Data-parallel Rasterization of Micropolygons with Defocus and Motion Blur

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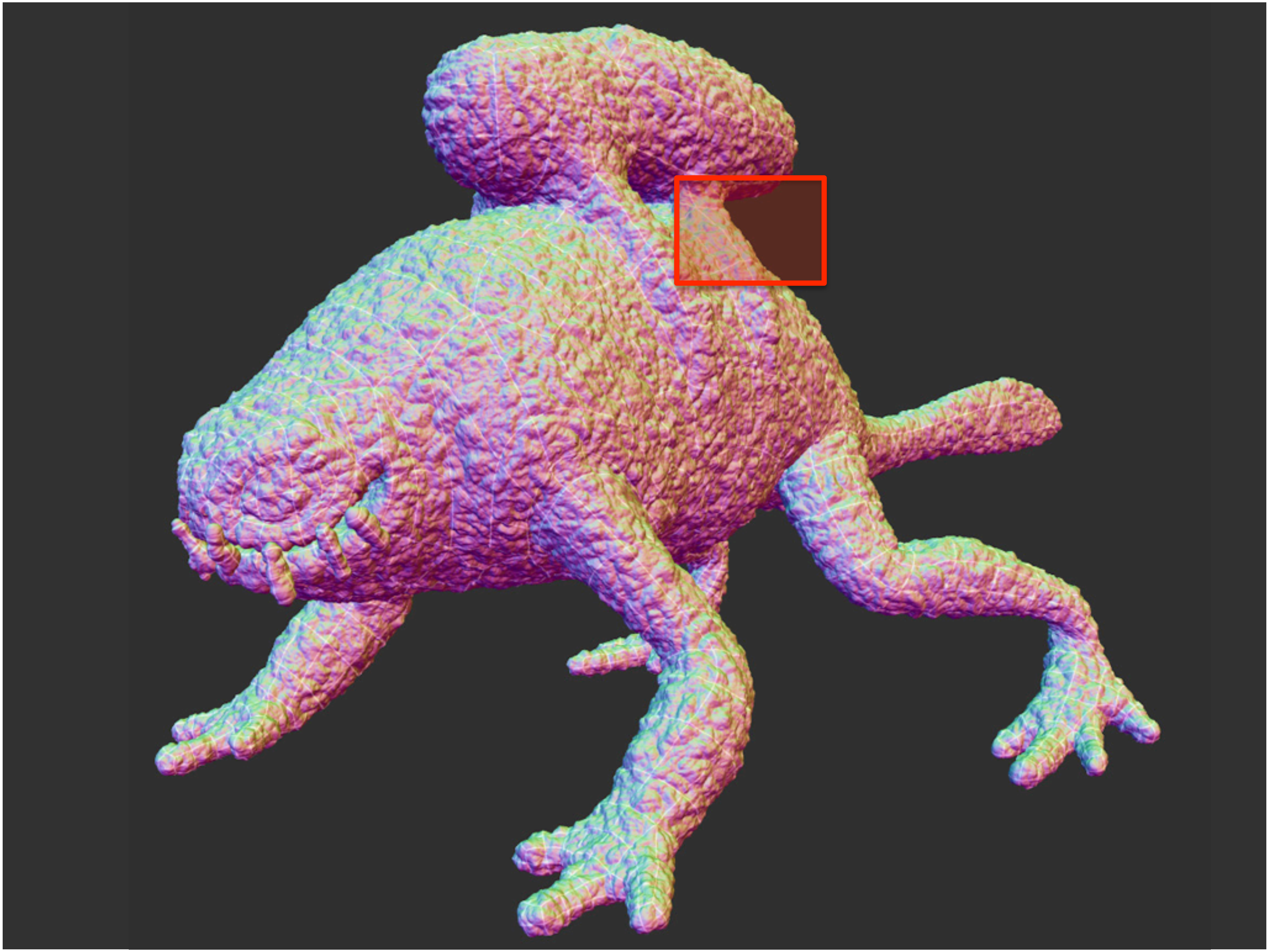
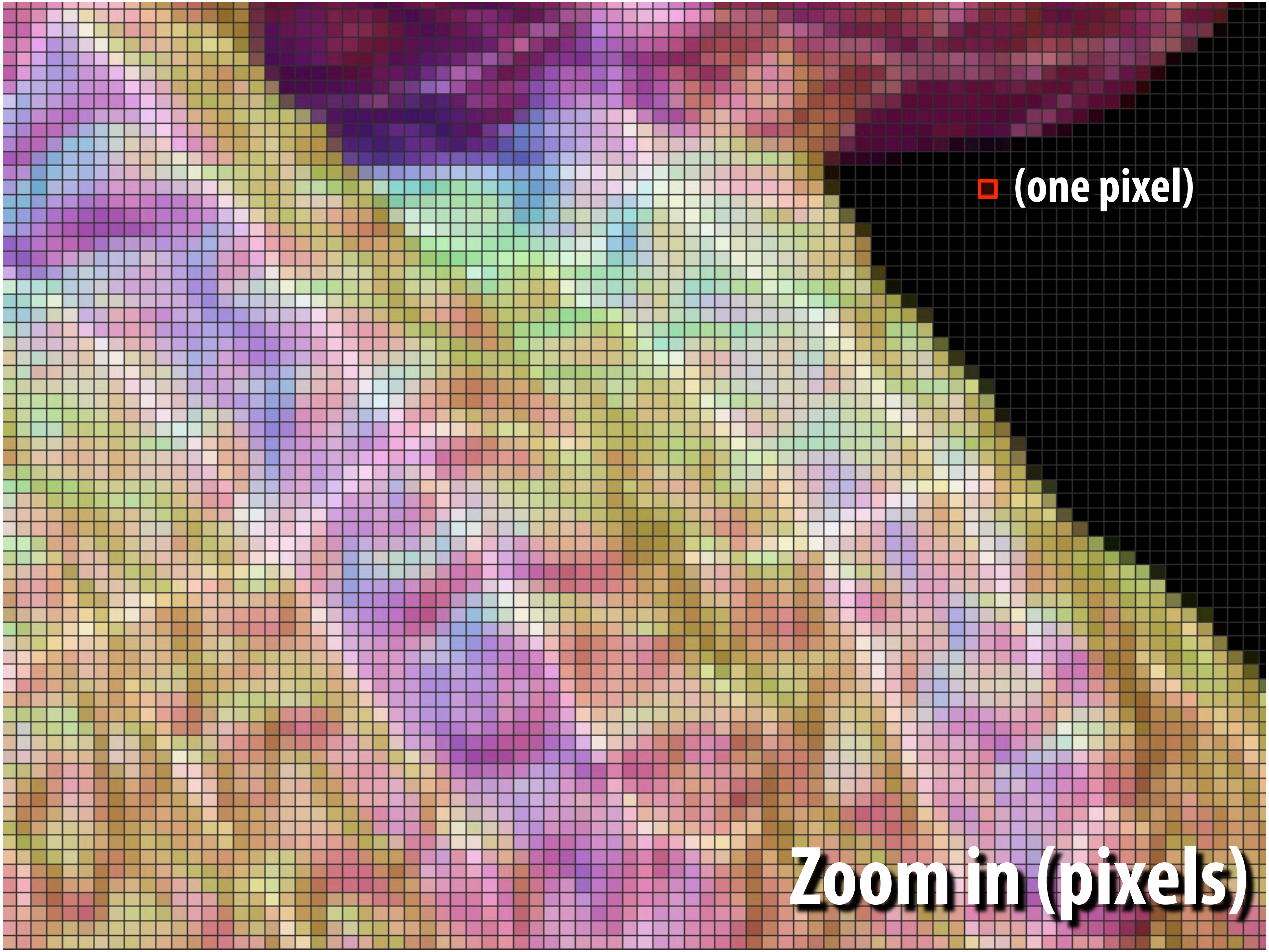
Detailed surfaces

