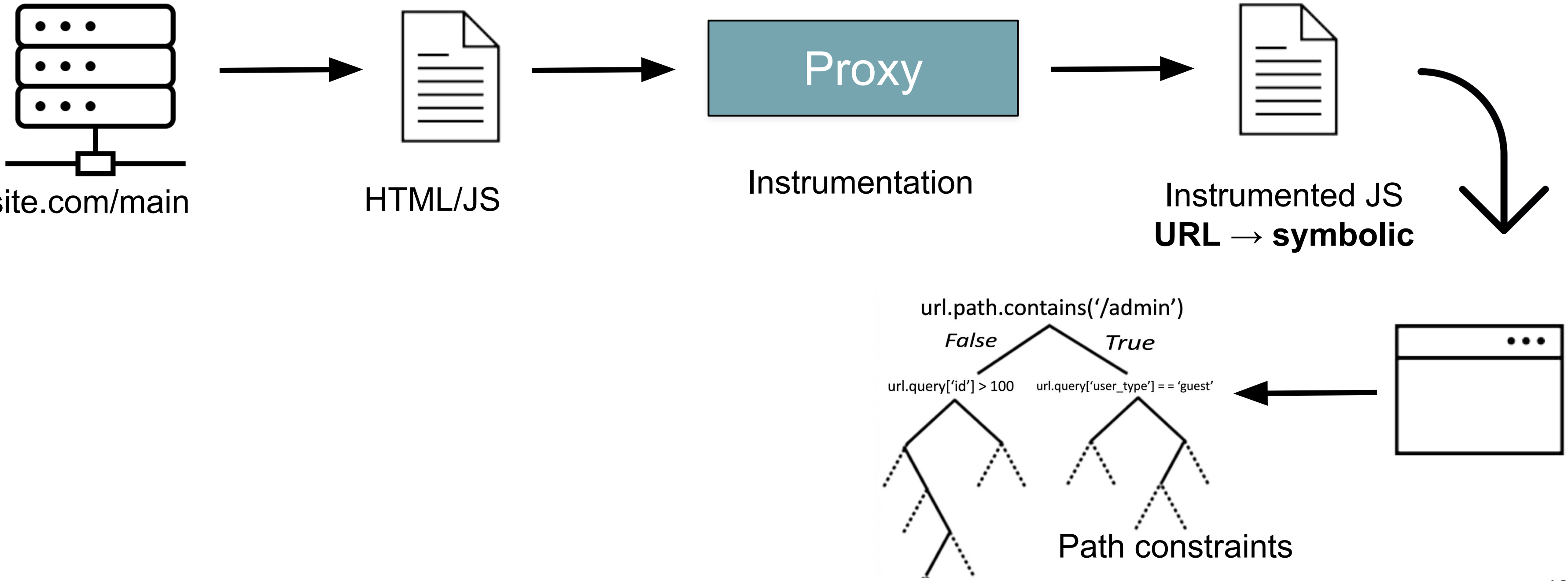

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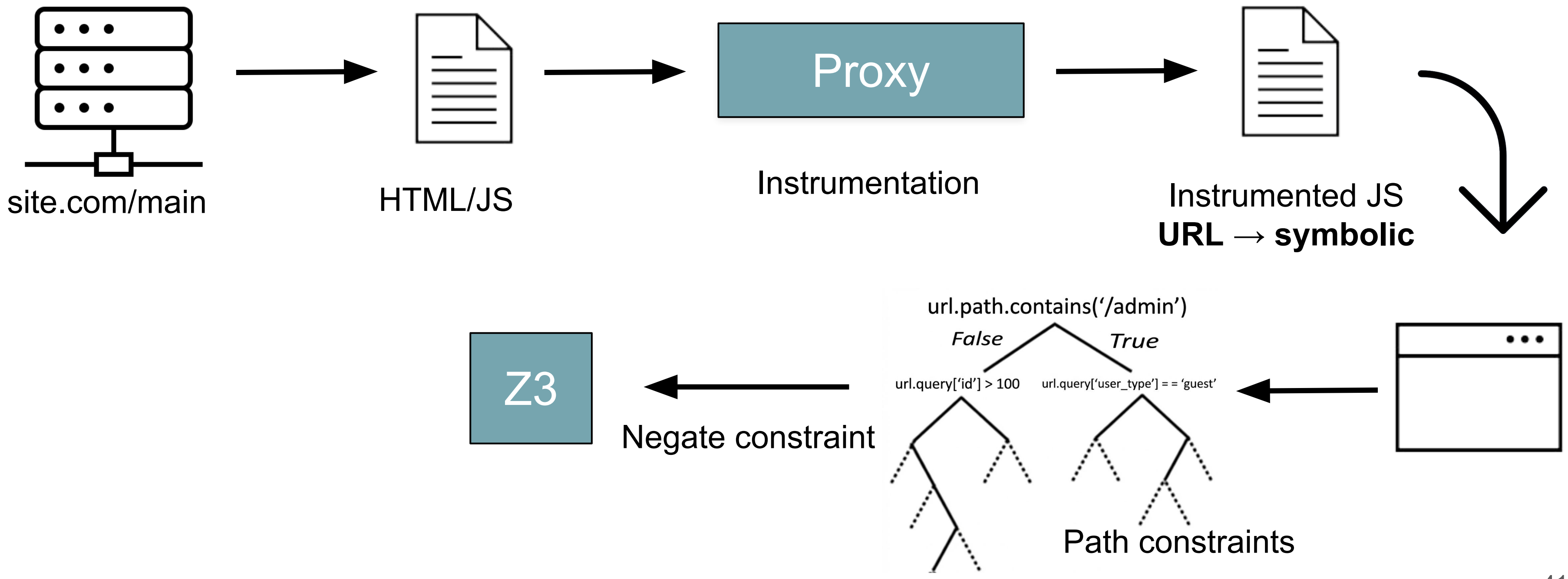

