Applications of AI in mechanobiology

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The keywords:

- Artificial Intelligence (AI):

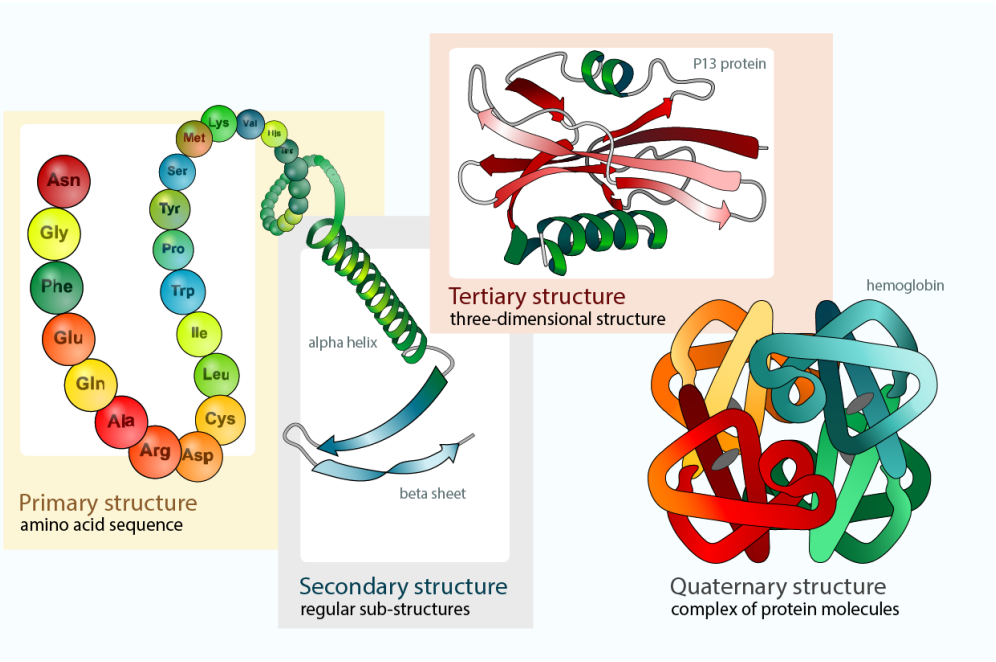
AI is the high-level concept of machines mimicking human cognitive functions, such as learning, problem-solving, and decision-making. E.g. A medical student follows the official hospital "Clinical Pathway" flowchart exactly as written in a manual.

- Machine Learning (ML):

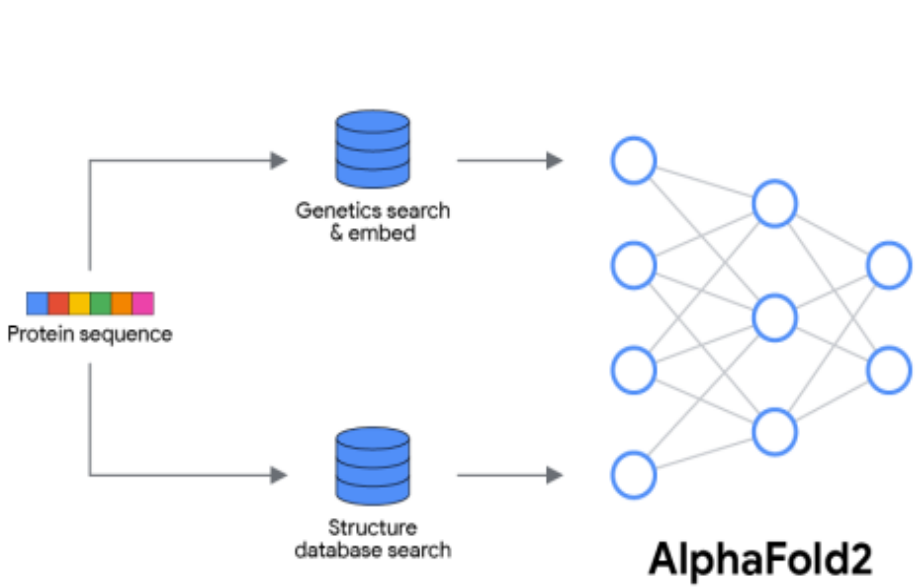
ML is a subset of AI. Instead of explicitly programming rules, we feed the computer massive amounts of data and allow it to identify patterns or statistical relationships on its own. E.g. A medical student reviews 500 past charts of patients with similar symptoms to guess the outcome based on previous trends.

