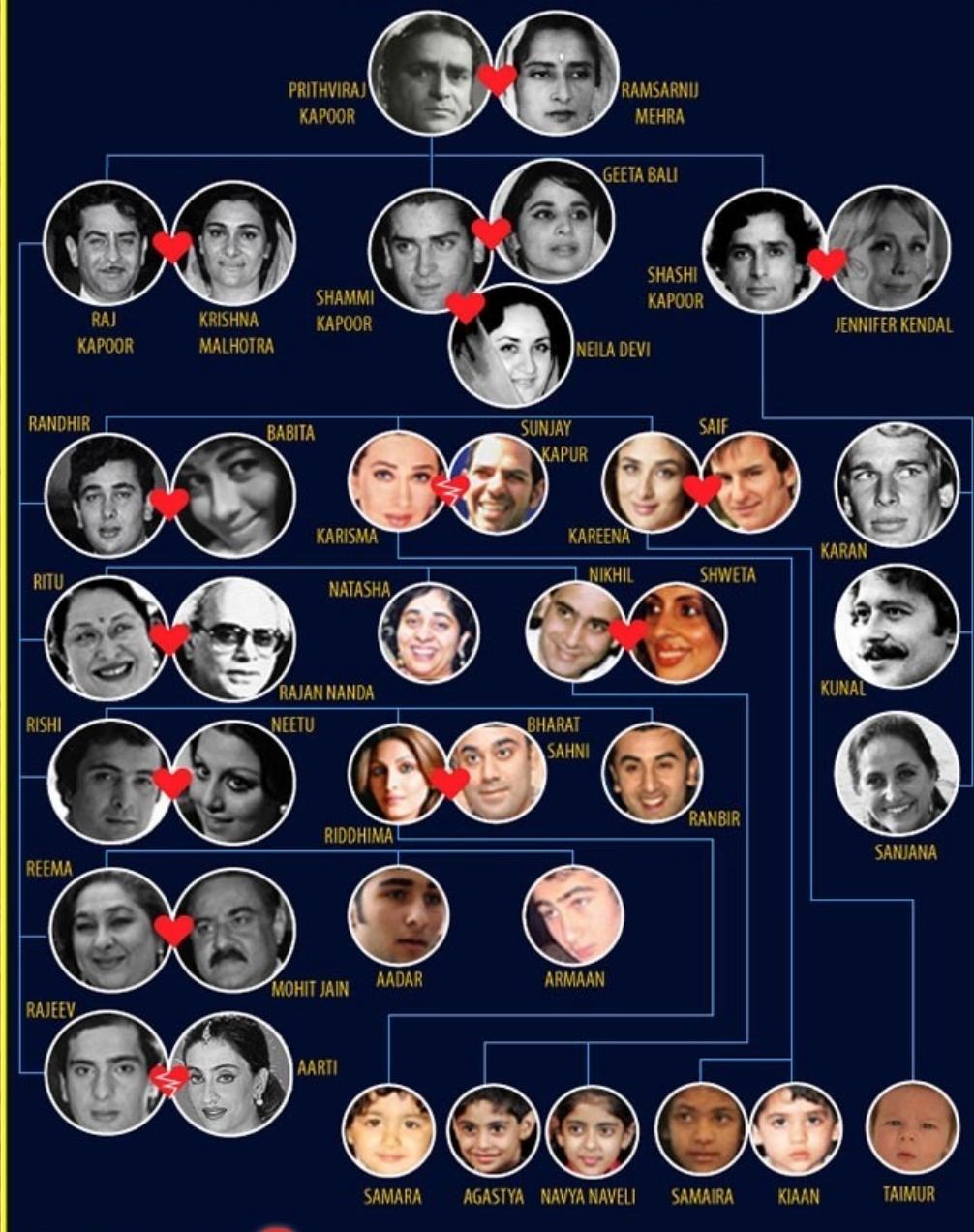


## THE KAPOOR FAMILY TREE



# Biology is a “happening” field

## New paradigms emerge very often

Paradigm: a set of concepts, ideas, etc.

Keep in mind while reading Biology (text) books

Writing / revising books cannot keep pace with new discoveries, observations, ...

# Today's topics

- Classification: domains, kingdoms, families, ...
  - Compartmentalization – trade offs during evolution
  - Tree of life or web of life?
- Cell – basic unit of life
  - A cell is crowded
- Multicellular versus unicellular
- Applications in day-to-day life

# Diversity of life forms visible to naked eye



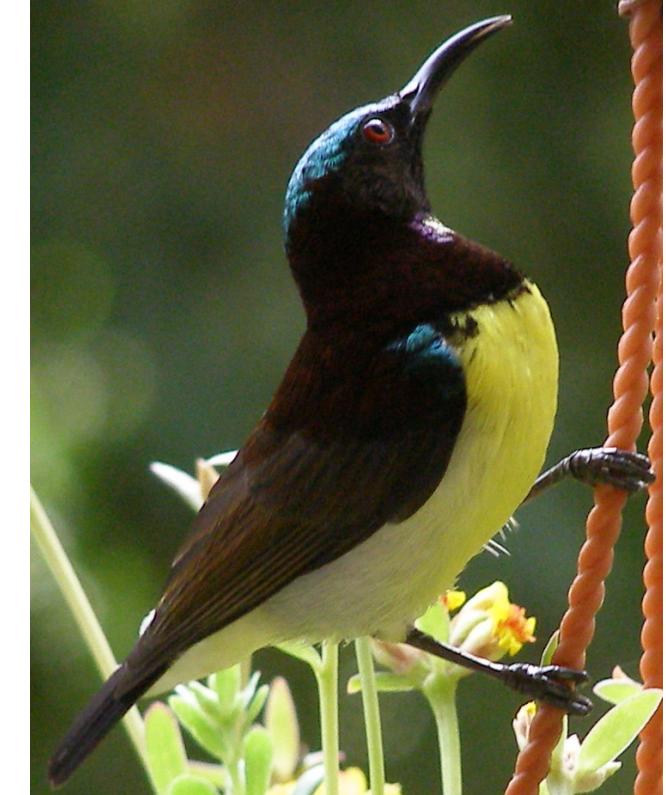
Apple tree



Donkey



Invisible bacterium



Sunbird

... but made of cells that share fundamental characteristics

# Diversity of life forms visible to naked eye

- Intellectual curiosity about diverse life forms that are visible to naked eye
  - How, or from where, did these diverse life forms originate?
  - How do they work?
- How are living organisms classified?
  - Classification is grouping based on shared characteristics
  - Taxonomy is the classification of living organisms

# Basis for the classification of organisms

- Morphological characteristics
  - Morphology means observable shape, form, or structure
- Phenotype and responses to environmental conditions
  - Phenotype refers to observable characteristics including morphology
- DNA sequencing (or genome sequencing)
  - This is a more recent development
  - Most powerful; difficult to decode genome (DNA) sequence

Linnaeus 1735 <sup>[65]</sup>	Haeckel 1866 <sup>[66]</sup>	Chatton 1925 <sup>[67]</sup>	Copeland 1938 <sup>[68]</sup>	Whittaker 1969 <sup>[69]</sup>	Woese et al. 1990 <sup>[70]</sup>	Cavalier- Smith 1998 <sup>[63]</sup>	Cavalier- Smith 2015 <sup>[71]</sup>
2 kingdoms	3 kingdoms	2 empires	4 kingdoms	5 kingdoms	3 domains	2 empires, 6 kingdoms	2 empires, 7 kingdoms
(not treated)					Bacteria		Bacteria
Vegetabilia	Plantae	Eukaryota	Plantae	Plantae Funai	Eucarya	Plantae Funai	Fungi Animalia

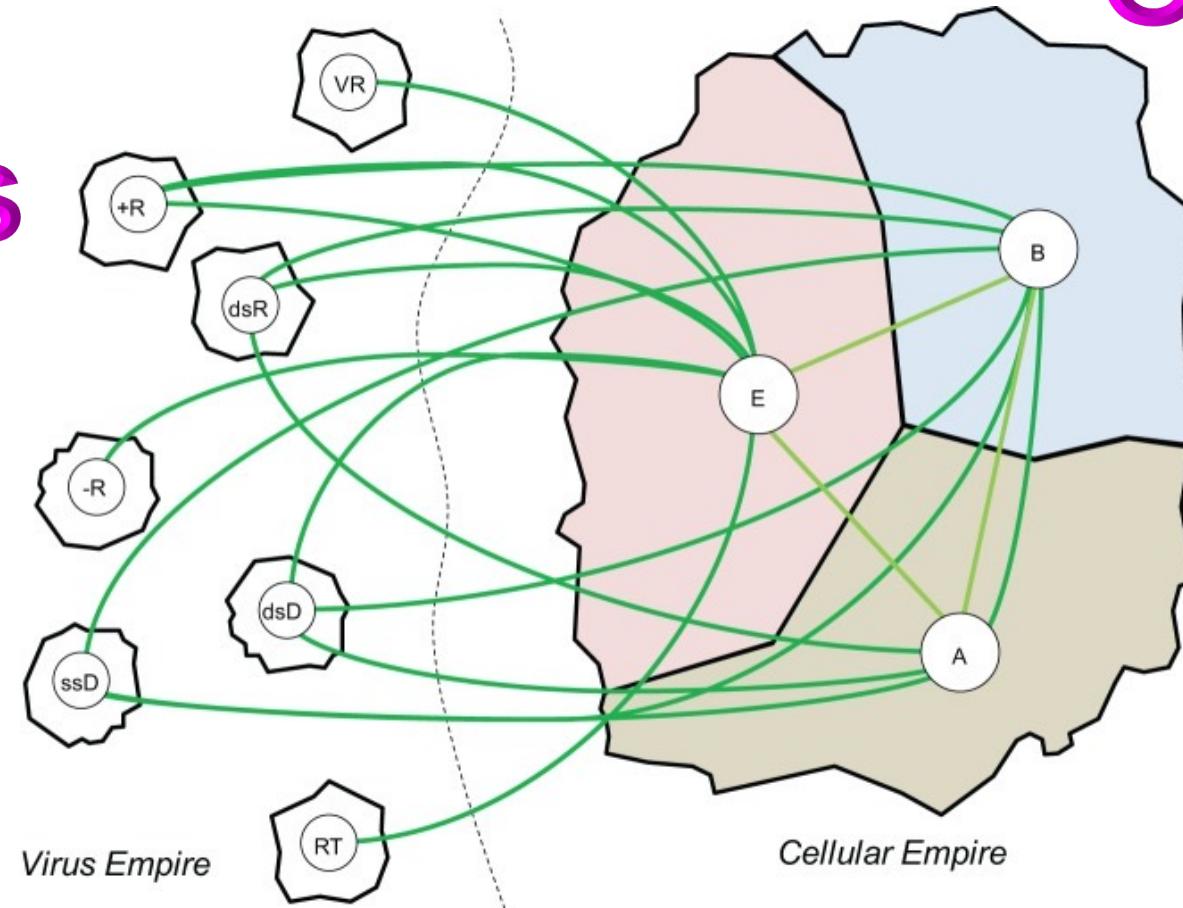
All these classifications have omitted viruses  
on the assumption that viruses are non-living

Authors of Reference #71 specifically mention that they prefer “super kingdom” instead of “empire”. Usage in the Wikipedia page deviates from that of the quoted authors.

# Classification of organisms including viruses

## Viruses

## Other than viruses



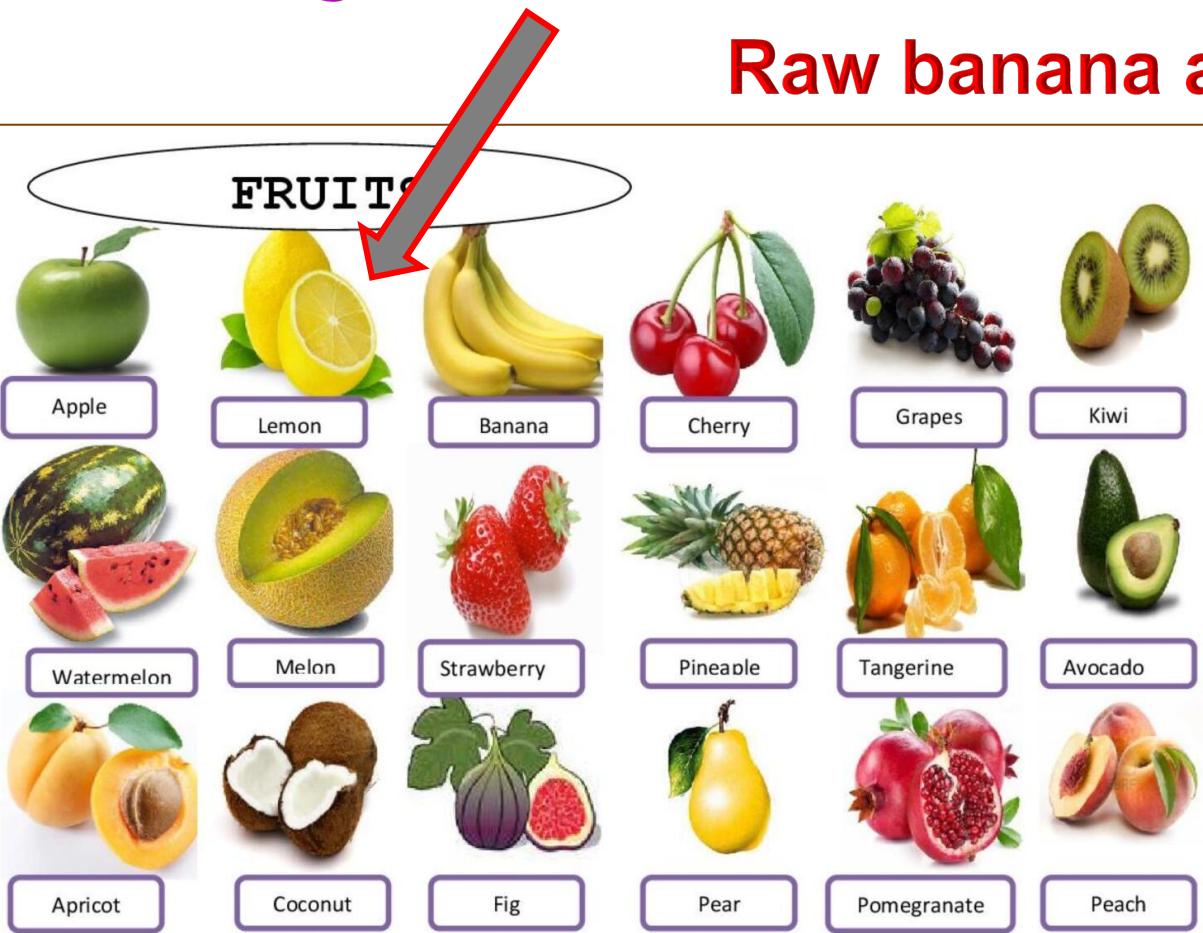
BC I	dsDNA	dsD
BC II	ssDNA	ssD
BC III	dsRNA	dsR
BC IV	(+) RNA	+R
BC V	(-) RNA	-R
BC VI	RNA RT	RT
BC VII	DNA RT	RT
	Viroids	VR

