Failure is not an option*

A journey through software bugs

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AIRBUS GROUP

Outline

1. Bugs!
2. Avoiding and Finding bugs
3. Bugs still happen
4. Why do bugs still happen ?!
5. Living with bugs

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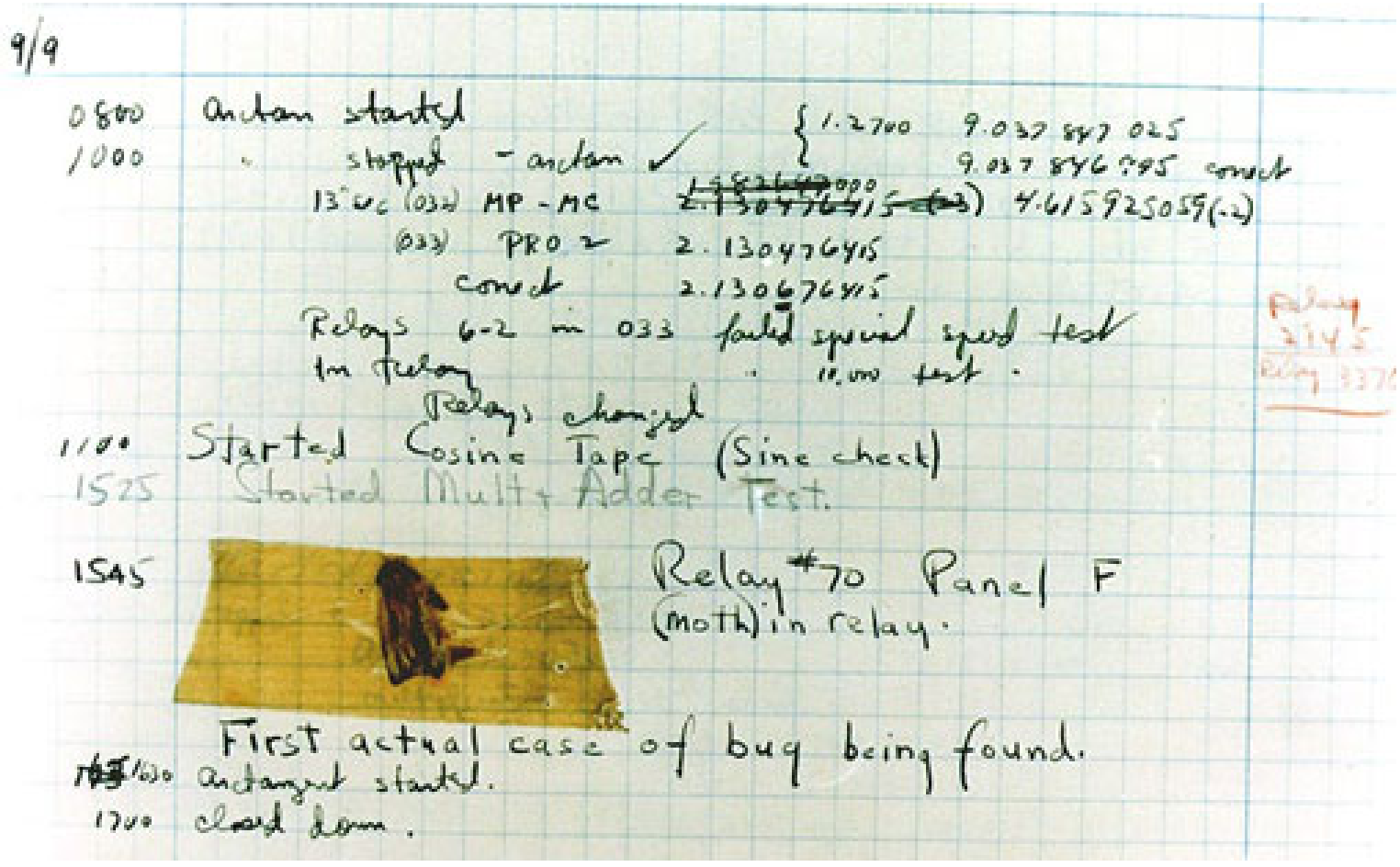
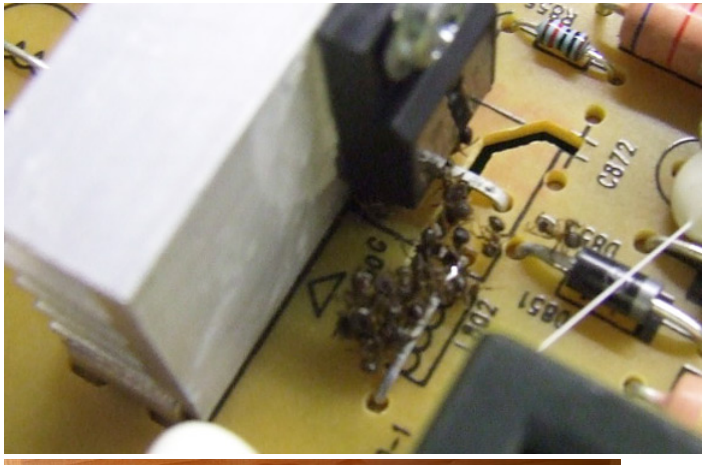
The ancestor of all bugs

