Data-Driven Intelligent Health Monitoring and Decision Support

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Agenda

- Towards the intelligent monitoring and the smart hospital
- Data-driven decision making
- Case studies
- Challenges / Open Research Areas
- Conclusions and Future Work

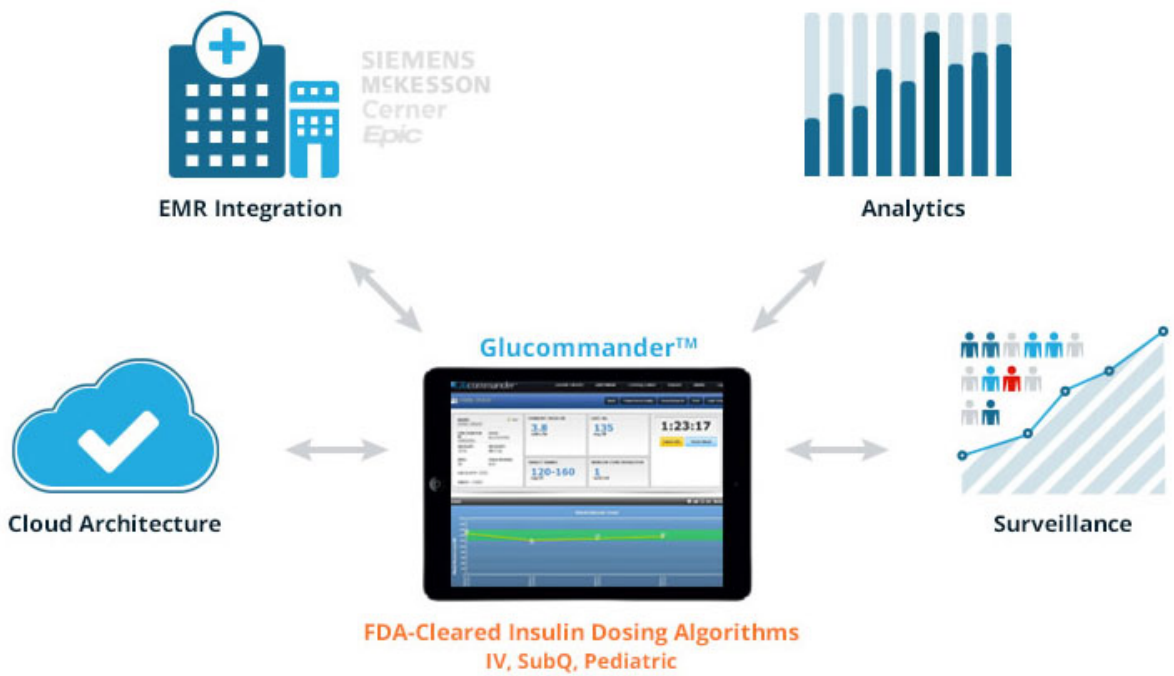
Electronic medical/health records, advanced inpatient information systems, remote patient monitoring, and wireless health technologies have arrived…

…sort of.

Computerized treatment systems can achieve improved outcomes…

…but they tend to be focused on specific physiological needs, and are difficult to integrate with other information systems,

…and there are significant barriers to integration: the API and data itself is often considered to be proprietary,



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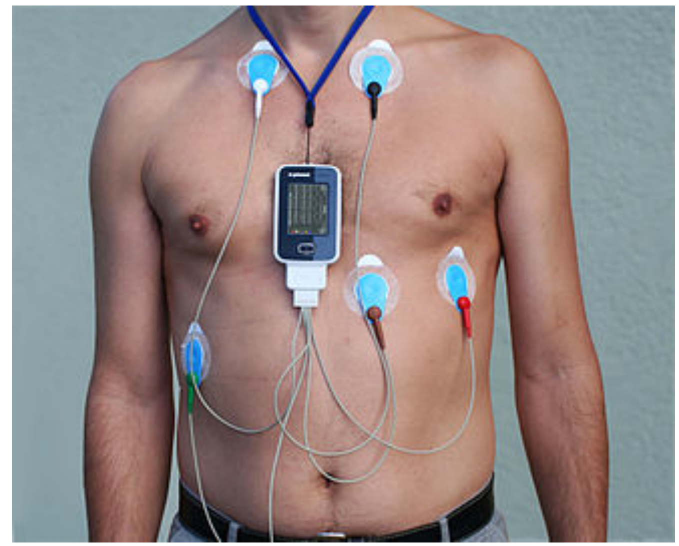
Remote Patient Monitoring (RPM) is becoming a standard approach…

…but RPM technologies are typically low-tech, not involving the use of real-time telemetry or allowing for long-term deployment in natural settings,

…it is hard to assure real-time connectivity in mixed home/work/recreational settings

…hospitals are ill-equipped to make the decision to discharge risky patients, especially with unproven remote monitoring technology

…security, privacy, liability, risk are significant considerations,

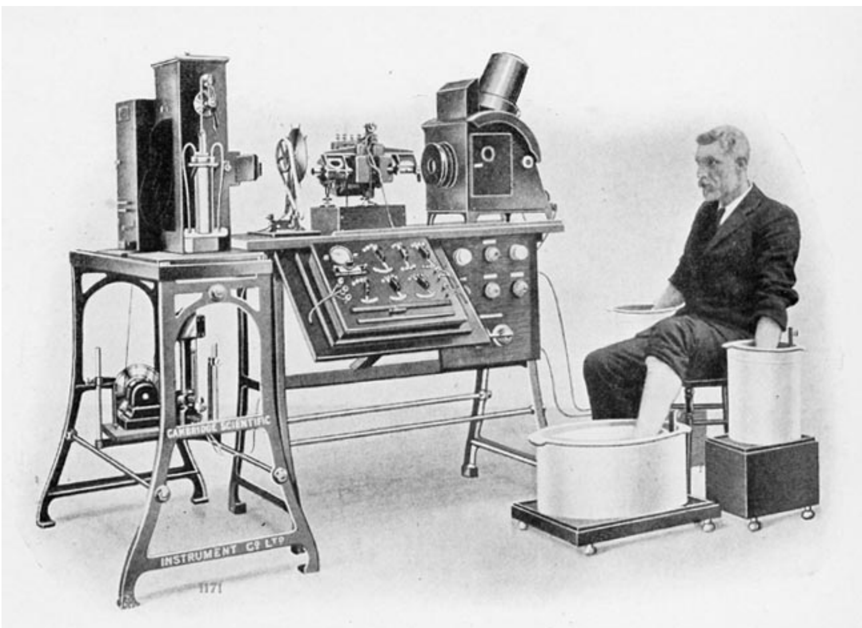


What’s Missing?

