

Adaptation and aging in pathogen-host systems

SFI/JSMF: Arrow of time, Adaptation and Aging meeting
October 2016

Jonathan Dushoff
McMaster University

Introduction

Evolution of a disease-host system

Homeostasis and cycling

Pathogen evolution

Cultural evolution

Host evolution

Aging and Adaptation

Aging

Adaptation

Outline

Introduction

Evolution of a disease-host system

Homeostasis and cycling

Pathogen evolution

Cultural evolution

Host evolution

Aging and Adaptation

Aging

Adaptation

Function through time

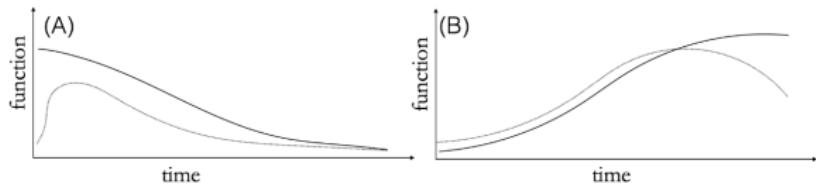
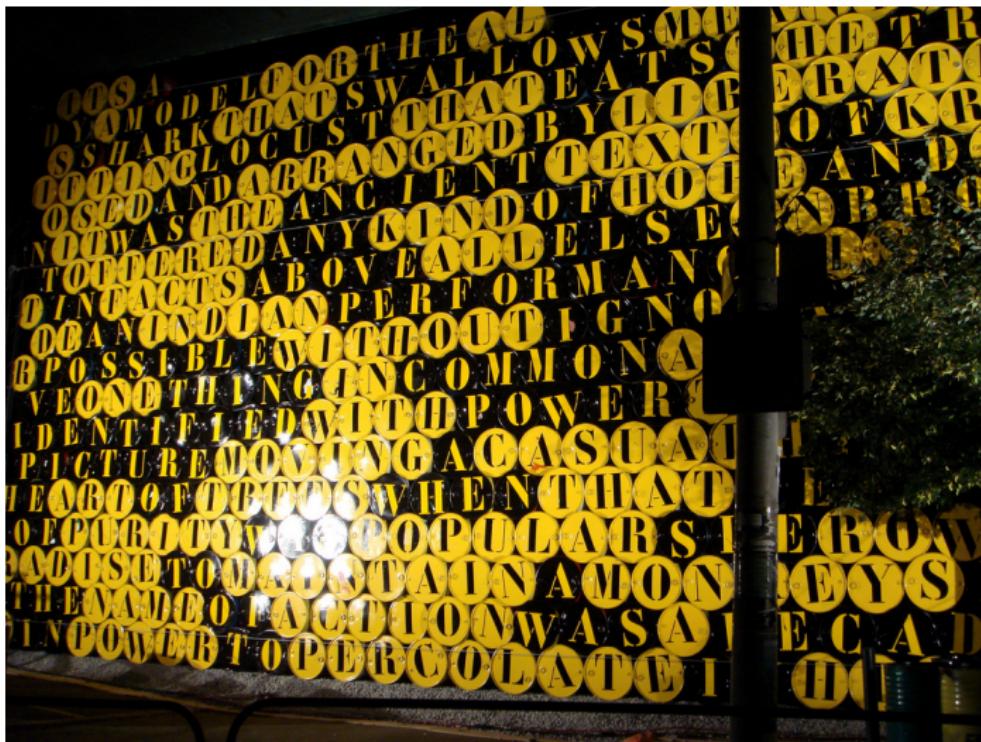


