



3) On Impact (Benefits) of Research

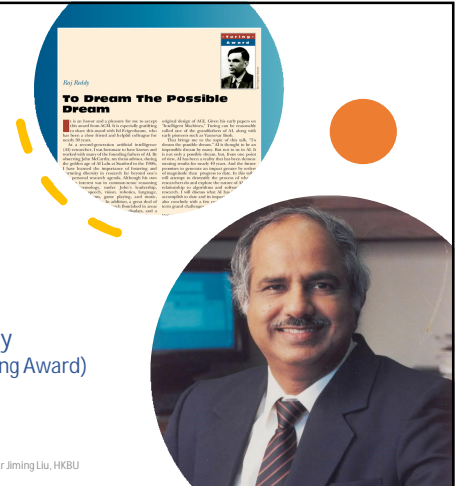
Jiming Liu

Dean of Science & Chair Professor in Computer Science

Hong Kong Baptist University

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Raj Reddy
(1994 Turing Award)

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Q1: Why Computer Science and AI?

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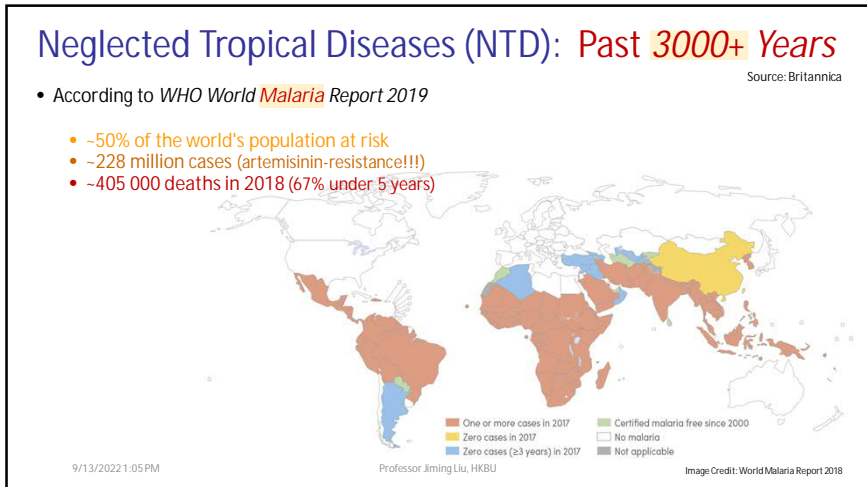
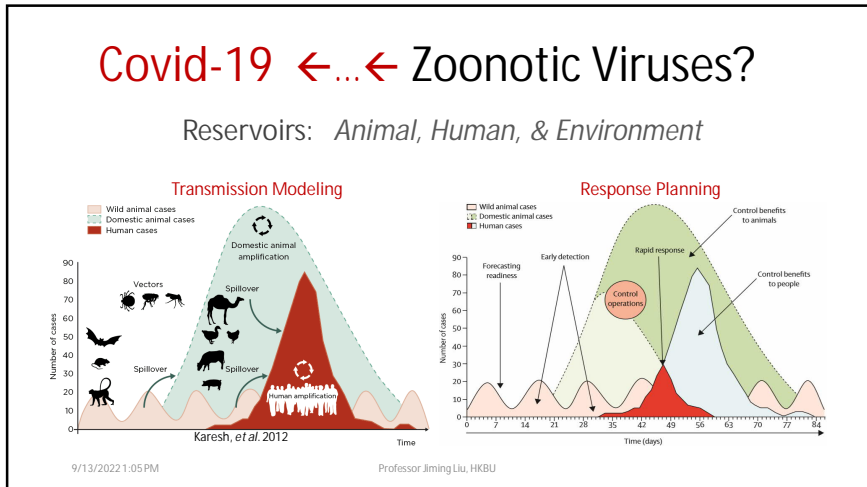
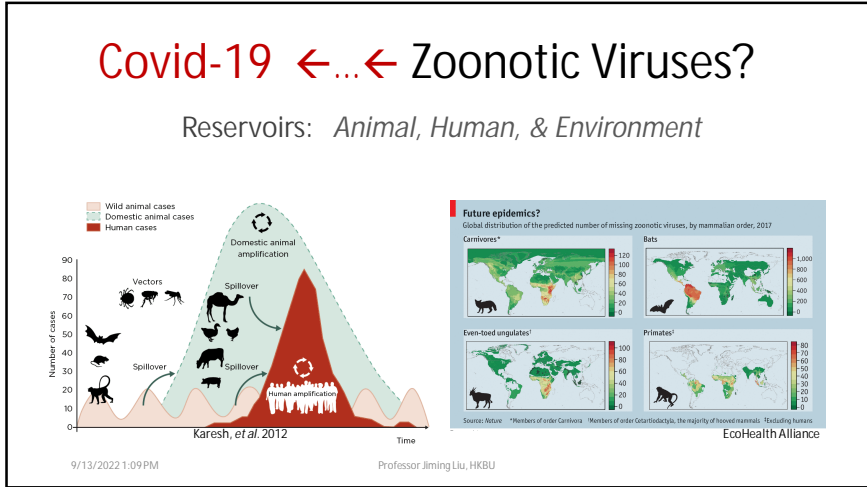
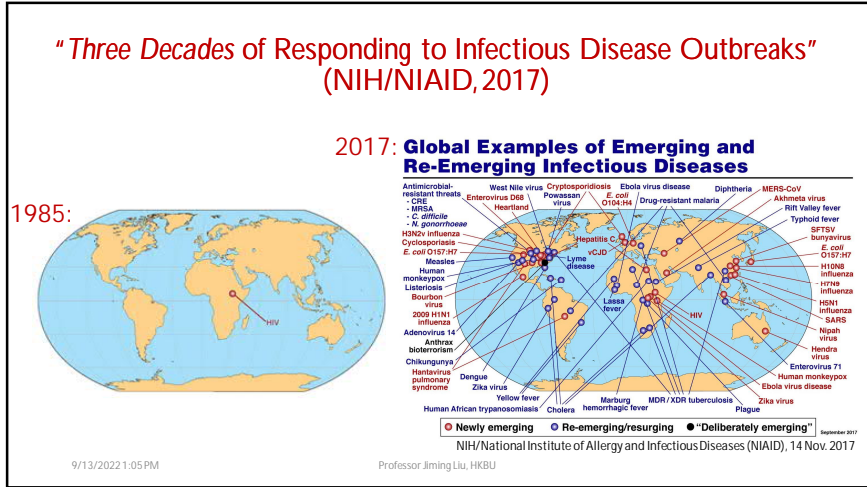
Emerging Diseases: Past 30+ Years

