The need for and progress in science for information protection and digital forensics

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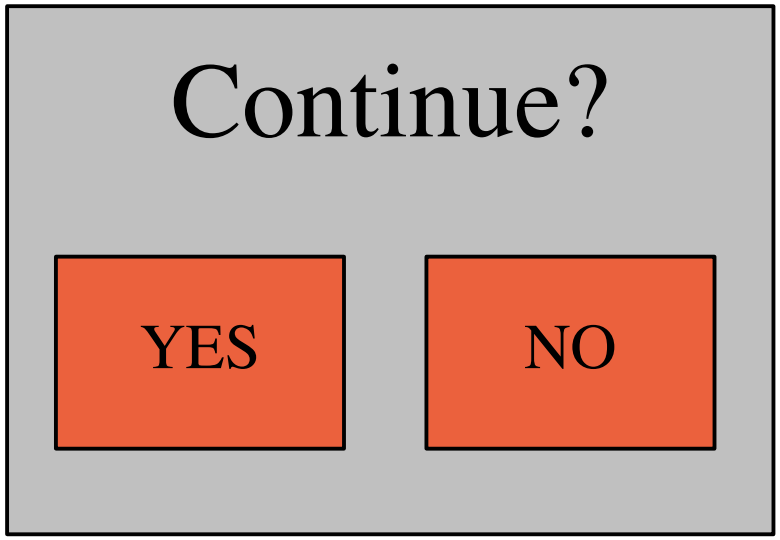
Outline

- Introduction – the basics and the need
- Science as a social activity
- A different physics – an attempt at a theory
- The future



Your speaker

- CEO - Fred Cohen & Associates / President CalSci
  - Enterprise information protection architecture
  - Digital forensics for (usually high-valued) legal cases
  - 501(c)3 research and educational institution
  - M.S. Advanced Investigation / Ph.D. Digital Forensics
- B.S. EE (C-MU '77), M.S. Info Sci (Pitt '81), Ph.D. EE (USC '86)
- >30 years of information protection R&D, design, engineering, testing, implementation, operation, etc.
- >20 years since first digital forensics case
- POST certified instructor in digital forensics, Guest lecturer FLETC, PMTS Sandia National Labs, etc.
- >>100 peer reviewed publications, many conference talks, …

The basics

- Science is about causality
  - A scientific theory:
    - C $\rightarrow^{M}$ E: Cause(C) produces Effect (E) via mechanism M
- The scientific method
  - Identifies the criteria for rejecting (or accepting, for now) a scientific theory
    - Hypothesize C $\rightarrow^{M}$ E
    - Perform experiments to refute
    - Failure to refute → confirmation
    - Enough confirmations and hypothesis becomes theory
    - One refutation and theory becomes refuted (wrong)
      - But it may still be useful for limited cases

Example science

- Hypothesis: The World is flat
- Experiment: Keep sailing West
  - See if you come back from the East
  - Lots of them didn't come back… confirmed
  - So many didn't come back → scientific theory
  - One made it around…
- Refutation – the theory was refuted (wrong)
  - But it may still be useful for limited cases
    - Do you account for the curvature of the Earth when you design a building?
    - Or do you assume the Earth is flat?

A problem with science

- Scientists are people too
  - People make mistakes → Science makes mistakes
  - Science corrects big mistakes and does it slowly
    - When someone notices “something wrong”
    - When the wrong thing is important enough to someone
    - Scientists will check it out, refute the old, propose new
    - Old workable science is still useful (F=ma)
  - People lie → science examines refutation carefully
    - Confirmation not so much – because it's not surprising
    - A new result that's important will get checked out
    - Once you lie in science - nobody will likely believe you again – and your old work will be largely discounted

Science (protection & forensics)

- Is digital forensics important enough to care?
  - It sends people to jail / kills / frees them
  - It forms a framework for the legitimacy of the courts – and civil society
  - The social contract fails if science does not aide justice
- Is information protection important enough?
  - We have created a highly dependent society
  - Advanced society may literally collapse without properly functioning information technology
- I think it's important enough, so I care... do you?

