# Agent-based models

## MATH 8xyz – Lecture 26

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# Outline

- What are agent-based models (ABM)
- When to use ABM
- When not to use ABM
- Some examples
- Antibiotic resistance in hospitals
- Effectiveness of contact tracing
- Contacts during Hajj

# What are agent-based models (ABM)

- Early in the life of these models, they were called IBM (individual-based models)
- Over the years, a "philosophical" distinction has emerged:
  - IBM are mathematical models that consider individuals as the units; e.g., DTMC, CTMC, branching processes, etc.
  - ABM are computational models whose study is, for the most part, only possible numerically

# ABM vs Network models

► Network models endow vertices with simple systems and couple them through graphs ► Can be ABM, but some networks can also be studied analytically ► Not enough time to go into this, a very interesting subject!

# When to use ABM

► ABM are very useful to decipher contact processes ► Classic mathematical models capture contact by using approximations of what contact could be like ► Classic models allow some flexibility (see section about incidence functions in Lecture 02) but they remain limited ► ABM can model actual trajectories of individuals, so given a definition of what a contact is (how close do you need to be for a contact to take place), can count them efficaciously

# ABM are very useful to understand behavioural responses

- ABM are very useful to understand behavioural responses

# When not to use ABM

► As with all tools, beware! ► There is a law of large numbers effects happening often: if you have many units, unless some emergent behaviour arises, you get the same results using ODEs...

# With this specific tool, beware!

- There is a certain tendency in CS people to create yet another system and seek adoption by users

# Some examples

► Antibiotic resistance in hospitals ► Effectiveness of contact tracing ► Contacts during Hajj

# Antibiotic resistance in hospitals

- D'Agata, Magal, Olivier, Ruand & Webb. Modeling antibiotic resistance in hospitals: The impact of minimizing treatment duration, Journal of Theoretical Biology (2007)

