8TH INTERNATIONAL COMMAND AND CONTROL RESEARCH AND TECHNOLOGY SYMPOSIUM
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NATIONAL DEFENSE UNIVERSITY
WASHINGTON, DC

A Theory of Interoperability Failures

Track 1: Coalition Interoperability
1330-1400, Wednesday, June 18, 2003

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SPAWAR Systems Center Charleston

Table of Contents

Outline

Backups

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Introduction

- Achieving interoperability among C4ISR systems remains a challenge for the U.S. Department of Defense
- Progress has been made in recent years through the use of:
  - directives and guidance
  - increased awareness
  - emphasis on capability vice platforms
  - integrated architectures
  - mission capability packages
- However ...

Introduction

One element missing from this mix is a coherent, verifiable theory of interoperability failures that captures the causes of interoperability faults in a form that practitioners can use to avoid problems in their own work

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Introduction

- **Purpose: Develop a theory of interoperability failures that can be confirmed through objective evidence**
- **Goal: To be able to efficiently collect the data required to create and validate prediction rules that can be used to make diagnostic decisions about conducting end-to-end interoperability testing of C4ISR equipment strings**

Earlier Related Work

- “*Interoperability: A New Paradigm*” 1999 paper by Paul Sutton where an analogy is drawn between interoperability and electronic equipment reliability
- Two papers presented in at last year’s ICCRTS & CCRTS by John Hamilton, Pam Sanders, CAPT John Melear, and George Endicott where interoperability is dealt with using an engineering life cycle model

See [Sutton, 1999] [Hamilton et al., 2002a] [Hamilton et al., 2002b]

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U.S. DoD Definition

"(1) The ability of the systems, units, or forces to provide services to and accept services from other systems, units, or forces, and to use the services so exchanged to enable them to operate effectively together, and (2) the condition achieved among communications-electronics systems or items of communications-electronics equipment when information or services can be exchanged directly and satisfactorily between them or their users. The degree of interoperability should be defined when referring to specific cases."

Source [CJCS, 2000]

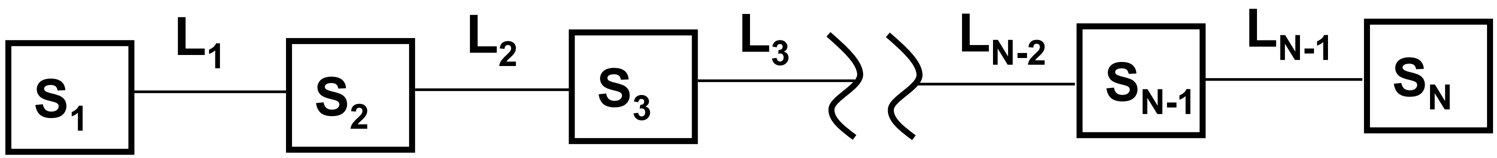
Sutton's Definitions

End-to-end interoperability *– "The probability of successful interoperation of all subscribers in a network under specified conditions for a given mission time."*

Interoperability failure *– "The inability of the network to meet specified interoperability levels, conditions, and requirements, such as minimum acceptable data transfer rate, quality of service, and maximum allowable latency."*

Source [Sutton, 1999]

Background Definitions



Equipment string ***– a serial sequence of N systems connected by N-1 links that provides a communications path between users to exchange information***

Functional thread ***– a construct consisting of the equipment string input, equipment string output, a description of the transformations to be performed and the conditions under which this should occur.*** **See [INCOSE, 2000]**

Definitions for this Paper

<u>Interoperability</u> – "The ability of two or more systems to exchange information and to mutually use the information that has been exchanged." **[IEEE, 1988]**

<u>Interoperability fault</u> – A defect or condition related to system interaction that causes a reproducible malfunction in the ability of two or more systems to exchange information and use the information once exchanged. Note: a malfunction is considered reproducible if it occurs consistently under the same circumstances. **[Adapted from FS-1037C, 1996]**

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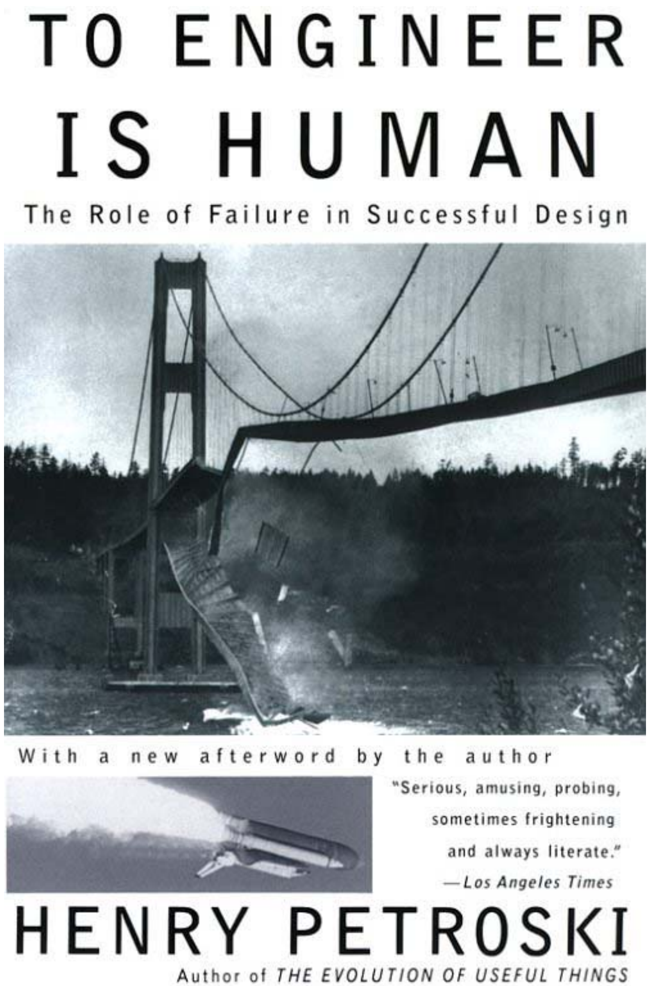
Definitions for this Paper

***Interoperability failure* – "The inability, due to an interoperability fault, of two or more systems to exchange information and to mutually use the information once exchanged."**

Why do we need a theory of interoperability failures?

