ClickMiner: Towards Reconstructing User-Browser Interactions from Network Traces

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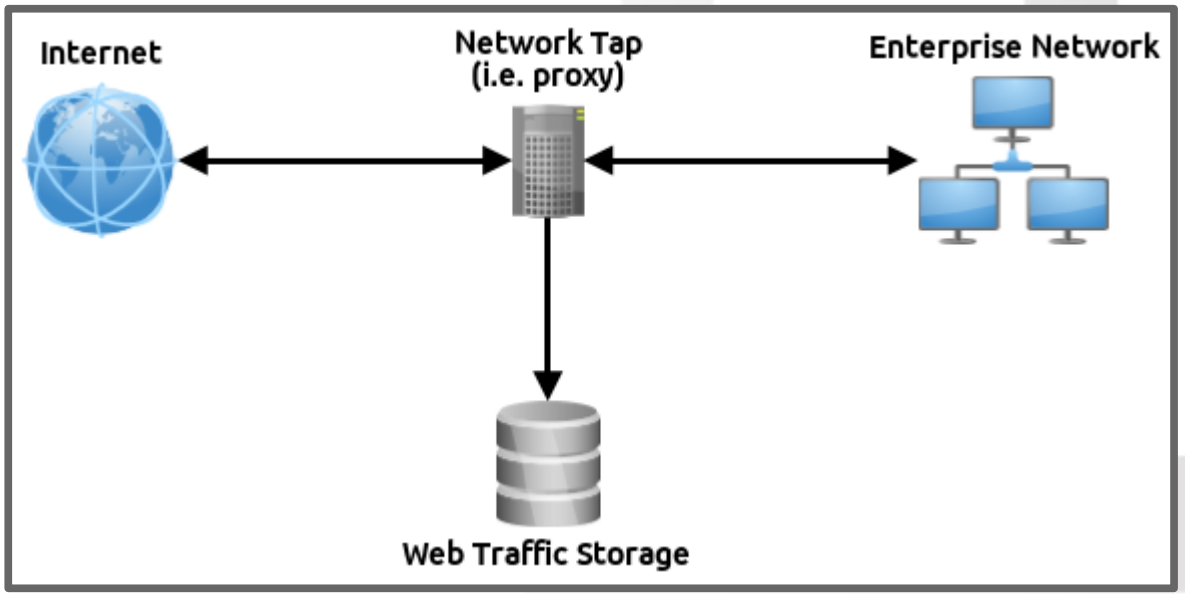
Network Security Intelligence

Application Scenario

- An enterprise has made an investment to record a window of ingress and egress network traffic from it's local network
- This data could aid in the forensic investigation of security incidents
  - ex. Web Security Incidents
    - Phishing, Social Engineering, Data Leakage
- How do we effectively analyze such large amounts of web traffic?



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Application Scenario

The modern web is becoming increasingly complex.

Increasing *Semantic Gap* between network traffic and user actions

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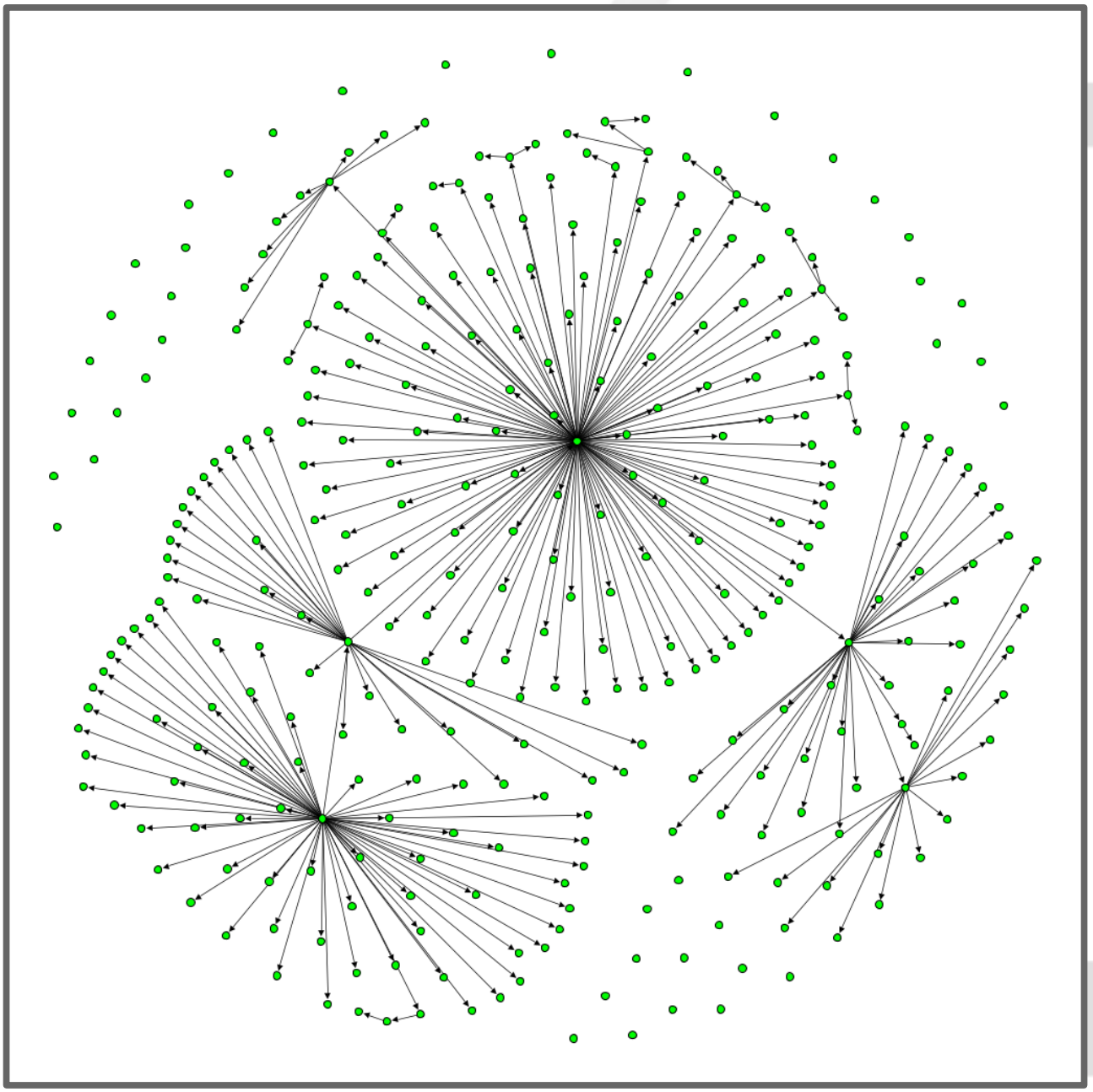
Application Scenario

Social Engineering Malware Download Scenario

- User searches for a crack to a particular game
- User is directed to a dubious site from the search results
- User downloads and installs a binary infected with malware from said site

