Static Detection of Vulnerabilities in Modern PHP Applications

Johannes Dahse

HackPra ’14, November 26th, Ruhr-University Bochum, Germany

1.1 Background

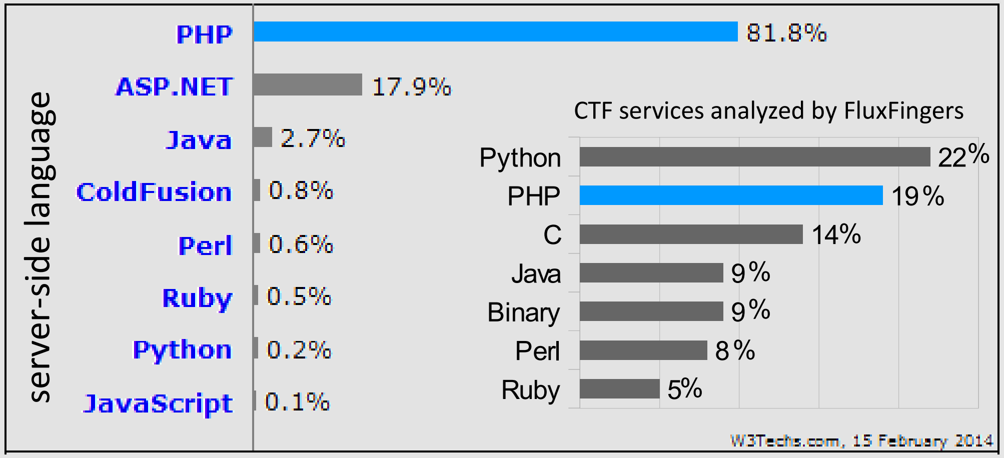
- @FluxReiners / websec.wordpress.com
- IT-Security Student, Ruhr-University Bochum (2006 - 2012)
- Co-founder CTF team *FluxFingers* (2007)
- Co-founder *HackerPraktikum*, *BadBank* Developer (2009)
- Penetration Tester / Code Auditer
- *RIPS 0.5* – Static Code Analyzer (2009 - 2011)
- *RIPS 1.0* – New rewritten prototype (2012 – today, 24/7)
- PhD Student at Chair for Systems Security, RUB (2013 - today)

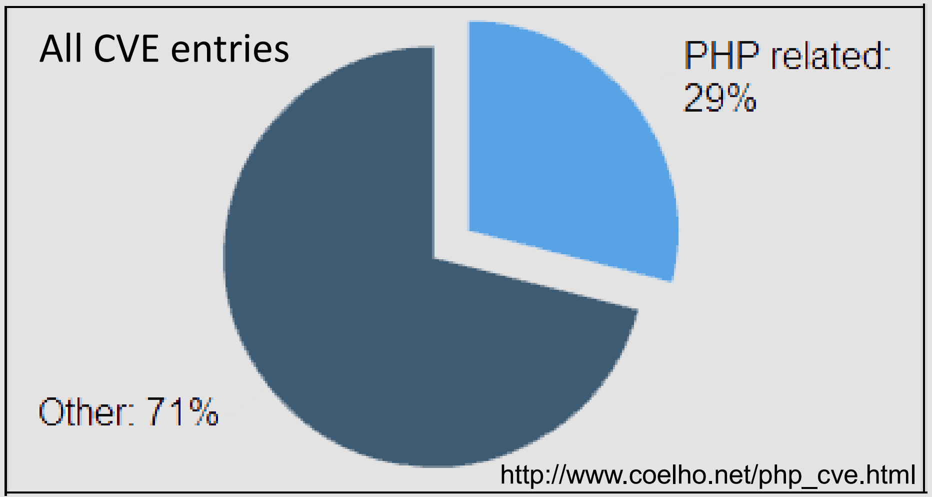
1.2 Why PHP?

WordPress
(23% of all websites)

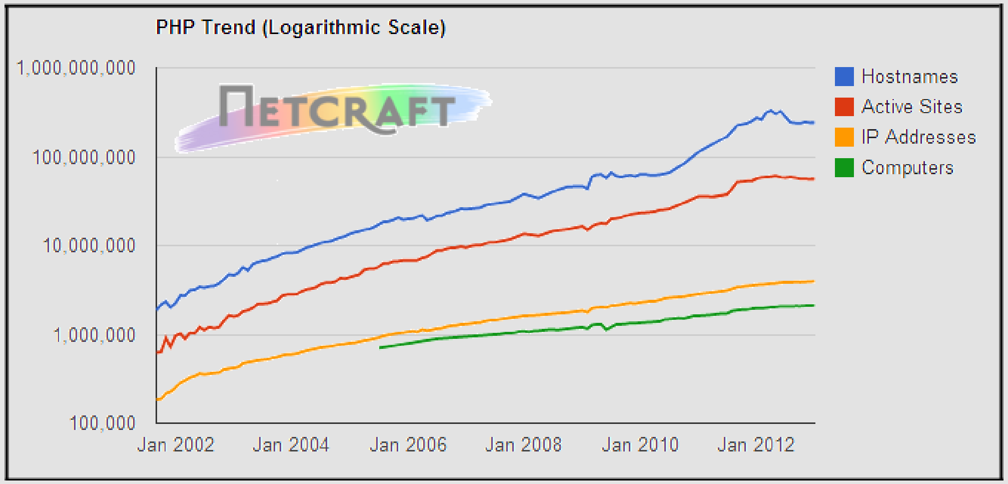
Joomla!
(3% of all websites)

http://w3techs.com





http://www.coelho.net/php_cve.html



1.3 Motivation

- SQL Injection in BadBank

```
$id = $_GET['id'];
$sql = "SELECT id, titel, hinweis
          FROM hinweise WHERE id = ".$id;
$result = mysql_query($sql);
```

- Cross-Site Scripting in BadBank

```
$order = $_GET['order'];
$html = " (nach " . $order . ")\n";
echo $html;
```

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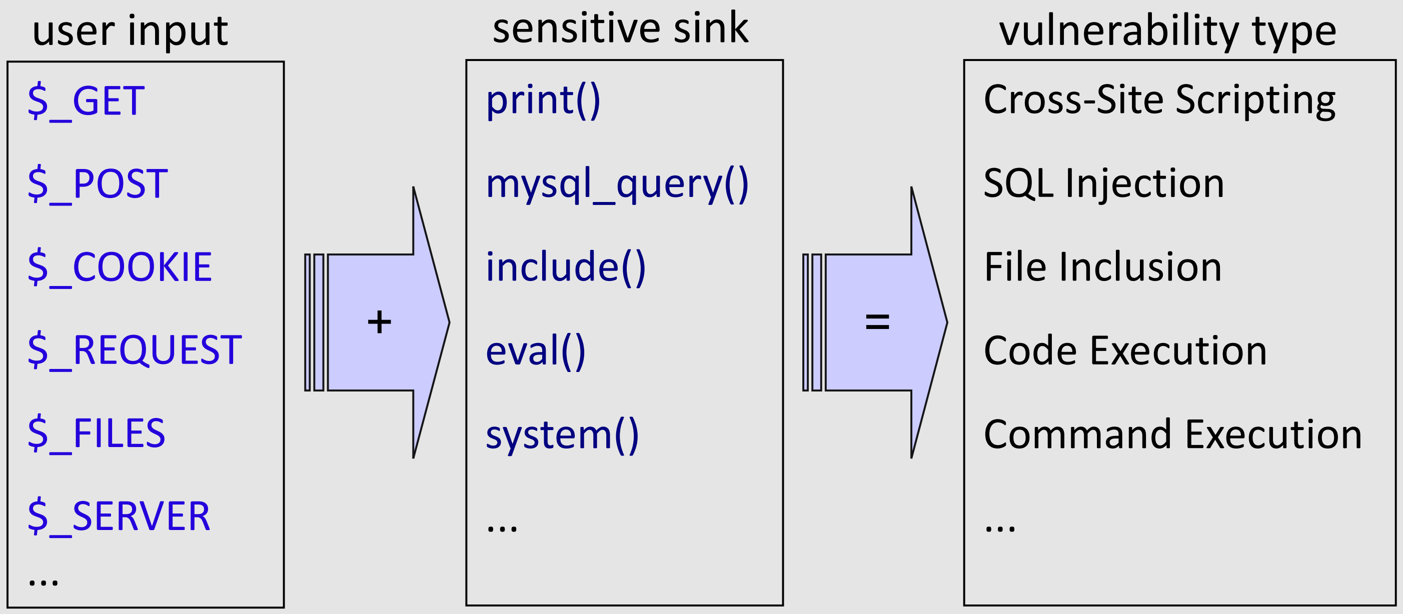
2. Static Code Analysis
3. Modern Vulnerabilities
4. Open Challenges

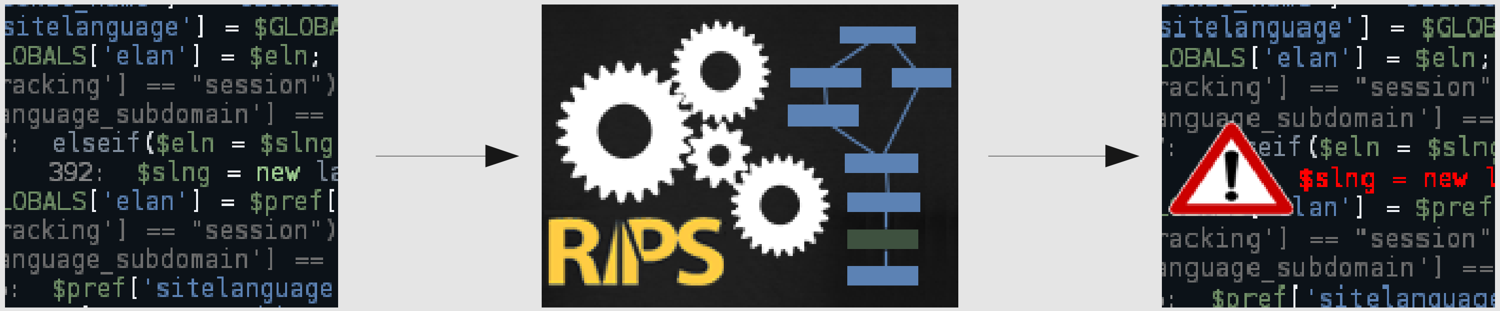
1.4 Taint-style Vulnerabilities



Note: Logical Flaws do not follow such a general concept and are harder to detect

RIPS 0.5

BadBank Demo Scan



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1.4 Taint-style Vulnerabilities

user input		sensitive sink		vulnerability type
$_GET		print()		Cross-Site Scripting
$_POST		mysql_query()		SQL Injection
$_COOKIE	+	include()	=	File Inclusion
$_REQUEST		eval()		Code Execution
$_FILES		system()		Command Execution
$_SERVER		...		...
...				

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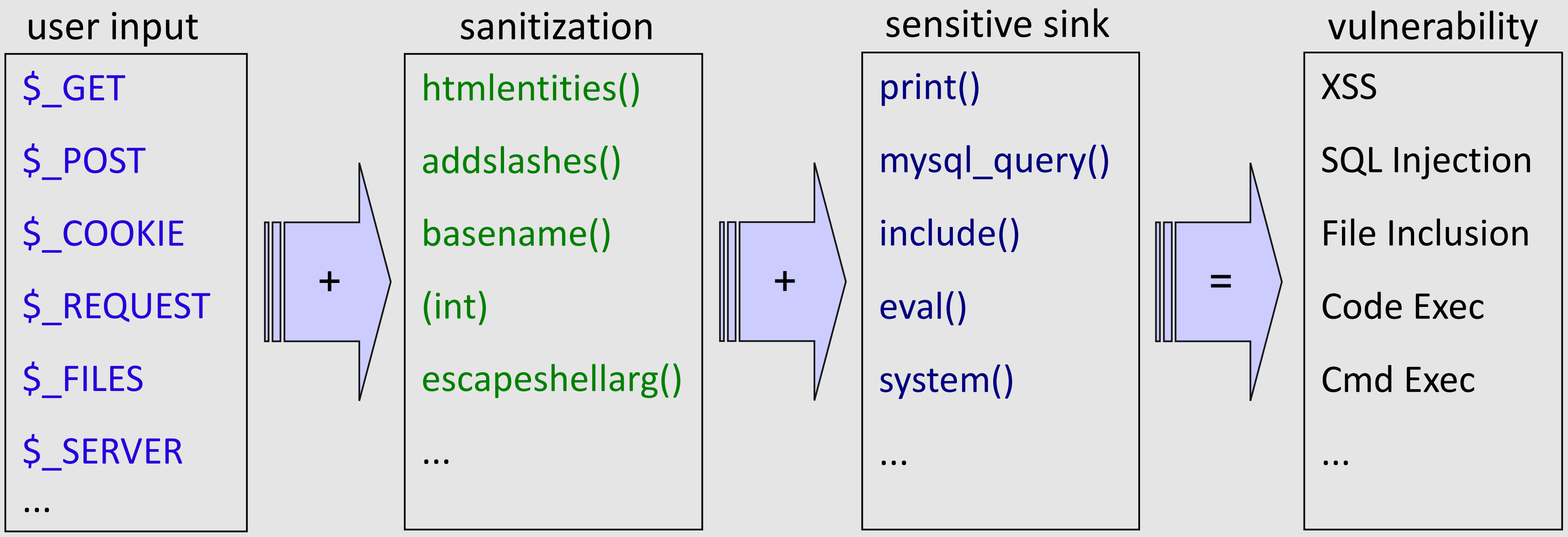
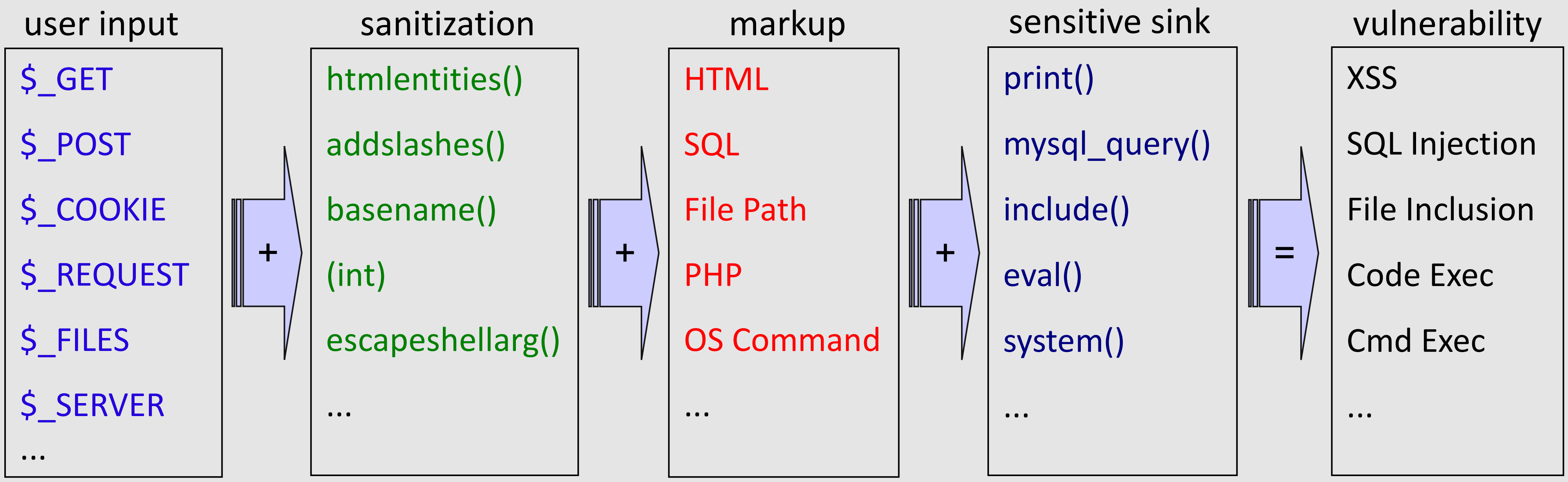
1.4 Taint-style Vulnerabilities



Refined concept of previous prototype and current tools on the market

1.4 Taint-style Vulnerabilities



user input		sanitization		markup		sensitive sink		vulnerability
$_GET		htmlentities()		HTML		print()		XSS
$_POST		addslashes()		SQL		mysql_query()		SQL Injection
$_COOKIE		basename()		File Path		include()		File Inclusion
$_REQUEST	+	(int)	+	PHP	+	eval()	=	Code Exec
$_FILES		escapeshellarg()		OS Command		system()		Cmd Exec
$_SERVER		...		...		...		...
...								

