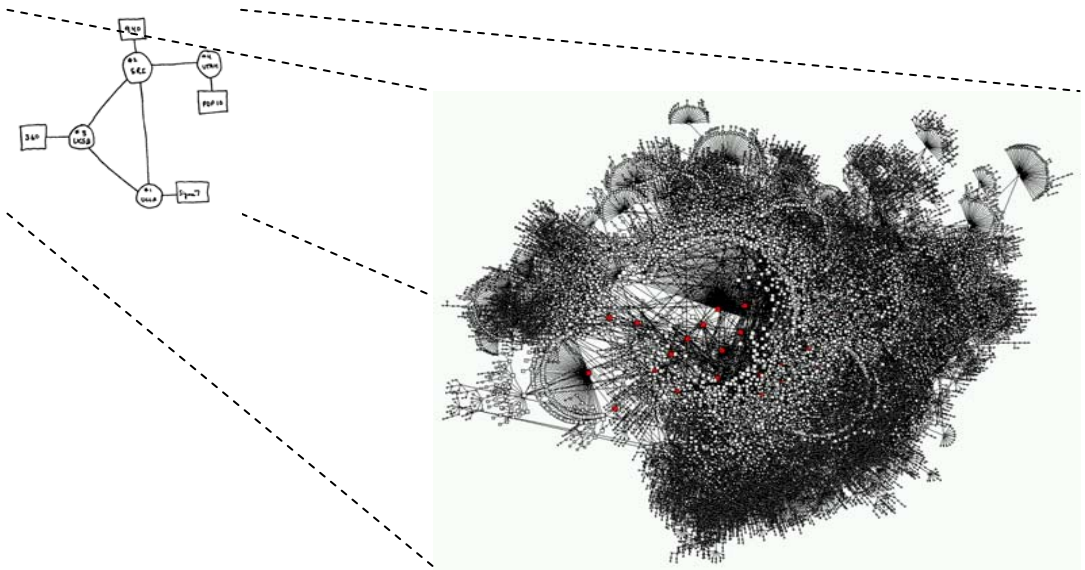
Finding Vulnerabilities in Web Applications

Christopher Kruegel
Secure Systems Lab, Technical University Vienna

Evolving Networks, Evolving Threats



- The past few years have witnessed a significant increase in the number of deployed web applications (and web services) as well as attacks targeting these systems

Web Applications

- Pervasive
  - deployed by virtually all companies, institutions, and organizations
- Critical
  - access/manage sensitive information
- Open
  - widely accessible through firewalls
- Dynamic
  - change frequently
- Vulnerable
  - untrained developers, time to market pressure

Web Application Attacks

- Significant fraction of reported security flaws
  - 26% of entries in CVE database
  - Snort 2.3, 1006 of 2564 signatures
- Large variety of attack vectors
  - cross-site scripting, SQL injection, command injection
  - weak cookies or session management
  - bypassing client-side validation
- Bug finding is difficult and tedious
  - automated solutions are necessary

Taint-Style Vulnerabilities

- Tainted data
  - potentially malicious data enters the program at specific points
  - data propagated through program
  - may reach sensitive sink, where it can lead to security problem
- Models important class of security flaws
  - cross-site scripting (XSS)
    - tainted data might enter through GET or POST requests
    - reaches an output function (which returns data to the user's browser)
  - SQL injection
  - command injection
- Attack can be prevented using sanitization functions

Web Application Attacks

- Cross-site scripting (XSS)
  - attacker injects HTML or Javascript into application output which is displayed and executed in victims browser
  - reflected vs. stored XSS variants
  - stealing of user data (cookies, credentials…)
  - redirecting login form to hackers web server
  - create exploit URLs and send phishing mails

Web Application Attacks

- SQL Injection
  - no validation before using input in database query
  - dynamically built SQL query problematic

    ```
    q = “select * from user where
    mail=‘” + mail + “‘ and pw=‘” + pw + “‘”
    ```

  - attacker sends value(s) with SQL keywords

    mail: ‘ or 1=1-- *pw*: ‘ or 1=1–

  - changes semantics of query

    ```
    q = “select * from user where mail=‘‘
    or 1=1--‘ and pw=‘‘ or 1=1--‘”
    ```

  - actual query

    ```
    q = “select * from user”
    ```

Bug Finding

- Black box approach
  - send input to system and evaluate response
  + every bug found is real
  + large number of programs can be checked (language-independent)
  - can only cover a certain number of input (test cases)

- White box approach
  - analyze source code
  + better precision, more bugs can be found
  - false positives
  - limited to supported programming languages

Black Box Solution

- Where to start
  - locate vulnerable application(s)
  - use user-defined list
  - crawl pages, start from seed address, follow (on-site) links
  - identify forms

