Adaptation and Natural Selection

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Adaptation

- Plants and animals are well adapted to their environments.
- The question is: Why?

Points of View

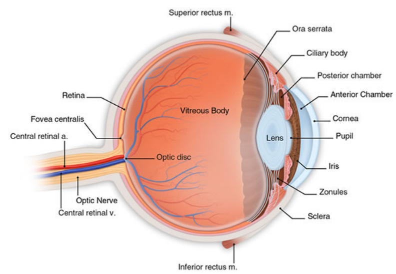
1809 *Natural Theology*, by William Paley

- Design implies a designer
- Evidence for God

1859 *Origin of Species*, by Charles Darwin

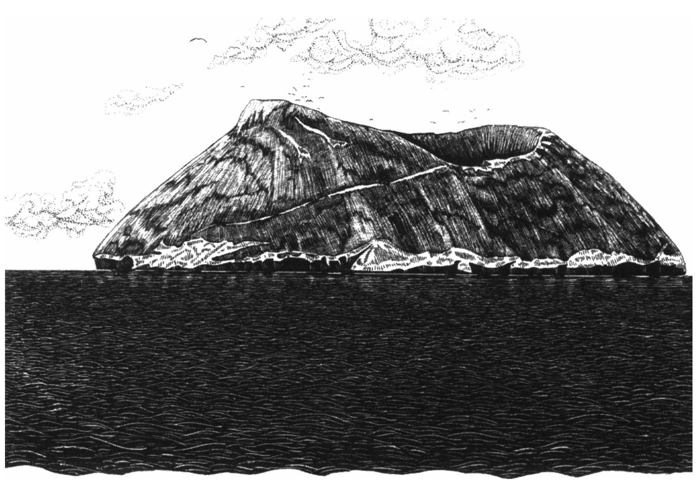
- Adaptation results from variation, selection, and heredity

Paley's most famous example: the eye

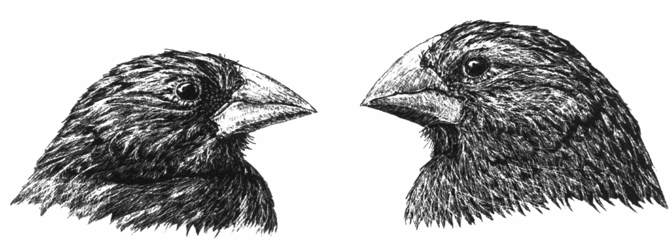


- A marvel of engineering.
- Interacting parts
- Irreducible complexity (Behe)
- How did Darwin explain adaptation?

Daphne Major, Galapagos Islands



Medium Ground Finch (*Geospiza fortis*)



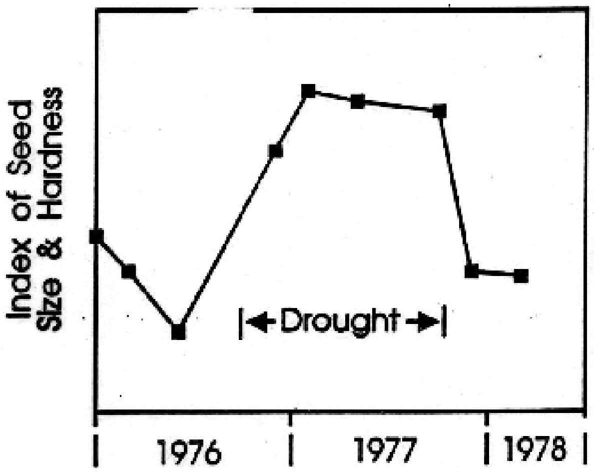
Peter and Rosemary Grant

Rosemary & Peter Grant
Have studied finches on Daphne Major since 1973.

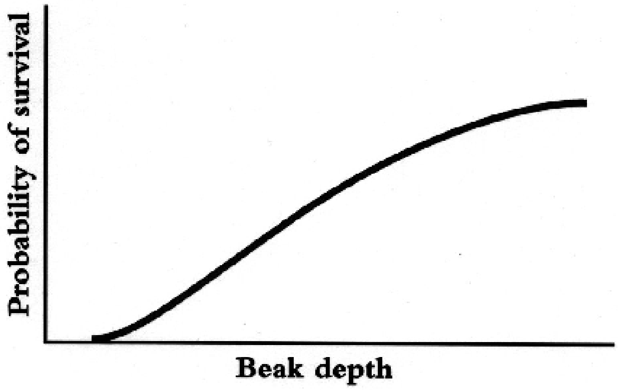
Their students Peter Boag and Laurene Ratcliffe

- There during drought of 1977.
- < 1 inch of rain fell.
- No seeds produced.
- Most of birds starved.

