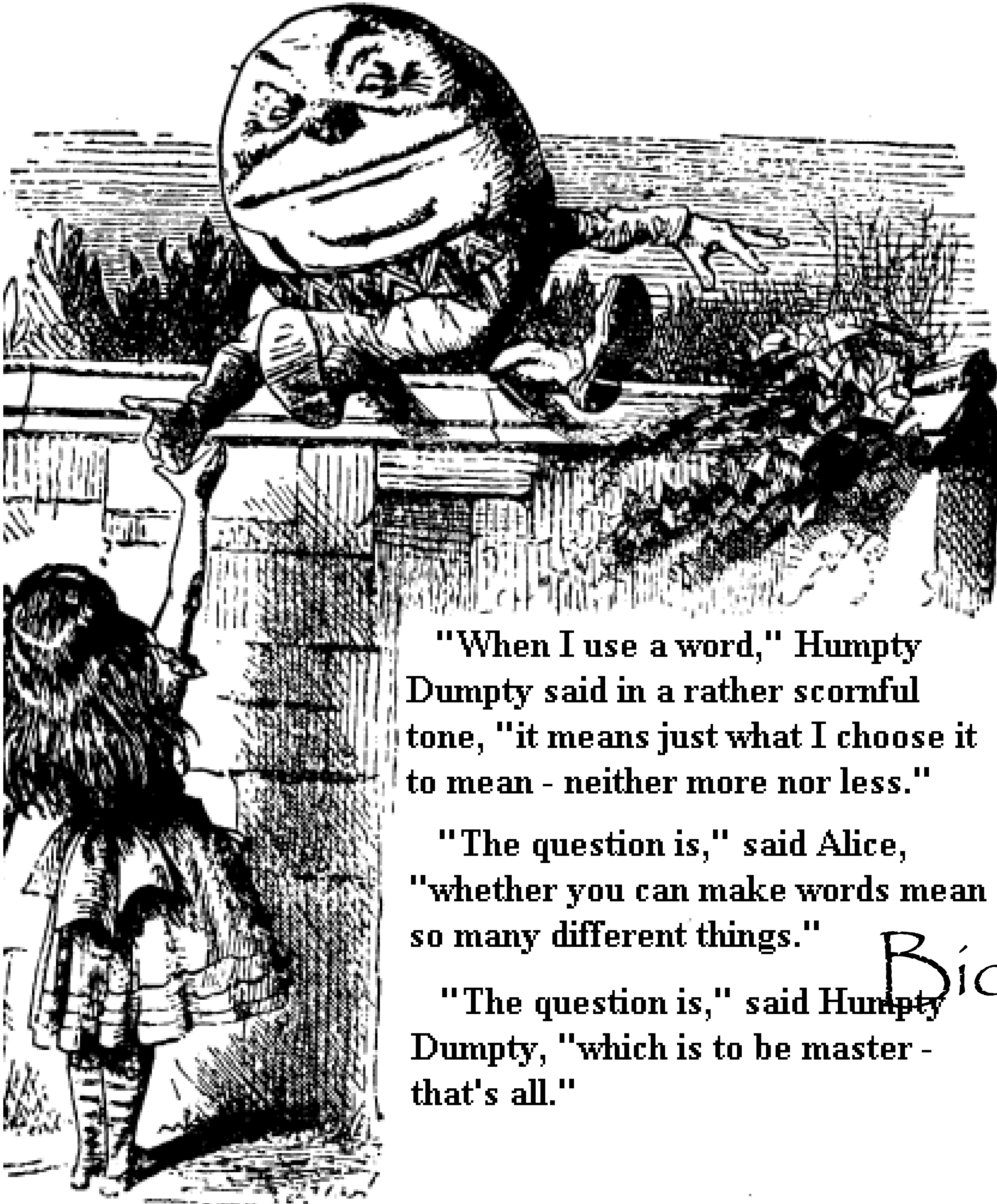
What's in a name?



"When I use a word," Humpty Dumpty said in a rather scornful tone, "it means just what I choose it to mean - neither more nor less."

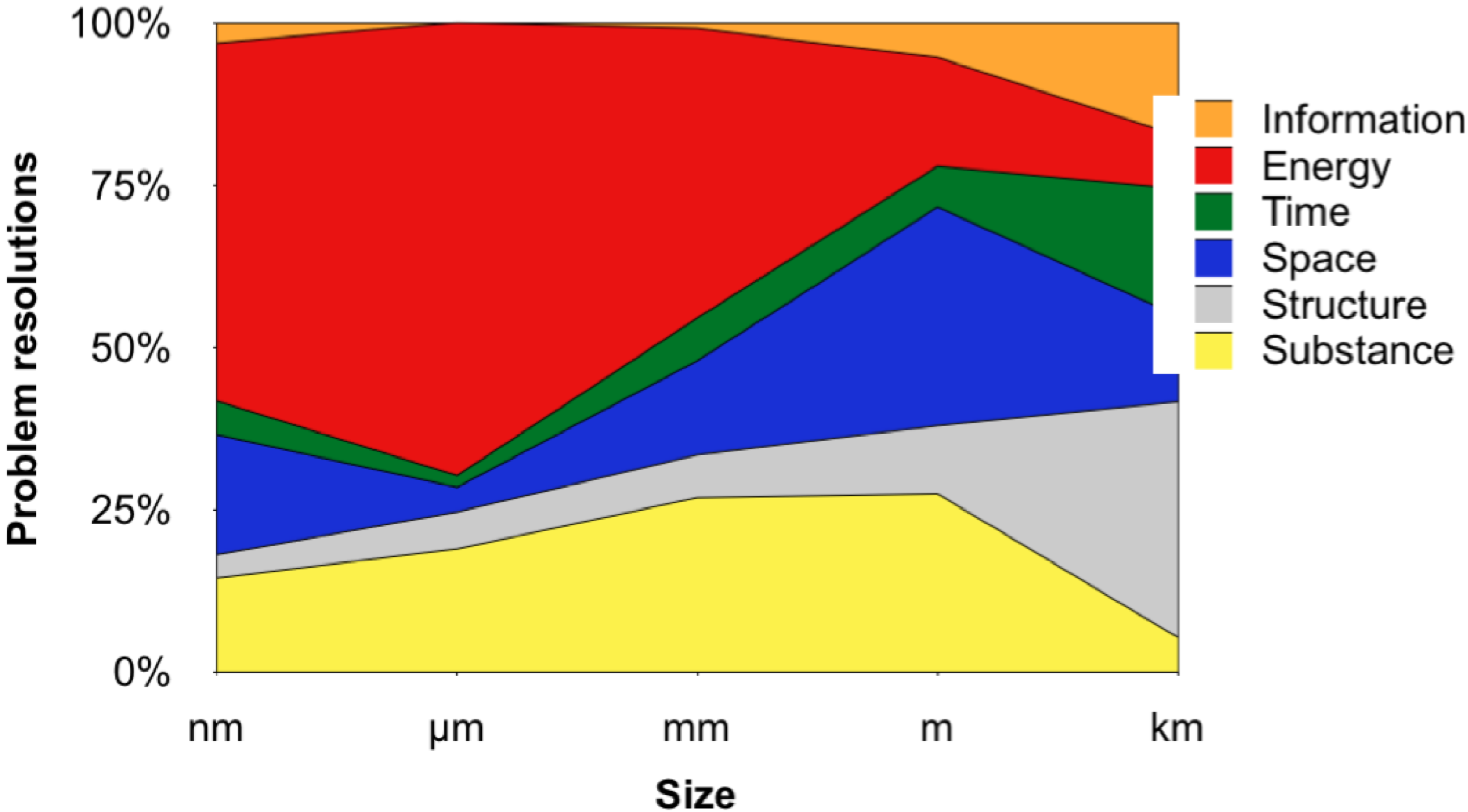
"The question is," said Alice, "whether you can make words mean so many different things."

"The question is," said Humpty Dumpty, "which is to be master - that's all."

