BIOLOGY PRACTICAL

LS1102

ROBERT JOHN CHANDRAN

Quantitative Methods in Biology

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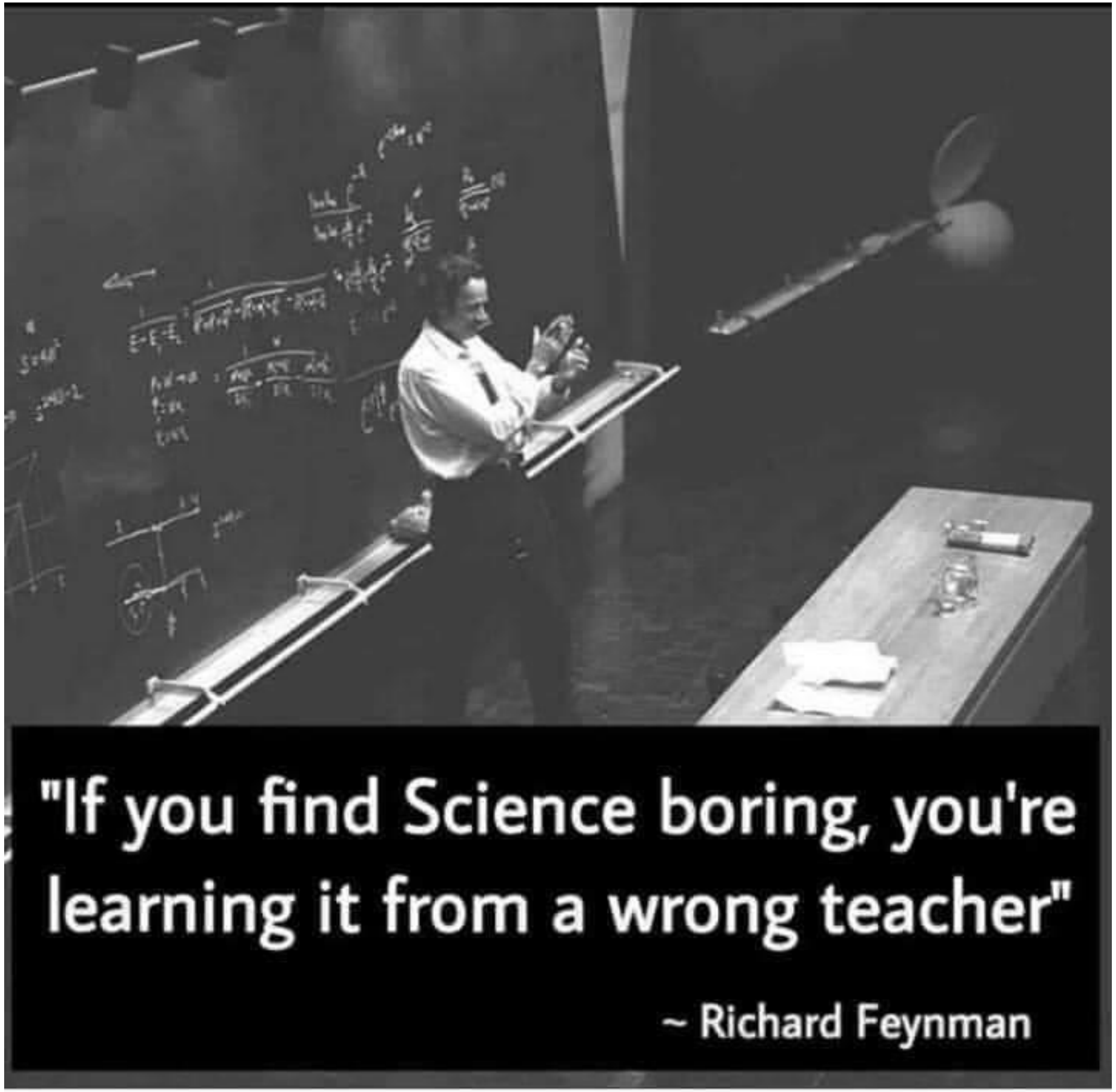
Biology is the study of living organisms



