

## Modeling and Reducing Spatial Jitter caused by Asynchronous Input and Output Rates



Evaluation Hcéres de l'UMR 9189 CRISTAL (8-10 octobre 2024)

Créneau Sciences I2C

# Contexte



- **Equipe Loki**  
Réconcilier la conception de systèmes interactifs avec les capacités humaines
- **Membre IUF Junior de 2018 à 2023**  
Projet : “Redesigning the interaction loop in interactive systems”
- **Google Faculty Research Award en 2019**
- **Article publié à ACM UIST en 2020**



Session 10B: Interaction Models

UIST '20, October 20–23, 2020, Virtual Event, USA



## Modeling and Reducing Spatial Jitter caused by Asynchronous Input and Output Rates

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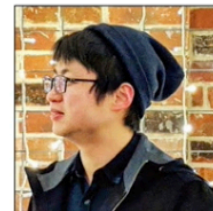
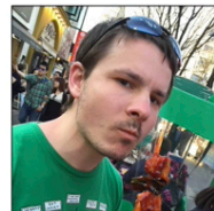
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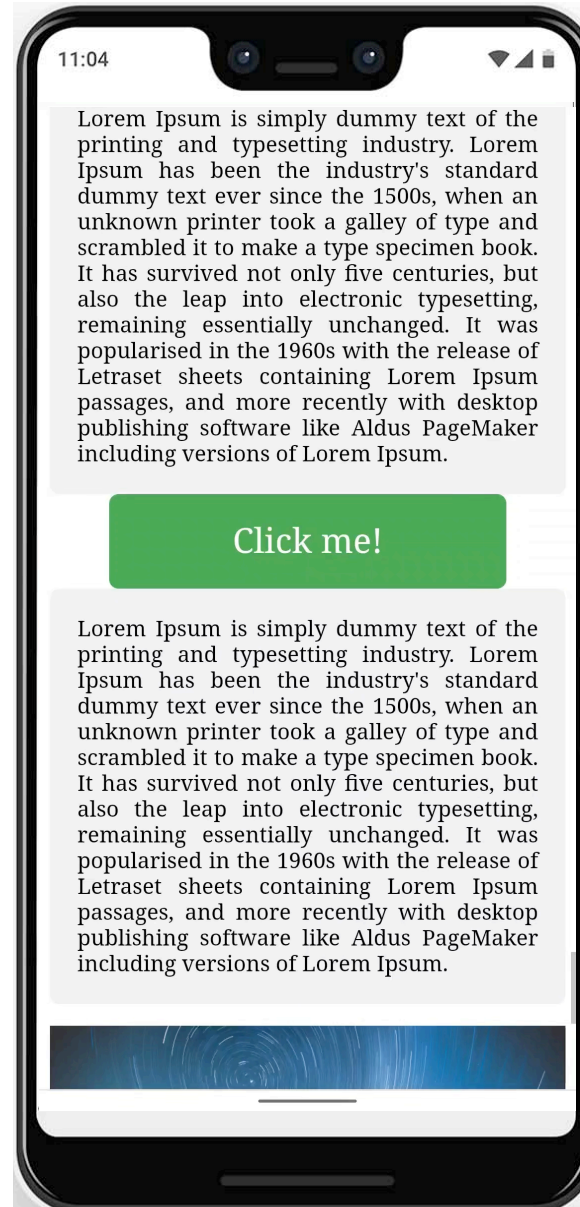
### ABSTRACT

Jitter in interactive systems occurs when visual feedback is perceived as unstable or trembling even though the input signal is smooth or stationary. It can have multiple causes such as sensing noise, or feedback calculations introducing or exacerbating sensing imprecisions. Jitter can however occur even when

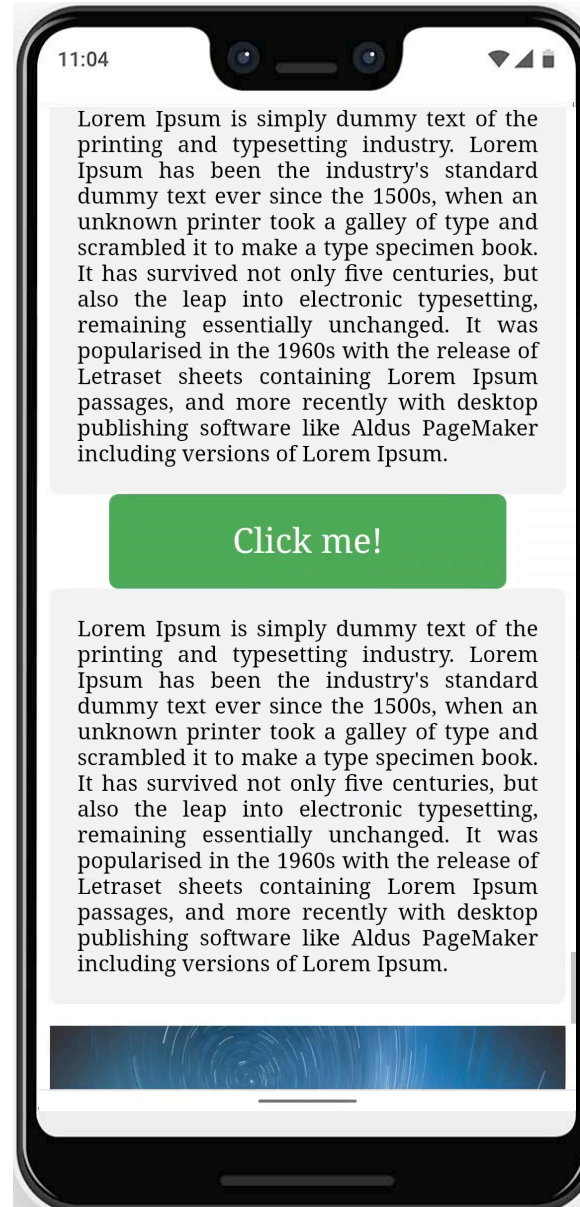
### INTRODUCTION

Jitter is defined as “*irregular random movement (as of a pointer or an image on a television screen); also : vibratory motion*” [20]. In signal processing, jitter is defined as a form of timing noise, which can have deterministic and random components. In the HCI literature however, it tends to denote

