EMBEDDED SOFTWARE SECURITY, SAFETY & QUALITY

Why it matters. What to do about it.

18-642 Overview
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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  ▼  355 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.

https://goo.gl/7dH0jO

Will “Diesel-Gate” Kill VW?
The scandal cost Martin Winterkorn his position as chief executive of VW  Photo: AP/Richard Drew
https://goo.gl/T96ezC
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

Overview

Chrysler recalls 1.4 million hackable cars
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,...)

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.

https://goo.gl/4bS5rd
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 arose. 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 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 of 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 fall 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
Lawsuit, 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

https://goo.gl/C9775V

thermostat bug plunges customers into cold

By James Billington https://goo.gl/RPv9V6
January 14, 2016 14:27 GMT

Smart thermostat has been leaving customers cold after suffering from a software bug that drained its battery.

the guardian

Samsung keyboard bug leaves 600m Android devices exposed to hackers

Vulnerability remains months after discovery, allowing hackers to eavesdrop on calls, steal data and activate camera, microphone and GPS remotely

Samuel Gibbs
7 June 2015

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

Patrick George 7/16/14

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.
There Are Too Many Examples

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

**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/o2FvqZ

Airbus confirms software configuration error caused plane crash

Airbus A400M flight recorder data confirms "quality issue" in setup caused failure.

https://goo.gl/4hbom9

https://goo.gl/l2RWUv
This Goes Far Beyond Transportation

Hacker Can Send Fatal Dose to Hospital Drug Pumps

https://goo.gl/l6QLEK

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.
Act As If Your Products Live Or Die By Their Software

BOM = Bill Of Materials

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

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Product Testing Won’t Find All Bugs

- 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

- (4) .. (0) ➔ See SIL on next slide

### Example Risk Table

<table>
<thead>
<tr>
<th>Consequence</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>Medium (3)</td>
</tr>
<tr>
<td>Medium</td>
<td>Low (1)</td>
</tr>
<tr>
<td>Low</td>
<td>Very Low (0)</td>
</tr>
</tbody>
</table>

**Probability Levels**
- Very High (4)
- High (3)
- Medium (2)
- Low (1)
- Very Low (0)

**Consequence Levels**
- Very High
- High
- Medium
- Low
- Very Low

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**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)

### Higher SIL Invokes Engineering Rigor

<table>
<thead>
<tr>
<th>Technique/Measure*</th>
<th>Ref</th>
<th>SIL1</th>
<th>SIL2</th>
<th>SIL3</th>
<th>SIL4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Fault detection and diagnosis</td>
<td>C.3.1</td>
<td>---</td>
<td>R</td>
<td>R</td>
<td>HR</td>
</tr>
<tr>
<td>2 Error detecting and correcting codes</td>
<td>C.3.2</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>HR</td>
</tr>
<tr>
<td>3a Failure assertion programming</td>
<td>C.3.3</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>HR</td>
</tr>
<tr>
<td>3b Safety bag techniques</td>
<td>C.3.4</td>
<td>---</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>3c Diverse programming</td>
<td>C.3.5</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>HR</td>
</tr>
<tr>
<td>3d Recovery block</td>
<td>C.3.6</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>3e Backward recovery</td>
<td>C.3.7</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>3f Forward recovery</td>
<td>C.3.8</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>3g Re-try fault recovery mechanisms</td>
<td>C.3.9</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>HR</td>
</tr>
<tr>
<td>3h Memorising executed cases</td>
<td>C.3.10</td>
<td>---</td>
<td>R</td>
<td>R</td>
<td>HR</td>
</tr>
<tr>
<td>4 Graceful degradation</td>
<td>C.3.11</td>
<td>R</td>
<td>R</td>
<td>HR</td>
<td>HR</td>
</tr>
<tr>
<td>5 Artificial intelligence - fault correction</td>
<td>C.3.12</td>
<td>---</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>6 Dynamic reconfiguration</td>
<td>C.3.13</td>
<td>---</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>7a Structured methods including for example, JSD, MASCOT, SADT and Yourdon.</td>
<td>C.2.1</td>
<td>HR</td>
<td>HR</td>
<td>HR</td>
<td>HR</td>
</tr>
<tr>
<td>7b Semi-formal methods</td>
<td>Table B.7</td>
<td>R</td>
<td>R</td>
<td>HR</td>
<td>HR</td>
</tr>
<tr>
<td>7c Formal methods including for example, CCS, CSP, HOL, LOTOS, OBJ, temporal logic, VDM and Z</td>
<td>C.2.4</td>
<td>---</td>
<td>R</td>
<td>R</td>
<td>HR</td>
</tr>
<tr>
<td>8 Computer-aided specification tools</td>
<td>[IEC 61508]</td>
<td>B.2.4</td>
<td>R</td>
<td>R</td>
<td>HR</td>
</tr>
</tbody>
</table>
Head Count: Half Designers, Half Testers

IEC 60730 Appliance Safety

Figure H.1 – V-Model for the software life cycle
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, ...
Security Matters for Industrial Systems!

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) 25.59%
- Improper Neutralization of Special Elements used in an SQL Command (SQL Injection) 13.11%
- Improper Control of Generation of Code (Code Injection) 13.11%
- Improper Neutralization of Restrictied Directory (Path Traversal) 10.79%
- Improper Limitation of Pathnames on System (Path Resolution) 10.79%
- Improper Authentication 9.09%
- Improper Input Validation 9.09%
- Resource Management Errors 8.26%
- Information Exposure 7.44%
- Improper Neutralization of Input During Web Page Generation (Cross-site Scripting) 7.44%
- Permissions, Privileges, and Access Controls 9.09%
- Cryptographic Issues 6.79%
- Improper Neutralization of Value of 'Restricted Directory' Parameter (Cross-site Request Forgery) 4.28%
- Improper Neutralization of Value of 'Environment Variable' Parameter (Cross-site Request Forgery) 0.83%
- Improper Access Control 0.83%
- Code 0.83%
- Improper Authorization 0.83%

Source: 2015 Dell Annual Security Report

- **26% Buffer Overflow or Similar**
- **6% Crypto Issues**
Industrial Controls Are Targets

The Bad Guys are after more than credit card numbers

Traffic light controls

When something that literally anyone in the world can access says "DEATH MAY OCCUR!!!" it's generally a good idea to build some kind of security around it.

Oops - no. For some reason, someone thought it would be a good idea to put traffic light controls on the Internet.

Making matters way, way worse is that these controls require no login credentials whatsoever. Just type in the address, and you’ve got access.

"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
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 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