Moth in relay



Still nowadays[1]



[1] http://www.theregister.co.uk/2010/11/26/ventblockers_2/

Valve's Steam on Linux[2]

Steam can clean your home and more

```
STEAMROOT="$(cd "${0%/*}" && echo $PWD)"

# Scary!
rm -rf "$STEAMROOT/"*
```

[2] https://github.com/valvesoftware/steam-for-linux/issues/3671

Haunted doors[3]

- Office doors are keycard-protected
- Doors were slow to open : 5 to 30s, sometimes more
- Everyone had his ninja techniques that seemed to open them faster :
  - swipe card slowly
  - swipe card quickly
  - swipe once and wait
  - swipe furiously over and over until door unlocks
  - stand on one foot
  - etc.

[3] http://thedailywtf.com/articles/The-Haunted-Door

Haunted doors

- One day, an employee stayed late and alone in the office
- He heard clicks from doors being unlocked
- Eventually found the authentication server
- It turns out that:
  - log file was very big
  - it took a long time to open it and append a new line
  - all the card swipes were correctly queued
  - the software was still working on card swipes from the day before
  - problem was made even worse by people swiping multiple times

$\Longrightarrow$ door unlockings were not 30s long but $\approx$ **30h** long

$\Longrightarrow$ 30s was the time you had to wait for any door to open ; no need to swipe any card

Bad guys have bugs too

- Linux.Encoder.1 ransomware design flaw[4]
  - derives AES key and IV from libc `rand()`
  - seeded with current system timestamp

  $\Longrightarrow$ recover key from file's creation time

  $\Longrightarrow$ no need to pay the ransom!
- Power Worm ransomware variant[5]
  - author wanted to simplify his task: same AES key for all victims
  - ransomware encrypted files and did not store the key
  - programming error made the key actually random

  $\Longrightarrow$ no way to recover the files

---

[4] `http://labs.bitdefender.com/2015/11/linux-ransomware-debut-fails-on-predictable-encryption-key/`

[5] `http://news.softpedia.com/news/epic-fail-power-worm-ransomware-accidentally-destroys-victim-s-data-during-encryption-495.shtml`

RC4 implementation error

A bad implementation

```
int main(int argc, char *argv[]) {
        unsigned char S[256], c;
        unsigned char key[] = KEY;
        int klen = strlen(key);
        int i,j,k;
        /* Init S[] */
        for(i=0; i<256; i++)
                S[i] = i;
        /* Scramble S[] with the key */
        j = 0;
        for(i=0; i<256; i++) {
                j = (j+S[i]+key[i%klen]) % 256;
                S[i] ^= S[j];
                S[j] ^= S[i];
                S[i] ^= S[j];
        }
        /* Generate the keystream and cipher the input stream */
        i = j = 0;
        while (read(0, &c, 1) > 0) {
                i = (i+1) % 256;
                j = (j+S[i]) % 256;
                S[i] ^= S[j];
                S[j] ^= S[i];
                S[i] ^= S[j];
                c ^= S[(S[i]+S[j]) % 256];
                write(1, &c, 1);
        }
}
```

RC4 implementation error

A good implementation

```
int main(int argc, char *argv[]) {
        unsigned char S[256], c;
        unsigned char key[] = KEY;
        int klen = strlen(key);
        int i,j,k;
        /* Init S[] */
        for(i=0; i<256; i++)
                S[i] = i;
        /* Scramble S[] with the key */
        j = 0;
        for(i=0; i<256; i++) {
                j = (j+S[i]+key[i%klen]) % 256;
                k = S[i];
                S[i] = S[j];
                S[j] = k;
        }
        /* Generate the keystream and cipher the input stream */
        i = j = 0;
        while (read(0, &c, 1) > 0) {
                i = (i+1) % 256;
                j = (j+S[i]) % 256;
                k = S[i];
                S[i] = S[j];
                S[j] = k;
                c ^= S[(S[i]+S[j]) % 256];
                write(1, &c, 1);
        }
}
```

RC4 implementation error

Exchanging values

Classical way (using temporary variable)

```
tmp = a
a = b
b = tmp
```

To show-off

```
a = a+b
b = a-b
a = a-b
```

```
a += b
b = a-b
a -= b
```

```
a = a^b
b = a^b
a = a^b
```

```
a ^= b
b ^= a
a ^= b
```

RC4 implementation error

The bug

The working idiom

```
a = a^b
b = a^b
a = a^b
```

The buggy adaptation

```
S[i] = S[i]^S[j]
S[j] = S[i]^S[j]
S[i] = S[i]^S[j]
```

RC4 implementation error

The bug

- When i=j, we have

```
S[i] = S[i]^S[i]
S[i] = S[i]^S[i]
S[i] = S[i]^S[i]
```

- i.e. actually

```
a = a^a
a = a^a
a = a^a
```

- $\Longrightarrow$ instead of exchanging a value with itself, we set it to 0
- $\Longrightarrow$ the RC4 state fills up with 0
- $\Longrightarrow$ the bitstream quickly degrades to a sequence of 0
- $\Longrightarrow$ encryption does not happen anymore

