SAFE and Secure: Deeply Integrating Security in a New Hazard Analysis

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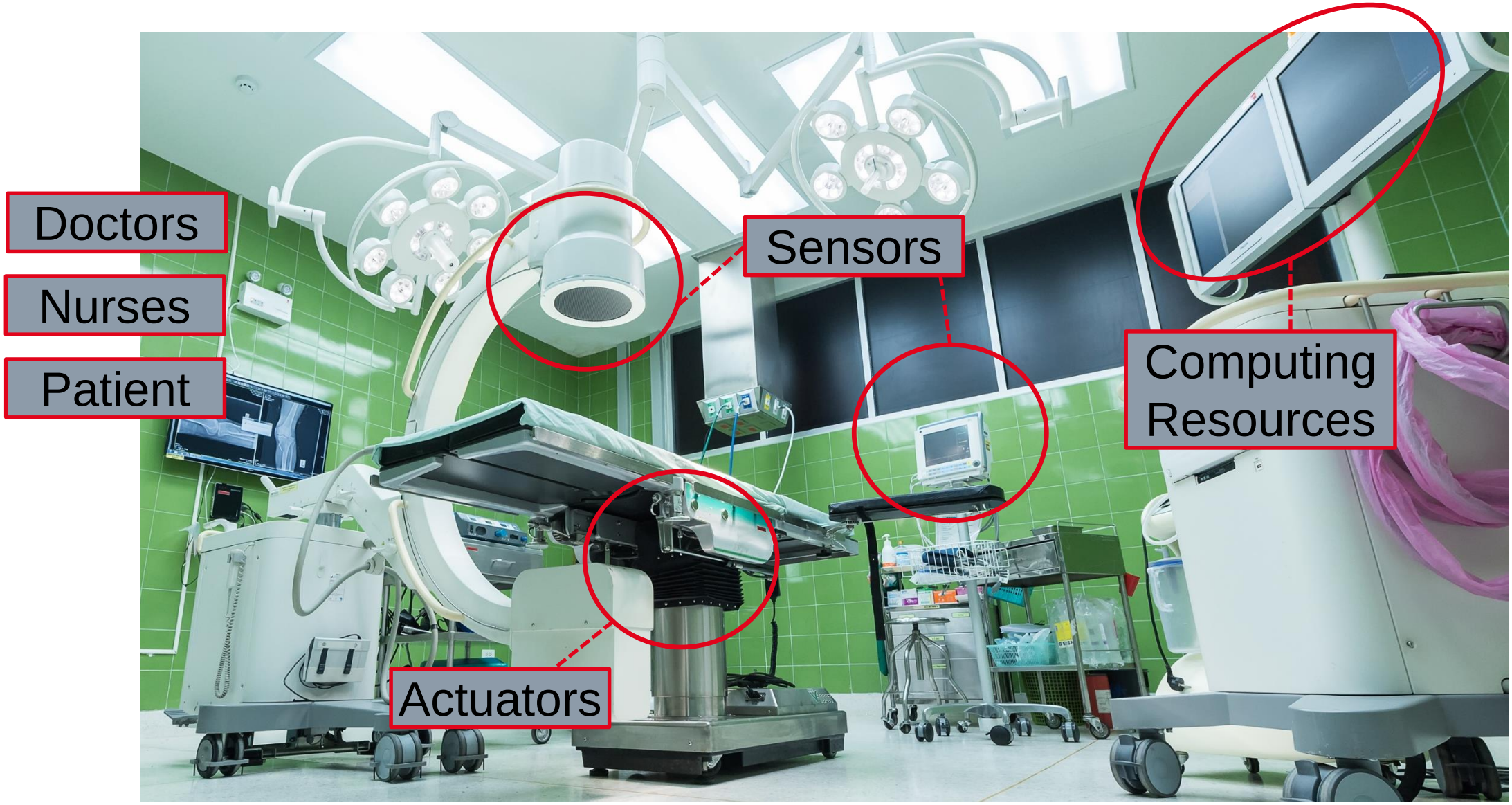
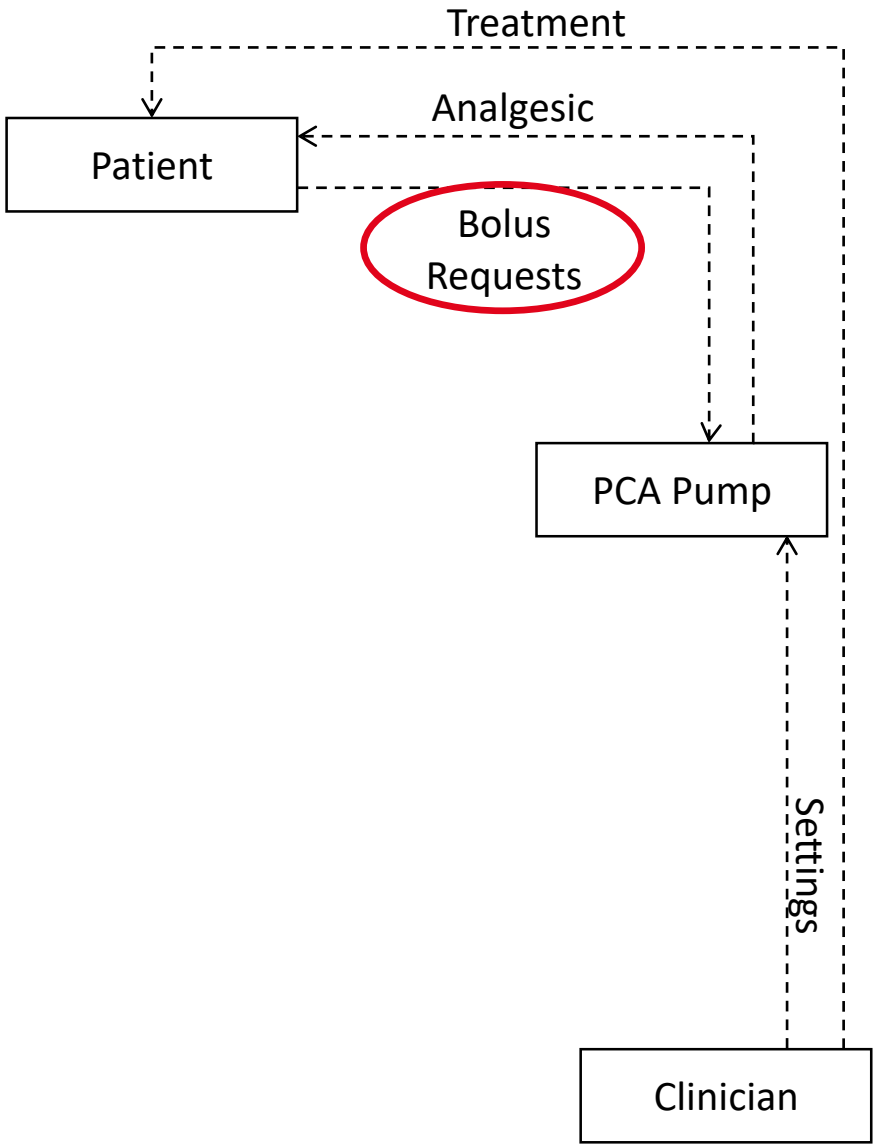
Example Cyber-Physical System: Operating Room



