On Analog Measurements and The Digital Nature of Things

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Abstract. In this essay it is argued that the properties attributed to physical objects are inherently digital quantities, while their experimentally estimated values are rather analog quantities, as acquired indirectly in a measurement process, regardless if it is classical or quantum.

A similar question to the contest theme, "Is Life Analog or Digital?", has been raised as a topic for discussion at the Edge.org Reality Club by Freeman Dyson awhile ago. The responses he got from the participants were rather dissapointing, let us cite here their consensus [1]:

- *Any real computer operating in the real world is partly digital and partly analog, and any living organism is an even more inextricable mixture of digital and analog components*
- *The concepts of digital and analog were invented to describe idealized models of human-designed machines, and are far too narrow to encompass the subtleties of living creatures*

An antiquated sound recorder works definitely analog, while a brand new portable media player is surely a digital device, but what to tell about reality? According to the dictionary definition [2], reality is assumed to be in the most general setting

the state of things as they actually exist

i.e everything at all scales, from fundamental particles up to the whole Universe. In the less general meaning, reality could be also assumed as

a thing that is actually experienced or seen

which is much closer to our human abilites.

Our knowledge about reality is based on interactions with objects (physical entities, things) we are able to perceive and recognize. Recurrent objects are then classified, systematized and analyzed, which may reveal an internal structure with some sub-objects, which are then also classified, systematized and analyzed, and so on. These activities lead to accumulation of symbolical and numerical data attributed to the respective objects. A particle databook [3] is a good example of a particular set of such data, but we have to include much more, e.g., physicochemical handbooks, biological systematics, galaxy catalogs, etc., i.e., everything we know.

Are this accumulated knowledge analog or it is rather digital?

This question may sound silly at the first sight, because there are many technical possibilities that could be used here for data representation or recording, and they should be rather irrelevant here.

Analog representations use the changes of a physical medium, which are proportional in the respective values to the recorded or transmitted data. These changes have to be measured and the results recalculated to recover the original data. Measurement errors and/or external influence cannot be fully eliminated and the data are always slightly distorted (analog noise).

In digital representations the data are encoded as definite sequences of symbols, before being recorded or transmitted in a lower-level analog process. To get the data back, this symbols have to be identified in the intermediate analog data recovered from the physical medium and appropriately decoded. The distortions of the low-level analog data are routinely eliminated here, with additional possibilities of integrity checking or error correction.

In consequence, analog data are always medium-dependent, while their digital incarnations may exist as abstractions, enjoing the independendence from any physical medium. Symbolical data are therefore always inherently digital, regardless of what they represent. Therefore, the answer to another silly-looking question: "Is Schoedinger equation analog or digital?" is "Certainly digital!".

Physical properties, as attributed to the respective physical objects are then also digital quantities. For example the physical properties of the electron like its mass, electric charge, etc., are inherently digital quantities, but their values have to be determined through appropriate measurements. Measurement outcomes are usually analog quantities, acquired indirectly as proportional to something else, e.g. read out as a dial position on the measuring apparatus. In contemporary measurement setups analog outcomes are routinely converted into a digital form, but this rarely means recreation of the original digital quantity (it may be so e.g. in counting measurements), it is done rather for convenience of further processing.

Measurement setups have to be parametrized appropriately, to allow repetitions, adjustments, changes, etc. Values of this parameters are given as proportional to some chosen "units of measurement" and in relation to some chosen "reference values". Therefore, this parameters are inherently analog quantities. Measurements "happen" in such parametrized setups, at definite values of the chosen parameters. In a sense, these parameter values are measurement outcomes for measurements performed at "events", in an "event space" assumed as the respective medium.

The set of parameters common to various different measurement setups, together with appropriate extrapolations or idealizations introduced to accomodate for various ranges of the parameter values, may be at some point promoted to an abstract "parameter space". Newtonian spacetime and Hamiltonian phase space are two well-known examples of such parameter spaces in the context of classical mechanics, and the respective parameters, i.e. time, spatial coordinates and momenta are then analog quantities.

Are there any changes when switching to the quantum world?

Classical measurement setups are also routinely used to perform quantum measurements, which gives rise to a vast quantum-classical problematics with lot of puzzles and still unsolved problems.

Fortunately, there are representations of quantum mechanics where quantum and classical physics could be put on equal footing. In so called phase-space representations of quantum mechanics [4] both quantum states and observables are represented by phase-space functions. Although the underlying quantum phase-spaces are generally rather abstract parameter spaces than "genuine" phase spaces, it is possible to proceed in many cases exactly in the same way as in classical statistical mechanics.

The main difference between classical and quantum cases here is in the representation of states. Classical states of single particles may be represented directly by the respective phase-space points, and a phase-space distribution function gives the respective probability density. Due to the well-known uncertainty principle, quantum states cannot be represented in the same way as the classical ones. Namely, a minimum phase-space volume not smaller than $(\frac{h}{2})^N$ have to be always reserved for a quantum state [5], and a quantum phase space distribution cannot be generally regarded as probability density. But fortunately enough the expectation values of observable quantities could be still evaluated in the classical way, as phase-space integrals, and therefore quantum phase-spaces as such differ only locally from their classical counterparts.

Quantum particles have to be treated always as extended objects, not point-like particles, but the phase-space itself will not become divided into phase-space cells for holding the particles or "digitized" in another way. In contrary, a quantum state cannot be fully confined in any finite phase-space cell (cf. [5] and references therein), therefore the underlying phase-space have to remain essentially the same as in the purely classical setting, i.e., analog.

In summary, it seems that Nature as we know it is inherently digital but our measurement toolkit and the derived measurement results are rather analog. Man-made digital data records, whatever they are, ranging from Sumerian clay tables, filled up with cuneiform writings, up to the newest holographic records, are always based on some recording medium. And what is the medium underlying our digital Nature? The fundamental particles are believied to have no internal structure, or at least it is unknown to us yet. Therefore, in a sense, Nature is digital in abstraction of the Unknown.

References

1. The Reality Club: *Is Live Analog or Digital?* `http://www.edge.org/discourse/analog_digital.html`
2. Oxford English Dictionary, 3rd Ed. (2008) `http://www.oxforddictionaries.com/view/entry/m_en_gb0690180`
3. K. Nakamura et al. (Particle Data Group), J. Phys. **G 37** 075021 (2010) `http://iopscience.iop.org/0954-3899/37/7A/075021`
4. J.J. Wlodarz: Phys. Letters **A 286** 97-101 (2001)
5. J.J. Wlodarz: Int. J. Theoret. Phys. **42** 1075-1085 (2003)