

It's About Time

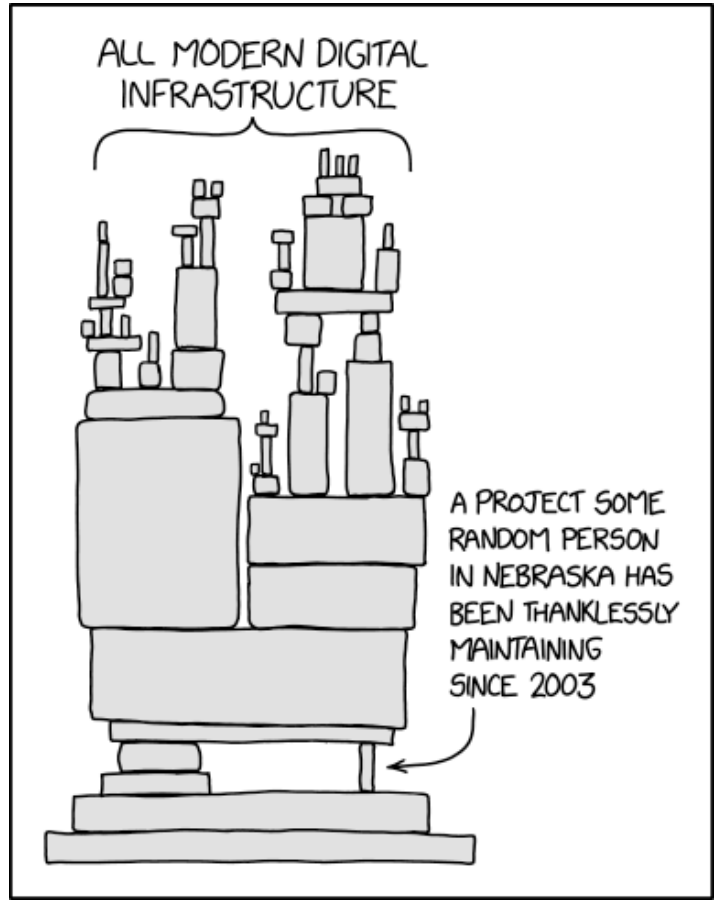
A Blueprint for Operating Resilient and Authenticated NTP at Scale

2026-10-14, SREcon26 EMEA

Raphi Seebacher, Staff Engineer

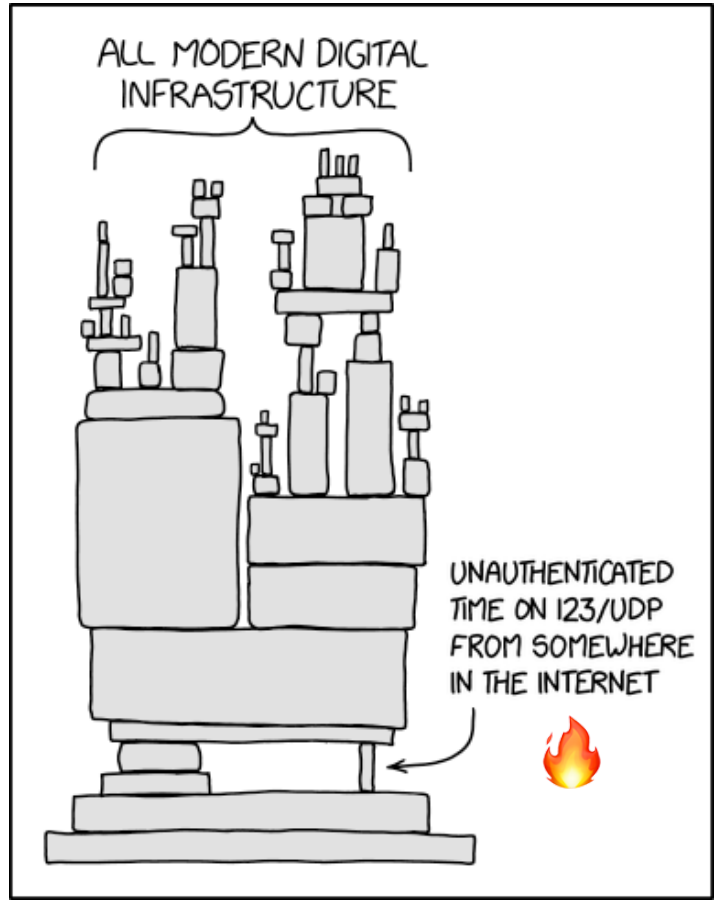
00 Why time?

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"Dependency", Randall Munroe, xkcd #2347, https://xkcd.com/2347, CC BY-NC 2.5



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Adapted from "Dependency", Randall Munroe, xkcd #2347, https://xkcd.com/2347, CC BY-NC 2.5

How about you set the time on your server ahead by 5 years.

Got any idea what would happen?

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NANOG mailing list, web.archive.org/web/20250129092516/
https://mailman.nanog.org/pipermail/nanog/2016-May/085683.html

All your **SSL certs** would **expire**.

All your **TOTPs**, like Google Authenticator, would **fail**.

All your **IPSEC tunnels** would **drop** and refuse to restart.

Many of your **cronjobs** would **go nuts**, possibly deleting all logs.

Much of your **DNSSEC** would **expire**.

Many of your **backups** would be **deleted** since they "expired".

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NANOG mailing list, web.archive.org/web/20250129092516/
https://mailman.nanog.org/pipermail/nanog/2016-May/085683.html

2019-06-14, Ticket 1204236: Please check ntp service

Hello,
can you please check the ntp service on box001 and box002
Our device receives a **stratum 14** and therefore has an **out of sync** issue.
Best regards,
John Doe

```
device > show ntp
     remote           refid         st t when poll reach   delay   offset jitter
==============================================================================
+10.12.1.4      213.156.227.131    14 u  193  256   377   0.452   -0.242   0.049
*10.12.1.5      213.156.239.131    14 u  148  256   377   1.381    0.184   0.116
```

Our **Active Directory** relies on these same NTP servers. We just want to avoid AD **problems**.

