Static Detection of Access Control Vulnerabilities in Web Applications

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UCDAVIS

Access Control Vulnerability

- Failure to guard privileged resource
  - A chain is as strong as its weakest link

- 14.15% web applications have it [07' WASC]
  - Difficult to design and implement perfect checks
- Culprit of privilege escalation attacks
  - Exposure of sensitive information or operations

Predictable URLs

- Bloomberg obtained unpublished earnings of NetApp and Disney in Nov., 2010

http://media.netapp.com/documents/financial-fy11-q2.pdf
http://media.netapp.com/documents/financial-q1-fy11.pdf
http://media.netapp.com/documents/financial-10-q4.pdf

LEAKED

Bloomberg

File posted **without any required password**

NetApp

File obtained from **"a restricted area of the company's website"**

- Lohmus Haavel & Viisemann obtained trading information of Business Wire and profited $8 million

http://website/press_release/**08/29/2007/00001.html**

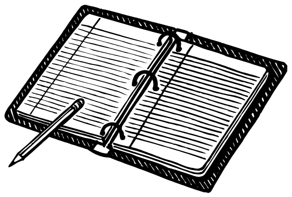
Cause of Access Control Vulnerability

- *Forced browsing*
  - Directly accessing hidden URLs
    - Often in violation of developers' intensions
    - URLs are predicted
- Root cause of access control vulnerability
  - Developers often make implicit assumptions with regard to allowed accesses
  - Security by obscurity is insufficient

Key Challenge

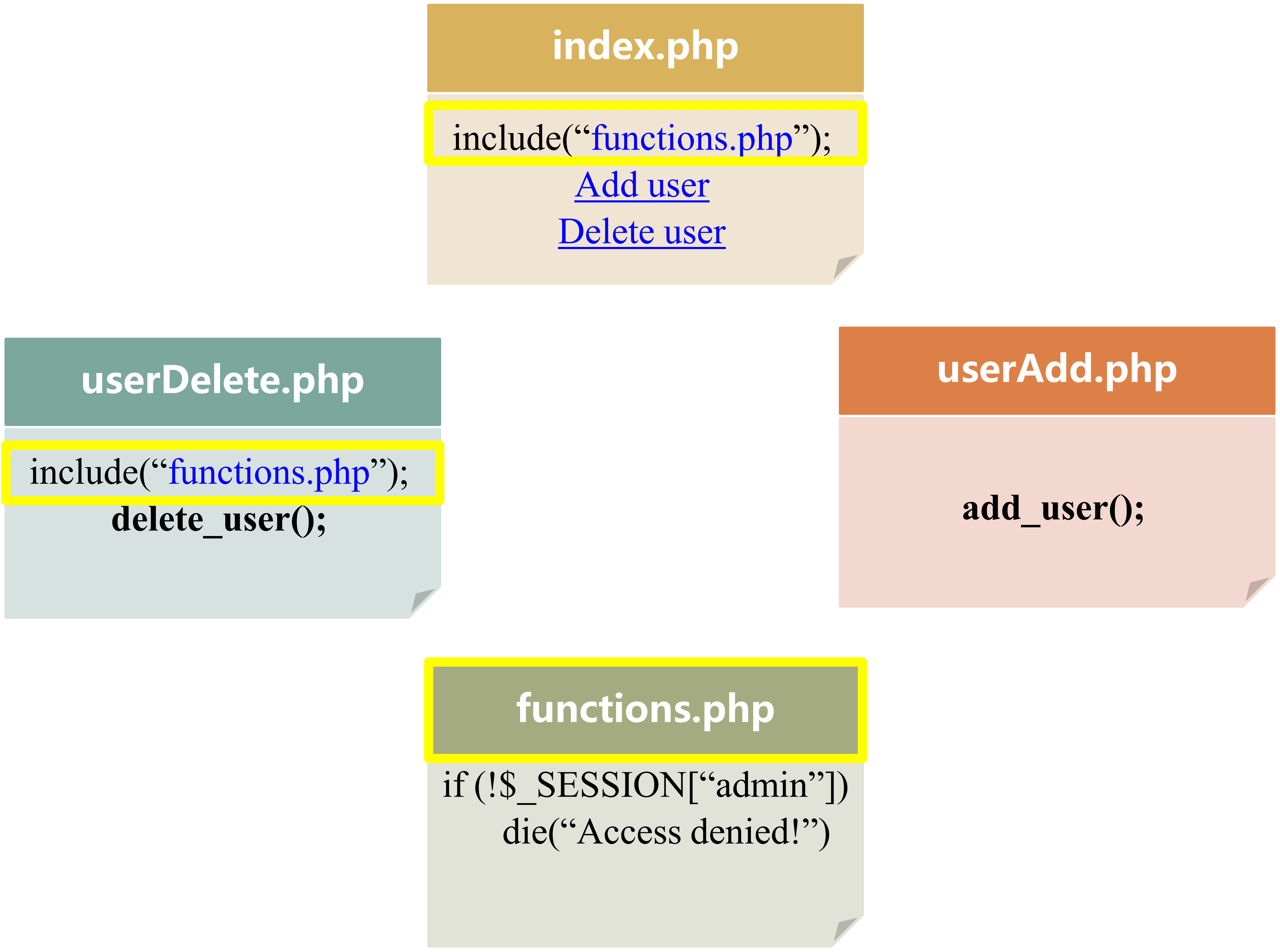
- Automated detection
  - Lack of a general characterization and specification for access control vulnerability

