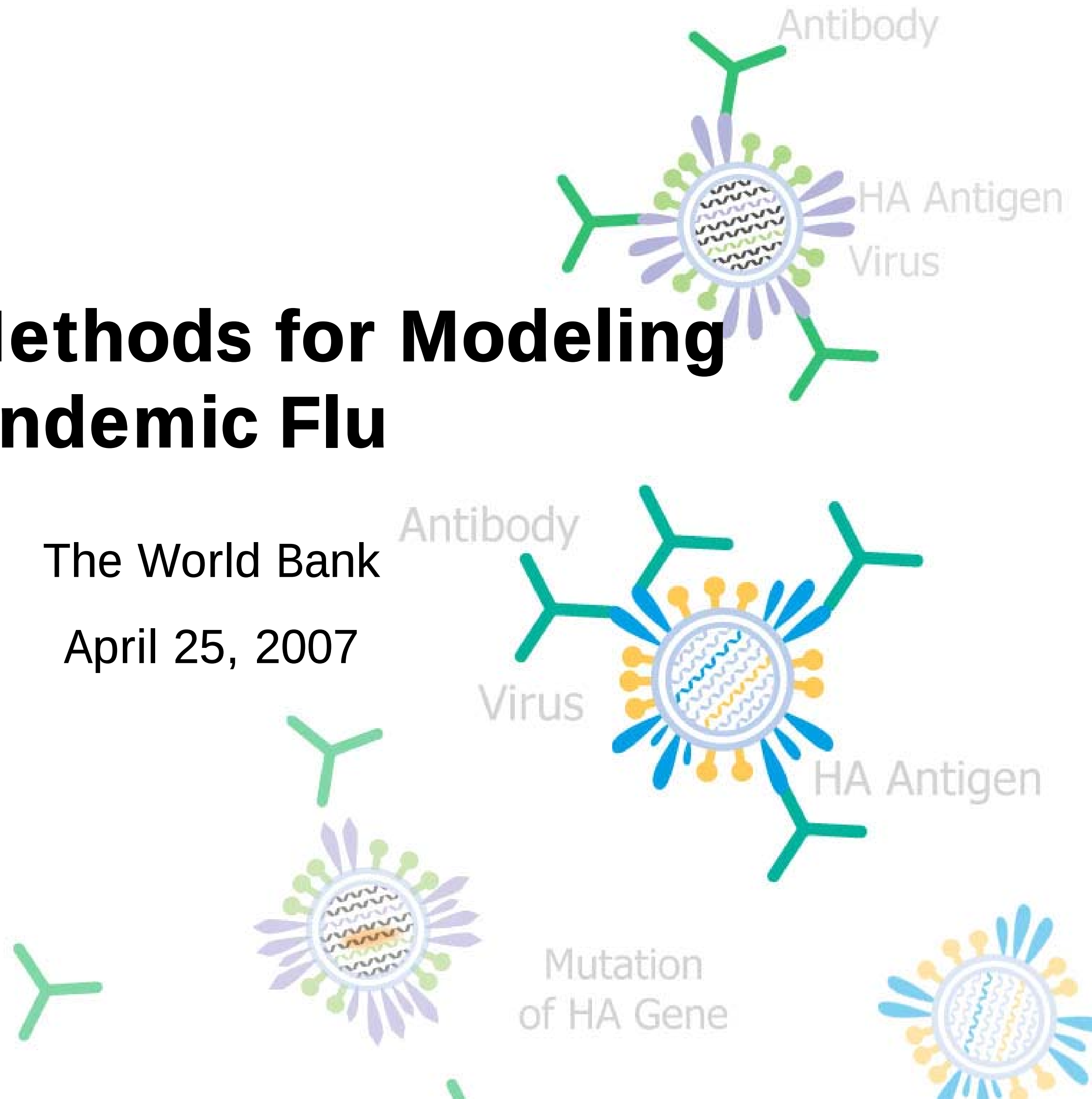
Analytical Methods for Modeling Pandemic Flu

The World Bank

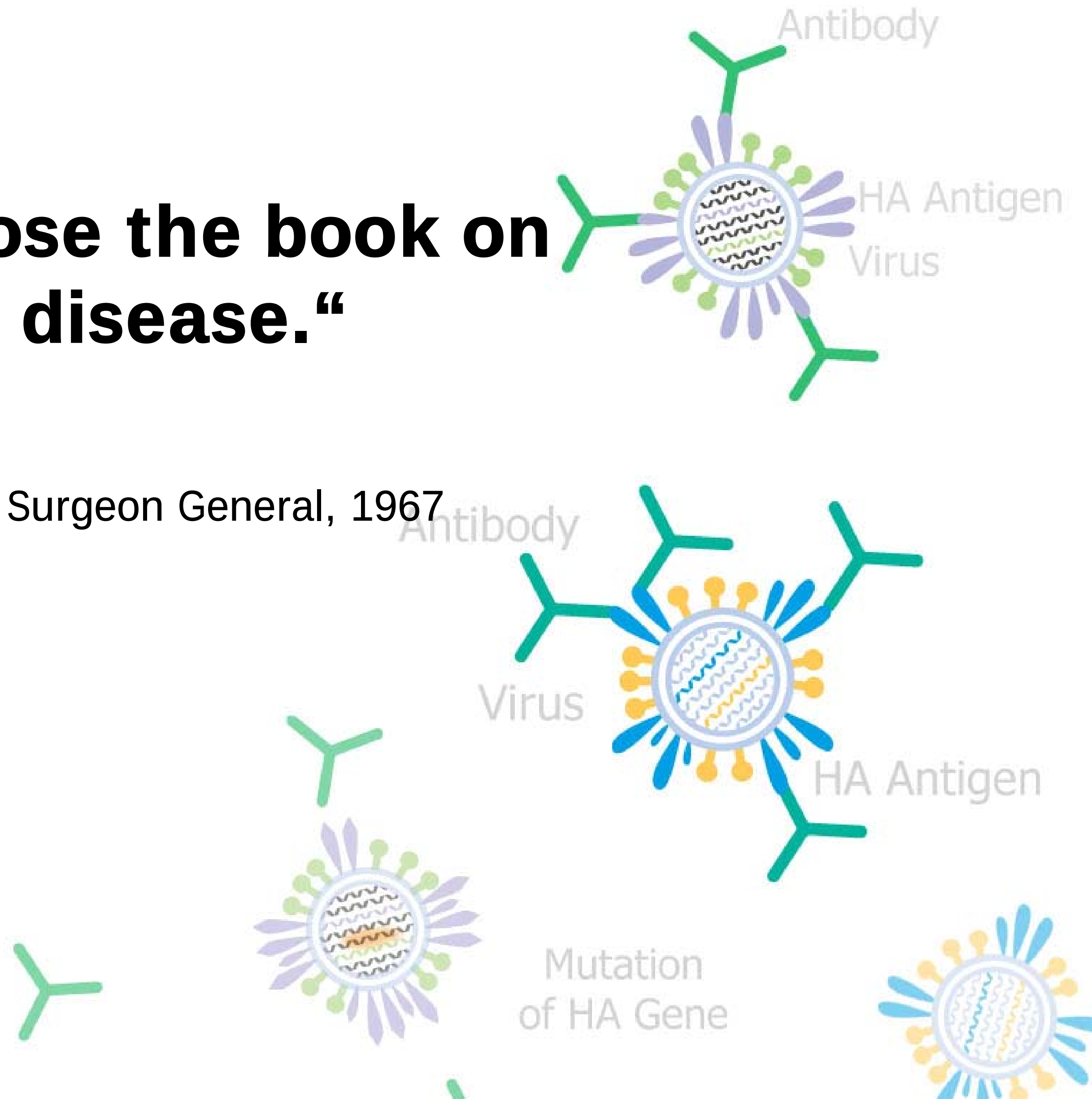
April 25, 2007



THE WORLD BANK

It is “time to close the book on infectious disease.“

-William Stewart, US Surgeon General, 1967



Infectious Disease Today

- At least 30 infectious diseases for which there are no cures have been identified since 1967
- One-third of deaths worldwide are caused by infectious disease

Disease	Number (millions)	Percent
Respiratory Infection	3.9	6.90%
HIV/AIDS	2.8	4.90%
Diarrheal	1.8	3.20%
Tuberculosis	1.6	2.70%
Malaria	1.3	2.20%
Measles	0.6	1.10%
Pertussis	0.29	0.50%
Tetanus	0.21	0.40%
Meningitis	0.17	0.30%
Syphilis	0.16	0.30%

Agenda

- RMS Profile
- Why Modeling?
- Background on Infectious Disease
- Epidemiologic Modeling
- Pandemic Flu
- RMS Pandemic Flu Model
- Pandemic Flu Impacts
- Questions and Discussion

RMS Profile

The world's leading provider of products and services for the management of catastrophe risk

- Founded at Stanford University in 1989.
- 1,000+ employees worldwide, multidisciplinary development team includes blend of experts in hazard research, actuarial science, engineering and software development.
- Solely focused on independent view of risk quantification and risk management.
  - Independent re/insurance industry
  - Subsidiary of DMG Information
- Global presence:
  - Corporate office: Newark, California
  - Regional: Illinois, New Jersey, London, Tokyo, India, Paris, Zurich, Bermuda

What RMS Does

- RMS creates probabilistic models to inform clients on types of catastrophic events that can occur, how large can they be, at what frequency and how to manage that risk
- RMS does not forecast when and where a storm will occur or how many storms will occur in a given year
- RMS quantifies what the potential damage will be from natural and man-made catastrophes
  - Earthquakes
  - Hurricanes
  - Tornados
  - Terrorism
  - Pandemic Flu
  - Fire

Applications of RMS Results

- Return Period Loss Assessment
- Data Validation
- Reinsurance Adequacy, Pricing, Optimization
- Capital Adequacy
- Geographic Concentration / Accumulations
- Premium / Loss Evaluation
- Sensitivity Analysis
- Capacity Allocation
- Portfolio Diversification and Optimization
- Industry Loss (ILW)
- Securitizations
- Insurance Adequacy
- Business Continuity Planning
- Program Optimization

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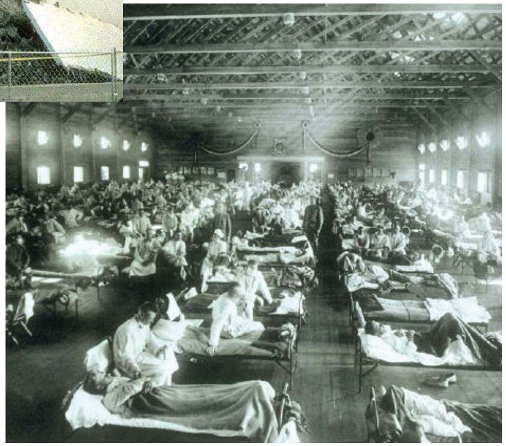
RMS Human Casualty Models

- Terrorism
  - United States
  - Global
- Earthquake
  - United States
  - Japan
  - China
- Influenza Pandemic: 31 countries
- Workers Comp Exposure Models:
  - Unknown data: address, construction type, building height
  - Time of day



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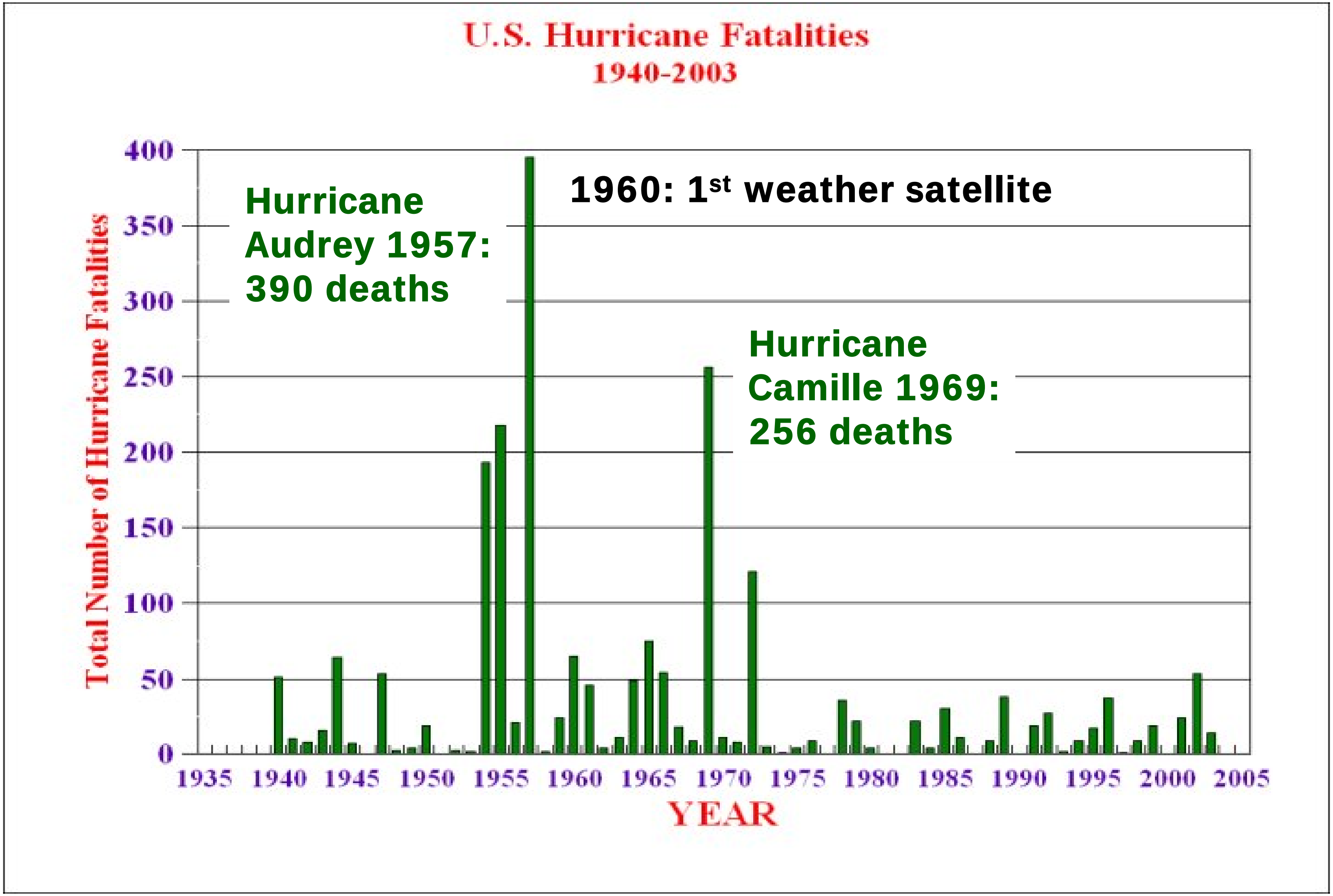
U.S. Hurricane Fatalities in the Modern Era



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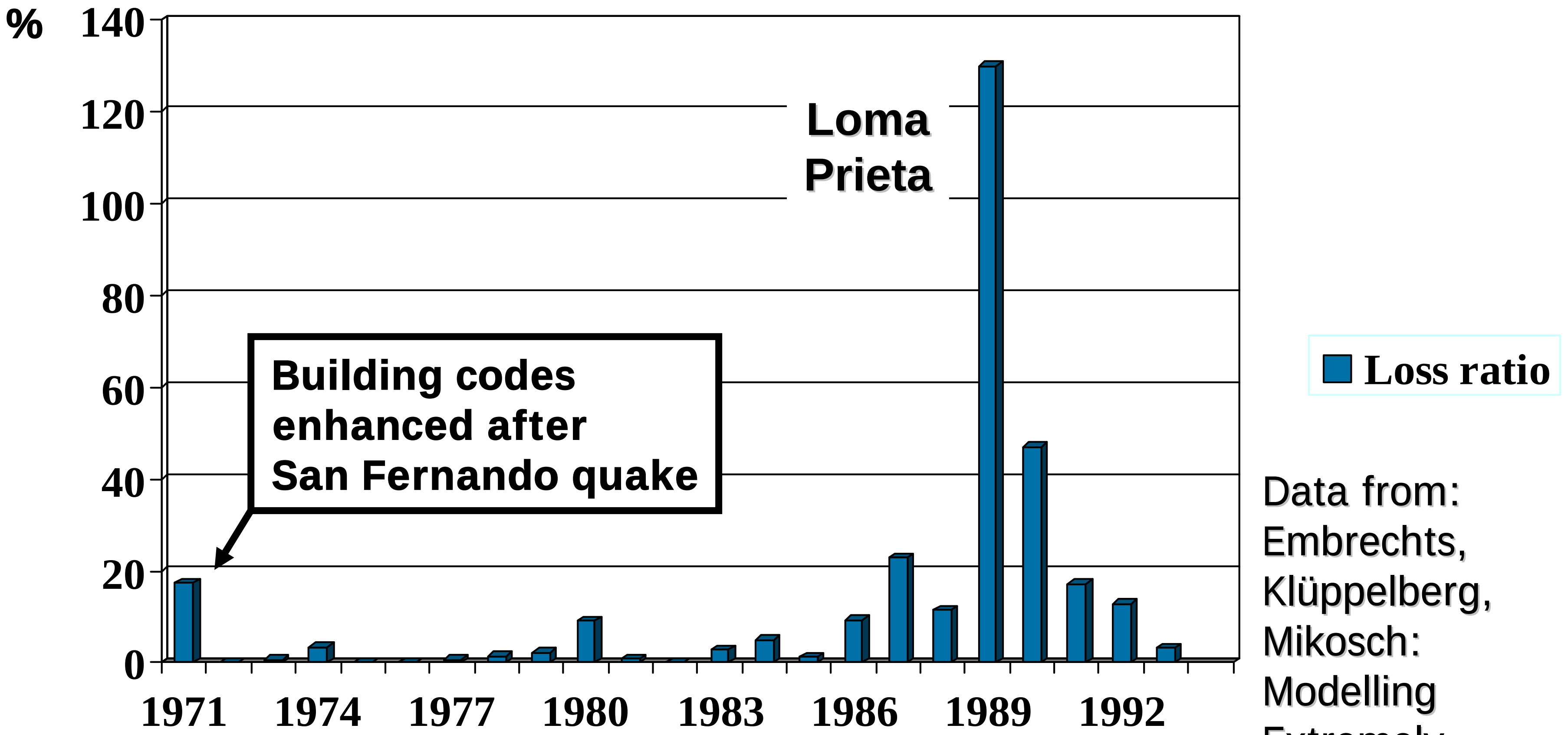
Annual Loss Ratios for Earthquake Insurance in California



Data from: Embrechts, Klüppelberg, Mikosch: Modelling Extremely Events

The loss ratio for 1994 was: 2272.7

Why Modeling?

