Vulnerability Analysis

Vulnerability

- A defect (bug) in one system component or in the way the component is used
- By exploiting the bug, a threat agent can fire an unexpected behavior of the component
- The behavior allows the agent to violate the security policy = difference between bugs and vulnerabilities

Vulnerability vs bug

- A bug may not result in a behavior that violates the security policy
- A bug that results in such a behavior is a vulnerability

  =

  any vulnerability is a bug but not the other way around

Taxonomies

- Several vulnerability taxonomies have been defined and may be adopted
- Each taxonomy has a goal (location discovery, evaluate the effects …)
- Before applying a taxonomy we need to understand whether such a taxonomy satisfies with our goals

Location of the vulnerability

- Actions that are executed
  - Procedural
- People executing the action
  - Organization
- Hardware or software tools
  - ICT tools that are used

Some examples

- Action
  - A password communicated in an envelope that is not sealed
- People
  - Several administrators for the same machine
  - Task assigned to people that are not trained
- Tool
  - A password transmitted in clear on a netwok
  - No bound controls on a vector index

Taxonomy on tool vulns

A further classification, useful but not very rigorous

- Specification
  - A tool that is more general than required (more functions, more parameters ...)
- Implementation
  - A coding error in the program of the tool
- Structural
  - The anomalous behavior arises when several components are integrated

Examples

- Specification = programming-in-the-large
  - A library is used that include more functions than those that are required
  - If someone succeeds in invoking some of the “useless” functions, anomalous behaviors may arise
  - Code reuse may introduce in a system some vulns in the code that is reused

Examples

- Implementation =
  - Well behaved input
  - No control on input parameters
  - Data and program confusion = jump into a data structure = stack /buffer/heap overflow
- These vulnerabilities strongly depend upon the native control in the language type system and in the language run time system

  = no overflows with strong data types

Examples

- Structural: due to the composition of several components that are
  - Correct in isolation
  - Uncorrect when component
- Problems in the TCP/IP stack
- Some components delegate security checks to other ones, their correctness depends upon checks in other components

Another classification

- It considers an attack that exploit the vulnerability
  - Who can implement the attack
    - Those who own a local account
    - Those who can interact with the machine
    - …
  - What can be achieved by the attack

Searching for vulns

- Any system can be described as the composition of standard and specialized (not standard) components
- Most vulns and exploits for standard components are well known
- The search should focus on
  - Not standard components
  - Structural vulns due to the composition of standard components with not standard ones
  - Vulns in standard components are the last to be searched

Vulns and vulnerability scanning

- A vulnerability scanner is a tool that returns a set of vulns for each computer node in a network
- The scanner identifies the OS and the applications running on the node through a fingerprinting algorithms
- Then it accesses a database that maps each OS and application into a set of of pubblic vulns
- Vulnerabity scanning is a proper subset of a vulnerability analysis, the easiest one

Fingerprint

- The main mechanism to identify the OS and the application is the transmission of IP packets that violates the specifications
- All the applications and the OS reply in a standard way to a standard packet
- Each OS and application has its own reaction to a wrong packet that violates the TCP/IP specification
- Several packets may be required to solve any ambiguity among distinct OSes/Components

Fingerprint and mapping

- The applications are discovered by analyzing the open ports in the node
- After discovering the OS and the applications each of them is mapped into a set of vulnerabilities
- The mapping is implemented by accessing pubblic databases that store any vulnerabilities of the OS or of any application

False and true positive

- The scanner will signal a vulnerability even if the component has been patched
- This is what is called a false positive
- The only strategy to distinguish false and true positive is to actually implement an attack that exploits the vulnerability
- Not always possible on production systems

Not a boolean world

		Existence (gold standard) Y	Existence (gold standard) N
Test outcome	Y	True positive	False Positive
	N	False negative	True Negative

The problem arises anytime we can only deduce the existence of an object from some symptoms and do not have a direct access to it

Not a boolean world

		Condition (as determined by "Gold standard")		
		Condition positive	Condition negative	
Test outcome	Test outcome positive	**True positive**	**False positive** (Type I error)	Precision = $\frac{\Sigma \text{ True positive}}{\Sigma \text{ Test outcome positive}}$
	Test outcome negative	**False negative** (Type II error)	**True negative**	Negative predictive value = $\frac{\Sigma \text{ True negative}}{\Sigma \text{ Test outcome negative}}$
		Sensitivity = $\frac{\Sigma \text{ True positive}}{\Sigma \text{ Condition positive}}$	Specificity = $\frac{\Sigma \text{ True negative}}{\Sigma \text{ Condition negative}}$	**Accuracy**

$$\text{accuracy} = \frac{\text{number of true positives} + \text{number of true negatives}}{\text{number of true positives} + \text{false positives} + \text{false negatives} + \text{true negatives}}$$

Vulnerabilities in non standard components

- We consider some tools to search for vulnerabilities in non standard component
- Not always we have the source code of the component available

Tainting analysis

- A static analysis of the source code that computes the set of program variables that may receive an input variable and so be overflown
- It returns a larger set than the actual one, worst case
- It can be improved by taking into account the procedure to copy the input value

Tainting analysis

- if x (y=input)
  else (y=z);
  w=y
- A tainting analysis tell us that w may have been tainted with an input value
- if x (y=input)
  else (y=z);
  copy (w, y)
- If copy checks the length of y before copying it into w, tainting but less danger

Discovering overflow

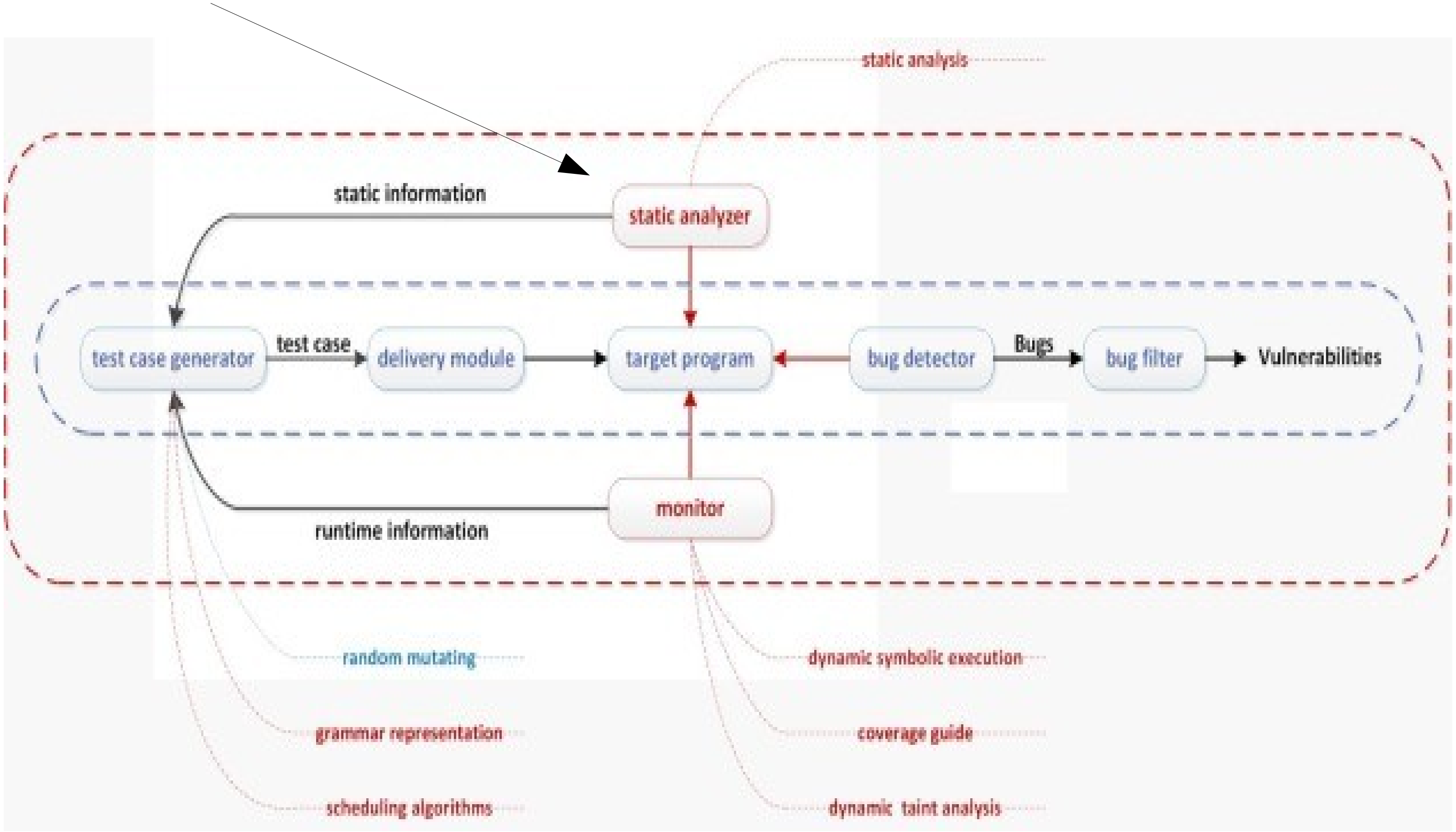
- There is a vulnerability anytime an input value is copied into a procedure parameter without checking its length (bug)
- It is worth attacking a procedure if it is executed with a large set of rights (vulnerability)
- A simple tainting analysis is not sufficient (false positive)

Fuzzing and fuzzer

- Fuzzing is a technique to search for vulnerabilities in a module
- The basic idea is to send malformed input to the module
- If the module crash, then the input is not controlled and a vulnerability is possible
- A fuzzer is a tool that automate this process by testing a huge number of inputs even in parallel

Fuzzer Architecture

If not possible=black box fuzzing



Mutation Based Fuzzing

- Little or no knowledge of the structure of the inputs is assumed
- Anomalies are added to existing valid inputs
- Anomalies may be completely random or follow some heuristics
- Requires little or no set up time
- Dependent on the inputs being modified
- May fail for protocols with checksums, those which depend on challenge response, etc.
- Example ToolS : Taof, GPF, ProxyFuzz, Peach Fuzzer, etc.

Mutation Based Example: PDF Fuzzing

- Google .pdf (lots of results)
- Crawl the results and download lots of PDFs
- Use a mutation fuzzer:
- Grab the PDF file
- Mutate the file
- Send the file to the PDF viewer
- Record if it crashed (and the input that crashed it)

Mutation-based	Super easy to setup and automate +	Little to no protocol knowledge required +	Limited by initial corpus −	May fail for protocols with checksums, or other complexity −

Generation Based Fuzzing

- Test cases are generated from some description of the format: RFC, documentation, etc.
- Anomalies are added to each possible spot in the inputs
- Knowledge of protocol should give better results than random fuzzing
- Can take significant time to set up
- Examples

  SPIKE, Sulley, Mu-4000,
  Codenomicon,
  Peach Fuzzer, etc…

Example Specification for ZIP file

```
<!--  A.  Local file header -->
  <Block name="LocalFileHeader">
    <String name="lfh_Signature" valueType="hex" value="504b0304" token="true" mut
    <Number name="lfh_Ver" size="16" endian="little" signed="false"/>
    ...
    [truncated for space]
    ...
    <Number name="lfh_CompSize" size="32" endian="little" signed="false">
      <Relation type="size" of="lfh_CompData"/>
    </Number>
    <Number name="lfh_DecompSize" size="32" endian="little" signed="false"/>
    <Number name="lfh_FileNameLen" size="16" endian="little" signed="false">
      <Relation type="size" of="lfh_FileName"/>
    </Number>
    <Number name="lfh_ExtraFldLen" size="16" endian="little" signed="false">
      <Relation type="size" of="lfh_FldName"/>
    </Number>
    <String name="lfh_FileName"/>
    <String name="lfh_FldName"/>
    <!--  B.  File data -->
    <Blob name="lfh_CompData"/>
  </Block>
```

Mutation vs Generation

Mutation-based	Super easy to setup and automate +	Little to no protocol knowledge required +	Limited by initial corpus −	May fail for protocols with checksums, or other complexity −
Generation-based	Writing generator is labor intesive for complext protocols −	have to have spec of protocol (frequently not a problem for common ones http, snmp, etc…) −	Completeness +	Can deal with complex checksums and dependencies +

White box vs. black box fuzzing

- Black box fuzzing: sending the malformed input without any verification of the code paths traversed
- White box fuzzing: sending the malformed input and verifying the code paths traversed. Modifying the inputs to attempt to cover all code paths.

Technique	Effort	Code coverage	Defects Found
black box + mutation	10 min	50%	25%
black box + generation	30 min	80%	50%
white box + mutation	2 hours	80%	50%
white box + generation	2.5 hours	99%	100%

Evolutionary Fuzzing

- Attempts to generate inputs based on the response of the program
- Autodafe
- Prioritizes test cases based on which inputs have reached dangerous API functions
- Evolutionary Fuzzing System
- Generates test cases based on code coverage metrics
- This technique is still in the alpha stage :)

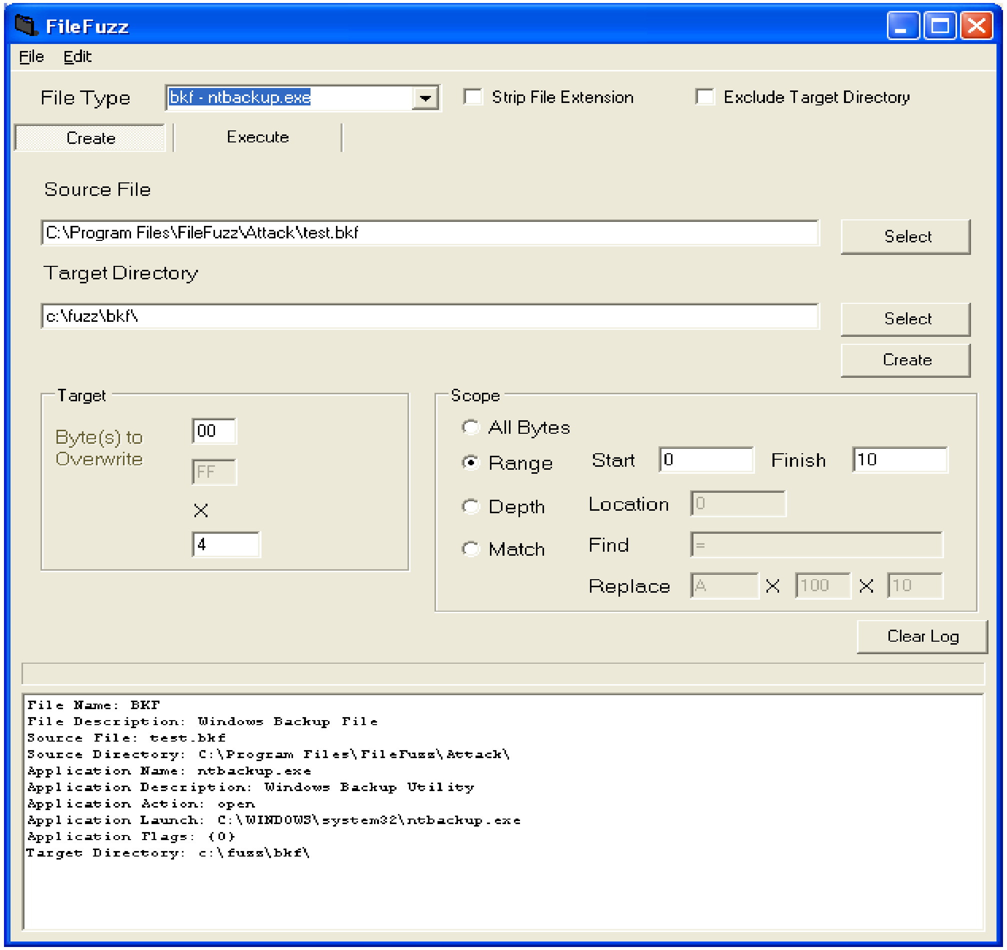
Fuzzing and fuzzer: Phases

1. **Identify target**
2. **Identify inputs**
3. **Generate fuzzed data**
4. **Execute fuzzed data**
5. **Monitor for exceptions**
6. **Determine exploitability**

Fuzzing and fuzzer: Phases and tools

- Command line arguments
- Environment variables
  - Sharefuzz (www.immunitysec.com)
- Web applications
  - WebFuzz
- File formats
  - FileFuzz
- Network protocols
  - SPIKE (www.immunitysec.com)
- Memory
- COM Objects
  - COMRaider
- Inter-Process Communication (IPC)

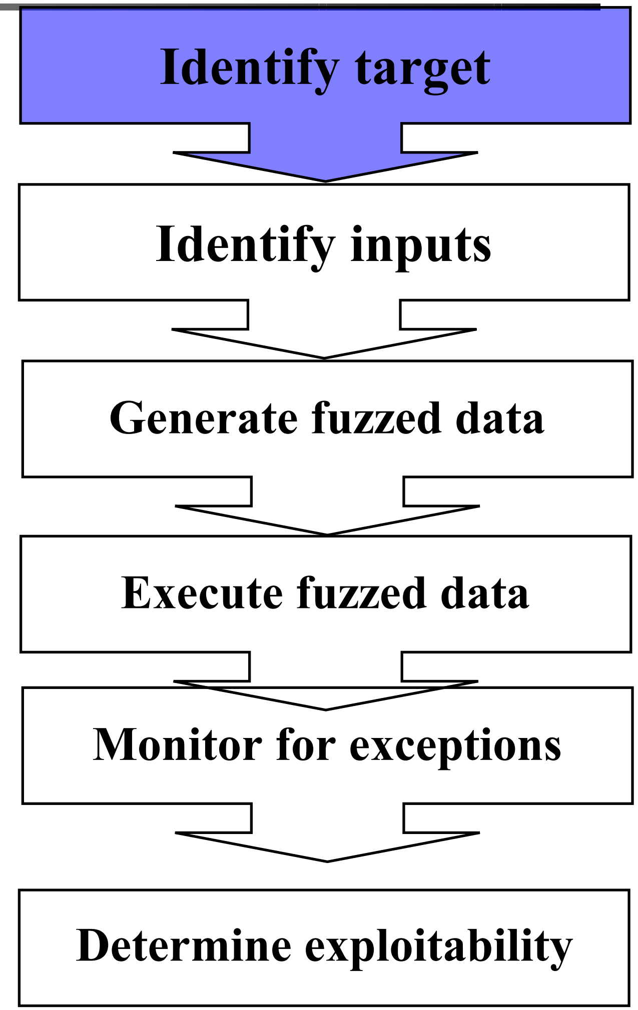
FileFuzz



FileFuzz
File
Edit
File Type
bkf - ntbackup.exe
Strip File Extension
Exclude Target Directory
Create
Execute
Source File
C:\Program Files\FileFuzz\Attack\test.bkf
Select
Target Directory
c:\fuzz\bkf\
Select
Create
Target
Byte(s) to Overwrite
00
FF
X
4
Scope
All Bytes
Range
Start
0
Finish
10
Depth
Location
0
Match
Find
Replace
A
100
10
Clear Log
File Name: BKF
File Description: Windows Backup File
Source File: test.bkf
Source Directory: C:\Program Files\FileFuzz\Attack\
Application Name: ntbackup.exe
Application Description: Windows Backup Utility
Application Action: open
Application Launch: C:\WINDOWS\system32\ntbackup.exe
Application Flags: {0}
Target Directory: c:\fuzz\bkf\

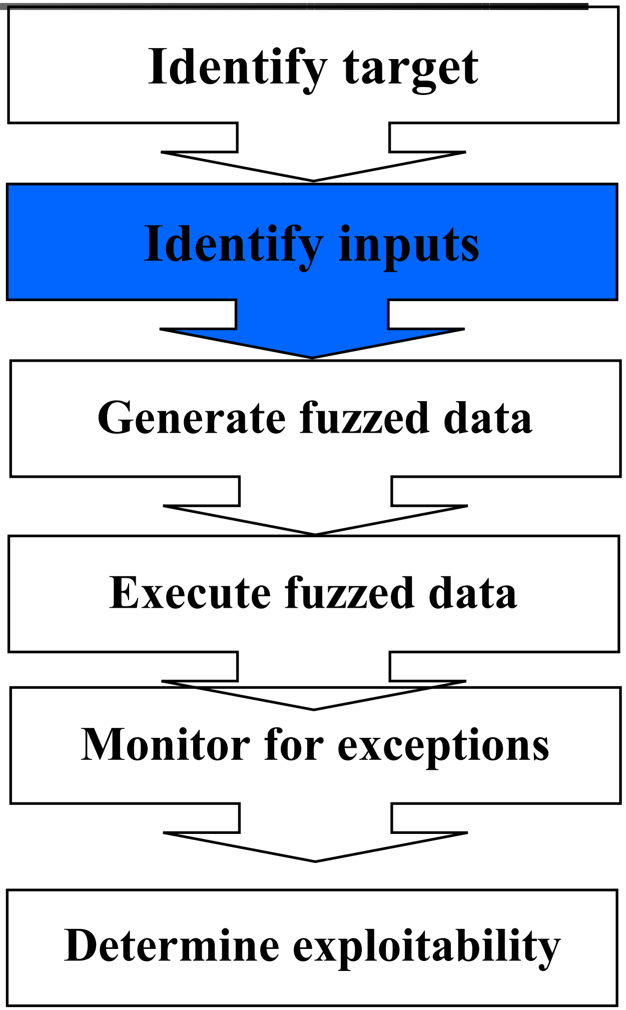
FileFuzz – Identify Target

- Application vs. file type
  - One file type ➠ multiple targets
- Vendor history
  - Past vulnerabilities
- High risk targets
  - Default file handlers
    - Windows Explorer
    - Windows Registry
  - Commonly traded file types
    - Media files
    - Office documents
    - Configuration files



FileFuzz – Identify Inputs

- Proprietary vs. open formats
  - Vendor documents
  - Wotsit.org
  - Google
- Binary files
  - e.g. images, video, audio, office documents, etc.
  - Headers vs. data
- Text files
  - e.g. *.ini, *.inf, *.xml
  - Name/value pairs



