Course "Debugging"

Debugging – An Introduction

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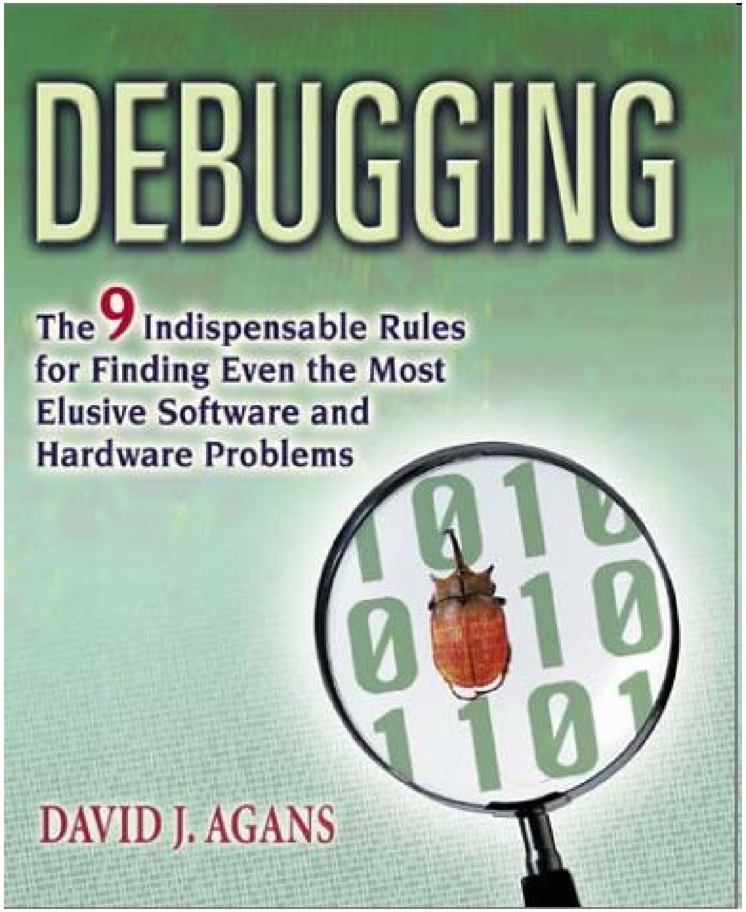
- Universal method of debugging
- 9 rules with subrules and examples ("war stories")

- Rule 1:
  - Understand the system
- Rule 2:
  - Make it fail
- Rule 3:
  - Quit thinking and look

Source

- David J. Agans:
  "Debugging – The 9 indispensable rules for finding even the most elusive software and hardware problems", Amacom, NY, 2002
  - Only 180 pages
  - A fun read!



Proven Rules

- We will cover 9 generic methodological rules to be used during debugging
- Derived from long experience
- Proven to work:
  - Engineers quickly improve in their debugging skills when they learn to use these rules
  - Most engineers already apply most of the rules
    - more or less precisely, consciously, and consequently

Obvious?

- Most of these rules may look obvious

BUT:

- Obvious does not mean easy
- It is not obvious how to apply them to any one problem
- Often neglected in the "heat of the battle"
- Few people follow all of these rules naturally
  - "Debugging is an art"

Universal

The rules work for

- software
- computer hardware
- other electronics
- cars
- houses
- human bodies
- etc.

- We will focus on software
  - (and more on systems rather than code)
  - but use many examples from other areas as well

The rules work if the system

- has been designed wrong
- has been built wrong
- has been used wrong
- is broken

What the rules are about

The purpose of the rules is to

- help determine the causes of misbehavior (defects)
- help correct the causes of misbehavior

The purpose is <u>not</u> to

- prevent defects ("process management")
- detect the presence of defects ("testing", "use")
- decide whether a defect should be corrected (an aspect of "quality management")

Debugging terminology

(For software only:)

- First the programmer does something wrong, or fails to do something that is required
  - This is called an **error**
  - Errors are events and are performed by humans
- As a result of the error, the software may have incorrect structure
  - This is called a **defect** (or fault)
- As a result of the defect, the software may behave incorrectly when executed
  - This is called a **failure**
- During testing or use, we observe failures and conclude there must be a defect
- **Debugging is primarily about locating the defect**