1. **Research Overview**
    1. Example Application
    2. Research Landscape
2. Our Approach
3. Payoffs
4. Next Steps

A Networked Medical Application

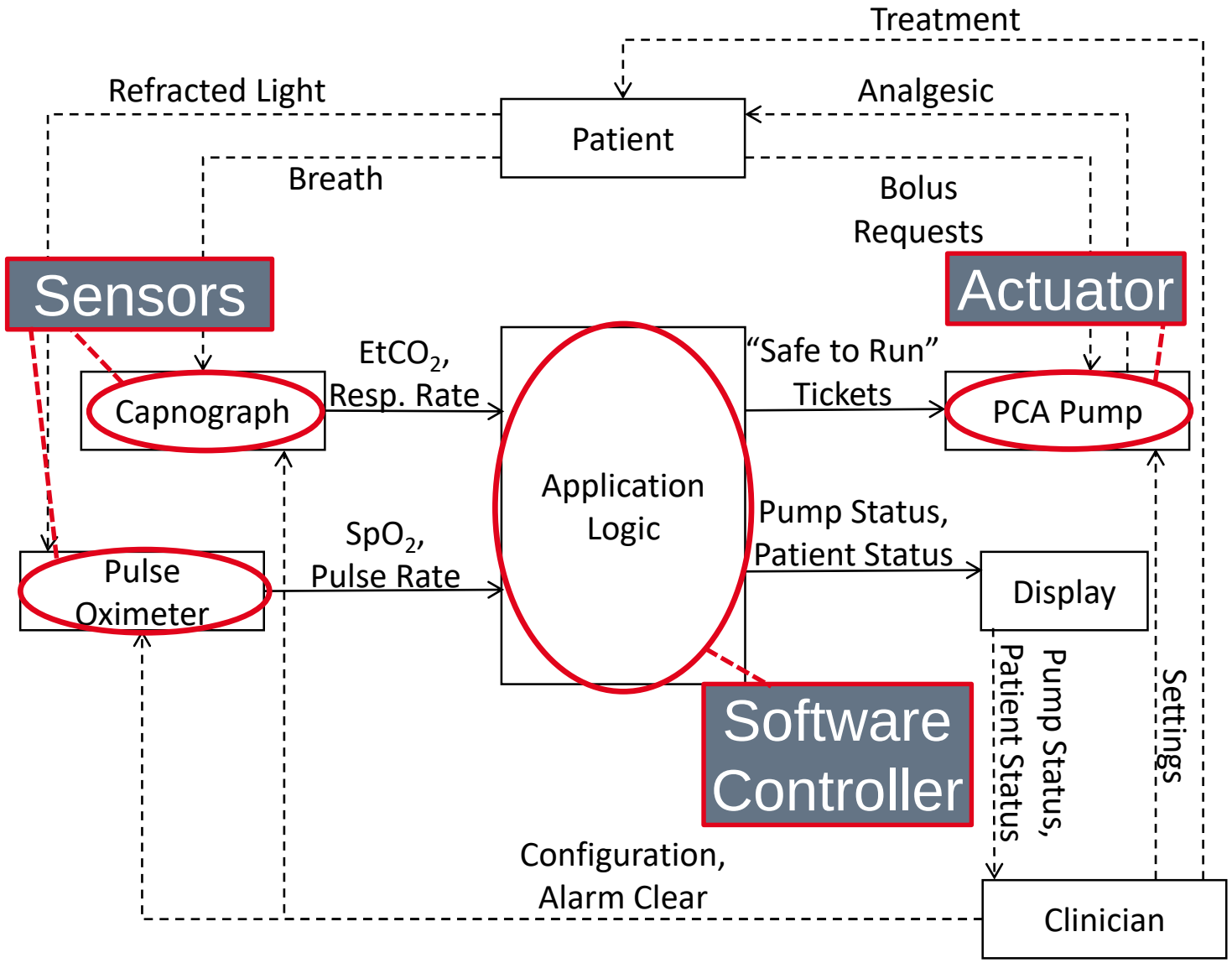


In the status quo, hospitals use "patient-controlled analgesia" pumps to manage temporary, severe pain.

Patients push a button to send a "bolus request" to trigger administration of a strong – typically opioid – analgesic.

Safety problems exist, but anesthesiologists have suggested integrating common sensors and simple application logic into a "closed loop" system.

