Seventh Annual
Cyber-Physical Systems Principal Investigators' Meeting
Arlington, VA | October 31 – November 1, 2016

Collaborative: Executable Distributed Medical Best Practice Guidance (EMBG) System for End-to-End Emergency Care from Rural to Regional Center Hospitals (NSF 1545002 & NSF 1545008)

PI: Shangping Ren, CS IIT

PI: Lui Sha, CS UIUC

Dr. Richard Berlin, Carle Hospital

ILLINOIS INSTITUTE OF TECHNOLOGY

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Carle

OREGON HEALTH & SCIENCE UNIVERSITY

Participating Graduate Students

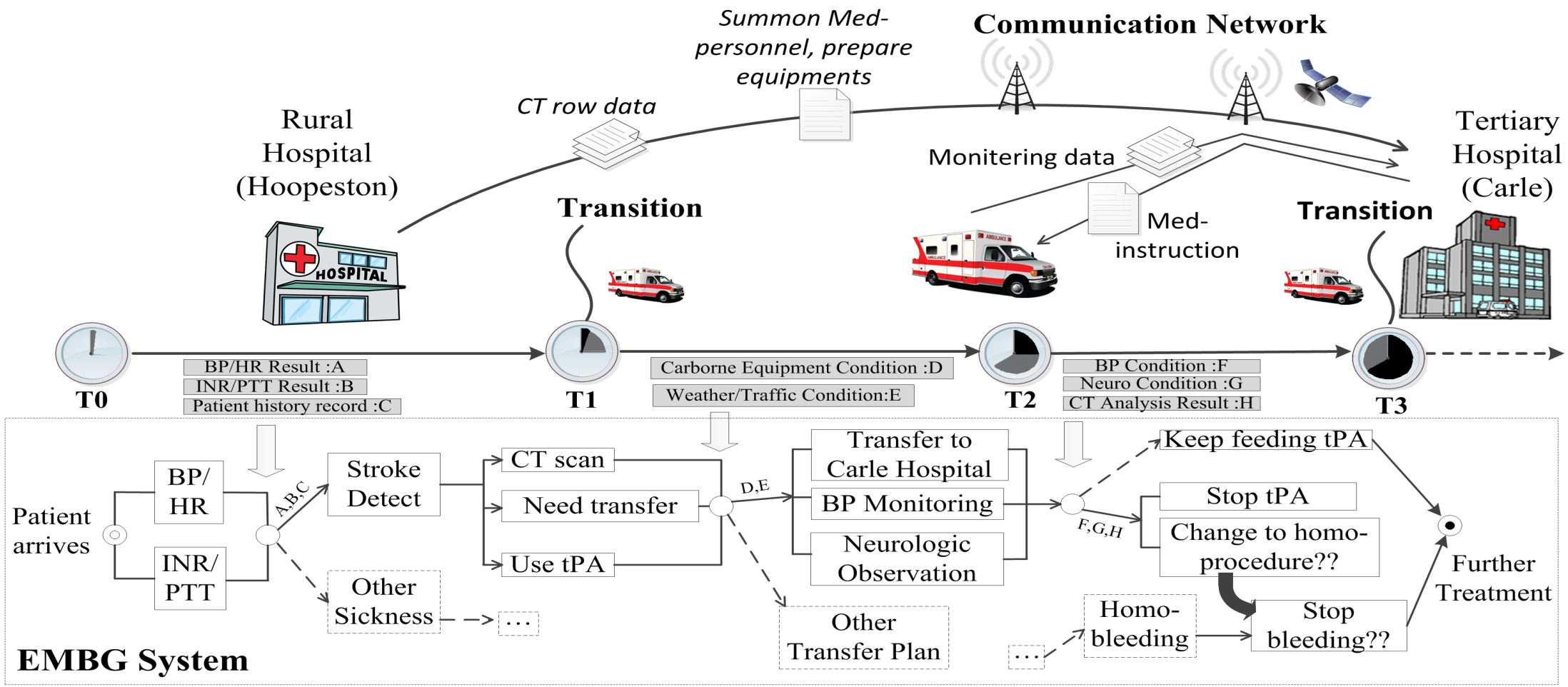
- Chunhui Guo, cguo13@hawk.iit.edu (PhD, IIT)
- Zhichen Fu, zfu11@hawk.iit.edu (PhD, IIT)
- Maryam Rahmaniheris, rahmani1@illinois.edu (PhD, UIUC)
- Mohammad Hosseini, shossen2@illinois.edu (PhD, UIUC)
- Andrew Y.-Z. Ou, ou9@illinois.edu (PhD, UIUC)
- PoLiang Wu, wu87@illinois.edu (Postdoc, UIUC)
- Yu Jiang, jy1989@illinois.edu (Former Postdoc at UIUC, faculty at Tsinghua)

Illinois Institute of Technology http://gauss.cs.iit.edu/~code/
University of Illinois at Urbana-Champaign http://publish.illinois.edu/mdpnp-architecture/

Some Factual Data

- More than 60 Million people live in rural area
- Doctor:patient ratio
  - ➢metropolitan area = 1:330
  - ➢rural area = 1: 2,000
- 1 in 10 patients experience an adverse event (AE) in ambulance care
- Computerizing medical best practice protocol has reduced death rate for sepsis patients by 17%

