Explicating SDKs: Uncovering Assumptions Underlying Secure Authentication and Authorization

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Microsoft Research

University of Virginia

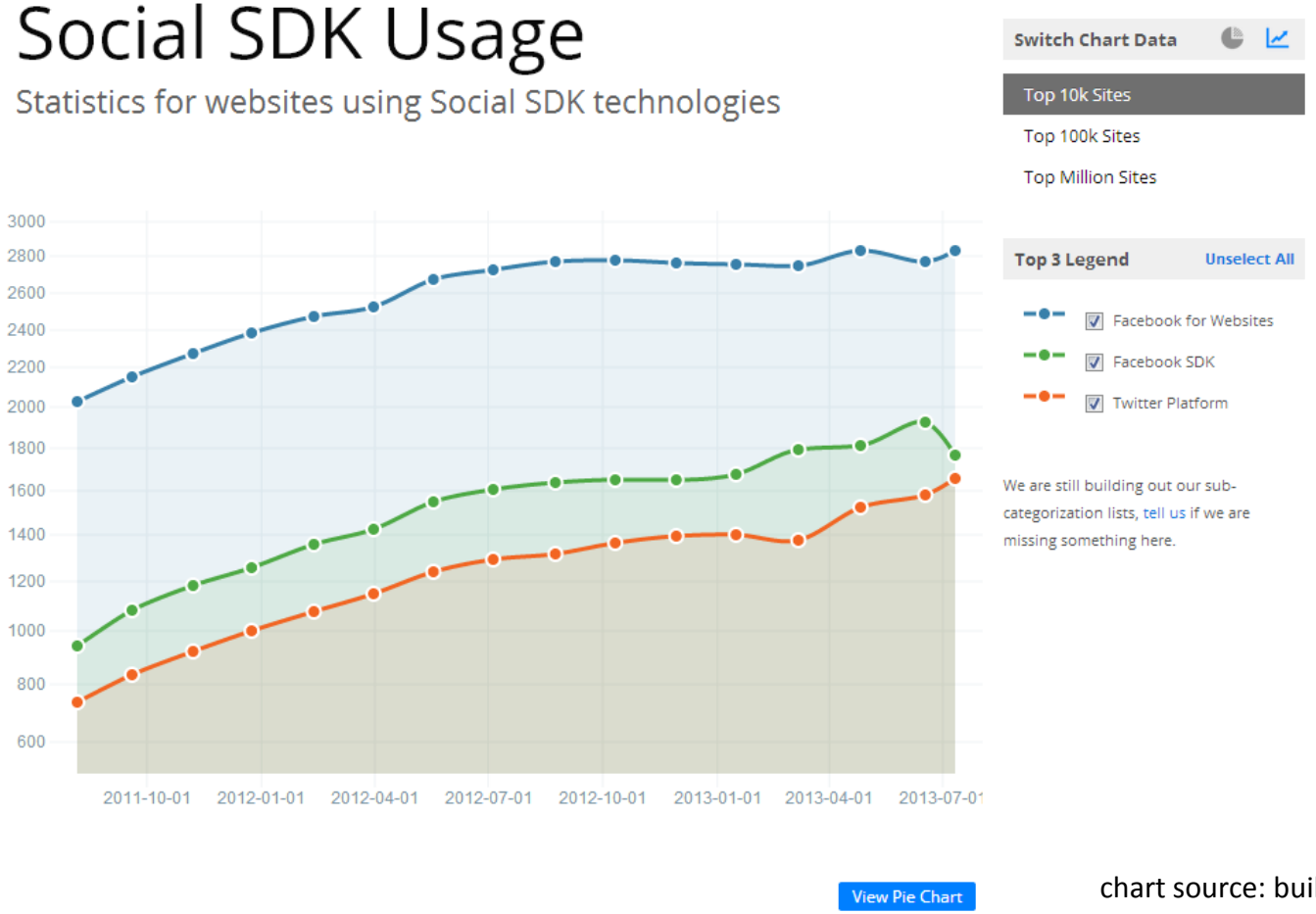
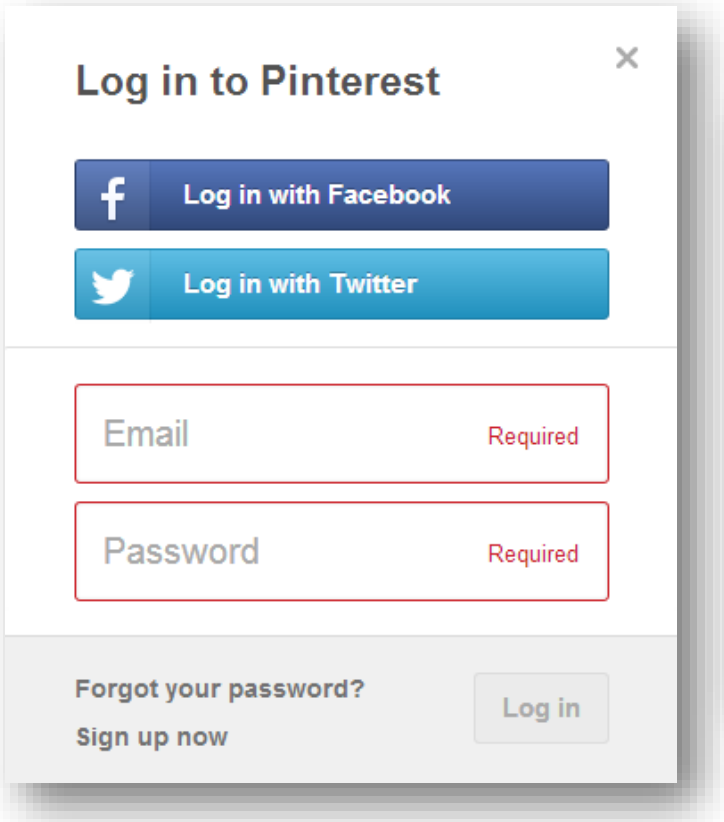
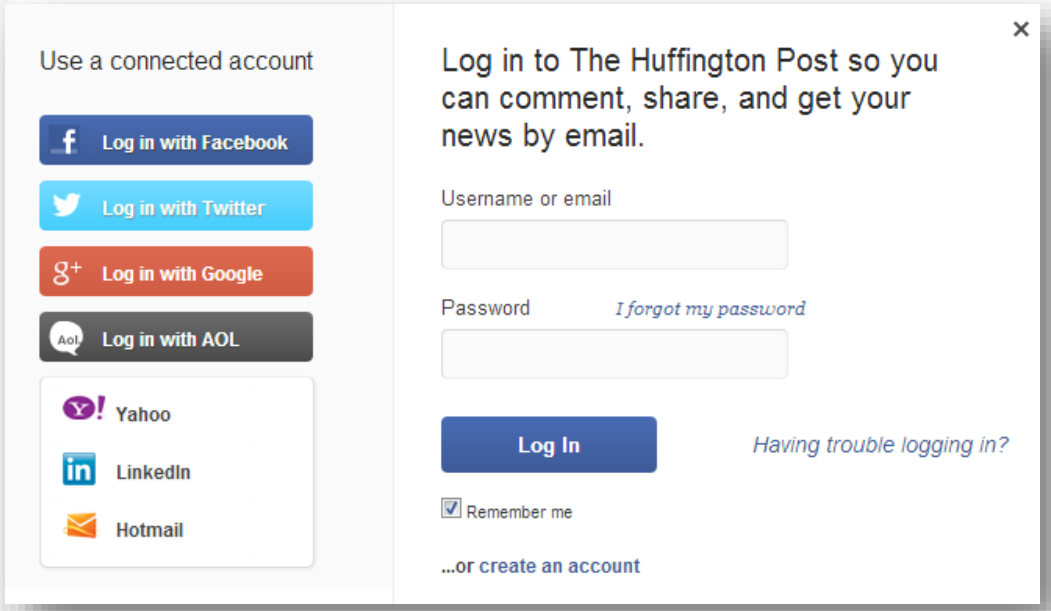


chart source: builtwith.com

Most modern apps are empowered by online services.

Single Sign-On Service





Constructing a URL to the OAuth Dialog

To invoke the OAuth Dialog, redirect the user's browser to a URL of the form:

```
https://www.facebook.com/dialog/oauth/?
    client_id=YOUR_APP_ID
    &redirect_uri=YOUR_REDIRECT_URL
    &state=YOUR_STATE_VALUE
    &scope=COMMA_SEPARATED_LIST_OF_PERMISSION_NAMES
```

Parameters

The OAuth Dialog supports the following parameters which may be passed in the URL string:

If the developers follow the guides properly, will the application be secure?

