[ICWE'19]

Catch & Release:
An Approach to Debugging Distributed Full-Stack JavaScript Applications

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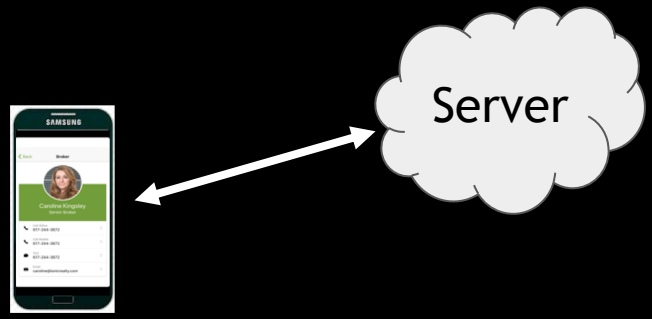
Debugging is hard...

Debugging
distributed programs
is harder than
centralized programs...



volatility,
misconfigurations,
partial failure,
middleware problems,
reproducibility...

Key Idea

- *Catch & Release(**CandoR**)*

1. **Transform** a distributed application into its semantically equivalent ***centralized variant***
2. **Isolate** and **fix bugs** in the centralized variant

   : separating the **programmer-written code** from configuration/environmental issues as suspected bug causes
3. **Replay** the fixes on the distributed version

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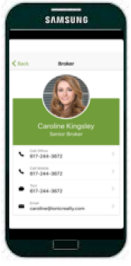
Full-stack JS Apps: JavaScript everywhere



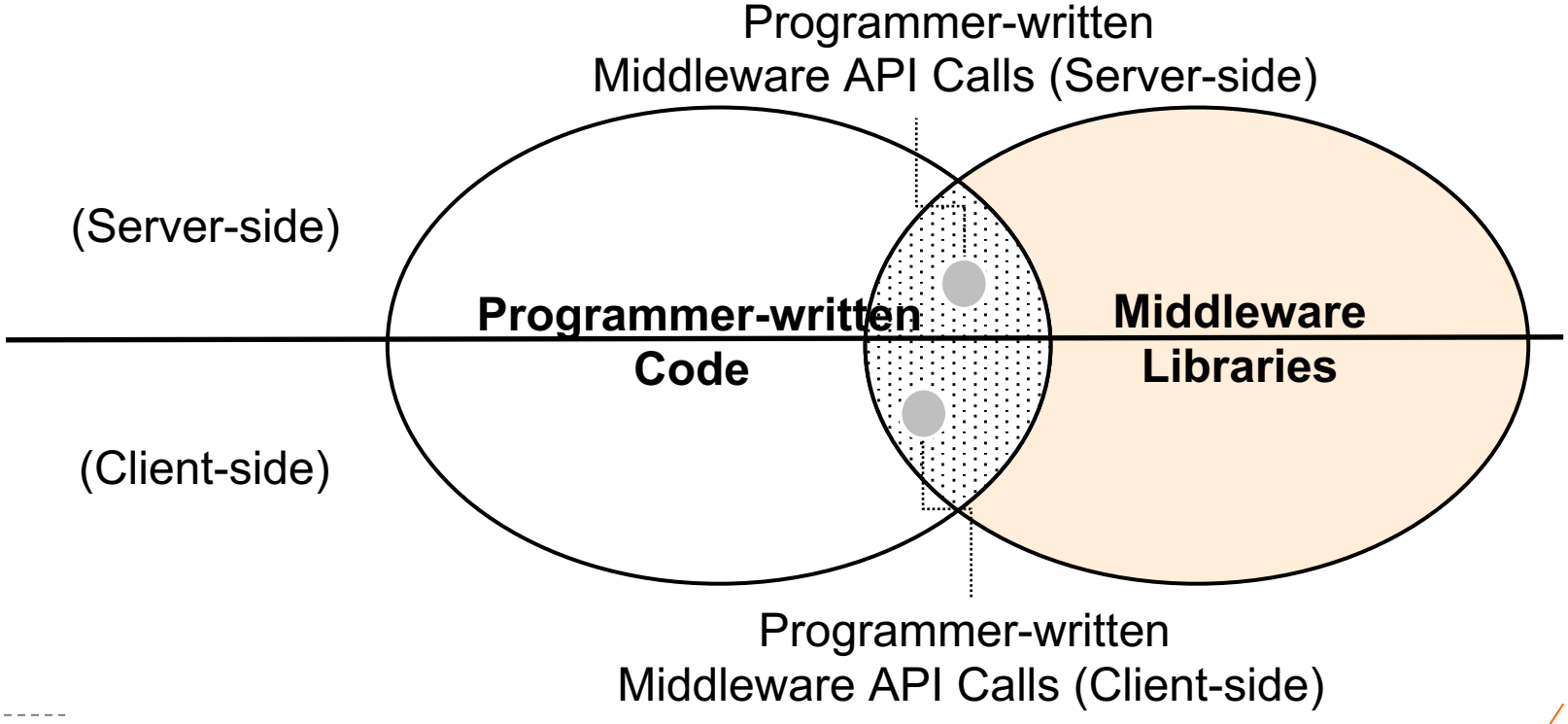
Remote Execution

Server

web client
--angular, react-native, Etc.

web server
(with Node.js)

Distributed Apps:
Middleware and Programmer-written Code



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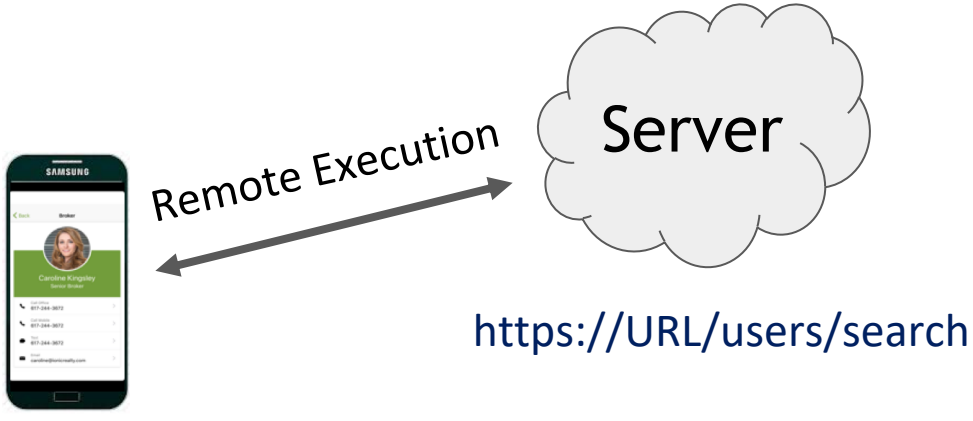
Full-stack JS Apps: BrownNode



(Programmer-written Code)

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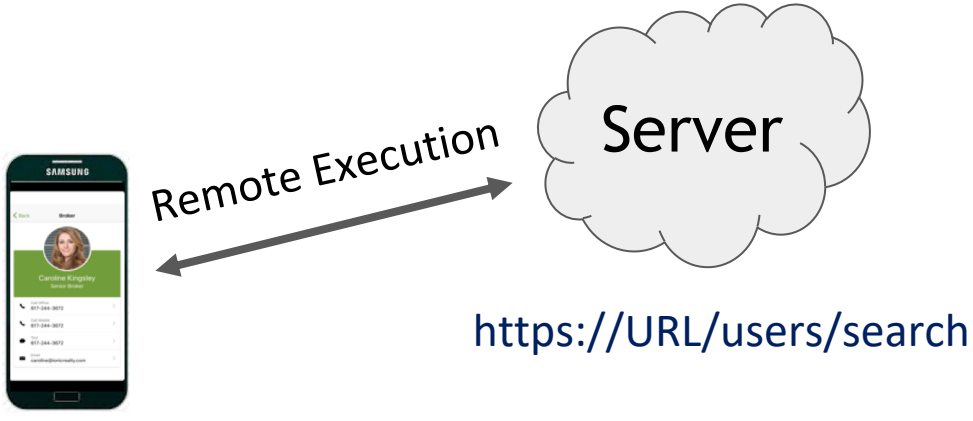
Full-stack JS Apps: BrownNode



(Middleware mis-config.,
Intermittent network)

