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

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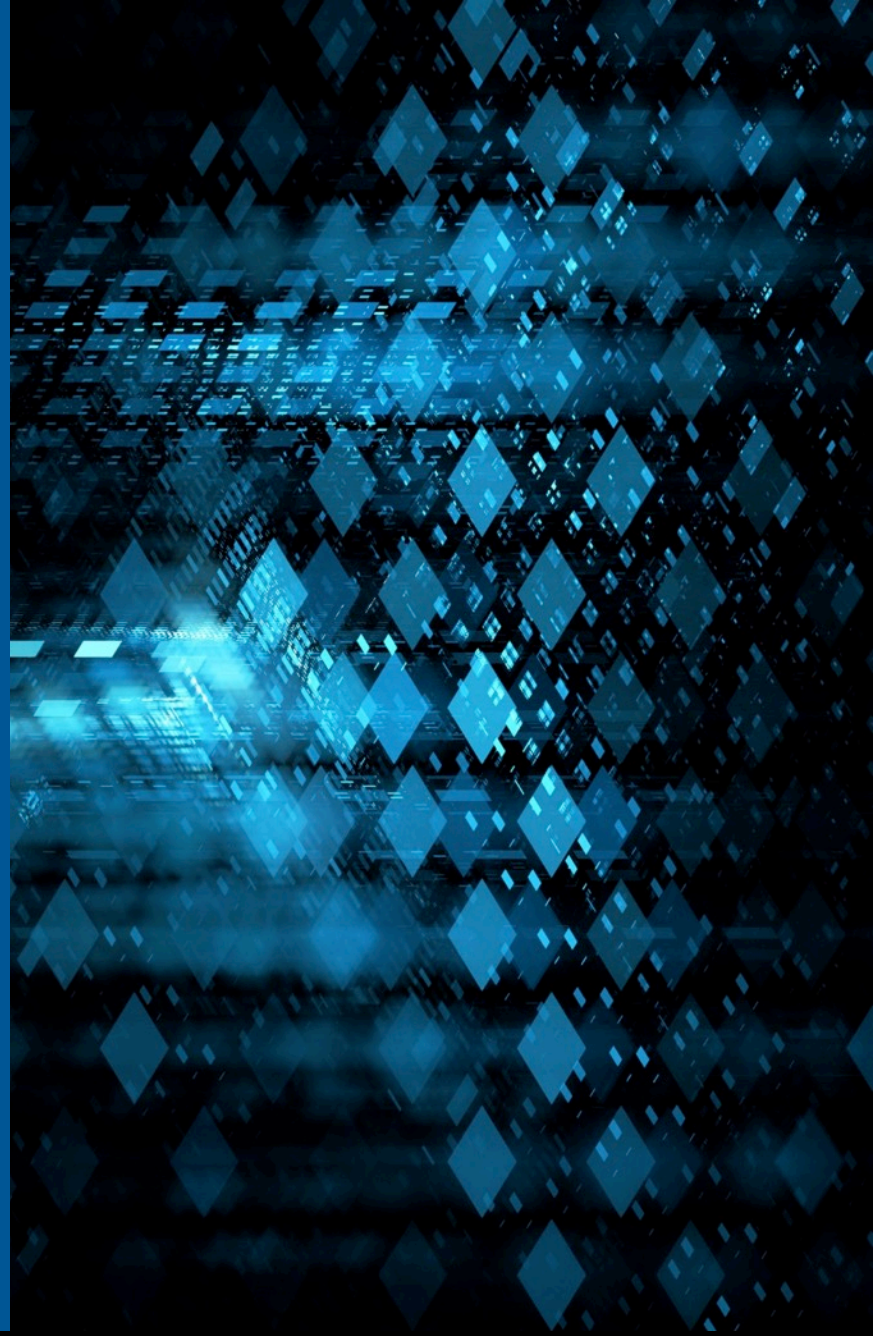