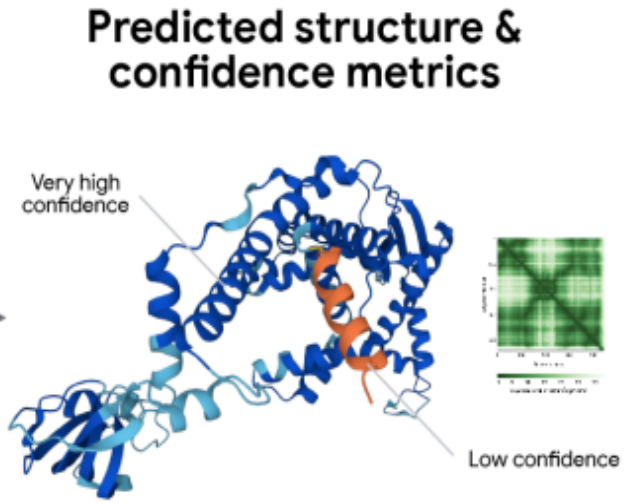
- Deep Learning (DL):

DL is a specialized, advanced subset of Machine Learning. It uses "Artificial Neural Networks," which are inspired by the structure of the human brain, composed of layers of "neurons" that process information. E.g. A senior attending physician looks at an MRI scan. They don't think about the math or the flowchart; their brain intuitively recognizes the pattern of the pathology because they have seen thousands of these images before.

