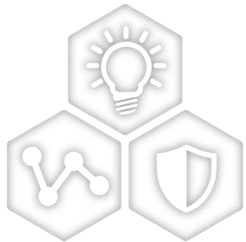


# The Role of National Time Scales for Critical Infrastructure



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A Leading Provider of Smart, Connected and Secure Embedded Control Solutions



SMART | CONNECTED | SECURE

Tim Kelly  
Greg Wolff

# Agenda

- **Coordinated Universal Time (UTC)**
- **Time scale function**
- **Time scale considerations**

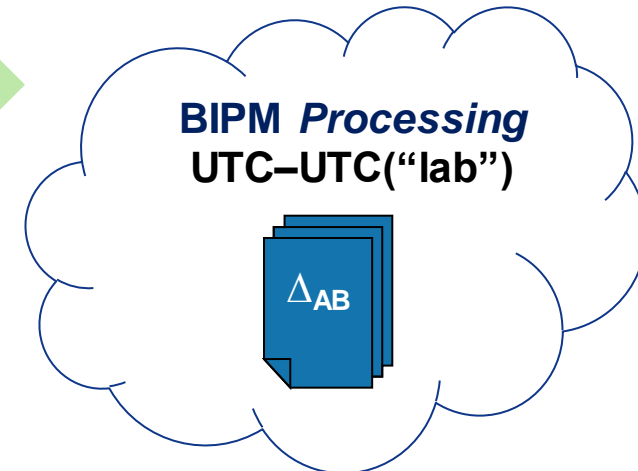
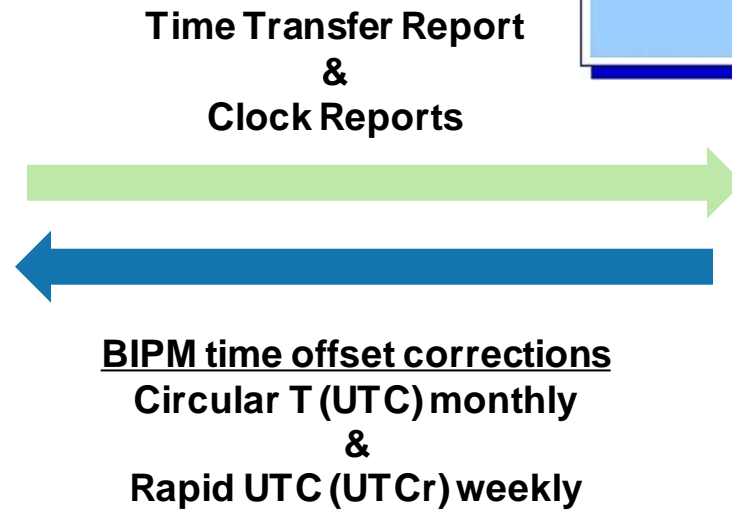
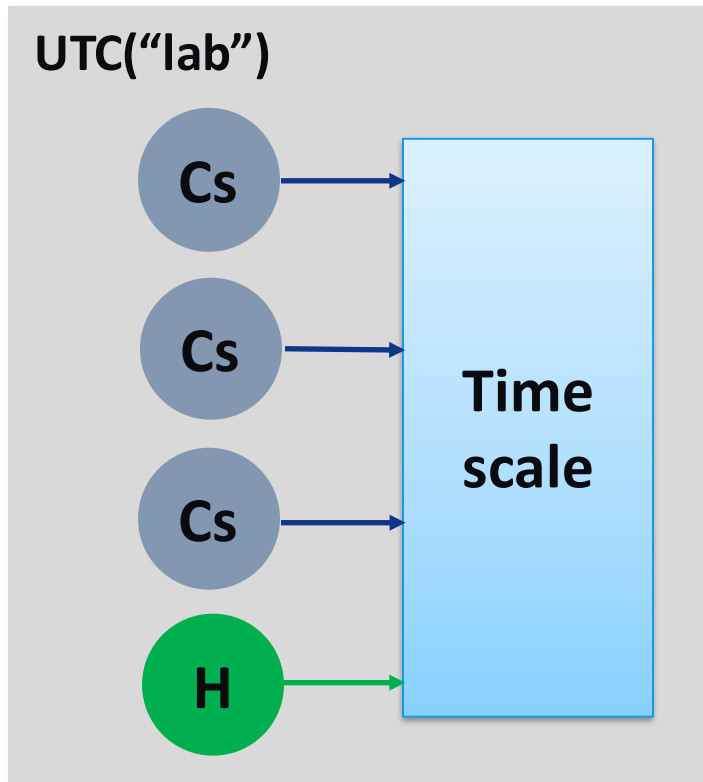
# Coordinated Universal Time (UTC)