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resilient & authenticated

time synchronization

for 10k globally distributed nodes.

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01 Fundamentals
02 Architecture
03 Operations
04 Security
05 2038

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01 Fundamentals

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Time scales: What to sync to?

Astronomical

GMT – Greenwich Mean Time
historical, mean solar time at Greenwich

UT1 – Universal Time
modern, the Earth's actual rotation

Atomic

TAI – International Atomic Time
counts seconds, monotonically

UTC – Coordinated Universal Time
= TAI – leap seconds

UTC(k) = UTC realized by laboratory *k*

⚠ **Earth rotation wanders** → UT1 and UTC drift apart
DUT1 = UT1 – UTC kept within **±0.9 s**

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A clock: oscillator + counter



time = era epoch + counter

Type	Free-running drift per day
Quartz	seconds
OCXO	10s to 100s of µs
Caesium	10s of ns

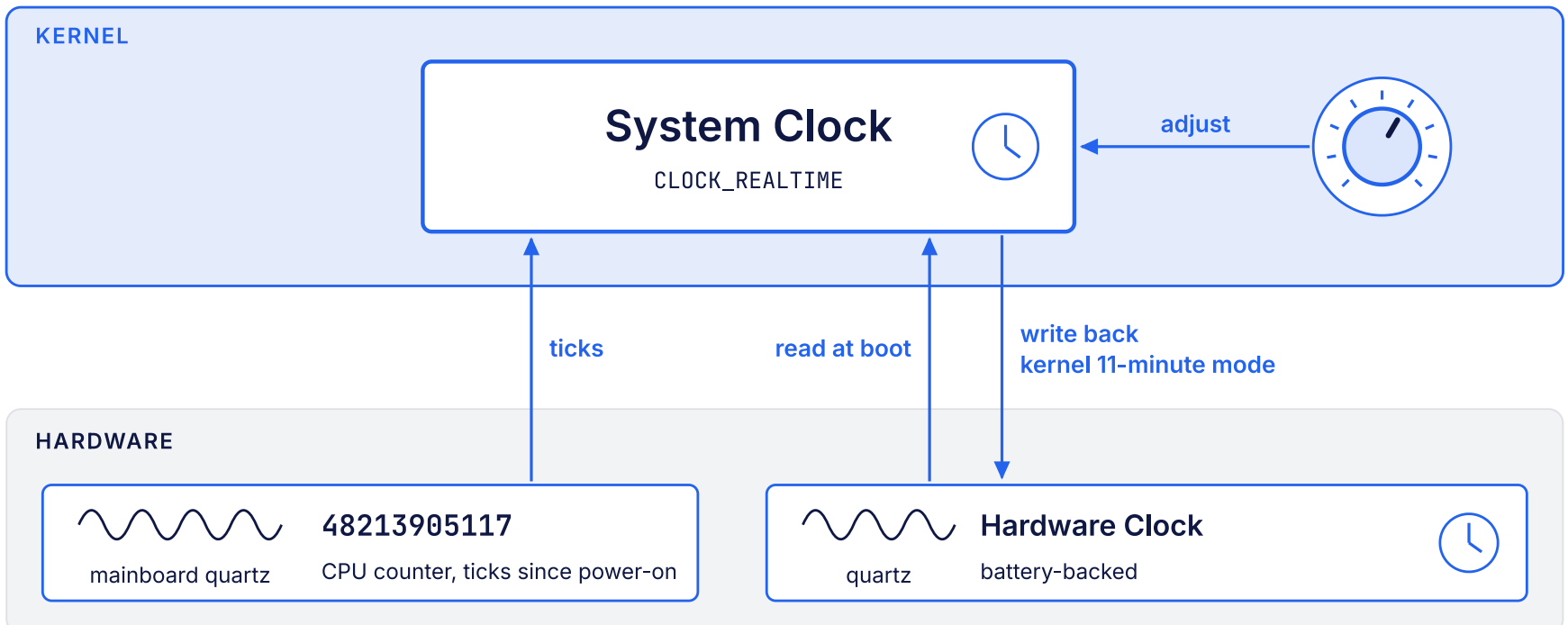
⚠ **Frequency error**

Type	Stored as	Era epoch
`time_t`	`int32` (legacy)	1970-01-01
GPS week	10 bits	1980-01-06
NTP	`uint32`	1900-01-01

⚠ **Counter rollover**

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Clocks on a node



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How to adjust a clock?

REFERENCE TIME	CLOCK STEP ⚠	CLOCK SLEW
00:00:00	00:00:02	00:00:02
00:00:01	00:00:03	00:00:03
00:00:02	00:00:02	00:00:03.5
00:00:03	00:00:03	00:00:04.0
00:00:04	00:00:04	00:00:04.5
00:00:05	00:00:05	00:00:05
00:00:06	00:00:06	00:00:06