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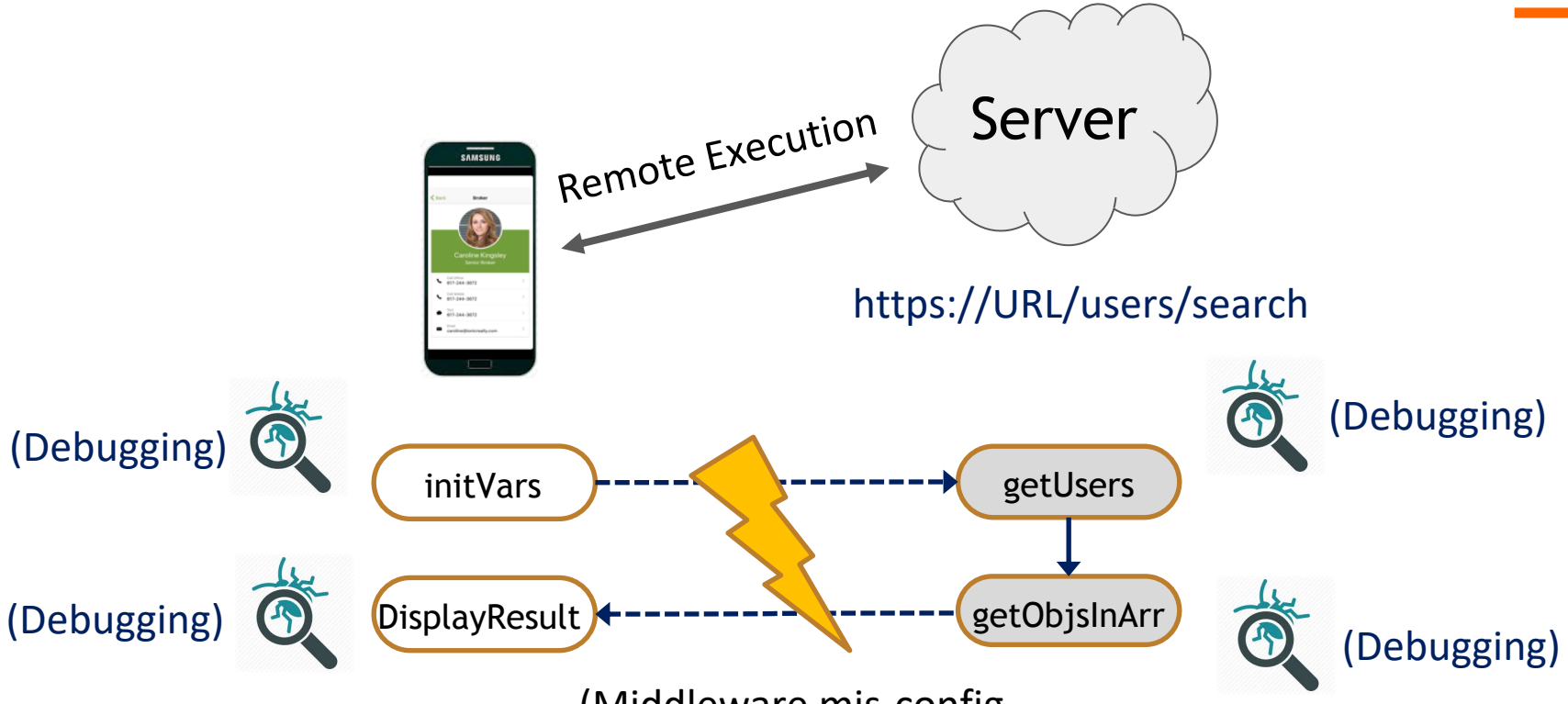
Full-stack JS Apps: BrownNode



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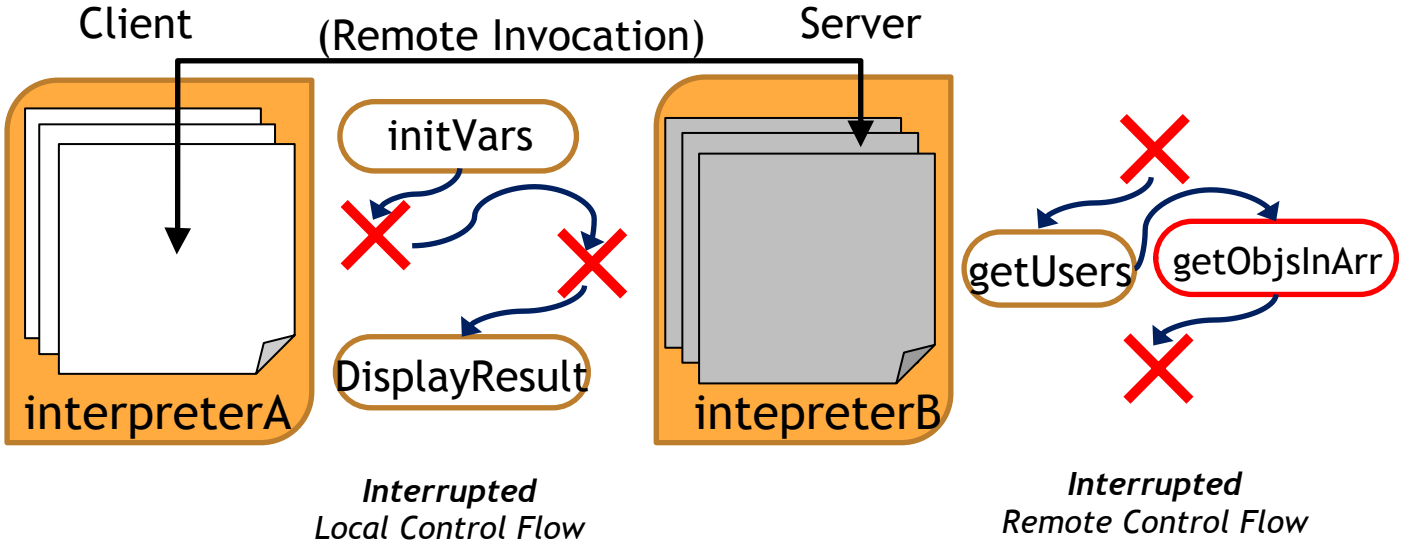
Full-stack JS Apps: BrownNode



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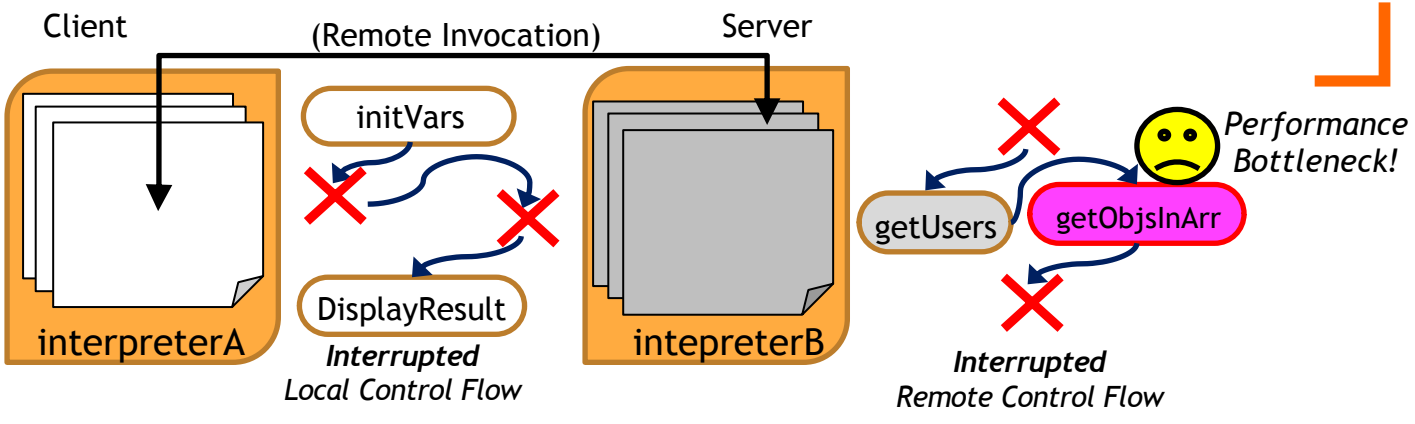
Full-stack JS Apps: BrownNode