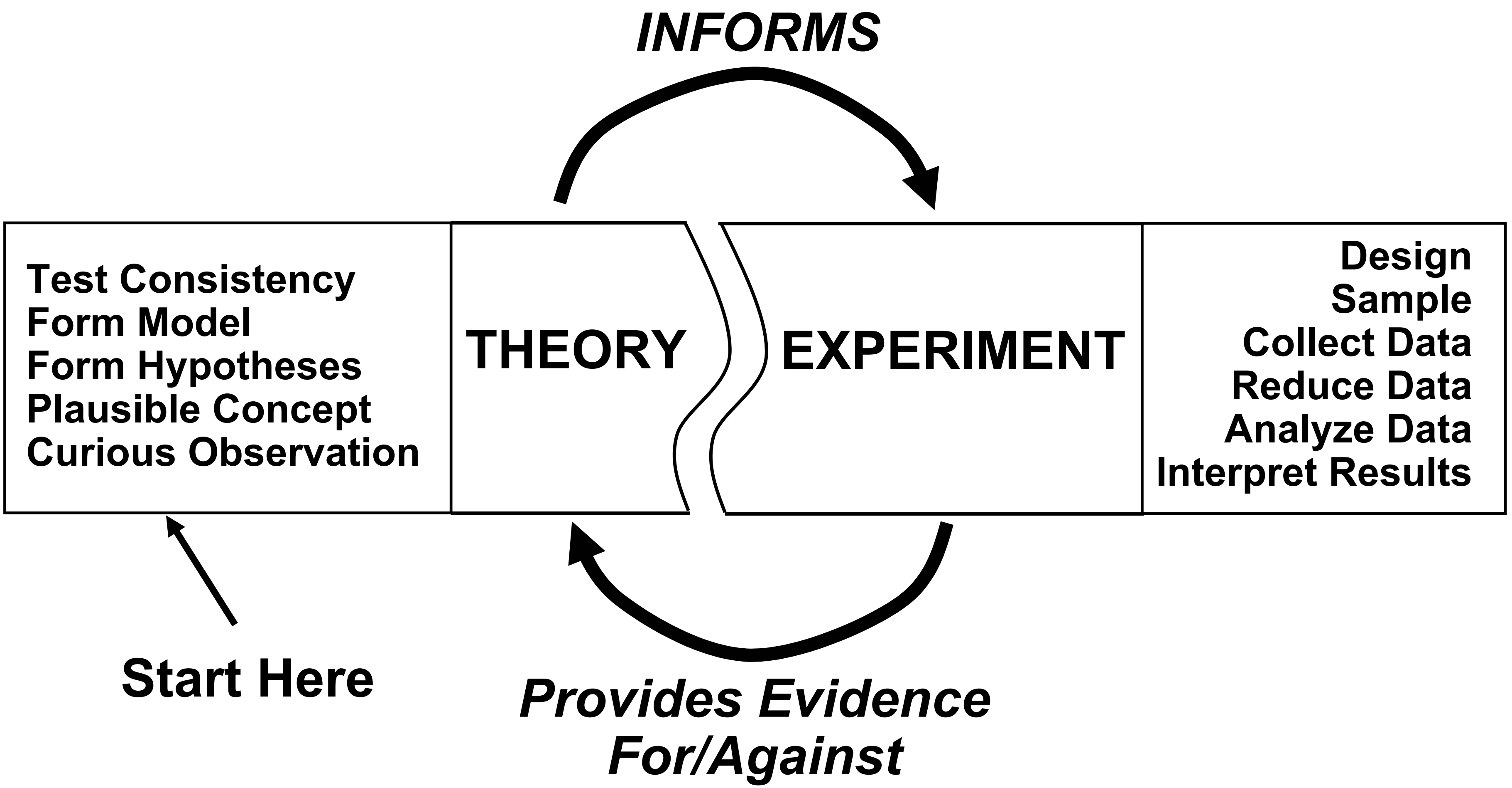
The Role of Failure in Design



True advances in engineering design often depend on gaining a deeper understanding of how things fail. Think of 19th century steel railroad bridges and the de Havilland Comet aircraft.

Why should we think that designing system of systems that resist interoperability failures would be any different?

