Two Models of Digital Forensic Examination

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Outline

- Background and Introduction
- An existing model
- Analysis of the existing model
- A proposed alternative model
- Analysis of the alternative model
- Summary, conclusions, and further work

My background

- California Sciences Institute
  - 501(c)(3) non-profit California research and educational institution - WASC accreditation candidacy pending
  - Ph.D. Program in digital forensics (Fall 2009)
- Fred Cohen & Associates
  - Enterprise information protection consulting
  - Digital forensics (high fees – no guarantees)
- Fred Cohen – Digital forensics
  - POST certified instructor, FLETC instructor, books and book chapters, papers, testimony in Federal, State, and Local courts

Previous models

- Carrier and Gladyshev
  - Model the forensic analysis process in terms of consistency and inconsistency and introduce various time-related concepts
- Stallard and Levitt
  - Semantic integrity checking (consistency)
- My basic notion and approach
  - If we are going to make a science of digital forensics, we need to develop a physics and a theory for applying that physics
  - This paper is about a theoretical model

Basic notions of forensics

- The evidence is a set of traces
  - A “trace” is a “bag of bits”
  - Normally an ordered sequence
  - It is the result of some digital process
  - The question is: “What process?”
  - How do we find out?
  - How sure are we? Why are we this sure?
- The evidence is latent in nature and technical
  - You need tools to see it and experts to explain it
  - What tools, and how can you trust them?
  - What experts, and how credible are they?

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Kwan et. al.

- A model of making decisions
  - About processing evidence in cases
  - Prioritizing resources based on likely outcomes
  - Modeling the legal process with the evidence
- The basic model
  - A legal requirement for a violation $L:\{I_1, ..., I_n\} \rightarrow V$
  - Sets of evidence chains $E: \{E_1, ..., E_o\}$ show L
  - Traces demonstrate evidence $T:\{t_1, ..., t_n\} \rightarrow E$
  - Evidence has weights and they sum
  - Enough weight and you exceed the V threshold

How a case is made

- Previous cases provide precedent
  - Necessary evidence chains to get a conviction
- Investigation takes resources
  - Desire to minimize resources per conviction
- Figure out how to spend resources
  - Identify $T \rightarrow E \rightarrow V$ and costs for each $t \in T$
  - Order investigation to find $t \in T$ for minimum cost
  - Go one step through E at a time
  - Since refutation cuts E, stop when E is cut
  - If cost effective, try alternative Es

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Kwan's optimization approach

- Problems include, without limit:
  - E is a POset
  - No method for evaluating costs or thresholds
  - Cost of a node in the POset has rewards for all Posets passing through the node
  - If a node is refuted, it cuts all Posets passing through it
  - Different valuation models produce different ordering of nodes for optimization
  - The method being used potentially leads to gaming of the system for the criminals
  - Clever criminals can optimize their activities to defeat prosecution (others get caught first)

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The context of the new model

Legal context

- Legal theory
- Application
- Methodology
- Jurisdiction
- Case type
- Proof standard
- Calendar
- Strategies
- Costs

Evidence

- Identify
- Collect
- Preserve
- Transport
- Store
- Analyze
- Interpret
- Attribute
- Reconstruct
- Present
- Destroy

Tools

- Methodology
- History
- Pedigree
- Reliability
- Testing
- Calibration
- Function
- Limitations

Litigants

- Due care
- Retention

People

- *Scientific*
- Knowledge
- Skills
- Experience
- Training
- Education
- *Non-scientific*
- Clarifying
- Observation
- Honesty
- Integrity
- Competence

Challenges

- Make/Miss
- Content
- Context
- Meaning
- Process
- Relationship
- Ordering
- Time
- Location
- Corroboration
- Consistency
- Accident/intent
- False positive
- False negative

Legal process

- Pre-legal
- First filing
- Notice
- Preservation
- Productions
- Disclosures
- Depositions
- Motions
- Sanctions
- Admissibility
- Pre-trial
- Testimony
- Disposition

Admissibility

- Relevance
- Original writing
- Authenticity
- Probative > Prejudicial
- Hearsay