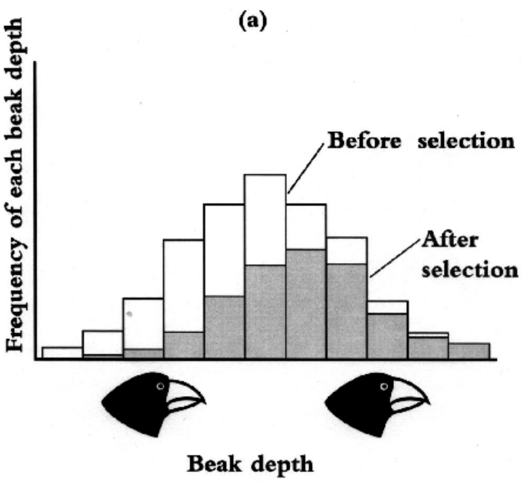
During drought, seeds were big and hard



Birds with deep beaks most likely to survive

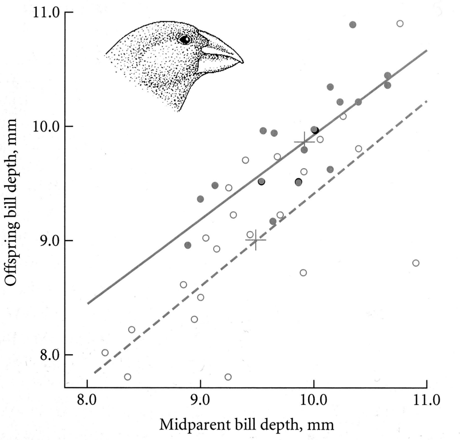


Frequency distribution moves right



- After selection, the average bird had a deeper beak.
- But will their offspring also have deeper beaks?

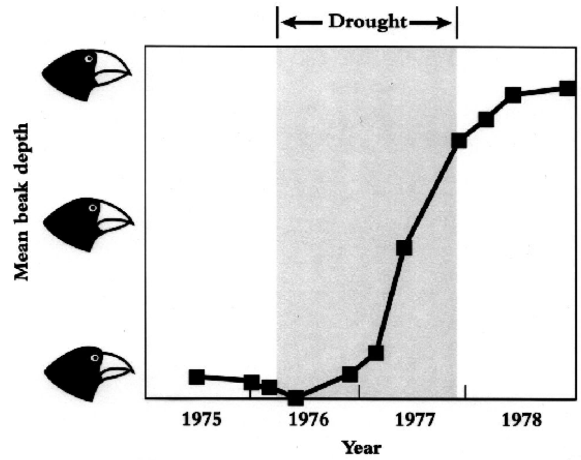
Heredity: offspring resemble parents



Offspring versus midparent. Before the drought (○ and dashed regression line) and after (● and solid line). Crosses (×) are mean midparent and offspring values.

(Futuyma, 1998)

Evolutionary change



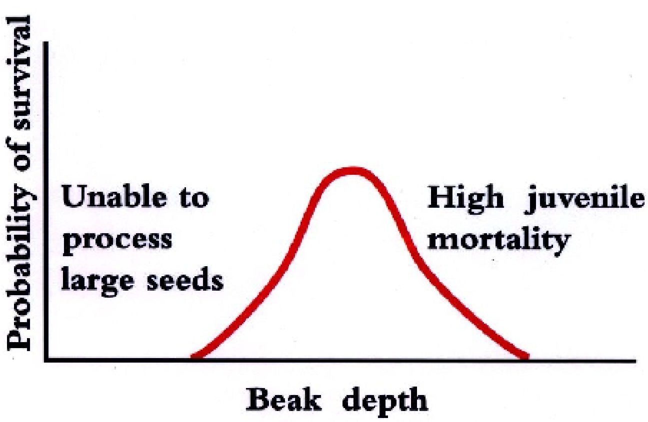
What does natural selection require?

