



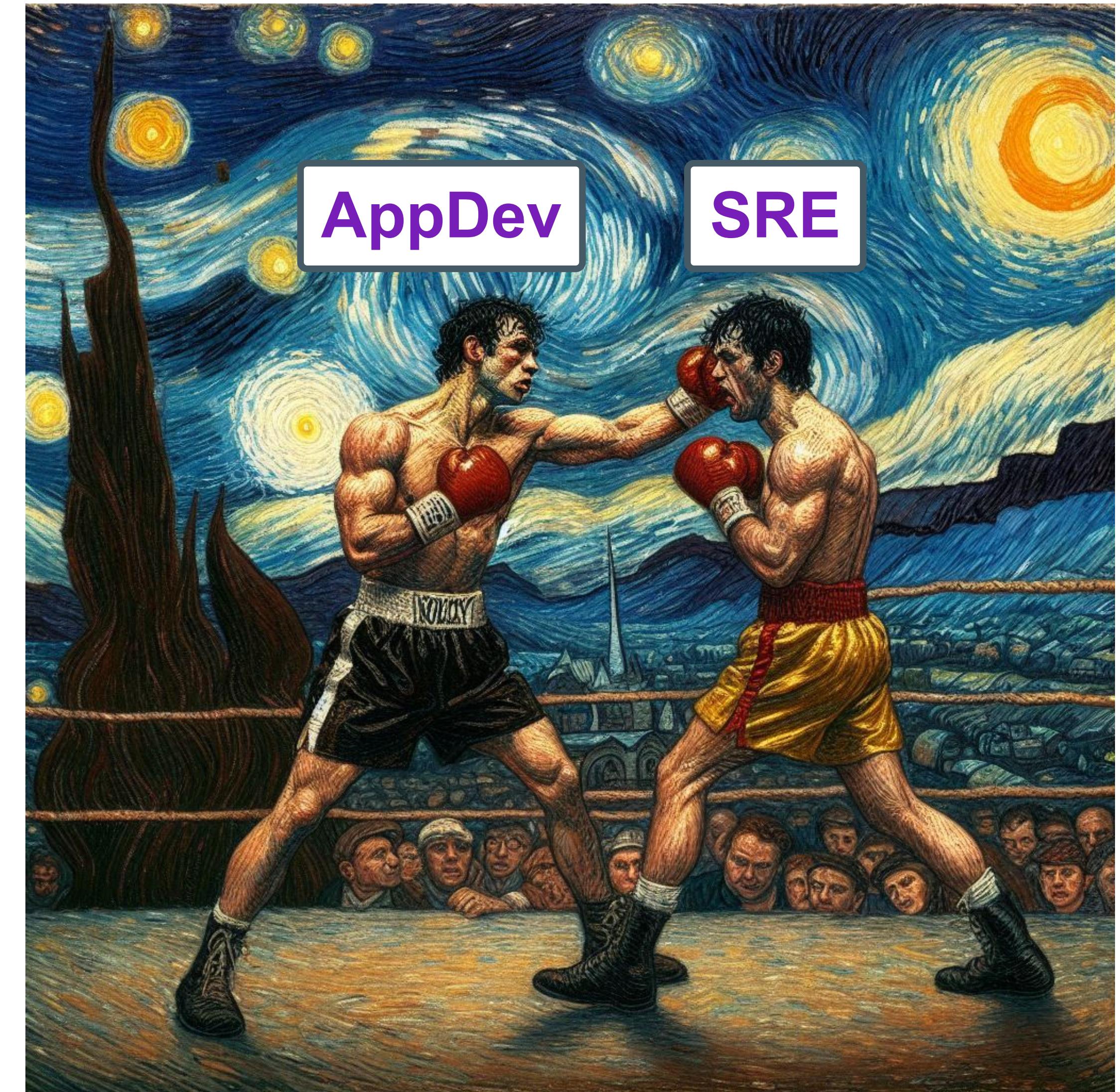
# Rock around the (synchronization)



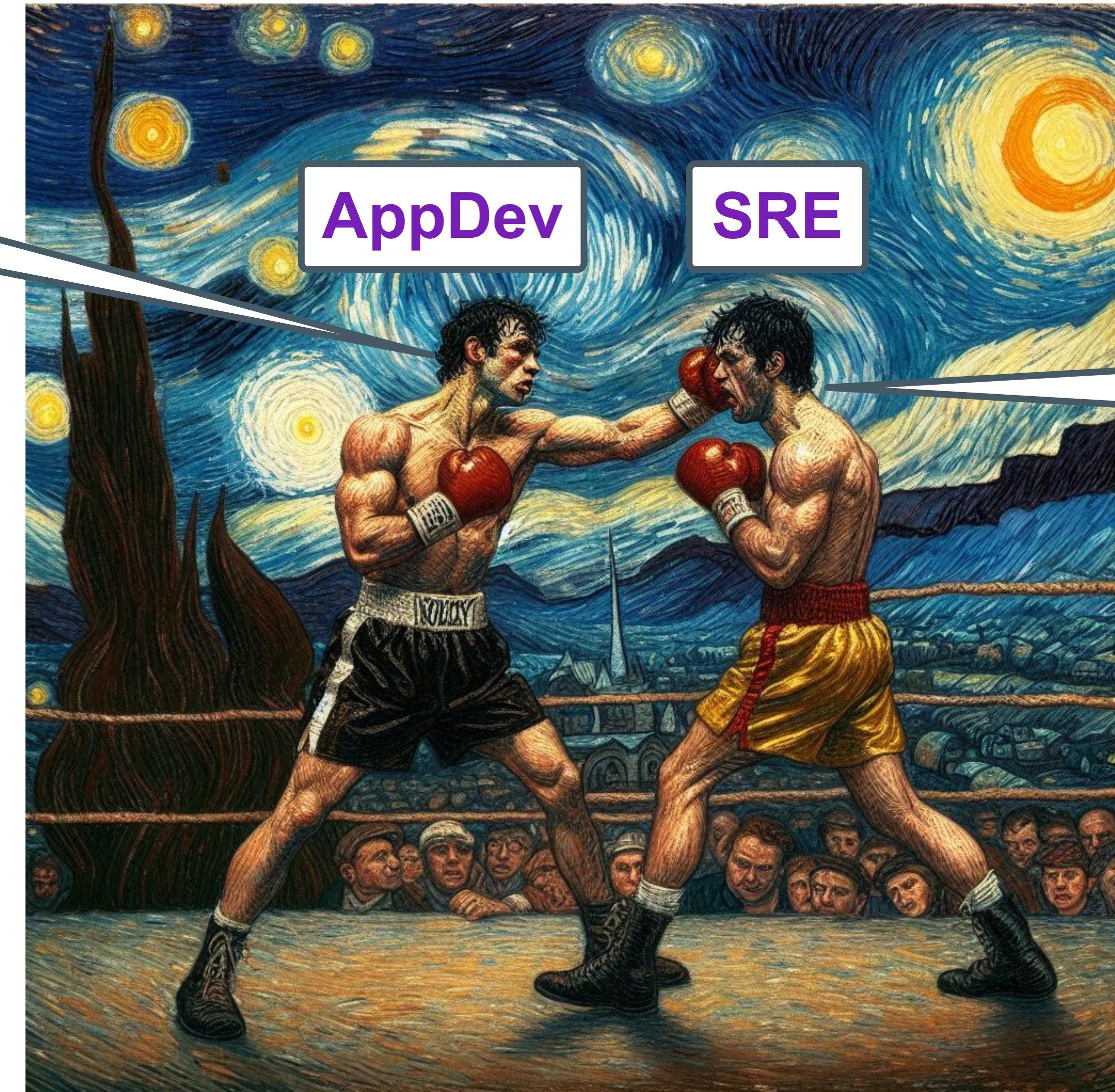
Improve performance  
with high precision time!

Lerna Ekmekcioglu

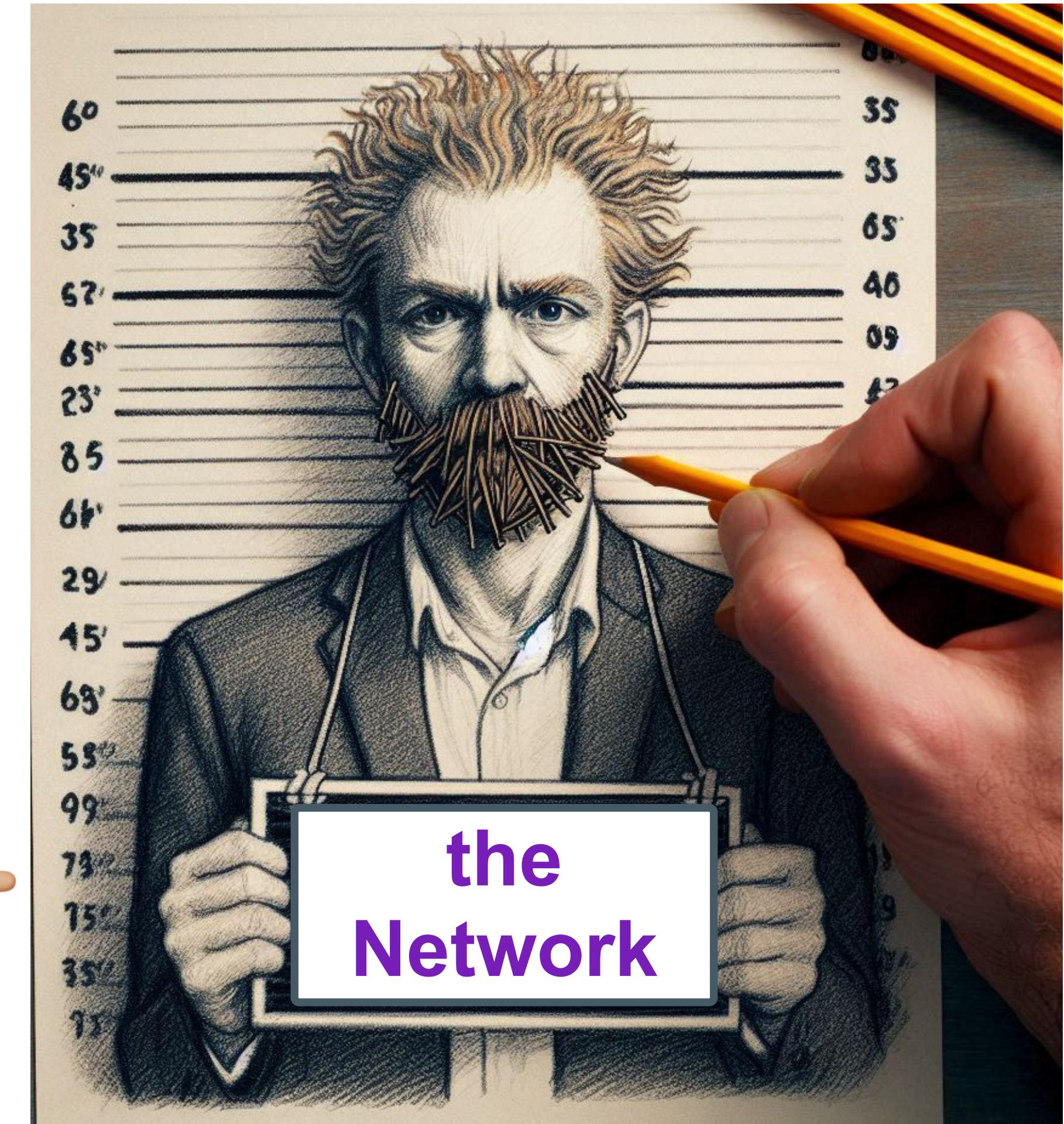
Sr Solutions Engineer, Clockwork Systems



My app is slow!  
It's the network!👉

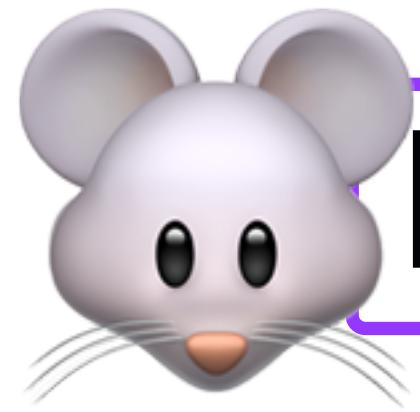


Is it the app or



?

Demo:  latencies

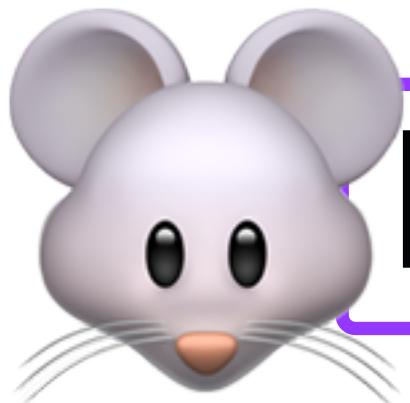


Ecommerce site



Demo: ➡ 2 latencies

Network pipe

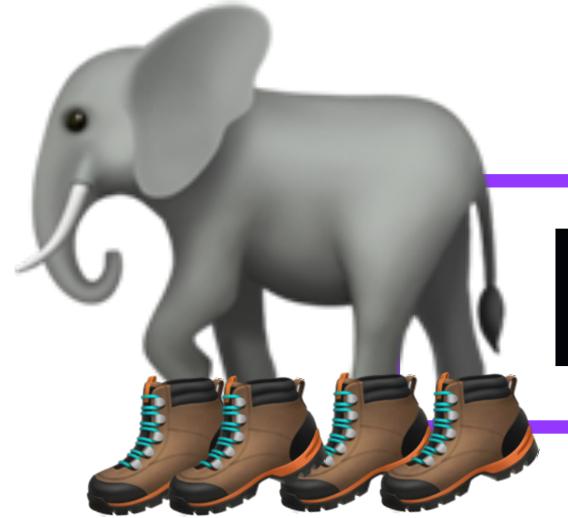


Ecommerce site

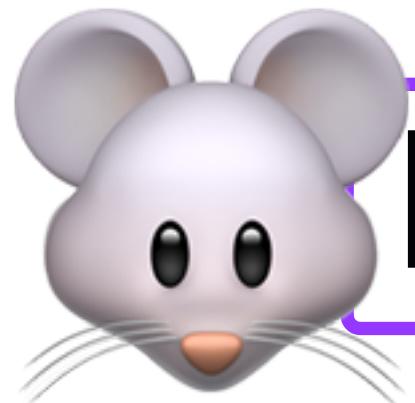


Demo: ➡️ 2 latencies

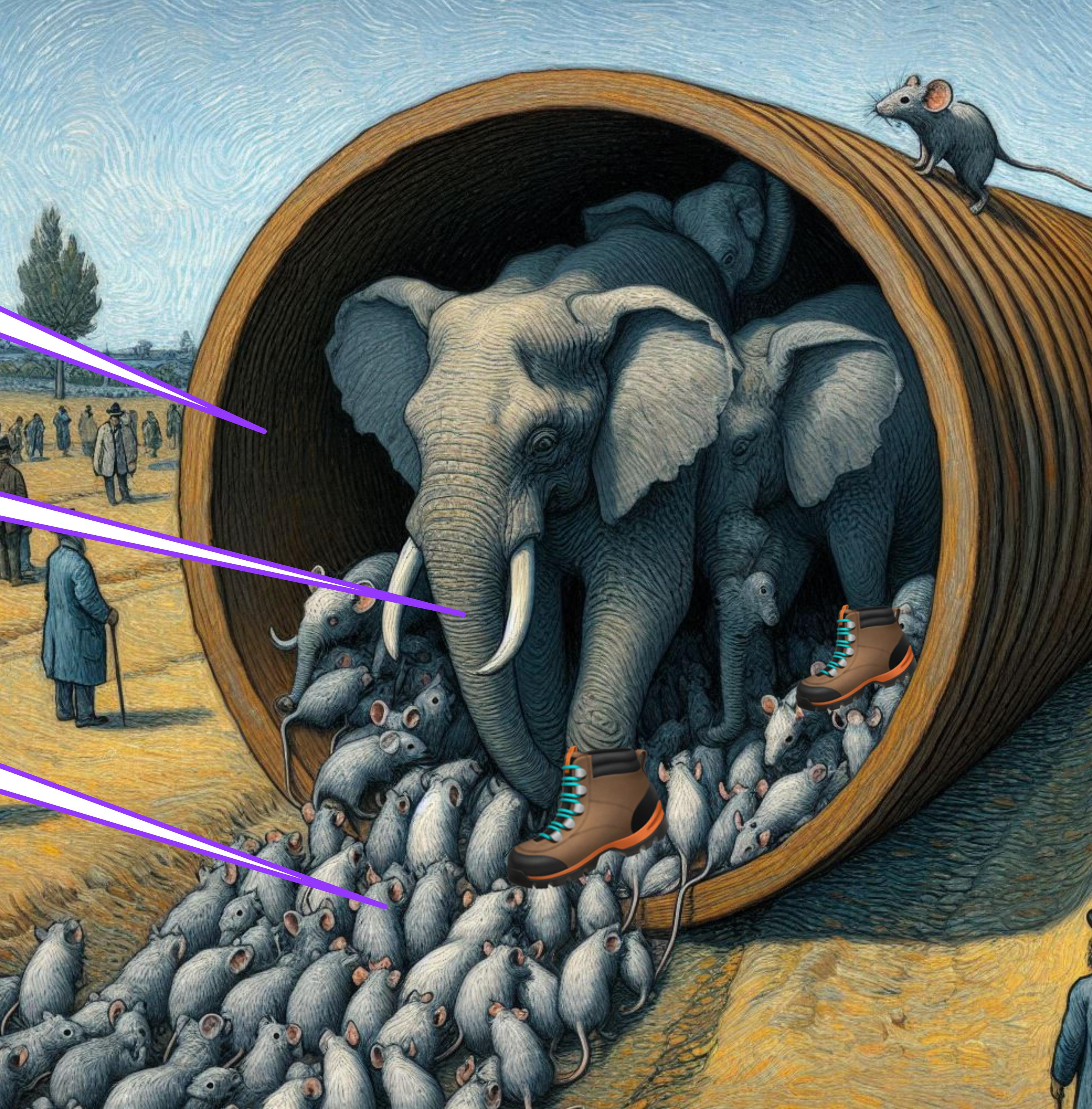
Network pipe



Data workload



Ecommerce site



# Demo: ➡ tail latencies for

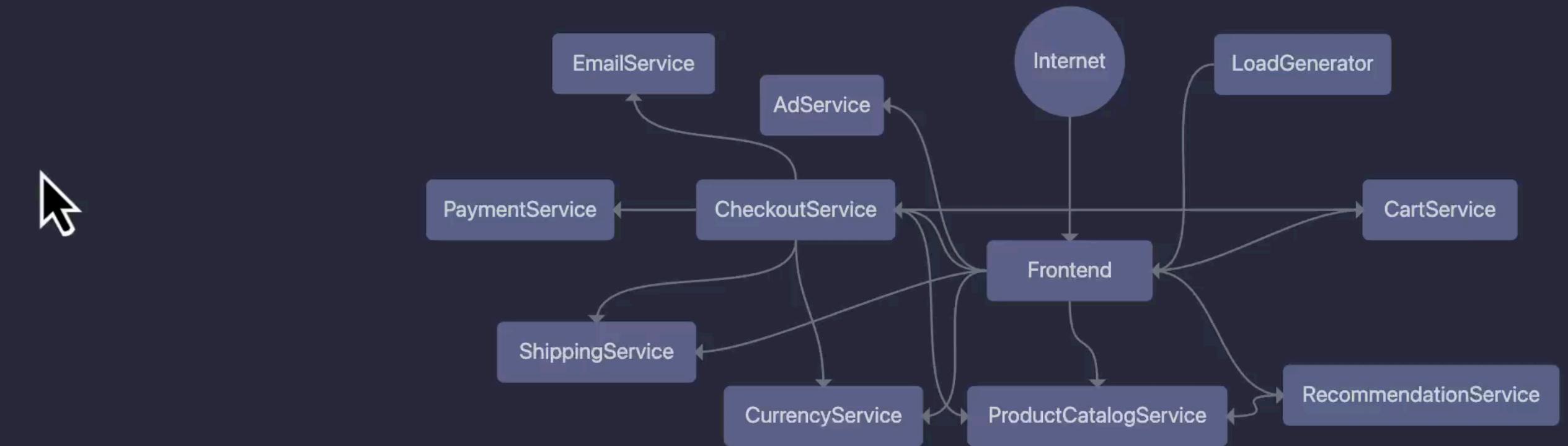


CLOCK  
WORK

Runs Tracing

8

## Microservices demo



| Name      | Cloud | Mode | Creation time        | Started by |                           |
|-----------|-------|------|----------------------|------------|---------------------------|
| demo-shsu | EKS   | CWCS | Tue, Oct 15, 5:26 PM | Lerna      | <button>Redeploy</button> |

[Online Boutique](#) [Jaeger](#) [Load Generator](#) [Clockwork Tracing](#) [Probe Mesh](#)

[Start new cluster](#)

# Demo: ➡ tail latencies for

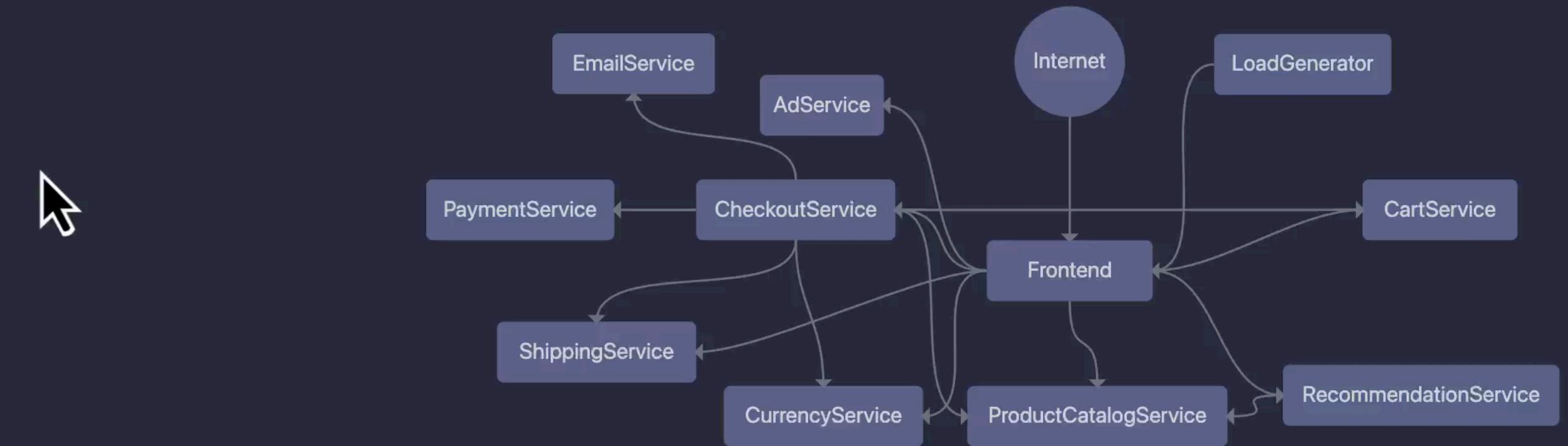


CLOCK  
WORK

Runs Tracing

8

## Microservices demo



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[Online Boutique](#) [Jaeger](#) [Load Generator](#) [Clockwork Tracing](#) [Probe Mesh](#)

[Start new cluster](#)

# Why do we need accurate time?

Minimize tail latencies  
and control congestion



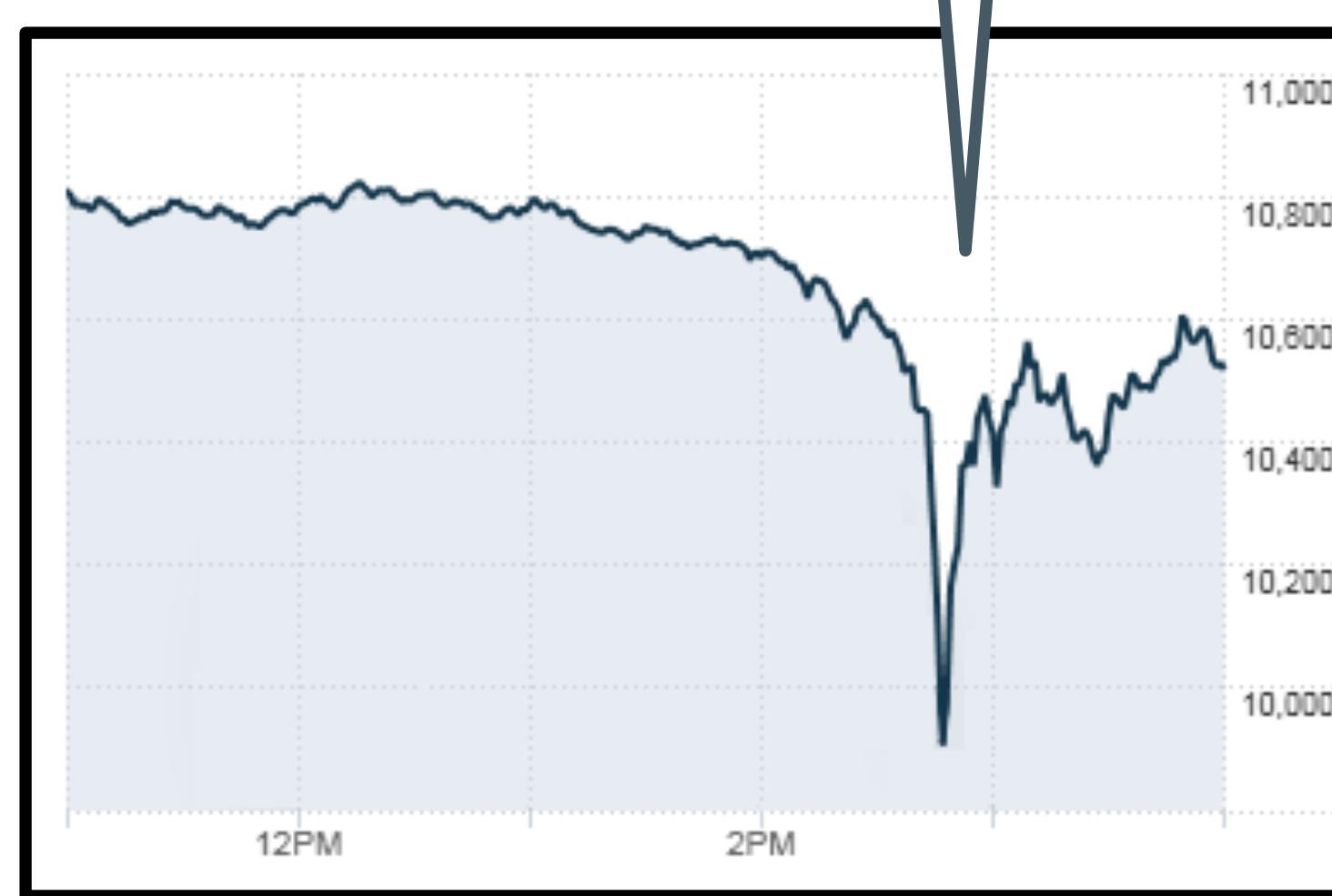
**Performance**

# Why do we need accurate time?

Minimize tail latencies  
and control congestion



Prevent market abuse



Performance



Max divergence  
from UTC 100µs

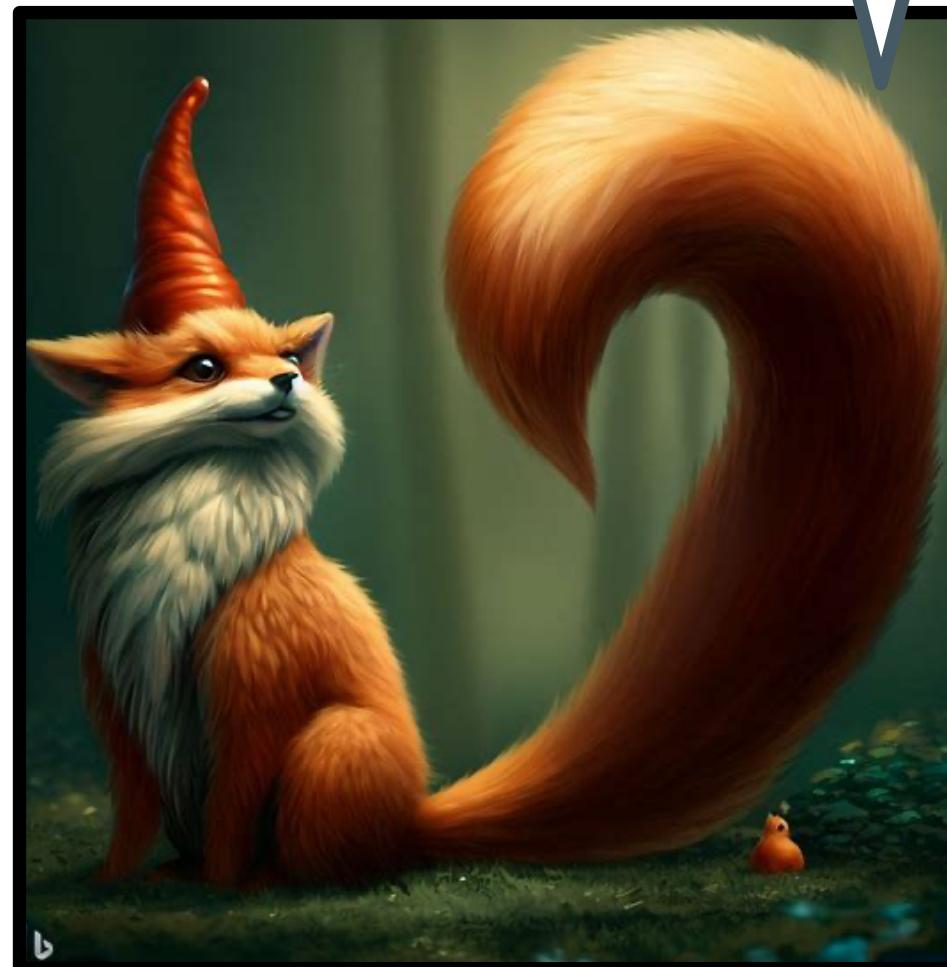
Compliance



[Flash crash, CC0](#)

# Why do we need accurate time?

Minimize tail latencies  
and control congestion



**Performance**



Prevent market abuse



**Compliance**



Max divergence  
from UTC 100µs

[Flash crash, CC0](#)

Prevent replay attacks



**Security**



Accurate  
timestamps  
on requests

[George Washington, CC0](#)

[Martha Washington, CC0](#)



# It's 10:00!



8 to 12?



9:00?



[Candle clock](#)  
CC BY-SA 3.0 DEED

[Ancient Persian water clock](#)  
CC BY-SA 3.0 DEED

[Pendulum Clock, CC0](#)



# It's 10:00!



8 to 12?



9:00?



It's 10:01!



Better precision



[Candle clock](#)  
[CC BY-SA 3.0 DEED](#)

[Ancient Persian water clock](#)  
[CC BY-SA 3.0 DEED](#)

[Pendulum Clock, CC0](#)

# Precise frequency



Quartz crystal

CC0

# Precise frequency

It's (Piezo)electric!

