Embryo Physics - EVO DEVO
January 15, 2014

Biotensegrity

Bioarchitecture

&

Dynamic Anatomy

A Unified Model

for

Dynamical Anatomy

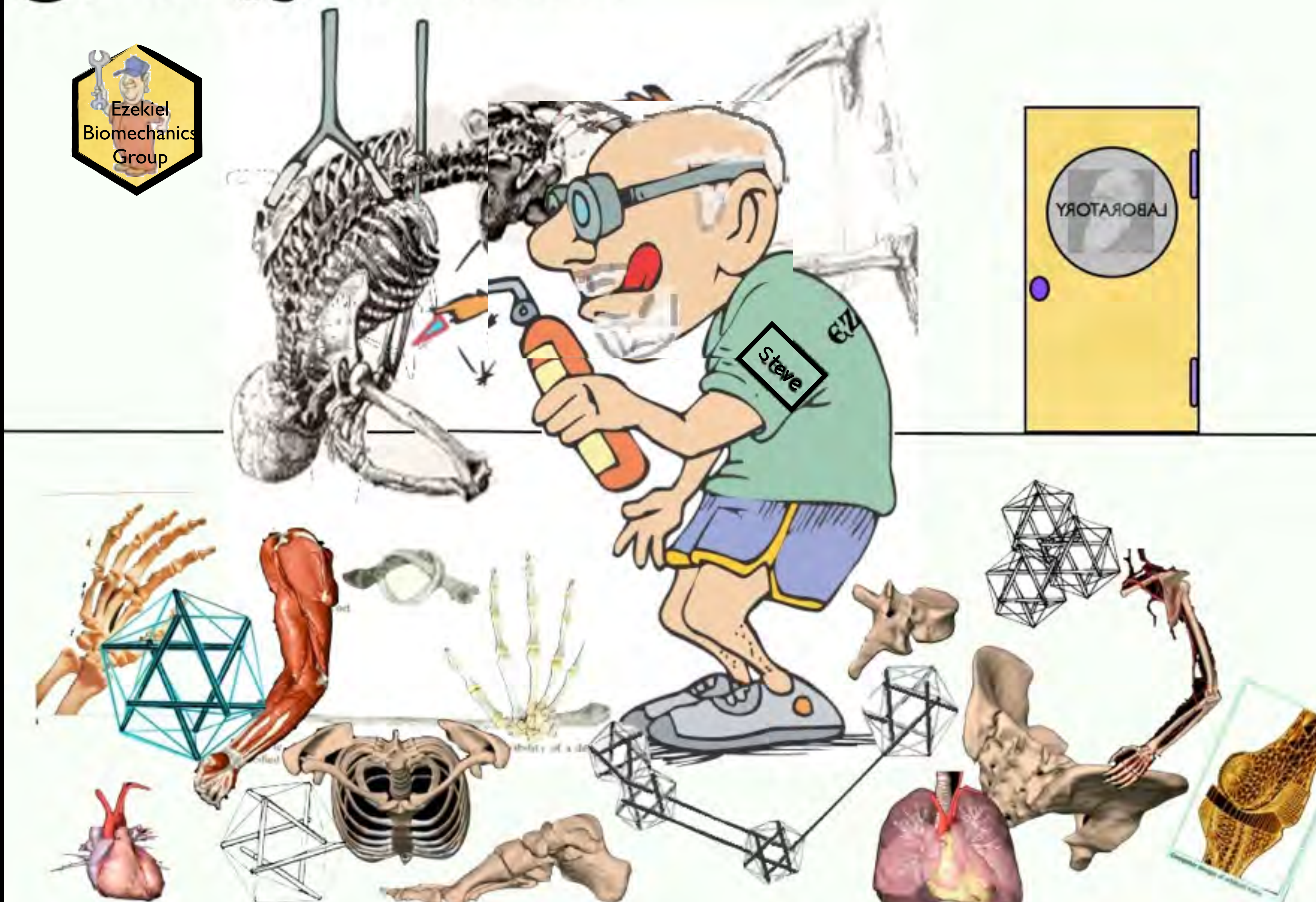
Stability

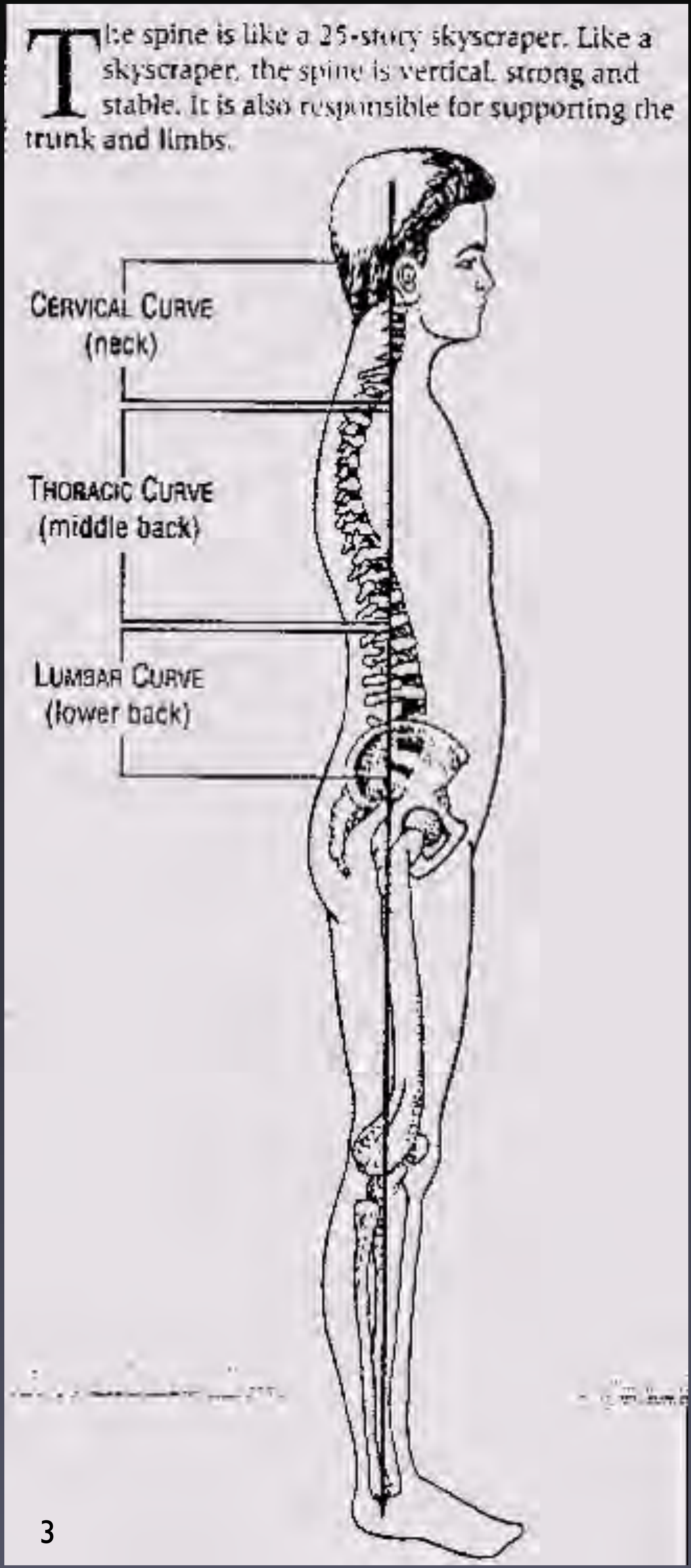
Mobility

Information Dissemination

Stephen M. Levin, MD
Ezekiel Biomechanics Group
McLain, Va

Ezekiel Biomechanics





The Paradigm

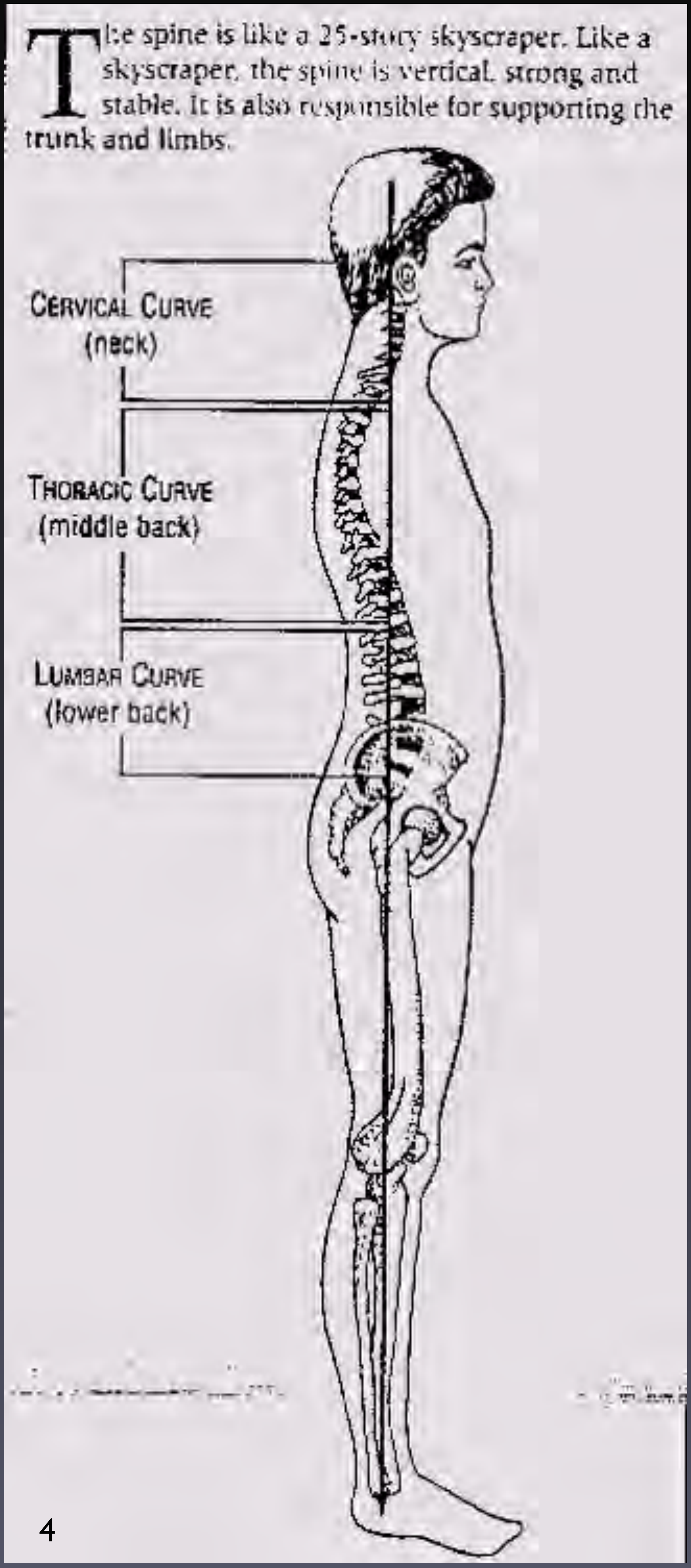
The Spine is a Column

"The spine is like a 25-story skyscraper.

Like a skyscraper, the spine is vertical, strong and stable.

It is also responsible for supporting the trunk and limbs."

Albert Schultz



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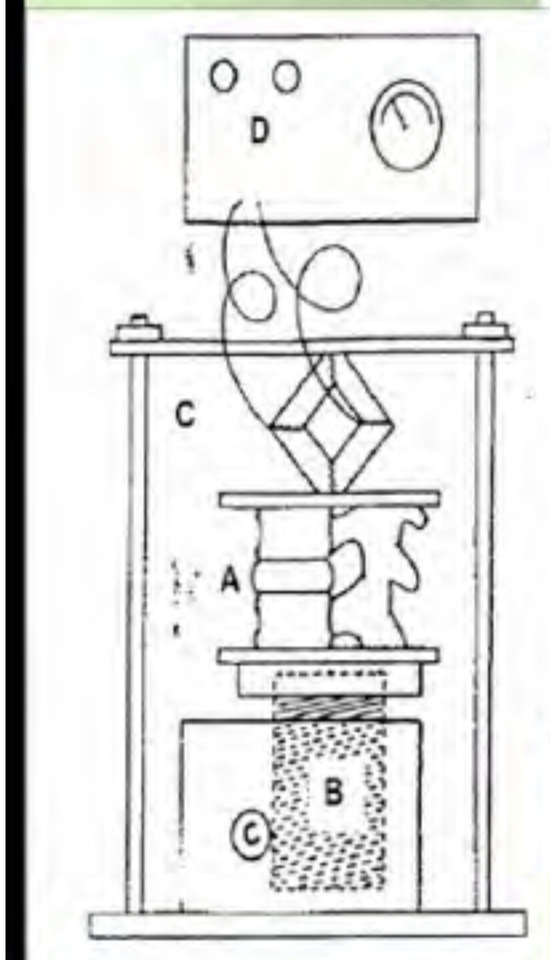
Based on this Model:
500,000 Spine Fusions/year @ $110,000+ each

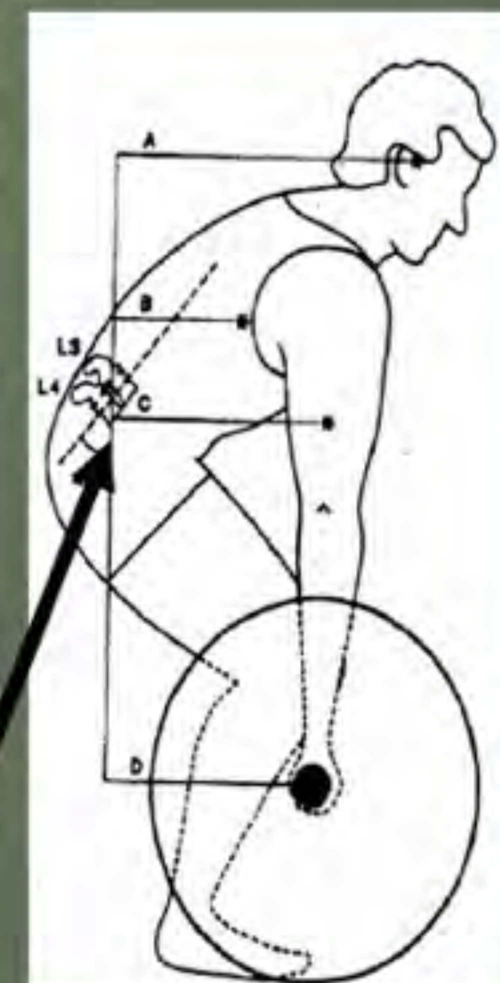
Cost:$55 Billion/Year!

Math Model for the Human Body



Calculation of Vertebral Strengths

Vertebrae	Percentage of Body Weight Carried	Mass in kg Carried by 72.7 kg Man	Breaking Strength (N)	Breaking Stress in g's'	Percentage of L4 Breaking Strength
T1	9	6.5	1,605	25.0	16.6
T2	12	8.7	2,140	25.0	22.1
T3	15	10.9	2,675	25.0	27.7
T4	18	13.1	3,211	25.0	33.2
T5	21*	15.2	3,746	25.0	38.7
T6	25*	18.1	4,459	25.0	46.1
T7	29*	21.0	5,173	25.0	53.5
T8	33*	23.9	5,864*	24.9	60.7
T9	37*	26.9	6,657*	25.2	68.9
T10	40*	29.1	7,277*	25.5	75.3
T11	44*	32.0	7,580*	24.2	78.4
T12	47*	34.2	7,835*	23.4	81.0
L1	50*	36.4	7,982*	22.4	82.6
L2	53*	38.5	8,584*	22.7	88.8
L3	56*	40.7	9,636*	24.1	99.6
L4	58*	42.2	9,667*	23.4	100.0
L5	60*	43.6	10,550*	24.6	109.1



Max: 9,600 N

Calculated: 36,000N

Calculated Loads Will:

Tear Muscle

Crush Bone

Exhaust Energy

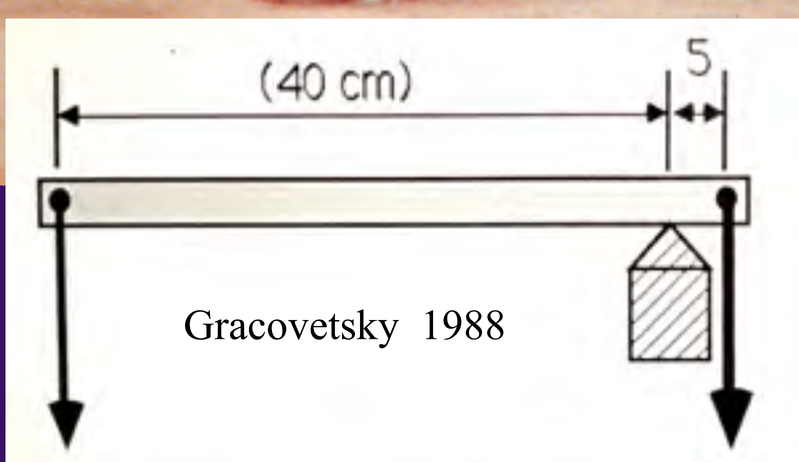
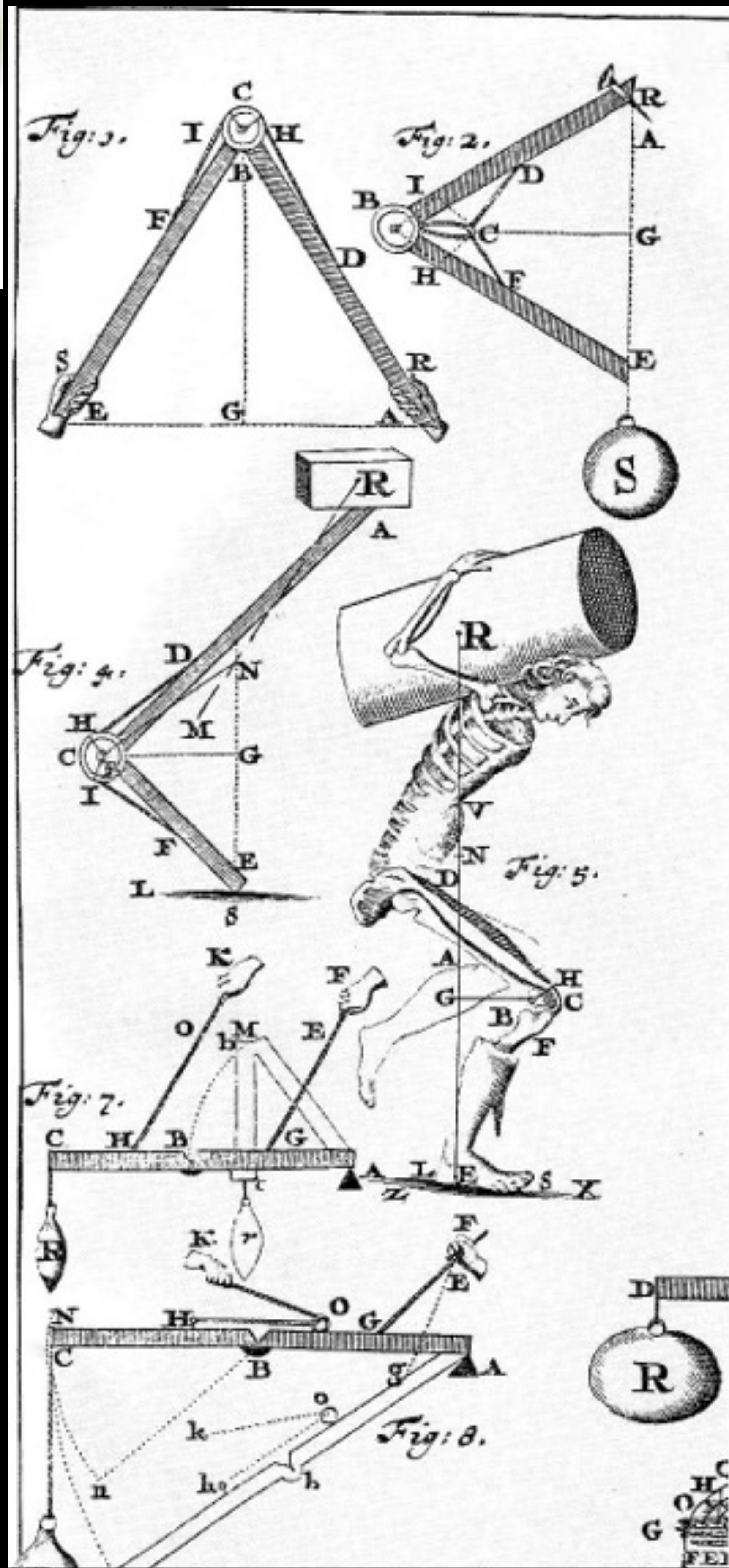
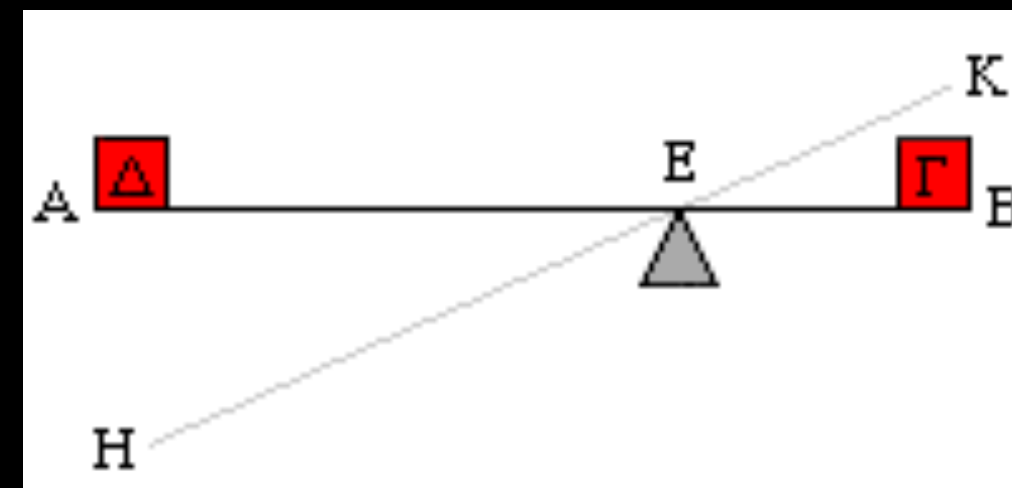


Fig. 2.1 A load of 200 kg located 40 cm from the fulcrum requires a muscle reaction force of 8 * 200 = 1600 kg. The erectores spinae group can generate a force of about 200 to 400 kg, a force of only one quarter to one half of that necessary. Hence, muscle power alone cannot lift such a load. Another supporting member is required.

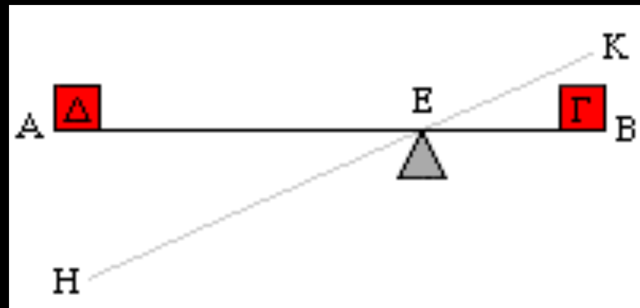
The erector spianegroup can generate a force of about 200 to 400kg, a force of only one quarter to one half of what is necessary.


Giovanni Borelli
(1608-1679)





The Lever
2-Bar Open Kinematic Chain



Characteristics of Lever Based Systems

Linear

Local

Structurally Discontinuous

Gravity Dependent

Unidirectional

High Energy Requirement

Rigid Joints for Stability

Characteristics of Biological Systems

NonLinear

Global

Structurally Continuous

Gravity Independent

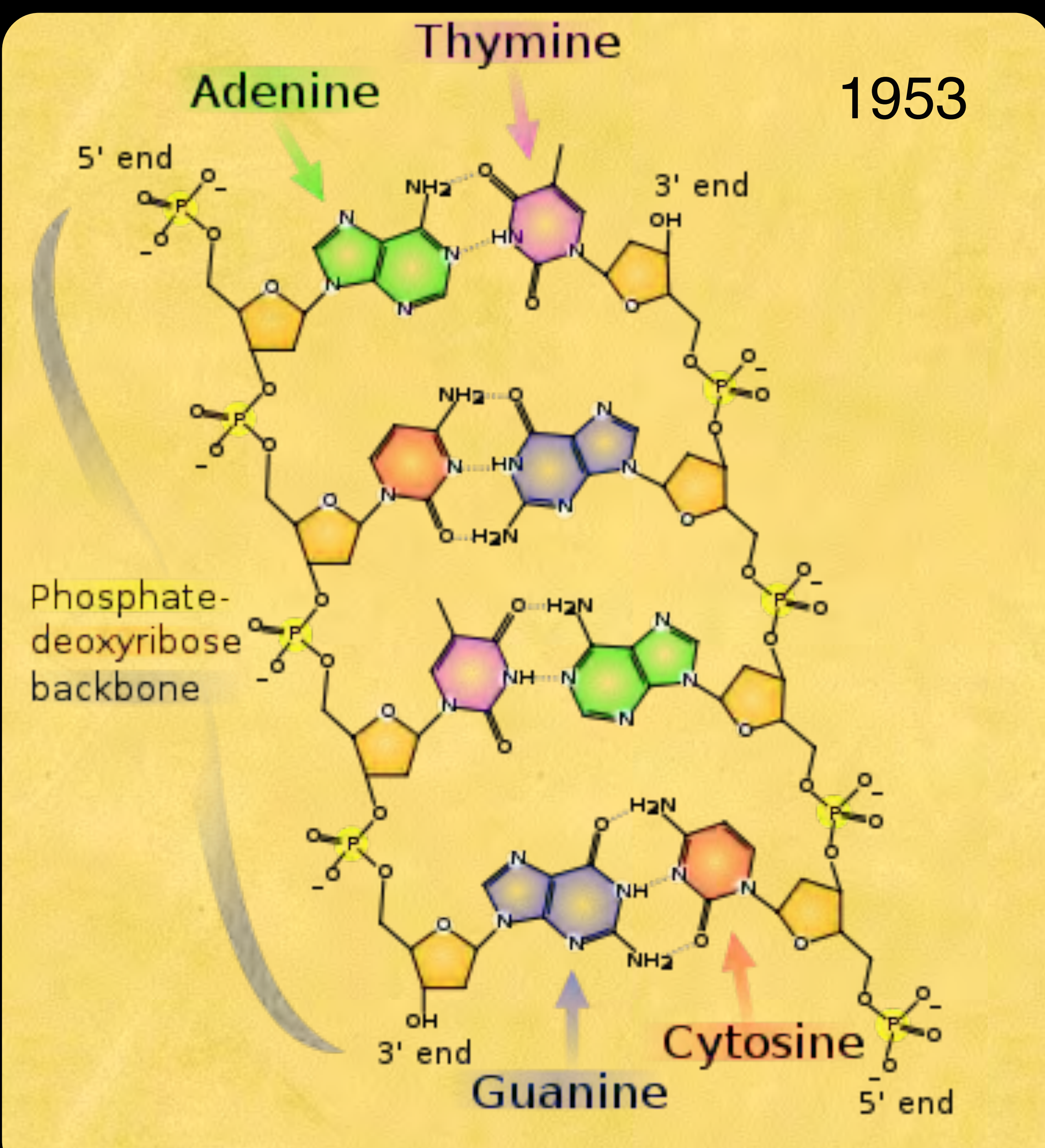
Omnidirectional

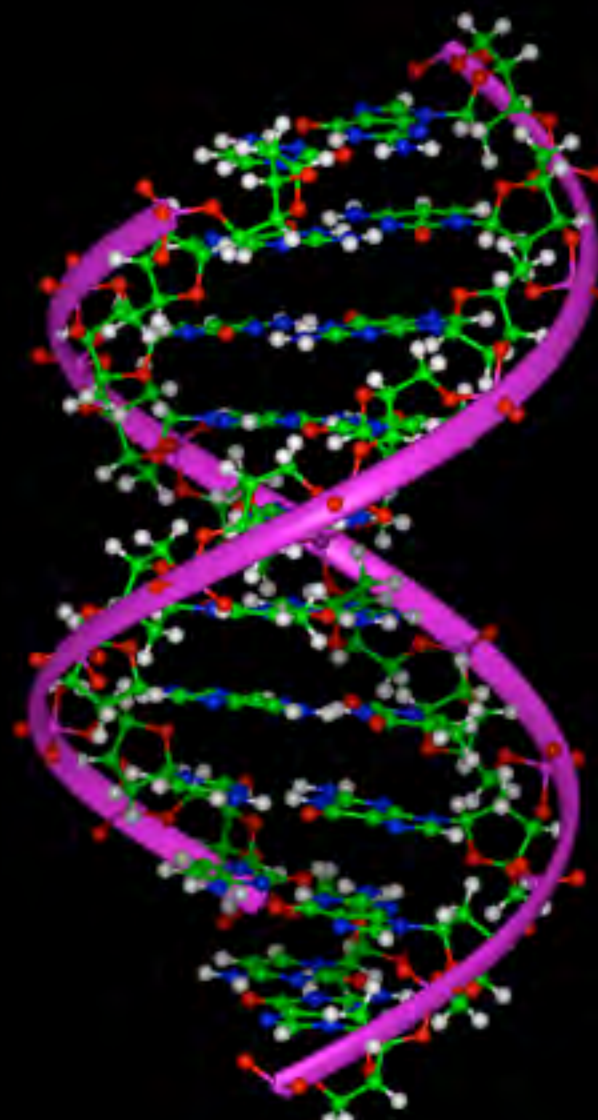
Low Energy Requirement

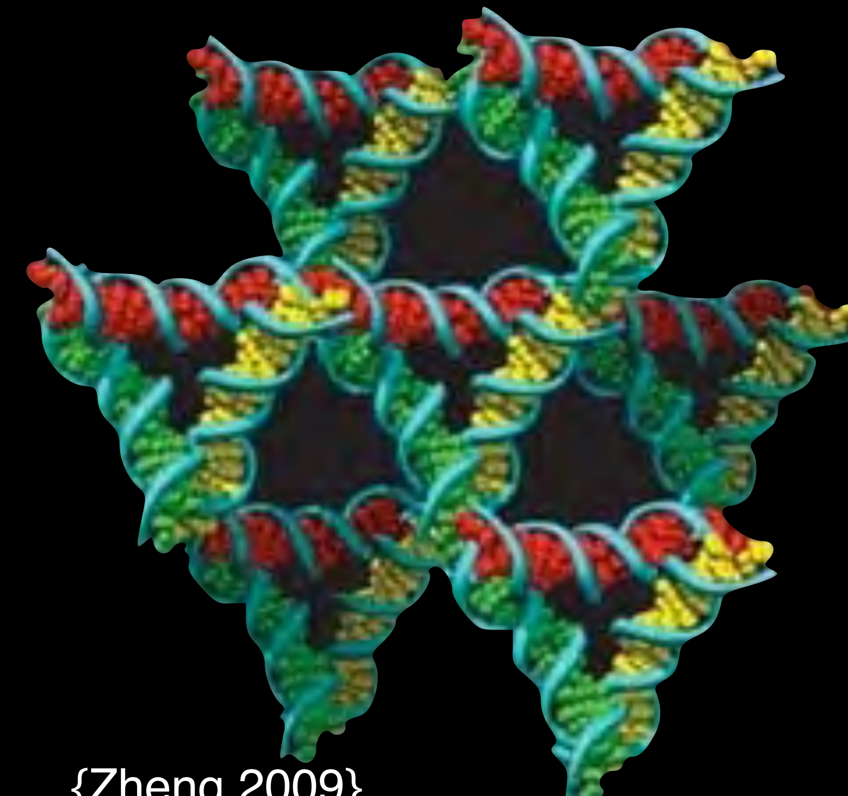
Stable with Flexible Joints

Biology is All About Structure

Organic Chemistry is Structural



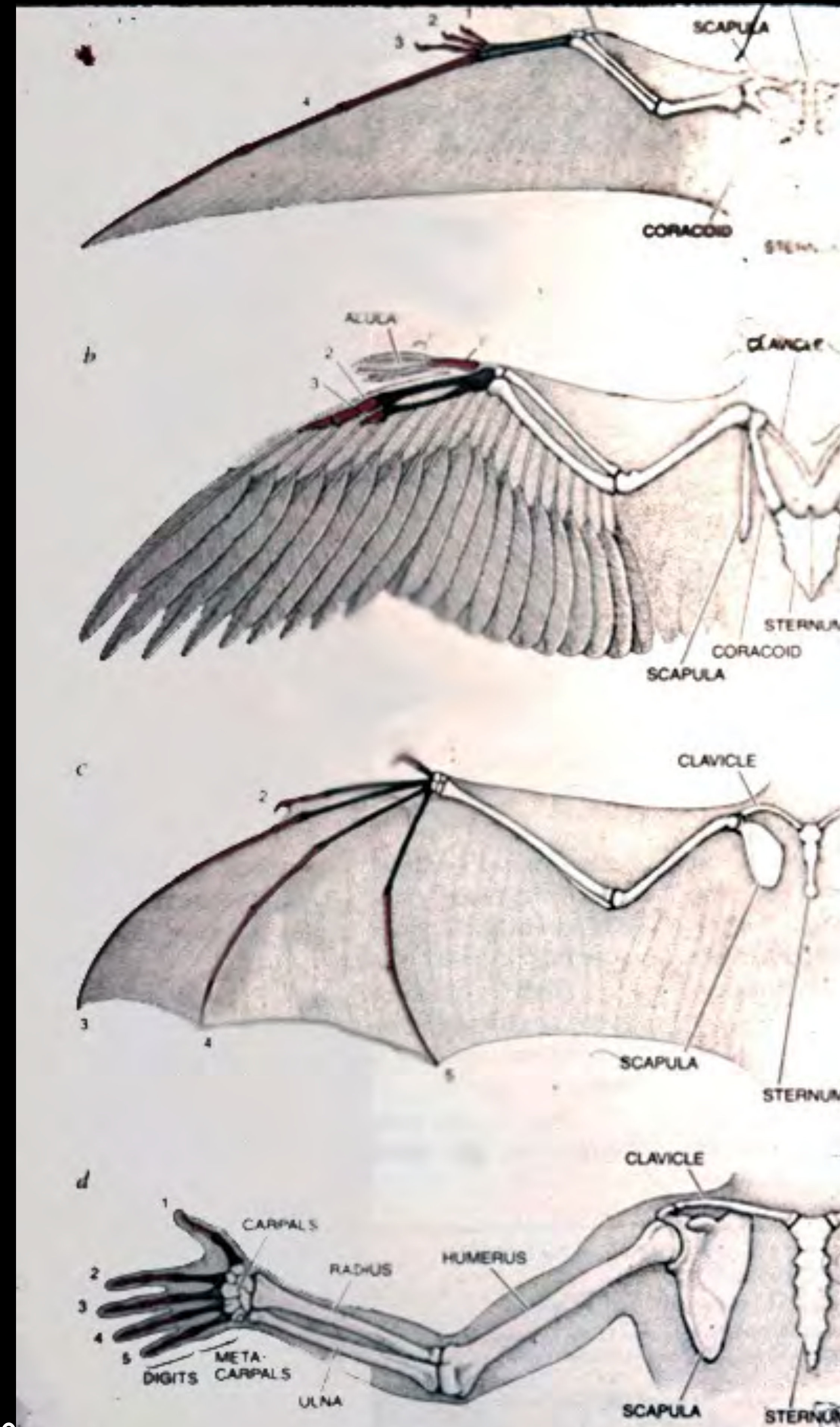




{Zheng 2009}

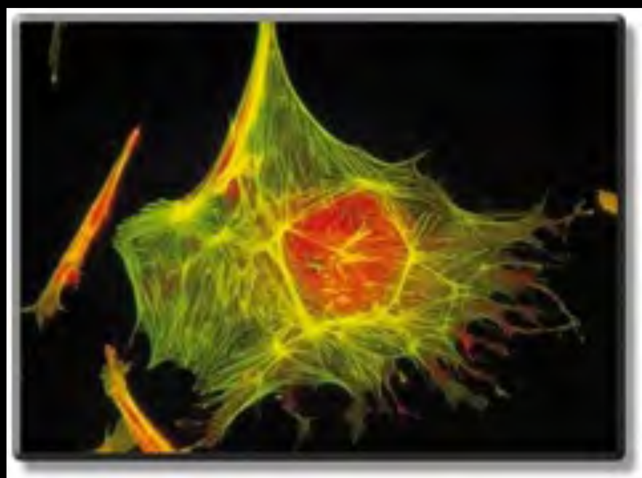
EVOLUTION OF STRUCTURE

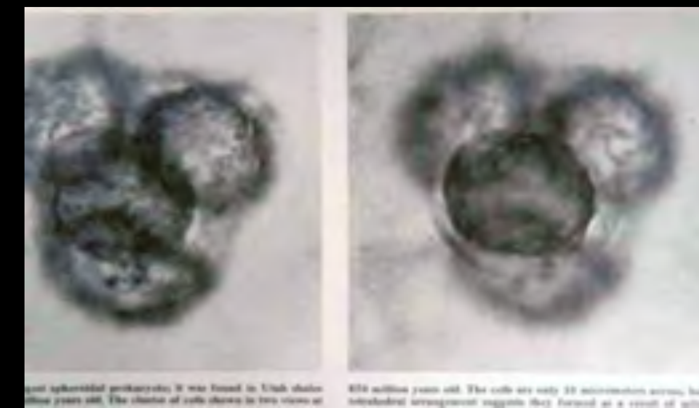
Is there a structural system that is consistent with evolution?

