DEPARTMENT OF COMPUTER SCIENCE
HONG KONG BAPTIST UNIVERSITY

3) On *Impact* (Benefits) *of Research*

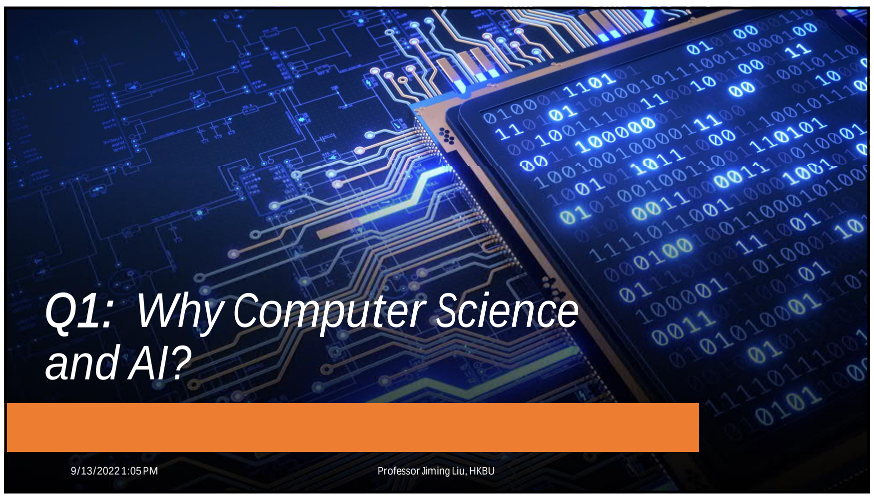
Jiming Liu

Dean of Science & Chair Professor in Computer Science

Hong Kong Baptist University

- "AI is thought to be an *impossible* dream by many. But *not* to us in AI. ...the future promises to generate orders of magnitude greater impact than its progress to date."

Raj Reddy
(1994 Turing Award)



Q1: Why Computer Science and AI?

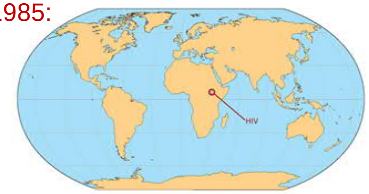
Emerging Diseases: Past *30+ Years*

NIAID Director Anthony S. Fauci, M.D., Highlights Lessons

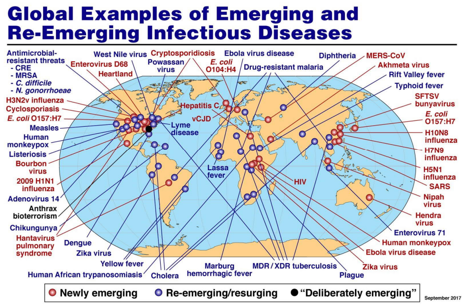
NIH National Institute of Allergy and Infectious Diseases

"*Three Decades* of Responding to Infectious Disease Outbreaks" (NIH/NIAID, 2017)

1985:



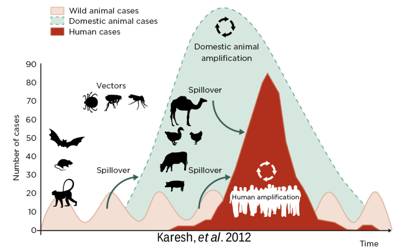
2017:



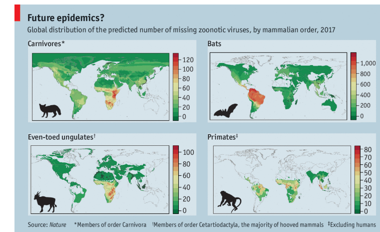
NIH/National Institute of Allergy and Infectious Diseases (NIAID), 14 Nov. 2017

Covid-19 ←…← Zoonotic Viruses?

Reservoirs: *Animal, Human, & Environment*



Karesh, *et al.* 2012

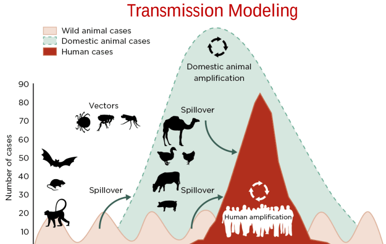


EcoHealth Alliance

Covid-19 ←…← Zoonotic Viruses?

