Attacking Browser Sandbox: Live Persistently and Prosperously

Yongke Wang, Bin Ma, Huiming Liu

Tencent Security Xuanwu Lab

Who Are We?

- **Tencent**
  - Largest social media and entertainment company in China
- **Tencent Security Xuanwu Lab**
  - Applied and real world security research
- **About us: Members of Advanced Security Team**
  - Yongke Wang (@Rudykewang)
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  - Huiming Liu (@liuhm09)

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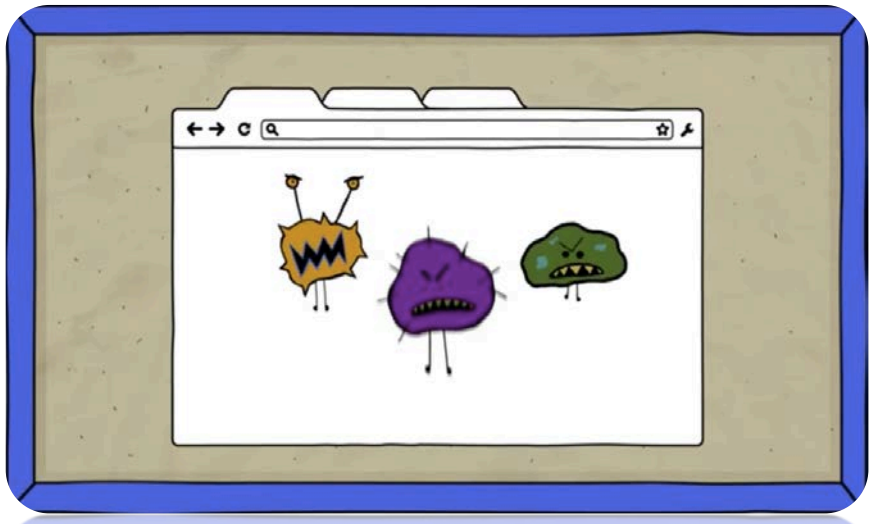
Outline

- 1. Sandbox Introduction
- 2. Previous Work and Motivation
- 3. Survive the Tab Closing -- Renderer Process Persistence
- 4. Survive the Device Rebooting -- Cache Persistence
- 5. Survive the Re-Install -- Clone Attack
- 6. Conclusion

Sandbox Introduction

- Mandatory access controlled environment
- Isolated Process when HTML rendering and JavaScript execution
- Limited resource access
- Limited IPC/kernel interaction access
- Site Isolation (new feature)
  - Enable by default in Chrome 67 on Win, Mac, Linux, and Chrome OS. May 2018



Sandbox Introduction

- Sandbox Escape is difficult
  - More and more new features and limitations
  - More/New features-> More bugs? Not for sandbox!
  - More gains -> More Pains
    - ZERODIUM pay **$500,000** for Windows' Chrome RCE with sandbox escape (previously: **$250,000**)
    - Google pay **$7,500** for Chrome RCE (No Sandbox Escape)

Change our mind: Attacking Sandbox Without Breaking it

- 1. What we can do inside the sandbox?

- 2. How about not breaking sandbox but living in it persistently and prosperously?

Related Work

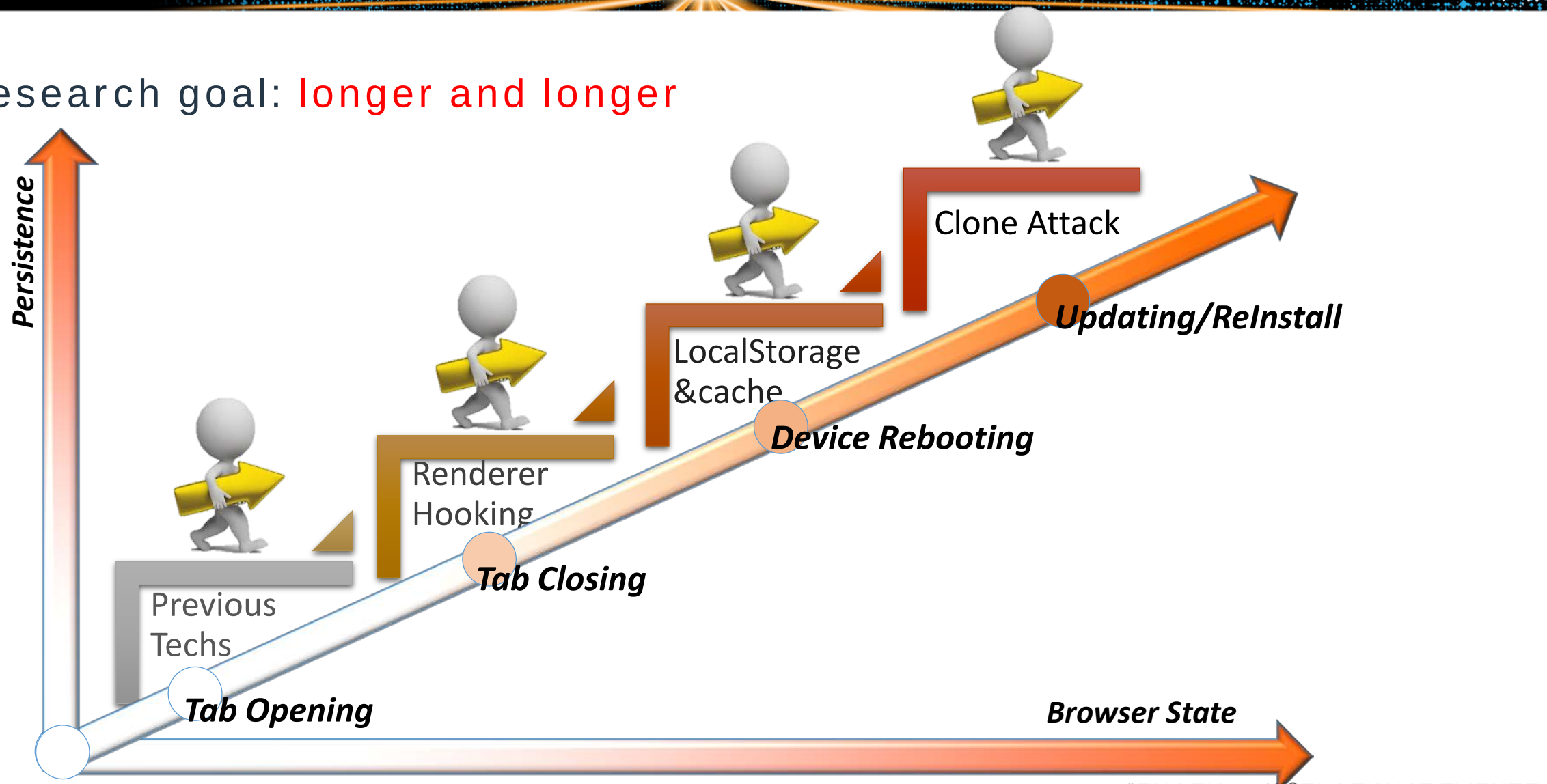
- Previous attack within sandbox
  - Renderer RCE
  - Credentials Stealing (cookie, token)
  - Lateral Movement (ports scanning)
  - Side Channel Attack (Meltdown, Spectre)
- When users close the tabs…All those attacks will gone.

Related Work

- Persistent Attack When tabs are open
  - 1. Retaining Communication
    - CORS/DNS Tunnel/WebSocket
  - 2. Retaining Control
    - XSS+Iframe/Click hijacking/Browser Event
- Persistence outside the sandbox
    - Escape the sandbox using vulnerabilities
- Not universal ,outdated or too hard...

How To Live in Sandbox After Closing the Tabs?

Our research goal: longer and longer



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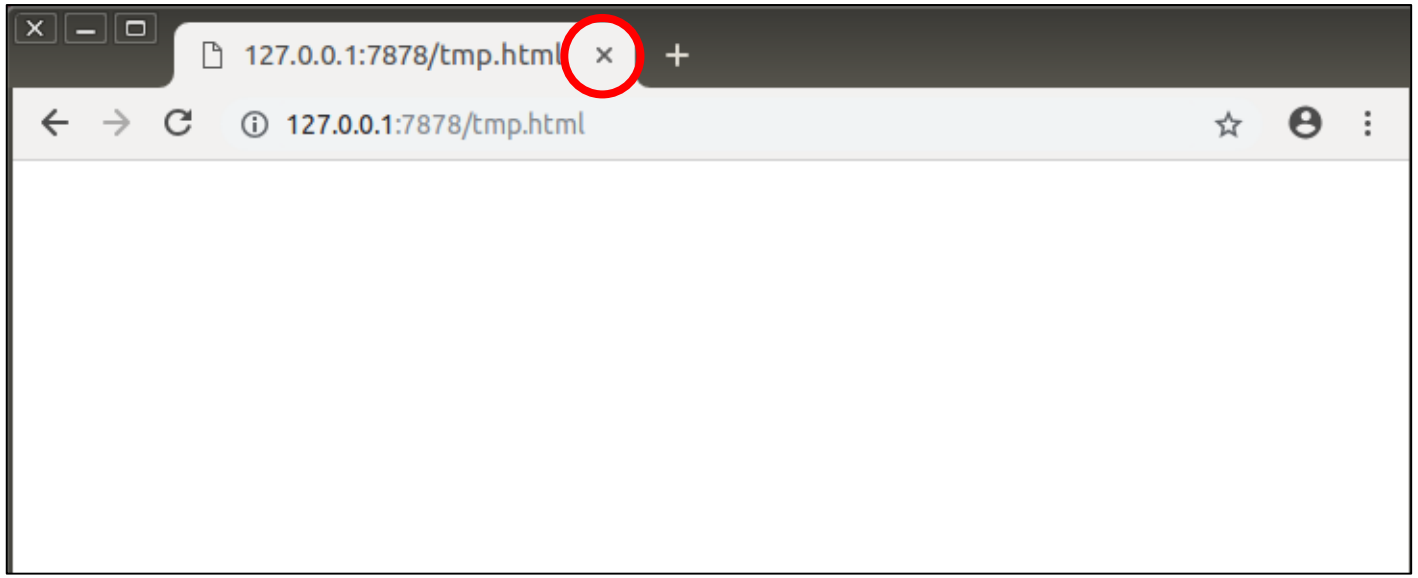
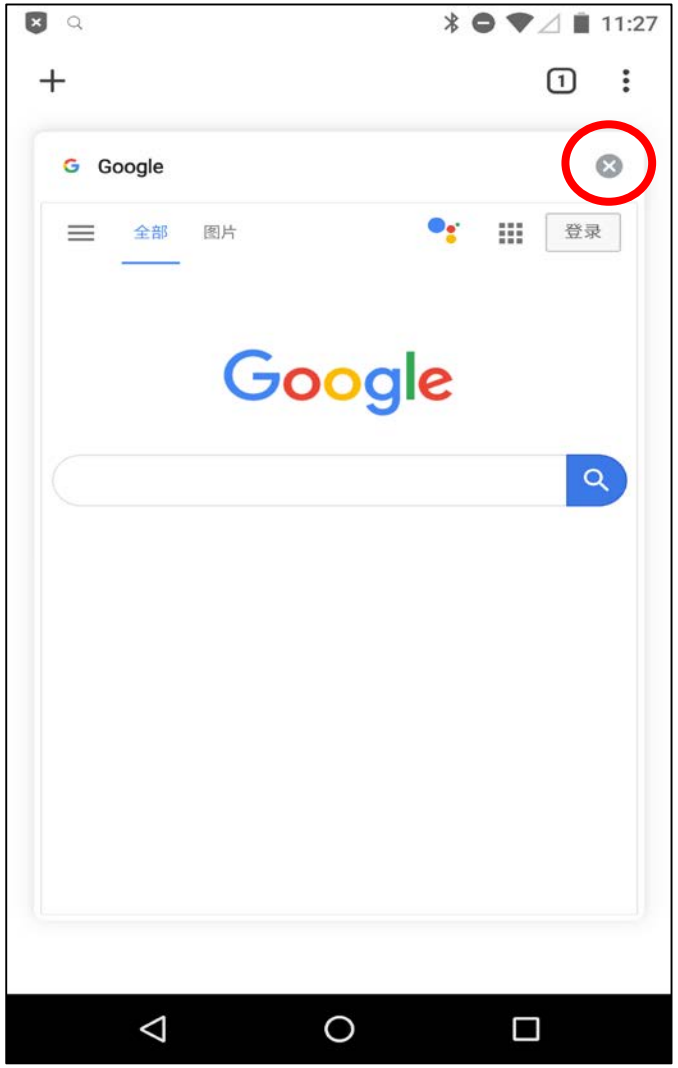
Renderer Process Persistence

- Goal - Survive the Tab Closing
- Method - Hook Exit function in renderer process





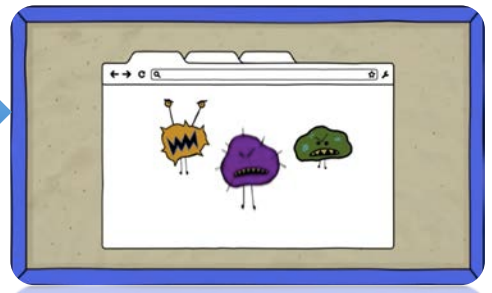
Renderer Process Persistence - Our Attack Strategy

Click Close Button

Don't Know whether Close Or Not?