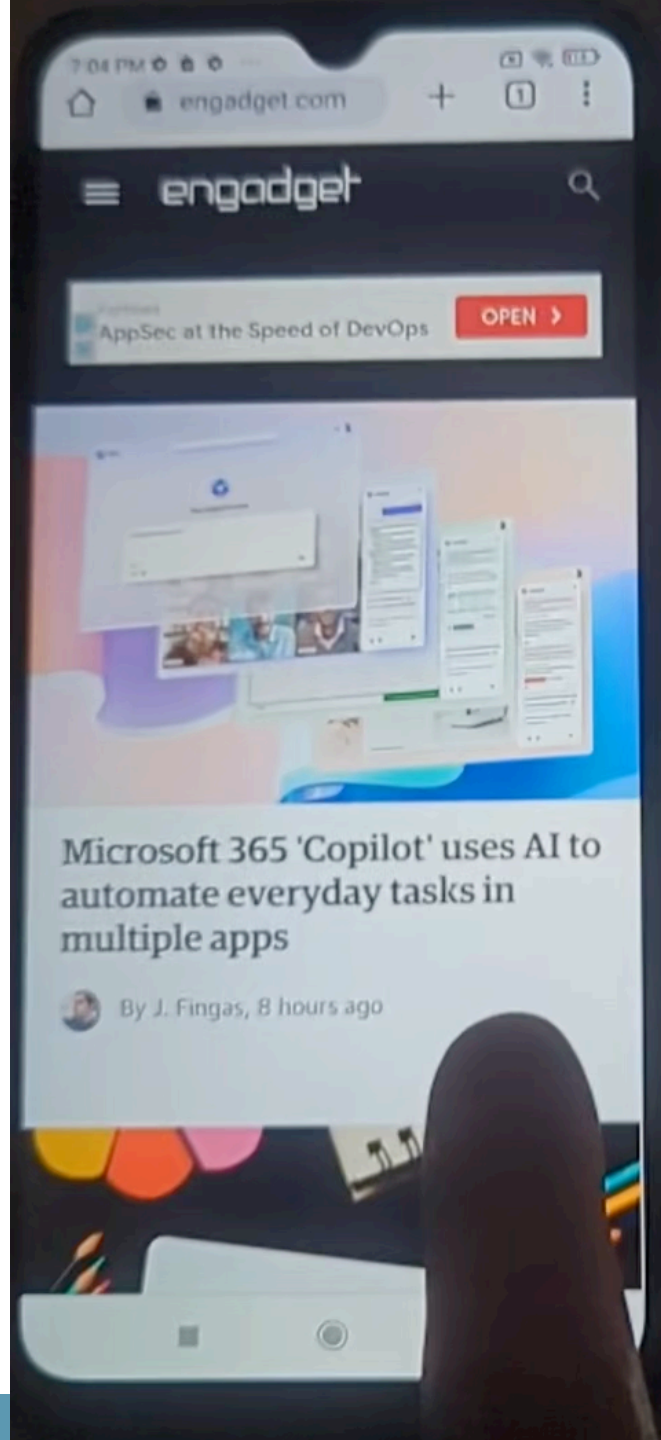




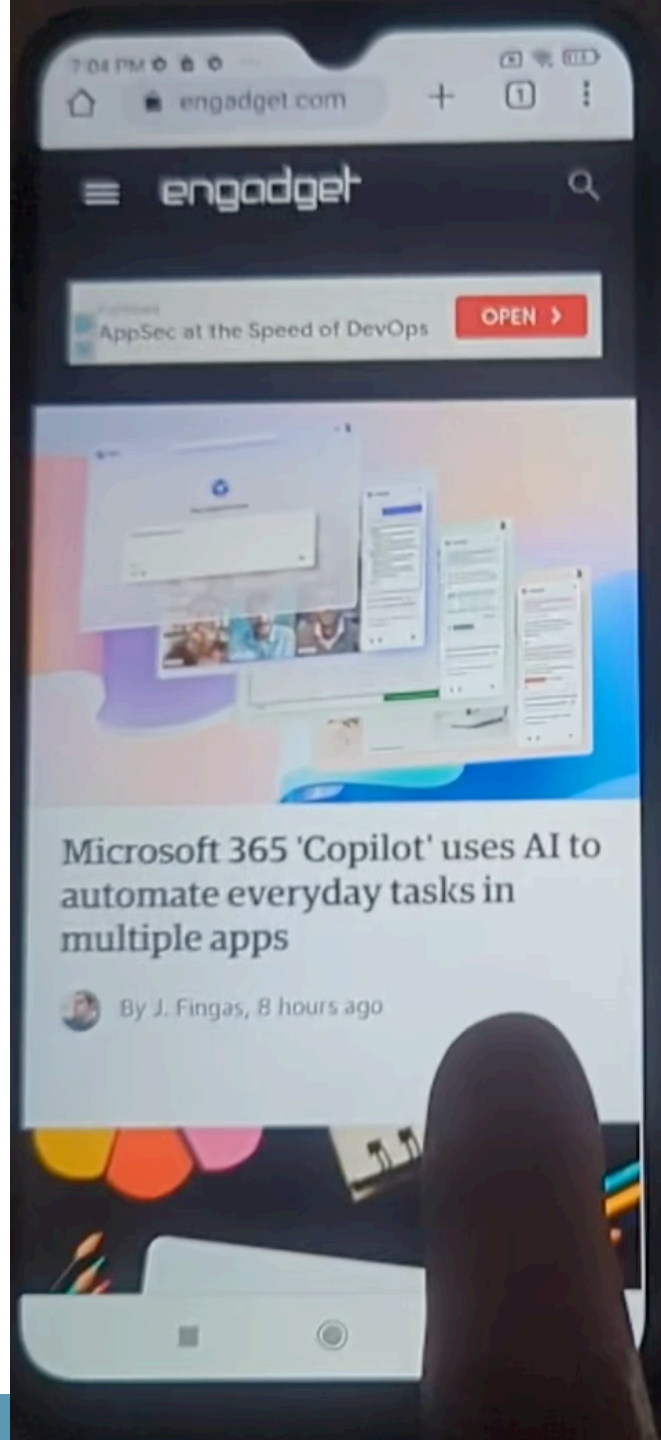




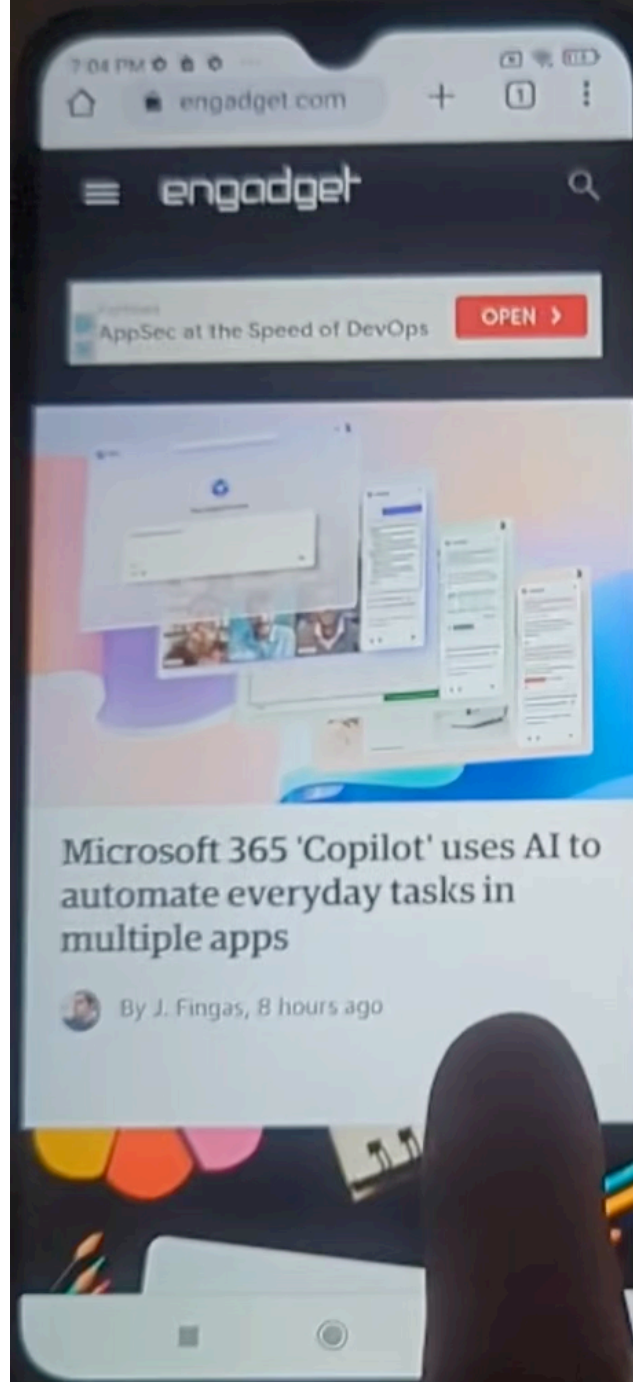
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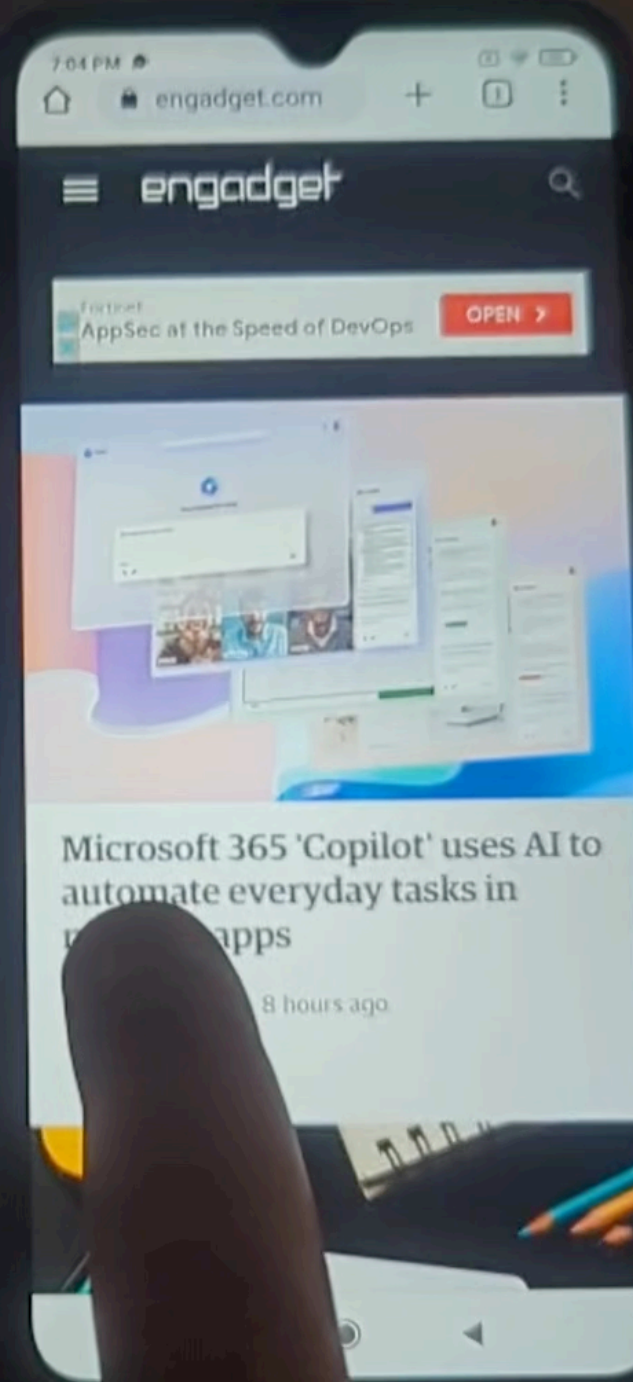
60 Hz



60 Hz



90 Hz



# Filtrage du bruit dans les systèmes interactifs

o

<https://gery.casiez.net/1euro/>

[G. Casiez et al. CHI'12]

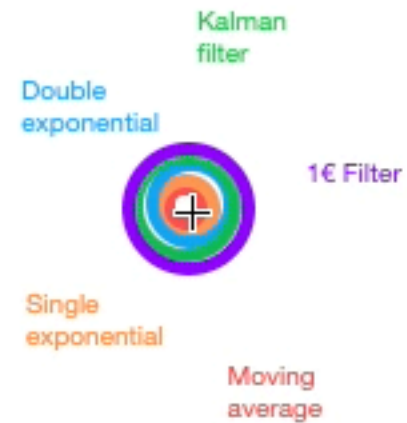
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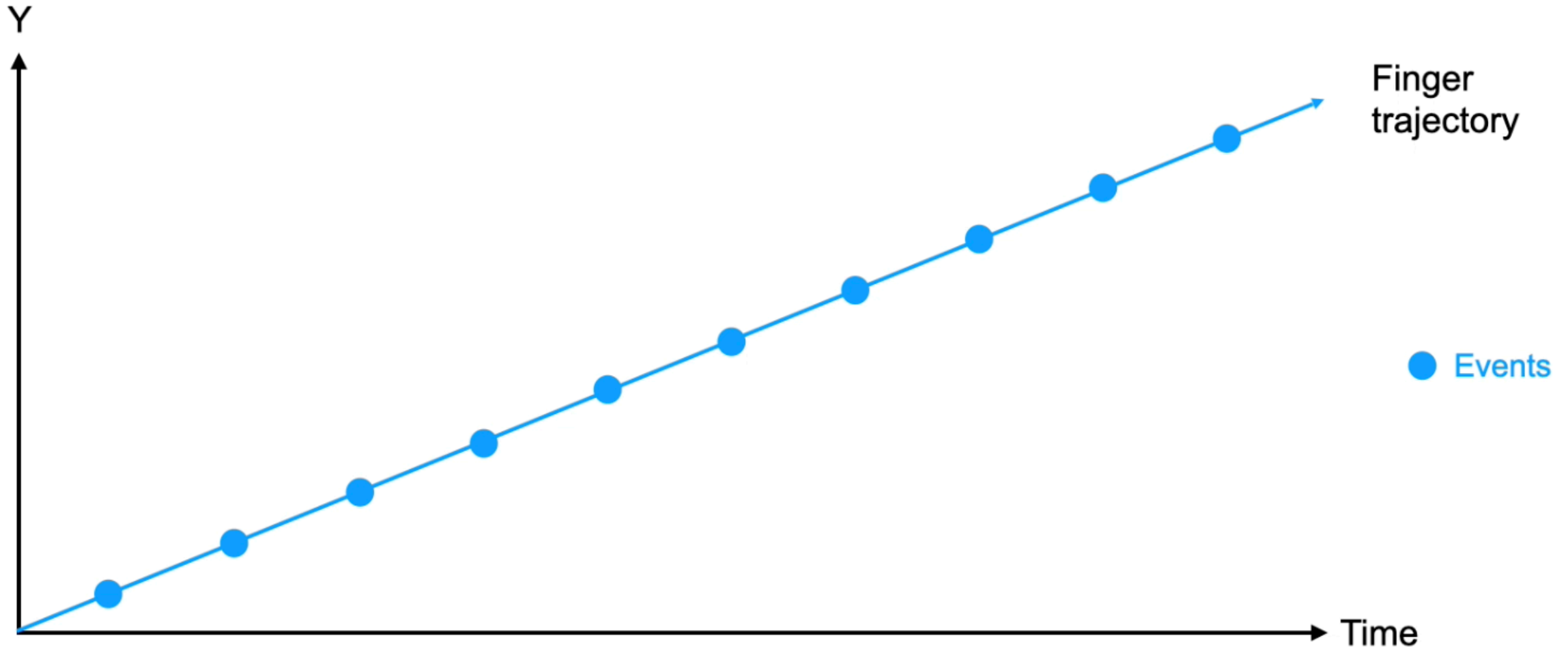
# Filtrage du bruit dans les systèmes interactifs



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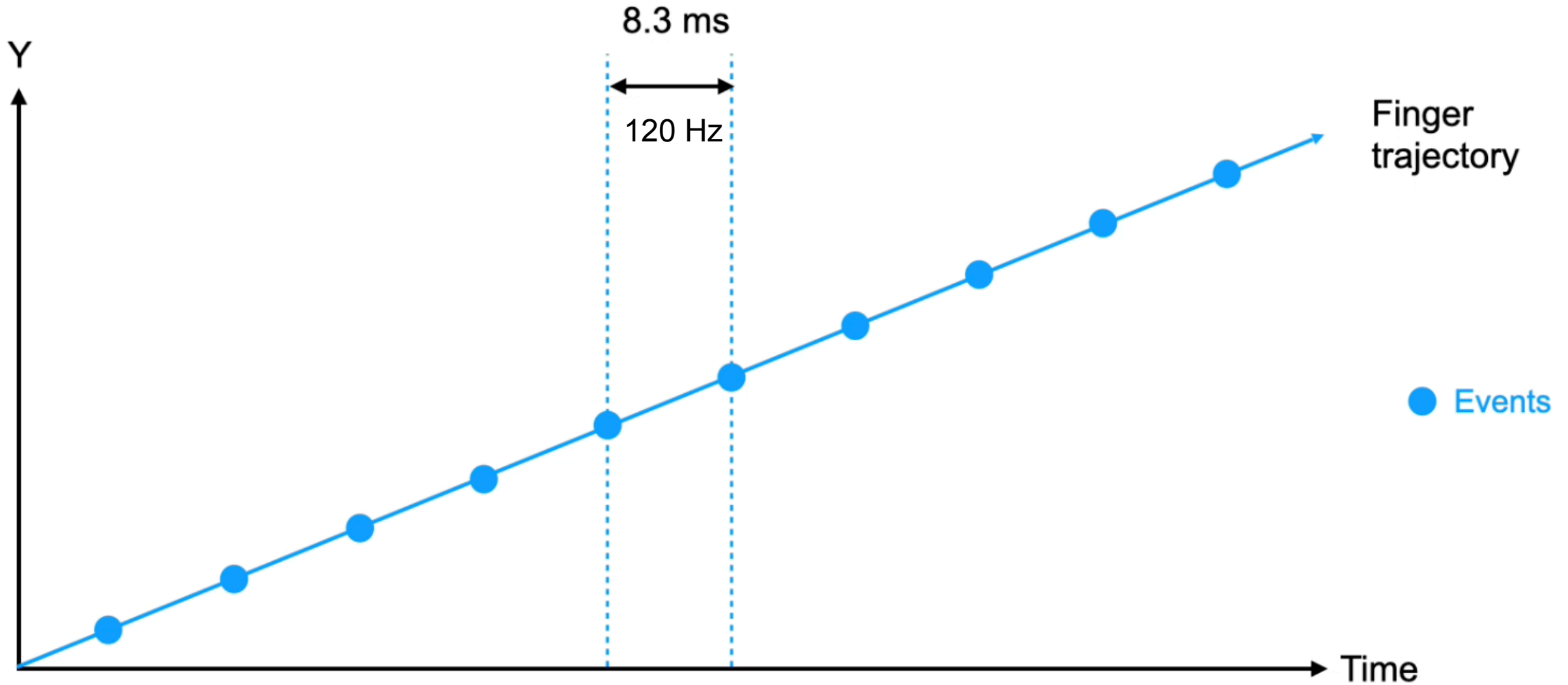
[G. Casiez et al. CHI'12]

