# Studying spread patterns of COVID-19 based on Spatiotemporal data

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# Motivation


7-Day Average of Daily New Cases per 100,000 People on Tuesday March 10, 2020
CANADA
Edmonton
Calgary
Vancouver
7-Day Average of Daily New Cases per 100,000
≤ 10
≤ 20
≤ 30
≤ 40
≤ 50
≤ 100
> 100
Hermosillo
Chihuahua
Culiacan
Torreón
Monterrey
Gulf of Mexico
Havana
MÉXICO
Data Source: New York Times
Map: The Polis Center at IUPUI

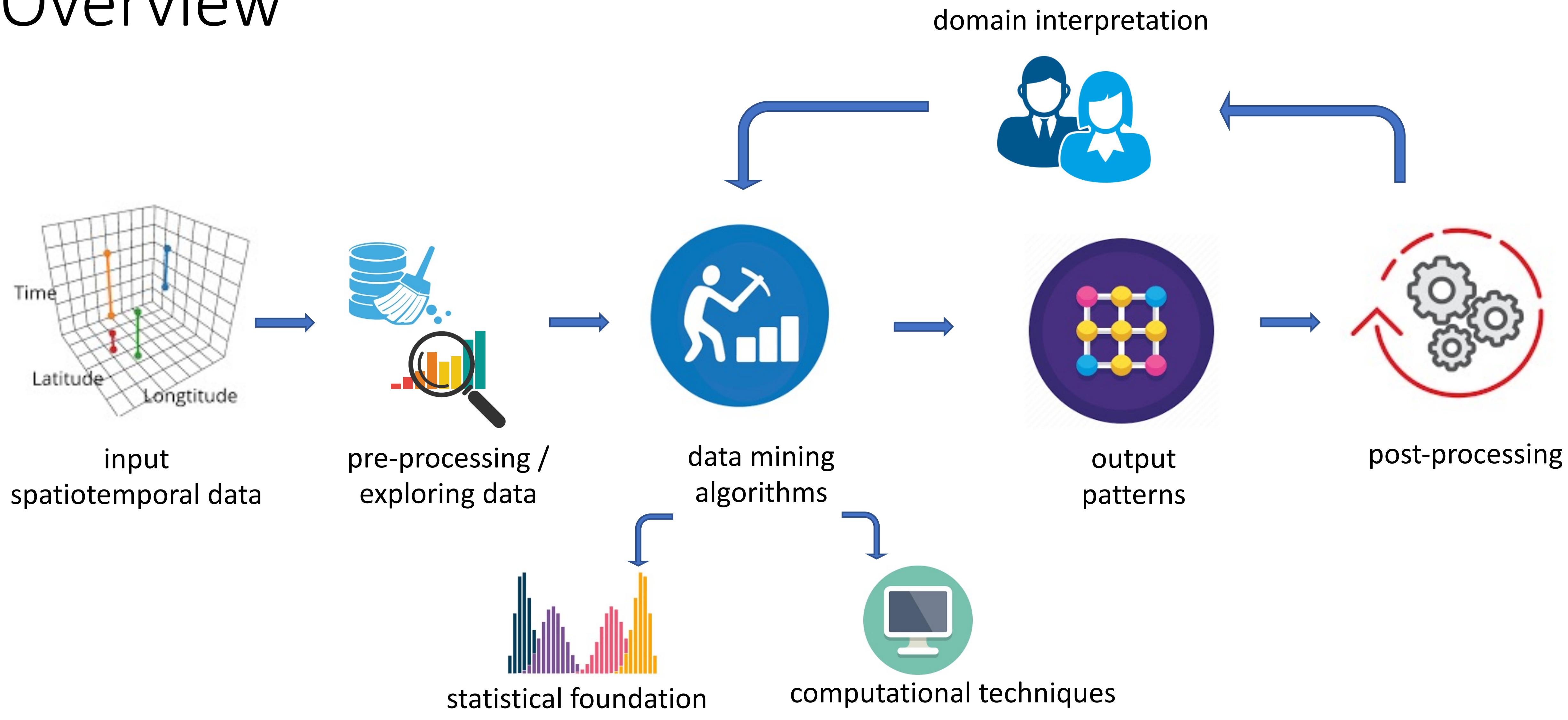

SORRY WE'RE CLOSED DUE TO COVID-19

# Motivation

# Outline

- Human routine behavior modeling
  - Challenges of behavior modeling
  - Properties of spatiotemporal data
  - Inverse reinforcement learning
  - Behavior patterns and epidemic spreads
- Structural learning on networks
  - Graph neural networks (GNN) for epidemiology
  - Basics of GNN and spatiotemporal GNN
  - GNN, SIR, and PDE
- Remote sensing
  - Potential of using remote sensing (RS) data in monitoring large-scale changes