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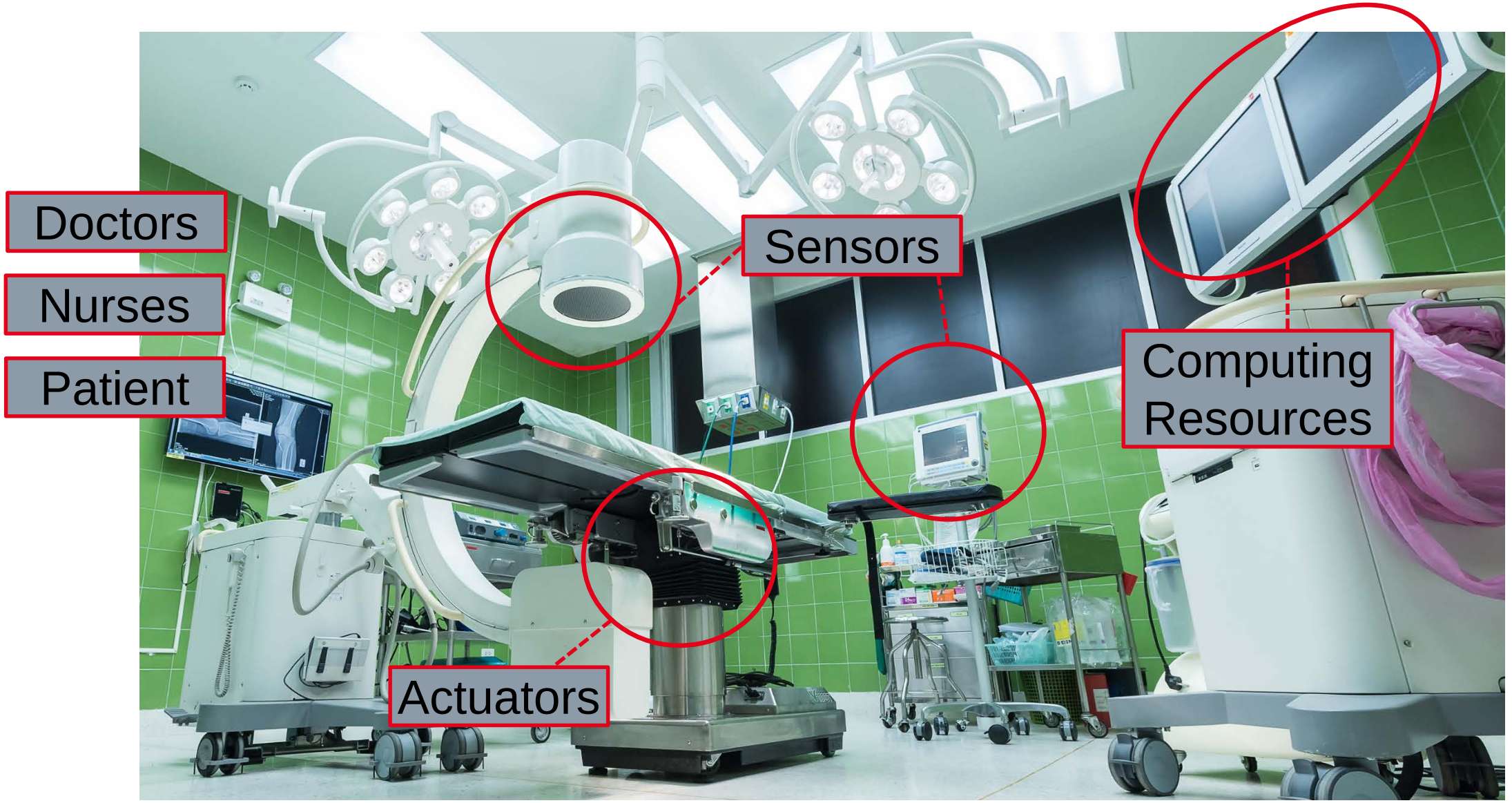
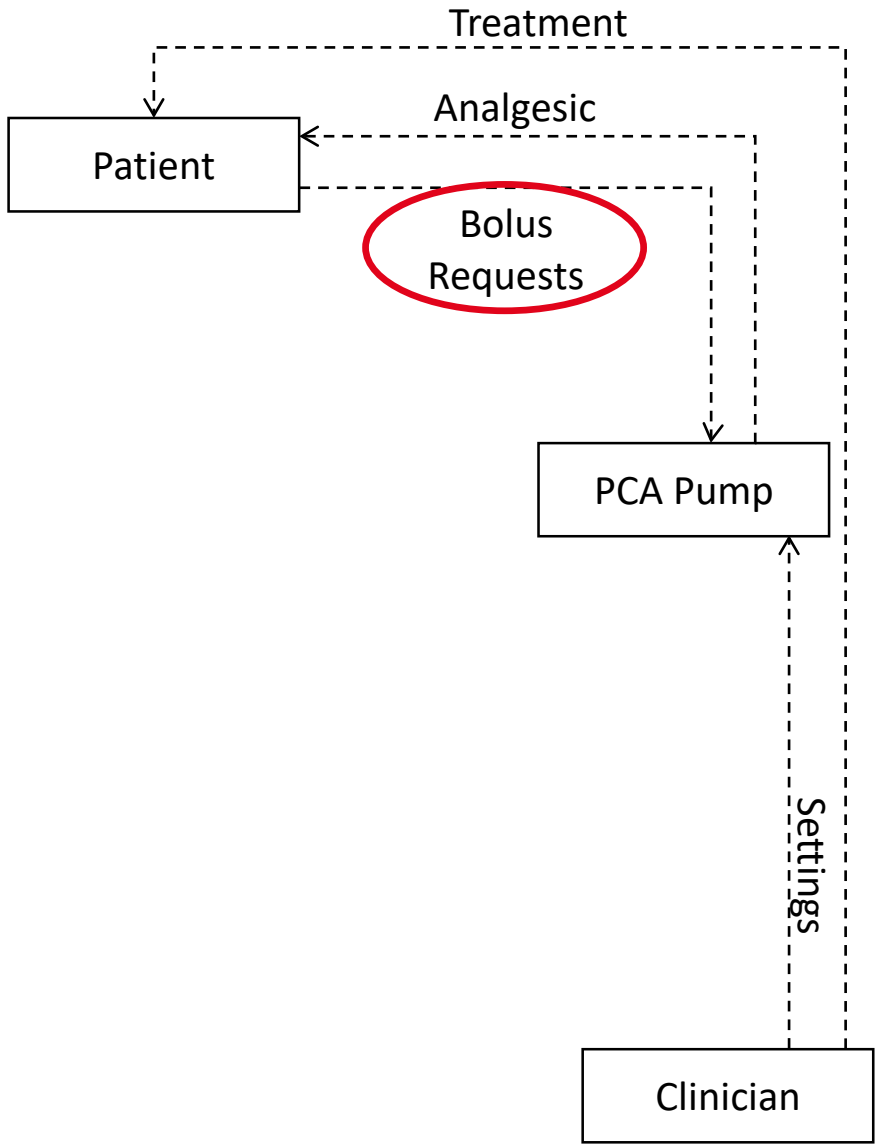
Example Cyber-Physical System: Operating Room