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



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Published online: May 11, 2016
EMBO reports Infectious disease intelligence Barbara A Han & John M Drake

I WATCH	II WARNING	III EMERGENCY
PREVENTATIVE MANAGEMENT Human infection has not been detected, but infection sources are present. Management efforts aimed at preventing spillover from latent sources.	INTERVENTION AND CONTAINMENT Spillover infection has occurred. Human disease has been verified. Management focused on human intervention.	CONTAINMENT AND DAMAGE CONTROL Disease outbreak threatens to overrun existing efforts to control spread and have the potential to exact high levels of human morbidity and fatality. Emergency responses are mounted for damage control.

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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)

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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.

ANALYTICS

- Disease risk mapping
- Data mining
- Statistical modeling

DATA

- Census data
- Business data
- Transportation data (e.g., road, networks, airline flows)
- Mobility (e.g., cell data records)
- Resistance
- Wild animal testing
- Livestock surveillance
- Climate/weather

ANALYTICS

- Transmission dynamics
- Phylodynamics

DATA

- Outbreak investigations
- Seroprevalence surveys in humans and animals
- Transmission pathways
- Vector monitoring

ANALYTICS

- Forecasting
- Scenario analysis

DATA

- Interventions
- Case counts
- Genetic sequences CTACTCCGTACC
- Resources (e.g., staffing, trained personnel, equipment, lab facilities, etc)

9/13/2022 SOCIETAL CONDITIONS (e.g. poverty) SOCIETAL RESPONSES

The Gartner Analytic Continuum

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Computer Science
and AI

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

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To See the Unseen

Q1: Why Computer Science and AI?