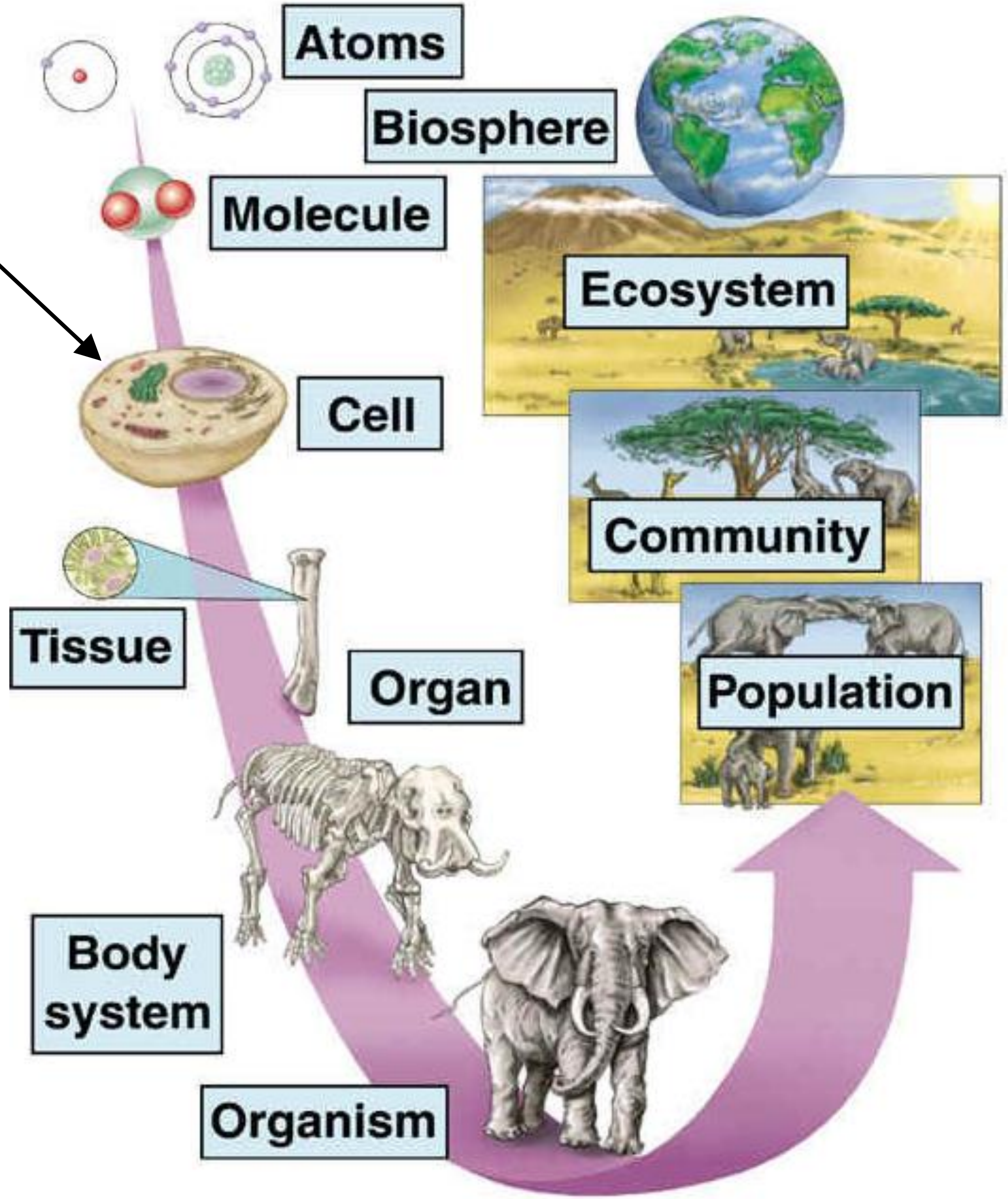
Goals of Science?

To understand

(1) The nature of *matter*
(2) The nature of *life*

Biology is the study of living organisms

The living **cell** is a critical level, and it packs enormous complexity



Biology is the study of living organisms

Questions we have dealt with in science

- What is the structure of a hydrogen atom/molecule?
- Why is mercury a liquid at room temperature?

- What is the structure of Hemoglobin?

So imagine the complexity of a cell!!

Biology is the study of living organisms

Structure of Biological Science

We are interested in the **principles** that govern

- Structure
- Development
- Function
- Behaviour
- Interactions
- Demography
- Distribution

Mathematical and Theoretical Approaches

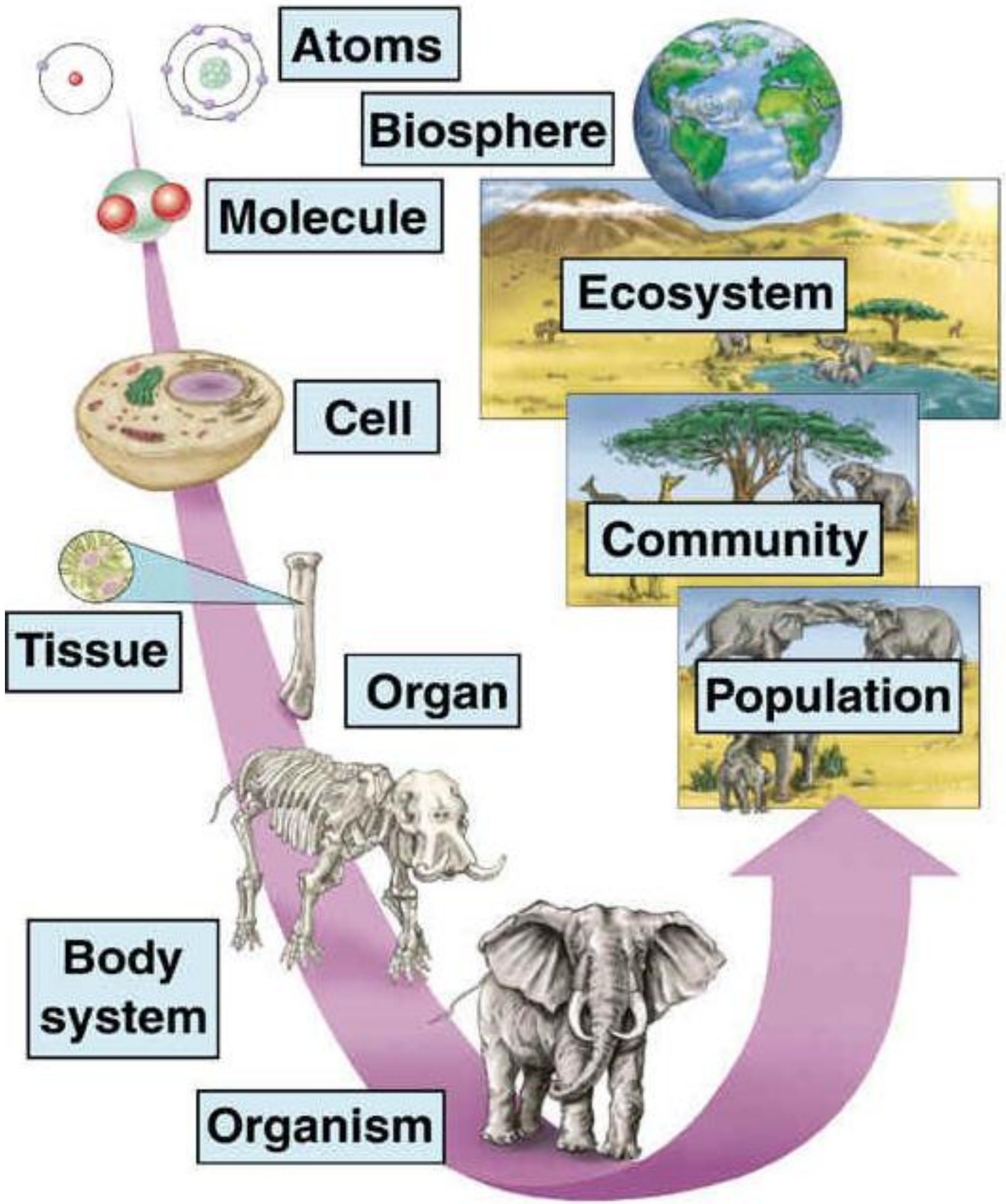
This often requires **mathematical** and **theoretical** analyses using abstractions of living systems . . .