Method 1: Close yourself

Method 2: If not, I'll kill you



Renderer Process Persistence

- Test result

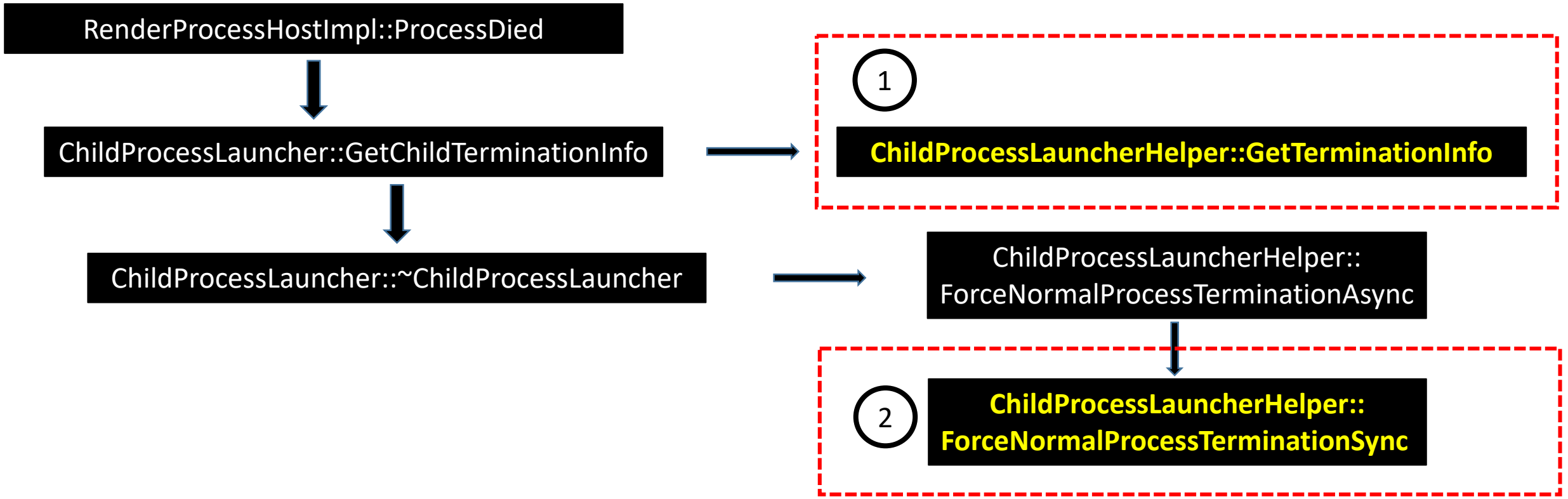
Browser	Platform	Result
Edge	Windows	√
IE	Windows	√
Firefox	Windows	√
Chrome	Windows	X
	Linux	X
	Mac	X
	Android	√

Edge IE and Firefox on Windows

- **Succeed** to survive tab closing
  - Hooking *TerminateProcess* API in renderer process
  - Only use Method 1 to close the tab

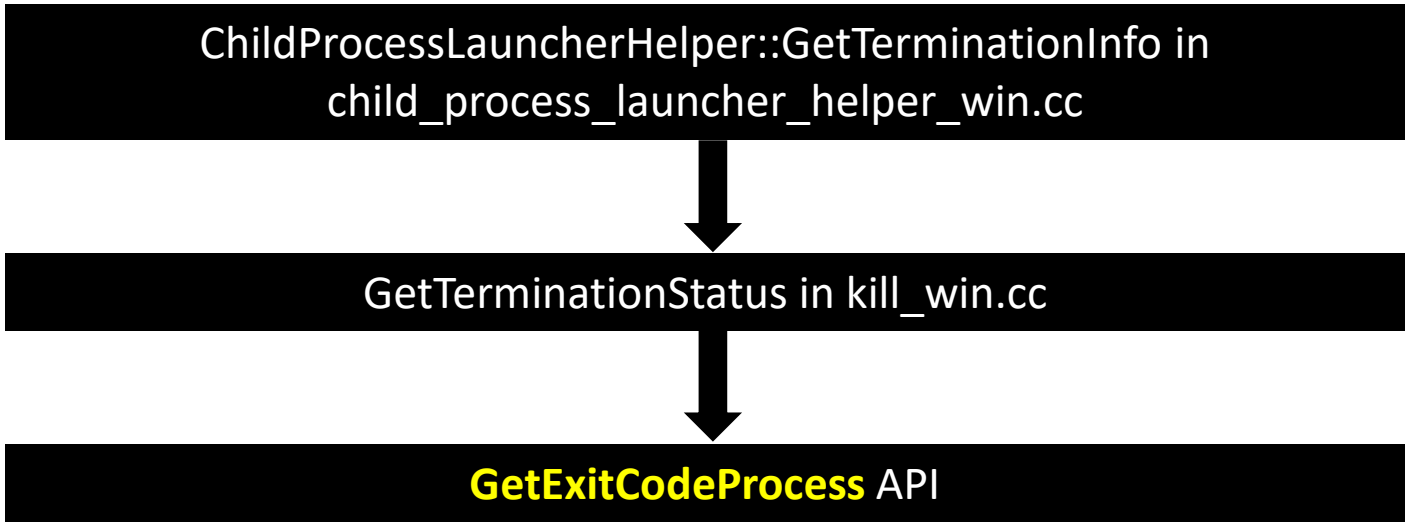
How Chrome closes the tab?

- Main Call Graph



Chrome on Windows

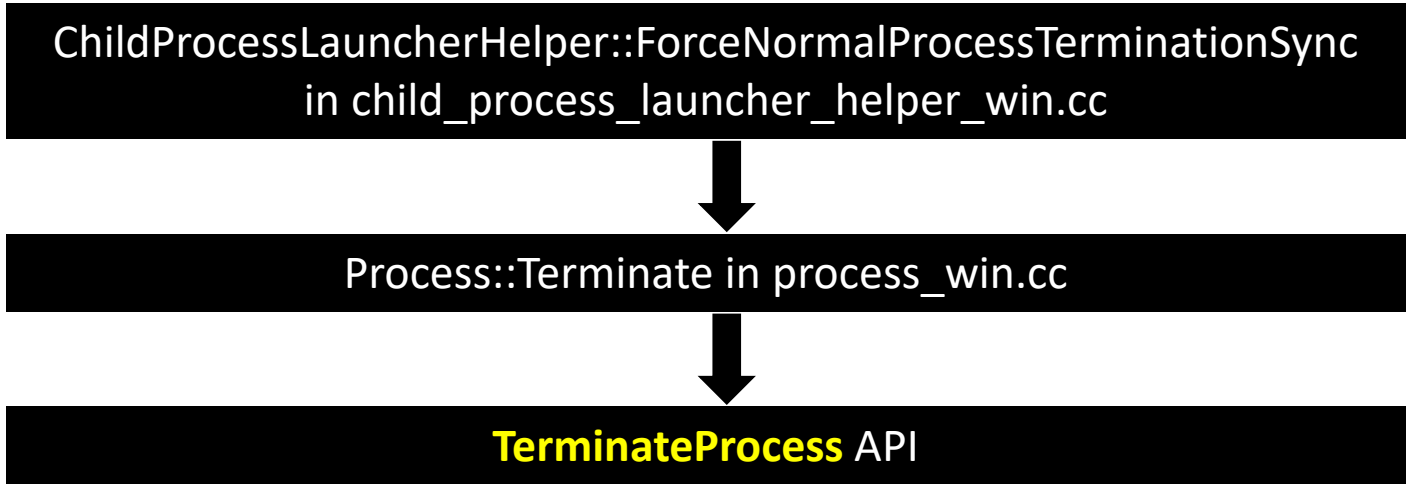
- Details of Function 1



- Usually, return “TERMINATION_STATUS_STILL_RUNNING” status

Chrome on Windows

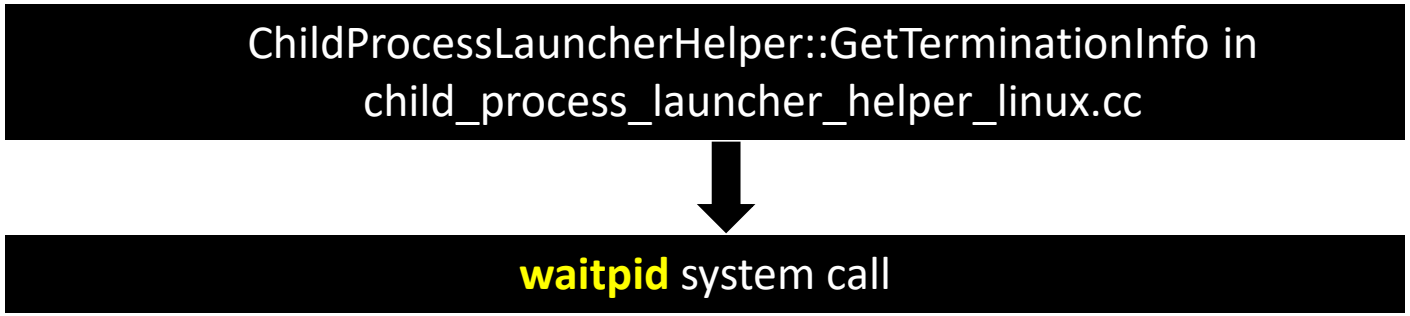
- Details of Function 2



Ref: https://docs.microsoft.com/en-us/windows/desktop/api/processthreadsapi/nf-processthreadsapi-terminateprocess

Chrome on Linux/Mac

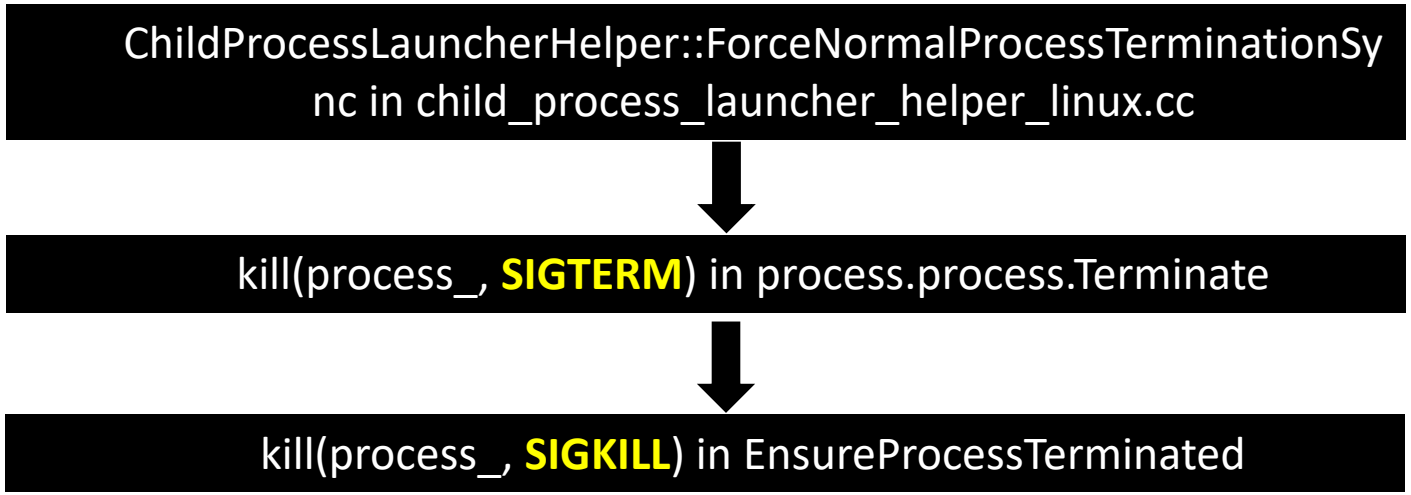
- Details of Function 1



- Usually, return “TERMINATION_STATUS_STILL_RUNNING” status

Chrome on Linux/Mac

- Details of Function 2



- So, the renderer process must die!!!

