

Analog vs Digital Terminology

American Journal of Physics, Sept 2015

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The blooming of digital computer technology has naturally spawned an evolving terminology describing the relevant concepts. I think it is time to attempt to clarify our use of the terms analog, digital, sampling, and quantization. Our literature and teaching often seem to conflate the terms digital, quantized, and sampled, and to oppose them to the term analog. Much clarification comes from simply observing the function of an analog to digital converter (ADC), schematically illustrated in Fig. 1.

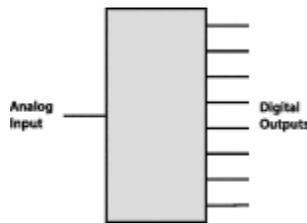


Fig. 1.

A schematic analog to digital converter (ADC)—a device that evaluates and displays the values of the N digits required in the digital representation of the single analog input. In a typical electronic implementation, each of these quantities is a voltage.

The ADC converter has one input quantity (a voltage) and N output quantities (voltages). The output quantities are the numerical magnitudes of the digits that express the input quantity as the weighted sum of integral powers of a chosen base quantity. In the pictured example, the converter will output eight digits to represent the now digitized input quantity. All of these quantities (voltages) may be constant or varying in time; they may also be sampled values of a time varying quantity or be restricted to certain quantized values. None of these properties is, per se, relevant to the analog/digital distinction of the input versus the output. For example, a time varying voltage can be sampled into a time series of sampled analog voltages and sent over a single wire pair. Indeed, a practical ADC converter circuit will sample and hold the analog quantity to a constant analog value during the digitization process. Once “digitized,” each sample requires N voltages to represent the values of the N digits. The distinguishing feature of digital vs analog representations of a quantity is that the digital representation explicitly displays the value of each of the digits that express the quantity in a chosen base.

It is true that the exact digital representation of a quantity would in general require an infinite number of digits. In practice, we restrict our expressions (and our computer computations) to a finite number of digits. In this practical sense, our digital expressions are always quantized by the finite gap between expressible quantities. This is simply a “rounding” effect and is not peculiar to digital expressions; an analog readout, such as a needle moving across a scale, has its own practical limitation of a minimum discernible increment. Of course, it is also trivially true of the digital representation that the value of each digit is restricted to the B integer values (0 to $B-1$) appropriate

to the chosen base B . For the base 2, each digit is restricted to the values 0 and 1. Many writers seem to refer to this as a “quantization” of digital quantities. We should no more think of this as the quantization of a binary quantity than we would think this of the restriction of decimal digits to the integer values 0–9.

Finally, writers sometimes equate the terms “digital” and “binary.” The concept of digitization is not restricted to the use of the base 2. For example, the decimal quantity 12 is the digital representation of a dozen, digitized to the base 10. Decimal, octal, and hexadecimal bases are not uncommon as choices for the base of digitization. Assembly languages are typically written in hexadecimal quantities. Of course, much of the power and simplicity of modern computers follows from the choice of the base 2, because each digit can then have only two (binary) values. This choice enormously simplifies hardware implementation.

The digital concept (the weighted sum of integer powers of a chosen base) is today so commonly used that its beauty and utility are not consciously appreciated. Somewhere in our teaching the digital representation should be critically contrasted with an alternative, such as the Roman numeral system.

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