EMBEDDED SOFTWARE SECURITY, SAFETY & QUALITY

Why it matters. What to do about it.

18-642 Overview
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EDGE CASE RESEARCH

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One Software Mistake Is All It Takes

Bad software can tarnish the brand...or kill the company

Knight Capital Says Trading Glitch Cost It $440 Million
By NATHANIEL POPPER  AUGUST 2, 2012 9:07 AM  356 Comments

Runaway Trades Spread Turmoil Across Wall St.

Errant trades from the Knight Capital Group began hitting the New York Stock Exchange almost as soon as the opening bell rang on Wednesday, Brendan McDermid/Reuters

The Knight Capital Group announced on Thursday that it lost $440 million when it sold all the stocks it accidentally bought Wednesday morning because a computer glitch.

Will “Diesel-Gate” Kill VW?

The scandal cost Martin Winterkorn his position as chief executive of VW
Photo: AP/Richard Drew

https://goo.gl/7dHOjO

https://goo.gl/T96ezC
Overview

- **Software quality problems are pervasive**
  - Are you going to wait until you’re on CNN to do something about it?

- **Your company lives or dies by its software quality**
  - Software is a core competency … … whether you like it or not
  - Embedded software requires unique skills & technical approaches

- **More product-level testing won’t make this problem go away**
  - Need good practices, development process, development skills

- **Get serious about software quality**
  - Daily practices, process support, training, metrics

Chrysler is recalling 1.4 million vehicles that can be remotely hacked over the Internet.
Embedded Software Is Challenging

- **Customers expect “perfect” embedded SW**
  - Everyday desktop quality software isn’t good enough
  - Bugs can lead to class action lawsuits
  - Upgrades can be painful to deploy

- **Significant technical challenges**
  - Limited hardware resources
  - Real-time operation
  - Interaction with system-specific sensors and actuators

- **Most embedded software is Mission Critical**
  - **Safety**: someone gets killed or injured
  - **Mission Critical**: failure results in unacceptable loss (money, business,...)

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**MyFord Touch problems: Ford to issue upgrade**

Glitches in MyFord Touch software that replaces knobs and buttons with a touchscreen have led to plummeting user approval ratings for Ford cars.

Charles Arthur and agencies  
Monday 7 November 2011 03:51 EST

The motor company Ford has discovered belatedly that touchscreens don’t make a great replacement for the knobs and buttons of a dashboard - especially if the touchscreens are plagued with software glitches.

The company says it will send memory sticks to 250,000 customers in the US offering a software upgrade for its glitch-prone MyFord Touch system, which replaces the standard dashboard knobs and buttons with a touchscreen.
Some Code Is Pervasively Bad

TOYOTA’S SPAGHETTI CODE

3. Software assembly for power train ECU
After the 4th Steering Committee, rebuilding of engine control and actions for software assembly were started.

(1) Achievements

① Identification of current issues with software assembly ..... Ongoing
  • There are C sources for which there is no specification document. (e.g., communication related)
  • Specification document and C source do not correspond one-to-one. (e.g., cruise, communication related)
② Activities to improve the spaghetti-like status of engine control application were started.
  (Control structure reform has already started in Engine Div. In coordination with this, software structure reform will be carried out. As a first step, it has been decided to transfer two employees from Engine Div. and carry out trial with purge control.)

Because structure design is not being implemented, a “spaghetti” state arises, both TMC and suppliers struggle to confirm overall situation.

Without care, systems can quickly get too big and complex, and like dinosaurs, will eventually go extinct.

TOYOTA’S SPAGHETTI CODE

Toyota’s killer firmware: Bad design and its consequences

Michael Dunn - October 28, 2013
On Thursday October 24, 2013, an Oklahoma court ruled against Toyota in a case of unintended acceleration that lead to the death of one the occupants. Central to the trial was the Engine Control Module’s (ECM) firmware.

