DISH-TREND: INTERVENTION MODELING SIMULATOR THAT ACCOUNTS FOR TREND INFLUENCES

WINTER SIMULATION CONFERENCE 2021

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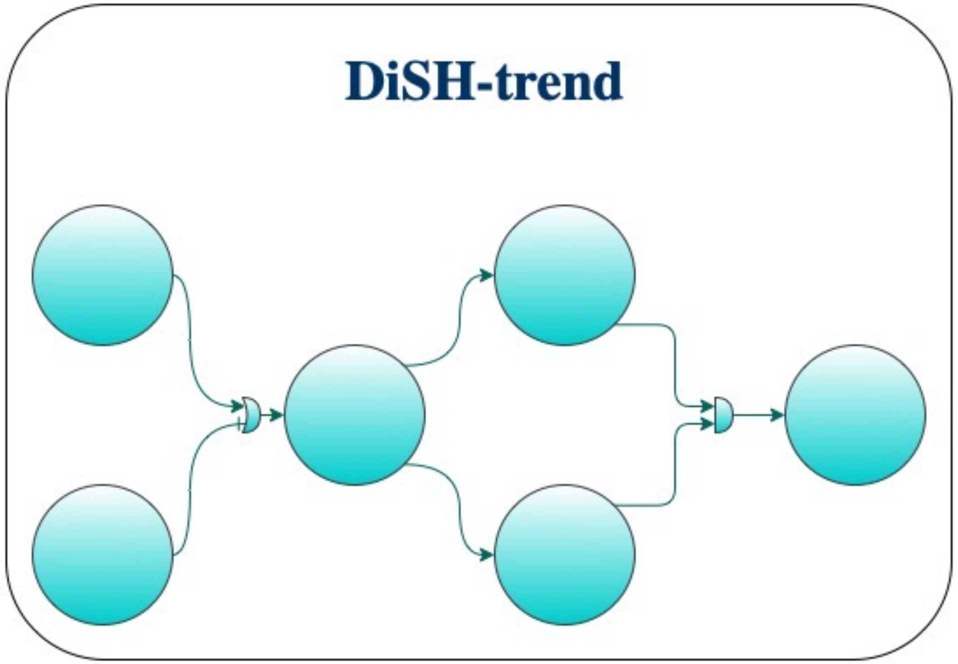
INTRODUCTION

- Dynamic network models – crucial in understanding complex system dynamics
- Nodes = components, edges = interactions
- Applications: biology, psychology, sociology, economics, politics, and engineering
- Interventions = constraints on values, or structural modifications



SIMILAR MODELING APPROACHES

- Boolean networks (Albert et al 2008)
- Discrete networks (Sayed et al 2017)
- Bayesian networks (Needham 2007, Wilkinson et al 2007)
- ODE-based models (Materi and Wishart 2007)
- Rule-based models (Faeder et al 2005)
- Petri nets (Chaouiya et al 2007)

DISH (DISCRETE STOCHASTIC HETEROGENEOUS) SIMULATOR

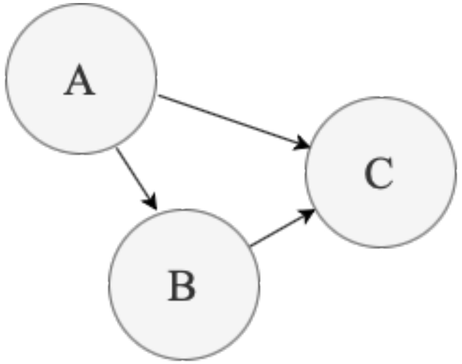
- Discrete levels (extension from Boolean networks)
- Update functions (Boolean)
- BioRECIPES model representation: element-focused
- Simulation schemes: simultaneous vs sequential
- Value toggling (enforced value constraints)

