

COVID-19

Model for Dynamic Analysis of Combination Interventions for Disease Elimination - Using Reinforcement Learning

“Work-In-Progress”

Disease Prediction and Prevention Modeling Lab

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Collaborators



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Disease Prediction and Prevention Modeling Lab

Current Simulation Modeling Overview

I. SETUP INTERVENTION 1 - Contact Reduction

actualIPC	reducedIPC	startContactReduction	stopContactReduction
1	0.4	70	200

II. SIMULATE - USING OPTION 1 or 2

OPTION 1 - national level

Jurisdiction	Set-Country
Country-level	US
Mixing	Select-Origin-City
yes	New York
num-origins	
20	
<input type="button" value="setupCities"/> <input type="button" value="simulate"/>	

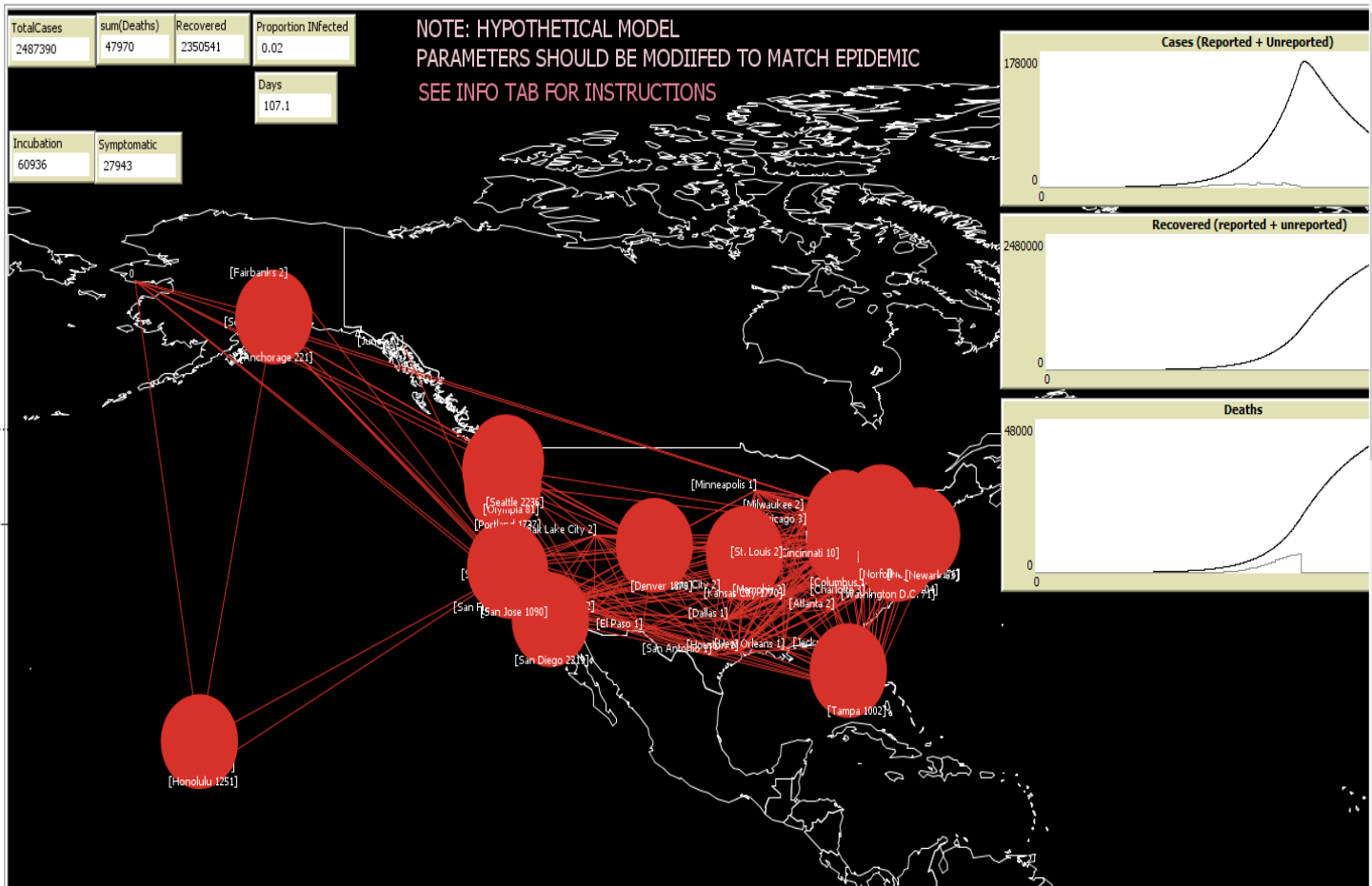
<-- only if US (takes population size for full Metropolitan area)

OPTION 2- world

Set-Origin-Country	<input type="button" value="setupCountry"/> <input type="button" value="Simulate"/>
Belgium	

