The Impact of Leap Seconds on Digital Time Services

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Outline of the presentation

- Description of NIST Internet Time Service
- Digital Time Formats
- Digital Time keeping
- Incorporating leap seconds
- Difficulties with current methods
- Possible solutions
- Conclusions

NIST Internet Time Service

- NIST operates 45 time servers connected to the public Internet
- Servers are located at 28 sites in the US
  - Several sites have multiple servers
- Servers are synchronized to UTC(NIST) with an uncertainty of order 1 ms RMS
- Ensemble of servers receives approximately **75 000** requests per second for time in standard formats (mostly NTP format)
  - About 6.5×10^9 requests per day

System time formats

- Seconds (and fractions) since epoch
  - Network Time Protocol uses 1900.0
  - Other choices: 1970.0, 1980.0, …
- Time scale of network services is UTC
  - Systems are source of legal time
    - Other time scales not acceptable
- Conversion to hh:mm:ss or MJD or … performed by end application or display system

Computer clocks

- Oscillator generates periodic "ticks"
- Register incremented on each tick
  - Increment value is adjustable in software
    - Adjusts effective frequency of oscillator
  - Base value can also be changed
    - Introduces time step
- Register is basis for all system time functions and network interactions
- Register holds time interval relative to system-defined epoch

Definition of a positive leap second

- Display equivalents of internal time register:

	UTC
Day N	23:59:58
Day N	23:59:59
Day N	23:59:60
Day N+1	00:00:00

There is no binary representation for 23:59:60 either in the system clock or in the message formats

Realization of a leap second

- Time tags during a positive leap second:

	UTC	Computers	
Day N	23:59:58	C	(23:59:58)
Day N	23:59:59	C+1s	(23:59:59)
Day N	23:59:60	C+1s	(23:59:59)
Day N+1	00:00:00	C+2s	(00:00:00)

Standard method stops the clock at 23:59:59 for an extra second. 23:59:59 transmitted twice

Difficulties with the definition

- Transmitted time sequence is binary equivalent of:

  23:59:59 .0, .1, …, .8, .9, .0, .1, …, .8, .9, …
- Time Stamps can reverse causality
- Calculated time interval is not correct
  - Important for high-speed financial trading
    - Time intervals measured in milliseconds
- Leap second in middle of day in California, Asia, and Australia
- Impact much greater now than in 1972

Non-standard realization - 1

- Repeat 00:00:00 instead of 23:59:59

	UTC	Computers	
Day N	23:59:58	C	(23:59:58)
Day N	23:59:59	C+1s	(23:59:59)
Day N	23:59:60	C+2s	(N+1, 00:00:00)
Day N+1	00:00:00	C+2s	(N+1, 00:00:00)

Leap second is added on the wrong day

Some commercial NTP servers work this way

Non-standard realization - 2

- Amortize leap second by rate adjustment over some interval ending at end of leap second.
  - Transmitted time is monotonic
  - Time error and time interval error of order 0.5 s over amortization interval
    - Amortization interval not specified in any standard
  - Example: Google: googleblog.blogspot.com
    - Use non-linear time adjustment (cosine taper)
    - Google time is ***NOT*** traceable to national time standards

Impact of the leap second - 1

- Direct impact (only NIST servers):
  - NIST servers will transmit about 2×75000 time messages with a time equivalent to 23:59:59 UTC
- Indirect impact
  - Systems do not recognize advance notice parameter, don't do anything at leap second
    - 1 s error persists until next calibration
      - Treated as transmission error, query is repeated
      - Time step > 128 ms not accepted, system crashes
      - Time error causes control loop to oscillate
- Users shut down systems to avoid ambiguity

Impact of leap second - 2

- Proliferation of private time scales
  - Monotonic time advance (e.g. Google, posix)
  - Real-time (navigation, event recording, ...)
- Number of affected users not decreasing
  - Versions of Windows ignore advance notice
- Upgrades re-introduce problems cured in previous version of operating system
  - Leap second applied twice
  - Leap second applied with incorrect sign
  - Leap second applied at wrong epoch

Use TAI instead of UTC

- Timing laboratories and NMIs compute TAI but do not transmit it
- UTC(lab) is generally the legal time scale, not TAI(lab)
- Simple switch to TAI would produce a big time step

Discontinue Leap Seconds

- No change to existing UTC time scale
- No additional leap seconds beyond those already added
- Magnitude of dut1 parameter no longer bounded
  - Increase on order of 1 minute per century
- **NIST does not have an official position on this question**

Conclusion

- Leap seconds have significant impact on digital time services
- Impact is not decreasing with time
- Impact causes widespread use of non-standard time
- Discontinuing leap seconds would cause dut1 parameter to increase
  - Rate of increase currently about 1 minute per century
  - Uncertainty of dut1 parameter not impaired
- The price of continuing leap seconds is not worth the benefit of keeping dut1 small
- **NIST does not have an official position on this question**