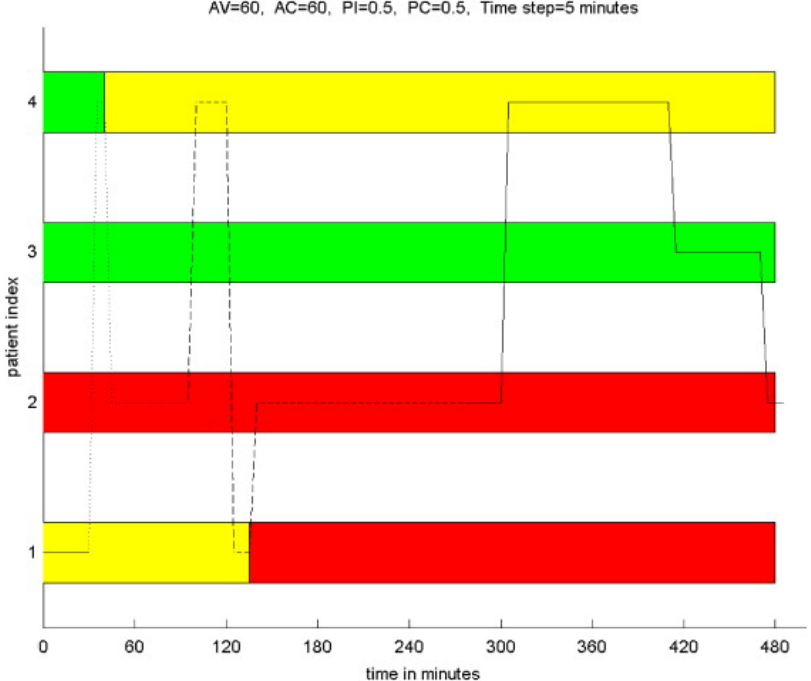
# An IBM that's almost an ABM

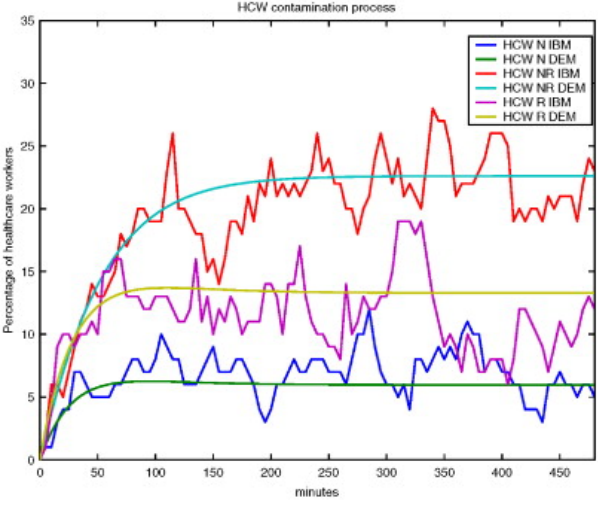
► This work is a good illustration of the "cultural proximity" between IBM and ABM ► Model is stochastic and individual-based, in good enough form that approximating ODE can be derived ► Allows for very specific tracking of the status of individuals through the process (almost an ABM in this sense)

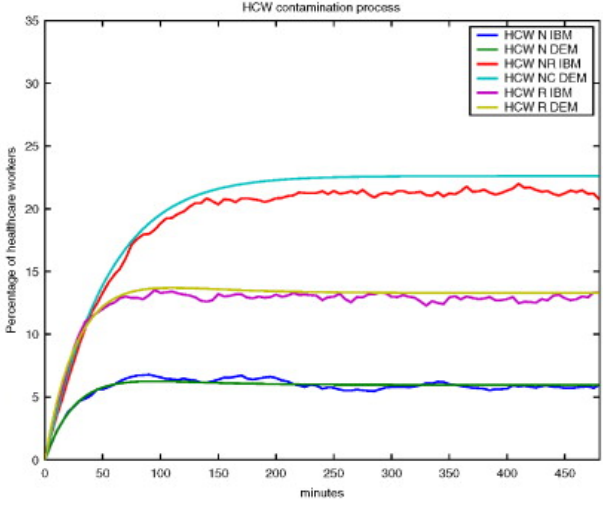
# The setup

- Three processes:
  1. admission and exit of patients
  2. infection of patients by HCW (health care workers)
  3. contamination of HCW by patients

- Contamination of HCW is "transient": they are carriers, if they wash their hands properly, they become OK - Each day has 3 shifts of 8h for HCW - Patients are put in contact by visits of HCW - Rules for contaminations per unit time


AV=60, AC=60, PI=0.5, PC=0.5, Time step=5 minutes
patient index
4
3
2
1
0
60
120
180
240
300
360
420
480
time in minutes


HCW contamination process
HCW N IBM
HCW N DEM
HCW NR IBM
HCW NR DEM
HCW R IBM
HCW R DEM
Percentage of healthcare workers
minutes
0
5
10
15
20
25
30
35
0
50
100
150
200
250
300
350
400
450

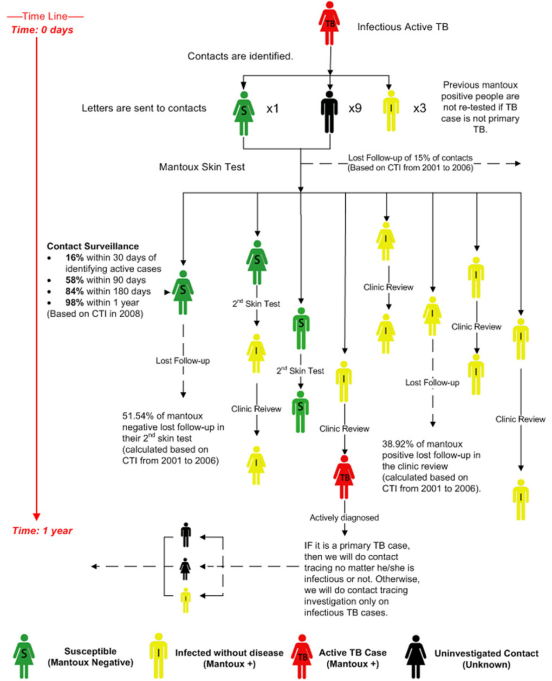

HCW contamination process
HCW N IBM
HCW N DEM
HCW NR IBM
HCW NC DEM
HCW R IBM
HCW R DEM
Percentage of healthcare workers
minutes
0
5
10
15
20
25
30
35
0
50
100
150
200
250
300
350
400
450