  - RS for studying effects of climate change on epidemics
  - RS for studying impacts of the pandemic

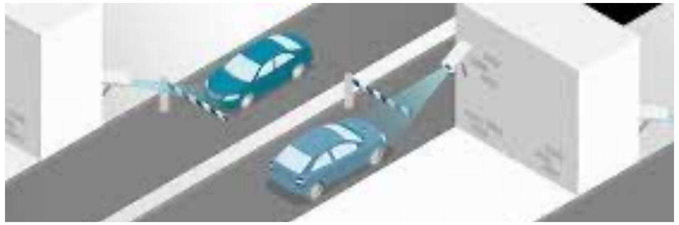
# Overview


domain interpretation
Time
Latitude
Longtitude
input
spatiotemporal data
pre-processing /
exploring data
data mining
algorithms
output
patterns
post-processing
statistical foundation
computational techniques

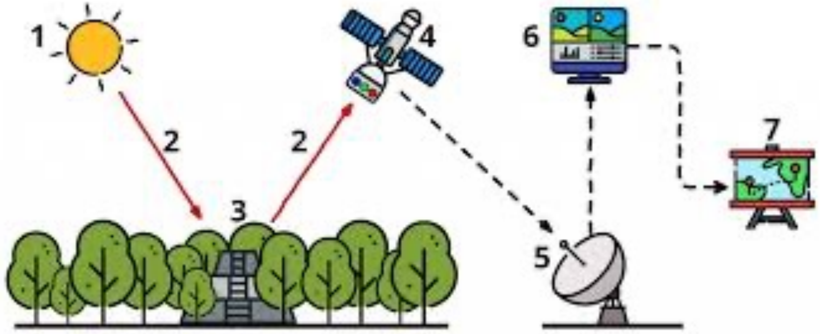
# Spatiotemporal Data Types

- Event or process model
    - Daily routine behavior
    - (human navigation trajectories)


- Temporal change model
    - Traffic model (GNN)
    - (moving speed, acceleration, and directions)



- Temporal snapshot model
    - Remote sensing data
    - (trajectories of raster data, points, lines, and polygons)



# Data Type 1: event or process model

# Event or process model – behavior modeling

- Challenges of behavior modeling
- Properties of spatiotemporal data
- Inverse reinforcement learning
- Behavior patterns and epidemic spreads

