ENVIRONMENTAL STUDIES AND LIFE SCIENCES

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ENVIRONMENTAL STUDIES AND LIFE SCIENCES

BIOMIMETICS

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BIOMIMETICS

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- Biomimetics is the application of biological methods and systems found in nature to the study and design of engineering systems and modern technology.
- Also known as Bionics, biognosis, biomimicry or bionical creativity engineering.

BIOMIMETICS-Strategies and principles

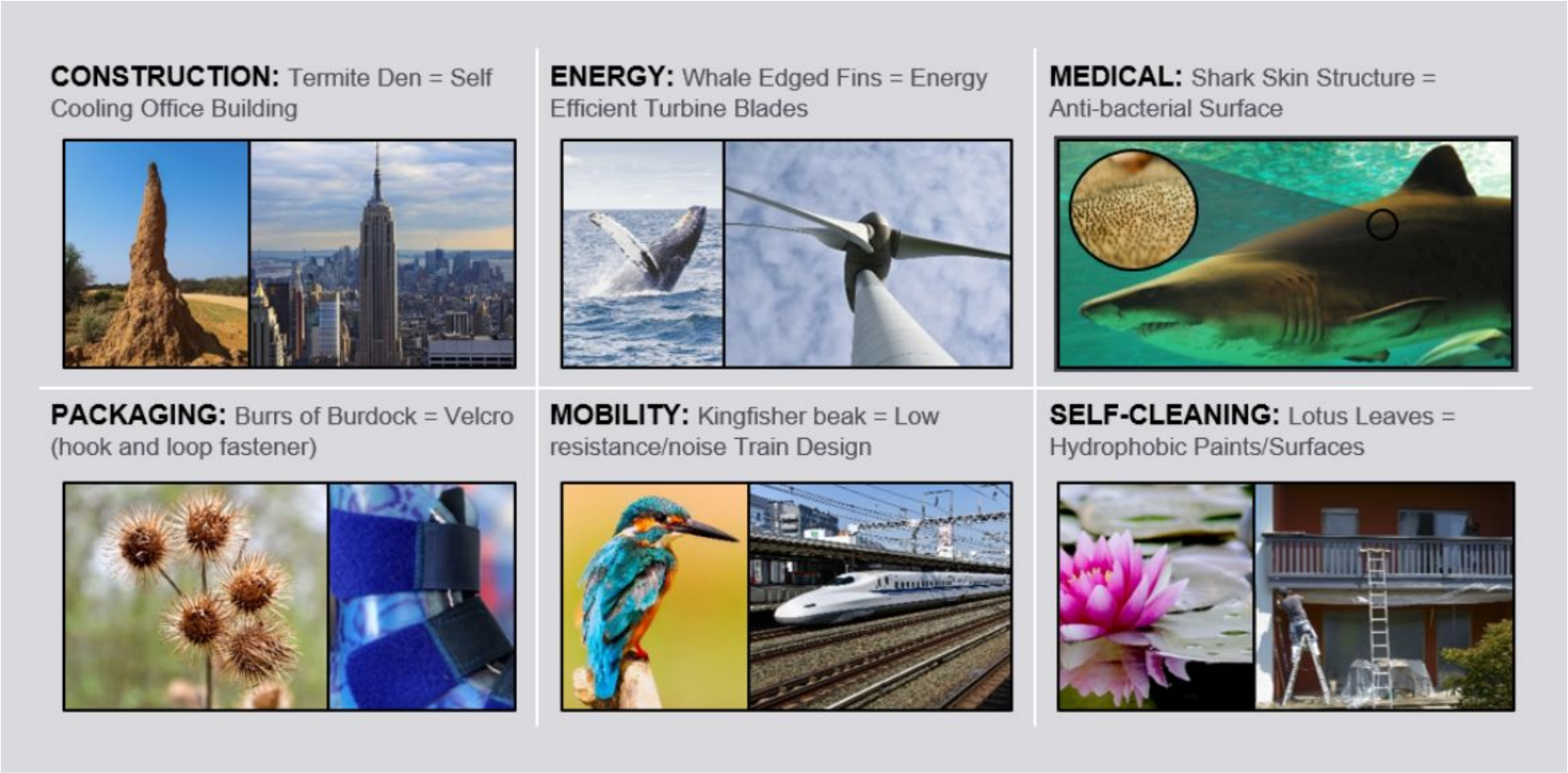
- Nature fits form to function, utilizes a variety of non orthogonal forms and design methods in its constructions to ensure maximization in terms of structural efficiency.
- It minimizes the required input of material.
- Nature recycles everything, Uses waste as a resource.
- Nature uses an ordered hierarchy of structures.
- Nature banks on diversity, constantly mutating and adapting in a flexible and dynamic flow of change.
- Nature self assembles and generates structural organization on all scales.
- Nature is resilient to changes and self healing.
- Nature optimizes rather than maximize, using the least materials for optimal structure and function.

BIOMIMETICS

In Europe, Japan, and the USA, biomimetics is being recognized as the technology of the future and there is increasing interest and funding.

In particular, global companies such as Ford, General Electric, Herman Miller, HP, IBM, and Nike are collaborating with scientists and designing laboratories to explore novel technologies.

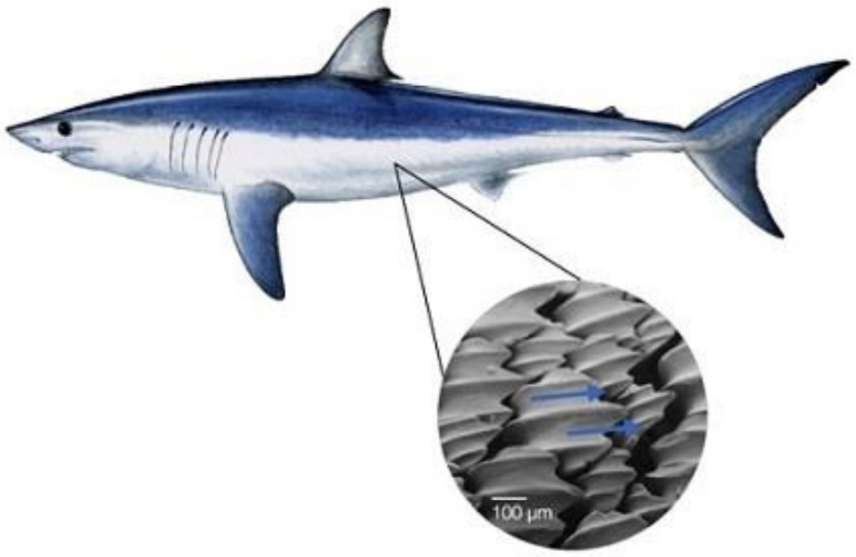
BIOMIMETICS- APPLICATION

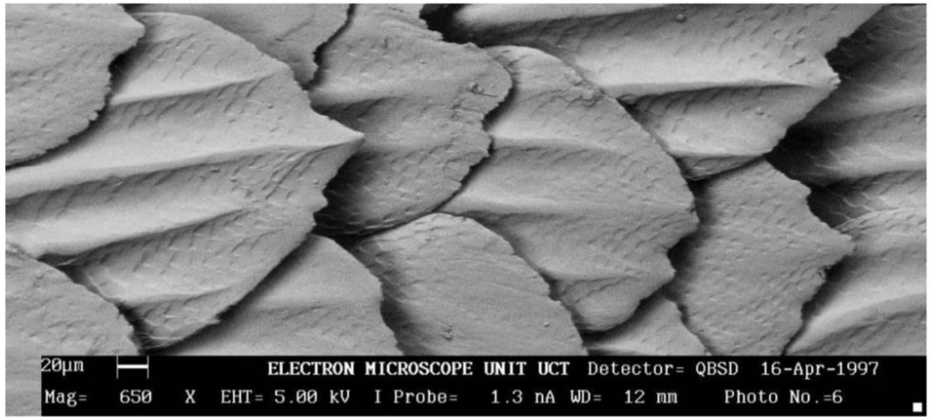


https://www.futurebridge.com/

BIOMIMETICS- APPLICATION

- Shark skin is constructed of overlapping scales.
- Nature through evolution, has ensured that water flows over the scales extremely efficiently, helping the shark to reach high speeds.





https://illumin.usc.edu/

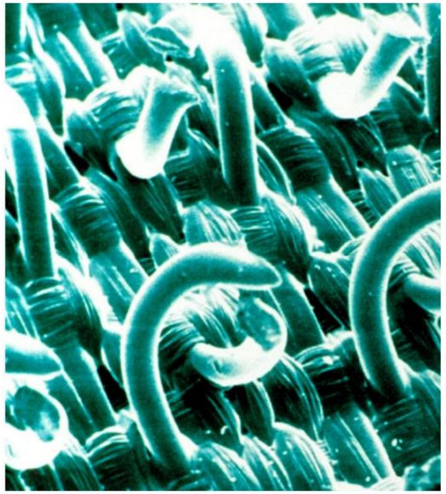
BIOMIMETICS- APPLICATION

- Special alignment and grooved structure of denticles embedded in shark skin decrease drag and thus greatly increase swimming proficiency.
- Airbus fuel consumption down 1.5% when “shark skin” coating applied to aircraft.
- It is possible to increase the efficiency of Air planes up to 4% by adjusting riblets.
- Brings increase of speed up to 1.56%.
- The results of the use of riblets are a – reduction of the total drag, – a higher glide ratio and – a better handling of the aircraft.

BIOMIMETICS- APPLICATION

- Small hooks enable seed-bearing burr to cling to tiny loops in fabric.
- Velcro fastening was invented in 1941 by Swiss engineer George de Mestral, who took the idea from the burrs that stuck to his dog's hair.
- Under the microscope he noted the tiny hooks on the end of the burr's spines that caught anything with a loop - such as clothing, hair or animal fur.
- The 2-part Velcro fastener system uses strips or patches of a hooked material opposite strips or patches of a loose- looped weave of nylon that holds the hooks

https://www.bloomberg.com/



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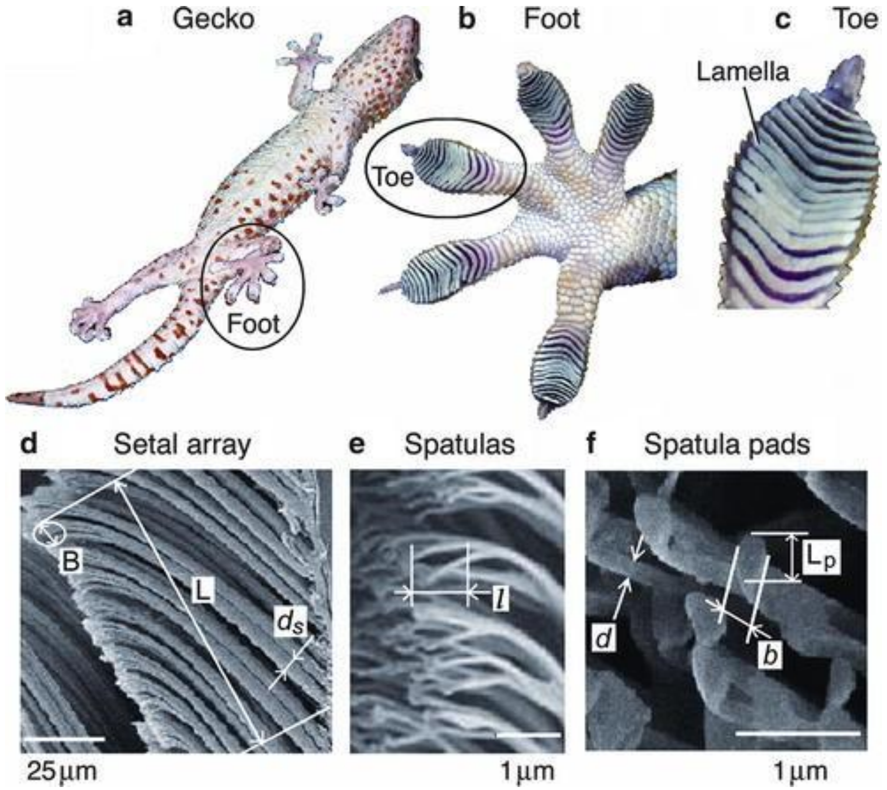
BIOMIMETICS- APPLICATION

BIOMIMETICS- APPLICATION

- The fastest train in the world at speeds of up to 200 miles per hour, Japan’s Shinkansen Bullet Train was a marvel of modern technology.
- But there was one major problem after its initial debut: noise. Each time the train emerged from the tunnel, it caused a change in air pressure that caused thunder-like sounds that were a nuisance from a quarter of a mile away.
- The train’s chief engineer, a bird-watcher, had an idea: taking inspiration from the shape of a bird’s beak to make it more aerodynamic.
- The resulting design was based on the narrow profile of a kingfisher’s beak, resulting in a quieter train that also consumes 15% less electricity and goes 10% faster than before.

BIOMIMETICS- APPLICATION

- Gecko is a nocturnal lizard which has adhesive pads on the feet to assist in climbing on smooth surfaces.
- Geckos hang single-toed from walls and walk along ceilings using fine hairs on feet.
- Gecko’s feet comprise of lamellae. Lamellae are equipped with setae; each seta ends in a spatula-like structure.
- Nanoscale spatulae interact with wall atoms; generate Van der Waal’s forces. The adhesive system demonstrates high friction.



https://link.springer.com/

BIOMIMETICS- APPLICATION

- Gecko Tape is a material covered with nanoscopic hairs that mimic those found on the feet of gecko lizards.
- These millions of tiny, flexible hairs exert van der Waals forces that provide a powerful adhesive effect. One square centimeter of gecko tape could support a weight of one kilogram.
- University of California - Berkeley created an array of synthetic micro-fibres using very high friction to support loads on smooth surfaces.
- Gecko-footed robots could climb to the roof and emplace permanent anchors for suspension of utilities, transportation, or even entire lunar bases.

TRAINING SHOES WITH GRIP

https://link.springer.com/

BIOMIMETICS- APPLICATION

- A butterfly's wings are one of nature's most remarkable materials.
- These tiny but complex structures reflect light in such a way that specific wavelengths interfere with each other to create intensely vivid colors one could only find in nature.
- By carefully studying this process, engineers at Qualcomm have been able to mimic this effect, allowing them to develop a system that produces colored electronic screens that are extremely efficient and can be viewed under any light conditions.

https://inhabitat.com/

BIOMIMETICS- APPLICATION

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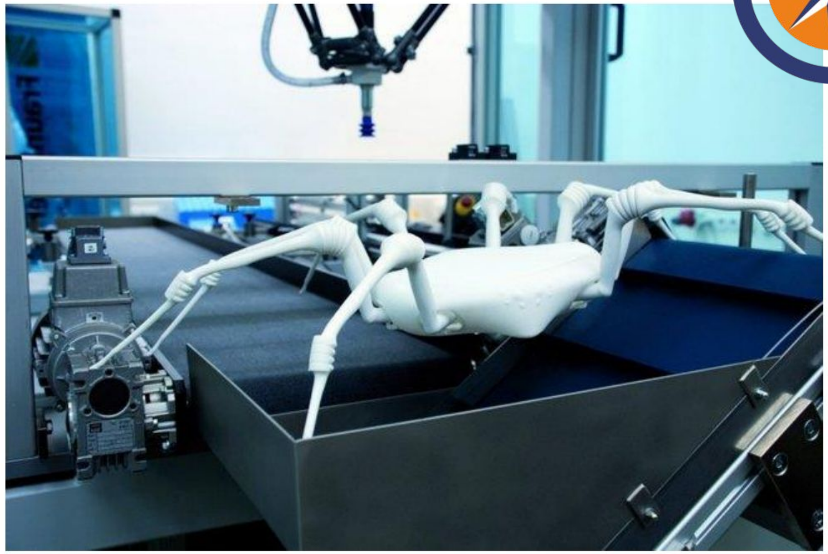
- The ability to squeeze through tight spaces and turn on a dime makes the spider an ideal model for lifesaving robots that could make their way through rubble after a disaster to locate survivors.
- Researchers at Germany's Frauenhofer Institute say this robot can be cheaply reproduced using 3D printers.
- After natural catastrophes and industrial or reactor accidents, or in fire department sorties, it can help responders, for instance by broadcasting live images or tracking down hazards or leaking gas.



https://www.theverge.com/

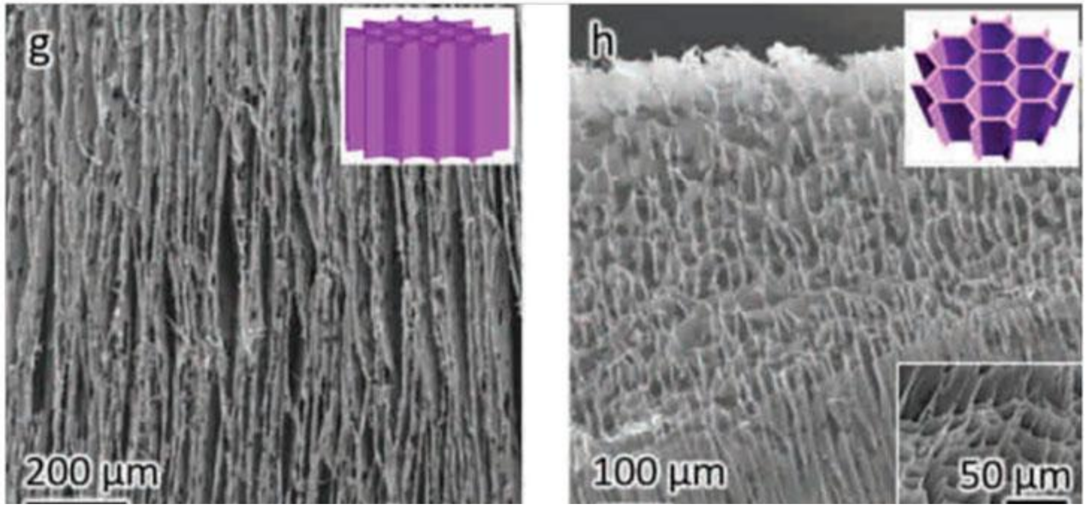
BIOMIMETICS FOR SPACE APPLICATIONS

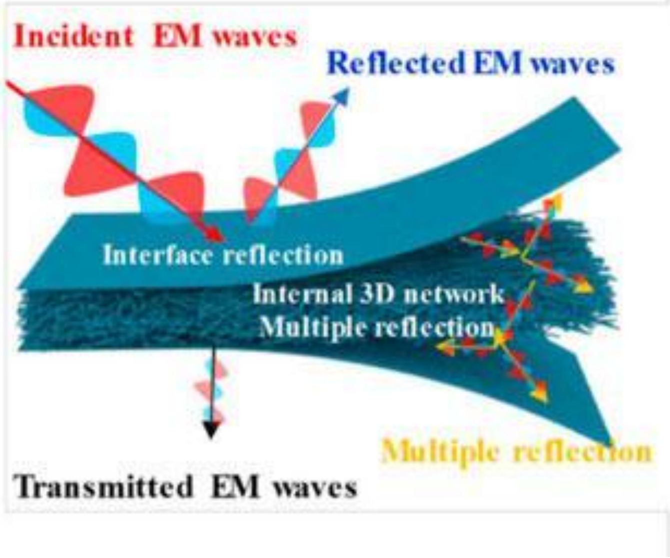
- Space environment, presents a challenging setting due to existing conditions of low to zero gravity, high temperature fluctuations, elevated levels of UV, electromagnetic and particulate radiation, reactive atomic oxygen, as well as natural micrometeoroids and space debris.
- There are recent advances in biomimetic research and developments within the space industry.
- Due to highly fluctuating temperatures within space environment enormous range of extremes, heat flow as well as temperature management and control are crucial steps to maintain the integrity of space systems.
- **Bio-inspired porous carbon** showed promising results regarding their thermal protection of spacecrafts during the re-entry process into planetary atmospheres.

doi.org/10.3389/frspt.2022.1000788

BIOMIMETICS FOR SPACE APPLICATIONS

- Recently, researchers have developed lightweight and flexible materials for the protection of structures and equipment against electromagnetic radiation.
- Experiments show that electromagnetic interference can be successfully shielded by substituting conventional metal shields with ones inspired by cellular architecture with tiny pores mimicking cell walls as aerogels.