Beyond the code

Double-checked locking pattern does not work[6]

Single threaded version of a singleton instantiation

```
1  class Foo {
2    private Helper helper = null;
3    public Helper getHelper() {
4      if (helper == null)
5          helper = new Helper();
6      return helper;
7      }
8    // other functions and members...
9    }
```

[6] http://www.cs.umd.edu/~pugh/java/memoryModel/DoubleCheckedLocking.html

Beyond the code

Double-checked locking pattern does not work

Multithreaded version of a singleton instantiation

```
1  class Foo {
2    private Helper helper = null;
3    public synchronized Helper getHelper() {
4      if (helper == null)
5          helper = new Helper();
6      return helper;
7      }
8    // other functions and members...
9    }
```

Beyond the code

Double-checked locking pattern does not work

Multithreaded version of a singleton instantiation using the double-checked locking pattern.
Most calls to `getHelper()` will not be synchronized (better performance).

```
1   class Foo {
2   private Helper helper = null;
3   public Helper getHelper() {
4     if (helper == null)
5       synchronized(this) {
6         if (helper == null)
7           helper = new Helper();
8       }
9     return helper;
10    }
11  // other functions and members...
12  }
```

Beyond the code

Double-checked locking pattern does not work

Actual code that can be executed (after JIT)

```
1   call   01F6B210                    ; allocate space for Helper,
2                                      ; return result in eax
3   mov    dword ptr [ebp],eax         ; EBP is "helper" field. Store
4                                      ; the unconstructed object here.
5   mov    ecx,dword ptr [eax]         ; dereference the handle to
6                                      ; get the raw pointer
7   mov    dword ptr [ecx],100h        ; Next 4 lines are
8   mov    dword ptr [ecx+4],200h      ; Helper's inlined constructor
9   mov    dword ptr [ecx+8],400h
10  mov    dword ptr [ecx+0Ch],0F84030h
```

Beyond the code

Compiler optimizations may “optimize” security checks [7,8]

Example with overflow check:

```
unsigned int len;
...
if (ptr + len < ptr || ptr + len > max) return EINVAL;
```

- For the compiler, `ptr + len < ptr` can mean `len < 0`
- this is impossible (`len` is unsigned).

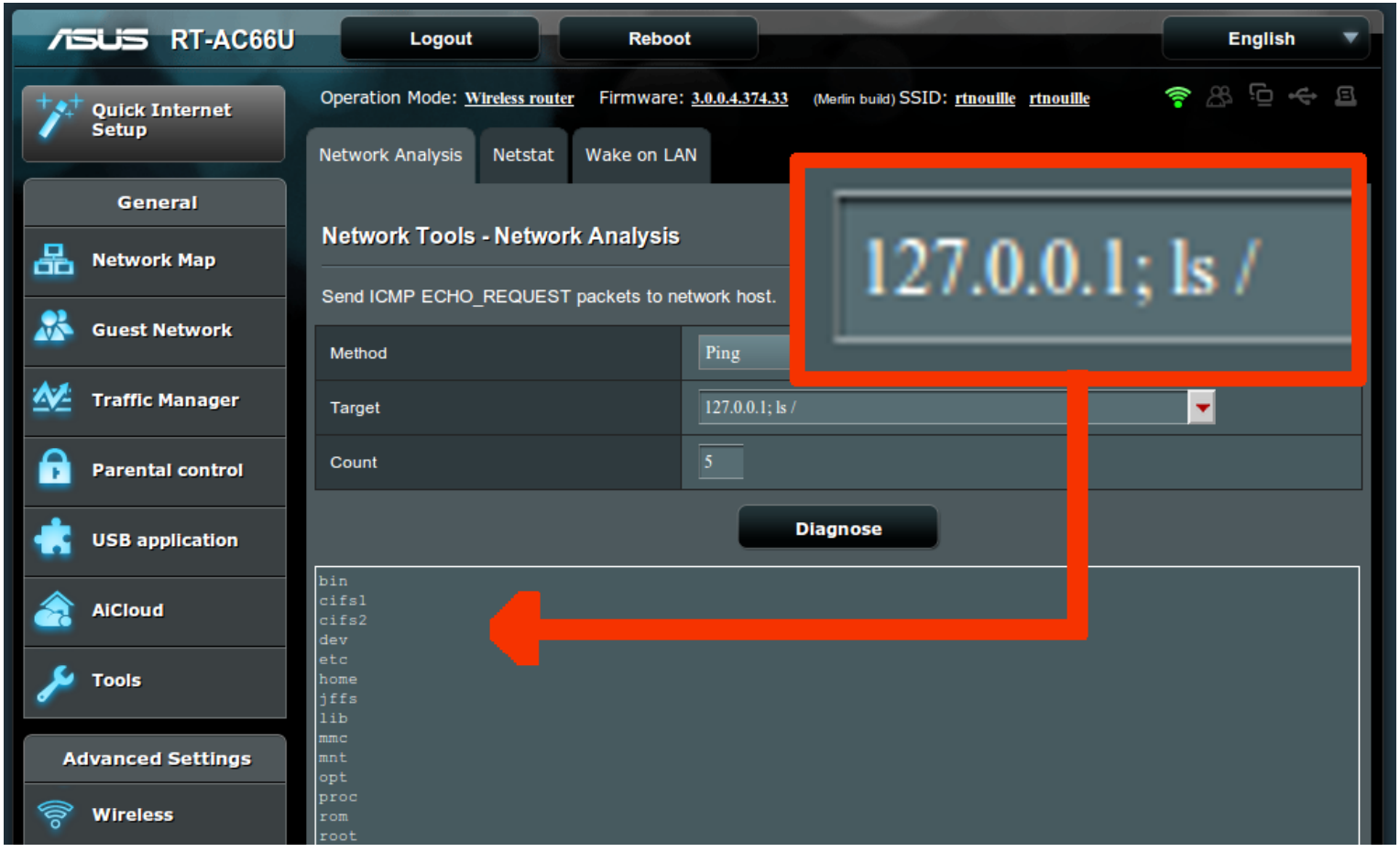
$\Longrightarrow$ the overflow check can be optimized out