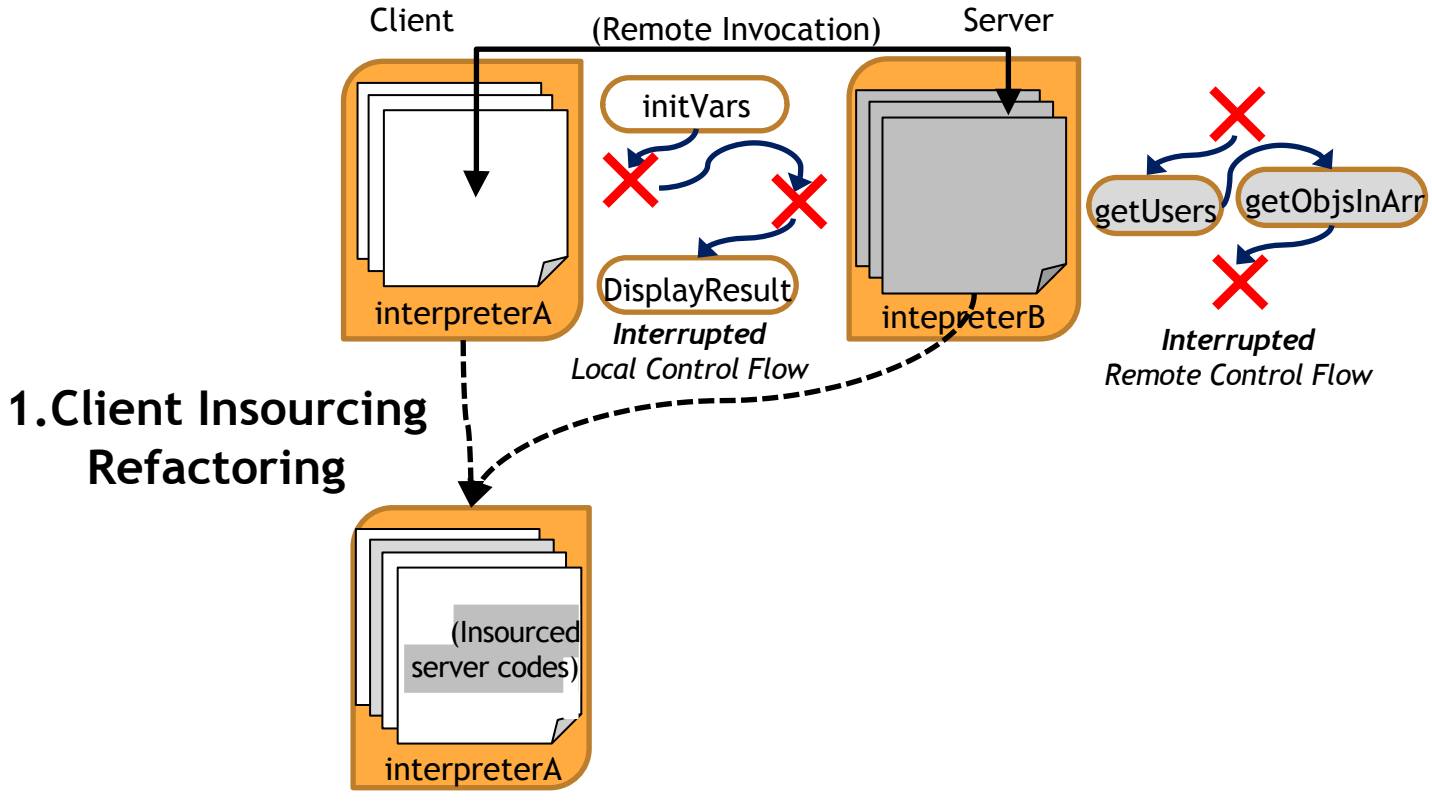

```
$.ajax({
 url: '/users/search',
 data:{
   fName:
$('#fName').val(),
 ...},
 type: 'POST',
 success:
function(data){
  $('#results').text(
   JSON.stringify(data)
);}});
```

```
var express = require('express'),
app = express.createServer(..);
var users=[]; ...
app.post('/users/search',
function(req, res) {
  var data = req.body;
  var result=getUsers(data);
  res.send(result);});

function getUsers(sUser) {
 return getObjsInArray(sUser,users);
}
```

```
function getObjsInArray(obj, array) {
 var foundObjs = [];
 for (var i=0; i<array.length;i++){
  for(var prop in obj) {
   if(obj.hasOwnProperty(prop)) {
    if(obj[prop]===array[i][prop])
    {
      foundObjs.push(array[i]);
      break;
   }}}}
 return foundObjs;
}
```

Client Insourcing Refactoring:
Undoing Distribution



Centralized App

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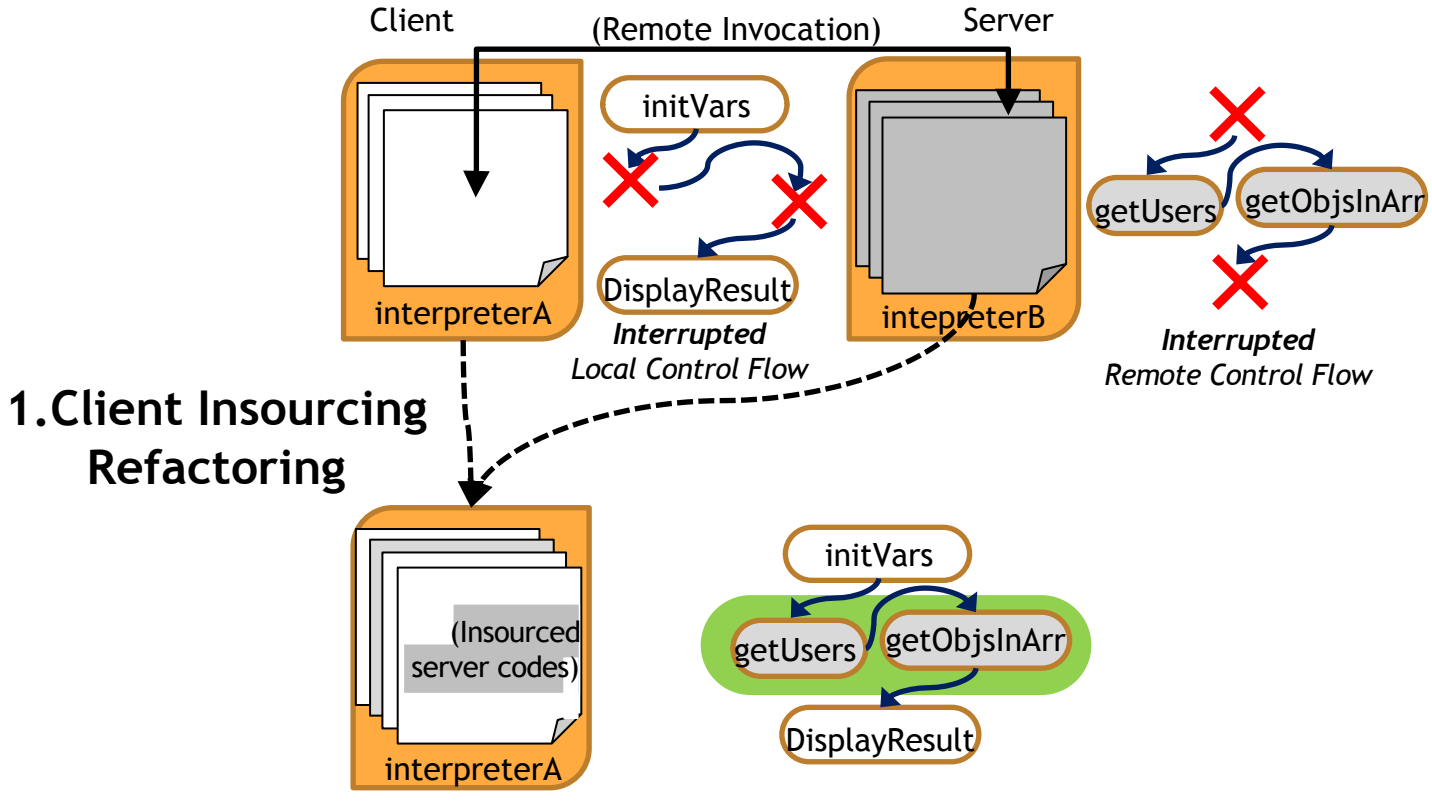
Client Insourcing Refactoring:
Undoing Distribution



