Acute Care Patient Bedside Telemetry Monitor Datastream Processing, Visualization, and Querying with Splunk: A Tale in Carts

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Framework

Parallel Simulated Systems / Clinical Environment Engineering
- Bedside clinical **informatics** systems research

- **Setting**
  - TESTPILOT
  - SimCode
  - CIRRUS
  - CREW
  - ASCENT AED
  - STORM

- **Methods**
  - ARGUS
  - Existing approaches
  - BIRDSS-I

- **Results**
  - PERSEUS
  - MeTeOR

- **Next Steps**
  - Machine learning
  - NAViGATOR
Cart #1: Setting

Pre-pre-Splunk
Setting

RIH

• “Can we use simulation to test a new ER before it opens?”
Yes.

“Can we use simulation to test a new ER before it opens?”
  - TESTPILOT

“Can we use simulation to see what happens during a hospital code?”
  - SimCode

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**Setting**

- RIH
  - “Can we use simulation to test a new ER before it opens?”
    - TESTPILOT
  - “Can we use simulation to see what happens during a hospital code?”
    - SimCode

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**Preliminary Analysis of In-Hospital Cardiopulmonary Resuscitation Simulation (SimCode) Training Program**


From the Departments of Biomedical Engineering, Emergency Medicine, Warren Alpert Medical School, Providence RI, the Departments of Nursing and Risk Management, Rhode Island Hospital, Providence, RI and the Rhode Island Hospital Medical Simulation Center, Providence RI.
Setting

RIH

- “Can we use simulation to test a new ER before it opens?”
  - TESTPILOT
- “Can we use simulation to see what happens during a hospital code?”
  - SimCode
- “Why is CPR universally bad?”

Yes.

Yes(!)

Maybe(!)

Maybe.
Setting

- **RIH**
  - “Can we use simulation to test a new ER before it opens?”
    - TESTPILOT: Yes.
  - “Can we use simulation to see what happens during a hospital code?”
    - SimCode: Yes(!)
  - “Why is CPR universally bad?”
    - “It could be the instructors?”
      - CIRRUS: Maybe(!)
    - “Maybe we need more people to do CPR?”
      - CREW

- **TESTPILOT**
  - “Can we use simulation to test a new ER before it opens?”
    - TESTPILOT: Yes.

- **SimCode**
  - “Can we use simulation to see what happens during a hospital code?”
    - SimCode: Yes(!)

- **CIRRUS**
  - “Why is CPR universally bad?”
    - “It could be the instructors?”
      - CIRRUS: Maybe(!)

- **CREW**
  - “Maybe we need more people to do CPR?”
Setting

RIH
- “Can we use simulation to test a new ER before it opens?” Yes.
  - TESTPILOT
- “Can we use simulation to see what happens during a hospital code?” Yes(!)
  - SimCode
- “Why is CPR universally bad?”
  - “It could be the instructors?” Maybe(!)
    - CIRRUS
  - “Maybe we need more people to do CPR?” Maybe.
    - CREW
  - “What happens if you use AEDs?”
Setting

RIH
- “Can we use simulation to test a new ER before it opens?”
  - TESTPILOT
  Yes.
- “Can we use simulation to see what happens during a hospital code?”
  - SimCode
  Yes(!)
- “Why is CPR universally bad?”
  - “It could be the instructors?”
    - CIRRUS
    Maybe(!)
  - “Maybe we need more people to do CPR?”
    - CREW
    Maybe.
  - “What happens if you use AEDs?”
    - ASCENT AED
    Maybe.
  - “Ok, forget the people, let’s make machines do the work.”
Cart #2: Methods

Pre-Splunk
“Catching the problem earlier”

- Common pathways to (medical) code blue
  - Primary cardiac arrhythmic arrest (VF / VTach; bradycardia)
  - Hypoperfusive / hypotensive arrest
  - Hypoxic / hypercarbic arrest

Systems in place

- Continuous patient monitoring with central telemetry system
- Alarm parameters
- Staff responsibilities

Failures of systems in place

- Failure to detect (accurately)
- Failure to recognize (adequately)
- Failure to respond (appropriately)
Methods

Research + Development Program Aims / Phases

• “To better understand the alarm fatigue resulting from existing bedside patient monitoring telemetry systems and create a non-proprietary mechanism to augment the analysis and delivery of critical information to clinical providers.”

• “To comparatively evaluate the performance and utility of existing and experimental patient monitoring telemetry systems with human factors engineering, simulation and patient tracer methods.”