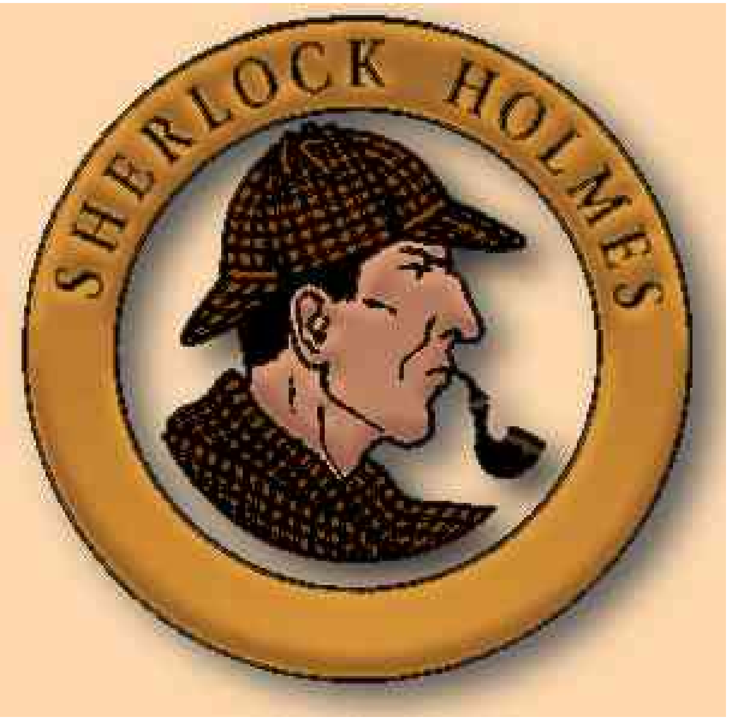
Tatatataaaaa: The nine rules

1. Understand the system
2. Make it fail
3. Quit thinking and look
4. Divide and conquer
5. Change one thing at a time
6. Keep an audit trail
7. Check the plug
8. Get a fresh view
9. If you don't fix it, it ain't fixed

Rule 1: Understand the System

- "It is not so impossible, however,
  that a man should possess all knowledge
  which is likely to be useful to him in his work,
  and this I have endeavoured
  in my case to do."

  Sherlock Holmes



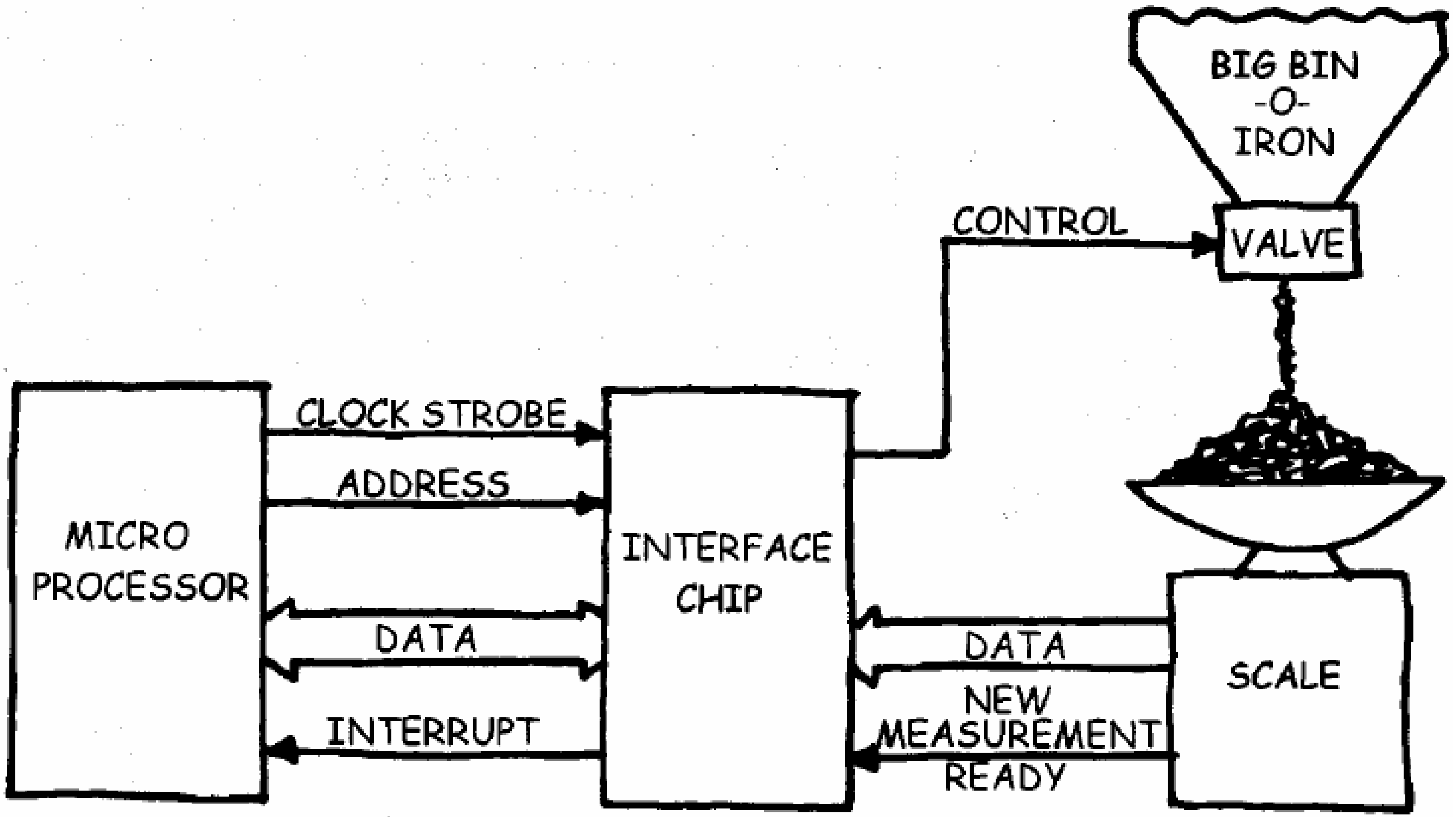
Understand the system: The war story (1)

