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Agent-based and network models

Lecture 06

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September 2023

Agent-based models (ABM)

Network models

Agent-based models (ABM)

- What are agent-based models

- When to use ABM

- When not to use ABM

- Some examples

Network models

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ABM \neq IBM

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

Agent-based models (ABM)

What are agent-based models

When to use ABM

When not to use ABM

Some examples

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 X 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

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Some examples

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

Agent-based models (ABM)

What are agent-based models

When to use ABM

When not to use ABM

Some examples

Antibiotic resistance in hospitals

D'Agata, Magal, Olivier, Ruan & 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

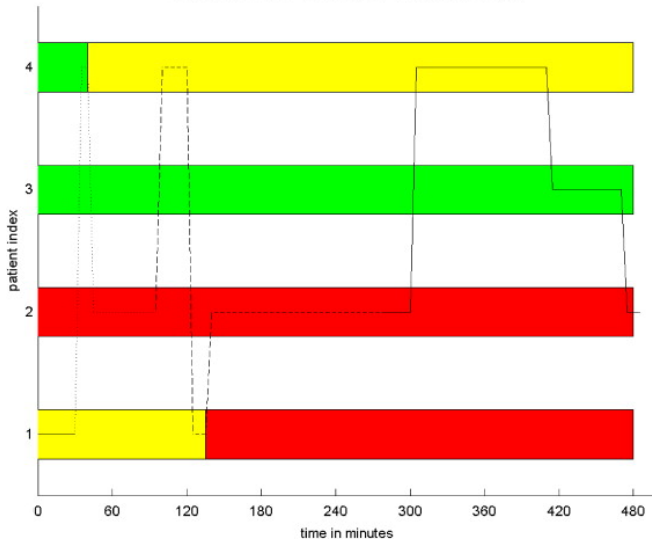
Contamination of HCW is “transient”: they are carriers, if they wash their hands properly, they become OK

Each day has 3 shifts of 8h for HCW

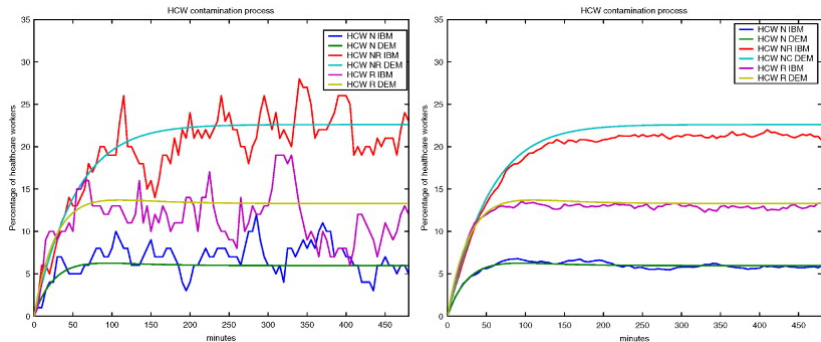
Patients are put in contact by visits of HCW

Rules for contaminations per unit time

AV=60, AC=60, PI=0.5, PC=0.5, Time step=5 minutes



Patient-HCW contact diagram for four patients and one HCW during one shift. Patient status: uninfected (green), infected with the non-resistant strain (yellow), infected with the resistant strain (red). HCW status: uncontaminated (plain), contaminated with the non-resistant strain (dotted), contaminated with the resistant strain (dashed)