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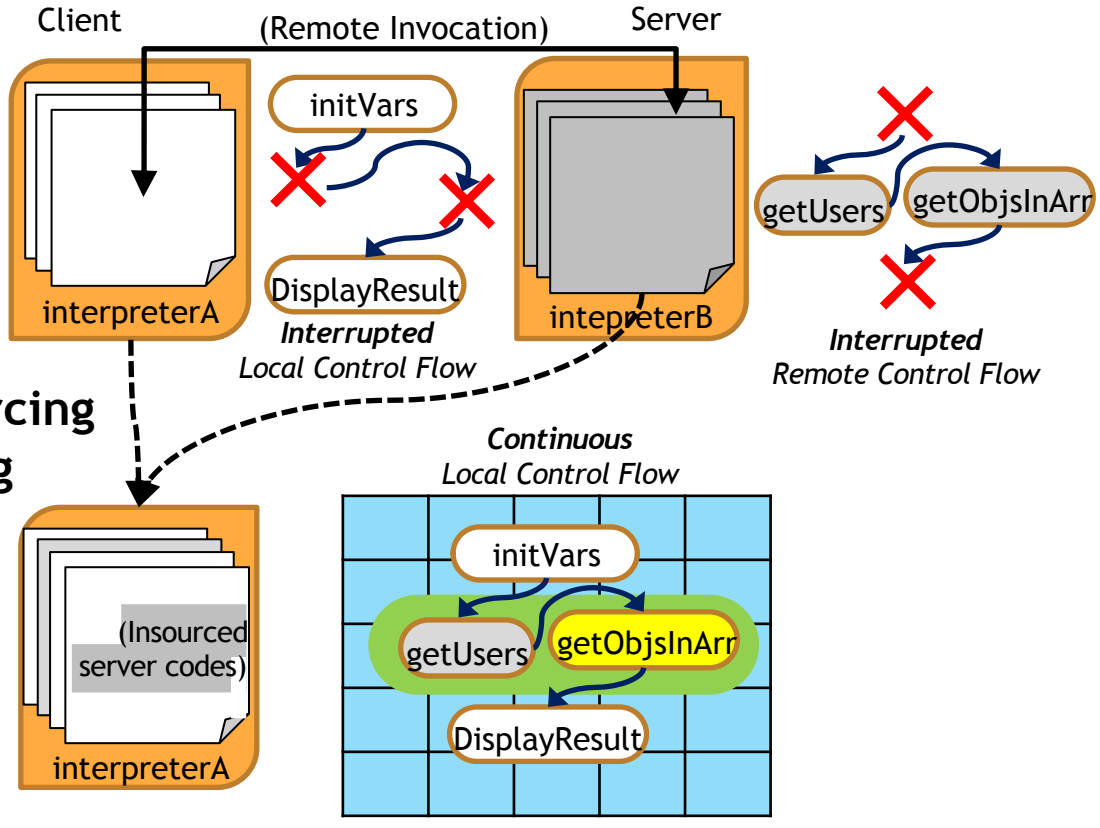
Catch & Release (CandOR)



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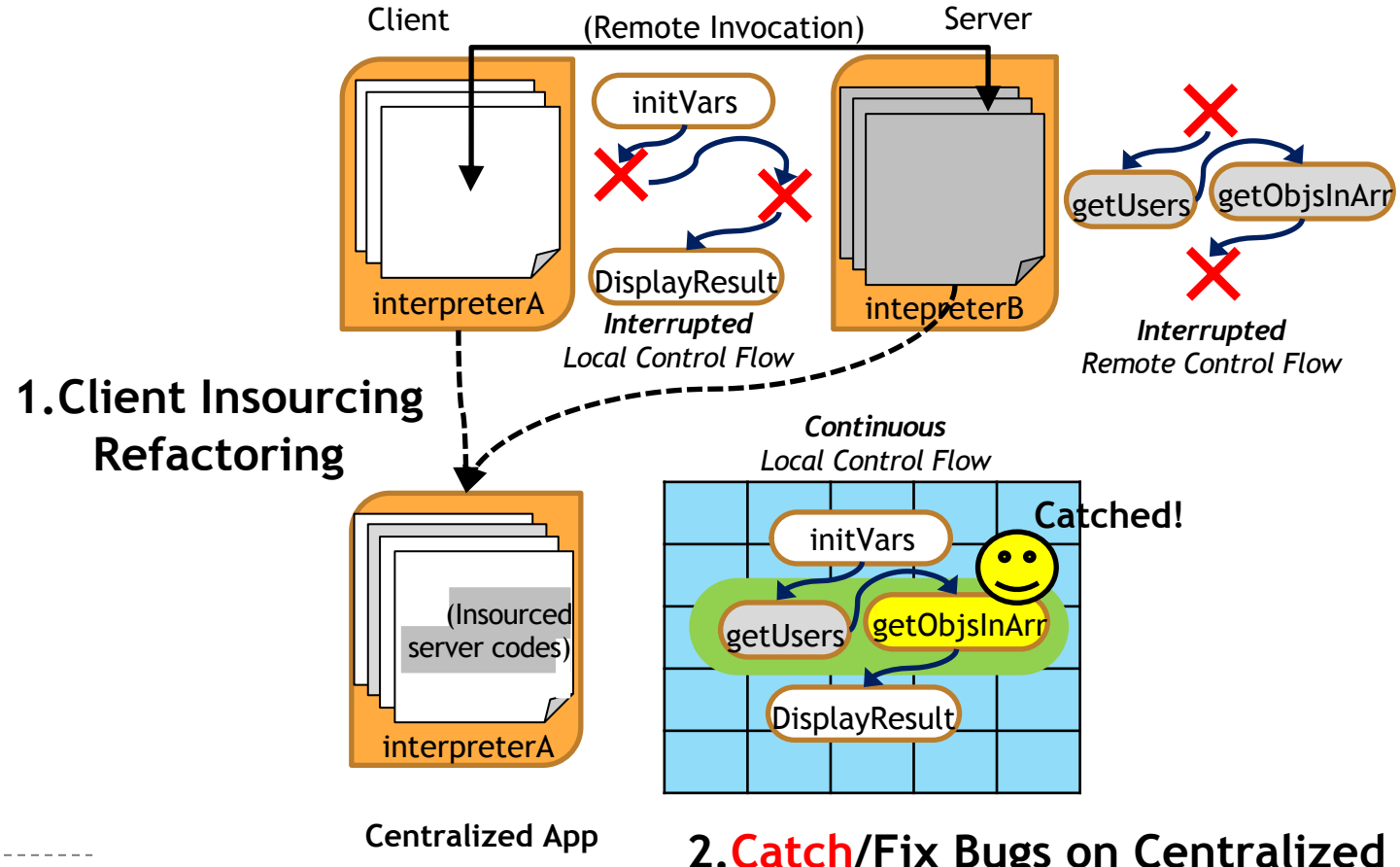
Catch & Release (CandOR)



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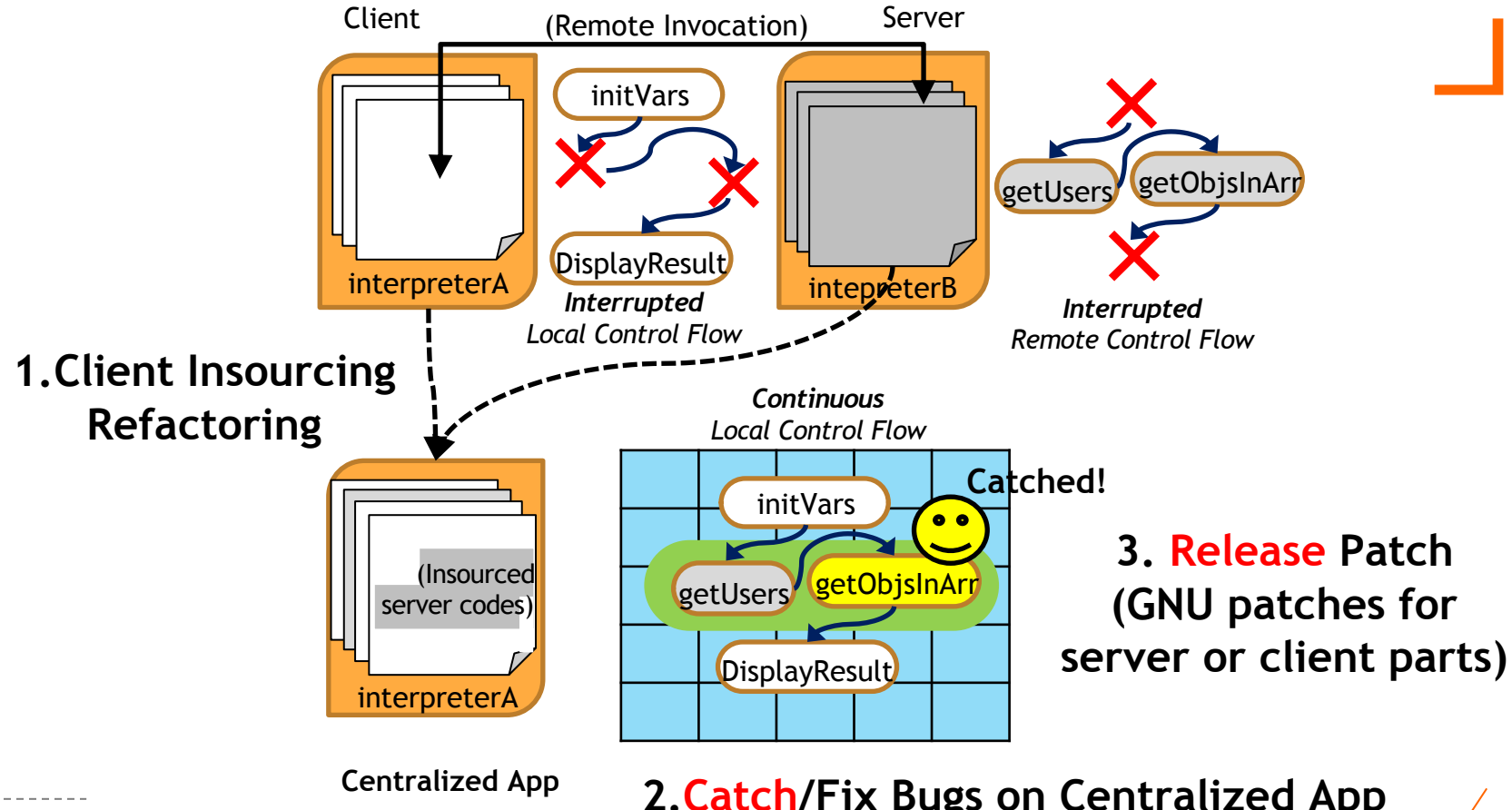
Catch & Release (CandOR)