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To Dream the Possible Dream

Q1: Why Computer Science and AI?

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Q2: What and How?

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To See the Unseen: *How Disease Transmits*

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Infection Dynamics

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Credit: CDC

Predicting the Future

Population level

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COVID-19 Projections

Last updated May 12, 2020 (Pacific Time)
Epid | Update Notes | Article

United States of America

Daily infections and testing

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Limits of Existing Models

Population level

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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**

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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

	G1	G2	G3	G4	G5	G6	G7
(A) Households	0.95	0.92	0.87	0.82	0.68	0.54	0.41
(B) Schools	0.64	0	0	0	0	0	0
(C) Workplaces	0	0	0	0	0	0	0
(D) Public/Community	0.06	0.08	0.1	0.1	0.1	0.1	0.05

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

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Prediction: Seeing the *Unseen Risks*

EClinicalMedicine
Published by THE LANCET

Wuhan

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

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Key to Unveiling *Meta-Population* Transmission

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

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

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

Contact: Individuals' mutual exposure in the same physical environment

[Vespignani 2012]

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

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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.

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To Dream the Possible Dream:
Computer Science for Safety

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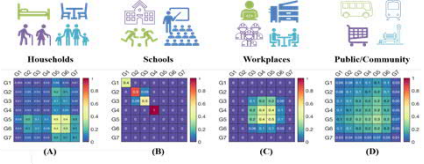
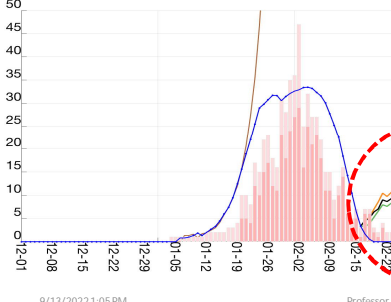
Unsolved Puzzle


- How disease transmits among different **age-groups**, in major **social settings**
 - How **future risks** and trends may evolve
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Science of Reopening

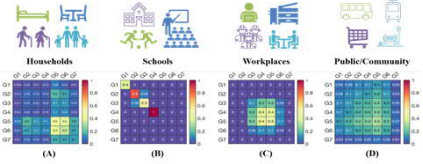
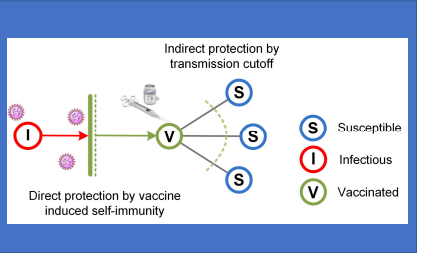




$$I_{t+1} = \mathbb{K}_t I_t = g(S_t B C A) I_t$$


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On Herd Immunity

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


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pubs.rsc.org/pubs/101487

Essence of Herd Immunity: Individual Decisions

Vaccination cost-benefit analysis

Social network

- Nodes V : individuals
- Edges L : social closeness
- Status σ : decision-making

Decision costs

- Disease infection: ξ
- Vaccination: ζ

↓

Game-theoretic analysis

- Risk of infection: $\hat{\lambda}$
- Cost ratio: $r_c = \xi/\zeta$

• Decision equilibrium

↓

• Cost function


$$F(\sigma) = F(\sigma, r_c, \hat{\lambda})$$

• Cost minimization

$$\hat{\sigma} = \min_{\sigma \in \{1\}} \{F(\sigma)\}$$

• Cost-minimized choice

$$\hat{\sigma} = \begin{cases} +1, & \text{if } r_c \leq \hat{\lambda} \\ -1, & \text{if } r_c > \hat{\lambda} \end{cases}$$



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

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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)