The main route is of course **experimental** (including observations) to investigating all of this.

Theoretical analyses involves the articulation of theories, mechanisms, and hypotheses . . .

Mathematical analyses involves development of mathematical models to capture these ideas for testing, applications, and prediction . . .

Biology is the study of living organisms



In moving from one level to a higher level, we don't model or carry forward all the details

The **problem of relevant detail**

Mathematical and Theoretical Approaches

The use of mathematical approaches in biology is quite old

Started with describing patterns and population dynamics

- growth of rabbit populations (Fibonacci numbers)
- growth of human populations (exponential growth)
- Effects of small pox was modeled
- Various ideas in evolutionary biology were analysed using mathematical tools (e.g., Müllerian mimicry)

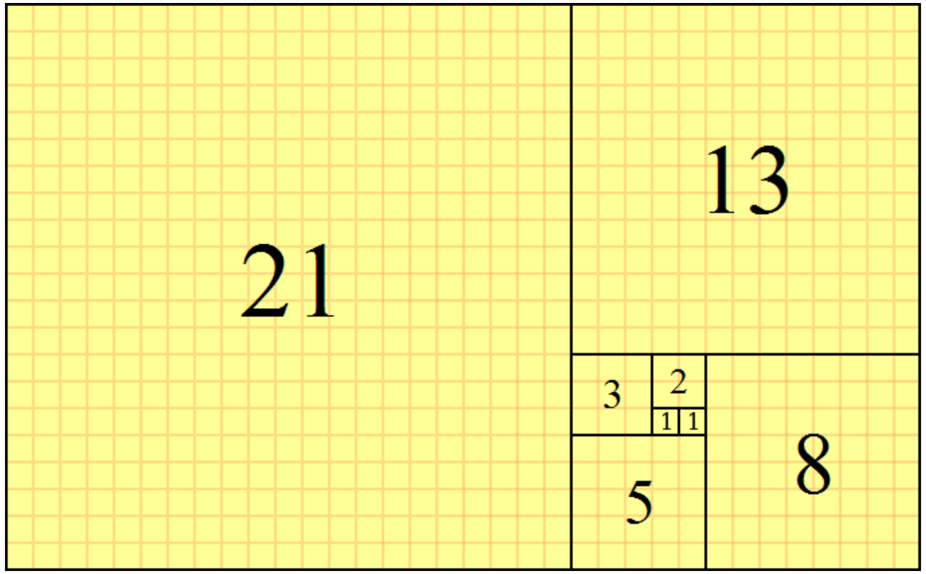
Mathematical and Theoretical Approaches

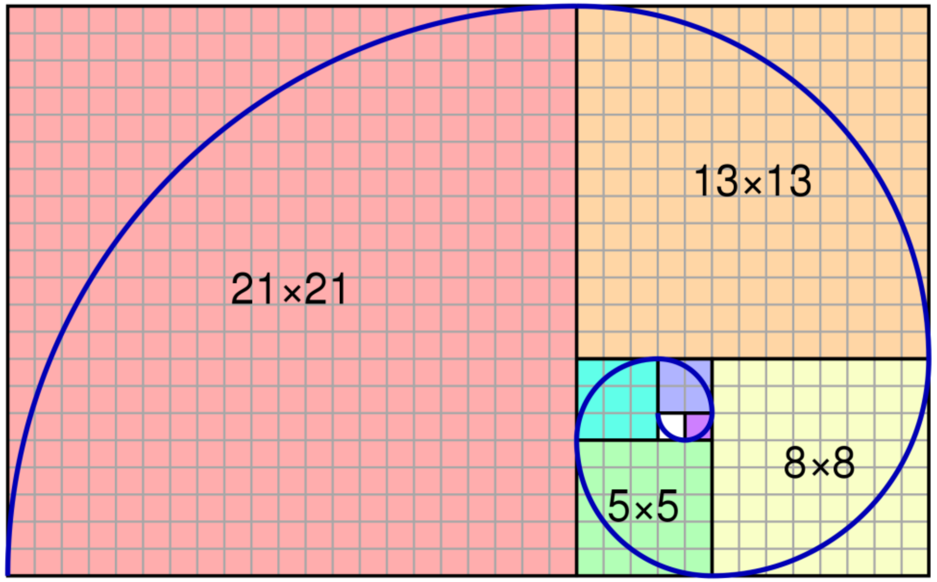
The use of mathematical approaches in biology is quite old

Fibonacci numbers form a sequence F_n

0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, . . .

