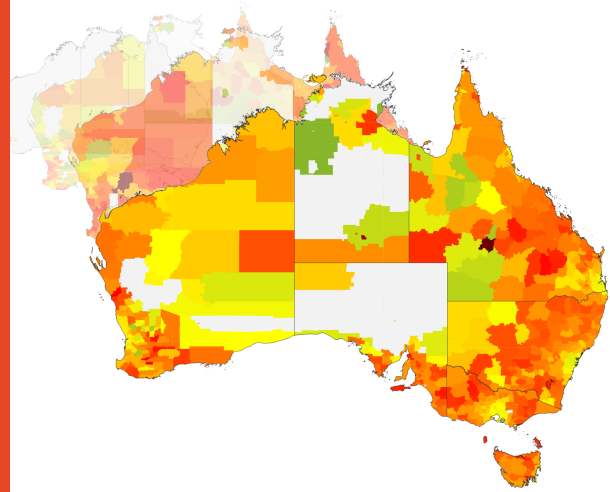
Introducing the AceMod Simulator

Australian Census-based Epidemic Modelling

Oliver Cliff

December 13, 2017



THE UNIVERSITY OF SYDNEY

Why simulate flu pandemics?

3000
Fatalities

18,000
Hospitalisations

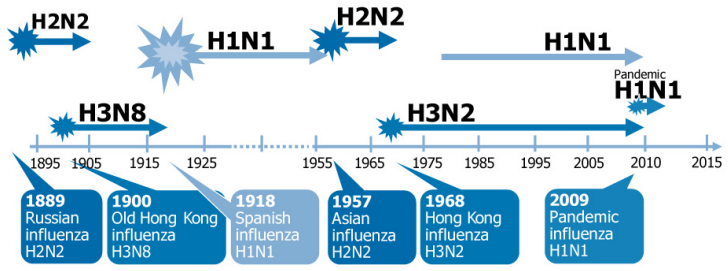
310,000
Consultations

85,000,000 AUD
Cost

Why simulate flu pandemics?

FIGURE

Recorded human pandemic influenzas since 1885 (early sub-types inferred)



Source: European Centre for Disease Prevention and Control (ECDC) 2009

Reproduced and adapted (2009) with permission of Dr Masato Tashiro, Director, Center for Influenza Virus Research, National Institute of Infectious Diseases (NIID), Japan.

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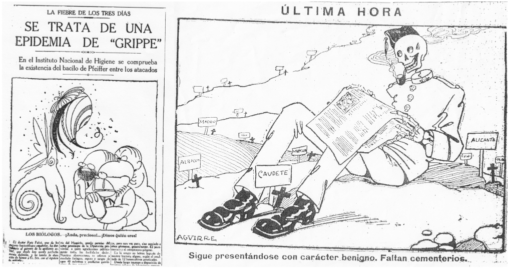
[1] Lifted from http://www.eurosurveillance.org/content/10.2807/ese.15.01.19458-en

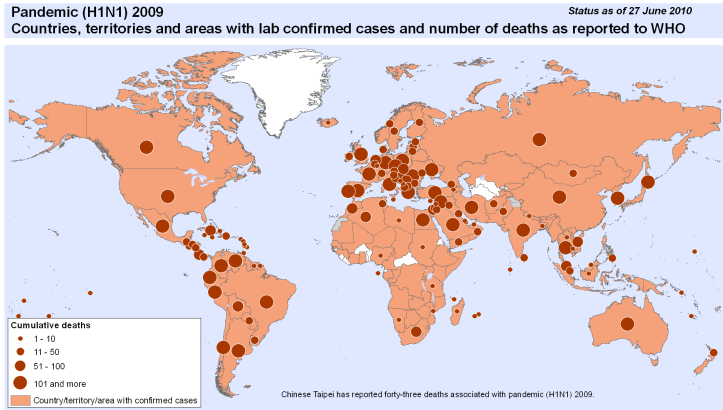
H1N1 (1918-19) – Spanish Flu

- **Globally**
  - 20-40M suspected deaths;
  - Approximately 500M ill (over 30% of the population).
- **Australia**
  - 15,000 deaths in Australia
  - Approximately 4M ill (40% of the population).



H1N1 (2009) – Swine Flu

- **Globally**
  - 250-500K fatalities
- **Australia**
  - 77-191 fatalities
  - 40K confirmed cases



Compartmental model

- **S**usceptible to getting infected;
- **I**nfectious to other individuals;
- **R**ecovered and immune.

Compartmental model

- **S**usceptible to getting infected;
- **I**nfectious to other individuals;
- **R**ecovered and immune.

