

Evolution of Sex – How Humans Reproduce and Try to Regulate How Others Reproduce



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<https://www.pascalgagneux.com/copy-of-116>

ANBI 116

Human Sexuality in an Evolutionary Perspective
Evolution of Sex

How Humans Reproduce and Try to Regulate How Others Reproduce

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PROF. PASCAL GAGNEUX

The course will explore the evolution of sexual reproduction including its costs and advantages. Human reproduction, like that of all other mammals is strictly sexual. This requires the existence of two sexes and precludes the persistence of successful genetic combinations across generations. This course will consider the evolutionary advantages and costs of sex. We will discuss the genetics of sex-determination, molecular recognition between gametes, fetal tolerance during pregnancy, genetic mating.

Sex is a charged Subject:

We will be discussing sex, sexual behavior, anatomy, genetics, heredity, sexually transmitted diseases, diseases of reproduction, taboos, religious and otherwise, genital mutilation, sexual violence, sexual exploitation, politics as these relate to sex and gender, reproductive technology as applied to humans.

My goal is not to shock you, but rather to share knowledge, promote critical thinking and novel perspectives.

Sex is a charged Subject:

Please share information without trying to shock.

If/when you detect real or perceived biases in what I am saying, please bring it up in class or in office hours.

What is Sex?

	broad definition	
	narrow definition	ANBI 116 ♀

Any process that brings together and mixes the genetic material from different individuals into a new single individual. The eukaryotic sexual cycle, including the formation of gametes, dedicated sex cells.

A way of classifying individuals. A way of regulating behavior. Isogamous microbes vs anisogamous eukaryotes; A pleasurable hobby; Length of diploid stage can range from most of the time to just prior to meiosis; could sex have started as an "infection"/ manipulation by selfish genetic element to spread across lineages? modes of development/physiology; Classification; Pleasure; Reconciliation; Taboo; Power; Profit; Mechanism for repairing DNA damage gone awry? Bringing together good mutations; Combining bad mutations and purging.

Practice Question: Give two different definitions of Sex.

Sex is the process leading to the exchange of genetic information between individual organisms.

Sex is the fusion of two haploid cells carrying reshuffled genetic information and leading to the formation of a new diploid organism.

Deep Time: 3 billion years of life



Life on our planet is 3 billion years old. All living life forms appear related.

Practice Question: What is the evidence that all life forms are evolutionarily related?

All life forms share DNA or RNA as their molecules of inheritance. All cellular life forms carry DNA encoding ribosomal RNA

The doctrine of evolution?



"the originator of the doctrine of evolution"
Jean Baptiste Lamarck!

not quite, but was congratulated by Charles Darwin for "drawing attention to the probability of all change in the organic"

Lamarck was one of the naturalists who started realizing that species/ life forms change over time.

He had the mistaken idea that acquired characteristics such as a long neck of an ancestral giraffe could be passed on to the next generation.

Practice Question: What is the problem with the notion of inheritance of acquired characters?

Such characters would have to trickle from the phenotype of the organism to its genome in order to be inherited.

Biological novelty by combining random change and non-random survival/reproduction



Charles Darwin



13 species of finches from common ancestor in 2.3 My

1. Sharp-shinned hawk
2. Sharp-shinned hawk
3. Sharp-shinned hawk
4. Sharp-shinned hawk
Photos from Galapagos Archipelago

The crew on his ship through out some of the best evidence for evolution: the remains of the turtles from different islands. Years later, Darwin used studies of bird (the Galapagos finches) to realize the patterns.

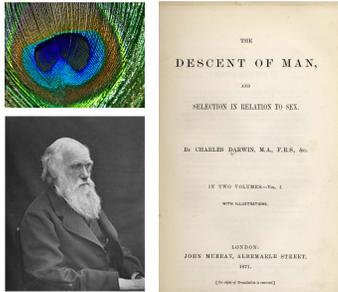
He came up with the idea that natural selection could be responsible for shaping populations of organisms.

Russel Wallace had the same idea while collecting biological specimens in Southeast Asia.

Practice question: What excellent evidence of evolution was thrown into the ocean from the ship that Darwin traveled to the Galapagos Island with?

Tortoises, each Island having independent evolution of slightly different species.