- Data is always best
- Models are only as good as their inputs
- Infectious disease pandemics are high consequence and low frequency events
- Modeling it the best way to understand the spread of infectious disease
- Modeling allows us to explore what is possible

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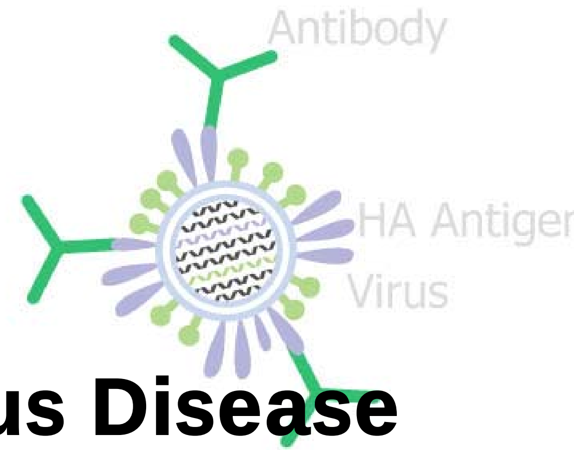
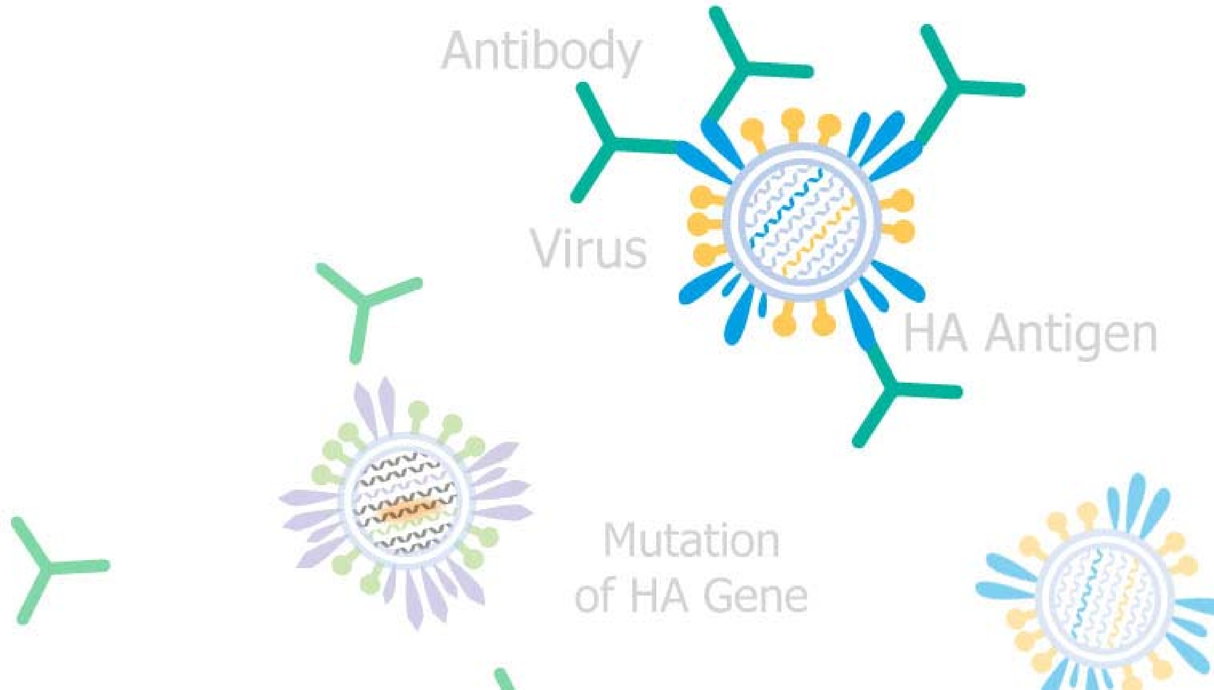
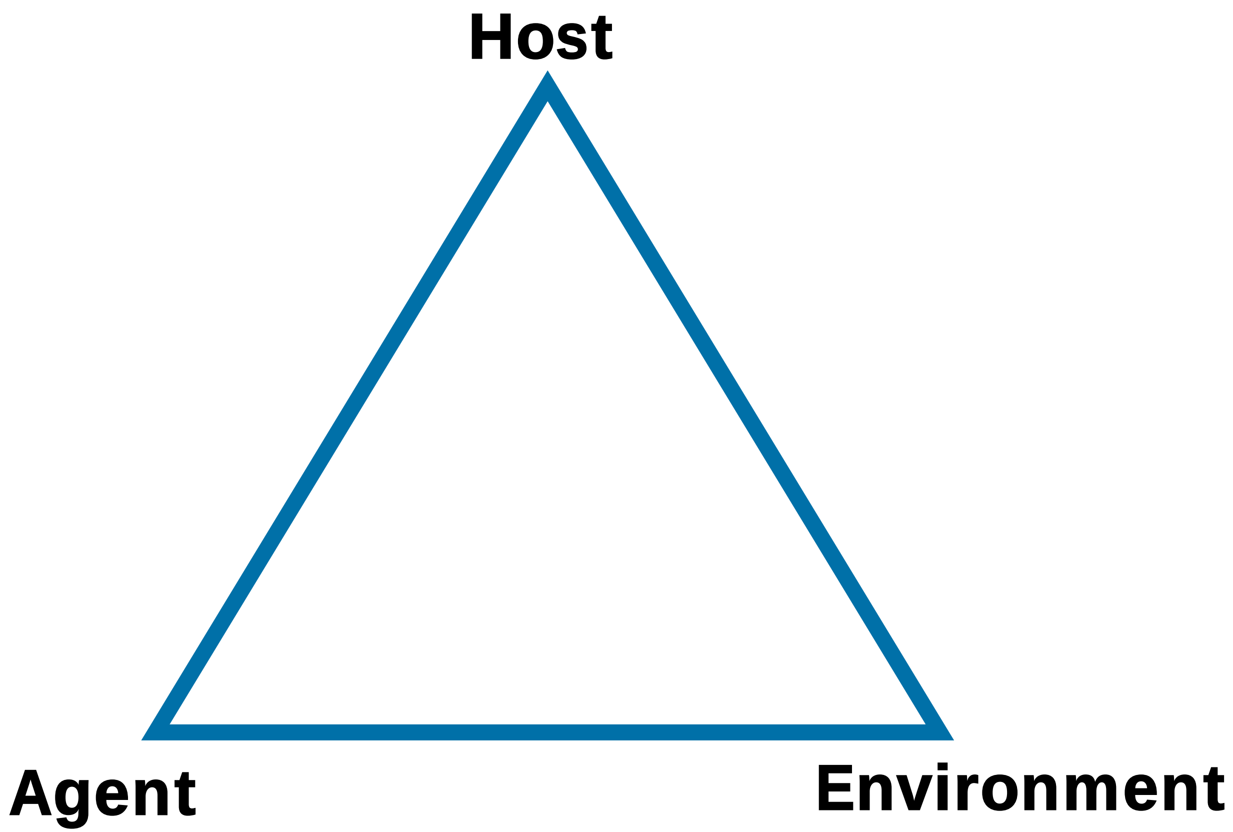


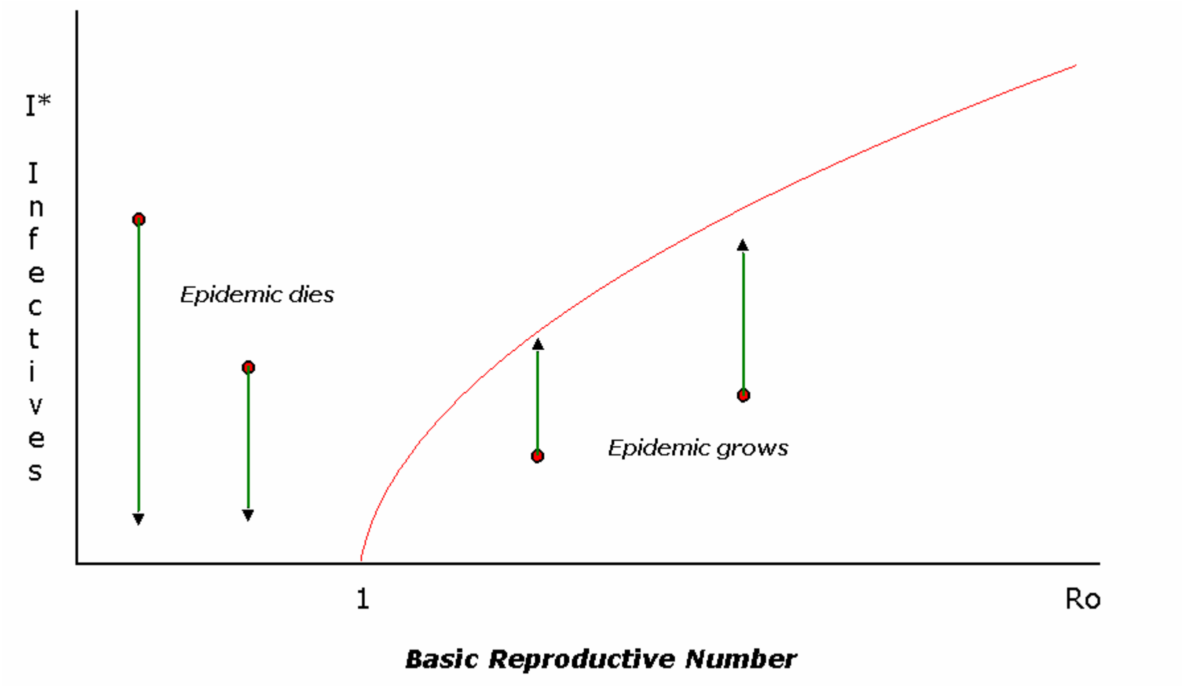
Characteristics of an Infectious Disease



Infectious Disease Triad



Transmissibility



Number of secondary infections generated by a typical infectious individual in a population of mostly susceptibles at a demographic steady state

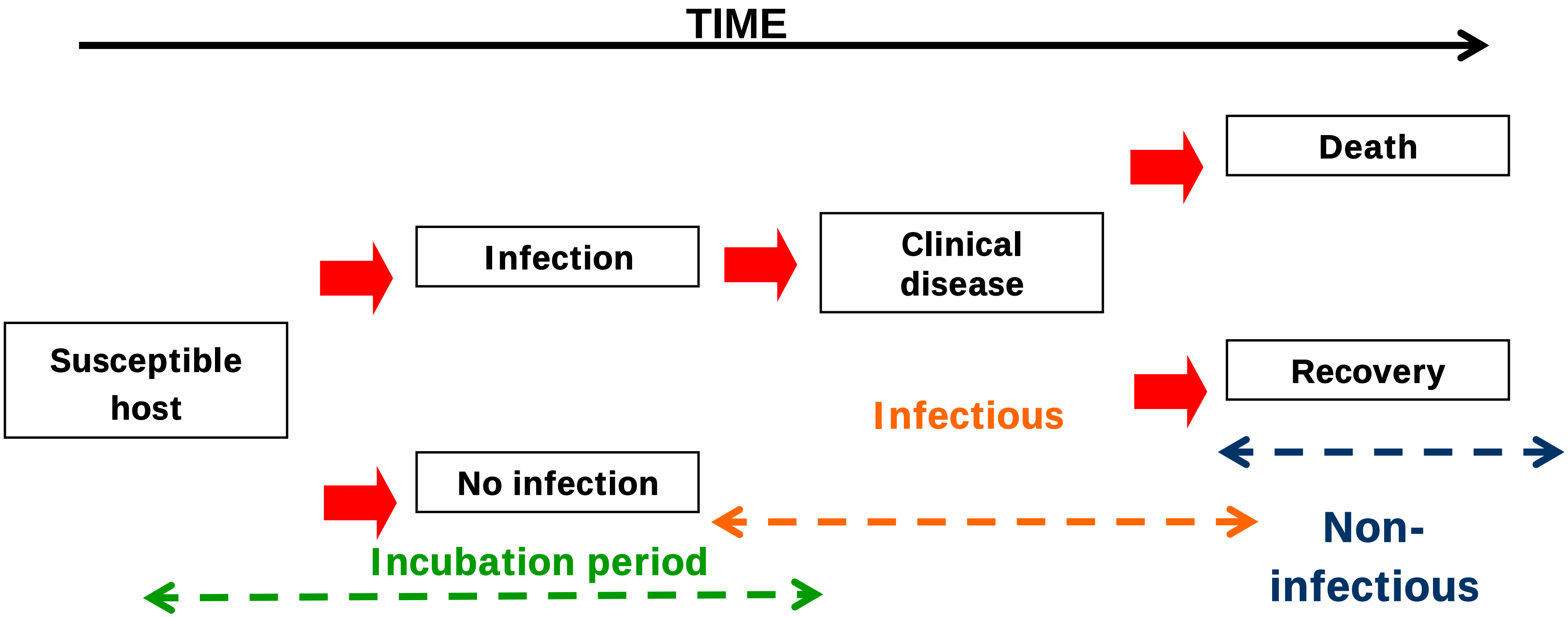
$R_{0,}$ Basic Reproductive Number, is a function of:

- The number of contacts
- The probability of transmission given a contact
- Time an individual is infectious

Severity

- Some measurement of the severity of disease
- Death Rate- number of fatalities per number of infected
- Typically the parameter that gets media attention
- Not always straightforward
  - Asymptomatic infections
  - Sub-clinical Infections
  - What about severe complications?

The Characteristics of an Infectious Disease

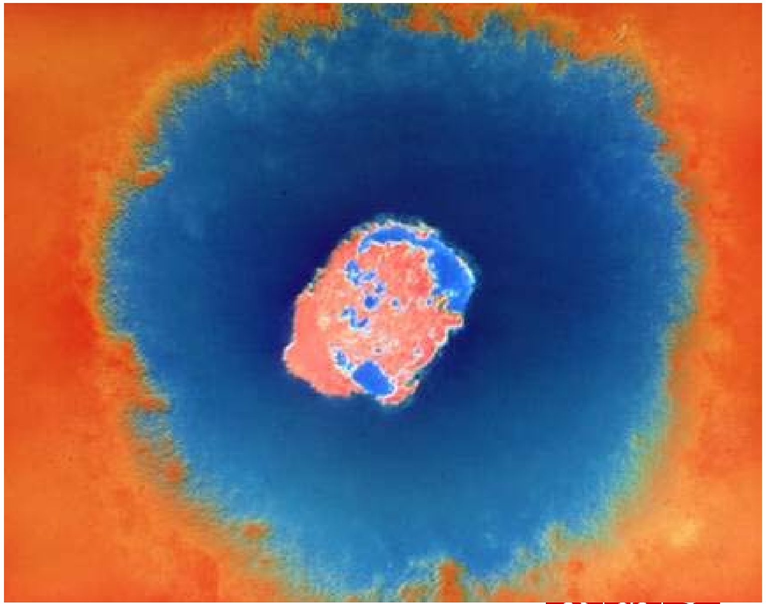


A Tale of 4 Viruses

- Smallpox
- HIV
- SARS
- Influenza

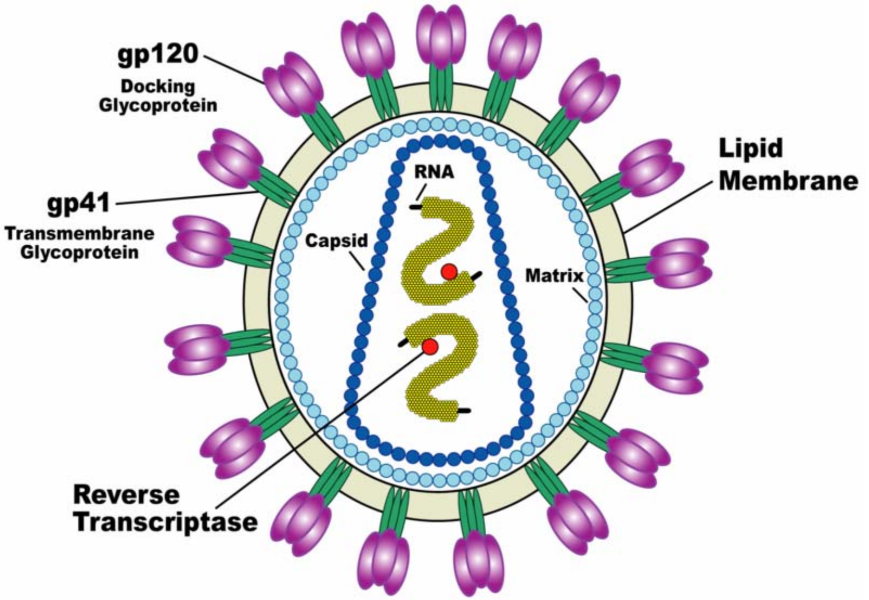
Smallpox

- Variola major or Variola minor
- Not notably infectious in the prodromal period
- 12 day incubation period
- Airborne transmission
- Estimated to have killed more than 300 million in the 20th century alone
- ~30% fatality rate



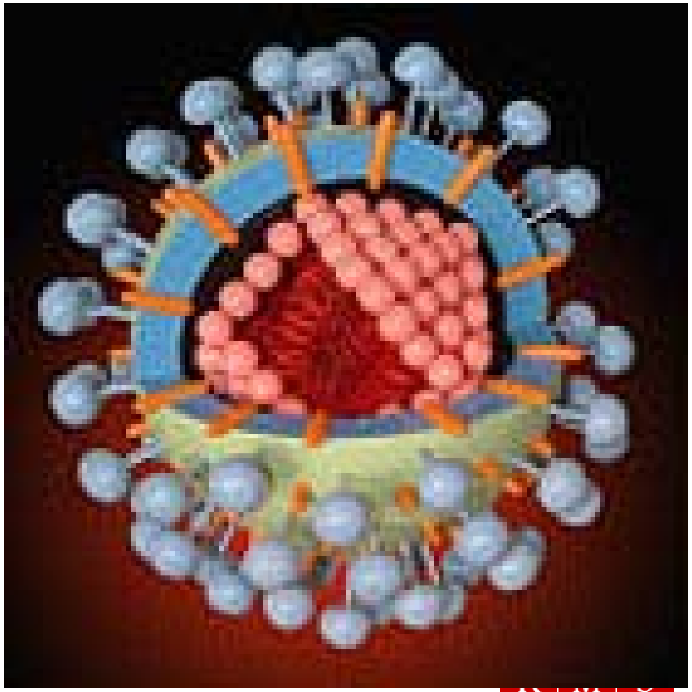
HIV

- Retrovirus
- Extremely high genetic variability
- Extremely long latency period
- 25 million deaths since 1980
- Bloodborne, sexual, and mother-to-child transmission
- No known cure