$$F_n = F_{n-1} + F_{n-2}$$





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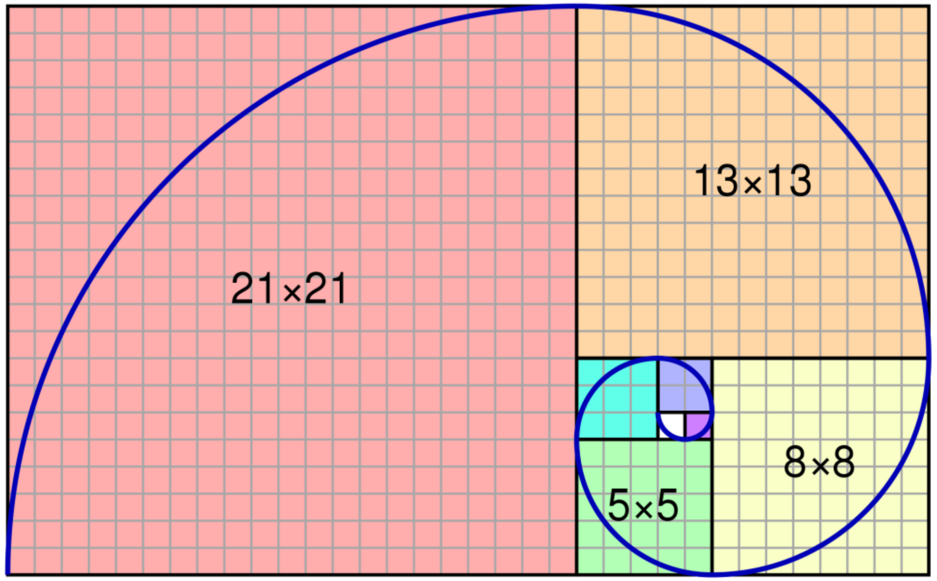
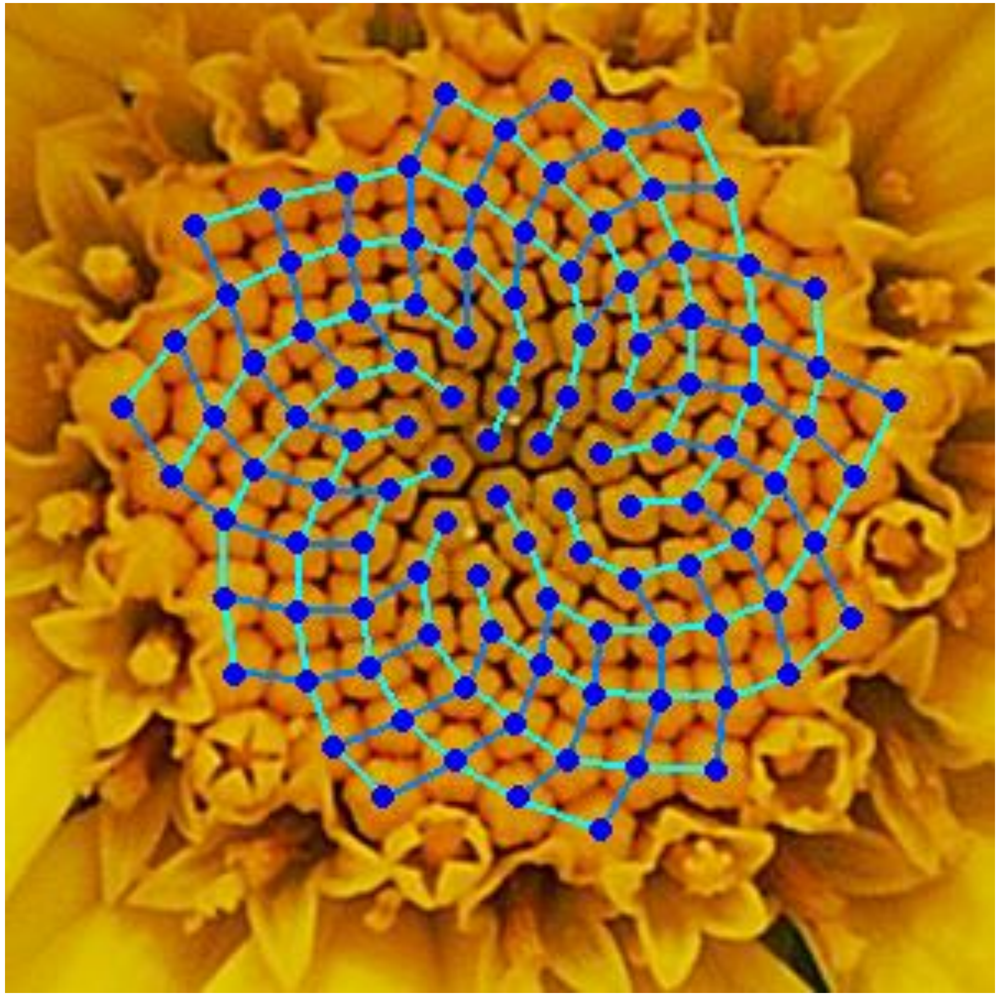


Yellow chamomile flower head showing the Fibonacci numbers in spirals consisting of 21 (blue) and 13 (aqua). Such arrangements have been noticed since the middle ages.



How populations grow . . .