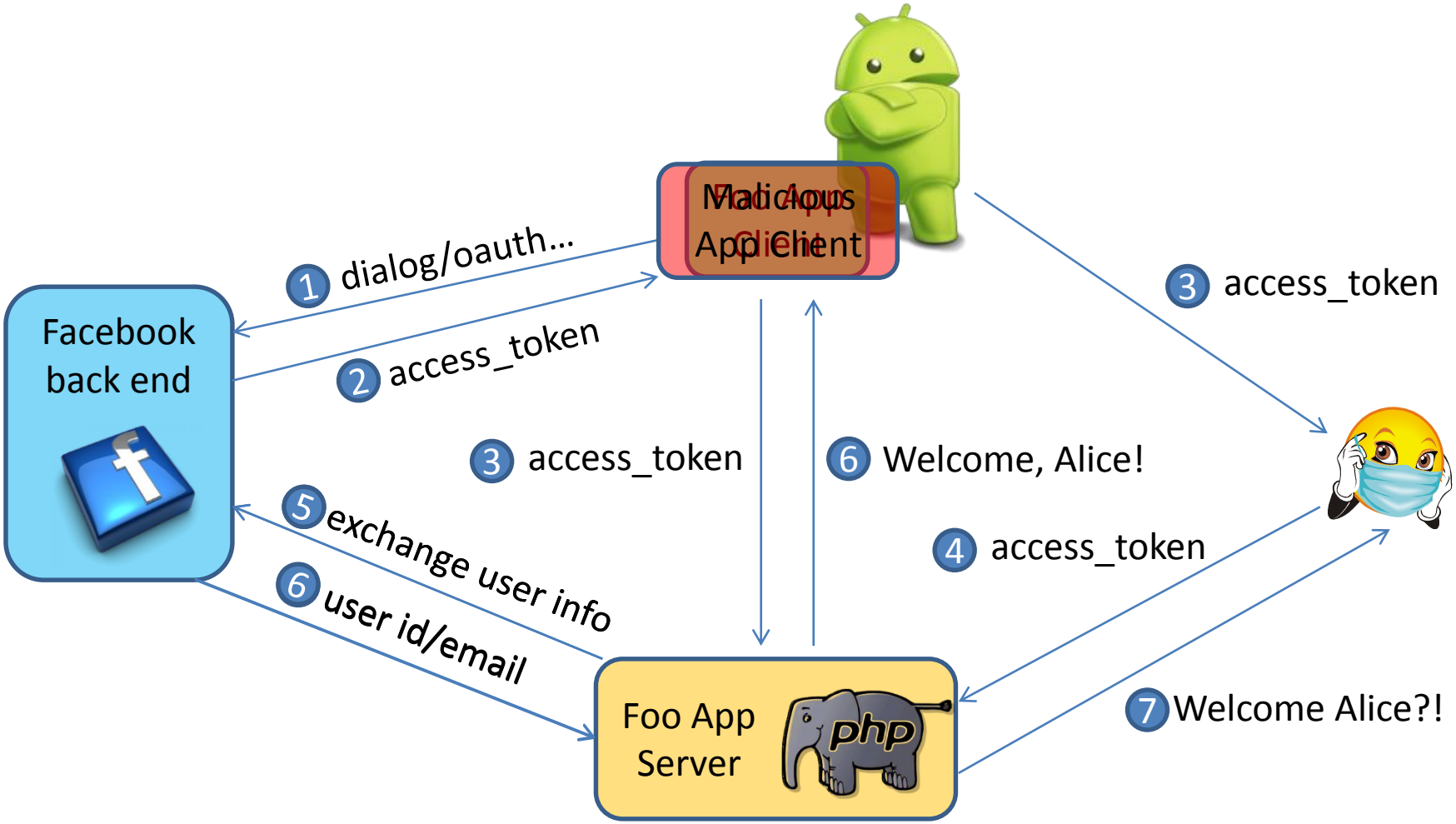
client_id	Yes	Your App ID. This is called client_id instead of app_id for this particular method in order to be compliant with the OAuth 2.0 specification.
redirect_uri	Yes*	[illegible] Domain as specified in your app's settings, a Canvas URL of the form https://apps.facebook.com/YOUR_APP_NAMESPACE or a Page Tab URL of the form https://www.facebook.com/PAGE_USERNAME/app_YOUR_APP_ID
scope	No	A comma separated list of permission names which you would like the user to grant your application. Only the permissions which the user has **not** already granted your application will be shown
state	No	A unique string used to maintain application state between the request and callback. When Facebook redirects the user back to your redirect_uri, this parameter's value will be included in the response. You should use this to protect against Cross-Site Request Forgery.
response_type	No	The requested response type, one of code or token. Defaults to code. If left unset, or set to code the Dialog's response will include an OAuth code which can be exchanged for an access token as per the server-side authentication flow. If set to token, the Dialog's response will include an oauth user access token in the fragment of the URL the user is redirected to - as per the client-side authentication flow.
display	No	The display mode with which to render the Dialog. One of page, popup or touch. Defaults to page when the user is using a desktop browser or the dialog is invoked on the www.facebook.com domain. Defaults to touch when the user is using a mobile browser or the dialog is invoked on the m.facebook.com domain. No other display type is allowed on m.facebook.com. In page mode, the OAuth dialog is displayed in the full Facebook chrome. In 'popup' mode, the OAuth dialog is displayed in a form suitable for embedding in a popup window. This parameter is automatically specified by most Facebook SDK, so may not need to be set explicitly.

*__Important:__ When using the JS SDK, do not specify client_id or redirect_uri - these will be set by the SDK.

The requested response type, one of code or token. Defaults to code…

Facebook documentation example

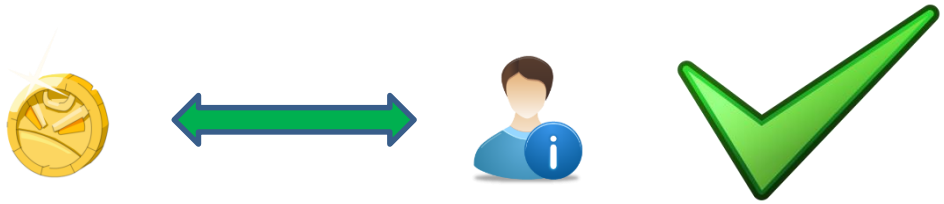
Possible Impersonation Attack



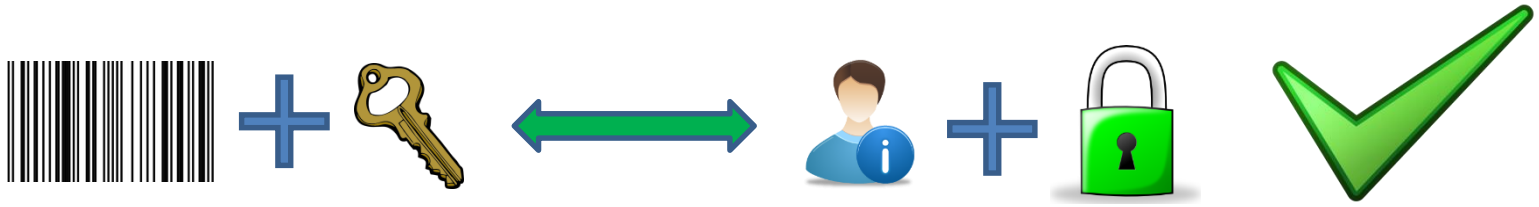
Video Demo

Who's to blame?

Developers?



SDK providers?



Developer guide does not explicitly state that token flow MUST not be used for server-side authentication.

If developers follow the guides properly, will the applications be secure?

The requested response ty
token. Defaults to code…

No.

- Not because of vulnerabilities in SDKs.
- Due to ***implicit assumptions*** about how to use them.

