Can Evolution Cross Adaptive Valleys?

Alan R. Rogers

April 28, 2015

Consider the words: rat, rut, rum, & sum

- Each differs by one letter from preceding word.
- Each correctly spelled and means something.
- Last differs from first at every position.

Now try the same game beginning with “brain of a rat.”

The longer the word or phrase, the harder the game gets.

Michael Denton arges that this, in microcosm, is the problem of evolving complex adaptations.

In his view, each species is trapped on an “island of function.”

Not a new idea

> The entirety of an organic being forms a coordinated whole, a unique and closed system, in which the parts mutually correspond and work together in the same specific action through a reciprocal relationship. None of these parts can change without the others changing as well. (Cuvier, 1825)

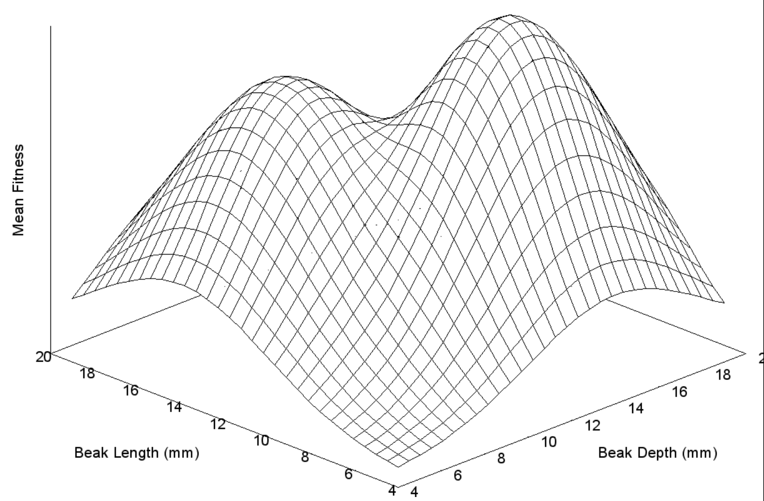
Yet eye evolution did not have this problem

Each step was an improvement.
Some evolutionists argue this is always so:

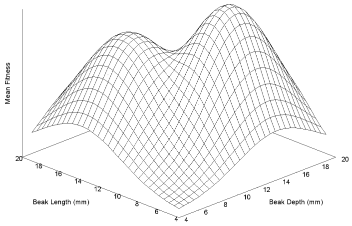
> *“There can be no going downhill—species can’t get worse as a prelude to getting better.” (Dawkins, 1996)*

Others are not sure.

The metaphor of the “fitness surface”



The metaphor of the "fitness surface"

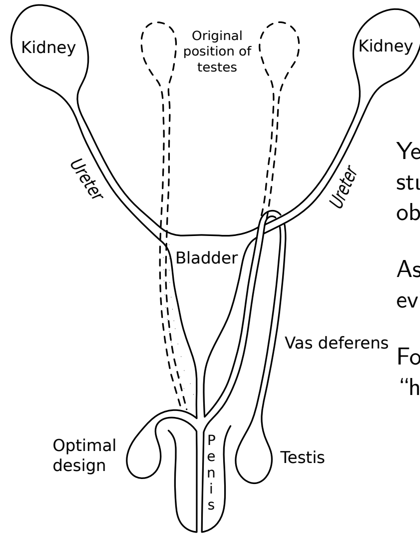


Selection always pushes uphill. Population may get stuck on lower peak.

Does fitness surface really have multiple peaks?

Can evolution cross valleys?

Are fitness surfaces really that complex?



Yes: when a population gets stuck on an inferior peak, we observe poor design.

As you know, there is lots of evidence of that.

For another example, consider "handedness" in snails.