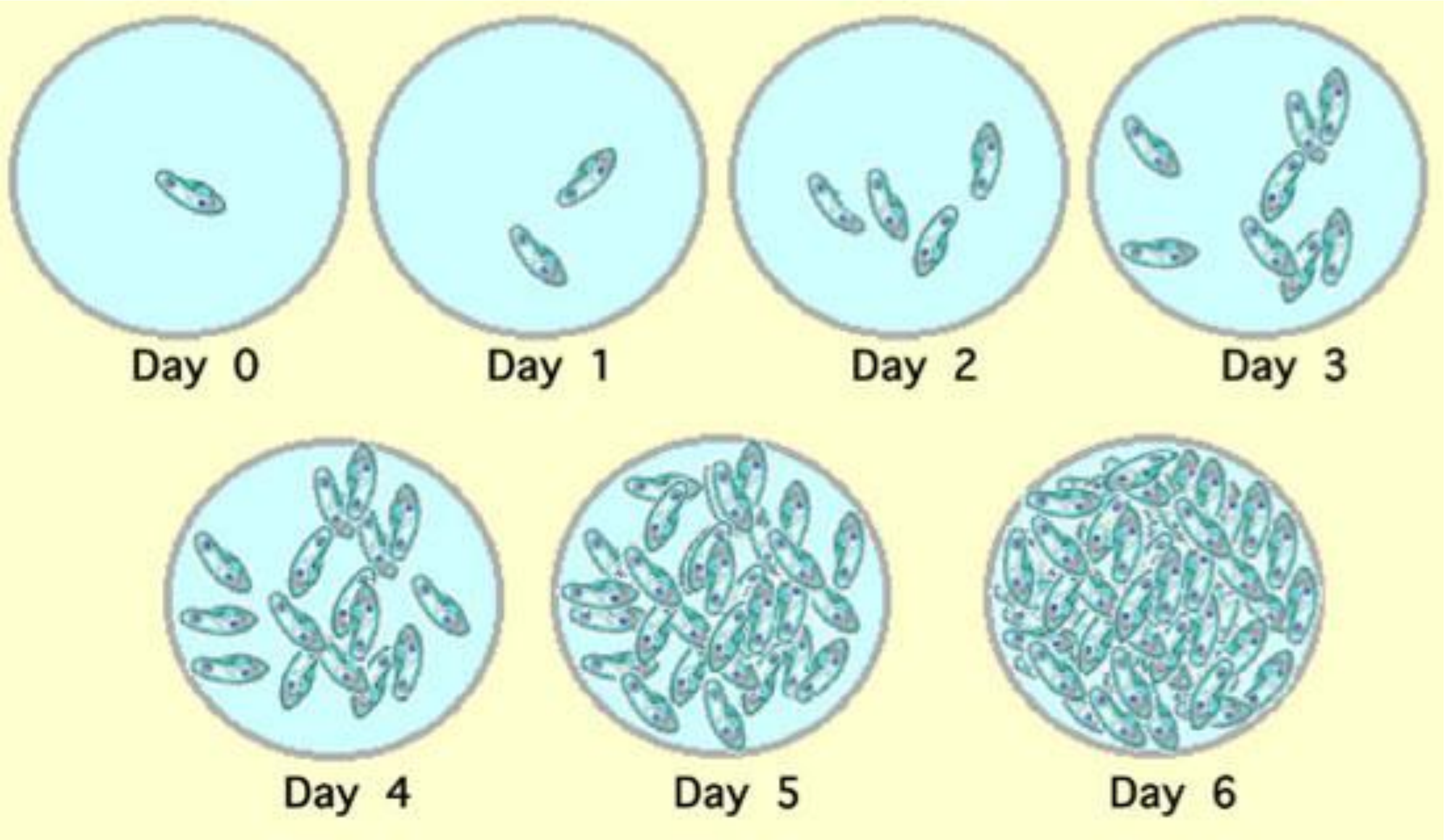
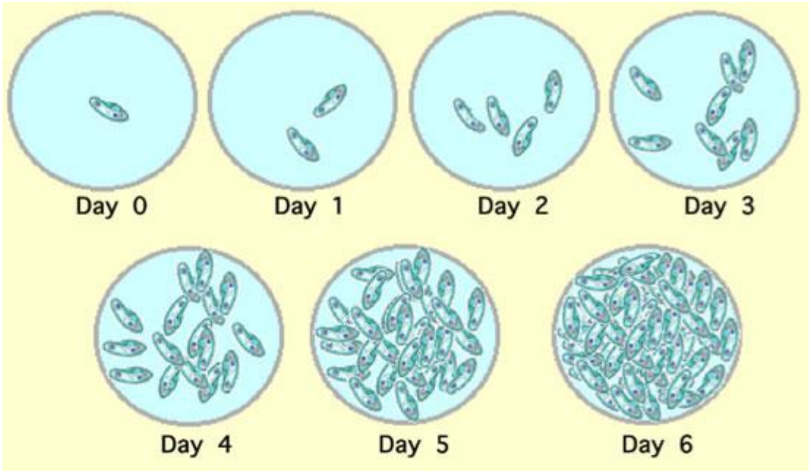
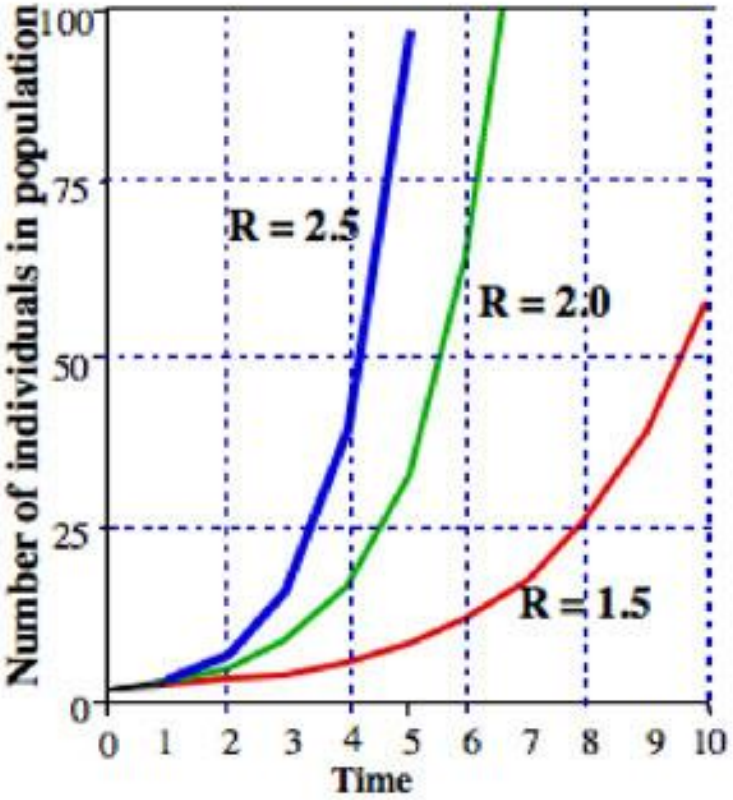
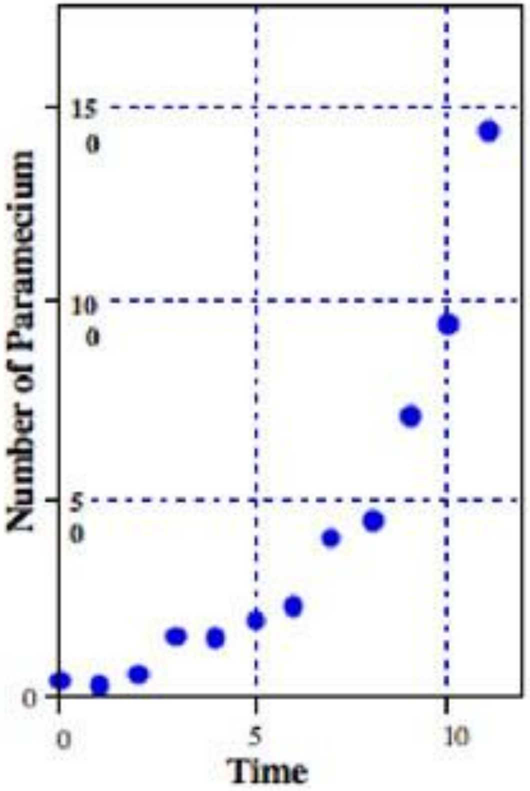