Application Scenario

Requests: 328
Edges: 287
Clicks: 6
Time: 2m 56s



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Application Scenario

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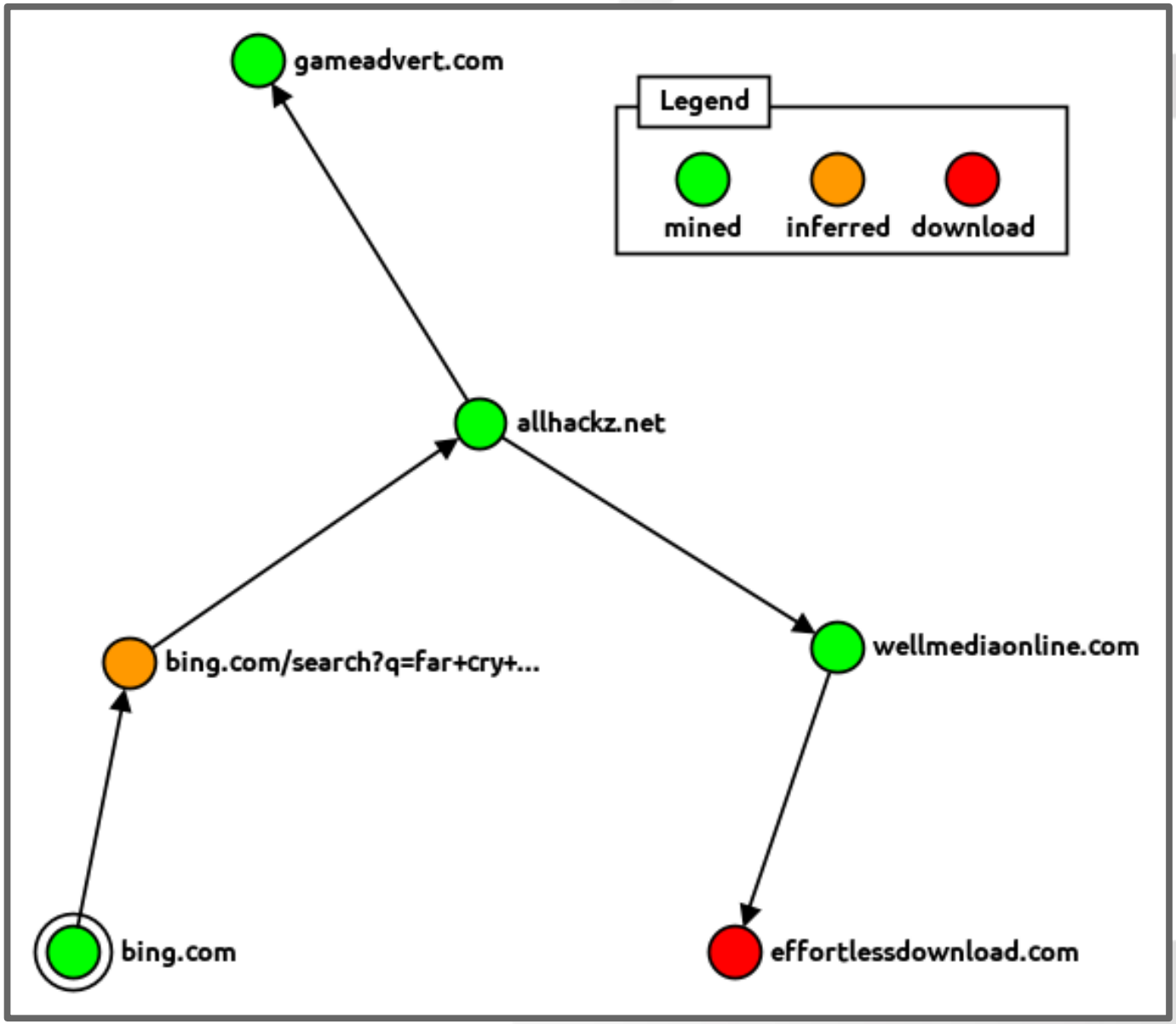

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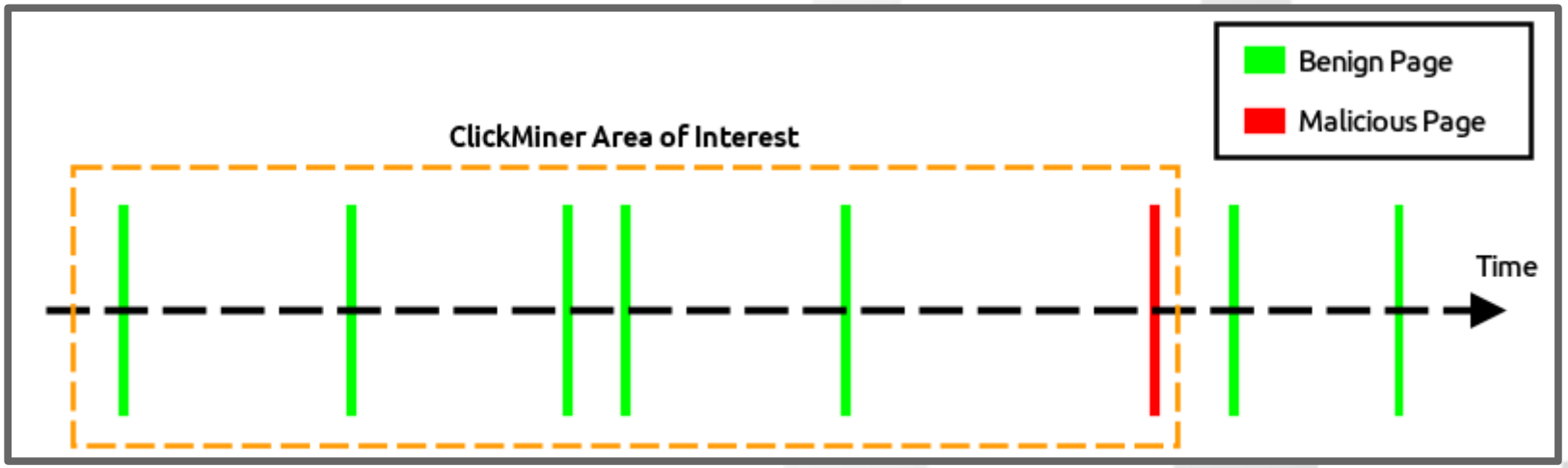
Interesting user-browser interactions

"What was a user's browsing behavior during a time window preceding (and including) a social engineering or phishing attack, or other relevant security incidents and anomalies?"



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User-Browser Interaction

Click

- A user interaction that causes the browser to initiate an HTTP request for a new web page.
  - Mouse click on an image with an `onclick` event
  - Touch gesture on a form submit button
  - Pressing Enter while focused a link
  - Typing a URL into the address bar
  - Clicking on a bookmarked link

ClickMiner's Goals

- Accurately reconstruct the steps taken by the user to reach the attack page
- Filter out irrelevant requests

Previous Approach

Referrer Graph

- Node: HTTP request
- Edge: Defines request referrer → request referred relationship

ReSurf*

- Referrer-based click inference (*RCI*)
- Build *Referrer graph* from traffic
- Prune referrer graph based on heuristics
  - ex. Timing information between requests

*G. Xie et al. ReSurf: Reconstructing web-surfing activity from network traffic. In IFIP Networking Conference, 2013, 2013.

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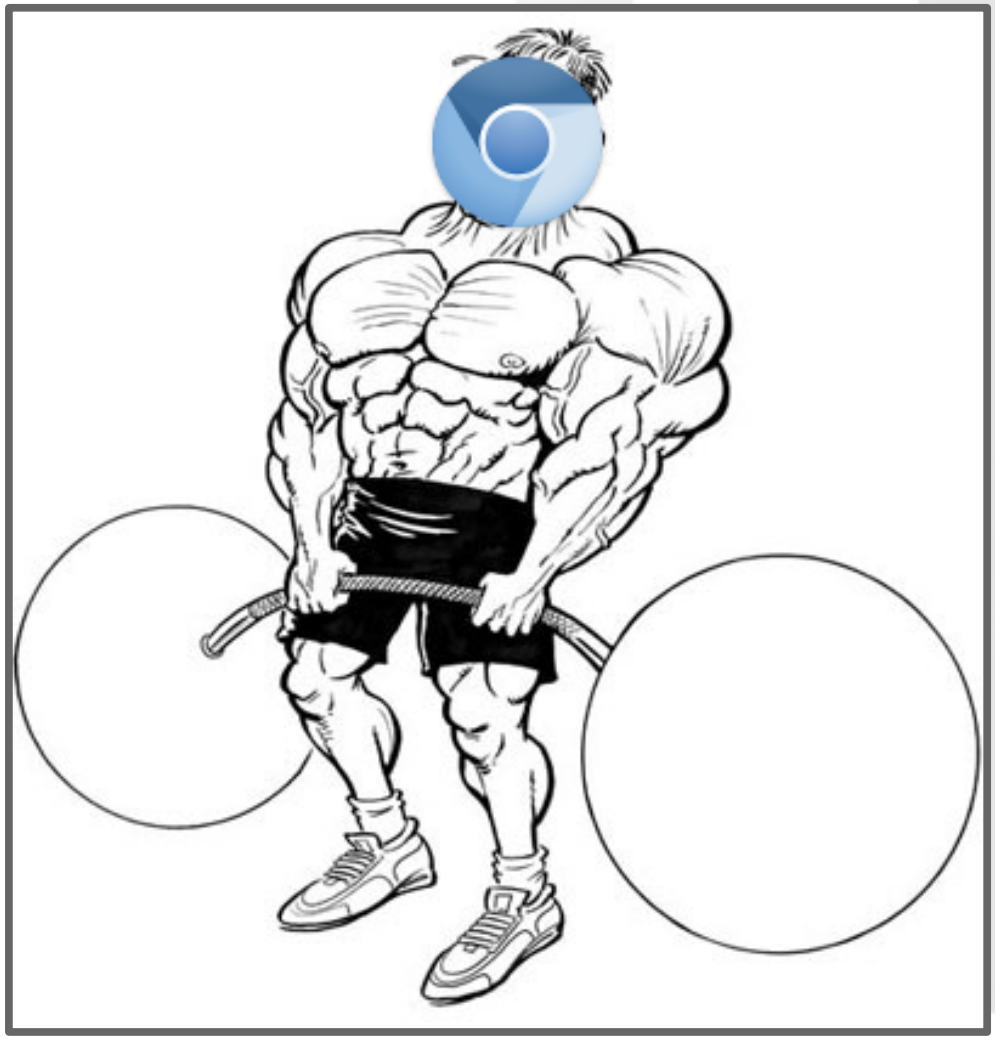
ClickMiner Approach

"Let the browser do the heavy lifting."