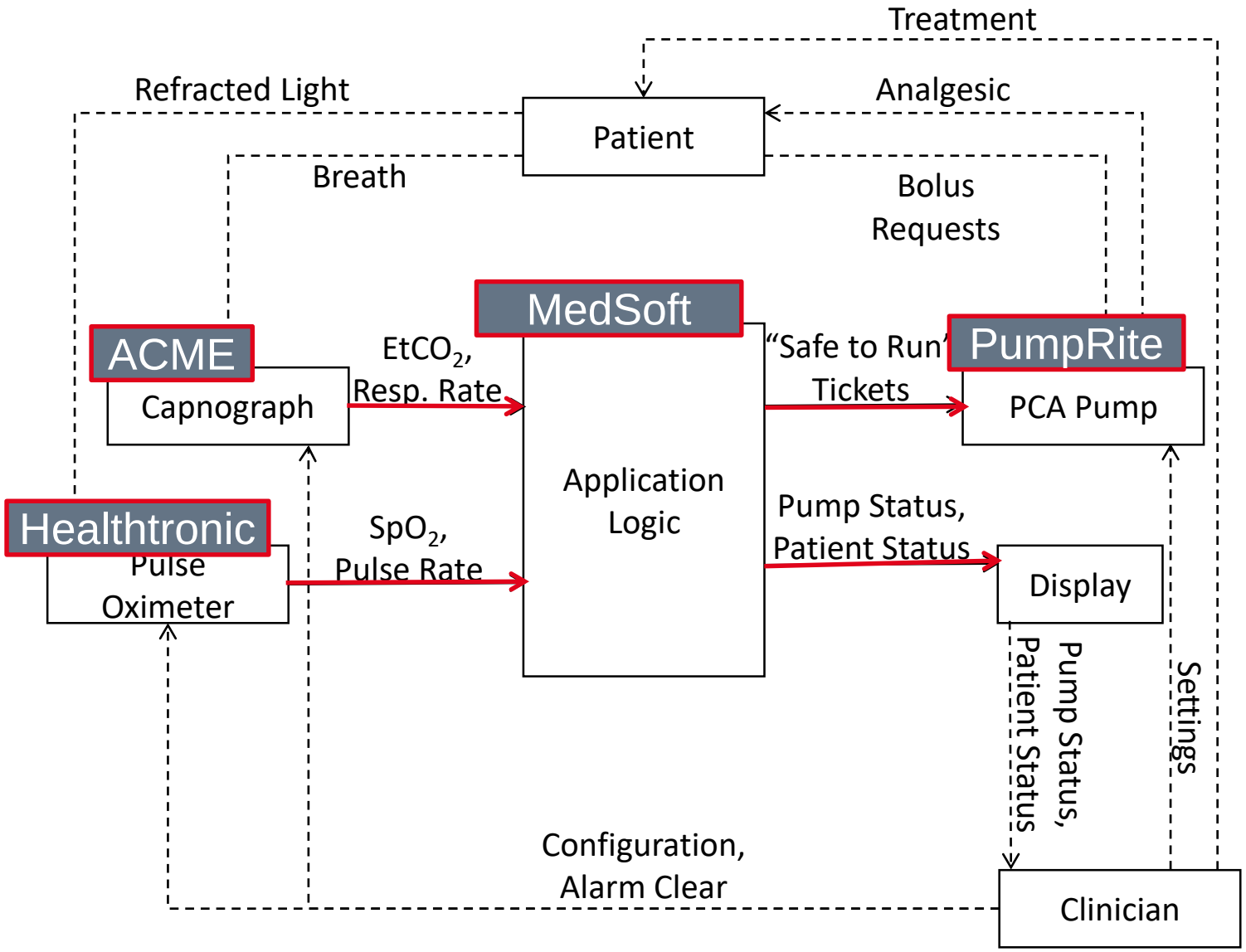
A Networked Medical Application



Here's a conceptual view of what an integrated system might look like:

- **Sensors** – Measure respiratory health, ie: SpO_2, respiratory and pulse rates, etc.
- **Controller** – Software to convert sensor readings into overall "health score" and enable / disable PCA pump
- **Actuator** – The PCA pump modifies the patient (ie, controlled process) through responding (or not) to bolus requests

