
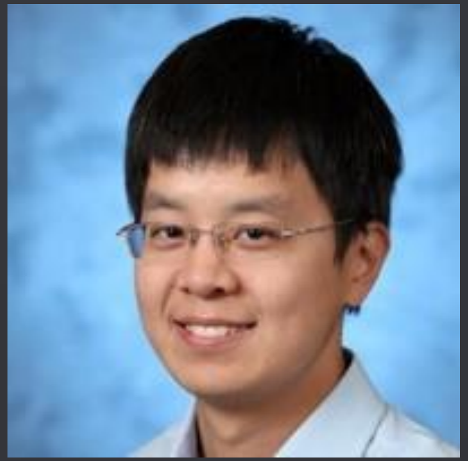

Lei Yang Shiqiu (Edward) Liu Marco Salvi

# A SURVEY OF TEMPORAL ANTIALIASING TECHNIQUES

Eurographics 2020, State of the Art Report (STAR), May 26, 2020

NVIDIA

# AGENDA

## Introduction to Temporal Antialiasing

Overview of the algorithm components

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## Challenges

The unsolved problems and future directions

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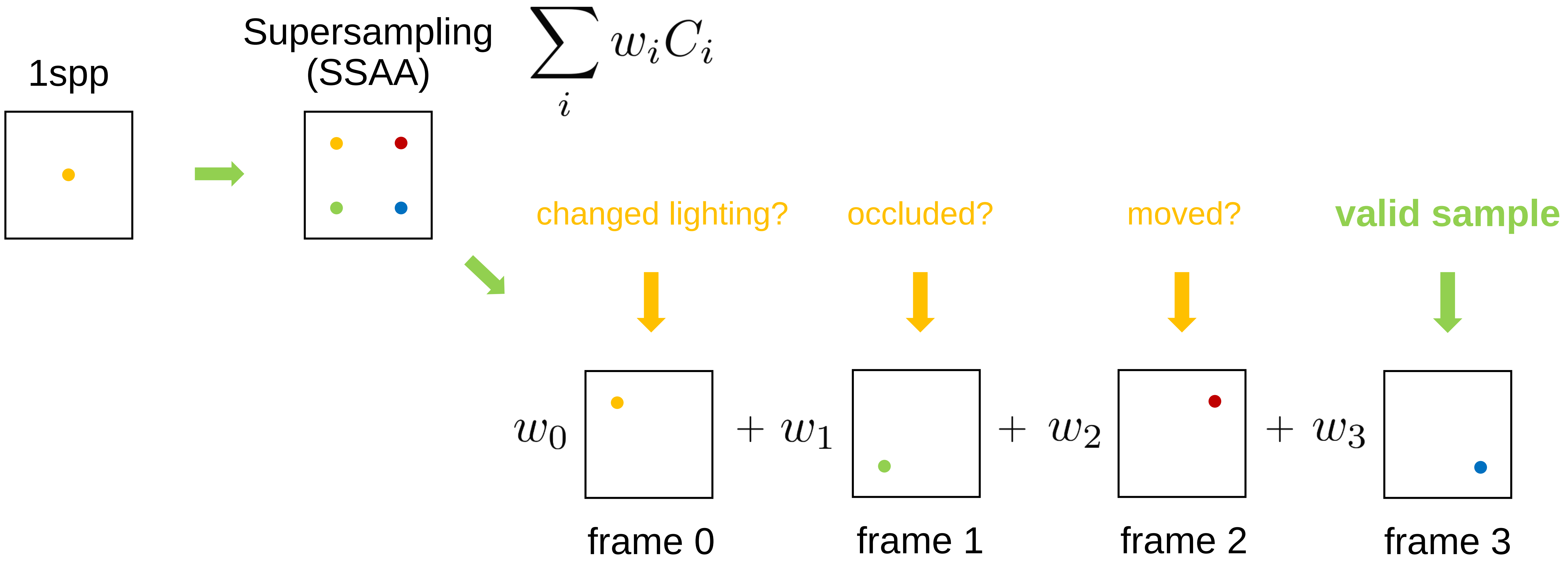
# TEMPORAL ANTIALIASING (TAA)

## Overview

- De facto standard for antialiasing in today's high-end 3D real-time renderers
- Particularly suitable for deferred renderers, replacing MSAA
- Misnomer – traditionally used for "temporal aliasing" reduction (a.k.a. motion blur)

# TEMPORAL ANTIALIASING (TAA)

## a.k.a. temporally amortized supersampling



# BRIEF HISTORY

## How TAA has evolved

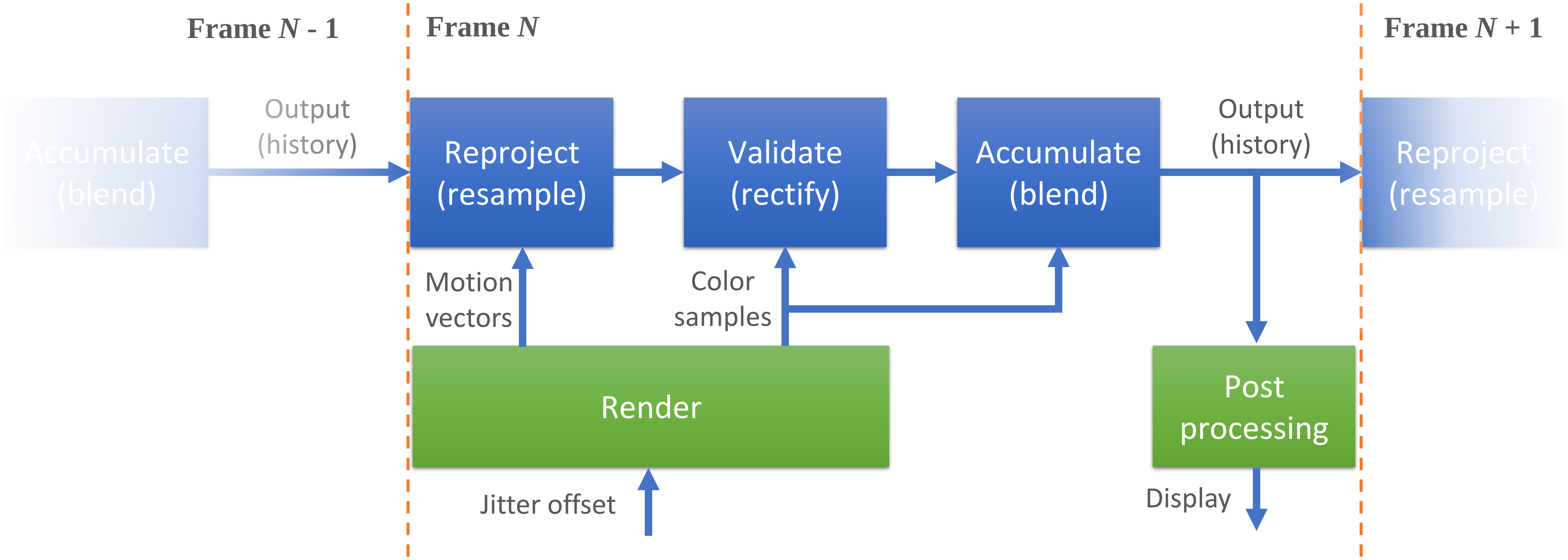
| | History reprojection (reverse reproj.) | Exponential smoothing History reuse | History resampling | History rejection/ adaptive blending | History clipping/ clamping | Hybrid spatial + temporal antialiasing | Subpixel reconstruction/ Temporal upsampling | Checkerboard rendering | TAA in Variable-Rate Shading | TAA in HDR | Machine learning |
|---|---|---|---|---|---|---|---|---|---|---|---|
| [NSL*07, SJW07] | ✓ | ✓ | | ✓ | | | | | | | |
| [YNS*09] | | ✓ | ✓ | ✓ | | | ✓ | | | | |
| [HEMS10] | | ✓ | | ✓ | | | ✓ | | | | |
| [Sou11] | | | | ✓ | | ✓ | | | | | |
| [Mal12] | | | | ✓ | | | ✓ | | | | |
| [Kar14,Xu16,Sal16] | | | ✓ | ✓ | ✓ | | | | | ✓ | |
| [Dro14] | | | ✓ | ✓ | | ✓ | ✓ | | | | |
| [Jim16] | | | ✓ | | ✓ | ✓ | ✓ | | | | |
| [Aal16, Epi18] | | | | | | | ✓ | | | | |
| [PSK∗16, XLV18] | | | | | | | | | ✓ | | |
| [EM16, Wih17, dCI17] | | | | ✓ | ✓ | | | ✓ | | | |
| [Sal17, Nvi20*] | | | | ✓ | ✓ | | ✓ | | | | ✓ |

✓ Signifies contributions to the corresponding topic

* Released after this paper; see GTC 2020 talk “DLSS 2.0 – Image reconstruction for real-time rendering with deep learning” by Edward Liu

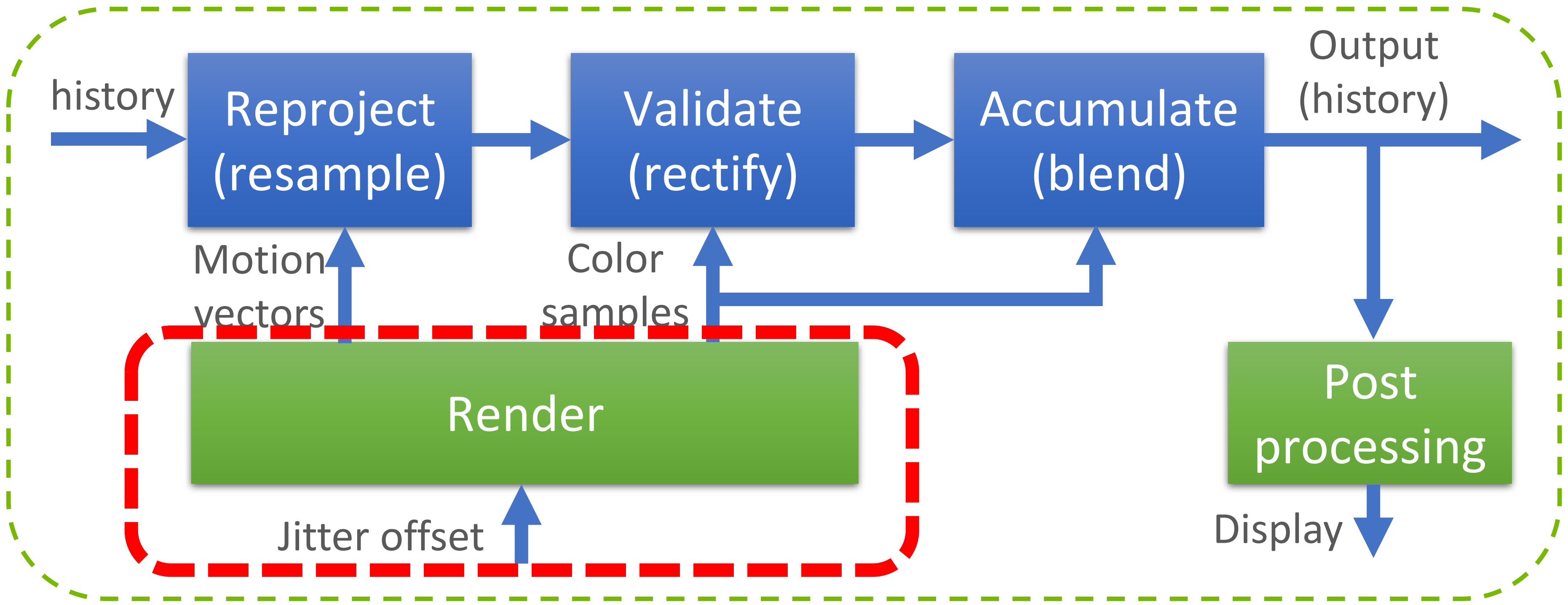
# TEMPORAL ANTIALIASING

## Basic building blocks and flow

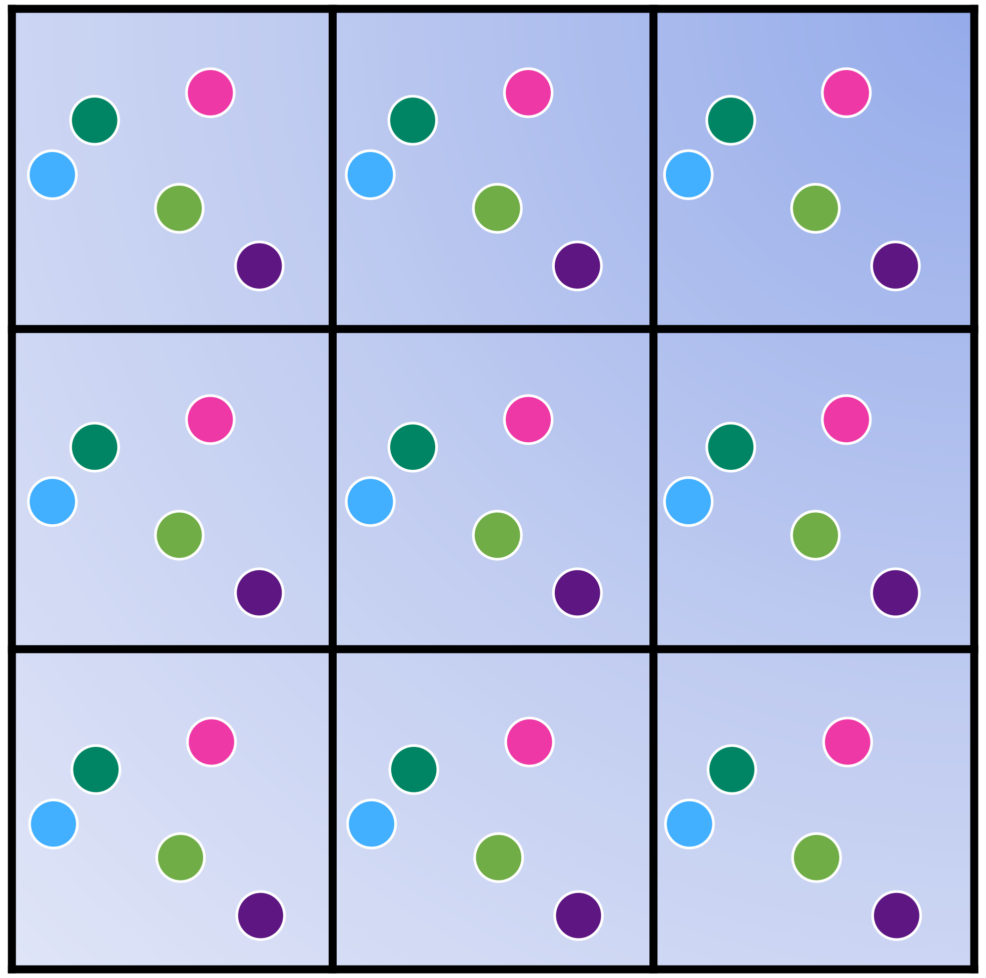


# SAMPLE GENERATION

## Viewport jittering

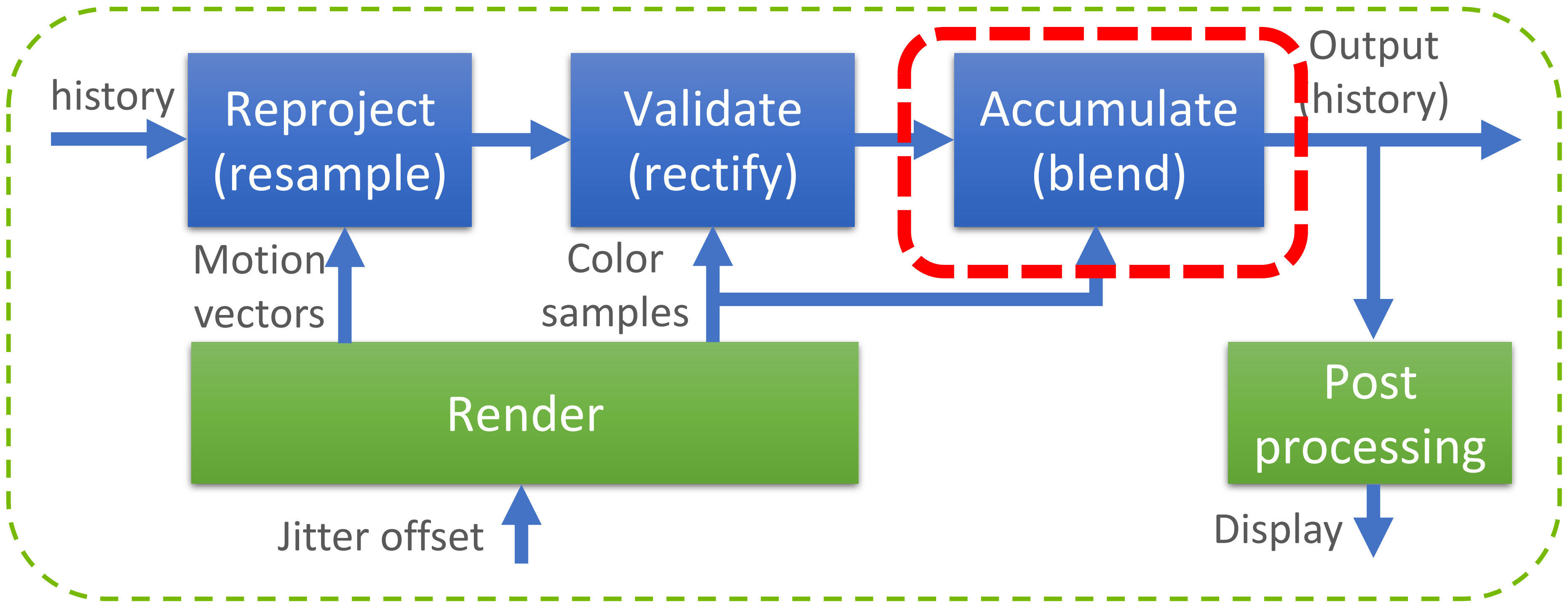


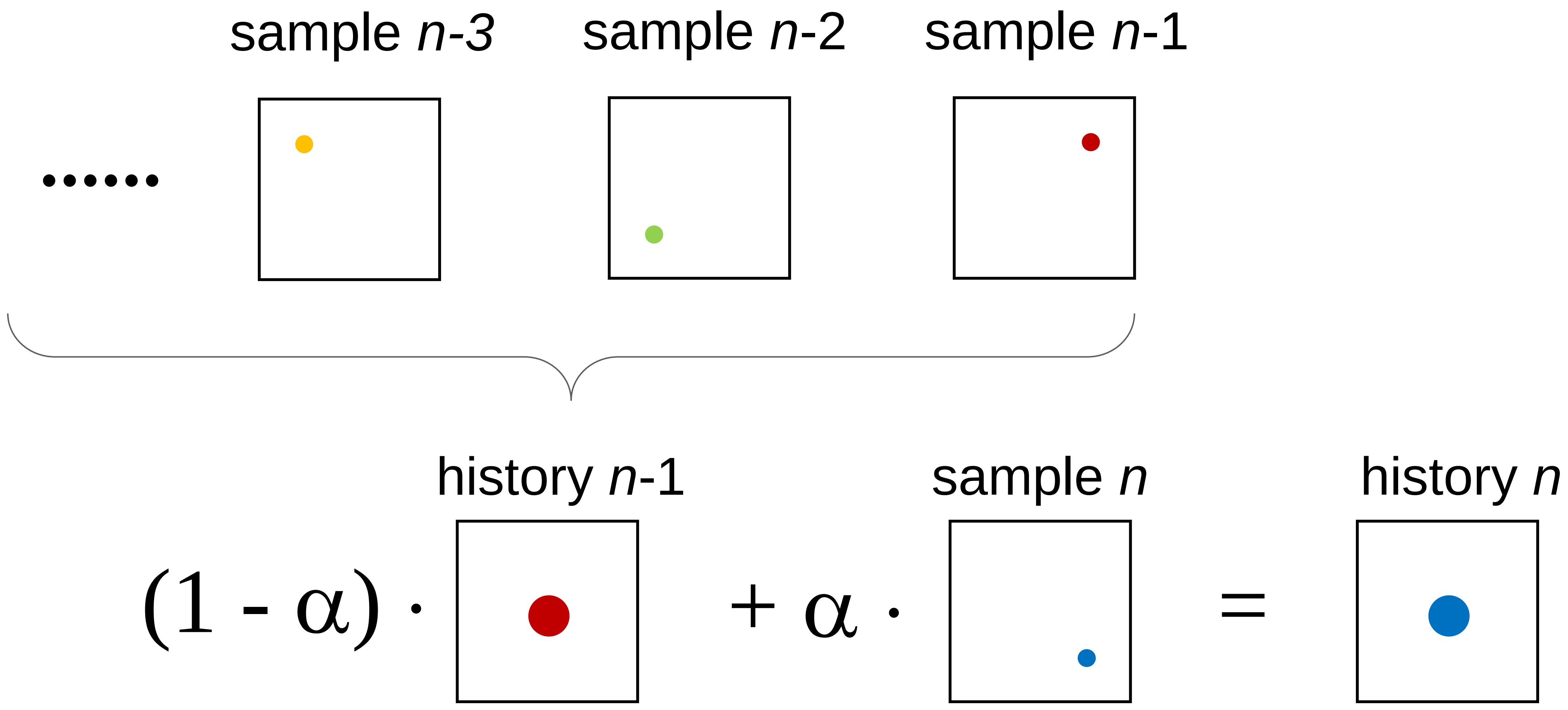

- Draw samples from a low discrepancy progressive sequence
  - E.g. Halton(2,3)
- Adjust projection matrix to apply the subpixel offset per frame
  - All pixels use the same offset



