Evolution and its Role in Science and Society

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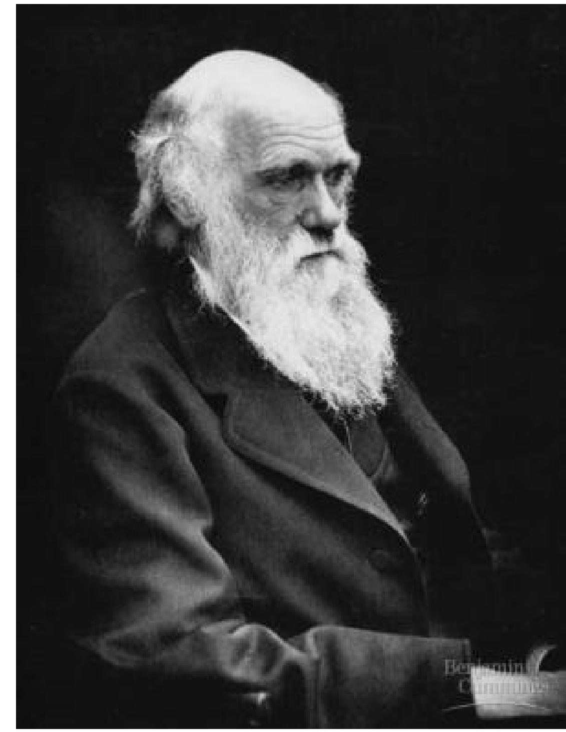
Evolutionary Biology

2009

200th anniversary of Darwin's birth

150th anniversary of *The Origin*



Darwinism and evolutionary biology are often seen as being solely of academic interest

Importance of evolutionary biology for science and society vastly underestimated

Time for an update!

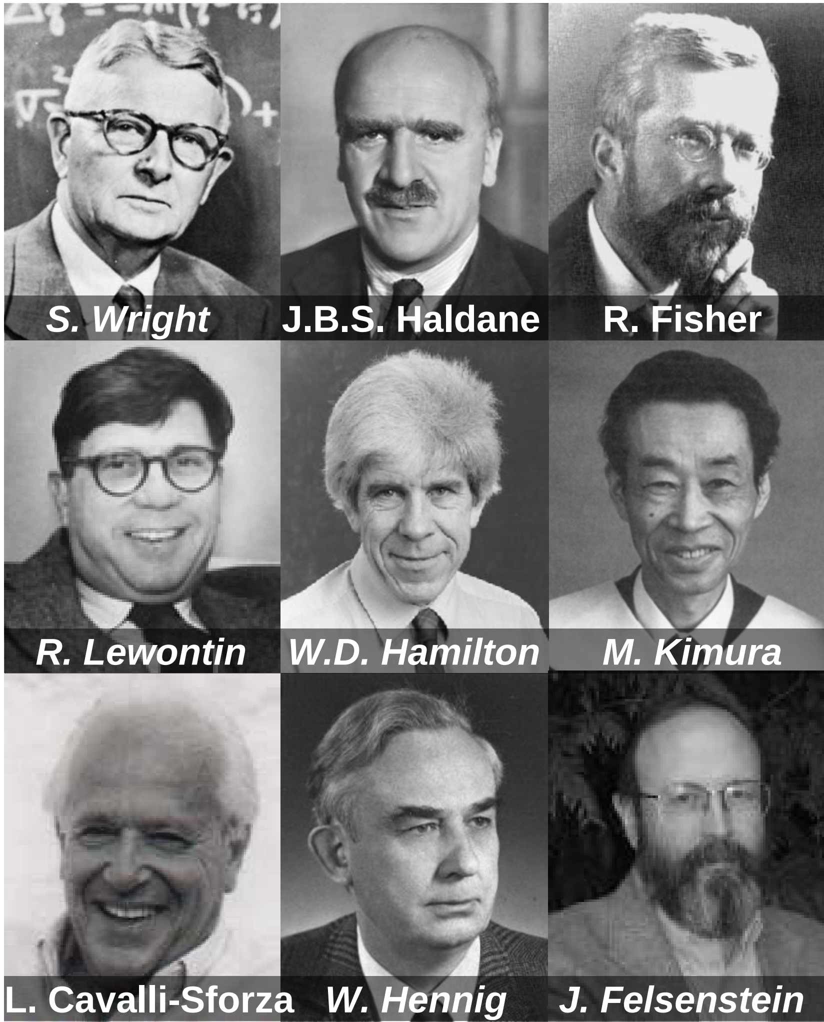
I will give a sampling of some recent studies to show the vast range of problems that modern Darwinism can address

Modern Darwinism

Progressed a long way from Darwin !

Modern evolutionary biology:
based on population & quantitative genetics, experimental evolution, phylogenetics & theory

In medicine and agriculture
no one could do without
any of these techniques.



Improvement of Crops & Animals

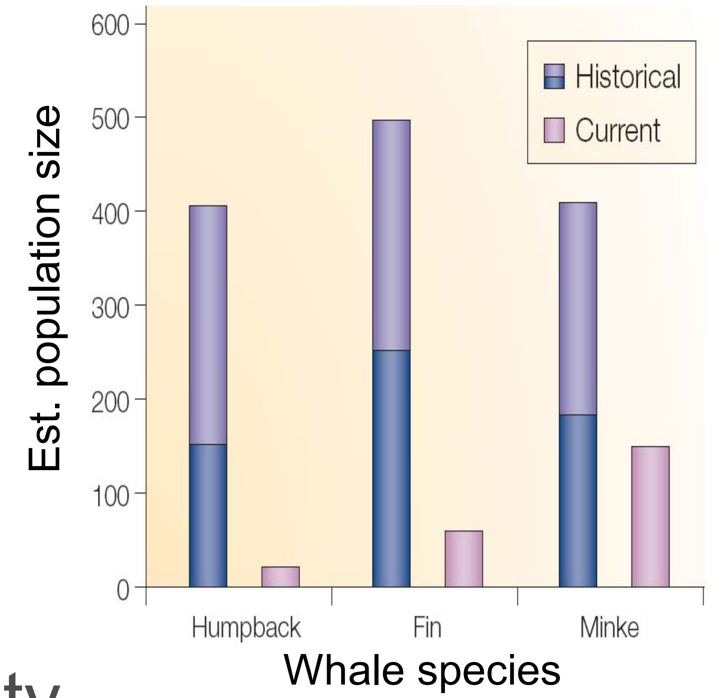
Earliest applications were in agriculture: **artificial selection**

From ca. 10 000 yrs bp onwards humans have started to domesticate and improve various plants and animals for their own use. But over the last century methods from **quantitative genetics** have allowed for greatly improved selection schemes.

Conservation Biology

Many applications in conservation biology, e.g. to

- manage natural and captive populations to avoid loss of genetic diversity
- estimate population sizes
- detect and define invasive species
- understand population connectivity



Helps to set guidelines for helping preserve rare species & biodiversity.

Roman & Palumbi (2003) Whales before whaling in the North Atlantic. *Science* 301: 508–10

Fisheries Management

In fisheries management potential for evolutionary change in harvestable biomass has long been neglected. Yet, profound effects.

Traditional method

minimum size restriction

only large fish are caught

<u>but</u> causes selection for

(1) maturation at smaller size & lower age

(2) selection for slow growth to stay below mesh size

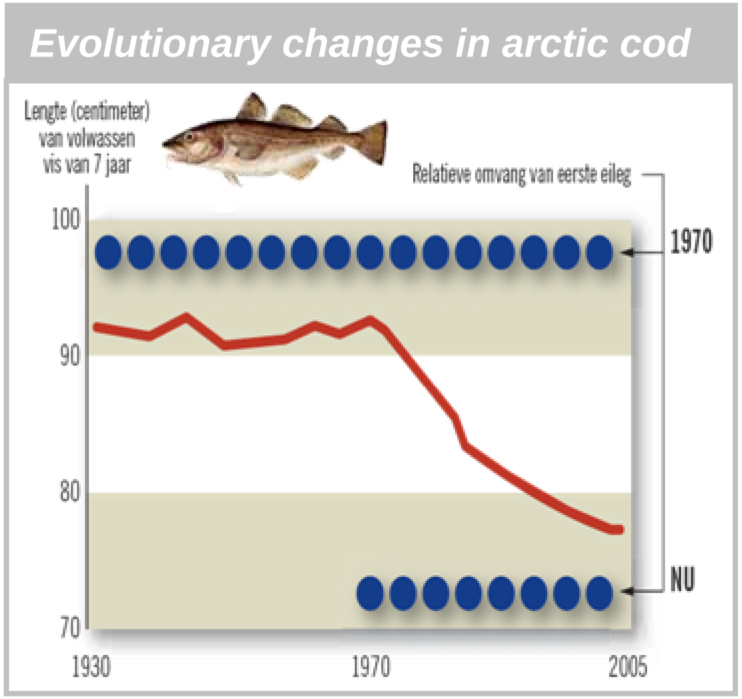
maximum size limits preferred

(1) fast-growing genotypes favoured by selection

(2) age structure broadens - increases spawning stock

(3) ecosystem services of large animals restored

EU project Fisheries-induced Evolution (FinE)