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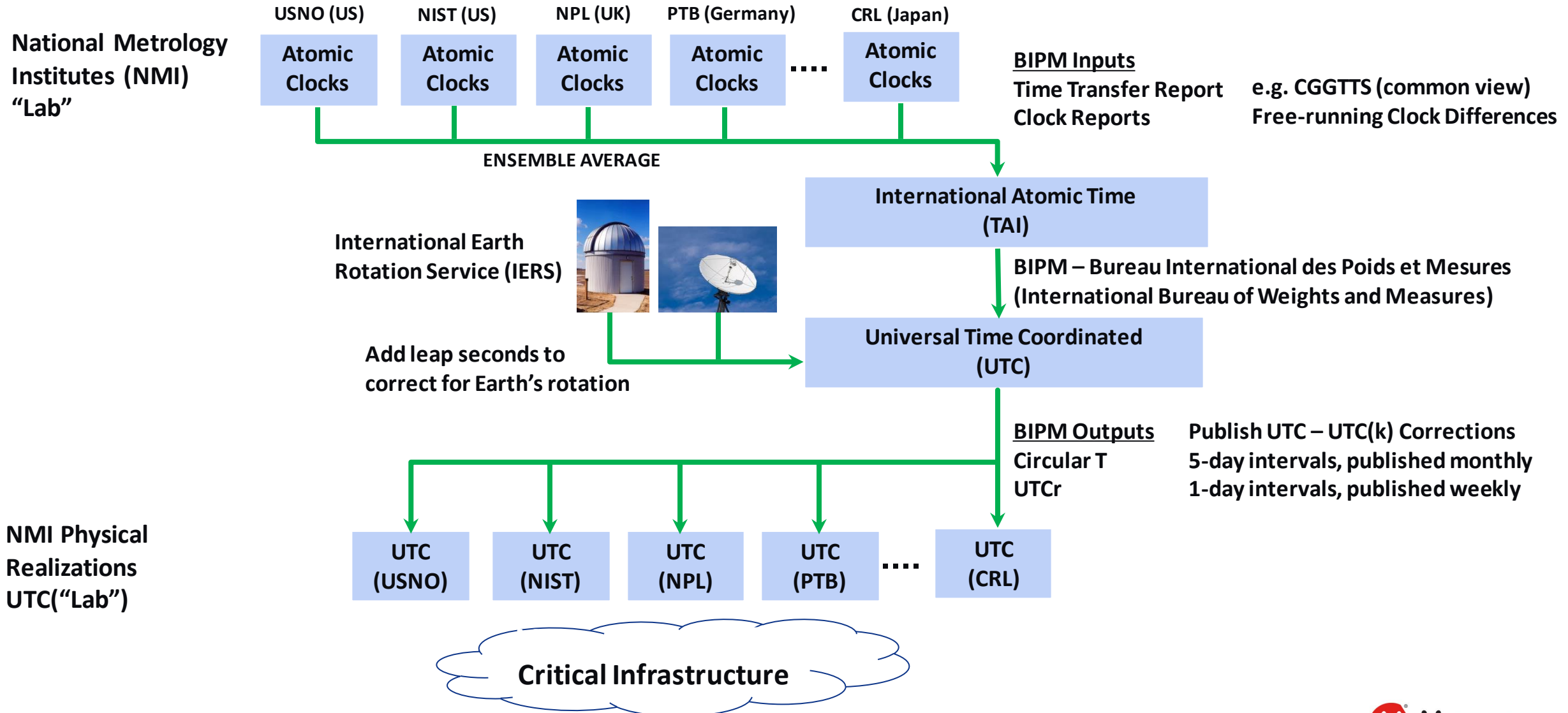
The International Bureau of Weights and Measures (BIPM)