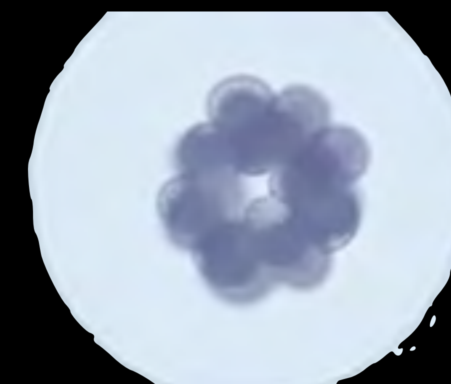


Homologous Structures

Structurally Related







Evolution of Structure

Self Organizing

Hierarchical

(On-site construction)

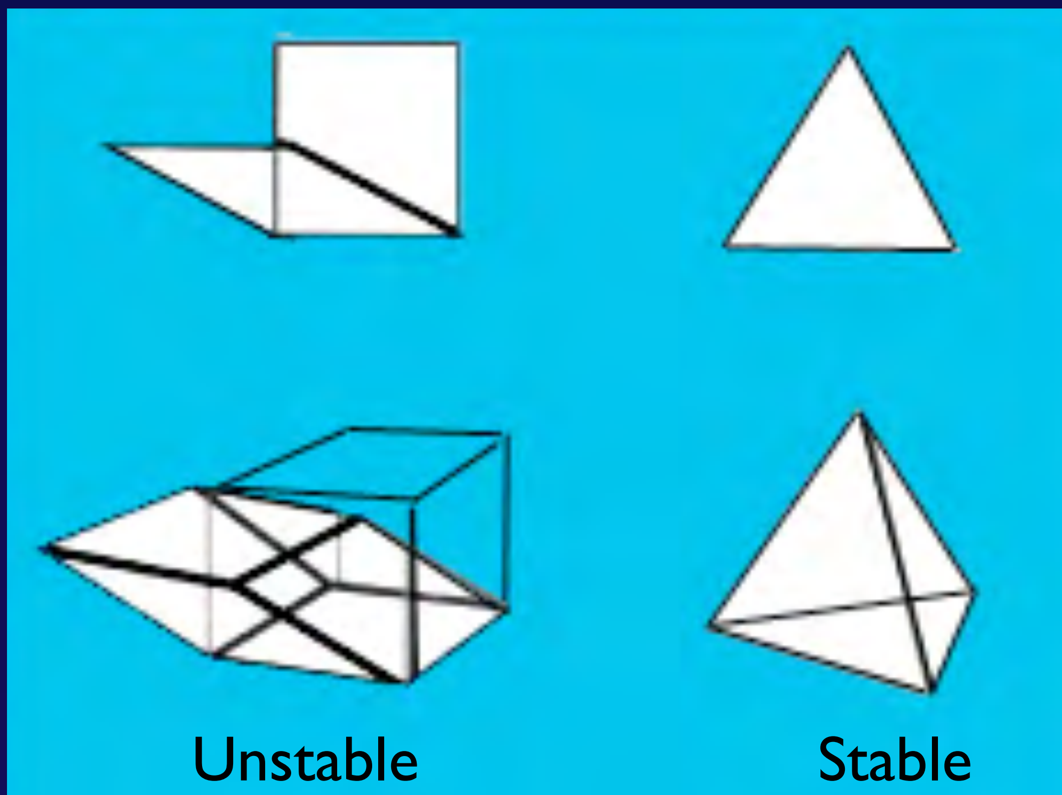
structural continuum

Stable with Flexible Joints

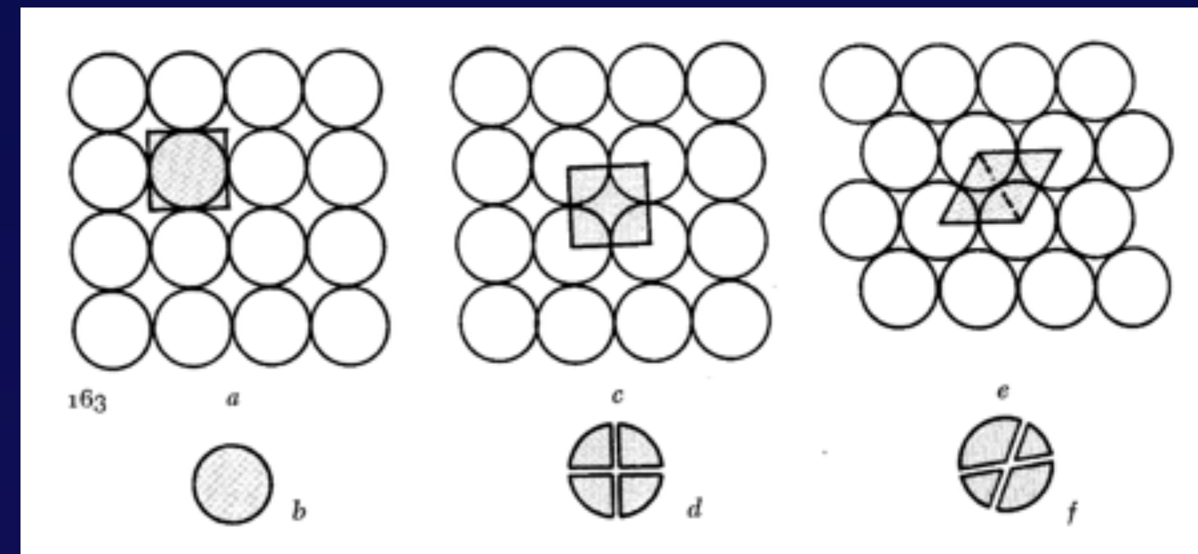
Omnidirectional

Energy Efficient

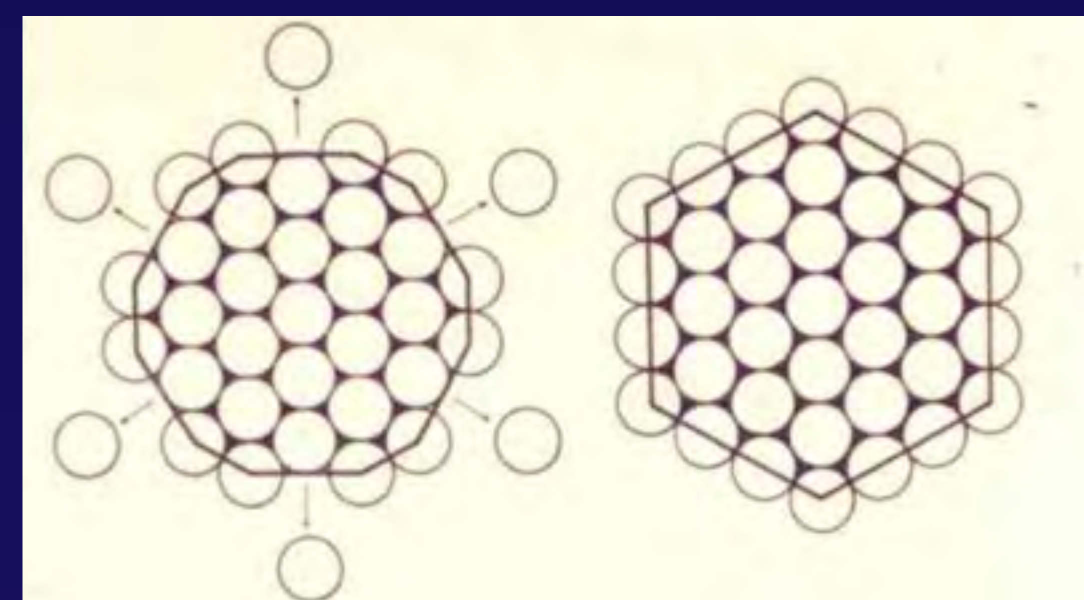
Construction Rules: How to Build an Organism



Triangulation/Truss



Closest Packing



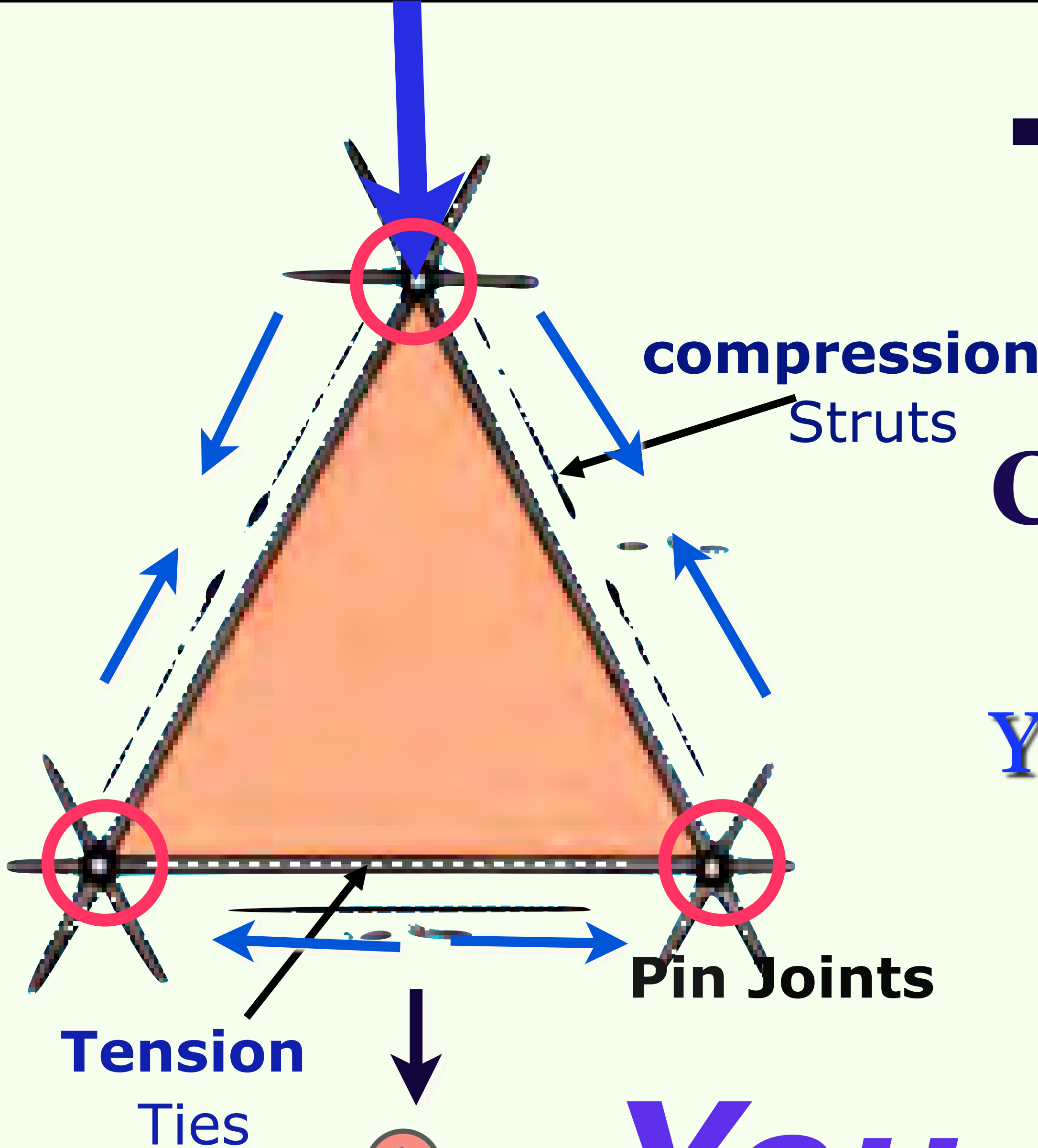
DETERMINISTIC

Obedience to set rules of structure

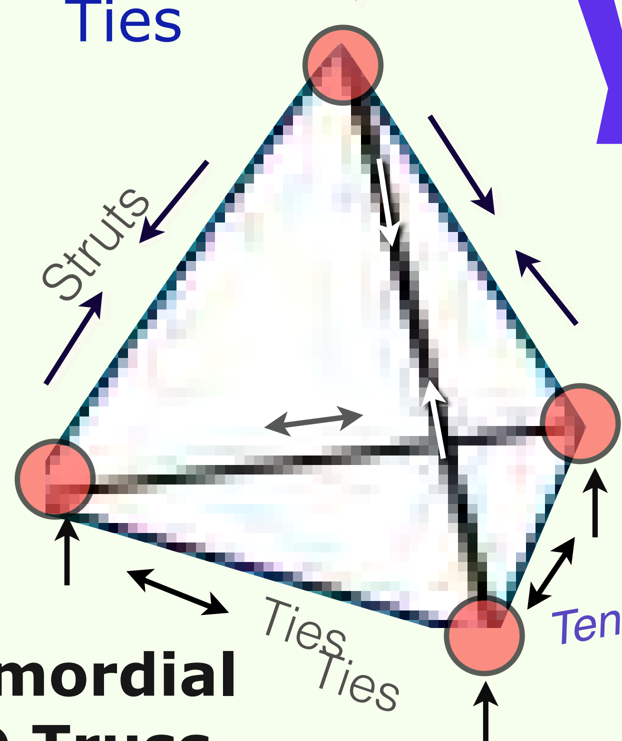
Trusses

Common Sense:
and Rules of Logic

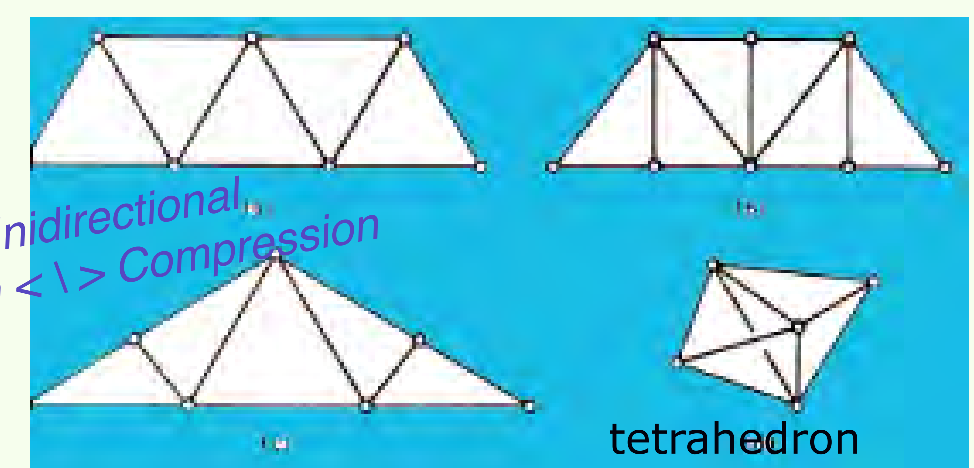
You have flexible joints and can stand up



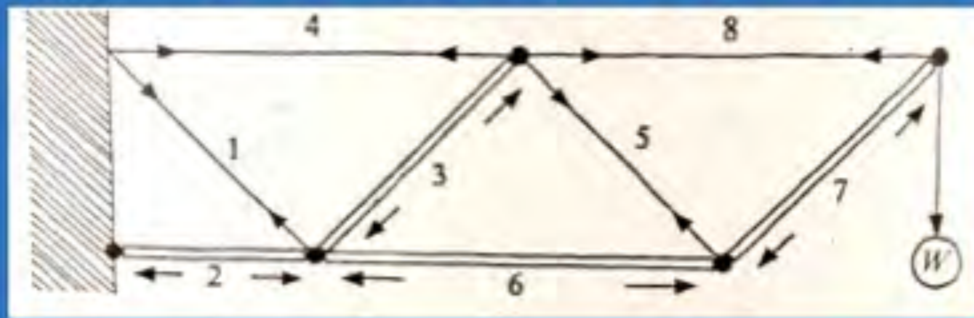
You Are a Truss!

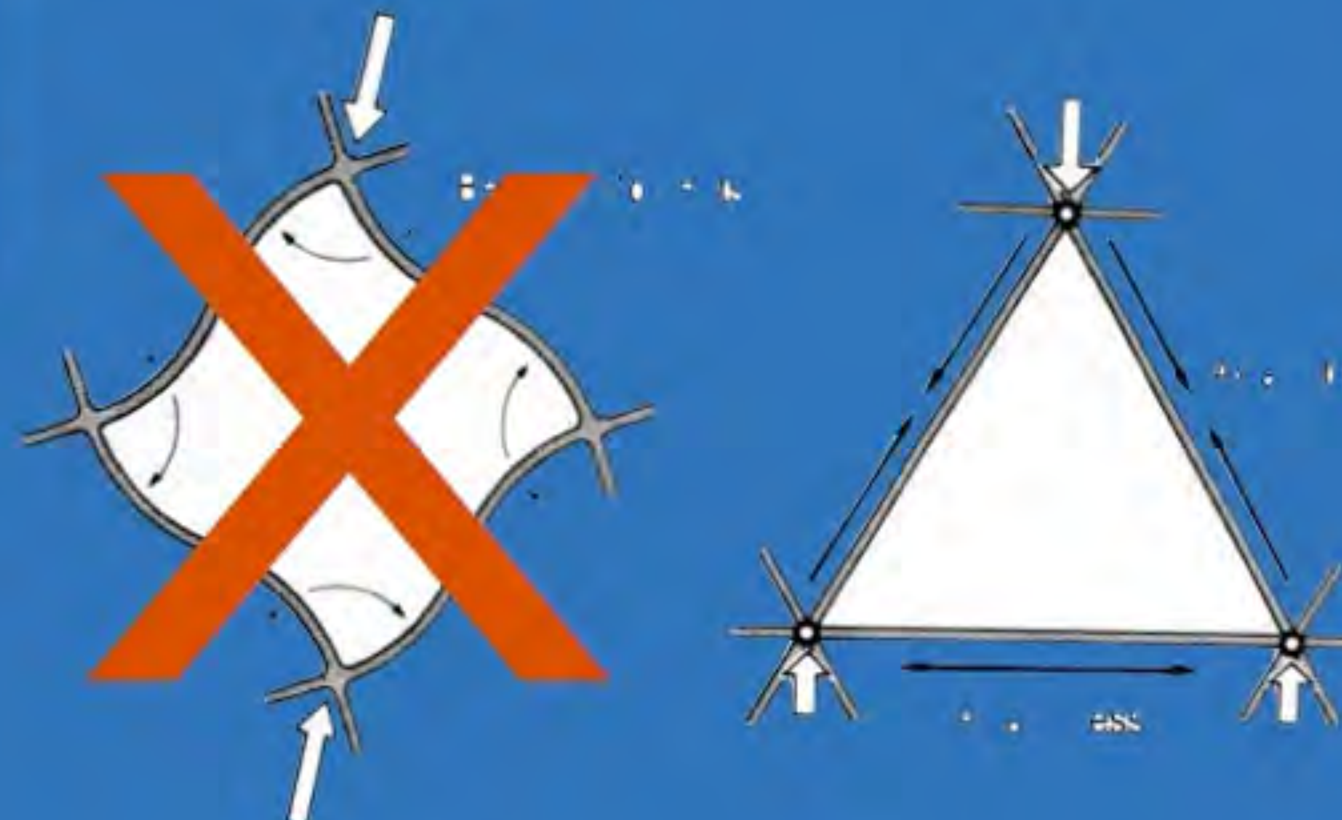


Primordial 3D Truss



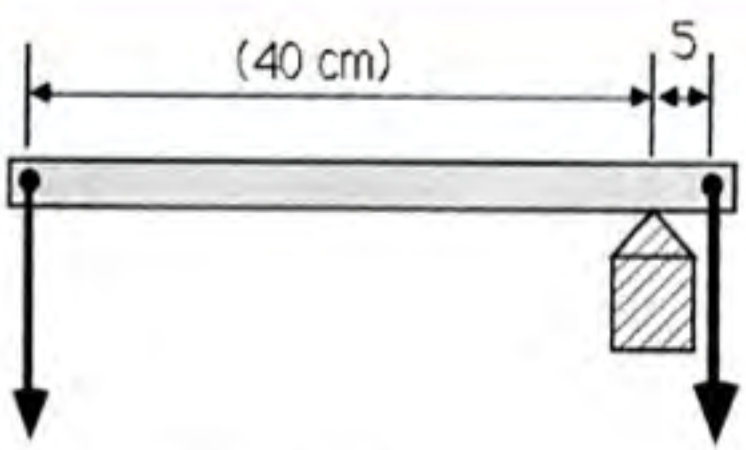
Trusses

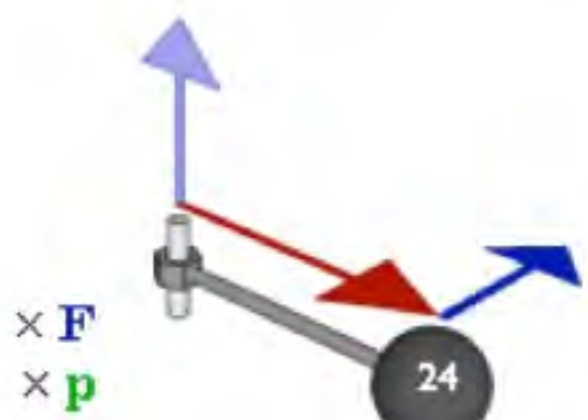


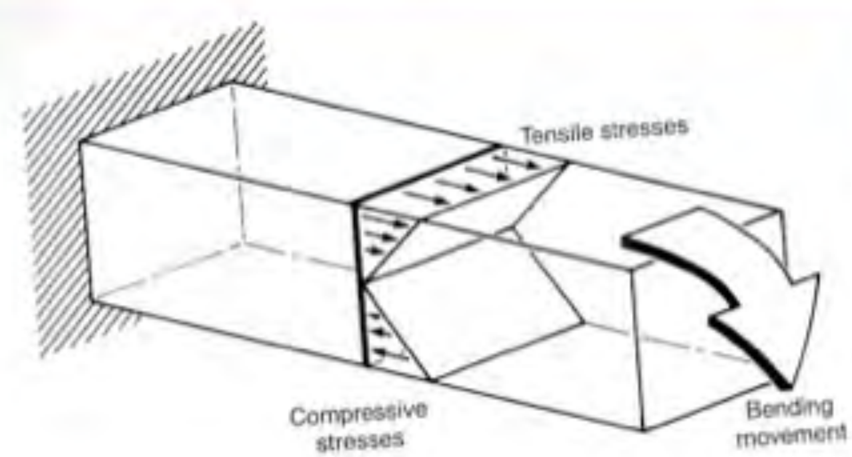


NO

~~Levers~~ ~~Torque~~ ~~Shear~~ ~~Bending Moments~~

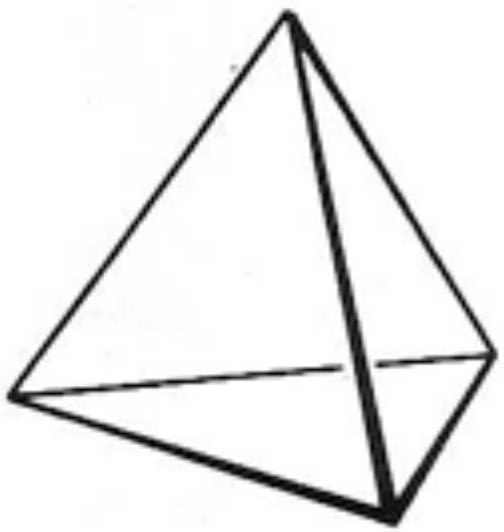






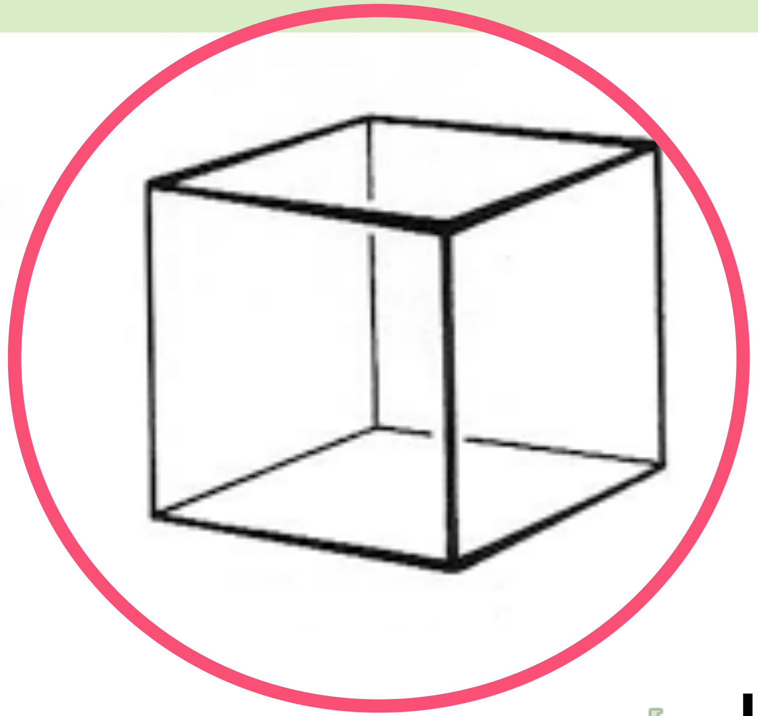
Pick a Truss

Regular Solids (Polyhedra)



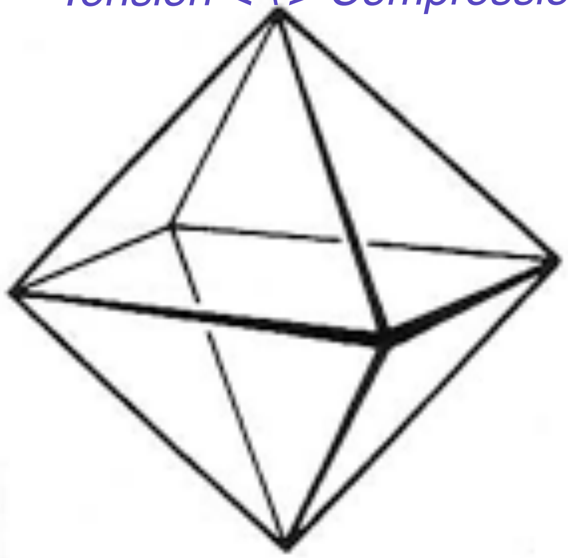
Tetrahedron

Unidirectional
Tension < \ > Compression



Hexa

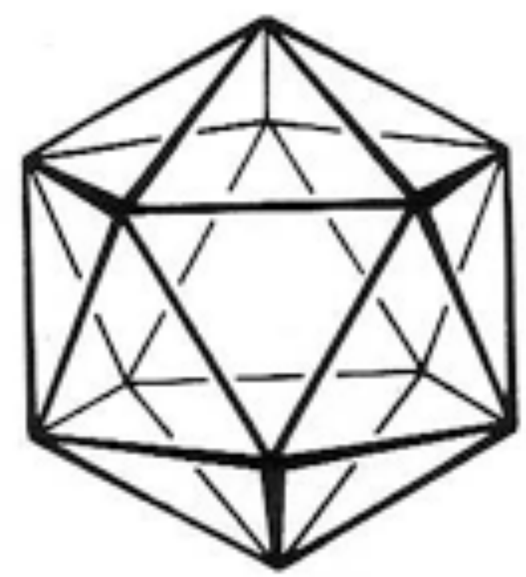
- **(Unstable)**



Unidirectional
Tension < \ > Compression

Octa

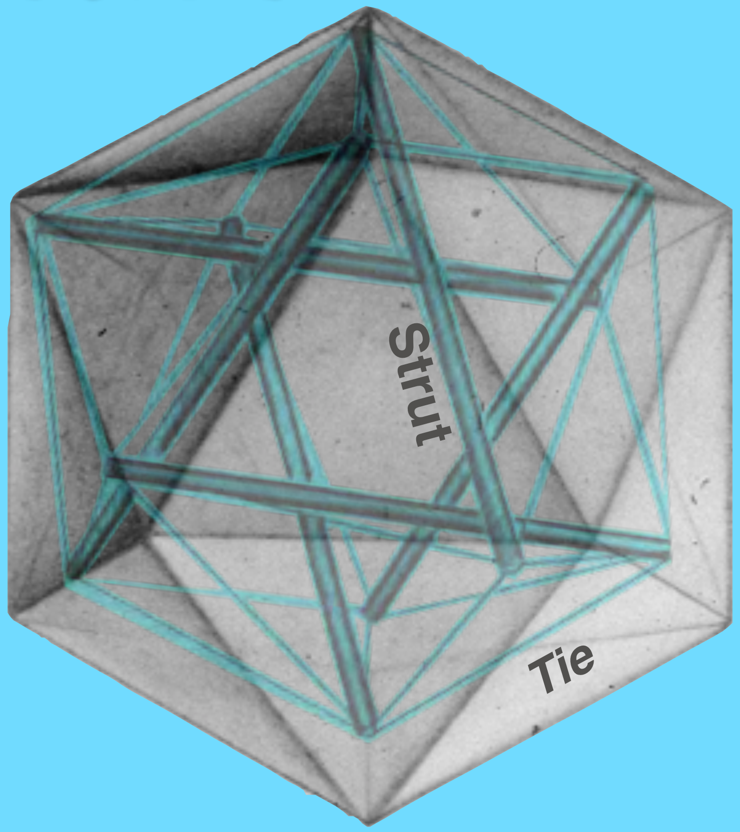
Dodeca



Icosa

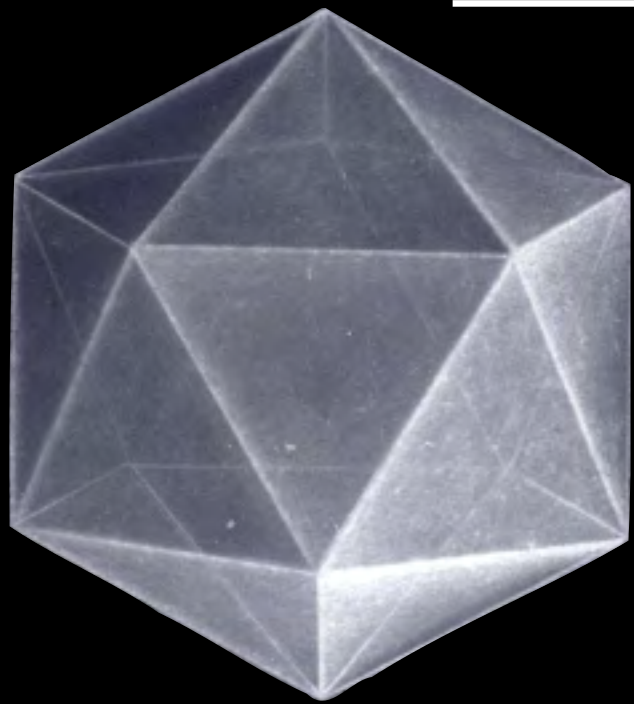
Of the Trusses, The Icosahedron is the Most Suitable Because:

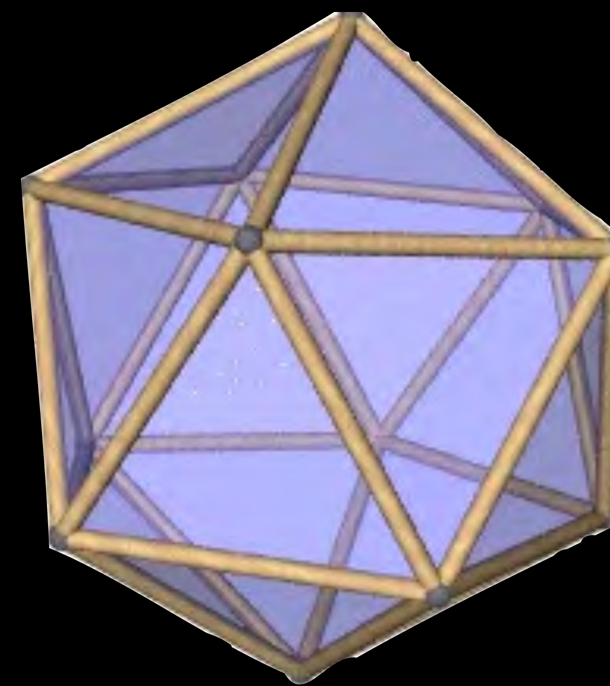
- ☑ Largest Volume for Surface Area
- ☑ Close Packing
- ☑ Exo/Endo Skeletal
- ☑ Omni Directional
- ☑ Hierarchical
- ☑ Nonlinear



Tensegrity

Icosahedron

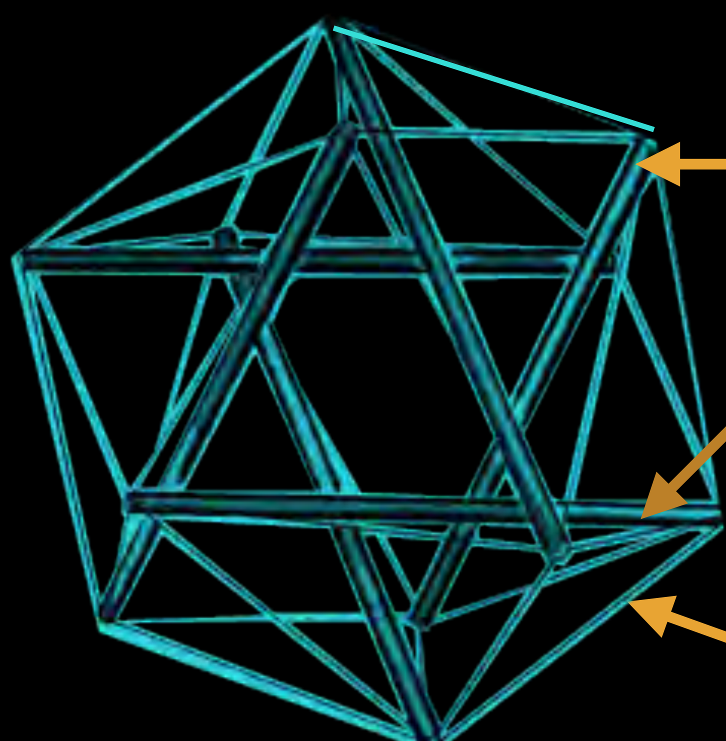




ExoSkeleton

Tensegrity Icosahedron

(Tension Integrity)



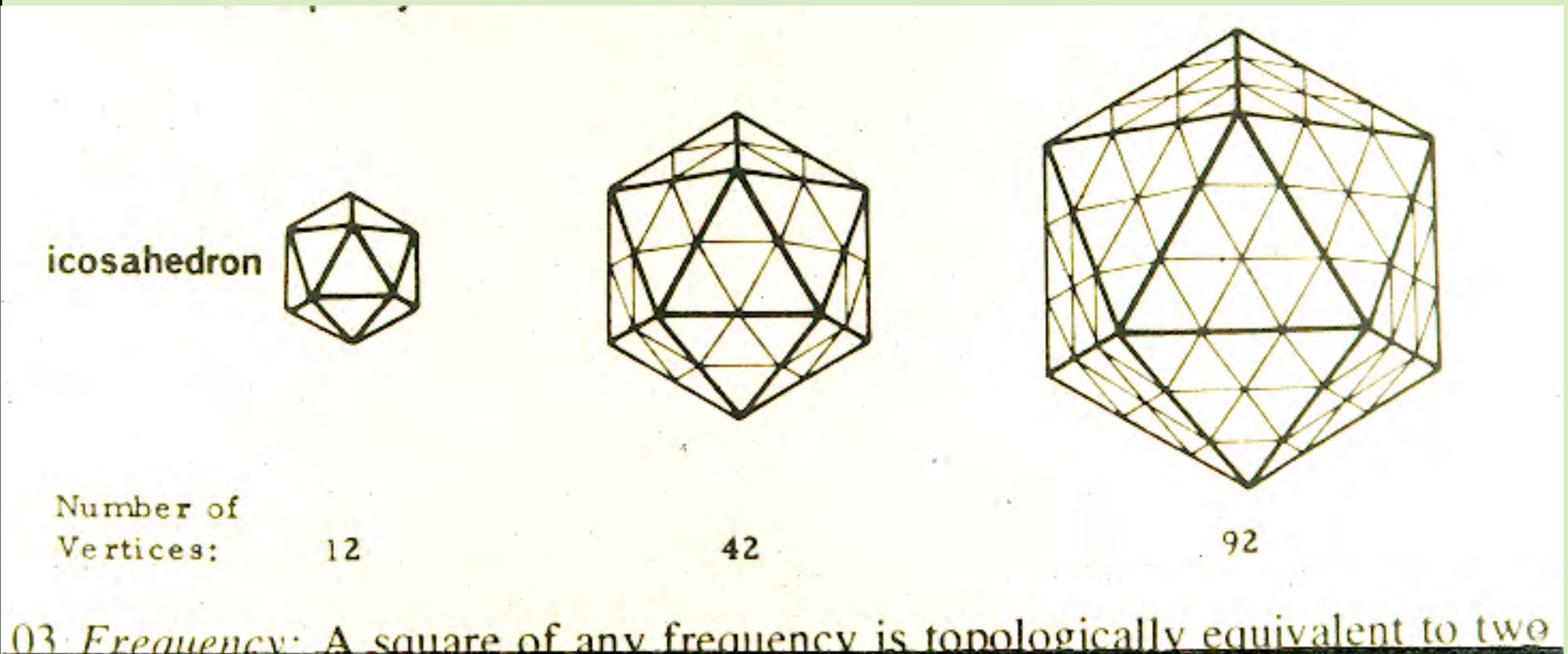
Strut

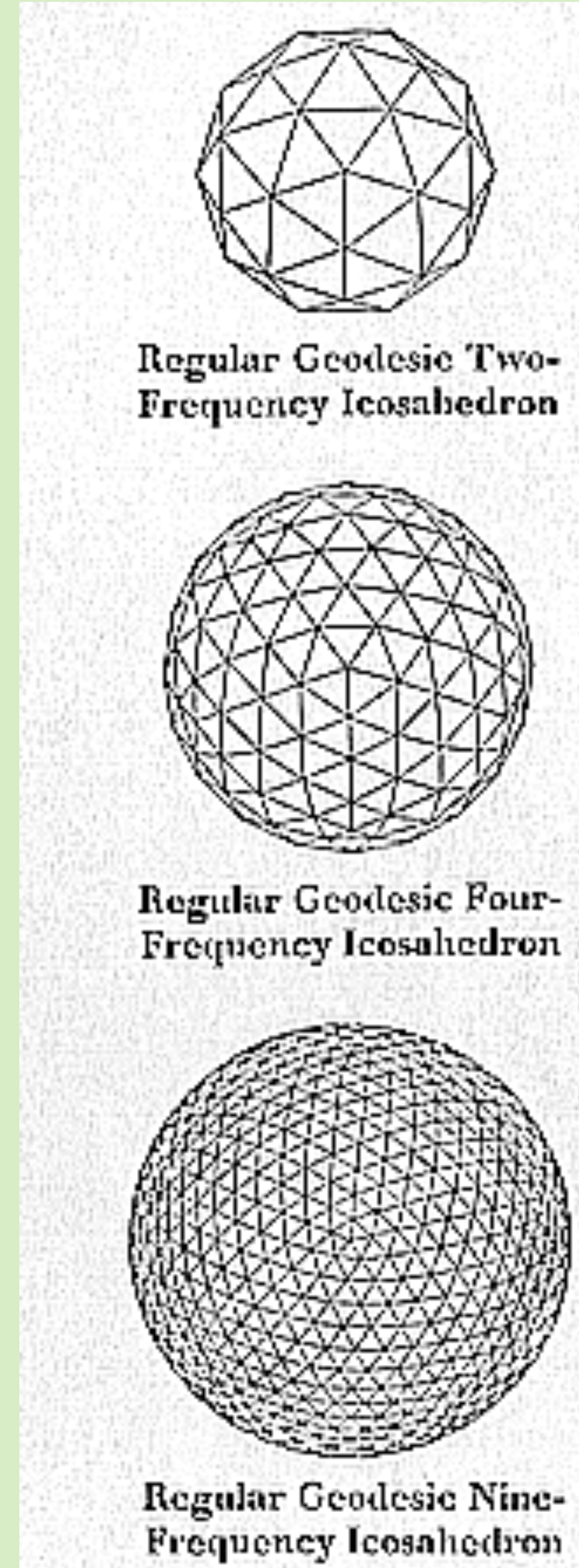
EndoSkeleton

CONTINUOUS TENSION -

Tie DISCONTINUOUS COMPRESSION

"Floating Compression" Snelson

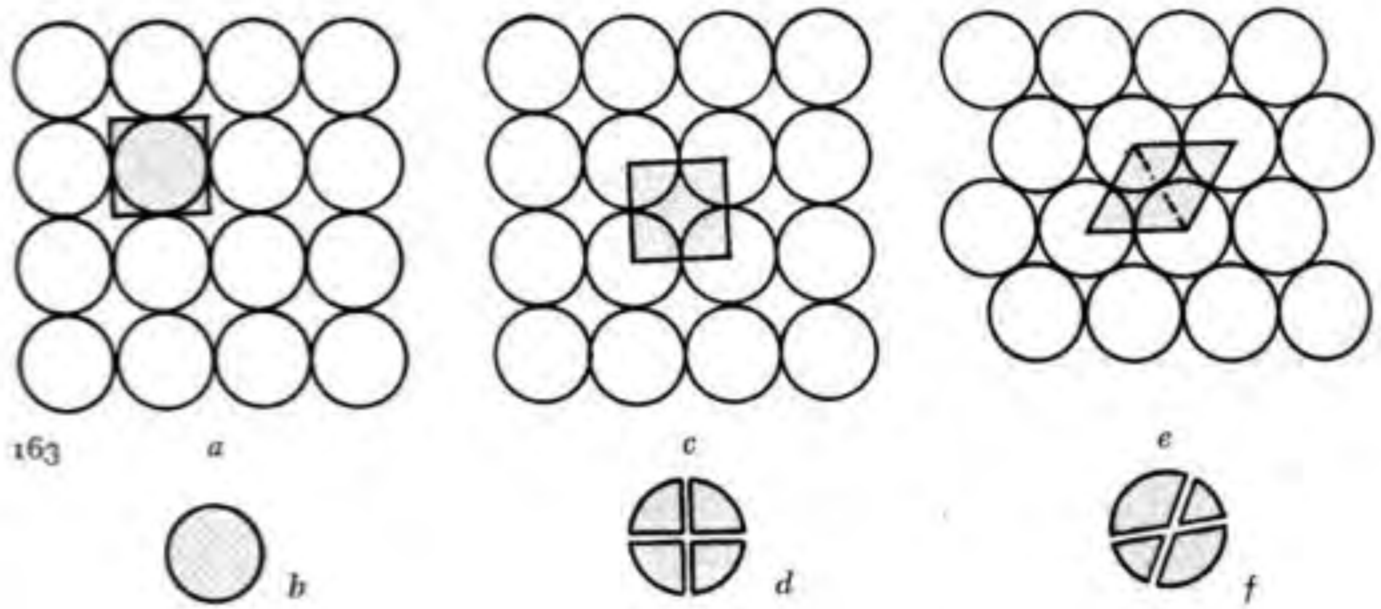




Icosahedral Shells

Kissing #: 12, 32, 42, 92, 122, 132, 162, ...