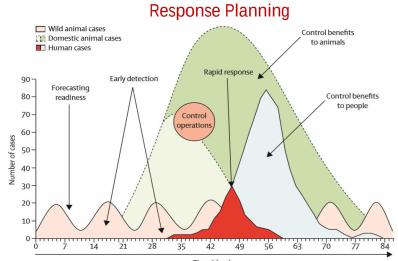
Reservoirs: *Animal, Human, & Environment*

Transmission Modeling



Karesh, *et al.* 2012

Response Planning



Neglected Tropical Diseases (NTD): Past *3000+ Years*

Source: Britannica

- According to *WHO World Malaria Report 2019*
  - ~50% of the world's population at risk
  - ~228 million cases (artemisinin-resistance!!!)
  - ~405 000 deaths in 2018 (67% under 5 years)

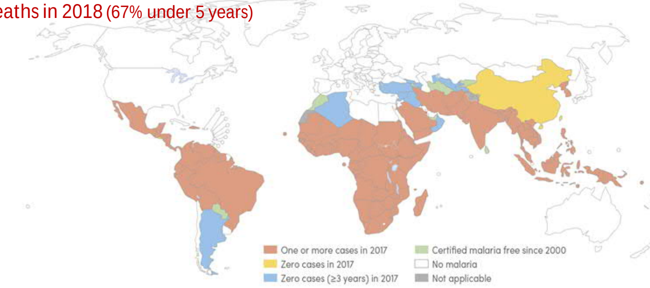
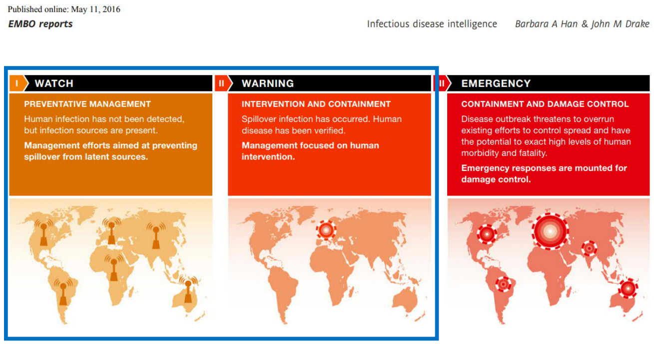


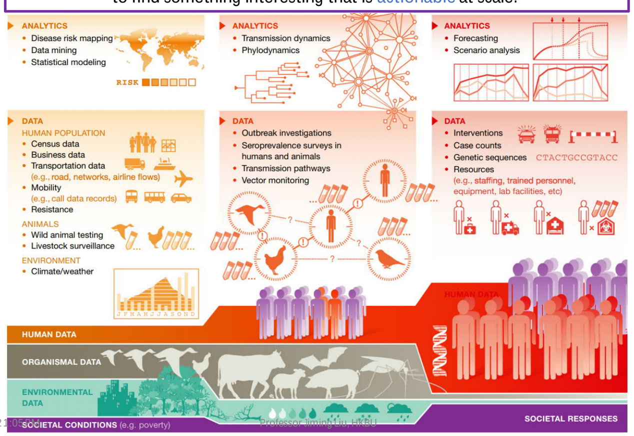
Image Credit: World Malaria Report 2018

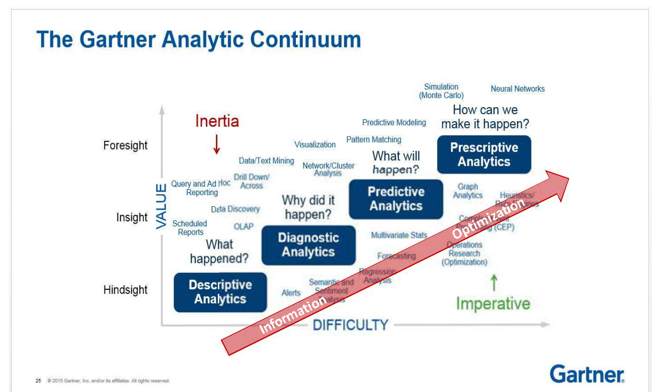


Data

- CDC and/or clinical data
- Weather or climate data
- Census data
- Geospatial data (to superimpose hundreds of feeds like terrain, land use, or transportation for situational awareness in complex emergencies)
- Drug Administration data (e.g., mobile app reporting, to detect adverse events and medication errors)
- Tweets (to extract the number of people who were hospitalized or sick from air/vector/water/food-borne illnesses

Using big data is not just to find something interesting for the sake of discovery, but to find something interesting that is actionable at scale.





Computer Science and AI

- Abstractions & representations
- Theoretical / computational characterization
- Algorithmic thinking & problem solving
- Data
- Realities

To See the Unseen

Q1: Why Computer Science and AI?