BC: Baltimore Class

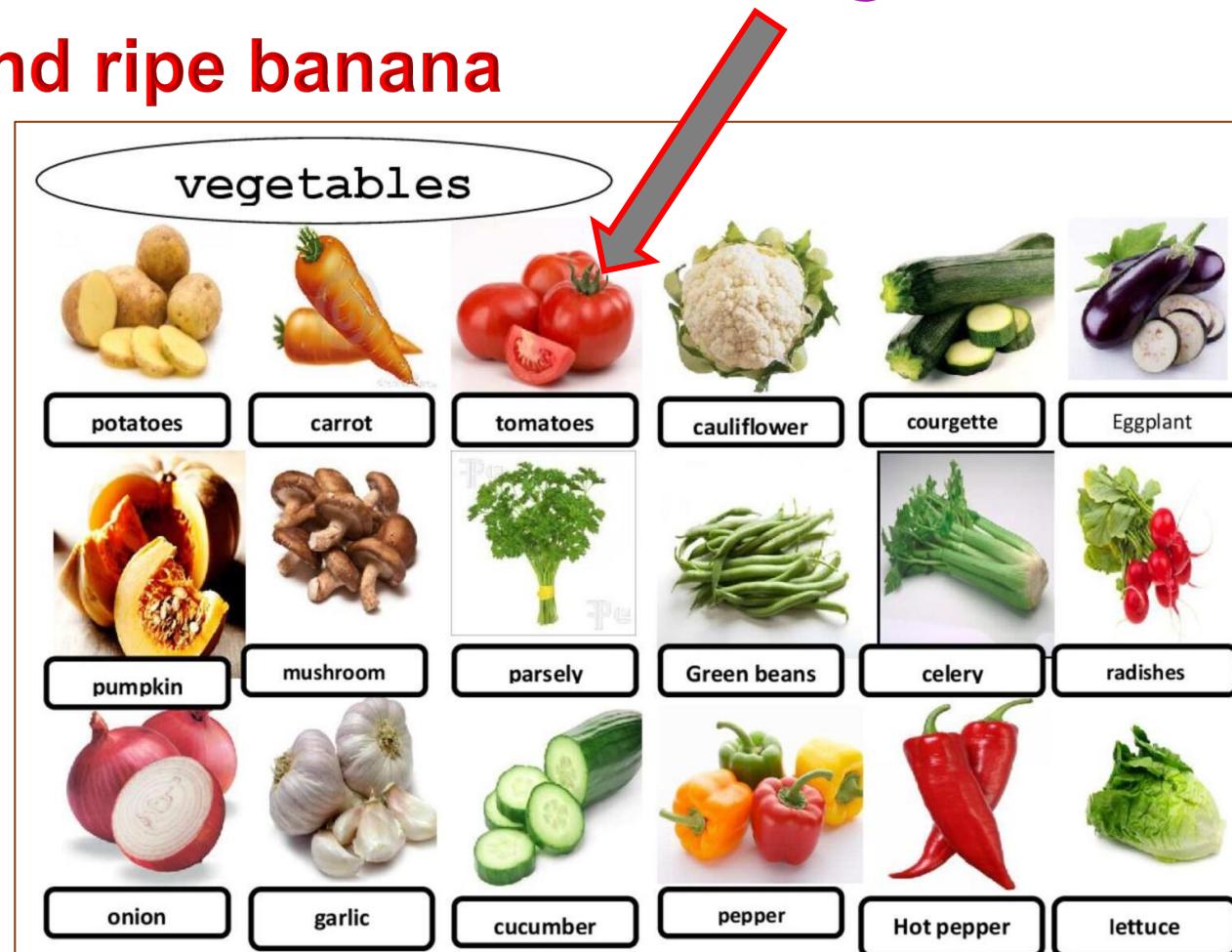
A classification scheme proposed by  
David Baltimore (1975 Nobel prize)

# Grouping fruits and vegetables

Is lemon a fruit  
or a vegetable?



Raw banana and ripe banana



Is tomato a fruit  
or a vegetable?

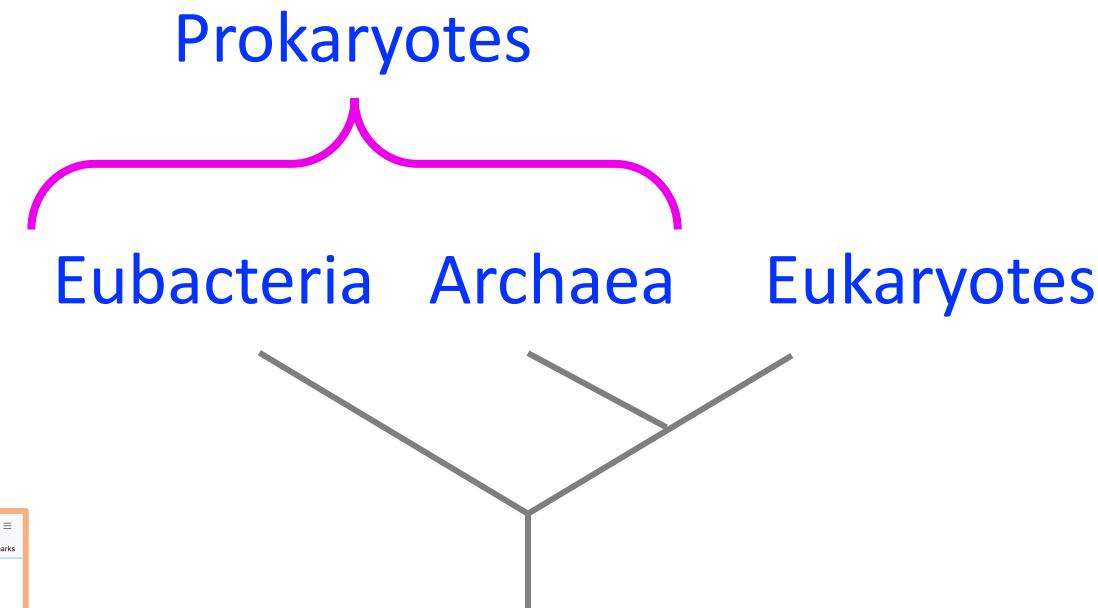
- Classification: domains, kingdoms, families, ...
  - Compartmentalization – trade offs during evolution
  - Tree of life or web of life?
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  - A cell is crowded
- Multicellular versus unicellular
- Applications in day-to-day life

# Major domains of living systems

- Prokaryotes = before nucleus
- Eukaryotes = good nucleus
  - Here, “good” means “true”, “well formed”

# Major domains of living systems

by Carl Woese (end of 20<sup>th</sup> century)



Carl Woese

From Wikipedia, the free encyclopedia

Carl Richard Woese ([woezy](#); [2] July 15, 1928 – December 30, 2012) was an American microbiologist and biophysicist. Woese is famous for defining the Archaea (a new domain of life) in 1977 by phylogenetic taxonomy of 16S ribosomal RNA, a technique he pioneered that revolutionized microbiology. [3][4][5][6] He also originated the RNA world hypothesis in 1967, although not by that name. [7] Woese held the Stanley O. Ikenberry Chair and was professor of microbiology at the University of Illinois at Urbana–Champaign. [8][9][10] nickname big chesse

Contents [hide]

- 1 Life and education
- 2 Work and discoveries
  - 2.1 Early work on the genetic code
  - 2.2 Discovery of the third domain
  - 2.3 Evolution of primary cell types
- 3 Perspectives on biology
- 4 Honors and scientific legacy
- 5 Selected publications
  - 5.1 Books

[and discoveries](#)

Carl Woese



Woese in 2004

Born July 15, 1928  
Died December 30, 2012 (aged 84)  
Syracuse, New York, U.S.

Group of proto cells

Based on 16S rRNA sequence comparison

# Major domains of living systems

Prokaryotes	Eubacteria	Unicellular organisms e.g., bacteria
	Archaea	Unicellular organisms Share characteristics of eubacteria and eukaryotes
Eukaryotes		Unicellular to multicellular organisms e.g., baker's yeast, potato, humans
Viruses		Do not have a cell of their own Always dependent on a host

# Compartmentalization

Floor plan of an affluent home



[http://zenlibs.com/a\\_floorplan-of-a-house/](http://zenlibs.com/a_floorplan-of-a-house/)

A 1-room tenement



[www.studenthandouts.com/01-Web-Pages/01-Picture-Pages/10.07-Industrial-Revolution/1-Riis-Family-Living-in-One-Room-New-York-City-Slum-1890.htm](http://www.studenthandouts.com/01-Web-Pages/01-Picture-Pages/10.07-Industrial-Revolution/1-Riis-Family-Living-in-One-Room-New-York-City-Slum-1890.htm)

Tenement: a room that by itself is a residence

# Having compartments



## Some advantages

- Specific compartment for each function
- Privacy and independence of activity

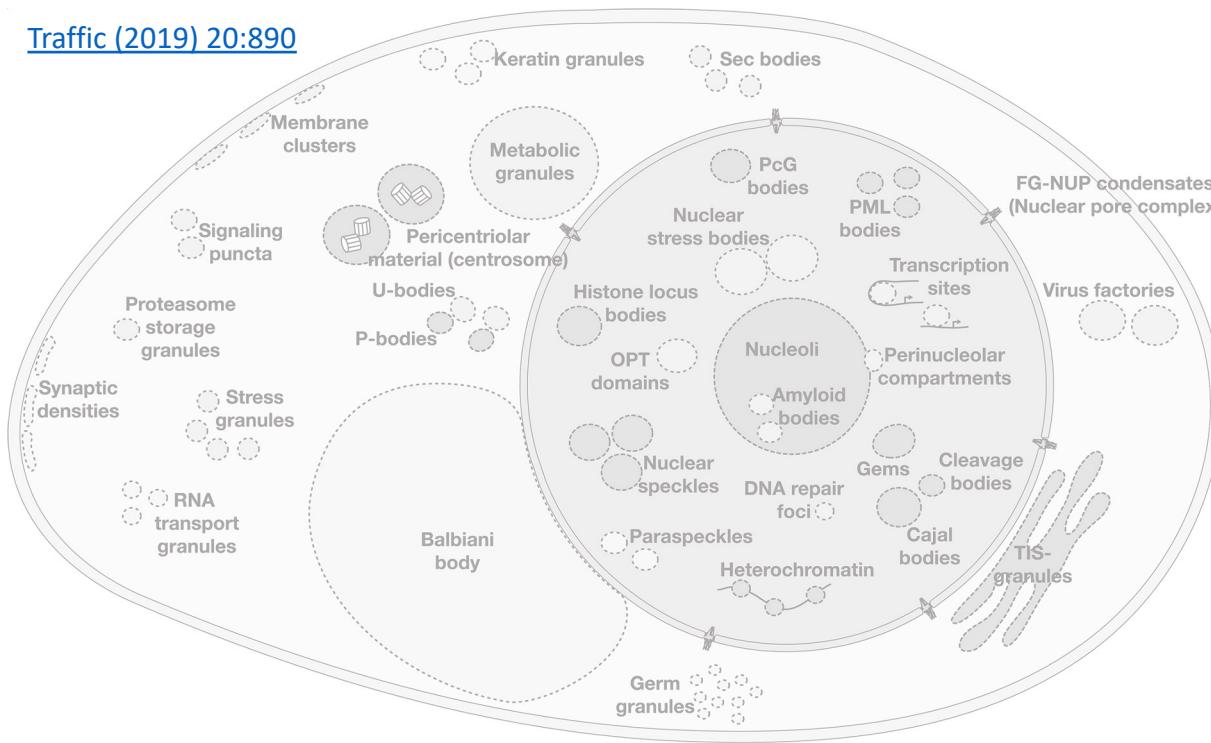
## Some disadvantages

- Expensive to maintain
- Difficult to adapt
- Constrains moving (shifting)

[http://zenlibs.com/a\\_floorplan-of-a-house/](http://zenlibs.com/a_floorplan-of-a-house/)

# Old view: no compartments in bacteria

[Traffic \(2019\) 20:890](#)

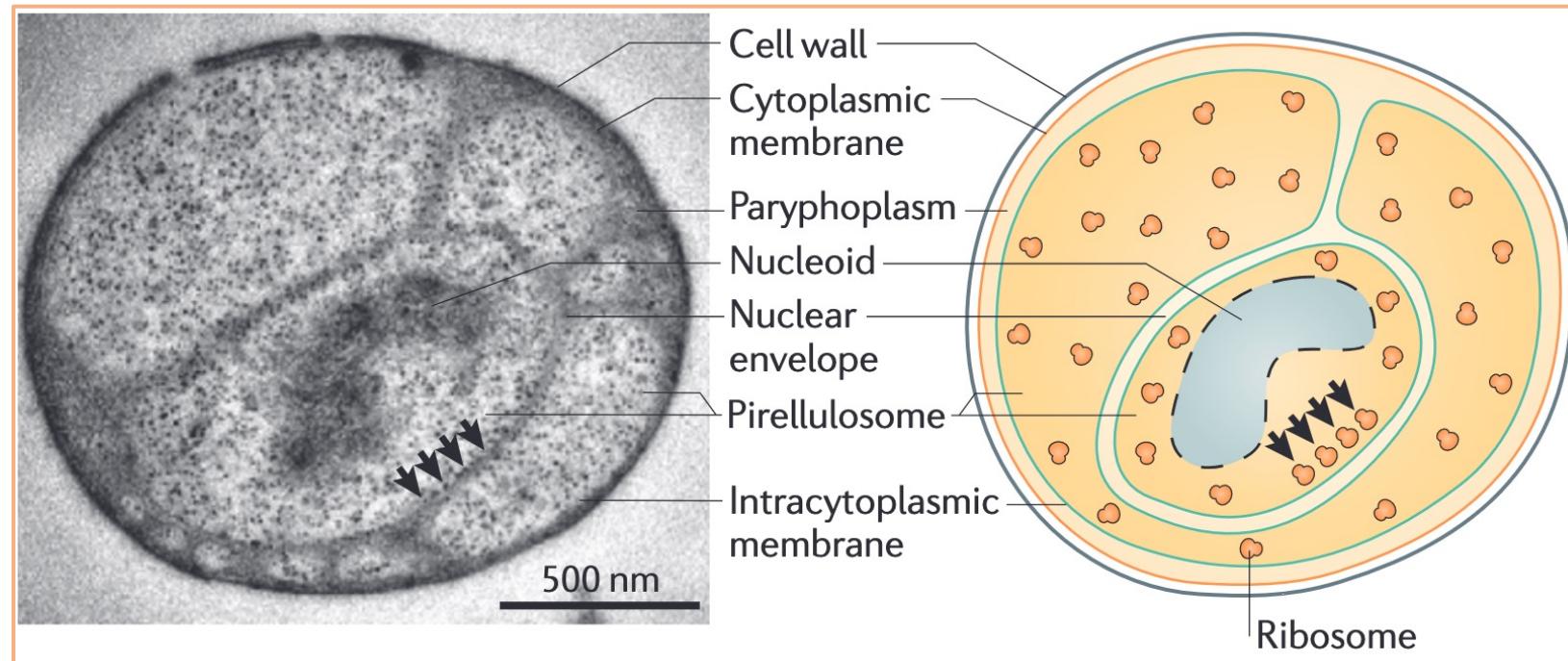


- Prokaryotes also have compartments
- These are not membrane-bound (**there are exceptions**)
- Formed by a phenomenon called liquid-liquid phase separation