Sexual Selection



Next to Natural selection, Darwin also conceived of sexual selection: the force shaping organism exerted by the choice of mating partners.

Novelty by combining random change and non-random survival/reproduction

Sexual Selection



Male - Male Competition



Female Choice



Male-male competition was very palatable to Victorian era men
Female choice, with its immense empowering of females much less so.

Practice question: What is the difference between natural and sexual selection?
Natural selection refers to the differential survival and sexual selection to the differential reproduction of individual organism.



If you see weird things in nature, it likely evolved by sexual selection

Practice question:

What is generally a safe assumption when you observe weird features animals and their behavior?

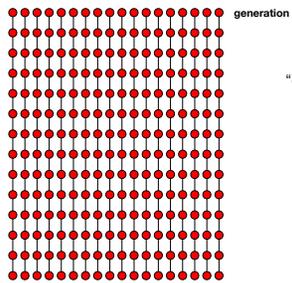
That these are related to sex and reproduction.

Korean Documentary on Sexual Selection

This program was produced by broadcasting and communication development fund of the Ministry of Science and ICT(Republic of Korea)

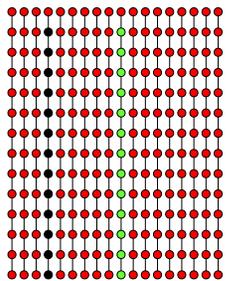


Principles of Evolution



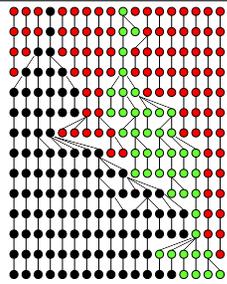
Inheritance:
"entities make copies of themselves – they replicate"

Principles of Evolution



Variation
that is heritable,
comes about by
random mutation

Principles of Evolution

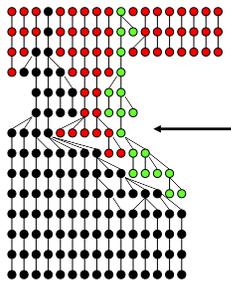


Differential
reproductive
SUCCESS

Due to differences in
mortality and/or fertility,
highly deterministic,
not random.

↓
Changes of frequency over time:
Evolution

Principles of Evolution



Population size
(numbers of copying entities)

← "Bottleneck"

Small populations undergo more
rapid changes in frequencies of
variable units.

Inheritance: genetics and culture!



How can inheritance across 4 generations be explained? Is it shared "blood"? Blood is a mixture of liquid and particles (cells) and secreted proteins, blood blends when mixed with other blood. BUT DNA is particulate and can only be shuffled.

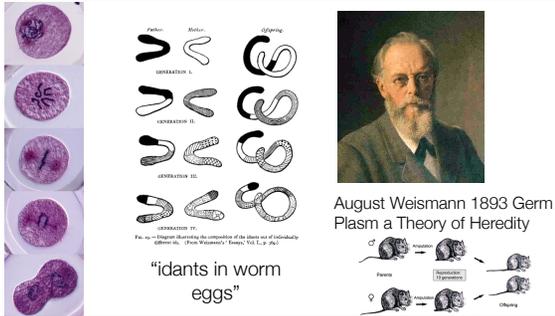
Genetic inheritance is powerful but many inherited traits are **non-genetic**: language, beliefs, wealth, poverty, education, infections, diet, lifestyle. **Human culture is a powerful inheritance system of its own!**

Carriers of heredity?

blending inheritance (half bloods?)
 gemules?
 inheritance of acquired characteristics?
 particulate inheritance (DNA & RNA)

Early theories of inheritance formulated notions of blended inheritance, liquid-like gambles that could absorb the experiences of each generation....
 These all failed to explain why sometimes, grand-children loom more similar to their grandparents than to their parents.....

Soma and Germ Line



The stuff of heredity, is particulate and is only passed on through specialized cell: the germ line. The rest of the body (the soma) serves as the vehicle to get these sexual cells to the right place: meeting with sex cells from other individuals.

Practice Question: What is the difference between somatic and germ cells?
 Somatic cells are the majority of the cells in the body, germ cells can give rise to gametes.