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

A Networked Medical Application

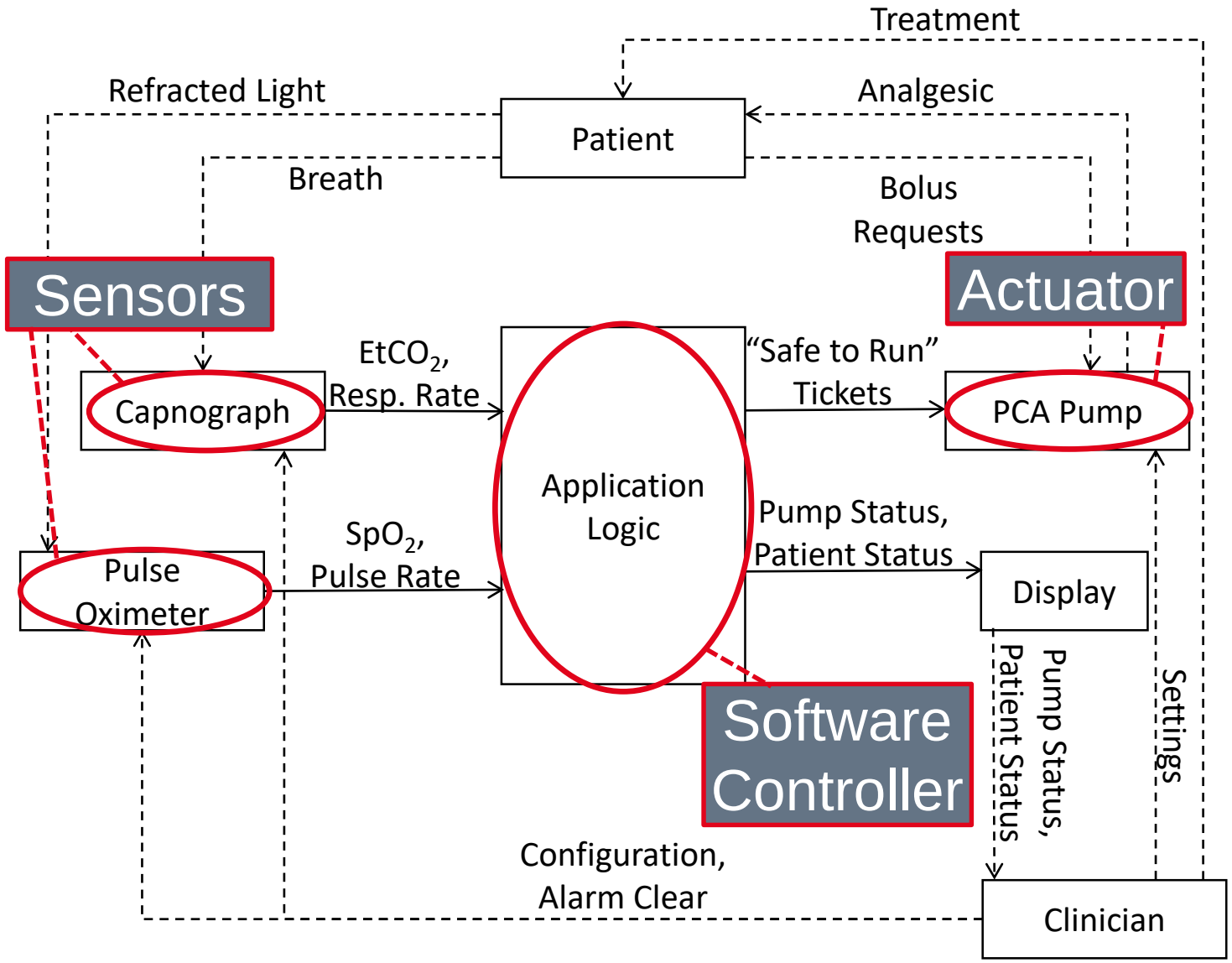


In the status quo, hospitals use "patient-controlled analgesia" pumps to manage temporary, severe pain.

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.