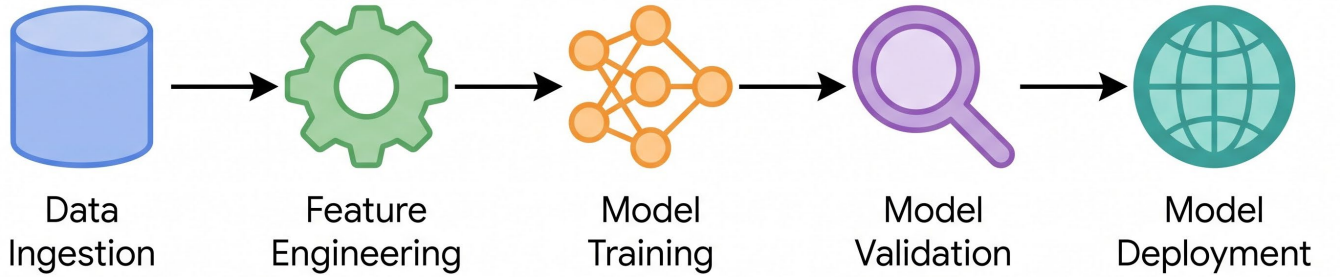


AlphaFold as an example of ML



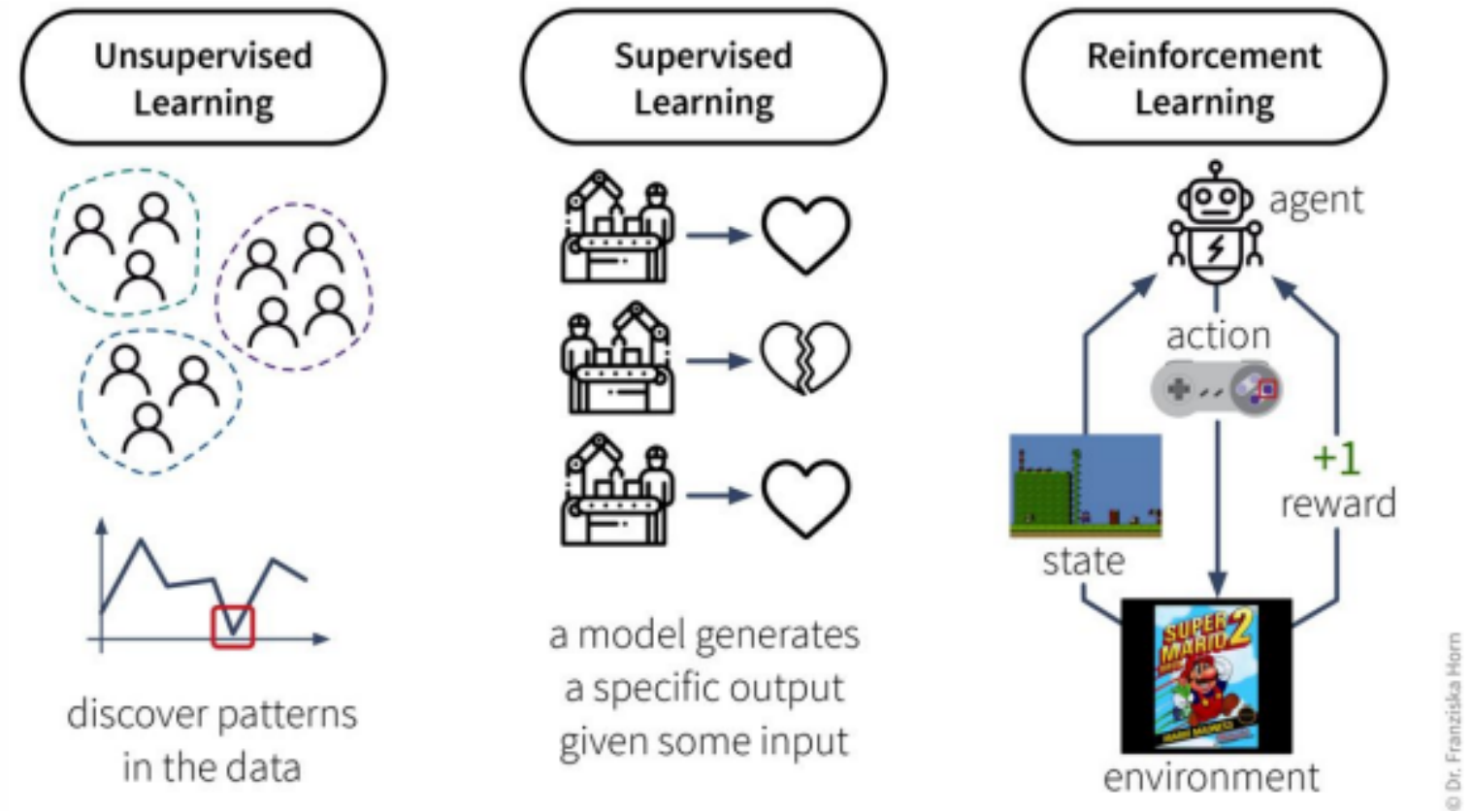


Training the ML model



- **Input:** Patient data (vitals, lab results, clinical history).
- **Feature Extraction:** The system highlights what matters (e.g., blood pressure, heart rate).
- **Prediction:** The model makes a probabilistic guess (e.g., "85% probability of sepsis").

The triad of machine learning approaches

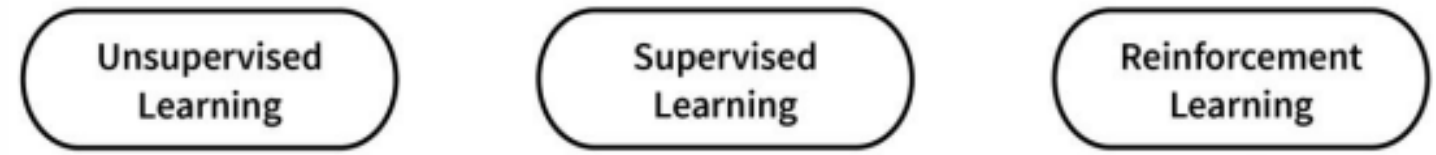


massive datasets (eg genomic sequences or patient history) and identifies segments or "clusters" that are statistically similar

"labelled" (e.g., "Pneumonia" or "Healthy") chest X-rays -> to associate the visual patterns in the image with the correct label.

patient's real-time physiological data: heart rate, blood pressure, oxygen saturation, a processed EEG signal used to measure the depth of anesthesia.