• Toyota’s electronic throttle control system (ETCS) source code is of unreasonable quality.
• Toyota’s source code is defective and contains bugs, including bugs that can cause unintended acceleration (UA).
• Code-quality metrics predict presence of additional bugs.
• Toyota’s fail safes are defective and inadequate (referring to them as a “house of cards” safety architecture).
• Misbehaviors of Toyota’s ETCS are a cause of UA.

Toyota Says It's Settled 338 Cases So Far In Acceleration MDL

By Aebra Coe

Law360, New York (July 22, 2015, 11:37 AM ET) -- Attorneys on both sides of multidistrict litigation over deaths and injuries caused by alleged unintended acceleration in Toyota Motor Corp. vehicles told a California federal judge on Tuesday that the settlement process continues to hum along, with deals reached in 338 cases, up from 289 in March.
This is the bad line of code for Heartbleed:

```c
memcpy(bp, pl, payload);
```

- Classic buffer overflow vulnerability
  - Copies “payload” bytes from `pl` to `bp`
  - Reads other user’s data, including secret keys, if payload value is too big

How Heartbleed Works: The Code Behind the Internet's Security Nightmare

By now you've surely heard of Heartbleed, the hole in the internet’s security that exposed countless encrypted transactions to any attacker who knew how to abuse it. But how did it actually work? Once you break it down, it's actually incredibly simple. And a little hilarious. But mostly terrifying.
Large Scale Production = Big Problems

Nest Learning Thermostats in the UK fail to spring forward to British Summer Time

By James Billington
January 14, 2016 14:27 GMT

thermostat bug plunges customers into cold

https://goo.gl/Rpv9V6

Honda, Yes Honda, Recalls 175,000 Cars For Unintended Acceleration

Bloomberg reports that all new hybrid Honda Fit subcompact and Vezel small crossover models sold in Japan since last will be recalled due to a software problem with the engine control system. They did not elaborate, but said the problem could lead to unintended acceleration.

https://goo.gl/Hrr7ci
There Are Too Many Examples

- A steady stream of software mishaps, recalls, etc.

Airbus confirms software configuration error caused plane crash
Airbus A400M flight recorder data confirms "quality issue" in setup caused failure.

Hackers remotely kill a Jeep on the highway—with me in it

Miller attempts to rescue the Jeep after its brakes were remotely disabled, sending it into a ditch. © ANDY GREENBERG/WIRED

https://goo.gl/o2FuqZ

https://goo.gl/4hbom9

https://goo.gl/l2RWUv
HACKER CAN SEND FATAL DOSE TO HOSPITAL DRUG PUMPS

Hospira's drug infusion pumps include a serial cable (the wide grayish-white cable with the single red stripe on one edge) that connects the communications module to the main pump board. Because the libraries don’t require authentication, Rios found that anyone on the hospital’s network—including patients in the hospital or a hacker accessing the pumps over the Internet—can load a new drug library that alters the limits for a drug.

https://goo.gl/l6QLEK

Crypto weakness in smart LED lightbulbs exposes Wi-Fi passwords

More evidence the Internet of things treats security as an afterthought.

In the latest cautionary tale involving the so-called Internet of things, white-hat hackers have devised an attack against network-connected lightbulbs that exposes Wi-Fi passwords to anyone in proximity to one of the LED devices.

The attack works against LIFX smart lightbulbs, which can be turned on and off and adjusted using iOS- and Android-based devices.

https://goo.gl/tHGIA0
Act As If Your Products Live Or Die By Their Software

- **Software**: 0% of BOM cost, 90% of product differentiation
- **Electronic Controller**: 10% of BOM cost, Mostly commodity
- **Mechanical System**: 90% of BOM cost, Mostly commodity

BOM = Bill Of Materials
Testing bad software simply makes it less bad
- Testing cannot produce good software all on its own

One third of faults take more than 5000 years to manifest
Adams, N.E., "Optimizing preventive service of software product," IBM Journal of Research and Development, 28(1), p. 2-14, 1984. (Table 2, pg. 9, 60 kmonth column)
- Your customers will regularly experience bugs that you will not see during testing
- For most products, you can’t even test 5000 years
For YOUR product, what is the worst possible outcome:

- For a software bug?
  - People killed or injured?
  - Property damage?
  - Cost to deploy a fix?
  - Loss of brand reputation?