FileFuzz – Generate Fuzzed Data

- Binary files
  - Breadth (All or Range)
    - Identify potential weaknesses

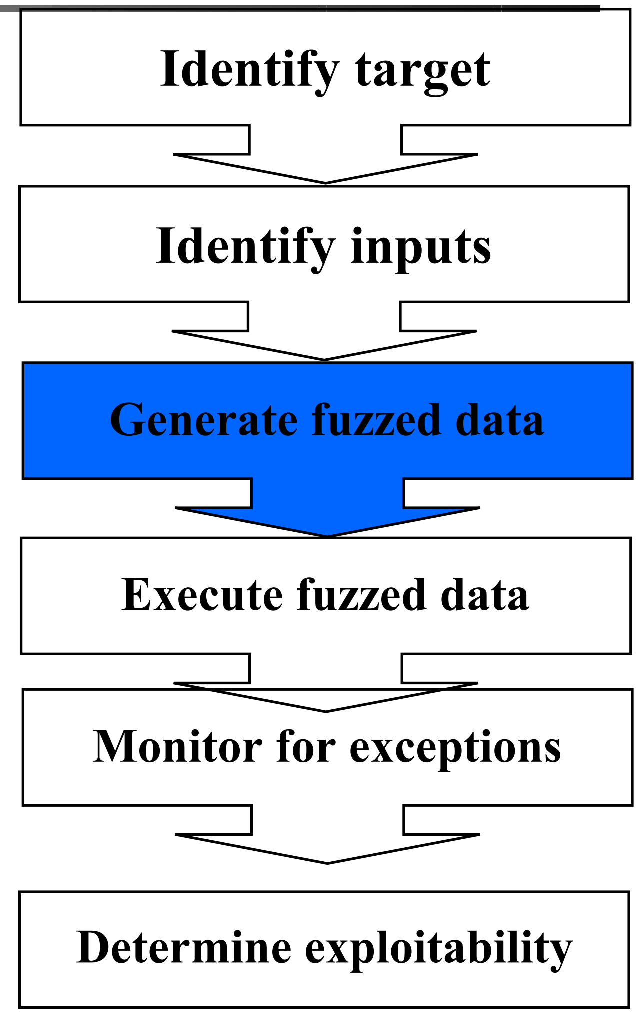
```
FF FF FF FF 00 00 DB FE 0B 00 C5 00 00 01 E8 03 ;
                    ÿÿÿÿ..Ûþ..Å...è.
D7 FF FF FF FF 00 DB FE 0B 00 C5 00 00 01 E8 03 ;
                    ×ÿÿÿÿ.Ûþ..Å...è.
D7 CD FF FF FF FF DB FE 0B 00 C5 00 00 01 E8 03 ;
                    ×Íÿÿÿÿÿþ..Å...è.
```

  - Depth
    - Determine level of control/influence

```
D7 CD FD 9A 00 00 DB FE 0B 00 C5 00 00 01 E8 03 ; ×Íýš..Ûþ..Å...è.
D7 CD FE 9A 00 00 DB FE 0B 00 C5 00 00 01 E8 03 ; ×Íþš..Ûþ..Å...è.
D7 CD FF 9A 00 00 DB FE 0B 00 C5 00 00 01 E8 03 ; ×Íÿš..Ûþ..Å...è.
```

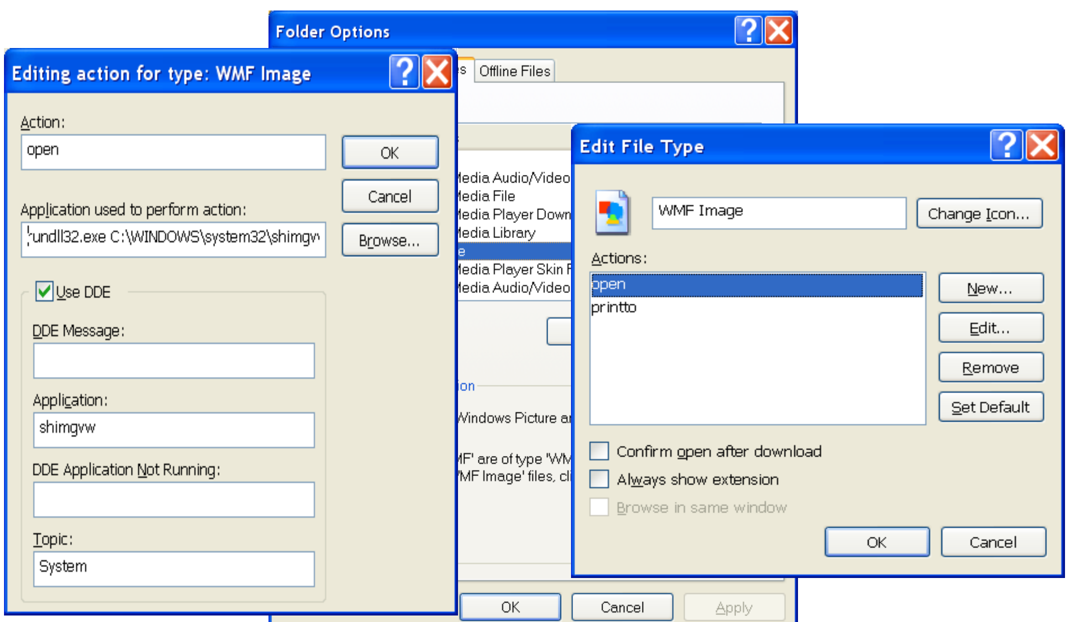
- Text Files
  - name = value

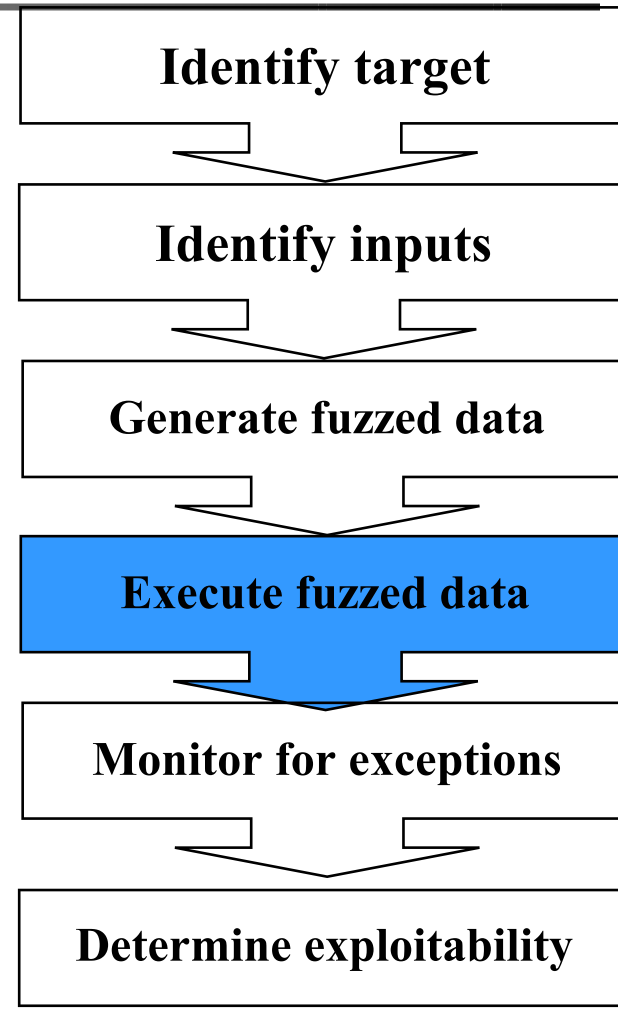
```
file_size = 10
file_size = AAAAA
file_size = AAAAAAAAAA
```



FileFuzz – Execute Fuzzed Data

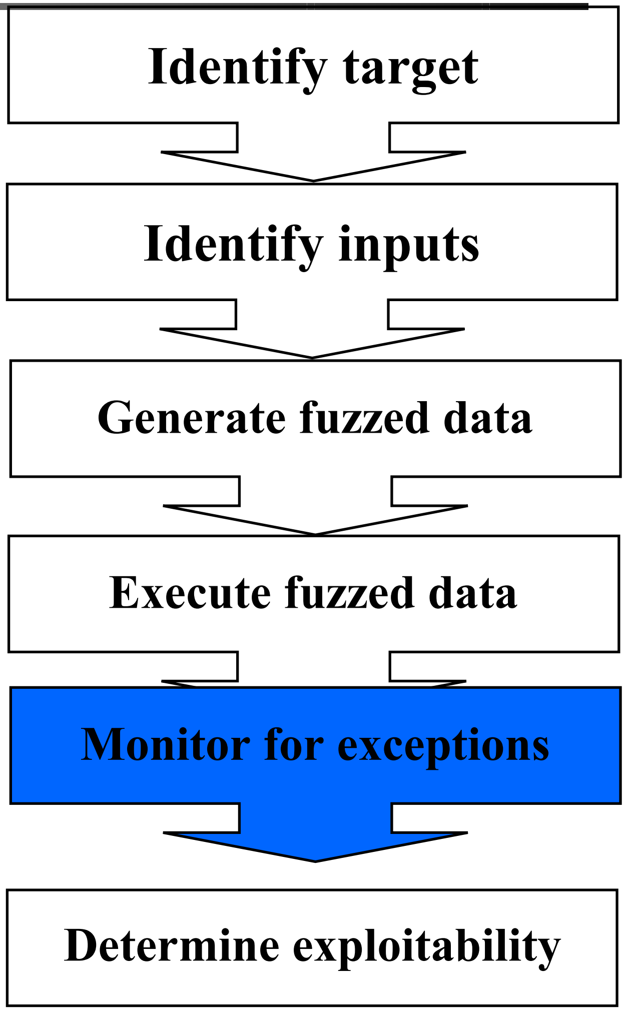
- Command line arguments
  - Windows explorer
    - Tools…Folder Options…File Types





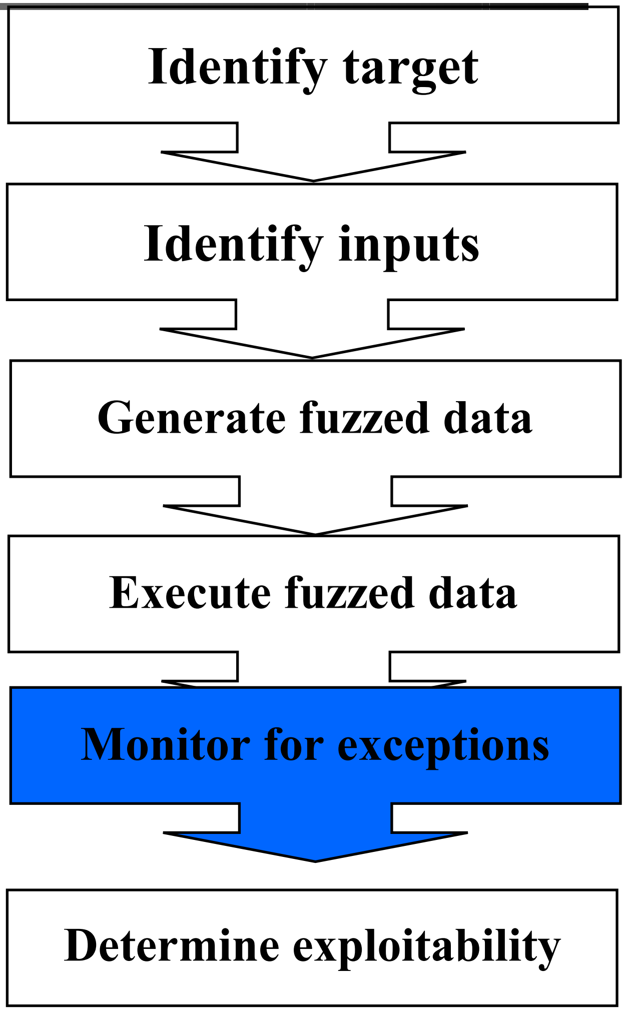
FileFuzz – Monitor for Exceptions

- Visual
  - Error messages
  - Blue screen
- Event logs
  - System logs
  - Application logs
- Debuggers
- Return codes
- Debugging API



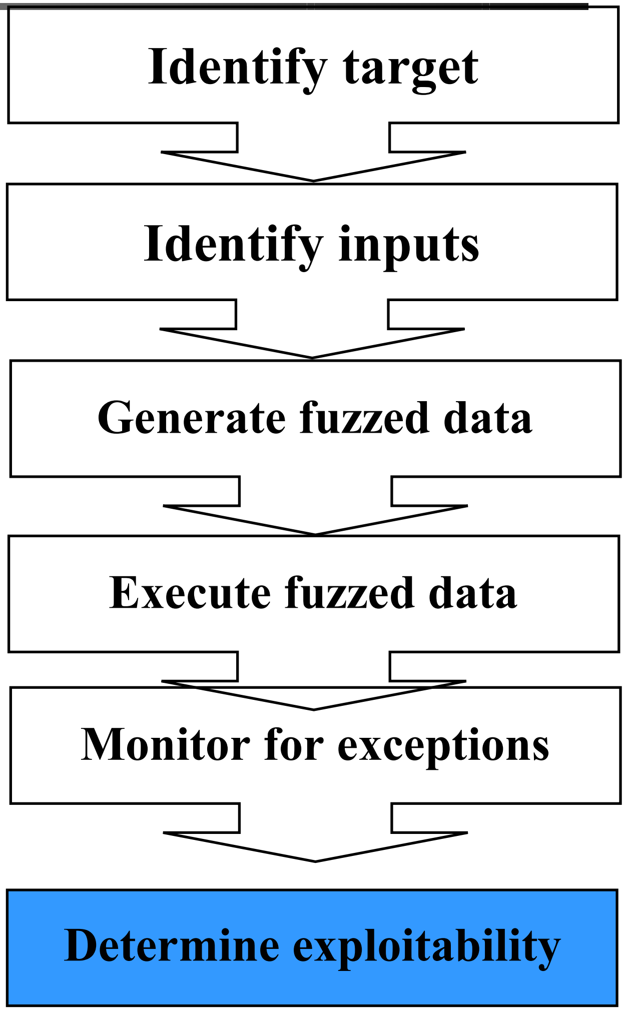
FileFuzz – Monitor for Exceptions

- Execute
  - Automated and repeated
- Monitor
  - Library - libdasm
  - Capture
    - Memory location
    - Registry values
    - Exception type

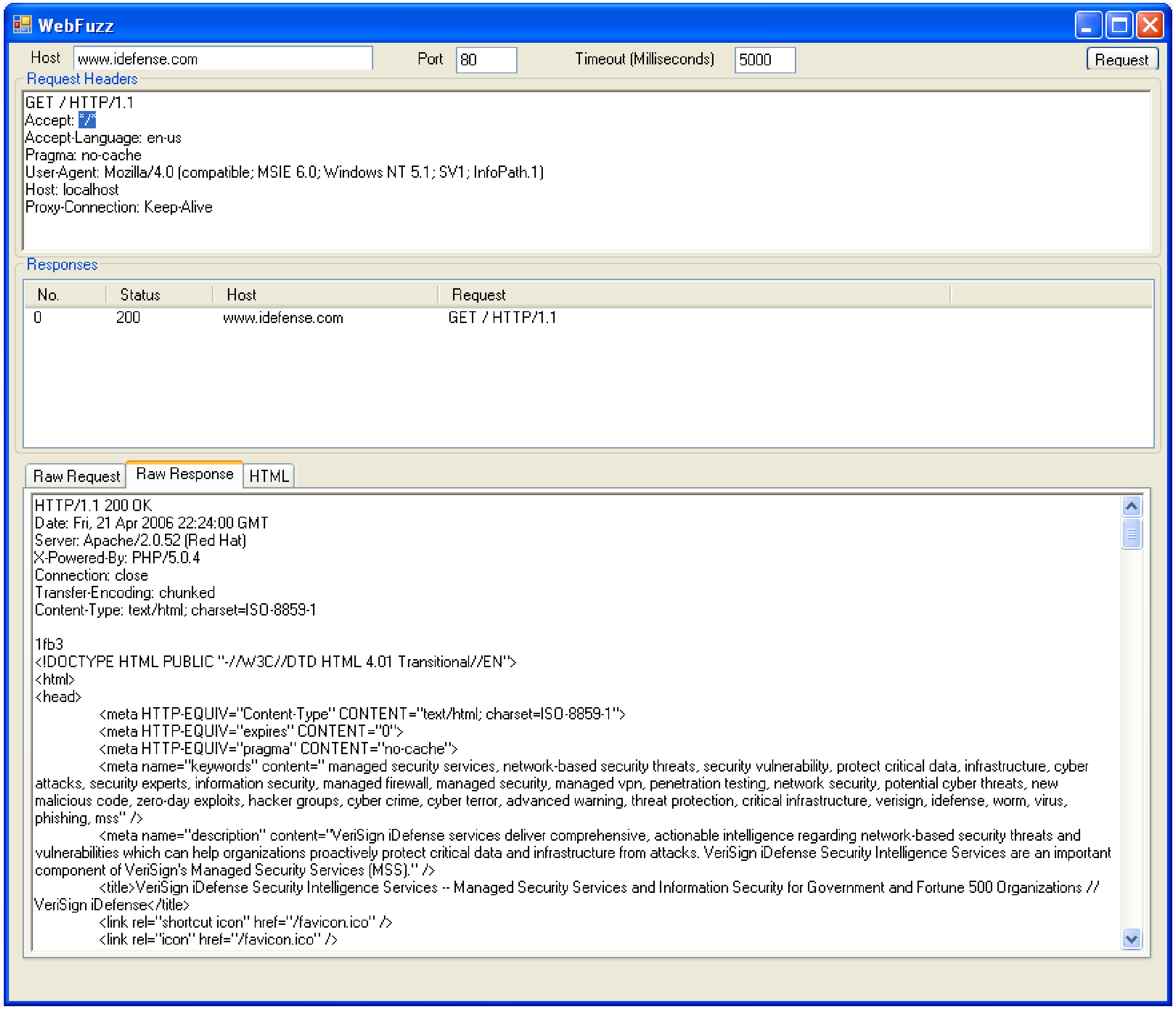


FileFuzz – Determine Exploitability

- Skills = Disassembly + Debugging
- Vulnerability types
  - Stack overflows
  - Heap overflows
  - Integer handling
    - Overflows
    - Signedness
  - DoS
    - Out of bounds reads
    - Infinite loops
    - NULL pointer dereferences
  - Logic errors
    - Windows WMF vulnerability (MS06-001)
  - Format strings
  - Race conditions



WebFuzz



WebFuzz
Host www.idefense.com
Port 80
Timeout (Milliseconds) 5000
Request
Request Headers
GET / HTTP/1.1
Accept: */*
Accept-Language: en-us
Pragma: no-cache
User-Agent: Mozilla/4.0 (compatible; MSIE 6.0; Windows NT 5.1; SV1; InfoPath.1)
Host: localhost
Proxy-Connection: Keep-Alive
Responses
No. Status Host Request
0 200 www.idefense.com GET / HTTP/1.1
Raw Request
Raw Response
HTML
HTTP/1.1 200 OK
Date: Fri, 21 Apr 2006 22:24:00 GMT
Server: Apache/2.0.52 (Red Hat)
X-Powered-By: PHP/5.0.4
Connection: close
Transfer-Encoding: chunked
Content-Type: text/html; charset=ISO-8859-1
1fb3
<!DOCTYPE HTML PUBLIC "-//W3C//DTD HTML 4.01 Transitional//EN">
<html>
<head>
<meta HTTP-EQUIV="Content-Type" CONTENT="text/html; charset=ISO-8859-1">
<meta HTTP-EQUIV="expires" CONTENT="0">
<meta HTTP-EQUIV="pragma" CONTENT="no-cache">
<meta name="keywords" content=" managed security services, network-based security threats, security vulnerability, protect critical data, infrastructure, cyber attacks, security experts, information security, managed firewall, managed security, managed vpn, penetration testing, network security, potential cyber threats, new malicious code, zero-day exploits, hacker groups, cyber crime, cyber terror, advanced warning, threat protection, critical infrastructure, verisign, idefense, worm, virus, phishing, mss" />
<meta name="description" content="VeriSign iDefense services deliver comprehensive, actionable intelligence regarding network-based security threats and vulnerabilities which can help organizations proactively protect critical data and infrastructure from attacks. VeriSign iDefense Security Intelligence Services are an important component of VeriSign's Managed Security Services (MSS)." />
<title>VeriSign iDefense Security Intelligence Services -- Managed Security Services and Information Security for Government and Fortune 500 Organizations // VeriSign iDefense</title>
<link rel="shortcut icon" href="/favicon.ico" />
<link rel="icon" href="/favicon.ico" />

WebFuzz – Identify Target

Server vs. Application

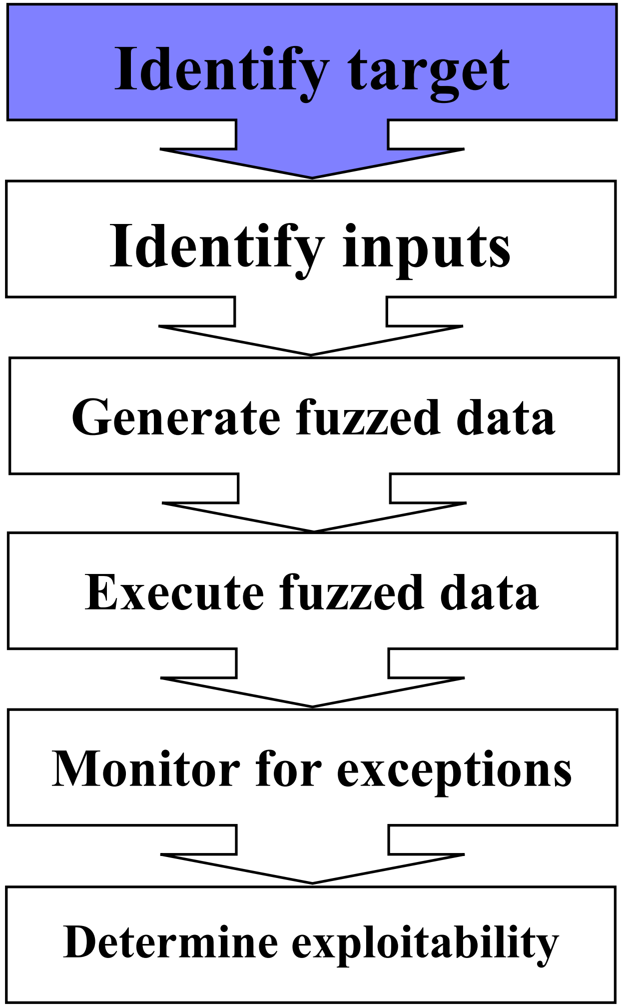
- Targeting applications can uncover server vulnerabilities