Refined concept of new prototype

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1.5 Lessons Learned

1. Its *easy* to built a static code analysis tool that detects **simple vulnerabilities**

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1.5 Lessons Learned

1. Its *easy* to built a static code analysis tool
   that detects **simple vulnerabilities**
2. Its *challenging* to built a static code analysis tool
   that detects **sophisticated vulnerabilities**
3. Its *hard* to built a static code analysis tool
   that detects **sophisticated vulnerabilities**
   in **large applications** with acceptable **performance**
   and a **low false positive** rate

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RIPS 1.0

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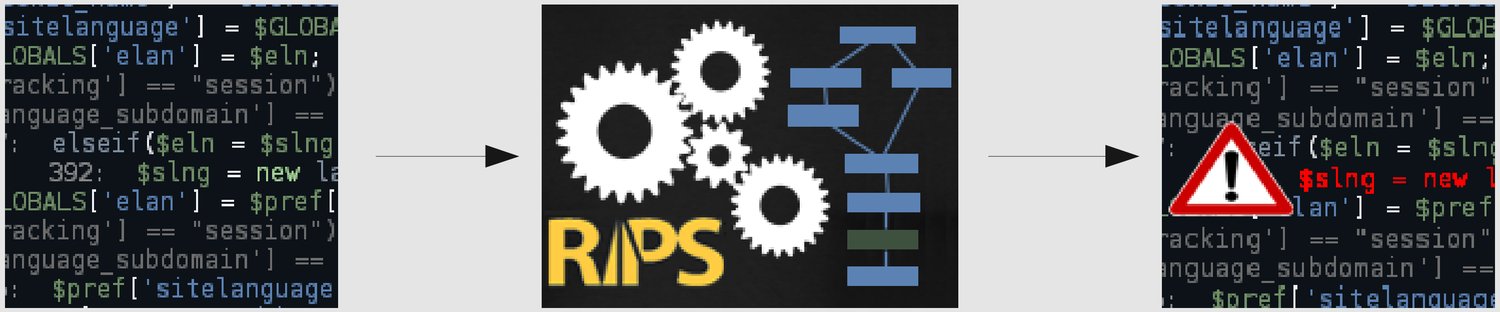

Static Detection of Vulnerabilities in Modern PHP Applications

2. Static VS Dynamic Code Analysis

	Static analyze code without execution	**Dynamic** analyze code while execution
Code Coverage	full	Single execution path
Data Coverage	Compile-time data	Runtime data (valid for environment)
Decidability	Halting Problem	Real data

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2. Static Code Analysis

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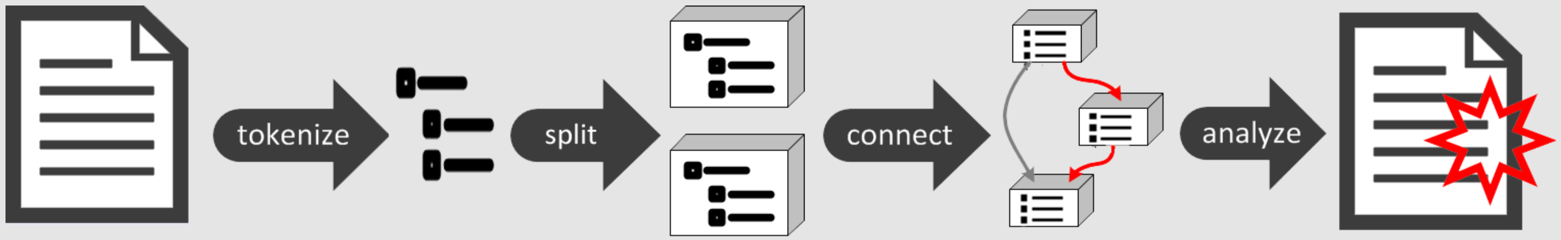
2.1 Overview

- Load all PHP files
- Tokenize PHP code and build an Abstract Syntax Tree (AST)
- Split AST into Basic Blocks
- Connect Basic Blocks to a Control Flow Graph (CFG)
- Analyze data flow through CFG
- RIPS uses *block* and *function summaries*



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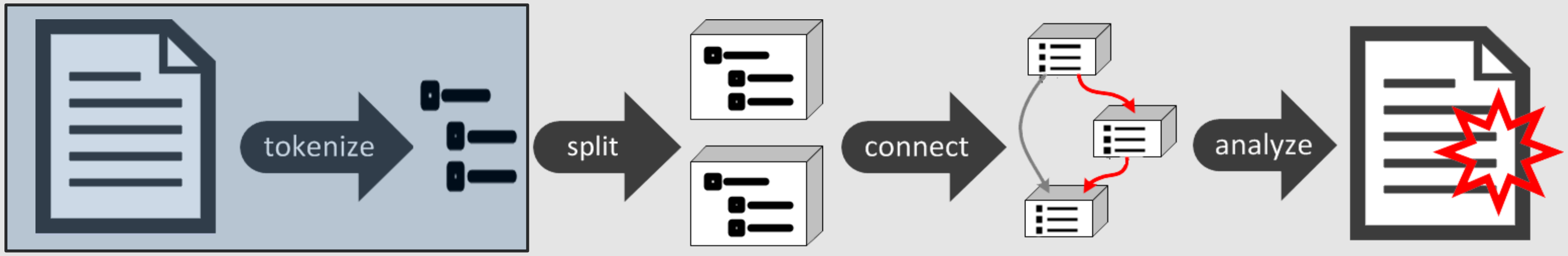
2.2 Abstract Syntax Tree

```
$cookie = $_COOKIE['text'];
```

- Tokenize Code
- Parse tokens according to PHP syntax
- Structure tokens into a tree representation
- AST allows to parse semantics without dealing with punctuation or delimiters



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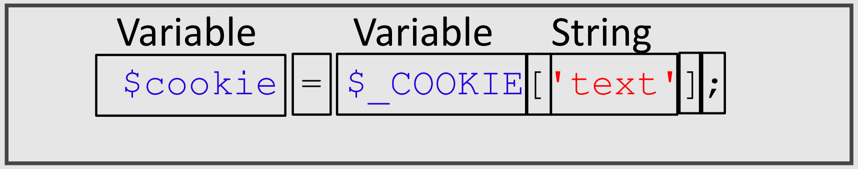

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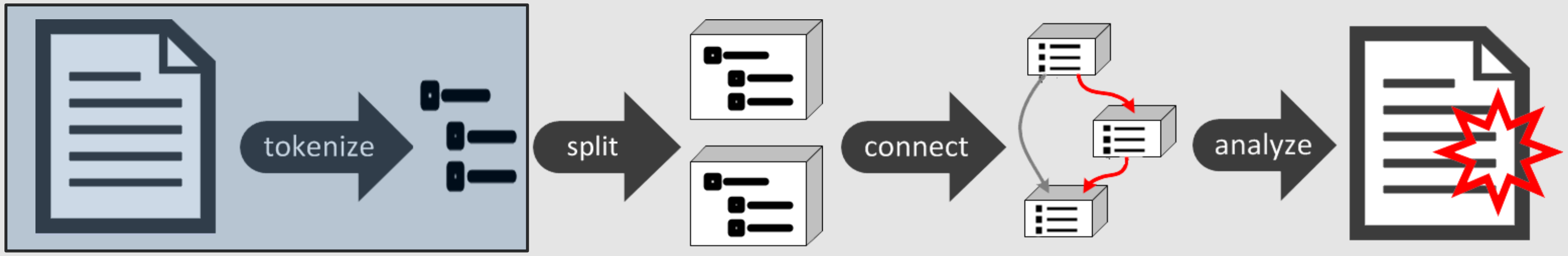

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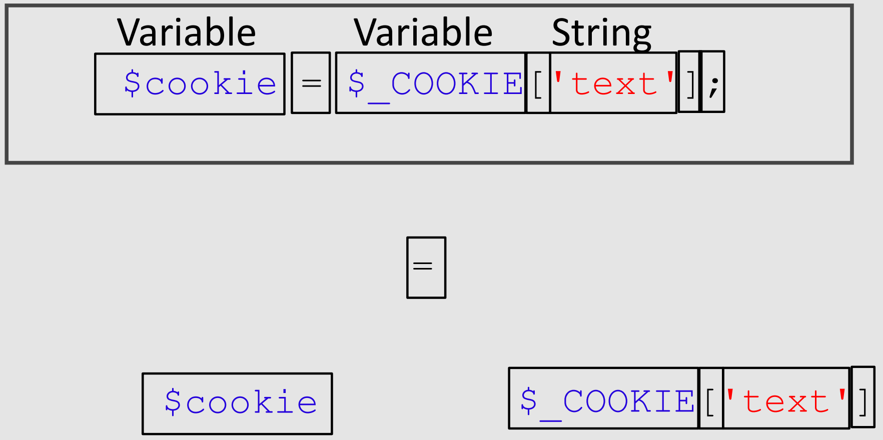

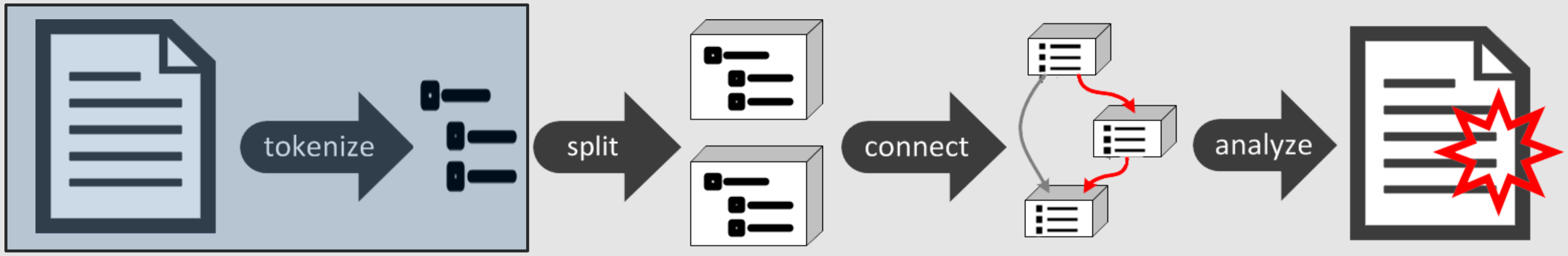

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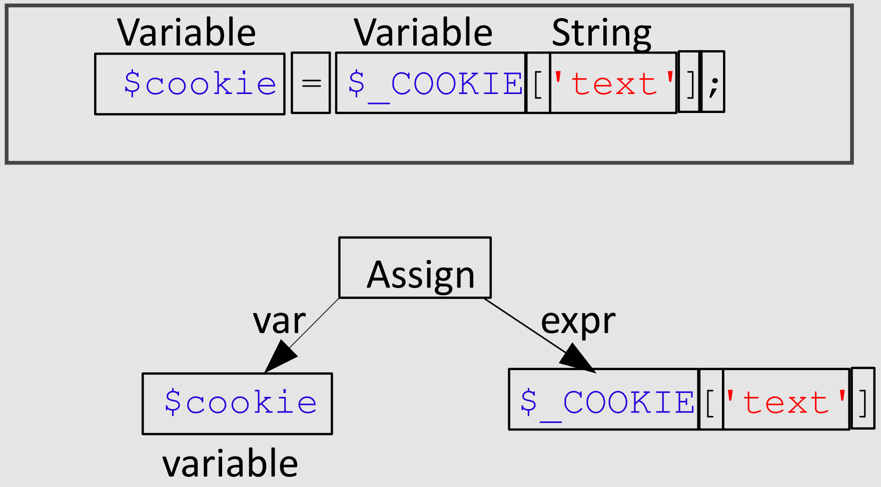

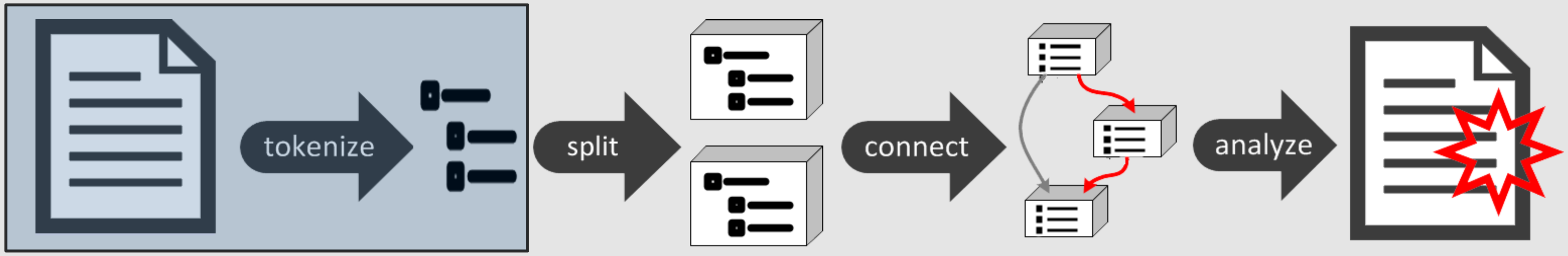

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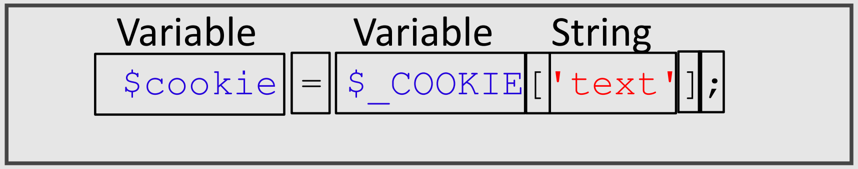
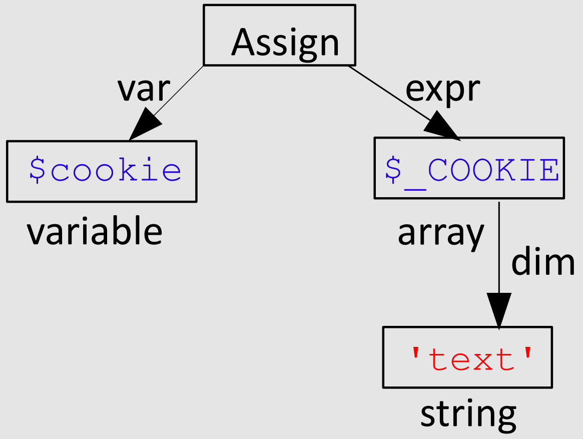
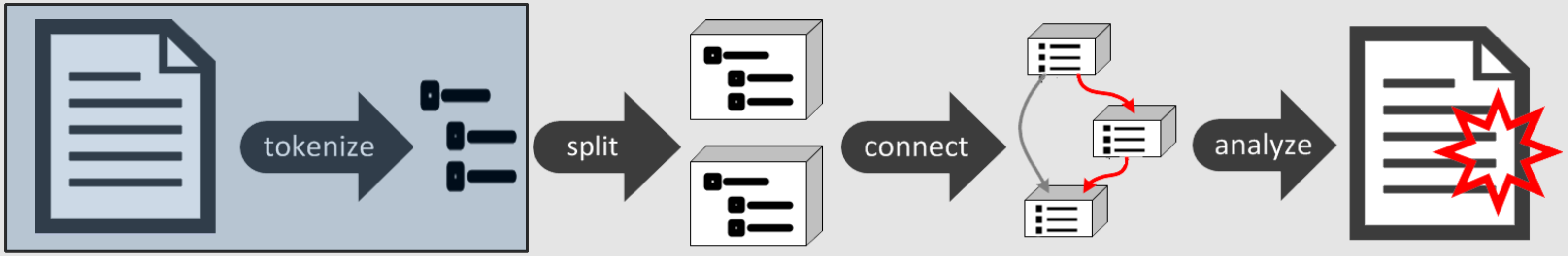