Reinforcing Relationship Between Theory and Experiment



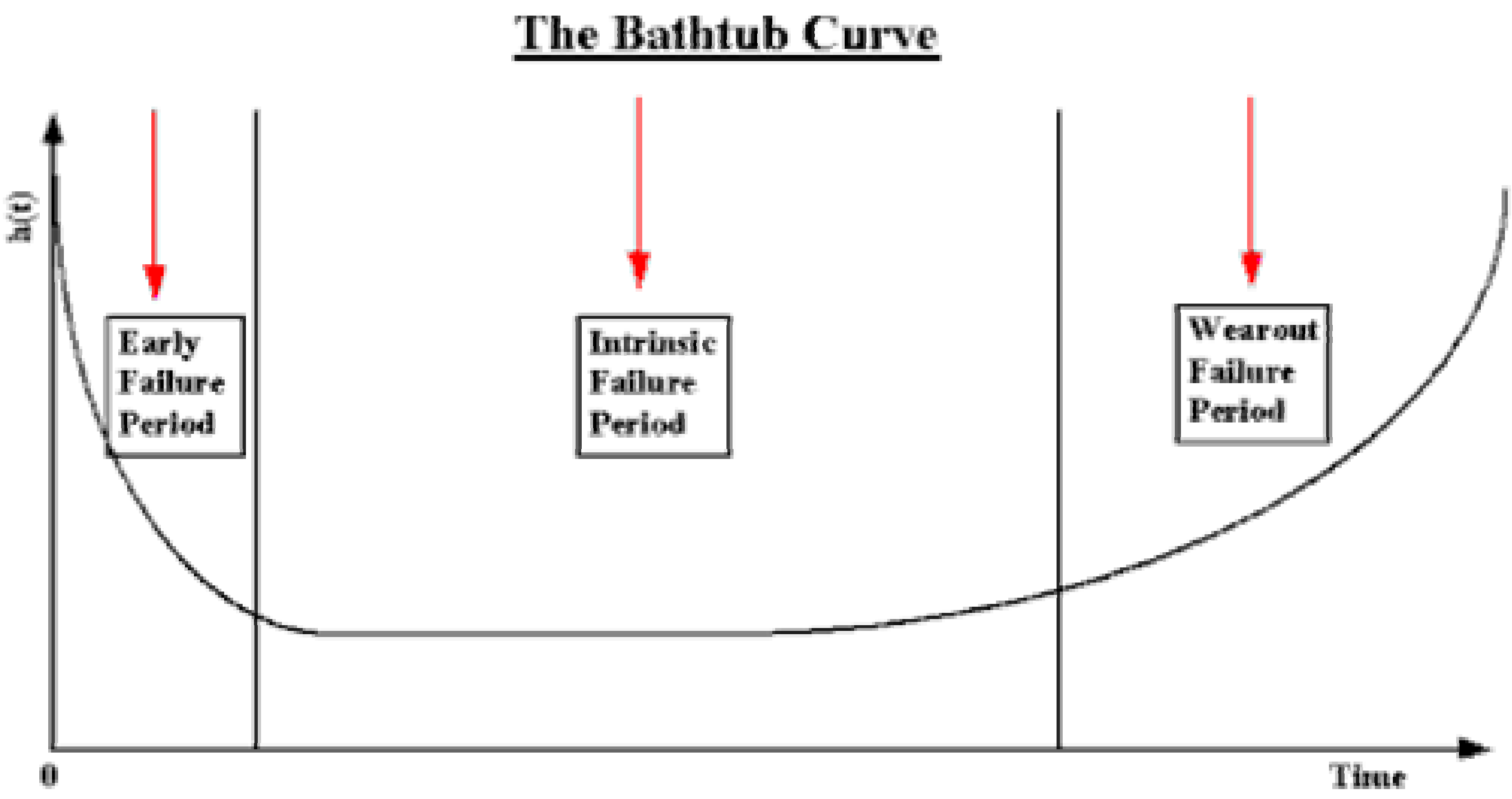
Sutton's Analogy

- Interoperability: A New Paradigm
- Draws on the analogy of electronic equipment reliability to postulate a theory of interoperability failures
- Assumes random interoperability failures and a constant interoperation failure rate
- Leads to a large list of potential contributing factors to be studied

On the right track ... But, Challenge the Assumptions!

See [Sutton, 1999]

Reviewing the Bathtub Curve



Source [NIST, 2003]

Extending Sutton's Analogy

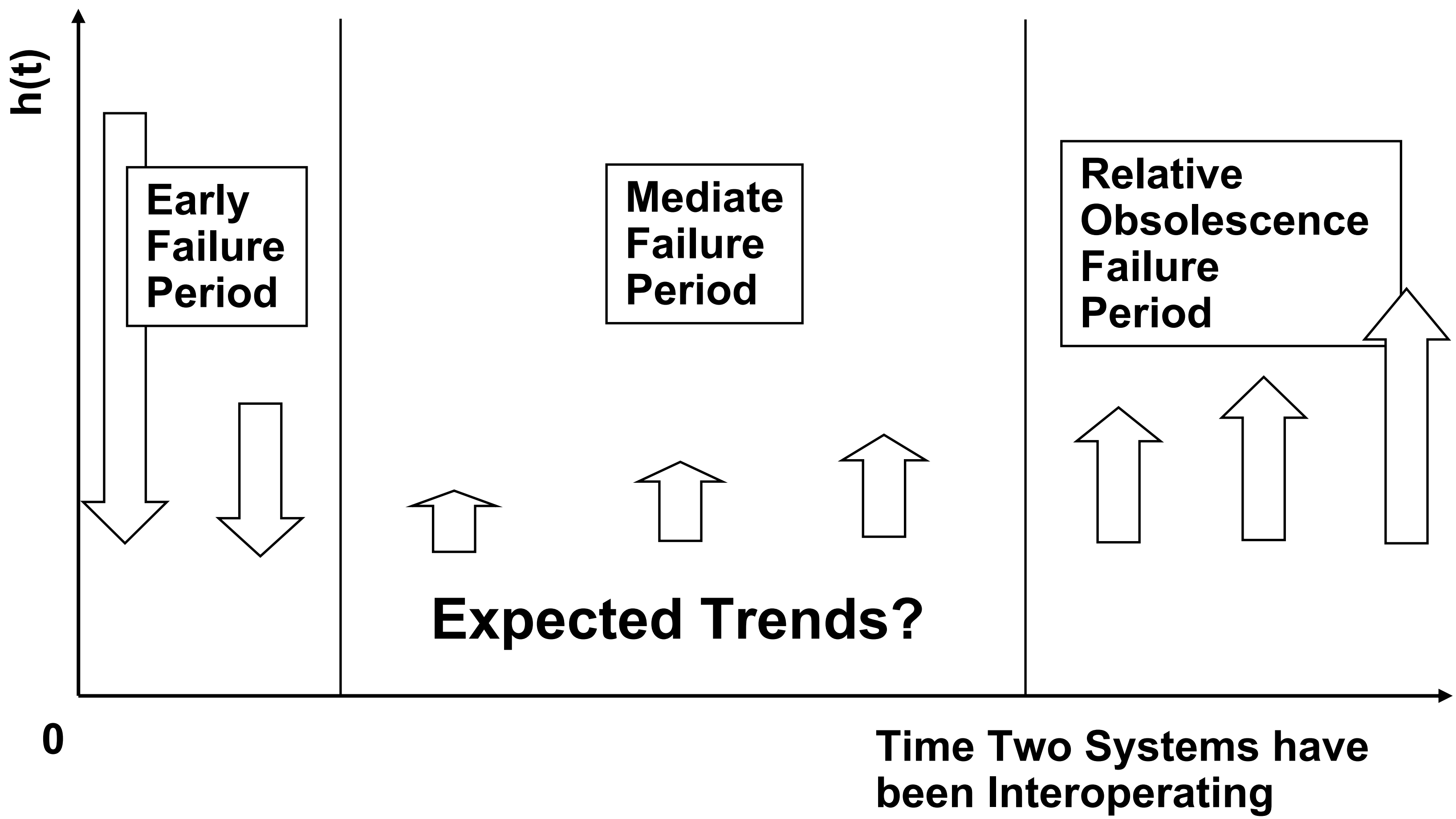
- Consider interoperability interaction between two systems over time
- Assume resulting model can be applied to equipment strings by pair-wise extension
- Power of analogy is that "*different failure mechanisms may tend to dominate at different times*"
- Time in this analogy is the time that two systems have been interoperating