The triad of machine learning approaches

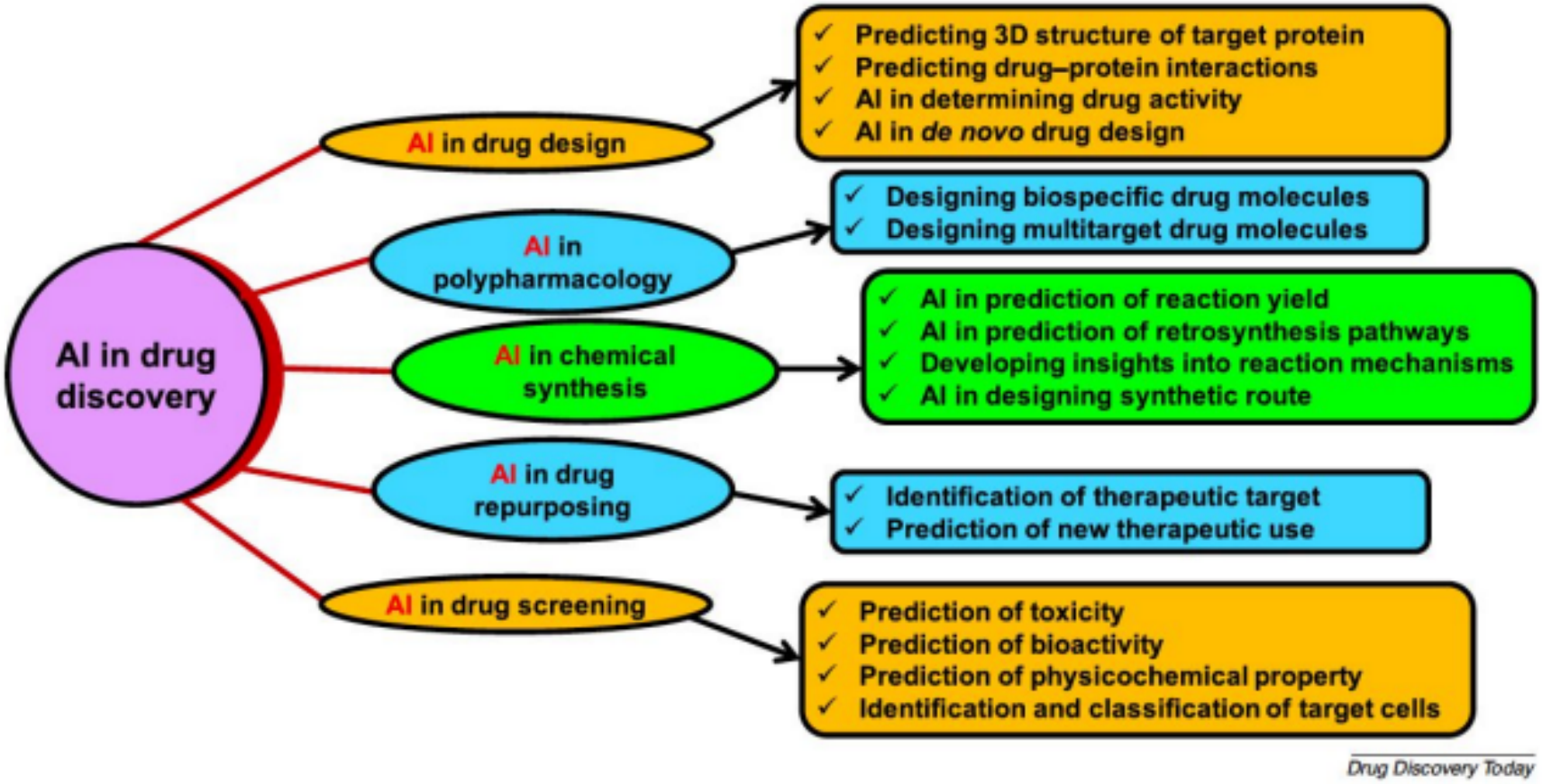


You release a dog into a park with 20 other dogs and step back. You don’t give any commands. You just watch. Over time, you notice the dogs naturally form groups: the fast dogs chase each other, the shy dogs hang out by the fence, and the food-motivated dogs stay near the picnic tables.

You are teaching a dog to "Sit." Every time the dog sits, you give it a treat and say "Good sit." Every time it stands, you say nothing. You are providing the dog with constant, explicit feedback.

You are teaching a dog to run an agility course (jumping over hurdles, weaving through poles). You don't tell the dog exactly how to position its paws for every jump. Instead, you provide a reward (a treat or praise) only when it successfully completes the obstacle or finishes the course faster.

Drug design is a problem/environment largely denoted by a large amount of noise



Gemini & ChatGPT= "Full-Stack" AI systems

- **The "Education" Phase (Self-Supervised Learning)**

In this phase, the AI is given billions of pages of text from the internet, books, and articles. It doesn't have a teacher. Instead, it plays a game of "fill-in-the-blank." It hides a word in a sentence and tries to predict it.