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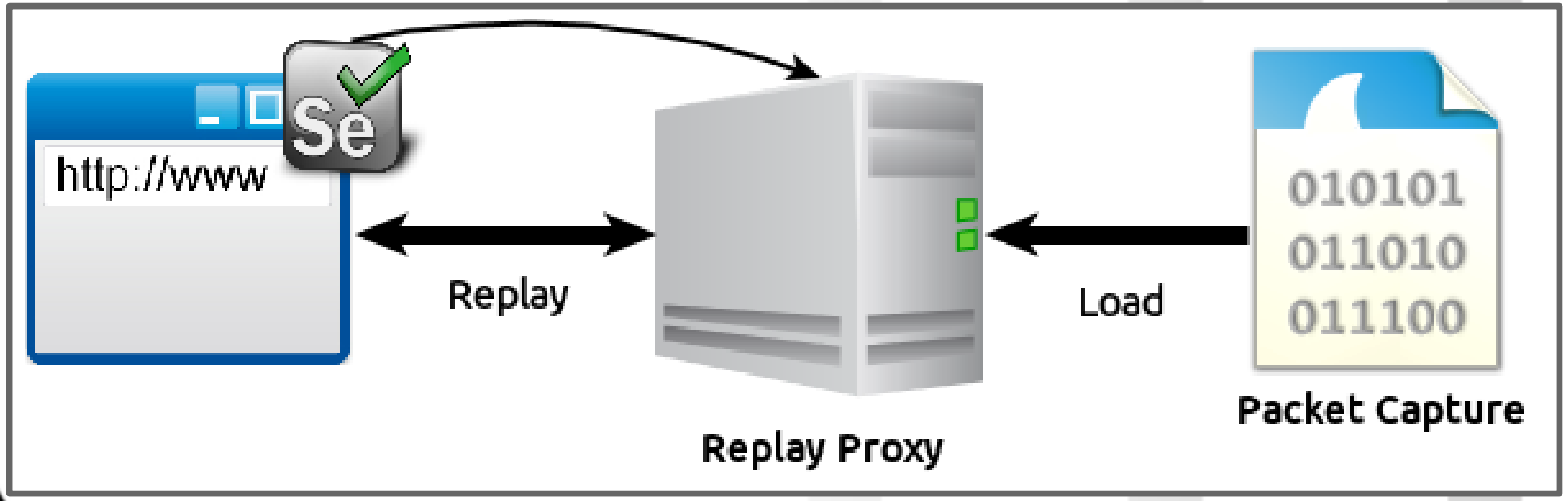
ClickMiner Approach

Replay web traffic within an instrumented browser.



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Contributions

- ClickMiner, a system dedicated to automatic reconstruction of clicks from web traffic.
- Evaluate both ClickMiner and RCI in a user study.
- Case study involving a real social engineering-based malware download attack.

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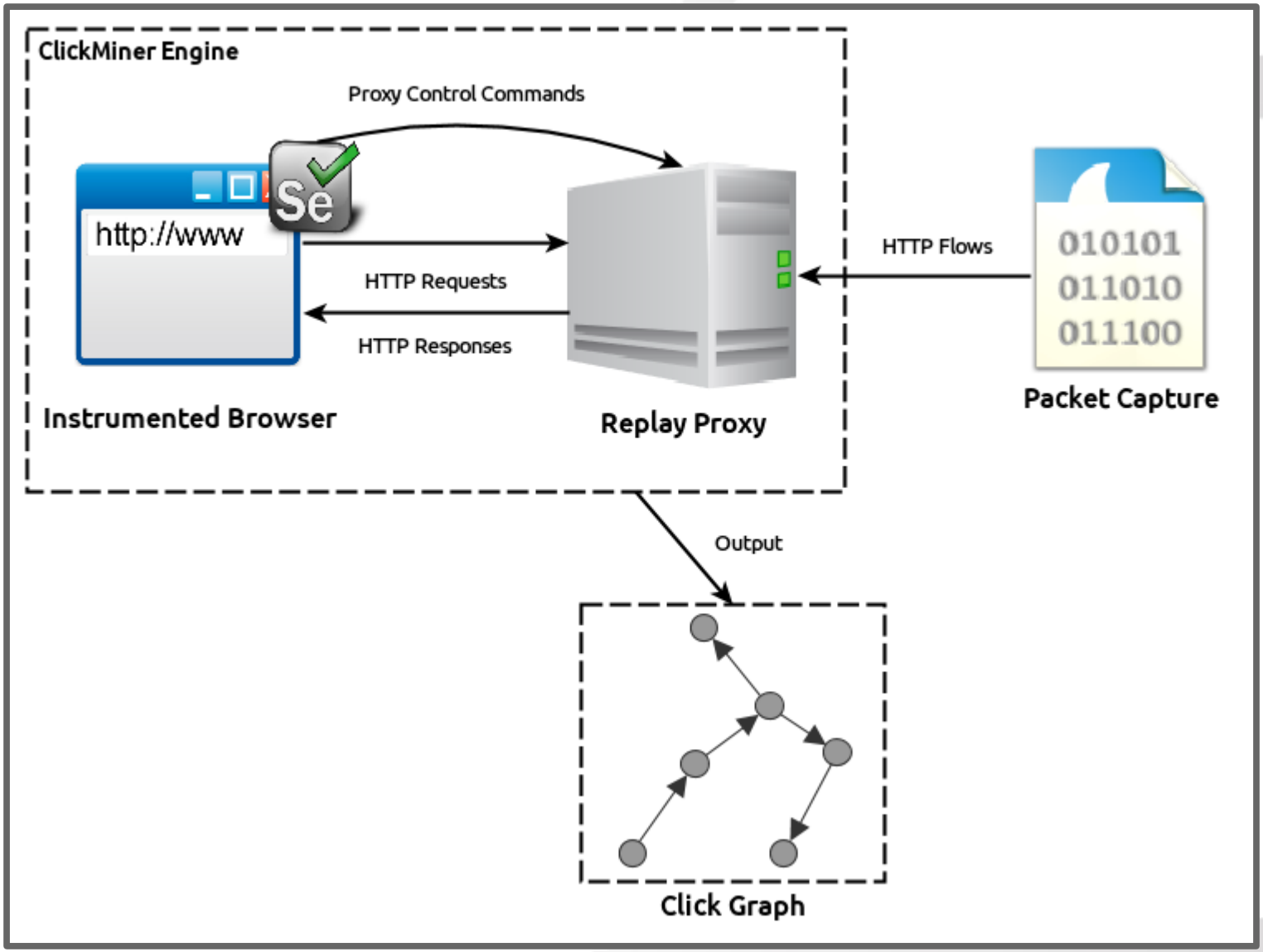
System Design