EPIDEMIOLOGY PARAMETERS (CHANGE AS NEEDED)

pc	stop_days
0.4	1000
Latent_Duration	Delta_t
4.6	0.1
Infectious_Duration	
1.9	
Case_Fatality_Rate	maxJuris
0.02	2000



Current Simulation Modeling- Prediction

I. SETUP INTERVENTION 1 - Contact Reduction

actualPC	reducedPC	startContactReduction	stopContactReduction
1	0.4	70	200

TotalCases	sum(Deaths)	Recovered	Proportion Infected
2487390	47970	2350541	0.02

Days
107.1

NOTE: HYPOTHETICAL MODEL
PARAMETERS SHOULD BE MODIFIED TO MATCH EPIDEMIC
SEE INFO TAB FOR INSTRUCTIONS

II. SIMULATE - USING OPTION 1 or 2

OPTION 1 - national level

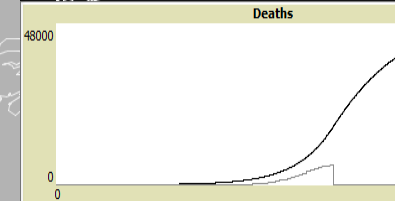
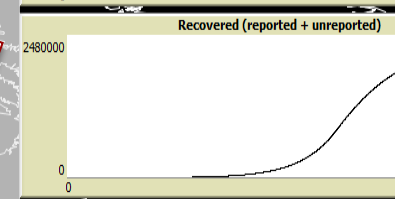
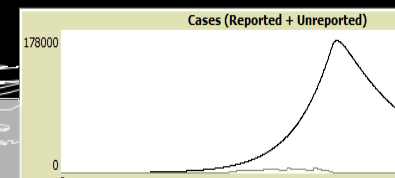
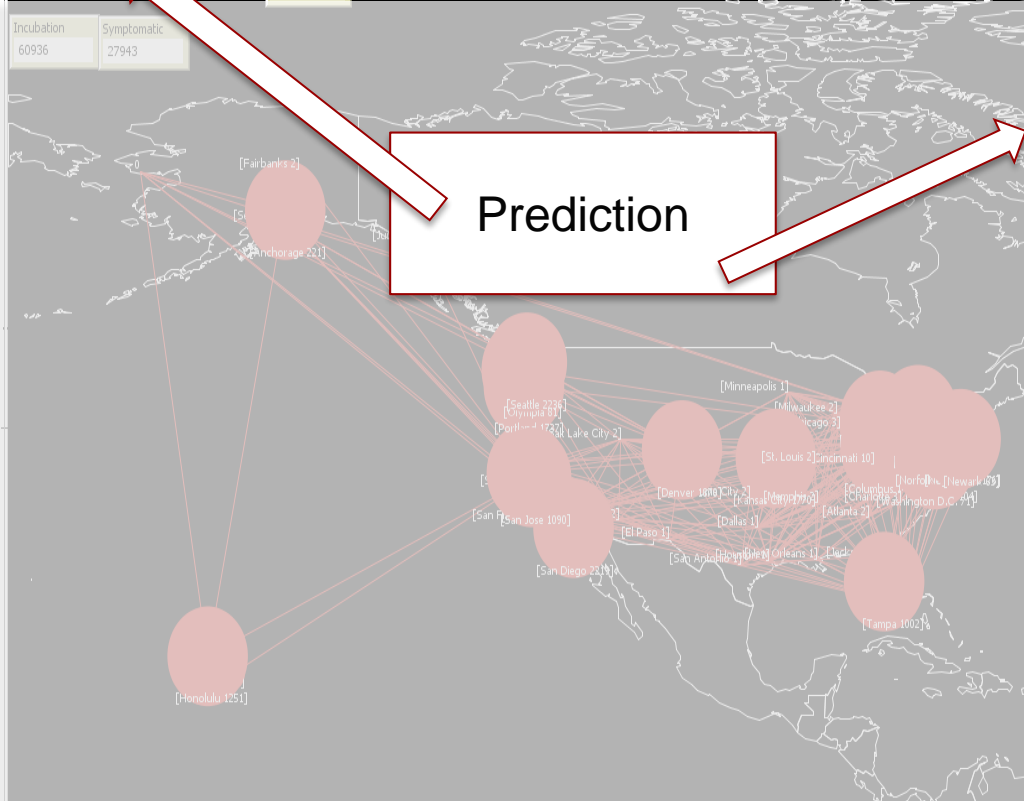
Jurisdiction: Country-level
Set-Country: US
Mixing: yes
Select-Origin-City: New York
num-origins: 20
setupCities simulate