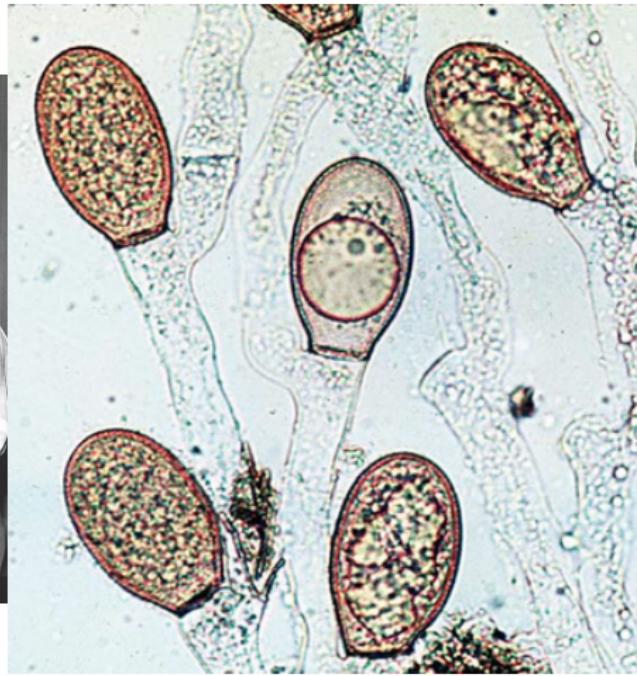
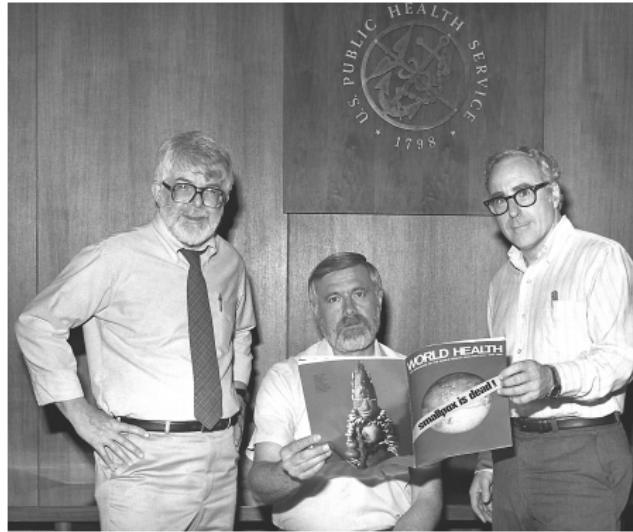
Figure 1. The arrow of time as measured through the effect of aging on function (A) and independently through the effects of adaptation on function (B). Aging can be treated as a systematic decline in function through time starting from an ideal initial configuration (solid line) or an initial period of growth or pruning during which function increases followed by systematic decline (dashed line). Adaptation is always assumed to increase function from an initial minimum. Adaptation can continue to increase indefinitely (solid line) or experience a decline independent of age-effects at some time following a programmed critical period (dashed line). The impact of the arrow of time on function throughout life needs to consider both aging and adaptation.

Disease-host relationships

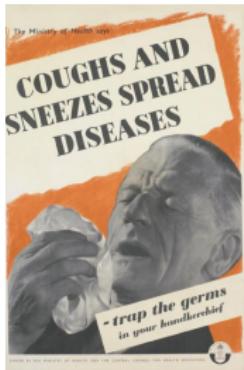
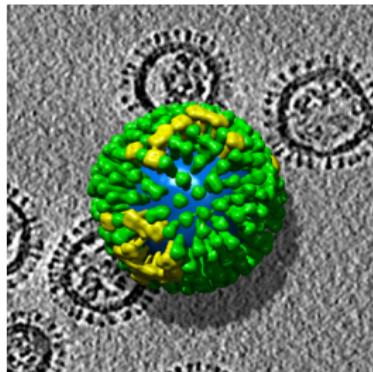
Intimate enemies