- Situation: A microprocessor-based valve controller, built from a re-used design

- Problem: When the scale had a new measurement, the interface chip never passed on an interrupt to the processor
  - Even that was difficult to find out
  - No progress in finding out why

Understand the system: The war story (2)

* The system:



Understand the system: The war story (3)

- Critical event: A fellow engineer insisted that the designer reads the entire interface chip data book
  - page 37:
    "The chip will interrupt the microprocessor on the first deselected clock strobe"
  - The design never had deselected clock strobes:
    a few wires had been saved in the original design
    - as the original system had no interrupts at all

Understand the system: The essence

- You cannot find problems if you do not understand how the system is *supposed* to work
- Essentially, you have to "read the instructions"
  - Preferably *before* things go wrong

- Experience shows that the least understood parts of a complex system invariably have the most problems
  - You need the understanding at *design time*!

- Unfortunately, understanding a complex (software) infrastructure can be extremely time-consuming
  - This is usually the most time-consuming rule to follow
  - But also usually the most worthwhile

Understand the system: Read everything

- Subrule: Read everything, cover to cover
  - The finer the detail you miss, the more difficult the resulting problem

- War story:
  - 3-circuit boards had worked OK for some time
  - 4-circuit boards (otherwise identical) were introduced
  - They failed when they became hot. Nobody knew why.
  - Piece-by-piece comparison found different (but almost equivalent) types of memory chips to be the only difference
  - The design had accommodated all requirements of both types, except one: Wait time between read accesses.
  - The 4-circuit board chips required a longer time
  - (The 3-c. b. chips were also used beyond specification)

Understand the system: Know your basics

- Subrule: You need to understand the fundamentals of your technology
  - If you do not know what a strobe is, you cannot understand the data book
  - If you do not know what a low-endian word representation is, perfectly clean data may look garbled to you
  - If you specify UTF-8 without knowing what it is, you may never understand why your Umlaut characters do not show up as intended
  - If you understand only vaguely the purpose of methods you call, you will never find the defects in your program's logic
  - etc.

Understand the system: Know the landscape

- Subrule: You need to understand the purpose and interface of all major parts of your system and how they work together
  - Example: While riding your car, there is suddenly a regular tap-tap-tap sound.
  - Candidate parts: Engine, tires, fan
    - To make this list, you need to know your parts and their behavior
  - Diagnosis 1: It is getting faster as you go faster
    - So it is not the fan
  - Diagnosis 2: When you downshift, the tap-tap-tap stays the same
    - So it is not the engine, but the tires
    - To know this, you need to understand transmissions

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Rule 2: Make it fail

- "There is nothing like first-hand evidence."