But suppose we don't care?

- Without a reliable C $\rightarrow^{m}$ E model
  - We make a lot of mistakes (which happens anyway)
  - Those mistakes don't get corrected
  - They may be replaced by other mistakes
- How's that working out for you?
  - We pay too much and get too little
  - Snake oil sales prosper in the marketplace
  - We still do ridiculous things we did 25 years ago
    - Change your password how often?
- A scientific approach may help us get to “right”

The draft NITRD issue

- 10-year effort
- Develop an organized, cohesive foundation to the body of knowledge – a rigorous scientific foundation to cybersecurity
  - Organize disparate areas of knowledge
  - Discover universal laws
  - Apply the rigor of the scientific method
  - Predictive, explanatory, general purpose laws
  - Scientific bases for engineered cybersecurity solutions

The list of stuff

- Methods to model adversaries
- Component, policy, and system composition
- Control theory for maintaining security in the presence of partially successful attacks
- Sound methods for ~~integrating humans in the system~~: usability and security
- Quantifiable, forward-looking security metrics ~~(using formal and stochastic modeling methods)~~
- Measurement methodologies and test beds for security properties
- Comprehensive, open, and anonymized data repositories

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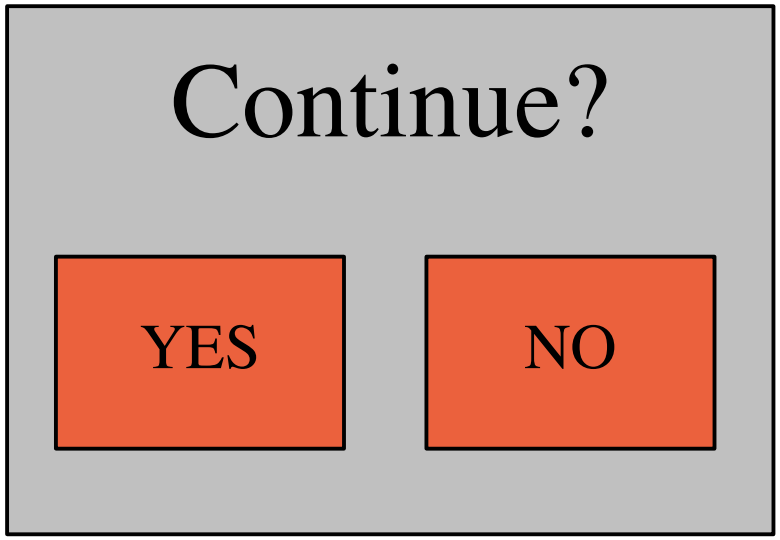

Some simple questions

- What is the definition of risk?
  - What are its units?
  - What is the standard of measurement?
  - Is it an absolute quantity?
- What can we do to it?
  - Transfer: Is there any benefit to the shell game?
  - Reduction: By how much and with what method?
  - Avoidance: What are the units of reward?
  - Acceptance: Only if we know what it is…
  - ARE THOSE THE ONLY THINGS TO DO?

Consensus: Digital Forensics

- The “scientific community” in digital forensics lacks consensus even around the very basic notions
- Compared to the consensus on human activity producing global climate change (86% or more) the basic notions of digital forensics are not at consensus levels:
  - Digital evidence is made of bit sequences.
  - You can observe bits without altering them.
  - You can duplicate bits without removing them.
  - Digital evidence is trace evidence

Challenge!!!