Ref: https://www.gnu.org/software/libc/manual/html_node/Termination-Signals.html

Renderer Process Persistence

Renderer Process Persistence

Chrome on Android - Overall Introduction

- The parent process of renderer is **webview_zygote**, not browser process
- Browser process **cannot** call “waitpid” to get renderer process status like Linux/Mac

```
bash-3.2$ adb shell ps -A | grep webview_zygote
webview_zygote 6628   1     1455016  39704   0  S  webview_zygote32
bash-3.2$
bash-3.2$ adb shell ps -A | grep com.android.chrome
u0_a56         10780  3730  1844440  115592  0  S  com.android.chrome
u0_i0          11380  6628  1691024  73760   0  S  com.android.chrome:sandboxed
u0_a56         11456  3730  1815700  72236   0  S  com.android.chrome:privileged_process0
```

Chrome on Android - Different from Windows/Linux/Mac

- The difference:

Browser process didn’t terminate renderer forcibly!

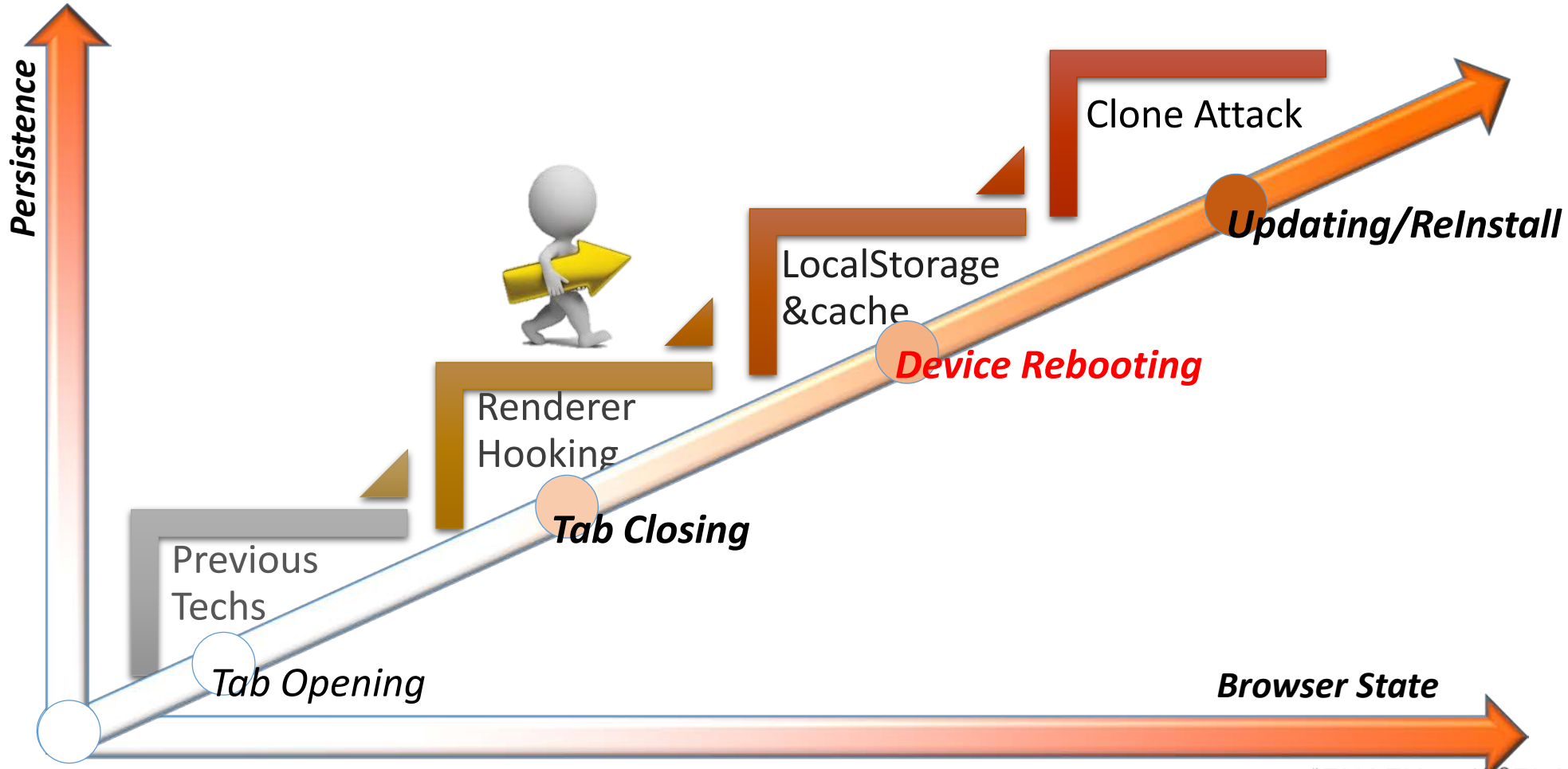
Still under fixing, we will not provide more details.

Comment 14 by [redacted]@chromium.org on Wed, Mar 13, 2019, 11:12 PM GMT+8 (11 days ago)

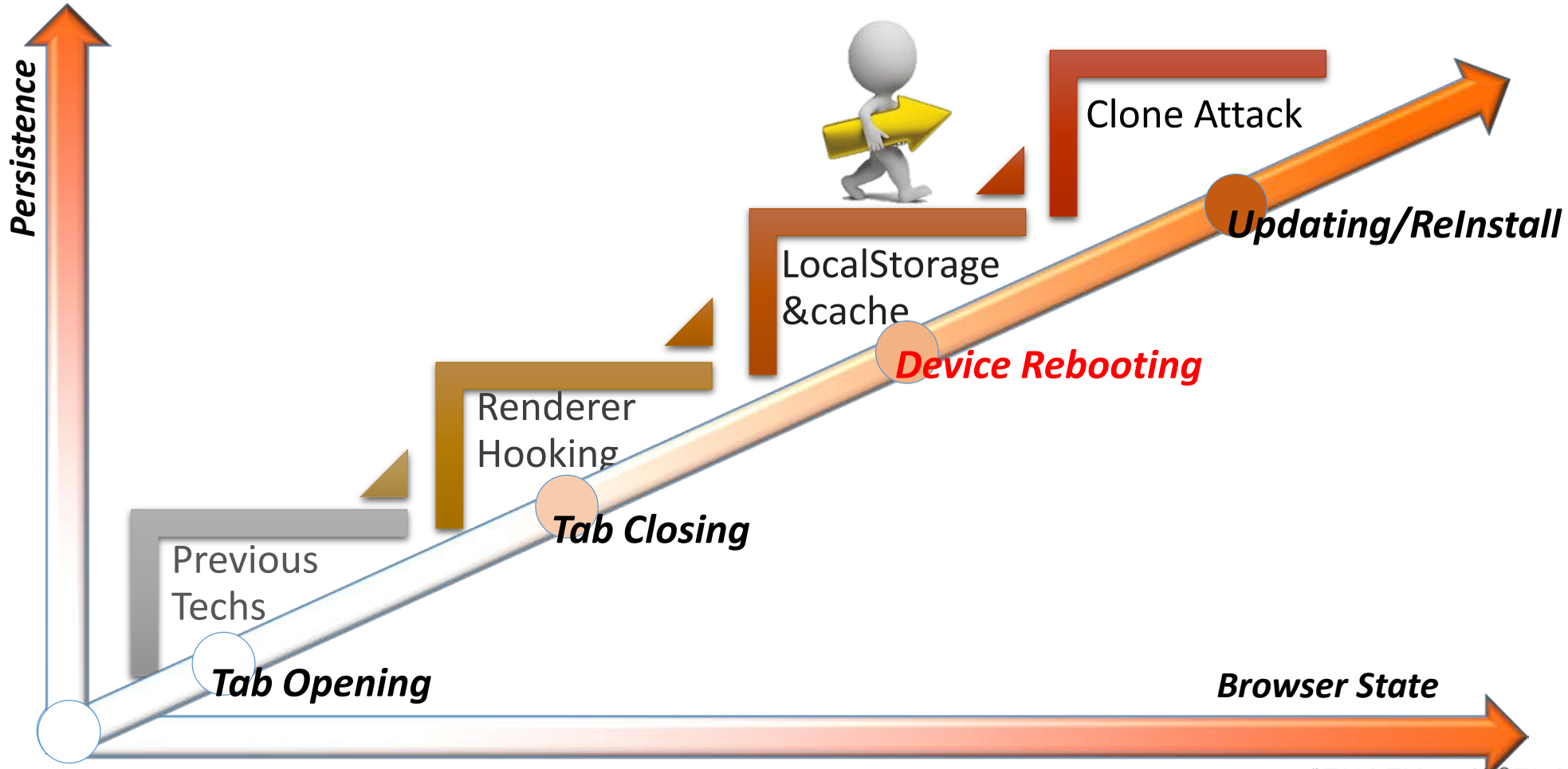
Labels: reward-topanel

Note to panel: this is a little more severe than on desktop because there are a finite number of processes declared in manifest, meaning that it'd be pretty easy for an attacker to get into every renderer process.

We survive tab closing!



Survive the Browser Closing?



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Cache Persistence

- Why Cache?
  - Performance
  - Quick frequently-used resources accessing
  - Quick frequently-used code execution
- Why we focus on Cache?
  - Widely used by all browsers
  - Cache can exist for a long time
  - Cache can be poisoned

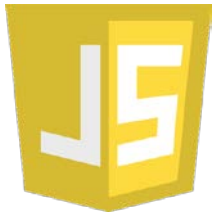
Cache Persistence

- After research, we aim at:

HTTP Cache

CSS

HTML



JavaScript

- Method: Try to poison HTTP Cache to gain persistence

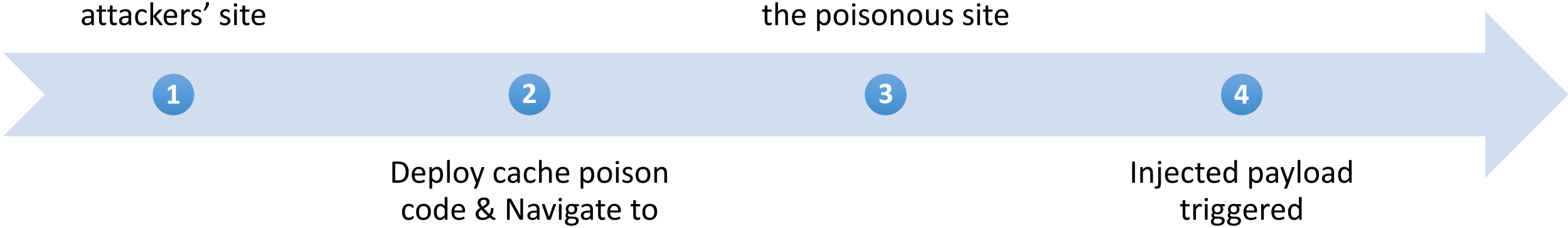
Cache Persistence – Test Result

- Works well on Chrome on Windows/Linux/Mac
- Works on all most browsers which support **Cache Web API**

Browser	Platform	Persistence Result
Chrome	Windows	√
	Linux	√
	Mac	√
	Android	?
Others		?

Cache Persistence

- Attack strategy



Step1: Gain remote code execution within sandbox

- Exploitable RCE bugs on Chrome in recent years

CVE	Description	Severity	Fixed Version
CVE-2018-6065	V8:Derived Class Integer Overflow	High	65.0.3325.146
CVE-2018-6122	V8:Wasm Type Confusion	High	66.0.3359.170
CVE-2018-16065	V8:ToBIgInt SideEffect UAF	High	69.0.3497.81
CVE-2018-17463	V8:JIT Type Confusion	High	70.0.3538.67
CVE-2018-17480	V8:Value Serialization OOB	High	71.0.3578.80
bug-880207	V8: JIT OOB RW	High	71.0.3578.80
CVE-2019-5755	V8: JIT OOB RW	High	72.0.3626.81
CVE-2019-5782	V8: JIT OOB RW	High	72.0.3626.81
CVE-2019-5786	Blink: FileReader UAF	High	72.0.3626.121