# Behavior Modeling — Challenges

**Why is this hard?**

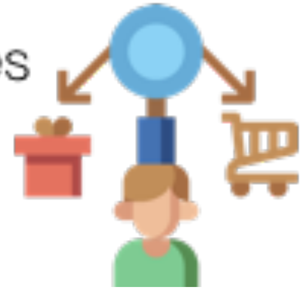
– Human behavior is highly complex

– Activities vary over time

– Interdependencies among activities

– Habit with periodic behaviors

– Individual preferences



**Model requirements**

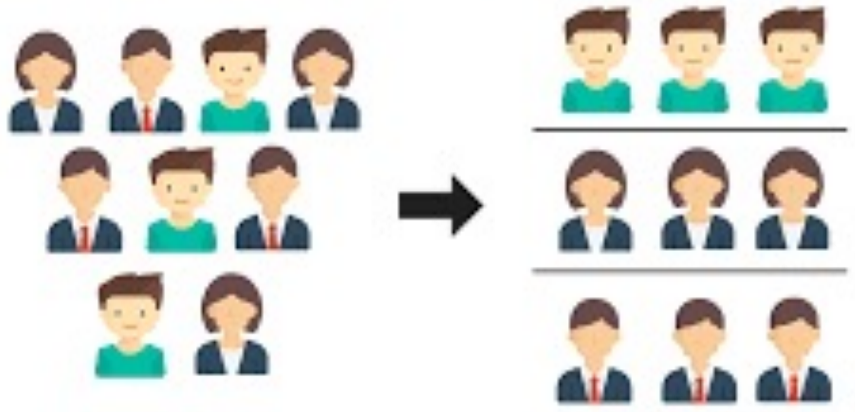
– Capture activities in continuous time

– Predict the relationship between activities and health status

– Provide timely and interpretable prediction

# Properties of spatiotemporal data

- Inter-disciplinary nature
- Continuous space and time
- Spatial relationships among the variables
  - Observations are not independent and identically distributed (i.i.d)
- Spatial structure of errors
- Nonlinear interactions in feature space
  - people with similar characteristics tend to cluster together in the same neighborhoods



# Properties of spatiotemporal data

How to capture implicit spatiotemporal relationships?

# Data-driven approach

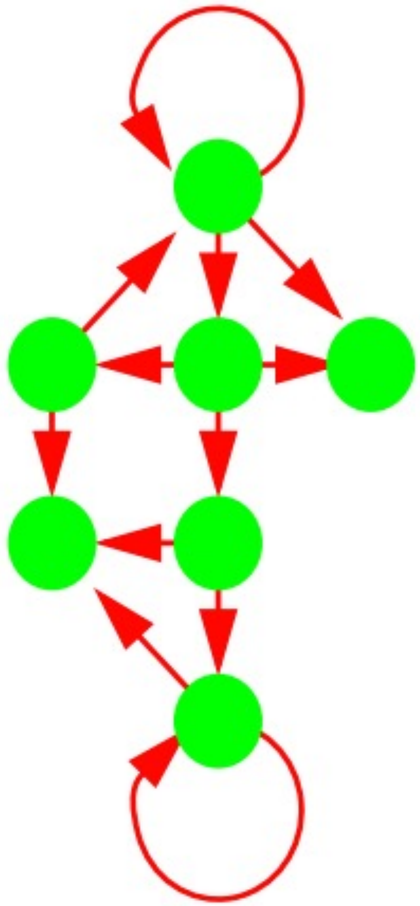
- One way -- incorporate spatial and temporal information into the data mining process, e.g., inverse reinforcement learning.

What is Reinforcement Learning?