EMBG System --- A Medical GPS

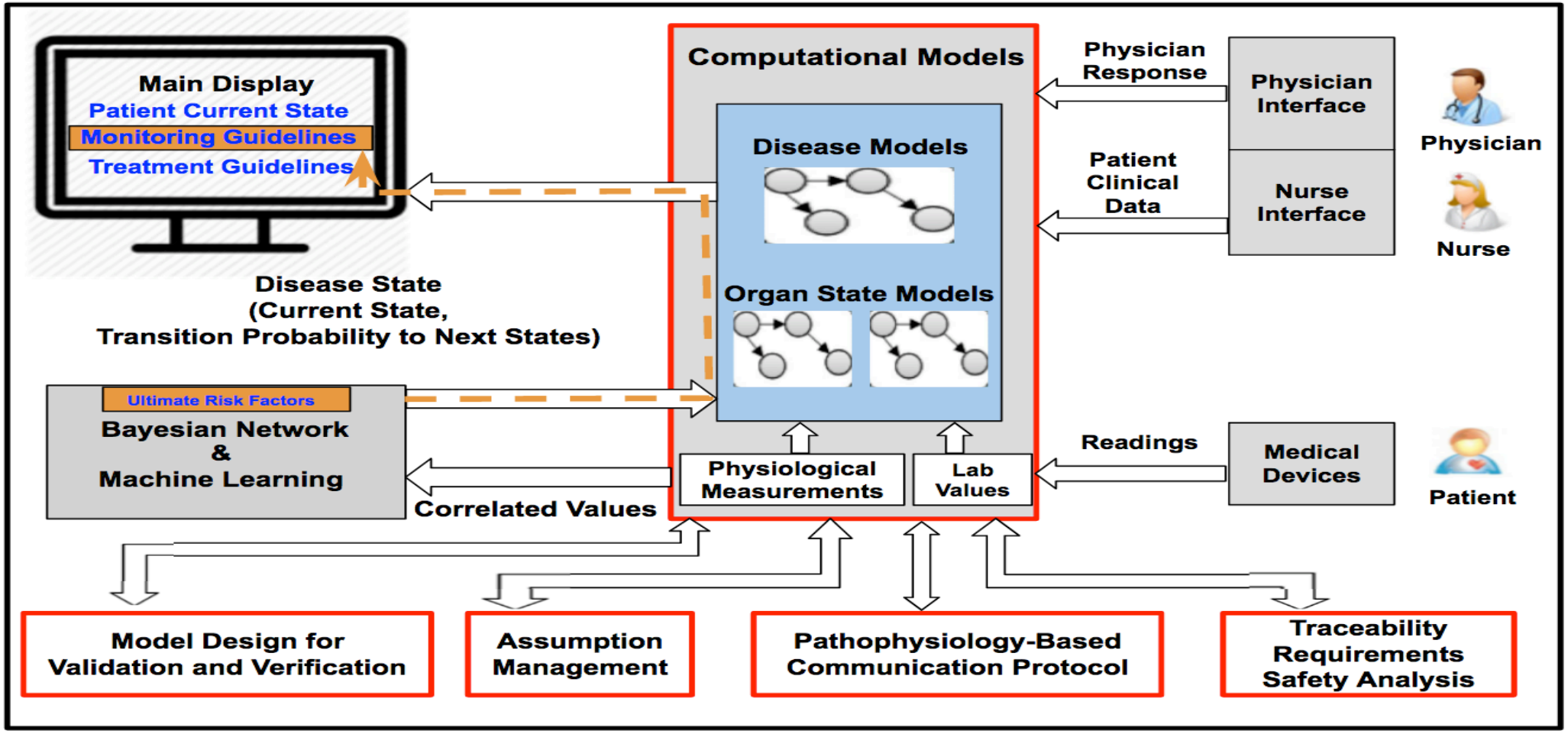


Challenges

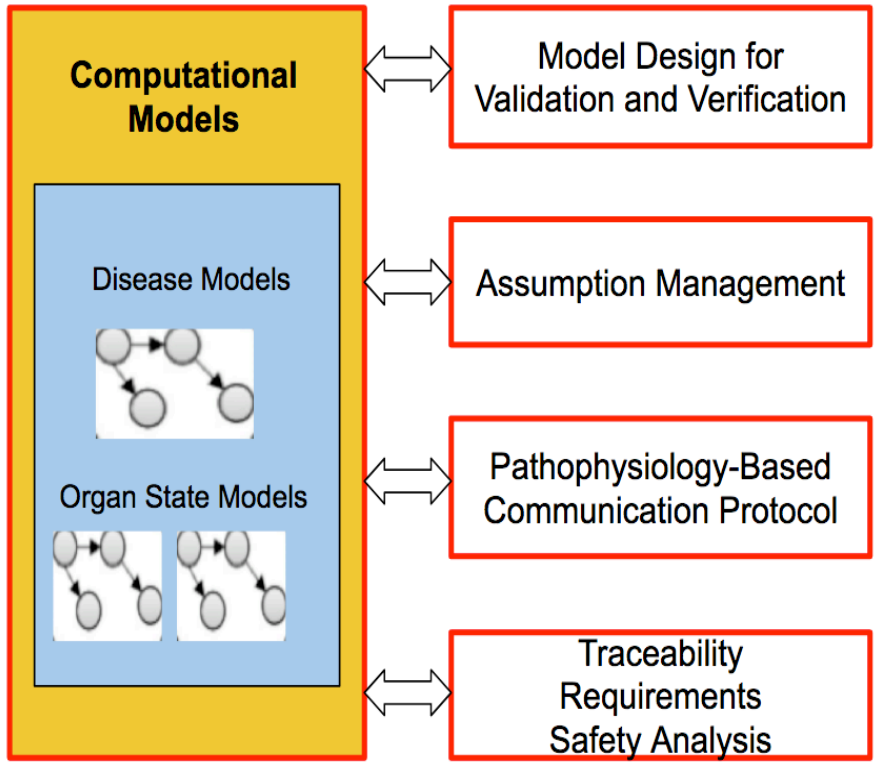
Ensure end-to-end safety and effectiveness of emergency patient care under distributed and mobile environment:

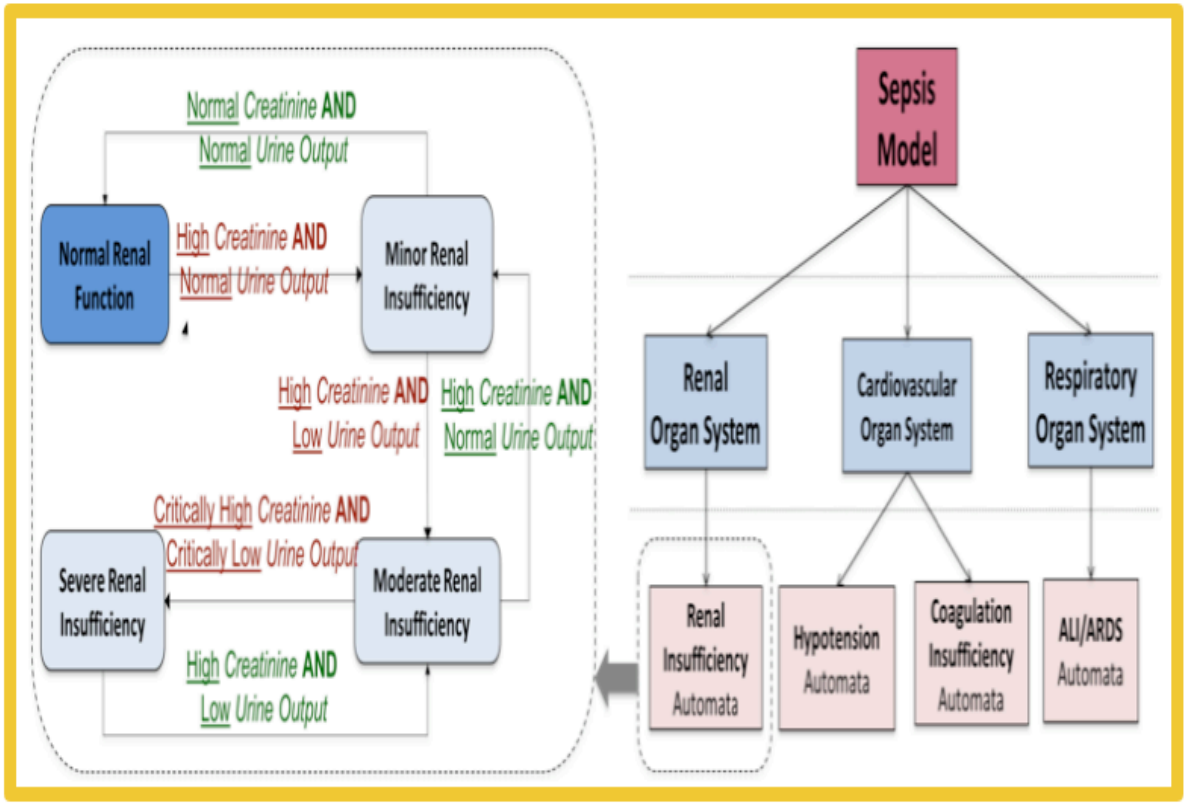
1. Executable pathophysiology and medical best practice models
2. Model design for validation and verification
3. Specify, validate and trace assumptions in system design and evolution
4. Dynamic patient condition monitoring in ambulance under limited and variable bandwidth
5. Ensure end-to-end traceability from clinical and system requirements, safety analysis, to design and implementation
6. Clinical evaluations for transitioning research results into medical practices

EMBG System Overview



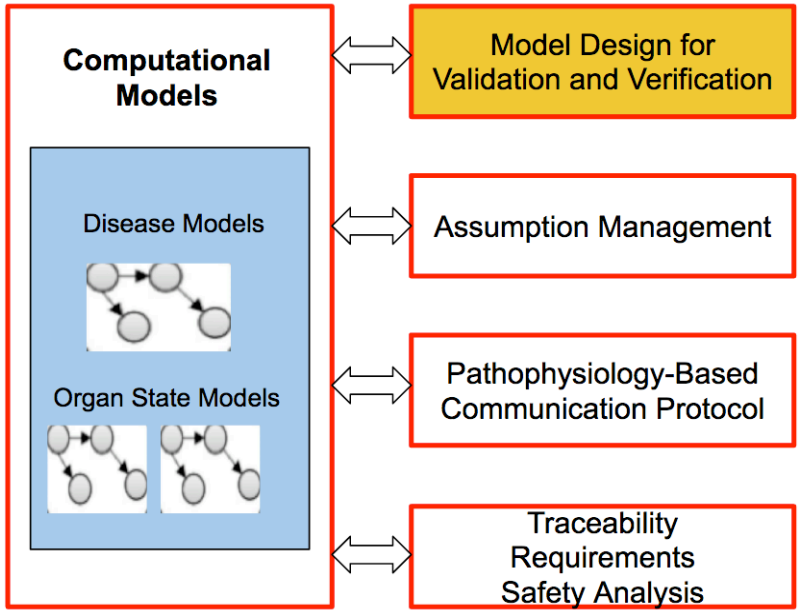
Computational Organ-Centric Disease Model

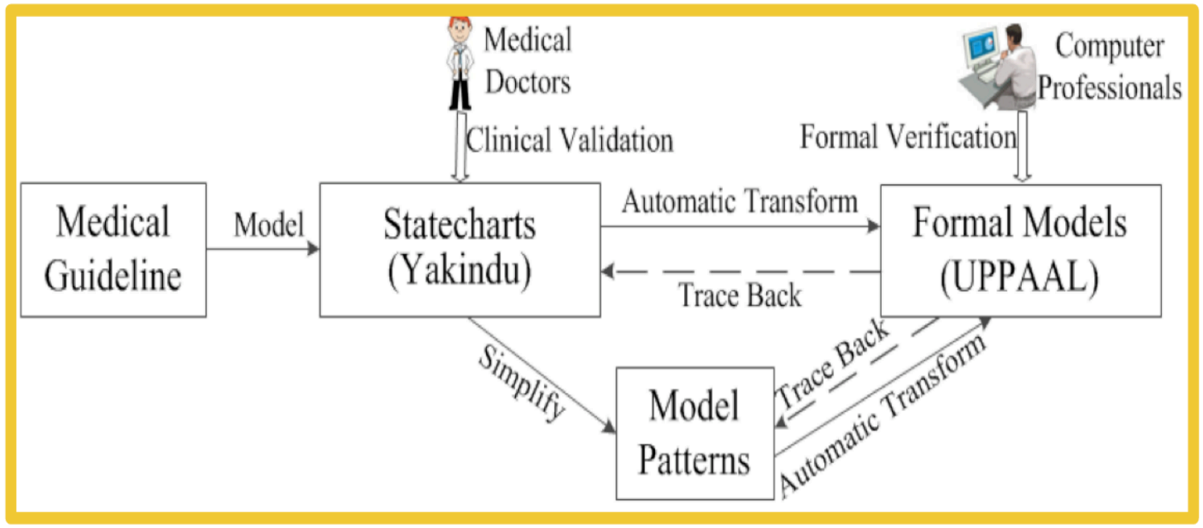




http://publish.illinois.edu/cpsintegrationlab/people/701-2-2/

Model Design for Validation and Verification





http://gauss.cs.iit.edu/~code/student_chunhui.html

Danger of Implicit Assumptions

FDA Medical Device Class I Recall: Dräger Evita V500 Ventilators, 12/2015
http://www.fda.gov/MedicalDevices/Safety/ListofRecalls/ucm480135.htm

- Ventilators shut down without low battery alarm. This could cause patient injury or death.