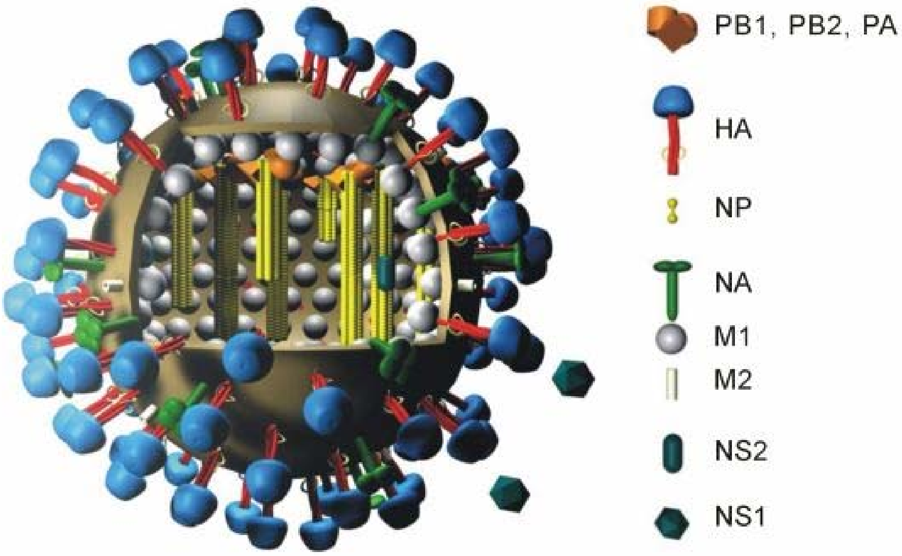
SARS

- Coronavirus
- Mortality rate of ~10%
- One epidemic resulting in 775 deaths
- No treatment, vaccine in production
- Low transmissibility
- Airborne transmission

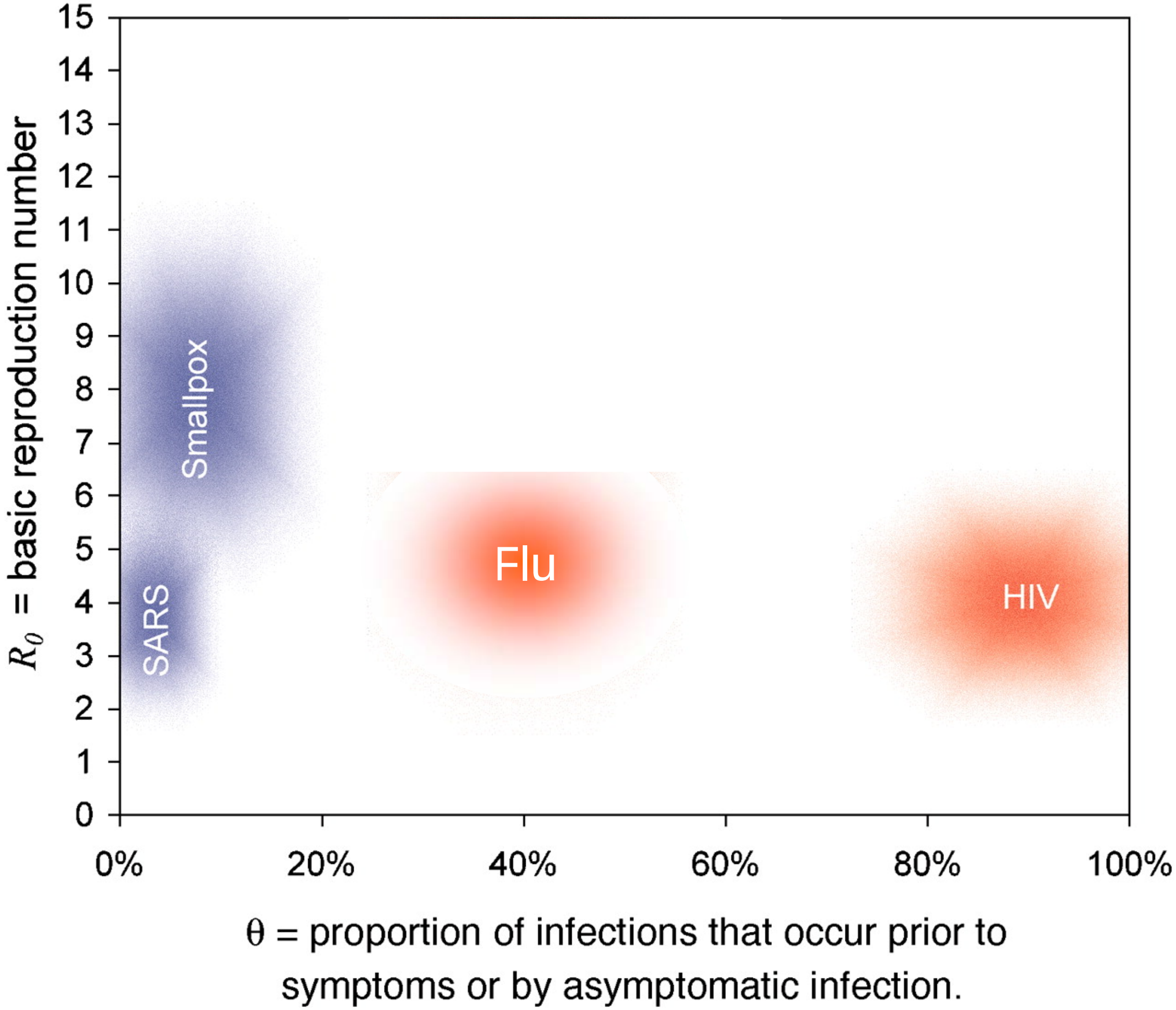


Influenza

- Orthomyxoviridae or influenza virus
- 1918 Pandemic killed 25 million people in 25 weeks
- Leading cause of infectious disease death worldwide
- Vaccines and antivirals available
- Low death per case ratio
- Moderate transmissibility
- Airborne transmission
- Animal reservoirs



What makes infections controllable?



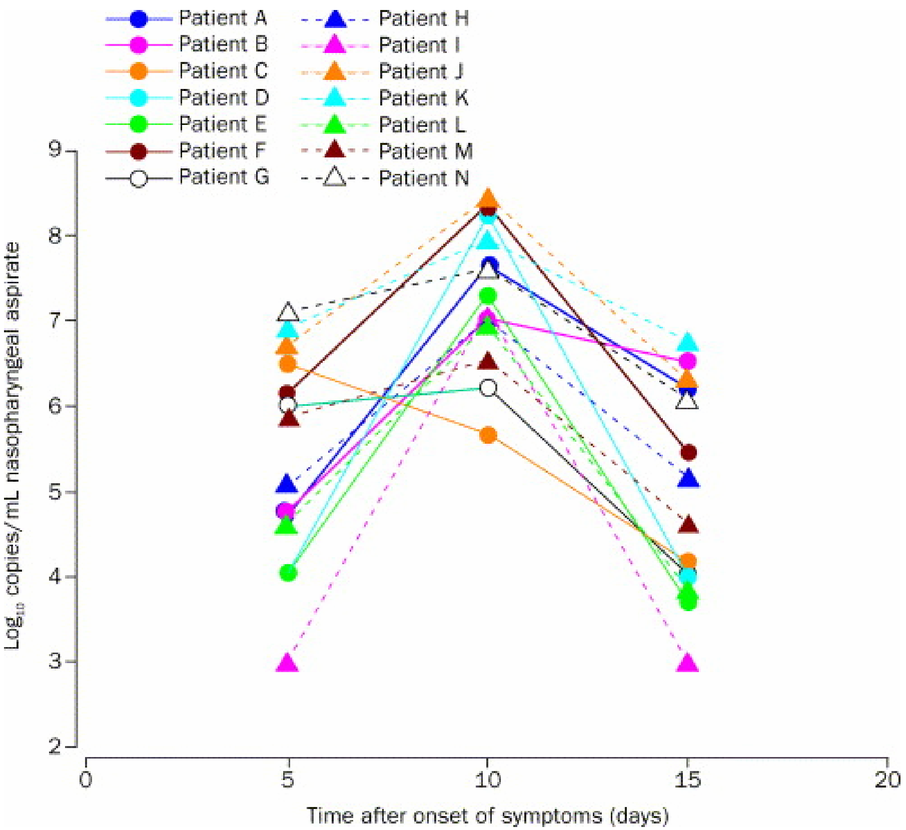
C Fraser et al., *Proc. Natl. Acad. Sci. USA* 2004

ALSO:
Serial interval
(time between infections):

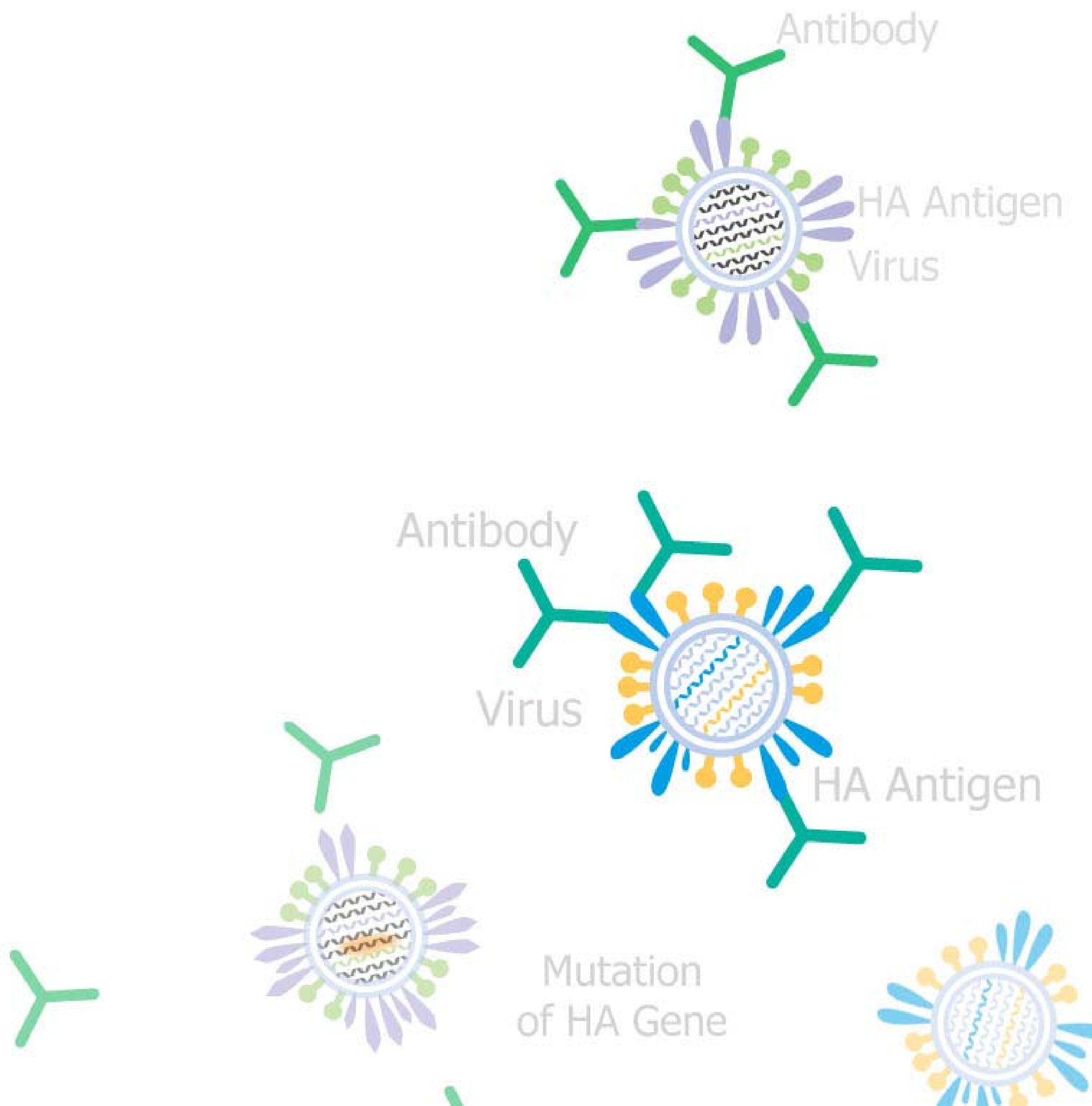
Determines speed
with which interventions
must occur

The difference between SARS and Flu

SARS	Pandemic Influenza
~8000 cases, 775 deaths (10%)	100s of millions infected, 2% or less died in 1918
R_0 ~ 3	R_0 ~ 2.5
Serial interval or generation time ~ 8.5 days	~ 4 days
People show symptoms before they are infectious	People can be infectious before they are symptomatic
Quarantine and isolation tremendously successful	Quarantine and isolation have limited benefit
No drugs or vaccine	Very limited supplies
Hospital transmission important	Community transmission major route

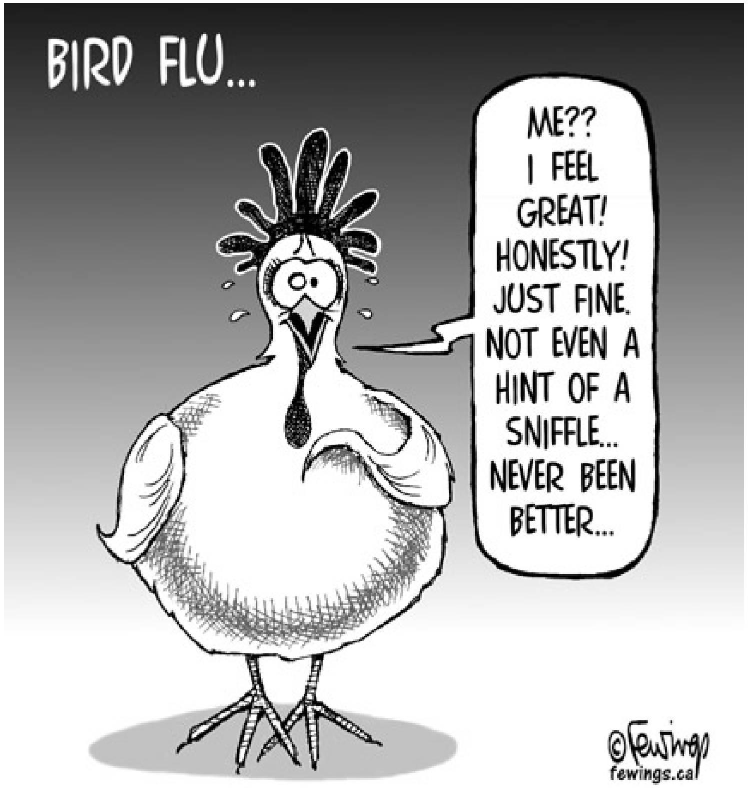


Pandemic Flu



Influenza

- Bird virus
- Genetically diverse
- All waterfowl infected at least once
- Mostly with Low Pathogenicity Avian Influenza (LPAI)
- Rarely with High Pathogenicity (HPAI)
- Media reports of ‘Bird flu’ are typically HPAI



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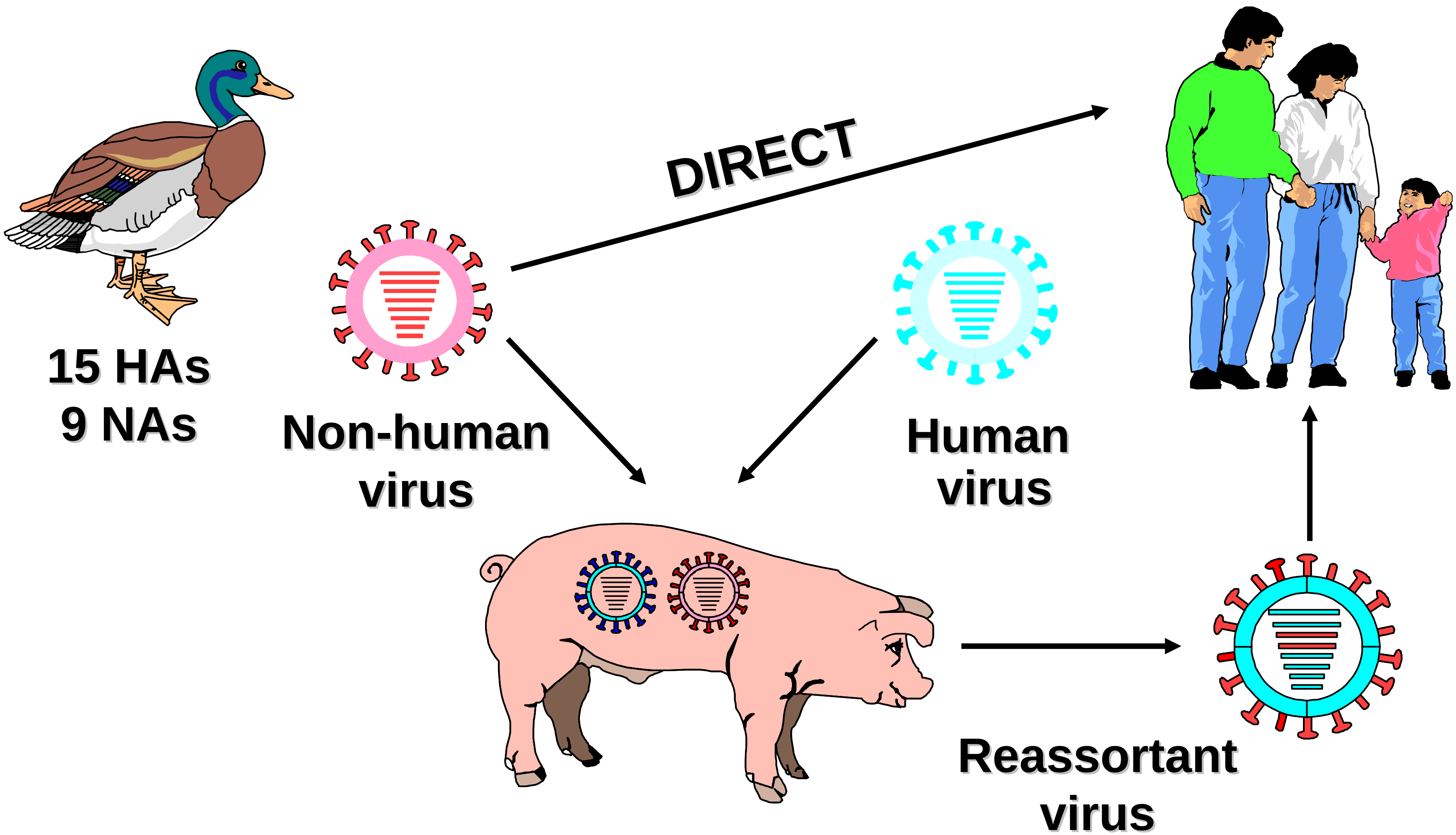
How Pandemics Start



Cross-species transmission

- Mammals (people, pigs, horses) can also be infected with influenza
- Infection difficult with bird viruses
- Virus has to adapt (e.g. mutate) to transmit in mammals
- If a transmissible virus emerges, can cause a pandemic - no immunity