- Could be rewritten `len > max-ptr`

[7] `http://www.kb.cert.org/vuls/id/162289`
[8] `http://bsidespgh.com/2014/media/speakercontent/DangerousOptimizationsBSides.pdf`

Good old injection

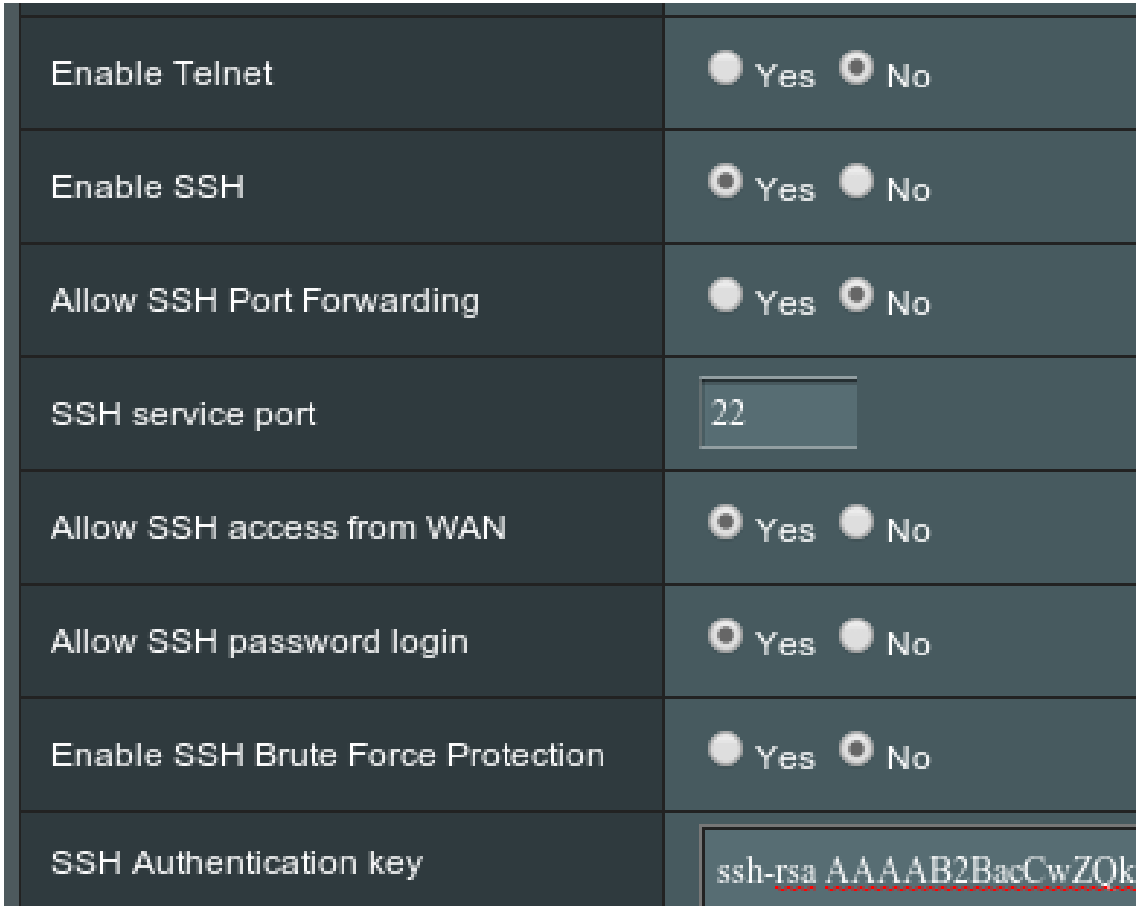
W00t! I just rooted my router!