OPTION 2- world

Set-Origin-Country: Belgium
setupCountry Simulate

EPIDEMIOLOGY PARAMETERS (CHANGE AS NEEDED)

pc: 0.4	stop_days: 1000
Latent_Duration: 4, 6	Delta_i: 0.1
Infectious_Duration: 1, 9	
Case_Fatality_Rate: 0.02	maxJuris: 2000



Current Simulation Modeling- What-if analysis

I. SETUP INTERVENTION 1 - Contact Reduction

actualPC	reducedPC	startContactReduction	stopContactReduction
1	0.4	70	70

II. SIMULATE - USING OPTION 1 or 2

OPTION 1 - national level

Jurisdiction	Set-Country
Country-level	US
Mixing	Select-Origin-City
yes	New York
num-origins	
20	
setupCities	simulate

OPTION 2- world

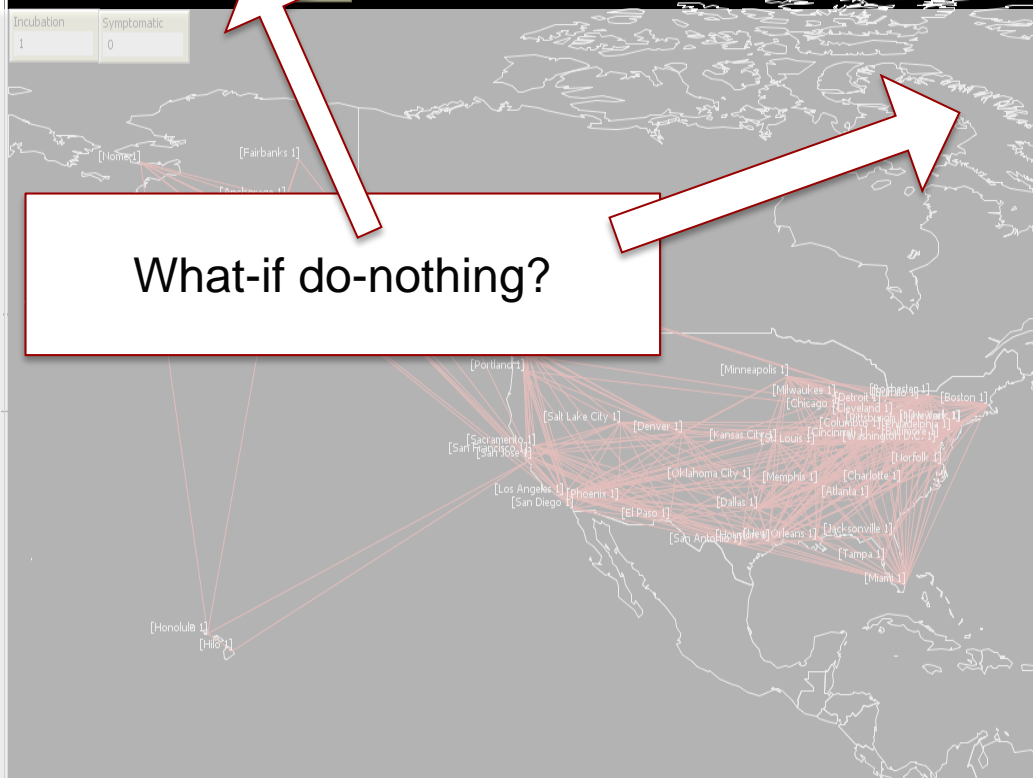
Set-Origin-Country	setupCountry	Simulate
Belgium		

EPIDEMIOLOGY PARAMETERS (CHANGE AS NEEDED)

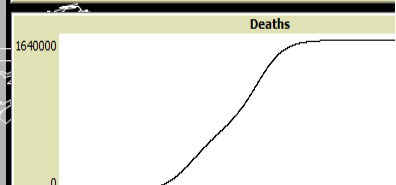
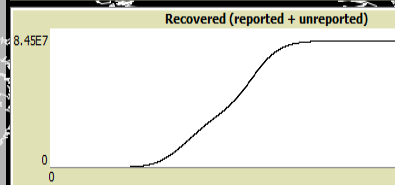
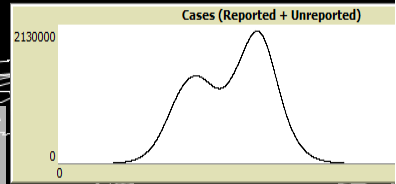
pc	stop_days
1	1000
Latent_Duration	Delta_t
4.6	0.1
Infectious_Duration	
1.9	
Case_Fatality_Rate	maxJuris
0.02	2000

TotalCases	sum(Deaths)	Recovered	Proportion Infected
78846210	1576924	77269285	0.77
Days			

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What-if do-nothing?