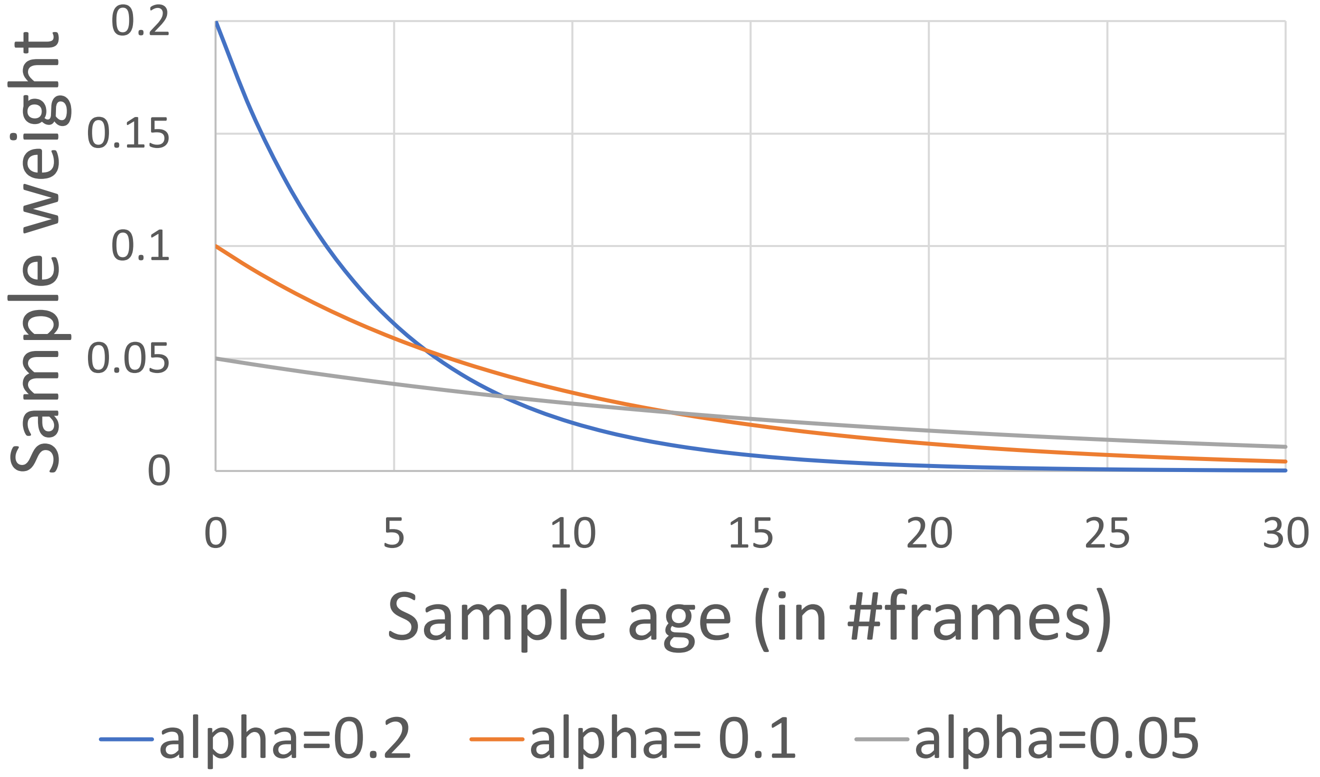
# SAMPLE ACCUMULATION

## Reuse resolved color, not individual samples



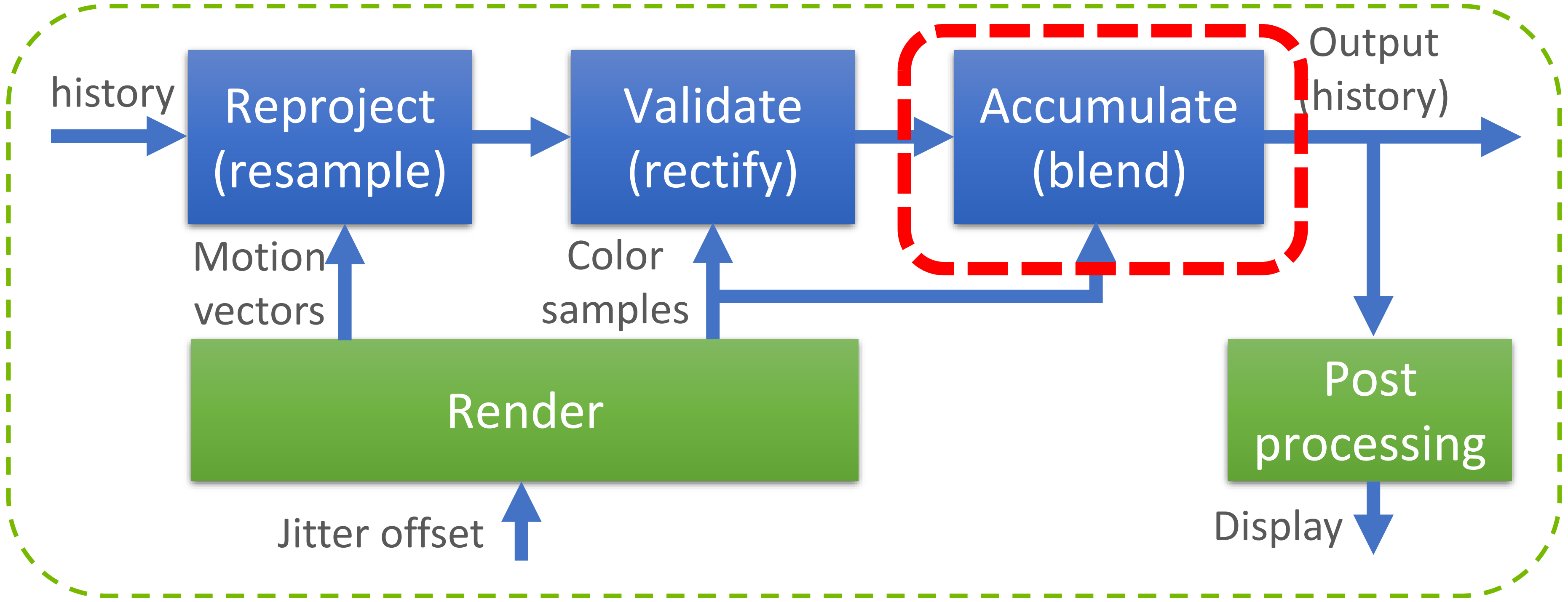




### Exponential smoothing

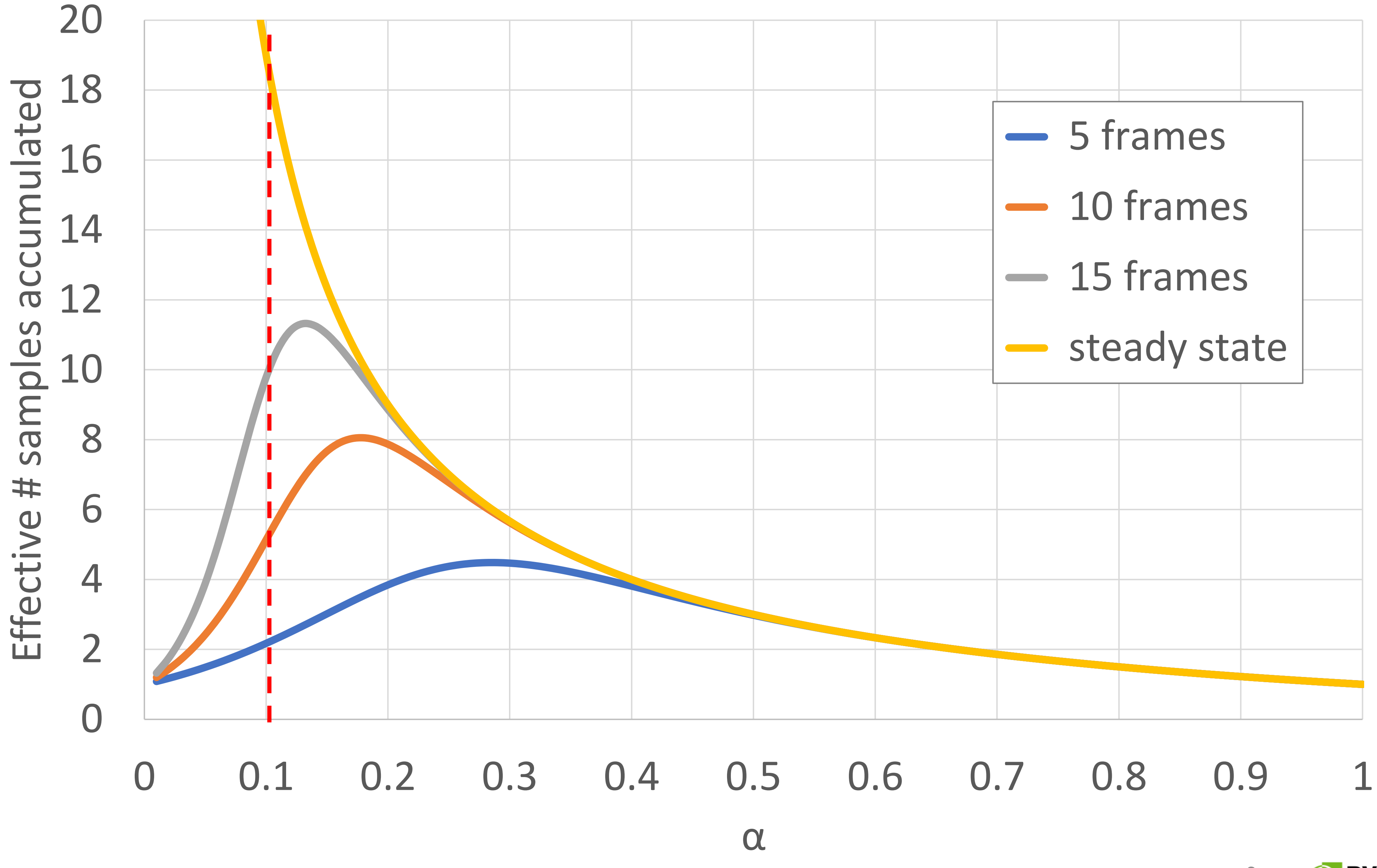


# SAMPLE ACCUMULATION

## Exponential smoothing

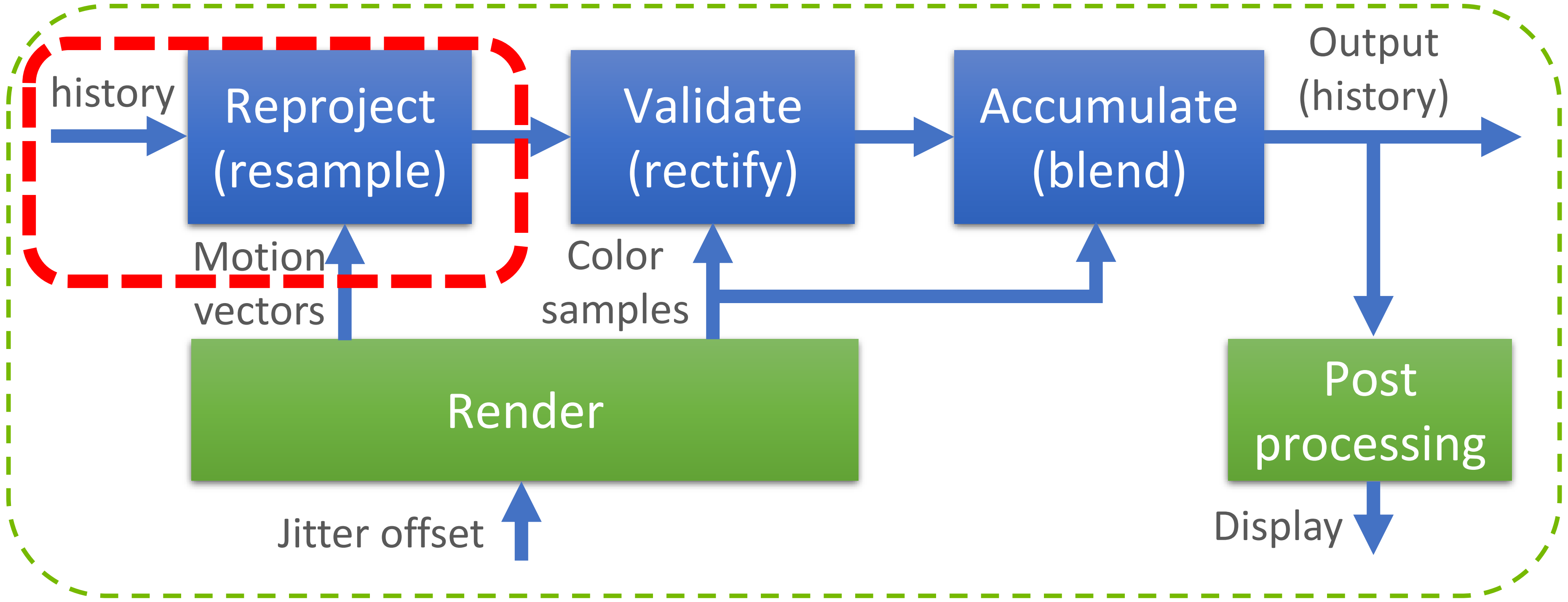



- Assign lower weights to older (possibly stale) samples
- Uneven weights can reduce the quality of antialiasing
- Optional: use adaptive $\alpha$