A Networked Medical Application



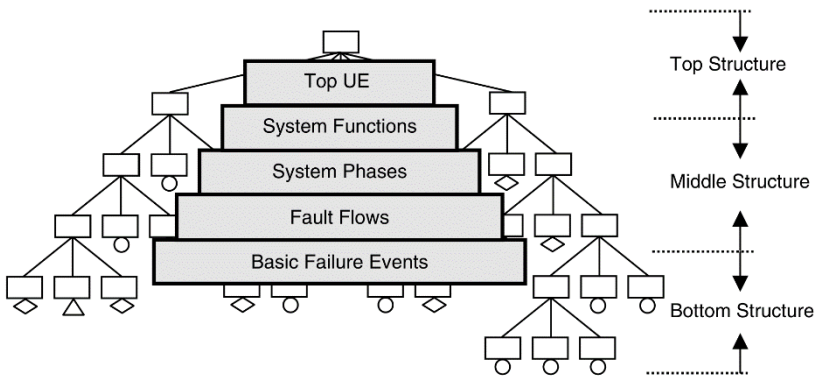
The system is (conceptually) simple, but exposes a number of complexities:

- **Heterogeneous Components** Different vendors may supply medical, networking, and computational components
- **Variability** – The exact configuration isn't known until the system is deployed and about to be used on a patient
- **Network Enablement** Components expose behaviors, including actuation commands, over network interfaces

Research Landscape

FMEA Worksheet

Item	Failure Mode	Failure Rate	Immediate Effect	System Effect		
A						
B						
C						
D						



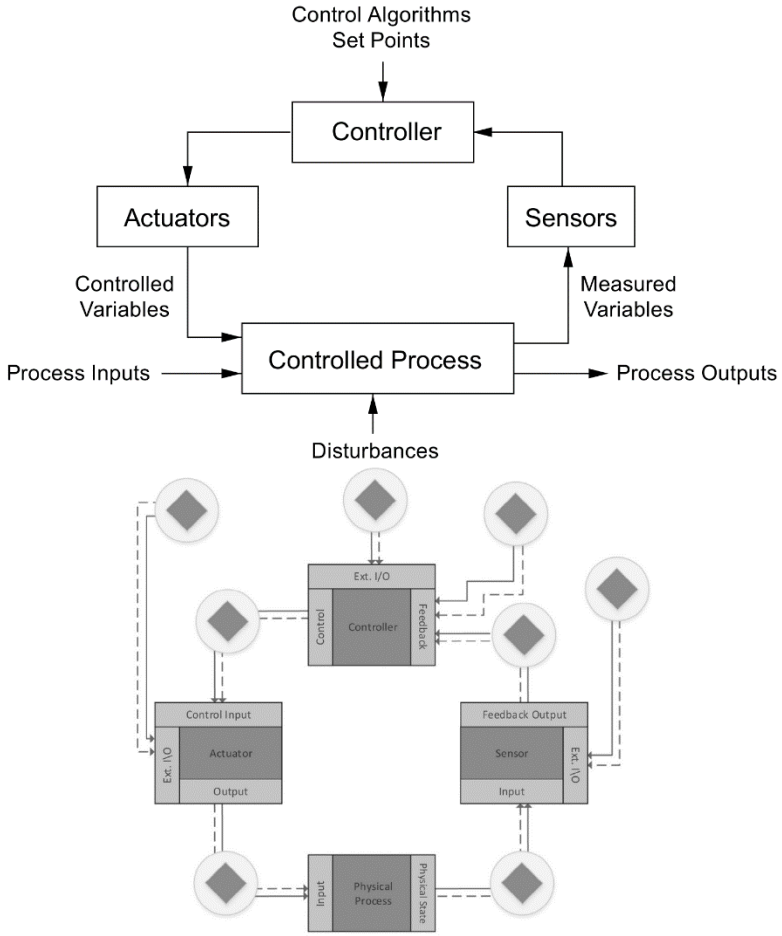
Example FMEA worksheet and FTA diagram, from Ericson's *Hazard Analysis Techniques for System Safety*

Traditionally, safety of critical systems is analyzed using *hazard analyses*.