- What to do
  - attack each form parameter
  - user-selectable attack plug-ins
  - analysis of the responses
  - decision whether form / page is vulnerable
  - possible generation of exploit code

Attack Plug-ins

- SQL injection
  - inject single quote ‘ into form parameter
  - assumption
    - unfiltered input leads to syntactically incorrect SQL statement
  - response analyzed for occurrence of suspicious keywords
    - indication for errors, exceptions, …
  - keywords receive weights
  - total confidence factor calculated

Attack Plug-ins

- Cross-site scripting
  - works only for reflected attacks
  - inject simple script
  - assumption
    - unfiltered input is included in response
  - response analyzed for presence of injected script
    - also make sure that script is executable
  - different scripts injected that make use of script obfuscation
    - lowercase/uppercase characters , different character encodings, …

Results

- Evaluation run
  - seeded with Google results for „login“ search
  - 25,064 crawled sites
  - 21,627 web forms
- 4 attack plug-ins used
  - SQL Injection: 6,63%
  - Simple XSS: 4,30%
  - Enhanced XSS: 5,60%
  - Form-Red. XSS: 5,52%
- Some vulnerable sites

  eBay, Austrian Finance Ministry, Geizhals (price management), Crit.org (security associated content), Apple (developer access)

Results

- Query vulnerable site using `Whois` service
- Notify site administrator
  - send one mail per subdomain
  - 591 mails sent (239 default office@...)
- Administrator response
  - 306 „recipient unknown“
  - 48 detail inquiries
  - eBay gave us a call :)
- General impression
  - large scale probing for vulnerable services quite possible
  - at the time, few people were really concerned

White Box Solution

- Data flow analysis (DFA)
  - static analysis technique
  - operates on program's control flow graph
  - defines properties
    - lattice of elements (what values can properties take)
    - transfer functions (how do operations change properties)
  - for each program point and variable
    - what values of property are possible (over all program paths)

- Allows to answer the following question
  - *Is it possible that tainted data reaches a sensitive sink?*

Pixy

- Pixy
  - static analysis engine for detecting taint-style vulnerabilities
  - runs on PHP scripts
  - currently, XSS detection implemented
  - high precision
  - fast
  - open source

- Interesting challenges
  - weak typing of scripting languages
  - use of aliases (instead of pointers)
  - *scalability despite precise analysis*

Pixy‘s Taint Analysis

- Taint Analysis
  - at the core
  - determine which variables might be tainted (for each program point)
- Effects of built-in functions modeled in a configuration file
  - specification of the returned taint value depending on the input parameters
  - e.g., `nl2br($in)`: returns tainted if `$in` is tainted
  - of course, not application-specific (nothing to do for users of Pixy)
  - default: return tainted (→ safe)

Pixy‘s Alias Analysis

- Problem with stand-alone taint analysis
  - no information about alias relationships
    - explicit aliasing: `$a =& $b`
    - call-by-reference parameters
    - access to global variables (`global` keyword)
  - can lead to false positives and false negatives

  → support taint analysis with additional alias analysis

- First application of alias analysis to scripting languages ever

Pixy‘s Literal Analysis

- Additional precision through literal analysis
  - path pruning
  - *variable file inclusions*
- Potential applications
  - variable variables
  - variable array indices
  - variable function calls

Resolving Includes

- File inclusions in scripting languages
  - can be tricky, because
    dynamic, conditional, and even recursive

- Solution
  - use iterative algorithm consisting of two steps
  - first stage
    transitively resolve static includes
  - second stage
    if there are any dynamic includes, resolve them with literal analysis
  - repeat as long as there are includes left
  - fast, yields good results, easy to implement

Analysis Precision

- All applied analyses are
  - flow-sensitive
  - inter-procedural
  - context-sensitive

  → high precision
  (in addition to mutual support between the analyses)

- Limitations
  - object-oriented features are treated in an optimistic way
  - no support for aliases between arrays

Results

- Scanned six real-world applications

Program	Lines of Code	Vulnerabilities
PhpNuke 6.9	17,479	24
PhpMyAdmin 2.6.0	89	9
Gallery 1.3.3	3,529	3
Simple PHP Blog 0.4.5	20,792	8
Serendipity 0.8.4	6,588	2
Yapig 0.95b	5,128	5

- Vulnerabilities: 51 (15 previously unknown)
- False positives: 33
- Less than a minute for every scanned file

Results

- Breakdown of false positives
  - 13: conservative treatment of file reads
  - 7: aliasing between arrays
  - 6: partial sanitization (double quotes)
  - 5: syntactically incomplete branches
  - 2: custom regular expression sanitization

Conclusions

- Web application vulnerabilities
  - many widely-deployed and accessible applications
  - many vulnerabilities
- Bug finding is important
  - black box and white box approaches
- Black box approach
  - language independent
  - few false positives
- White box approach
  - high precision