"Just-in-Time" Training of Anomaly Detectors (With Scarce Data)

Addressing Training Issues In Modern Intrusion Detection

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How to distinguish between “good” and “bad” changes of a web application?

Intrusion Detection

Detect attempts to compromise a *system*.

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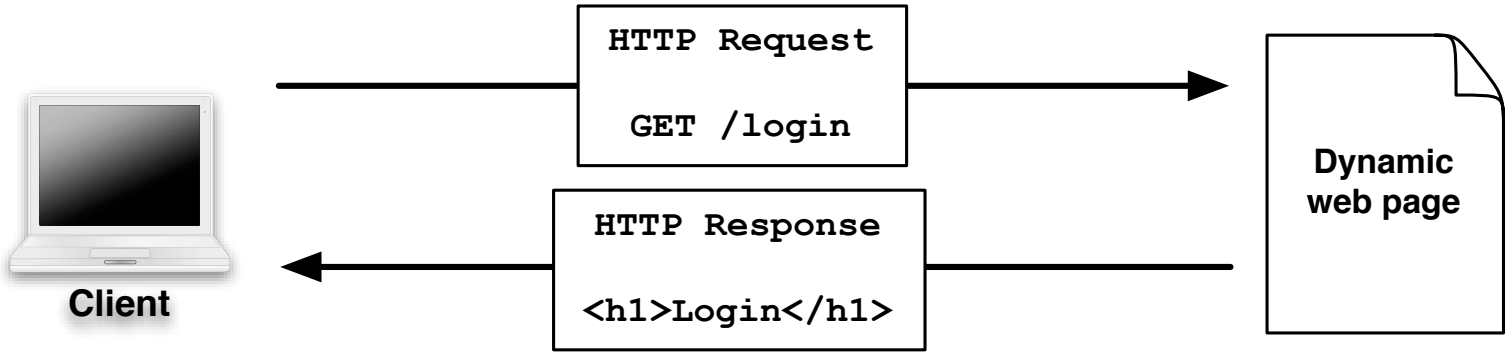
- *Modern* intrusion detection deals with a great diversity of systems with really loose boundaries.
  The system could be:
  - an application (e.g., a web application),
  - a service —how do you define its boundaries?
  - all 2.0 bells and whistles.

Let's focus on attacks against web applications

Target: a website. Entry point: a vulnerable web application.

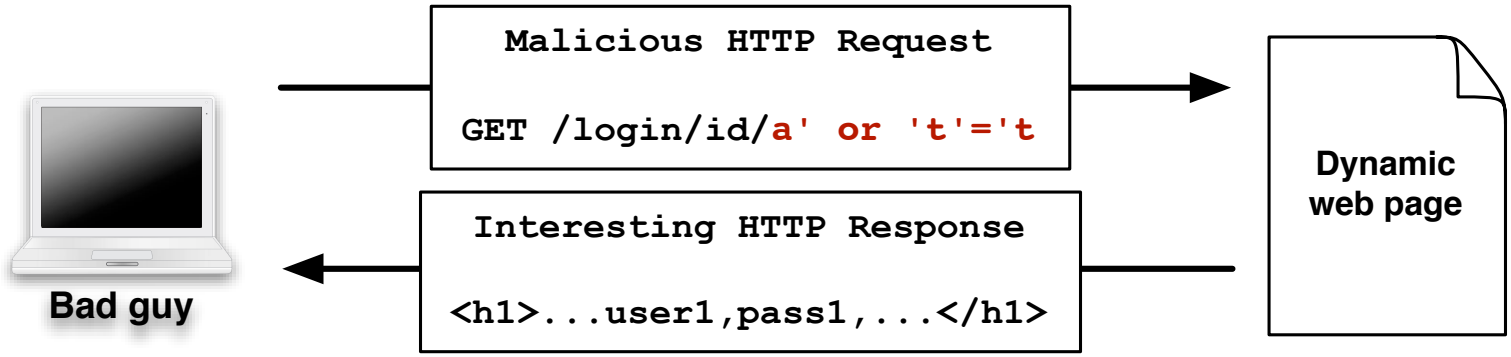
Let's focus on attacks against web applications

This is how HTTP is supposed to work. Straightforward.



Let's focus on attacks against web applications

This is how a bad guy takes advantage of a vulnerable site to steal data from the server.



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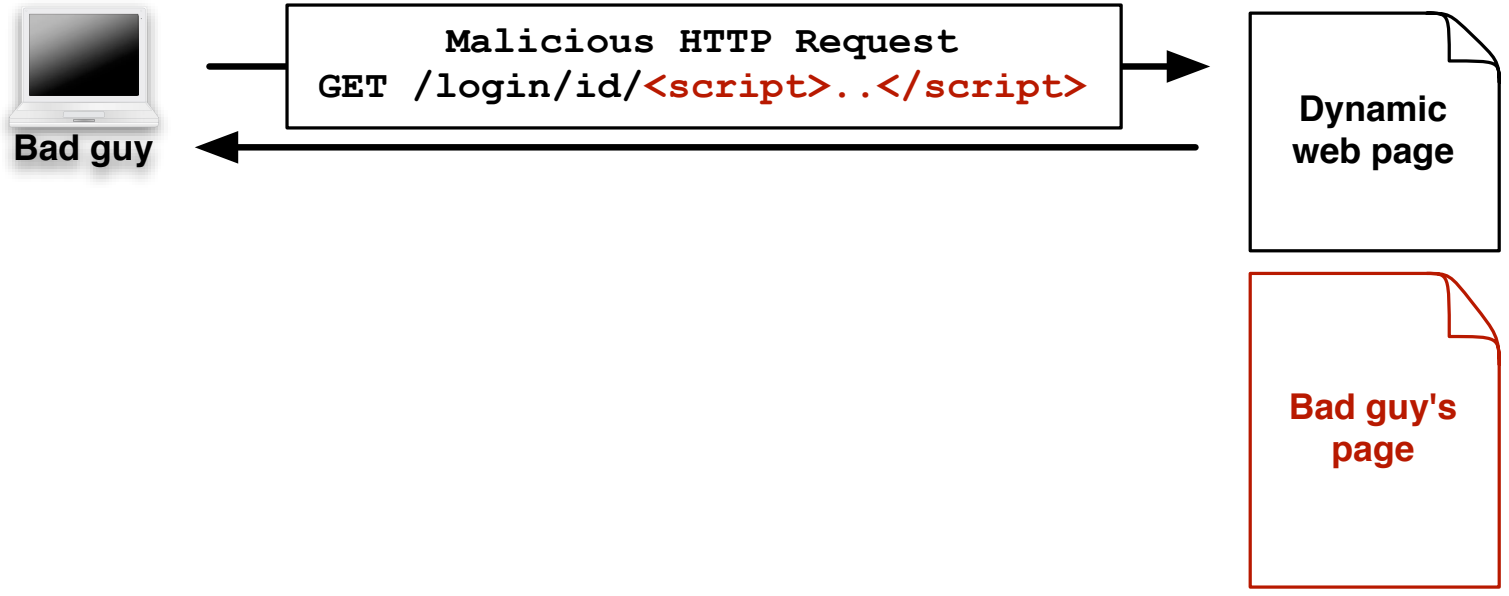
This is how a smart bad guy turns a page into an indirect "malware spreader".



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This is how a smart bad guy turns a page into an indirect "malware spreader".

- And now the unlucky client joins all the other hosts in the botnet like a vampire joins his/her new friends.
- **What if someone deploys a vulnerable, popular Facebook application? :)**

Web Application Anomaly Detection

Learning benign HTTP interactions (i.e., requests and responses)