- **Incidence** of new infecteds;
- **Prevalence** of the disease;
- **Attack rate** of the season;

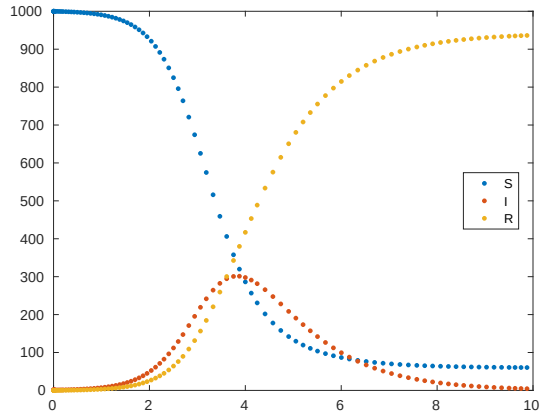
Deterministic differential equations

$$\frac{\mathrm{d}\boldsymbol{S}}{\mathrm{d}t} = -\frac{\beta \boldsymbol{I}\boldsymbol{S}}{N}$$
$$\frac{\mathrm{d}\boldsymbol{I}}{\mathrm{d}t} = \frac{\beta \boldsymbol{I}\boldsymbol{S}}{N} - \gamma \boldsymbol{I}$$
$$\frac{\mathrm{d}\boldsymbol{R}}{\mathrm{d}t} = \gamma \boldsymbol{I},$$

where

$N =$ population size

$$R_0 = \frac{\beta}{\gamma}.$$



Agent-based models

Three layer model:

- Population data from the census.
- Mobility data through commuting patterns;
- Epidemic model from disease dynamics (empirical or simulated);

Used extensively:

- Elveback et al. (1976);
- Longini et al. (2004,2005);
- GLEAM: Balcan et al. (2010);
- FluTe: Chao et al. (2010)

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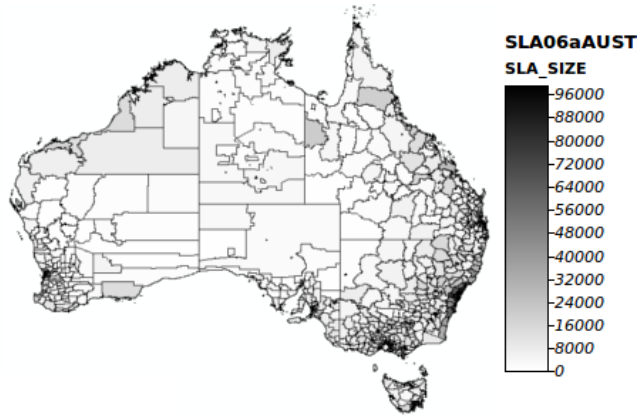
Emphasis on demographics.

AceMod

- 2006 Australian census data;
- 19.8 million individuals in 1,422 statistical local areas (SLAs).
- Cycles of two 12-hour periods ("day" and "night");
  - Daytime mixing groups: work, school, grade, class
  - Nighttime mixing groups: household, household cluster, community (CD), neighbourhood (SLA)



Agents

Attributes

- Sex: Male or Female
  - For generation only.
- Age:
  - 0–4: N/A
  - 5–18: School
  - 19–34: Work
  - 35–64: Work
  - 65+: Work

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Generation

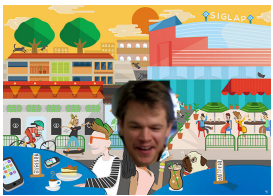
1. Create household (size) based on CD-level housing statistics;
2. Draw family composition (conditional on size);
   - Lone;
   - Family (SPF, CWOC, CWC);
   - Share house;
3. Draw sex (if needed).
4. Draw age.

Nighttime mixing groups

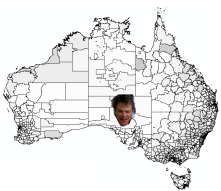
The larger the group, the lower the transmission probability.

(a) Household

(b) Cluster



(c) Community (CD)



(d) Neighbourhood (SLA)

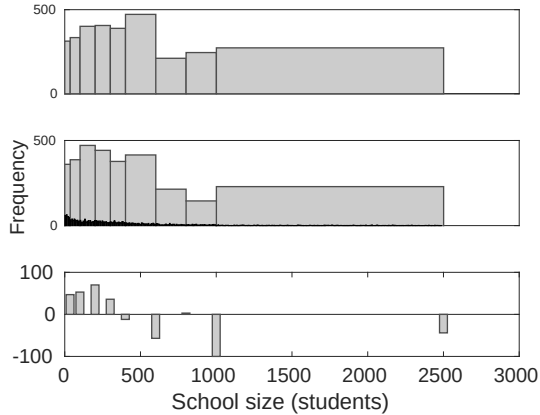
Work mixing groups

- Number of agents travelling from home community (CD) to working community (DZN) is known.
- Randomly select agents to move from CD to DZN
- Group workers into working groups of approximately 20 people.