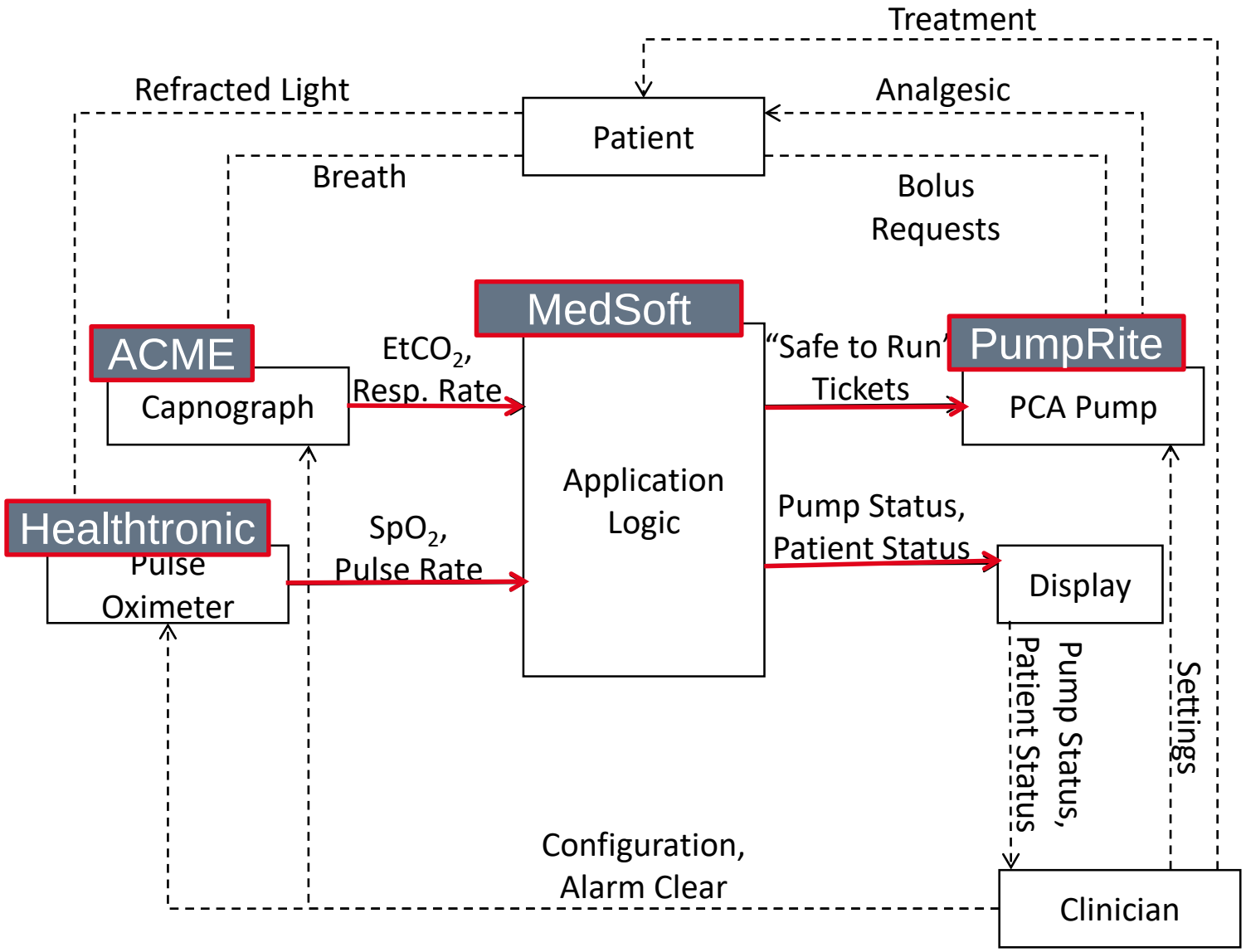
A Networked Medical Application



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

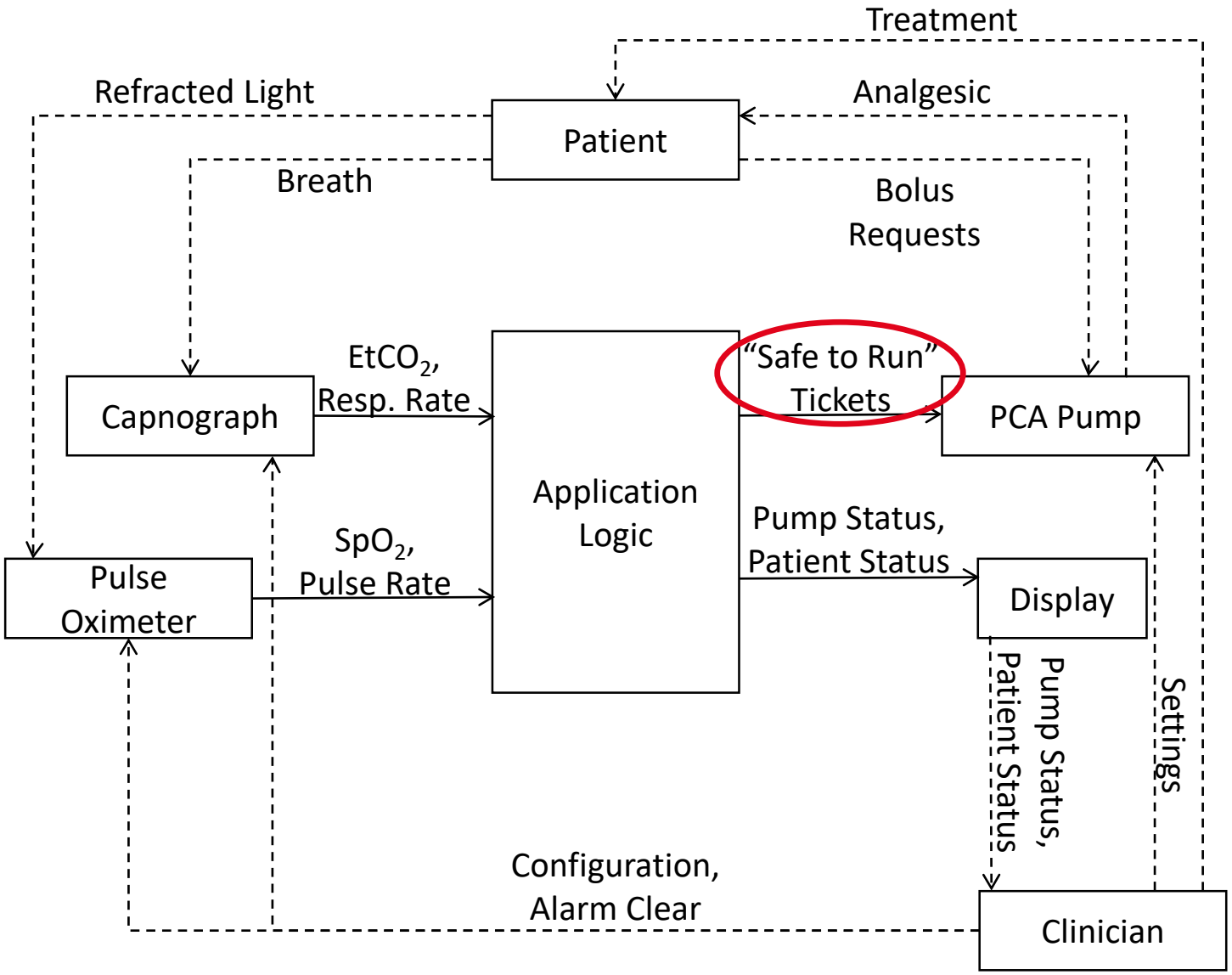
A Networked Medical Application



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