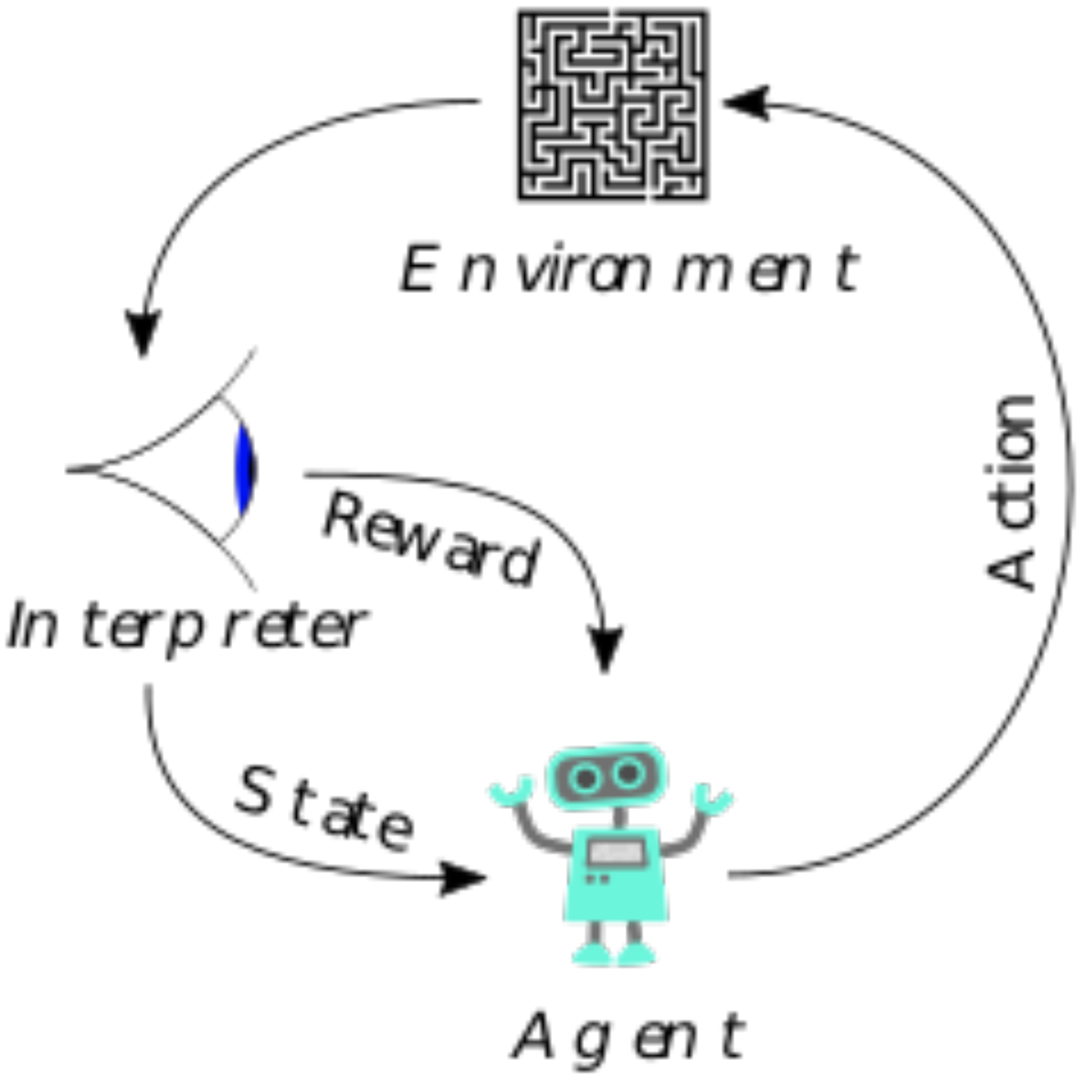
# Background – Markov decision process

A *Markov decision process* (MDP) model contains:

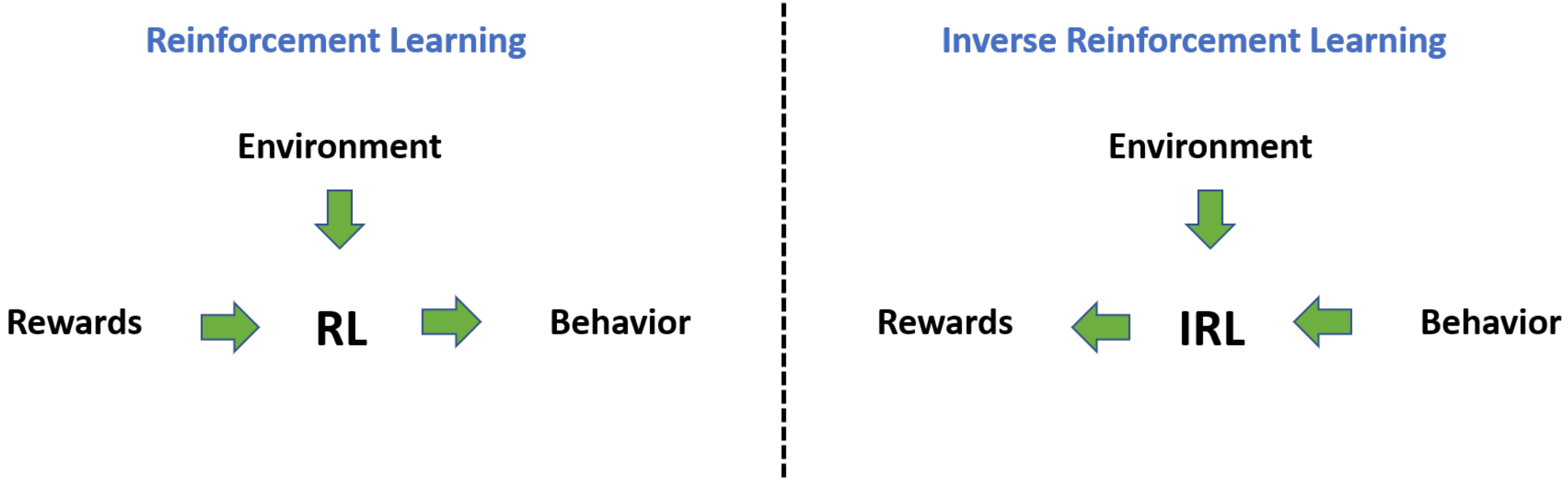
- A set of possible states *S*
- A set of possible actions *A*
- A real valued reward function *R(s, a)*
- A transition matrix *P*