Bionics
Bionique
Biognosis
Biomimicry
Biomimetics
Bio-inspiration
Bio-inspired design

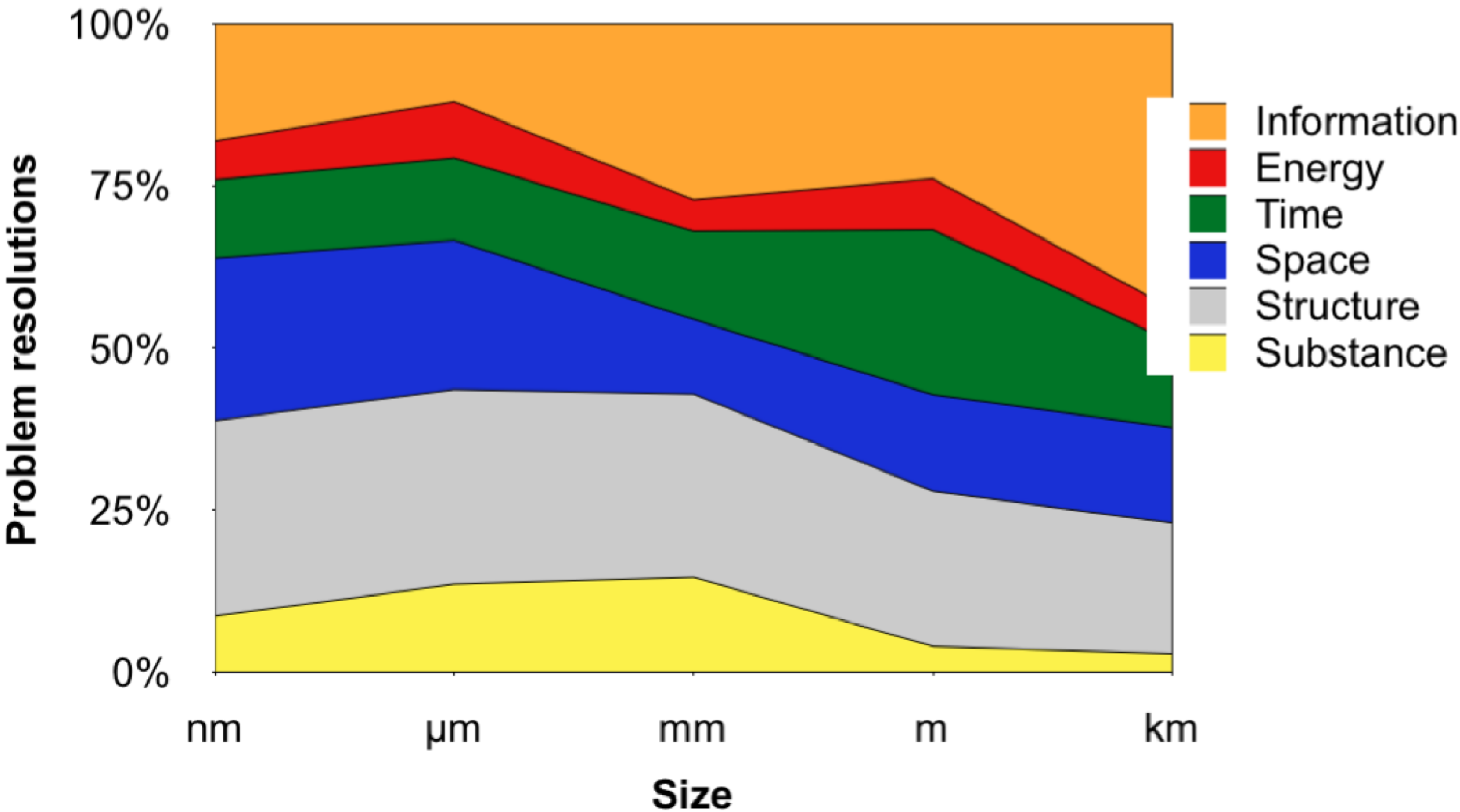
Biological mechanisms are obviously sustainable within the constraints of spaceship Earth, so biomimetics can provide a paradigm for the survival of a technical culture. Since natural selection has provided the quality control, this abstraction is also a compendium of best practice. A comparison of biology and technology should therefore provide formulations for truly sustainable technology.

Solving problems the technological way

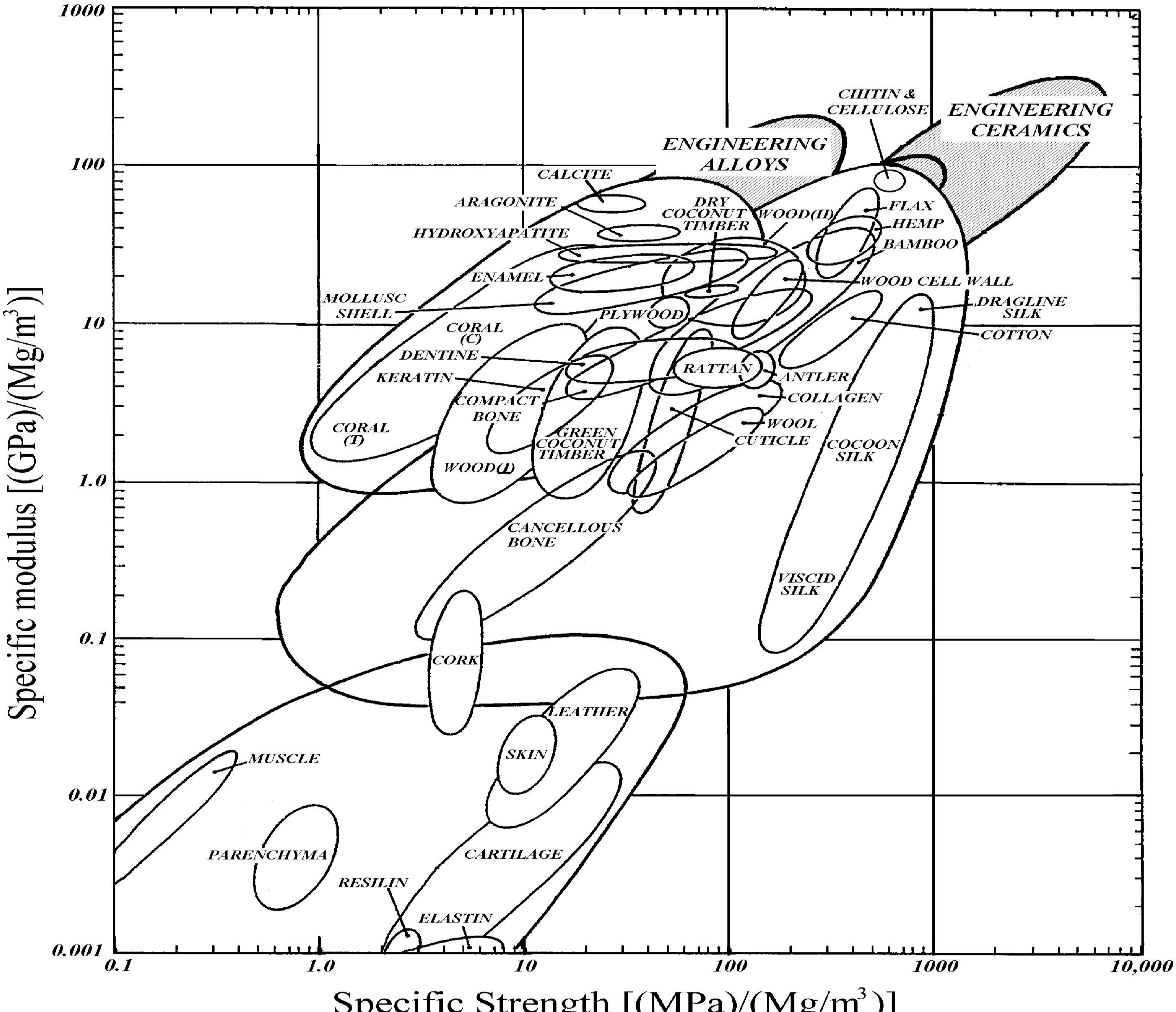


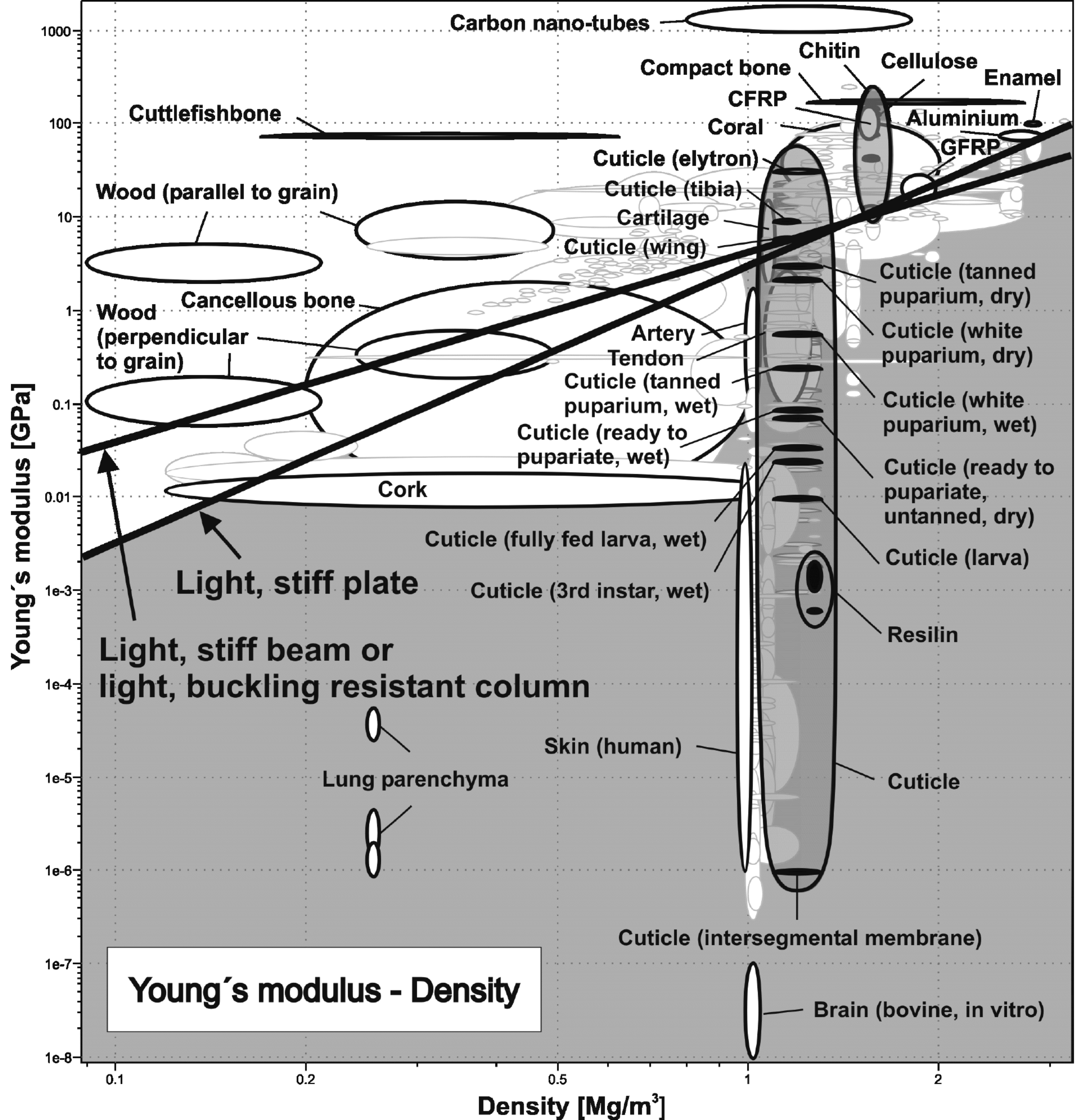
Vincent et al. (2006) RSJ Interface 3: 471-482