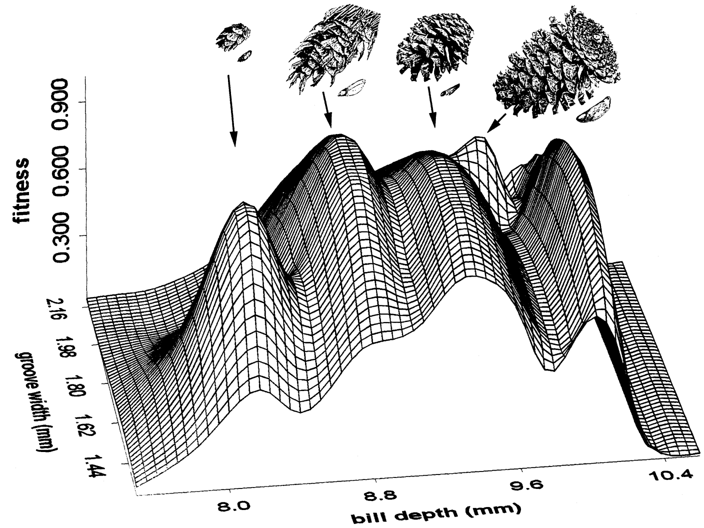
Left- and right-handed snails

The loneliness of the left-handed snail

- Both coils work fine.
- But they cannot mate.
- Rare type has disadvantage.
- Each coil constitutes a fitness peak.
- Most snail populations are right-handed, but not all.
- How do the switches happen?

Red Crossbills

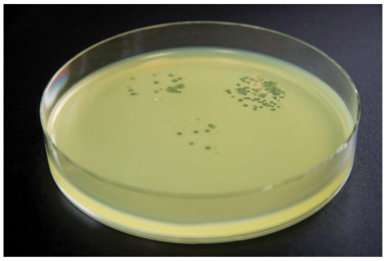
Crossbill Fitness Surface



What these examples show

- Fitness surfaces really are complex
- Populations somehow get from one to another.
- How?

Bacteriophage experiment (Burch and Chao, 1999)



- Colony of bacteriophages ("phages") grows in a dish of bacteria.
- Each "plaque" contains offspring from a single phage.
- After infecting new plate, there will be 5×10^9 phages in 5 phage generations.

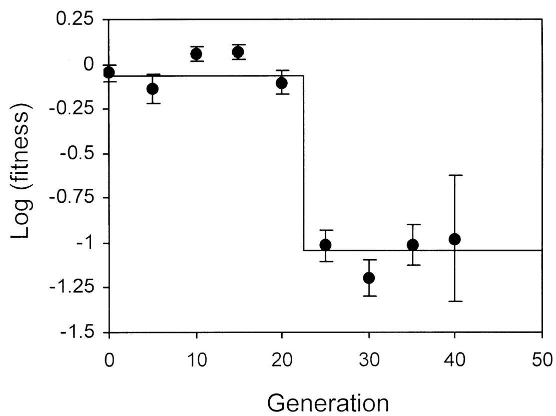
Phase 1 of experiment of Burch and Chao

Repeated bottlenecks of 1 individual

1. Start new colony, with particles from 1 plaque, i.e. with descendants of 1 phage.
2. Let colony grow for 5 phage generations.
3. Repeat.

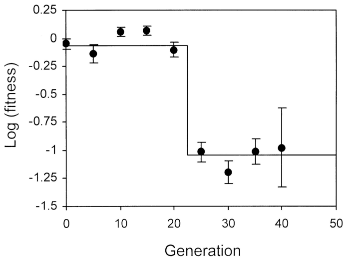
Random forces overwhelm force of selection. Fitness declines as deleterious alleles become common.

Repeated bottlenecks force population into adaptive valley



Burch and Chao, 1999

Fitness decline caused by single mutation



- Fitness declines suddenly in generation 22.
- Sudden decline implies that decline was caused by a single deleterious mutation.