STEP

SLEW

adjtimex system call

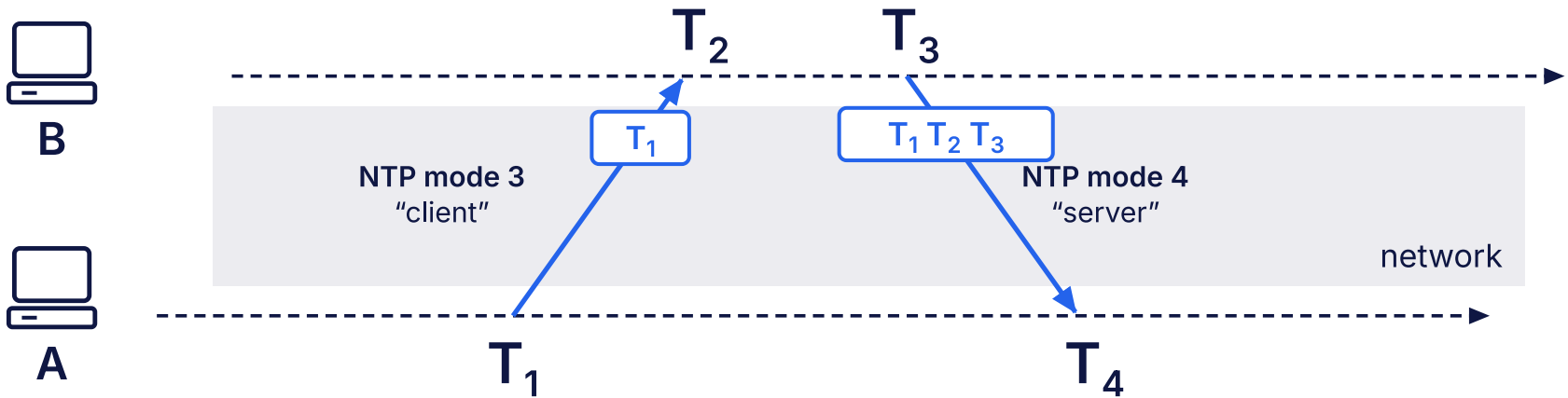
slew rate < `MAX_SLEW_RATE`

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Network Time Protocol: Get time over the network

Exchange of timestamps over IP networks, 123/UDP, RFC 5905 (NTPv4).

David L. Mills (1938–2024)
created NTP, RFC 958, 1985



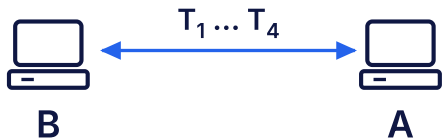
Offset	**θ** = T(B) – T(A)	**= (T2–T1 + T3–T4) / 2**
Round-trip delay	**δ** = T(ABA)	**= (T4–T1) – (T3–T2)**

⚠ **Asymmetric path & jitter** introduce errors in the offset.

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Network Time Protocol: Make the offset trustworthy

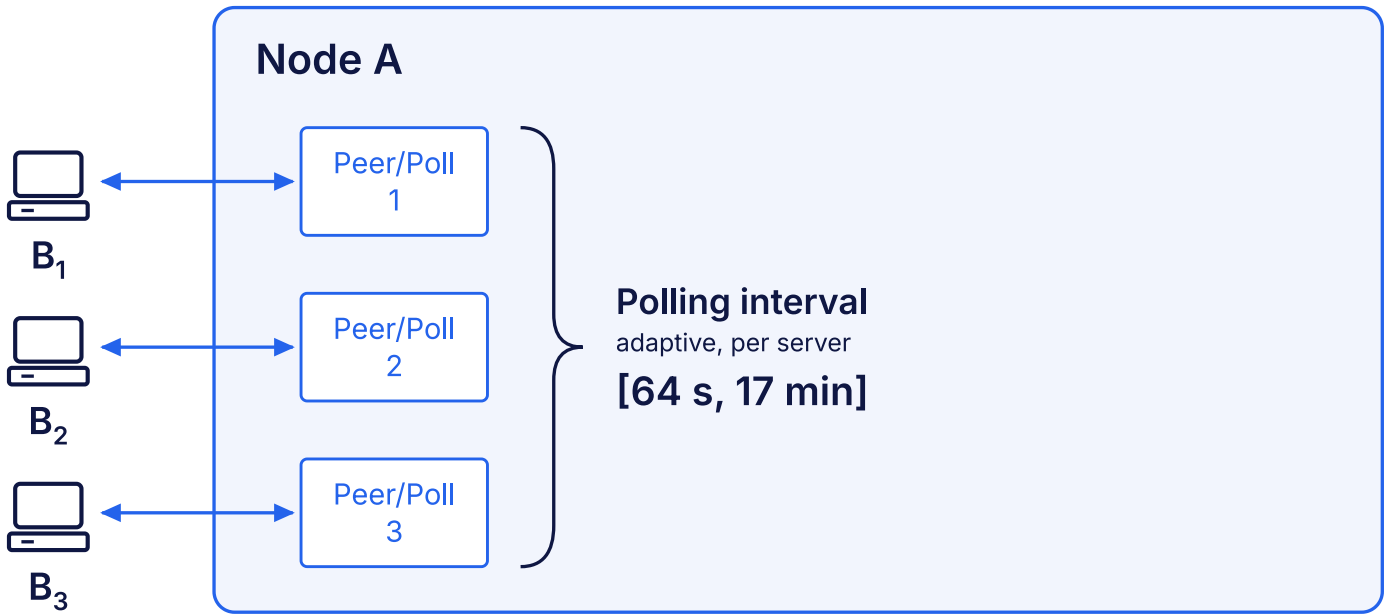
Robustness through multiple sources: keep the **truechimers**, discard the **falsetickers**.