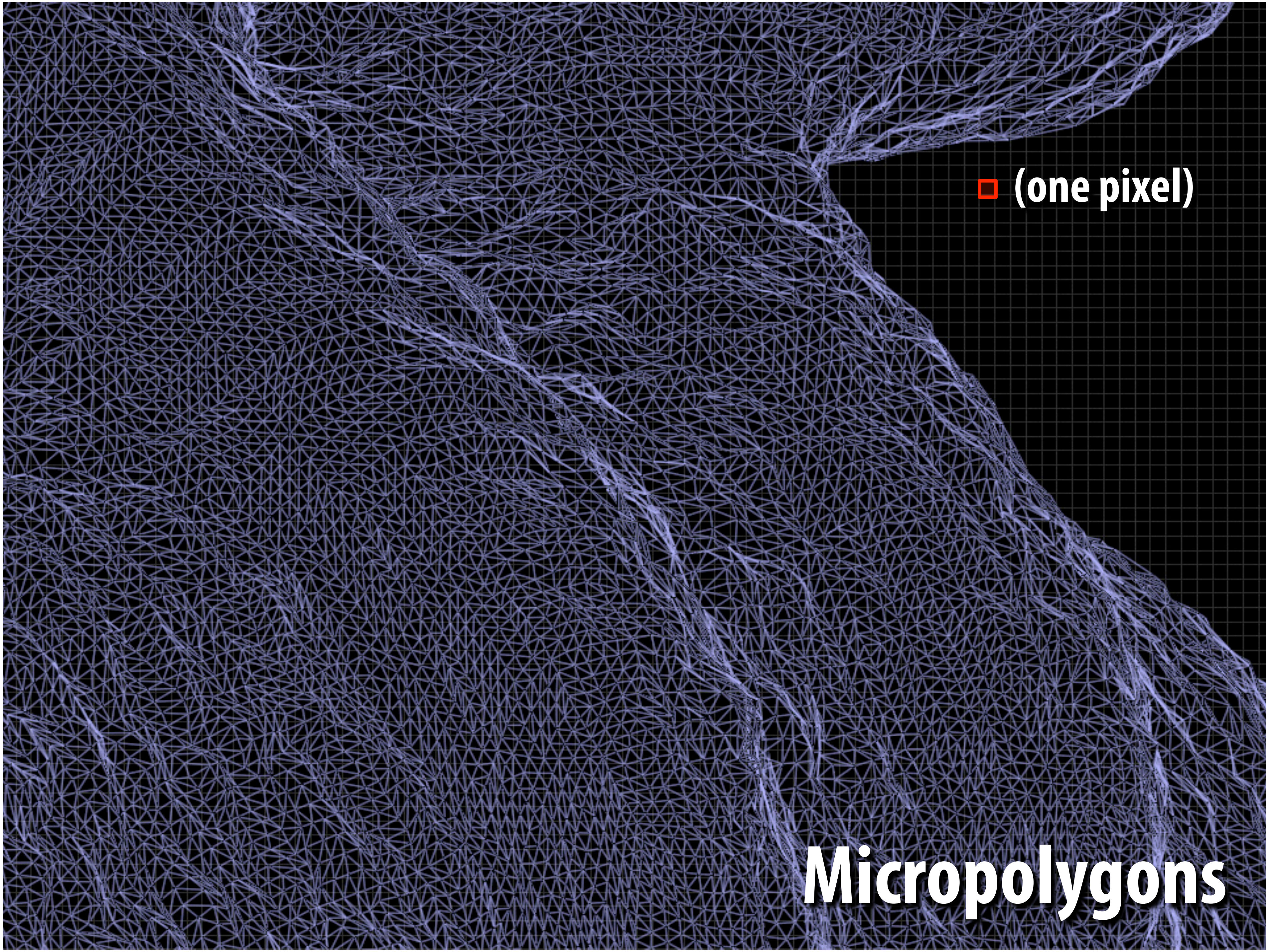
Credit: DreamWorks Pictures, Shrek 2 (2004)