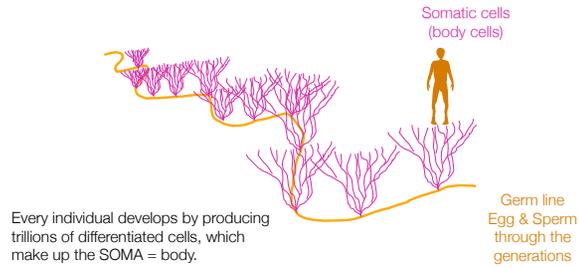
Cutting long enough to evolve away?

Dating to Dynasty 6 and specifically to the Service of Nesi (Pharaoh) Teti (2355-2343 BCE)
 4500 years > 200 generations



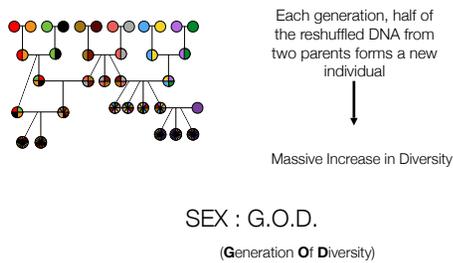
Just like the mouse tails cut off along successive generations by Weissmann, over 200 generation of male circumcision has not caused baby boys born without a prepuce. Aposthia, the rare occurrence of boys born with congee tail absence of the foreskin does exist, but is not higher in societies where male circumcision is practiced.
 Practice question: What does the practice of circumcision in the middle east illustrate about the inheritance of acquired characteristics?
 Most males in these societies are still born with a prepuce, proving that 200 generations of cutting has failed to translate into an inherited character.

Germ Line and Soma



Then germ line represents a potentially immortal lineage of cells. These cell produce gametes, the sex cells of males and females. The rest of the body consisting of exclusively mortal cells, could be considered to be just "an excuse of sex cells for making the next generation's sex cells"

Just Add Sex

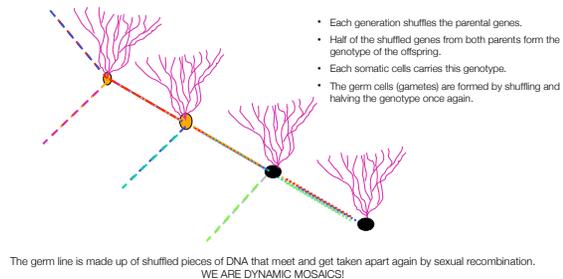


Sexual recombination produces novel and unique combinations each generation and for each individual.

How is Sex like GOD?

It is an important mechanism for the Generation Of Diversity.

The Germ Line is not a simple line:



The germ line is made up of shuffled pieces of DNA that meet and get taken apart again by sexual recombination.

WE ARE DYNAMIC MOSAICS!

Practice question: What is the germ line?

The un-interrupted lineage of cells that give rise to reproductive cells (gametes) and to germ cells in the embryo.

Mechanisms of Evolution

Natural selection : "survival of the fittest"

Neutral evolution...drift : "survival and reproduction of the luckiest"

(history and geography...islands)

Sexual selection : "reproduction of the sexiest"

Natural selection operates in populations, where individuals better adapted to current circumstances are favored over those less well adapted. Such "fitness" is always dependent on context.

Evolution is also influenced by random (stochastic) events: the composition and size of populations that colonize new habitat, or happen to survive major disease or natural disasters.

Finally, under sexual selection, individuals that manage to out reproduce others in a population, will leave more offspring and in so doing, shape the future evolution of descendant populations.

Evolution in a nut shell:

Replicating entities.

Heritable variation between entities.

Differential survival and **reproduction**.

Evolution by natural selection, drift, and sexual selection
is the organizing principle of modern life sciences.

Practice question :

What are the three requirements for evolution?

Replication, inheritance, differential survival and reproduction

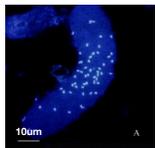
What is the stuff of inheritance?

Replicators?



cells, organisms, viruses

nucleic acids/ genomes



Root hair of strawberry plant, $2n = 56$



Somatic chromosomes in root tip cells stained with DAPI. Metaphase chromosomes of *F. xananassa* 'Nyoho' ($2n = 56$).

Hybrid strawberries have 4 times more DNA than their ancestors.

Adding water salt and detergent allows to free the DNA from the inside of cells and their nuclei (a second bag of membrane containing the chromosomes).