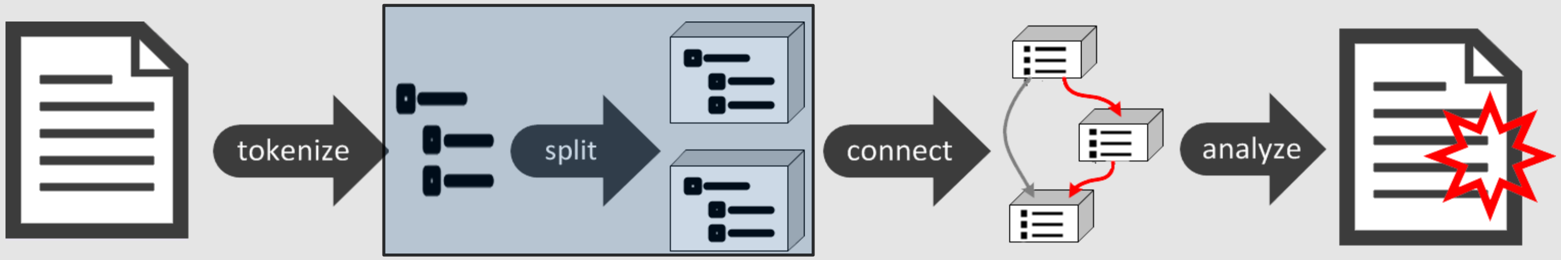




2.3 Basic Block

- Split AST at *jump nodes*
- *Single input, single output* code block
- Simulate data flow in basic block
- Precisely model PHP built-in features
- Summarize data flow

```
...
if(isset($_COOKIE['text'])) {
  $cookie = $_COOKIE['text'];
  $s = $cookie;
}
else {
  $cookie = trim($default);
  $s = $cookie;
}
...
```



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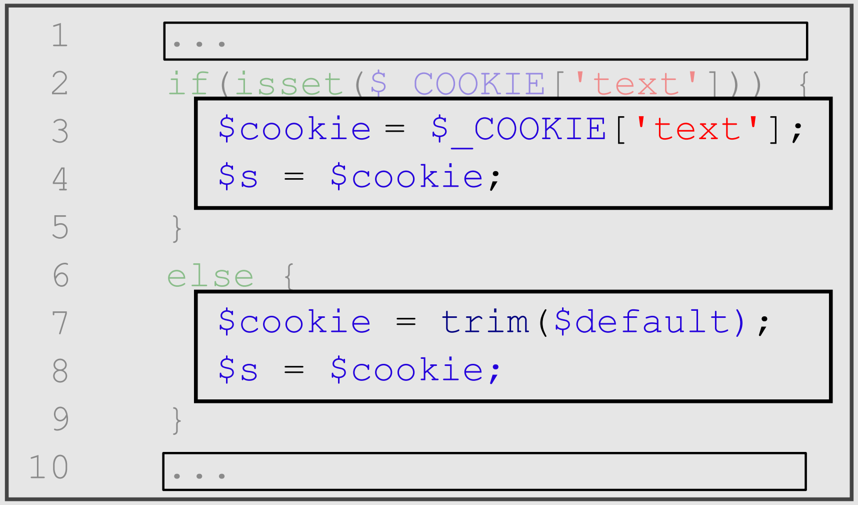
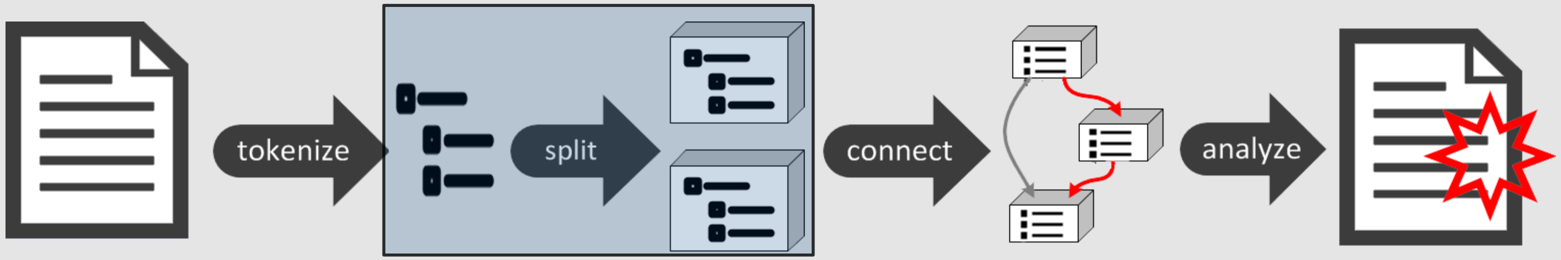


```
...
if(isset($_COOKIE['text'])) {
    $cookie = $_COOKIE['text'];
    $s  = $cookie;
}
else {
    $cookie  = trim($default);
    $s  = $cookie;
}
...
```



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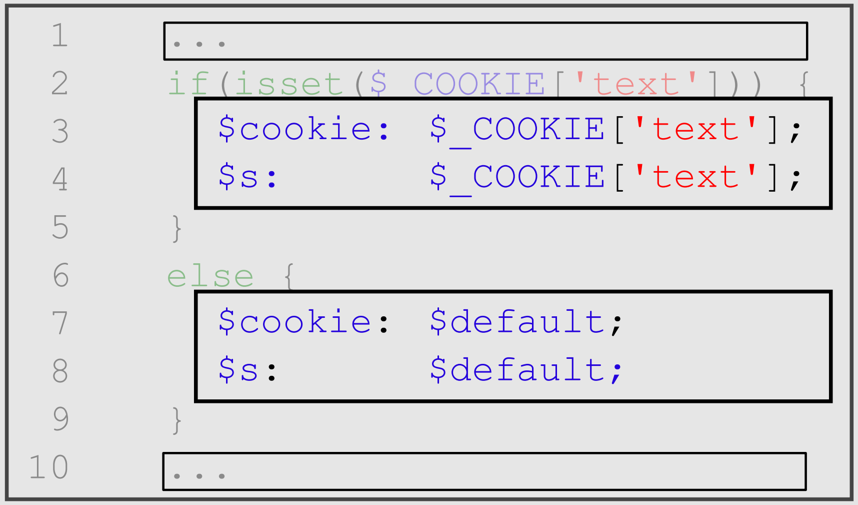

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if(isset($_COOKIE['text'])) {
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    $s:       $_COOKIE['text'];
}
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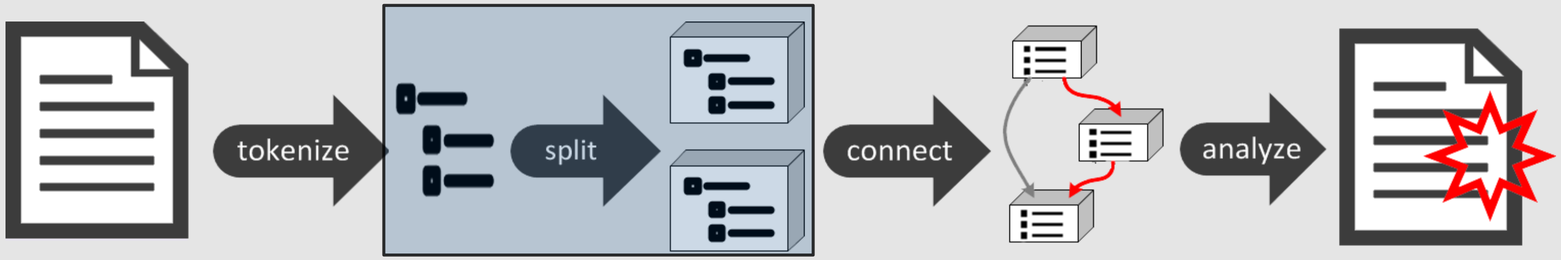

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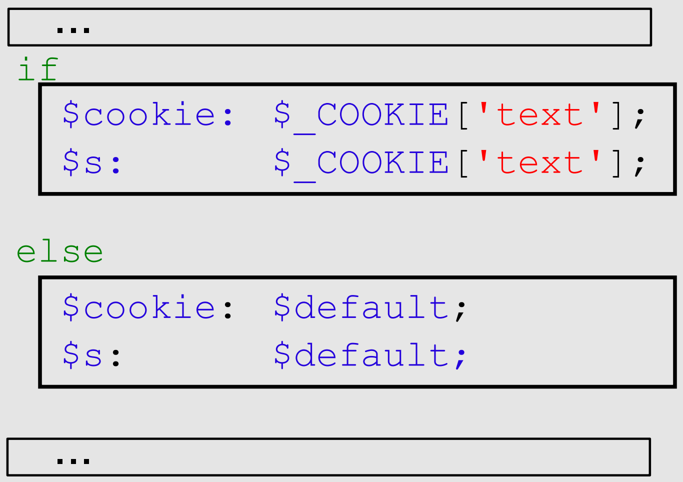
2.4 Control Flow Graph

- Connect basic blocks to CFG
- Edges are jump conditions
- Represents all code paths
- Efficient data flow analysis on block summaries



```
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if
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  $cookie:  $default;
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...
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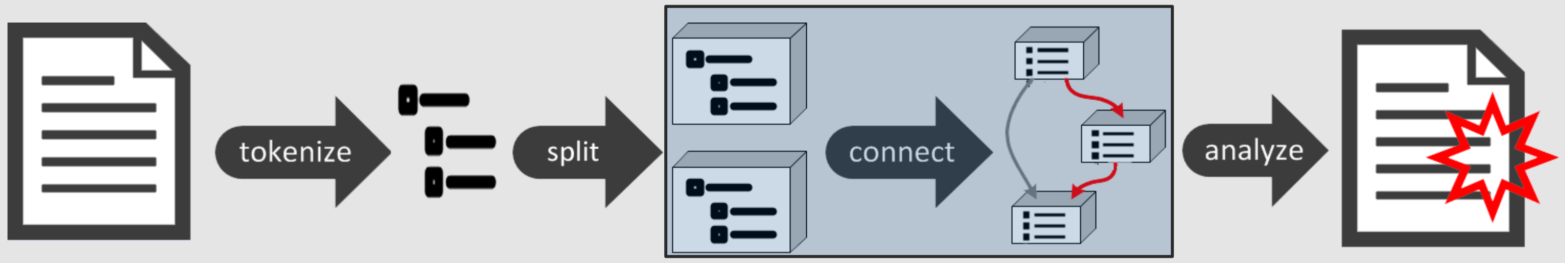

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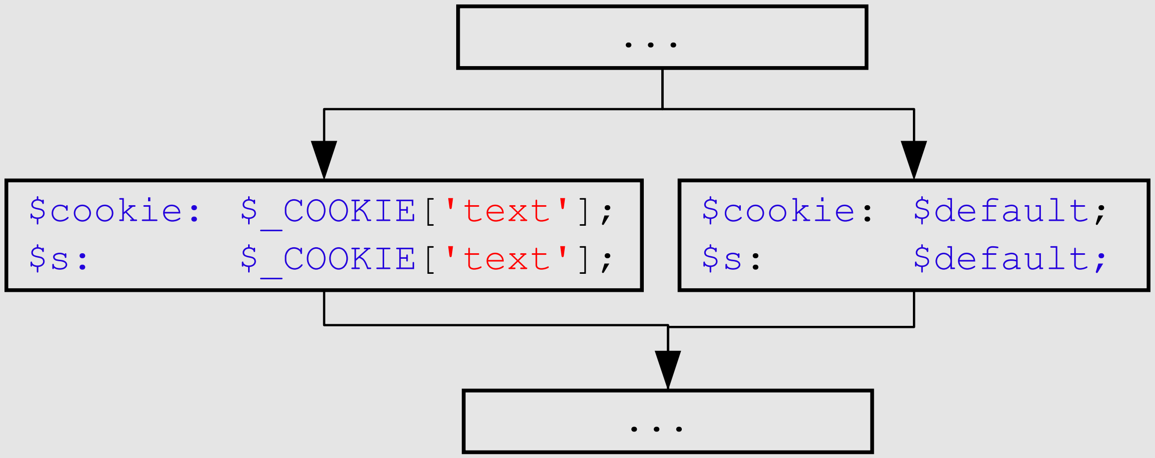

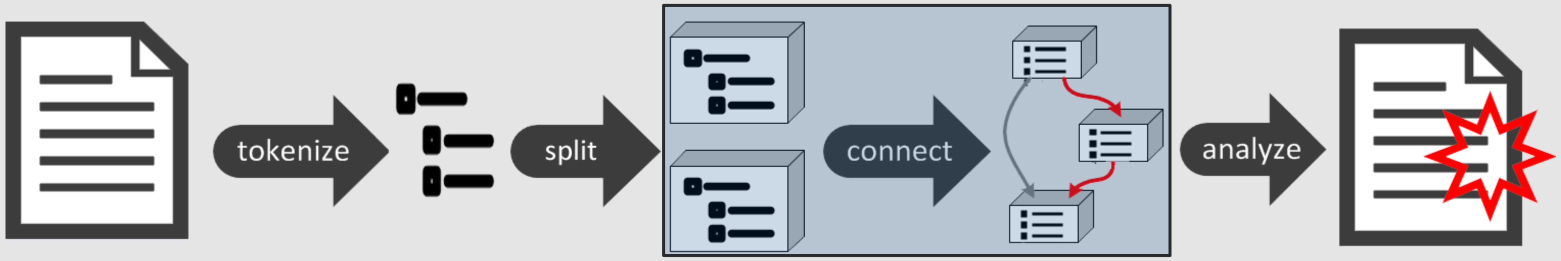

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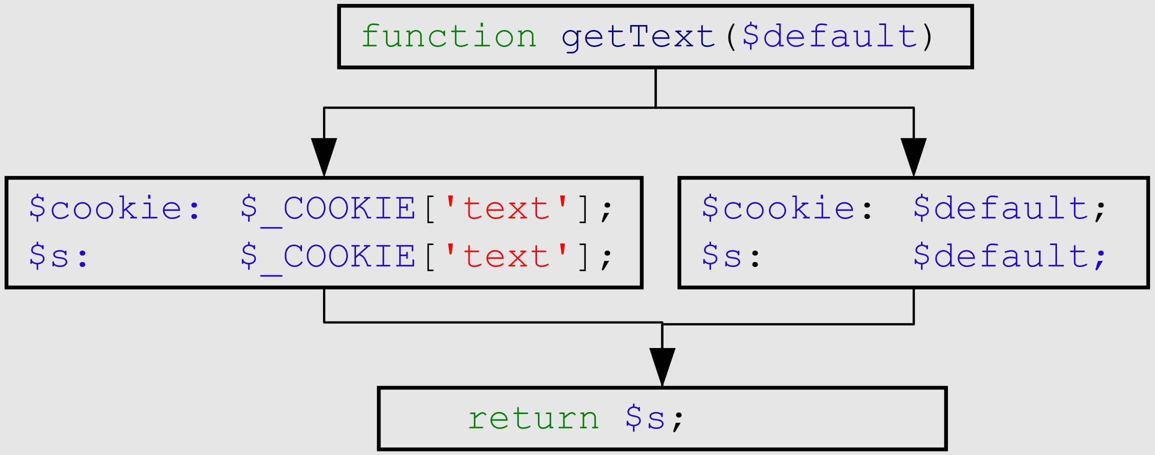
2.5 Inter-procedural Analysis

- Call to user-defined function invokes intra-procedural analysis of this function
- Effects of function are stored in *function summary*

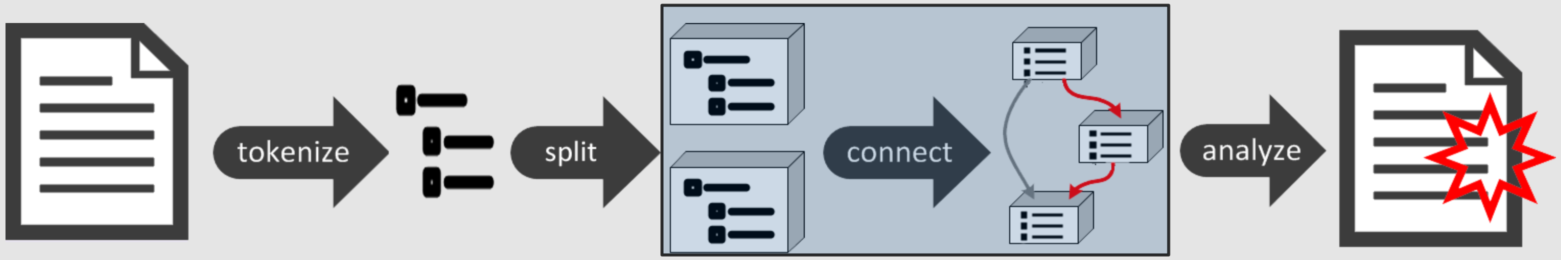