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/comment/<par1>/<par1-val>
```

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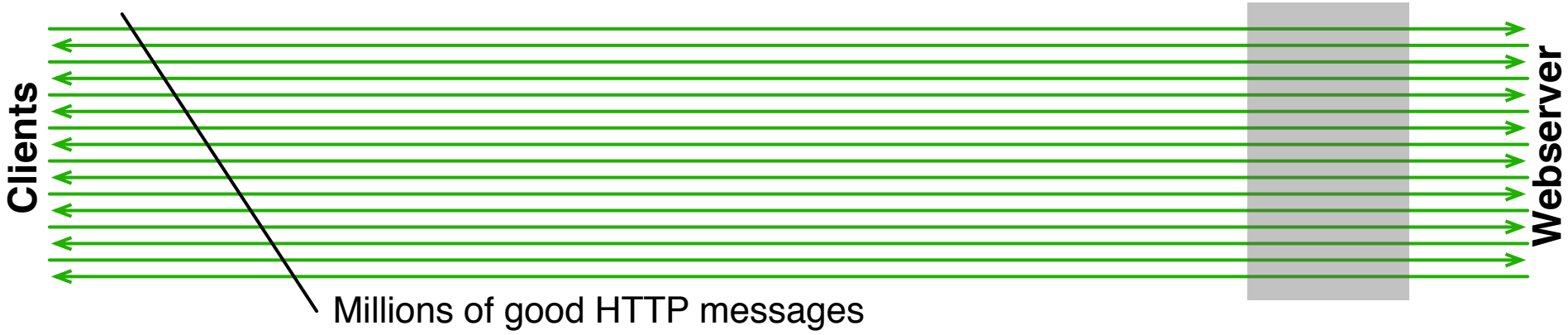

Modeling benign HTTP interactions

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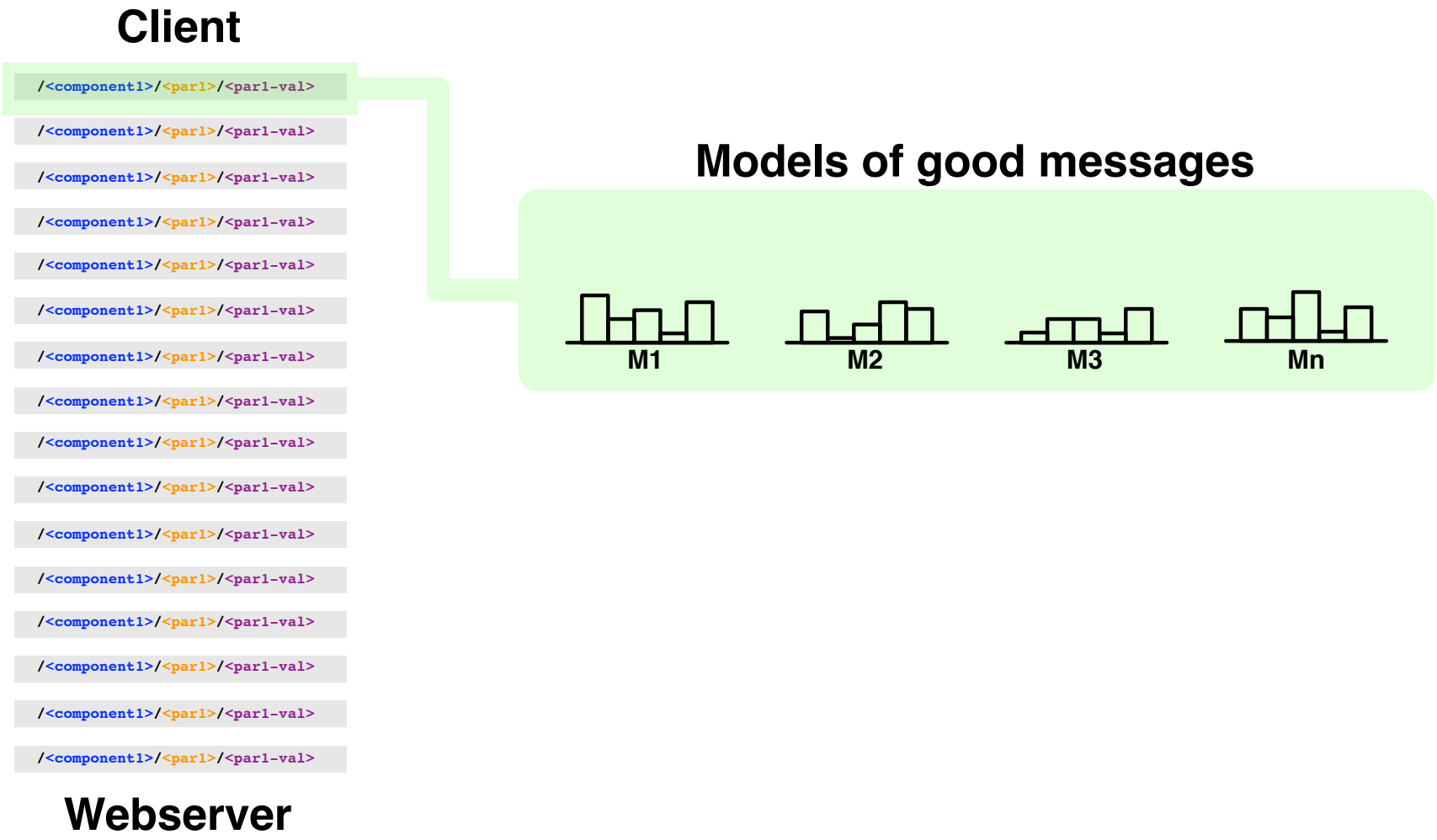

Modeling benign HTTP interactions

Client

/<component1>/<par1>/<par1-val>
/<component1>/<par1>/<par1-val>
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/<component1>/<par1>/<par1-val>
/<component1>/<par1>/<par1-val>
/<component1>/<par1>/<par1-val>
/<component1>/<par1>/<par1-val>
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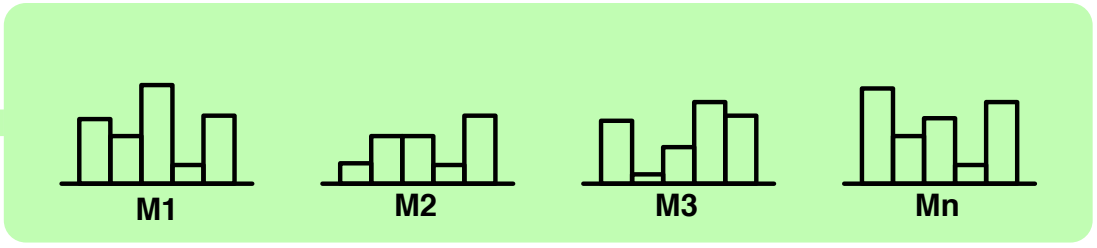
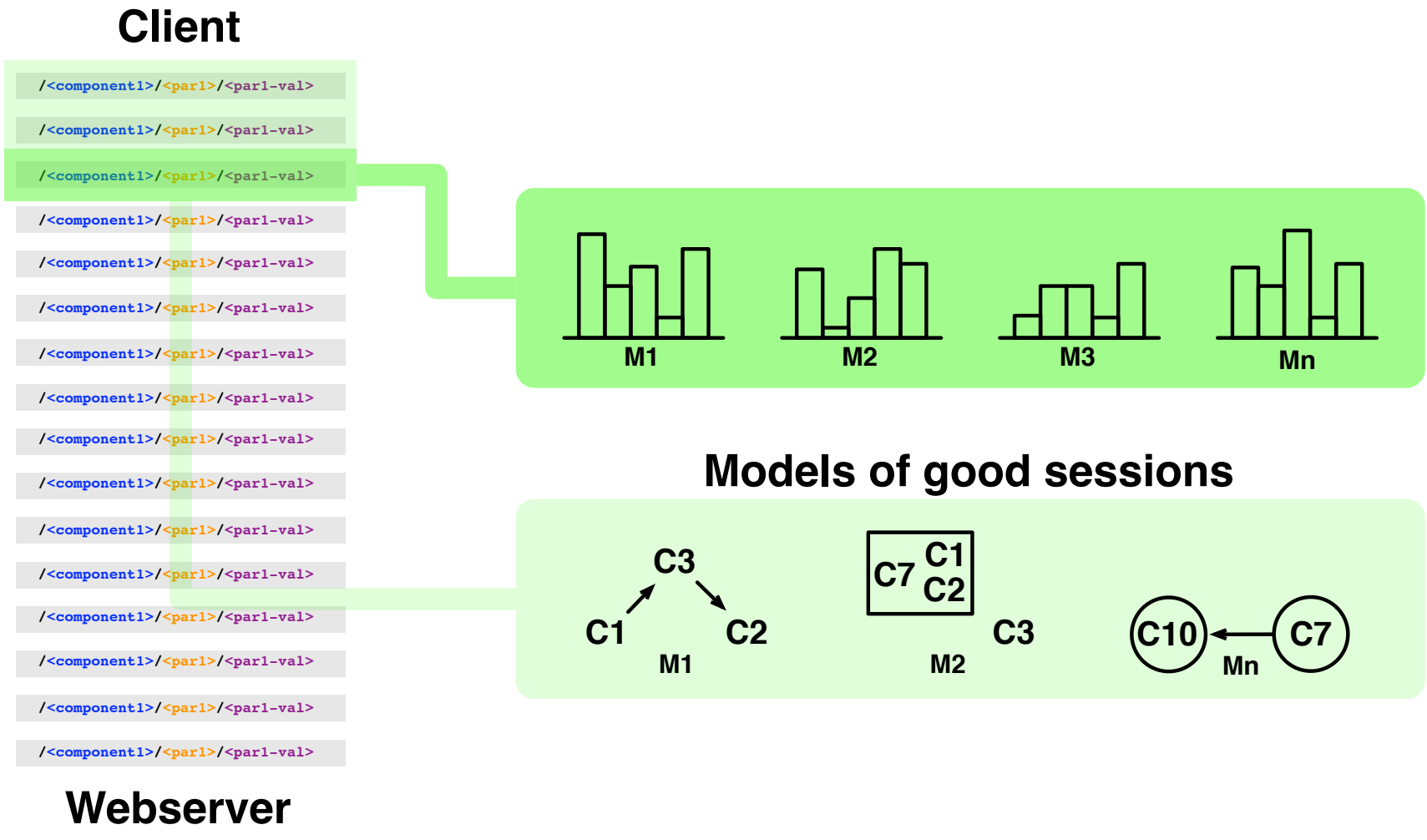
Webserver



Example of models

— parameter string length
— numeric range
— probabilistic grammar of strings
— string character distribution

Modeling benign HTTP interactions



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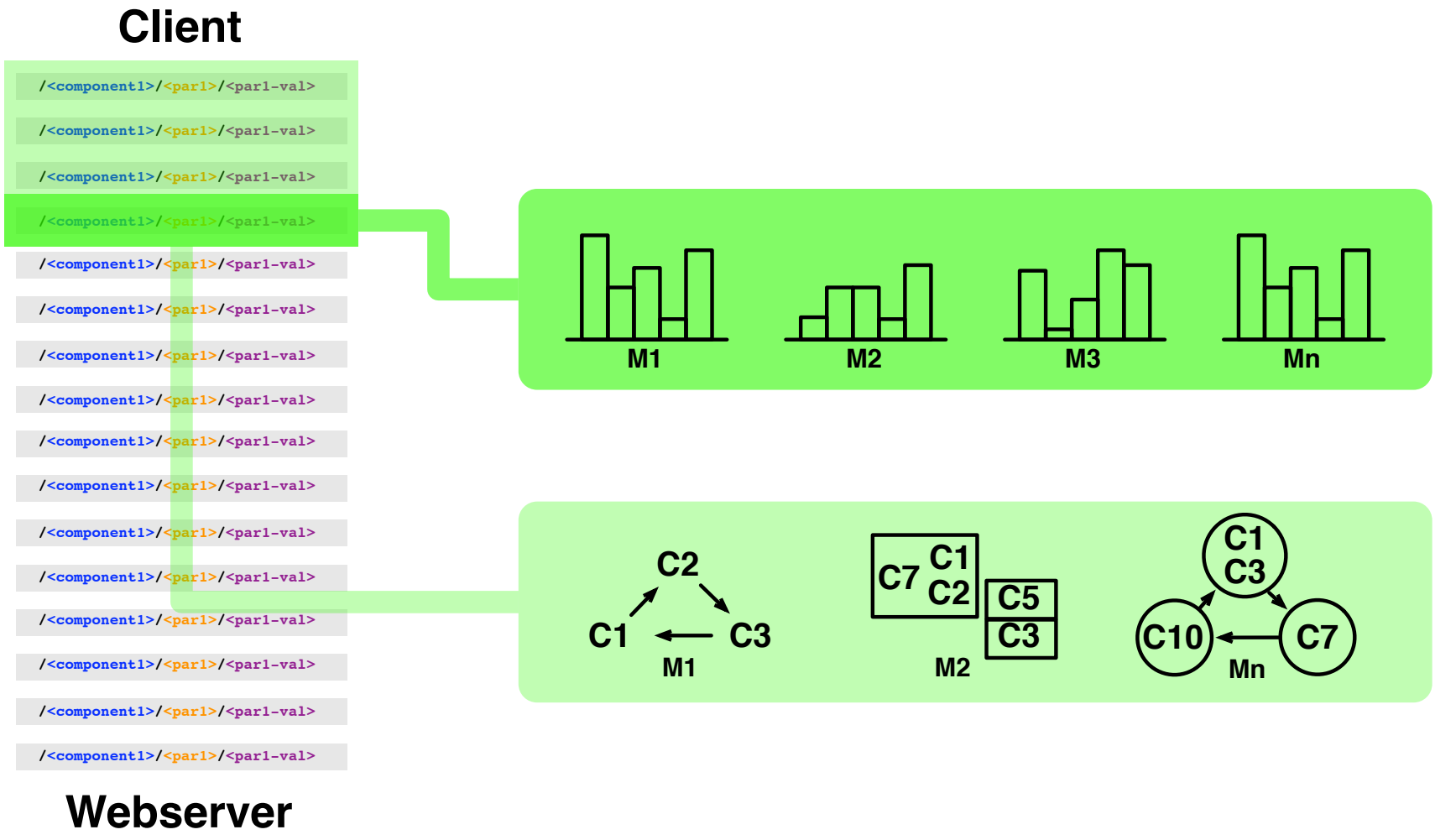

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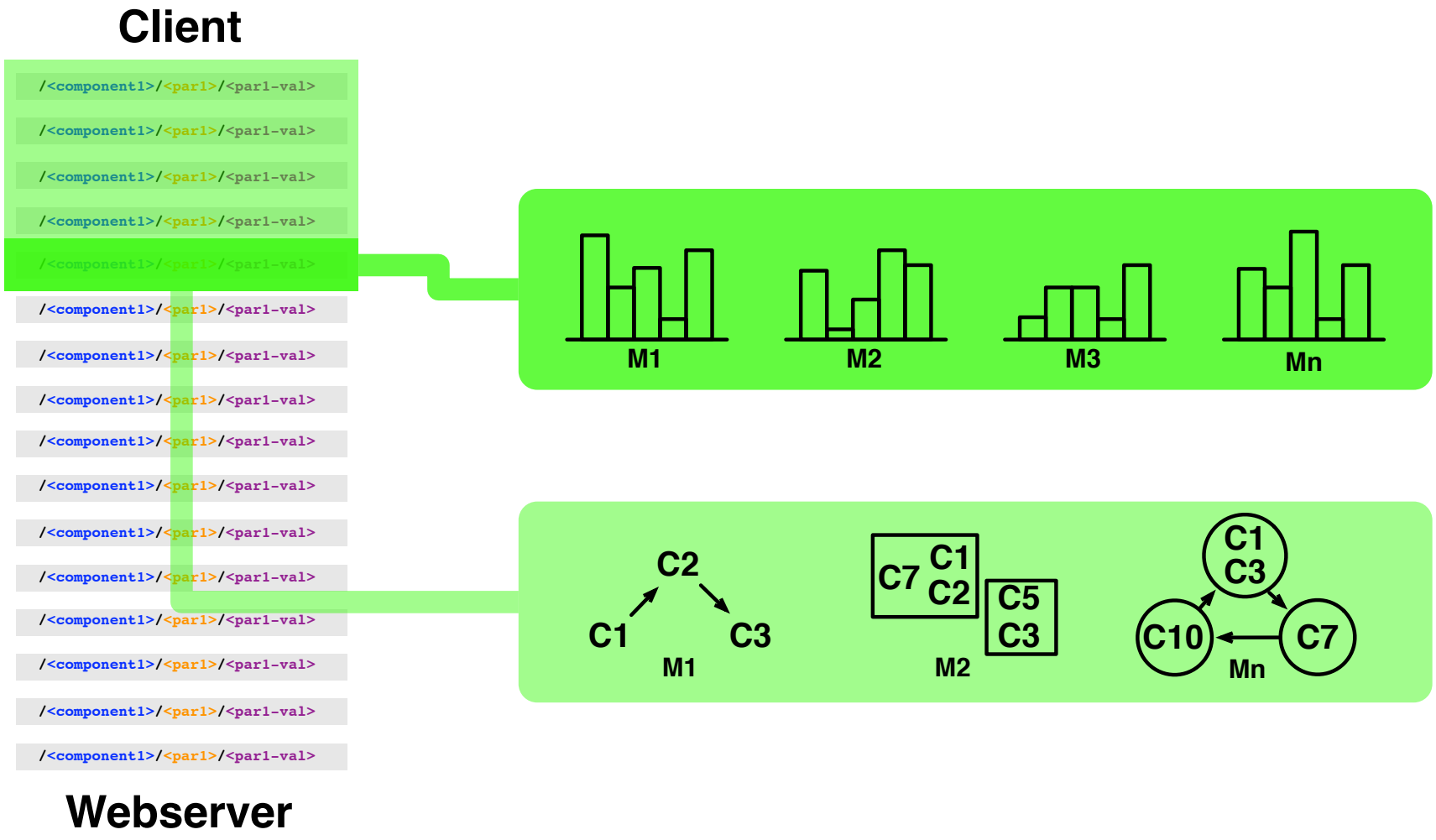

