Agent-based models
MATH 8xyz – Lecture 26

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Winter 20XX

Outline

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

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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
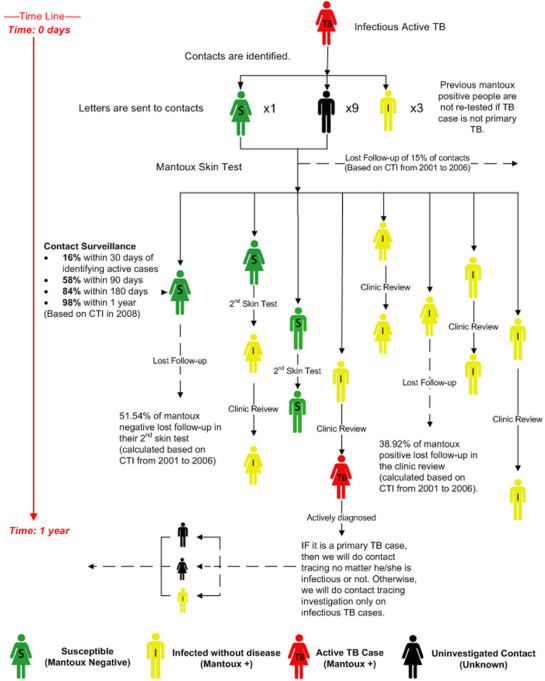
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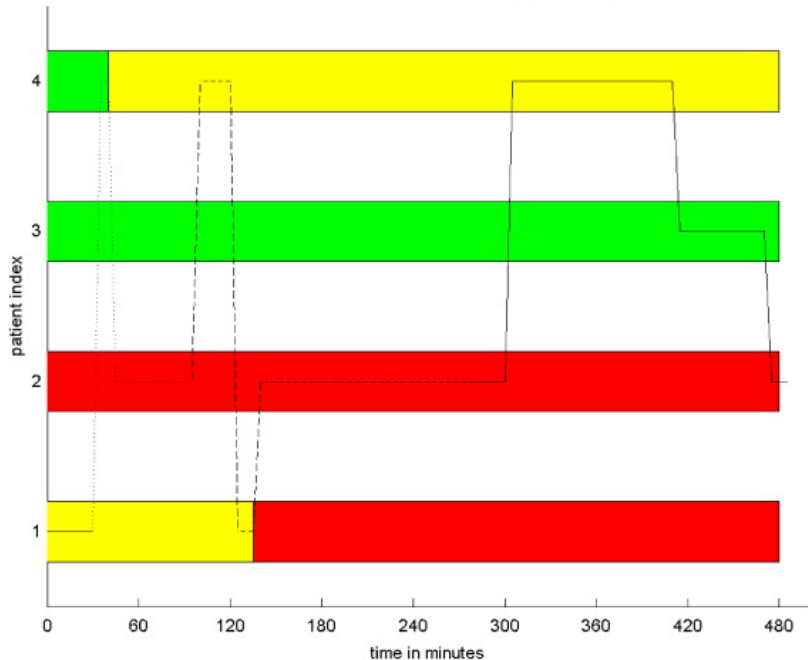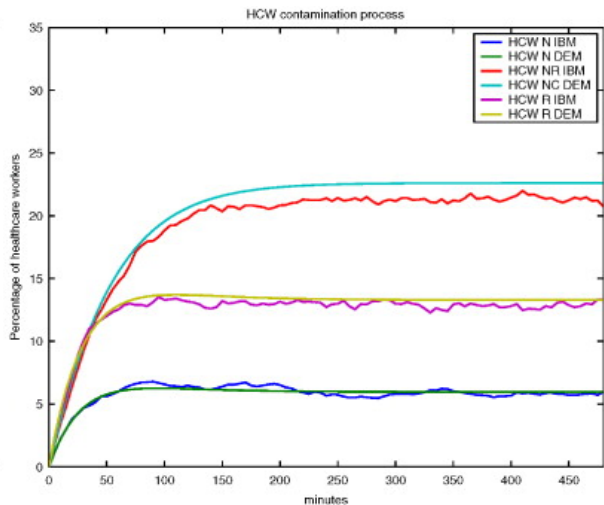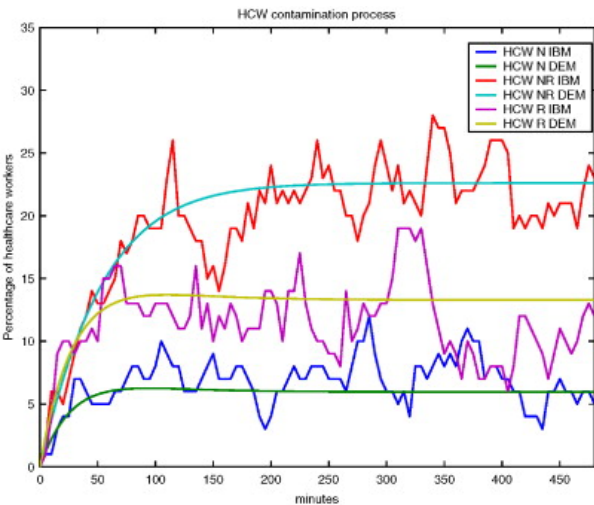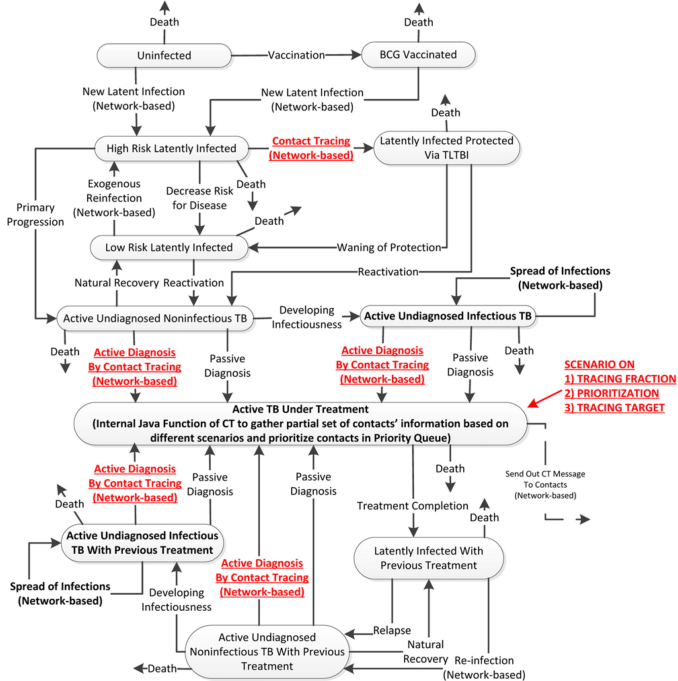
Effectiveness of contact tracing

