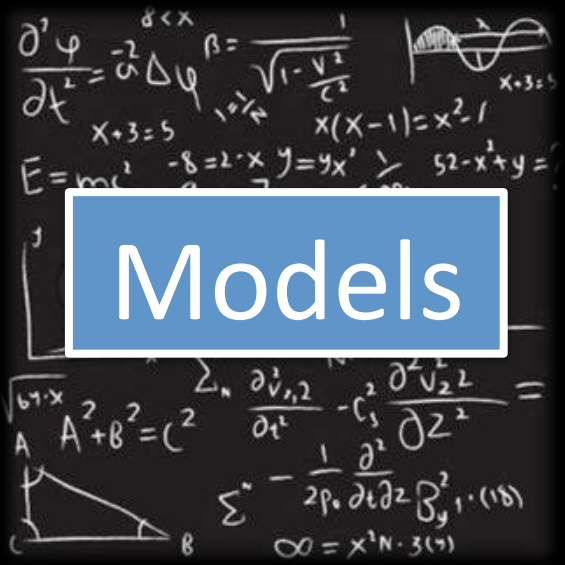
What is Science?



and

DAIDD 2015

Steve Bellan, PhD, MPH

Postdoctoral Fellow, University of Texas at Austin

Telling Science as a Story

- Are stories objective?
- The importance of a narrative
- Communication
- But what is Science?

What is Science?

- The Process

- The Body of Knowledge

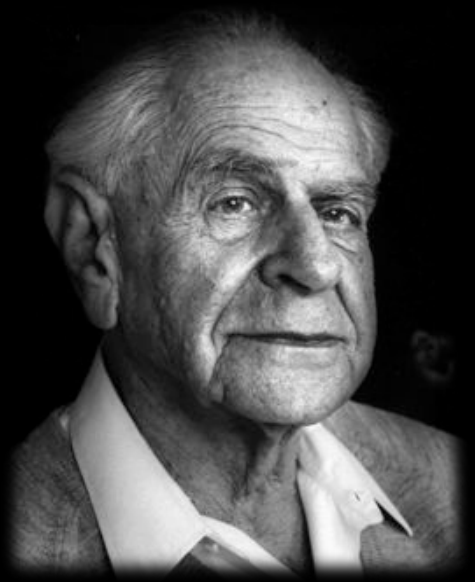
Science as a Process

1. the systematic observation of natural events and conditions in order to discover facts about them and to formulate laws and principles based on these facts. – *Academic Press Dictionary of Science & Technology*

2. Science alone of all the subjects contains within itself the lesson of the danger of belief in the infallibility of the greatest teachers in the preceding generation… I can also define science another way: Science is the belief in the ignorance of experts. – *Feynman*

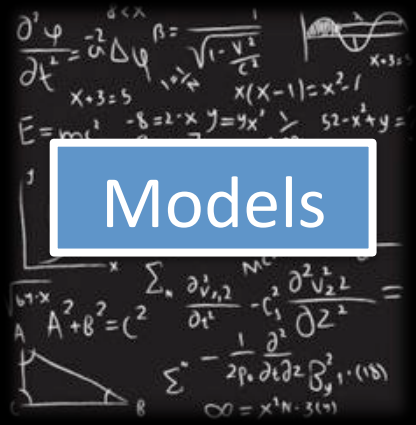
Philosophy of Science

- Karl Popper
  - Empirical Falsification
- Thomas Kuhn
  - Subjectivity
  - Normal Science
  - Scientific Crises
  - Paradigm Shifts



Theory and Observation

- Theory
  - Explanations
  - Guesses
  - Ideas



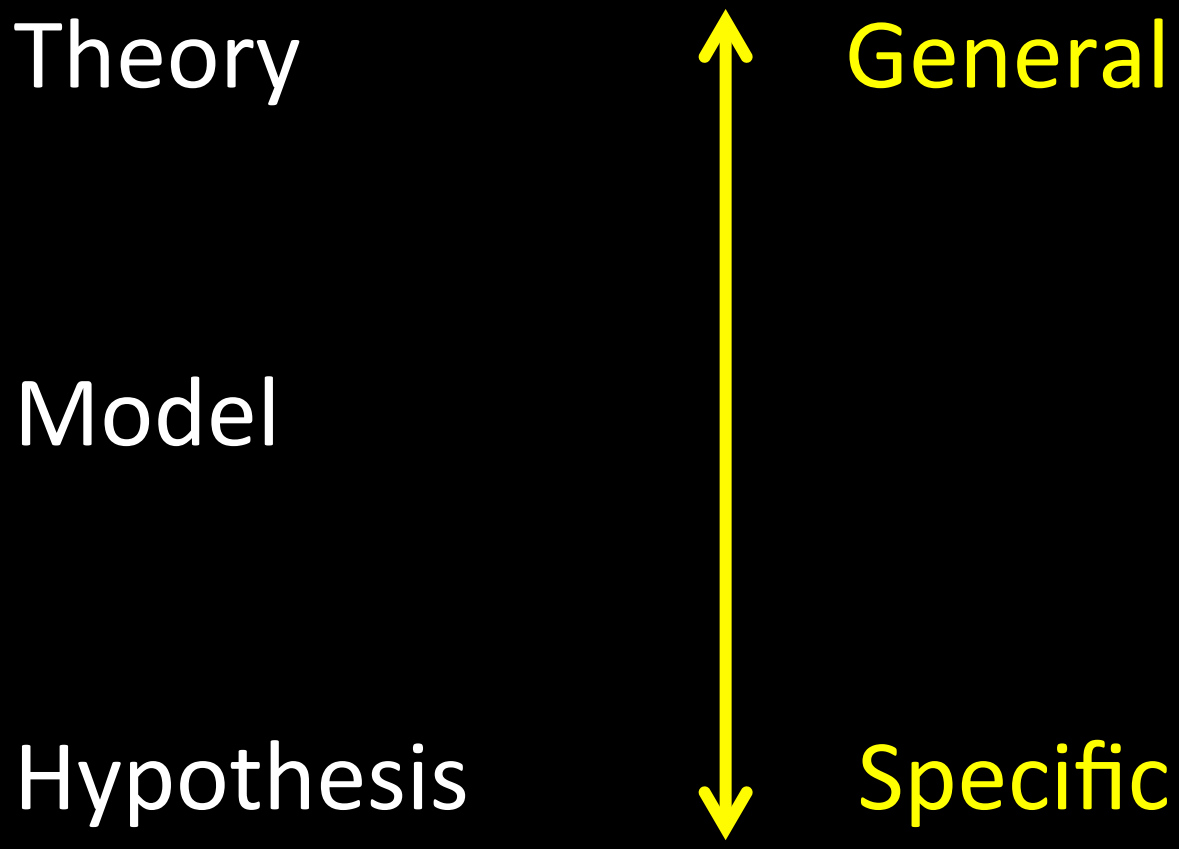
- Observation
  - Anecdotes
  - Expert opinion
  - Systematic qualitative data
  - Systematic quantitative data