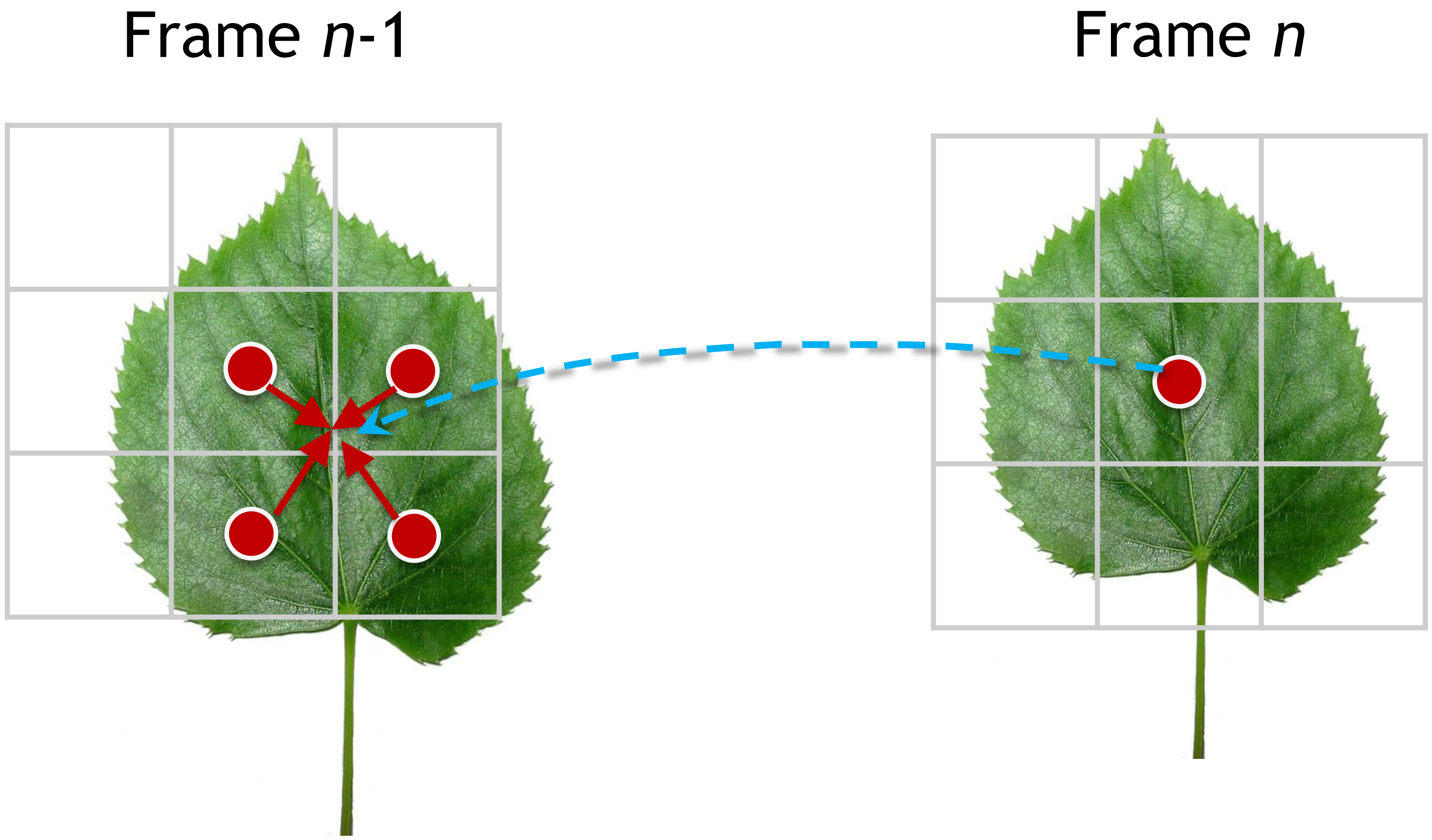


# HISTORY REPROJECTION

## for moving objects / camera

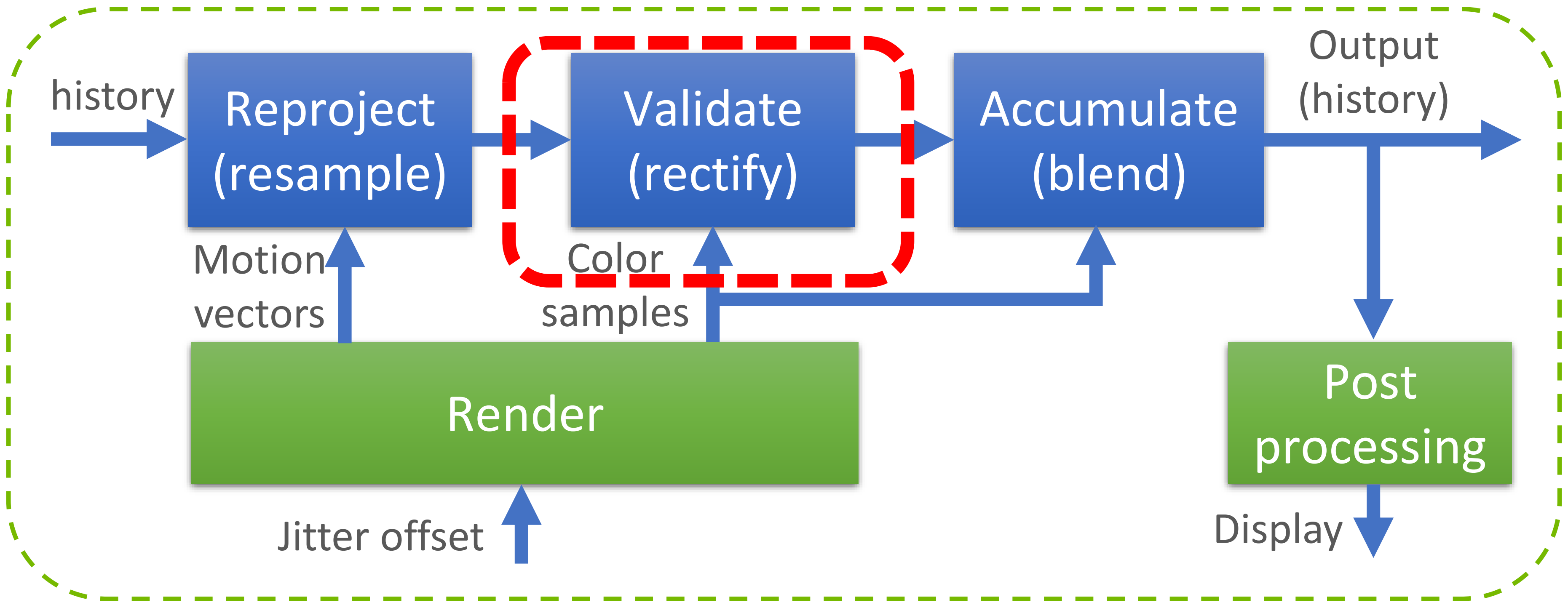



- Reuse history under motion
- Motion vector
  - From camera matrices + 3D positions (static objects)
  - From forward rendering passes (animated objects)
- Image resampling
  - Bilinear, bicubic, …

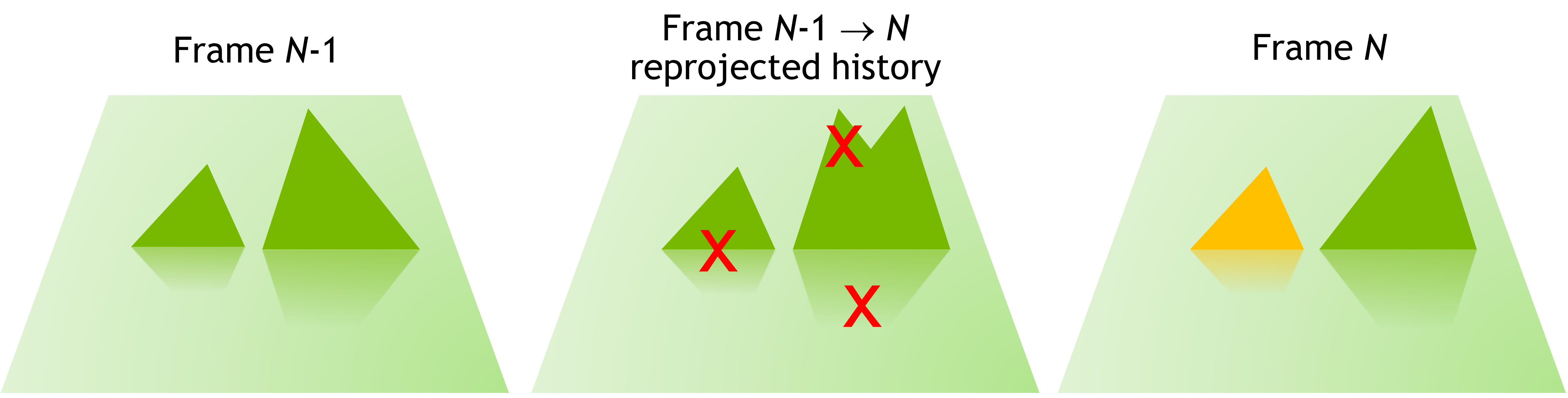


# HISTORY VALIDATION

## Avoid reusing false/stale data

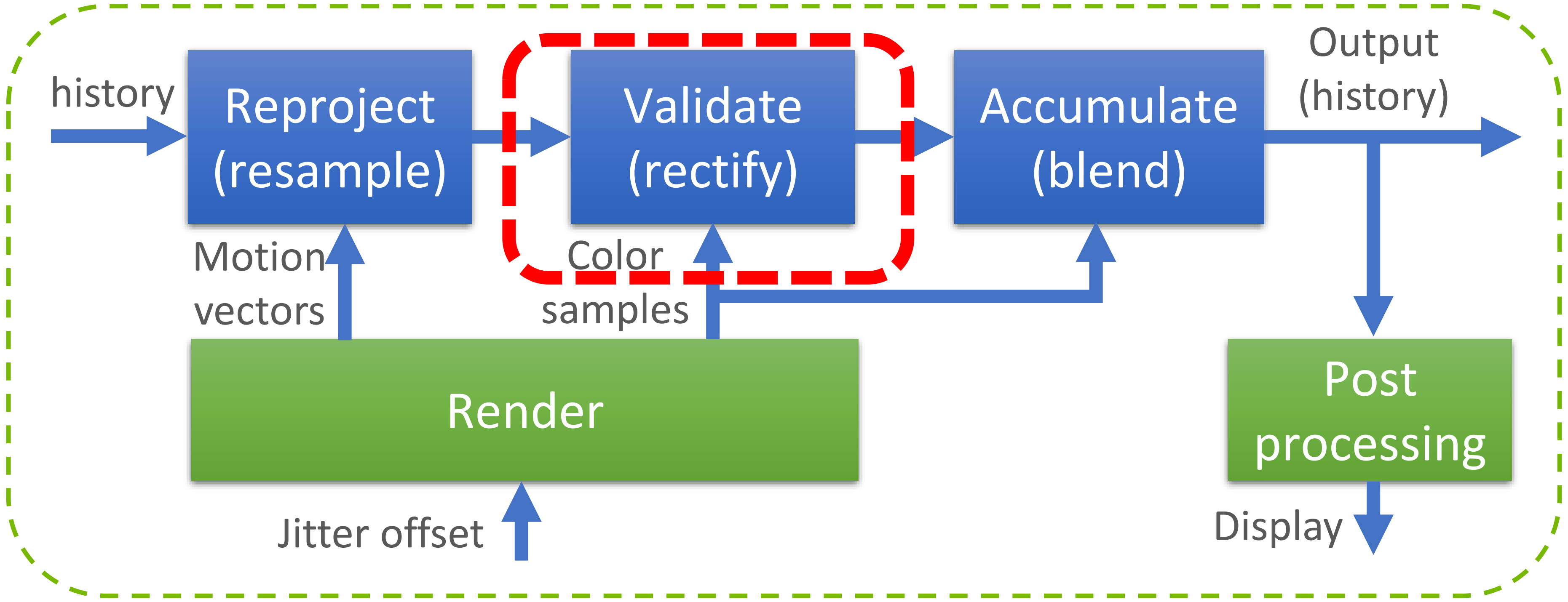



- History color can be wrong
  - Disocclusion
  - Shading changes
  - Incorrect motion vector
- Fix history color
  - Rejection
  - Rectification

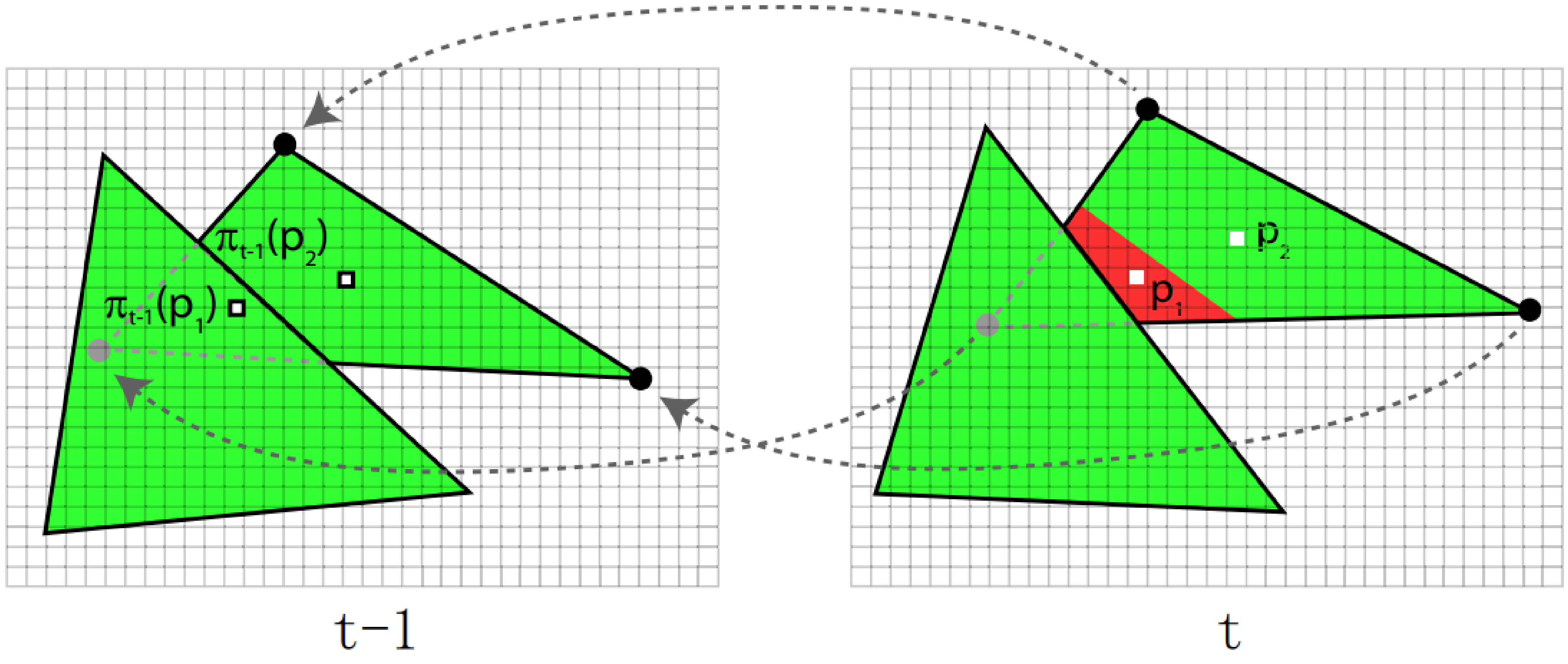


# HISTORY REJECTION

## Avoid reusing false/stale data

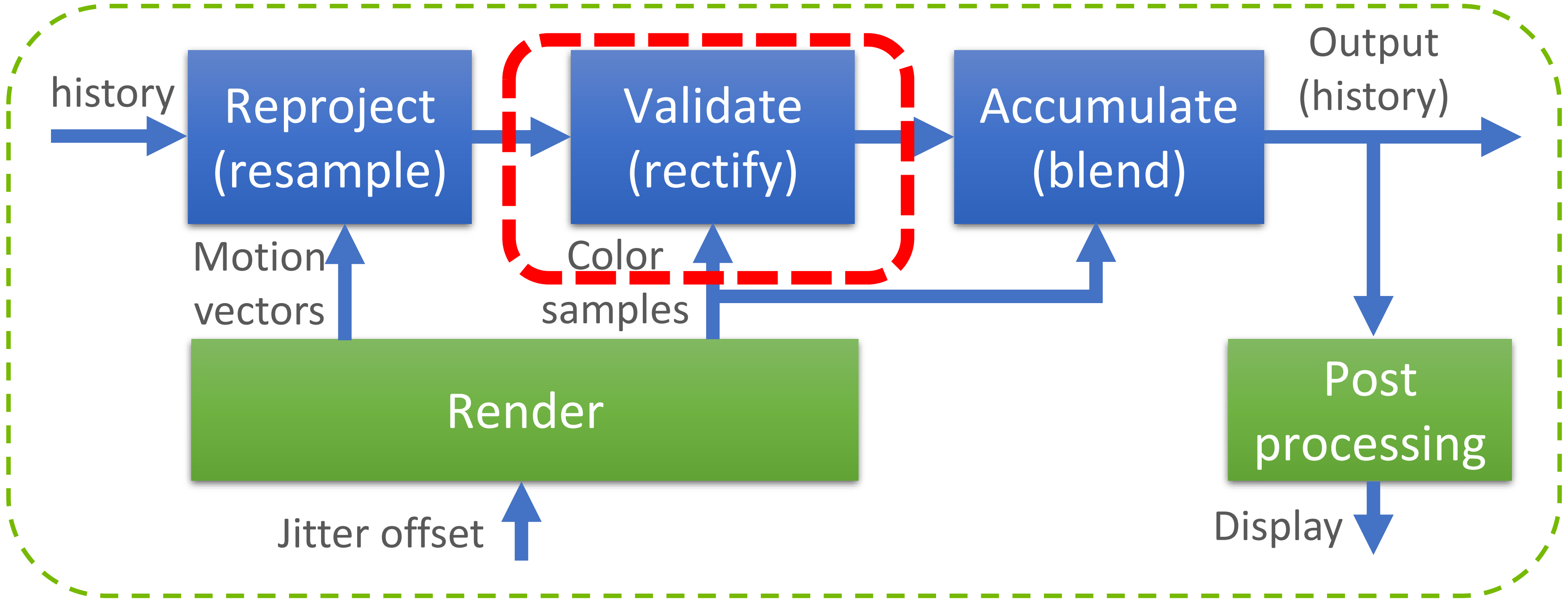



- Detect invalid history based on
  - Depth
  - Surface normal
  - Object/primitive ID
  - Color (filtered)
- Reject or fade out invalid color
  - Clamp $\alpha$

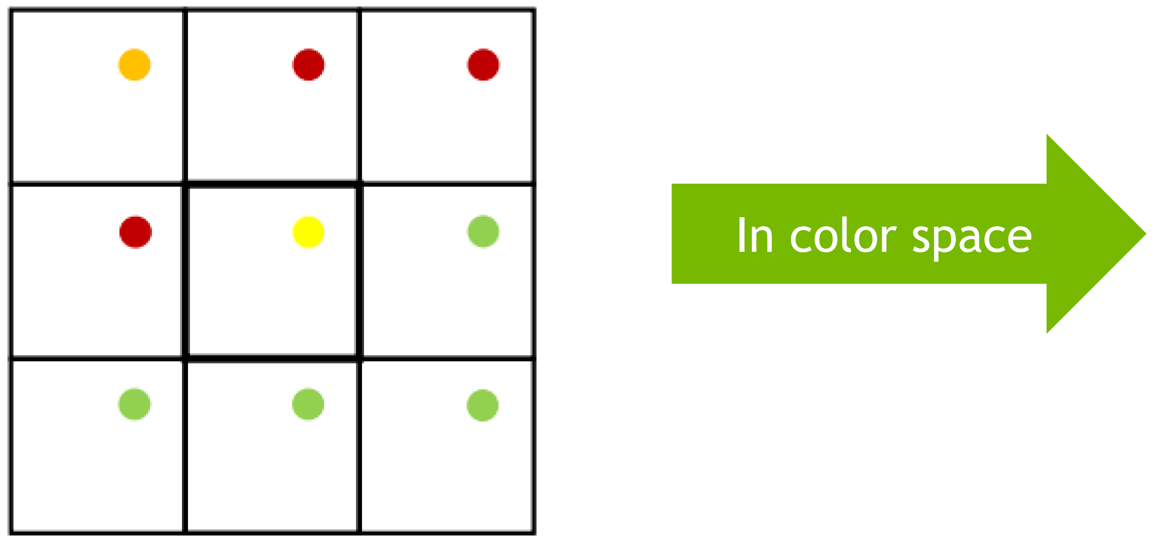


# HISTORY RECTIFICATION

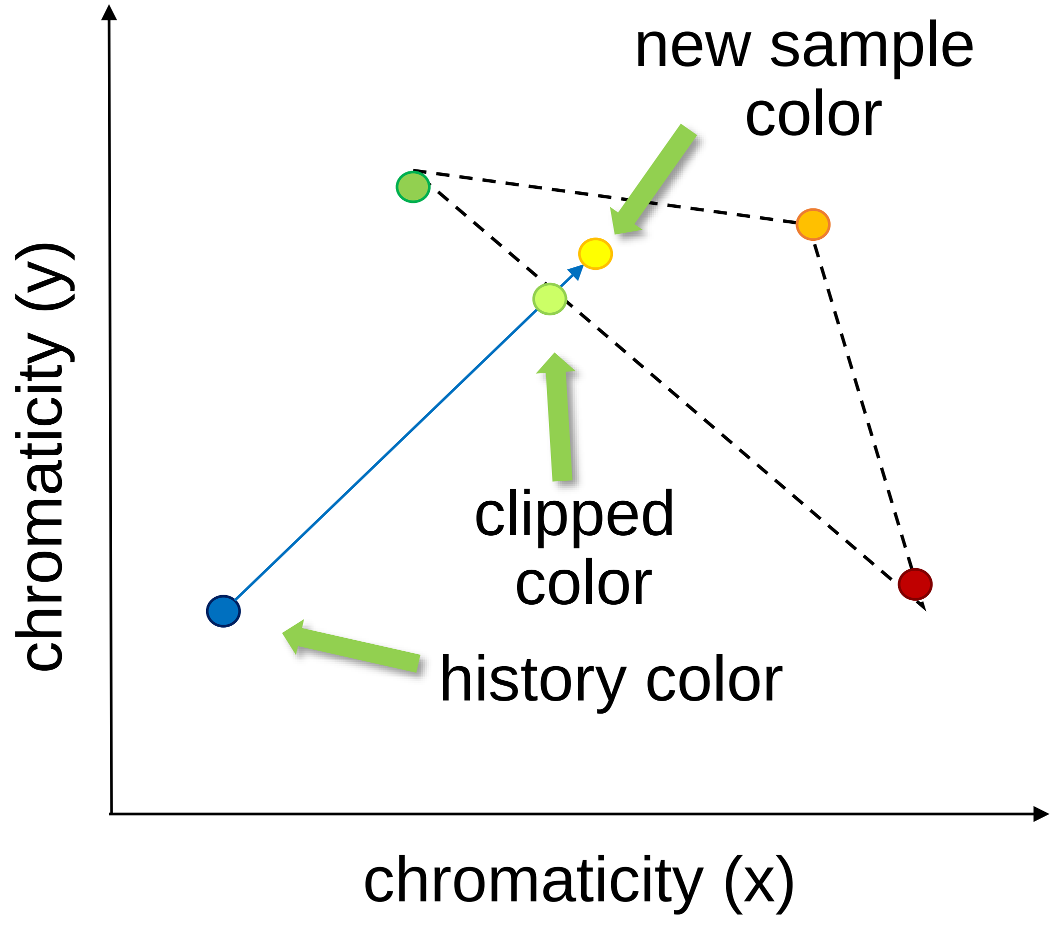
Make history more consistent with new color samples




