Internet Security [1]

VU 184.216

Testing

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News from the Lab

- *Challenge 4 – XSS*
  - continues yet another week
  - so far, solved by 17 people
  - *respect! It's getting tougher...*
  - JOHANNES "Demon Reflective" FERNER 0wned fakebook first
    - congrats!!

- *Challenge 5* will be announced next week
  - Java programming assignment
  - based on things you'll hear about in the next lecture

Outline

- So far … offensive approach – exploit flaws
  - low level network attack
  - mid level protocol attacks
  - high level application attacks
- Today … defensive approach – avoid making these mistakes
- Terminology
  - types of (security relevant) test methods
  - static testing
  - dynamic testing
  - penetration testing
- Automatic testing: tools, tools, tools...

Overview

- When system is designed and implemented
  - correctness has to be ***tested***
- Different types of tests are necessary
  - validation
    - is the system designed correctly?
    - does the design meet the problem requirements?
  - verification
    - is the system implemented correctly?
    - does the implementation meet the design requirements?
- Different features can be tested
  - functionality, performance, ***security***

Testing

- Edsger Dijkstra

  Program testing can be quite effective for showing the presence of bugs, but is hopelessly inadequate for showing their absence.

- Testing
  - analysis that discovers what *is* and compares it to what *should be*
  - should be done throughout the development cycle
  - necessary process
  - but not a substitute for sound design and implementation
  - for example, running public attack tools against a server cannot prove that service is implemented securely

Testing

- Classification of testing techniques
  - white-box testing
    - testing all the implementation
    - path coverage considerations
    - faults of commission
    - find implementation flaws
    - but cannot guarantee that specifications are fulfilled
  - black-box testing
    - testing against specification
    - only concerned with input and output
    - faults of omissions
    - specification flaws are detected
    - but cannot guarantee that implementation is correct

Testing

- Classification of testing techniques
  - static testing
    - check requirements and design documents
    - perform source code auditing
    - theoretically reason about (program) properties
    - cover a possible infinite amount of input (e.g., use ranges)
    - no actual code is executed
  - dynamic testing
    - feed program with input and observe behavior
    - check a certain number of input and output values
    - code is executed (and must be available)

Testing

- Automatic testing
  - testing should be done continuously
  - involves a lot of input, output comparisons, and test runs
  - therefore, ideally suitable for automation
  - testing hooks are required, at least at module level
  - nightly builds with tests for complete system are advantageous

- Regression tests
  - test designed to check that a program has not "regressed”, that is, that previous capabilities have not been compromised by introducing new ones

Testing

- Software fault injection
  - go after effects of bugs instead of bugs
  - reason is that bugs cannot be completely removed
  - thus, make program fault-tolerant
  - failures are deliberately injected into code
  - effects are observed and program is made more robust

Security Testing

- Many of the introduced testing techniques can also be used to identify *security problems*

- Testing must happen at all different development cycle phases
  - test method depends on development phase
  - requirements analysis phase
  - design phase
  - implementation phase
  - (pre-)rollout phase

Security Testing – Requirements Analysis Phase

- Software / System requirements usually only include functional requirements
  - security requirements are often omitted
- If a feature's security requirements are not explicitly stated, …
  - … they will not be included / considered in the design
    - the system will be insecure *by design*
  - … the programmers will not implement them
  - … they will not be tested
- Describe how system reacts to exceptional / attack scenarios

Security Testing – Design Phase

- Design level
  - not much tool support available
  - manual design reviews
  - formal methods
  - attack graphs

- Formal methods
  - formal specification that can be mathematically described and verified
  - often used for small, *safety*-critical programs / program parts
    - e.g., control program for nuclear power plant
    - e.g., cryptographic protocols
  - state and state transitions must be formalized and unsafe states must be described
  - *model checker* can ensure that no unsafe state is reached