10T+2



Closest Packing

120^0

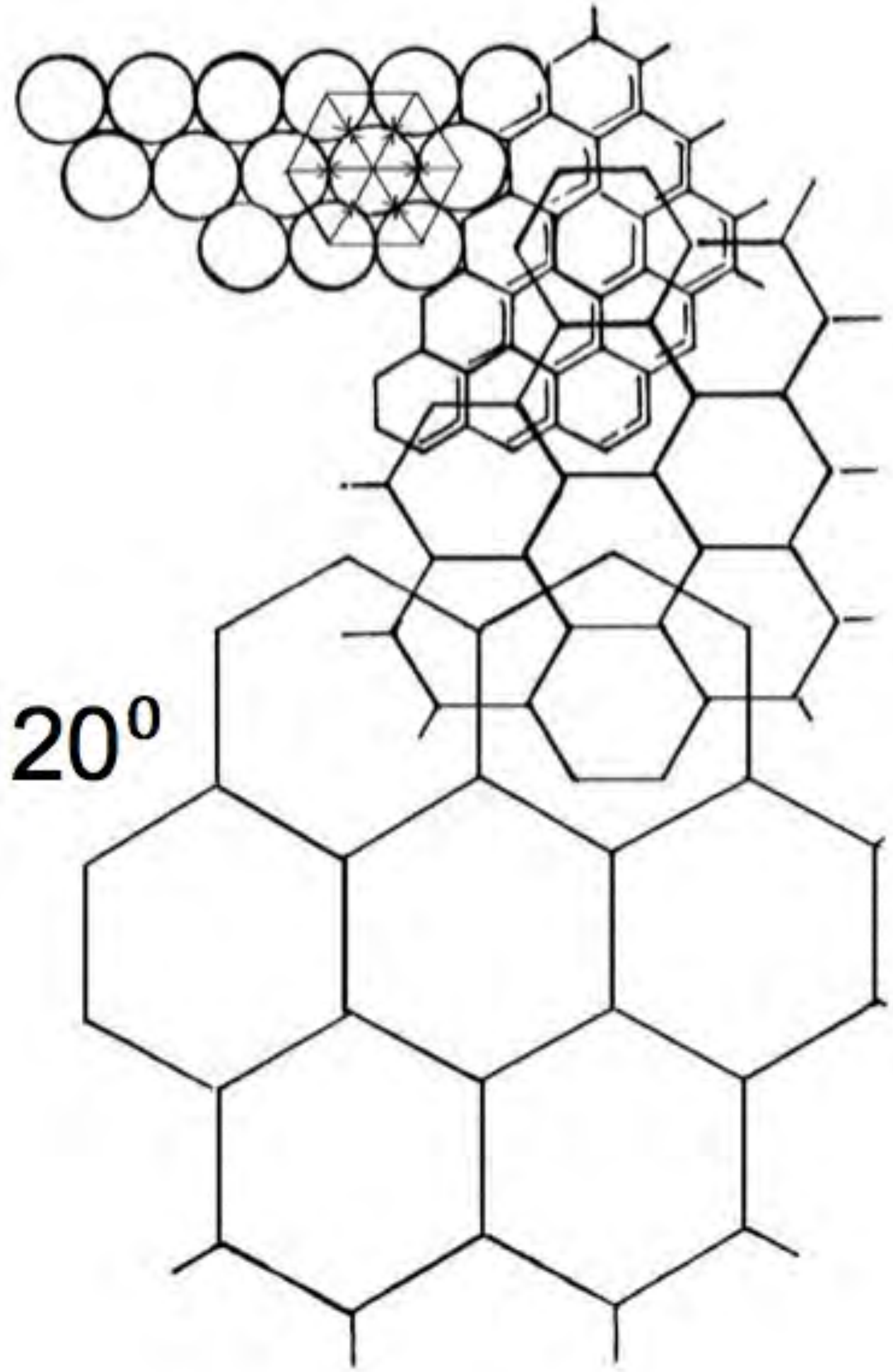
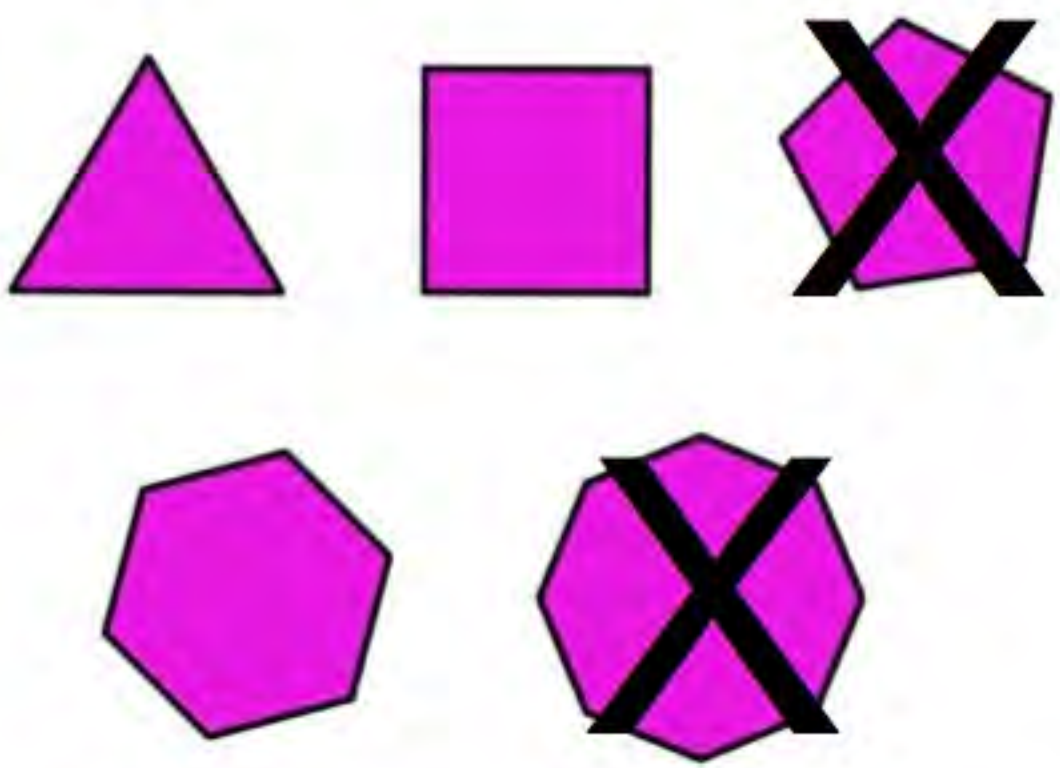
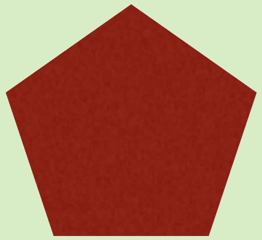
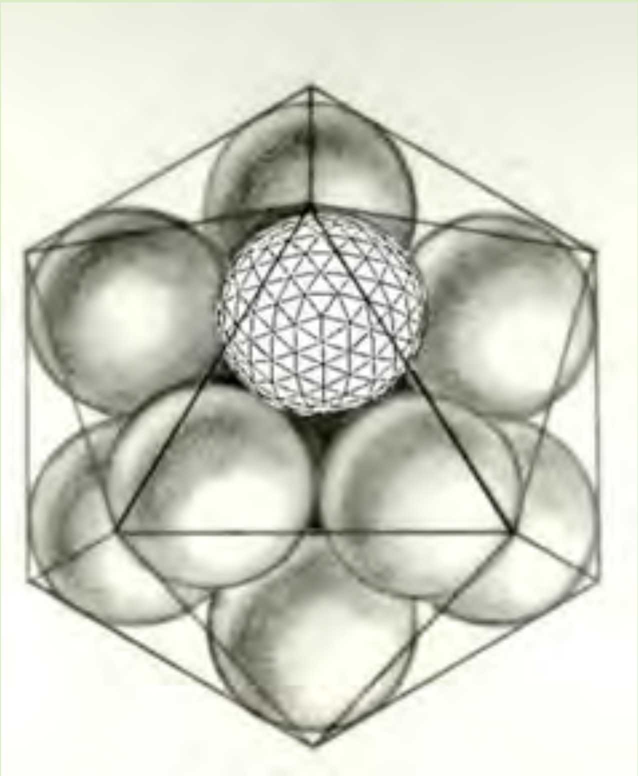


FIGURE 1
HIERARCHICAL CLOSE-PACKING —
CIRCLES TO HEXAGONS
HEXAGONAL BALANCE OF INTRINSIC
AND EXTRINSIC FORCES

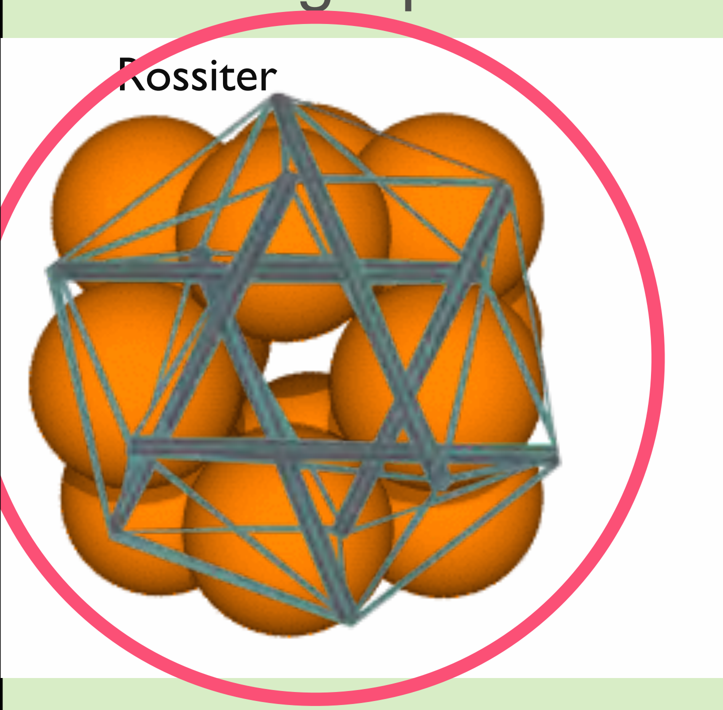


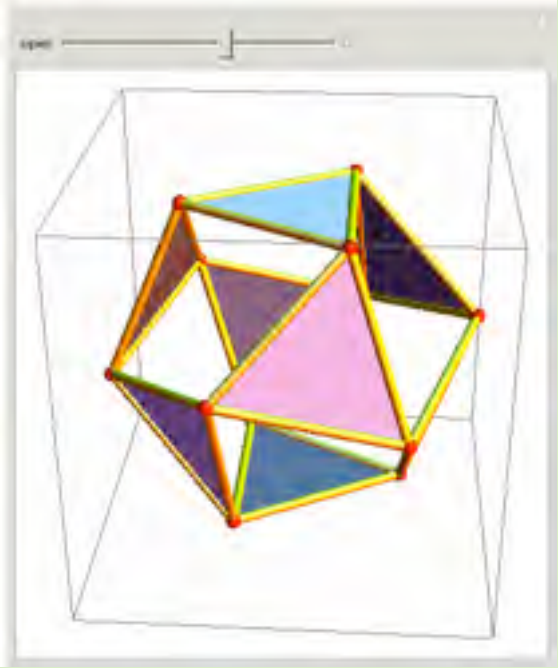
3-D Close Packing



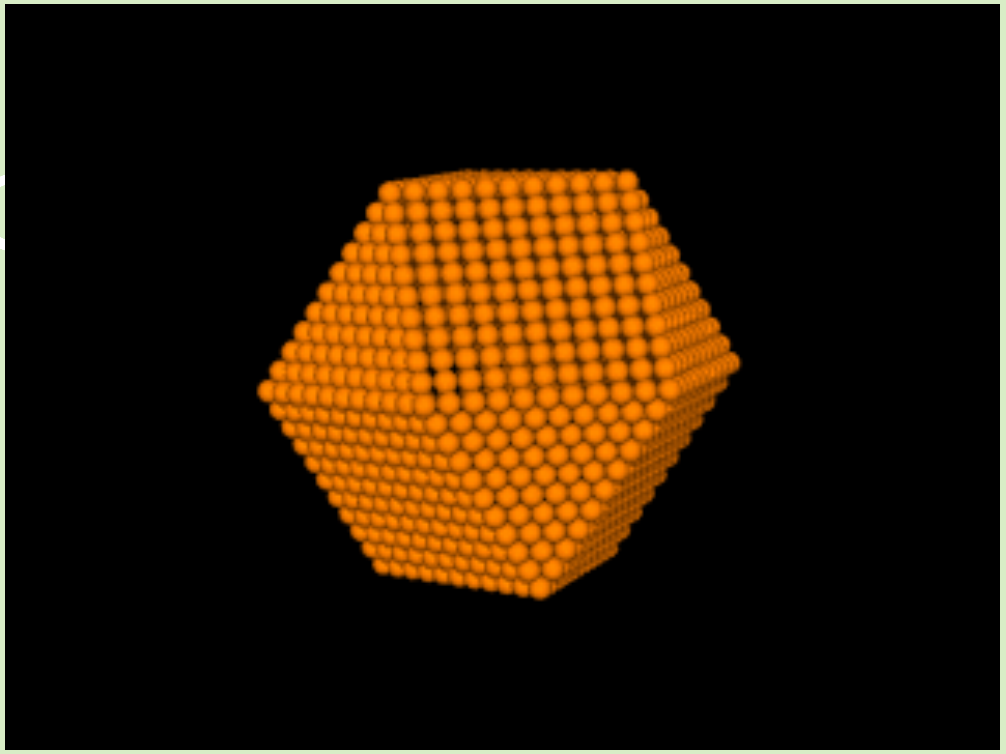


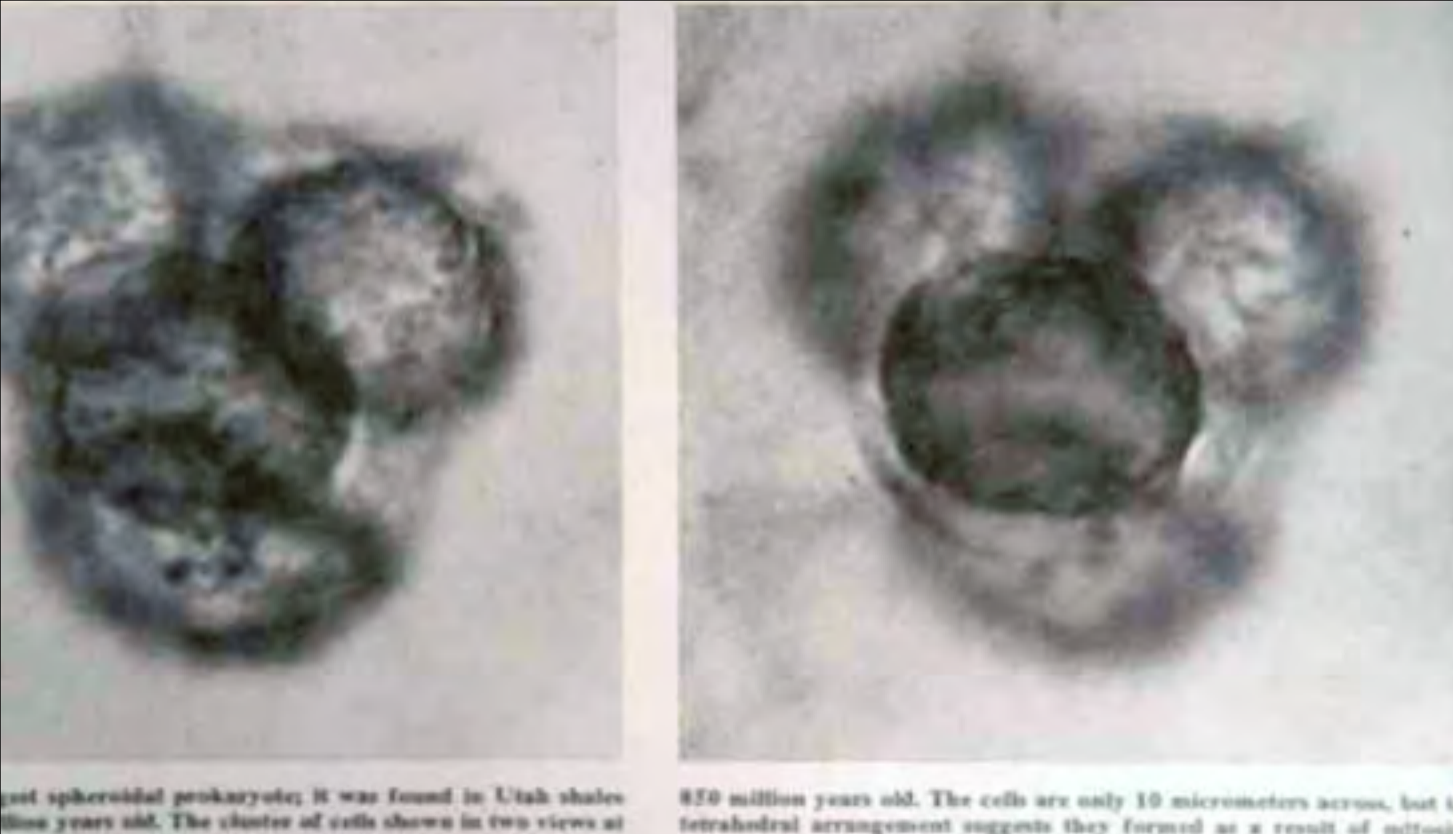
Kissing Spheres





Cuboctahedron ⟷ Icosahedron

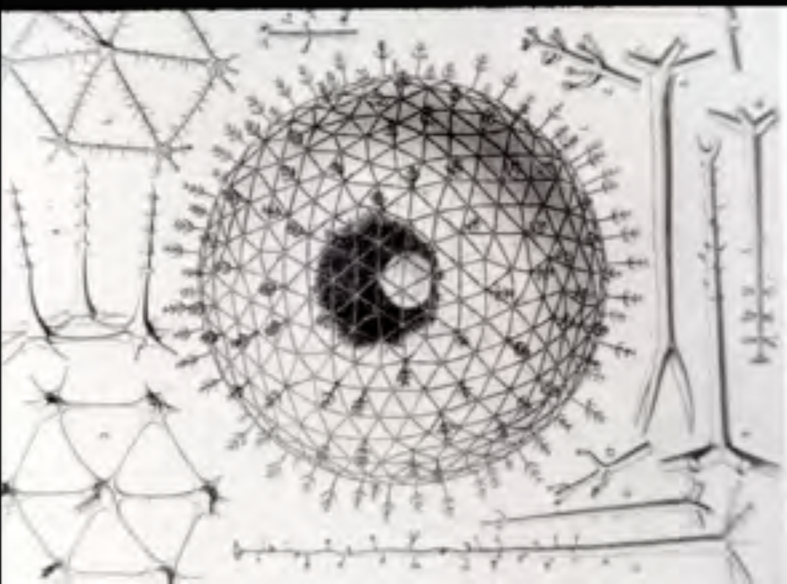




800 million yo cells
10μ
Tetrahedral

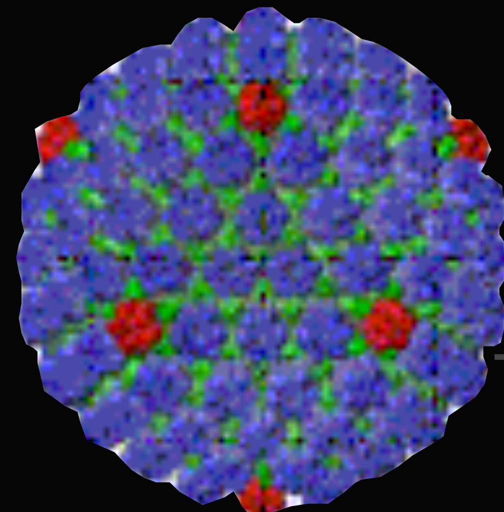
SELF ORGANIZATION

700 million yo fossilized Cell Colony

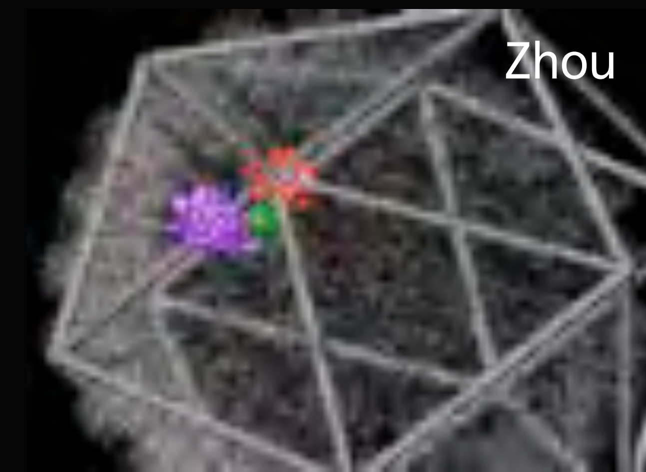


Radiolaria

Polio Virus

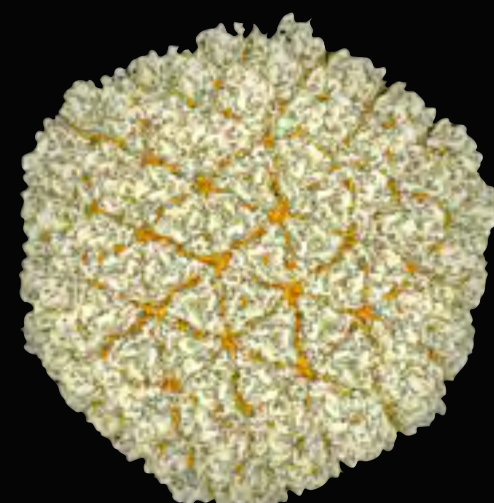


Mold

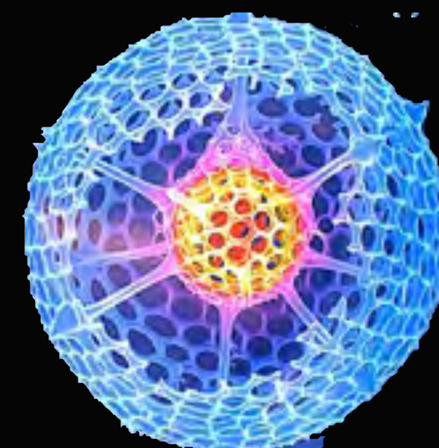


Pyruvate dehydrogenase

Dandelion



Rice Dwarf Virus

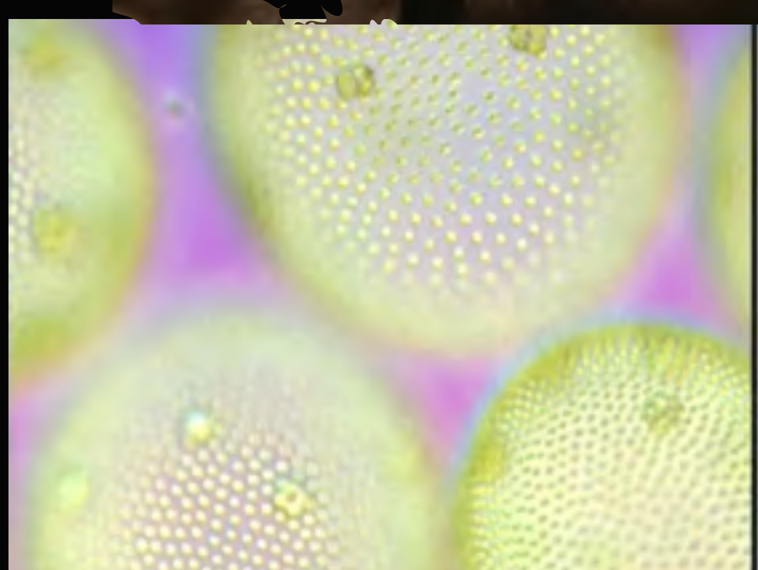


Radiolaria

HIV

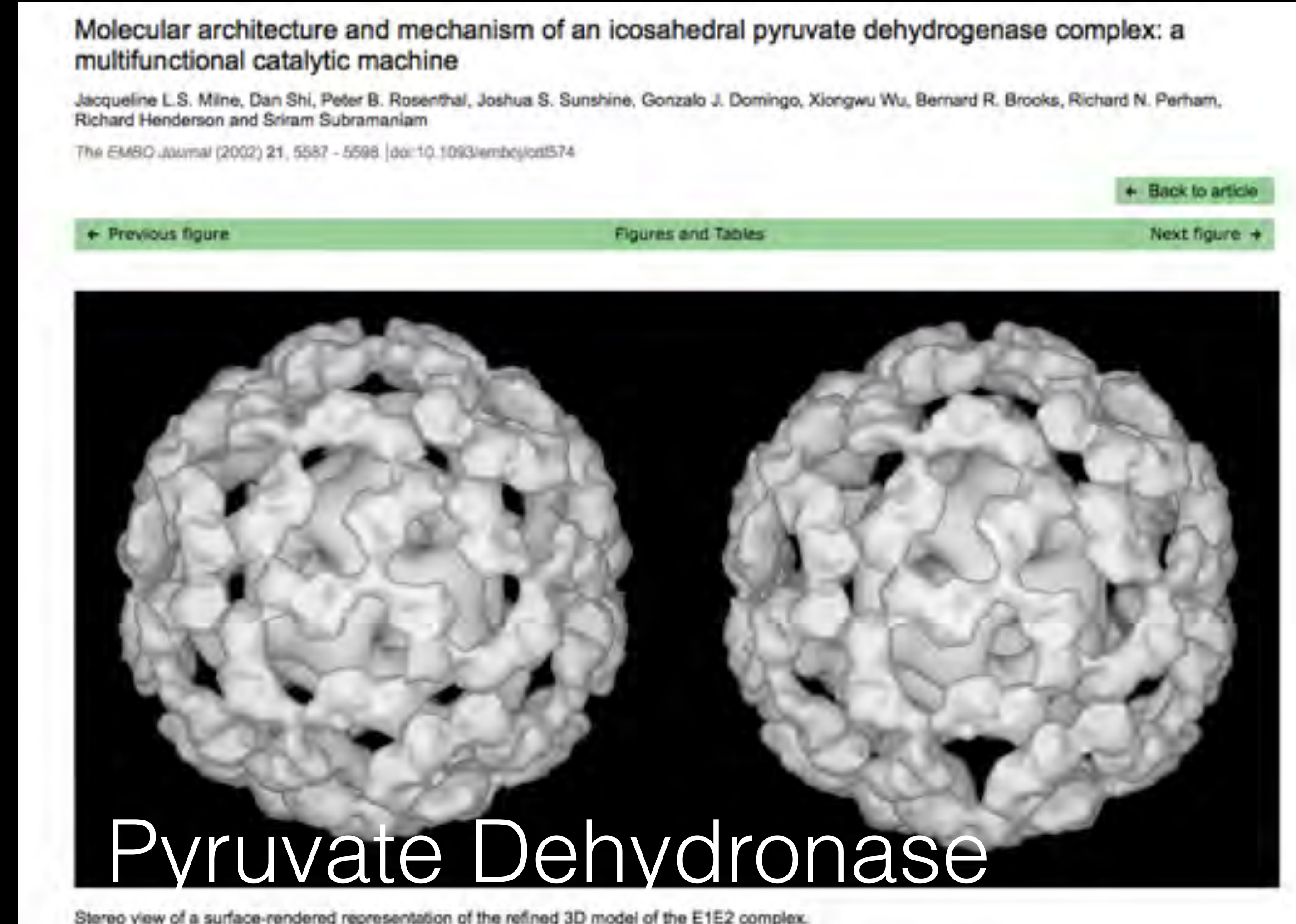
Pufferfish

Tyco Supernova



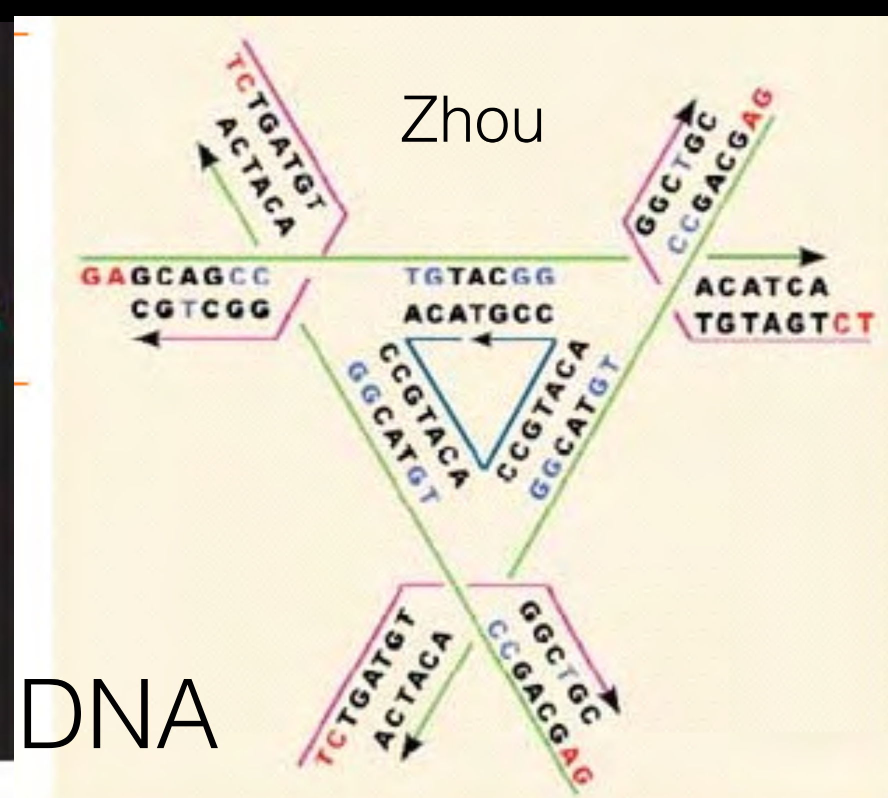
Volvox

Raspberry



The tensegrity triangles self-assemble to form 3D lattices

© Nature

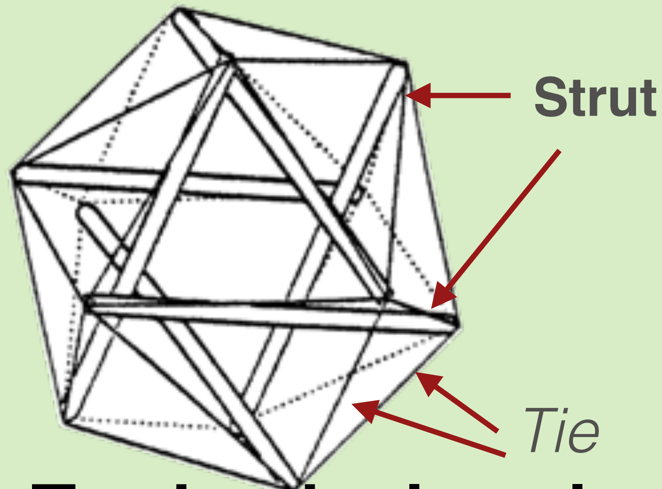


The tensegrity triangles are made up of three DNA helices

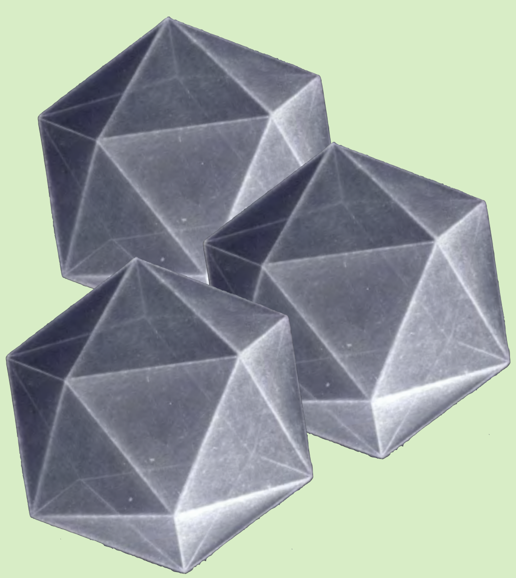
© Nature

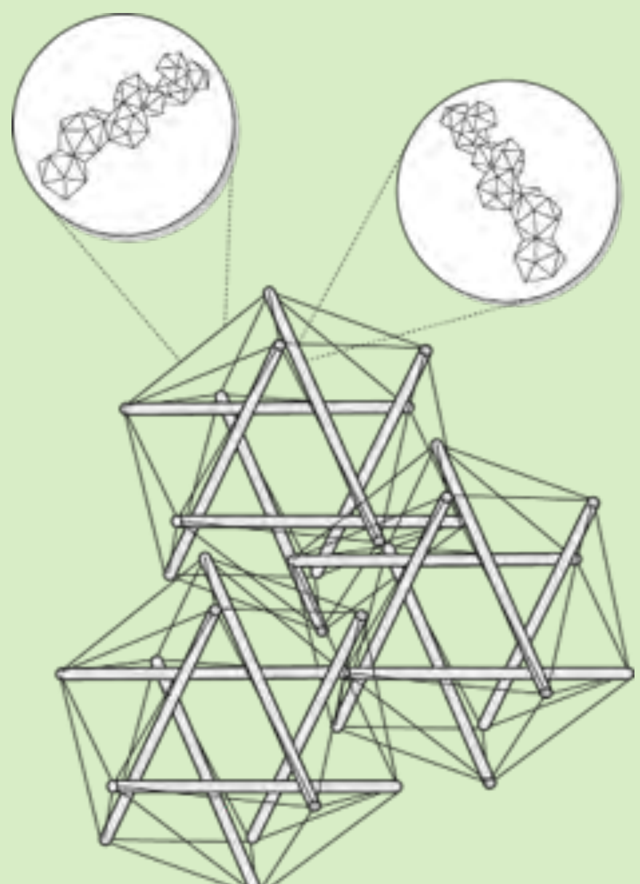
Tensegrity

Tension Integrity



Endoskeletal

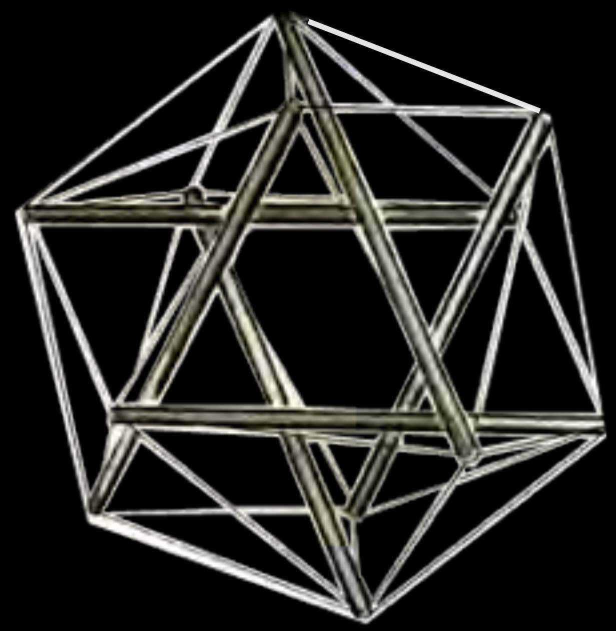




Hierarchy

properties of tensegrity icosahedron

Self Organizing



Hierarchical

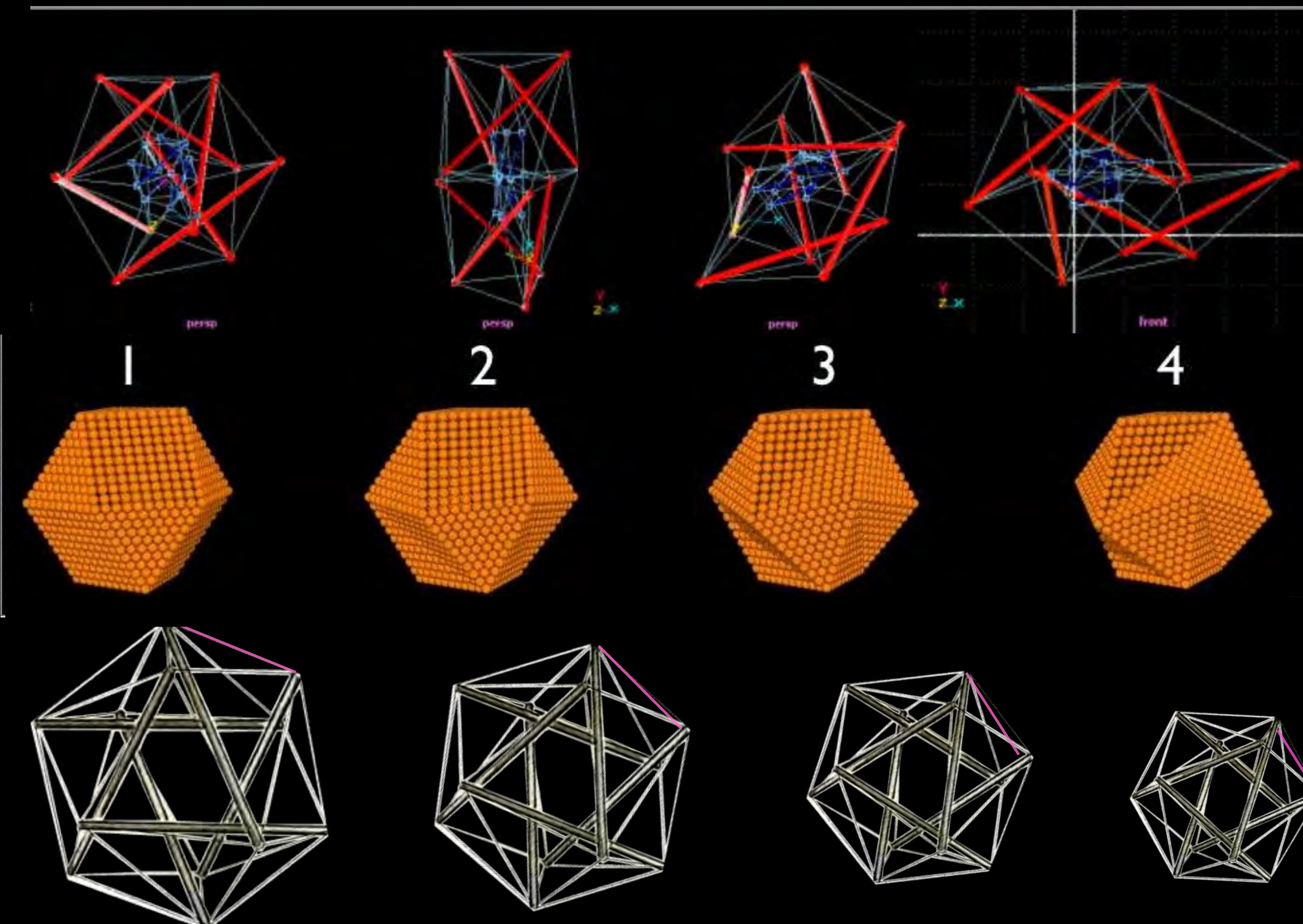
(On-site construction)