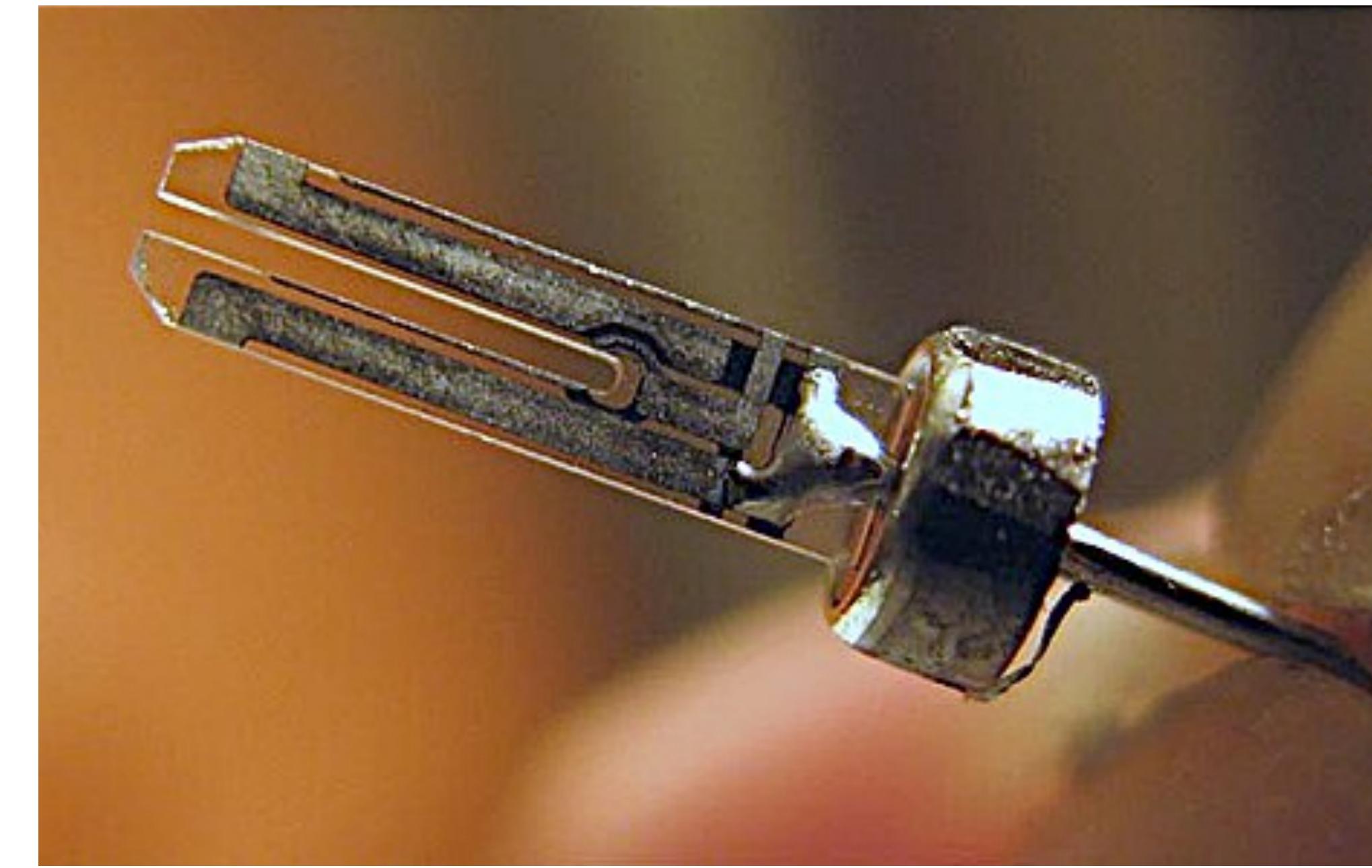


electric field mechanical force



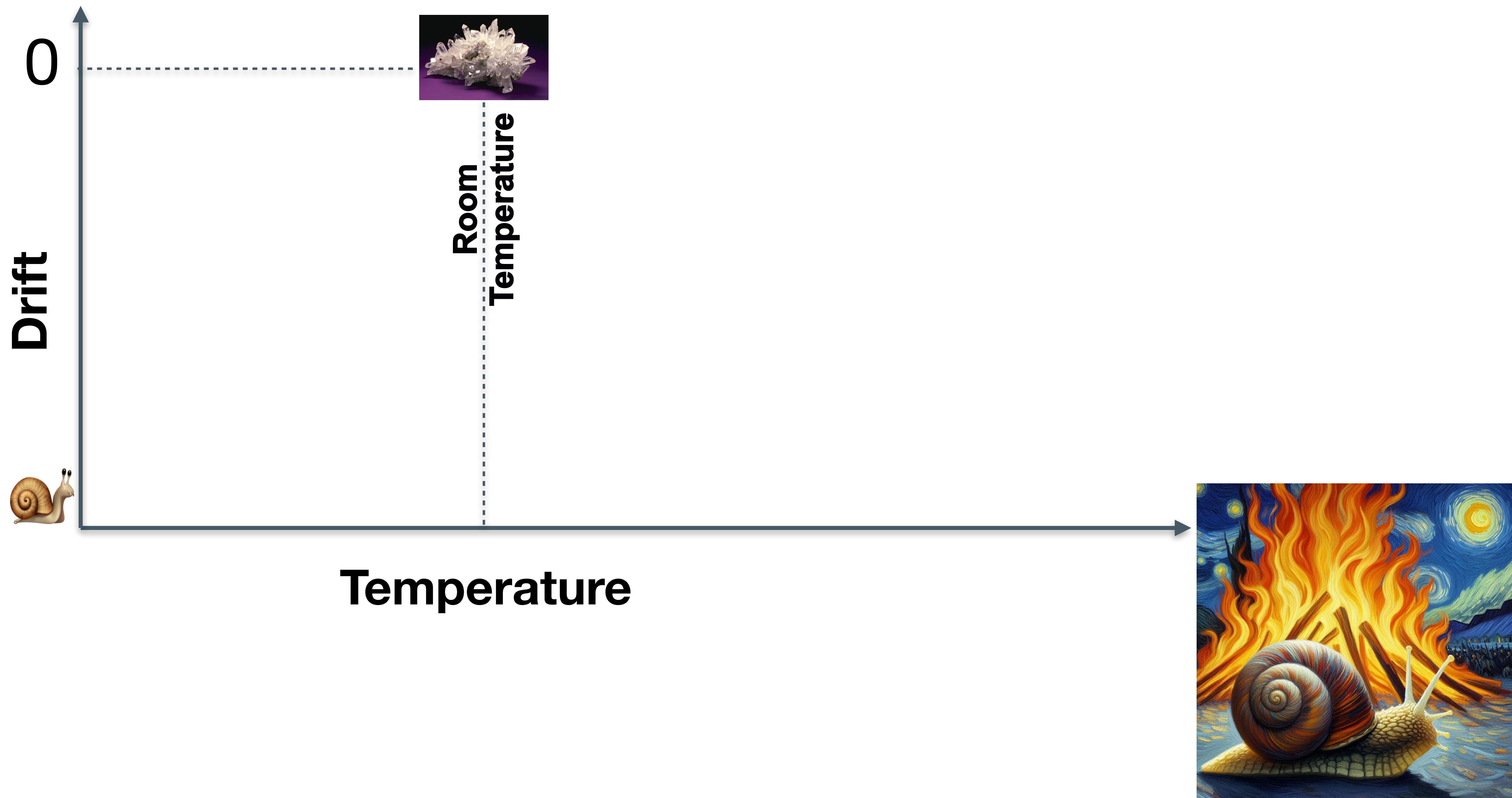
Quartz crystal

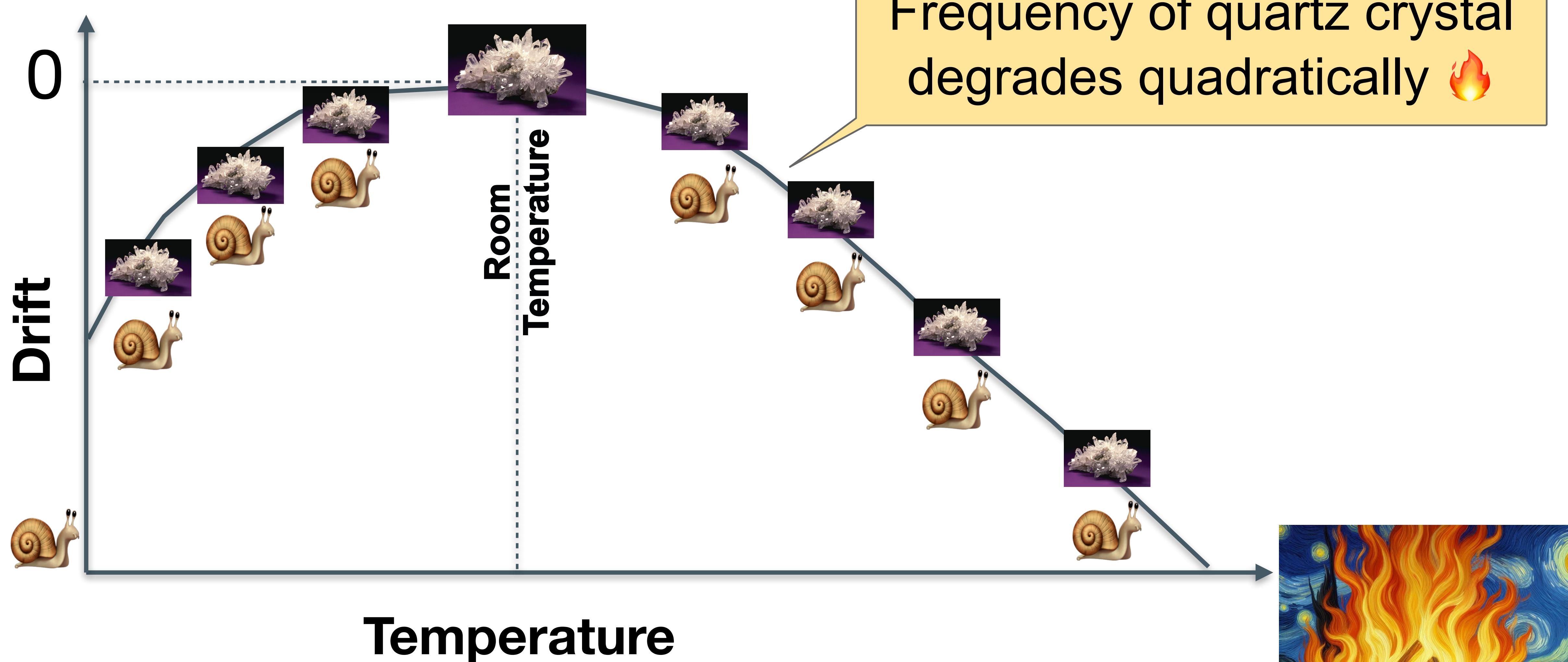
[CC0](#)



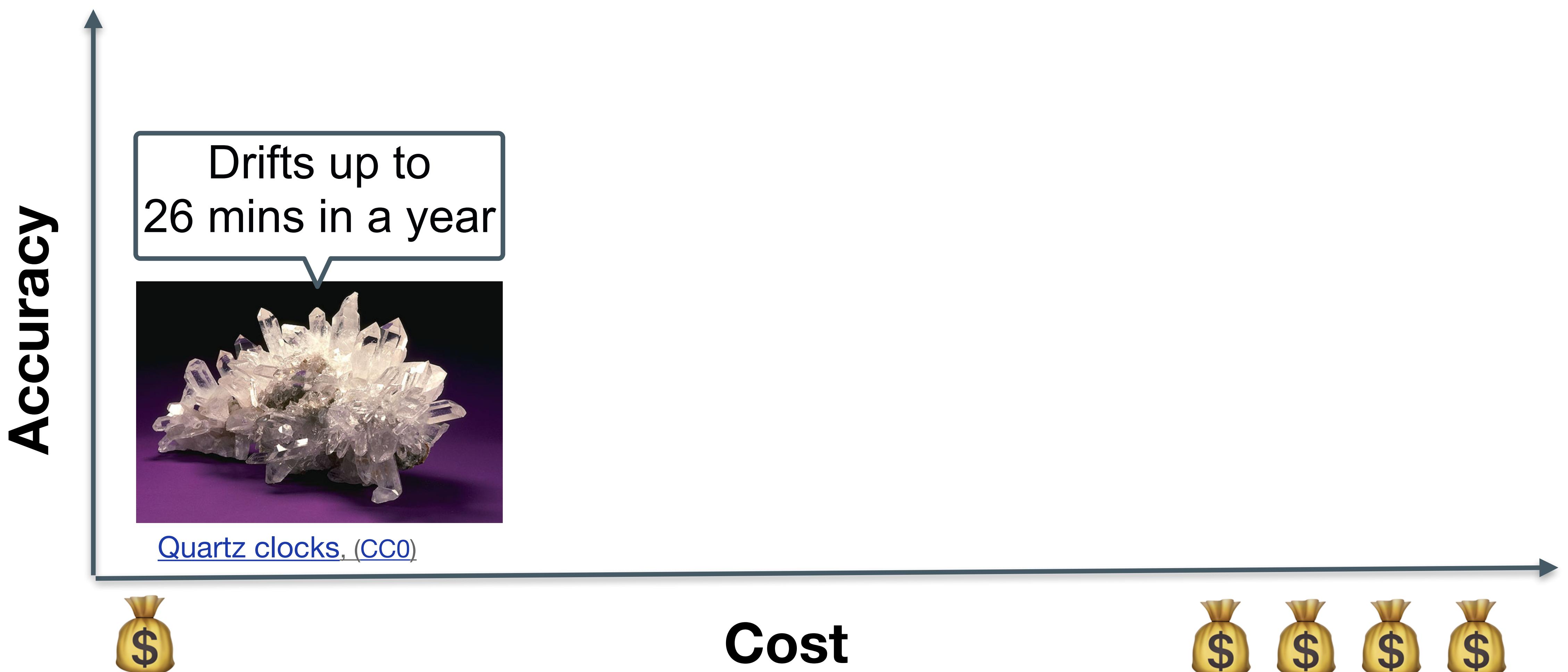
Quartz crystal tuning fork

[CC0](#)

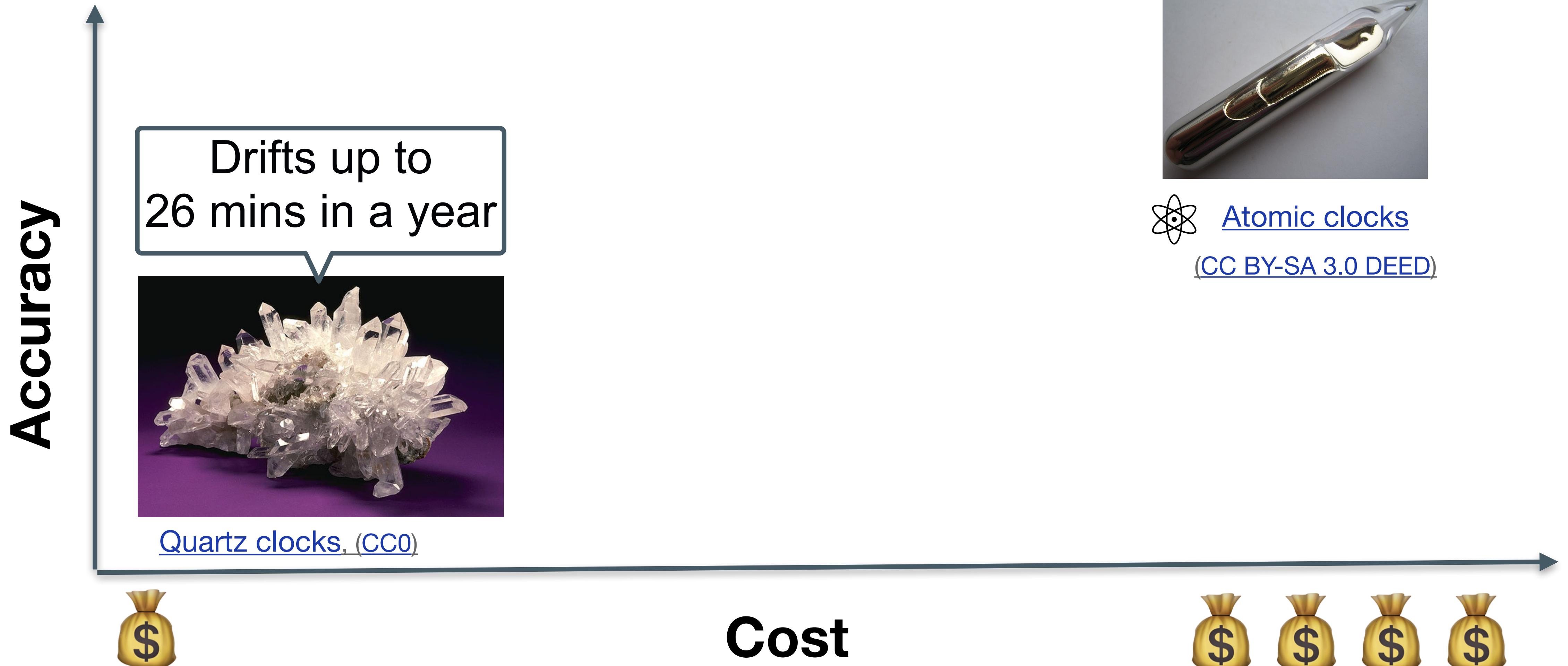




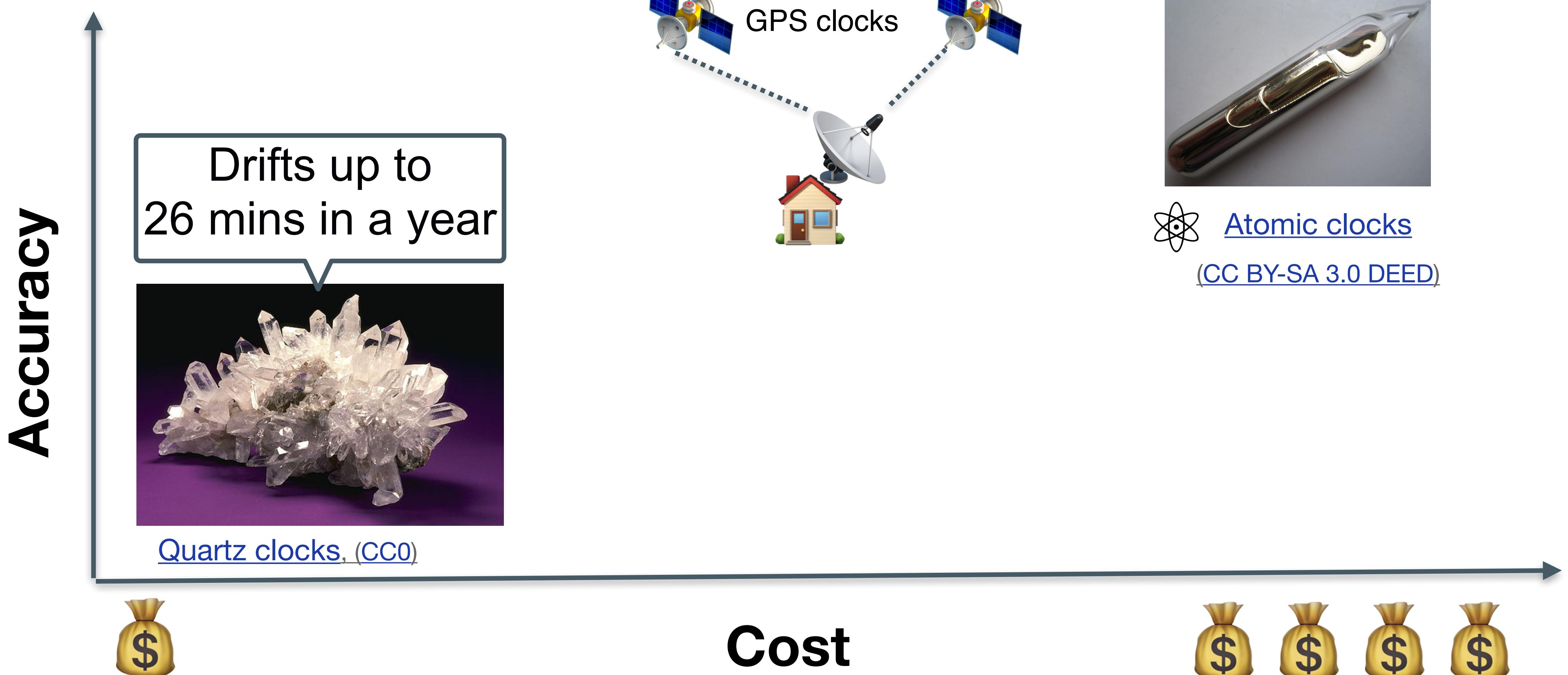
# Time sources



# Time sources



# Time sources



# Bonnie and Clyde



[Bonnie and Clyde, Library of Congress collection](#)  
[\(CC0\)](#)

# Bonnie and Clyde



[Bonnie and Clyde, Library of Congress collection](#)  
[\(CC0\)](#)



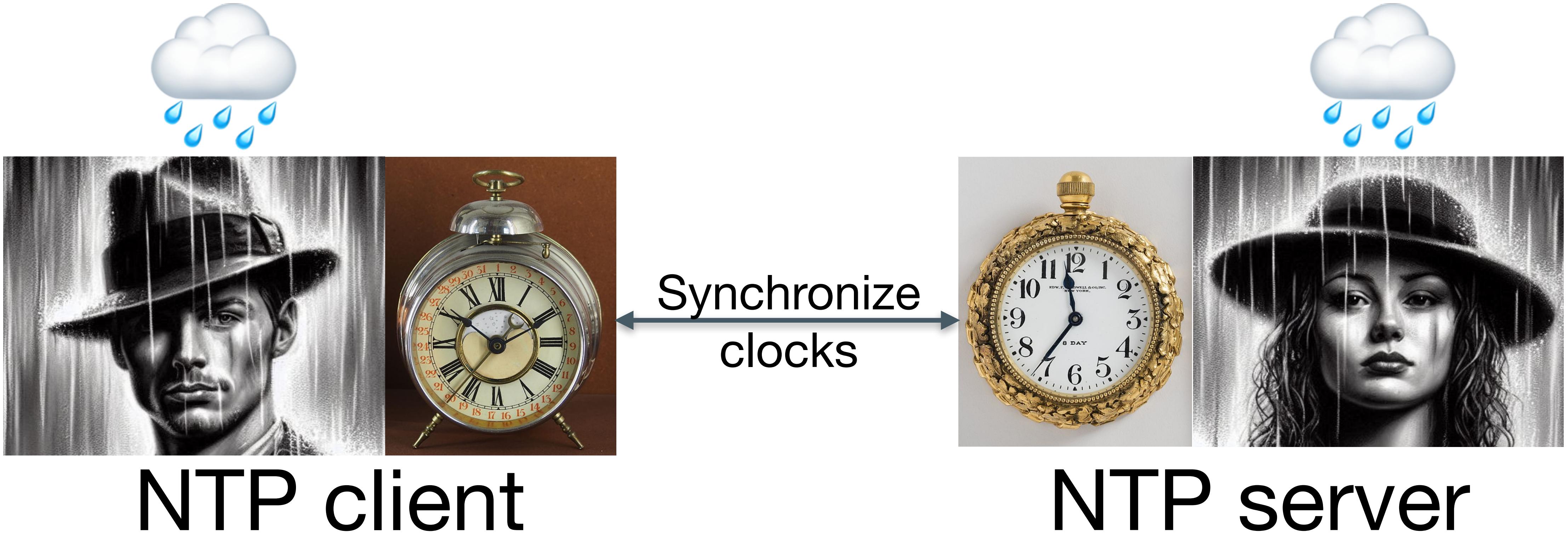
[Bonnie and Clyde](#)  
[\(CC0\)](#)



# Bonnie and Clyde



# Bonnie and Clyde

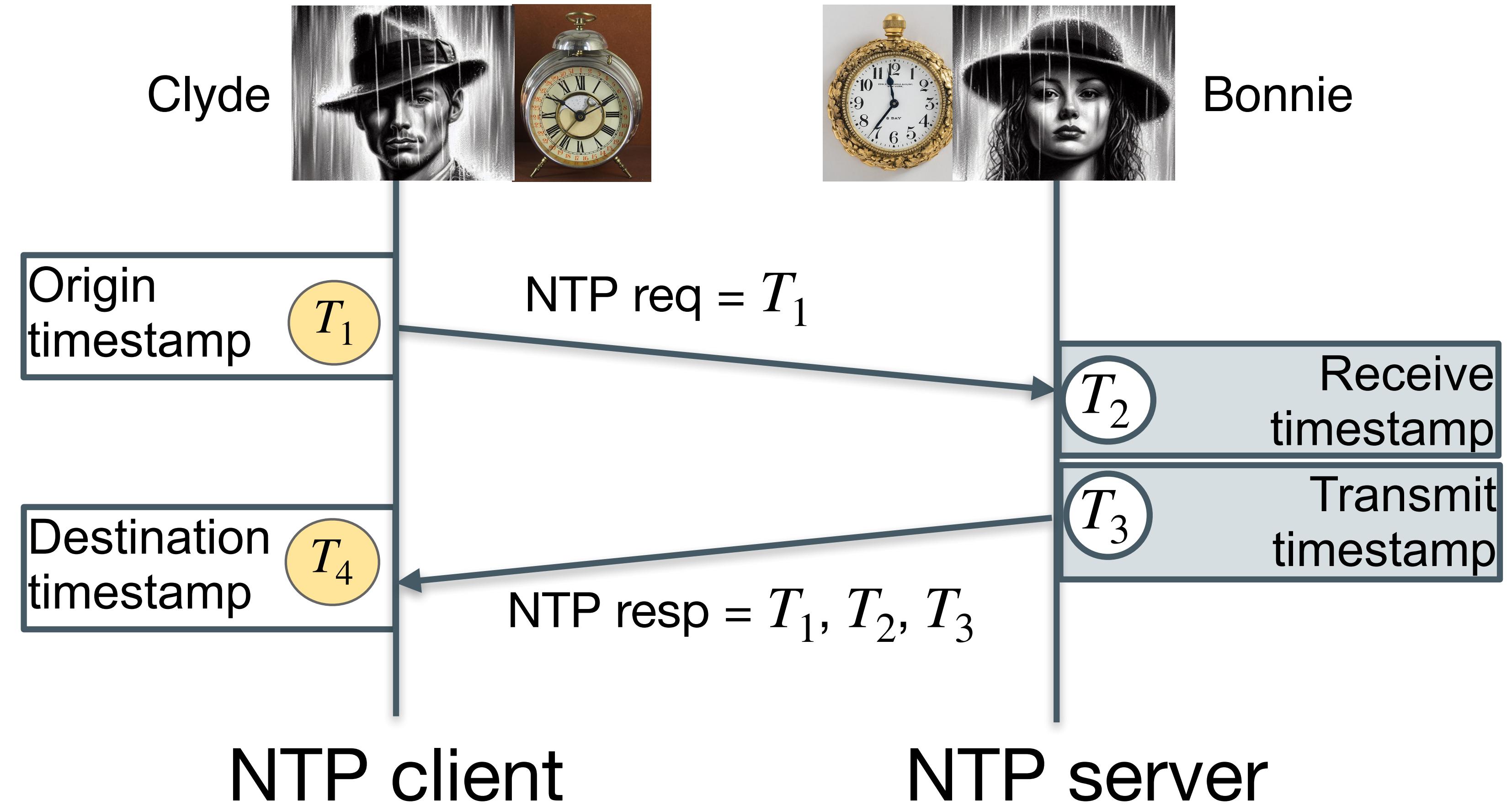


# So Bonnie and Clyde travel in time to use NTP



[DeLorean Time Machine](#) by [JMortonPhoto.com](#) & [OtoGodfrey.com](#) (CC BY-SA 4.0)

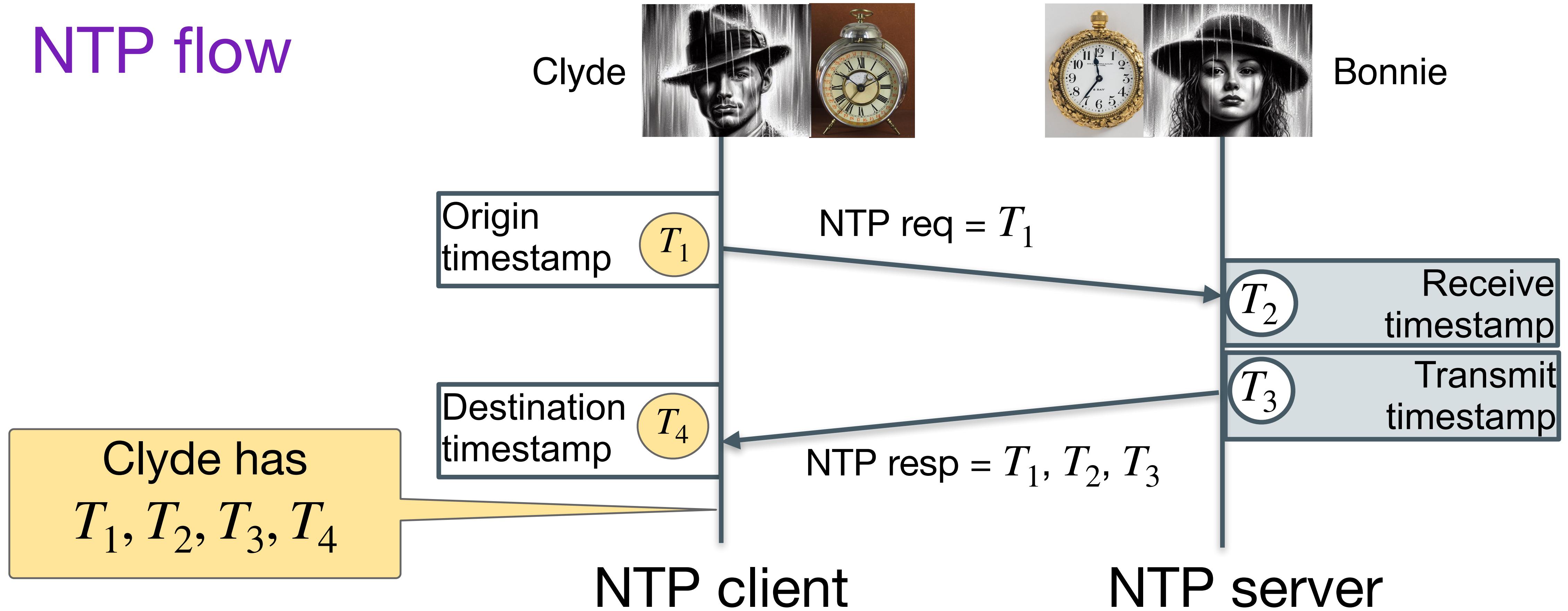
# NTP flow



[1900 desk clock \(CC0\)](#)

[1900 clock \(CC0\)](#)

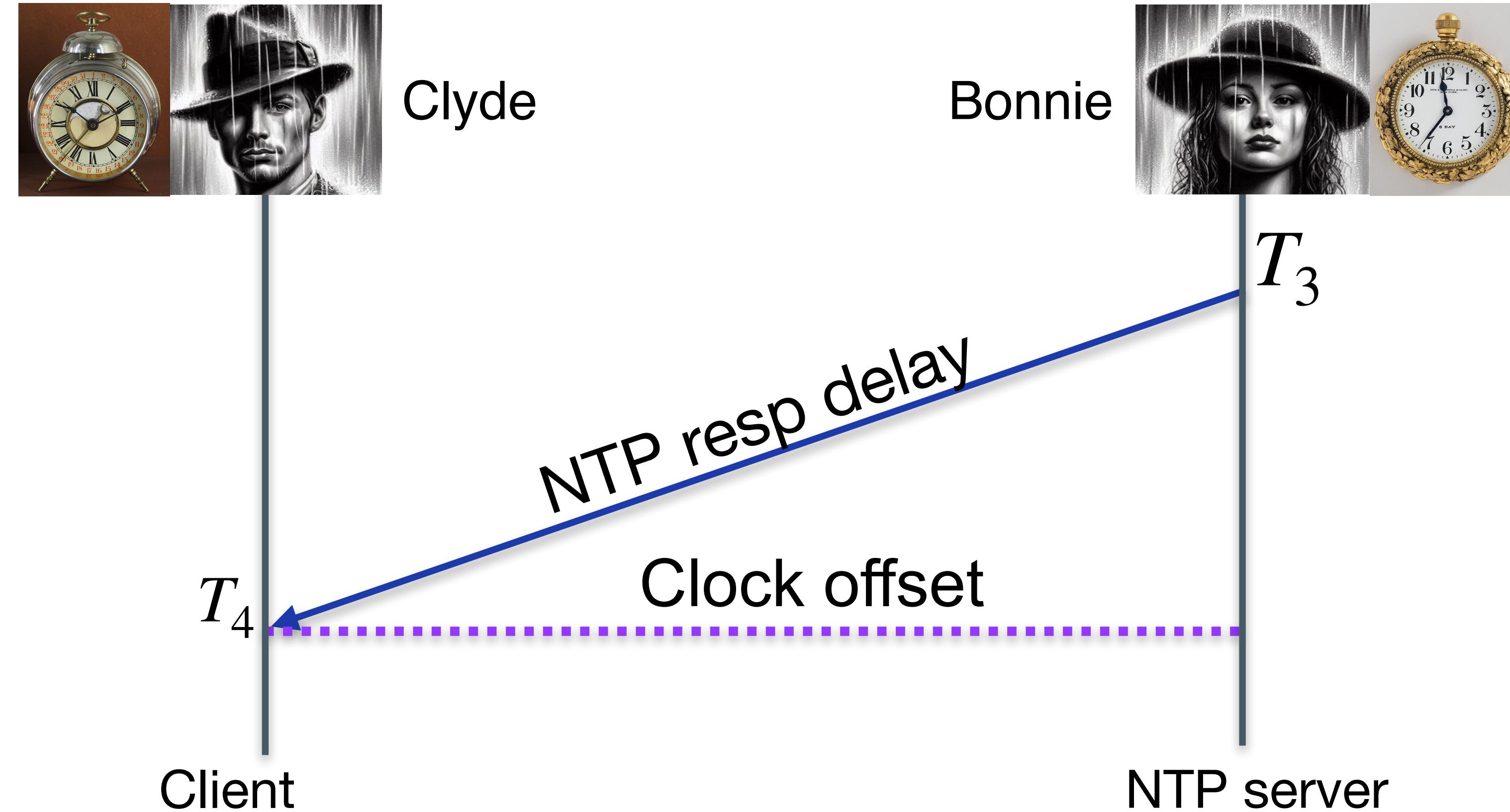
# NTP flow



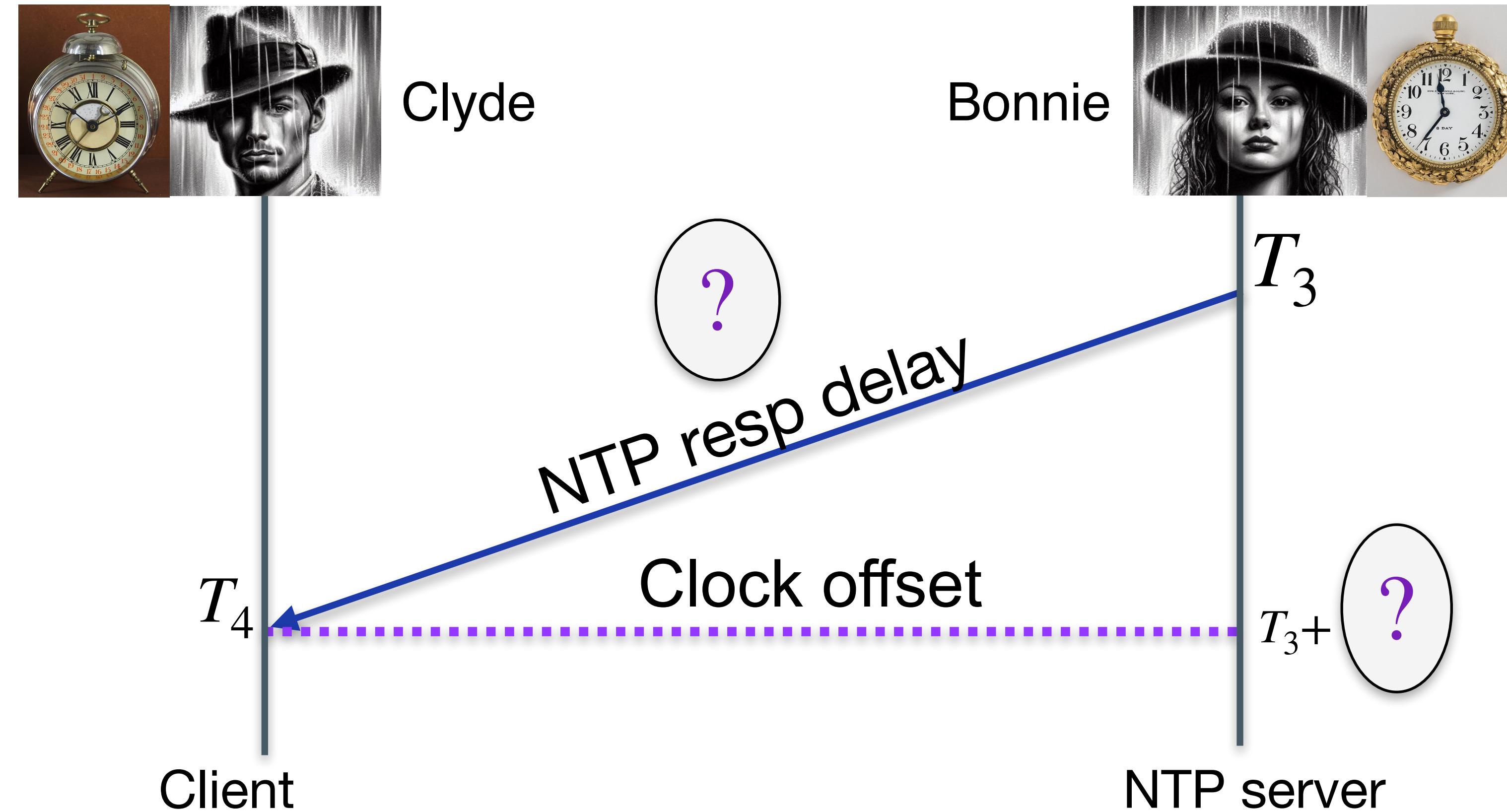
[1900 desk clock \(CC0\)](#)

[1900 clock \(CC0\)](#)

