Maths vs. COVID-19

Julia Gog
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1. Introductions

• Me
• Research interests BC (before COVID-19)
• Then COVID-19 happened
My “normal” jobs:
Professor of Mathematical Biology, DAMTP, University of Cambridge
David N. Moore Fellow in Mathematics, Queens’ College, Cambridge

Centre for Mathematical Sciences, University of Cambridge
Queens’ College, Cambridge
Multiple cocirculating strains models for evolving viruses

Patterns of spatial transmission Influenza pandemic 2009 in the US

Signals - virus bioinformatics

Contagion! – the BBC pandemic Citizen science on UK mixing and movement

Broadly, using mathematics to understand infectious disease dynamics
2. Maths of epidemics... applied to COVID-19

- Roles of modelling
- What we can learn from classic results
- Building insight and intuition
Roles of modelling for fighting COVID-19

- Specific predictions (forecasting)
- Exploratory scenarios (“what if we do this intervention?”)
- Understanding drivers behind observed patterns (see below)
- Building intuition and useful language (see next 2 slides)

With few introductions, expect heterogeneity in timing:
Epidemic upswing in some regions weeks before others

With many introductions, expect synchrony and spikier:
Trajectory similar in different regions, only 1-2 week lags

(Observed patterns emerging at the time were consistent with many introductions.)

(Extract from report presented to SPI-M 2nd March 2020, using insights from the spatial model for the UK calibrated by the BBC pandemic project, adapted for COVID-19)
Classic SIR results – valuable for building robust insight

What happens when we intervene to reduce transmission (e.g. a lockdown)? Depends on strength of transmission reduction, when the intervention is applied.

Coloured lines give different trigger values for application of intervention (after X% have been infected), and assume intervention continues to end of epidemic. Horizontal axis gives strength of intervention (0 stops all transmission, 1 does nothing). Vertical axis is (left) peak prevalence or (right) final size relative to an unmitigated epidemic. R=3 for this plot.

Crux of the maths: SIR has a constant of motion.

\[
\begin{align*}
\dot{S} &= -rSI \\
\dot{I} &= +rSI - I,
\end{align*}
\]

\[
F(S, I) = S + I - r^{-1} \log S.
\]
Some of the things we can see from this:
- Need intervention early and strong
- If intervention weak: can bring down peak more than total size (c.f. “flatten the curve”)
- If intervention strong: even more important to apply early

This simple approach should not replace models including more details, but if predictions from more complex models deviate substantially from those shown here, the factors behind that difference should be identified.

Written up here with more discussion on use in this context:
https://doi.org/10.1098/rstb.2020.0263
Not always true that more elaborate models are better.

For yielding insights and building intuition, simple is good:

\[ y(n) = aR^n \]

- **Cases after** \( n \) infection generations
- **Multiplicative constant**
- **Most famous parameter of 2020**

\[ R = 1.2, \ a = 1000 \]
Suppose this represents hospitalisations. What happens if the parameters change?

\[ y(n) = aR^n \]

In red:
- boost \( a \) by 50%

In blue:
- boost \( R \) by 50%

### Examples

- \( R = 1.8, a = 1000 \)
- \( R = 1.2, a = 1500 \)
- \( R = 1.2, a = 1000 \)

50% more transmissible
50% higher severity
3. The scientific response to modelling COVID-19

• Modellers are go!
• JUNIPER and friends
• Some of the topics we have been addressing
COVID-19 patents admitted to hospital UK by day
Source: UK Government Coronavirus Dashboard
A call to wider maths and physics research community

Amplify signal, not noise (e.g. reviews, sharing key papers to colleagues)

Communicate to public (dispel misinformation, comment on what models can and can’t do)

Contribute to research (join up with larger efforts, start from state of the art)

How you can help with COVID-19 modelling

Julia R. Gog

Many physicists want to use their mathematical modelling skills to study the COVID-19 pandemic. Julia Gog, a mathematical epidemiologist, explains some ways to contribute.

While the COVID-19 pandemic continues its global devastation, the instinctive reaction from scientists is "how can we help?" I will try to answer this in general terms for colleagues with expertise in mathematics and modelling, but who may have little or no prior experience with infectious disease modelling.

Clearly, the set of things that would not help includes rediscovering results that disease modellers have known for decades — or for more than a century in the case of some things circulating now as if they are new ideas. Nor would it help to send your first attempts at running the classic susceptible–infectious–recovered (SIR) epidemic model to your local epidemiologist, who already has an e-mail folder full of 'my_first_epidemic.xls' from well-meaning friends and also a small outbreak of plots from correspondents who have just discovered the log-scale option. But, then, the question is how to usefully contribute. Here are some immediate options.