Current Simulation Modeling- What-if

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2487390	47970	2350541	0.02

Days
107.1

NOTE: HYPOTHETICAL MODEL
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II. SIMULATE USING OPTION 1 or 2

OPTION 1 - National level

Jurisdiction:

Country:

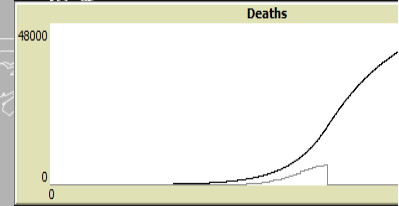
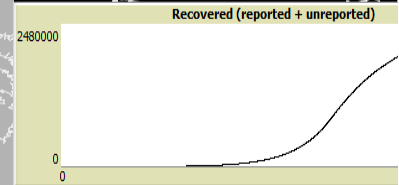
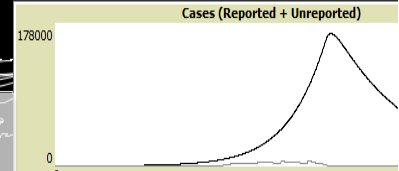
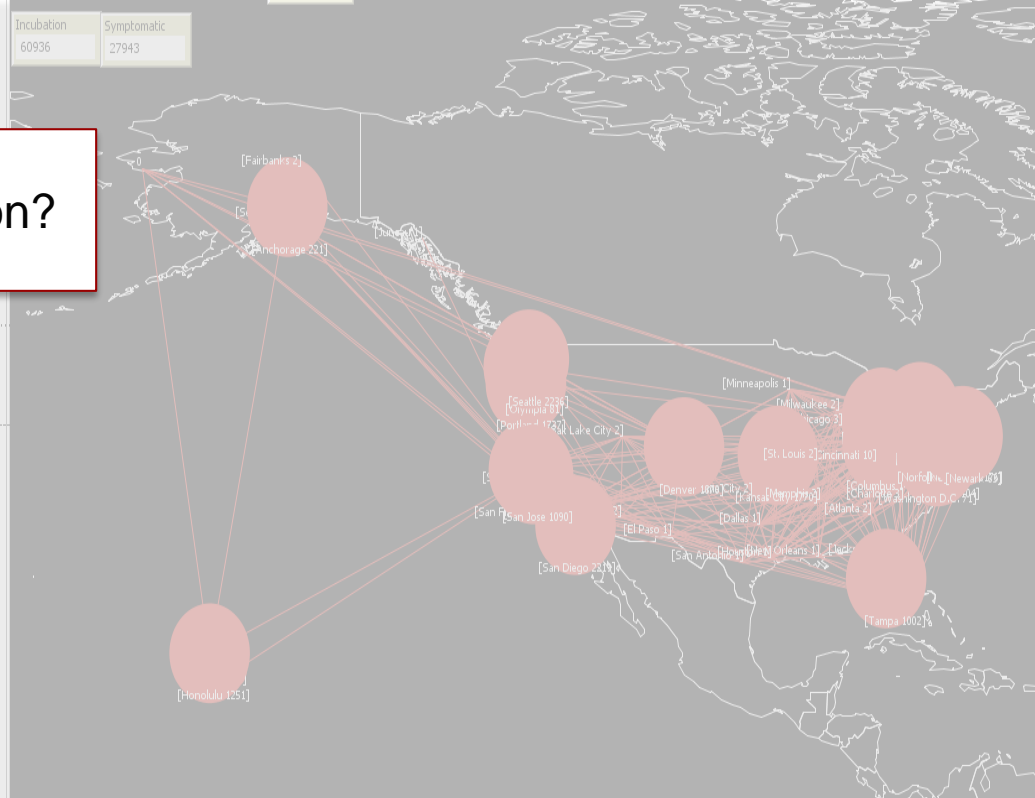
What-if intervention?

OPTION 2 - world

Set-Origin-Country:

EPIDEMIOLOGY PARAMETERS (CHANGE AS NEEDED)

pc	stop_days
0.4	1000
Latent_Duration	Delta_i
4,6	0.1
Infectious_Duration	
1,9	
Case_Fatality_Rate	maxJuris
0.02	2000



Current Simulation Modeling- What-if

I. SETUP INTERVENTION 1 - Contact Reduction

actualPC	reducedPC	startContactReduction	stopContactReduction
1	0.4	70	130

TotalCases	sum(Deaths)	Recovered	Proportion Infected
77769582	1555387	76213966	0.76
			Days
			456.9

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II. SIMULATE - CHANGING OPTION 1 or 2

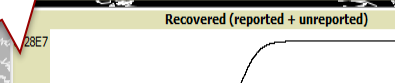
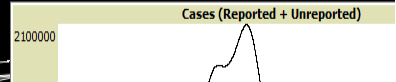
OPTION 1: Personal level

Jurisdiction: [Country-level] Set-Country: [US]

What-if intervention?