Get color distribution from 3x3 neighborhood




Convex hull clipping



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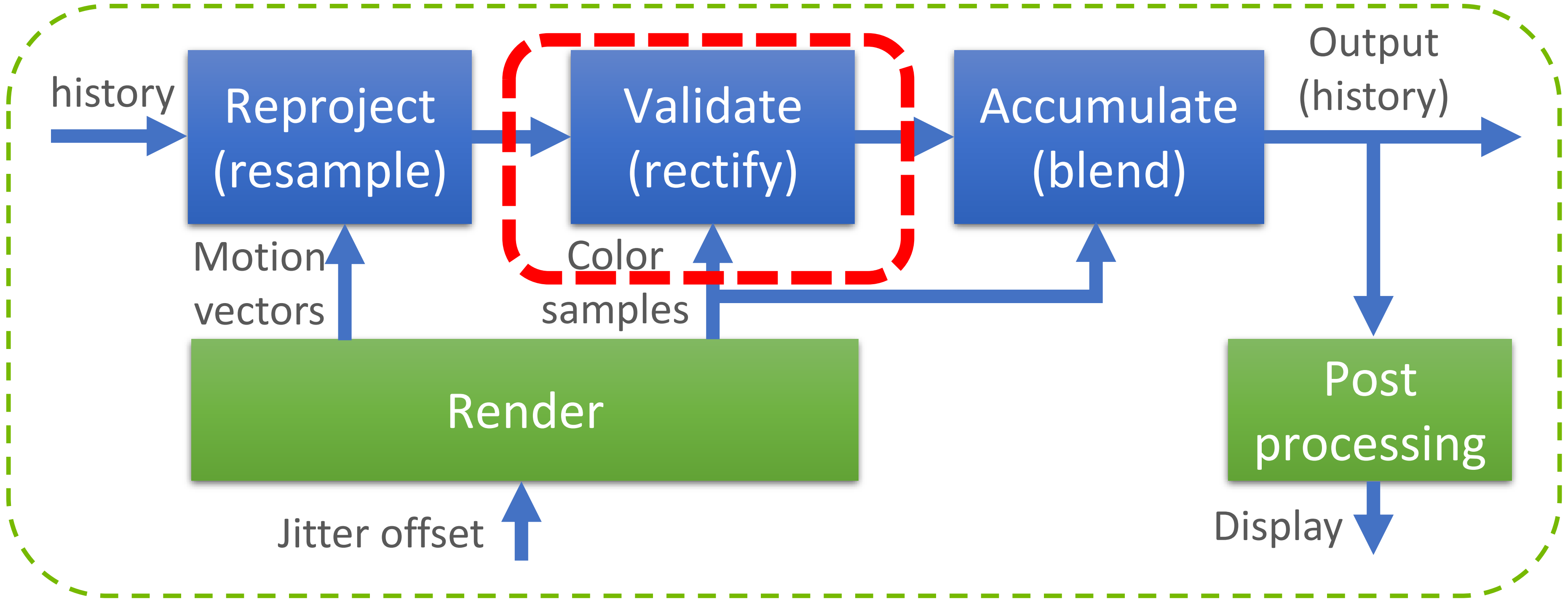
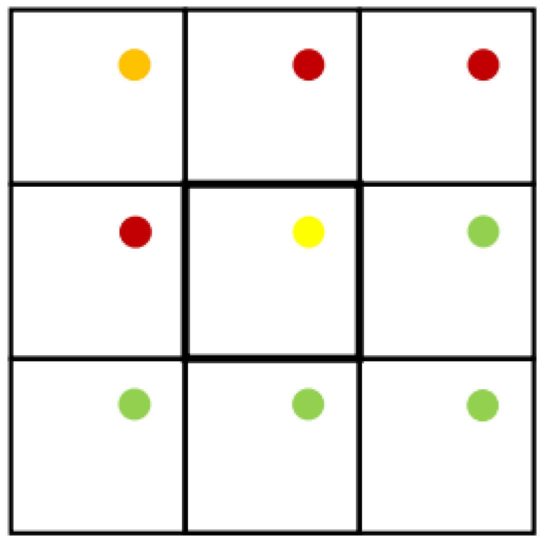
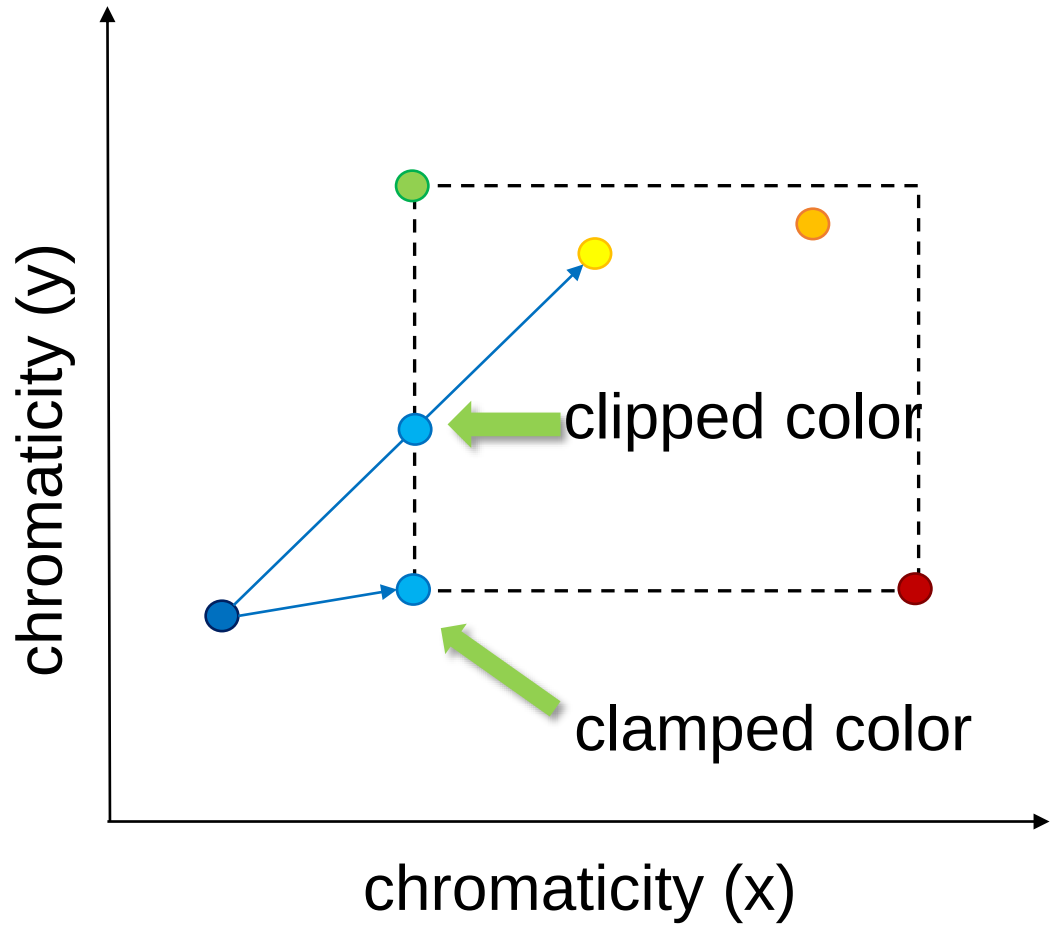



## AABB clipping/clamping

Get color distribution from 3x3 neighborhood



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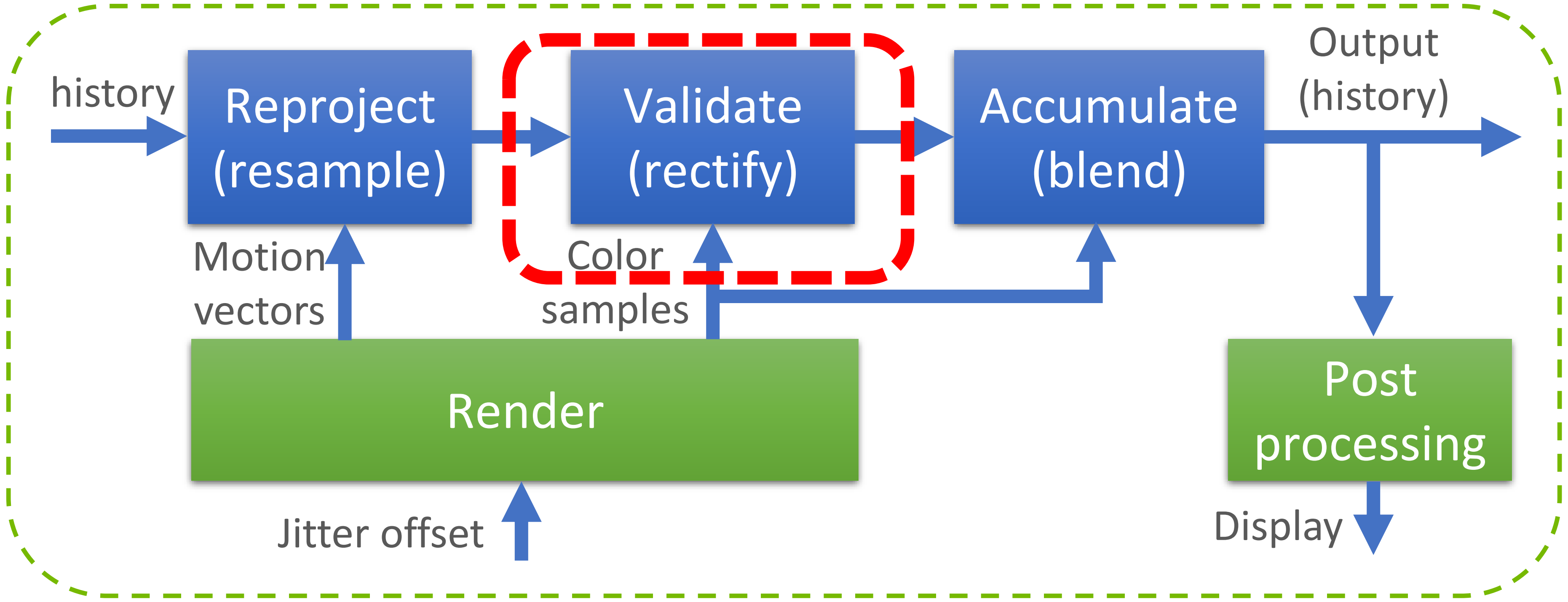
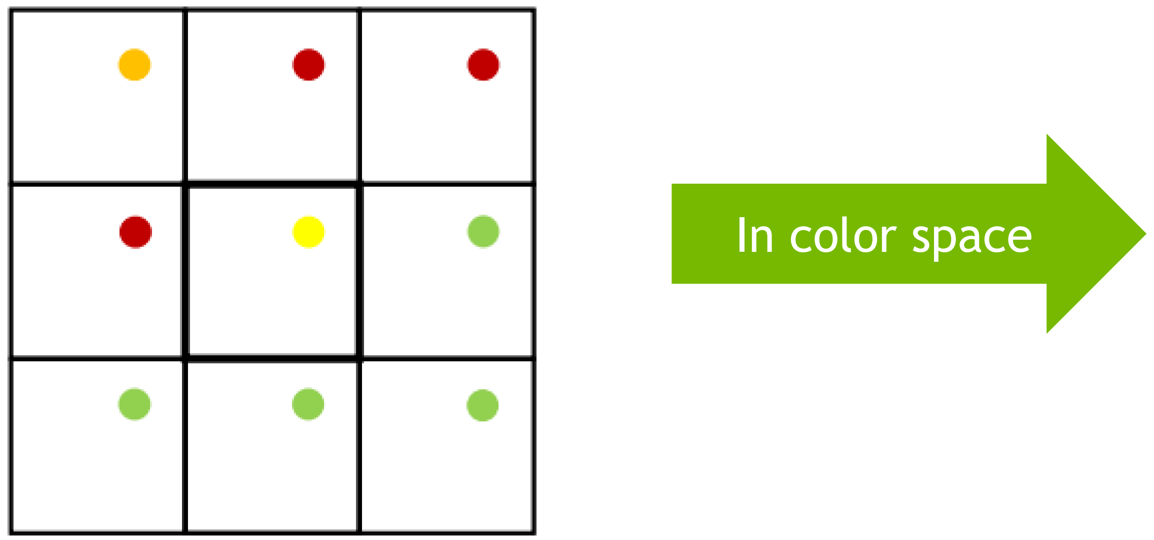
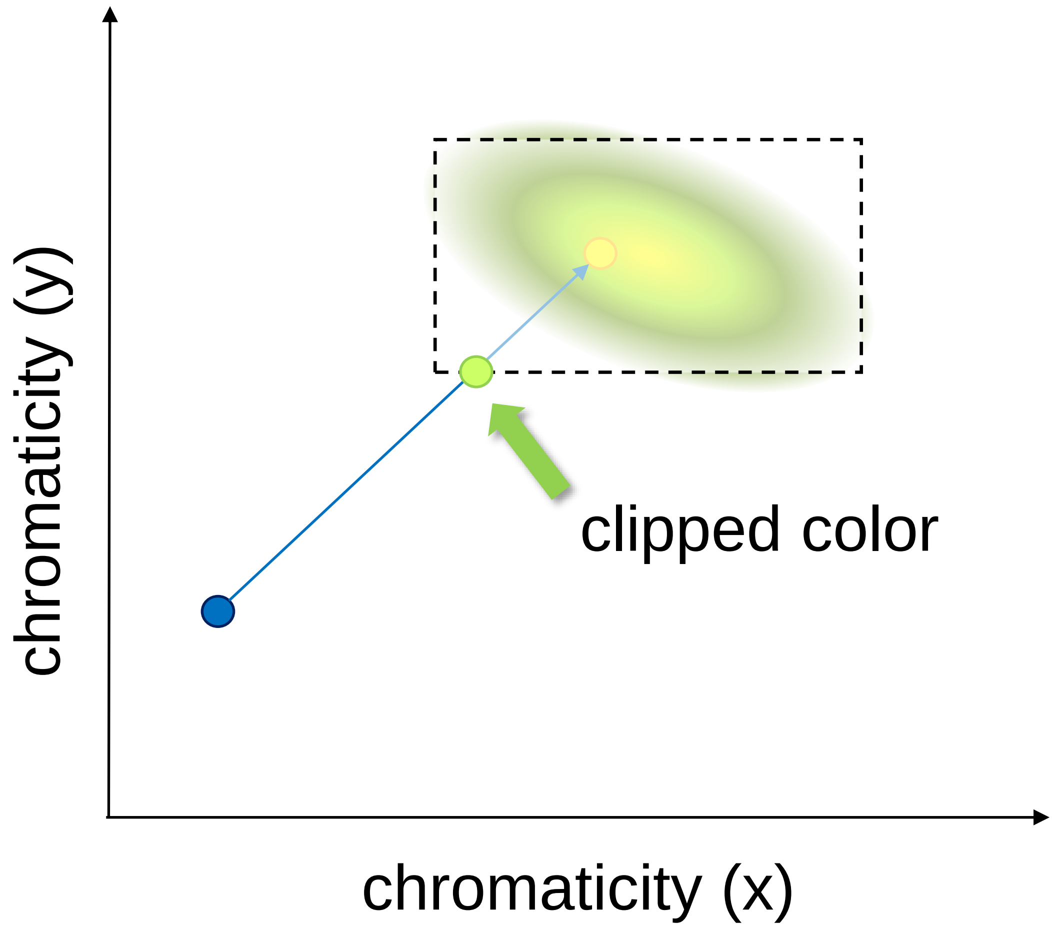



