

Understanding Motifs of Program Behaviour and Change

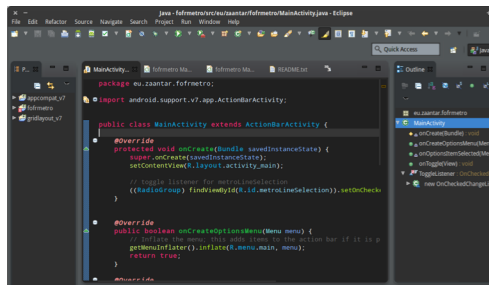
Saba Alimadadi
saba@northeastern.edu

All truths are easy to understand once they are discovered;
the point is to discover them.

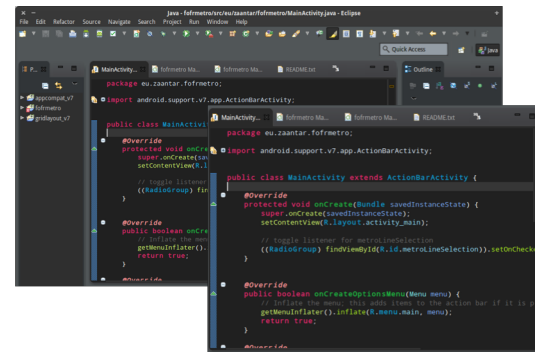
— Galileo Galilei

Search

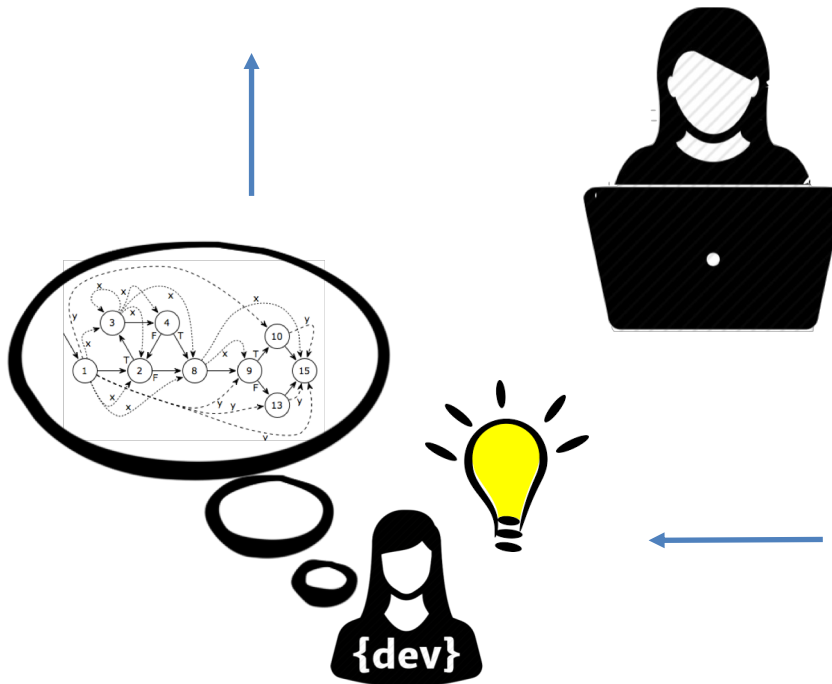
Relate



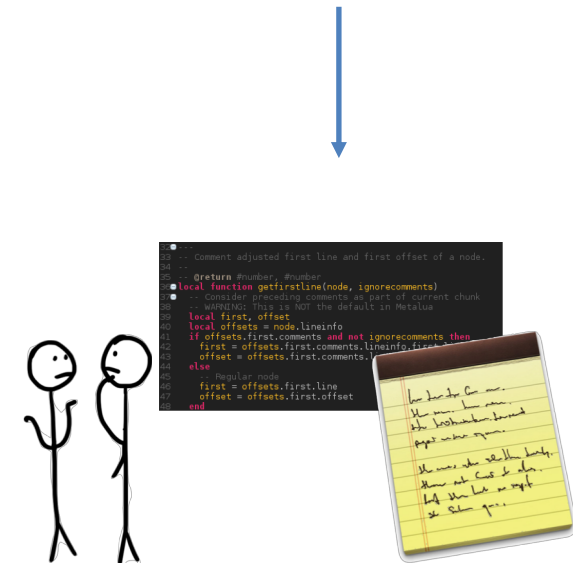
```
package eu.zaantar.fofmetrio;  
  
import android.support.v7.app.ActionBarActivity;  
  
public class MainActivity extends ActionBarActivity {  
  
    @Override  
    protected void onCreate(Bundle savedInstanceState) {  
        super.onCreate(savedInstanceState);  
        setContentView(R.layout.activity_main);  
  
        // Toggle listener for metro selection  
        (findViewById(R.id.metro_line_selection)).setOnClickListener(  
            new OnClickListener() {  
                @Override  
                public void onClick() {  
                    // TODO: Implement this method  
                }  
            }  
        );  
  
    }  
  
    @Override  
    public boolean onOptionsItemSelected() {  
        // TODO: Implement this method  
        return true;  
    }  
  
}
```



```
package eu.zaantar.fofmetrio;  
  
import android.support.v7.app.ActionBarActivity;  
  
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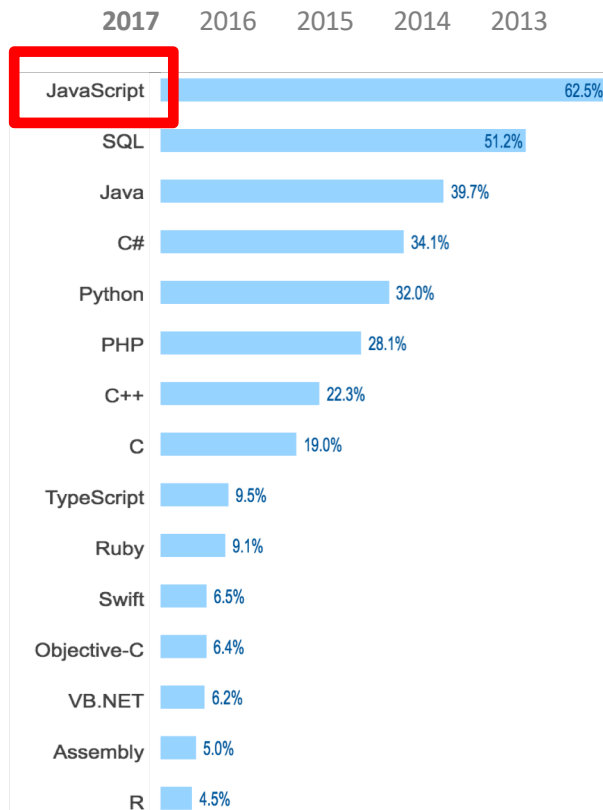


Model

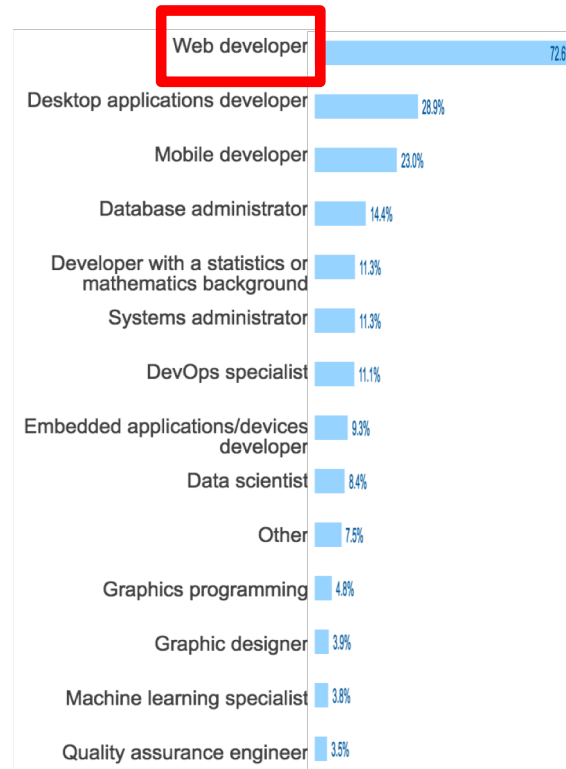


Collect

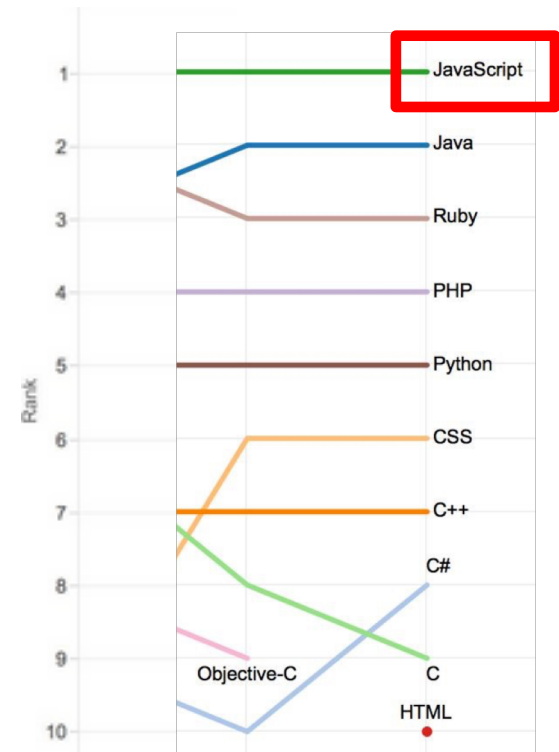
JavaScript: Most popular language



JavaScript: Most developer roles



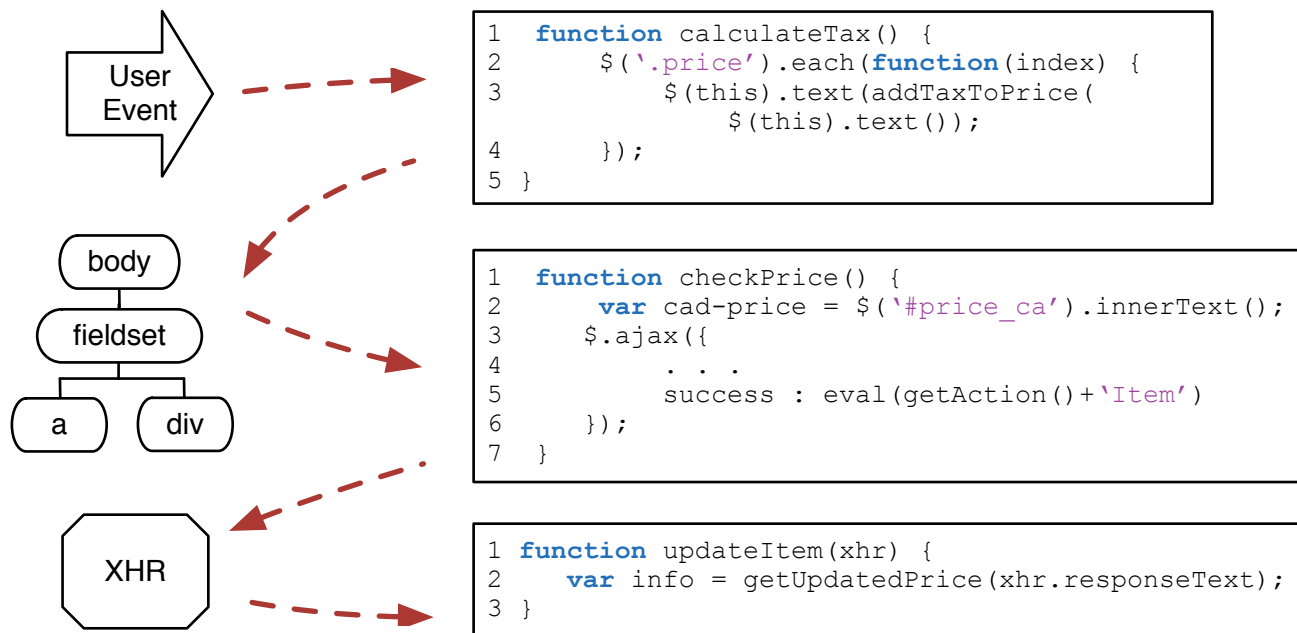
JavaScript: Top languages on GitHub



Challenge 1.

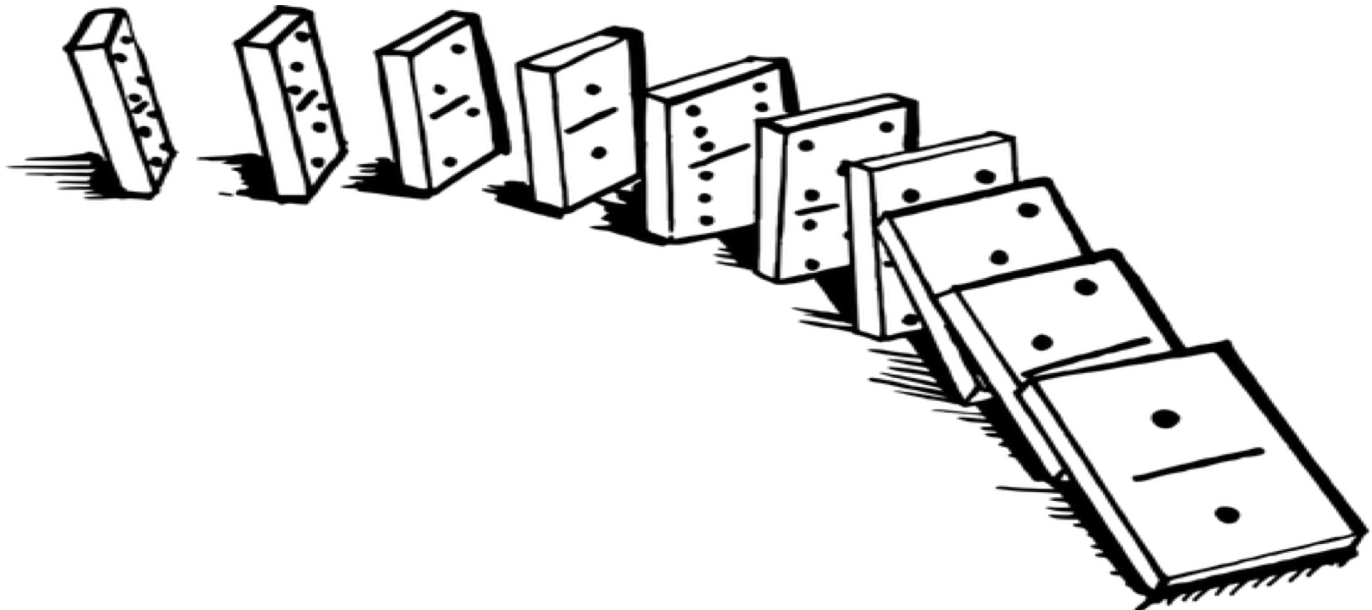
Hidden and Complex Interactions

- Understanding entities and interactions
- Dynamic, asynchronous, event-driven execution



Challenge 2. Constant **Change**

- Software must continually change to adapt to the changing environment.