- **The "Specialized Training" Phase (Supervised Fine-Tuning)**

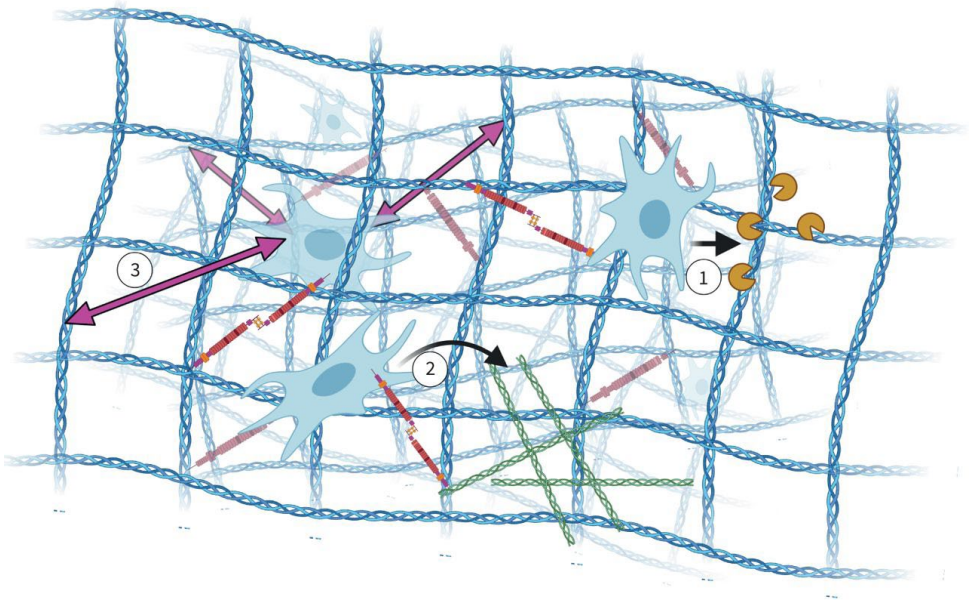
Now that the model knows how to speak, we need to teach it how to be an assistant. Human trainers provide "gold standard" examples: *"If a user asks X, the ideal response is Y."*

- **The "Fine-Tuning for Manners" Phase (Reinforcement Learning)**

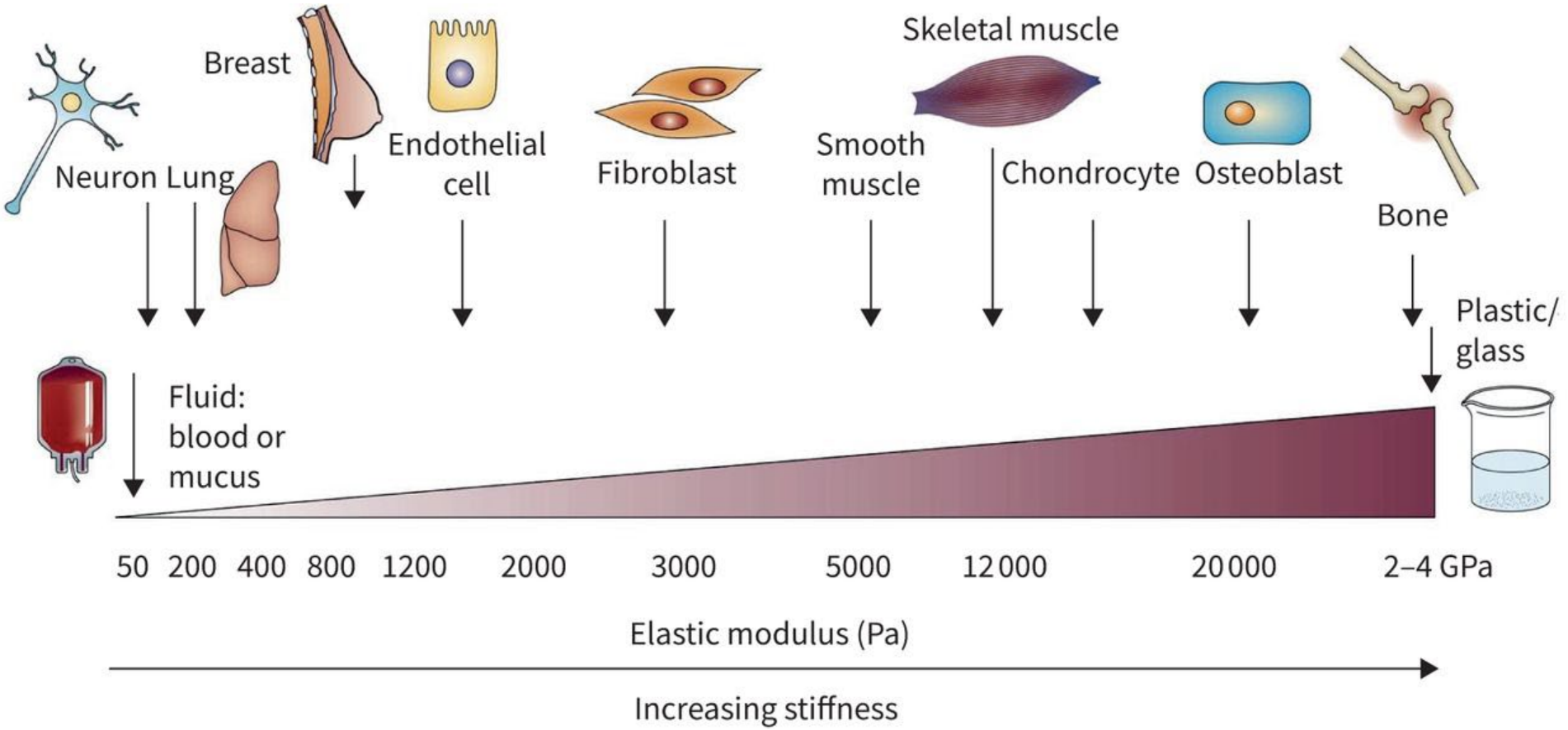
Finally, the model is put into the real world. It generates a response, and a human rates that response: "That's a good, helpful answer" or "That's a rude, biased, or incorrect answer." The model receives a reward for good behavior.