- There are only about 500 peer reviewed articles on digital forensics in the literature
  - Terminology is not widely agreed or uniformly applied – lots "made up"
  - Testability, validation, and scientific principles have not been widely addressed
  - The small corpus of published results limits the scientific basis for statements
  - Claims w/out supporting experiments common.
- "The State of the Science of Digital Evidence Examination" - 2011 IFIP DF conference

Consensus: Info. Protection

- We have some reasonably consistent words
  - Most CISSPs use many of the same words
    - Although they don't mean exactly the same things
  - There are 10,000+ peer reviewed articles
    - ~5 real journals (outside of cryptography)
    - Scores of peer reviewed conferences
  - Testability, validation, and scientific principles have not been widely addressed
  - Claims w/out supporting experiments common
  - Lots of long-term mistakes and rote approaches
  - Words are not consistently enforced in publications
  - No standard wordings (like there are in psychology)

Info Pro Big Problems

- There are almost no scientific experiments
  - No widely used theory of measurement
  - Almost no useful metrics
    - Progress in the attack graph with time (units?)
  - Almost no scientifically valid experiments
  - We don't even have a physics...
- A big part of the problem:
  - We have a purely mathematical basis
  - It ignores the people and processes
- A big part of the solution:
  - Social sciences integrated with artificial sciences

Another social problem

- Science is about refutation
  - When you say something, expect a challenge
    - On a rational and relevant basis
  - If you can't answer the challenge, you're refuted
    - Sort of – for now...
- But decision-makers in this space don't like it
  - Example: risk aggregation in large-scale systems
  - Example: computer viruses vs. trusted systems
  - Example: security theater vs. measurable basis
- We could use some executives who seek refutation rather than "yes – you're right"

And another critical issue

- Information protection involves people
  - As a field we don't seem to apply the human research areas to our work very often or well
    - Sociology, psychology, social psychology, etc.
    - Behavioral models and cognitive limitations
    - Decision-making methodologies and metrics
  - Without addressing the human aspects, we are destined to fail to meet our protection objectives
- A saying of mine
  - The “hard” sciences are the easy sciences
  - The “soft” sciences are the hard sciences

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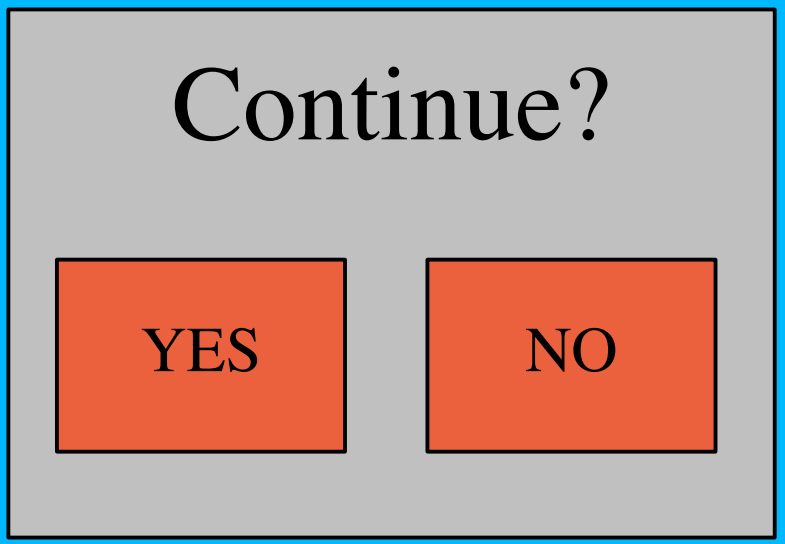