Credit: Pixar Animation Studios, Toy Story 2 (1999)

Credit: Crytek

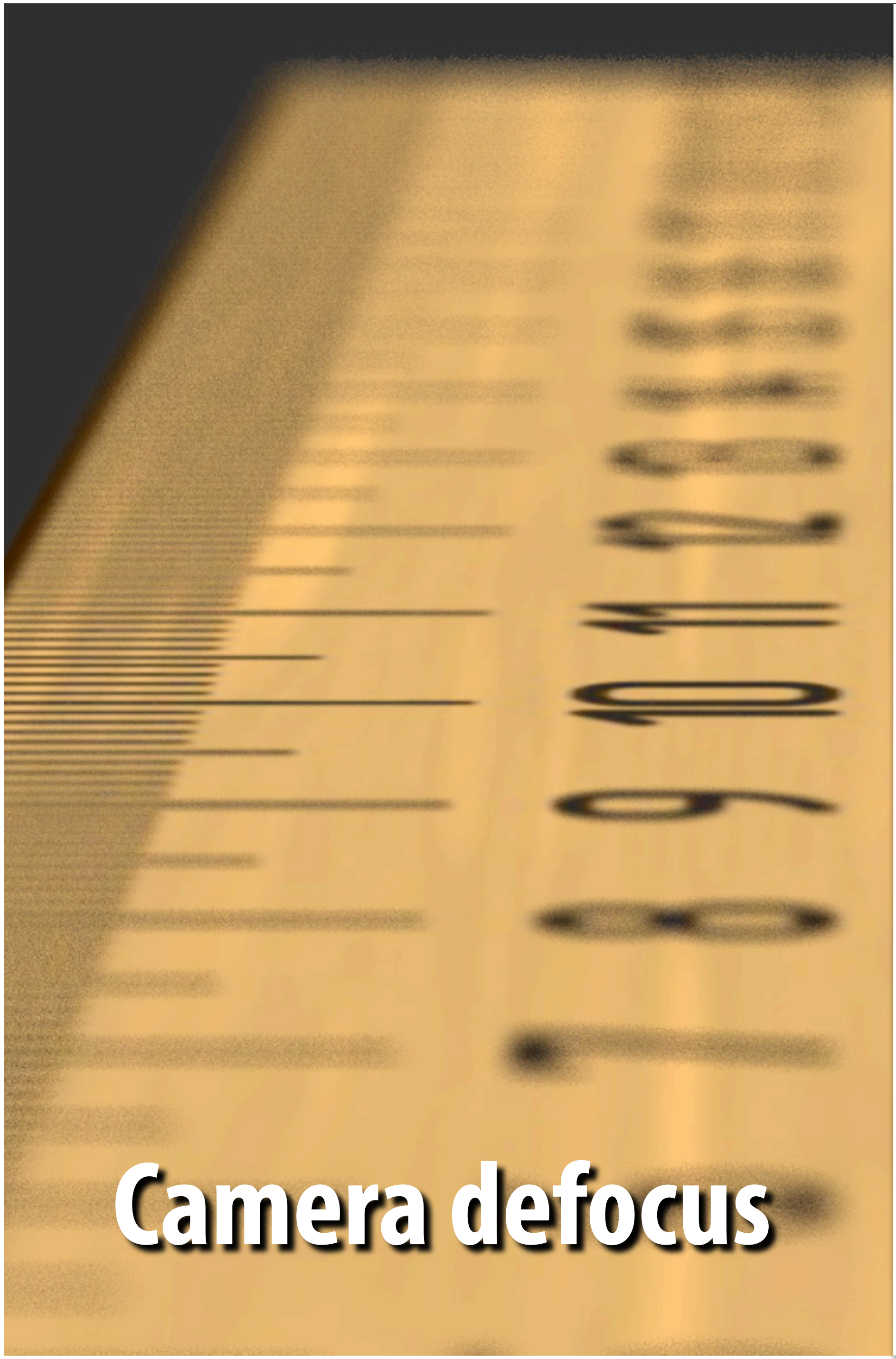



(one pixel)
Zoom in (pixels)