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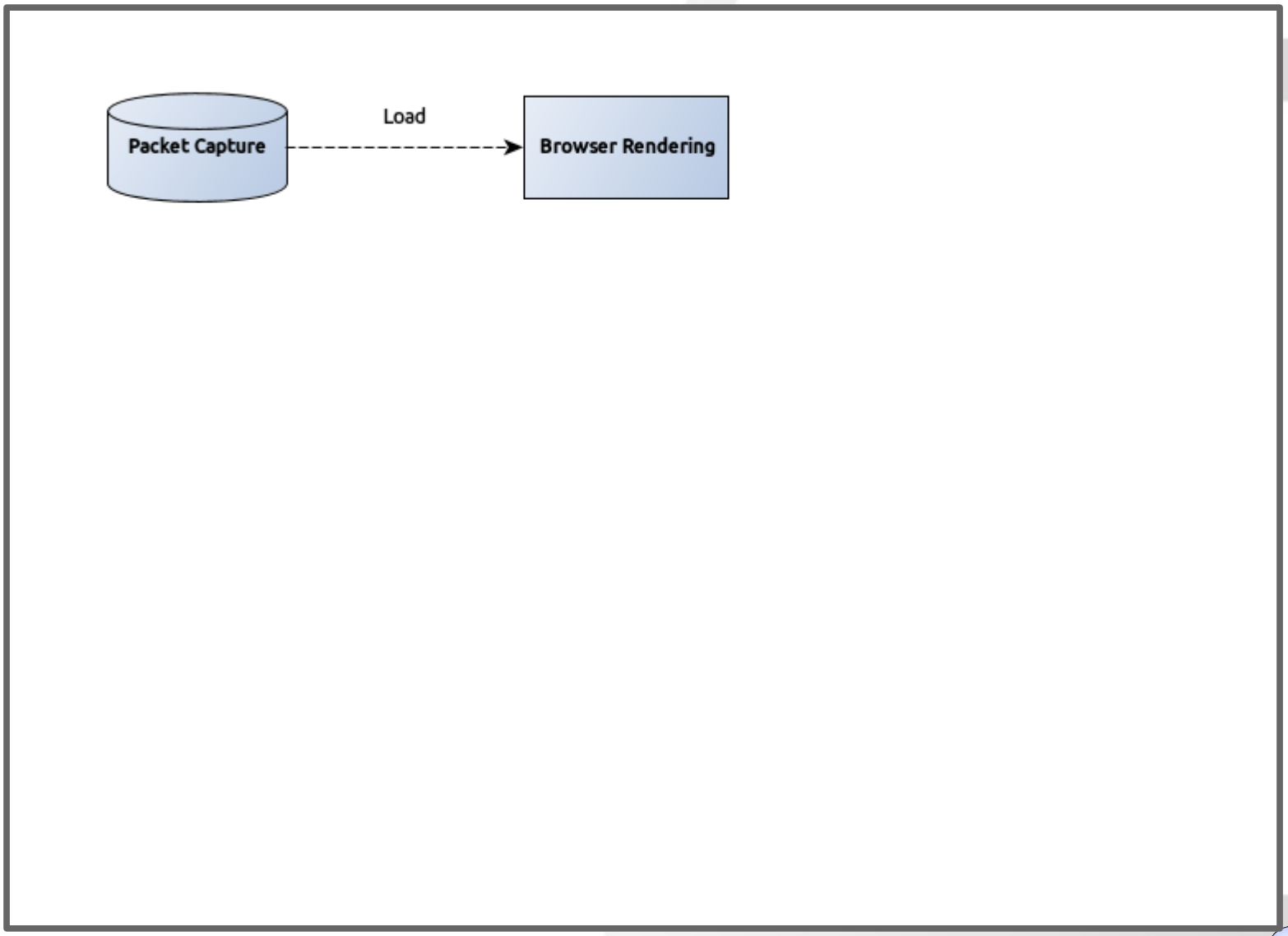
Replay Algorithm (Simplified)



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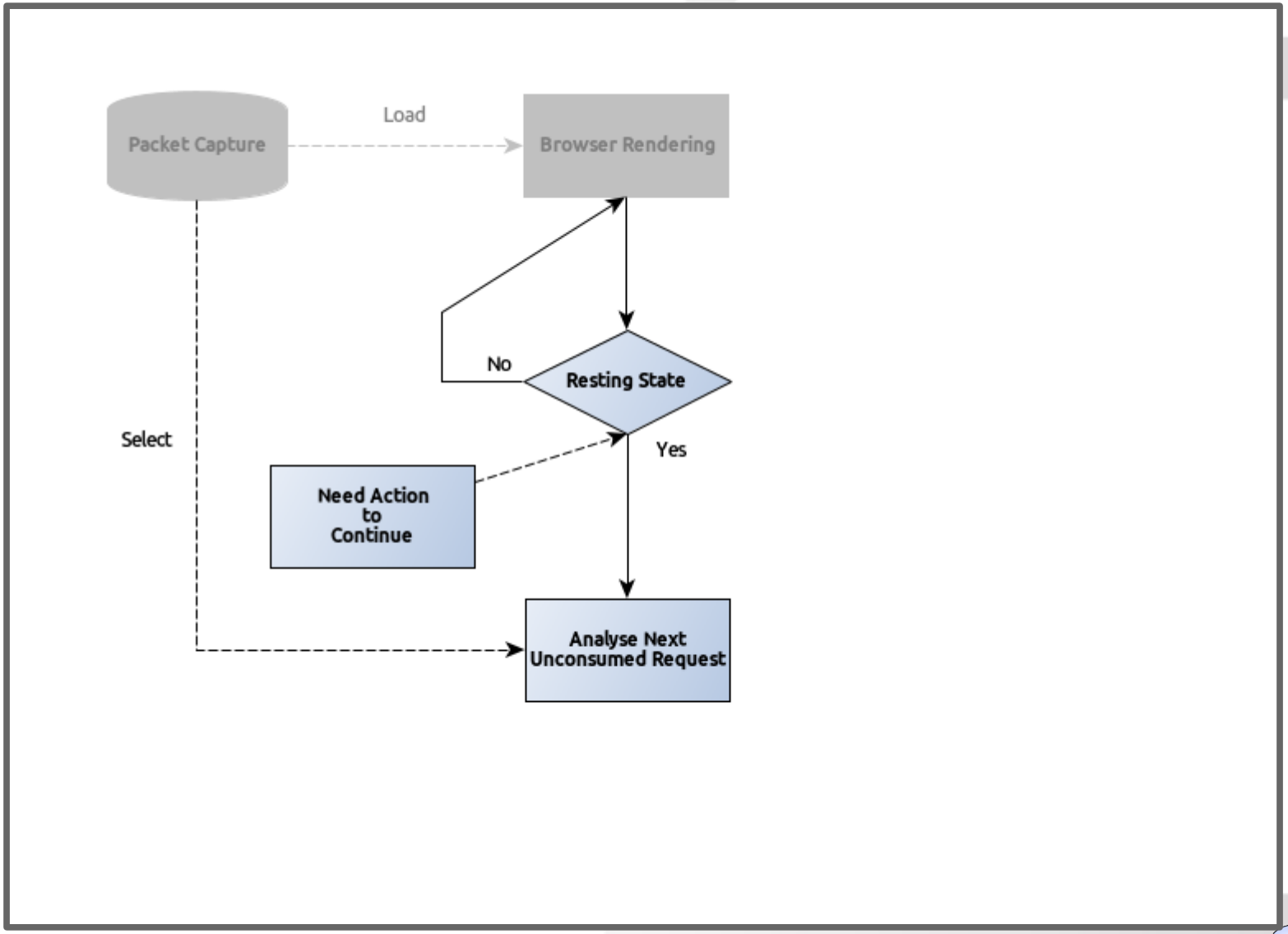

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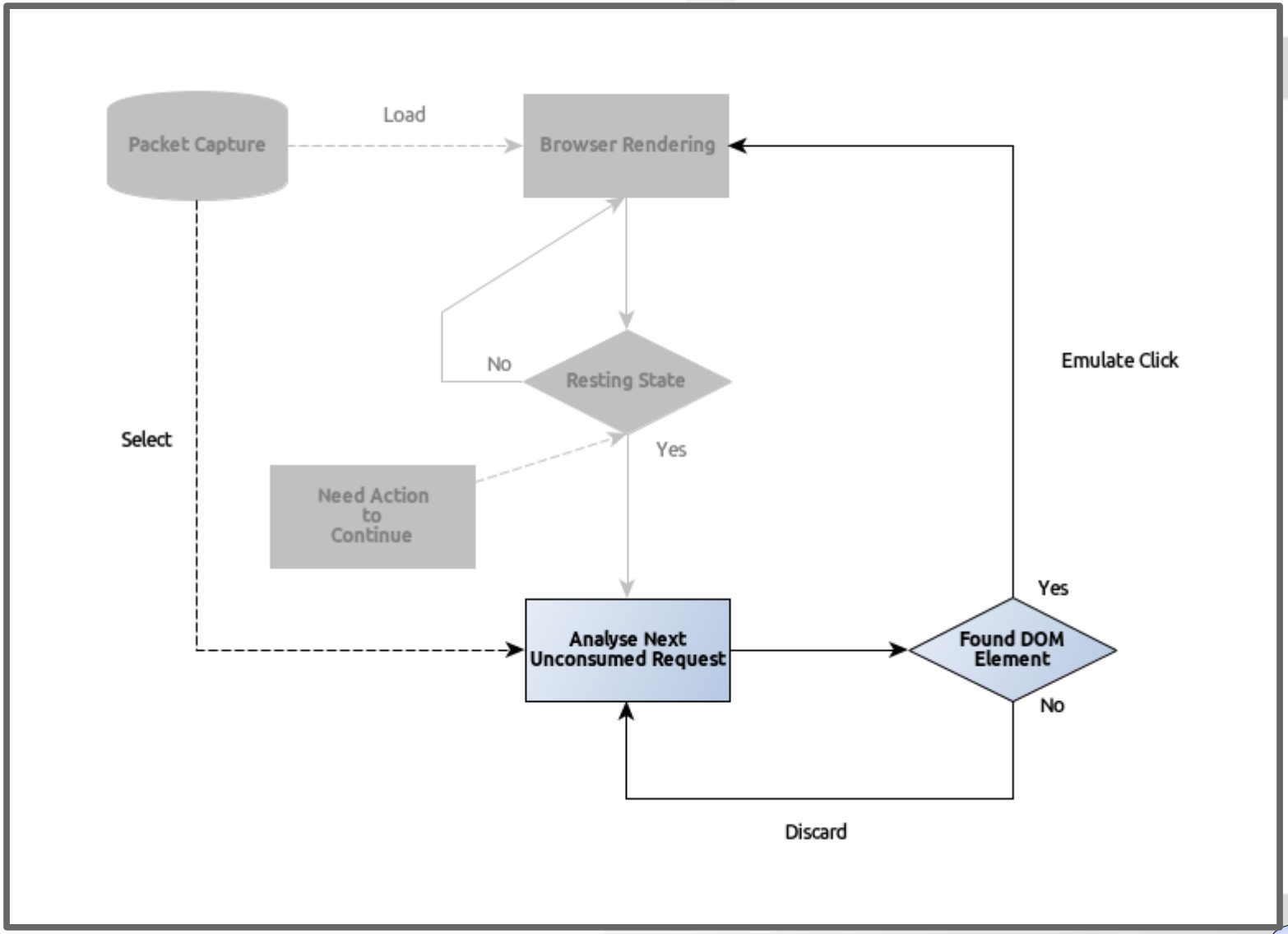