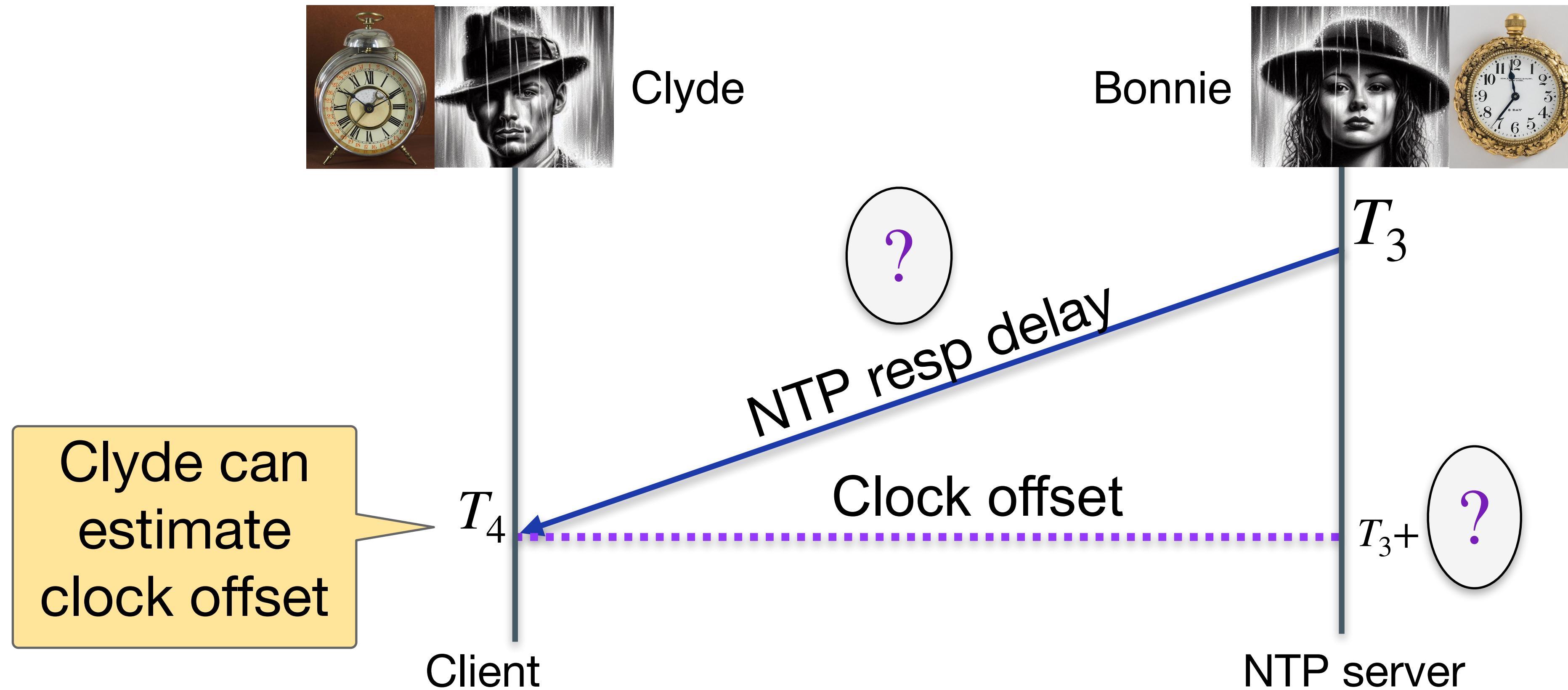
# NTP: estimating clock offset



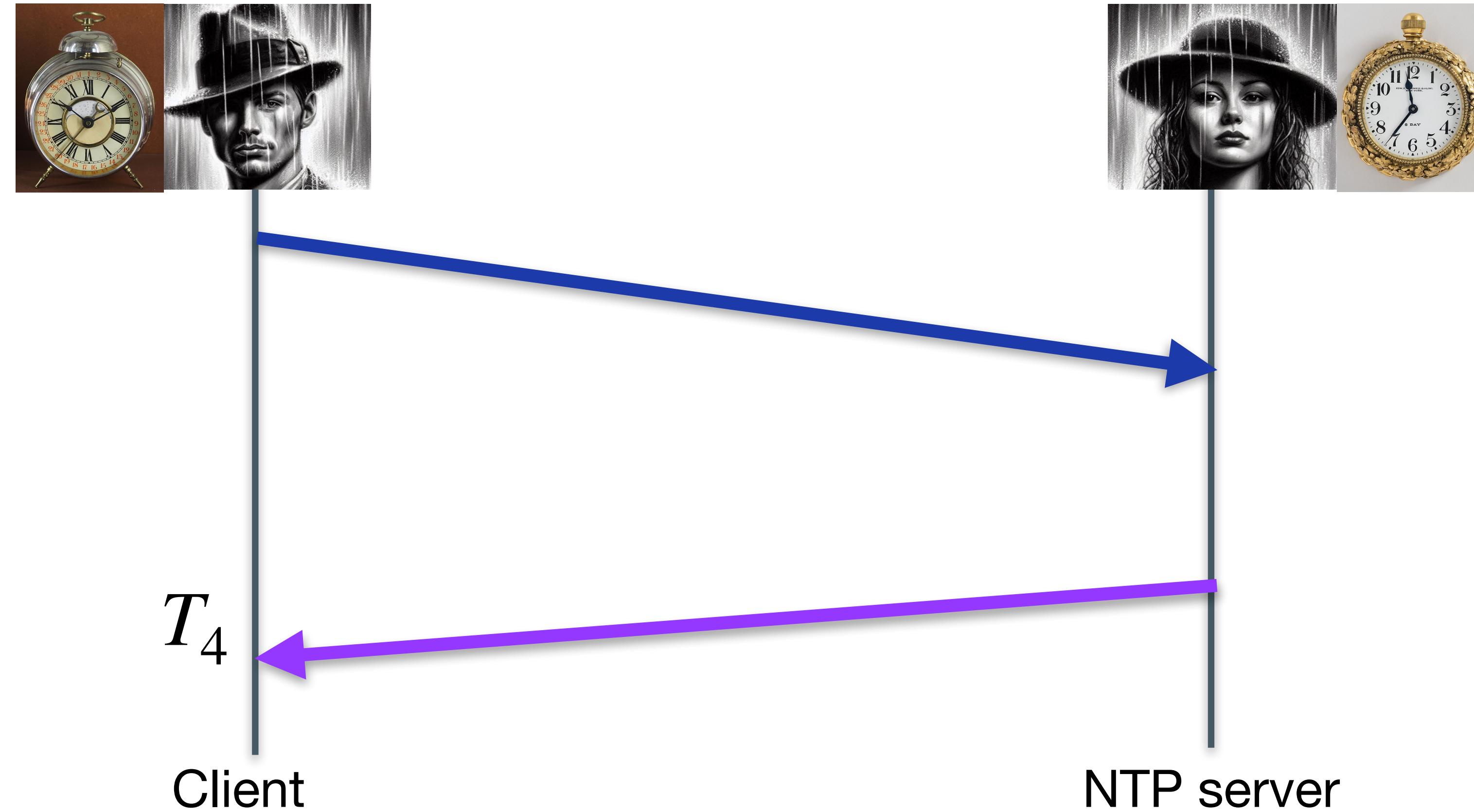
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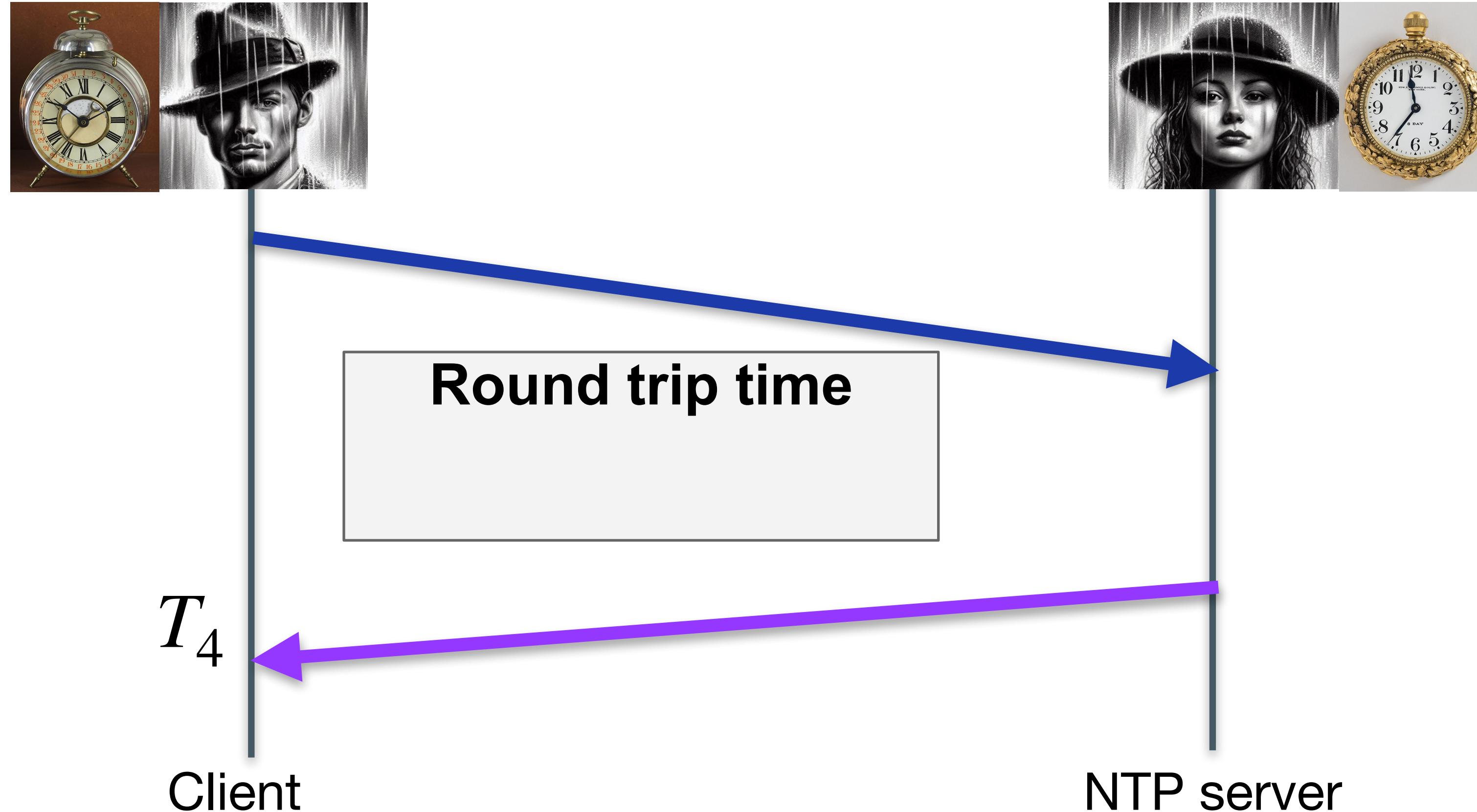
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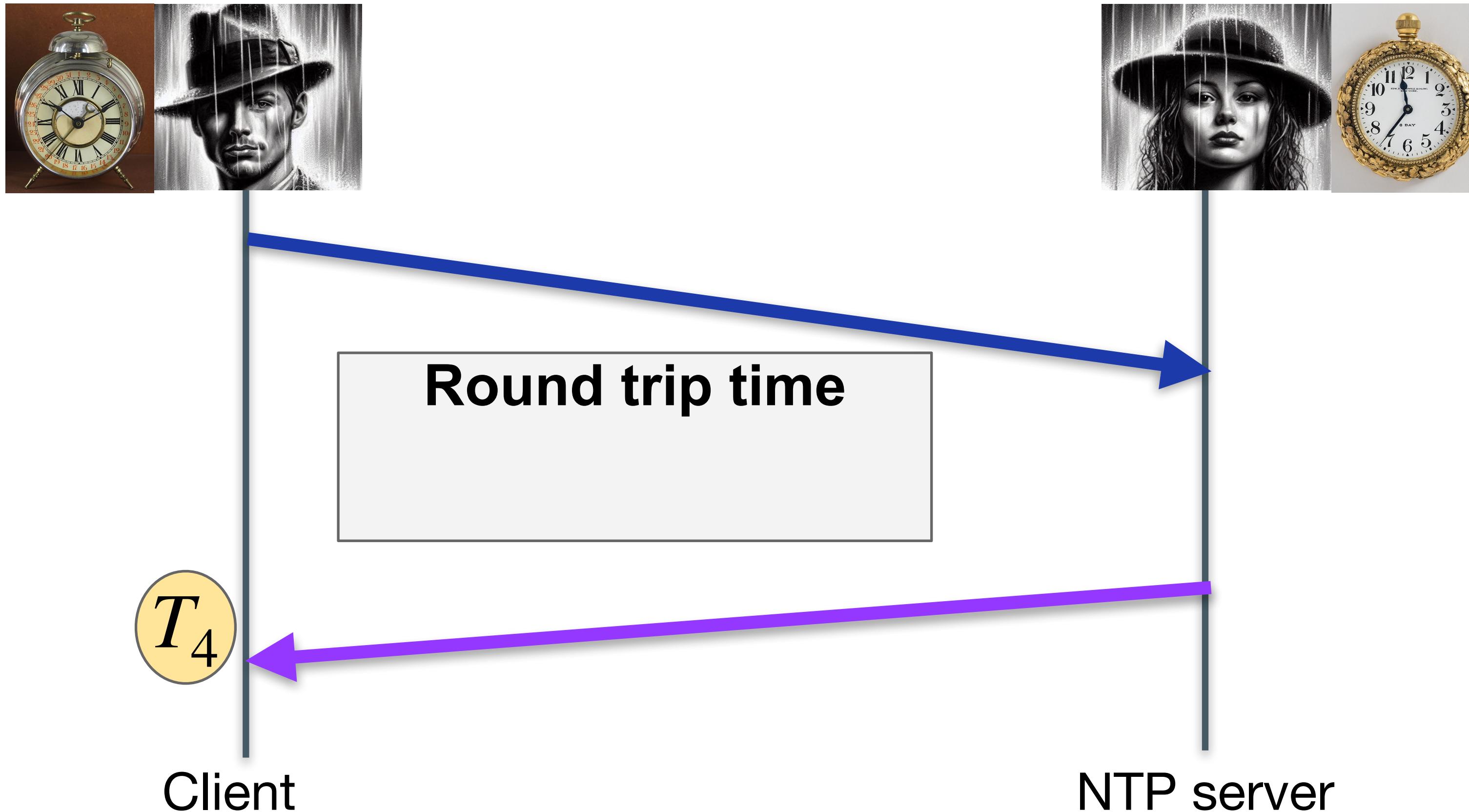
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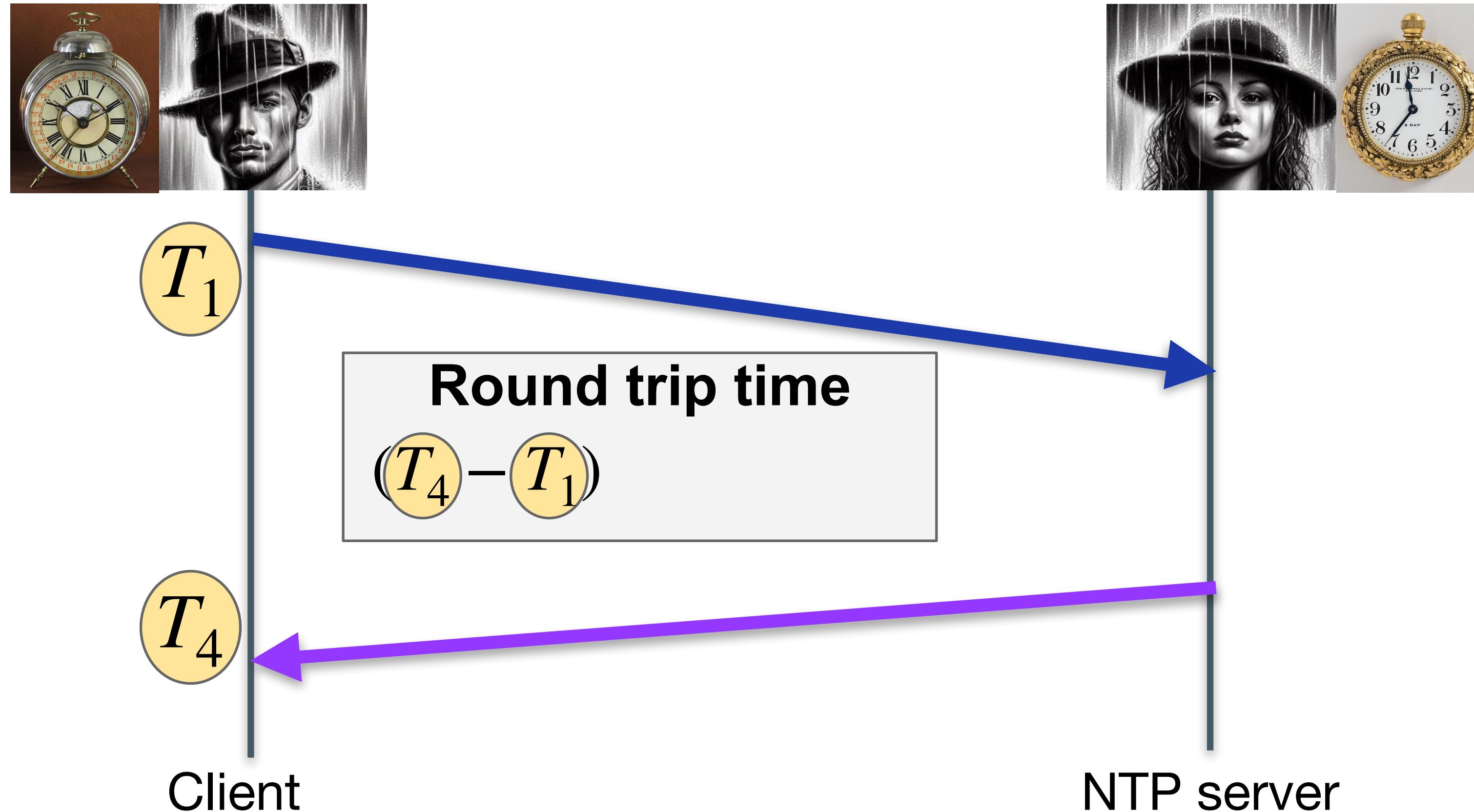
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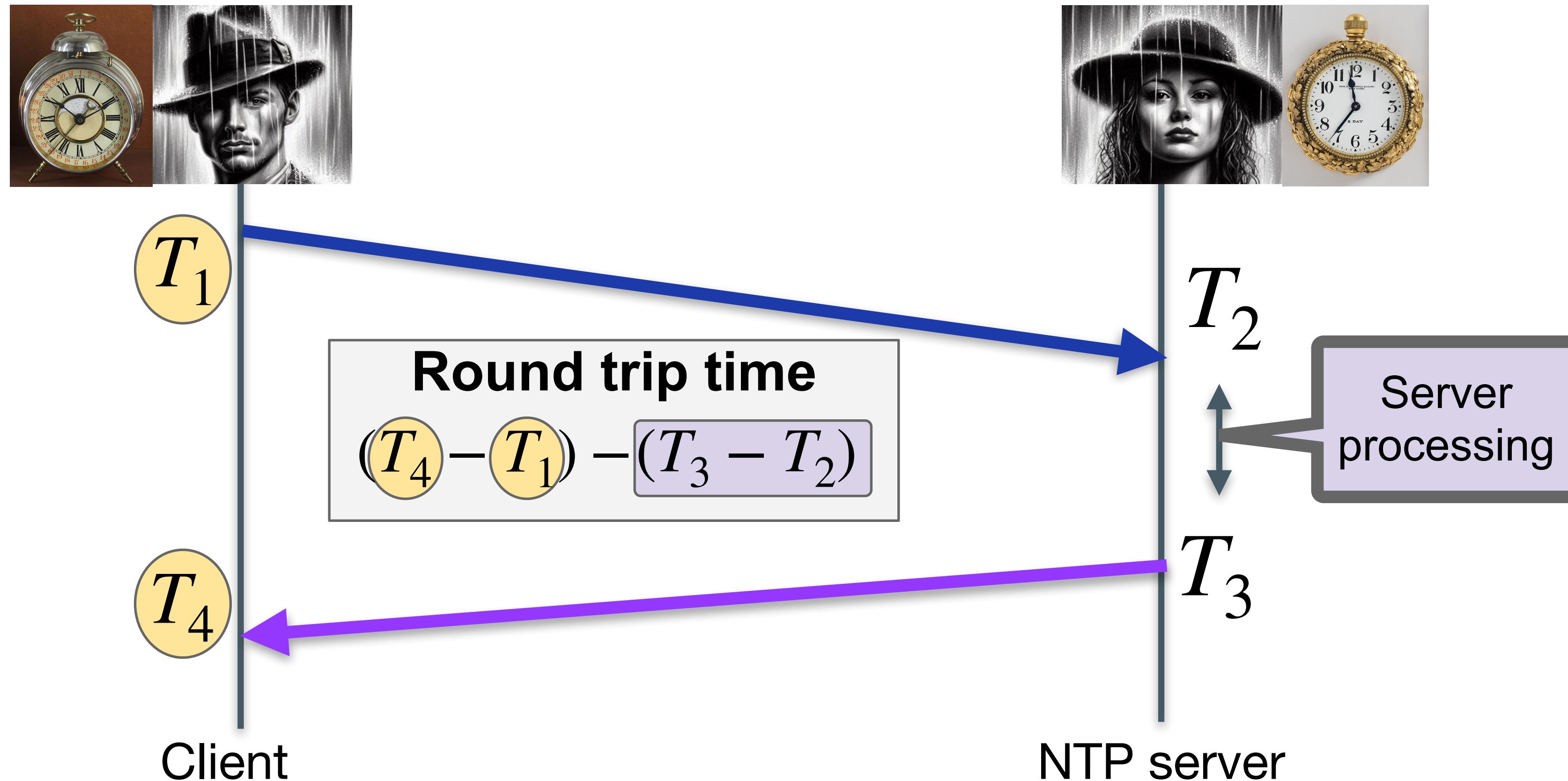
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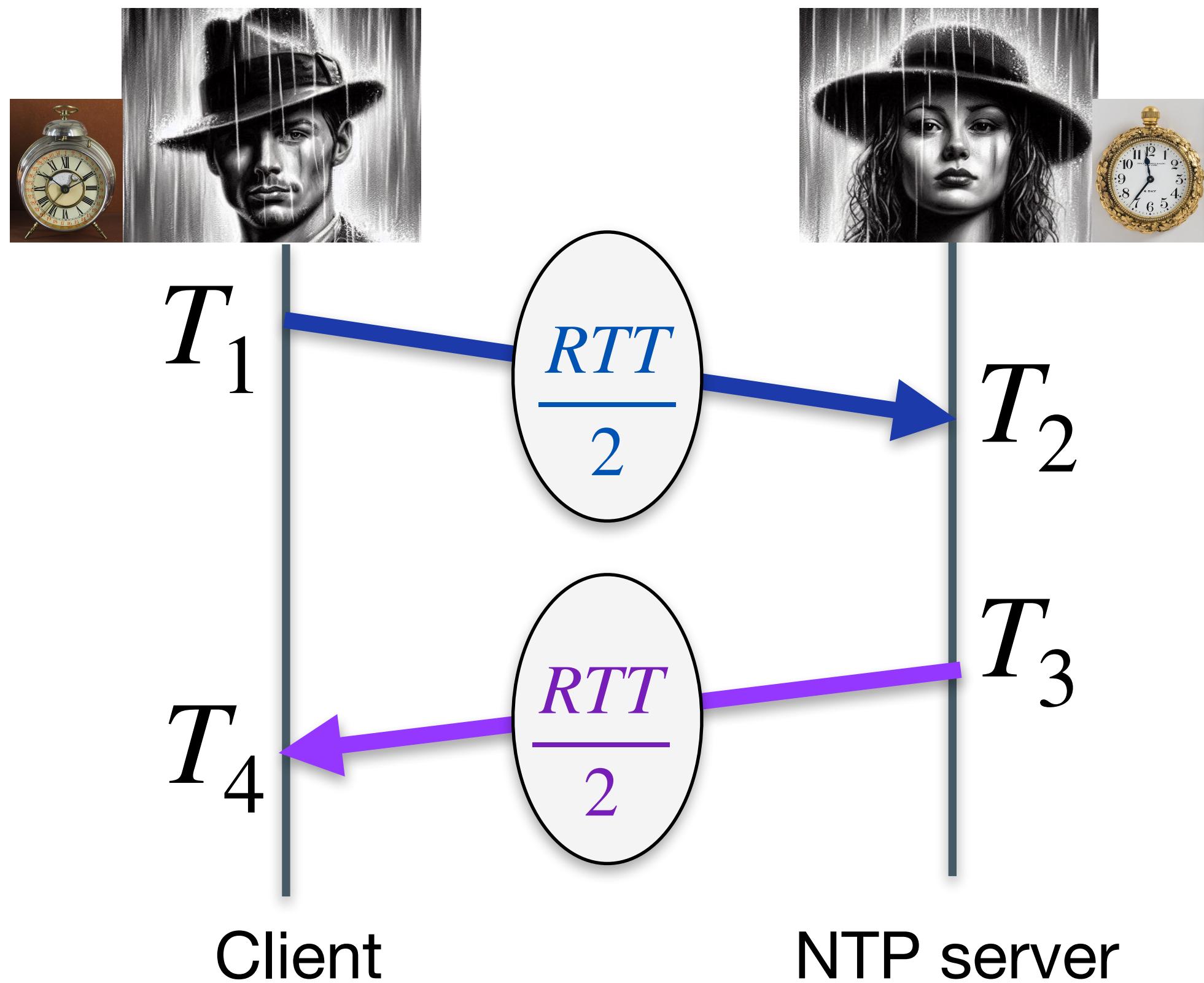
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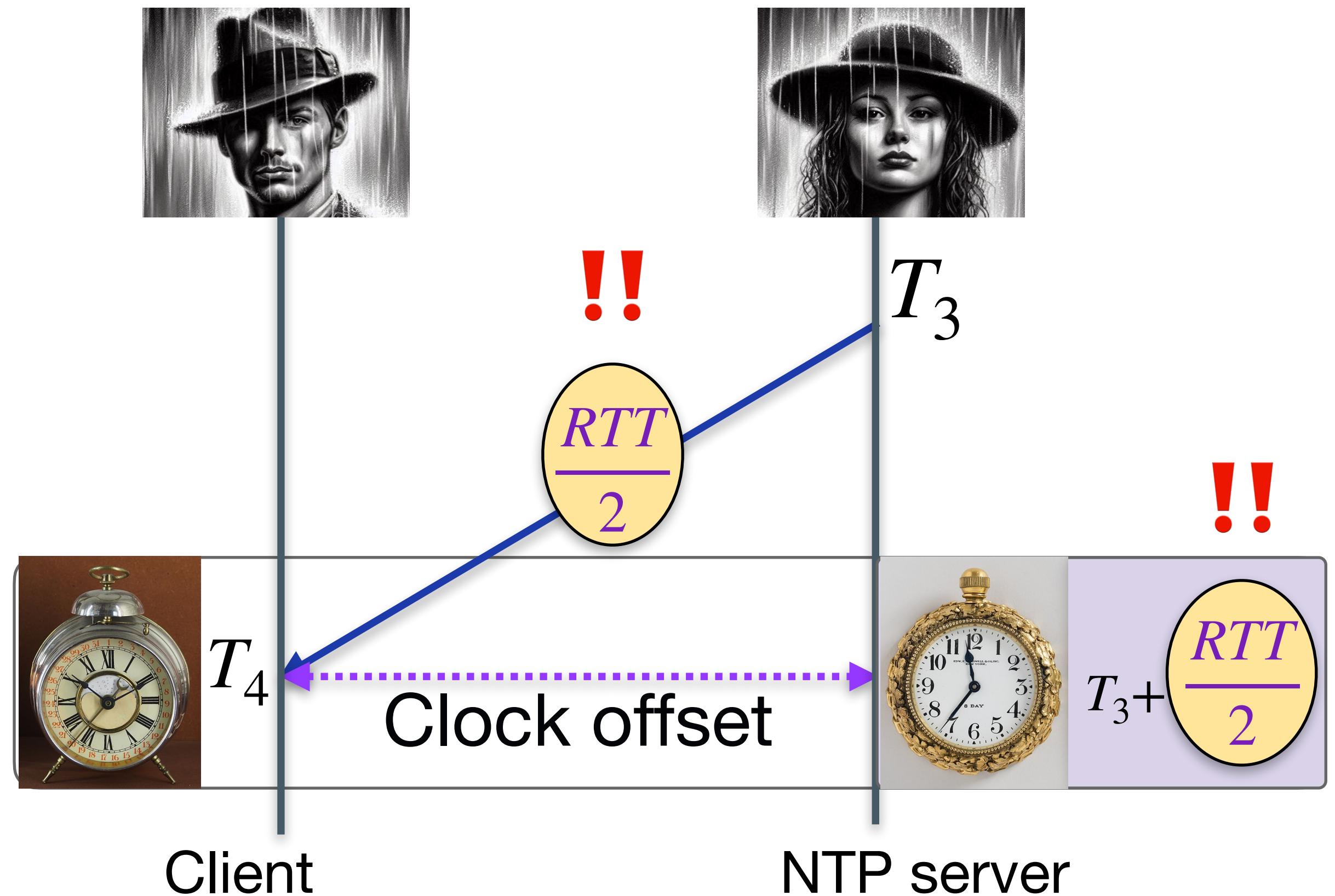
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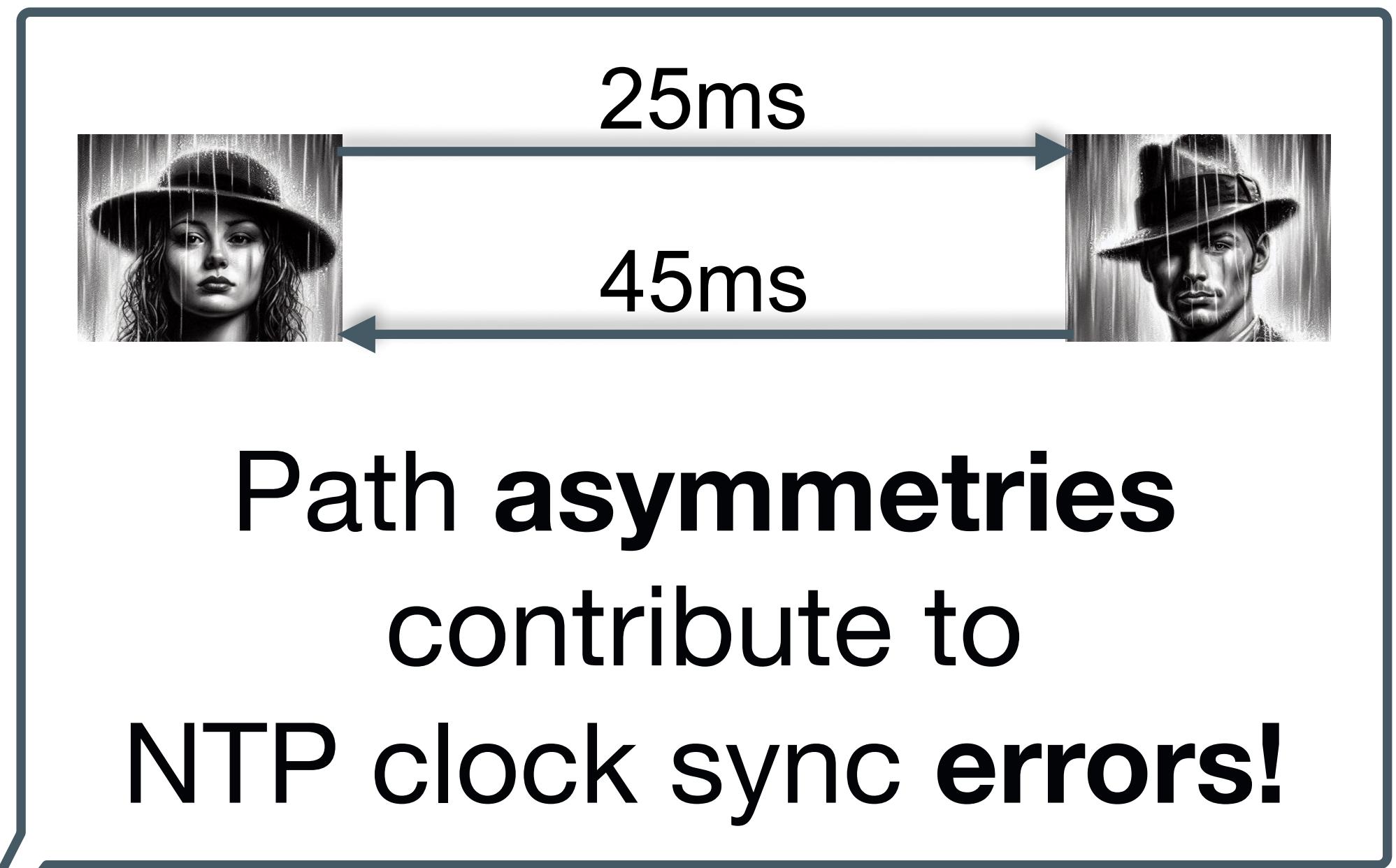
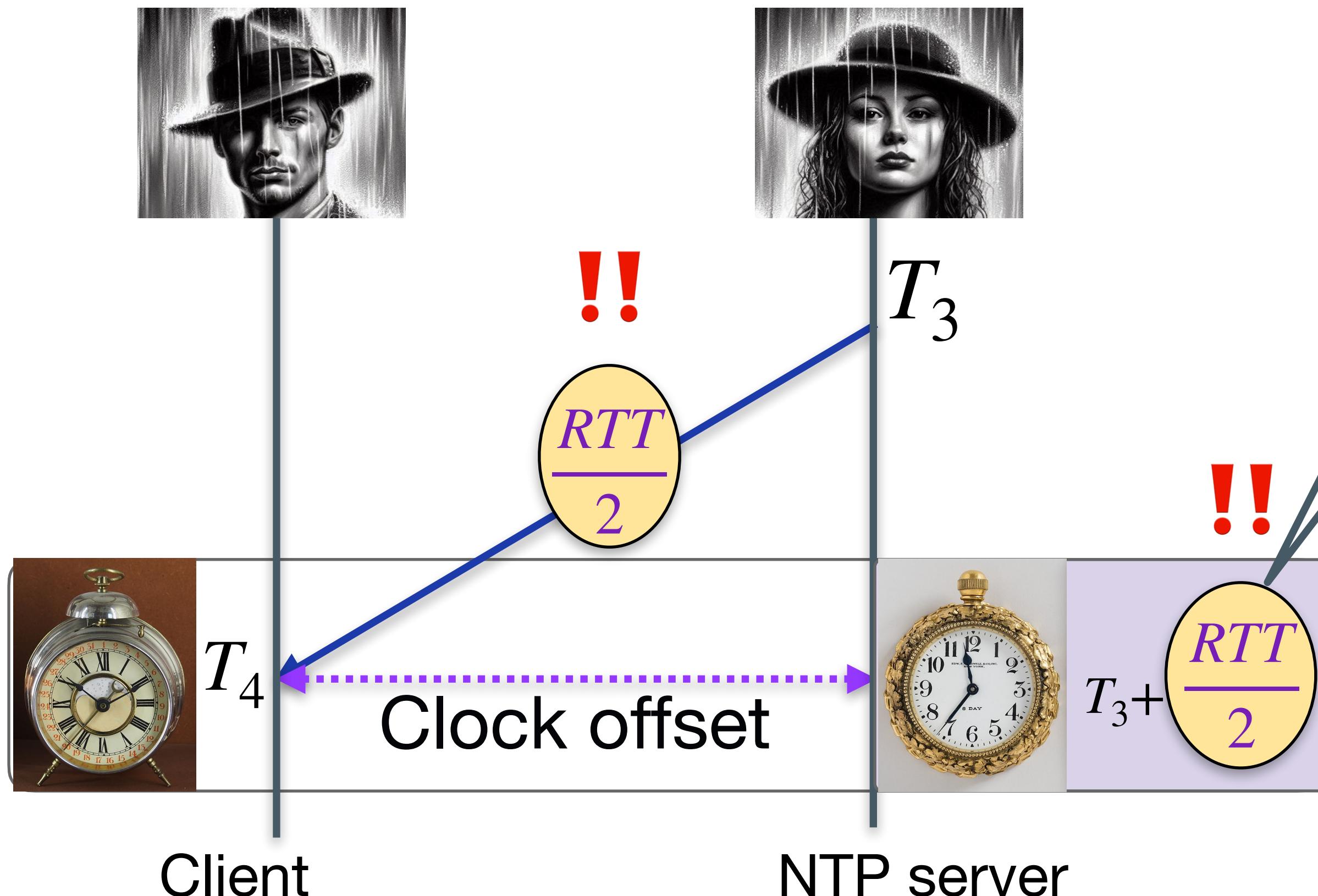
!!

**NTP assumes  
request and response  
delays are equal**

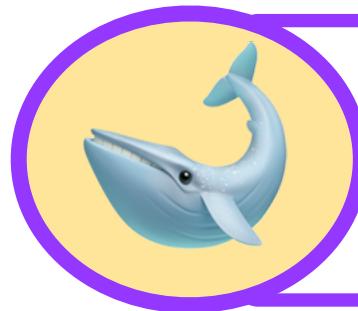
# NTP: estimating clock offset



# NTP: estimating clock offset



# NTP: Disciplining the clock to minimize clock offset $\theta$



Best practice

Slew

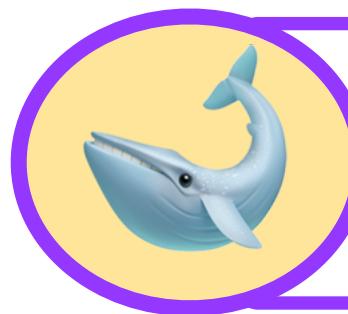


or



$\theta < 125ms$

# NTP: Disciplining the clock to minimize clock offset $\theta$



Best practice

Slew

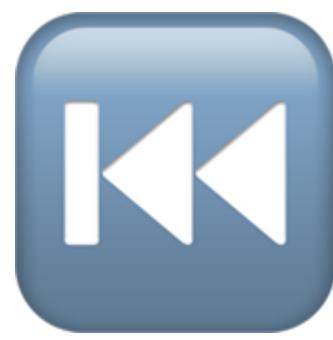


or

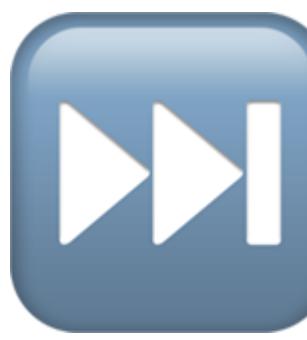


$\theta < 125ms$

Step

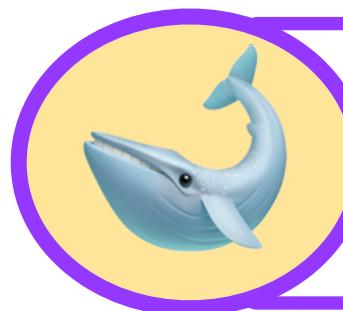


or



$125ms < \theta < 1000s$

# NTP: Disciplining the clock to minimize clock offset $\theta$



Best practice

Slew

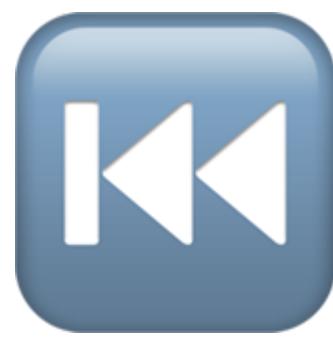


or

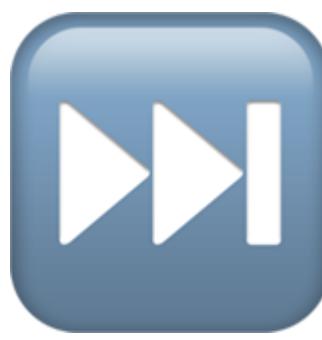


$\theta < 125ms$

Step



or



$125ms < \theta < 1000s$

Alert



$\theta \geq 1000s$

# Times are hard during the Great Depression

## The Shamrock Shakedown

August 29, 2024

### Outlaws Turn to Algorithms!



AND CLYDRES

head of Henry Franklin  
many different cities

the day after the  
banking crisis could be seen  
out on the streets of New York  
as many as one thousand  
robbers and bandits got together  
and planned their next move.