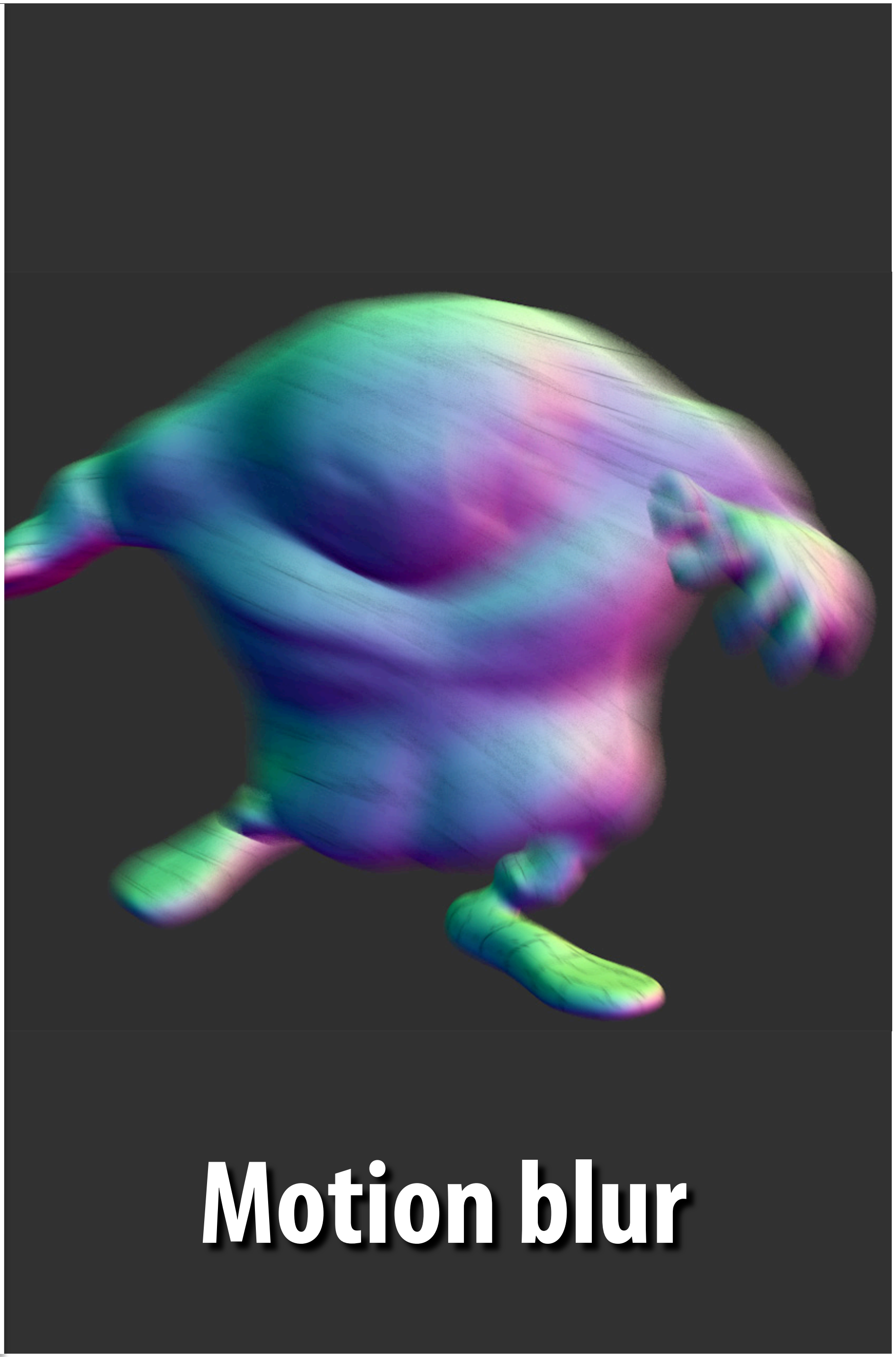


□ (one pixel)

Micropolygons



Camera defocus



Motion blur

Rendering goals

Highly detailed surfaces (micropolygons)

Accurate camera defocus and motion blur

[Future] real-time system

How do we evolve the real-time graphics pipeline to enable efficient micropolygon rendering?

This talk: rasterizing micropolygons

How is micropolygon-sample coverage computed efficiently?

How expensive are motion blur and defocus?