[www.studenthandouts.com/01-Web-Pages/01-Picture-Pages/10.07-Industrial-Revolution/1-Riis-Family-Living-in-One-Room-New-York-City-Slum-1890.htm](http://www.studenthandouts.com/01-Web-Pages/01-Picture-Pages/10.07-Industrial-Revolution/1-Riis-Family-Living-in-One-Room-New-York-City-Slum-1890.htm)

# New observations...

A bacterium with a nucleus and nuclear membrane



*Gemmata obscuriglobus*

A planctomycetes (found in both aquatic and terrestrial habitats)

[Nat. Rev. Microbiol. \(2011\) 9:403](#)

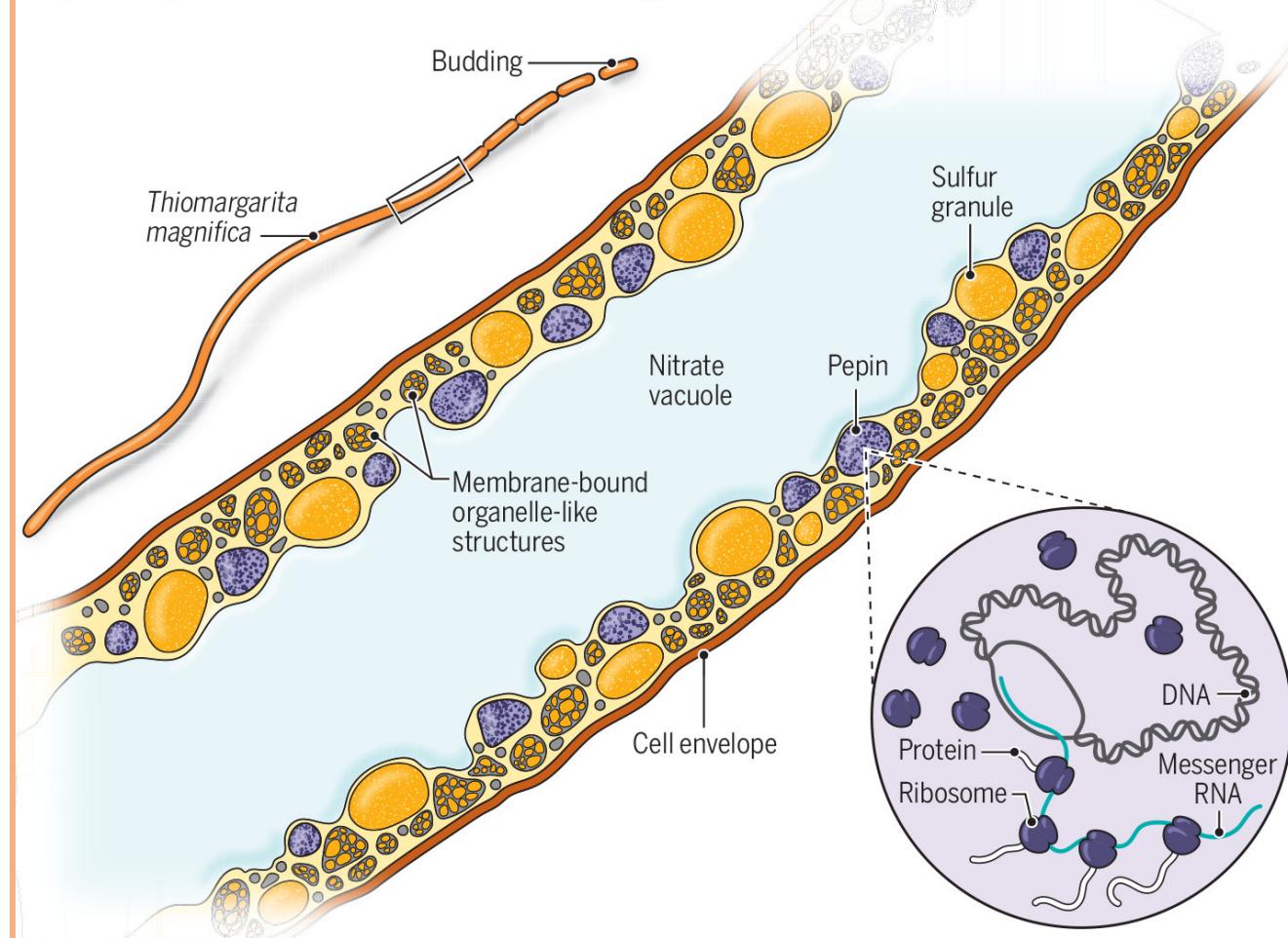
# A bacterium that is not a microbe

A new discovery challenges the prevailing view of the boundaries of bacterial cell size

Nearly 1 cm in length

## *Thiomargarita magnifica*

The large vacuole of *Thiomargarita magnifica* is likely filled with nitrate, and the thin layer of cytoplasm contains sulfur granules, which are involved in metabolism. Adenosine triphosphates (ATP) synthases localize to the intracytoplasmic membrane network, functionally increasing the surface area available for generating ATP. Also embedded in the cytoplasm are “pepins.” These membrane-bound vesicles are the site of RNA and protein synthesis and are also observed in the daughter cells that bud from the end of the filament.



← ⏪ ⏹ https://www.science.org/content/article/giant-sulfur-eating-microbe-found

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HOME > NEWS > ALL NEWS > GIANT SULFUR-EATING MICROBE FOUND

NEWS | BIOLOGY

# Giant Sulfur-Eating Microbe Found

15 APR 1999 · BY BERNICE WUETHRICH

SHARE:

Scientists have made a dazzling find in the sediment below the waters of Namibia's Skeleton Coast: a new species of bacterium whose diameter is about 100 times larger than that of the average bacterium. "They were so large, at first we could not believe they were bacteria," says Heide Schulz, a microbiologist at the Max Planck Institute for Marine Microbiology in Bremen, Germany, who [reports](#) the finding in tomorrow's issue of *Science*.

The new bacterium, named *Thiomargarita namibiensis*, or the "Sulfur pearl of Namibia," has cells three-quarters of a millimeter in diameter and consumes sulfide and nitrate. Schulz found it while trying to determine whether an unusual species of sulfide-eating microbe common off the coast of Chile could be found elsewhere. While examining sediment cores

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<https://www.science.org/content/article/giant-sulfur-eating-microbe-found>

# Compartmentalization: good or bad?

Trade offs during evolution

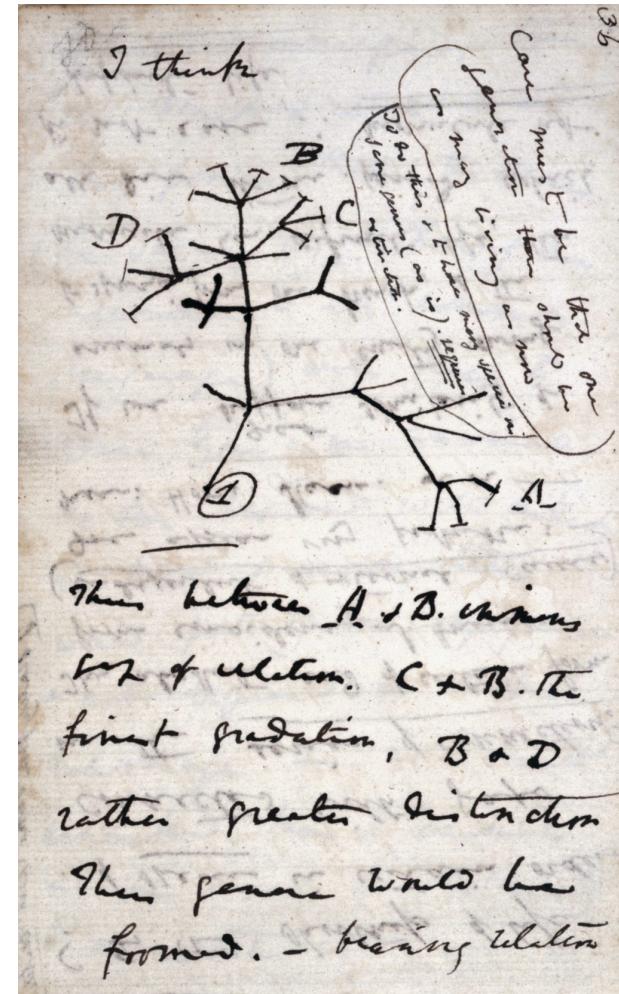


- Classification: domains, kingdoms, families, ...
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# Tree of Life (illustrated by Charles Darwin; 1837)

I think

(p) 36

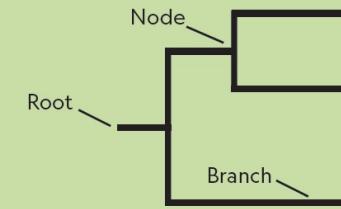


Case must be that one generation  
then should be as many living as  
now.

To do this & to have many species in  
same genus (as is) requires  
extinction.

Thus between A & B  
immense  
gap of relation. C & B, the  
finest gradation. B & D  
rather greater distinction.  
Thus genera would be  
formed. — bearing relation

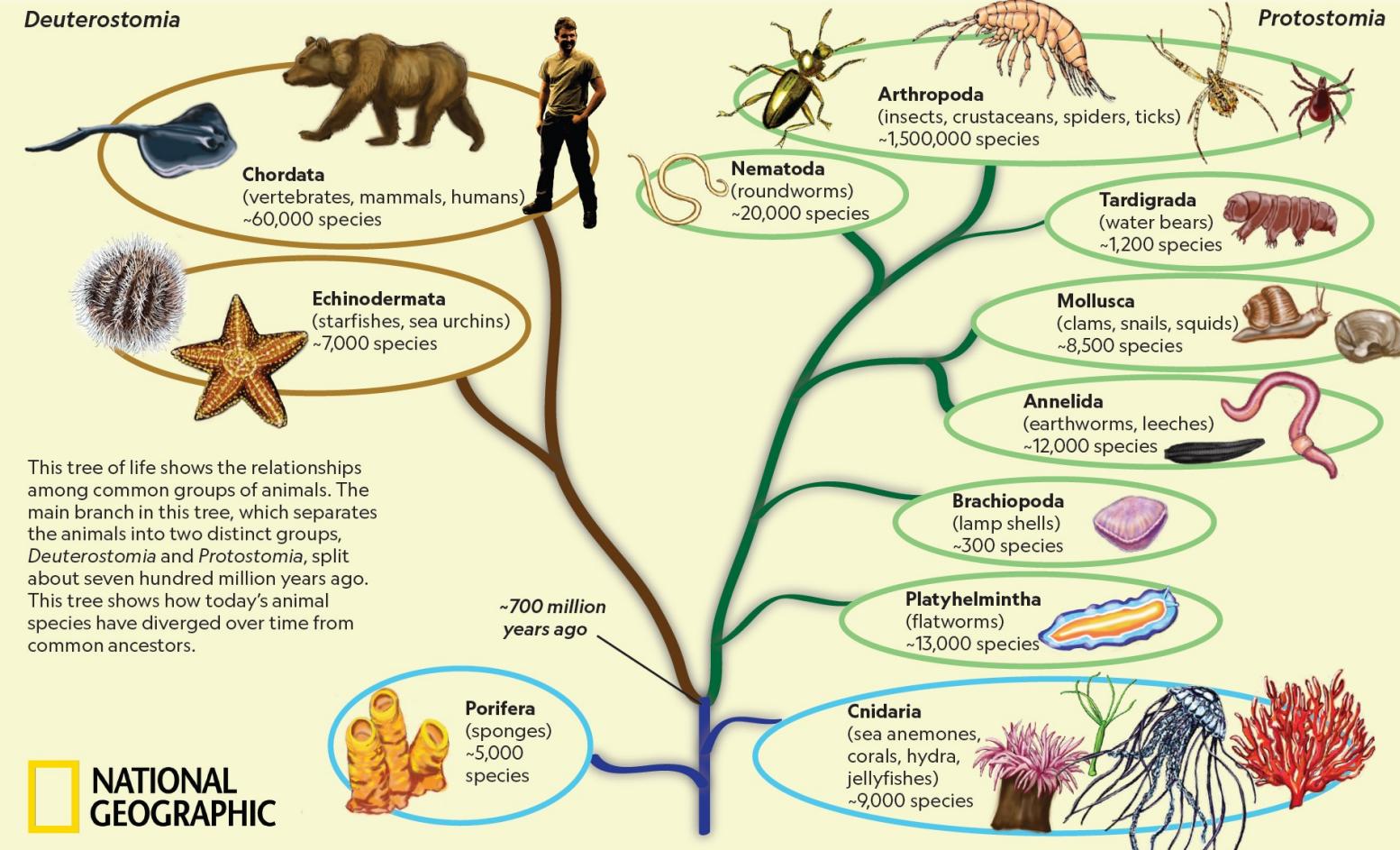
# Tree of life



## I THE TREE OF LIFE

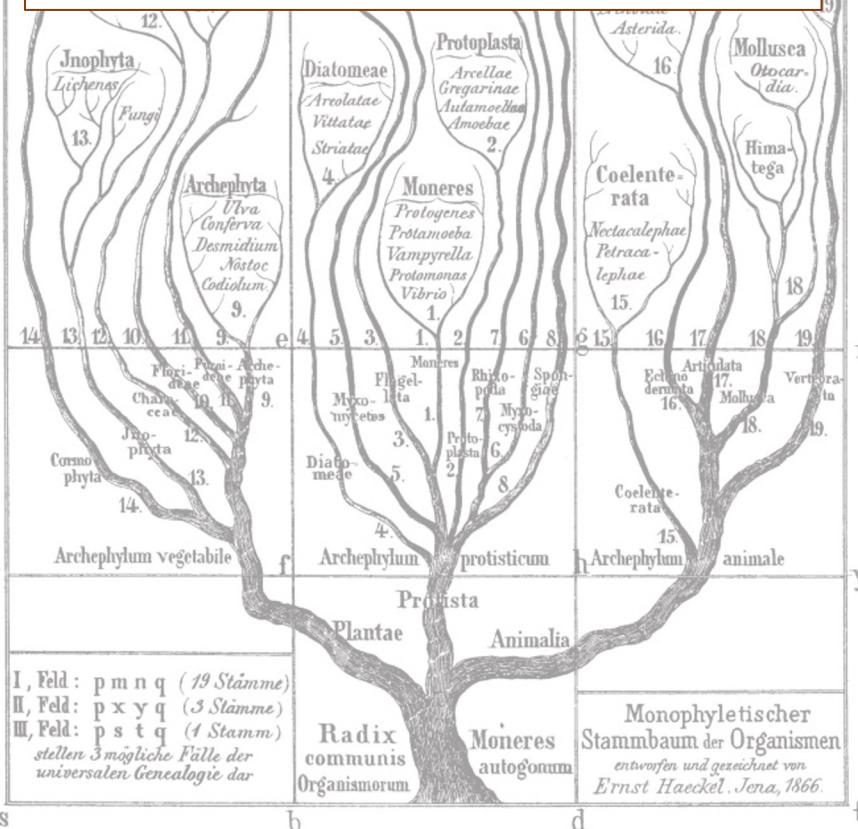
A phylogenetic tree shows the evolutionary relationships among different organisms. The branches of the tree show where genetic or physical similarities and differences between organisms begin or end.

A phylogenetic tree is like a family tree. The root of the tree represents a distant ancestor of the species that appear at the ends of the branches. The branches separate at nodes, or points where ancestral lines split into new lines of evolution.