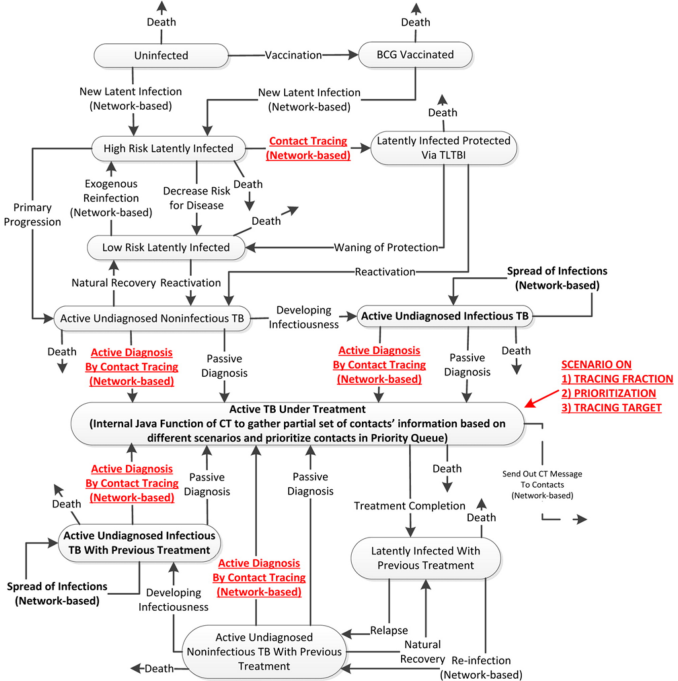
# Effectiveness of contact tracing

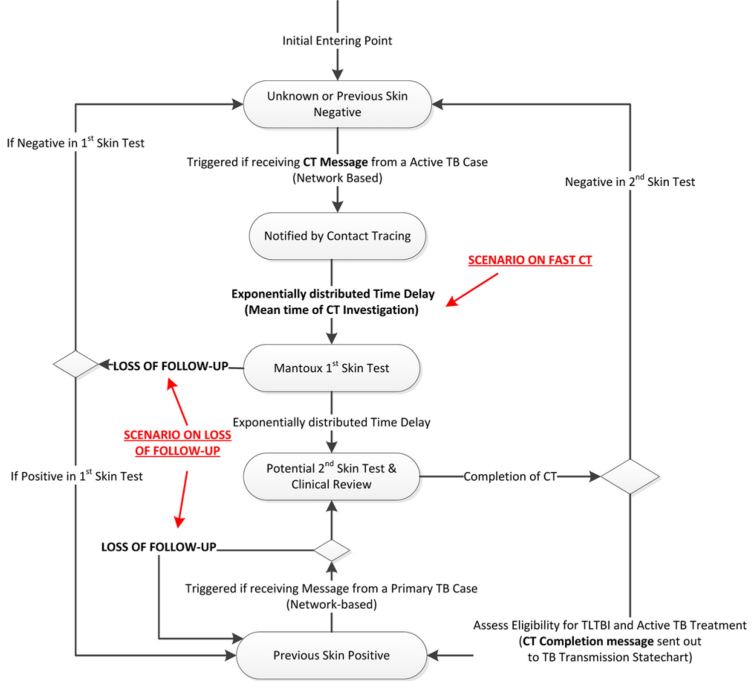
- Tian, Osgood, Al-Azem & Hoeppner. Evaluating the Effectiveness of Contact Tracing on Tuberculosis Outcomes in Saskatchewan Using Individual-Based Modeling, Health Education & Behavior (2013)

