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

PI: Shangping Ren, CS IIT; PI: Lui Sha, CS UIUC; Karen White, MD, Carle Foundation Hospital

Award Number: NSF CNS1545008; Award Date: September 21, 2015

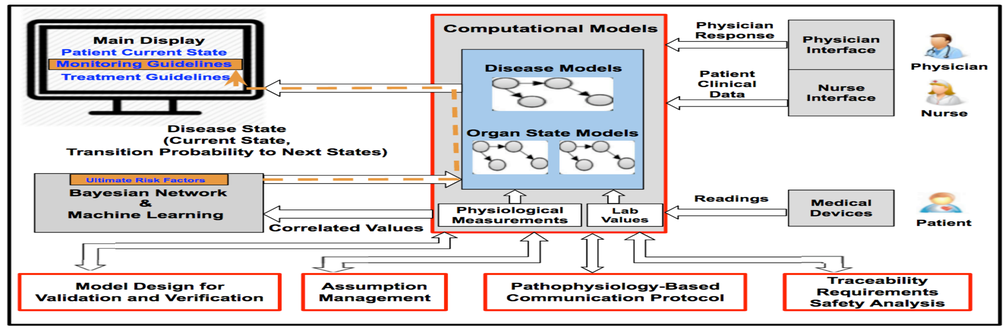
Challenges:

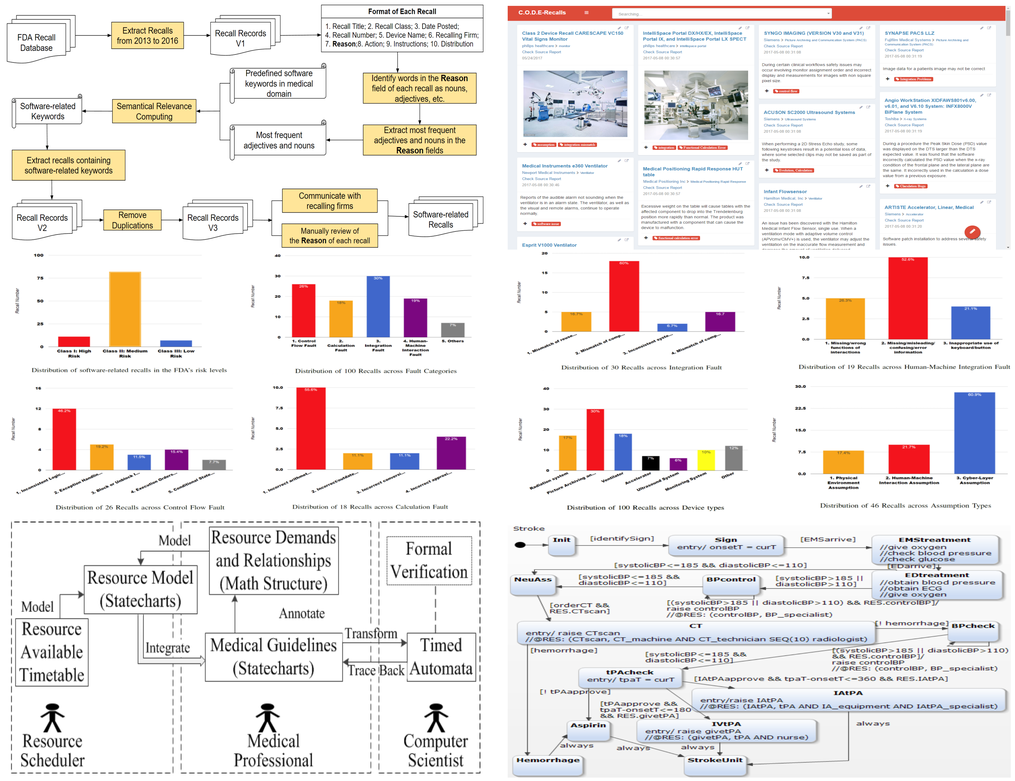
Preventable Medical Errors are the 3rd leading cause of deaths in America. GPS based navigation transform maps and chosen routes into real-time guidance. Can we similarly transform the practice of medicine?