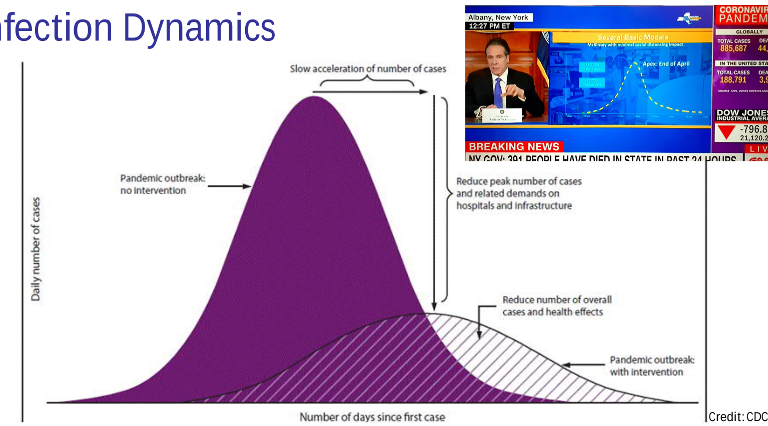
To Dream the Possible Dream

Q1: Why Computer Science and AI?

Q2: What and How?

To See the Unseen:
How Disease Transmits

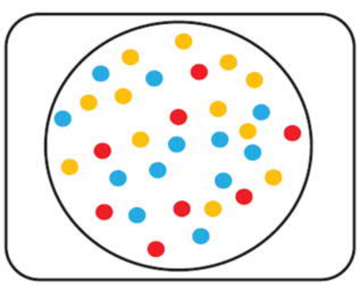
Infection Dynamics

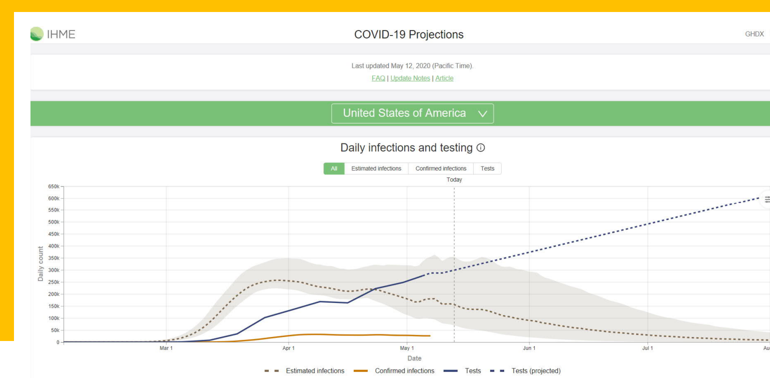


Credit: CDC

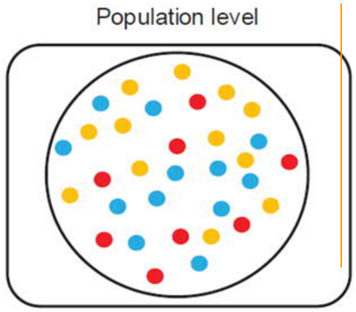
Predicting the Future

Population level





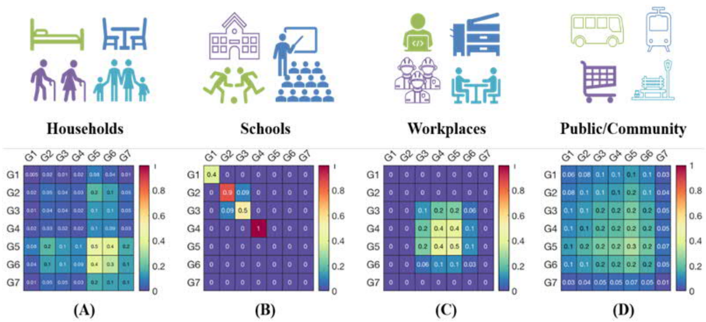
Limits of Existing Models



Unsolved Puzzle

- How disease transmits among different age-groups, in major social settings
  - How future risks and trends may evolve
  - What are the right distancing strategies
  - When will be SAFE to reopen

Close Contacts, and *Setting*-Related Transmissions?