# Coordination of national metrology institutes

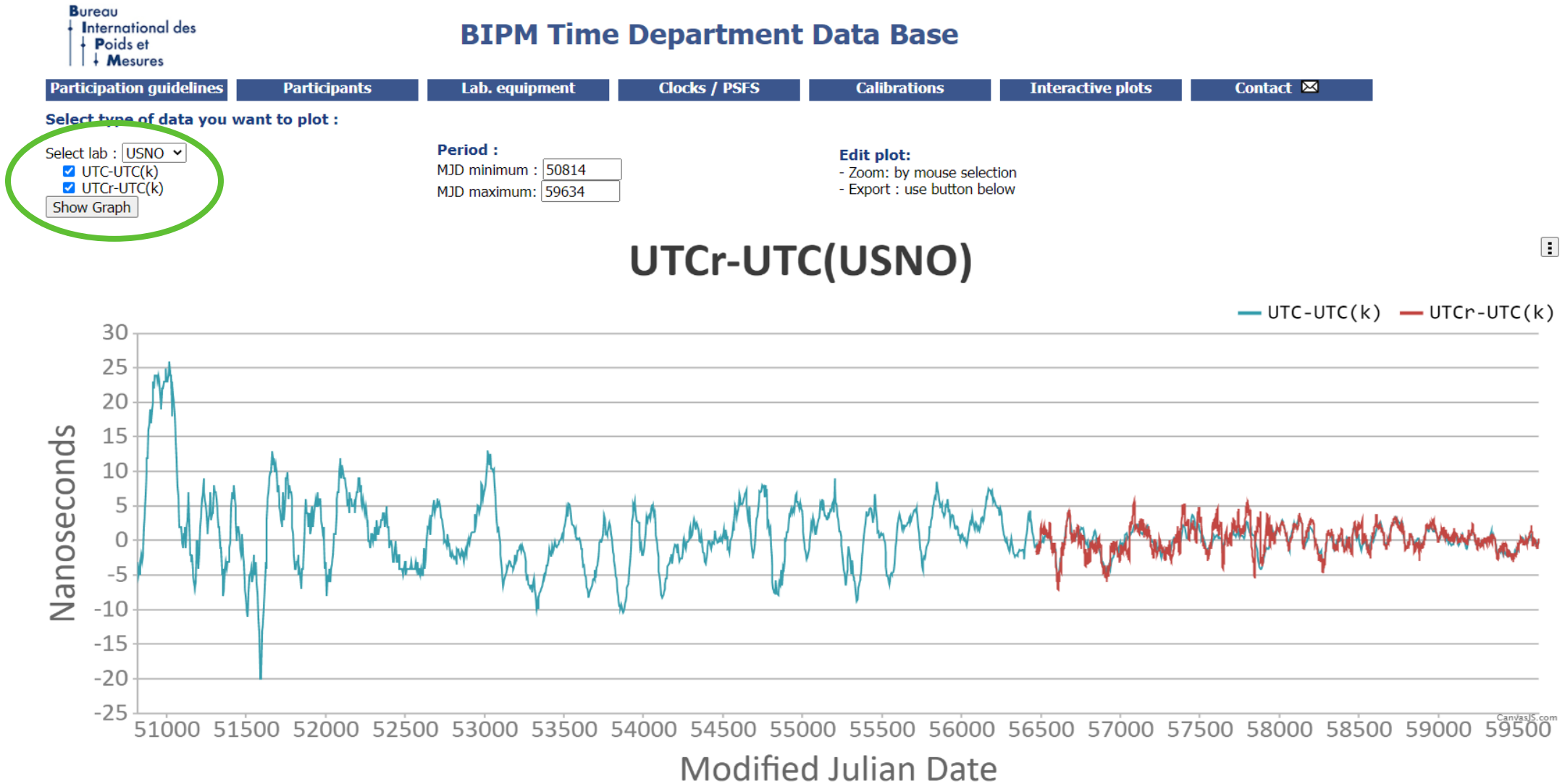
Time offset between every national metrology institute (“lab”) and BIPM is observed with two-way and/or GNSS common-view time transfer methods