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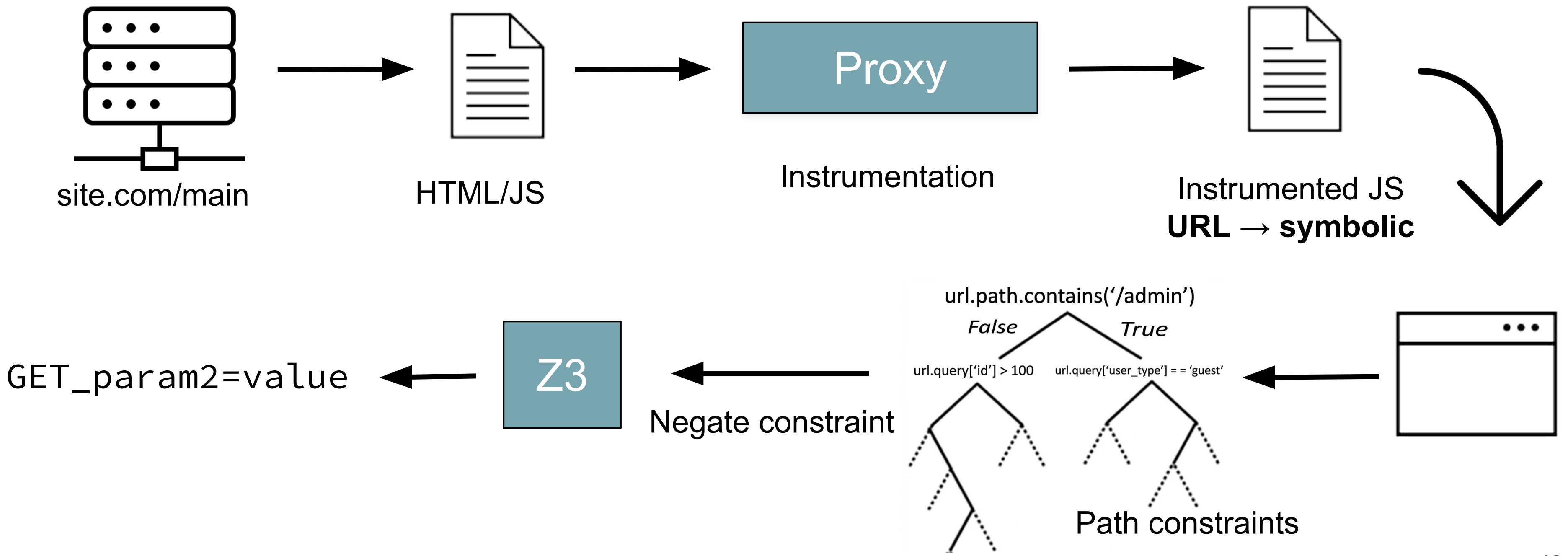