Vendor history

- Past vulnerabilities

High risk targets

- Popular applications
- External applications
  - Wikis
  - Web mail
  - Discussion boards
  - Blogs



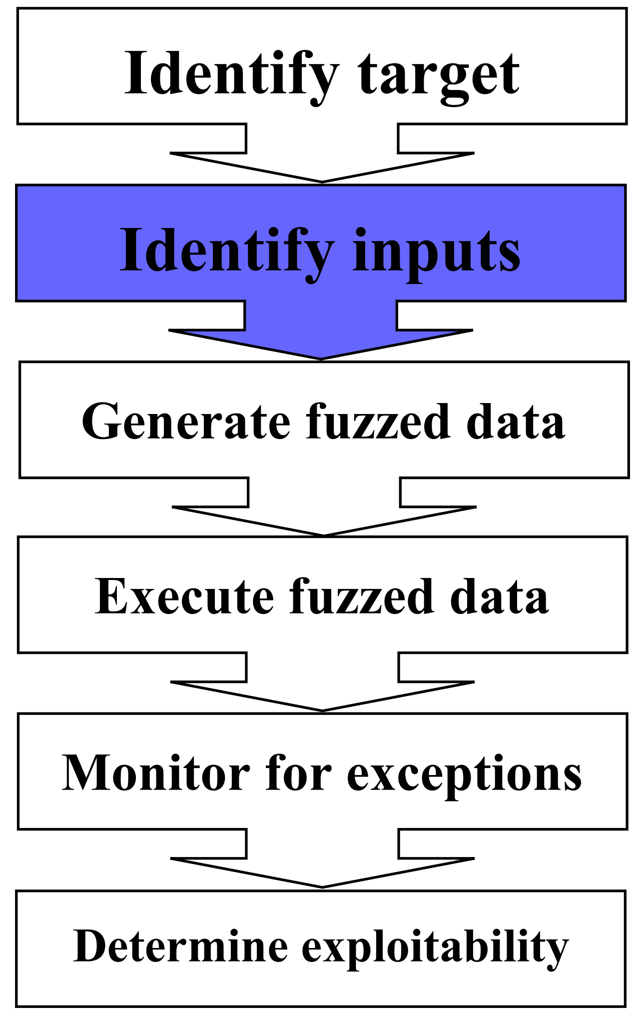
WebFuzz – Identify Inputs

Potential input vectors
- Method
- Request-URI
- Protocol
- Headers
- Cookies
- Post data

Reconnaissance
- Web forms
- Authentication
- Hidden fields
- Client side scripting

Manual Tools
- Proxies
- LiveHTTPHeaders

Automated Tools
- Spiders



WebFuzz – Generate Fuzzed Data

Intelligent fuzzing

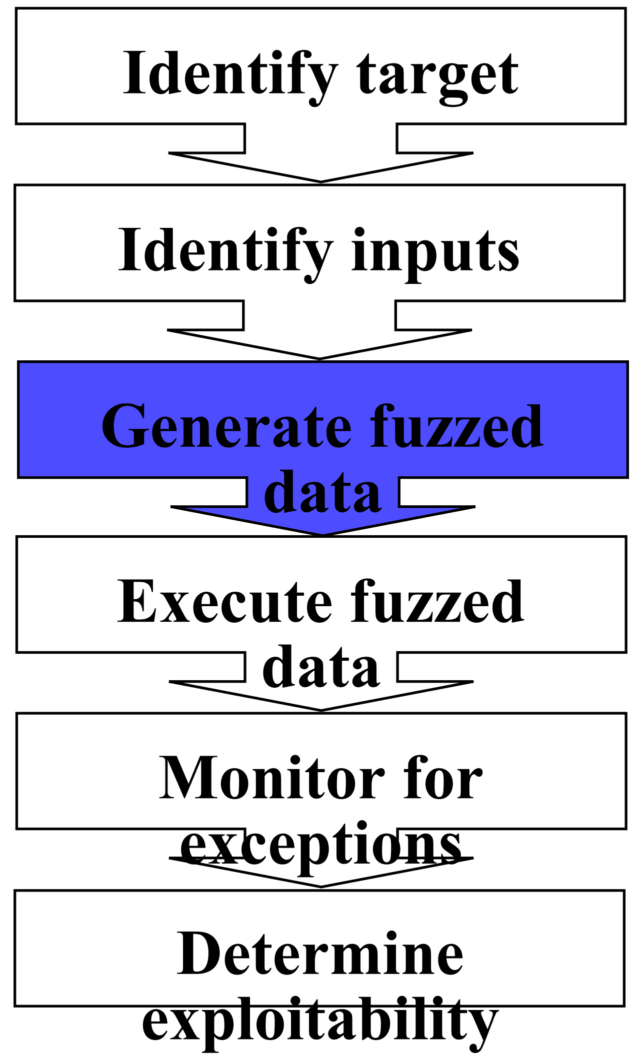
- Start with legitimate web request
- Build template to mutate requests

Request format

```
[Method] [Request-URI] HTTP/[Major Version].[Minor Version]
[HTTP Headers]
[Post Data]
```

Fuzz Template

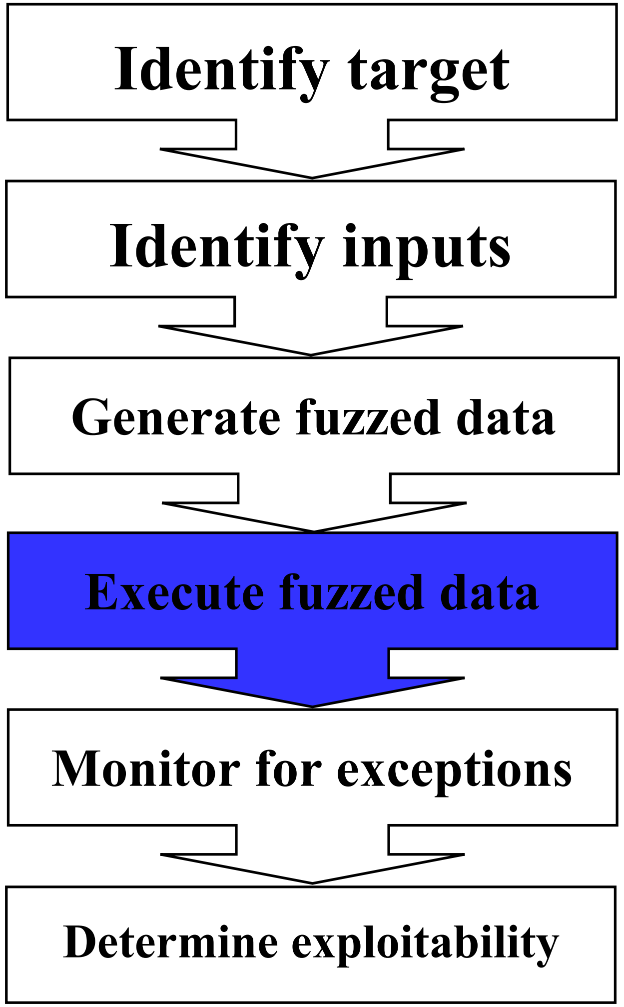
```
[Methods] /[Traversal]/page.html?x=[SQL]&y=[XSS] HTTP/1.1
Accept: */*
Accept-Language: en-us
Pragma: no-cache
User-Agent: Mozilla/4.0 (compatible; MSIE 6.0; Windows NT 5.1; SV1; InfoPath.1)
Host: [Overflow]
Proxy-Connection: Keep-Alive
```



WebFuzz – Execute Fuzzed Data

Fuzz classes

- Directory traversal
- Format strings
- Overflow
- SQL Injection
- XSS Injection

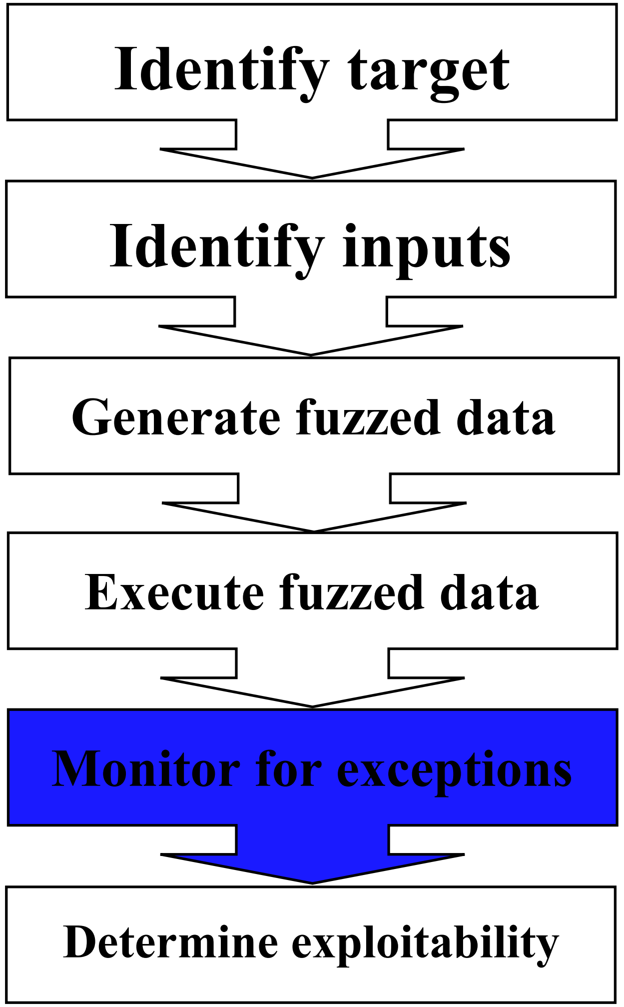


WebFuzz – Monitor for Exceptions

Execute
- Automated and repeated

Monitor
- HTML response
  - Error messages
- Raw response
  - User input
- Status codes

Kill
- Set timeout



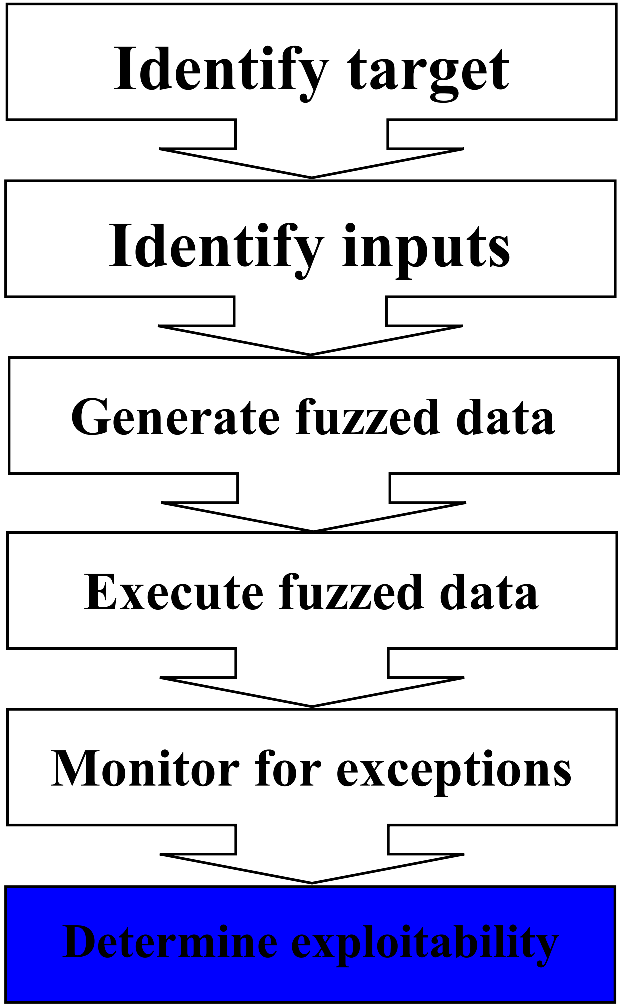
WebFuzz – Determine Exploitability

Skills

- HTTP
- HTML
- Client side scripting
- SQL

Vulnerability types

- Denial of service
- Cross site scripting (XSS)
- SQL injection
- Directory traversal/Weak access control
- Weak authentication
- Weak session management (cookies)
- Buffer overflow
- Improperly supported HTTP methods
- Remote Command Execution
- Remote Code Injection
- Vulnerable Libraries
- HTTP Request Splitting
- Format Strings



Lessons about Fuzzing

- Protocol knowledge is helpful
  - Generational beats random, better specification make better fuzzers
- Using more fuzzers is better
  - Each one will vary and find different bugs
- The longer you run (typically) the more bugs you'll find
- Guide the process, fix it when it break or fails to reach where you need it to go
- Code coverage can serve as a useful guide

Interesting Fuzzing Results

Time to first failure (TTFF)

To measure the relative maturity of a given protocol, the time to first failure (TTFF), or the time to the first instance when that a protocol crashes, is used. It

The average time for first failure of all tests in 2016 was about 1 hour (1.4 hours). This represents a very slight decrease over 2015 (1.7 hours), which might be attributable to a more diverse range of tests run in 2016.

5 most mature protocols (average time to first failure, in hours and days)

Protocol suite	2016 time to first failure	2015 time to first failure	2016 test runtime (avg)
TLS Client (Core IP)	9.6 hours	5.4 hours	10.5 hours
SSH2 (Core IP)	6.8 hours	1.9 hours	22.6 hours
SSH Server (Core IP)	4.9 hours	0.7 hours	5.96 hours
802.11 (Core IP)	4.2 hours	1 hour	11.8 hours
ICMPv6 (Core IP)	2.7 hours	1 hour	2.3 days

5 least mature protocols (average time to first failure, in minutes and seconds)

Protocol suite	2016 time to first failure	2015 time to first failure	2016 test runtime (avg)
IEC-61850 MMS (ICS)	6.6 seconds	13.2 seconds	5.7 hours
MODBUS PLC (ICS)	1.8 minutes	6 seconds	35 minutes
SNMP Trap (Remote Management)	1.8 minutes	3.6 minutes	57 minutes
MQTT (ICS)	9.9 minutes	2.1 minutes	1.3 hours
DNP3 (ICS)	14 minutes	3.6 minutes	2.6 hours

Fuzzing Maturity Model

	Types	Test cases	Time (hours)	Instrumentation	Allowed failures	Test harness integration	Processes	Documentation	Other requirements
5 : Optimized	G T	infinite infinite	720	O,A,D	none	Yes	S,C	RR,S,P,B,C	U2
4 : Integrated	G T	infinite infinite	168	O,A,D	none		S,C	RR,S,P,B,C	
3 : Managed	G T	2,000,000 5,000,000	16	O,A	Tr		S	RR,S,P,B	
2 : Defined	G (T)	1,000,000 (5,000,000)	8	O	Tr		S	RR,S,P	
1 : Initial	G/T	100,000	2	O	Tr,As			RR	
0 : Immature									

G = Generational fuzzer
T = Template fuzzer
O = Human observation
A = Automated instrumentation
D = Developer tooling
Tr = Transient failures
As = Non-DoS assertion failures

S = Attack surface analysis
C = Software component analysis
RR = Results and summary
P = Test plan
B = Document baseline test configuration
U2 = Use two different fuzzers per type

Fuzzing Maturity Model

- Level 0: Immature

  If no fuzzing has been performed on any attack vector in a target, the target is at FTMM Level 0. If minimal fuzzing has been done, but does not meet the Level 1 requirements, then the target is still at FTMM Level 0.

- Level 1: Initial

  Level 1 represents an initial exposure to fuzz testing. Either generational or template fuzzing is used on the known attack vectors of the target, For each tested attack vector, fuzzing should be performed for at least 2 hours or 100,000 test cases, whichever comes first.

Fuzzing Maturity Model

- Level 2: Defined

  The starting point for Level 2 is an attack surface analysis of the target. For each attack vector, a generational fuzzer should be used for 8 hours or 1 million test cases, whichever comes first. If a generational fuzzer is unavailable for an attack vector, a template fuzzer can be used instead, for at least 8 hours or 5 million test cases, whichever comes first.

- Level 3: Managed

  Both generational and template fuzzing must be performed for each attack vector in Level 3. The generational fuzzer must be run for 16 hours or 2 million test cases, whichever comes first, while the template fuzzer must be run for 16 hours or 5 million test cases. Automated instrumentation must be used.

Fuzzing Maturity Model

- Level 4: Integrated

  Level 4 increases the fuzzing time per fuzzer type to one week. There is no longer a minimum threshold for test cases—for each attack vector, a generational fuzzer and a template fuzzer must both be run until the minimum required time is reached.

- Level 5: Optimized

  Level 5 increases testing time to 30 days for each fuzzing type, and requires the use of at least two different fuzzers per fuzzing type. Because fuzzing is an infinite space problem, and because different fuzzers work differently, using two generational and two template fuzzers increases the probability of locating vulnerabilities

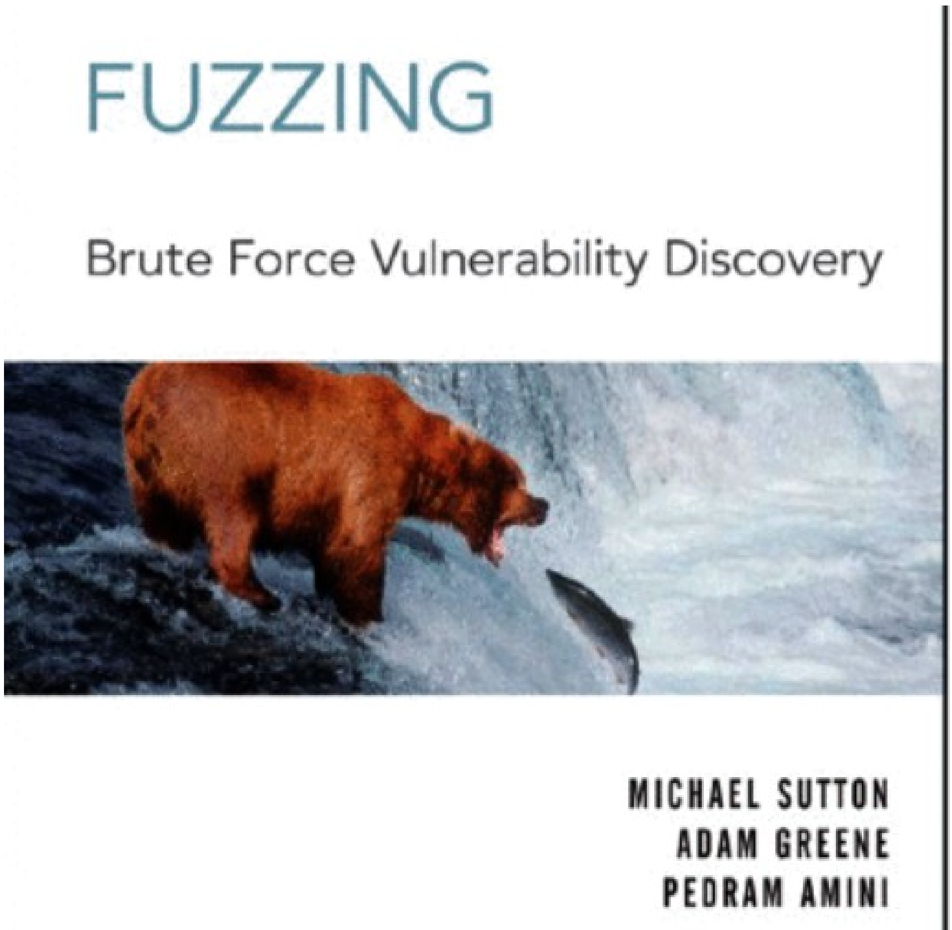
Fuzzing and the IOT

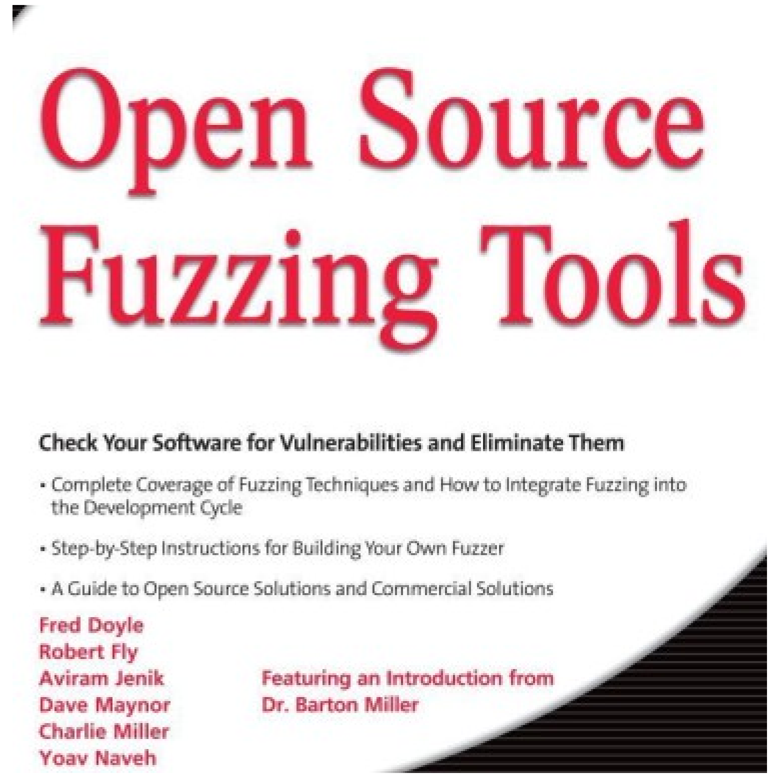
- Most IOT systems includes sensors and devices that run proprietary software
- One day the owner of a factory asked this question:

  How can I be sure that the sensors in my factory are reliable, secure and do not send some information to my competitors?

  Fuzzing is one of the few techniques that can be applied

Fuzzing and fuzzer





Non standard vulns in general

- To discover other vulns in a component, we consider that the vulns in a component defines a systemic property, the robustness of the component
- Systemic = it depends upon the component and the relation among components
- There is a relation among
  - Search of vulns
  - Robustness

Robustness in ICT

- Robustness of a module =
  - The module ability of avoiding damage to the overall system even if its specifications are violated
- Violation of the specifications =
  - Inputs differs from the specified one
  - Available resources differs ...
  - ... (enumerating badness)
- A generalization of fuzzing that considers inputs only

Robustness in biology

- Redundancy
- Modularity
- Feedback
  - Monitoring of the behavior of a component
  - Tuning of the beheavior of a component
  - Confinment of anomalous behavior
- Uncorrect components are confined and replaced
- No single point of failure

If any of these features is not satisfied a vulnerability is possible

Robustness vs Vulnerability

- Any set of rules that defines how to build a robust module (best solution, best approaches) also defines a set of rules to discover vulnerabilities
- If the rules are violated, then the module is not robust, then there are some vulnerabilities
- As we have seen in fuzzing a crash (violation) signals a potential vulnerability

Robustness

- It differs from performance, efficiency, ease of use, ...
- It can be increased only by decreasing performance, efficiency, ease of use, ...