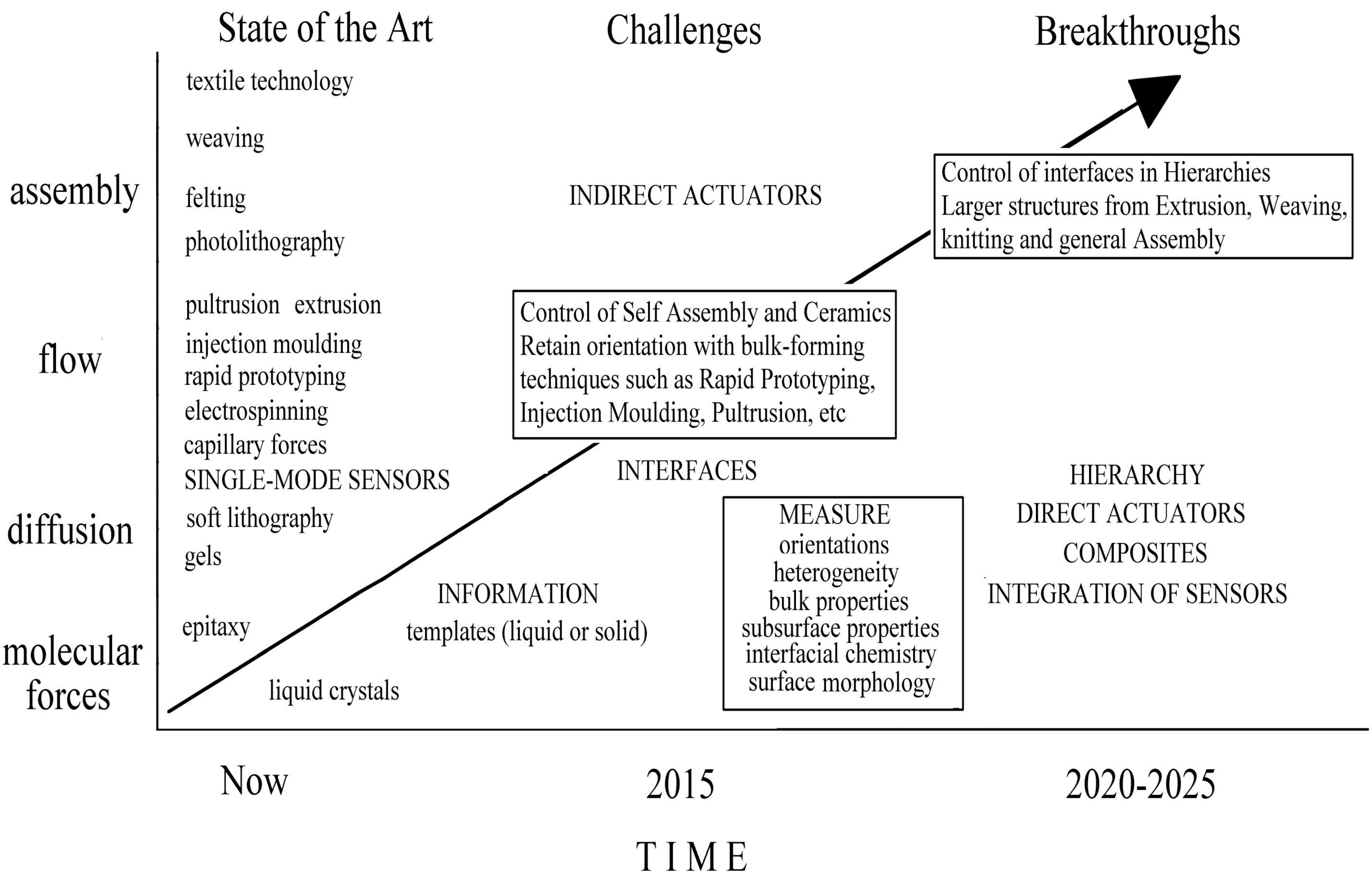
Solving problems the biological way



Vincent et al. (2006) RSJ Interface 3: 471-482

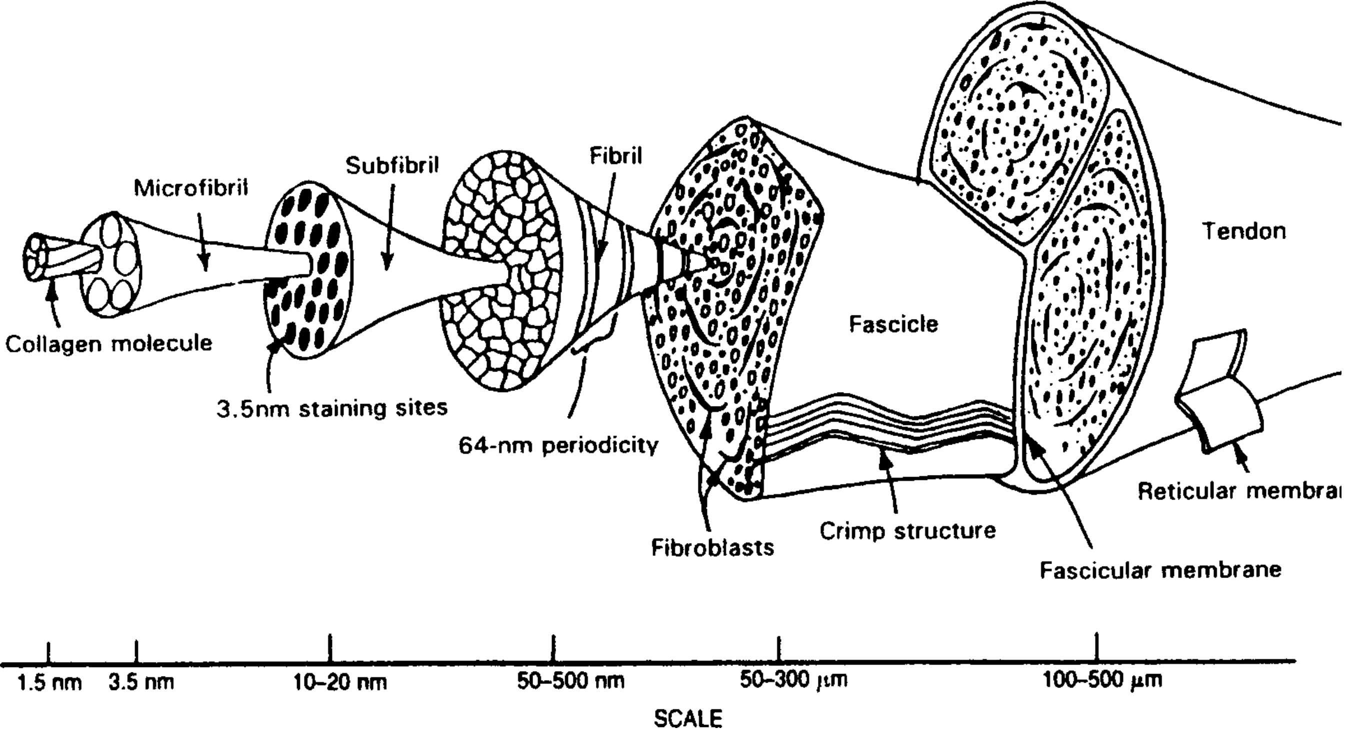

ENGINEERING CERAMICS
CHITIN & CELLULOSE
ENGINEERING ALLOYS
CALCITE
ARAGONITE
HYDROXYAPATITE
DRY COCONUT TIMBER
WOOD(II)
FLAX
HEMP
BAMBOO
WOOD CELL WALL
ENAMEL
MOLLUSC SHELL
PLYWOOD
DRAGLINE SILK
COTTON
CORAL (C)
DENTINE
KERATIN
RATTAN
ANTLER
COLLAGEN
COMPACT BONE
WOOL
CUTICLE
CORAL (T)
GREEN COCONUT TIMBER
COCOON SILK
WOOD(I)
CANCELLOUS BONE
VISCID SILK
CORK
LEATHER
SKIN
MUSCLE
PARENCHYMA
CARTILAGE
RESILIN
ELASTIN
1000
100
10
1.0
0.1
0.01
0.001
0.1
1.0
10
100
1000
10,000
Specific modulus [(GPa)/(Mg/m^3)]
Specific Strength [(MPa)/(Mg/m^3)]