Figure 1: Changes in a population of Paramecium over a six day period. Each individual in the population divides once per day.

How populations grow . . .







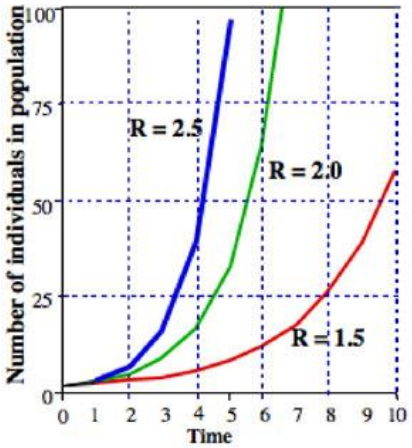
$$N(t) = 2\,N(t-1)$$

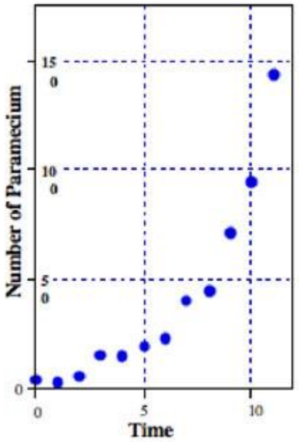
$$\textbf{Eq. 1}:\; N(t) = 2^{t} N(0)$$

$$\textbf{Eq. 2}:\; N(t) = R^{t} N(0)$$

Mathematical and Theoretical Approaches

How populations grow . . .





$$\textbf{Eq. 3:}\ \frac{d(N(t))}{dt} = rN$$

$$\textbf{Eq. 4:}\ N(t) = N(0)e^{rt}$$

Starting with a single individual . . .

$$\textbf{Eq. 5:}\ \ln(N(t)) = rt$$

$$\textbf{Eq. 6:}\ \frac{d\ln(N(t))}{dt} = r$$

Euler’s constant (e) =2.718282

The Idea of Density Dependence Modifies the Exponential Equation

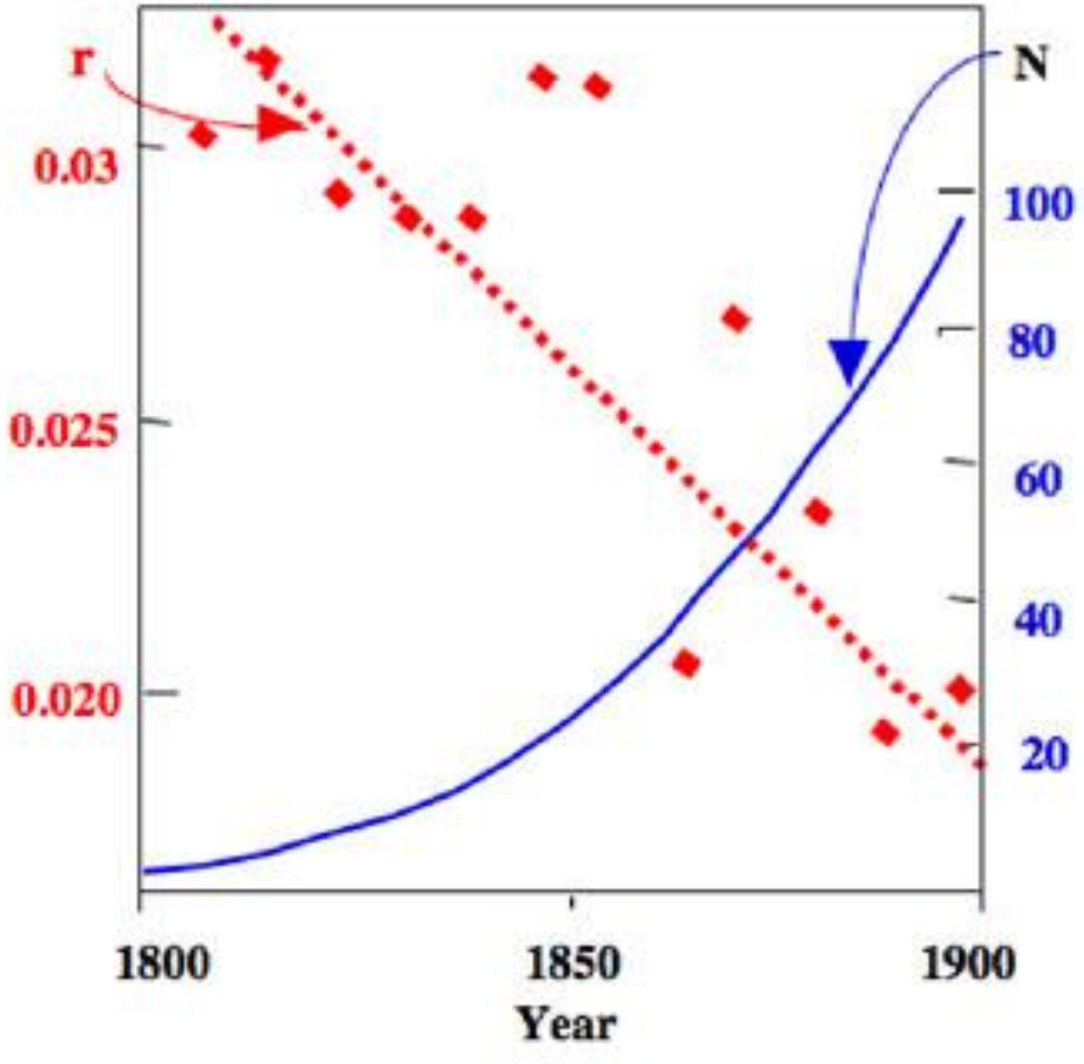
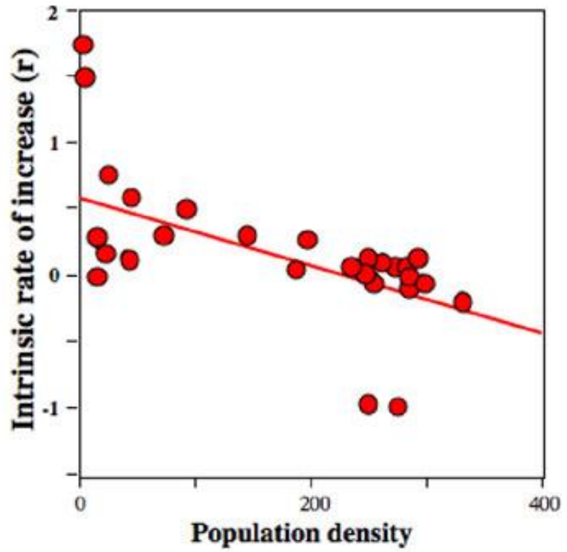