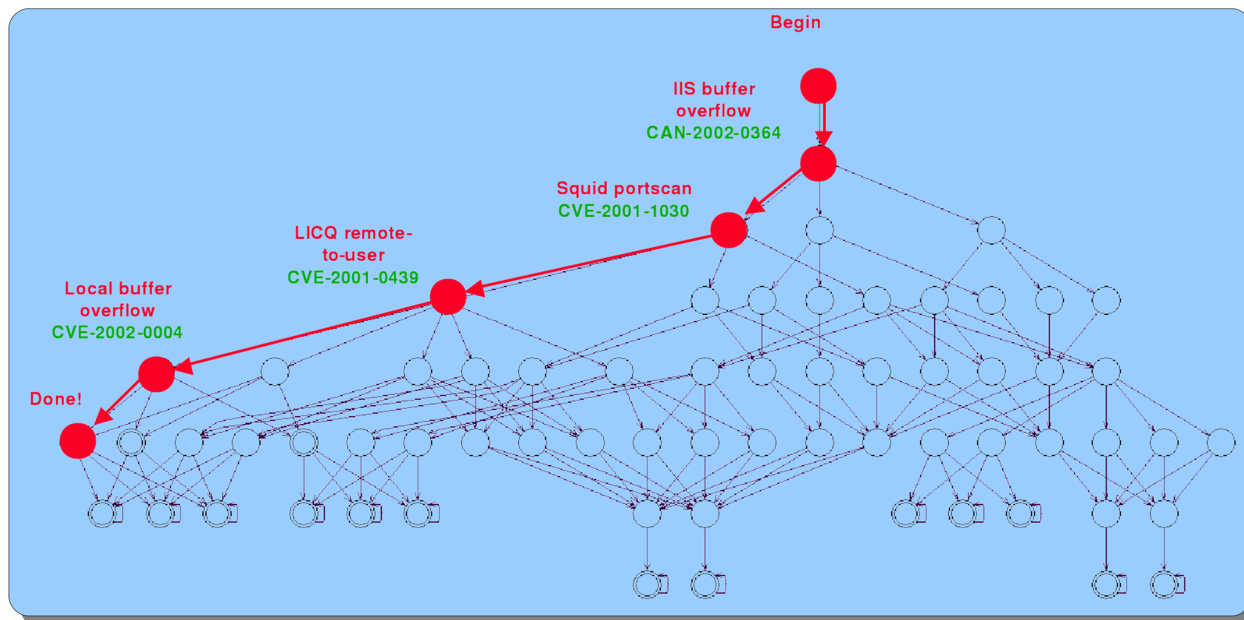
Security Testing – Design Phase

- Attack graph
  - given
    - a finite state model, M, of a network
    - a security property P
  - an attack is an execution of M that violates P
  - an attack graph is a set of attacks of M

- Attack graph generation
  - done by hand
    - error prone and tedious
    - impractical for large systems
  - automatic generation
    - provide state description
    - transition rules