Drill down at http://all.net/

The new model

- Laws: $L:\{l_1, ..., ln\}$, $R:\{r_1, ..., r_m\}$, $LxR \rightarrow [F|T]$
- Violations: $V:LxR \rightarrow [-1 ... 0 ... 1]$
- Hypothesized claims: $H=\{H_1, ..., H_n\}$, $H \subset V$
- Events: $E: \{e_1, ..., e_o\}$
  - Filings, statements, etc. non DFE
- Traces: $T:(t_1, ...,t_q)$ {all subsequences of T}
  - All subsets of the bag of bits
- Trace (internal) consistency: $C:TxT \rightarrow [-1...1]$
- Demonstration consistency: $D:TxE^* \rightarrow [-1..1]$

New model (continued)

- $P:\{p_1, \ldots, p_n\}, \forall p \in P, p \rightarrow \{c \subset C, d \subset D, c \not\subset C, d \not\subset D\}$
  - The forensic procedures confirm or refute type C and type D consistency
- Resources $R:(T,\$,C,E)$
  - Time, Money, Capabilities, and Expertise
- The Schedule $S:(s1, s2, \ldots), \forall s \in S,$
- $s:(l \subset L, r \subset R, h \subset H, e \subset E, t \subset T, c \subset C, d \subset D, p \subset P, r \subset R, t, t')$
  - The schedule is a sequence of spans of time in which laws, relations, hypotheses, events, traces, type C and D consistency and inconsistency, forensic procedures, and resources apply.

Example: an email extract

From ???@??? Fri, 15 May 2009 02:39:41
Return-path: <svein@willassen.no>
Received: from smtpin126-bge351000 ([10.150.68.126])
by ms283.mac.com (Sun Java(tm) System Messaging Server 6.3-7.04 (built Sep 26 2009 64bit)) with ESMTP id <0KJP00J852A8S8J0@ms283.mac.com> for dr.cohen@mac.com; Fri, 15 May 2009 09:39:41 -0700 (PDT)
Original-recipient: rfc822;dr.cohen@mac.com
Received: from mail-bw0-f162.google.com ([209.85.218.162])
by smtpin126.mac.com (Sun Java(tm) System Messaging Server 6.3-8.01 (built Dec 16 2008; 32bit)) with ESMTP id <0KJP0018P29JIHD0@smtpin126.mac.com> for dr.cohen@mac.com (ORCPT dr.cohen@mac.com); Fri, 15 May 2009 09:39:41 -0700 (PDT)
X-Brightmail-Tracker: AAAAAA==
Received: by mail-bw0-f162.google.com with SMTP id 6so3067145bwz.30 for <dr.cohen@mac.com>; Fri, 15 May 2009 09:39:41 -0700 (PDT)
MIME-version: 1.0
Received: by 10.204.57.138 with SMTP id c10mr3481822bkh.56.1242405581619; Fri, 15 May 2009 09:39:41 -0700 (PDT)
In-reply-to: <C93BF973-C2E2-4CA7-B77B-EB48283A4028@mac.com>
Date: Fri, 15 May 2009 18:39:41 +0200
Message-id: <2e67f5b00905150939r2e34c9d9n96688c4ac7f5ea98@mail.gmail.com>
Subject: Re: A question on your dissertation and an experiment to try
From: Svein Yngvar Willassen <svein@willassen.no>
To: Cohen Fred <dr.cohen@mac.com>
Content-type: text/plain; charset=UTF-8
Content-transfer-encoding: quoted-printable

- An email header
- Asserted as:
  - Original writing
  - Received in New Jersey
- Type C
- Type D

What's the problem?

- Type C problems identified (so far)
  - “From “ separator ???@??? and date format
  - “From “ offset from last Received (False+)
  - Received: times in the same second (how fast?)
  - Gmail message-ID but emitted from non-gmail account (passes through Google later – Google added AFTER earlier “Received:”?)
  - Message server built after Message Received!
  - Server versions inverted w.r.t. Build time stamps
- Type D problems identified (so far)
  - Received in NJ inconsistent with all time zones
- Lots of traces extracted from the original trace

This is only the beginning

- Which if these are actually spoliation?
  - And how do we tell?
- How many more traces are there?
  - In this specific sequence?
  - Are there other sequences?
  - How about cross-sequence C consistency?
- How do these relate to other events?
  - Version numbers of servers and dates and times
  - Anchor events tying down other facets
  - Character sets available on machines at times
- Where does it end?