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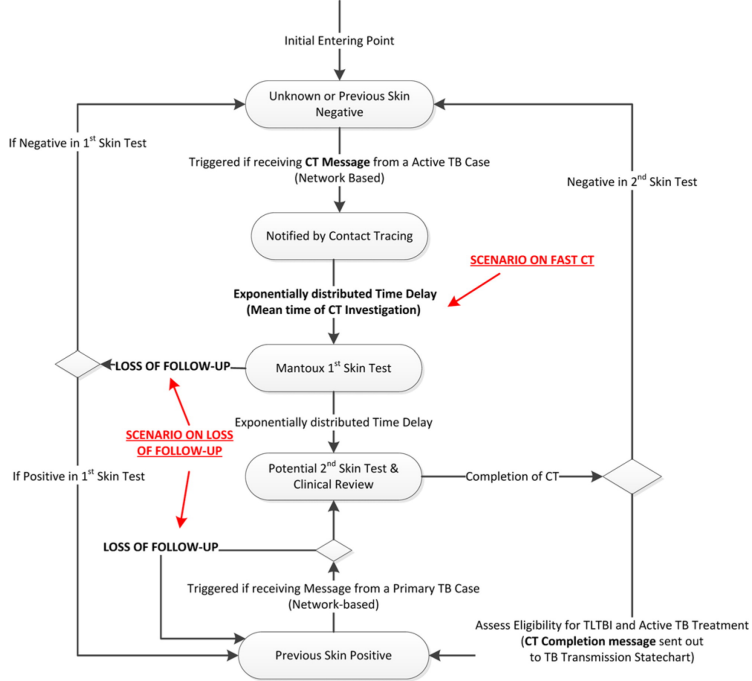
Evaluation of contact tracing in TB