Different goals



Scales



Outline

Introduction

Evolution of a disease-host system

Homeostasis and cycling

Pathogen evolution

Cultural evolution

Host evolution

Aging and Adaptation

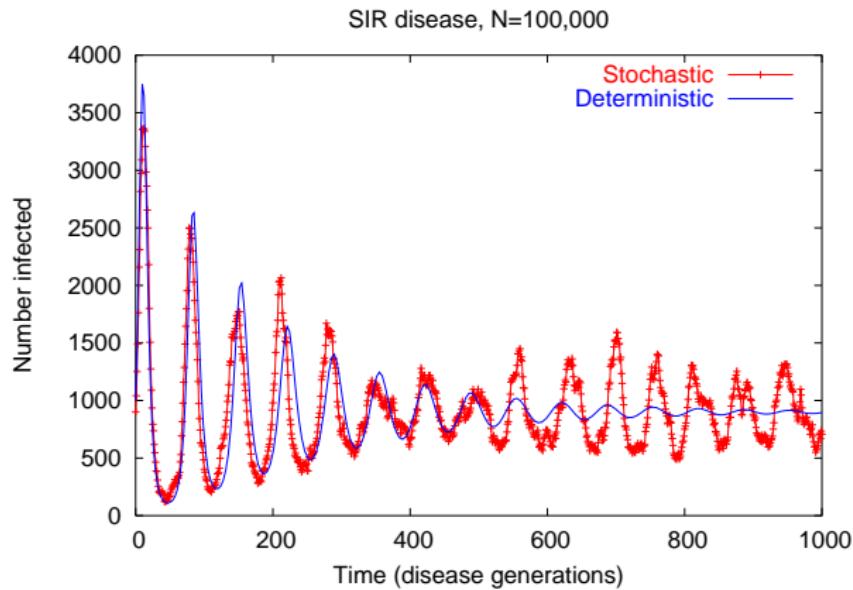
Aging

Adaptation

Evolution of a disease-host system

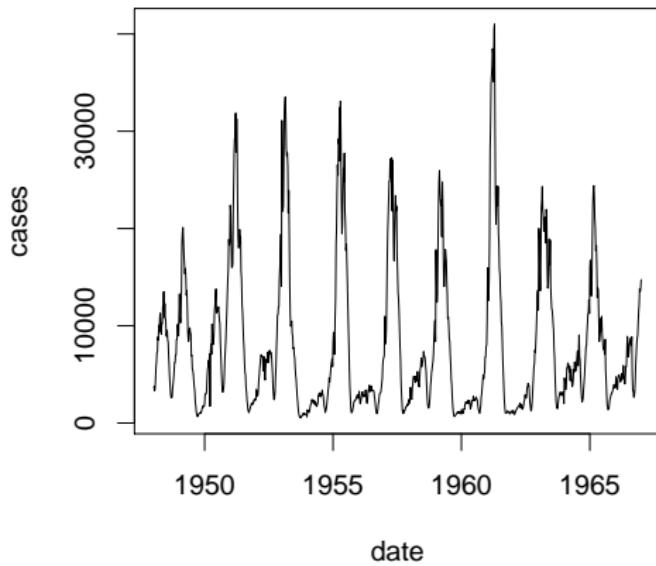
- ▶ Homeostasis and cycling
- ▶ Pathogen evolution
- ▶ Cultural evolution
- ▶ Host evolution