```
function getText($default)

$cookie:  $_COOKIE['text'];
$s:       $_COOKIE['text'];

$cookie:  $default;
$s:       $default;

return $s;
```



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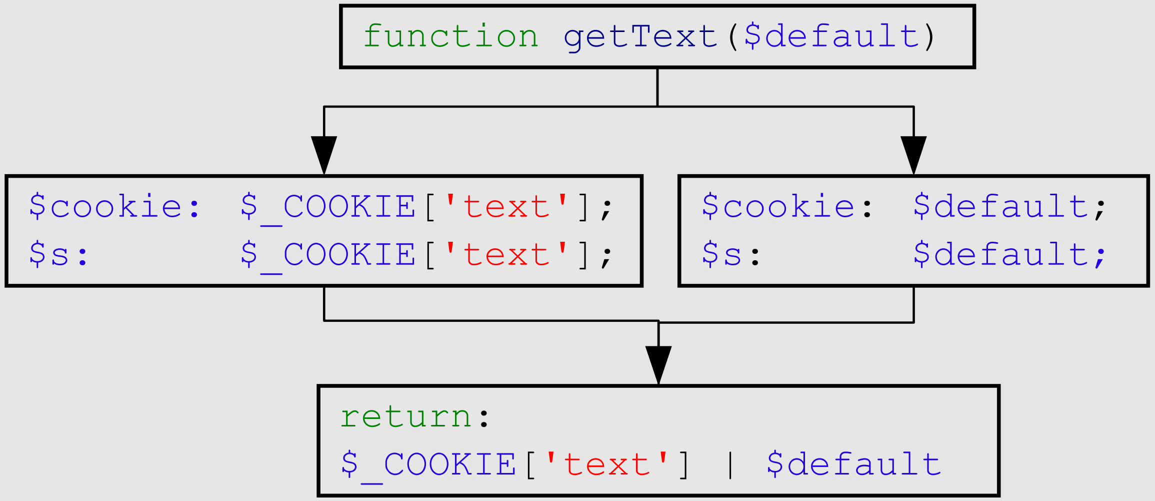
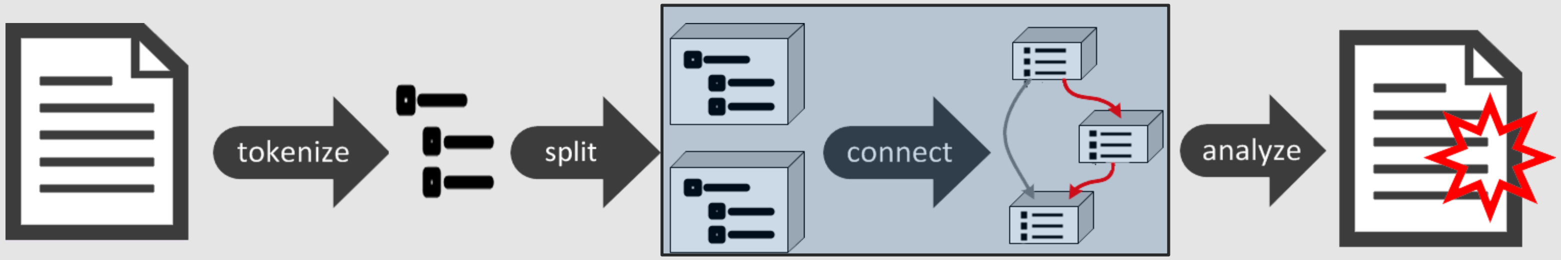


```
function getText($default)

$cookie:  $_COOKIE['text'];
$s:       $_COOKIE['text'];

$cookie:  $default;
$s:       $default;

return:
$_COOKIE['text'] | $default
```



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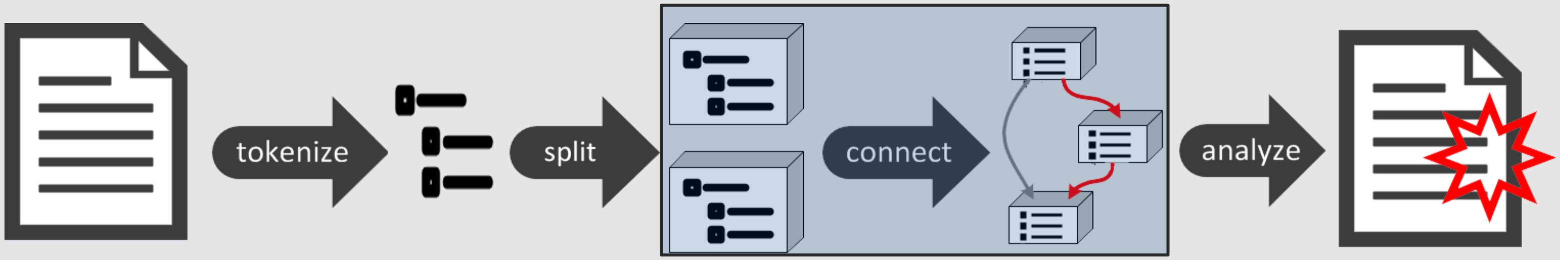
```
function getText($arg1)
return: $_COOKIE['text'] | $arg1
```

```
...
$text = getText('foo');
...
```



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function getText($arg1)
return: $_COOKIE['text'] | $arg1
```
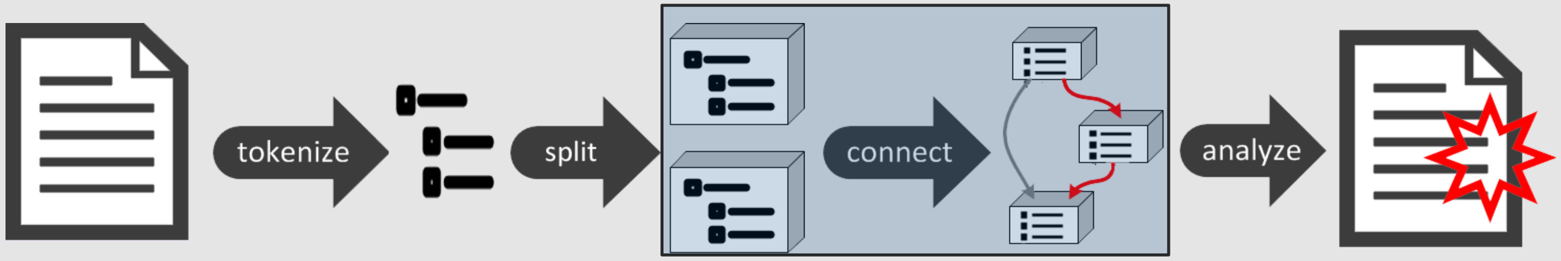
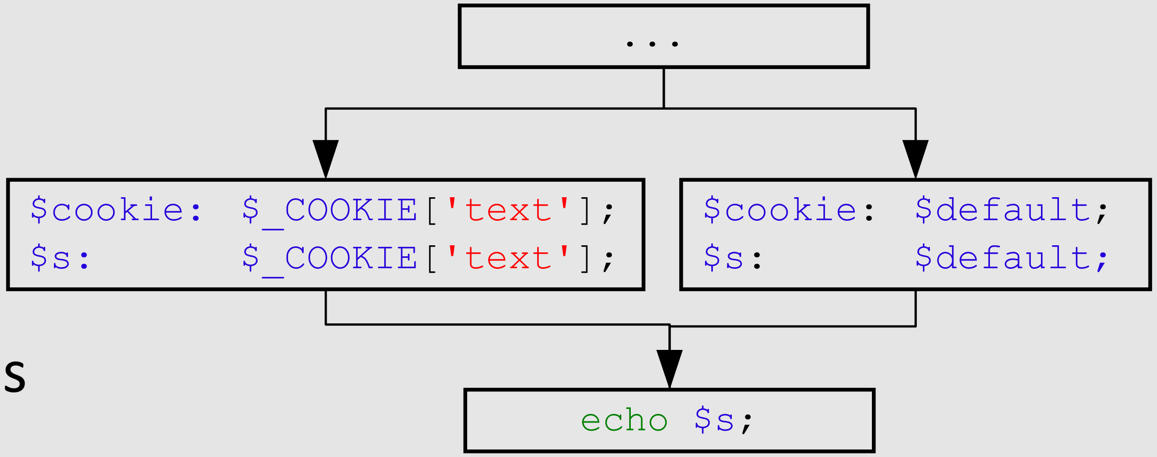

```
$text: $_COOKIE['text']|'foo'
```



2.6 Taint Analysis

- Identify a configured set of sensitive sinks
- Resolve sensitive arguments from previous block summaries
- Issue vulnerabilty report if argument is resolved to a source

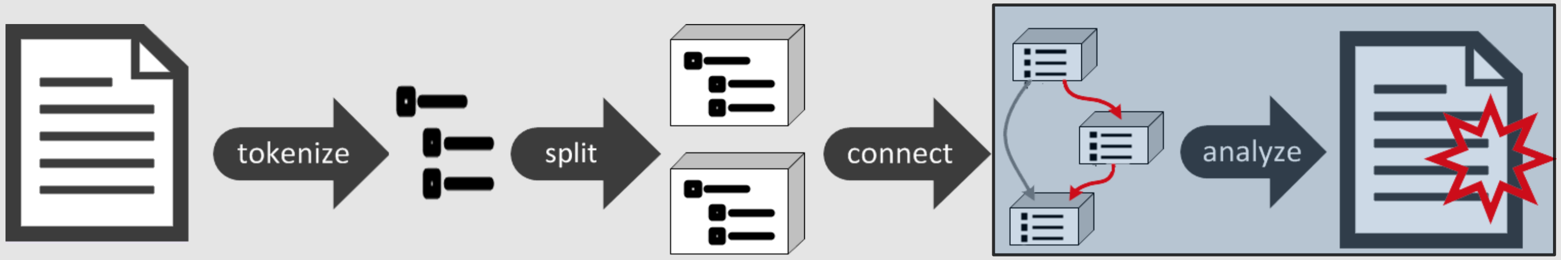


```
...
```

```
$cookie:  $_COOKIE['text'];
$s:       $_COOKIE['text'];
```

```
$cookie:  $default;
$s:       $default;
```

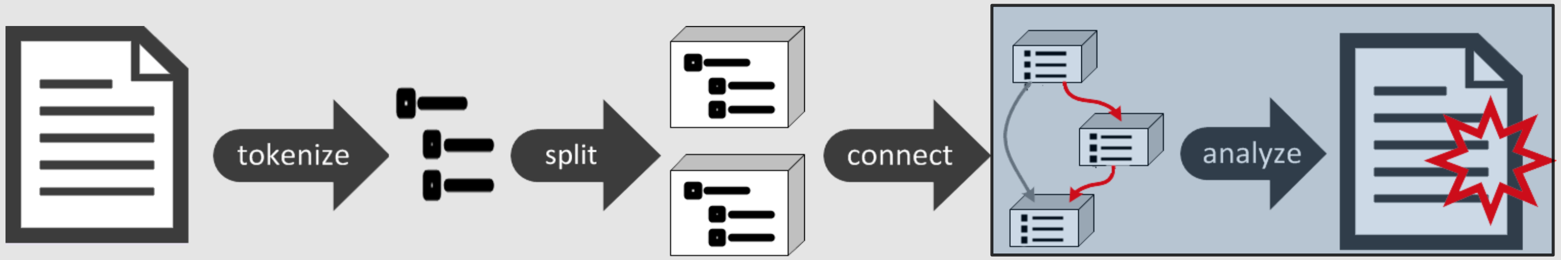
```
echo $s;
```



2.7 Context-sensitive String Analysis

- Resolve all strings (markup) of a sensitive argument
- Replace sources with a placeholder
- Invoke markup parser
- Evaluate sanitization of each source regarding its markup context

```php
$s = addslashes($_GET['s']);
if($mode == 1) {
   $where = "name = '$s'";
}
else {
   $where = "id = $s";
}
mysql_query('SELECT *
   FROM users ' . $where);
```