No Free Lunch Theorem

Robustness

- Let us consider a program that given the name of a worker returns the worker's salary
- The program is
  - correct if the salary is correct for any worker
  - high performance if the salary is computed in a very short time
  - easy to use if you learn ho to use it in a short time
  - robust ????

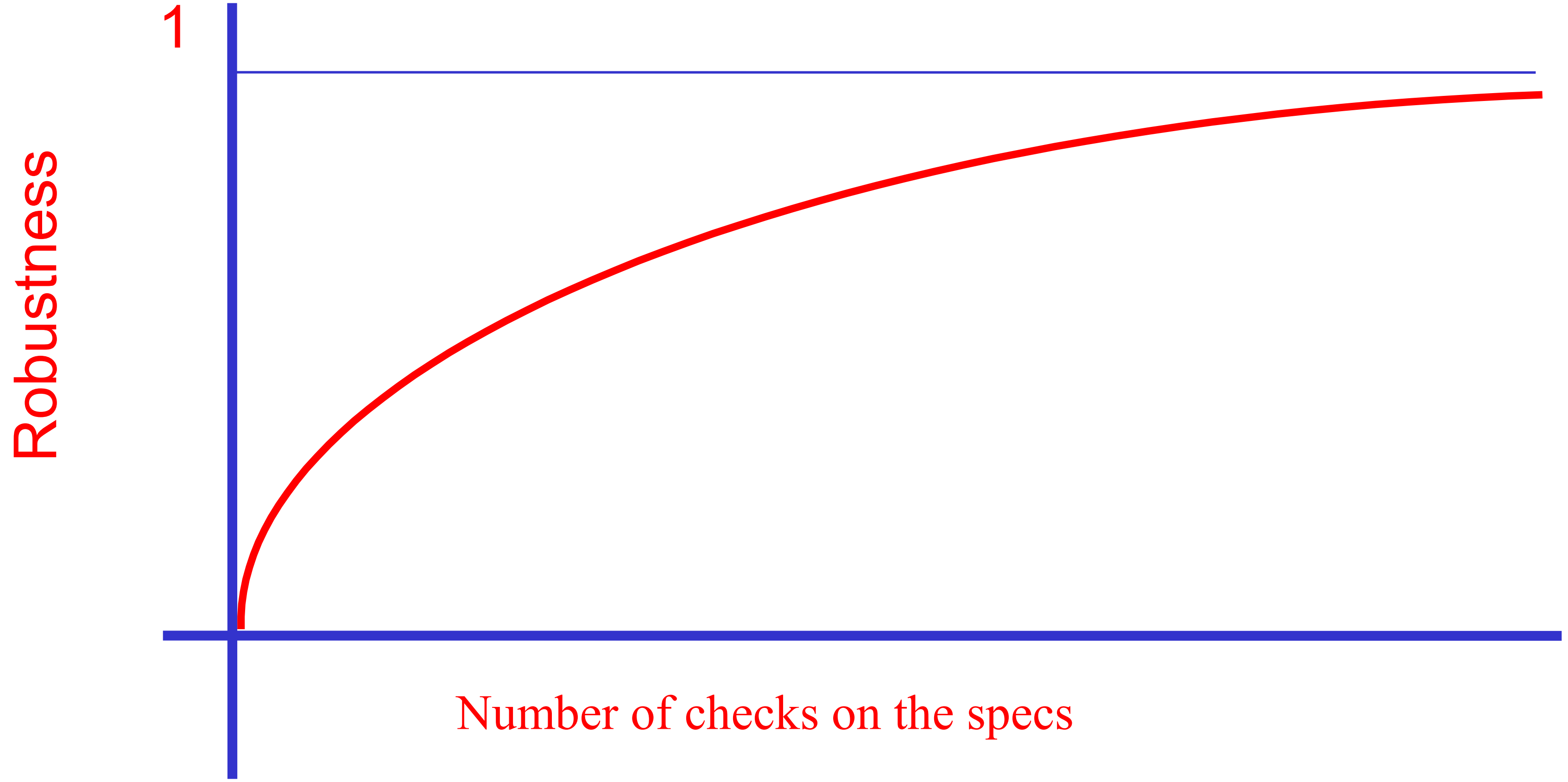
Robust .... what happens if

- Wrong record format in the file
- No worker with the name
- The name is 457 characters
- The allocated memory is smaller than expected
- No file with the worker names
- No file with info to compute the salary
- No disk ....

How much robustness ....

- It is almost impossible to define in advance any violation (this proves the weakness of enumerating badness)
- Robustness is not a 0/1 property
- A robustness measure lies in the range 0..1
- 1 is an asimptotic values
- Robustness depends upon the number of checks in the module program to discover violations before using an input or a resource

How much robust?



How much robust?

- The value depends upon the number of checks
- Robustness $\rightarrow$1 if the number of checks $\rightarrow \infty$
- Assuming specs are correct, usually checks are useless because the probability the specs are violated is neglectable
- A compromise is required because the number of checks reduces the overall performance

  $\rightarrow$ they slow downs the component because they are implemented through instructions as any other function

Robustness

- It has been experimentally confirmed that even trivial checks can improve the component robustness
- This implies that complex checks should be adopted only after trivial ones
- Most efficient checks are those related to data types (inputs etc)

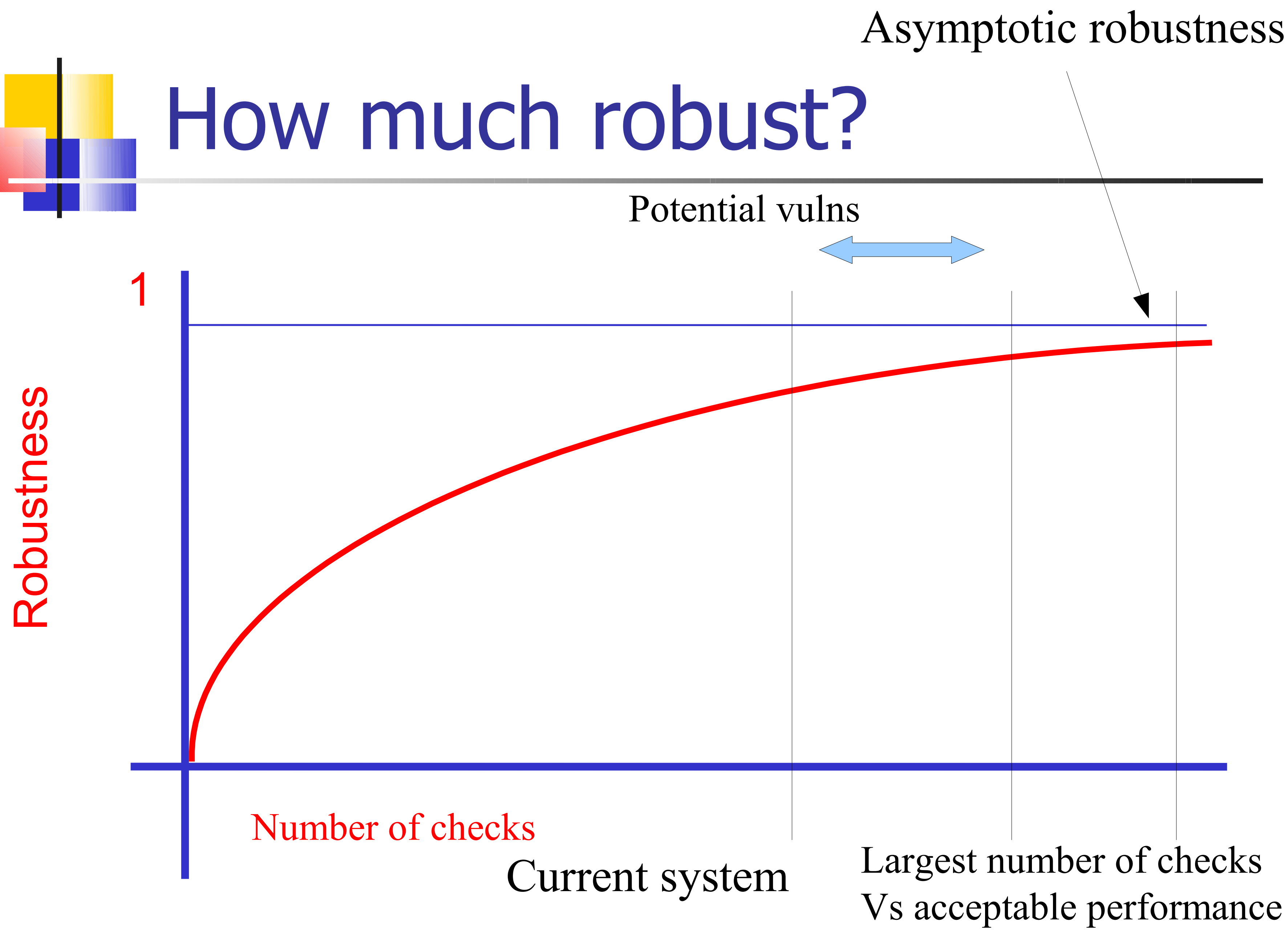
Robustness vs Vulns

- In an ideal system all the modules implement any control
- The ideal system is the asymptote of those that apply more and more checks
- Any difference between the ideal system and the current one may be a vulnerability
- If it is a vulnerability depends upon the context and the cost of the control
- Any set of guidelines to build a system also defines the potential vulns of the system

Robustness vs Vulns

- Some differences between the ideal system and the current one cannot be avoided if some controls have not been adopted to satisfy some performance requirements
- Other differences may be unrelated to performance and, hence, controls should be introduced
- The key strategy to discover vulnerabilitie evaluates the cost of missing control and contrasts it against the required efficiency and the resulting risk

How much robust?



Safety vs Security

- Robustness may also be adopted to evaluate the safety of a system
- Security differs because we are interested in robustness with respect to intelligent attacks rather than to random failures

Safety vs Security

- Safety is proportional to the ratio of anomalous behaviors vs the overall number of behaviours
- A fault results in an anomalous behavior but, if faults are not related with one another, then the ratio shows the cases where faults are not controlled and confined
- In security, the attacker tries to force the system to behave in an anomalous way by attacking those components that influence the behavior of interest
- Safety = random faults / Security = intelligent faults

Safety vs Security

- Both applies the notion of probability and of risk
- Safety is focused on independent probability distribution (law of large numbers)
- Security is focused on conditional probability
  - There are some vulns, hence
  - There are some attackers, hence
  - The attacker can implement the attacks ...

Design principles for robustness (Saltzer&Schroder) or rules to discover vulnerabilities

- Economy of mechanisms
- Fail safe default (Default deny)
- Complete mediation
- Open design
- Separation of privilege
- Least Privilege
- Least common mechanism
- Psychological Acceptability
- Work factor
- Compromise recording

8 or 10 principles?

- After introducing the first 8 principles, S&S say:

  Analysis of traditional physical security systems have suggested two further design principles which, unfortunately, apply only imperfectly to computer systems

- The principles applies to both a system and the mechanisms we introduce to secure the system

P1-Economy of mechanisms

Keep the design as simple and small as possible = keep it simple stupid = kiss rule

- Simple implies that less things can go wrong and when errors occur, they are easier to find, understand and fix
- Vulns are proportional to the complexity of a mechanisms and to the code to implement it

  cyclomatic number to find software bug
- Complexity can be achieved by composition
- SO Hardening = remove useless OS functionalities for applications of interest

P1- Economy of mechanism

- Esokernel and microkernel=
  Avoid the implementation of complex functions in the kernel

- A strong integration between the OS kernel and the applications not only violates modularity principles but helps the spreading of errors (cascade failures)

P1- Economy of mechanisms

- Simplify the interface
- Complex operations should be implemented by composing simple operations
- If the operations are rather complex (and hence powerful), we may be forced to allow a user to invoke a powerful operation even to implement simple operations and this increases the user rights (related to the least privilege principle)

P2-Fail safe default (Default deny)

Base access decisions on permission rather than exclusion

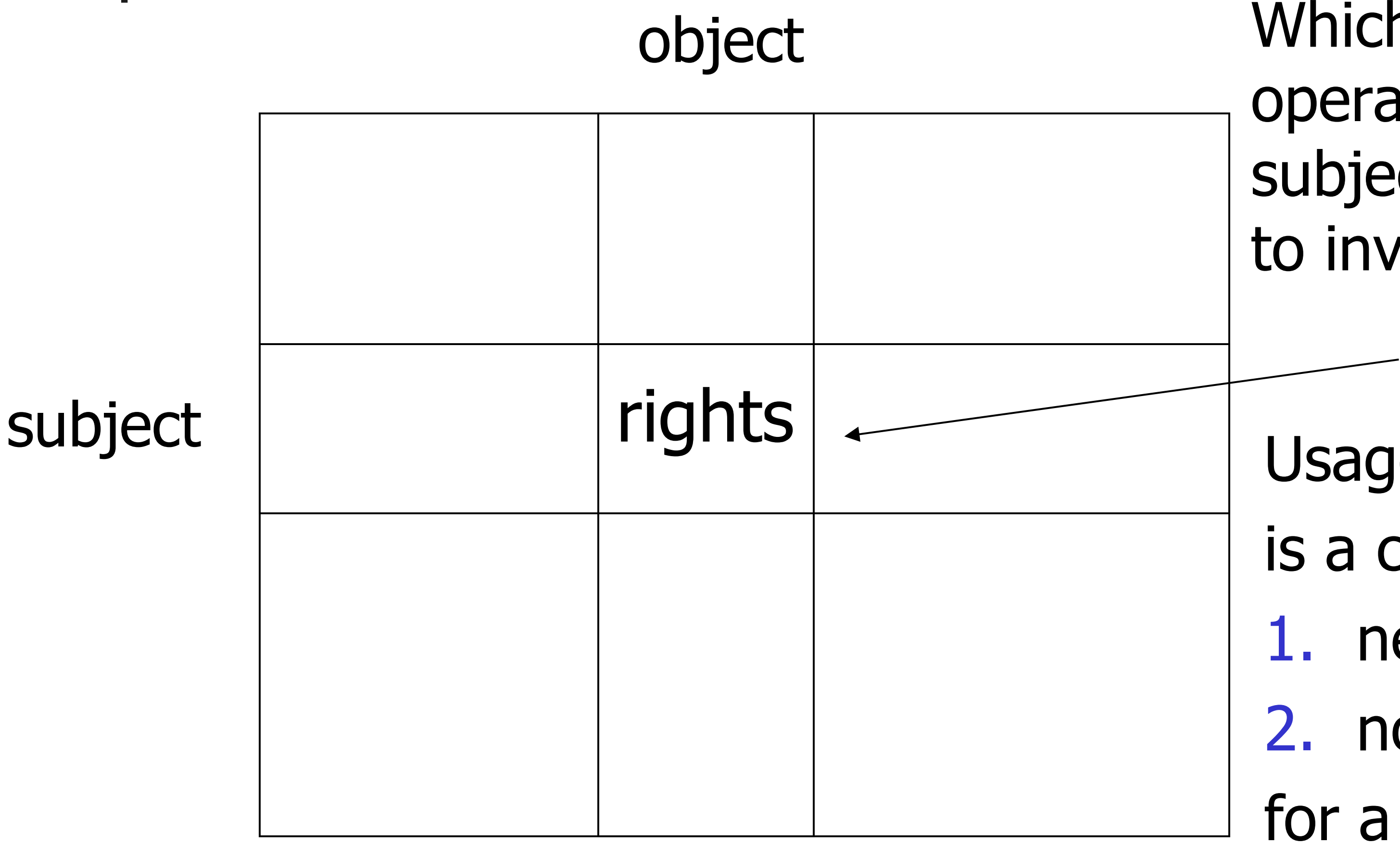
- Burden of proof is on the principal seeking permission
- If the protection system fails, then legitimate access is denied but this also denies illegitimate access
- The initial state of the system is correct

P3-Complete Mediation

Every access to every object must be checked for authority

- Usually it is done once, on first access, but if permissions change later one, unauthorized accesses may be possible
- Performance gains achieved by caching the result of an authority check should be examined skeptically
- Each operation that is not controlled is a potential vulnerability as it may be invoked without authority

P3 - Access control matrix



Which object operations the subject is entitled to invoke

Usage of acm is a condition

1. necessary
2. not sufficient

for a secure system

Access control matrix

- Security requires this matrix exists for each system layer
- Furthermore, there is also a matrix for each application or virtual machine at the application layer
- Coherency among these matrices
- A matrix may be so large that it has to be stored on a secondary storage

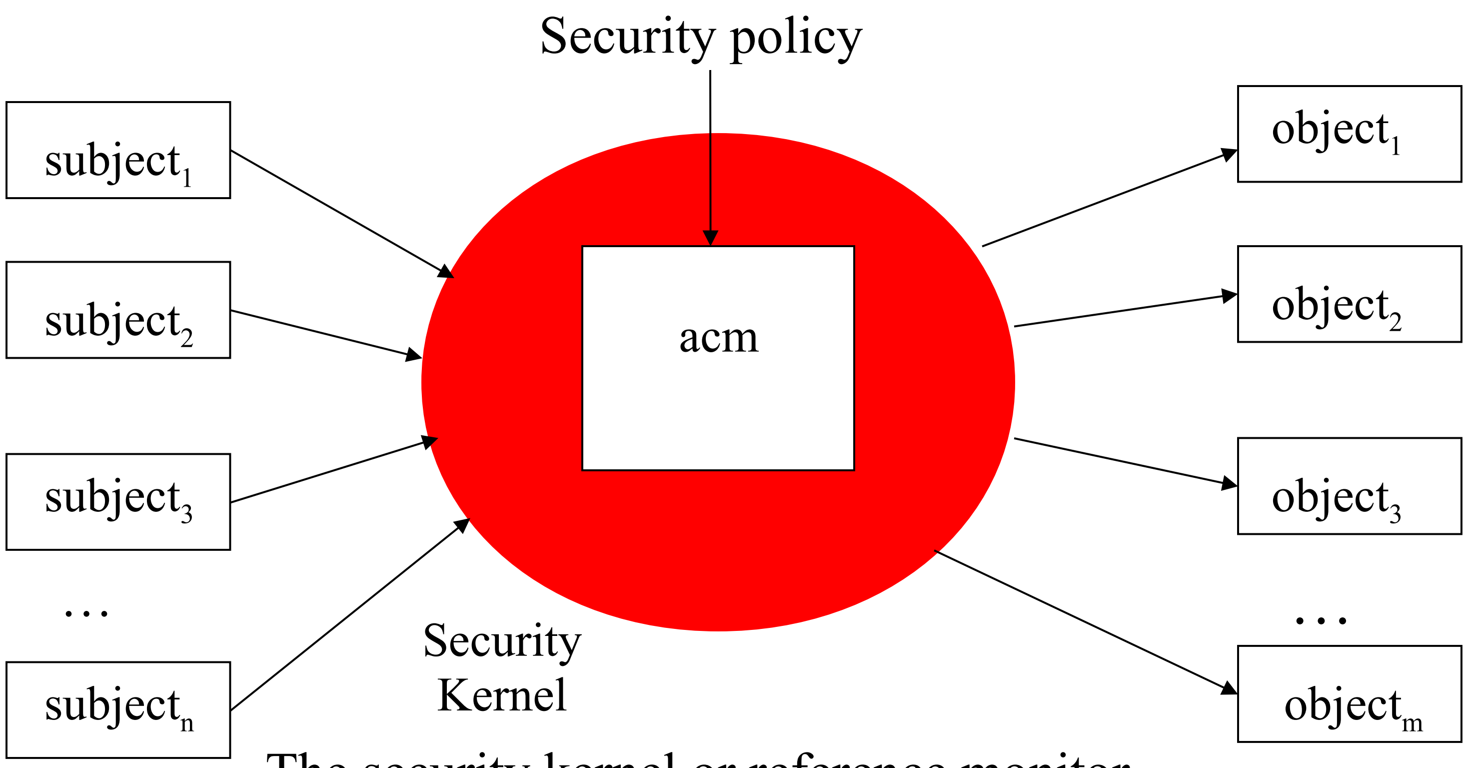
Rights in acm[i,j] -I

- DAC security policy = assigned by the owner of the j-th object
- MAC security policy = they also depends on the levels of the i-th subject and the j-th object
- In both cases the subject may have to actually satisfy further constraints before using the rights that the matrix assignes

Rights in acm[i,j] -II

- The access control or protection matrix is a highly dynamic data structure
- Dynamicity is due to
  - Dynamic creation and distruction of subjects and objects
  - Some security policies dynamically updates the rights of each subject according to the operations the considered subject has invoked

Acm: a typical implementation



The security kernel or reference monitor (TCB) mediate the subject attempts to invoke the operations defined by the objects

Access Control Matrix

- This is a logical data structure for which a large number of concrete implementations is possible
- Sometime the acm is not implemented by a matrix
- Problems arises when no all the subjects are known in advance (network services)
  - In this case, a row of the acm is paired with a class of subjects
  - Rules to map each subject into a class have to be defined

Security Kernel o Reference Monitor

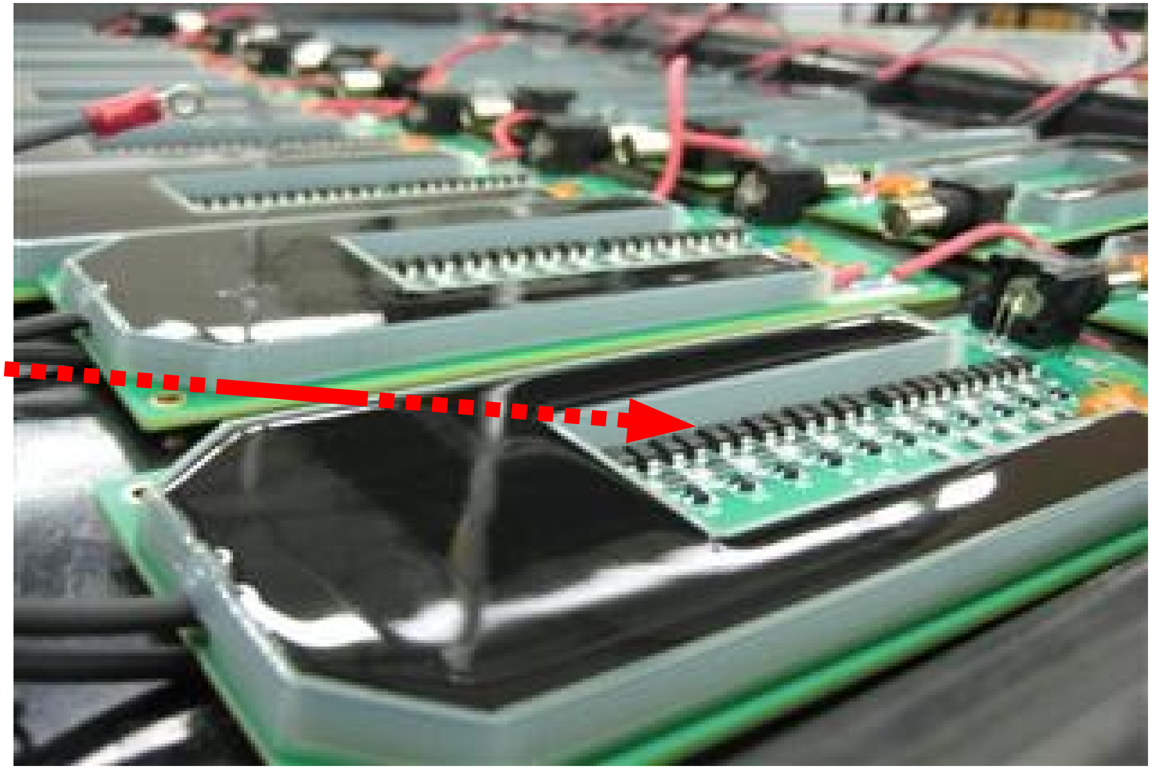
- It belongs to the Trusted Computing Base (TCB) = its correctness is a necessary condition for the correct implementation of the security policy
- As small as possible to apply formal techniques to prove its correctness
- A basis for induction proof of security properties
- In some systems it is stored in a tamper proof memory to prevent illegal updates

Tamper proof

- A component where any physical attack is
  - Prevented or at least
  - Detected
- All the components are glued with silicone
- Memory chipes are protected by an electrified grid that cancel any information as soon as an attack is attempted

Silicone tamper proof

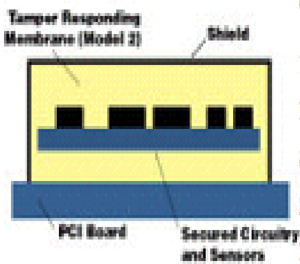
Silicone



Secure Coprocessor

IBM 4758 hardware

The IBM PCI Cryptographic Coprocessors are state-of-the-art secure subsystems that you can install in server systems to perform DES and public-key cryptography. You can also load software for highly sensitive processing, such as the minting of electronic postage, which must perform its intended function even when under the physical control of a motivated adversary.