- Specification for automated detection
  - Manual specification
    - Time-consuming, and often absent
  - Probabilistic-based inference
    - Imprecise and computationally expensive



Key Insights

- Source code of an application implicitly documents intended accesses of each *role*
- Access control policy can be extracted from differences in *per-role sitemaps*



index.php

```
include("functions.php");
Add user
Delete user
```

userDelete.php

```
include("functions.php");
delete_user();
```

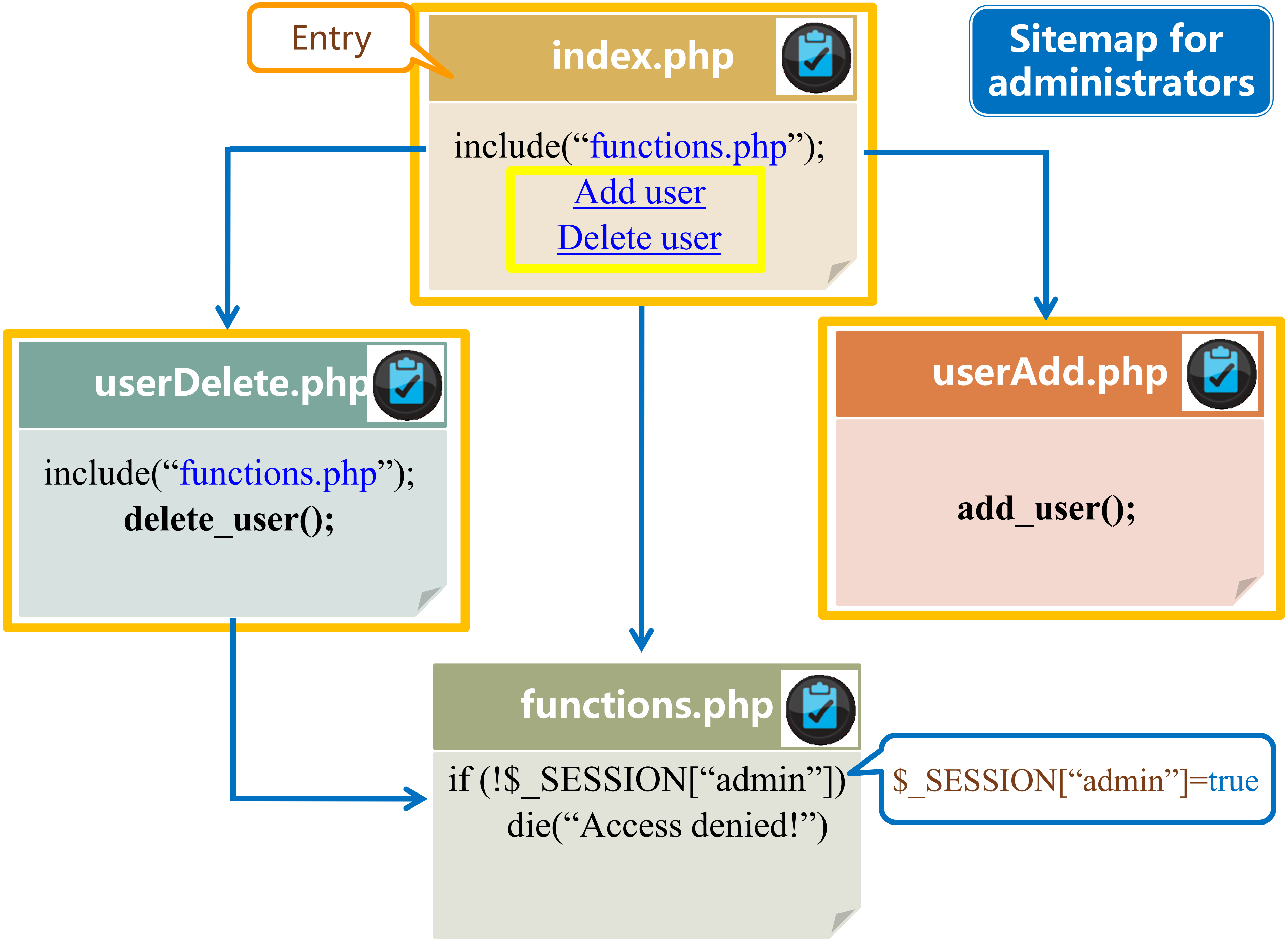
userAdd.php

```
add_user();
```

functions.php

```
if (!$_SESSION["admin"])
    die("Access denied!")
```

Sitemap for administrators



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functions.php:

```
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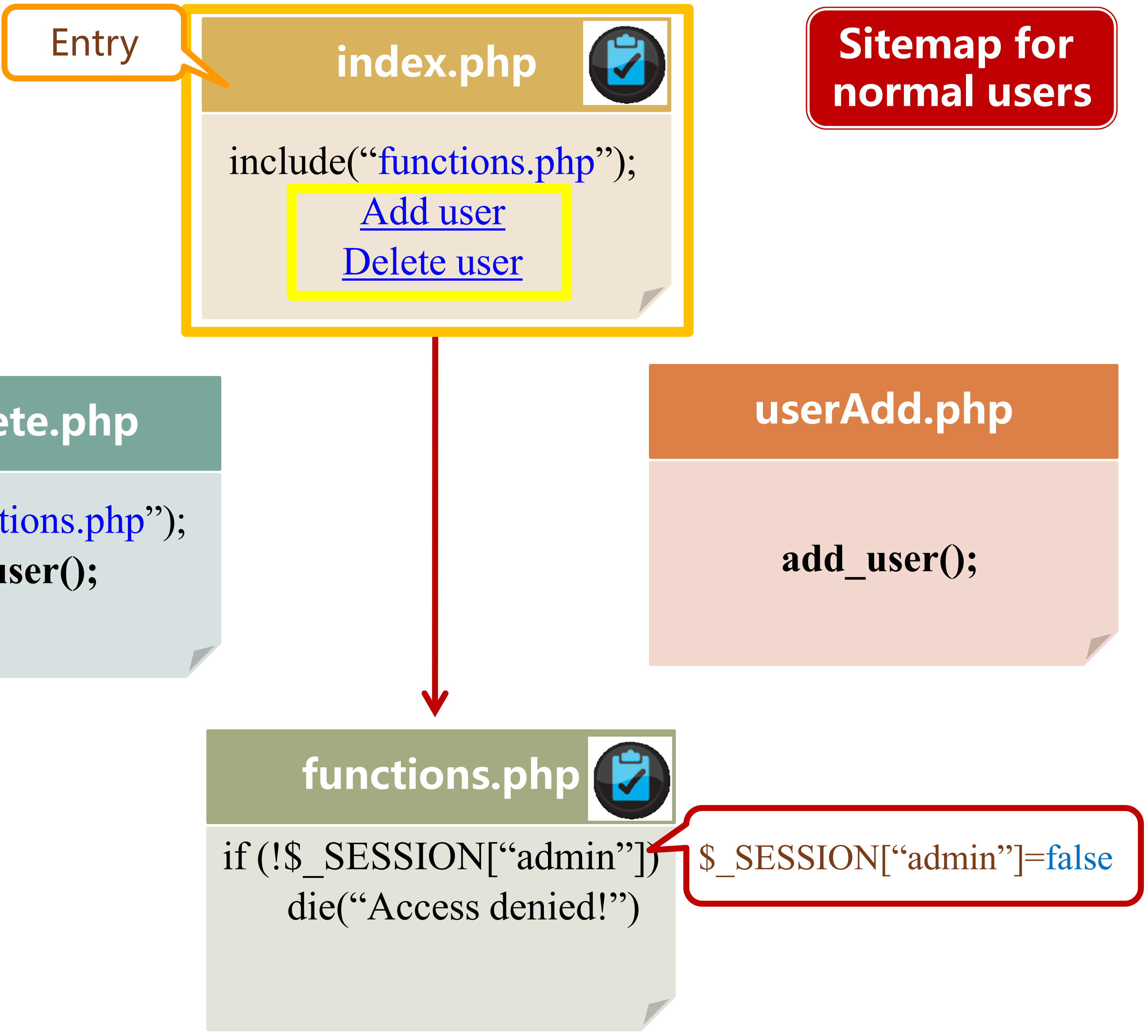
Sitemap for normal users



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delete_user();
```