# BIPM processing



# UTC - UTC("lab") time differences on BIPM site



01-01-1998

07-03-2013

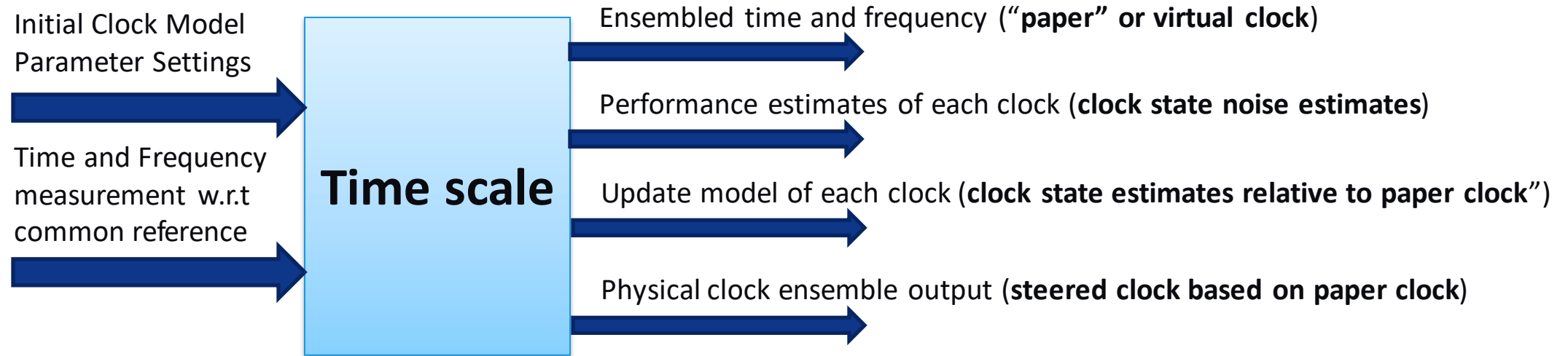
02-24-2022

# Time scale

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Functional description

# What is a time scale?



“... time is a defined quantity (dependent on algorithms, definitions, and procedures) and not intrinsic to the atomic clocks used to generate time.” – Allan and Barnes

“The purpose of a time scale is to create a virtual clock from an ensemble of physical clocks whose differences from each other are measured at a sequence of dates.” – Greenhall

Beyond the precise definition of constructing a “virtual clock” is also the practical need to generate a physical ensemble clock and a UTC steered clock.



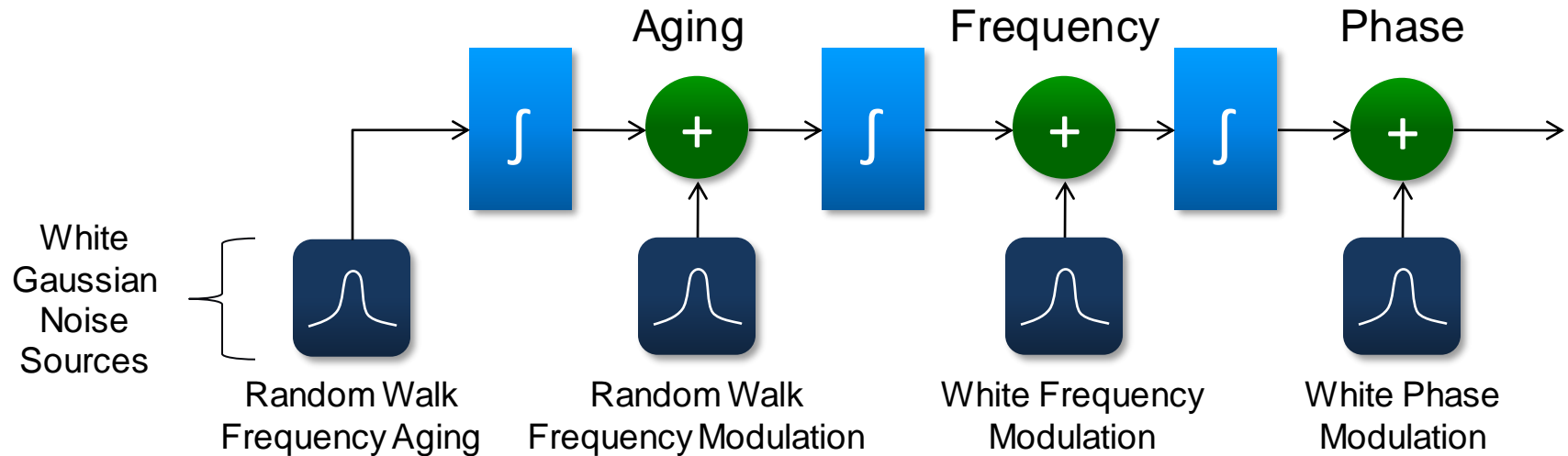
# Clock model

**Clock state differences relative to paper clock**

$$\vec{x}(t) = \begin{bmatrix} u(t) \\ x(t) \\ y(t) \\ w(t) \end{bmatrix}$$

Name	Units	Description
u	ns	Phase (observable)
x	ns	Phase, without white phase noise
y	ns/day	Frequency
w	ns/day <sup>2</sup>	Frequency aging