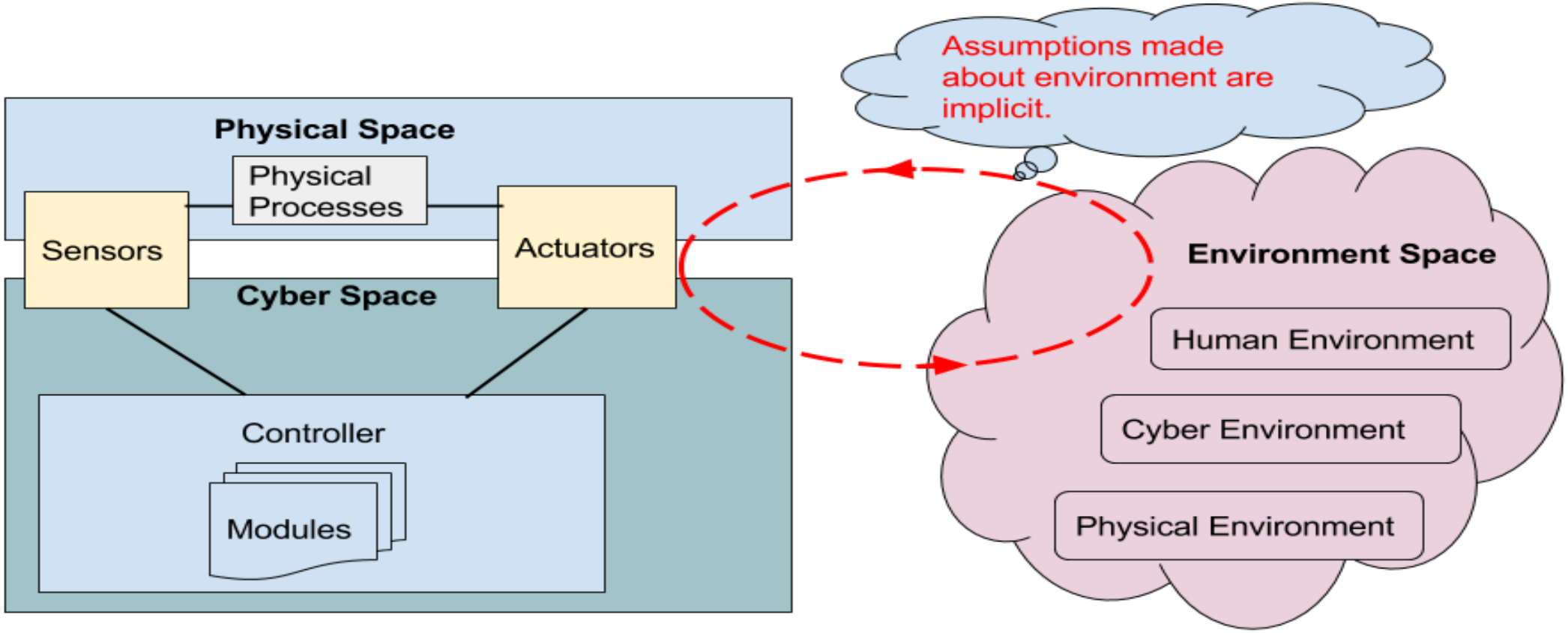
Battery Impactors:

- Temperature (Physical Environment)
- Frequent restarting of ventilators (Human Environment)

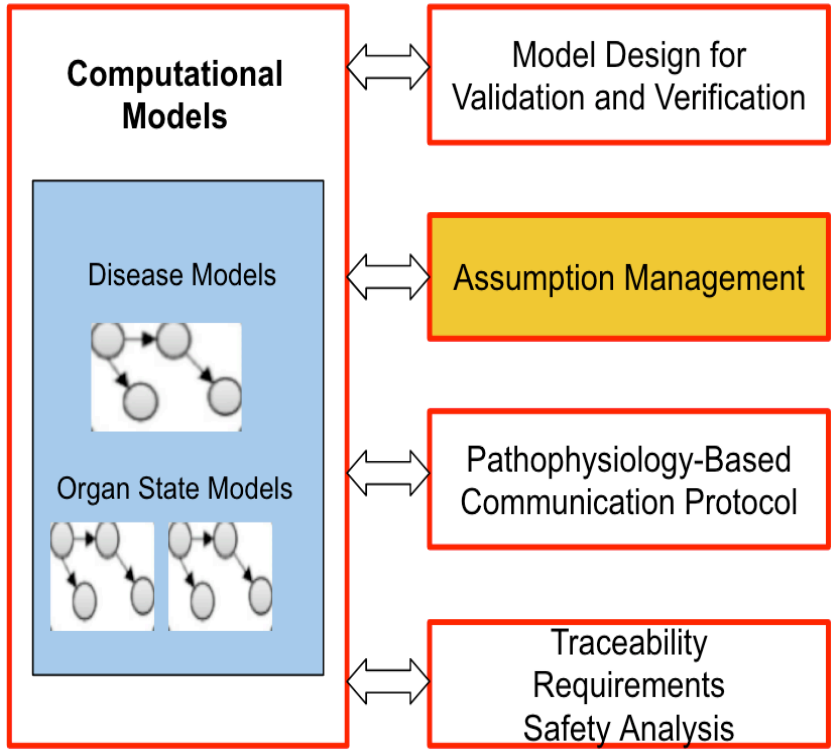
Implicit assumptions:

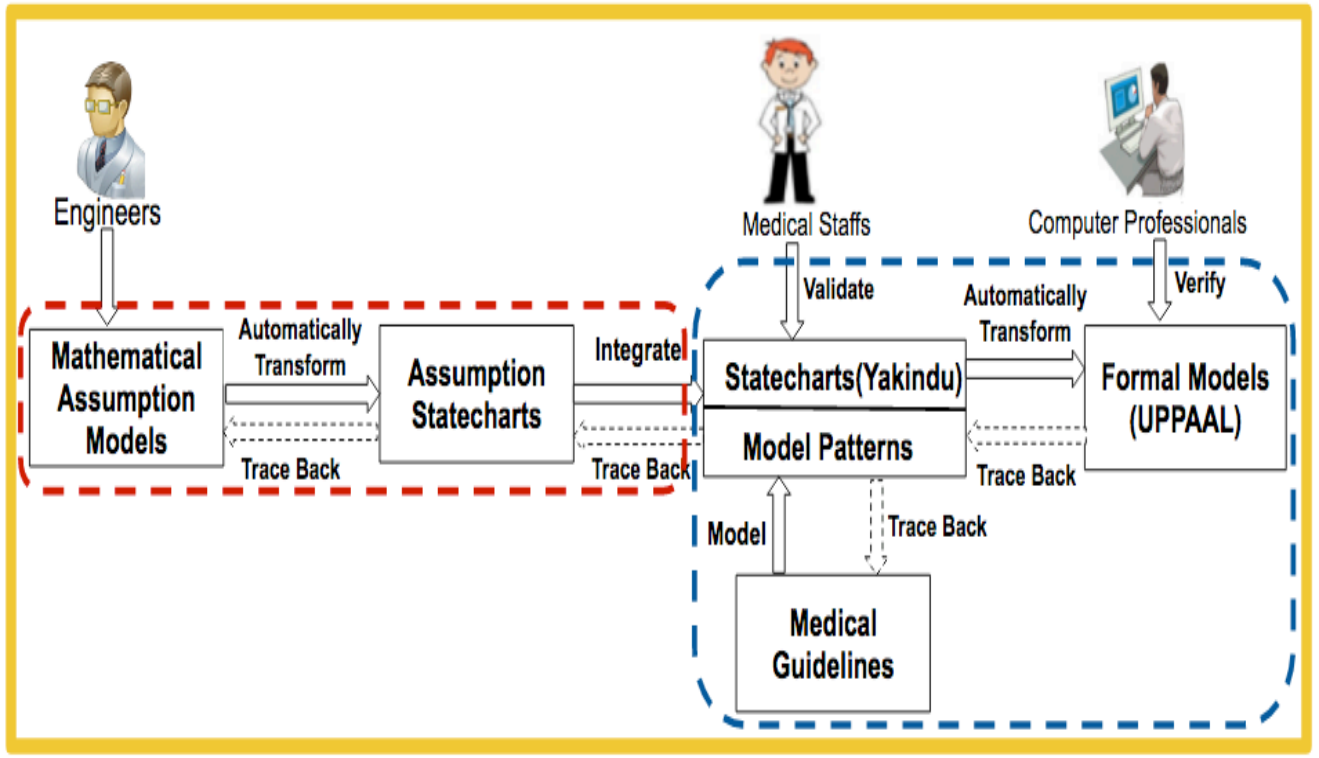
- Ventilators are installed in temperature controlled areas
- Ventilators should not restart within 3 minutes