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Network Time Protocol: Make the offset trustworthy

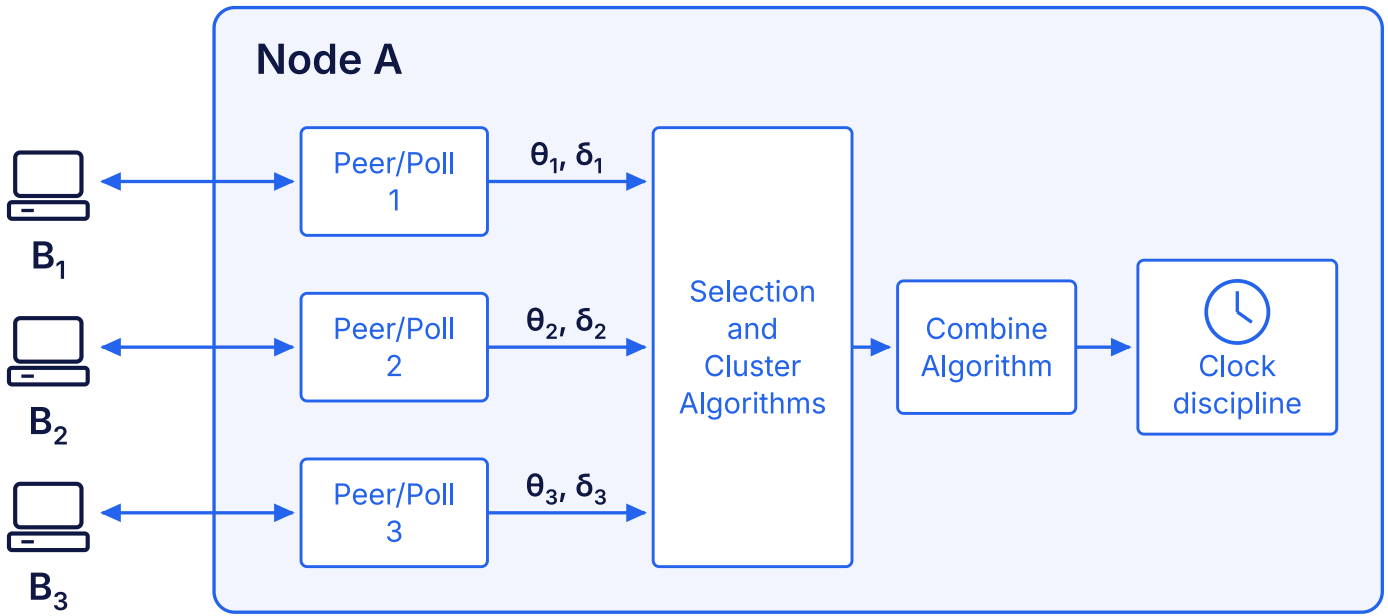
Robustness through multiple sources: keep the **truechimers**, discard the **falsetickers**.



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Network Time Protocol: Make the offset trustworthy

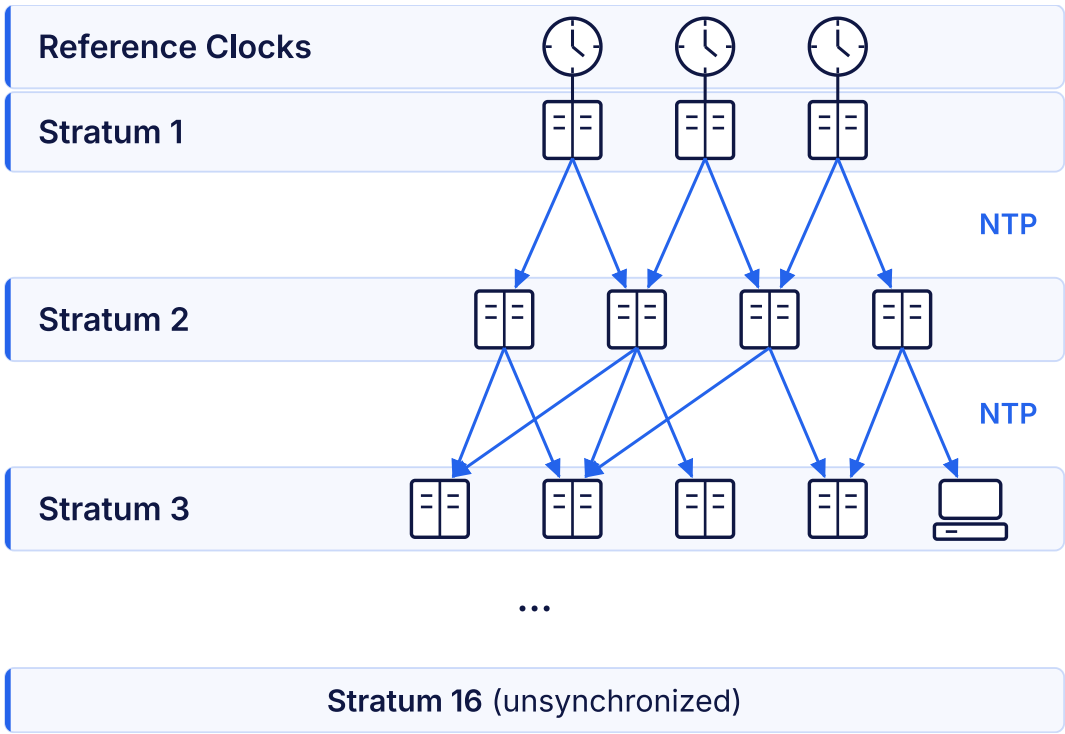
Robustness through multiple sources: keep the **truechimers**, discard the **falsetickers**.



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Network Time Protocol: Scale to the internet

A hierarchy of clock strata.



Time accuracy with NTP
LAN ~1 ms
WAN ~10 ms

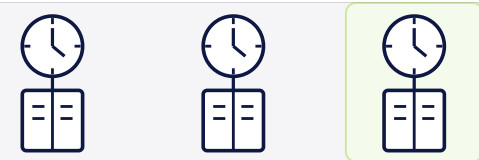
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02 Architecture

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Time sync architecture overview

Stratum 1
Reference Clocks



The 10k Fleet



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Stratum 1: Reference clocks

Where time comes from: an atomic clock somewhere.

Diversity: topological, political, technical.