structural continuum

Stable with Flexible Joints

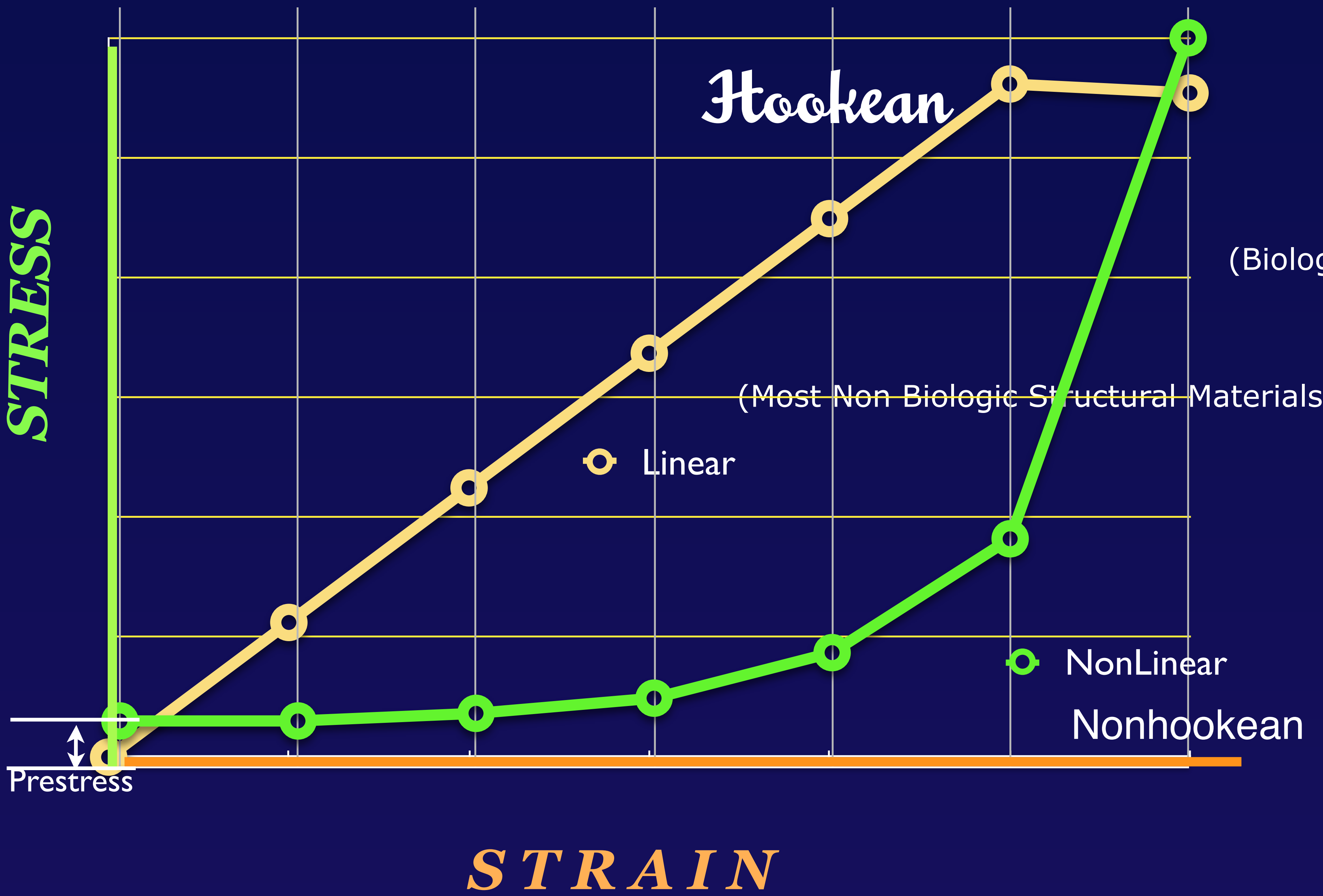
Omnidirectional

Energy Efficient



Denser and Stronger

Energy Efficient



Nonlinear Biomaterials

(Biologic Structures)

Collagen
Fascia
Bone
Cartilage
Muscle
Tendons
Ligaments

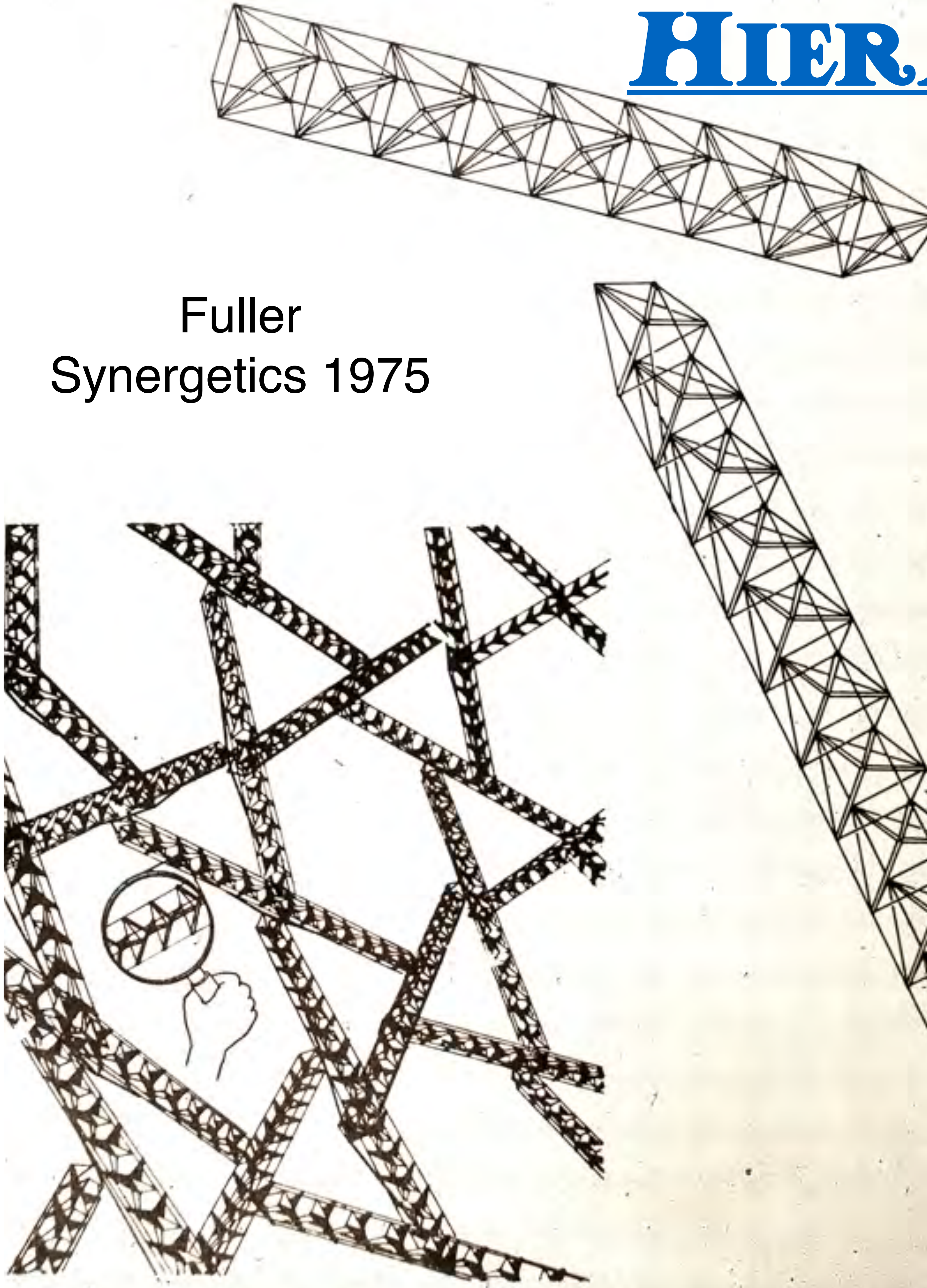
"(Non Linearity) is an essential requirement for the existence of life as we know it"

J.E. Gordon

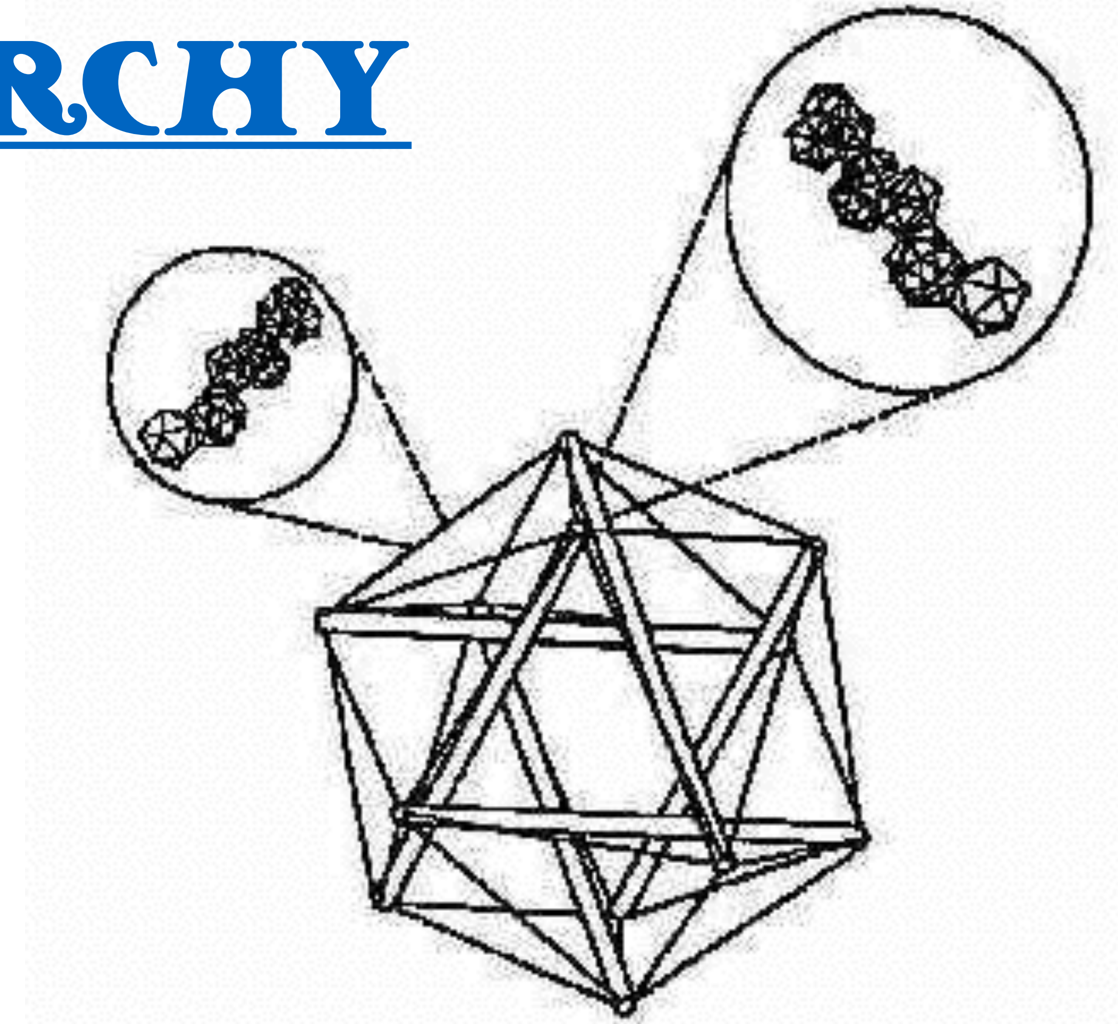
Hookean

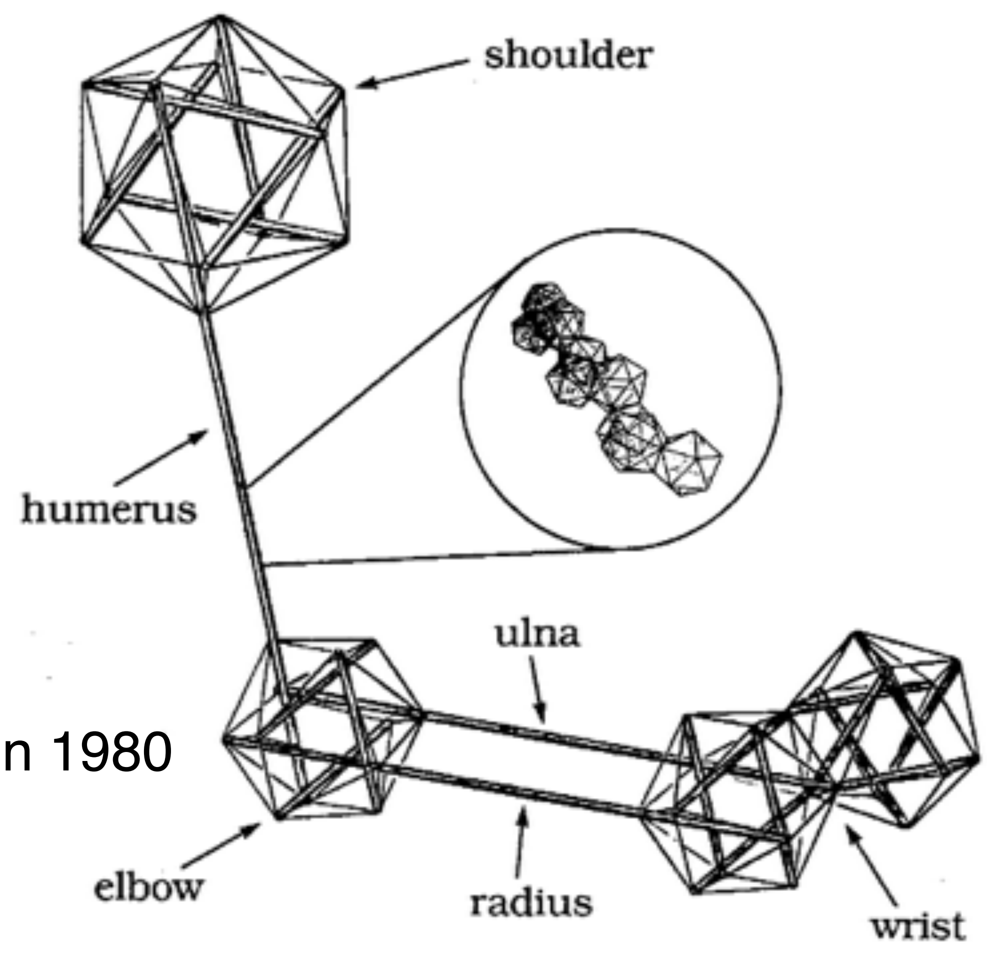
Hierarchy

Fuller
Synergetics 1975

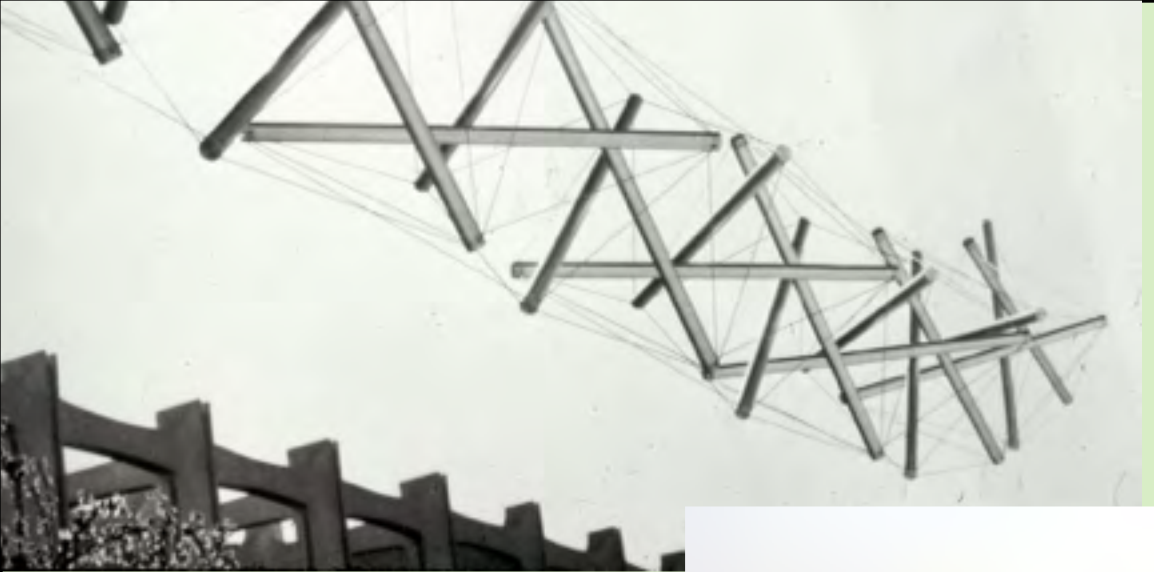


g. 740.21 *Tensegrity Masts as Struts: Miniaturization Approaches Atomic Structur*





Levin 1980



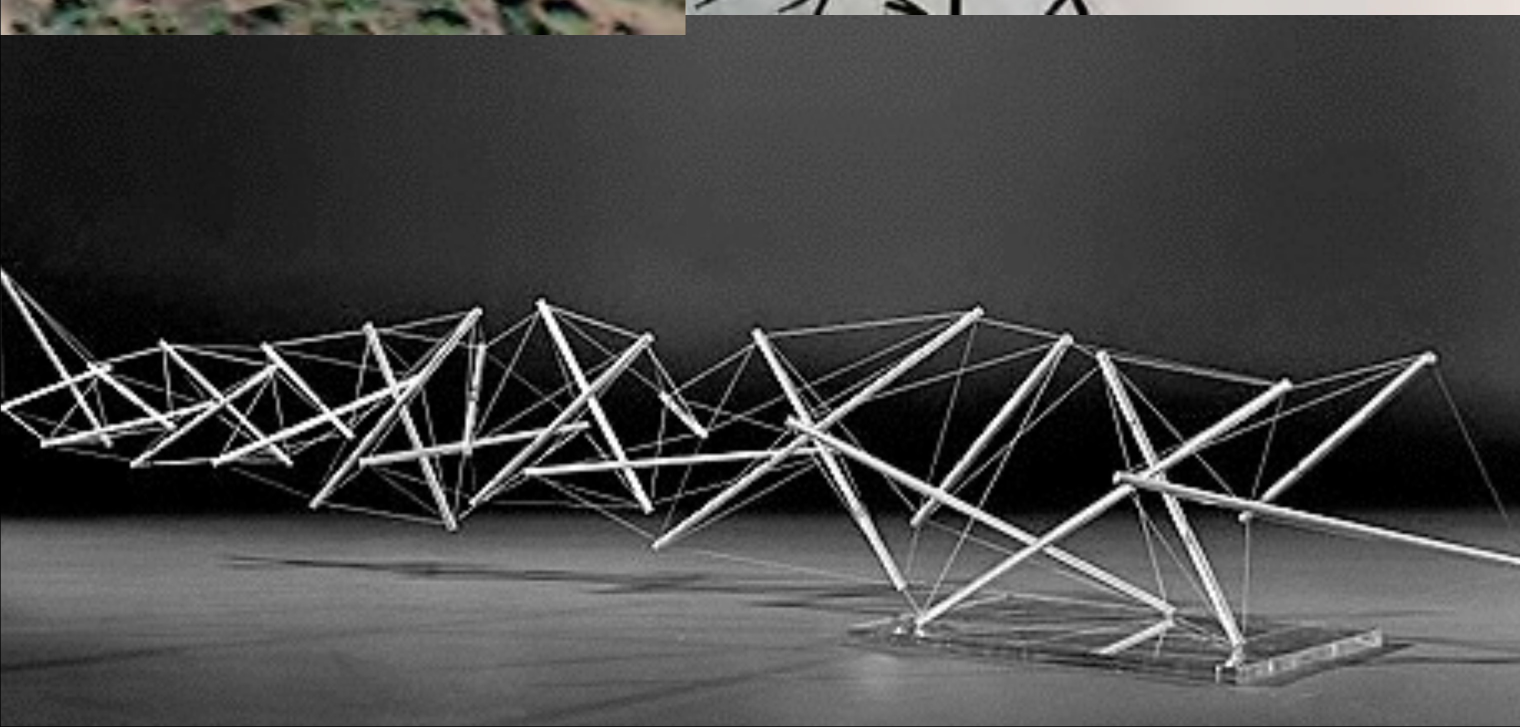

Burkhardt


Snelson

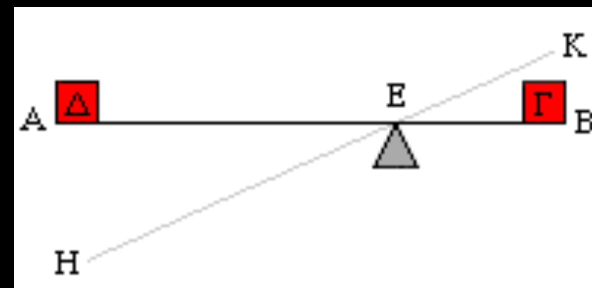

Burkhardt


Snelson


Snelson




Snelson



Mechanical Characteristics	Lever Systems	Biologic Systems	Tensegrity Systems
Stress/Strain	Linear	NonLinear	NonLinear
Stress Distribution	Local	Global	Global
Structural Distrib	Discontinuous	Continuous	Continuous
Gravity	Dependent	Independent	Independent
Stability	Unidirectional	Omnidirectional	Omnidirectional
Energy Costs	High	Low	Low
Joints	Rigid	Flexible	Flexible

Construction Matter

MECHANICS

SOLID

Hooke's Law
Poisson's Ratio
Young's Modulus
Euler Buckling

Soft Matter

"Soft matter is ubiquitous. We are all soft matter."
Emppu Salonen
Laboratory of Physics and Helsinki Institute of Physics Helsinki University of Technology

?
Deborah Number

LIQUID

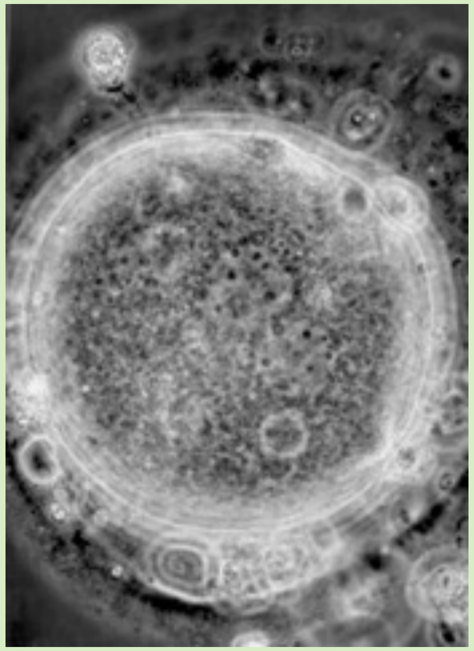
Reynold Number

GAS

Boyle's Law
Reynold Number

F O A M S

C O L L O I D S E M U L S I O N S



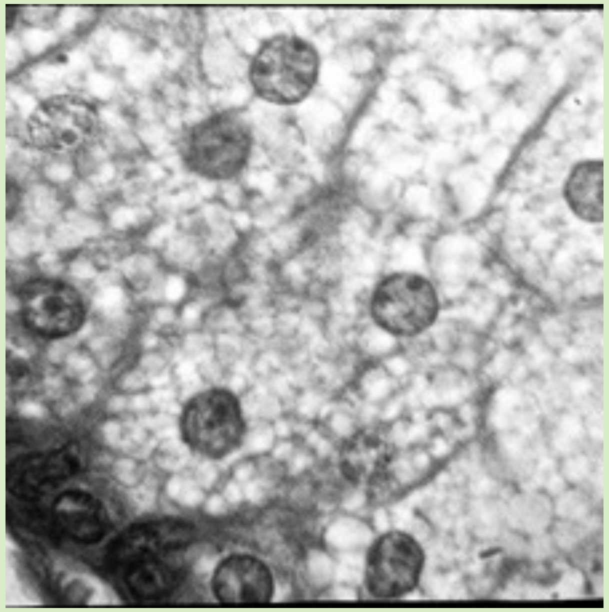
Ovum

2-day Embryo

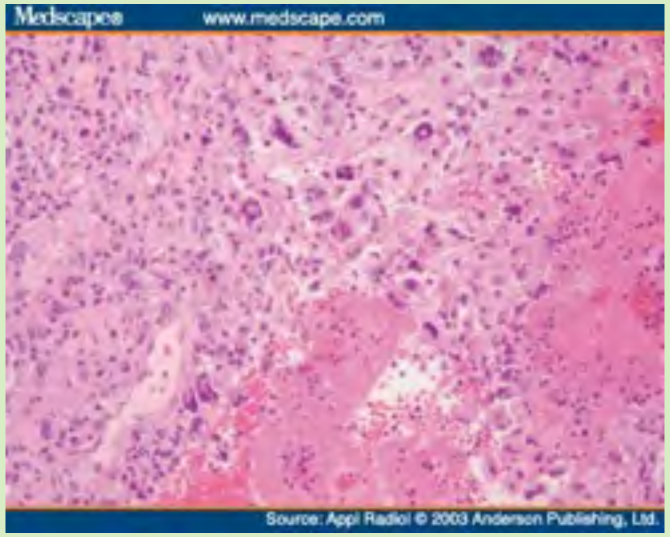
Pbursariandos

Cartilage

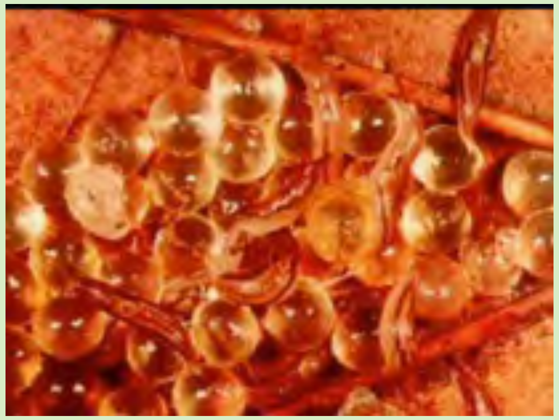
Bone



Fat Cells



Sarcoma



Frogs Eggs

F O A M S

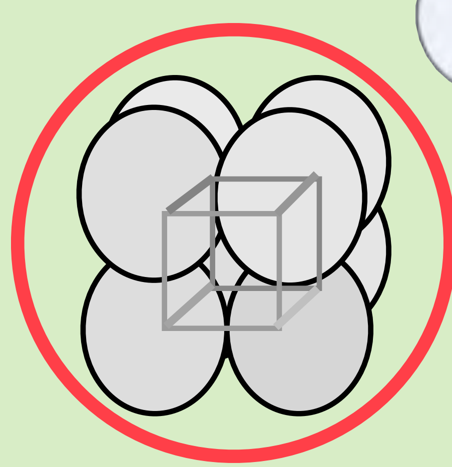
C O L L O I D S & E M U L S I O N S

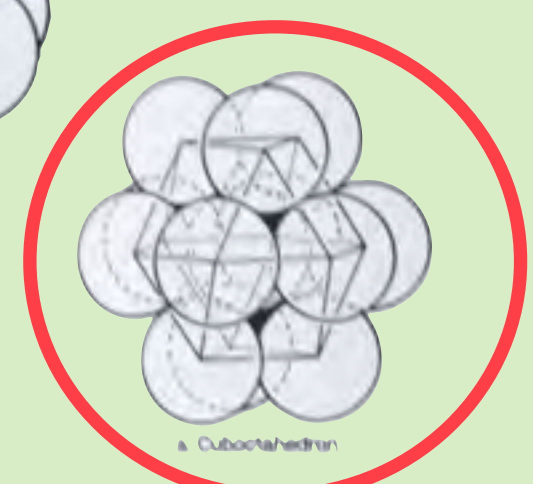
* Only Three films ever meet to form the edge of a bubble

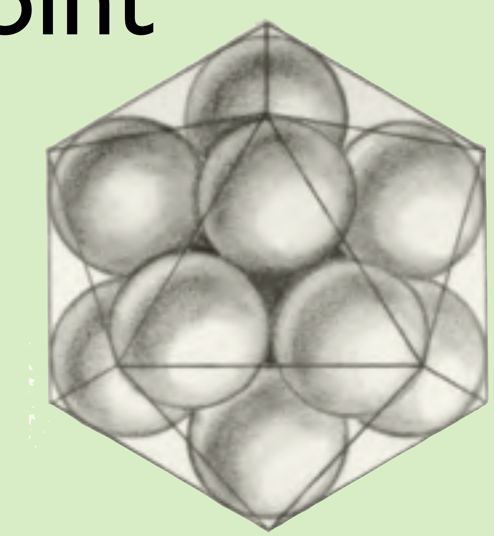
* Any Two adjacent films always meet at an angle of 120^0

*Exactly Four Edges ever come together to meet at a point

2-day Embryo







(Unstable)

F O A M S

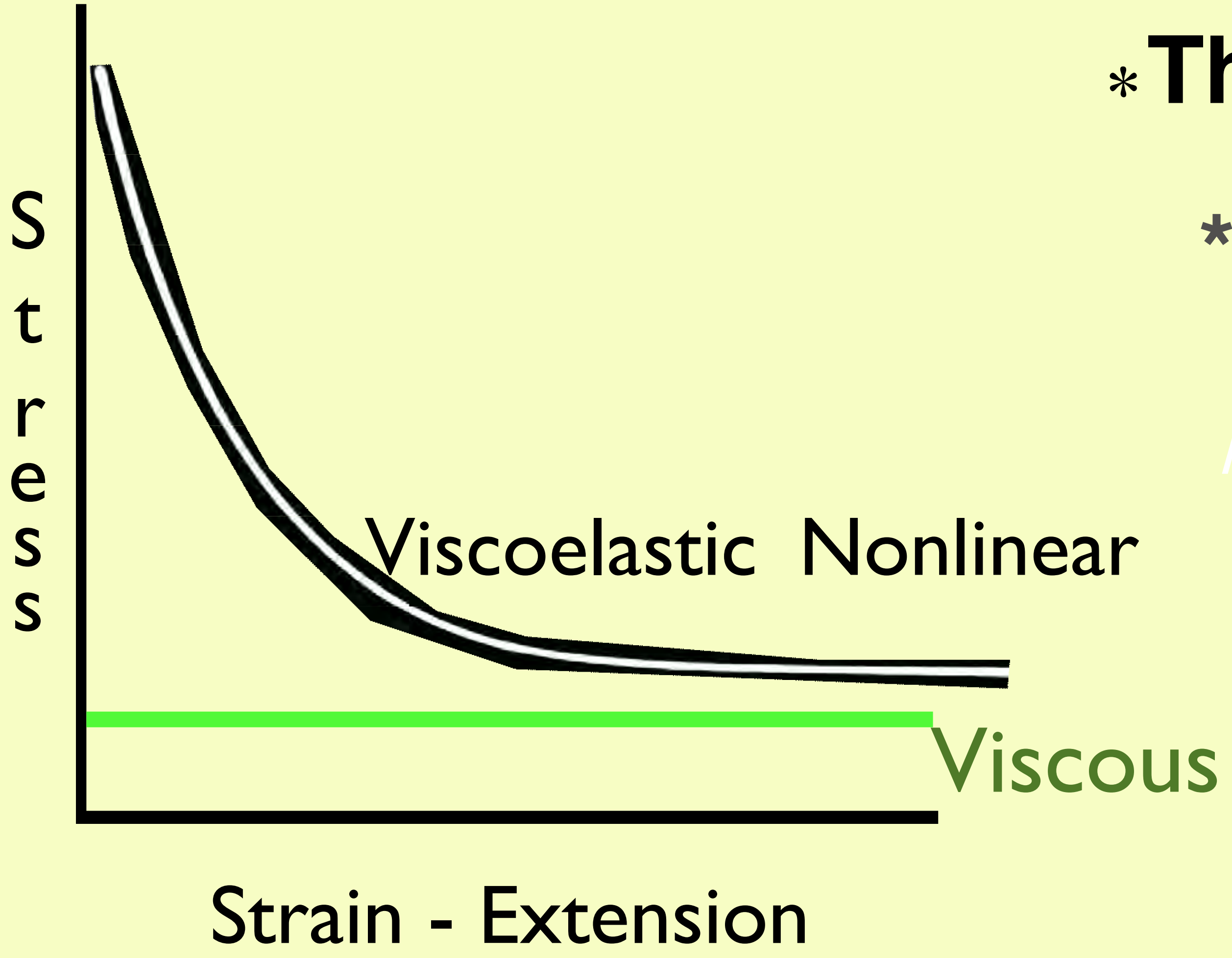
C O L L O I D S & E M U L S I O N S

*Spacial Interaction is important (Mesoscopic Organization-you can't judge a foam by one bubble)