After filtering the extraction, adding cold rubbing alcohol (isopropanol) precipitates DNA where the two fluids touch, DNA can be fished out and admired.

How can one prepare DNA from living cells?

Detergent, water and salt mixed to lyse the cells (lipid rich membranes of the cell and the nucleus dissolve); Straining away the rough parts; Adding cold rubbing alcohol to precipitate the DNA from the soap salt water solution into white slimy goop...

The Red Queen Hypothesis for the maintenance of sex



The late Leigh Van Valen



The Red Queen Hypothesis for the maintenance of sex

The shuffling of genetic identity allows escape from infection!

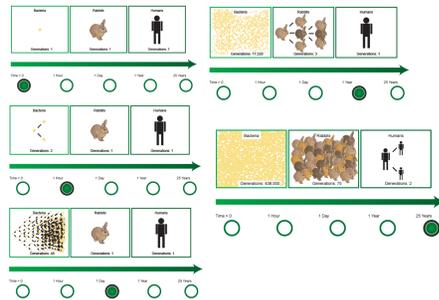
Van Valen, L. (1973). A new evolutionary law. *Evolutionary theory*, 1, 1-30.

Carroll, L., Haughton, H., & Carroll, L. (2009). *Alice's adventures in Wonderland; and, Through the looking-glass and What Alice found there*. New York: Penguin Classics.

Practice Question: What is the Red Queen Hypothesis in Biology?

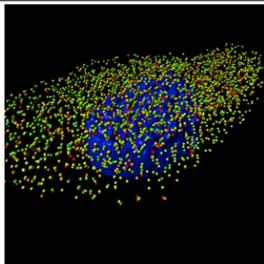
The Idea that large, long-lived organisms need to find ways of changing in order to escape from more rapidly evolving parasites and pathogens.

Generation time of a bacterium: hours



Large bodied and long-lived mammals such as humans are out-evolved by microbes with very short generation times.

Generation time of a virus: minutes to hours

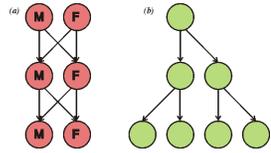


newly generated Influenza A virus RNA in infected mammalian cell after 8 hours

A 3D rendering generated using Imaris software of an MDCK cell (cocker spaniel dog cell) infected with influenza A/WSN/1933 (H1N1) virus with four influenza viral RNA segments identified by fluorescent in situ hybridization: different viral proteins can be seen: PB2 (red spots), PB1 (green spots), PA (orange spots), and NP (yellow spots). The cell nucleus is labeled in blue based on DAPI staining. Reprinted from PLoS Pathog 10(3). - See more at: <http://www.bitplane.com/learning/visualizing-influenza-a-viral-rna-assembly-during-infection-virology#sthash.PZGzVBzo.dpuf>

Researchers led by Dr. Seema Lakdawala from the NIH National Institute of Allergy and Infectious Diseases recently used Imaris software to observe influenza A replication dynamics in three dimensions.

Two-fold cost of sex



Adds to that the cost of potential conflict between sexes!

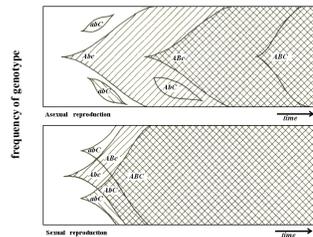
First pointed out by John Maynard Smith

An asexual population can grow twice as fast as a sexual population. (Sex requires two sexes, males don't reproduce... and are often badly behaved....)

Also: Sex obliterates good combinations each generation (via recombination)! A winning genetic type of a clonal population reproducing asexually, maintains the same winning combination across generations.