Signal to noise
Rather than adding noise, amplify the signal. The numerical examples cited above are straightforward: compare current values for the number of infected cases with the early predictions, for instance. However, as the pandemic continues we should have access to similar real-time data for other countries. Communicating the public
The world wants to know what the science says about their decisions, but there is great danger in miscommunication when media interest is amplifying the voice of the most qualified but not necessarily those most qualified. You can contribute to the broader literature, including some great real-time papers are aimed at colleagues with literature already; reading only these will not get you up to speed.) If you have extra time, share what you learn with people around you. The wider public, if you have that gift. Communicate to the public

Then RAMP!
(Rapid Assistance in Modelling the Pandemic – a scheme convened by the Royal Society)
JUNIPER was created informally mid-2020, funded by UKRI from November 2020, brings together researchers from several universities.

**Principal Investigators**
Professor Matt Keeling, University of Warwick
Professor Julia Gog, University of Cambridge

**Senior Scientific Programme Manager**
Dr Ciara Dangerfield, University of Cambridge

**Co-Investigators**
Dr Ellen Brooks-Pollock, University of Bristol
Dr Hannah Christensen, University of Bristol
Dr Leon Danon, University of Bristol
Professor Daniela De Angelis, University of Cambridge
Dr Louise Dyson, University of Warwick
Dr Ian Hall, University of Manchester
Professor Deirdre Hollingsworth, University of Oxford
Dr Thomas House, University of Manchester
Dr Christopher Jewell, Lancaster University
Dr Petra Klepac, University of Cambridge & LSHTM
Dr TJ McKinley, University of Exeter
Dr Lorenzo Pellis, University of Manchester
Dr Jonathan Read, Lancaster University
Dr Michael Tildesley, University of Warwick

**Scientific Writers** (Plus Magazine & Millennium Maths Project)
Rachel Thomas, University of Cambridge
Dr Marianne Freiberger, University of Cambridge

+MANY more

maths.org/juniper
Twitter: @JuniperConsort1
JUNIPER has in-house science writing expertise with direct interaction with researchers, and rapid and wide dissemination through plus magazine http://plus.maths.org/

For broad audience – school students, public, media and also ‘explainers’ e.g. as cited on gov.uk every week with R and growth rates.

Likewise, a growth rate of -4% indicates the epidemic is shrinking faster than a growth rate of -1%. Further technical information on growth rate can be found on Plus magazine.

http://plus.maths.org/
Some of the topics I’ve been involved in (as one researcher among many)

Schools

Higher Education

B.1.1.7

Spatial patterns

NPI options

Understanding R biases

B.1.617.2

Vaccination


Robert Challen, Louise Dyson, Chris Overton, Laura Guenane-Bincon, Leon Danon, Julia Gog;

2021-05-13

4. Some very live research themes

- The effects of vaccination
- Who to target with vaccination?
Capturing the effect of vaccination

Vaccine, three effects, (θ=1 in each case is no effect)

θ_{sus} : reduced rate of becoming infected
θ_{trans} : reduced infectiousness (if infected)
θ_{dis} : reduced chance of severe disease

Note:
Disease blocking: θ_{sus} × θ_{dis}
Transmission blocking: θ_{sus} × θ_{trans}
Connect this back to insights from earlier

\[ y(n) = aR^n \]

In red: drop \( a \) by 50%

In blue: drop \( R \) by 50%
Vaccination rollout – who should we target with vaccination

What should the vaccine priority order be?
• The most vulnerable (highest chance of severe disease)?
  • Those put at risk by their work?
  • Those most needed at work?
• Those most connected with other people?

Complex ethical issues here for society. Mathematical modelling can show the population consequences of the options...
What insights can we gain from simple approach?

Model population as two equally sized groups:

- **Vulnerable**: $d$ times higher probability of severe disease (e.g. hospitalization)
- **Mixers**: $m$ times higher rate of mixing (with anyone)

Mixing matrix proportion to:

$$M_0 = \begin{bmatrix} 1 & m \\ m & m^2 \end{bmatrix}$$

https://www.medrxiv.org/content/10.1101/2021.03.14.21253544v2
\[ R_0 \frac{(1 - v_1) + (1 - v_2)m^2 + \theta_S \theta_I (v_1 + v_2 m^2)}{1 + m^2} \]
Best strategy to reduce disease?

If vaccine has some transmission blocking effects, then it *can* be better to target vaccination to reduce transmission, rather than directly protecting the vulnerable.

Many caveats – including:

This slightly depends on timescales: a very short term optimum is often to vaccinate the vulnerable.

This is also limited to two populations, but reality is a spectrum of mixing and vulnerability.

Combining these: optimal strategy under more realistic conditions could be to vaccinate the extremely vulnerable first, and then pivot to the most mixing (but will depend on precise population distribution).

+ see ongoing work on vaccine escape...

[https://www.medrxiv.org/content/10.1101/2021.03.14.21253544v2](https://www.medrxiv.org/content/10.1101/2021.03.14.21253544v2)