# Evaluation of contact tracing in TB

- Evaluation of contact tracing in TB

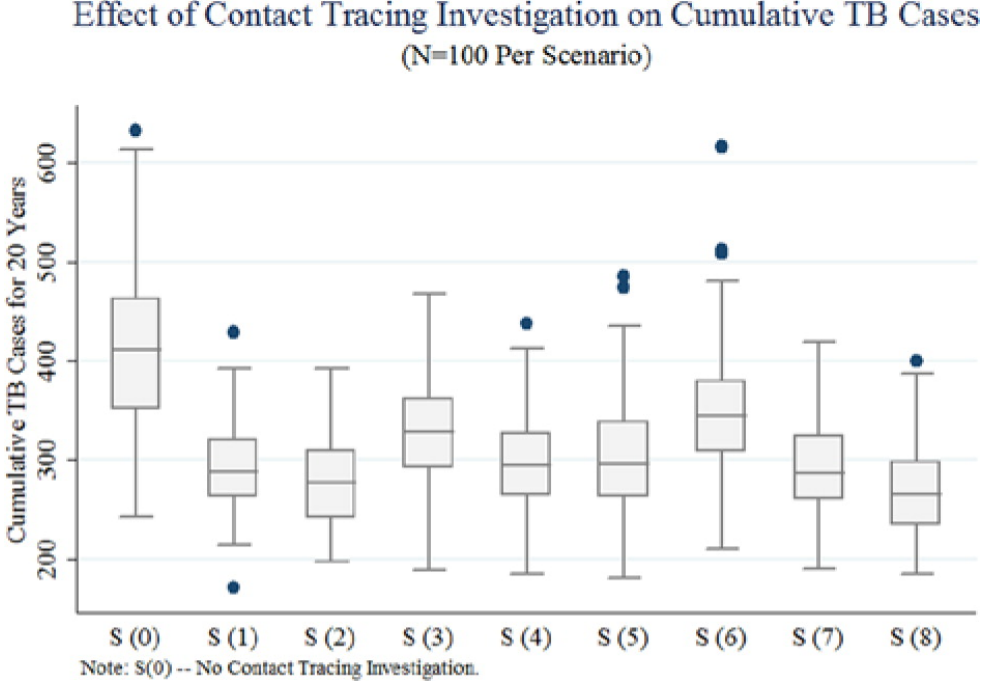

Time Line
Time: 0 days
Infectious Active TB
Contacts are identified.
Letters are sent to contacts
x1
x9
x3
Previous mantoux positive people are not re-tested if TB case is not primary TB.
Mantoux Skin Test
Lost Follow-up of 15% of contacts (Based on CTI from 2001 to 2006)
Contact Surveillance
16% within 30 days of identifying active cases
58% within 90 days
84% within 180 days
98% within 1 year
(Based on CTI in 2008)
2nd Skin Test
Lost Follow-up
Clinic Review
51.54% of mantoux negative lost follow-up in their 2nd skin test (calculated based on CTI from 2001 to 2006)
38.92% of mantoux positive lost follow-up in the clinic review (calculated based on CTI from 2001 to 2006).
Actively diagnosed
IF it is a primary TB case, then we will do contact tracing no matter he/she is infectious or not. Otherwise, we will do contact tracing investigation only on infectious TB cases.
Time: 1 year
Susceptible (Mantoux Negative)
Infected without disease (Mantoux +)
Active TB Case (Mantoux +)
Uninvestigated Contact (Unknown)


Death
Death
Uninfected
Vaccination
BCG Vaccinated
New Latent Infection (Network-based)
New Latent Infection (Network-based)
Death
High Risk Latently Infected
Contact Tracing (Network-based)
Latently Infected Protected Via TLTBI
Exogenous Reinfection (Network-based)
Decrease Risk for Disease
Death
Primary Progression
Death
Low Risk Latently Infected
Waning of Protection
Natural Recovery
Reactivation
Reactivation
Spread of Infections (Network-based)
Active Undiagnosed Noninfectious TB
Developing Infectiousness
Active Undiagnosed Infectious TB
Death
Active Diagnosis By Contact Tracing (Network-based)
Passive Diagnosis
Active Diagnosis By Contact Tracing (Network-based)
Passive Diagnosis
Death
SCENARIO ON
1) TRACING FRACTION
2) PRIORITIZATION
3) TRACING TARGET
Active TB Under Treatment
(Internal Java Function of CT to gather partial set of contacts' information based on different scenarios and prioritize contacts in Priority Queue)
Active Diagnosis By Contact Tracing (Network-based)
Passive Diagnosis
Passive Diagnosis
Death
Send Out CT Message To Contacts (Network-based)
Death
Treatment Completion
Death
Active Undiagnosed Infectious TB With Previous Treatment
Latently Infected With Previous Treatment
Spread of Infections (Network-based)
Developing Infectiousness
Active Diagnosis By Contact Tracing (Network-based)
Relapse
Natural Recovery
Re-infection (Network-based)
Active Undiagnosed Noninfectious TB With Previous Treatment
Death