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BIOMIMETICS FOR SPACE APPLICATIONS

- Landing of unmanned spacecrafts on surface of another planet is violent and associated with enormous impact forces.
- Several actions and measures have been taken to protect sensitive equipment and payloads against those forces.
- Option of dealing with high impact forces is demonstrated by the peel of the pomelo fruit.
- Peel of the pomelo fruit demonstrates a thick layer with open cell foam structure of varying pore size which protects the fruit inside from damage when falling from trees.
- This impact damping and energy dissipating capabilities are implemented in artificial versions of the foam to apply in space systems.

doi.org/10.3389/frspt.2022.1000788

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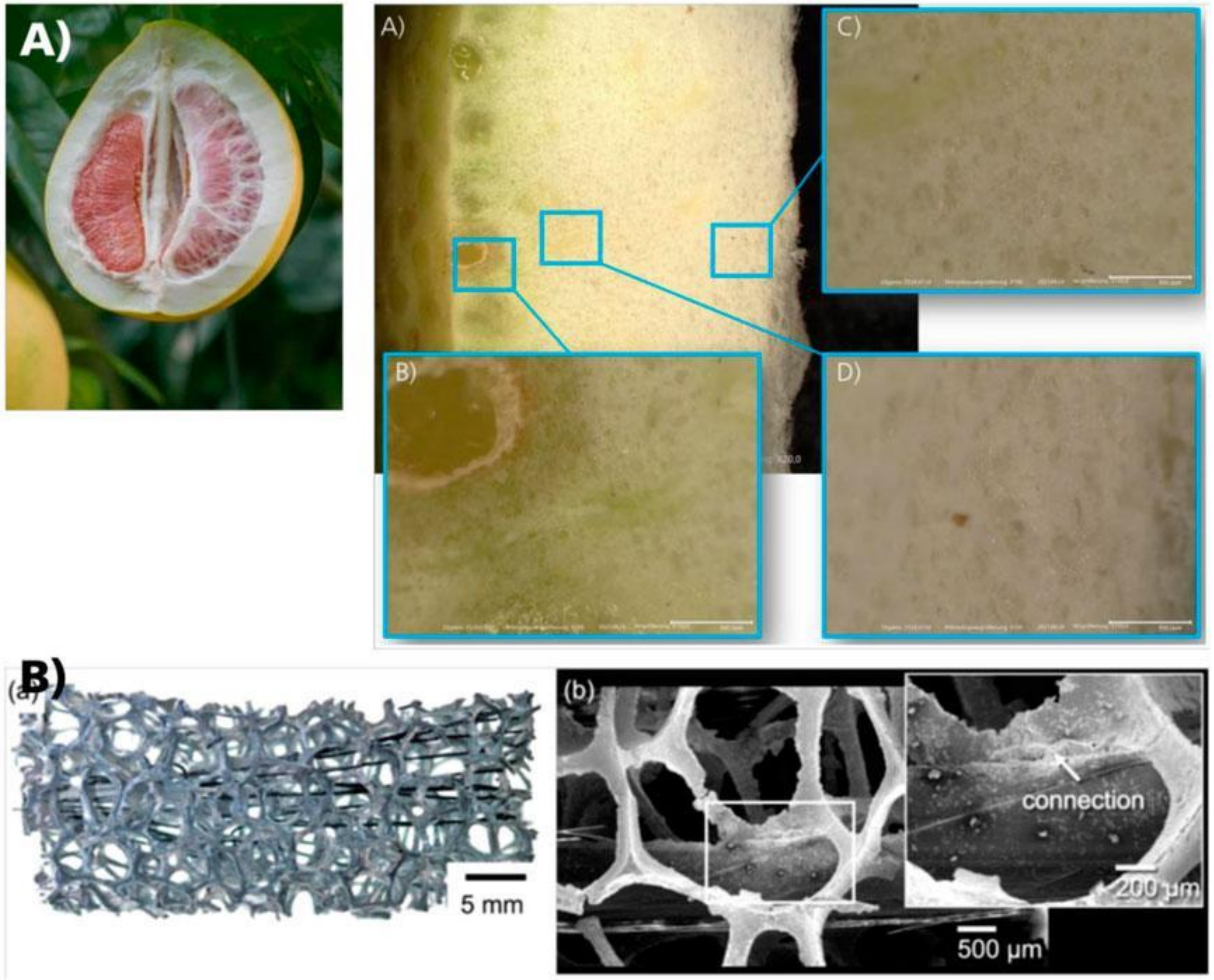
BIOMIMETICS FOR SPACE APPLICATIONS



Pomelo peel as dampener,
(A) Photographs of the honey pomelo's peel.
(B) Photograph of an Aluminium foam sample showing the connection between the fibre bundle and the foam matrix

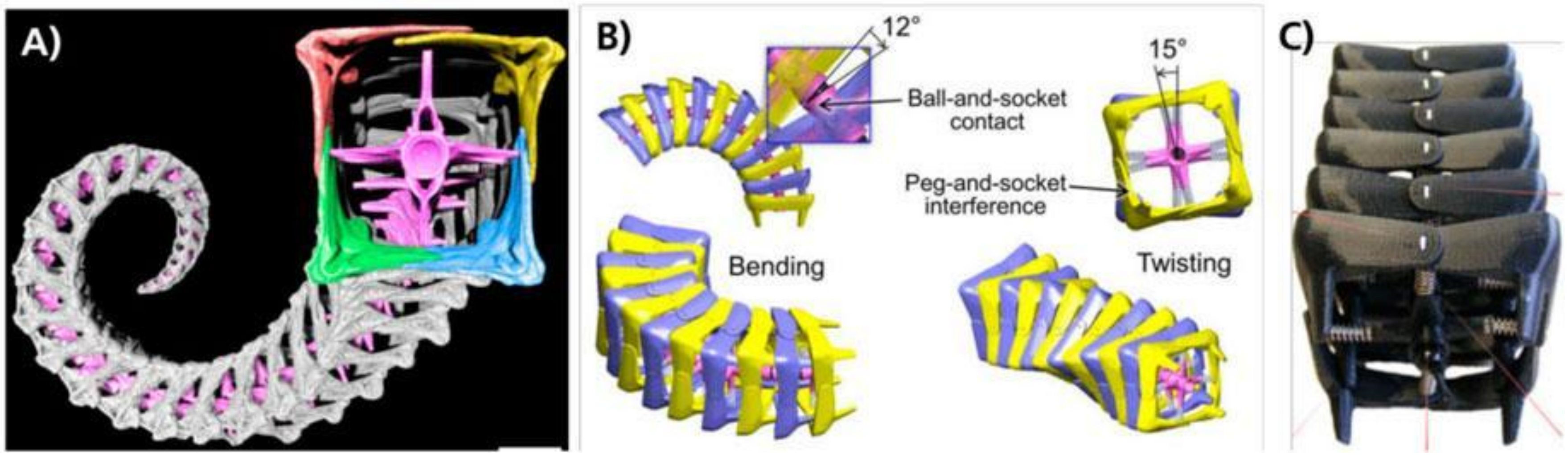
doi.org/10.3389/frspt.2022.1000788

BIOMIMETICS FOR SPACE APPLICATIONS

- As space debris has become a major topic of concern, recent efforts have concentrated on space debris removal and mitigation measures.
- Robotic systems inspired by octopi arms have already been proposed for space debris removal.
- Their great mobility, maneuverability and adaptability makes them very suitable to wrap around complex target shapes.
- Seahorses use their tail for grasping activities involving different diameter objects.
- Arrangement like continuously decreasing square cross-section in their tail made from four individual plates connected through special joints, provide great bending and torsion abilities for grasping, especially of a diverse range of shapes and sizes.
- In addition, due to specialized construction, their tails shows great fracture resistances under crushing and impact forces.

doi.org/10.3389/frspt.2022.1000788

BIOMIMETICS FOR SPACE APPLICATIONS



Seahorse tail inspired robotic arm

doi.org/10.3389/frspt.2022.1000788

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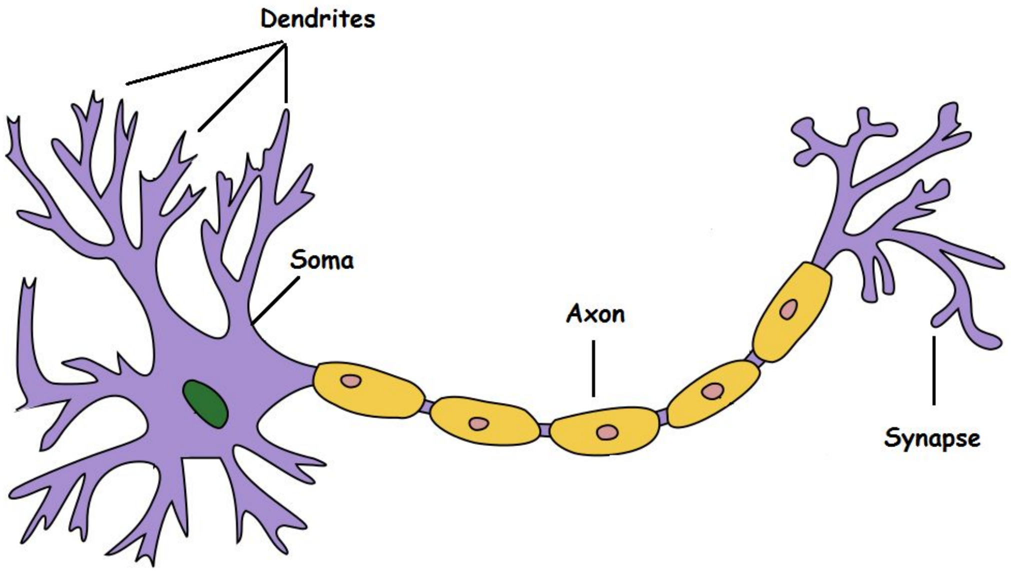
BIOINSPIRED ANN

BIOINSPIRED ANN

- A biological neuron has three types of main components; dendrites, soma (or cell body) and axon.
- Dendrites receives signals from other neurons.
- The soma, sums the incoming signals. When sufficient input is received, the cell fires; that is it transmit a signal over its axon to other cells.

Human Biological Neuron



towardsdatascience.com

BIOINSPIRED ANN

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- In the human brain, a typical neuron collects signals from others through a host of fine structures called *dendrites*.
- The neuron sends out spikes of electrical activity through a long, thin stand known as an *axon*, which splits into thousands of branches.
- At the end of each branch, a structure called a *synapse* converts the activity from the axon into electrical effects that inhibit or excite activity in the connected neurons.

BIOINSPIRED ANN

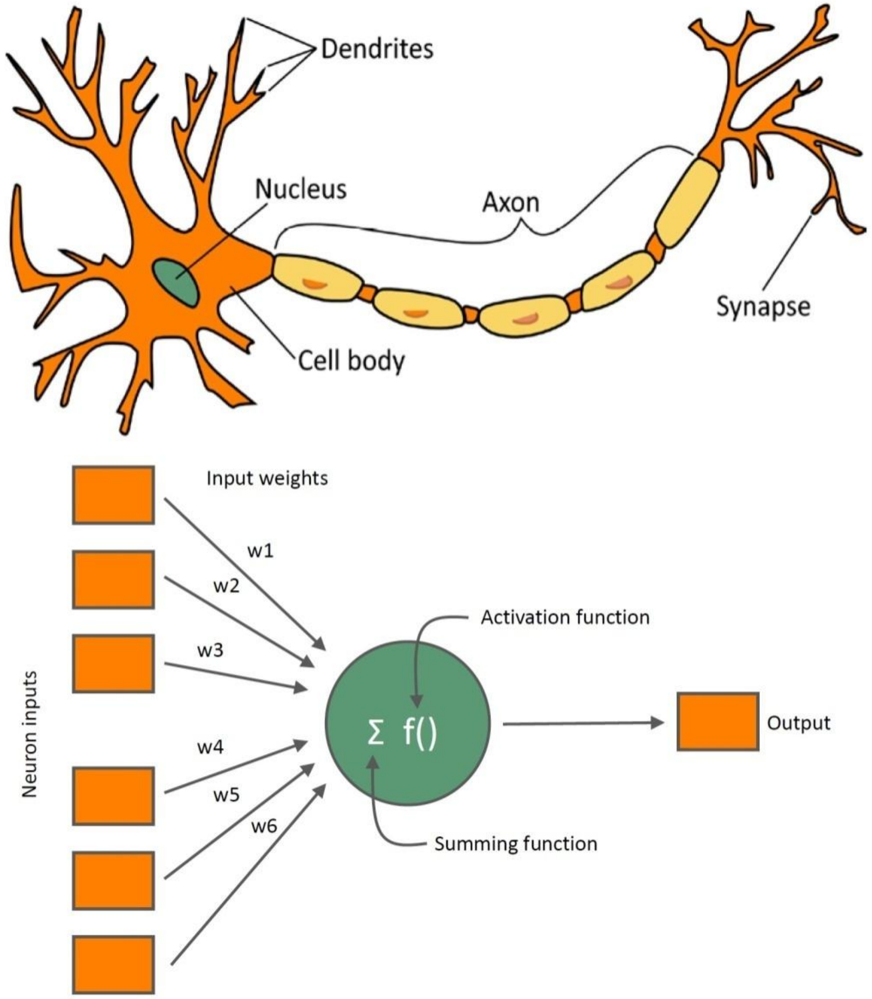
Artificial Neural Network-ANN is an information processing system that has certain performance characteristics in common with biological nets.

Several key features of the processing elements of ANN are suggested by the properties of biological neurons:

- The processing element receives many signals.
- Signals may be modified by a weight at the receiving synapse.
- The processing element sums the weighted inputs.
- Under appropriate circumstances (sufficient input), the neuron transmits a single output.
- The output from a particular neuron may go to many other neurons.

BIOINSPIRED ANN

- From experience: examples / training data
- Strength of connection between the neurons is stored as a weight-value for the specific connection.
- Learning the solution to a problem = changing the connection weights



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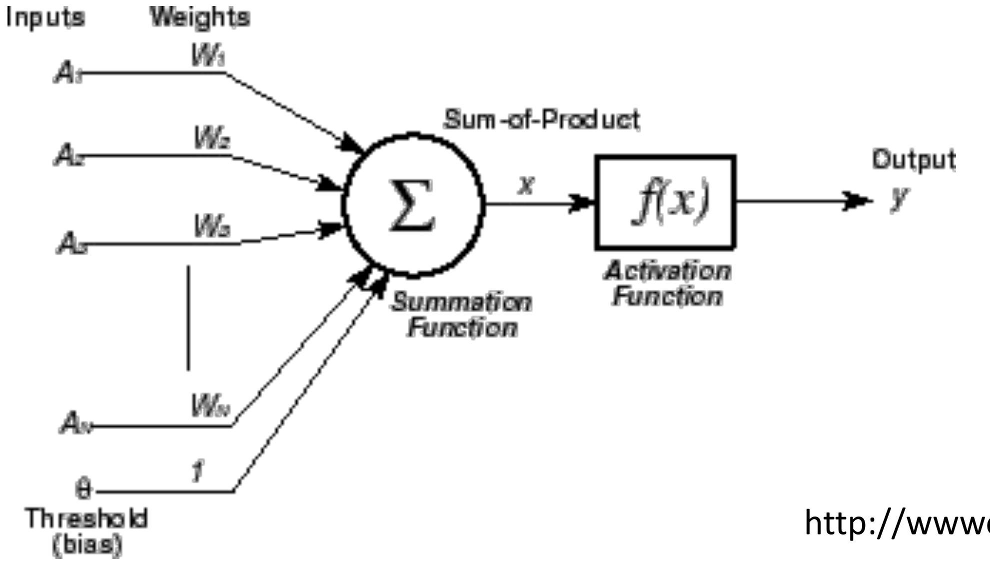
BIOINSPIRED ANN

ANNs have been developed as generalizations of mathematical models of neural biology, based on the assumptions that:

- Information processing occurs at many simple elements called neurons.
- Signals are passed between neurons over connection links.
- Each connection link has an associated weight, which, in typical neural net, multiplies the signal transmitted.
- Each neuron applies an activation function to its net input to determine its output signal.



http://wwwold.ece.utep.edu/

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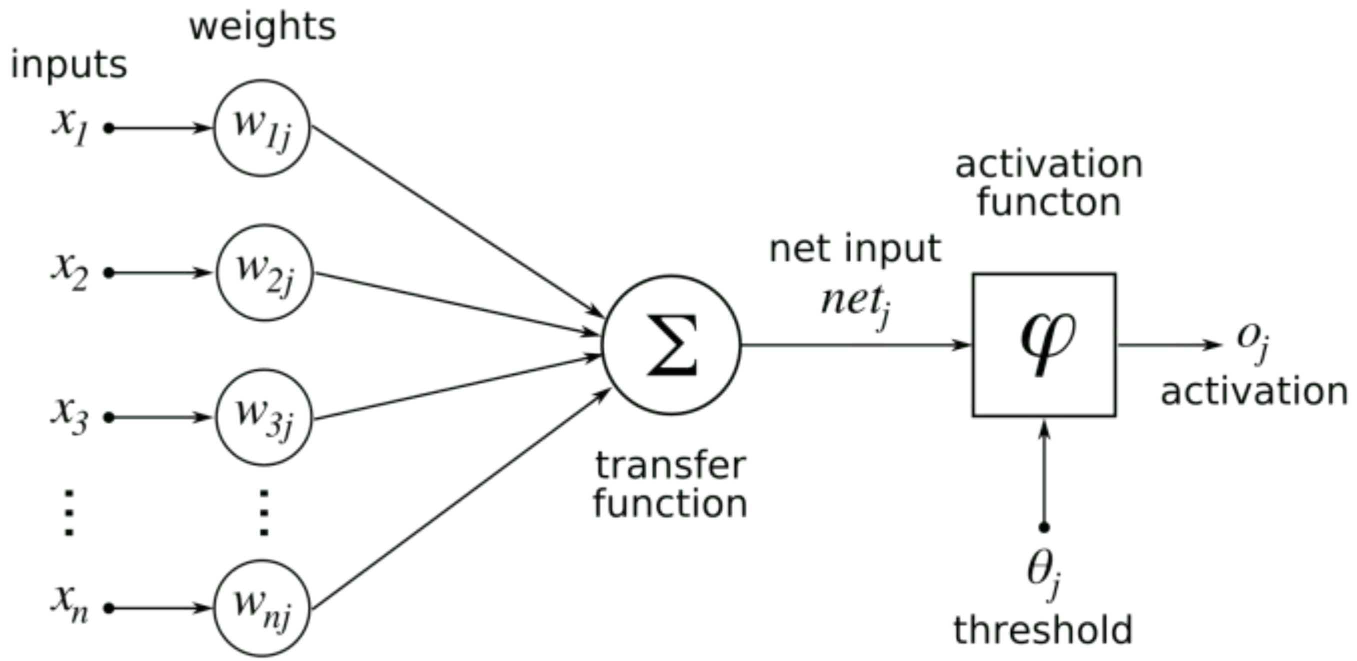
Artificial Neural Network