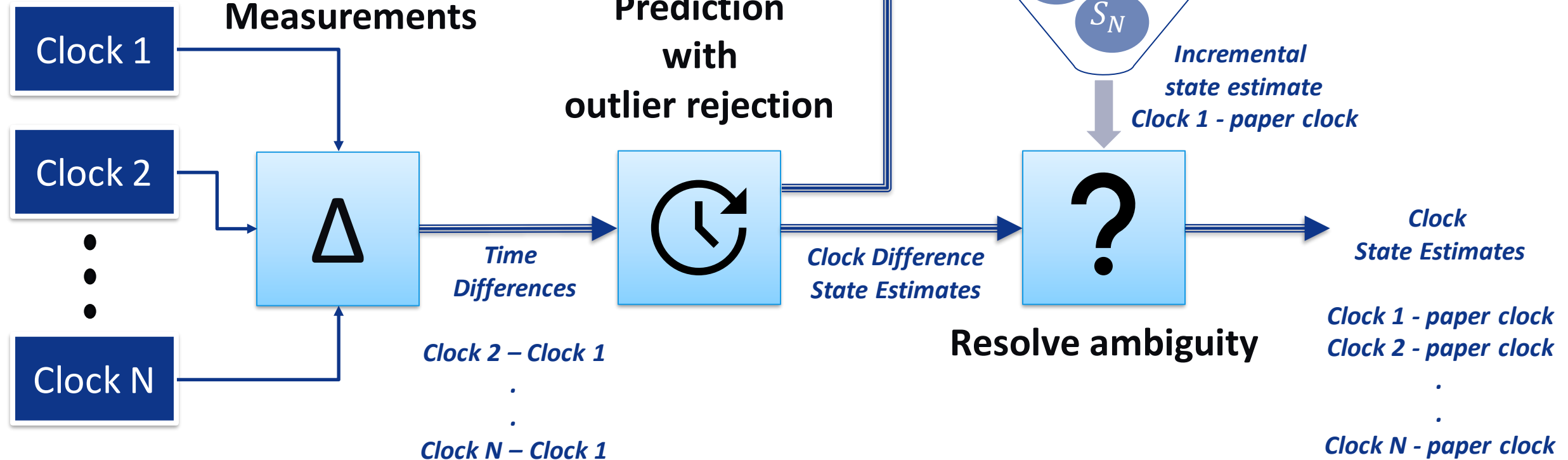
**Process noise model relationship to the estimation states**



Analogous to Position, Velocity, and Acceleration equations of motion

# Time scale ensemble

Atomic frequency references



# Time scale coordination

## Universal time standards

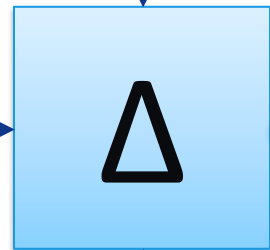
UTC(1)

UTC(2)

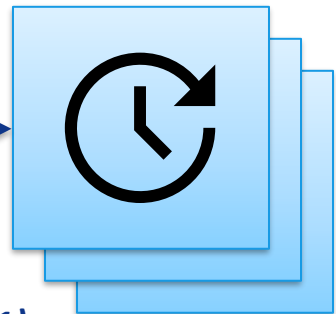
⋮

UTC(k)

## Observables



## State estimation filters with outlier rejection

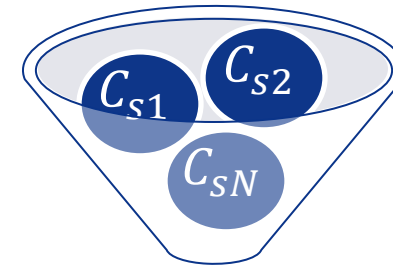


Time Differences

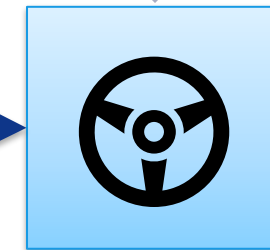
Steer Clock – UTC(1)  
Steer Clock – UTC(2)