Recent influenza A outbreaks & pandemics

Influenza A pandemics since 1800

Year	*Virus*	*Origin*
1830	?	Russia
1836	?	Russia (?)
1889	H2	Russia
1899	H3	?
1918	H1N1	Europe/USA
1957	H2N2	China
1968	H3N2	China
(1977	*H1N1*	*Reintroduction)*

Other outbreaks of novel strains, since 1953 (WHO surveillance established)

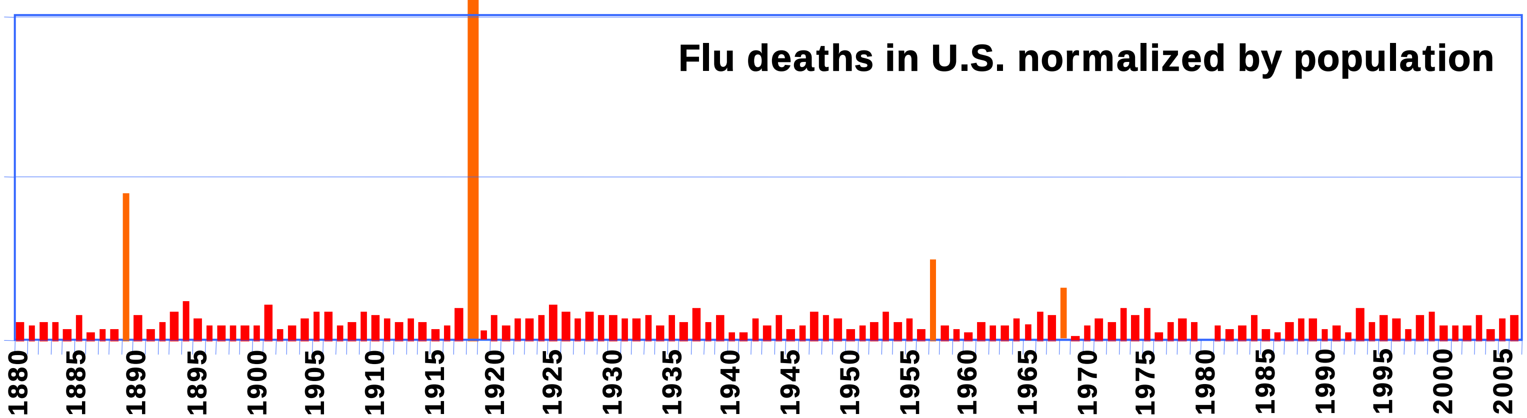
Year	*Virus*	*Location*	*Source*	*Cases (Deaths)*
1976	Swine (H1N1)	USA	Pigs	>100 (1)
1996	H7N7	UK	Ducks	1 (0)
1997	H5N1	Hong Kong	Chickens or ducks	18 (6)
1999	H9N2	Hong Kong	Chickens or ducks	2 (0)
2003	H7N7	Netherlands	Chickens	90-300 (1)
2003-	H5N1	Global	Ducks	300 (175)

1976 outbreak resulted in mass vaccination across USA.

Historical Catalog of Influenza Global Pandemics

U.S. Statistics

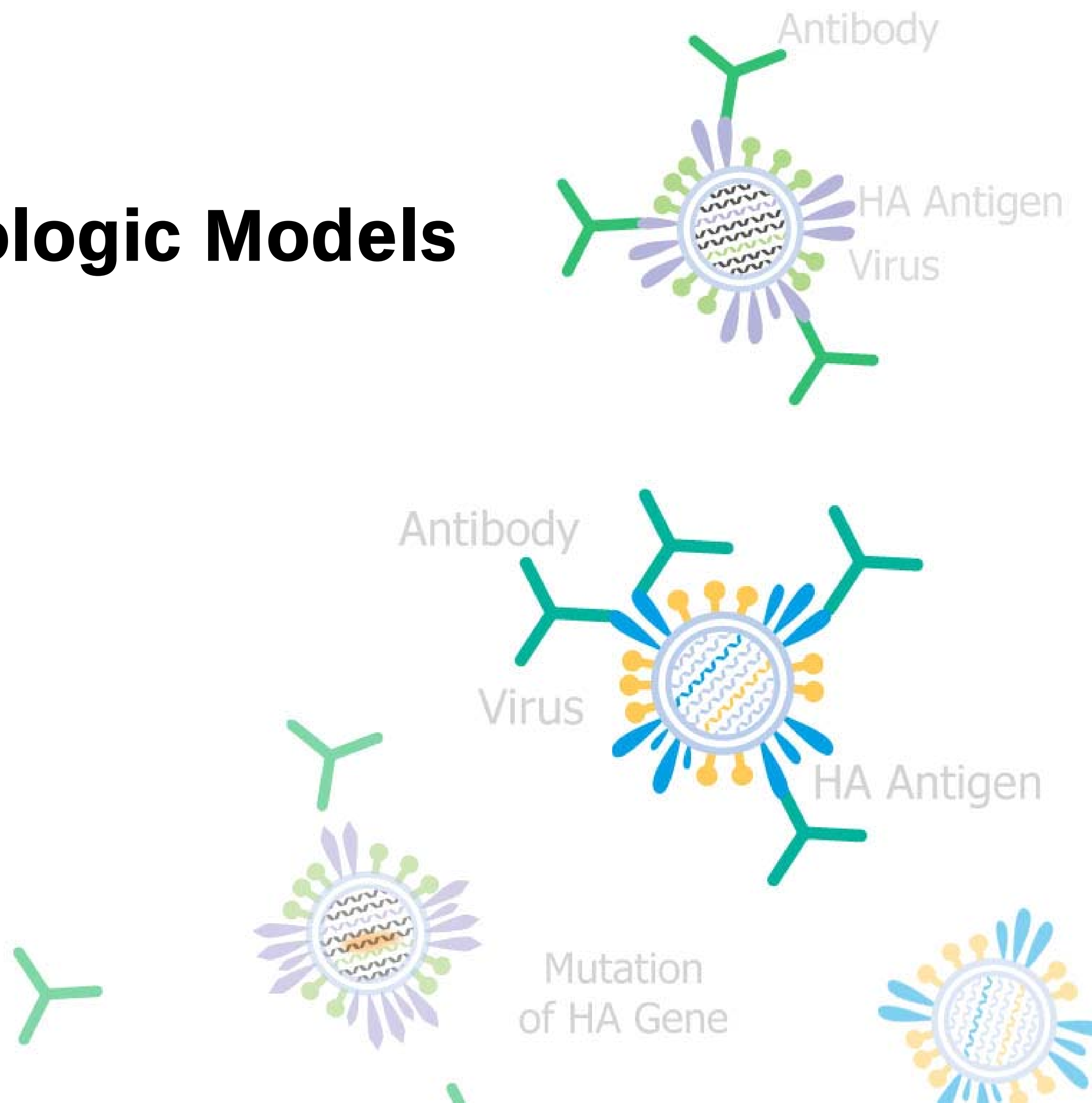
	Virus	Deaths in US	Mortality % of pop	Multiple of today's mortality	# Cases (million)	Infection Rate	Years since previous Pandemic
1889	???	**50,000**	**0.079%**	7	?	?	
1918	**H1N1**	**500,000**	**0.670%**	55	**32**	**30%**	**29**
1957	**H2N2**	**70,000**	**0.040%**	3	**39**	**22%**	**39**
1968	**H3N2**	**40,000**	**0.020%**	2	**33**	**17%**	**11**
2006	**H5N1?**	?	?				**38**
Ave year		**36,000**	**0.012%**		**30**	**10%**	**29.3**



Pandemic flu uncertainties

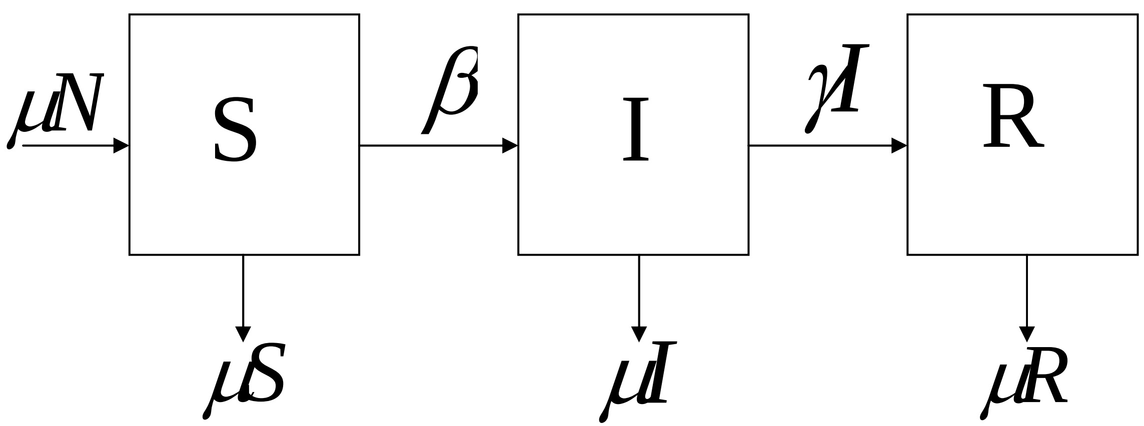
- Transmissibility of virus
- Where transmission occurs
- Lethality of virus & case characteristics
- The effect of ‘social distance measures’
- The effect of vaccination and antivirals
- Quality and timeliness of surveillance
- The effect of quarantine
- Logistics constraints
- ?????

Basic Epidemiologic Models

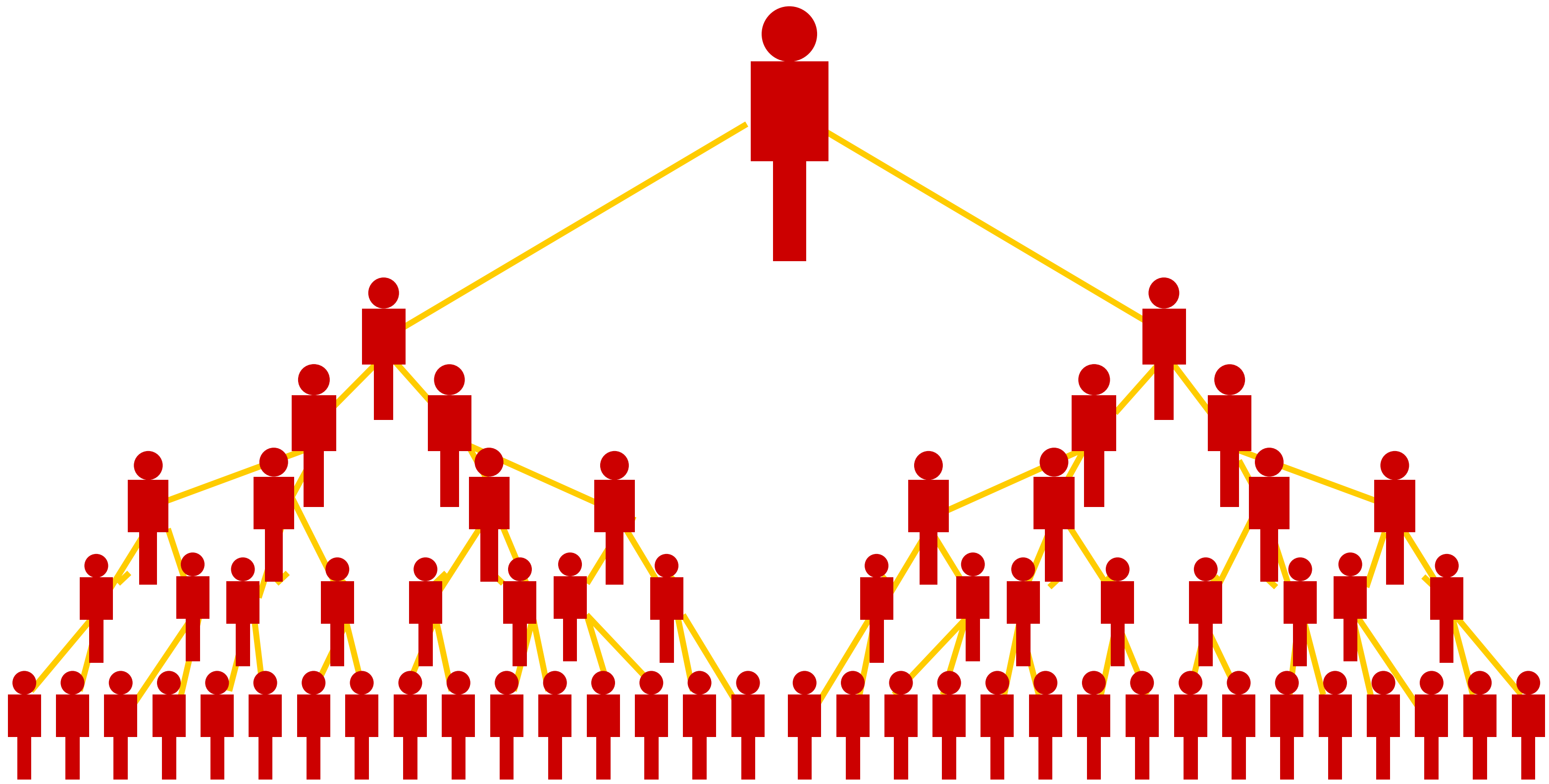


SIR Model

- Compartmentalized closed system differential equation model first proposed by Kermack and McKendrick in 1927 to explain observations of plague and cholera
- The complexity of the models has increased with advances in computing
- Variations on the SIR model have become the standard for deterministically modeling infectious disease epidemics

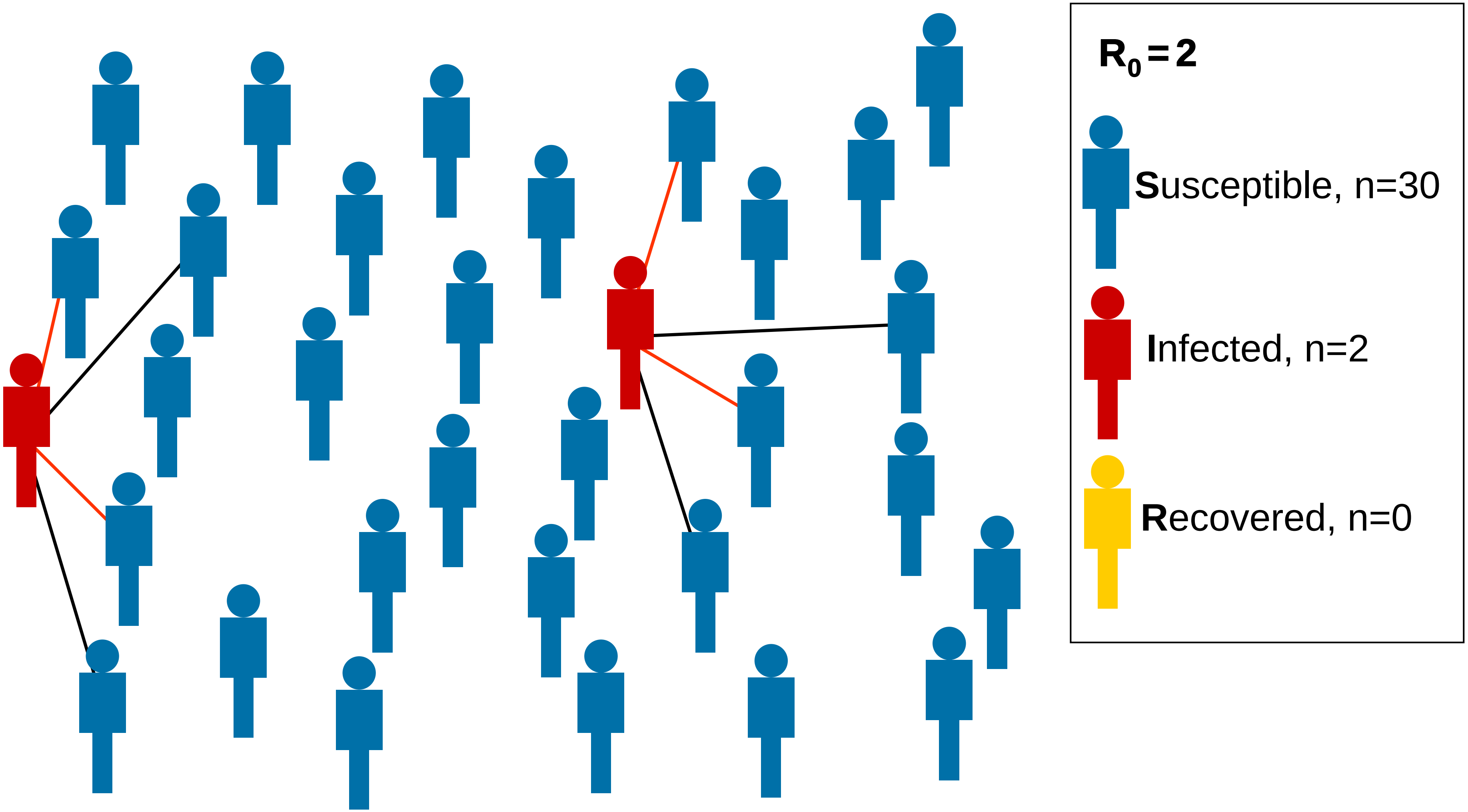


Exponential Growth?