Theory, Models, Hypotheses

- Theory = set of statements that provides an explanation of phenomena
  - Logically complete & falsifiable
- Model = abstract representation of phenomena
- Hypothesis = testable statement derived from a theory

Adapted from Susan Simm (UC Irvine)

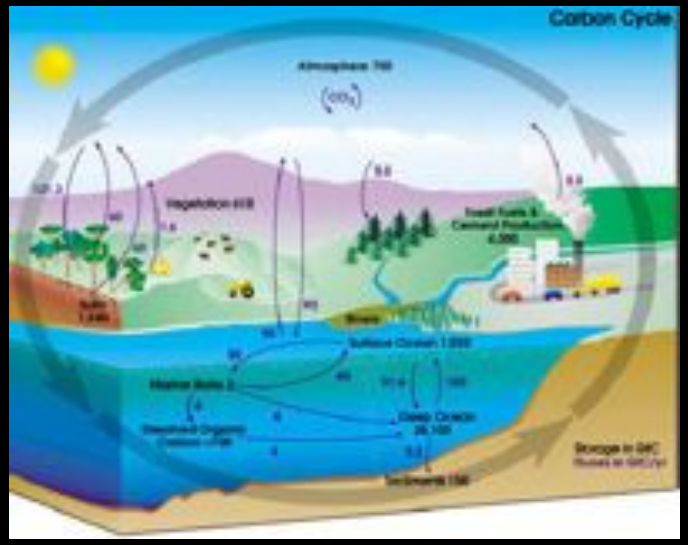
Theory, Models, Hypotheses



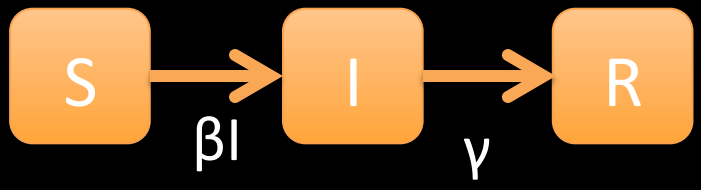
Types of Models

- Physical

- Conceptual



- Mathematical



$$\frac{\partial}{\partial a}\ln f_{a,\sigma^2}(\xi_1)=\frac{(\xi_1-a)}{\sigma^2}\qquad f_{a,\sigma^2}(\xi_1)=\frac{1}{\sqrt{2\pi}\sigma}\exp\left[-\frac{(\xi_1-a)^2}{2\sigma^2}\right]$$

$$\int T(x)\cdot\frac{\partial}{\partial\theta}f(x,\theta)dx=\mathrm{M}\left(T(\xi)\cdot\frac{\partial}{\partial\theta}\ln L(\xi,\theta)\right)\qquad \int\frac{\partial^2}{\partial\theta^2}f(x,\theta)dx=0$$

Models

- When you create a model you are

  proposing what you think could be

  the most important things

  to explain an observed phenomenon

Utility of Models

- All models are wrong but some are useful.
  George Box

- Goal of models is to predict and to explain

Science as a Story

- Are stories objective?
- The importance of a narrative
- Communication
- Story of the process or the body of knowledge?

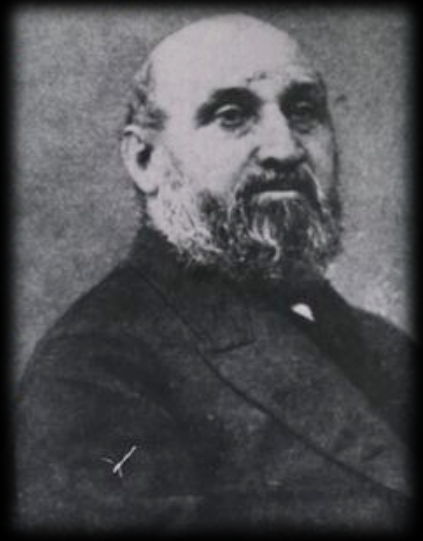
Miasmatic Theory of Disease

Disease = poisoning by foul emanations from soil, air, water

model

The Black Death as Miasma

Advocates



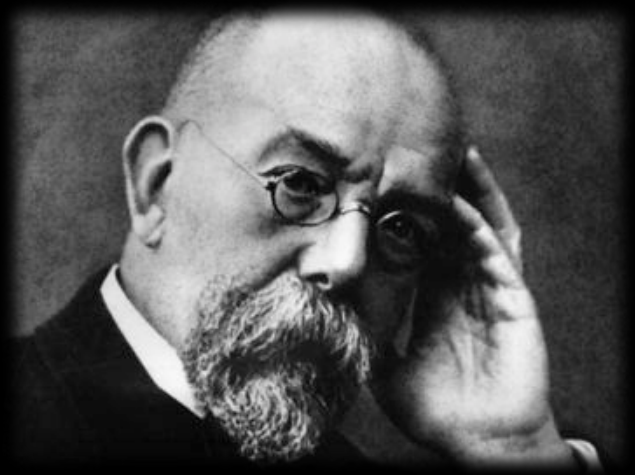
William Farr
1851 London
cholera outbreak

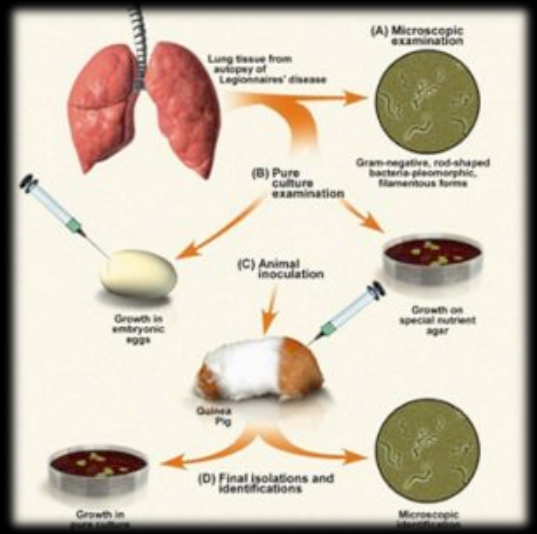
Florence Nightingale

Germ Theory

- Louis Pasteur

- Robert Koch





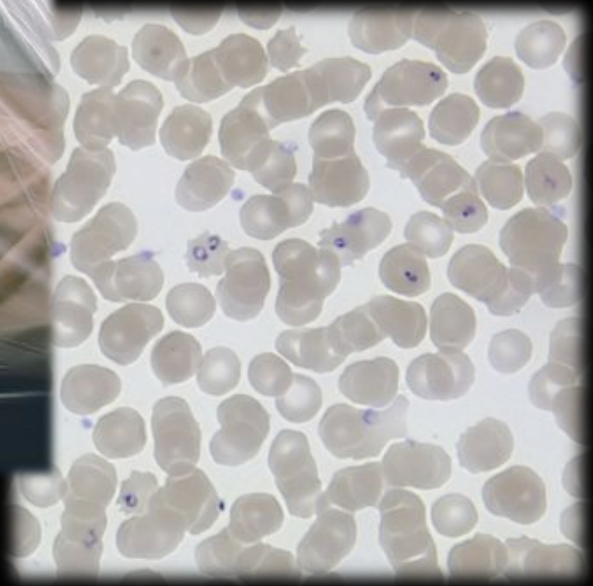
Koch's postulates in
The Genesis of Germs
Gilken (2007)