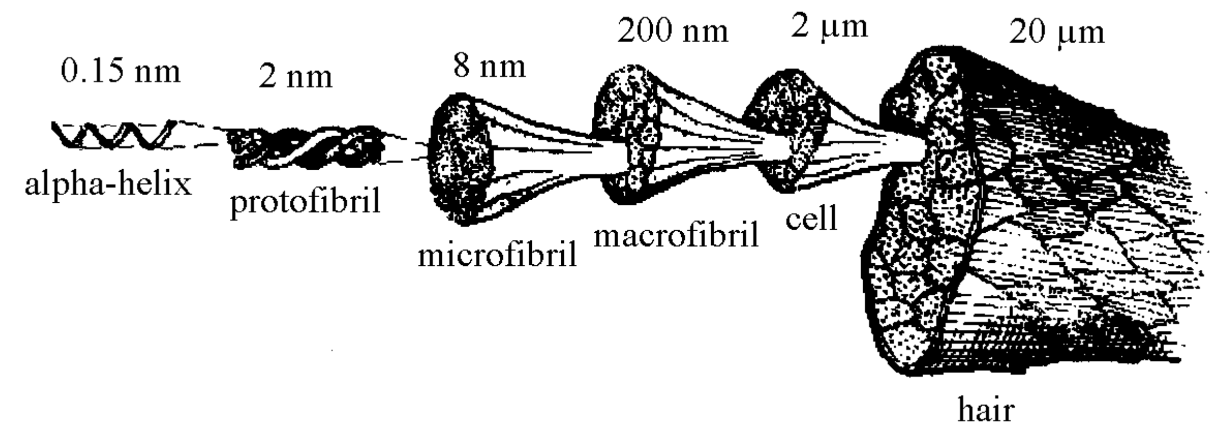

Carbon nano-tubes
Chitin
Cellulose
Compact bone
Enamel
CFRP
Aluminium
Cuttlefishbone
Coral
GFRP
Cuticle (elytron)
Cuticle (tibia)
Wood (parallel to grain)
Cartilage
Cuticle (wing)
Cuticle (tanned puparium, dry)
Cancellous bone
Wood (perpendicular to grain)
Artery
Cuticle (white puparium, dry)
Tendon
Cuticle (tanned puparium, wet)
Cuticle (white puparium, wet)
Cuticle (ready to pupariate, wet)
Cuticle (ready to pupariate, untanned, dry)
Cork
Cuticle (fully fed larva, wet)
Cuticle (larva)
Light, stiff plate
Cuticle (3rd instar, wet)
Resilin
Light, stiff beam or light, buckling resistant column
Skin (human)
Lung parenchyma
Cuticle
Cuticle (intersegmental membrane)
Young´s modulus - Density
Brain (bovine, in vitro)
Young´s modulus [GPa]
1000
100
10
1
0.1
0.01
1e-3
1e-4
1e-5
1e-6
1e-7
1e-8
0.1
0.2
0.5
1
2
Density [Mg/m³]

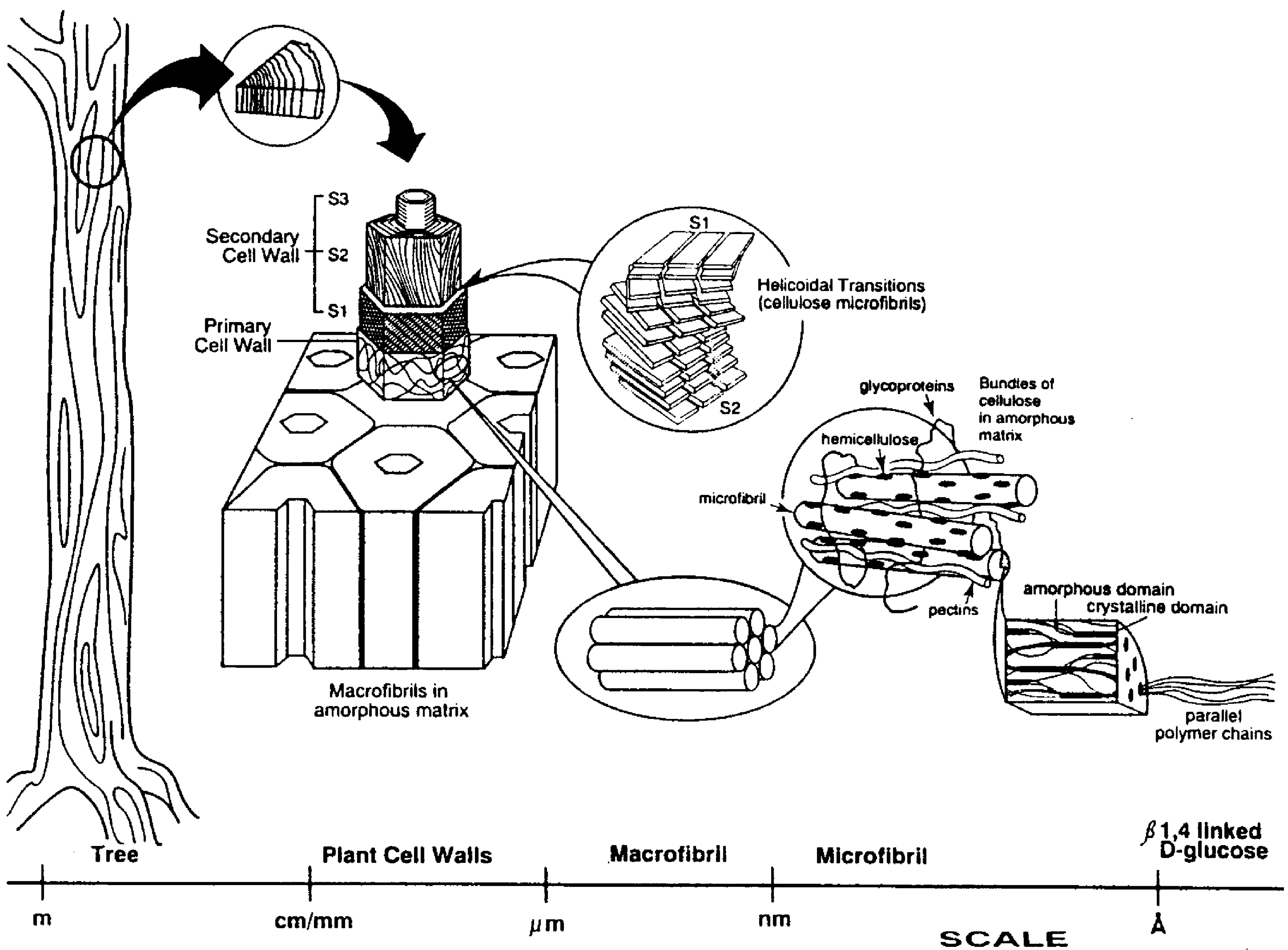

State of the Art
Challenges
Breakthroughs
assembly
flow
diffusion
molecular forces
textile technology
weaving
felting
photolithography
pultrusion extrusion
injection moulding
rapid prototyping
electrospinning
capillary forces
SINGLE-MODE SENSORS
soft lithography
gels
epitaxy
liquid crystals
INDIRECT ACTUATORS
Control of interfaces in Hierarchies
Larger structures from Extrusion, Weaving, knitting and general Assembly
Control of Self Assembly and Ceramics
Retain orientation with bulk-forming techniques such as Rapid Prototyping, Injection Moulding, Pultrusion, etc
INTERFACES
HIERARCHY
DIRECT ACTUATORS
COMPOSITES
INTEGRATION OF SENSORS
MEASURE
orientations
heterogeneity
bulk properties
subsurface properties
interfacial chemistry
surface morphology
INFORMATION
templates (liquid or solid)
Now
2015
2020-2025
TIME