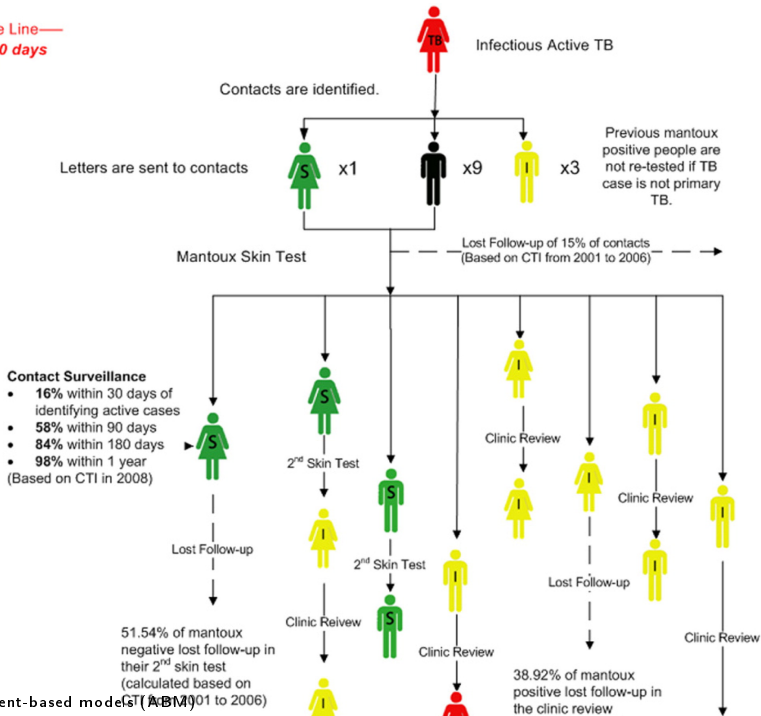


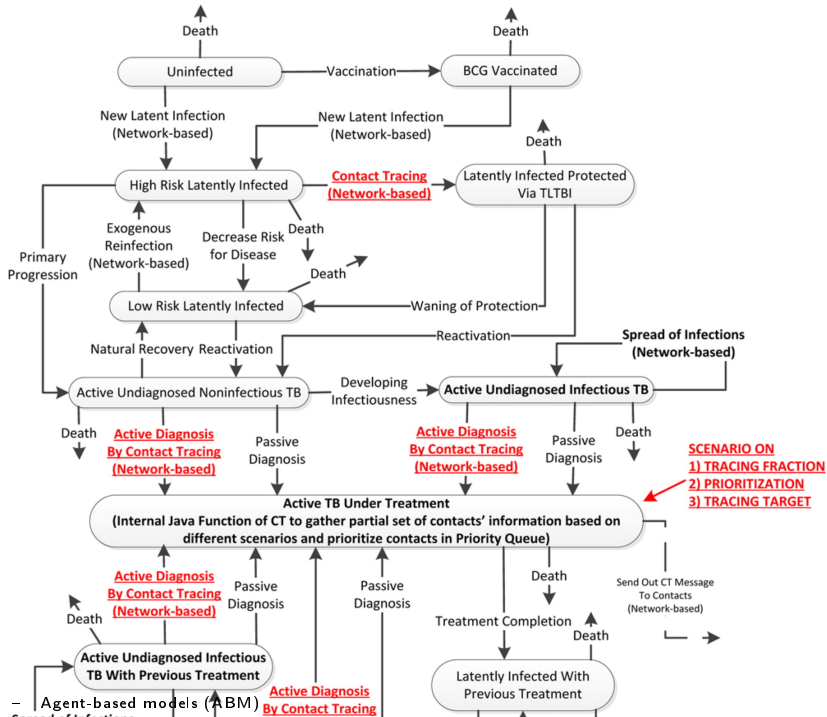
The left (respectively the right) figure corresponds to 1 trajectory (respectively the average over 80 trajectories) of the IBM during one shift, with no exit and admission of patients, and no changes in the infection status of patients