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The size of the space

- L is finite, and defined by the specific laws.
- R is usually expressible as a combinational logic expression, with metric thresholds.
- H is unlimited in possible makeup, but H is defined by documents, not very alterable and time limited by the schedule.
- E can be very large, but in most cases it is a few hundred to a few thousand asserted events including statements by the parties in depositions, testimony, and so forth.

Size of the space (continued)

- More sizes
  - T is the size of all sets of all states
  - In a particular matter, T is the available traces
  - For m bits of traces, $|T|=\sum(m!n)2^n$ for n=1 to m
    - 64 bit trace→$3*10^{31}$ possible actual traces
  - C is $|T|^2$
    - 64 bit trace →10^{63}
  - D is |T|*|power set of E|
- Exhausting C or D is infeasible for any real case
  - Exhausting consistency checks is infeasible
  - What is a “thorough” job?

Forensic procedures

- P is the size of all instruction sequences executed on all subsets of T and E
- |Instruction set|$^{\text{|number of instructions executed|}}$
  - 100 instruction instruction set
  - 10^9 instructions per second for 1 second
  - |P|≈ 1 followed by 10^{18} 0's.
- |P| in reality is – perhaps 10^3-10^4?
  - scientific methodology properly applied
  - executed by tools that have been tested, calibrated, demonstrated to be reliable
  - Applied by suitable experts

Resources and schedule

- R and S constrain process
  - Time limits→limited P and exploration of C/D
  - Money limits→limited P, time, capabilities, expertise
  - Capabilities limit→limited P
  - Expertise limits→limited P
- S changes with time and situation
  - The sands literally shift underneath you
  - No analytical methods are available to optimize at this level of complexity
  - Game theory doesn't come close to it
  - The skill of the participants rules the day

Returning to the example

- How many more traces are there?
  - We now know the answer – and it hurts!
- How many more procedures may there be?
  - An enormous number in total – but which are probative and how reliable are they?
  - We don't even know how many more there may be for a single email header!
- How do we test the reliability of the apparent inconsistencies?
  - We need an experimental base and samples and lots of procedures to test

More on the example

- Resources are constrained – even for this email
  - How do we find out about the Message-ID field in context of other similar fields?
  - How do we identify the source of the version number/time inversion problem?
  - We haven't even looked up the IP addresses vs. host names and time zones
  - What about the internal ESMTP IDs? Are they in proper sequence?
  - Is Google really adding GMAIL Message-IDs to all non ID'd messages?
  - Is the originator on a 10-net using the proper ...

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Summary

- Earlier models are less comprehensive
  - The new model is more so
  - Optimization in previous models was problematic – but this one is no better
- The present model
  - Clearly shows complexity challenges with traces and examination of traces
  - Shows the size of the problem space for what it is and dispels any notions of "comprehensive"
  - Brings a notion of how to apply redundancy to understanding trace and event consistency
  - Introduces type C and D consistency

Summary

- Procedures are extremely limited today
  - Major effort is needed to create and test new procedures for types C and D consistency
  - Understanding the class of P seems important
- Resource limits and schedule
  - The notion of resource limits and schedule introduce a more complex and more realistic optimization arena
  - Many new challenges appear to be put forth by this model and its potential application
  - Game theory appears to be too weak for this class of problems – at least as it exists today

