AI & IoT for Medicine
CSE 521S Wireless Sensor Networks

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AI for Precision Medicine

- Data-driven tools for precision medicine
  - Phenotype complex diseases
  - Predict individual outcomes and treatment effects
  - Discover risk factors
  - Support clinical decisions

- Extract knowledge from diverse data

Electronic Health Record (EHR)
- Collected in hospitals
- Complex and high-dimension data

Internet of Things (IoT)
- Longitudinal monitoring in daily life
- Noisy and lossy data
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IoT: Internet of Things

- Convergence of
  - Devices: processor + sensors + radio, embedded OS
  - Wireless: connect millions of devices to the Internet
  - Cloud: scalable real-time data processing
  - Analytics: make sense of sensor data

- Real-time monitoring and control
  - Smart*: healthcare, house, manufacturing, transportation, grid…

- We are in the golden age of Internet of Things!
Miniaturized Devices

- Processor + Sensors + Wireless
- **Miniature hardware manufactured economically in large numbers**
- Networked for monitoring and control → Internet of Things

![Smart Dust (UCB)]
Wireless Clinical Monitoring

- Clinical deterioration in hospitalized patients
  - 4-17% suffer adverse events (e.g., cardiac or respiratory arrest).
  - Up to 70% of such events could have been prevented.
  - Clinical deterioration is often preceded by changes in vitals.

- Real-time patient monitoring in general hospital wards
  - Current practice: collect vital signs manually every 5-10 hours
  - Wireless monitoring: collects data every minute

- Goal: Early warning of clinical deterioration $\rightarrow$ improved outcome
Wireless Clinical Monitoring

Potential for Detecting Events

Pulmonary edema

Sleep apnea

Bradycardia

Wearables

- Commonly available: step, heart rate, sleep stages
- More sensing modalities
  - Oxygen saturation (SpO2)
  - Skin temperature
  - Breathing rate
  - Heart rate variability
  - ECG
  - Stress
- 500+ million wearables sold in 2021

Unprecedented monitoring capability outside hospitals!
IoMT: Internet of Medical Things

- **Wearables**: wristband, watch, ring...
  - Long-term, non-obtrusive monitoring

- **Connectivity**: Bluetooth, WiFi, cellular
  - Remote monitoring and intervention

- **Cloud**: computing and storage
  - Scalable to large population

- **Analytics**: machine learning
  - Predict outcomes and support intervention

“I believe, if you zoom out into the future, and you look back, and you ask the question, 'What was Apple's greatest contribution to mankind?', it will be about health.” --Tim Cook
IoMT for Precision Medicine

- **Perioperative care**
  - Surgical complications after pancreatic surgery [Standard of Care in Surgical Prehabilitation]
  - Recovery outcomes after spine surgery
  - Surgical outcomes of periacetabular osteotomy for hip dysplasia [NIH R01]

- **Mental health care**
  - Depression and weight loss of older adults undergoing behavioral therapy [NIH R01]
  - Mental disorders in the community [NIH All of Us]
  - Dynamic cognitive function in youth with diabetes
Need: Predict Outcomes of Pancreatic Surgery

- Pancreatic cancer has a 5-year survival rate less than 5%.

- Surgery is the only cure but commonly followed by complications.

- Predict postoperative complications before surgery
  - **Decision support**: suitability for surgery
  - **Intervention**: pre-habilitation

Joint work with Chet Hammill (Surgery), Jingwen Zhang, Dingwen Li, Ruixuan Dai (CSE)
Prediction Problem

- **Wearable time series**: step count, heart rate, sleep stage

![Example of step and heart rate data collected by Fitbit](image)

- **Complications**: composite outcome of readmission or severe complications within 30 days of hospital discharge

![Time series of sleep stages](image)
Robust Prediction of Surgical Complications

- Machine learning models outperform standard surgical risk scores.
  - $x^2$ AUPRC
  - $x^3$ sensitivity at the same specificity

<table>
<thead>
<tr>
<th>Data Source</th>
<th>AUROC</th>
<th>AUPRC</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random weighted classifier</td>
<td>0.5097 (0.0585)</td>
<td>0.4322 (0.0469)</td>
<td>0.1520 (0.0854)</td>
<td>0.8583 (0.0504)</td>
</tr>
<tr>
<td>NSQIP with Clinical Characteristics</td>
<td>0.6114 (0.0000)</td>
<td>0.4075 (0.0000)</td>
<td>0.2800 (0.0000)</td>
<td>0.8571 (0.0000)</td>
</tr>
<tr>
<td>ML with Clinical Characteristics</td>
<td>0.7632 (0.0085)</td>
<td>0.7374 (0.0206)</td>
<td>0.5800 (0.0699)</td>
<td>0.8583 (0.0083)</td>
</tr>
<tr>
<td>Wearable Data</td>
<td>0.7326 (0.0074)</td>
<td>0.7192 (0.0154)</td>
<td>0.5480 (0.0440)</td>
<td>0.8583 (0.0083)</td>
</tr>
<tr>
<td>Clinical Characteristics + Wearable Data</td>
<td><strong>0.8802 (0.0050)</strong></td>
<td><strong>0.8871 (0.0087)</strong></td>
<td><strong>0.8320 (0.0160)</strong></td>
<td><strong>0.8583 (0.0083)</strong></td>
</tr>
</tbody>
</table>

- NSQIP: American College of Surgeons National Surgical Quality Improvement Program
- AUROC: Area Under the Receiver Operating Characteristic Curve
- AUPRC: Area Under the Precision-Recall Curve
Mental Health Crisis

- Mental disorders are prevalent.
  - ~3.8% of the population (i.e., 280 million) experience depression (WHO).