# Illustration du problème

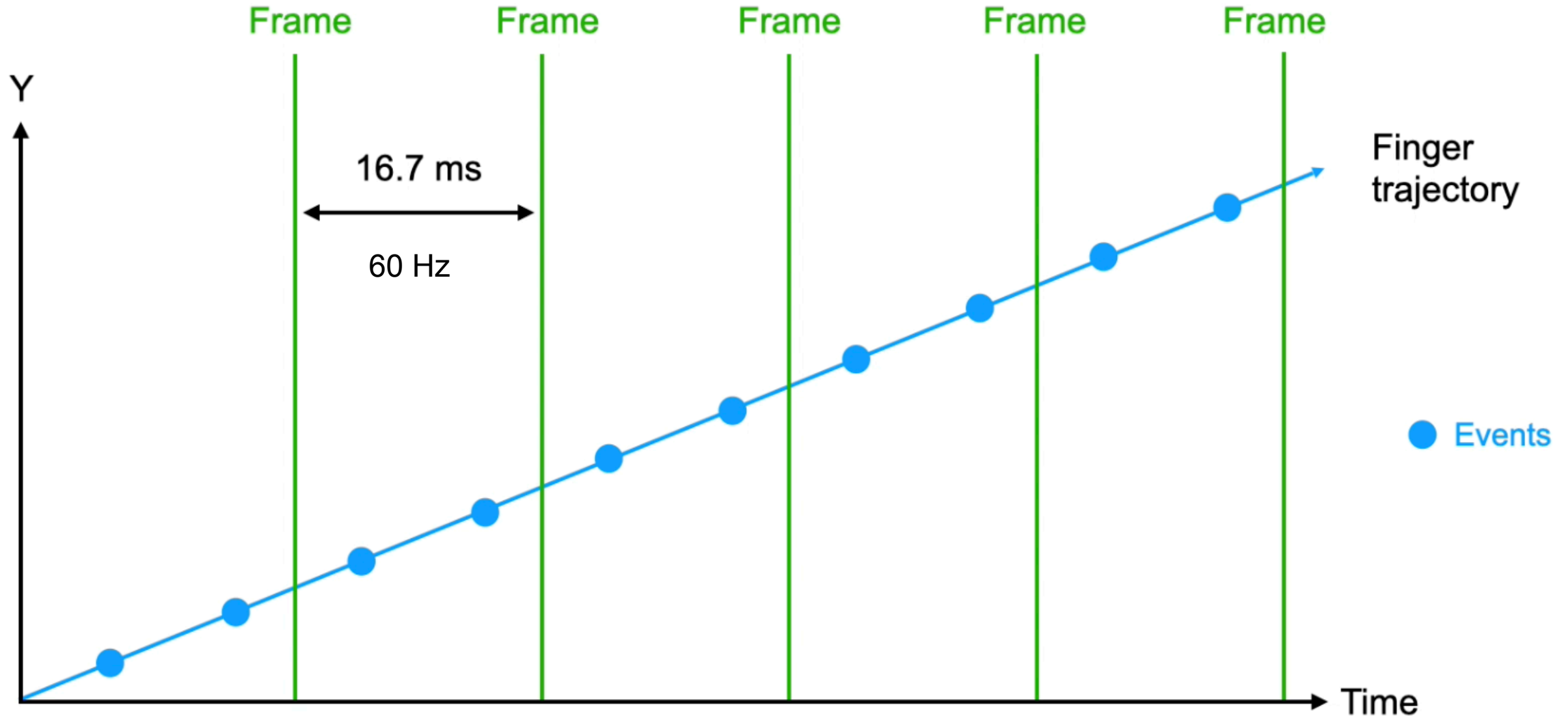




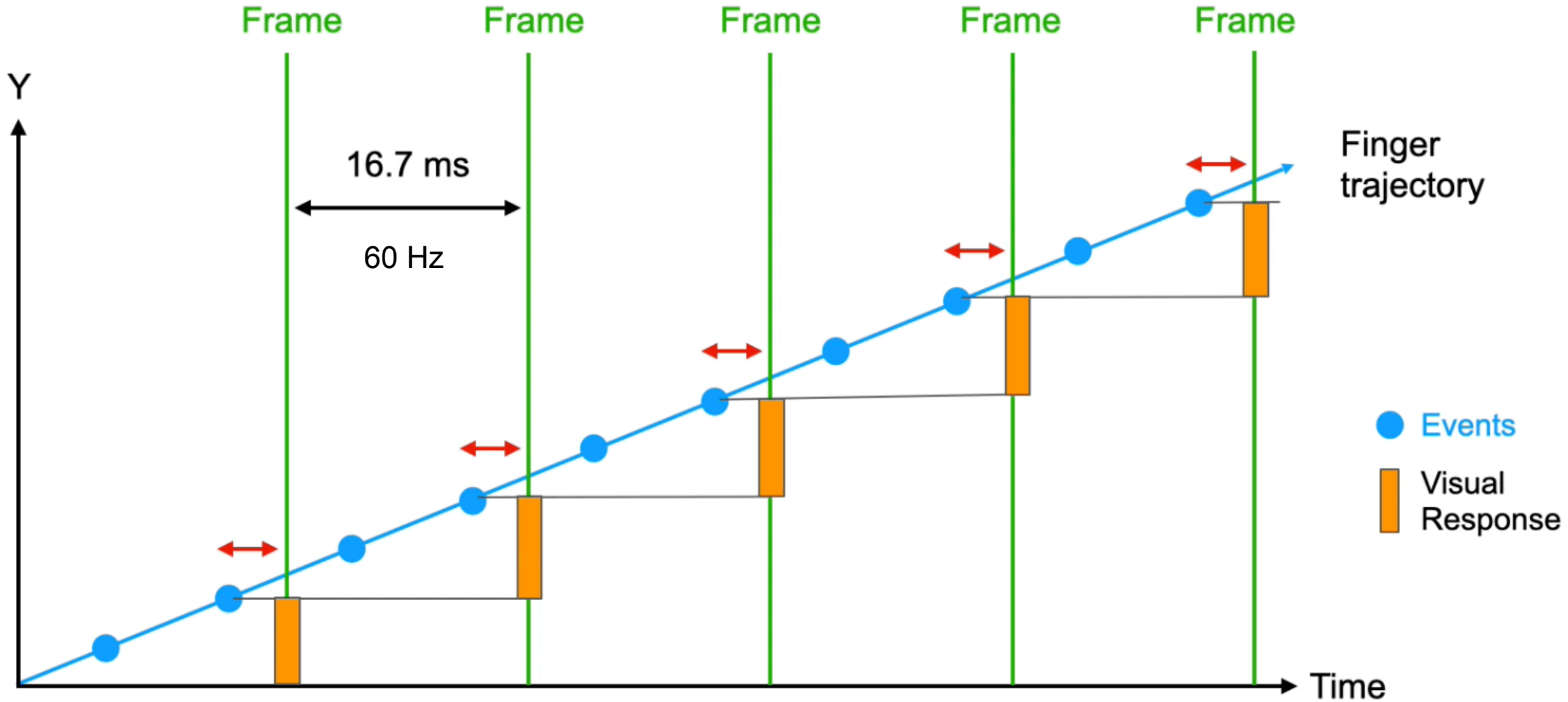
# Illustration du problème



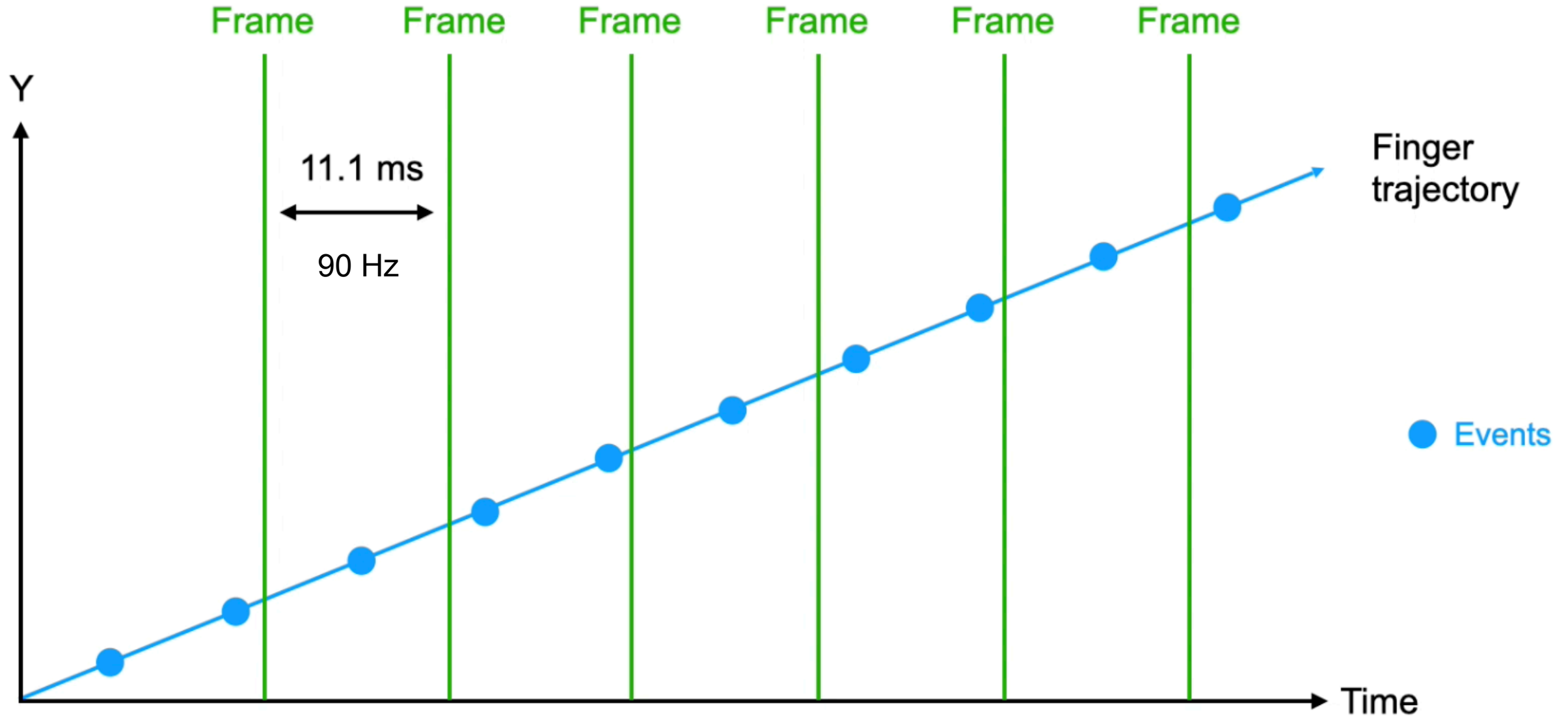
# Illustration du problème



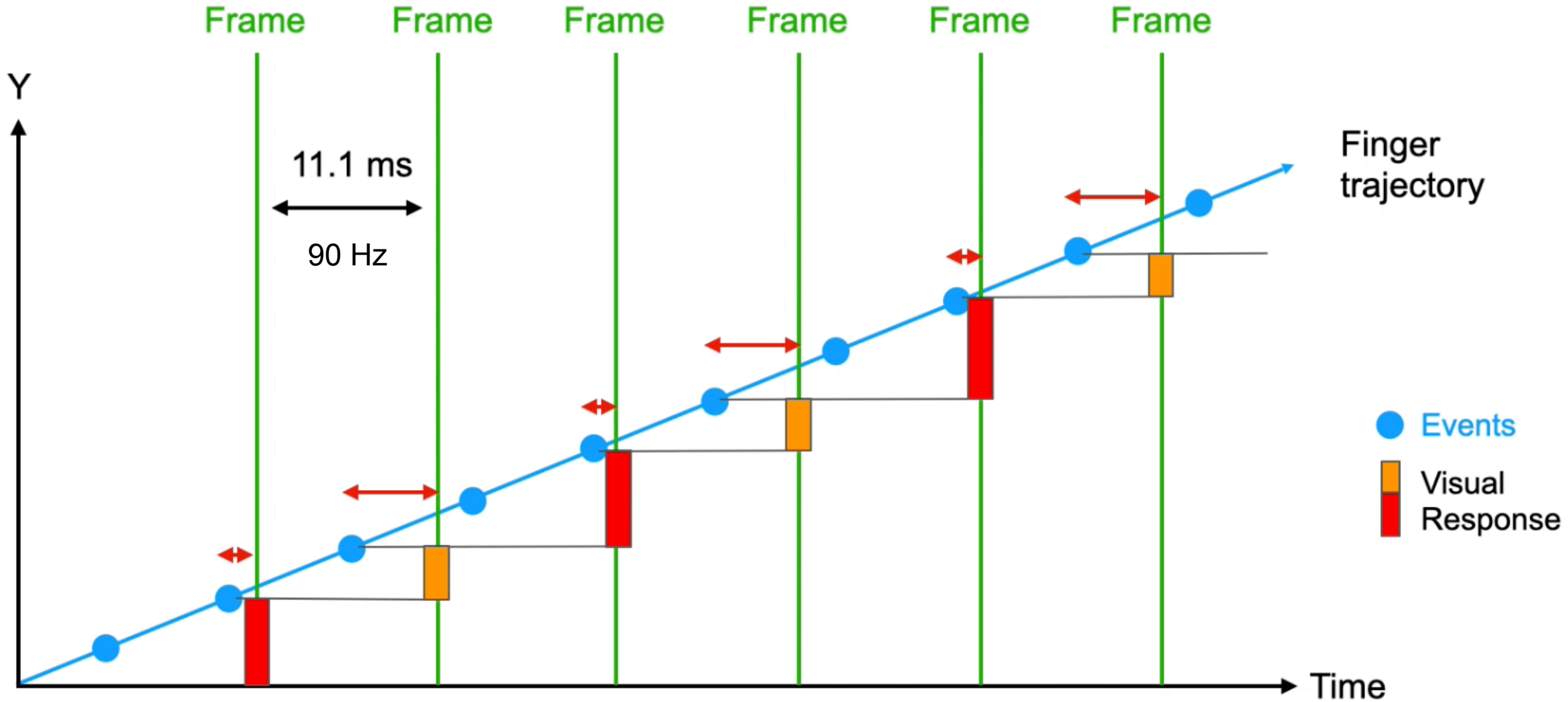
# Illustration du problème



# Illustration du problème



# Illustration du problème



## Appendix: Characterizing $\overline{|\Delta L|}$

We develop the formulation of  $\overline{|\Delta L|} = f(F_i, F_d)$  in a simple case.