-A neuron receives input, determines the strength or the weight of the input, calculates the total weighted input, and compares the total weighted with a value (threshold)
-The value is in the range of 0 and 1
- If the total weighted input greater than or equal the threshold value, the neuron will produce the output, and if the total weighted input less than the threshold value, no output will be produced

https://bdtechtalks.com/

Characterization

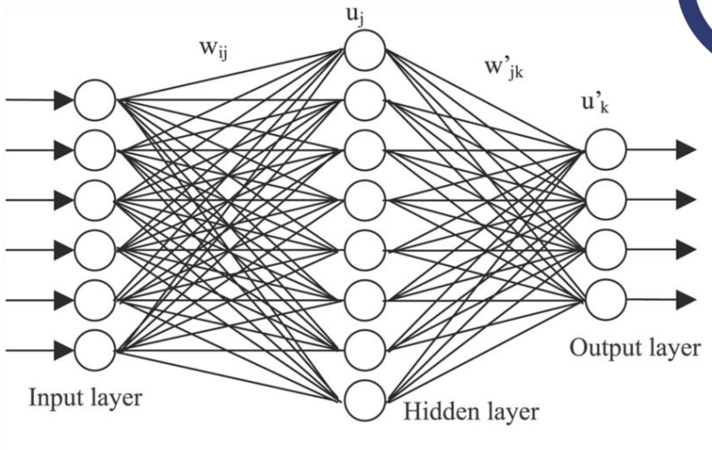
- Architecture
  - a pattern of connections between neurons
    - Single Layer Feedforward
    - Multilayer Feedforward
    - Recurrent
- Strategy / Learning Algorithm
  - a method of determining the connection weights
    - Supervised
    - Unsupervised
    - Reinforcement
- Activation Function
  - Function to compute output signal from input signal

Some Properties of Artificial Neural Networks

- Assembly of simple processors
- Information stored in connections
- Massively Parallel
- Massive connectivity
- Fault Tolerant
- Learning and Generalization Ability
- Robust
- Individual dynamics different from group dynamics
- All these properties may **not** be present in a particular network

BIOINSPIRED ANN

- Input Layer - The activity of the input units represents the raw information that is fed into the network.
- Hidden Layer - The activity of each hidden unit is determined by the activities of the input units and the weights on the connections between the input and the hidden units.
- Output Layer - The behavior of the output units depends on the activity of the hidden units and the weights between the hidden and output units.
- This simple type of network is interesting because the hidden units are free to construct their own representations of the input.
- The weights between the input and hidden units determine when each hidden unit is active, and so by modifying these weights, a hidden unit can choose what it represents.



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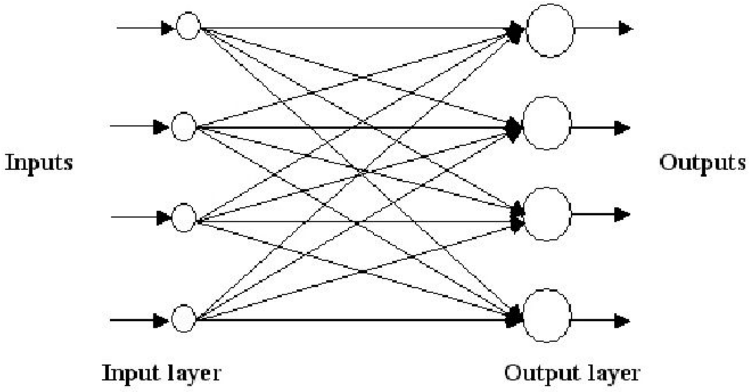
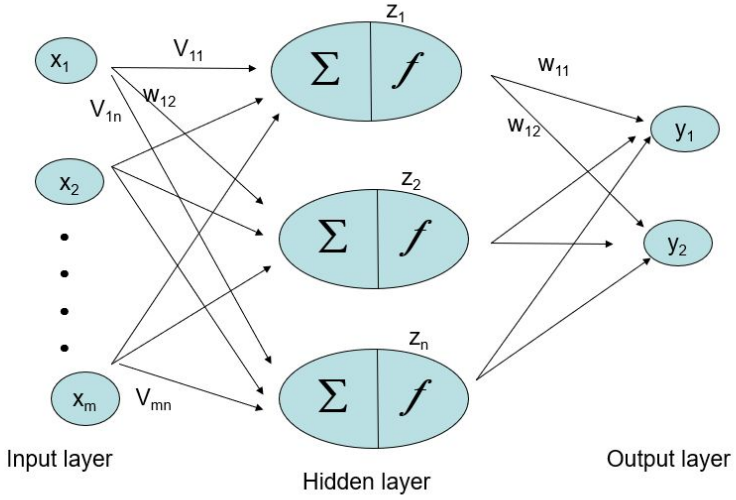
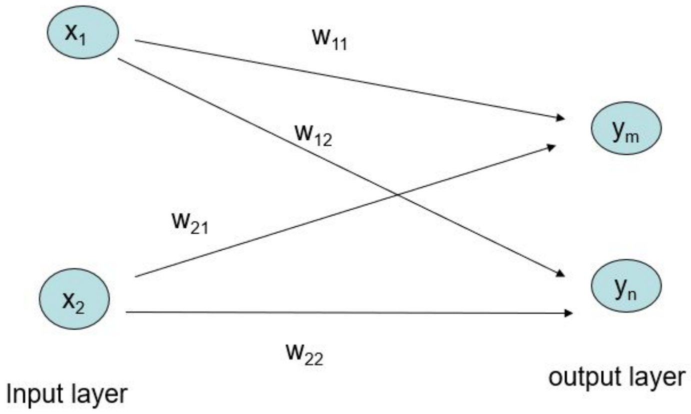


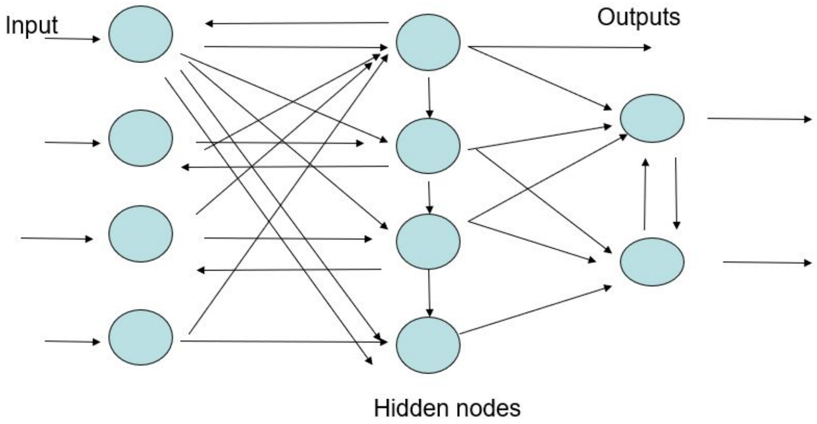
Multilayer Neural Network



Single Layer Feedforward NN



Recurrent NN



https://www.researchgate.net/

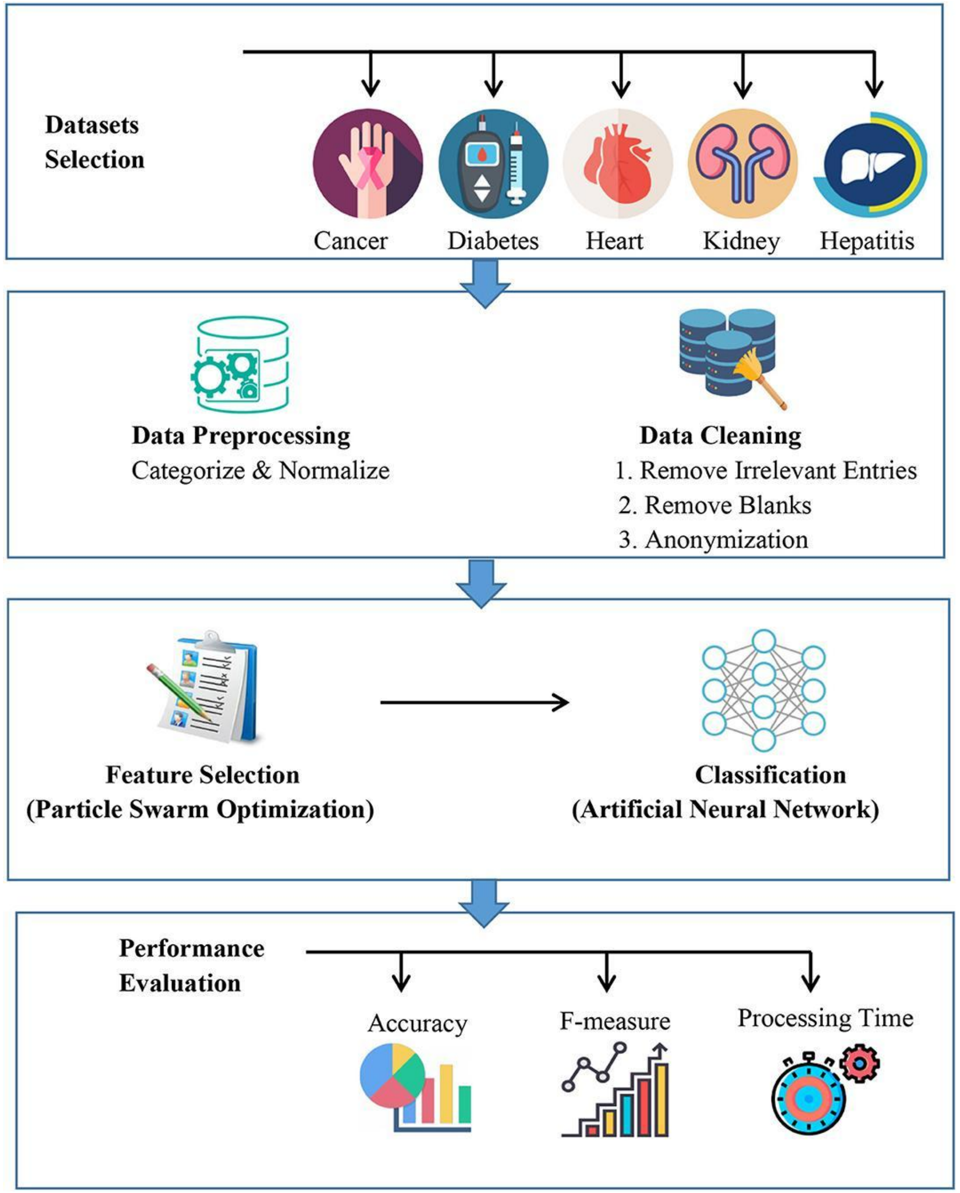
BIOINSPIRED ANN

- ANN is currently a 'hot' research area in medicine.
- Research is on modeling parts of the human body and recognizing diseases from various scans (e.g. cardiograms, CAT scans, ultrasonic scans, etc.).
- Neural Networks are used experimentally to model the human cardiovascular system.
- Diagnosis can be achieved by building a model of the cardiovascular system of an individual and comparing it with real time physiological measurements taken from the patient.

BIOINSPIRED ANN

- A model of an individual's cardiovascular system must mimic the relationship among physiological variables (i.e., heart rate, systolic and diastolic blood pressures, and breathing rate) at different physical activity levels.
- If a model is adapted to an individual, then it becomes a model of the physical condition of that individual.
- If this routine is carried out regularly, potential harmful medical conditions can be detected at an early stage and thus make the process of combating the disease much easier.

BIOINSPIRED ANN



www.frontiersin.org

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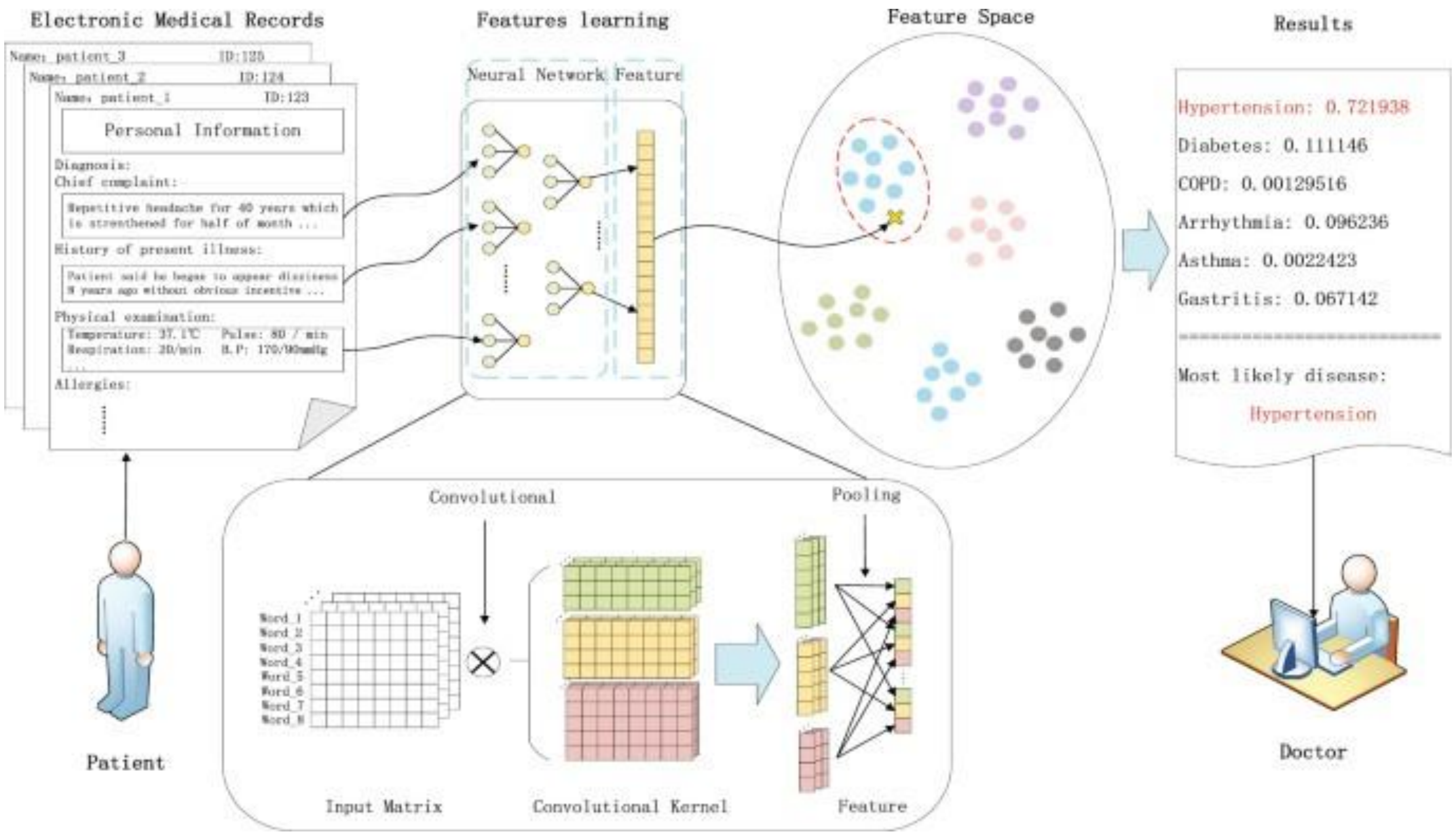
BIOINSPIRED ANN



Convolutional neural network extract semantic feature vectors of unstructured electronic medical records and map them to the feature space, finally classifier calculates probable probability of each disease and select highest probability of the disease .

www.nature.com

THANK YOU

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BIOSENSORS

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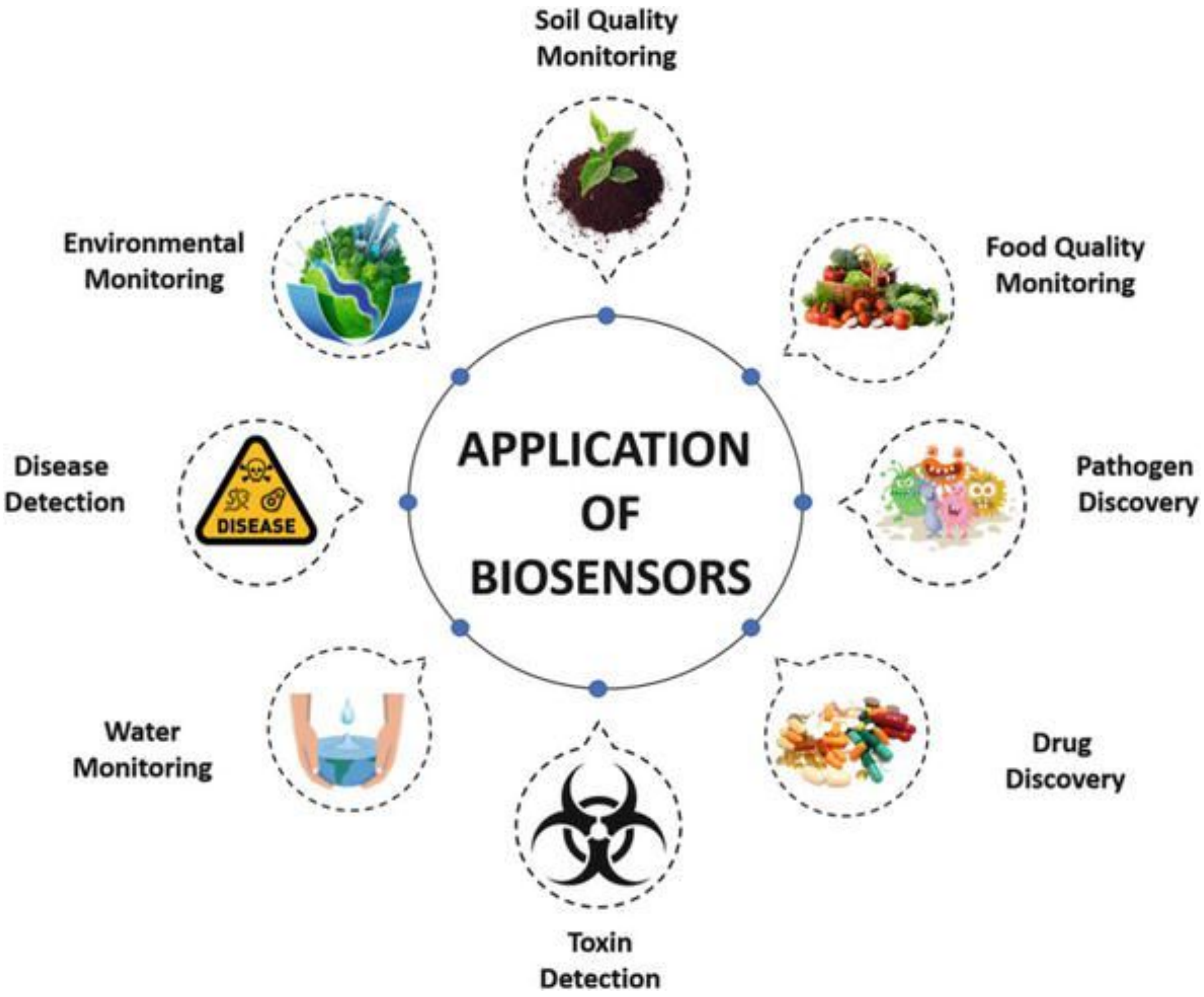
BIOSENSORS

- Biosensors can be defined as analytical devices which include a combination of biological detecting elements like sensor system and a transducer.
- The sensitive biological element, e.g. tissue, microorganisms, organelles, cell receptors, enzymes, antibodies, nucleic acids, etc., is a biologically derived material that interacts with, binds with, or recognizes the analyte under study.
- Biosensors are nowadays ubiquitous in biomedical diagnosis, point-of-care monitoring of treatment and disease progression, environmental monitoring, food control, drug discovery, forensics and biomedical research.
- A wide range of techniques can be used for the development of biosensors.
- Their coupling with high-affinity biomolecules allows the sensitive and selective detection of a range of analytes.

www.ncbi.nlm.nih.gov

APPLICATION AREAS



www.intechopen.com

BIOSENSORS

A typical biosensor consists of the following components.