# Background – Reinforcement Learning

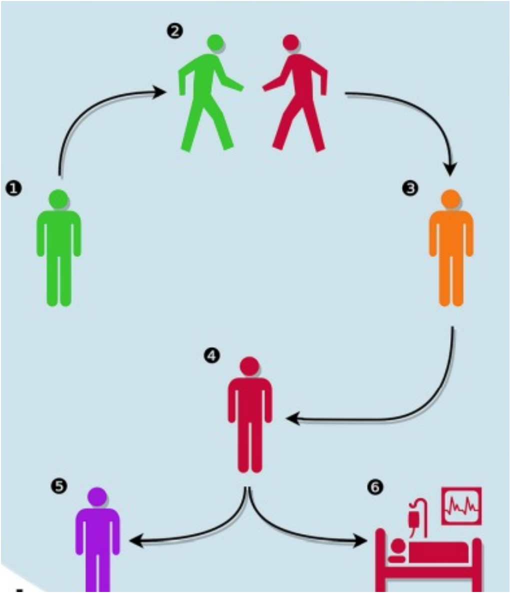


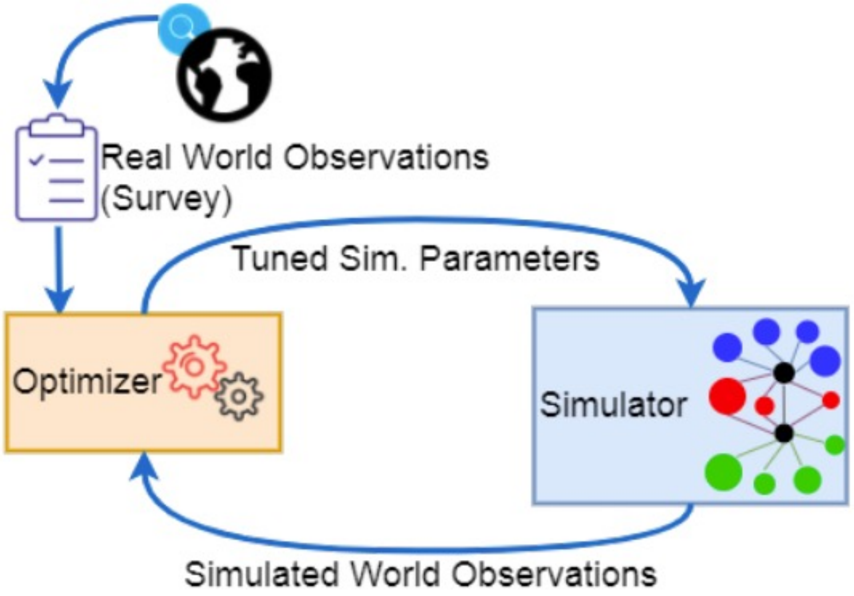
# Background – Inverse Reinforcement Learning



# Behavior patterns and epidemic spreads

Susceptible → Exposed → Infectious → Recovered






Ohi, Abu Quwsar, et al. "Exploring optimal control of epidemic spread using reinforcement learning." *Scientific reports* 10.1 (2020): 1-19.
Singh, Meghendra, et al. "Behavior model calibration for epidemic simulations." *Proceedings of the 17th International Conference on Autonomous Agents and MultiAgent Systems*. 2018.