Good old injection

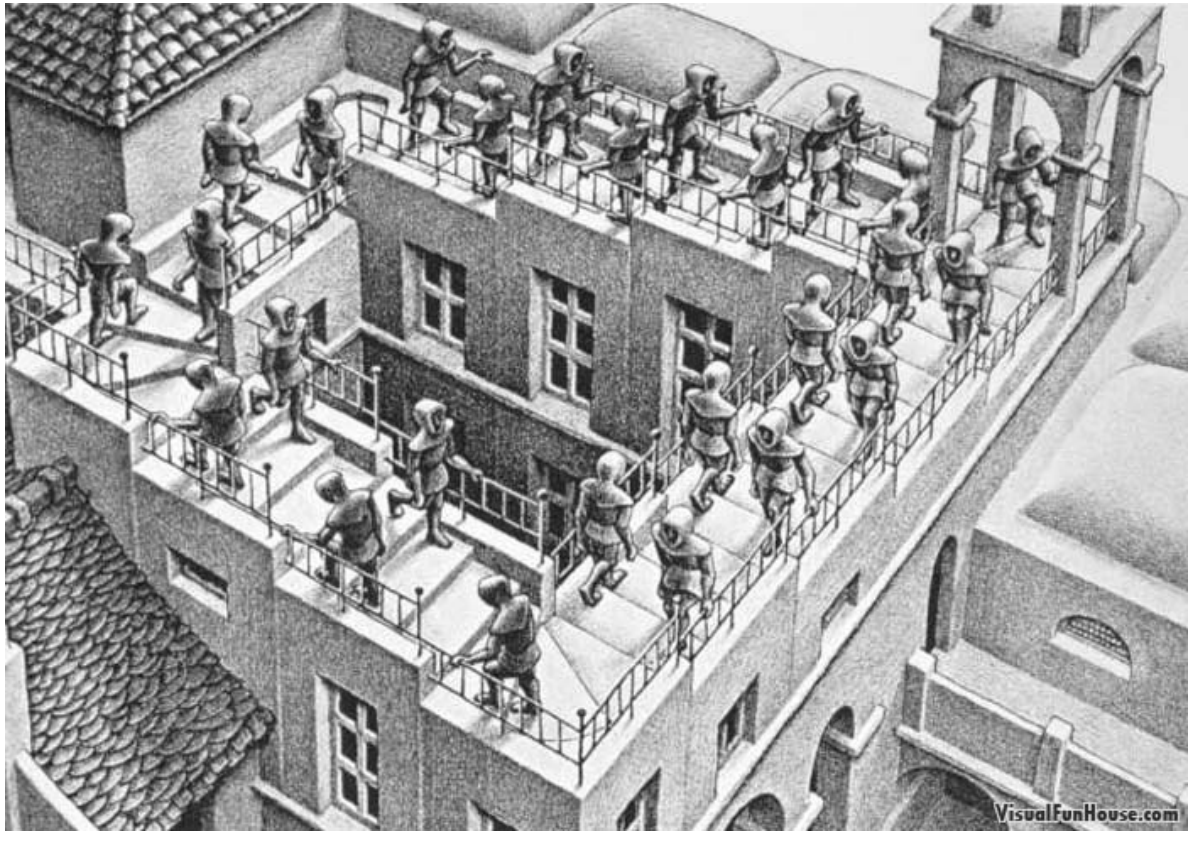
On another tab, not so far away

Oh! Actually I was already root.



Good old injection

Escalate privileges to ... where you already are



Whois stack buffer overflow (CVE-2003-0709)

The bug and the fix

The textbook case of buffer overflows

```
$ whois -g $(perl -e "print 'A'x2000")
Segmentation fault
```

```
- sprintf(p--, "-%c %s ", ch, optarg);
+ snprintf(p--, sizeof(fstring), "-%c %s ", ch, optarg);
```

Whois stack buffer overflow (CVE-2003-0709)

Impact

- non-privileged program ; not SUID

$\Longrightarrow$ escalate your privileges to ... where you already are ?

- what about all the websites proposing a whois service that actually ran whois through a CGI ?

$\Longrightarrow$ **escalate your privileges from anonymous web client to local shell**

Shellshock

Hard to analyze impact

- Bug: bash allows attackers to execute commands through specially crafted environment variables
- Impact: web servers using CGI scripts
- Impact: OpenSSH: users can bypass ForceCommand with `SSH_ORIGINAL_COMMAND`
- Impact: DHCP clients: some call bash scripts and transmit DHCP server parameters through environment variables
- ...

Debian/OpenSSL crypto-disaster

Very hard to analyze impact

- Bug: entropy for key generation limited to 15 bits
- Impact: SSL/TLS and X509 certificates
- Impact: ssh host and user keys
- Impact: Tor relays
- Impact: DH sessions keys can be recovered: PFS is broken. Impact is in the past!
- Impact: strong DSA keys can be recovered when used with a bad RNG! Impact is contagious!
- ...

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3 Bugs still happen

4 Why do bugs still happen ?!

5 Living with bugs

Best practices

- Software Configuration Management / Version Control
- Bug tracker
- Coding style

Software engineering

- Software architect
- Requirements
- V-Cycle, Agile methods, . . .
- Procedures

Assurance levels

- MISRA software guidelines
- ISO 26262
- DO-178b
- ...

Formal methods

- Model checking
- Abstract interpretation
- Theorem provers

Audits and tests

- Test campaigns
- Automatic tests (Find calls to dangerous functions like `system()`, `strcpy()`, `...`)
- Fuzzing

Certifications

- Common Criteria
- DO-178C (Software considerations in airborne systems and equipment certification)
- ...