Applications of AI in mechanobiology

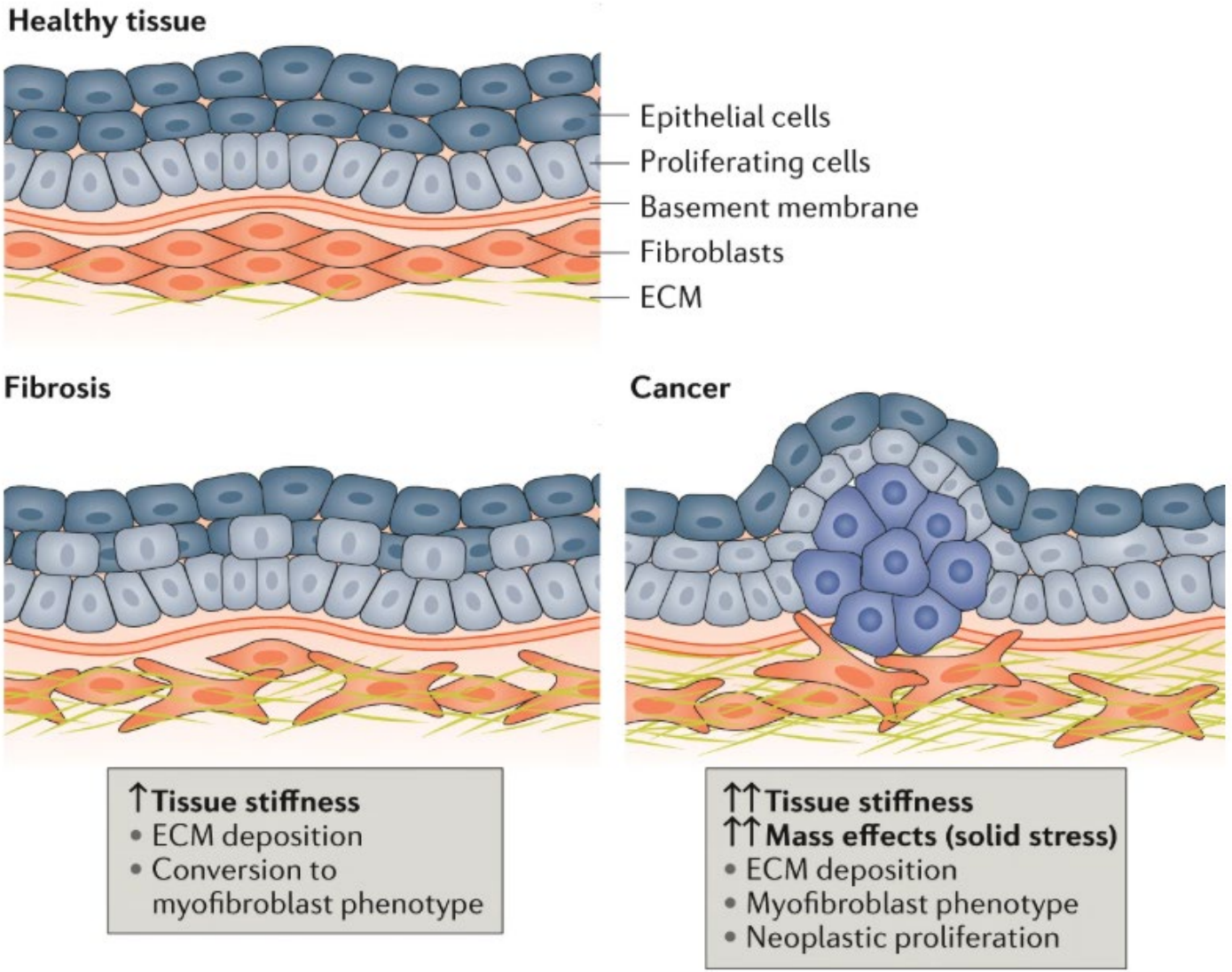
Extracellular matrix (ECM) architecture and remodelling. Cells reside in a fibrous network of collagens (blue) to which they bind, as well as to fibronectin (brown) that also binds to collagen. During maintenance and remodelling,
1) cells secrete proteases that degrade the collagen network (blue).
2) cells deposit new ECM components such as collagens (green), and
3) forces (purple double-headed arrows) are transmitted to the embedded cells.