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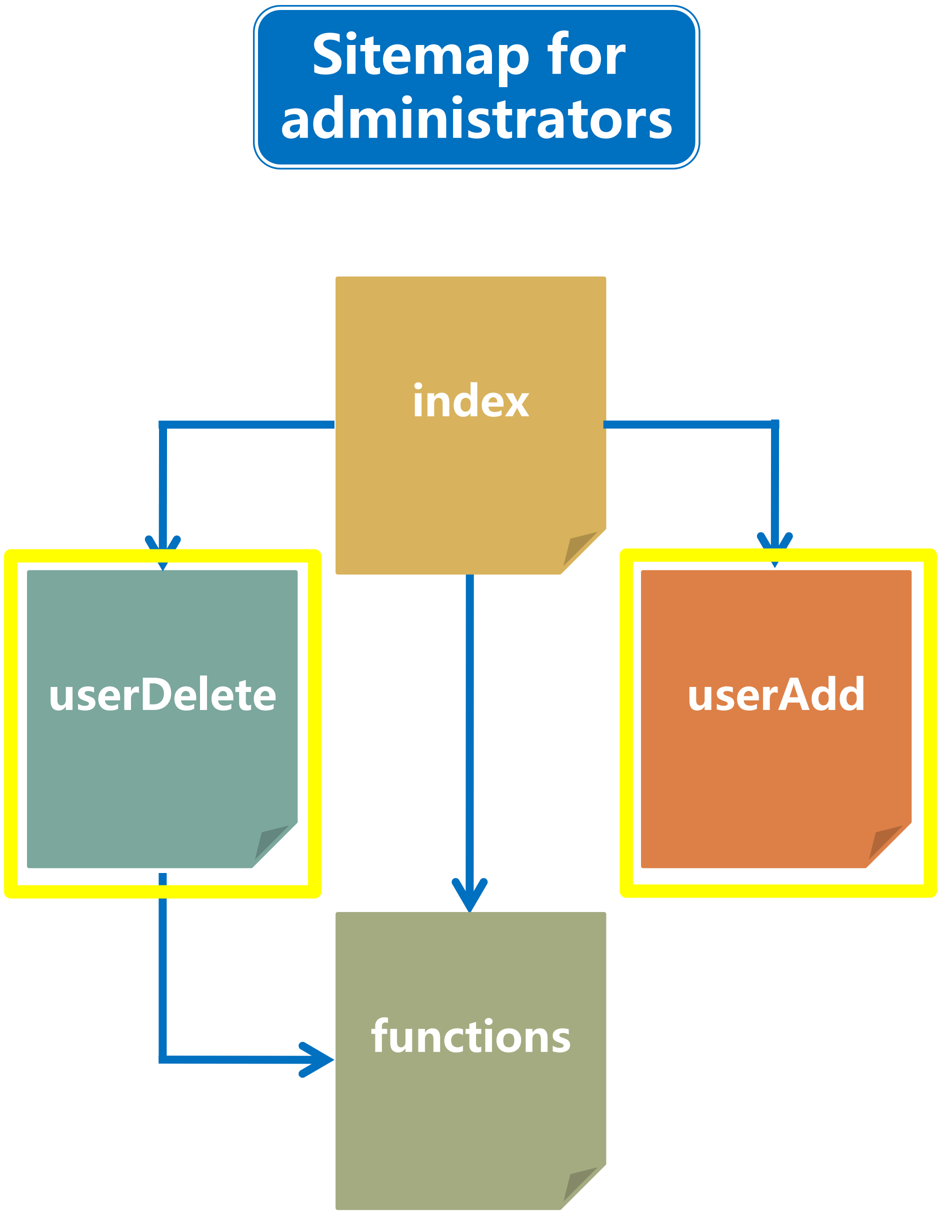