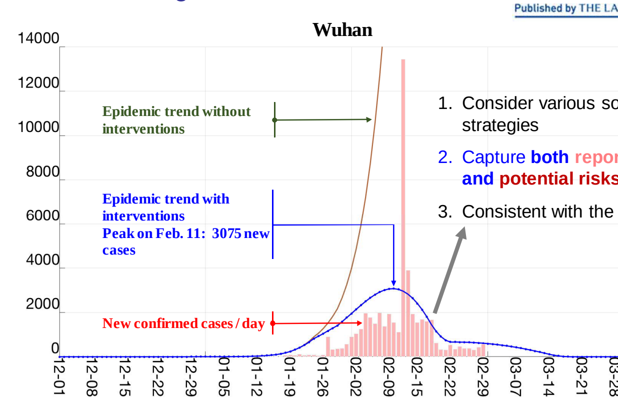


Age Groups
G1: 0-6;
G2: 7-14;
G3: 15-17;
G4: 18-22;
G5: 23-44;
G6: 45-64;
G7: >= 65

Observation: Initial COVID-19 transmissions in Wuhan took place mainly in **households** and **public places**

Prediction: Seeing the *Unseen Risks*

EClinicalMedicine
Published by THE LANCET

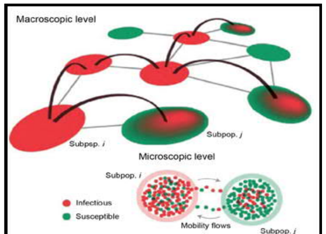


1. Consider various social distancing strategies
2. Capture **both** reported cases **and potential risks**
3. Consistent with the actual situations

Key to Unveiling *Meta-Population* Transmission

- To understand, predict, and control epidemic dynamics by characterizing age-specific or spatial *sub-populations*

$$I_{t+1} = \mathbb{K}_t I_t = g(S_t B C A) I_t$$



[Vespignani 2012]

S_t: Susceptible population
B: Infection acquiring rate
C: Contact matrix
A: Infection transmission rate

Contact: Individuals' mutual exposure in the same physical environment

By Yang, Pei, Xia, & Liu, *et al.*

Unveiling Hidden Diffusion Networks

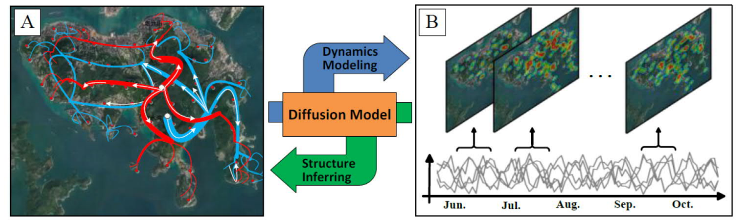


FIGURE 5. Traditional method and inverse engineering analysis method for modeling, analyzing, and inferring of infectious disease. (A) Traditional method: modeling and analysis of infectious disease by given contact network. (B) Inverse engineering: inferring dynamic social contact patterns using temporally observed incidences.

Q1: Why Computer Science and AI?

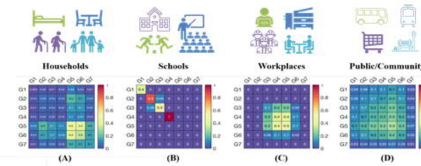
To Dream the Possible Dream

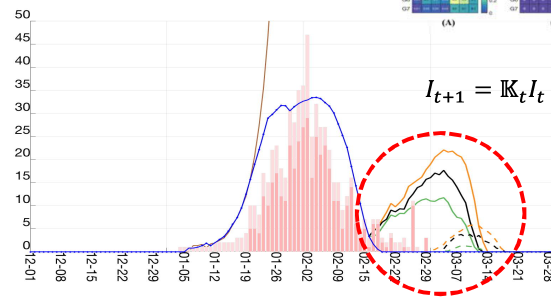
To Dream the Possible Dream: *Computer Science for Safety*

Unsolved Puzzle

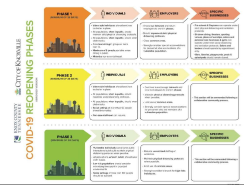
- How disease transmits among different age-groups, in major social settings
  - How future risks and trends may evolve
  - What are the right distancing strategies
  - When will be SAFE to reopen