Theory of Mosquito-Borne Transmission

Aedes aegypti

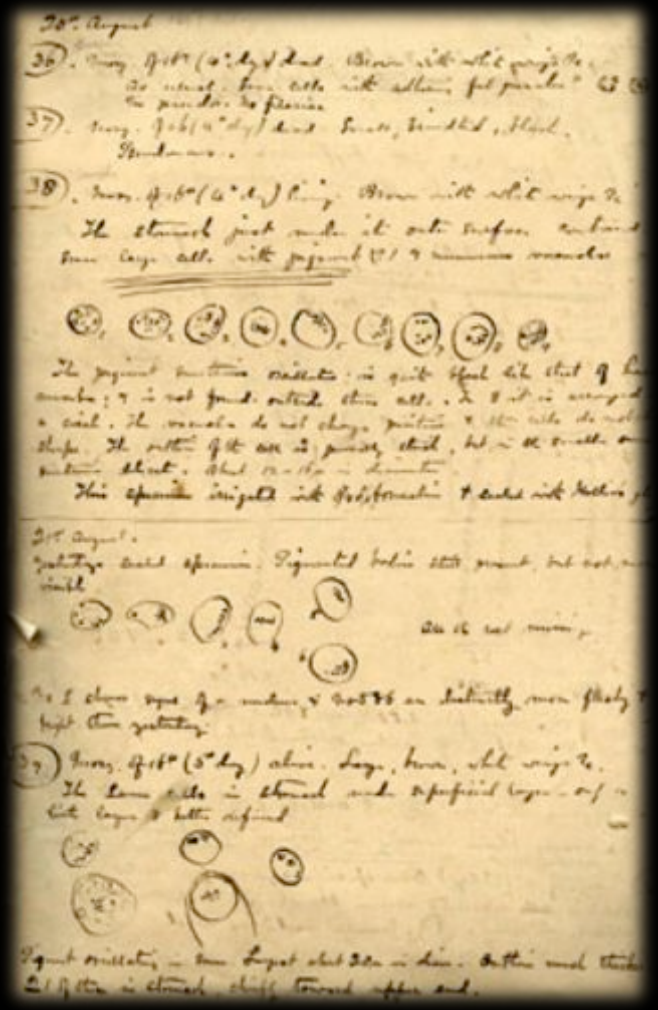
Anopheles gambiae

Homo sapiens



Plasmodium falciparum

Ronald Ross & Malaria



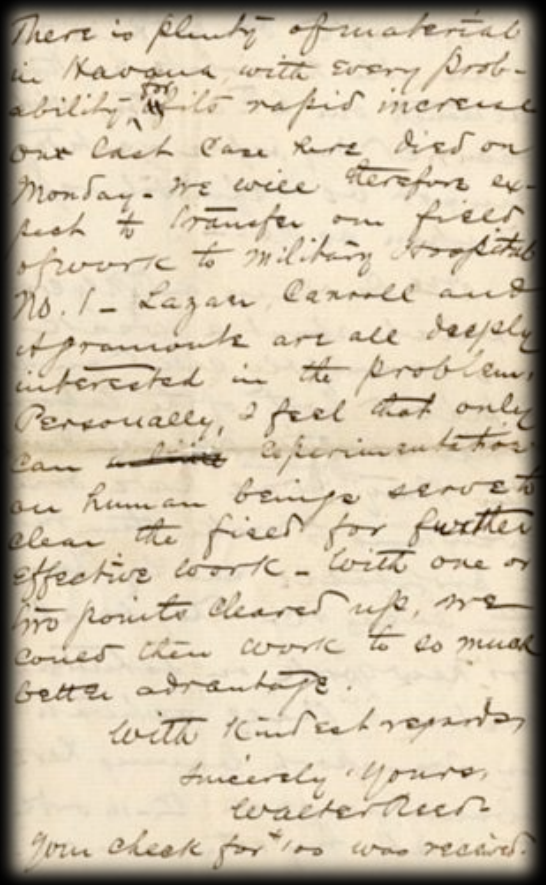
Ross' 1897 drawings of *Plasmodium* oocysts

After 2 years of feeding various insects on malarious patients Ross tried an *Anopheles* sp. and found the infectious life state microscopically.

models and data

Walter Reed & Yellow Fever

Letter from Walter Reed to George Miller Sternberg
July 24, 1900



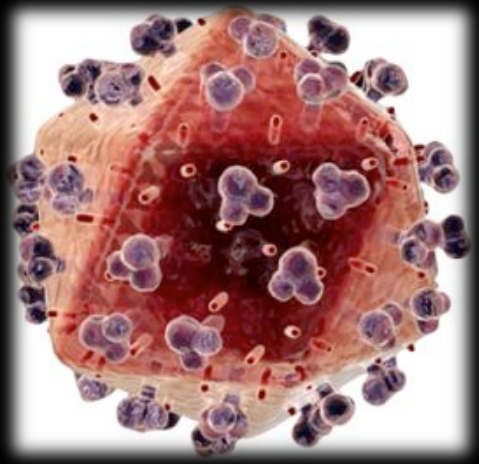
There is plenty of material in Havana with every probability of rapid increase. One case came died on Monday. We will therefore ask to transfer our field of work to Military Hospital No. 1 – Lazear, Carroll and myself are all deeply interested in the problem. Personally, I feel that only experimentation on human beings serve to clear the field for further effective work – with one or two points cleared up, we could then work to so much better advantage.

With kindest regards,
Sincerely Yours,
Walter Reed

Your check for $100 was received.

Credit Am Trop Med Hyg

"Personally, I feel that only can experimentation on human beings serve to clear the field for further effective work -- with one or two points cleared up, we could then work to so much better advantage."



yellow fever virus

models and data

experimental infections

Theory of Mosquito-Borne Transmission

- So mosquitoes transmit disease…
- But what aspects of mosquito biology are most important in determining disease burden?

  Population density?

  Mosquito lifespan?

  Bite rate?

  Mosquito movement?

  Reproduction?

Can these inform effective interventions?