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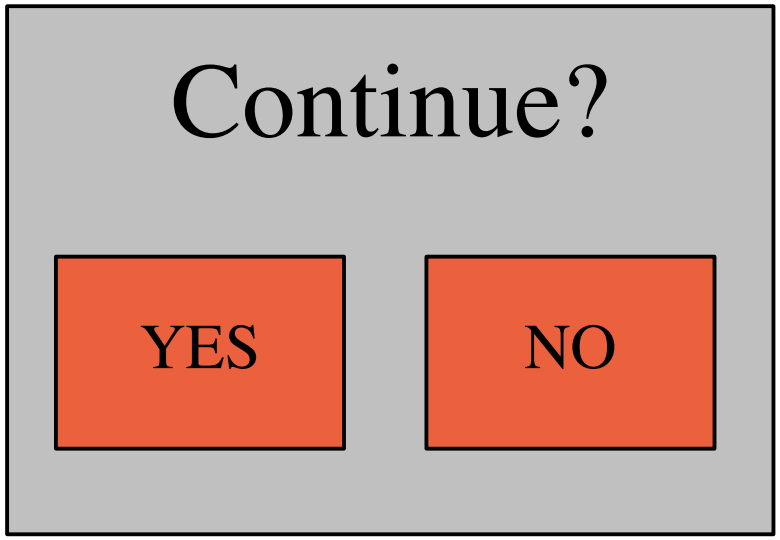
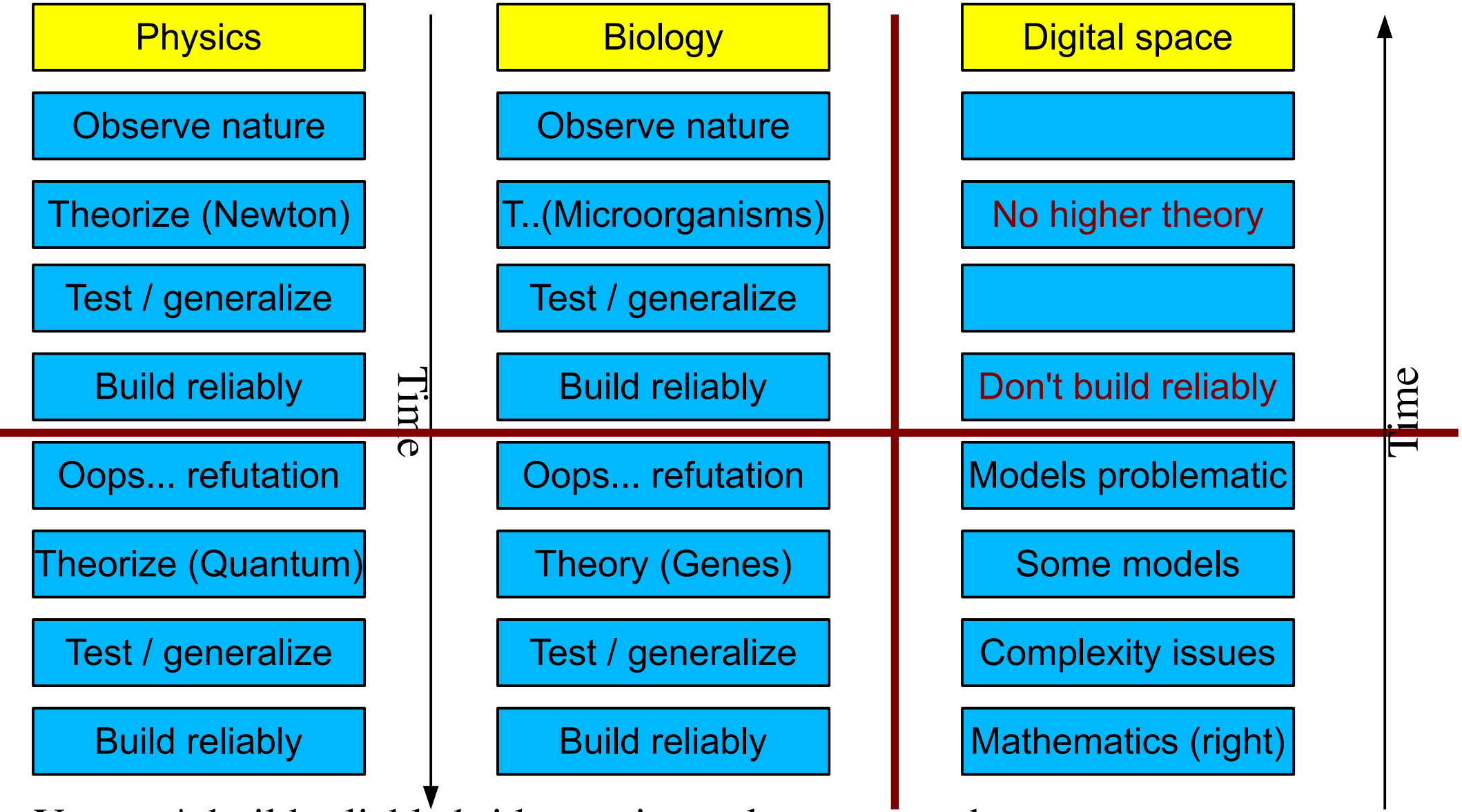


How did some sciences form?