National Metrology Institutes

PTB
Physikalisch-Technische Bundesanstalt
Nationales Metrologieinstitut

NIST NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY U.S. DEPARTMENT OF COMMERCE

Universities



FAU Friedrich-Alexander-Universität Erlangen-Nürnberg

Infrastructure Providers

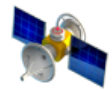
NETNOD

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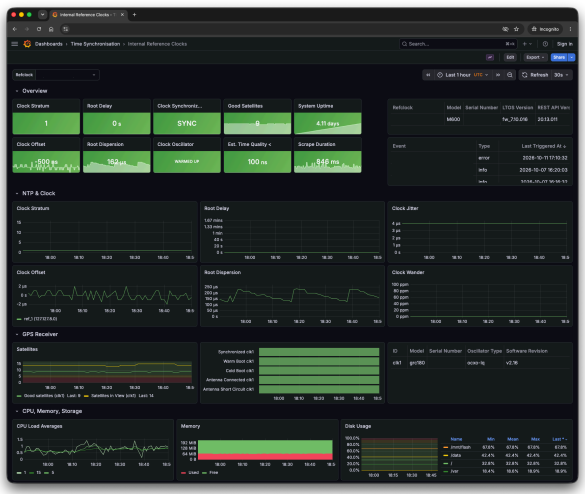
Stratum 1: Running your own reference clock

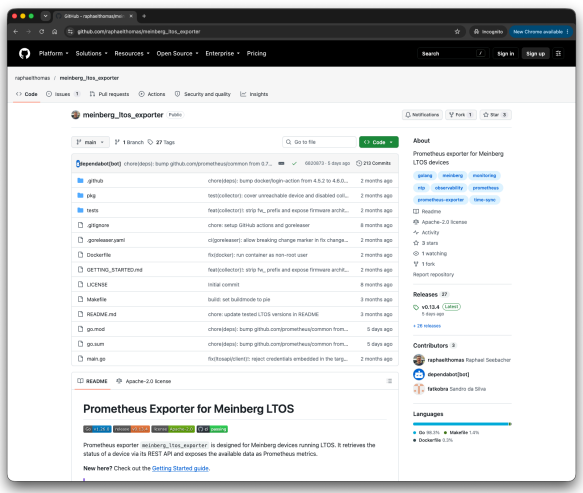


Meinberg LANTIME M600/GPS



GNSS (x, y, z, t)



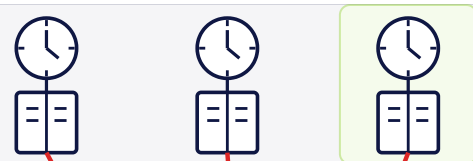


github.com/raphaelthomas/meinberg_ltos_exporter

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Time sync architecture overview

Stratum 1
Reference Clocks



~~So, point our 10k nodes at the stratum 1 servers?~~

The 10k Fleet



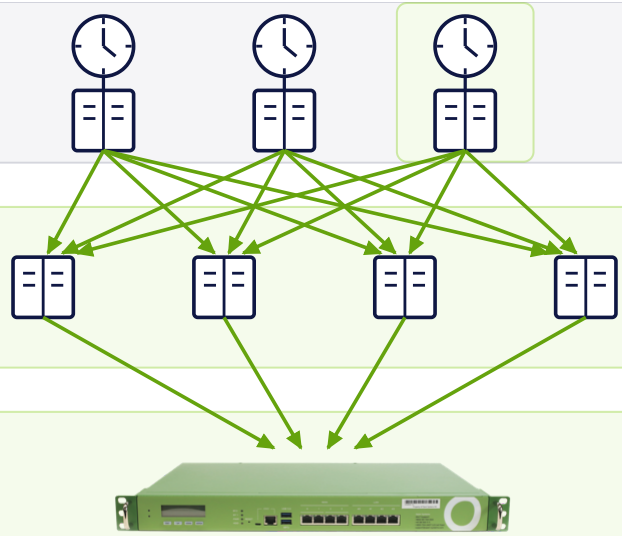
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Time sync architecture overview

Stratum 1
Reference Clocks

Stratum 2
Time Dissemination

The 10k Fleet



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Stratum 2: Time dissemination around the world

What? Get time from **all** stratum 1 reference clocks. Disseminate time to the 10k fleet.

Why? Control and scale: protect stratum 1 reference clocks from our load, hide the fleet.

Geographically distributed nodes

virtual machines in DC and on Azure



RFC 9109 **NTPv4: Port Randomization**

```
- IP 192.0.2.5.123   > 192.0.2.1.123: NTPv4, Client
+ IP 192.0.2.5.41242 > 192.0.2.1.123: NTPv4, Client
```

⚠ Traffic spoofing, ISP blocking

RFC 9769 **NTP Interleaved Modes**

Server sends the effective transmit timestamp in the next packet for improved accuracy.

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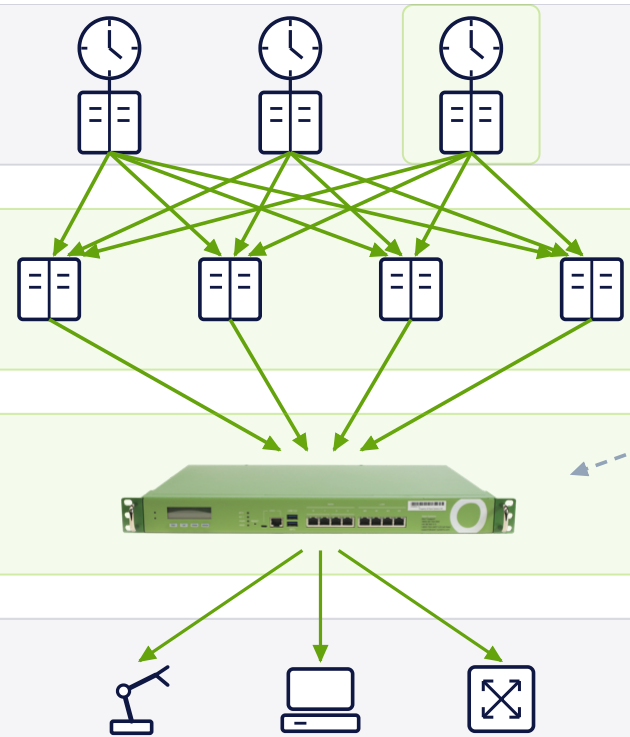
Time sync architecture overview