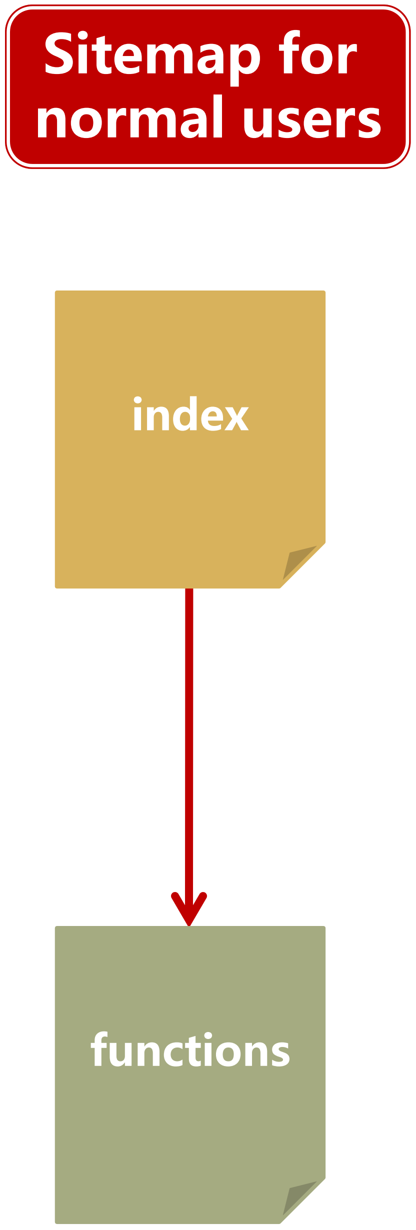
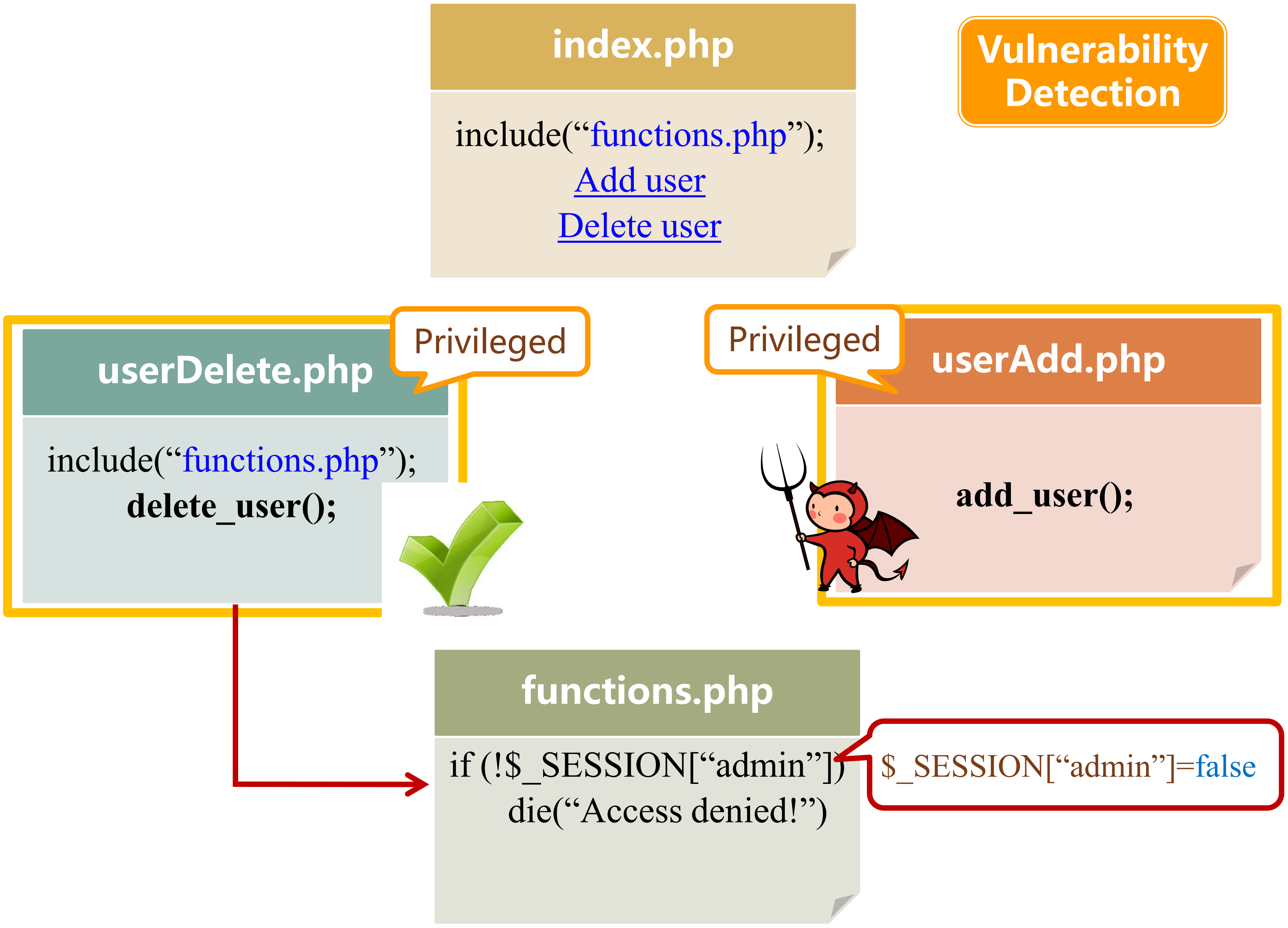