M-CPS Environment Space



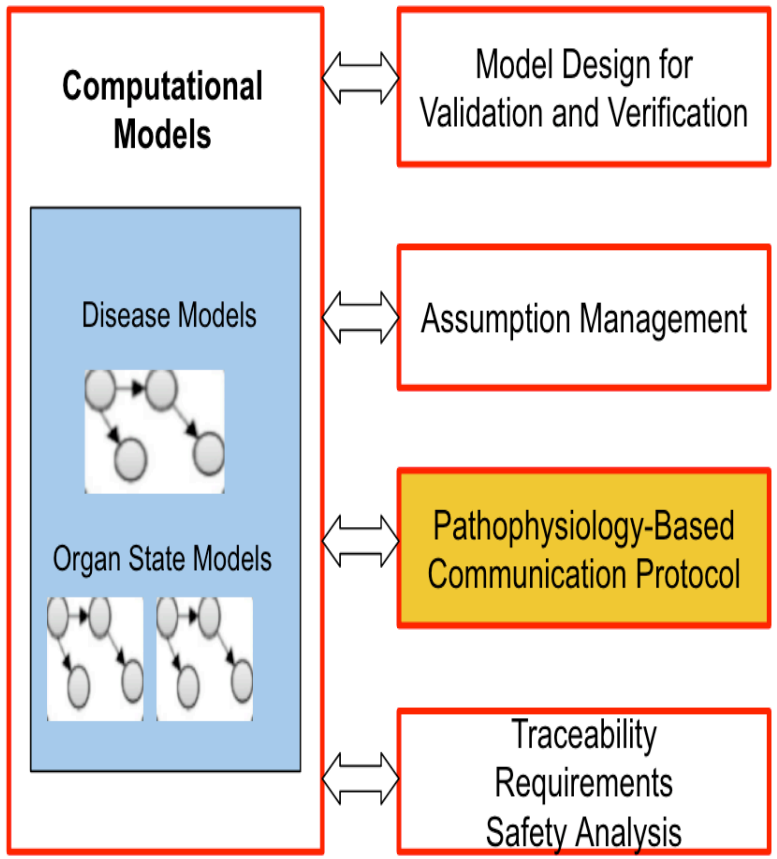
M-CPS Environment Assumption Management

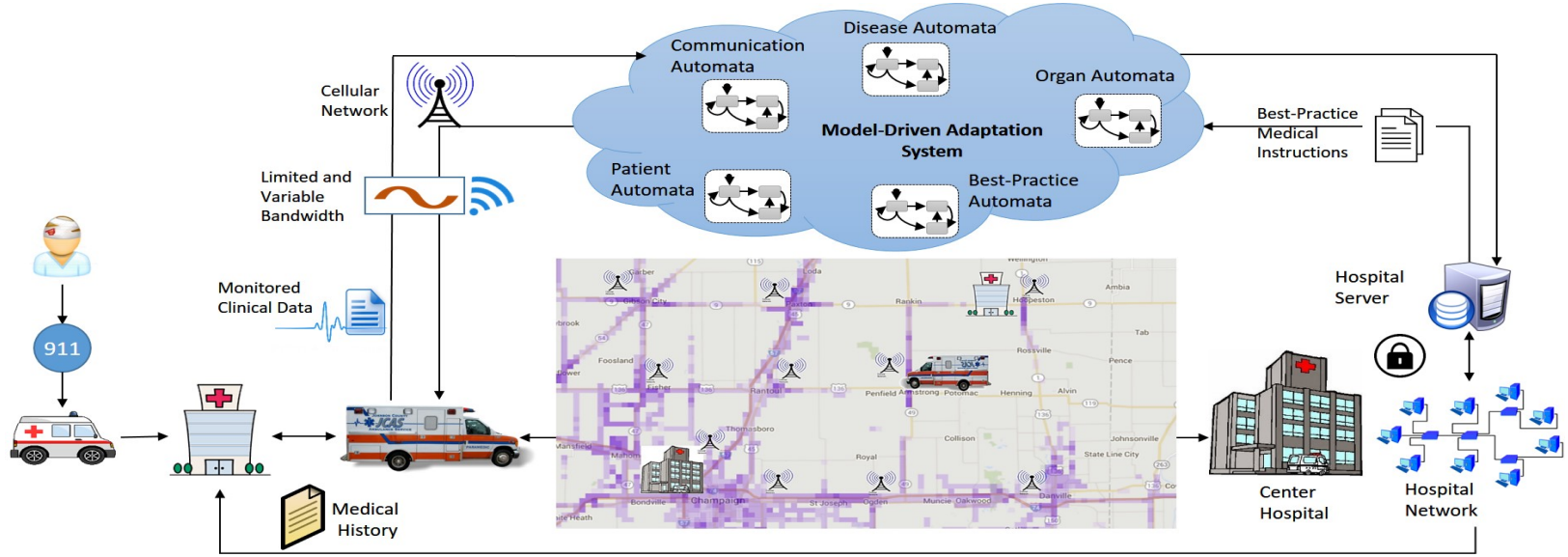


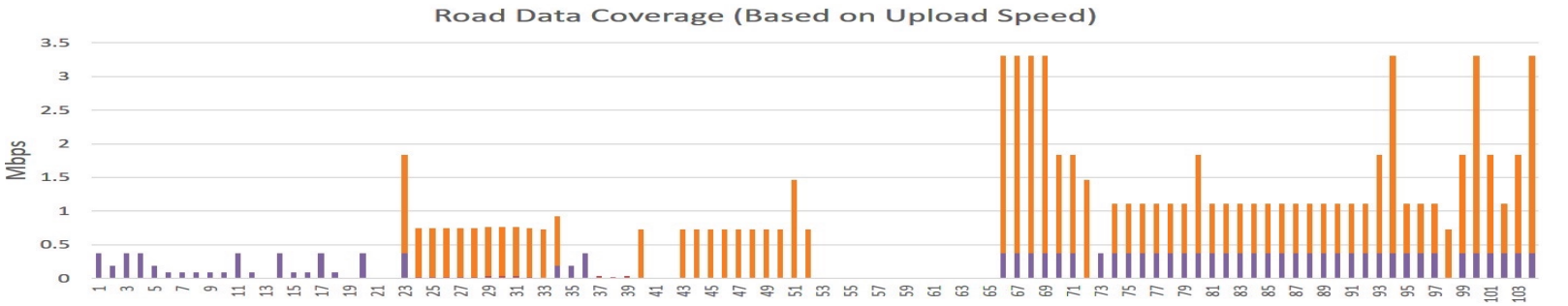


http://gauss.cs.iit.edu/~code/student_fzhicheng.html

Pathophysiology-Based Communication Protocol

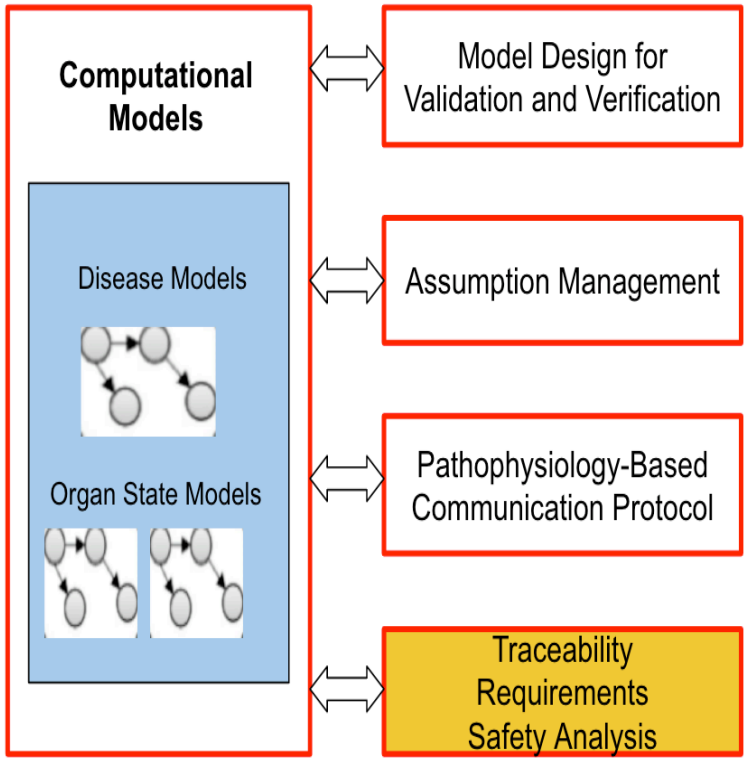


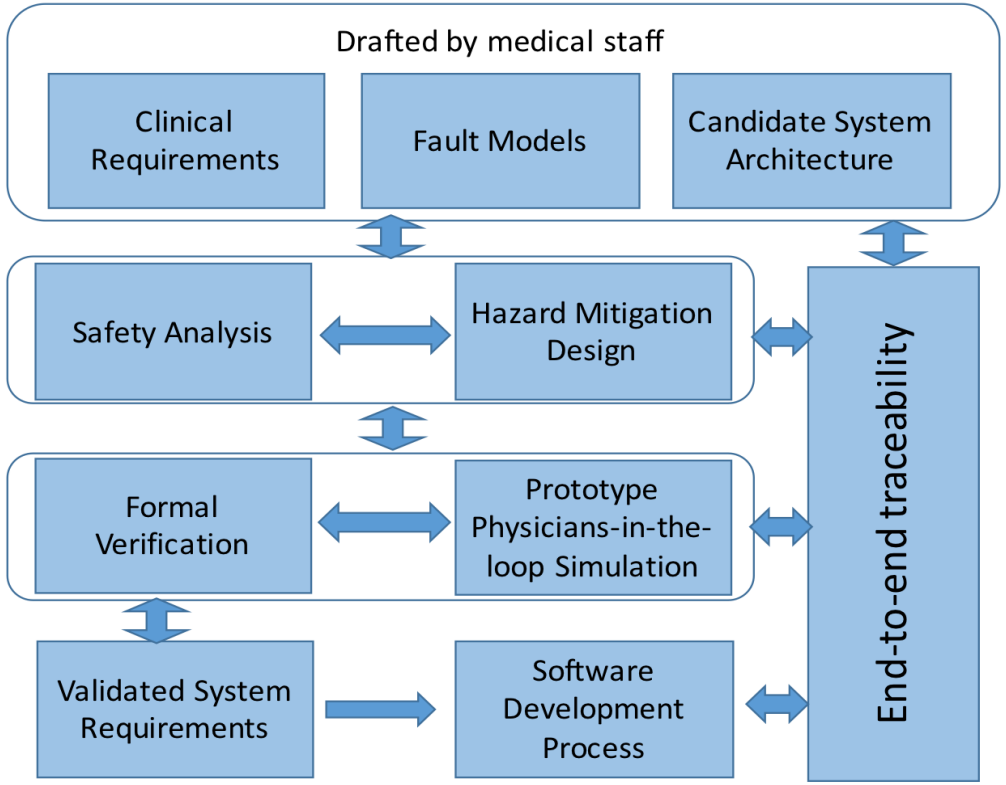




http://web.engr.illinois.edu/~shossen2/

Traceability, Requirements and Safety Analysis



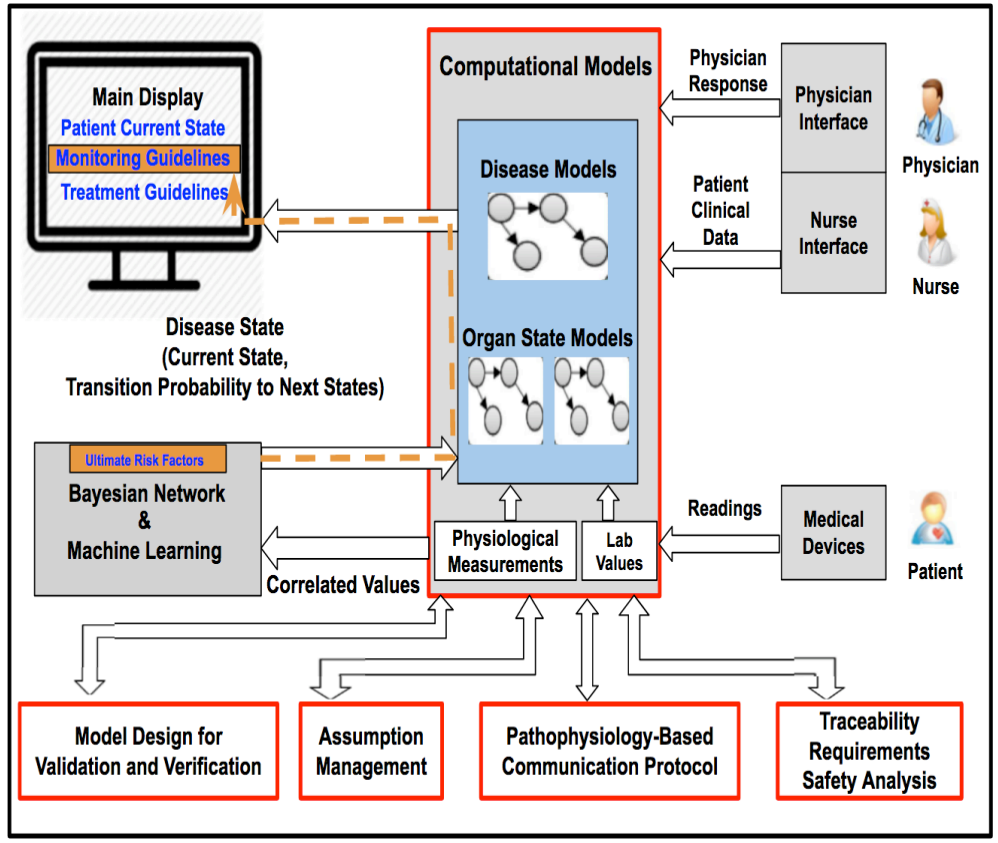


http://www.yzou.cc/

Accomplishments

- Organ-centric medical best practice guidance system prototypes (UIUC, Carle, OHSU)
- Pathophysiological model-driven communication (UIUC, Carle EMS)
- Verifiable and validatable statecharts for disease and treatment models (IIT)
- Statechart model patterns for modeling medical guidelines (IIT)