Stratum 1
Reference Clocks

Stratum 2
Time Dissemination

Stratum 3
The 10k Fleet

Stratum 4+
Customer Infrastructure



NTP Pool
pool.ntp.org

optional

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03 Operations

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Time Observability - Telemetry

Telemetry from every clock on every node.

Metrics: the clock, and each of its sources

```
synced      yes
stratum       3
offset   -18 µs
```

```
RMS offset    43 µs
frequency -11.8 ppm
max error     0.9 ms
```

```
source state reach  offset   error  age
B₁       *    377   -21 µs  0.4 ms  42 s
B₂       +    377   +12 µs  0.5 ms  51 s
B₃       x    377   +2.1 s  0.3 ms  38 s
```

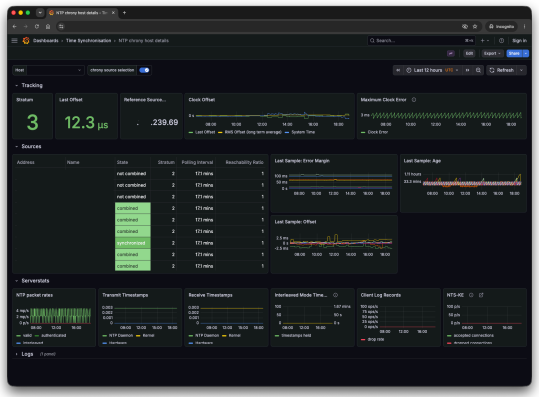
Logs

```
2026-04-19 18:05:56 WARN  System clock was stepped by -0.184736 seconds
2026-05-03 22:28:20 WARN  System clock interference detected (another NTP client?)
2026-05-04 12:04:21 WARN  System clock was stepped by 3532.017151 seconds
```

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Time Observability - Dashboards & Alerting

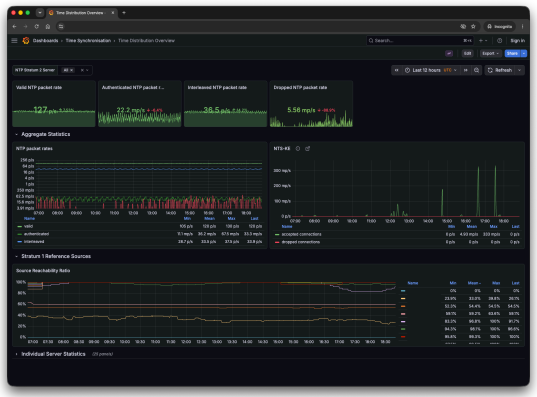
Single clock



Alerts

- **Offset** out of bounds
- **Unexpected stratum**
- Source **reachability** drops
- Clock **stepped** after boot

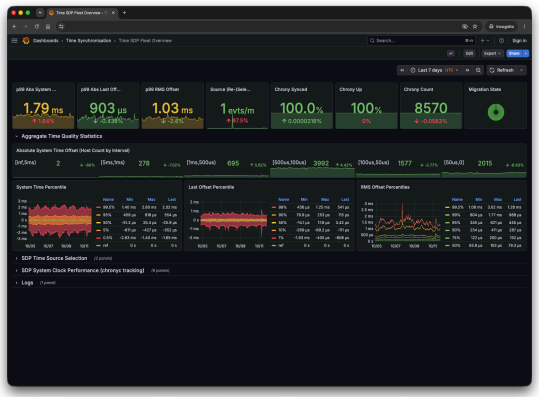
Stratum 2 servers



Alerts

- Stratum 1 **reachability** drops
- **Falseticker** among sources
- Own **stratum** not 2
- **Packet rates**: served, dropped

Fleet-wide



Alerts

- **Offset** percentiles (p99)
- Share of **unsynchronized** nodes
- **Stratum** distribution shifts

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2025-03-18, Ticket 2195142: NTP Sync not working

"We face Issues in Production that our PLCs can not connect to the NTP Server"

```
# tcpdump -i $INTERFACE -nn "udp port 123 and host $HOST"
2025-03-18 10:03:50.278215   10.138.80.60 → 10.12.1.4    NTP 90 NTP Version 4, client
2025-03-18 10:03:50.305834   10.138.80.60 → 10.12.1.4    NTP 90 NTP Version 4, client
2025-03-18 10:03:50.331972   10.138.80.60 → 10.12.1.4    NTP 90 NTP Version 4, client
```

Root cause: Client rate limited due to requests in bursts, 27 ms apart.

PLC vendor's answer
Burst "to increase synchronization accuracy".
NTP according to NTPv3 (RFC 1305, 1992), not NTPv4 (RFC 5905, 2010).