Facebook documentation example

Implicit Assumptions

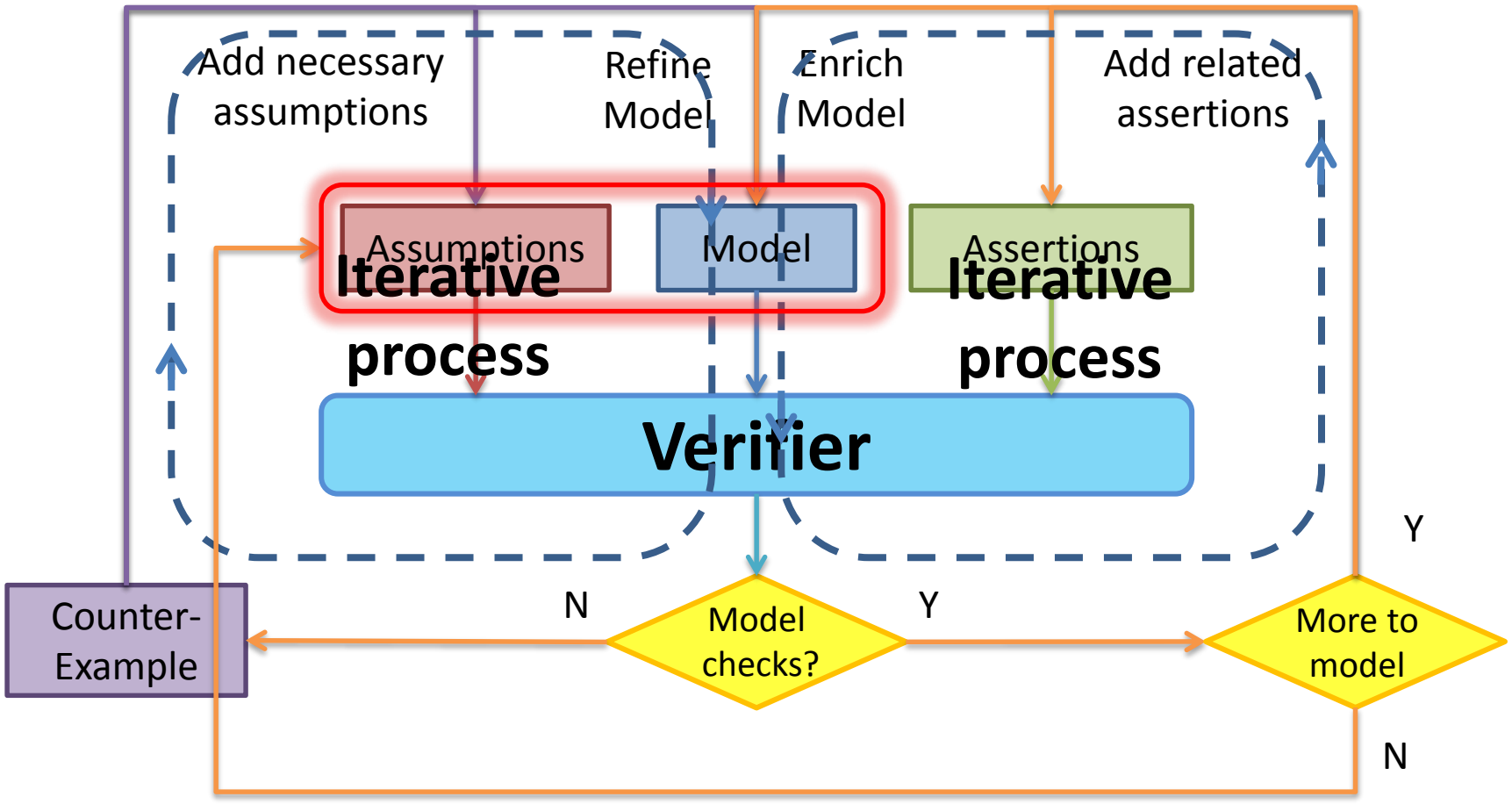
Assumptions that are

- not clearly stated in the SDK's developer guides;
- related to how the SDK should be used;
- **essential for application's security property**.

Goal of this project:

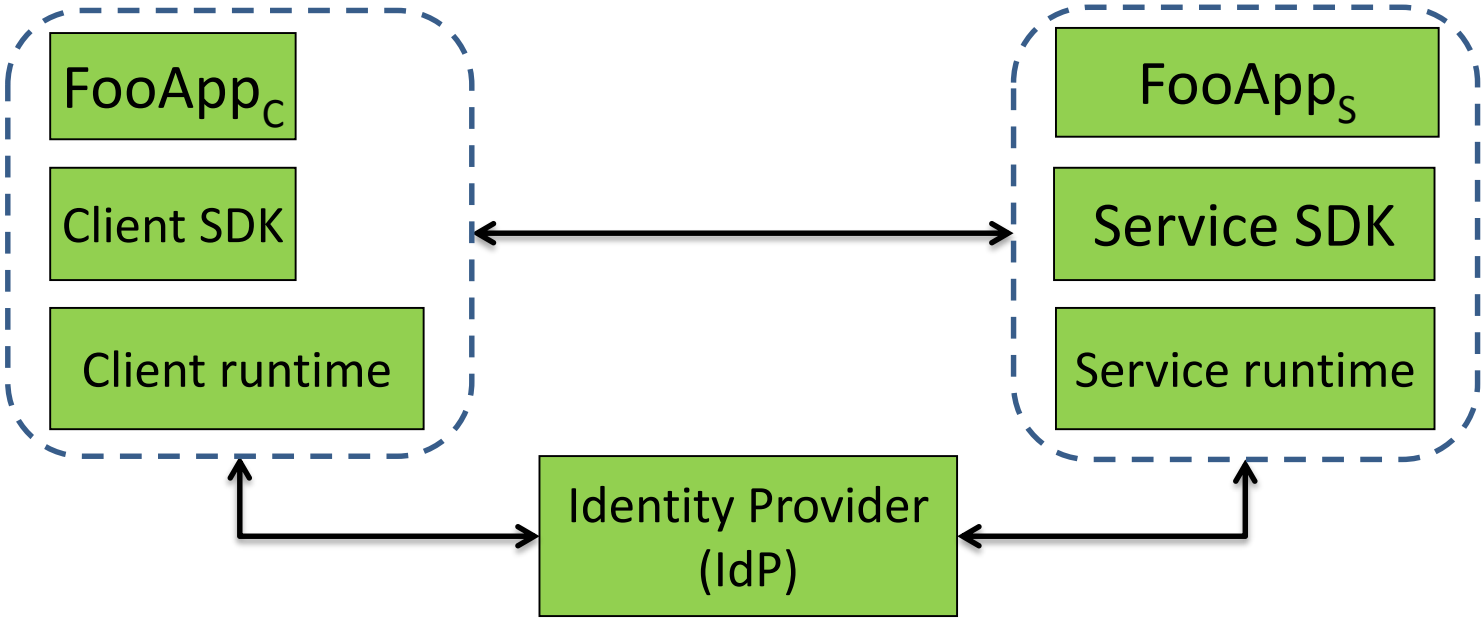
systematically find these implicit assumptions

General Approach

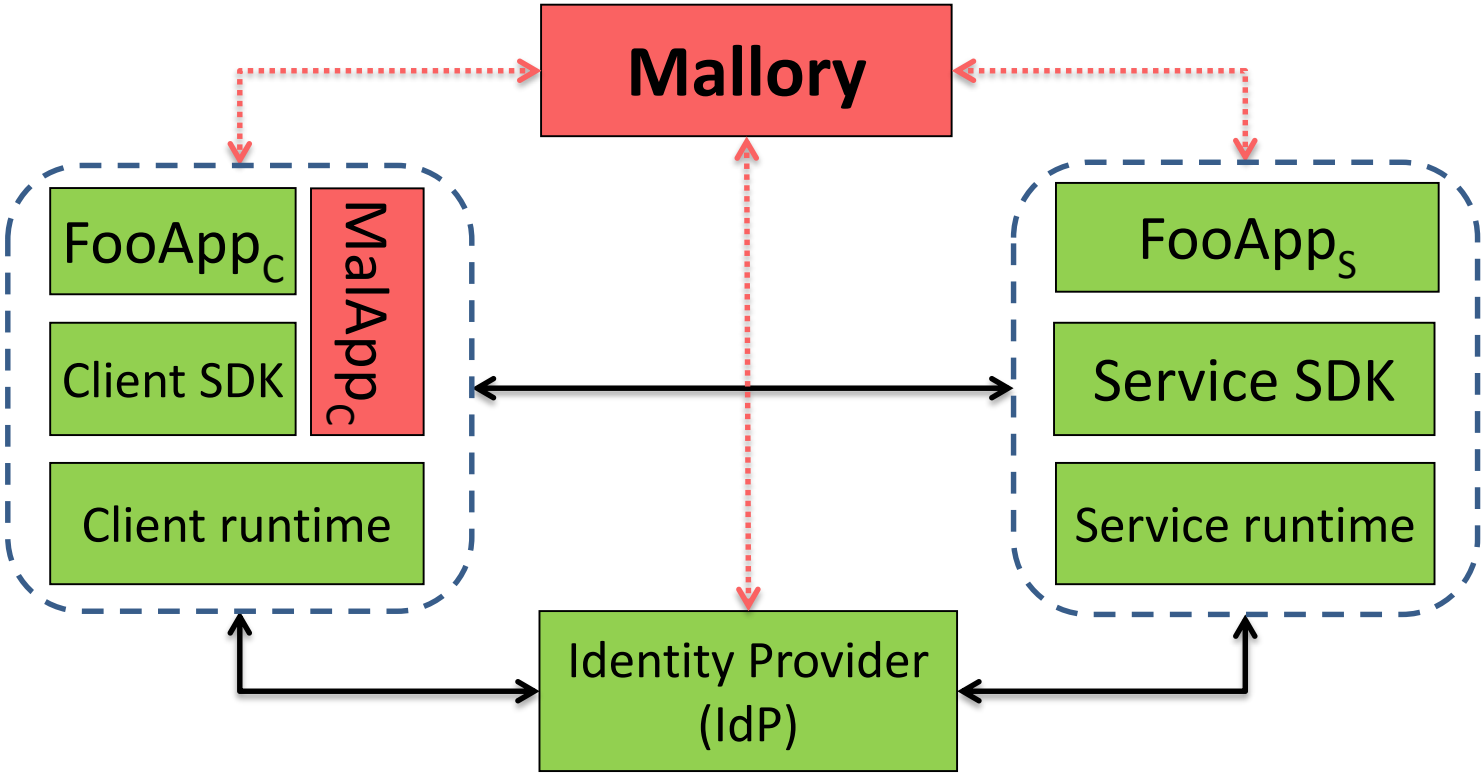


General Approach

System Architecture



Threat model



Desired Security Properties

Authentication

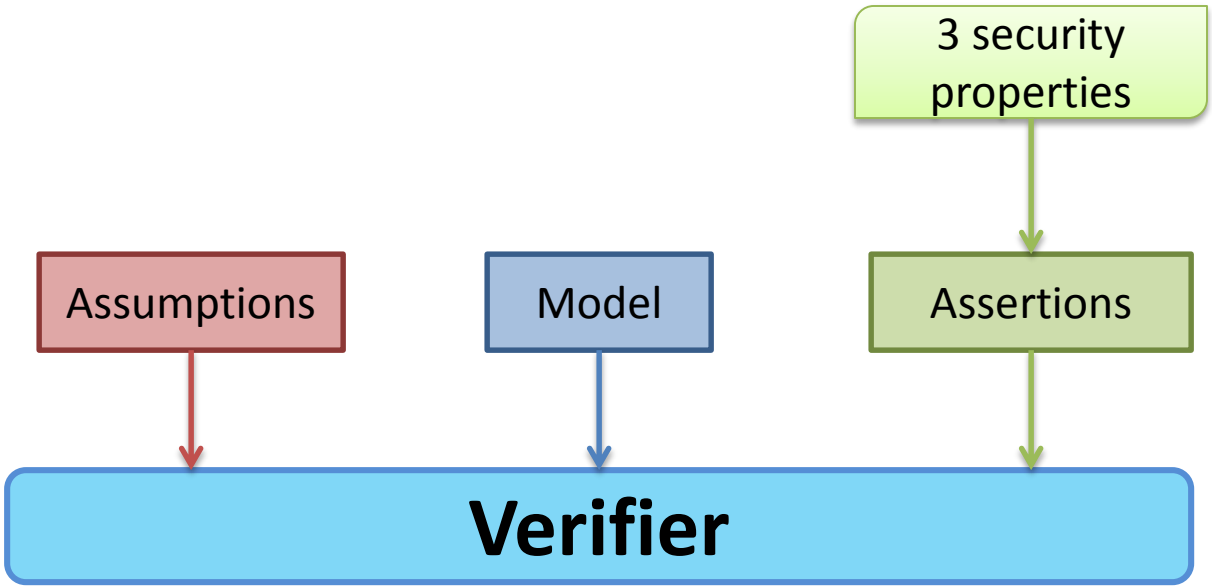
Mallory cannot sign into Foo app as Alice.

