Case Critical Care Bioinformatics Project

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History of Monitoring

Phase 1: **Clinical** monitoring
- 1960-1980
- React to clinical events
History of Monitoring

Phase 1: **Clinical** monitoring
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Phase 2: **Physiological** monitoring
- 1980-2000
- React to single, simple pathophysiological events
History of Monitoring

Phase 1: **Clinical** monitoring
- 1960-1980
- React to clinical events

Phase 2: **Physiological** monitoring

![Graph showing ICP and CPP over time with annotations]

- ICP (torr)
- CPP (torr)
- 5 min

**ICP** and **CPP** measurements over time with annotations highlighting significant events.
History of Monitoring

Phase 1: **Clinical** monitoring
- 1960-1980
- *React* to clinical events

Phase 2: **Physiological** monitoring
- 1980-2000
- *React* to single, simple pathophysiological events

Phase 3: **Multi-Modal** monitoring
- 2000-present
- *React* to multiple, complex pathophysiological events
History of Monitoring

Phase 1: Clinical monitoring
• 1960-1980
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Phase 3: Multi-Modal monitoring
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History of Monitoring

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Blood bank

Intracranial Pressure

Cerebral Perfusion Pressure

Cerebral Blood Flow

Phillips Monitors

Brain Tissue Oxygenation

Intracerebral Microdialysis

EEG-BIS

Lab Med

Phillips PACS

Eclipsys
None of this information is integrated

This inability to simply *integrate* and time-synchronize all physiologic data simultaneously into one dataset has been a major limiting factor in intensive care monitoring.
None of this data is processed.
None of this data is processed

Some monitors display raw trends but even basic analyses (mean, median, standard deviations) are nearly impossible to perform.

Conceptually, analysis has been restricted to linear and univariate statistical models.

New Electronic Order Set at UHCMC

Notify physician:

- HR < 60 or > 125 bpm
- SBP < 90 or > 180 mm Hg
- Respirations < 10 or > 30 per minute
- Pulse oximetry < 90% SaO₂
- Temperature < 35.0 or > 38.8°C Celsius
- Urine Output < 50 mL per hour
- Blood Glucose < 60 or > 130 mg/dL
- Cardiac Index < 2 L/min/m²
None of this data is processed

Some monitors display raw trends but even basic analyses (mean, median, standard deviations) are nearly impossible to perform.

Conceptually, analysis has been restricted to linear and univariate statistical models.

There may be untapped, and clinically valuable information buried in commonly acquired physiologic signals.
This is the “state-of-the-art”

Phillips Monitors
- Heart Rate
- Respiratory Rate
- Blood Pressure
- $O_2$ Saturation
- Temperature
This is the “state-of-the-art”

Phillips Monitors
Heart Rate
Respiratory Rate
Blood Pressure
O₂ Saturation
Temperature
The way we chart information at the ICU bedside is **archaic, abstruse, and illogical.**

Multiple streams of continuous, electronic critical care data are sampled on some regular or irregular basis and laboriously transcribed onto a critical care record in an arbitrary arrangement...

It is not much of a stretch to compare a stockbroker poring over a length of ticker tape with today’s intensivist leafing through a ream of ICU records.
The medical industry has not embraced the use of intelligent data analysis and visualization tools to any significant degree, and we are well behind other disciplines such as the financial, aviation, industrial process control, and military industries in the adoption of these technologies.
Future of Monitoring

Phase 4: *Integrated Multi-Modal* monitoring

- Integrating multiple physiological parameters
- Processing the data in real-time
- Presenting the information in a user-friendly way

The goal is to understand and manage complex physiology to *prevent* pathophysiological events
Critical Care Bioinformatics Working Group

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  Linda Smitley
  Peter Thomas, PhD
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  Chris Wilson, PhD
Phase 1: Data Integration

Development of proof of concept data collection system, built from “Commercial Off The Shelf” components, that will connect with current patient monitoring devices.

The goal will be to collect and integrate not only the parametric data but also acquire the underlying waveforms at high sampling rates.
Phase 2 will be divided into two phases:

In **Phase 2a**, we will develop trend detection and data processing software.