Science of Reopening

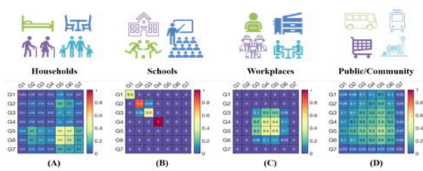


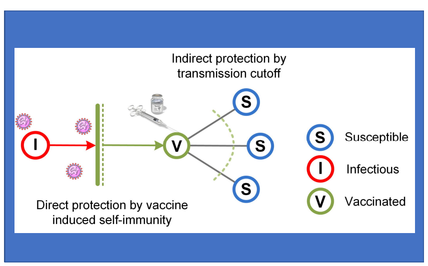


$$I_{t+1} = \mathbb{K}_t I_t = g(S_t B C A) I_t$$



On *Herd Immunity*





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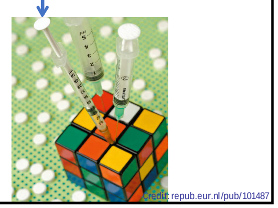
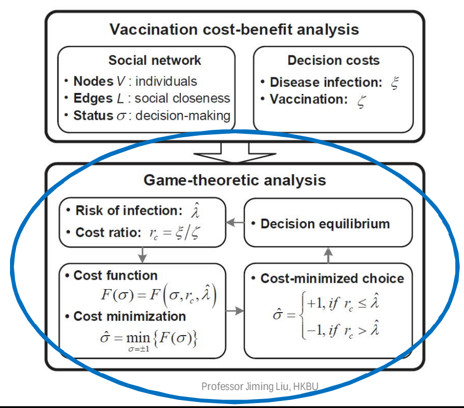


Essence of Herd Immunity: *Individual Decisions*



To Dream the Possible Dream:
AI for the "Last Mile"

Neglected Tropical Diseases (NTD): Past *3000+ Years*

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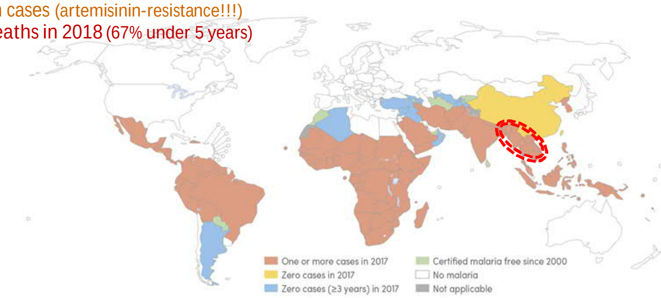
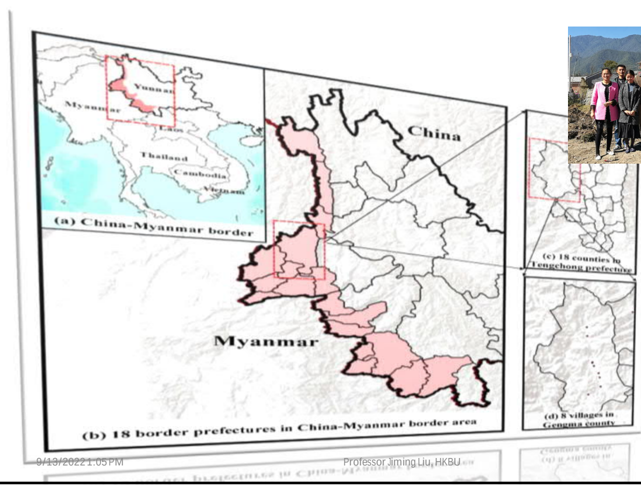


Image Credit: World Malaria Report 2018



China-Myanmar border area. (a) and (b) highlight the region that we are going to carry out the experimental evaluation and onsite validations, which covers 18 prefectures, 180 counties, and 1,554 villages.

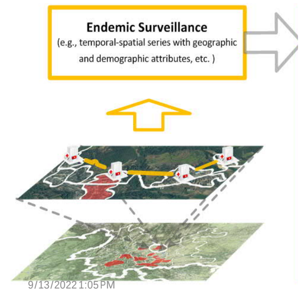
By Liu, Liu, & Zhou, *et al.*

… in *Disease Control*

- Abstractions & representations
- Theoretical / computational characterization
- **Algorithmic thinking & problem solving**
- Data
- **Realities**

Machine Learning: To Reveal *What's Happening*

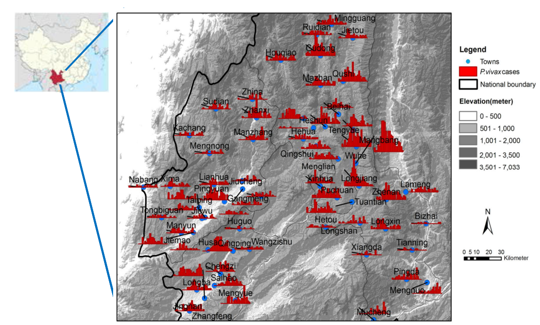
- Endemic Surveillance
  - Spatio-temporal observations of infections and environmental attributes
- Inferring the Underlying Diffusion Network



