"Paradigm shift or measurement based feedback?"

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by

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Overview

❖ Introduction
❖ Evidence for repetitive failure
❖ Preventing repetitive failure
❖ Paradigm shift or measurement?
❖ Other concerns - diagnosis
A growing problem

The amount of software in consumer electronic products is currently doubling about every 18 months.

- Line-scan TVs have ~250,000 lines of C.
- There are around 200,000 lines of C in a car.
- Most consumer devices, washing-machines and so on have a few K of software.
- The Airbus A340 and Boeing 777 are totally dependent on software, (more later...).
Problems - real or imagined?

Airbus A340 G-VAEL 16/09/94, Heathrow:

- Software error calculated fuel incorrectly.
- Both screens went blank, "Please wait ...".
- Plane turned right when instructed to turn left.
- Plane descended at 9 degrees when instructed to descend at 3 degrees.

Not all of these yet believed fixed.
Problems - real or imagined?

and ships . . . :

- The ultimate high-tech USS Yorktown was left dead in the water off the coast of Virginia for an hour on a weekend in September, 1997 due to software failure.
- The ship had to be rebooted.
- (Perhaps there should be an international flag signal for "Please wait ...").
Problems - real or imagined?

Cars too...:

- 22/July/1999. General Motors has to recall 3.5 million vehicles because of a software defect. Stopping distances were extended by 15-20 metres.
- Federal investigators received almost 11,000 complaints as well reports of 2,111 crashes and 293 injuries.
- Recall costs? (An exercise for the reader).
not forgetting ...

Ariane5:-(

Paradigm v. measurement: v. 1.0, 08/Sep/1999, (slide 7)
How Ariane 5 failed ...

Actuator (steering) software actually written in Ada, but it is equivalent to the following C code:

```c
short s;
double d;
...
s = d;
```
In Ariane 5, the following sequence occurred:

- A 64-bit floating point number was forced into a 16-bit integer in a non-critical component.

- When it overflowed, the programming language (Ada) generated an exception which was allowed to shut down the system including critical components for actuator control.

- The system had twin-channel redundancy but the same software was running in each channel.

- If a sloppier language had been used, there would have been no crash.
<table>
<thead>
<tr>
<th>System</th>
<th>Defect Rate</th>
<th>% reboots</th>
</tr>
</thead>
<tbody>
<tr>
<td>W’95 + Office</td>
<td>1 every 42 minutes</td>
<td>28%</td>
</tr>
<tr>
<td>Mac OS + Office</td>
<td>1 every 188 minutes</td>
<td>56%</td>
</tr>
<tr>
<td>Unix (Software development)</td>
<td>&lt; 1 per year</td>
<td>100%</td>
</tr>
<tr>
<td>Linux (Various)</td>
<td>None experienced in 2 years</td>
<td>-</td>
</tr>
</tbody>
</table>
A few more recent vignettes ...

- **Aug. 1999**: MCI Worldcom's international frame relay network suffers major software collapse.

- **Aug. 1999**: ERNIE, (UK premium bond generator) had software defects causing thousands of genuine winners not to be paid anything.

- **Sep. 1998**: LTCM, a financial house in New York lost 44% of fund value due to defects in computer model September, 1998.

- **Jul. 1998**: Northern Examination Board, UK: The exam results of 100,000 students were affected by defects in the marking software, July 1998
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An observable fact

Software systems are unique amongst engineering systems in that their behaviour is dominated by repetitive failure. Why?
Definitions of fault and failure

Software failure is characterised by:

- **Fault**
  - Static property (identified before run-time)
  - Can be identified in either design or source code as a 'mistake'
  - Not all faults fail

- **Failure**
  - Dynamic property (identified at run-time)
  - Defined to be difference between actual and expected run-time behaviour.
  - Every failure is caused by at least one fault.
The relationship between fault and failure

All faults

Those faults which fail
How do faults lead to failure?

- **Ed Adams of IBM (1984) found that**
  - ~33% of all faults only failed < once every 5000 execution years
  - The most common failures, (> once every 5 years) were caused by only 2% of the faults.
  - Any correction had about a 15% chance of introducing a problem at least as big into the system.