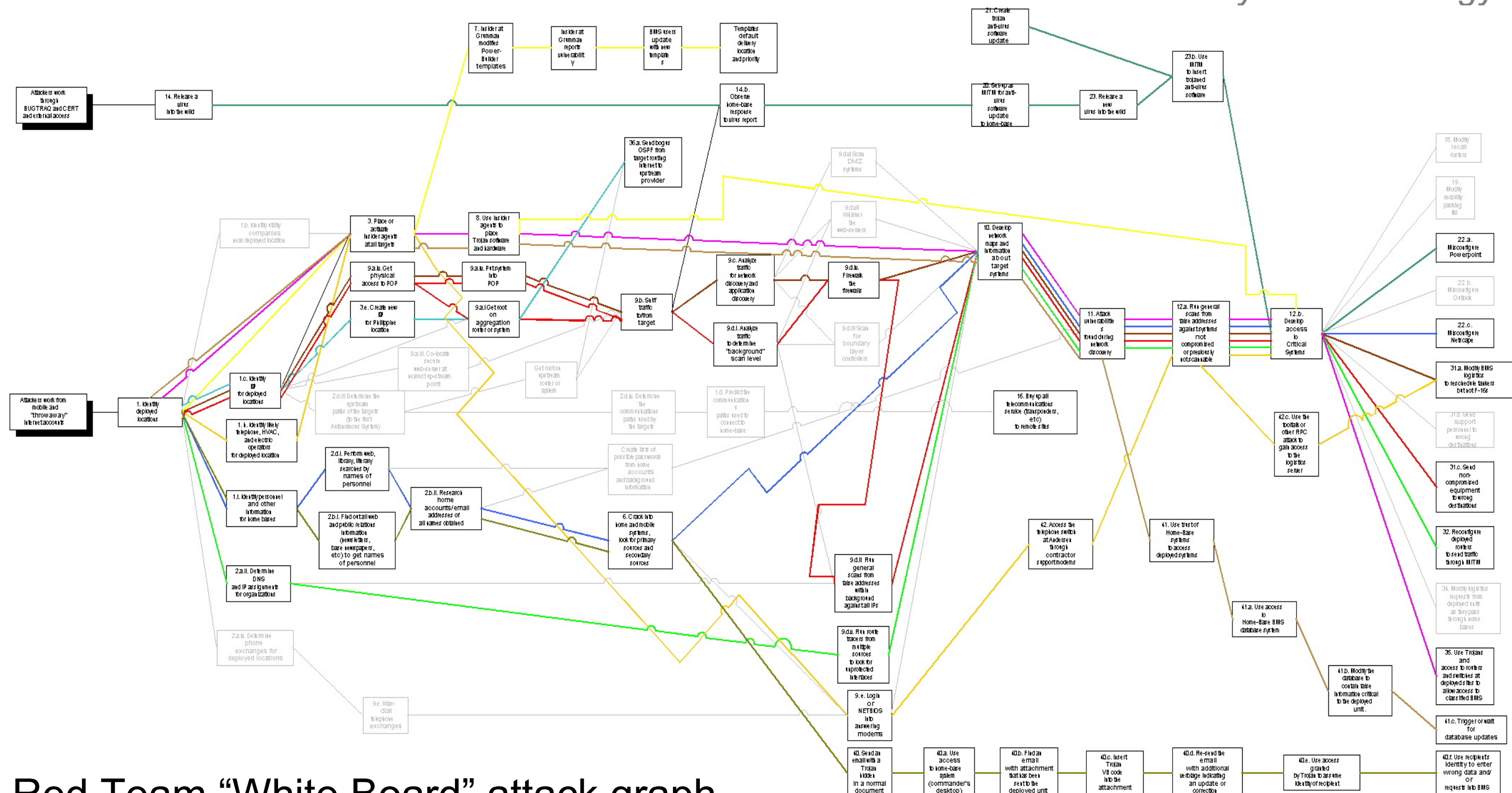
Security Testing – Attack Graphs

Security property (LTL):
G(*intruder*.privilege(host) < *root*)