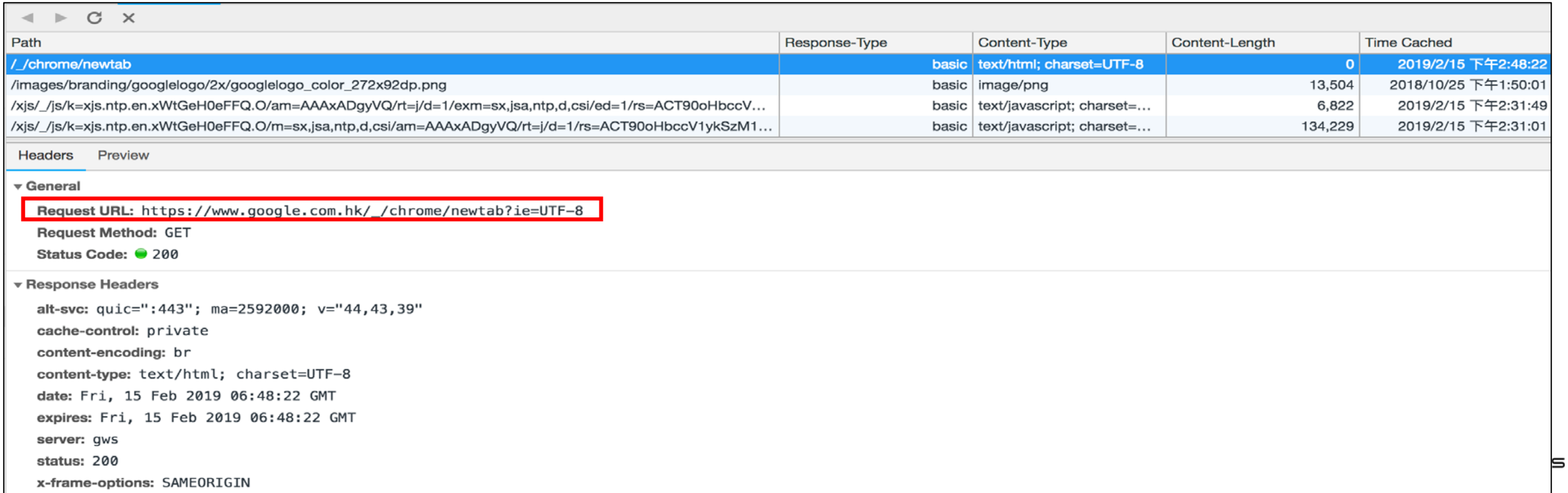
Step 2: Deploy cache poison code

- Hook *ScriptController::ExecuteScriptAndReturnValue* to deploy our poison code

```
async function attack(key) {
    let cache = await caches.open(key);
    let req = new Request("https://www.our-carefully-chosen-site.com");
    let res1 = new Response('<html><script>alert("hacked!!!")</script></html>',
                                    {headers:{'Content-Type':'text/html',}});
    await cache.put(req,res1);
}
caches.keys().then(
    function(key) {
        attack(key);
});
```

Step 2: Then navigate to target site to inject payload

- A Good Target Site Case:
  - “www.google.com” cached “**https://www.google.com/_/chrome/newtab?ie=UTF-8**”
  - Chrome will try to load this cache **every time** when opening a new tab



Path	Response-Type	Content-Type	Content-Length	Time Cached
/_/chrome/newtab	basic	text/html; charset=UTF-8	0	2019/2/15 下午2:48:22
/images/branding/googlelogo/2x/googlelogo_color_272x92dp.png	basic	image/png	13,504	2018/10/25 下午1:50:01
/xjs/_/js/k=xjs.ntp.en.xWtGeH0eFFQ.O/am=AAAxADgyVQ/rt=j/d=1/exm=sx,jsa,ntp,d,csi/ed=1/rs=ACT90oHbccV…	basic	text/javascript; charset=…	6,822	2019/2/15 下午2:31:49
/xjs/_/js/k=xjs.ntp.en.xWtGeH0eFFQ.O/m=sx,jsa,ntp,d,csi/am=AAAxADgyVQ/rt=j/d=1/rs=ACT90oHbccV1ykSzM1…	basic	text/javascript; charset=…	134,229	2019/2/15 下午2:31:01

Headers Preview

General

Request URL: https://www.google.com.hk/_/chrome/newtab?ie=UTF-8

Request Method: GET

Status Code: 200

Response Headers

alt-svc: quic=":443"; ma=2592000; v="44,43,39"

cache-control: private

content-encoding: br

content-type: text/html; charset=UTF-8

date: Fri, 15 Feb 2019 06:48:22 GMT

expires: Fri, 15 Feb 2019 06:48:22 GMT

server: gws

status: 200

x-frame-options: SAMEORIGIN

Step 3 & 4: Victims open target site, Payload triggered

- Persistent code execution under www.google.com
- Surviving even you restart browser or device

Evaluation - How long can we survive?

- Key field
  - <Cache-Control>
    - *E.g. Cache-Control:public, max-age=31536000*
  - <Expires>
    - Valid if No <Cache-Control>
    - *e.g. Expires: Wed, 24 Oct 2020 07:28:00 GMT*

- Valid time of persistence is limited
  - > 2 days in our test case

How to gain longer persistence?

- Some websites store javascript code in localStorage
  - To improve Speed / Efficiency
- Data stored in localStorage has no expiration time

Poison localStorage to achieve long time survival

Evaluation

- We analysed the top **10213** domains/subdomains
  - **4234** domains store javascript functions in their localStorage
  - Including **airbnb**, **wikipedia**, **mail.ru** and many other popular sites

- It‘s not a vulnerability but it opens a door to achieve long time control for attackers.

A new obstacle appear: Site Isolation

Our attack methods not work under this condition

HTTP Cache & Local Storage

Chrome site isolation Introduction

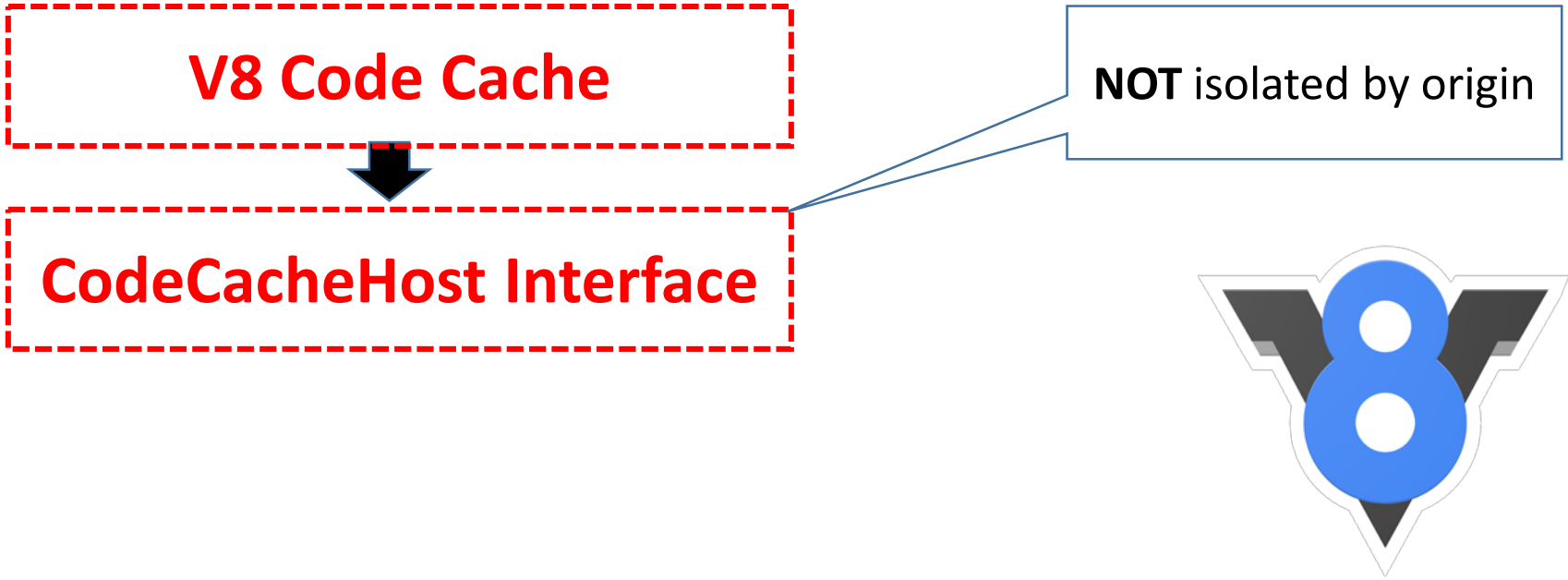
- Enabled by default in Chrome 67 on Win/Mac/Linux/Chrome OS
- For mitigating attacks like “Spectre”
- Pages from different websites -> different sandboxed processes

How can we defeat site isolation?

- All roads lead to Rome

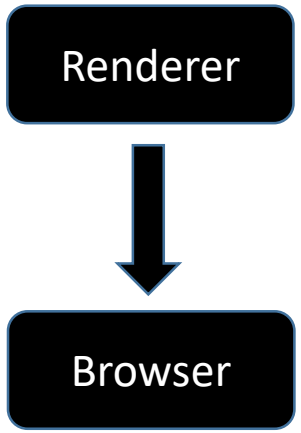
Cache Persistence

- After research, we aim at:



CodeCacheHost interface

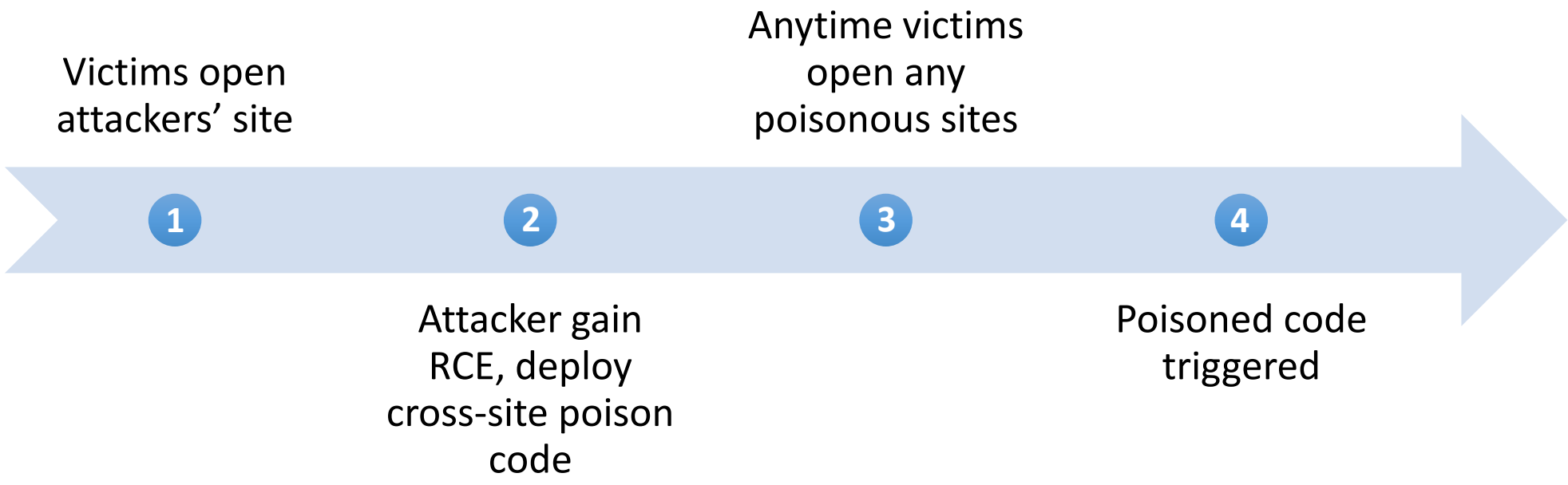
- **Core Function**: *DidGenerateCacheableMetadata*



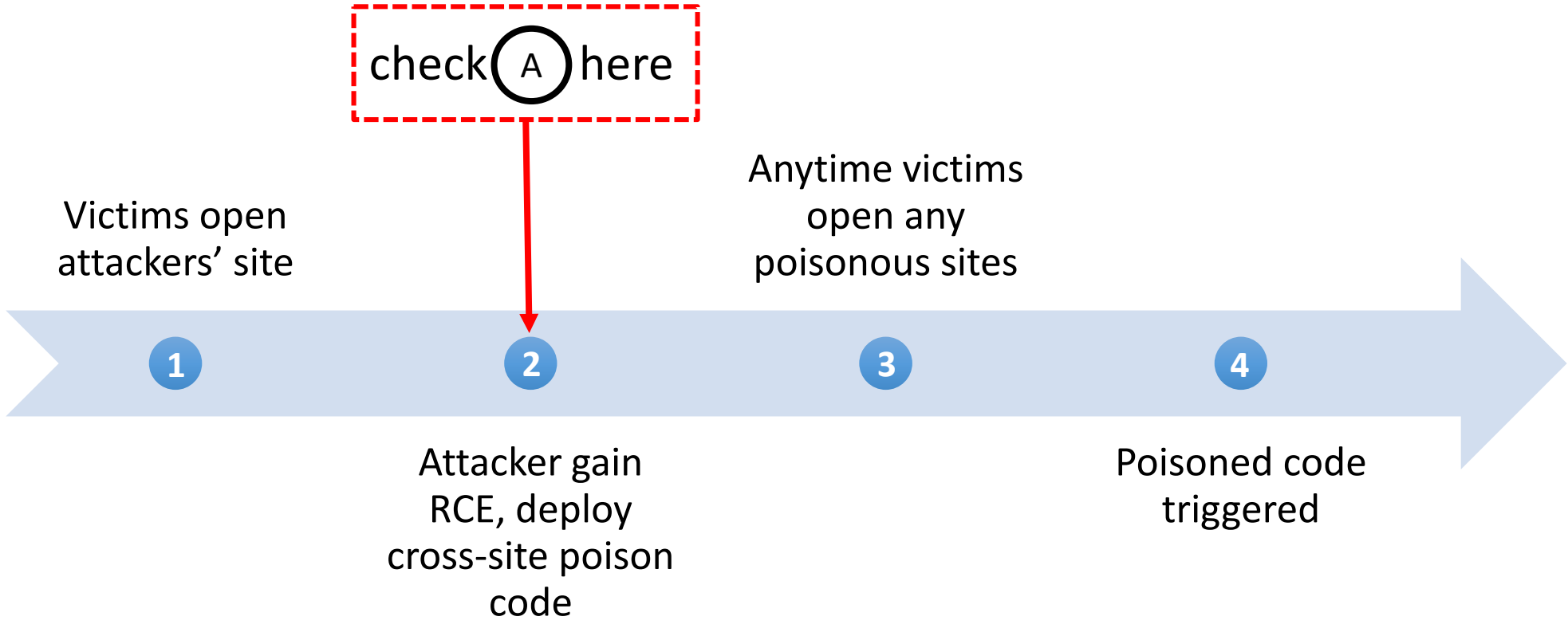

```
interface CodeCacheHost {
  // Requests that the browser cache |data| associated with |url| and
  // |expected_response_time|.
  DidGenerateCacheableMetadata(CodeCacheType cache_type,
                               url.mojom.Url url,
                               mojo_base.mojom.Time expected_response_time,
                               array<uint8> data);
```