## Additional reading for those who may be interested



Charles Darwin published the idea of a tree of life in *On the Origin of Species* in 1859. Seven years later, German zoologist Ernst Haeckel painstakingly drew up a much more comprehensive tree (pictured). This represented Earth's wealth of species in the context of evolution — a concept he dubbed phylogeny (*General Morphology of Organisms*; 1866).

The root of the tree symbolizes a common primordial ancestor from which all other forms emerged. Haeckel developed his tree over almost 1,000 pages, basing it on palaeontological, embryological and systemic data — a precursor to modern biology's phylogenetic trees.

He also coined the term ecology ('oecologie'), describing it as "the whole science of the relations of the organism to the environment including, in the broad sense, all the 'conditions of existence'".

Haeckel's ideas were harbingers for discoveries such as that by ecologist Santiago Soliveres and colleagues, who demonstrated that ecosystem multifunctionality depends on high species richness (*Nature* 536, 456–459; 2016).

# Web of life

- NO single progenitor of all bacteria
  - Tree of life is a misnomer
- A set of proto cells led to modern-day bacteria
  - Extensive exchange of genetic material among them



# Additional reading for those who may be interested

*Phil. Trans. R. Soc. B* (2009) **364**, 2221–2228  
doi:10.1098/rstb.2009.0032

*Review*

## The practice of classification and the theory of evolution, and what the demise of Charles Darwin's tree of life hypothesis means for both of them

W. Ford Doolittle\*

*Department of Biochemistry and Molecular Biology, Dalhousie University, Halifax, Nova Scotia, Canada*

Debates over the status of the tree of life (TOL) often proceed without agreement as to what it is supposed to be: a hierarchical classification scheme, a tracing of genomic and organismal history or a hypothesis about evolutionary processes and the patterns they can generate. I will argue that for Darwin it was a hypothesis, which lateral gene transfer in prokaryotes now shows to be false. I will propose a more general and relaxed evolutionary theory and point out why anti-evolutionists should take no comfort from disproof of the TOL hypothesis.

**Keywords:** tree of life; lateral gene transfer; horizontal gene transfer;  
prokaryote genome evolution; phylogenetics

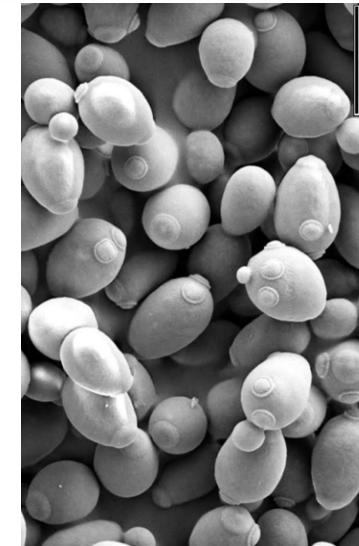
Doolittle argues in favor of a “web of life” (WoL) in place of a “tree of life” (ToL). Rampant horizontal (lateral) gene transfer observed among prokaryotes forms an important evidence in support of WoL.

- Classification: domains, kingdoms, families, ...
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# Cell is the basic unit of life



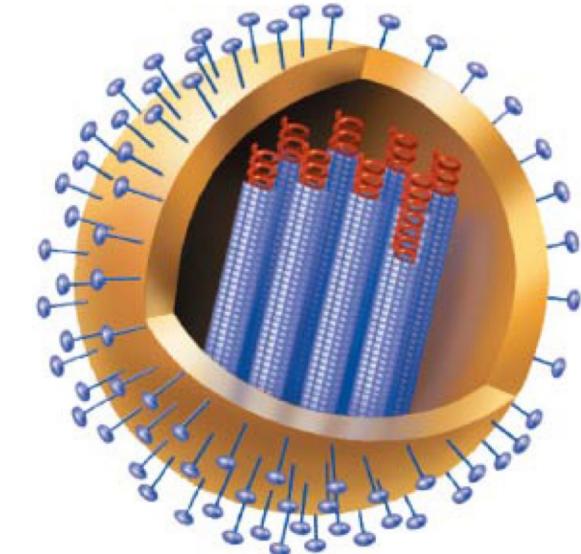
Elephant, egret



Yeast



*E. coli*



Influenza virus

Cells of living systems share many fundamental characteristics

- Unicellular or multicellular
- Large variation in size, habitat, etc.,
- Virus: does it have a cell? If not, what is it made of?

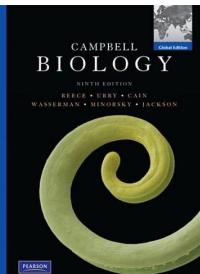


Figure 19.3

<https://www.cdc.gov/vibrio/investigations/rawoysters-05-19/images/ecoli.jpg>

[https://en.wikipedia.org/wiki/Saccharomyces\\_cerevisiae](https://en.wikipedia.org/wiki/Saccharomyces_cerevisiae)

# How big is a cell?

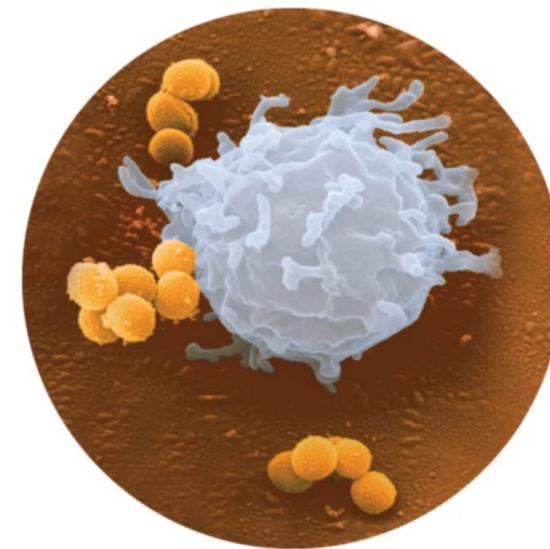
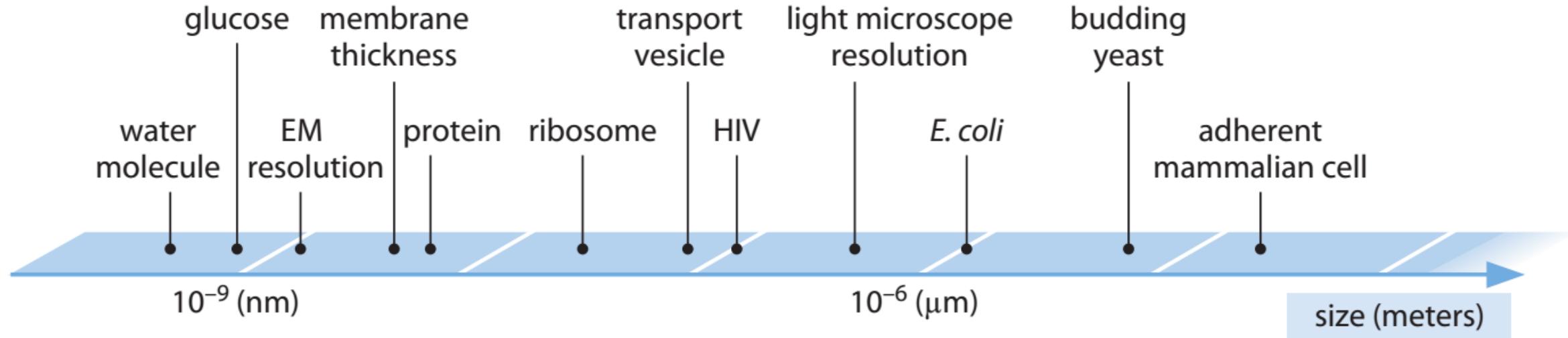


Figure 43.1  
Campbell Biology (10<sup>th</sup> ed.)  
Figure 1.1  
Cell Biology by the numbers

Lymphocyte (translucent white)  
A type of cell found in human blood  
Bacteria (yellowish brown)

# How big can be a cell?

- Most cells are not visible to the naked eye
  - Is there any cell that is visible to naked eye?
  - If yes, have you seen one? Or, touched it?

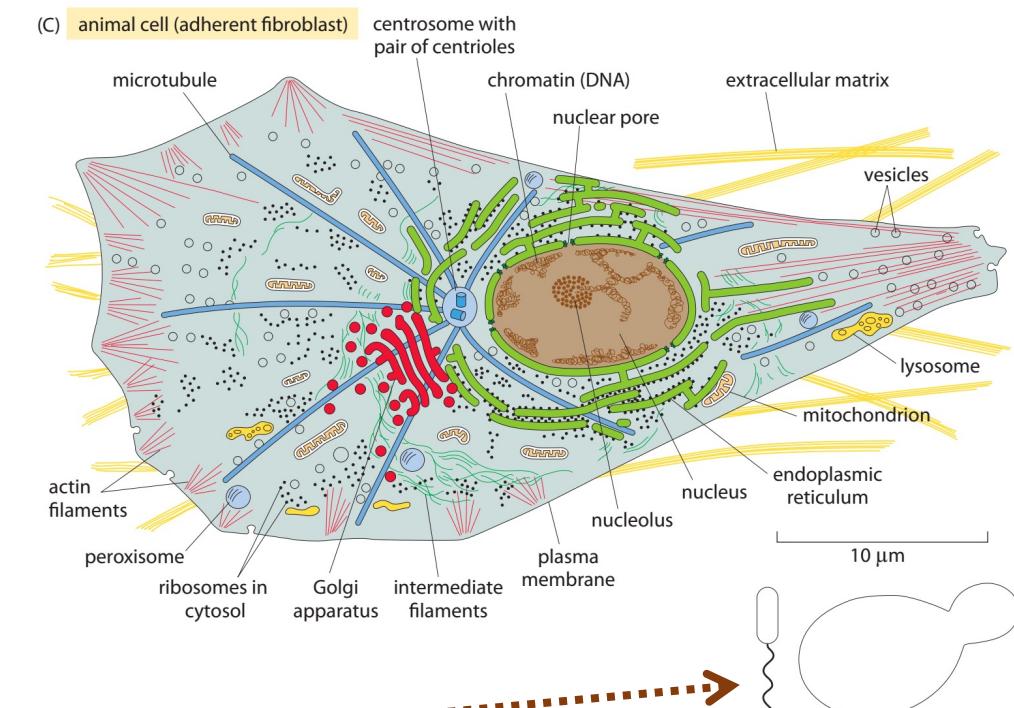
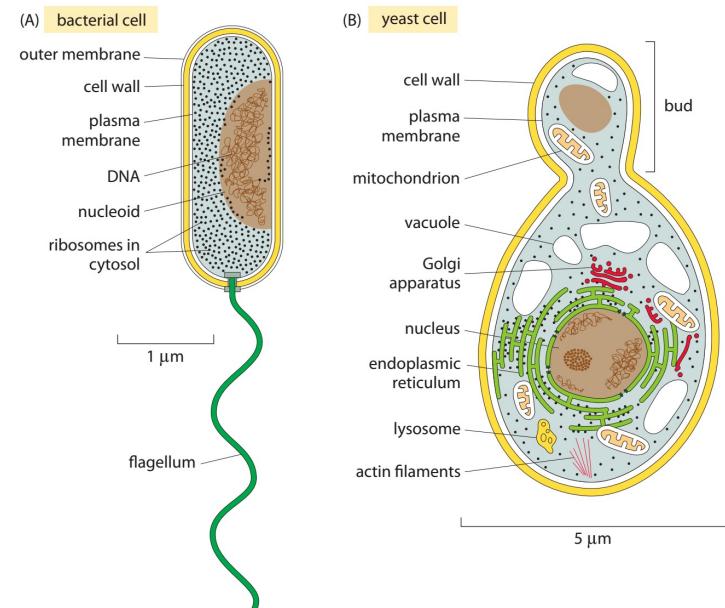
# Typical range of sizes of cells

Domain	Diameter ( $\mu\text{m}$ )
Prokaryote	0.1 to 5
Archaea	0.1 to 0.2
Eukaryote	10 to 100

The assumption that cells are spherical is not universally valid

# Pictorial depiction of variation in size

Do not make any effort to memorize names of cellular components

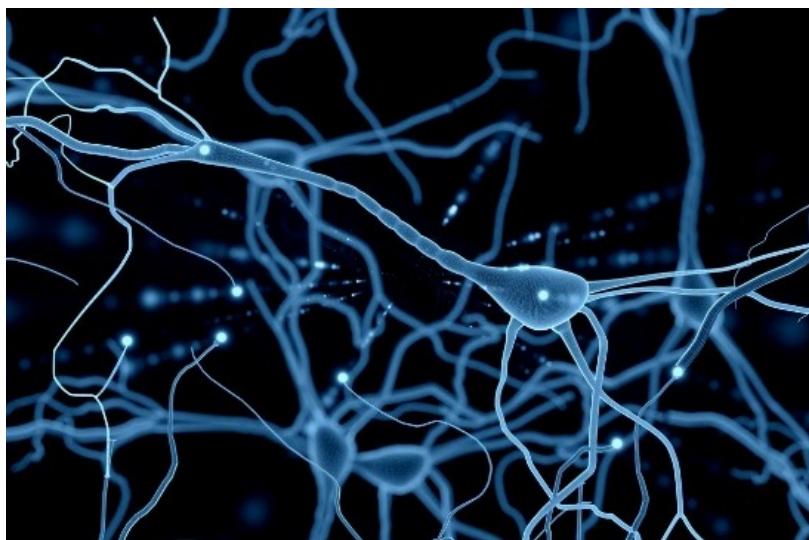
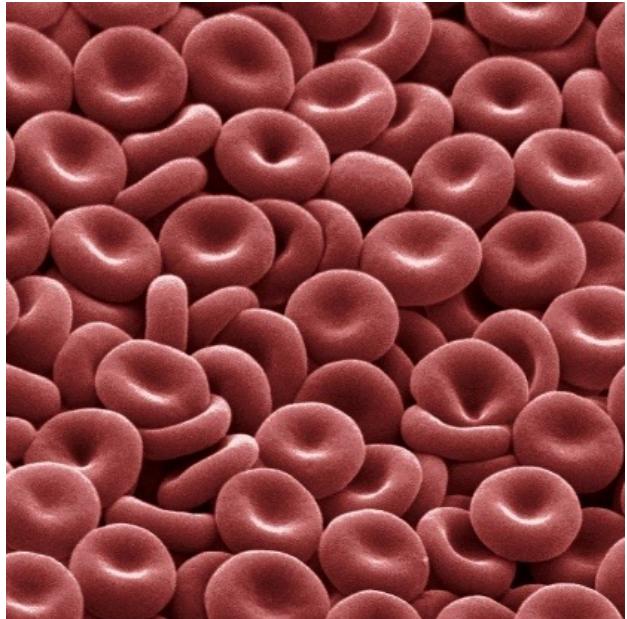


## Scale

Bacterial cell	1 μm
Yeast cell	5 μm
Animal cell	10 μm

Figure 0-1 from Cell Biology by the numbers by Ron Milo and Rob Phillips

# Cells: structure and function



- Erythrocytes (red blood cells)
  - Biconcave, no nucleus, and flexible to squeeze through blood vessels
  - Red in colour due to haemoglobin
- Neurons (nerve cells)
  - Long projections called axons to send electrical signals to other cells