*The systems are in non-equilibrium

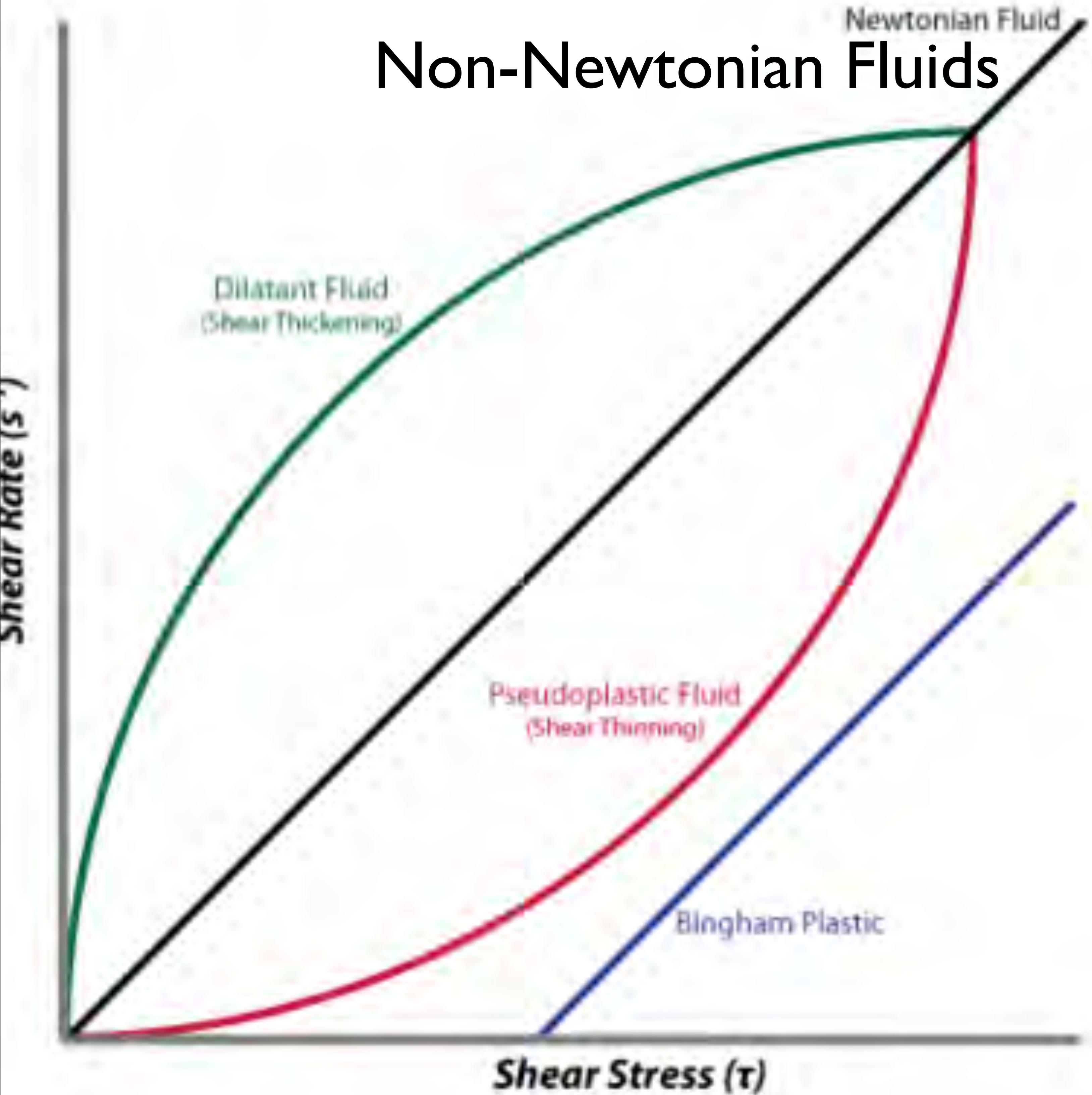
*The systems are nonlinear

* Foster Emergent Properties



Soft Matter

Non-Newtonian Fluids



Thixotropic

Dilatant

Shear Thinning

Shear Thickening

(Jacketing)

Kelvin

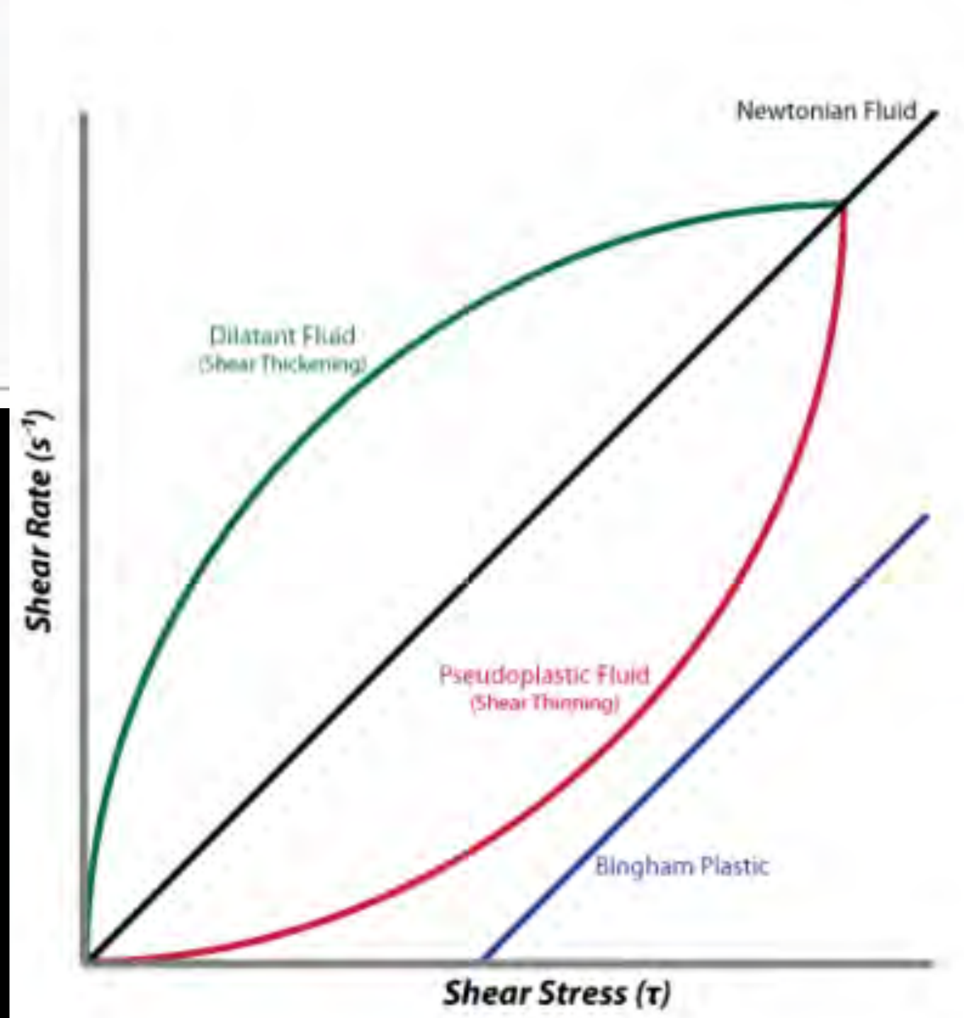
Bingham

Jamming

Comparison of non-Newtonian, Newtonian, and viscoelastic properties

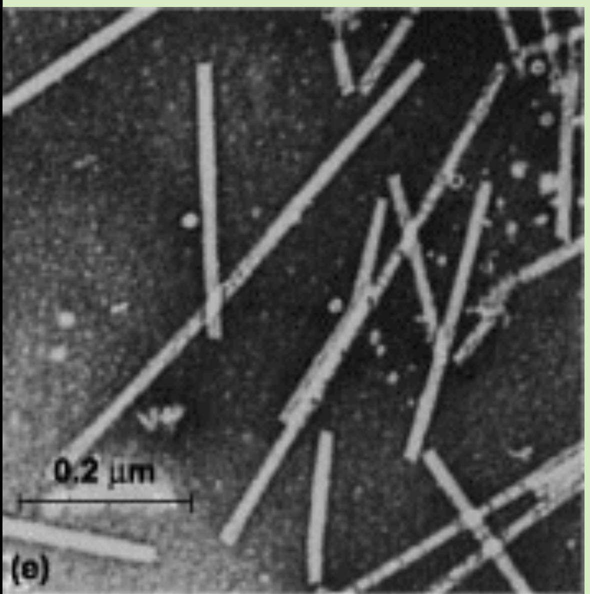
Viscoelastic	Kelvin material	"Parallel" linearstic combination of elastic and viscous effects[1]	Some lubricants, whipped cream
	Thixotropic	Apparent viscosity decreases with duration of stress[2]	Yogurt, xanthan gum solutions, aqueous iron oxide gels, gelatin gels, pectin gels, synovial fluid, hydrogenated castor oil, some clays (including bentonite, and montmorillonite), carbon black suspension in molten tire rubber, some drilling muds, many paints, many floc suspensions, many colloidal suspensions
Time-independent viscosity	Shear thickening (dilatant)	Apparent viscosity increases with increased stress[3]	Suspensions of corn starch in water, sand in water, Silly Putty
	Shear thinning (pseudoplastic)	Apparent viscosity decreases with increased stress[4][5]	Nail polish, whipped cream, ketchup, molasses, syrups, paper pulp in water, latex paint, ice, blood, some silicone oils, some silicone coatings
	Generalized Newtonian fluids	Viscosity is constant Stress depends on normal and shear strain rates and also the pressure applied on it	Blood plasma, custard, water

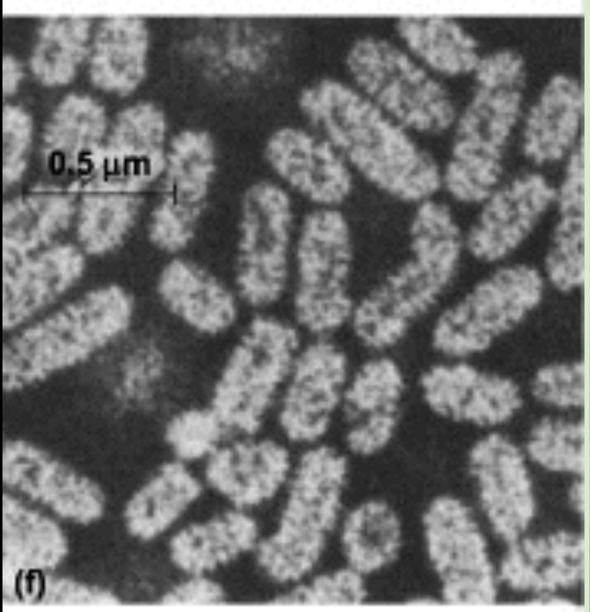
Soft Matter

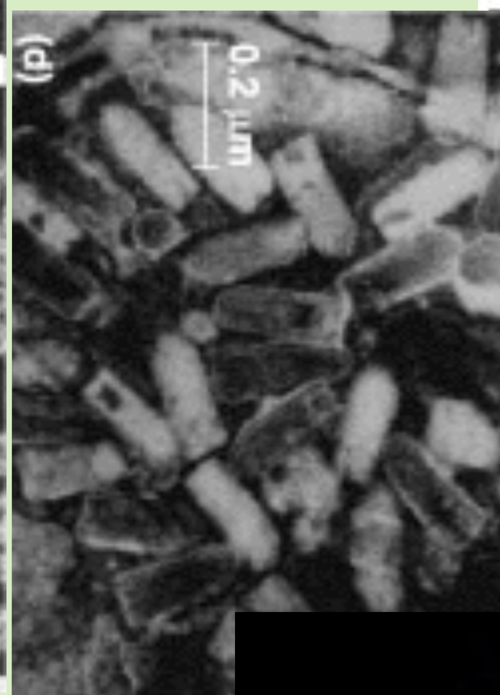


Symmetry Breaking

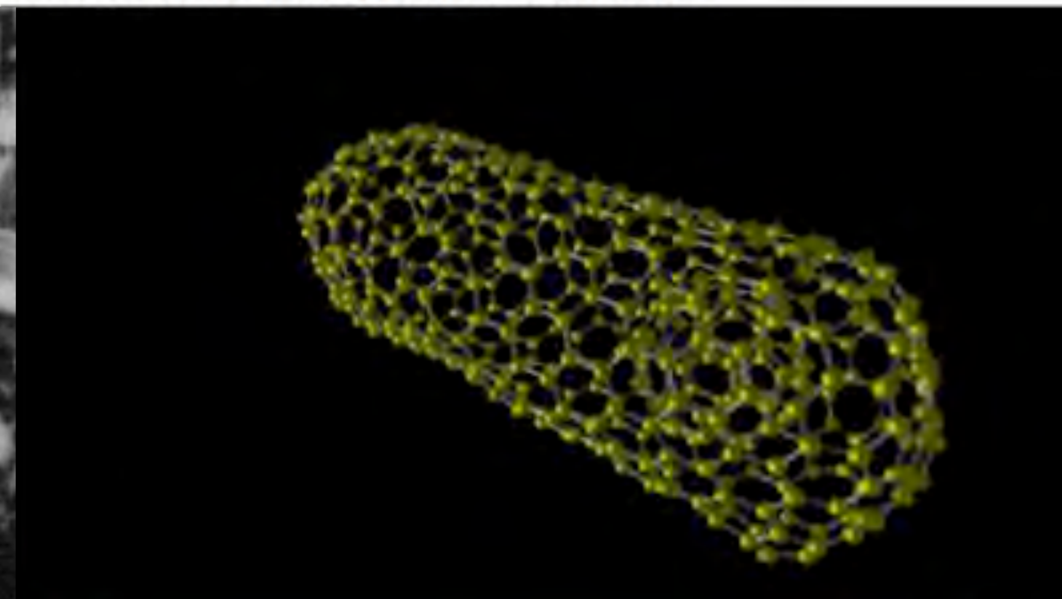
Not Everything is Round

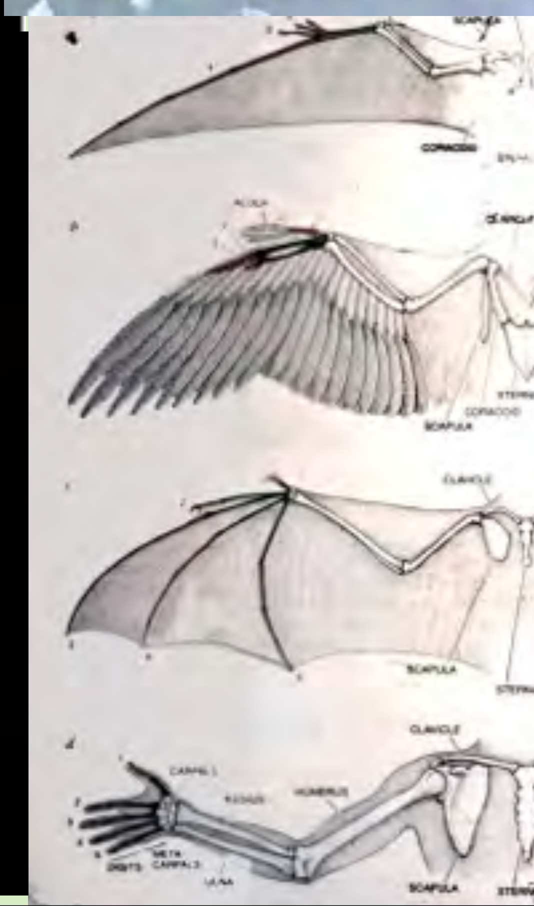


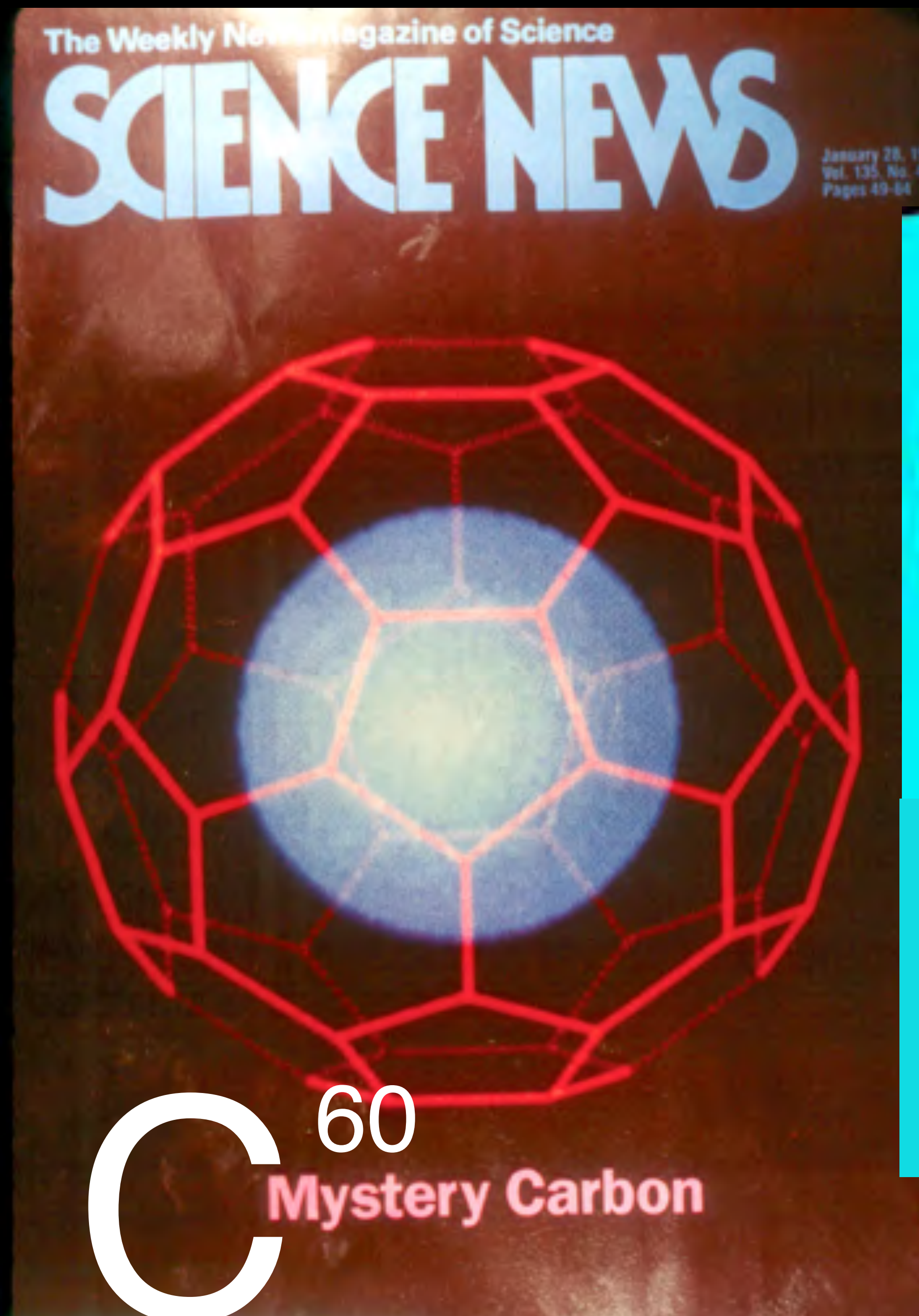




carbon nanotube memory element in NanoHive-1

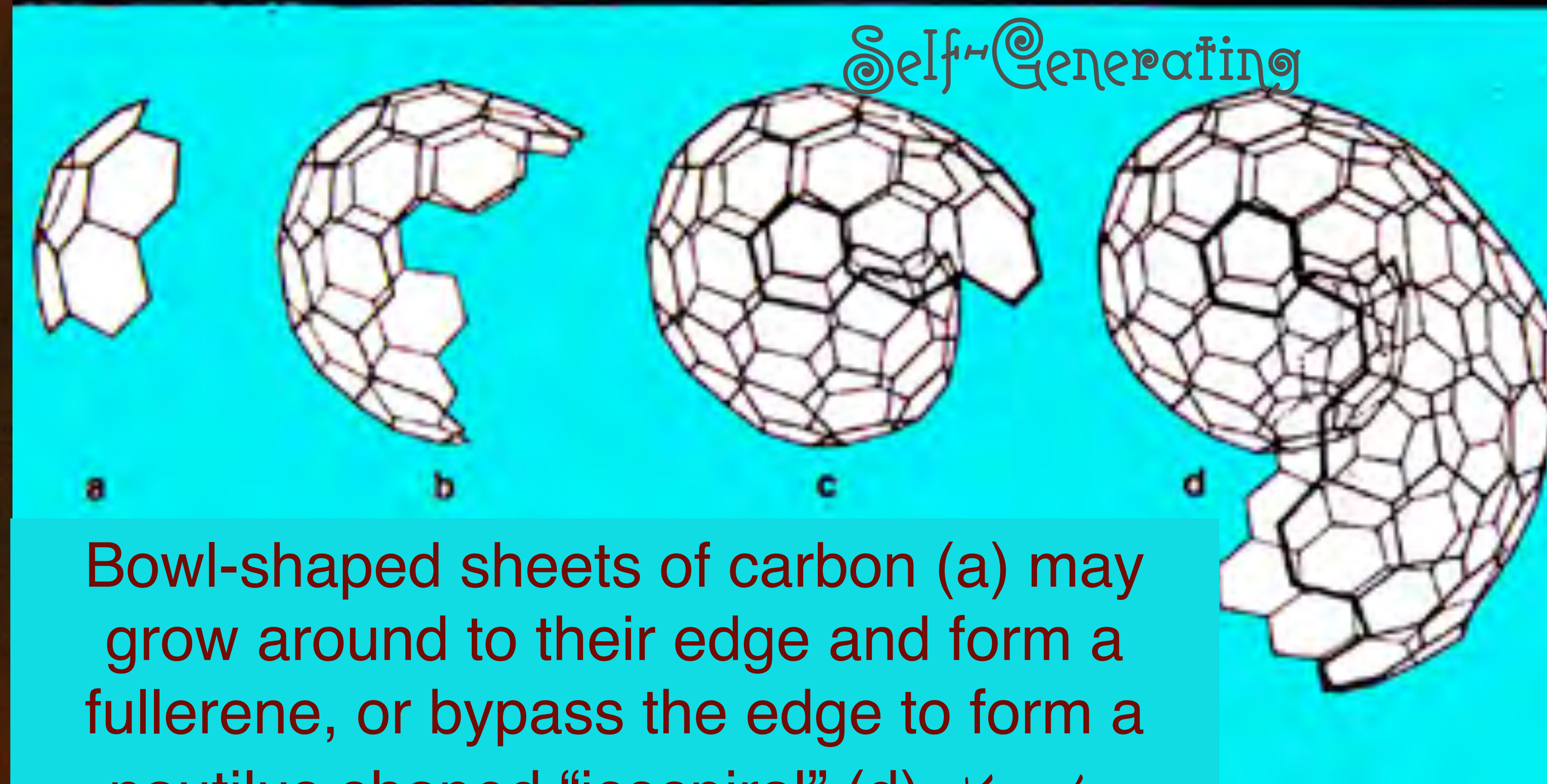






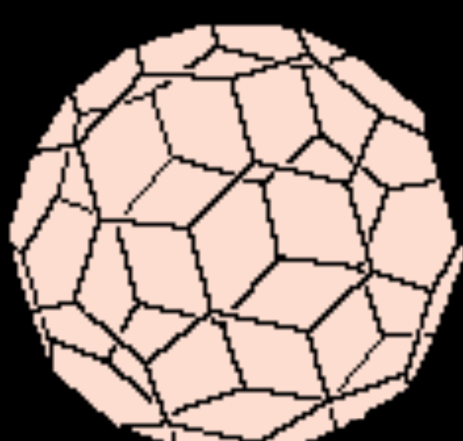
C_{60}

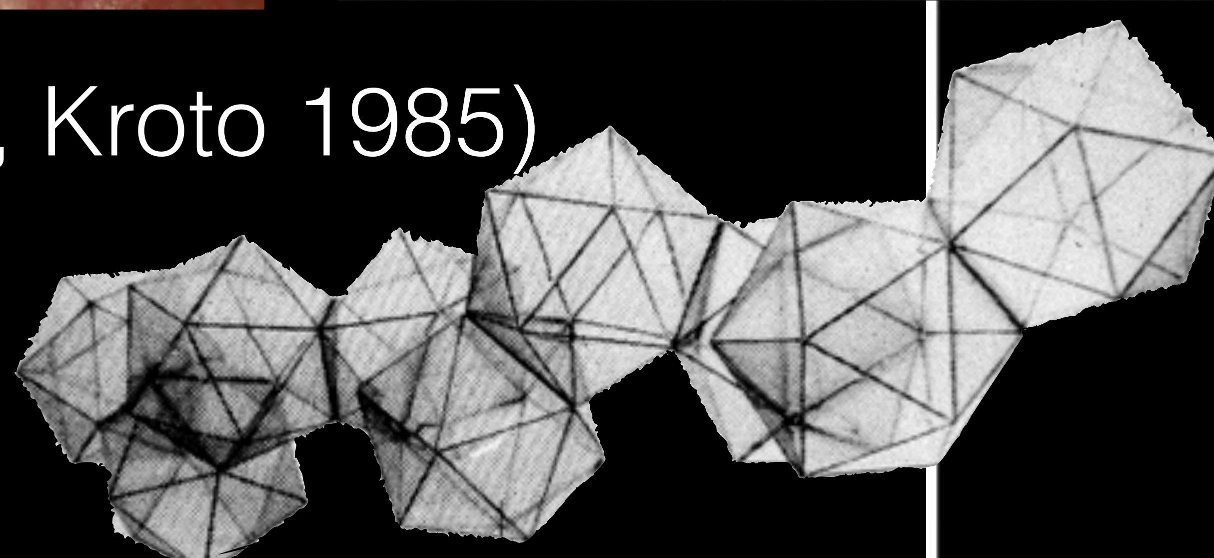
icOSPiRaL

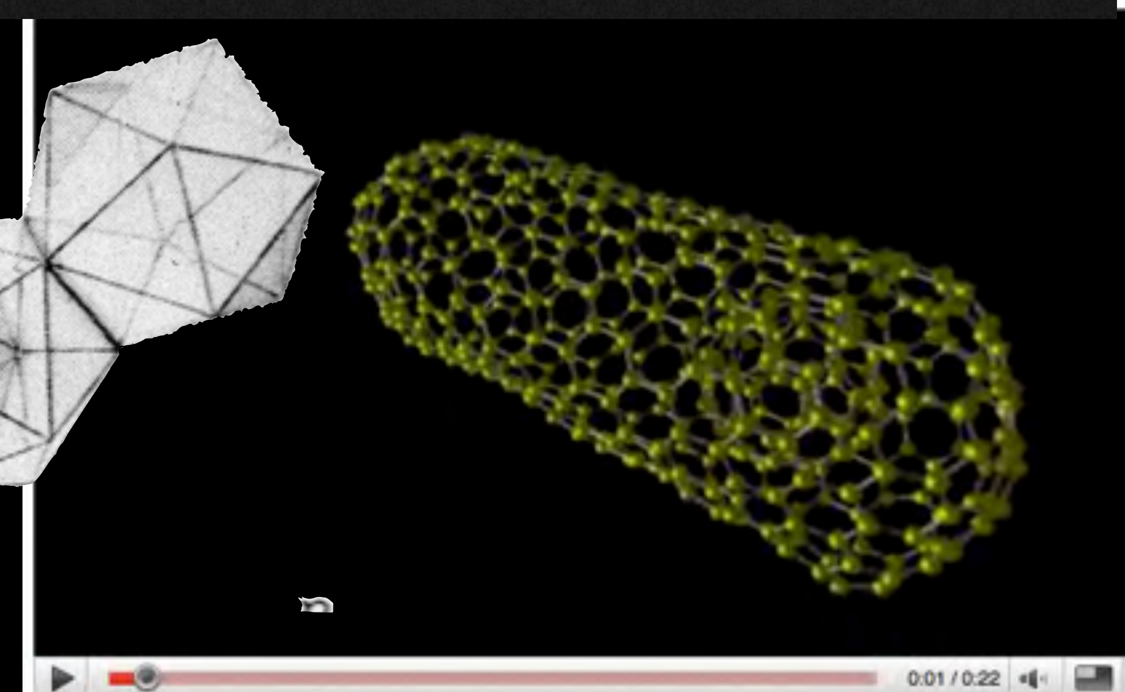


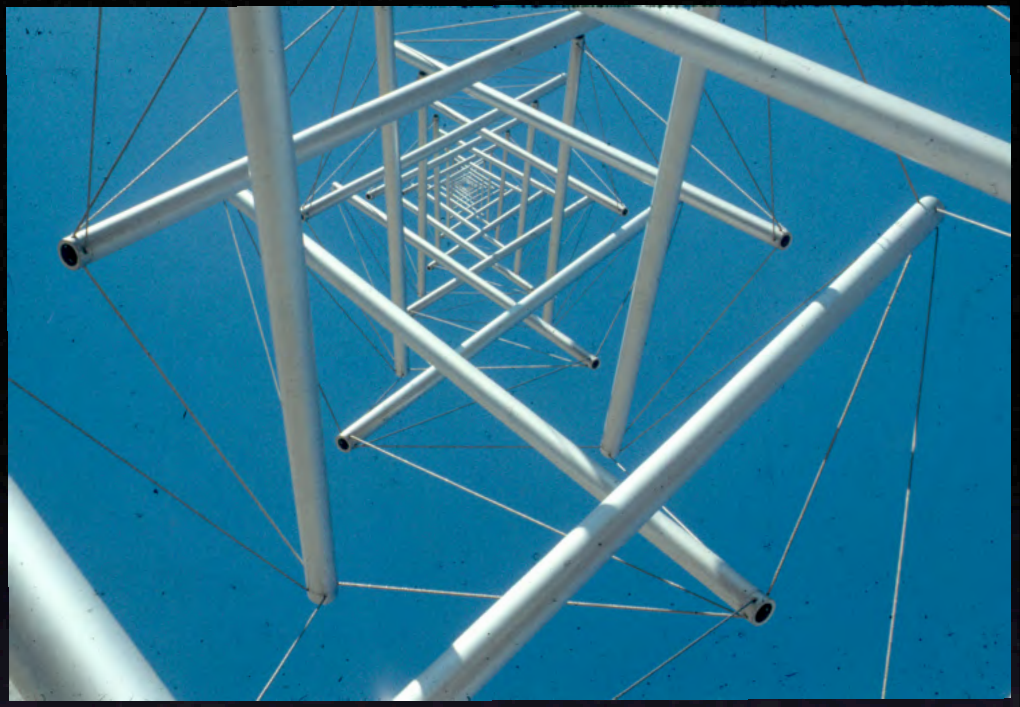
Bowl-shaped sheets of carbon (a) may grow around to their edge and form a fullerene, or bypass the edge to form a nautilus shaped "icospiral" (d). *Kroto*

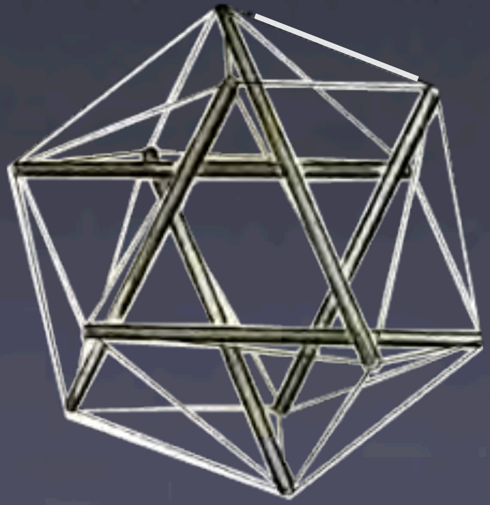
(Curl, Smalley, Kroto 1985)