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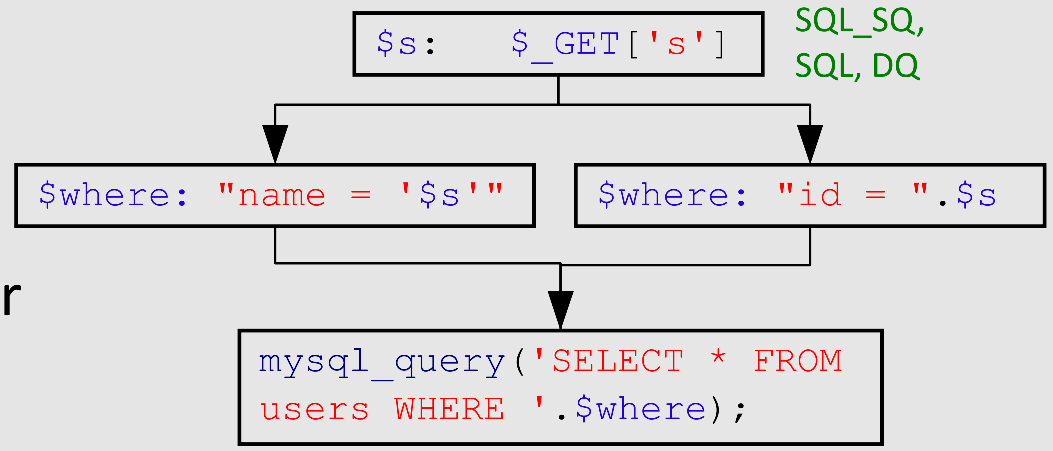


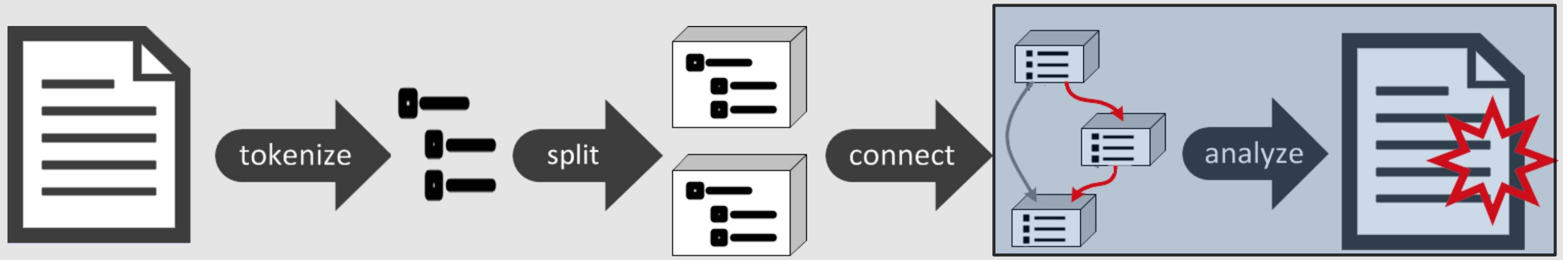
```
$s:    $_GET['s']
```

SQL_SQ, SQL, DQ

```
$where: "name = '$s'"
```

```
$where: "id = ".$s
```

```
mysql_query('SELECT * FROM
users WHERE '.$where);
```



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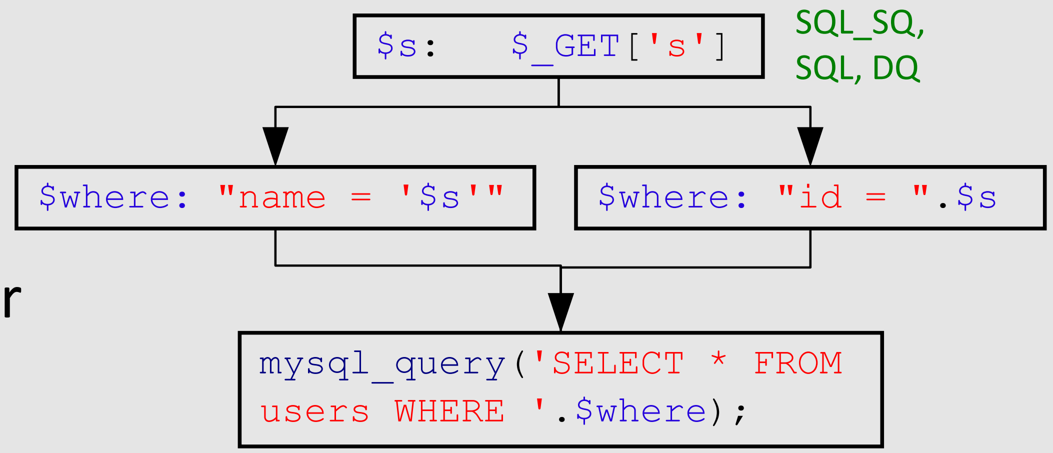

```
$s:    $_GET['s']
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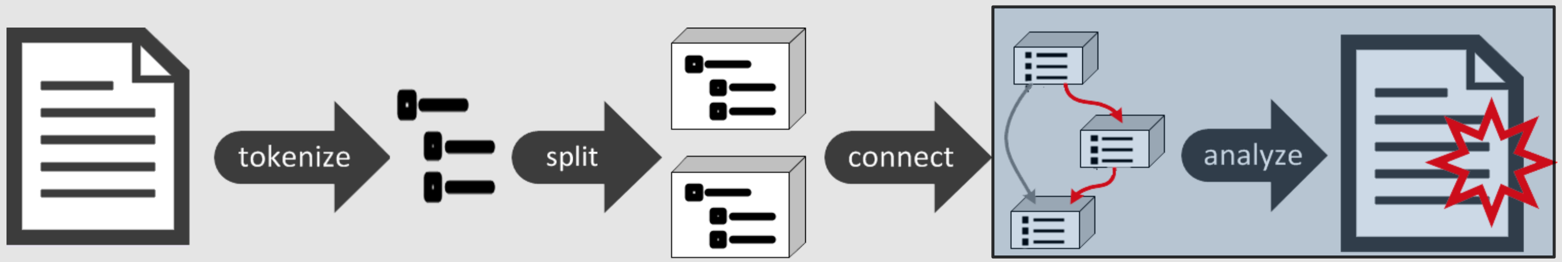
SQL_SQ,
SQL, DQ

```
$where: "name = '$s'"
$where: "id = ".$s
mysql_query('SELECT * FROM
users WHERE '.$where);
```

```
SELECT * FROM users WHERE name = 'S'  SQL_SQ
SELECT * FROM users WHERE id = S      SQL_NQ
```



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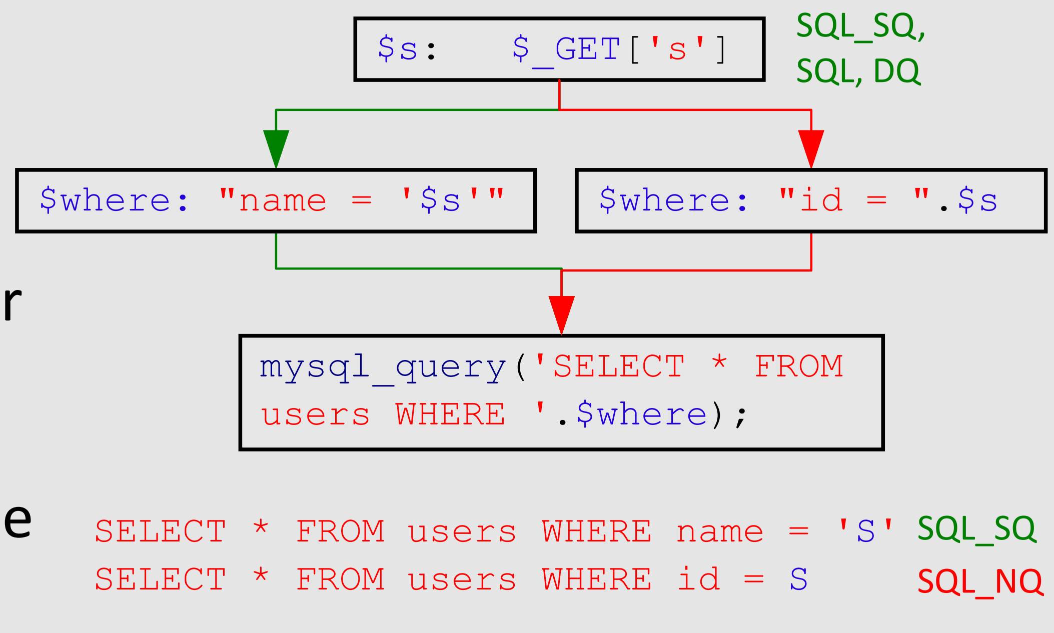

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$where: "id = ".$s
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```
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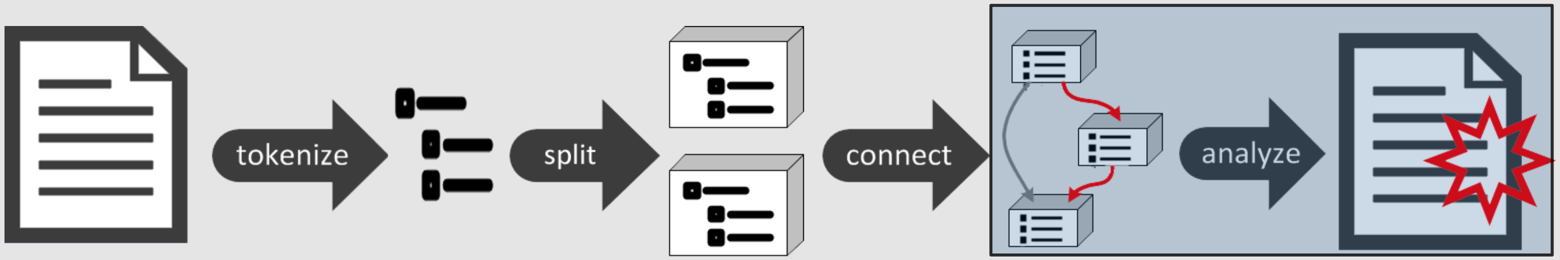
```

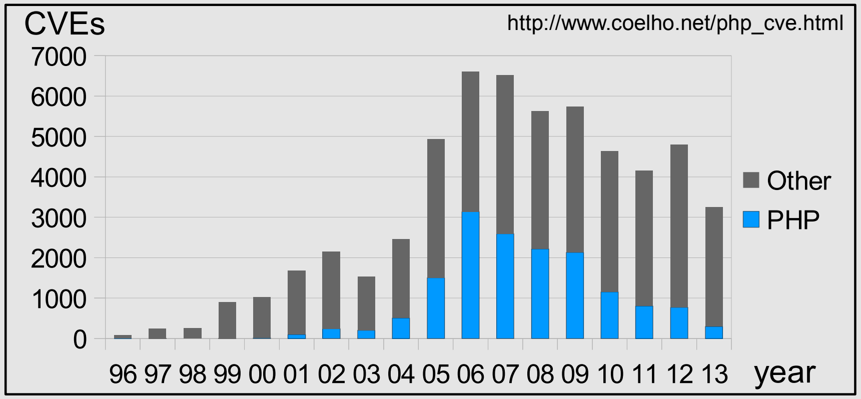
```
SELECT * FROM users WHERE name = 'S'
SELECT * FROM users WHERE id = S
```

SQL_SQ
SQL_NQ



3. Detecting *Modern* Vulnerabilities

- Taint-style concept remains: source → sink
- Data flow is more complex
  - Dynamic language features
  - Array Handling
  - PHP built-in features
  - **Input sanitization + validation**
  - Object-Oriented Programming
- More LOC (100k-200k)



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3.1 Analyze Exceptional Sources

- Often sanitized: $_GET, $_POST, and $_REQUEST
- Often overlooked: $_SERVER, $_FILES, and $_COOKIE
- Examples:

PHP Source	Developer Assumption	Exploit Example
$_SERVER['PHP_SELF']	*/index.php*	*/index.php/"><svg+onload=alert(1)>*
$_SERVER['REQUEST_URI']	*/index.php?payload=%22%27*	GET /?a='or(1)=1-- HTTP/1.0 or IE
$_SERVER['HTTP_HOST']	localhost	Host: ' or (1)=1-- -
$_FILES['picture']['name']	alphanumeric.jpg	'or (1)=1-- -.jpg

- RIPS analyzes sources context-sensitively

3.2 Precise Array Handling

- PHP superglobals ($_GET, $_POST, etc.) are arrays
- RIPS analyzes built-ins precisely
- Array keys are tainted too (Drupal)

```
SugarCRM 6.5.18                          /include/export_utils.php
function export($type, $records) {
   $records = explode(',', $records);
   $records = "'" . implode("','", $records) . "'";
   $where = "{$focus->table_name}.id in ($records)";
}
export(clean($_REQUEST['module']), $_REQUEST['uid']);
```

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3.2 Precise Array Handling

- PHP superglobals ($_GET, $_POST, etc.) are arrays
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```
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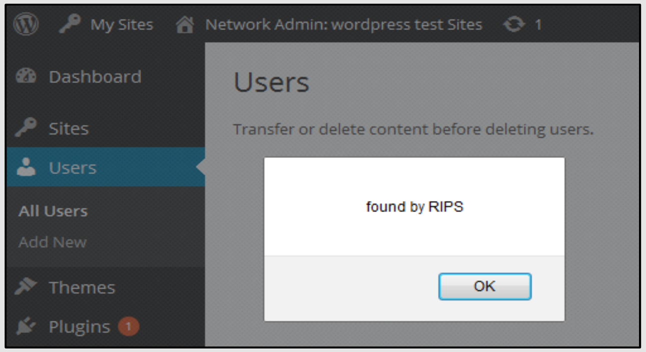
   $records = "'" . implode("','", $records) . "'";
   $where = "{$focus->table_name}.id in ($records)";
}
export(clean($_REQUEST['module']), $_REQUEST['uid']);
```

```
Wordpress 4.0.1              /wp-admin/network/users.php
function confirm_delete_users($users) {
   foreach($_POST['allusers'] as $key => $val) {
      echo "<input name='user[]' value='{$val}'/>\n";
   }
}
allusers[0]='><script>alert('found by RIPS')</script>
```



Users

Transfer or delete content before deleting users.

found by RIPS

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3.3 Object-Oriented Programming

Assist *backwards-directed* data flow analysis with *forwards-directed* data propagation

osCommerce 2.3.4 /admin/backup.php

```php
class Upload {
    function parse($name) {
        $this->set_filename($_FILES[$name]['name']);
    }
    function set_filename($filename) {
        $this->filename = $filename;
    }
}

$sql_file = new Upload();
if ($sql_file->parse('sql_file') == true) {
    $read_from = $sql_file->filename;
}
tep_db_query("insert into " . TABLE_CONFIG . " values
          ('DB_RESTORE', '" . $read_from . "', '6', '')");
```

3.3 Object-Oriented Programming

Assist *backwards-directed* data flow analysis with *forwards-directed* data propagation

osCommerce 2.3.4 /admin/backup.php

```
class Upload {
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3.3 Object-Oriented Programming

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3.3 Object-Oriented Programming

Assist *backwards-directed* data flow analysis with *forwards-directed* data propagation

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3.3 Object-Oriented Programming

Assist *backwards-directed* data flow analysis with *forwards-directed* data propagation