Get color distribution from 3x3 neighborhood




Variance clipping

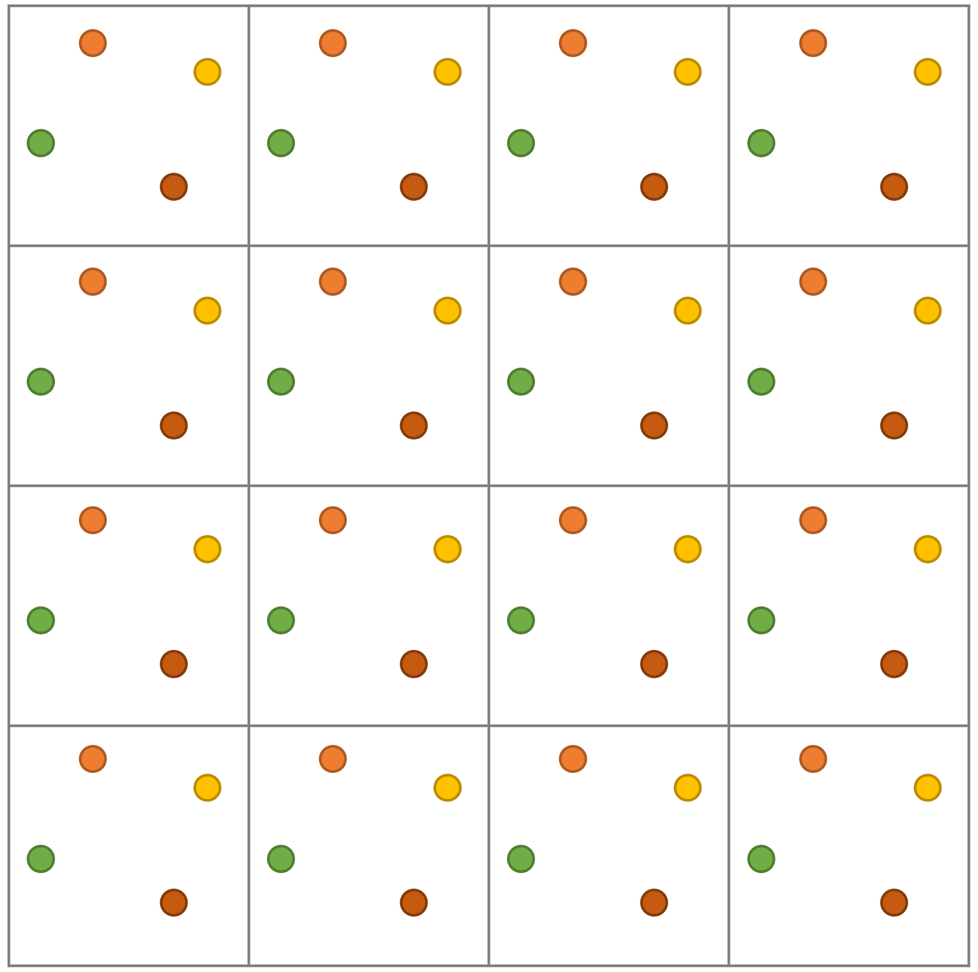


# TEMPORAL UPSAMPLING

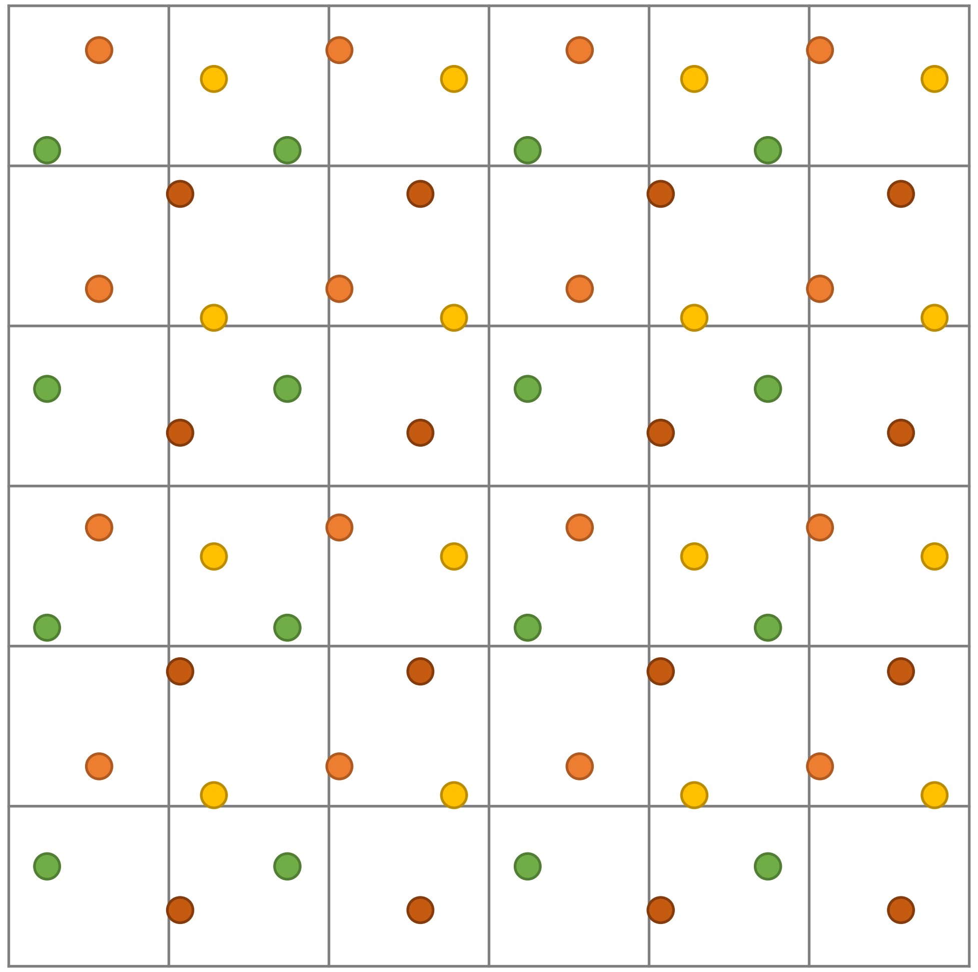
## Boosting output resolution

- Keep input (sample) resolution, increase history (output) resolution

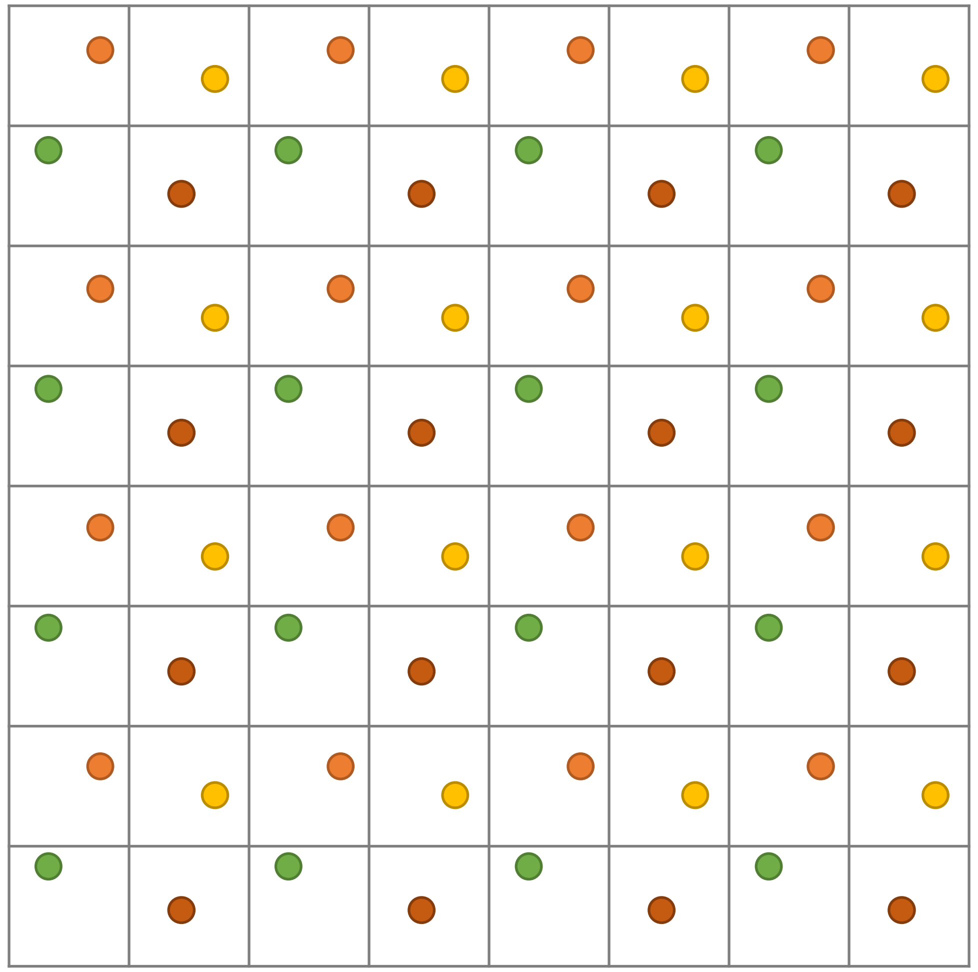
Regular TAA



TAA + 1.5x Upsampling



TAA + 2x Upsampling

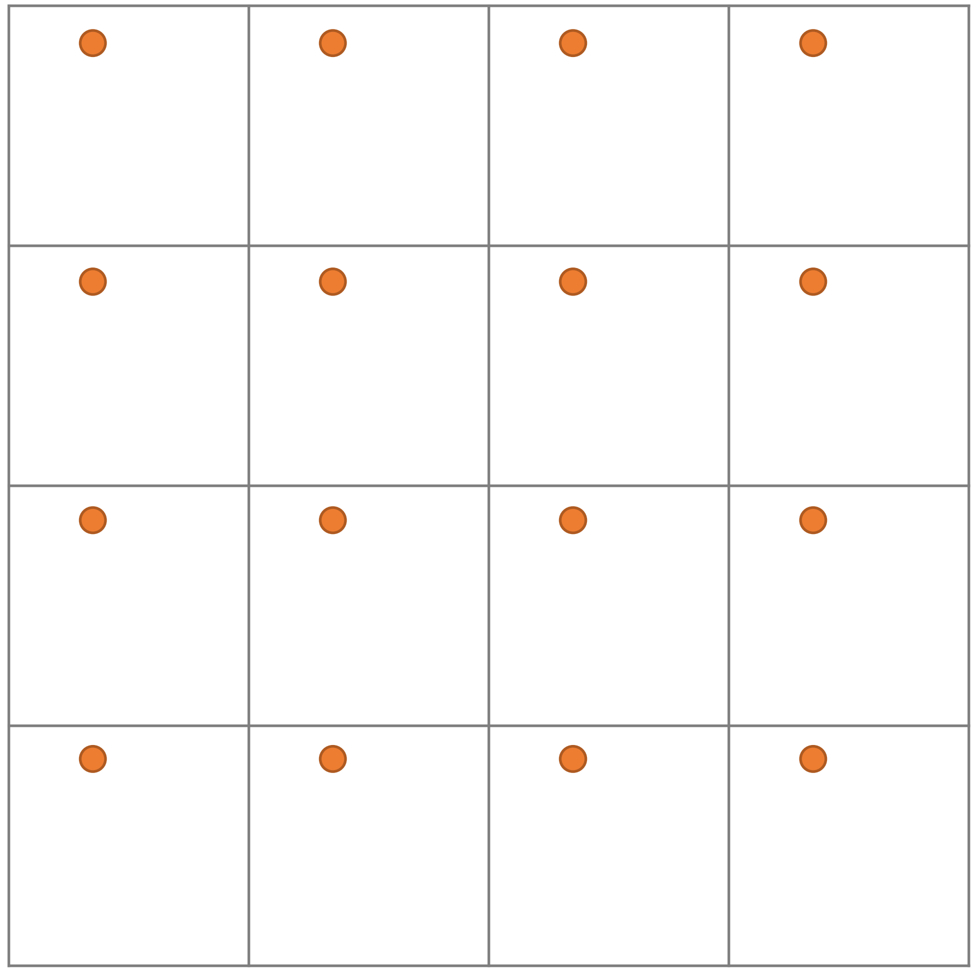


# TEMPORAL UPSAMPLING

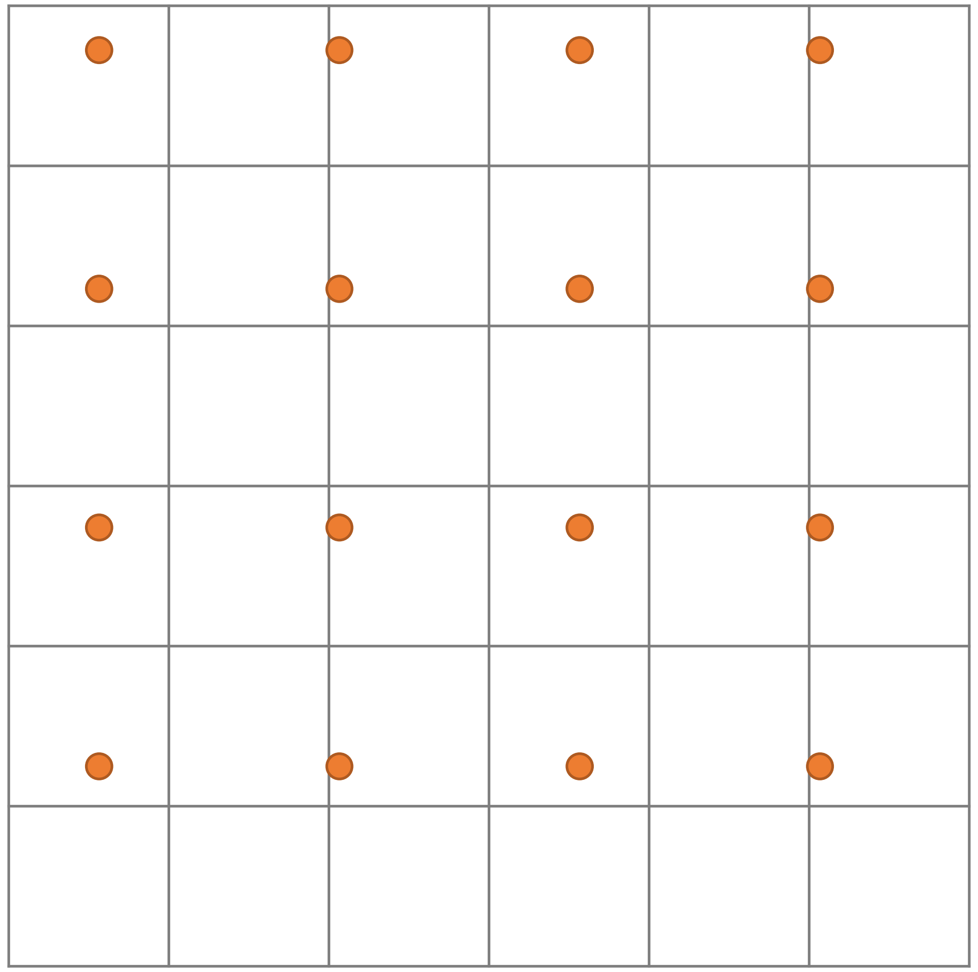
## Scaling-aware sample accumulation

- Step 1: spatial upscaling from current frame samples

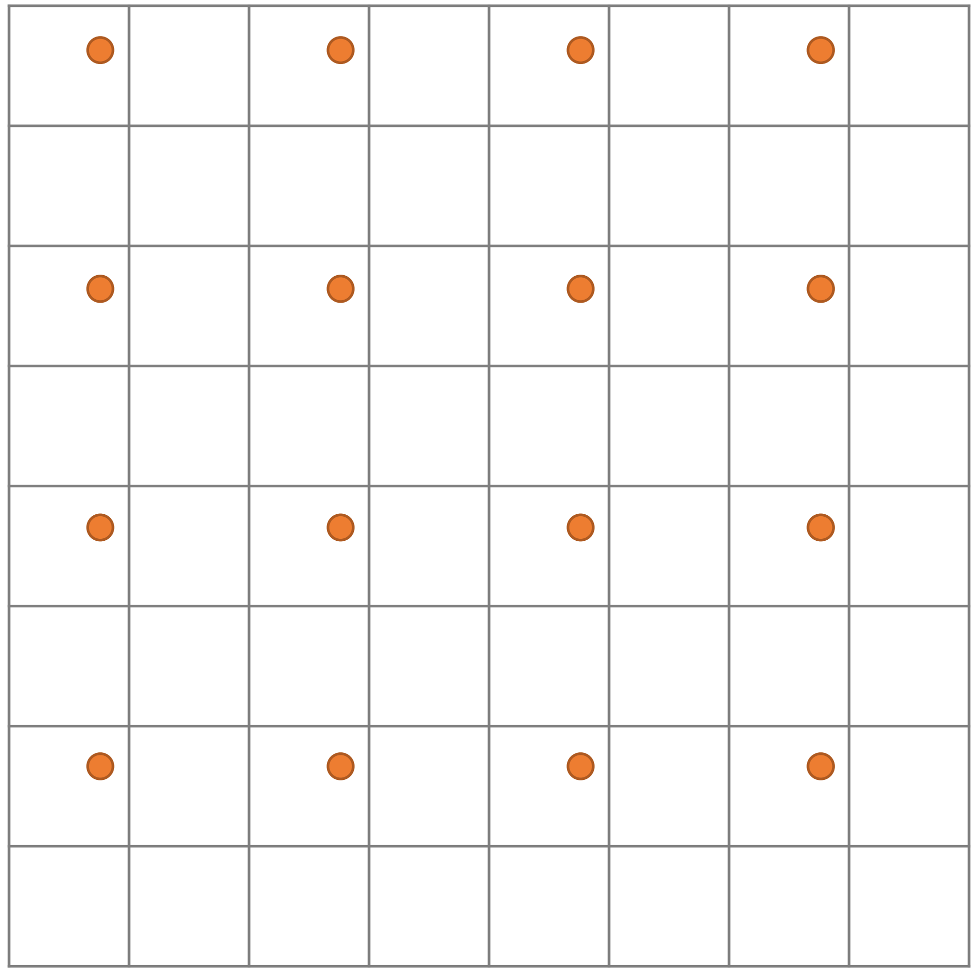
Regular TAA



TAA + 1.5x Upsampling



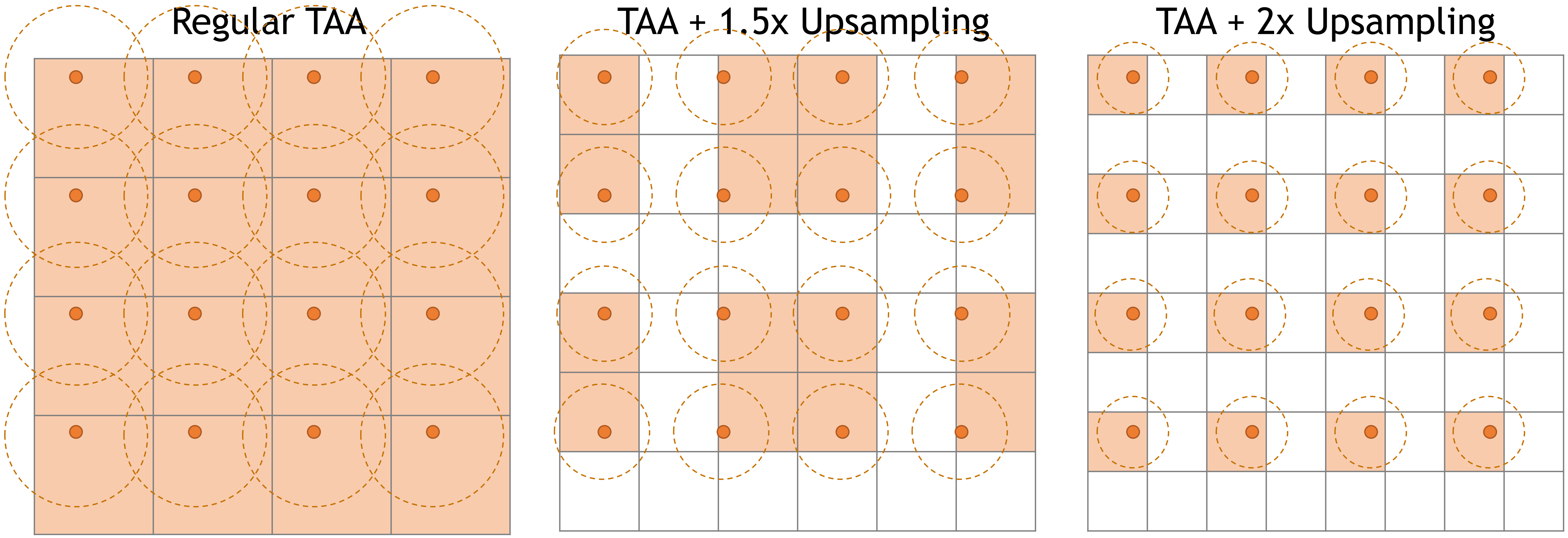
TAA + 2x Upsampling



# TEMPORAL UPSAMPLING

## Scaling-aware sample accumulation

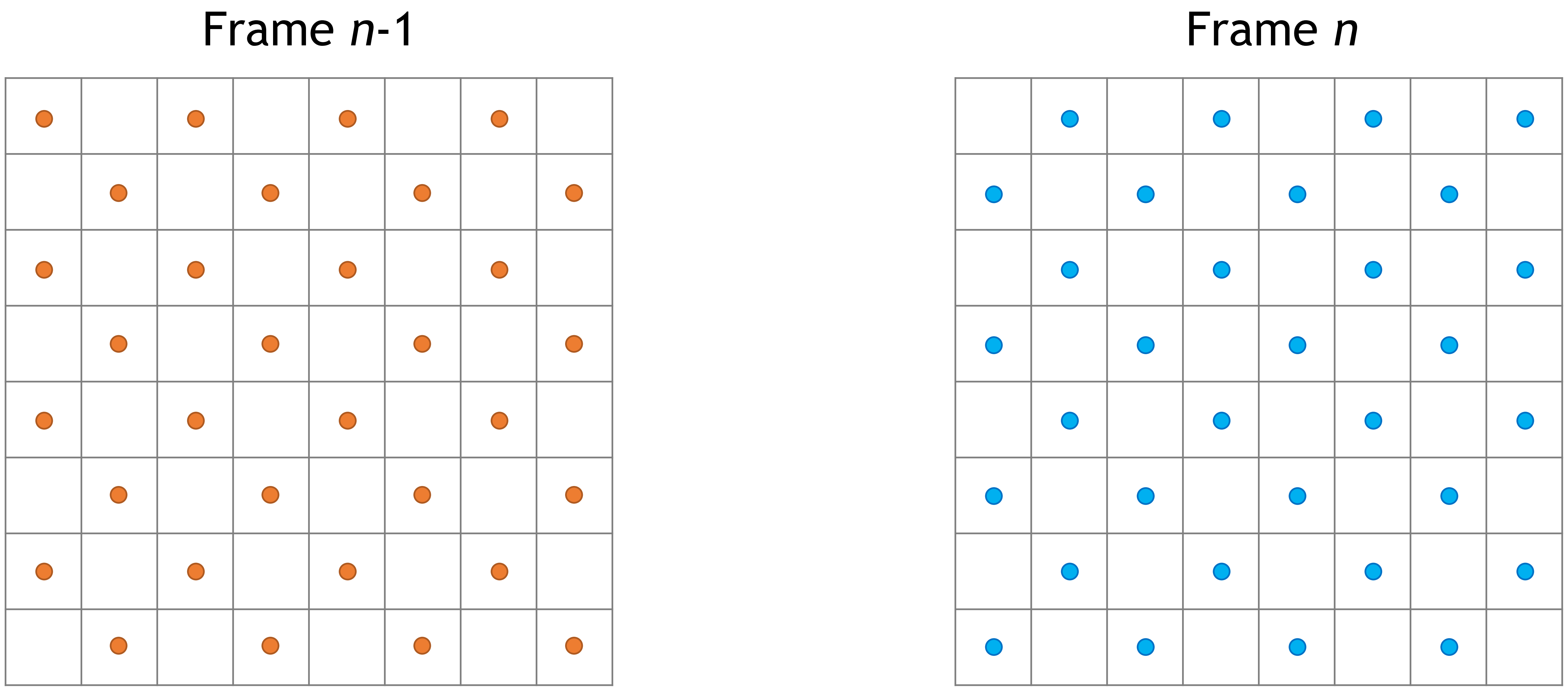
- Step 2: adaptive blending based on sample location and upscaling factor

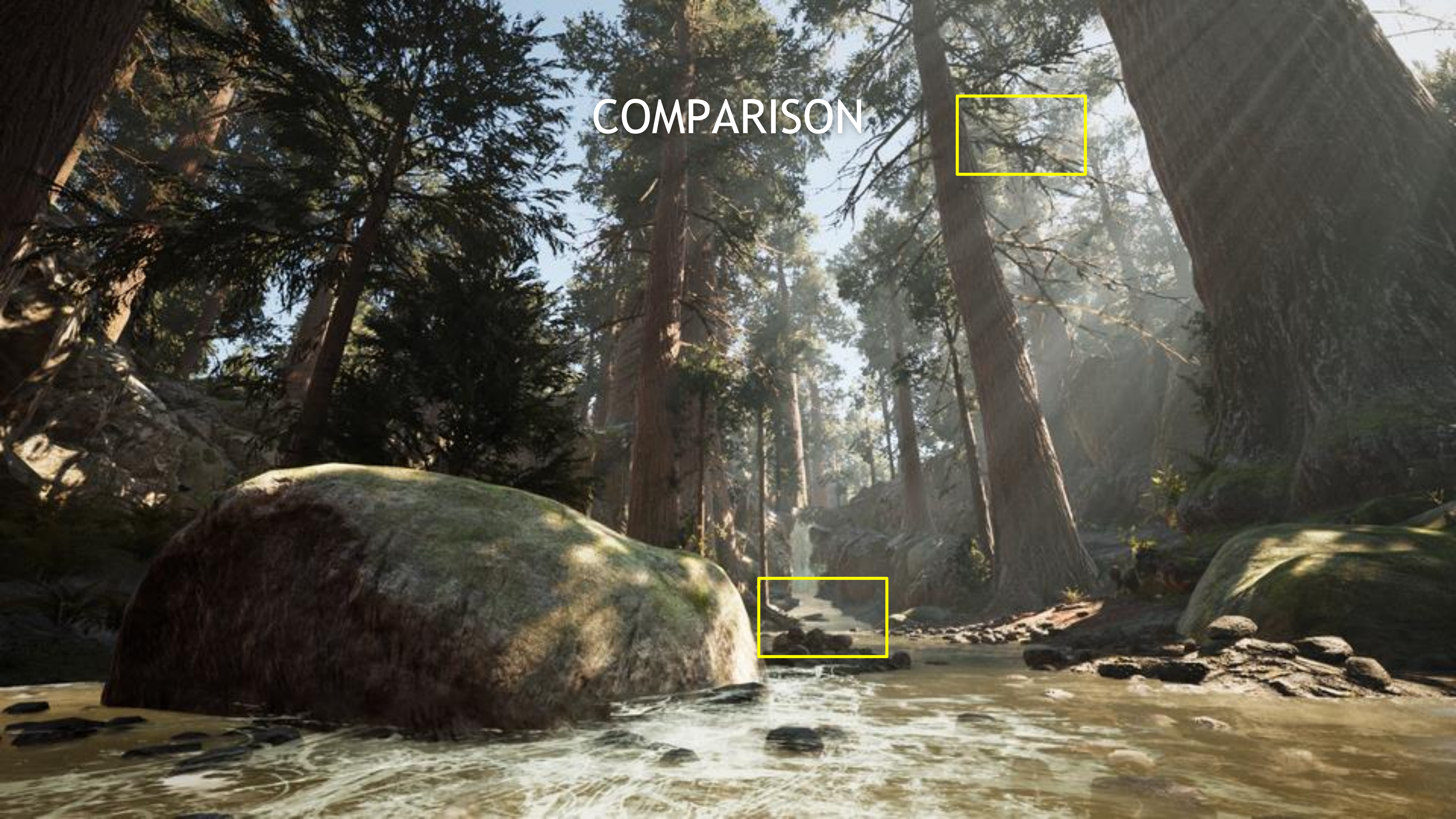