Tissue stiffness differs depending on the tissue

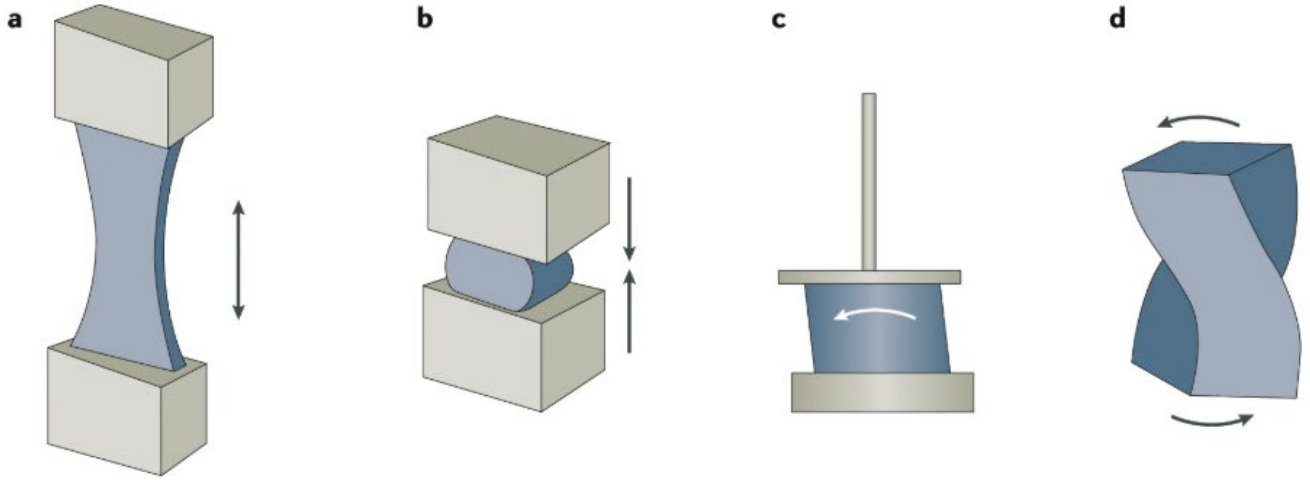


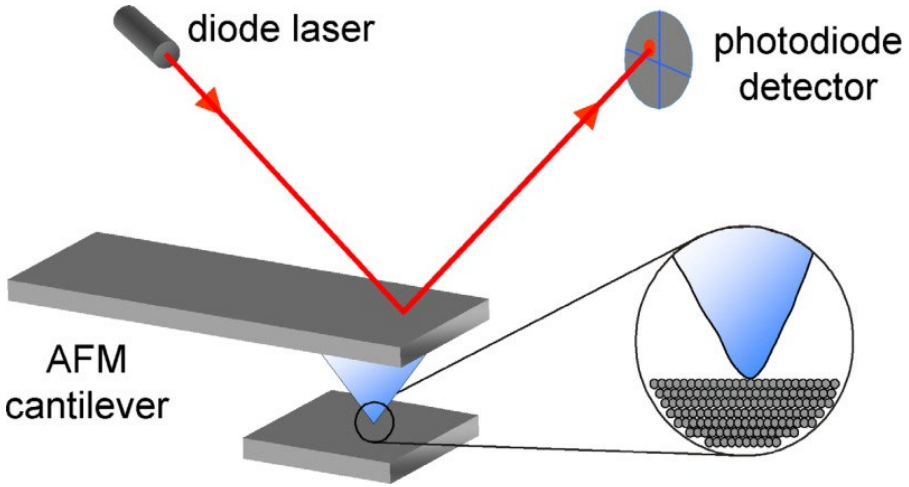
ECM in Healthy vs Disease models



Guimarães, Carlos F., et al. "The stiffness of living tissues and its implications for tissue engineering." *Nature Reviews Materials* 5.5 (2020): 351-370.