- Change propagates and affects other parts of the program



Challenge 3.

Higher-Level Understanding

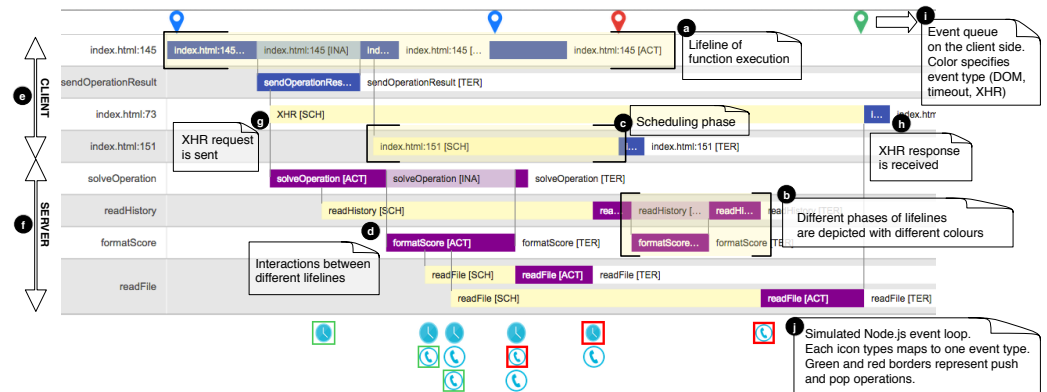
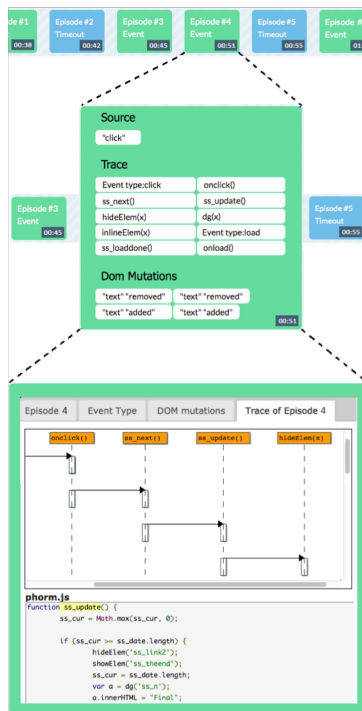
- Making the bridge between execution details and motifs of behaviour
- Overload by information in large traces

Total Time	Activity
554.9 ms 18.9 %	▶ Evaluate Script
393.2 ms 13.4 %	▶ Parse HTML
109.5 ms 3.7 %	▶ s_Via rs=ACT90oHL93uXakCn3IdRwIk7ttUh...
91.5 ms 3.1 %	▶ b.port1.onmessage rs=ACT90oHL93uXakC...
40.4 ms 1.4 %	▶ Recalculate Style
35.3 ms 1.2 %	▶ Update Layer Tree
31.0 ms 1.1 %	▶ Run Microtasks
24.0 ms 0.8 %	▶ XHR Ready State Change
16.8 ms 0.6 %	▶ Finish Loading
15.4 ms 0.5 %	▶ Composite Layers
14.5 ms 0.5 %	▶ (anonymous) search?q=execution+trace&riz=...
14.4 ms 0.5 %	▶ dispatchOnMessage VM224 extensions::me...
13.0 ms 0.4 %	▶ Layout
12.6 ms 0.4 %	▶ Paint
11.9 ms 0.4 %	▶ d search?q=execution+trace&riz=1C5CHFA...
6.5 ms 0.2 %	▶ Hit Test
6.3 ms 0.2 %	▶ DOM GC
6.1 ms 0.2 %	▶ (anonymous) rs=ACT90oHL93uXakCn3IdR...
5.5 ms 0.2 %	▶ DOM GC
5.1 ms 0.2 %	▶ _Ed.C search?q=execution+trace&riz=1C5C...
4.8 ms 0.2 %	▶ (anonymous) rs=AA2YtTsX96LEIPKyUllunFy...
4.0 ms 0.1 %	▶ Receive Response
1.3 ms 0.0 %	▶ (anonymous) rs=AGLTcCOqXRNQO029u9W...
0.9 ms 0.0 %	▶ (anonymous) rs=ACT90oHL93uXakCn3IdR...
0.8 ms 0.0 %	▶ dispatchOnDisconnect VM224 extensions::...
0.8 ms 0.0 %	▶ dispatchOnConnect VM224 extensions::me...
0.7 ms 0.0 %	▶ Receive Data
0.6 ms 0.0 %	▶ Major GC

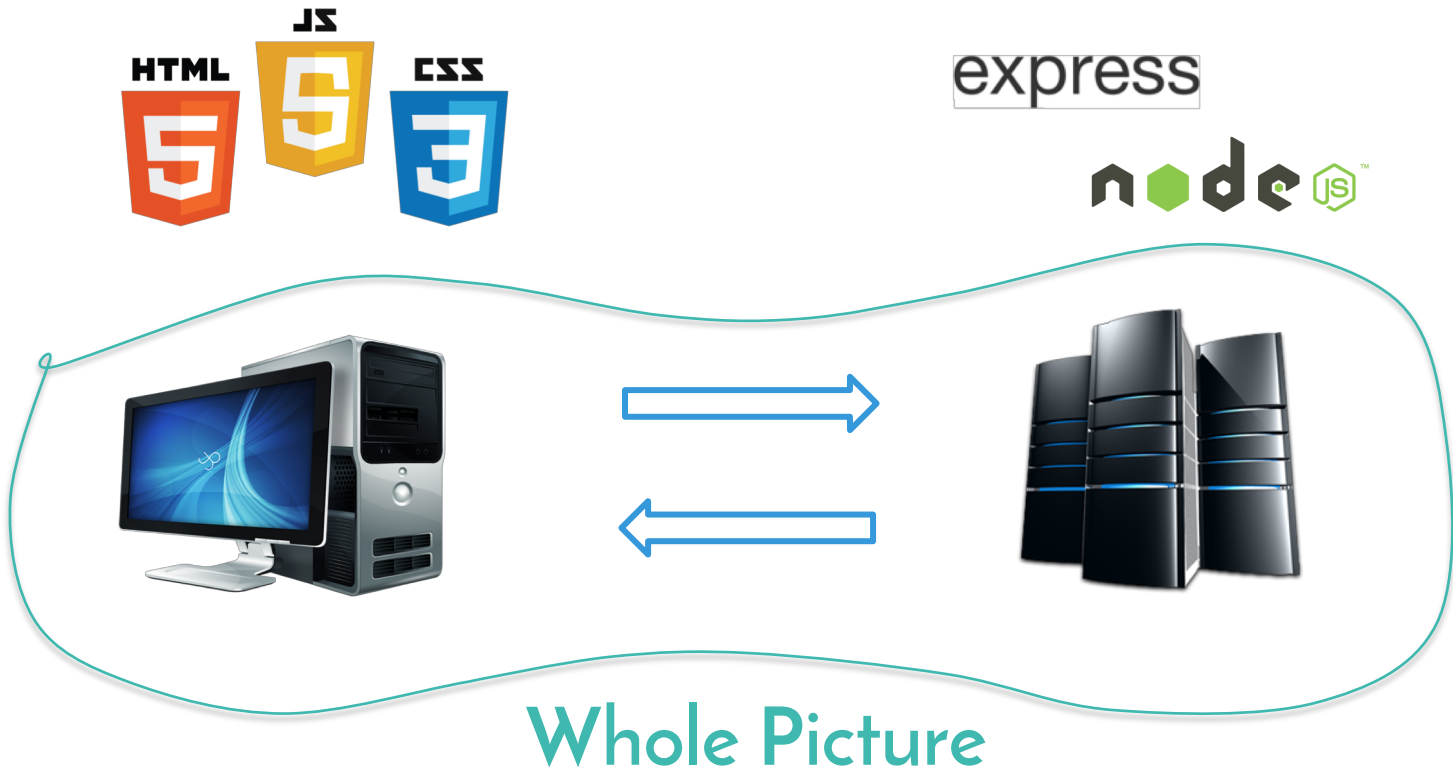
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0.7 ms 0.0 %	▶ Receive Data
0.6 ms 0.0 %	▶ Major GC

1. Understanding Hidden and Complex Interactions



Understanding JavaScript Apps

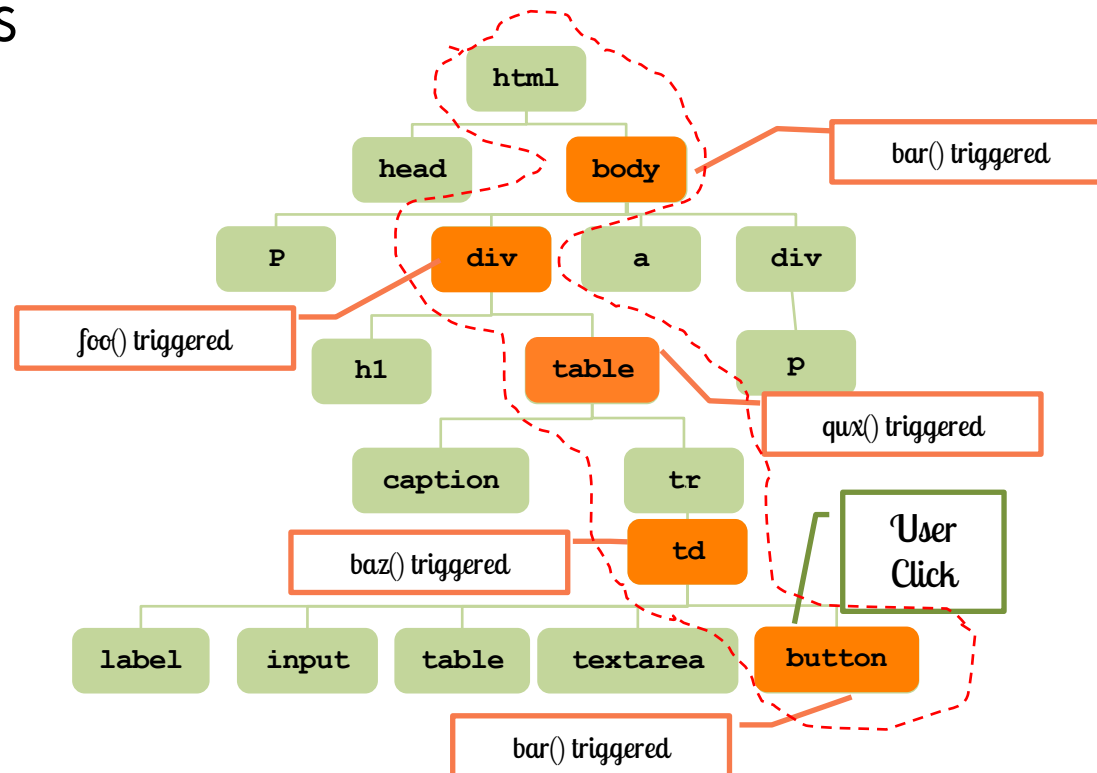


Understanding Dynamic and Asynchronous Interactions