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(a) China-Myanmar border

(b) 18 border prefectures in China-Myanmar border area

(c) 18 counties in Tongchong prefecture

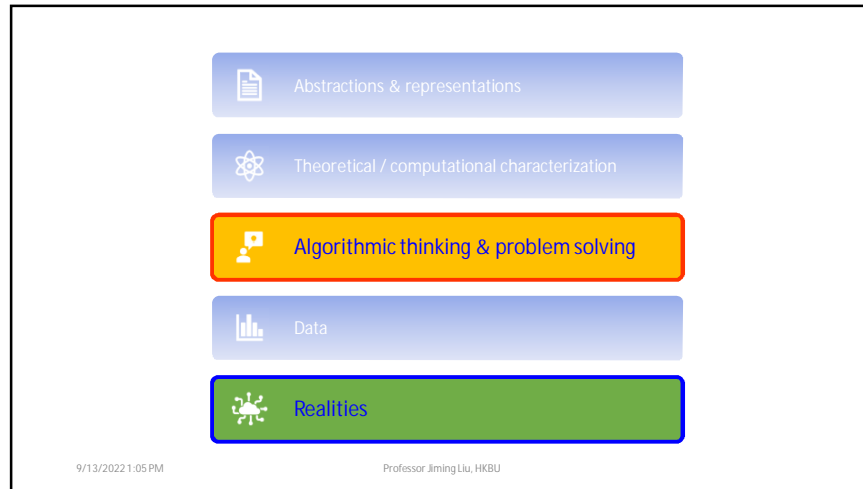
(d) 8 villages in Gezaoma county

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.

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... in *Disease Control*

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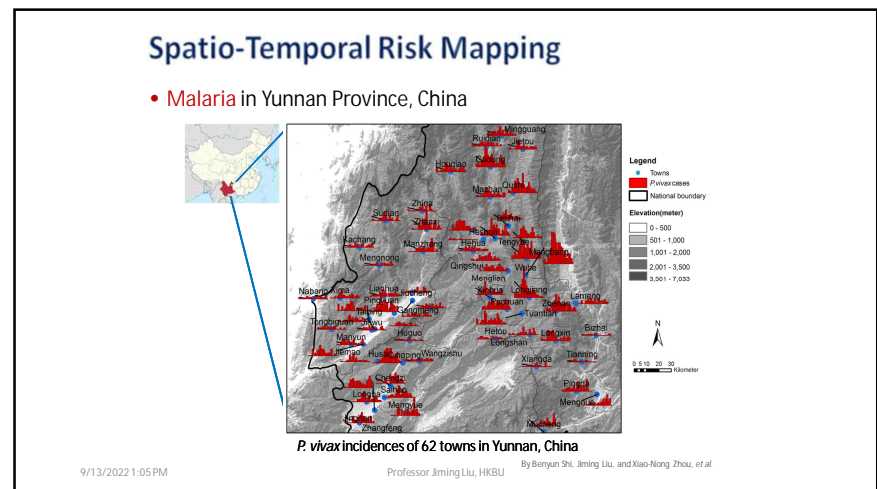
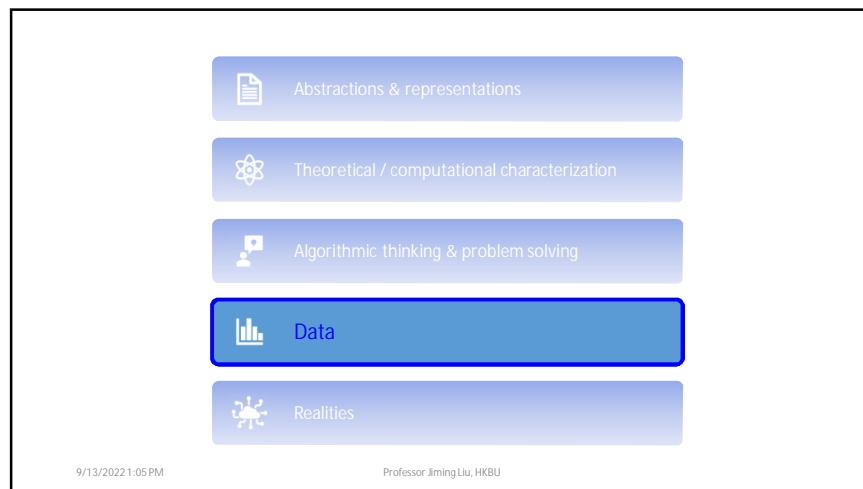


Machine Learning: To Reveal *What's Happening*

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

Endemic Surveillance
(e.g., temporal-spatial series with geographic and demographic attributes, etc.)