Analyte:

- A substance of interest that needs detection.
- For instance, glucose is an ‘analyte’ in a biosensor designed to detect glucose.

Bioreceptor:

- A molecule that specifically recognizes the analyte is known as a bioreceptor.
- Enzymes, cells, aptamers, deoxyribonucleic acid (DNA) and antibodies are some examples of bioreceptors.
- The process of signal generation (in the form of light, heat, pH, charge or mass change, etc.) upon interaction of the bioreceptor with the analyte is termed bio-recognition.

www.ncbi.nlm.nih.gov

Transducer:

- The transducer is an element that converts one form of energy into another.
- In a biosensor the role of the transducer is to convert the bio-recognition event into a measurable signal.
- This process of energy conversion is known as signalisation.
- Most transducers produce either optical or electrical signals that are usually proportional to the amount of analyte–bioreceptor interactions.
- The transducer works in a physicochemical way: optical, piezoelectric, electrochemical, electrochemiluminescence etc., resulting from the interaction of the analyte with the biological element, to easily measure and quantify.

www.ncbi.nlm.nih.gov

Electronics:

- This is the part of a biosensor that processes the transduced signal and prepares it for display.
- It consists of complex electronic circuitry that performs signal conditioning such as amplification and conversion of signals from analogue into the digital form.
- The processed signals are then quantified by the display unit of the biosensor.

www.ncbi.nlm.nih.gov

Display:

- The display consists of a user interpretation system such as the liquid crystal display of a computer or a direct printer that generates numbers or curves understandable by the user.
- This part often consists of a combination of hardware and software that generates results of the biosensor in a user-friendly manner.
- The output signal on the display can be numeric, graphic, tabular or an image, depending on the requirements of the end user.

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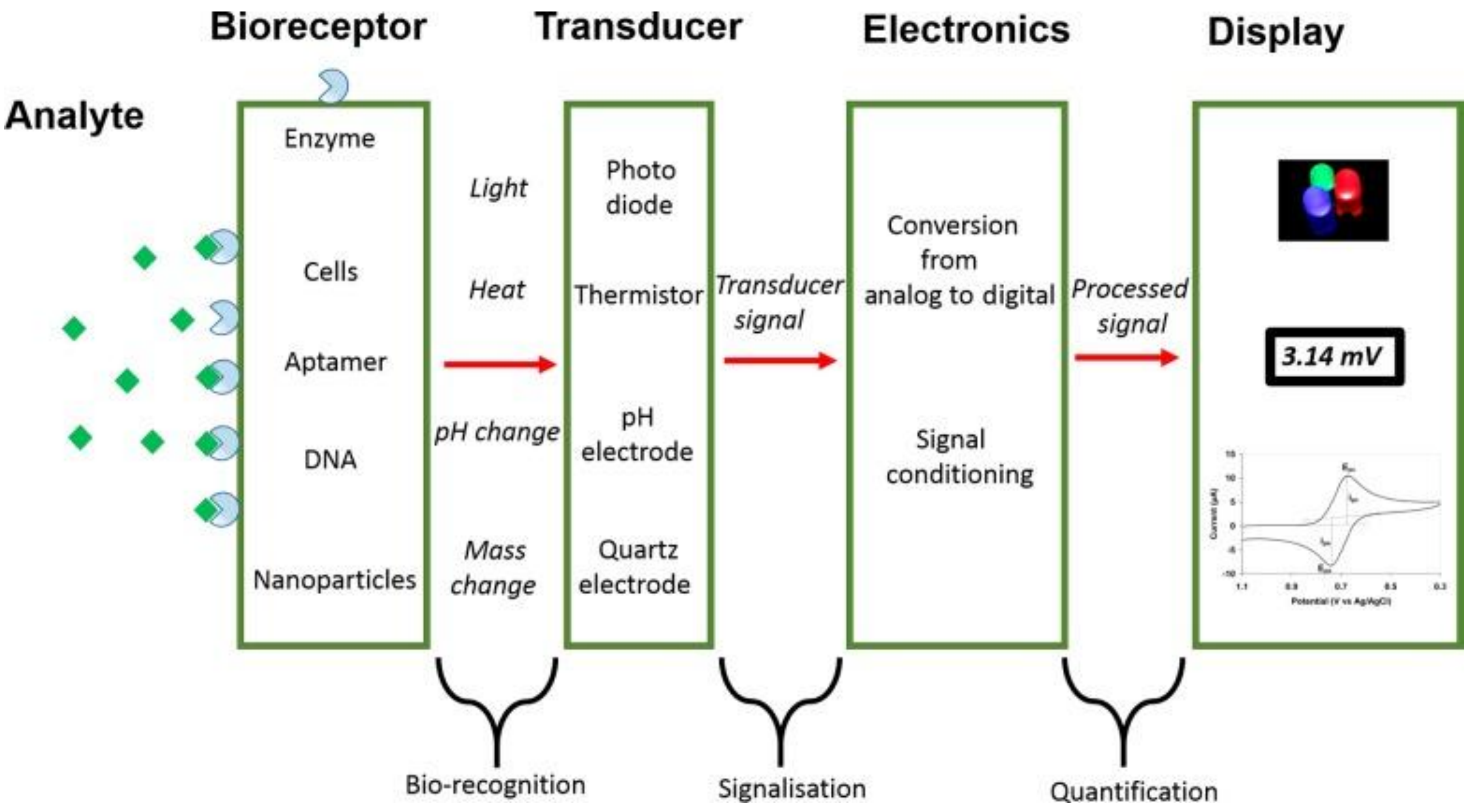
BIOSENSORS

- In a summary a biosensor typically consists of a bio-receptor (enzyme/antibody/cell/nucleic acid), transducer component (semi-conducting material/nanomaterial), and electronic system which includes a signal amplifier, processor & display
- In a biosensor, the bioreceptor is designed to interact with the specific analyte of interest to produce an effect measurable by the transducer.
- High selectivity for the analyte among a matrix of other chemical or biological components is a key requirement of the bioreceptor.

BIOSENSORS



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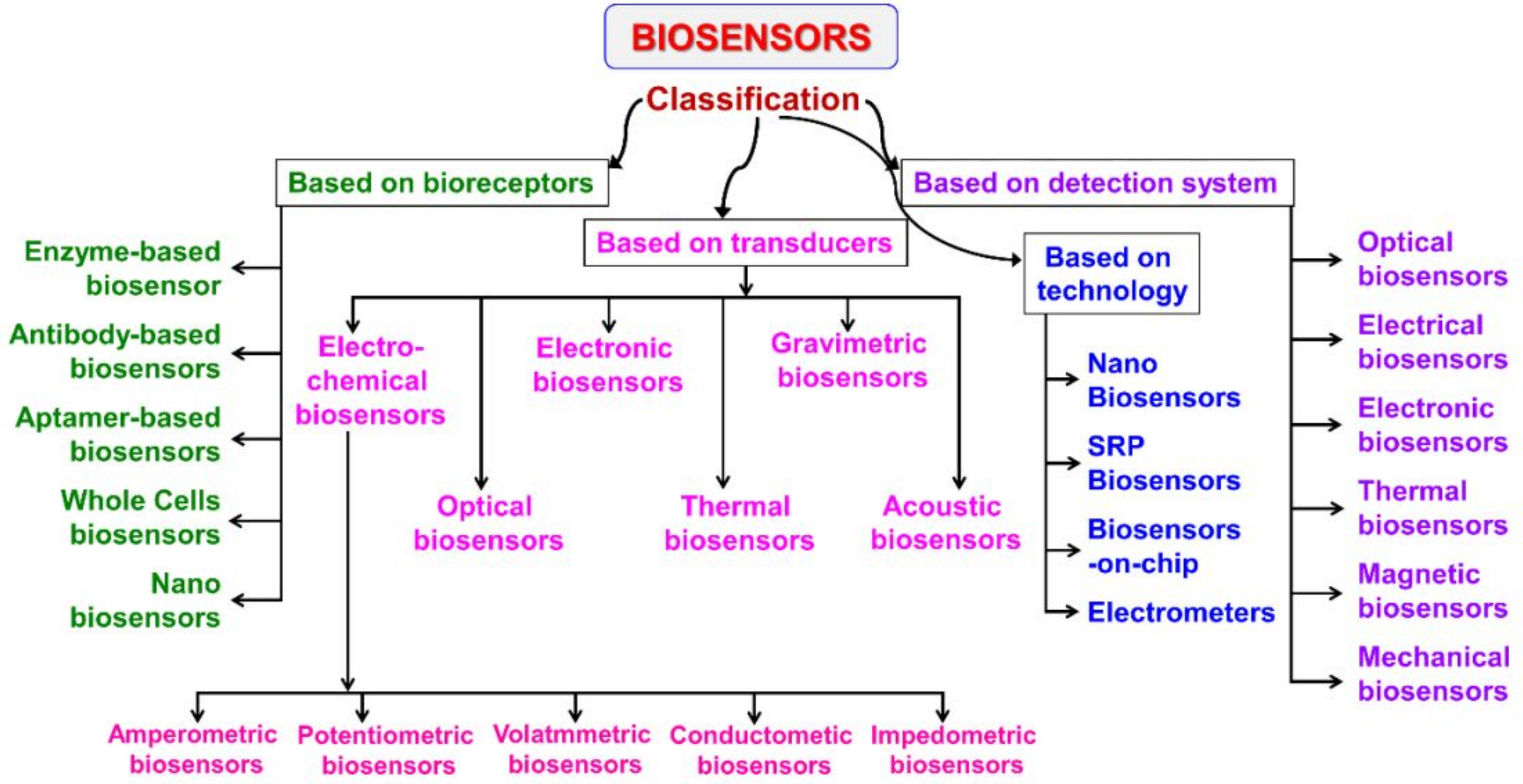
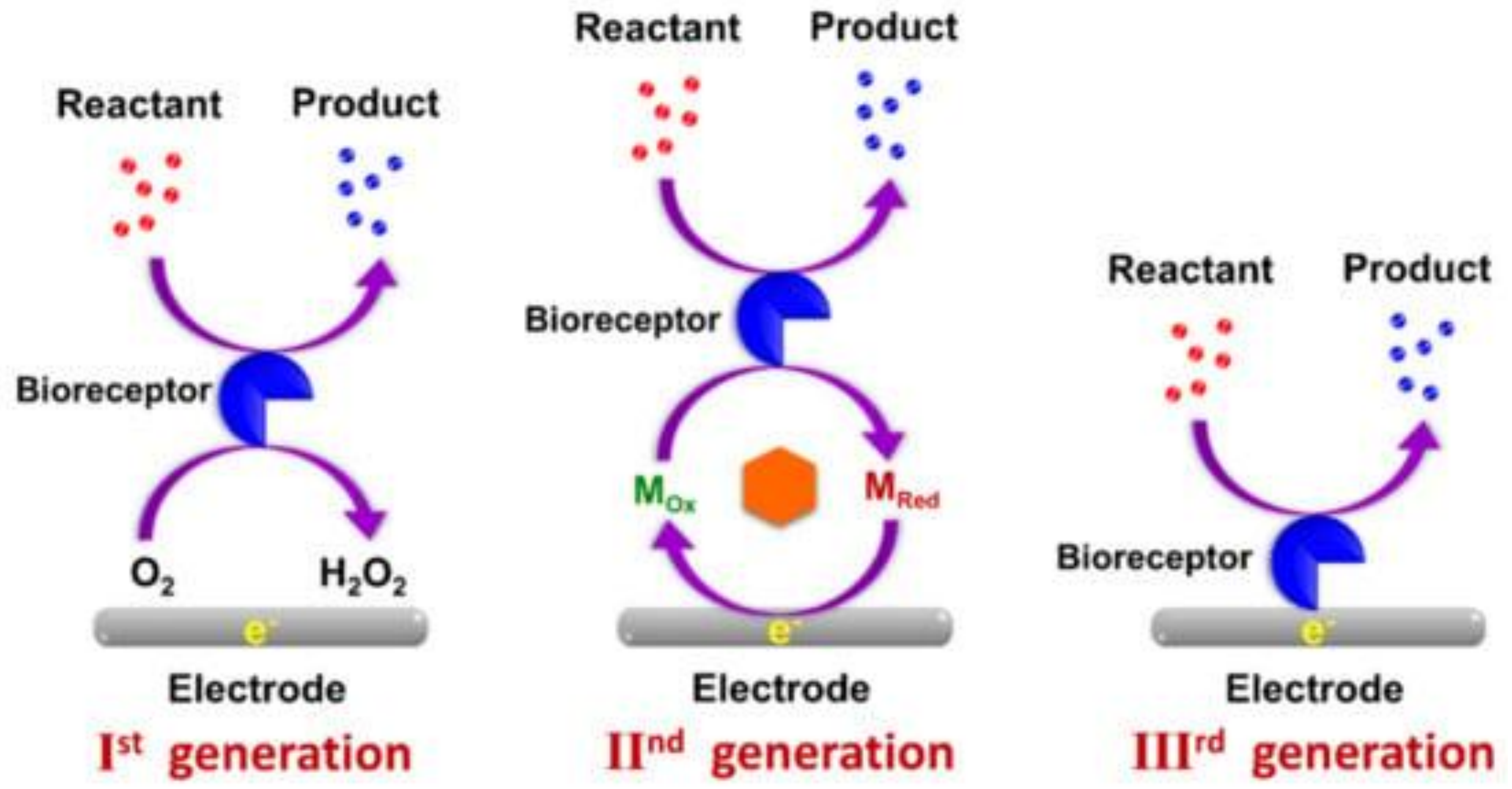
BIOSENSORS



www.mdpi.com

BIOSENSORS

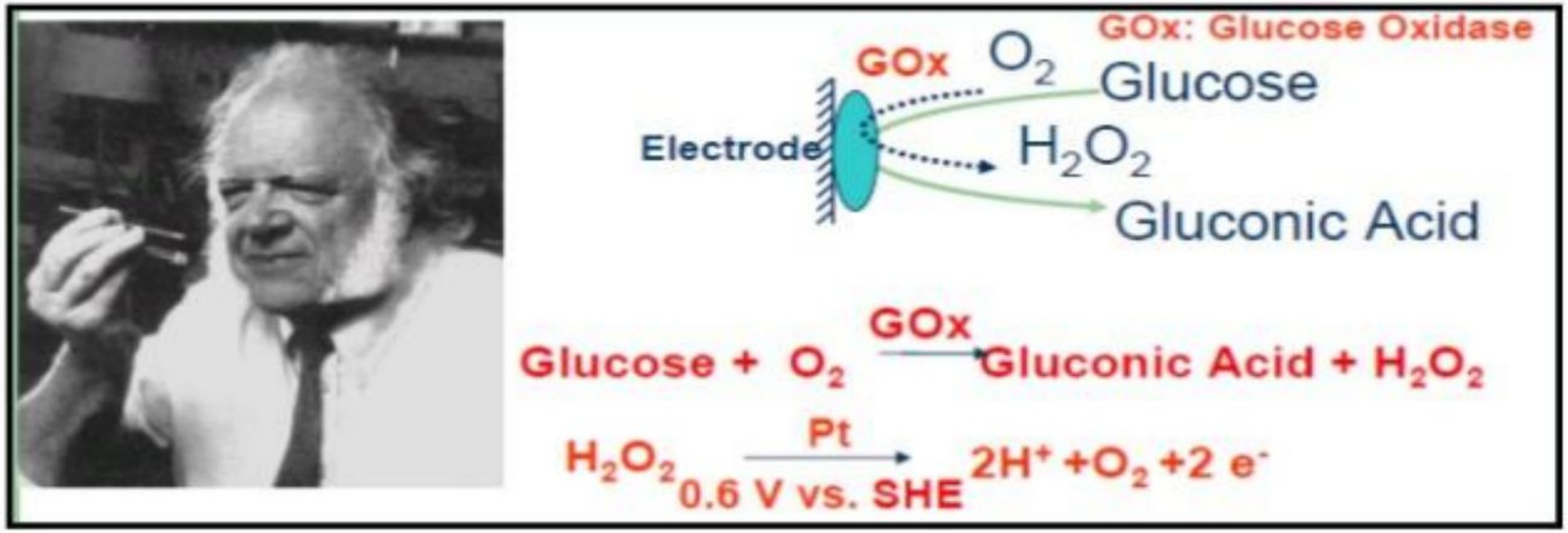


Three generations of the biosensor construction (M_{OX}: Oxidized mediator; M_{Red}: Reduced mediator).

www.mdpi.com

- The first 'true' biosensor was developed by Leland C. Clark in 1956 for oxygen detection. He is known as the 'Father of Biosensors' and his invention of the oxygen electrode bears his name: 'Clark electrode'

Professor Leland C Clark (1918–2005)



The first and the most widespreadly used commercial biosensor: the blood glucose biosensor – developed by *Leland C. Clark in 1962*

There are certain static and dynamic attributes that every biosensor possesses.