1. Variation
   - Birds differed in beak depth.
2. Variation affects survival or reproduction
   - Deep beaks survived better
3. Heredity
   - Offspring resemble parents

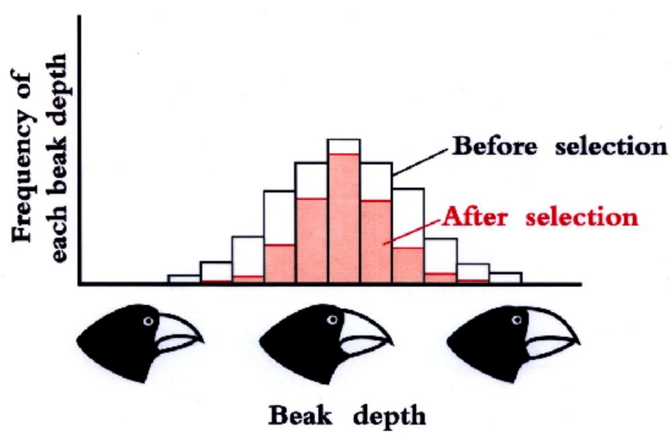
When these conditions are met, natural selection is operating.

- Not only does selection cause change.
- It also prevents it.
- The form that prevents change is called *stabilizing selection*

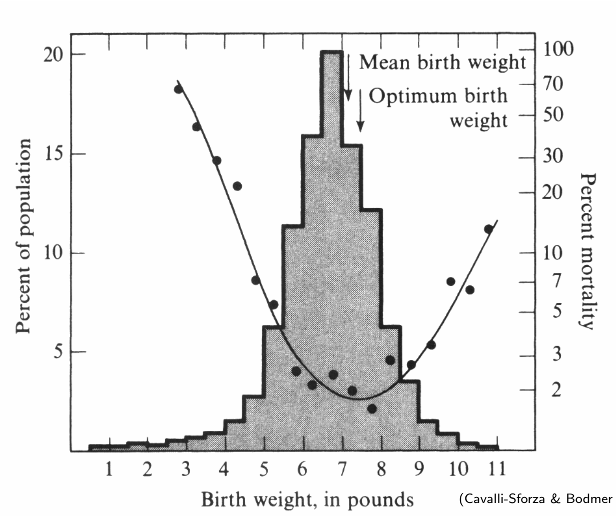
Stabilizing selection gives advantage to center



Stabilizing selection prevents evolutionary change



Stabilizing selection on human birth weight



(Cavalli-Sforza & Bodmer 1971)

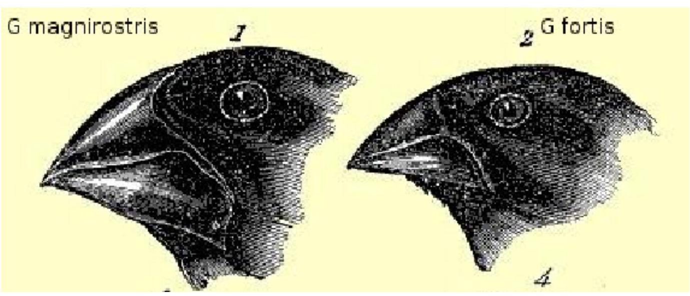
What happened after the drought on Daphne Major?

Did selection

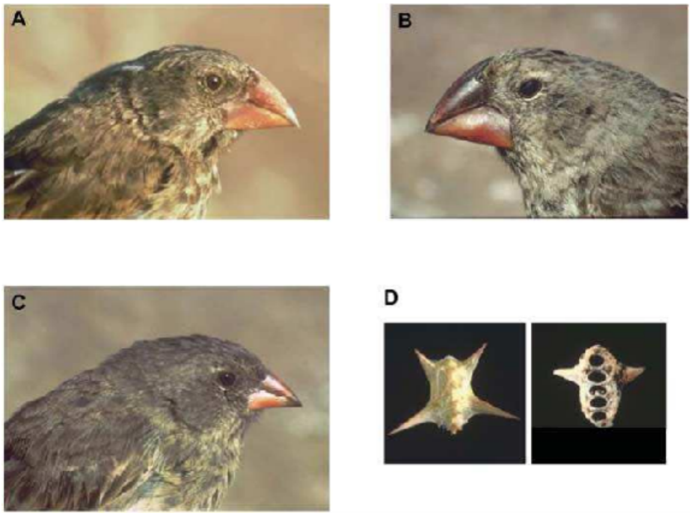
1. move beak size back where it started?
2. keep beaks at their new larger size?
3. keep increasing beak size?