In **Phase 2b**, we will develop a user-friendly and intuitive interface using vendor supplied software.
Phase 2a: Data Processing

Time domain analysis
- Mean, variance, etc

Frequency domain analysis
- Windowed spectral analysis, PSD, Periodogram, etc

Entropy measures
- Shannon entropy, approximate entropy, sample entropy, interval entropy, and spectral entropy

Linear stochastic signal models
- Regression, correlation analysis, coefficient of variation, time domain modeling (AR, ARMA, etc)

Scale independent or power-law techniques
- Correlation dimension, Detrended Fluctuation Analysis, …
Phase 2a: Data Processing

<table>
<thead>
<tr>
<th></th>
<th>Total Recording Time (Sec)</th>
<th>Detected R-Wave</th>
<th>Average Heart Rate (B/Min)</th>
<th>Average Breaths Per Minute</th>
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<td>Subject 1</td>
<td>1425</td>
<td>2129</td>
<td>89.64</td>
<td>9.17</td>
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<td>1208</td>
<td>1659</td>
<td>82.40</td>
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<td>2657</td>
<td>54.06</td>
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<th></th>
<th>DFA</th>
<th>SD1C</th>
<th>SD2C</th>
<th>SD1C to SD2C Ratio</th>
<th>Conditional Entropy</th>
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<tr>
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<td>0.1485</td>
<td>0.23</td>
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<td>Subject 2</td>
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<td>0.0645</td>
<td>0.14</td>
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<td>Subject 3</td>
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<td>0.0586</td>
<td>0.1430</td>
<td>0.40</td>
<td>1.30</td>
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</table>

<table>
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<tr>
<th></th>
<th>R-Tot</th>
<th>T-Tot</th>
<th>T</th>
<th>T</th>
<th>HrT</th>
<th>HrT</th>
<th>T-Hr</th>
<th>T-Hr</th>
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<tbody>
<tr>
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<td>3.44</td>
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<td>Subject 2</td>
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<td>3.23</td>
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<td>-0.66</td>
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<td>3.78</td>
<td>0.15</td>
<td>0.22</td>
<td>0.12</td>
</tr>
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</table>
Phase 2a: Data Processing

Normal Breathing (15BPM)

Poincaré plot (RR vs previous RR)

RR\text{delayed} vs Resp

Time shifted 2.2 sec <---

Resp from EEG

Vent Flow

2 ECG components

Color Code (with 2.2 sec delay)

Inspiration
Mid-breath
Expiration

ECG Vector
Phase 2a: Data Processing

Large Slow Smooth Breath

Poincaré plot
(RR vs previous RR)

Color Code
(with 2.6 sec delay)
- Inspiration
- Mid-breath
- Expiration

ECG Vector

Resp from EEG

Vent Flow

2 ECG components

RR\textsubscript{delayed} vs Resp

Time shifted 2.6 sec <---

R-R interval

0.4

1.0

1.2
Phase 2b: Data Visualization

Edward R. Tufte, PhD

SECOND EDITION
The Visual Display of Quantitative Information
EDWARD R. TUFTE
Phase 2b: Data Visualization

Edward R. Tufte, PhD

“SPARKLINES”

- Glucose 130
- Glucose 130
- Glucose 130
- Glucose 130
- Respiration 16
- Temperature 38.2
- WBC 8,800
Edward R. Tufte, PhD

“SPARKLINES”

glucose 130

respiration 16

temperature 38.2

WBC 8,800
Phase 2b: Data Visualization

Edward R. Tufte, PhD

“SPARKLINES”
Phase 2b: Data Visualization

Edward R. Tufte, PhD

“SPARKLINES”

- Glucose: 130
- Respiration: 16
- Temperature: 38.2
- WBC: 8,800
Phase 2b: Data Visualization

Borrowing from Genomics

Self-organizing Map

Distance Map Projection
Phase 3: Multi-Center Collaboration

University Hospitals Case Medical Center

- Patient Monitoring
  - PACS (Philips)
  - Medical Record (Eclipsys)
  - Physiology/ Waveform (Data Acquisition)

- Dedicated Storage

Dedicated Storage

- MySQL Database

- FIREWALL

- VPN interface and "sockets"

- UCSF

- DB

- Storage Area Network (SAN)

- Children’s Hospital Boston

Non-HIPAA compliant local "sandbox"

HIPAA/HL7 compliant data center
Conclusions

• Intensive care monitoring has remained the same for 30 years.

• The medical industry has not incorporated advances in computer science, engineering, signal processing, and mathematics.

• This project, with tight collaboration between clinicians, physiologists, engineers, and computer scientists will create an integrated suite of software and hardware for advanced patient monitoring.
Conclusions

The impact of this project cannot be overestimated - it has the potential to fundamentally change the way medicine is practiced, improving both efficiency and patient outcome.
“It is time for this nation to take a clearly leading role in space achievement…

I believe we possess all the resources and talents necessary. But… we have never made the national decisions or marshaled the national resources required for such leadership.

I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the moon and returning him safely to the earth.”

President John F. Kennedy
May 25, 1961
Thank You