Homeostasis and cycling



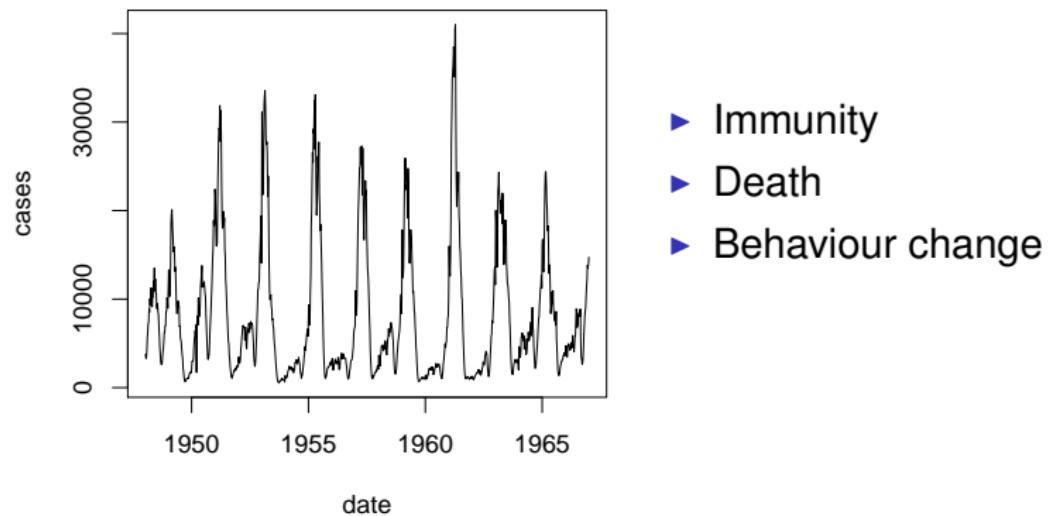
Homeostasis and cycling

Measles reports from England and Wales



Homeostasis and cycling

Measles reports from England and Wales



Pathogen evolution

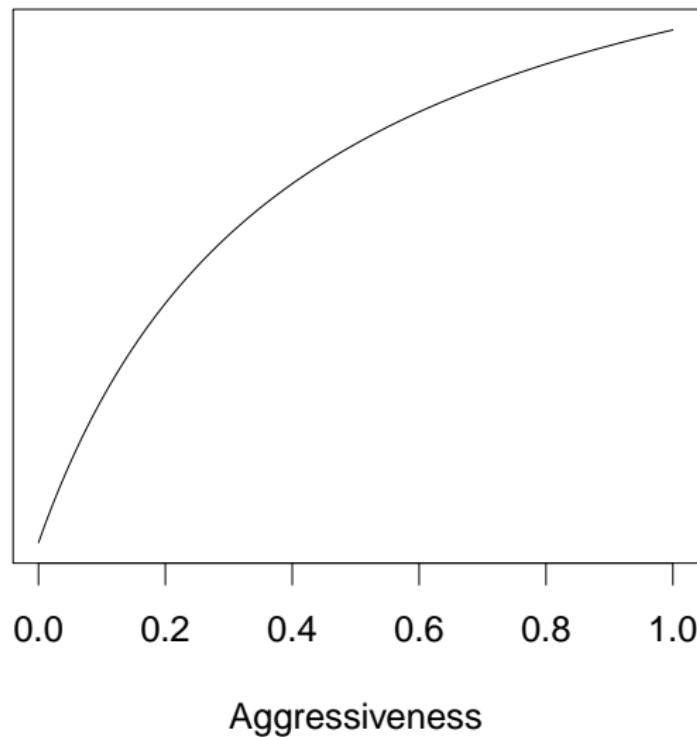
- ▶ How “virulent” should a pathogen be?
- ▶ What do we mean by “virulence”?
- ▶ Damage to host depends on host response
- ▶ Do host-pathogen systems evolve to be benign?

Pathogen “aggressiveness”

- ▶ Pathogens that replicate faster (or use more “virulence factors”) may:
 - ▶ Provoke a stronger immune response
 - ▶ Kill their host (or kill it faster)
 - ▶ Transmit more effectively