- JavaScript: dynamic, event-driven, asynchronous
- Hidden and complicated entities and their relations

Understanding Dynamic and Asynchronous Interactions

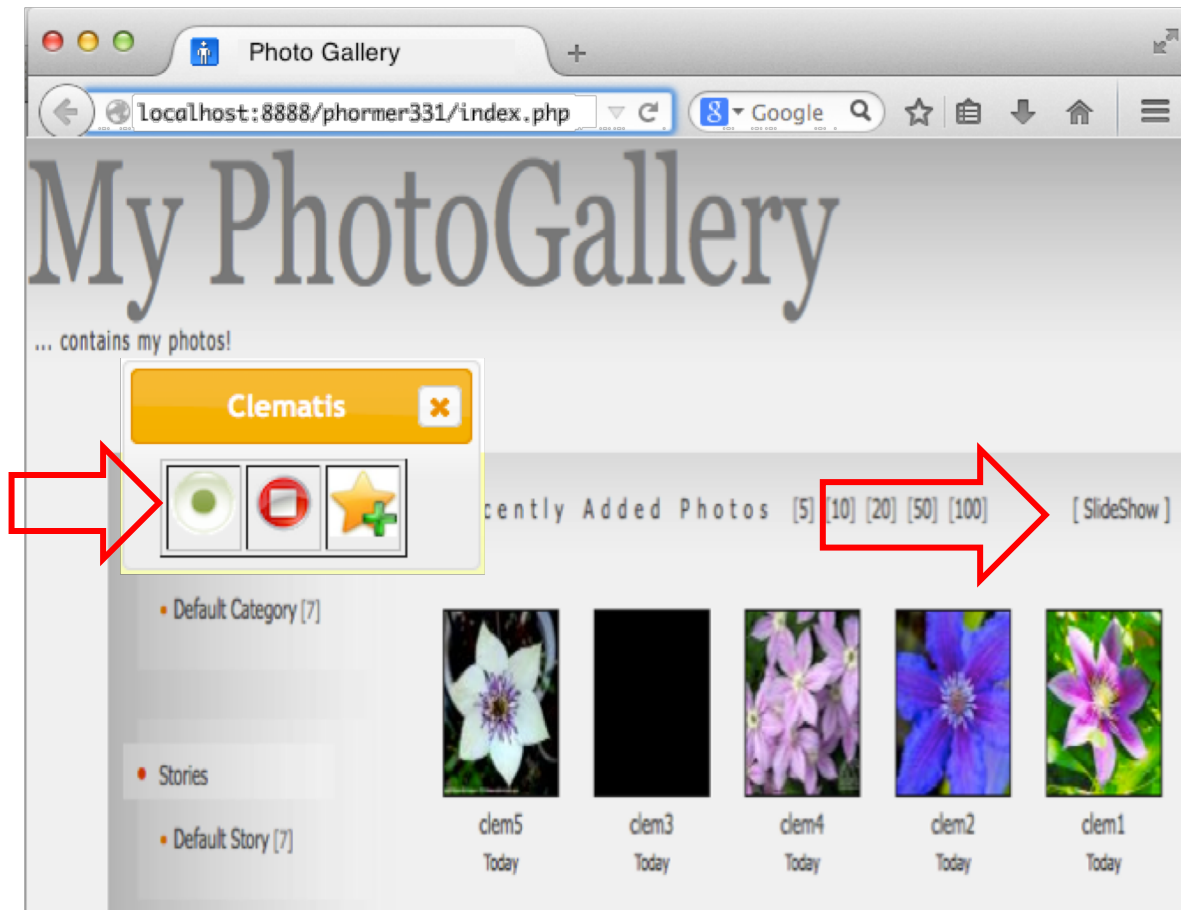
- JavaScript: dynamic, event-driven, asynchronous
- Hidden and complicated entities and their relations



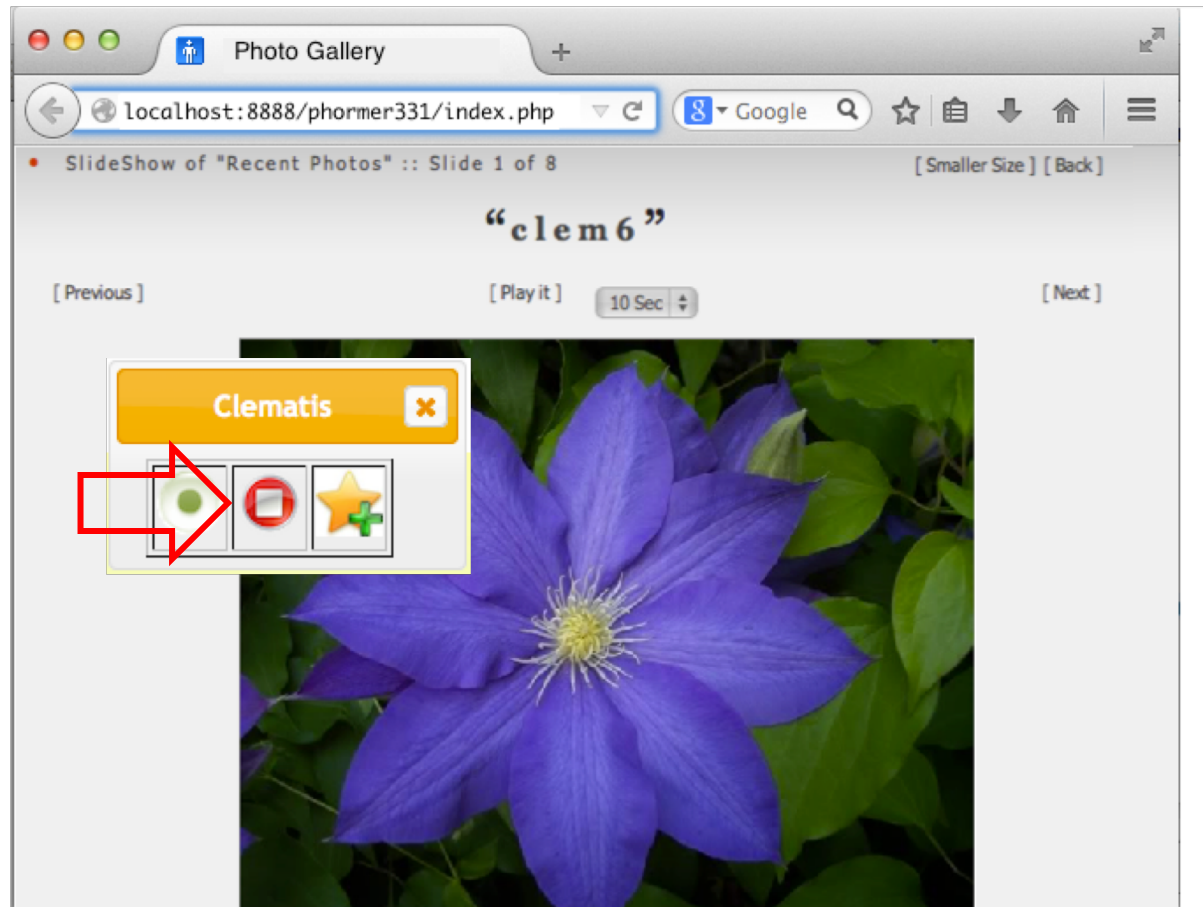
Usage Scenario



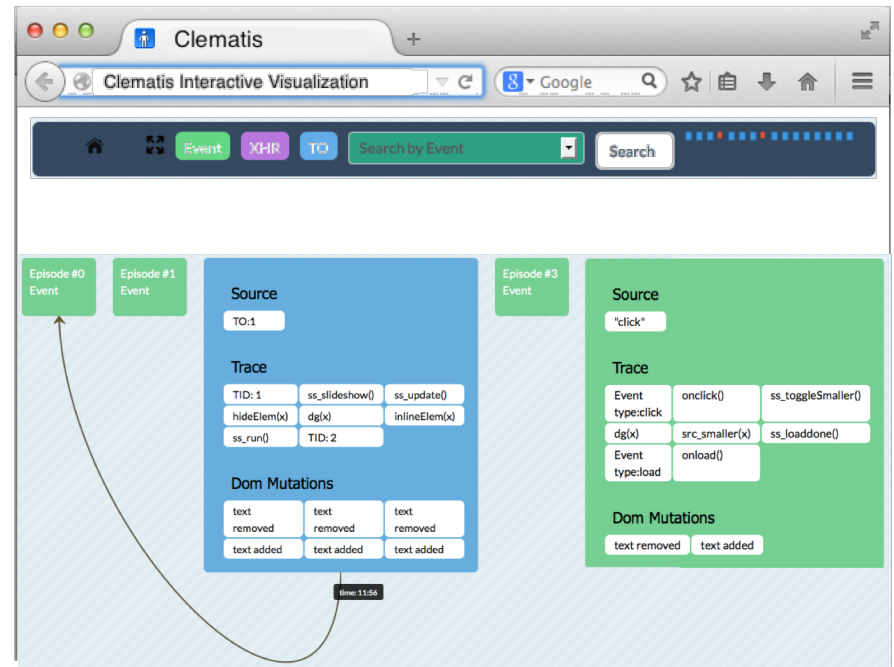
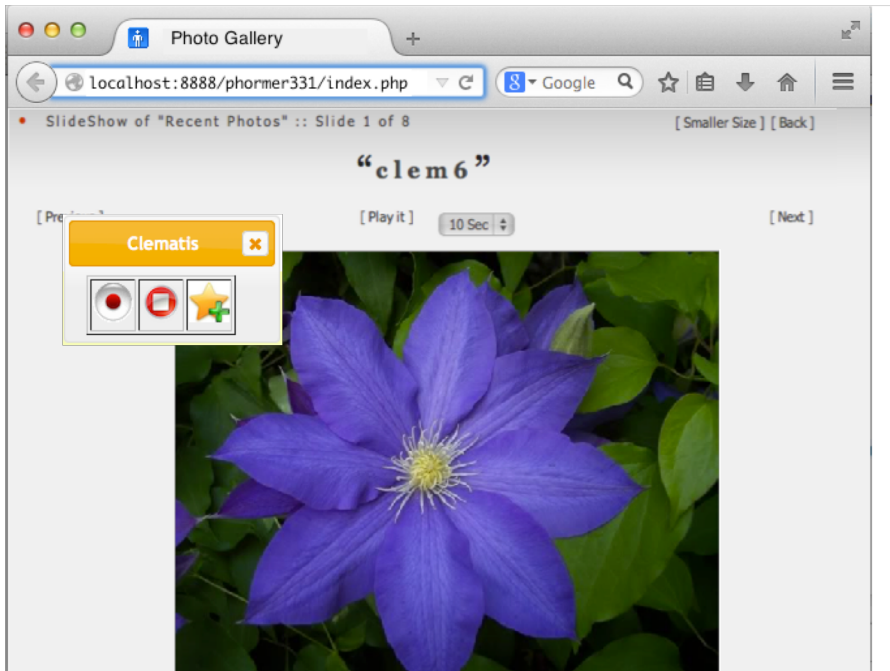
Usage Scenario



Usage Scenario



Usage Scenario



Approach: Clematis

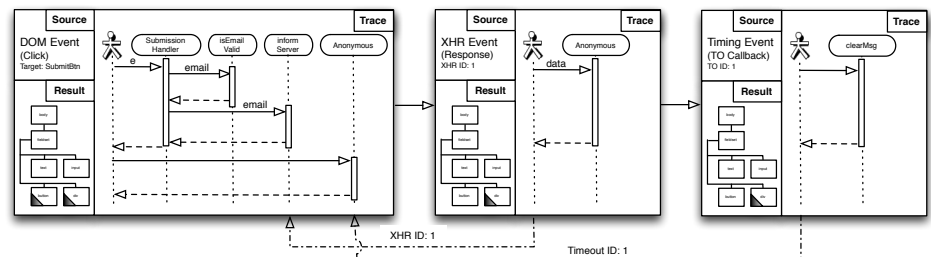
Application →

1. Instrument automatically

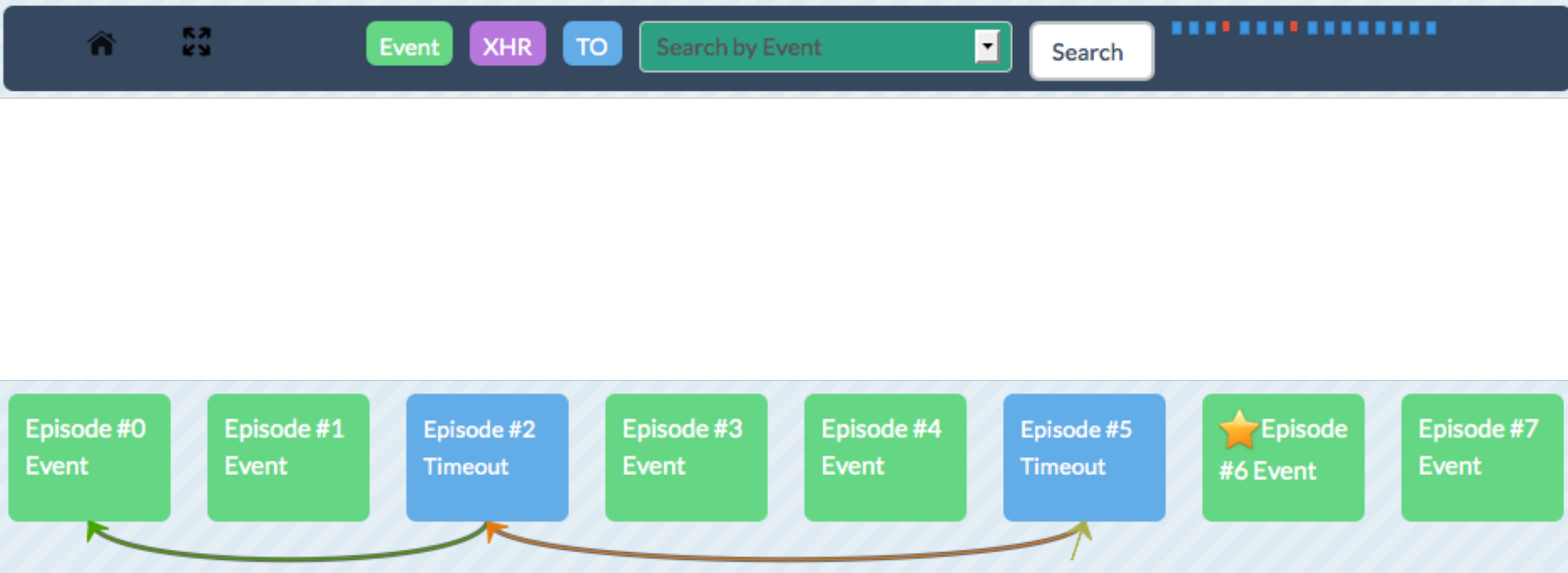
2. Collect traces

3. Infer a behavioural model

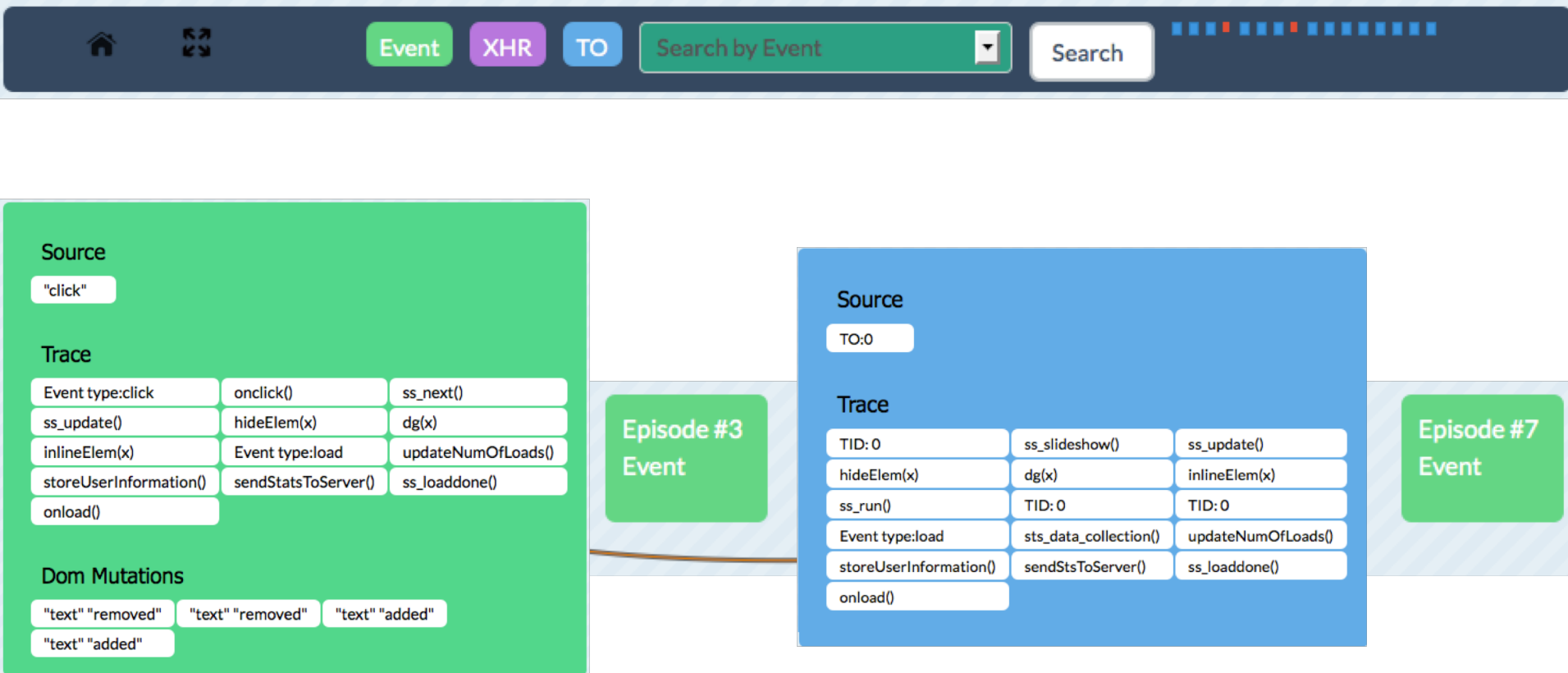
4. Visualize the model



Visualization: Overview



Visualization: Zoom Level 1





Event

XHR

TO

Search by Event



Search

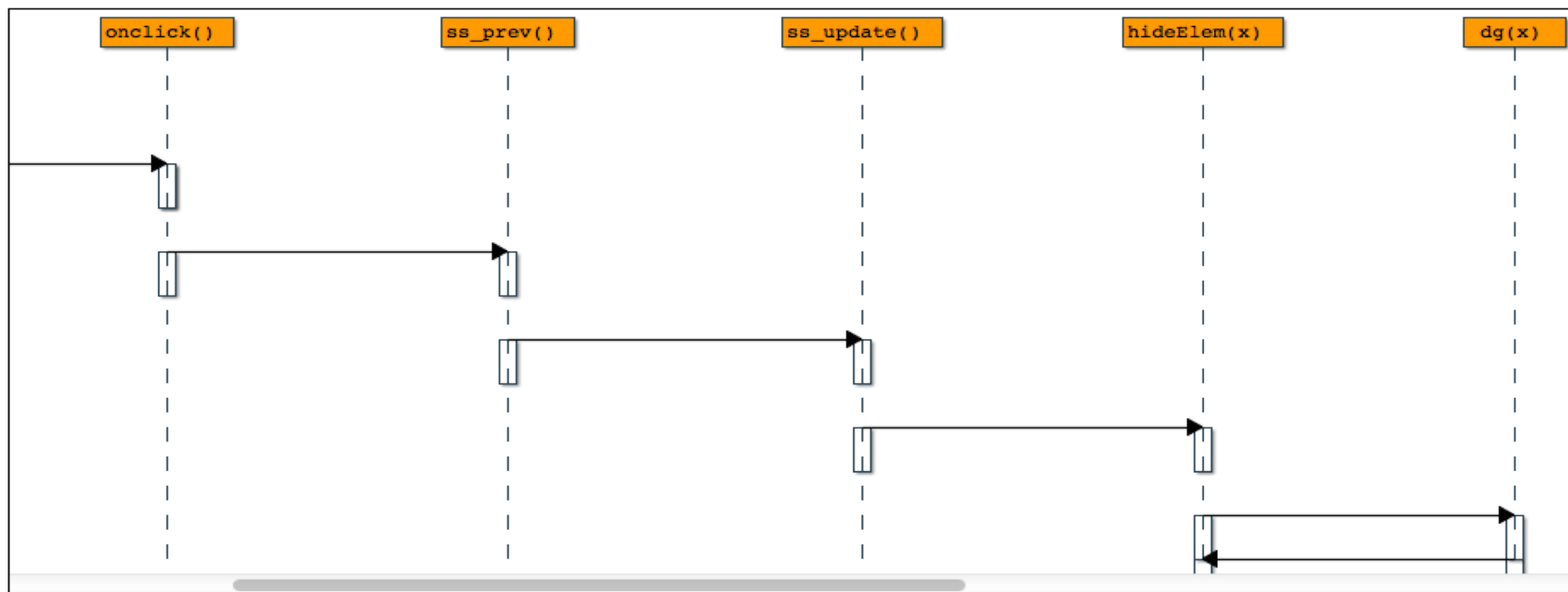


Episode 5

Event Type

DOM mutations

Trace of Episode 5



phorm.js

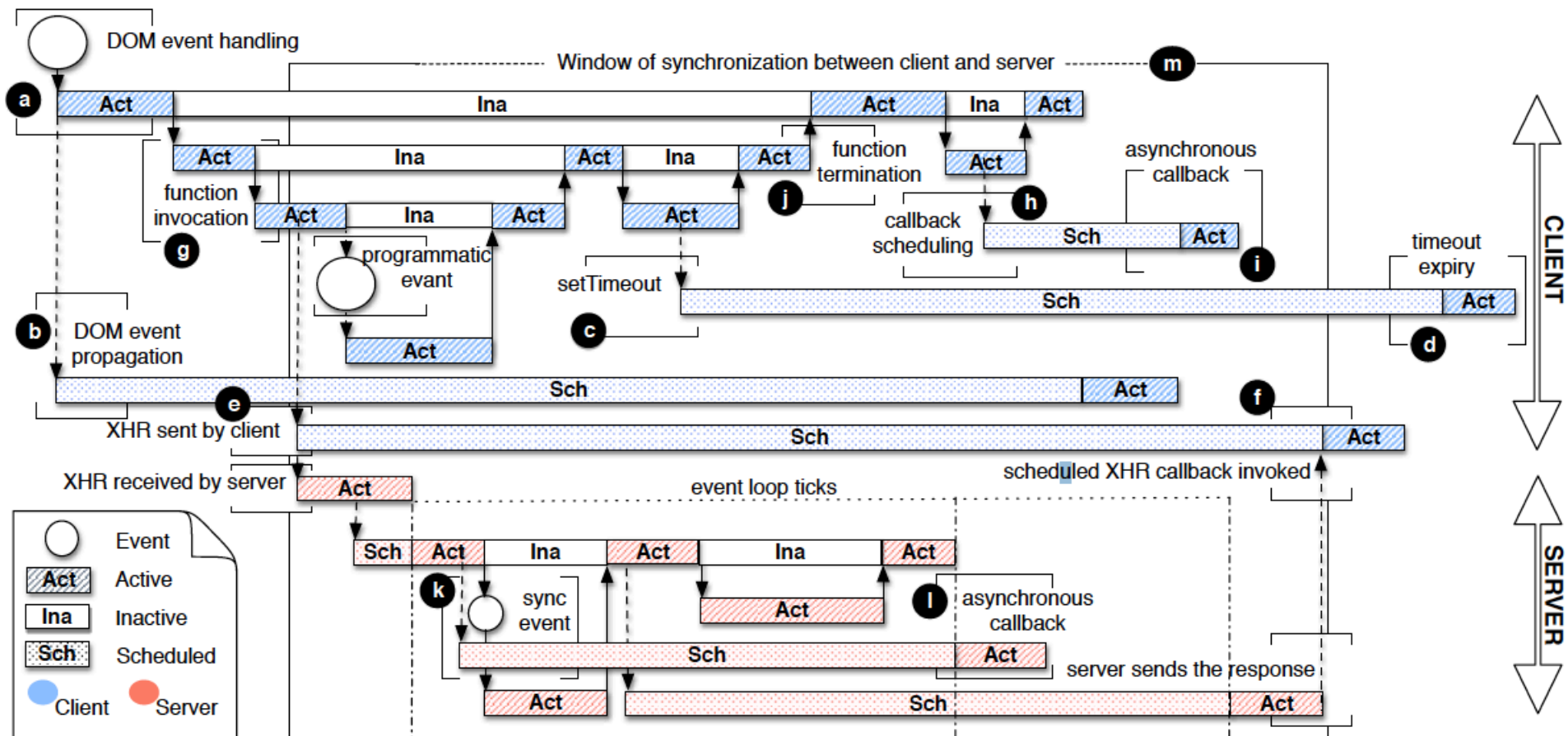
```
function ss_update() {
    ss_cur = Math.max(ss_cur, 0);

    if (ss_cur >= ss_date.length) {
        hideElem('ss_link2');
        showElem('ss_theend');
        ss_cur = ss_date.length;
        var a = dg('ss_n');
        a.innerHTML = "Final";
        if (ss_play)
            ss_playpause();
    }
}
```

Visualization: Zoom Level 2

Next: Sahand

Understanding Full-Stack JS



Visualization

Client-Side

Analysis



Connecting client and server



Server-Side

Analysis



Evaluation

Does using our approach improve developers' performance in program comprehension tasks?



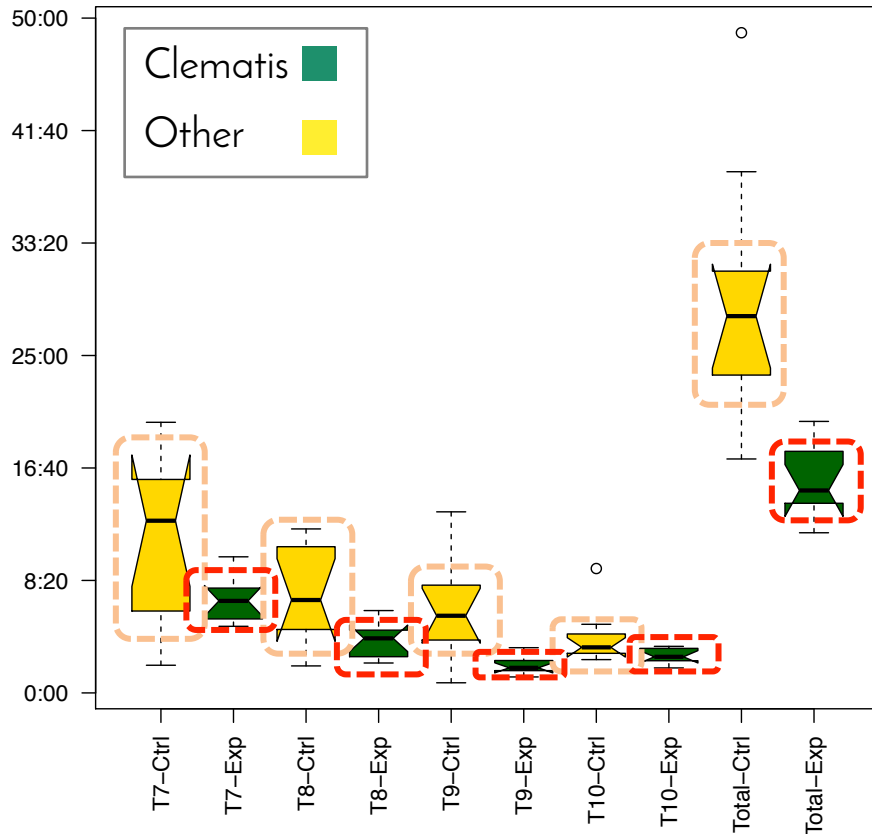
Controlled Experiment

- Participants
 - 20 from industry (overall: 60)
 - Experimental group: our approach