Sex allows for faster evolution

shuffling of DNA during sexual recombinations creates novel recombinations



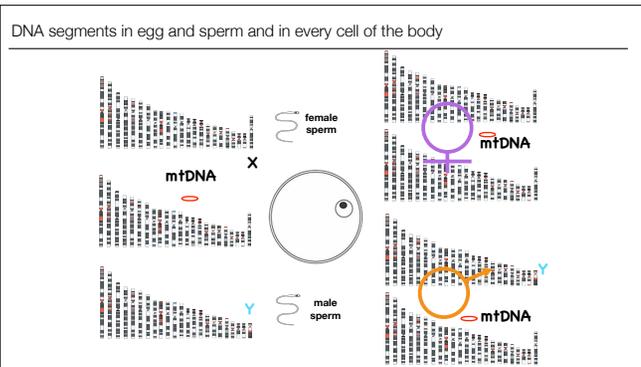
Crow and Kimura 1965

The cost appears to be worth it as sex allows for faster evolution of hosts faced by evolutionary speed demon microbes
Sexual Recombination allows novel genetic variants ("evolutionary ideas") to spread across the population faster.

Genome transmission by bonobos

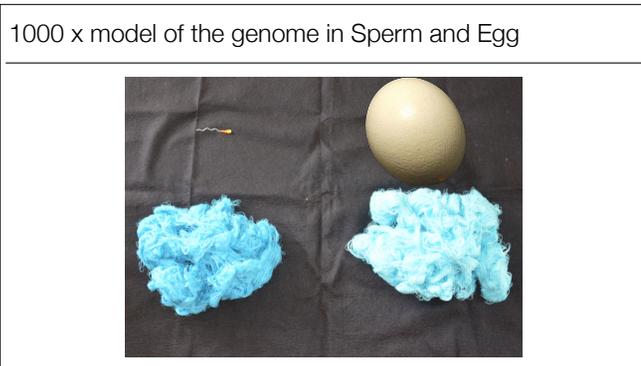


Chances are the female is not ovulating, so the males sperm would not even get pass her cervix, which is kept shut by specialized mucus.



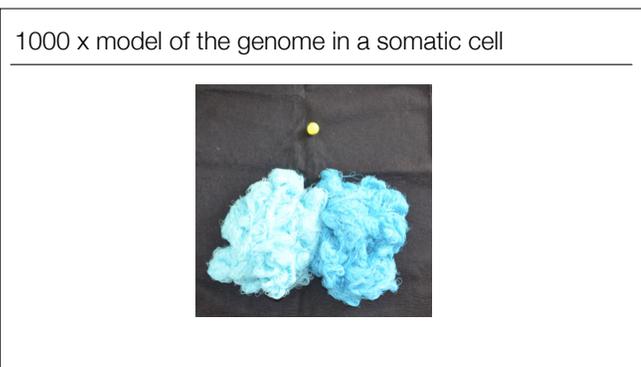
The complement of chromosomes in human gametes (haploid = single copy of each chromosome) and body (somatic) cells (diploid two copies of each chromosome except for males who have a single X chromosome and a Y chromosome).

How many pieces of DNA are there in the genome of a human?
46, visible as chromosome when a cell is dividing.



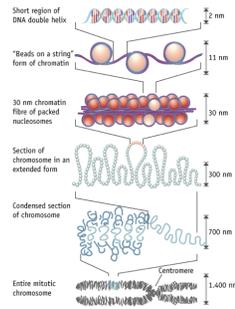
Egg 130 micron
times 1000 = 130 mm = 13 cm
Somatic cell 20 micron 2cm diameter
Sperm 60 micron times 1000 = 6 cm long

How long is the haploid genome of each of our cells and how many “letters” base pairs does it contain?
About 1 meter long and it contains 3 billion bp.



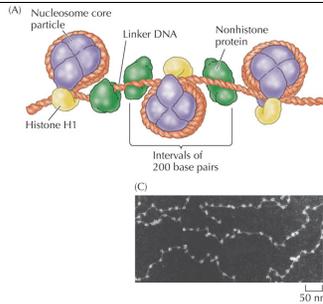
How does all this DNA fit in a single cell?
By extremely compact packaging into chromatin and further compacting into chromosomes.