Example: what-if contact reduction through social distancing

- Start day 70
- Stop day 130



EPIDEMIOLOGY PARAMETERS (CHANGE AS NEEDED)

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Cases (Reported + Unreported)
178000

Several what-if analysis of interest - to reduce $*pc$

1. What combinations of interventions?

- Quarantine of infected persons diagnosed through
 - Symptom-based testing
 - (what % showing symptoms?)
 - Contact-tracing and testing
 - (what % to test?)
 - Universal testing
 - (what % to test, and where?)
- Social distancing
 - (what populations and locations?)

2. When to apply this combination intervention?

- Ramping-up and scaling-down phases
 - When to start and stop intervention?

(* p = transmission risk, c = contacts per persons)

II. SIMULATE

OPTION 1 - national

Jurisdiction

Country-level

Mixing

yes

num-origins

20

OPTION 2 - world

Set-Origin-Country

Belgium

EPIDEMIOLOGY PA

(CHANGE AS NEED)

pc

0.4

Latent_Duration

4,6

Infectious_Duration

1,9

Case_Fatality_Rate

0.02

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Influenced by dynamics of disease and past decisions

A disease elimination strategy should thus be a planned "sequence" of decisions

(* p = transmission risk, c = contacts per persons)

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 - Ramping-up and scaling-down phases
 - When to start and stop intervention?

Influenced by dynamics of disease and past decisions

An elimination strategy should thus be a “planned” “sequence” of decisions

Challenging: too many combinations to exhaustively explore

Simplest: $20^{3 \times 52}$ (3 types of interventions each at 20 possible levels for a 52 week period)

(*p= transmission risk, c = contacts per persons)

Research Focus

- Develop a model to identify best disease elimination strategies
 - combination of interventions
 - sequence /phases

Formulation of Decision Question

- At time t
- Given “*observable*” system state = $[Q_I, Q_E, H, R, D]_t$ *
 - Q_I = % infectious (symptomatic and diagnosed)
 - Q_E = % exposed (asymptomatic and diagnosed)
 - H = % hospitalized
 - R = % recovered
 - D = % dead
- What is optimal policy sequence = $\{[s, u, c]_t, [s, u, c]_{t+1}, [s, u, c]_{t+2}, \dots \dots\}$ *
 - s = % social distancing
 - u = % universal testing
 - c = % testing reached through contact tracing
- to “optimally” lead to zero infections or disease elimination?

*denominators- total population; assume closed system

Formulation of Optimality (objective function)

Optimal trade-off in Total Costs, Benefits, and Consequences

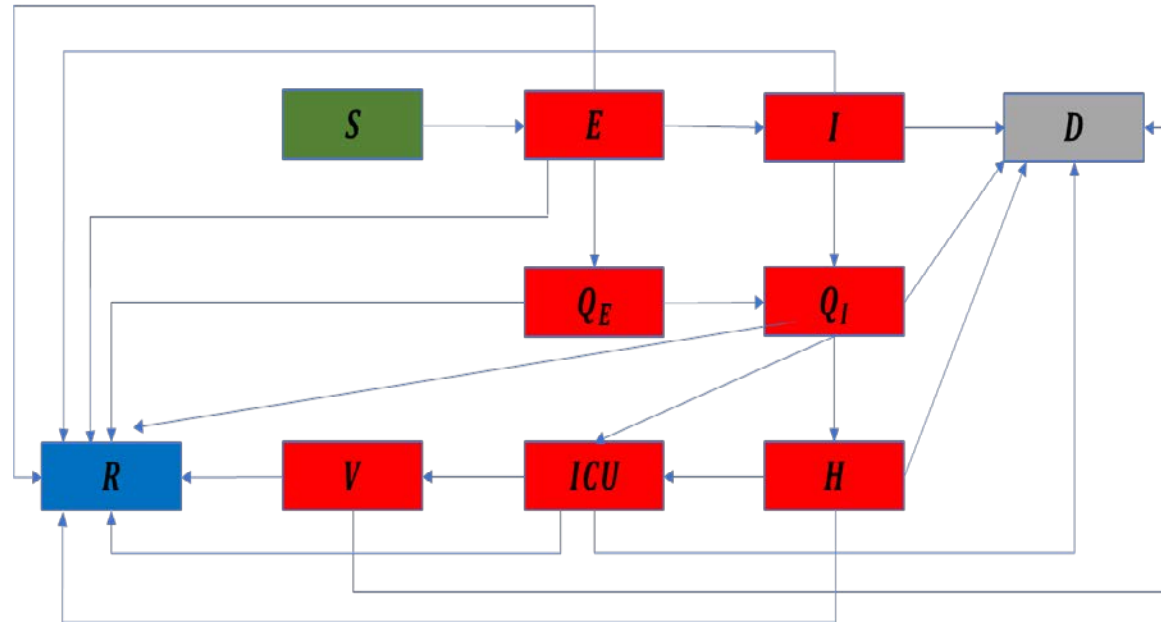
- Maximize QALYs (quality-adjusted life-years lived)
 - Value per person per year
 - 1 healthy
 - (0,1] sick
 - 0 death
- Maximize productivity
 - Economic value per person per year
 - 0 Unemployed
 - (0,1] partial
 - 1 Employed
- Minimize cost
 - Unit costs
 - Contact tracing and testing
 - Universal testing
 - Hospitalization
- Subject to: Constraints (supply constraints)
 - Strict v what-if
 - Hospital capacity (number who can receive care)
 - Testing (=number with test outcome)₁₂