Selectivity

- Selectivity is the most important feature of a biosensor.
- Selectivity is the ability of a bioreceptor to detect a specific analyte in a sample containing other admixtures and contaminants.

Reproducibility

- Reproducibility is the ability of the biosensor to generate identical responses for a duplicated experimental set-up.
- Reproducibility is characterised by the precision and accuracy of the transducer and electronics in a biosensor.

Precision is the ability of the sensor to provide alike results every time a sample is measured and accuracy indicates the sensor's capacity to provide a mean value close to the true value when a sample is measured more than once.

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Stability

- Stability is the degree of susceptibility to ambient disturbances in and around the biosensing system.
- These disturbances can cause a drift in the output signals of a biosensor under measurement causing an error in the measured concentration and can affect the precision and accuracy of the biosensor.

Sensitivity

- The minimum amount of analyte that can be detected by a biosensor defines its limit of detection (LOD) or sensitivity.
- In a number of medical and environmental monitoring applications, a biosensor is required to detect analyte concentration of as low as ng/ml or even fg/ml to confirm the presence of traces of analytes in a sample.

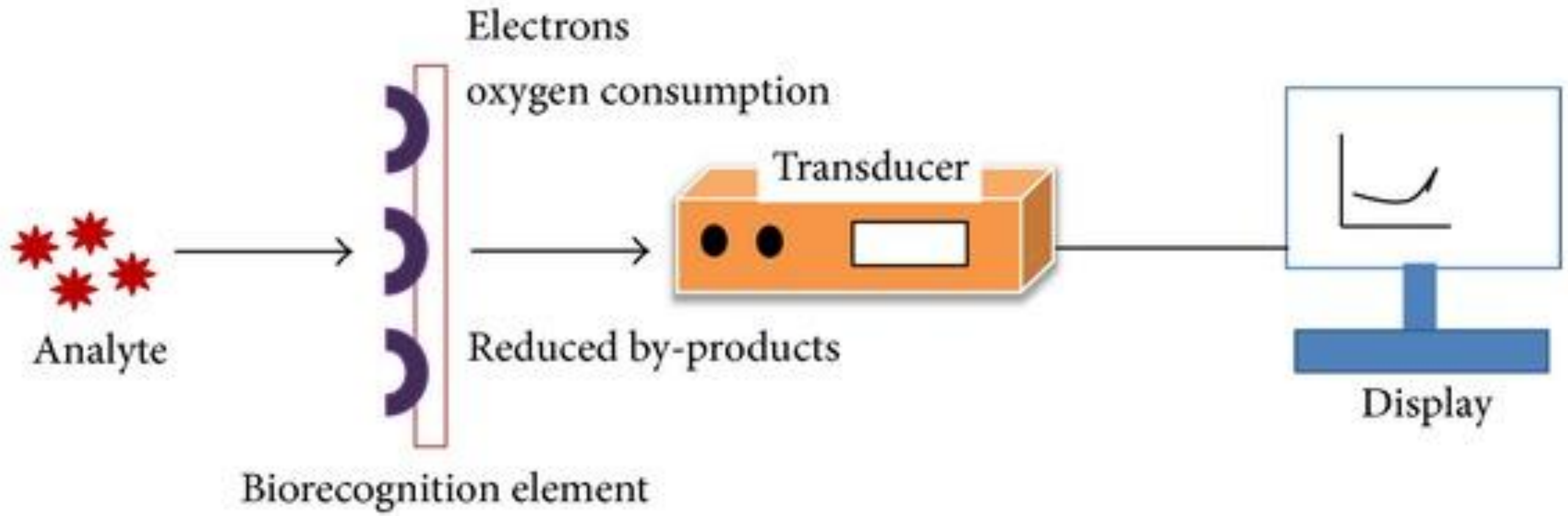
Linearity

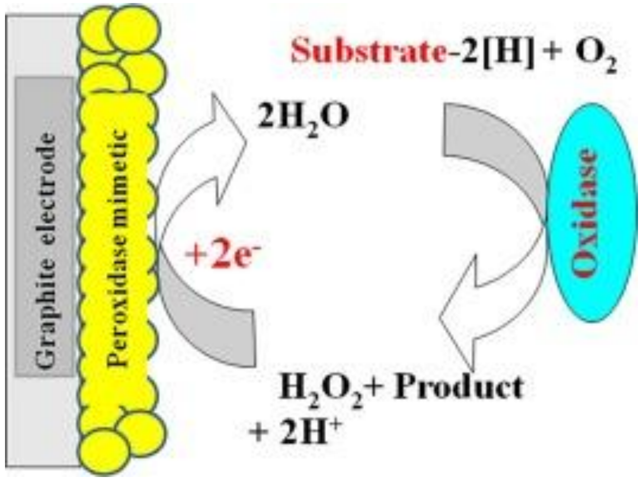
- Linearity is the attribute that shows the accuracy of the measured response (for a set of measurements with different concentrations of analyte) to a straight line, mathematically represented as $y=mc$, where c is the concentration of the analyte, y is the output signal, and m is the sensitivity of the biosensor.
- Linearity of the biosensor is associated with the resolution of the biosensor and range of analyte concentrations under test.
- The resolution of the biosensor is the smallest change in the concentration of an analyte that is required to bring a change in the response of the biosensor.

BIOSENSORS

- **Linearity**: Linearity of the sensor should be high for the detection of high substrate concentration.
- **Sensitivity**: Value of the electrode response per substrate concentration
- **Selectivity**: Chemical interference must be minimized for obtaining correct result
- **Response time**: Time necessary for having 95% of the response

ELECTROCHEMICAL BIOSENSORS





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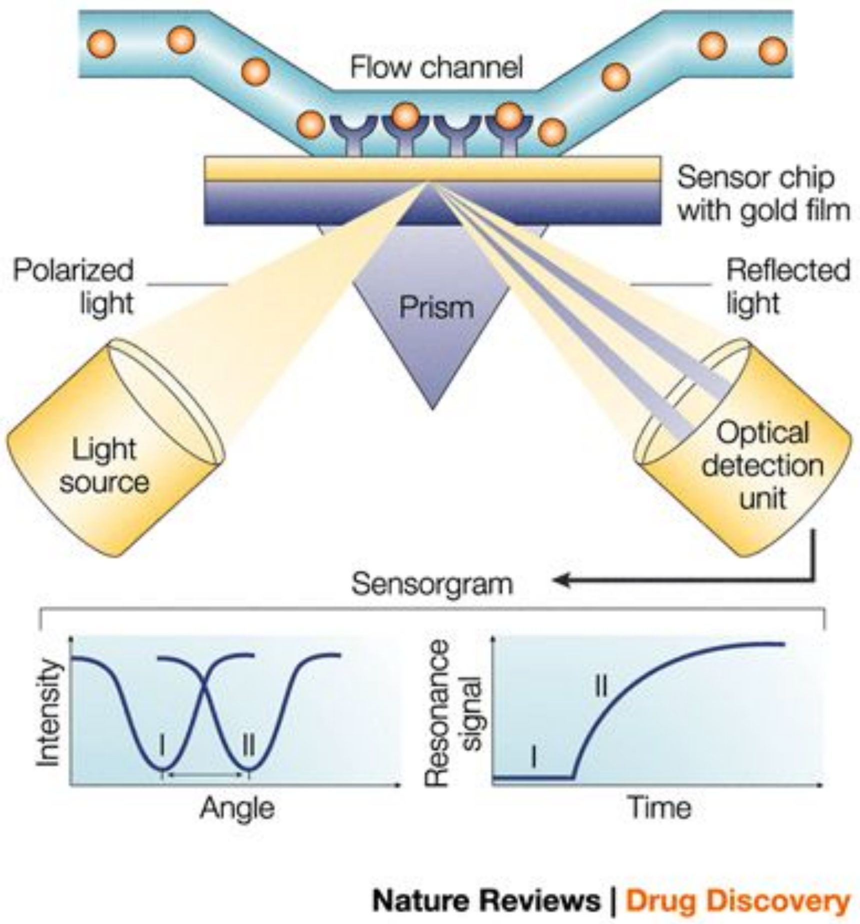
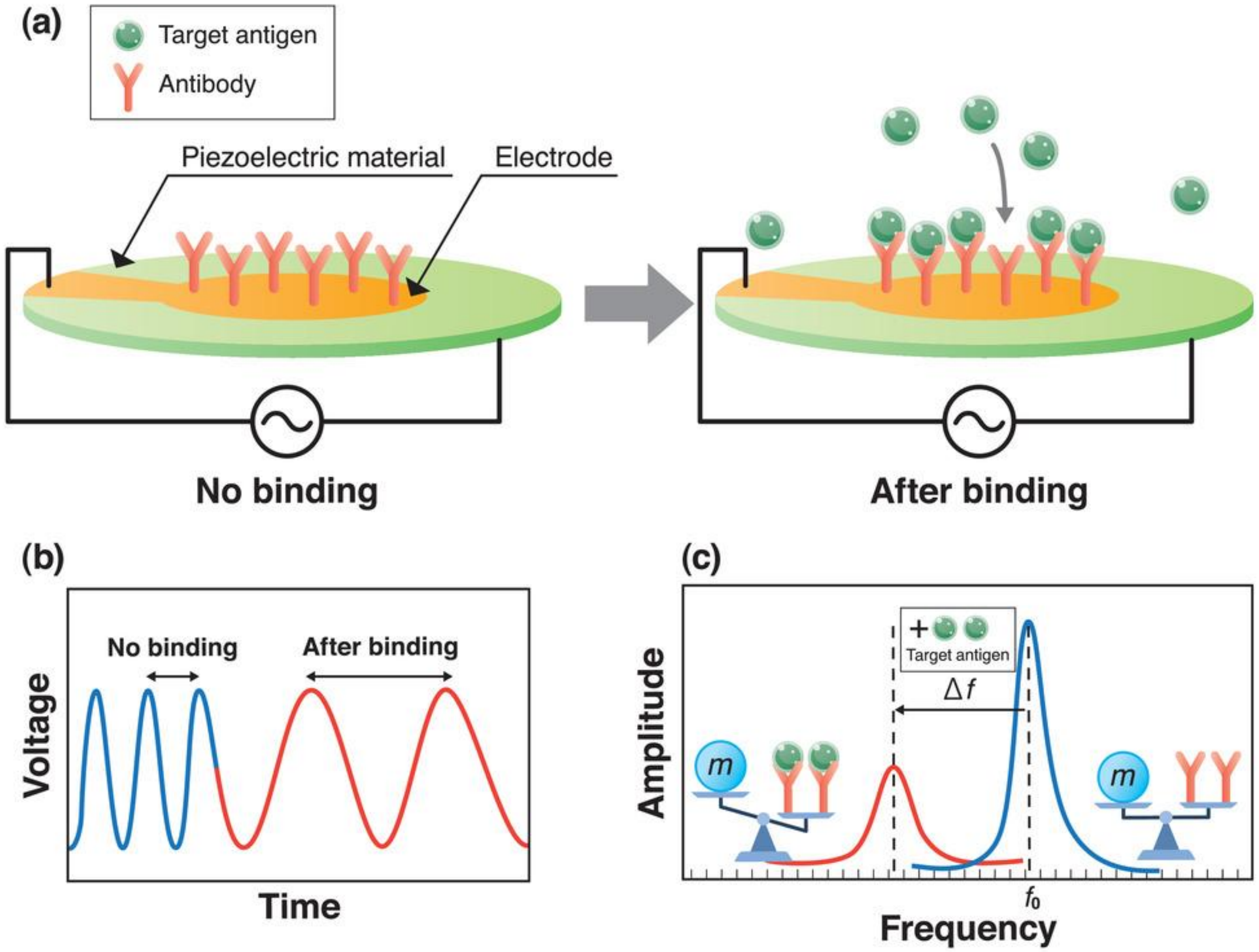
OPTICAL BIOSENSORS



PIEZOELECTRIC BIOSENSORS



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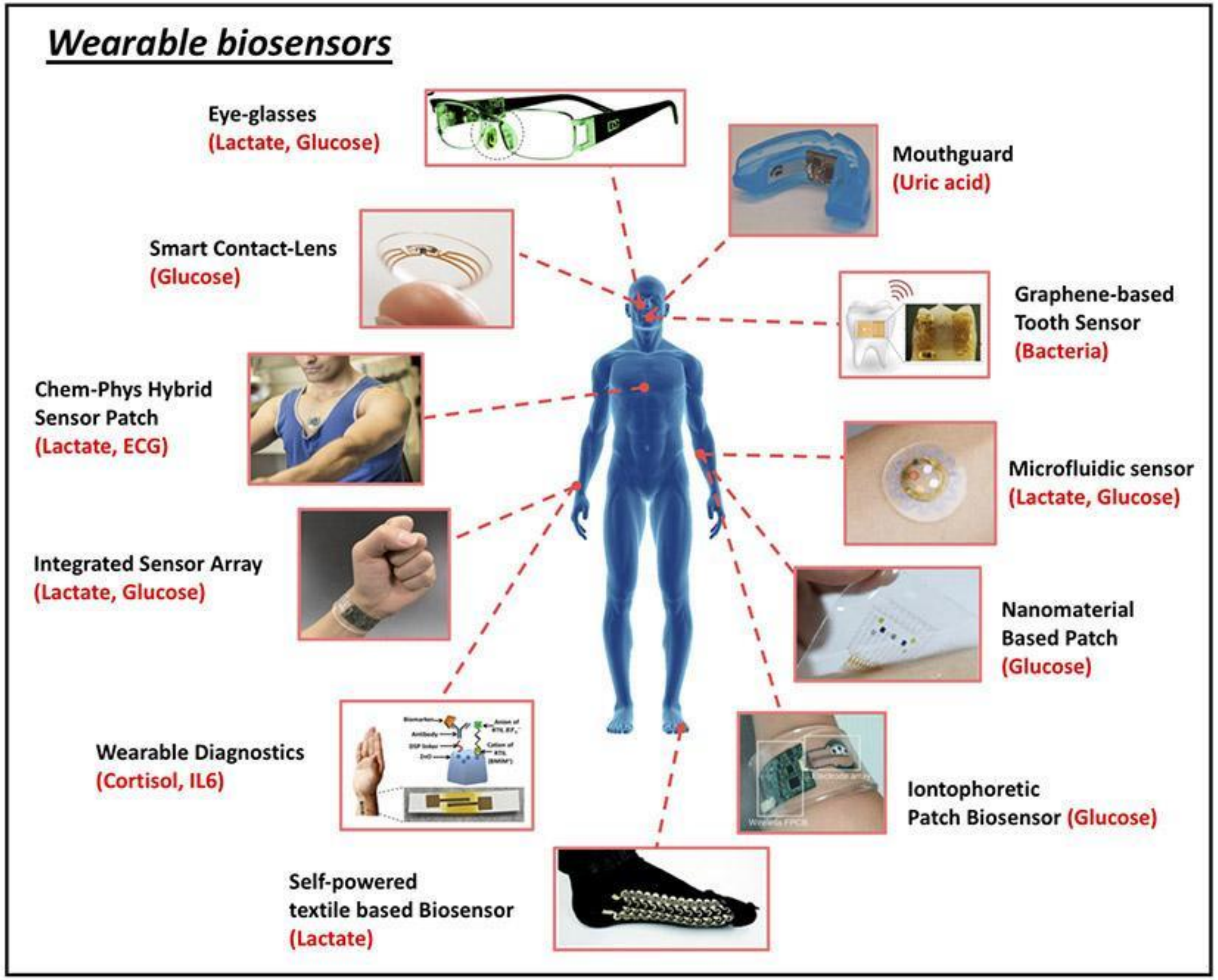
BIOSENSORS



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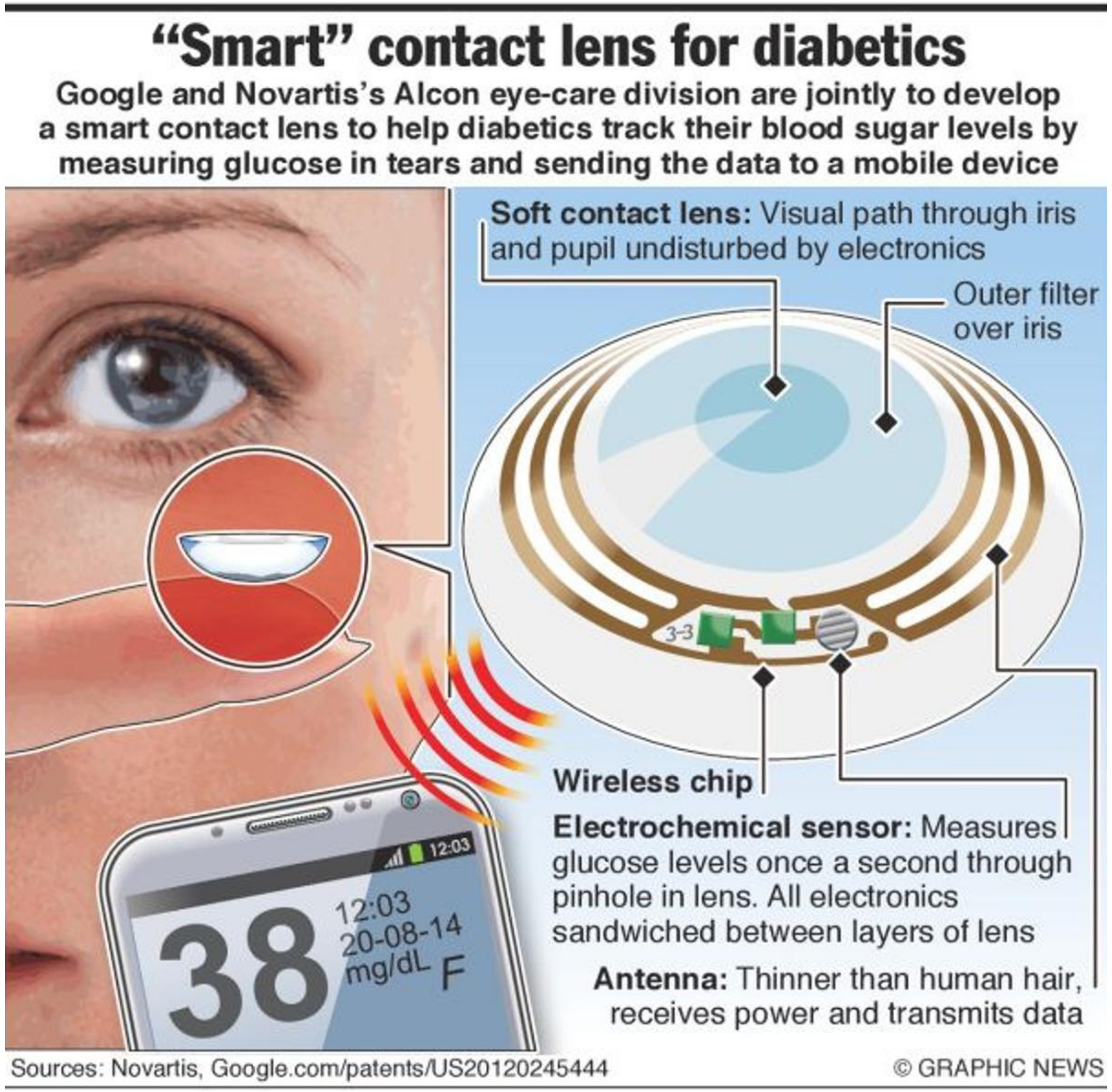
BIOSENSORS