- How can we make medical knowledge executable in the form of a guidance system, verifiable by formal method and validated in hospitals?
- How can we know:
  - if the changes in clinical environment may invalidate the assumptions embedded in the medical workflow?
  - patient's condition change s, is the medical workflow still applicable when facing with unexpected delays?
- Medical guidelines evolve and guidance system for critical care need FDA approval. Tracking the requirement changes effect on safety analysis and corresponding software changes is challenging.

Solutions:

- **Computational pathophysiology**: In the guidance system, medical knowledge is represented as networked medical best practice work flow automata and organ pathophysiology automata; Model development (UIUC), Model verification (IIT); Guidance system validation (Carle, OHSU, OSF)
- **Resource availability and environmental assumption management** : Environmental model and resource availability model are developed modularly but jointly verified with the best practice work flow (IIT)
- **End-to-end traceability** from clinical and system requirements, safety analysis, to design and implementation (UIUC)
- **Device fault model**: Study of software-related causes in the FDA medical device recalls (IIT)
- **Distributed guidance system** across regional hospital, satellite hospital and patient transfer (UIUC)





Scientific Impact:

- **Computational pathophysiology:**
  - Executable model of medical knowledge in the form of networked organ disease automata and best practice automata using statechart model tools
- **Integrated model verification and clinical validation**:
  - The statechart model's stimulation capability allows close interaction with physicians to check the validity of the model
  - The computer-aided translation of statechart Model to UPPAAL verifies the software design integrity.
  - Clinical system assumption management system to help prevent assumption faults.

Broader Impact:

- **Cardiac arrest resuscitation guidance system**: Cardiac Arrest is deadly and there is no room for errors. Our system has been approved for Phase 1 clinical evaluation at Carle Foundation Hospital. New: University of Chicago Med School now works with us to extend it for neonatal and pediatric resuscitation
- **Sepsis best practice systems:**
  - **Carle hospital network:** Sepsis has a high mortality rate caused by complex multi-organ failures. Our guidance system has been approved by Carle to start preparing on the clinical evaluation at Carle's satellite hospitals.
  - **NEW: OSF Children Hospital:** Our current sepsis guidance has been designed for adults. OSF Children Hospital has decided to work with us to extend it for pediatric sepsis
- **Heart transplant:** We have been working with OHSU on the requirements and high level designs for a heart transplant perioperative guidance system.
- **Education**: We start developing best practice guidance system based sepsis training course for the new Carle-UIUC Medical School's medical students.

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

[1] Chunhui Guo, Zhicheng Fu, Zhenyu Zhang, Shangping Ren, and Lui Sha, Model and Integrate Medical Resource Available Times and Relationships in Verifiably Correct Executable Medical Best Practice Guideline Models, ICCPS, 2018 (under review)
[2] Chunhui Guo, Zhicheng Fu, Zhenyu Zhang, Shangping Ren, and Lui Sha, Model and Integrate Medical Resource Availability into Verifiably Correct Executable Medical Guidelines, ICCAD, 2017.
[3] Chunhui Guo, Zhicheng Fu, Shangping Ren, Yu Jiang, and Lui Sha, Towards Verifiable Safe and Correct Medical Best Practice Guideline Systems, COMPSAC, 2017.
[4] Chunhui Guo, Zhicheng Fu, Shangping Ren, Yu Jiang, Maryam Rahmaniheris, and Lui Sha, Pattern-Based Statechart Modeling Approach for Medical Best Practice Guidelines - A Case Study, CBMS
[5] Zhicheng Fu, Chunhui Guo, Zhenyu Zhang, Shangping Ren, YuJiang, and Lui Sha, Study of Software-Related Causes in the FDA Medical Device Recalls, ICECCS, 2017.
[6] Zhicheng Fu, Chunhui Guo, Shangping Ren, Yu Jiang, YiZong Ou, and Lui Sha, Modeling and Integrating Human Interaction Assumptions in Medical Cyber-Physical System Design, CBMS, 2017.
[7] Zhicheng Fu, Chunhui Guo, Shangping Ren, Yu Jiang, Lui Sha. Modeling and Integrating Physical Environment Assumptions in Medical Cyber-Physical System Design. DATE, 2017.