- Health systems (including university hospitals) need evidence that it is a net positive to enable clinical research by investing in (1) accurate data capture, (2) integration and automation “add-ons”, (3) data analytics.
- The emergence of advanced patient monitoring services is hindered by a vicious cycle:
  - Clinical acceptance & regulatory delay (separate issues)
  - Market opportunity
  - Investment in innovative technology and clinical trials
- There are significant multidisciplinary challenges:
  - Quantification and visualization of actionable risk
  - Architecture (where does the intelligence exist?)
  - Resources
  - Does real-time telemetry of medical data actually work?

Medical Devices and Diagnostic Equipment

Stage Zero: complex, centralized



Photograph of a Complete Electrocardiograph, Showing the Manner in which the Electrodes are Attached to the Patient, In this Case the Hands and One Foot Being Immersed in Jars of Salt Solution

http://en.wikipedia.org/wiki/Image:Willem_Einthoven_ECG.jpg.
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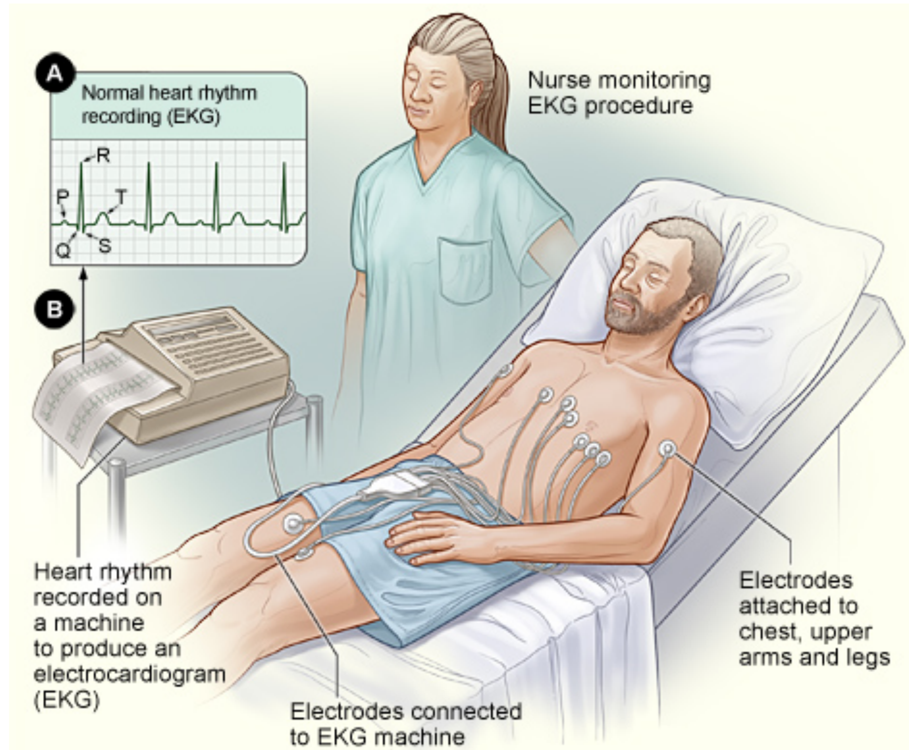
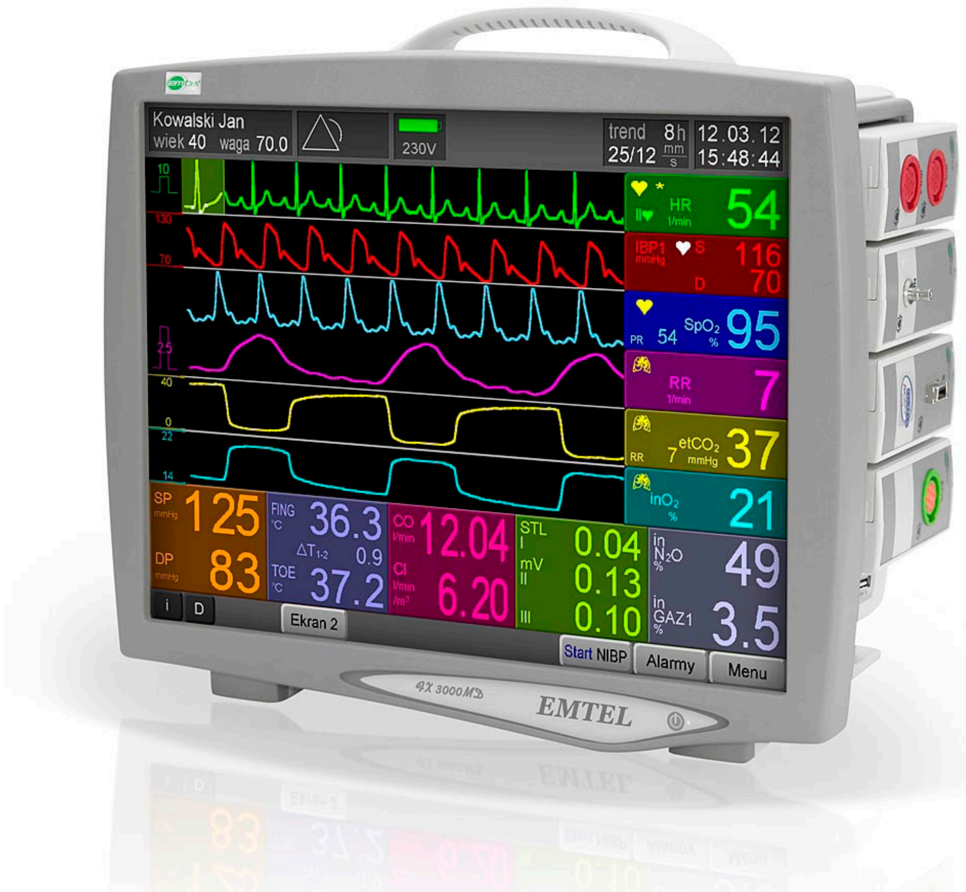
Wave One: decentralized, simple