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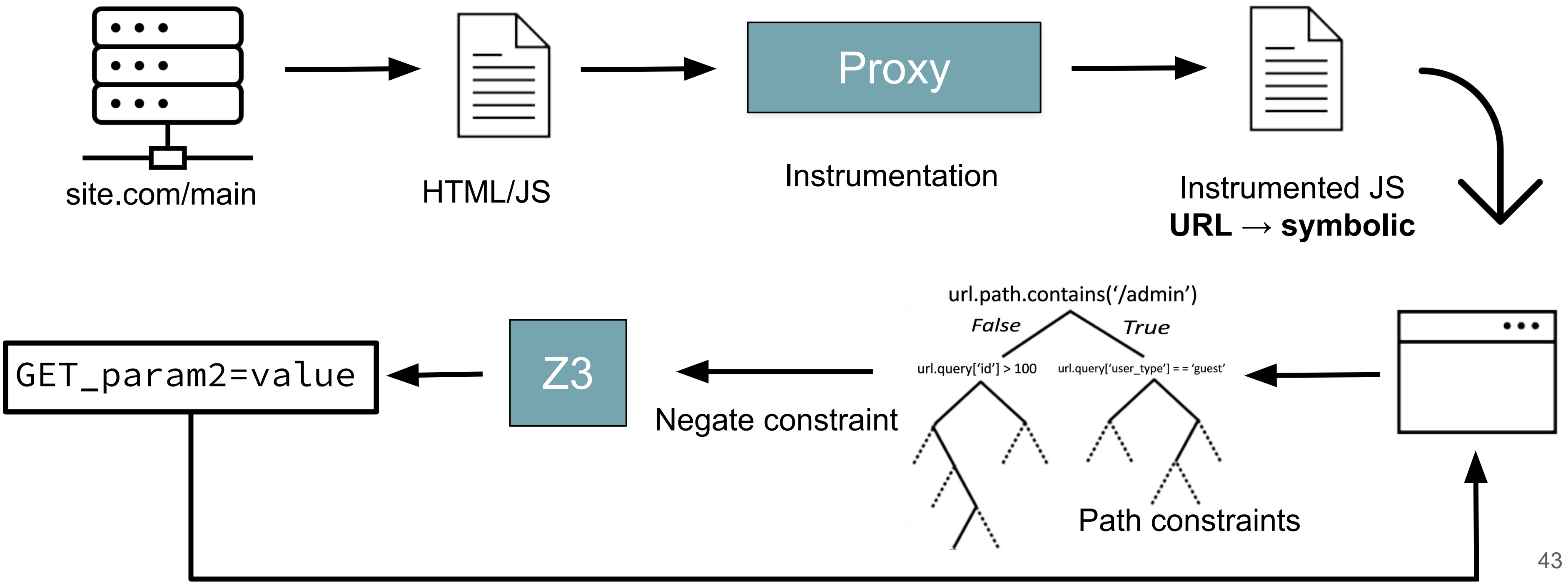