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

PI: Lui Sha, CS UIUC; Karen White, MD, Carle Foundation Hospital; PI: Shangping Ren, CS IIT

Award Number: NSF CNS1545002; Award Date: September 21, 2015

Challenges:

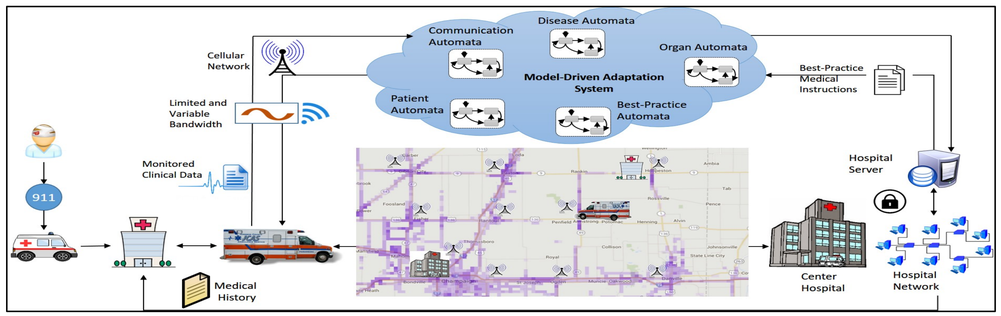
Preventable Medical Errors are the 3rd leading cause of deaths in America. GPS based navigation transform maps and chosen routes into real-time guidance. Can we similarly transform the practice of medicine?

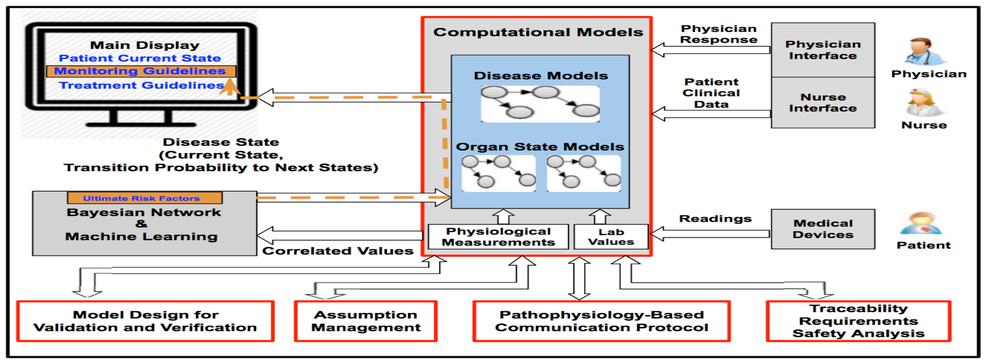
- How can we make medical knowledge executable in the form of a guidance system, verifiable by formal method and validated in hospitals?
- How can we know:
  - if the changes in clinical environment may invalidate the assumptions embedded in the medical workflow?
  - patient's condition change s, is the medical workflow still applicable when facing with unexpected delays?
- Medical guidelines evolve and guidance system for critical care need FDA approval. Tracking the requirement changes effect on safety analysis and corresponding software changes is challenging.

Solutions:

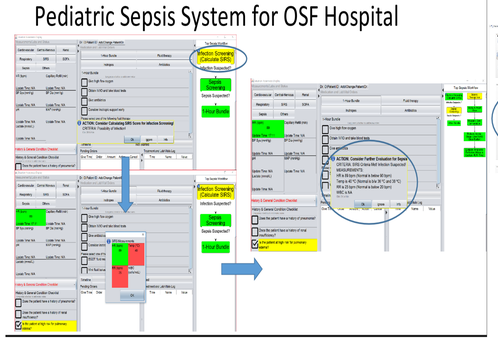
- **Computational pathophysiology**: In the guidance system, medical knowledge is represented as networked medical best practice work flow automata and organ pathophysiology automata; Model development (UIUC), Model verification (IIT); Guidance system validation (Carle, OHSU, OSF)
- **Resource availability and environmental assumption management** : Environmental model and resource availability model are developed modularly but jointly verified with the best practice work flow (IIT)
- **End-to-end traceability** from clinical and system requirements, safety analysis, to design and implementation (UIUC)
- **Device fault model**: Study of software-related causes in the FDA medical device recalls (IIT)
- **Distributed guidance system** across regional hospital, satellite hospital and patient transfer (UIUC)