Key of Code Cache

Attack Strategy

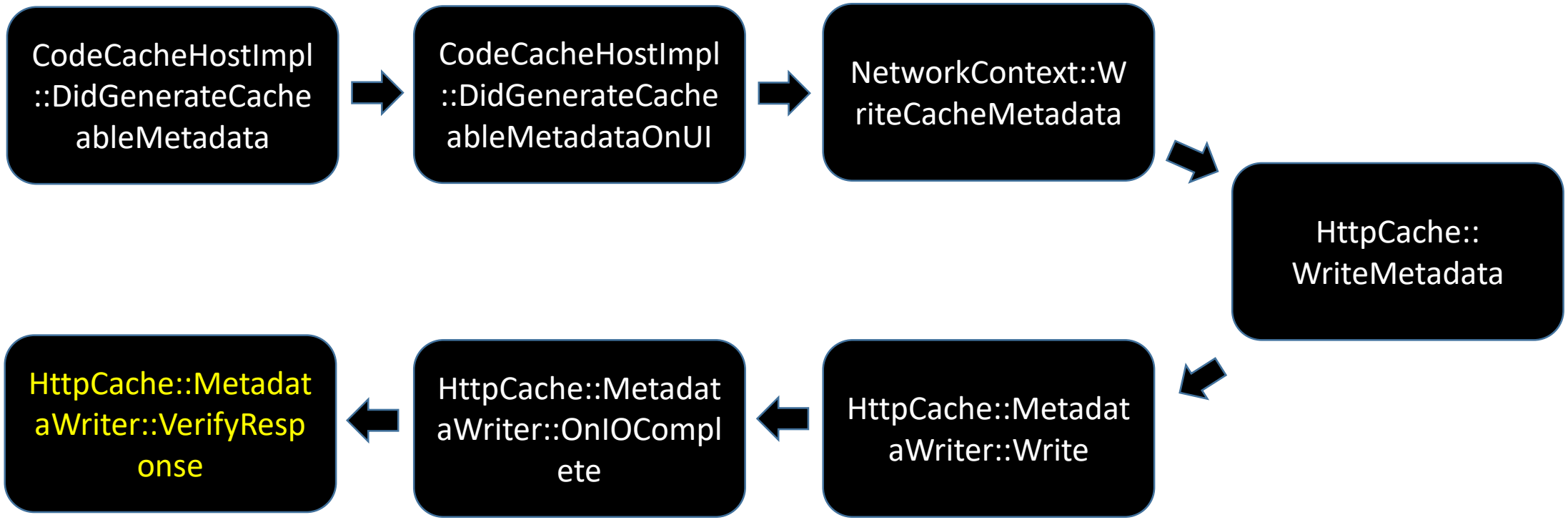


When implement, we need to bypass check A



Details of Check A

- The step 2 triggers call graph of *DidGenerateCacheableMetadata* **in browser process**



Check A happens

Details of Check A

```
void HttpCache::MetadataWriter::VerifyResponse(int result) {
        //…
        const HttpResponseInfo* response_info = transaction_->GetResponseInfo();
        //…
        if (response_info->response_time   != expected_response_time_)   A
                return SelfDestroy();
        //…
}
```

- “expected_response_time_” is parameter of the above core function
- response_time:
  - in the HTTP response header
  - may be cached in HTTP Cache

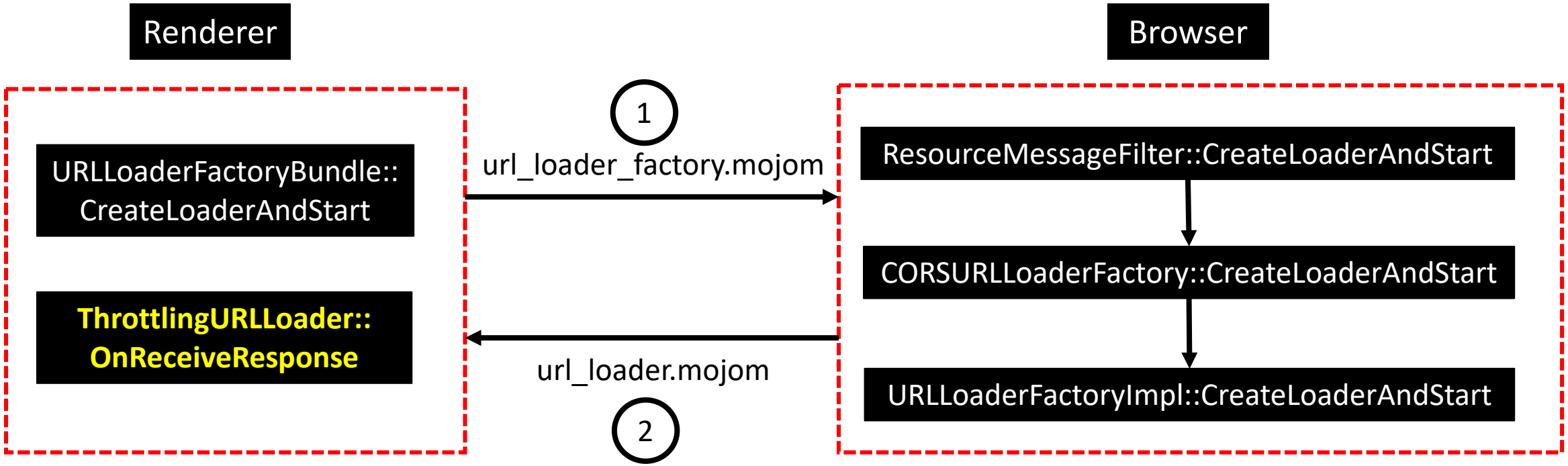
How to Bypass Check A?

- Get the HTTP Cache response header

- Renderers fetch web resources by themselves!
  - Browser process requests resources from HTTP Cache first
  - If got nothing, then requests from web network
  - For external scripts, renderers fetch from browser by *ScriptLoader::FetchClassicScript*

How to Bypass Check A?

- Flow Graph of Renderer fetch web resources from browser process



How to Bypass Check A?

- Succeed Getting Response Header

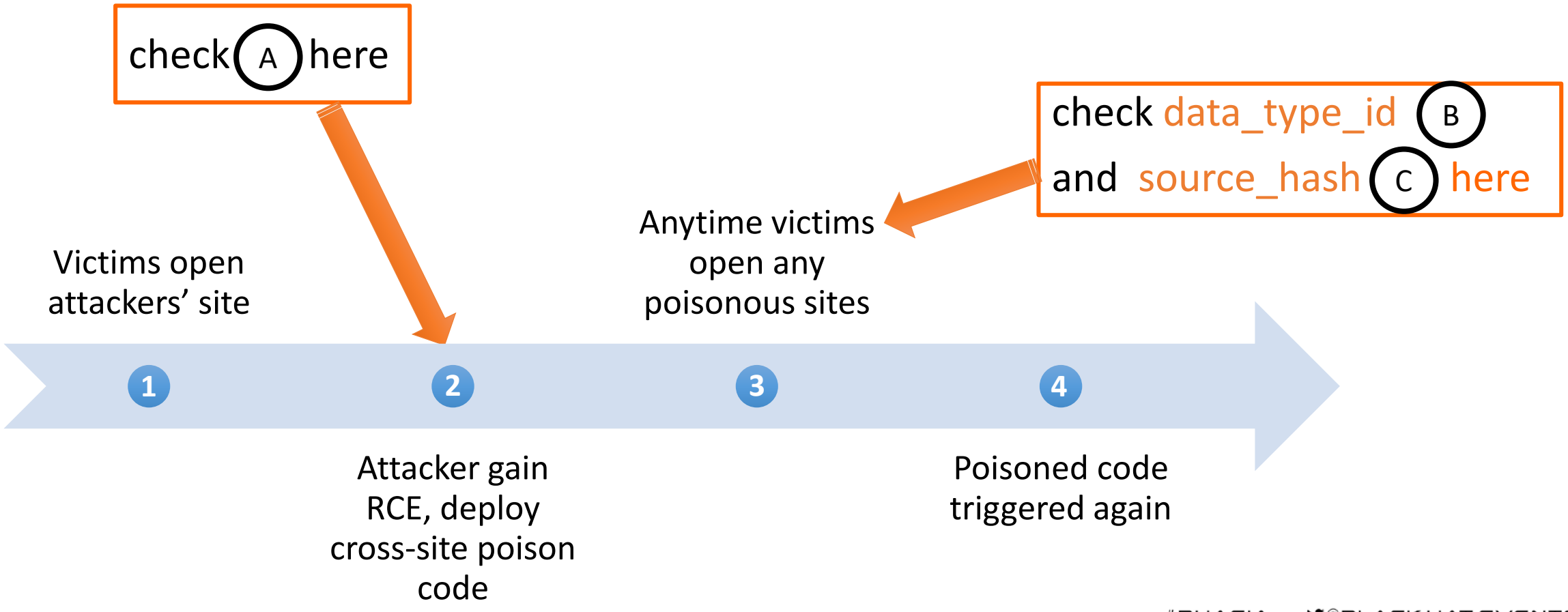
```
ThrottlingURLLoader::OnReceiveResponse(const
network::ResourceResponseHead& response_head)
```

```
struct ResourceResponseHead : ResourceResponseInfo {
    base::TimeTicks request_start;
    base::TimeTicks response_start;
};
```

```
struct ResourceResponseInfo {
    base::Time request_time;
    base::Time response_time;
    //…
}
```

Succeed bypassing check A

Done? No! More Checks when visiting the target website



Details of Check B

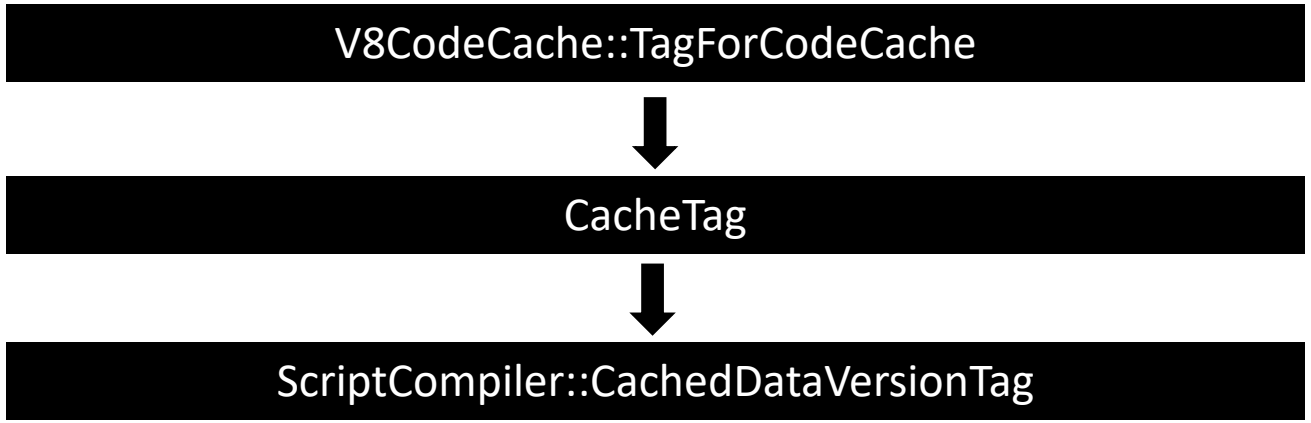
- CHECK B in *ScriptCachedMetadataHandler::GetCachedMetadata*

```
scoped_refptr<CachedMetadata>
ScriptCachedMetadataHandler::GetCachedMetadata(uint32_t data_type_id) const {
        if (!cached_metadata_ || cached_metadata_->DataTypeID() != data_type_id   2
                return nullptr;
        return cached_metadata_;
        //…
}
```