▶ 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

Clinic Review

Clinic Review

Clinic Review

Lost Follow-up

2nd Skin Test

Clinic Review

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)

Clinic Reivew

Clinic Review

38.92% of mantoux positive lost follow-up in the clinic review (calculated based on CTI from 2001 to 2006).

Actively diagnosed

Time: 1 year

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.

Susceptible (Mantoux Negative)

Infected without disease (Mantoux +)

Active TB Case (Mantoux +)
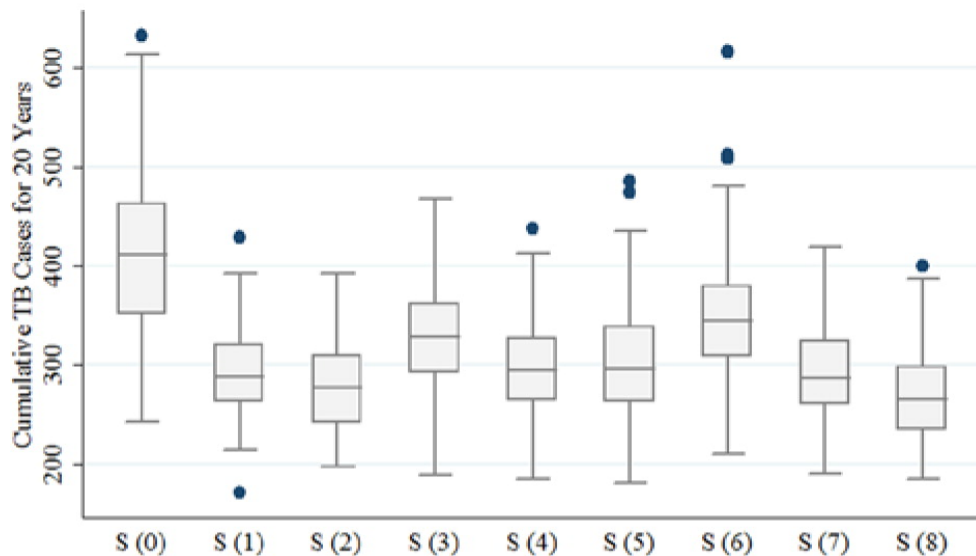
Uninvestigated Contact (Unknown)

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

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

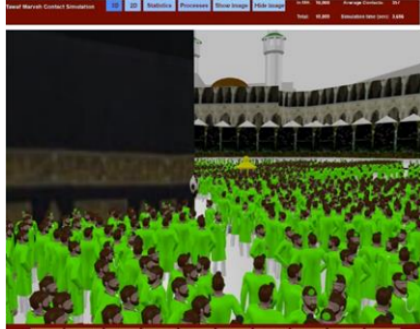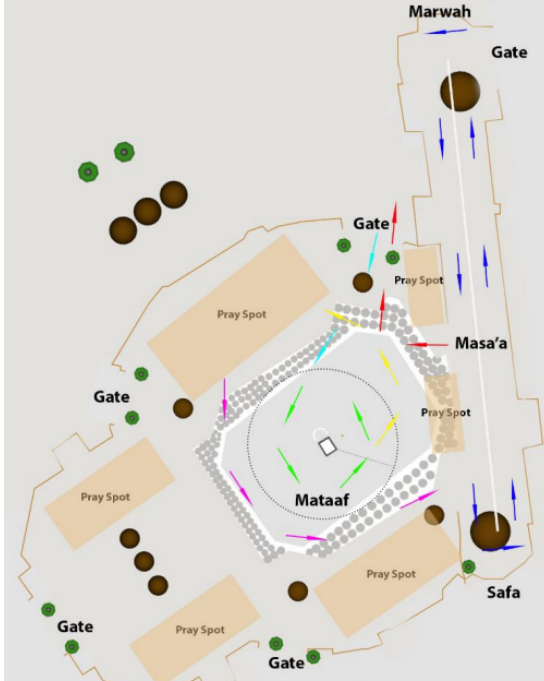- ▶ YouTube: Sa'ee in pre-COVID-19 times