See [Sutton, 1999]

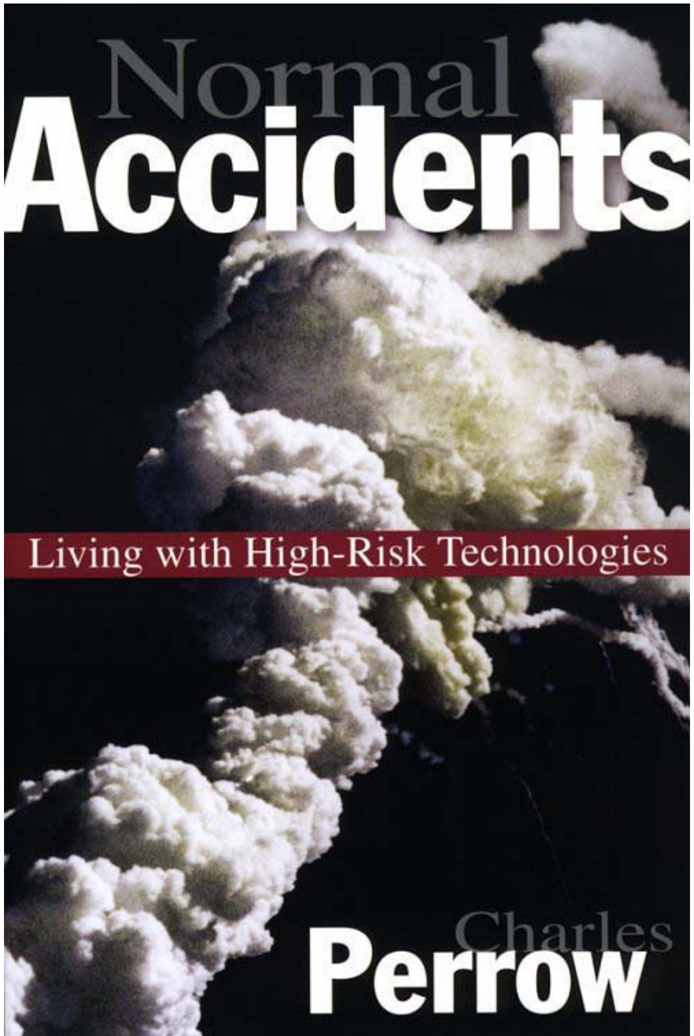
Three Postulated Time Periods

- **Early — relatively high failure rate; the two systems have little or no experience interoperating with each other.**
- **Mediate — relatively low failure rate; the two systems have some experience and a history of interoperating with each other.**
- **Relative obsolescence — relative failure rate that increases over time; occurs when one system's hardware or software is upgraded faster than the other system.**

Three Postulated Time Periods



Interoperability and Complexity



Critical System Properties:
Survey and Taxonomy[1]

Original version published in *Reliability Engineering and System Safety*, Vol. 43, No. 2, pp. 189–219, 1994

John Rushby
Computer Science Laboratory
SRI International
Menlo Park CA 94025 USA

Technical Report CSL-93-01, May 1993
Revised February 1994

More to the picture than a life distribution model based on the time two systems have been interoperating — character of system-to-system interaction also need to be considered…

See [Perrow, 1984] **See [Rushby, 1994]**

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System Interaction & Coupling

Interaction ***– "Ranges from "linear" to "complex," refers to the extent to which the behavior of one component in a system can affect the behavior of other components."***

Coupling ***– "can range from "loose" to "tight," refers to the extent to which there is metaphorical "slack" or "flexibility" in the system. Loosely coupled systems are usually less time constrained than tightly coupled one, can tolerate things being done in different sequences than those expected, and may be adaptable to different assumptions than those originally considered."***

Source [Rushby, 1994, Chapter 4, p. 42]

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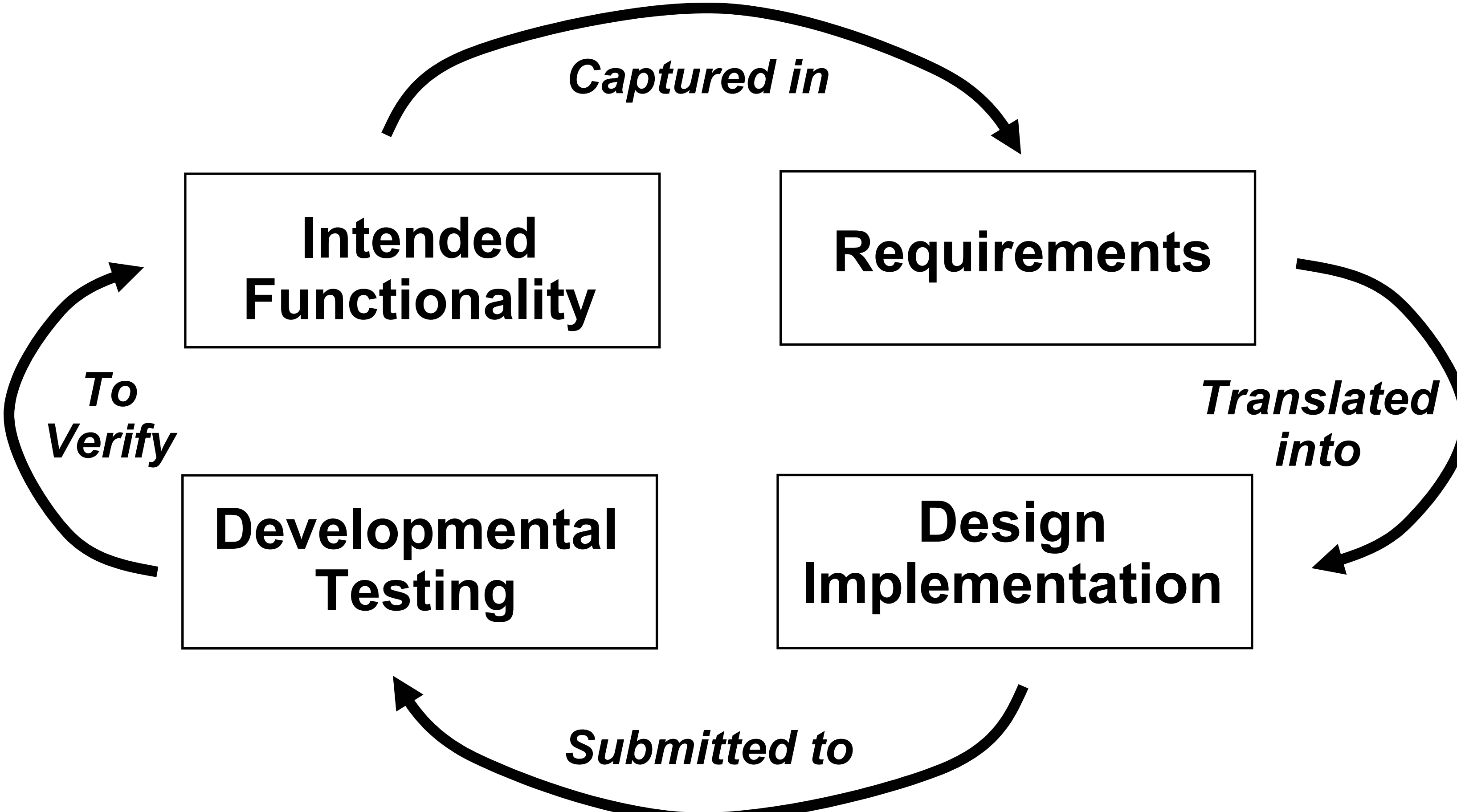
Early Failure Period