- For a malicious attack?

- Hint: *The answer is the same* for both bugs and successful attacks

**Regulation is likely to increase**

- IEC 60730 safety standard required for European appliances
- Security standards are already proliferating
Every system is assumed to be unsafe by default

- It is up to you to proactively show that it is safe
  
  » Example: DEF STAN 00-55 Parts 1 & 2

1. Collect risks
   - What can go wrong? What does “safe” really mean?

2. Assign risk severity
   - What types of mishaps are most important to avoid?

3. Perform risk mitigation
   - How can you avoid hazards and activation of hazards?

4. Develop software to acceptable level of integrity
   - Ensure that risk mitigation is successful
## Risk Identification & Assessment

- **Create a** Hazard Log (list of hazards), including HAZOP
- **PHA (Preliminary Hazard Analysis)** & Risk Table

- E.g. Consequence
  - $100M loss
  - $1M loss
  - ...
  - $100 loss

- E.g. Probability
  - Every minute
  - Weekly
  - ...
  - Every 10 years

<table>
<thead>
<tr>
<th>Example Risk</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very High</strong></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>Very High (4)</td>
</tr>
<tr>
<td>Medium</td>
<td>High (3)</td>
</tr>
<tr>
<td>Low</td>
<td>Medium (2)</td>
</tr>
<tr>
<td>Very Low</td>
<td>Medium (2)</td>
</tr>
<tr>
<td></td>
<td>Low (1)</td>
</tr>
<tr>
<td></td>
<td>Very Low (0)</td>
</tr>
</tbody>
</table>

- (4) .. (0) ➔ See SIL on next slide
SIL = Safety Integrity Level
- SIL4 = catastrophic
- SIL1 = minor injuries
- Used to determine required level of engineering rigor

Example: IEC 61508
- HR = Highly Recommended
- R = Recommended
- NR = Not Recommended (don’t do this)
Head Count: Half Designers, Half Testers

IEC 60730 Appliance Safety
Gold Standard: Fagan Style Inspection

- Pre-review meeting
- Formal meeting
- Written review report
- Follow-up and possible re-inspection
- The more formal the review, the higher the payoff

Good reviews find 50%+ of defects for about 10% of project cost

- Defects are found early, when they are cheaper to fix and cause less disruption
- Why is it so many designers say they don’t have time to do peer reviews?

Other technical issues are crucial for good embedded software

- Watchdog timers, mutexes, Rate Monotonic Scheduling, interrupts, exception handling, reducing code complexity, secure update, timekeeping, performance optimization, …
Attacks can affect the physical world

Attacks Against SCADA Systems Doubled in 2014: Dell
By Mike Lennon on April 13, 2015
Dell SonicWALL saw global SCADA attacks increase against its customer base from 91,676 in January 2012 to 163,228 in January 2013, and 675,186 in January 2014.

Key SCADA Attack Methods

- Improper Neutralization of Special Elements used in an OS Command (OS Command Injection): 1.65%
- Improper Neutralization of Special Elements used in an SQL Injection: 0.83%
- Improper Control of Generation of Code (Code Injection): 0.83%
- Improper Authentication: 1.32%
- Cross-Site Request Forgery: 2.48%
- Improper Restriction of Operations within the Bounds of a Memory Buffer: 3.31%
- Improper Limitation of Enumeration of Directories (Path Traversal): 11.31%
- Improper Handling of Eight-Byte Restriction (Path Traversal): 13.13%
- Improper Input Validation: 25.59%
- Information Exposure: 28.64%
- Improper Neutralization of Input During Web Page Generation (Cross-site Scripting): 36.59%
- Resource Management Errors: 37.69%
- Credentials Management: 45.77%
- Permissions, Privileges, and Access Controls: 48.36%
- Cryptographic Issues: 5.79%
- Improper Preparation of Data for External Transfer: 5.79%
- Improper Access Control: 6.47%
- Improper Input Verification: 6.74%
- Improper Resource Management: 7.44%
- Improper Authorization: 7.77%
- Improper Use of System Call: 8.26%
- Improper No-Data-Flow Policy Enforcement: 9.09%
- Improper Handling of Eight-Byte Restriction (Path Traversal): 13.13%

