Mathematical models in outbreak response

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Lukas Richter

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Background

Outbreaks:
Influenza, 2009
MERS-Cov (Middle-East Respiratory Syndrome)
Ebola, West Africa, DRC
Zika Virus, Brazil

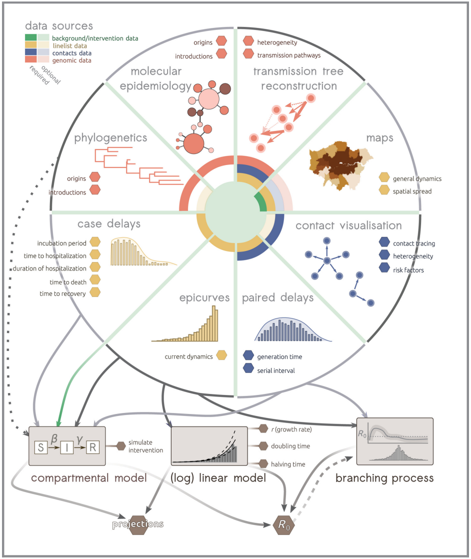
Objective/Goal

during outbreak:
exploit all data
inform response team in real time
in general (also non outbreak situation)
allow evidence based decisions
compare/assess interventions
policy evaluation (before/after in), vaccine programmes
track of WHO targets (HIV, HCV)

Types of models

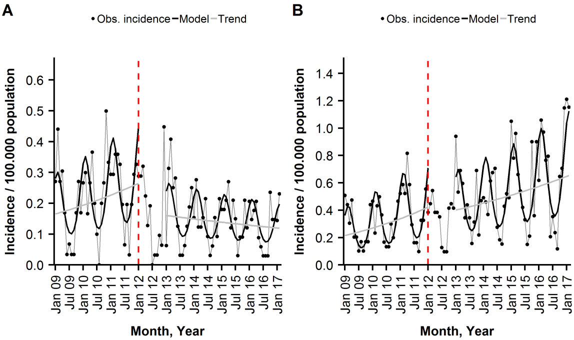
dynamic, mathematical (SIR)
statistical (e.g. Poisson regression)
Bayesian statistics
spacial stats/models
-> visualise outcome

Example of outbreak analytics workflow.



IPD

Figure: Monthly incidence of (A) PCV10 ST-IPD and (B) non-PCV10 ex ST 6A-/19A-IPD, among the ≥50 years old, observed and modelled by a segmented negative binominal regression, Austria, January 2009-February 2017, shown are overall and seasonal trends.



Richter et al. 2019

IPD2

Model

$$
\begin{aligned}
\log\left(Y_t\right) = & \log\left(pop_t\right) + \beta_0 + \beta_1\, t + \beta_2\, \sin\left(\frac{2\pi t}{12}\right) \\
& + \beta_3\, \cos\left(\frac{2\pi t}{12}\right) + \beta_5\, (t - t_0)^+ \\
& + \mathbb{1}_{t-t_0>0}\left[\beta_4 + \beta_6\, \sin\left(\frac{2\pi t}{12}\right) + \beta_7\, \cos\left(\frac{2\pi t}{12}\right)\right]
\end{aligned}
$$

with

$$
(x)^+ = \begin{cases} x, & \text{if } x > 0, \\ 0, & \text{otherwise.} \end{cases}
$$

Zika [1]

Humans:

$$\frac{dS_h}{dt} = \mu_h N_h - \frac{\beta_h b}{N_h} S_h I_v - \mu_h S_h$$
$$\frac{dI_h}{dt} = \frac{\beta_h b}{N_h} S_h I_v - (\gamma_h + \mu_h) I_h$$
$$\frac{dR_h}{dt} = \gamma_h I_h - \mu_h I_h$$

Vectors:

$$\frac{dS_v}{dt} = \mu_v N_v - \frac{\beta_v b}{N_h} I_h S_v - \mu_v S_v$$
$$\frac{dE_v}{dt} = \frac{\beta_v b}{N_h} I_h S_v - (\delta + \mu_v) E_v$$
$$\frac{dI_v}{dt} = \delta E_v - \mu_v I_v$$

Zika2

```
Lv       <-          # life span of mosquitos (in days)
Lh       <-          # life span of humans (in days)
Iph      <-          # Infectious period in humans (in days)
IP       <-          # Infectious period in vectors (in days)
EIP      <-          # Extrinsic incubation period in adult mosquitos
muv      <-          # mortality of mosquitos
muh      <-          # mortality of humans
gamma    <-          # recovery rate in humans
delta    <-          # extrinsic incubation rate
b        <-          # Biting Rate
betah    <-          # Probability of transmission from vector to host
betav    <-          # Probability of transmission from host to vector
Nh       <-          # Number of humans (Population of Cali 2.4 million)
m        <-          # Vector to human ratio
Nv       <-          # Number of vectors
R0       <-          # Reproductive number
b        <-          sqrt((R0 ^2 * muv*(muv+delta) * (muh+gamma)) /
                     (m * betah * betav * delta)) # biting rate

TIME     <-          # Number of years to run the simulation for
```

Zika3

S_h: Susceptible Humans
I_h : Infected/Infectious humans
R_h: Humans recovered from infection (with lifelong immunity)
S_v: Susceptible vectors
E_v: Exposed vectors

GO ??

a

Conclusion

Here comes the conclusion

Thank you!
Any questions?

[1] Neil M. Ferguson et al. "Countering the Zika Epidemic in Latin America". In: *Science* 353.6297 (July 22, 2016), pp. 353–354. ISSN: 0036-8075, 1095-9203. DOI: 10.1126/science.aag0219. pmid: 27417493. URL: https://science.sciencemag.org/content/353/6297/353 (visited on 06/19/2019).

[2] Polonsky Jonathan A. et al. "Outbreak Analytics: A Developing Data Science for Informing the Response to Emerging Pathogens". In: *Philosophical Transactions of the Royal Society B: Biological Sciences* 374.1776 (July 8, 2019), p. 20180276. DOI: 10.1098/rstb.2018.0276. URL: https://royalsocietypublishing.org/doi/10.1098/rstb.2018.0276 (visited on 06/18/2019).

[3] Lukas Richter et al. "Invasive Pneumococcal Diseases in Children and Adults before and after Introduction of the 10-Valent Pneumococcal Conjugate Vaccine into the Austrian National Immunization Program". In: *PloS One* 14.1 (2019), e0210081. ISSN: 1932-6203. DOI: 10.1371/journal.pone.0210081. pmid: 30629620.