Most hazard analysis techniques pre-date modern levels of interconnectivity, though:

- FMEA (1949)
- FTA (1950s)

Research Landscape



Example basic and security-extended control loops from Leveson (2011) and Schmittner et al. (2017)

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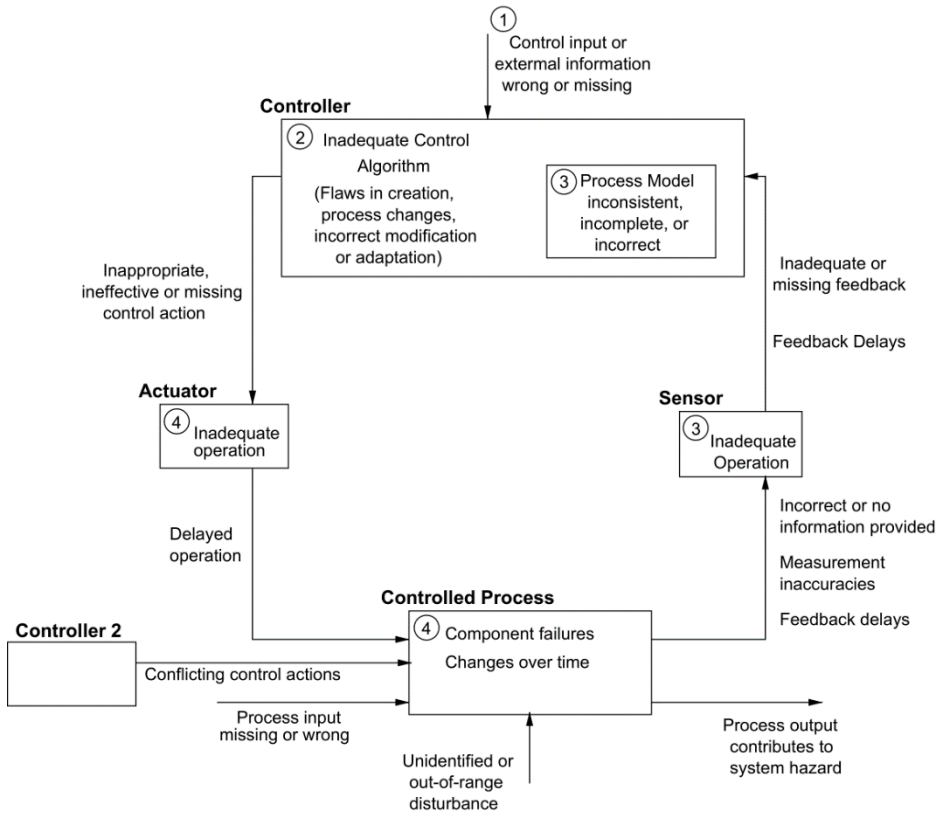
Security has been integrated in some of these techniques (see Schmittner SAFECOMP16)

System Theory integrated recently (2011) by Leveson

- STPA-Sec and STPA-SafeSec followed

	Safety-Focused	**Security-Aware**
Traditional Causality	FMEA, FTA, etc.	FMEA (Sec), FTA (Sec)
System Theoretic	STPA	STPA-Sec, STPA-SafeSec, SAFE

The Role of Guidewords



Example guidewords from Leveson (2011)

All of these techniques rely on the concept of *guidewords*.

- Terms used to guide analysis and ensure minimum coverage of basic concepts
- Almost always ad hoc, with no traceability to existing literature

Objective:

Unified set of semantic error/effect concepts, based on well-established literature, usable for safety and security.

1. Research Overview
2. **Our Approach**
   1. Dolev-Yao
   2. Worked Example
3. Payoffs
4. Next Steps

Systematic Analysis of Faults and Errors

Systematic Analysis of Faults and Errors (SAFE) is a new hazard analysis technique that works with STPA on technical elements of systems

- Importantly, SAFE can use any supplied set of guidewords

For this work, my co-authors and I wanted to look for a foundational basis for safety and security overlap.