  Sherlock Holmes

Make it fail: What and why

- For efficient debugging, you must be able to reproduce the failure at will
  - You need to find out the exact steps to make it fail

Why you need this:

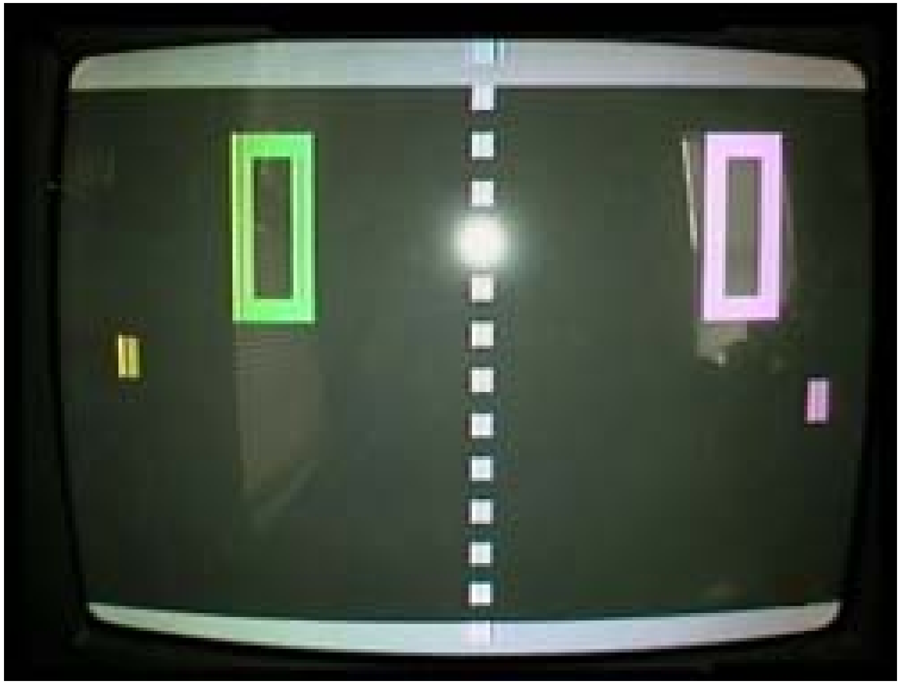
1. To look at the failure itself
   - and understand its characteristics
2. To be able to focus on finding the cause
   - rather than worry how to make it fail at all
3. So you can tell when you have fixed it

Make it fail: Practical hints

- Do it again
  - After you found out how to make it fail, do it once more to make sure you have the right procedure
- Start at the beginning
  - Make sure you can reproduce the failure from a repeatable (clean) initial state: restart everything from scratch
- Automate
  - If making it fail involves a lot of steps, automate their execution
    - see the war story below
  - If the conditions of the failure are rare, create them artificially
    - e.g. an allergy test by explicitly applying allergens
    - e.g. create heavy-load conditions to provoke a known heavy-load failure

Make it fail: War story (Automation)

- Context: Debugging an analog TV 'Pong' game
- Problem: The ball would sometimes wrongly bounce off the 'practice wall'
  - Manual playing kept attention away from observing the failure
- Automation:
  - Both ball position (x, y) and paddle position (y) were represented by voltages
  - Connect paddle y to the ball y voltage and the game will play itself



Make it fail: War story (Stimulation)

- Context: A house
- Problem: A particular window leaks in heavy rain -- but only sometimes
- Stimulation: Create artificial heavy rain by using a hose
  - The leaking happens only when the rain comes from southeast
  - Closely investigating the window finds a break in the caulking at that side of the window
  - After fixing the caulking, another hose test confirms that the defect has been fixed

Make it fail: What if it's intermittent?

- Some failures appear to be irreproducible (intermittent)

- But they aren't:
  - The factors evoking the failure are fixed
    - (remember?: laws of nature!)

- However
  - a. you may not know what the particular factors are
    - and there may be many to choose from or
  - b. you may not be able to control those factors
    - or the ones you would like to check for

Make it fail: What if it's intermittent? (2)

If you do not know the relevant factors:

- Try to find *some* relevant factor by trying to make the failure more frequent

- Method: trial-and-error experiments
  - Guess all kinds of conceivable factors
  - Change them and observe
  - If multiple factors are involved, only randomization helps
    - but randomize systematically

- Sometimes making it fail somewhat more often may be the best you can achieve
  - but that may be very helpful

Make it fail: What if it's still intermittent? (3)

If you cannot control the relevant factors
(or just still don't know them):

- Instrument the system to capture enough information about the few failures you get and about normal executions
  - and compare those two kinds
- Systematic differences usually provide the clue for finding and fixing the problem

- Problem: How can you make sure you fixed it?
  - You need to find a failure signature: Any run showing these conditions will fail
  - Then after your corrections, when you see such a run, but no failure, you know you have removed your problem.

Side note:
Never throw away a debugging tool

- You should keep useful ad-hoc debugging aids as if they were part of a product
  - Design them well, implement cleanly and document them
  - Store them in the version control archive etc.