- **Pfleeger and Hatton (1997) found (amongst other things)**
  - static faults and dynamic failure were highly correlated in a high reliability system.
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Control Process feedback - the essence of engineering improvement
Language standardisation disobeys control process feedback in several important ways:-

- It is characterised by unconstrained creativity
- It completely ignores measurement
- The 'must not break old code' rule means feedback is crippled so although things are continually added, nothing ever gets taken out in practice.
- It is a political as well as a technical process. Daft things get left in.

A control process engineer would conclude that languages can never get better.
Occurrence rates in F77 applications
Dependence on known fault modes in C applications.
Failure of statically detectable faults

Data derived from CAA CDIS

Average
dynamic
testing

Thorough
dynamic
testing

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- **Paradigm shift is characterised by:-**
  - Fashion /marketing focus
  - Creativity driven
  - The complete absence of measurement
  - Maximises things the engineer CAN do.

- **Control process feedback is characterised by:-**
  - Engineering focus
  - Measurement and analysis of failure
  - Ruthless elimination of known failure modes
  - Maximises things the engineer can NOT do.
Overview

❖ Three measurement-driven lessons:
  - Defect density is relatively independent of programming language
  - Defect density is almost constant with time in the last two decades
  - Independent implementations of the same algorithm in the same programming language can vary in size by factors of at least 3.
1. Defect density is relatively independent of language

**Part of a worldwide survey of defect densities:**

<table>
<thead>
<tr>
<th>Source</th>
<th>Language</th>
<th>Errors / KLOC</th>
<th>Formal methods used</th>
<th>Life-cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siemens - operating systems</td>
<td>Assemblers</td>
<td>6-15</td>
<td>No</td>
<td>Release</td>
</tr>
<tr>
<td>IPL - language parser</td>
<td>C</td>
<td>20-100</td>
<td>No</td>
<td>Dev. only</td>
</tr>
<tr>
<td>NAG - scientific libraries</td>
<td>Fortran</td>
<td>3</td>
<td>No</td>
<td>Release</td>
</tr>
<tr>
<td>Praxis - Air-traffic control</td>
<td>C</td>
<td>1.25</td>
<td>Yes</td>
<td>Release</td>
</tr>
<tr>
<td>Lloyds - language parser</td>
<td>C</td>
<td>1.4</td>
<td>Yes</td>
<td>Release</td>
</tr>
<tr>
<td>IBM cleanroom</td>
<td>Various</td>
<td>3.4</td>
<td>Part</td>
<td>Release</td>
</tr>
<tr>
<td>IBM normal</td>
<td>Various</td>
<td>30</td>
<td>No</td>
<td>Release</td>
</tr>
<tr>
<td>Loral - IBM MVS</td>
<td>Various</td>
<td>0.5*</td>
<td>Part</td>
<td>Projected</td>
</tr>
<tr>
<td>Basili &amp; Perricone (1984)</td>
<td>Fortran</td>
<td>6-16</td>
<td>No</td>
<td>Release</td>
</tr>
<tr>
<td>Compton &amp; Withrow (1990)</td>
<td>Ada</td>
<td>2-9</td>
<td>No</td>
<td>Release</td>
</tr>
</tbody>
</table>
2. Defect density is relatively constant with time
3. Independent implementations vary dramatically

- In the Knight-Leveson (1986) experiment:
  - 27 versions of the same algorithm were developed independently in Pascal
  - The smallest had around 300 lines and the largest was over 1000 lines.
  - The most reliable did not fail in 1 million trials, the least reliable failed nearly 10,000 times.
Object-Oriented and its implementation languages are a true paradigm shift characterised by:-

- Great certainty that it is 'the way to go'
- Almost no measurement
- Enormous marketing

It may well be the way to go but without measurement based feedback, we simply don't know. Here are some recent measurements:-
Relative time to fix defects in C++
v. Pascal (Humphrey)

<table>
<thead>
<tr>
<th></th>
<th>C++</th>
<th>Pascal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code review</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Unit testing</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>After unit testing</td>
<td>60</td>
<td>20</td>
</tr>
</tbody>
</table>
Measurement feedback on object-orientation, (Hatton, 1998)
Summary of known measurements

- C++ OO systems have comparable defect densities to conventional C or Pascal systems.

- Each defect in a C++ OO system takes between 2 and 3 times longer to fix than a conventional system. This is true for both simple defects AND difficult ones. The whole distribution is right shifted.