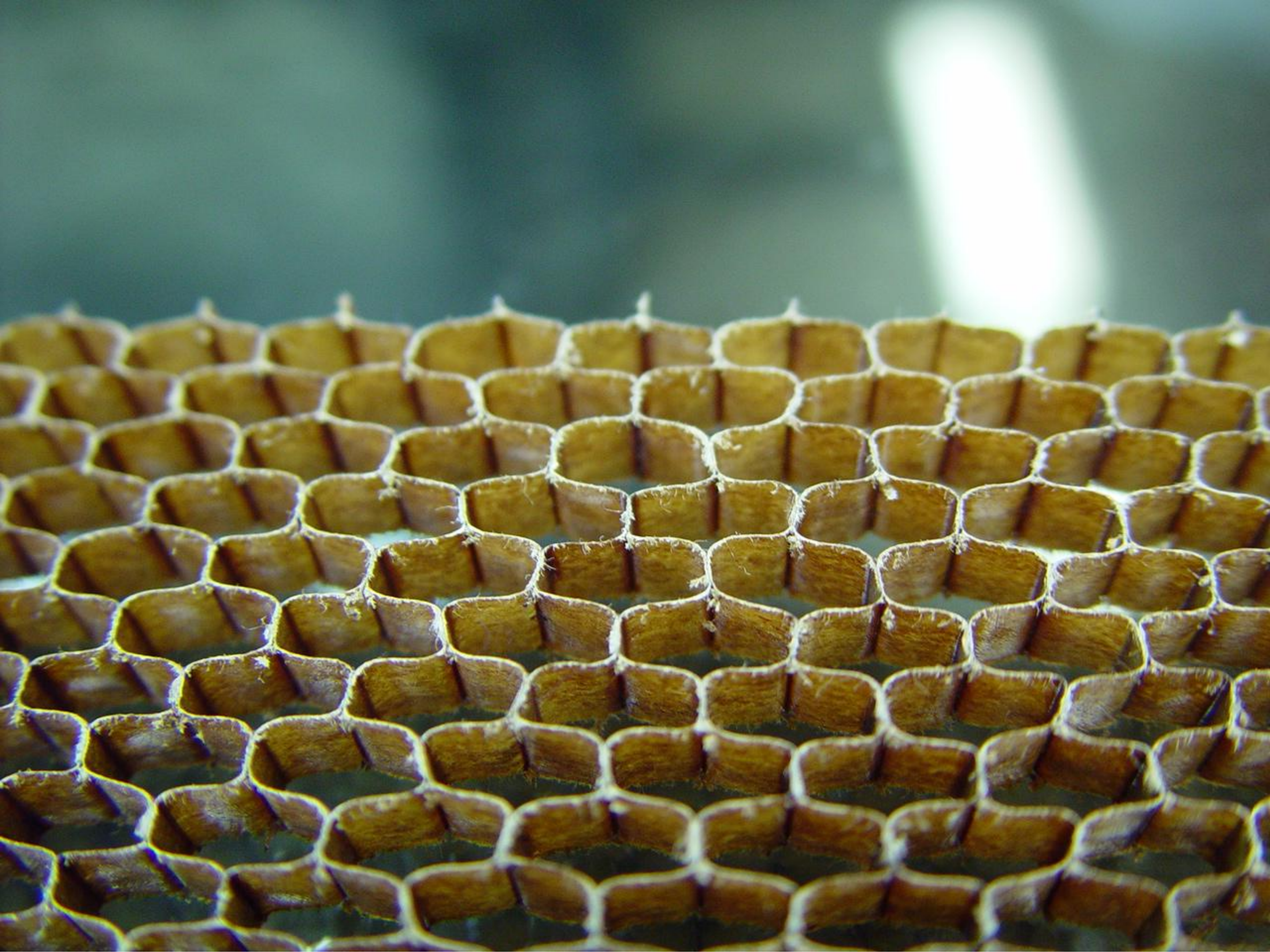
Remember . . .

- in technology, shape is expensive, material is cheap
- in biology, material is expensive, shape is cheap

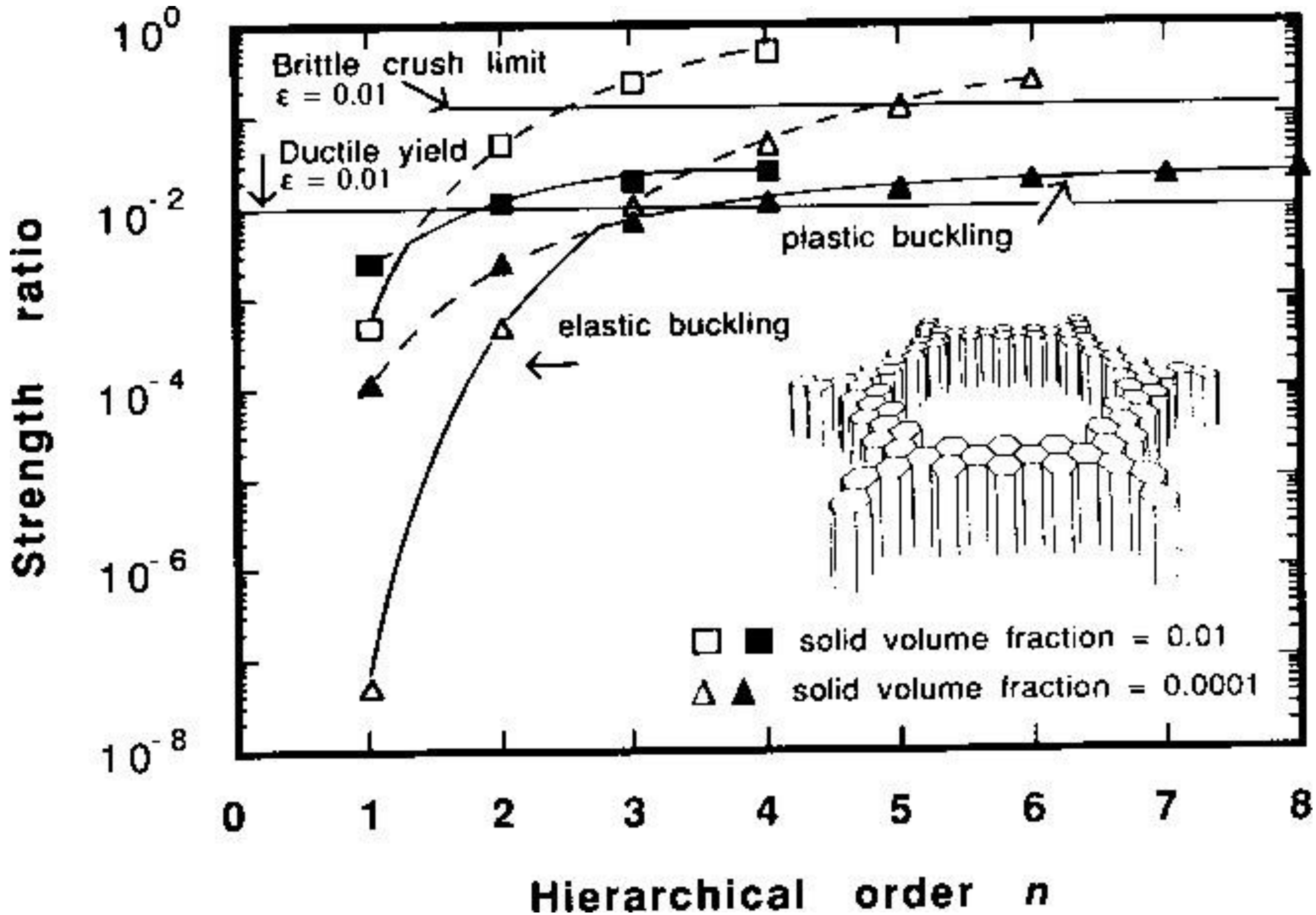

Collagen molecule
Microfibril
Subfibril
Fibril
3.5nm staining sites
64-nm periodicity
Fascicle
Tendon
Fibroblasts
Crimp structure
Fascicular membrane
Reticular membrai
1.5 nm
3.5 nm
10–20 nm
50–500 nm
50–300 μm
100–500 μm
SCALE


0.15 nm
2 nm
8 nm
200 nm
2 μm
20 μm
alpha-helix
protofibril
microfibril
macrofibril
cell
hair


S3
Secondary Cell Wall
S2
S1
Primary Cell Wall
S1
Helicoidal Transitions (cellulose microfibrils)
S2
glycoproteins
Bundles of cellulose in amorphous matrix
hemicellulose
microfibril
pectins
amorphous domain
crystalline domain
parallel polymer chains
Macrofibrils in amorphous matrix
Tree
Plant Cell Walls
Macrofibril
Microfibril
β 1,4 linked D-glucose
m
cm/mm
μm
nm
Å
SCALE