Source: 2015 Dell Annual Security Report

26% Buffer Overflow or Similar
6% Crypto Issues

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Industrial Controls Are Targets

The Bad Guys are after more than credit card numbers

A hydroelectric plant

French electric companies apparently like to put their hydroelectric plants online. Tentler found three of them using Shodan.

This one has a big fat button that lets you shut off a turbine. But what’s 58,700 Watts between friends, right? It’s not just France that has a problem. The U.S. Department of Homeland Security commissioned researchers last year to see if they could find industrial control systems for nuclear power plants using Shodan. They found several.

Tentler told DHS about all the power plants he found -- actually, DHS called him after he accessed one of their control systems.

“a big fat button lets you shut off a turbine”

(No login credentials required)
Security testing isn’t enough
- Bad code is especially vulnerable
- Testing mostly finds known problems

Need to address:
- Security requirements
- Characterize threats & risks
- Security risk management plan
- Deploying security patches

Myriad technical issues
- Secure update, cryptography, input validation, least privilege, code quality, passwords, privacy, web interface, error handling, secure coding, …
Testing Alone Won’t Fix Bad Software

- You can’t test in quality, safety, or security

- In an ideal world, throw it away and start over
  - But, the world is not ideal ...

- Incremental Reengineering
  - Identify & fix high risk modules
  - Clean sheet for each module; don’t try to derive design from code

- Improvement Requires cultural change
  - Requires commitment to good software at all levels of organization
  - Commitment must survive a “but we have to ship next week” crisis

https://goo.gl/i7Ue6N
Top 10 Embedded SW Warning Signs

1. Software time estimates are driven by external dates
2. Process steps skipped during schedule crunches
3. Software development is simply “coding” plus “testing”
4. Poor traceability from product test to requirements
5. Bugs due to poor code style & complexity
6. Bugs in software fault detection/recovery
7. No Security Plan; no Safety Plan
8. Tester:Developer ratio too far from about 1 : 1
9. More than about 5-10% of bugs are found in product test
10. Fewer than 50% of defects are found by peer review
The Path To Good Software

CAPABLE PEOPLE
ROBUST PROCESS
BEST-PRACTICE TECHNOLOGY

+ BAKED-IN SOFTWARE QUALITY
Software Quality, Safety & Security

- Software is crucial for providing value
  - But – even a single line of bad code can kill a product (or a company)
  - Writing software is a high-stakes profession. Take it seriously.

- Good software requires process + technology + people
  - Embedded software requires unique technical approaches
  - You can’t test quality, safety, or security into software

- Good process enables good software
  - Whether “V” or agile, need to actually follow a good process
  - Typically need 1:1 head count for testers:developers
  - Peer reviews find 50%+ of defects on the cheap – why aren’t you doing them?

- Safety and security are essential – don’t wait until there is a loss event
  - Most embedded software is safety critical or mission critical
  - Security is required in essentially all embedded software
What Happens Next?

- **Assess where you are**
  - How good is your code quality?
  - How good are your software, process & technical skills?
  - How good are your safety & security practices?

- **Improve process, skills, technology**
  - Ensure you are doing effective peer reviews
  - Formalize and follow a reasonable software process
  - Adopt/adapt relevant safety & security standards
  - Ensure developers have strong embedded software & process skills

- **Cultural change**
  - Make software quality a first class company goal, not a sideline
  - Daily practices, process support, training, metrics