http://www.nhlbi.nih.gov/health/health-topics/images/ekg.jpg

Medical Devices and Diagnostic Equipment

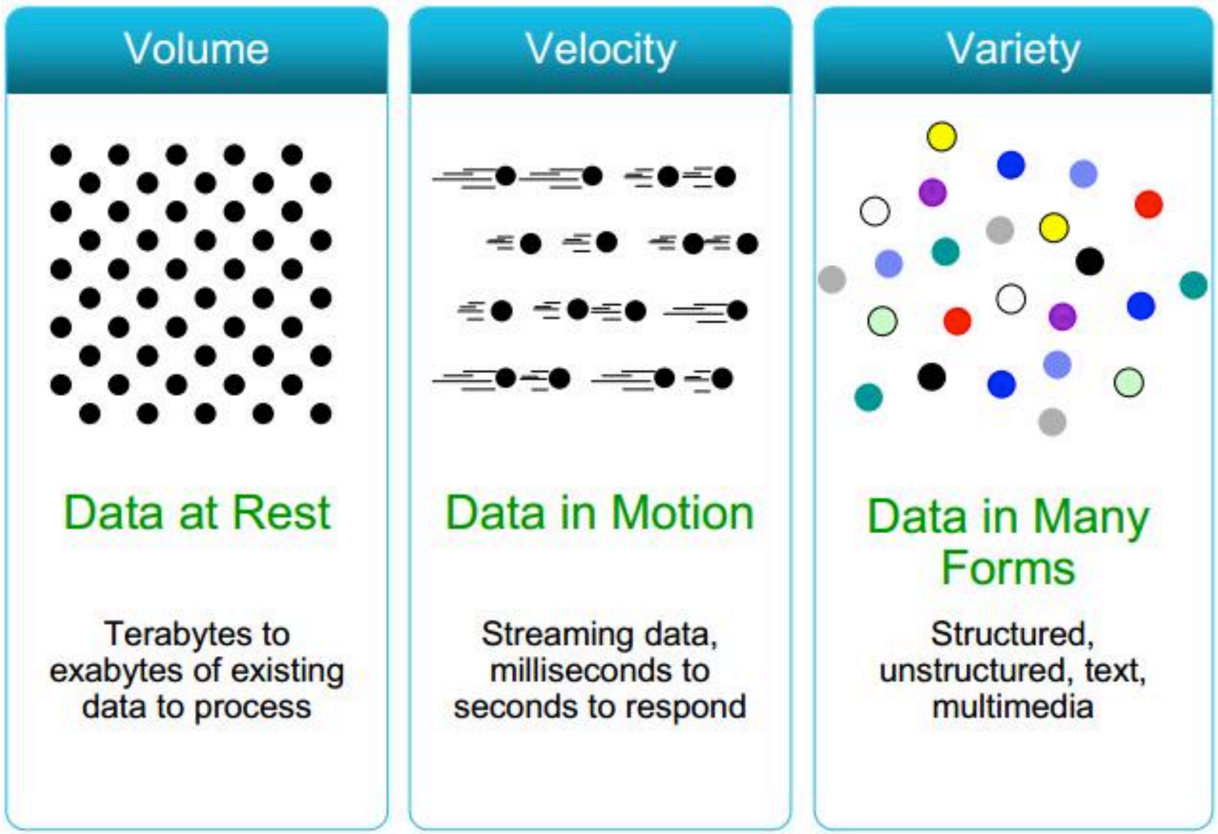
Wave Two: further decentralized, but more complex



Intelligent Monitoring Goals

- Environmental design and technology integration that enable seamless patient care.
- Bring today's smart technologies to in all areas of clinical care
  - Emergency department (ED)
  - Operating rooms (ORs)
  - Floor
  - Intensive or acute care units (ICUs), treatment areas such as radiology, pharmacy, etc.
  - Quality analytics and policy level decisions

Big Data in Healthcare



Retrospective patient encounters

Real time acquisition and analysis for rapid decisions

Clinical notes, diagnosis, and procedure codes

The challenges

- Management
- Computation
- Analytics
- Visualization
- Ethics
- Training

Examples

Personal medicine

Predictive monitoring

Decision support

Policy implementation

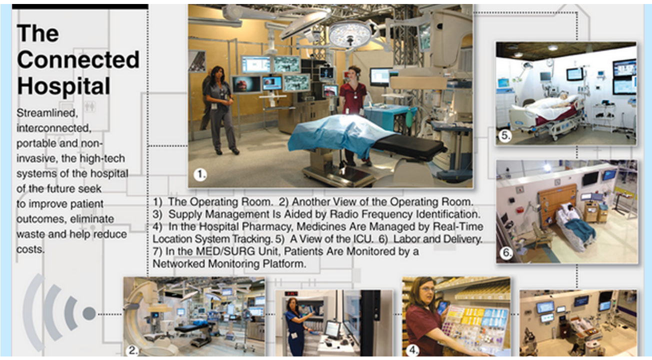
Healthcare System Complexity

- System boundaries are lacking, fuzzy, and/or ill-defined
- Both clinicians, patients, and family differ in technology use patterns and interact with data in different ways
- Individuals in the healthcare system (e.g., physicians, interns, nurses, patients) use rules and mental models that are internalized and change temporally
- People and system(s) adapt to local contingencies

Healthcare System Complexity

- Complex interactions between humans and systems produce tensions and continual system integration produce new, potentially unexpected behaviors
- The system interactions are non-linear and often unpredictable. This lack of predictability is however accompanied by general patterns of behavior.
- Self-organization is inherent through simple locally applied rules.

Heterogeneous Environments



Fully connected and high tech: Electronic Health Records, RFID, real-time monitoring . . .

No EHR, minimal monitoring, rural settings, completely different care model . . .

Home environment, remote monitoring in the wild . . .

Why Patient Monitoring?

- Clinical decision support
- Care coordination
- Review of historical data
- Individualized models
- Retrospective data mining and model building
- Measure severity of illness
- Optimization of resource allocation – (e.g. bed assignment, room transfers, patient triage)
- Automated data fusion and ‘conflict resolution’
- Quality control through assessment and evaluation of performance (outcomes, LOS, infection rates, costs, etc.)

