Vulnerability Assessment and Secure Coding Practices for Middleware

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Roadmap

- **Part 1:** Vulnerability Assessment Process
- **Part 2:** Secure Coding Practices

Key Issues for Security

- Need independent assessment
  - Software engineers have long known that testing groups must be independent of development groups
- Need an assessment process that is NOT based solely on known vulnerabilities
  - Such approaches will not find new types and variations of attacks

Key Issues for Security

- Automated Analysis Tools have Serious Limitations
  - While they help find some local errors, they
    - MISS significant vulnerabilities (false negatives)
    - Produce voluminous reports (false positives)
- Programmers must be security-aware
  - Designing for security and the use of secure practices and standards does not guarantee security

Addressing these Issues

- We must evaluate the security of our code
  - The vulnerabilities are there and we want to find them first
- Assessment isn't cheap
  - Automated tools create an illusion of security
- You can't take shortcuts
  - Even if the development team is good at testing, they can't do an effective assessment of their own code

Addressing these Issues

- First Principles Vulnerability Assessment (FPVA)
  - A strategy that focuses on critical resources
  - A strategy that is not based solely on known vulnerabilities
- We need to integrate assessment and remediation into the software development process
  - We have to be prepared to respond to the vulnerabilities we find

Goal of FPVA

- Understand a software system to focus search for security problems
- Find vulnerabilities
- Make the software more secure

"A vulnerability is a defect or weakness in system security procedures, design, implementation, or internal controls that can be exercised and result in a security breach or violation of security policy."
- Gary McGraw, *Software Security*

i.e., a bad thing

First Principles Vulnerability Assessment

Step 1: Architectural Analysis
Step 2: Resource Identification
Step 3: Trust & Privilege Analysis
Step 4: Component Evaluation
Step 5: Dissemination of Results

Studied Systems

Condor, University of Wisconsin
Batch queuing workload management system

SRB, SDSC
Storage Resource Broker - data grid

MyProxy, NCSA
Credential Management System

glExec, Nikhef (in progress)
Identity mapping service

CrossBroker, Universitat Autònoma de Barcelona (in progress)
Resource Manager for Parallel and Interactive Applications

Gratia Condor Probe, NCSA (in progress)
Feeds Condor Usage into Gratia Accounting System

Condor Quill, University of Wisconsin (in progress)
DBMS Storage of Condor Operational and Historical Data

Wireshark, wireshark.org (in progress)
Network Protocol Analyzer

Condor Privilege Separation, University of Wisconsin (soon)
Restricted Identity Switching Module

First Principles Vulnerability Assessment
Understanding the System

Step 1: Architectural Analysis

- Functionality and structure of the system, major components (modules, threads, processes), communication channels
- Interactions among components and with users

Step 1: Architectural Analysis User Supplied Data

- All attacks ultimately arise from attacker (user) communicated data
- If not, your system is malware: mere installation causes a security violation
- Attack surface: Interfaces available to the attacker
- Important to know where the system gets user supplied data
- What data can users inject into the system

Step 1: Architectural Analysis

- Create a detailed big picture view of the system
- Document and diagram
  - What processes/hosts exist and their function
  - How users interact with them
  - How executables interact with each other

Step 1: Architectural Analysis External Services Used

- How are external programs used
- External services
  - Database (DBMS, LDAP, DNS, …)
  - Web server
  - Application server
  - Other
- External executables launched
  - Signs in the code: **`popen system exec*`**

Step 1: Architectural Analysis Process Communication Channels

- What exists between…
  - Servers
  - Client and server
  - Client/Server and external programs
    - DBMS
    - DNS
    - LDAP
    - Kerberos
    - File services: NFS AFS ftp http …
    - Helper applications
- Shows interaction between components

Step 1: Architectural Analysis Communication Methods

- OS provides a large variety of communication methods
  - Command line
  - Files
  - Creating processes
  - IPC
    - Pipes
    - FIFO's or named pipes
    - System V IPC
    - Memory mapped files
  - Environment
  - Sockets
  - Signals
  - Directories
  - Symbolic links

Step 1: Architectural Analysis Command Line

- Null-terminated array of strings passed to a starting process from its parent
- Convention is that **`argv[0]`** is the path to executable file
- Signs in code
  - C/C++: **`argc argv`**
  - Perl: **`$0 @ARGV`**
  - Sh: **`$0 $1 $2… $# $@ $*`**
  - Csh: **`$0 argv`**