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USS Yorktown

- 1996: used as a Smart Ship program test bed: 27 dual 200 MHz Pentium Pro
- 1997: crew member enters a zero into a database field

$\Longrightarrow$ division by zero

$\Longrightarrow$ crashes all computers

$\Longrightarrow$ propulsion system fails

$\Longrightarrow$ ship is dead in the water for 3h

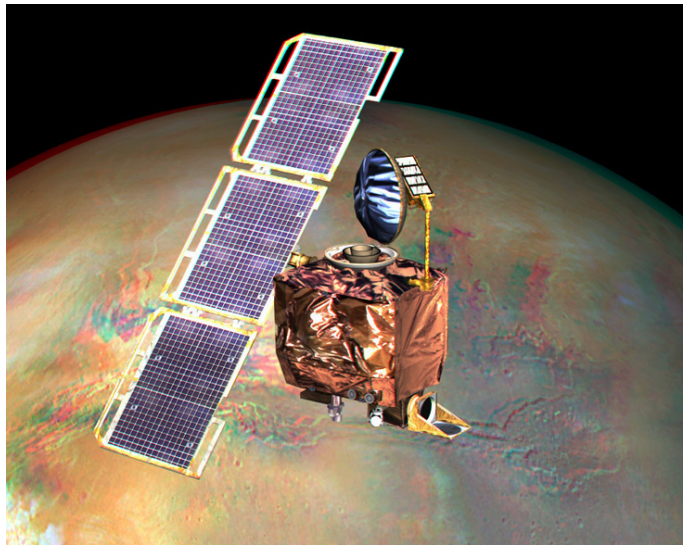
F22 raptor[9]

- First flight from Hawaii to Japan
- All system crashed when crossing latitude 180°
- Had to follow their tankers to go back home

[9] http://www.theregister.co.uk/2007/02/28/f22s_working_again/

Mars climate orbiter[10]

- one team used English units (inches, feet, etc.)
- another used metric units
- no need to say more



[10] http://www.jpl.nasa.gov/news/releases/99/mcoloss1.html

Patriot Missile[11]

- Time tracked by 0.1 increments
- 0.1 has no exact representation as a binary floating point
- Time tracking slowly drifted
- 0.3s drift in 100h
- 0.3s drift equals 600m at missile speed equals it can't follow its target
- workaround: reboot the system regularly

[11] https://en.wikipedia.org/wiki/MIM-104_Patriot#Failure_at_Dhahran

787 Dreamliner[13]

A Model 787 airplane that has been powered continuously for 248 days[12] can lose all alternating current electrical power due to the generator control units simultaneously going into failsafe mode,

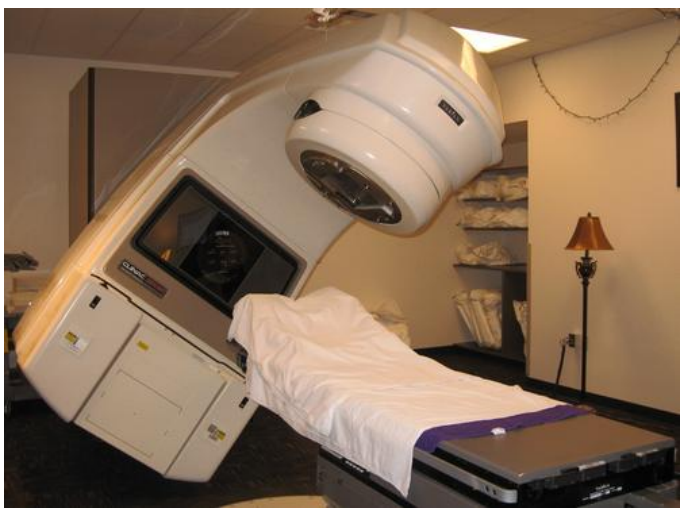
- 248 days $= 2^{31}$ 100^{th} of a second
- coincidence ?

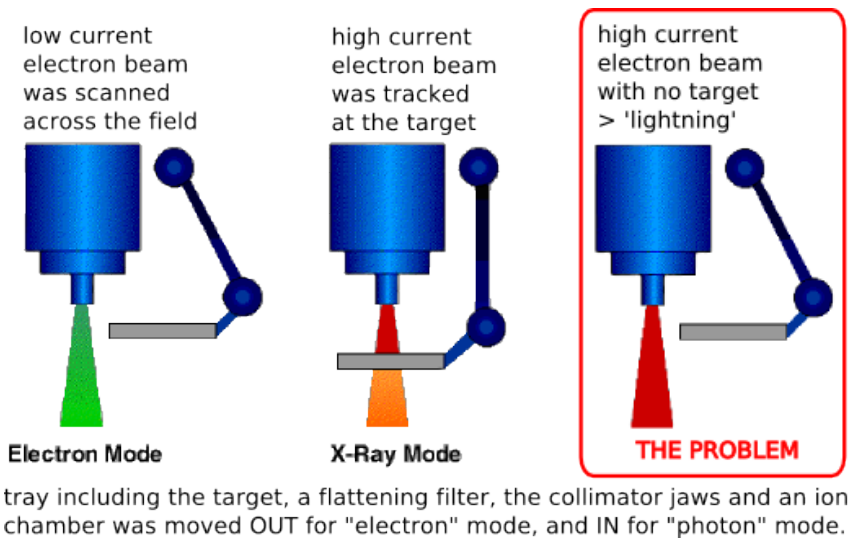
[12] this should not happen in normal operational conditions

[13] `http://www.engadget.com/2015/05/01/boeing-787-dreamliner-software-bug/`

Therac 25[14,15]

- Radiotherapy machine used in 80's
- VT-100 terminal connected to PDP-11 computer driving the device
- Two modes:
  - Direct low energy electron beam
  - X-Ray created from high energy electron beam hitting a target





tray including the target, a flattening filter, the collimator jaws and an ion chamber was moved OUT for "electron" mode, and IN for "photon" mode.