"Smart" contact lens for diabetics
Google and Novartis's Alcon eye-care division are jointly to develop a smart contact lens to help diabetics track their blood sugar levels by measuring glucose in tears and sending the data to a mobile device
Soft contact lens: Visual path through iris and pupil undisturbed by electronics
Outer filter over iris
Wireless chip
Electrochemical sensor: Measures glucose levels once a second through pinhole in lens. All electronics sandwiched between layers of lens
Antenna: Thinner than human hair, receives power and transmits data
12:03
38
12:03
20-08-14
mg/dL
F
Sources: Novartis, Google.com/patents/US20120245444
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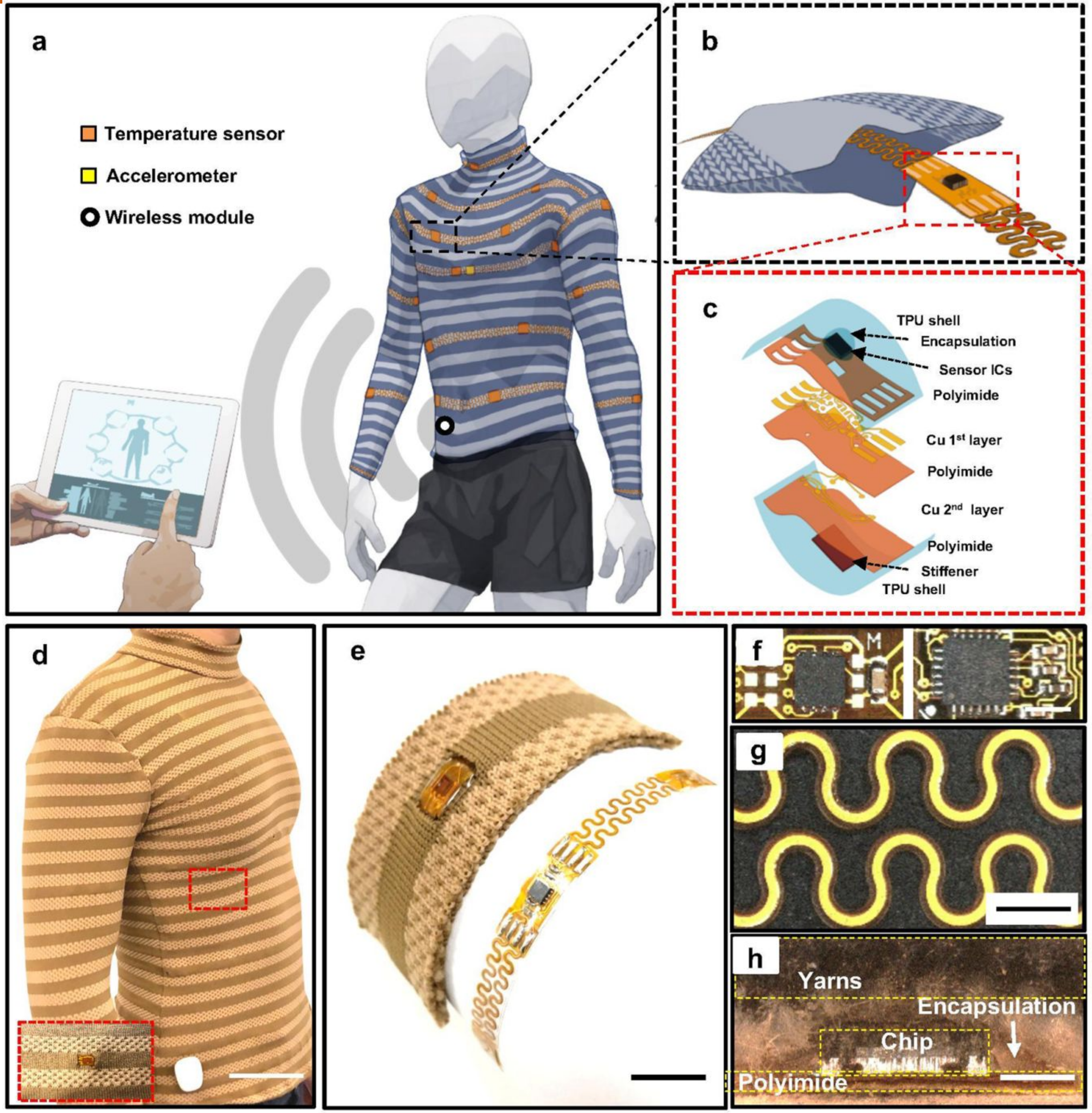
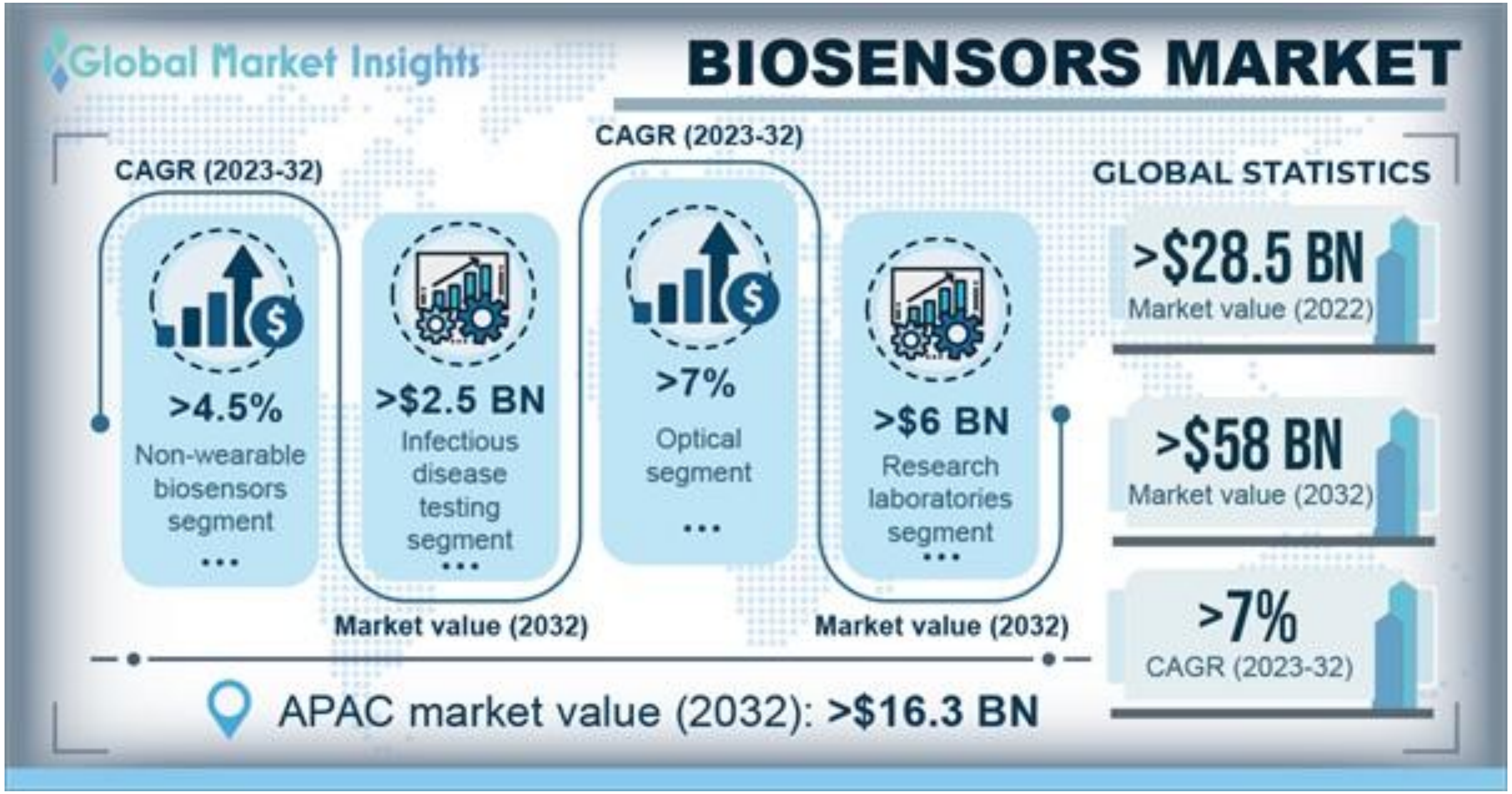
BIOSENSORS



www.nature.com

BIOSENSORS



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THANK YOU

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ENVIRONMENTAL STUDIES AND LIFE SCIENCES

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ENVIRONMENTAL STUDIES AND LIFE SCIENCES

3D Bioprinting

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Department of Biotechnology

PES UNIVERSITY

3D Bioprinting

- 3D printing, is driving major innovations in many areas, such as engineering, manufacturing, art, education and medicine.
- Recent advances have enabled 3D printing of biocompatible materials, cells and supporting components into complex 3D functional living tissues.
- 3D bioprinting is being applied to regenerative medicine to address the need for tissues and organs suitable for transplantation.
- 3D bioprinting involves additional complexities, such as the choice of materials, cell types, growth and differentiation factors, and technical challenges related to the construction of tissues.
- Addressing these complexities requires the integration of technologies from the fields of engineering, biomaterials science, cell biology, physics and medicine.
- 3D bioprinting has already been used for the generation and transplantation of several tissues, including multilayered skin, bone, vascular grafts, tracheal splints, heart tissue and cartilaginous structures.
- Other applications include developing high-throughput 3D-bioprinted tissue models for research, drug discovery and toxicology.

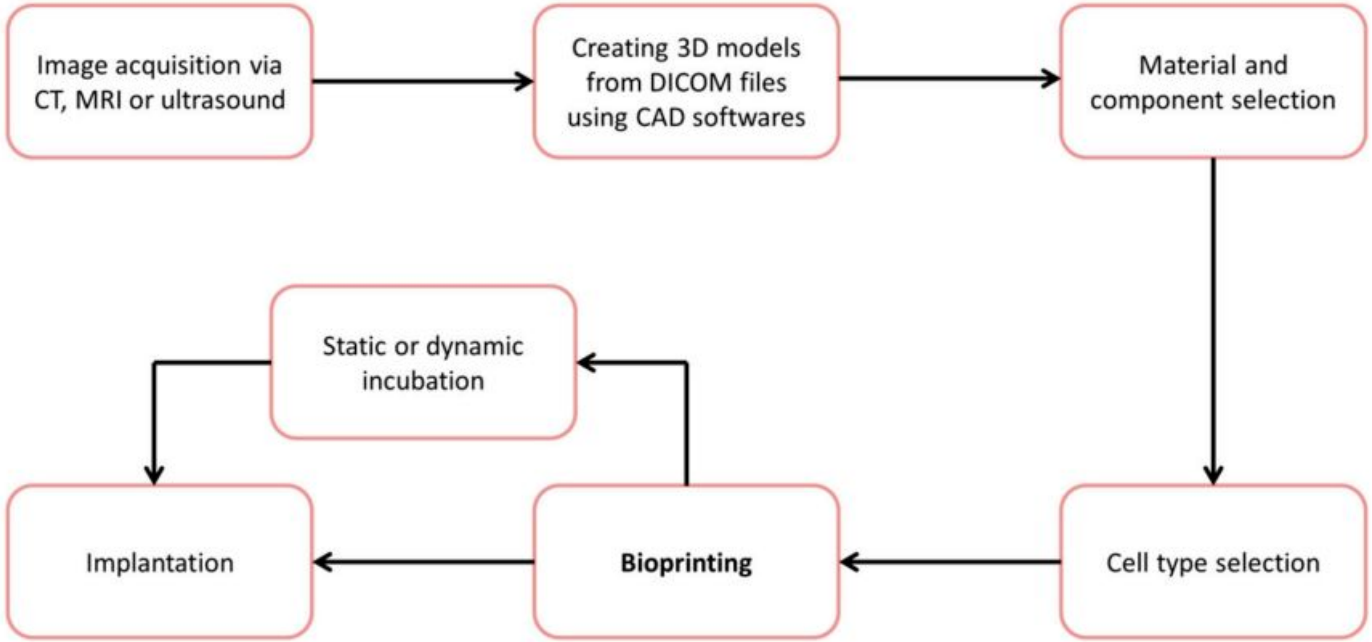
doi:10.1038/nbt.2958

3D Bioprinting

- 3D printing was first described in 1986 by Charles W. Hull. In his method, which he named ‘sterolithography’, thin layers of a material that can be cured with ultraviolet light were sequentially printed in layers to form a solid 3D structure.
- Development of solvent-free, aqueous based systems enabled the direct printing of biological materials into 3D scaffolds that could be used for transplantation.
- A related development was the application of 3D printing to produce medical devices such as stents and splints for use in the clinic.
- In a typical process for bioprinting 3D tissues imaging of the damaged tissue and its environment can be used to guide the design of bioprinted tissues.
- The choice of materials and cell source is essential and specific to the tissue form and function. These components have to integrate with bioprinting systems such as inkjet, microextrusion or laser-assisted printers.

doi:10.1038/nbt.2958

3D Bioprinting Process



Schematic of Bioprinting Scaffolds for clinical use. Digital 3D images obtained from CT, MRI or ultrasound, are used to design a suitable scaffold with 3D slicing and CAD software; materials from printing are chosen depending upon the application, and can consist of polymers, ceramics, and bioactive components; cells are selected dependent on the application, a bioink can consist of singular or multiple cell types.

doi:10.3390/ma11112199

3D Bioprinting - Bioprinters

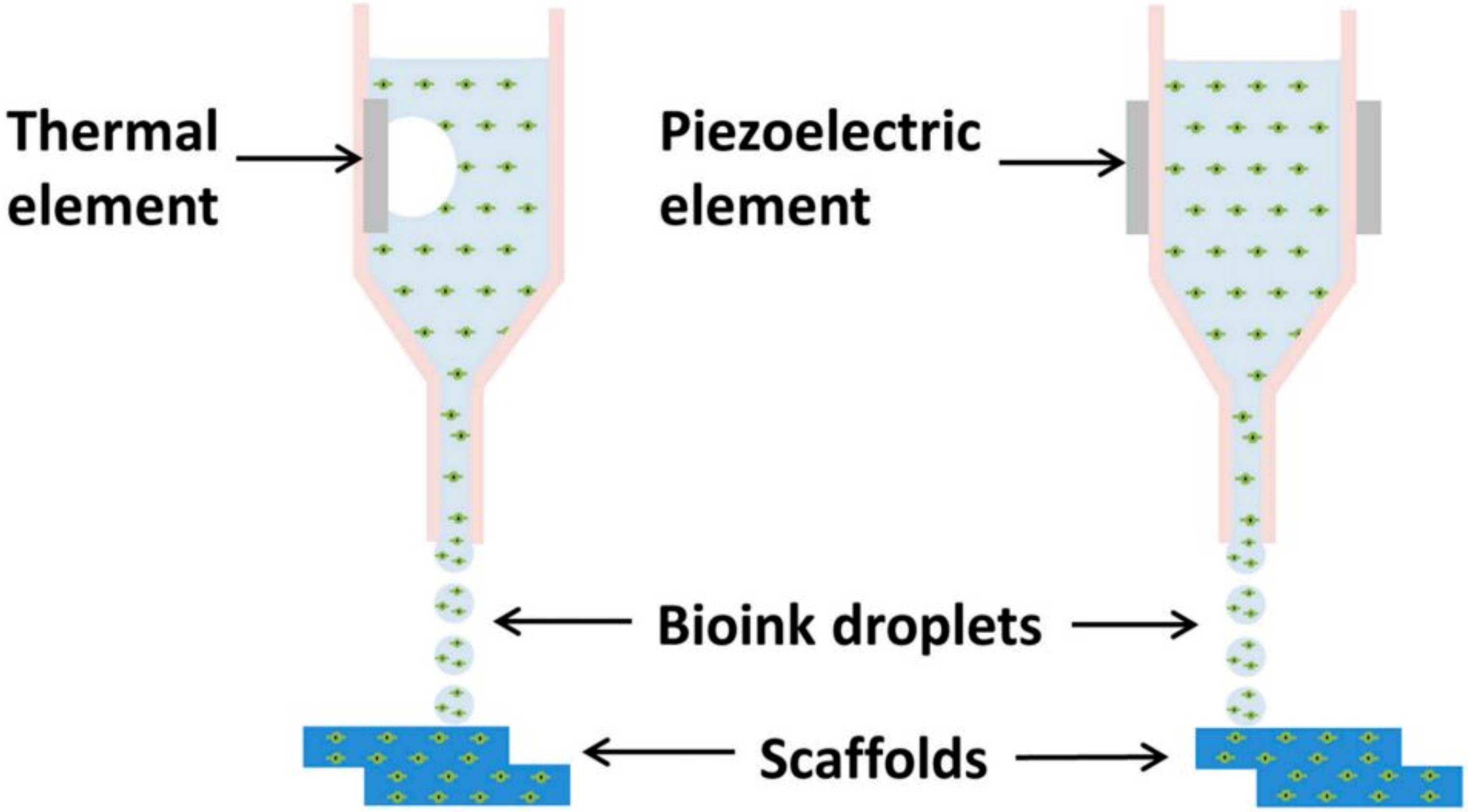


Figure 2. Schematic of Inkjet-based Bioprinting. Thermal inkjet uses heat-induced bubble nucleation that propels the bioink through the micro-nozzle. Piezoelectric actuator produces acoustic waves that propel the bioink through the micro-nozzle.