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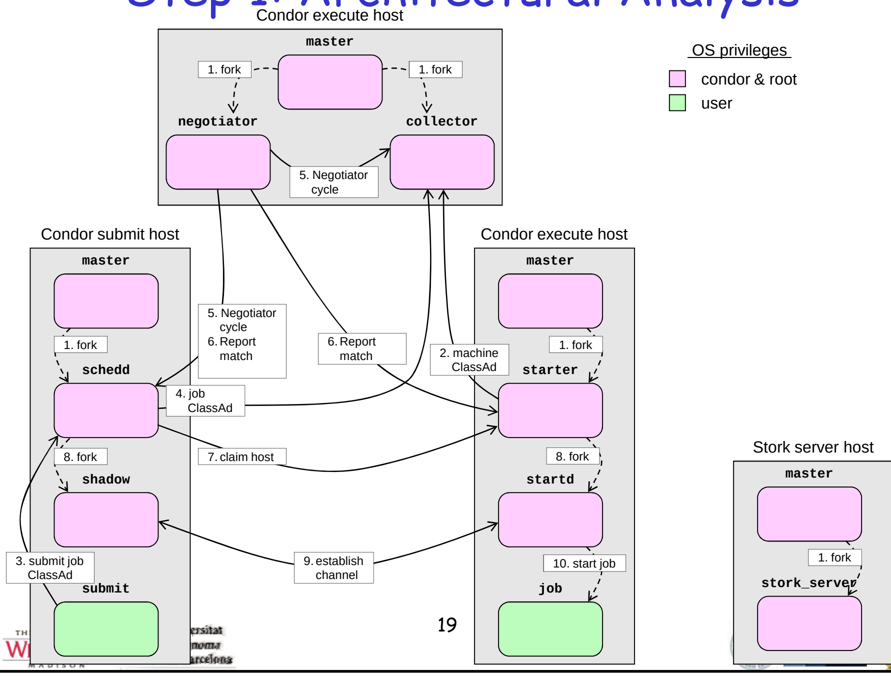
Step 1: Architectural Analysis Sockets

- Creates a communication path
  - processes on same host
  - between hosts using protocols such as TCP/IP
- Can be stream or message based
- Signs in code
  - C/C++: **`socket bind connect listen accept socketpair send sendto sendmsg recv recvfrom recvmsg getpeername getsockname setsockopt getsockopt shutdown`**

Step 1: Architectural Analysis IPC

- Inter- and Intra-host communication methods
- Some can pass file descriptors between processes
- Signs in code:
  - Pipes: **`pipe`**
  - SysV Message Q: **`msgget msgctl msgsnd msgrcv`**
  - SysV Semaphore: **`semget shmctl semop`**
  - SysV Shared Mem: **`shmget shmctl shmat shmdt`**
  - Memory mapped files: **`mmap`**

Step 1: Architectural Analysis



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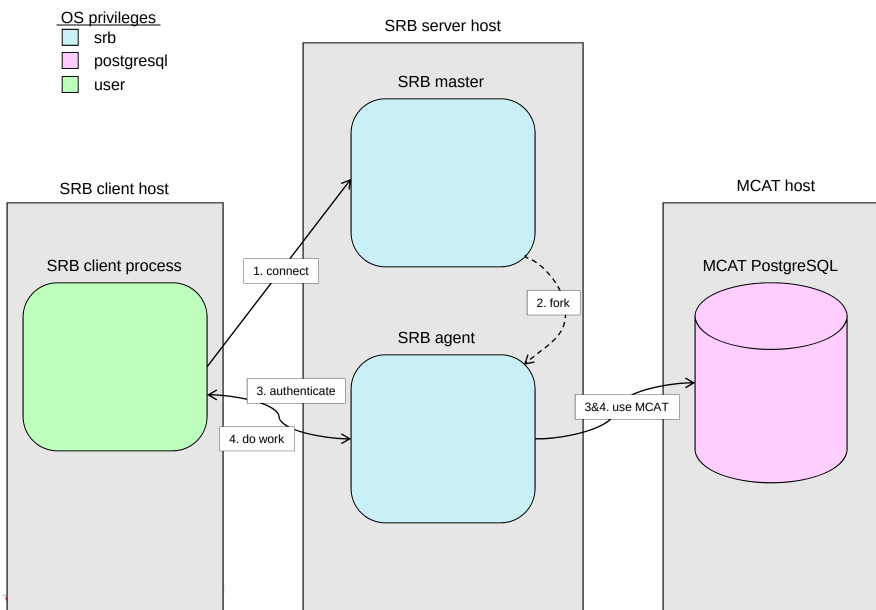
Step 1: Architectural Analysis