Ways to measure stiffness





Atomic Force Microscopy

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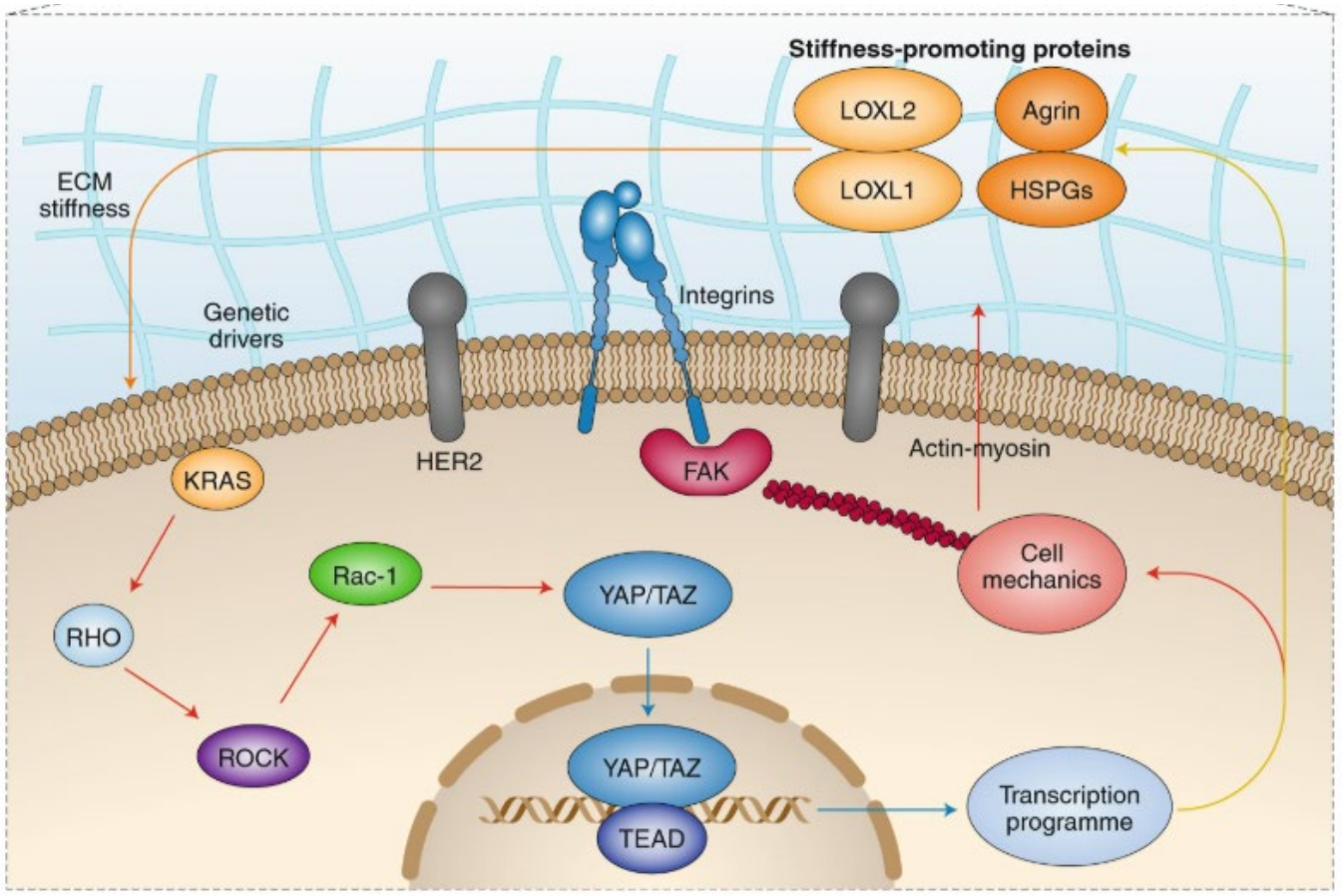
Mechano-sensing: sensing of ECM mechanical properties



Mechano-sensing & cell functions