Somesh Jha, et al *"Generation of Scenario Graphs Using Model Checking"*

Security Testing – Attack Graphs

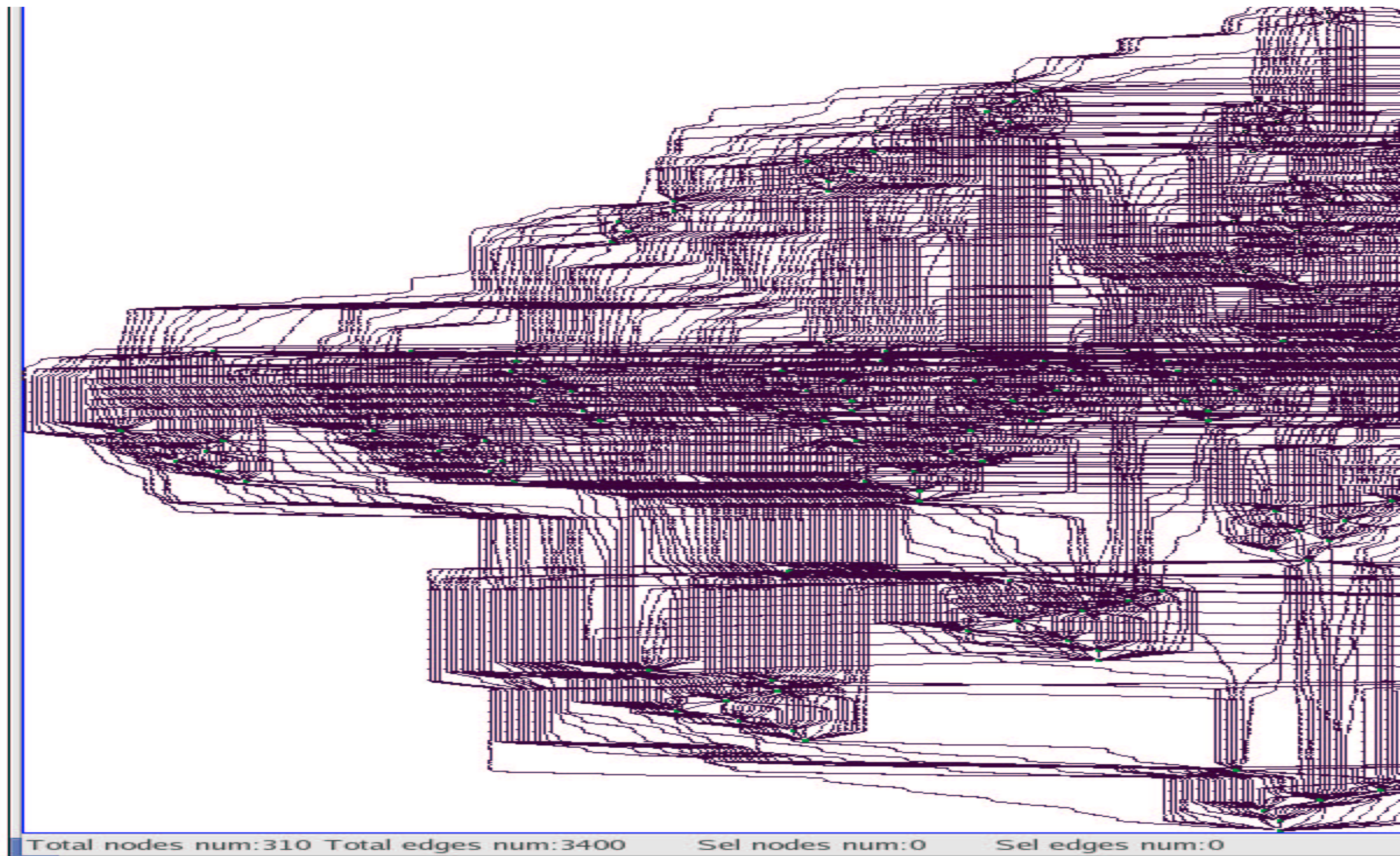


Sandia Red Team “White Board” attack graph from DARPA CC20008 Information battle space preparation experiment

Security Testing – Attack Graphs

P = Attacker gains root access to Host 1.

4 hosts
30 actions
310 nodes
3400 edges



Security Testing – Implementation

- Implementation Level
  - detect known set of problems and security bugs
  - more automatic tool support available
  - target particular flaws
  - reviewing (auditing) software for flaws is reasonably well-known and well-documented
  - support for static and dynamic analysis
  - ranges from "how-to" for manual code reviewing to elaborate model checkers or compiler extensions

Static Security Testing

- Manual auditing
  - code has to support auditing
    - architectural overview
    - comments
    - functional summary for each method
  - OpenBSD is well know for good auditing process
    - 6 -12 members since 1996
    - comprehensive file-by-file analysis
    - multiple reviews by different people
    - search for bugs in general
    - proactive fixes: try to find and fix bugs before they are used in the wild
  - Microsoft also has intensive auditing processes
    - every piece of written code has to be reviewed by another developer

Static Security Testing

- Manual auditing
  - tedious and difficult task
  - some initiatives were less successful
    - Sardonix (security portal)

Crispin Cowan: "Reviewing old code is tedious and boring and no one wants to do it.".

- Linux Security Audit Project (LSAP)

Statistics for All Time

Lifespan	Rank	Page Views	D/l	Bugs	Support	Patches	Trkr	Tasks
1459 days	0(0.00)	4,887	0	0(0)	0(0)	0(0)	0(0)	0(0)

Static Security Testing

- Syntax checker
  - parse source code and check for functions are known to introduce vulnerabilities
    - e.g., `strcpy()`, `strcat()` (as we will see in the buffer overflows lecture)
  - also limited support for arguments (e.g., variable, static string)
  - only suitable as first basic check
  - cannot understand more complex relationships
  - no control flow or data flow analysis

  - examples / tools (all open source)
    - `flawfinder` (c/c++)
    - `RATS` (Rough Auditing Tool for Security, c/c++/perl/python/php)
    - `ITS4` (c/c++)

Static Security Testing

- Syntax checker: `flawfinder`
  - find potential security flaws ("hits") in source code
  - limited to C/C++

```
int main(int argc, char **argv)
{
  if (argc > 1)
  {
    char buf[32];
    strcpy(buf, argv[1]);
    printf("this was the first argument: %s\n", buf);
  }
```

never !!

no !!

nein !!

non !!