The secure Coprocessor module is mounted on a two-thirds length PCI version 2.1 board and fits in a single slot that provides +5.0VDC +/- 15% and +12VDC +/-15% power and meets other environmental requirements as listed in chapter 2 of the General Information Manual. (3.3VDC variations of the Models 002 and 023 are also available to OEM customers and used in IBM @server pSeries, and IBM @server iSeries and IBM @server zSeries servers.) The sealed Coprocessor module incorporates physical penetration, power sequencing, temperature, and radiation sensors to detect physical attacks against the encapsulated subsystem. Batteries provide backup power that is active from the time of factory certification until the end of the product's useful life. Any detected tamper event results in loss of power which immediately causes the zeroization of internal secrets and the destruction of the factory certification.

Complete mediation + fail safe default

- If both principles are applied
  - The system starts in a secure state
  - Provided that the security kernel is correct, only secure transictions are enabled
- Induction proofs on reachable states
- If fail safe default does not hold no induction basis exists

Complete mediation+ fail safe default

Let us assume that to grant a right R on an operation op the object Ob(op) has to be updated

- In the initial state no subject owns the right of updating Ob(op)
- No subject can grant this right
- Hence no subject can be granted this right

Access control matrix

- An implicit assumption is that the identity of the subject is checked before accessing the matrix

  $\Rightarrow$ how can we control that a subject that claims of being A is A

  - Explicit check in the security kernel
  - Password
  - One-time password
  - Challenge response
  - Electronic signature

One time password

- A function F with at least two parameters
  - S a secret value
  - N the number of received requests (defined in an implicit or explicit way)
- The subject to be authenticated computes and transmits F(S, N)
- The receiver computes again F(S, N) and checks
- Synchronization on the value of N

Challenge - response

- Partners agree on a function F and keep it secret
- F has an input parameter x
- One of the partners sends y (challenge)
- The receiver computes F(y) and sends back the result
- Also the challenger computes F(y) to check whether the response is correct

Complete mediation: problems

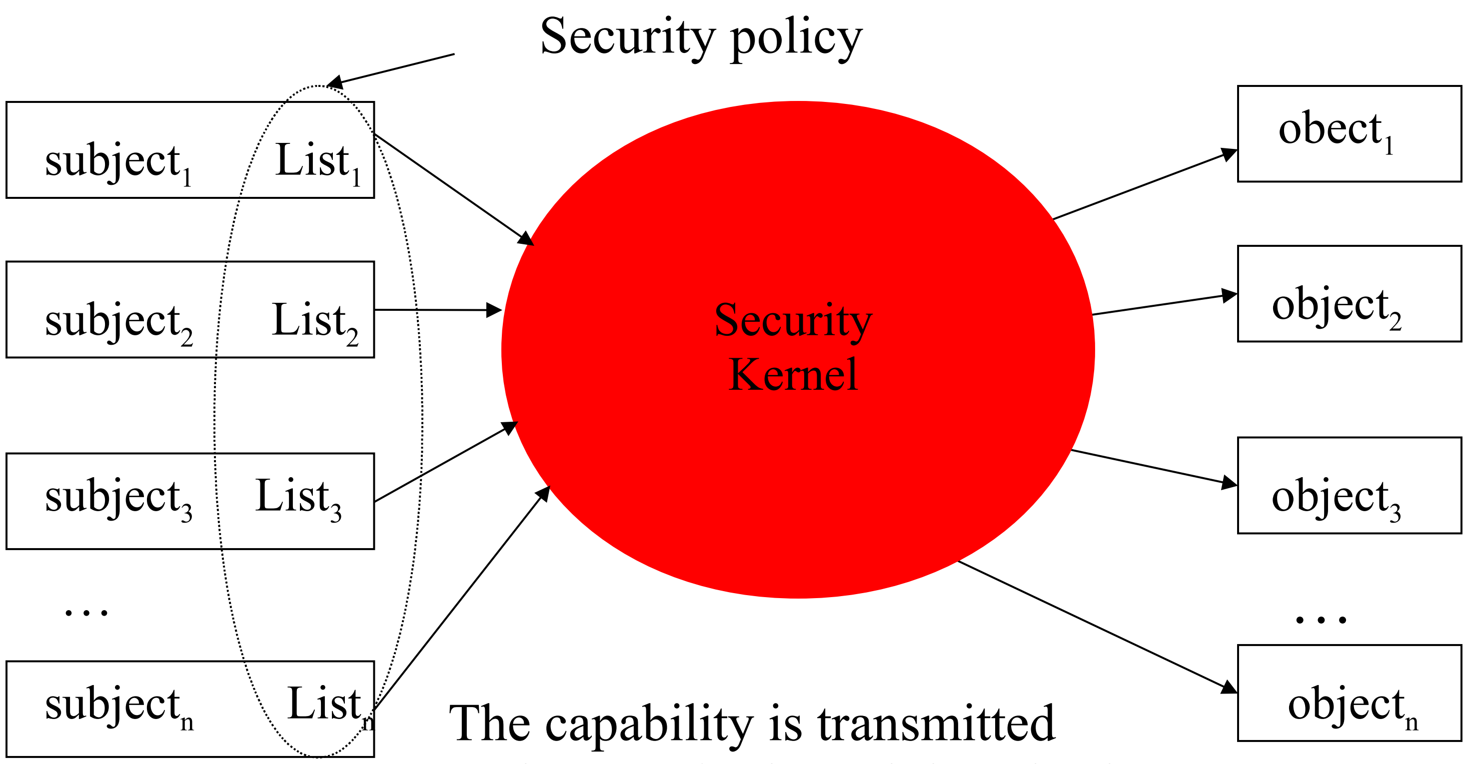
- High performance in the access to acm is required due to the huge number of checks
- An implementation where a centralized data structure is shared among all the subjects and the objects usually cannot achieve an acceptable performance
- A distributed solution is to be preferred so that the overhead is independent of the number of objects

Solutions - 1

- Capability list= a row based organization of the matrix
  - A capability is a pair <object address , rigths>

    = a generalization of pointer also know as a protected pointer
  - When invoking an operation, the subject specifies which of its capability has to be used for the operation

Acm as capability lists



The capability is transmitted
to the security kernel that checks
whether it enables the operation
The SK does not manage the ACM

Capability -I

- Invocation $op_i(obj_j$, par, n) = execute the i-th operation of the j-th object as enabled by the n-th capability in the subject list
- If S transmits a capability to another subject S' then S can delegate S' to invoke an operation S' is not entitled to
- Capability = ticket for an object
- Delegation increases the number of instances of a given rights that, in turn, increases the complexity of right revocation

Capability - II

- Capabilities are generated by the security kernel that distributes them to the subject
- A subject should only be able
  - to store
  - to read (use)
  - to copy (delegation)
  - but not to update a capability
- Only the kernel can update a capability
- The probability of a successful attack against the security policy increases since rights are stored in the subject

Capability -III

- In some cases the MMU may implement an efficient hw/fw support for capabilities at the OS levels
- The capability list is stored in the MMU
- The MMU
  - checks the rights in parallel with the address translation
  - prevent a subject from updating its list

Capability -IV

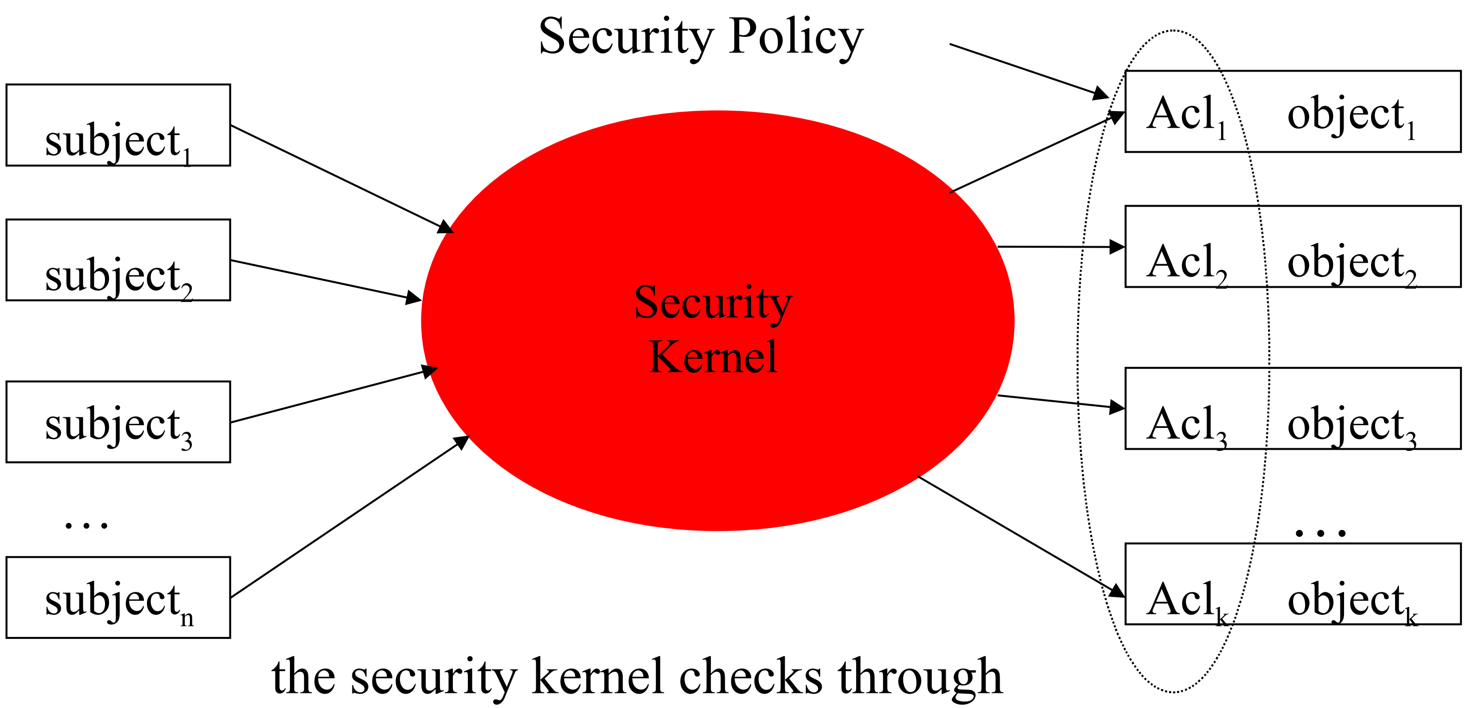
- Address translation exploits a segment/page table that store the physical address
- For each segment/page some operations are defined in a predefined set

  (read, write, fetch)
- Some processors do not check the rights if the segment/page has already be loaded in the cache or if the address has already been traslated from logical to physical

Complete Mediation - 2

- Access control list = a column based organization of the acm
- One list for each object
- Each list element stores the rights of all the subjects on a distinct object
- Here the control can be implemented by the Security Kernel or be delegated to the object
- A centralized structure for each object

ACM: ACL



the security kernel checks through the object ACL that the security policy is satisfied
The checks may also be implemented by the object

Access control list

- A more flexible solution may be achieved through
  - Partition of the subjects
  - The sequential scanning of the list (no direct access is possible because the subject does not know its position)

If subject $\in$ Set1 *then* {op1, op2}

else If subject $\in$ Set2 *then* {op3, op4} ⇕ this is an ACL!

else {op5}

- the subjects are partitioned into three sets
- this can grant rights even to subjects not known in advance. This is not possible for capabilities and it may be adopted to define acls for web services

HW/FW support for ACL

- Associative memory where the key may be
  - Subject $\rightarrow$ set of rights
  - Subject, operation $\rightarrow$ boolean
- FPGA that implements a function that is a chain of *if statements* about
  - Sets of users
  - Priority among sets

ACL vs Unix files

- Each file is paired with a bit array that defines
  - Owner rights
  - Group owner rights
  - Other users rights

  this is an implementation of the file ACL
- It adopts classes of users due to missing information on all the system users

ACL and file descriptor

```
struct stat {
mode_t st_mode; // File type & mode          access control list + set uid bit
ino_t st_ino; // i-node number
dev_t st_dev; // device number (file system)
dev_t st_rdev; // device n. for special files
nlink_t st_nlink; // number of links
uit_t st_uid; // user ID of owner
gid_t st_gid; // group ID of owner
off_t st_size; // size in bytes, for reg. files
time_t st_atime; // time of last access
time_t st_mtime; // time of last modif.
time_t st_ctime; // time of last status change
long st_blksize; // best I/O block size
long st_blocks; // number of 512-byte blocks
}
```

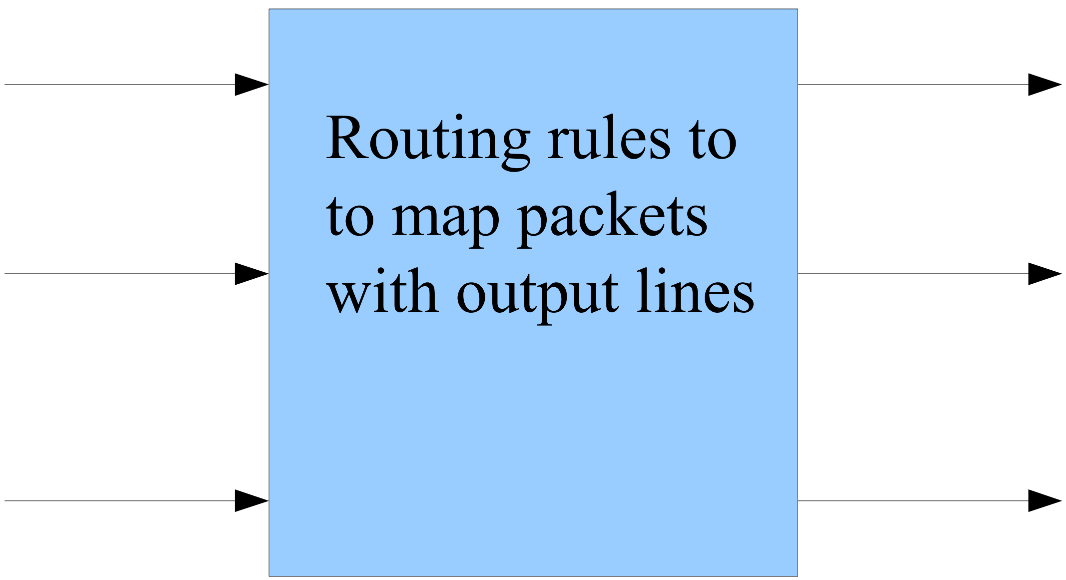
Unix/Linux -I

- ACL are defined in terms of process identifier
  - Real user ID → owner
  - Effective user ID
  - Saved user ID

in Linux we also have

  - File system ID

ACL for message routing



ACL for both input and ouput lines

Input lines

Output lines

ACL for message routing

- Router ACLs are built by composing two cases

  IP $Range_1$ $\rightarrow$ route

  packets from these nodes are routed

  IP $Range_2$ $\rightarrow$ drop

  packets from these nodes are dropped

- A list is built for each input/output connection to specifies the IP addressed in the packets that can cross the connection
- List = order is important
- Ranges because some addresses may be unknown
- This protects the network where messages are routed

ACL & Router

- ACL of input 1
  - 131.114.*.* → route
  - 131.4.5.6 → route
  - 131.4.*.* → drop

swapping two rules changes everything

Traffic from 131.114.*.* is routed and all the traffic from 131.4.*.* is dropped but that from 131.4.5.6

- ACL of output 1
  - 131.114.*.* → drop
  - 131.4.*.* → drop

No address in 131.4.*.* and in 131.4.*.* can send traffic to the network connected to output 1

Routing in Linux: iptables

- Input chain: rules for the packets addressed to the node
- Output chain: rules for the packets produced by the node
- Forward chain: rules for the packets that cross the node
- Default allow $\rightarrow$ transform into a default deny by creating the list of packets to be routed and add “drop all” at the end

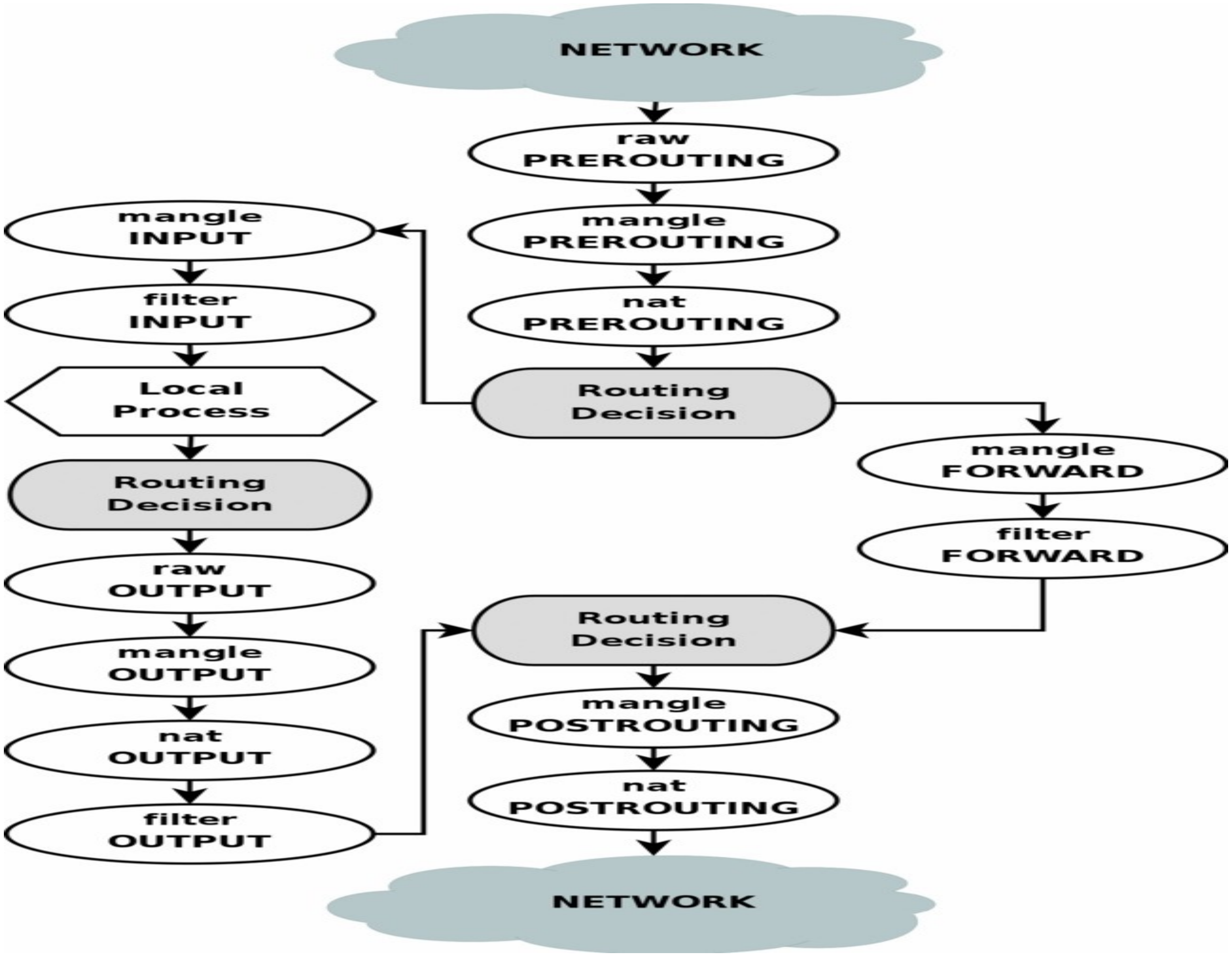
Routing in Linux

- Drop
- Route
- Return – return to the invoking chain
- Queue – transmit to user space
- Log
- Reject
- Dnat/Snat/Masquerade

Nat table

- Prerouting chain= any input packet
- Postrouting chain = any output packet
- NAT may change the addresses in a packet
- Applied before INPUT and after OUTPUT/FORWARD

The overall architecture



Examples

- iptables –A INPUT –p UDP drop

  A new rule is inserted in the input chain to drop any UDP packet
- iptables –A INPUT –p TCP –dport 156 drop

  Drop any TCP packet addressed to port 156
- iptables – N newcontrol

  Create a new chain where new controls can be later inserted

An important point

- Anyone is aware and agrees on the importance of controlling the network traffic that enters a network
- These controls are critical and they are mostly implemented in the border router that connects a network to a pubblic one
- Are there any reasons to check the traffic leaving a network?