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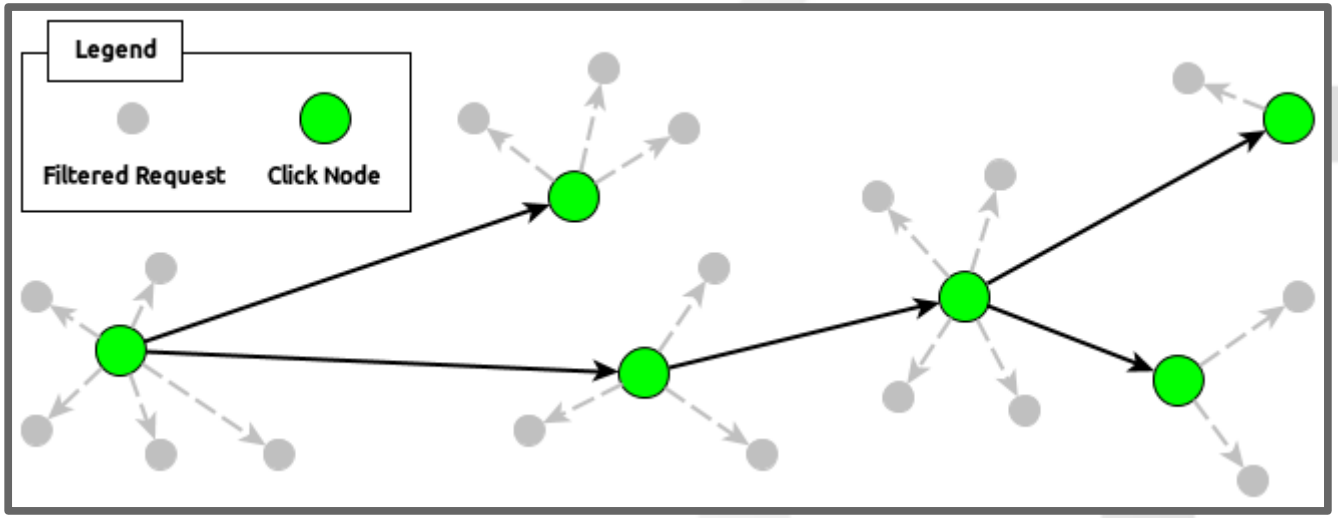
Click Graph



Nodes: annotated HTTP Requests (p, e, q)

- p = source page
- e = element clicked
- q = request generated

Edge: $(p_w, e_w, q_w) \rightarrow (p_y, e_y, q_y)$

- p_y reached as a consequence of q_w

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Additional Challenges

- Request URLs with dynamic content
- JavaScript mediated requests
- Browser Cache

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Additional Challenges

Dynamically generated request can have different URLs between recording and replay

Request URLs with dynamic content

- URL parameter values
  - Randomly generated
  - Time-dependent
  - System-dependent
- Dynamically generated paths

Replay proxy utilizes an *approximate* matching algorithm for HTTP requests

Additional Challenges

Approximate matching algorithm compares HTTP requests based on:

```
http://sample.com/a/c?var1=a1&var2=b2
http://sample.com/a/c?var1=a1&var3=c3

Domain Path Parameters Values
```

If a match is found its response is served otherwise respond with HTTP `404`.

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Additional Challenges

JavaScript Mediated Clicks

- DOM elements with JavaScript event handlers

Network-oriented best effort approach

- Discover JavaScript mediated elements
- Activate each one
- If expected HTTP request is generated then we've found the element
  - Otherwise respond with HTTP 204

Additional Challenges

Browser Cache

- Requests satisfied by the browser cache exhibit no response payload
- Requests with missing response payloads can not be replayed.
- *Best effort* replay skips gaps to continue processing what traffic remains.

Augmented Click Inference

ClickMiner might fail to detect click via replay

- Leverage the referrer graph
- Fill in click paths with partial click nodes

(***Click Graph***) + (***Referrer Graph***)

↓

Augmented Click Graph

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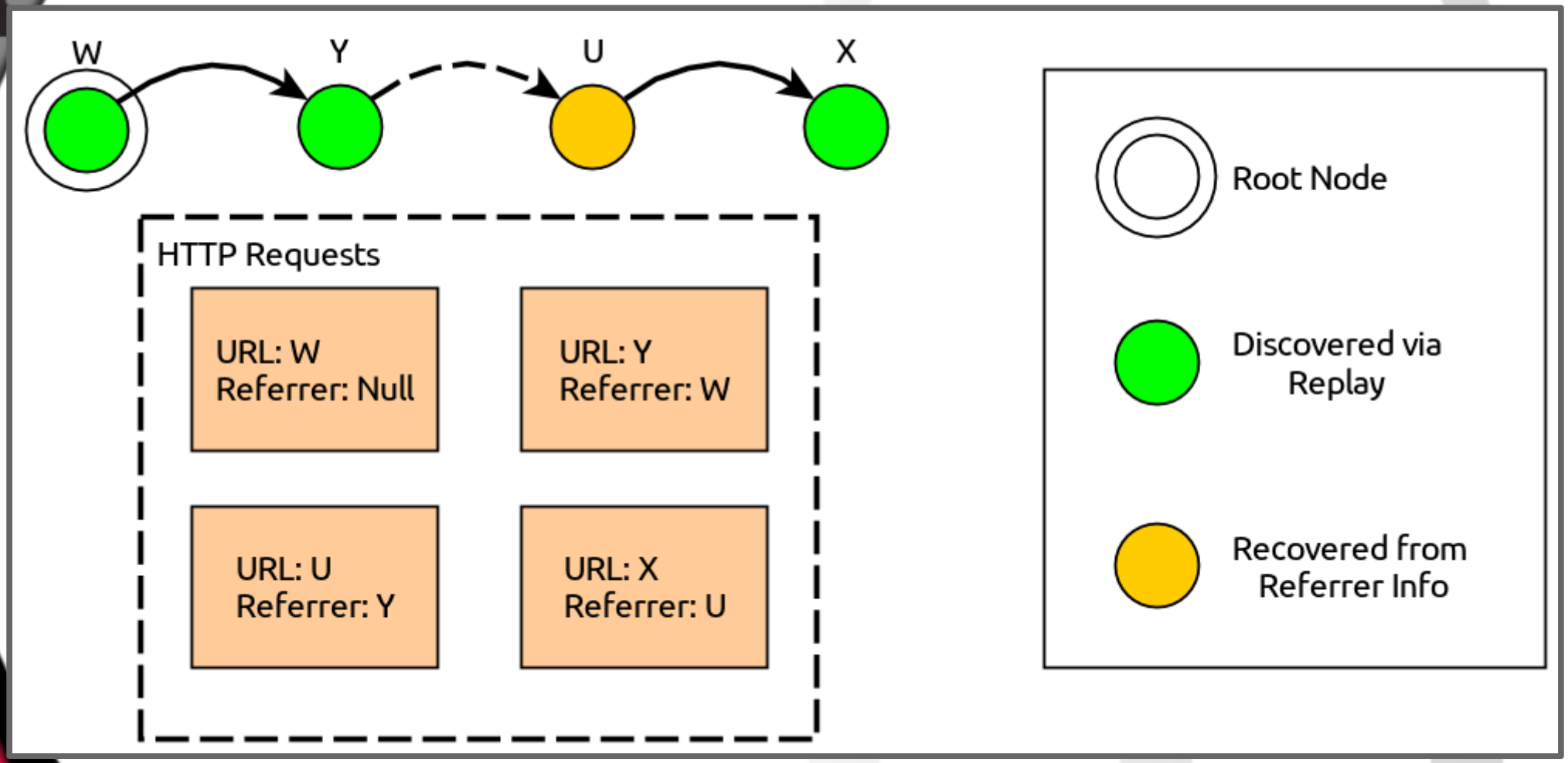
Augmented Click Inference