We decided to start with guidewords for a number of reasons:

- Dictate failure modes considered by analysts
- Are intuitively understandable / don’t require extensive training
- SAFE’s configurability provides an excellent vehicle for testing them

A Dolev-Yao Based Guideword Set

Guidewords based on the Dolev-Yao model exhibit three desirable properties:

- Emphasize error *observability* – No mention of error cause
  - Separating cause from effect is a key part of SAFE & enables numerous benefits
- (Near) Completeness – Every* error type can be described
- (Near) Minimality – Removing a guideword from the set means that some errors cannot be described

System Safety	Dolev-Yao	Network Security
None	Read	Violate Privacy
Corrupt Value	Modify Existing	Craft Arbitrary Packets
Late / Dropped Message	Delay / Drop	Increased Latency / Packet Loss
Early Message	Craft and Send	Impersonate, Deny Service

** Barring pathological error behaviors*

Worked Example – Methodology

We repeatedly re-performed part of SAFE's original evaluation (on application logic) using different guideword sets

We identified six improvements:

- Alarms – To alert a clinician of a problem that requires intervention
- Timeouts – To prevent message "flooding"
- Timestamps – To prevent delayed tickets from being used
- Negative Ticket Values – Specify "unsafe" time windows
- Cryptographic Hashing/Signing – To prevent message forgery
- Encryption – To prevent snooping on private medical data

Worked Example – Evaluation

Tried to judge how likely a guideword set was to suggest a potential design improvement

Dolev-Yao fared well, though sample size / subjectivity prohibit drawing firm conclusions

	Dolev-Yao	Avizienis Taxonomy	STPA-SafeSec	STPA/ STPA-Sec
Alarms	✓	✓	✓	✓
Timeouts	?	✓	?	✓
Timestamps	✓	✓	✓	✓
Negative Ticket Values	?	?	?	?
Cryptographic Hashing/Signing	✓	✗	✓	?
Encrypted Tickets	✓	✗	✗	✗

Legend: Will the guideword set suggest the design improvement?	
✓	probably
?	possibly
✗	probably not

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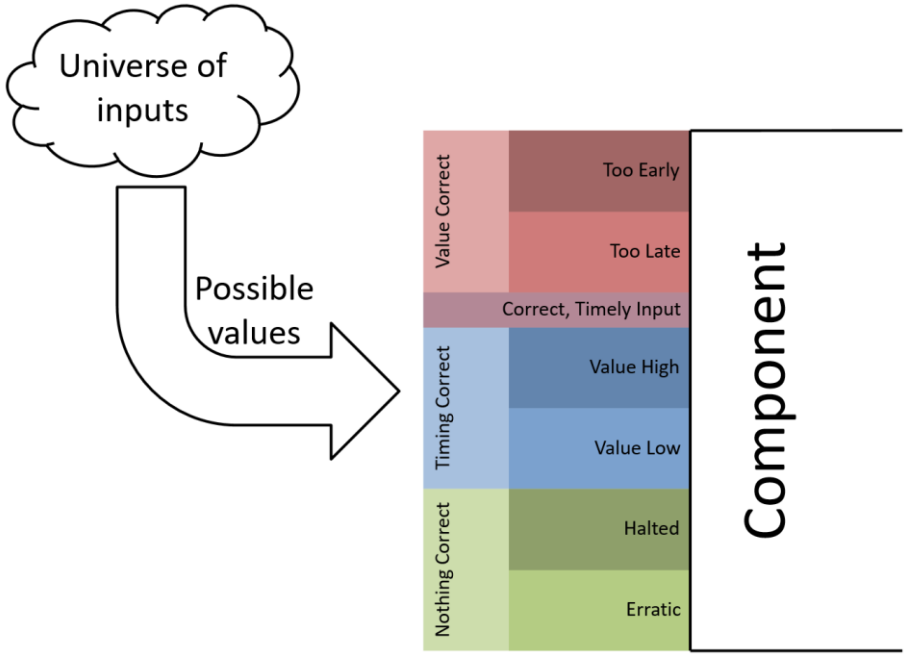
3. **Payoffs**
   1. Effects Based Analysis
   2. Explicit Adversary Model
4. Next Steps