Controlling the output traffic

- The control of output traffic is an important mechanism to discover successful attacks against the network (egress filtering)
- If someone is controlling a node X and stealing information in X we can discover the illegal connections of X to some outside network
- These controls can discover Zombies to implement a DDOS

Egress filtering

- It controls the traffic that is attempting to leave the network.
- Before an outbound connection is allowed, it has to pass the filter's rules
- Advantages
  - Discover malware
  - Stop contributing to attacks
  - Block unwanted services

ACMatrix, subjects and objects

- As the number of subjects and objects increases, the complexity of
  - defining the ac matrix
  - checking its correctness
  - achieving full mediation

  strongly increases
- Some solutions have been proposed to simplify the definition of this matrix

Role vs subject

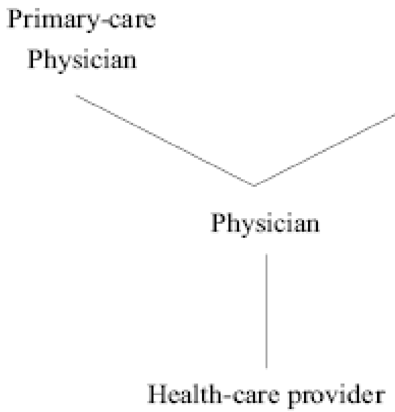
- The notion of role is useful when (subject = a final user)
- Role =
  - A professional profile and the corresponding rights
  - Strongly depends upon the applicative environment
- Any role is paired with
  - A set of users that can be assigned that role
  - A set of rights
- Role Based Access Control
- Rights are not assigned to users but to roles
- A user U acquires the rights when a role is assigned to U
- When U leaves the role, it loses the role rights

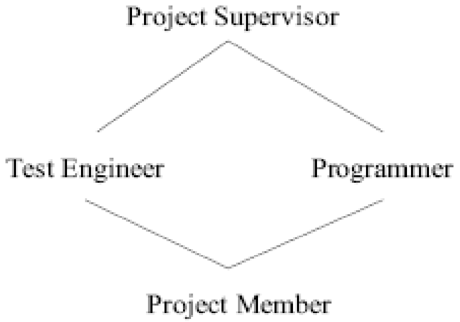
Role- II

- Rules define when
  - a role may be assigned
  - it is lost
- The rules may consider previous operations the users execute
- Any role change may require a password to identify the user and the role

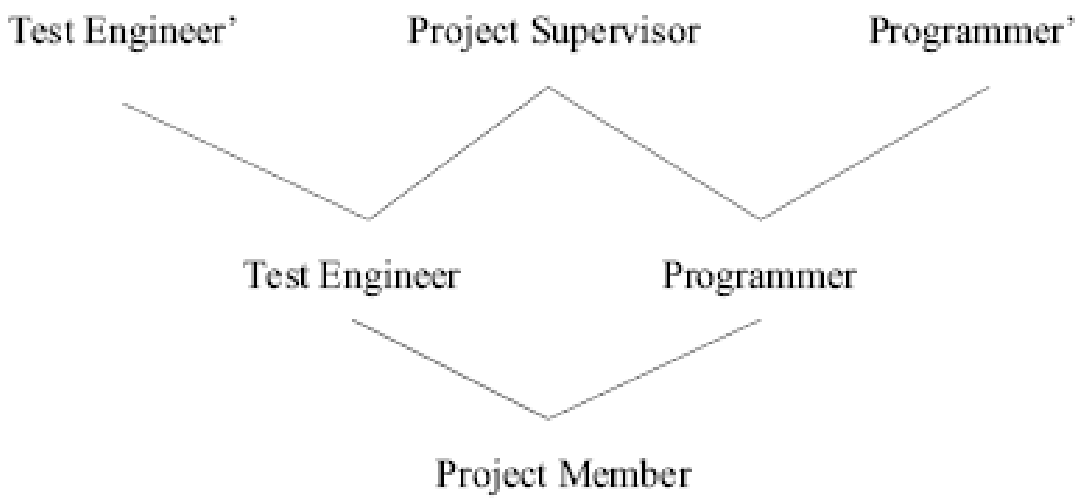
Role hierarchy - I

- Role may be partially ordered
- A role R1 is larger than a role R2 if R1 includes all the rights of R2

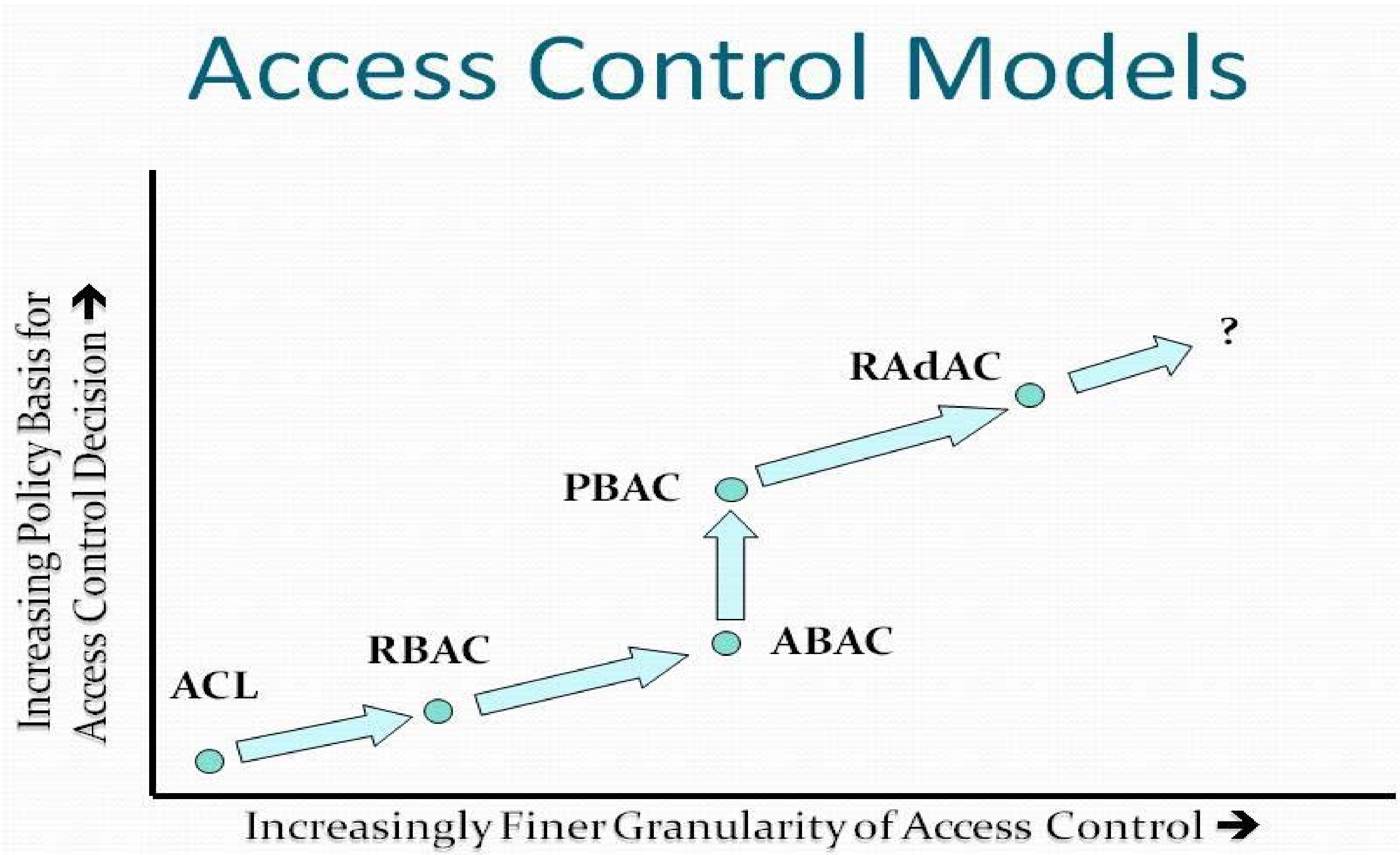




Hierarchy II



Other models (defined in the following)



Attribute Based Access Control

- Each subject is paired with a set of attributes
- The right of invoking an operation is a function of the current values of the attributes
- Not supported by standard OSes but only at the application level (database management systems)
- It could be supported at the OS level provided that a standard set of attributes for all the user is defined

ABAC

- Attributes =
  - Role
  - Security level
  - IP address of the user system
- As an example the operation can be executed if
  - Role= system manager
  - (Role= system manager) AND (ip = local)
  - (Level > confidential) AND (ip = local) AND (8 <local time <16)

Risk Based Access Control

- The risk posed to the system because of the operation is evaluated
- The evaluation takes into account attributes of the system, of the user etc to decide whether the rights should be granted
- No reasonable implementation

P4-Open Design - I

The design should not be secret

or

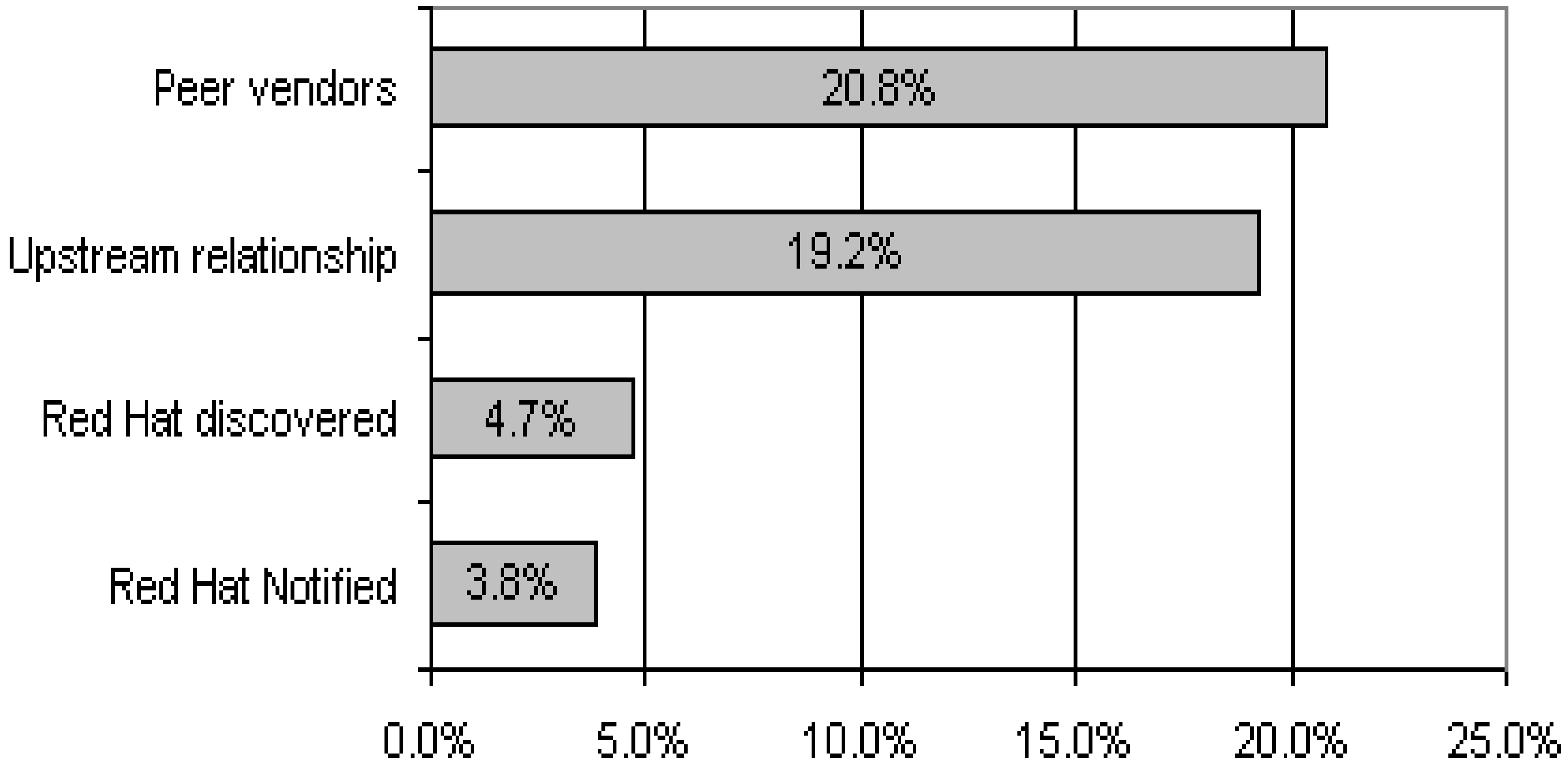
The security should not depend on the secrecy of the design or of the implementation

- Popularly misunderstood to mean that source code should be public

P4-Open Design - II

- A system peer review is fundamental to discover vulns in the design and/on in the implementation
- An open source implementation is useful only if
  - it results in a peer review
  - any peer that discovers a vulnerability communicates it to the owner
- The open design is useless if
  - no peer review (no peer) or
  - discovered vulns are not revealed to the owner
- Strength and weakness of open source

Vulns vs open design



P5 - Separation of privilege

Where feasible, a protection mechanism that requires two keys to unlock it is more robust and flexible than one that allows access to the presenter of only a single key

or

Require multiple conditions to grant privilege

- Separation of duty
- Defence in depth

P5 – Separation of privilege

- A complex operation should be decomposed into simpler operations
- Each simple operation is enabled by a proper rights
- We can control that the subject owns both
  - The right of invoking the complex op
  - The right of invoking each simple op

Example

- Op = trasfer some money from account1 to account2
- 5 rights
  - Transfer money
  - Read account1
  - Update account1
  - Read account2
  - Update account2
- Someone can transfer money but not from account1 or to account2

Defence in depth

- Flat network
  - any node can interact with any other one
  - a hub that connect all the nodes
- Segmented network
  - Network is partitioned into subnetwork
  - One hub for each subnetwork
  - Hub are connected by routers
  - Router ACLs determine which traffic can enter or leave a network

P6 – Least privilege - I

Every subject should operate using the least set of privileges necessary to complete its job

or

A subject should be given only those privileges it needs to complete its task and only for the time to complete it

- Owning a useless access right is a vuln
- Rights granted as needed, revoked after used
- The ac matrix is a dynamic data structure
- Rights are assigned and revoked as the computation evolves

P6 – Least privilege - II

- This principle should be applied even if the security policy is static as it defines how rights should be managed rather than how they are assigned to each subject
- If, in a given time interval, a subject does not need a right then this right should be revoked and the acm should be updated to prevent the subject from using the right in the time interval
- The right is granted at the end of the interval
- Extreme version of can know/need to know

Least Privilege - III

- Protection Domain Switching = the same subject is executed but the rights in the proper positions of the acm are updated
- Protection Domain Switching = update of an acm row
- We can have a PD switching even without a context switching
- The corresponding overhead is a function of the implementation level and the adopted implementation of the acm (capability vs acl)
- Revoking a right is not simple with capabilities

Least Privilege - IV

- An alternative definition of this principle focuses on minimizing the size of the protection domains
- As the size of the protection domain decreases, it also decreases the risk due to an attack against the considered subject
- If the protection domains are not small then revoke grants when not needed and grant when needed

Least Privilege - V

- The system designer has to choose the proper compromise because a full application of this principle may result in low performances
  - ⇔ for each command that is executed, the acm should to be updated
  - ⇔ the asymptotic system is too slow

Least privilege – In principle

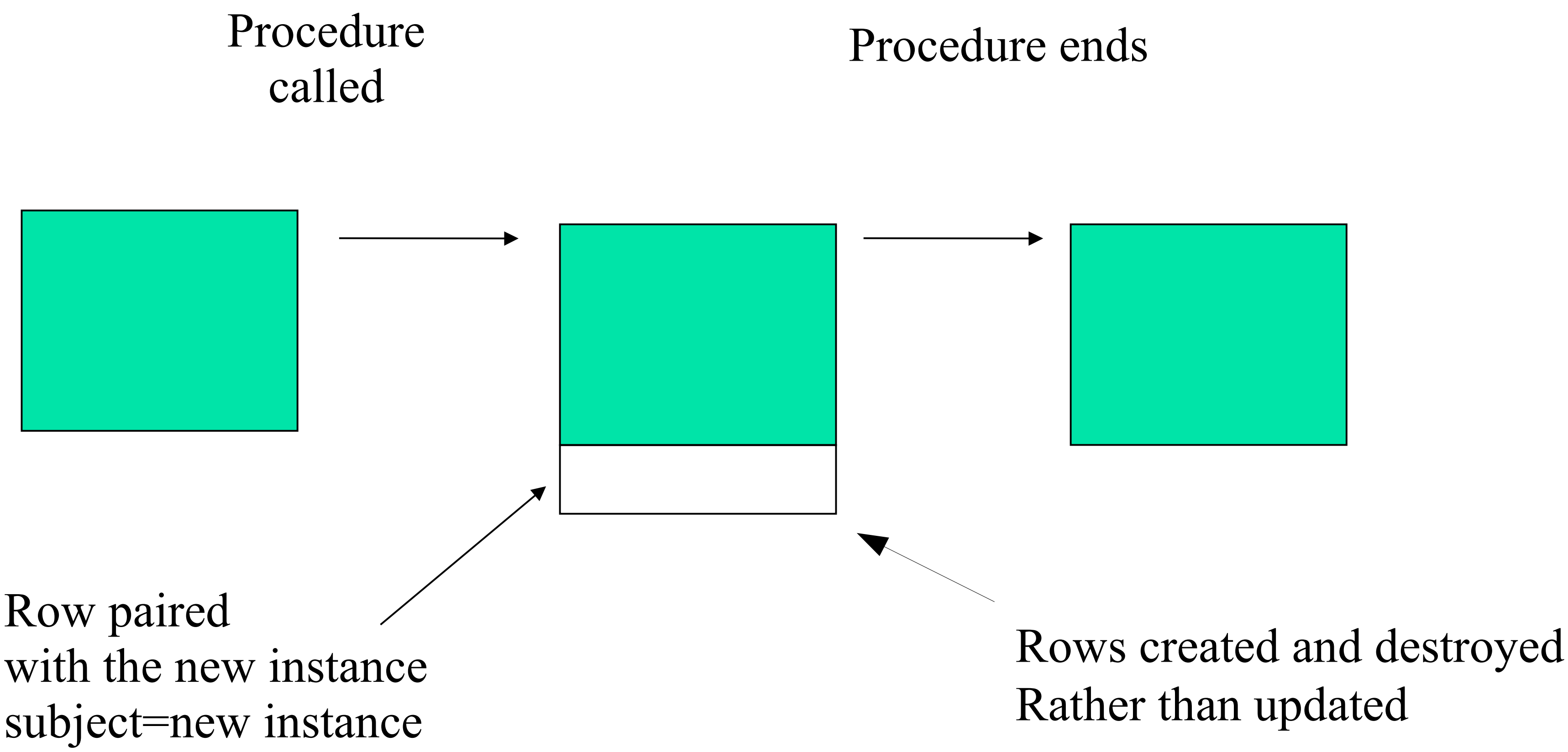
When/how the domain switching is fired

1) Through further, proper instructions
2) Some language constructs also fire the domain switching

Least Privilege – Common solution

- In the classical solution pairs a domain switching occurs when
  - A procedure (method) is called
  - A procedure (method) returns
- A new row is created (call) and destroyed (retun) rather than updating a row
  - When the procedure is invoked, a new row that defines its rights is created
  - The row is destroyed when the procedure returns
  - Rights are paired with the instance of a procedure executed by (or on behalf of) a subject rather than with the procedure code or with the subject

History of the ac matrix



Least Privilege – Common solution

- The rights in the new row are a function of
  - The private variables of the method (they depends upon the variable types),
  - Input parameters (type of the parameters and the kind of access to the parameters)
- The structure of the program into classes/ methods defines the strategy to manage the rights granted to the subiects on the program data structures
- The programmer can choose the size of each protection domain
- Domain switching is handled in an automatic way

Example

Op(x, y)
a : ….