Authorization

Mallory cannot access data that Alice have not granted permission to Mallory.

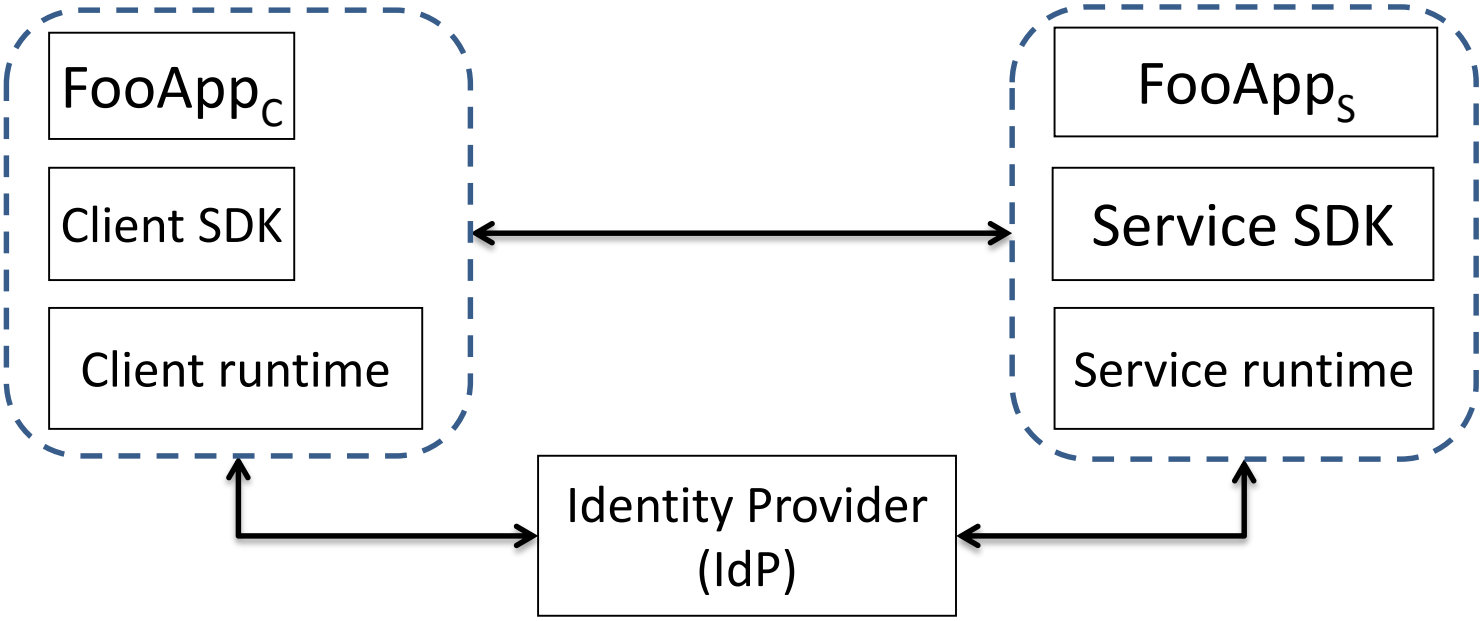
Association

The **user identity**, **user's permission** (authorization result), and **session identity** must represent the same person.

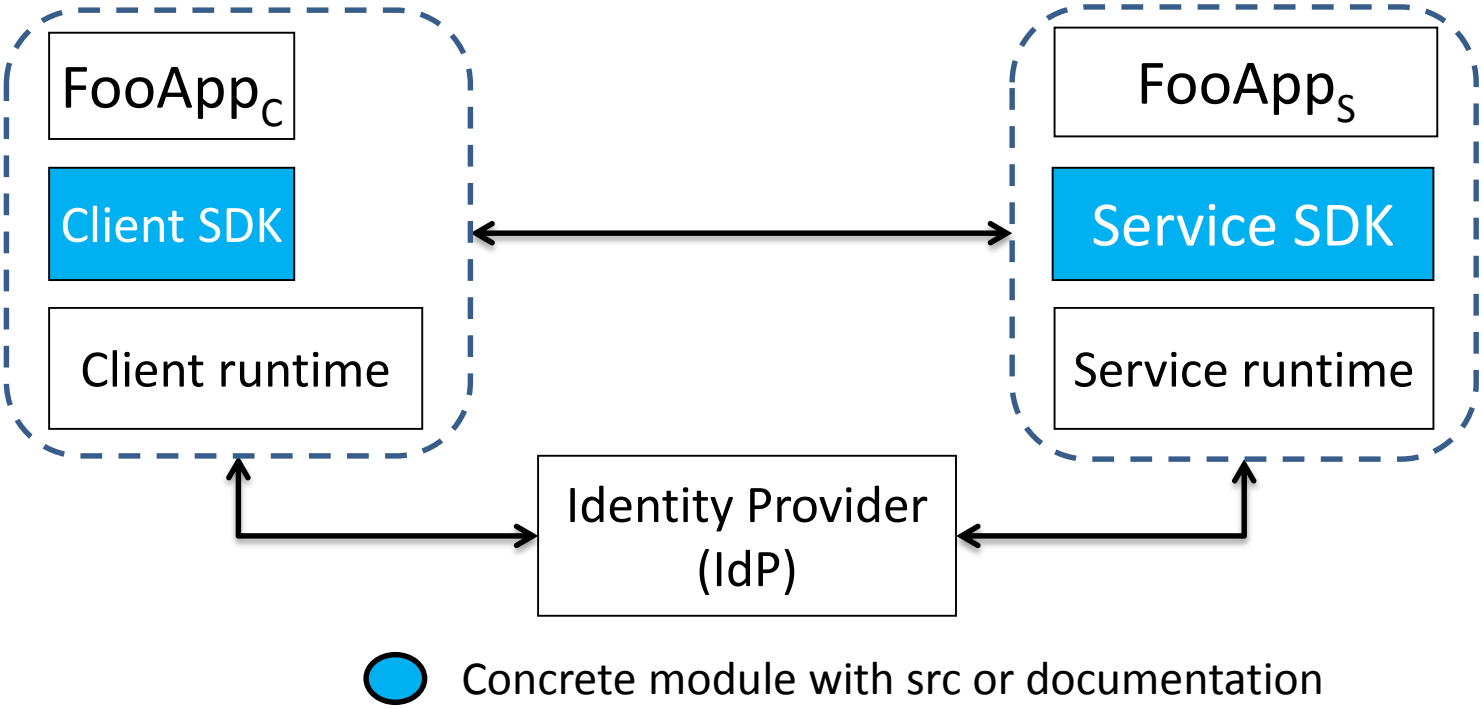



```
assert(logged_in_user != _Alice);
```