- Abstractions & representations
- Theoretical / computational characterization
- Algorithmic thinking & problem solving
- **Data**
- Realities

Spatio-Temporal Risk Mapping

- Malaria in Yunnan Province, China



P. vivax incidences of 62 towns in Yunnan, China

By Benyun Shi, Jiming Liu, and Xiao-Nong Zhou, *et al.*

... in *Machine Learning*

Machine Learning (ML): To Reveal *What's Happening*

- Endemic Surveillance
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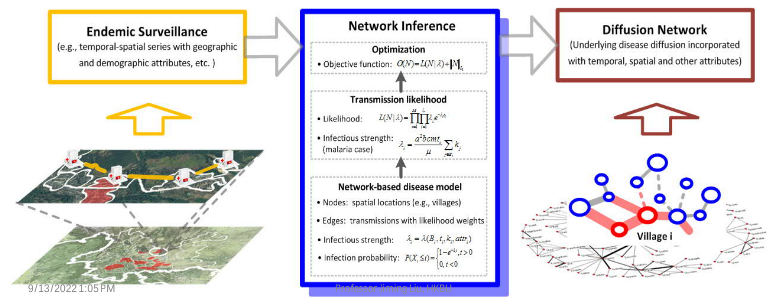
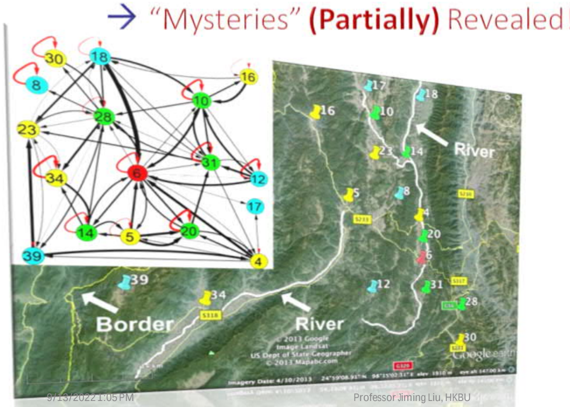
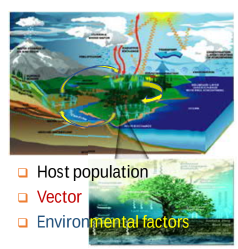


Diffusion Network

→ "Mysteries" **(Partially)** Revealed!

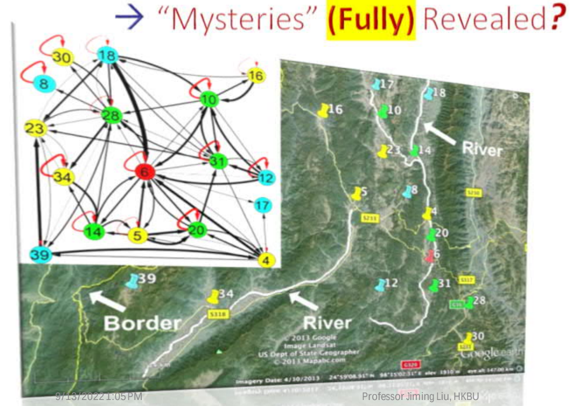


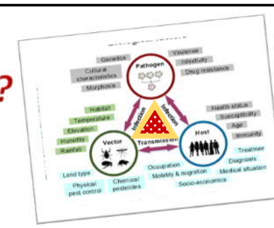


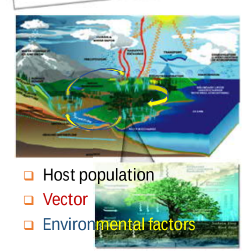
- Host population
- Vector
- Environmental factors

Diffusion Network

→ "Mysteries" **(Fully)** Revealed?







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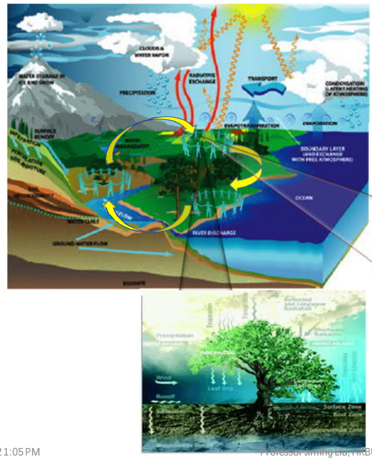
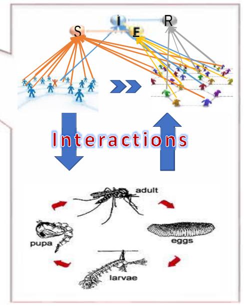
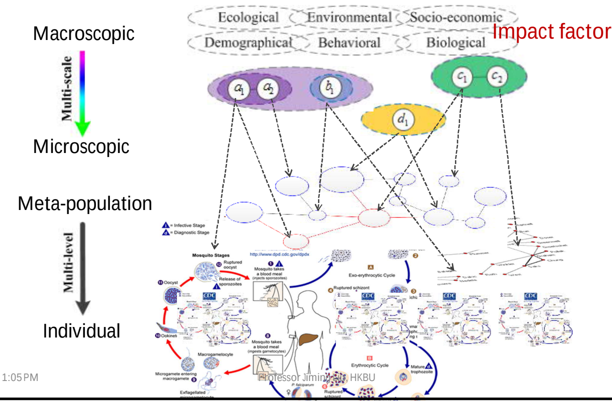