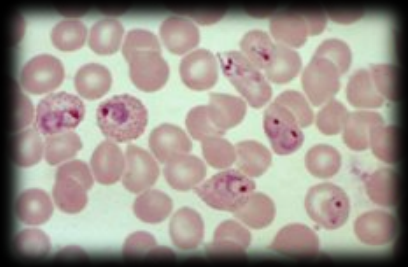
Ross' *A Priori* Pathometry

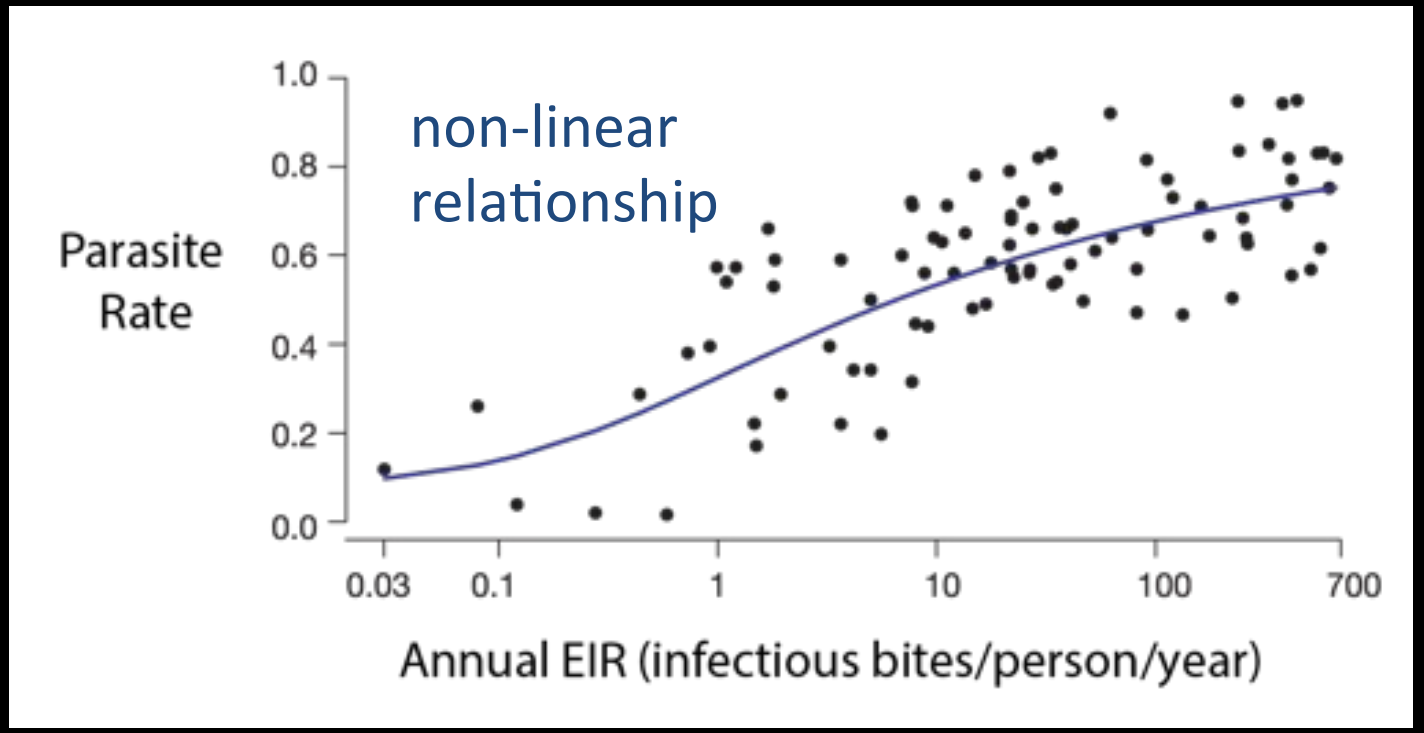
"what percentage of diminution in mosquito-borne disease may be expected to follow a given percentage reduction in the number of mosquitoes?"

Ross (1902).

Anopheles quadrimaculatus larvae

Stimulation of Empirical Research: Quantifying transmission





Smith et al. (2005). *Nature*.

Ross Model of Malaria Transmission

- causal relationship between
  ratio of mosquitoes to humans &
  # infected humans

- unnecessary to kill every mosquito
  to end transmission

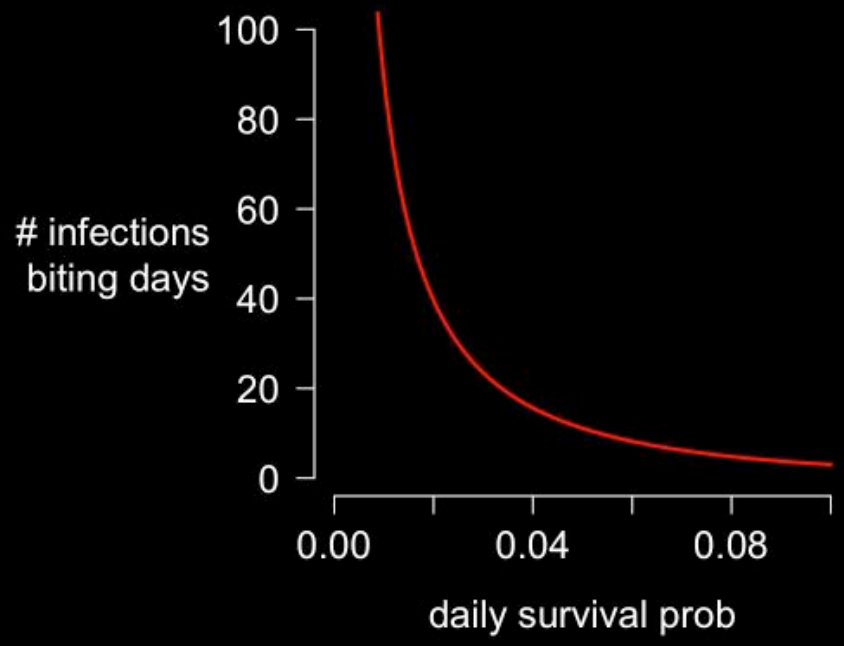
Mosquito Longevity

- Global Malaria Eradication Program (1955-1969)