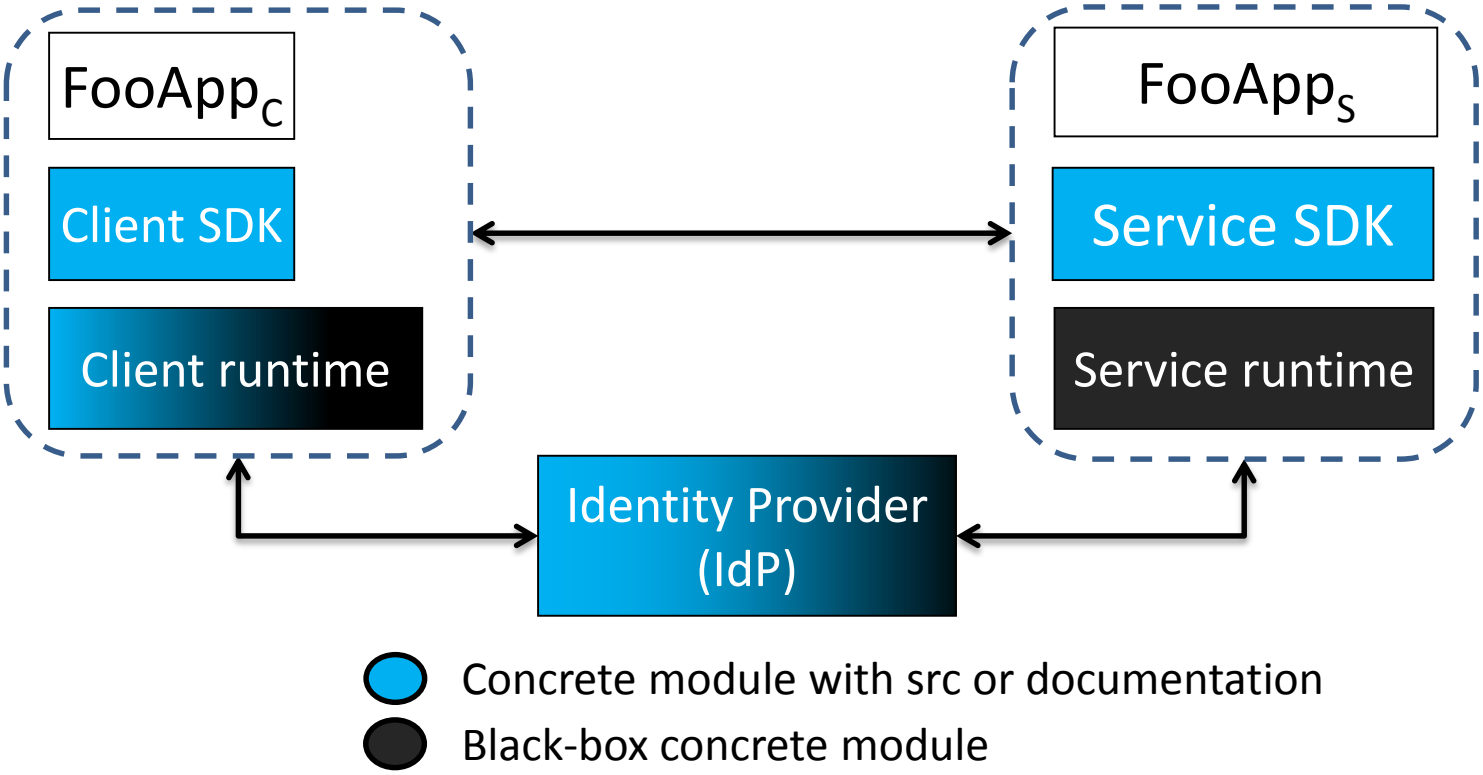
System Architecture



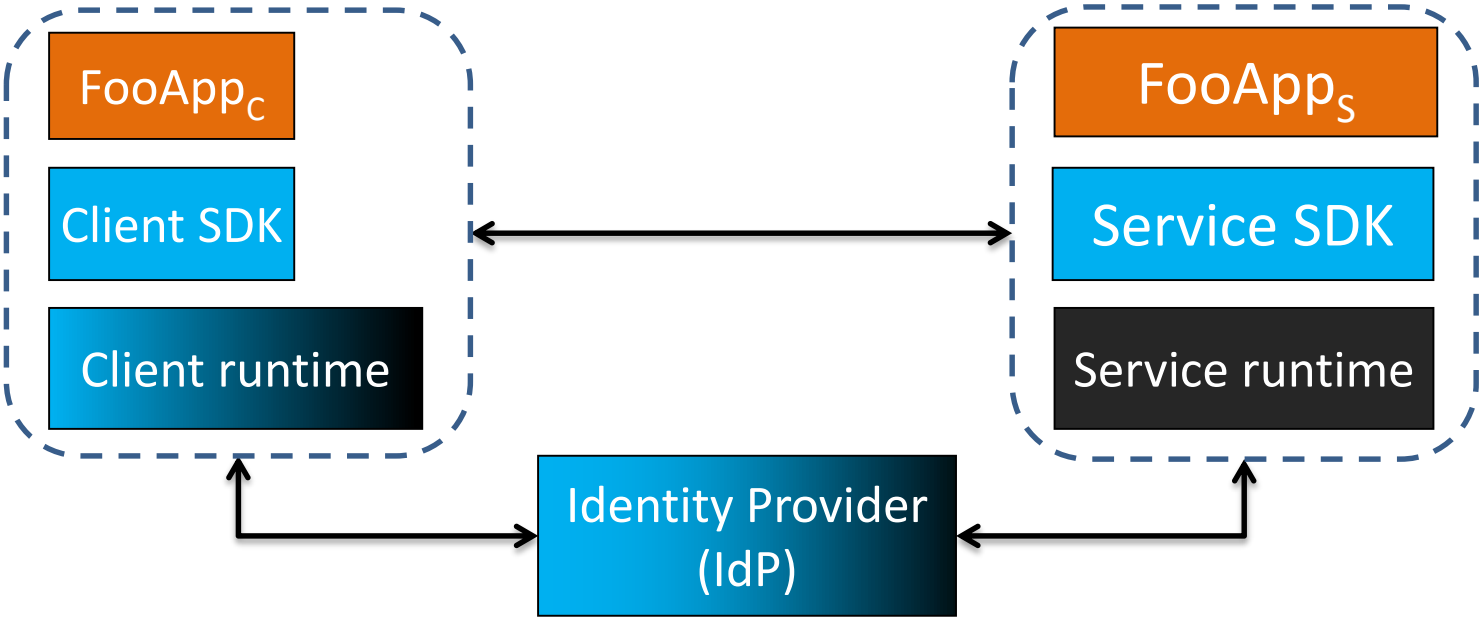
Modeling SDKs



Modeling underlying system layer



Modeling Foo application

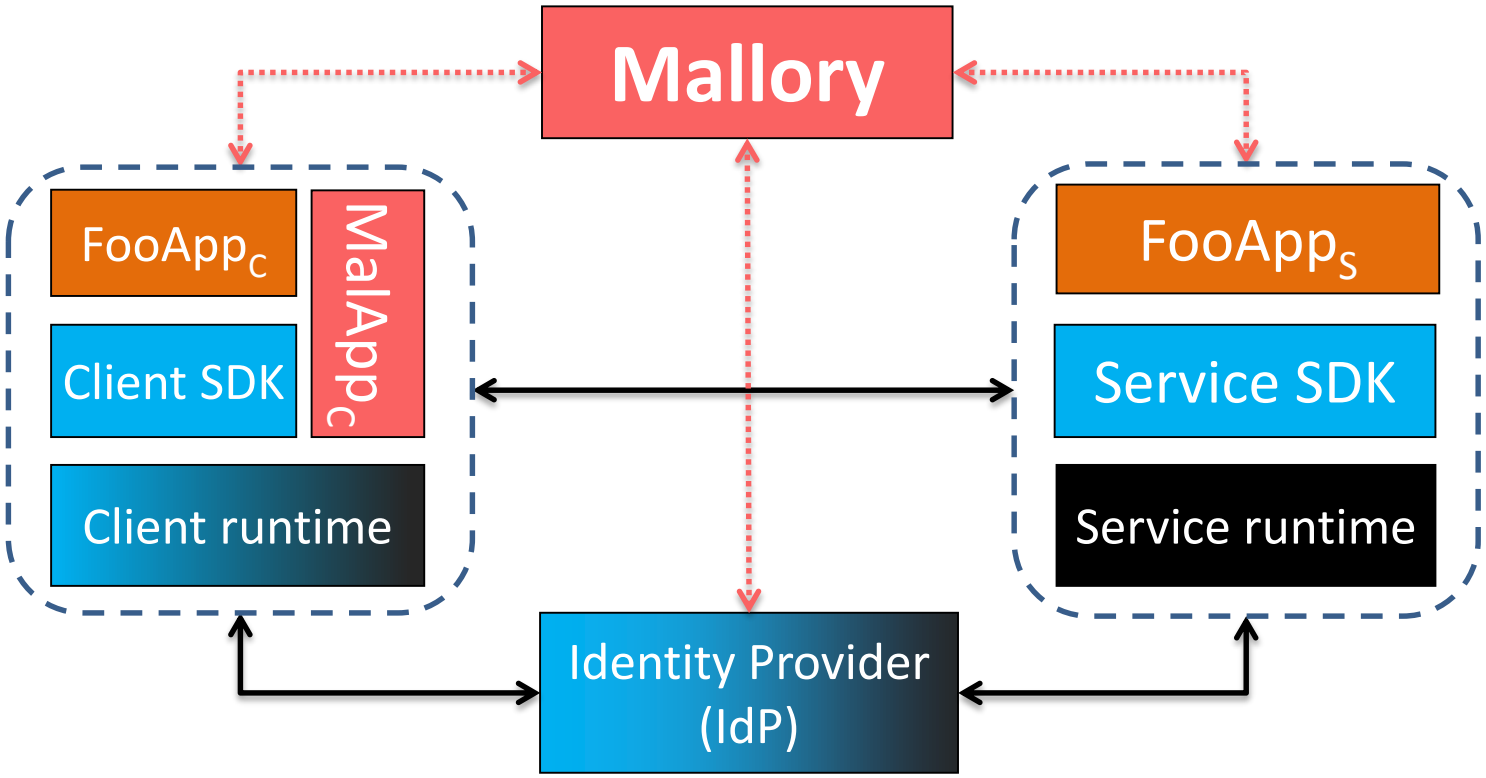


Concrete module with src or documentation

Abstract module subject to dev guide

Black-box concrete module

Modeling Mallory