• “To prepare and disseminate a non-proprietary medical technology interface toolbox for continued medical device and informatics research at the study institution and beyond.”
Methods

Research + Development (Phase 1; 2010-2012)

• Existing systems
• Intervention
• Data access (middle layers)
Existing Systems (RIH ED, 2010)

- 100,000 adult census / year
- Patient monitor telemetry system
  - System as intended
    - HP/Philips telemetry system
    - Monitored spaces:
      - 12 critical care
      - 45 urgent care
      - 7 observation unit
    - Central stations:
      - 1 in critical care (hallway)
      - 3 in urgent care
      - 1 in observation unit
Methods

Existing Systems (RIH ED, 2010)

- System in *operation*
  - 1 of 5 system PCs (A9-15) non-booting
  - All alarm speakers (actively) disconnected
  - No rhythm printers connected
  - Positioned at secluded non-clinical stations
  - Used by <50% of attending ED clinicians...
    ...yet anecdotal reports of “saves.”
Methods

- Existing Systems (RIH ED, 2010)
  - Accessible Real-time clinical Guidance through Updated Signals [ARGUS]
Methods

Existing Systems (RIH ED, 2010)

• **1 of 10** VT runs (HR 150 x 3min) detected by providers

• **0 of 10** S.Brady (HR 20 x 3 min) detected by providers
Methods

Intervention

- Improve relevance of telemetry system
  - Settings re-configuration, signal:noise
- Improve “visibility” of telemetry system
  - Monitors moved to clinician / RN stations
- Improve usability of telemetry system
  - Trackpad interface, routine maintenance
- Reduce workplace footprint of system
  - Low volume alerts
  - User-specified printing
- Increase userbase
  - User awareness + familiarity
Methods

Intervention

Previous default alarm / threshold settings:
- Low blood pressure: \( \leq 90 \text{ mmHg} \)
- High blood pressure: \( \geq 160 \text{ mmHg} \)
- Low heart rate: \( \leq 50 \text{ bpm} \)
- High heart rate: \( \geq 120 \text{ bpm} \)
- Low pulse oximetry: \( \leq 90\% \)
- Respiratory alarms: apnea alarm ON, bradypnea alarm ON, tachypnea alarm ON

Revised default settings
- Low blood pressure: \( \leq 90 \text{ mmHg} \) (no change)
- High blood pressure: \( \geq 200 \text{ mmHg} \)
- Low heart rate: \( \leq 40 \text{ bpm} \)
- High heart rate: \( \geq 130 \text{ bpm} \)
- Low pulse oximetry: \( \leq 89\% \)
- Respiratory rate: apnea alarm OFF, bradypnea alarm OFF, tachypnea alarm OFF
  (based on the expectation that apneic patients will quickly develop other vital sign abnormalities / arrhythmias).
Methods

Intervention
Methods

Intervention
Methods

Post-intervention (RIH ED, 2012)

- **8 of 10** VT runs (HR 150 x 3 min)
  
  detected by providers

- **3 of 10** S.Brady (HR 20 x 3 min)
  
  detected by providers
Methods
Methods

ARGUS...

- Live environment, 2 week alarm sample dataset review
- VTach alarm PPV 0.02 (3 of 124)
- SBrady alarm PPV 0.56 (9 of 16)

...PERSEUS (Push Electronic Relay for Smart Alarms for End User Situational Awareness)!
Methods

Data access (middle layers)

- Existing systems
  - [Philips Research Data Export (RDE)] $ 20k
  - BedMaster
  - ixTrend 3k euros
  - Capsule
  - MediCollector $ 1.5k
  - OpenICE
Methods

- Data access (middle layers)
  - BIRDSS-I
Methods

- Data access (middle layers)
Cart #3: Results

Splunk!
Results

- Research + Development (Phase 2; 2012-2017)
  - Data acquisition (lower layers)
  - Data analytics
Results

Data acquisition (lower layers)
Results

- Data acquisition (lower layers)
  - MeTeOR
Results

- Data acquisition (lower layers)
  - MeTeOR
Results

- Data acquisition (lower layers)
  - MeTeOR
Results

- Data acquisition (lower layers)
  - MeTeOR
Results

- Data acquisition (lower layers)
  - MeTeOR
Results

- "Just" data
- Dev-ops
Results

- Data acquisition (lower layers)
  - Splunk
  - ELK stack (Elastic Search, Logstash, Kibana) open source
Results