Static Security Testing


```
$ flawfinder base.c

Flawfinder version 1.27, (C) 2001-2004 David A. Wheeler.
Number of dangerous functions in C/C++ ruleset: 160
Examining base.c

base.c:13:  [4] (buffer) strcpy:
  Does not check for buffer overflows when copying to destination.
  Consider using strncpy or strlcpy (warning, strncpy is easily misused).

base.c:12:  [2] (buffer) char:
  Statically-sized arrays can be overflowed. Perform bounds checking,
  use functions that limit length, or ensure that the size is larger than
  the maximum possible length.

Hits = 2
```

Static Security Testing


```
$ rats base.c

Entries in c database: 336
...
Analyzing base.c
base.c:12: High: fixed size local buffer
Extra care should be taken to ensure that character arrays that are
allocated on the stack are used safely.  They are prime targets for buffer
overflow attacks.

base.c:13: High: strcpy
Check to be sure that argument 2 passed to this function call will not copy
more data than can be handled, resulting in a buffer overflow.

Total lines analyzed: 23
Total time 0.000237 seconds
97046 lines per second
```

Static Security Testing


```
int main(int argc, char **argv)
{
        if (argc > 1)
        {
                char buf[32];
                if (strlen(argv[1]) < 32)
                {
                        strcpy(buf, argv[1]);
                }
                else
                {
                        memcpy(buf, argv[1], 31);
                        buf[31] = 0;
                }
                printf("this was the first argument: %s\n", buf);
        }
```

Adding boundary check...

Static Security Testing


```
$ flawfinder good.c
...
good.c:14:  [4] (buffer) strcpy:
  Does not check for buffer overflows when copying to destination.
  Consider using strncpy or strlcpy (warning, strncpy is easily misused).
good.c:12:  [2] (buffer) char:
  Statically-sized arrays can be overflowed. Perform bounds checking,
  use functions that limit length, or ensure that the size is larger than
  the maximum possible length.
good.c:17:  [2] (buffer) memcpy:
  Does not check for buffer overflows when copying to destination. Make
  sure destination can always hold the source data.
good.c:13:  [1] (buffer) strlen:
  Does not handle strings that are not \0-terminated (it could cause a
  crash if unprote

Hits = 4
```

… even though it could do better here, all static tools have their limits ...

Static Security Testing

- Annotation-based systems
  - programmer uses annotations to specify properties in the source code (e.g., this value must not be NULL)
  - analysis tool checks source code to find possible violations
  - control flow and data flow analysis is performed
  - problems are *undecidable* in general, therefore trade-off between *correctness* and *completeness*
    - *decidable*: there exists an algorithm that is guaranteed to return the correct answer in a *finite* amount of time
    - *undecidable*: Problem for which there *cannot* exist an algorithm that is guaranteed to terminate in all cases
  - examples / tools
    - `SPlint`
    - `eau-claire`
    - `UNO` (uninitialized vars, out-of-bounds access)

Static Security Testing

- Annotation-based systems: `SPlint`
  - tool for statically checking C programs for security vulnerabilities and coding mistakes
  - http://www.splint.org

```
static char bar1(/*@null@*/    char *s) { return *s; }
static char bar2(/*@notnull@*/char *s) { return *s; }

int main(/*@unused@*/int argc, char **argv) {
  char *foo = NULL;
  if (bar1(foo) == bar2(foo)) {
    printf("we survived %s\n", argv[0]);
    // but we never do!!
  }
```

Annotations

Static Security Testing


```
$ splint base.c
Splint 3.1.2 --- 13 May 2009

base.c: (in function bar1)
base.c:4:11: Dereference of possibly null pointer s: *s
A possibly null pointer is dereferenced. Value is either the result of a function
which may return null (in which case, code should check it is not null), or a global,
parameter or structure field declared with the null qualifier. (Use -nullderef to
inhibit warning)
base.c:3:34: Storage s may become null

base.c: (in function main)
base.c:14:24: Null storage foo passed as non-null param: bar2 (foo)
A possibly null pointer is passed as a parameter corresponding to a formal parameter
with no /*@null@*/ annotation. If NULL may be used for this parameter, add a
/*@null@*/ annotation to the function parameter declaration. (Use -nullpass to inhibit
warning)
base.c:13:14: Storage foo becomes null

Finished checking --- 2 code warnings
```