Both systems go through this process … faults can be introduced in first three blocks and not detected in the last

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Early Failure Period

Expected causes:

- Missing or inadequate requirements
- Design flaws
- Inadequate testing

System selction criteria:

- System introduced in last 5 years
- First use or major upgrade
- Mix of 1) tightly and loosely coupled and 2) linear and complex interactions

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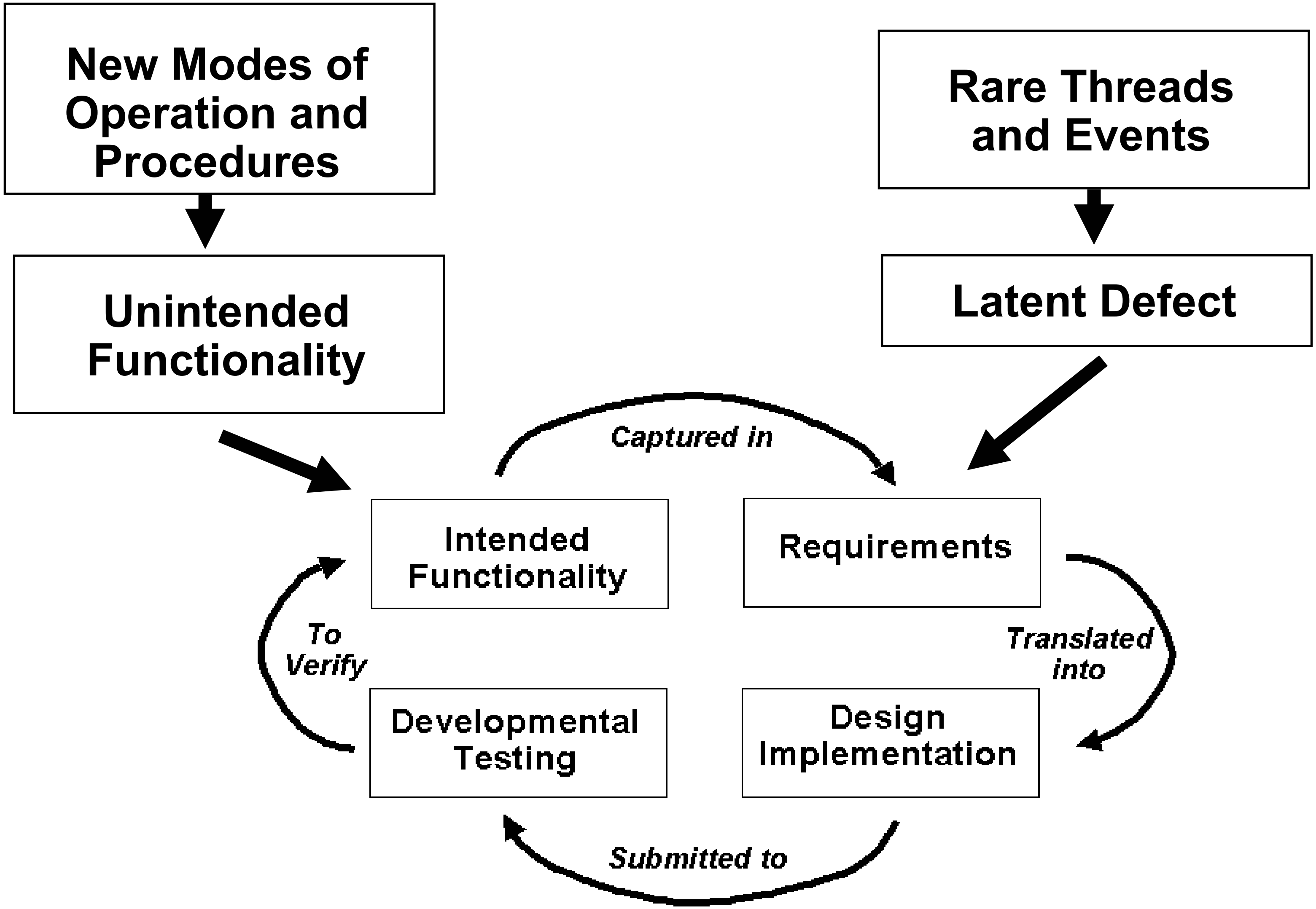
Mediate Failure Period



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Mediate Failure Period

Expected causes:

- New modes of operation and procedures leading to unintended functionality
- Rare threads or events that trigger latent defects

System selction criteria:

- Systems interoperating for at least 18 to 24 months before experiment, exercise, or failure occurance.
- Mix of 1) tightly and loosely coupled and 2) linear and complex interactions