 - Control group: Chrome (+ other DevKits)
- Procedure
- Data collections
 - Duration
 - Accuracy

Results



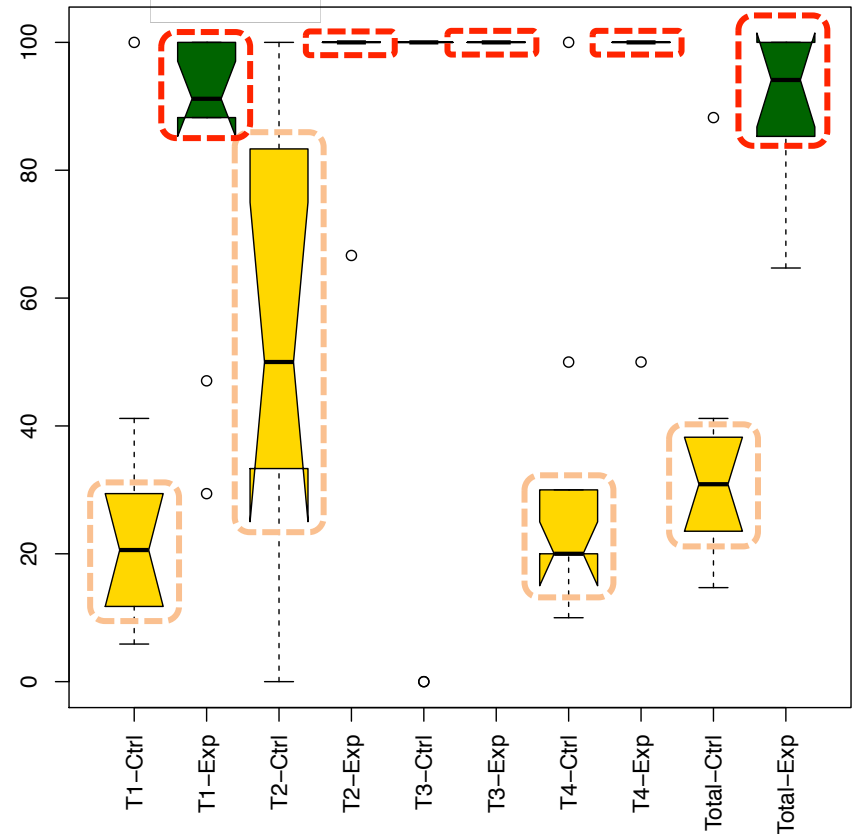
Duration (mm:ss)



50% faster



Accuracy (%)



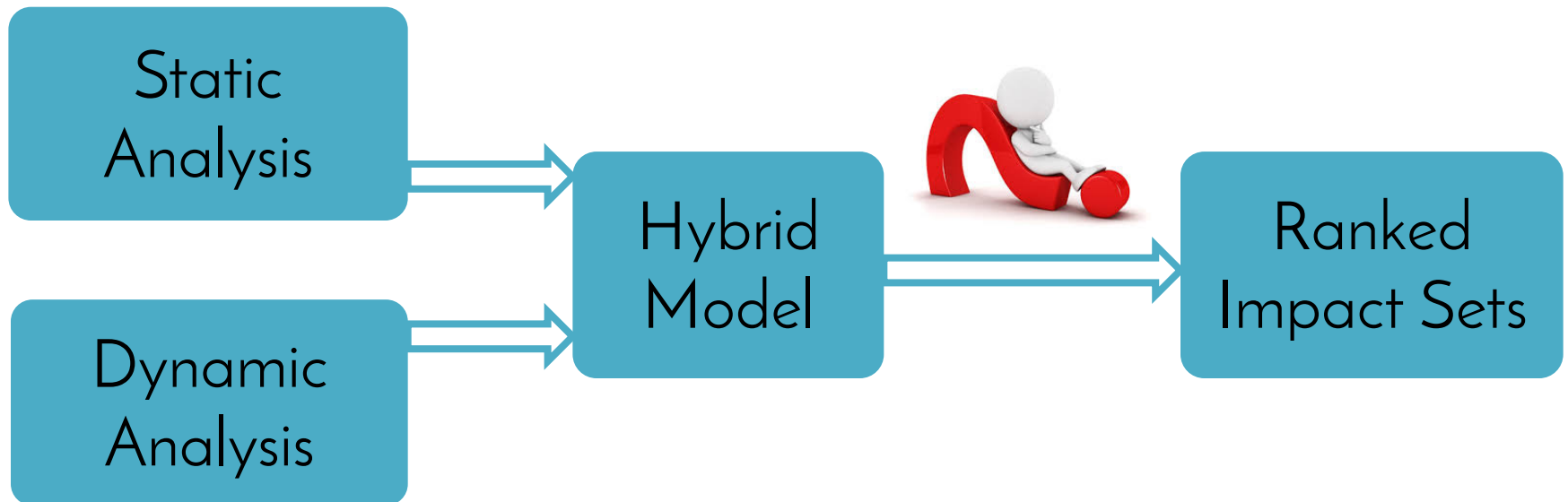
160% more accurate



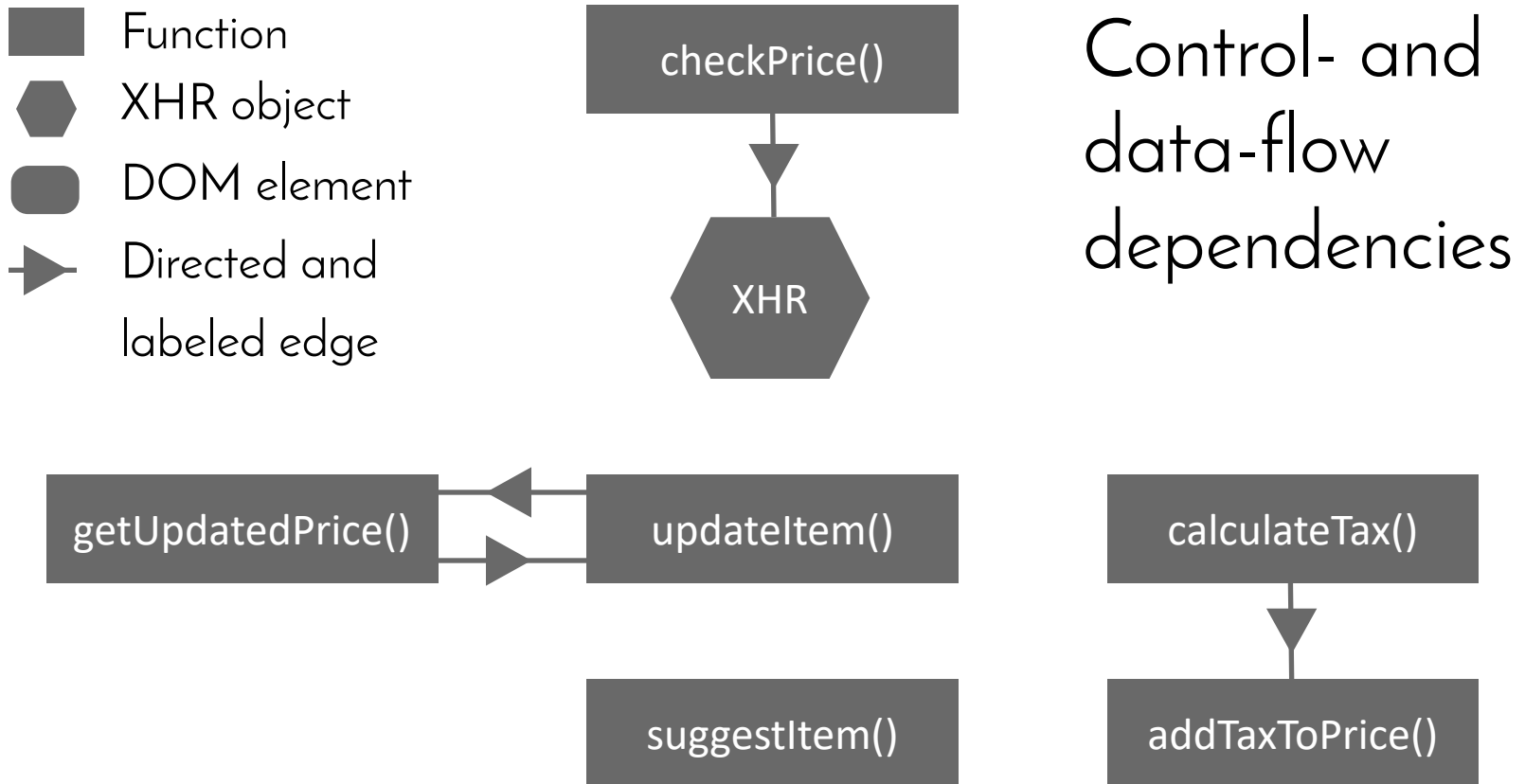
2. Understanding The Impact of Change

- **Goal:** identifying parts of the program that are potentially affected by a change.
- Challenging due to features of JavaScript
- DOM-sensitive event-aware hybrid change impact analysis

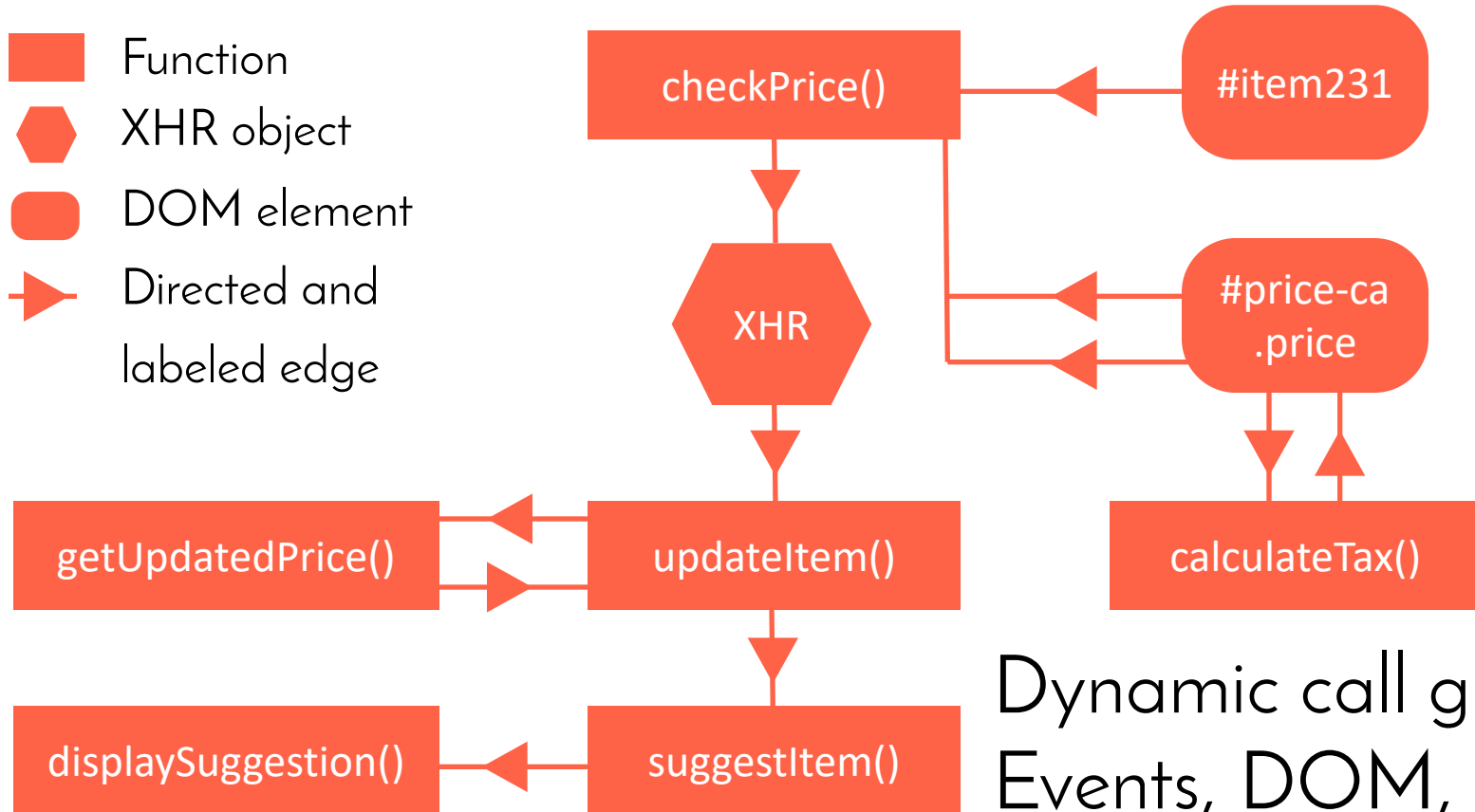
Hybrid Analysis: **Tochal**



Example: Static Model

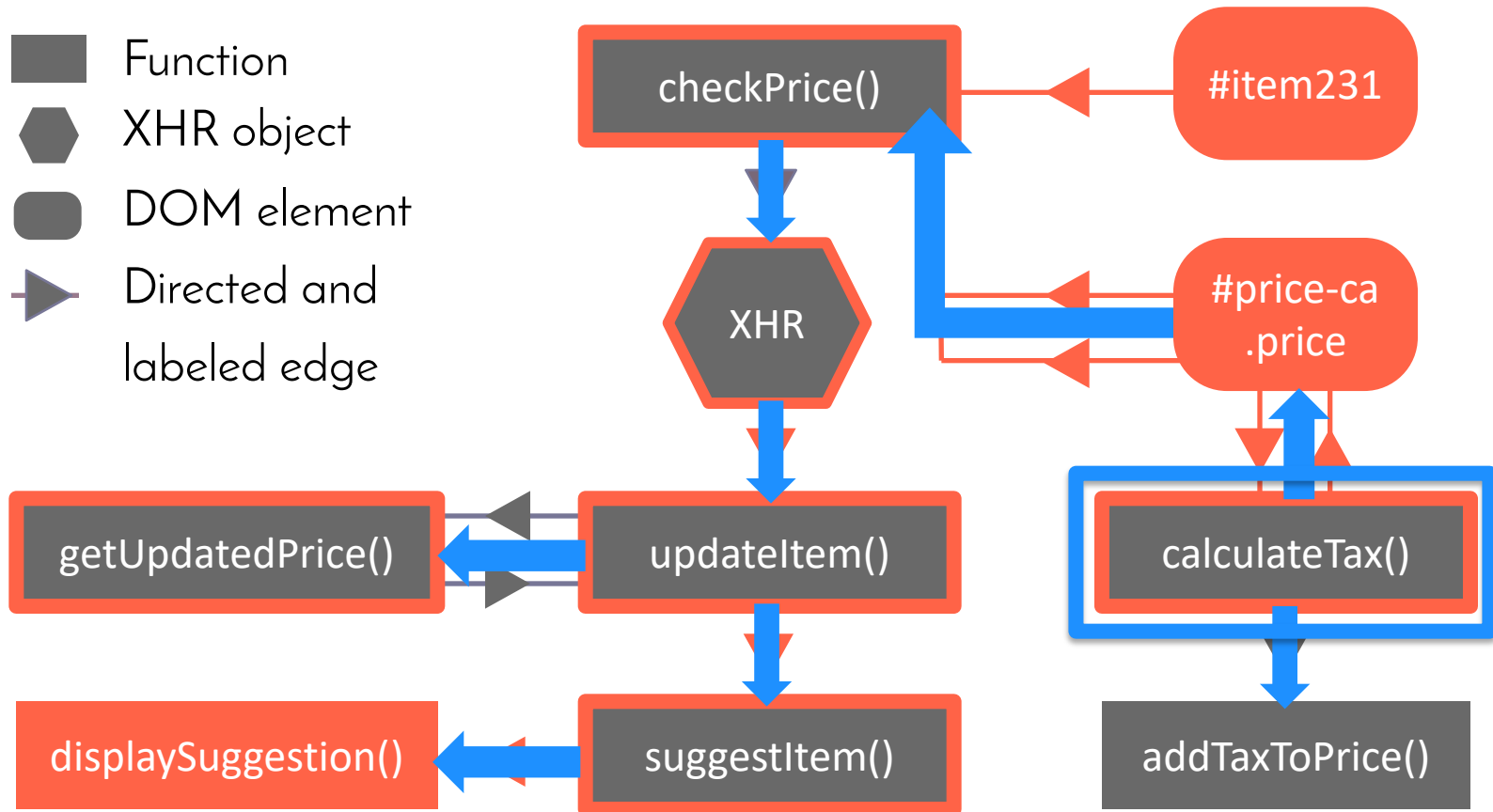


Example: Dynamic Model



Dynamic call graph
Events, DOM, XHR's,
JS Dynamism

Example: Hybrid Analysis



Experiment: Design

- 12 participants from industry

- Performed 4 tasks

Task	Description
T1	Finding the potential impact of a DOM element
T2	Finding the potential impact of a JavaScript function
T3	Finding a conflict after making a new change (<u>no ranking</u>)
T4	Finding a bug in JavaScript code

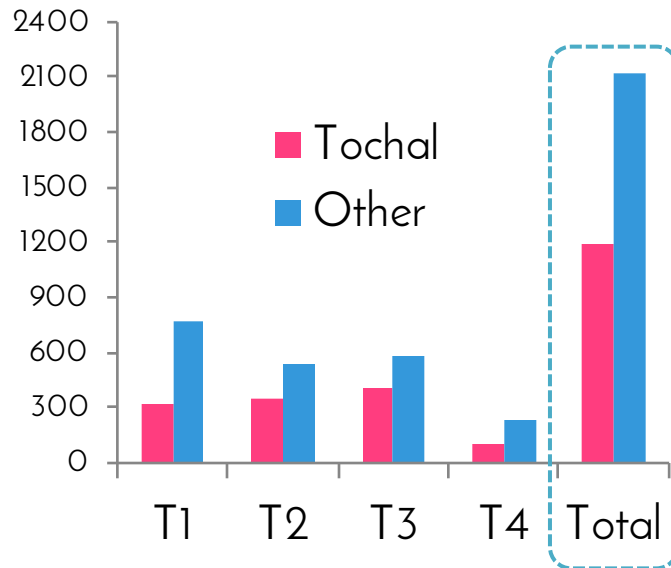
- We measured task completion duration and accuracy



User Experiment: Results



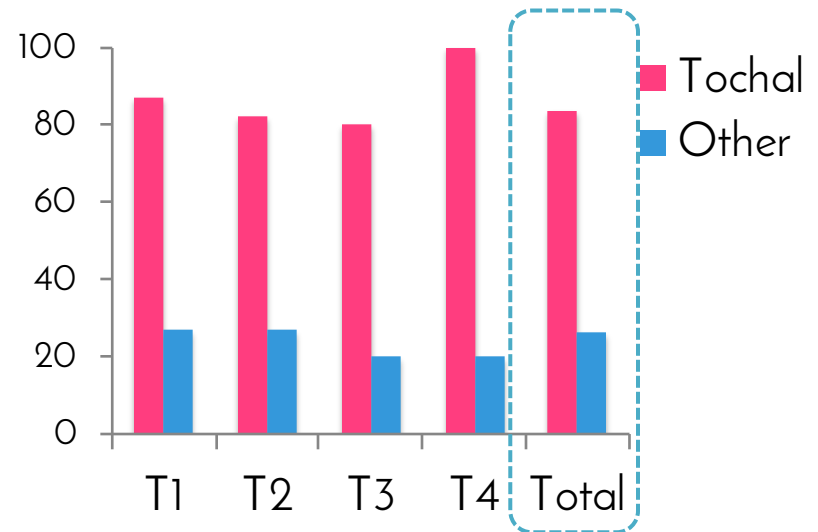
Duration



80% faster

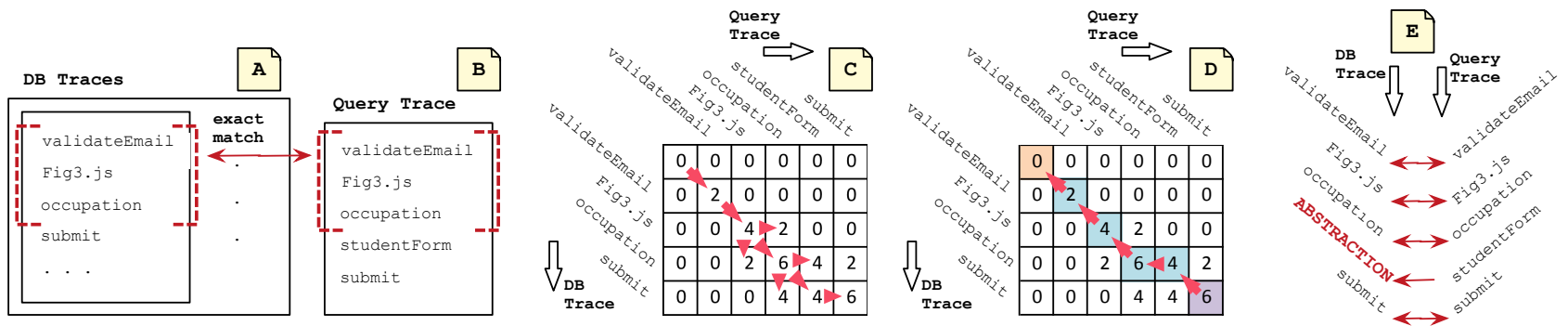


Accuracy



2 times more accurate

3. Understanding Motifs of Behaviour



Overwhelming Information

The diagram shows a web form with the following elements:

- Email:** A text input field.
- Address:** A text input field.
- Occupation:** A dropdown menu with "Select one" and a downward arrow. Below it, a dashed box contains "Student" and "..." with a red arrow pointing to the Degree field.
- Degree:** A dropdown menu with "Select one" and a downward arrow.