[14] https://en.wikipedia.org/wiki/Therac-25

[15] http://web.mit.edu/6.033/www/papers/therac.pdf

Therac 25

How this was possible

Big engineering failure

- no hardware interlocks to prevent high energy mode without target (previous models had it)
- open-loop controller: the software could not check the device was working correctly
- a flag was set and reset by incrementing and decrementing it. Sometimes overflow occurred.
- when hitting X (X-Ray), ↑ then E (change X-Ray to Electron beam), then ↵ then B (beam on) in less than 8s
- system displayed `MALFUNCTION 54` ; no explanation in the manual ; operator press P to proceed anyway
- vendor always denied that overdose could be possible

Toyota Unintended Acceleration[17]

- Some critical variables are not protected from corruption
- No hardware protection against bit flips
- Buffer Overflow, Invalid Pointer Dereference and Arithmetic, Race Conditions, Unsafe Casting, Stack Overflow (bug bingo!)
- Cyclomatic Complexity[16] over 50 (untestable) for 67 functions. Over 100 for the throttle angle function.
- Used Recursion (dangerous with fixed size stack) ; failed the worst-case stack depth analysis
- Watchdog only monitored 1 task out of 24
- and too many more to fit here!

[16] measure of the complexity of the control flow graph
[17] `http://www.sddt.com/files/BARR-SLIDES.pdf`

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Best practices

- best practices are not followed
- tools are not used

Formal methods

Formal methods did not prevent them because

- They were invented after most of those event happen precisely to prevent them from happening again
- They were not used (time/money constraints, incompetence)
- They cannot be applied yet to most our non-critical software (Openssl, Javascript code, . . .)
- They only find what they have been made to look for

Complexity

- system are more and more complex
- we are not smarter!

Human condition

- tiredness, mood, hangover, . . .
- working memory is volatile
  - lasts at most 20s
  - stands no interruption
- working memory can hold only 7 ± 2 things

High cognitive load

Low cognitive load

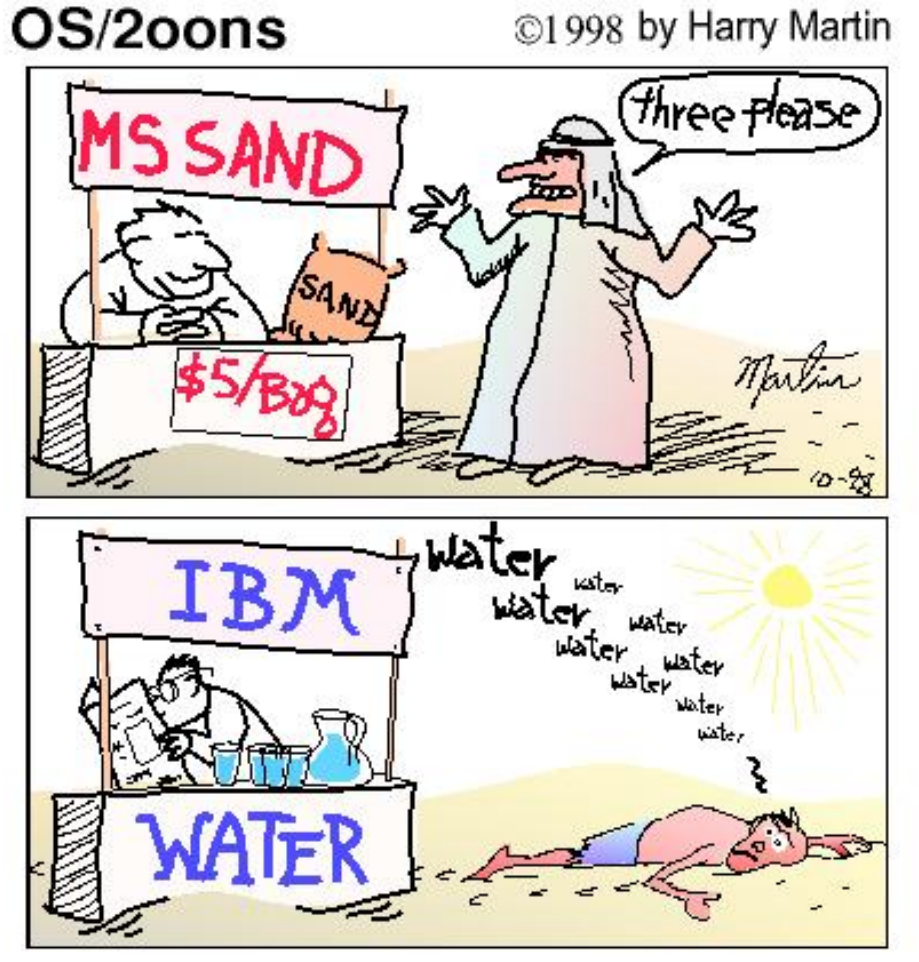
Low cognitive load too

Communication issues

- same units ?
- ambiguous API ?