Maximizing pathogen reproduction

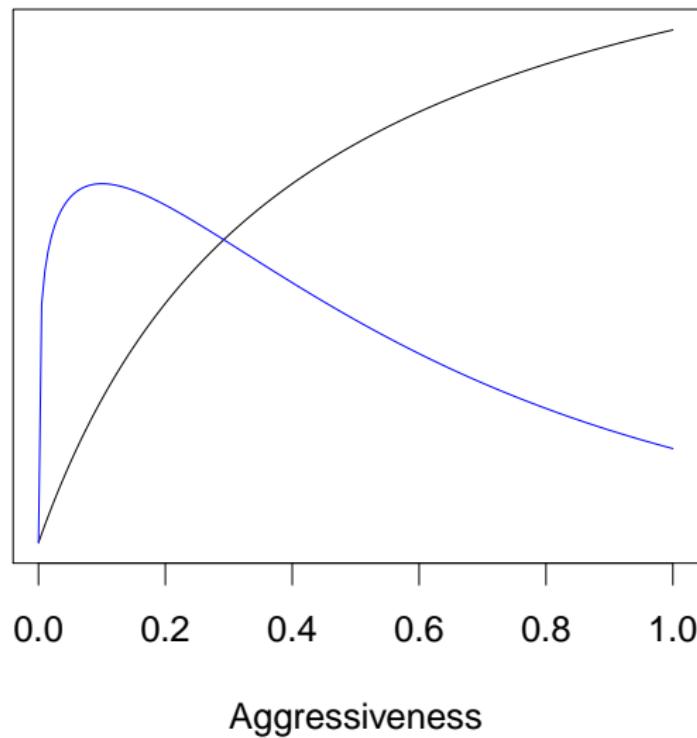
Transmission



Aggressiveness

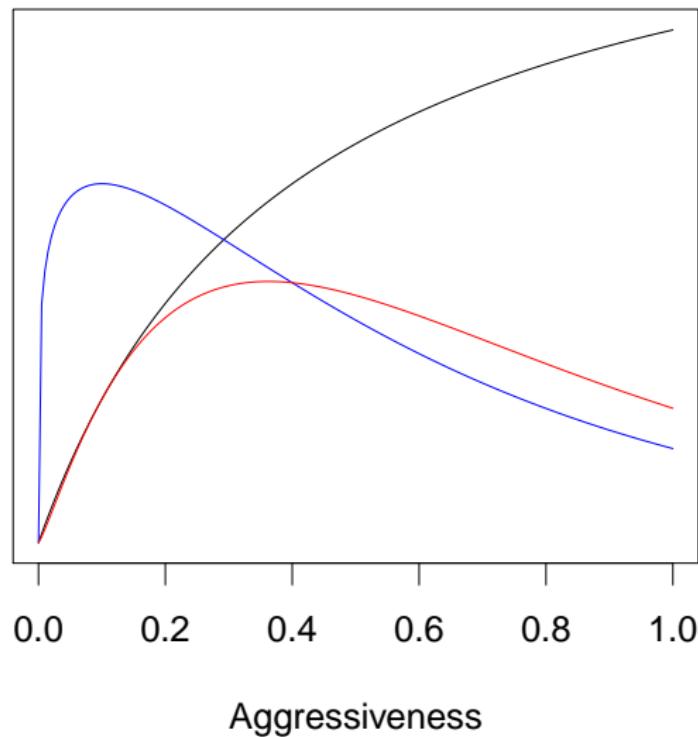
Maximizing pathogen reproduction

Duration

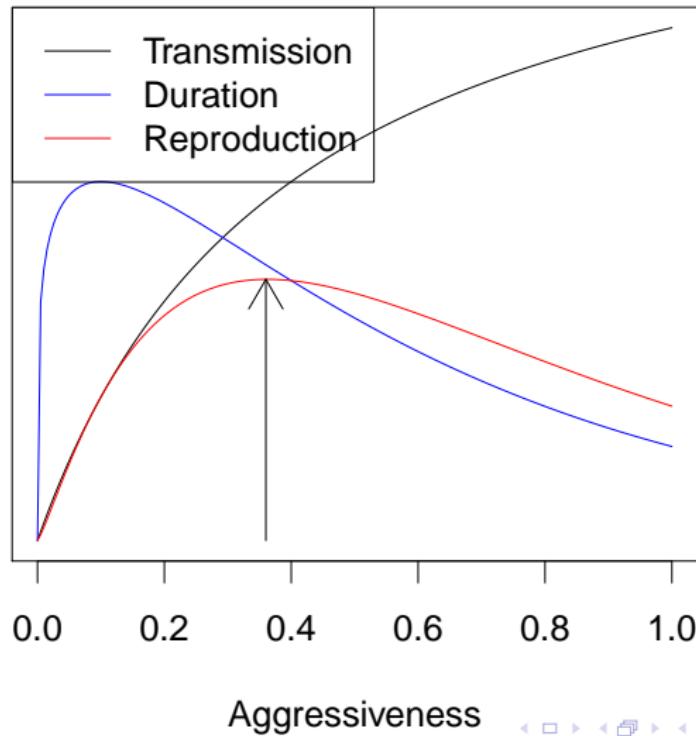


Maximizing pathogen reproduction

Reproduction = transmission \times duration



Maximizing pathogen reproduction



Life history

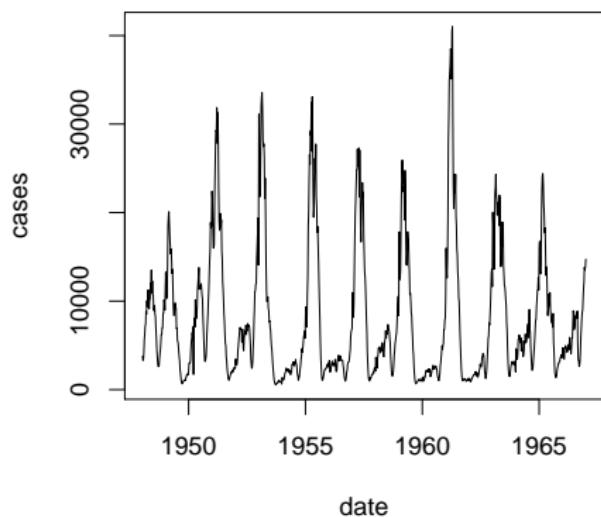
- ▶ Duration of infectiousness
- ▶ Some diseases need you to be out and about to transmit
 - ▶ measles, influenza, syphilis
- ▶ Others may be happy if you're lying in bed
 - ▶ malaria, dengue
- ▶ Or may benefit from severe damage
 - ▶ Ebola?, anthrax