doi:10.3390/ma11112199

3D Bioprinting - Bioprinters

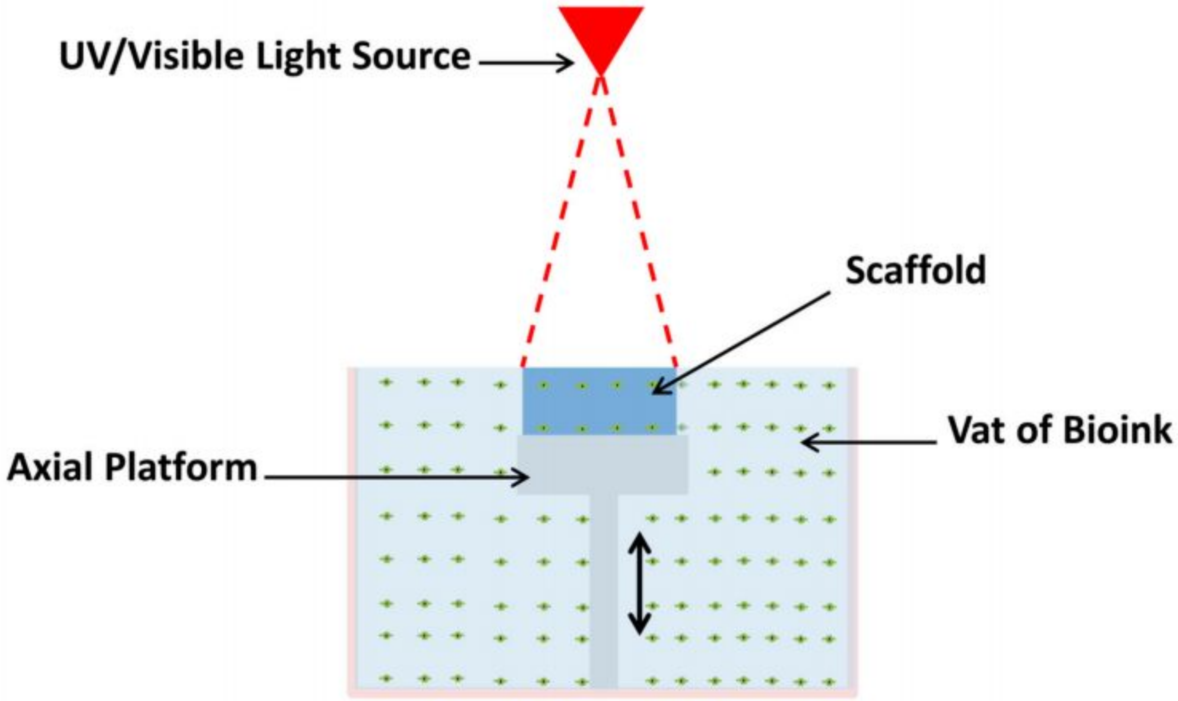


Figure 3. Schematic of Stereolithography Bioprinting. Photopolymerization occurs on the surface of the vat where the light-sensitive bioink is exposed to light energy. Axial platform moves downward the Z-axis during fabrication. This layer-by-layer technique does not depend on the complexity of the design, rather on its height.

doi:10.3390/ma11112199

3D Bioprinting - Bioprinters

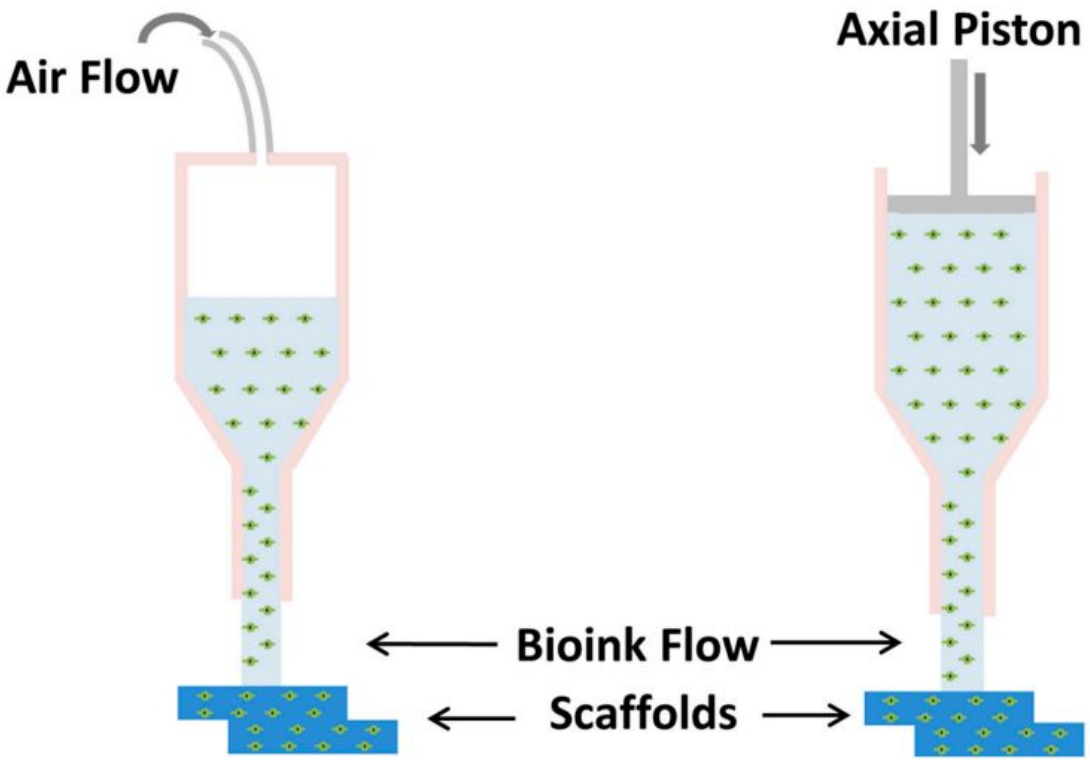
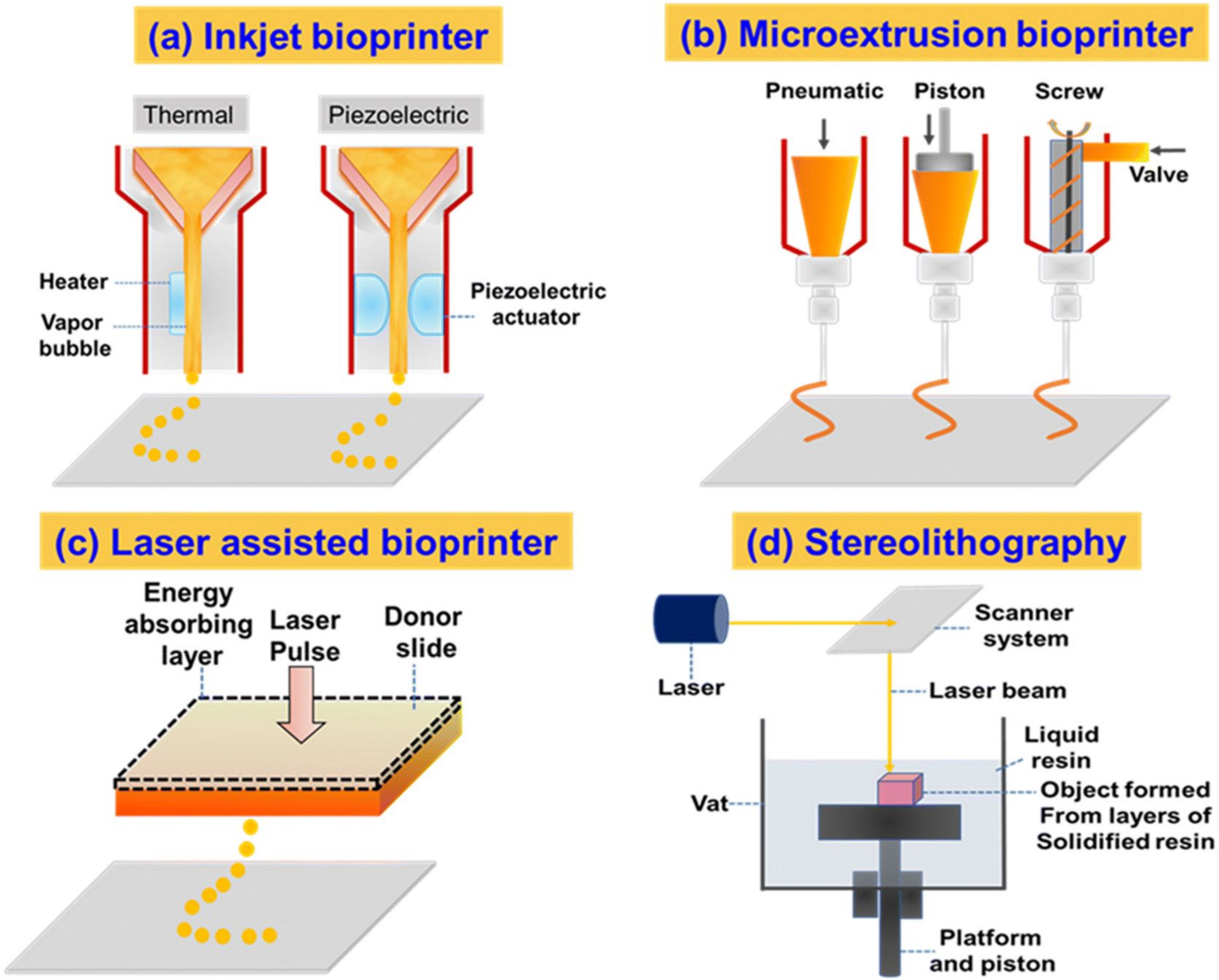


Figure 5. Schematic of Extrusion-based Bioprinting; from left, pneumatic-based and right, mechanical-based. Struts are extruded via pneumatic or mechanical pressure through micro-nozzles. Extrusion-based techniques can produce structures with great mechanical properties and print fidelity.

doi:10.3390/ma11112199

3D Bioprinting - Bioprinters



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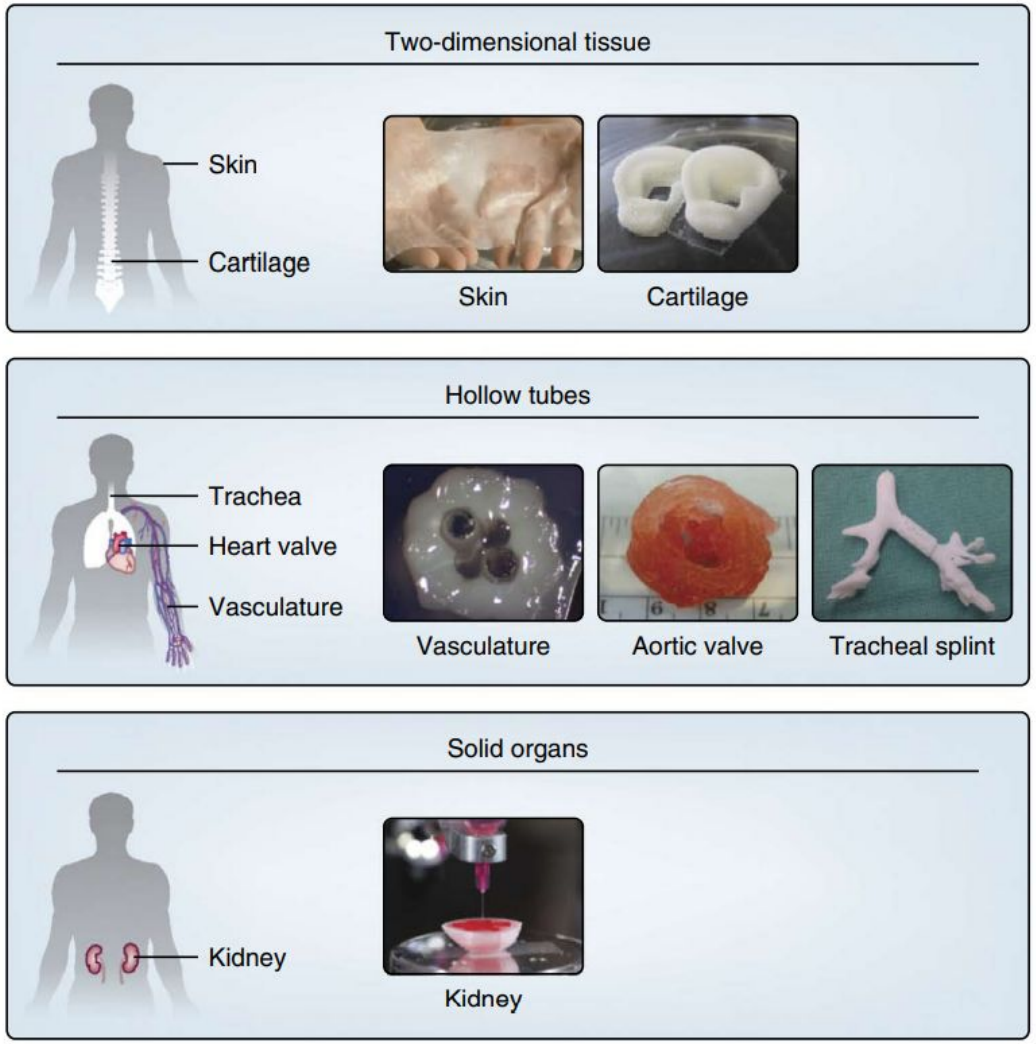
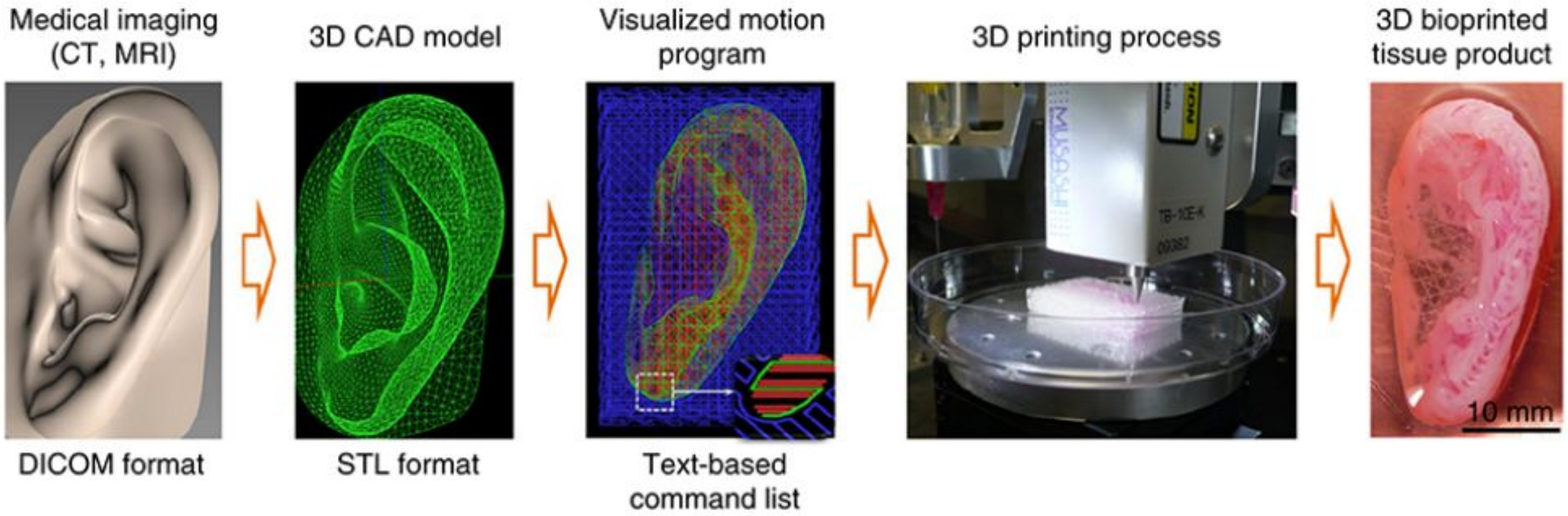
3D Bioprinting (Human scale bioprinted tissue)



doi:10.1038/nbt.2958

3D Bioprinting (Human scale bioprinted tissue)



The 3D bioprinting process. Image: Wake Forest, *Nature Biotechnology*

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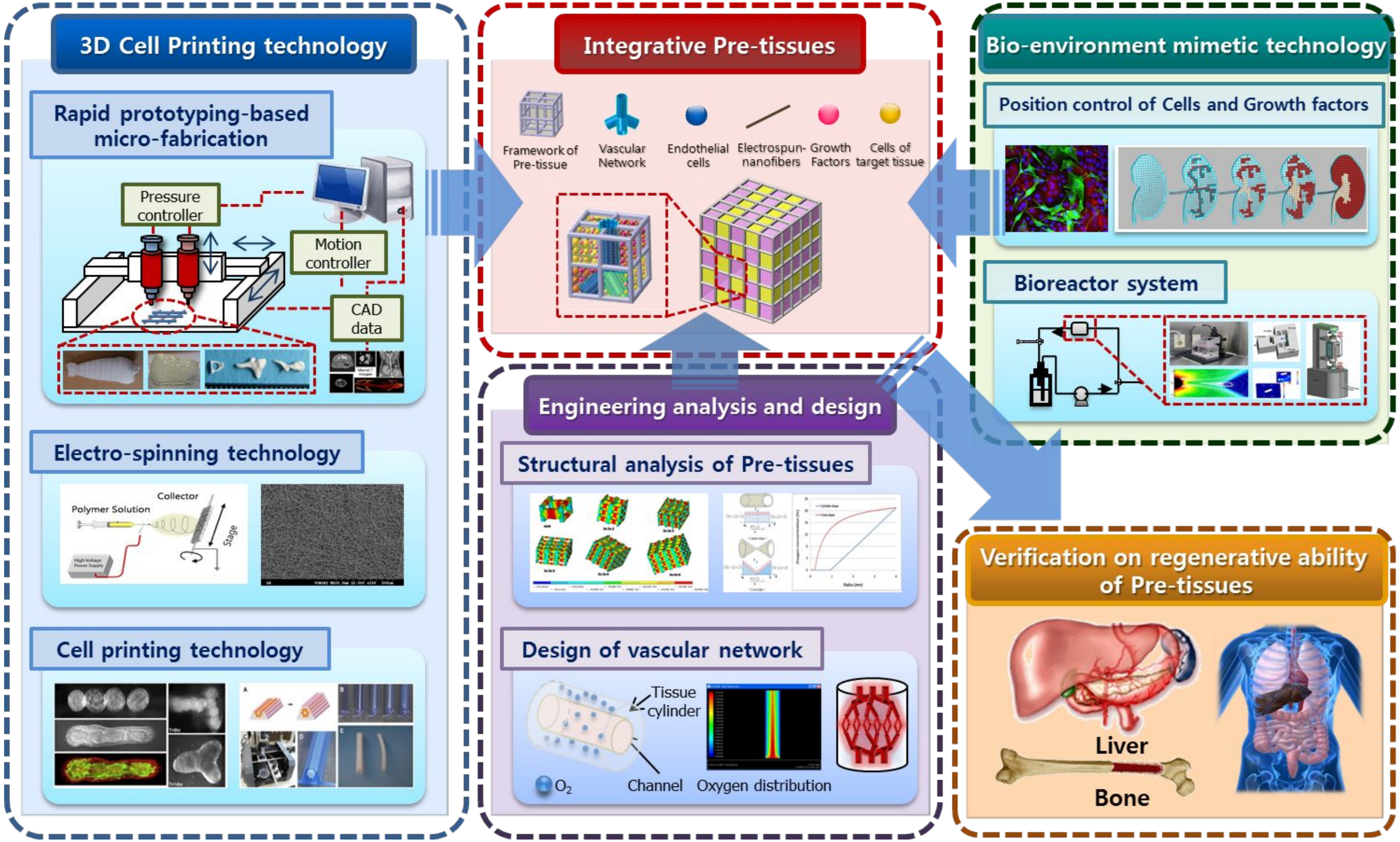
3D Bioprinting



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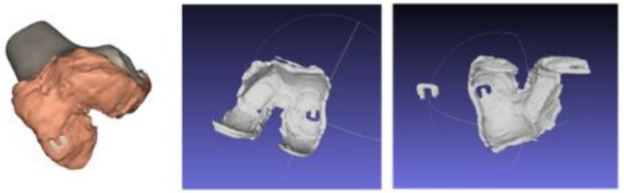
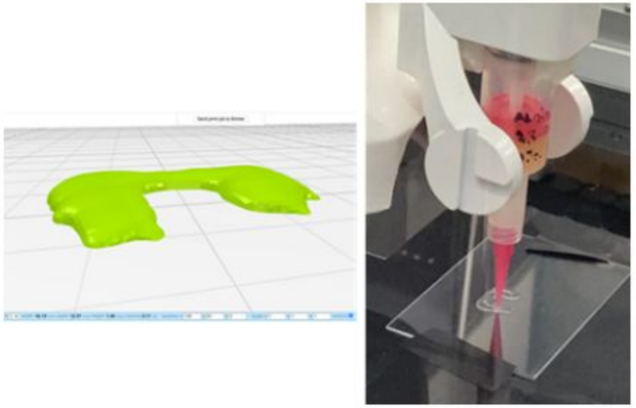
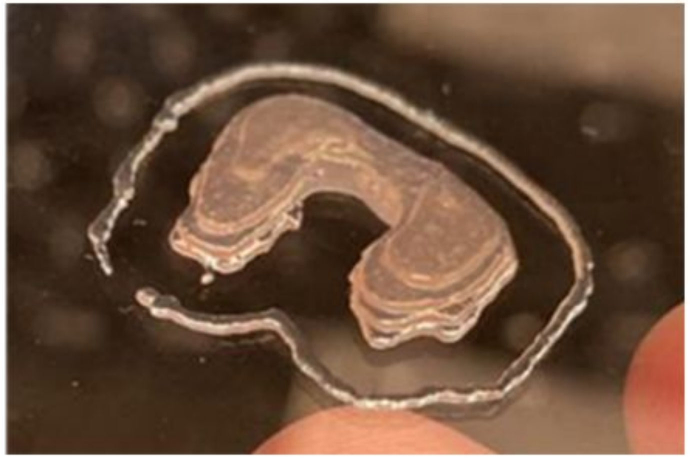
3D Bioprinting



A representative 3D reconstructed model of the osteoarthritic knee joint from the RESTORE Project's online database, together with STL models of the femoral cartilage with a horse-shoe-shaped cartilage patch designed to fit the lesion.