- Over 50% of patients are not recognized or treated.

- Clinical visit is time-consuming and expensive.
  - Hindering timely diagnosis and intervention

- Detect mental disorders with wearables devices?
  - Unobtrusive, multi-modal sensing
  - Activities, heart rate, and sleep are associated with mental health
Detect Mental Disorders in the Community

- Detect mental disorder (depression & anxiety) using
  - wearable data: multi-variate time series of daily features
  - patient characteristics: age, race, ethnicity, gender, education, smoke, alcohol

- All of Us program: 8,996 participants with wearables (1,247 with mental disorders)

- WearNet: deep model for detecting mental disorders

Joint work with Thomas Kannampallil (Informatics), Laura Jean Bierut (Psychiatry), Ruixuan Dai (CSE)
Personalized Prediction of Treatment Response

- Statistical analysis → **population-level** effectiveness of treatment
- **Personalized** prediction of treatment response → **precision** medicine
- **Machine learning from RCT data**
  - Clinical (baseline): age, anxiety…
  - Fitbit (2 months): heart rate, sleep
  - Depression outcome (at 6 month)

Randomized Controlled Trial of Depression Therapy

- **Group randomization**
  - Random split (71 : 35)
  - 106 patients

- **6-month trial period**
  - **Intervention**
    - Behavior therapy
  - **Control**
    - No treatment
  - Positive outcome
  - Negative outcome

- Baseline clinical measurements
- Continuous wearable data

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Oncology Early Warning System

- Predict clinical deterioration of hospitalized cancer patients

- Inpatient data from EHR
  - 128 static variables
  - 41 time-series variables

- Static and time series variables
  - make complementary contributions to prediction of clinical deterioration
  - have cross-modal correlation

Joint work with Patrick Lyons, Marin Kollef, Brian Gage (Medicine), Dingewen Li (CSE)
CrossNet

- **Unified** deep recurrent model for integrating static and time-series inputs
- **Multi-modal fusion**: integrating heterogeneous input data
- **Cross-modal imputation**: exploiting cross-modal correlation

**CrossNet detects $10x$ deterioration events than MEWS at the same false alarm rate**

<table>
<thead>
<tr>
<th>Model</th>
<th>Alarm rate control</th>
<th>False alarm control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sensitivity</td>
<td>Specificity</td>
</tr>
<tr>
<td>MEWS</td>
<td>0.3358(0.0115)</td>
<td>0.8257(0.0142)</td>
</tr>
<tr>
<td>C. BRITS</td>
<td>0.3899(0.0134)</td>
<td>0.9394(0.0097)</td>
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<tr>
<td>S. BRITS</td>
<td>0.3891(0.0122)</td>
<td>0.9396(0.0105)</td>
</tr>
<tr>
<td>CrossNet</td>
<td><strong>0.4218(0.0130)</strong></td>
<td><strong>0.9486(0.0093)</strong></td>
</tr>
</tbody>
</table>

MEWS: Modified Early Warning Scores

Predict Postoperative Complications

- Anticipatory management for perioperative contingency planning
- Preemptive and early identification of risk factors
- Example: OR-ICU handoff [ARHQ R01]

Predict Clinician Burnout based on EHR Logs

Unobtrusively monitor and assess the risk of burnout in real time

Available in most hospitals

Deep Neural Networks

Running in Background (Unobtrusive)

Many people with cognitive impairment struggle to complete daily activities

Use AI to recognize cognitive errors and support daily functions

Support People with Subjective Cognitive Decline

Simple Cooking Task

Make oatmeal on the stove

Smart Camera

Capture performance and detect errors

Smart speaker

Deliver context-sensitive cues

Joint work with Lisa Connor, Carolyn Baum (Occupational Therapy), Ruiqi Wang, Jaehwan Jeong (CSE)
Significant **clinical information** can be learned from diverse data.

AI is key to extract clinical information from complex clinical data.

Rigorous **clinical studies** are needed to validate IoMT models.

Precision medicine: Personalized prediction $\rightarrow$ **intervention** $\rightarrow$ outcome

Close collaboration between AI and clinical researchers is essential

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**AI for medicine research:** [https://www.cse.wustl.edu/~lu/iomt.html](https://www.cse.wustl.edu/~lu/iomt.html)
Grading

- Projects 60%
  - Proposal and presentation: 10%
  - Demo I: 5%
  - Demo II: 5%
  - Final report and demo: 40%

- Critiques 30%

- Participation 10%
Critiques

- Half-page *critiques* of research papers
- Due by 10am on class day
- Back-of-envelop - NOT whole essays

**Critique requirement**
Project

- Three students per team
  - Need permission for a bigger or smaller team.

- Develop/integrate **software/hardware**
- Perform **experiments** on real systems and data
- Write a **paper**
- **Demos**
Steps

1. Pick your favorite topic
2. Form a team
3. Propose a design
4. Analyze and Implement your solution
5. Evaluate your solution
6. Demo 1, 2 and Final Demo
7. Write a technical report
Get Started Early

- Think about topics and ideas
- Talk to TA and me
- Put together a team

- A lot of work (and fun) throughout the semester!
Logistics

- Guidelines and slides are on the class **homepage**.  
  - http://www.cse.wustl.edu/~lu/cse521s/

- Communication will be through **Piazza**.  
  - E.g., Search for teammate
Support

- Prof. Chenyang Lu <lu@wustl.edu>
- Projects: Ruiqi Wang <ruiqi.w@wustl.edu>
- Critiques: Jingwen Zhang <jingwen.z@wustl.edu>
- Make appointment for meetings.
- Post on Piazza for Q&A.
Next Class

- Project topics and discussion

- **In person** by Ruiqi Wang