- They may be useful again – even in unexpected ways

- War story:
  - When the TV 'Pong' game was shown to the investor, he asked for a "two practice walls mode"
  - Reason: *"For selling this thing, we need a demo mode to be run in the shop windows"*
  - Solution: The "robot player" developed as a debug aid

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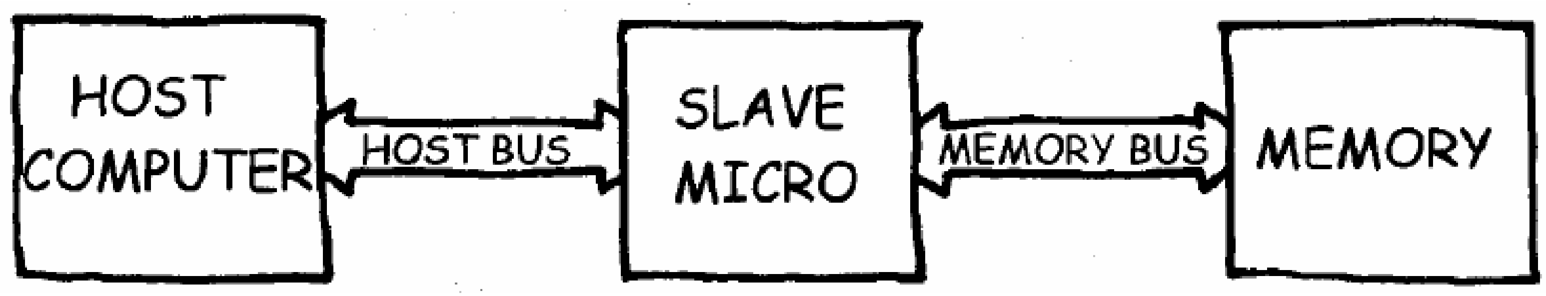
Rule 3: Quit thinking and look

- "It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts."

  Sherlock Holmes

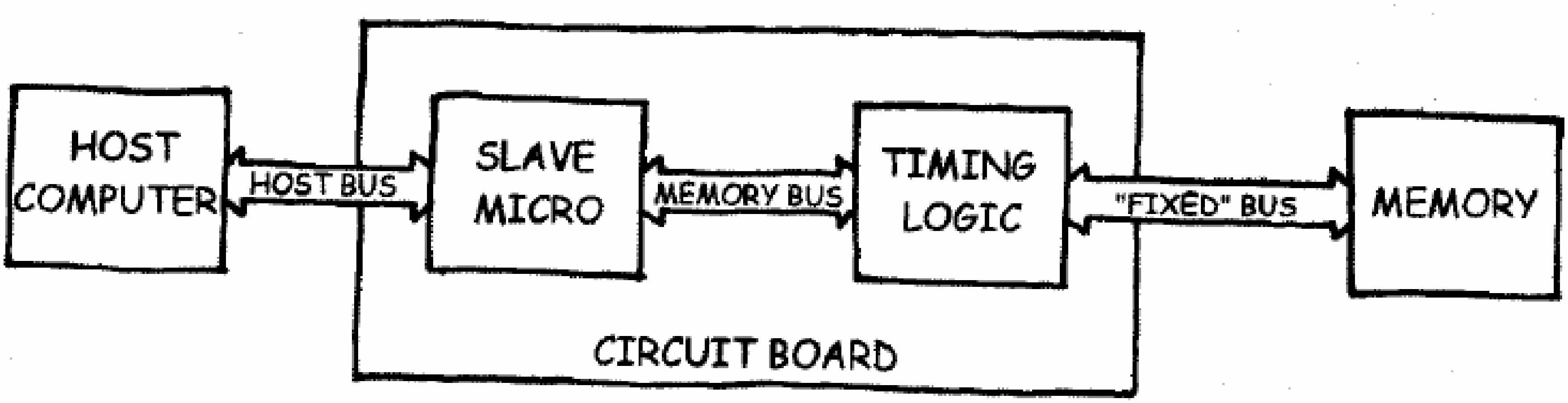
Quit thinking and look: War story

- PC card with slave microprocessor failed sometimes after the program upload
  - Memory checksum was incorrect
- Several junior engineers were assigned to fix this
- Their first test: Repeated writes into a register on the card microprocessor
  - Result was always correct



Quit thinking and look: War story (2)

