

Perceptual Metrology: A Future Frontier in Human Well-Being

 Cristhian Paredes^{1,†}  Stephanie Numa-Vergel²

¹Instituto Nacional de Metrología de Colombia – INM (CO)

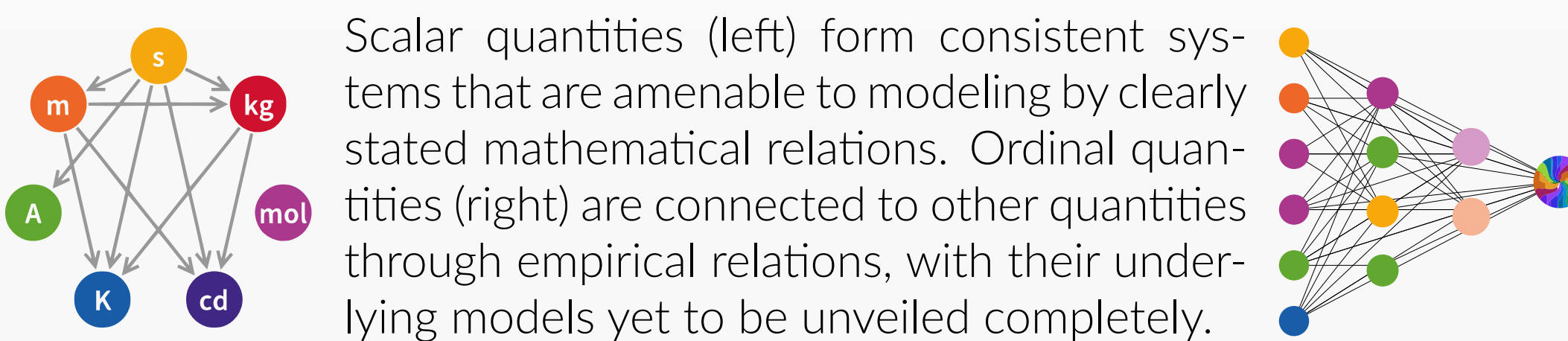
²Corporación Colombiana de Investigación Agropecuaria – AGROSAVIA

Metrology has served humankind as the scaffold of science, technology, and commerce. Attaining discoveries, making developments and performing transactions rely of information that results from performing measurements and applying models. With metrology, we are committed to study measurements in a broad sense, without discrimination of the level of uncertainty or field of application [1]. This contemplates from the simple counting of wine bottles in a case, to the experimental setting of the rigorous *mises en pratique* that reference the SI Base Units to invariable fundamental properties of the Universe. However, the wideness of metrology has carried an ongoing discussion about which kind of properties are considered within the realm of the measurables. Specially, the measurability of ordinal and nominal properties has sparked extensive debate within the metrological community.

In this poster we explore perceptual properties as a topic relevant to the discussion on measurability, and present examples of how they offer opportunities for metrology to make a greater impact on the world. Perceptual metrology examines the specific characteristics of phenomena, bodies, or substances, **as experienced by living beings**. While properties such as taste, smell, and visual comfort are inherently subjective, we present some ways how some of these experiences might be susceptible to quantification and modeling. Perceptual metrology aims to develop new tools and metrics to assess variables that have often been deemed unmeasurable.

MEASURABLE PROPERTIES

Measurements are currently constrained to quantities: properties that can be expressed in terms of a number and a reference. This encompasses **scalar properties**, whose instances can be compared algebraically using units as references, and **ordinal properties**, whose instances can be ordered logically using agreed-upon reference procedures. Outside this spectrum are the **nominal properties** that describe non-quantifiable characteristics, such as chemical identity or shape [1].



Ordinal properties may evolve to more uniformly applicable concepts where their difference with scalar properties seems to blur. For instance, the measure of the strength of earthquakes in terms of the Richter scale is being replaced by the Moment Magnitude Scale, which relates to the amount of energy released by the earthquake, in Joules.