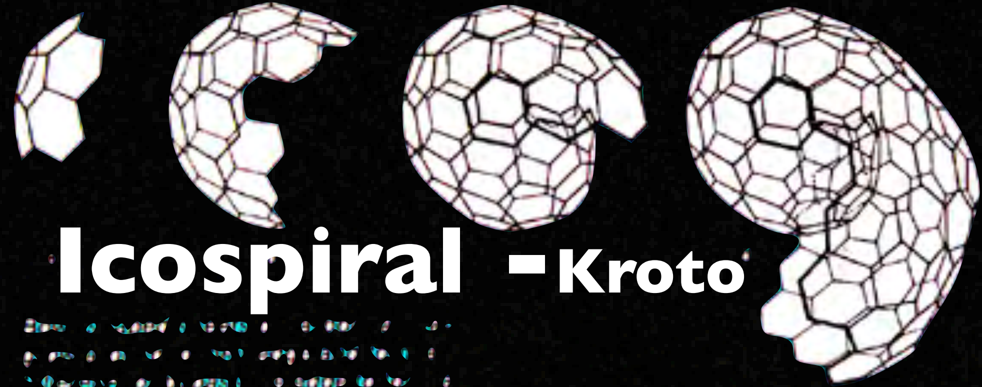






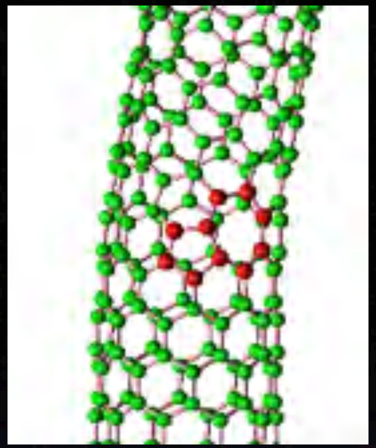
Log Spiral

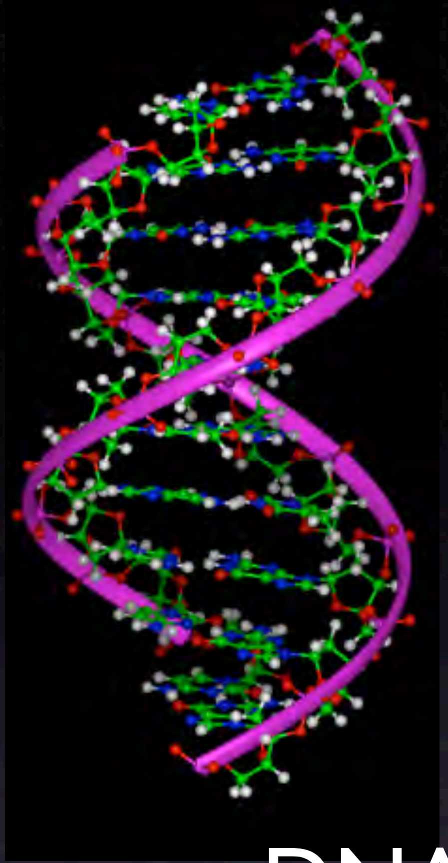
Floating Compression



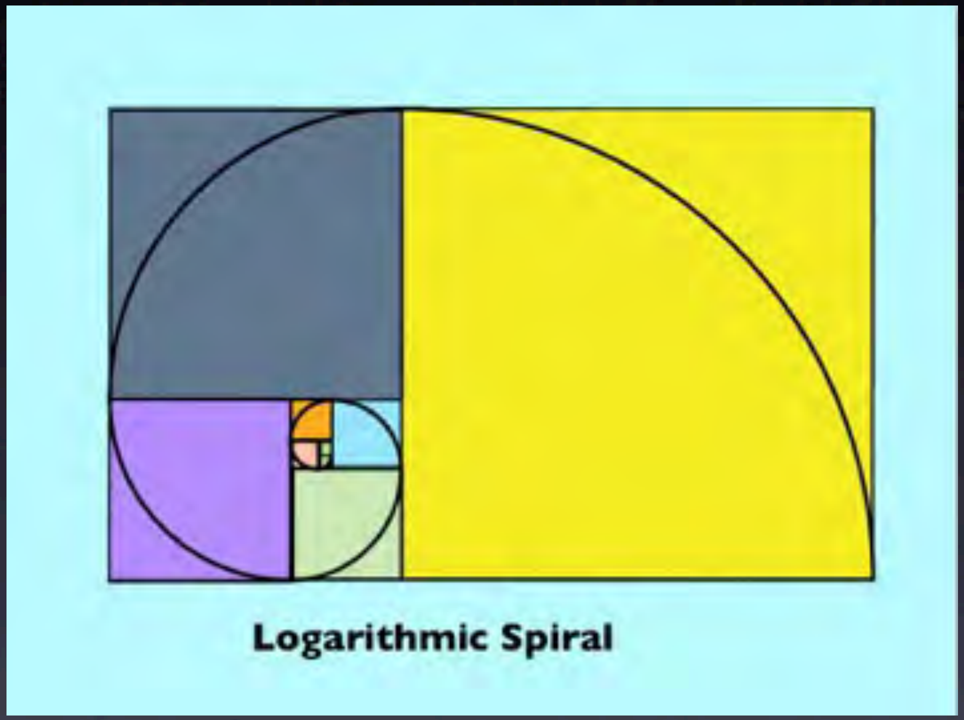
Icospiral -Kroto

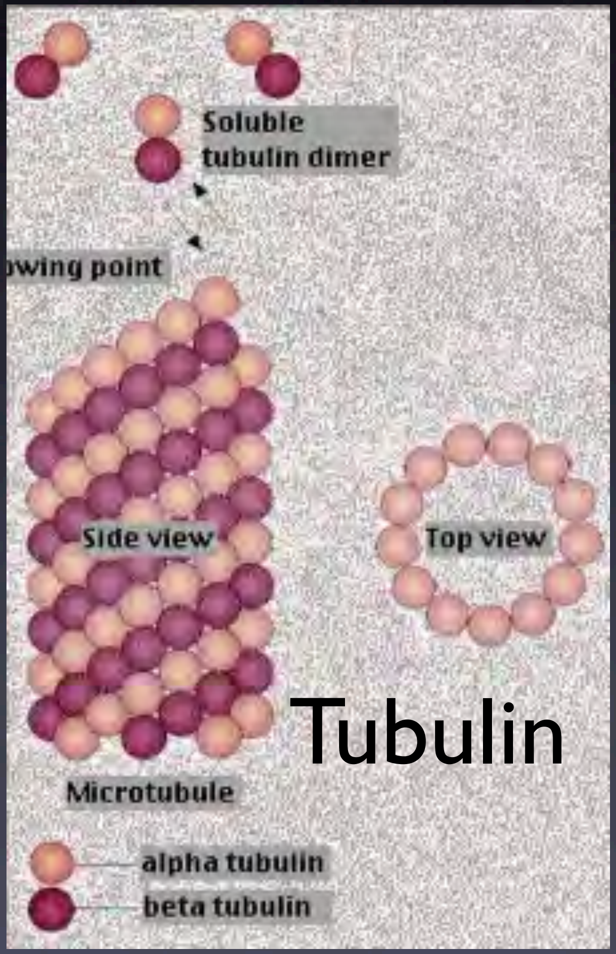
Nanotubule





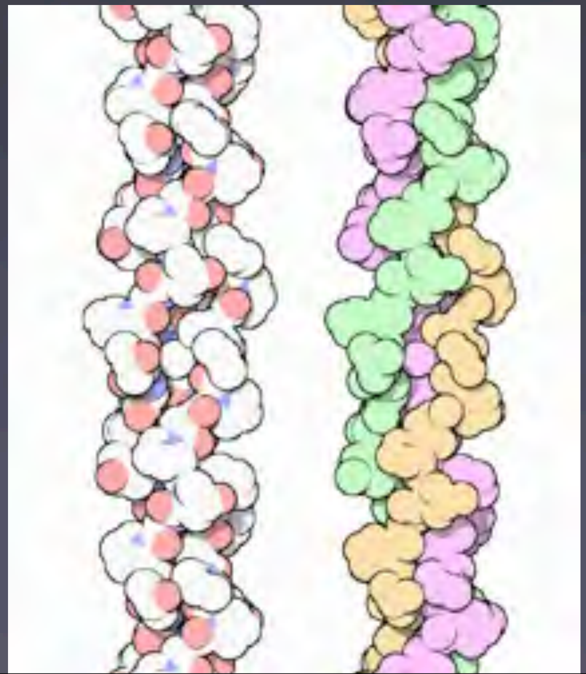
DNA

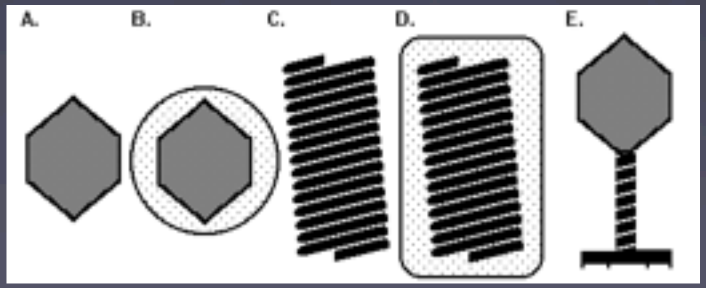




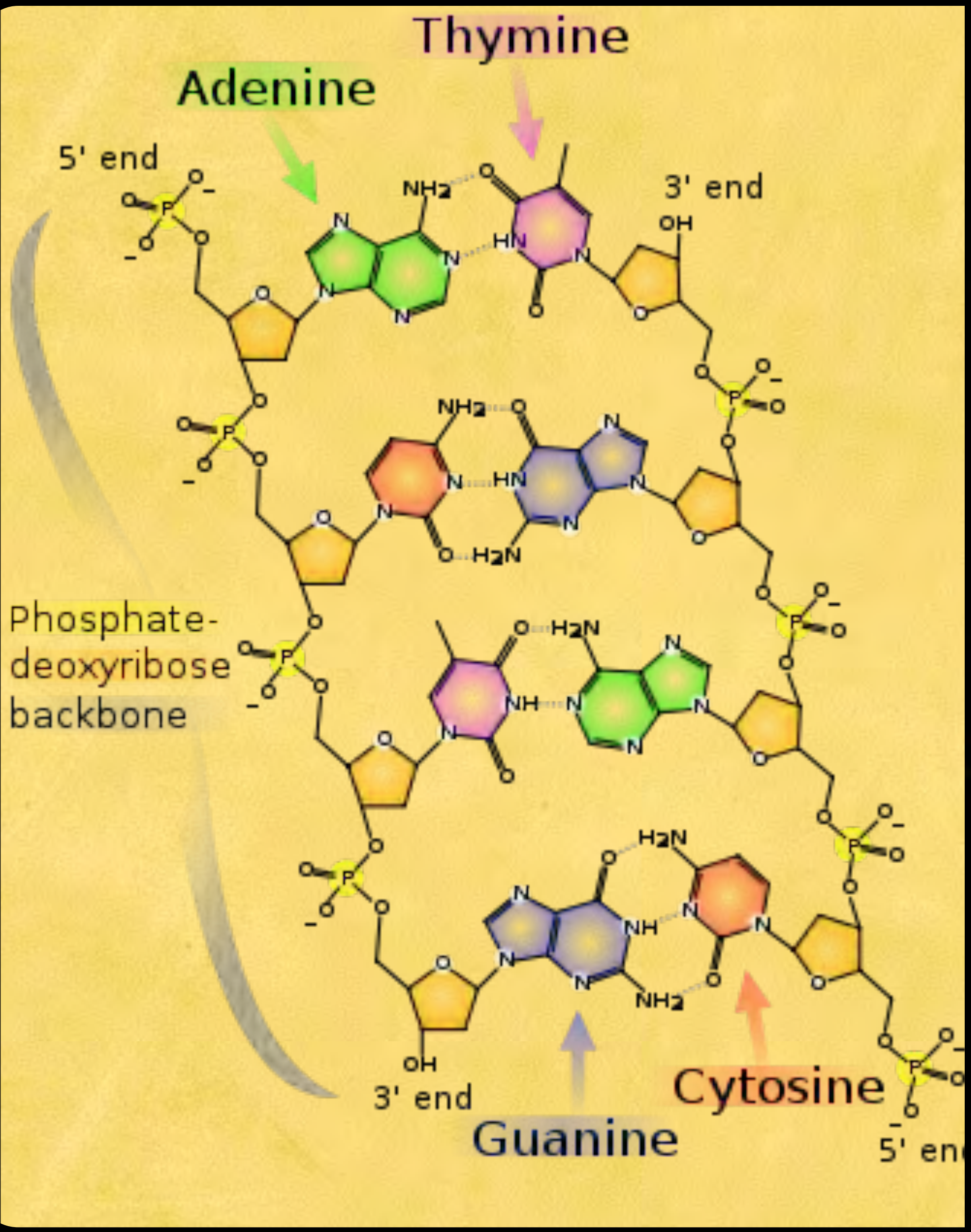
Tubulin

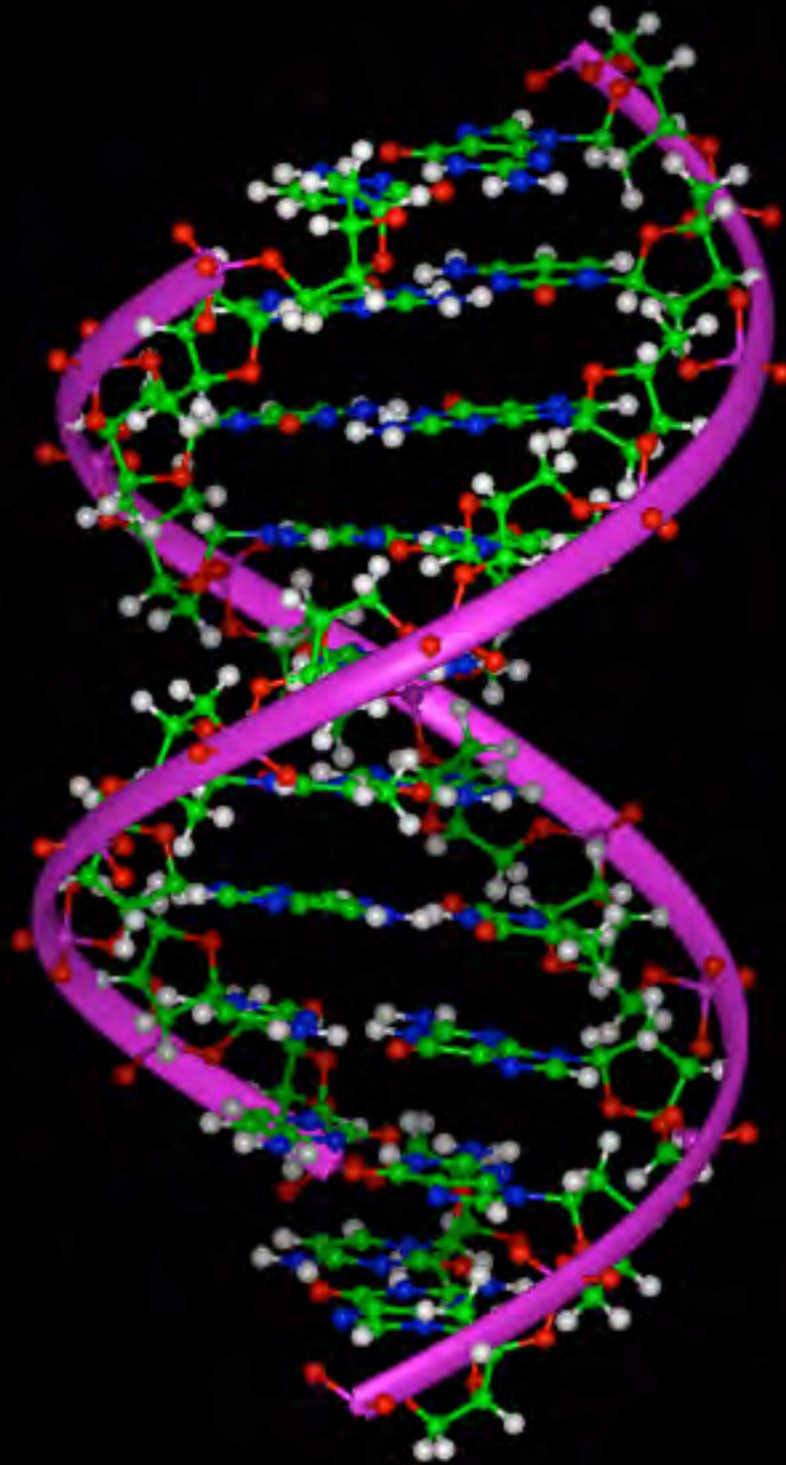
Collagen

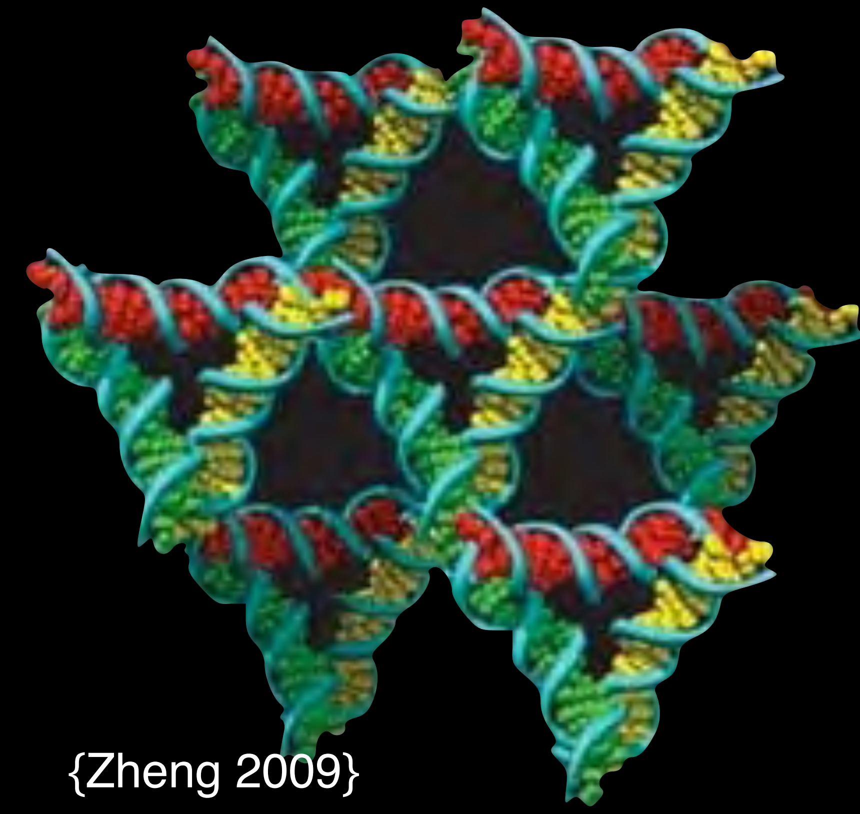




Virus

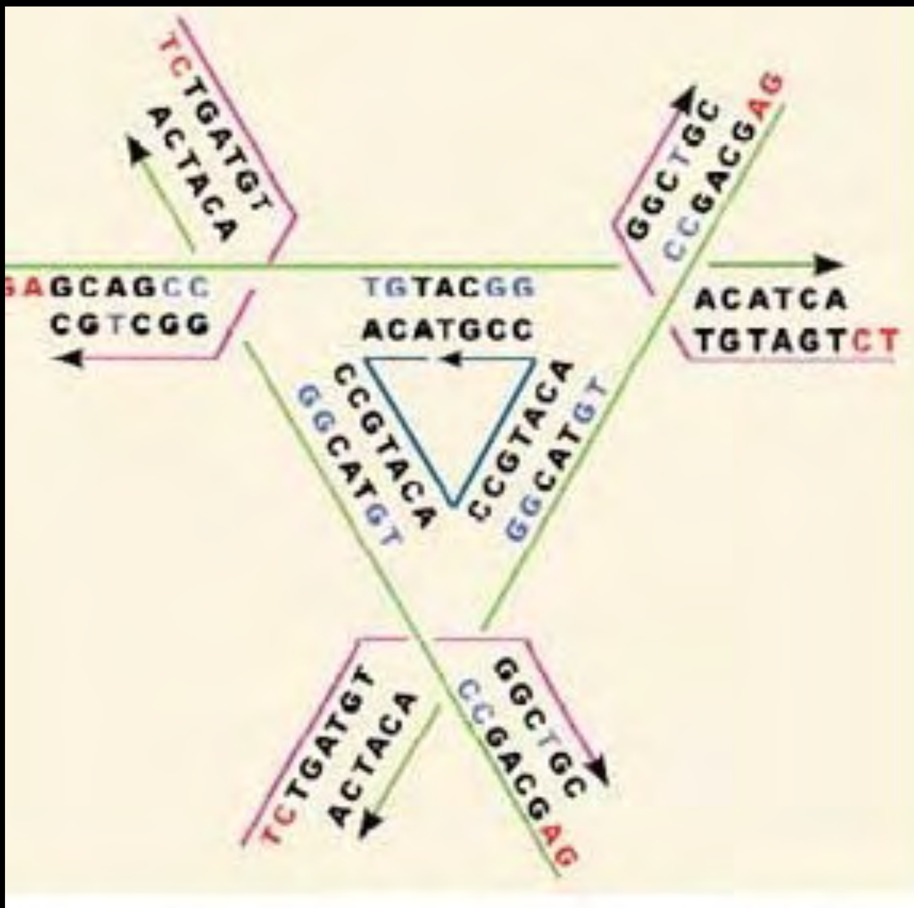




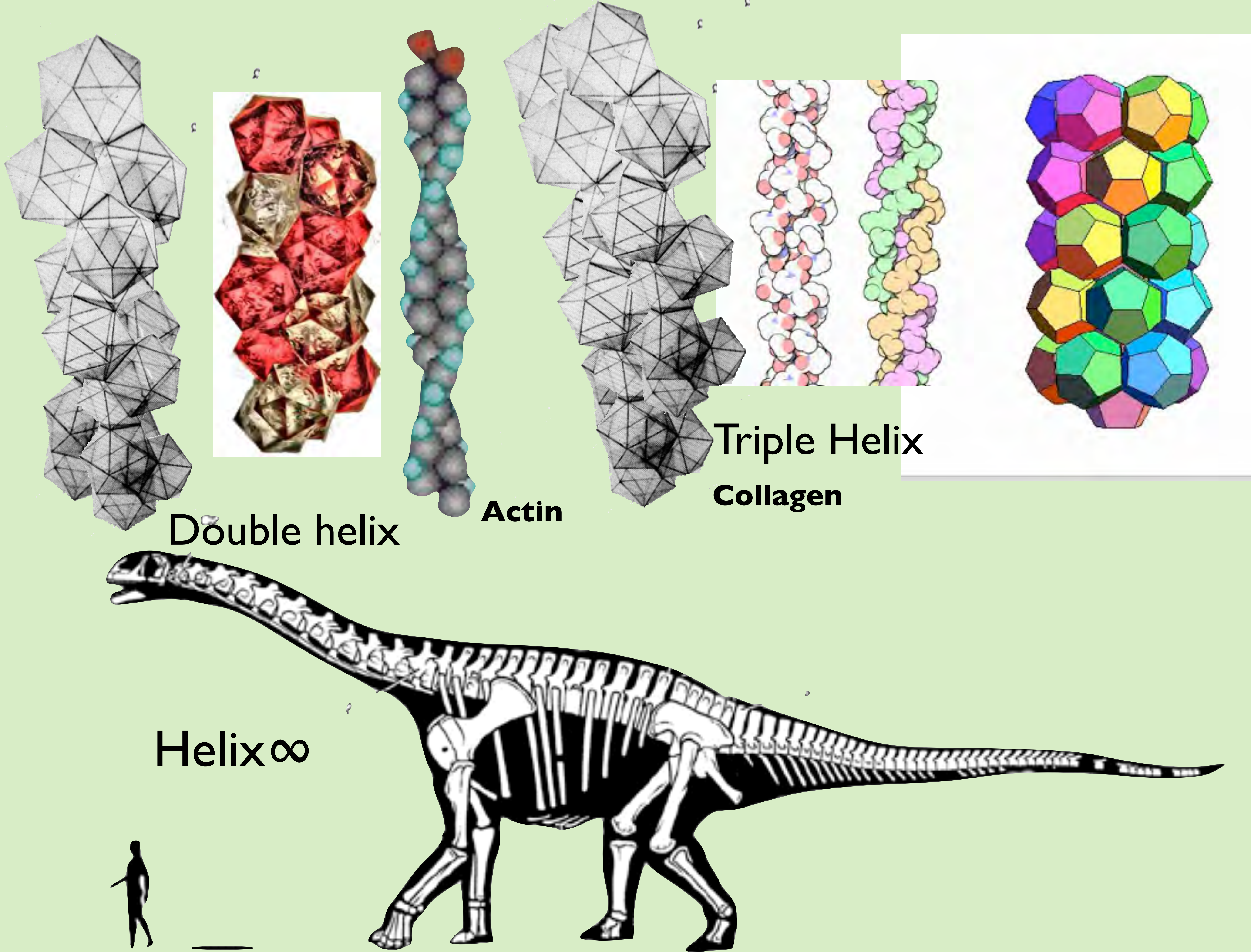


{Zheng 2009}

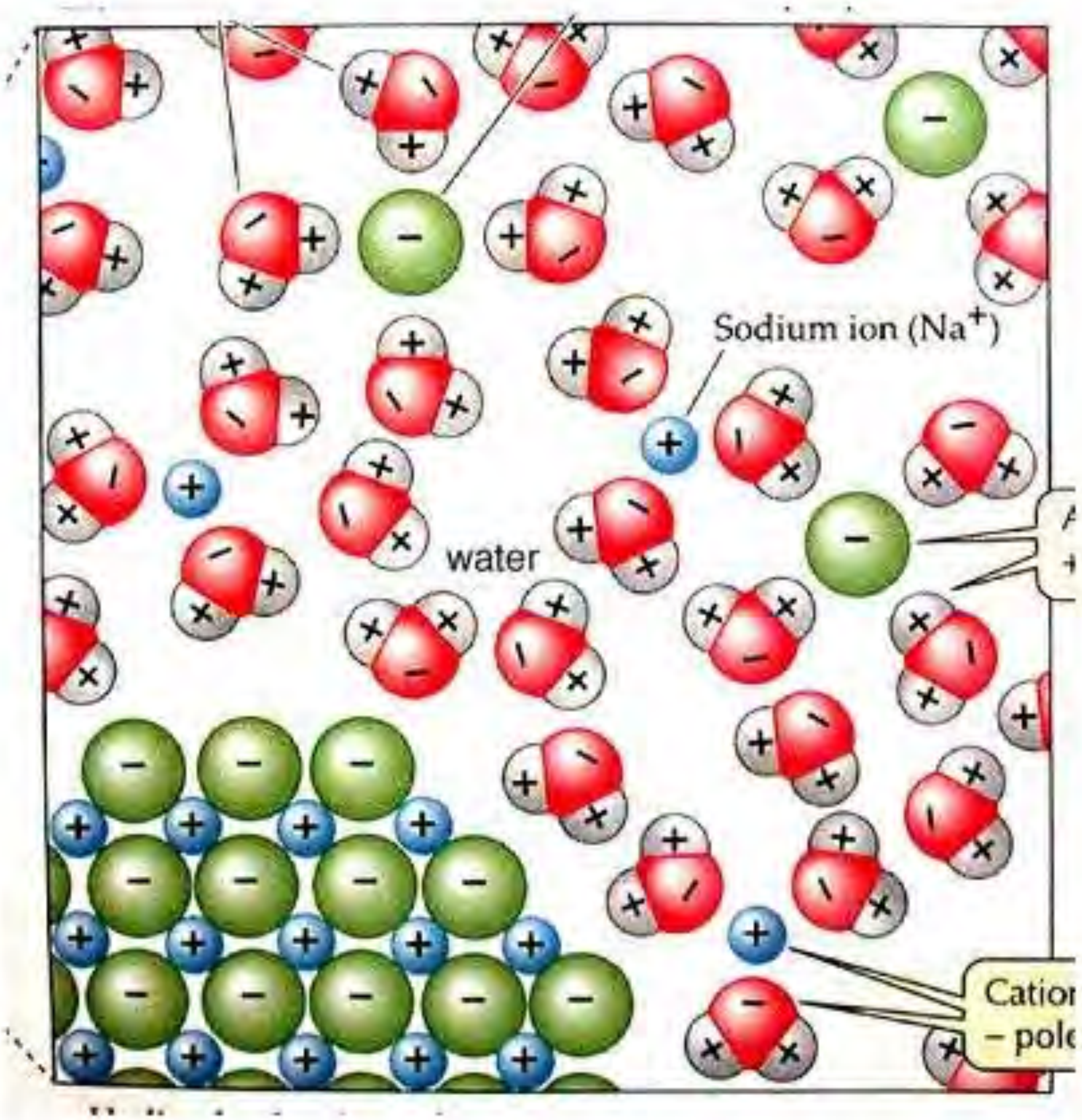
The tensegrity triangles self-assemble to form 3D lattices



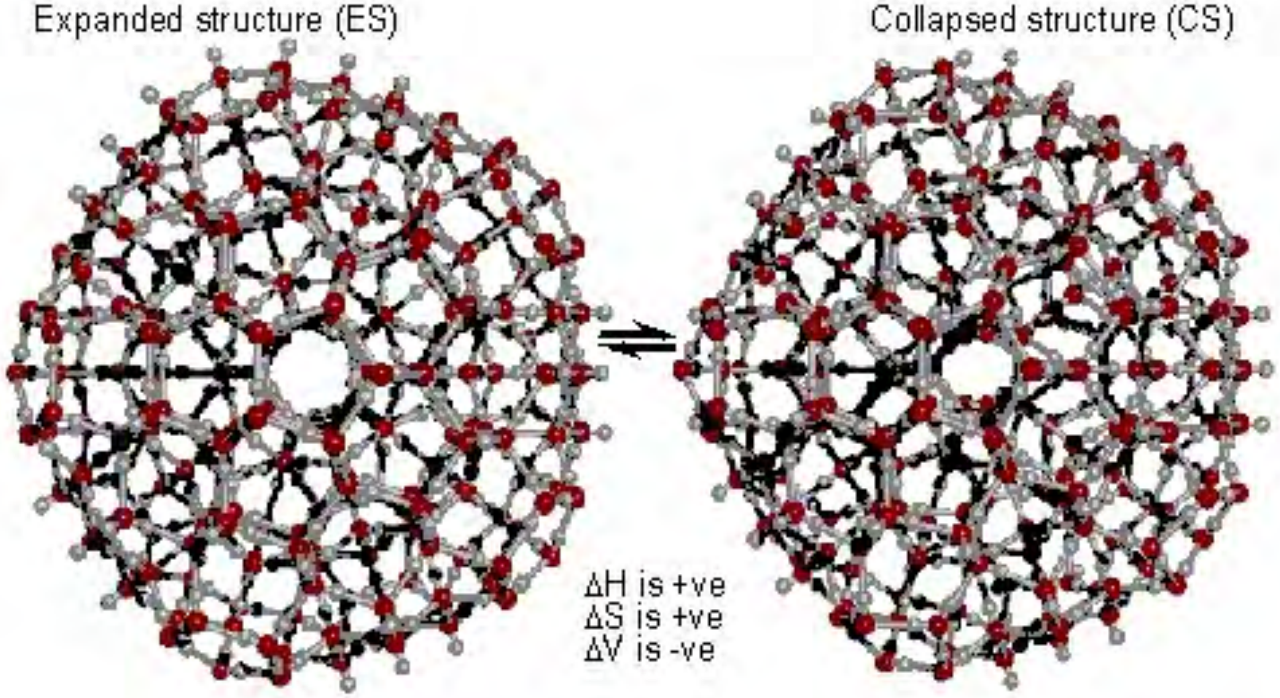
The tensegrity triangles are made up of three DNA helices