First, let us define  $r \in \mathbb{R}$  such that

$$F_i = F_d \times r \quad (21)$$

We distinguish  $r$ 's floor  $c = \lfloor r \rfloor = \left\lfloor \frac{F_i}{F_d} \right\rfloor \in \mathbb{I}$ , and  $r$ 's fractional part  $a = \{r\} = \left\{ \frac{F_i}{F_d} \right\} \in [0, 1)$ :

$$\frac{F_i}{F_d} = \lfloor r \rfloor + \{r\} = a + c \quad (22)$$

We can re-express  $\overline{|\Delta L|}$  from Equation (11) as

$$\begin{aligned} \overline{|\Delta L|} &= \frac{1}{n} \sum_{j=1}^n |\Delta L(j)| \\ &= \frac{1}{n} \sum_{j=1}^n \left| \frac{1}{F_d} + \frac{1}{F_i} \left( F_i \cdot S + \frac{j-1}{F_d} - F_i \cdot S + \frac{j}{F_d} \right) \right| \\ &= \frac{1}{nF_i} \sum_{j=1}^n |c + a + c(j-1) + \lfloor F_i \cdot S + a(j-1) \rfloor - c j - \lfloor F_i \cdot S + a j \rfloor| \\ &= \frac{1}{nF_i} \sum_{j=1}^n |a + \lfloor F_i \cdot S + a(j-1) \rfloor - \lfloor F_i \cdot S + a j \rfloor| \\ &= \frac{1}{nF_i} \sum_{j=1}^n |\lfloor F_i \cdot S + a j \rfloor - \lfloor F_i \cdot S + a(j-1) \rfloor| \end{aligned} \quad (23)$$

$$\overline{|\Delta L|} \equiv \frac{2 \frac{F_{in}}{F_{out}}}{1 - \frac{F_{in}}{F_{out}}}$$

$S = S_i - S_d$  represents the difference of the offsets of the output and input signals, assuming their frequency is constant for simplicity. If we consider:

- (i) that  $S_i$  and  $S_d$  are defined null at  $j = 0$ , then  $F_i \cdot S = 0$ ;
- (ii) or, that their difference itself  $S$  is very small—which would likely be the case if all values are expressed in the International System of Units, i.e. in seconds and hertz—then we could also discard the  $F_i \cdot S$  component;
- (iii) or, that  $S$  and  $F_i$  are expressed in *integer* values, e.g. integral amounts of milliseconds and kiloHertz to maintain orders of magnitude, then the two  $F_i \cdot S$  components can be taken out of the floor functions, and cancel each other.

In all three cases, we can simplify Equation (23) as:

$$\overline{|\Delta L|} = \frac{1}{nF_i} \sum_{j=1}^n |\lfloor a j \rfloor - \lfloor a(j-1) \rfloor - a| \quad (24)$$

By definition,  $\lfloor a j \rfloor$  is the largest integer  $m \leq a j$ :

$$\lfloor a j \rfloor = m \in \mathbb{I} : \frac{m}{a} \leq j < \frac{m+1}{a} \quad (25)$$

$$\lfloor a(j-1) \rfloor = m_2 \in \mathbb{I} : \frac{m_2}{a} \leq j-1 < \frac{m_2+1}{a} \quad (26)$$

Since  $a \in [0, 1)$ ,  $\lfloor a j \rfloor - \lfloor a(j-1) \rfloor$  is either 0 or 1. In particular, it is equal to 0 if the intervals defined in Equations (25) and (26) are the same, i.e. if  $m = m_2$ , and equal to 1 otherwise.

$$\begin{aligned} \lfloor a j \rfloor - \lfloor a(j-1) \rfloor = 0 &\iff \frac{m}{a} \leq j-1 < j < \frac{m+1}{a} \\ &\iff \frac{m}{a} + 1 \leq j < \frac{m+1}{a} \end{aligned} \quad (27)$$

Complementarily,  $\lfloor a j \rfloor - \lfloor a(j-1) \rfloor = 1$  if  $m_2 = m - 1$ :

$$\begin{aligned} \lfloor a j \rfloor - \lfloor a(j-1) \rfloor = 1 &\iff \frac{m}{a} \leq j \text{ and } j-1 < \frac{m_2+1}{a} \\ &\iff \frac{m}{a} \leq j < \frac{m}{a} + 1 \end{aligned} \quad (28)$$

Thus, for any integer  $x$  in any interval  $\mathcal{I} = \left[ \frac{m}{a}, \frac{m+1}{a} \right)$  with  $m \in \mathbb{I}$  and  $a \in [0, 1)$ ,

$$\lfloor a x \rfloor - \lfloor a(x-1) \rfloor = \begin{cases} 1 & \text{if } x \in \left[ \frac{m}{a}, \frac{m+1}{a} \right) \\ 0 & \text{if } x \in \left[ \frac{m+1}{a}, \frac{m+2}{a} \right) \end{cases} \iff x = \frac{m}{a} \quad (29)$$

Furthermore,

$$\begin{aligned} \lfloor a j \rfloor - \lfloor a(j-1) \rfloor &\in \{0, 1\} \\ &\iff \lfloor a j \rfloor - \lfloor a(j-1) \rfloor - a \in \left\{ -a, 1-a \right\} \\ &\iff |\lfloor a j \rfloor - \lfloor a(j-1) \rfloor - a| \in \left\{ a, \frac{F_{in}}{F_{out}} \right\} \end{aligned} \quad (30)$$

To generalize, we can partition any interval  $I = [1, n]$  into intervals  $\mathcal{I}_k = \left[ \frac{k-1}{a}, \frac{k}{a} \right)$ ,  $k \in \{1, \dots, na\}$ , so that Equation (29) holds:  $\lfloor a x \rfloor - \lfloor a(x-1) \rfloor = 1$  since in every  $\mathcal{I}_k$  interval, i.e.  $\lfloor na \rfloor$  times overall within  $I$ . Consequently,  $\lfloor a x \rfloor - \lfloor a(x-1) \rfloor = 0$  the rest of the time, i.e.  $n - \lfloor na \rfloor$  times within  $I$ . Combining this with Equation (30), we have that:

$$\begin{aligned} \overline{|\Delta L|} &= \frac{1}{nF_i} \sum_{j=1}^n |\lfloor a j \rfloor - \lfloor a(j-1) \rfloor - a| \\ &= \frac{a \lfloor na \rfloor + a(n - \lfloor na \rfloor)}{nF_i} \\ &= \frac{(1-2a) \lfloor na \rfloor + na}{nF_i} \end{aligned} \quad (31)$$

When  $n$  is very large, we consider that  $\frac{\lfloor na \rfloor}{n} \sim a$ , and thus:

$$\overline{|\Delta L|} \sim \frac{2a(1-a)}{F_i} \quad (32)$$

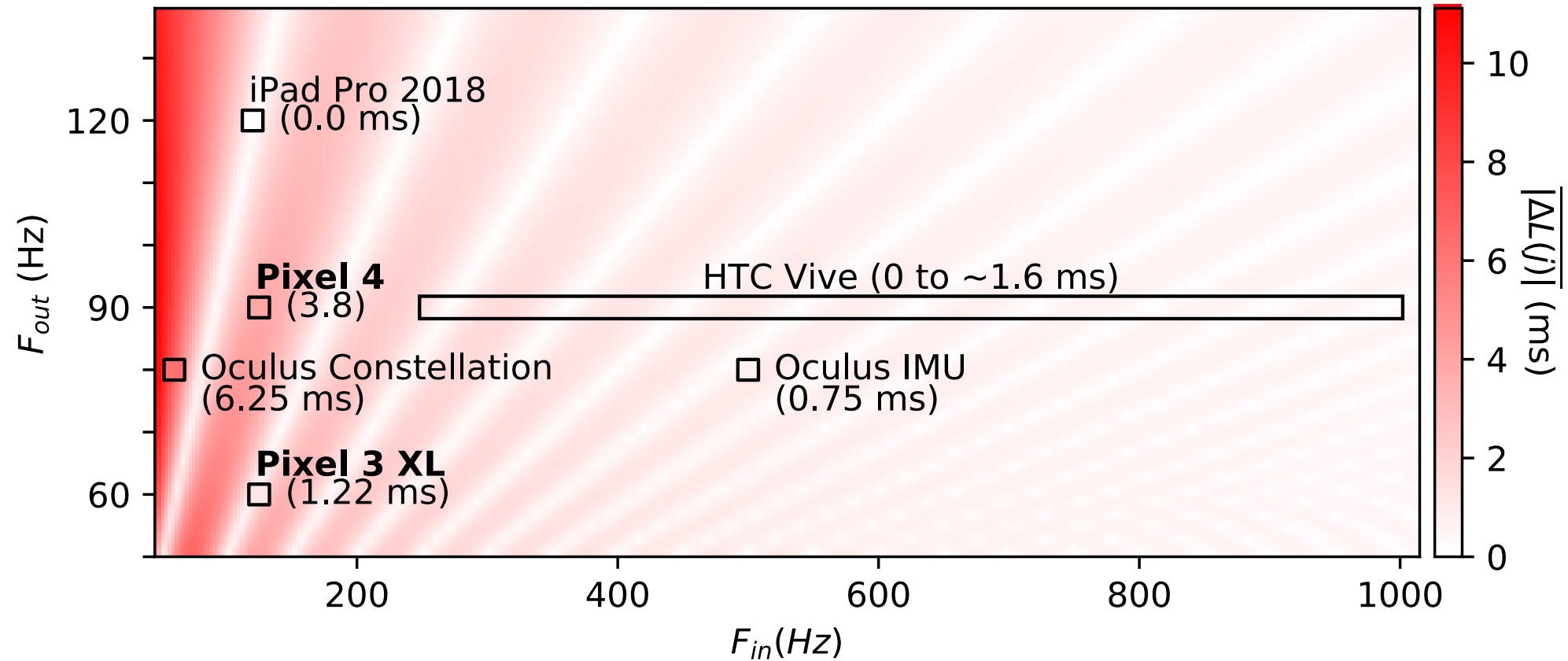
The resulting curve perfectly overlaps the ones obtained through repeated simulation (Figure 2). From this, we can easily characterize the 'bumps' formed by the curve of  $\overline{|\Delta L|}(F_d)$ , and in particular their maximum:

$$a_{max} = \arg \max(\overline{|\Delta L|}) = \arg \max \left[ a(1-a) \right] = \frac{1}{2} \quad (33)$$

$$F_{dmax} = \frac{F_i}{c + a_{max}} = \frac{F_i}{c + \frac{1}{2}} \text{ for any } c \in \mathbb{I} \quad (34)$$

Using Equation (32), we can calculate

$$\max(\overline{|\Delta L|}) = \frac{1}{2F_i} \text{ at } F_d = F_{dmax} \quad (35)$$




$$\begin{aligned} \overline{|\Delta D|} &= \frac{1}{n} \sum_{i=1}^{n-1} |\Delta D(t_i)| \\ &= \frac{1}{n} \sum_{i=1}^{n-1} |P_{\text{out}}(t_i) - P_{\text{in}}(t_i) - P_{\text{out}}(t_{i-1}) + P_{\text{in}}(t_{i-1})| \end{aligned}$$



- 12 participants
- 2 smartphones (Pixel 3 XL ou Pixel 4)
- x 3 tâches (recherche, navigation, lecture)
- x 3 tailles de pages (10, 20, 30 sections)
- x 2 directions (haut en bas et bas en haut)

Find the button  
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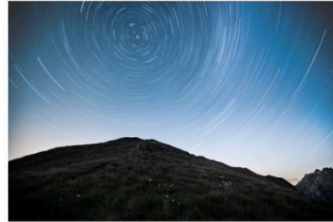
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Navigation task