Dynamics
- Meta-population
- Vector: Extended Ross-Macdonald model
- Environmental factors
- Human mobility



Multi-Level Models & Multi-Scale Impacts



- Abstractions & representations
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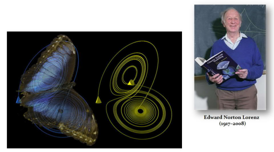
Q3: Multiple *Scales* are *Inter-Related*... How?

Butterfly Effect



Complex Spatio-Temporal *Dependencies*

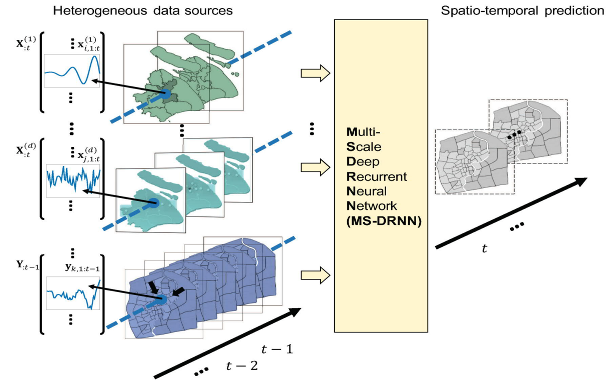
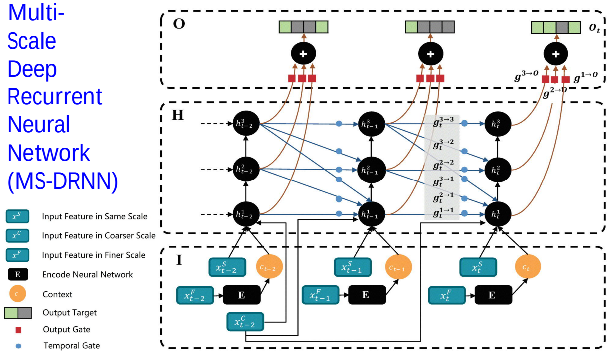


Illustration of the idea behind the proposed MS-DRNN. Given a spatio-temporal dataset with the target variable $\mathbf{Y}_{:t-1}$ and multiple covariates $\mathbf{X}^{(1)}_{:t}, \cdots, \mathbf{X}^{(d)}_{:t}$ observed from d heterogeneous data sources, MS-DRNN aims to integrate the data from various sources and capture the complex dependencies among them for making predictions on $\mathbf{y}_t$.

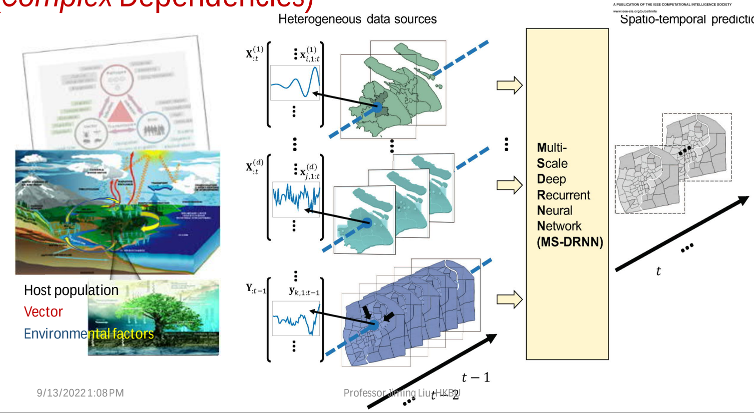
Multi-Scale Deep Recurrent Neural Network (MS-DRNN)