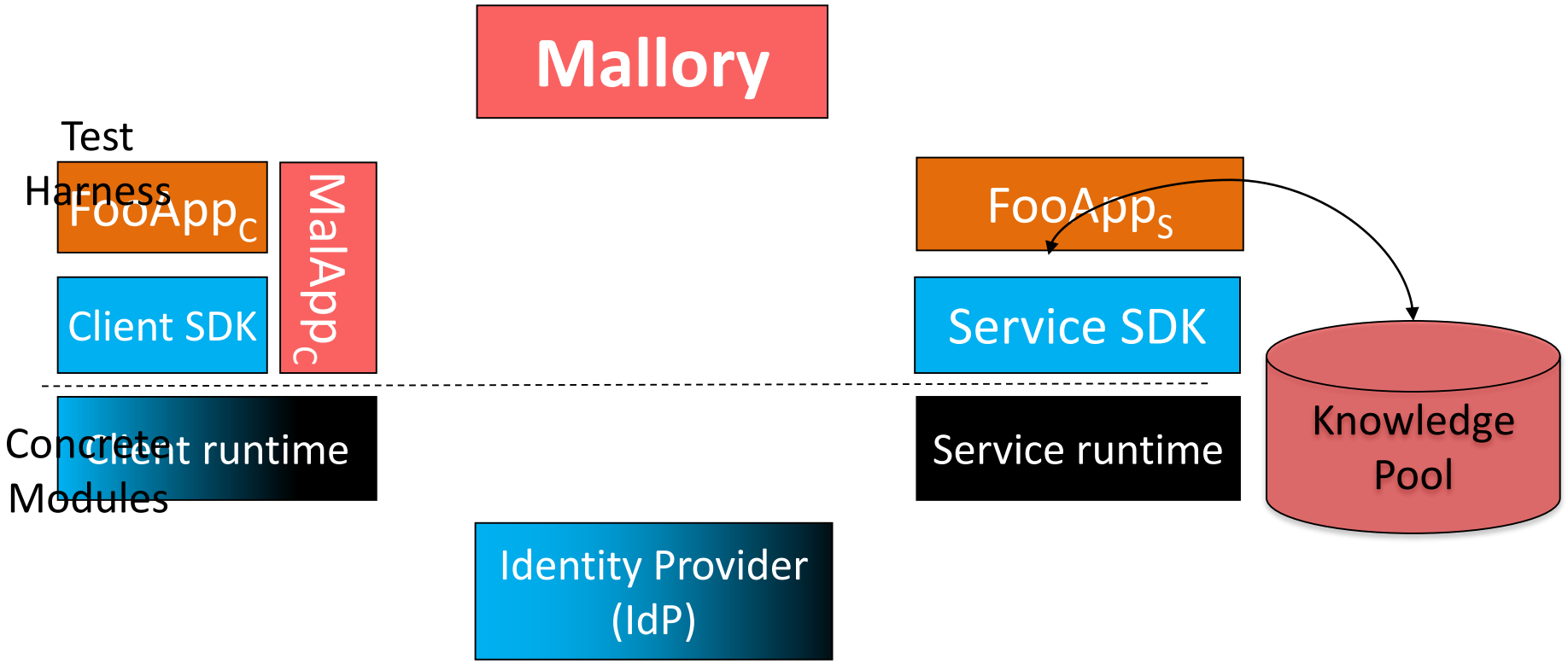
Concrete module with src or documentation

Black-box concrete module

Abstract module subject to dev guide

Abstract module subject to knowledge pool

Modeling Mallory

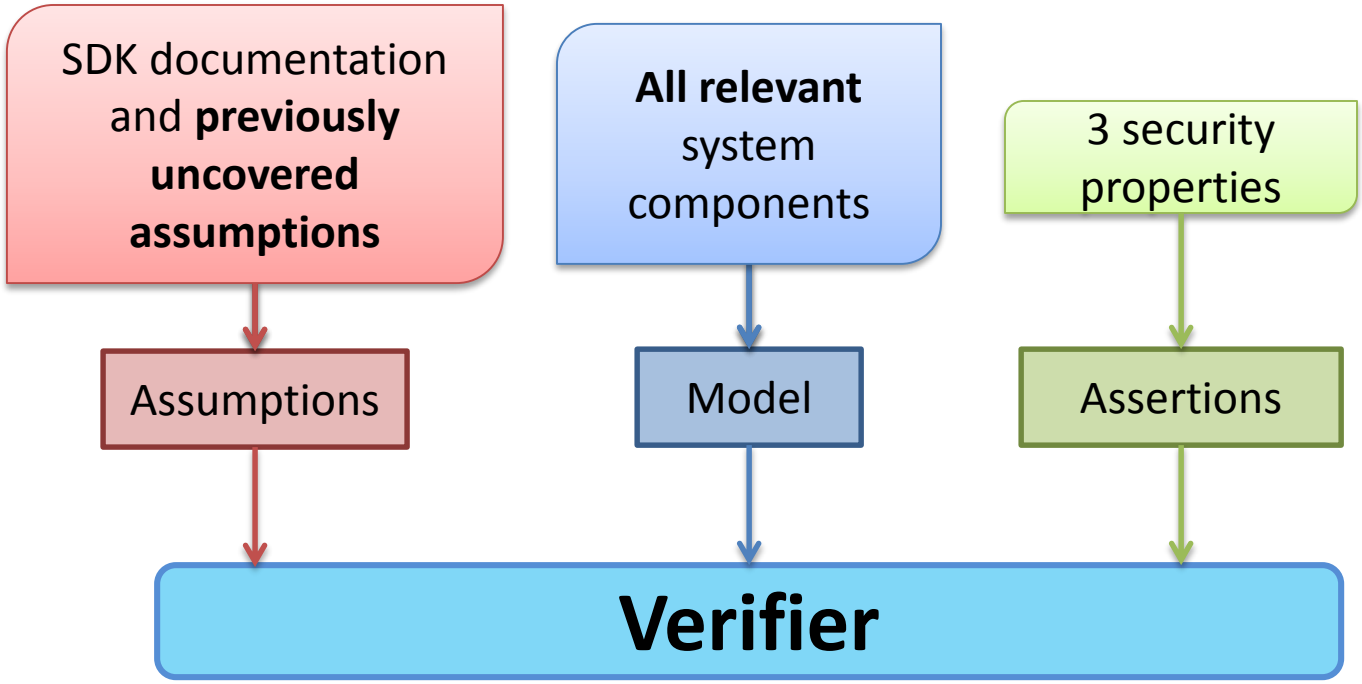


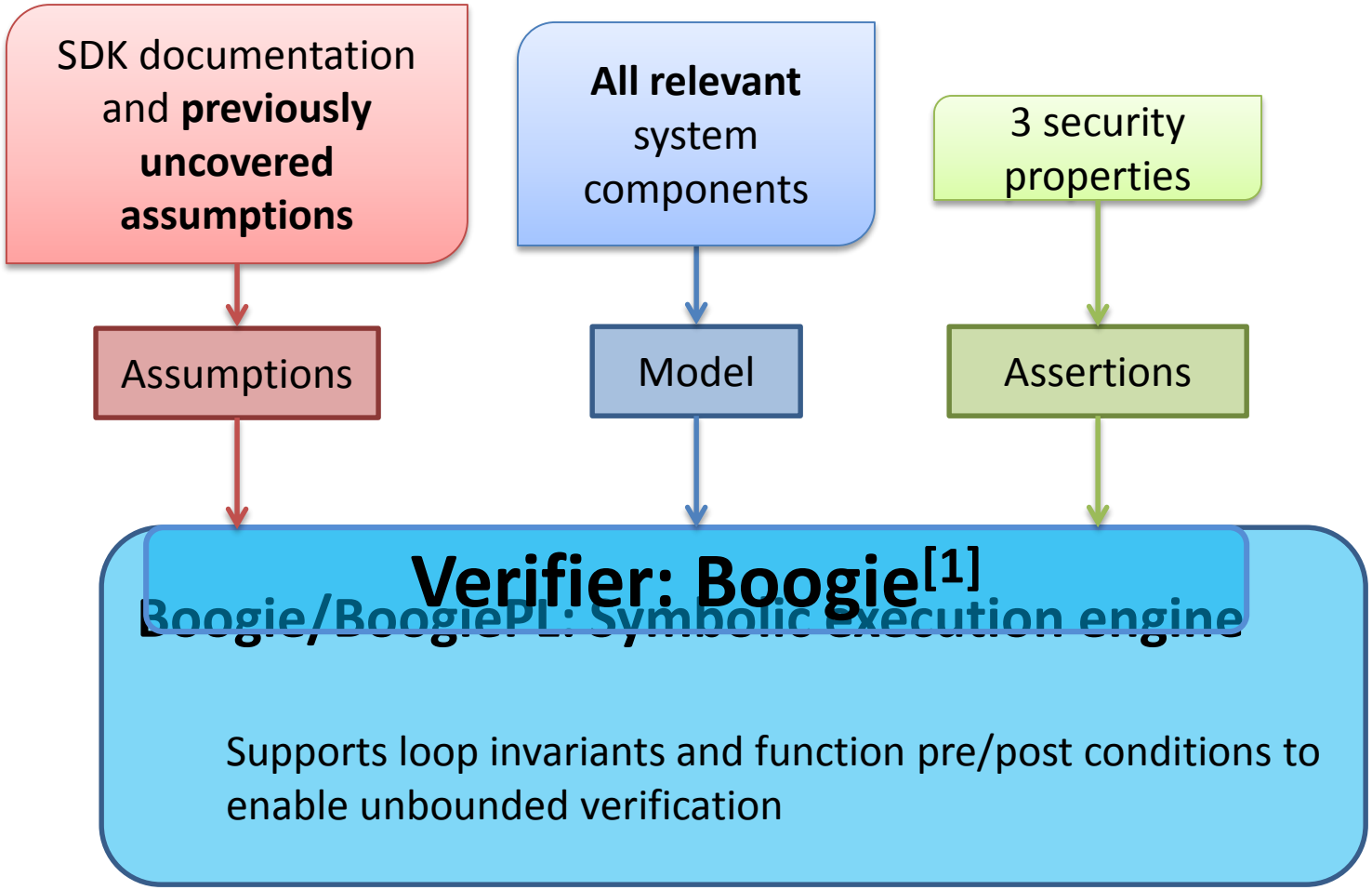
Concrete module with src or documentation