- Submit:** A button at the bottom right.

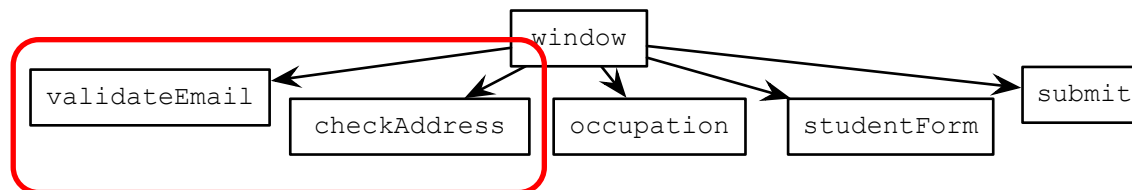
Annotations include a red box around the Email and Address fields with a circled 'I' above it, and a dashed box around the Occupation and Degree fields with a circled 'B' next to it.

```

1 <form>
2   Email: <input type="email" id="email">
3   Address: <input type="text" class="addr">
4   Occupation: <div class="dropdown" id="occupation">
5     <button class="dropbtn">
6       Choose one</button>
7     <div class="dropdown-content">
8       <a href="#">Academic</a>
9       <a href="#">Industry</a>
10    </div>
11  </div>
12  <input type="submit" value="submit">Submit</input>
13 </form>
  
```

```

1 $("#email").addEventListener("change", validateEmail, ←
2   false);
3 $(".addr").click(checkAddress);
4 $(".dropdown-content").addEventListener("change", ←
5   occupation, false);
6 function validateEmail () {
7   // do stuff
8 }
9 function checkAddress() {
10  // do more stuff
11 }
  
```



Approach: Sabalan

DB Traces

```
change  
transition  
grouped  
stacked  
index.html:11  
showPopup  
removePopup  
foo  
Baz
```

							foo
							bar
							foo
							bar
							baz
							validateEmail
							checkAddress
							occupation
							submit
							bar
							baz

Query Trace

```
foo  
bar  
validateEmail  
checkAddress  
occupation  
studentForm  
submit  
foo  
change  
transition
```

Approach: Sabalan

DB Traces

change							foo
transition							bar
grouped							foo
stacked							bar
index.html:11							baz
showPopup							validateEmail
removePopup							checkAddress
foo							occupation
Baz							submit
							bar
							baz

Query Trace

foo
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Approach: Sabalan

DB Traces