"We're going to do all we  
can to help our country," said a man  
in a suit and hat. "We're going to  
make sure that every man  
has a job and every woman  
has a home."

He was right. In just a few days,  
the economy had improved significantly.  
Unemployment rates were down  
from 25% to 10%, and the stock market  
had recovered most of its losses.

But there was still one problem:  
the Great Depression.

C. DO NEWSPAPER  
a Revolution in the Banks

one reason for the decline in  
unemployment rates was that many  
people had lost their jobs.

But there was another reason:  
the Great Depression.

MALEST  
WALL ST

Today's Headline  
Finance

"The stock market has  
been declining for the  
past several months, and  
we are worried about what  
will happen if it continues  
to fall," said a spokesman  
for the Federal Reserve.

He was right. In just a few days,  
the stock market had dropped by  
over 20%.

But there was still one problem:  
the Great Depression.

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# Times are hard during the Great Depression

# The Shamrock Shakedown

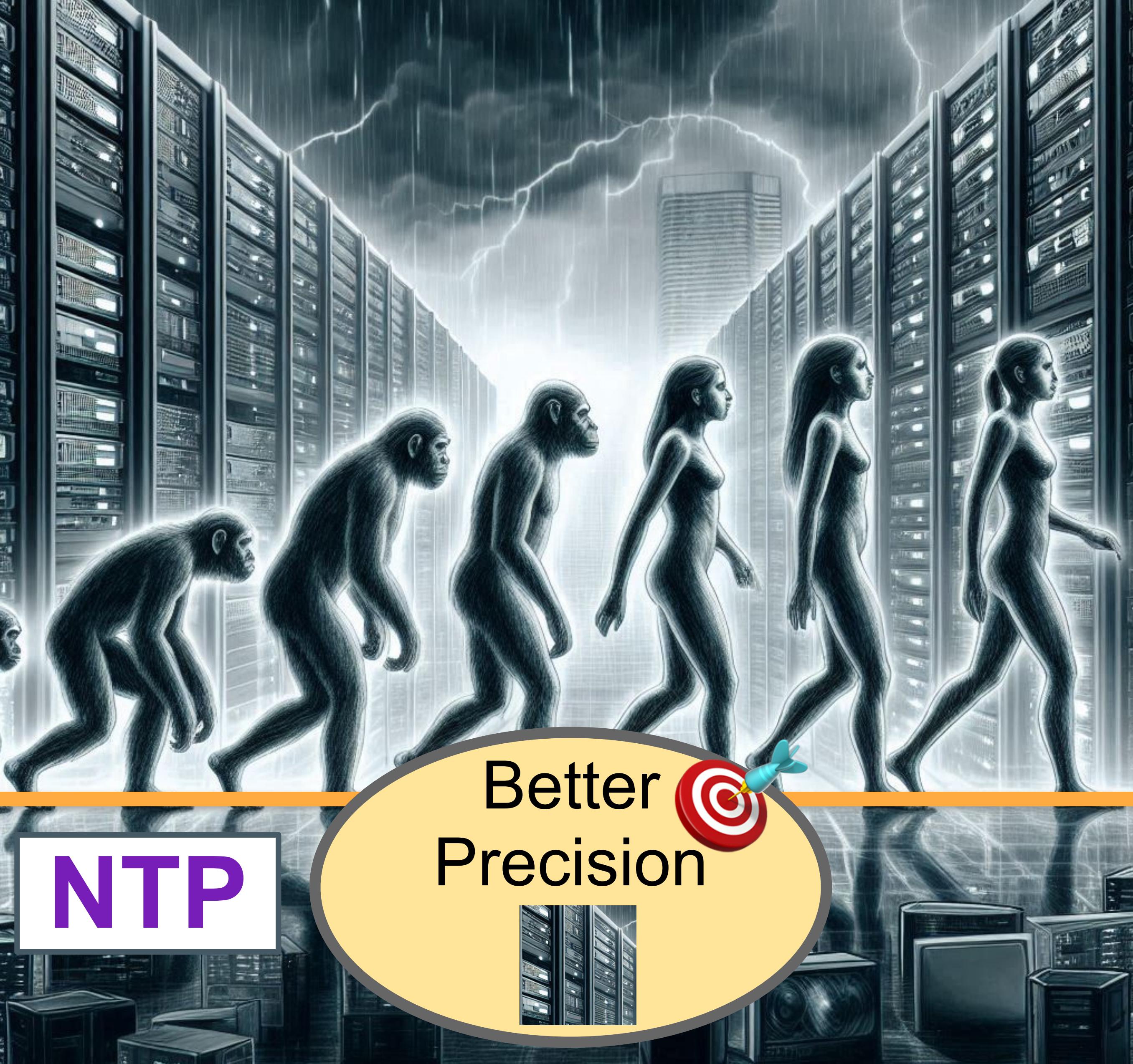
August 29, 2024

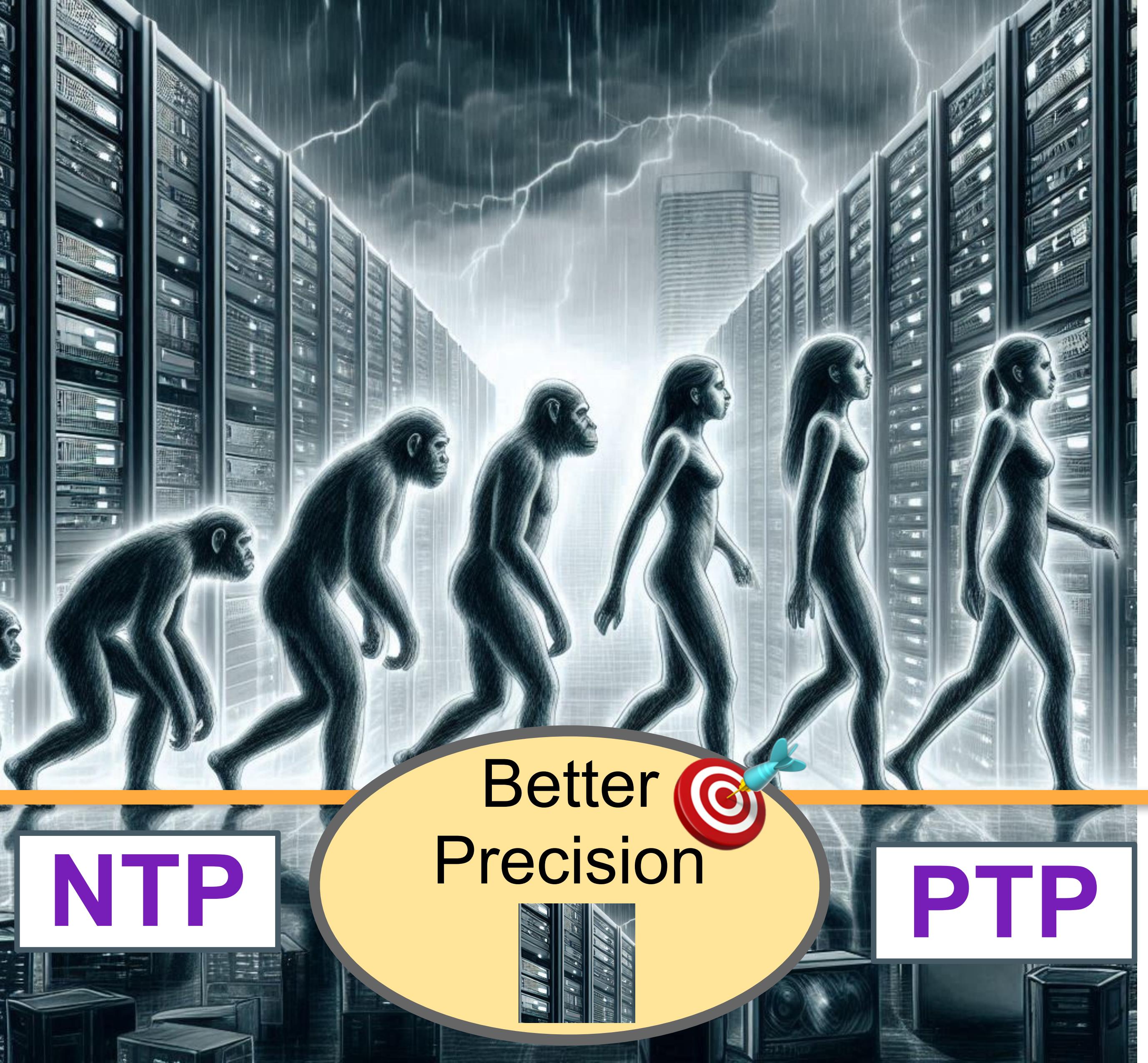
# Outlaws Turn to Algorithms!



# Bonnie and Clyde Launch High-Stakes Hedge Fund

PTP: IEEE 1588 ⚡





## PTP: IEEE 1588 ⚡

Relies on electrical engineering concepts



PTP ⚡

PTP ⚡

For fine grained accuracy

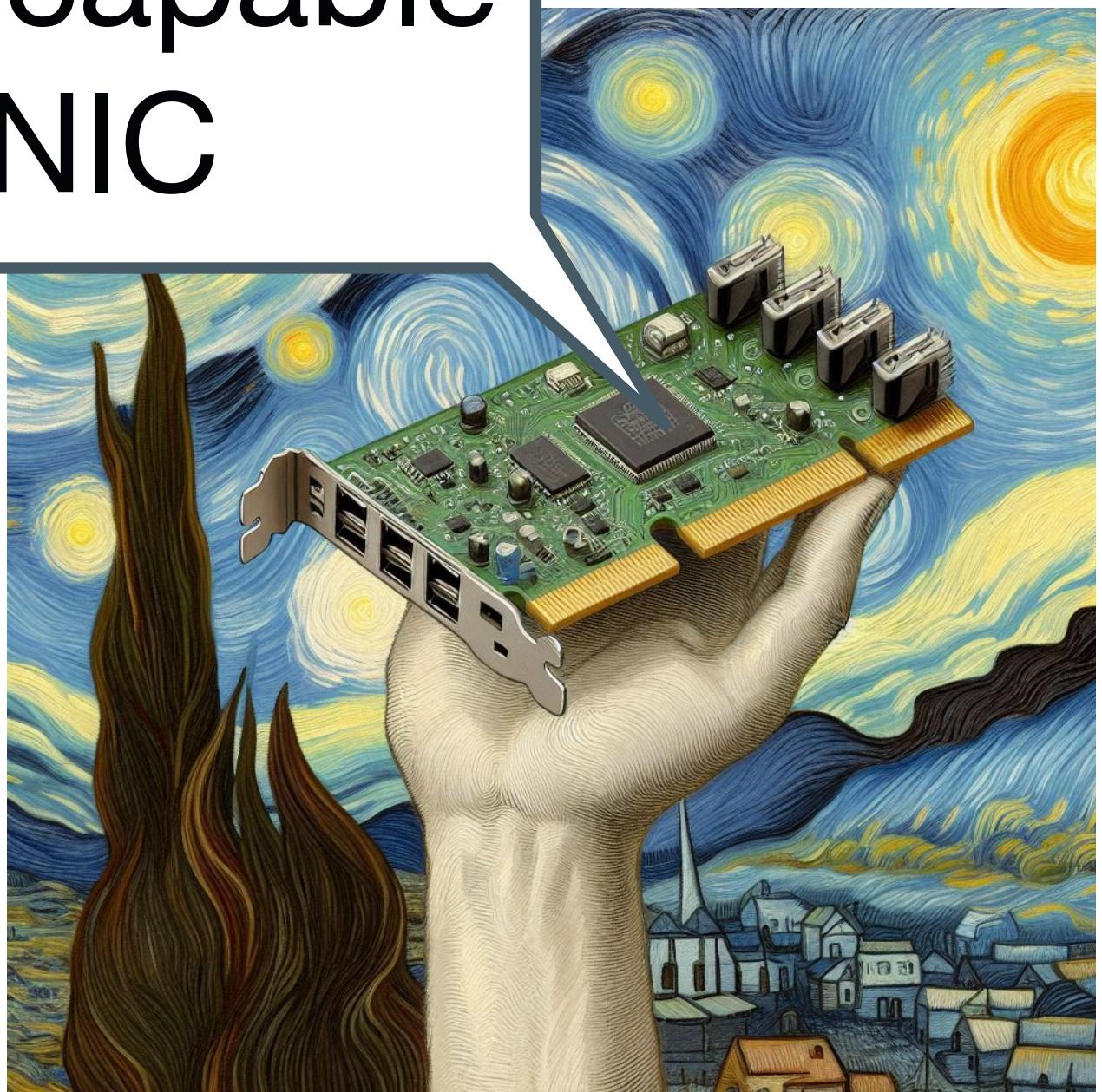


PTP ⚡

For fine grained accuracy



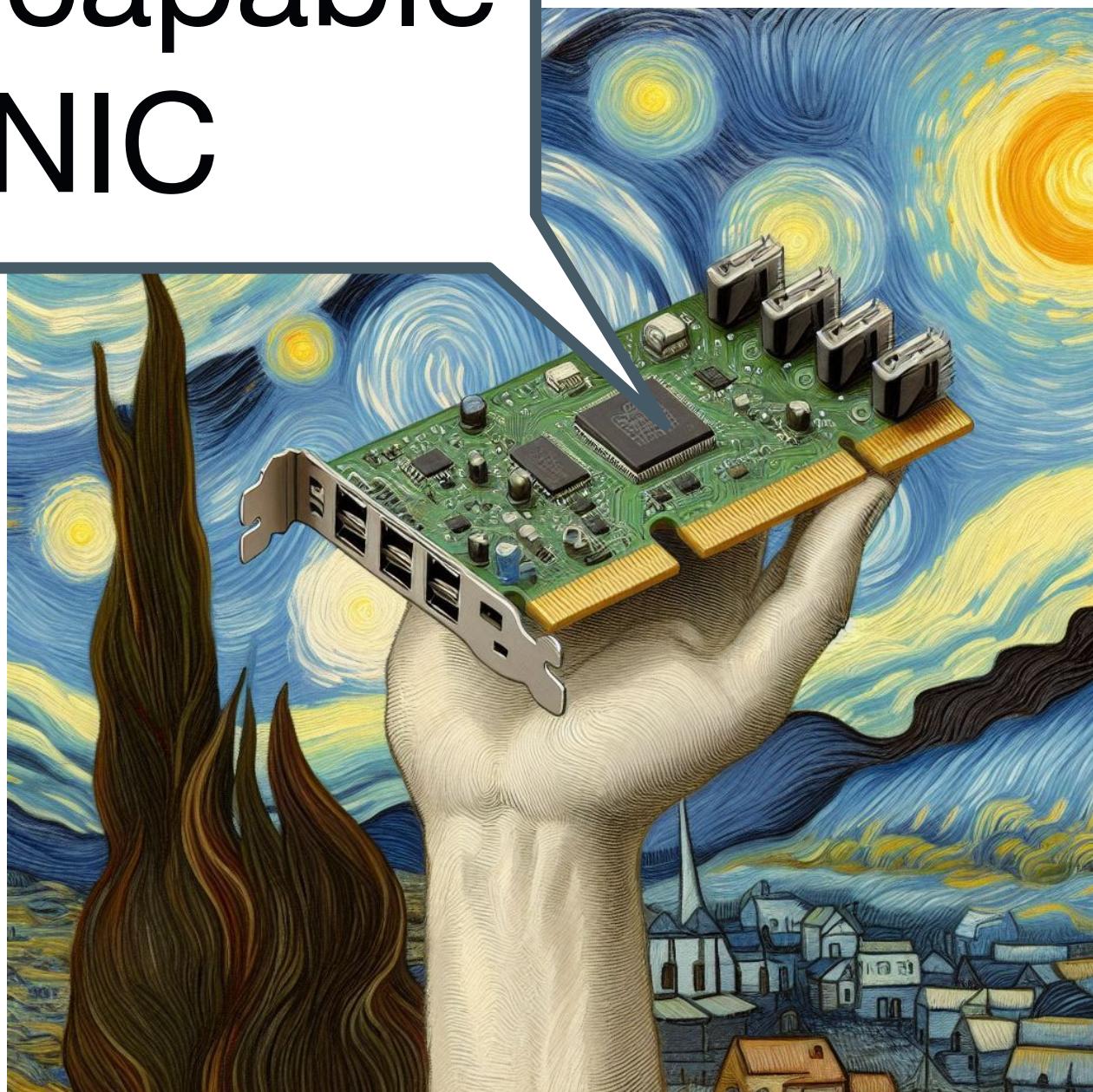
PTP capable  
NIC



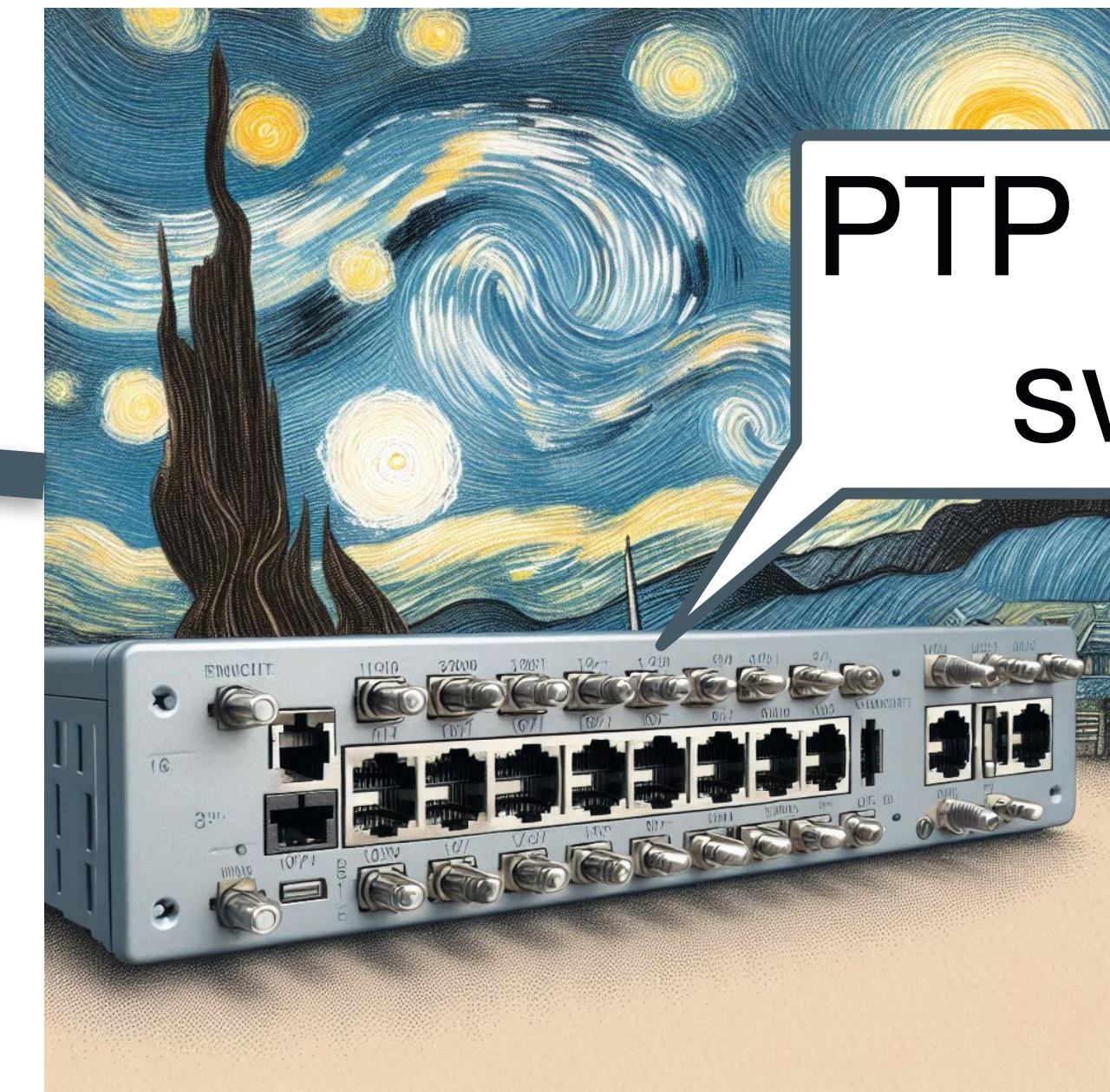
PTP ⚡

For fine grained accuracy 🕸️💸

PTP capable  
NIC



PTP capable  
switch



October 28, 2024

# The Shamrock Shakedown

October 28, 2024

## B&C Ventures' NextGen Heist expands to the cloud!

ND CLYDRES

news of today's financial  
events from around the world.

Our team has been hard at work on this project, and we're excited to share our findings with you. This is a major milestone in our mission to bring transparency and accountability to the world of finance.

As you can see, this project is not just about a new website or interface. It's about creating a more transparent and accountable system for everyone involved in the financial industry.

We believe that by making the financial system more transparent, we can help to prevent corruption and ensure that everyone involved in the industry is held accountable for their actions.

This is just the beginning of what we have planned for the future. We are committed to continuing to improve and expand our services, and we invite you to join us on this journey towards a more transparent and accountable financial system.

CLOUD NEWSPAPER  
A Revolution in Financial News

Cloud News is revolutionizing the way people consume financial news. Our platform allows users to access breaking news, analysis, and commentary from a variety of sources, all in one place. Our mission is to make financial news accessible and easy to understand for everyone, regardless of their background or expertise.



MAEST  
WALL ST

Today's Stock Market  
Trends and Analysis

Market Watch  
Analyze the latest market trends and predictions from our team of experts.

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Analyze the latest market trends and predictions from our team of experts.

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Analyze the latest market trends and predictions from our team of experts.

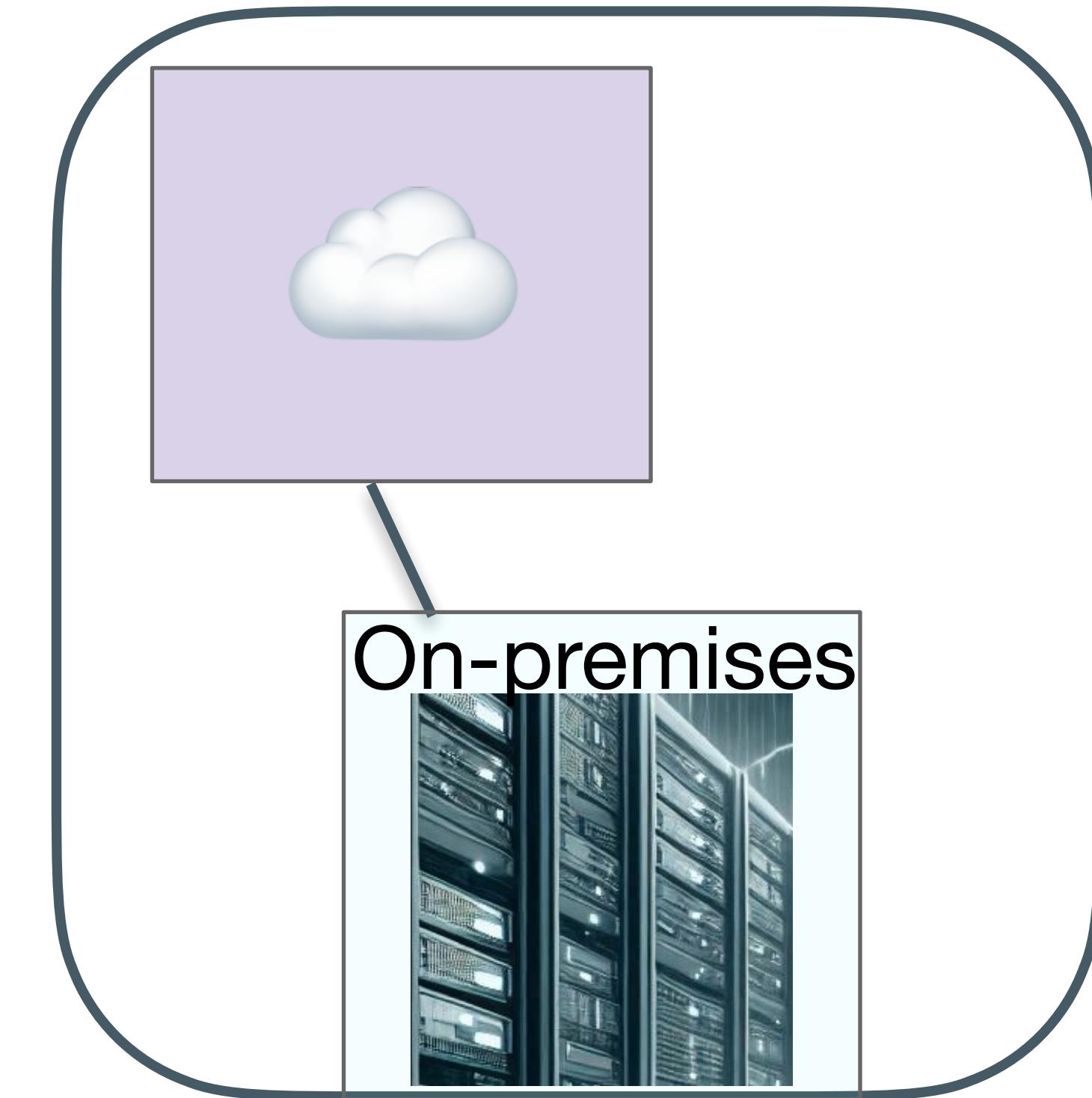
Market Watch  
Analyze the latest market trends and predictions from our team of experts.

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Huygens

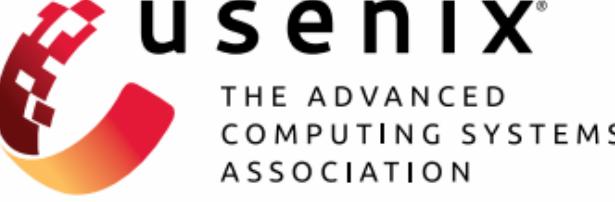


Better  
precision



# Huygens clock synchronization

- ▶ Software based
- ▶ High precision 



The Advanced Computing Systems Association

## Exploiting a Natural Network Effect for Scalable, Fine-grained Clock Synchronization

Yilong Geng, Shiyu Liu, and Zi Yin, *Stanford University*; Ashish Naik, *Google Inc.*;  
Balaji Prabhakar and Mendel Rosenblum, *Stanford University*; Amin Vahdat, *Google Inc.*

<https://www.usenix.org/conference/nsdi18/presentation/geng>



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# Huygens clock synchronization

- ▶ Software based
- ▶ High precision 

Measures  
one way delays



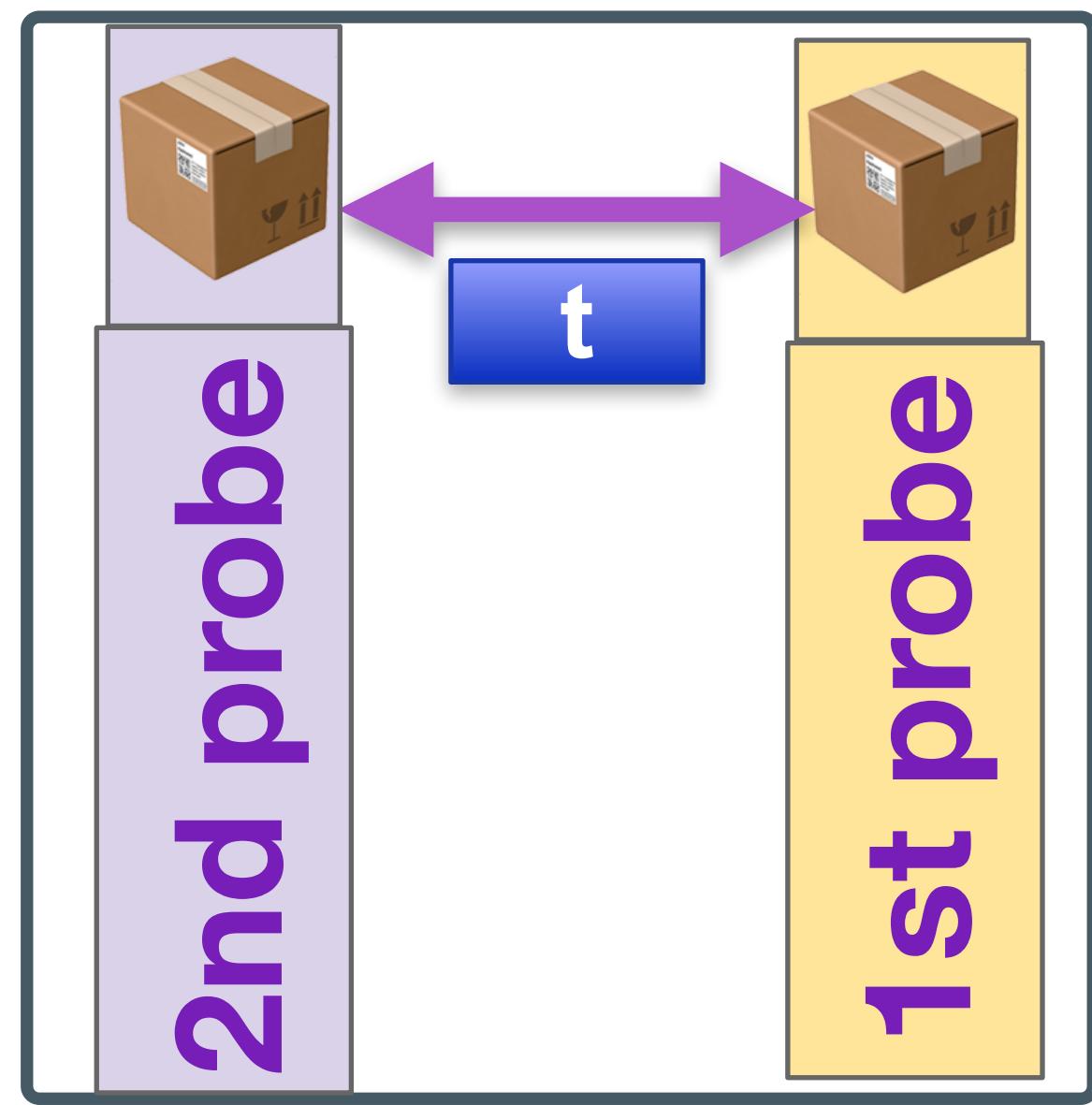
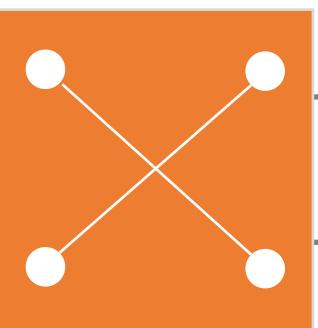
**Exploiting a Natural Network Effect for Scalable,  
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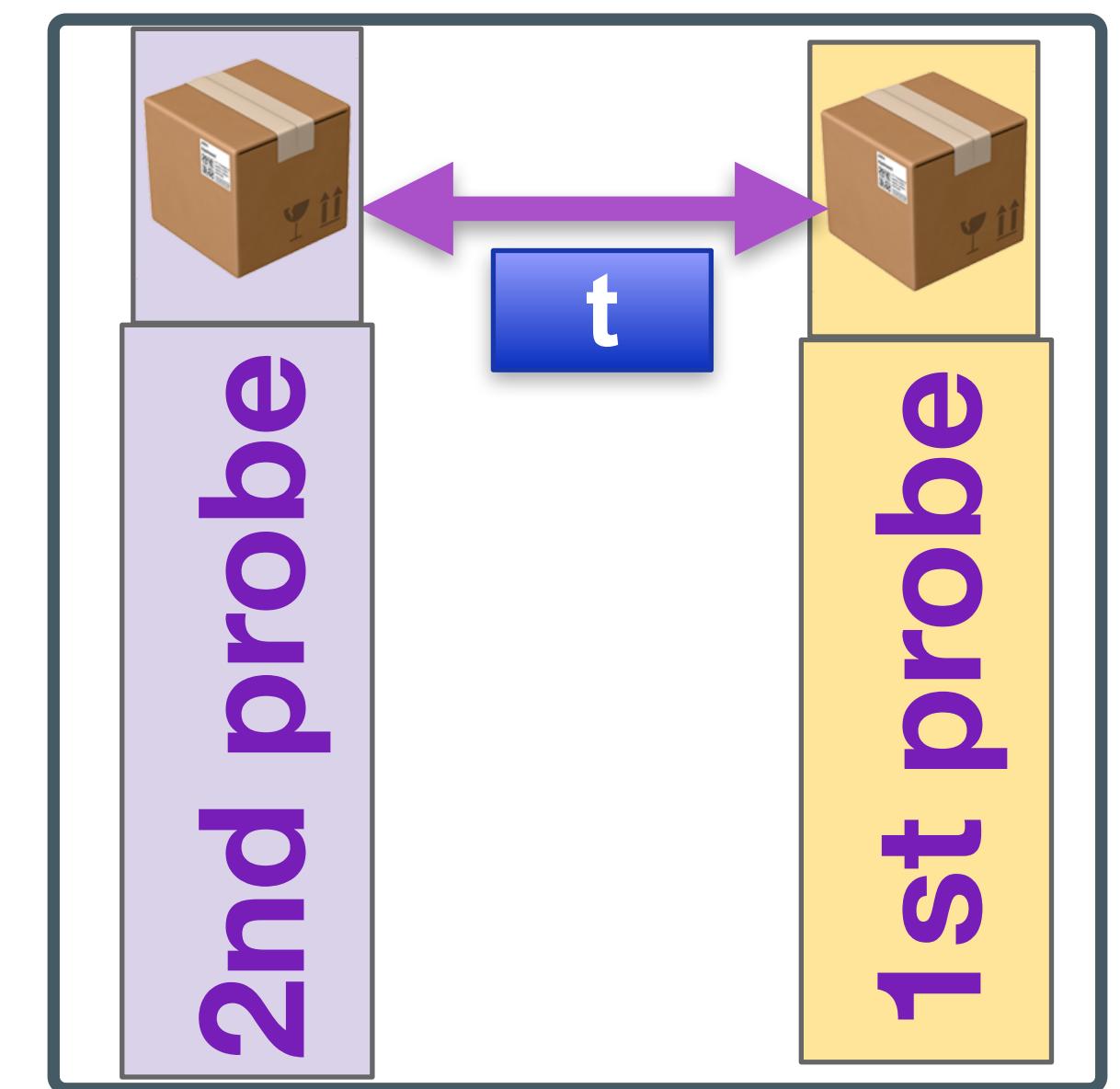
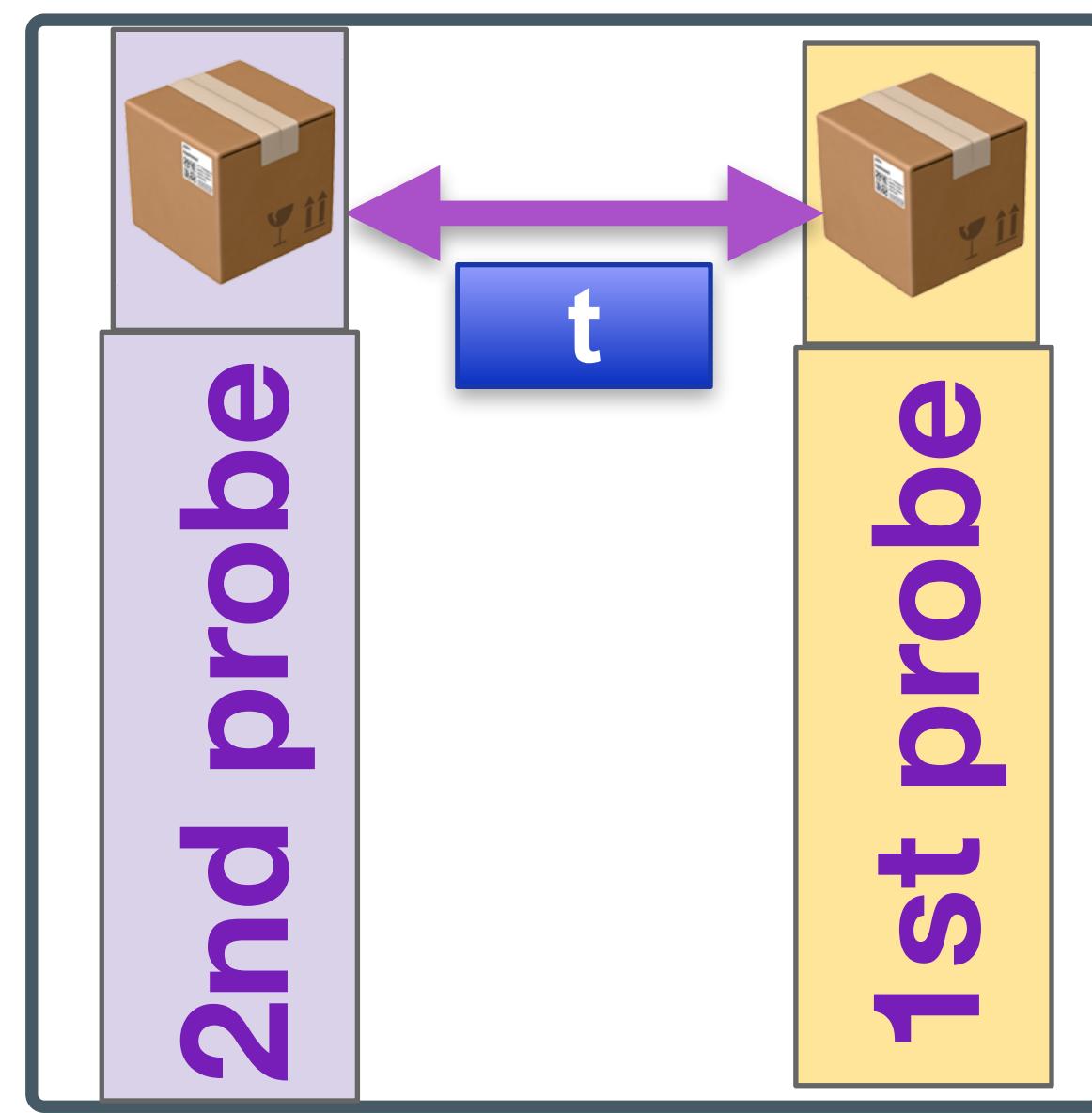
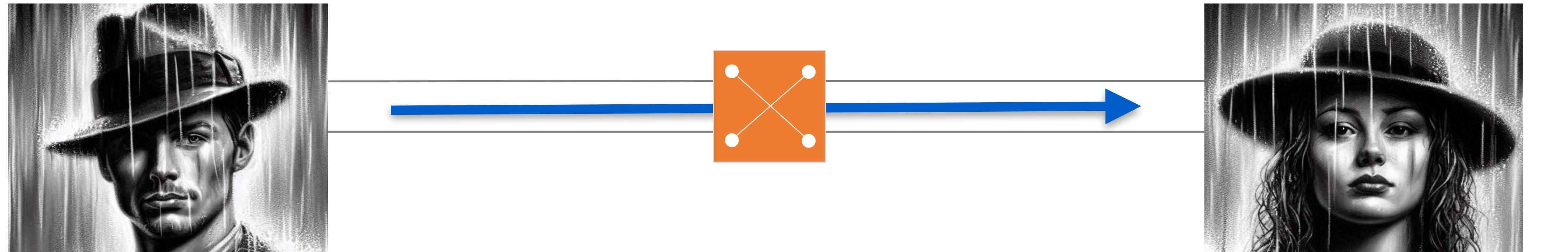
<https://www.usenix.org/conference/nsdi18/presentation/geng>