# CHECKERBOARD RENDERING

## Temporal upsampling with a special sampling pattern

- Alternating checkerboard pattern between odd and even frames
- Fixed 1:2 upsampling rate; uses MSAA or target-independent rasterization




COMPARISON

# COMPARISON

One input frame | Temporal-antialiased output | 1080p -> 1440p Temporal-upsampled output

# CHALLENGES

# BLURRINESS

## Culprit #1: History resampling

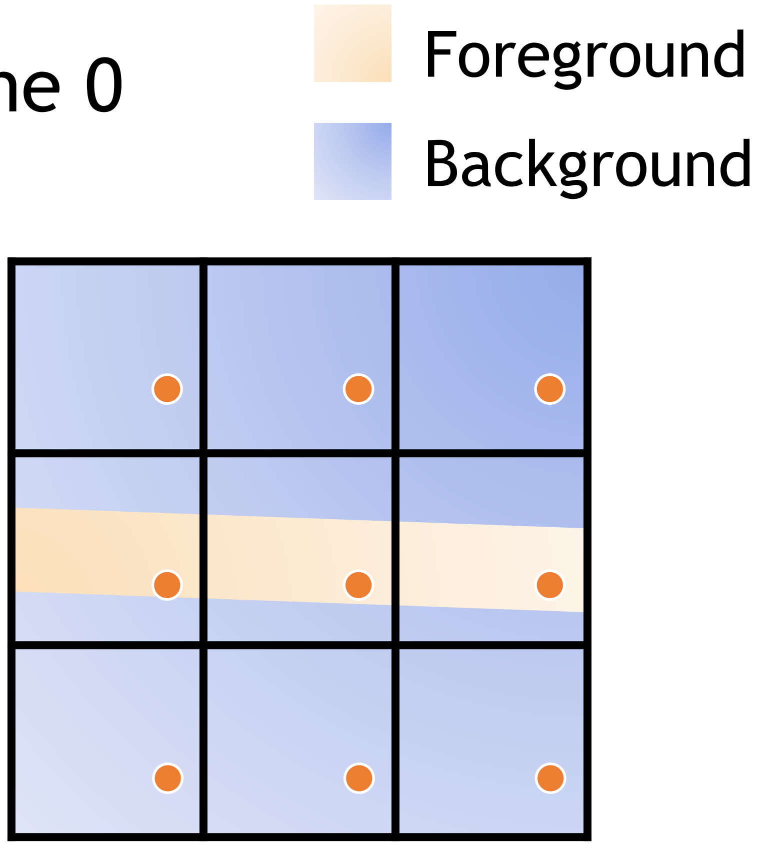
- History reprojection involves image resampling
- Repeated resampling over multiple frames → loss of high frequency details
- Quality improves with better (more expensive) resampling filters

# BLURRINESS

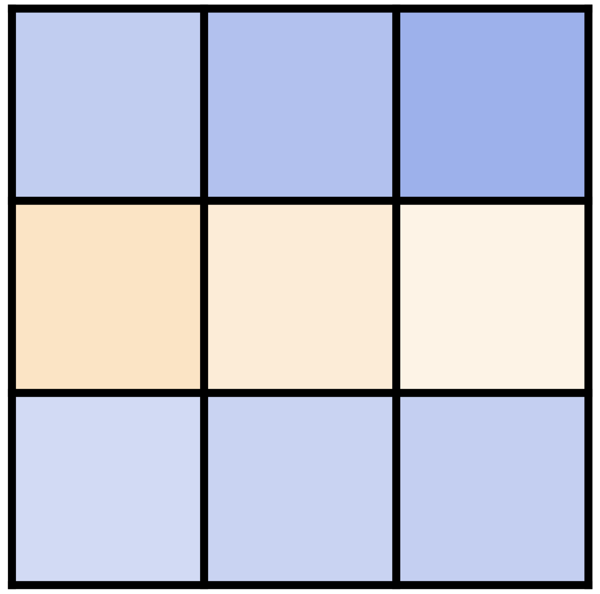
## Culprit #2: History-clipping/clamping

- History clipping / clamping use current frame color to rectify history samples
- Can often incorrectly remove detailed features in history

Frame 0




Output color / history



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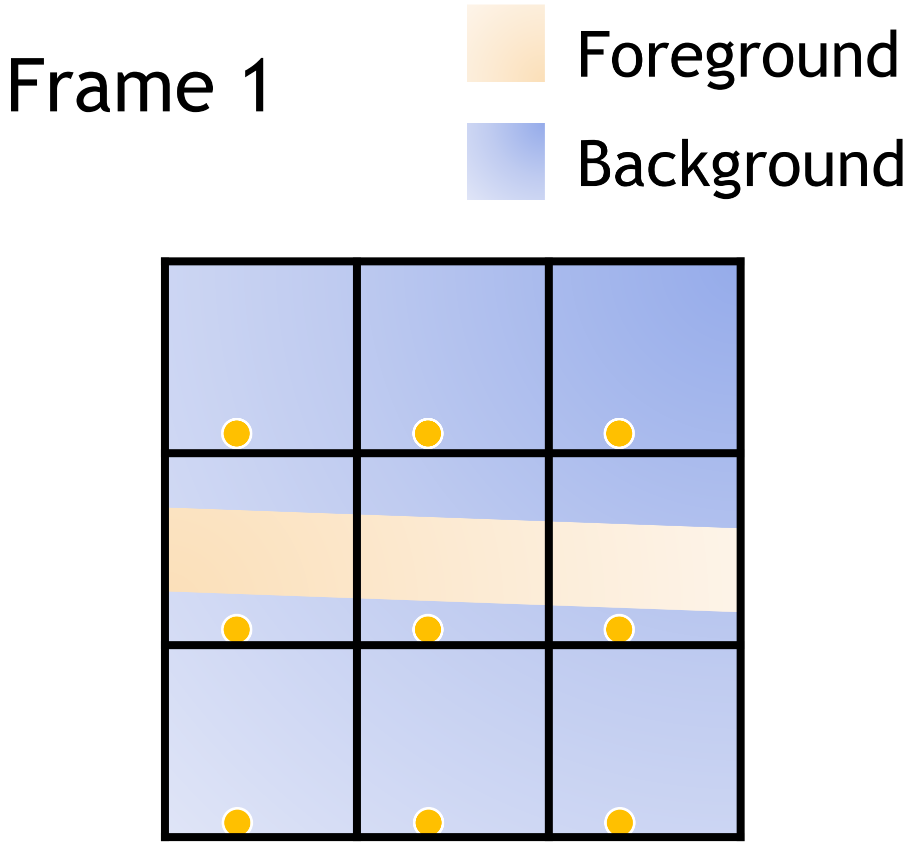