FROM DISH TO DISH-TREND

- Algebraic update function: weighted sums of regulation functions
  - $B(\boldsymbol{A},\boldsymbol{I}) = \sum_{i=1}^{k}\left(w_i^{(p)}\prod_{q\in\mathbb{I}_{p,i}} A_{i,q}\right) - \sum_{j=1}^{l}\left(w_j^{(n)}\prod_{r\in\mathbb{I}_{n,j}} I_{j,r}\right)$ (WEIGHTED SUM-OF-PRODUCTS)
  - $F(\boldsymbol{A},\boldsymbol{I}) = \frac{\lceil L\cdot|B(\boldsymbol{A},\boldsymbol{I})|\rceil}{L}\cdot \mathrm{sign}(B(\boldsymbol{A},\boldsymbol{I}))$
- Adding trend-based regulation
  - $B_{trend}(A,I) = \sum_{i=1}^{k}\left(w_i^{(p)}\prod_{q\in\mathbb{I}_{p,i}} \Delta A_{i,q}\right) - \sum_{j=1}^{l}\left(w_j^{(n)}\prod_{r\in\mathbb{I}_{n,j}} \Delta I_{j,r}\right)$
- Hybrid regulation – the sum of level-based and trend-based regulation
- Beyond linear models – any polynomial of $A_{i,q}$, $\Delta A_{i,q}$, $I_{j,r}$, and $\Delta I_{j,r}$

SMALL EXAMPLE

- 3-element network
- A – controlled input
- t=1: B remains unchanged
- t=4: B increased by A(t=3) - A(t=0)



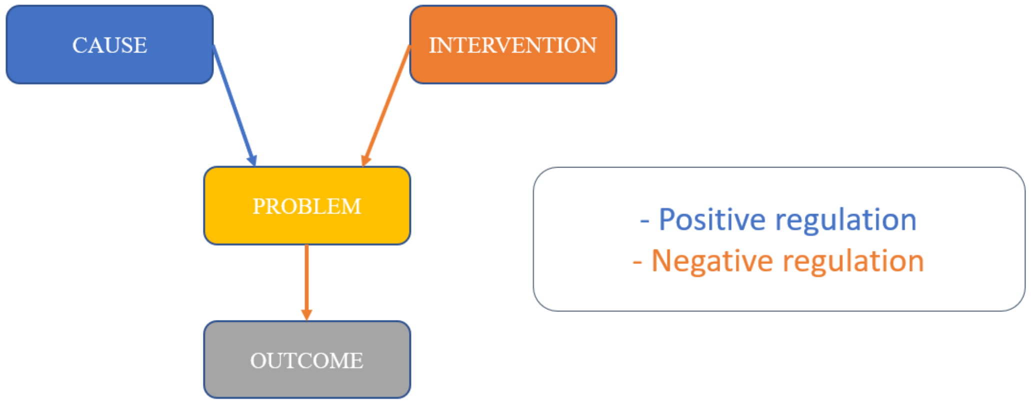
dB = dA
dC = 0.5*A+0.5*dB

Toggle sequence of A: v=0.2, (v=0.6, t=2), (v=0.4, t=3)