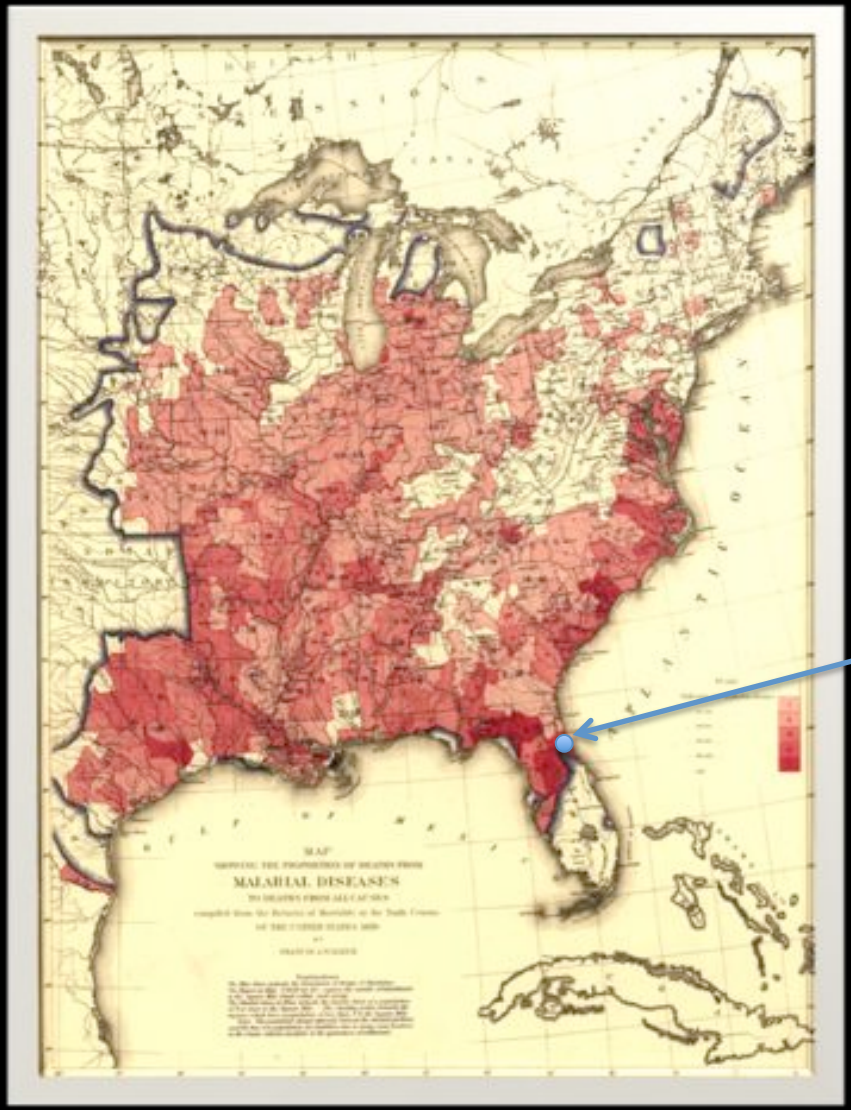
- Mosquito Survival

  Transmission depends
  on survival of
  extrinsic incubation period
  & life expectancy thereafter

(survival probability)^{EIP} X (life expectancy)



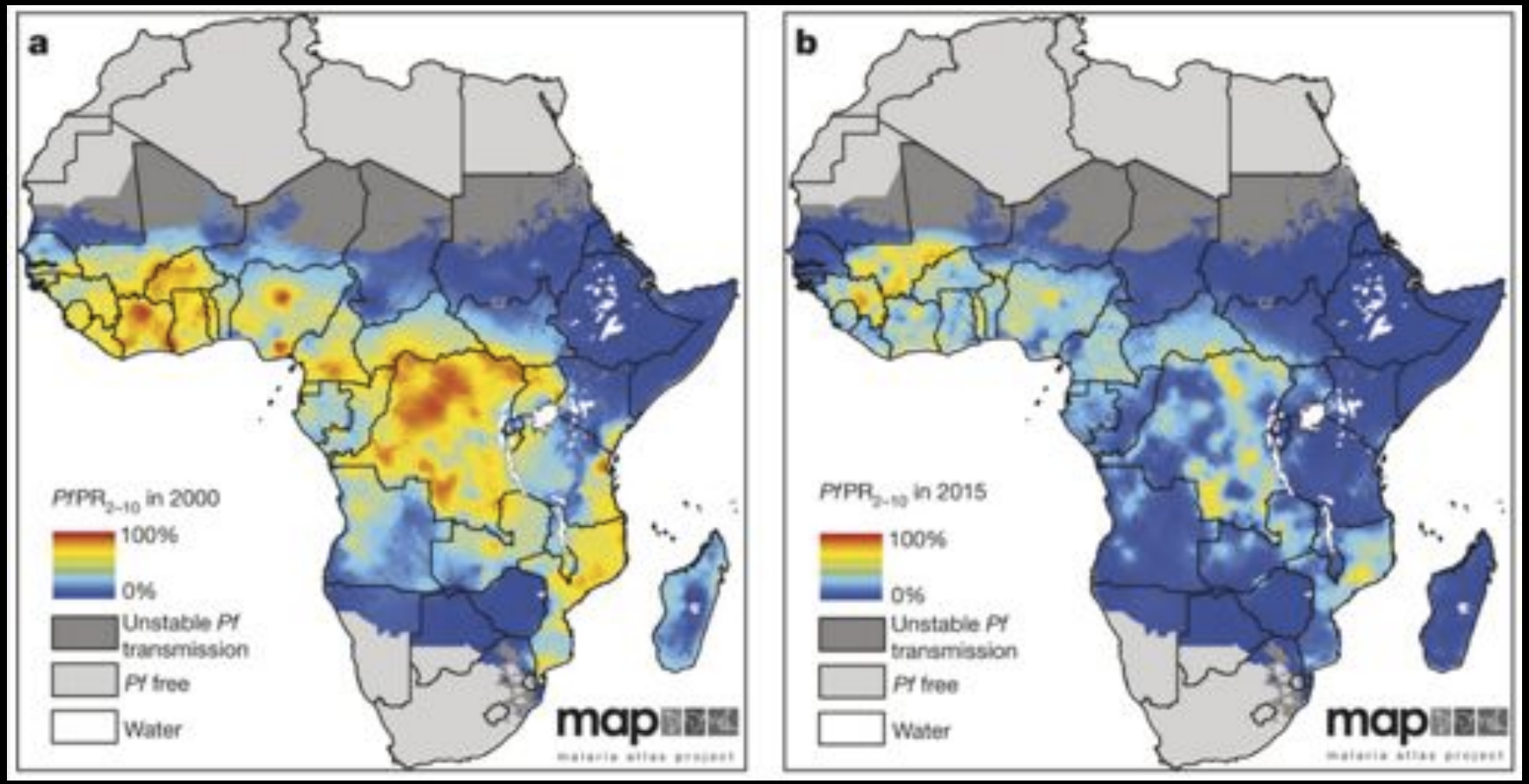
Mosquito Control



Mosquito Control

Parasite Prevalence

2000 2015



What was the point of this story?

- Successive discoveries by testing ideas (models) against observations (data)
- Models drive empirical developments and vice versa
- Complicated relationships required mathematization of models

Perspectives from Two Disciplines

Classical Epidemiology	Mechanistic Epidemiology
Data-Centric	Process-Centric
(Public Health)	(Disease Ecology)
Risk Factors	Infectious Disease Dynamics
Biostatistics	Mathematical Modeling

Classical Epidemiology

- Does A cause B?