Initial Entering Point
Unknown or Previous Skin Negative
If Negative in 1st Skin Test
Triggered if receiving CT Message from a Active TB Case (Network Based)
Negative in 2nd Skin Test
Notified by Contact Tracing
SCENARIO ON FAST CT
Exponentially distributed Time Delay (Mean time of CT Investigation)
LOSS OF FOLLOW-UP
Mantoux 1st Skin Test
Exponentially distributed Time Delay
SCENARIO ON LOSS OF FOLLOW-UP
If Positive in 1st Skin Test
Potential 2nd Skin Test & Clinical Review
Completion of CT
LOSS OF FOLLOW-UP
Triggered if receiving Message from a Primary TB Case (Network-based)
Assess Eligibility for TLTBI and Active TB Treatment (CT Completion message sent out to TB Transmission Statechart)
Previous Skin Positive

# Scenarios

► They can then formulate scenarios Scenario illustration ► They then run these scenarios and compare results


Effect of Contact Tracing Investigation on Cumulative TB Cases
(N=100 Per Scenario)
Cumulative TB Cases for 20 Years
200
300
400
500
600
S (0)
S (1)
S (2)
S (3)
S (4)
S (5)
S (6)
S (7)
S (8)
Note: S(0) -- No Contact Tracing Investigation.

# Contacts during Hajj

- Tofighi, Asgary, Tofighi, Najafabadi, Arino, Amiche, Rahman, McCarthy, Bragazzi, Thommes, Coudeville, Grunnill, Bourouiba and Wu. Estimating Social Contacts in Mass Gatherings for Disease Outbreak Prevention and Management (Case of Hajj Pilgrimage), Tropical Diseases, Travel Medicine and Vaccines

# Contacts during Hajj

► In a mass gathering event like Hajj, lots of people come together originating from many countries ► If propagation occurs during the event, this has the capacity to spread infection far and wide when individuals (pilgrims here) return home ► Contacts during part of the event are really specific in their configuration

# The setup

► Word of warning: I am quite fuzzy on the specifics :) ► Pilgrims enter Masjid al-Haram mosque through several gates ► Proceed to Mataaf (area around Kaaba), circle the Kaaba 7 times counterclockwise (process is the Tawaf) ► Then do seven trips between Safa and Marwah (process is the Sa'ee)