# Cells have adapted as per functional requirements

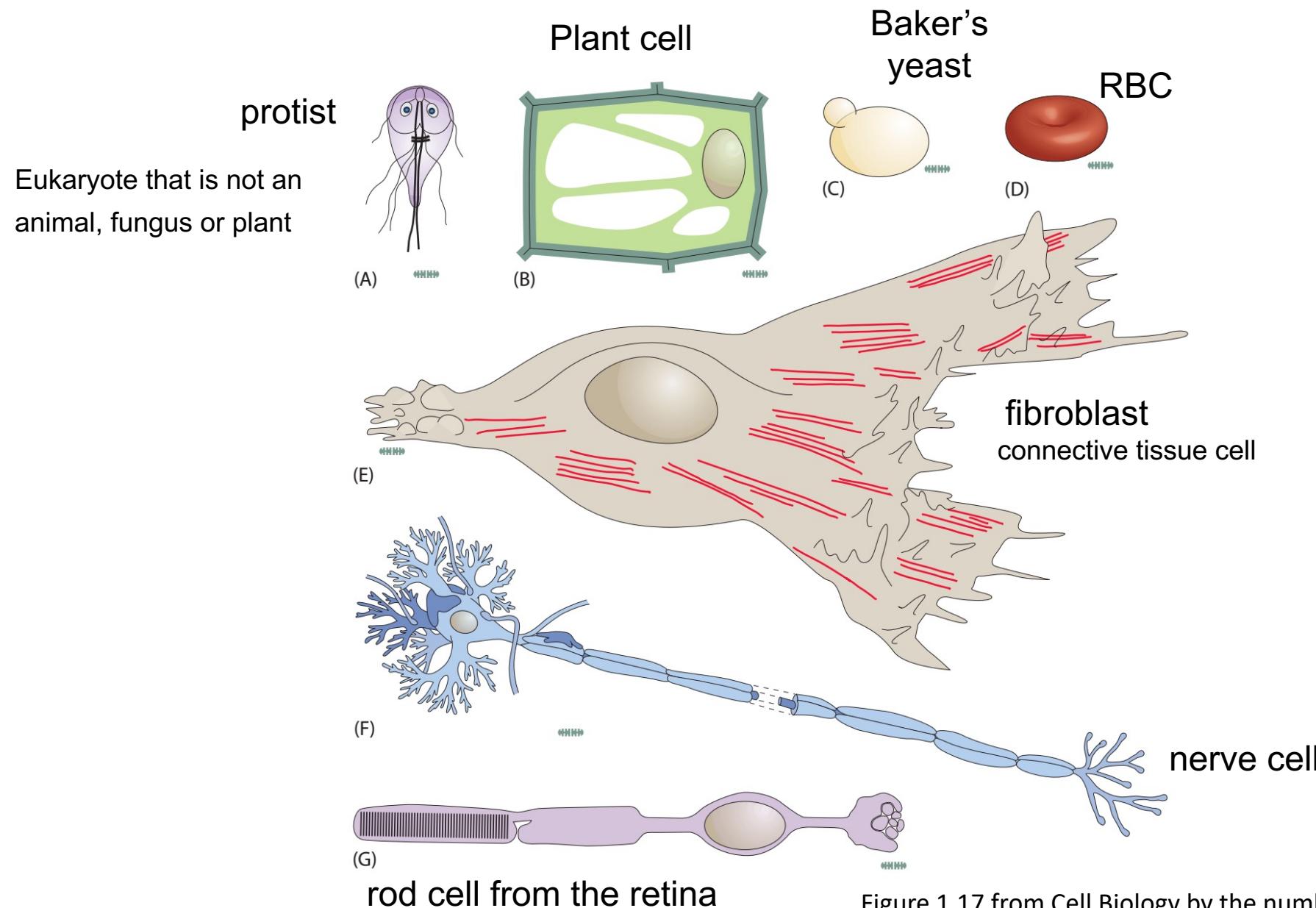


Figure 1.17 from Cell Biology by the numbers by Ron Milo and Rob Phillips

# A phage (= virus that infects bacteria)

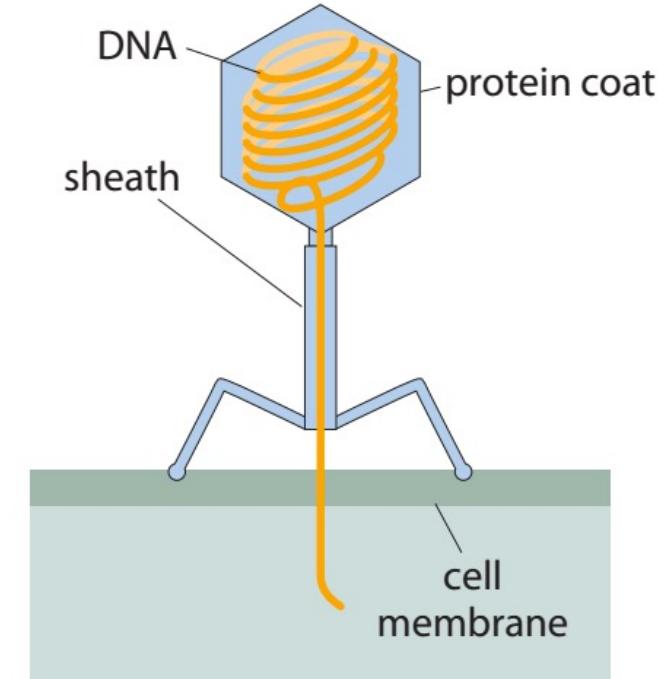
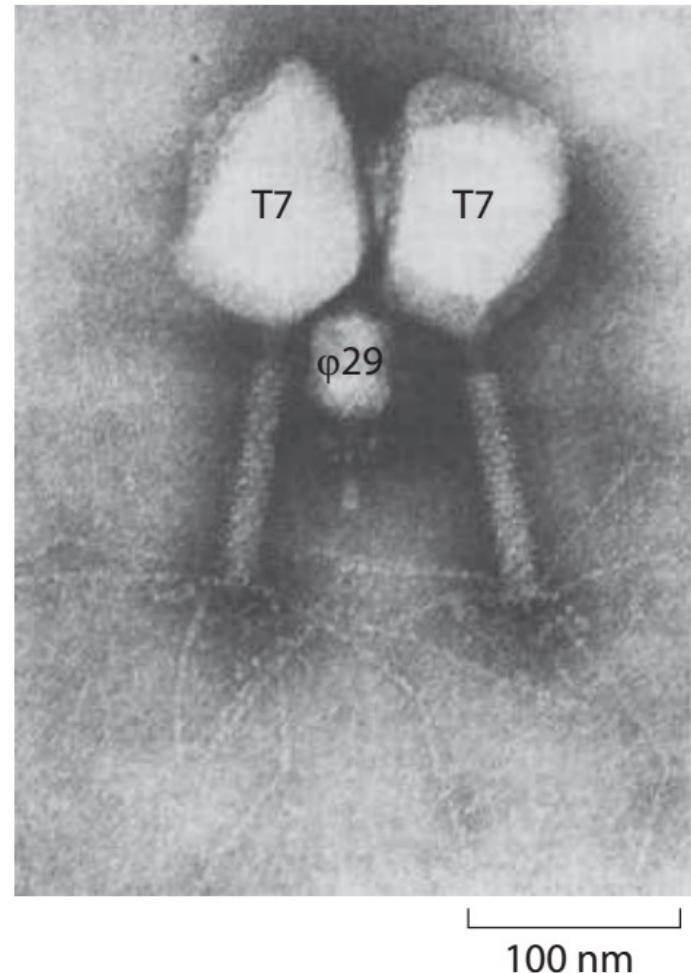


Figure 1.2 from Cell Biology by the numbers by Ron Milo and Rob Phillips

# Sizes of viruses

- T7 phage (previous slide) is one of the smaller viruses
- Sizes of viruses vary greatly
- Some viruses are larger than bacteria
  - These are called giant viruses
  - One such virus has been isolated from the Powai lake by Prof. Kiran Kondabagil of BSBE



Saturday, March 11, 2023

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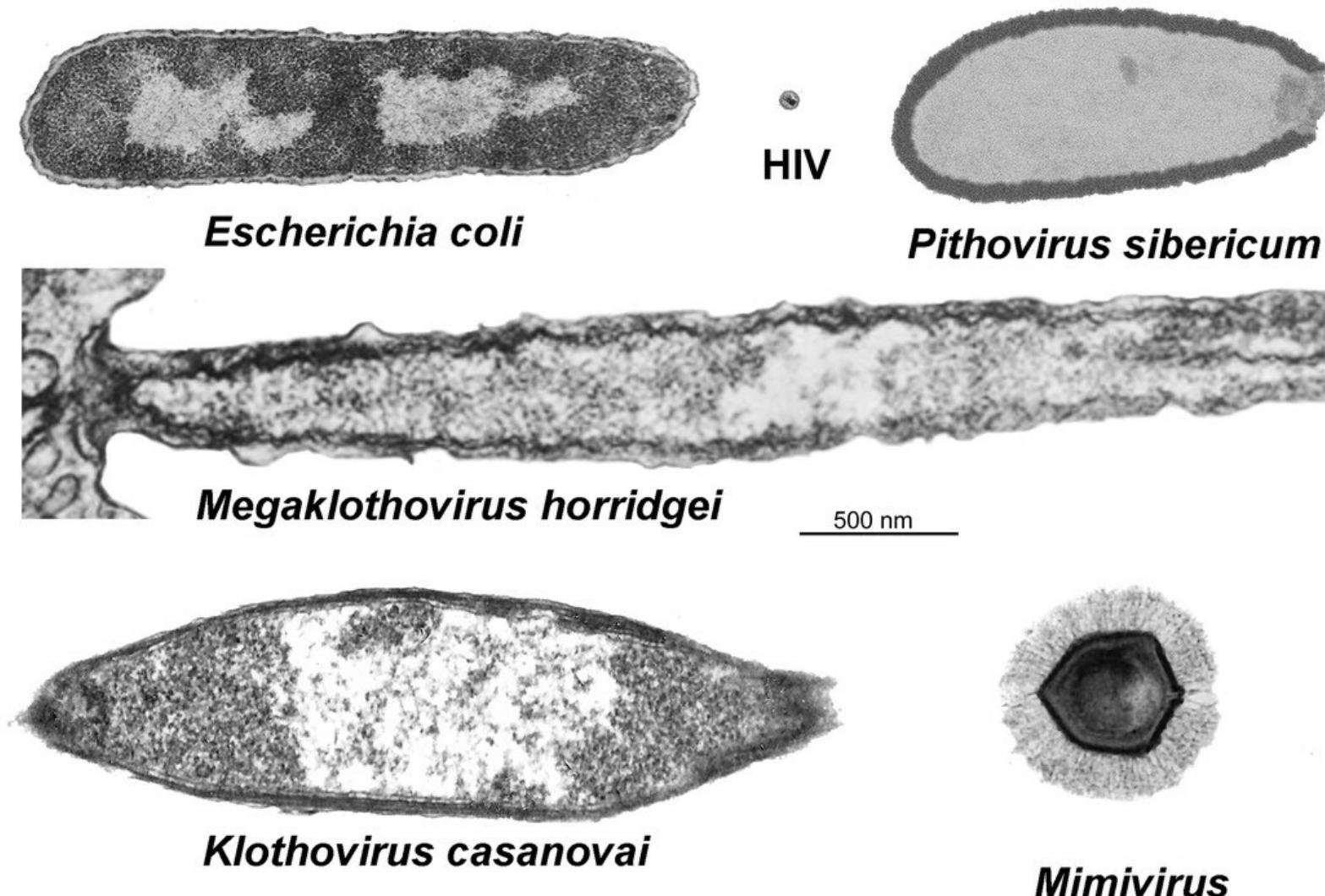
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## IIT-Bombay study finds giant viruses, and the unique protein they make, in Mumbai lakes

IIT-Bombay study has found giant amoeba-attacking viruses that make the unique protein. Harmless to humans, the viruses are believed to play role in sustaining local ecosystem.

**SANDHYA RAMESH** 13 December, 2019 05:23 pm IST**Most Popular** [Lingavat Mahasabha to reviv](#)<https://theprint.in/science/iit-bombay-study-finds-new-protein-which-can-aid-creation-repair-of-dna-in-mumbai-lakes/334674/>

# Giant viruses



- Classification: domains, kingdoms, families, ...
  - Compartmentalization – trade offs during evolution
  - Tree of life or web of life?
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# Order of magnitude

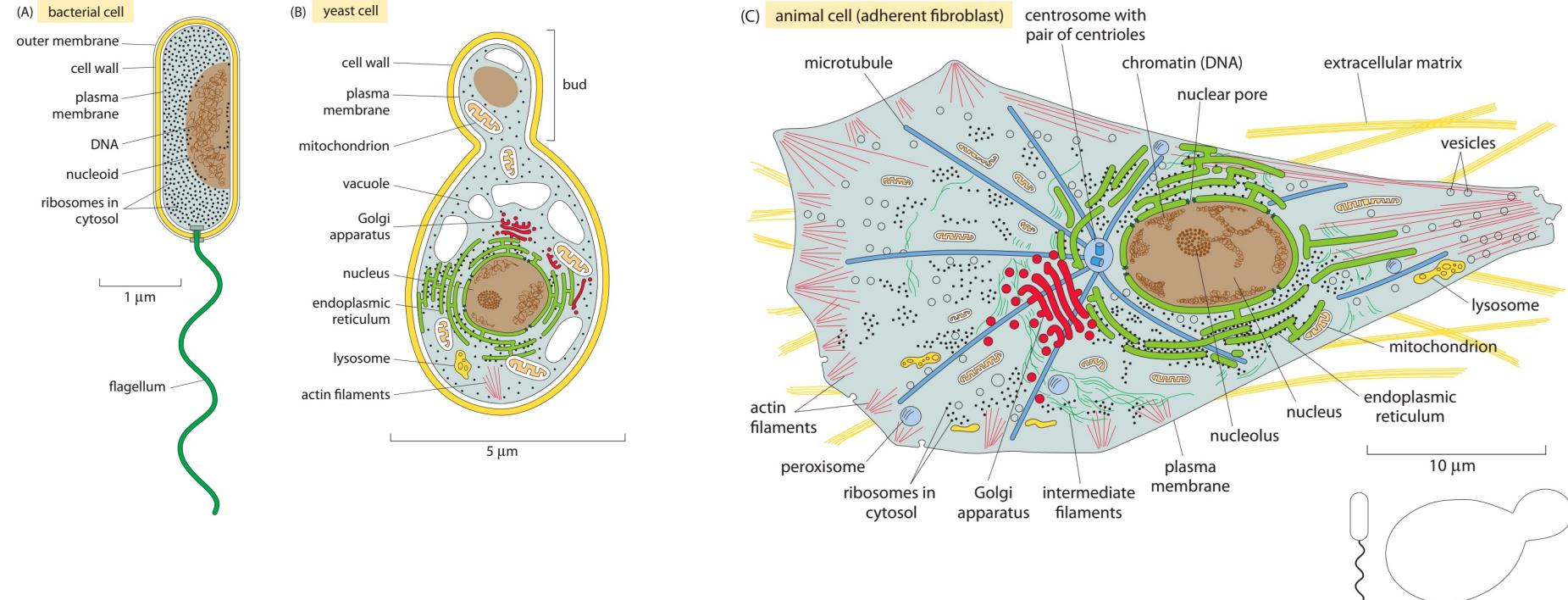
$$O \approx \log_{10}(\text{number})$$

Take the floor value (= nearest lowest integer)