Update sequence: B, C, C, B, C

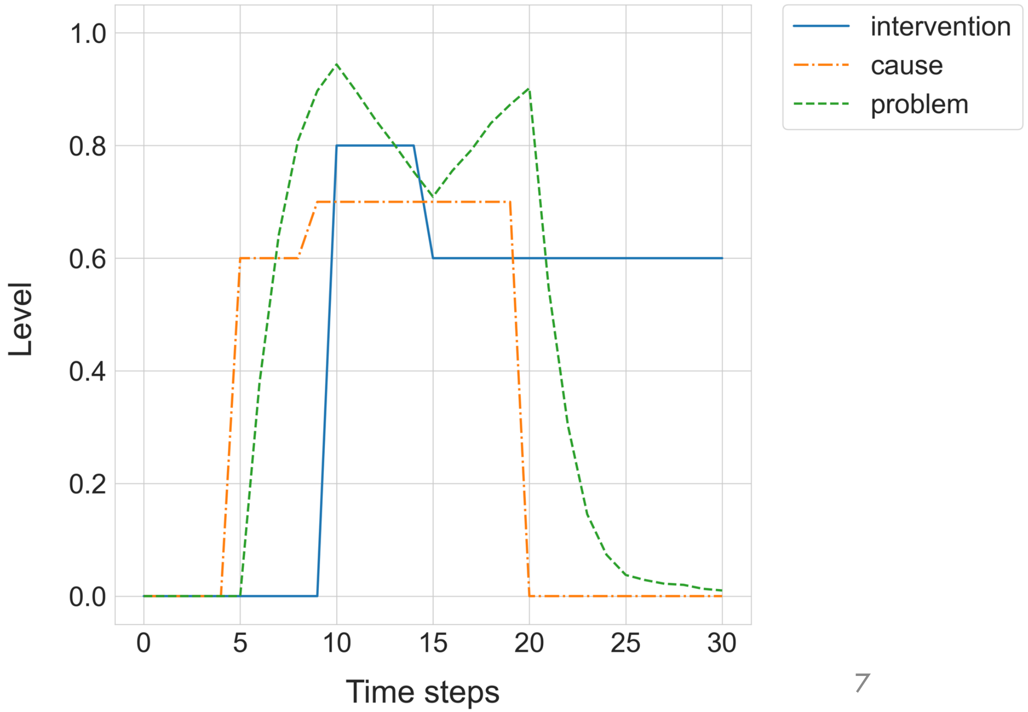
	t=0	t=1	t=2	t=3	t=4	t=5
A:	0.2	0.2	0.6	0.4	0.4	0.4
B:	0.1	0.1	0.1	0.1	0.3	0.3
C:	0	0	0.1	0.4	0.4	0.7

INTERVENTION TOY MODEL



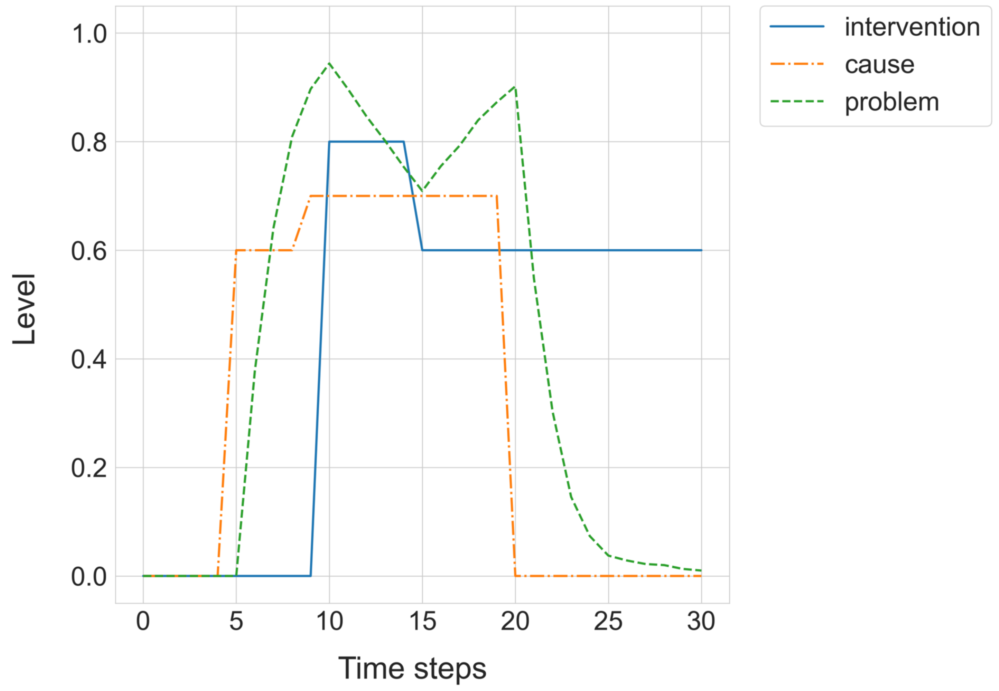
- 4-element network
- Linear model
- 5 tested scenarios:

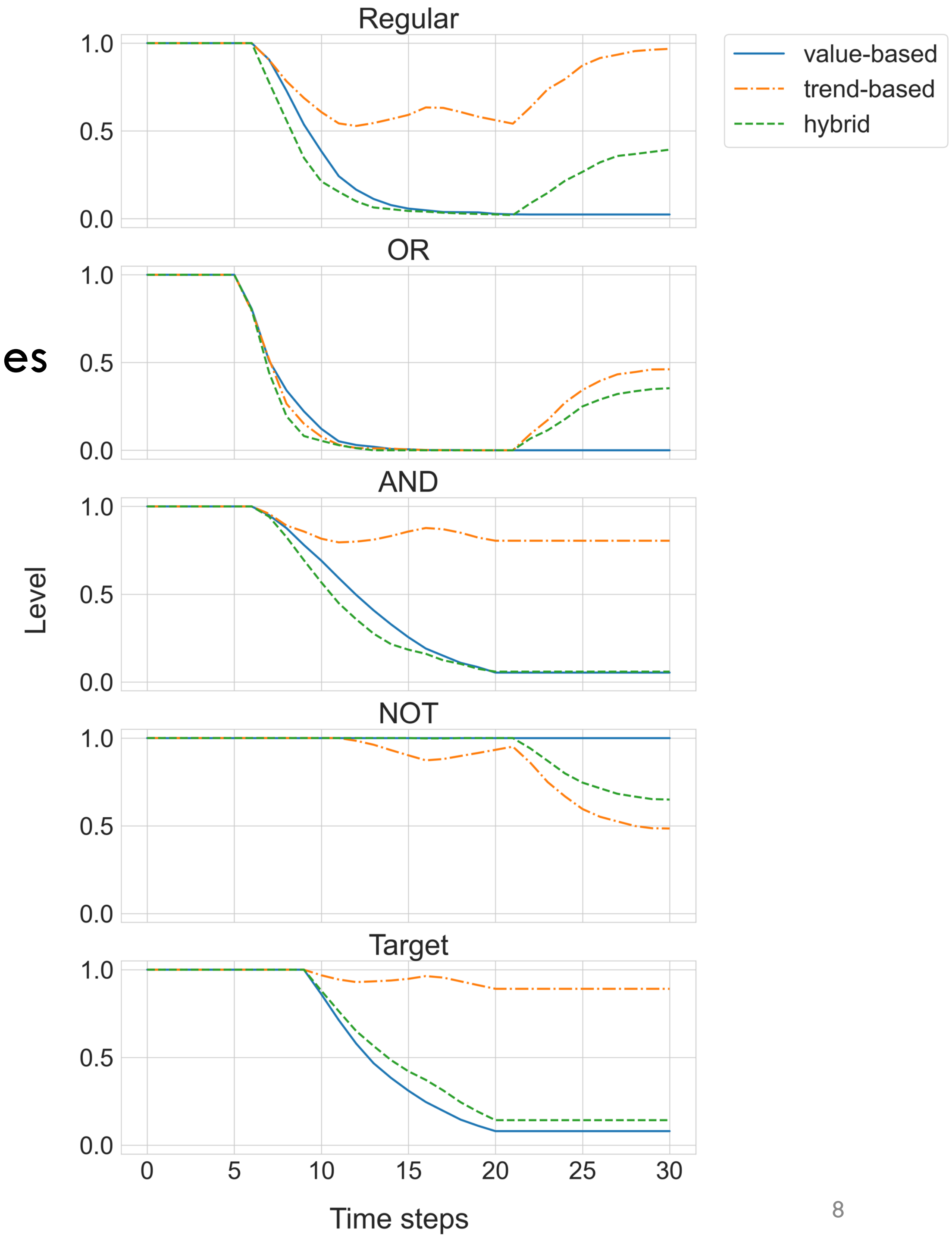
Scenario	Negative regulation
Regular	d(OUTCOME) = -PROBLEM
OR	d(OUTCOME) = -(PROBLEM + CAUSE)
AND	d(OUTCOME) = -(PROBLEM * CAUSE)
NOT	d(OUTCOME) = PROBLEM
Target	d(OUTCOME) = -(PROBLEM * CAUSE) only when CAUSE=0.7