Evaluating user action fuzzer on a large-scale crawl

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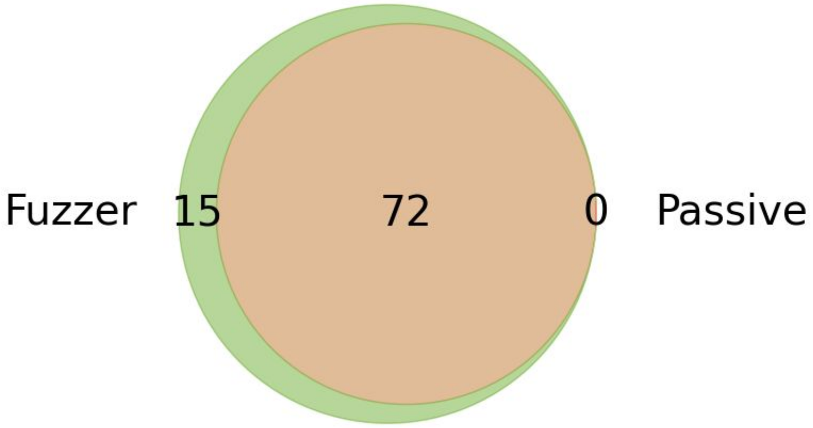
RQ1: Fuzzing user interaction improves DOM-XSS detection

Fuzzing improves DOM-XSS confirmed flows discovery by 21% (compared to Passive)

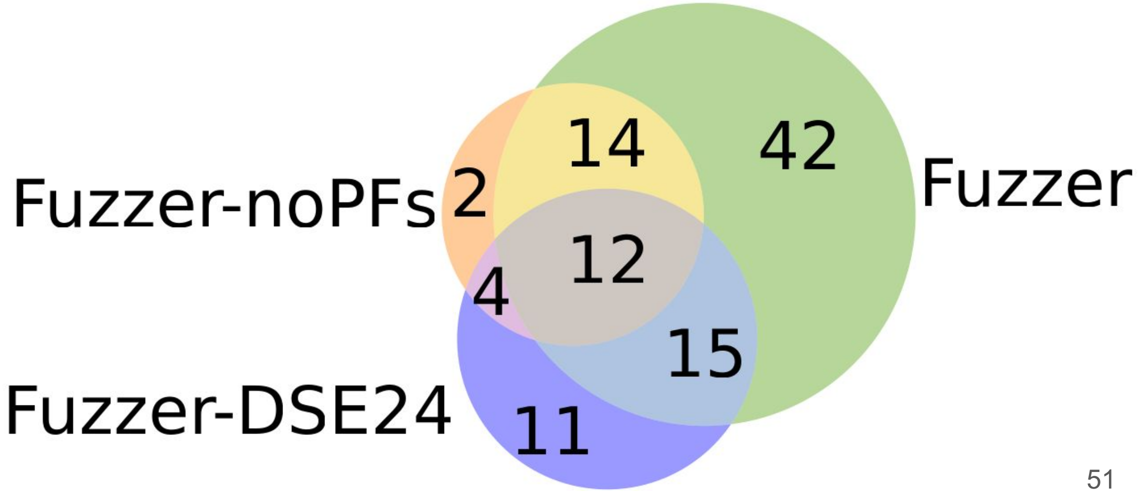


Confirmed flows discovered after five repetitions and after deduplicating flows

RQ2: DSE synthesizes PFs that trigger new vulnerabilities

Fuzzer-noPFs strips parameters and fragments from each target URL before Fuzzing

Symbolic execution generates new parameter combinations:



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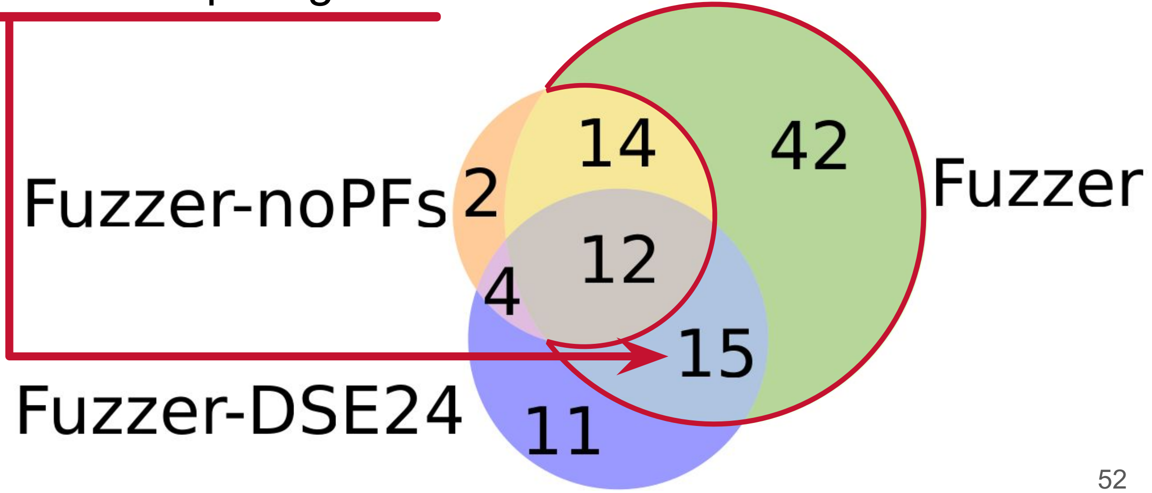

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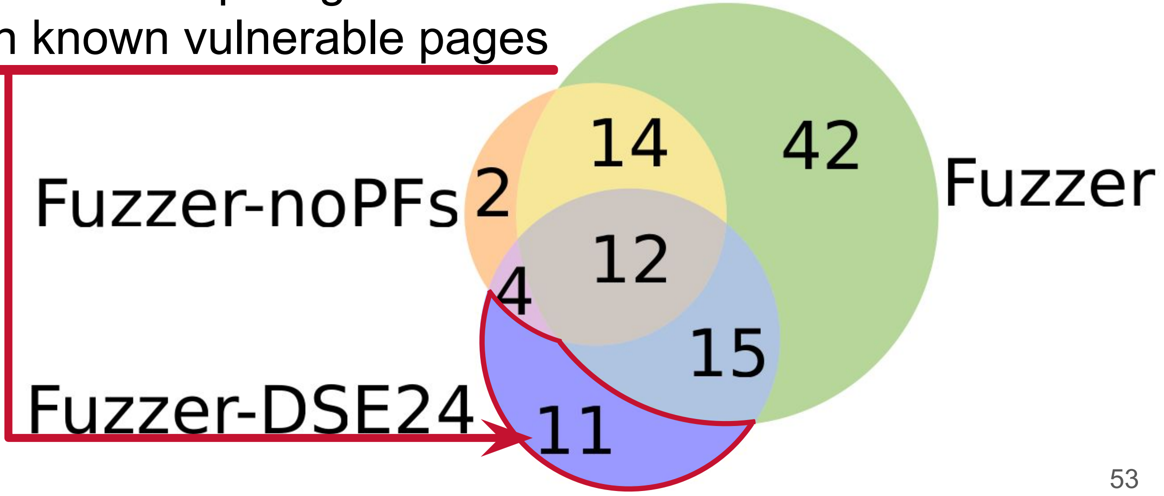

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Symbolic execution generates new parameter combinations:

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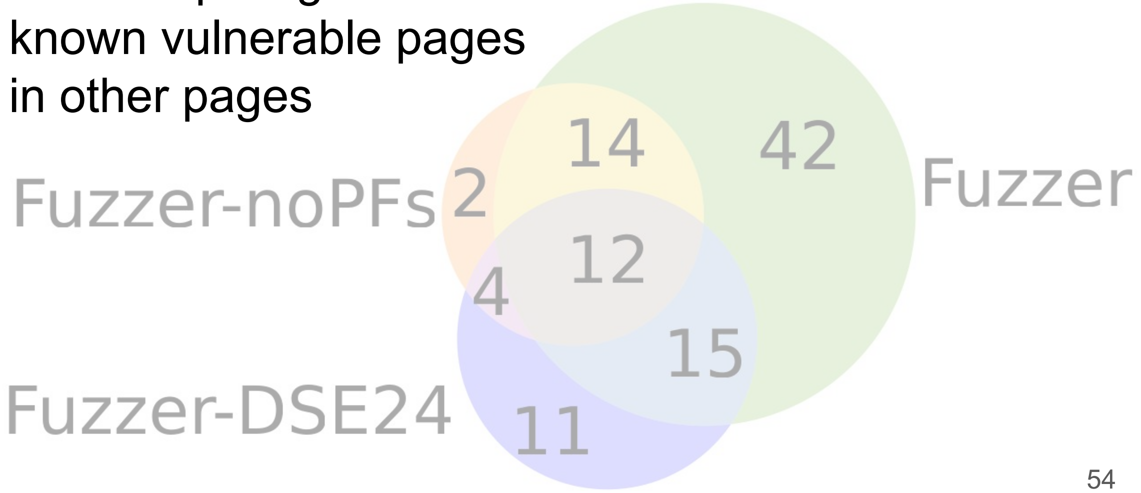
- reveals new vulnerabilities on known vulnerable pages
- reveals 10 new vulnerabilities in other pages



RQ3: Comparison with prior work

Metric	DOMsday (replication) aka Passive	TalkGen (replication)	TalkGen	DOMsday	25mFlows
Date	04/2025	04/2025	09/2020	08/2017	11/2013
Pot. flows (per 1k pages)	45.5	76.6	40.3	116.7	?
Conf. flows (per 1k pages)	1.6	1.5	18.5	72.0	16.2

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Most impactful factor introducing a difference in confirmed flows:

- URL encoding mechanism evolution: inflates confirmed flows by 5x

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URL encoding	**Yes**	**Yes**	**No**		

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Metric	DOMsday (replication) aka Passive	TalkGen (replication)	TalkGen	DOMsday	25mFlows
Date	04/2025	04/2025	09/2020	**08/2017**	11/2013
Pot. flows (per 1k pages)	45.5	76.6	40.3	116.7	?
Conf. flows (per 1k pages)	1.6	1.5	18.5	72.0	16.2
URL encoding	**Yes**	**Yes**	**No**	**No**	

RQ3: Comparison with prior work

Metric	DOMsday (replication) aka Passive	TalkGen (replication)	TalkGen	DOMsday	25mFlows
Date	04/2025	04/2025	09/2020	08/2017	**11/2013**
Pot. flows (per 1k pages)	45.5	76.6	40.3	116.7	?
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URL encoding	**Yes**	**Yes**	**No**	**No**	**No**

Conclusion

- **194** / 44,480 (0.44%) of analyzed popular web pages still suffer from DOM-XSS
  - ↪ Enables code execution in the browser of a victim
  - ↪ Reduction compared to prior studies largely due to **URL encoding mechanism**

- Our fuzzer improves DOM-XSS confirmed vulnerability detection by 15%
- Symbolic execution generates variations of URLs that trigger new page behavior
  - ↪ rediscovered 26% of confirmed flows that require URL parameters found in the wild
  - ↪ confirmed 20 unique confirmed flows that were not discovered via Fuzzing

More in the paper

- Web archiving method to improve determinism in web analysis
- DSE outperforms other PF-generating approaches like ZAP and Wapiti
- How we overcome several challenges in analyzing the web at scale

DOM-XSS Detection via Webpage Interaction Fuzzing and URL Component Synthesis

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  - ↪ Reduction compared to prior studies largely due to **URL encoding mechanism**
- Our fuzzer improves DOM-XSS confirmed vulnerability detection by 15%
- Symbolic execution can find new vulnerabilities by generating variations of URLs

Nuno Sabino, Darion Cassel, Rui Abreu, Pedro Adão, Lujo Bauer and Limin Jia