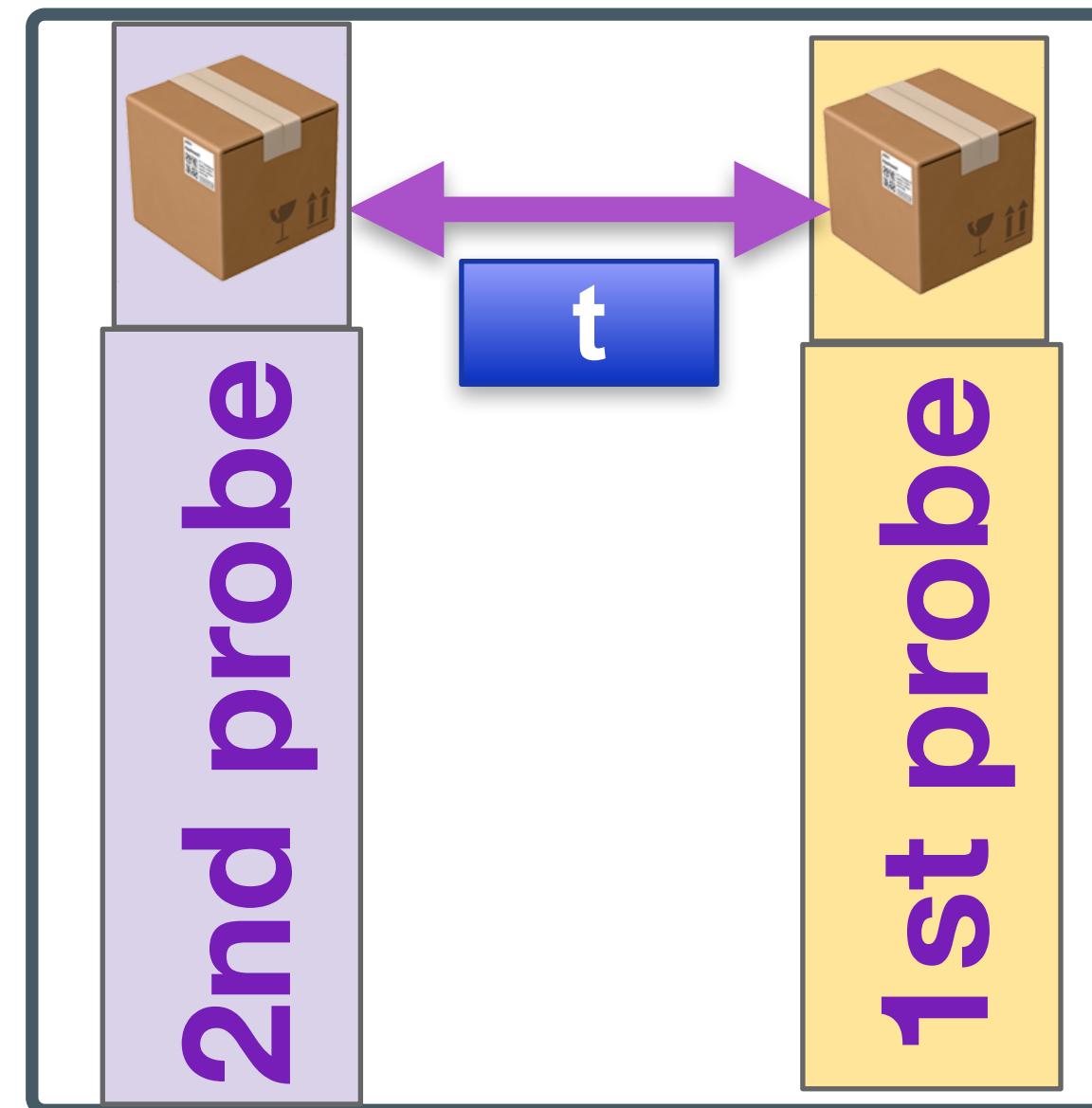
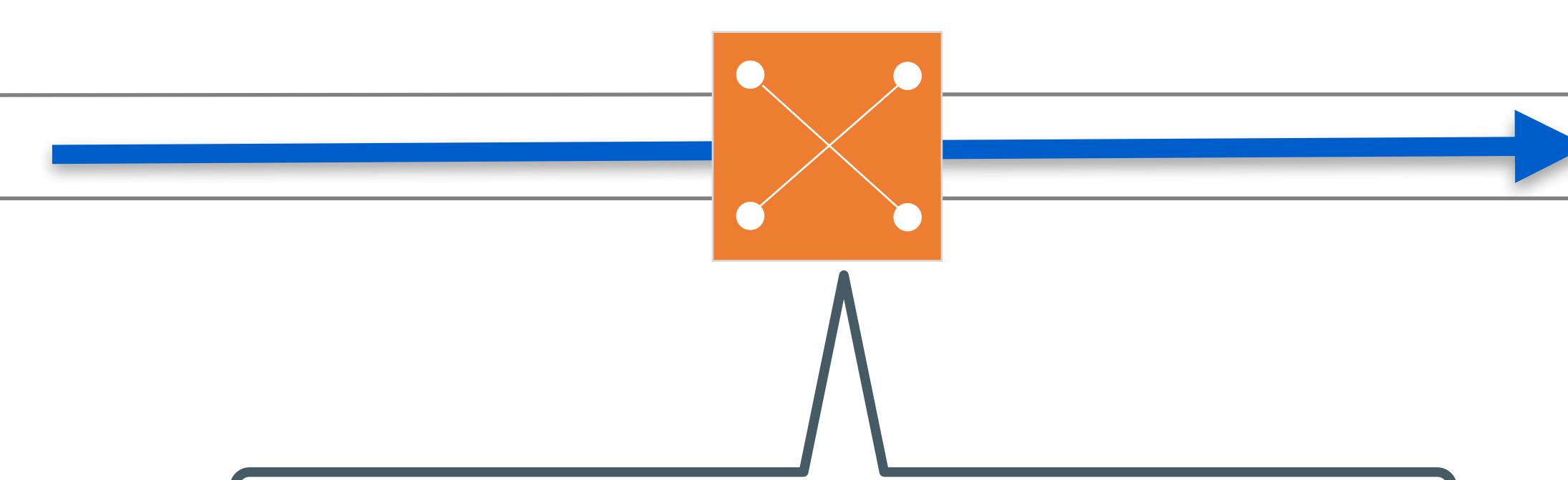
# Huygens: Coded probes



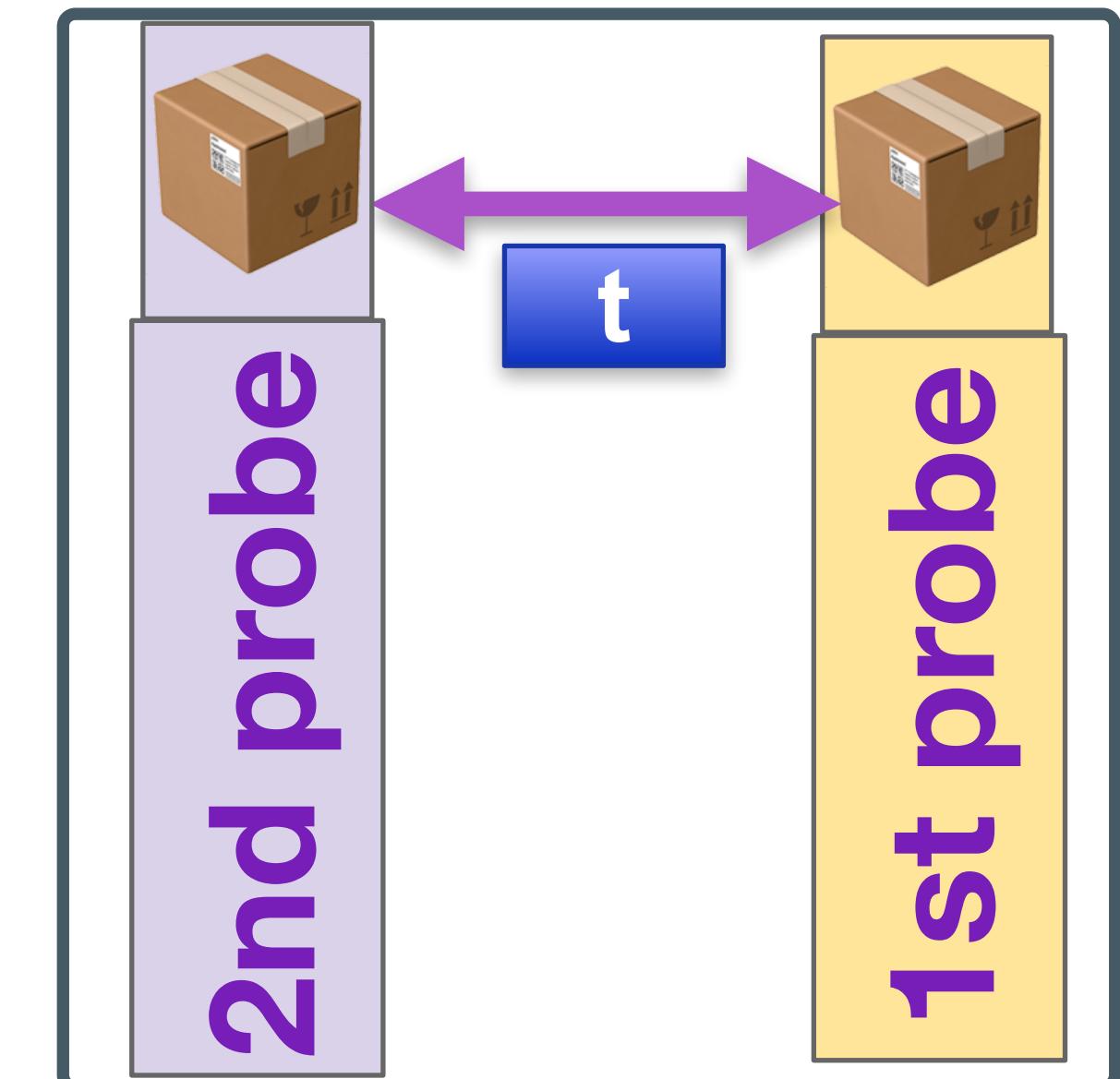
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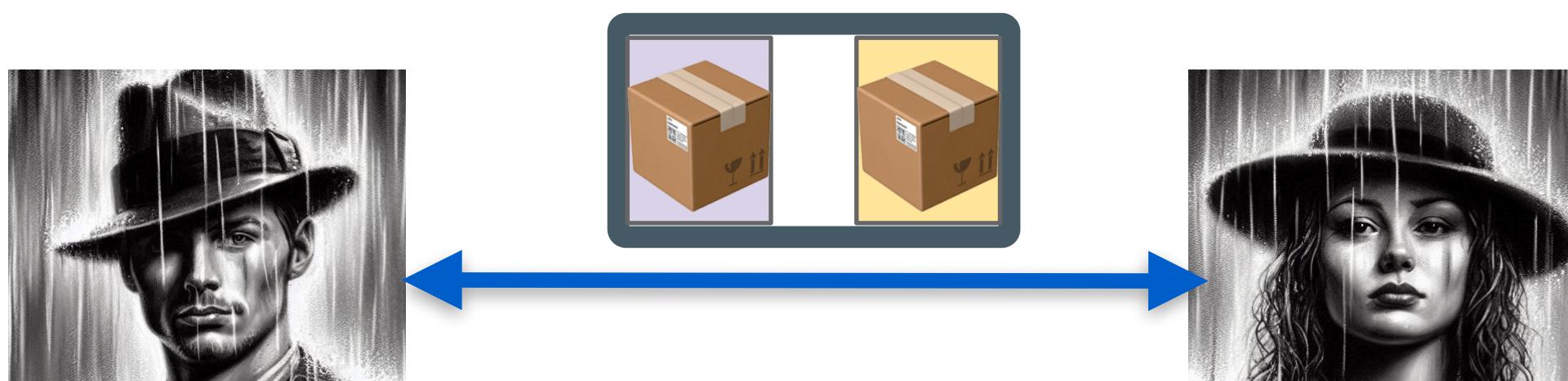
# Huygens: Coded probes



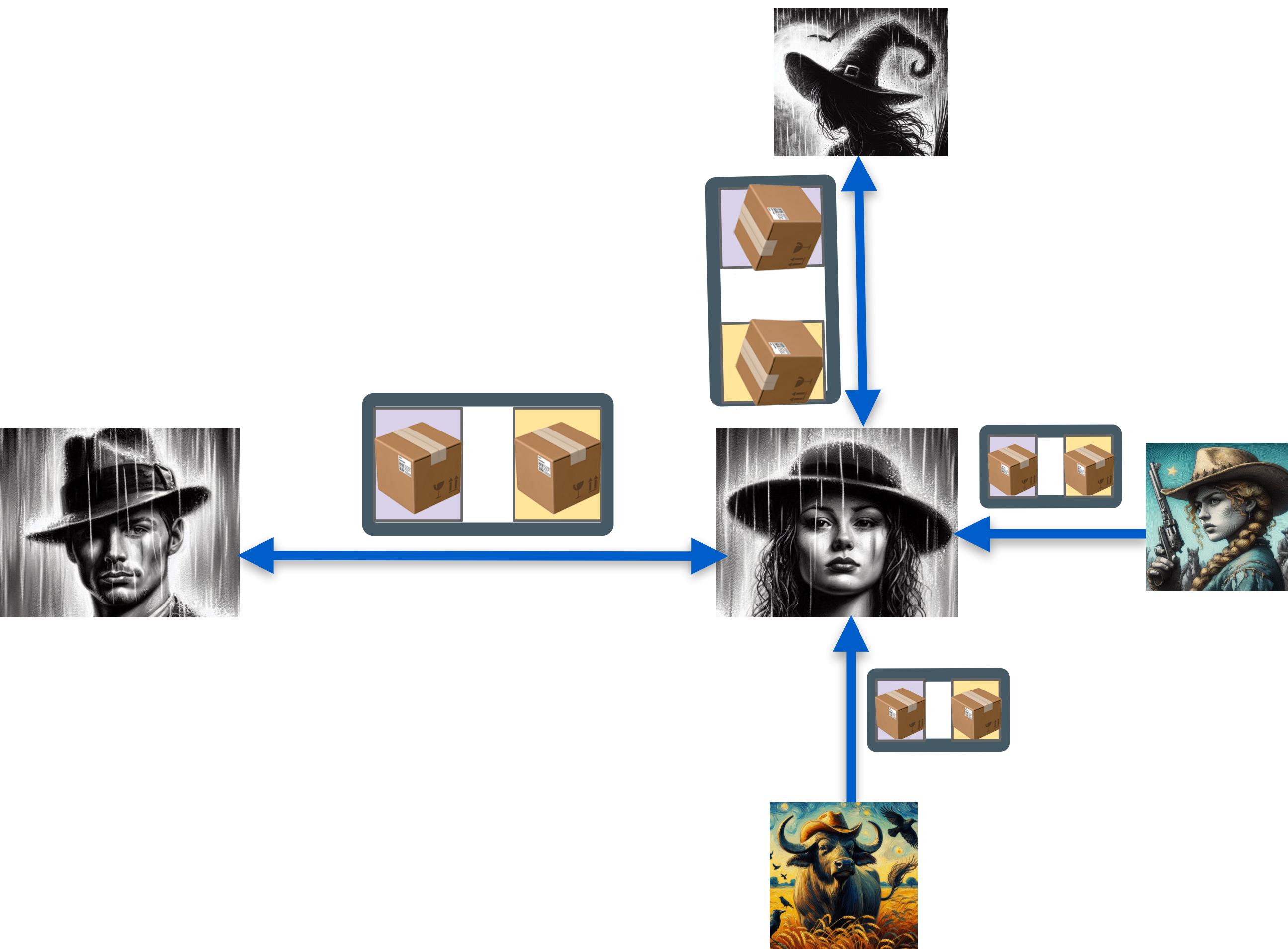
**Pure coded probes:**  
If  $t$  remains the same  
then the probe pair  
didn't suffer from delays



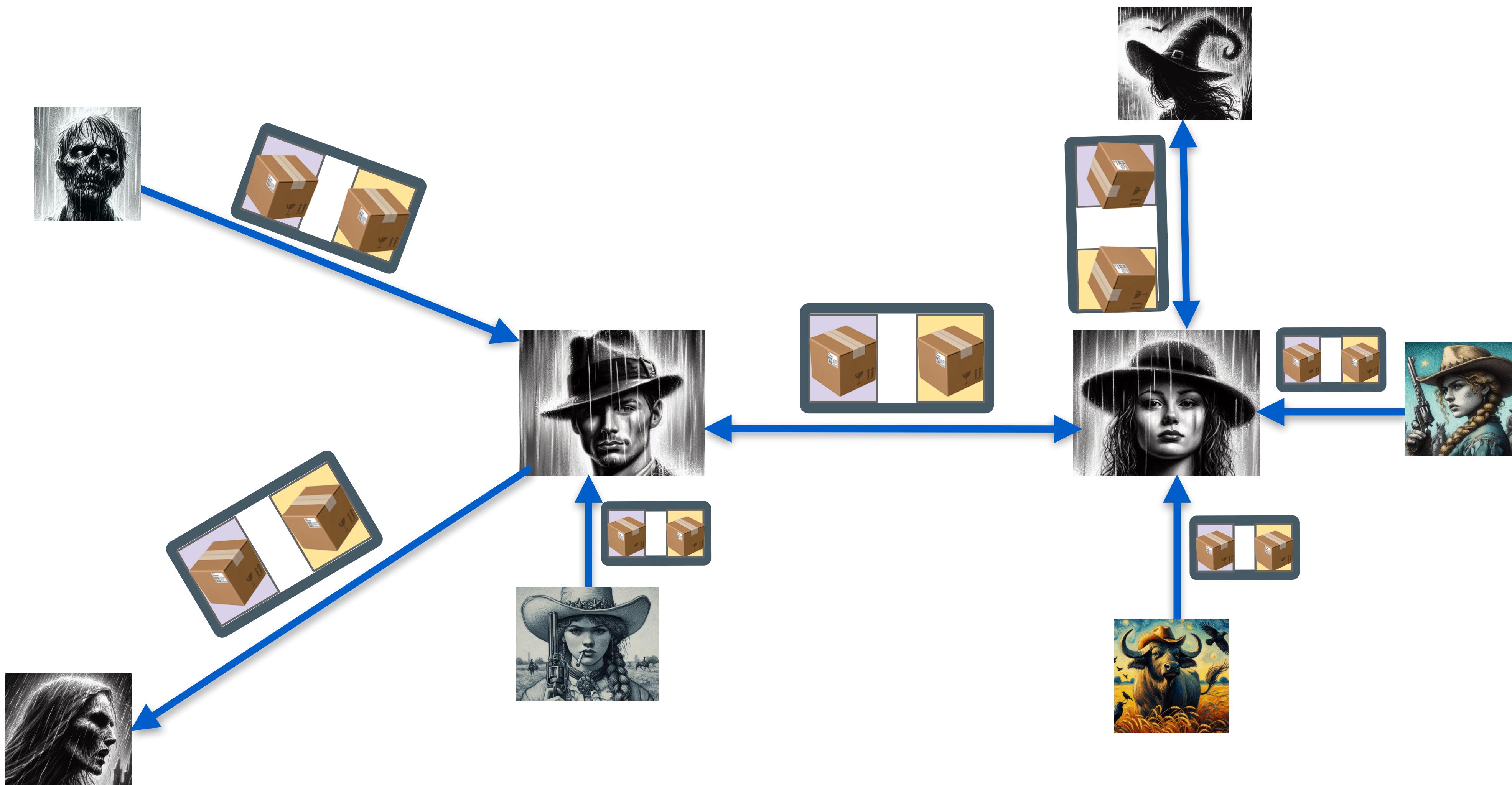
# Huygens: probe mesh



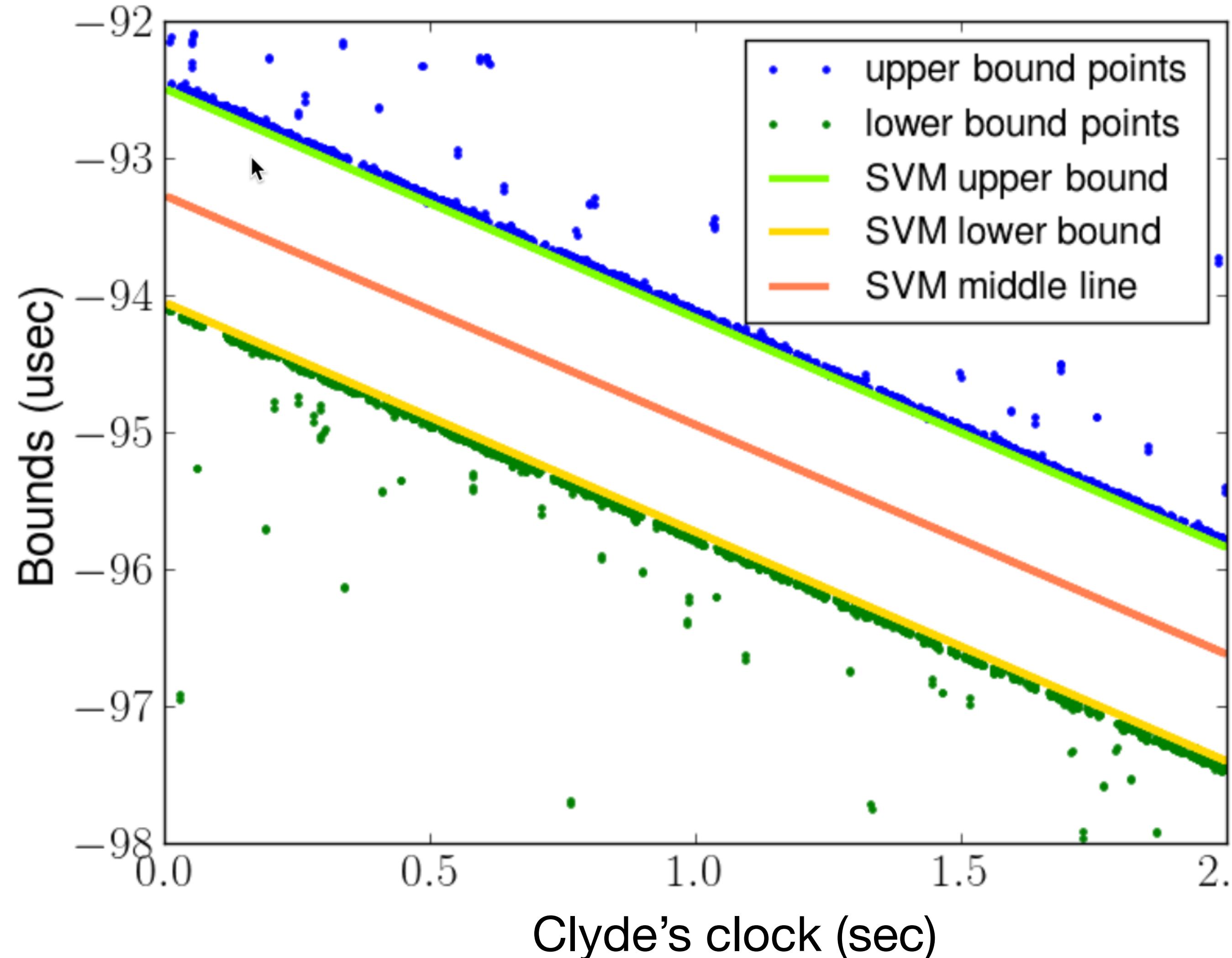
# Huygens: probe mesh



# Huygens: probe mesh

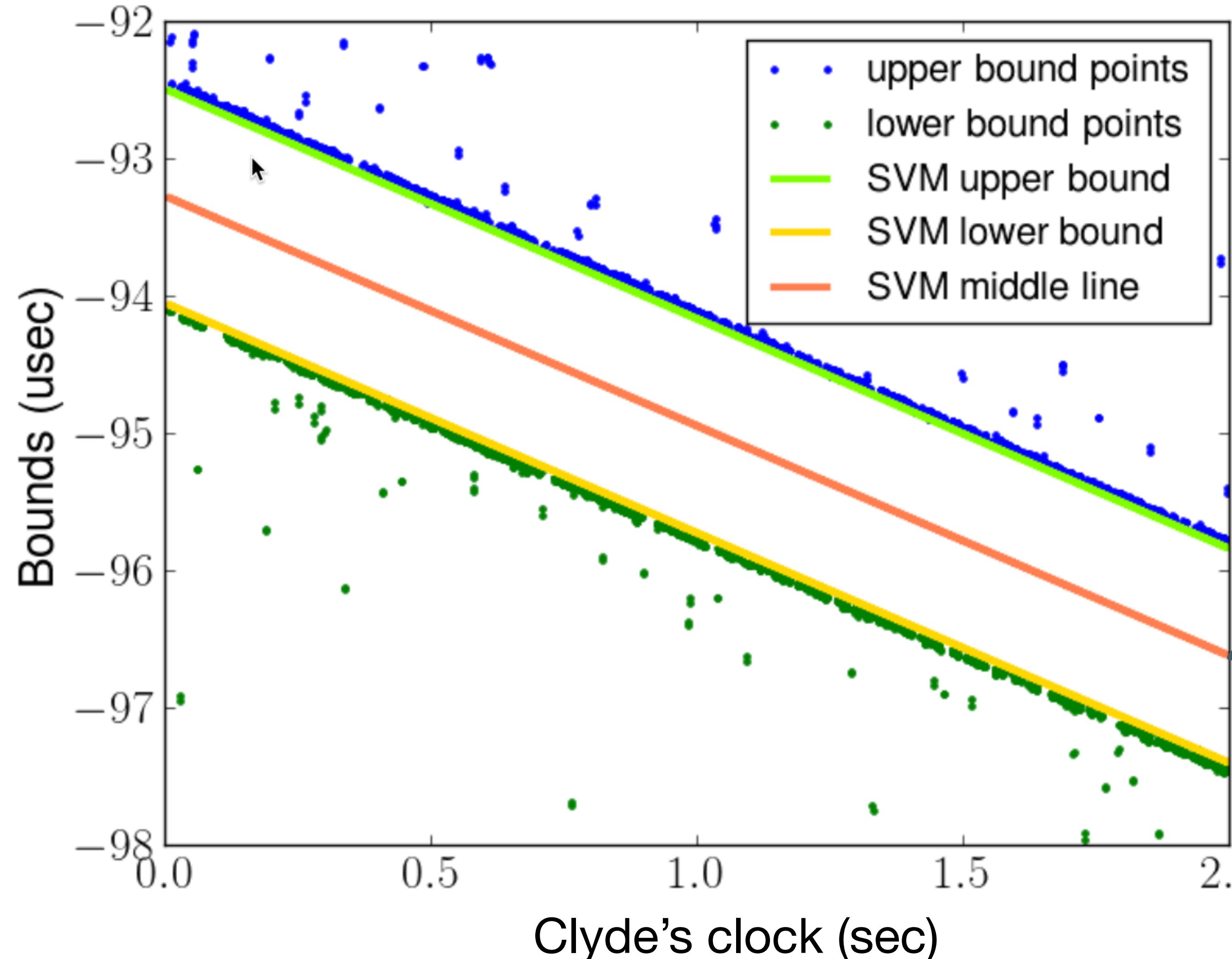


# Huygens: estimating offset and drift (step 1)



Over 2 second intervals  
as temperature is constant

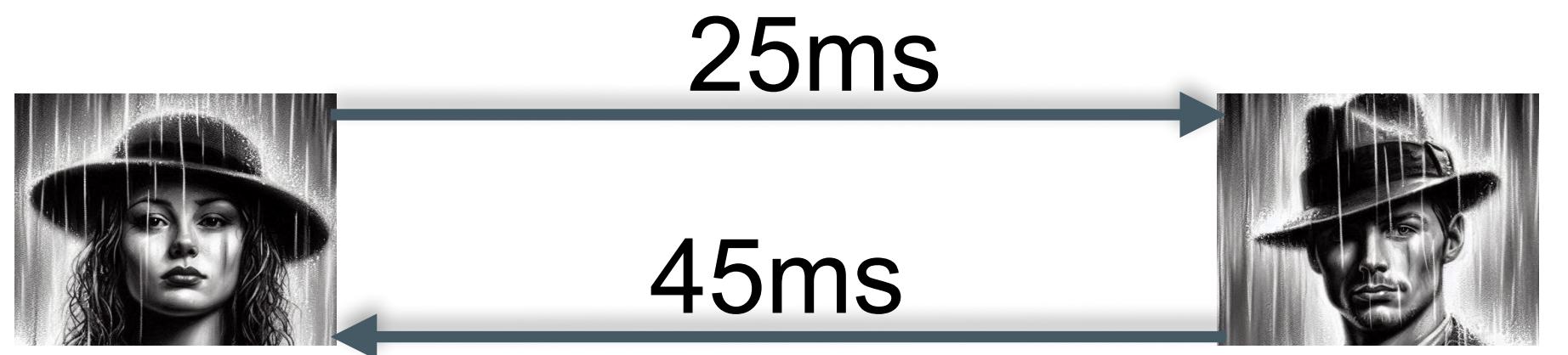
# Huygens: estimating offset and drift (step 1)



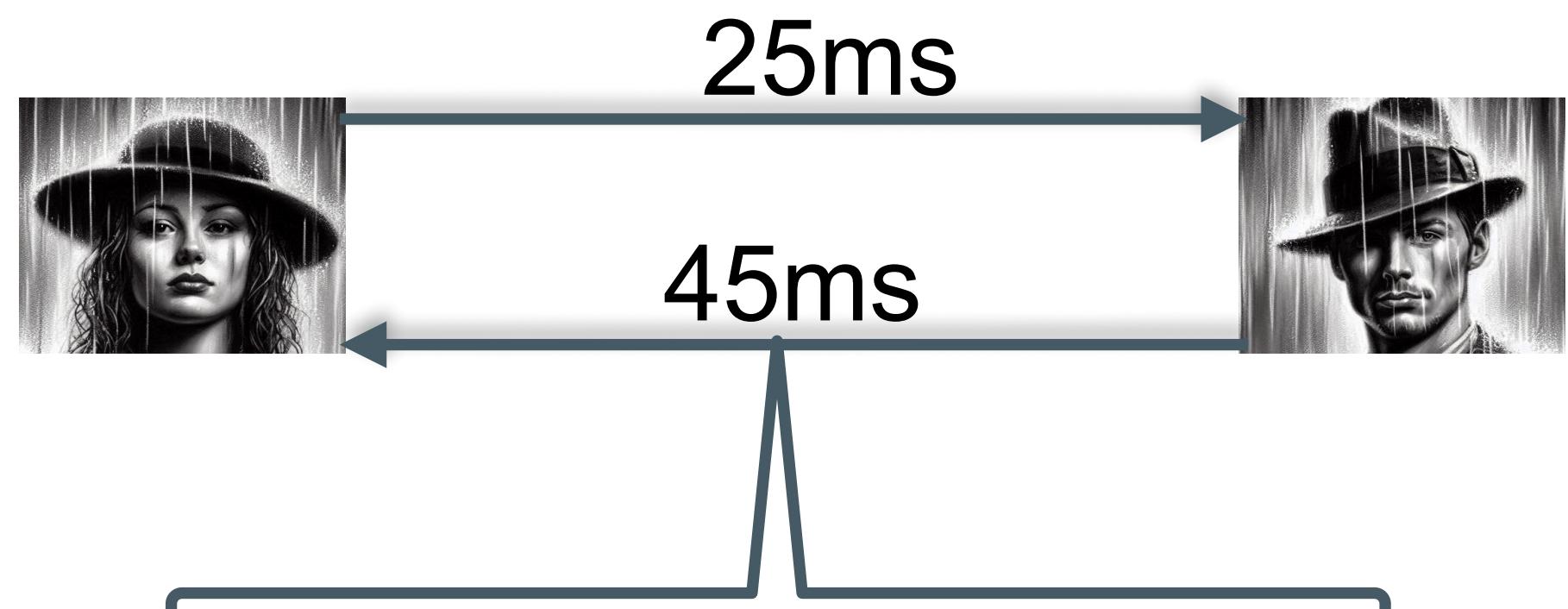
Apply ML classifier  
for high precision estimation  
of offset and drift

Over 2 second intervals  
as temperature is constant

# NTP: pairwise synchronization



# NTP: pairwise synchronization



Prone to errors  
due to  
path asymmetry

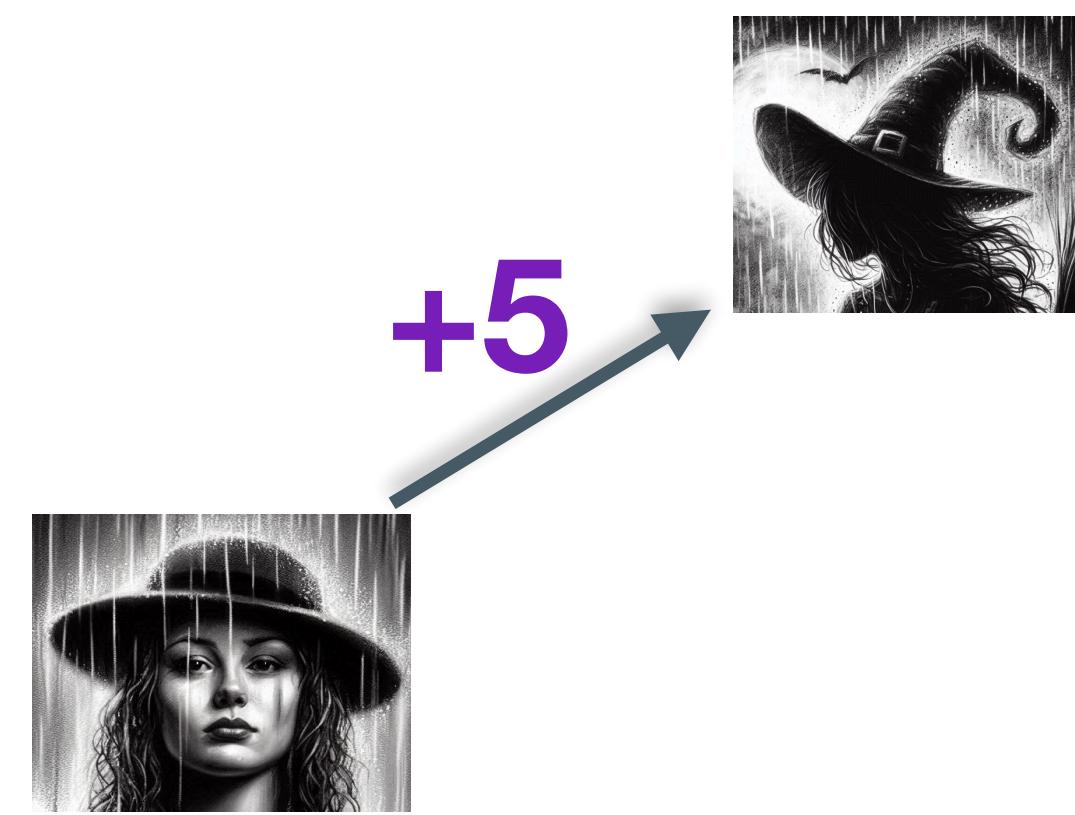


# Huygens

Clock sync is  
transitive!