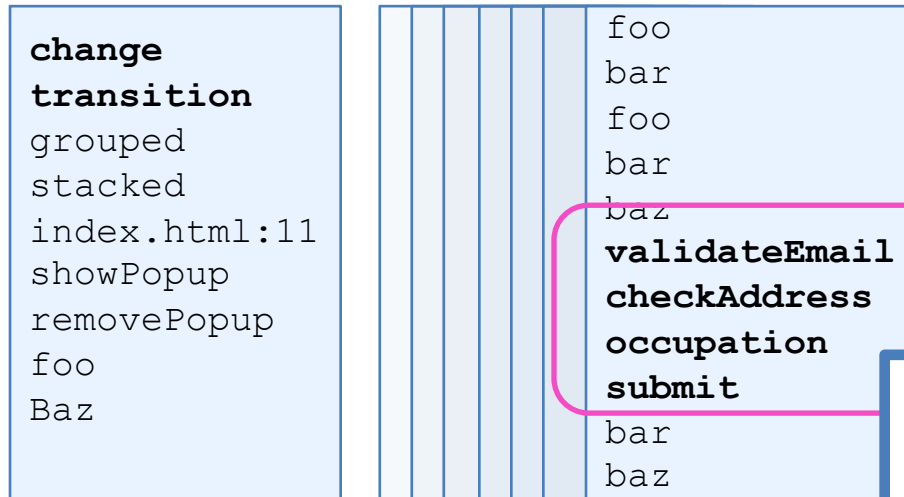
change							foo
transition							bar
grouped							foo
stacked							bar
index.html:11							baz
showPopup							validateEmail
removePopup							checkAddress
foo							occupation
Baz							submit
							bar
							baz

Query Trace

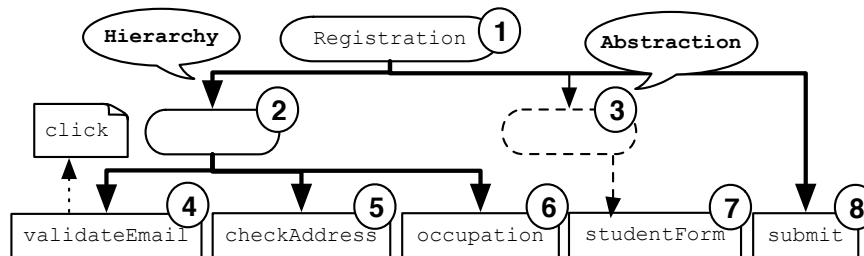
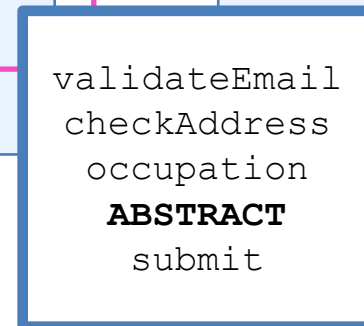
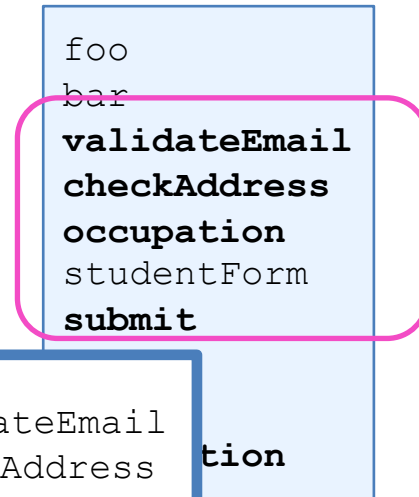
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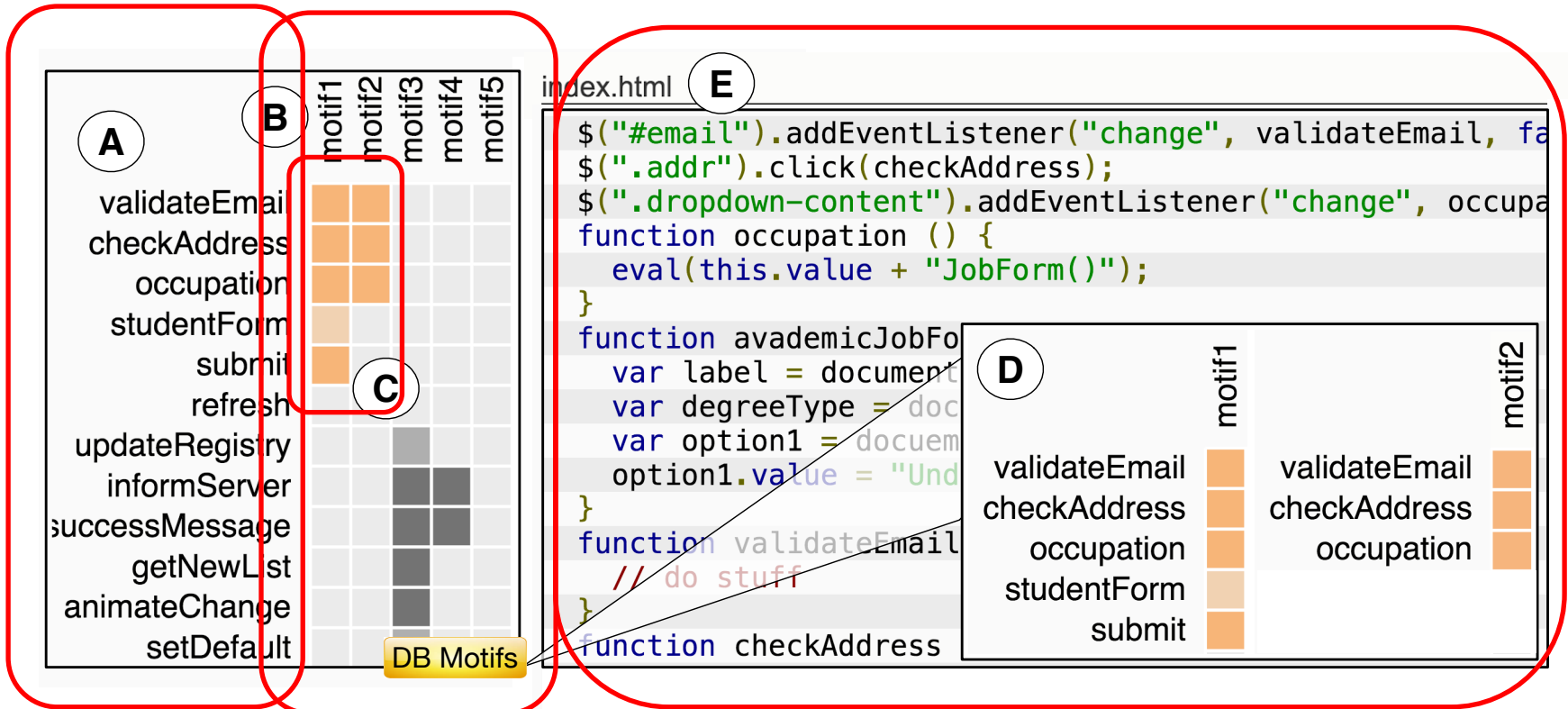
DB Traces



Query Trace

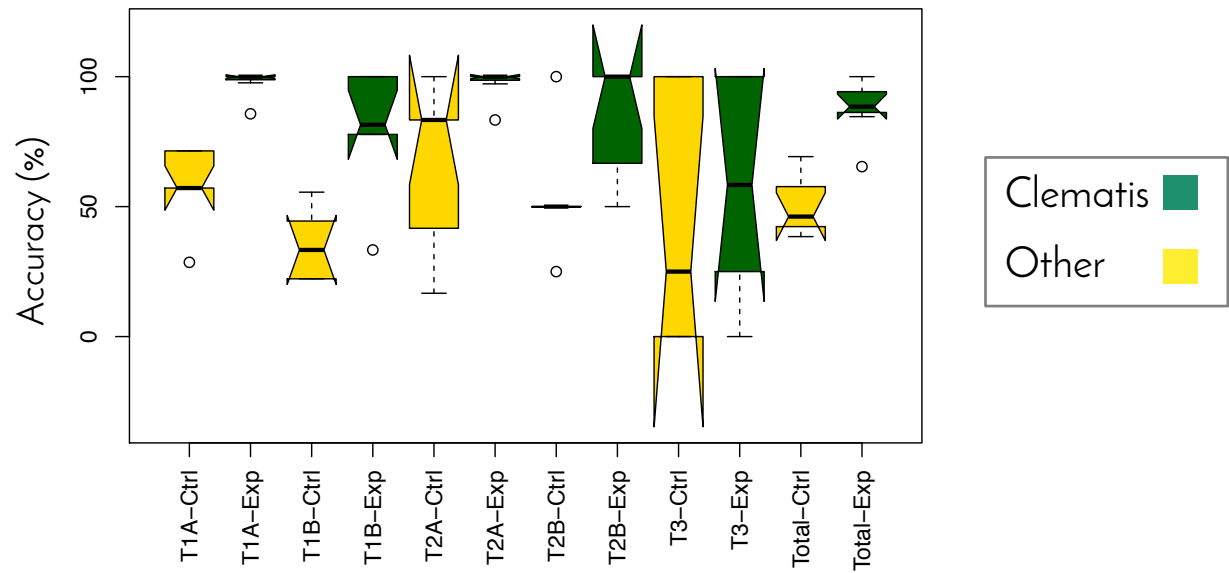


Visualization

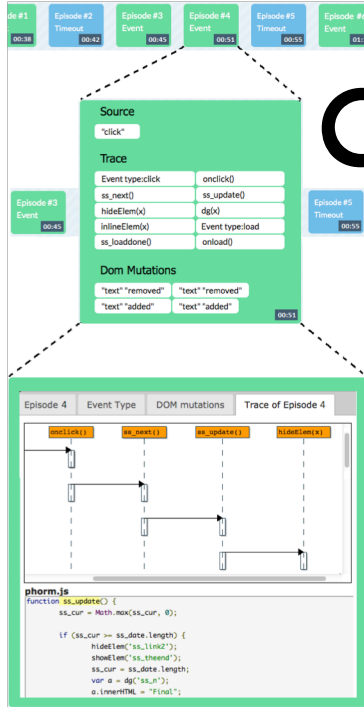


Evaluation Results

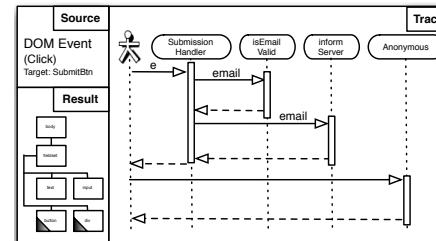
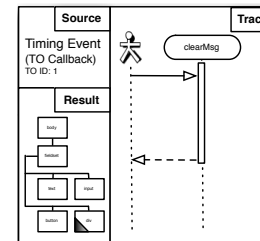
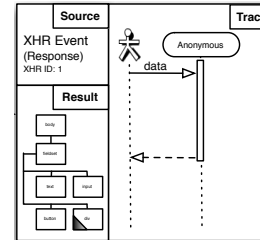
50% more accuracy

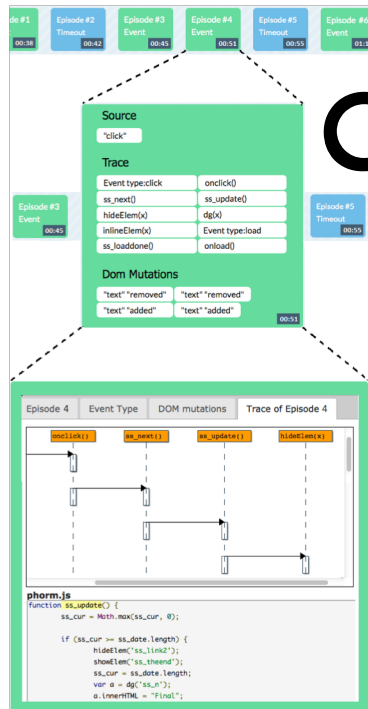


Clematis



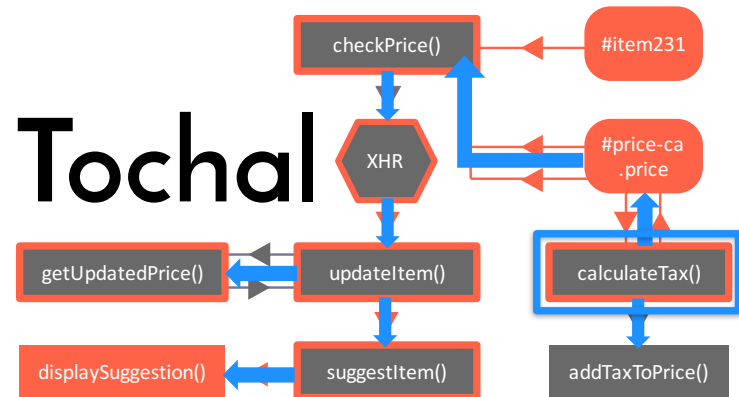
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5.5 ms	0.2 % DOM GC
5.1 ms	0.2 % _Ed.C search?q=execution+trace&rtz=1C5C...
4.8 ms	0.2 % (anonymous) rs=AA2YrTsx9BLfPKYUlnNFV...
4.0 ms	0.1 % Receive Response
1.3 ms	0.0 % (anonymous) rs=AGLTcCQoXRNQ0029u9W...
0.9 ms	0.0 % (anonymous) rs=ACT90oHL93uXakCn3dR...
0.8 ms	0.0 % dispatchOnDisconnect VM224 extensions:me...
0.8 ms	0.0 % dispatchOnConnect VM224 extensions:me...
0.7 ms	0.0 % Receive Data
0.6 ms	0.0 % Major GC





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Tochal

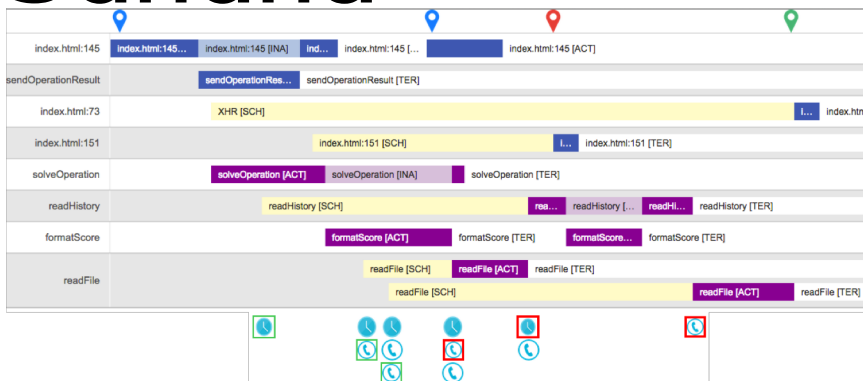


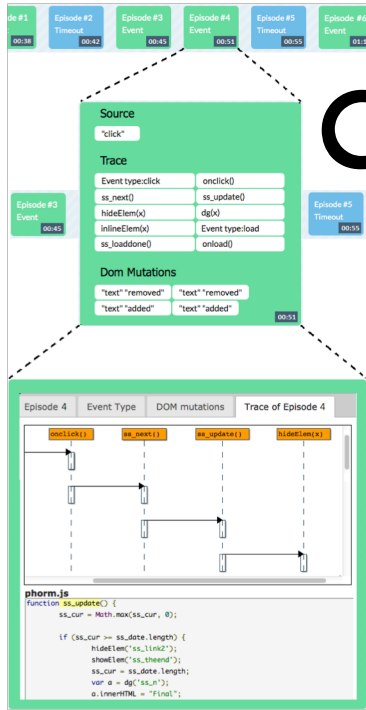
Client

Server

Total Time	Activity	Total Time	Activity
554.9 ms	18.9% Evaluate Script	554.9 ms	18.9% Evaluate Script
393.2 ms	13.4% Parse HTML	393.2 ms	13.4% Parse HTML
109.5 ms	3.7% s_Via rs=ACT90oHL93uXakCn3dRwIk7ttU...	109.5 ms	3.7% s_Via rs=ACT90oHL93uXakCn3dRwIk7ttU...