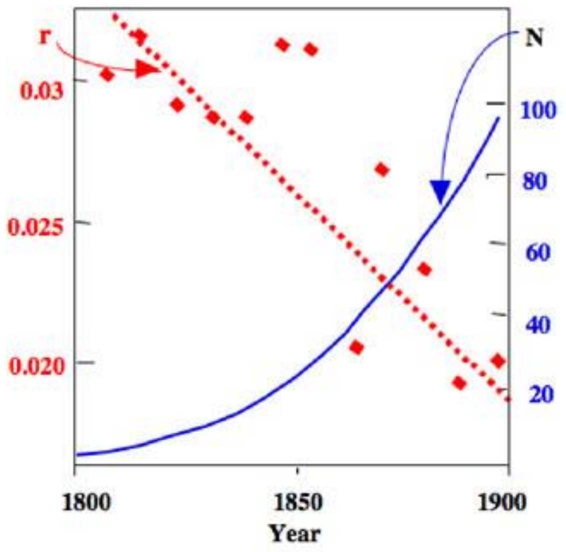
Figure: Growth of the human population of the USA during the nineteenth century (blue curve), and estimates of the intrinsic rates of increase during that period (red data points)

Note the general tendency for *r* to decrease throughout the century even while the overall population is increasing.



For Paramecium

The Idea of Density Dependence Modifies the Exponential Equation



$$\textbf{Eq. 7:}\quad \frac{dN}{dt} = rN$$

$$\frac{dN}{dt} = [f(N)]N$$

If we assume a linear function: $f(N) = a - bN$

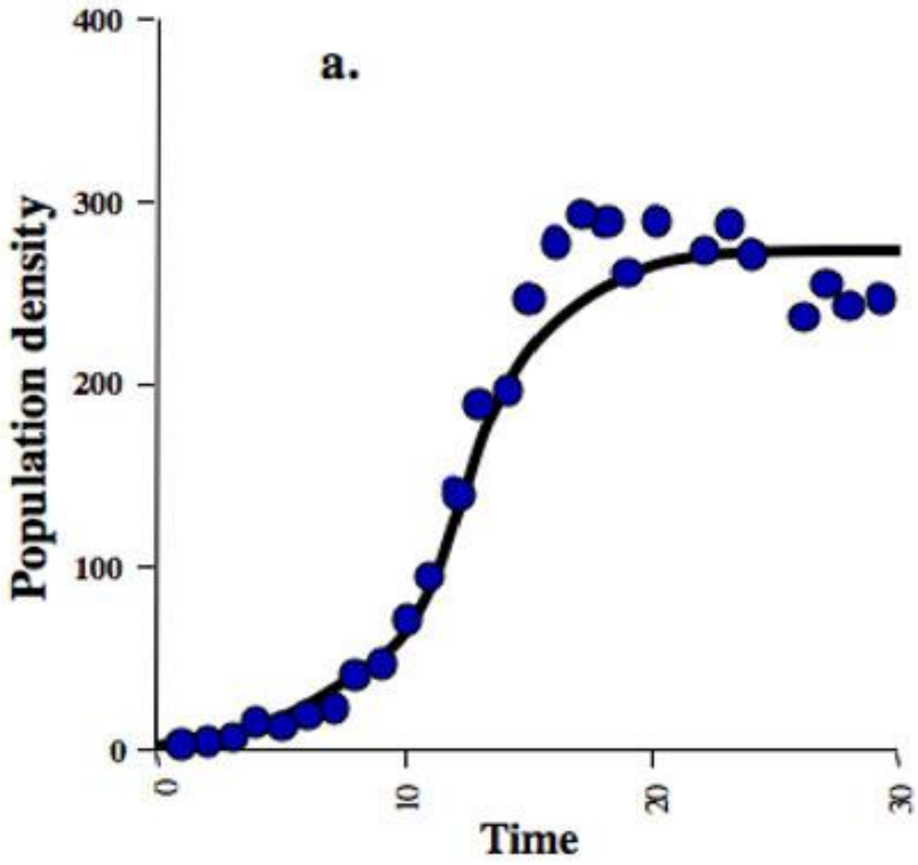
(Of the form $Y = a - bX$)

$$\frac{dN}{dt} = [f(N)]N = (a - bN)N = aN - bN^2$$

$$\frac{dN}{dt} = aN - bN^2$$

The Idea of Density Dependence Modifies the Exponential Equation

$$\frac{dN}{dt} = aN - bN^2$$



Mathematical and Theoretical Approaches

The concept of 'Carrying Capacity'

$$\frac{dN}{dt} = aN - bN^2$$

$$\textbf{Eq. 8:}\quad \frac{dN}{dt} = rN\left(\frac{K - N}{K}\right)$$

K – Carrying Capacity

Figure: Tropical American caterpillar with parasitic wasps emerging and forming cocoons on the caterpillar's back

Mathematical and Theoretical Approaches

Modeling simple to very complex phenomena

E.g., Modeling the Eukaryotic Cell Cycle

- Protein concentrations, reaction rates, compartmentalization, regulation, biosynthesis, degradation, interactions . . .