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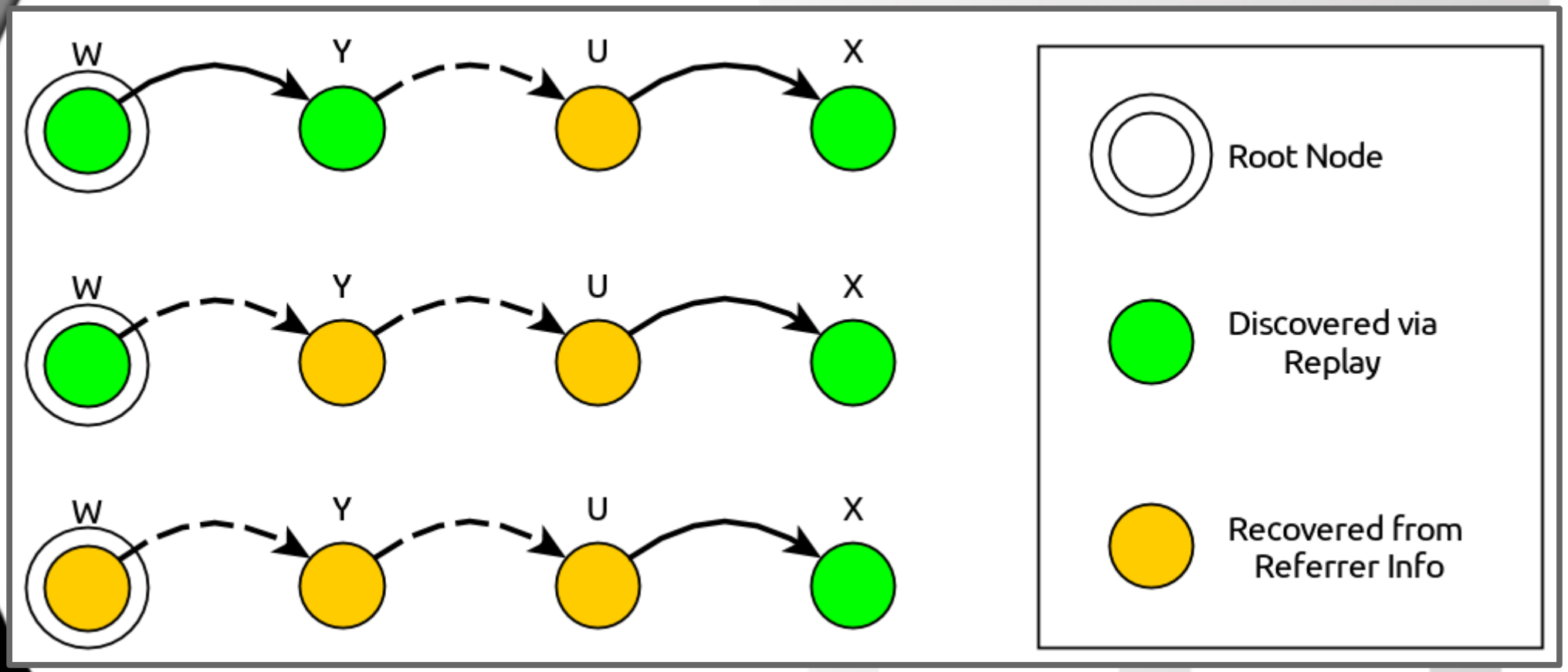
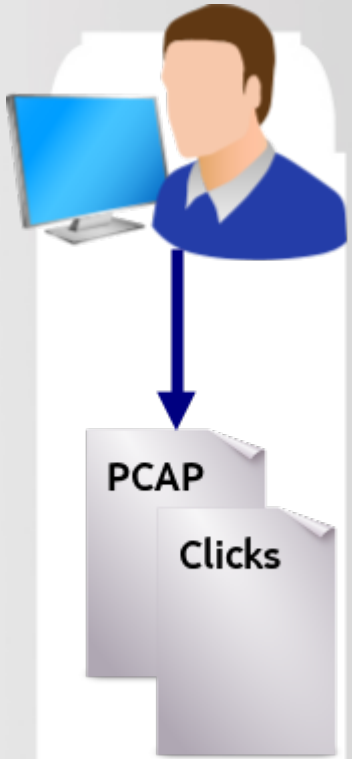
Augmented Click Inference



Evaluation

- Data Requirements
  - Clicks recorded at the browser level
    - Ground truth
  - Raw network traces
- User Study
  - Users performed generic web browsing activities
  - 21 Participants, 24 Traces
  - 2 Groups
    - Group 1: browser caching disabled
    - Group 2: browser caching enabled with “warmed up” cache



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Results

Summary

- Avg. between 82% and 90% of clicks correctly reconstructed
- Avg. between 0.74% and 1.16% false positives
- Greatly outperforms referrer-based approach

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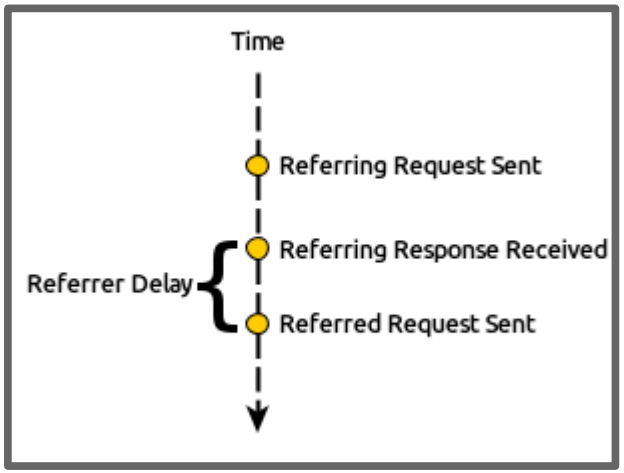
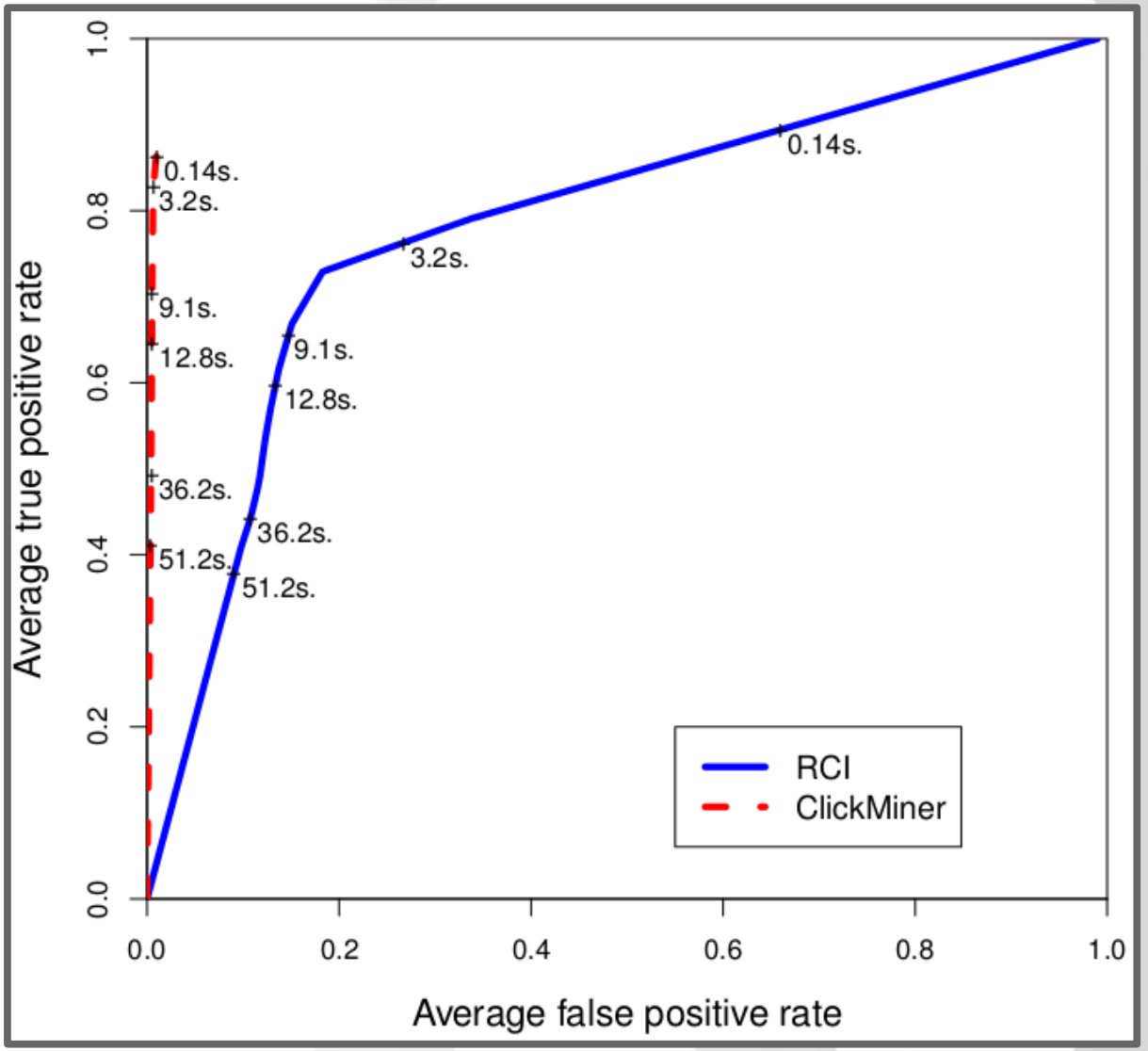
Results