- SRB



First Principles Vulnerability Assessment
Understanding the System

Step 2: Resource Identification

- Key resources accessed by each component
- Operations allowed on those resources

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Step 2: Resource Analysis

- A resource is an object that is useful to a user of the system and is controlled by the system
  - Data
    - files
    - DBMS
    - memory
  - Physical entities
    - Disk space
    - CPU cycles
    - Network bandwidth
    - Attached devices (sensors, controllers)

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Step 2: Resource Identification Documenting Resources

- What resources exist in the system
- What executables/hosts control the resource
- What operations are allowed
- What does an attacker gaining access to the resource imply

Step 2: Resource Identification Files

- Represented by a path
- File descriptors represent files in program
  - From opening or creating a file
  - Inherited from parent process
- Contents can be data, configuration, executable code, library code, scripts
- Signs in code:
  - C/C++: `open creat fopen dlopen *stream`

Step 2: Resource Identification Standard File Descriptors

- Convention is creating process opens file descriptors 0, 1 and 2 for use by the created process to be used as standard in, out, and err
- Functions and libraries often implicitly use these and expect them to be opened
- Signs in code
  - C/C++: **`stdin stdout stderr STDIN_FILENO STDOUT_FILENO STDERR_FILENO getchar gets scanf printf vprintf vscanf cin cout cerr`**

Step 2: Resource Identification Directories

- List of named file system objects
- Operations:
  - Get list of entries
  - Create entry
  - Rename entry
  - Delete entry
- Entries have metadata like type, size, and owner
- Signs in code:
  - C/C++: **`opendir readdir closedir creat open`** (with **`O_CREAT`**) **`fdopen mkdir mkfifo mknod symlink link unlink remove rename rmdir`**

Step 2: Resource Identification Symbolic Links

- File system object that contains a path (referent)
- When evaluating a path the operating system follows the referent in the link
- Operations:
  - Create symbolic link (can't modify)
  - Read referent
- Signs in code:
  - C/C++: implicitly in any function taking a path, **`symlink`** **`readlink`**

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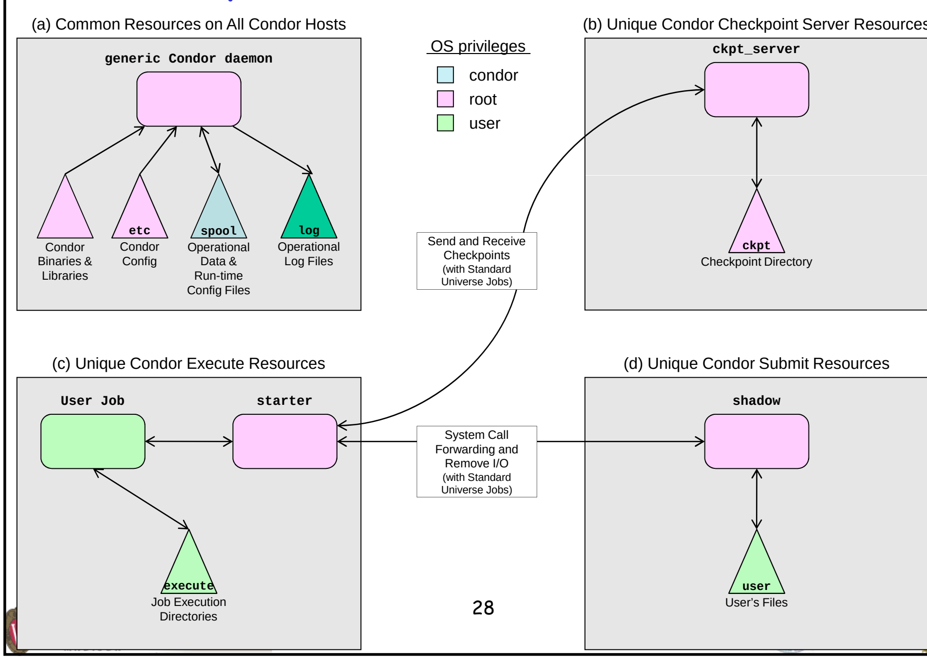
Step 2: Resource Identification