- If two subjects (programs) invoke this op, each program has its own row, we have two local copies of a or one copy if shared variables are supported (depends upon the type of a)
- Each row enables the program to access its own parameters and private (non shared) local variables
- If a static acm is adopted, the management of rights is rather more complex and access of a program to the parameters of the other program is simplified

Least Privilege – Common solution

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Least Privilege - Amplification

- It may be useful if the set of rights of the invoked procedure differs from that of the invoker

  An example is a procedure in the run time support of an object oriented language that needs to know an object implementation
- Rights are amplified: provided that some rights are owned, other may be granted
- Amplification is misleading because we are interested in granting a distinct set of rights rather than a larger set

Least privilege vs objects

- The least privilege principle assumes an object decomposition that is fully coherent with an object oriented methodology
- A simple object defines a small protection domain (a few variables) that can be simply managed
- Even if a simple object is successfully attacked, the impact of this attack is low impact and the attack can be easily detected
- Sharing among objects should always be minimized

Least privilege – message passing

- In a message passing environment, subjects are processes/threads interacting through ports or channels
- To satisfy the principle
  - Distinct ports implement distinct operations,
  - Ports can be opened/closed (created/destroyed) for a set of users
  - If an interaction is legal, then the corresponding port is open/created
  - The port is closed/destroyed as soon as the interaction is no longer possible

Least privilege – message passing

- Closed port $\neq$ (open port + mechanism to discard messages)
  - The overhead to discard messages is much lower if the port is closed or if does not exist
  - Messages can be discarded as they are routed
- If discarding is too much expensive, the subject can do nothing because it is always busy to discard messages
  (Denial of Service)

Least Privilege – Unix - I

- OS like Unix violates this principle because root owns any right (the target of any attack)
- This strongly simplifies attacks, any procedure executed by root is a target, 2 steps escalations
- Management countermeasures such as having distinct administrators for a system
- Further technological countermeasures
  - recording (logging) any operation root invokes (where???)
  - 2F authentication

Least Privilege – Recording

- A log is a read + append only file
- This may be guaranteed
  - In a physical way = print the file
  - Logical way = hash chain
- Blockchain
  - Replicated data structure
  - Each block includes
    - Hash of the records in the block
    - Hash of the previous and next block
    - Voting or proof of work

Least Privilege – Unix - II

- Chroot constrains the access to the file system by defining a new root
- Jail (BSD) makes it possible to constrain other operation such as network connection
- These are implementation of sandbox = a minimal environment for untrusted application

Sandbox

- Definitely a bad idea
- Any sandbox has been violated
  - Chrome browser from Oct. 2008 more than 40 sandbox related vulnerabilities out of 1523 total
- When the subject escapes the sandbox, no other countermeasure exist
- Two distinct problems
  - Discover the sandbox
  - Escape the sandbox
- Current implementation=virtual machine

Privileged Access Management

- They help secure, control, manage and monitor privileged access to critical assets.
- They take the credentials of privileged accounts – i.e. admin – and put them inside a secure repository (a vault) isolating the use of privileged accounts to reduce the risk of those credentials being stolen.
- System administrators need to go through the PAM system to access their credentials, at which point they are authenticated and their access is logged.
- When a credential is checked back in, it is reset to ensure administrators have to go through the PAM system next time they want to use the credential.

P7- Least common mechanism

Minimize the amount of mechanisms common to more than one user and depended on by all users

- Mechanisms should not be shared
  - Information can flow along shared channels
  - Covert channels
- Isolation
  - Virtual machines
  - Host and Network Segmentation

P7- Least common mechanism

- A powerful mechanism, if useful, should be decomposed into simpler ones
- If just one mechanism is used to implement several operations
  - If several subjects are granted the rights of invoking the mechanism they are also granted all the rights
  - This hides the fact that there are several distinct operations and several distinct rights
  - The least privilege cannot be satisfied

P7 – Least common mechanism

- By decomposing operations into simpler ones we can better satisfy separation of privilege and least privilege
- Simpler operations makes it possible to assign to each subject only the rights it needs and it is entitled to
- Notice all S&S principles dictate some design rules if a design cannot satisfy a rule this points out some weaknesses in the final system

P8 - Psychological Acceptability

The human interface should be designed for ease of use so that users routinely and automatically accept the protection mechanisms correctly

or

Do not adopt policies users will surely violate

- Security mechanisms should not increase the complexity of accessing resource
  - Hide complexity introduced by security mechanisms
  - Ease of installation, configuration, use
  - Human factors critical here

Last two principles

- Recall they have been introduced because even if the other are satisfied a vulnerability is possible
- They are useful if some attacks are successful in spite of the adoption of the previous principles
- Anticipate the presence of vulnerabilities and possible failures

P9 – Work factor

Compare the cost of circumventing the mechanism with the resources of a potential attacker

- The probability of a successful attack increases with the resources the attacker can access
- The cost of circumventing a mechanism is the attacker work factor
- A mechanism is better than another if it can be defeated only through a larger amount of work
- Several mechanisms can be defeated only by indirect strategies, such as waiting for an hardware failure
- Reliable work estimates are very complex anytime several attacks (attack chain) are required to violate a system

P9 – Work factor

- Most attacks require a privilege escalation
- The number of attacks in these escalations and their attributes determine the amount of work of an attacker
- Attributes
  - Success probability
  - Automated or not
  - Wait for some external condition

P10 – Compromise recording

Mechanisms that reliably record a compromise of information may replace more elaborate ones that completely prevent loss

- If they produce a tamperproof record that is reported to the owner, they support the discover of unauthorized use.
- In computer systems it is difficult to guarantee discovery after the system has been attacked.
- Logical damage (and internally stored records of tampering) can be undone by a clever attacker

P10 – Compromise recording

- Useful to collect information about attacks, goals and threat
- Any collected information can be used to evaluate the robustness that a system may offer as well as to improve the accuracy of the various analysis in a risk assessment

Compromise recording

- A log file that records, at least, any of
  - Login attempt
  - Failed login
  - Access to critical resources
- Protection of log file
  - write once memory (e.g. paper)
  - insert a sequence number to discover log manipulation
  - insertion in a record of a value that is a function of all the previous records (hash pointer)
- Forensics = the file should be structured so that it can be used to prosecute the attacker and as a legal source of evidence in an investigation

Logging policies

What happen when a file is full?

- Throw away – all the data are destroyed
- Reset – rotation within a file
- Rotate – rotation among several files
- Compress and archive – stored in a low cost memory (there are some laws that require that some data are preserved)

Throwing away log files

- The worst solution
  - The files are a source of evidence and of information about security
  - They may also be useful for safety
- Even if the law entitles us to destroy the logs shortly after they are collected, it is better to preserve them for some months
  - This is the interval of time that is required to discover any intrusion

Rotating log files

- N distinct files
  - logfile.1 , logfile.2, … logfile.n
- Each day a distinct file is used

Compress and archive

- Better solution that takes into account
  - Forensics investigation
  - Commercial problems with clients, suppliers
- Log are copied onto low cost, removable memory devices

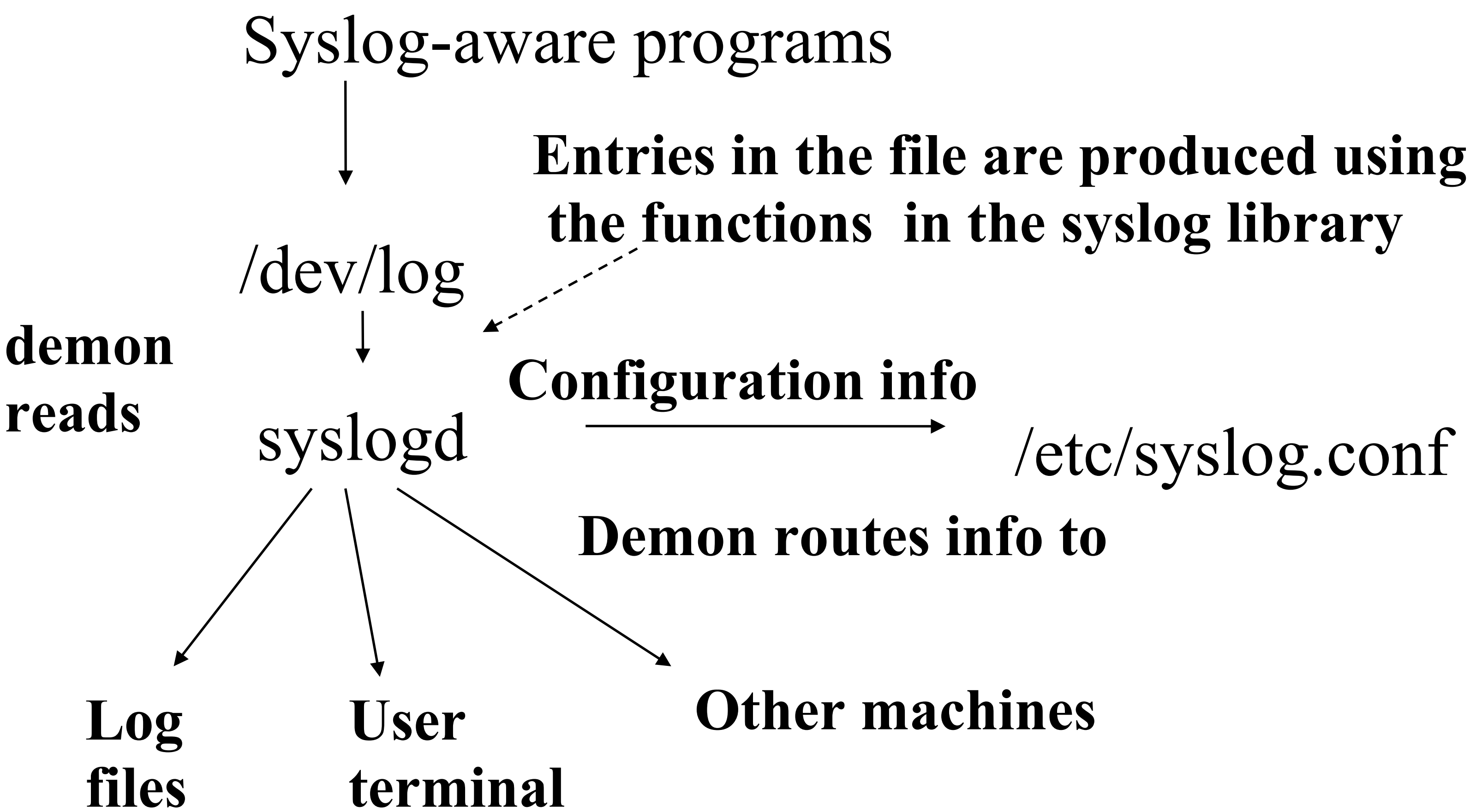
Syslog

- A logging system to store information produced by the kernel and by system utilities
- It enables a classification of log messages according to the source and the critical level of the event
- Messages can be addressed to several destinations

Syslog: 3 elements

- Syslogd /etc/syslog.conf
  - A demon that implement the logging
  - It is programmed through a configuration file
- openlog, syslog, closelog
  - Procedures to produce event to be logged
- logger
  - User command to produce a log

Syslog


Syslog-aware programs
Entries in the file are produced using the functions in the syslog library
/dev/log
demon reads
syslogd
Configuration info
/etc/syslog.conf
Demon routes info to
Log files
User terminal
Other machines

Syslogd: configuration

- Configuration info in /etc/syslog.conf
- A text file
  - White lines and those beginning with # are ignored
  - ***Selector*** <TAB> ***action***
  - mail.info /var/log/maillog

Selector

- Identifies
  - The source – the program (‘facility’) that is transmitting the message
  - The message severity level
- Sintax
  - facility.level
  - facility names and severity levels have to be selected in a predefined set

Facility names

Facility	Used by
kern	kernel
user	user process, default
mail	mail system
daemon	System daemons
auth	Security and authorization related commands
lpr	printer spooling system
news	Usenet news system

Facility names

Facility	Used by
uucp	UUCP
cron	cron daemon
mark	Timestamps produced with a fixed frequency
local0-7	local message
syslog	syslog internal messages
authpriv	Private or system messages
ftp	ftp daemon, ftpd
*	further facilities

Severity level

Level	That means approx.
emerg (panic)	Panic situation
alert	Urgent situation
crit	Critical condition
err	other errors
warning	warning
notice	worth an analysis
info	info
debug	debugging info

Selector

- Several facilities separated by ‘,’
  - daemon,auth,mail.level action
- The composition of several selectors by ‘;’
  - daemon.level1; mail.level2 action
- The OR composition of selectors is expressed through ‘|’ –un a message matches if it matches at least one selector.
- ‘*’ or ‘none’, (all or none) can be used

Selector

- The level defines the lowest level of a logged message
  - mail.warning, matches any message from the mail system with a level that is, at least, warning
- 'none' is used to neglect some facilities .
  - *.level1;mail.none   action

Any facility, a level not smaller than level1 but neglect the mail facility

Action: message handling

Action	That means
filename	Append the message to a local file
@hostname	send the message to hostname
@ipaddress	send the message to the node with the specified IP address
user1, user2,…	write the message on the screen of any of these users if the user is logged
*	write the message on any screen

syslog

Program	Facility	Levels	Description
amd	auth	err-info	NFS automounter
date	auth	notice	Display and set date
ftpd	daemon	err-debug	ftp daemon
gated	daemon	alert-info	Routing daemon
gopher	daemon	err	Internet info server
halt/reboot	auth	crit	Shutdown programs
login/rlogind	auth	crit-info	Login programs
lpd	lpr	err-info	BSD line printer daemon

syslog

Program	Facility	Levels	Description
named	daemon	err-info	Name sever (DNS)
passwd	auth	err	Password setting programs
sendmail	mail	debug-alert	Mail transport system
rwho	daemon	err-notice	remote who daemon
su	auth	crit, notice	substitute UID prog.
sudo	local2	notice, alert	Limited su program
syslogd	syslog, mark	err-info	internet errors, timestamps

syslog

- openlog (*ident, logopt, facility*);
  - Messages are logged as specified by logopt
  - They all begin with ident
- Syslog (*priority, message, parameters*…);
  - message is sent to syslog, that logs it according to priority level
- close ( );

Logopt

- LOG_CONS
  Write directly to system console if there is an error while sending to system logger.
- LOG_NDELAY
  Open the connection immediately (normally, the connection is opened when the first message is logged).
- LOG_NOWAIT
  Don't wait for child processes that may have been created while logging the message.
- LOG_ODELAY
  The converse of LOG_NDELAY; opening of the connection is delayed until syslog() is called. (This is the default, and need not be specified.)
- LOG_PERROR
  (Not in POSIX.1-2001.) Print to stderr as well.
- LOG_PID
  Include PID with each message.

Blockchain vs Log

- By storing the information on a blockchain rather than in a file we increase the complexity of an attack against the log
- The mechanisms that protect the blockchain simplify the usage of its information in a forensics investigation and in a legal one

Security vs ICT security

- All the principles previously discussed do not fully characterize ICT security
- The two peculiar features of ICT security are
  - Automatic attack
  - The virtual machine hierarchy

Virtual machine hierarchy

- Any ICT system is a hierarchy of virtual machines
- Each virtual machine
  - Defines a set of mechanisms = a programming language
  - The defined mechanism abstracts and hides those of the underlying machine
  - Any machine can be a standard one, with all the consequent implications on vulns

Why ICT security is difficult?

- Vulns may be discovered in the specs and in the implementation of a virtual machine VM
- Vulns cannot be abstracted because a vulnerability in VM results in attacks against any machine of the stack that runs on top of VM

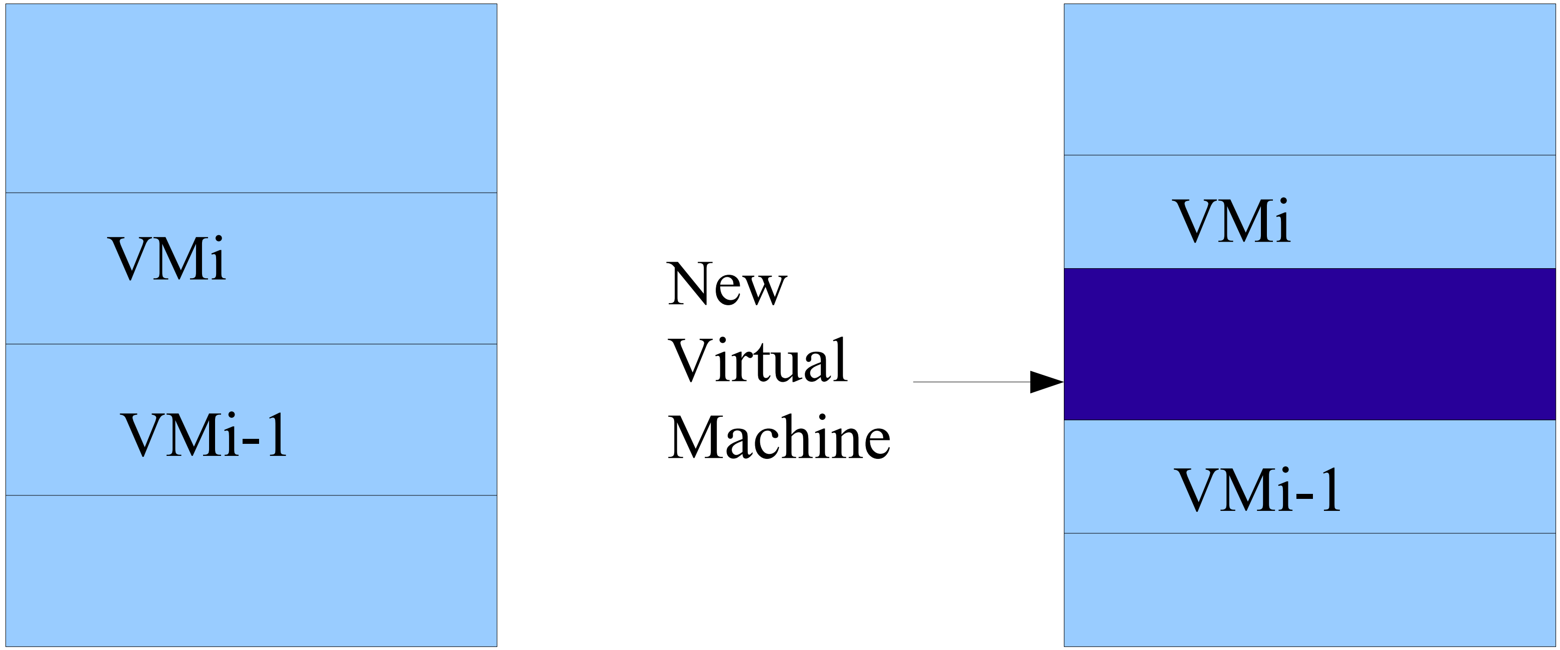
⇔ a vuln in the hardware architecture makes it possible to attack any VM running on it

⇔ a vuln in the OS makes it possible to attack any application it supports

Going down

- A trend in attack is attacking low level virtual machine
- By controlling a low level of the hierarchy any higher level can be attacked
- An interesting attack is the one that inserts a further virtual machine in the hierarchy
  - Difficult to be detected
  - High impact from a security perspective

Blue Pill Attack



Blue Pill Attack

The new machine can

- return fake information about the system states to upper layer virtual machines
- transmit to the underlying machines commands that differ from those received by higher VMs
- *Machine in the middle*, a generalization of man in the middle
- A first example in the next slides

Hardware vulnerabilities last news (13th of March, 2018)

CTS has been researching the security of AMD's latest Zen processors for the past six months and has made concerning discoveries:

1. The AMD Secure Processor, the gatekeeper responsible for the security of AMD processors, contains critical vulnerabilities. This integral part of most of products, including workstations and servers, is currently shipped with multiple vulnerabilities that could allow attackers to permanently install malicious code inside the Secure Processor itself. These vulnerabilities could expose customers to industrial espionage that is virtually undetectable by most security solutions.
2. A set of security vulnerabilities in the Secure Processor could allow attackers to steal network credentials – even on systems guarded by Microsoft's latest Credential Guard technology. This could allow attackers to spread through otherwise secure and up-to-date corporate networks

Hardware vulnerabilities last news (13th of March, 2018)

3. Secure Encrypted Virtualization, a key security feature that AMD advertises as one of its main offerings to cloud providers could be defeated as soon as attackers obtain malicious code execution on the EPYC Secure Processor.

4. The Ryzen chipset, a core system component that AMD outsourced to a Taiwanese chip manufacturer, ASMedia, is currently being shipped with exploitable manufacturer backdoors inside.These backdoors could allow attackers to inject malicious code into the chip. The chipset is a central component on the motherboard, responsible for linking the Ryzen processor with hardware devic such as WiFi and network cards, making it an ideal target for attackers.

Hardware vulnerabilities last news (13th of March, 2018)

Vulnerabilities	Impact
MASTERKEY-1 ***MASTERKEY-2*** ***MASTERKEY-3***	▪ Persistent malware running inside AMD Secure Processor ▪ Bypass firmware-based security features such as *Secure Encrypted Virtualization* (SEV) and *Firmware Trusted Platform Module* (fTPM) ▪ Network credential theft. Bypass *Microsoft Virtualization-based Security* (VBS), including *Windows Credential Guard* ▪ Physical damage to hardware (SPI flash wear-out, etc.) ▪ Affects: *EPYC, Ryzen, Ryzen Pro, Ryzen Mobile*. Successfully exploited on *EPYC* and *Ryzen*

Hardware vulnerabilities last news (13th of March, 2018)

RYZENFALL-1 ***FALLOUT-1***	▪ Write to protected memory areas, including:
	  ○ Windows Isolated User Mode and Isolated Kernel Mode (VTL1)
	  ○ AMD Secure Processor Fenced DRAM – Allows direct tampering with trusted code running on AMD Secure Processor. Only applicable to select *Ryzen* motherboards
	▪ Network credential theft. Bypass *Microsoft Virtualization-based Security (VBS)* including *Windows Credential Guard*
	▪ Enables memory-resident *VTL1* malware that is resilient against most endpoint security solutions
	▪ Affects: *EPYC, Ryzen, Ryzen Pro, Ryzen Mobile*. Successfully exploited on *EPYC, Ryzen, Ryzen Pro* and *Ryzen Mobile*

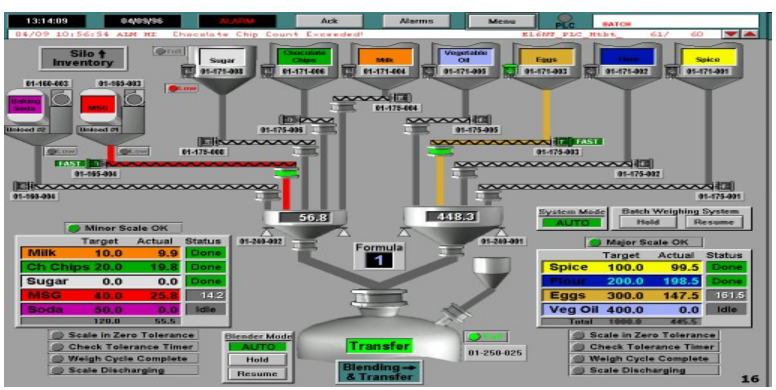
RYZENFALL-2 ***FALLOUT-2***	▪ Disable *Secure Management RAM (SMRAM)* read/write protection ▪ Enables memory-resident SMM malware, resilient against most endpoint security solutions ▪ Affects: *EPYC, Ryzen, Ryzen Pro*. Successfully exploited on *EPYC, Ryzen, Ryzen Pro*. *Ryzen Mobile* is not affected

RYZENFALL-3 ***FALLOUT-3***	▪ Read from protected memory areas, including:
	  ○ Windows Isolated User Mode and Isolated Kernel Mode (VTL1)
	  ○ Secure Management RAM (SMRAM)
	  ○ AMD Secure Processor Fenced DRAM. Only applicable to select *Ryzen* motherboards
	▪ Network credential theft. Bypass *Windows Credential Guard* by reading secrets from VTL1 memory
	▪ Affects: *EPYC, Ryzen, Ryzen Pro*. Successfully exploited on *EPYC, Ryzen, Ryzen Pro*. *Ryzen Mobile* is not affected

RYZENFALL-4	▪ Arbitrary code execution on AMD Secure Processor ▪ Bypass firmware-based security features such as *Firmware Trusted Platform Module* (fTPM) ▪ Network credential theft. Bypass *Microsoft Virtualization-based Security* (VBS), including *Windows Credential Guard* ▪ Physical damage to hardware (SPI flash wear-out, etc.) ▪ Affects: *Ryzen, Ryzen Pro*. Successfully exploited on *Ryzen, Ryzen Pro*.
CHIMERA-FW ***CHIMERA-HW***	▪ Two sets of manufacturer backdoors: One implemented in firmware, the other in hardware (ASIC) ▪ Allows malware to inject itself into the chipset's internal *8051 architecture* processor ▪ The chipset links the CPU to USB, SATA, and PCI-E devices. Network, WiFi and Bluetooth traffic often flows through the chipset as well ▪ Malware running inside the chipset could take advantage of the chipset's unique position as a middleman for hardware peripherals ▪ Affects: *Ryzen, Ryzen Pro*. Successfully exploited on *Ryzen* and *Ryzen Pro*.