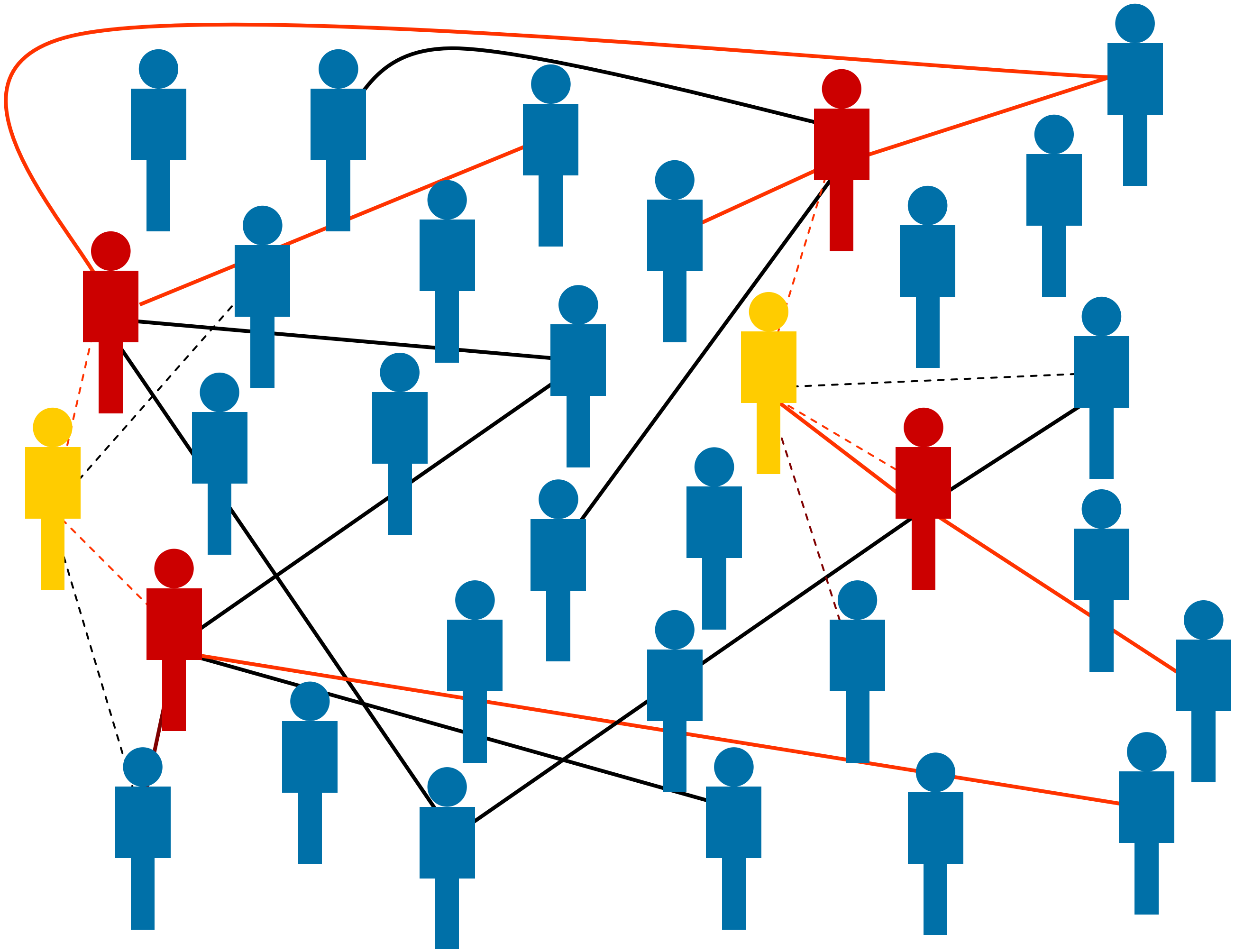


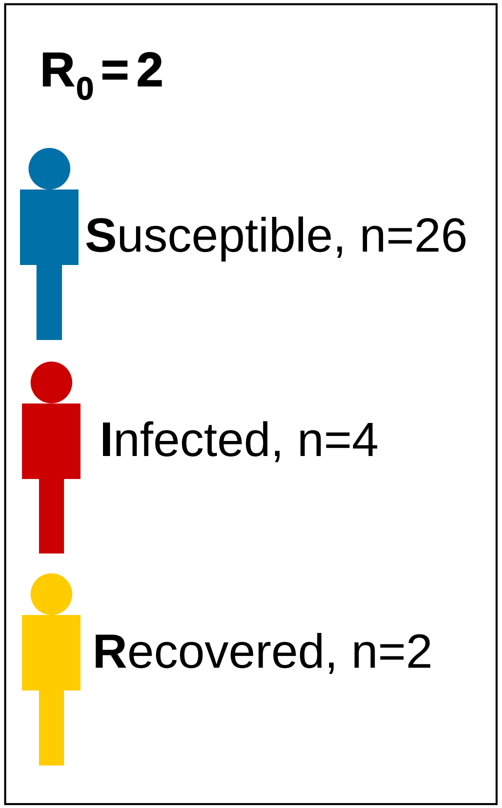
Why doesn't the entire population get the virus?