# Behavior patterns and its impacts on epidemic spreads

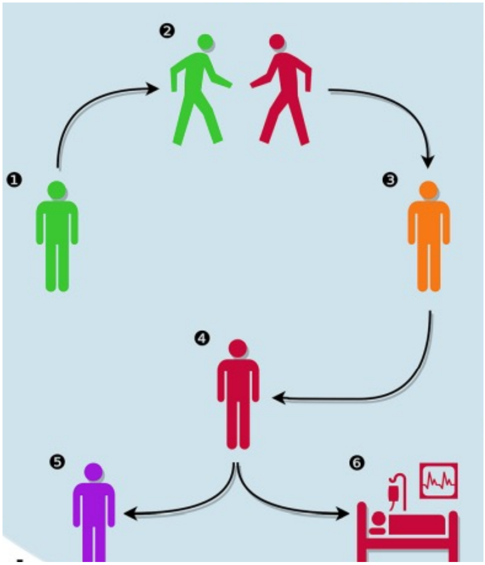
## Define the Markov decision process (MDP) <S, A, P, R>:

S all possible health states of an agent

A avoid touch eyes; avoid touching nose; avoid touching mouth;
Possible responses: never, sometimes, or always ⬄ 351 actions

P Transitions in the state space, given an action a in A

R + reward: not getting infected;
- reward / cost: taking an action



# Behavior patterns and epidemic spreads

$$V_d(a) = \sum_{i=d}^{D} \{ \underbrace{(1 - cost_a)}_{\text{net reward}} * \underbrace{(1 - P_i(S \rightarrow E|a))}_{\text{probability of not transitioning to the exposed state on day i}} \}$$

| | |
|---|---|
| $cost_a$ | cost associated with the action a |
| $P_i(S \rightarrow E\|a)$ | Probability of transitioning from susceptible (S) to exposed (E) on the $i^{th}$ day, given taking the action a |
| $D$ | Total number of days of the simulation |

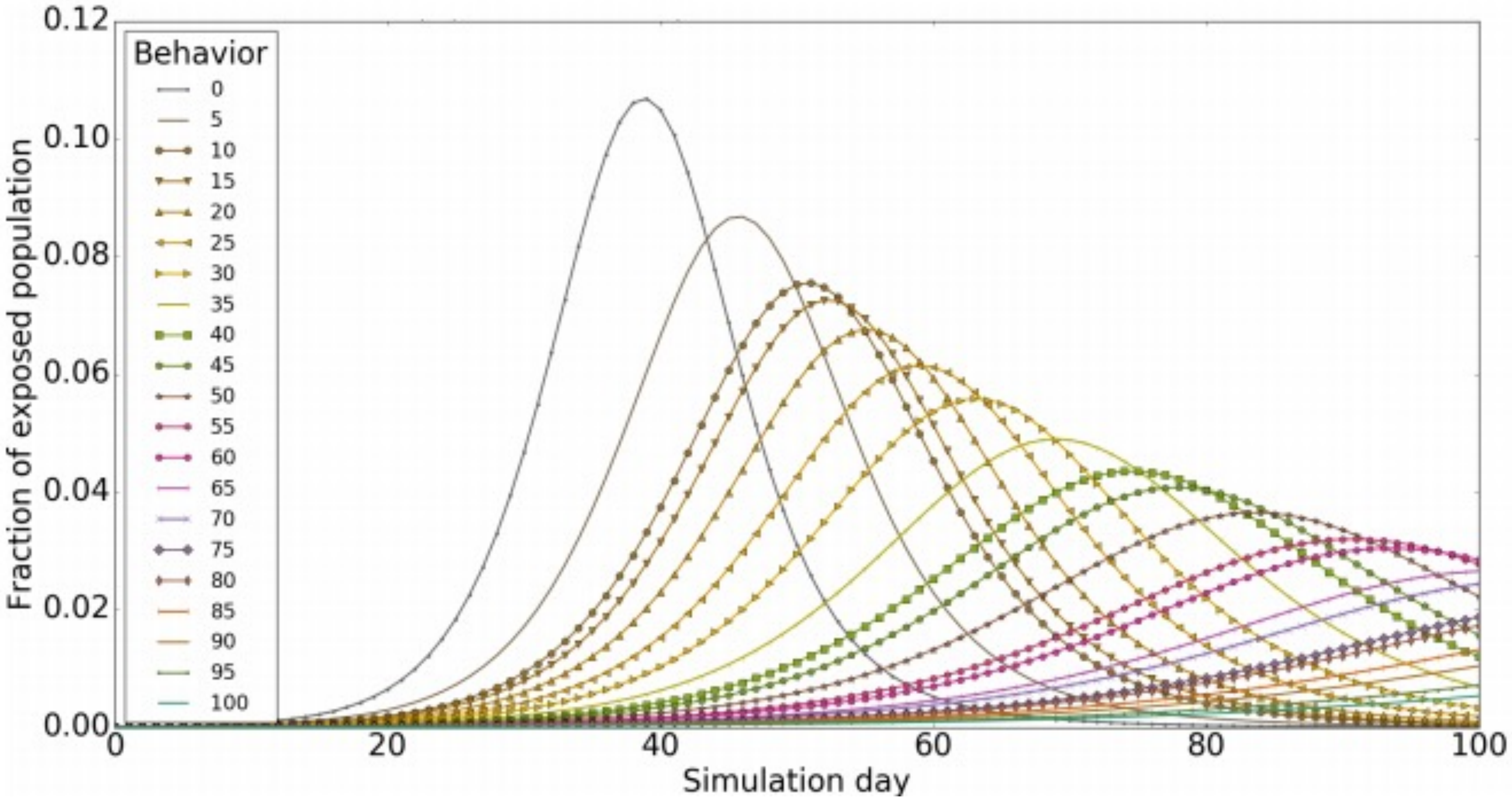
# Behavior patterns and epidemic spreads