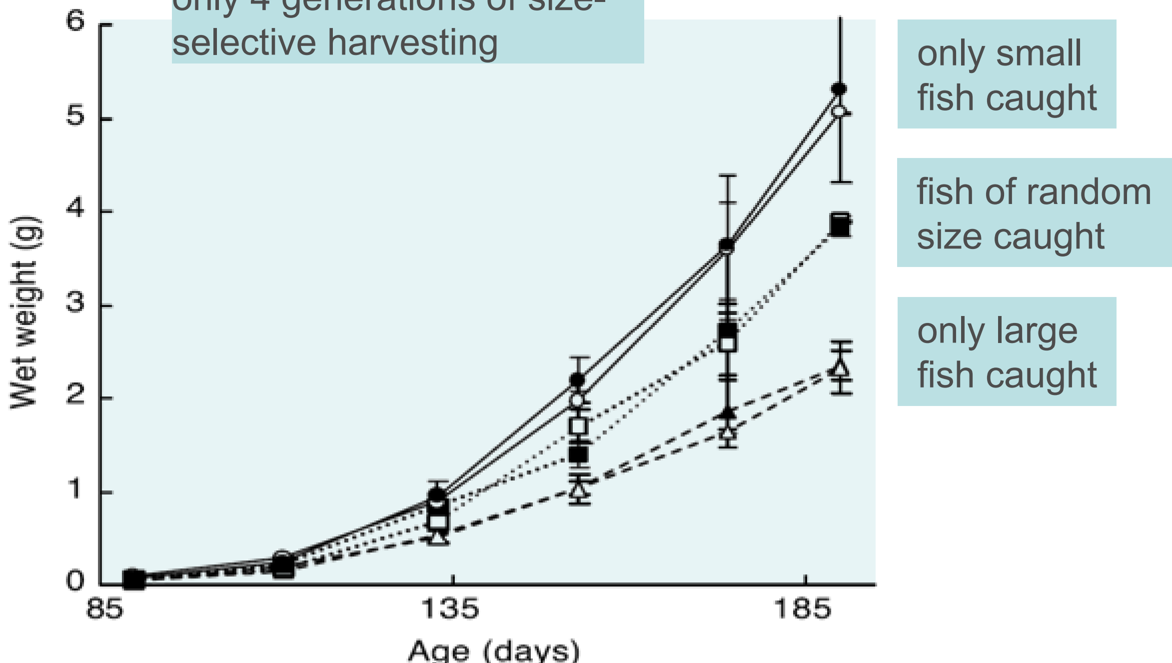


Jørgensen *et al.* (2007) Managing evolving fish stocks. *Science* 318: 1247-1248.

Fisheries Management

Harvest-induced evolutionary changes can occur very quickly, but stocks take ca. 50 times as long to recover.
A "Darwinian debt" to be paid by future generations!

Atlantic Silverside



Conover & Munch (2002) *Science* 297: 94-96

Evolution & Global Change

Climate Change mesocosm experiment

EU project Euro-Limpacs

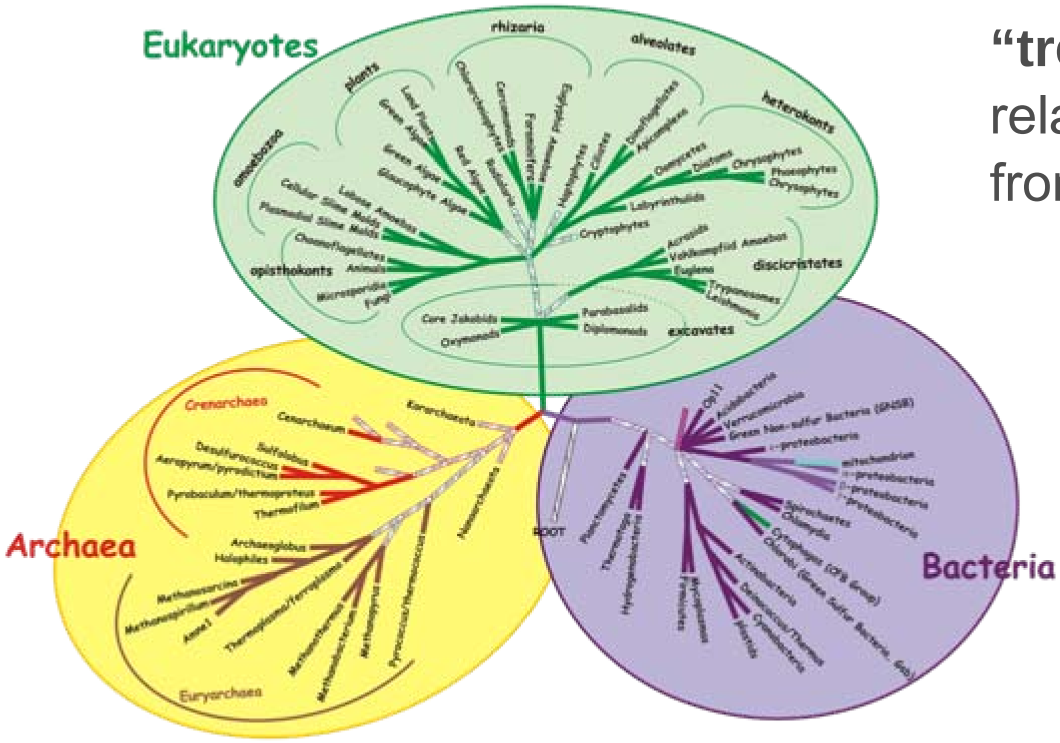
48 3000 l zooplankton mesocosms
2 temperature regimes

1. Significant evolution after 5 months of exposure to higher temperature regime (ambient + 4°C)

2. Adapted UK populations significantly better in competition with southern immigrants (French) than non-evolved populations

Van Doorslaer *et al.* 2007
Global Change Biology

Phylogenetics



from Baldauf *et al.* in *Assembling the Tree of Life*, 2004

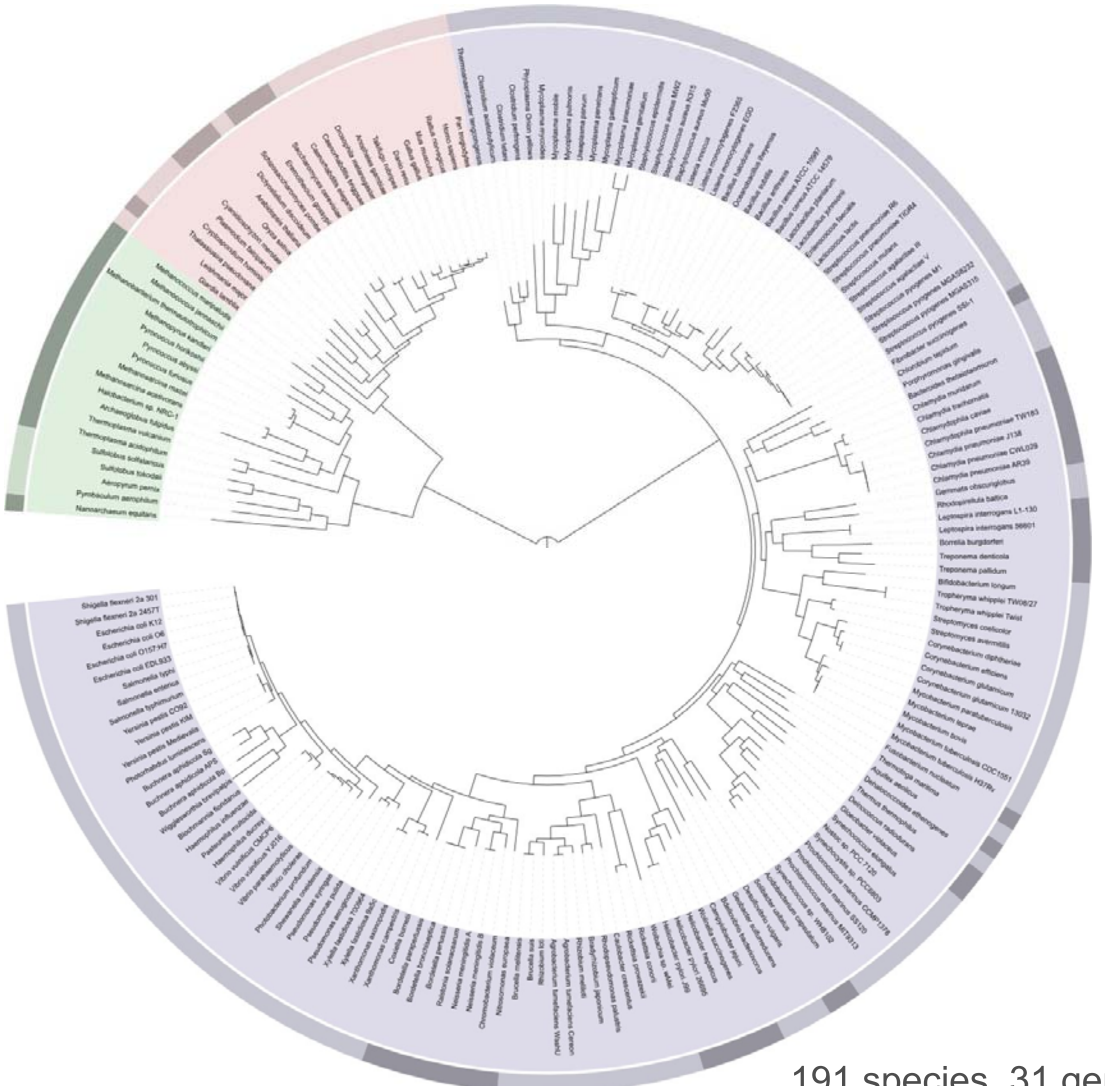
“tree building”: infer evolutionary relationships between taxa, mostly from DNA sequences