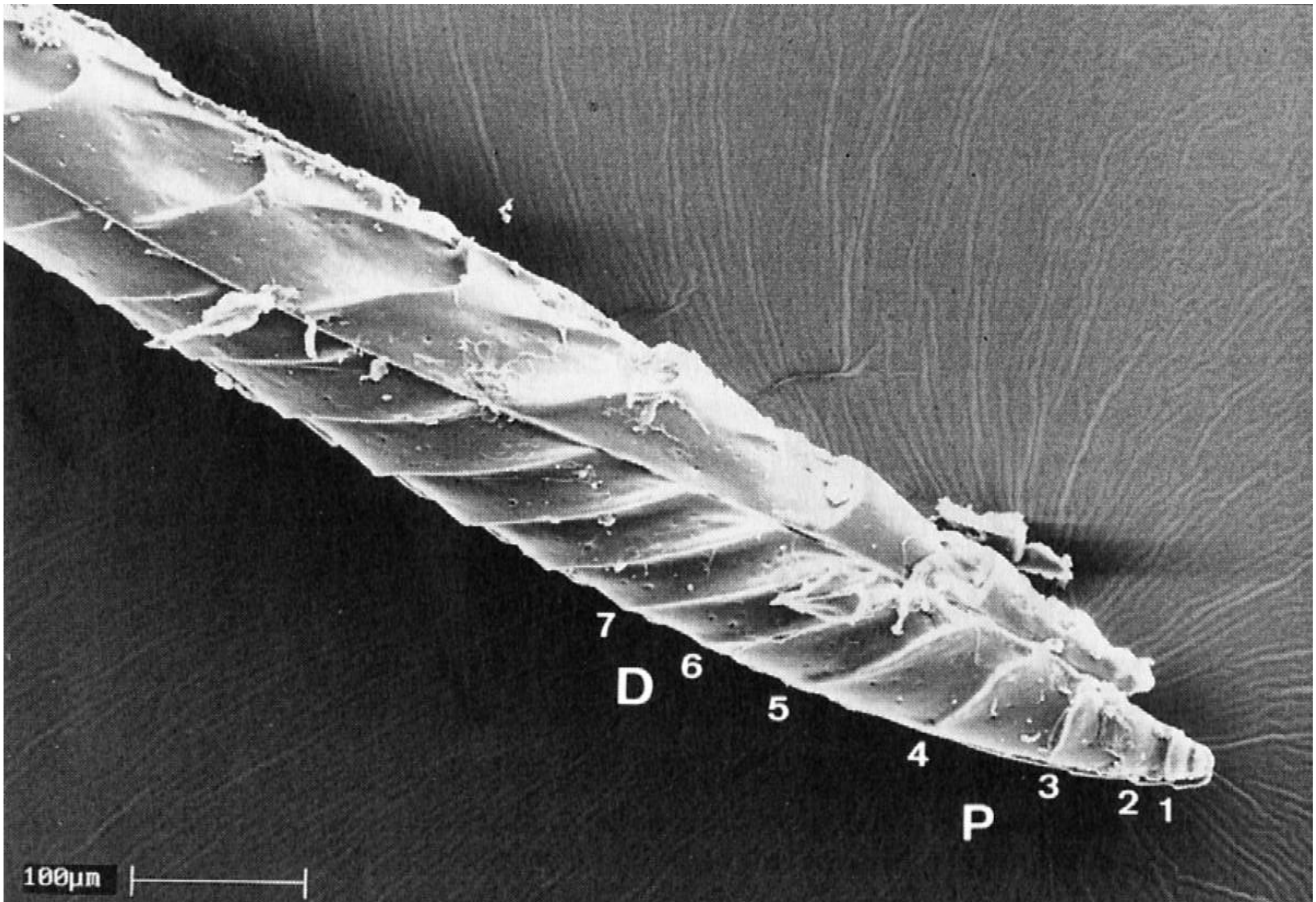


Strength by suppression of buckling

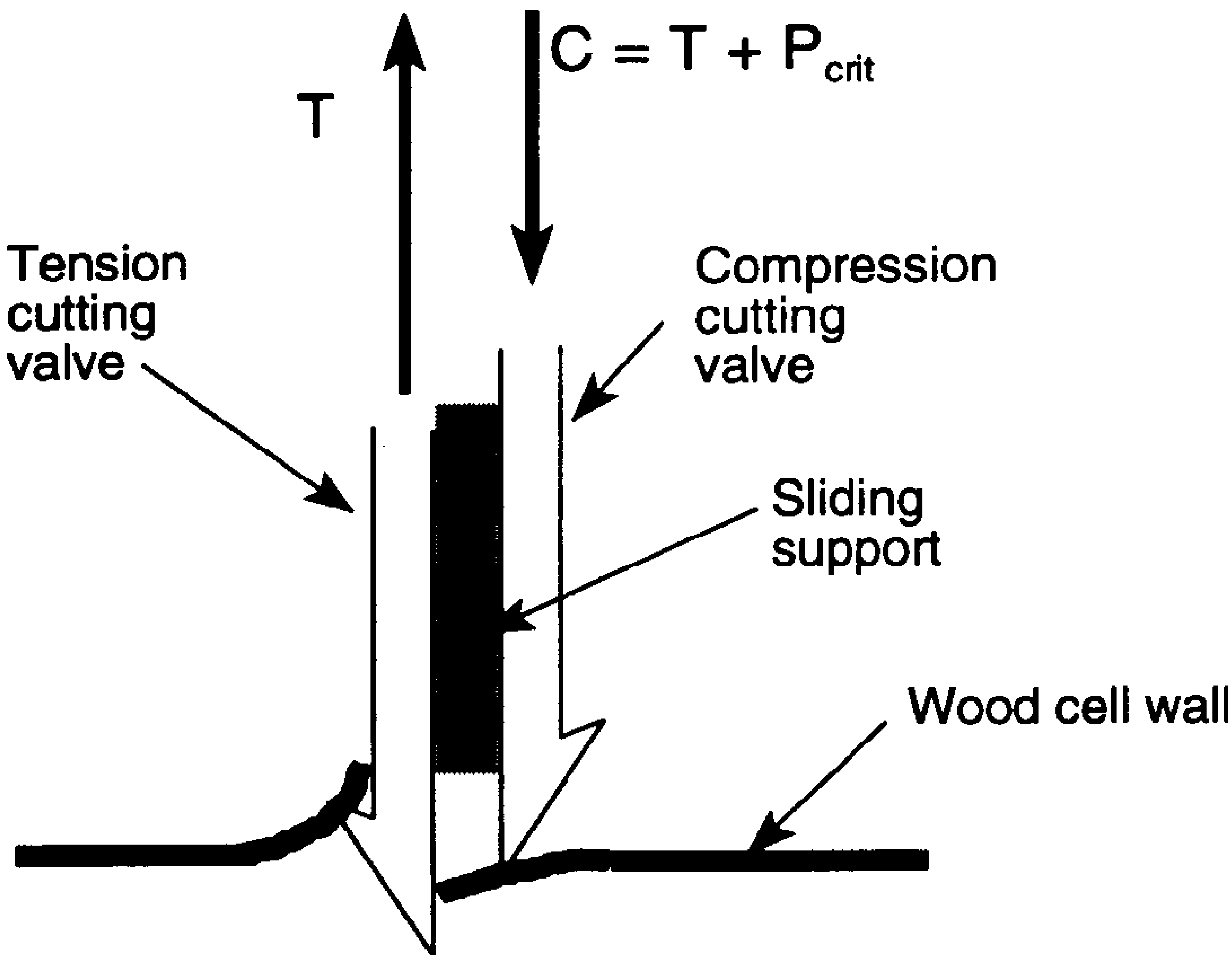


Sirex gigas

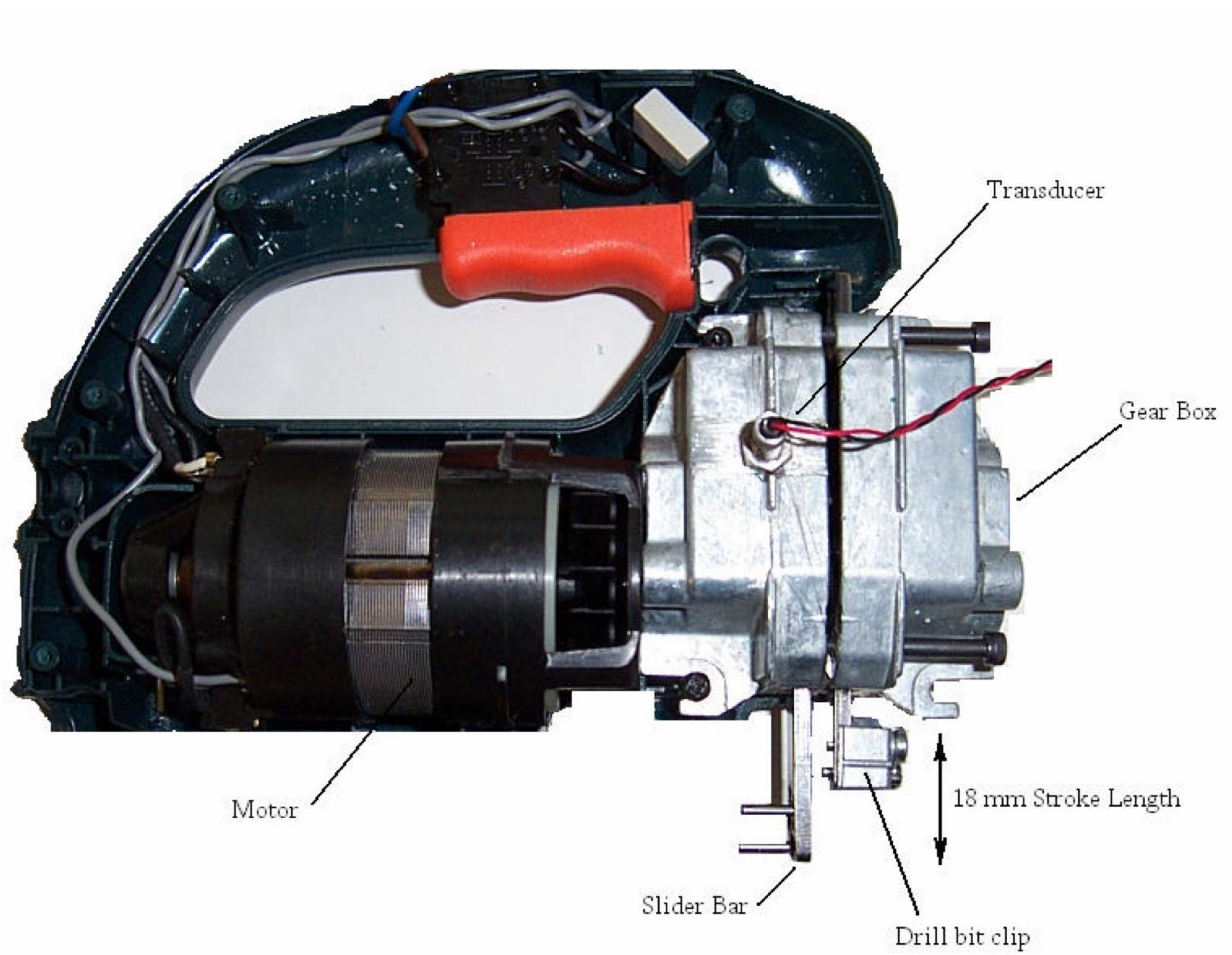
Sirex ovipositor

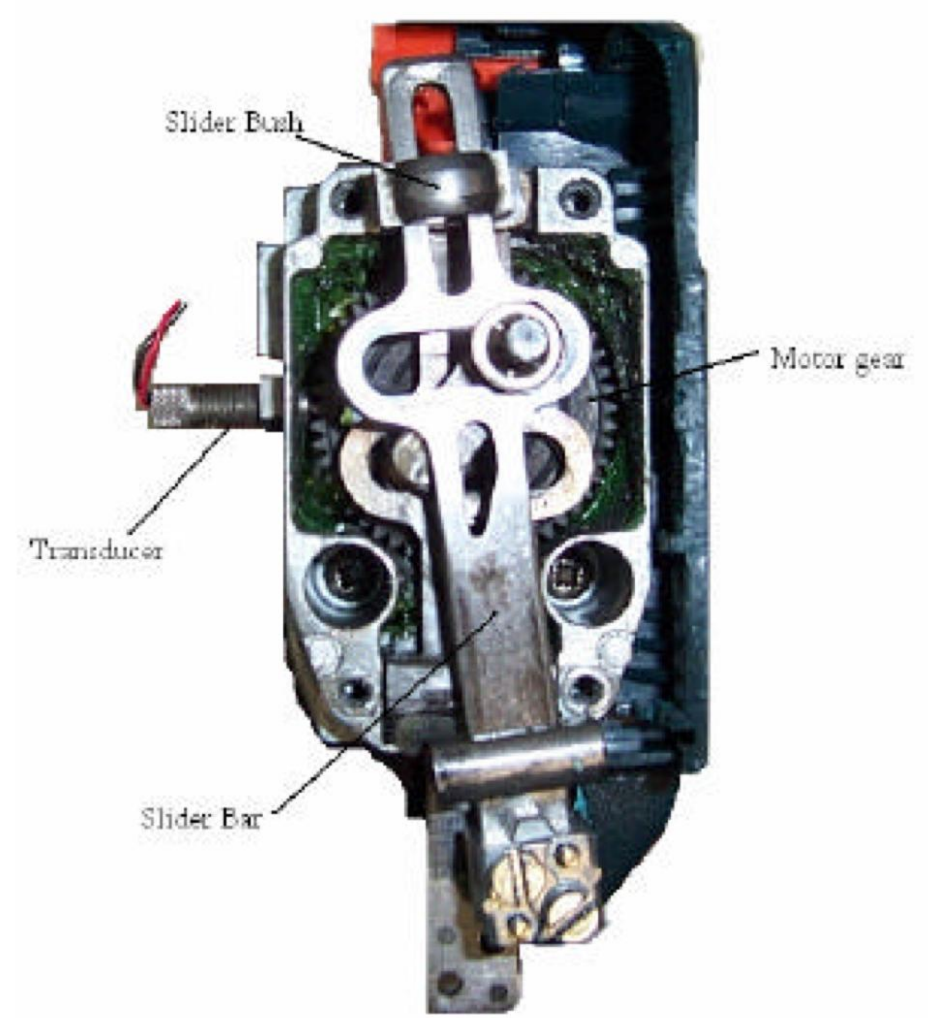


Reciprocating drill



Biomimetic drill

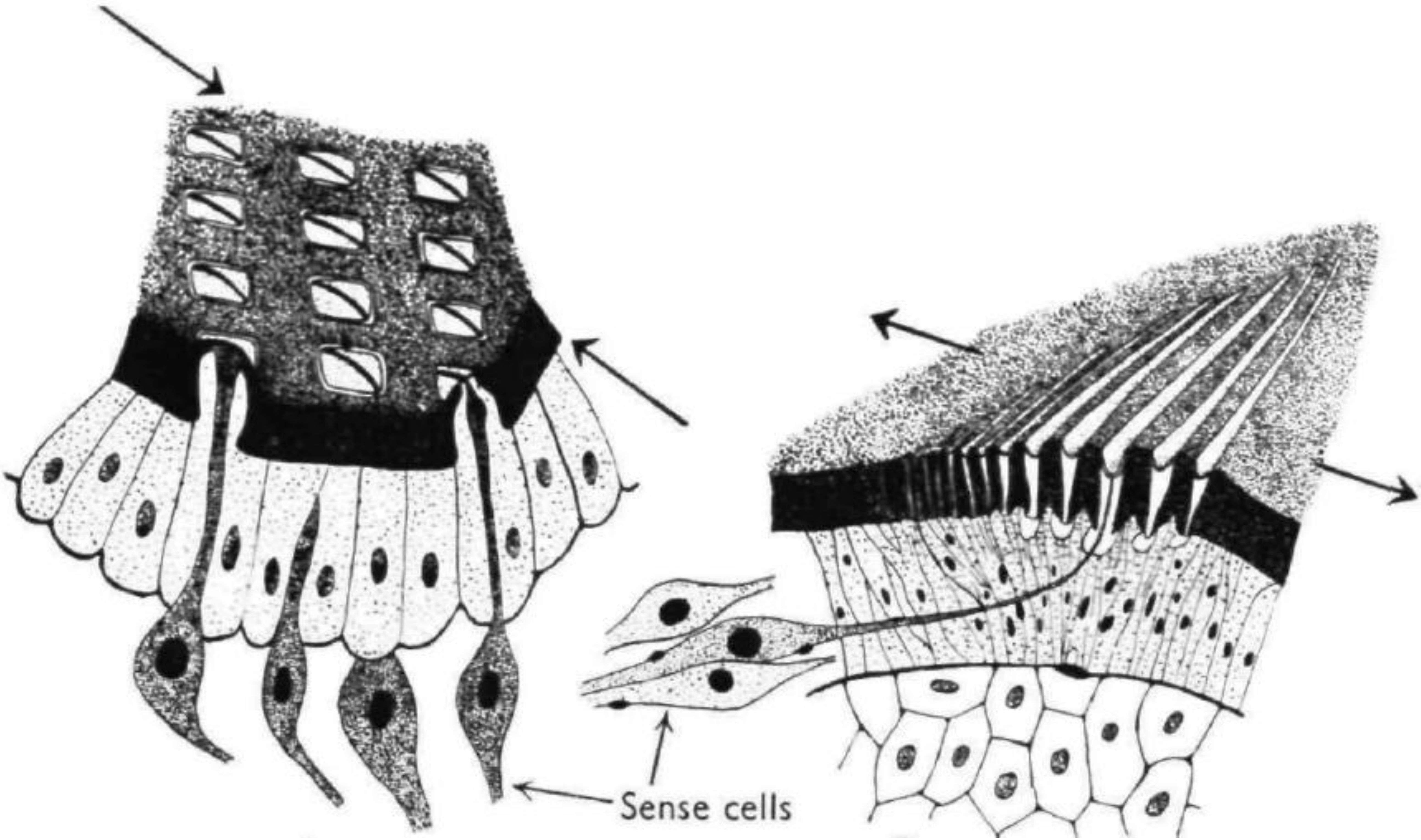




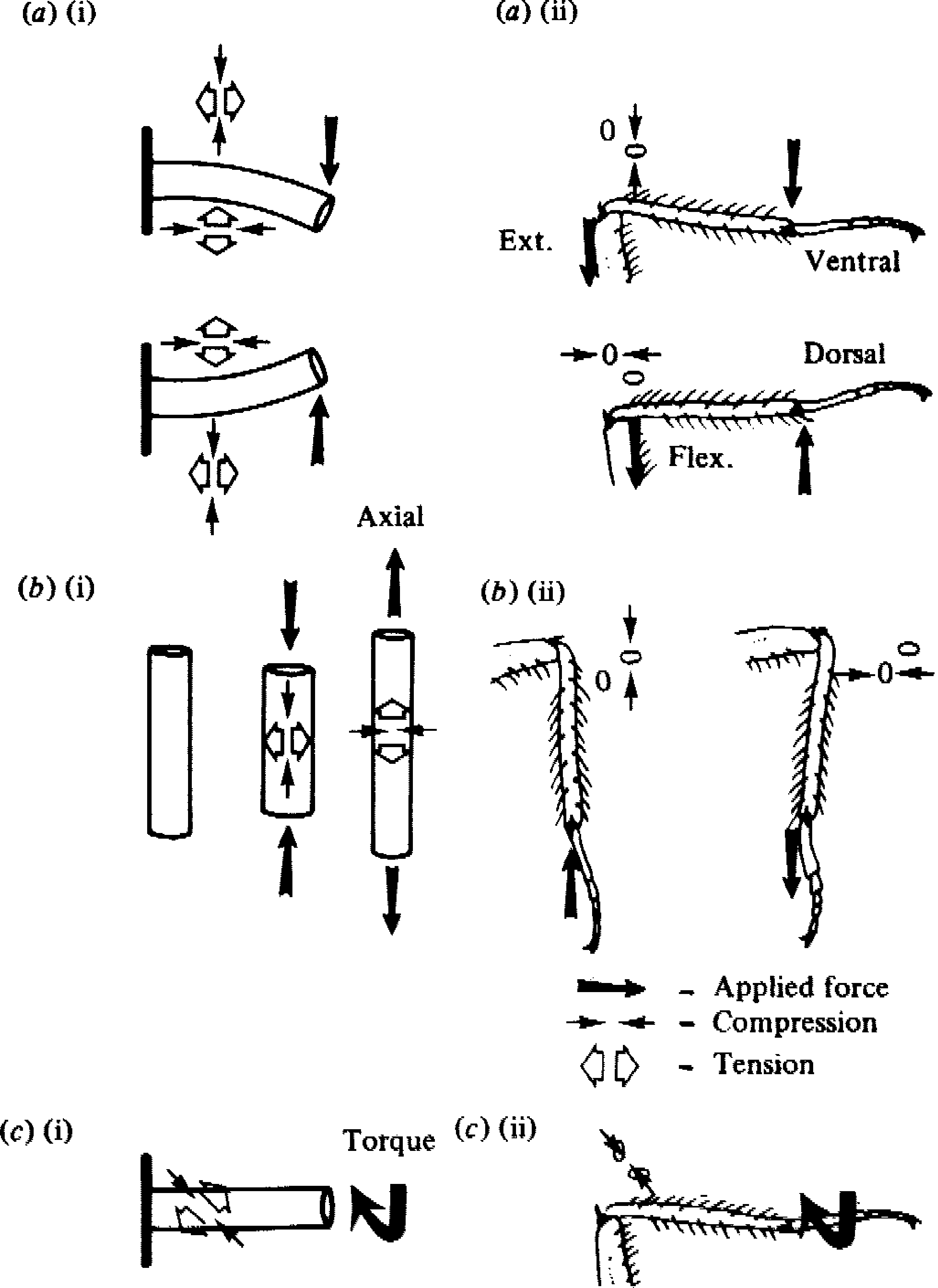
Drill bit

Comparison of drills

	Biomimetic drill	Beagle 2/Mole [Kochan et al, 1999]	USDC [Bar-Cohen et al, 2001]
Drill diameter (m)	**0.018**	**0.02**	**0.003**
Power (W)	**3 (max)**	**5(peak)**	**5**
Drilling speed (m/s)	**~10^{-4} (soil)** **~3×10^{-5} (rock)**	**~2×10^{-4} (soil)**	**~10^{-4} (rock)**
Q (m^3/s)	**$\pi \times 0.009^2 \times 10^{-4}$ (soil)** **$\pi \times 0.009^2 \times 3 \times 10^{-5}$ (rock)**	**$\pi \times 0.01^2 \times 2 \times 10^{-4}$ (soil)**	**$\pi \times 0.0015^2 \times 10^{-4}$ (rock)**