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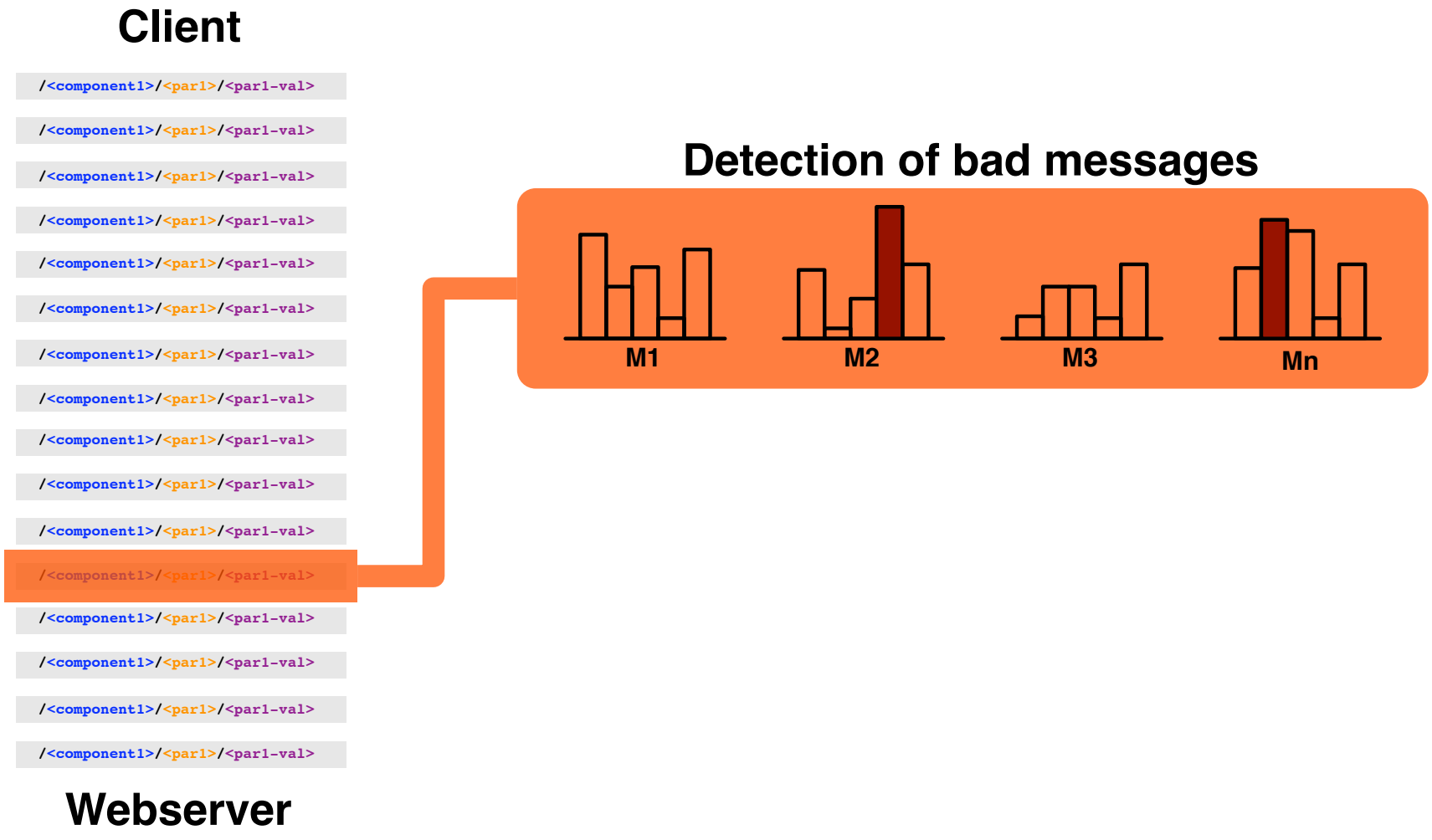

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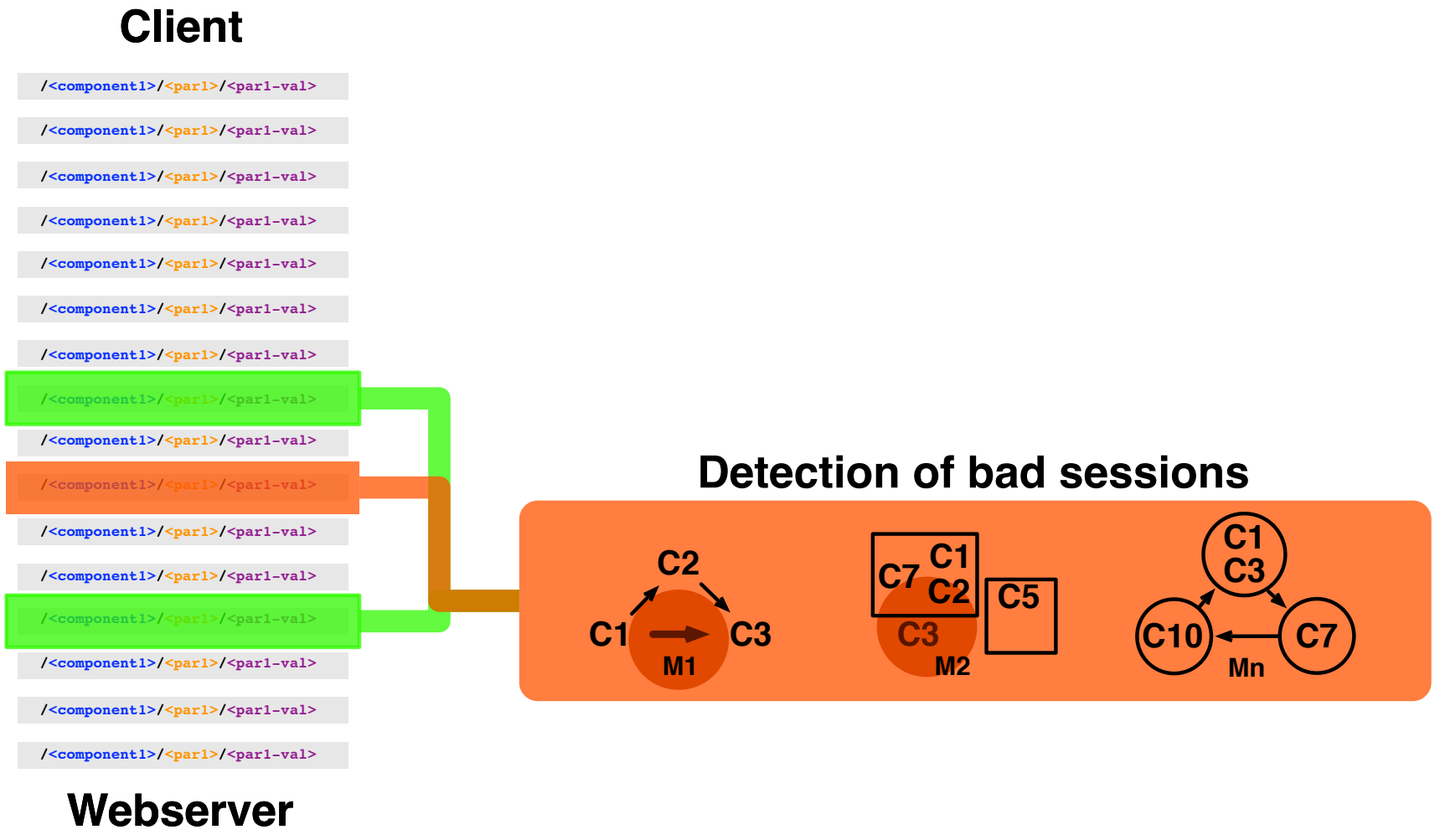

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In practice, what if the protected website suddenly changes?

- site changes means changes in the good behavior,
- changes in the good behavior means obsolete training,
- obsolete training leads to FP.

What type of changes are we concerned about?

Those that affect normality models.

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- **Request:** e.g., new parameters, new domains for parameters, L10N, I18N.
  - Example (I18N): `3/12/2009 3:00 PM GMT-08`, `3 May 2009 3:00`, `now`.
  - Affect: string length, char distribution, string grammar.

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- **Response:** e.g., new DOM nodes, rearrangement of DOM nodes.
  - Example (AJAX): several nodes are enriched with client-side code.
  - Affect: any tree-based DOM normality models.

What type of changes are we concerned about?

Those that affect normality models.

- **Session:** e.g., reordering of paths in a typical session, add/rem. of authentication.