On the other hand, nominal properties are not considered measurable properties as they cannot be compared in terms of lesser or greater.^a These properties are instead *examined* using a *reference examination procedure* [2]. However, take as an example the **nominal quantity shape**, which for a metallic sphere can have the value **round**. It could be argued that after using optical interferometry to measure any deviation from roundness at a microscopic level, some spheres may be considered more round than others, giving rise to sphericity as a property [3], where the limits between nominal and scalar properties blur.

^aNominal properties are upgrading from being in a single entry of the current version of the VIM, to composing the new sixth chapter of the document in its upcoming version.

BIOLOGICAL PERCEPTION IN MEASURING SYSTEMS

At the heart of many measurement systems are **sensors and detectors**: devices that either produce an output proportional to the property being measured or trigger a response once a specific threshold is reached [1]. Interestingly, living organisms possess specialized sensory organs that continuously monitor their environment, functioning in a manner similar to human-made sensors. We explore two examples where these similarities are harnessed synergistically: in the use of molluscs to monitor water quality, and the use of insects' antennae to measure volatile substances. These examples illustrate how the perceptual capabilities of living organisms can inform and enhance the measurement of properties that are of significant interest to humans.

Drinking water quality monitoring using mussels and clams

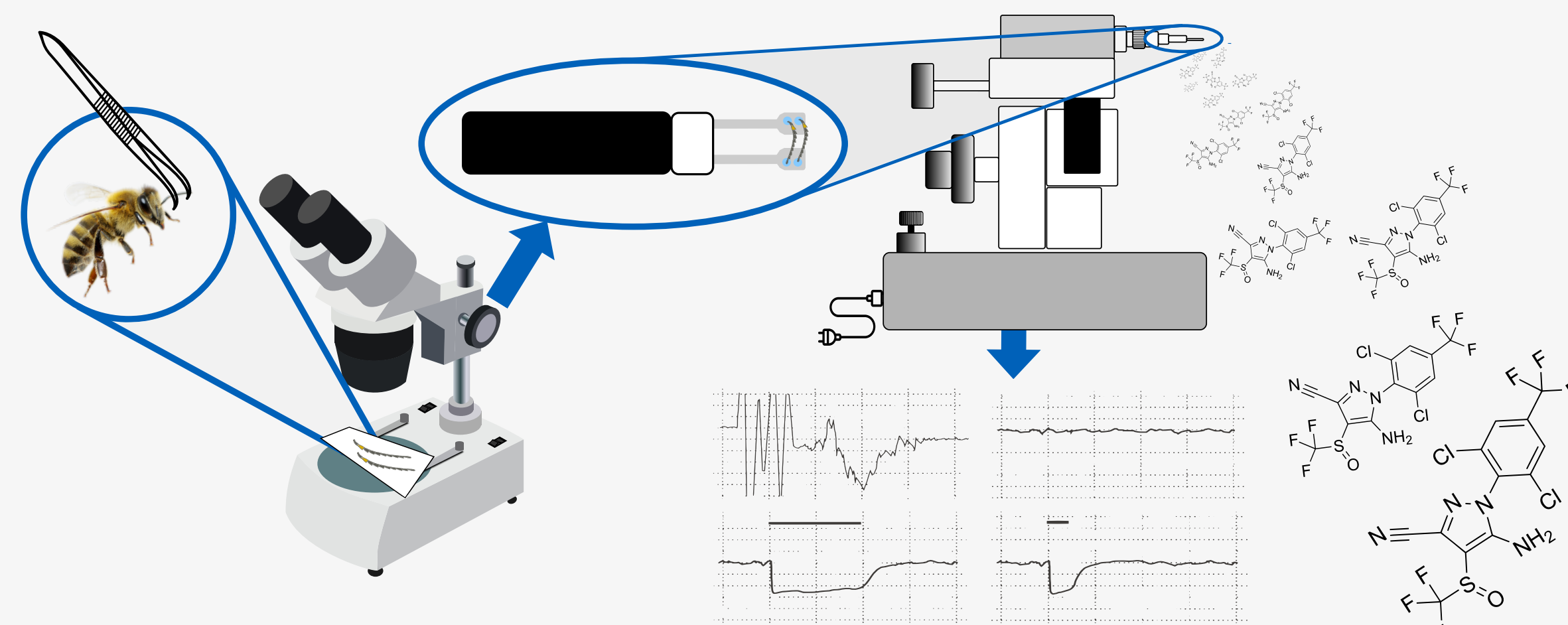
The **flavor of water to bivalve molluscs** may be of interest to humans. Molluscs like mussels and clams filter large volumes of water continuously and are exceptionally sensitive to pollutants. When exposed to undesired chemical substances, bivalves alter their typical behavior and close their shells. Monitoring the molluscs's shell movements is an easier task than performing a laboratory analysis. Therefore, they provide an early alarm system indicative of pollution in the water supply systems. This simple yet clever approach serves humans by protecting drinking water sources and reducing the risk of adverse health effects associated with chemical exposure. [4]



