



CAREER: Embracing Complexity: A Fractal Calculus Approach to the Modeling and Optimization of Medical Cyber-Physical Systems

Challenges:

- Physiology exhibits *non-Gaussian*, *multi-fractal* and *non-stationary* characteristics
- Model inter-patient *asymmetric variability & interdependence* among physiological processes
- *Accurate yet compact* mathematical models of physiology

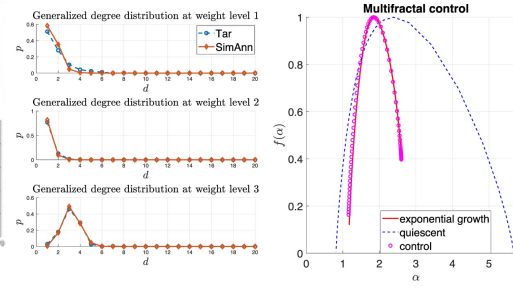
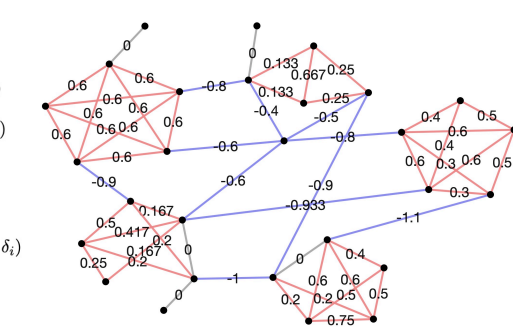
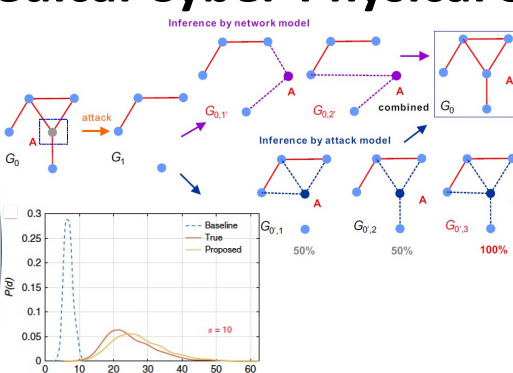
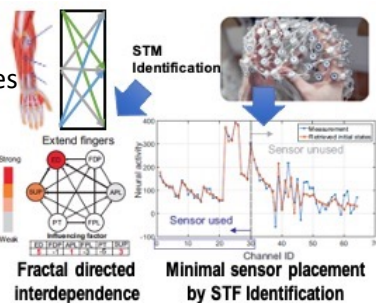
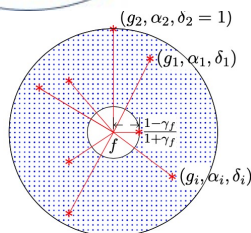
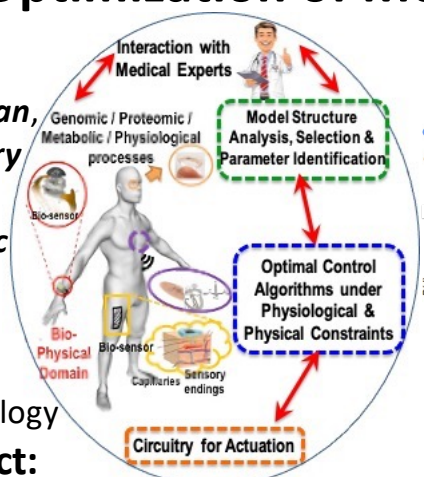
Approach & scientific impact:

- Compact accurate mathematical models
- Fast & accurate model identification
- Fractal control algorithms

Key innovations & scientific impact:

1) Spatiotemporal Fractal (STF) models:

- *Maximum causal non-extensive entropy principle* by exploiting micro-dynamics (increments) of bioprocesses
- *Robust data-driven* inference of *fractal interdependence* of physiological processes
- *Guaranteed optimality* to achieve *full observability* of physiological systems via STF with *minimal sensing efforts*



- 2) Infer the CPS interdependence under malicious influences:
 - Causal inference tool for deciphering complex interdependency of a composable CPS with unknown dynamics and unknown attacks
- 3) Ricci curvature-based decomposition & mining of CPS interdependence:
 - Ollivier-Ricci curvature reveals the hierarchical & community structure of a CPS interdependency without a priori knowledge on the number and size of communities (in polynomial time)
- 4) Approximate submodular functions for nonsubmodular (NSM) CPS optimization:
 - NSM function f is δ away from submodular g
 - *Theorem*: δ -ASMF has constant performance guarantee penalized by δ
- 5) Control of unknown CPS-network dynamics:
 - Weighted multifractal network and its control

Broader Impact:

- Fundamental & pioneering mathematical & algorithmic tools for all CPS areas, bioengineering, applied mathematics, synthetic & system biology,...
- 3 PhDs graduated, 2 PhDs soon to graduate, 2 PhDs from underrepresented minority
- More than 12 high-school and 10 undergraduate students mentored & advised on CPS topics
- 100X better or fundamentally new ideas not only for CPS areas but also other scientific disciplines

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