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... in Machine Learning

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

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

Endemic Surveillance
(e.g., temporal-spatial series with geographic and demographic attributes, etc.)

Network Inference

Optimization

- Objective function: $Q(N) = \sum_{i,j} N_{ij}$

Transmission likelihood

- Likelihood: $L(N, I) = \prod_{i,j} p_{ij}^{N_{ij}}$
- Infectious strength: $\lambda_i = \frac{\sum_j N_{ij} \beta_j}{\mu}$ (malaria case)

Network-based disease model

- Nodes: spatial locations (e.g., villages)
- Edges: transmissions with likelihood weights
- Infectious strength: $\lambda_i = f(\beta_i, \rho_i, \mu_i, \text{attr}_i)$
- Infection probability: $P(I_i, S_i) = \begin{cases} 1 - e^{-\lambda_i} > 0 \\ 0, \text{ if } \lambda_i = 0 \end{cases}$

Diffusion Network
(Underlying disease diffusion incorporated with temporal, spatial and other attributes)

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Diffusion Network

→ “Mysteries” (Partially) Revealed!

- Host population
- Vector
- Environmental factors

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Diffusion Network

→ “Mysteries” (Fully) Revealed?

- Host population
- Vector
- Environmental factors

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Dynamics

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

Interactions

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Multi-Level Models & Multi-Scale Impacts

Macroscopic

Multi-scale ↓

Microscopic

Meta-population

Multi-level ↓

Individual

Impact factors

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- Abstractions & representations
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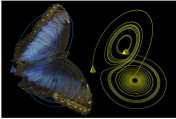

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Q3: Multiple Scales are Inter-Related... How?

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Butterfly Effect

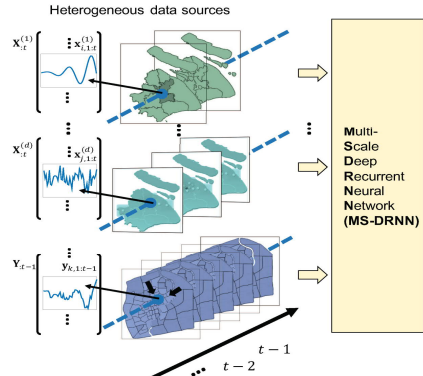



*Edward Norton Lorenz
1917-2008*

Complex Spatio-Temporal Dependencies

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Heterogeneous data sources



Spatio-temporal prediction

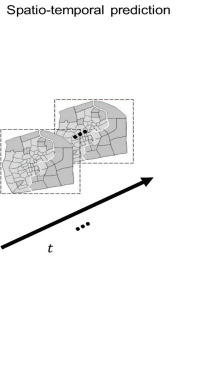
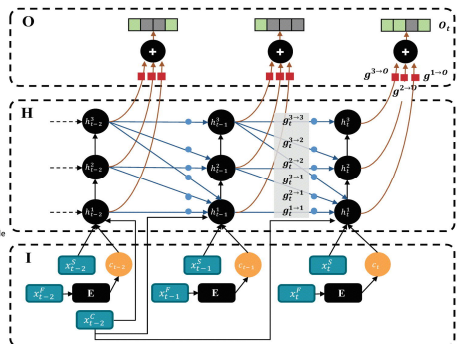


Illustration of the idea behind the proposed MS-DRNN. Given a spatio-temporal dataset with the target variable Y_{t-1} and multiple covariates $X_{t-1}^{(1)}, \dots, X_{t-1}^{(d)}$ observed from d heterogeneous data sources, MS-DRNN aims to integrate the data from various sources and capture the complex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

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

- Input Feature in Same Scale
- Input Feature in Coarser Scale
- Input Feature in Finer Scale
- Encode Neural Network
- Context
- Output Target
- Output Gate
- Temporal Gate