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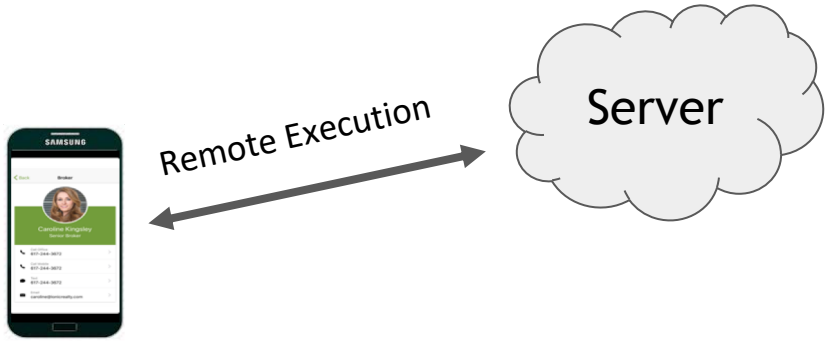
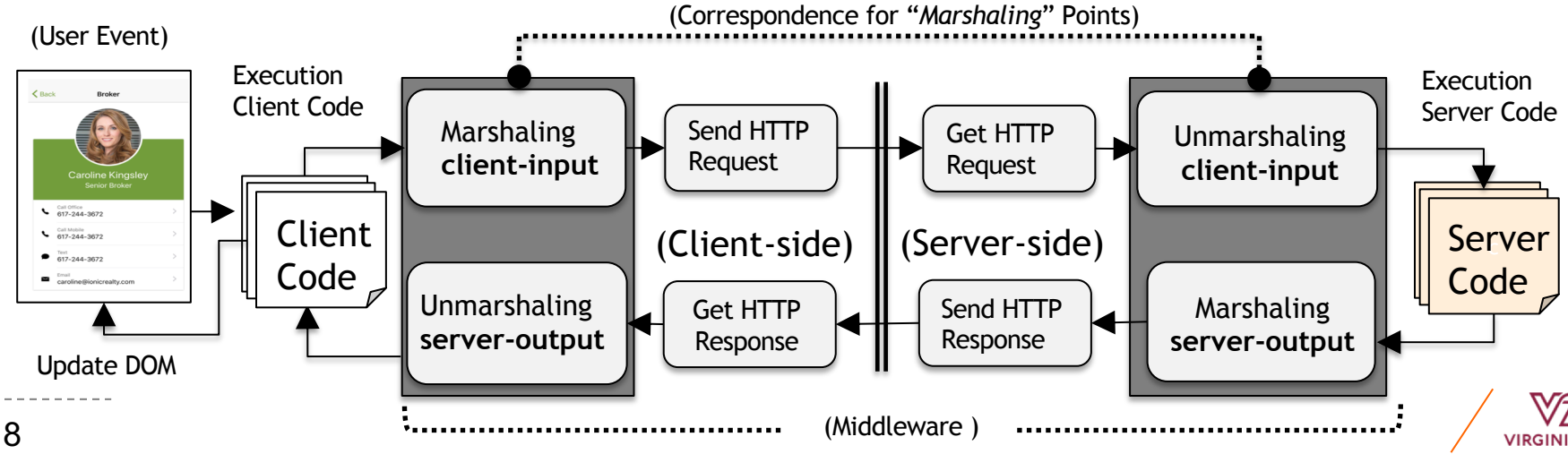
Details for Client Insourcing Refactoring





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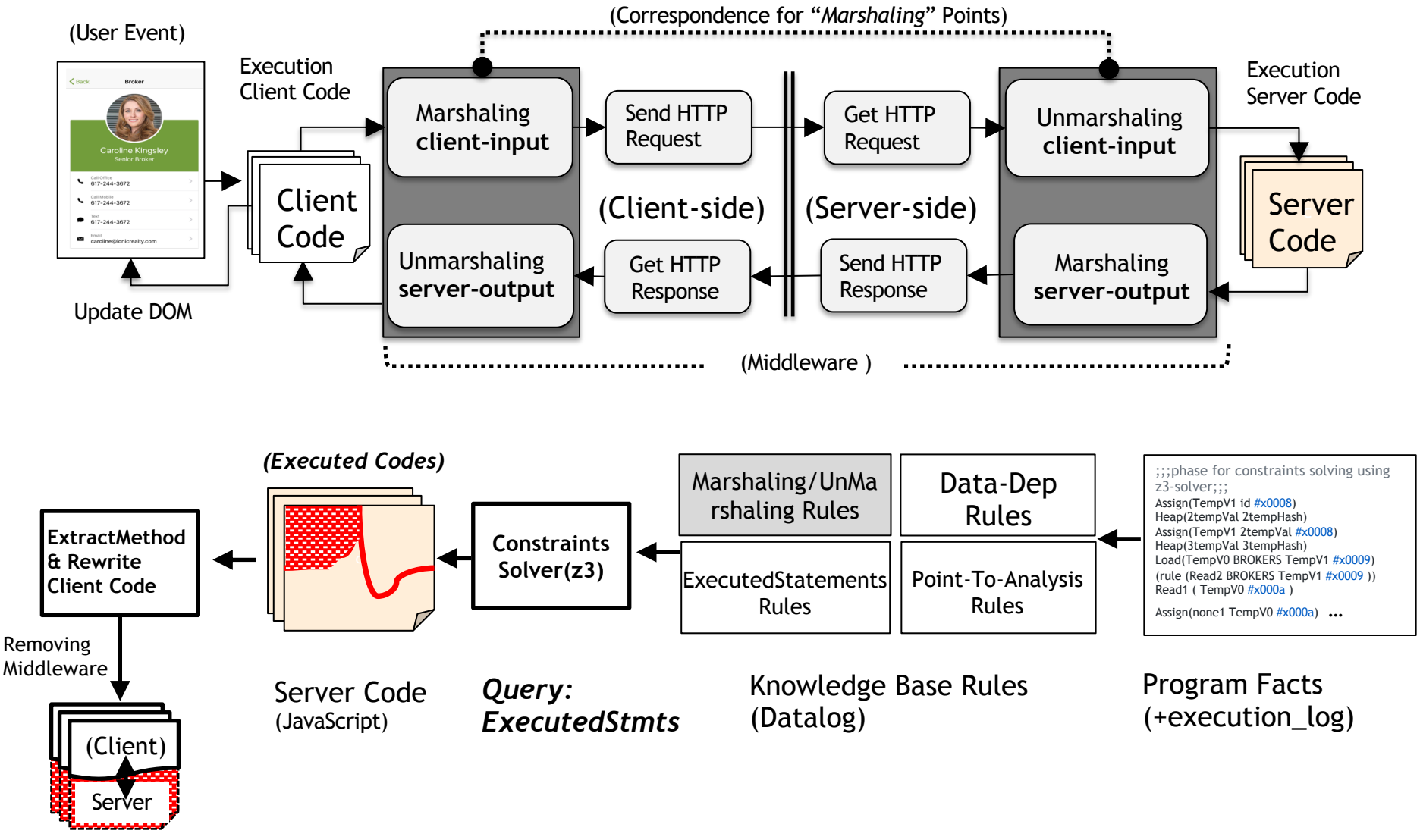
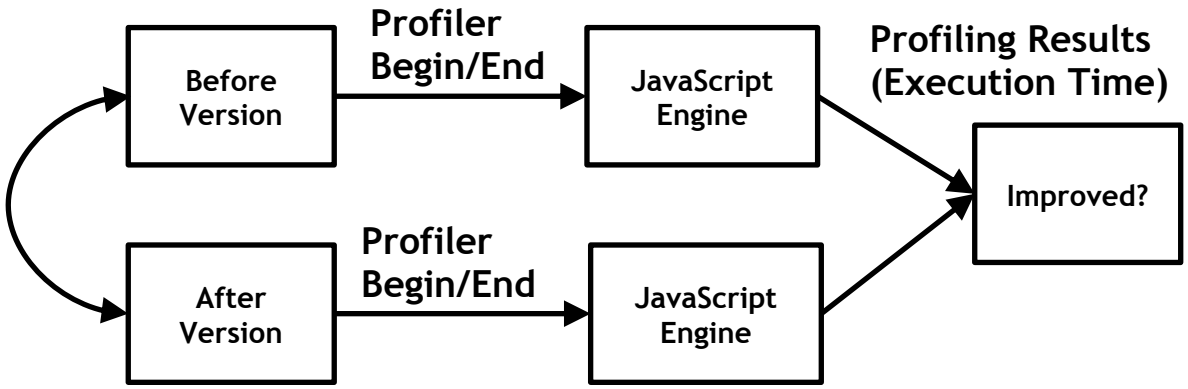