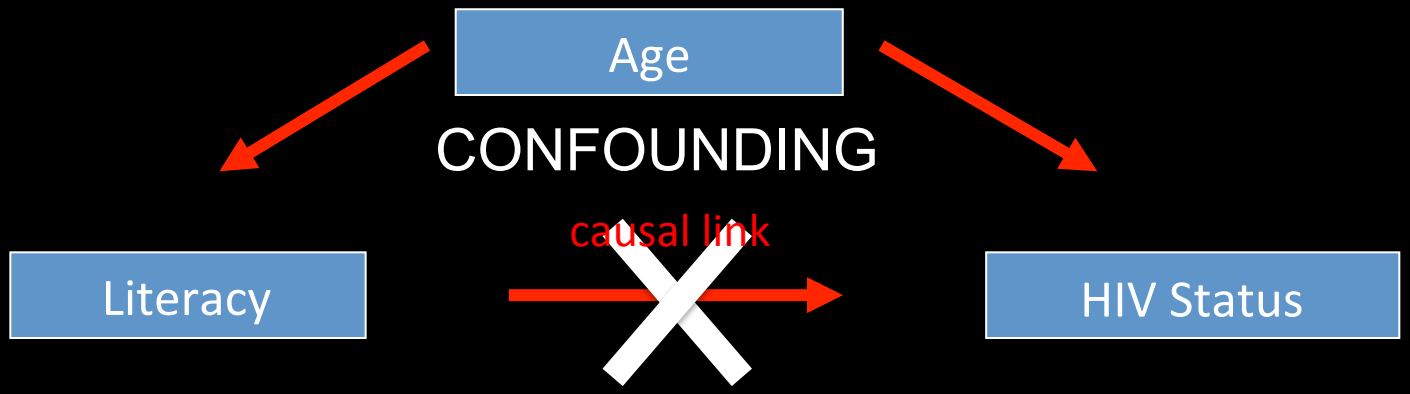
Classical Epidemiology

- Does literacy cause HIV?

Individual	Literate	HIV infected
1	0	0
2	0	0
3	0	0
4	0	1
5	1	1
6	1	0
7	1	1
8	1	1

HIV prevalence 3X greater amongst literate

- Find correlations that imply causality by accounting for
    1. random error: do we have enough data?
    2. bias: are design & analysis valid?



Classical Epidemiology

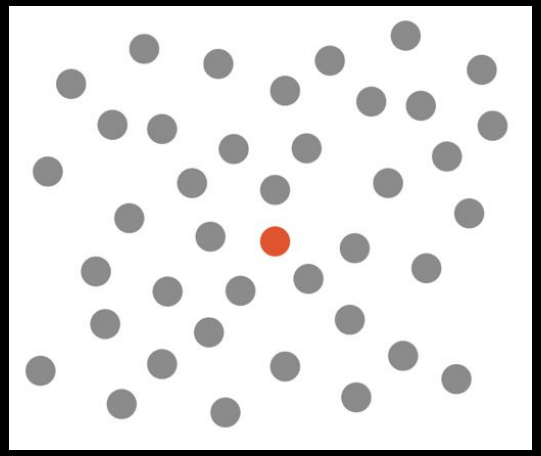
Infer causation via carefully identified correlations

Minimize bias via:

- study design: e.g. randomization, blinding
- analytical methods: e.g. causal inference modeling

Mechanistic Epidemiology

- Scale up from individual processes to population patterns



Mechanistic Epidemiology

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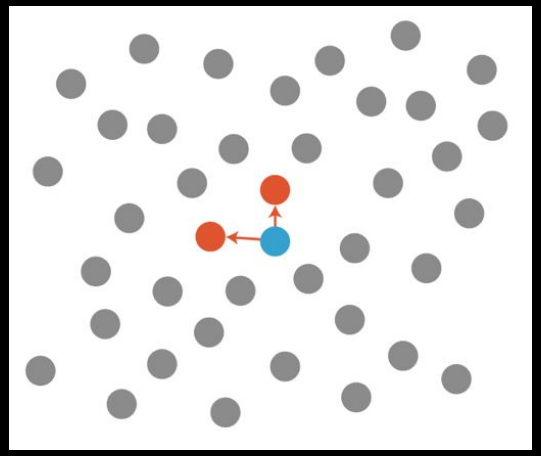

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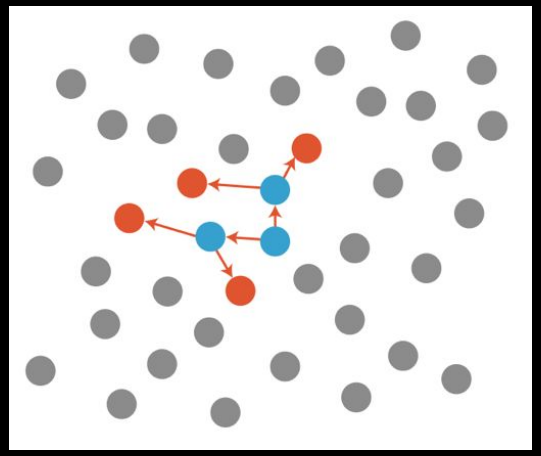

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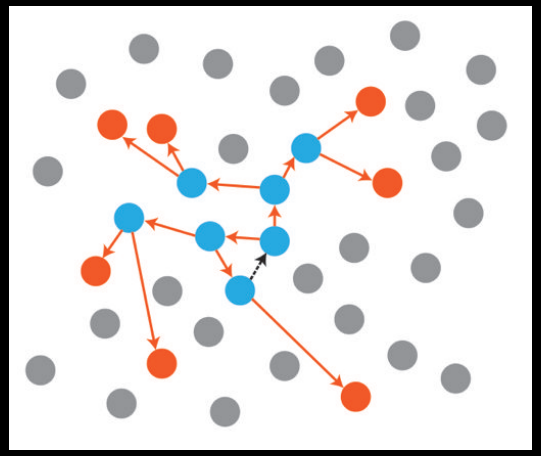

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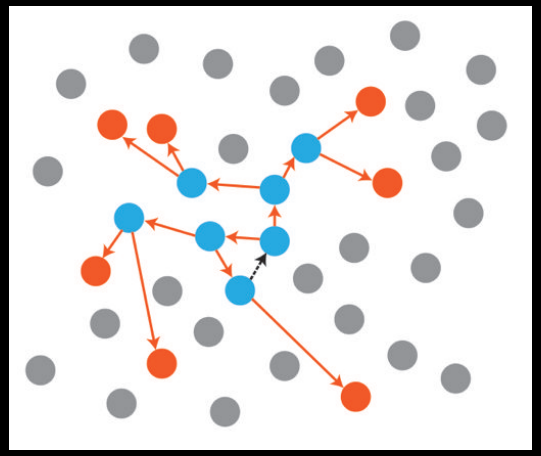
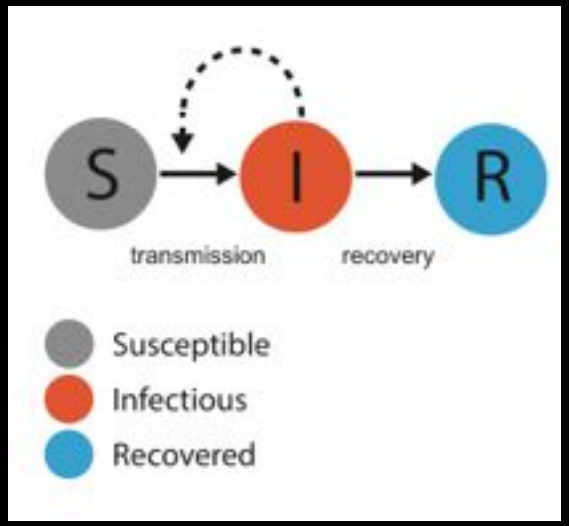