A Networked Medical Application



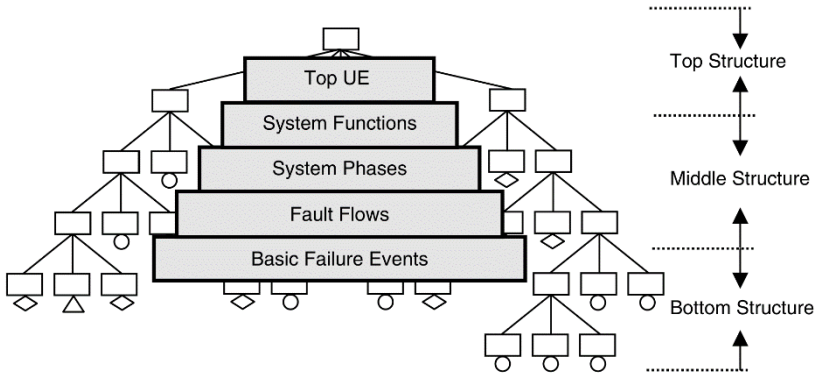
Previous research (by Arney et al.) has shown that rather than send "on/off" commands leave the system vulnerable to network dropout.

They suggest using "tickets" that specify time windows where it's safe to respond to bolus requests.

Research Landscape

FMEA Worksheet

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



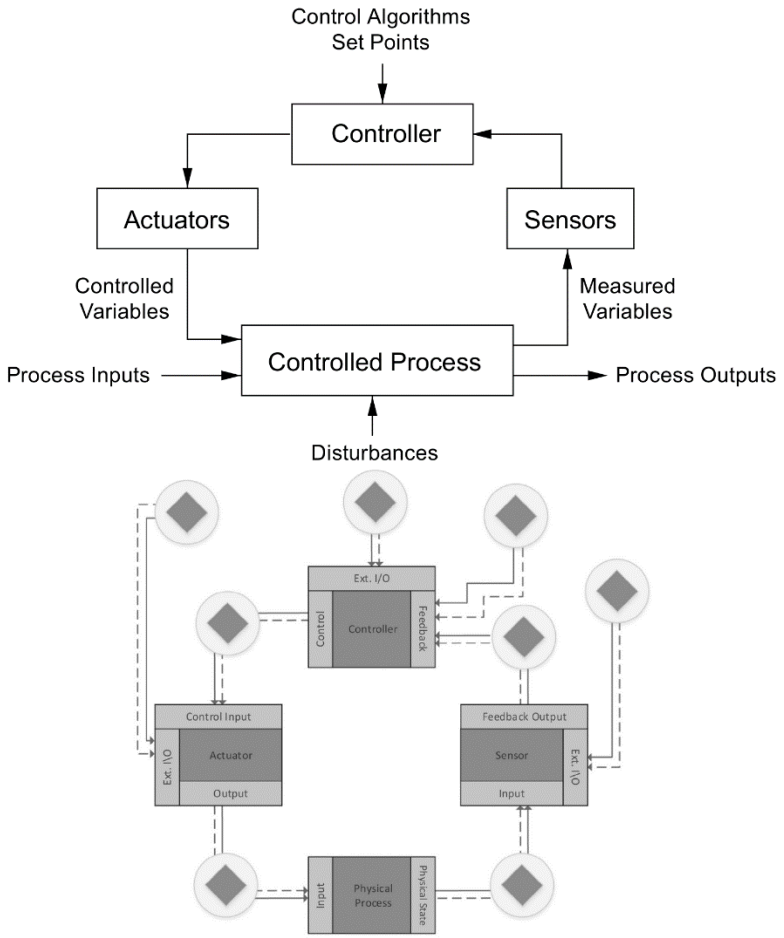
Example FMEA worksheet and FTA diagram, from Ericson's *Hazard Analysis Techniques for System Safety*