RESULTS

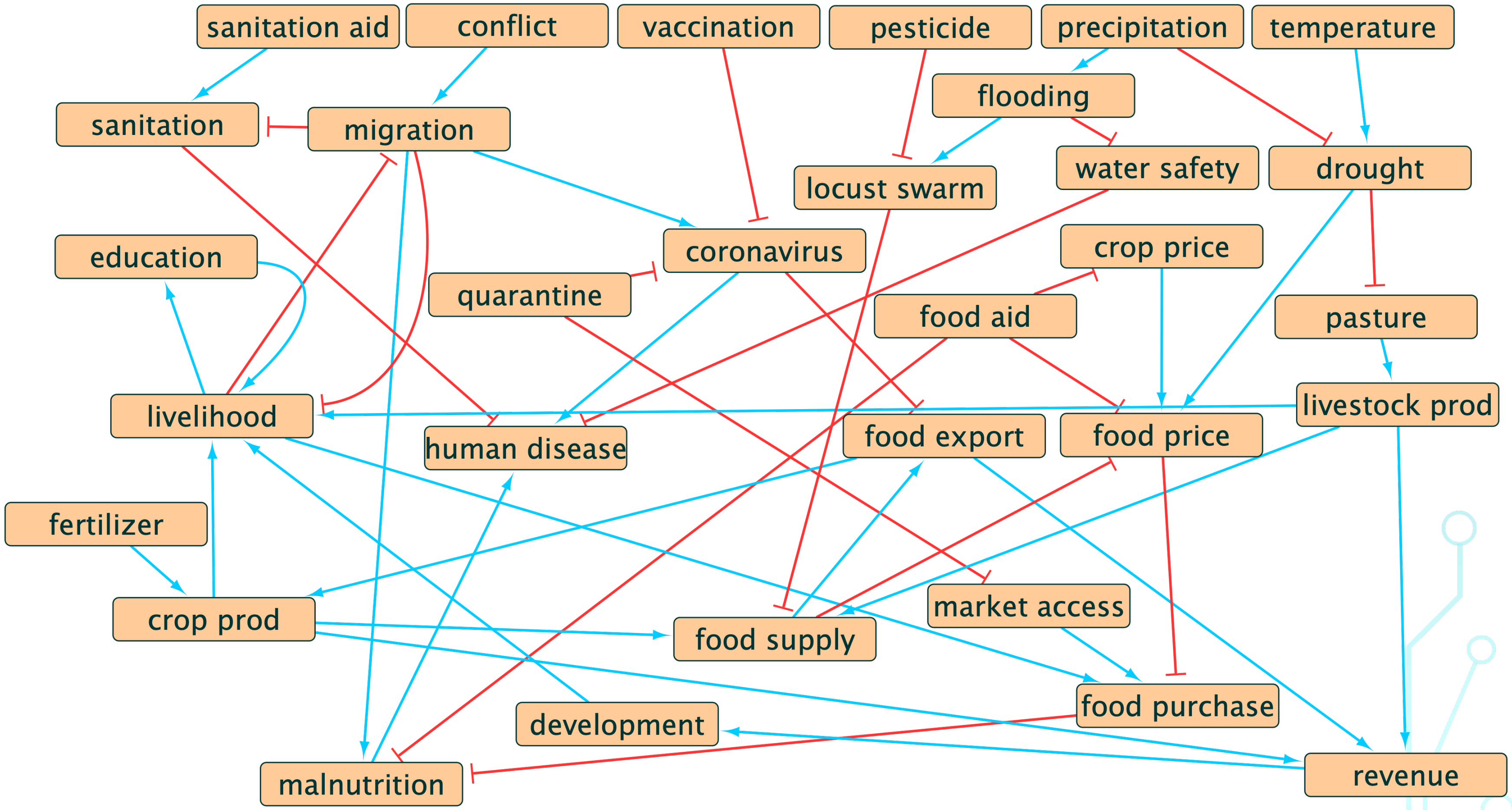
- Toy model, 5 scenarios, 3 regulation types
- Execution time: 0.37-0.54 s