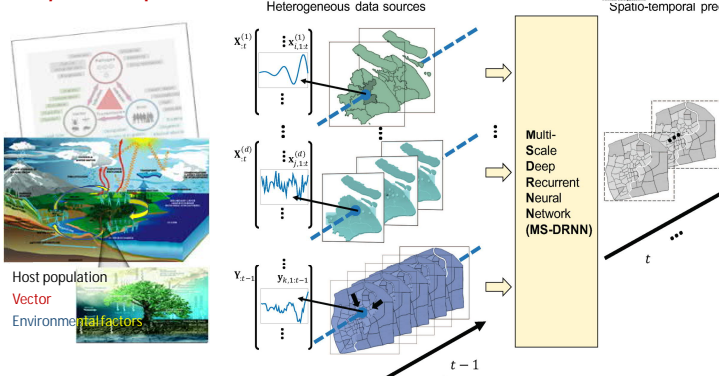
- 1) Encoder and decoder structures in module **I** integrates heterogeneous data.
- 2) Hierarchical structure in module **H** captures multiple spatio-temporal effects on target variable caused by covariates from different sources.
- 3) Integrative effects at varying scales in module **O** generate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

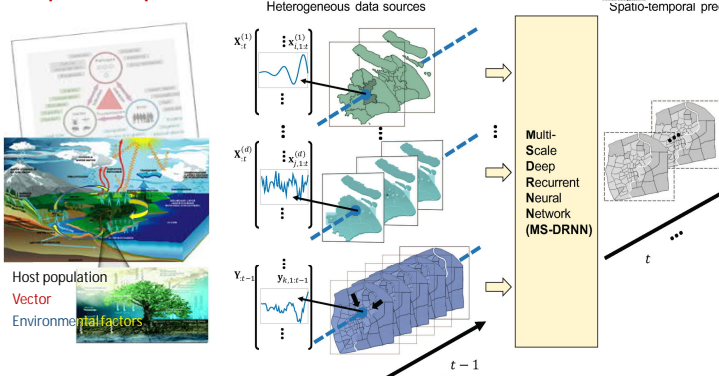
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ML Challenge: Unseen Interactions (Complex Dependencies)

IEEE TRANSACTIONS ON NEURAL NETWORKS AND LEARNING SYSTEMS
A PUBLICATION OF THE IEEE COMPUTATIONAL INTELLIGENCE SOCIETY

Spatio-temporal prediction





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ML Challenge: *Unseen Interactions* (Complex Dependencies)

IEEE TRANSACTIONS ON NEURAL NETWORKS AND LEARNING SYSTEMS

Heterogeneous data sources

Biological factors

Temporal prediction

Host population Vector Environmental factors

$X_t^{(1)}$

$X_t^{(2)}$

$Y_{k,t-1}$

$t-1$

t

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- Abstractions & representations
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Global Malaria Eradication, by 2030

GLOBAL TECHNICAL STRATEGY FOR MALARIA 2016-2030

Yunnan, China

SEA and GMS Countries

Global Eradication

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Image Credit: Google Maps

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OPINION

Systems thinking in combating infectious diseases

Shang Xia^{1,2,3,5}, Xiao-Nong Zhou^{1,2,3,5} and Jiming Liu^{4,5*}

Systems thinking in combating infectious diseases

Abstract

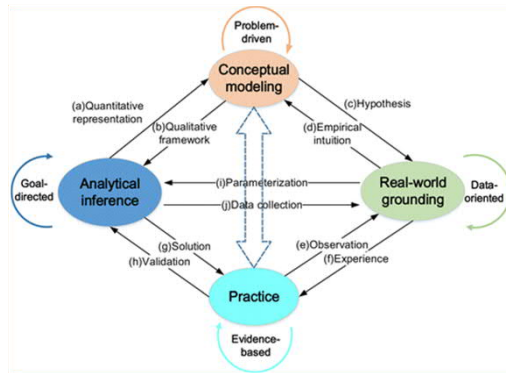
The transmission of infectious diseases is a dynamic process determined by disease pathogens and/or parasites, vector species, and human populations, and characterized by the intrinsic mechanisms of the disease transmission, temporal, spatial, and social interactions. We further develop the general steps 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

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Complex Systems Approaches



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Problem-Oriented Modeling/Learning

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