Simulation, Step 1

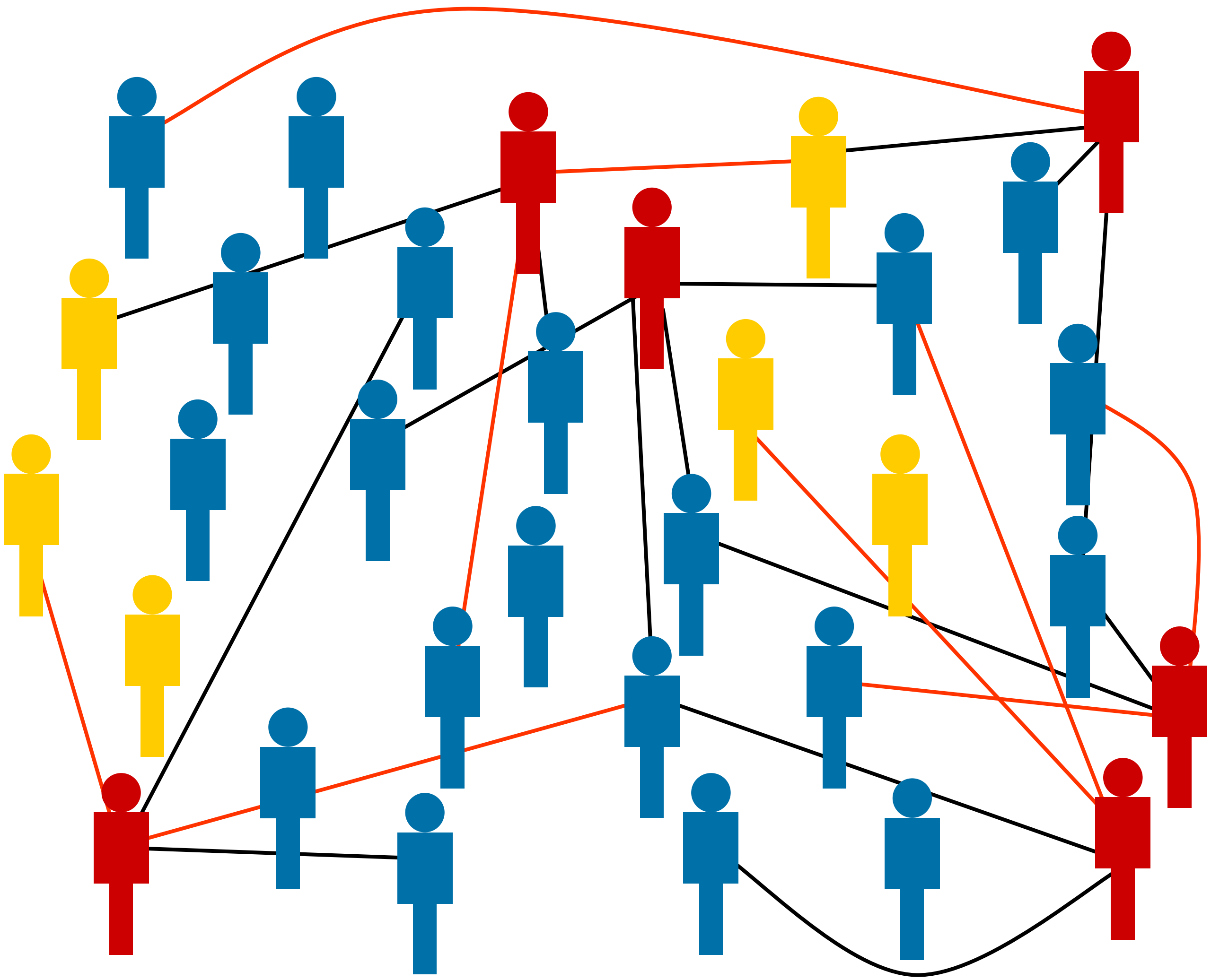


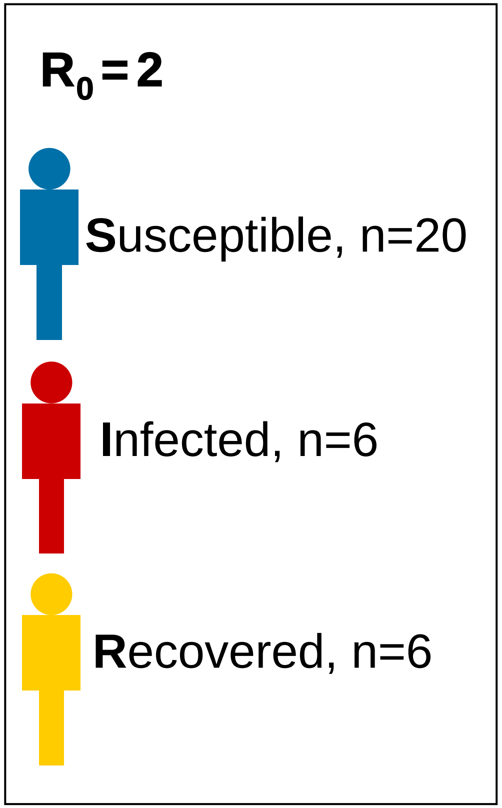
Simulation, Step 2



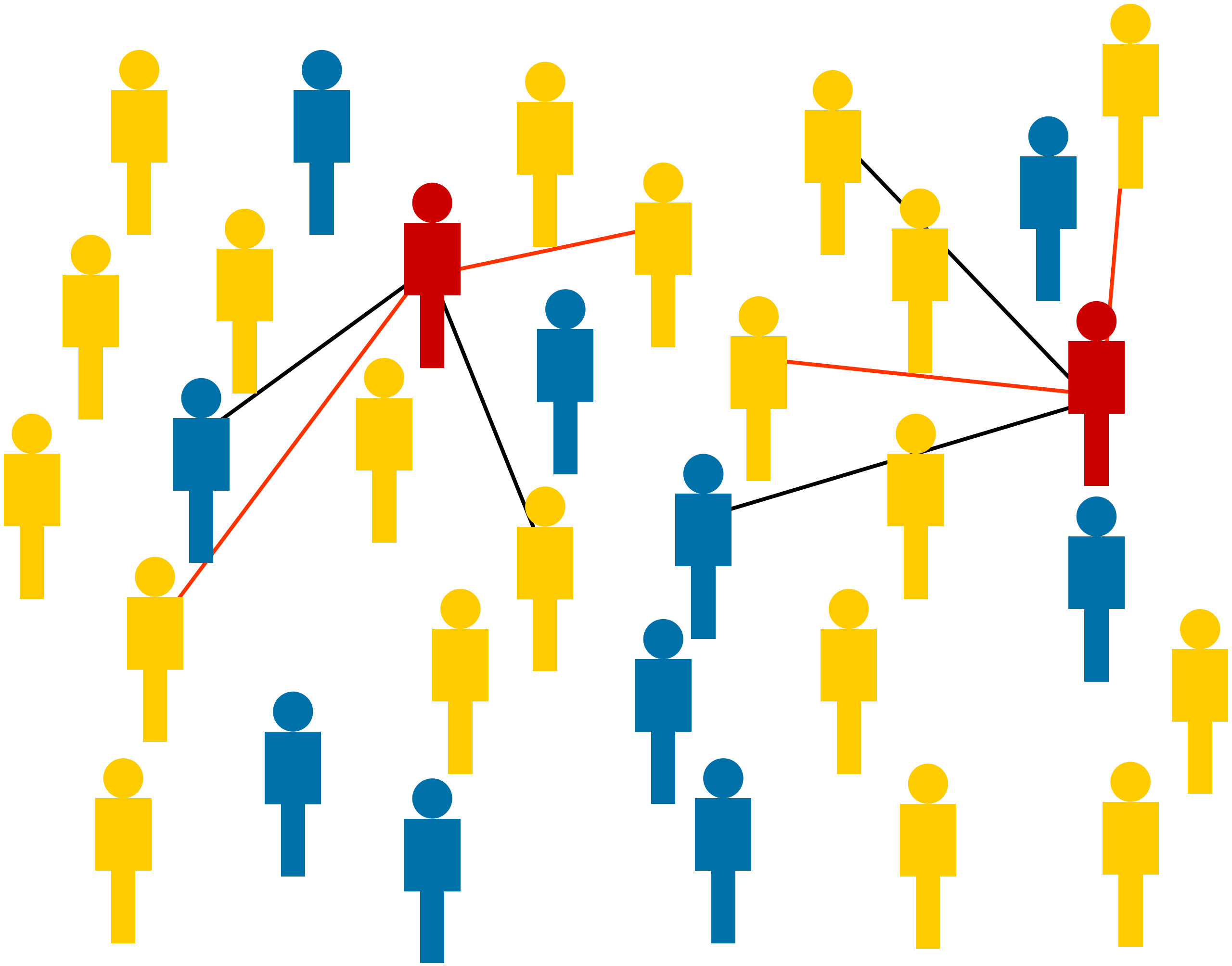


Simulation, Step 3





Simulation, Final Step



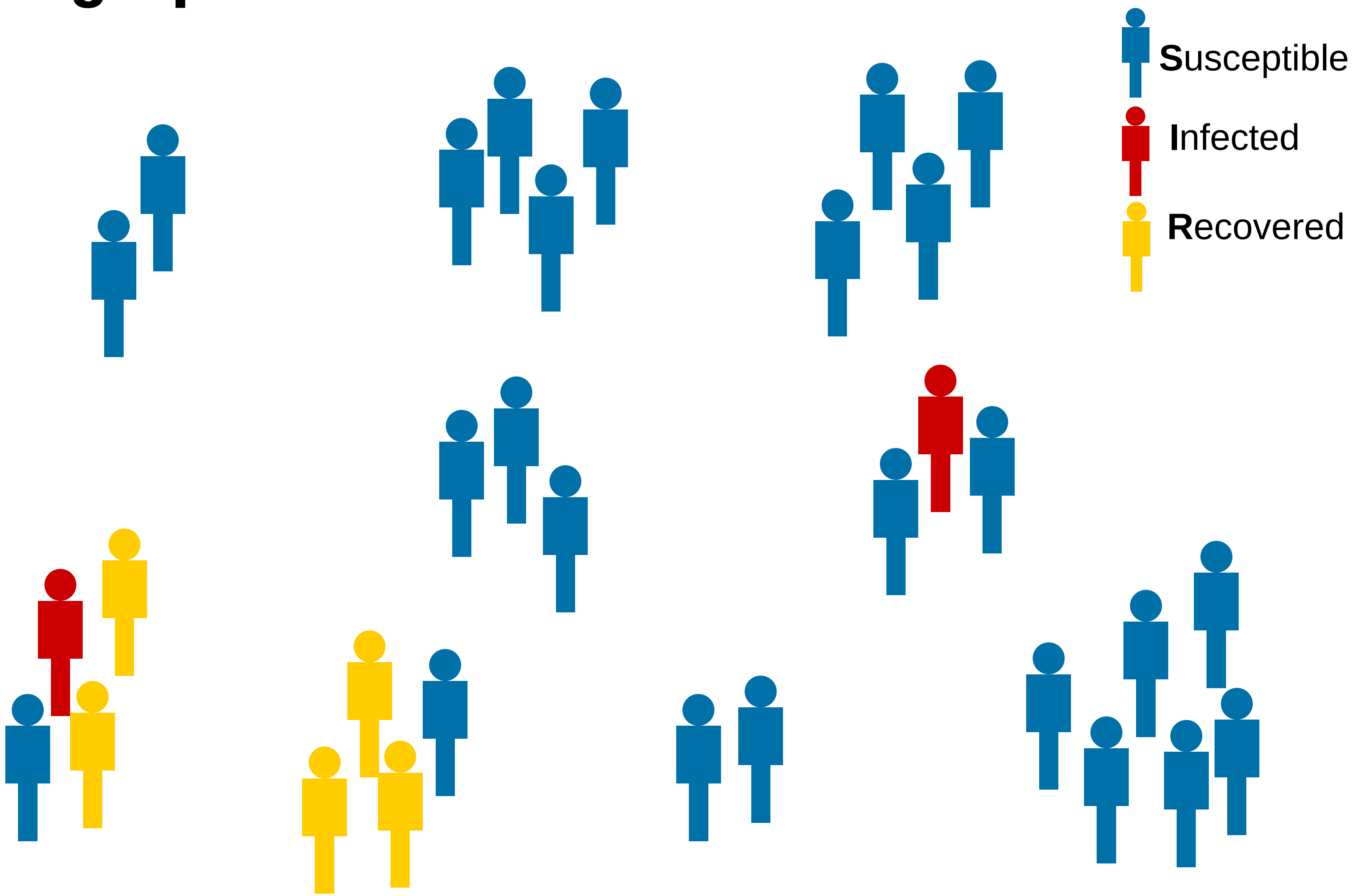
$R_0 = 2$

Susceptible, n=9

Infected, n=2

Recovered, n=21

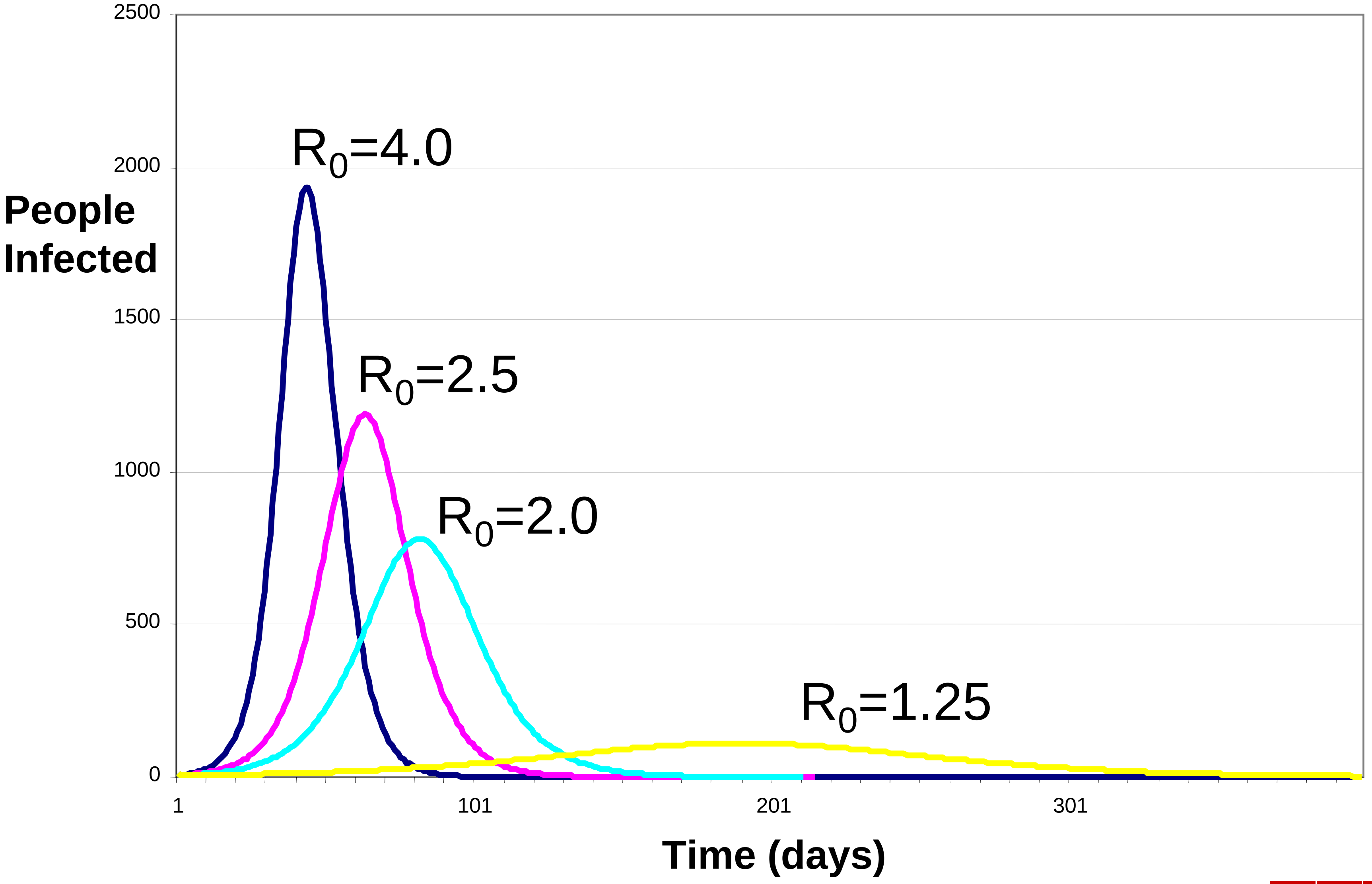
Geographical Limits to Growth



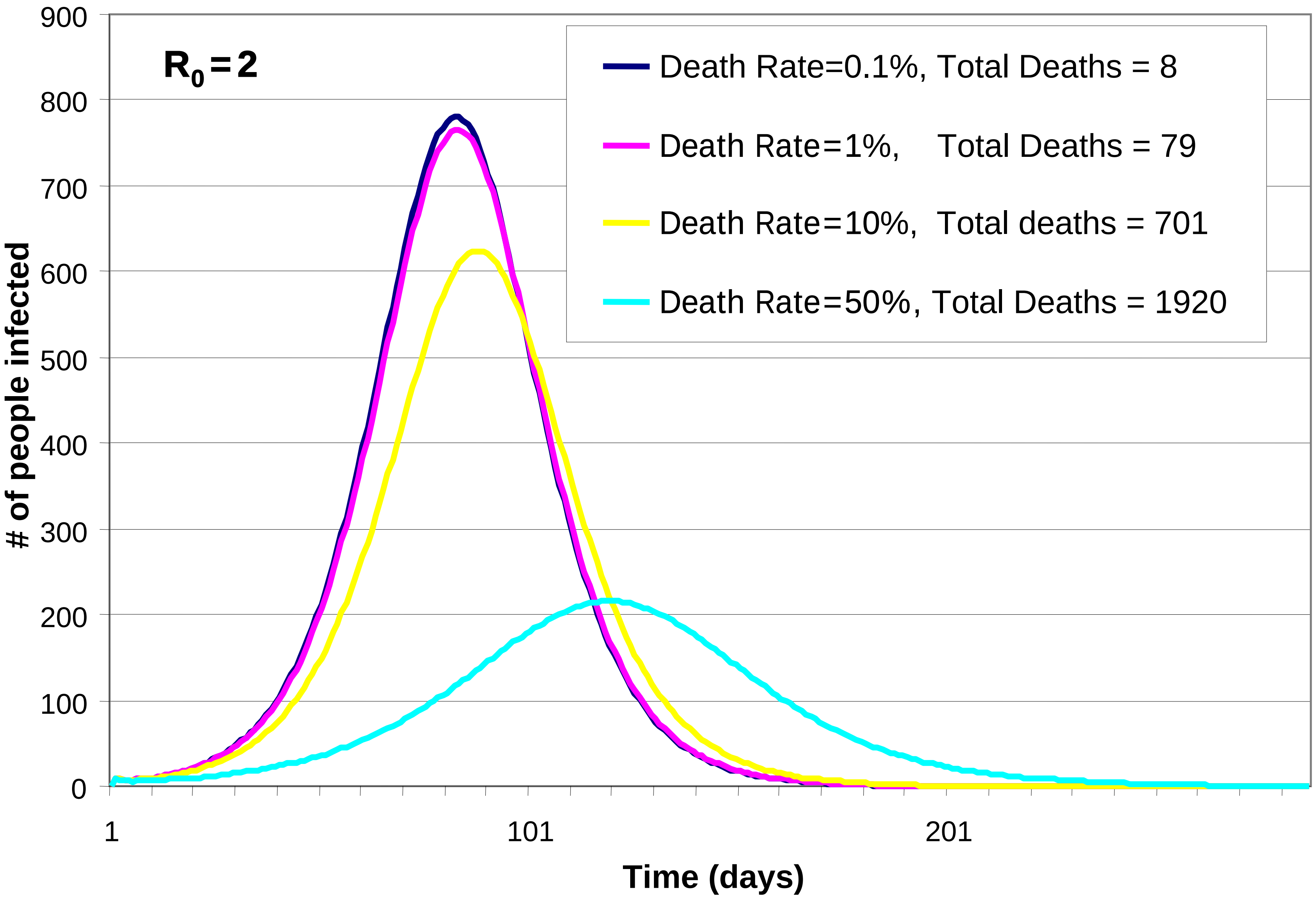
Factors Limiting Viral Spread

- Herd Immunity- Transmission cannot be sustained if there are not a sufficient number of susceptibles
- Quarantine- Sick people are less likely to be in the community transmitting disease
- Residual Immunity- Infection or vaccination with a similar strain
- Mortality- Dead people are less likely to transmit disease
- Medical Treatment- Reduces contacts and some treatments may also reduce transmission probabilities
- Geography- Most people stay within a small geographic region

Effect of R_0 on an Epidemic, no mortality



Effect of High Mortality Rates in Limiting Infection



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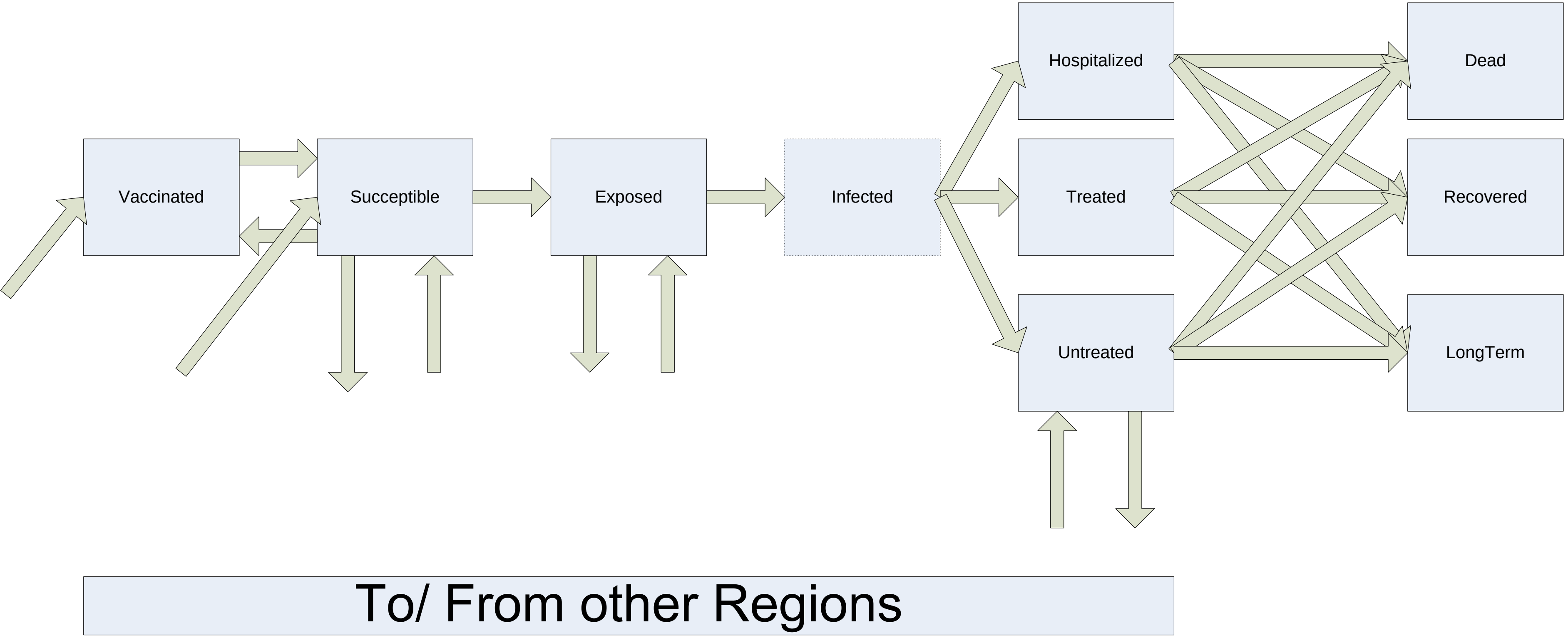
An Example SIR Framework



Drawbacks of Epidemiologic Modeling

- Model is only as good as its inputs
- Without a thorough understanding of the inputs and their relative impact SIR models can be “black boxes”
- Can be very unstable
- Deterministic (one set of initial conditions, leads to one answer)
- Requires many runs of the model to understand uncertainty and the impact of each variable

Benefits of Epidemiologic Modeling

- Model progresses in small timesteps
- Interventions can be added at any time
- Efficacy of different interventions can be compared
- Can understand transmission dynamics
- Simulation modeling using the SIR framework can be used to characterize uncertainty
- Infinitely adaptable to fit different diseases, initial conditions, and interventions

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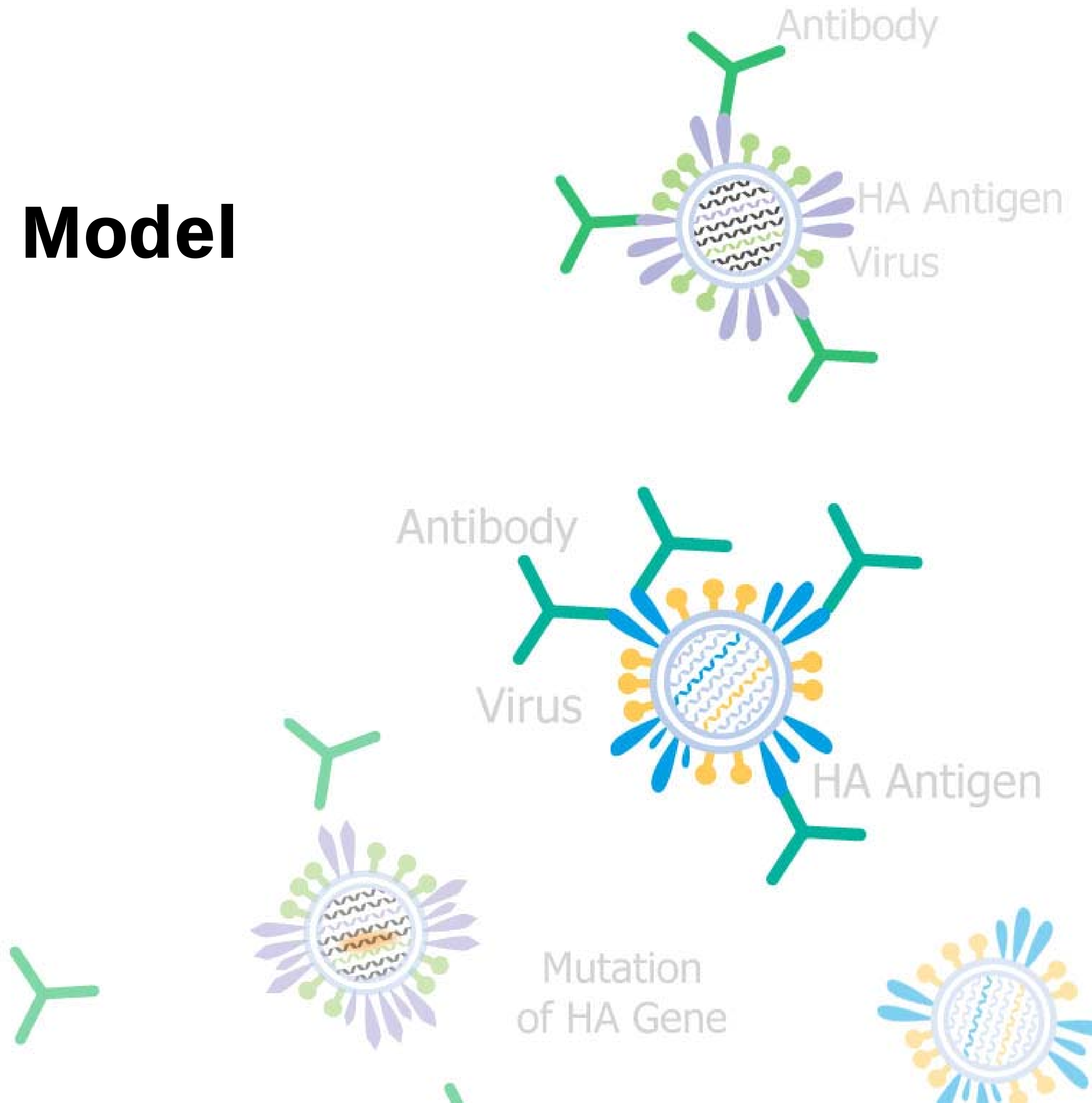
RMS Pandemic Model

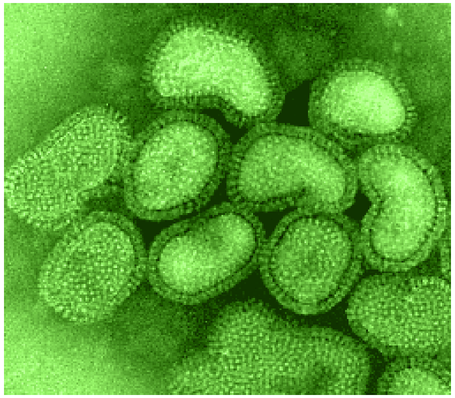


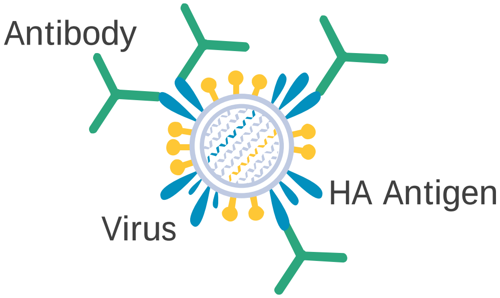
Influenza Pandemic Modeling Framework

Epidemiological Model

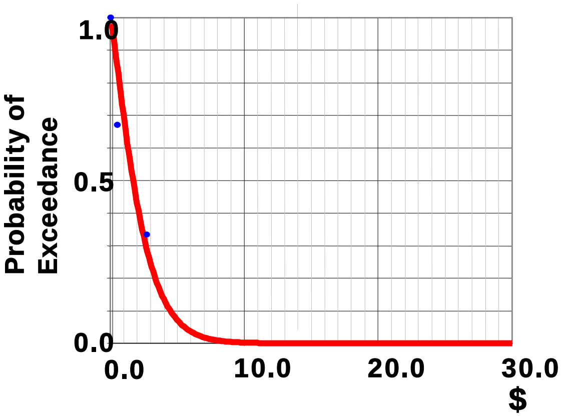
Stochastic Model

Probabilistic Model





Influenza Scenarios



Combination of Death per Case (DpC) and Initial Reproductive Number (R0)

RMS Stochastic Model Framework

1 Probability of Pandemic	Frequency assumptions
2 Infectiousness and lethality	Matrix of 42 initial R_0 / mortality assumptions
3 Demographic impact	3 age profiles
4 Location of outbreak	5 regions of outbreak
5 Vaccine production	Severity dependent vaccine production scenarios
6 National Counter-Measures	Severity dependent country-level counter measures
7 Pandemic Lifecycle	3 year pandemic lifecycle

Annual Probability of Pandemic

- In the 20th century, influenza pandemics occurred in 1918, 1957 and most recently in 1968. Before then, a pandemic occurred in 1889.

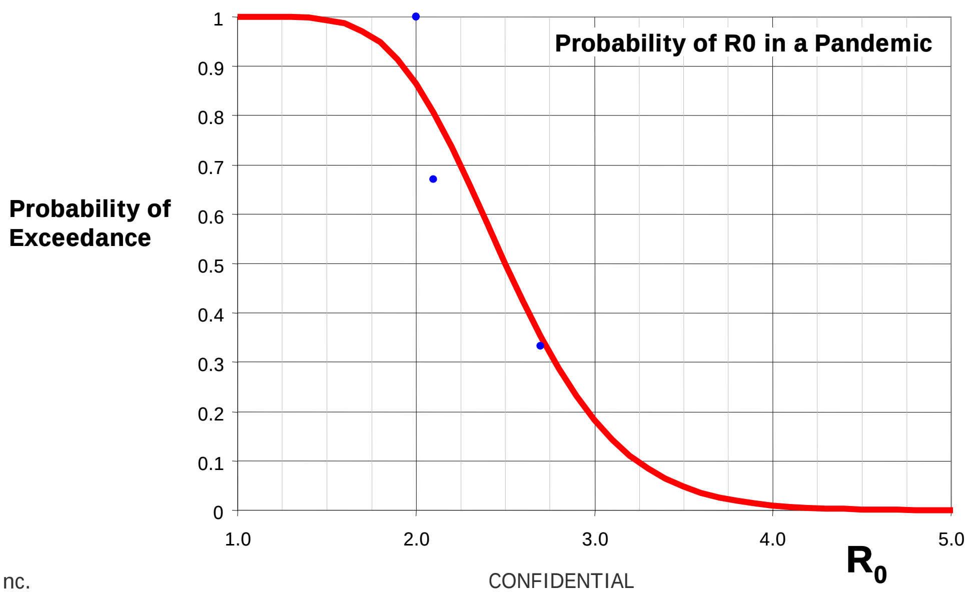
- Pandemics occur randomly in time. The elapsed interval since the previous pandemic is not necessarily a guide to the imminence of the next pandemic. An empirical baseline historical average estimate of pandemic frequency is 4 per 120 years, i.e. 3.3%.

- Conditional on a candidate pandemic virus circulating, (as is the case with H5N1), the annual probability of reassortment might be increased above the baseline historical average, depending on the number of cases of avian flu in humans.