Black-box concrete module

Abstract module subject to dev guide

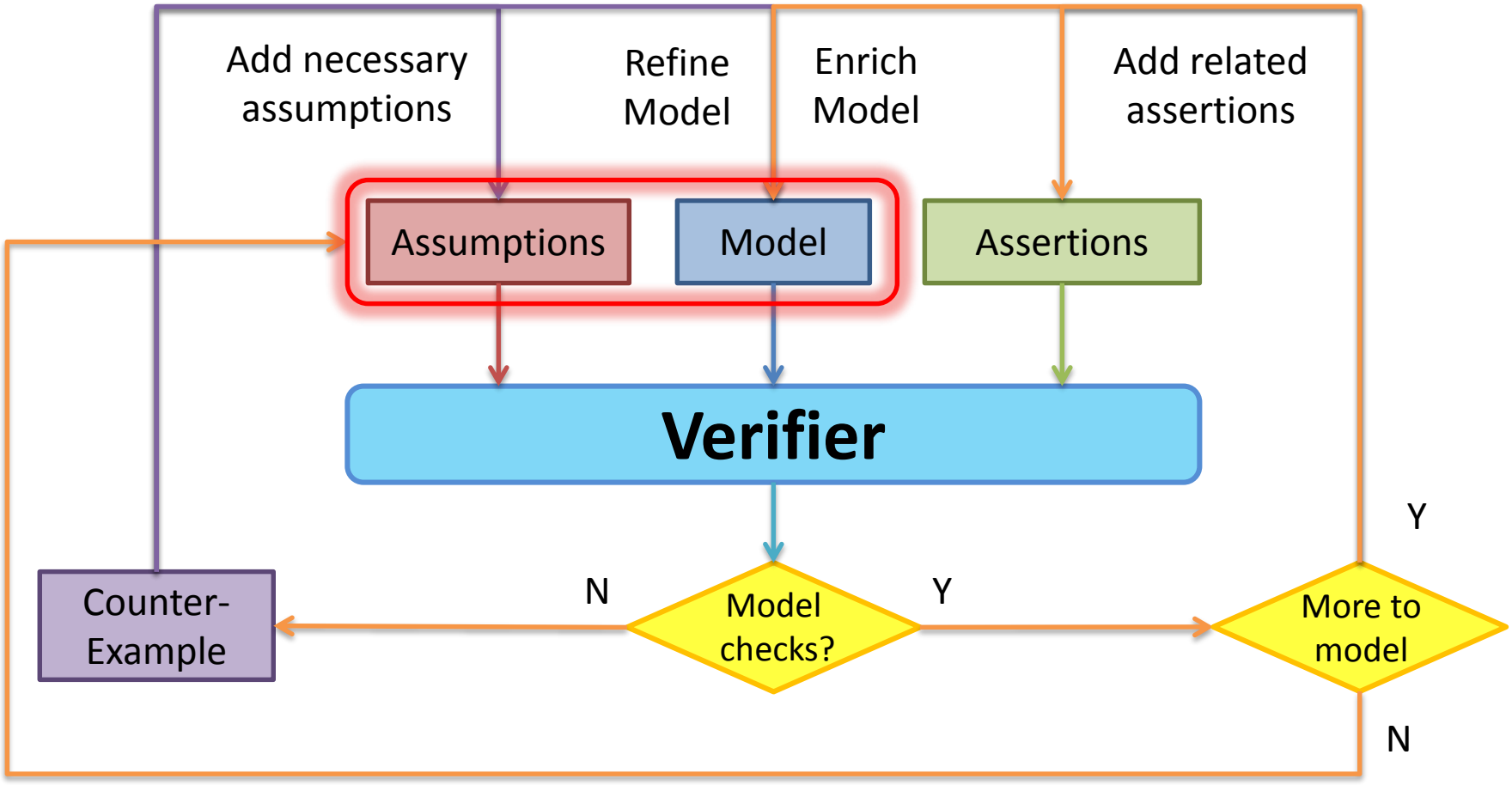
Abstract module subject to knowledge pool


SDK documentation and **previously uncovered assumptions**
All relevant system components
3 security properties
Assumptions
Model
Assertions
Verifier



[1]: Boogie: An Intermediate Verification Language. http://research.microsoft.com/en-us/projects/boogie/

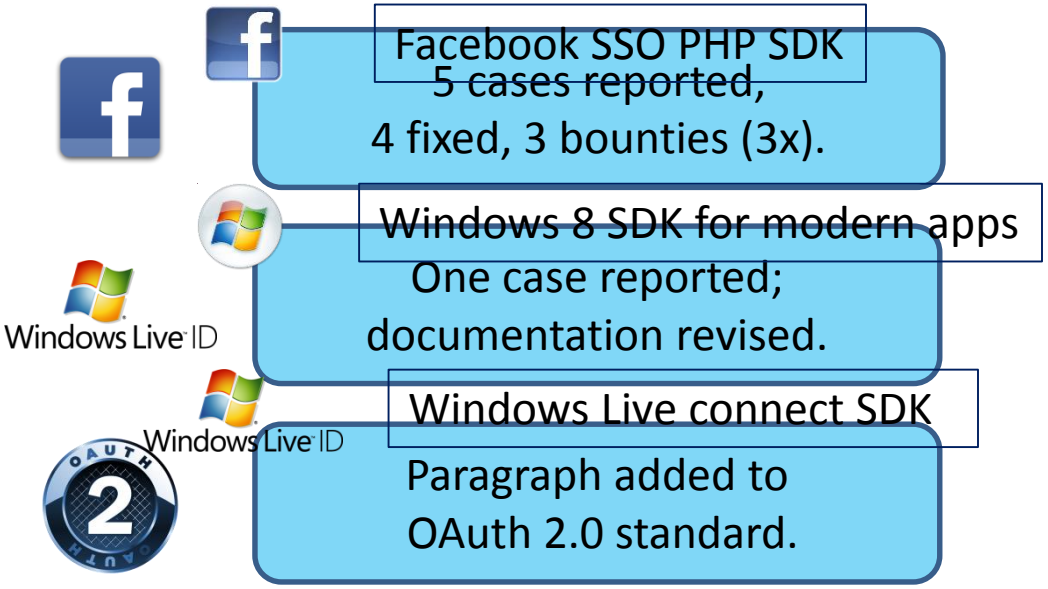
Results


Add necessary assumptions
Refine Model
Enrich Model
Add related assertions
Assumptions
Model
Assertions
Verifier
Counter-Example
N
Model checks?
Y
More to model
Y
N

Results overview

Explicated three SDKs: (6 months)

Many implicit assumptions were found:



Majority of tested apps vulnerable due to failure to ensure at least one uncovered assumption.

SDK models

```
protected function getUserFromAvailableData() {
 if ($signed_request) {
   ...
  $this->setPersistentData('user_id',
                           $signed_request['user_id']);
  return 0;
 }
 $user = $this->getPersistentData('user_id', $default = 0);
 $persist_token =
      $this->getPersistentData('access_token');
 $access_token = $this->getAccessToken();
 if ($access_token &&
     !($user && $persist_token == $access_token)) {
       $user = $this->getUserFromAccessToken();
       if ($user)
         $this->setPersistentData('user_id', $user);
       else $this->clearAllPersistentData();
  }
  return $user;
}

public function getLogoutUrl() {
   return $this->getUrl(
      'www',  'logout.php',
      array_merge(array(
         'next' => $this->getCurrentUrl(),
         'access_token' => $this->getAccessToken(), ), ...));
 }
```

Facebook PHP Source code

```
procedure  {:inline 1} getUserFromAvailableData()  returns (user:User) {
  if (IdP_Signed_Request_Records__user_ID[signed_request] != _nobody) {
        ...
       user := IdP_Signed_Request_Records__user_ID[signed_request];
       call setPersistentData__user_id(user);
       return;
  }
  call user := getPersistentData__user_id();
  call persisted_access_token := getPersistentData__access_token();
  call access_token := getAccessToken();
  if (access_token >= 0 &&
      !(user != _nobody && persisted_access_token == access_token)) {
         call user := getUserFromAccessToken(access_token);
         if (user != _nobody) {
           call setPersistentData__user_id(user);
         } else {
           call clearAllPersistentData();
         }
  }
  return;
}
procedure {:inline 1} getLogoutUrl()
 returns (API_id: API_ID, next__domain: Web_Domain, next__API: API_ID,
           access_token: int)  {
      API_id := API_id_FBConnectServer_login_php;
      call access_token := getAccessToken();
      call  next__domain,  next__API := getCurrentUrl();
}
```

Boogie PL Model

API models

Constructing a URL to the OAuth Dialog

To invoke the OAuth Dialog, redirect the user's browser to a URL of the form:

```
https://www.facebook.com/dialog/oauth/?
    client_id=YOUR_APP_ID
    &redirect_uri=YOUR_REDIRECT_URL
    &state=YOUR_STATE_VALUE
    &scope=COMMA_SEPARATED_LIST_OF_PERMISSION_NAMES
```