Methods

- Prediction model
- Decision analytic model

Prediction Model

System dynamics modeling (differential equations modeling)

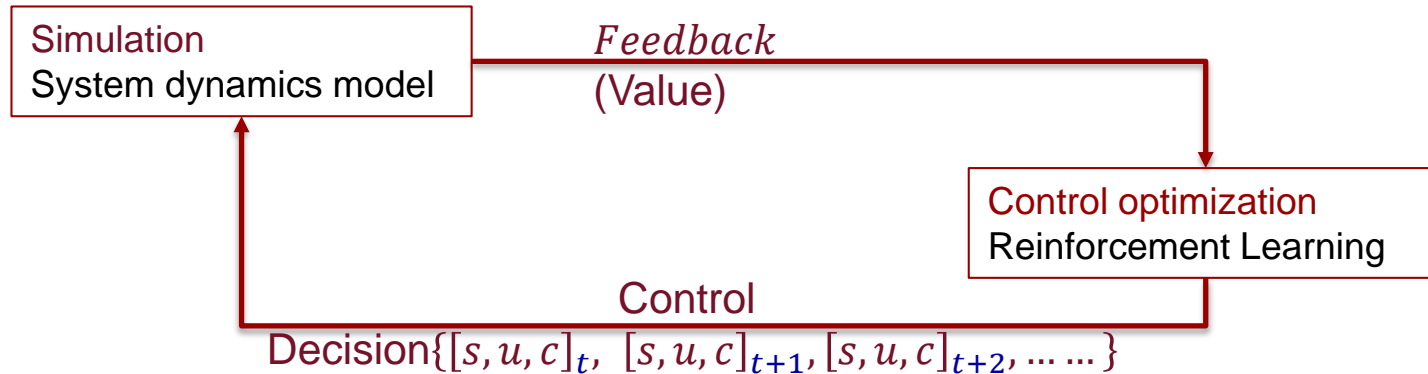


- S = the number of **susceptible** persons,
- E = the number of **exposed (asymptomatic or presymptomatic)** persons,
- I = the number of **infected (symptomatic)** persons,
- Q_I = the number of **tested and diagnosed** who are infected and symptomatic,
- Q_E = the number of **tested and diagnosed** who are infected and asymptomatic,
- H = the number of **hospitalized** persons,
- ICU = the number of persons in **ICU**,
- V = the number of persons on **ventilation**,
- R = the number of persons **recovered**,
- D = the number of **deaths**,

Decision Analytic Method

- Reinforcement Learning

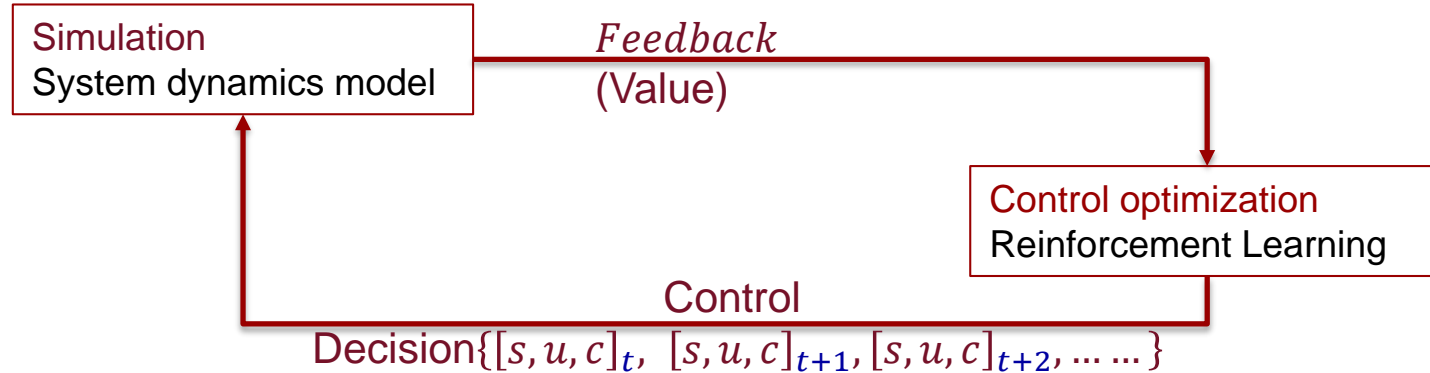
(simulation based control optimization)