91.5 ms	3.1% b.port1onmessage rs=ACT90oHL93uXakC...	91.5 ms	3.1% b.port1onmessage rs=ACT90oHL93uXakC...
40.4 ms	1.4% Recalculate Style	40.4 ms	1.4% Recalculate Style
35.3 ms	1.2% Update Layer Tree	35.3 ms	1.2% Update Layer Tree
31.0 ms	1.1% Run Microtasks	31.0 ms	1.1% Run Microtasks
24.0 ms	0.8% XHR Ready State Change	24.0 ms	0.8% XHR Ready State Change
16.8 ms	0.6% Finish Loading	16.8 ms	0.6% Finish Loading
15.4 ms	0.5% Composite Layers	15.4 ms	0.5% Composite Layers
14.5 ms	0.5% (anonymous) search?q=execution+trace&tz=...	14.5 ms	0.5% (anonymous) search?q=execution+trace&tz=...
14.4 ms	0.5% dispatchOnMessage VM224 extensions:me...	14.4 ms	0.5% dispatchOnMessage VM224 extensions:me...
13.0 ms	0.4% Layout	13.0 ms	0.4% Layout
12.6 ms	0.4% Paint	12.6 ms	0.4% Paint
11.9 ms	0.4% d search?q=execution+trace&tz=1C5CHFA...	11.9 ms	0.4% d search?q=execution+trace&tz=1C5CHFA...
6.5 ms	0.2% Hit Test	6.5 ms	0.2% Hit Test
6.3 ms	0.2% DOM GC	6.3 ms	0.2% DOM GC
6.1 ms	0.2% (anonymous) rs=ACT90oHL93uXakCn3dR...	6.1 ms	0.2% (anonymous) rs=ACT90oHL93uXakCn3dR...
5.5 ms	0.2% DOM GC	5.5 ms	0.2% DOM GC
5.1 ms	0.2% _EdC search?q=execution+trace&tz=1C5C...	5.1 ms	0.2% _EdC search?q=execution+trace&tz=1C5C...
4.8 ms	0.2% (anonymous) rs=AA2YtTx96LEIPKyUllNFV...	4.8 ms	0.2% (anonymous) rs=AA2YtTx96LEIPKyUllNFV...
4.0 ms	0.1% Receive Response	4.0 ms	0.1% Receive Response
1.3 ms	0.0% (anonymous) rs=AGLTcCQqXRNQOQ29u9W...	1.3 ms	0.0% (anonymous) rs=AGLTcCQqXRNQOQ29u9W...
0.9 ms	0.0% (anonymous) rs=ACT90oHL93uXakCn3dR...	0.9 ms	0.0% (anonymous) rs=ACT90oHL93uXakCn3dR...
0.8 ms	0.0% dispatchOnDisconnect VM224 extensions:me...	0.8 ms	0.0% dispatchOnDisconnect VM224 extensions:me...
0.8 ms	0.0% dispatchOnConnect VM224 extensions:me...	0.8 ms	0.0% dispatchOnConnect VM224 extensions:me...