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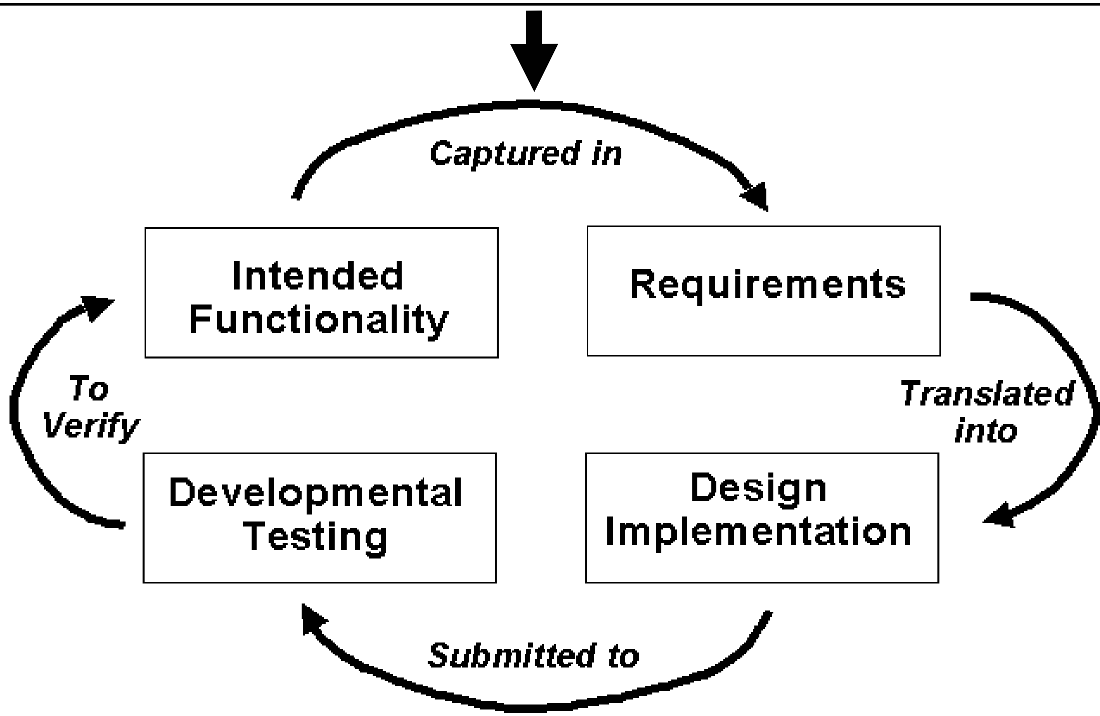
Relative Obsolescence Failure Period

One or more hardware and/or software upgrades in one system relative to another introducing interoperability faults



Relative Obsolescence Failure Period

Expected causes:

- Missing or inadequate requirements
- Design flaws
- Inadequate testing

System selction criteria:

- System introduced more than 5 years ago
- No major upgrades in last 3 years
- Mix of 1) tightly and loosely coupled and 2) linear and complex interactions

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Creating a Prediction Rule Based on the Theory

- First, build a Statistical Prediction Rule (SPR) to make binary "yes" or "no" decisions about a paricular system-to-system pair will have an interoperability failure
- Then, extend the resulting model to equipment strings using pair-wise analysis

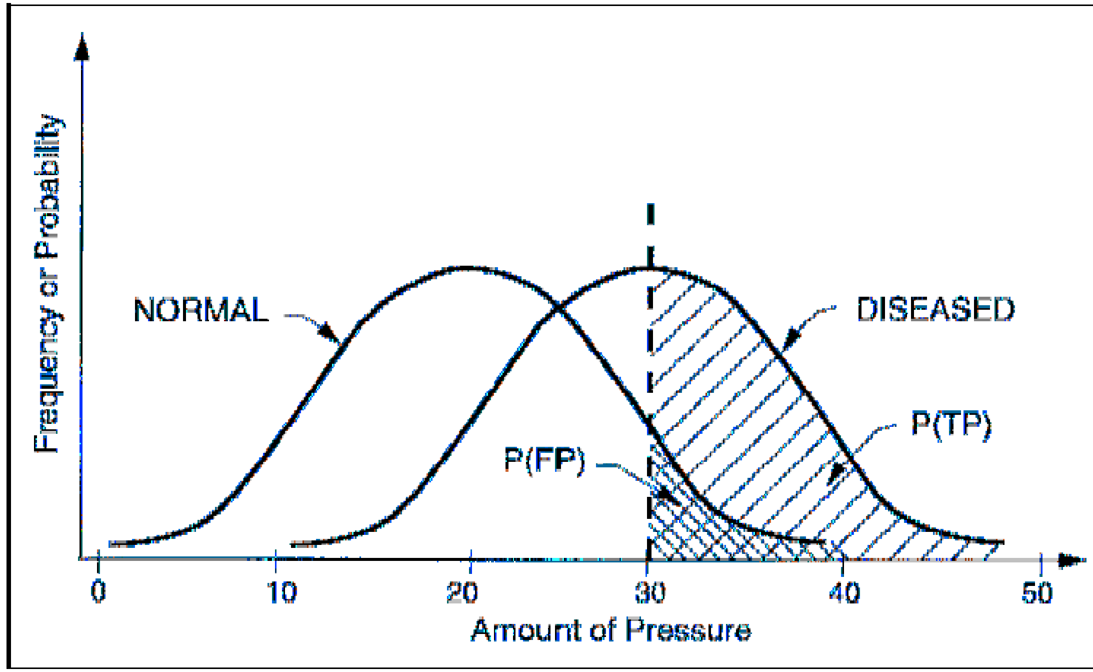
Statistical Prediction Rules

- **Statistical analysis is used to quantify the power of candidate predictive variables to discriminate between positive and negative instances of the diagnostic alternatives under study**
- **Variables may be added to a SPR and assigned their respective weights in a stepwise fashion**
- **An SPR can be constructed using both <u>objective</u> and <u>subjective</u> factors**
- **An SPR ends up being a set of <u>variables</u> and <u>weights</u>**

From [Swets et al., 2000]

Statistical Prediction Rules

Consider this example to understand how Statistical Prediction Rules work. Shown here are probability distributions of eye pressures for both healthy people and those with glaucoma. Establishing a decision threshold of 30 for diagnosing patients with glaucoma results in an accurate diagnosis of about 50% of the diseased population, P(True Positive), while about 10% of the healthy population will be mis-diagnosed with the disease P(False Positive) or false alarms.