Infectiousness Modeling

Long-tailed distribution for the Basic Reproductive Ratio R_0

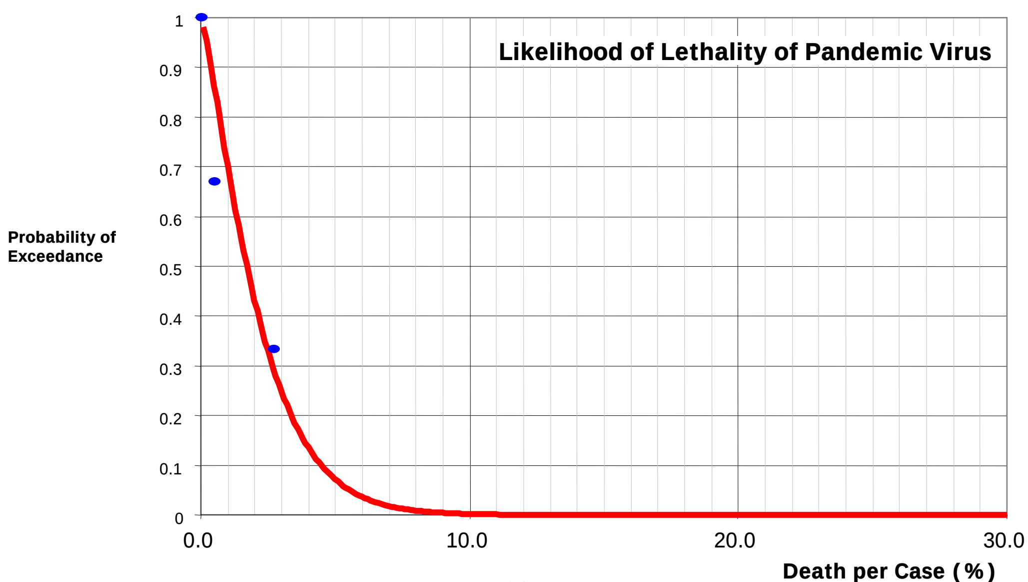
- There is considerable variability in R_0 due to a wide range of factors that may compound the process of infection spread.
- A Lognormal distribution is appropriate for representing this variability, since it can be constructed as a product of a number of multiplicative virological factors.
- Expert scientific judgement parameterizes the distribution with a median value of 2.5, and a 1% chance of exceeding 4.0.
- The distribution is truncated at 1.0, the minimum epidemic threshold.



Lethality Modeling

Long-tailed distribution for the Death Per Case DpC

- The Death Per Case (DpC) is modeled by a Weibull distribution:
  - Pr (DpC > X) = exp (- $[X/A]^B$)
- This type of distribution is commonly used for statistical survivor analysis.
- It is assumed that there is a 1/3 chance of exceeding the DpC in 1918, corrected for improved mortality since then.



Infectiousness & Lethality of Pandemic Viruses

Representative Pandemic Scenarios

Initial Deaths per Case		B	C	D	E	F	G
30 %	7	0.179%	0.353%	0.793%	4.1%	12.2%	20.8%
10 %	6	0.074%	0.206%	1.236%	3.7%	Niger Virus	8.8%
5 %	5	0.047%	0.116%	0.833%	2.4%	3.4%	3.8%
2.5 %	4	0.030%	British Influenza	0.393%	Hanoi Flu	1.8%	1.2%
1 %	3	0.014%	0.063%	0.169%	0.585%	0.711%	0.768%
0.5 %	2	0.010%	1957 0.054%	0.103%	0.196%	Turkish Flu	0.496%
0.1 %	1	Normal 0.003%	0.019%	1968 0.033%	0.040%	0.070%	0.081%

1.0 1.5 2.0 2.5 3.0 3.5 4.0

0.75 1.25 1.75 2.25 2.75 3.25 3.75

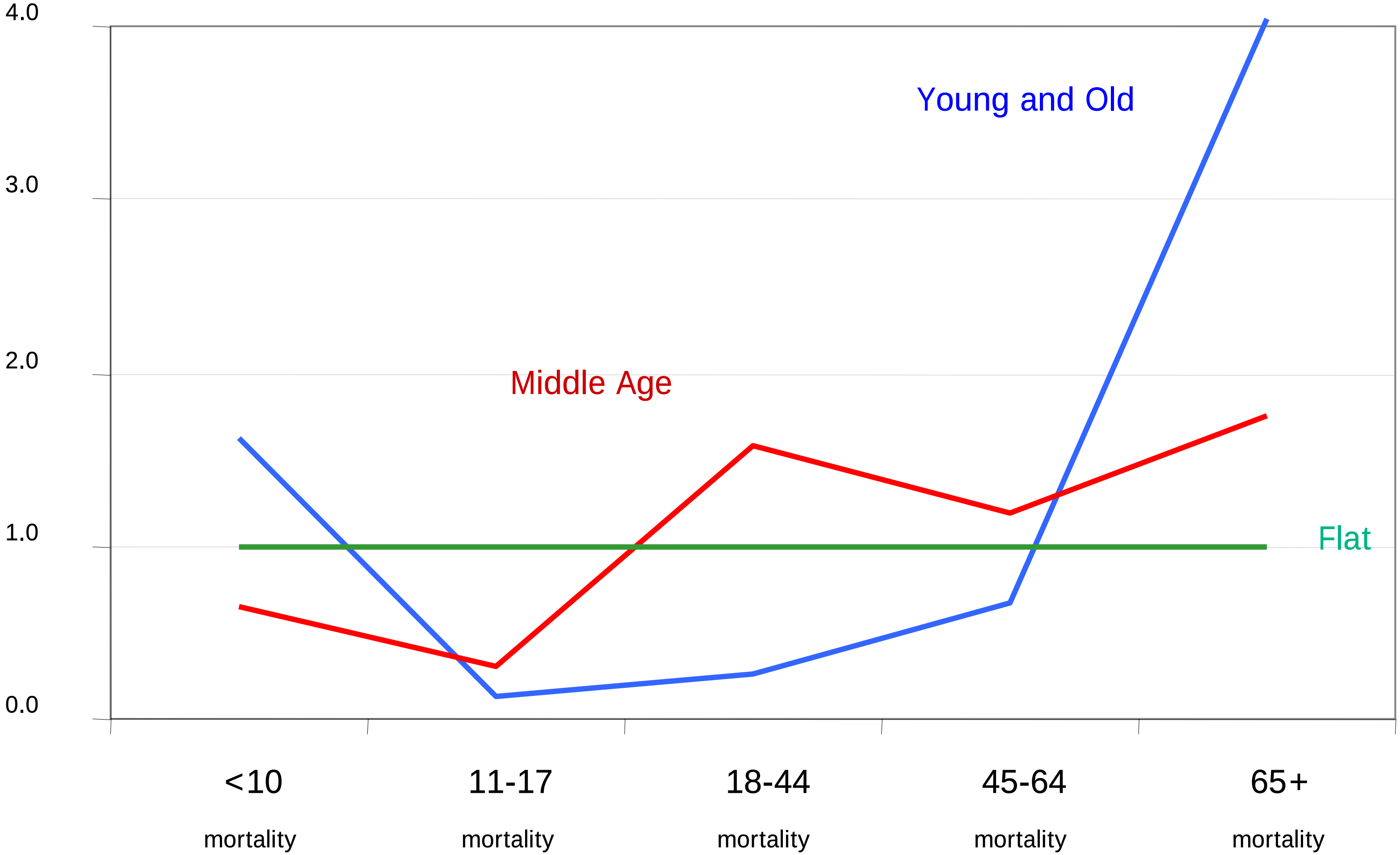
R_0 Initial Reproductive Number

Pandemic Severity

Very Severe
Severe
Moderate
Moderate Slow
Mild

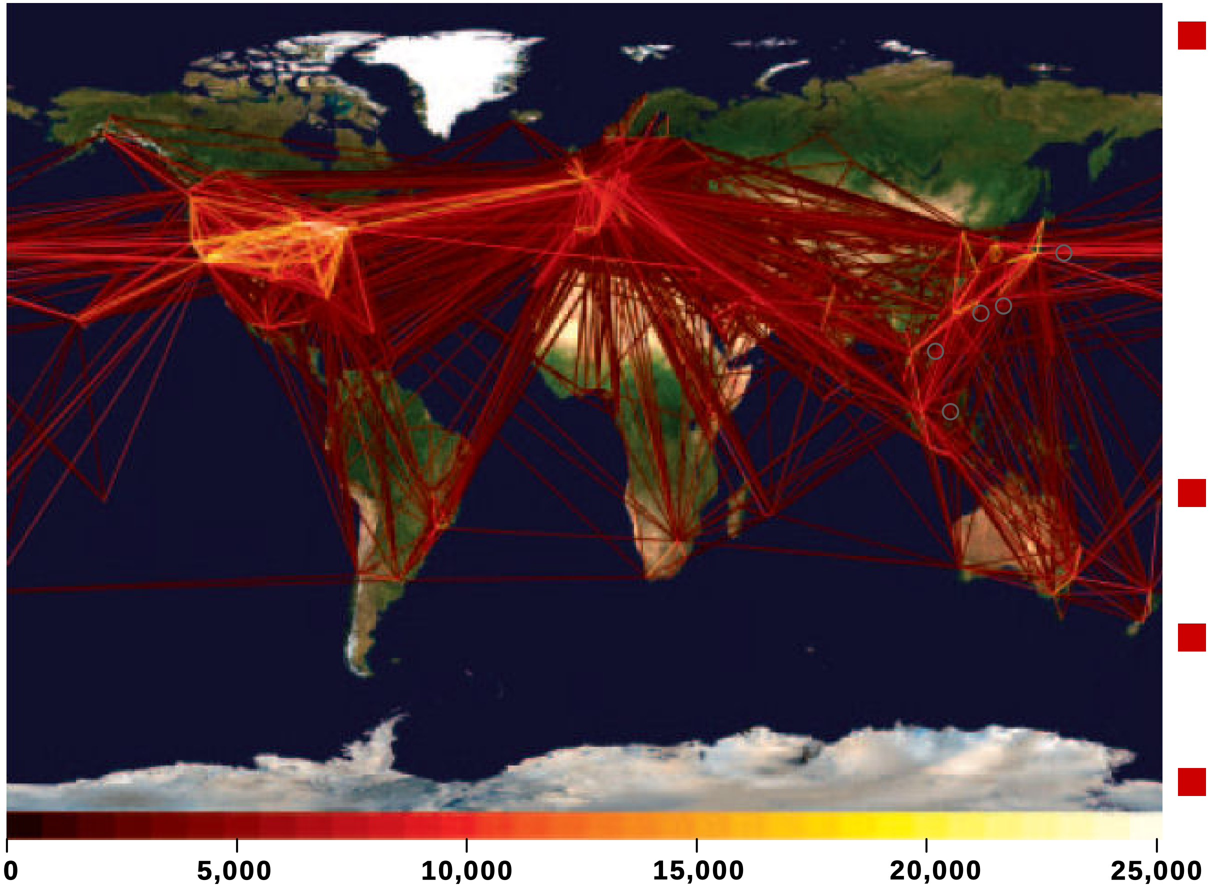
Reference Mortality for an Unprotected Population Without intervention

Demographic Profile



- ‘Cytokine storm’ kills young adults with strong immune response systems
- More severe pandemics may cause higher losses to young healthy individuals

Region of Origin: International Spread Model



Volume of passenger trips **per day** between international airports

- Outbreak source in each of five regions
  - 1 'Under-developed' SE Asia
  - 2 Japan, Hong Kong, Taiwan
  - 3 Russia, Balkans, Eastern Europe
  - 4 Western Countries
  - 5 Africa & ROW
- Different probabilities per region
- Modeled spread rate across the globe
- Incorporates national measures to contain, prevent and delay spread

Vaccination is not a panacea

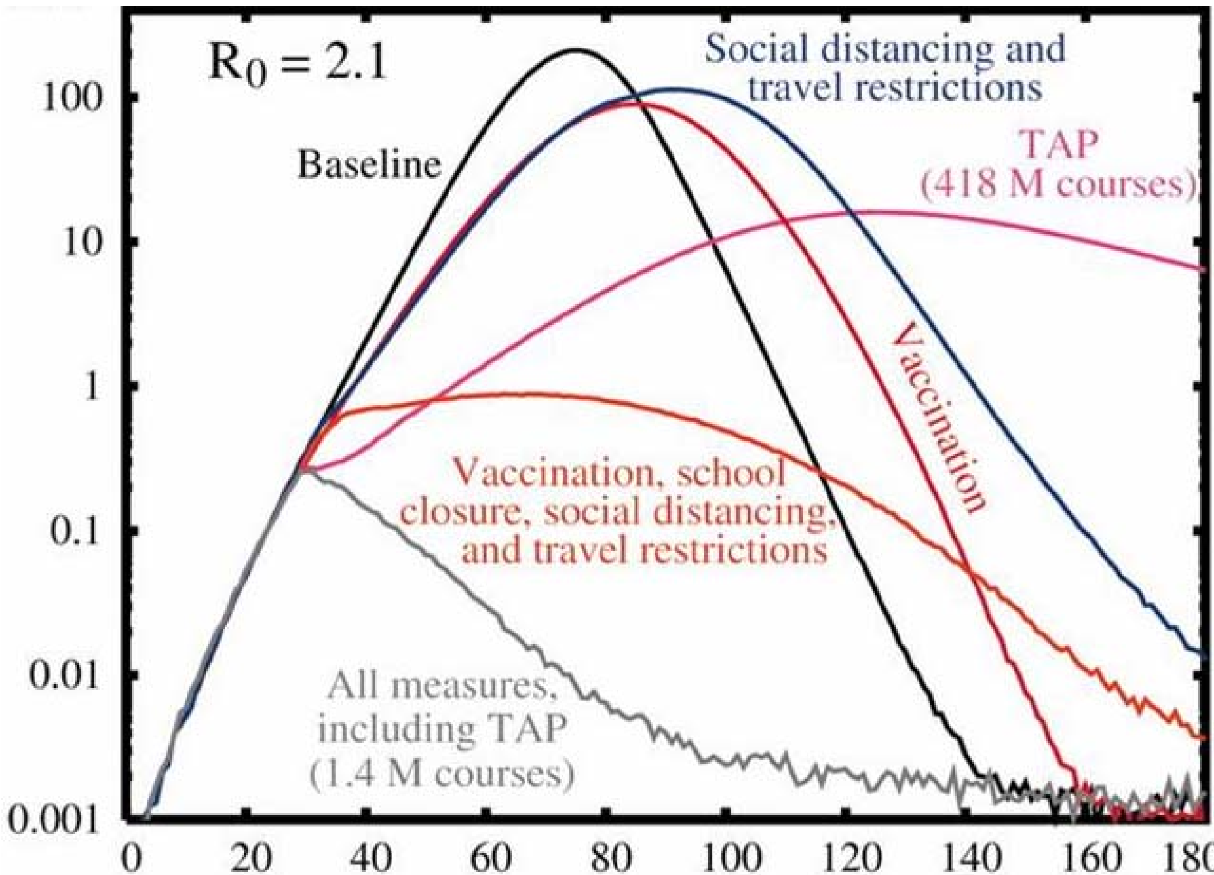
- Vaccines are designed to cause protective antibodies against the HA antigen
- Specific to a single viral strain
- Currently, egg-based production method
- Effectiveness of cross-immunity or a poorly matched strain is unknown
- United States currently has limited manufacturing capabilities
- Vaccination priorities vary by country

National Response Measures

	Antiviral Strategy	Primary Healthcare	Containment and Quarantine
United States	Tamiflu stockpile, Domestic vaccine production Target Group Prioritization	Deployable mass casualty capability used to supplement hospitals.	Patient isolation and identification, monitoring, quarantine of contacts
Japan	Tamiflu stockpile, Domestic vaccine production	**Coordination of different levels of medical supply structure**	**School closures, work hour reduction, public transportation closure**
Taiwan	Target Group Prioritization **Oseltamivir stockpile**	Hospitals activated in accordance with the needs of flu pandemic.	Isolation, closing schools and restricting public gatherings Border control
UK	Contribution of 18 m USD for flu vaccine production Tamiflu stockpile, Domestic vaccine production	NHS will establish ways of caring for large numbers of patients on a scale outside normal experience,	Public health and/or 'social distancing' measures to reduce morbidity and/or contain spread
Thailand	Target Group Prioritization Tamiflu stockpile, Domestic vaccine production Target Group Prioritization	**Increase hospital capacity; develop availability for field hospitals.**	**Screening of travelers, possible quarantine measures**
Malaysia	**Antiviral stockpile;** **Target Group Prioritization**	**Hospital System-Weak System**	**Quarantine areas within a three km radius of any suspected case. house to house checks.**
China	**Antiviral stockpile; Domestic Vaccine Production** **Target Group Prioritization**	**All medical resources mobilize and set up temporary clinics – Weak system**	**Alert System; Possible quarantine. Travel restrictions**
South Korea	**Antiviral stockpile;** **Target Group Prioritization**	**Hospital system**	**Alert System; Possible quarantine. Travel restrictions**

National Response Measures

- Quarantine
- Social distancing-travel restrictions, school closures
- Response of the healthcare system
- Pharmaceuticals
- Vaccination



Key Response Variables Affecting Pandemic

- Vaccine production speed, efficacy and manufacturing capacity
- Vaccination implementation
- Behavior of individuals
- Resources and initiative applied by government responders
- Time before pandemic arrival