Identify optimal policy-

A sequence of decisions that optimally leads to disease elimination

Decision Analytic Method - Reinforcement Learning (simulation based control optimization)



Identify optimal policy-

A **sequence** of (**combination controls**) decisions that optimally lead to disease elimination (**completion of task**)

Analogous to autonomous helicopter control

-Identify **sequence** of **combination controls** (main-rotor's blade tilt, tail rotor pitch, rotor plane/ cyclic pitch) for successful **completion of task**

Expected output

Model output: *Optimal policy = a sequence of decisions=*

$$\{[s, u, c]_t, [s, u, c]_{t+1}, [s, u, c]_{t+2}, \dots, [s, u, c]_{t+N}\} \mid [Q_I, Q_E, H, R, D]_t$$

- Helps in planning response strategies and resource allocation decisions
- Helps eliminate bad decisions

$[Q_I, Q_E, H, R, D]_t$ = **observed state of system at time t** (reported cases of disease)

Q_I = the number of **tested and diagnosed** who are infected and symptomatic,

Q_E = the number of **tested and diagnosed** who are infected and asymptomatic,

H = the number of **hospitalized** persons,

ICU = the number of persons in **ICU**,

V = the number of persons on **ventilation**,

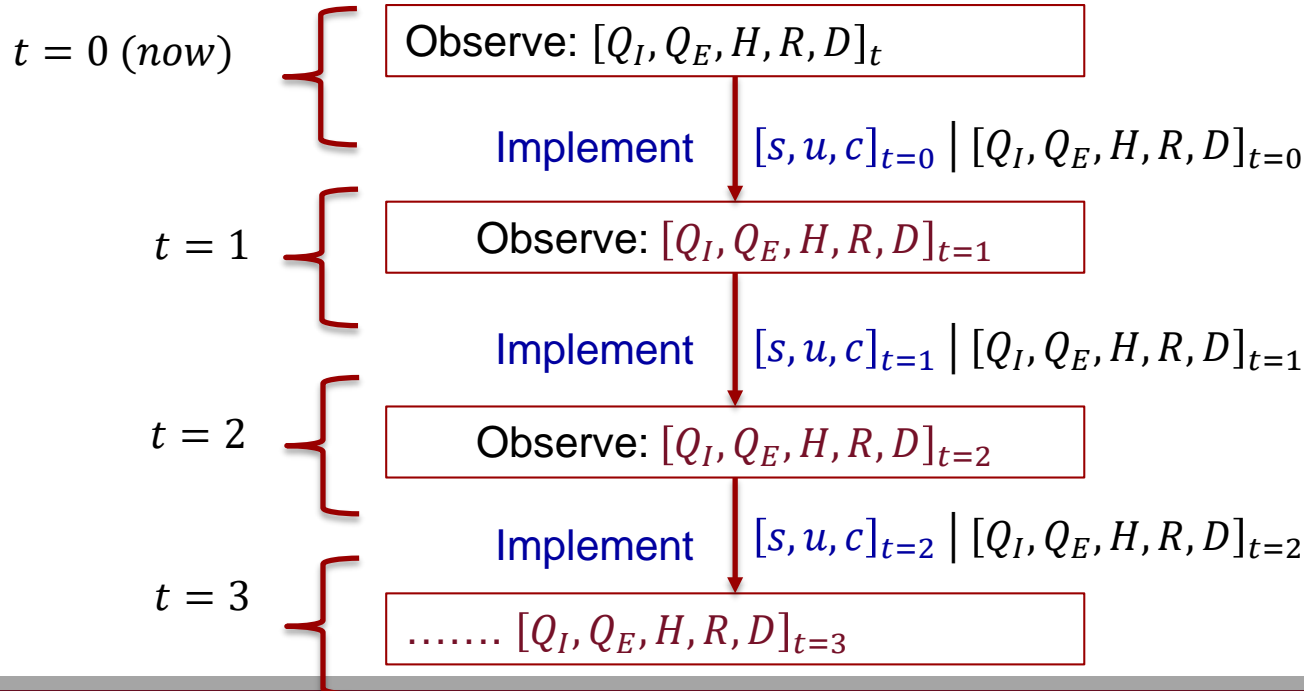
R = the number of persons **recovered**,