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

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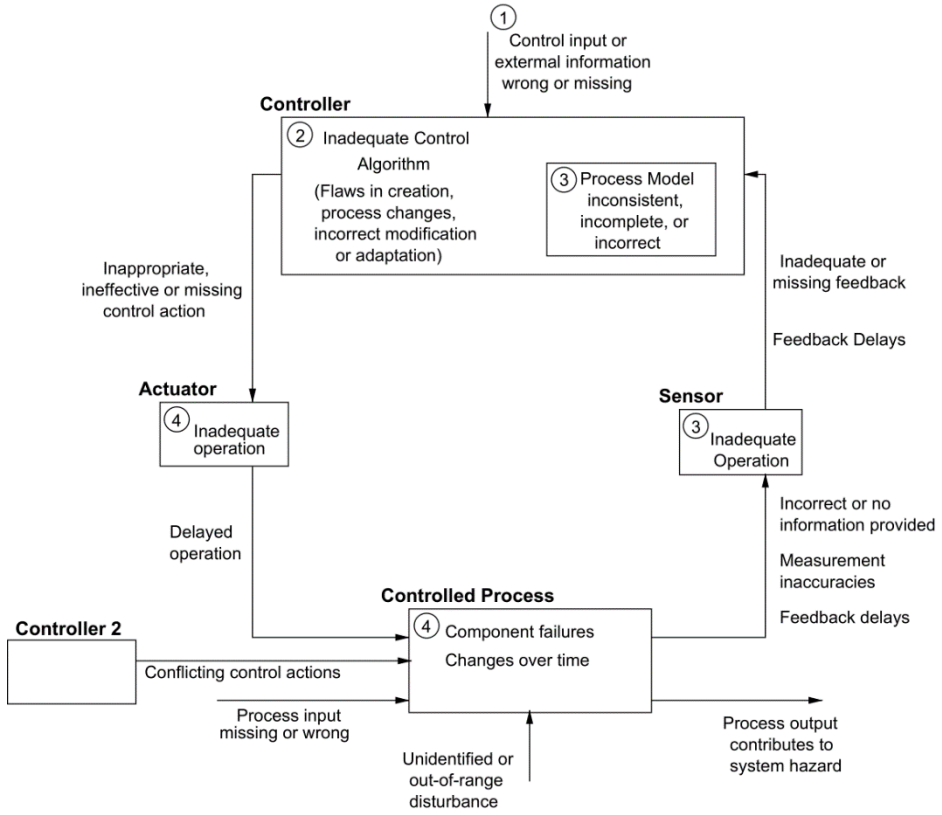
Security has been integrated in some of these techniques (see Schmittner SAFECOMP16)

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
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SAFE and Dolev-Yao