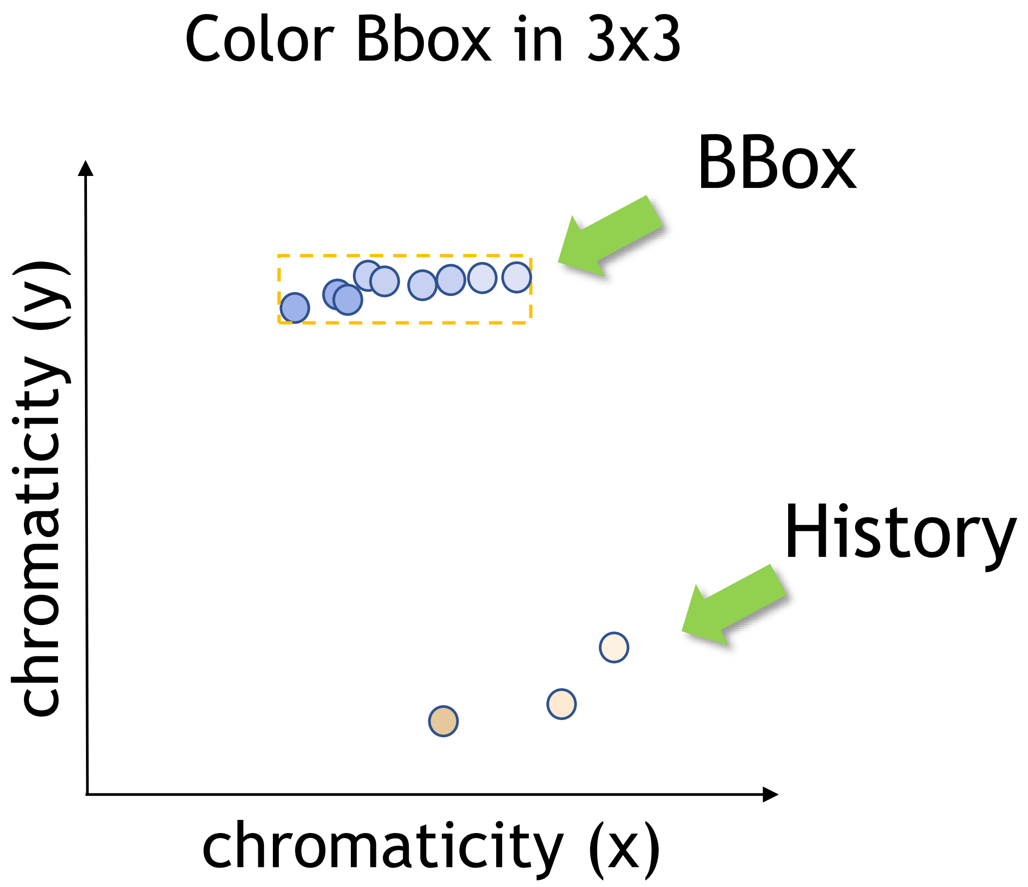


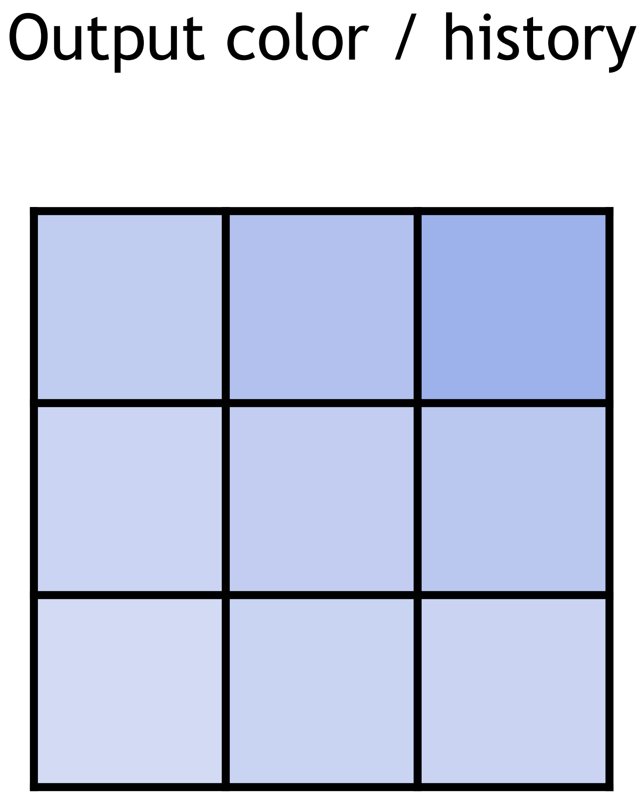

# BLURRINESS

## Culprit #2: History-clipping/clamping

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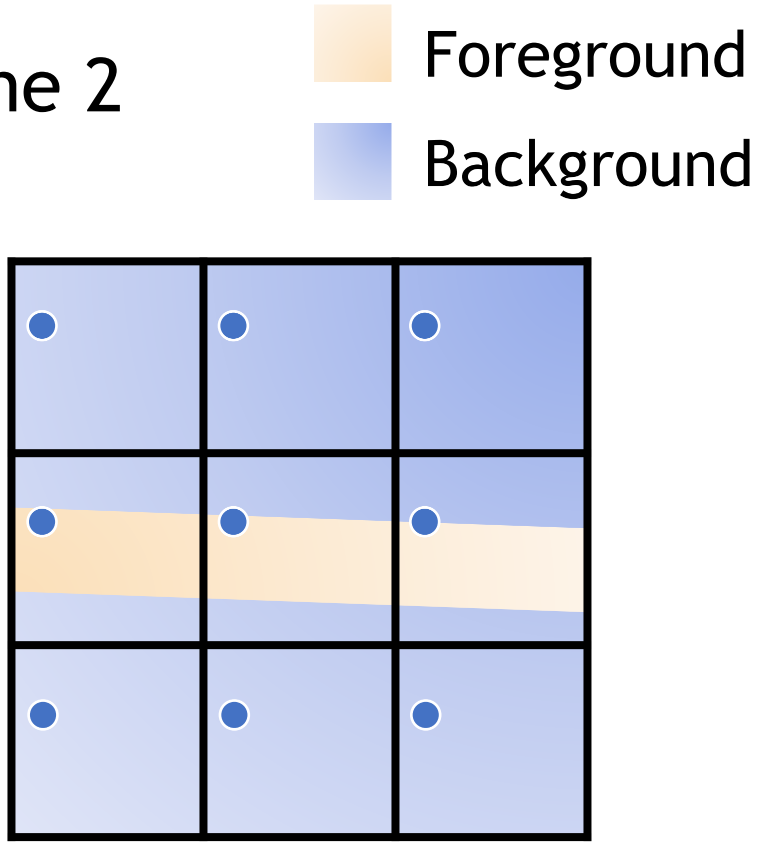
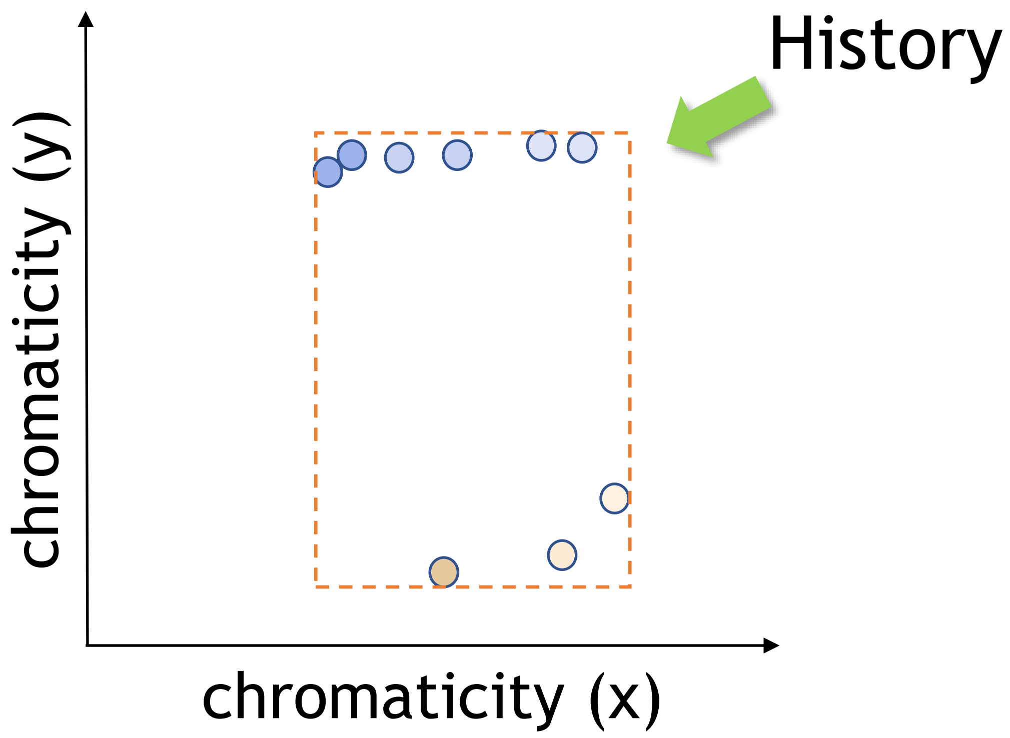
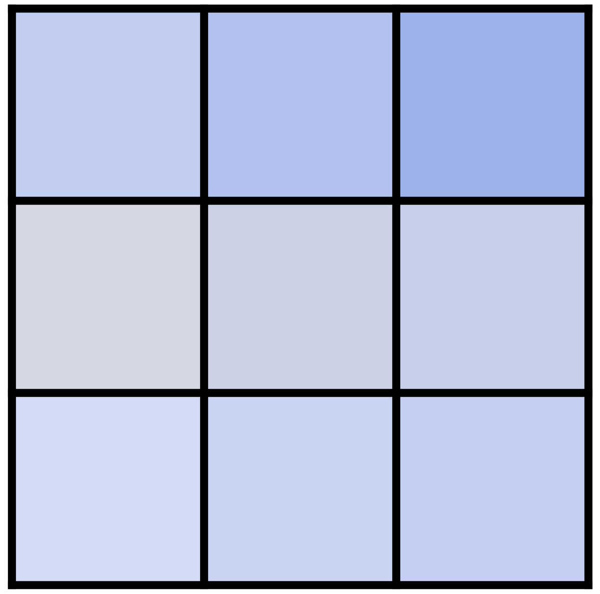
Frame 2




Color Bbox in 3x3




Output color / history



# BLURRINESS

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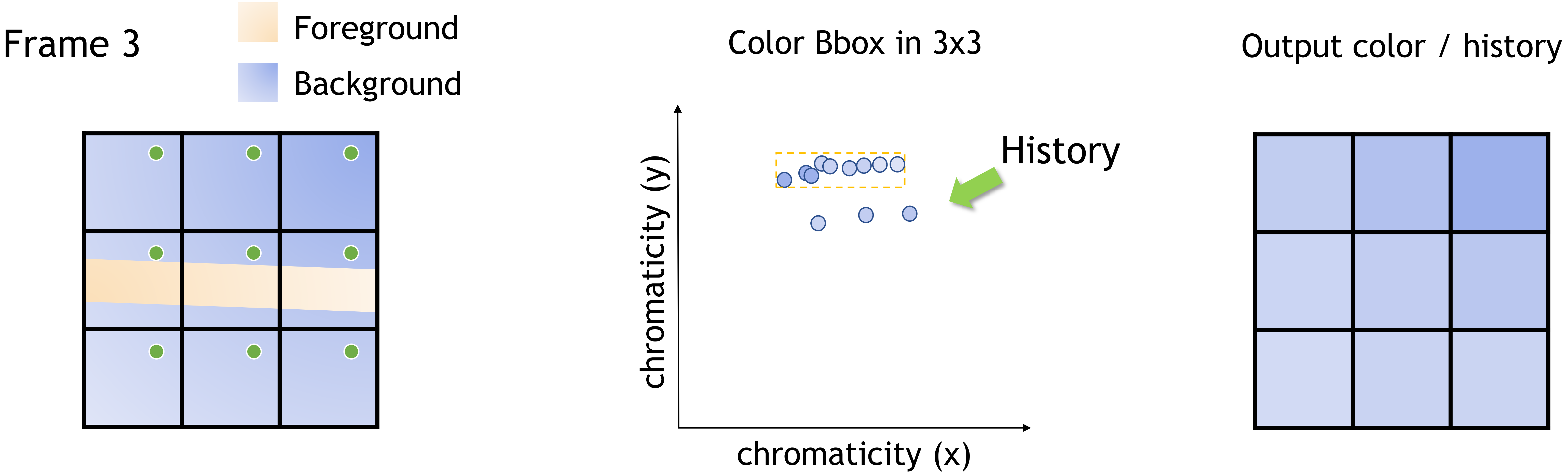



Reconstruction with clamping

Reconstruction w/o clamping

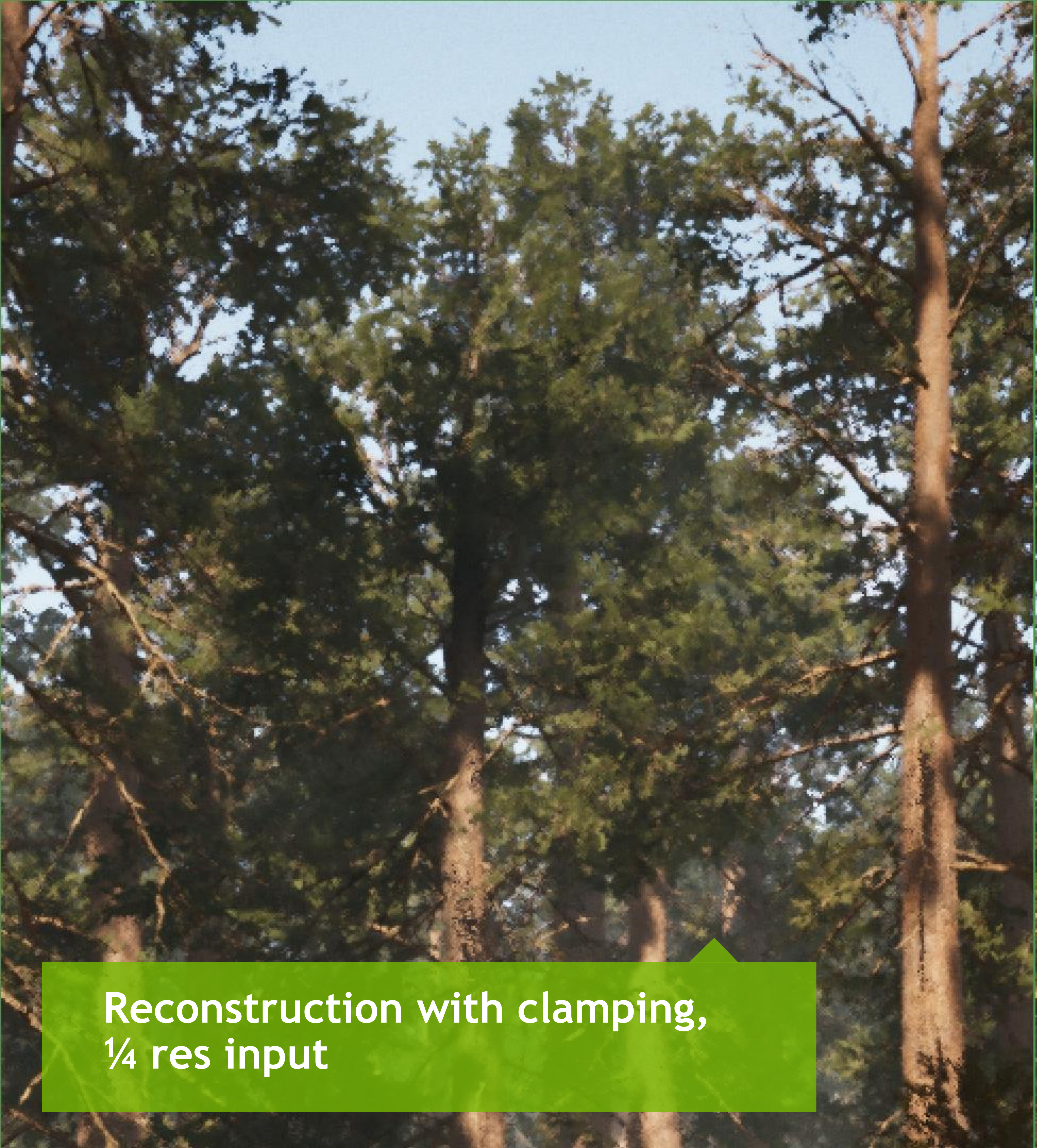
# BLURRINESS

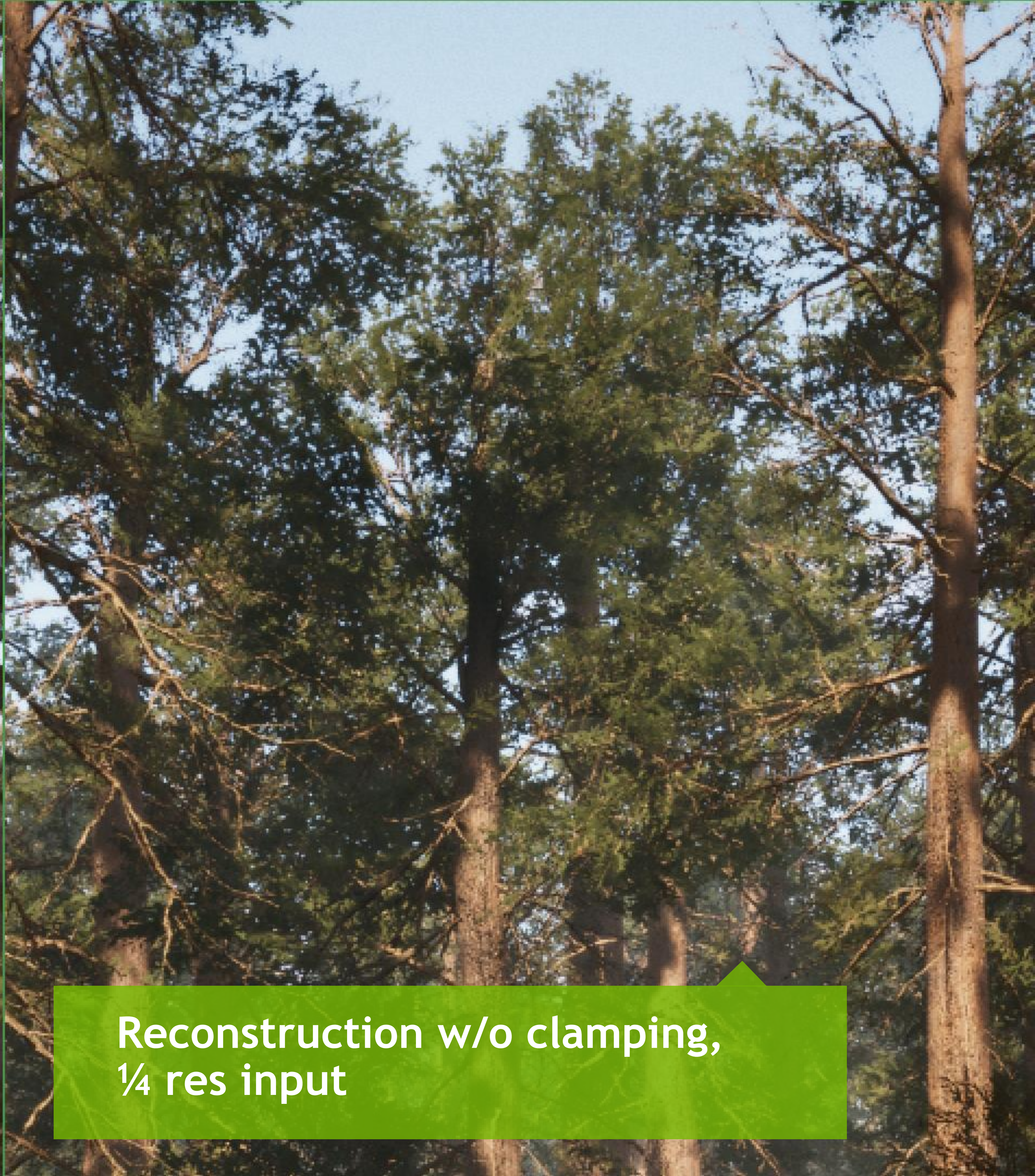
## Culprit #2: History-clipping/clamping