D = the number of **deaths**,

Expected output

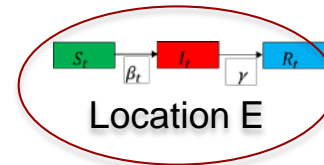
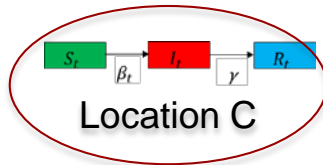
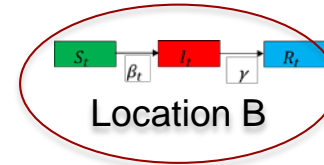
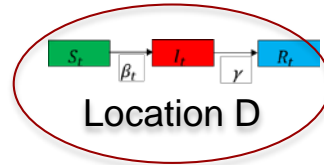
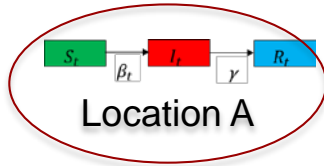
Model output: *Optimal policy = a sequence of decisions=*
 $\{[s, u, c]_{t=0}, [s, u, c]_{t=1}, [s, u, c]_{t=2}, \dots, [s, u, c]_{t=N}\} \mid [Q_I, Q_E, H, R, D]_{t=0}$

Implementation: update based on observation



Phase I

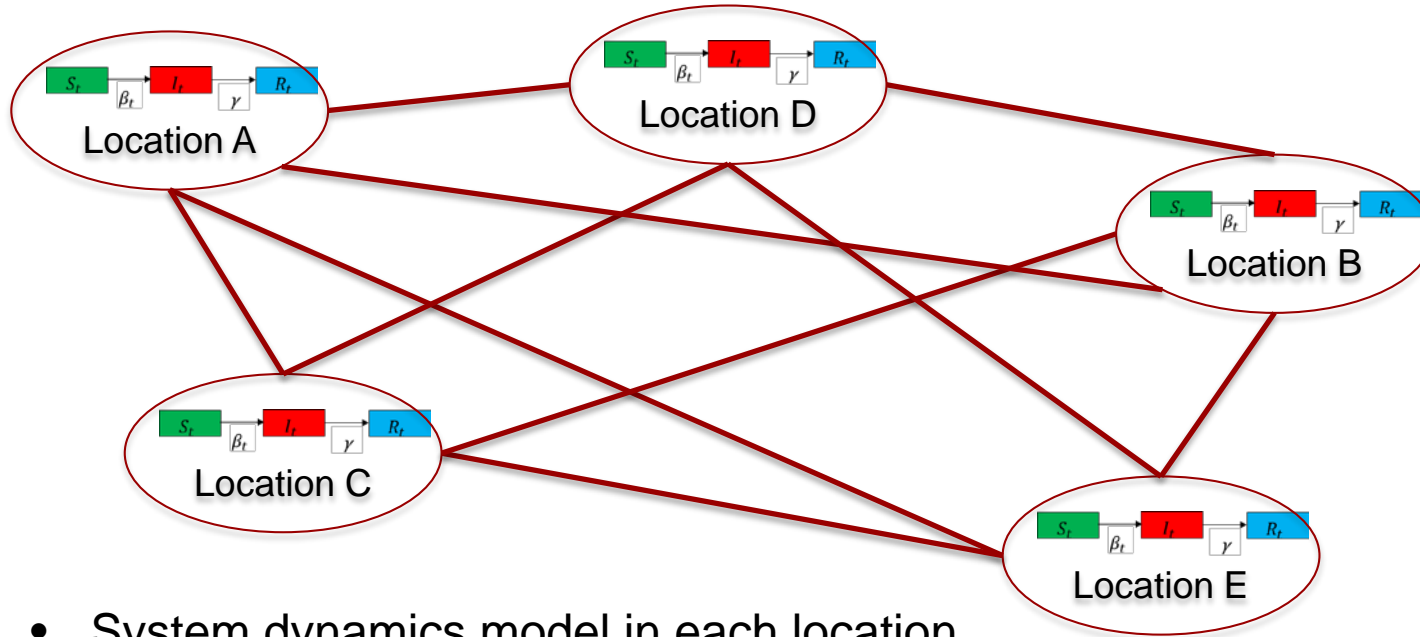
- Independent jurisdiction models



- System dynamics model in each location

Phase II

- Interactions between jurisdictions



- System dynamics model in each location
- Locations connected through network

Persons Interested in Collaborating Contact

Chaitra Gopalappa

chaitrag@umass.com

Research lab

Disease Modeling Lab

Objective: Develop new mathematical and computational methods necessary to analyze complex decisions related to public policy

Collaborators

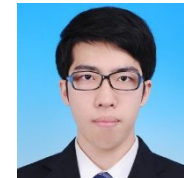
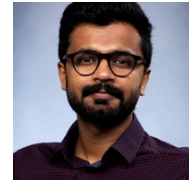
- CDC - U.S. Centers for Disease Control and Prevention
- WHO- World Health Organization
- IARC- International Agency for Research on Cancer
- PAHO- Pan-American Health Organization
- UNAIDS – Joint United Nations Agencies Programmed on HIV/AIDS
- UNICEF - United Nations International Children's Emergency Fund

Funded By

- National Institutes of Health
- National Science Foundation
- World Health Organization



Graduate and undergraduate students



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The Commonwealth's Flagship Campus