  - Example (auth):
    `/site` $\rightarrow$ `/auth` $\rightarrow$ `/blog`
    `/site` $\rightarrow$ `/auth` $\rightarrow$ `/files`

    `/site` $\rightarrow$ `/files|/blog|/auth`.
  - Affect: sequence-based session models.

Is this an issue?

Todays' websites change pretty often.

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Between Jan 29 and Apr 13, 2009, we crawled:

- 2,264 websites drawn from Alexa's Top 500 and googling,
- 3,303,816 pages instances total,
- 1,390 snapshots for each website.

What type of, and how many, changes have we found?

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- YouTube (dramatic change)
  - richer interaction to let user rearrange widgets,
  - this meant lots of new parameters,
  - lots of req/res/ses changes.

What type of, and how many, changes have we found?

- Yahoo! Mail
  - new parameter for enhaced and localized search,
  - new valid values for parameters,
  - not many response changes,

What type of, and how many, changes have we found?

- MySpace
  - unfortunately, we found this didn't change too much.

What type of, and how many, changes have we found?

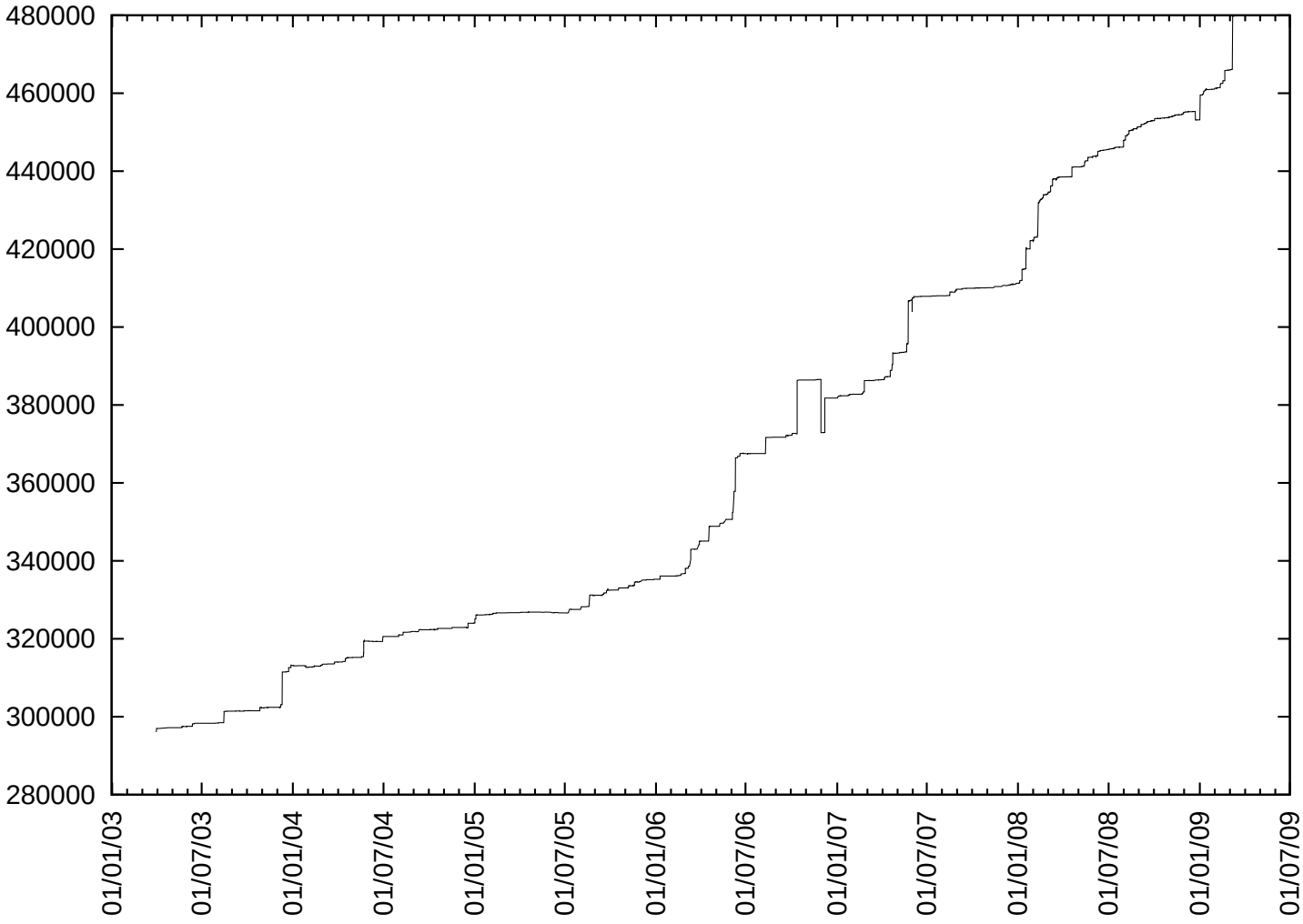
- All:
  - 40% have new resource paths,
  - 30% have new parameters.

Is this really an issue?

Todays webapps' code change pretty often.

Is this really an issue?

WordPress' code. Only LOC that handle HTTP requests are shown.



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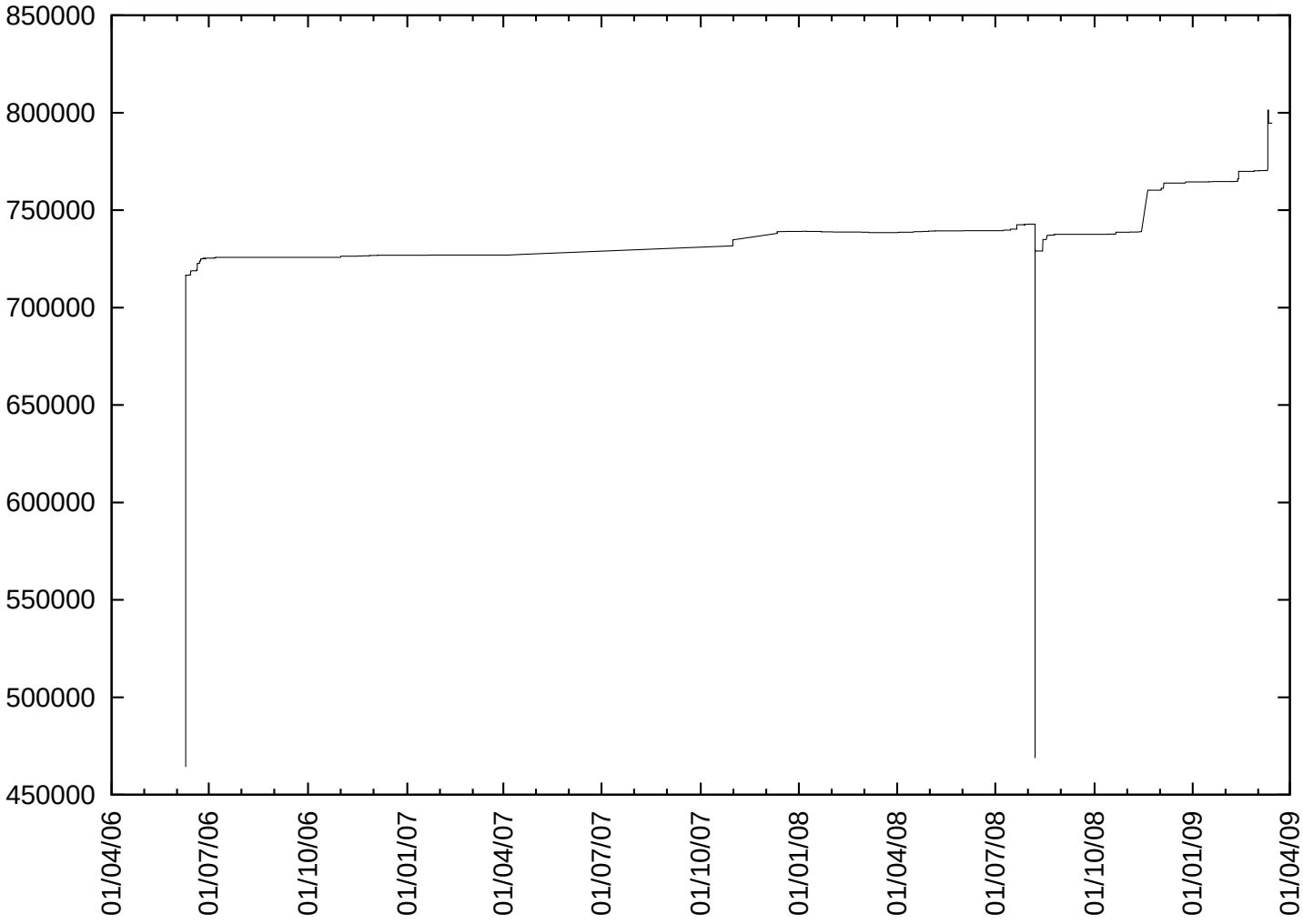
MovableType Open Source's code. Only LOC that handle HTTP requests are shown.



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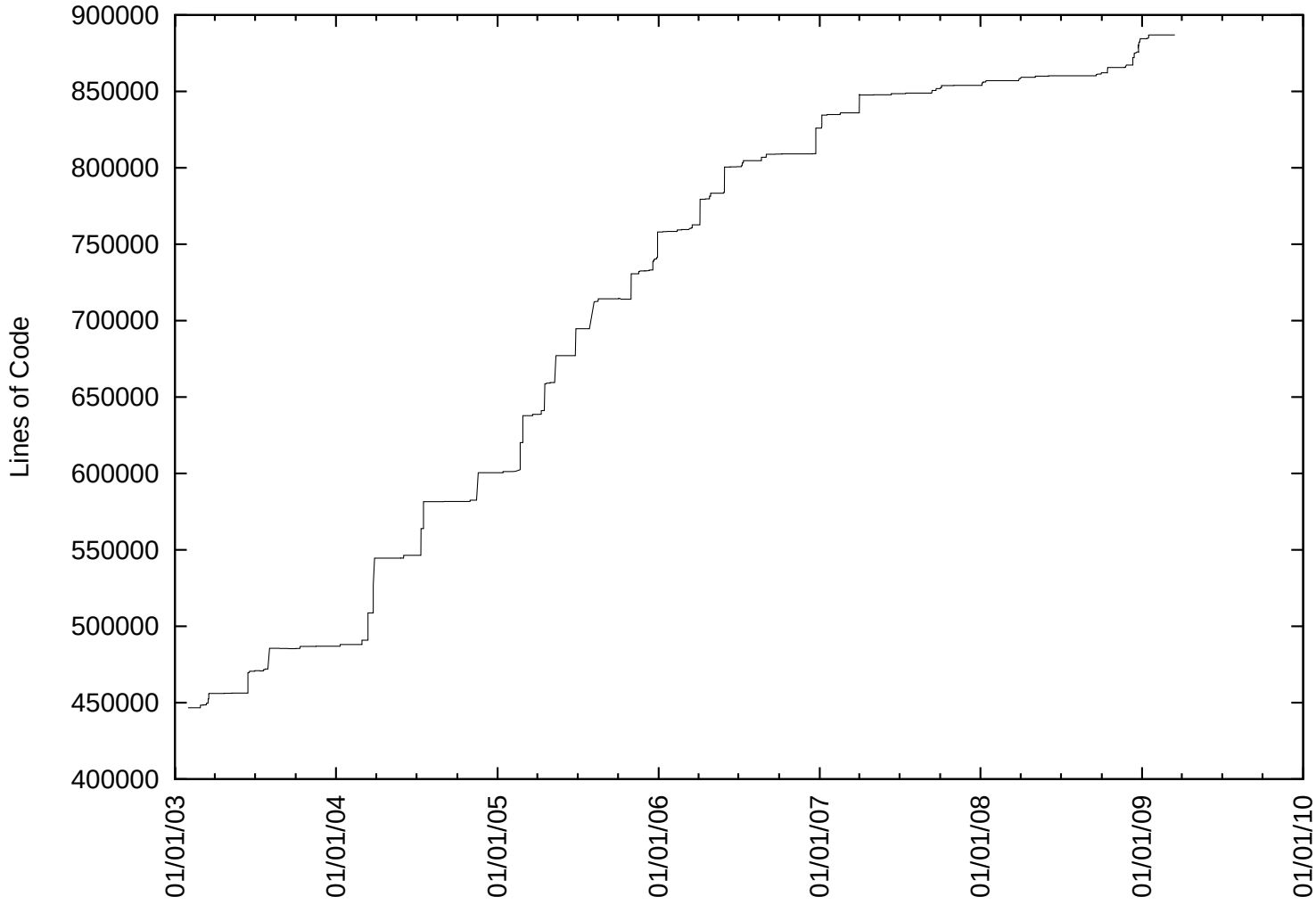
PhpBB's code. Only LOC that handle HTTP requests are shown.



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- Real-world training Q' and testing datasets Q, $Q \cap Q' = \varnothing$:
  - 823 unique web applications,
  - 36,392 unique resource paths,
  - 16,671 unique parameters,
  - 58,734,624 HTTP messages;
  - 1000 real-world attacks.

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  - 823 unique web applications,
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  - 1000 real-world attacks.
- We drifted Q, obtaining a known Q_{drift}