Institute	Approximate number of students (N)	$\log_{10} N$	Order of magnitude
IIT Bombay	13,000	4.114	4
IIT Kharagpur	15,000	4.176	4
IIT Goa	900	2.954	2

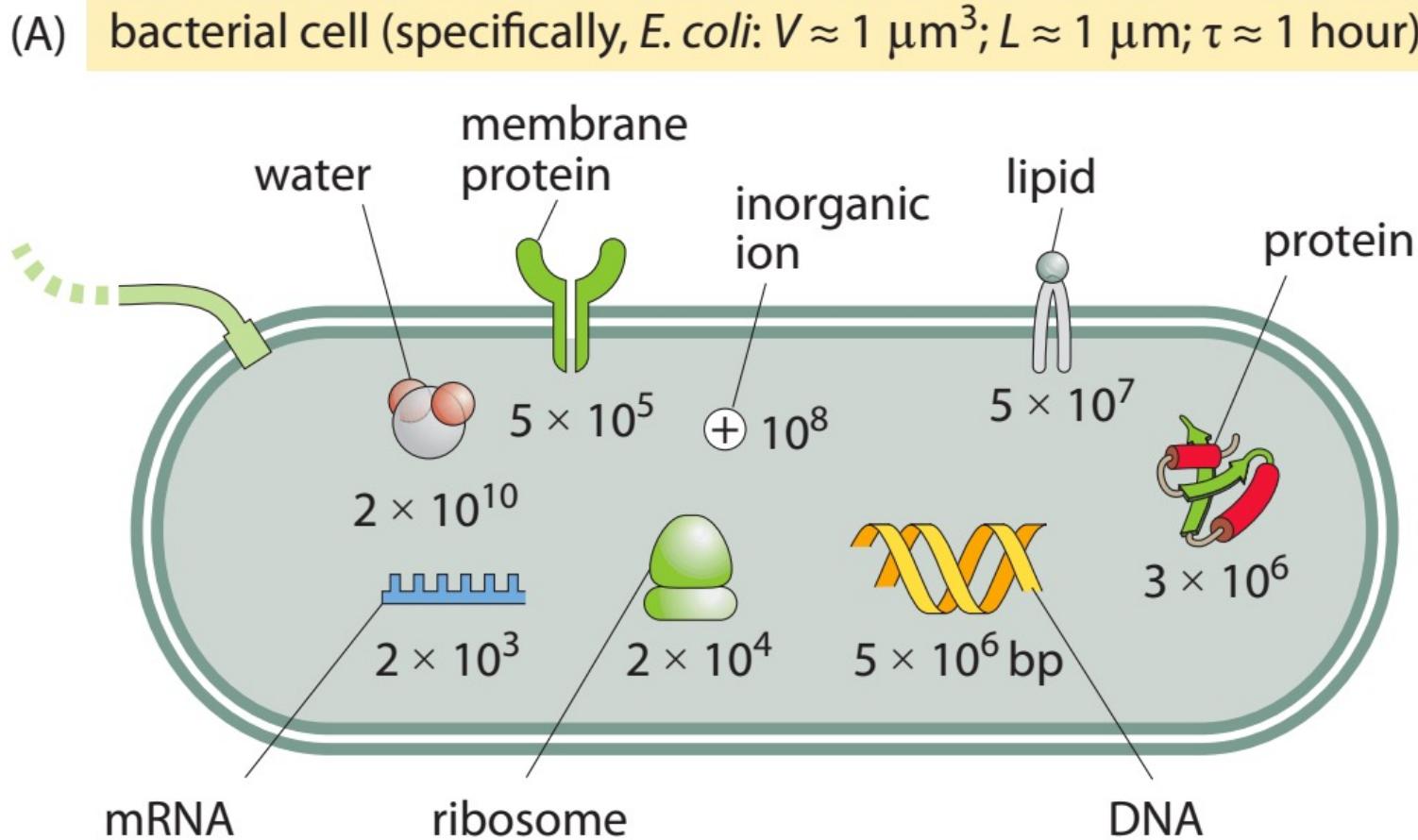
# Outcome of reductionistic approach

## Cell components are known

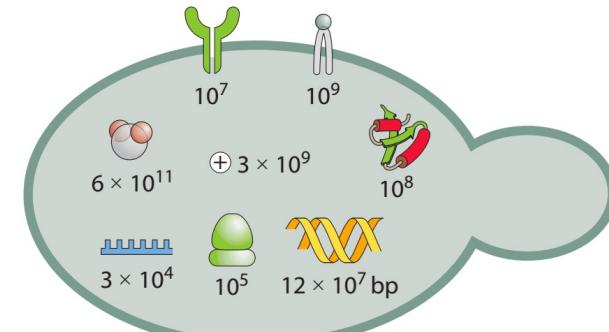


**Do not make any effort to memorize names of cellular components**

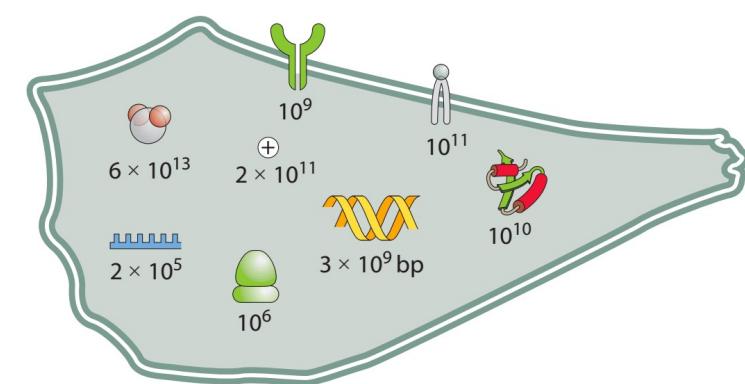
# An order of magnitude census of cell components



(B) yeast cell (specifically, *S. cerevisiae*:  $V \approx 30 \mu\text{m}^3$ ;  $L \approx 5 \mu\text{m}$ ;  $\tau \approx 3 \text{ hours}$ )



(C) mammalian cell (specifically, HeLa:  $V \approx 3000 \mu\text{m}^3$ ;  $L \approx 20 \mu\text{m}$ ;  $\tau \approx 1 \text{ day}$ )

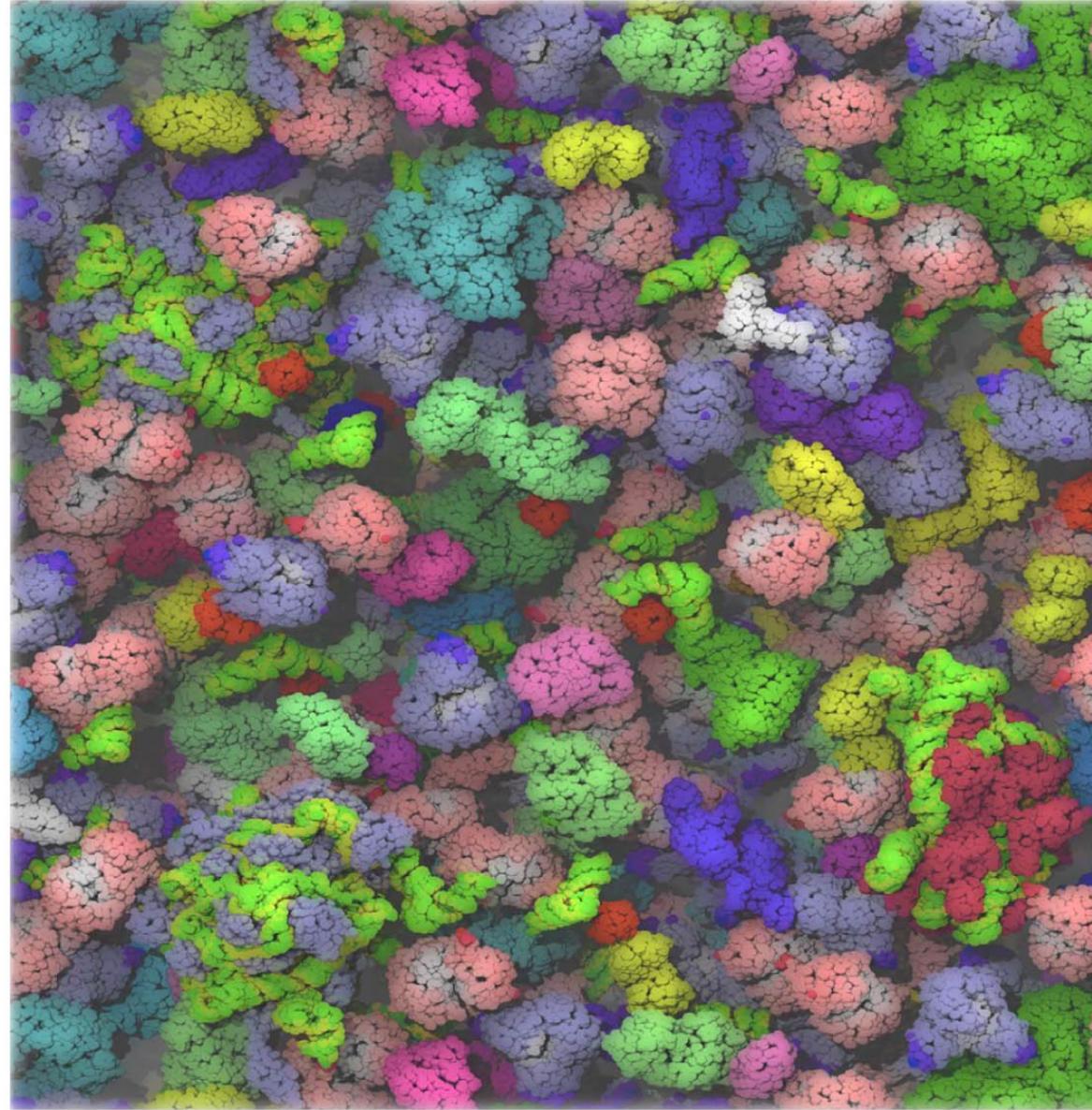


# Metaphor for a cell?



<https://www.quora.com/How-secure-it-is-while-traveling-in-Mumbai-Local-Train-during-rush-hours>

# Model for the inside of a bacterial cell



<https://www.youtube.com/watch?v=2fobDHl11c>

# Inventory of the contents of the cytoplasm model

	Name	Mw	#
●	Adk	24	14
●	AhpC	187	7
●	Asd	80	4
●	Bcp	11	8
●	CspC	7	72
●	CysK	64	13
●	DapA	125	2
●	DnaK	41	11
●	Efp	20	14
●	Eno	91	18
●	Fba	78	6
●	Frr	21	7
●	FusA	69	22

	Name	Mw	#
●	GapA	142	10
●	GlnA	621	1
●	GltD	94	3
●	GlyA	91	15
●	GpmA	55	4
●	Hns	5	7
●	Hup	15	12
●	IcdA	92	43
●	IlvC	54	18
●	Mdh	65	13
●	MetE	84	213
●	Mop	845	2

	Name	Mw	#
●	PanB	140	2
●	Pgk	41	26
●	Pnp	190	3
●	Ppa	116	9
●	PpiB	18	7
●	PurA	94	4
●	PurC	42	7
●	Pyr	308	3
●	RpiA	46	3
●	Rpo	260	4
●	SerC	79	11
●	SodA	46	13
●	SodB	42	9

	Name	Mw	#
●	Suc	142	4
●	Tig	48	9
●	TpiA	54	5
●	Tsf	61	12
●	TufA	84	181
●	Upp	45	11
●	UspA	31	7
●	50S	1,355	10
●	30S	788	10
●	tRNA-C	24	37
●	tRNA-Q	24	37
●	tRNA-F	25	37
●	GFP	26	8

- Classification: domains, kingdoms, families, ...
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## Large organisms: a single blob versus several cells

Blob means a "drop" of thick, viscous liquid

A 1958 Hollywood movie



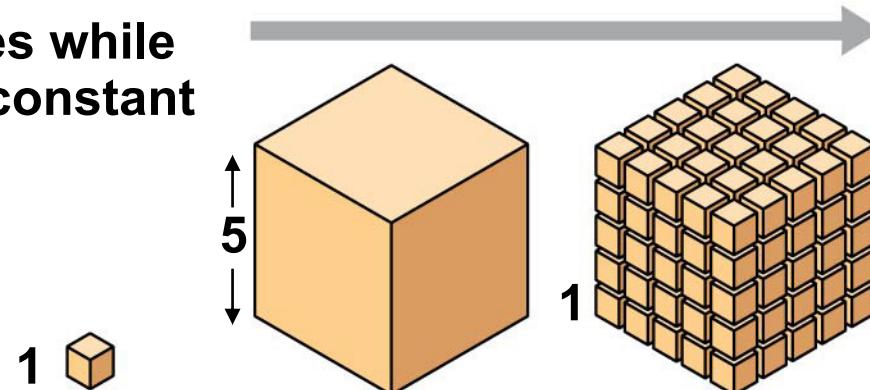
STARRING  
**STEVEN McQUEEN** ANETA CORSEAUT · EARL ROWE  
PRODUCED BY  
**JACK H. HARRIS · IRVIN S. YEAWORTH, JR. · THEODORE SIMONSON AND KATE PHILLIPS**  
DIRECTED BY  
SCREENPLAY BY  
FROM AN IDEA BY IRVINE H. MILLGATE  
A TONYLYN PRODUCTION · COLOR BY DE LUXE

# Square-cube (or cube-square) law

- A mathematical principle
- Describes the relationship between volume (cube) and area (square) as a shape's size increases or decreases
- Galileo Galilei (1638): ratio of two volumes > ratio of their surfaces,
- Applied in a variety of fields including Engineering and Biology

# Surface area to volume ratio

Surface area increases while total volume remains constant



**Total surface area**  
[sum of the surface areas (height  $\times$  width) of all box sides  $\times$  number of boxes]

6

150

750

**Total volume**  
[height  $\times$  width  $\times$  length  $\times$  number of boxes]

1

125

125

**Surface-to-volume (S-to-V) ratio**  
[surface area  $\div$  volume]

6

1.2

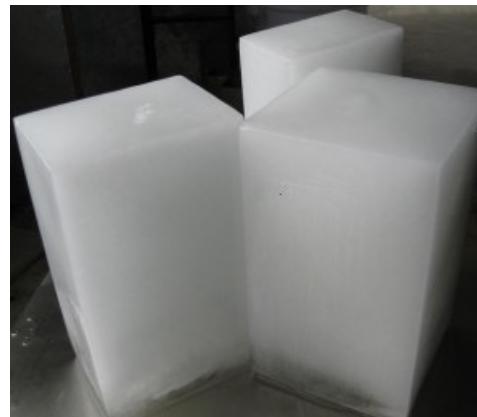
6

# Surface area to volume ratio



<https://churumuri.files.wordpress.com/2009/10/09oct22kpn95.jpg?w=900&h=692>

... in a cup or a saucer?