Natural selection vs Marketing

Illustrated by Windows winning over OS2



Marketing mysteries of the Universe.

End Users

They make mistakes. They are unpredictable.

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Keep it simple

KISS: Keep It Simple, Stupid.

Hardening, Compartmentalization

- Least privilege
- Privilege separation
- SE Linux, App Armor
- PaX, GrSecurity
- Sandboxes

Giant bags of mostly water

Very interesting parallel with car safety[19,20]

In the 60's:

- whistle blowers:

  "Vehicle interiors are so poorly constructed from a safety standpoint that it is surprising that anyone escapes from an automobile accident without serious injury."

  – Journal of the American Medical Association, 1955

  Unsafe at any speed[18]

- engineers:
  - Cars are safe – they do not explode, catch fire, ...
  - Accidents are due to bad drivers
  - Educating drivers will solve the problem

Sounds familiar ?

[18] https://en.wikipedia.org/wiki/Unsafe_at_Any_Speed
[19] http://kernsec.org/files/lss2015/giant-bags-of-mostly-water.pdf
[20] https://www.youtube.com/watch?v=C_r5UJrxcck

Giant bags of mostly water

Nowadays cars

Mindset changed:

- 3 point seat belts ; pre-tensioners
- airbags everywhere
- ABS
- Electronic Stability Control
- Head Injury Protection
- life module
- collision sensors
- independent mandatory crash tests and public rating
- . . .

Shame

- Having lice was synonym of poverty and bad hygiene

$\Longrightarrow$ people were ashamed to have them

$\Longrightarrow$ did not tell anyone

$\Longrightarrow$ other children could be infested without noticing (only eggs for instance)

$\Longrightarrow$ infestation would come back over and over

- Mindset has changed
- When one child has some, all the classroom is informed

$\Longrightarrow$ children are checked and cleaned during the same time period.

Sounds familiar ?

ICFP'99 programming contest: Optimizing non-player characters

http://www.cs.tufts.edu/~nr/icfp/problem.html

```
((0 1 2 3 4 9 20 (IF (AND (EQUALS (VAR "where") 1) (EQUALS (VAR "v
         (EQUALS (VAR "state") 0)) (DECISION 0
              "^A parrot perches on a branch high up in the elm tr
    ((ELSEIF (AND (EQUALS (VAR "verb") 0) (EQUALS (VAR "state") 0)
              (DECISION 0
                        "^A parrot sits half-hidden among the bran
     (ELSEIF (AND (EQUALS (VAR "verb") 6) (EQUALS (VAR "state") 1)
              (DECISION 3
                        "Your throw goes wild, and you barely brus
      (ELSEIF (AND (EQUALS (VAR "state") 1)) (DECISION _ ""))
      (ELSEIF (AND (EQUALS (VAR "verb") 10) (EQUALS (VAR "state")
              (DECISION _ "The parrot takes no notice of you."))
      (ELSEIF (AND (EQUALS (VAR "verb") 10) (EQUALS (VAR "state")
              (DECISION _ "The parrot takes no notice of you."))
      (ELSEIF (AND (EQUALS (VAR "verb") 10) (EQUALS (VAR "state")
              (DECISION _ "The parrot takes no notice of you."))
[...]
```

ICFP programming contest: Optimizing characters

- Character files are compiled into a program
- Grammar, semantics, time and size of each instruction are given
- You must create a program that optimize a character file in size and time
- Your program must run in less than 30 minutes
- You have 72h to write your program

ICFP programming contest: Optimizing characters

- Complex problem
- Limited time

$\Longrightarrow$ There will be ~~blood~~ bugs!

ICFP programming contest: Optimizing characters

- The input is a valid output
- Better give a non-optimized valid answer than a wrong answer or no answer at all
- Easy to compare an answer with the input by evaluating it on several points

Winning team solution[21]

- Used a supervisor
- Initialize a variable with the input
- Run several optimizers
- Each time an answer is proposed, it is tested
- if correct and better than the current answer, replace it
- at 29m30s, output the current best answer

[21] `http://caml.inria.fr/pub/old_caml_site/icfp99-contest/`

The Chaos Monkey[22,23]

- In the cloud, resilient architectures should handle the crash of a machine
- The Chaos Monkey runs in the Amazon Web Services (AWS)
- It randomly terminate instances (during working hours)

the best defense against major unexpected failures is to fail often

Netflix

[22] `http://techblog.netflix.com/2012/07/chaos-monkey-released-into-wild.html`
[23] `https://github.com/Netflix/SimianArmy`

Conclusion

- Defense in depth
- Everything can fail
- Make things that can work in degraded mode
- Use supervisors, watchdogs
- Think one move ahead

Conclusion

Failure is not an option*

*option: something that you can avoid