  - 6,749 new session flows,
  - 6,750 new parameters,
  - 5,785 modified parameters.

In this way, the set of changes in web application behavior was explicitly known.

Details on how we built Q_{drift}

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- New session flows

/login	/index
/index	/login
/article	/article

Details on how we built Q_{drift}

- new parameters

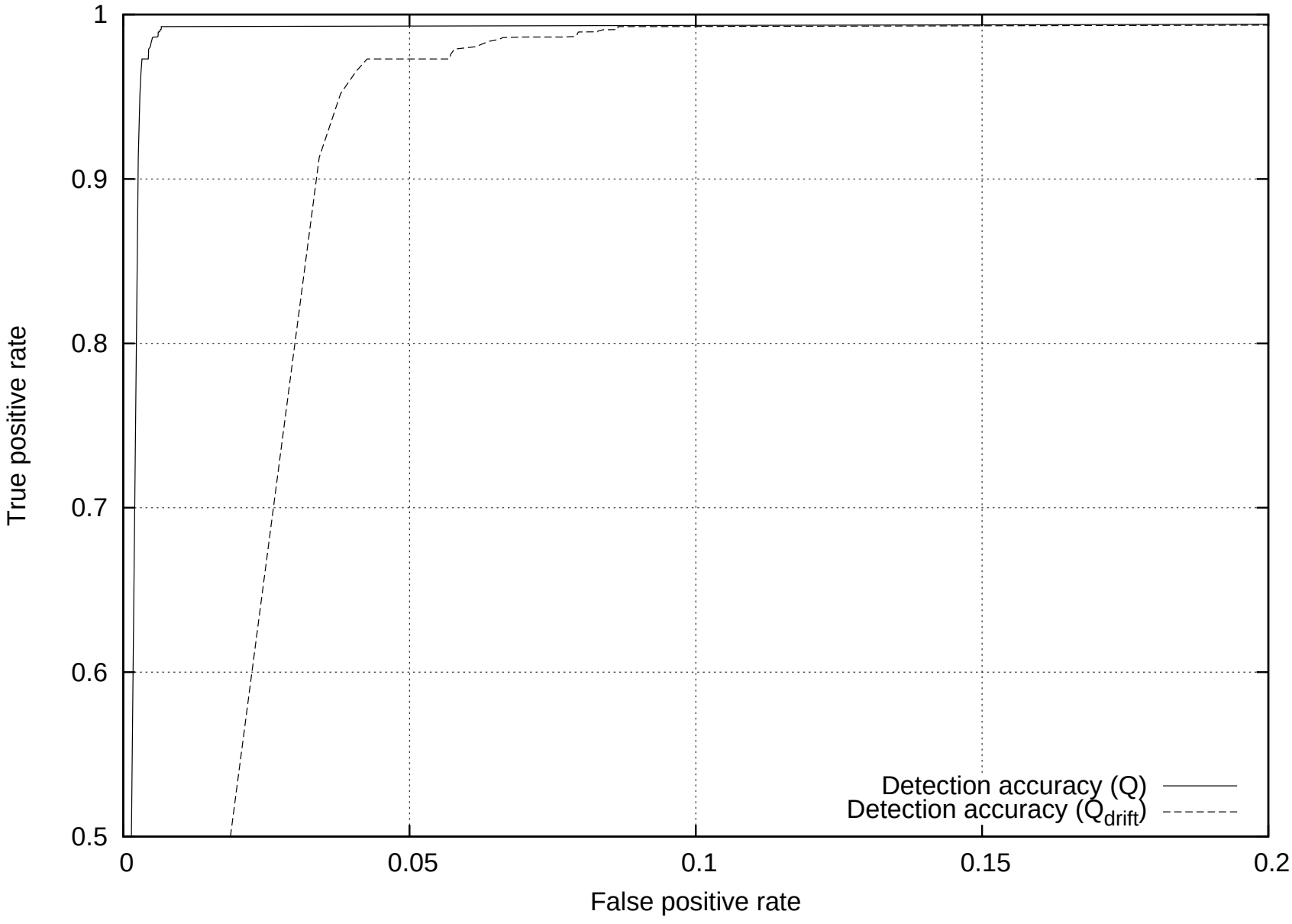
`/nav?id=21&mode=text`	`/nav?pk=21&attr=text`
`/all?filter=2009`	`/all?filter=2009&pag=true`
`/get?id=21`	`/retrieve?id=21`

Details on how we built Q_{drift}

- modified parameters

  `?date=1944-10-14` `?date=yesterday&fmt=smart`

Effects on detection



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- How about a full-retraining?
  - OK, but where do you get clean training data if you just deployed the app?
  - isn't it quite expensive?
- Wouldn't it be great to have the IDS automatically figure out relevant changes and update the models just-in-time?

HTTP responses contain good clues about changes!

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- links $\rightarrow$ resources and parameters candidates,