The answer is more interesting than any of these.

An invading species



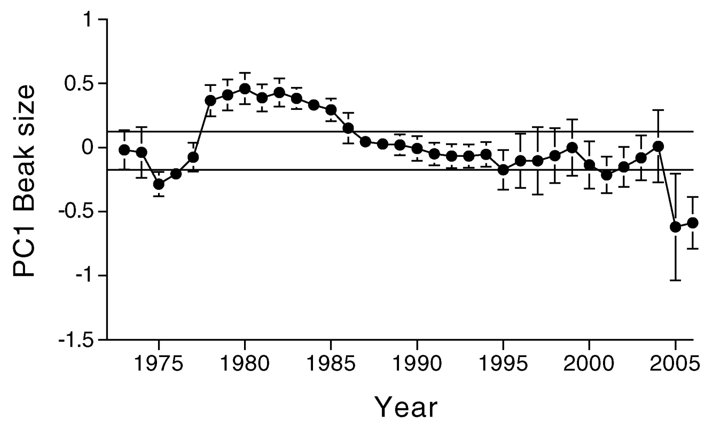
- In 1982, a few individuals of *Geospiza magnirostris* arrived on Daphne Major.
- By 2003, these big finches were eating most of the big, hard seeds.



The drought of 2003–2004

- Almost no rain fell.
- Plants did not make seeds.
- In previous drought, large-billed *G. fortis* individuals survived on large seeds.
- In 2004, those were eaten by *G. magnirostris*.
- By 2005, only 83 *G. fortis* and 13 *G. magnirostris* survived.

G. fortis beak size declined in 2003–2004.



Selection produced adaptative change

- During 1977, deep beaks were better, so selection made beaks deeper.
- During 2003–2004, shallow beaks were better, so selection made beaks shallower.

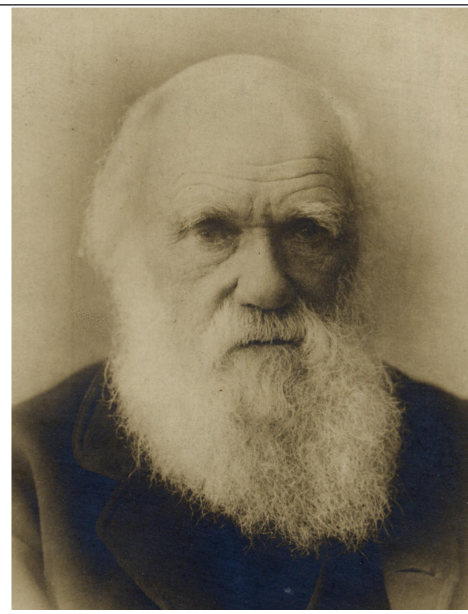
What about the eye?

- Much more complex
- Lens useless without retina
- Retina useless without lens
- How can such structures evolve?

Charles Pritchard

(1866)

First to argue that vertebrate eye could not plausibly evolve.



Charles Darwin

First to refute Pritchard's argument (1872).

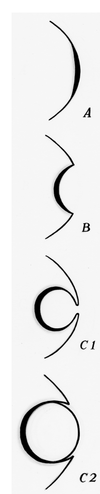
Yet the argument just won't die.

The weakness of arguments about implausibility

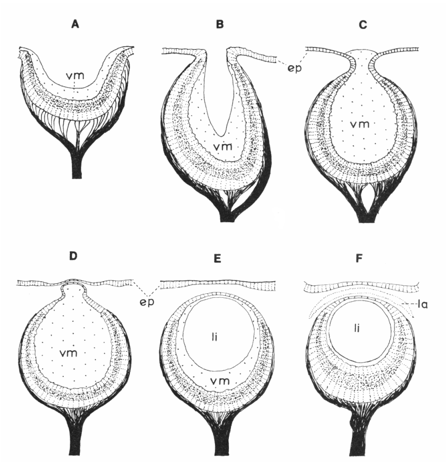
- Pritchard's claim is about plausibility.
- To refute it, we only need to invent a plausible story in which eyes do evolve.
- No evidence is needed.
- The story does not even need to be true.