# Tawaf in pre-COVID-19 times

- YouTube: Tawaf in pre-COVID-19 times

# Tawaf - Socially distanced version

- YouTube: Tawaf - Socially distanced version

# Sa’ee in pre-COVID-19 times

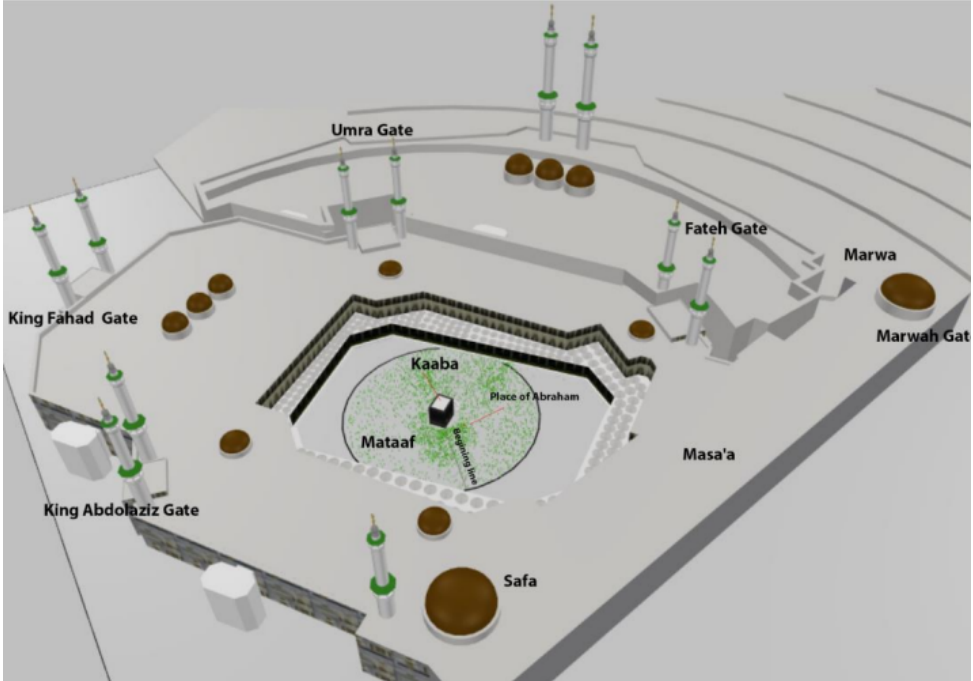
- YouTube: Sa’ee in pre-COVID-19 times

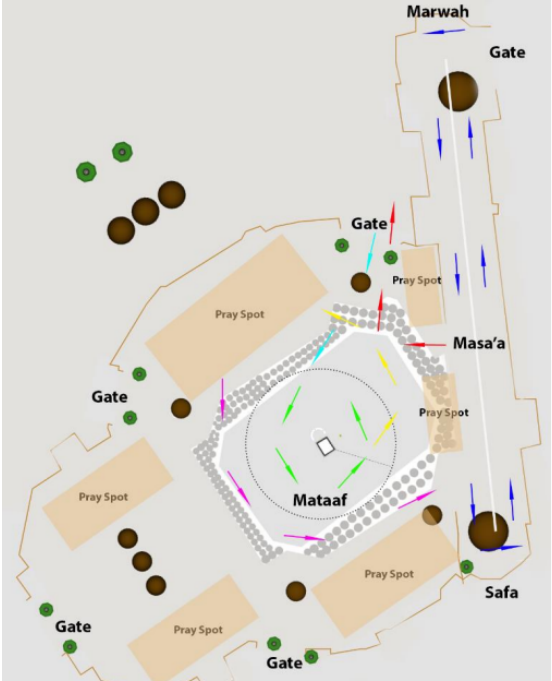
# Sa’ee - Socially distanced version

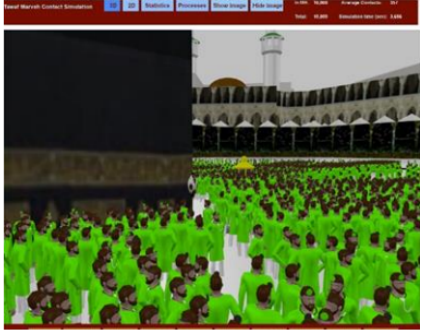
- YouTube: Sa’ee - Socially distanced version

# Crowd dynamics

► Typically high density crowds ► Very specific mixing patterns ► Opportunities for transmission are very high ► However, control mechanisms are also available ► Understanding contact patterns and frequency would help


Umra Gate
Fateh Gate
Marwa
King Fahad Gate
Marwah Gat
Kaaba
Place of Abraham
Mataaf
Masa'a
King Abdolaziz Gate
Safa


Marwah
Gate
Gate
Pray Spot
Pray Spot
Masa'a
Gate
Pray Spot
Pray Spot
Mataaf
Pray Spot
Safa
Gate
Pray Spot
Gate



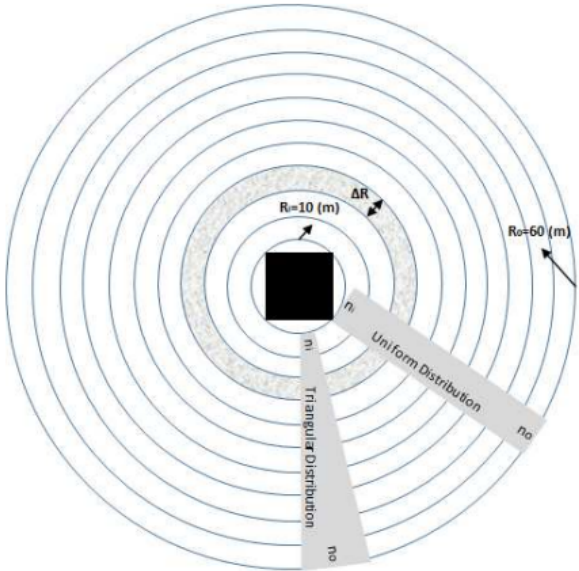



Figure 5. The general setting of Tawaf and pilgrim distribution in social distancing

# Simulation video 1

- YouTube: Hajj simulation 1

# Simulation video 2

- YouTube: Hajj simulation 2

# Bibliography I