Sitemap for administrators
index
userDelete
userAdd
functions


Sitemap for normal users
index
functions



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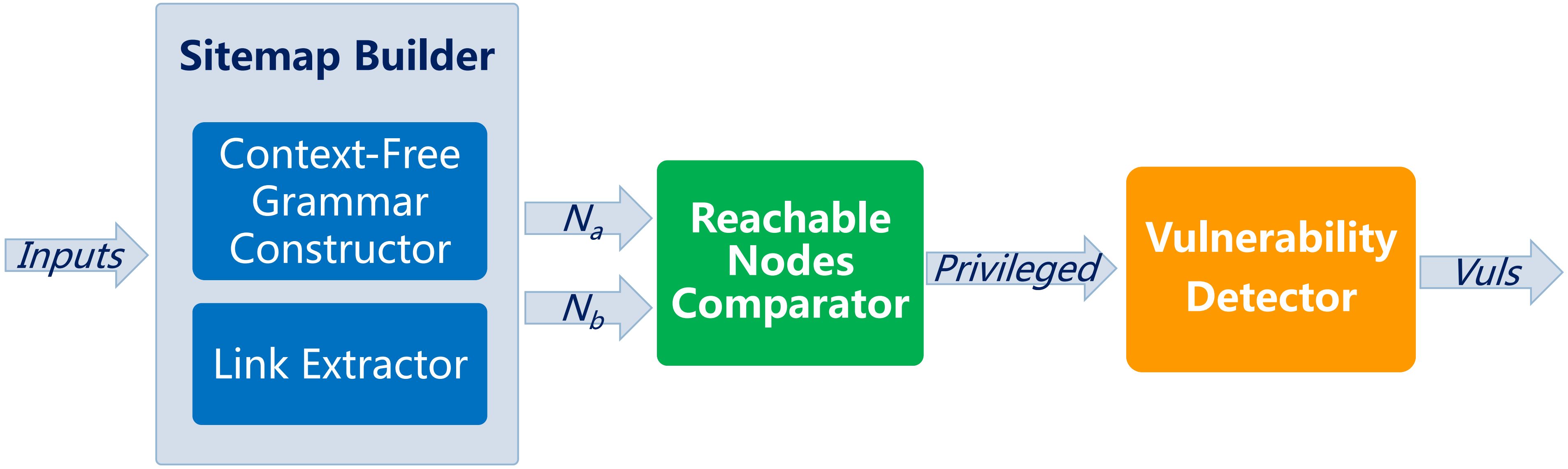
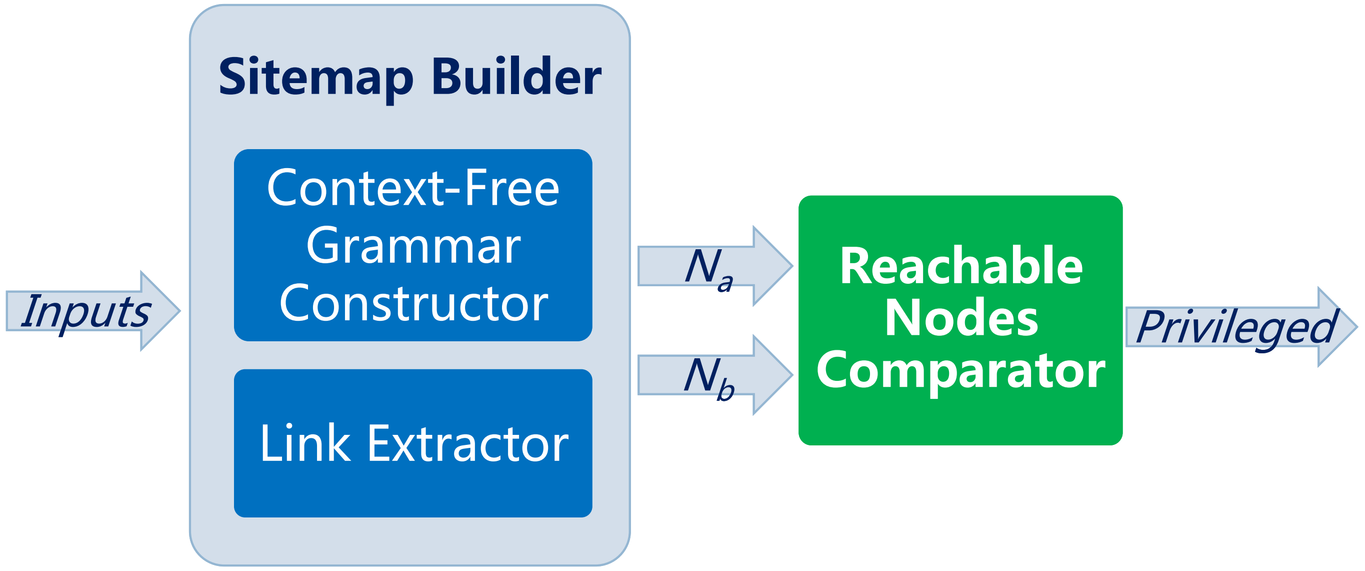
Technical Approach



Inputs	(source code, entry points, and role-based states)
N_a	explicitly reachable nodes of role *a* (administrators)
N_b	explicitly reachable nodes of role *b* (normal users)
Privileged	privileged nodes
Vuls	vulnerabilities

Sitemap Builder



Context-Free Grammar Constructor: Statically generates CFGs to approximate dynamic outputs of web pages