Parameters

The OAuth Dialog supports the following parameters which may be passed in the URL string:

Parameter	Required?	Description
client_id	Yes*	Your App ID. This is called client_id instead of app_id for this particular method in order to be compliant with the OAuth 2.0 specification.
redirect_uri	Yes*	Should not be set when using the JS SDK to invoke the dialogsThe URL to redirect to after the user clicks a button in the dialog. The URL you specify must be a URL of with the same Base Domain as specified in your app's settings, a Canvas URL of the form https://apps.facebook.com/YOUR_APP_NAMESPACE or a Page Tab URL of the form https://www.facebook.com/PAGE_USERNAME/app_YOUR_APP_ID
scope	No	A comma separated list of permission names which you would like the user to grant your application. Only the permissions which the user has **not** already granted your application will be shown
state	No	A unique string used to maintain application state between the request and callback. When Facebook redirects the user back to your redirect_uri, this parameter's value will be included in the response. You should use this to protect against Cross-Site Request Forgery.
response_type	No	The requested response type, one of code or token. Defaults to code. If left unset, or set to code the Dialog's response will include an OAuth code which can be exchanged for an access token as per the server-side authentication flow. If set to token, the Dialog's response will include an oauth user access token in the fragment of the URL the user is redirected to - as per the client-side authentication flow.
display	No	The display mode with which to render the Dialog. One of page, popup or touch. Defaults to page when the user is using a desktop browser or the dialog is invoked on the www.facebook.com domain. Defaults to touch when the user is using a mobile browser or the dialog is invoked on the m.facebook.com domain. No other display type is allowed on m.facebook.com. In page mode, the OAuth dialog is displayed in the full Facebook chrome. In 'popup' mode, the OAuth dialog is displayed in a form suitable for embedding in a popup window. This parameter is automatically specified by most Facebook SDK, so may not need to be set explicitly.

***Important:** When using the JS SDK, do not specify client_id or redirect_uri - these will be set by the SDK.

Facebook Dialog API documentation

```
procedure {:inline 1} dialog_oauth(IdPLoggedInUser:User,
client_id: AppID,
redirect_domain: Web_Domain, scope:Scope,
response_type:ResponseType)
returns (r:int, Response_data: int)
modifies Access_Tokens__TokenValue, Access_Tokens__user_ID,
Access_Tokens__Scope;
modifies Codes__user_ID,Codes__App_ID,Codes__Scope;
modifies …
{
   var access_token:int, code:int, sr:int;

   …
   if (response_type==_Token || response_type==_Signed_Request){
       havoc access_token; //it means "access_token := *;"
       …
       IdP_Signed_Request_signature[sr]:=ValidIdPSignature;
       IdP_Signed_Request_oauth_token[sr]:=access_token;
       IdP_Signed_Request_code[sr]:=code;
       IdP_Signed_Request_user_ID[sr]:= IdPLoggedInUser;
       IdP_Signed_Request_app_id[sr]:= client_id;
    }
    if (response_type==_Token) {
        Response_data:=access_token;
    } else if (response_type==_Code) {
        Response_data:=code;
    } else {
        Response_data:=sr;
    }
    r:=200;
}
```

Boogie model

Example vulnerability from Facebook SDK

1

The examples are a good place to start. The minimal you'll need to have is:

```
require 'facebook-php-sdk/src/facebook.php';

$facebook = new Facebook(array(
  'appId'  => 'YOUR_APP_ID',
  'secret' => 'YOUR_APP_SECRET',
));

// Get User ID
$user = $facebook->getUser();
```

3

Login or logout url will be needed depending on current user state.

```
if ($user) {
  $logoutUrl = $facebook->getLogoutUrl();
} else {
  $loginUrl = $facebook->getLoginUrl();
}
```

Example assumption from Facebook SDK

```
procedure {:inline 1} getLogoutUrl()
returns (API_id: API_ID, …)
modifies …;
{
    var test_t:int ;
    call access_token := getAccessToken();
    call test_t := getApplicationAccessToken();
    assume(access_token != test_t);
    API_id := API_id_FBConnectServer_login_php;
…
    return;
}
```

Assumption (in the model)

Assumption (in plain text):
getLogoutUrl() must not return an application access token to the client.

Best outcome:
Facebook fixed their SDK code so this assumption is not needed in the newer version.

Example assumption from Windows Live

```
function saveRefreshToken($refreshToken)
{
    // save the refresh token associated with the user
id on the site.
}
function handleTokenResponse($token, $error = null)
{
    $authCookie = $_COOKIE[AUTHCOOKIE];
    $cookieValues = parseQueryString($authCookie);
…
    if (!empty($token->{ REFRESHTOKEN }))
    {
        saveRefreshToken($token->{ REFRESHTOKEN });
    }
…
```

function saveRefreshToken(…)
{
    // save the refresh token associated with the user id on the site.
}

associate refresh token with the user ID obtained from the global variable $_COOKIE

Two interpretations

associate refresh token with the user ID obtained from the refresh token passed into the function

original Live ID developer guide

```
procedure {:inline 1} saveRefreshToken (refresh_token_index:
int, RP_Cookie_index: int)
modifies RP_Refresh_Token_index;
{
        var user: User;
        //call user := get_User_ID(RP_Cookie_index);
        user := Refresh_Token__user_ID[refresh_token_index];
        if (user == _nobody) {return;}
        RP_Refresh_Token_index[user] := refresh_token_index;
}
```

Example assumption from Windows Live

```
procedure {:inline 1} saveRefreshToken (refresh_token_index: int,
RP_Cookie_index: int)
modifies RP_Refresh_Token_index;
{
        var user: User;
        call user := get_User_ID(RP_Cookie_index);

        user := Refresh_Token__user_ID[refresh_token_index];
        if (user == _nobody) {return;}
        RP_Refresh_Token_index[user] := refresh_token_index;
}
```

```
    LiveConnectServer.bpl(200,23): inline$login_live_com_oauth20_token_srf$9$Ret
urn
    RPCallbackPHP.bpl(60,21): inline$requestAccessTokenByVerifier$3$anon0$1
    RPCallbackPHP.bpl(57,23): inline$requestAccessTokenByVerifier$3$Return
    RPCallbackPHP.bpl(85,3): inline$handlePageRequest$3$anon8_Then$1
    RPCallbackPHP.bpl(88,4): inline$handlePageRequest$3$anon9_Then
    RPCallbackPHP.bpl(34,22): inline$handleTokenResponse$7$anon0
    RPCallbackPHP.bpl(37,3): inline$handleTokenResponse$7$anon3_Then
    RPCallbackPHP.bpl(4,2): inline$get_User_ID$11$anon0
    RPCallbackPHP.bpl(27,2): inline$saveRefreshToken$7$anon3_Else
    RPCallbackPHP.bpl(21,23): inline$saveRefreshToken$7$Return
    RPCallbackPHP.bpl(37,3): inline$handleTokenResponse$7$anon3_Then$1
    RPCallbackPHP.bpl(39,22): inline$handleTokenResponse$7$anon2
    RPCallbackPHP.bpl(88,4): inline$handlePageRequest$3$anon9_Then$1
    test_harness.bpl(60,2): inline$call_an_API_on_foo_service_app_from_foo_app_f
rom_alice_device$0$anon0$1
    test_harness.bpl(375,3): inline$foo_client_app_calls$0$anon5_Then$1
    test_harness.bpl(364,23): inline$foo_client_app_calls$0$Return
    test_harness.bpl(440,3): inline$takeAction$0$anon5_Then$1
    test_harness.bpl(590,3): anon2_LoopBody$1

Boogie program verifier finished with 0 verified, 1 error

D:\Research\Explicated-SDKs-master\models\model_LiveConnectSDK>
```

```
D:\Research\Explicated-SDKs-master\models\model_LiveConnectSDK>B
s.bpl specificDecls.bpl LiveConnectSDK.bpl RPCallbackPHP.bpl Liv
pl knowledge_pool.bpl  test_harness.bpl
Boogie program verifier version 2.2.30705.1126, Copyright (c) 20
ft.

Boogie program verifier finished with 1 verified, 0 errors

D:\Research\Explicated-SDKs-master\models\model_LiveConnectSDK>
```

Example assumption from Windows Live

```
function saveRefreshToken($refreshToken)
{
    // save the refresh token and associate it with the
user identified by your site credential system.
}

function handleTokenResponse($token, $error = null)
{
    $authCookie = $_COOKIE[AUTHCOOKIE];
    $cookieValues = parseQueryString($authCookie);


    if (!empty($token))
…
```

new Live ID developer guide

Testing Popular Apps

Facebook showcase applications

Popular Windows 8 modern applications using Facebook SSO

Testing Results

Test Set	Number of Apps	Vulnerable
Illustrative example	27	21 **(78%)**
Assumption A1 (in the paper)	7	6 **(86%)**
Assumption A6 (in the paper)	21	14 **(67%)**

Conclusion

Missed **implicit assumptions** can lead to many vulnerabilities when integrating third-party services.

What we advocate: SDK providers **explicate SDKs** before release.

- Fix SDK Code
- Develop Automated Checker
- Improve SDK documentation

Thank you!

Visit project website for more info:
http://www.cs.virginia.edu/~yz8ra/ExplicatingSDKs_website/

Models available at: https://github.com/sdk-security/Explicated-SDKs

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