- The left-side date_type_id is read from V8 code cache
- The right-side “data_type_id” is computed in V8CodeCache::TagForCodeCache

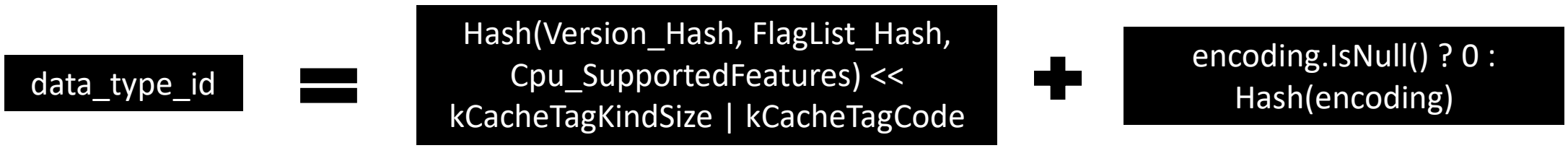
Details of Check B

- What is data_type_id?
  - data_type_id is computed in *V8CodeCache::TagForCodeCache*



Bypass of Check B

- The calculating formula of data_type_id



- Characteristics
  - Public
  - Unchanged (for the specific chromium/chrome version)

Succeed bypassing check B

Details of Check C

- CHECK C in *SerializedCodeData::SanityCheck*

```
SerializedCodeData::SanityCheckResult SerializedCodeData::SanityCheck(Isolate*
                        isolate,   uint32_t expected_source_hash) const {
    //…
    uint32_t source_hash = GetHeaderValue(kSourceHashOffset);
    //…
    if (source_hash != expected_source_hash)   3
                        return SOURCE_MISMATCH;
    //…
}
```

- “source_hash” is read from V8 code cache
- “expected_source_hash” is computed in *SerializedCodeData::SourceHash*

Bypass of Check C

- What is source_hash?

```
source_hash = IsModule() ? (source_length | 0x80000000) : source_length;
```

- For no-module script, the source_hash is **script source length**
- source length is public and basically unchanged

Succeed bypassing check C

Implementation of Cache Persistence – With Site Isolation

- Version: On Chromium 72.0.3582.0
- Target Example

```
https://apis.google.com/_/scs/abc-static/_/js/k=gapi.gapi.en.1YQiBIu1zGM.O/m=gapi_iframes,googleapis_client,plusone/rt=j/sv=1/d=1/ed=1/rs=AHpOoo8jmooDqnwUNQ5CPVlex635ObQRZg/cb=gapi.loaded_0
```

- Survive browser restarting
- Survive device restarting

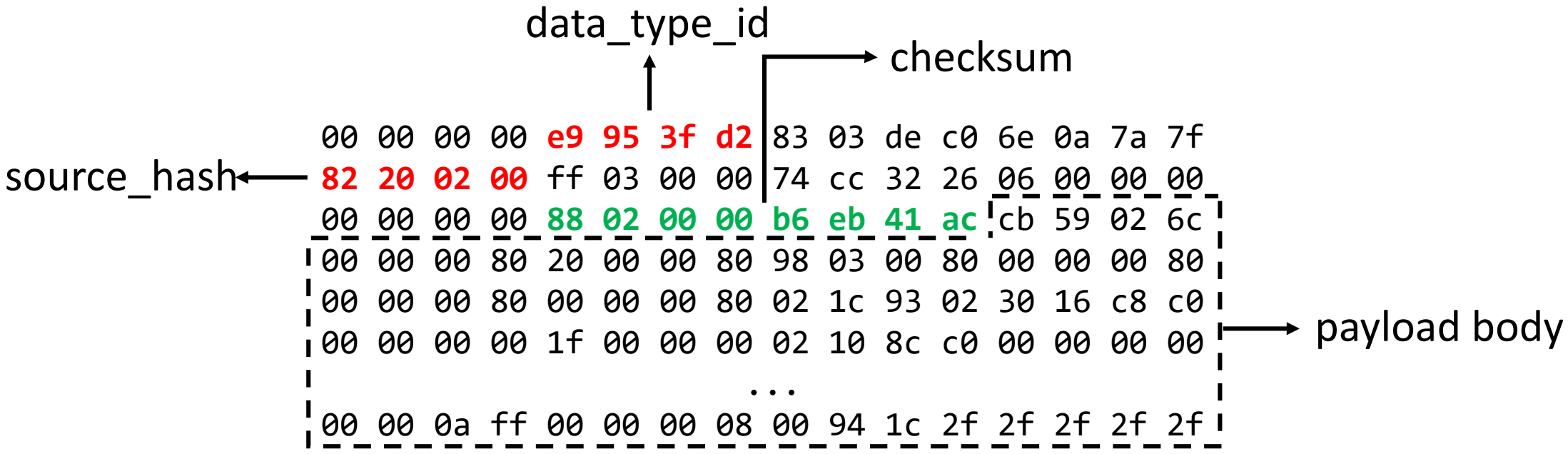
Step 1 - Get Response Time

- Hook *ThrottlingURLLoader::Start*
  - modify the “url” field of “url_request” to target URL

```
void ThrottlingURLLoader::Start(
                        scoped_refptr<network::SharedURLLoaderFactory> factory,
                        int32_t routing_id,
                        int32_t request_id,
                        uint32_t options,
                        network::ResourceRequest* url_request,
                        scoped_refptr<base::SingleThreadTaskRunner> task_runner) {
    //…
    GURL original_url = url_request->url;
    //...
    start_info_ = std::make_unique<StartInfo>(factory, routing_id, request_id, options,
                                              url_request, std::move(task_runner));
    //...
}
```

Step 2 - Construct Our Payload

- Format of Payload



Step 2 - Construct Our Payload

- Modify chromium
  - Modify the “produce_cache_options” to “kProduceCodeCache” to produce cache

```
v8::Local<v8::Value> ScriptController::ExecuteScriptAndReturnValue( … ) {
      //...
      std::tie(compile_options, produce_cache_options, no_cache_reason)
                        = V8CodeCache::GetCompileOptions(v8_cache_options, source);
      //...
     V8CodeCache::ProduceCache(GetIsolate(), script, source, produce_cache_options, compile_options)
     //...
}
```

kProduceCodeCache

Step 2 - Contruct Our Payload

- Generate Payload
  - Load the “payload.html”, get the payload of ”payload.js” in *RendererBlinkPlatformImpl::CacheMetadata*

payload.html

```
<html>
<script type="text/javascript" src="payload.js"></script>
</html>
```

payload.js

```
function test(){
      alert('hacked!!!');}
test();
```

Step 3 - Cross-Site Poison of V8 Code Cache

- Hook *RendererBlinkPlatformImpl::CacheMetadata*
  - modify the “url” to target URL
  - modify the “data” to our constructed Payload

```
void RendererBlinkPlatformImpl::CacheMetadata(blink::mojom::CodeCacheType cache_type,
                        const blink::WebURL& url,
                        base::Time response_time,
                        const char* data,
                        size_t size) {
    //...
    std::vector<uint8_t> copy(data, data + size);
    GetCodeCacheHost().DidGenerateCacheableMetadata(cache_type, url,
                                    response_time, copy);
    //...
}
```

Mitigation of Cache Persistence – With Site Isolation

- Code cache Key = URL + Origin
  - Origin must be provided by browser process, not renderer

- Compromised renderer can not modify code cache under other origins

Mitigation of Cache Persistence – With Site Isolation

- Chromium fixes on 72.0.3613.0 using “GeneratedCodeCache” plan

```
// Uses a site isolated code cache that is keyed on the resource url and the
// origin lock of the renderer that is requesting the resource. The requests
// to site-isolated code cache are handled by the content/GeneratedCodeCache
// When this flag is enabled, the metadata field of the HttpCache is unused.
const base::Feature kIsolatedCodeCache = {"IsolatedCodeCache",
                                          base::FEATURE_DISABLED_BY_DEFAULT};
```

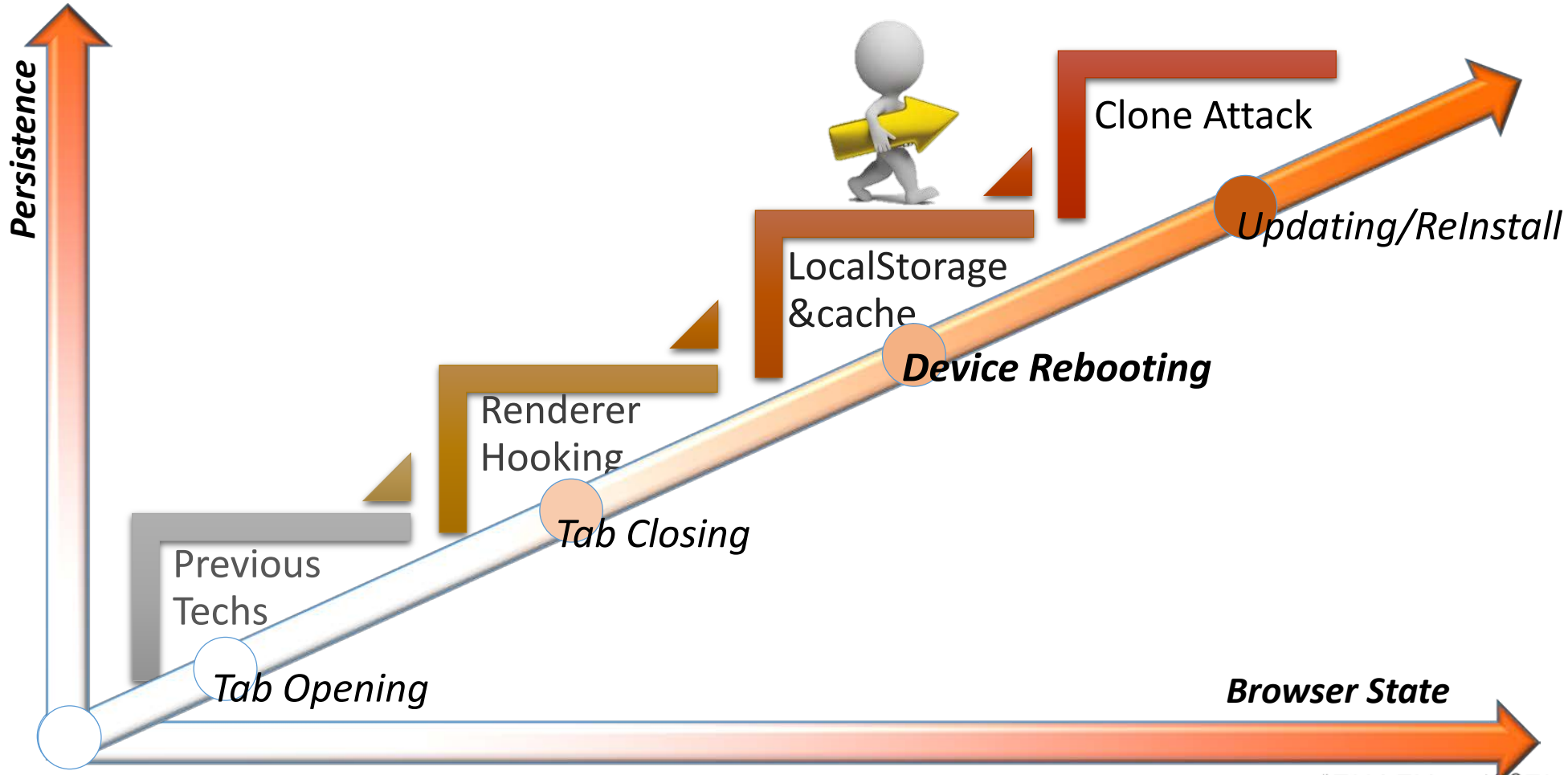
```
// Uses a site isolated code cache that is keyed on the resource url and the
// origin lock of the renderer that is requesting the resource. The requests
// to site-isolated code cache are handled by the content/GeneratedCodeCache
// When this flag is enabled, the metadata field of the HttpCache is unused.
const base::Feature kIsolatedCodeCache = {"IsolatedCodeCache",
                                          base::FEATURE_ENABLED_BY_DEFAULT};
```