0.7 ms	0.0% Receive Data	0.7 ms	0.0% Receive Data
0.6 ms	0.0% Major GC	0.6 ms	0.0% Major GC

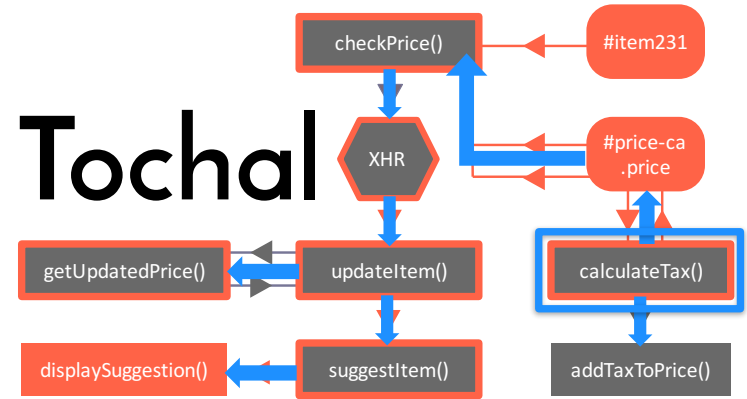
Sahand





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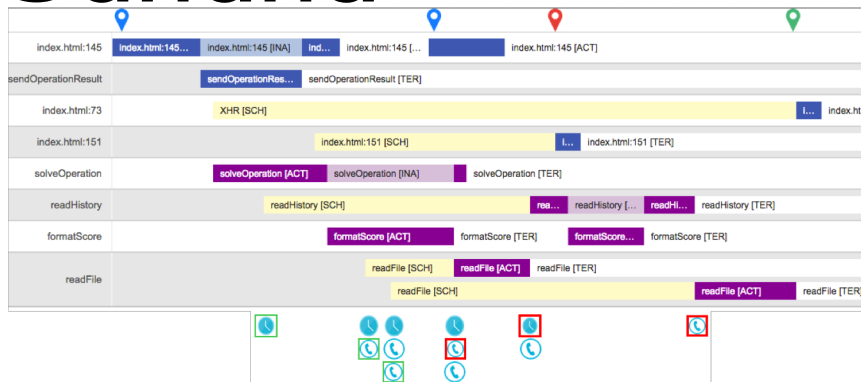
Tochal

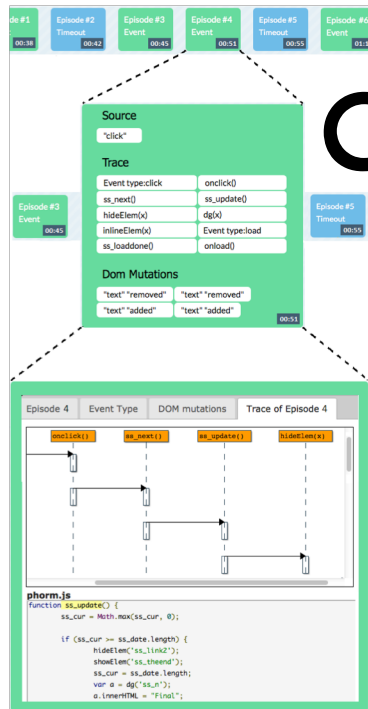


Total Time	Activity
554.9 ms	18.9 % Evaluate Script
393.2 ms	13.4 % Parse HTML
109.5 ms	3.7 % s_Via rs=ACT90oHL93uXakCn3dRwIk7ttU...
91.5 ms	3.1 % b.port1.onmessage rs=ACT90oHL93uXakC...
40.4 ms	1.4 % Recalculate Style
35.3 ms	1.2 % Update Layer Tree
31.0 ms	1.1 % Run Microtasks
24.0 ms	0.8 % XHR Ready State Change
16.8 ms	0.6 % Finish Loading
15.4 ms	0.5 % Composite Layers
14.5 ms	0.5 % (anonymous) search?q=execution+trace&rtz=...
14.4 ms	0.5 % dispatchOnMessage VM224 extensions:me...
13.0 ms	0.4 % Layout
12.6 ms	0.4 % Paint
11.9 ms	0.4 % d_search?q=execution+trace&rtz=1C5CHFA...
6.5 ms	0.2 % Hit Test
6.3 ms	0.2 % DOM GC
6.1 ms	0.2 % (anonymous) rs=ACT90oHL93uXakCn3dR...
5.5 ms	0.2 % DOM GC
5.1 ms	0.2 % _Ed.C search?q=execution+trace&rtz=1C5C...
4.8 ms	0.2 % (anonymous) rs=AA2YtTx96LEPKYUllNFV...
4.0 ms	0.1 % Receive Response
1.3 ms	0.0 % (anonymous) rs=AGLTcCQqXRNQOQ29u9W...
0.9 ms	0.0 % (anonymous) rs=ACT90oHL93uXakCn3dR...
0.8 ms	0.0 % dispatchOnDisconnect VM224 extensions:...
0.8 ms	0.0 % dispatchOnConnect VM224 extensions:me...
0.7 ms	0.0 % Receive Data
0.6 ms	0.0 % Major GC

Total Time	Activity
554.9 ms	18.9 % Evaluate Script
393.2 ms	13.4 % Parse HTML
109.5 ms	3.7 % s_Via rs=ACT90oHL93uXakCn3dRwIk7ttU...
91.5 ms	3.1 % b.port1.onmessage rs=ACT90oHL93uXakC...
40.4 ms	1.4 % Recalculate Style
35.3 ms	1.2 % Update Layer Tree
31.0 ms	1.1 % Run Microtasks
24.0 ms	0.8 % XHR Ready State Change
16.8 ms	0.6 % Finish Loading
15.4 ms	0.5 % Composite Layers
14.5 ms	0.5 % (anonymous) search?q=execution+trace&rtz=...
14.4 ms	0.5 % dispatchOnMessage VM224 extensions:me...
13.0 ms	0.4 % Layout
12.6 ms	0.4 % Paint
11.9 ms	0.4 % d_search?q=execution+trace&rtz=1C5CHFA...
6.5 ms	0.2 % Hit Test
6.3 ms	0.2 % DOM GC
6.1 ms	0.2 % (anonymous) rs=ACT90oHL93uXakCn3dR...
5.5 ms	0.2 % DOM GC
5.1 ms	0.2 % _Ed.C search?q=execution+trace&rtz=1C5C...
4.8 ms	0.2 % (anonymous) rs=AA2YtTx96LEPKYUllNFV...
4.0 ms	0.1 % Receive Response
1.3 ms	0.0 % (anonymous) rs=AGLTcCQqXRNQOQ29u9W...
0.9 ms	0.0 % (anonymous) rs=ACT90oHL93uXakCn3dR...
0.8 ms	0.0 % dispatchOnDisconnect VM224 extensions:...
0.8 ms	0.0 % dispatchOnConnect VM224 extensions:me...
0.7 ms	0.0 % Receive Data
0.6 ms	0.0 % Major GC

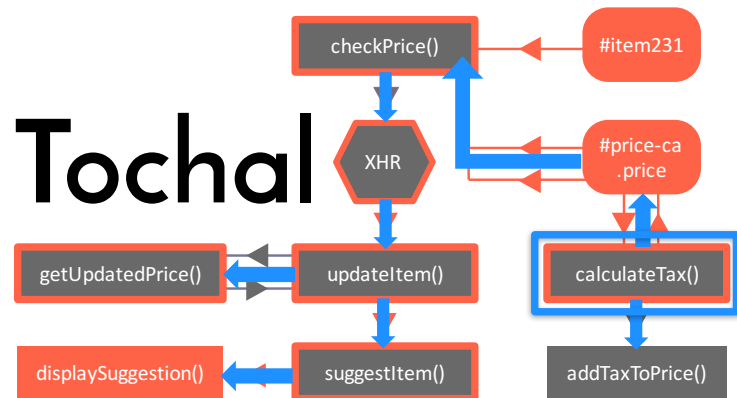
Sahand





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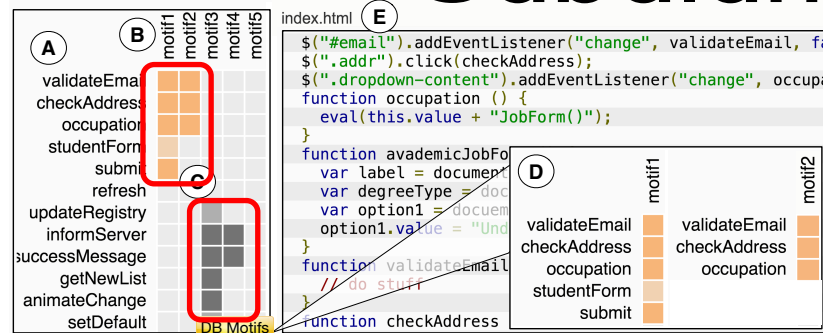
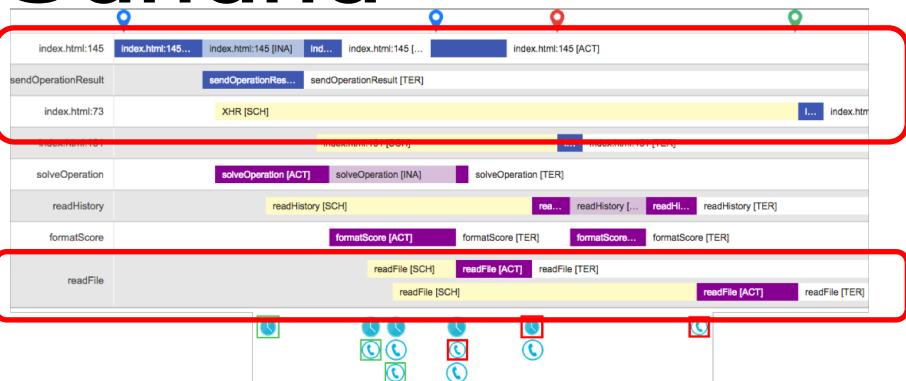


Total Time	Activity
554.9 ms	18.9 % Evaluate Script
393.2 ms	13.4 % Parse HTML
109.5 ms	3.7 % s_Via rs=ACT900HL93uXakCn3dRwIk7ttUh...
91.5 ms	3.1 % b.port1.onmessage rs=ACT900HL93uXakCn3dRwIk7ttUh...
40.4 ms	1.4 % Recalculate Style
35.3 ms	1.2 % Update Layer Tree
31.0 ms	1.1 % Run Microtasks
24.0 ms	0.8 % XHR Ready State Change
16.8 ms	0.6 % Finish Loading
15.4 ms	0.5 % Composite Layers
14.5 ms	0.5 % (anonymous) search?q=execution+trace&fz=1C5C...
14.4 ms	0.5 % dispatchOnMessage VM224 extensions:me...
13.0 ms	0.4 % Layout
12.6 ms	0.4 % Paint
11.9 ms	0.4 % d search?q=execution+trace&fz=1C5C...
6.5 ms	0.2 % Hit Test
6.3 ms	0.2 % DOM GC
6.1 ms	0.2 % (anonymous) rs=ACT900HL93uXakCn3dRwIk7ttUh...
5.5 ms	0.2 % DOM GC
5.1 ms	0.2 % _EdC search?q=execution+trace&fz=1C5C...
4.8 ms	0.2 % (anonymous) rs=AA2YtTs9BLFIPKJUlInNFV...
4.0 ms	0.1 % Receive Response
1.3 ms	0.0 % (anonymous) rs=AGLTcCQpXRNQ029u9W...
0.9 ms	0.0 % (anonymous) rs=ACT900HL93uXakCn3dRwIk7ttUh...
0.8 ms	0.0 % dispatchOnDisconnect VM224 extensions:me...
0.8 ms	0.0 % dispatchOnConnect VM224 extensions:me...
0.7 ms	0.0 % Receive Data
0.6 ms	0.0 % Major GC

Total Time	Activity
554.9 ms	18.9 % Evaluate Script
393.2 ms	13.4 % Parse HTML
109.5 ms	3.7 % s_Via rs=ACT900HL93uXakCn3dRwIk7ttUh...
91.5 ms	3.1 % b.port1.onmessage rs=ACT900HL93uXakCn3dRwIk7ttUh...
40.4 ms	1.4 % Recalculate Style
35.3 ms	1.2 % Update Layer Tree
31.0 ms	1.1 % Run Microtasks
24.0 ms	0.8 % XHR Ready State Change
16.8 ms	0.6 % Finish Loading
15.4 ms	0.5 % Composite Layers
14.5 ms	0.5 % (anonymous) search?q=execution+trace&fz=1C5C...
14.4 ms	0.5 % dispatchOnMessage VM224 extensions:me...
13.0 ms	0.4 % Layout
12.6 ms	0.4 % Paint
11.9 ms	0.4 % d search?q=execution+trace&fz=1C5C...
6.5 ms	0.2 % Hit Test
6.3 ms	0.2 % DOM GC
6.1 ms	0.2 % (anonymous) rs=ACT900HL93uXakCn3dRwIk7ttUh...
5.5 ms	0.2 % DOM GC
5.1 ms	0.2 % _EdC search?q=execution+trace&fz=1C5C...
4.8 ms	0.2 % (anonymous) rs=AA2YtTs9BLFIPKJUlInNFV...
4.0 ms	0.1 % Receive Response
1.3 ms	0.0 % (anonymous) rs=AGLTcCQpXRNQ029u9W...
0.9 ms	0.0 % (anonymous) rs=ACT900HL93uXakCn3dRwIk7ttUh...
0.8 ms	0.0 % dispatchOnDisconnect VM224 extensions:me...
0.8 ms	0.0 % dispatchOnConnect VM224 extensions:me...
0.7 ms	0.0 % Receive Data
0.6 ms	0.0 % Major GC

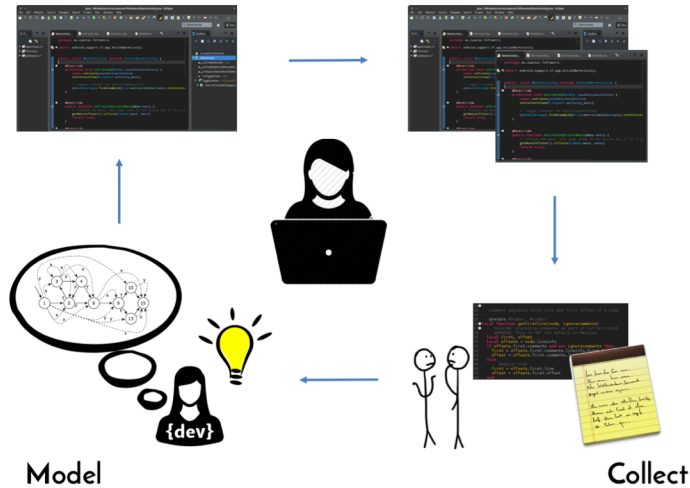
Sahand

Sabalan

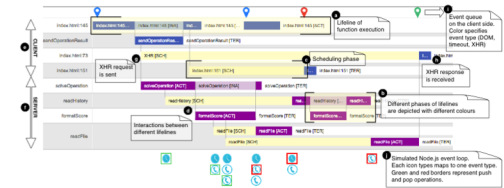


Search

Relate



1. Understanding Hidden and Complex Interactions



7

2. Understanding The Impact of Change



- **Goal:** identifying parts of the program that are potentially affected by a change.
- Challenging due to features of JavaScript
- DOM-sensitive event-aware hybrid change impact analysis

25

3. Understanding Motifs of Behaviour