How to estimate $P_i(S \rightarrow E|a)$ ?

$$\frac{dS}{dt} = \mu - (\beta I + \mu)S,$$
$$\frac{dE}{dt} = \beta SI - (\mu + \sigma)E,$$
$$\frac{dI}{dt} = \sigma E - (\mu + \gamma)I,$$
$$\frac{dR}{dt} = \gamma I - \mu R.$$

| Variable | Value |
|---|---|
| ODE simulation duration | 100 days |
| $\mu$ | 0.0 |
| $\beta$ | [0.3, 0.6] |
| $\gamma$ | 0.125 |
| $\sigma$ | 0.5 |
| Initial proportion of exposed agents | 0.0001 |
| Initial proportion of infectious agents | 0.0001 |
| Initial proportion of susceptible agents | 0.9998 |
| Initial proportion of recovered agents | 0.0 |

# Behavior patterns and its impacts on epidemic spreads



# Behavior pattern modeling - IRL

Given $< S, A, P >$ of an MDP + estimate of an optimal policy $* \pi$

estimate an optimal reward function $R$

The objective function $J(C)$

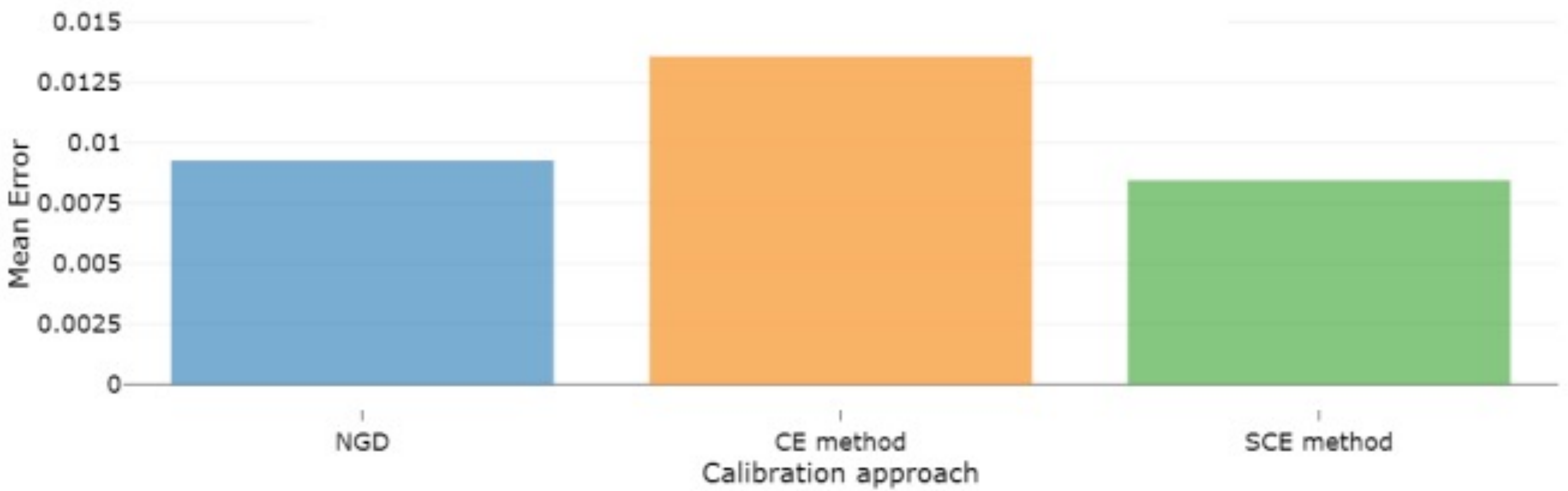
$$J(C) = \frac{1}{2 * |C|} \sum_{b \in B} (N_{C_b} - N_b)^2$$