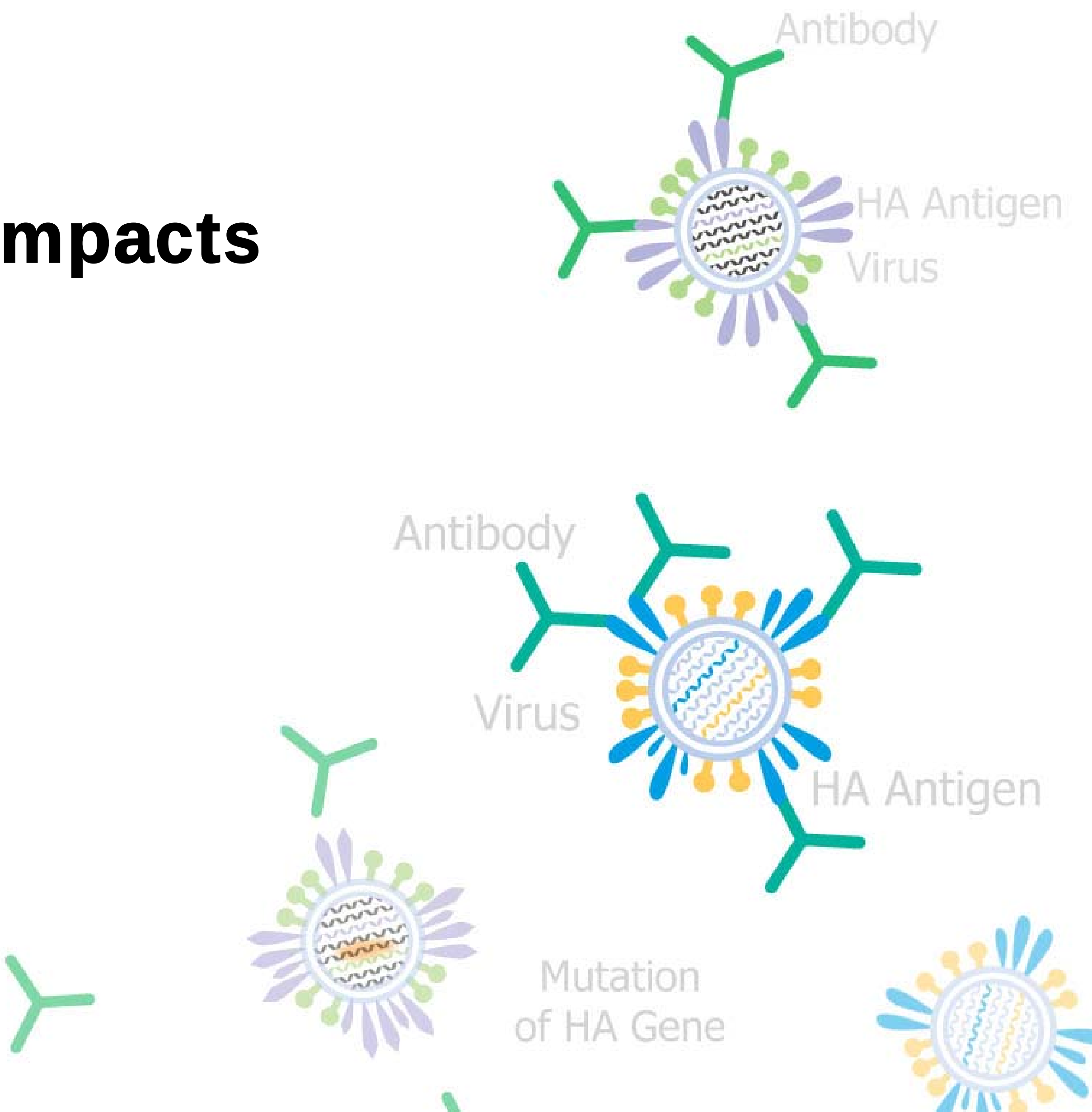
Moderately sensitive to:

- Tamiflu stockpiles
- Primary healthcare quality
- Warning (Disease surveillance capability)

Less sensitive to:

- Location of initial outbreak
- Closure of borders and imposed travel restraints

Pandemic Flu Impacts



Scenarios

Fictitious illustrations of potential influenza pandemics	Infectiousness (Speed of spread)	Pathogenicity ("lethality")	Illness Demographic (Ages worst hit)	Pandemic Severity
E4 **Hanoi Flu Pandemic** Fairly severe pandemic –H5N1 reassortment - originating in Southeast Asia, Similar to 1918 virus characteristics	Rapid spread R0=2.7	Moderately high DpC = 2.8%	Immune response hits middle age	Severe
F2 **Turkish Flu** Moderate pandemic – H5N1 shift, More severe than 1957 pandemic	V. Rapid spread R0=3.1	Moderate DpC = 0.5%	All ages equally affected	Moderate
D1 **British Influenza** Mild but likely pandemic – H1N1 drift, Similar to 1968 pandemic	Slow spread R0=2.0	Low DpC = 0.05%	Old and young worst affected	Mild
F6 **Niger Virus** Very severe pandemic – Highly pathogenic H5N1 reassortment. Unprecedented but feasible	V. Rapid spread R0=3.8	Very high DpC = 33%	Immune response hits middle age, Children infected but not sick	Very Severe

Fictional Scenario: Hanoi Flu Pandemic

Severity:	**Severe**
Type:	H5N1 reassortment
R0:	2.75
DpC:	2.5% initial
Age:	‘Cytokine Storm’ Mortality Profile
Origin:	Vietnam [Region 1]
Start:	Jan 2007
Vaccine:	5 months to production, 20% increased manufacturing capacity, 75% efficacy
Response:	Government plans executed as expected
Lifespan:	Yr 2 impact 10% of year 1
Precedent:	Similar virus parameters to 1918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Hanoi flu spreads to Japan

Yamaguchi Province under enforced quarantine

Thursday, February 22, 2007

TOKYO, Japan (CNN) – Suspected cases of the deadly Hanoi flu in four provinces of Japan prompted official action to contain the epidemic by sealing off roads and preventing travel.

Fears of infection running through Japanese cities prompted swift action by authorities overnight.

Emergency plans were implemented and stockpiles of Tamiflu were issued to healthcare teams across the country.

Civil rights protestors demanding drugs for all were last night blockading health ministry buildings in Osaka.
happen first.

But it says even a mild pandemic could kill 1.4 million people and cost $330 billion.

Blockades last night prevented travelers from leaving Tokuyama city, location of several suspected cases of Hanoi flu, now ravaging Vietnam and China.

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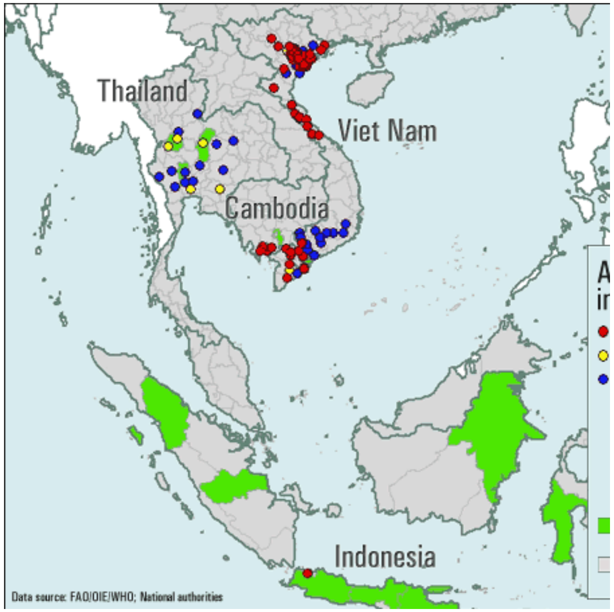

Timeline: First Two Months

Jan 2007

Initial cluster of 30 unusual flu cases in Northwestern Vietnam leads to additional cases in Hanoi.

Stock markets worldwide react badly to the news

By the end of the month 13 are dead in Vietnam and 200 in hospital.

Over 1,000 cases are confirmed. World Health Organization team in Hanoi issues stockpiled anti-viral drugs to health teams

All known contacts of confirmed cases are quarantined and given anti-virals

A suspected case is reported in Hong Kong

Analysis from case-tracing suggests the R0 to be above 2.5, and possibly as high as 3.2. Lethality unable to be measured yet

RMS provides clients with a broad range estimate of likely worldwide impact of pandemic

Feb 2007

22 cases now confirmed in Hong Kong. Suspected cases reported in China and Japan. Japan declares national pandemic alert

WHO criticized for delays in announcing stage 3 global pandemic ("We need to be sure" says spokesman)

Australia closes its borders – only air travel 'essential to national security' allowed in and out. Traffic reduced by 99% but 4,000 people still enter Australia per day. Border closure delays pandemic entering Australia by 2 weeks

Air travel in SE Asia heavily impacted

Impact appears low in children; symptoms suggest immune-response causes of death

Analysis of speed of spread suggests R0 is 2.5 to 2.9. Death rate of cases appears to be less than 5%. RMS model revises estimates of spread, lethality and likely age profile.

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H5N1 cases in north Vietnam could signal new flu virus

WHO official warns against panic

Monday, January 15, 2007

HANOI, Vietnam (CNN) – A cluster of 30 cases of unusual flu in farmers in Bavi was this morning confirmed as H5N1 – probably passed between them.

This could be the first indication that the avian flu virus has mutated to be able to passed from human to human. If so it could trigger a pandemic across the world – something that has been feared for some time.

However health officials warned against a panic reaction before tests can confirm that these were caused by a new strain of the H5N1 virus.

Vietnamese officials were urging caution but also preparing for the worst. They have requested the release of drugs stockpiled by the World Health Organization to assist them in containing any potential outbreak.

A surveillance team from Institute of Tropical Diseases in Hanoi confirms that cases in farming families in Bavi province are caused by H5N1

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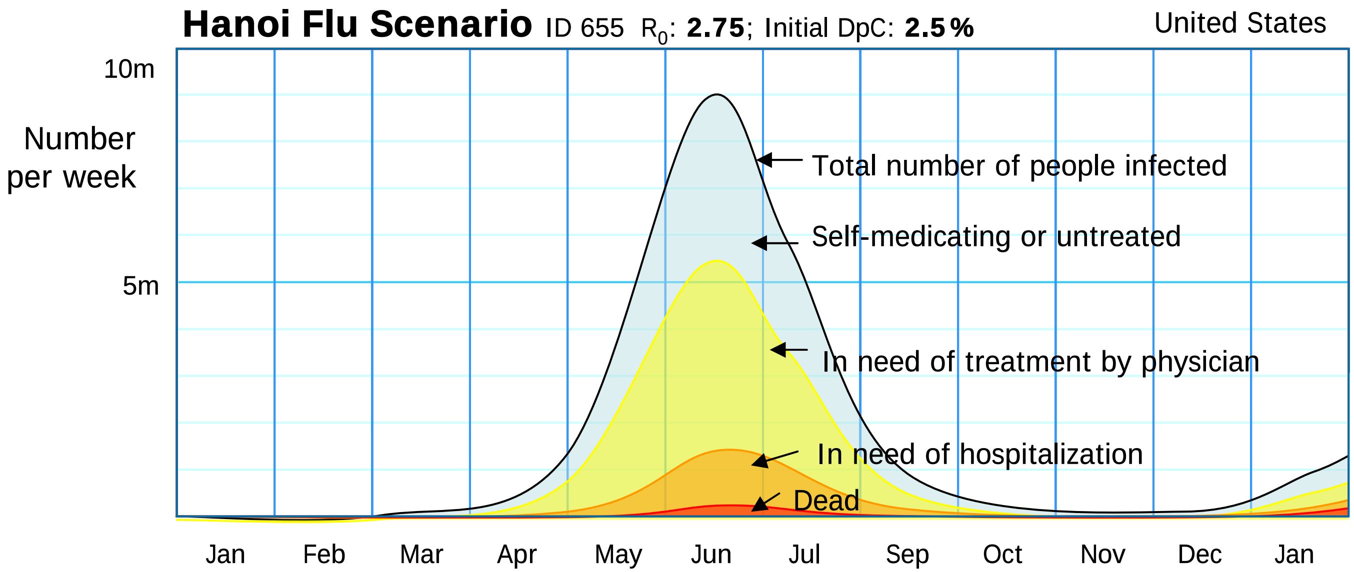
Impact of 'Hanoi Flu' Scenario on US

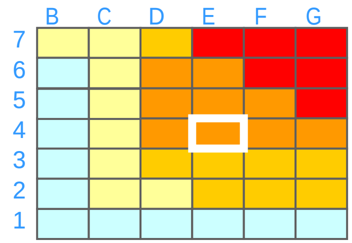
- 800,000 people die (0.27% of US population)
- 25% of the population are made sick
- 4.8 million people need hospital care
- 40 million people need treatment
- Among the US workforce, 333 millions days of lost production due to staff sickness
- Loss of about 7% productivity in the worst 3 month period, 2% of national production for the year

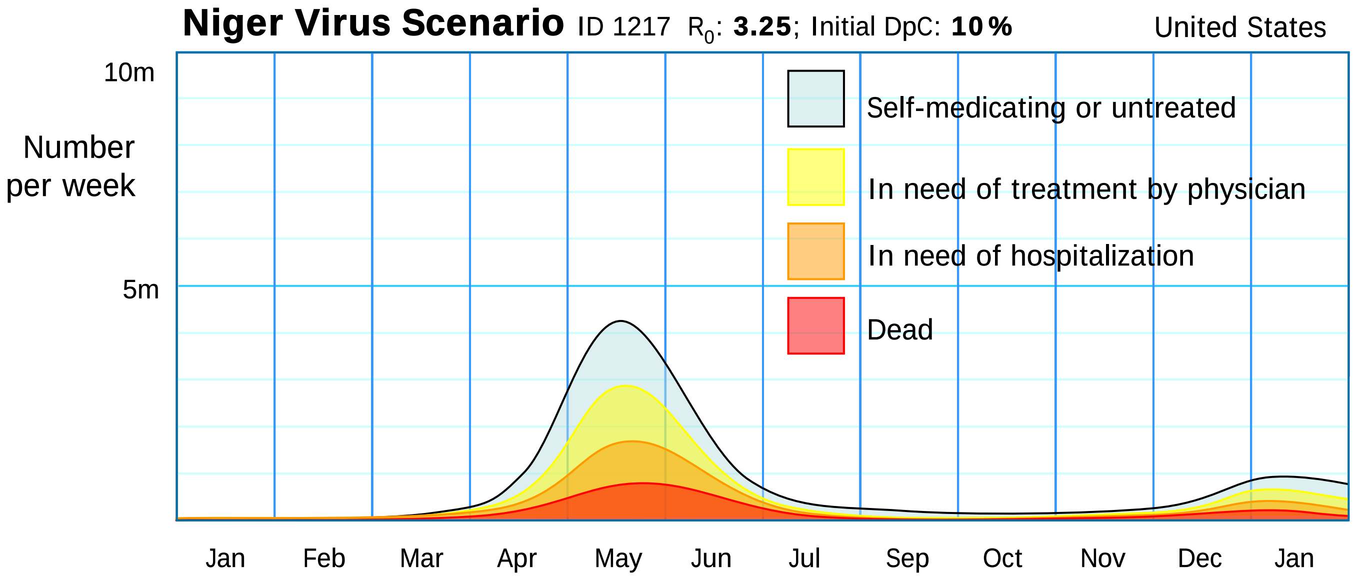
Economic impact of Hanoi Flu

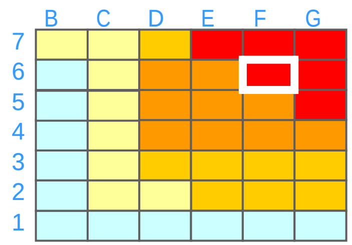
- Congressional Budget Office estimates 5% of lost US GDP in severe pandemic similar to 1918
- Other studies
  - McKibbon & Sidorenko: 5.5% of GDP in US
  - Cooper: 6% of GDP in US
  - Kennedy, Thompson & Vujanovic: 6% of GDP Australia
  - New Zealand Treasury: 5-10% of GDP, New Zealand
  - James & Sargent: 0.3 to 1.1%, Canada & Advanced Economies
- Economic activity expected to snap back after pandemic ends
- Some studies (e.g. J&S) conclude minimal impacts on retail sales, shipping or supply chains

Comparison of Two Pandemic Scenarios









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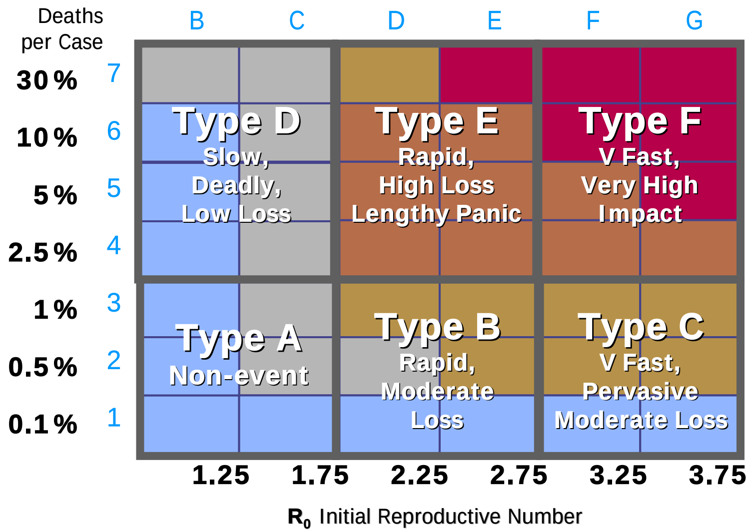
Pandemic type affects economic loss

	Direct Cost	Supply Shock	Demand Shock
A Non-Event	**Minimal**	**Minimal**	**Initial, short lived**
B Rapid, Moderate	**Moderate**	**Moderate**	**Lengthy but subsiding**
C V Fast, Pervasive	**Moderate-High**	**Everyone affected**	**Short, subsiding**
D Slow, Deadly, Low Loss	**Minimal**	**Minimal**	**Panic**
E Rapid, High Loss	**High**	**High**	**Lengthy**
F V Fast, V High Impact	**Very High**	**Very High**	**Short but severe**



Economic sectoral impact from pandemic

	Direct Cost	Supply Shock	Demand Shock
Travel and tourism	-	•	●
Public gatherings	-	•	●
Public transport	-	•	●
Education	-	•	●
Retail high street	-	•	●
Large labor industries	-	●	•
Fragile Businesses	-	●	•
Life insurance	●	•	+
Medical Suppliers	+	•	-
Pharmaceuticals	+	•	-
On-line retail	-	•	+
Telecoms	-	•	+
Virtual companies	-	○	+
Pension Funds	○	•	-

Business Continuity Planning for Pandemic

1. Ensure continuity of essential services and operations during an extended period of high illness rates in the workforce
2. Ensure that its employees do not, through their office interaction, suffer any higher rates of infection than the general population
3. Ensure that as soon as the pandemic cycle is over, the company resumes operations rapidly and competitively

Measures include:

- Duplication of staffing of critical operations
- Home-working
- Pre-emptive office closures
- Minimizing travel
- Managed or minimized customer interaction
- Suspension of certain trading activities (e.g. new sales of life insurance)
- Staff health monitoring

Cats have tails

- Pandemic influenza, like other catastrophe perils, has severe events of diminishing likelihood
- A “1918” event does not represent a worst case
- The US pandemic preparedness plan prepares for up to 2 million fatalities
- A worst case would be a virus with the pathogenicity of H5N1 and the infectiousness of H1N1, but this is extremely unlikely
- Extreme events are limited by behavioral actions by the public and the resources and ingenuity of our public protection systems

Conclusion

- Despite advances in healthcare infectious disease is still the greatest catastrophic threat facing human populations
- Modeling helps us understand and plan for what has happened and for what is possible
- Modeling is currently the best method to understand the spread of infectious disease and the implications of interventions

Model Specifications for Influenza

- **Geographic Scope** – 31 countries
  - Australia, Austria, Belgium, Brazil, Canada, China, France, Germany, Hong Kong, India, Indonesia, Ireland, Italy, Japan, Malaysia, Netherlands, Philippines, Poland, Russia, Singapore, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, Turkey, United Kingdom, United States, Vietnam
- **Exposure Analyze**: Deaths, hospitalized, critical care, infected
- **Analysis Types**: Deterministic (Scenario), Probabilistic (OEP)
- **Stochastic Model:** 1,890 unique scenarios; vary based on virus infectiousness and lethality of virus, demographic impact, location of outbreak, and pandemic lifecycle