- Components using inheritance have been observed to have 6 times the defect density, (Shepherd & Cartwright, 1998).

How much of this is attributable to C++ is unknown.
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Diagnosis

One of the central ways of improving feedback is good failure diagnosis. However, several factors inhibit diagnosis:

- System complexity and coupling
- Engineer over-optimism leading to poor diagnostics and hence to poor diagnosis
- and measurement suggests, increasingly complex paradigms.
An example from real life, Airbus A320 AF319, 25/8/88, (Mellor (1994)):-

- MAN PITCH TRIM ONLY, followed in quick succession by ...
- Fault in right main landing gear
- Fault in electrical flight control system computer 2
- Fault in alternate ground spoilers 1-2-3-5
- Fault in left pitch control green hydraulic circuit
- Loss of attitude protection
- Fault in Air Data System 2
- Autopilot 2 shown as engaged when it was disengaged
- LAVATORY SMOKE
Difficult, (distant/poor)

“Please wait ...”

• This appeared on the pilot's and co-pilot's main console on Airbus A340 G-VAEL in Sept, 1994 over Heathrow.
Difficult, (distant/poor)

"Please wait ..."

- An acceptable substitute might have been:

  "The Flight Management System has collapsed, rebooting will take slightly less than N of your Earth minutes. Try whistling."
"System stressed ..."

- This appeared on the cash registers of the author’s local pub.
“System stressed...”

- An hour of exciting discussion about communication protocols, deadlocks and such later, the author and friend realised an acceptable substitute might have been:-

“Printer out of paper”. 
“Error -23009: there are already more than 64 TCP or UDP streams open {tcp:104}”

- This appeared on the screen of the author’s new Macintosh G3 desktop running Apple’s latest and greatest version of OS 8, (“the computer for the rest of us”).
Moderate, (close/poor)

“Error -23009: there are already more than 64 TCP or UDP streams open {tcp:104}”

- Two desolate hours later the author realised that an acceptable substitute might have been:
  “Modem not responding”.
“Button push ignored”

- This appears on the Flight Management System of a McDonnell-Douglas MD-11, (Drury (1997))

  It is not clear what the programmer is trying to convey. “Paris is the capital of France” would have been equally useful.

- The pilot also noted “The airplane [computer system] manuals were written as though by creatures from another planet”.
Speaking of other planets, note the following excerpt from IBM OS Data management ...

- "If the control password has read without password protection, its secondary passwords must also have read without password protection. A request for a read only or for a read write secondary password will result in a read without password secondary password. If a read without password control password is changed to either a read only or read write control password, all its secondary passwords will automatically become read write secondary passwords."

Imagine trying to diagnose a failure back to a fault in this requirement.
"Line 23: Incompatible types"

- Typical C compiler speak.

- The annoying thing here is that the compiler writer knows precisely what the types are but is determined to bring a little excitement into the programmer’s sad, miserable life.

- When the programmer searches the ISO C standard for enlightenment ...
Compatible types, oh joy ...

- The ISO C standard states in essence:-
  - Compatible types are the same, but compatible types need not be identical.

- Now the Oxford English Dictionary states:-
  - Identical = the same.
**Easy (close/good)**

Dereference pointer contents 0x0 at
strlen(...) called from
line 126 of myc_constexpr.c called from
line 247 of myc_evalexpr.c called from
line 2459 of myc_expr.c

This is called a **stack trace**. It points unerringly at the responsible code line and usually takes a matter of moments to fix.
The reasons for repetitive failure

The following factors very commonly appear:-

- We don’t learn from our mistakes
- We are ruled by unconstrained creativity i.e. fashion, rather than sound engineering
- Software engineers expect their systems to work rather than accepting their inevitable failure and planning accordingly
- Paradigm shifting appears to be making diagnosis more difficult
- Software systems are getting much larger and more tightly coupled in general
Repetitive failure in the outside world

- Just to show that reluctance to learn isn’t solely the preserve of software engineers...
  - The DC-10 cargo door saga
    - In the *six months* prior to the dreadful crash of the Turkish Airlines DC-10 in Paris in March 1974, there had been *no less than* 1000 cargo door incidents amongst the then 100 strong fleet of DC-10s. They were disregarded.
    - In this incident, the cargo door fell off, and the resulting depressurisation caused the cabin floor to collapse severing vital control cables..
Feedback in action ...