Tree of Life
important conclusions
(1) 3 major domains not 2
(2) thermophilic last universal common ancestor
(3) mitochondria + chloroplasts are coopted bacteria

Ribosomal Database Project II
606,879 SSU rRNAs

Applications ribotyping: environmental microbiology, identification of disease-causing bacteria (e.g. *H. pylori*), mining bacteria for novel products.

Tree of Life based on whole genomes



Whole genomes (completed+draft)

Jan. 2009: 8,871

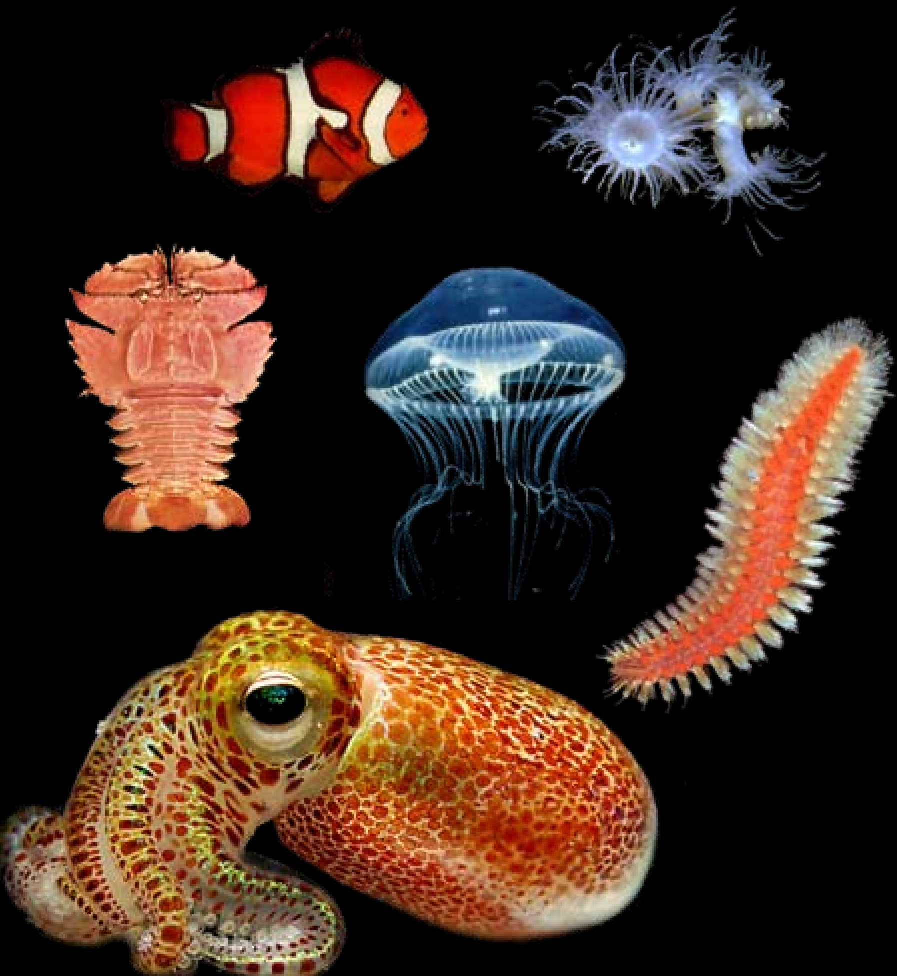
Eukaryotes: 1,111
Bacteria: 2,968
Archaea: 154
Plasmids: 1,851
Viruses: 2,787

Jan. 2008: start of the **1000 Genomes Project**, which will sequence the complete genomes of at least a thousand people from around the world

191 species, 31 gene orthologs

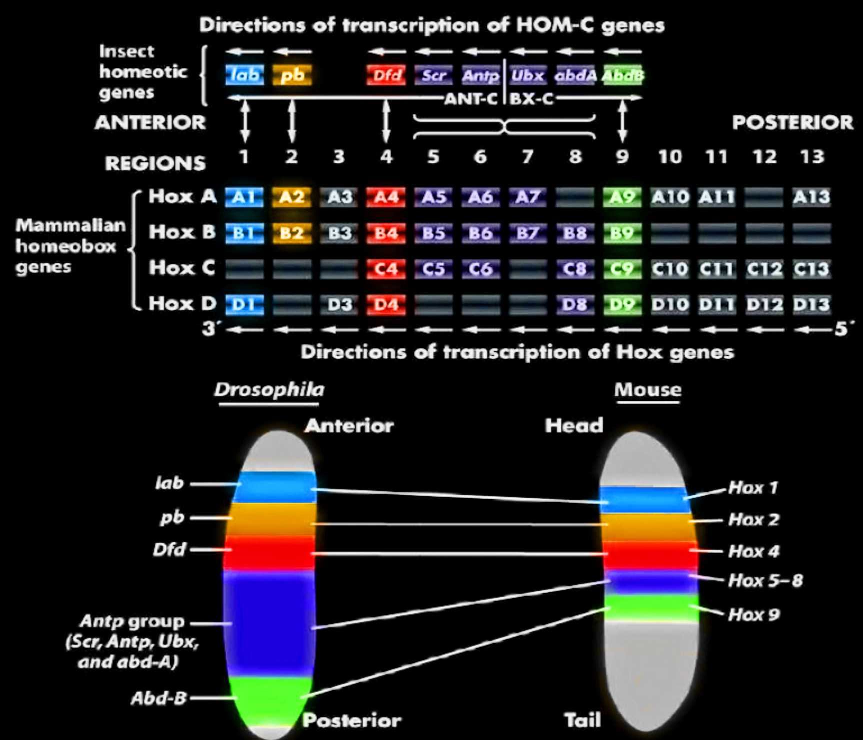
Ciccarelli *et al.* (2006) Toward automatic reconstruction of a highly resolved tree of life. *Science* 311: 1283-7

Evolution & Development



Evo-Devo
compare developmental processes of different animals and plants to determine how developmental processes evolved

E.g. *Hox* genes in eye & brain development



Lee *et al.* (2003) *Hox* genes and morphological novelty in *Euprymna scolopes Nature* 424: 1061-1065
Halder, Callaerts & Gehring (1995) Induction of ectopic eyes by targeted expression of the *eyeless* gene in *Drosophila*. *Science* 267: 1788-92