Static Security Testing

- Annotation-based systems: `SPlint`
  - Annotations for APIs

```
int main(int argc, char** argv) {
  char *str;
  if(argc < 2)
    exit(0);
  str = (char *)malloc(sizeof(char) * (strlen(argv[1])+1));
  strcpy(str, argv[1]);
  printf("Input String: %s \n", str);
  return 1;
}
```

`char *strcpy(char /*@notnull@*/ str, char *src);`

`malloc` might return NULL
`strcpy` needs non-NULL dest param

Static Security Testing


```
$ splint mem.c
Splint 3.1.2 --- 13 May 2009

mem.c: (in function main)
mem.c:10:10: Possibly null storage str passed as non-null param: strcpy (str, ...)
  A possibly null pointer is passed as a parameter corresponding to a formal
  parameter with no /*@null@*/ annotation.  If NULL may be used for this
  parameter, add a /*@null@*/ annotation to the function parameter declaration.
  (Use -nullpass to inhibit warning)
   mem.c:9:9: Storage str may become null

mem.c:12:12: Fresh storage str not released before return
  A memory leak has been detected. Storage allocated locally is not released
  before the last reference to it is lost. (Use -mustfreefresh to inhibit
  warning)
   mem.c:9:3: Fresh storage str created

Finished checking --- 2 code warnings
```

Static Security Testing

- Model checking
  - programmer specifies security properties that have to hold
  - models realized as state machines
  - statements in the program result in state transitions
  - certain states are considered insecure
  - usually, control flow and data flow analysis is performed
  - example:
    - In Unix systems, *model checking* might verify that a program obeys the following rule: A setuid-root process should not execute an untrusted program without first dropping its root privilege.
    - race conditions
    - creating a secure chroot jail
  - examples / tools
    - `MOPS` (an infrastructure for examining security properties of software)

Static Security Testing

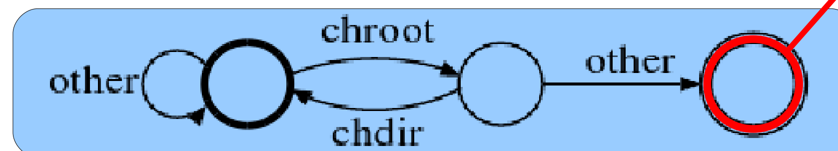
- Model checking, example
  - [http://www.cs.ucdavis.edu/~hchen/paper/ccs02.pdf]
  - suppose a process uses the **`chroot`** system call to confine its access to a sub filesystem. In this case, the process should immediately call **`chdir("/")`** to change its working directory to the root of the sub filesystem.

`chdir("/");` missing

```
// Here the current directory is "/var/ftp"
chroot("/var/ftp/pub");

filename = read_from_network();
// filename could be „../../etc/passwd"
fd = open(filename, O_RDONLY);
```

insecure state!



Static Security Testing

- Meta-compilation (Dawson Engler, Stanford University)
- Programmer adds simple system-specific compiler extensions
  - these extensions check (or optimize) the code
  - flow-sensitive, inter-procedural analysis
  - not *sound*, but can detect many bugs
  - no annotations needed, instead states and state transitions
  - example extensions
    - system calls must check user pointers for validity before using them
    - disabled interrupts must be re-enabled
    - to avoid deadlock, do not call a blocking function with interrupts disabled
    - freed pointers must not be dereferenced / freed

Static Security Testing

- Meta-compilation, example
  - [http://www.stanford.edu/~engler/p27-hallem.pdf]
  - define state, state transitions and actions for certain states

```
state decl any_pointer v;

start:
        { kfree(v) } ==> v.freed;

v.freed:
        { *v }       ==> v.stop,
             { err("using %s after free!", mc_identifier(v)); }
    |
        { kfree(v) } ==> v.stop,
             { err("double free of %s!", mc_identifier(v)); };
```

Static Security Testing

- Meta-compilation, example

```
int contrived(int *p, int *w, int x) {
  int *q;
  if(x) {
    kfree(w);
    q = p;
    p = 0;
  }
  if(!x)
    return *w;
  return *q;
}

int contrived_caller (int *w, int x, int *p) {
  kfree (p);
  contrived (p, w, x);
  return *w;
}
```

safe

using 'q' after free!

using 'w' after free!