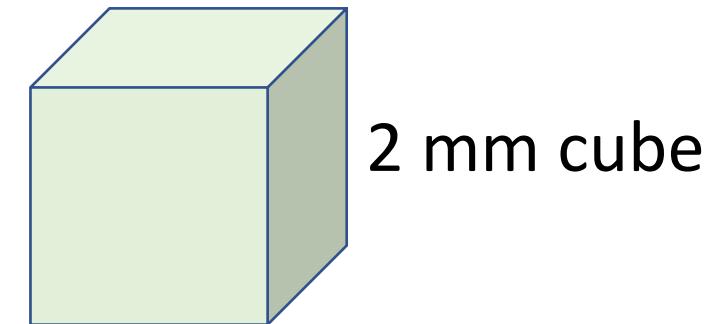
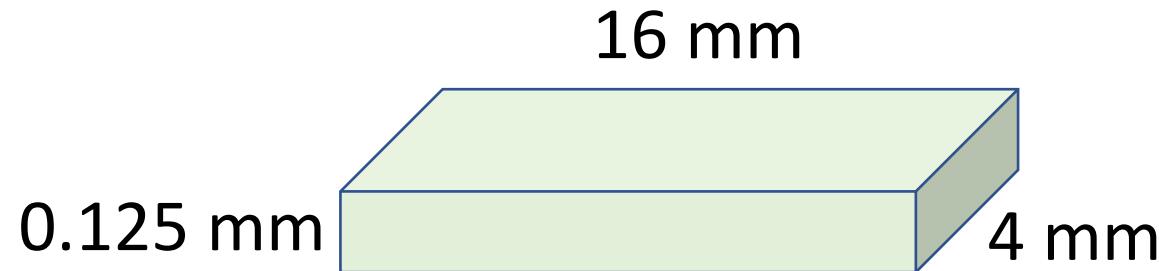
room heater

Ice: large blocks or small cubes?

<http://myduhawk.com/news/space-heaters-dubuque-ia/>

# Surface area to volume ratio

- Should the surface area to volume ratio be large or small
  - Depends upon the function of a cell
- Surface area to volume ratio can be altered by changing shape also



# Natural laws limit cell size

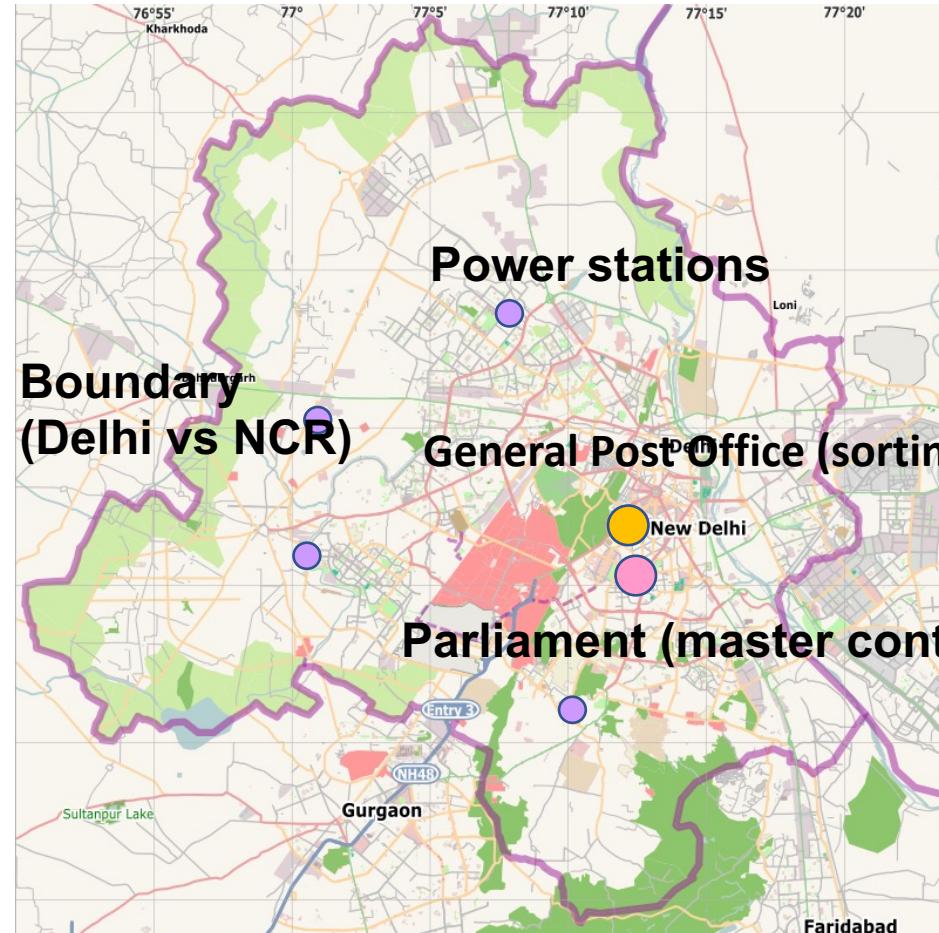
- A cell must be at least large enough to house the components it needs to survive and reproduce
- Certain amount of surface area is needed to obtain nutrients from the environment and dispose of waste
- Surface area decreases relative to the volume as cell size increases
  - Sets the upper limit for cell size

# Multi-cellularity

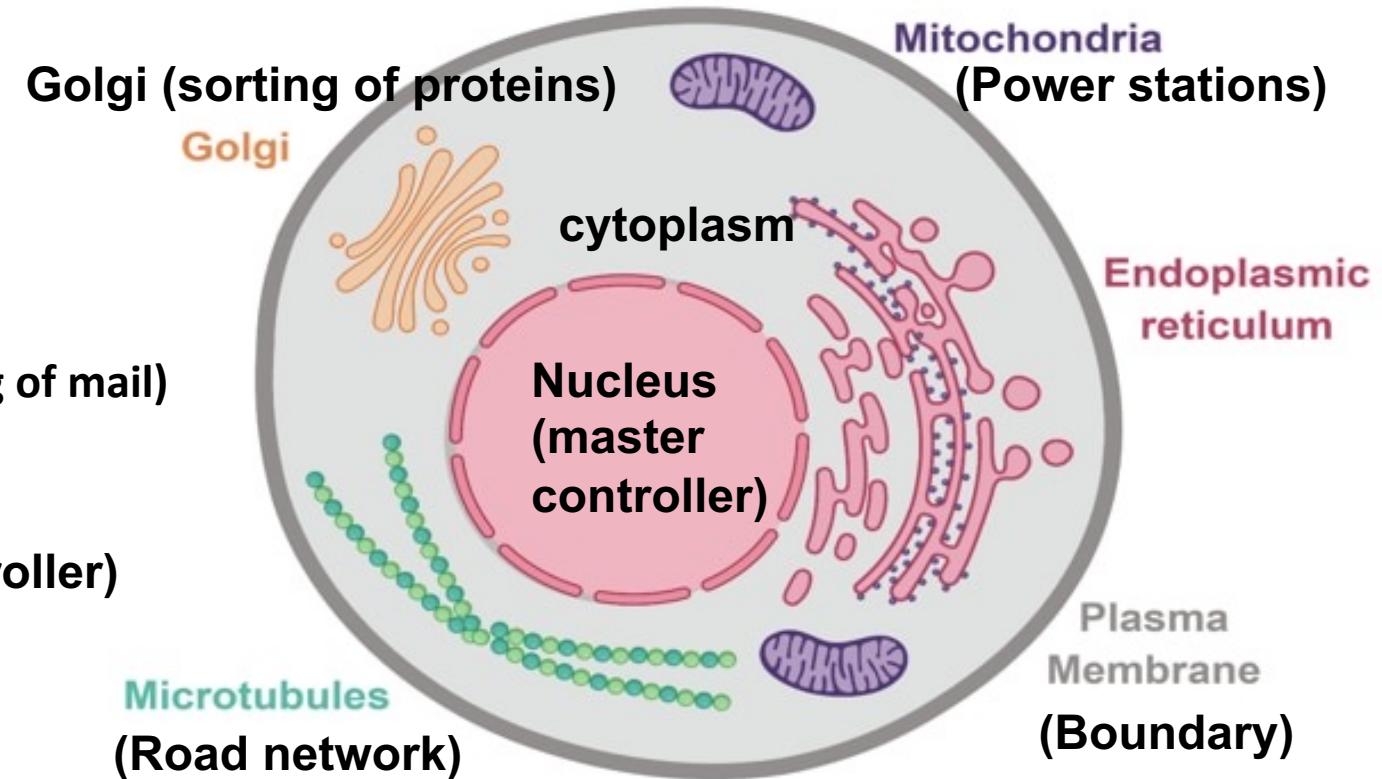
- Helps in efficient exchange of heat and matter
  - Cell is an thermodynamic open system
- A larger organism does NOT mean proportionately larger cells
  - Better to have more cells than a single large cell
  - Allows specialization based on functional requirements

# Cell volume and surface area

- Challenges of having a larger volume – intra-cellular diffusion of molecules
  - Small molecules take an hour to move 1 mm by diffusion
  - Absorption of nutrients, dissemination of signals, and disposal of waste products – exceedingly difficult at large cytoplasmic volumes
- Possible solutions: multi-cellularity and compartmentalization
  - Specialized organelles compartmentalize essential functions
  - Specialized transport systems

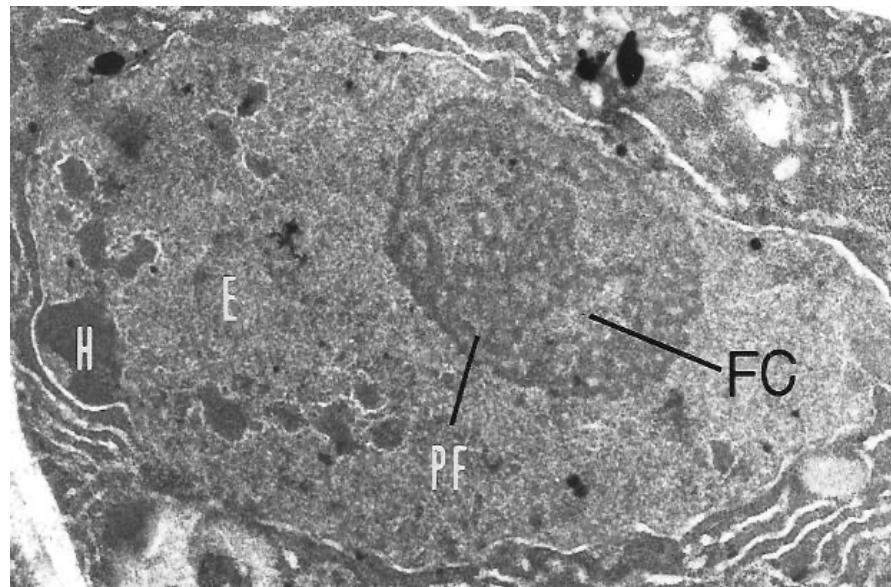
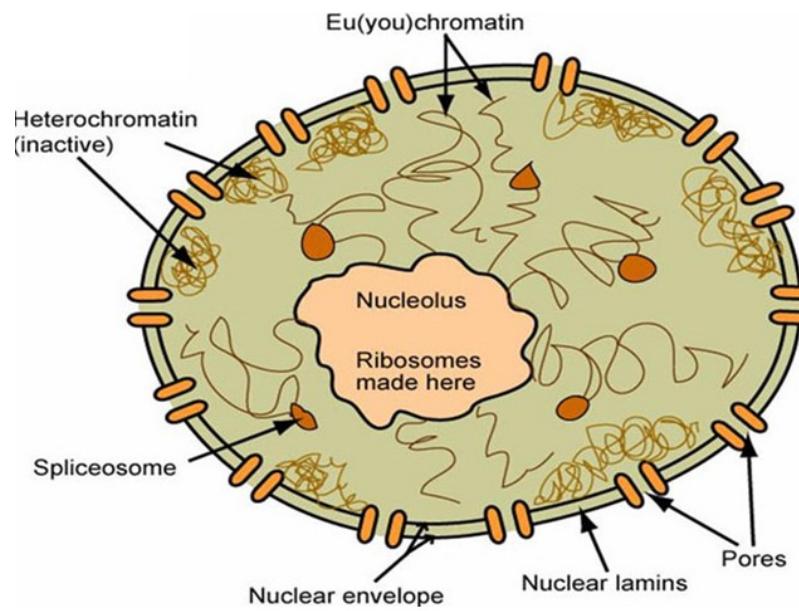


Map of New Delhi



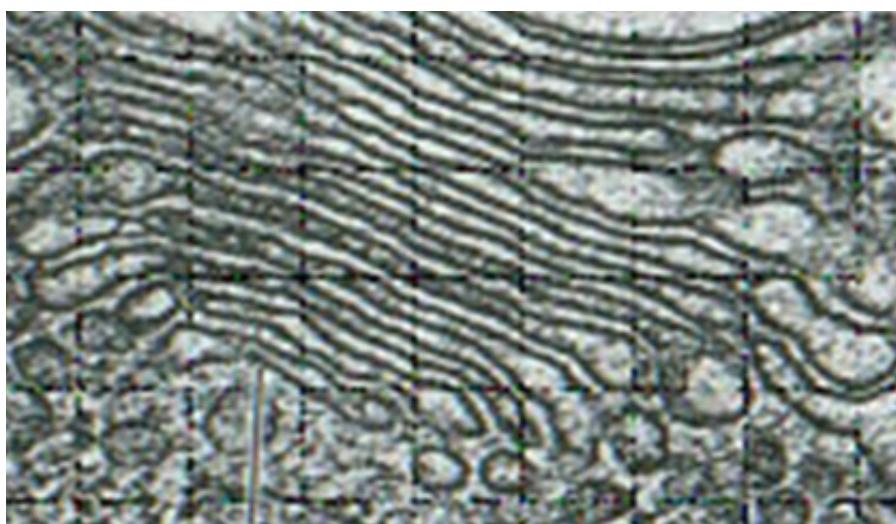
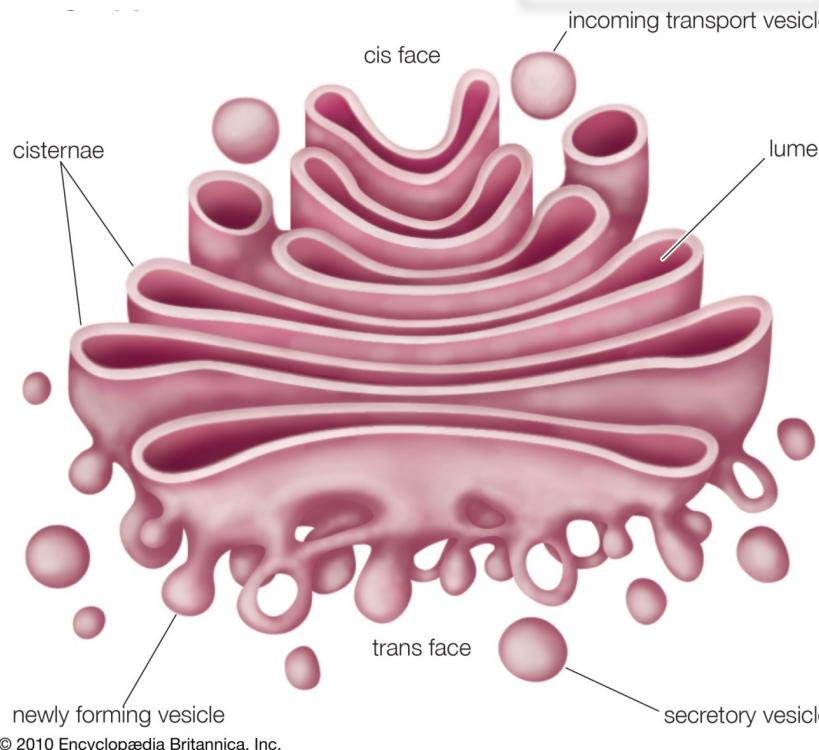
Schematic of a cell