Human Disease

Evolution of SIV and HIV viruses

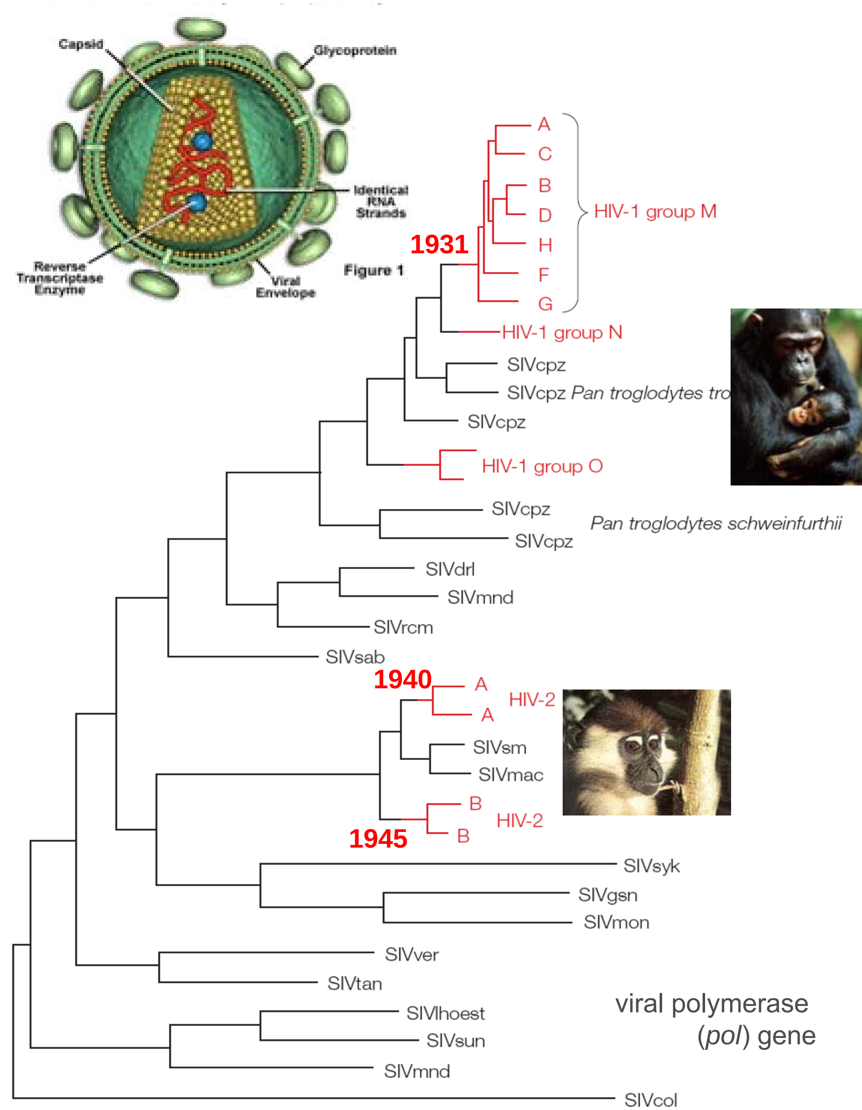
multiple transfers to humans from chimps and Sooty Mangabeys and vervet monkeys

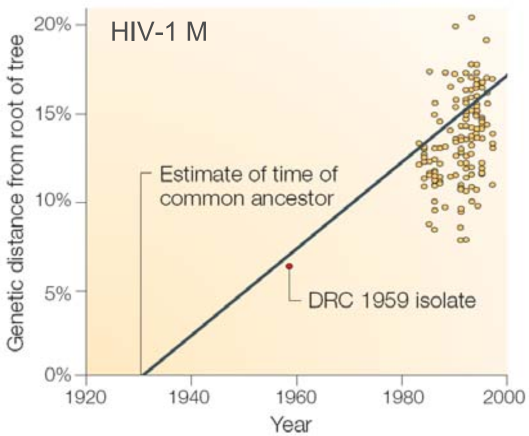
HIV-2: four jumps

HIV-1: three jumps

very fast evolution within patients

dating possible by extrapolating from known dates of the ages of samples





Lemey *et al.* (2003) Tracing the origin and history of the HIV-2 epidemic. *PNAS* 100: 6588-92

Forensics

Science 14 March 1997:
Vol. 275. no. 5306, pp. 1559 - 1560
DOI: 10.1126/science.275.5306.1559

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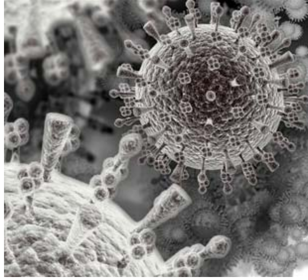
NEWS & COMMENT

Forensic Science: Phylogenetic Analysis: Getting Its Day in Court

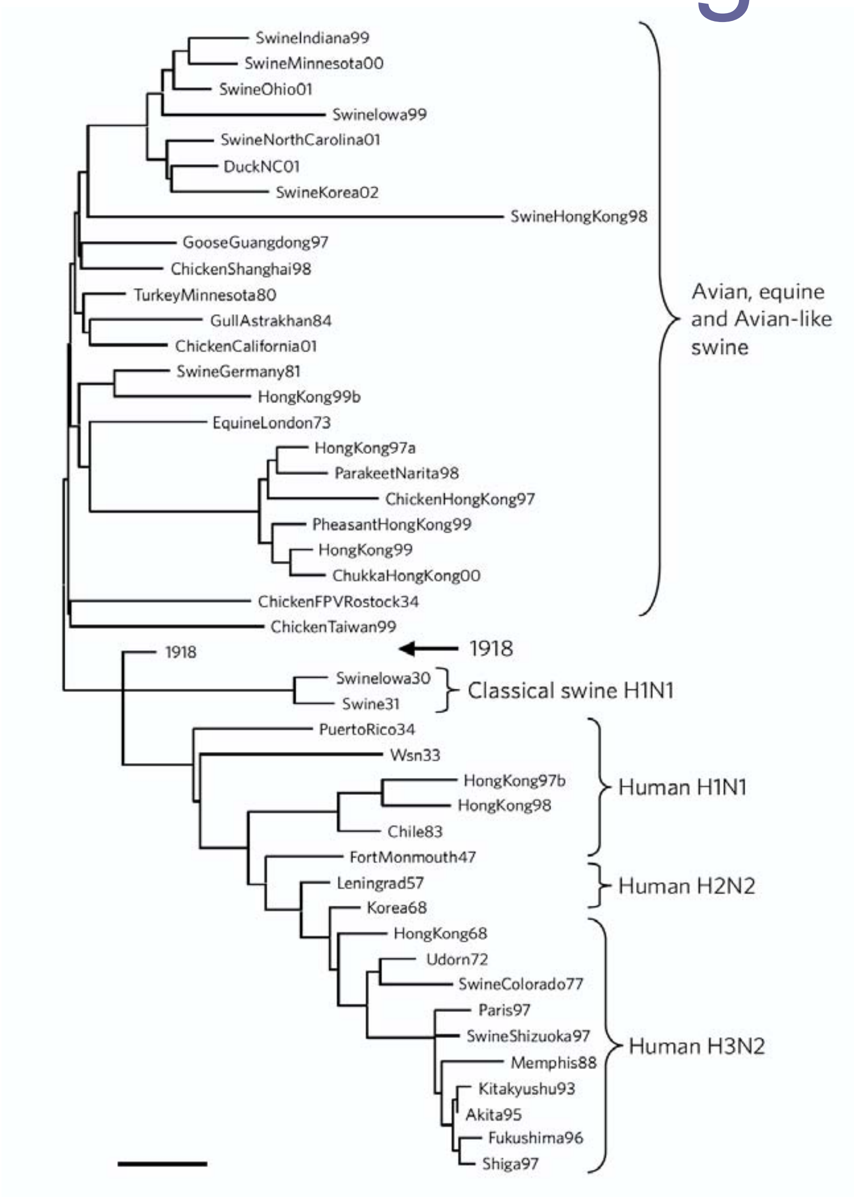
Gretchen Vogel

Blood often figures prominently in trials for attempted murder--but not usually as the weapon. Later this spring, however, prosecutors in Lafayette, Louisiana, will attempt to prove that Richard J. Schmidt, a gastroenterologist in that city, tried to kill his former lover by injecting her with HIV-infected blood from one of his patients.

The alleged use of blood as a weapon may not be the only unusual feature of the trial. As part of his case, the district attorney wants to introduce a type of DNA analysis never before used in a criminal trial in the United States: phylogenetic analysis, a technique that compares DNA samples from various sources--different HIV isolates in this case--to see how closely they are related. The prosecution hopes to show that the virus infecting Schmidt's accuser, Janice Trahan Roberts, is most likely to have come from one of the physician's patients. Schmidt's lawyers have challenged the admissibility of the phylogenetic analysis, however, arguing that the technique is inherently more uncertain than DNA fingerprinting, which is widely accepted in the courts as a means of matching DNA samples. They also argue that in this case, the controls used and the laboratory work are seriously flawed.