LARGER MODEL – FOOD INSECURITY IN ETHIOPIA

- 31 nodes, 49 edges
- 10 inputs:
  - Temperature
  - Precipitation
  - Pesticide
  - Medical treatment
  - Fertilizer aid
  - Sanitation aid
  - Food Aid
  - Conflict
  - Quarantine
  - Vaccination

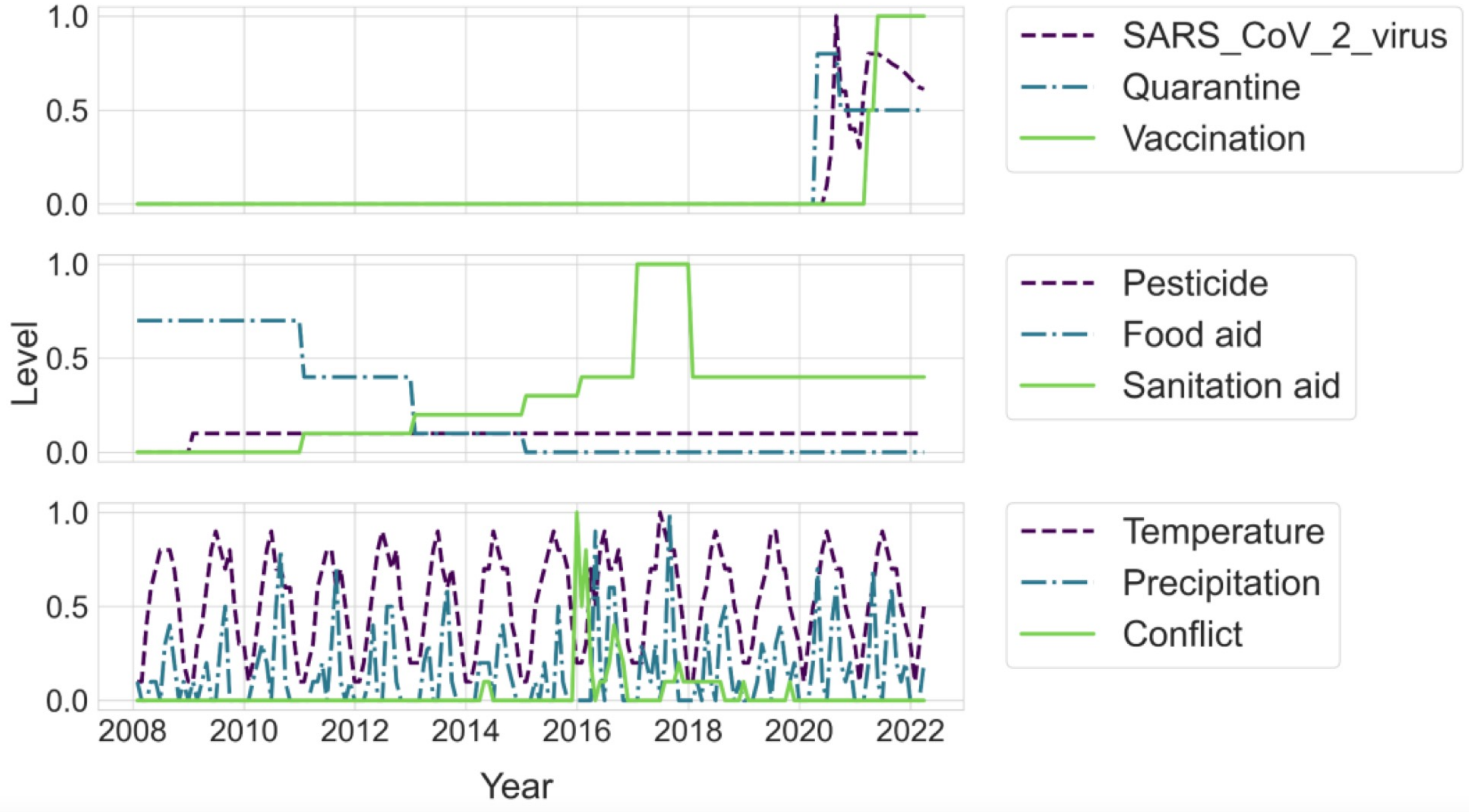


LARGE MODEL – DATA SOURCES

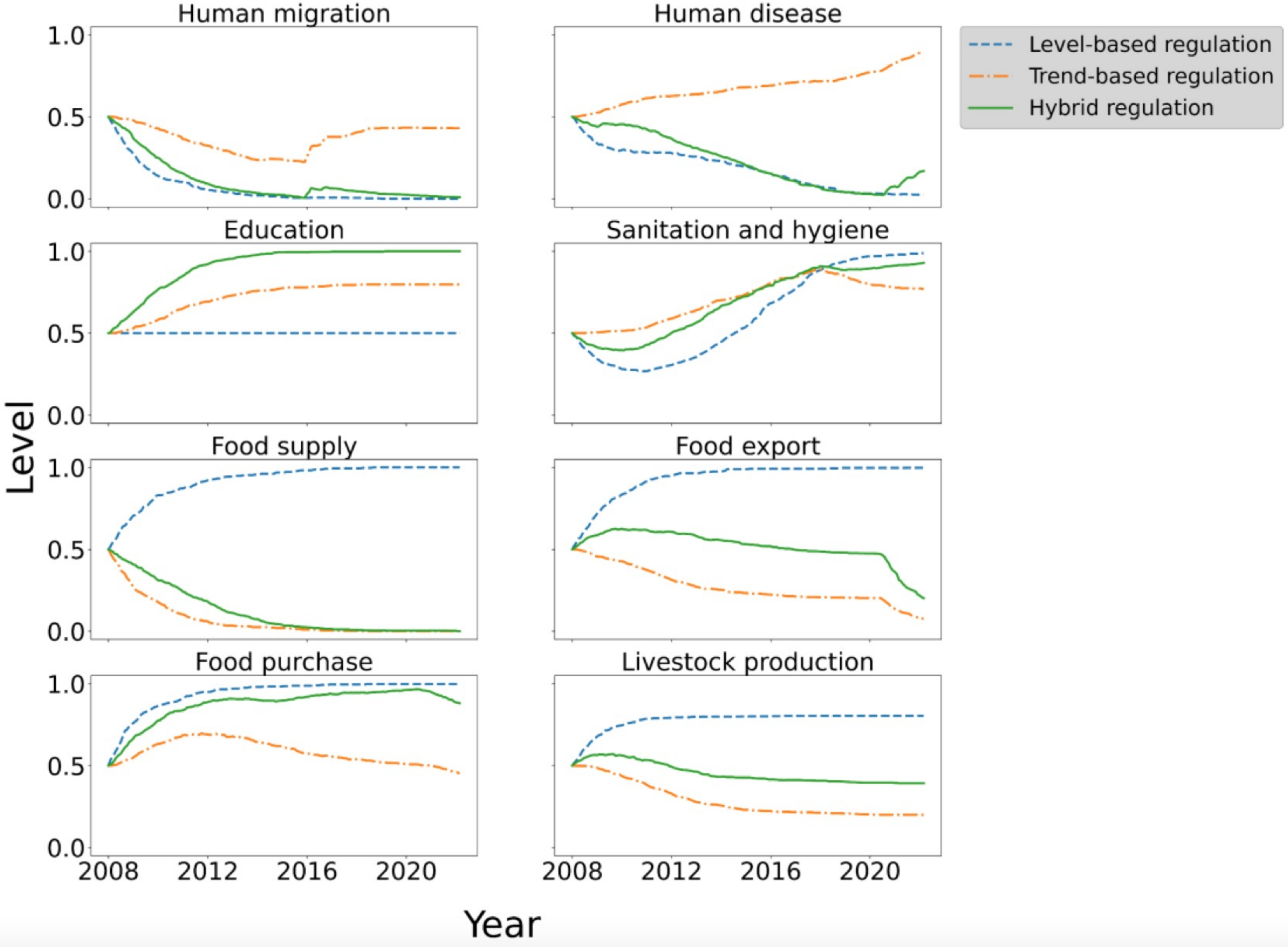
Variable	Source	Reference	Resolution (spatial and temporal)
Conflict	ACLED	Raleigh et al 2010	Ethiopia/daily
Food aid	FAOSTAT	FAOSTAT	Ethiopia/yearly
Pesticide	FAOSTAT	FAOSTAT	Ethiopia/yearly
Precipitation	CHIRPS	Funk et al 2005	Oromia/daily
Quarantine	EPHI	EPHI	Ethiopia/monthly
Sanitation and hygiene aid	USAID	USAID Database	Ethiopia/yearly
SARS-CoV-2 virus	OWID	OWID; Roser et al 2020	Ethiopia/daily
Temperature	ERA5	ERA5; Hersbach et al 2020	Oromia/daily
Vaccination	WHO	WHO	Ethiopia/daily