Contributions

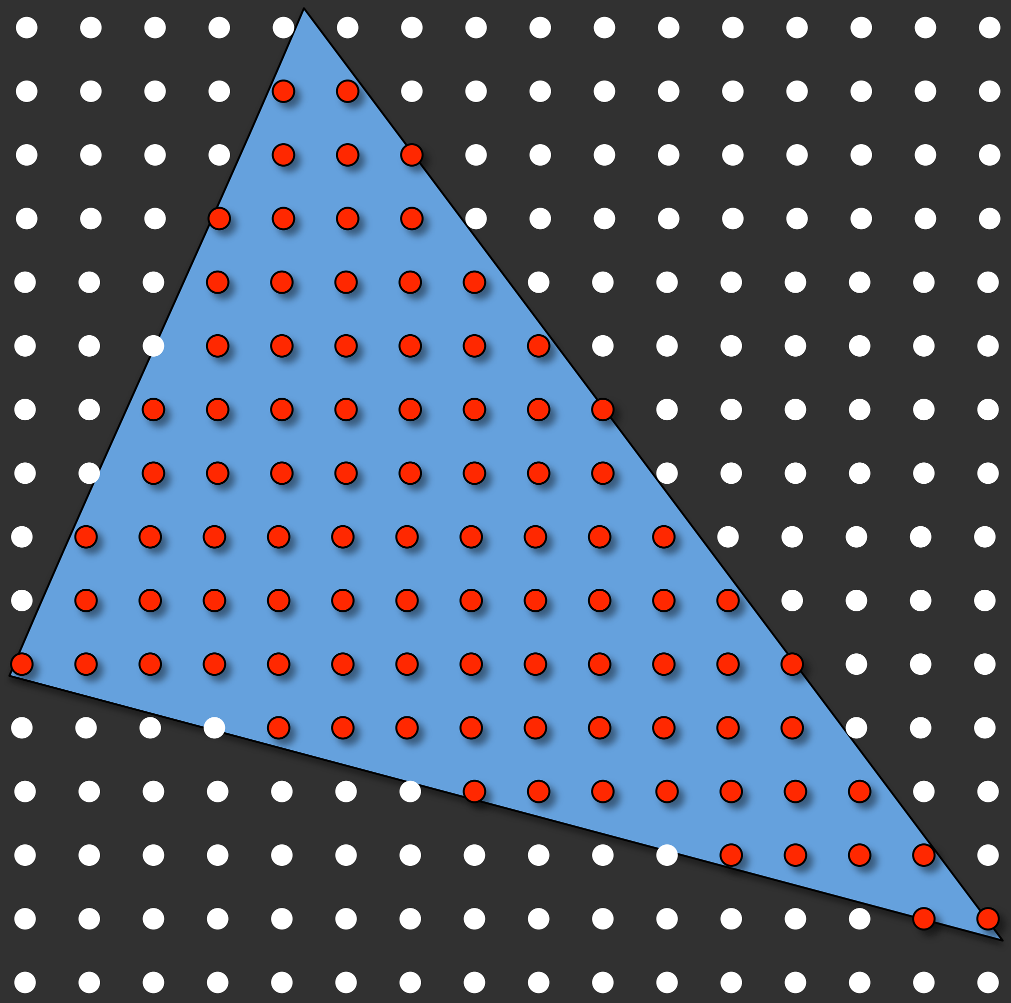
Design and analysis of three data-parallel algorithms for micropolygon rasterization

- Re-optimize rasterization for micropolygon workloads
  - NOBLUR
- Extend rasterizer to support camera defocus and motion blur
  - INTERVAL: vector implementation of Pixar algorithm
  - INTERLEAVE: leverage interleaved sampling for better perf

BACKGROUND

(no motion, no defocus)

Rasterization



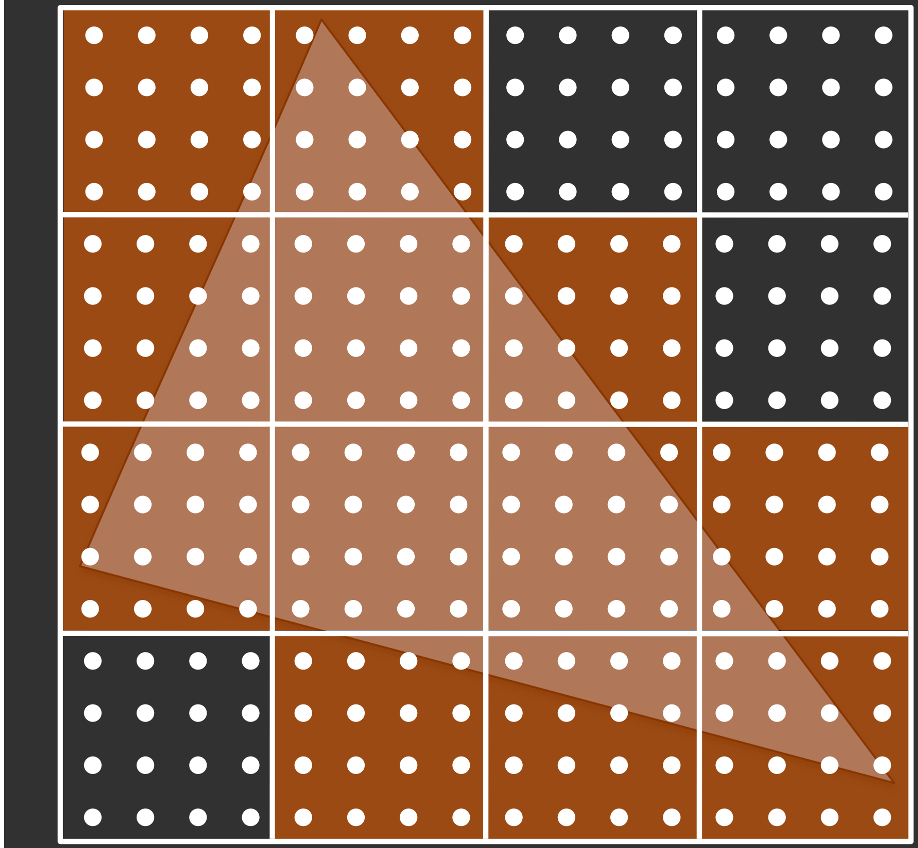
Step 1: per-polygon preprocessing (setup)