```
<a href="/account/retrieve?id=22&type=ext" />
<a href="/account/history?aid=446825759916" />
```

HTTP responses contain good clues about changes!

- forms $\rightarrow$ resources candidates,

```
<form name="newform" target="/account/newhandler">
 <!--fields-->
</form>
```

HTTP responses contain good clues about changes!

- fields $\rightarrow$ parameters and also new candidate values.

```
<input type="text" name="new_parameter" />
<select name="subject">
  <option>General</option>
  <option>User interface</option>
  <option>Functionality</option>
  <option>New value for 'subject'</option>
</select>
```

Parsing HTTP responses to update models

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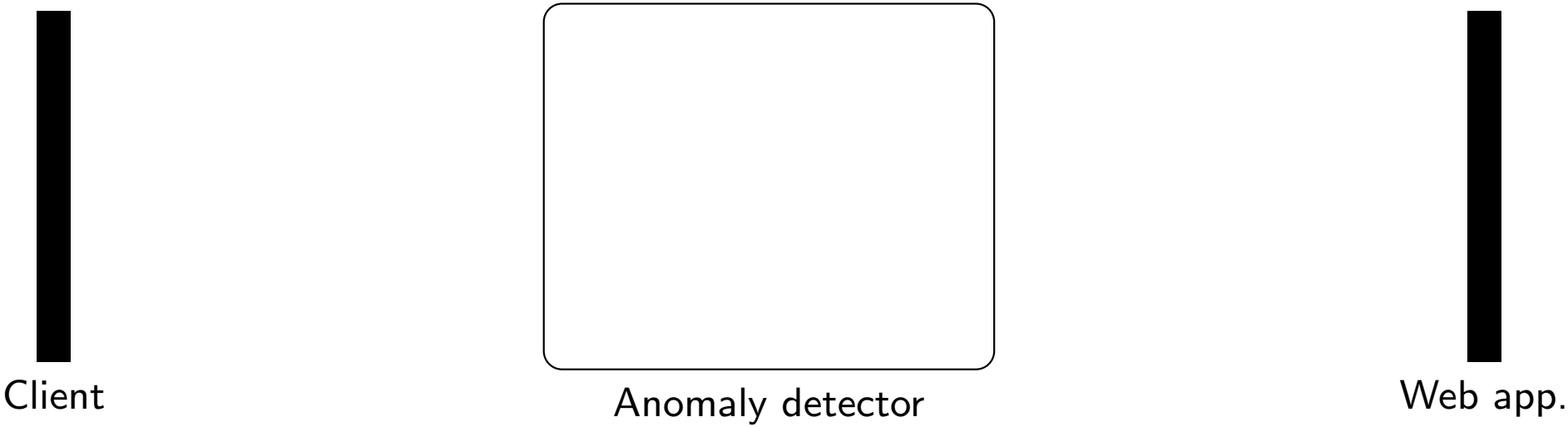

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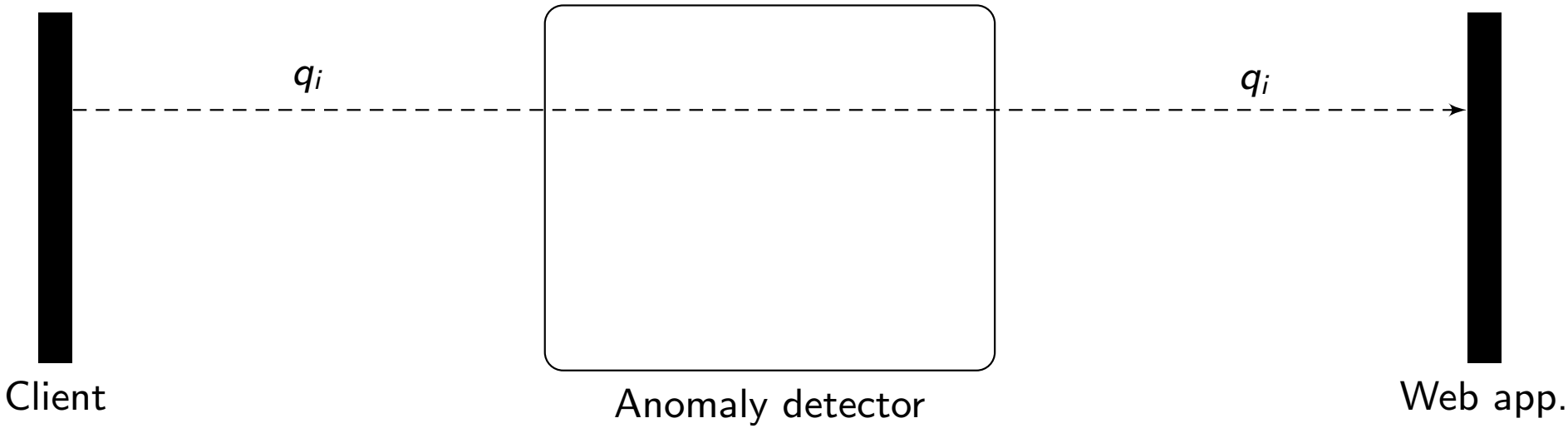

for each request q_i

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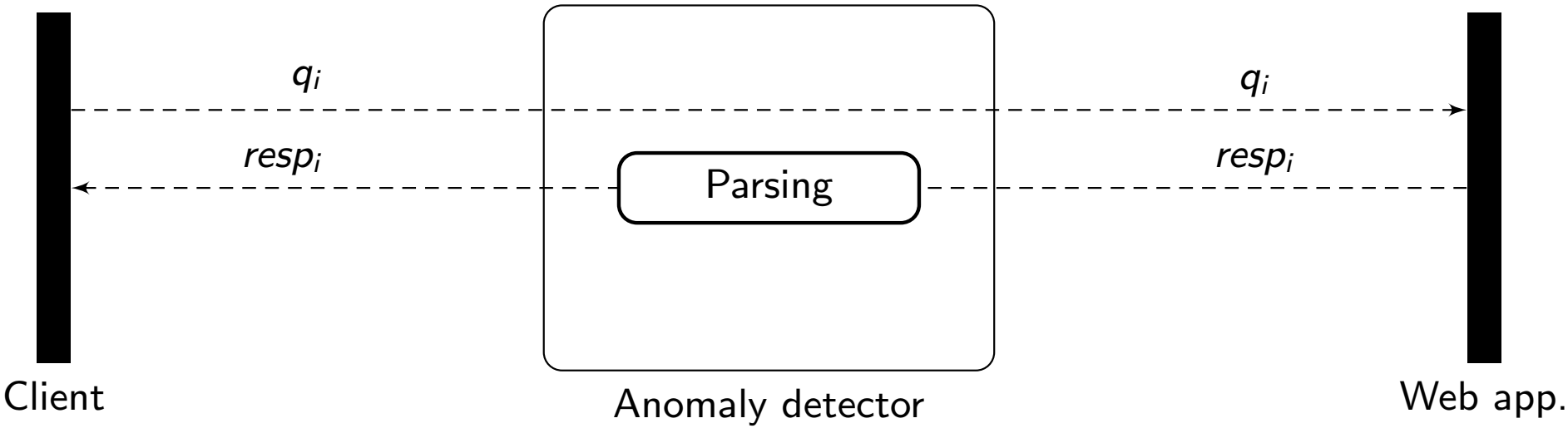

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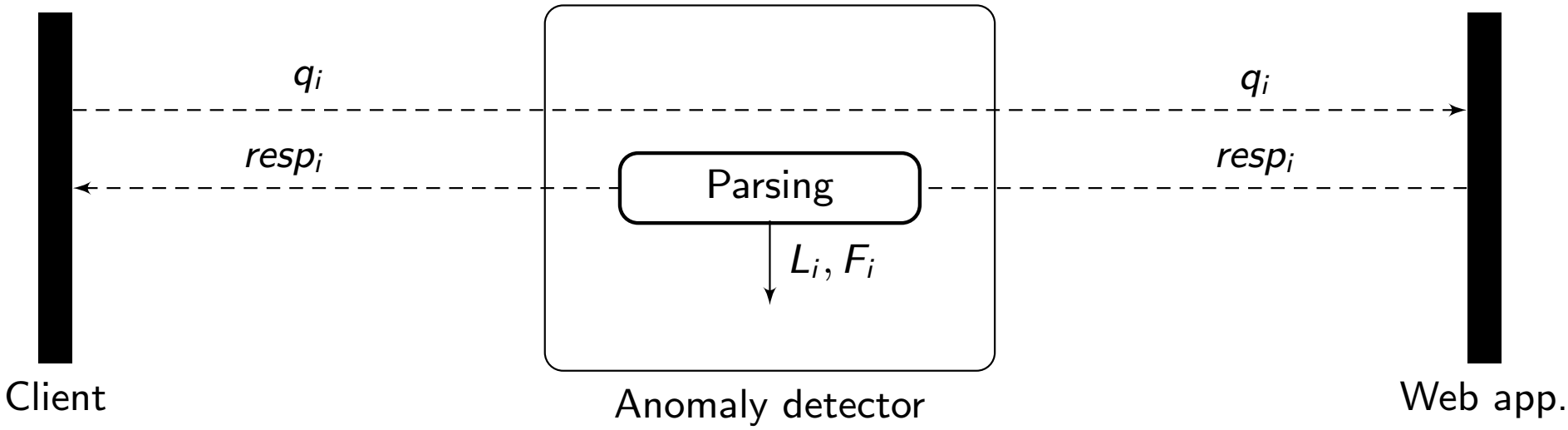

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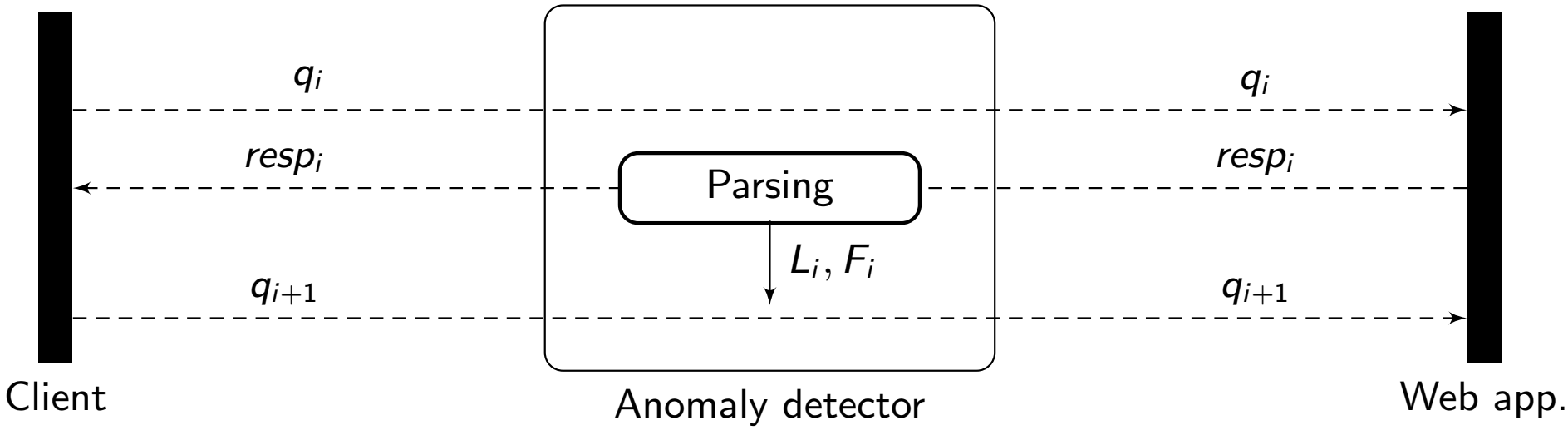

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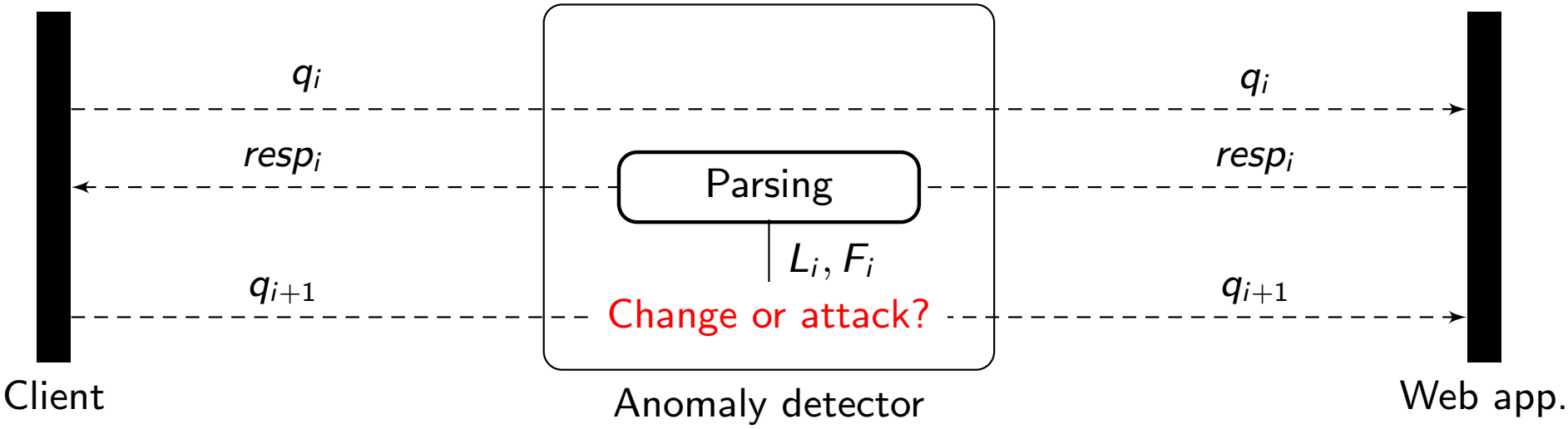

for each request q_i

intercept the corresponding response $resp_i$

extract parmeters and values from links, forms, fields

at next request q_{i+1}

compare parameter and values to spot legit changes

Example

q_i = `GET /page?id=14`

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$resp_i$ =