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Results

Trace Number	HTTP Requests	Recorded Clicks	Mined Clicks avg (stddev)	Matching Clicks avg (stddev)	TPR	FPR
1	3925	21	50.80 (0.40)	20.00 (0.00)	95.24%	0.79%
2	1114	25	39.00 (0.00)	25.00 (0.00)	100.00%	1.29%
3	2884	16	41.00 (0.00)	13.00 (0.00)	81.25%	0.98%
4	1030	10	16.00 (0.00)	10.00 (0.00)	100.00%	0.59%
5	3405	23	46.20 (0.75)	22.80 (0.40)	99.13%	0.69%
6	3800	21	51.60 (0.80)	19.00 (0.00)	90.48%	0.86%
7	4891	11	30.20 (0.40)	11.00 (0.00)	100.00%	0.39%
11	9247	37	75.00 (2.61)	32.20 (0.75)	87.03%	0.46%
14	6508	32	50.00 (1.10)	28.00 (0.00)	87.50%	0.34%
16	1167	32	28.60 (0.49)	22.00 (0.00)	68.75%	0.58%
18	4073	20	76.60 (1.50)	17.20 (0.40)	86.00%	1.47%
22	5005	23	51.40 (0.80)	21.00 (0.00)	91.30%	0.61%
23	722	14	15.00 (0.00)	11.00 (0.00)	78.57%	0.56%
Average	3674.69	21.92	43.95	19.40	89.63%	0.74%
Stddev	2350.46	7.88	18.21	6.60	9.58	0.34

Caching Disabled

Network Security Intelligence

Results

Trace Number	HTTP Requests	Recorded Clicks	Mined Clicks avg (stddev)	Matching Clicks avg (stddev)	TPR	FPR
8	4786	28	64.40 (0.80)	21.00 (0.00)	75.00%	0.91%
9	2212	19	42.80 (1.60)	14.00 (0.00)	73.68%	1.35%
10	1639	15	23.20 (0.40)	15.00 (0.00)	100.00%	0.50%
12	1219	10	15.60 (0.49)	7.00 (0.00)	70.00%	0.71%
13	1250	15	17.00 (0.00)	13.00 (0.00)	86.67%	0.32%
15	500	34	34.20 (0.40)	28.00 (0.00)	82.35%	1.33%
17	4682	25	63.00 (0.00)	19.00 (0.00)	76.00%	0.94%
19	2239	21	38.00 (1.26)	19.20 (0.40)	91.43%	0.85%
20	3980	21	117.00 (1.26)	19.00 (0.00)	90.48%	2.48%
21	2312	18	60.60 (0.49)	16.00 (0.00)	88.89%	1.93%
24	943	22	28.40 (0.49)	14.40 (0.49)	65.45%	1.52%
Average	2342.00	20.73	45.84	16.87	81.81%	1.16%
Stddev	1428.86	6.33	28.11	5.10	10.61	0.64

Caching Enabled

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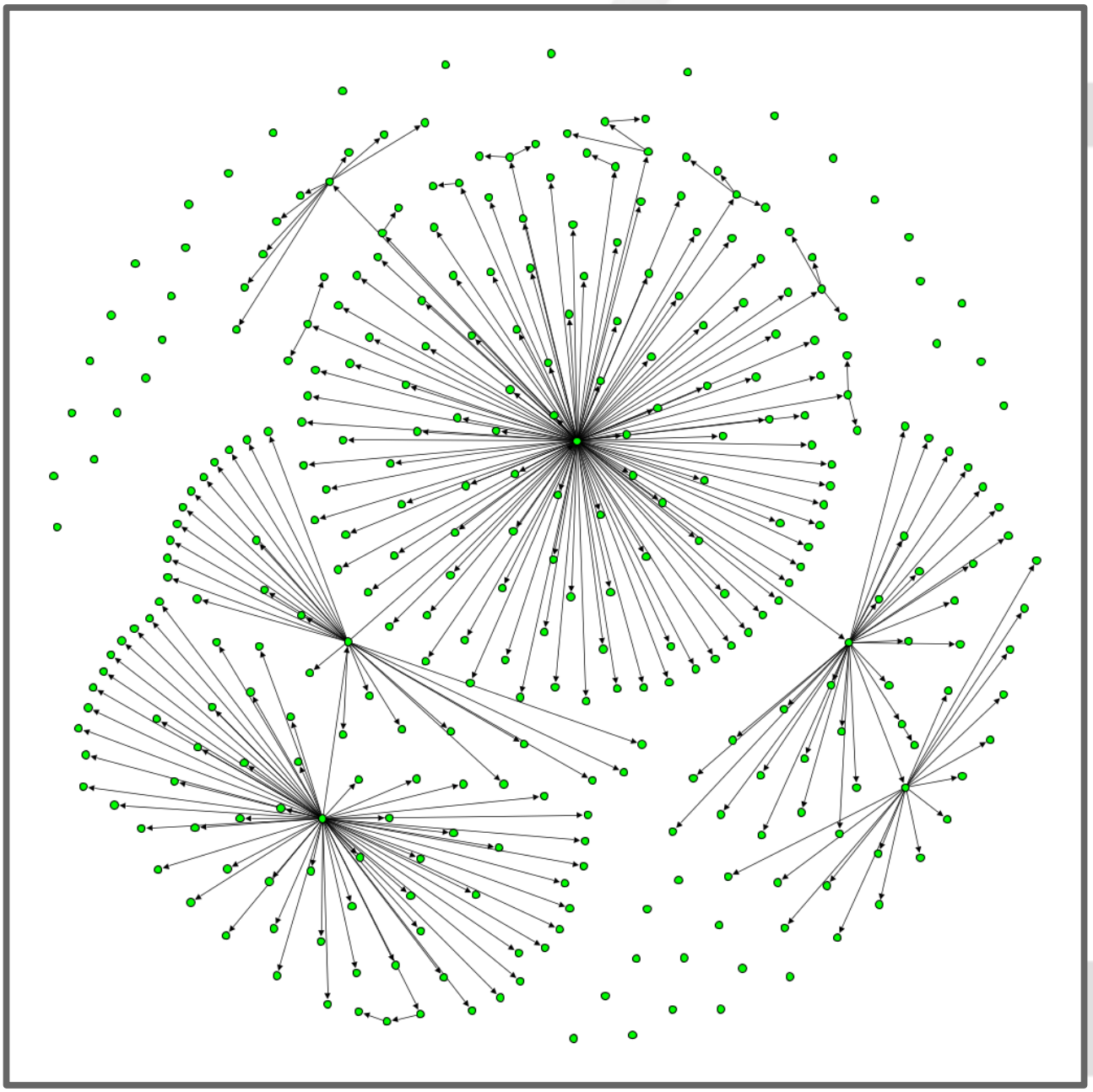
Case Study