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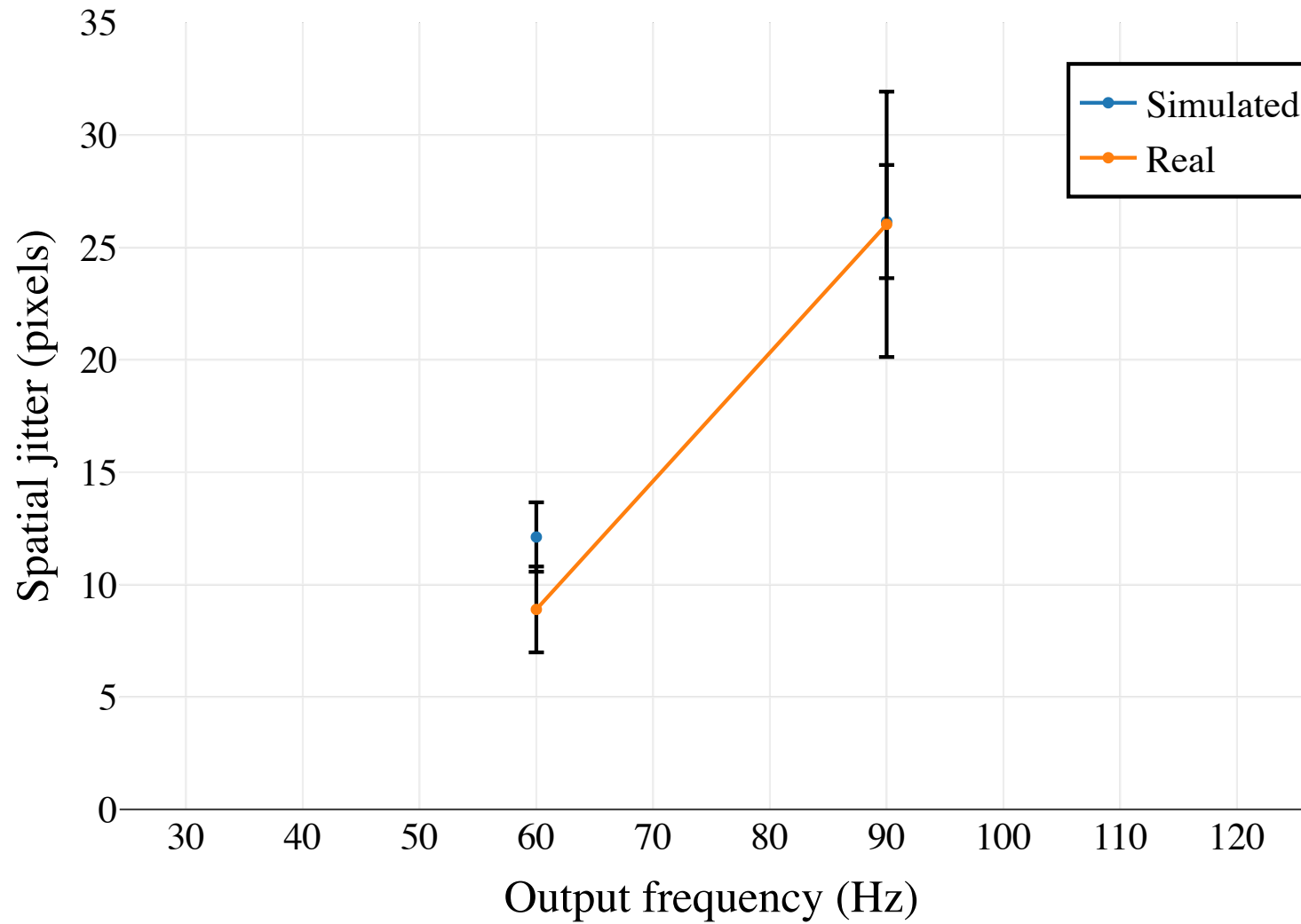
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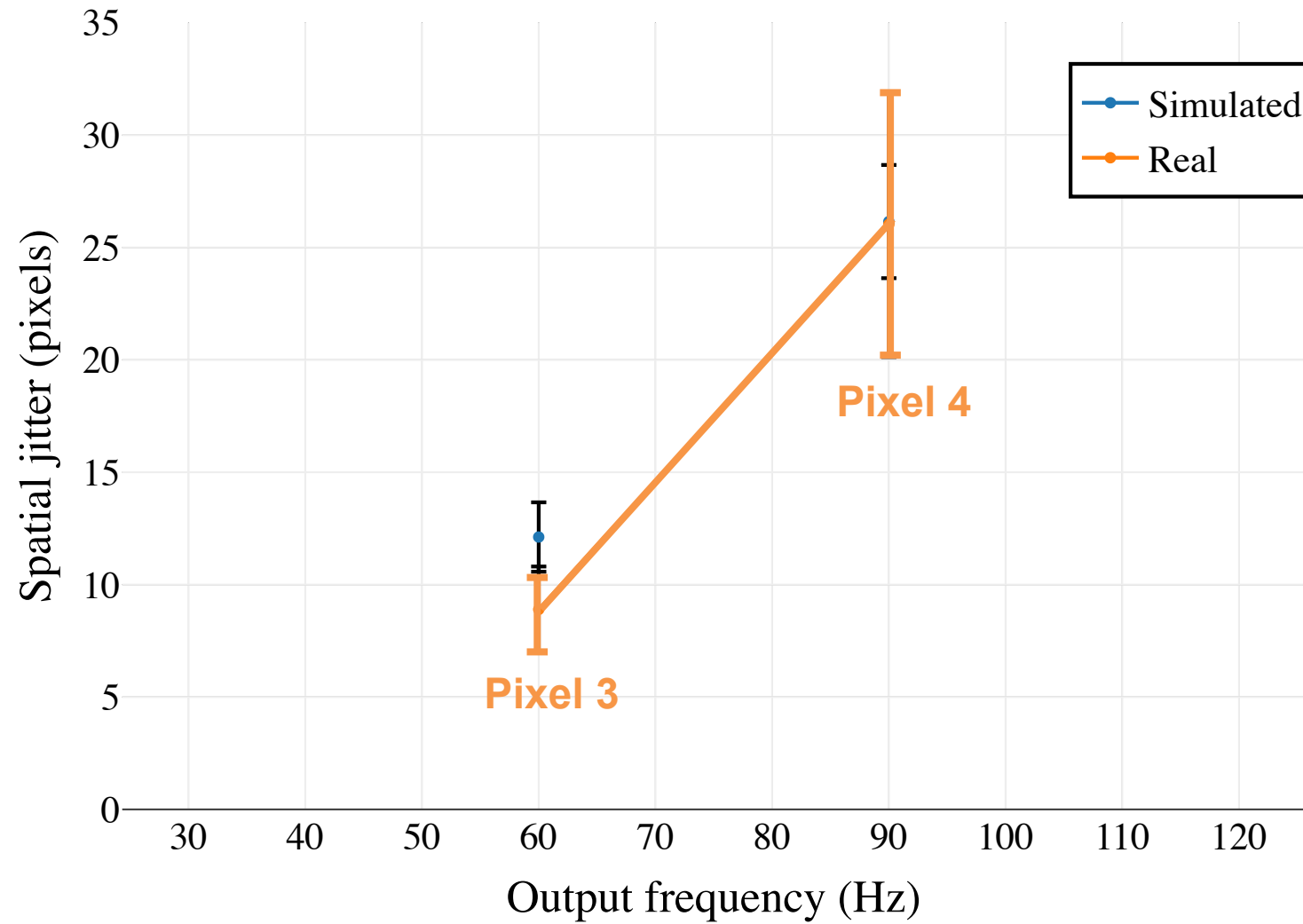


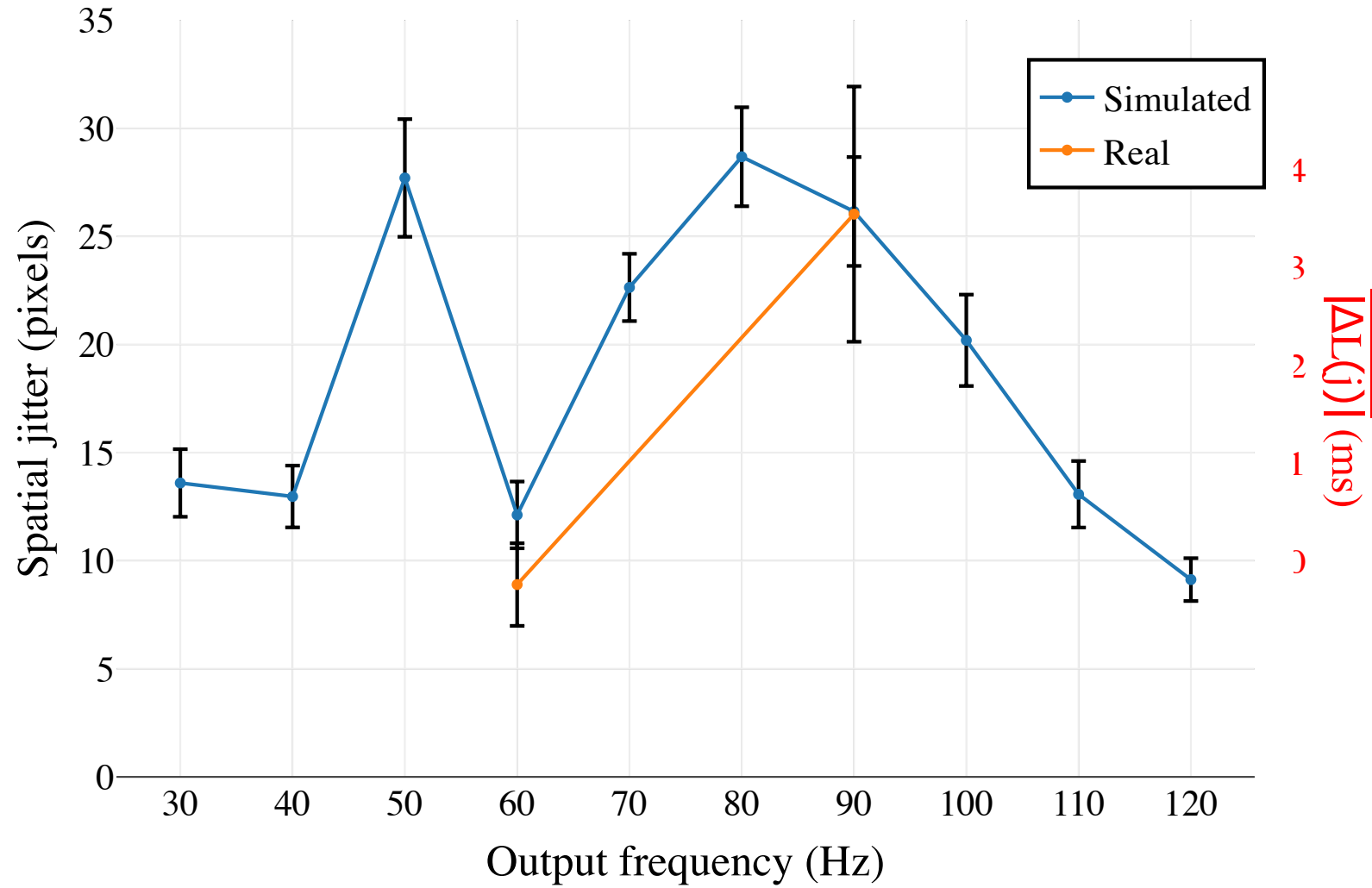
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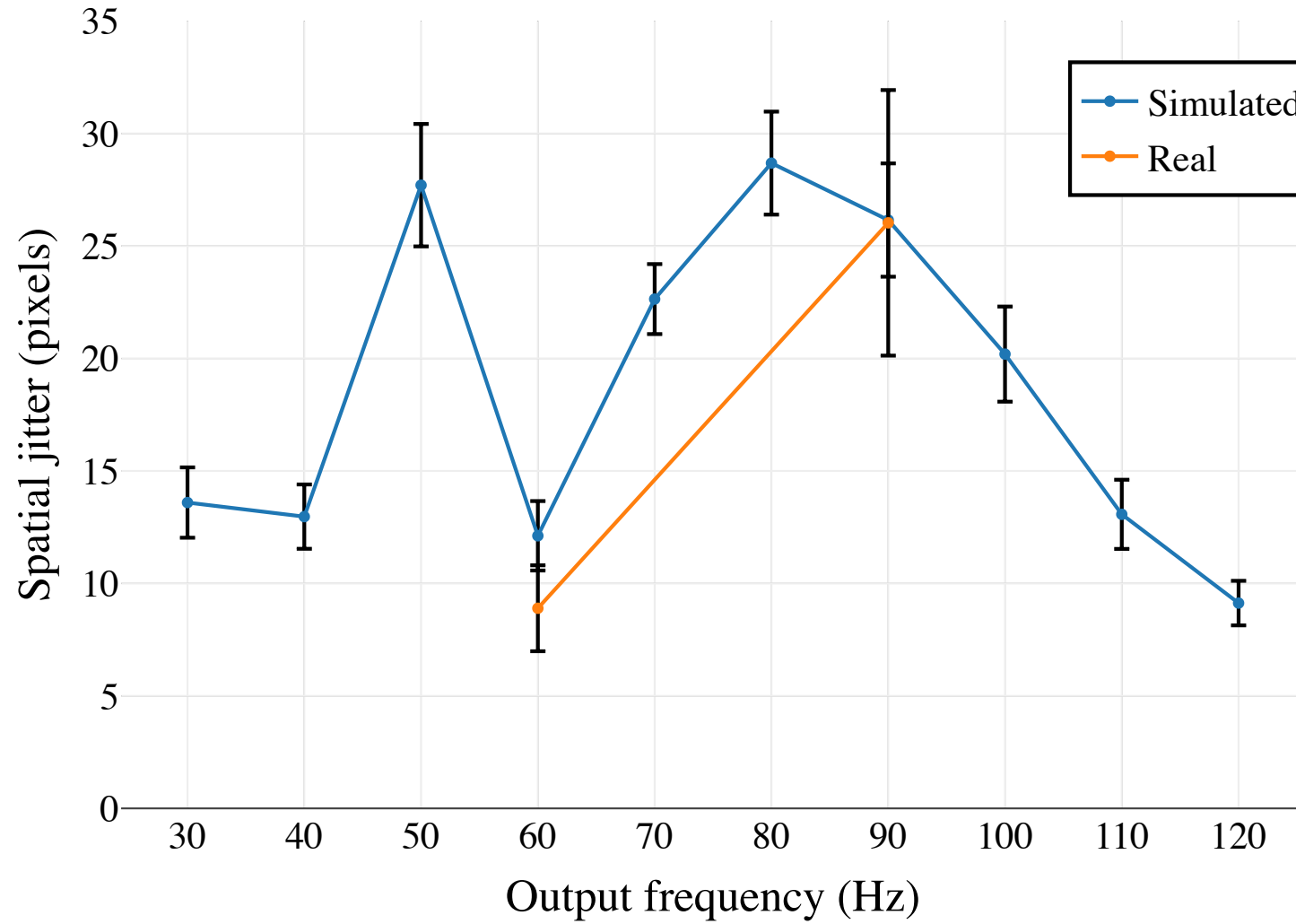
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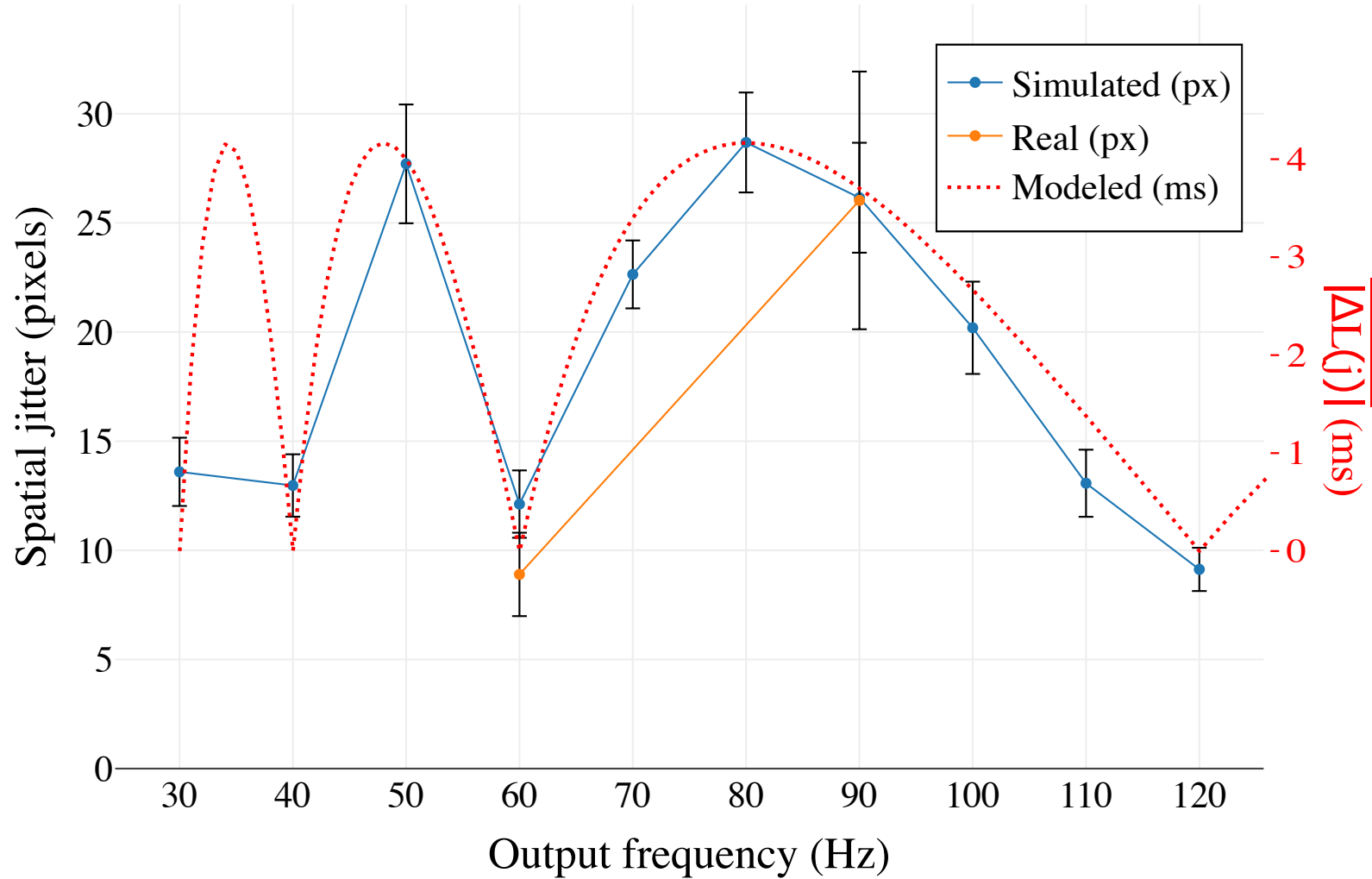
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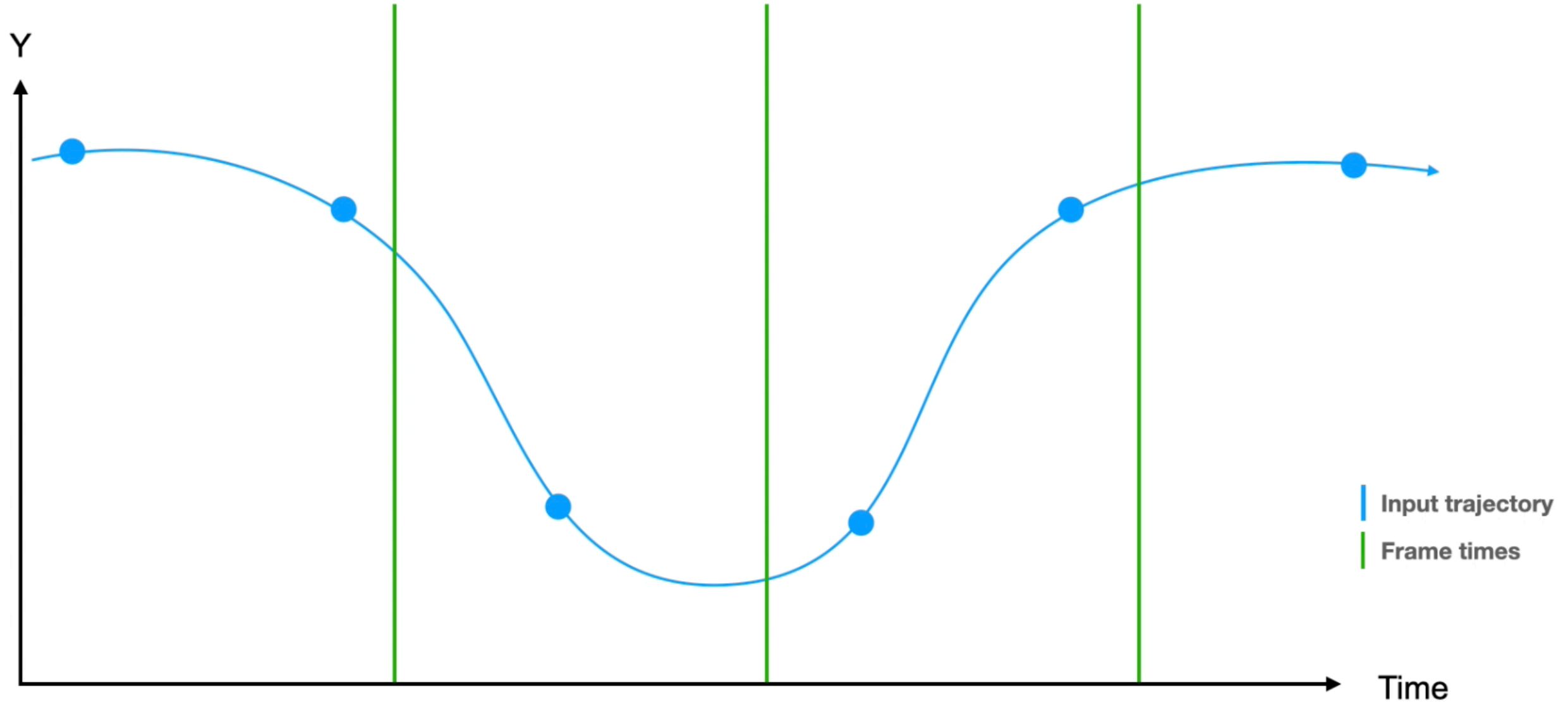