⋮  
Steer Clock – UTC(k)

## Time scale ensemble & steer clock filter



Paper Clock – Steer Clock



Steer clock

Steer Clock – UTC

UTC(lab)

Time standard for critical infrastructure

# Time scale

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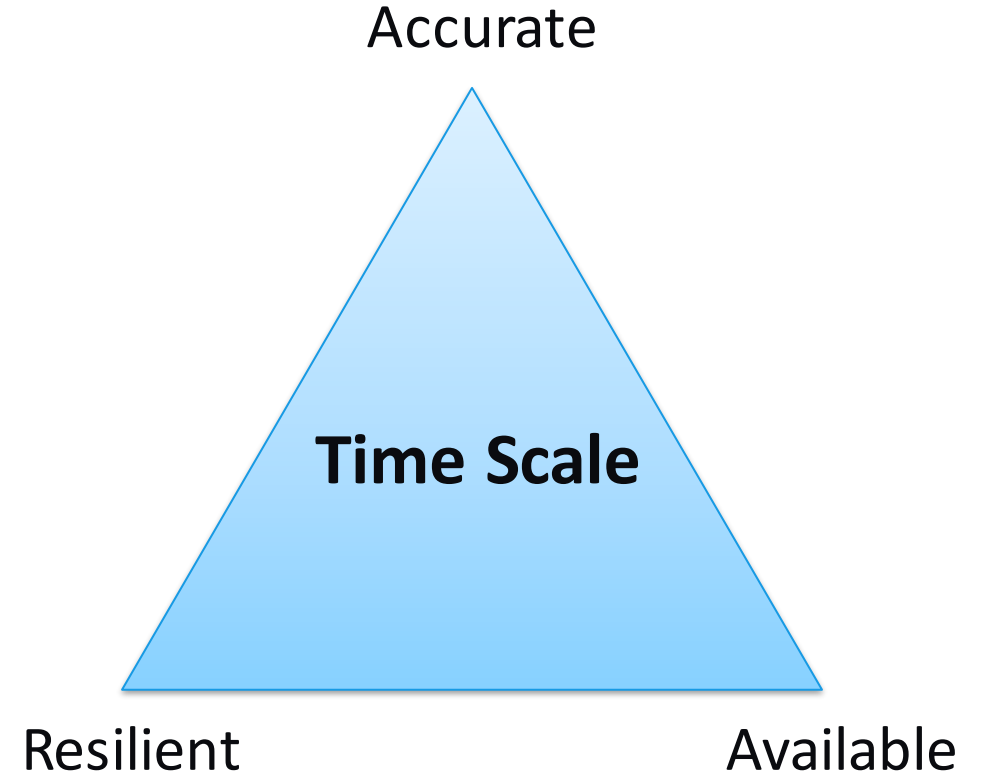
Considerations

# Practical time scale requirements

- **Automatic operation**
  - Startup
  - Steady-state forever – even if OS hangs
  - Fault detection
  - Unattended operation – no human judgment needed ever
- **Real-time signal generation**
- **Robustness**
  - No events can ever stop the time scale
  - Includes unanticipated events
  - Includes unusual events
- **Software update**
- **Transients are normal – in fact, they are the expected**
  - System Startup
  - Adding clocks
  - Dropping clocks
  - Clock failures
  - Missing measurement data
  - Rejected measurement data
- **Adapt to changes in clock properties**
  - Each clock type has different noise processes
- **Cyber security**
  - GPS validation
  - System security

# Advantages of a time scale

- **Accuracy:** Time scale gets the most performance out of each contributing clock with robust fault detection based on the ensemble filter learning the states and noise of each clock
- **Resiliency:** The timescale can run independently of GNSS. It is resilient to cyber-attacks using state estimations and other validation methods
- **Availability:** Supports redundant time and frequency sources and fault-tolerant clock generation. Since the virtual “paper” clock is based on optimal weights of all clocks, impact due to a clock outage is negligible to time scale output



# Summary

- **Coordinated Universal Time (UTC)**

- Time scale systems have traditionally been used as instruments reserved for scientific measurements performed by metrology labs

- **Time scale function**

- With today's clock technologies, it's possible to maintain traceability to UTC without dependency on GNSS

- **Time scale considerations**

- When constructing a time scale system, consideration should be given to both “performance” and “practical” characteristics if the goal is to serve national critical infrastructure
- With the global threat of GNSS vulnerability on the rise, the role of a country's national time scale is changing from being a scientific measurement instrument to a vital part of a country's critical infrastructure.