Electroantennography: Transduction of insects' olfactory response

Electroantennography (EAG) is an electrophysiological technique that measures the electrical responses of an insect's antennae to chemical stimuli. By recording these responses, it is possible to determine how insects detect and process odors, including pheromones and environmental cues.

EAG serves as a powerful tool in fields ranging from pest control to ecological monitoring, enabling the development of targeted strategies that may reduce the reliance on conventional insecticides [5]. This technique enhances our understanding of insect olfaction and paves the way for innovative, sustainable approaches to managing pest populations more sustainably and with fewer negative environmental impacts.



The typical EAG setup involves to anesthetize the insect, remove one or both antennae, and fixing them between two microelectrodes with conductive gel. The changes in electrical properties in response to stimuli are amplified and measured.

BIOMIMETIC SENSING ARRAYS: ELECTRONIC NOSES AND MOUTHS

Electronic noses and electronic mouths embody the principles of soft metrology by transforming subjective sensory attributes—such as smell, taste, and sound—into objective, quantifiable data. These systems measure underlying physical parameters and use machine learning algorithms, including neural networks, support vector machines, and ensemble methods, to model the relationship between chemical signals and human perception [6]. By integrating these advanced algorithms, electronic noses and mouths not only capture complex sensory information but also improve uncertainty quantification, driving more robust and comparable measurement systems. Ultimately, they pave the way for innovative, sensor-based approaches that redefine how we monitor and interpret the world through the lens of perceptual metrology.

Imagine a city where a network of biomimetic sensors continuously monitors urban air quality not just for chemical pollutants but also for odors that affect our daily lives. Electronic noses deployed across the city could capture and quantify complex odor profiles in real time, in a similar fashion to current atmospheric pollution sensor networks. This information would provide a comprehensive map of urban olfactory landscapes. This data would enable city planners and environmental agencies to identify and mitigate odor pollution hotspots, improving air quality and enhancing human well-being. By integrating these advanced sensing technologies with machine learning algorithms, cities can move toward a future where the subtle aspects of environmental quality are as measurable and manageable as traditional pollutants.

HELMHOLTZ AND PERCEPTUAL QUANTITIES

The 19th century physicist Hermann von Helmholtz argued that measuring was not a merely technical process, but instead, a process related to our perceptual and cognitive experiences [7]. In his view, measurement is rooted in how we naturally process sensory information: we perceive spatial relationships, temporal sequences, and qualitative differences in our environment, and these perceptual processes guide how we assign numerical values to physical phenomena.

Helmholtz's perspective reminds us that measurement is not just about raw numbers—it also involves how these numbers relate to and are interpreted by living systems.



Consider for example plant nutrition: while it is straightforward to chemically quantify the total amount of phosphorus in a soil sample, determining the fraction of phosphorus that is actually available for plant uptake demands an understanding of the dynamic interactions within the rhizosphere. In this case, the measurement process extends beyond objective quantification to encompass the plant's perception of its nutrient environment. The question drifts from *how much of an element is in a sample*, to **how much can be perceived or utilized by the plant..**

Method-defined measurands have improved our ability to estimate bioavailable nutrients by establishing standardized procedures that mimic natural conditions. However, ensuring comparability and compatibility across different settings remains a significant challenge. Ultimately, harmonizing these methods is essential for fully harnessing the power of metrology to address complex biological questions on the matter.

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[†] Corresponding author, caparedes@inm.gov.co