Fitting a genome into a cell: genome packaging



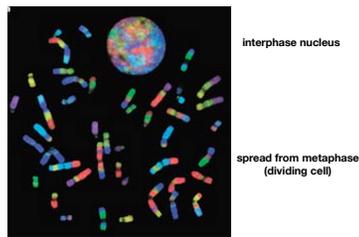
a representation of how DNA is packaged into a chromosome

Fitting a genome into a cell: genome packaging



uncoiling the supercoiled chromosome reveals chromatin, DNA wrapped around histones like beads on a string

Fitting a genome into a cell: genome packaging



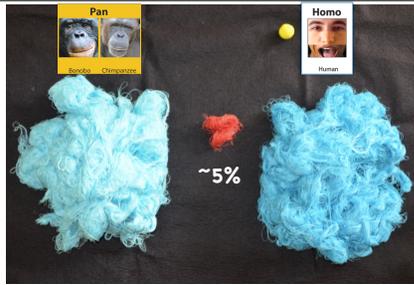
Human chromosomes painted with probes from sorted gibbon chromosomes

Ferguson Smith 1997 European Journal of Human Genetics

Metaphase, when the cell is ready to divide, is when chromosomes can be seen as compact rods.

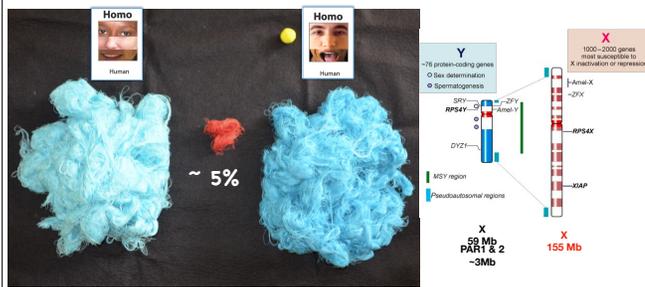
When a cell is busy living (not replicating) during interphase, the DNA is decondensed into "puffs"

1000 x model of haploid genome



The amount of DNA differing between a human and a chimpanzee is approx 5% including all the stretches of DNA that are absent in one and present in the other species.

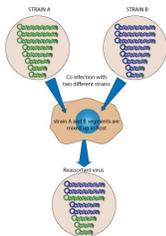
1000 x model of haploid genome



The missing second X-chromosome and differing Y-chromosome make human males about 5% different from human females.

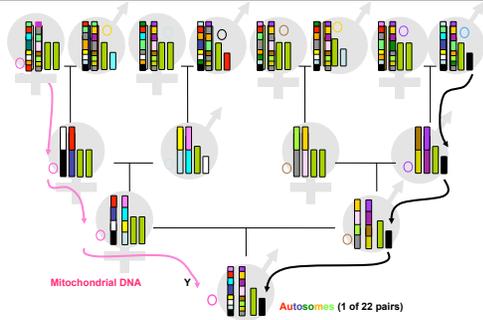
On the fast lane: viruses have sex too!!

Many viruses can exchange genetic material during co-infection by multiple strains: essentially adding viral sex to their rapid evolution



Some viruses can have “sex too”
e.g. Influenza A viruses co infecting the same host cell can exchange RNA segments.

Modes of inheritance: uniparental & biparental



Not all DNA is reshuffled: mitochondria DNA and most of the Y chromosome DNA are passed on uni-parentally.

What 2 different parts of our genomes do not get reshuffled but are rather inherited from one parent only?

Mitochondrial DNA and most of the Y-chromosome

Asexual Reproduction



yeast budding



Bdelloid rotifer
(80 million year old
asexual)



potato sprouting



flatworm splitting

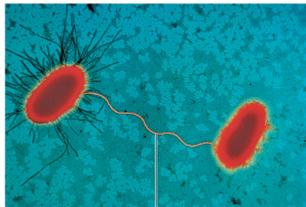
Plenty of eukaryotic species can reproduce asexually

Practice question: Name three different eukaryotic species that can reproduce asexually.

Yeast, rotifers, many plants and flatworms, whiptail lizards, komodo dragons, some sharks.

Prokaryote / Microbial Sex

Bacterial Conjugation



Sex pilus

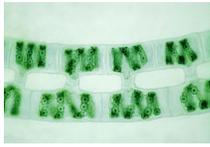
1 μ m

Bacteria exchange genetic tricks, such as resistance genes against antibiotics

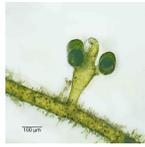
Practice question: How can bacteria have sex?

They can exchange DNA through conjugation; passing it to another cells through a sex pilus.

Sex among Algae



Spirogyra conjugation



Vaucheria taylorii
sex organs

The conjugation tubes between the two algal filaments allow the contents of one cell to fuse with those of the other, forming a zygote. The characteristic spiral chloroplasts are clearly visible.