Types of Patient Monitoring

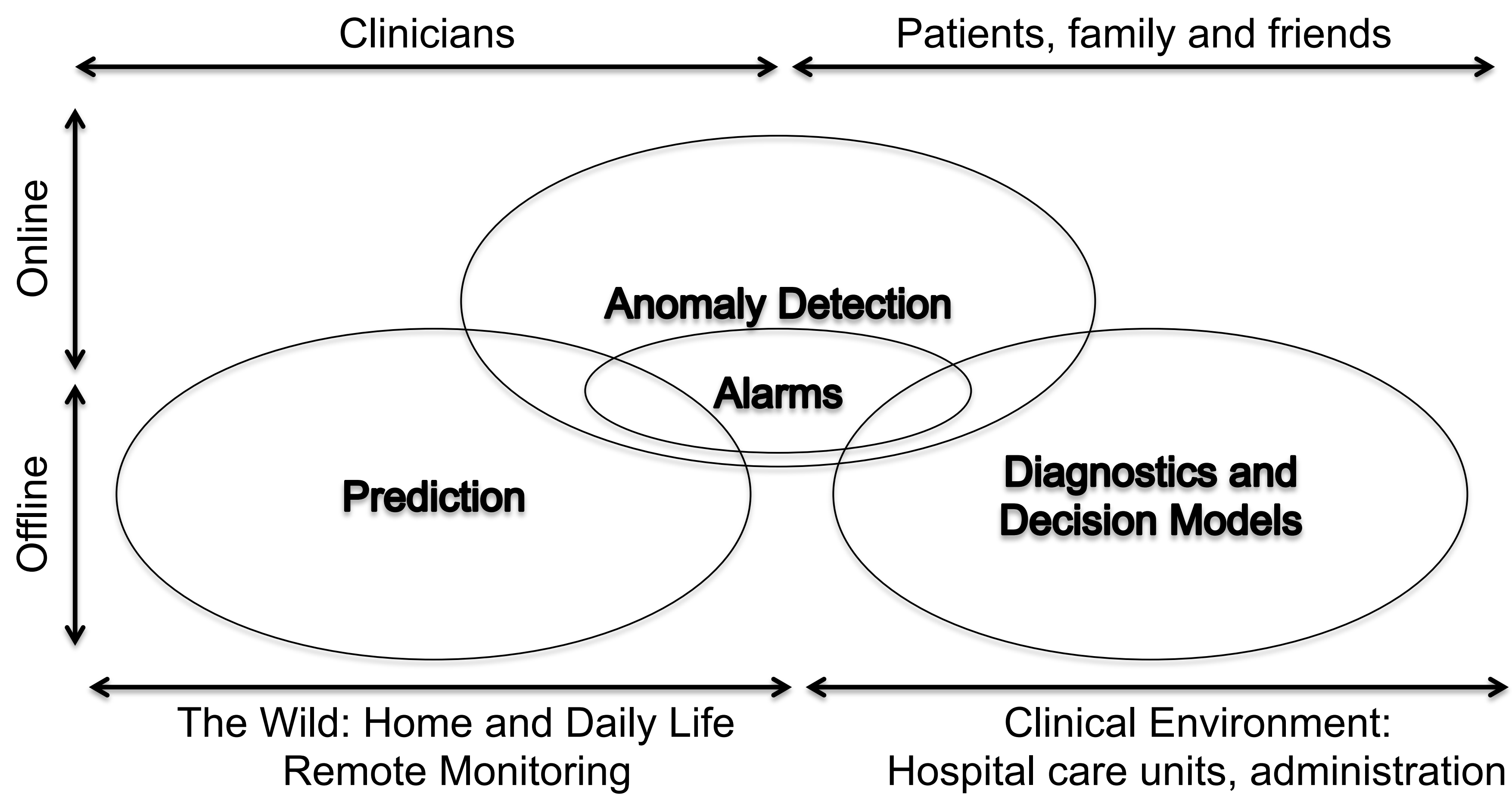
"Repeated or continuous observations or measurements of patients, their physiological function, and the function of life support equipment for the purpose of guiding and assessing the efficacy of patient management decisions, such as therapeutic interventions." (Gardner and Shabot)

- Automated (noise prone) → false alarms
- Semi-automated (decision support, human filters)
- Manual (integrative, low-cost, traditional, subjective) (Usually well trained, intelligent monitors!)

Monitoring Use Cases

- Paramedics (light/variable)
- ER (light/variable)
- OR (hyper-intensive)
- ICUs (intensive)
- General Wards (light)
- Clinics (light)
- Outpatient / Home (light)

Monitoring World



Challenges In-Hospital Monitoring

- Staffing is often the limiting resource
- Acuity and complexity of patients and technology is increasing
- Trainees and physician extenders are at the front line
- Alarms and pages are as distracting as they are frequent
- Bedside rounding is inefficient
- Knowing where to deploy under-utilized resources isn't intuitive

Goals of Patient Monitoring

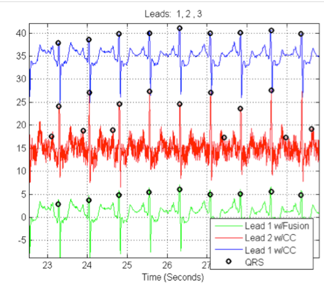
- Sickest patients – highest level of monitoring
- Global awareness
- Understand patient past, present, and current health
- Understand trends related to history of present illness
- Improve patient handoffs and team communication
- Expert knowledge to more novice clinicians
- Bring attention and understanding to situation and modify workflow – e.g. influence rounding order, notification to attending physician

Online Intelligent Monitoring

ICUs

Physiologic

Real-time EKG, respiration rate, etc.



ICUs, Floor

EMR

EMR Clinical

Periodic vitals, lab values, diagnoses, procedures, prior events, patient past and present illness history, clinical notes, events

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Data Fusion

Predictive Models

Display Results

Predict Clinical Events

Identify Clinical Events / Allocate Resources

- Emergent Intubation
- Massive Hemorrhage
- Emergent transfer to ICU
- Severe Sepsis & Septic Shock
- Patient triage from to lower and higher level units
- Readmissions

Events that lead to increased complications, length of stay, cost, and risk of unanticipated in-hospital death.