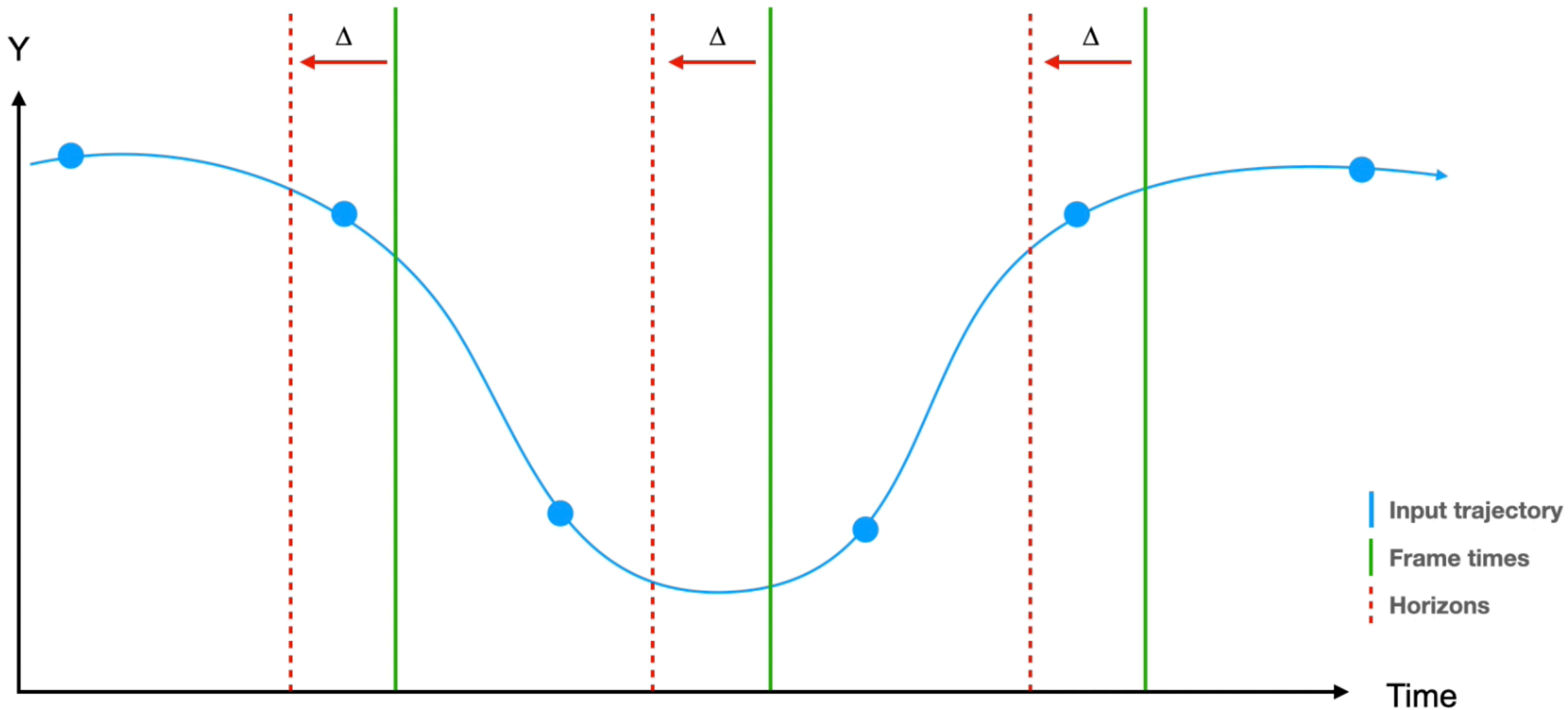




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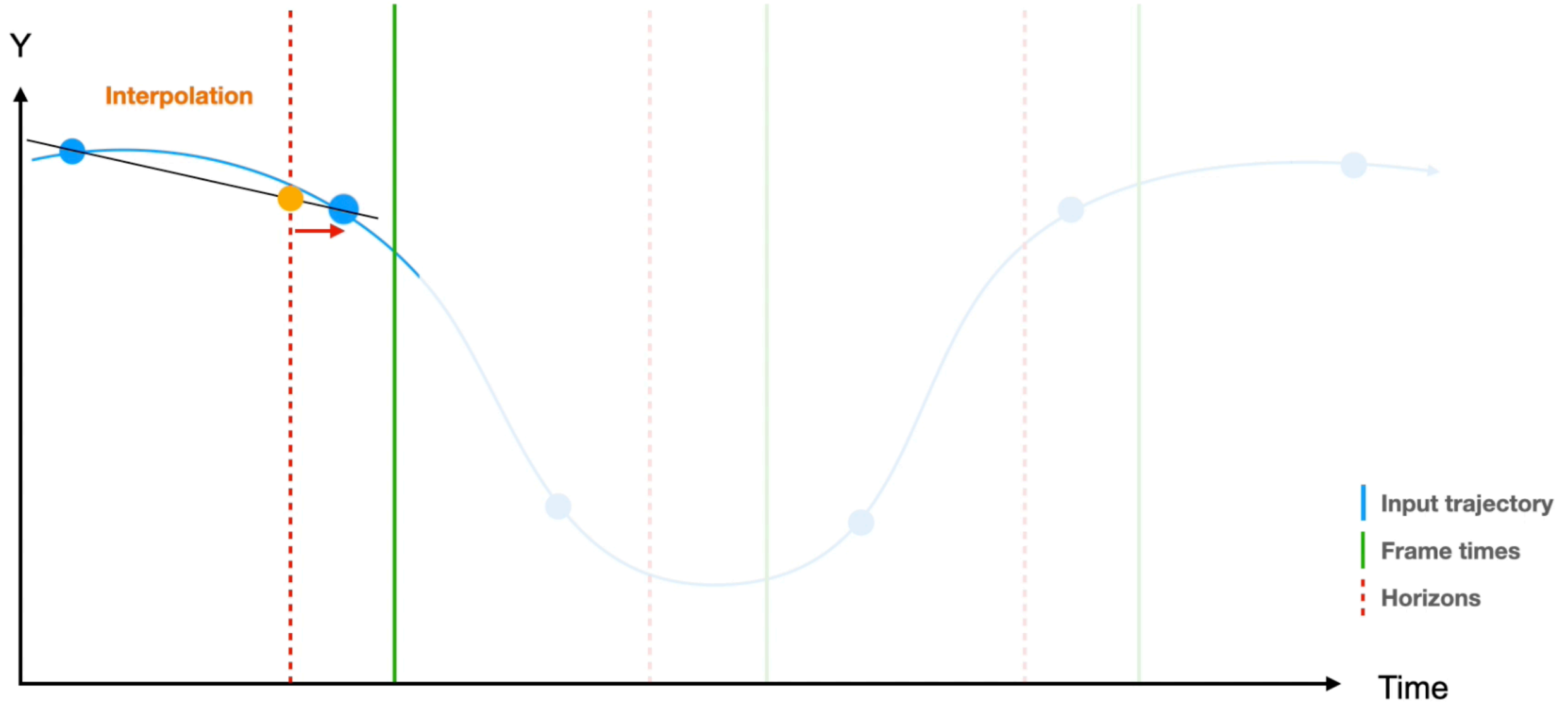