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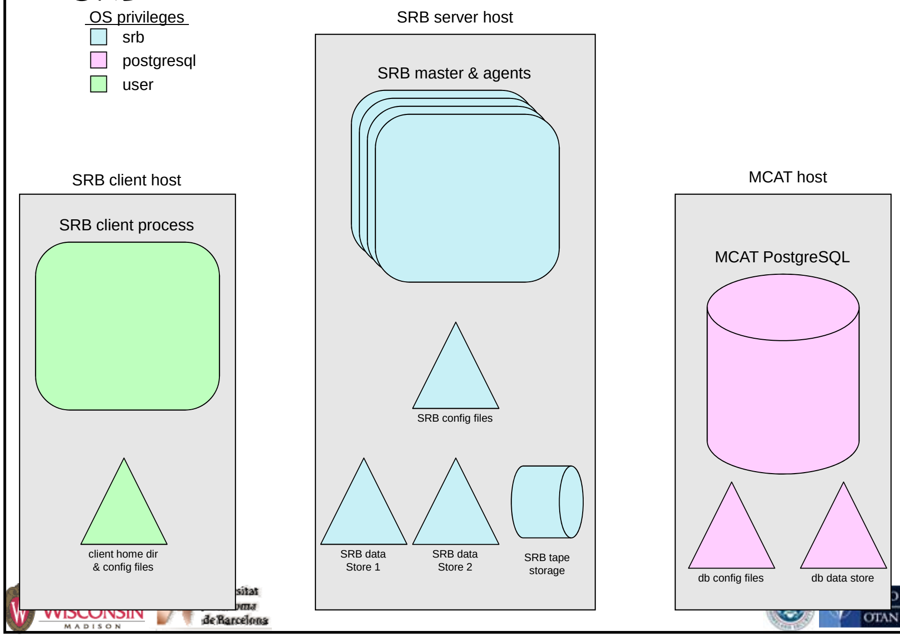
Step 2: Resource Identification

- SRB



First Principles Vulnerability Assessment
Understanding the System

Step 3: Trust & Privilege Analysis

- How components are protected and who can access them
- Privilege level at which each component runs
- Trust delegation

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Step 3: Trust & Privilege Analysis Process Attributes

- What user/group is the process started as
- Is the process setuid/setgid
- Any unusual process attributes
  - **`chroot`**
  - Process limits
  - Uses capabilities
- uid/gid switching
- uid/gid sensitive behavior

Step 3: Trust & Privilege Analysis

- Privilege is the authorization for a user to perform an operation on a resource
- Role is a set of privileges assigned to users to create classes of users such as admin
- Authentication
  - Is it performed correctly and securely
  - If an attacker can authenticate as another user they gain their privileges

Step 3: Trust & Privilege Analysis
Privileges in the System

- What privileges exist in the system
- Do they map appropriately to operations on resources
- Are they fine grained enough
- How are they enforced

Step 3: Trust & Privilege Analysis
External Privilege Systems

- System used: OS, DBMS, …
- Accounts and privileges used
- Purpose of each account
- Does the program use external privileges to enforce its privilege model
- Are minimal privileges used
- Use of root or admin accounts require special attention

Step 3: Trust & Privilege Analysis Trust

- An executable trusts another when
  - It relies on a behavior in the other
  - Doesn't or can't verify the behavior
- Implicit trust
  - The operating system
  - Process with root privilege on the same host
    - they can do anything
  - Processes with same uid on the same host
    - they can do anything to each other
  - All the code in your executable including libraries

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Step 3: Trust & Privilege Analysis Bad trust

- Not validating data from another trust domain for proper form (form, length, range)
- Bad assumptions
  - User supplied data is in proper form
  - Data passed through client is unchanged
    - Need a cryptographic signature
    - Happens with hidden input field and cookies in HTML

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Step 3: Trust & Privilege Analysis More Bad Trust

- Bad assumptions (cont.)
  - Client validated data
    - Client can be rewritten or replaced
    - Good to validate on the client, but server validation is required
- Not validating data from trusted processes
  - Allows an attack to spread
  - Not defense in depth

First Principles Vulnerability Assessment Search for Vulnerabilities

Step 4: Component Evaluation

- Examine critical components in depth
- Guide search using:
  - Diagrams from steps 1-3
  - Knowledge of vulnerabilities
- Helped by Automated scanning tools (!)