Early intervention can save lives & improve outcomes.

Predicting Adverse Events

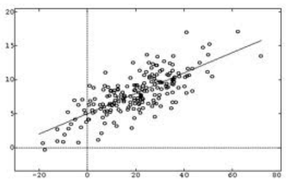
- Situation and environment interactions
  - ICU vs. non-ICU events
- Clinically significant vs. statistically significant
- Existing safety nets
  - Risk scores
  - Monitors
  - Medical Emergency Response
- Prediction does not imply appropriate response

Offline – the Data

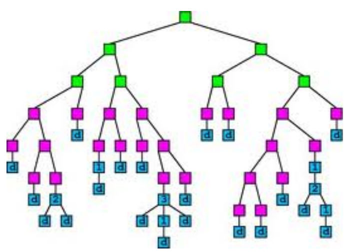
- Bedside monitors:
  - 54,000,000,000 records with unique ID & time stamps
  - Statistical & dynamical calculations
- EMR Data Warehouse:
  - 460,000 unique stays in hospital beds
  - 145,000 admissions
  - 87,000 patients
- Clinical Events Database adjudicated by clinicians:
  - 320 massive transfusions in 3900 SICU admissions
  - 256 emergent intubations in 2625 MICU admissions
  - 68 new sepsis cases in 955 MICU & SICU admissions
  - 128 Medical Emergency Team activations over 9 months
  - 76 direct transfers to ICU over 9 months

Offline – the Models

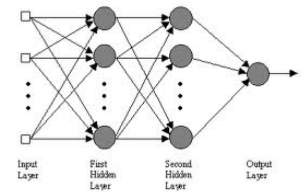
Statistical Methods



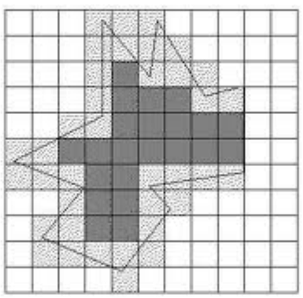
- Linear and Logistic regression
  – Function fitting methodology
- Bayesian networks
  – Estimation of conditional probabilities
- Discriminant analysis
  – Hyperplanes that separates classes
- Decision trees
  – Partition of the input space based on a set of data splitting



AI Methods

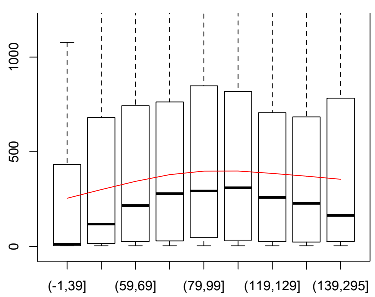


- Neural Networks
  – Optimization of a global objective function
- Rough Set Theory
  – Capture impreciseness in data based on approximations