# Nucleus contains the DNA



- DNA is the genetic material
  - Think of it as an instruction manual
- Nucleus is the hard drive
- In the city analogy, the nucleus is the government

# Sorting and transportation

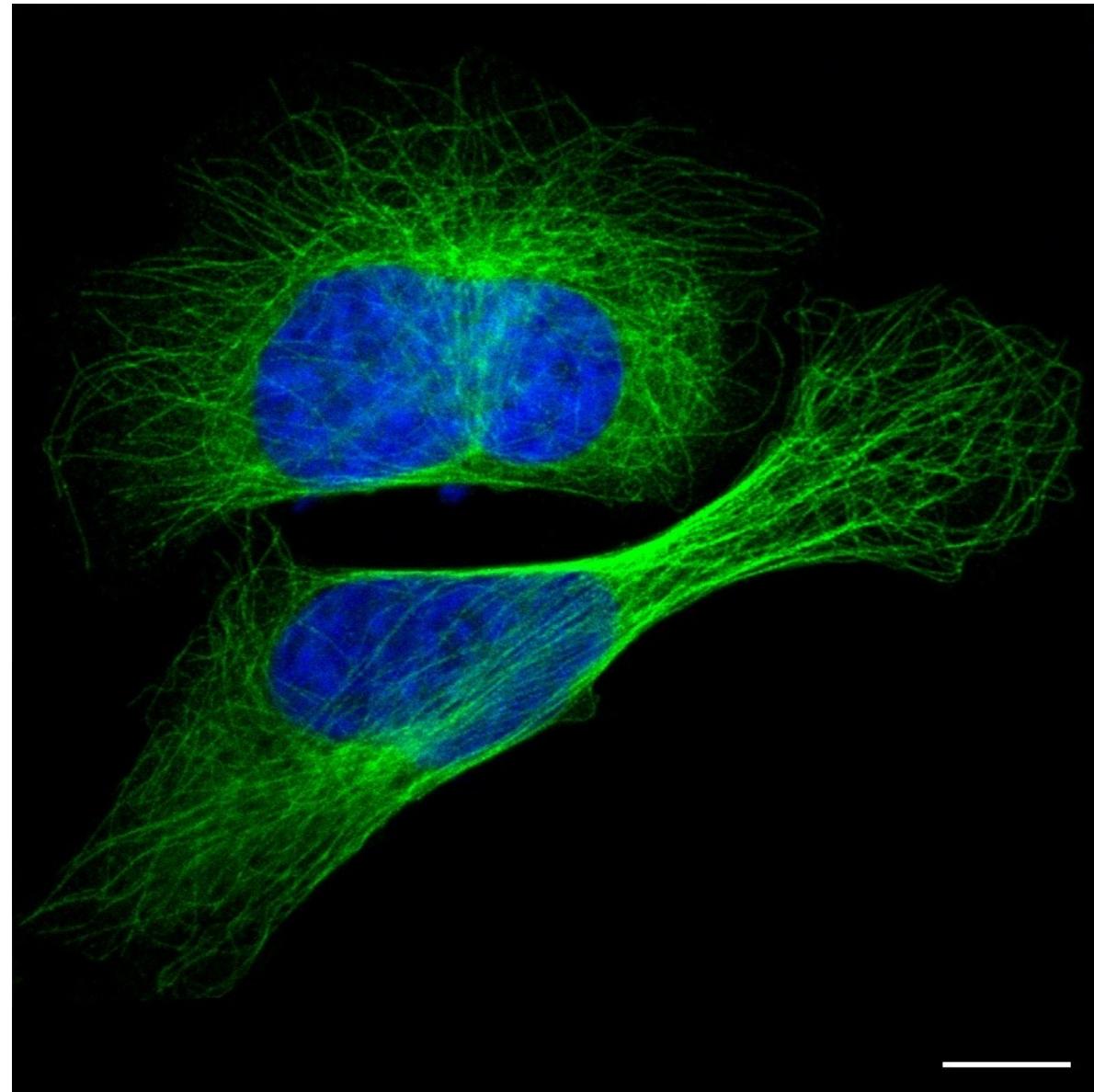


- Golgi is like a Post Office
- Forms small cargo-containing spherical bodies called vesicles
- Exocytosis: sending proteins outside the cell

# Sorting and transportation



# Cytoskeleton: the road network

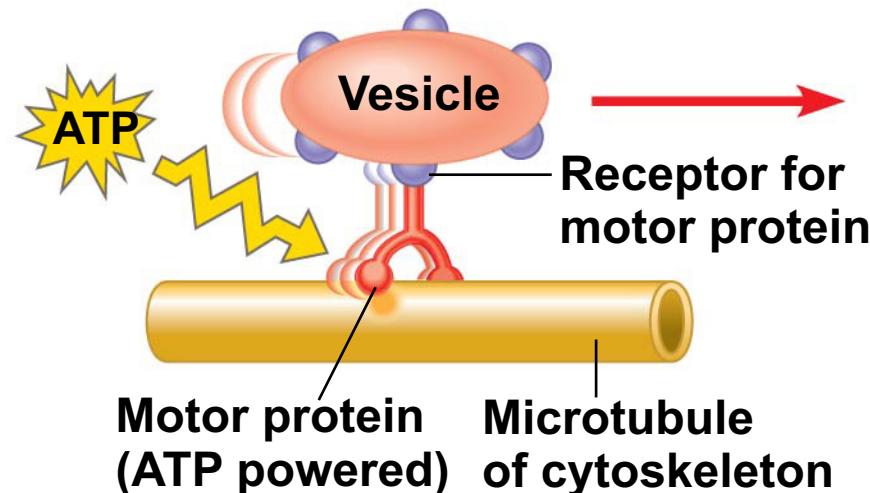


- Cytoskeleton:
  - Actin
  - Microtubules
  - Intermediate filaments

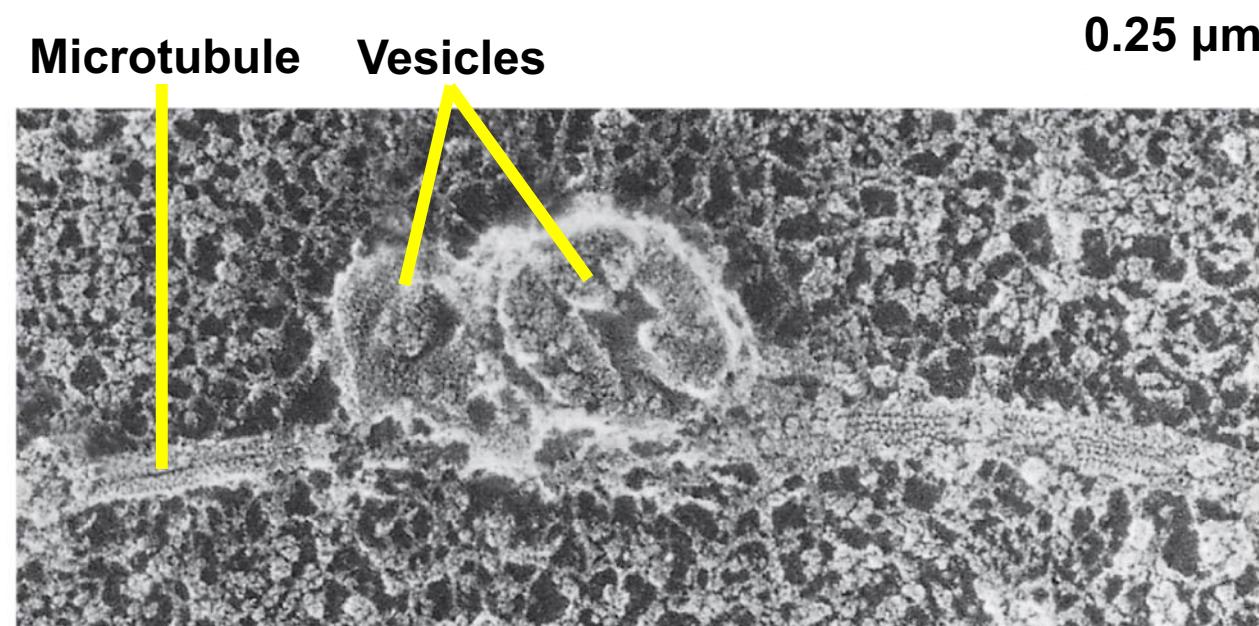
Blue sphere: nucleus

Green lines: microtubules

# Motor proteins



Motor proteins “walk” vesicles along cytoskeletal fibers.



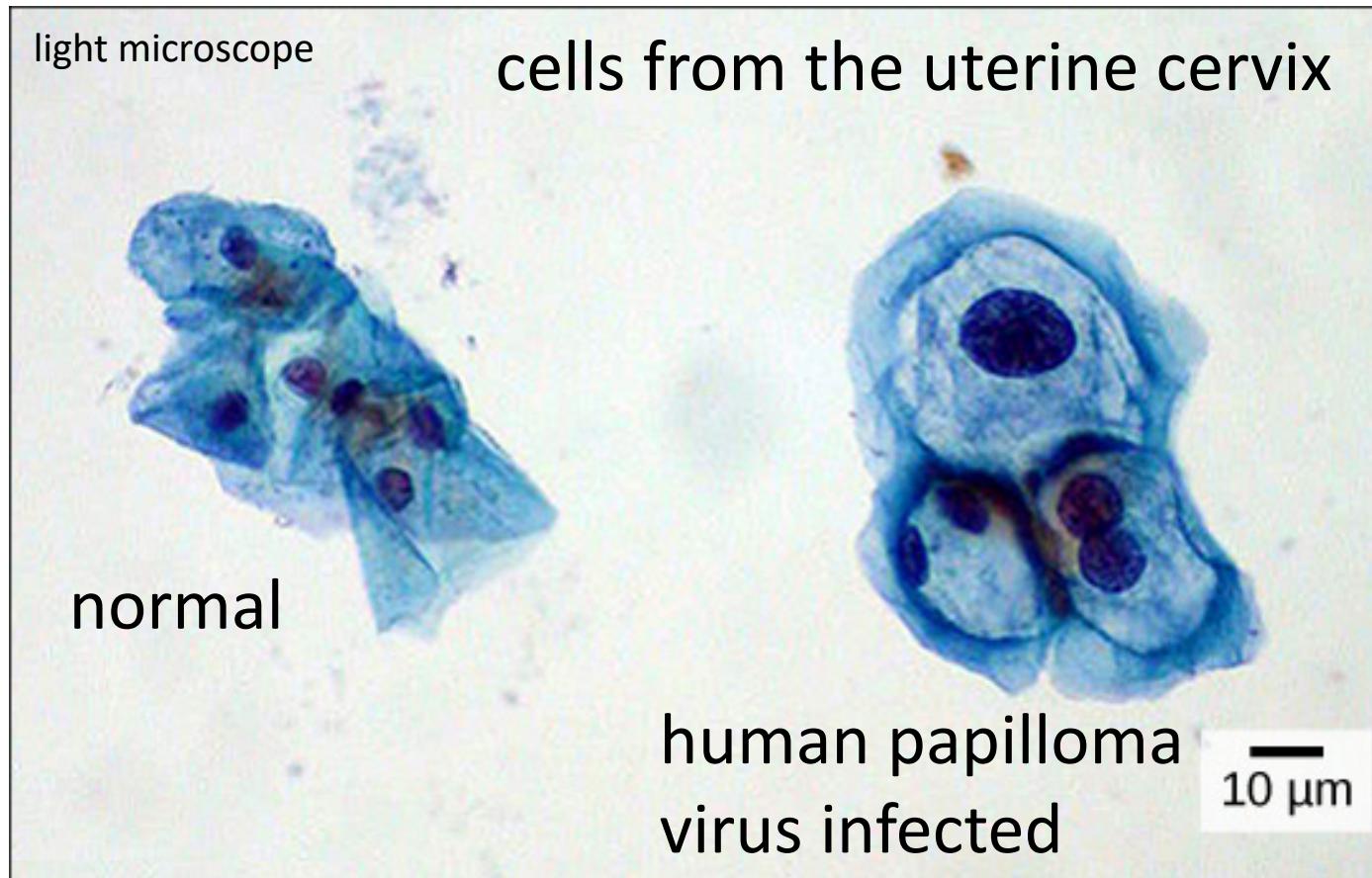
Scanning electron micrograph of a squid giant axon

Axon: is the extension of a nerve cell (or neuron)

Shown are two neurotransmitter-containing vesicles moving towards the tip of the axon

- Classification: domains, kingdoms, families, ...
  - Compartmentalization – trade offs during evolution
  - Tree of life or web of life?
- Cell – basic unit of life
  - A cell is crowded
- Multicellular versus unicellular
- Applications in day-to-day life

# Why bother? Pap smear test



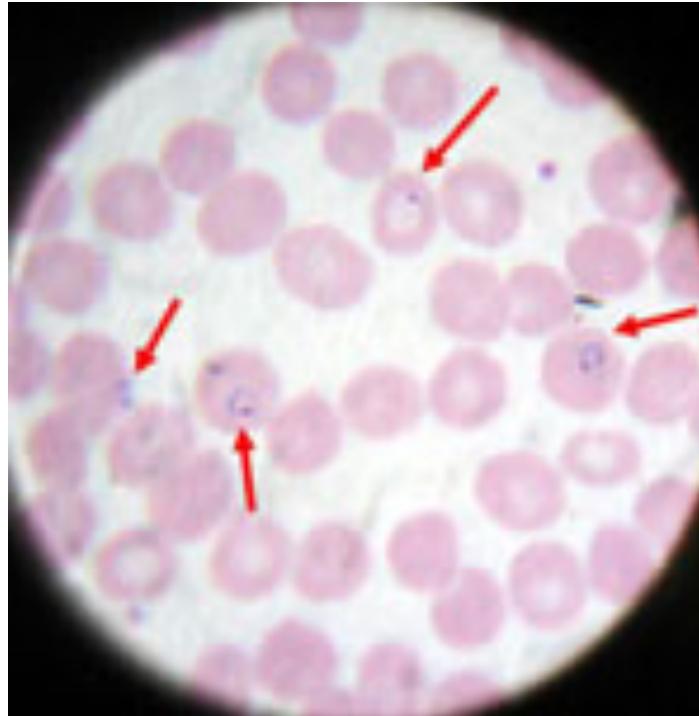
- (i) larger in size
- (ii) two nuclei each in two cells

Pap smear test – for early detection of cancer and viral infections

Routine test... followed up by other sensitive tests, if warranted

Happiness & well-being (individual)  
Lower healthcare burden (economy)

# Why bother? Diagnosis of malaria



- Visualize blood cells stained with a dye that turns DNA purple
- Microscopy in a hospital to detect malaria parasites in RBCs
- Image analysis is being tested to make the process more efficient and reliable

# Why bother? Diagnosis of sickle cell anemia

https://www.medprimetech.com

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