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2025-03-25, Ticket 2198399: NTP sync issue

"We are having errors reported from those devices concerning NTP sync and would like to investigate the root cause."

```
# tcpdump -i $INTERFACE -nn -vvv "udp port 123 and host $HOST and udp[9] = 0 and udp[20:4] = 0x52415445"
2025-03-25 19:12:56.636369  10.12.1.107 → 10.3.3.1      NTP 90 NTP Version 3, client
2025-03-25 19:12:56.636512     10.3.3.1 → 10.12.1.107   NTP 90 NTP Version 3, server
2025-03-25 19:12:56.647495  10.12.1.107 → 10.3.3.1      NTP 90 NTP Version 4, client
2025-03-25 19:12:56.647579     10.3.3.1 → 10.12.1.107   NTP 90 NTP Version 4, server

Rate exceeded. The server has temporarily denied access because the client exceeded the rate threshold
    Origin Timestamp:   2025-03-25 18:12:56.016342211 UTC
    Receive Timestamp:  2025-03-25 18:12:56.016342211 UTC
    Transmit Timestamp: 2025-03-25 18:12:56.016342211 UTC
```

Root cause: Client rate limited due to NTPv3 and NTPv4 in parallel, 11 ms apart.

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04 Security

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Authenticating time

⚠️ **Manual** symmetric keys
Scalability?

❌ **NTP Autokey** (RFC 5906, 2010)
Vulnerable

✅ **Network Time Security**
(RFC 8915, 2020)

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Network Time Security (RFC 8915)

PHASE 1 · INFREQUENT

Network Time Security Key Establishment (NTS-KE)

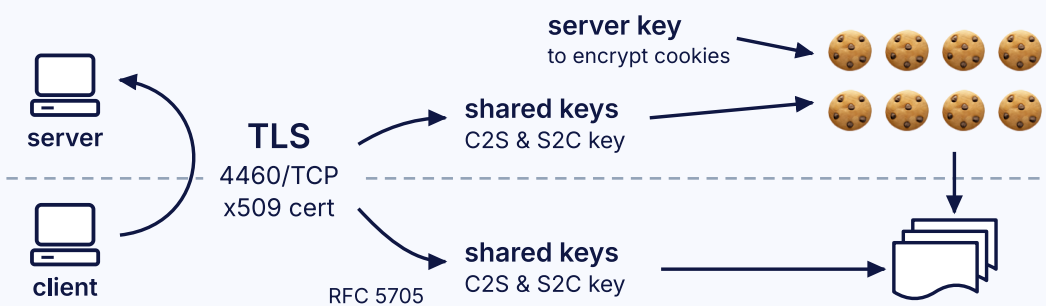
PHASE 2 · EVERY POLL

Network Time Protocol with Extension Fields

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Network Time Security (RFC 8915)

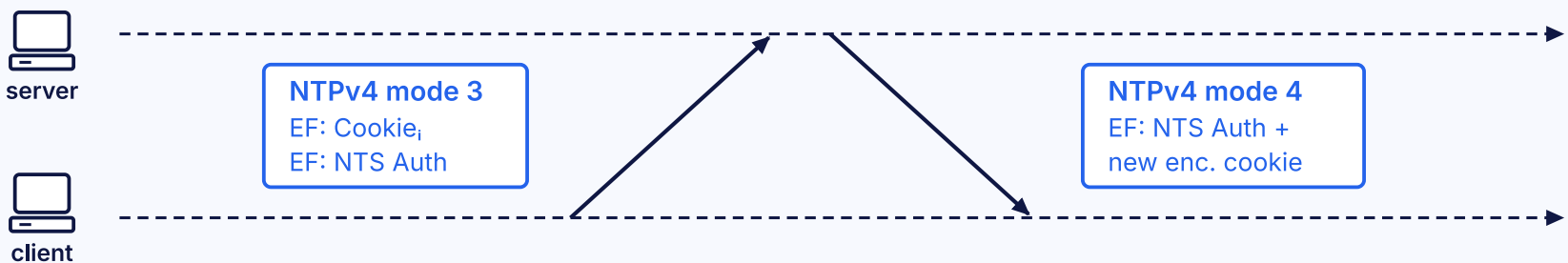
NTS Key Establishment (NTS-KE)