- Modeling and integrating implicit assumptions into M-CPS design (IIT)
- End-to-end traceability from clinical and system requirements, safety analysis, to design and implementation (UIUC & IIT)
- Completed pre-clinical validation of the guidance system prototypes with Carle and OHSU medical center on high-impact diseases, e.g. sepsis and heart transplant peri-operative (UIUC, Carle, OHSU), current waiting for FDA approval for clinic trial

Scientific Impact

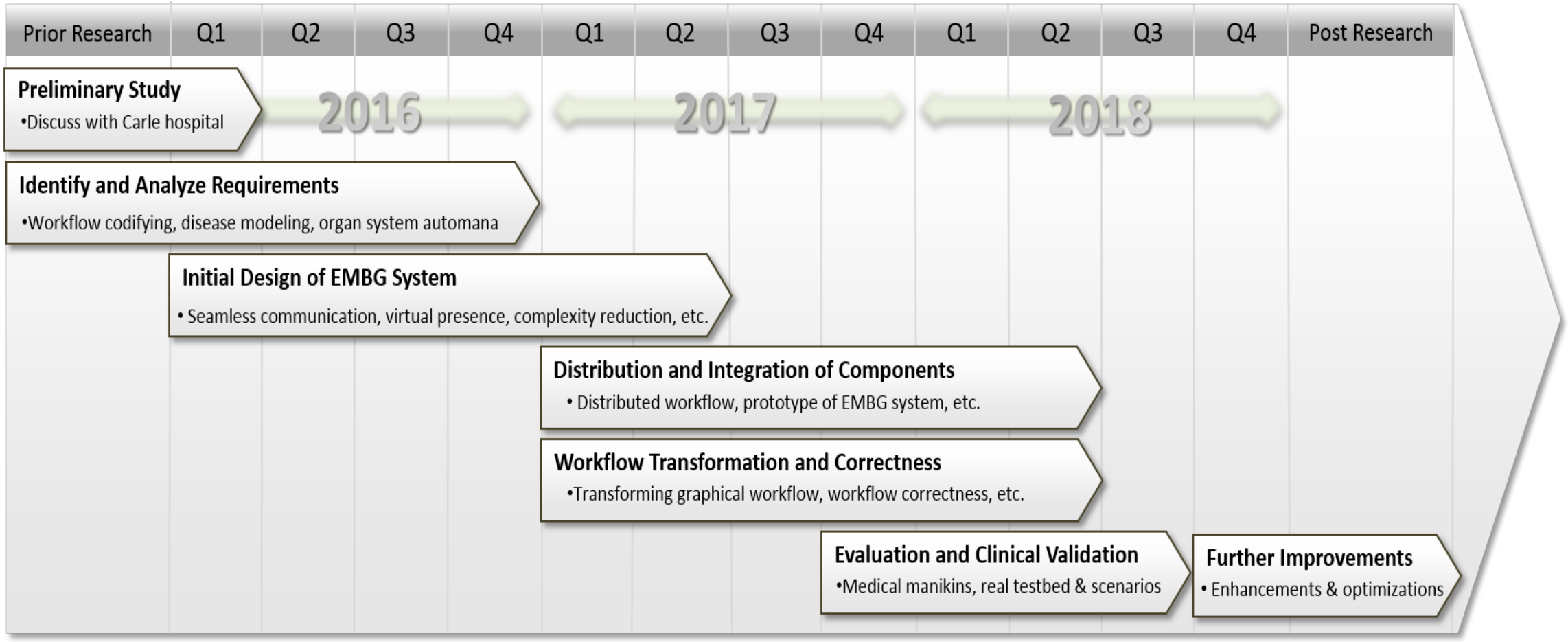


- Computational pathophysiology [1]
- Bayesian network for early sepsis detection[2]
- Mental workload reduction system designs for medical staff [3]
- Pathophysiology-driven and bandwidth-compliant communication protocols [4]
- Verifiable medical guideline models [5][6]
- Statechart model patterns [6][7]
- Physical environment assumption management [8]