Malware download incident from user study

- User visited `bing.com`
- User searched with term “far cry 3 hackz tools crack”
- User clicked on `allhackz[dot]net` from search results
- User clicked on “Download” button, opened two pages
  - `gameadvert[dot]com`
  - `wellmediaonline[dot]com`
- From `wellmediaonline[dot]com` download started via script from `effortlessdownload[dot]com`

Case Study



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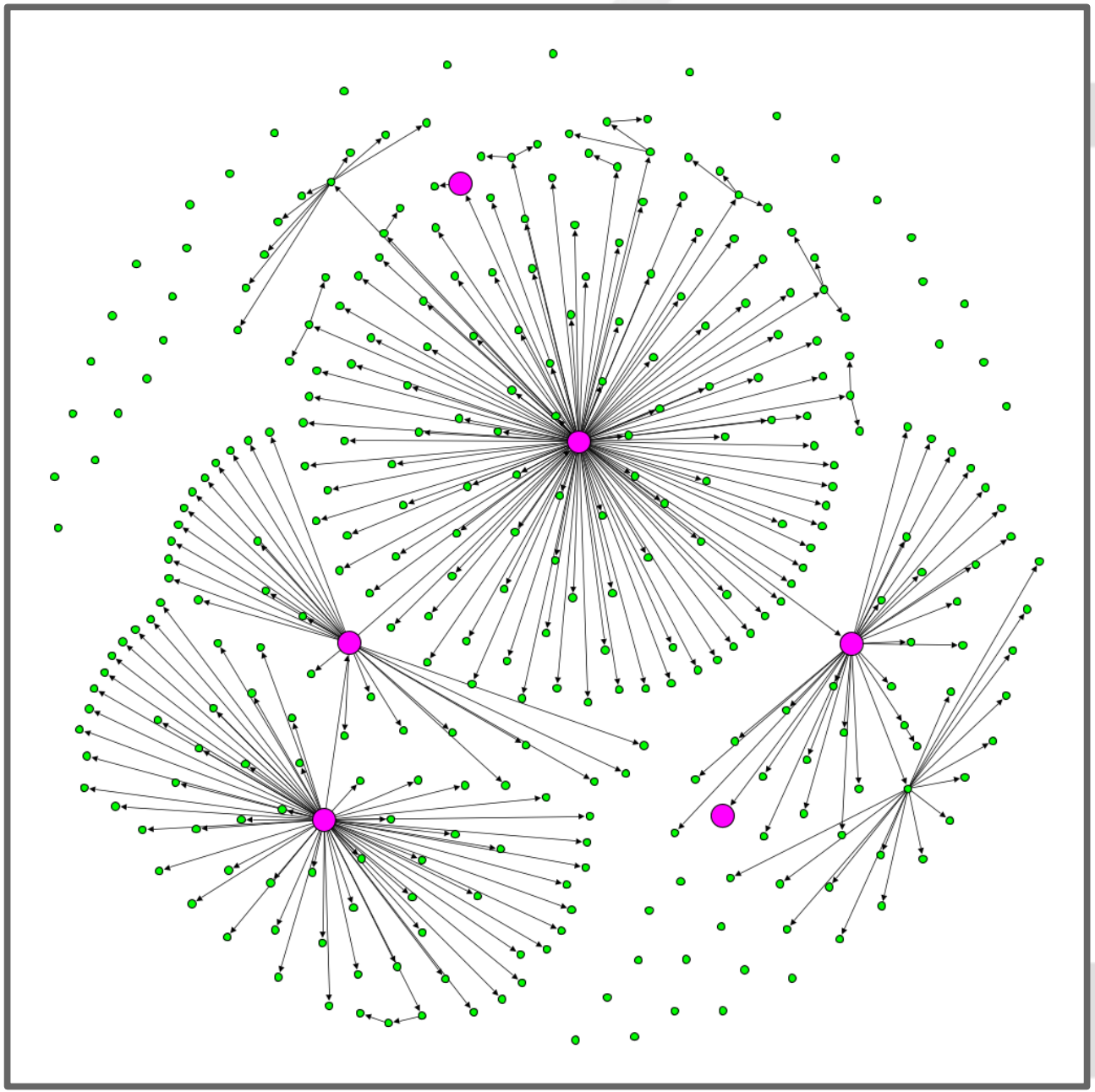

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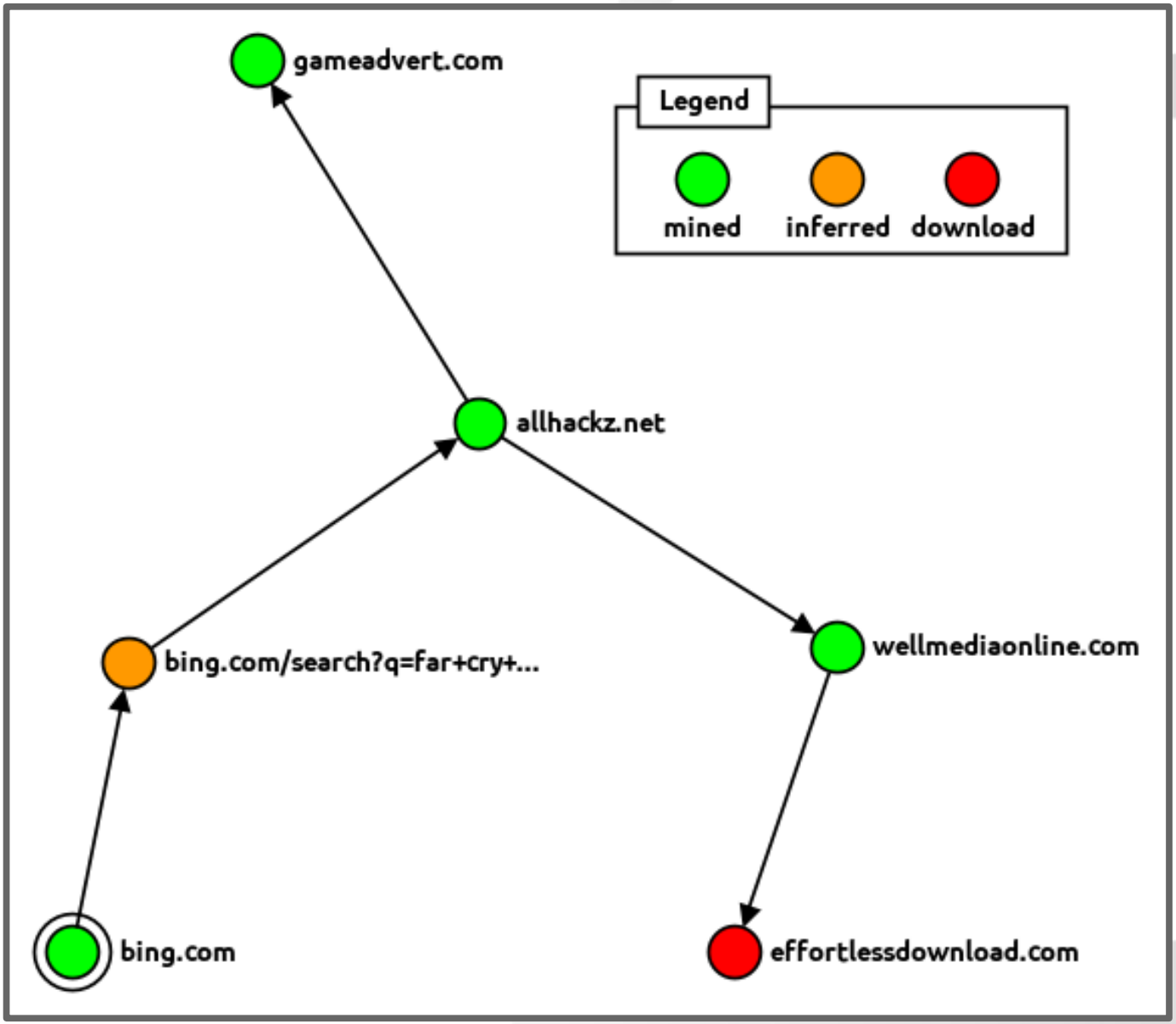

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Conclusion

- Importance of aiding the forensic analysis of web traffic traces
- ClickMiner, reconstructs user-browser interactions from network traces
- Through a user study we demonstrate:
  - Correctly reconstruct between a 82% and 90% of clicks
  - Low false positives
  - Outperforms exclusive referrer-based approach

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