Reconstruction with clamping

Reconstruction without clamping

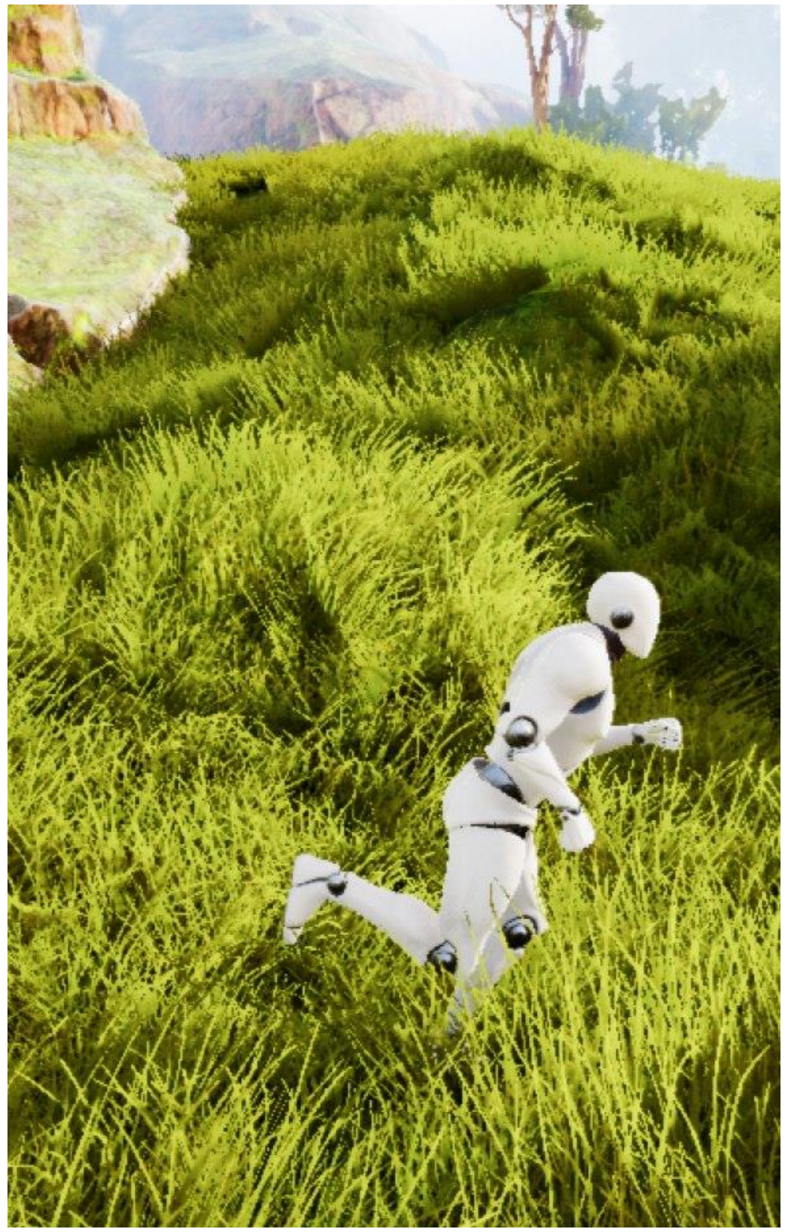
Clamping + sharpening


Reconstruction with clamping,
¼ res input


Reconstruction w/o clamping,
¼ res input

# GHOSTING

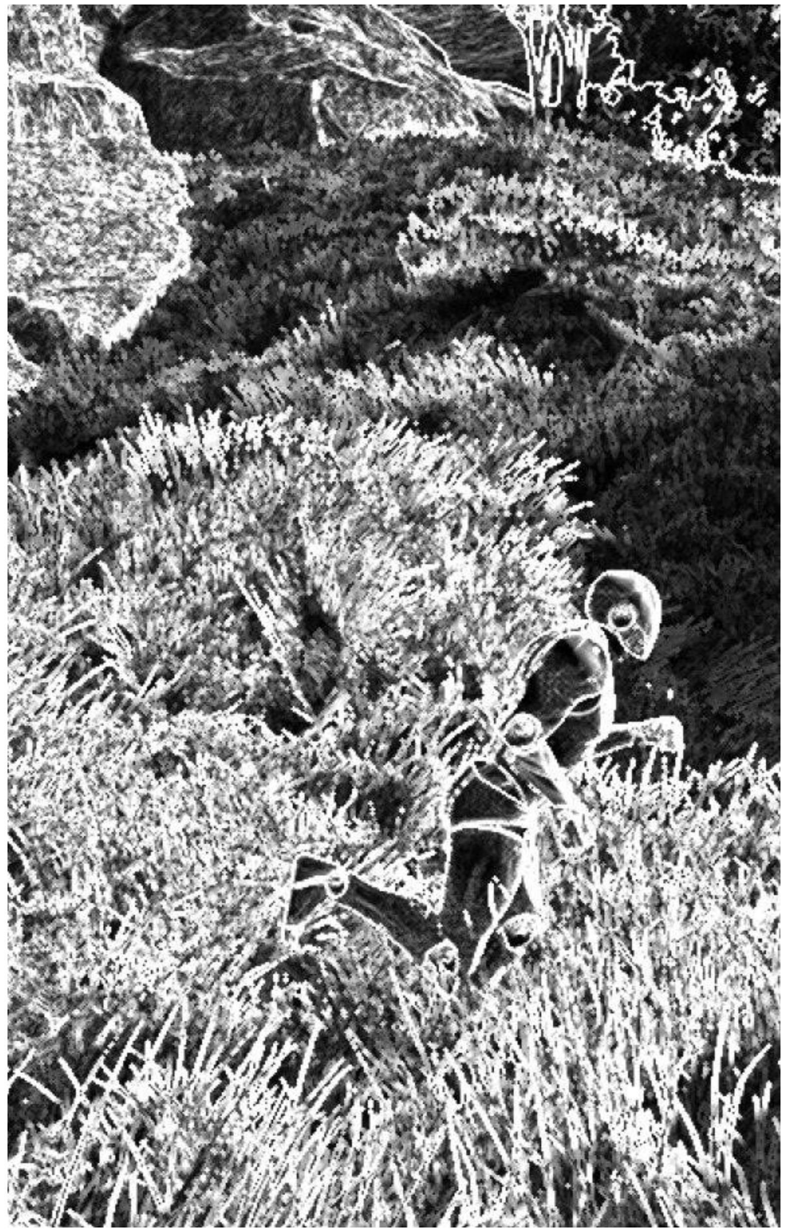
## Imperfect history clamping



1spp Input from current frame

Reconstructed by TAA

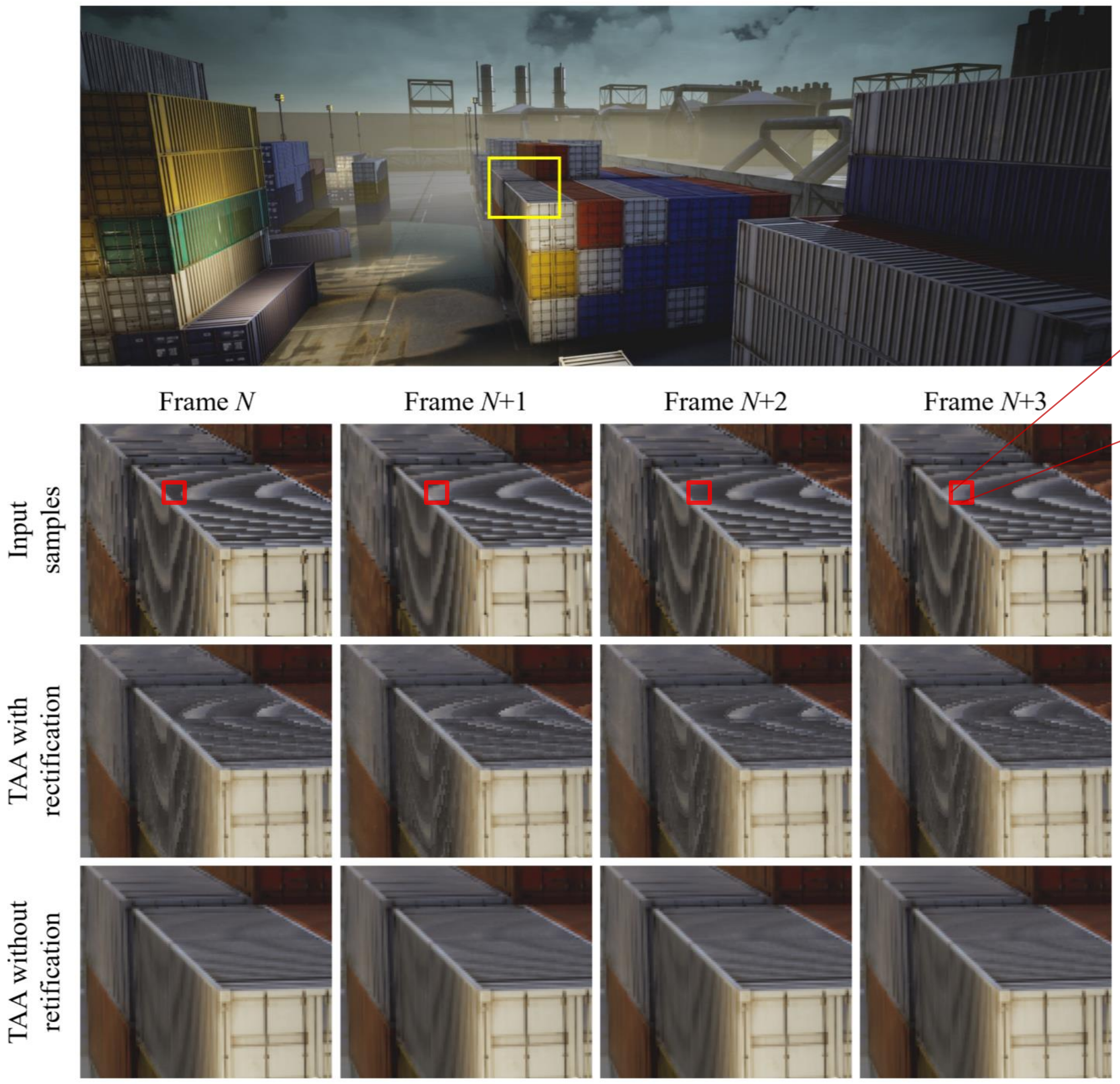
Obvious ghosting on grass

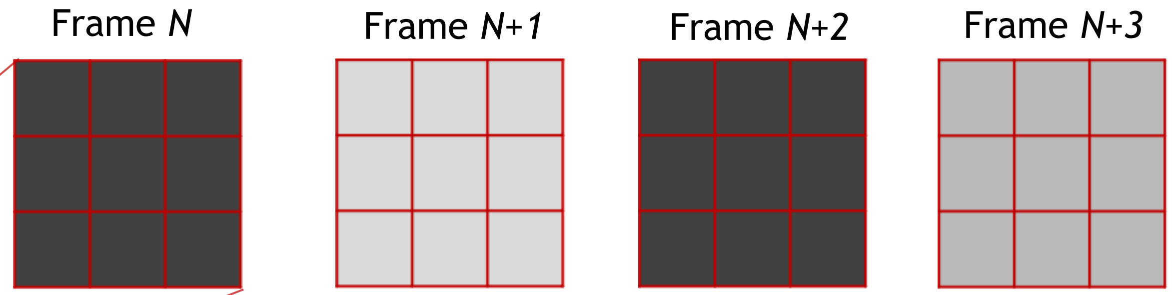


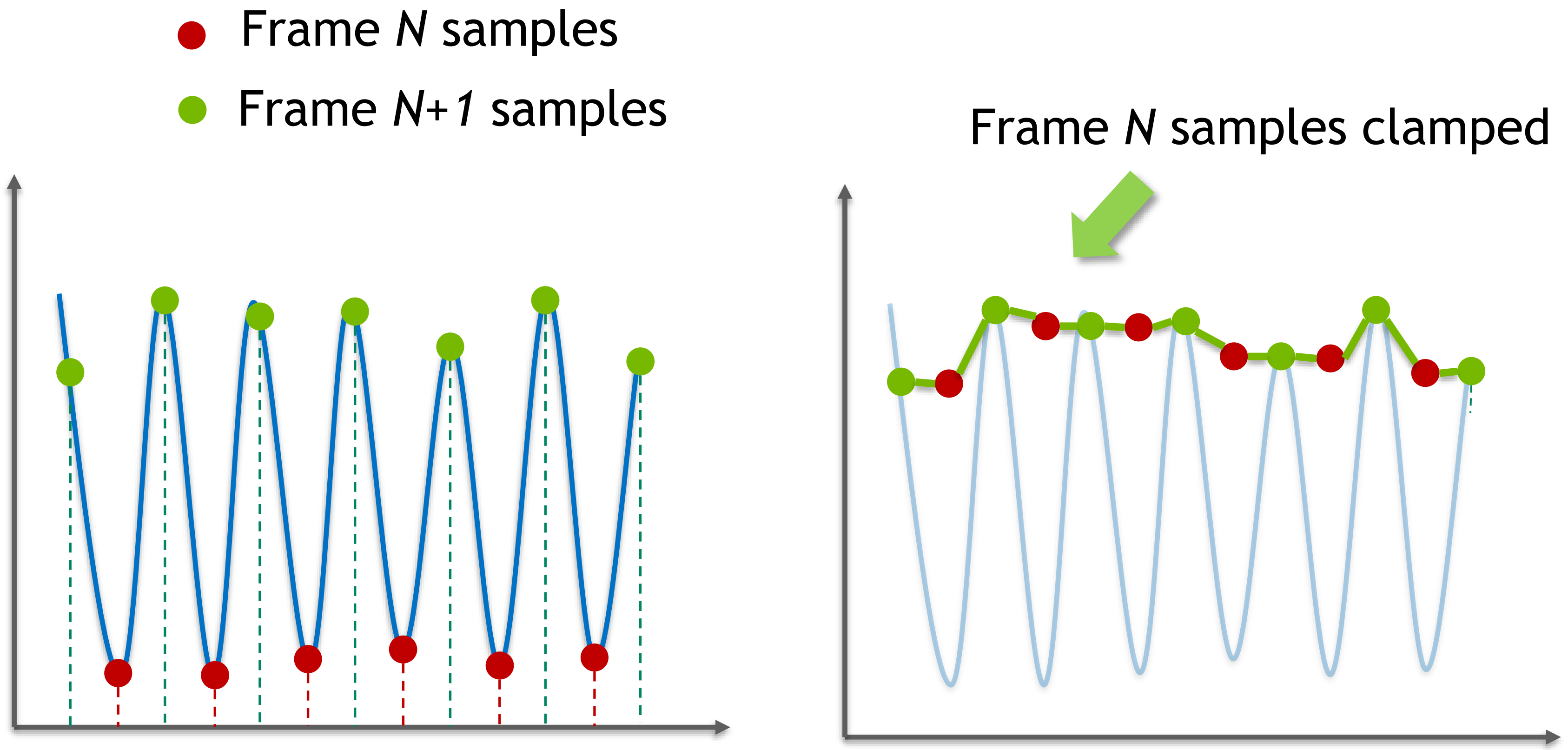
Bbox used for clamping visualized

# TEMPORAL INSTABILITY AND MOIRÉ

## Incorrect history rectification prevents sample accumulation




Temporal upsampling (2x)
Reconstructed with clamping

Temporal upsampling (2x)
Reconstructed w/o clamping

# UNDERSAMPLING ARTIFACTS

## Newly disoccluded or invalidated region

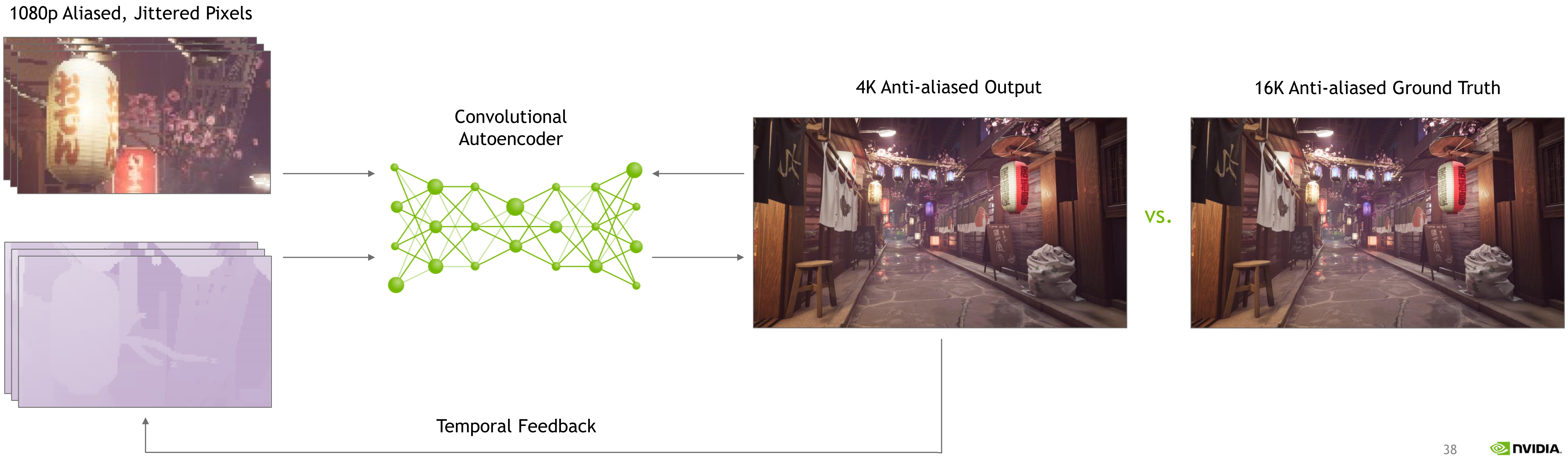
- Regions without enough samples accumulated appear aliased

# WHAT’S NEXT?

# WHAT'S NEXT?

## DLSS 2.0: machine learning showing promise

- The handcrafted heuristics can be replaced by a neural network
- Trained from thousands of images; achieves much higher quality image reconstruction

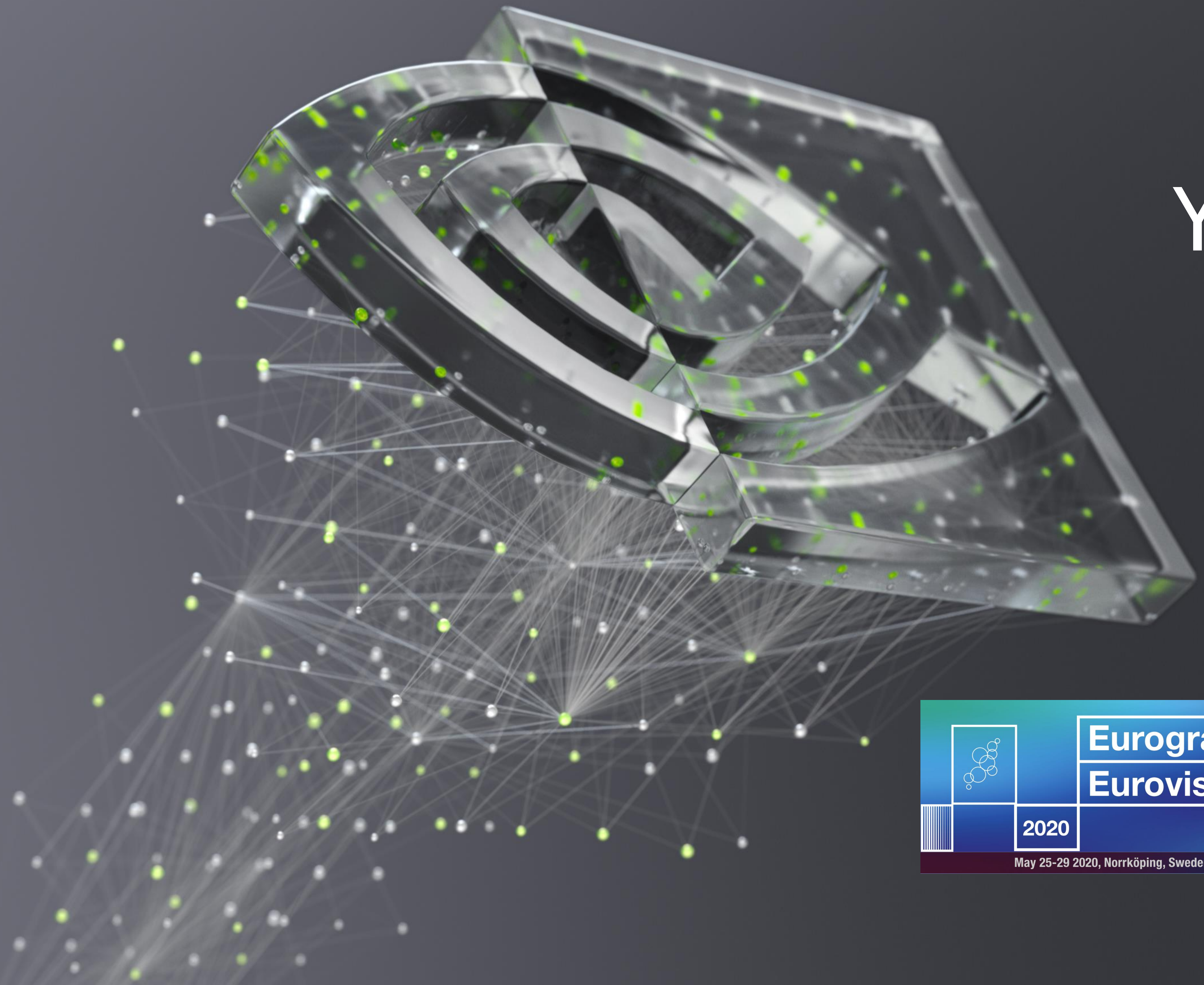



1080p TAA
540p→1080p DLSS 2.0
540p→1080p TAAU

# NOT COVERED

## Further reading

- More details and references in the paper on every topic
- Other related topics in the paper
  - TAA, HDR and color spaces
  - TAA performance
  - Variable rate shading
  - Temporal denoising
- More on DLSS 2.0
  - GTC 2020 talk: https://developer.nvidia.com/gtc/2020/video/s22698



# Thanks for Your Attention!

Eurographics
Eurovis
2020
#EGEV20
May 25-29 2020, Norrköping, Sweden

NVIDIA