Systematic Analysis of Faults and Errors (SAFE) is a new hazard analysis technique (full disclosure: from my dissertation) 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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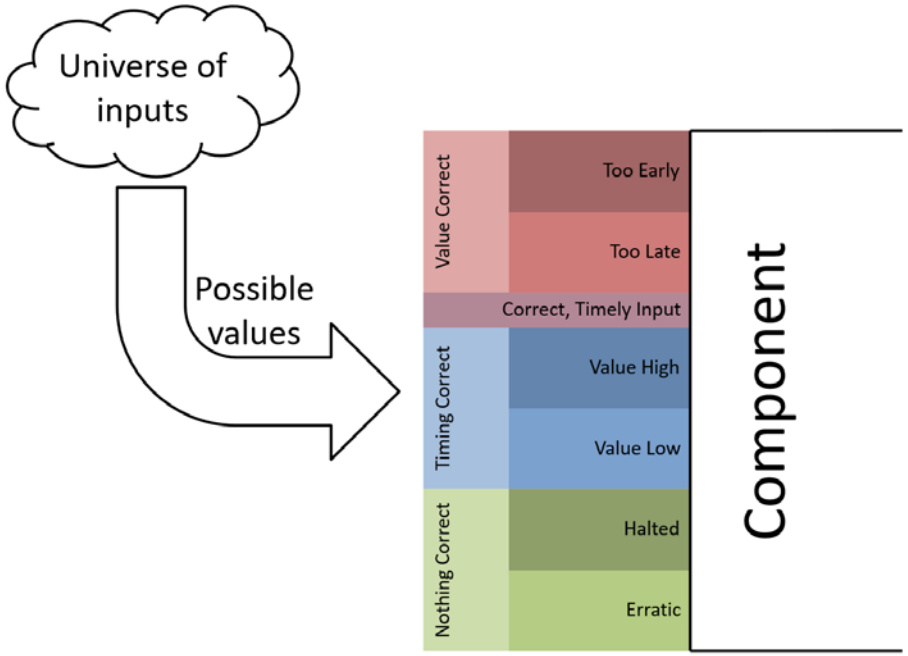
3. **Payoffs**
    1. Effects Based Analysis
    2. Explicit Adversary Model
4. Next Steps

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

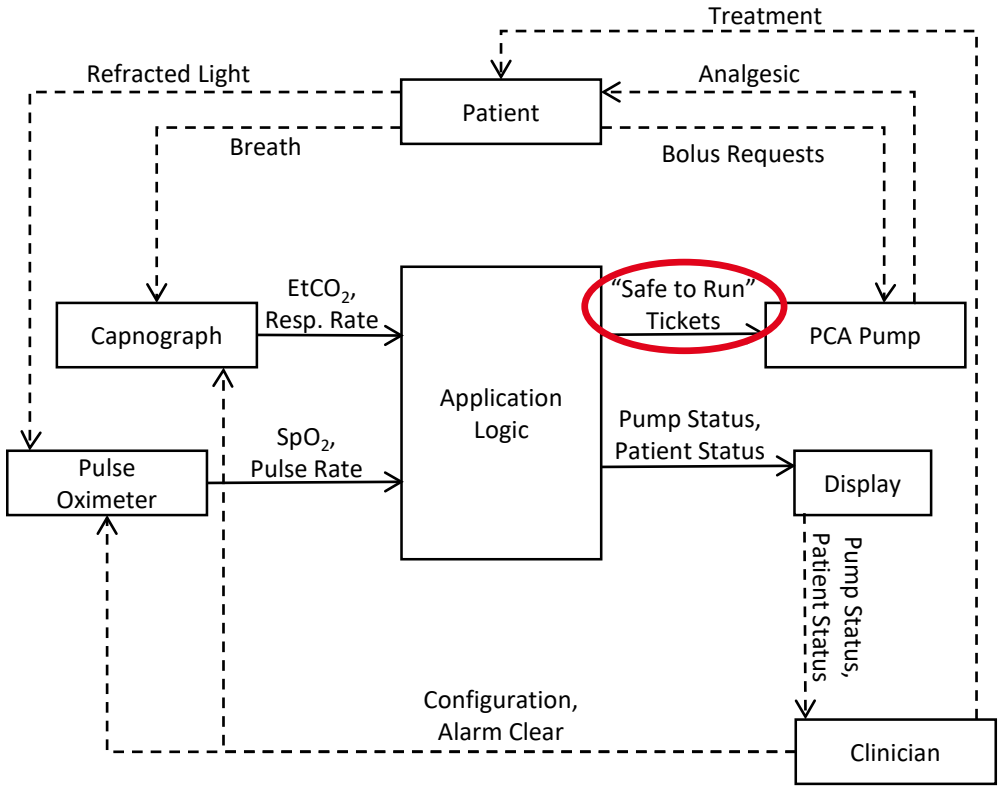
Partial Independence / Compositionality

- 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)

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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