Is rabies more virulent than influenza?

- ▶ Longer latent period
- ▶ Longer infectious period
- ▶ Longer recalcitrant period

Cycling

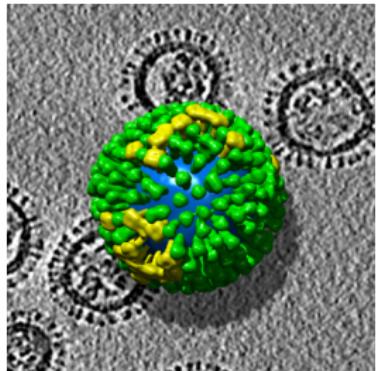
Measles reports from England and Wales



Compared to this optimum, pathogens are selected to be:

- ▶ faster (more virulent) on the upswing
- ▶ slower (less virulent) on the downswing

Death vs. recovery



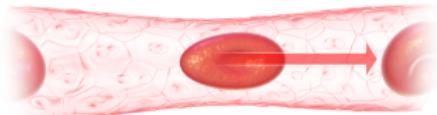
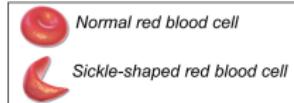
- ▶ At one scale, these look about the same to the pathogen
- ▶ On another scale, it depends on duration of immunity
- ▶ On yet another scale, recovery may always be better