- Clip, back face cull, compute edge equations

- Make point-in-polygon tests cheap

Step 2: compute candidate sample set

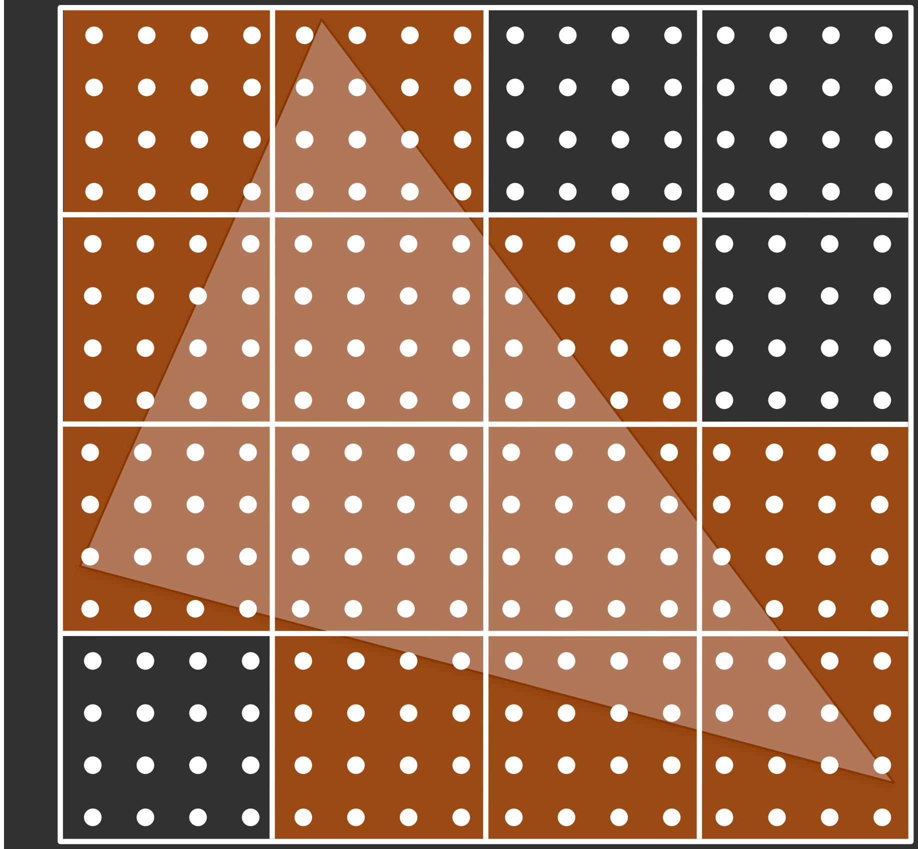
- Coarse reject/accept of samples