Hypothetical steps in evolution of eye

A eye spot
B eye cup
C1 pin-hole camera eye
C1 primitive lens



Are these steps plausible?



Yes! They can all be found in living organisms today.

Conclusion: eye evolution *is* plausible.

Pritchard was wrong!

But what really happened?

How can we find out?

Darwin's story makes a prediction

1. Retinas evolved early.
2. Lenses evolved late.

We can test this prediction using similarities and differences among the eyes of living animals.

Traces of common descent

We resemble close relatives because of genes we inherited from common ancestors.

It is the same with species.

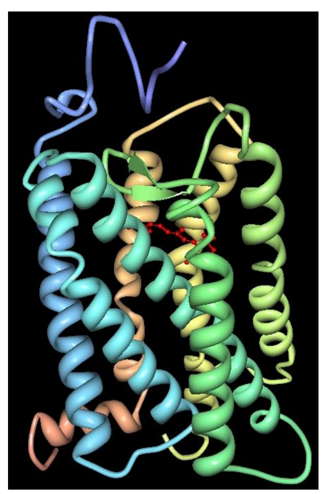
Using such similarities, let us work out the evolutionary history of eyes.

Many eyes resemble ours

But some of this is misleading.

Let's start simple—with proteins.

Opsins: light-sensitive proteins



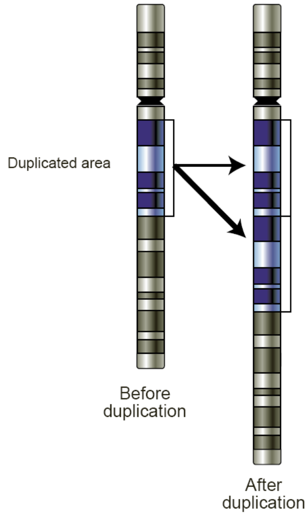
Nature makes several kinds of light-sensitive protein.

Yet all animals that see do so with one type: opsins.

Did all these evolve from a single primordial opsin?

If so, then related species should have similar opsins. Do they?

Why we have several kinds of opsin



When cells divide, the DNA duplicates.

Sometimes the machinery stutters, and some DNA is copied twice.

We may end up with two copies of some gene, and the new copy may evolve a new function.

Eventually, we end up with a family of related genes.

What you have in common with apes and old world monkeys

- One opsin adapted to dim light.
- Three for color vision.

Most mammals only have 2 opsins for color vision.

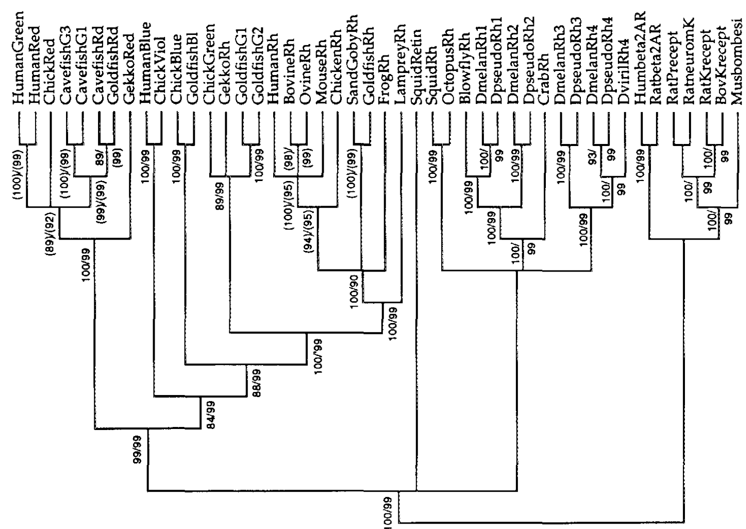
One of these must have duplicated in the common ancestor of apes, humans, and old world monkeys.