(Left): The horse-shoe-shaped cartilage patch model was created using various imaging techniques to unravel the 3D architecture of the tissues and control the positioning of print heads to place bioink in a 3D shape for a patient-specific match. (Right): 3D bioprinting process of the patch using Brinter® Rotary Tool print head and bioink material mixed with cells, spheroids or organoids.



The completed cartilage patch bioprinted using the Brinter® Rotary Tool print head.

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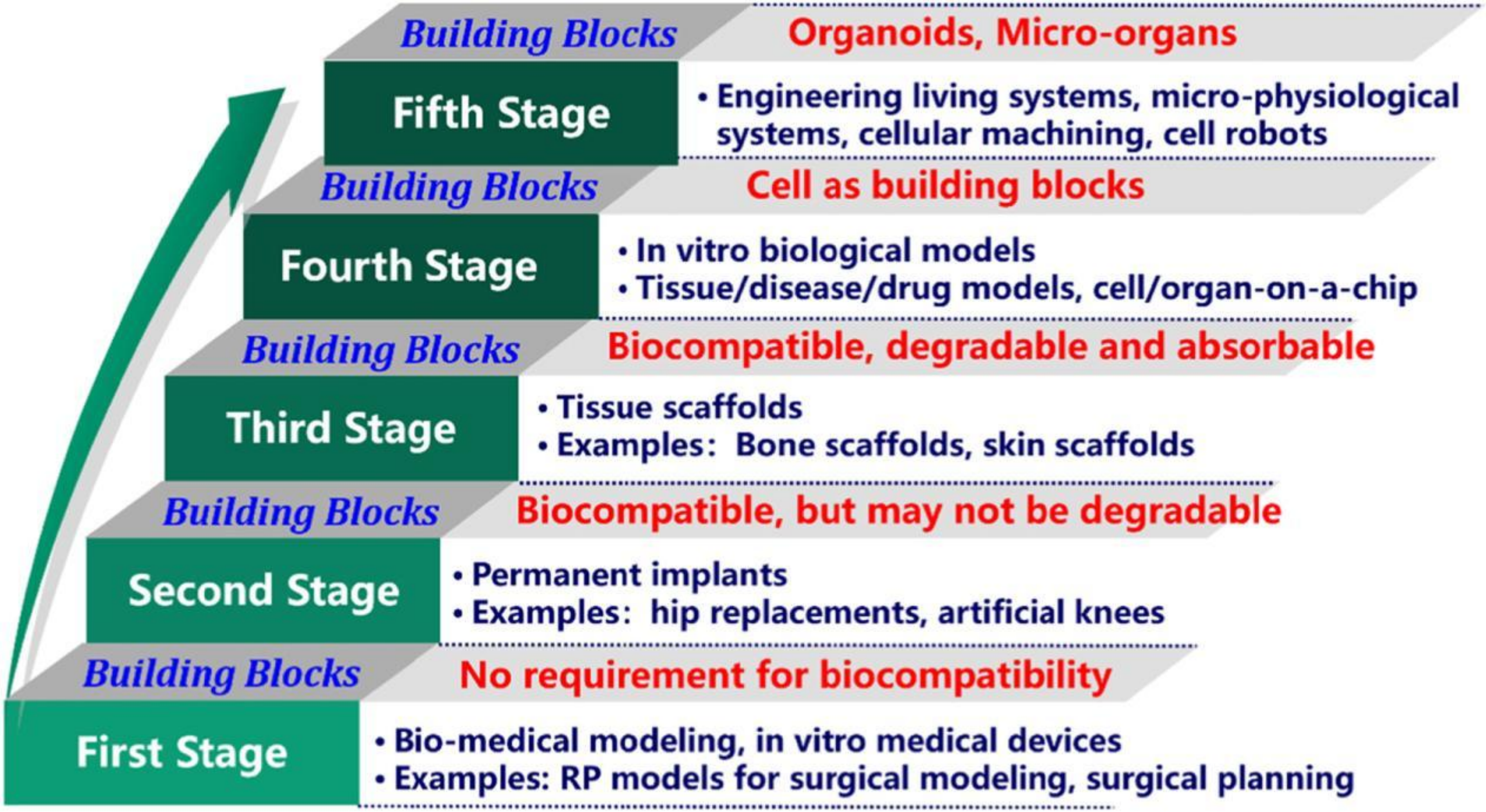
3D Bioprinting



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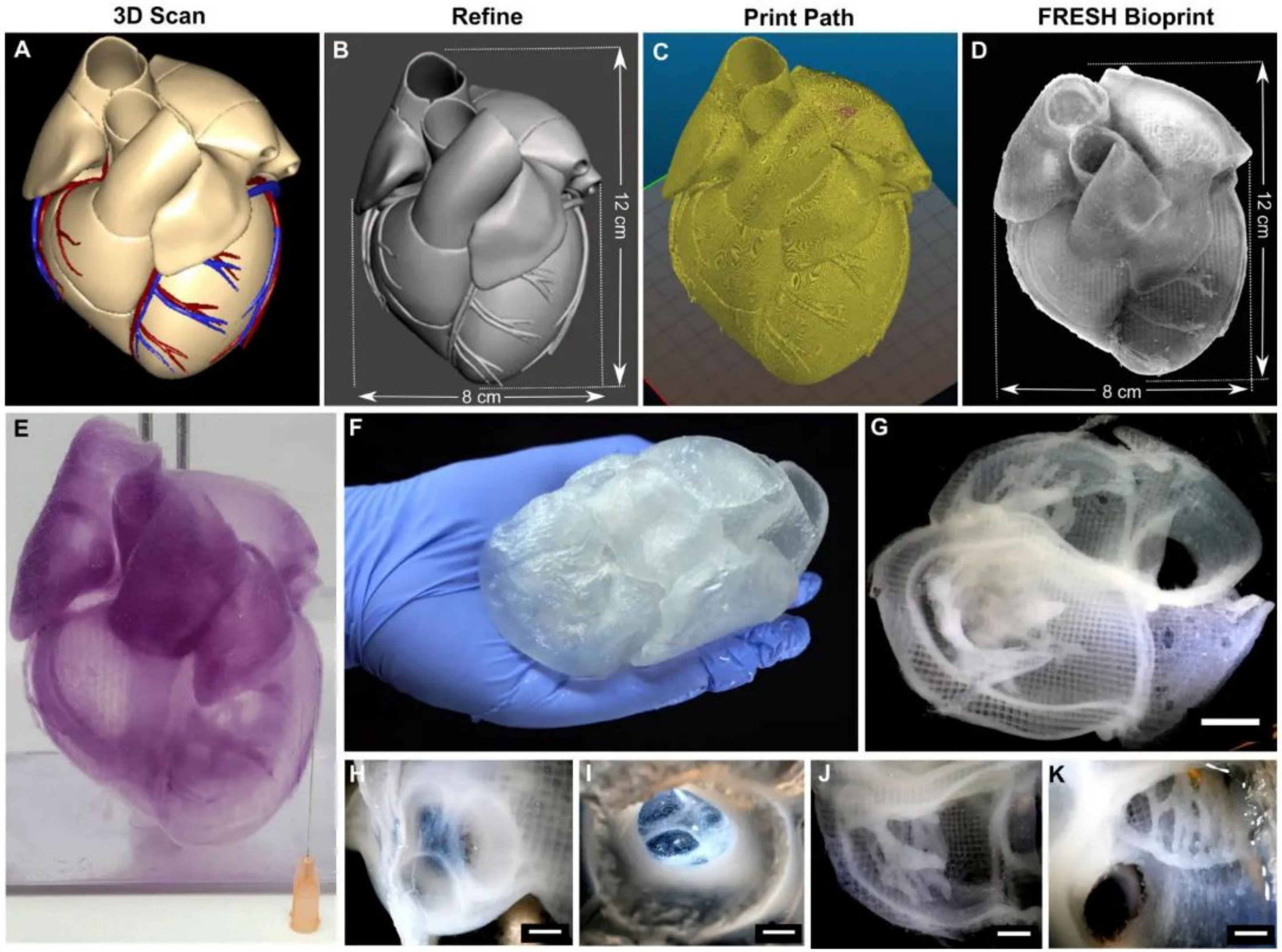
3D Bioprinting



Modeling incorporates imaging data into the final 3D printed object. Credit: Carnegie Mellon University College of Engineering

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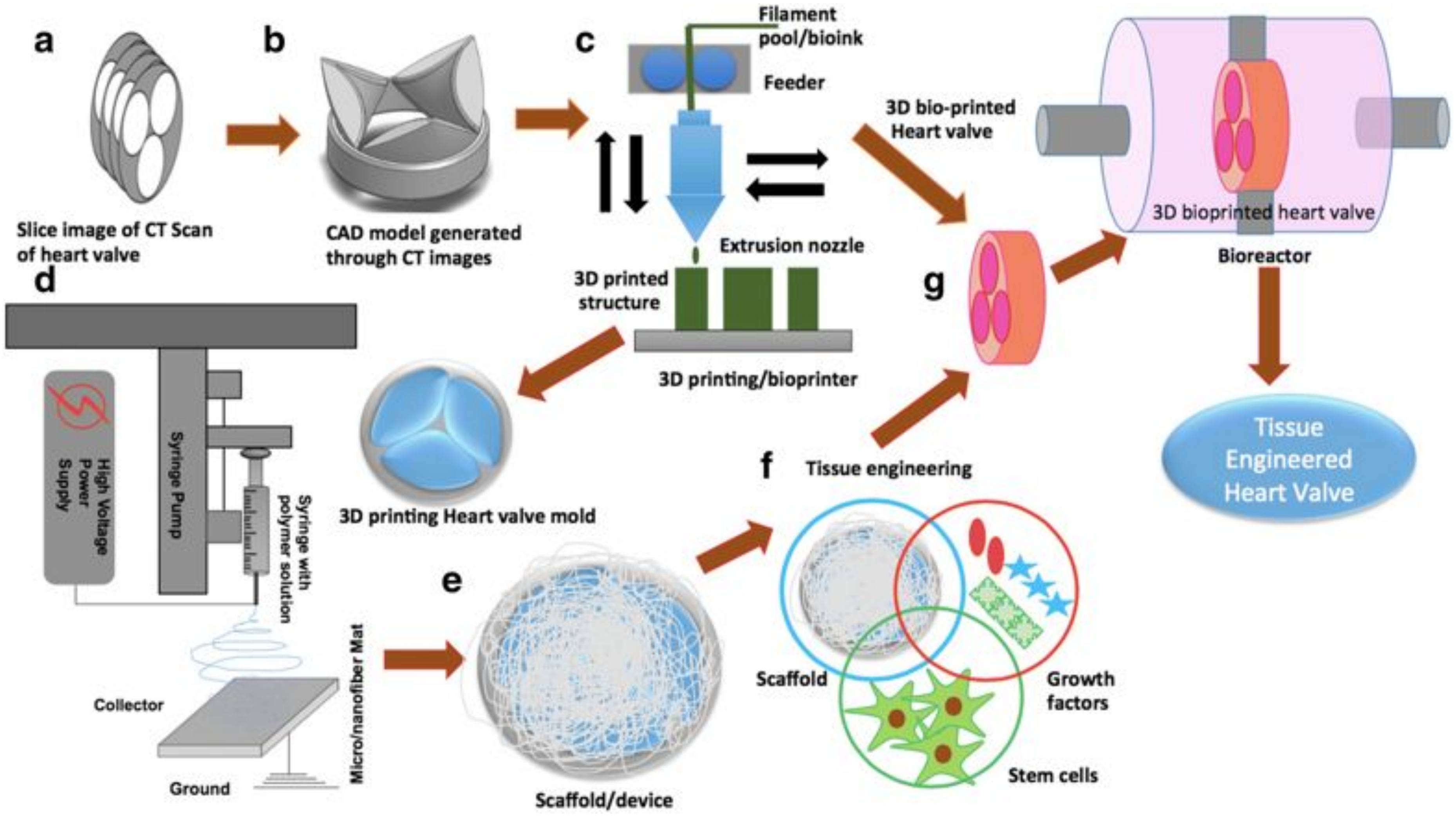
3D Bioprinting



https://3dprint.com/

3D Bioprinting

Proposed process for the generation of 3D heart valves through bioprinting to arrive at functional tissue engineered heart valves
(a) slice of CT images,
(b)3D CAD model generation,
(c)3D bioprinting through bioink/ 3D printing through polymer scaffold,
(d)3D printed scaffold,
(e)scaffold ready
(f)Development of tissue through combining cells, growth factors and developed scaffold,
(g)Development and initial tissue remodeling in bioreactor

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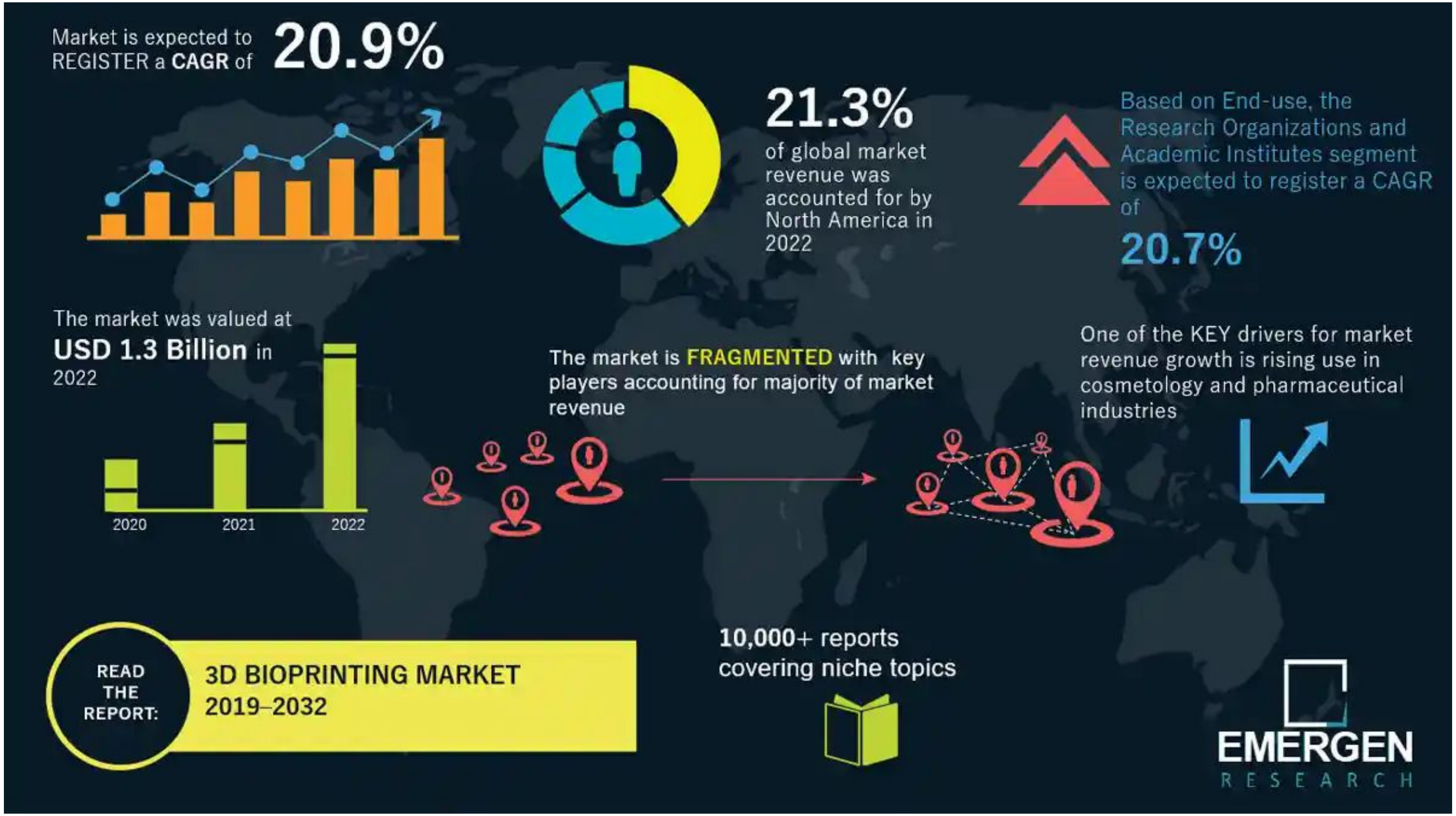
3D Bioprinting



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