(User Event)
(Correspondence for "Marshaling" Points)
Execution Client Code
Execution Server Code
Broker
Caroline Kingsley
Senior Broker
Client Code
Marshaling client-input
Send HTTP Request
Get HTTP Request
Unmarshaling client-input
Server Code
(Client-side)
(Server-side)
Unmarshaling server-output
Get HTTP Response
Send HTTP Response
Marshaling server-output
Update DOM
(Middleware)
(Executed Codes)
ExtractMethod & Rewrite Client Code
Constraints Solver(z3)
Marshaling/UnMarshaling Rules
Data-Dep Rules
ExecutedStatements Rules
Point-To-Analysis Rules
;;;phase for constraints solving using z3-solver;;;
Assign(TempV1 id #x0008)
Heap(2tempVal 2tempHash)
Assign(TempV1 2tempVal #x0008)
Heap(3tempVal 3tempHash)
Load(TempV0 BROKERS TempV1 #x0009)
(rule (Read2 BROKERS TempV1 #x0009))
Read1 (TempV0 #x000a)
Assign(none1 TempV0 #x000a) ...
Removing Middleware
(Client)
Server
Server Code (JavaScript)
Query: ExecutedStmts
Knowledge Base Rules (Datalog)
Program Facts (+execution_log)

Performance Bottleneck Patterns for (centralized) JavaScript [17] (Selakovic, M. et al., ICSE'15)

```
function getObjsInArray(obj, array) {
 var foundObjs = [];
 for (var i=0; i<array.length;i++){
  for(var prop in obj) {
   if(obj.hasOwnProperty(prop)) {
    if(obj[prop]===array[i][prop])
    {
      foundObjs.push(array[i]);
      break;
   }}}}
 return foundObjs;
}
```

GNU Patch

```
5,18c1,16
<(original code for getObjsInArray)
---
> function getObjsInArray(obj, array) {
>  var foundObjs = [];
>  var keys = Object.keys(obj);
>  for (var i=0; i < array.length; i++){
>   for (var j = 0, l = keys.length; j <
  l; j++) {
>   var key = keys[j];
>   if (obj[key] === array[i][key]) {
>     foundObjs.push(array[i]);
>     break;
> }}}
> return foundObjs;
> }
```



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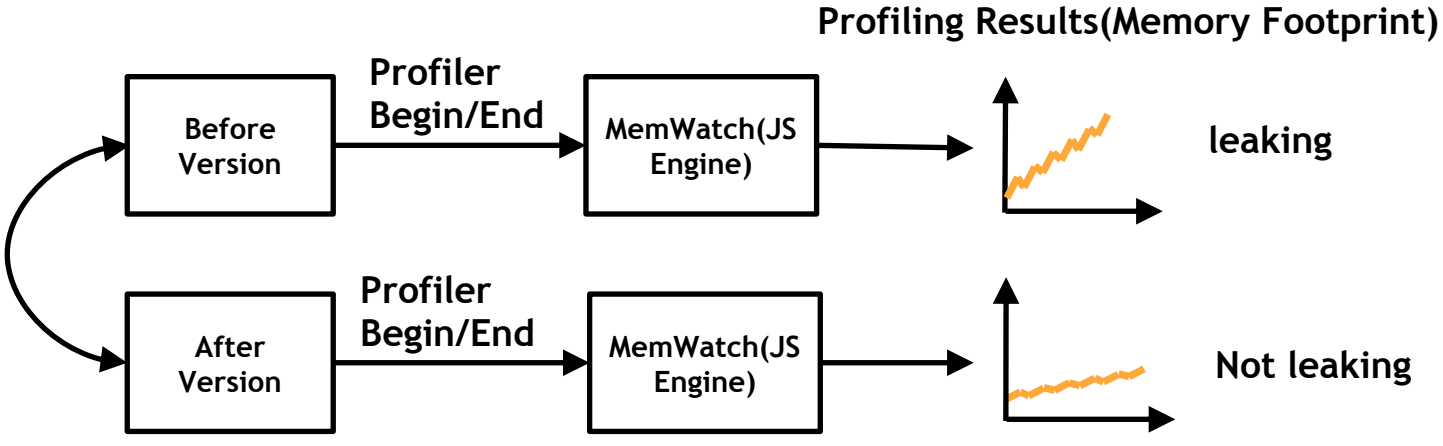
Memory Leak (memwatch[11]*)*



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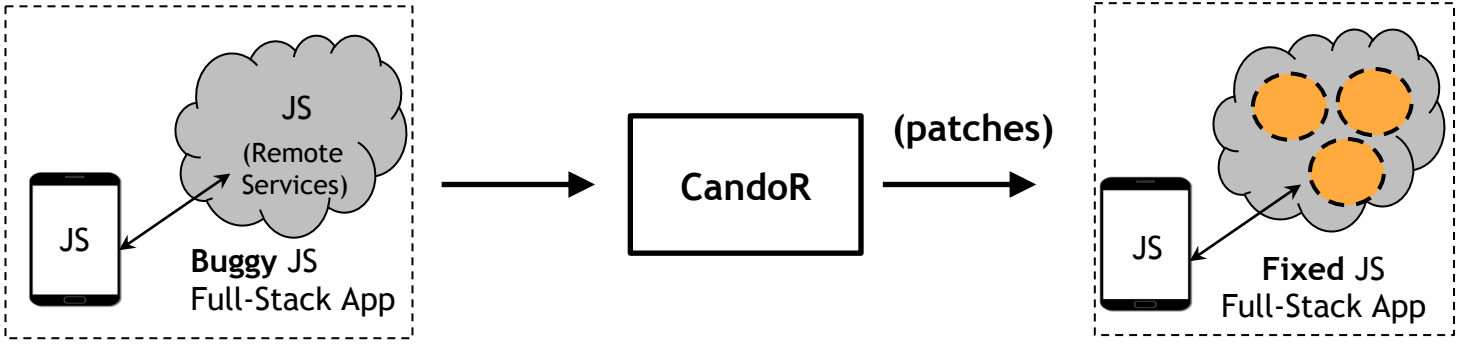

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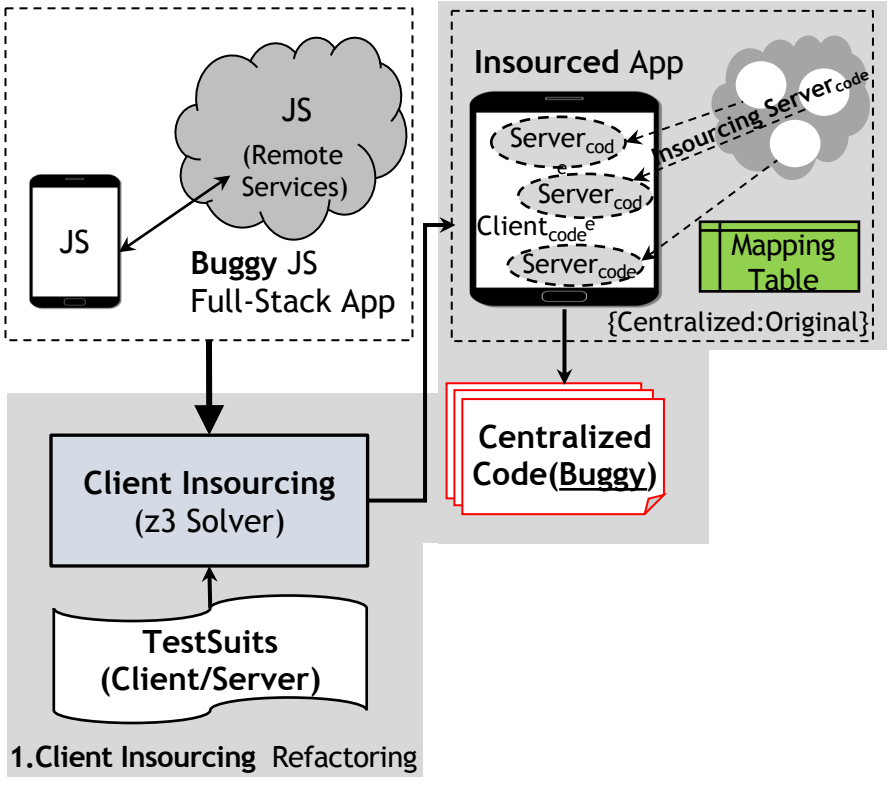