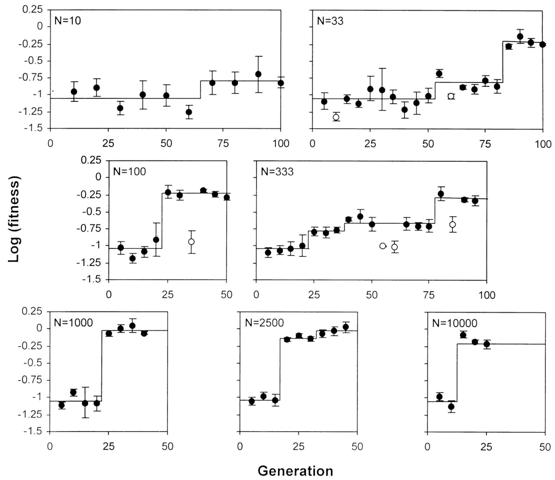
Burch and Chao, 1999

Phase 2 of experiment of Burch and Chao

No more bottlenecks

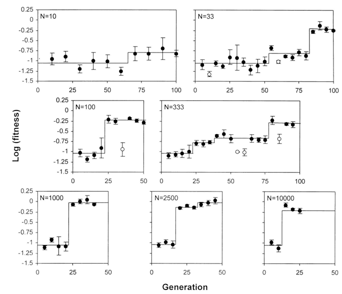
- Just like phase 1, except that new colonies are started using cells from many plaques, i.e. from many viral individuals.
- No bottleneck in population size.
- Selection overwhelms random forces. Fitness recovers.

Population evolves out of adaptive valley



Burch and Chao, 1999

Evolving out of the valley



Burch and Chao, 1999

- N is # of plaques founding each new colony.
- When N is modest, recovery takes several steps.
- Must be new mutations.
- Population has evolved to a new fitness peak.

What we've learned

- Populations can cross adaptive valleys.
- But experimental conditions were extreme: repeated bottlenecks of 1 individual.
- Do they also happen in nature?

We can't be sure.

Wright's shifting balance theory

- Random changes in gene frequencies.
- In small populations, random changes can be important.
- Can move a population downhill against the force of selection.
- A means of crossing adaptive valleys.

Sewall Wright (1932)

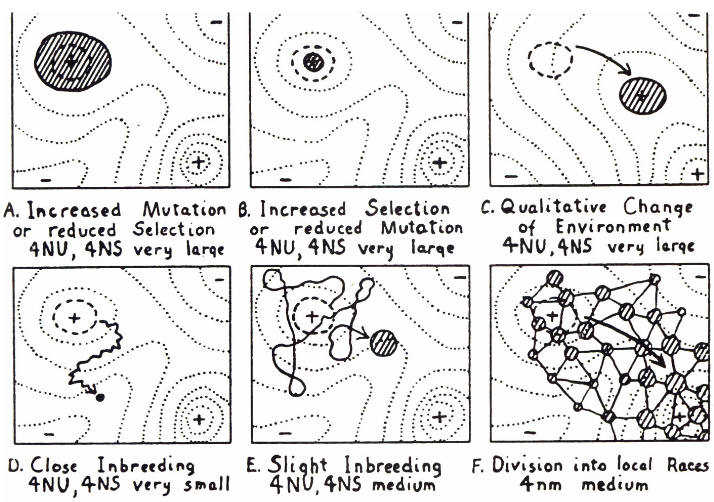


FIG. 4. Field of gene combinations occupied by a population within the general field of

The trouble with Wright's idea

Theory indicates that the average time until peak shift can be huge, if the population size and the fitness surface remain unchanged.

Example: For a valley has a 5% selective disadvantage:

Population size	Time in generations
100	about 10^6
500	about 10^{23}

(Age of earth is 4.55×10^9 years.)

No process this slow can account for the complex adaptations we see in nature.

But many things can speed this process up

For example, (1) ridges in fitness surface, or (2) phenotypic plasticity, or (3) asymmetric migration, or (4) a changing fitness landscape, or (5) shallow adaptive valleys, or (6) a continuous distribution in space, or (7) variation in phenotypic variance, or (8) on a correlated character, or (9), multiple small peak shifts.

But we don't know whether *any* of these are important in nature.

Bottom line

- Fitness surfaces *are* rugged.
- Organisms *do* sometimes switch to new adaptive peaks.
- There are many conceivable explanations.
- We don't know which are important.

But no miracle is needed.