$$C^* = \arg\min_C J(C)$$

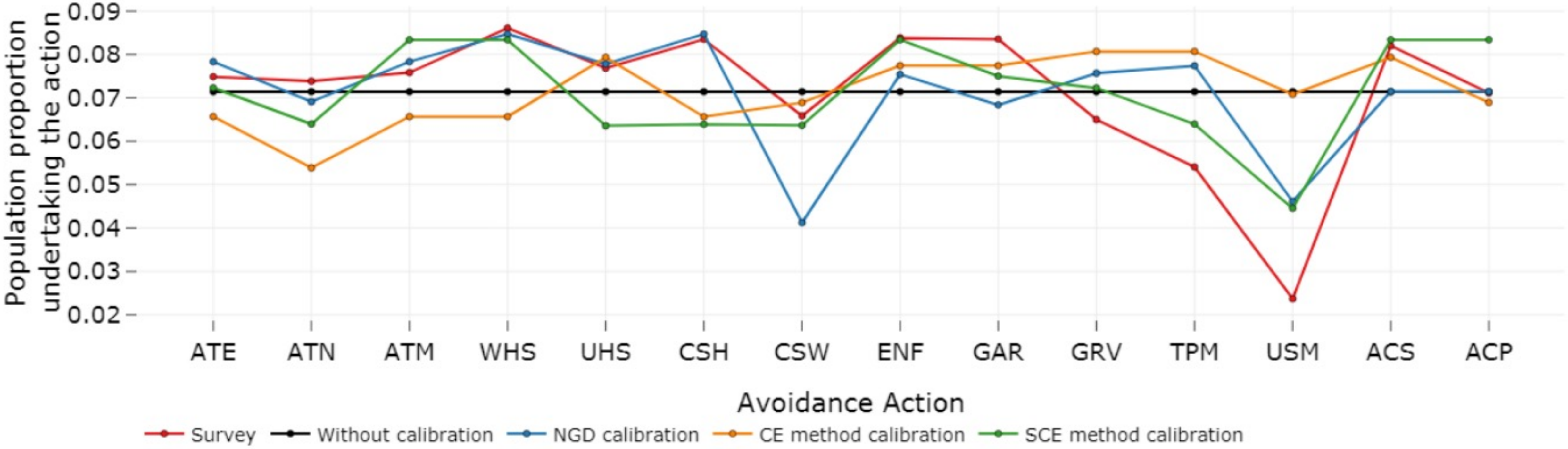
# Behavior pattern modeling - IRL

## Three optimization methods for behavior model calibration

- Numerical Gradient Descent (NGD)
- Cross Entropy (CE)
- Smoothed-Cross Entropy (SCE)



# Behavior pattern modeling - IRL



# Data Type 1: event or process model – conclusion

- Challenges of behavior modeling
- Properties of spatiotemporal data
- Inverse reinforcement learning
- Behavior patterns and epidemic spreads

# Q&A

# 5 minutes break