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

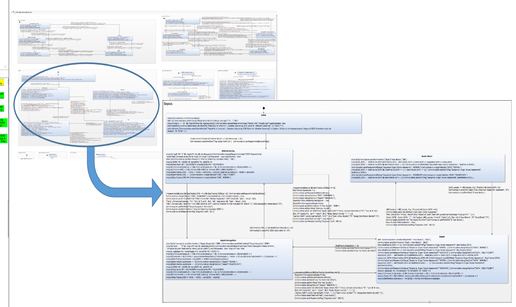




Pediatric Sepsis System for OSF Hospital



Organ-Centric Yakindu Model (Magnified Sepsis Machine)



[1] Andrew Y.-Z. Ou, Yu Jiang, Po-Liang Wu, Lui Sha, Richard B. Berlin Jr.: Preventable Medical Errors Driven Modeling of Medical Best Practice Guidance Systems. J. Medical Systems 41(1) 2017
[2] Yu Jiang, Houbing Song, Rui Wang, Ming Gu, Jiaguang Sun, Lui Sha: Data-Centered Runtime Verification of Wireless Medical Cyber-Physical System. IEEE Trans. Industrial Informatics 13(4):, 2017
[3] Mohammad Hosseini, Yu Jiang, Richard R. Berlin, Lui Sha, Houbing Song: Toward Physiology-Aware DASH: Bandwidth-Compliant Prioritized Clinical Multimedia Communication in Ambulances. IEEE Trans. Multimedia 19(10), 2017
[4] Mohammad Hosseini, Richard R. Berlin, Lui Sha: A physiology-aware communication architecture for distributed emergency medical CPS. ICCPS 2017: 83
[5] Mohammad Hosseini, Richard B. Berlin Jr., Lui Sha: Physiology-Aware Rural Ambulance Routing. ICHI 2017: 332-337
[6] Mohammad Hosseini, Yu Jiang, Ali Yekkehkhany, Richard R. Berlin, Lui Sha: A Mobile Geo-Communication Dataset for Physiology-Aware DASH in Rural Ambulance Transport. MMSys 2017
[7] Mohammad Hosseini, Yu Jiang, Richard R. Berlin, Lui Sha, Houbing Song: Towards Physiology-Aware DASH: Bandwidth-Compliant Prioritized Clinical Multimedia Communication in Ambulances. CoRR abs/1707.04918, 2017

Scientific Impact:

- **Computational pathophysiology:**
  - Executable model of medical knowledge in the form of networked organ disease automata and best practice automata using statechart model tools
- **Integrated model verification and clinical validation**:
  - The statechart model's stimulation capability allows close interaction with physicians to check the validity of the model
  - The computer-aided translation of statechart Model to UPPAAL verifies the software design integrity.
  - Clinical system assumption management system to help prevent assumption faults.

Broader Impact:

- **Cardiac arrest resuscitation guidance system**: Cardiac Arrest is deadly and there is no room for errors. Our system has been approved for Phase 1 clinical evaluation at Carle Foundation Hospital. New: University of Chicago Med School now works with us to extend it for neonatal and pediatric resuscitation
- **Sepsis best practice systems:**
  - **Carle hospital network:** Sepsis has a high mortality rate caused by complex multi-organ failures. Our guidance system has been approved by Carle to start preparing on the clinical evaluation at Carle's satellite hospitals.
  - **NEW: OSF Children Hospital:** Our current sepsis guidance has been designed for adults. OSF Children Hospital has decided to work with us to extend it for pediatric sepsis
- **Heart transplant:** We have been working with OHSU on the requirements and high level designs for a heart transplant perioperative guidance system.
- **Education**: We start developing best practice guidance system based sepsis training course for the new Carle-UIUC Medical School's medical students.

ILLINOIS INSTITUTE OF TECHNOLOGY
ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
Carle
THE UNIVERSITY OF CHICAGO 1890
OREGON HEALTH & SCIENCE UNIVERSITY OHSU
Children's Hospital of Illinois at OSF Saint Francis Medical Center