Emerging Diseases



Taubenberger *et al. Nature* 2005, 2006

1918 Spanish flu pandemic

50-100 million people killed worldwide

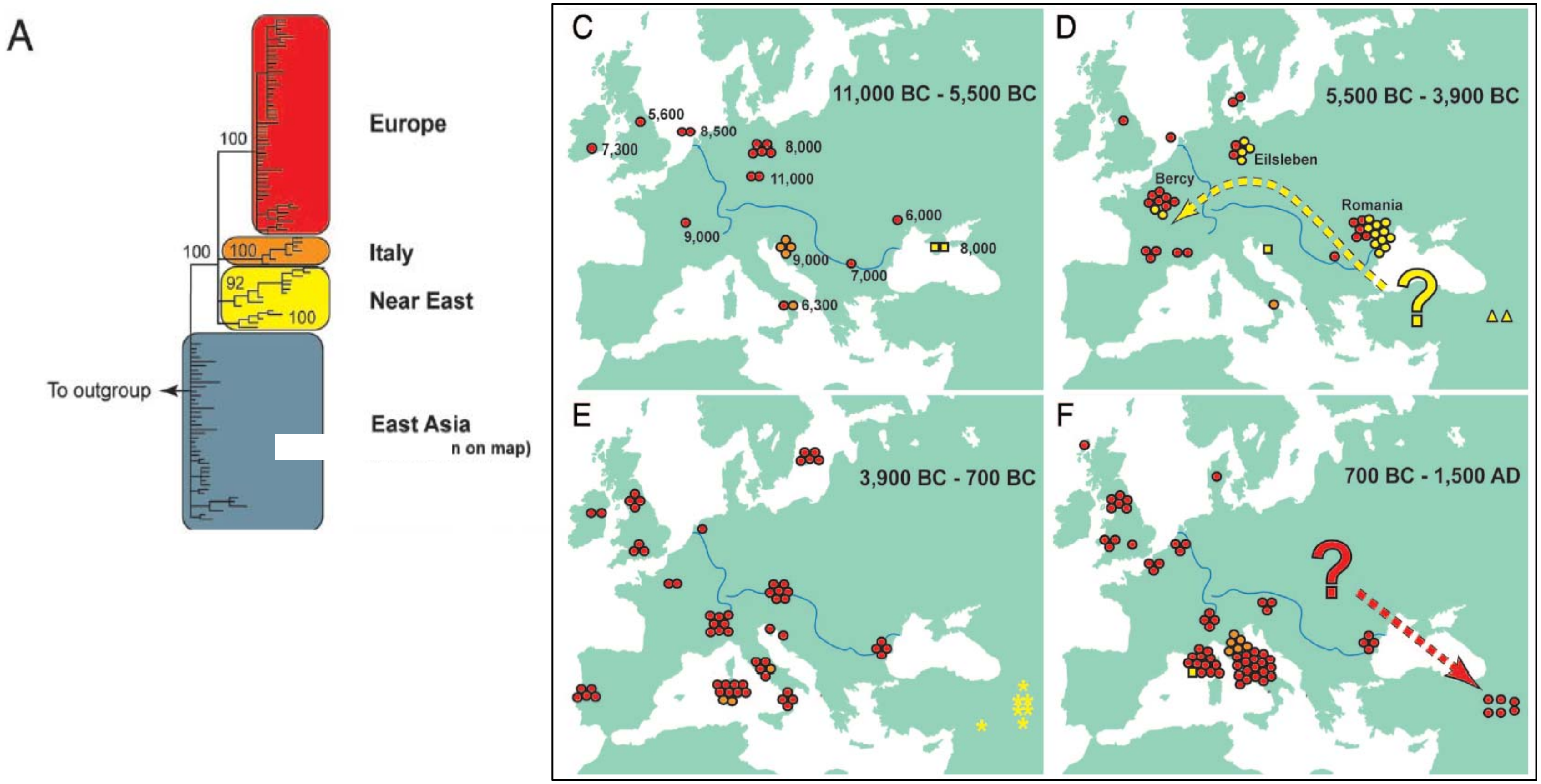
death rate 2-20% (normally 0.1%)

Flu virus from Alaskan victim buried in permafrost sequenced

Phylogenetic analysis: 1918 virus probably of avian origin - virulent H5N1 avian influenza may well become zoonotic !!

Alaskan victim buried in permafrost

Molecular archeology
e.g. domestication of pigs



Ancient DNA can be amplified to gain insight in historical human migrations, ancient trade relationships, domestication of crops and livestock, etc...

Larson *et al.* (2007) Ancient DNA, pig domestication, and the spread of the Neolithic into Europe. *PNAS* 104: 15276-15281

Paleogenomics

Neanderthal

Febr. 2009: first draft sequence of the complete genome of a Neanderthal determined, using material from a 38,000 Y old Neanderthal bone from Vindija Cave, Croatia. Human and Neanderthal populations diverged about 500,000 YBP. Little evidence for hybridization.

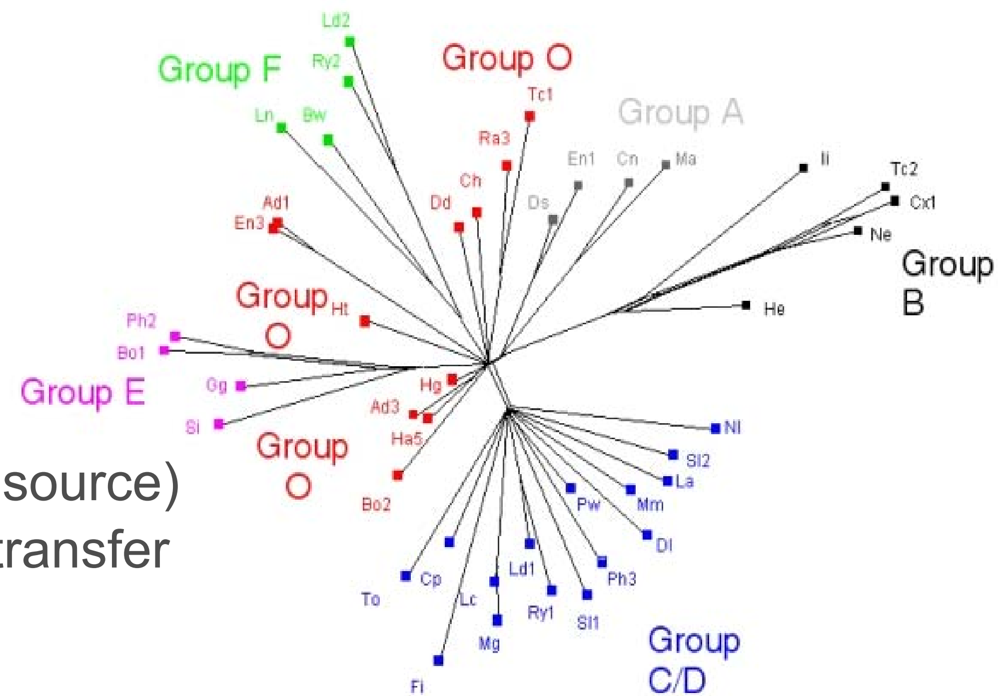
Woolly Mammoth

13 million bp sequenced from 28,000 Y old specimen preserved in Siberian permafrost. Mammoths diverged from elephants 5-6 MYBP.

Green *et al.* (2006) Analysis of one million basepairs of Neanderthal DNA. *Nature* 444: 330-6
Noonan *et al.* (2006) Sequence and analysis of Neanderthal genomic DNA. *Science* 314: 1113-8
Poinar *et al.* (2006) Metagenomics to Paleogenomics: Large-scale sequencing of mammoth DNA. *Science* 311: 392-4

Literature

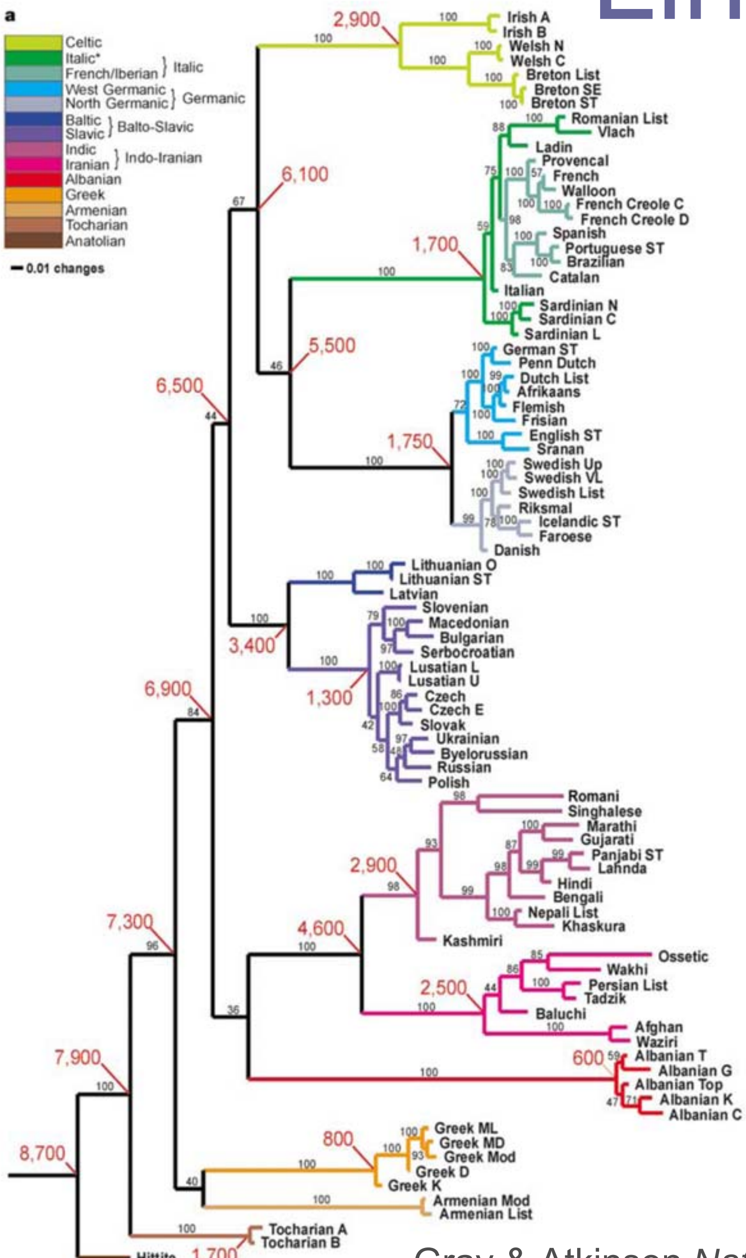
Methods not limited to DNA sequences. Biologists applied phylogenetic methods to determine **relationship among** various versions of historical **manuscripts**, such as *The Canterbury Tales*