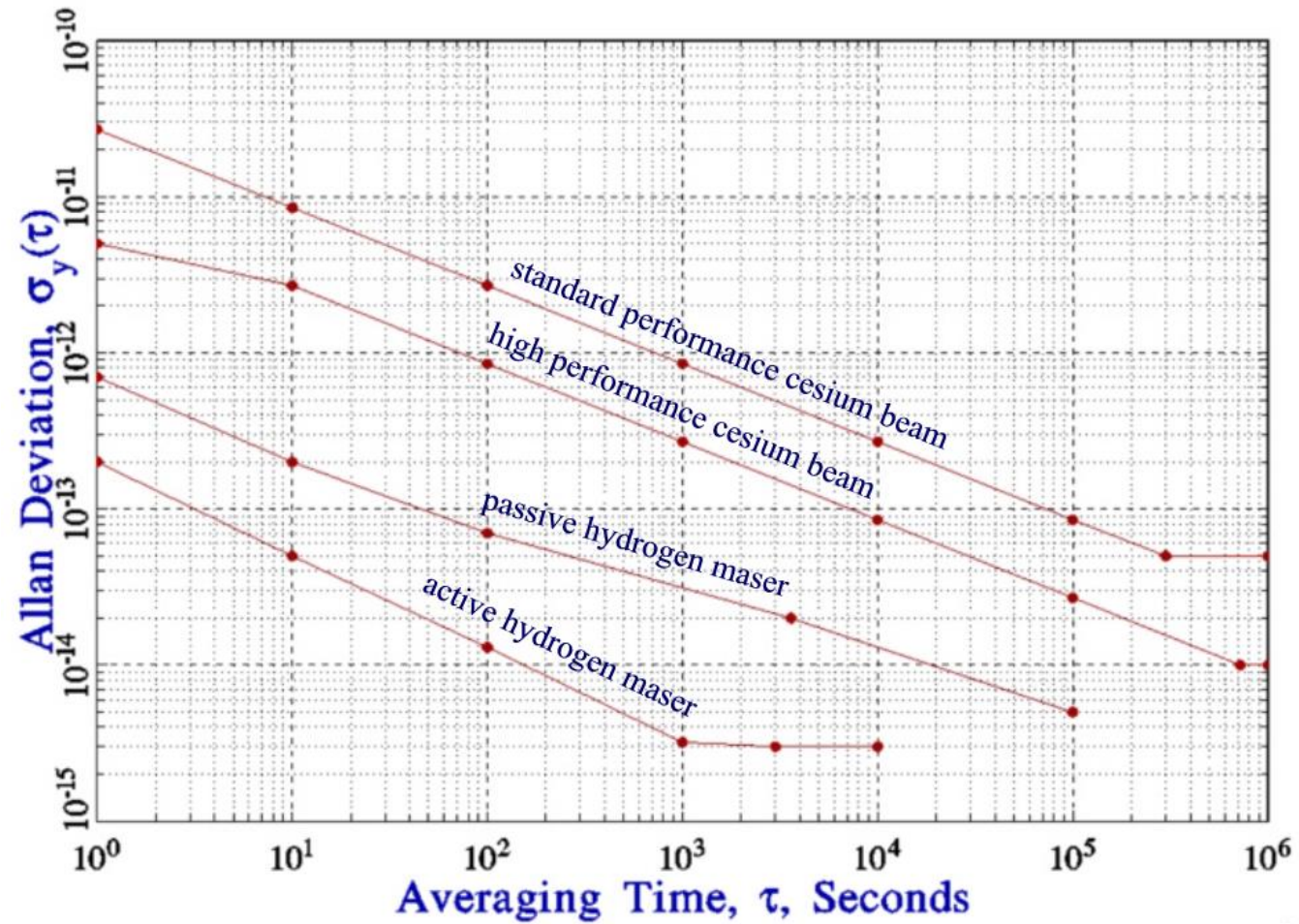
# The Role of National Time Scales for Critical Infrastructure

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Thank you



# Frequency Stability of Atomic References



Slide 32