RESULTS – LARGE MODEL

- Execution time:
  - Level-based: 68.7 s
  - Trend-based: 71.2 s
  - Hybrid: 74.7 s



RESULTS – LARGE MODEL



CONCLUSIONS

- Trend-based regulation resolves some of the level-based counter-intuitive behaviors
- Hybrid regulation gives more modeling flexibility
- DiSH-trend simulator can be used to model multi-domain complex systems
- Major advantages:
    - Highly tunable
    - Robust to missing data
    - Easy to automate and integrate with other software

ACKNOWLEDGEMENTS

Natasa Miskov-Zivanov, PhD

MeLoDy lab

Mechanisms and Logic of Dynamics

Kara Bocan, PhD

Cheryl Telmer, PhD

Khaled Sayed, PhD

Adam Butchy

Yasmine Ahmed

Casey Hansen

Emilee Holtzapple

Gaoxiang Zhou

Niteesh Sundaram

Evan Becker

Handa Ding

Collaborators

- George Wittenberg, MD, PhD, Neurology, UPitt
- Peter Spirtes, PhD, Philosophy, CMU
- Brent Cochran, PhD, School of Medicine, Tufts
- Sandra Cascio, PhD, Immunology, UPitt
- Michael Lotze, MD, UPCI, UPitt
- Christof Kaltenmeier, MD, UPCI, UPitt
- Ed Hovy, PhD, LTI, CMU
- Robert Stephens, PhD, NCI, NIH

https://www.nmzlab.pitt.edu

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DARPA

ACKNOWLEDGEMENTS

- MeLoDy Lab (N. Miskov-Zivanov lab)
- Kara Bocan and Khaled Sayed
  (ex lab members)
- Collaborators: Brad Goodman, Robyn Kozierok, Zoe Henschield, Lynette Hirschman, Pam Bhattacharya, and Pascale Proulx
- DARPA grant W911NF-18-1-0017
- WSC conference