- Data analytics
  - Bedside clinical informatics applications
Results

- Data analytics
  - Predictive functions
Results

- Data analytics
  - Associated applications
Results

- Data acquisition
- Data analytics

(5.2017 update)
Cart #4+: Next Steps

More Splunk!
Next Steps

► Research + Development (Phase 3; 2017+)
  • Experimental applications
  • Dissemination
Next Steps

► Experimental Applications
  • Real-time / Near-real-time data processing
    – QoS
Next Steps

- Experimental Applications
  - Physiologic datastream acquisition
    - NAViGATOR program
      - Non-contact vitals
  - Temperature
  - Heart rate / pulse
  - Respiratory rate
  - Pulse oximetry
  - Co-oximetry / CO
  - Hemoglobin
  - Perfusion
Next Steps

- Experimental Applications
  - Delivering more than an Amazon package
Next Steps

► Dissemination
  • Open-source hardware and software **toolkit**
    • Research use  (**not for clinical or commercial use; EULA**)  
    • Waveforms:  EKG (<3 leads)  
      SpO2/pleth  
      invasive (CVP, Aline, ICP)  
  • Numerics:  vital signs (HR, RR, BP, SpO2, Et)  
  • Alarms  
  • ~99.83% data acquisition (15 beds)
Next Steps

- Dissemination
  - Open-source hardware and software toolkit
    - Distribution
    - Python-> Windows, Mac, Linux/Raspbian
    - GitHub repository -> AHRQ OCKT
Next Steps

- Dissemination
  - De-identified **datasets** (24/7/365 * 15 bedside monitors)
Next Steps

Dissemination

- De-identified, *annotated datasets*
  - ATOMICS (Annotation of Telemetry signals for Medically Important and Clinically Significant events) database
  - 15 beds, 50% monitoring -> approx. 100 “red alarms” / day
Next Steps

 ► Dissemination

 ● Open code for real-time / near-real-time data acquisition
   ○ Open-source alternative to commercial systems for *research purposes
 ● Open code for real-time / near-real-time data processing
   ○ QoS
 ● Open datasets for playback
   ○ Critical event replication (e.g., M+M)
     - Accurate, precise, high-resolution physiologic datastreams
 ● Device testing
 ● Open datasets for un-/structured machine learning
 ● ED-focused datasets a la PhysioNET (MIT-BIH ; MIMIC-I/II/III)
Take Home Points/Lessons Learned

- **Bedside** clinical informatics on live (ED) patient datastreams
  - Automated monitoring for signals detection
  - Automated analyses for algorithm development

- **Bedside implementation** into clinical workflow is the challenge
  - Device and datastream access in open, safe, meaningful manner:
    - De-identified populational datasets for open sharing (web repositories)
    - Patient-specific datasets with clinical correlates for approved on-site research
  - Device and datastream intervention:
    - Real-time / near-real-time processing at the bedside
    - Integration into existing infrastructure and systems

- **Compute / outcomes in** **challenging context**
  - EDs: Busy, stressful, restricted, noisy, malodorous environments
  - Providers + patients: Busy, stressed people
Research Teams + Co-investigators

- Rhode Island Hospital Medical Simulation Center
  -> Lifespan Medical Simulation Center
- Sim core team
  - F. Overly, L. Brown, J. Callahan, J. Taveira, G. Jay
  - D. Werner, M. Jones, J. Devine, S. Marcotte, M. Dannecker, A. Sousa
  - Physician and Nurse Clinical + Simulation Educators
- Program- / Project-specific Teams
  - TESTPILOT: M. Shapiro, R. Boss, J. Dunbar, R. Sciamacco
  - SimCode: D. Lindquist, I. Jenouri, K. Dushay, D. Haze, J. Foggle, D. Tammaro
  - CIRRUS: R. Al-Rasheed
  - CREW: J. Schoen
  - STORM: B. Choi, N. Asselin, C. Pettit
ARGUS / PERSEUS Program

- Rhode Island Hospital / Lifespan
  - Rhode Island Hospital Emergency Department
  - Lifespan Information + Network Services

- Brown University
  - D.Merck (3DLab), A.Oyalowo + U.Agrawal (RIH NeuroLOGIC Lab)

- Case Western Reserve University

- Red Forest Consulting (J.Gosbee)

- University of California San Francisco
  - X.Hu + team (Department of Nursing)

- Splunk for Good, Splunk
Research Teams + Co-investigators

▶ NAViGATOR Program

• Brown University
  – G.Capraro, L.Mercurio (Pedi EM)
  – C.Etebari, K.Luchette

• Philips Healthcare Research, Philips
Other Notable Carts
Thank You

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