David M. Dennis/age fotostock

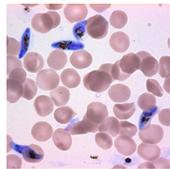
Can sex occur without the formation of specialized sex cells?

Yes, as in somatogamy or conjugation between body (somatic) cells of algae or fungi.

Sex among Protozoans



Hypotrichs (ciliated protozoa)



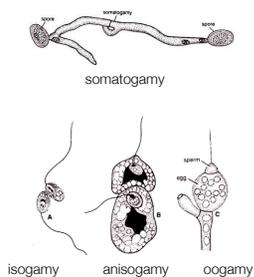
P. falciparum
(malaria parasite)
occasional sex

Malaria reproduces sexually in mosquitos and makes us sick when reproducing en masse asexually in humans.

Sex among Fungi



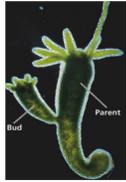
Phallus impudicus
(stink horn, a fungus)



The fungus sex is actually happening below ground between hyphae, the mushroom is a structure to spread asexual spores.

Practice Question: What is the difference between Isogamy and anisogamy?
In anisogamy, the gametes are of different size, small sperm, large egg.

Facultative Sex



Hydra (cnidarian)



Daphnia (water flea)



C. elegans (nematode)

Many species can alternate sexual and asexual reproduction. They can consist of males or hermaphrodites in their populations e.g. nematode *Cenorhabditis elegans*.

Vertebrates without Sex



Some populations of whiptail lizards in Arizona are all females



Aspidocelis neavesi, two females pseudomating to enhance ovulation



Brahmini blind snake (*Indotyphlops braminus*, a lizard) native to Africa and Asia, parthenogenetic, all females, most widespread land vertebrate

Asexual groups seem to be found only at the tip of phylogenetic trees.... i.e. they go extinct more often than sexual groups. They have a huge advantage the colonizing new habitats.

Practice question: What could be the advantage of losing sexual reproduction? Becoming better at colonizing new habitat by not investing in males and not having to look for mates.

Parthenogenesis in other vertebrates



sharks including this hammerhead in Georgia aquarium



Komodo Dragons

Sexes



snails
giant clam
born hermaphrodite

Ocellaris clownfish
Amphiprion, born male

California sheephead
born female

females
males
hermaphrodites
simultaneous
sequential
protogynous
proterandrous

No genders here, just sexes, separate or in the same individuals, simultaneous or sequential

Practice question: Name a hermaphrodite species that is male first and female later (proterandric hermaphrodite)

Clown fish (nemo).

Obligate Sexual Reproduction



Chimpanzees in Gombe National park,
Tanzania, about to mate

So far all known of the ~ 5000 mammalian species are obligate sexual reproducers.

Practice question: Are there mammals that can naturally reproduce without sex?

No, all 5000 species of mammals appear to be obligate sexual reproducers.

Sex in Humans: sexes, genders, symbols, words & norms!



Weird Human stuff: often sexually selected.



Evolution of Sex in Humans ?

Theodosius Dobzhansky quotes:



"Nothing in Biology Makes Sense Except in the Light of Evolution"
(The American Biology Teacher, Vol. 35, 1973).

"Human evolution cannot be understood as a purely biological process,
nor can it be adequately described as a history of culture.

It is the interaction of biology and culture. There exists a feedback between biological
and cultural processes".
(Mankind Evolving, p. 18, 1962)

Practice question:

One famous quote from biologist Dobzhansky is that "Nothing in Biology Makes Sense Except in the Light of Evolution".

Try to convey the meaning of the other famous quote about understanding human evolution.

Feedback between biology and culture needs to be considered.

Summary



Sex is a fascinating and highly charged topic.

Sex involving the exchange of DNA or RNA exists in single celled microbes and even viruses.

Sex involving the mingling and redistribution of chromosomes (highly packaged DNA) is key to the evolution Eukaryotes.

Sexual selection can produce formidable traits that appear non-adaptive in terms of survival.

Sex is G.O.D. (generation of diversity).

Sex appears particularly important for large long-lived animals, mammals are obligate sexual reproducers.

Human sex is an important part of culture, it shapes and is shaped by culture.