Evaluation – Persistence by V8 Code Cache

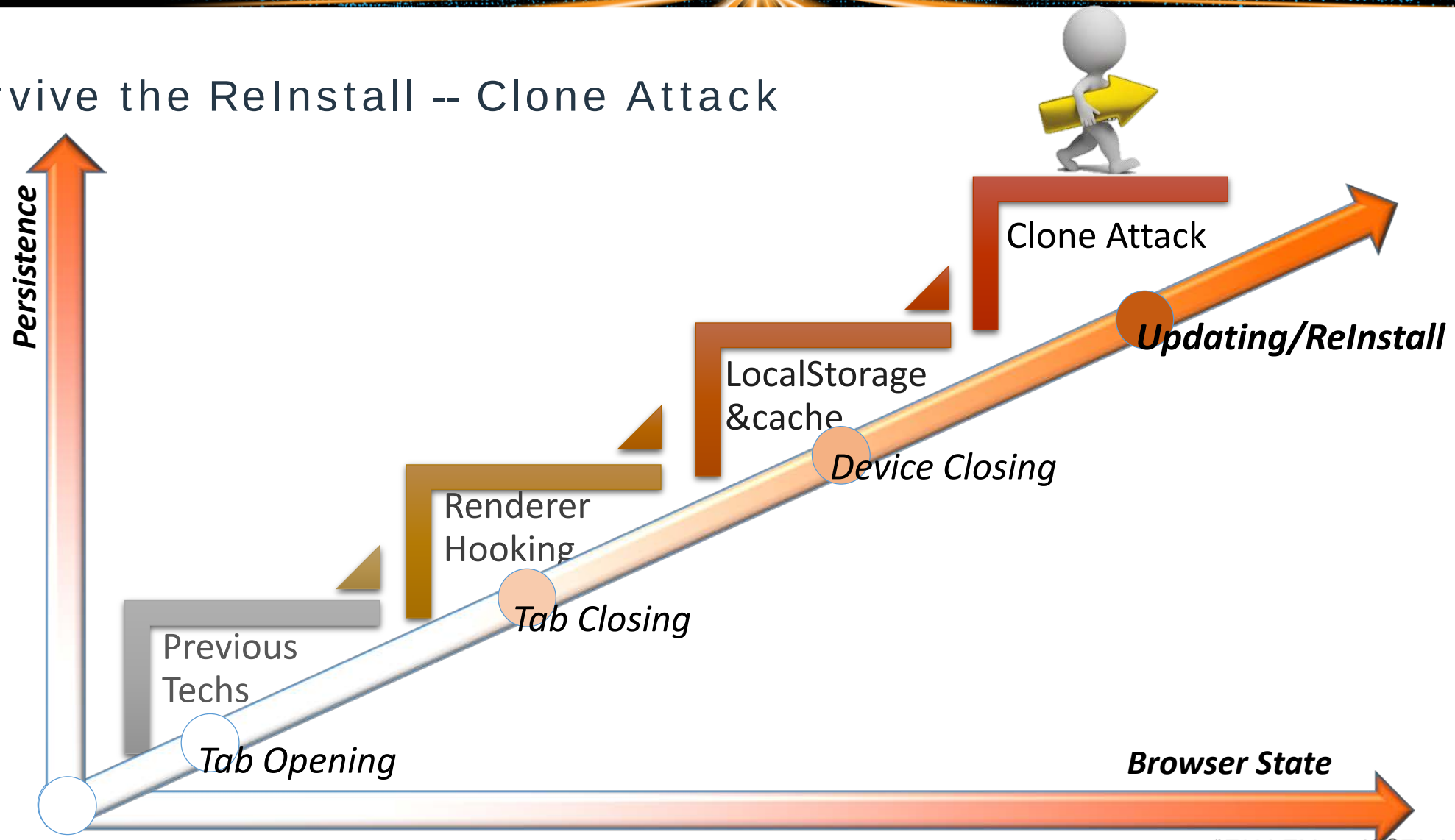
- Persistence will be invalid when:
  - Update chrome to a new version
  - Re-install chrome with caches cleared
  - Target URL updated with new version info

```
https://apis.google.com/_/scs/abc-static/_/js/k=gapi.gapi.en.1YQiBIu1zGM.O/m=gapi_iframes,googleapis_client,plusone/rt=j/sv=1/d=1/ed=1/rs=AHpOoo8jmooDqnwUNQ5CPVlex635ObQRZg/cb=gapi.loaded_0
```

Reinstall? Still not solved



5. Survive the ReInstall -- Clone Attack



Android WebView

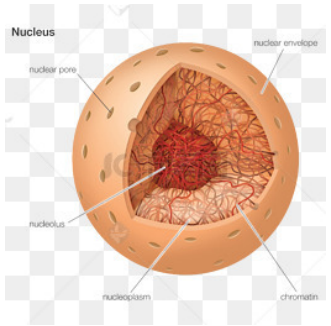
- **Browser of mobile**
- **Based on Chromium**
  - But can be configured by host App
- **Security policy of renderer process**
  - Share process with host App before Android N
  - Separated renderer process after Android O

Survive the ReInstall -- Clone Attack

- How to conduct a persistent attack on mobile?
  - From WebView to App
  - Retaining control
  - Remote and hidden

Clone Attack

What is Clone Attack



nucleus

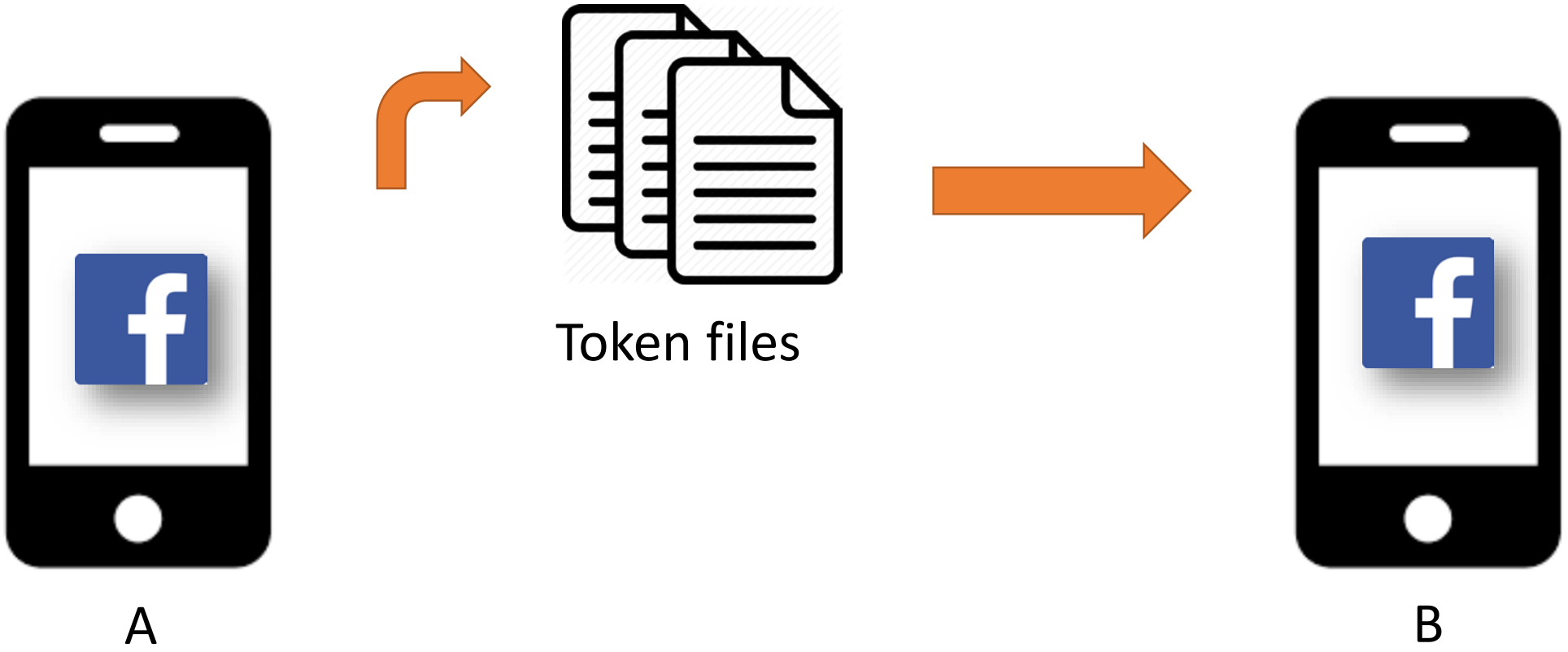
What is Clone Attack

Who is the nucleus of mobile App?

- **Cloud-based**
- **Stay logged in state**
- **IP and position change frequently**

Long-lived token files are necessary

What is Clone Attack



Account Persistence - Clone Attack

DEMO

The same account logged in different device at the same time

Clone Attack by RCE

How to steal token files?

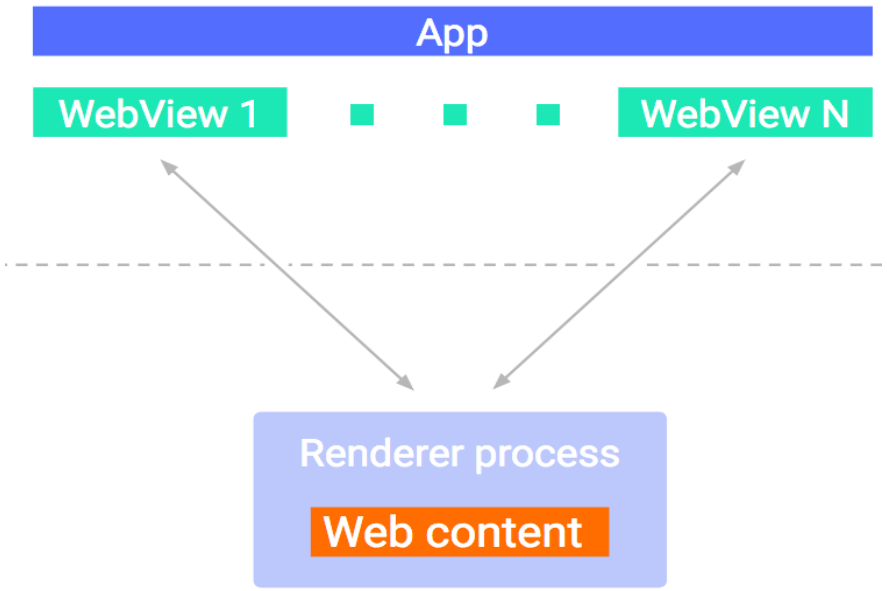
- **WebView share process with host App before Android N**
- **1-day or N-day to gain the RCE of WebView**
  - Fragmentation of Android System

Note: It is not the vulnerability of Facebook

Clone Attack by Misconfigured WebView

How to steal token files after Android O?

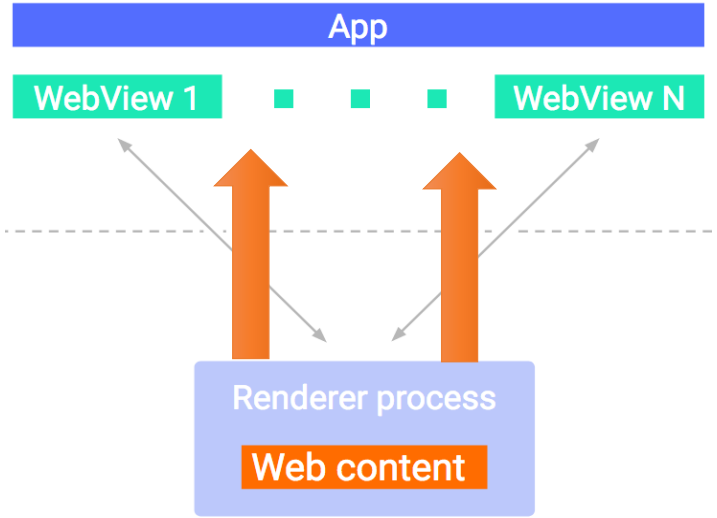
- **Isolated webview process**
  - **Limited to read or write disk**
  - **Can’t talk to network on its own**
- **Android App sandbox**



Misconfigured WebView

Clone Attack by Misconfigured WebView

- Misconfigured WebView - a door to App
  - **setAllowFileAccessFromFileURLs**
  - **setAllowUniversalAccessFromFileURLs**

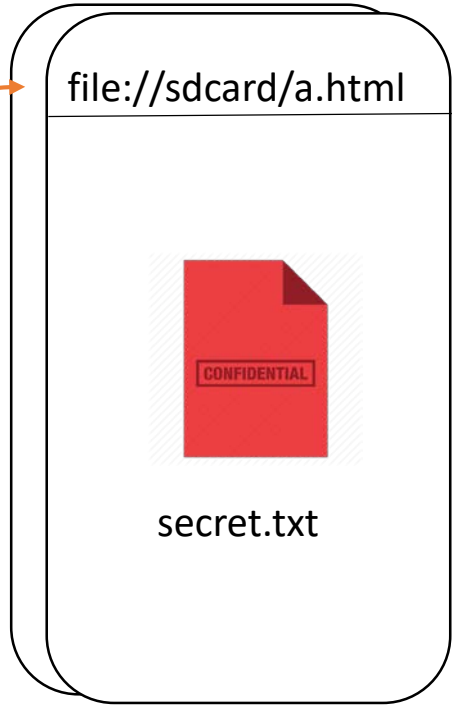


If either of them is set to TRUE, WebView will allow a file scheme URL to access the content of the App