Static Security Testing

- Model checking versus Meta-compilation (Engler, 2003)
  - [http://www.springerlink.com/content/wx4ppjhwgt696dt8/fulltext.pdf]
  - evaluated on 3 case studies over years
- General perception
  - meta-compilation: easy to apply, but finds rather shallow bugs
  - model checking: harder, but strictly better once done
- FLASH processor: ccNUMA (Cache Coherent Non-Uniform Memory Access) with cache coherence protocols in software
  - 1 bug deadlocks entire machine
  - code with many ad hoc correctness rules
    - `WAIT_FOR_DB_FULL` must precede `MISCBUS_READ_DB`
  - but they have a clear mapping to source code
  - easy to check with compiler

Static Security Testing

- Meta-compilation
  - scales
  - relatively precise
  - statically found 34 bugs, although code tested for 5 years
  - however, many deeper properties are missed

- Deeper properties
  - nodes never overflow their network queues
  - sharing list empty for dirty lines
  - nodes do not send messages to themselves

- Perfect application for model checking
  - bugs depend on intricate series of low-probability events
  - self-contained system that generates its own events

Static Security Testing

- The (known) problem
  - writing model is hard
  - someone did it for a similar protocol than ccNUMA
    - several months effort
    - no bugs
  - auto-extract model from code
- Result
  - 8 errors
  - two deep errors, but 6 bugs found with static analysis as well.
- Myth: model checking will find more bugs
  - in reality, 4x fewer

Static Security Testing

- Where meta-compilation is superior

	Static analysis	Model checking
	Compile → Check	Run/Simulate → Check
Don’t understand?	So what	Problem
Can’t run?	So what	Can’t play
Coverage?	All paths! All paths!	Executed paths
First question:	“How big is code?”	“What does it do?”
Time:	Hours	Weeks
Bug counts	100-1000s	0-10s
Big code:	10MLOC	10K
No results?	Surprised	Less surprised

Static Security Testing

- Where model checking is superior

- Subtle errors
  - run code, so can check its implications
  - static analysis better at checking properties in code
  - model checking better at checking properties implied by code

- Difference
  - static analysis detects ways to cause error
  - model checking checks for the error itself

Static Web Script Testing

- Our tool: `pixy`
  - developed by Nenad Jovanovic
  - analyzes PHP source code and automatically detects XSS/SQLi vulnerabilities
  - web interface: http://pixybox.iseclab.org/pixy/
  - client version downloadable

DEMO

Dynamic Security Testing

- *Run-time* checking between operating system and program
  - intercept and check system calls

- *Run-time* checking between libraries and program
  - intercept and check library functions
  - often used to detect memory problems
    - interception of `malloc()` and `free()` calls
    - emulation of heap behavior and code instrumentation
    - `purify, valgrind`
  - also support for *buffer overflow* detection
    - `libsafe`

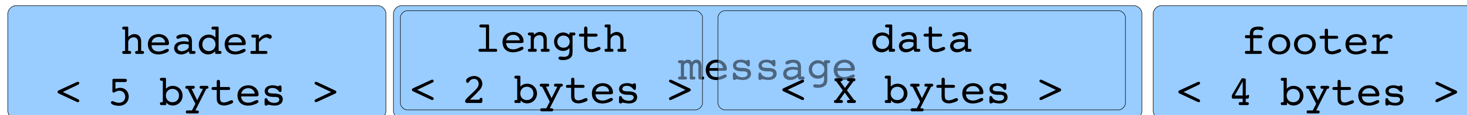
Dynamic Security Testing

- Profiling
  - record the dynamic behavior of applications with respect to interesting properties
- Obviously interesting to tune performance
  - `gprof`
- But also useful for improving security
  - sequences of system calls
  - system call arguments
  - same for function calls