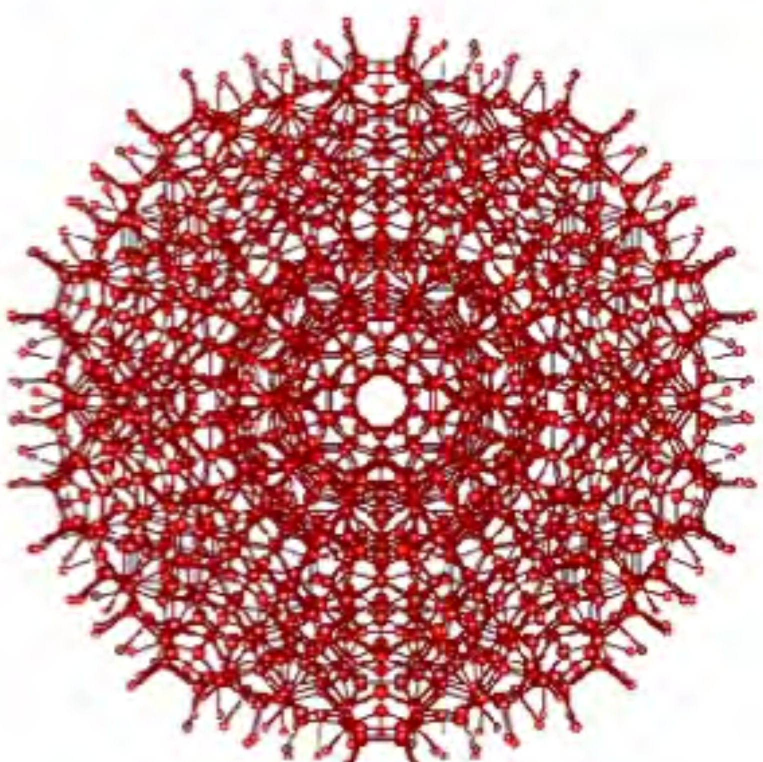


Double helix
Actin
Triple Helix
Collagen
Helix∞



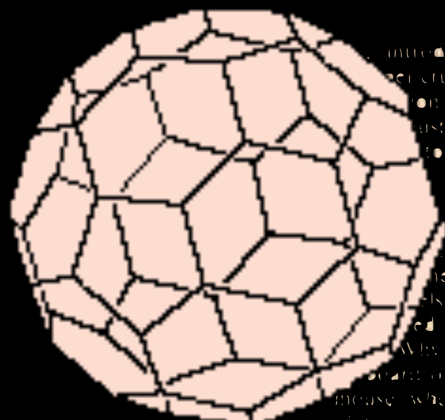
Water Clusters



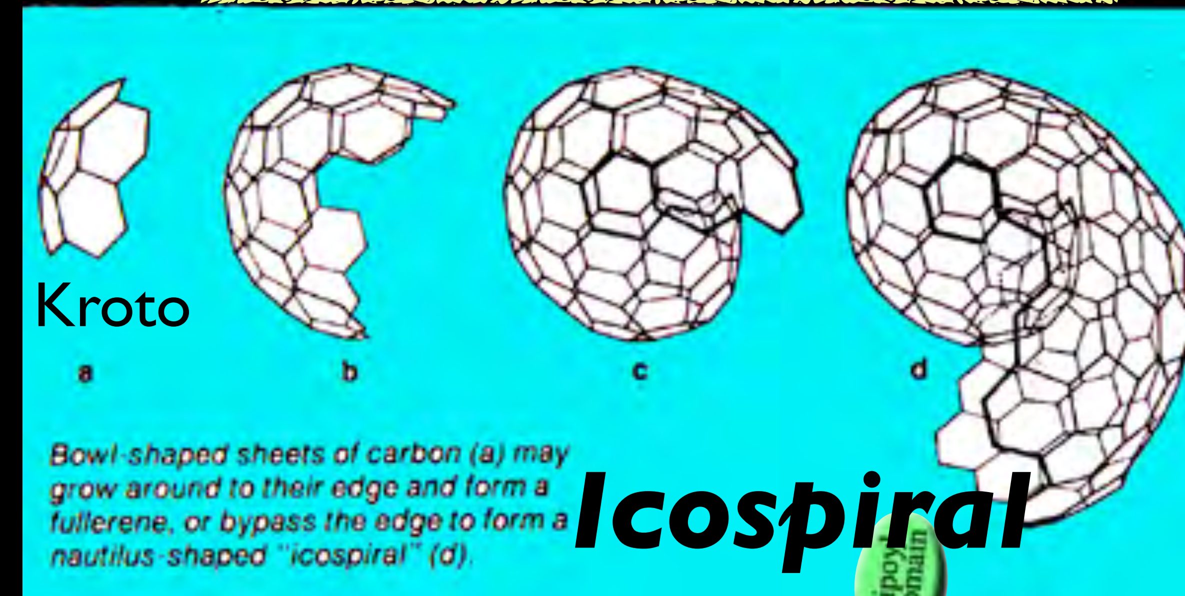


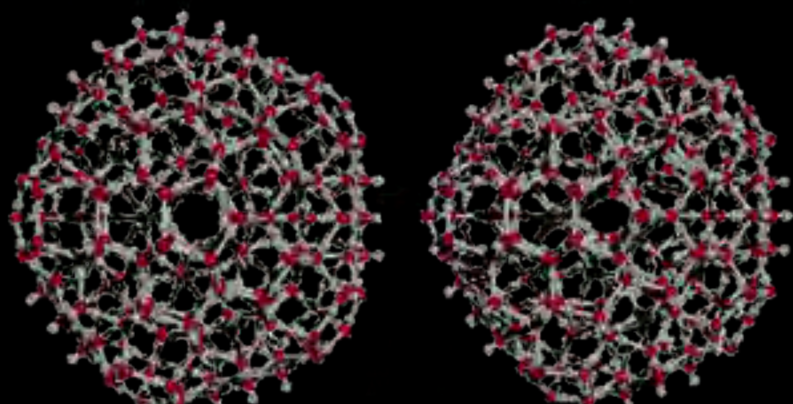
Icosahedral Water

Picometer 10^{-12} m

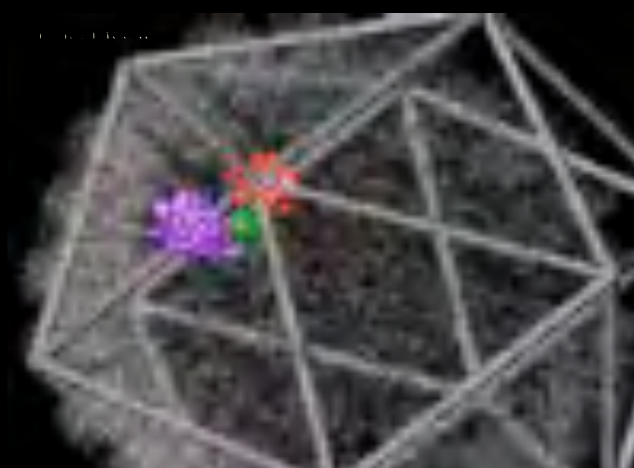


Carbon^{60}

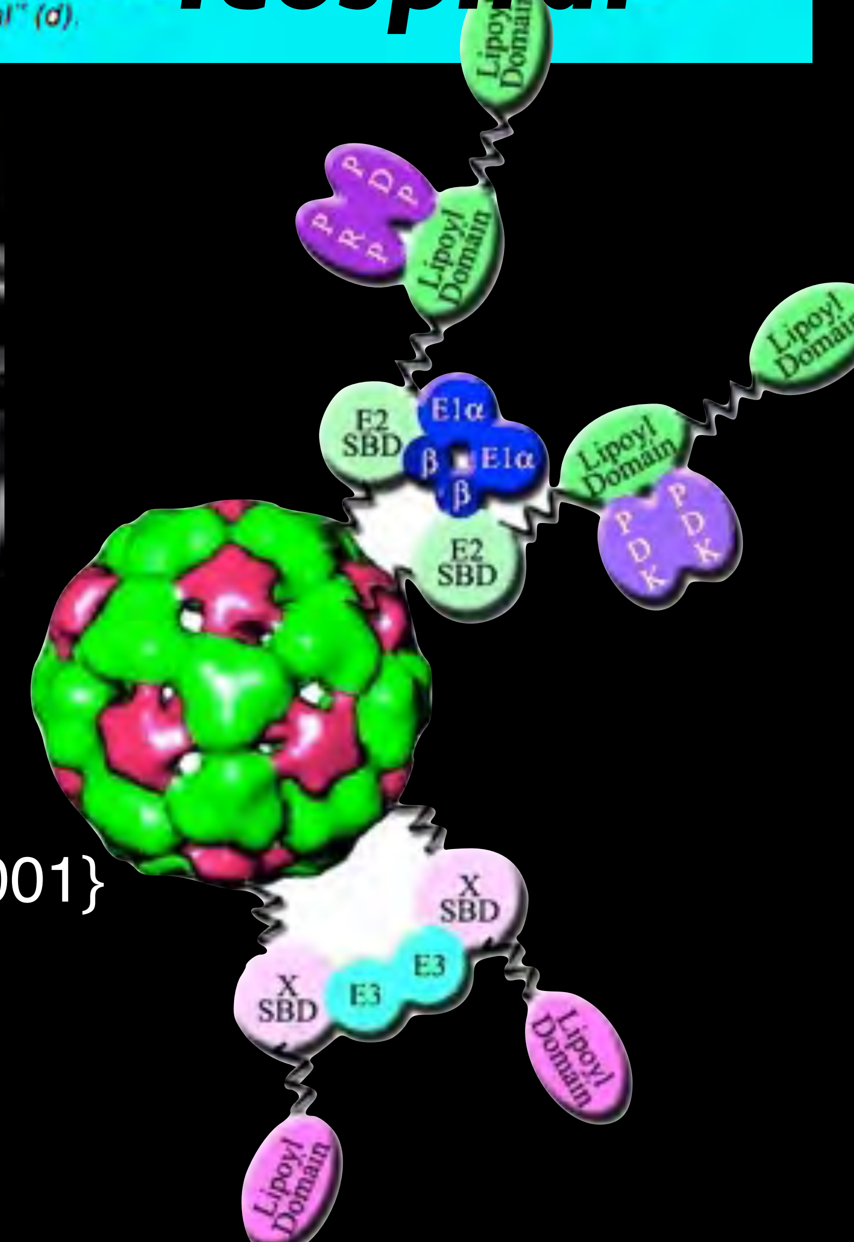




Icosaheral Water



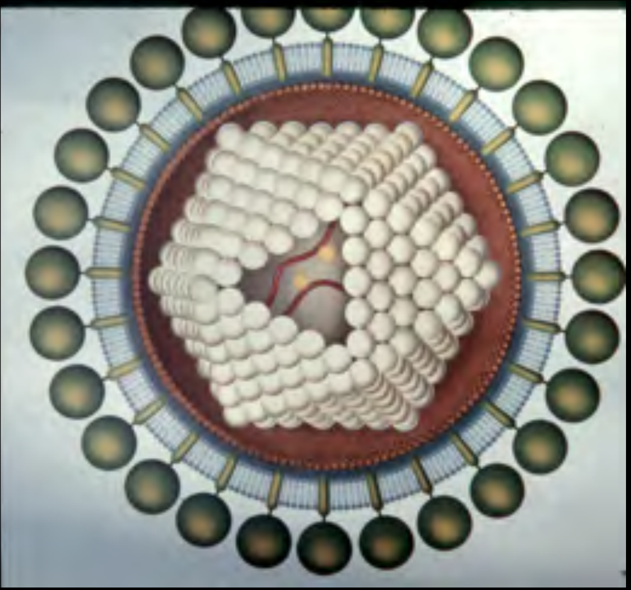
Pyruvate



{Zhou 2001}

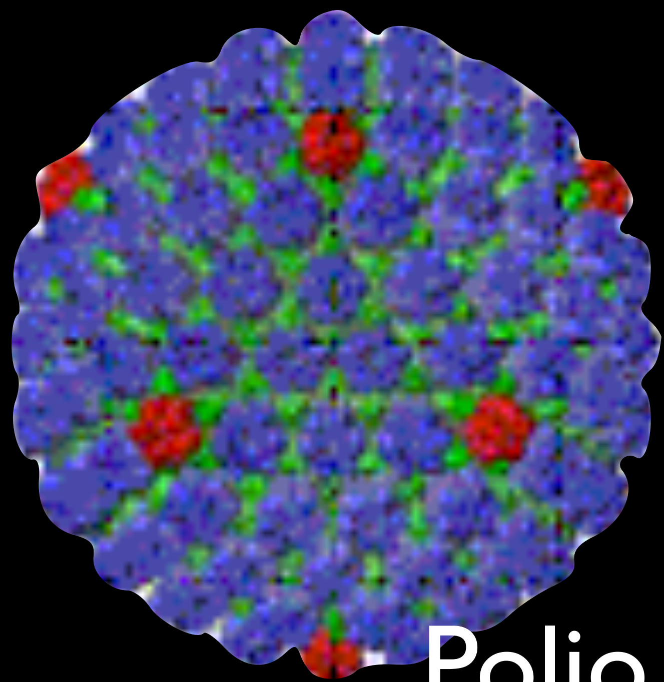
Prions

Virus

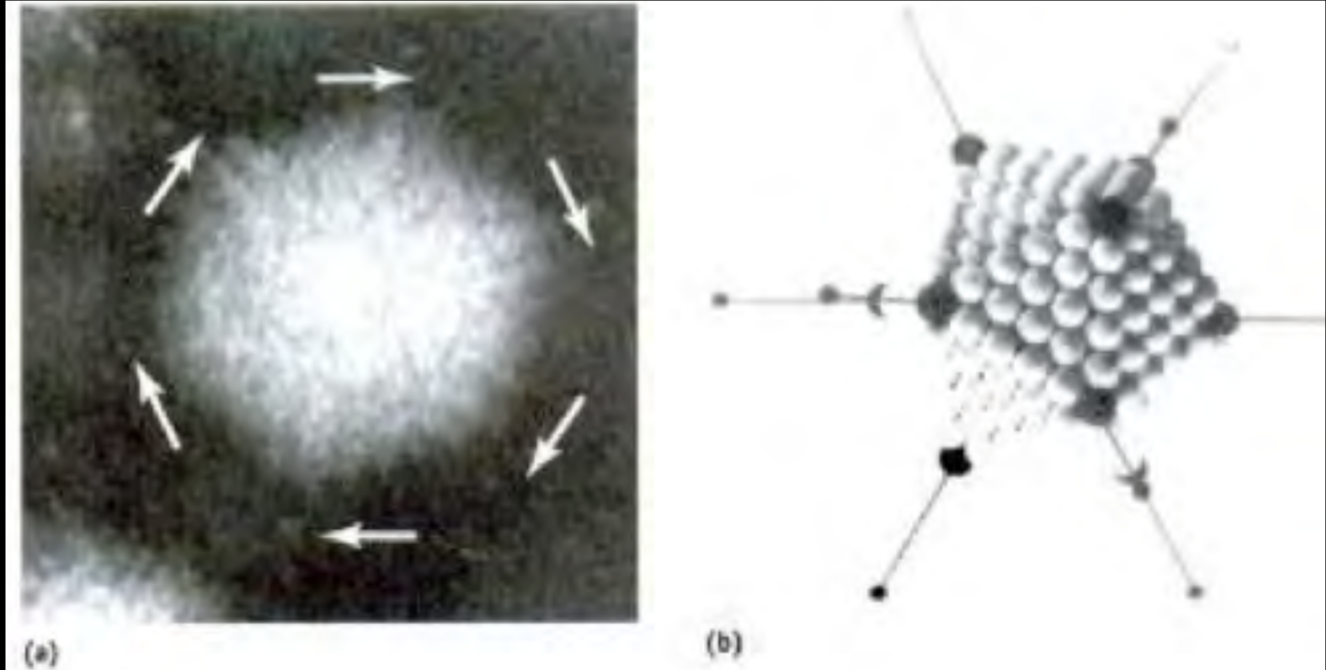


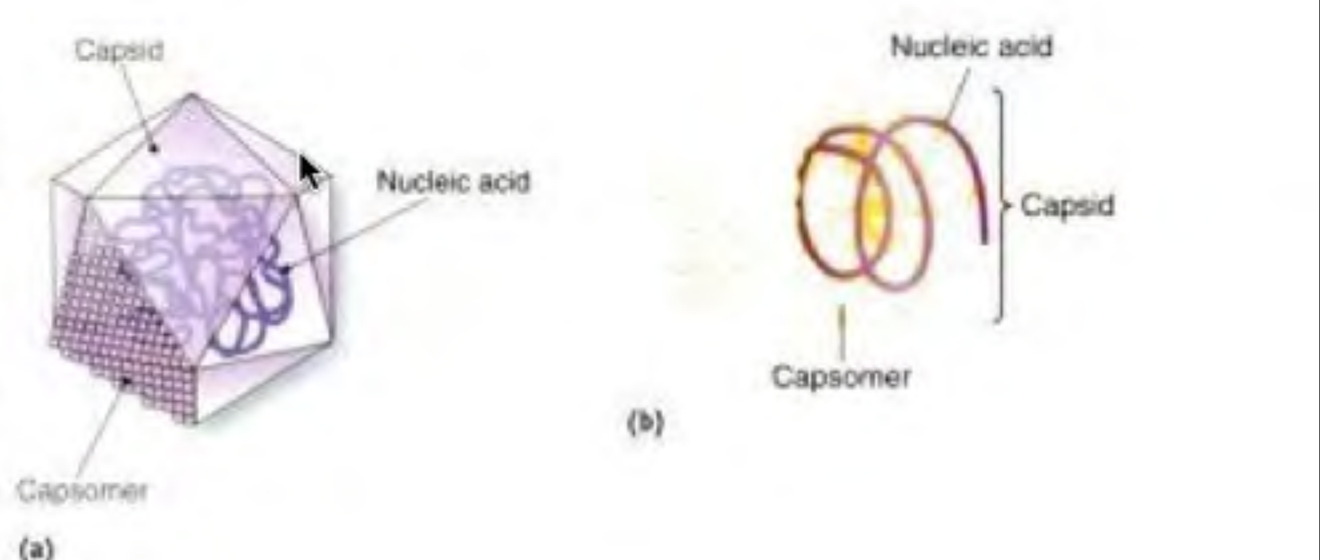
Nanometers 10^{-9}

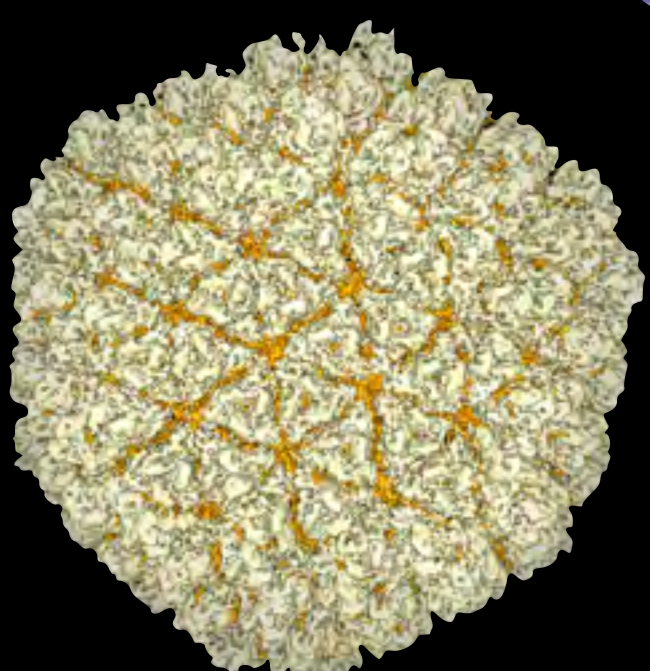
HIV 130nm



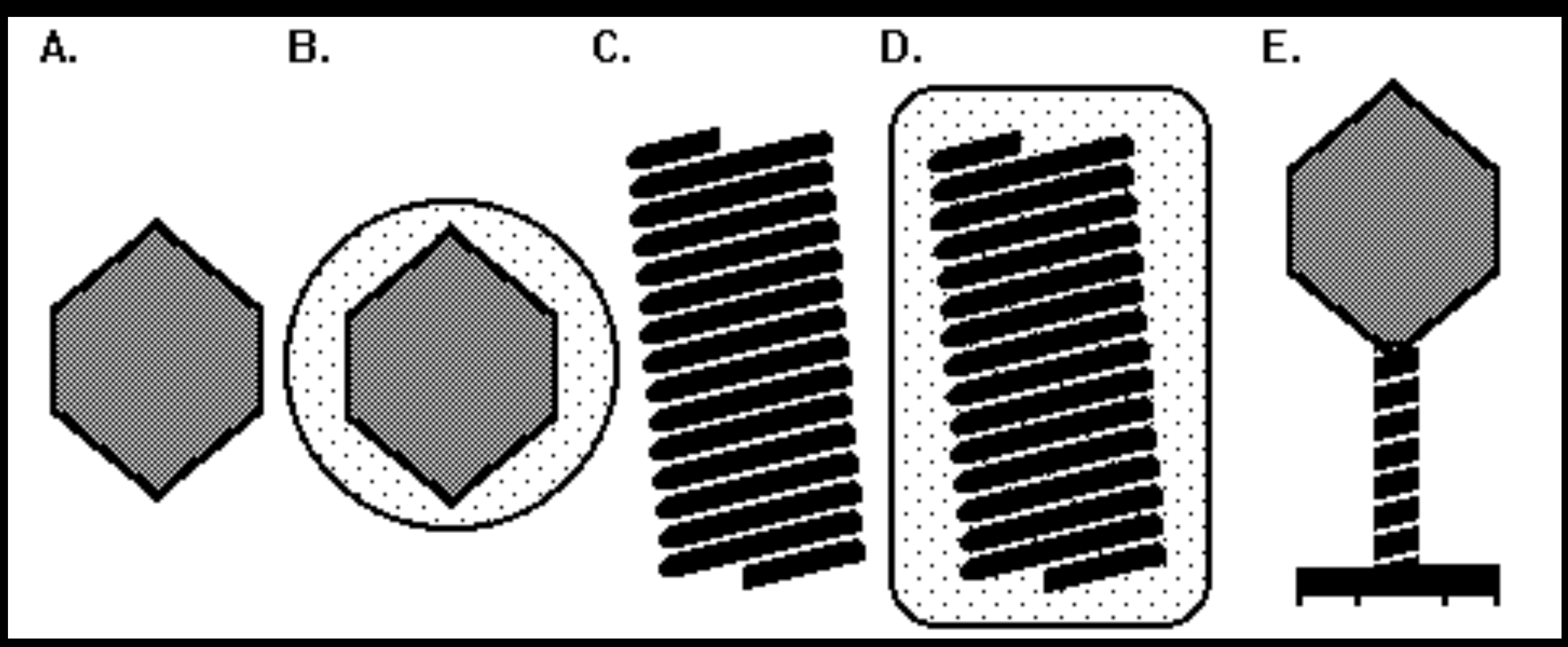
Polio



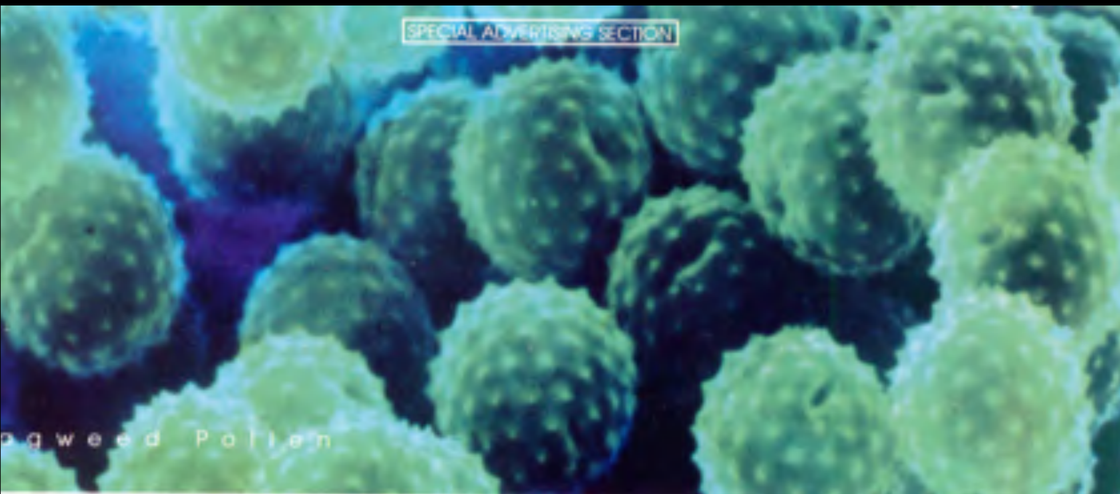




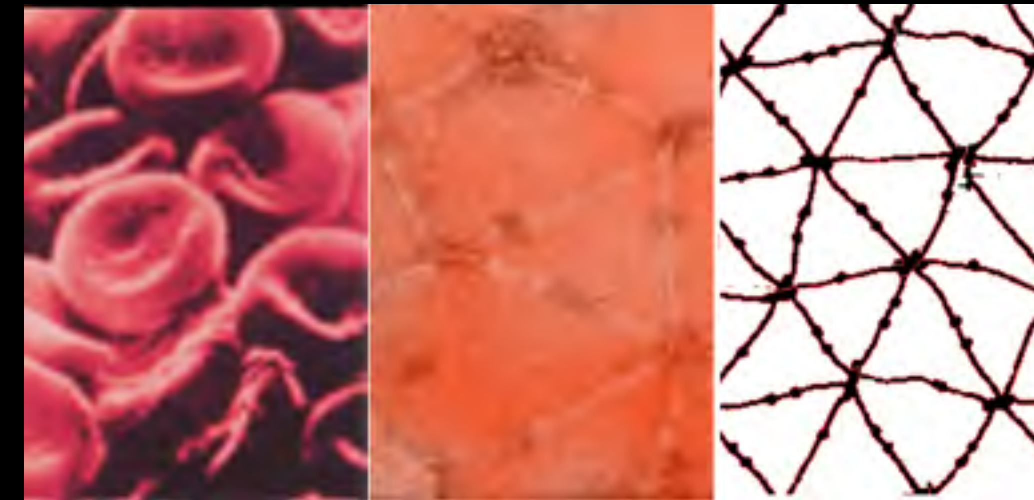
Dwarf Rice



Micrometer 10^{-6}



Pollen 10-25 μm

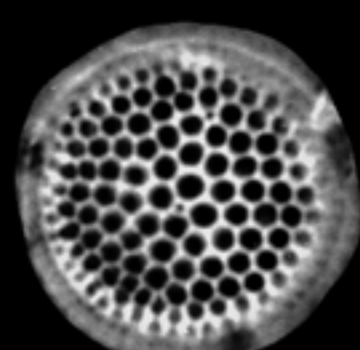


RBC 8 μm

Leucocyte 7-9 μm

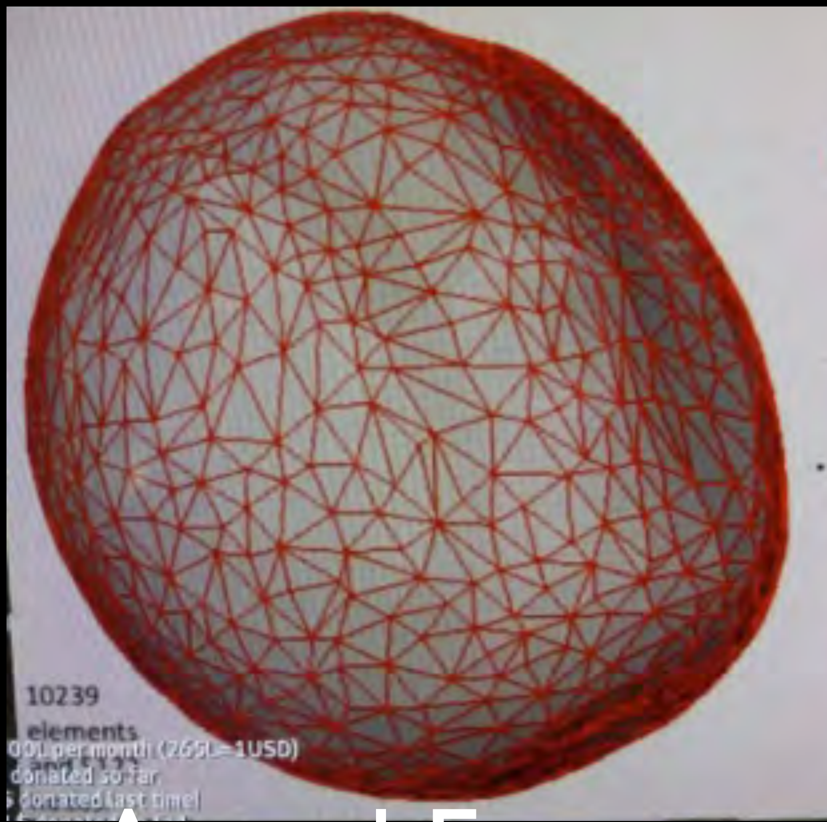
700million YO
Eukariote Cells 30 μm

Volvox 250-500μm



Diatom 10-150 μm

Milimeter 10^{-3}

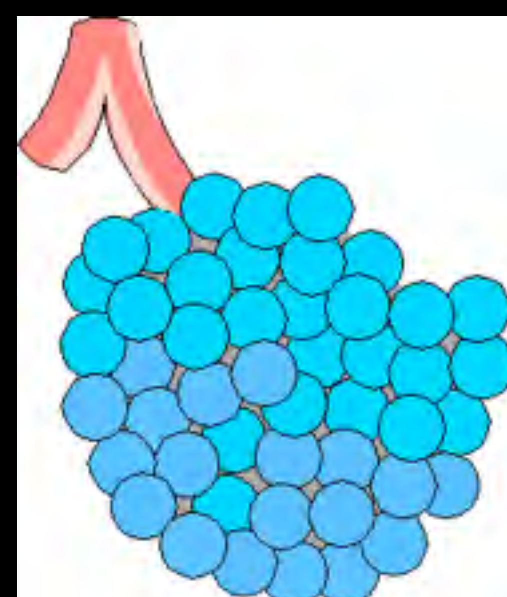


Atoxyl Egg

Fly Eye

L'équilibre doit être maintenu
Equilibrium must be maintained

Fascia

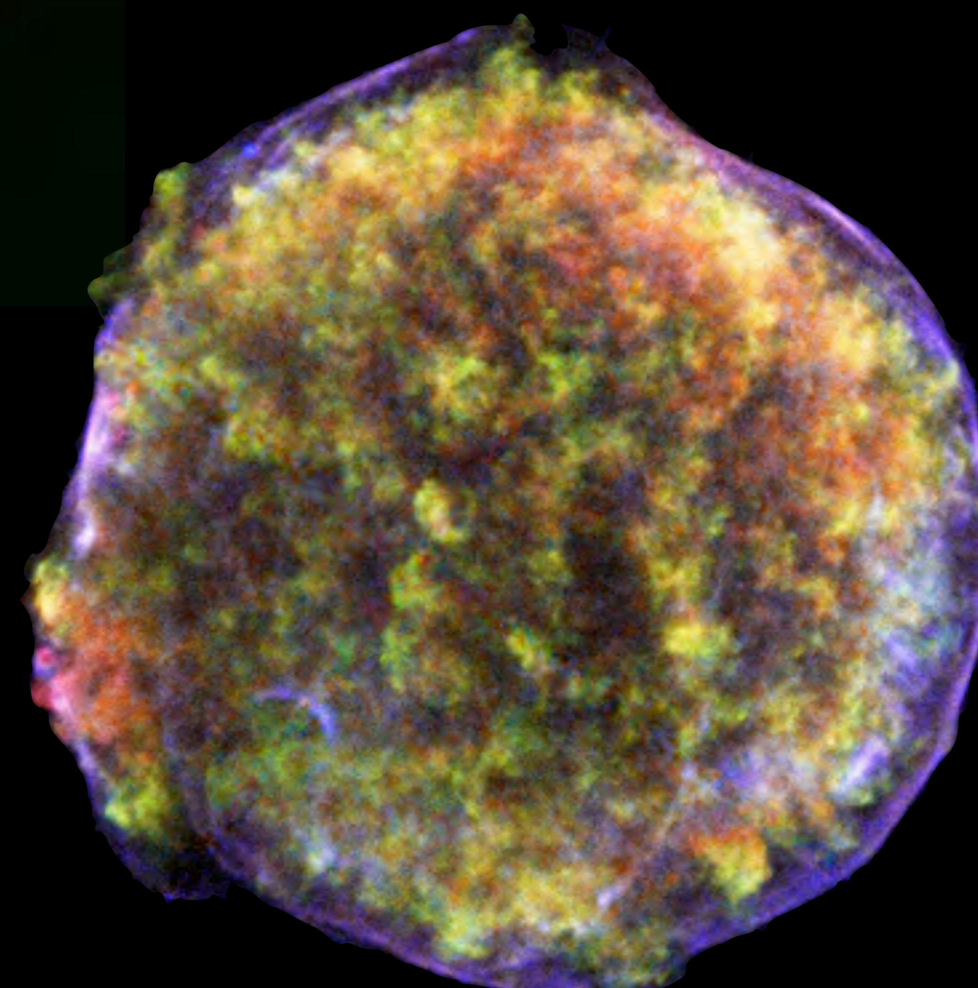


Lung

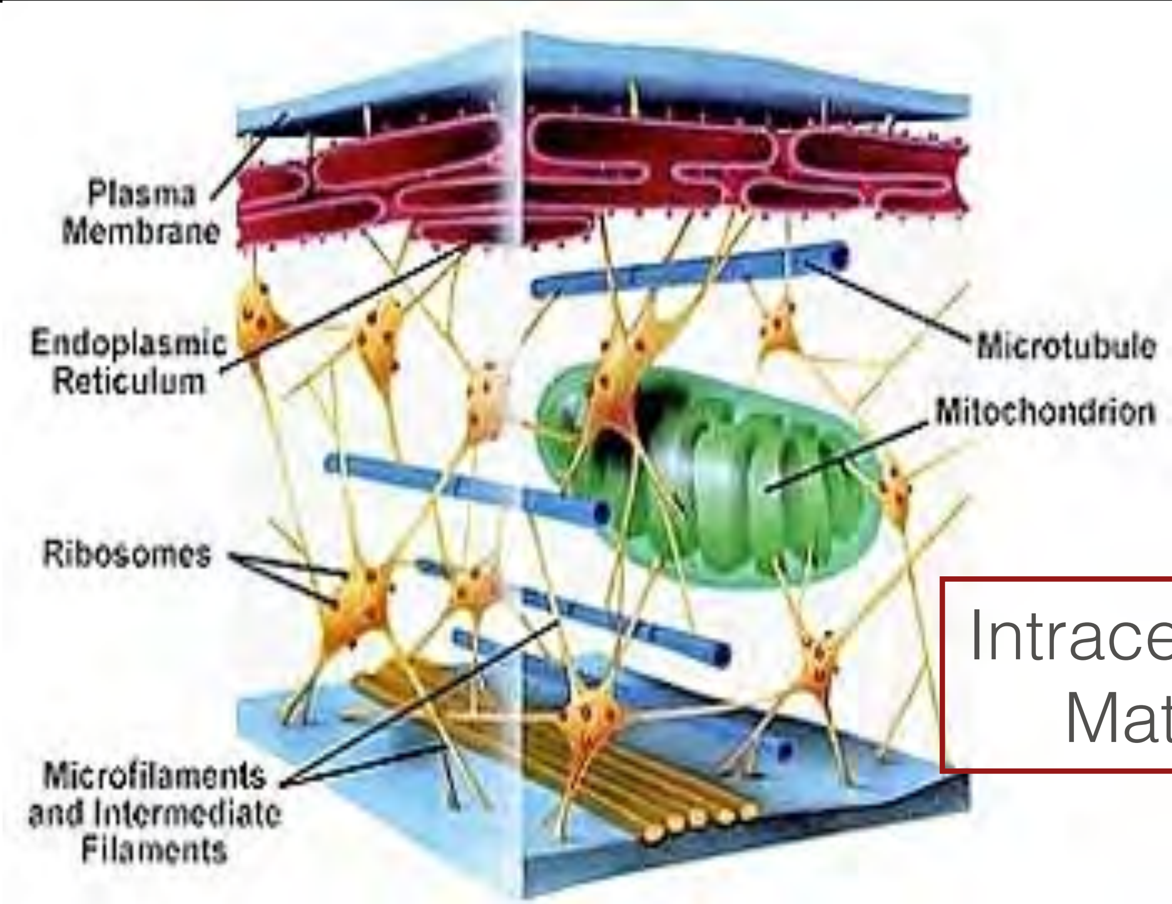
Angel Fish Ovary

CM +

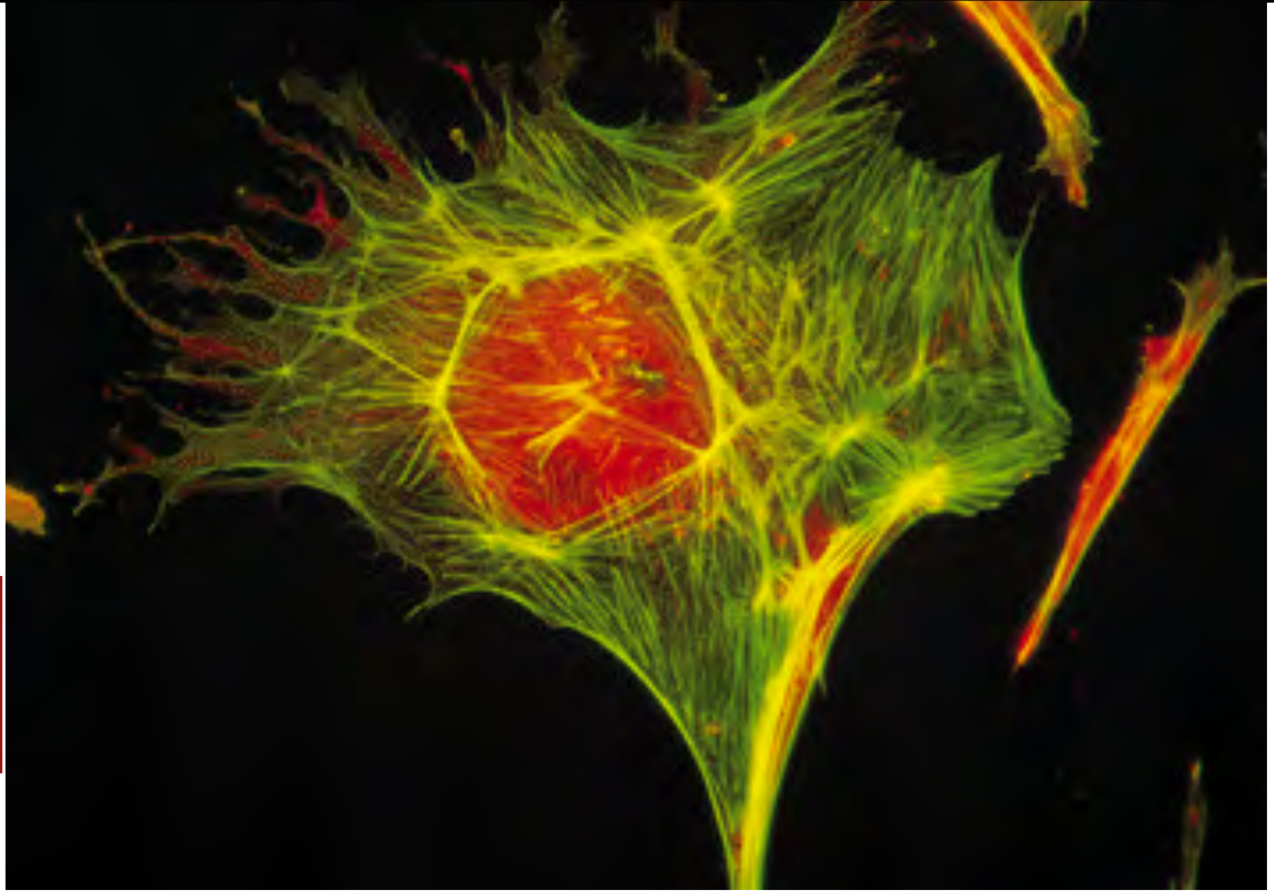
Giant Amoeba



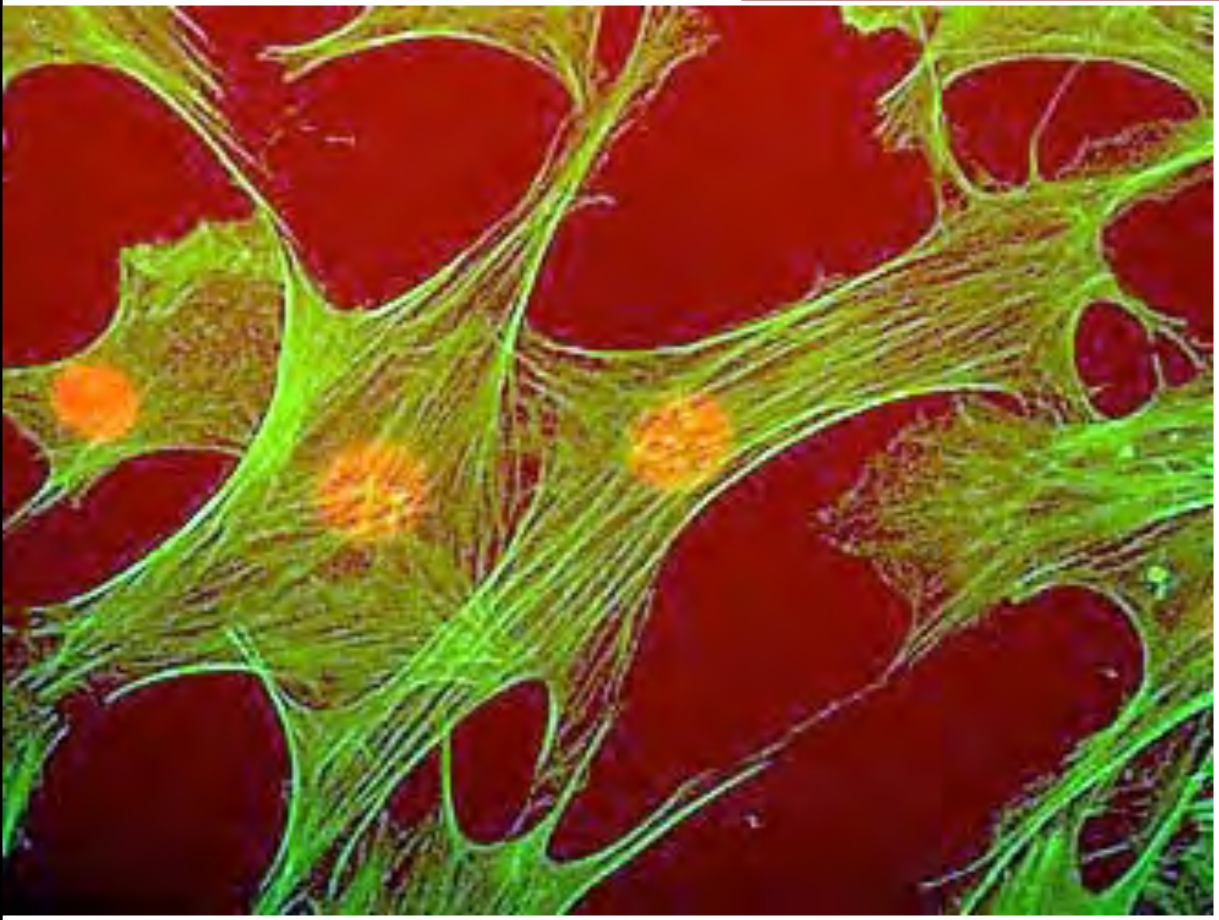
Tyco supernova



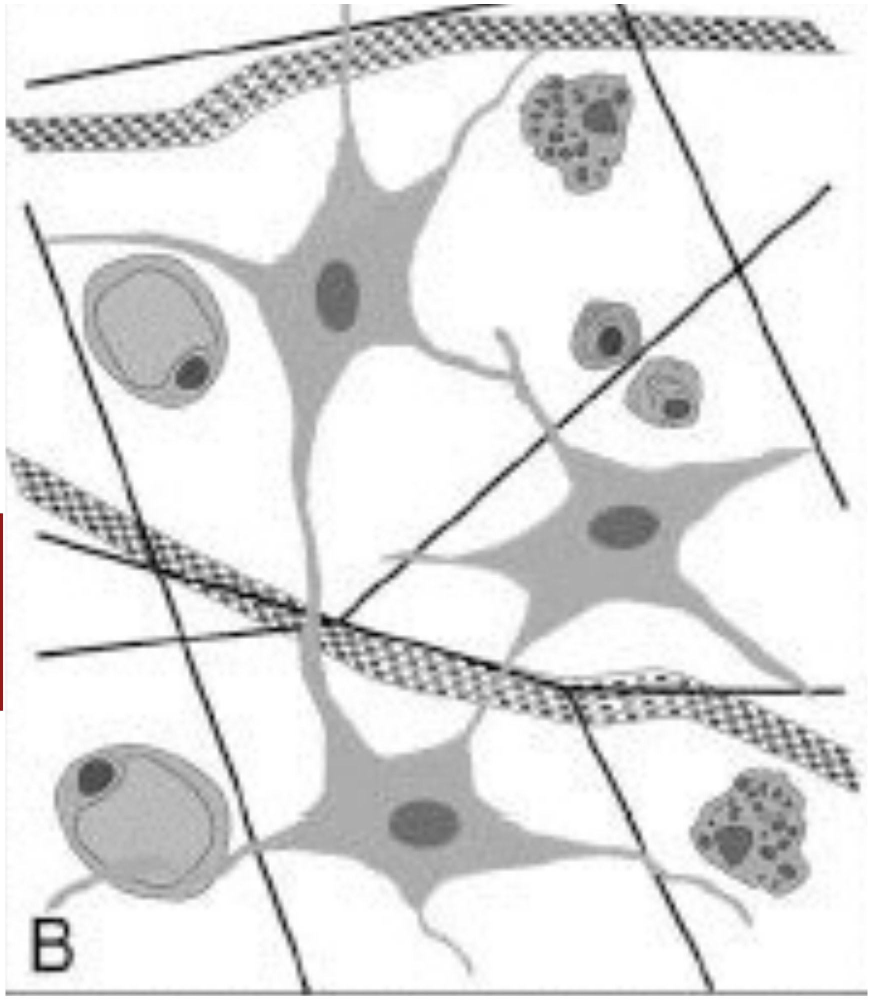
Intracellular Matrix



HIERARCHY



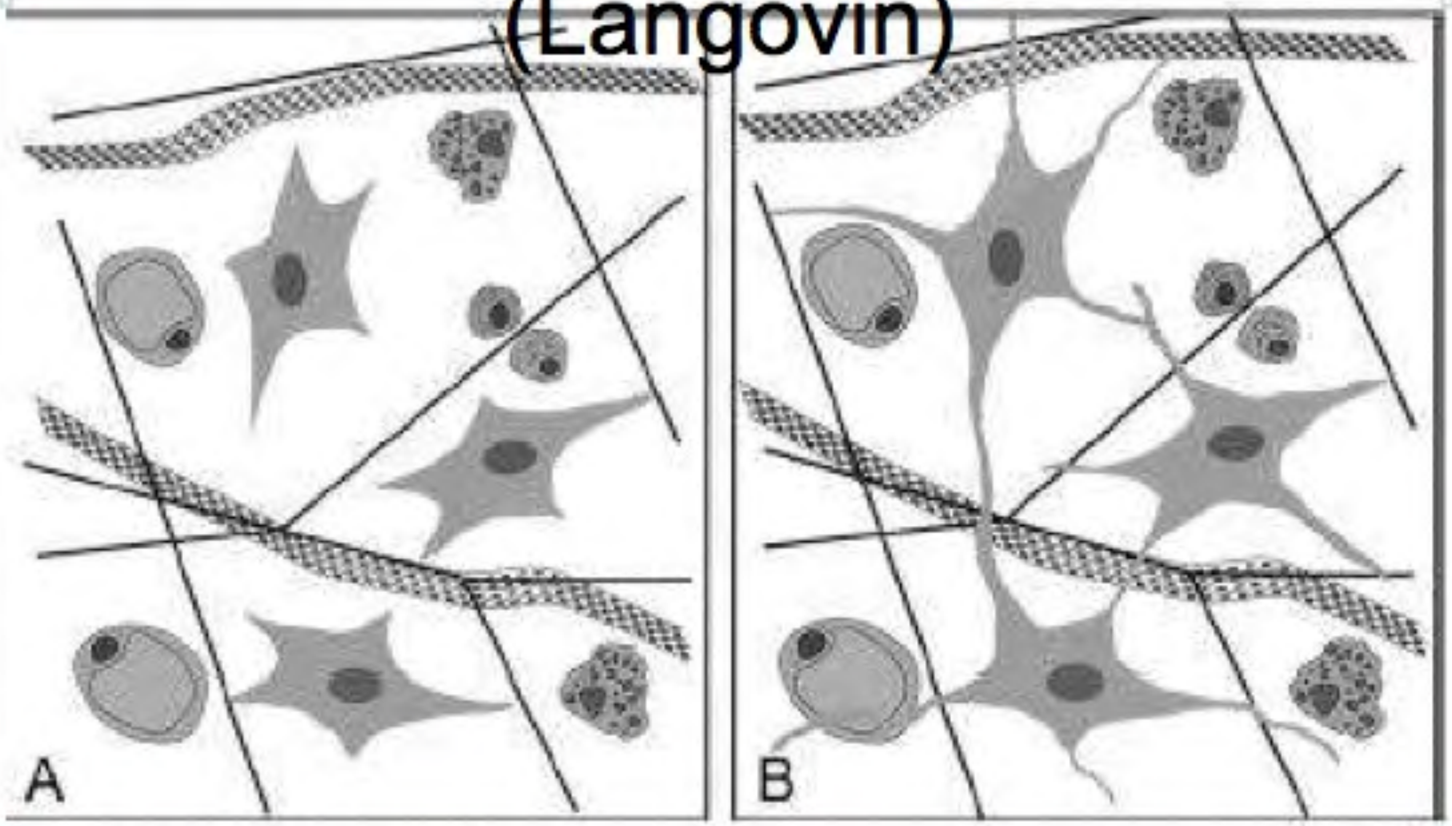
Extracellular Matrix



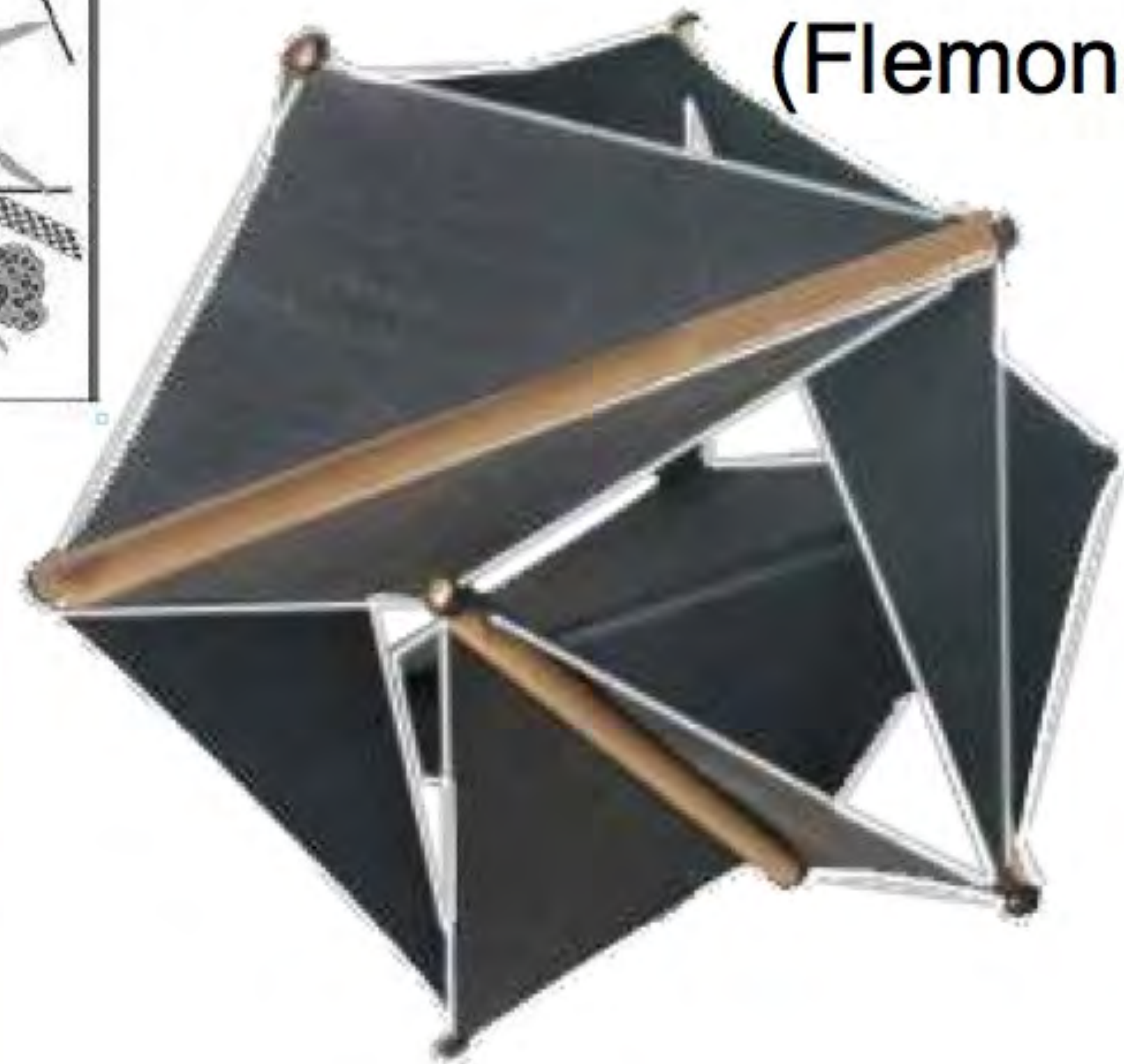
ECM (Langevin)