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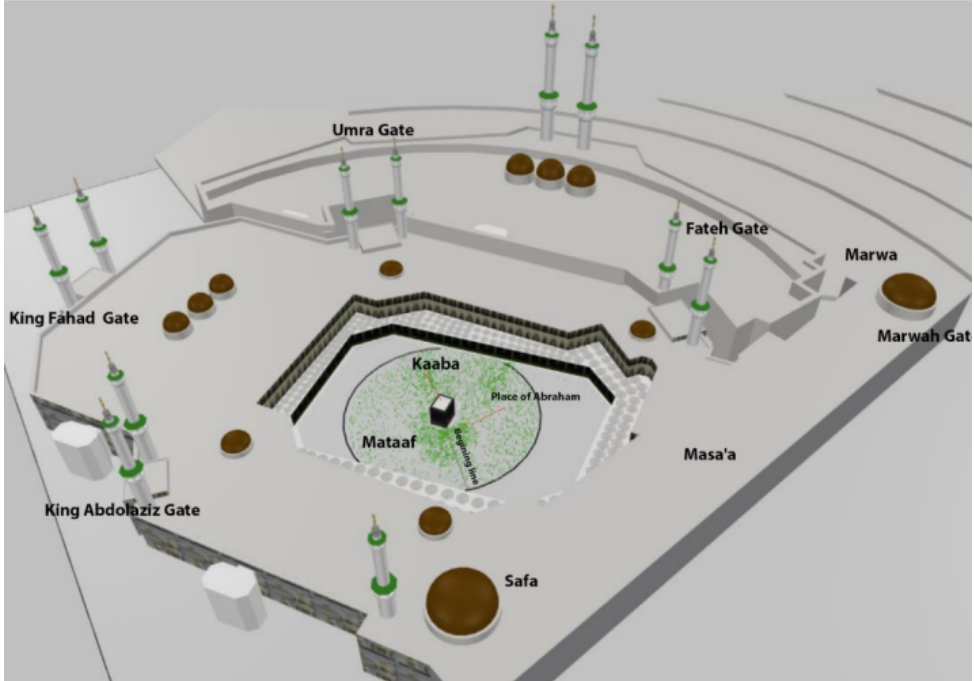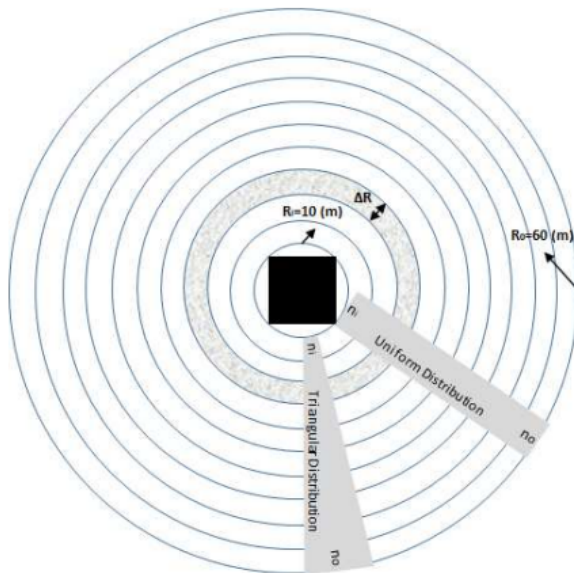
Figure 5. The general setting of Tawaf and pilgrim distribution in social distancing

Simulation video 1

- YouTube: Hajj simulation 1

Simulation video 2

▶ YouTube: Hajj simulation 2

Bibliography I