Dynamic Security Testing

- Fuzz testing (*fuzzing*)
  - brute-force vulnerability detection
  - penetrate program with lots and lots of (semi-)random input
  - monitor program for crashes, dead-locks, etc.
  - particularly successful in finding protocol/file parsing errors

- Tools
  - model minimal protocol specification



  - fuzzer will randomize input bytes, but follow specification rules
  - `OWASP JbroFuzzm`,
  - `SPIKE`,
  - `Powerfuzzer`

Security Testing – (Pre-)Rollout

- Prepare code for release:
  - remove debug code

```
if (checkPassword(user, passwd) ||
     user == “test”) {
  ...
```

  - remove debugging information, symbols, etc.
    - *strip* binary
  - remove sensitive information concerning possible weaknesses and untested code, disable debug output

```
if ($debug) {
  print(“user: $user\n”);
  print(“auth: $auth_status\n”);
  ...
```

  - reset all security settings, remove test accounts, etc.

Security Testing – (Pre-)Rollout

- Penetration testing
  - a penetration test is the process of actively evaluating your information security measures
  - somewhat similar to Inetsec challenges
  - common procedure
    - analysis for design weaknesses, technical flaws and vulnerabilities
    - the results delivered comprehensively in a report (to executive, management, and technical audiences)

- Why penetration testing: Why would you want it?
  - e.g., banks, gain and maintain certification (BS7799, NATO etc.)
  - assure your customers that you are security-aware
  - sink costs (yes, security bugs may cost you more)

Penetration Testing

- OK… so *how* do people do it?
  - general tool support available
    - `Nessus`
    - `ISS Internet Scanner`
    - `nmap`
  - tools available that can test a particular protocol
    - `Whisker (web, CGI-scanner)`
    - `Internet Security Systems (ISS)` Database scanner
  - tools for general web vulnerabilities
    - `SecuBat` (experimental tool that we developed, Kals et al. 2006)

Penetration Testing

- Different types of services
  - external penetration testing (traditional)
    - testing focuses on services and servers available from outside
  - internal security assessment
    - typically, testing performed on LAN, DMZ, network points
  - application security assessment
    - applications that may reveal sensitive information are tested

Penetration Testing

- Different types of services
  - wireless / remote access assessment
    - e.g., wireless access points, configuration, range, etc.
  - telephony security assessment
    - e.g., mailbox deployment and security, PBX systems, etc.
  - social engineering (e.g., Kevin Mitnick)
    - e.g., passwd security, “intelligence” of users, etc.

Special Tips when choosing supplier

- *Who* should do the penetration testing?
  - do they have the necessary background?
    - technical sophistication, good knowledge of the field, literature, certification, etc.?
  - does the supplier employ ex-"hackers"?
  - beware of "consultants" (let's be a little critical and provocative ;-))
    - *Junior* = Person who has just started and who doesn't necessarily know your domain better then you do ;-)
    - *Senior* = Person who manages, can present well, but has little technical knowledge ;-)

Special Tips when choosing supplier

- *Who* should *NOT* do penetration testing?
  - anyone who was not explicitly asked to do it
  - never pen-test a foreign/unknown system
    - you will (probably) be logged
    - illegal activity
    - laws might be different (stricter) in other countries (i.e. where is the server/system you are targeting located?)
    - you might be held responsible for any damage you cause on a system (e.g. SQL injection "`'or drop table foobar--`", DoS)

- Some students were inspired by the command- and SQL-injection lectures
  - thanks for the funny links & screenshots we received
    - e.g. derstandard.at – respect!
  - BUT: we want to encourage you to learn about security and writing secure code.... We don't want you to attend this course to end up in jail ;-)

Conclusion

- Testing
  - important part of regular software life-cycle
  - but also important to ensure a certain security standard
- Important at design *and* implementation level
  - design: attack graphs, formal methods, manual reviews
  - implementation: static and dynamic techniques
- Static techniques
  - code review, syntax checks, model checking, meta-compilation
- Dynamic techniques
  - system call and library function interposition, profiling

Outlook

- Next week, we'll take a look at some basic cryptography
  - no high-level, complicated math
  - just the basics
  - *DOs* and *DON'Ts*

- Learn from crypto-pitfalls in the past

- Possible attack scenarios on selected methods
  - basis for *challenge 5*