ECM/Fibroblasts/Fascia

(Langovin)

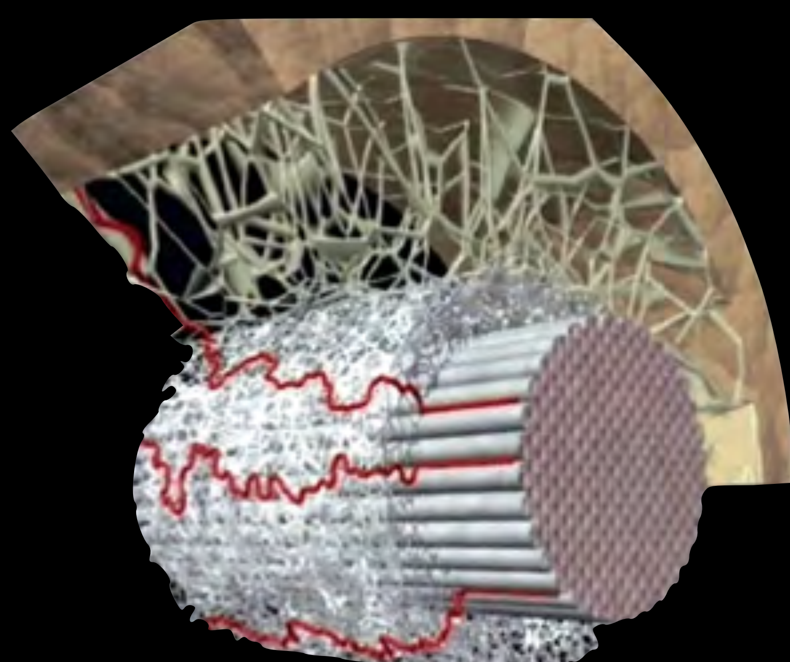


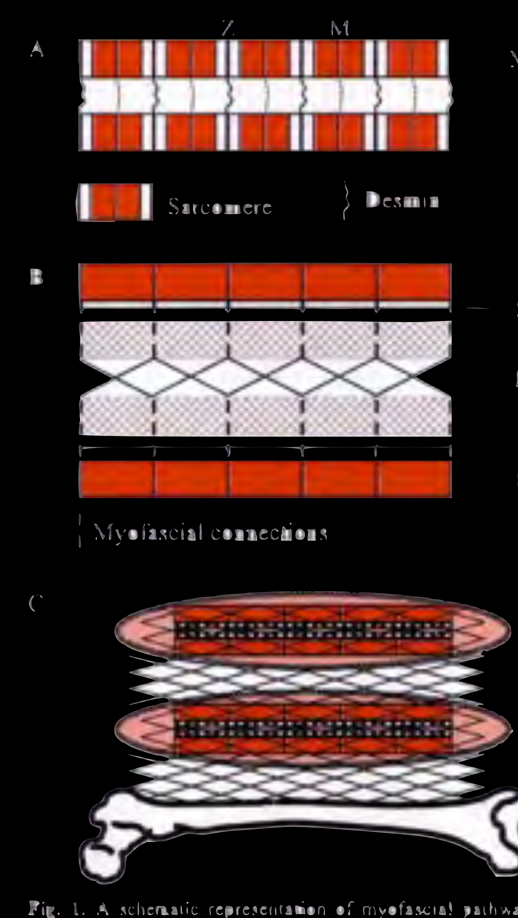
(Flemons)



(Guimberteau)

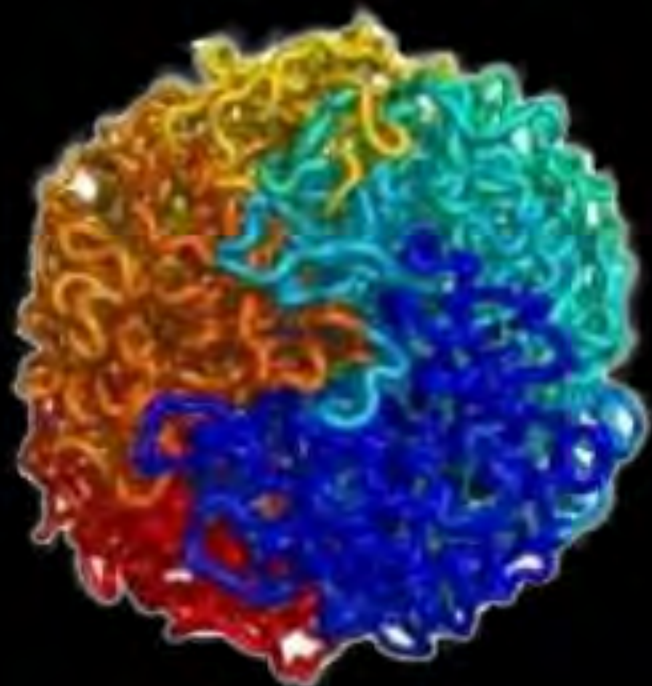

Thom

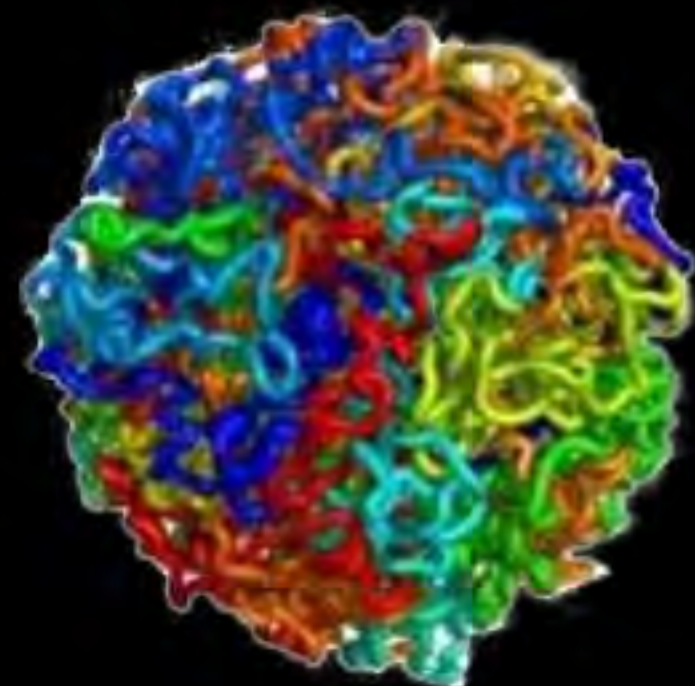


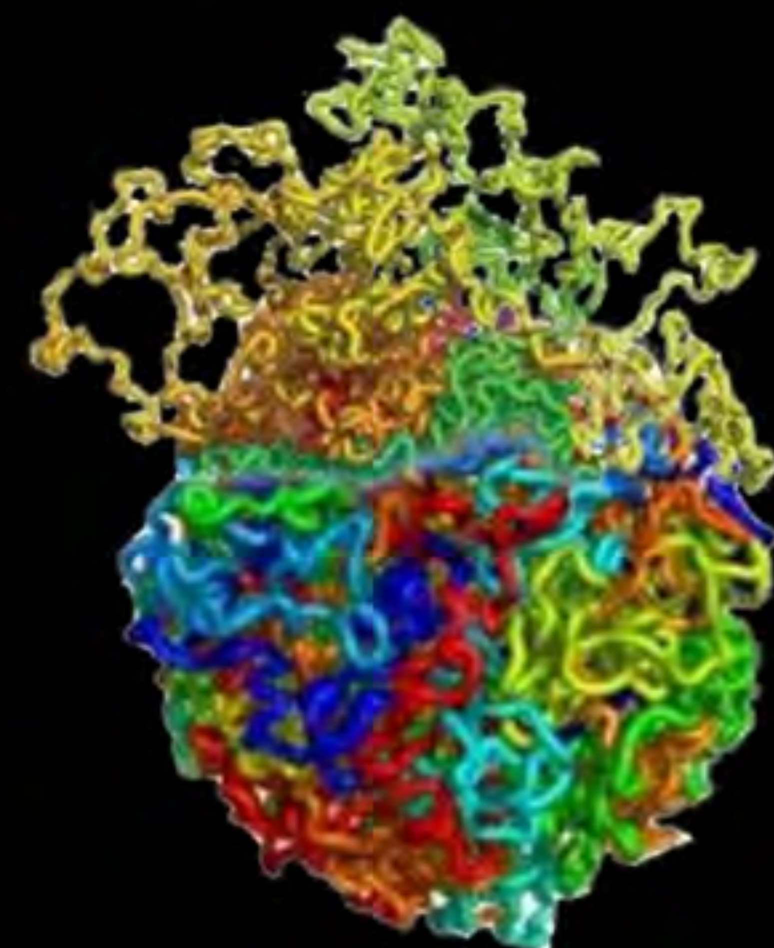

A
Z
M
Sarcomere
Desmin
B
Myofascial connections
C
Fig. 1. A schematic representation of myofascial pathway

THE FRACTAL NUCLEUS

Krawetz







A CONTINUOUS STRUCTURE

Comprehensive mapping of long-range interactions reveals folding principles of the human genome. Lieberman-Aiden E, et al. Science. 2009 Oct 9;326(5950):289-93.

Independent of Scale

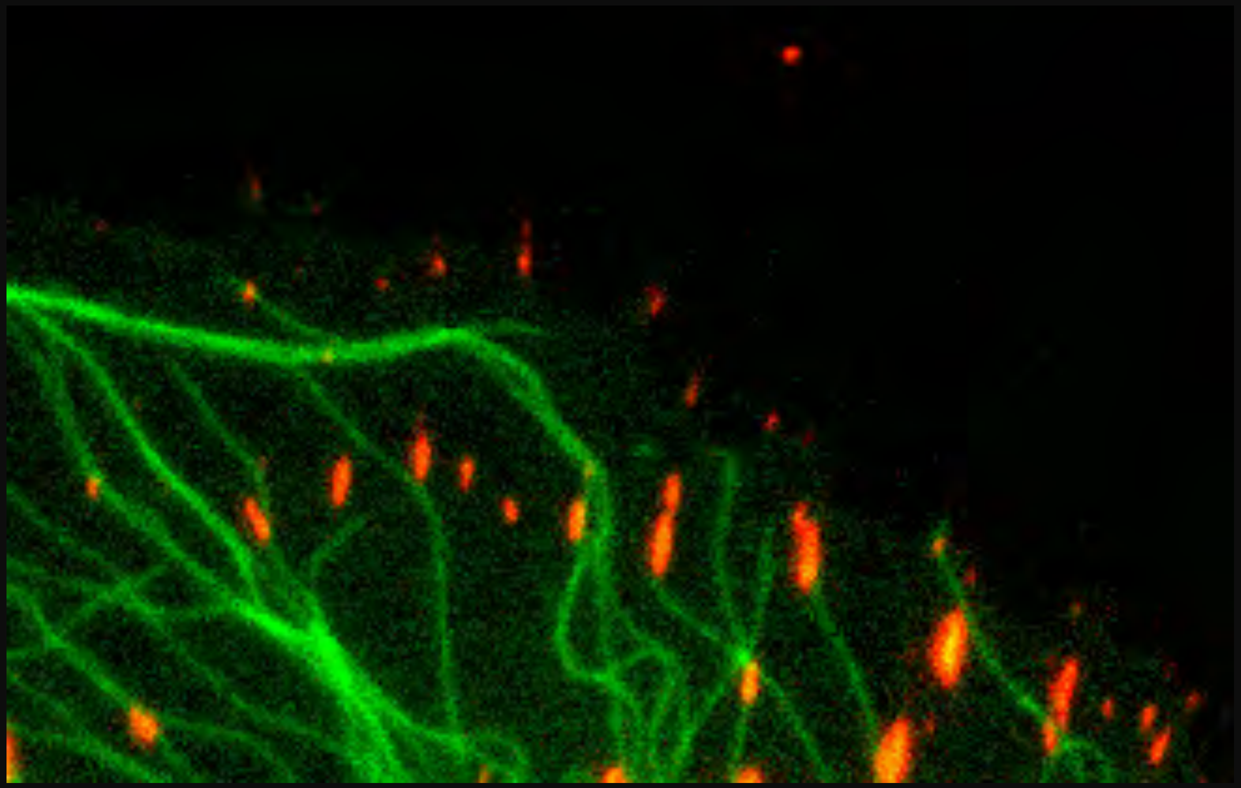
Tensegrity Described in:

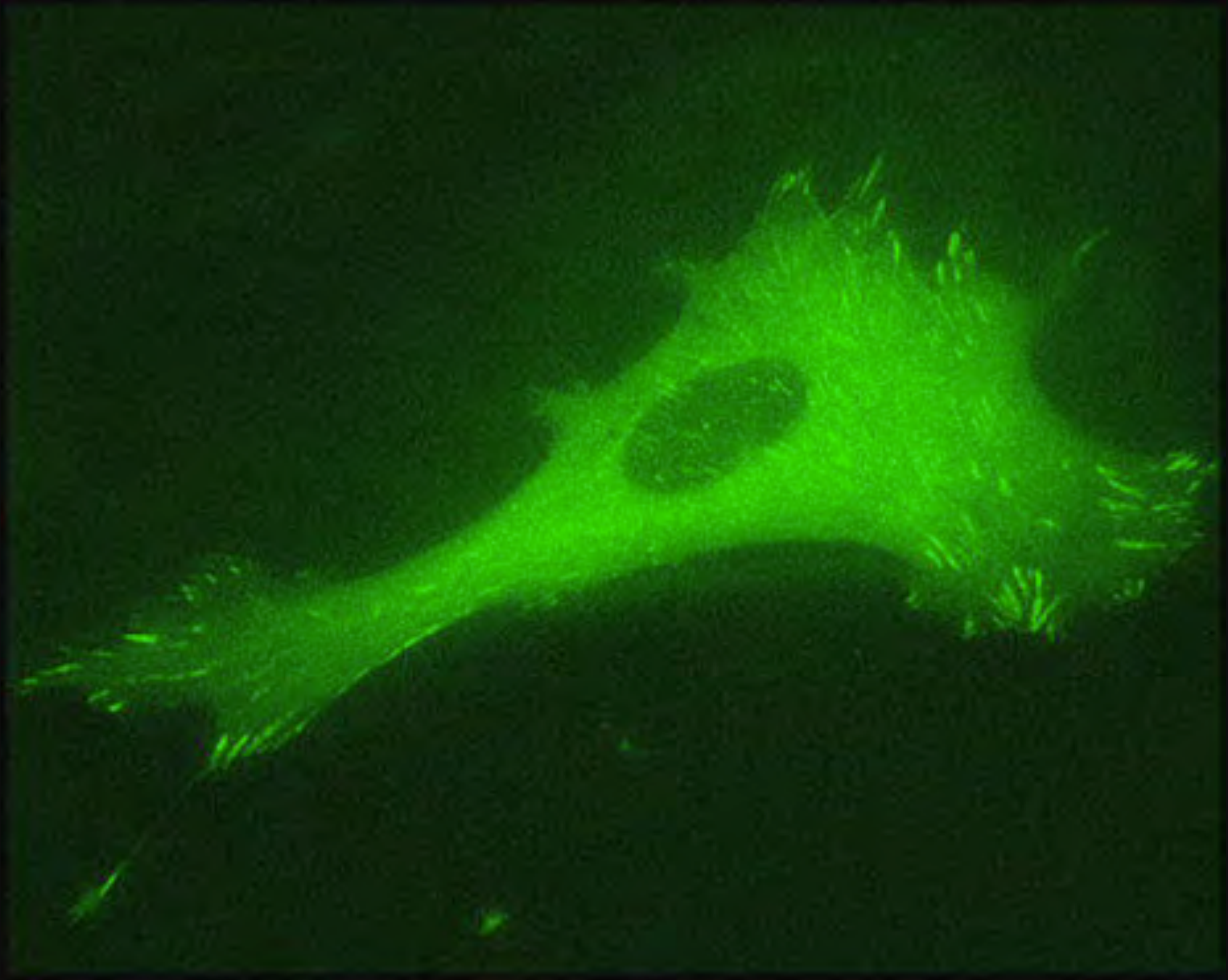
Lung	Liver
Eye	Intestine
Heart	Nerve
Kidney	Brain
Muscle	Thyroid
Bone	Skin
Nose	Fascia

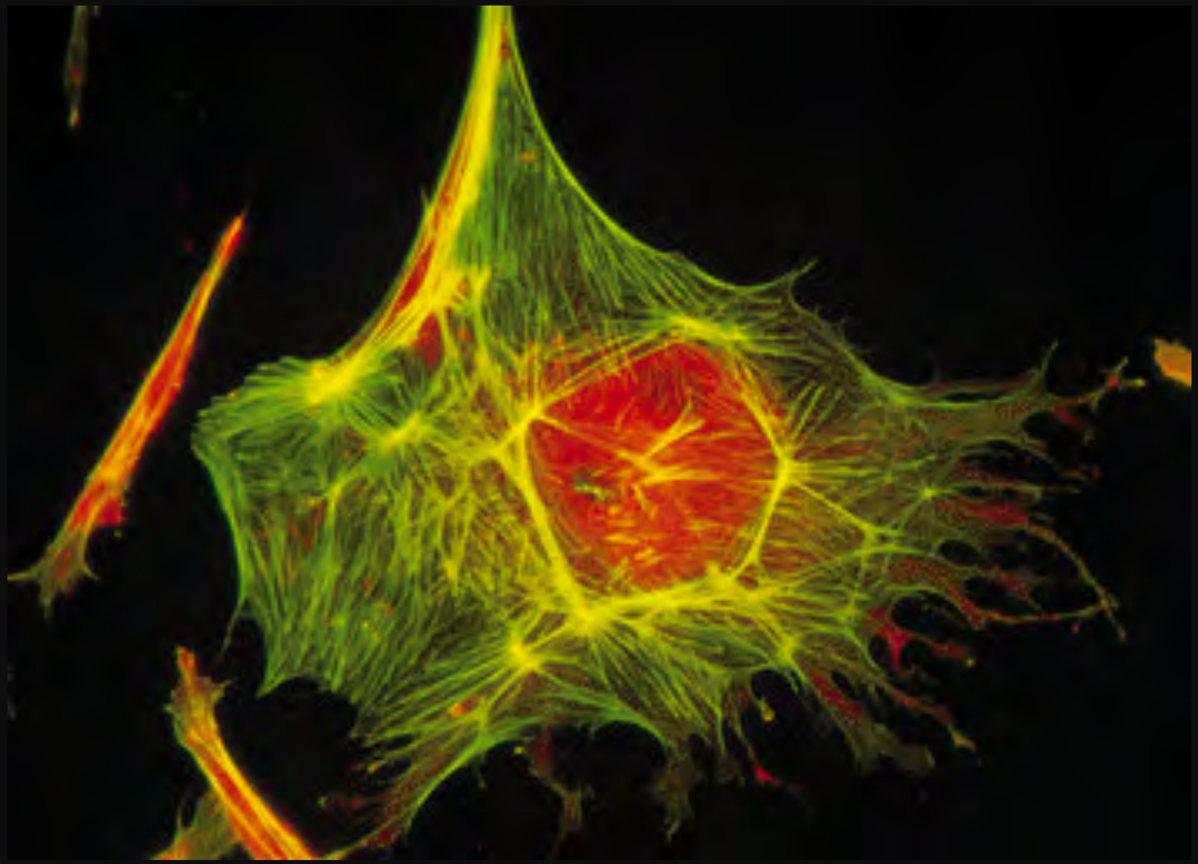
Cellular tensegrity: defining new rules of biological design that govern the cytoskeleton
Donald E. Ingber* Journal of Cell Science 104, 613-627 (1993)

Stephen Levin 1981
Donald Ingber 1985

2014
6,000 Articles
Tensegrity, Biology

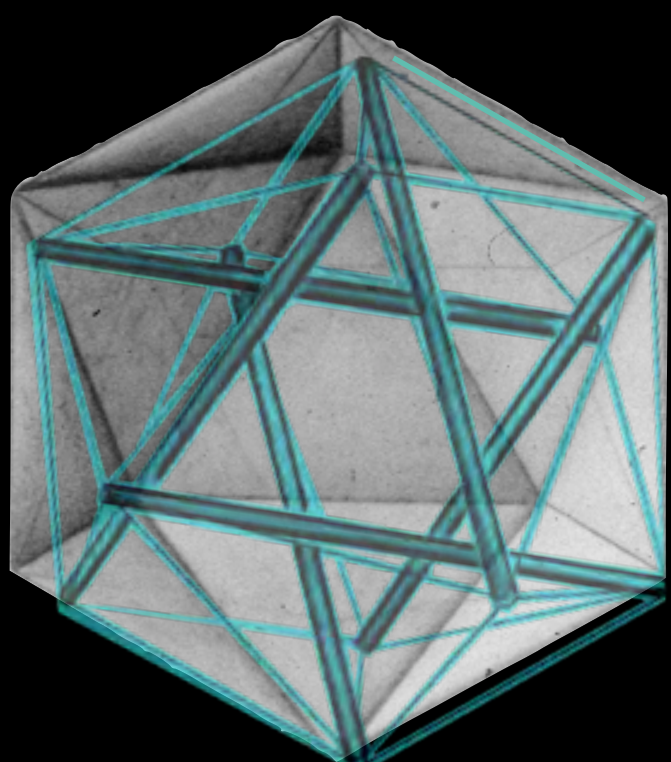




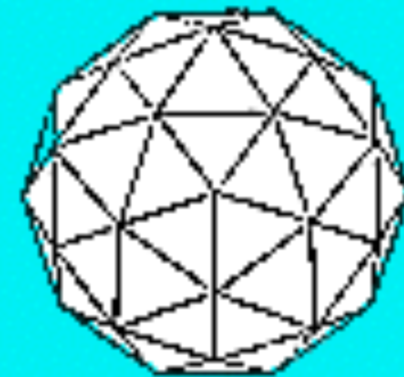


THE SRANGE ATTRACTOR

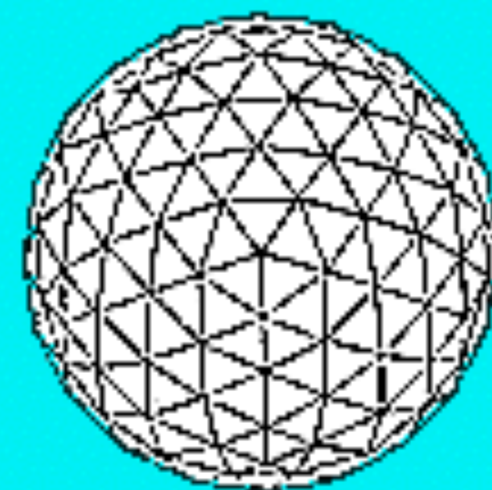
FRACTAL GENERATOR



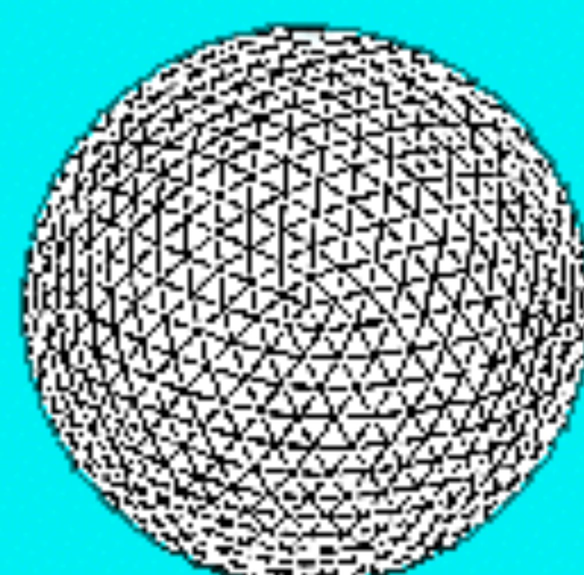
Exo/Endo-
Skeletal



Regular Geodesic Two-Frequency Icosahedron

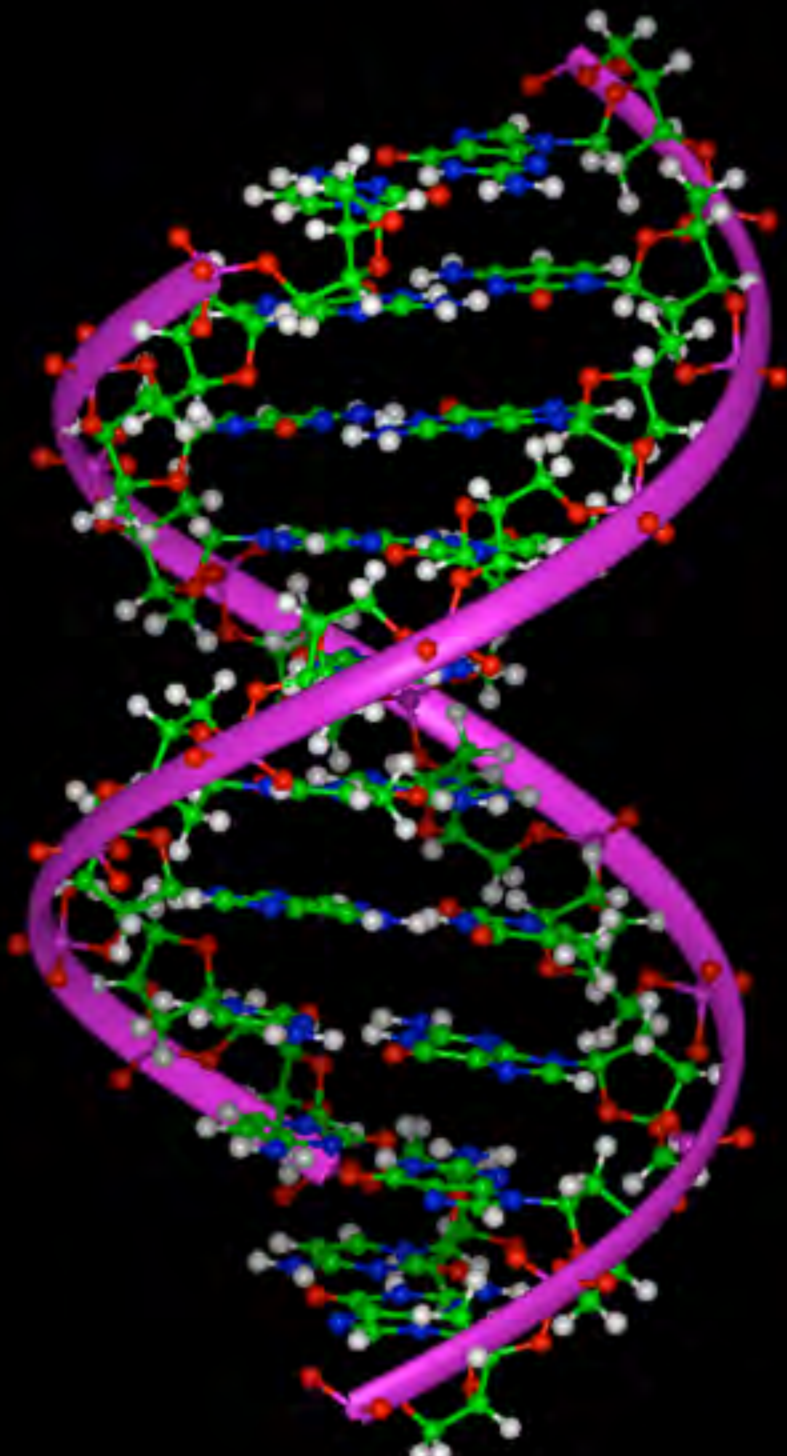


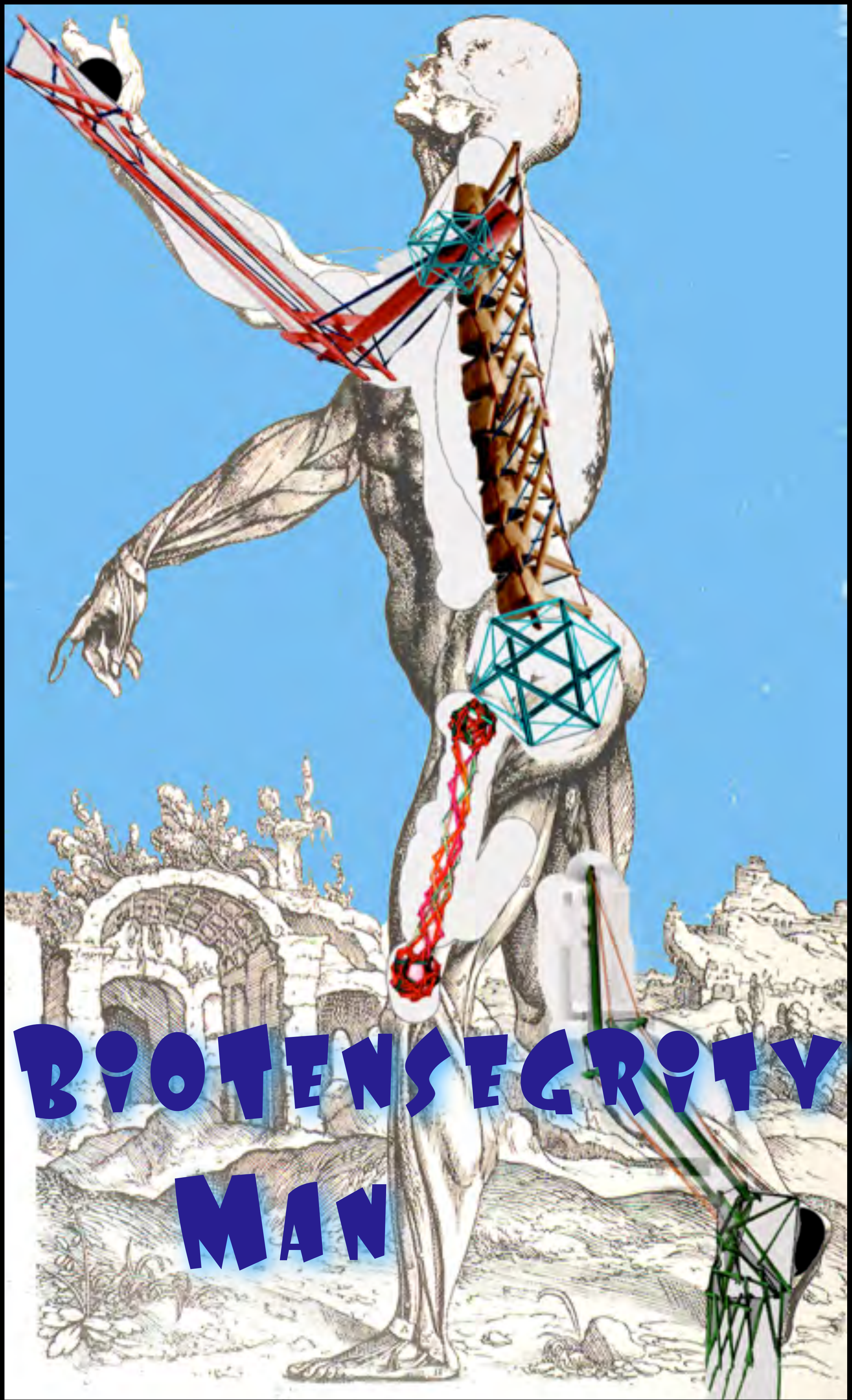
Regular Geodesic Four-Frequency Icosahedron

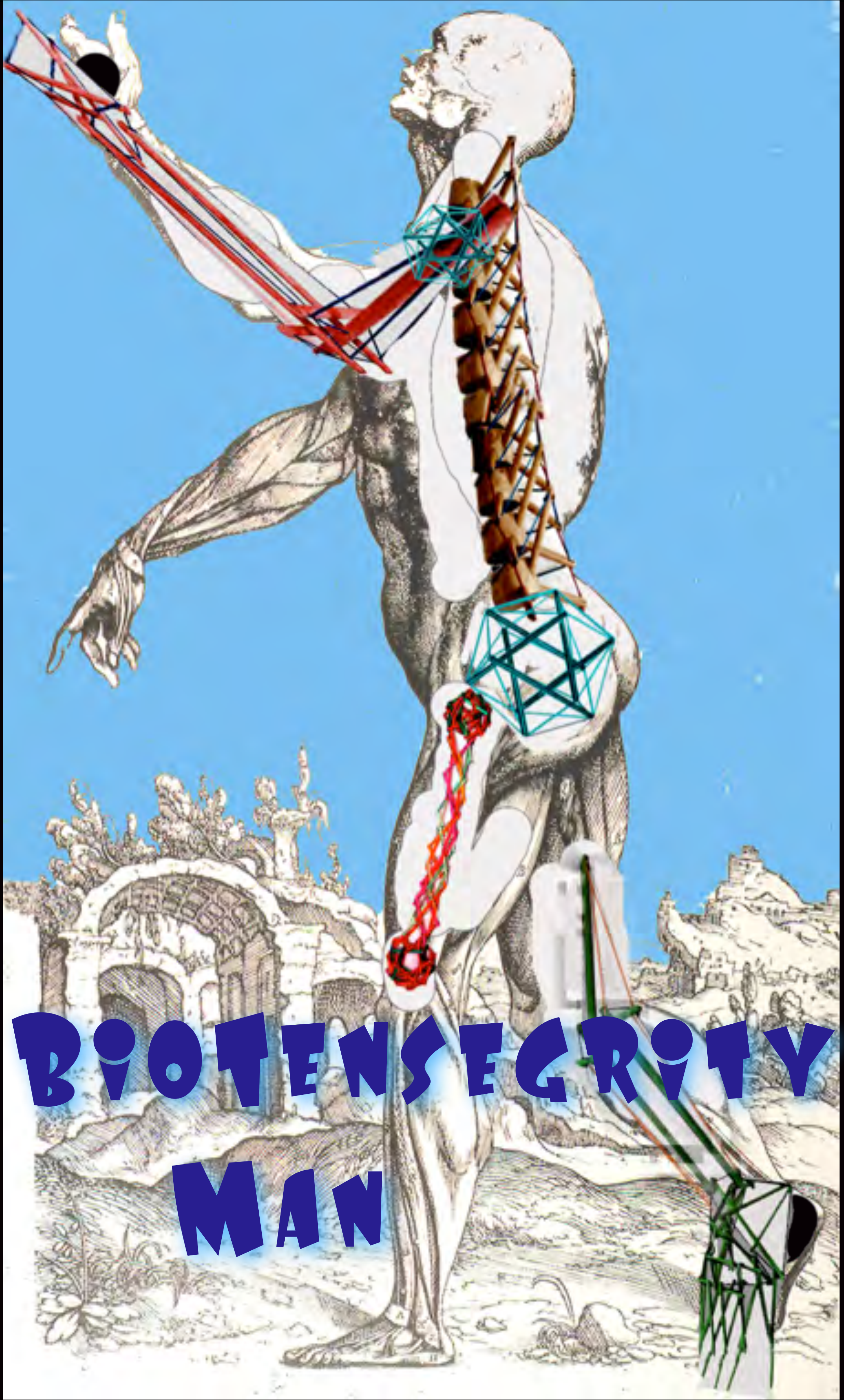


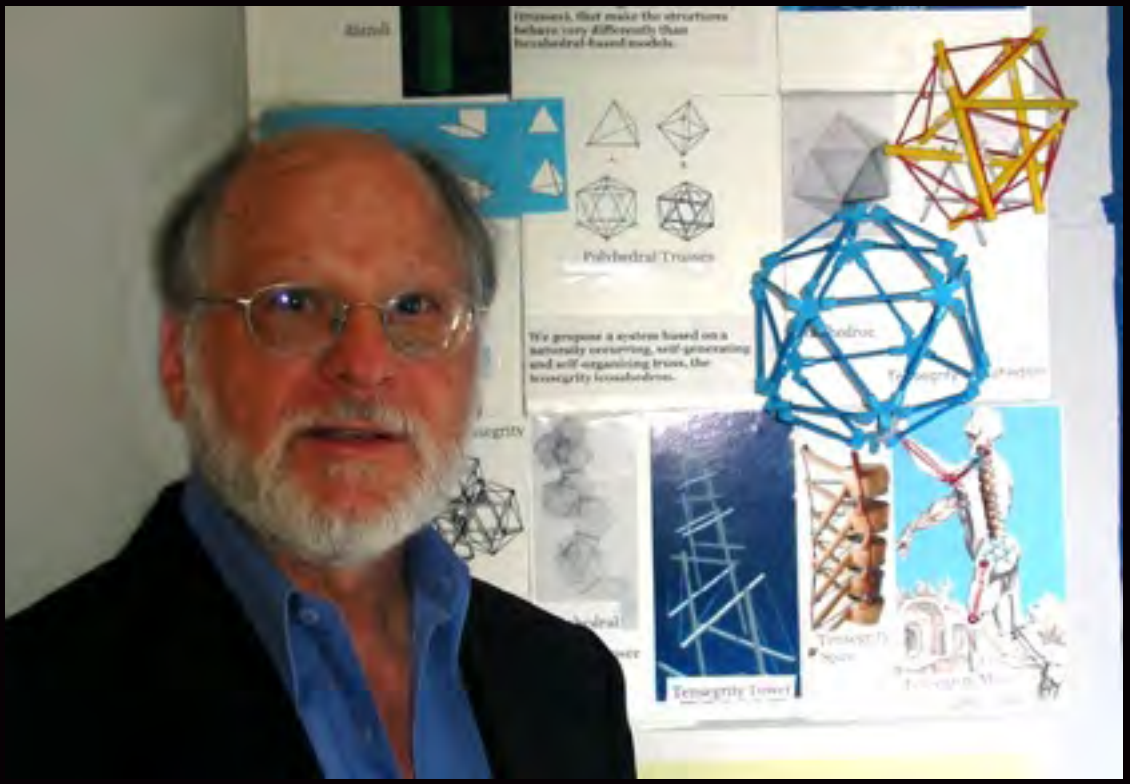
Regular Geodesic Nine-Frequency Icosahedron

Levin, SM. **The Primordial Structure**
34th Meeting of The International Society for the Systems Sciences.
pp 716-720 1990, Portland




BioTensegrity
Man





Thank you !

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McLean, Virginia 22102

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www.biotensegrity.com