Cultural evolution

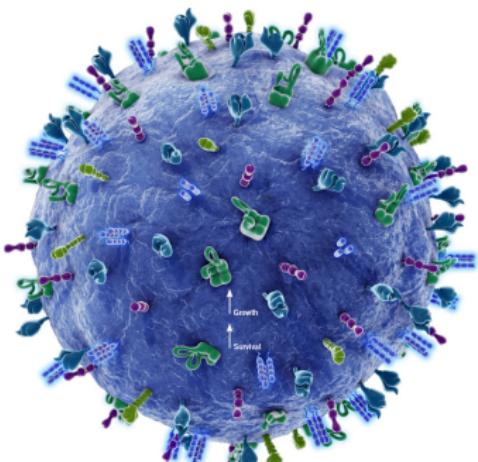


- ▶ People form understandings and rituals around pathogens
 - ▶ Measles parties
 - ▶ Shunning
 - ▶ Hand-washing

Host evolution



- ▶ Response balance
- ▶ Specialized responses
 - ▶ Innate systems
 - ▶ Acquired systems



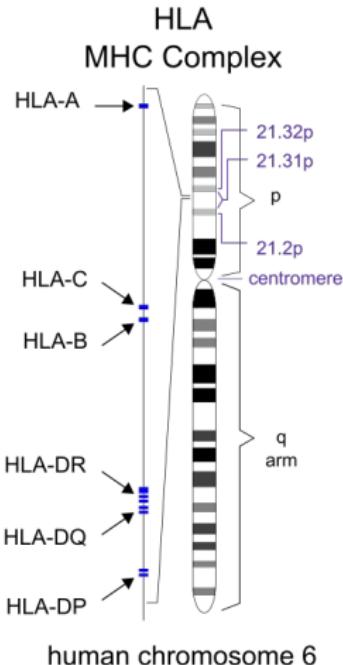
Tolerance

- ▶ Hosts can be infected productively without being clinically ill
- ▶ But the pathogen is not going to control itself



Host vs. pathogen

- ▶ Pathogen evolution may be attuned to attacking one particular host
- ▶ Host evolution needs to balance the need to fight many different kinds of pathogens



Outline

Introduction

Evolution of a disease-host system

Homeostasis and cycling

Pathogen evolution

Cultural evolution

Host evolution

Aging and Adaptation

Aging

Adaptation

Aging



Example: genetic imprinting

- ▶ What happens when paternal and maternal fitness are in conflict?



Virulence genes and antagonists

- ▶ Attack and defense genes that cancel out



Extreme responses

Host

- ▶ Sickle cell
- ▶ Cystic fibrosis
- ▶ Tay-Sachs

Pathogen

- ▶ var/EMP
- ▶ hemagglutinin loops
- ▶ TB DNA repair

The ecological endpoint

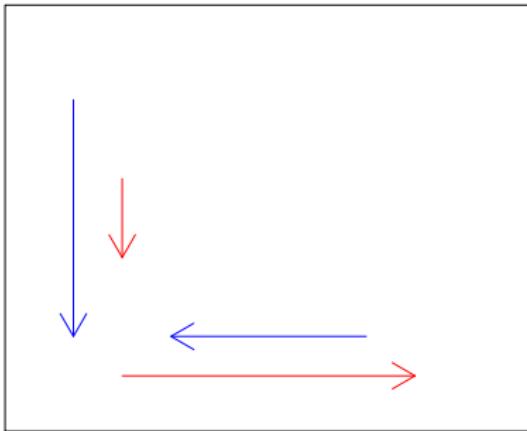
- ▶ Apparent competition: a “natural enemy” usually cannot eliminate a host unless it has a robust alternative host.
- ▶ The most common ecological endpoint of the arms race might be extinction of the pathogen
 - ▶ Depends also on whether the host keeps fighting

Adaptation

- ▶ Both parties have something in common:
 - ▶ all else equal, they value the fitness of the host
- ▶ This could set the stage for adaptation through time