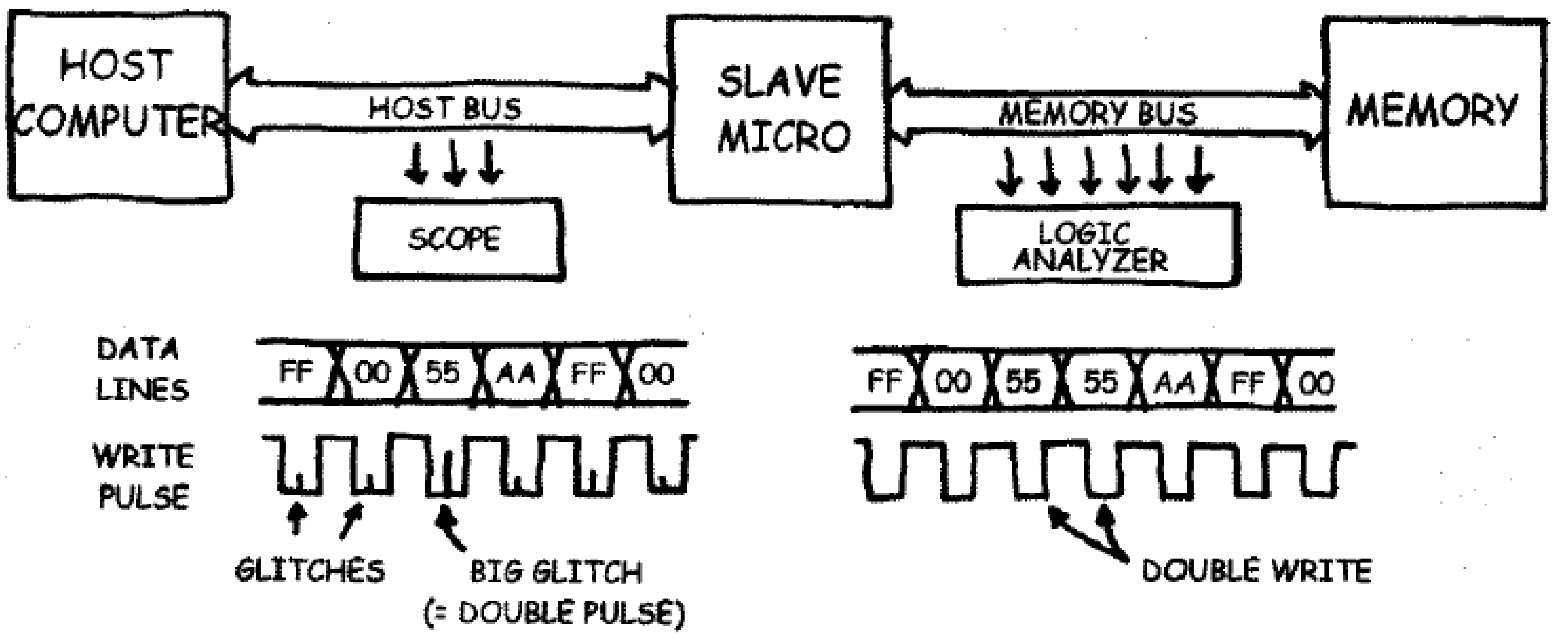
- Conclusion: Data transfer into the card works alright
- Next step: Understand the system
  - They analysed the memory interface circuits
  - They found that its timing design was borderline
- They assumed this was the problem
- They worked out an additional "fix-the-timing" circuit
  - That took several months!



Quit thinking and look: War story (3)

- Result: The card failed just as often as before
- Now a senior engineer stepped in and insisted they first see the actual failure
- He hooked up a logic analyzer to the memory bus and observed the results of repeated writes of the following pattern (to subsequent byte addresses): 00 55 AA FF
  - He sometimes found something like 00 55 55 AA FF
- So the writes to the card could be duplicate sometimes
  - He checked the write pulse to the card and found it to have noise which sometimes made it look like two pulses
- In the junior engineers "write register" test, this could not be observed
  - Writing the same value twice *to the same register* is not a problem

Quit thinking and look: War story (4)



Quit thinking and look: Subrules

- Subrule: See the failure
  - We tend to jump to conclusions when really what we are seeing is the consequence of a failure, not the failure itself
    - The junior engineers never saw the timing fail
- Subrule: See the details
  - Looking once is seldom enough
  - More typically, each looking provides a little more information; you will understand the failure bit by bit
- Subrule: Now you see it, now you don't
  - Seeing the actual low-level failure mechanism will be helpful later on when verifying a fix
- Subrule: Instrument the system
  - Looking from the outside may not be easy or good enough
  - Build observation aids (*instrumentation*) into the system