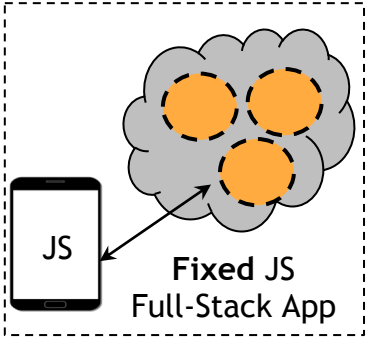

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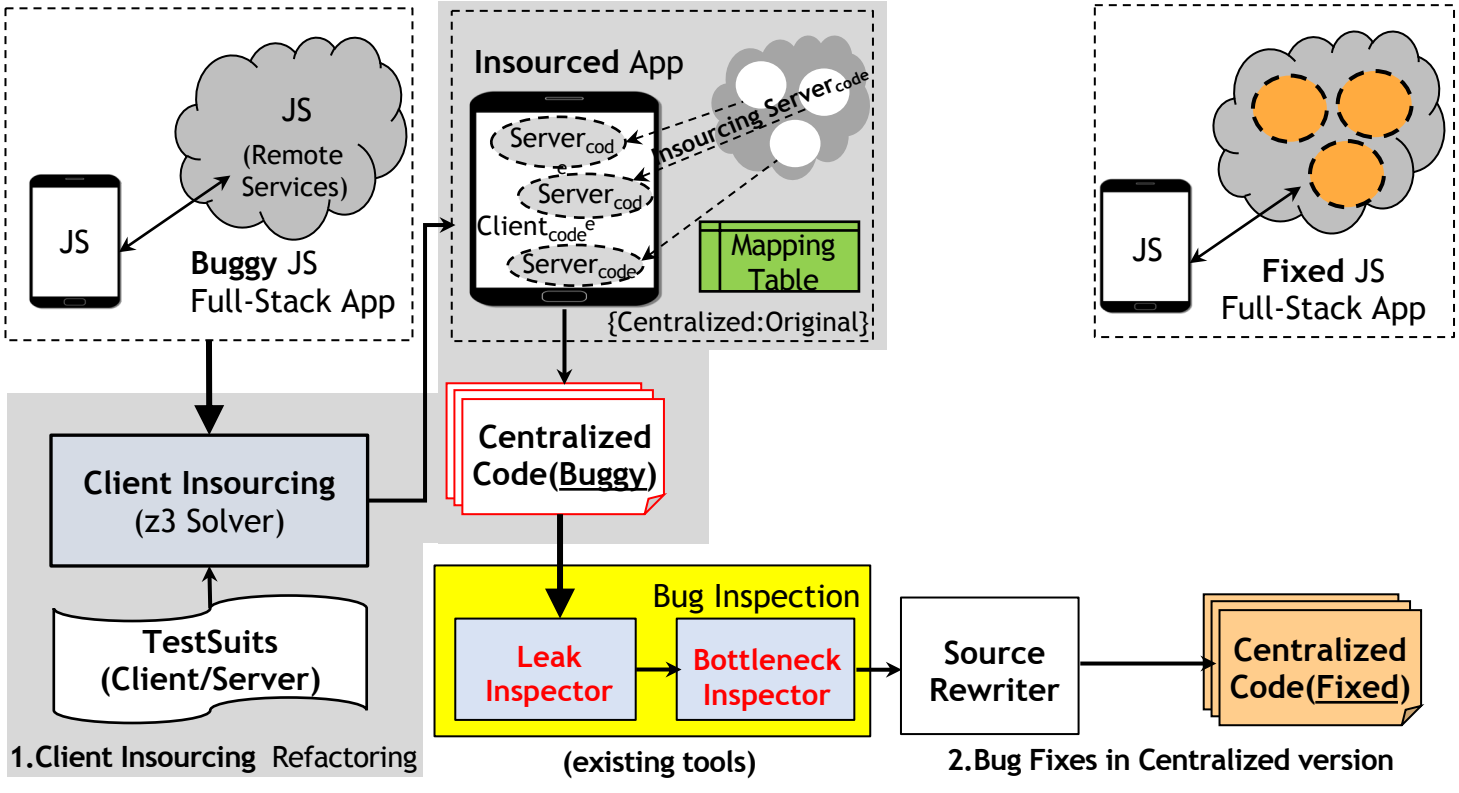

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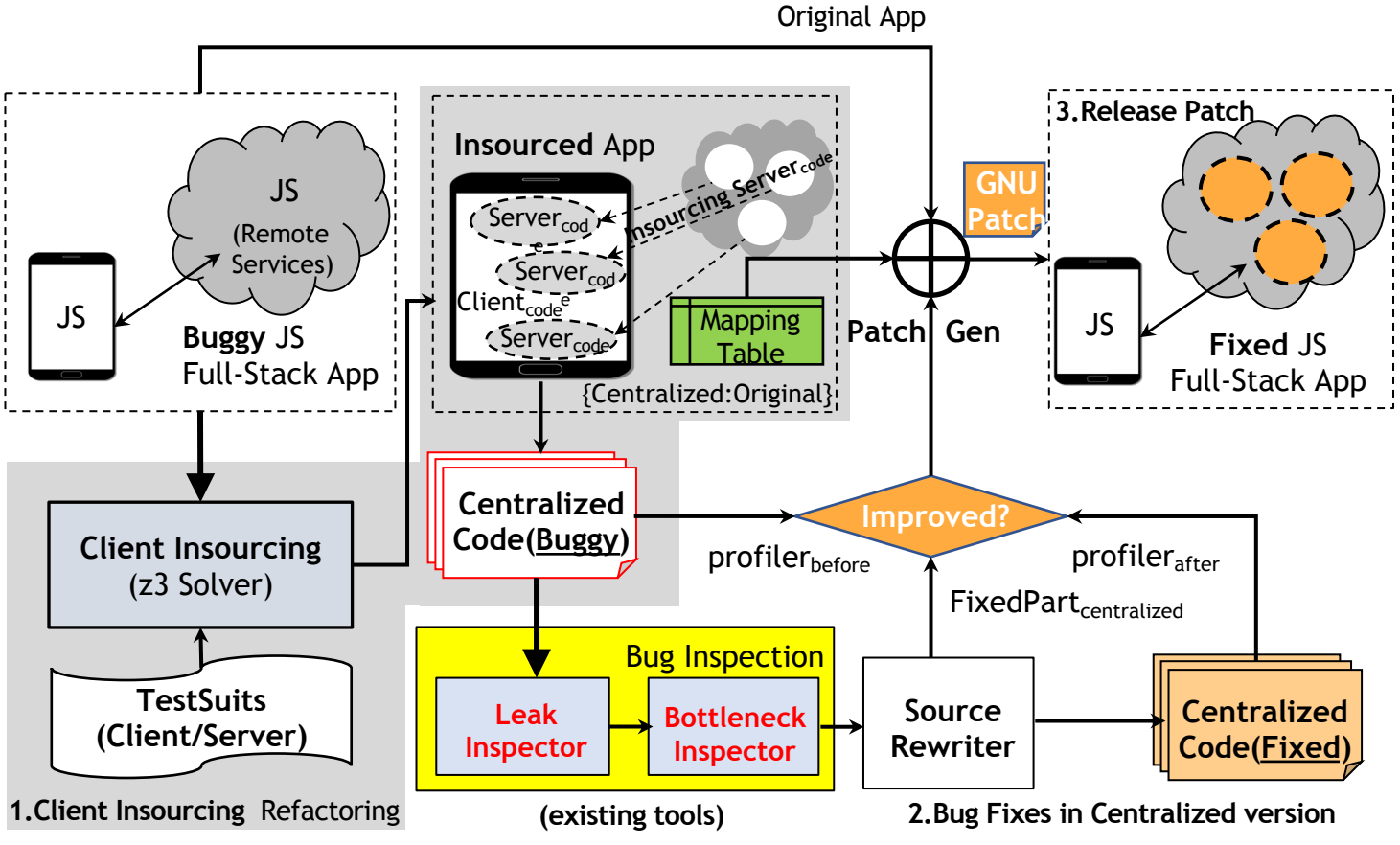

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Evaluation: Subject Applications

Subject Apps	Remote Services	Bug Types
theBrownNode [19]	/users/search /users/search/id	Inefficient iteration (Performance Bottleneck)
Bookworm [3]	/api/ladywithpet /api/thedea /api/theredroom /api/thegift	Misused APIs (Performance Bottleneck)
Search_leak [16]	/search_leak	Memory leak
ionic2_realty_rest [15]	/properties/favorites	Memory leak

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Evaluation: Client Insourcing