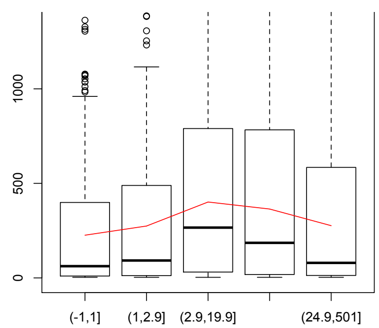


Offline – the Models

- Complex and non-linear relationships between prognostic factors and events

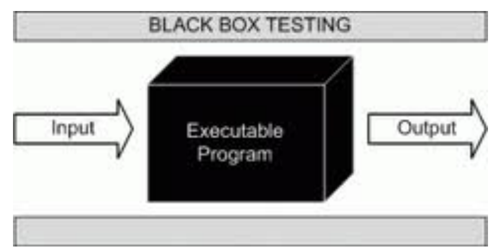


Heart rate

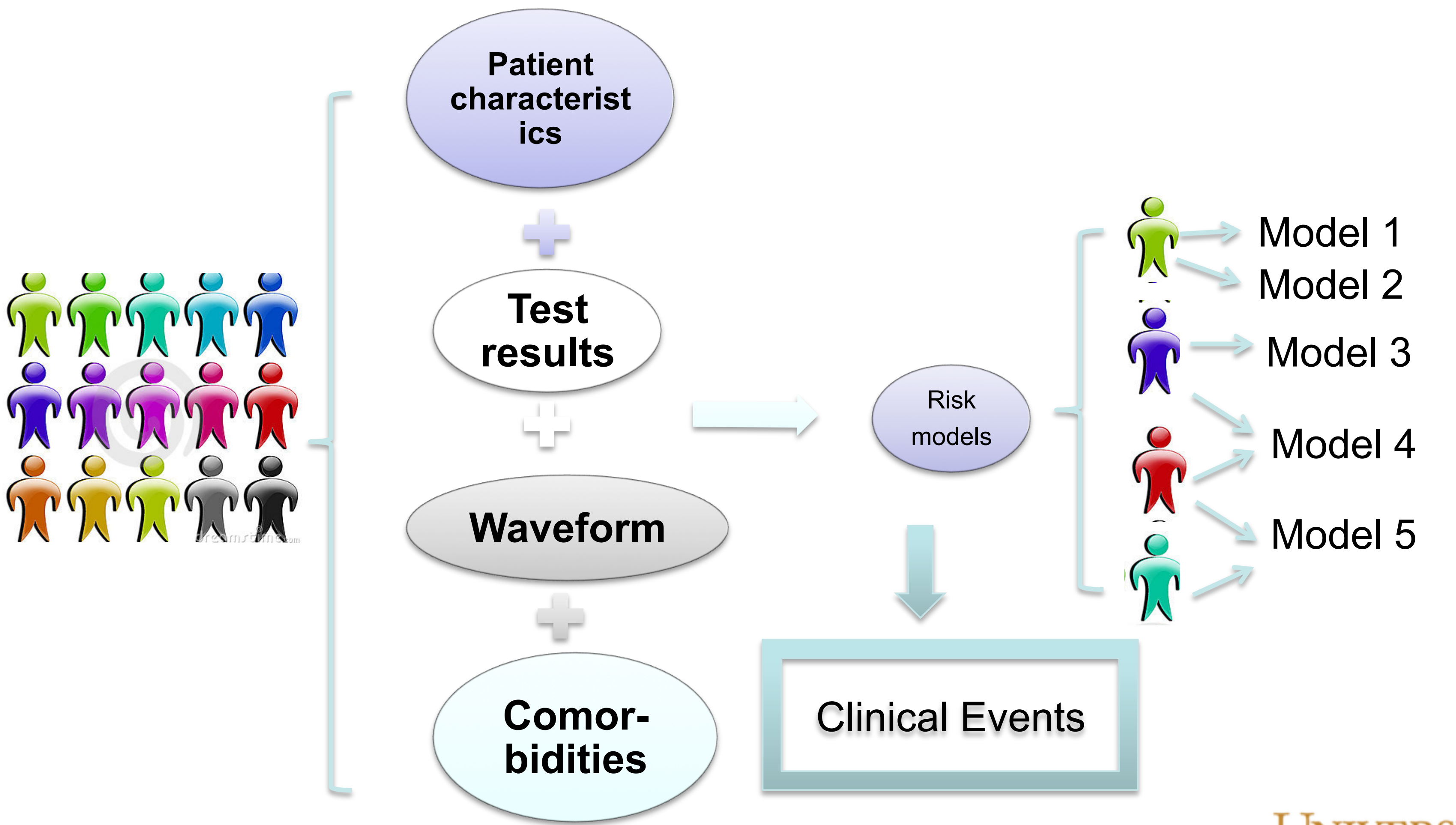


White blood cell count

- Heterogeneity
  - Patients are individual and unique cases, therefore, a unique model could not be applicable for all cases
- Clinical credibility
  - “Black box” methodologies



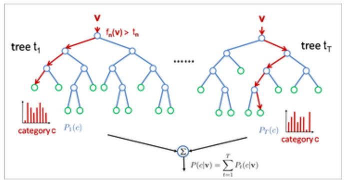
Offline – the Models

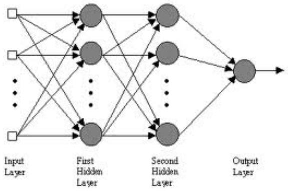


The Models

- Goals
  - Implement robust approaches to missing or low quality data
  - Develop ‘locally’ predictive models that multidimensional time series, discovered features, and integrate clinical patient characteristics from the electronic health record
  - Systems Integration and evaluation of models

if age= [45, 60) AND dzgroup = (Lung Cancer) AND meanbp=[60, 70) then: Survive = 22.86%, Die = 77.14%.





$$\log\left(\frac{p_i}{1-p_i}\right) = \alpha + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_p X_{ip}$$

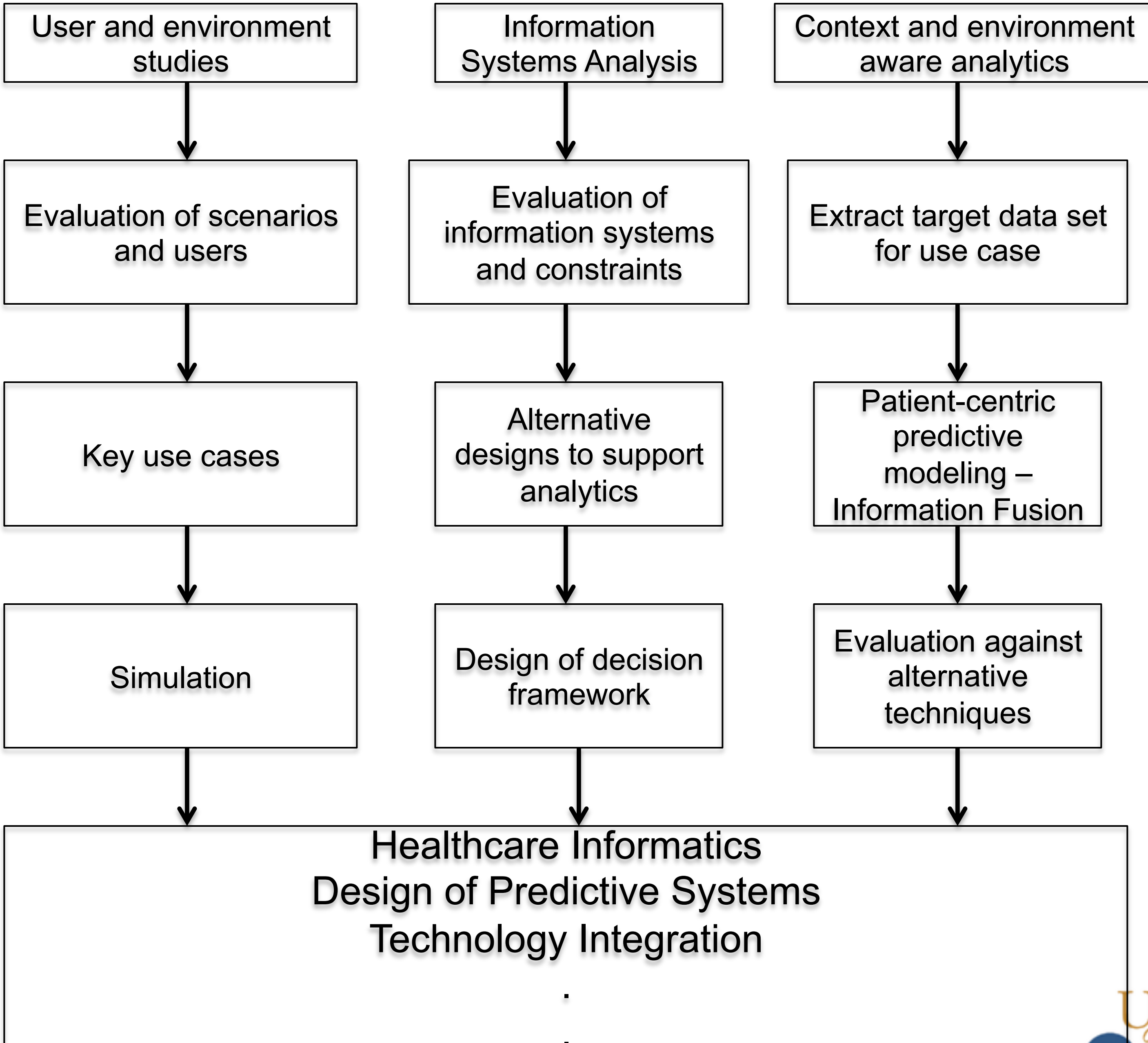
Transparency

Beyond Analytics

- Optimize clinical operations and patient care
  – Collect and receive “right” information at the right time
  – Route the right information to the right device and people
  – Display the information in formats that will adapt to existing clinical work flows
  – Culture change
  – Training the next generation and experienced clinicians