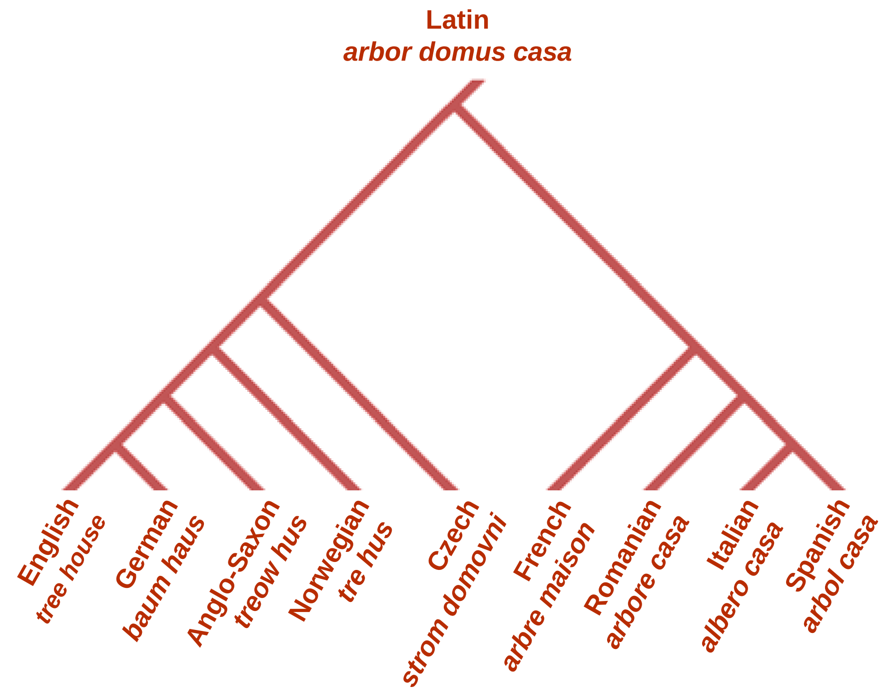
Barbrook *et al.* (1998) The phylogeny of the Canterbury Tales. *Nature* 394: 839

Similar challenges as in biology:
e.g. contamination (copying from >1 source)
cf. recombination & horizontal gene transfer
→ reticulate phylogenies

Linguistics

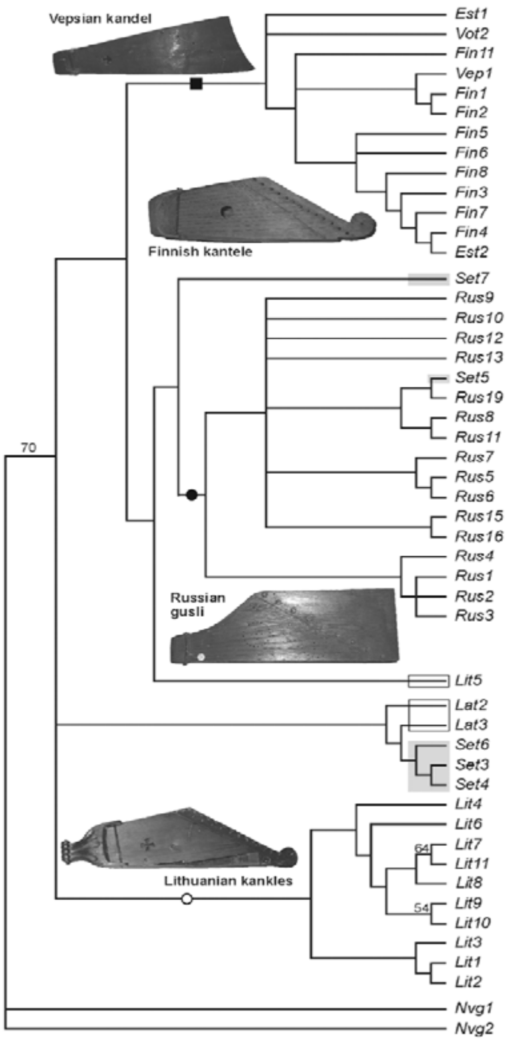


Similarity in vocabulary across languages also allows the construction of **language phylogenies**, shedding light on their historical relationship.



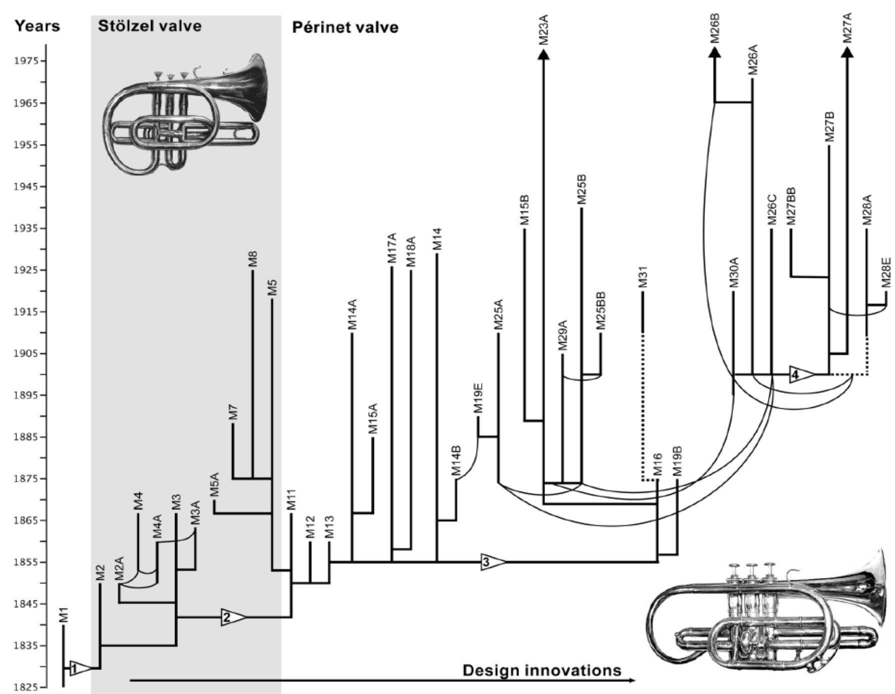
Gray & Atkinson *Nature* 2003

Cultural anthropology



Baltic psaltery

Evolutionary trees can also be constructed for cultural artefacts such as textiles, pottery, music instruments, arrow points, etc...., shedding light on their historical relationship and on innovation in design over time.



cornet

Temkin & Eldredge *Current Anthropology* 2007

Sociobiology

Social behaviour can be seen throughout nature

Darwinian paradox: *free-riders-problem* individuals that exploit group for own gain should experience a benefit

How can this conflict between individual & societal interests be resolved?

Evolutionary models from sociobiology and economic game theory try to provide an answer

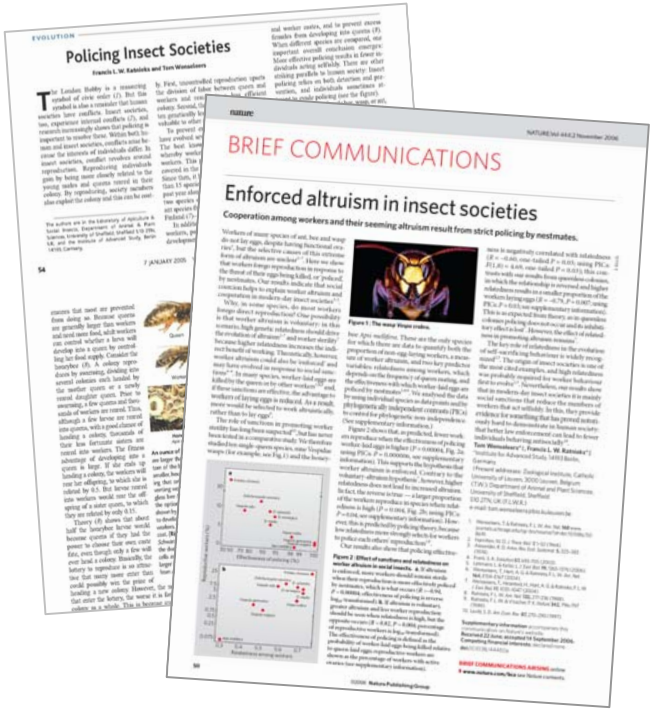
Insect Sociobiology

Conflicts between interests of individual & society also occur in **insect societies**

e.g. some bee workers may stop working to lay eggs
good for worker bee but not for bee society !