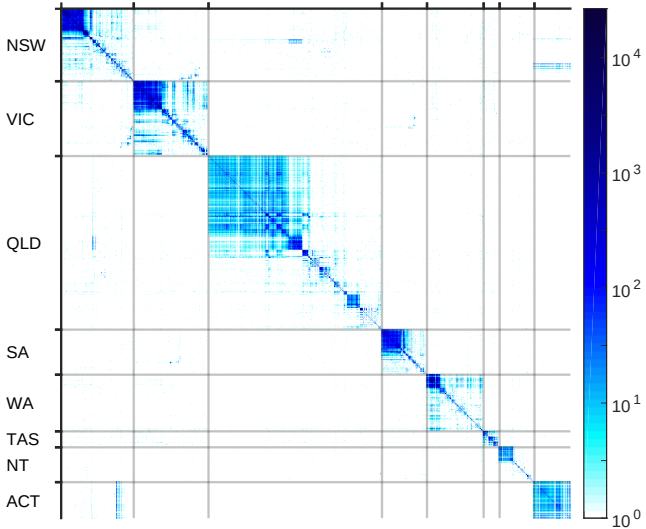
Populating Schools

Australian Bureau of Infrastructure, Transport and Regional Economics (BITRE)

1. Generate schools
   - 1.1 Uniformly distribute schools for each range
   - 1.2 Allocate school in SLA with enough students
   - 1.3 Randomly assign students to school
2. Assign teachers based on DZN

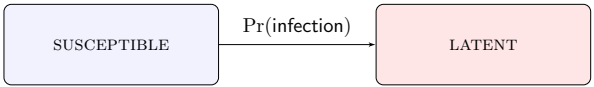


Demographics



Demographics

Transmission model



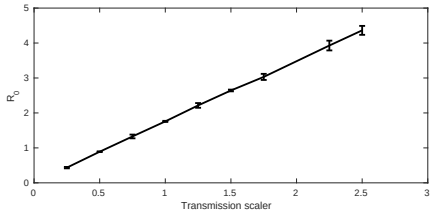
$$\Pr(\text{infection}) = 1 - \prod_{\text{contact groups}} \left[\prod_{\text{infected agents in g}} (1 - \text{transmission prob.}(t, \text{g})) \right],$$

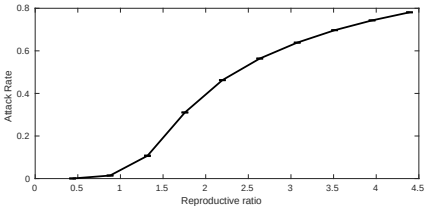
$$\text{transmission prob.}(t, \text{g}) = \text{scaling coefficient} \times \text{factor}(t) \times \text{base prob.}(\text{g}).$$

Transmission model

transmission prob.(t, g) = transmission scaler $\times$ infectivity(t) $\times$ base prob.(g).

- **Transmission scaler** modifies severity of the pathogen





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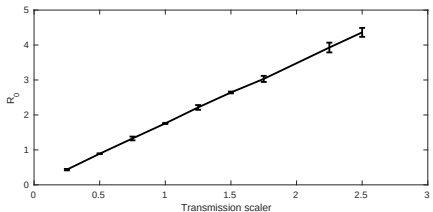
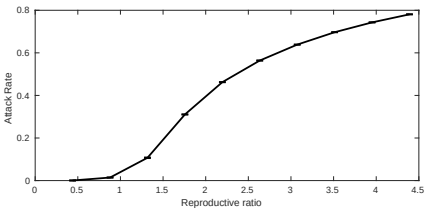
- **Infectivity** models transmissibility over time





Transmission model

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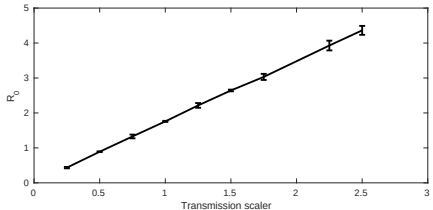
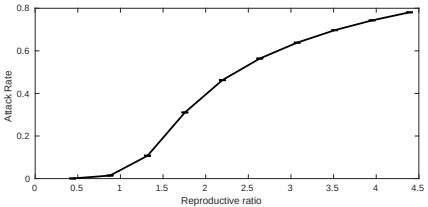
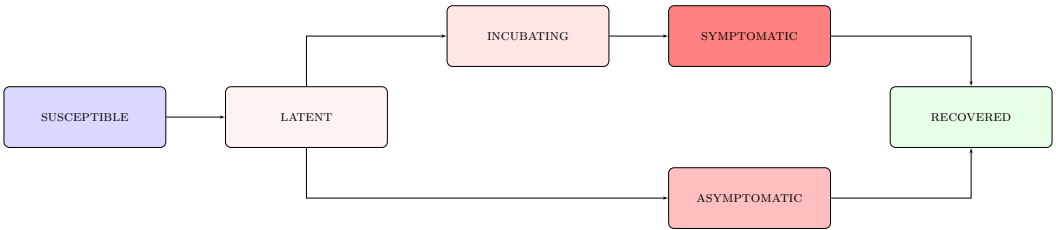
- **Transmission scaler** modifies severity of the pathogen
- **Infectivity** models transmissibility over time
- **Base probability** for the disease at incubation:
  - Function of transmission rate for: household, school, grade, and class
  - Function of contact probability for: cluster, community, neighbourhood, working group