Pathogen activity

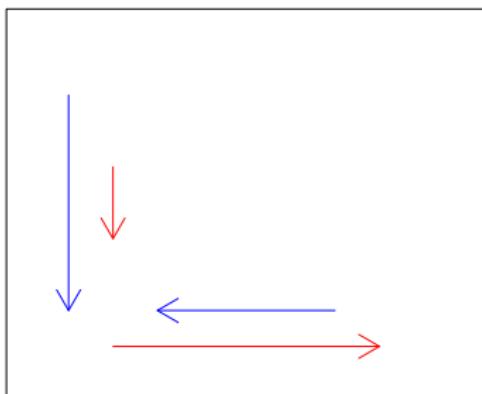
Non-target effects



Target effects

Pathogen activity

Non-target effects

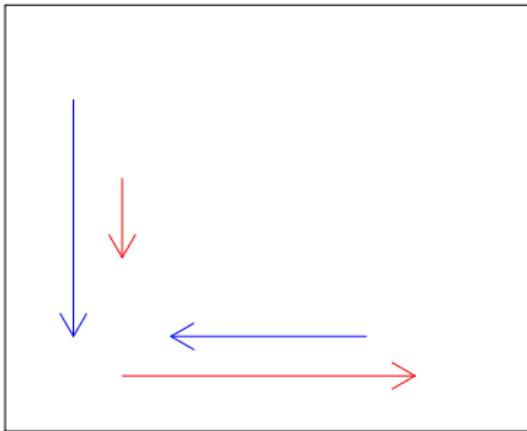


Target effects

- ▶ Common cold vs. meningitis
- ▶ Upper vs. lower respiratory tract infections
- ▶ Pulmonary vs extra-pulmonary TB

Pathogen activity

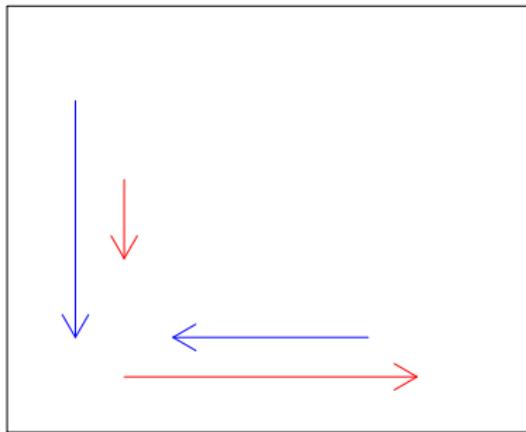
Non-target effects



Target effects

Immune activity

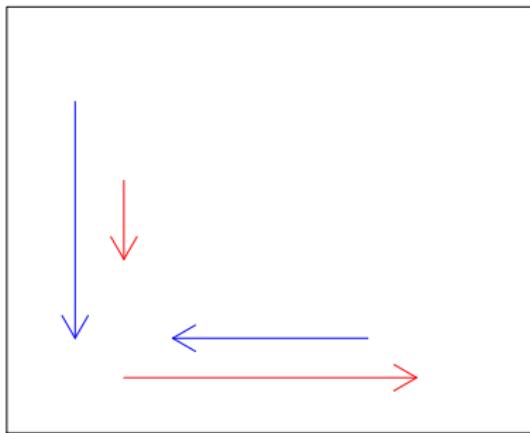
Non-target effects



Target effects

Immune activity

Non-target effects



Target effects

- ▶ More targeted responses
- ▶ Th balance?

Managed adaptation

- ▶ What might encourage adaptation towards lower-damage strategies?
 - ▶ Target transmission routes that favor higher pathogen aggressiveness
 - ▶ E.g., sedentary infector, or high titer required
 - ▶ High force of infection arenas
 - ▶ Target people with more severe symptoms
 - ▶ Isolation, interdiction, treatment

Thank you

- ▶ Audience
- ▶ Organizers
- ▶ Ben Bolker