Link Extractor: Extracts explicit links from CFGs

Context-Free Grammar Constructor

Sitemap Builder
Context-Free Grammar Constructor
Link Extractor

- CFG approximates dynamic output
  - PHP page → AST → IR → grammar rules → CFG
- Path exploration based on branch feasibilities
  - Z3 for arithmetic constraints
  - Our own string constraint solver for string constraints

```
function checkUser() {
  if (!$_SESSION["validUser"])
    header("Location: login.php");
}
checkUser();
sensitiveOperation();
```

Constraint: $_SESSION["validUser"] = false

- Only administrators can pass this check and reach sensitiveOperation()
- Normal users are redirected to "login.php"

Link Extractor

Sitemap Builder
Context-Free Grammar Constructor
Link Extractor

- Our link extraction algorithm
  - Does not directly intersect CFG with DFA
  - Efficiently extracts links from CFG based on DFA

```
echo "<div><a href=" . $lang . ".php>Anchor</a></div>";
```

CFG

S0 → S1 S2

S1 → "<div><a href="

S2 → S3 S4

S3 → "english" | "spanish" | "french"

S4 → ".php>Anchor</a></div>"

$\longrightarrow$

Links

- "english.php"
- "spanish.php"
- "french.php"

Vulnerability Detector

- Forced browsing on privileged pages with critical states of normal users

- Failed forced browsing
  - Redirects users to another location
  - Displays error messages
    - No sensitive information or operations
- When is a forced browsing successful?
  - CFG of administrators vs. CFG of normal users
    - No additional redirections in CFG of normal users
    - The CFG sizes are not significantly different

Implementation

- A static PHP analyzer
  - Based on work of Wassermann and Minamide
  - Adds support for roles
  - Connects nodes of a web application
  - Explores paths based on branch feasibilities
- Specification rules
  - Support abstract and concrete values of built-in types, and regular expressions

Evaluation

- Subjects
  - Seven applications
  - Less than ten lines of specifications for each
- Metrics
  - Effectiveness
    - Vulnerable nodes
    - False positives
  - Performance
    - Coverage
    - Analysis time

Subject	Files	LOC	
		PHP	HTML
SCARF	25	1,318	0
Events Lister	37	2,076	544
PHP Calendars	67	1,350	0
PHPoll	93	2,571	0
iCalendar	183	8,276	0
AWCM	668	12,942	5,106
YaPiG	134	4,801	1,271

Project	Privileged	Vulnerable	FP	Guarded	Admin		Normal	
					Node	Edge	Node	Edge
SCARF	4	1	0	3	19	149	15	69
SCARF (patched)	4	0	0	4	19	149	15	69
Events Lister v2.03	9	2	$\boxed{2}$	5	23	113	14	26
PHP Calendars	3	1	0	2	19	35	19	30
PHPoll v0.97 beta	3	$\boxed{3}$	0	0	21	63	19	58
iCalendar v1.1	1	0	0	1	51	292	50	292
AWCM v2.1	47	1	0	46	176	2,634	129	2,438
AWCM v2.2 final	47	0	0	47	180	2,851	133	2,612
YaPiG v0.95	11	0	0	11	54	260	44	154

Project	Nodes			Context-Free Grammar		Coverage	Time(s)
	Entry	Active	Orphan	Variables	Productions		
SCARF	1	19	0	158	719	100.0%	6.02
SCARF (patched)	1	19	0	159	719	100.0%	6.01
Events Lister v2.03	4	23	5	100	2,083	100.0%	3.84
PHP Calendars	3	15	0	48	255	80.0%	5.09
PHPoll v0.97 beta	5	21	6	115	224	100.0%	4.26
iCalendar v1.1	2	52	2	811	4,774	90.4%	760.62
AWCM v2.1	17	208	22	410	422	79.3%	89.48
AWCM v2.2 final	16	209	14	451	484	79.9%	108.51
YaPiG v0.95	7	59	3	332	532	91.5%	208.38

Conclusion

- First role-based static analysis
  - Detects access control vulnerabilities
  - Requires minimal manual effort
- Per-role sitemaps
  - Inference of privileged pages
  - Forced browsing to detect vulnerabilities
- Effective and scalable technique