You can't build reliable bridges using only quantum theory
You can't reliably cure diseases using only genetic theory

Approaches to protection science

- Mathematics
  - Keep building from the bottom
  - Hope to construct our way out of it
  - Complexity issues
- Archeology
  - NSF approach to DF
  - Requires a physics
  - Problematic for reliable results
- Engineering
  - Build and test
  - Find and fix
  - Requires a physics
  - Bridges are falling
- Social sciences
  - Statistics: Causality is too complex / unknown
    - P(x) problematic
    - Measure what? How?

Notions of a new approach

- Information physics
  - We may want a "physics of digital information" level to reduce complexity and allow composition based on physics properties
- Social sciences
  - We may want a "behavioral science" area to address the human and social factors associated with protection
- Fusion (***IRB decision is involved***)
  - Example: Deception experiments from ~2000
  - Human and group dynamics taken into account
  - Measured progress in attack graphs with time
  - Differential effects of 3 types of "deceptions"

Transfer vs. Trace

- **Natural world** forensics
  - **Transfer** is the scientific basis for trace evidence
  - When physical objects come into contact, each leaves part of itself with the other(s) (Locard misquote)
    - Scientific theory: Objects: Contact $\rightarrow^{\text{Transfer}}$ Traces
  - Traces found on objects are consistent with transfer from physical contact with other objects
- There is **no transfer in digital evidence**:
  - The **scientific basis** for evidence acceptance in the **natural world does not apply**
- But there are still **traces** (product of execution)
  - Scientific theory: FSM $\rightarrow^{\text{Execute}}$ Traces

A different physics?

- Some basic physics of the digital world:
  - **Digital data** is entirely **sequences of bits**
  - The atomic unit is the "bit"
  - Nothing smaller (finite granularity)
    - No longer dealing with the digital evidence
    - Smaller than a bit it's physical evidence
  - Finite bit granularity → finite time granularity
    - Bits can only store traces (of time) at finite granularity (a finite bit sequence)
- **Normal space: infinite** granularity space/time
- **Digital space: finite** granularity space/time

Finite granularity issues

- Finite granularity → time is a partial ordering
  - A before B (A<B), A after B (A>B), Can't tell (A≈B)
  - Traces as recorded are subject to Δt
    - What is the Δt for your traces / time stamps?
  - Is the claim a sequence of events?
    - Don't know Δt → don't know the sequence!
- Precision vs. accuracy
  - Trace time stamps are subject to delays, etc.
    - They look precise (2010-11-02 03:34:54.455)
    - But often aren't as accurate (off by 9 hours)
  - Mixed granularity misleading as to sequences
    - Some Windows time stamps at 1-day granularity

Convergence vs. divergence

- FSMs have "perfect" forward predictability
  - Given an FSM, initial state, and input sequence, all state and output sequences are precisely defined
  - Many FSMs and input sequences produce identical output sequences
  - **Digital space "converges" with time**
    - Traces do not uniquely identify causes!
    - $C \rightarrow^{m} E \not\Rightarrow E \rightarrow C$ – **Effect does not imply (unique) cause!**
- **Normal space** (physics) admits to only one past but many possible futures: E→C unique!!!
  - **Normal space "diverges" with time!**
    - **Effect implies unique cause**