The usual mammalian condition

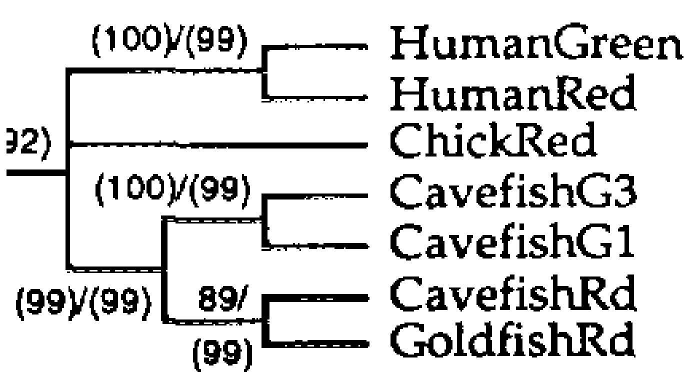
Most mammals only have 2 opsins for color vision.

Yet most other vertebrates have 4.

2 must have been lost in common ancestor of all mammals.



A branch of the opsin tree



(Chang, Crandall, Carulli, and Hartl, 1995)

Traces of common descent in opsins

Closely related species have closely similar opsin molecules.

They are also similar in the number of types of opsin.

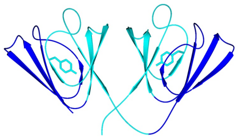
This pattern of nested similarities goes all the way back to the original opsin.

Our opsins have similarities with those of insects and cephalopods.

All opsins show evidence of common descent.

All eyes had a single origin.

Crystallins: lens proteins



Transparent proteins used in lens and cornea.

If lenses evolved early, then humans and insects should have similar crystallins.

But if lenses evolved late, . . .

Traces of common descent in crystallins

- Evidence of common descent throughout vertebrates.
- Yet insects have very different crystallins.
- So do cephalopods.

It appears that lenses evolved late.

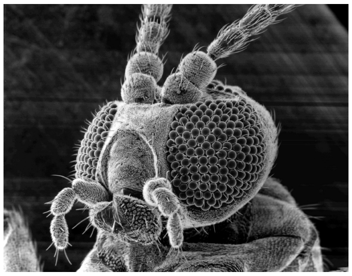
What about eye morphology?

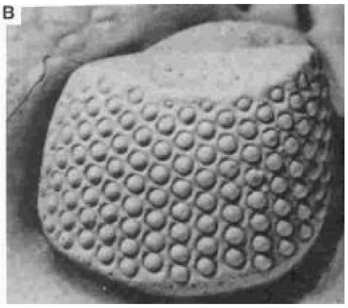
All vertebrates have eyes like cameras.

Canis familiaris

Pempheris japonica

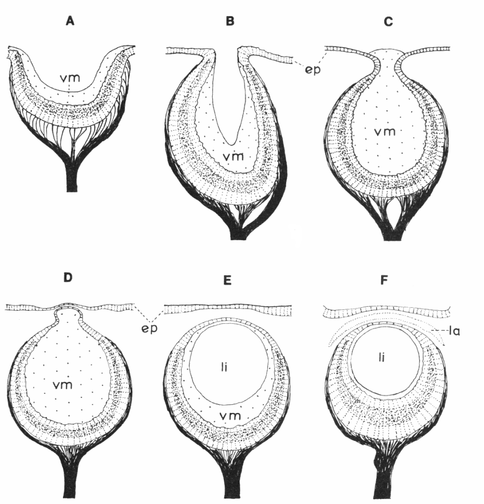
All arthropods have compound eyes.



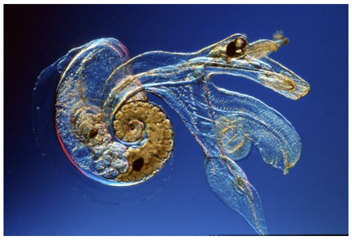


Even this trilobite.

Yet snails have an amazing variety of eyes.



Heteropod sea snails



Have eyes like slits.

Field of vision 180° wide but just a few degrees high.

Eye scans rapidly up and down to assemble image.

Traces of common descent in eye morphology

Closely related animals have closely similar eyes.

Yet these resemblances do not extend back as far as with opsins.

Like lens proteins, eye morphology evolved relatively recently.

Darwin's "just so" story

It seems that retinas evolved early, and that lenses and complex eyes evolved late, just as Darwin suggested.

Complex adaptations can evolve in small individually-adaptive steps.

Conclusions

Much of the public is still skeptical about evolution of complex adaptations.

Yet evidence is now strong.

Many early objections have faded in importance.

Perhaps this one will too.