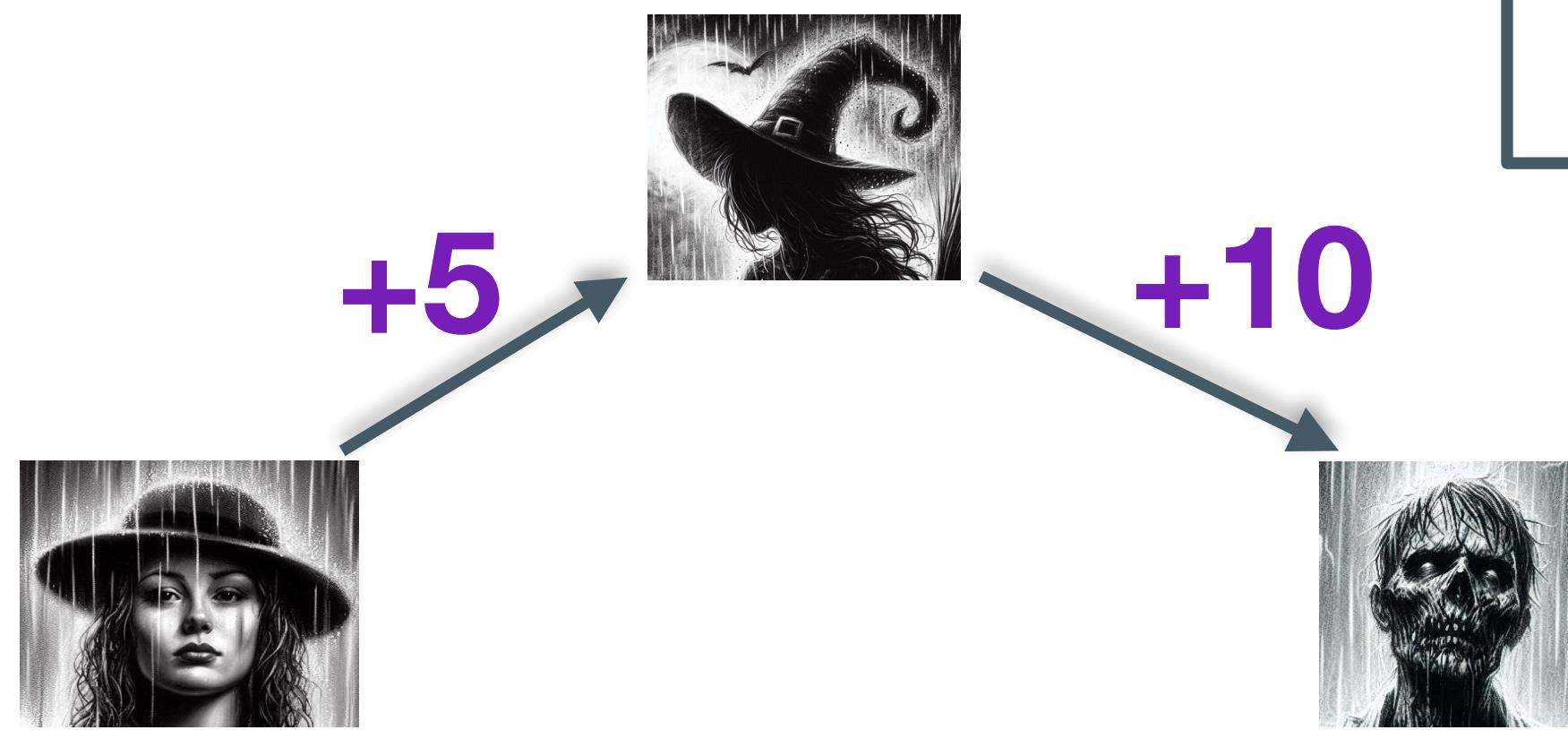
# Huygens



Clock sync is  
transitive!



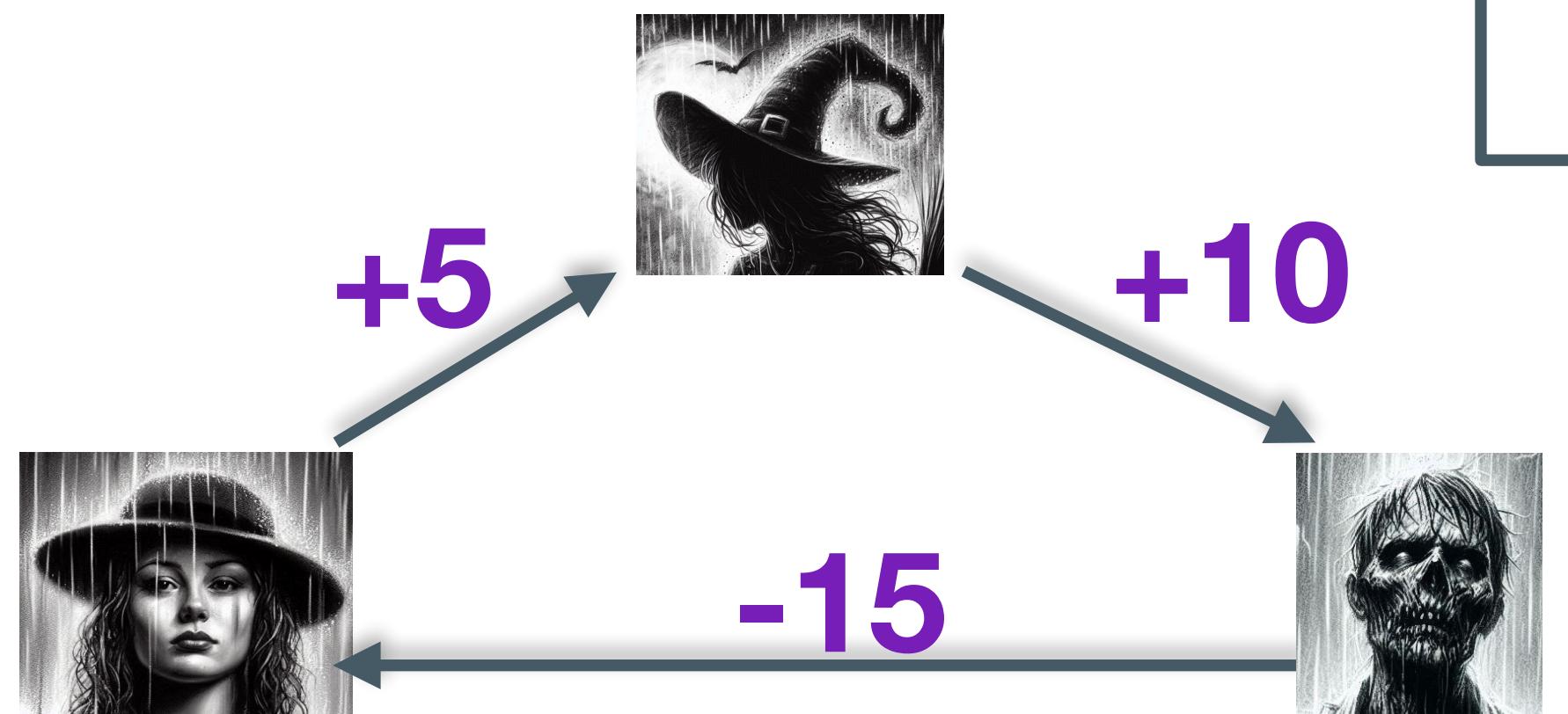
# Huygens



Clock sync is  
transitive!



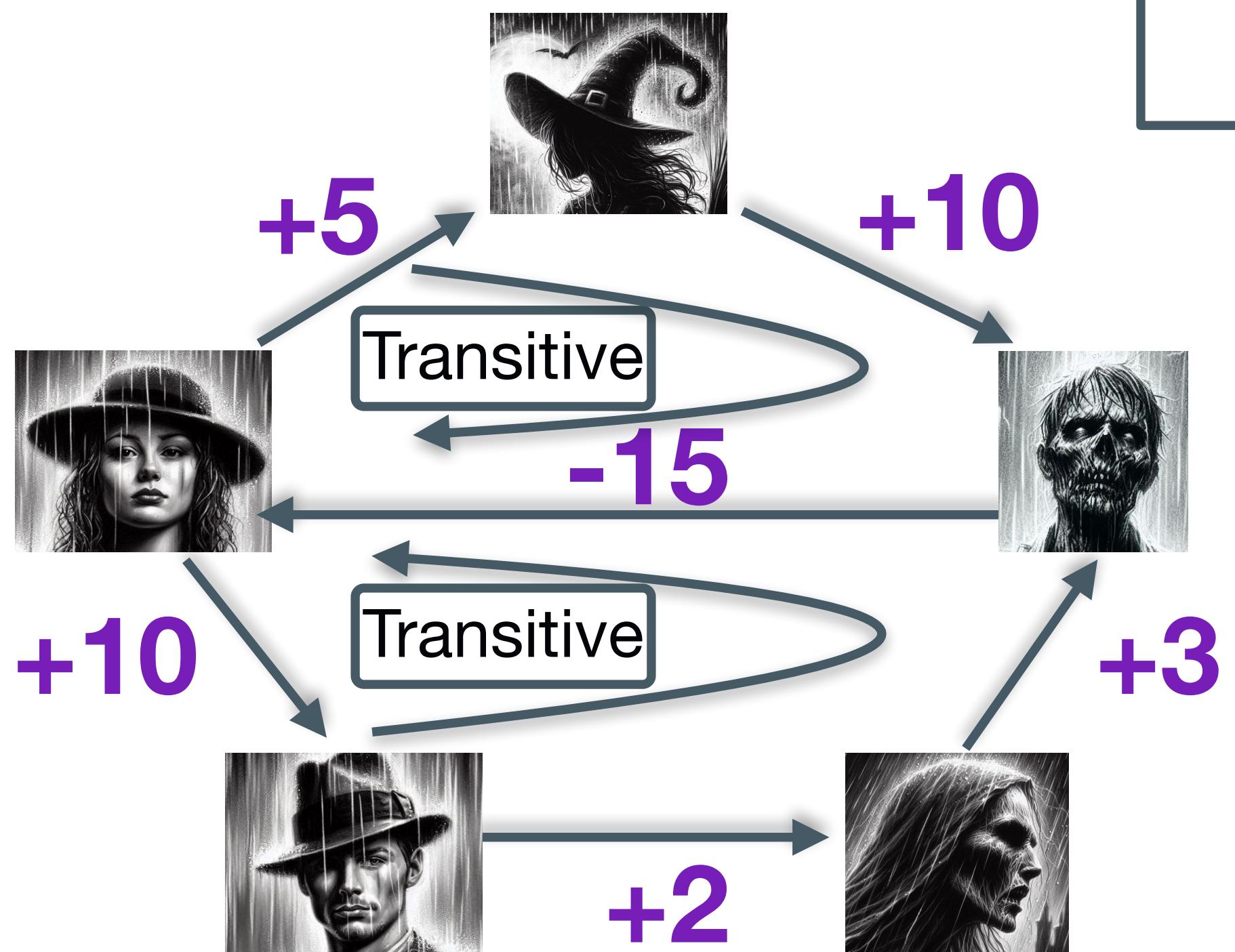
# Huygens



Clock sync is transitive!



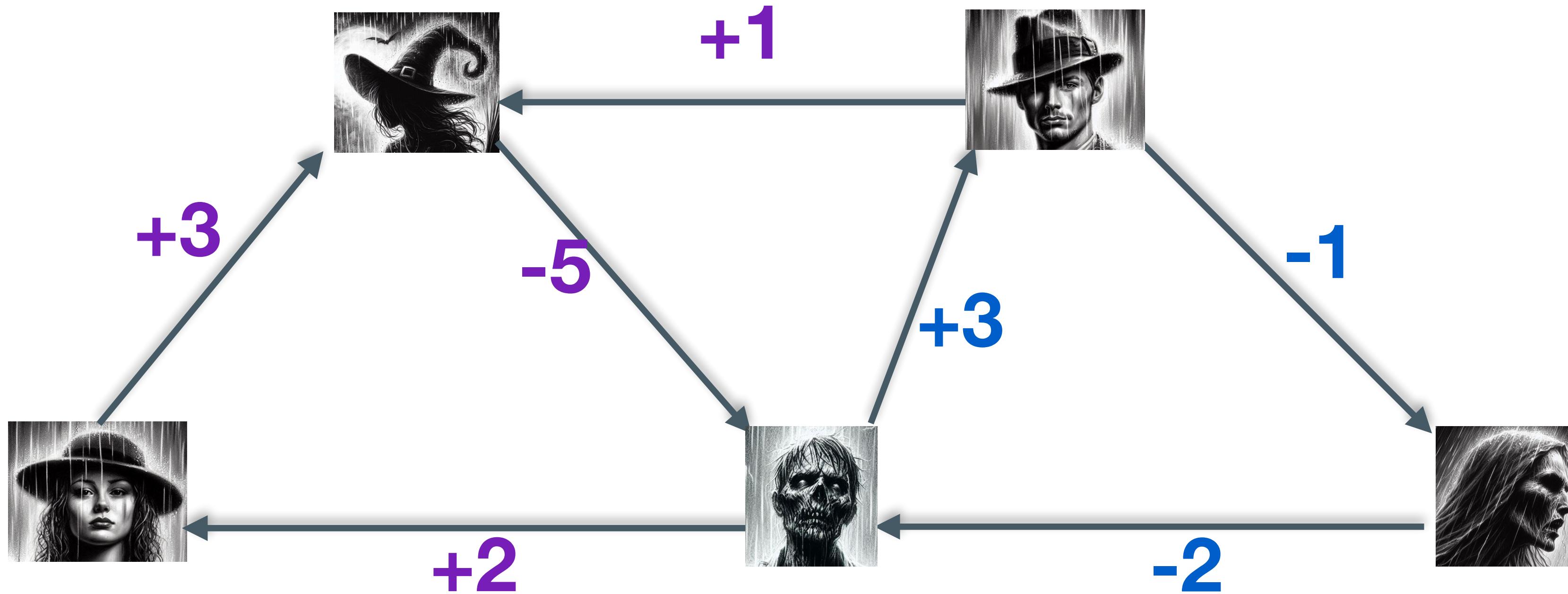
# Huygens



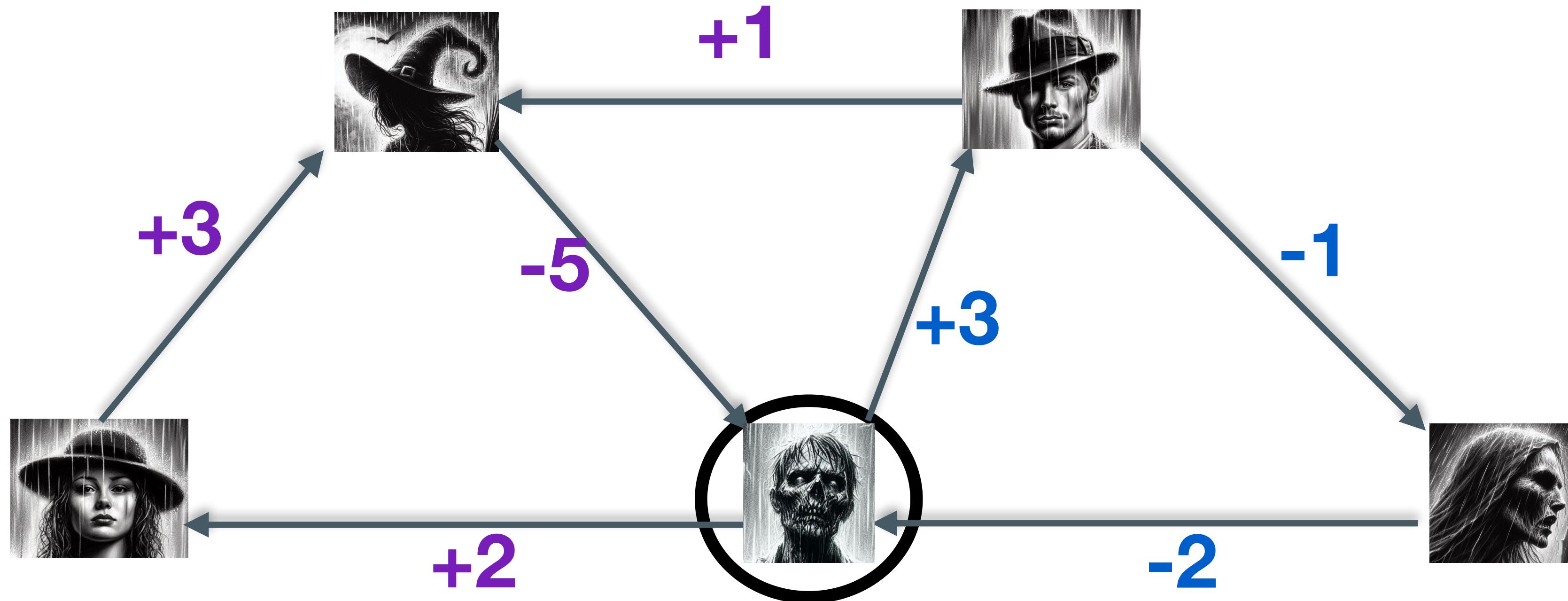
Clock sync is transitive!



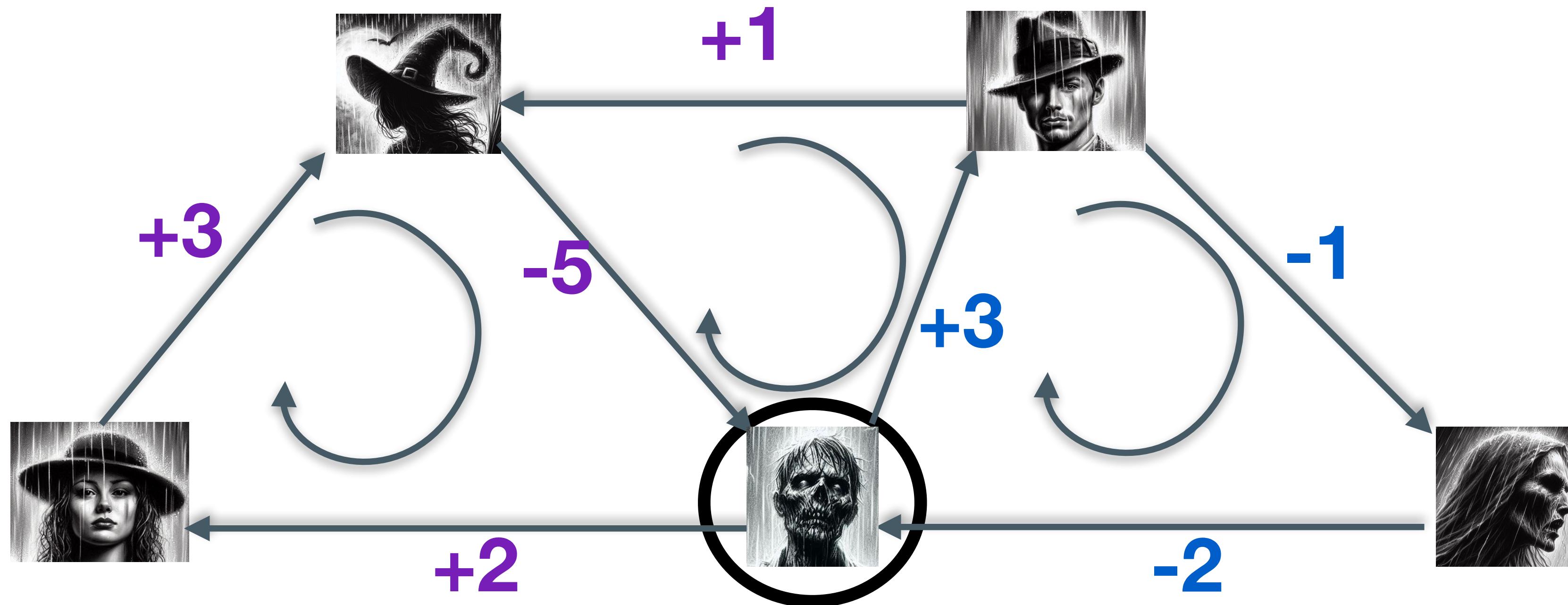
# Huygens: “*triangulating*” to minimize clock sync errors



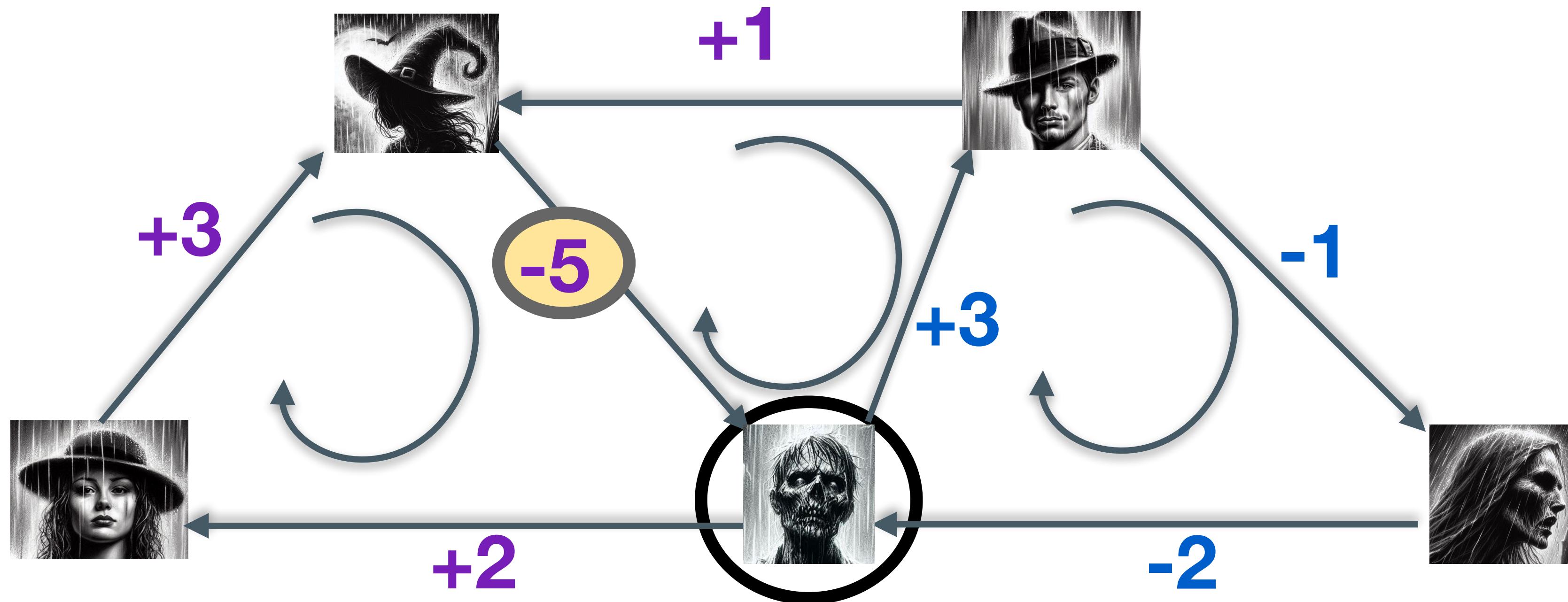
# Huygens: “*triangulating*” to minimize clock sync errors



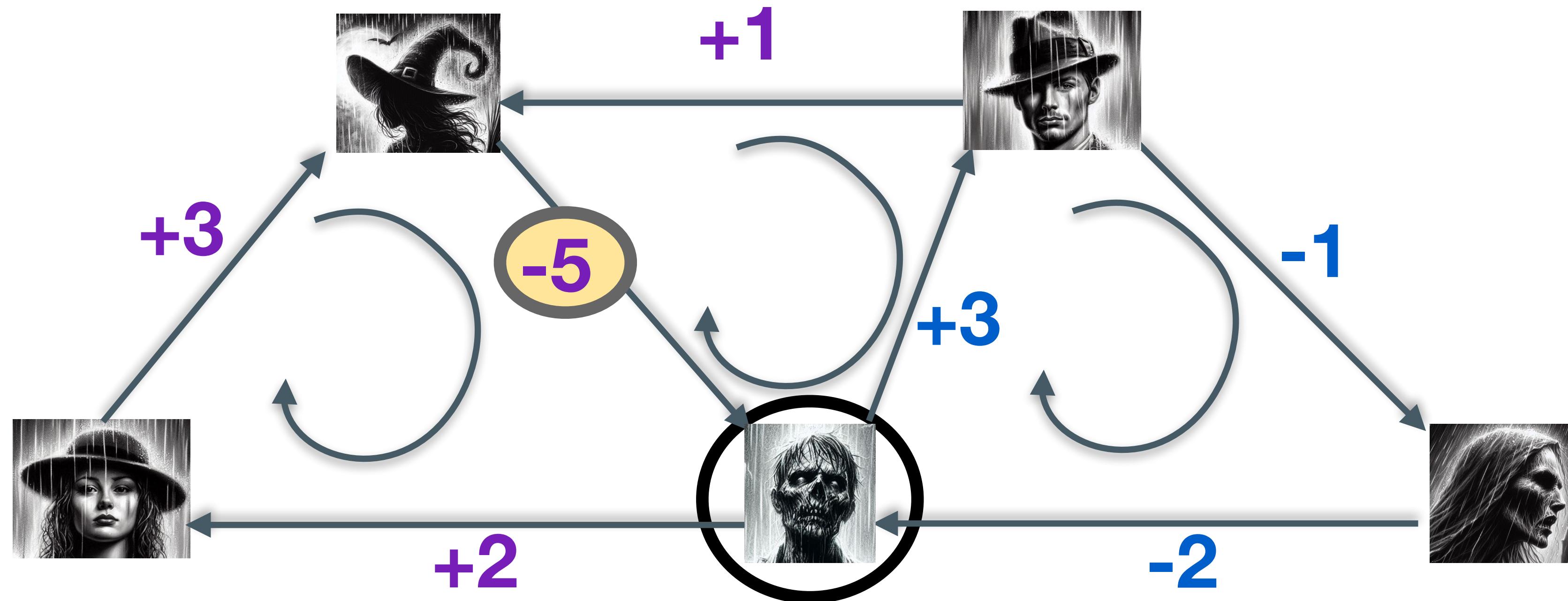
# Huygens: “*triangulating*” to minimize clock sync errors



# Huygens: “*triangulating*” to minimize clock sync errors

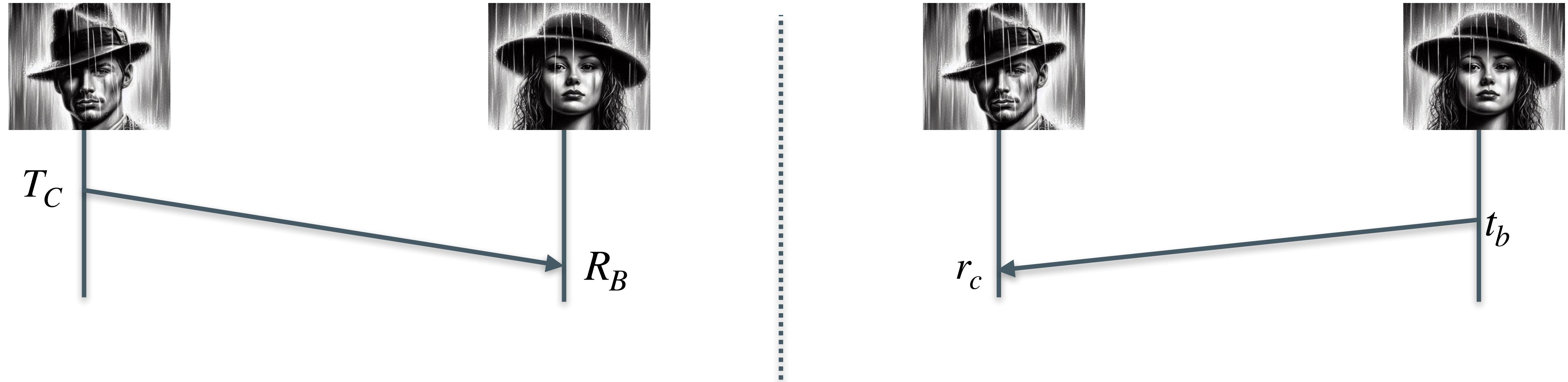


# Huygens: “*triangulating*” to minimize clock sync errors

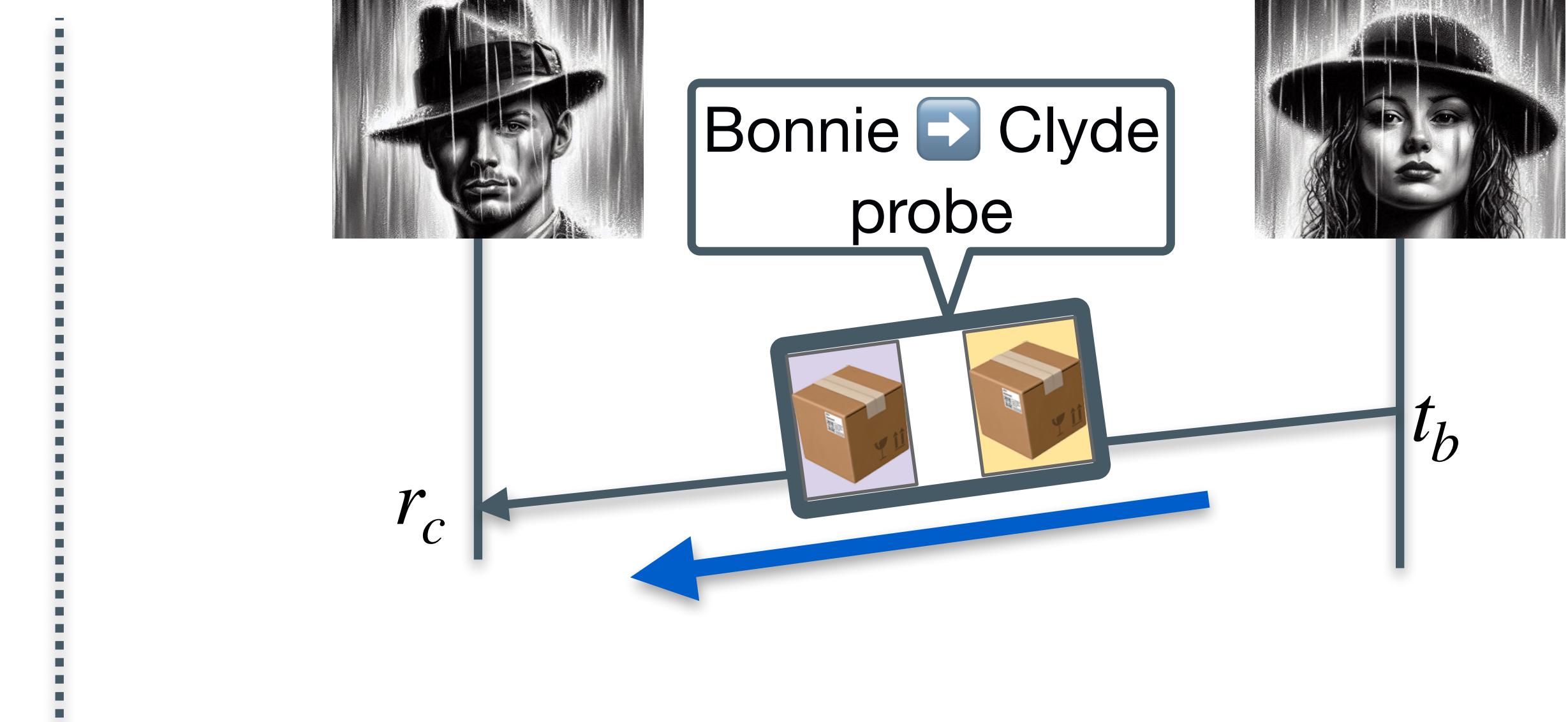
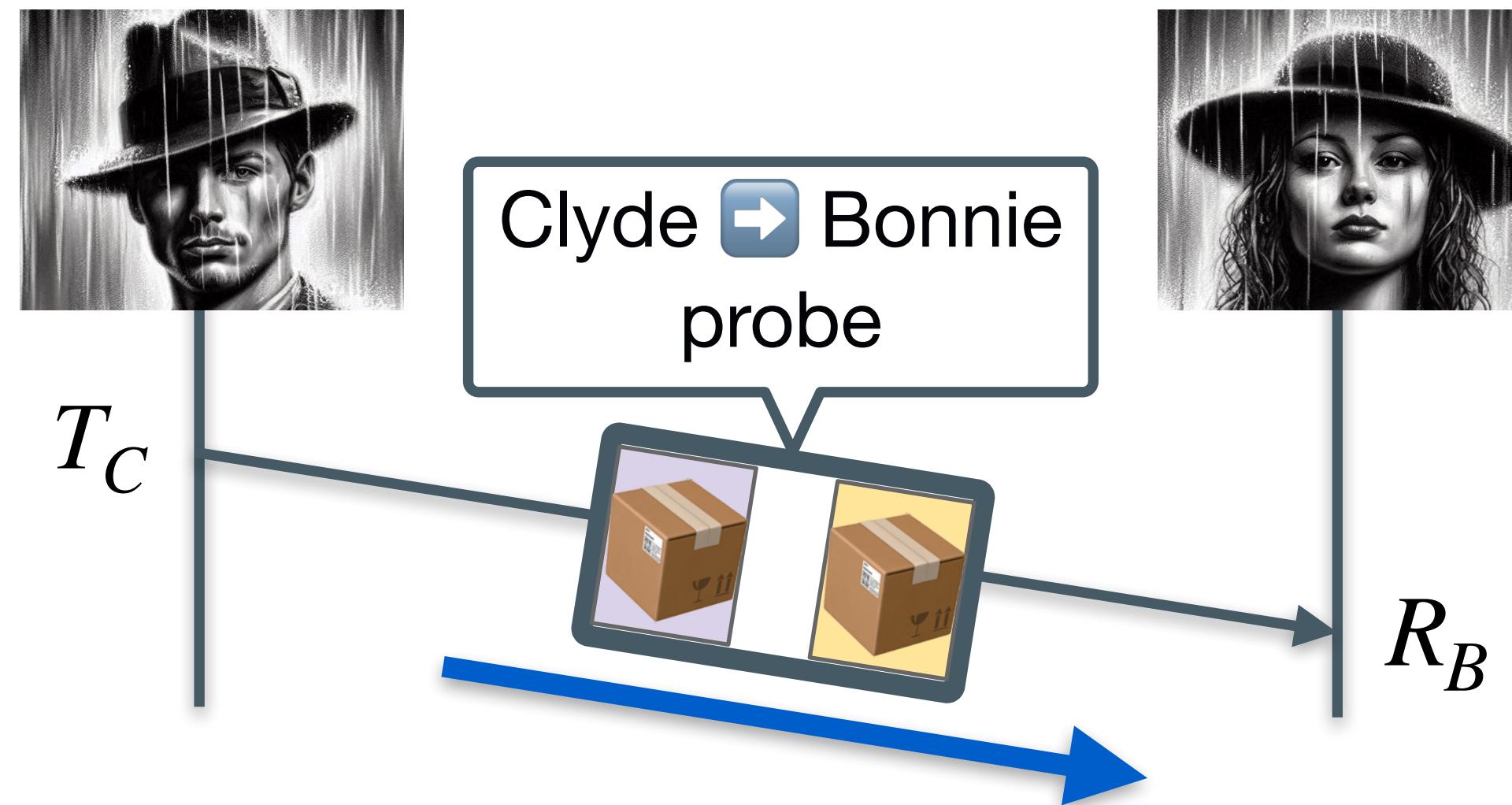