Approaches:

Deterministic: A system of ordinary differential equations
Stochastic: A statistical model of the distributions of protein concentrations in a population of cells.

Chance events and Uncertainty

Chance plays a big role in Biology

- Which individuals in a cohort of offspring survive
- Which mutation occurs in a gene sequence and how that affects the function of the protein

- Which species manages to disperse and colonize an empty site
- When and where do cataclysmic events happen

In finite populations, chance factors always play a role

Mathematical and Theoretical Approaches

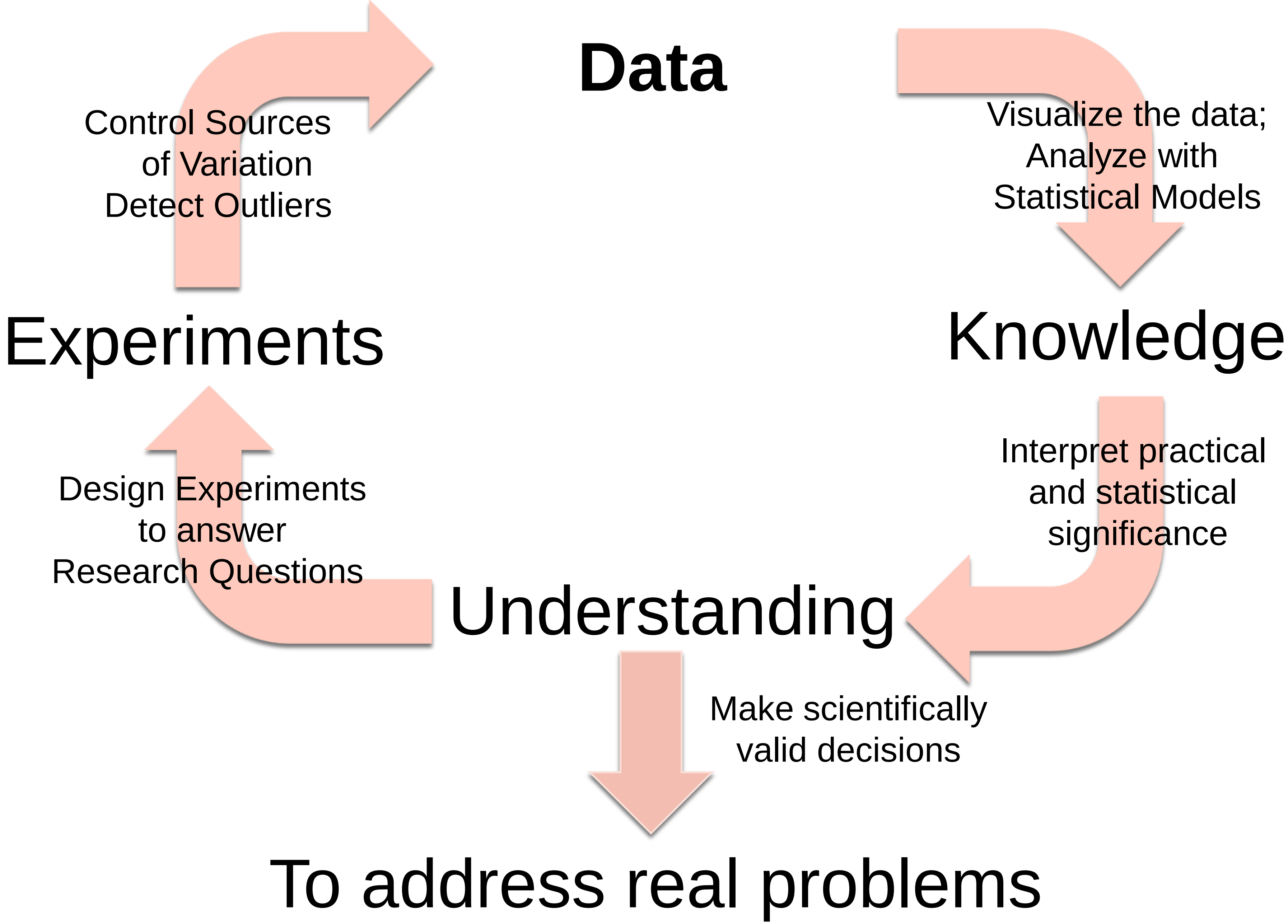
Chance events and Uncertainty: Experiments in Biology

Concept of population and sample

In experiments, we usually work with **samples,** and we collect **data.**

“Statistics is the science of learning from **data**, and of measuring, controlling, and communicating **uncertainty**; and it thereby provides the navigation essential for controlling the course of scientific and societal advances”

Statistical Models for Inference



Mathematical and Theoretical Approaches

Some human societies are **gerontocracies**, where elders make most of the important decisions

e.g., (i) where to take their herds for grazing,
(ii) where game are likely to be found for hunting
(iii) when to start the sowing in agriculture

Mathematical and Theoretical Approaches

Desert elephant herds of Africa, led by the matriarch, who makes critical decisions in the search of forage and water

Mathematical and Theoretical Approaches

Allegory of the cave - Plato (428 – 348 BC)