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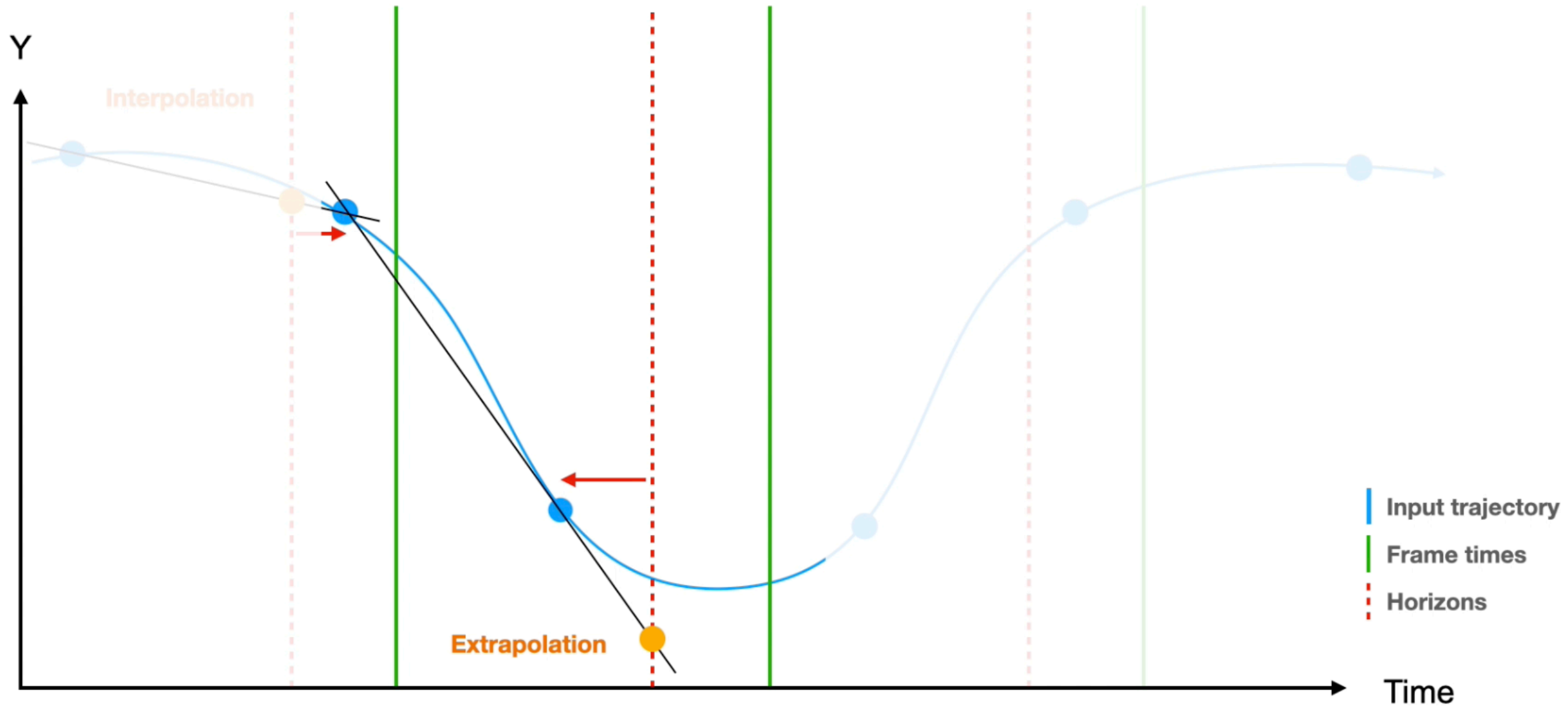




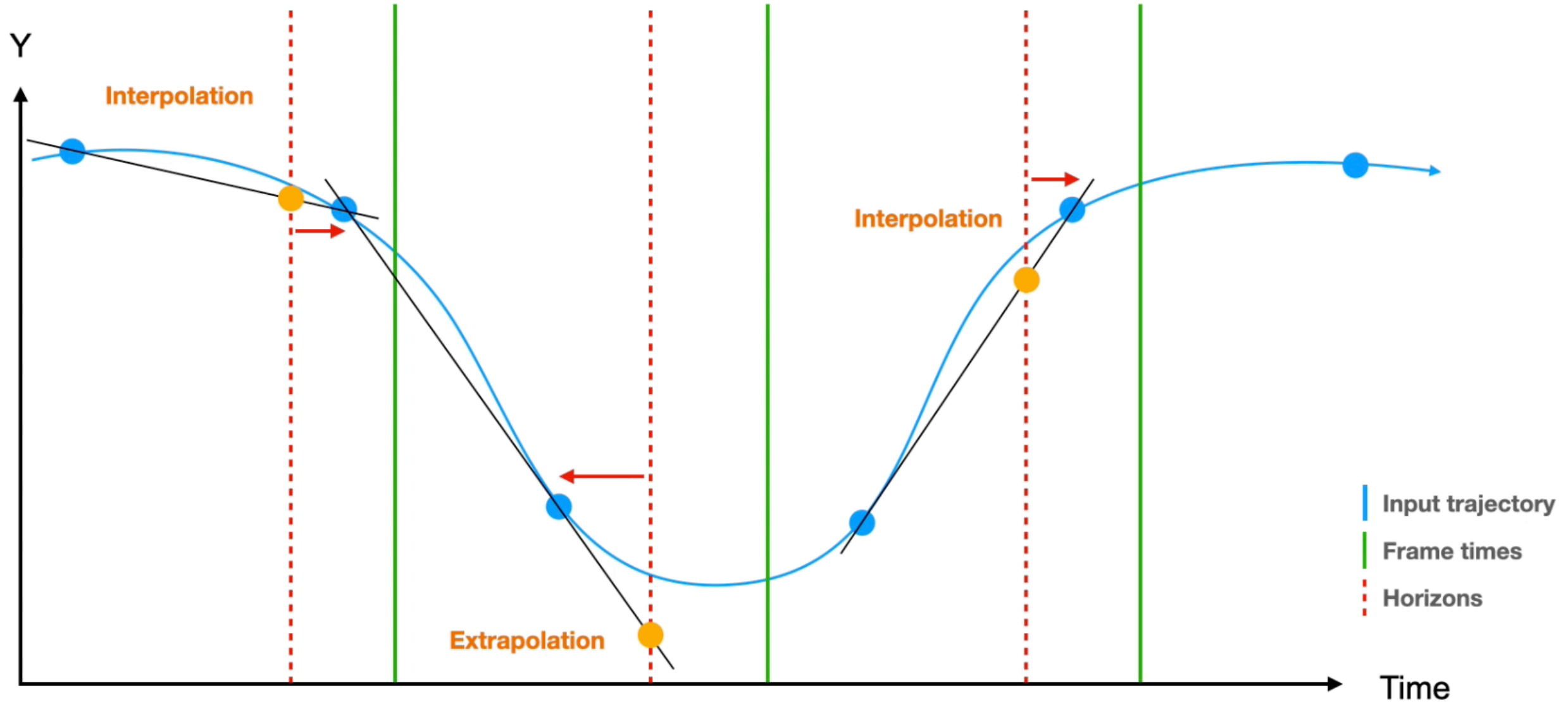
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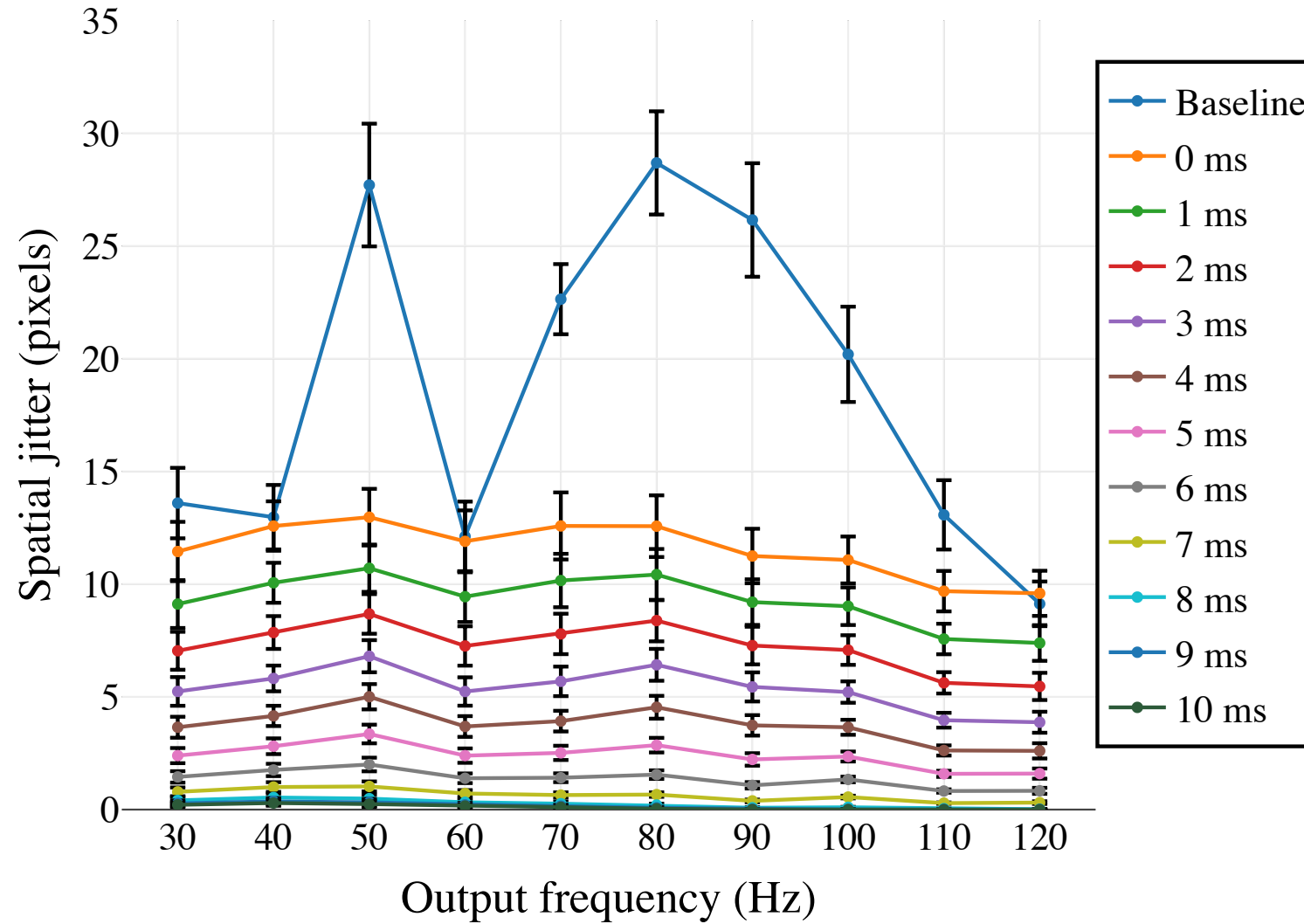