Research Issues

- Design and development of adaptable architectures that support heterogeneous environments and clinical teams
  - Patient-centric predictive modeling
  - Dynamic decision support tools
  - Context and environment aware analytics
  - Information prioritization
  - Visual analytics
  - Group communication protocols and models
  - Heterogeneous wireless devices
  - Alarm management


User and environment studies
Evaluation of scenarios and users
Key use cases
Simulation
Information Systems Analysis
Evaluation of information systems and constraints
Alternative designs to support analytics
Design of decision framework
Context and environment aware analytics
Extract target data set for use case
Patient-centric predictive modeling – Information Fusion
Evaluation against alternative techniques
Healthcare Informatics
Design of Predictive Systems
Technology Integration
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Electronic Health Record Surveillance

- Why?
  - Monitor variation of care within a given institute, population of patients, etc.
  - Identify patients at risk from long term trajectory
  - Syndromic surveillance
- Short-term decision making
  - Infection control and monitoring → Outbreaks
  - Treatment decisions
- Long-term decision making
  - Policy
  - Adherence to guidelines
  - Institutional comparison
  - Clinician comparison

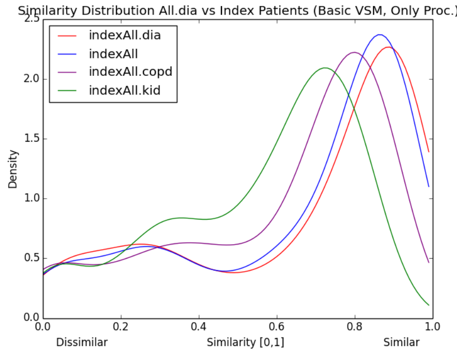
EHRs Great for Billing . . .

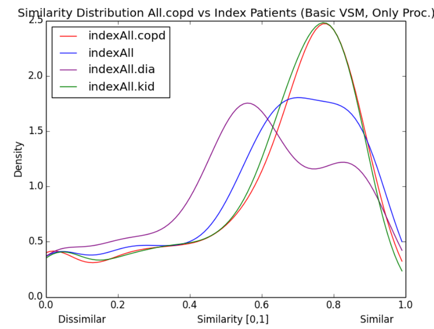
…but it is not clear that they can be used reliably and economically for quality improvement or clinical research,

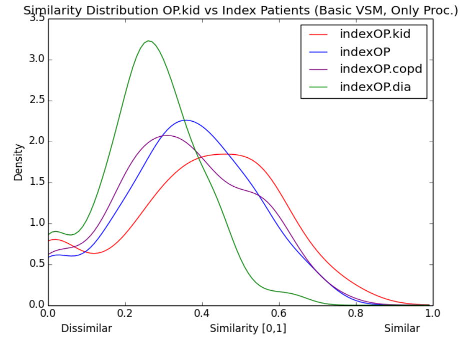
…there are many legal and administrative barriers to providing access to data,