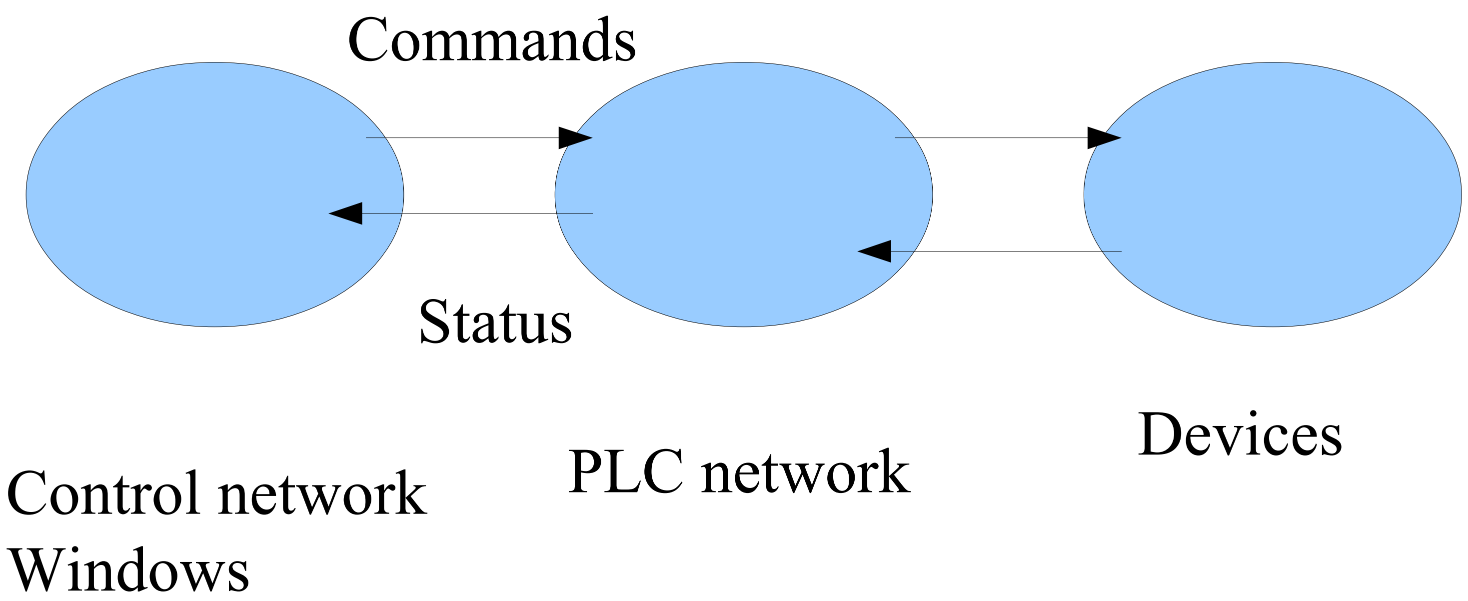
Industrial Control Systems

- Run automated processes on factory floors, power and chemical plants, oil refineries, etc.
- Specialized assembly code on PLCs (Programmable Logic Controllers)
  - PLCs are usually programmed from Windows
- <u>Not</u> connected to the Internet ("air gap")



Industrial Control Systems

- PLC sits inbetween the control network and the actual devices
- Programmed to control the devices



Stuxnet Attack Vector

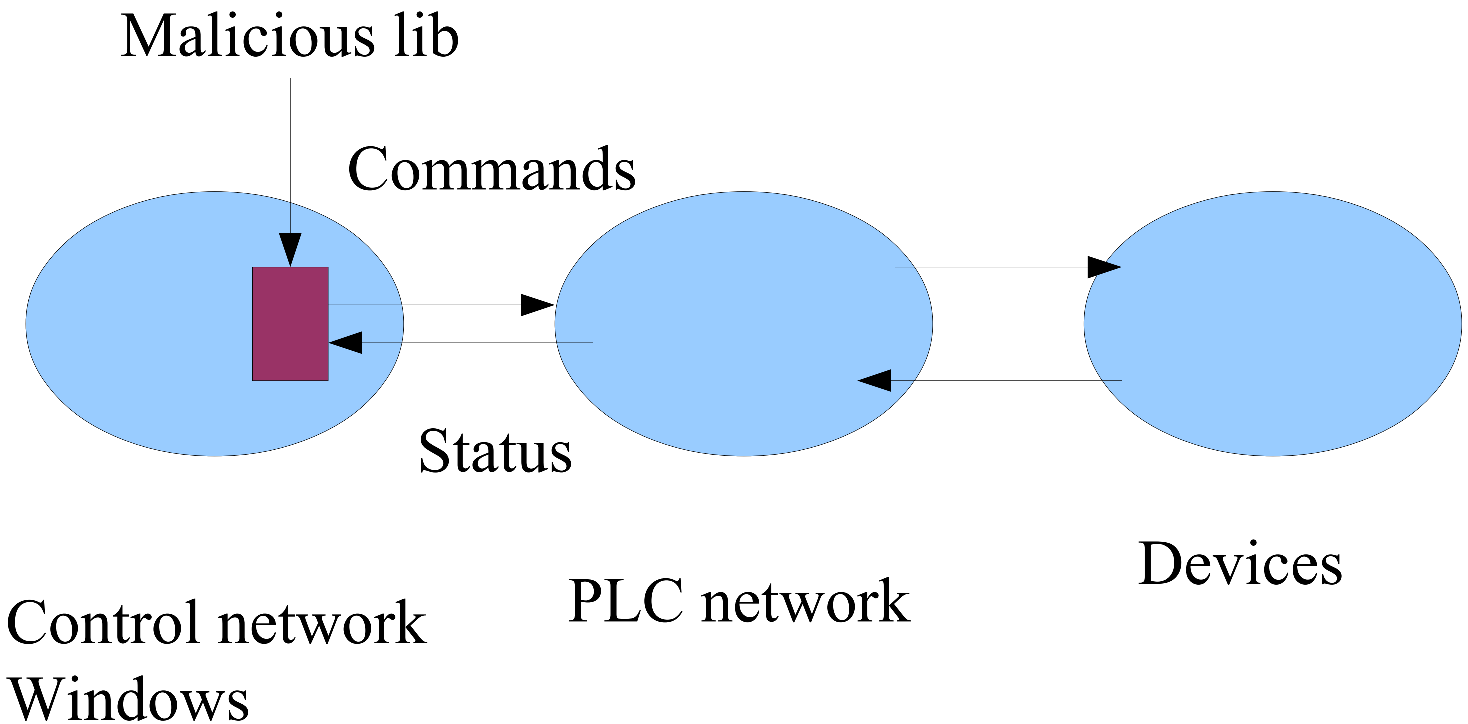
- Two strikingly different attack vectors
- Overpressure Attack
  - Increase centrifuge rotor stress
  - Significantly stronger
  - More stealthy
  - Less documented in literature
- Rotor Speed Attack
  - Increase/descrease rotor velocity
  - Overpressure centrifuge is dormant in this attack
  - Independent from previous attack
  - Less concern about detection

Not only the Attack Vector

- One of the side effect of the attack was the update of a library
- Every time the operator checks the pressure and the speed of the rotor the library returns the correct values it has copied before starting the attack
- In this way the operator has no mechanism to discover the ongoing attack
- The transmission of erroneous commands continues till the rotors are completely crashed (their central axes becomes elliptical)

In the middle

- Malicious library
- Unreliable interactions



Hierarchy and robustness - I

- Robustness at any level
  - Each VM should include the checks on the subjects and the objects of the corresponding level
  - The distribution of checks at the various VMs is the simplest way to minimize the overall overhead
  - This also guarantees that the checks of a VM cannot be violated by working at a lover level

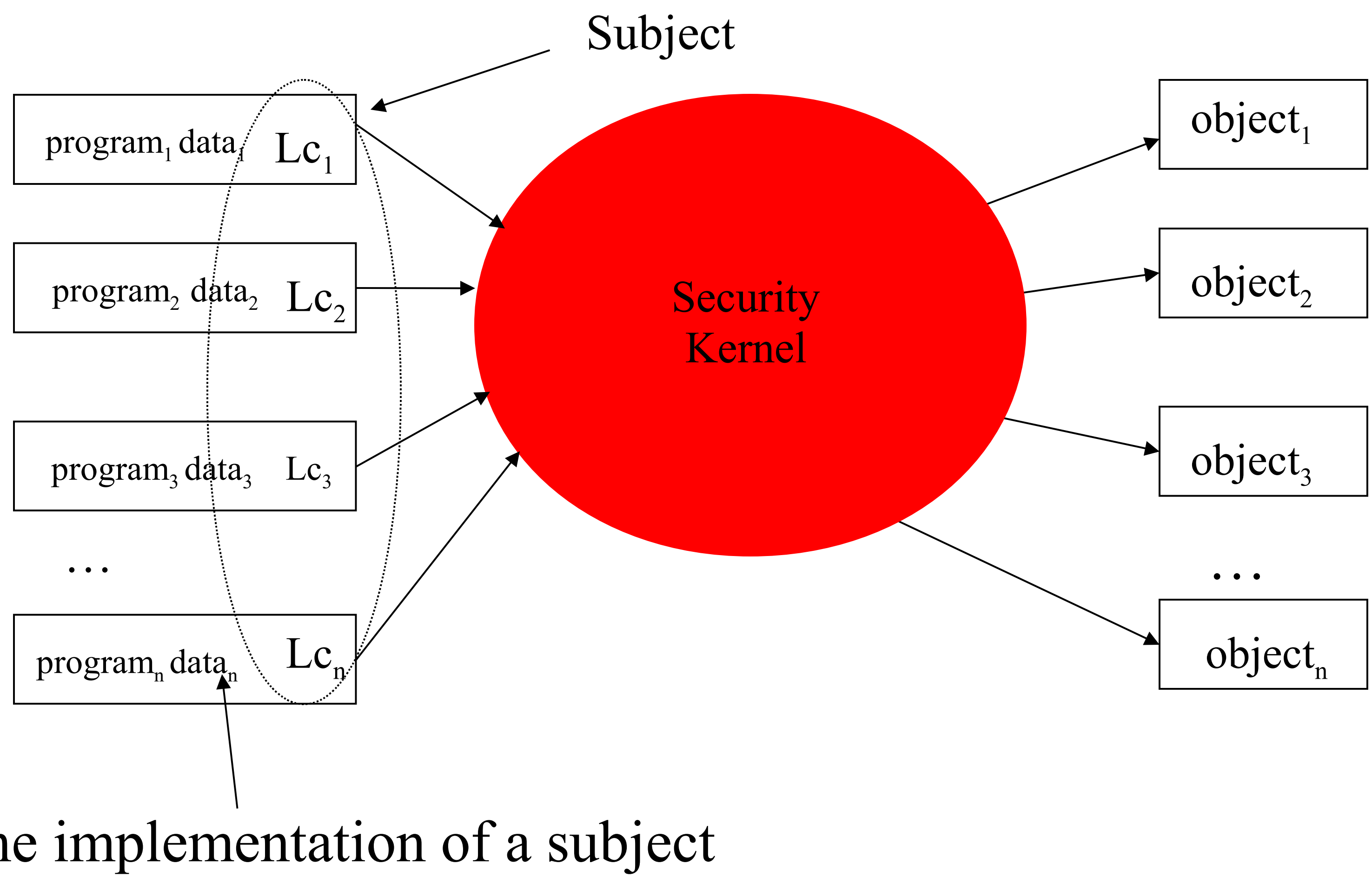
  If this strategy is not applied then either
  - A VM does not execute any checks

  or
  - The checks of a VM are delegated to another one but this increases the overall complexity
- Redundancy = checks are repeated in distinct VMs

Example - Capability

- VM(L), the machine at level L adopts a capability based solution to manage the rights of a subject
- VM(L-1), the underlying machine at level L-1
  - Implements the subjects and the objects of VM(L)
  - Manages some further objects that implement the capabilities of VM(L)
- The acm of VM(L-1) should guarantee that the subjects of VM(L) cannot manipulate their capabilities

Capability


Subject
program1 data1 Lc1
program2 data2 Lc2
program3 data3 Lc3
...
programn datan Lcn
Security
Kernel
object1
object2
object3
...
objectn
The implementation of a subject

Hierarchy and robustness - II

- Security policy and mechanism modularity in a hierarchy of VMs:
  - any VM defines a set of mechanisms that may be freely composed by the user of the VM to implement a security policy

    ⇔
  - Each VM exploits some assumptions on the security of these mechanisms that has to be guaranteed by at least one of the underlying VMs
  - Example: to prevent the manipulation of a capability we can apply
    - Encryption
    - Protection of a memory segment
    - Protection of a data structure
    - ….
- A distributed implementation of the TCB by several VMs

Hierarchy and robustness - III

- The robustness of a VM is a function of the robustness of the underlying VMs
- Even functionally equivalent machines have a very different robustness because of
  - The implementation of the machine
  - The implementation of the underlying machines

Robustness does not agree with abstraction ⇒

Robustness can be evaluated only in terms of the implementation

A common problem: example

- A memory area, in some memory of VMi is shared among several applications by distinct users of a VMi+k
- The applications that share the area may be not know in advance because they depend upon the users that are sharing VMi
- An application that can access an area can read in it some values left by another application or by another user
- This shows why cloud security is a big problem

Solution

- Any memory area that is either
  - released by an application or
  - garbage collected

  has to be reinitizialed to avoid any illegal information flow between two applications

  (covert channel)
- This holds for any memory area
  - cache,
  - main memory,
  - secondary storage

Solution

- In a system with severe security requirements, all the resources are partitioned into pools each with a distinct level
- The resource in a pool with a given level are shared only among applications run by users with the same security level
- Sharing is constrained to minimize unanticipated flow of information among applications with distinct security levels

A general principle …

- The previous example shows that sharing should be avoided or at least minimized to improve the security of a system
- A secure system
  - is as simple as possible
  - avoids sharing as much as possible
- This explains why a secure system is more expensive of a less secure one

Examples

- Memory segments are partitioned into subsets, each paired with a security level
- Traffic segregation = network channels are partitioned into subset, security critical information is transmitted only along some lines
  - Switchs rather than hubs
  - Partitioning of virtual lines created by tagging or by encryption
  - Distinct transmission frequency but low security
- It is important to understand that any system manages at least two levels of information

Two security levels

- User information
- Information to implement the security policy
- Distinct mechanisms have to be applied to protect the two kinds of information

Example

- A sniffer on a communication line reads any information transmitted along the line
- If a user information is transmitted the sniffer can read the information
- If a user password is transmitted and read by the sniffer then all the user information is lost

Sharing and Cloud

- Cloud archictecure result in large saving is that they are based upon pools of resources shared among user
- Elasticity = when a resource is not used it can be granted to any user that requires it
- What happens when a resource passes from one user to another one?

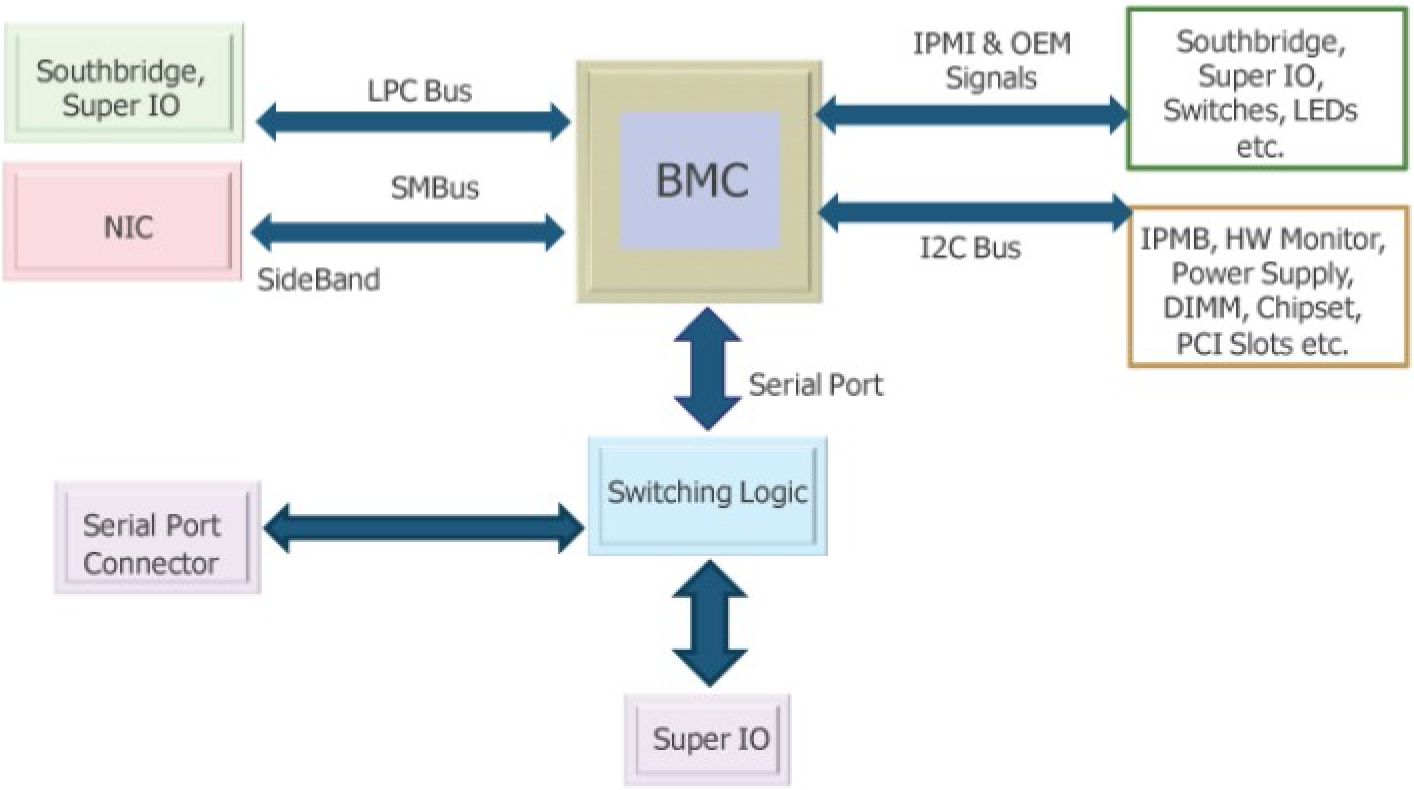
Cloud Management

- Intelligent Platform Management Interface (IPMI) is a set of computer interface specifications for an autonomous computer subsystem that provides management and monitoring capabilities independently of the host system's CPU, firmware (BIOS or UEFI) and operating system.
- IPMI defines a set of interfaces used by system administrators for out-of-band management of computer systems and monitoring of their operation.
- IPMI provides a way to manage a computer that may be powered off or otherwise unresponsive by using a network connection to the hardware rather than to an operating system or login shell. Another use case may be installing a custom operating system remotely.

Cloud Management

Baseboard Management Controller (BMC)

The embedded micro-controller: the second CPU



Cloud Management

Scanned all public IPs on May 7, 2013 using ZMap*.

Downloaded all X.509 certs from HTTPS servers.

Used identifying characteristics of default certificates.†

Platform	Devices on Public IPs
Supermicro IPMI	41,545
Dell iDARC	40,413
HP iLO	23,376
Total	105,334

Could root all these in parallel in minutes!

Cloud and Motherboard

- Chinese government agents sneaked spy chips into Super Micro servers used by Amazon, Apple, the US governmen giving Beijing's snoops access to highly sensitive data, according to a Bloomberg report today.
- The story had a huge impact on the markets: Super Micro, saw its share price drop by nearly 50 per cent; Apple's share price dropped by just under two per cent, and Amazon's dropped by more than two per cent.
- According to the report, tiny microchips that were made to look like signal conditioning couplers were added to Super Micro data center server motherboards manufactured by sub-contractors based in China.
- Those spy chips contained enough memory and processing power to effectively backdoor the host systems so that outside agents could, say, meddle with the servers and exfiltrate information.

Cloud and Motherboard

- The spy chip could have been placed electrically between the baseboard management controller (BMC) and its SPI flash or serial EEPROM storage containing the BMC's firmware. Thus, when the BMC fetched and executed its code from this memory, the spy chip would intercept the signals and modify the bitstream to inject malicious code into the BMC processor, allowing its masters to control the BMC
- The BMC is a crucial component on a server motherboard. It allows administrators to remotely monitor and repair machines, typically over a network, without having to find the box in a data center, physically pull it out of the rack, fix it, and re-rack it.
- The BMC and its firmware can be told to power-cycle the server, reinstall or modify the host operating system, mount additional storage containing malicious code and data, access a virtual keyboard and terminal connected to the computer, and so on. If you can reach the BMC and its software, you have total control over the box.

The chip …