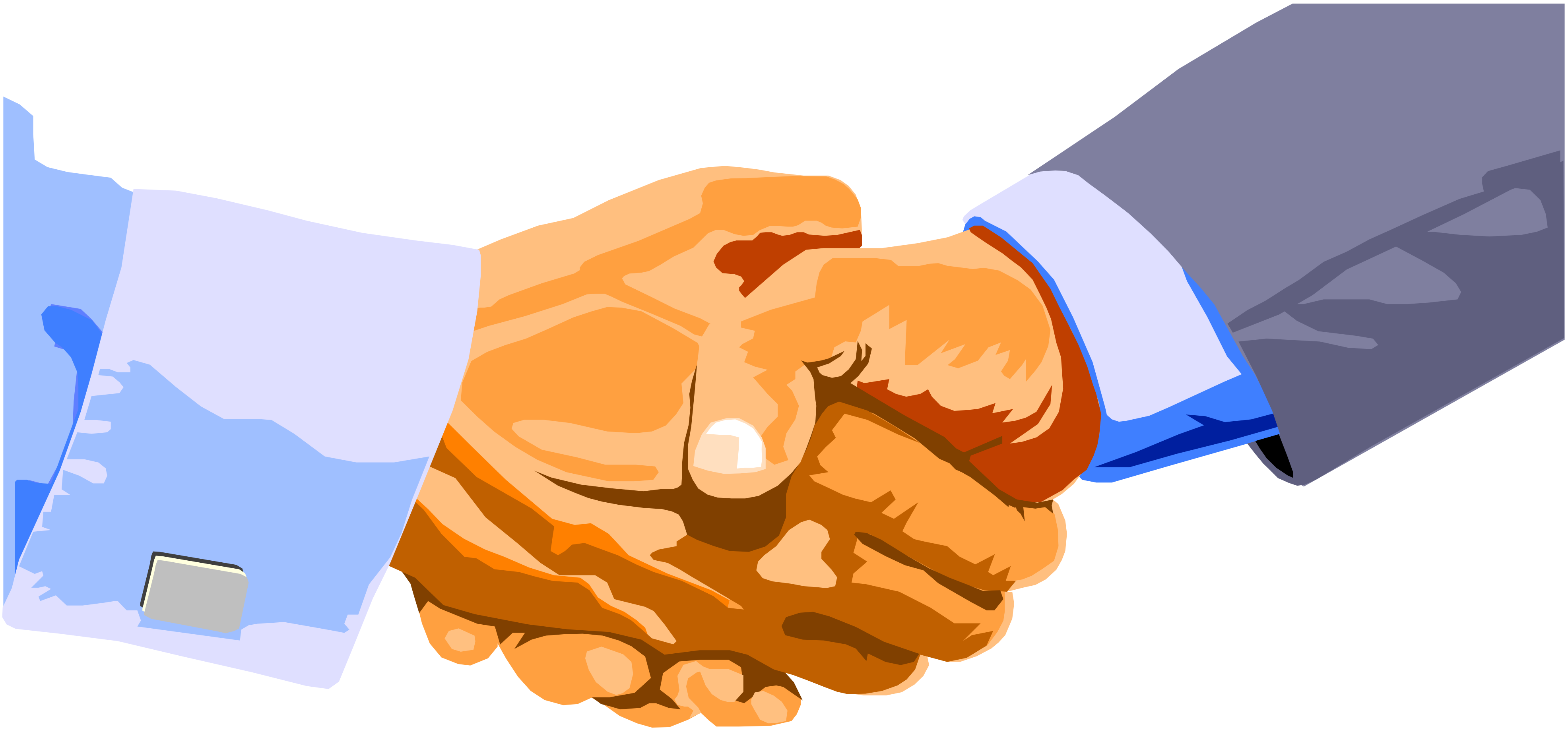
Conclusions

- We have the start of a scientific methodology
  - We now know that being “comprehensive” or “thorough” in examination of DFE is infeasible
  - We now know why this is so, and why it will likely remain infeasible for quite some time
  - We now have a theoretical model for developing metrics associated with examination
  - We have a basis for identifying complexity issues with forensic procedures
  - We can use the model along with complexity analysis to allocate resources within schedules
- But it's only a start

Future work

- A model is only a model
  - The development of the science of DFE examination is in its infancy
  - We need a well defined and accepted physics
  - We need to develop systematic and scientific procedures for type C and D consistency
  - We need clarity around the methodology and its proper application
  - We need to start to do complexity analysis to understand what is and is not feasible
- But without a model, we grope in the dark

Thank You



http://calsci.org/ - calsci at calsci.org

http://all.net/ - fc at all.net

Further Reading

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