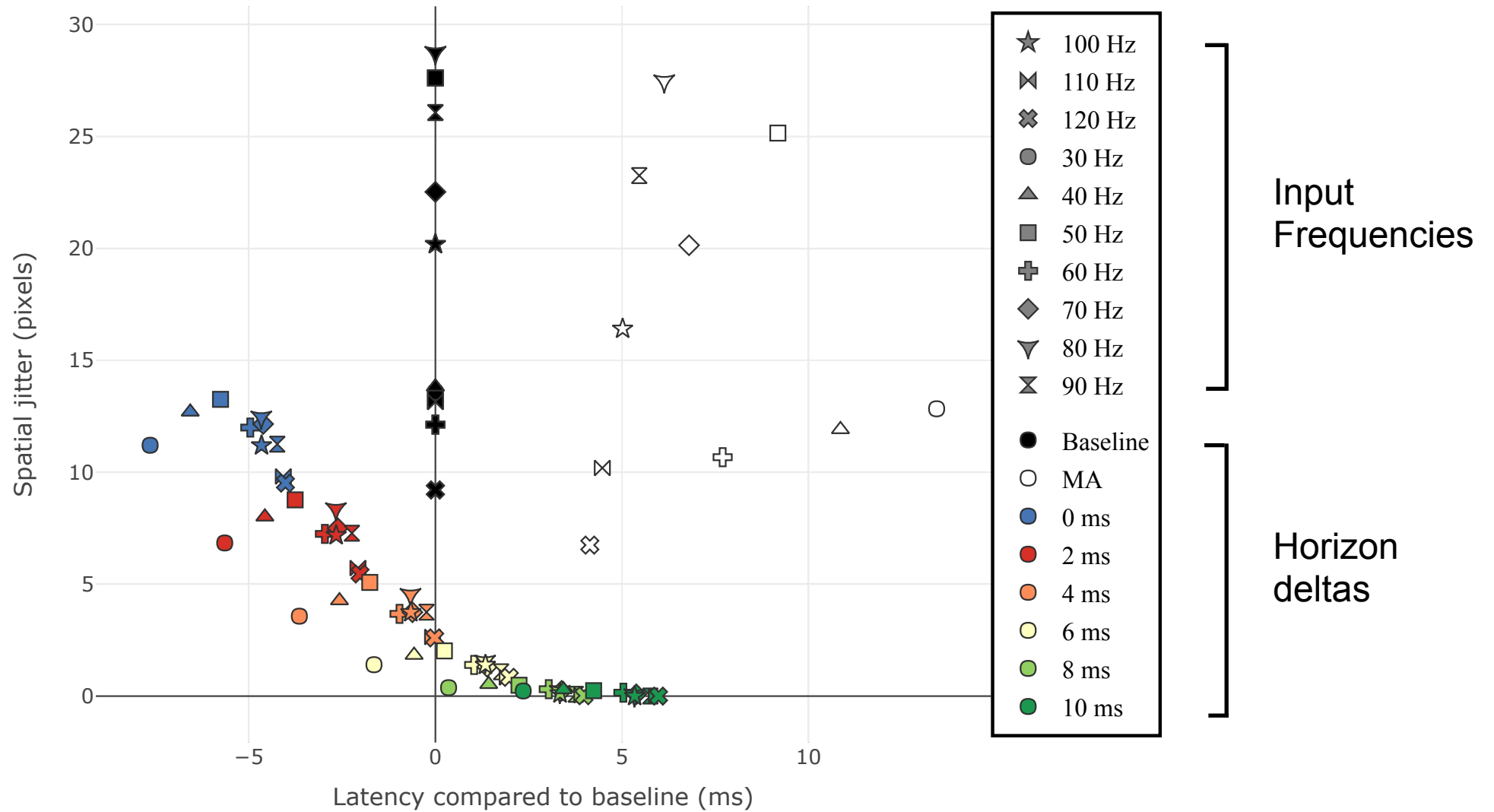
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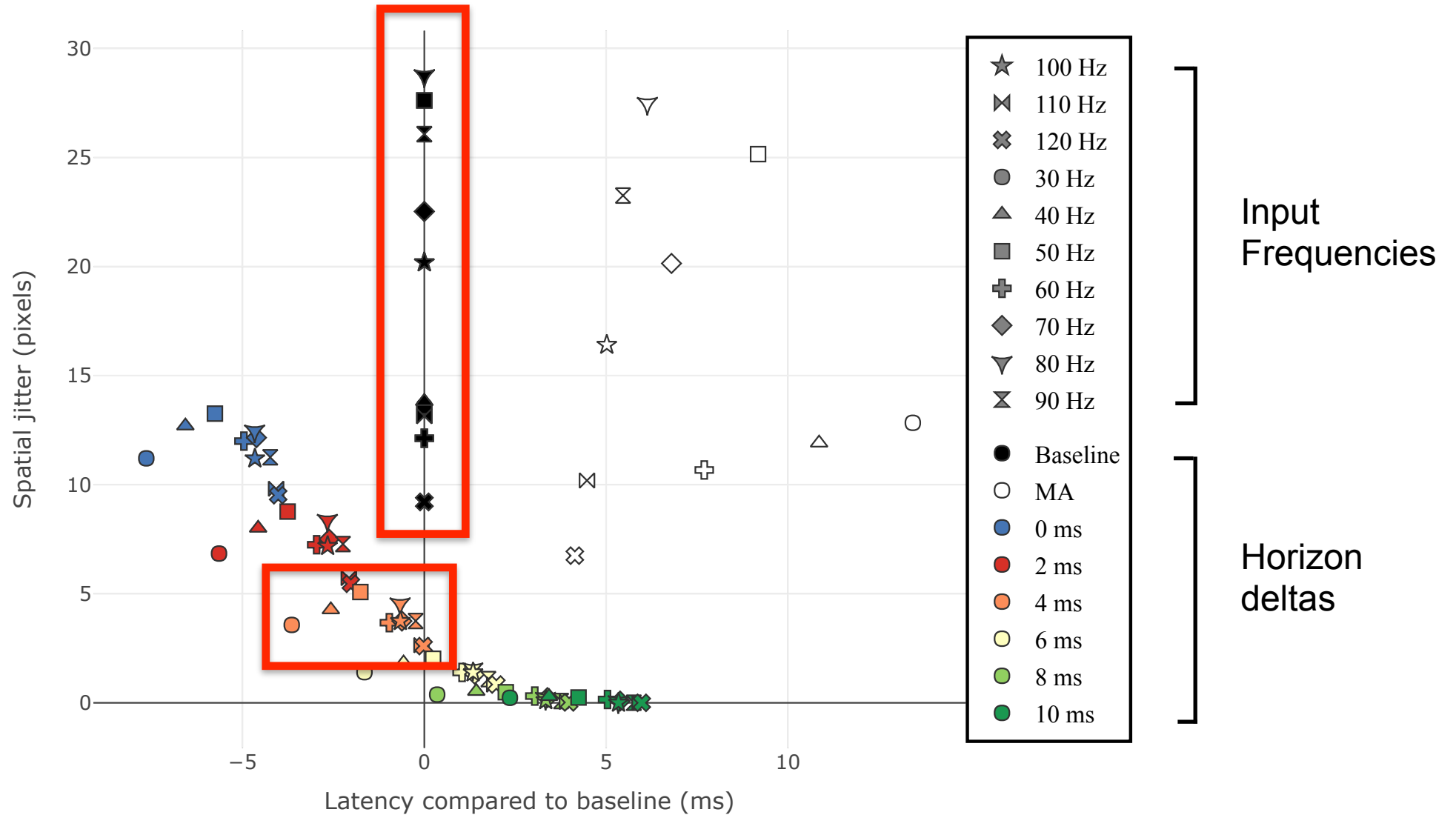


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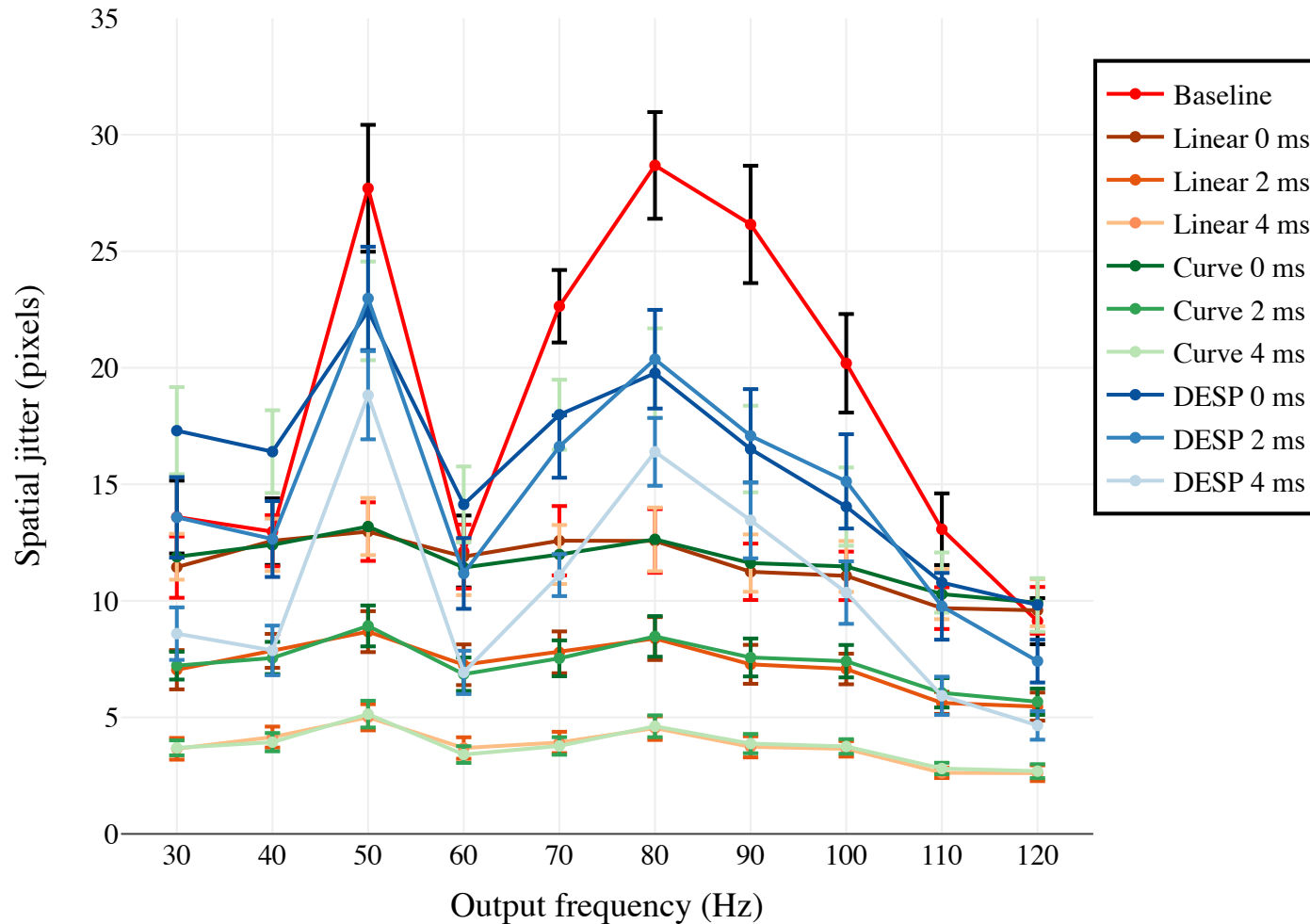




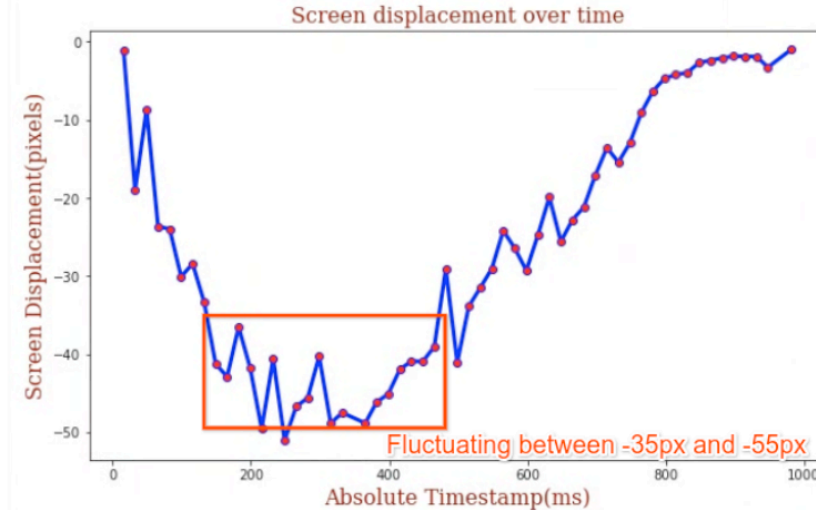
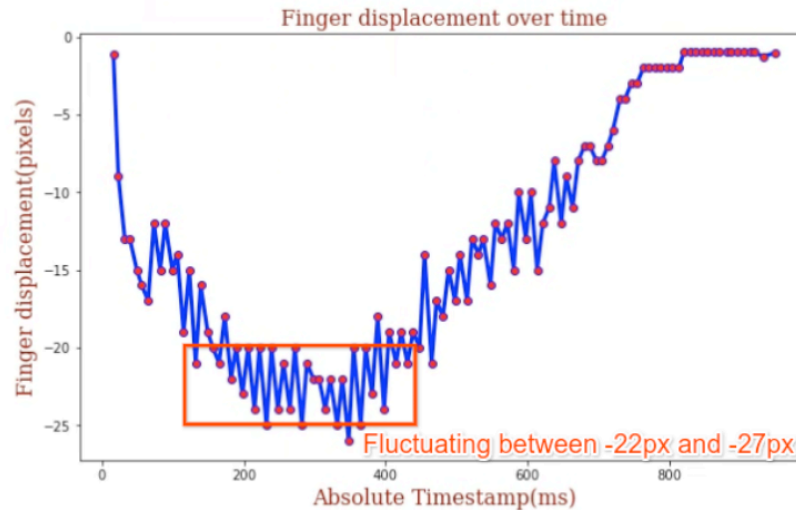




# Comparaison de techniques d'extrapolation



# Implémentation dans Chromium



*“To improve on it, we experimented with different algorithms, using automation to replay the same input over and over again and evaluating the screen displacement curves. After tuning, **this landed at the 1€ filter implementation that visibly and drastically improved the scrolling experience. With this filter, the screen tracks closely to your finger and websites smoothly scroll, preventing jank caused by inconsistent input events. The improvement is visible in our manual validation, on both top-end and low-end devices”***

<https://blog.chromium.org/2023/08/smoothing-out-scrolling-experience-in.html>



# Conclusion

- Identification d'une nouvelle cause de bruit spatial
- Proposition de deux métriques pour le mesurer
- Développement d'une nouvelle technique pour réduire ce phénomène
- Maintenant intégré sur tous les périphériques Android