Reduces estimation errors caused by **path asymmetry**

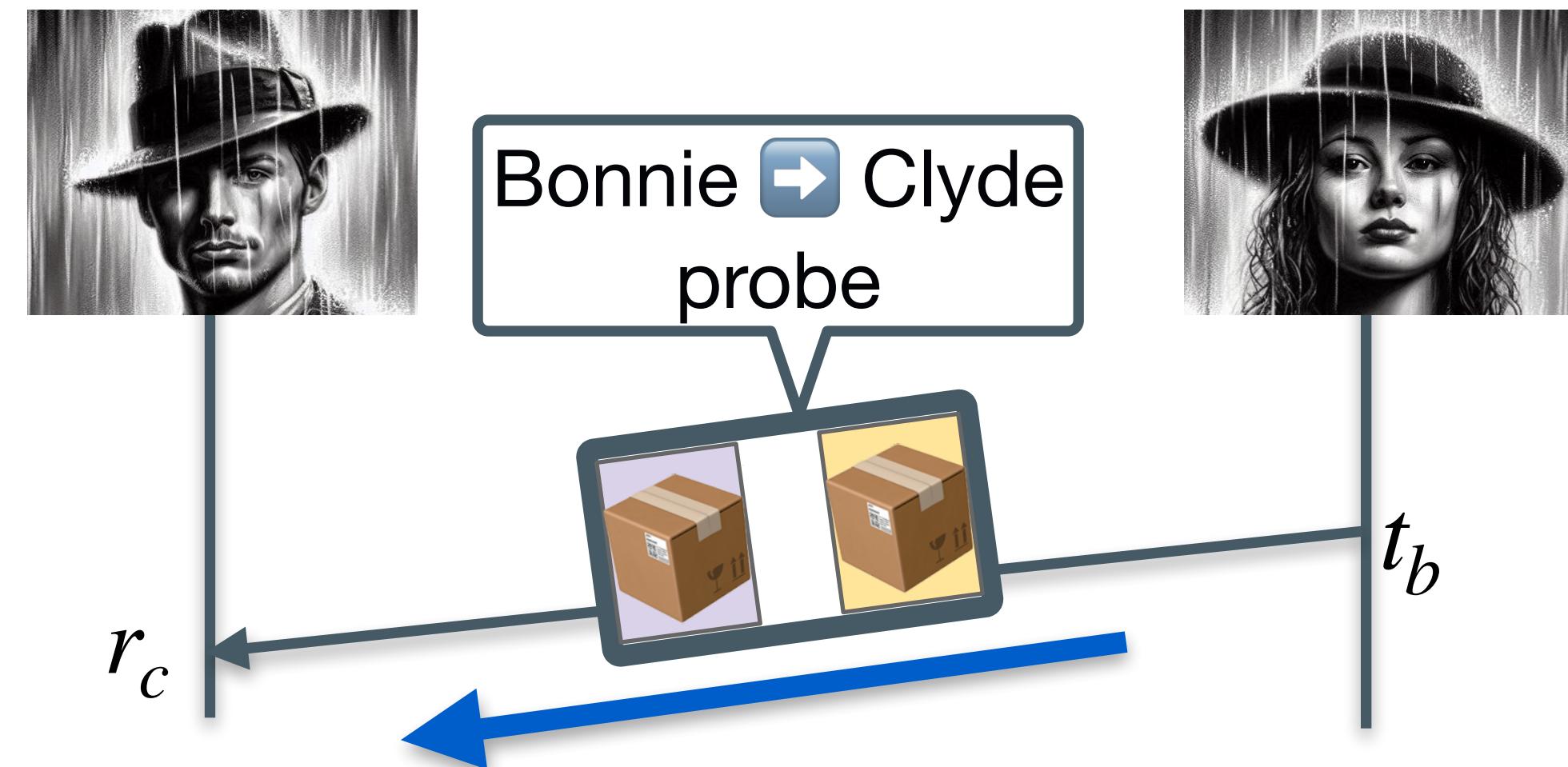
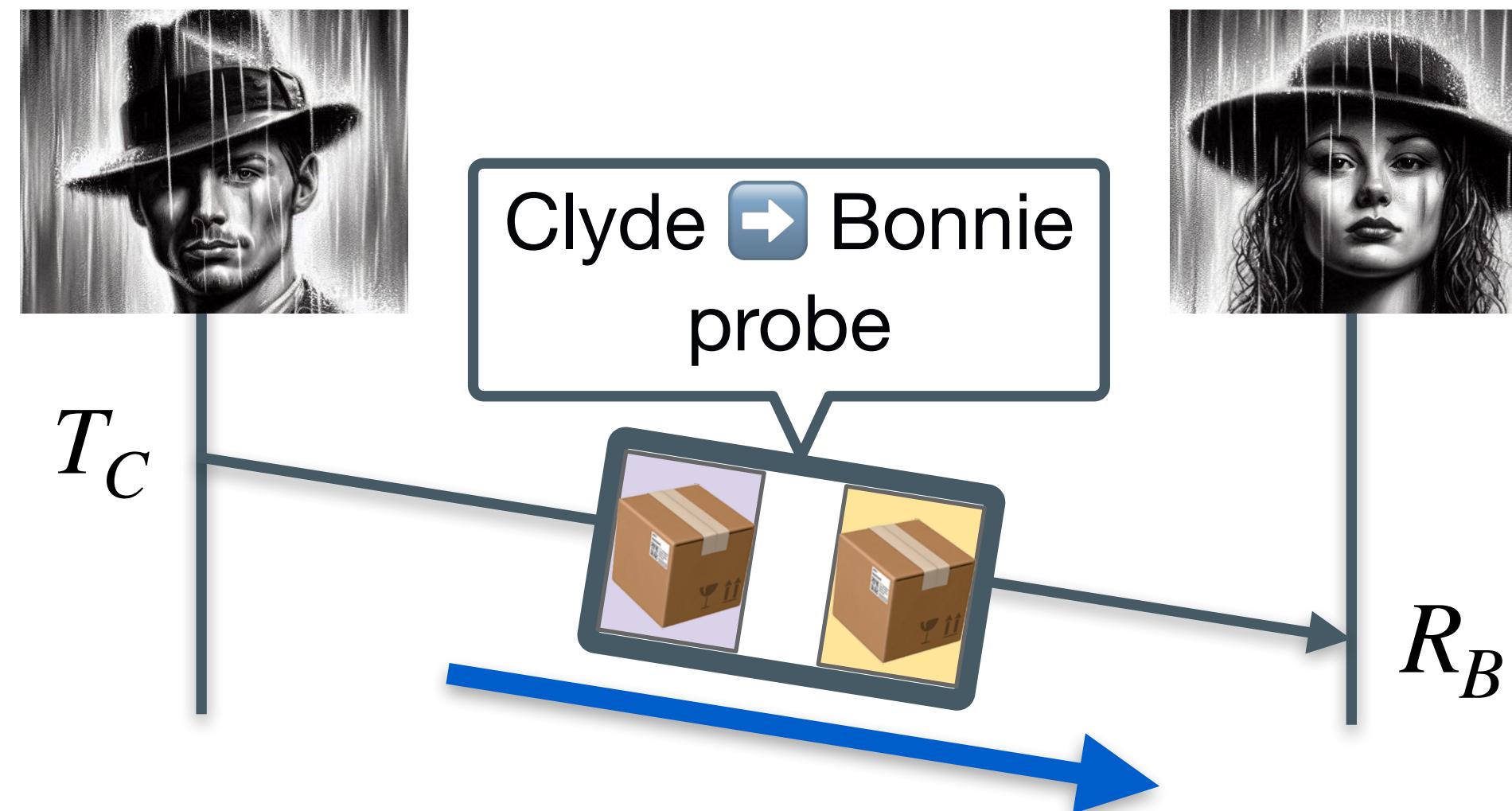
# Huygens: measuring one way delays



# Huygens: measuring one way delays



# Huygens: measuring one way delays



Measures forward and backward  
one way delays at a high precision



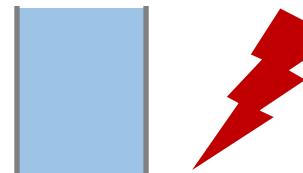
Sender



Receiver



Sender



Buffer overflow



Receiver

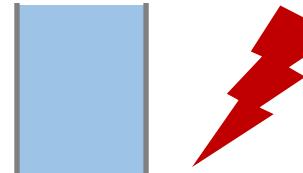


# Increase tail latencies

Retransmits,  
Timeouts



Sender



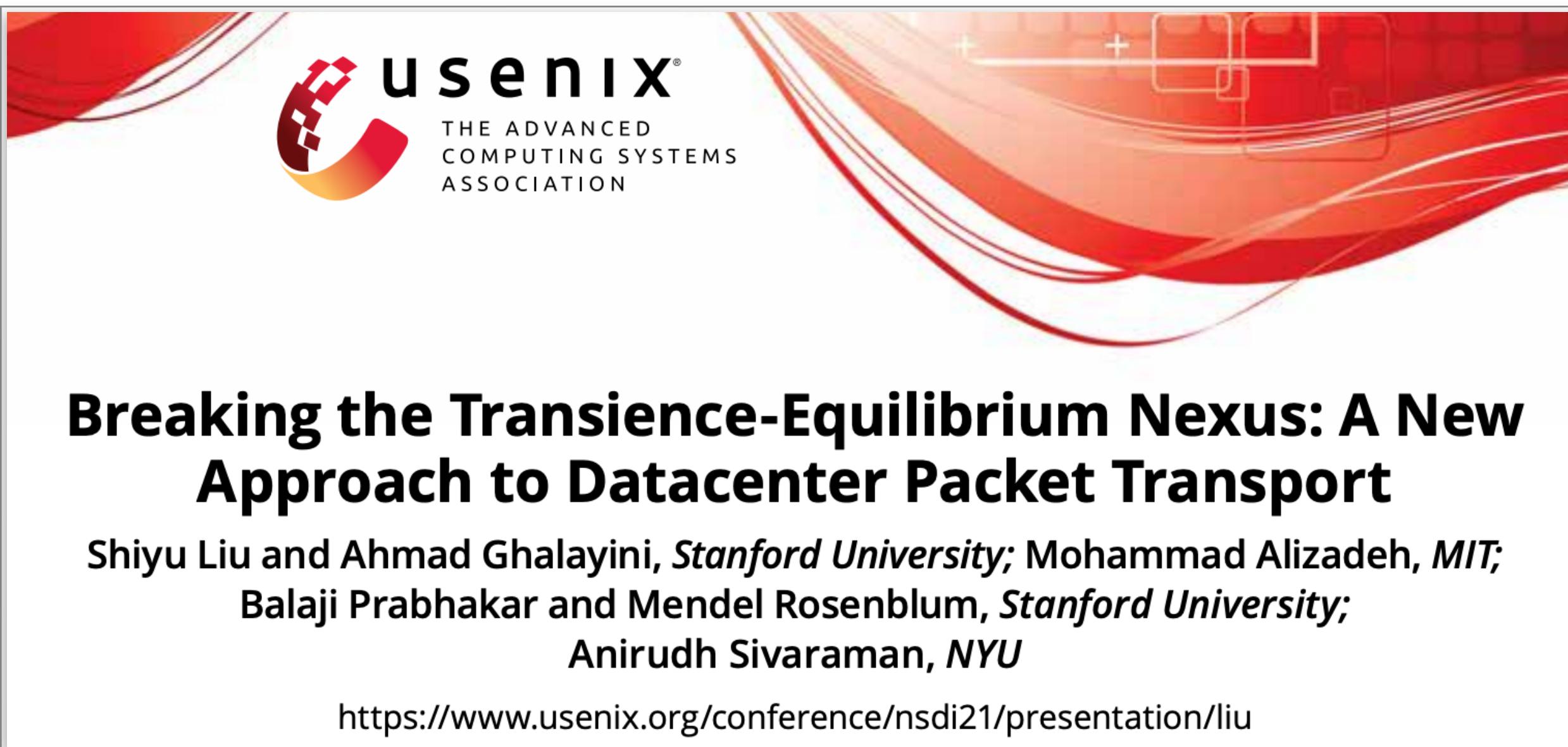
Buffer overflow



Receiver



# On-Ramp congestion control



The USENIX logo, featuring a stylized red 'E' icon followed by the word 'usenix' in a lowercase sans-serif font, with 'THE ADVANCED COMPUTING SYSTEMS ASSOCIATION' written below it. The background of the slide features a red and white abstract graphic of a network or data flow.

**Breaking the Transience-Equilibrium Nexus: A New Approach to Datacenter Packet Transport**

Shiyu Liu and Ahmad Ghalayini, *Stanford University*; Mohammad Alizadeh, *MIT*;  
Balaji Prabhakar and Mendel Rosenblum, *Stanford University*;  
Anirudh Sivaraman, *NYU*

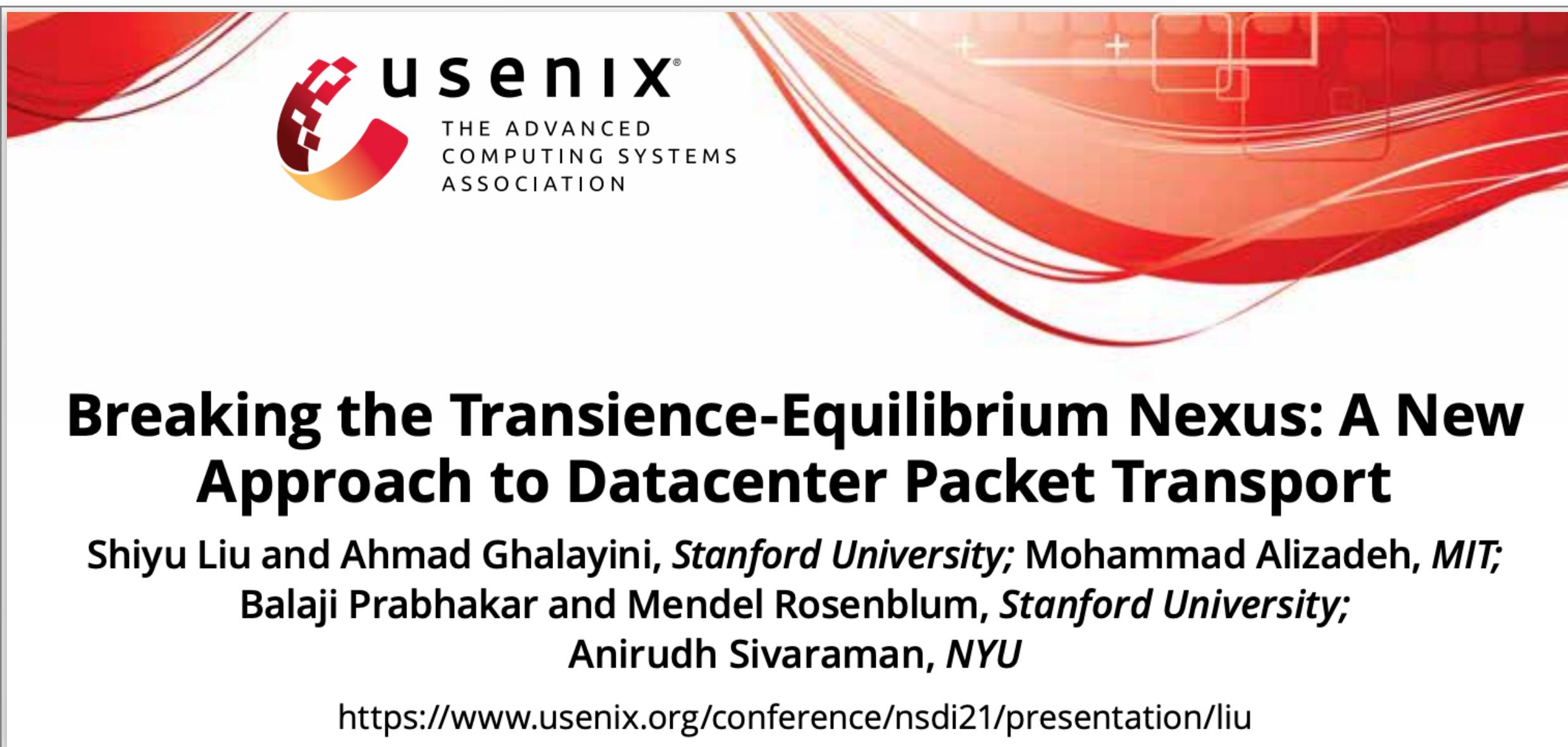
<https://www.usenix.org/conference/nsdi21/presentation/liu>

<https://www.usenix.org/conference/nsdi21/presentation/liu>



# On-Ramp congestion control

Detects congestion  
early and controls it



The USENIX logo, featuring a stylized red 'E' icon followed by the word 'usenix' in a lowercase sans-serif font, with 'THE ADVANCED COMPUTING SYSTEMS ASSOCIATION' written below it. The background of the slide features a blurred image of a highway with motion streaks.

**Breaking the Transience-Equilibrium Nexus: A New Approach to Datacenter Packet Transport**

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<https://www.usenix.org/conference/nsdi21/presentation/liu>

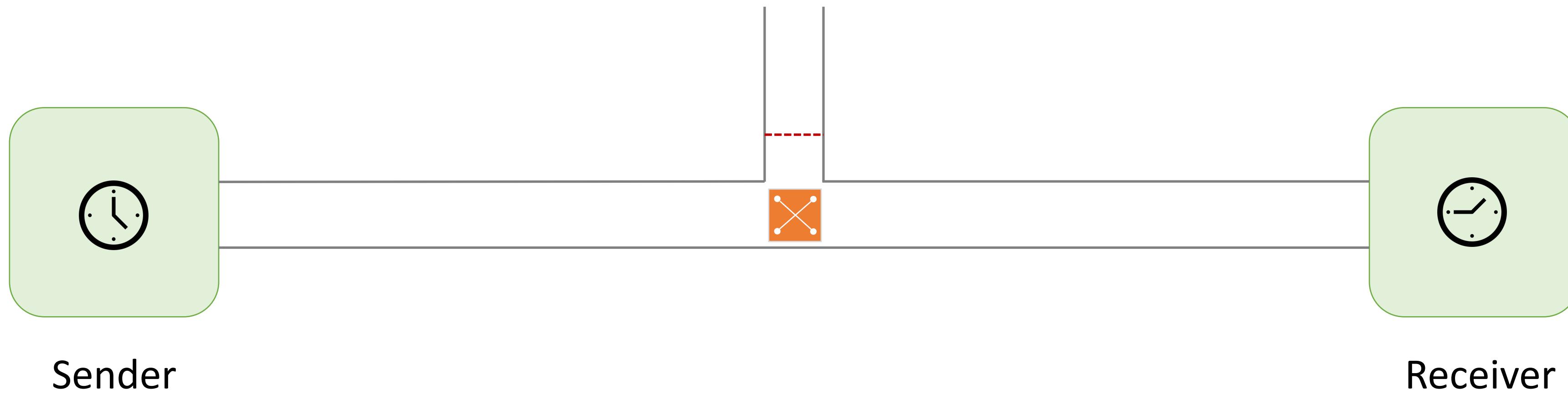
<https://www.usenix.org/conference/nsdi21/presentation/liu>



# On-Ramp: buffer headroom

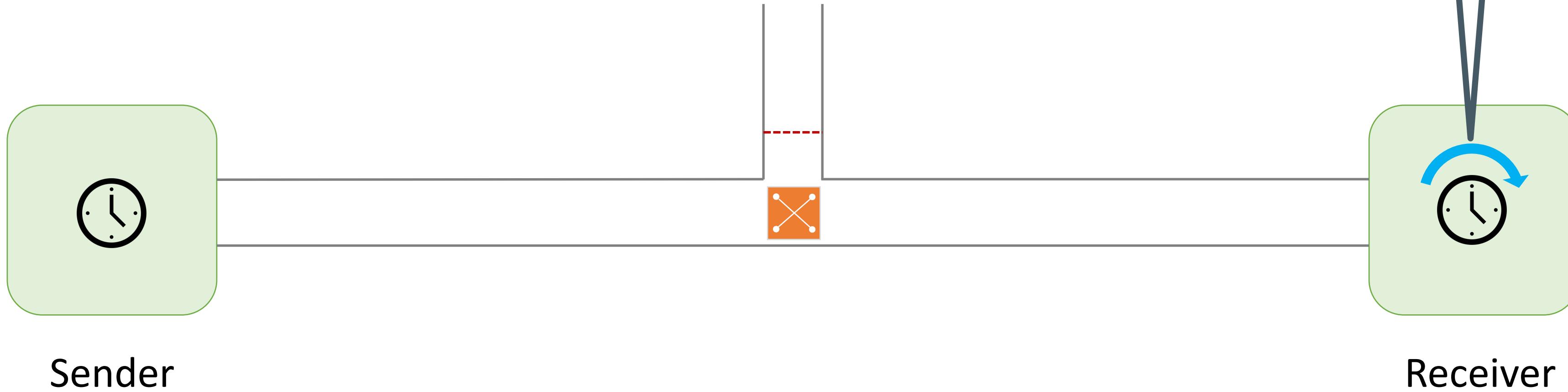


# On-Ramp: buffer headroom

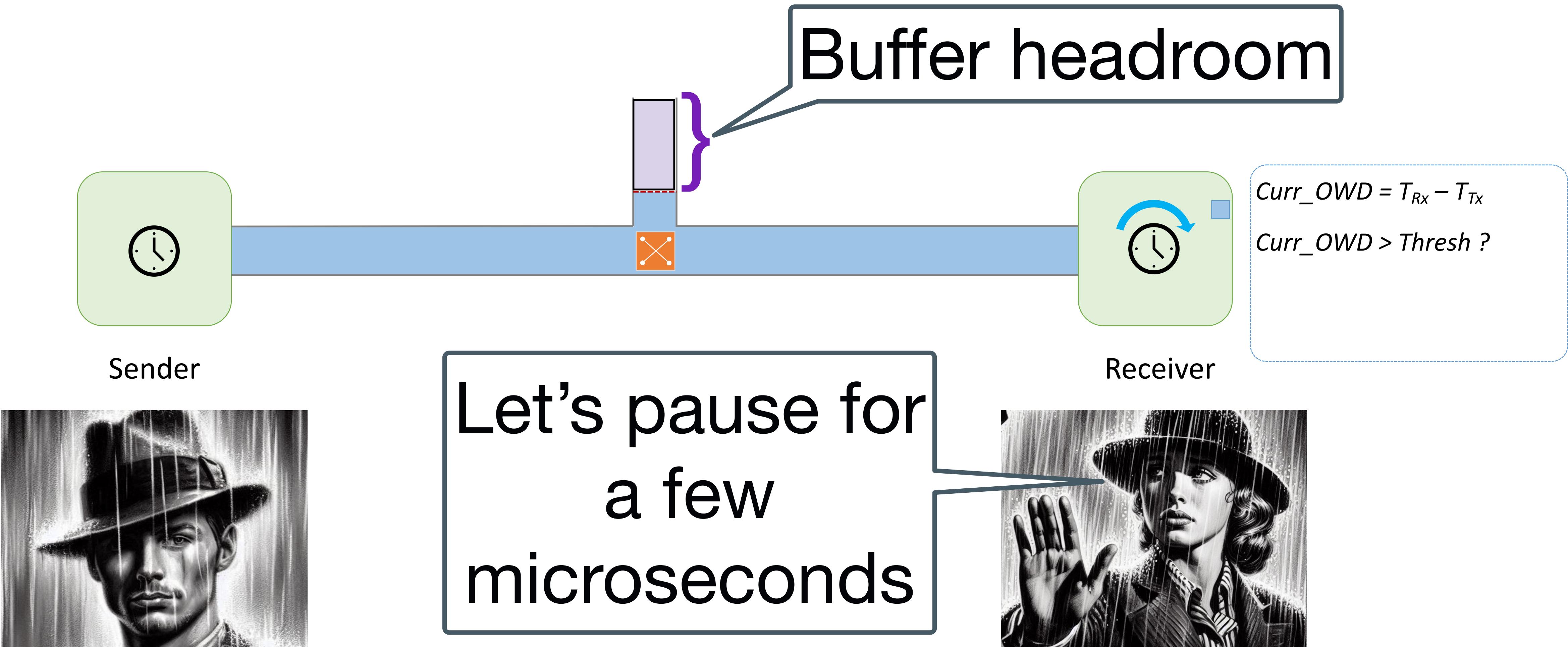


# On-Ramp: buffer headroom

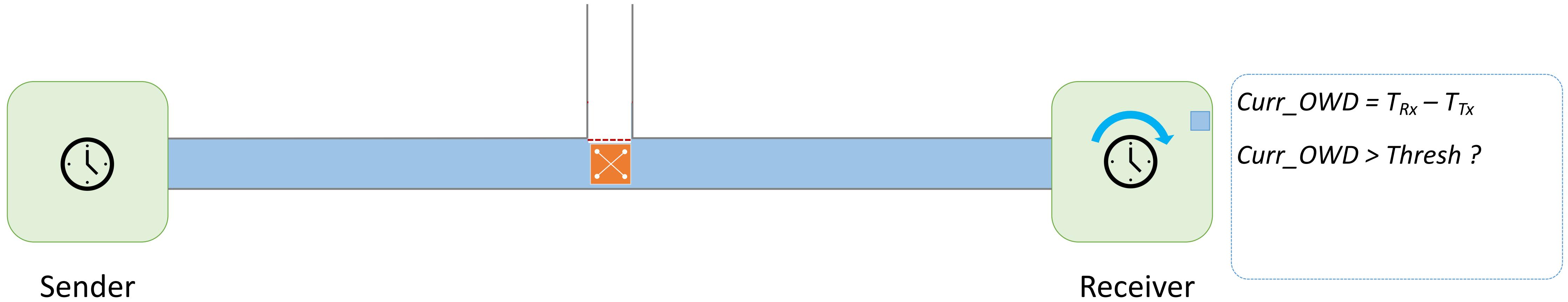
Clocks are synchronized



# On-Ramp: buffer headroom



# On-Ramp: buffer headroom



# On-Ramp: buffer headroom

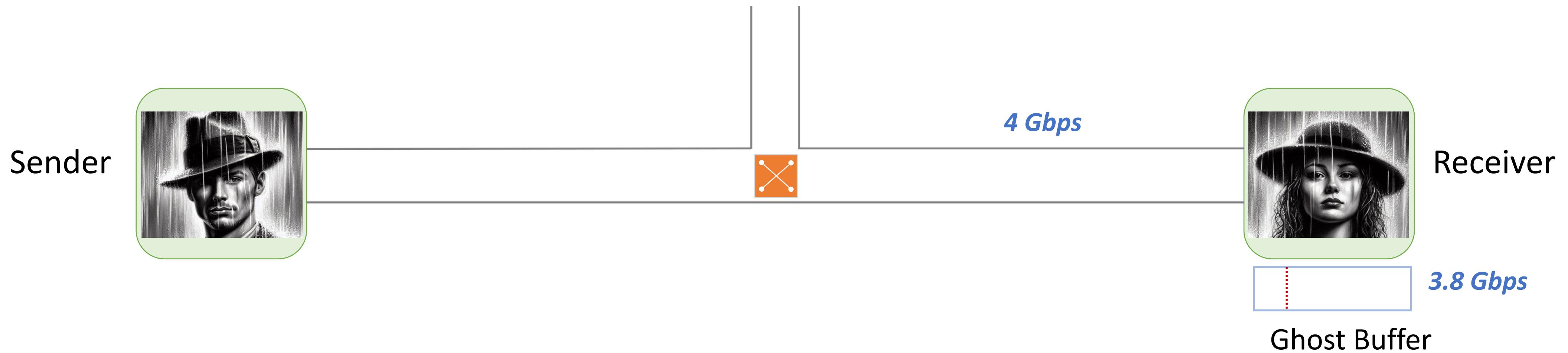
Eliminates retransmits,  
timeouts



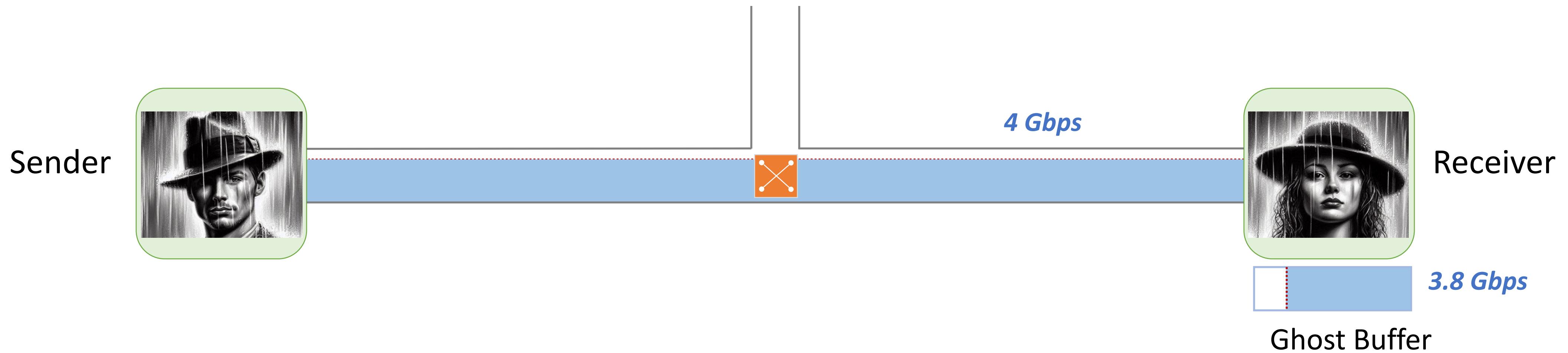
Bring it on!