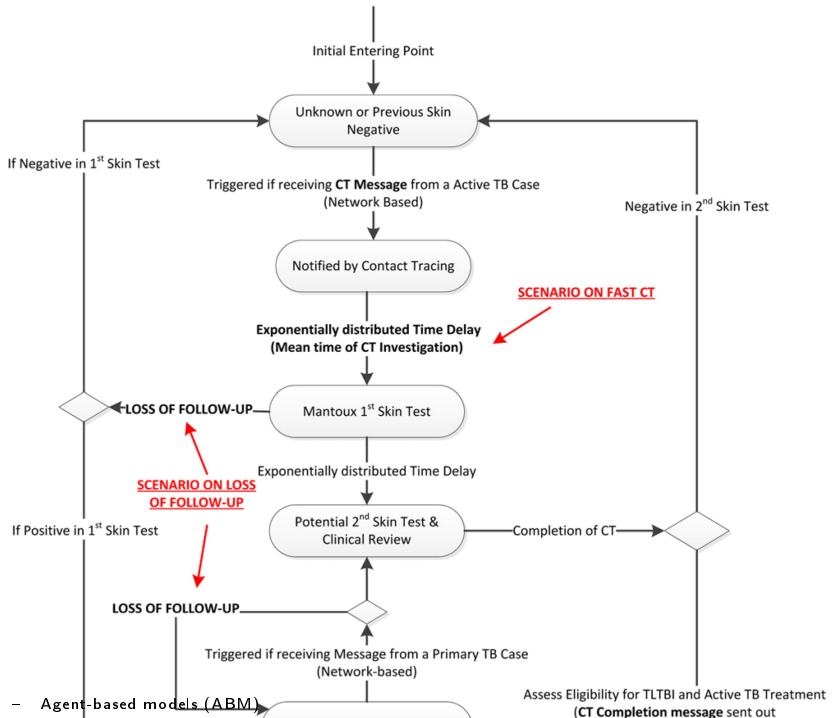
Effectiveness of contact tracing in TB

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

—Time Line—
Time: 0 days







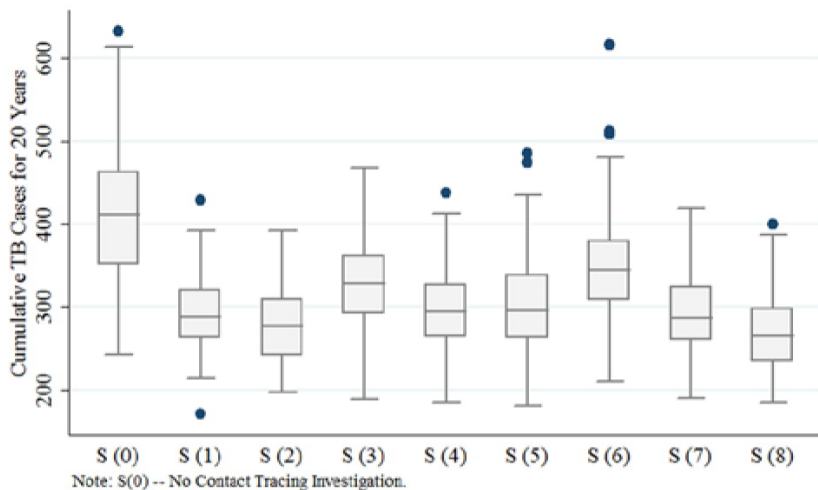
They can then formulate scenarios

Table 1. Scenario Definitions.

ID	Contact Tracing	Tracing Target	Loss to Follow-Up (%)	Priority	Tracing Fraction (%)
S0	Disabled	NA	NA	NA	NA
S1	Enabled	Infectious and primary tuberculosis	30-40	None	90
S2	Enabled	Infectious and primary tuberculosis	10	None	90
S3	Enabled	Infectious and primary tuberculosis	10	None	45
S4	Enabled	Infectious and primary tuberculosis	10	Age	45
S5	Enabled	Infectious and primary tuberculosis	10	Ethnicity	45
S6	Enabled	Infectious and primary tuberculosis	10	Reported times	45
S7	Enabled	Infectious and primary tuberculosis	10	Age and ethnicity	45
S8	Enabled	Infectious and primary tuberculosis	10	None	90 (Fast contact tracing)

They then run these scenarios and compare results

Effect of Contact Tracing Investigation on Cumulative TB Cases (N=100 Per Scenario)



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

So 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*)

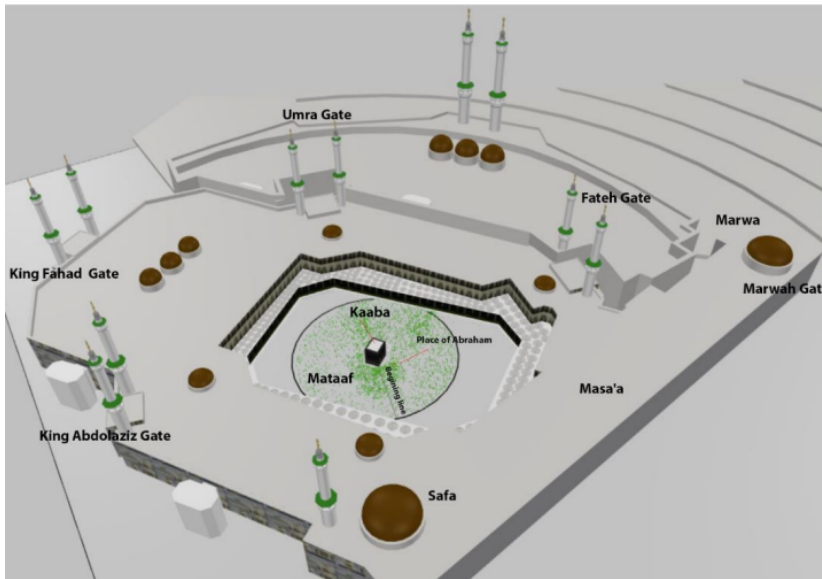
As you can gather from this:

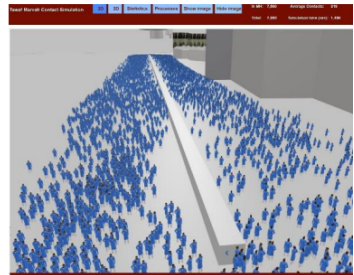
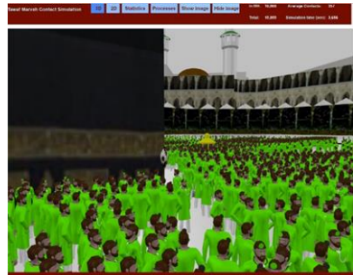
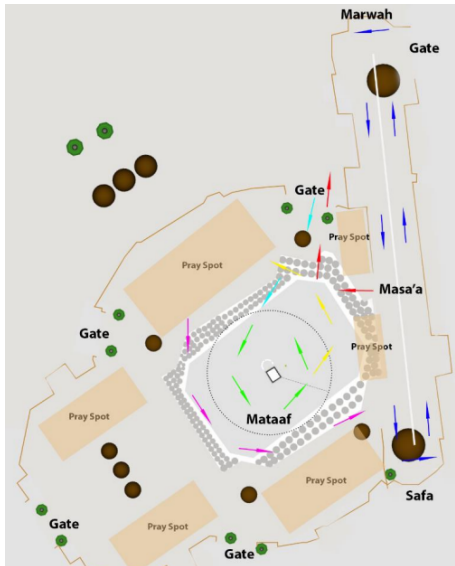
- ▶ Typically high density crowds
- ▶ Very specific mixing patterns

Opportunities for transmission are very high

However, control mechanisms are also available

⇒ understanding contact patterns and frequency would help





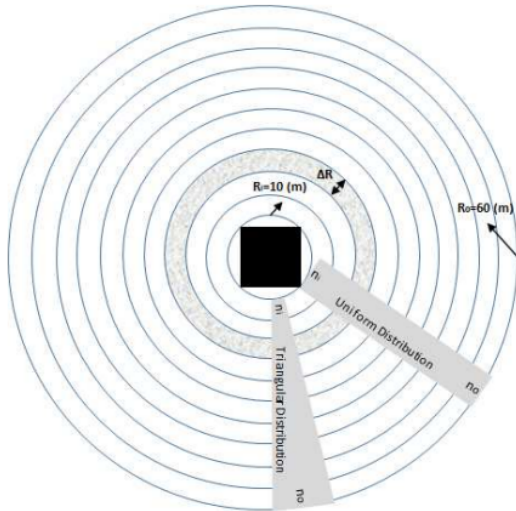


Figure 5. The general setting of Tawaf and pilgrim distribution in social distancing

Agent-based models (ABM)

Network models

Why use network models

Cadre général des modèles en réseaux

Network models

Why use network models

Cadre général des modèles en réseaux

Understand contact processes

Classic models allow a certain degree of flexibility, for instance by using specific incidence functions or group models, but this remains limited and an approximation

Like ABM, network models are used to make more realistic descriptions of the transmission of pathogens

Human life is organised in networks

Family

Friends

Workplace

...

Social network theory has been used for years, e.g., in a professional context (e.g., how to fluidify interactions within a company)

Network models

Why use network models

Cadre général des modèles en réseaux

Jenness SM, Goodreau SM and Morris M. EpiModel: An R Package for Mathematical Modeling of Infectious Disease over Networks. *Journal of Statistical Software*. 2018; 84(8): 1-47

EpiModel

R library providing tools to simulate and analyse network epidemiological models

Provides two types of approaches

- ▶ Simulation of ODE compartmental models (not so interesting)
- ▶ Simulation of network models

Their website has several useful tutorials

Part of the statnet meta-library