Quit thinking and look: Pump war story

- A person X did a favor to his neighbor P, who was a pump salesman
  - P: "Thanks. If ever you need a new well pump, I'll set you up with the best pump there is."
- While X is on a business trip, his wife W hears a strange new noise: a motor running for a few seconds every few hours.
- She calls P, he listens in and says: "It's the well pump".
- He calls his people and they replace the pump.
  - In the process, the well gets stirred and muddy
- The new pump works nicely (except for the mud)
  - **but the noise is still there as before.**
- Reason: X has left a compressor turned on in the garage

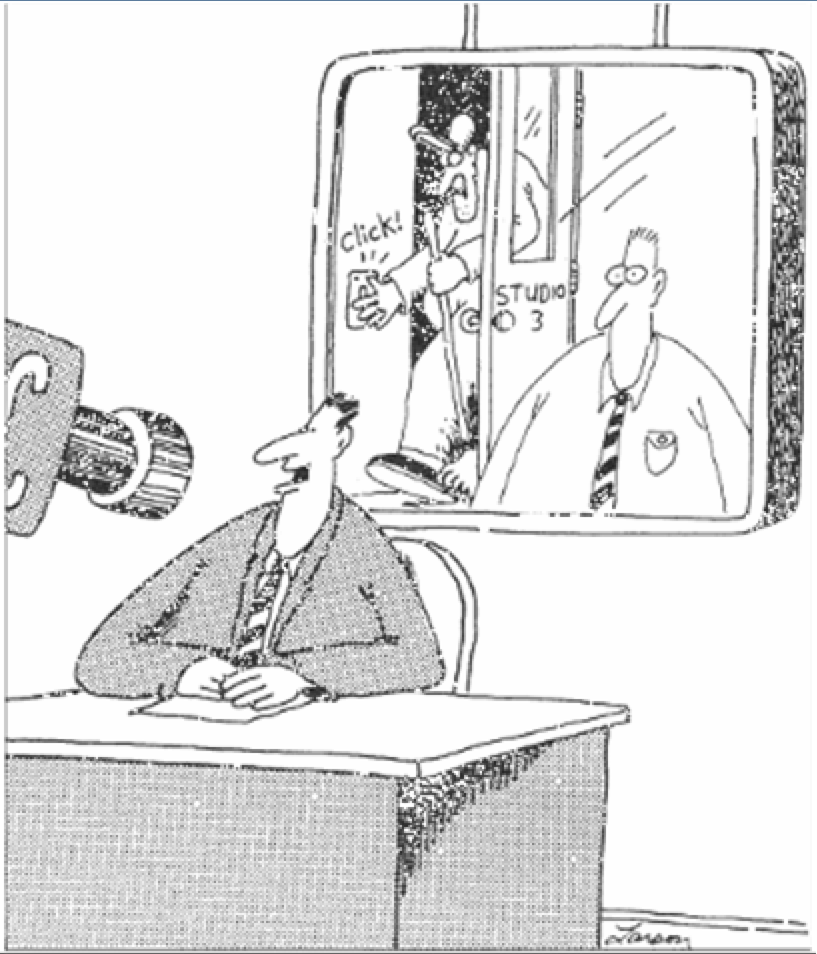
See the failure!

Quit thinking and look: Crash war story

- A server computer crashed late every night
  - Always at approximately the same time
- The administrators had restart logs, but no indication of the cause of the crashes
  - They figured it had to be "something automatic"
- They monitored processes for weeks, but found no correlations
- The one decided to stay late to actually observe the failure
  - and sure enough, shortly after 11pm, the computer failed: it lost its power supply
  - Reason: The janitor had pulled the plug, to use the outlet for the vacuum cleaner

See the failure!

Note: Janitor-related problems are fairly common!



"My next guest, on the monitor behind me, is an organized crime informant. To protect his identity, we've placed him in a darkened studio— so let's go to him now."