# On-Ramp: optimize goodput with bandwidth headroom

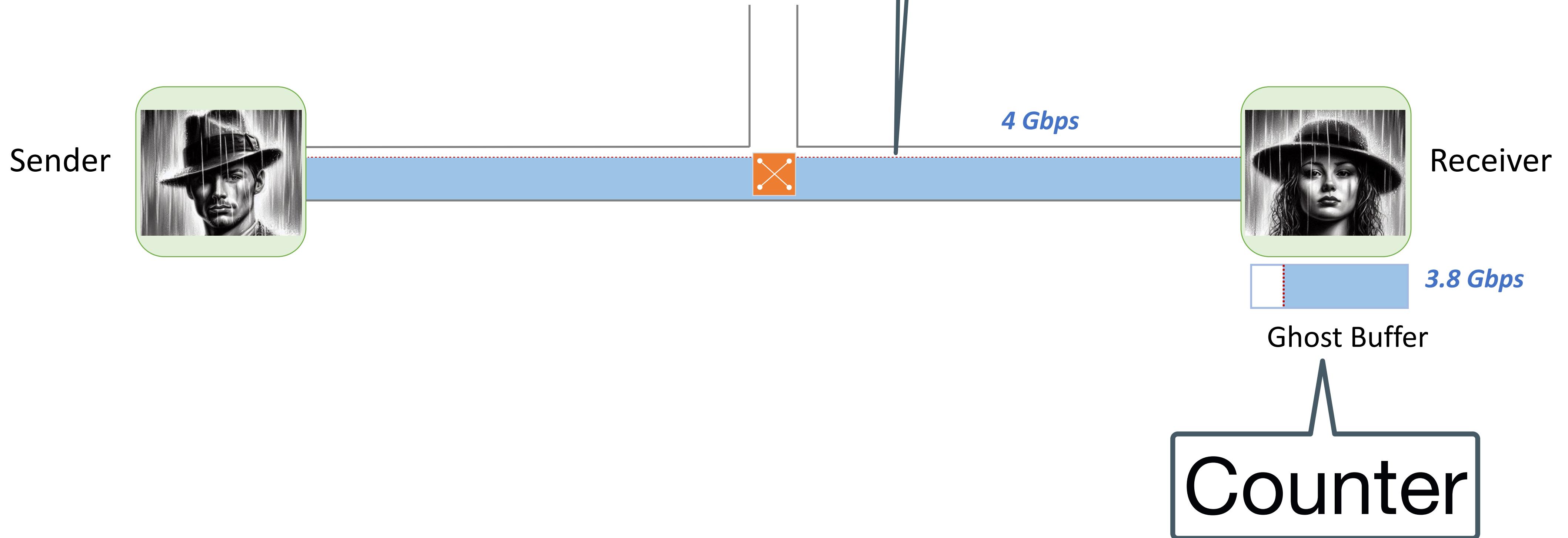


# On-Ramp: optimize goodput with bandwidth headroom



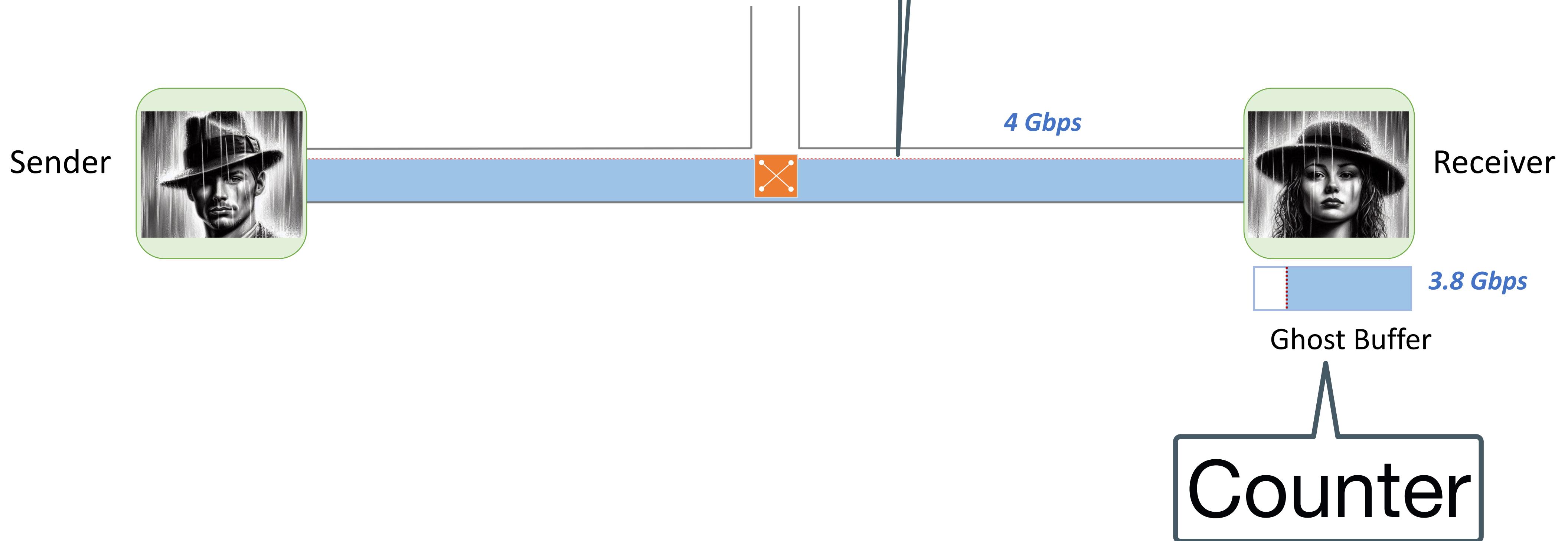
# On-Ramp: optimize goodput with bandwidth headroom

## Bandwidth headroom

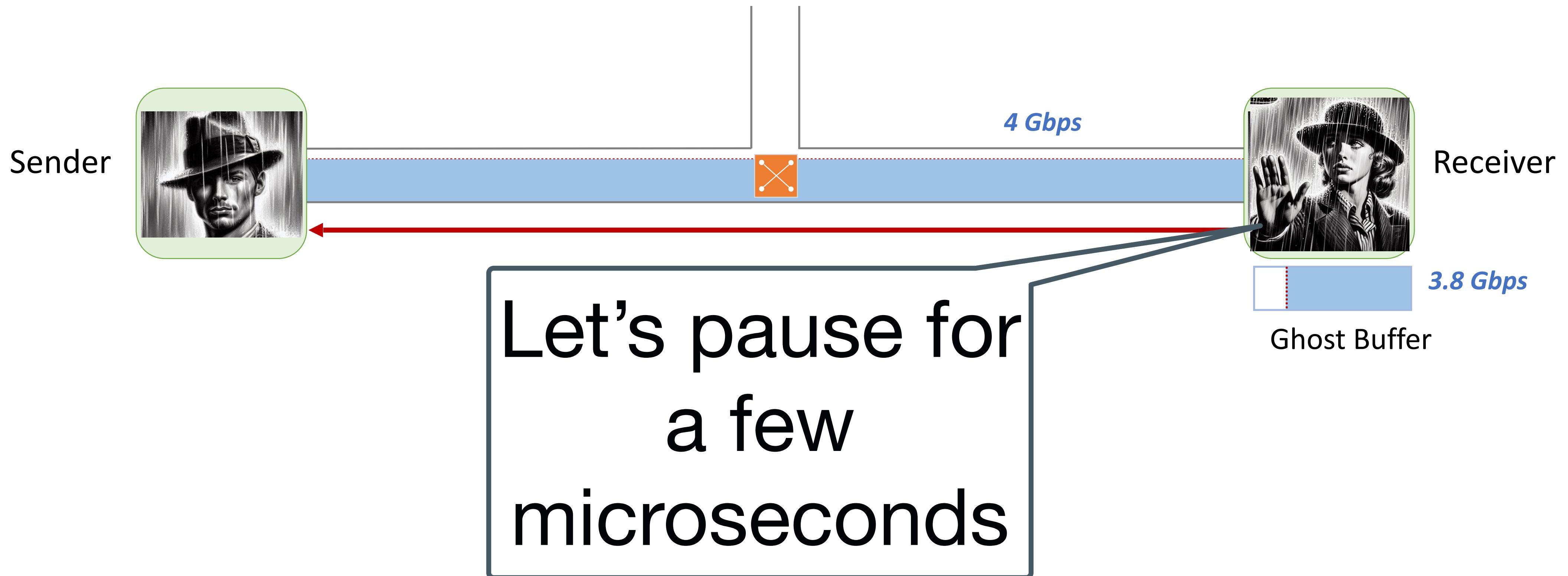


# On-Ramp: optimize goodput with bandwidth headroom

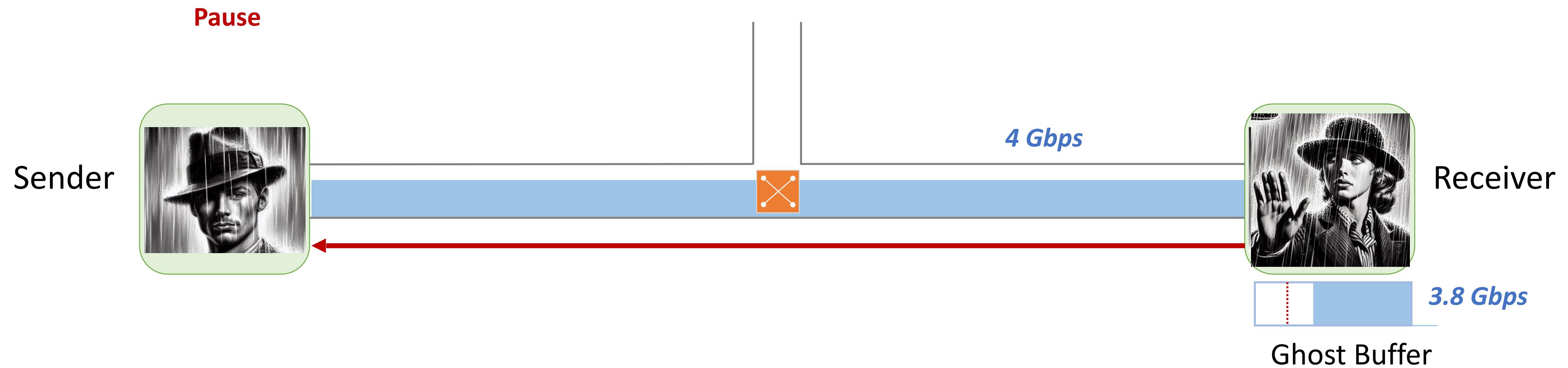
## Bandwidth headroom



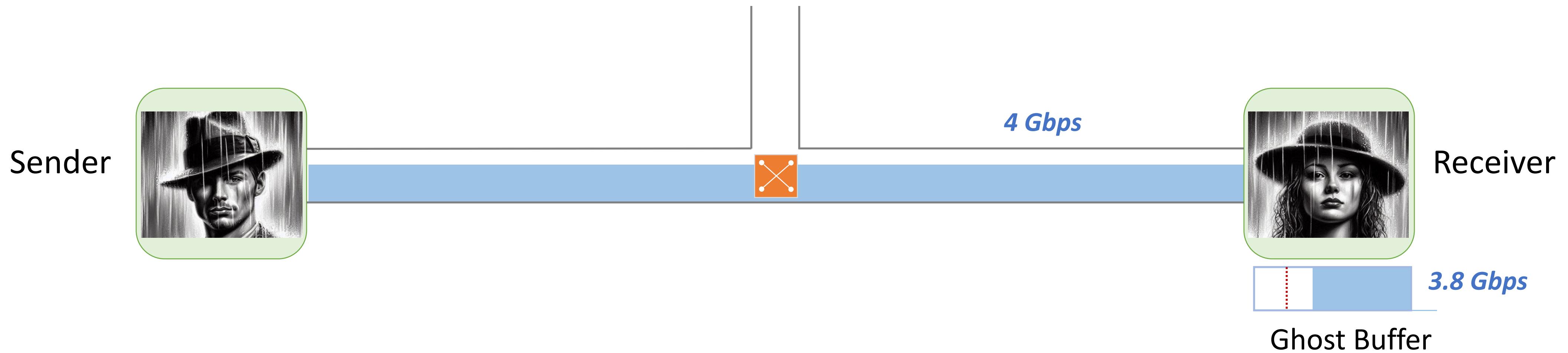
# On-Ramp: optimize goodput with bandwidth headroom



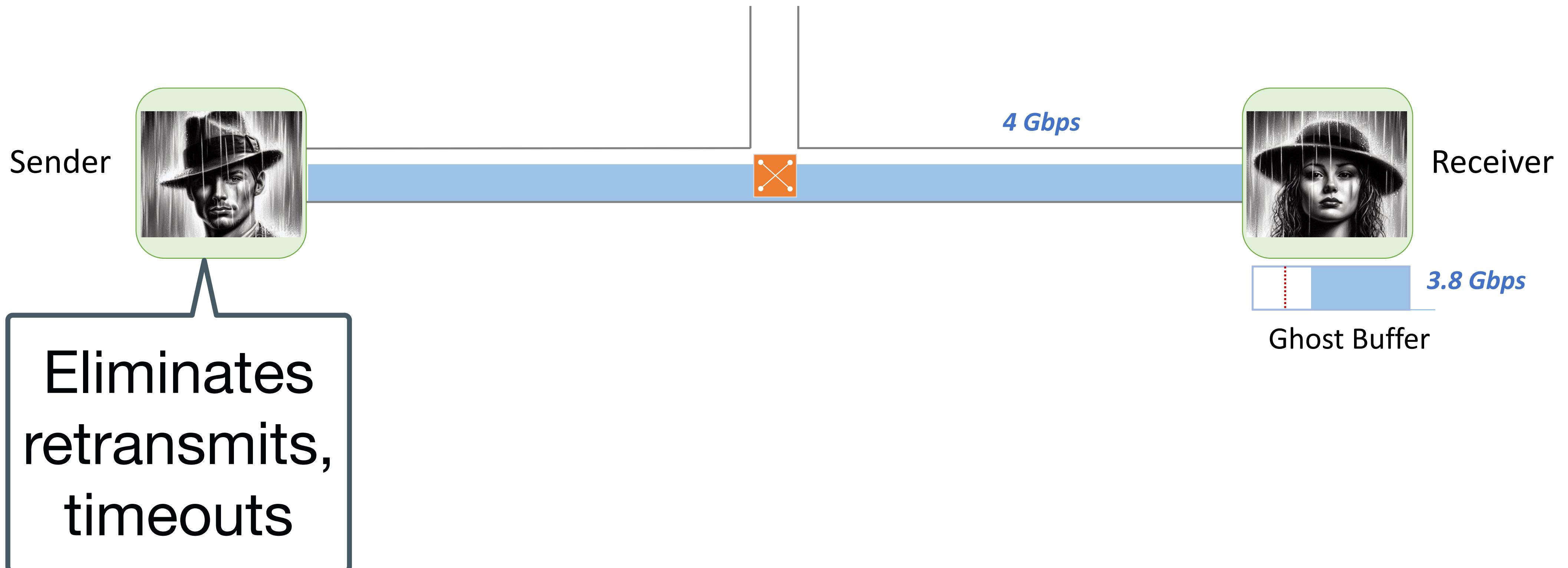
# On-Ramp: optimize goodput with bandwidth headroom



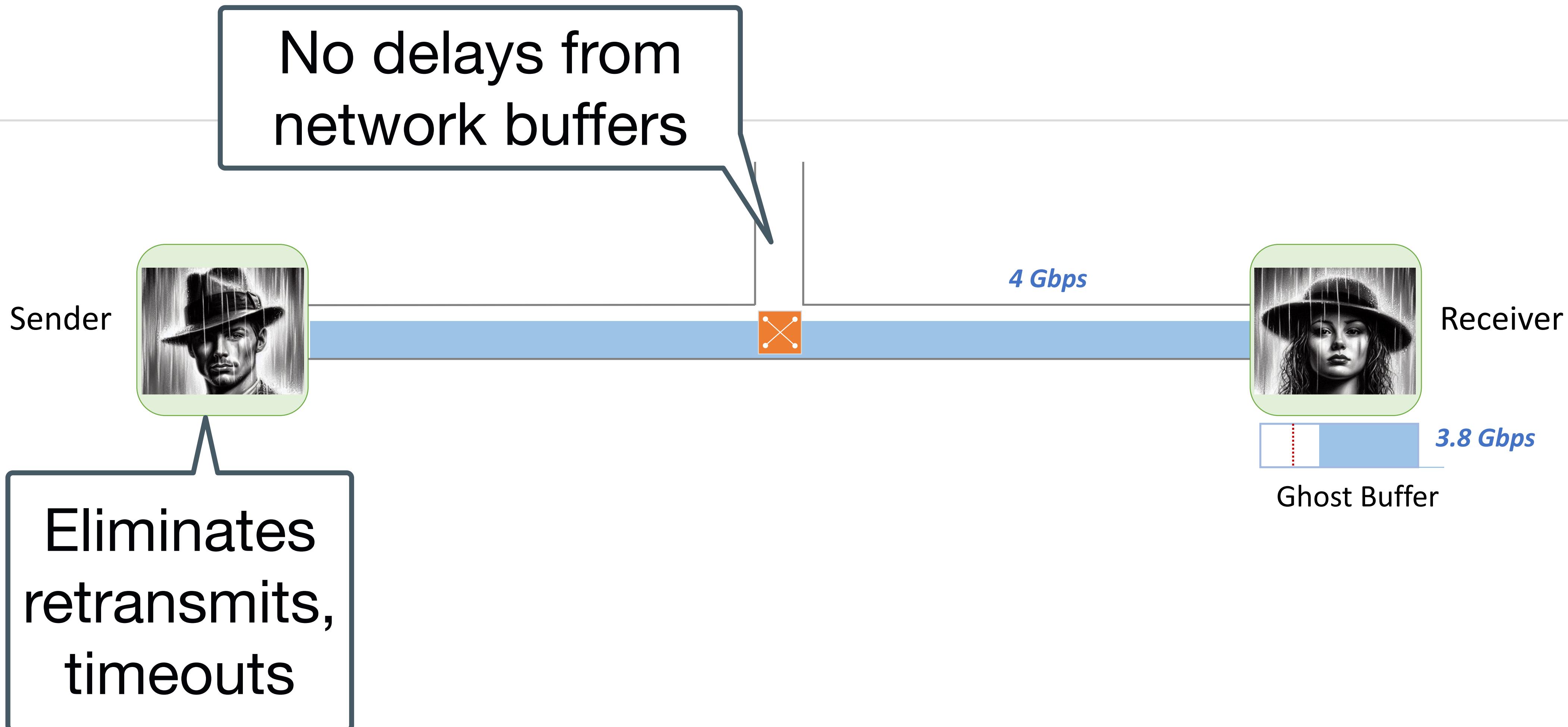
# On-Ramp: optimize goodput with bandwidth headroom



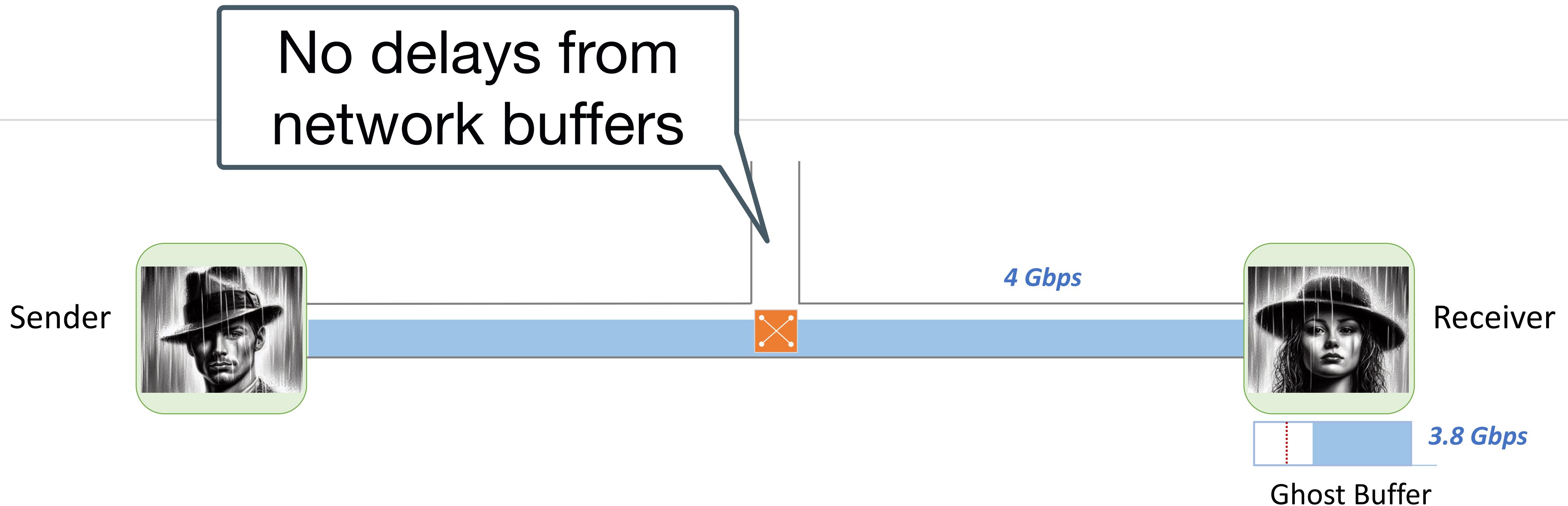
# On-Ramp: optimize goodput with bandwidth headroom



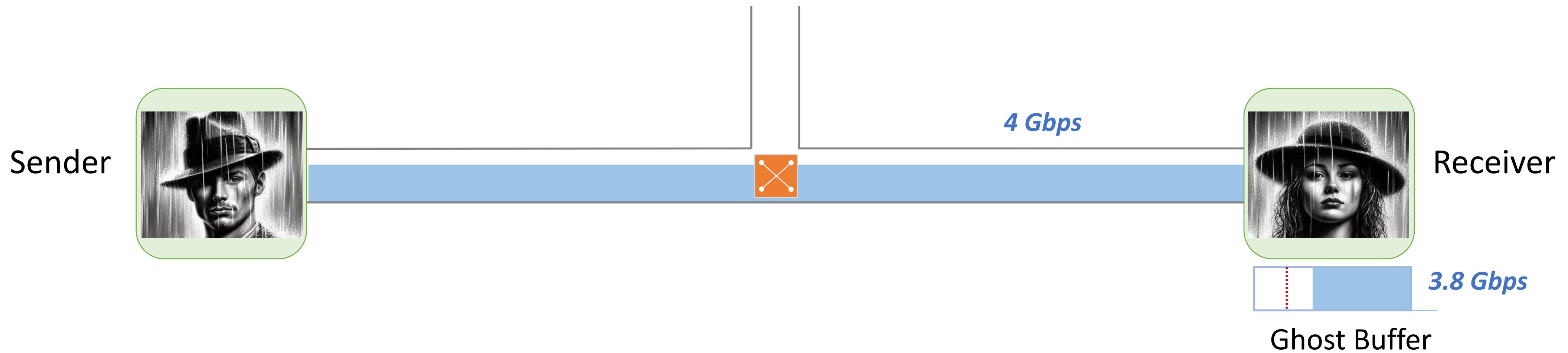
# On-Ramp: optimize goodput with bandwidth headroom



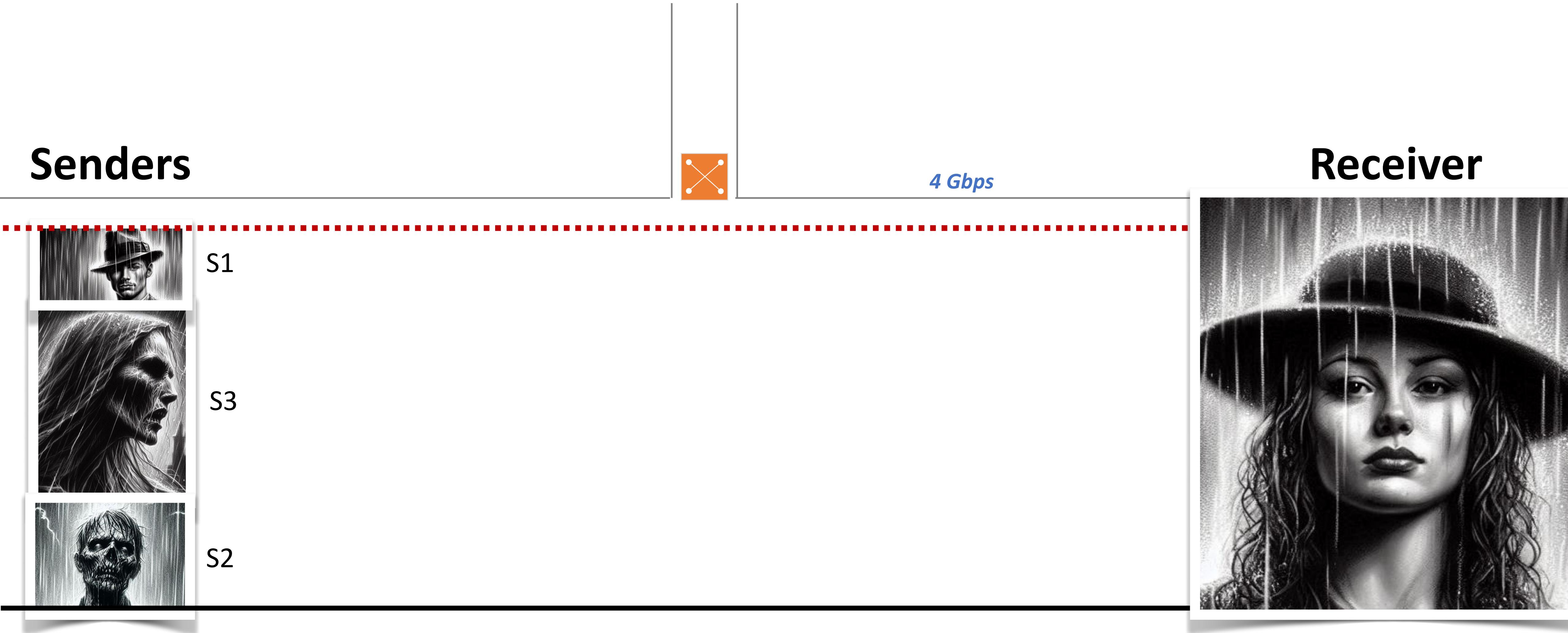
# On-Ramp: optimize goodput with bandwidth headroom



# On-Ramp: optimize goodput with bandwidth headroom



# Bandwidth slicing from receiver's end



# Bandwidth slicing from receiver's end

**Senders**



S1



S3



S2



*4 Gbps*



*2.3 Gbps*

**Receiver**



# Bandwidth slicing from receiver's end

**Senders**



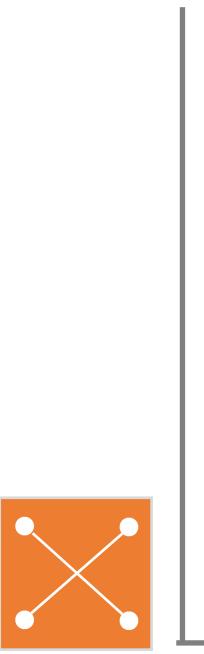
S1



S3



S2



*4 Gbps*

**Receiver**

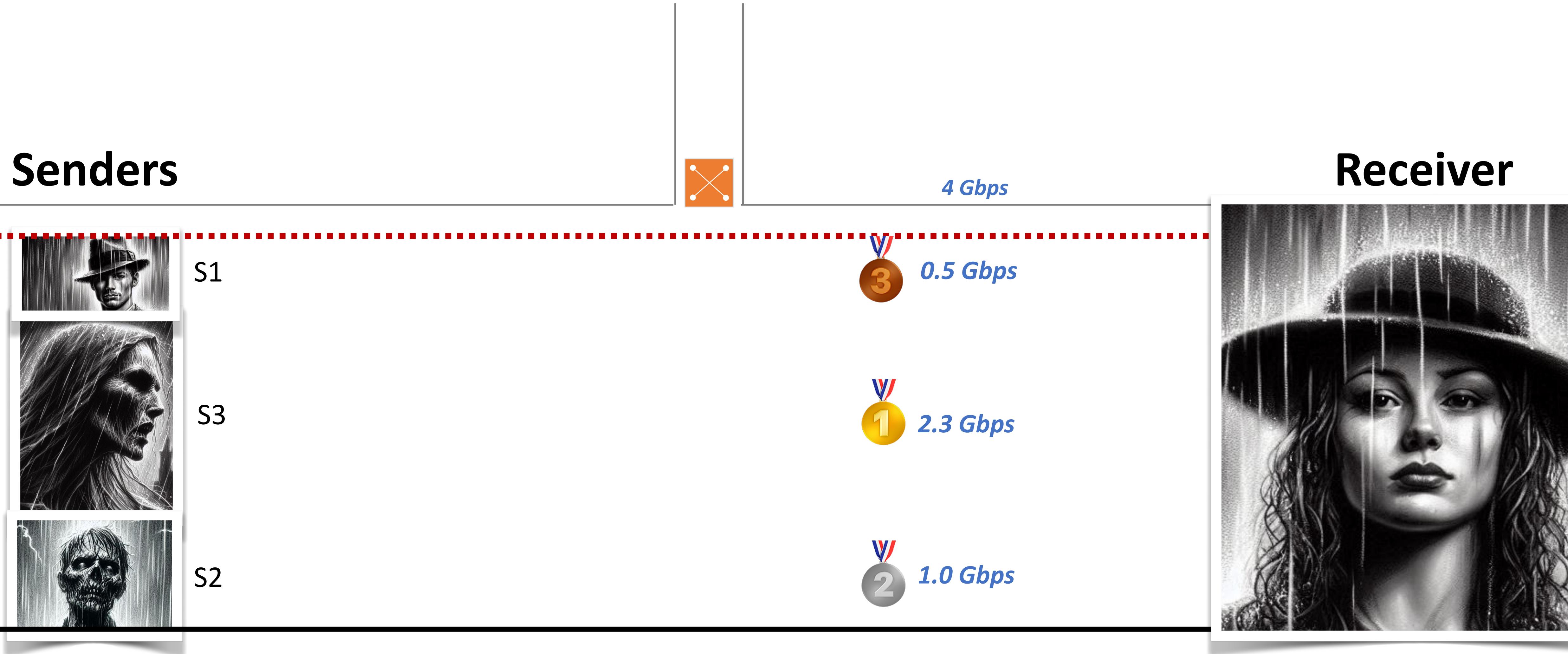


*2.3 Gbps*

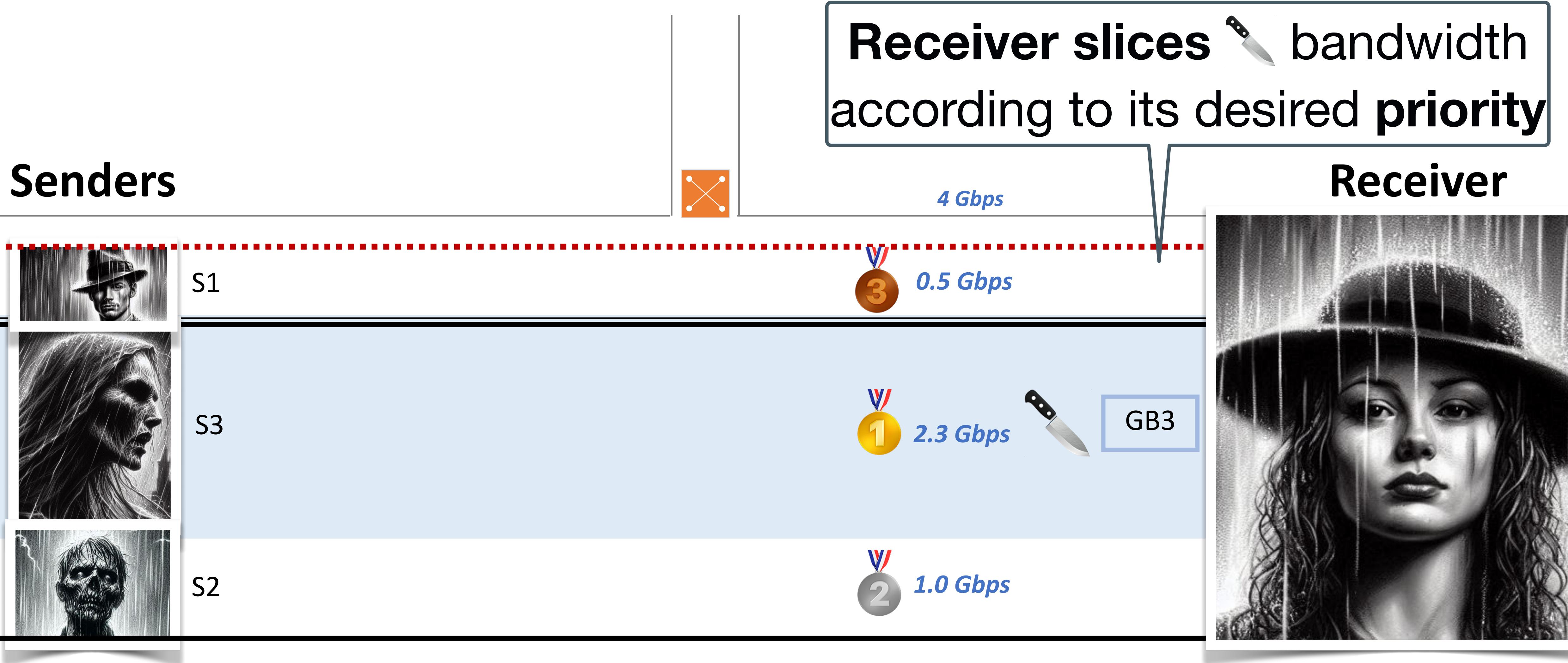


*1.0 Gbps*

# Bandwidth slicing from receiver's end



# Bandwidth slicing from receiver's end



# Bandwidth slicing from receiver's end

**Senders**



S1



S3



S2



**Receiver slices bandwidth according to its desired priority**

*4 Gbps*

*0.5 Gbps*

*2.3 Gbps*

*1.0 Gbps*

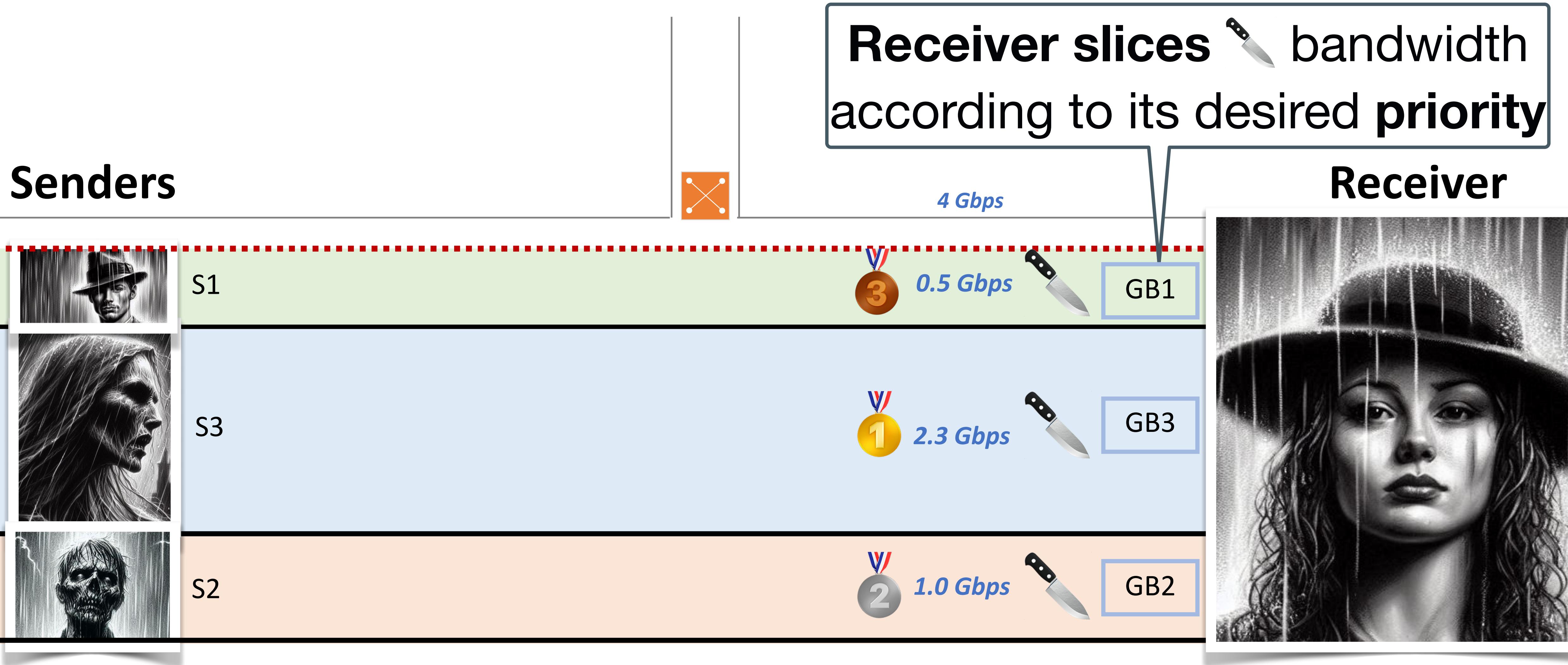
**Receiver**



GB3

GB2

# Bandwidth slicing from receiver's end



If it is



I did it!

If it is



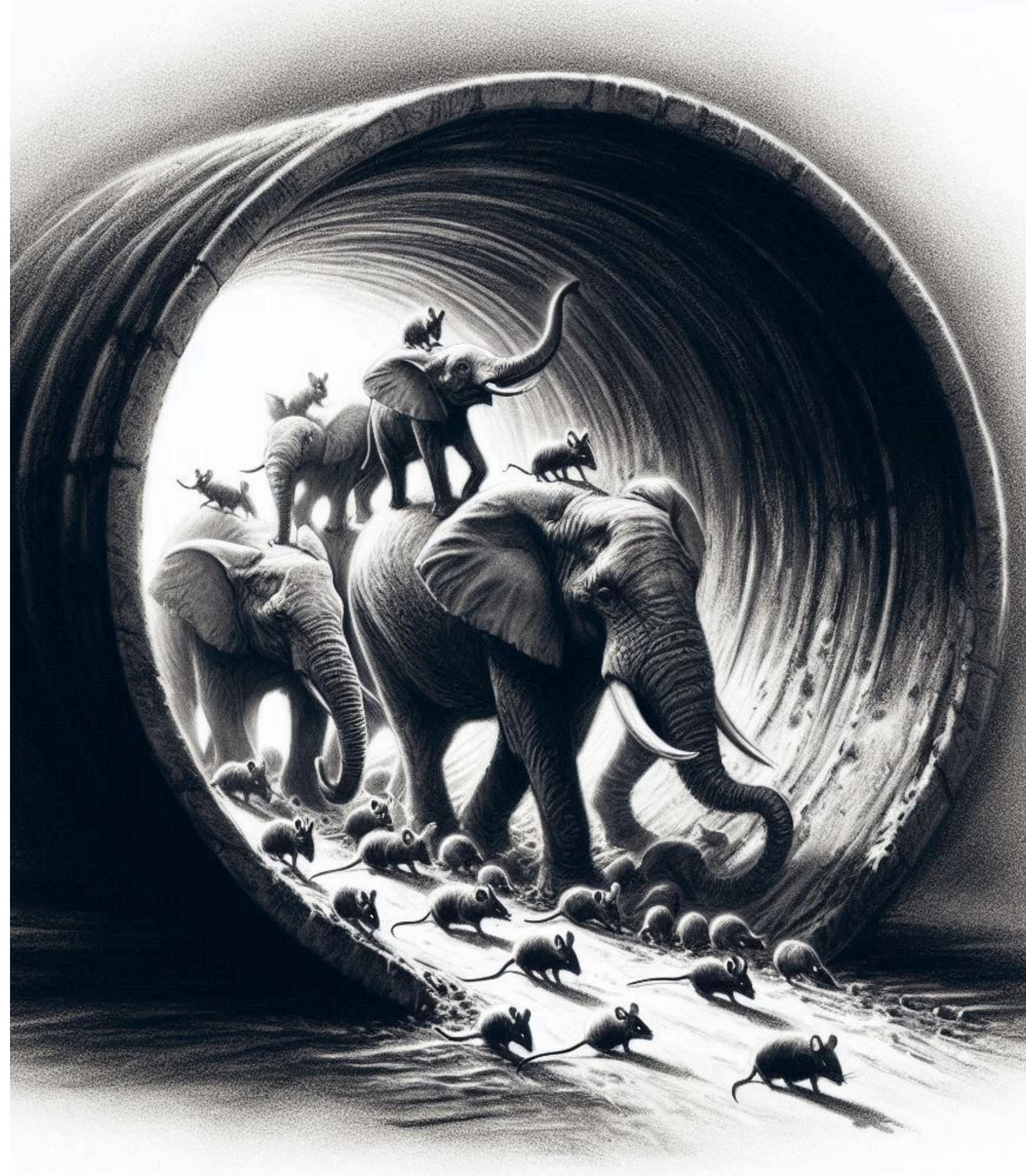
# Huygens

With **clock offsets and drifts**  
at a high precision, we can  
measure  **delays.**



# On-Ramp

If we know one way delays, we  
can **detect and control** upcoming  
**congestion at a high precision.**



# Thank You

Huygens



On-Ramp



**Lerna Ekmekcioglu**  
 [lerna@clockwork.io](mailto:lerna@clockwork.io)