Clone Attack by Misconfigured WebView

```
<script>
var xhr = new XMLHttpRequest();
xhr.open("GET","/data/data/com.myapp/secret.txt",true);
xhr.send();
</script>
```

/sdcard/a.html



WebView

Clone Attack by Misconfigured WebView

- How to make an App webview to load a file URL?
  - http:// to file:// ? NO
  - UXSS?
  - …

Custom URL Scheme

Clone Attack by Misconfigured WebView

Custom URL Scheme

```
<activity android:name="WebViewActivity">
        <intent-filter>
        <action android:name="android.intent.action.VIEW"/>
        <category android:name="android.intent.category.BROWSABLE"/>
        <data android:scheme="myapp" android:host="myhost.com"/>
        </intent-filter>
</activity>
```

AndroidManifest.xml

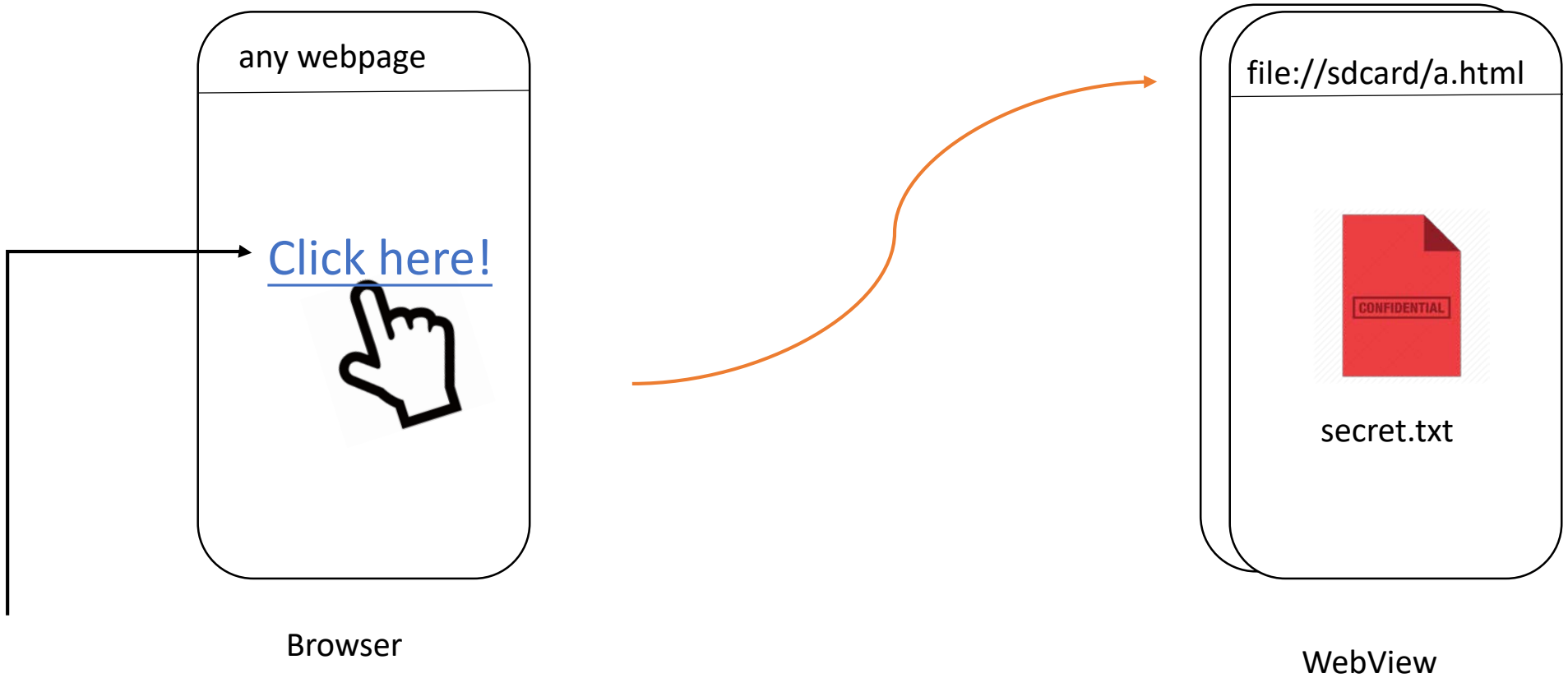
Clone Attack by Misconfigured WebView

Custom URL Scheme

```
protected void onCreate(Bundle instance) {
                    …
                    Intent intent = getIntent();
                    Uri uri = intent.getData();
                    //parse the url
                    webview.loadUrl(url);
                    …
}
```

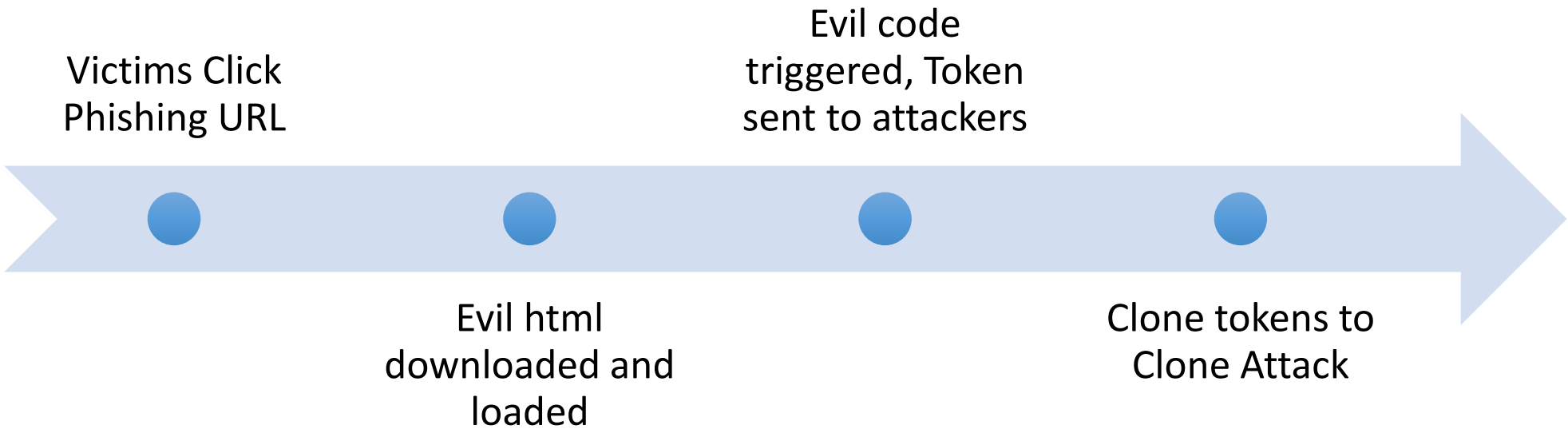
onCreate Function of Activity

Clone Attack by Misconfigured WebView



myapp://myhost.com/?url=file://sdcard/exp.html

Clone Attack by Misconfigured WebView



Bypass The Defense

- file URL check bypass

```
…
if url.startsWith(“file://”){
        //forbidden
};
if url.contains(“file://”){
        //forbidden
};
…
```

Bypass: case changing, white space, “../” etc

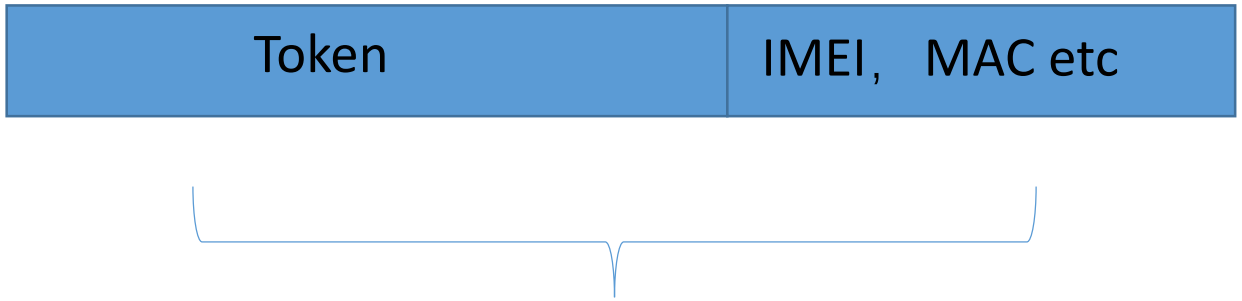
Bypass The Defense

- file URL check bypass

```
file:///data/data/com.app/../../../sdcard/xxx
file:///android_assets/../sdcard file:///android_res/../sdcard
file:///data/data/com.app/..\\..\\..\\sdcard/xxx
file:///data/data/com.app/%2e%2e/%2e%2e/%2e%2e/sdcard/xxx
file:/data/data/com.app/
...
```

Bypass The Defense

- token binding bypass



IMEI, MAC etc are stored in local file

Mitigation

- Keep setAllowFileAccessFromFileURLs and setAllowUniversalAccessFromFileURLs as false if you don't need
- Do not accept all external URL in your own App
- Save your token files safely (eg. KeyStore)

NO CLONING!

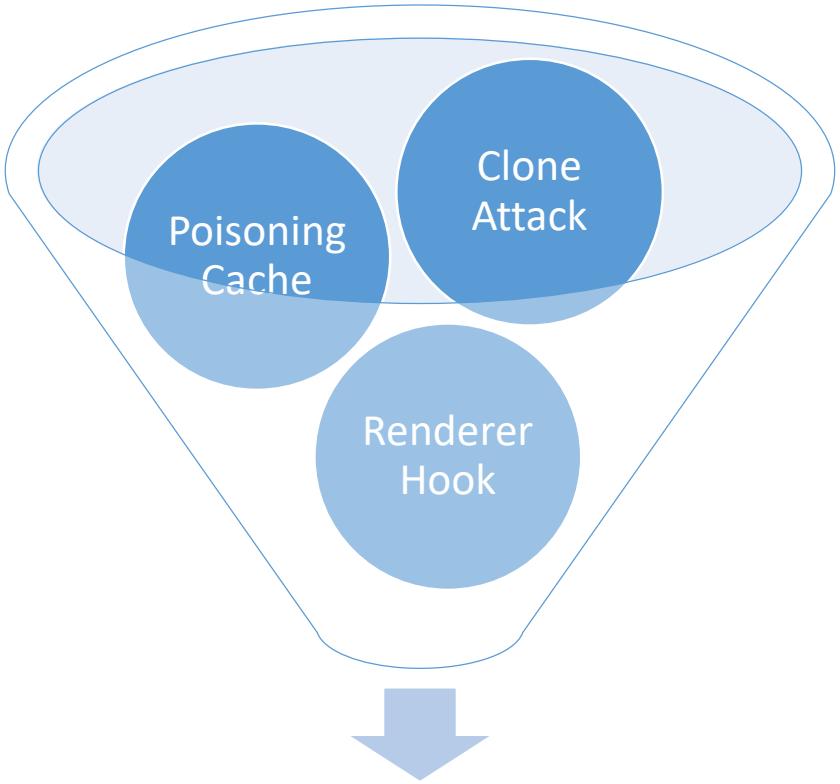
Evaluation

- 27 of top 200 apps are affected (A Chinese app store)
- category including finance, shopping, social networking etc
- scanned 1000+ apps, and 10% are affected

Outline

- 1. Sandbox Introduction
- 2. Related Work
- 3. Renderer Process Persistence
- 4. Cache Persistence
- 5. Account Persistence - Clone Attack
- **6. Conclusion**

What can we do inside the sandbox? Even with site-isolation!



Longer Enough to conduct many fancy attacks

Fancy Attacks Based on Our Research

- Stealing any related websites' cookies any time
- Phishing and Information collection any time
- Consistently port scanning and attacking in LANs on some conditions
- Clone victims identities and stay logged in

Conclusion

- Many fancy attack can be conducted without breaking the sandbox
- Attackers can steal victims' credentials, clone their accounts to achieve long-time control
- Sandbox is the best choice but not the silver bullet

Conclusion

- Innovation
  - Attack Strategies? New idea!
  - Living in limited environment persistently and prosperously

- Future Work
  - Browser sandboxes -> All sandboxes
  - Longer and longer time even permanent?

Sound Bytes

- Attack renderer process persistently even permanently
- Cache Persistence even with site isolation enabled
- A mind blowing persistent attack - Clone Attack

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