Step 4: Component Evaluation
Categories of Vulnerabilities

- Design Flaws
  - Problems inherent in the design
  - Hard to automate discovery
- Implementation Bugs
  - Improper use of the programming language, or of a library API
  - Localized in the code
- Operational vulnerabilities
  - Configuration or environment
- Social Engineering
  - Valid users tricked into attacking

Occur about equally

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Step 4: Component Evaluation
Many Types of Vulnerabilities

Buffer overflows
Injection attacks
  Command injection (in a shell)
  Format string attacks (in printf/scanf)
  SQL injection
  Cross-site scripting or XSS (in HTML)
Directory traversal
Integer vulnerabilities

Race conditions
Not properly dropping privilege
Insecure permissions
Denial of service
Information leaks
Lack of integrity checks
Lack of authentication
Lack of authorization

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Step 4: Component Evaluation Focusing the Search

- It's impossible to completely analyze a system for vulnerabilities
- From critical resources and try to think of ways an attack can be realized
- From vulnerabilities can occur in the code to resources
- Look for similar problems to prior security problems
- Focus on subsystem/resources that are
  - Important
  - Security related
  - Poorly written (little used)
  - Poorly tested
  - Developer/Testing functionality

Step 4: Component Evaluation Process Configuration

- How is an executable configured
  - Configuration file
  - Hard coded
  - Other
- What can be configured
  - How does it affect the application
  - Often reveals functional and architectural information

Step 4: Component Evaluation Communication Methods

- OS provides a large variety of communication methods
  - Command line
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  - Environment
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  - Directories
  - Symbolic links

First Principles Vulnerability Assessment Taking Actions

Step 5: Dissemination of Results

- Report vulnerabilities
- Interaction with developers
- Disclosure of vulnerabilities

Step 5: Dissemination of Results
Vulnerability Report

- One report per vulnerability
- Provide enough information for developers to reproduce and suggest mitigations
- Written so that a few sections can be removed and the abstracted report is still useful to users without revealing too much information to easily create an attack.

First Principles Vulnerability Assessment
Taking Actions

Step 5: Dissemination of Results

CONDOR-2005-0003

Summary:

Arbitrary commands can be executed with the permissions of the condor_shadow or condor_gridmanager's effective uid (normally the "condor" user). This can result in a compromise of the condor configuration files, log files, and other files owned by the "condor" user. This may also aid in attacks on other accounts.

Component	Vulnerable Versions	Platform	Availability	Fix Available
condor_shadow condor_gridmanager	6.6 - 6.6.10 6.7 - 6.7.17	all	not known to be publicly available	6.6.11 - 6.7.18 -
Status	**Access Required**	**Host Type Required**	**Effort Required**	**Impact/Consequences**
Verified	local ordinary user with a Condor authorization	submission host	low	high
Fixed Date	**Credit**			
2006-Mar-27	Jim Kupsch			

Access Required: local ordinary user with a Condor authorization

This vulnerability requires local access on a machine that is running a condor_schedd, to which the user can use condor_submit to submit a job.

Effort Required: low

To exploit this vulnerability requires only the submission of a Condor job with an invalid entry.

Impact/Consequences: high

Usually the condor_shadow and condor_gridmanager are configured to run as the "condor" user, and this vulnerability allows an attacker to execute arbitrary code as the "condor" user.

Depending on the configuration, additional more serious attacks may be possible. If the configuration files for the condor_master are writable by condor and the condor_master is run with root privileges, then root access can be gained. If the condor binaries are owned by the "condor" user, these executables could be replaced and when restarted, arbitrary code could be executed as the "condor" user. This would also allow root access as most condor daemons are started with an effective uid of root.

Step 5: Dissemination of Results Vulnerability Report Items

- Summary
- Affected version(s) and platform
- Fixed version(s)
- Availability - is it known or being exploited
- Access required - what type of access does an attacker require: local/remote host? Authenticated? Special privileges?
- Effort required (low/med/high) - what type of skill and what is the probability of success

Step 5: Dissemination of Results Vulnerability Report Items

- Impact/Consequences (low/med/high) - how does it affect the system: minor information leak is low, gaining root access on the host is high
- Only in full report
  - Full details - full description of vulnerability and how to exploit it
  - Cause - root problem that allows it
  - Proposed fix - proposal to eliminate problem
  - Actual fix - how it was fixed

Step 5: Dissemination of Results
Vulnerability Disclosure Process

- Disclose vulnerability reports to developers
- Allow developers to mitigate problems in a release

Now here's the really hard part:

- Publish abstract disclosures in cooperation with developers. When?
- Publish full disclosures in cooperation with developers. When?

Summary of Results
First Principles Vulnerability Assessment

Technique has been extremely successful

- found critical problems
- helped groups redesign software
- changed their development practices and release cycle management

First Principles Vulnerability Assessment (FPVA) white paper:
http://www.cs.wisc.edu/mist/papers/VA.pdf

Our Work -- Summary

Assess: We continue to assess new software systems

Train: We present tutorials and white papers, and continue to develop new educational materials

Research: Our results provide the foundation for new research to make FPVA less labor-intensive and improve quality of automated code analysis