What Time is It?

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Two Aspects to Telling Time

- Counting the length of a second

  – Can also be expressed as its reciprocal, frequency

- Determining the start of a day

  – Actually, the *middle* of a day (noon)

Frequency

- Many devices throughout history, with increasing accuracy
  - Water clocks (>± 15,000 ppm)
  - Hourglasses (? ppm)
  - Pendulum (grandfather) clocks (±12 to 120 ppm)
  - Spring-wound clocks with oscillating mass (± 2 to 7000 ppm)
- Most common today are electronic oscillators based on quartz crystals
  - Watch/computer accuracy (±30 to 100 ppm)
  - High-grade TCXO or OCXO can achieve ± 0.1 to 10 ppb

Frequency

- International definition of a second now entirely based on frequency; no relation to Earth's rotation
    - the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom
- Other timescales differ; e.g., POSIX defines a second as 1/86400th of a day
    - This causes no end of confusion

Frequency Measurement

- National laboratories and others operate the most accurate atomic clocks, hydrogen masers and cesium fountains, accurate to .00000015 ppb

  - U.S. has two official timekeeping agencies: United States Naval Observatory (USNO, military) and National Institute of Standards and Technology (NIST, civil)

- Others in U.S. include Applied Physics Lab (APL), involved with space travel, and Naval Research Lab (NRL)

How Long is a Second?

- "The man with one clock always knows what time it is. The man with two clocks is never sure."

- 57 labs across the globe participate in the coordination of a single timescale, Temps Atomique Internationale (TAI)

- Accuracy is published monthly in Circular T

- A "rapid" version is published weekly

Time of Day

- From ancient times, local noon determined using sundials and theodolites

- Fast travel (railroads) drove adoption of standardized time and time zones

- Universal Time (UT1) set at prime meridian (0° longitude), based on observations of distant quasars rather than the sun

- Length of a day varies as Earth's rotation speed changes (current trend is slowing)

Coordinated Universal Time (UTC)

- Reconciling the difference between hyper-accurate clocks and somewhat less accurate Earth

- UTC seconds synchronized with TAI seconds

- UTC allowed to deviate from UT1 ≤0.9 seconds

- Solution: leap seconds

  - Insertion: 23:59:58...23:59:59...23:59:60...00:00:00
  - Removal: 23:59:57...23:59:58...00:00:00

Wait... what?

- Yes, a (UTC) minute can have 61 or 59 seconds!

- There are many other traps awaiting you:
  `http://infiniteundo.com/post/25326999628/falsehoods-programmers-believe-about-time`

- Best not to roll your own date- and time-handling code if you can avoid it

Distributing Time

- Global Navigation Satellite Systems (GNSS)
    - U.S.: GPS
    - Russia: GLONASS
    - China: BeiDou
    - Europe: Galileo (just fully active Dec. 2016)
- Radio
    - U.S.: WWV, WWVH, WWVB
    - Canada: CHU
- Telephone
- Network (Internet)

Distributing Time Via GNSS

- The most accurate method available, and receiver modules are relatively cheap ($30-100)

- National labs use GNSS for comparison

- Accuracy

  - GPS: ±1μs spec, ±15ns in practice - UTC(USNO)

  - GLONASS: ±1ms spec, ±310ns in practice - UTC(SU)

  - BeiDou: ±100ns spec - UTC(NTSC)

  - Galileo: ±50ns spec (2σ) - Precise Timing Facility

Three Faces of NTP

- The protocol
- The software implementation, ntpd
- The timeserver pool, pool.ntp.org

NTP Protocol

- RFC 1305, Network Time Protocol
- RFC 4330, Simple Network Time Protocol

NTP Software

- Reference (ntp.org) software

- NTPsec, a fork

- chrony, an independently-developed implementation

- timesyncd, SNTP client-only software, part of systemd

NTP Timeserver Pool

- Volunteers who have agreed to provide their machines/bandwidth

- Inaccurate servers are detected and removed

- Joining the pool

  – Machine must be up and connected 24/7

  – Must run the reference NTP software

  – Connection must not have unreasonable or varying latency

  – Bandwidth requirement is not great, but must serve traffic with predictable latency (e.g., not on a busy web server)