Natural history of influenza



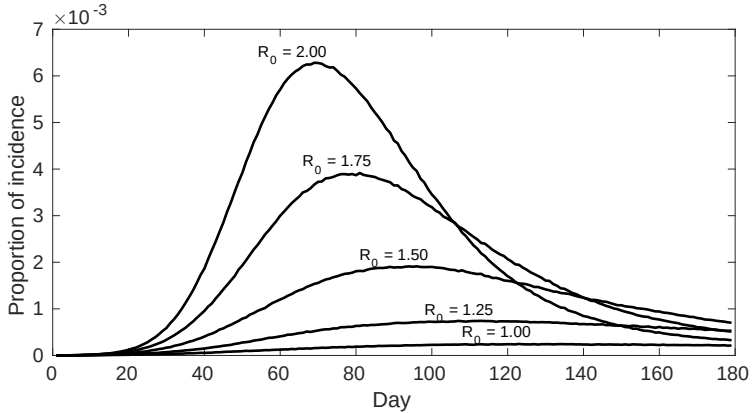
- Latent period: 1.2 days;
- Incubating period: 1.9 days;
- Infectious period: 4.1 days.

- 75% Symptomatic;
- Asymptomatic agents are half as infectious.

Prevalence heatmaps

Movies.

Epidemic Curves



Incidence by Age Groups

	Age Group	$R_0 = 1.0$	$R_0 = 1.25$	$R_0 = 1.5$	$R_0 = 1.75$	$R_0 = 2.0$
Cumulative number of community infections per 10K*	0-4	24.5	93.3	276	555	832
	5-18	498	1287	2520	3700	4570
	19-34	103.9	441	1361	2580	3600
	35-64	104.5	456	1376	2620	3650
	65+	143.4	609	1774	3280	4535
	Overall	175.9	599	1561	2770	3740
Cumulative number of national infections per 10K*	0-4	43.2	142.5	357	646	929
	5-18	796	1818	3140	4310	5140
	19-34	168.7	624	1637	2850	3830
	35-64	165.6	623	1637	2870	3860
	65+	208	779	2030	3520	4700
	Overall	284	841	1896	3090	4030

*Compared to the number of agents in that age group (e.g., per 10K 19-34 year olds).

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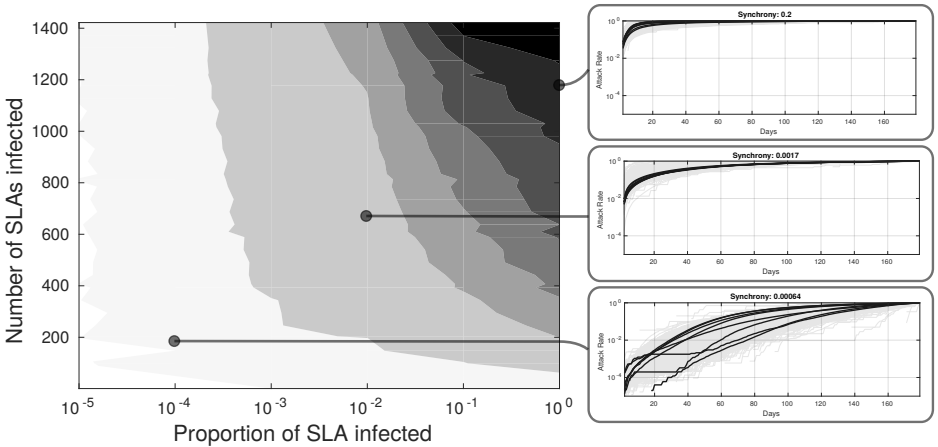
Synchrony


Number of SLAs infected
1400
1200
1000
800
600
400
200
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
Proportion of SLA infected
Synchrony: 0.2
Synchrony: 0.0017
Synchrony: 0.00064
Attack Rate
Days
20
40
60
80
100
120
140
160

Future directions

- **Analysis**
  - How has the contact network evolved from 2006 to 2011 and 2016?
  - Where does Australia sit in terms of synchrony and R_0?
- **Prediction**
  - Local information dynamics
  - Themodynamic interpretation of epidemics
- **Mitigation strategies**
  - Who to vaccinate? (Game theory)
  - Where/when to vaccinate? (Percolation centrality)