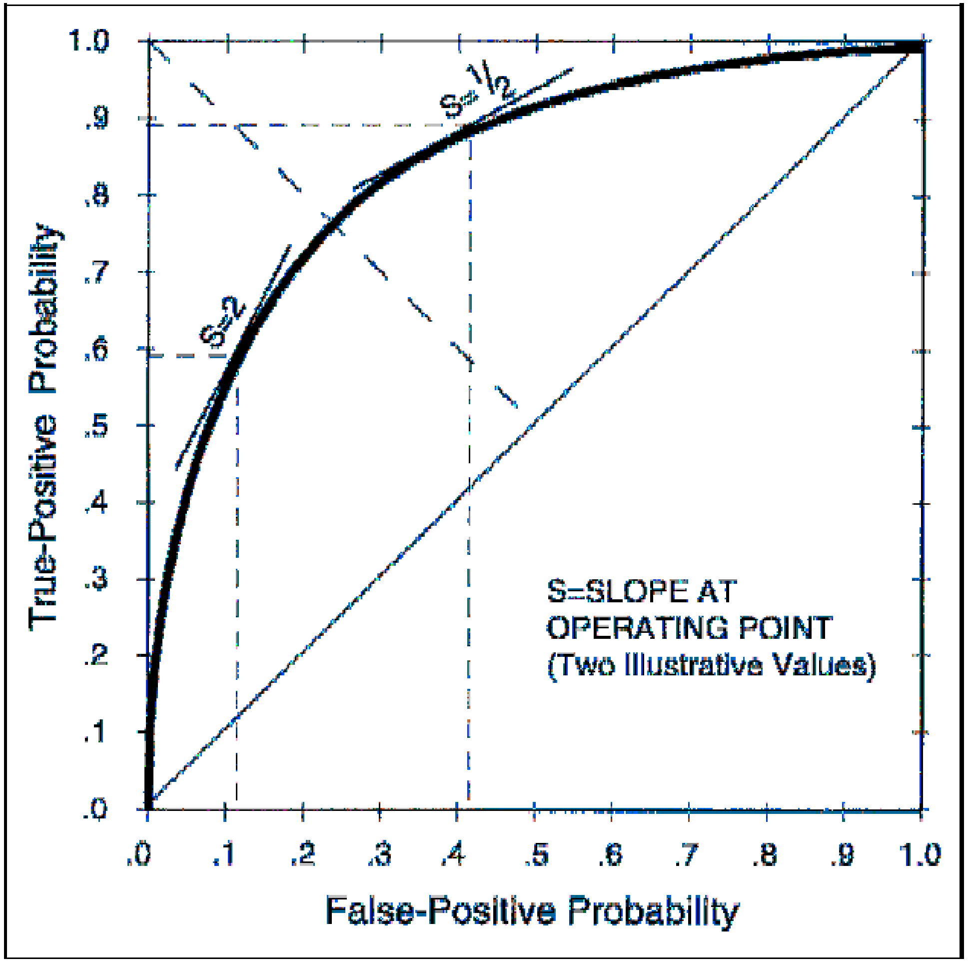


From [Swets et al., 2000]

Receiver Operating Characteristic

A Receiver Operating Characteristic (ROC) curve is created by plotting the areas under the distributions for each possible threshold value. For example, a threshold of 30 corresponds to the point where P(FP) x-axis = 0.1 and P(TP) y-axis = 0.5. This represents an approx threshold of S = 2. The diagonal line represents "chance" accuracy of 50/50 ratio True Positive to False Positive.

From [Swets et al., 2000]



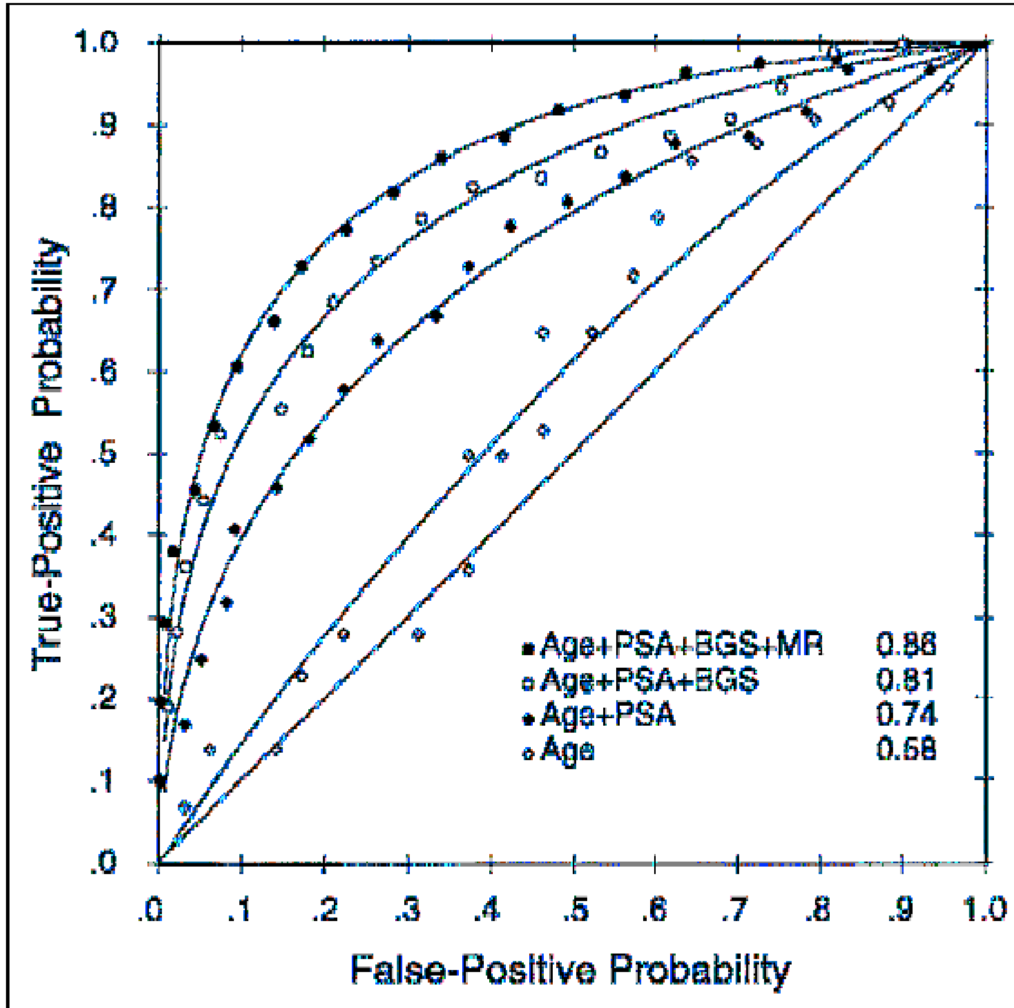
Where are these techniques being used?