```
<a href="/comments/retrieve?id=22&type=ext" />
<a href="/archive/yearly?y=2008" />

<form name="newform" target="/account/
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 <select name="subject">
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```

q_{i+1} = `GET /account/newhandler?new_parameter=1`
would rise a false positive.

How do we eliminate false positives?

- new parameters: we create a new model and we train it on values, if any.

How do we eliminate false positives?

- new session flows: we just reorder the session sequence.

How do we eliminate false positives?

- new values: we can guess the type (e.g., string, token). If not available, we trust the requests that follows.

Does it work?

Results on Q_{drift}

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Change type	Anomalies	False Positives	Reduction
New session flows	6,749	0	100.0%
New parameters	6,750	0	100.0%
Modified parameters	5,785	4,821	16.6%
Total	19,284	4,821	75.0%

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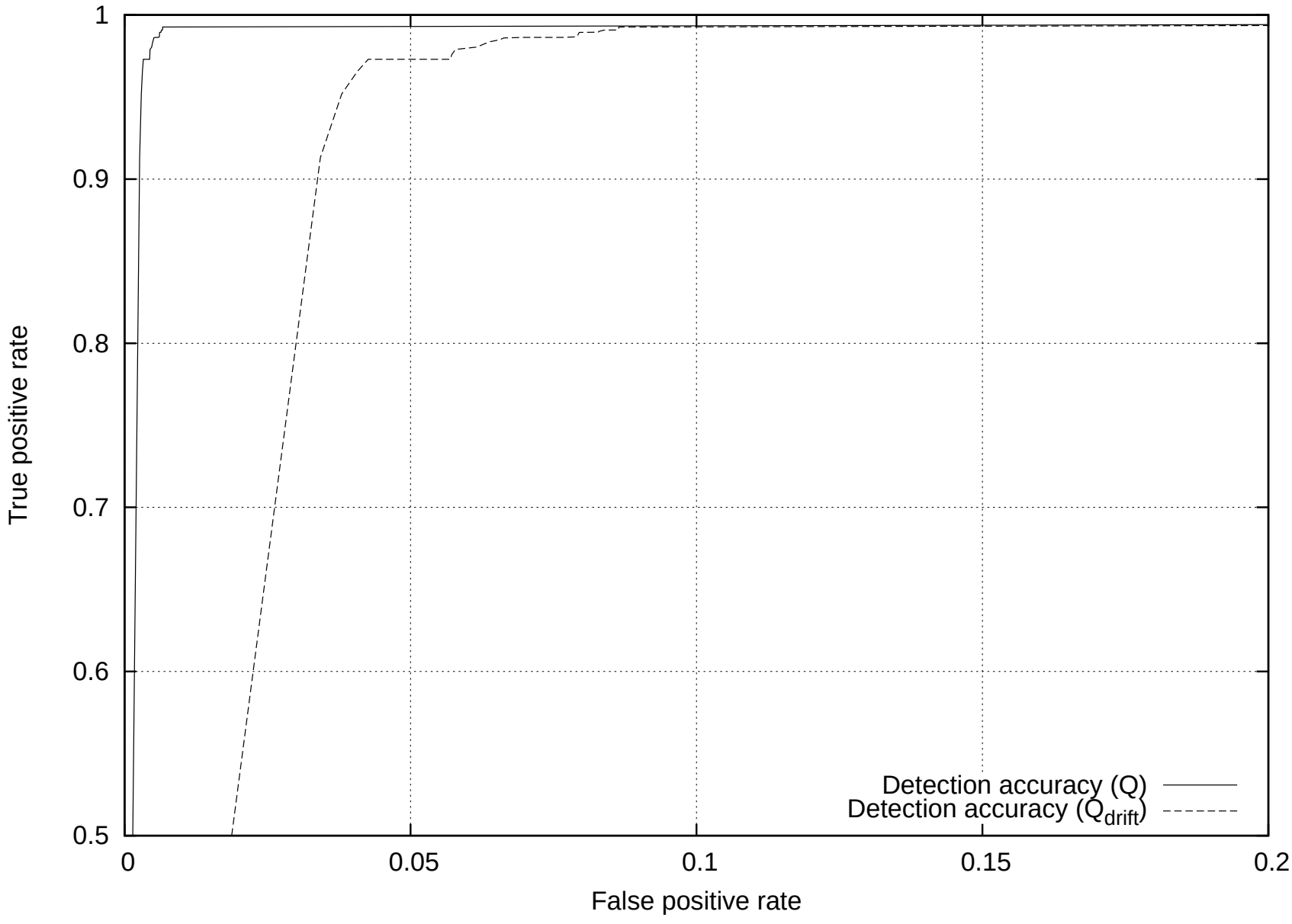

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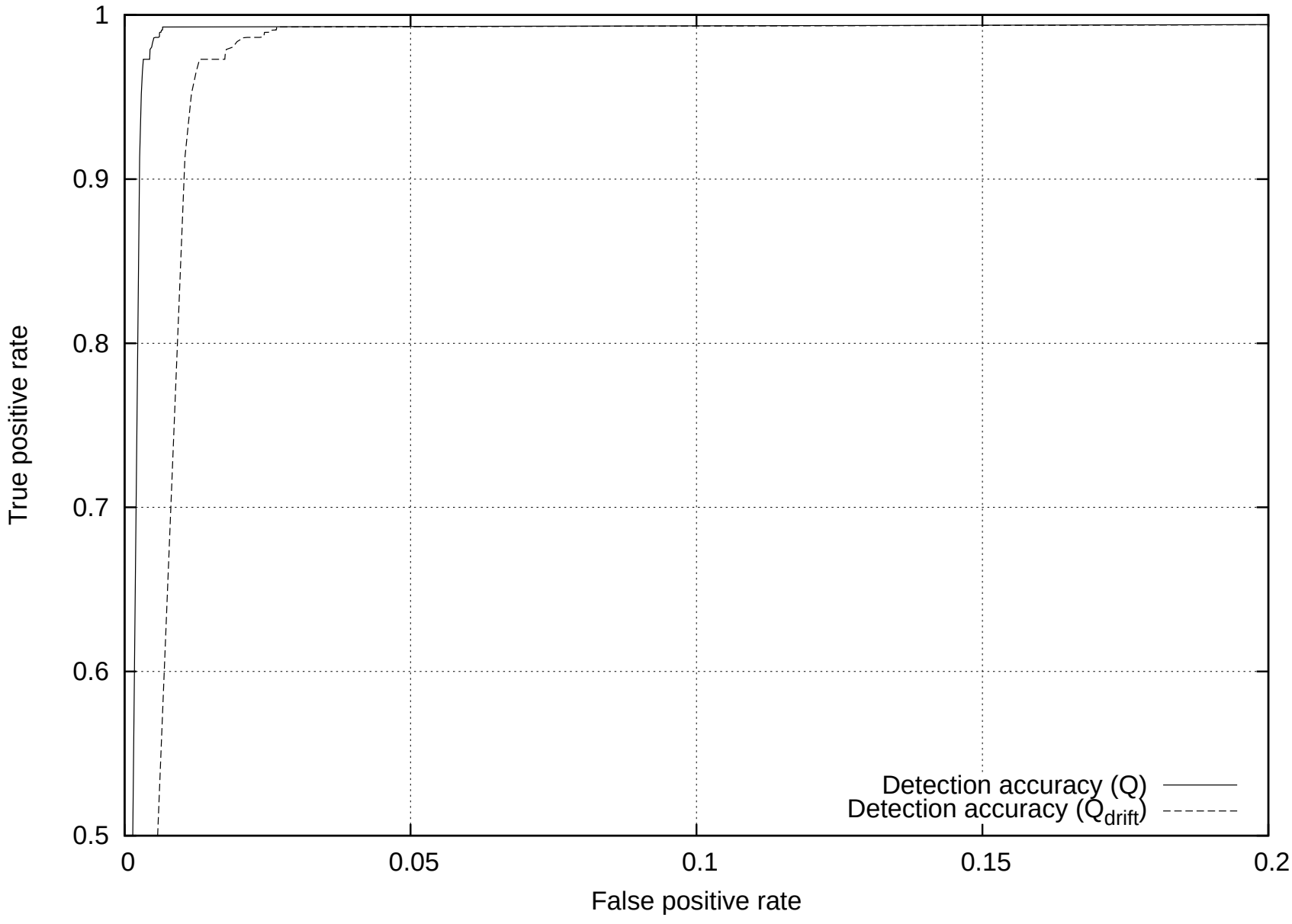

Assumptions, limitations and risks

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- Assumptions
  - can detect those changes that can be “guessed” from the responses

Assumptions, limitations and risks

- Limitations
  - modifications of existing parameters are only partially detectable,
  - JavaScript and rich client-side code is not analyzed, yet, but we believe they contain lots of insights!

Assumptions, limitations and risks

- Risks
  - it trusts the application as an oracle,
  - however, if somebody has already compromised it, we have another problem :)
  - right after a change occurs, the very first response is critical,
  - if somebody manages to tamper with that, models are poisoned

Conclusions

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- very simple and effective at reducing FP due to changes;

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- balance between:
  - exposure to model poisoning,
  - cost of false positives,
  - cost/feasibility of manual retraining;

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- future extensions:
  - risk mitigation: update a model only when a change in the corresponding response is observed at least k times;
  - client-side code inspection: todays' JavaScript libraries perform several task related to paramters and dynamic DOM construction!

Thanks! Questions?

Those interested in the omitted, "with scarce data"-part of the talk may come to NDSS 2010, San Diego.