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```

3.3 Object-Oriented Programming

Assist *backwards-directed* data flow analysis with *forwards-directed* data propagation

osCommerce 2.3.4 /admin/backup.php

```
  1 class Upload {
  2     function parse($name) {
  3         $this->set_filename($_FILES[$name]['name']);
  4     }
  5     function set_filename($filename) {
  6         $this->filename = $filename;
  7     }
  8 }

199 $sql_file = new Upload();
201 if ($sql_file->parse('sql_file') == true) {
202     $read_from = $sql_file->filename;
203 }
273 tep_db_query("insert into " . TABLE_CONFIG . " values
             ('DB_RESTORE', '" . $read_from . "', '6', '')");
```

3.4 Insufficient Sanitization

- Sanitization tags
- Encoding stack
- Decoding stack
- Escaping level

Pligg CMS 2.0.2 /admin/admin_categories.php

```
$parent = substr(addslashes($_REQUEST['parent']),9,100);
$sql = "update ".table_categories." set category_parent
         = " . $parent . " where category_id=" . $id . ";";
$db->query($sql);
```

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3.4 Insufficient Sanitization

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         = " . $parent . " where category_id=" . $id . ";";
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```

12345678901234567890'

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3.4 Insufficient Sanitization

- Sanitization tags
- Encoding stack
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1234567890123456789O\'

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12345678901234567890\

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$sql = "update ".table_categories." set category_parent
         = " . $parent . " where category_id=" . $id . ";";
$db->query($sql);
```

1, category_title=(SELECT password ...)

3.4 Insufficient Sanitization

- Sanitization tags
- Encoding stack
- Decoding stack
- Escaping level

Pligg CMS 2.0.2 /admin/admin_categories.php

```
$parent = substr(addslashes($_REQUEST['parent']),9,100);
$sql = "update ".table_categories." set category_parent
      = " . $parent . " where category_id=" . $id . ";";
$db->query($sql);
```

Mambo CMS 4.6.2 /includes/cmtclasses.php

```
$mosmsg = mosGetParam($_REQUEST, 'mosmsg', '');
$mosmsg = addslashes($mosmsg);
echo "\n<div class=\"message\">$mosmsg</div>";
```

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3.4 Insufficient Sanitization

- Sanitization tags
- Encoding stack
- Decoding stack
- Escaping level

```
Pligg CMS 2.0.2                         /admin/admin_categories.php
233 $parent = substr(addslashes($_REQUEST['parent']),9,100);
245 $sql = "update ".table_categories." set category_parent
         = " . $parent . " where category_id=" . $id . ";";
246 $db->query($sql);
```

```
Mambo CMS 4.6.2                             /includes/cmtclasses.php
88  $mosmsg = mosGetParam($_REQUEST, 'mosmsg', '');
90  $mosmsg = addslashes($mosmsg);
91  echo "\n<div class=\"message\">$mosmsg</div>";
```

```
Couch CMS 1.4                       /couch/includes/fileuploader/io.php
603 echo '<script type="text/javascript">';
621 $rpl = array( '\\' => '\\\\', '"' => '\\"' );
623 echo 'OnUploadCompleted("' . strtr($msg, $rpl) . '");';
623 echo '</script>';
```

3.4 Insufficient Sanitization

- Sanitization tags
- Encoding stack
- Decoding stack
- Escaping level

Pligg CMS 2.0.2 /admin/admin_categories.php

```
$parent = substr(addslashes($_REQUEST['parent']),9,100);
$sql = "update ".table_categories." set category_parent
      = " . $parent . " where category_id=" . $id . ";";
$db->query($sql);
```

Mambo CMS 4.6.2 /includes/cmtclasses.php

```
$mosmsg = mosGetParam($_REQUEST, 'mosmsg', '');
$mosmsg = addslashes($mosmsg);
echo "\n<div class=\"message\">$mosmsg</div>";
```

Couch CMS 1.4 /couch/includes/fileuploader/io.php

```
echo '<script type="text/javascript">';
$rpl = array( '\\' => '\\\\', '"' => '\\"' );
echo 'OnUploadCompleted("' . strtr($msg, $rpl) . '");';
echo '</script>';
```

```
</script><script>alert(1)</script>
```

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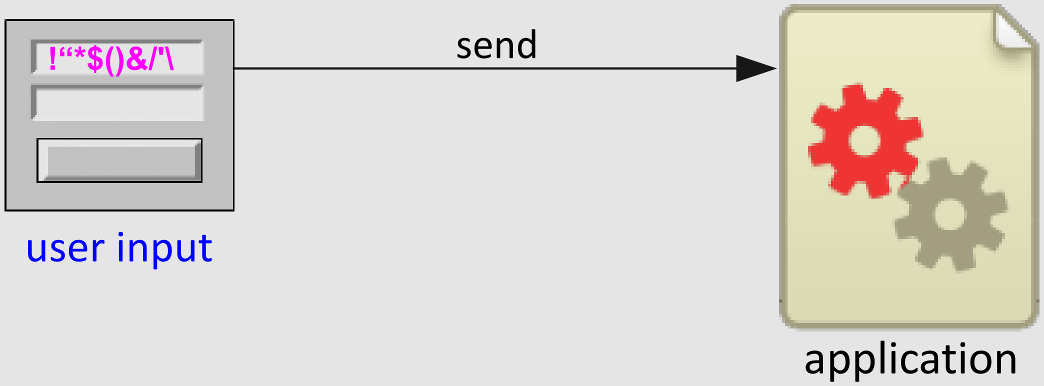
3.5 Second-Order Vulnerabilities

„First-Order“ SQL Injection:

```
$name  = $_POST['name'];
$pwd   = md5($_POST['pwd']);
$query = "INSERT INTO users VALUES('$name','$pwd')";
$result = mysql_query($query);
```



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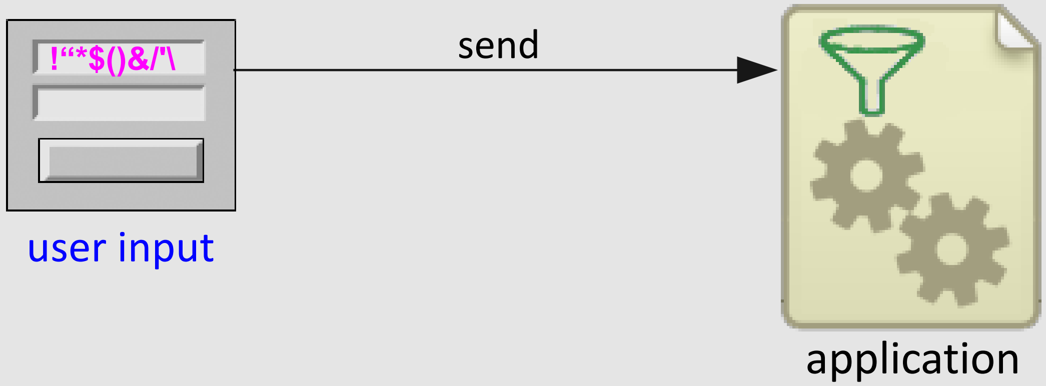
3.5 Second-Order Vulnerabilities

„First-Order“ SQL Injection (sanitized):

```
$name = mysql_real_escape_string($_POST['name']);
$pwd  = md5($_POST['pwd']);
$query = "INSERT INTO users VALUES('$name','$pwd')";
$result = mysql_query($query);
```



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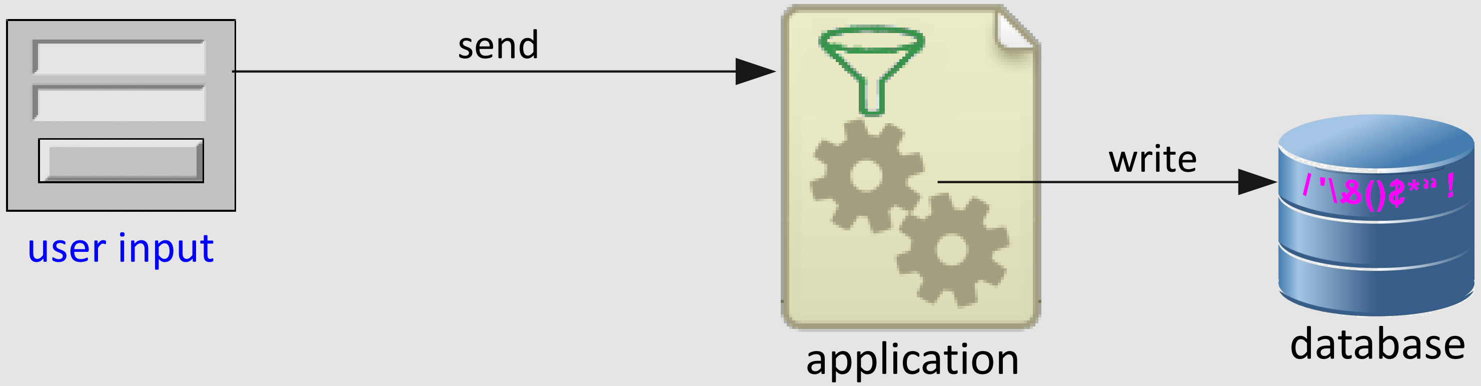
3.5 Second-Order Vulnerabilities

Database Write:

```
$name  = mysql_real_escape_string($_POST['name']);
$pwd   = md5($_POST['pwd']);
$query = "INSERT INTO users VALUES('$name','$pwd')";
$result = mysql_query($query);
```



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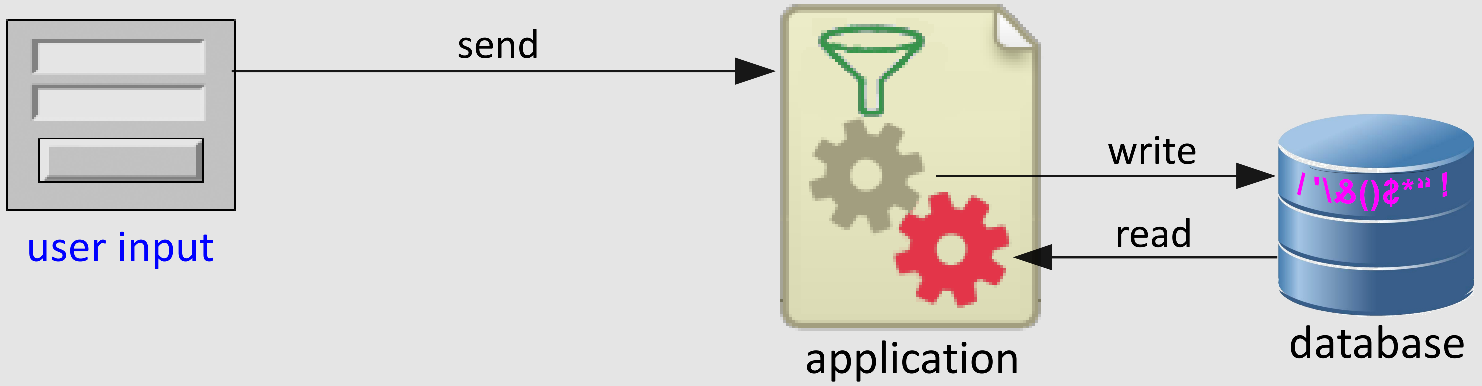
3.5 Second-Order Vulnerabilities

Database Read:

```
$query = "SELECT * FROM users WHERE id = 1";
$result = mysql_query($query);
$user = mysql_fetch_assoc($result);
echo $user['name'];
```



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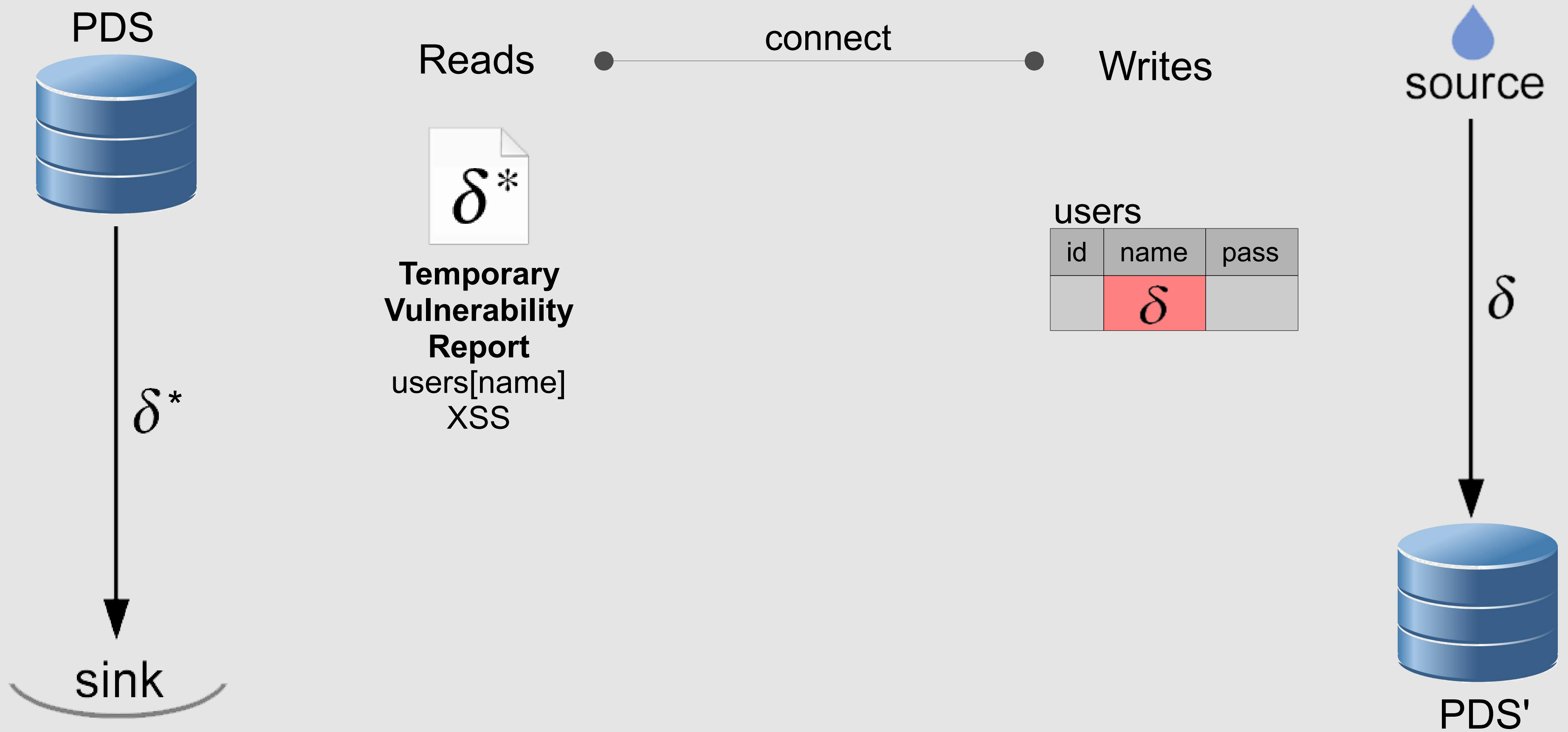
3.5 Second-Order Vulnerabilities



Temporary Vulnerability Report
users[name]
XSS

users

id	name	pass
	δ	

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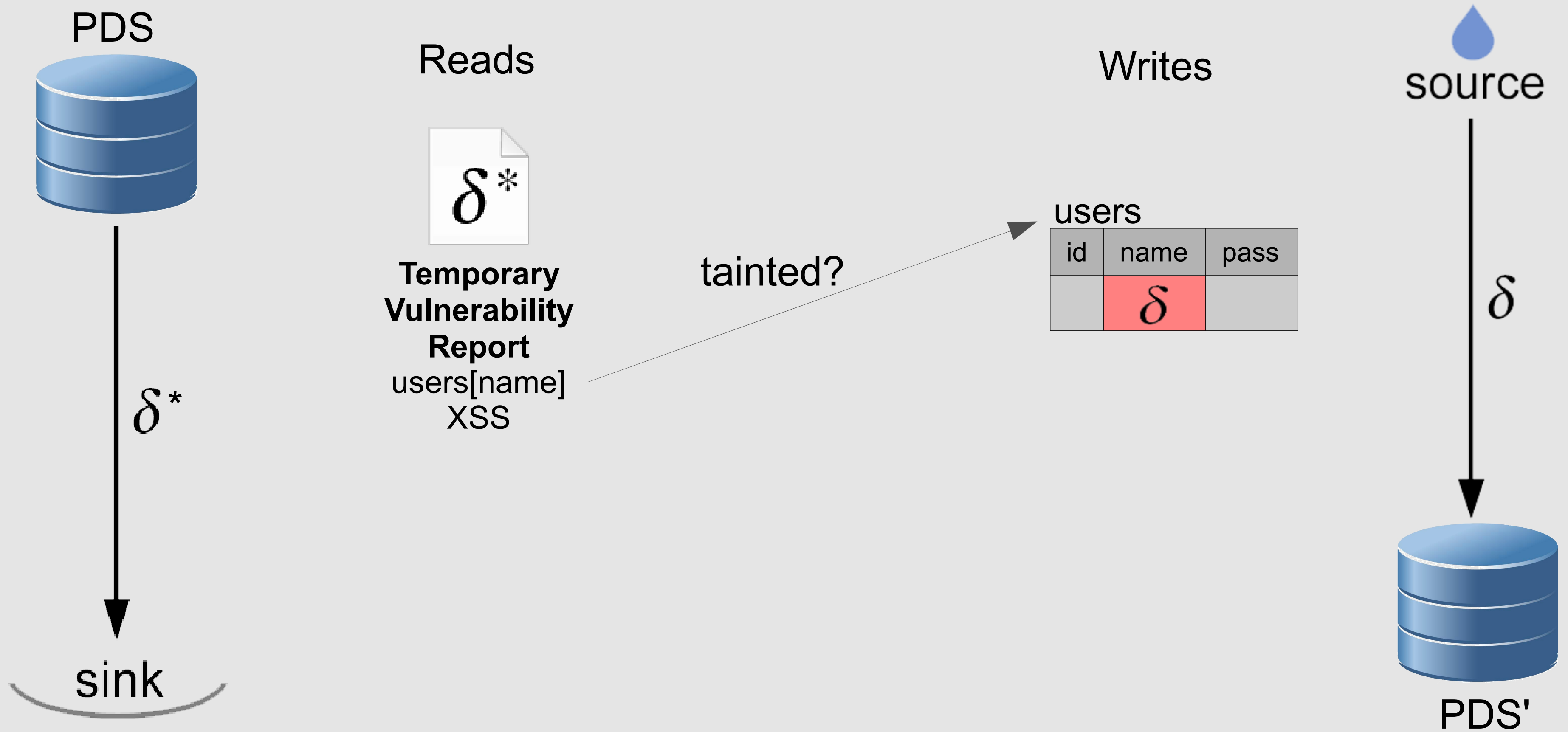
3.5 Second-Order Vulnerabilities



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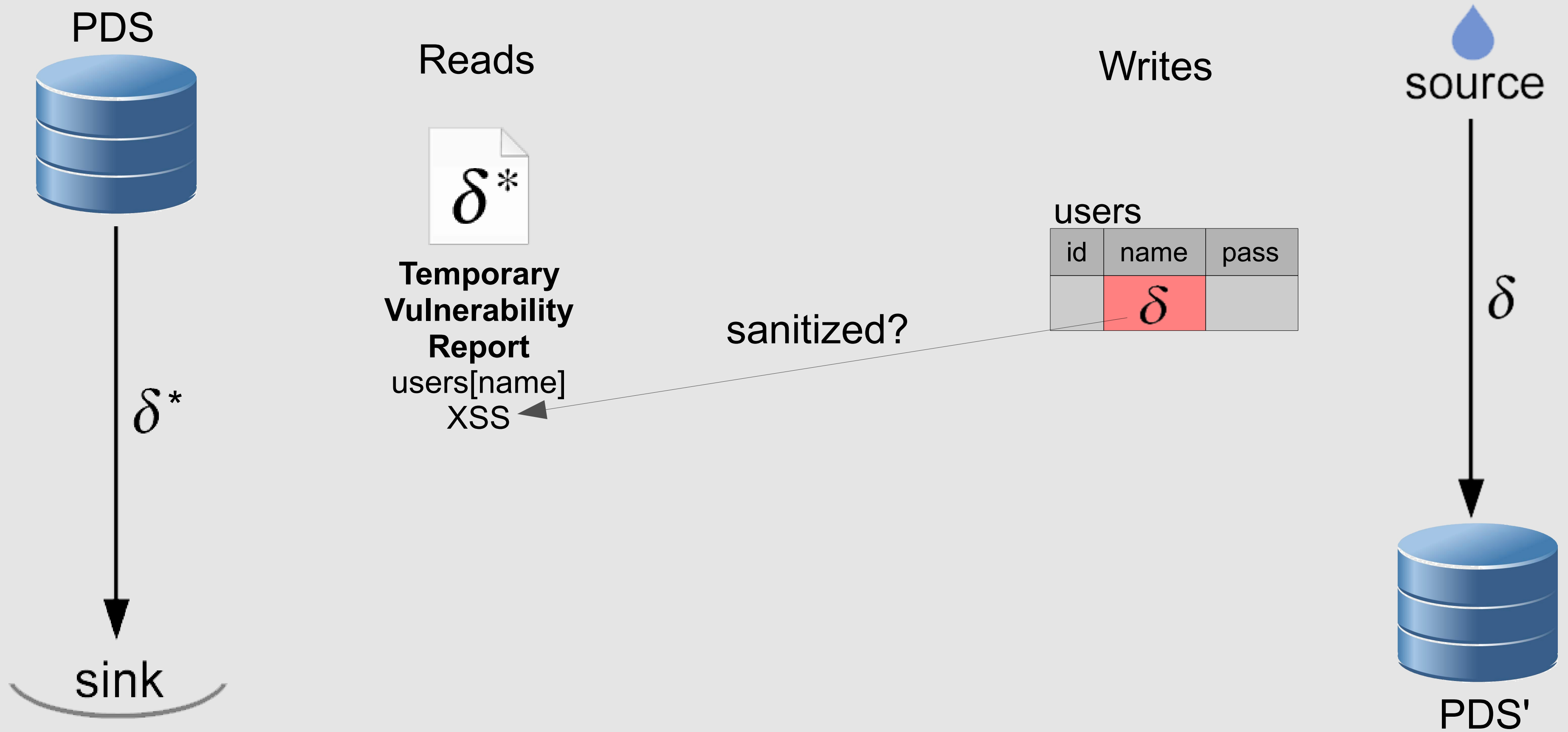
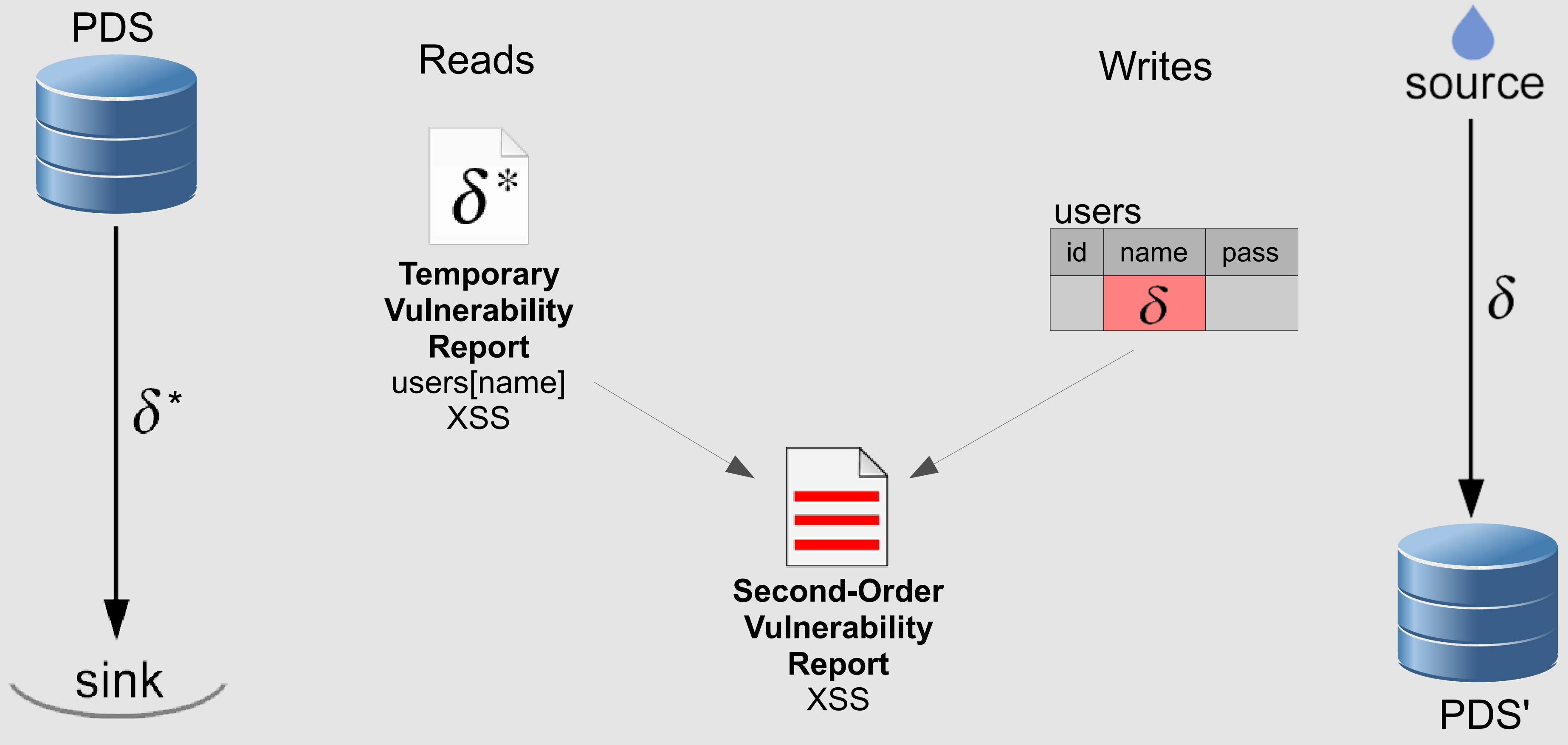
3.5 Second-Order Vulnerabilities



3.5 Second-Order Vulnerabilities



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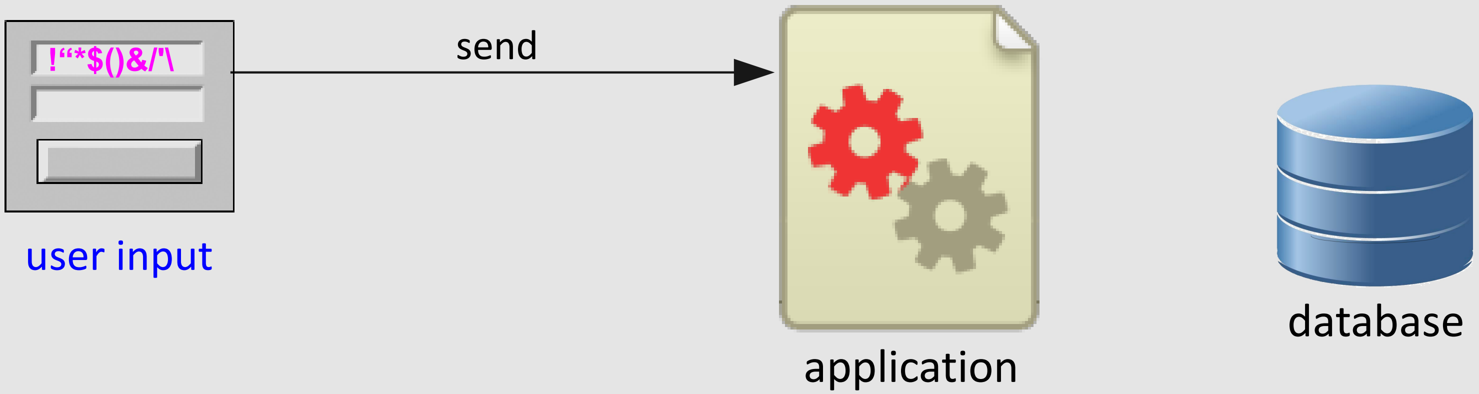
3.6 Multi-Step Exploits

„First-Order“ SQL Injection:

```
$name  = $_POST['name'];
$pwd   = md5($_POST['pwd']);
$query = "INSERT INTO users VALUES('$name','$pwd')";
$result = mysql_query($query);
```



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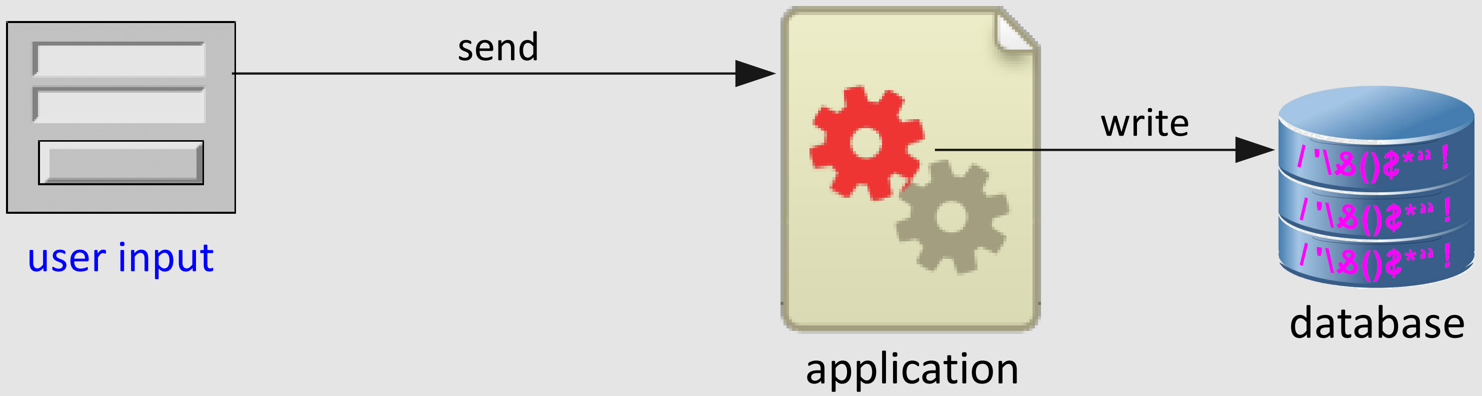
3.6 Multi-Step Exploits

Exploit „First-Order“ SQL Injection to taint database:

```
$name = $_POST['name'];          // ', 'payload')-- -
$pwd  = md5($_POST['pwd']);
$query = "INSERT INTO users VALUES('$name','$pwd')";
$result = mysql_query($query);
```



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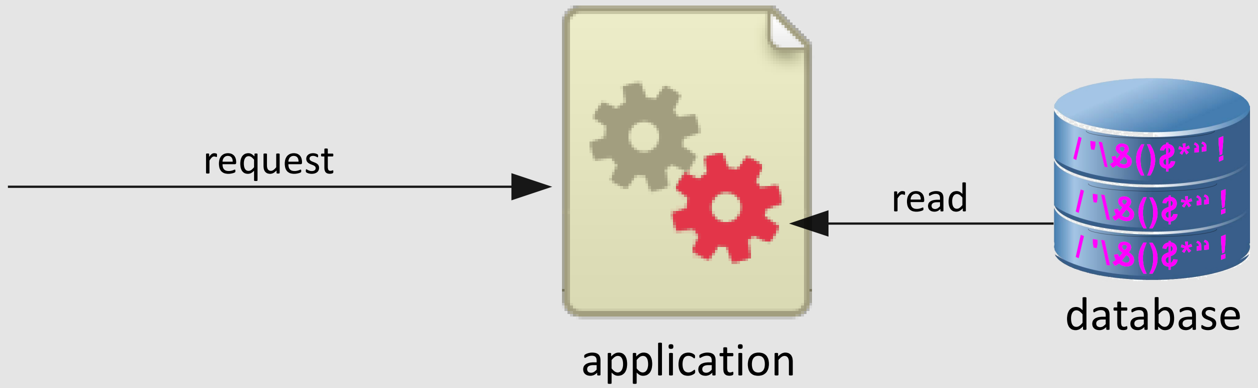
3.6 Multi-Step Exploits

Data from tainted database used in sensitive sink:

```
$query = "SELECT * FROM users WHERE id = 1";
$result = mysql_query($query);
$user = mysql_fetch_assoc($result);
file_put_contents($user['pwd'] . '.txt', $data);
```



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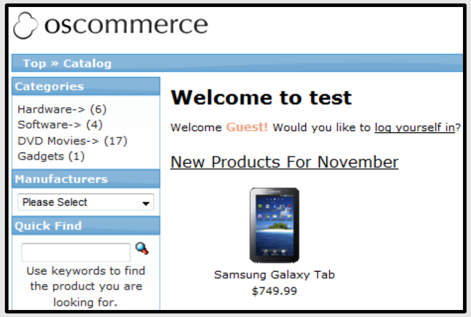
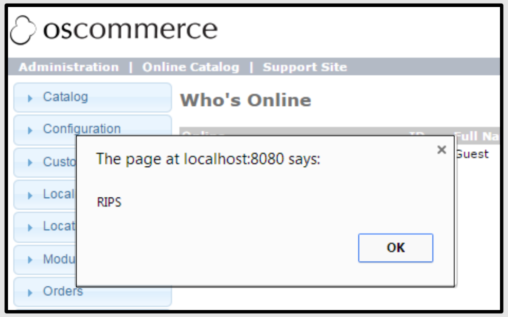
3.6.1 Multi-Step Exploit – osCommerce 2.3.4



Inject JavaScript (pXSS)

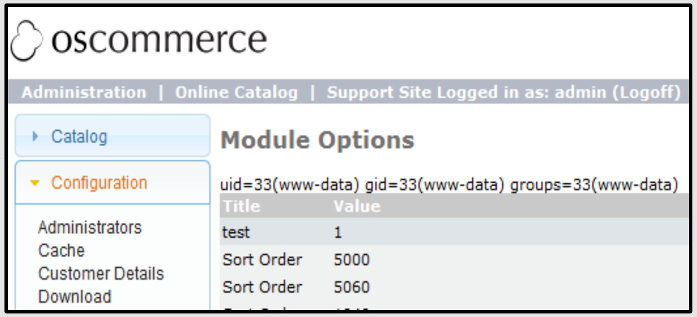


The page at localhost:8080 says:

RIPS

Admin triggers payload

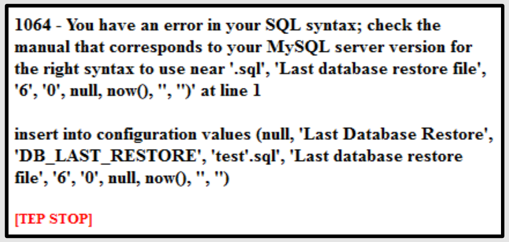
3. load



```
uid=33(www-data) gid=33(www-data) groups=33(www-data)
Title         Value
test          1
Sort Order    5000
Sort Order    5060
```

Remote Command Execution

1. trigger



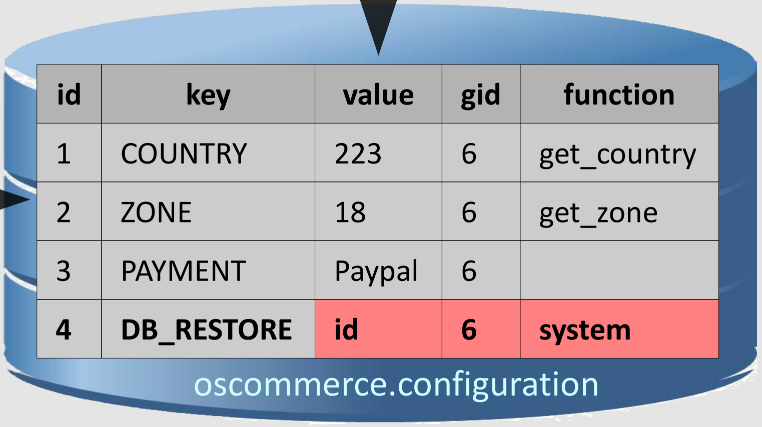
1064 - You have an error in your SQL syntax; check the manual that corresponds to your MySQL server version for the right syntax to use near '.sql', 'Last database restore file', '6', '0', null, now(), '', '')' at line 1

insert into configuration values (null, 'Last Database Restore', 'DB_LAST_RESTORE', 'test'.sql', 'Last database restore file', '6', '0', null, now(), '', '')

[TEP STOP]

SQL Injection (INSERT)

2. modify



id	key	value	gid	function
1	COUNTRY	223	6	get_country
2	ZONE	18	6	get_zone
3	PAYMENT	Paypal	6	
4	DB_RESTORE	id	6	system

oscommerce.configuration

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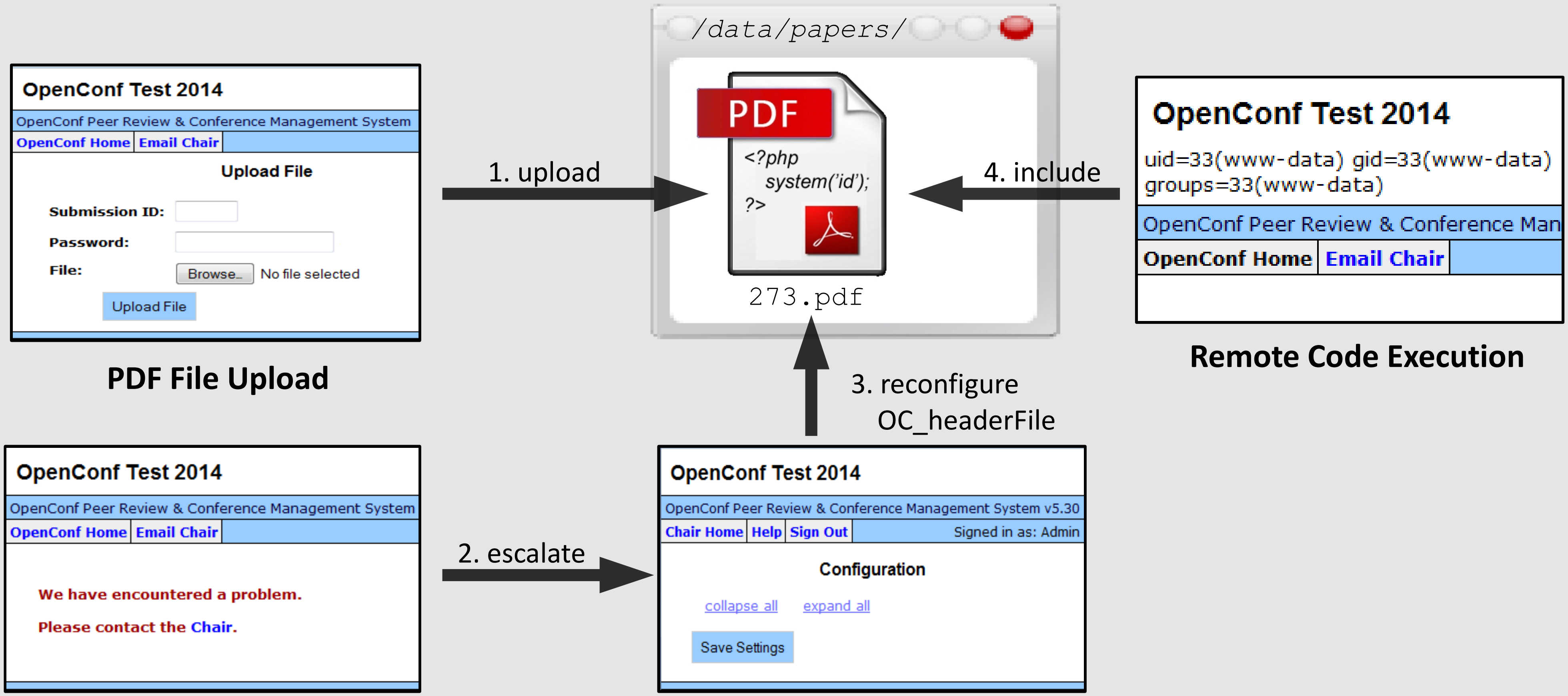
3.6.2 Multi-Step Exploit – OpenConf 5.30



```
<?php
  system('id');
?>
```

```
uid=33(www-data) gid=33(www-data) groups=33(www-data)
```

We have encountered a problem.

Please contact the Chair.

PDF File Upload

Remote Code Execution

Pre-auth SQLi

Second-Order LFI

3.7 Exceptional Vulnerability Types

- ✗ **Authorization Bypass**
- ✗ Cross-Site Request Forgery
- ✓ Cross-Site Scripting
- ✓ Code Execution
- ✓ Command Execution
- ✓ Connection String Injection
- ✓ Denial of Service
- ✓ Directory Listing
- ✓ **Execution After Redirect**
- ✓ File Delete
- ✓ File Disclosure
- ✓ File Inclusion
- ✓ File Overwrite
- ✓ File System Manipulation
- ✓ File Upload
- ✓ HTTP Response Splitting
- ✓ Information Leakage
- ✓ LDAP Injection
- ✓ Log Forgery
- ✓ **Mass Assignment**
- ✓ Memcached Injection
- ✓ Open Redirect
- ✓ **PHP Object Injection**
- ✓ **Reflection/Autoload Injection**
- ✗ Resource Contention
- ✓ Server-Side JavaScript Injection
- ✓ Server-Side Request Forgery
- ✓ Session Fixation
- ✓ SQL Injection
- ✓ Variable Manipulation
- ✗ **Weak Cryptography**
- ✓ **XML/XXE Injection**
- ✓ XPath Injection

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4. Open Challenges

- ✗ **Authorization Bypass**
- ✗ Cross-Site Request Forgery
- ✓ Cross-Site Scripting
- ✓ Code Execution
- ✓ Command Execution
- ✓ Connection String Injection
- ✓ Denial of Service
- ✓ Directory Listing
- ✓ **Execution After Redirect**
- ✓ File Delete
- ✓ File Disclosure
- ✓ File Inclusion
- ✓ File Overwrite
- ✓ File System Manipulation
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- ✓ Server-Side Request Forgery
- ✓ Session Fixation
- ✓ SQL Injection
- ✓ Variable Manipulation
- ✗ **Weak Cryptography**
- ✓ **XML/XXE Injection**
- ✓ XPath Injection

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4.1 Loops

```php
function insert_query($table, $array) {
    foreach($array as $key => value) {
        $fields .= $key . ",";
        $values .= "'" . $value . "',";
    }
    ...
    $this->write_query("INSERT INTO {$table} (" . $fields . ")
        VALUES ('" . $values . "')");
    return $this->insert_id();
}

$new_profile_field = array(
    "name"        => $db->escape_string($mybb->input['name']),
    "description" => $db->escape_string($mybb->input['description'])
);
$fid = $db->insert_query("profile", $new_profile_field);
```

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4.1 Loops

```php
function insert_query($table, $array) {
    foreach($array as $key => value) {
        $fields .= $key . ",";
        $values .= "'" . $value . "',";
    }
    ...
    $this->write_query("INSERT INTO {$table} (" . $fields . ")
        VALUES ('" . $values . "')");
    return $this->insert_id();
}

$new_profile_field = array(
    "name"        => $db->escape_string($mybb->input['name']),
    "description" => $db->escape_string($mybb->input['description'])
);
$fid = $db->insert_query("profile", $new_profile_field);
```

4.1 Loops

```php
function insert_query($table, $array) {
    foreach($array as $key => value) {
        $fields .= $key . ",";
        $values .= "'" . $value . "',";
    }
    ...
    $this->write_query("INSERT INTO {$table} (" . $fields . ")
        VALUES ('" . $values . "')");
    return $this->insert_id();
}

$new_profile_field = array(
    "name"        => $db->escape_string($mybb->input['name']),
    "description" => $db->escape_string($mybb->input['description'])
);
$fid = $db->insert_query("profile", $new_profile_field);
```

4.1 Loops

```php
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    "description" => $db->escape_string($mybb->input['description'])
);
$fid = $db->insert_query("profile", $new_profile_field);
```

```sql
INSERT INTO profile (name, description) VALUES ('$1', '$2')
```

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4.2 Frameworks

- Hard to analyze components lead to false negatives
- Query builders `$db->select('users')->where(array('id', $var));`
- Template engines `$template->assign('B', $var)`
- Reflection logic in configuration file `$controller();`

- Partial solution: Framework-specific configuration
- Problem: high maintainance overhead
- Drupageddon

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4.3 Path-sensitivity

- Infeasable paths lead to false positives
- Partial solution: *satisfiability solvers (Z3-str, S3)*
- Problem: Performance

```
...
if(!is_numeric($_GET['id'])) {
  $error = true;
}

if(!$error) {
  echo $_GET['id'];
}
```

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4.3 Path-sensitivity

- Infeasable paths lead to false positives
- Partial solution: *satisfiability solvers (Z3-str, S3)*
- Problem: Performance

```php
$numeric = is_numeric($_GET['id']);
...
if(!$numeric) {
  $error = true;
}

if(!$error) {
  echo $_GET['id'];
}
```

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Questions?

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If you think you have a stupid question,
just remember NASA engineers once asked Sally Ride
if 100 tampons were enough for a 7 day mission.

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Join the RIPS project!

(€ / CP)

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