My research: cooperation maintained by **social pressure**

Social insects have been solving such conflicts for millions of years!



EVOLUTION

Policing Insect Societies

Francis L. W. Ratnieks and Tom Wenseleers

nature

BRIEF COMMUNICATIONS

Enforced altruism in insect societies

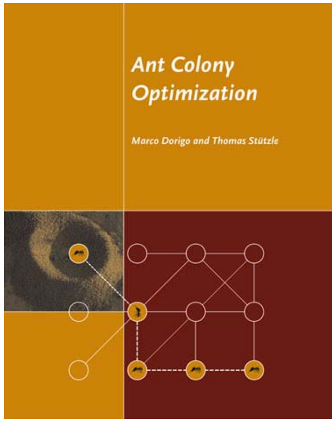
Cooperation among workers and their seeming altruism result from strict policing by nestmates.

Ratnieks & Wenseleers *Science* 2005
Wenseleers & Ratnieks *Nature* 2006

SOCIAL INSECT WORKERS COOPERATE TO SOLVE PROBLEMS

Evolutionary Algorithms

- Ant Colony Optimisation: algorithms based on behaviour of ants for solving dynamic problems



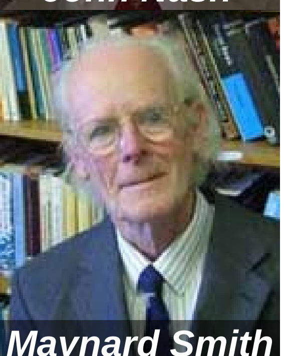
- Biologically inspired co-ordination and control systems: applications in robotics

- Genetic & evolutionary algorithms: better solution to complex problems

These NASA robots combine their sensory data in order to carry out cooperative tasks, like carrying a metal beam, more efficiently.

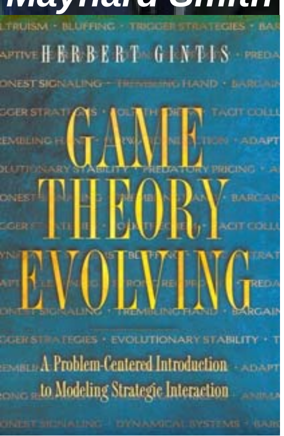
Source: NASA

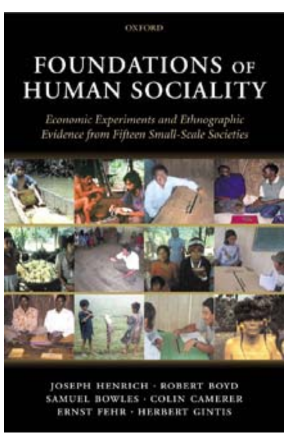
Human Sociality

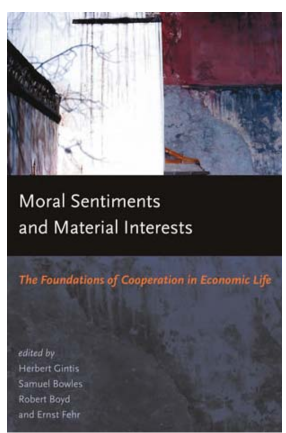


In **economics**, **evolutionary game theory** is used to predict how humans tend to act in situations of conflict and under what conditions they should cooperate with each other. **Evolutionary psychology** also uses Darwinian principles to try to understand the human mind. Important for understanding **bio-cultural basis of human sociality**.

Important applications:
e.g. auctions, helped raise more than $100 billion







Social Dilemmas in Medicine

vaccination campaigns
if disease is rare individual risk may not outweigh benefit
but cost for society if no one is vaccinated: epidemics

antibiotic use
can have individual risk if not administered
but overuse of antibiotics will cause cost
to society: antibiotic resistance

whose interests should be placed first?
those of the society or those of the
individual patient?

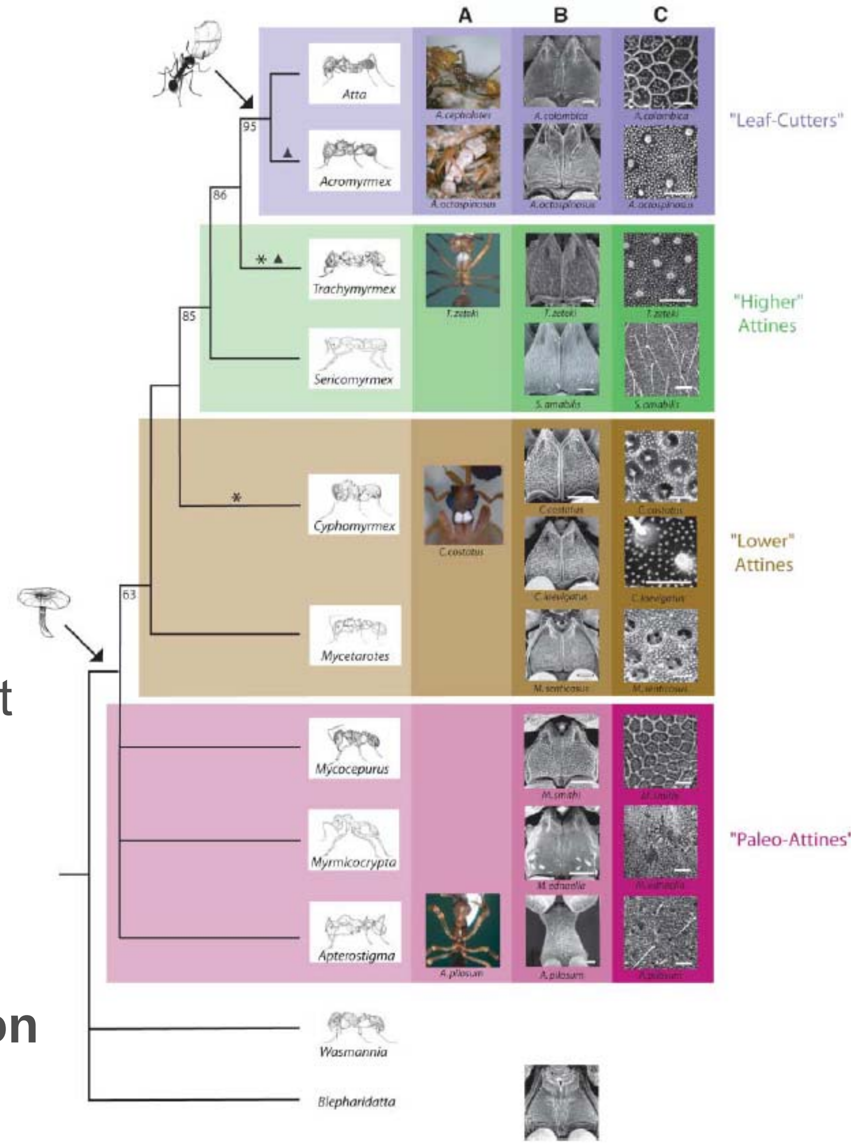
theoretical models can give guidance


Policy Forum

Do We Need to Put Society First? The Potential for Tragedy in Antimicrobial Resistance

Foster & Grundman (2006) *PLoS Medicine* 3: 1-4

Antibiotic use in Insect Societies



Leafcutter ants: engage in agriculture, collect leaves with which they farm a fungus for food

Cuticle harbours **Actinomycete bacteria** that secrete **antibiotics** which protect the fungus garden against other bacterial parasites

Ants have been using these for **over 50 million years**, yet **no antibiotic resistance** evolved

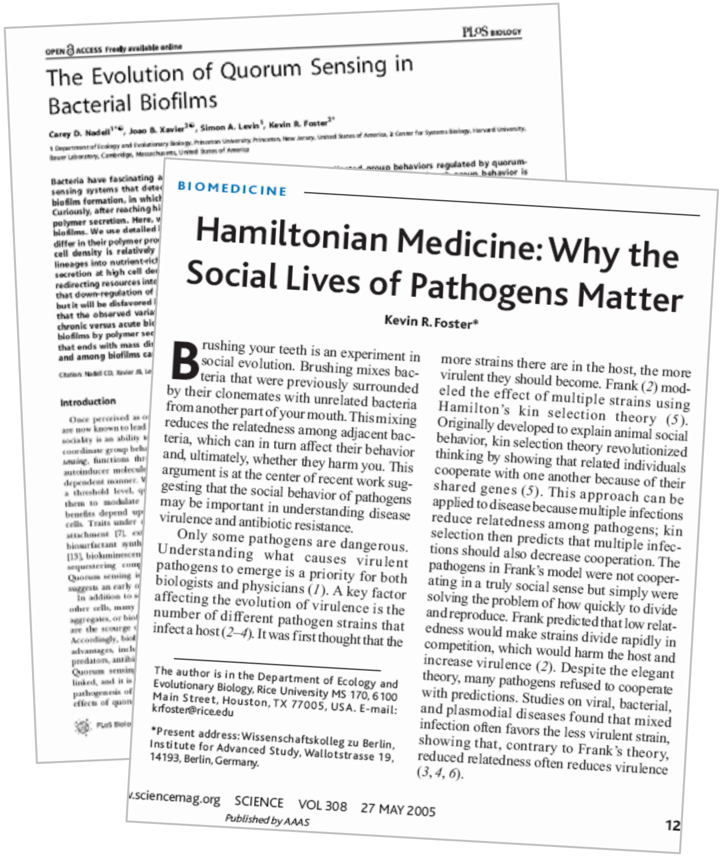
Johan Billen, Lab. of Entomology, U. of Leuven