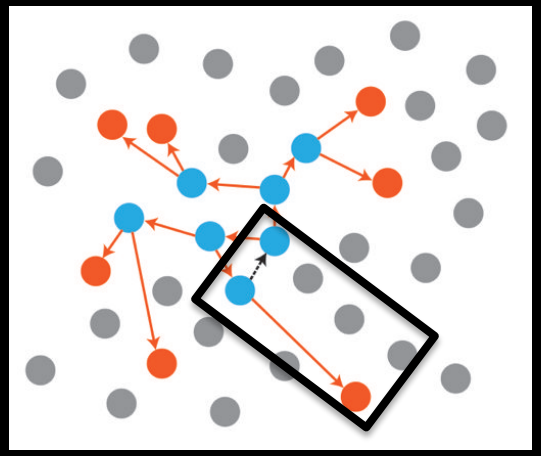
solid arrow = flow between disease states
dashed arrow = influence



How do contact processes cause epidemics?

Mechanistic Epidemiology

- Scale up from individual processes to population patterns



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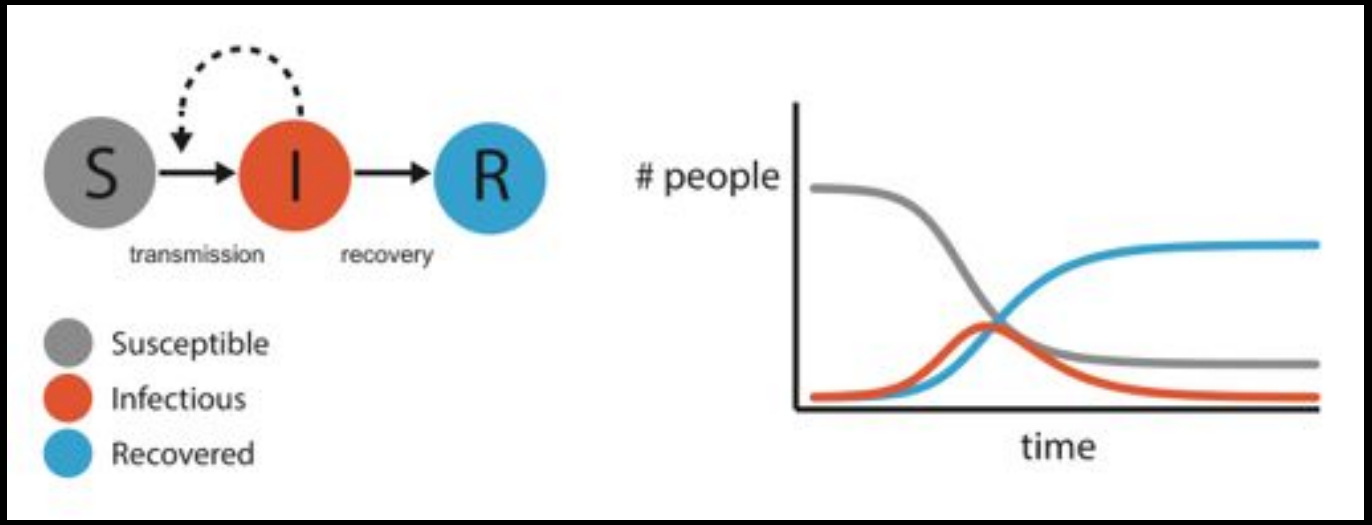
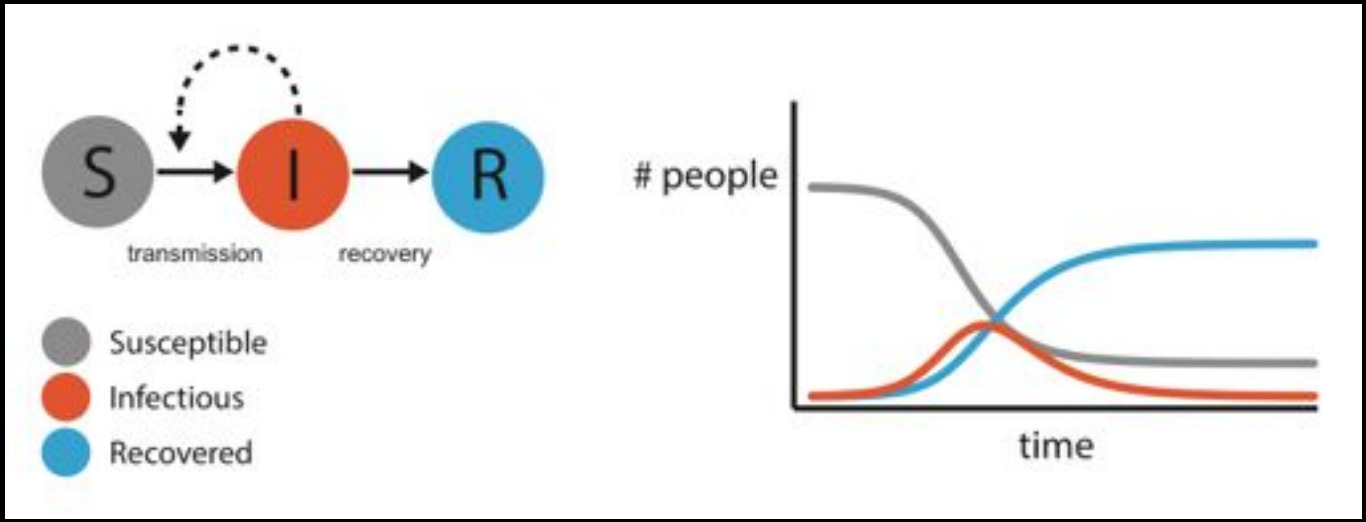


Mechanistic Epidemiology

- Scale up from individual processes to population patterns
- "What if" scenarios not amenable to experimentation