- **Numerous fields including medical diagnostics, predicting violence among criminals, weather forecasting, law school admissions, aircraft cockpit warnings, qualility of sound in opera houses, and predicting wine vintage quality.**
- **The following example is taken from the field of medical diagnosis where several different pieces of information are combined to judge whether prostrate cancer has spread in a patient...**

From [Swets et al., 2000]

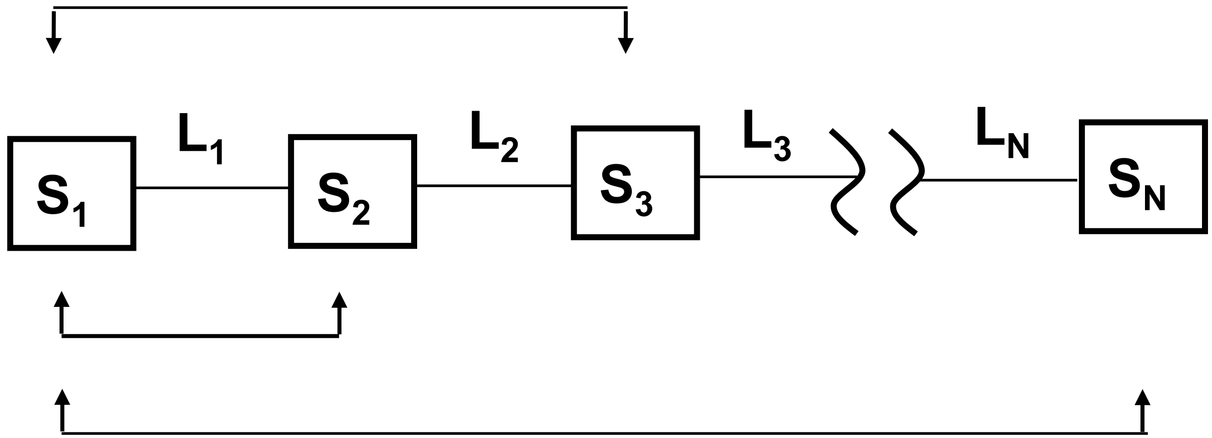
SPR for Prostrate Cancer

Empirical Receiver Operating Characteristic (ROC) curves for determining the extent of prostrate cancer, based on SPRs (Statistical Prediction Rules), using one, two, three, or four predictor variables. The closer to the upper left, the higher the SPR's accuracy.

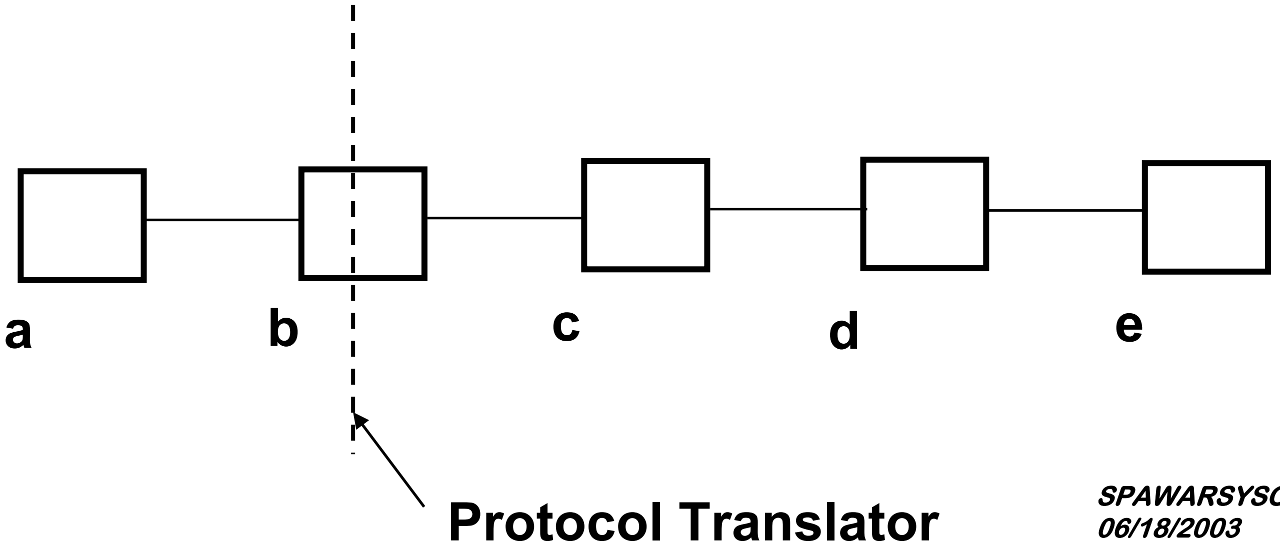


From [Swets et al., 2000]

Issues with Pair-wise Extension



Air Defense System Integrator (ADSI)



Next Steps

- Refine initial system selection criteria
- Collect and analyze data on initial systems to be studied
- Investigate establishing a center for studying interoperability failures at U.S. JFCOM, J8, Joint Interoperability and Integration (JI&I)
- Leverage NIST efforts and tools. (Error, Fault and Failure data collection and analysis tool)
- Foster a continuing dialog through this forum and others

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Summary

- A theory of interoperability failures has been developed
- It considers the interaction of two systems over time
- Postulates three distinct time periods:
  - Early
  - Mediate
  - Relative obsolescence
- Need to study some representative systems to refute or lend credence to the theory

Questions?

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Sutton's Problems with LISI

1. Does not address specific electrical interfaces
2. Does not address objects and object model compatibility
3. Assigns nominal values based on documentation, not objective system performance
4. Does not take into account that some systems may not need higher levels of interoperability to be considered successful
5. Does not explain how interoperability can be controlled, changed, or improved

Source [Sutton, 1999]

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