Precision time: A matter of atoms, clocks, and statistics

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Time is of the essence, especially in communications, navigation, and electric power distribution, which all demand nanosecond precision or better. Keeping these beating hearts of technology in near-perfect global synchronization requires the blending of statistics, atomic science, and technological innovations.

The ability to accurately measure a second in time is at the heart of many essential technologies; the most recognizable may be the Global Positioning System (GPS). In a paper accepted for publication in the AIP's journal Review of Scientific Instruments, a researcher at the National Institutes of Standards and Technology (NIST) and the University of Colorado at Boulder discusses how achieving a stable and coordinated global measure of time requires more than just the world's most accurate timepieces; it also requires approximately 400 atomic clocks working as an ensemble. According to the researcher, however, calculating the average time of an ensemble of clocks is difficult, and complicated statistics are needed to achieve greater accuracy and precision. These statistical calculations are essential to help counter one of the most important challenges in keeping and agreeing on time: distributing data without degrading the performance of the source clocks.

All atomic clocks operate in basically the same way, by comparing an electrical oscillator (a device engineered to keep time) with the transition frequency of an atom (one of nature's intrinsic time keepers). This atomic transition is a "flip" in the spin in the outermost electron of an atom – an event that is predictable with an accuracy of a few parts per ten quadrillion. Comparing the natural and engineered signals produces the incredibly stable "tick" of an atomic clock. Several algorithms are then used to estimate the time of the reference clock with respect to the ensemble of clocks. These calculations weed out as much error as possible and establish a reliable reference time. The researcher notes that there are strengths and weaknesses in each of these statistical steps, but these weaknesses can be mitigated to some extent by also including retrospective data. So in essence, determining the current time relies on understanding how accurately researchers were able to calculate time in the past. Even the next generation of atomic clocks and frequency standards are unlikely to eliminate the need for these timescale algorithms. However, keeping time and frequency signals and standards the same in all countries is essential and greatly simplifies international cooperation in areas such as navigation, telecommunication, and electric power distribution.

More information: "The Statistical Modeling of Atomic Clocks and the Design of Time Scales" is accepted for publication in the journal *Review of Scientific Instruments.*

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