Effects Based Analysis

Merging Safety and Security

- Reduced Overhead – Less rework / duplicated analysis effort
- Fewer problems “fall through the cracks” – Many safety and security problems interact
- See Friedberg et al. in 2016 “Journal of Information Security and Applications”

Effects Based Analysis



State space compression from Procter (2016)

Analysis Space Reduction

- Number of error causes are unbounded and may be unknowable
- Effects are (commonly) statically determinable and tightly bounded
- Similar to state-space reduction techniques in model checking

Effects Based Analysis

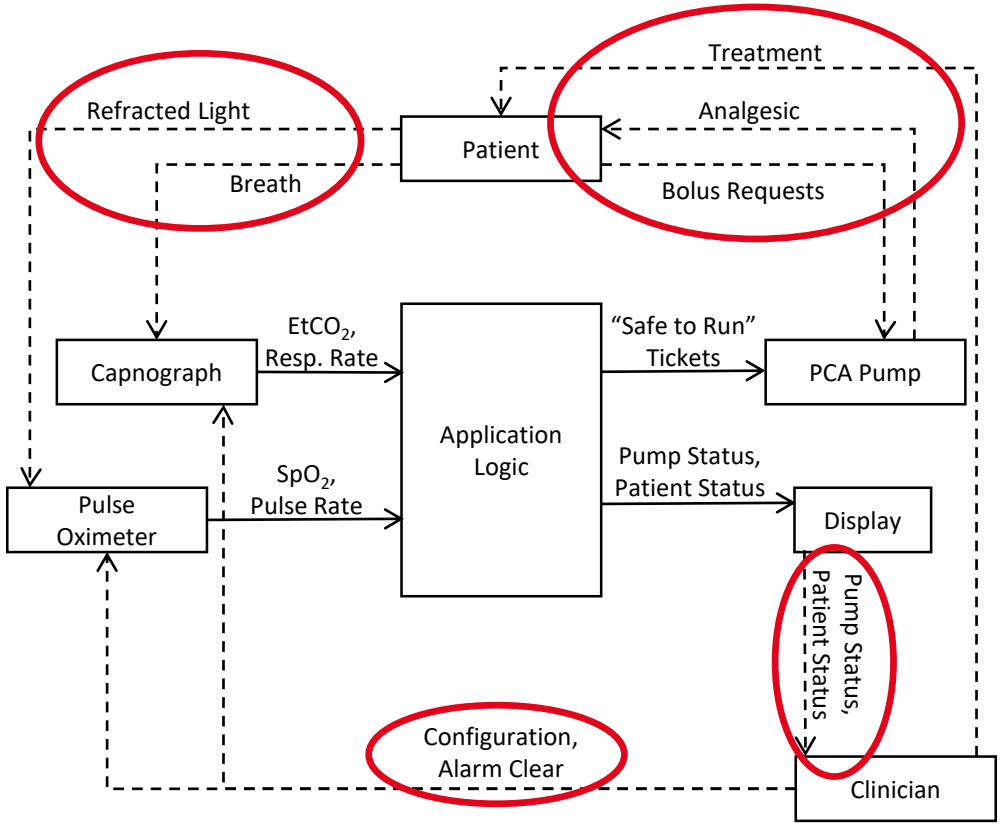
Partial Independence / Compositionality

- Components can be analyzed independent of their input-producers
  - (*Not* independent of output-consumers)

Formal Methods

- Similar efforts in pure-software space to automatically derive assumptions required for safe operation
- See Rushby's 2011 FACS "Assumption Synthesis"

Explicit Adversary Model Use



Dolev-Yao includes a complete set of of network based threats

- But it excludes all others, eg: compromised software/hardware (during development or at runtime)
- Threats that are excluded must be addressed (eg, physical security, TPM chips, etc) and *discharged as environmental assumptions*

Helpfully, all threats will necessarily manifest as a Dolev-Yao-classifiable error in successor components.

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Future Work

Guidance on when certain guideword sets are appropriate

- Sourced from academic, industrial, and governmental/regulatory authorities
- Deeply integrated with tooling and techniques [Procter and Hatcliff, ASSURE15]

Continue to move system safety and formal methods communities closer

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