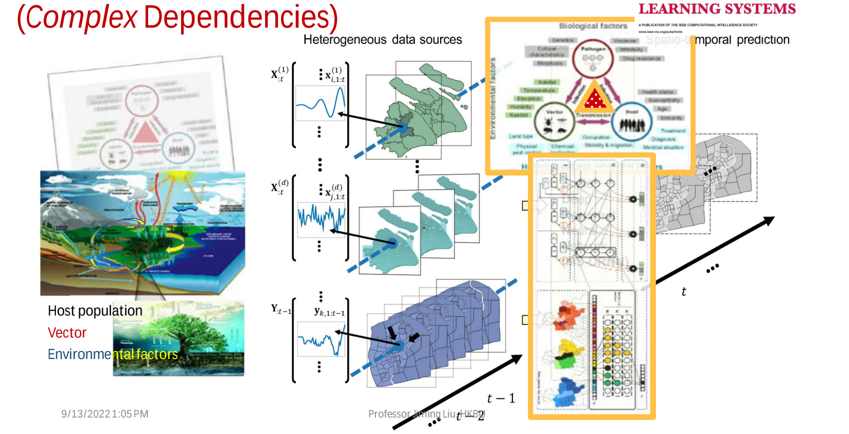
1) Encoder and decoder structures in module **I** integrates *heterogeneous* data.
2) Hierarchical structure in module **H** captures *multiple spatio-temporal effects* on target variable caused by covariates from different sources.
3) Integrative *effects at varying scales* in module **O** generate predictions.

ML Challenge: *Unseen Interactions* (*Complex* Dependencies)

IEEE TRANSACTIONS ON NEURAL NETWORKS AND LEARNING SYSTEMS



ML Challenge: *Unseen Interactions* (*Complex* Dependencies)



- Abstractions & representations
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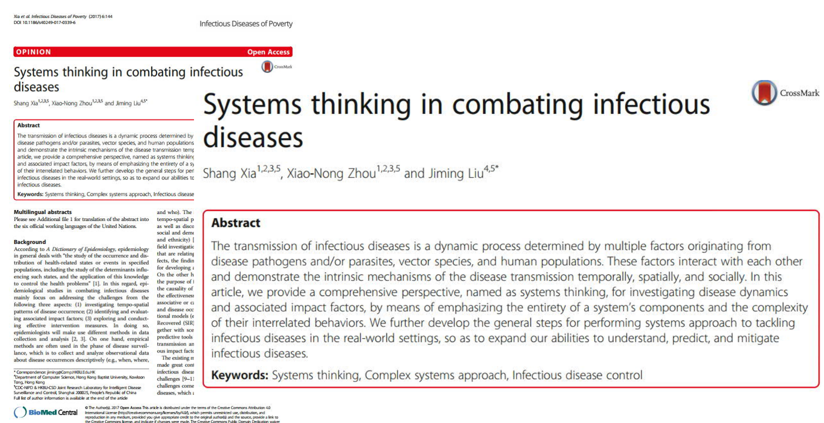
Global Malaria Eradication, by 2030

Image Credit: Google Maps



Infectious Diseases of Poverty

OPINION Open Access

Systems thinking in combating infectious diseases

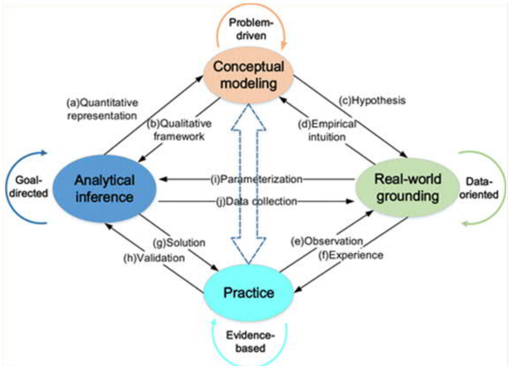
Shang Xia[1,2,3,5], Xiao-Nong Zhou[1,2,3,5] and Jiming Liu[4,5*]

Abstract

The transmission of infectious diseases is a dynamic process determined by multiple factors originating from disease pathogens and/or parasites, vector species, and human populations. These factors interact with each other and demonstrate the intrinsic mechanisms of the disease transmission temporally, spatially, and socially. In this article, we provide a comprehensive perspective, named as systems thinking, for investigating disease dynamics and associated impact factors, by means of emphasizing the entirety of a system's components and the complexity of their interrelated behaviors. We further develop the general steps for performing systems approach to tackling infectious diseases in the real-world settings, so as to expand our abilities to understand, predict, and mitigate infectious diseases.

Keywords: Systems thinking, Complex systems approach, Infectious disease control

Complex Systems Approaches



Problem-Oriented Modeling/Learning