Convergence details…

- Digital space converges with time
  - FSM: (I,O,S,m:{IxS}→{O,S'}) IF |I|>(|O|+|S|) THEN ∃(i,i')∈I:∃(o)∈O,∃(s)∈S, i→(o,s) and i'→(o,s)
  - Also note that $h(O) \leq h(I+S)$ (Shannon's *h*)
  - **Normal space diverges with time** *(2nd law of thermodynamics)*
  - **Digital space converges with time**
- You can't normally identify I^n from traces T
  - T: $|T|<|I^n|$, $\exists(i,i')\in I^n:\exists(t)\in T$, i→(t) and i'→(t)
  - In digital space, history is not uniquely determined by the present

Latent nature and tools

- Bits (and DFE) are (normally) latent in nature
  - Bits can't be directly observed with human senses
    - The bits must be observed through tools
  - How do we understand and trust the tools?
    - Most tools are computer programs (sequences of bits interpreted by FSMs)
    - How do we assess and present tool reliability?
  - A scientific methodology to evaluate tools?
    - No methodology → regardless of what the tools tell us, we don't know how to interpret it
    - What is the basis for trusting your tools?
    - In most cases, no basis is provided
    - Do you know the scientific principals and methods?

How do we know?

- How do we calibrate and test tools?
  - Calibration → validation with known samples
    - What known samples are right for the matter?
    - What is the "right" answer and how do we tell?
  - Testing involves software verification
    - Mathematical proofs
    - Tests against error models
  - A theory of measurement is needed:
    - What does the tool measure? How does it do it?
    - Do I need / can I use the same tool to test it?
    - Can I use a tool that doesn't reveal mechanisms producing its outputs?

Differences in physics …

- There are many more examples of differences between the physics of digital information and the physics of the natural world.
- For details see:
  - F. Cohen, "Digital Forensic Evidence Examination - 3rd ed.", ASP Press, 2011

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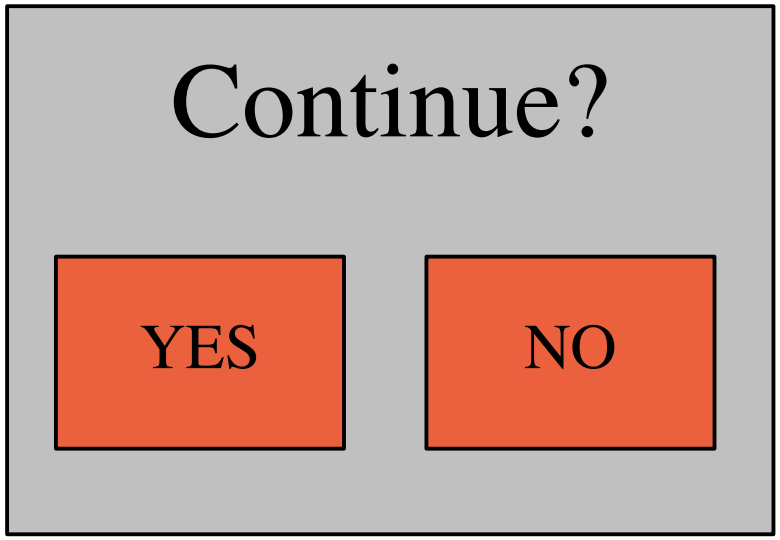

An engineering discipline

- An approach to building reliable protection
  - A science base that produces methodologies, scientific theories along with limitations, measurement methods, defined language and usage, and experimental basis for showing properties of components and composites.
  - A set of well tested tools and techniques for analysis and construction of mechanisms with known properties and identified limitations not requiring expertise in the lowest level of minutia.
  - A global feedback mechanism for improvement over time, including a rich set of peer reviewed publications, professional standards, and strong educational base with common real knowledge

Where from here?

- The social part of science...
  - Here I am – trying to convince you
    - If I do, you will try to convince others
  - In the marketplace of ideas, mindshare wins
    - For a while... until failures force abandonment
    - Refutation is king
  - The "meme"s that survive are more "fit"
    - In the environmental niches they live in
  - Evolution is not optimization
    - But refutation pushes us out of our gravity wells
- I would love to discuss your research...

Thank You

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