Broader Impact

- The project improves emergency care for people in rural areas.
- The validated and verified system will serve at central and southern Illinois with 1.2 million people.
- Successful pre-clinical evaluations are recommended for clinical trial.
- The cardiac arrest guidance system is submitted to FDA for the (pre-) approval process.

Where We Are and What's Next?



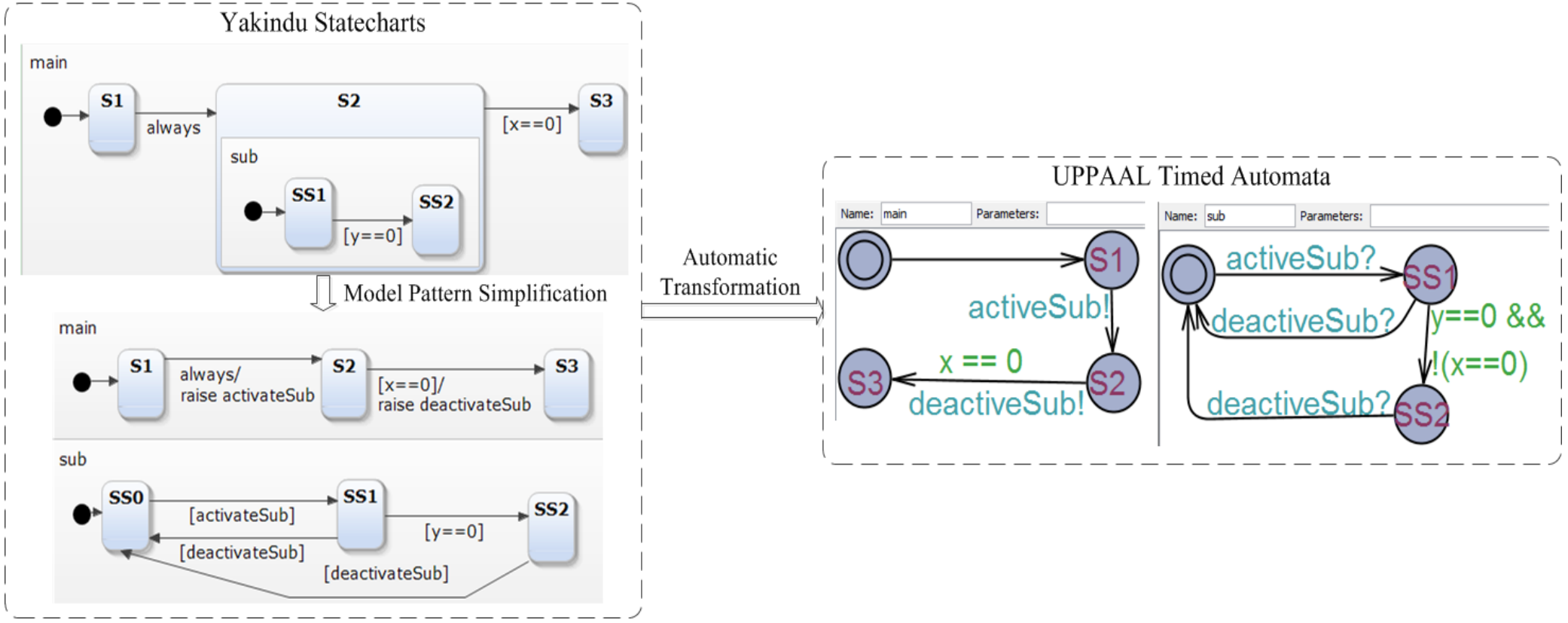
References

- [1] Maryam Rahmaniheris, PoLiang Wu, Lui Sha and Richard Berlin, "An Organ-Centric Best Practice Assist System for Acute Care", IEEE CBMS, 2016
- [2] Yu Jiang, Lui Sha, Maryam Rahmaniheris, Binhua Wan, Mohammad Hosseini, Pengliu Tan, Richard B. Berlin Jr., "Sepsis Patient Detection and Monitor Based on Auto-BN", Journal of Medical Systems, 2016
- [3] Andrew Y.-Z. Ou, Yu Jiang, Po-Liang Wu, Lui Sha , Richard Berlin, "Using Human Intellectual Tasks as Guidelines to Systematically Model Medical Cyber-Physical Systems", IEEE SMC, 2016. (Accepted)
- [4] Mohammad Hosseini, Jiang Yu, PoLiang Wu, Richard Berlin, ShangPing Ren, Lui Sha, "A pathophysiological model-driven communication for dynamic distributed medical best practice guidance Systems", Journal of Medical Systems, 2016
- [5] Chunhui Guo, Shangping Ren, Yu Jiang, PoLiang Wu, Lui Sha, Richard Berlin Jr., "Transforming Medical Best Practice Guidelines to Executable and Verifiable Statechart Models", IEEE ICCPS 2016.
- [6] Chunhui Guo, Zhicheng Fu, Shangping Ren, Yu Jiang, PoLiang Wu, Lui Sha, "Transforming Medical Best Practice Guidelines to Executable and Verifiable Statechart Models", ACM Transactions on CPS, 2016. (Submitted)
- [7] Chunhui Guo, Zhicheng Fu, Shangping Ren, Yu Jiang, Maryam Rahmaniheris, Lui Sha, "pStatecharts: Pattern-Based Statecharts for Modeling Medical Best Practice Guidelines", DATE 2017. (Submitted)
- [8] Zhicheng Fu, Chunhui Guo, Shangping Ren, Yu Jiang, Lui Sha, "Modeling and Integrating Physical Environment Assumptions in Medical Cyber-Physical System Design", DATE 2017. (Submitted)

Thank You

Q&A

Engineering Strategy: Simplification and Automation



Model and Integrate Implicit Assumptions in M-CPS Design and Implementation