NTS Cookie

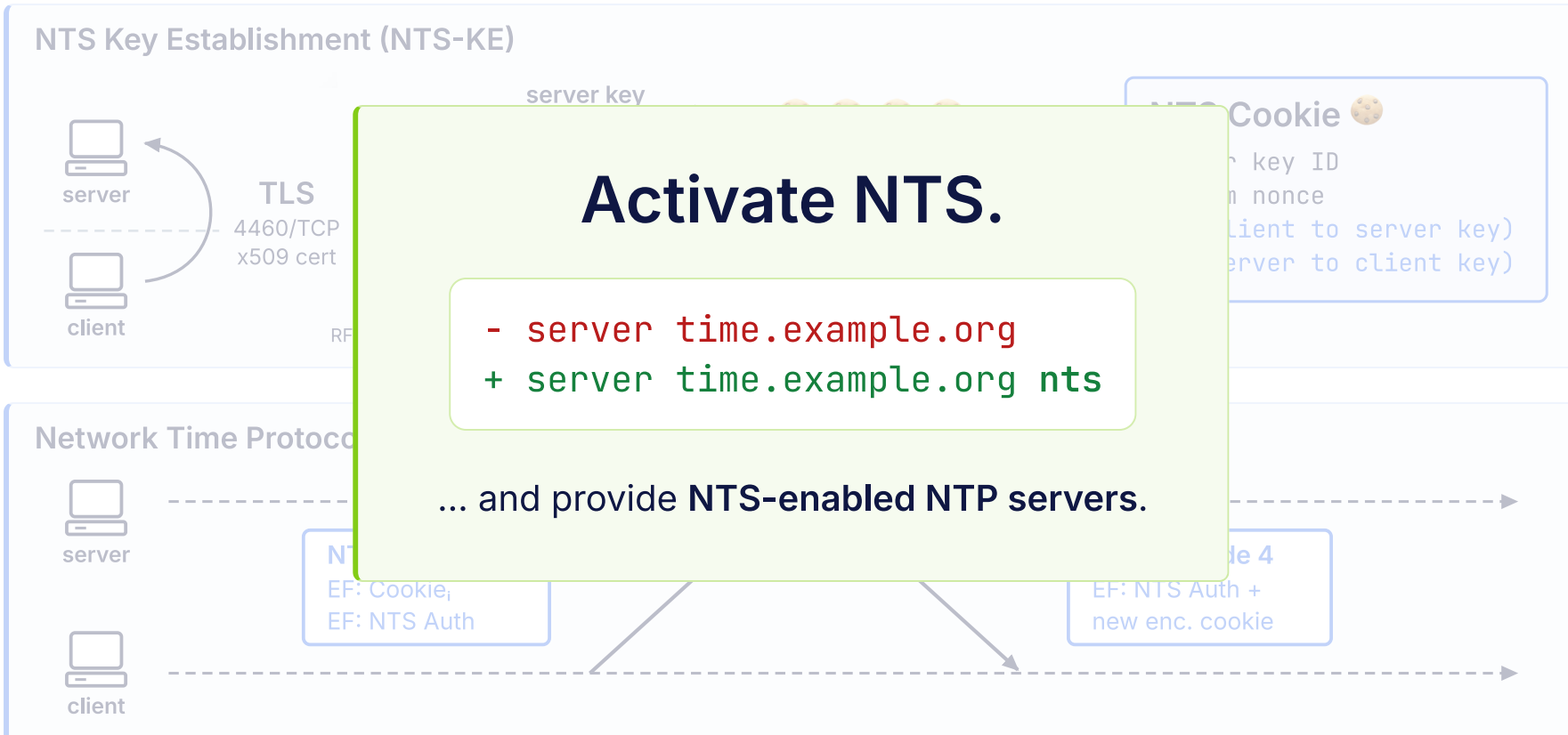
```
server key ID
random nonce
enc(client to server key)
enc(server to client key)
```

Network Time Protocol with Extension Fields



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Network Time Security (RFC 8915)



Activate NTS.

```
- server time.example.org
+ server time.example.org nts
```

... and provide **NTS-enabled NTP servers.**

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05 2038

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2038: Counter rollover epochalypse

time = era epoch + counter

Unix `time_t` , 32-bit

`int32` , seconds since 1970-01-01

```
 2147483646  2038-01-19 03:14:06
 2147483647  2038-01-19 03:14:07
-2147483648  1901-12-13 20:45:52
-2147483647  1901-12-13 20:45:53
```

64-bit `time_t` fixes it, if everything is rebuilt.

NTP timestamp

`uint32` , seconds since 1900-01-01

```
4294967294  2036-02-07 06:28:14
4294967295  2036-02-07 06:28:15
         0  1900-01-01 00:00:00
         1  1900-01-01 00:00:01
```

NTPv5 (draft) carries the era on the wire.

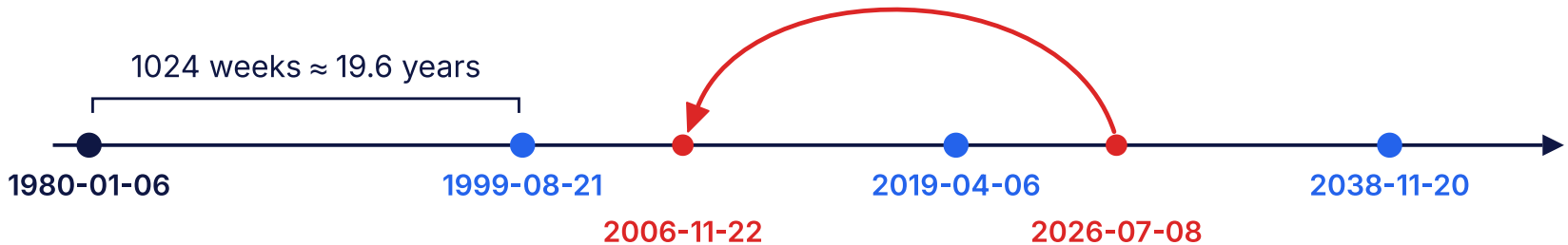
Inventory, test, update, ask your vendors – **epochalypse-project.org**

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GPS week rollovers

Counter: 10-bit GPS week number

Era epoch stored in GPS receiver **firmware**



Telstra, Australia · 2026-07-08

GPS card in the **wrong era**: reset to November 2006.

Timing loops: all sources agreed on **2006**.

Mobile network **severely degraded** for hours.

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https://www.telstra.com.au/content/dam/tcom/dynamic-media-projects/luke-campbell/TAP-Findings-for-Telstra-Outage.pdf

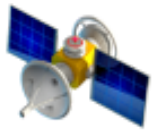
The NTP Time Sync Blueprint Checklist

- ☐ A named **timekeeper**?
- ☐ A **deliberately chosen hierarchy**? (own layer, documented, no loops)
- ☐ **5+ diverse sources**, no `prefer` ?
- ☐ **Every clock** reports offset, stratum, sync state?
- ☐ Alerts on **unexpected stratum**, **offset** and **falsetickers**?
- ☐ NTP daemon **hardened**? (mode 3/4 only, rate and step limits)
- ☐ **NTS** enabled (and provided)?
- ☐ **Rollovers** assessed? (GPS week, 2036, 2038)
- ☐ GNSS receiver **firmware** up to date?

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Epilogue: Sunday, 2025-12-21





GPS receiver passed its pivot date:
our reference clock fell back 19.6 years to **2006**.

No downstream impact. A firmware update fixed it.

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Everything depends on time.
Be a truechimer.

Raphi Seebacher
linkedin.com/in/raphael-seebacher

github.com/raphaelthomas/awesome-time

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