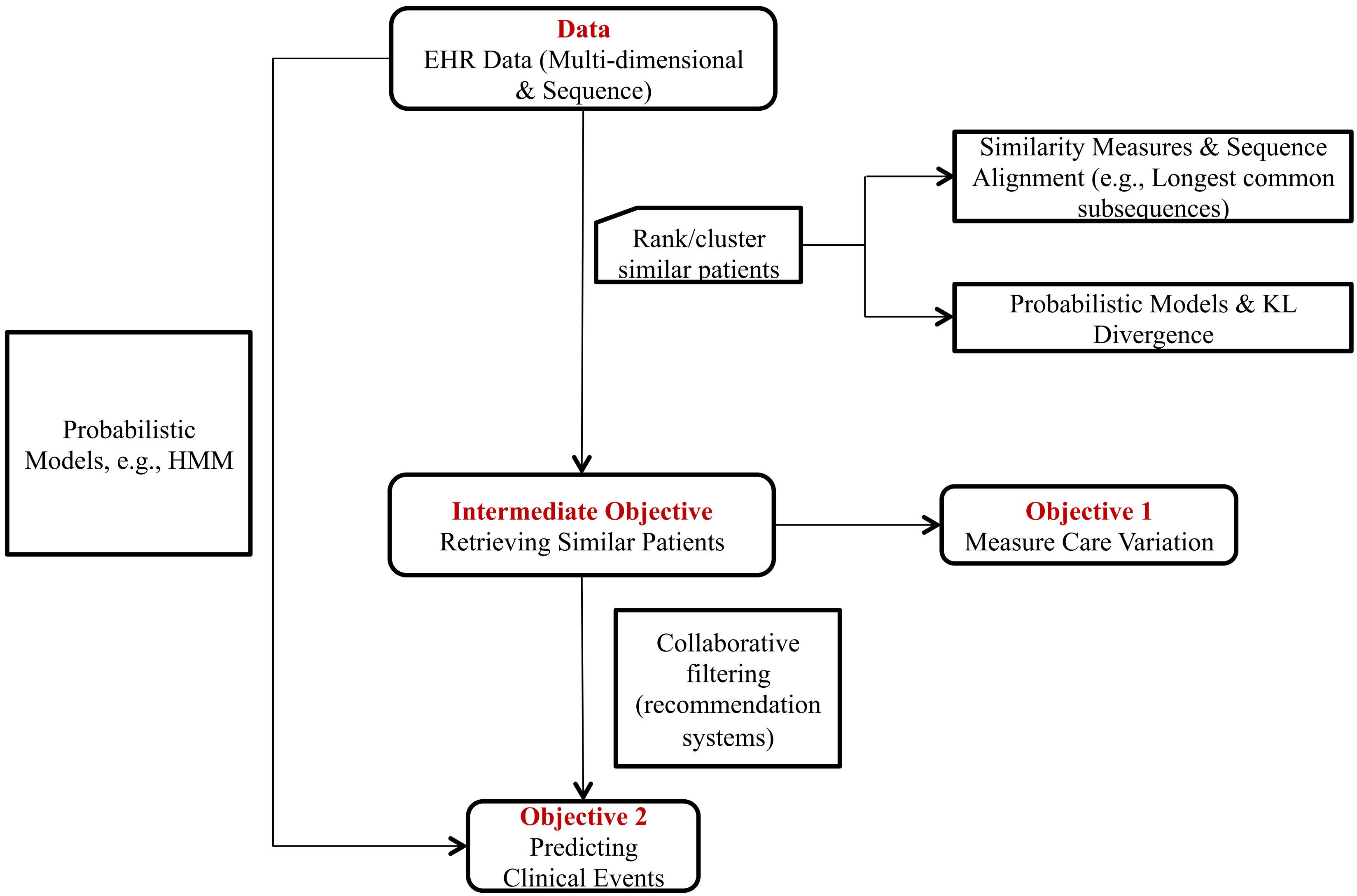
Monitoring of Care Variation

- Can we reimagine the use of the EHR for more systematic decision support?
- Patient 'search engine'
- Design metrics to measure similarity and compare distributions of care
- Measure the effect of technological integration on care variation








Data
EHR Data (Multi-dimensional & Sequence)
Similarity Measures & Sequence Alignment (e.g., Longest common subsequences)
Rank/cluster similar patients
Probabilistic Models & KL Divergence
Probabilistic Models, e.g., HMM
Intermediate Objective
Retrieving Similar Patients
Objective 1
Measure Care Variation
Collaborative filtering (recommendation systems)
Objective 2
Predicting Clinical Events

Multisite Surveillance of EHR Data

- College Health Surveillance Network (CHSN), a project funded by the Centers for Disease Control and Prevention (CDC) and lead by the University of Virginia, provides the **first national, multisite database** specific to the epidemiological trends and health service utilization for students attending 4-year universities in the U.S.
- Some statistics:
  - 23 participating Research I Universities including UVa
  - 4.17 M Visits among 802,255 individual students.
  - 2.99 M provider E+M visits
  - January 1, 2011-Current

Multisite Surveillance of EHR Data

- Analysis of care in different ‘mini’ health care infrastructures with different levels of integration
- Enhanced Model: Interconnected
  - College counseling centers are integrated with a student health service
  - Clinicians from both centers can collaborate on patient care and EMRs are shared
- Standard Model: Disconnected
  - College counseling centers are from student health service.
  - No shared information systems between systems

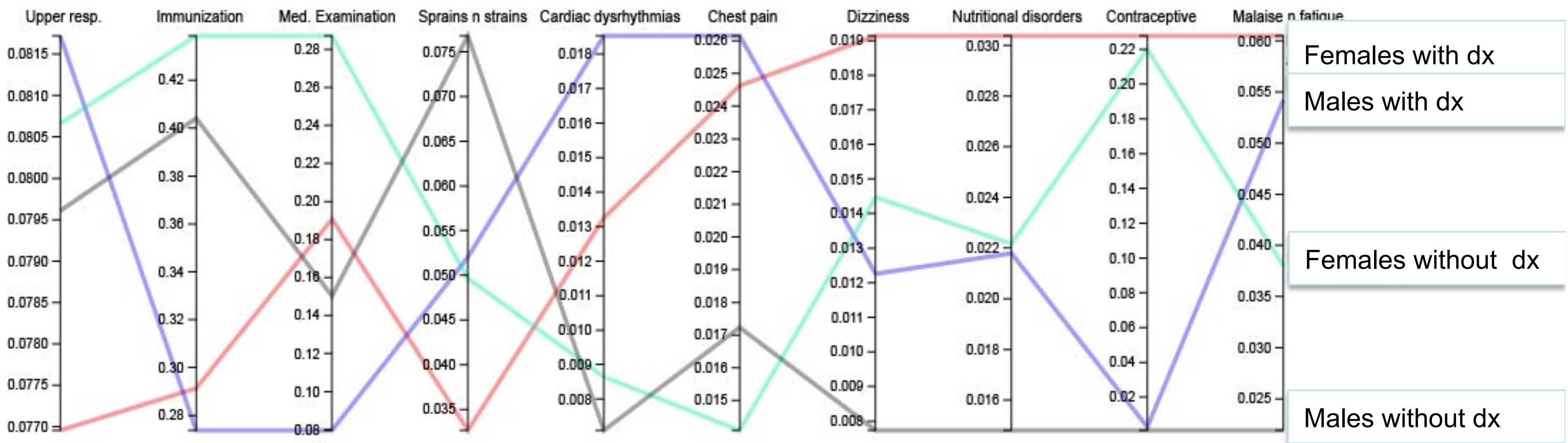
Findings

Q1: How does this change utilization patterns in students with a mental health dx?

- Findings:
  - In enhanced model, the average utility rate of primary care services is 15.72% lower than standard model
  - In enhanced model, the average utility rate for somatization purpose is 25% lower than standard model
  - In enhanced model, the average visit length for primary care is 13.8% less than in standard model

Prediction of Patient Trajectory

- Prediction of future events:
  – Prediction of anxiety and depression from distribution and sequences of diagnoses and procedures in patient visit history



Issues

Apple ResearchKit Turns iPhones Into Medical Diagnostic Devices

Posted 23 hours ago by Josh Constine (@joshconstine)

IT'S INSANELY EASY TO HACK HOSPITAL EQUIPMENT

Superbug Outbreak: Endoscope Manufacturer Sold Modified Device Without FDA Approval

By Philip Ross @ThisIsPRo p.ross@ibtimes.com on March 04 2015 9:26 AM EST

FDA opens the doors for mHealth apps

20, 2015

With Medicare Pay On The Line, Hospitals Push Harder To Please Patients

Summary

- Must understand existing information systems, workflow and cultural barriers to technology integration
- Transparent analytics must be BOTH clinically and statistically significant
- System designs must be both clinician centered and patient centered
- Communication must be enabled through disparate information sources to enhance care

Challenges

- Open data initiatives → we need to externally validated models and system designs!
- Training: Take advantage of data for building training simulators
- Metrics for success
- Automate data quality filters
- Paths to FDA approval
- Security and privacy concerns
- Technology integration to heterogeneous clinical workflows, environments, and patient populations