Currie, Poulsen, Mendenhall, Boomsma & Billen *Science* 2007

Evolution of Human Pathogens

Sociobiological theory is also used to explain **how human pathogens evolve**

E.g. to predict conditions under which bacteria should tend to produce common products, such as biofilms, which protect the bacteria against antibiotics



OPEN ACCESS Freely available online

PLoS BIOLOGY

The Evolution of Quorum Sensing in Bacterial Biofilms

Carey D. Nadell, Joao B. Xavier, Simon A. Levin, Kevin R. Foster

BIOMEDICINE

Hamiltonian Medicine: Why the Social Lives of Pathogens Matter

Kevin R. Foster*

Brushing your teeth is an experiment in social evolution. Brushing mixes bacteria that were previously surrounded by their clonemates with unrelated bacteria from another part of your mouth. This mixing reduces the relatedness among adjacent bacteria, which can in turn affect their behavior and, ultimately, whether they harm you. This argument is at the center of recent work suggesting that the social behavior of pathogens may be important in understanding disease virulence and antibiotic resistance.

Only some pathogens are dangerous. Understanding what causes virulent pathogens to emerge is a priority for both biologists and physicians (1). A key factor affecting the evolution of virulence is the number of different pathogen strains that infect a host (2–4). It was first thought that the more strains there are in the host, the more virulent they should become. Frank (2) modeled the effect of multiple strains using Hamilton's kin selection theory (5). Originally developed to explain animal social behavior, kin selection theory revolutionized thinking by showing that related individuals cooperate with one another because of their shared genes (5). This approach can be applied to disease because multiple infections reduce relatedness among pathogens; kin selection then predicts that multiple infections should also decrease cooperation. The pathogens in Frank's model were not cooperating in a truly social sense but simply were solving the problem of how quickly to divide and reproduce. Frank predicted that low relatedness would make strains divide rapidly in competition, which would harm the host and increase virulence (2). Despite the elegant theory, many pathogens refused to cooperate with predictions. Studies on viral, bacterial, and plasmodial diseases found that mixed infection often favors the less virulent strain, showing that, contrary to Frank's theory, reduced relatedness often reduces virulence (3, 4, 6).

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www.sciencemag.org SCIENCE VOL 308 27 MAY 2005

Published by AAAS

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Foster (2005) *Science* 308: 1269-70
Nadell, Xavier, Levin & Foster (2008) *PLoS Biology* 6: 171-9

Darwinian Medicine

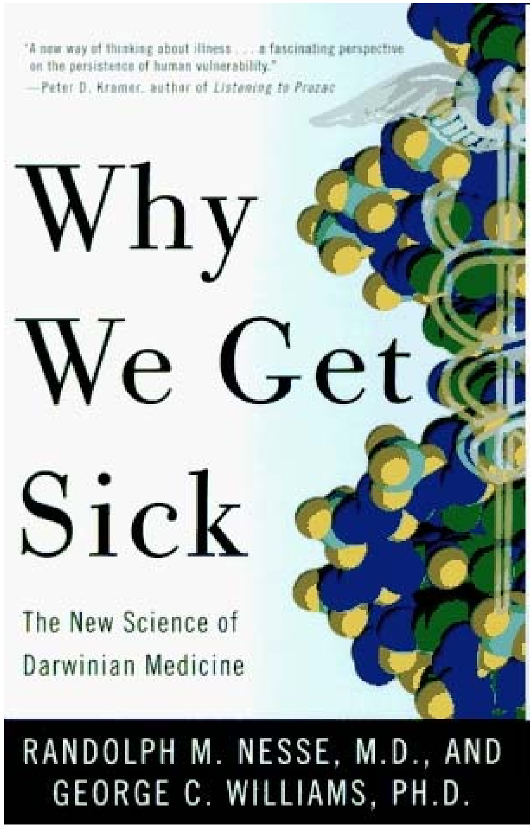
Evolutionary theory can help explain aging, cancer, infections, injury, intoxication, genetic diseases, allergy, problems during childbirth and mental disorders

e.g. evolved defenses

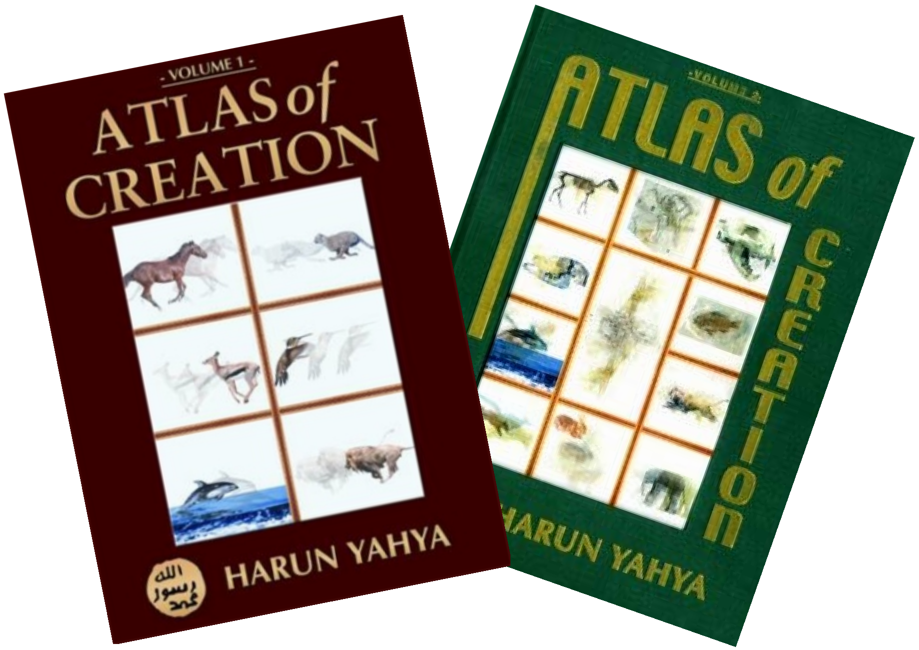
Much of clinical medicine relieves people's discomfort by blocking evolved defenses like fever, pain, nausea and diarrhea

Good strategy??

- pain is a defense against tissue damage
- nausea and vomiting and diarrhea are useful ways to rid the body of infection and toxins
- pregnancy sickness discourages mother from eating toxic substances that may harm her baby

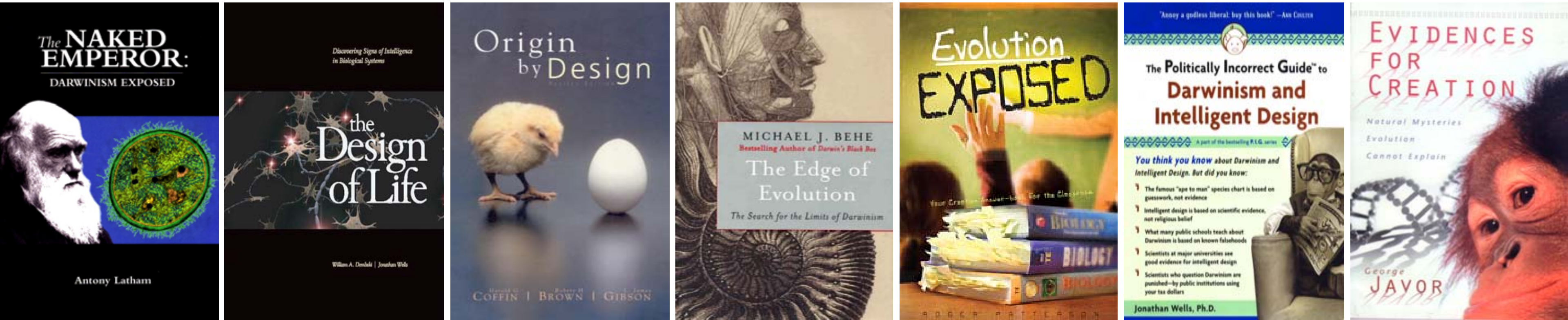


Public Outreach



Evolution subject to **ongoing attacks** by creationists both in the Western (*intelligent design*) and Islamic world (*Harun Yahya*).

Public outreach is a fundamental necessity!



Conclusion

Evolutionary biology has found important applications in vast range of fields: medicine, agriculture, conservation biology, archeology, linguistics, psychology, economics, informatics & engineering.

Evolutionists also have an important role in public outreach.

Clearly Darwinism can play an important role both for science & society at large!