Subject Apps	S_{ULOC}	C_{ULOC}	Remote Services	CI_{ULOC}
theBrownNode [19]	147	43	/users/search /users/search/id	37 36
Bookworm [3]	371	1814	/api/ladywithpet /api/thedea /api/theredroom /api/thegift	394 394 394 394
Search_leak [16]	34	13	/search_leak	17
ionic2_realty_rest [15]	453	387	/properties/favorites	24

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Evaluation: Performance Bottleneck

Remote Services	Bug Types	F_{ULOC}	P^{D}_{before} (P^{CI}_{before})	P^{D}_{after} (P^{CI}_{after})	$P^{d}_{improved}$ ($P^{CI}_{improved}$)
/users/search	Inefficient iteration	31	0.36ms	0.26ms	27.8%
			(0.19ms)	(0.13ms)	(31.58%)
/users/search/id	Inefficient iteration	31	1.7ns	1.19ns	29.53%
			(2.5ns)	(1.63ns)	(34.8%)
/api/ladywithpet	Misused APIs	18	5.89ms	4.99ms	15.28%
			(2.74ms)	(2.24ms)	(18.13%)
/api/thedea	Misused APIs	18	5.63ms	4.82ms	14.39%
			(2.71ms)	(2.25ms)	(16.97%)
/api/theredroom	Misused APIs	18	0.65ms	0.53ms	18.06%
			(1.87ms)	(1.56ms)	(16.58%)
/api/thegift	Misused APIs	18	1.17ms	1.04ms	11.11%
			(0.36ms)	(0.31ms)	(13.89%)

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Evaluation: Performance Bottleneck

Remote Services	Bug Types	F_{ULOC}	P^{D}_{before} (P^{CI}_{before})	P^{D}_{after} (P^{CI}_{after})	$P^{d}_{improved}$ ($P^{CI}_{improved}$)
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			(2.74ms)	(2.24ms)	(18.13%)
/api/thedea	Misused APIs	18	5.63ms	4.82ms	14.39%
			(2.71ms)	(2.25ms)	(16.97%)
/api/theredroom	Misused APIs	18	0.65ms	0.53ms	18.06%
			(1.87ms)	(1.56ms)	(16.58%)
/api/thegift	Misused APIs	18	1.17ms	1.04ms	11.11%
			(0.36ms)	(0.31ms)	(13.89%)

Distributed Version(Original)

Centralized Version(Proxy)

$$\frac{P_{before} - P_{after}}{P_{before}}$$

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Evaluation: Performance Bottleneck $\frac{P_{before} - P_{after}}{P_{before}}$

Remote Services	Bug Types	F_{ULOC}	P^{D}_{before} (P^{CI}_{before})	P^{D}_{after} (P^{CI}_{after})	$P^{D}_{improved}$ ($P^{CI}_{improved}$)
/users/search	Inefficient iteration	31	0.36ms (0.19ms)	0.26ms (0.13ms)	27.8% (31.58%)
/users/search/id	Inefficient iteration	31	1.7ns (2.5ns)	1.19ns (1.63ns)	29.53% (34.8%)
/api/ladywithpet	Misused APIs	18	5.89ms (2.74ms)	4.99ms (2.24ms)	15.28% (18.13%)
/api/thedea	Misused APIs	18	5.63ms (2.71ms)	4.82ms (2.25ms)	14.39% (16.97%)
/api/theredroom	Misused APIs	18	0.65ms (1.87ms)	0.53ms (1.56ms)	18.06% (16.58%)
/api/thegift	Misused APIs	18	1.17ms (0.36ms)	1.04ms (0.31ms)	11.11% (13.89%)

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Evaluation: Memory Leak

Remote Services	Bug Types	F_{ULOC}	P^{D}_{before} (P^{CI}_{before})	P^{D}_{after} (P^{CI}_{after})	$P^{D}_{improved}$ ($P^{CI}_{improved}$)
/search_leak	Memory leak	24	619.10kb	519.13kb	16.15%
			(476.16kb)	(409.10kb)	(14.08%)
/properties/favorites	Memory leak	42	824.62kb	511.37kb	37.99%
			(1431.28kb)	(922.51kb)	(35.54%)

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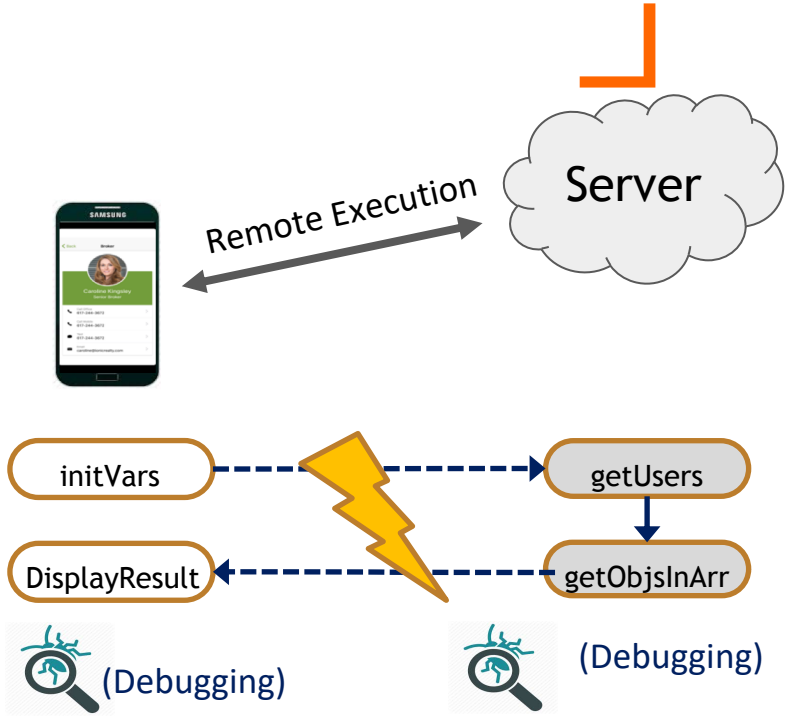
Debugging (State of the Practice)

Locate $ftn_{remote}^{n^{th}}$'s entry/exit points in server → Insert Start/End Profiler for $profile_{before}^{n^{th},server}$ → Insert Start/End Profiler in client $ftn_{client}^{n^{th}}$ for $profile_{before}^{n^{th},client}$ → (Run HTTP methods in client) → Collect $profile_{before}^{n^{th},server}$ / $profile_{before}^{n^{th},client}$ for $profile_{before}^{n^{th},all}$ → Apply Bug patches $P^{1...i}$ to $ftn_{remote}^{n^{th}}/ftn_{local}^{n^{th}}$ → (Run HTTP methods in client) → Collect $profile_{after}^{n^{th},server}$ / $profile_{after}^{n^{th},client}$ for $profile_{after}^{n^{th},all}$ $\xrightarrow[repeat\ (n-1...1)]{}$*... → Compare $profile_{before}^{1...n,all}$ and $profiles_{after}^{1...n,all}$



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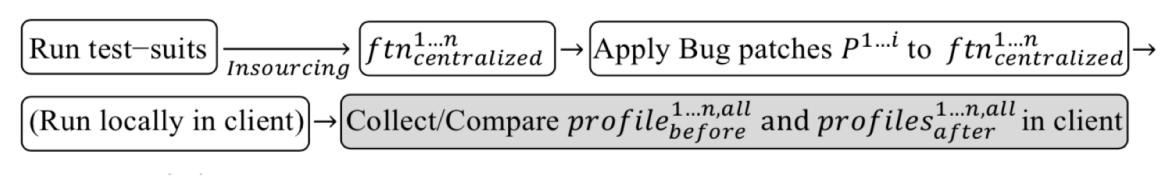
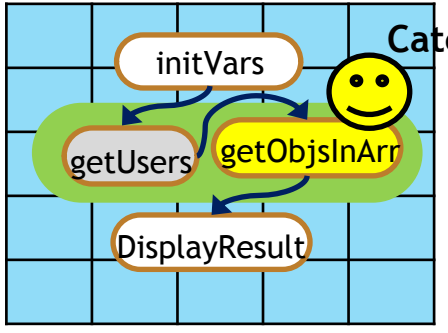
Debugging (with CandoR)



(Debugging)



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Related Work: Debugging Distributed Web Applications

- Client-side scripting to automatically exercise UI elements and to conduct state-based testing [8,10,12,13]
  - Approximate server-side app logic as simple states
- Record and Replay(R&R) is an execution framework that efficiently captures distributed execution traces [1,14]
- Performance & Memory debugging Tools for JavaScript
  - MemInsight, JITProf, DLint, JSweeter, BLeak, MemWatch
  - Currently, all these approaches need to be applied separately to the server or client parts of full-stack JavaScript applications

Conclusion, QnA

- We have presented a new debugging approach—**CandoR**—that facilitates the debugging of full-stack JavaScript applications.
- We plan to generalize our approach to **multi-lingual applications**, server and client are written by different programming languages.