Quit thinking and look: Instrument the system

At design time:

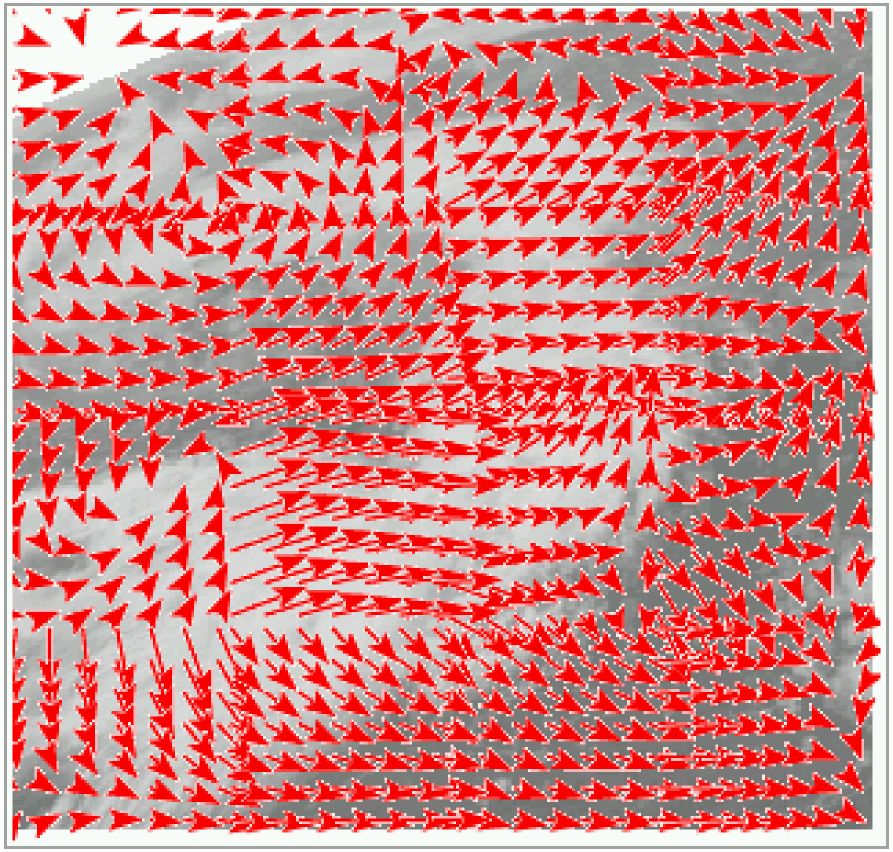
- In hardware (or embedded software) add plenty of monitor signals or even sensors or even displays
- In software, add plenty of tracing functionality
  - Preferably configurable at run time
  - Leave most of that in, even in production code
  - Use consistent, structured output formats for simple analysis
  - Always include time stamps

At debug time (ad-hoc instrumentation):

- Make sure the problem is still there after you built in your instrumentation
- Make sure it is still gone after you take it out (if any)

Quit thinking and look: War story

- A video compression software had surprisingly bad image quality on moving objects
- So the programmers analyzed the motion estimation
  - which encodes a moving object as an x/y translation of some part of the previous picture



Quit thinking and look: War story (2)

- They added code that would indicate motion estimation in the video by colored dots
  - Color for direction: down=orange, left=green etc.
  - Brightness for motion magnitude
  - The tests showed much fewer dots for left-right movements than for up-down movements

- They added output of all motion search results
  - and found that only few horizontal positions had matches

- There was a simple coding error in the horizontal search

See the details!

Quit thinking and look: Instrument the system (2)

- Sub-subrule: Don't be afraid to dive in
  - It is often advisable to do some preparation work (such as rebuilding the system with instrumentation put in) rather than try to debug "from the outside"
- Sub-subrule: Add instrumentation on
  - If your system is not instrumented (enough), you may be able to view some things at the existing network interfaces,
    - e.g. between application server and database server
- Instrumentation in daily life
  - Medicine: add-on (X-ray, ECG, EEG, etc.), built-in (marker genes etc.)
  - Plumbing: gauges (pressure, temperature, fill level), hydrogen sulfide added to natural gas

Quit thinking and look: Heisenberg principle

- The Heisenberg uncertainty principle:
  - When measuring location and momentum of a particle
  - it is impossible to measure both at once arbitrarily precisely
- Meaning (very roughly): It is a law of nature that instrumentation affects the observed system
- This principle often is at work in debugging, too (not literally, though)
  - Debuggers slow down the software and affect timing, change locations of code/data, neighbors, etc.
  - Instrumentation in the code increases code size and perhaps data size
  - Almost any change can influence instable hardware
- Hence, some problems disappear under instrumentation
  - They are often called 'Heisenbugs'

Quit thinking and look: Role of guessing

- The rule proposes looking to be better than guessing
- However, you often cannot get anywhere without guessing
- The rule is

  Guess only to focus the search
  - Positive example: the motion estimation war story
- After guessing you need to confirm your guess
  - Negative example: the pump war story

- There is one case where attempting a fix without confirming the guess may be the right idea:
  - The cause is highly likely and the fix is cheap
    - e.g. a burnt-out light bulb

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Thank you!