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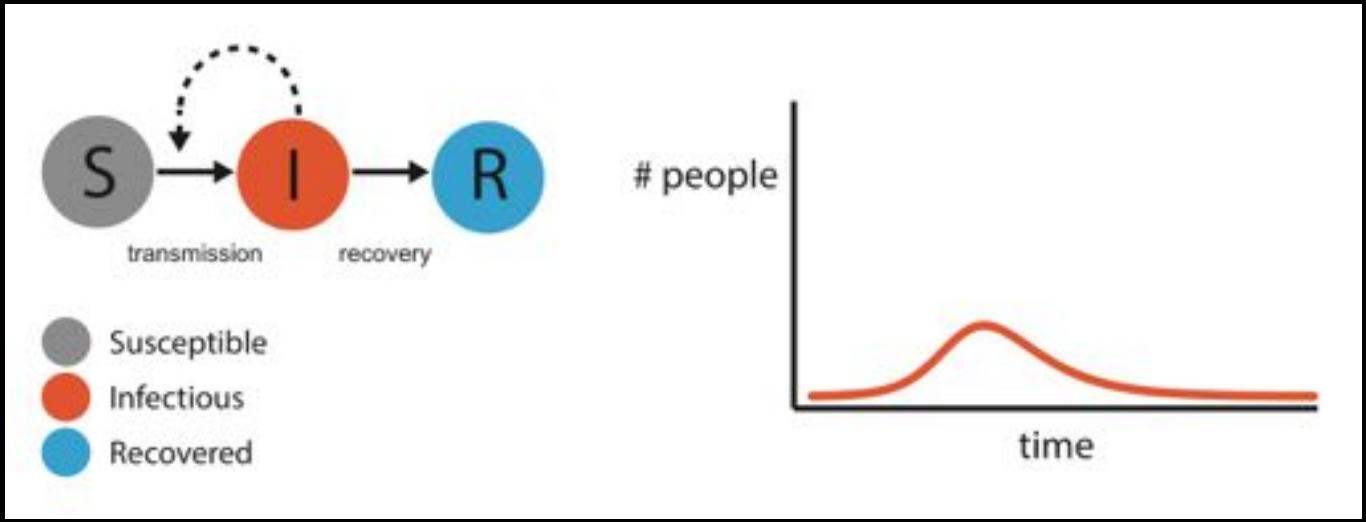
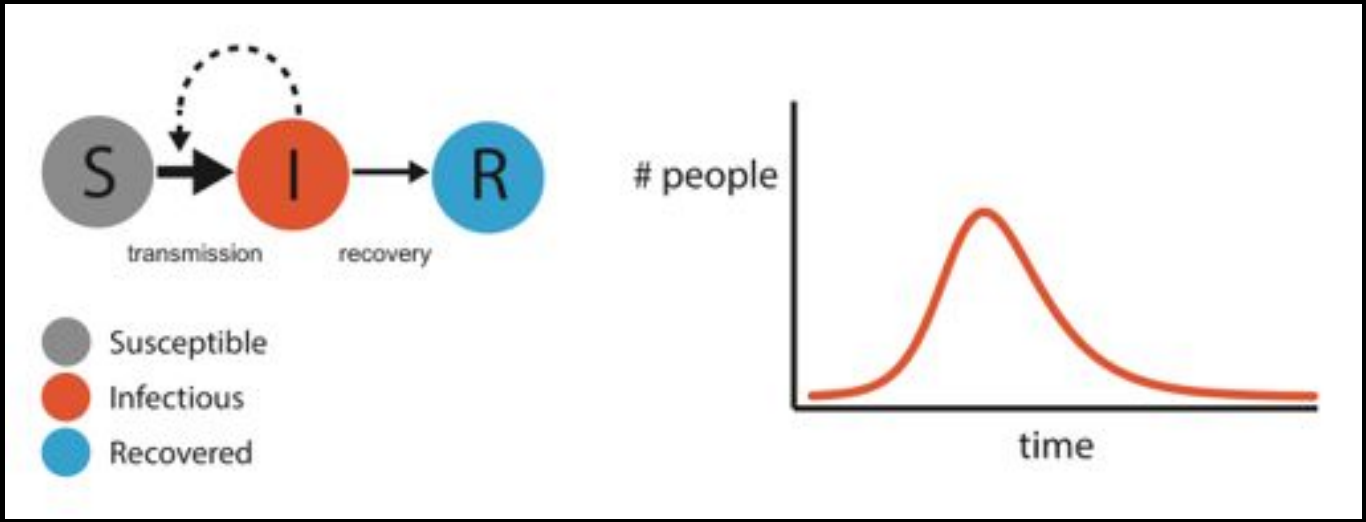


Mechanistic Epidemiology

- Scale up from individual processes to population patterns
- "What if" scenarios not amenable to experimentation

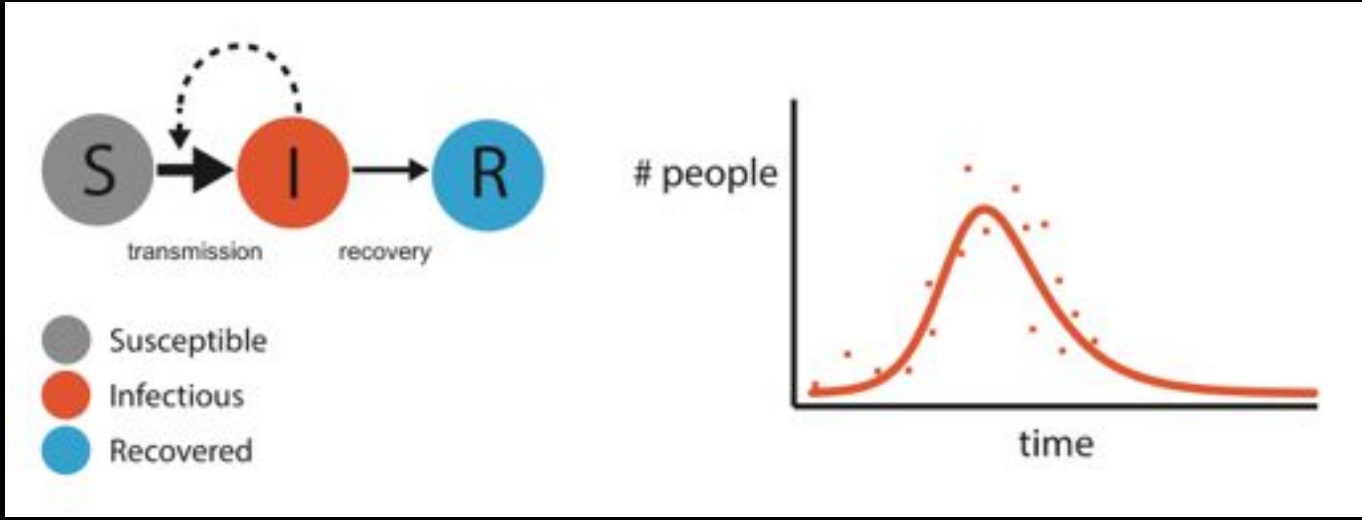
What if each person exposed 50% more people?



Mechanistic Epidemiology

- Scale up from individual processes to population patterns
- "What if" scenarios not amenable to experimentation

We can also compare process models to data.



Statistical Models (data-centric)

- Account for bias and random error to find correlations that may imply causality.
- Often the first step to assessing relationships.
- Assume independence of individuals (at some scale).

Dynamical Models (process-centric)

- Systems Approach: Explicitly model multiple mechanisms to understand their interactions.
- Links observed relationships at different scales.
- Explicitly focuses on dependence of individuals

What is Science? Data and Models

- Science = systematic process by which we construct narratives (theories) about the world
- Models = abstract representations of the world, created within this narrative framework
- Data allow us to falsify or assign probabilities to particular models and narrow down our understanding.

The End