Power/Q (J/m^3)	**11.7×10^7 (soil)** **3.9×10^8 (rock)**	**6.4×10^7 (soil)**	**7.07×10^9 (rock)**



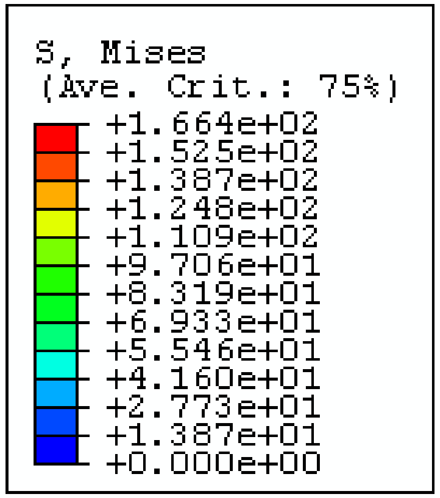
6. Diagrammatic drawings of the structure of an insect campaniform sensillum (A) and an arachnid slit sensillum (B). The arrows show the probable direction of strain which excites the sensilla. (A: based on drawings of the basal plate sensilla on the haltere of *Calliphora* (Pflugstaedt, 1912); B: based on a drawing of the lyriform organ on the patella of a spider (Vogel, 1923).)



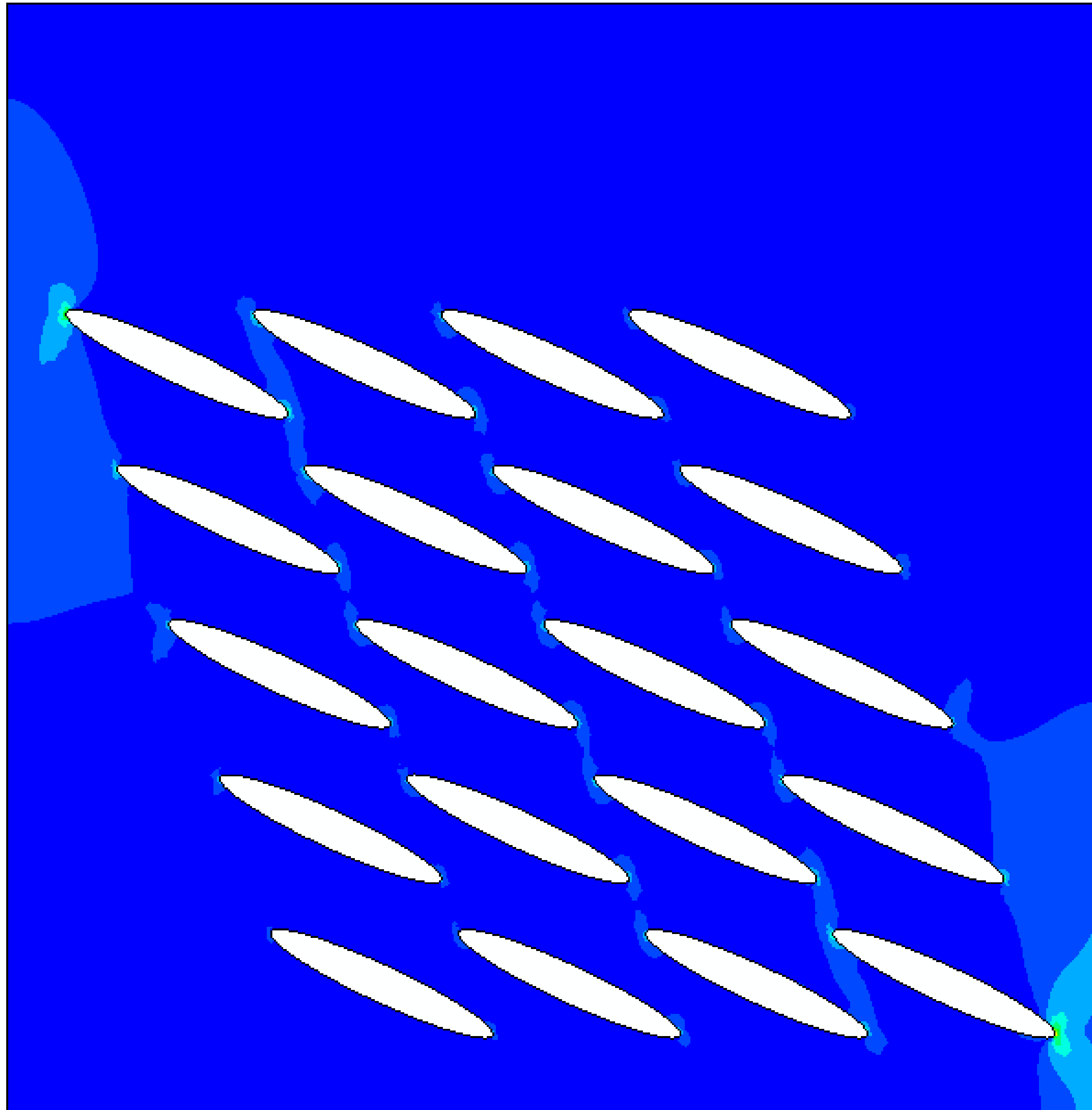
Campaniform sensilla on a cockroach leg

Two sensilla orientated orthogonally can detect all deformations with μm sensitivity

Distribution of equivalent stress



An array of holes is more sensitive and can be tuned for resonance. It is also safe!



What biology can offer

- low risk verified design
- low energy requirement
- autonomy (technology of 'self-')

Where biology can differ

- technical pastiche (swarms, ants)
- function, not form (beware mediaevalism!)
- everything is a system with context

Lessons

- There is a basic mis-match: technology is analytical, biology is descriptive
- But this allows huge changes in context
- Biological solutions are mostly simple and robust
- Bio-solutions can have control built in to the material and the design

Recommendations

- True interdisciplinary team needed
- The biologist must be there at all times
- Develop objective (ontological?) analysis
- Recognise that many solutions are not used by biology . . .
- . . . and that biological solutions may be non-optimal in a technical context
- Frame problems as FUNCTIONS