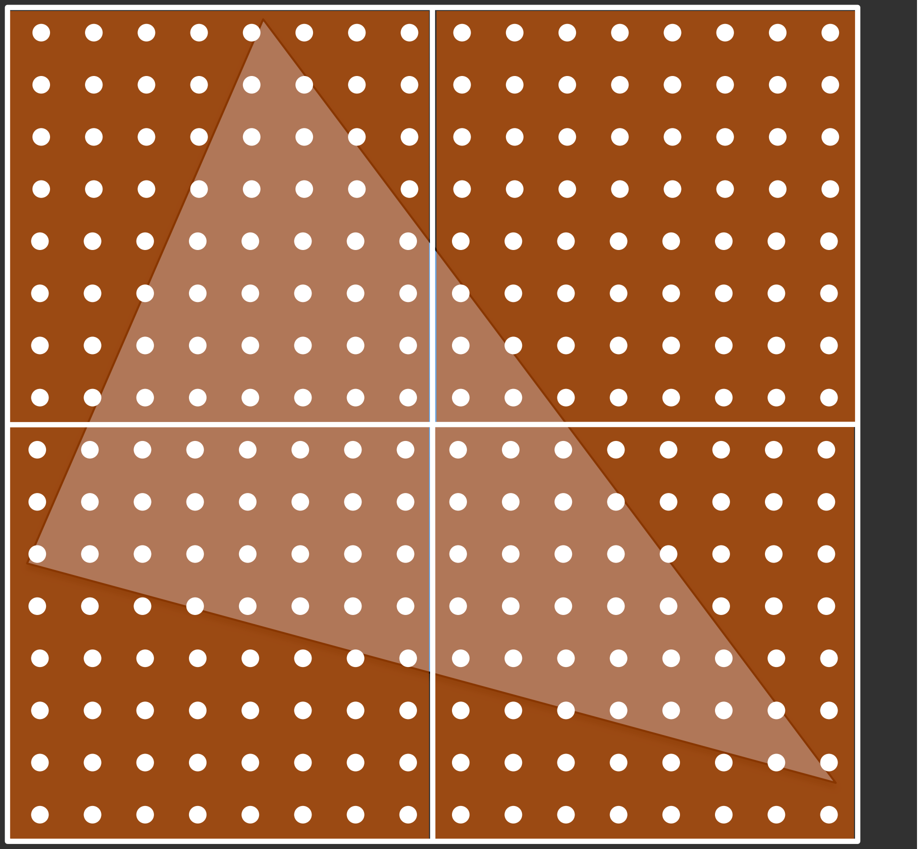
Coarse uniform grid

Step 2: compute candidate sample set

- Coarse reject/accept of samples



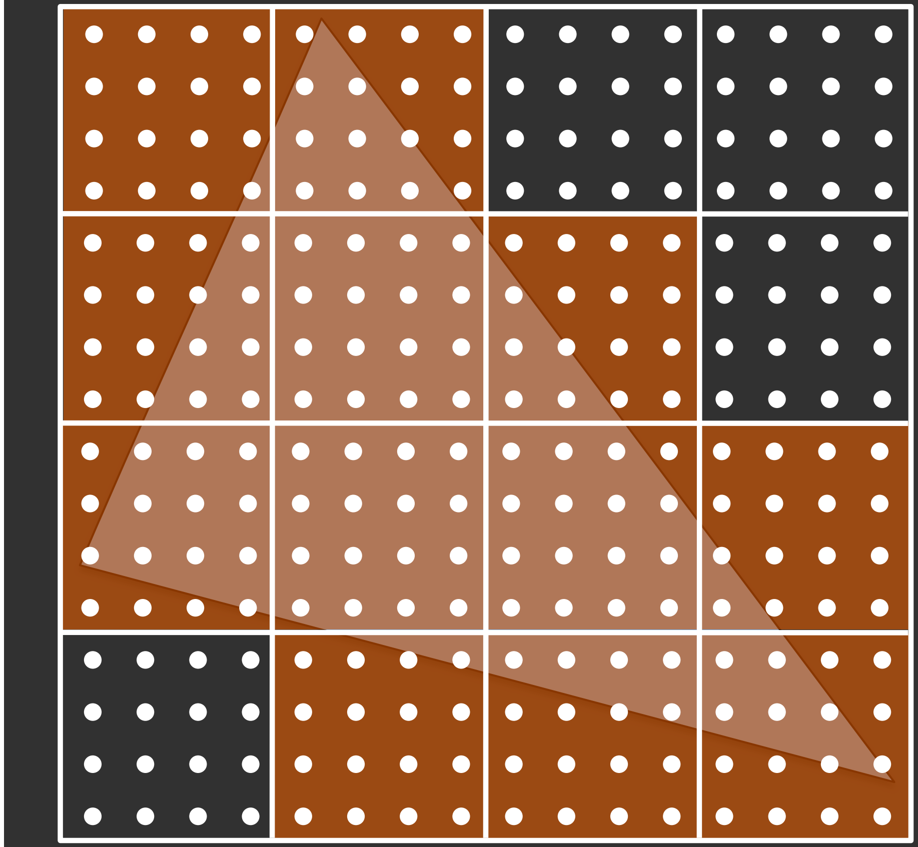
Coarse uniform grid



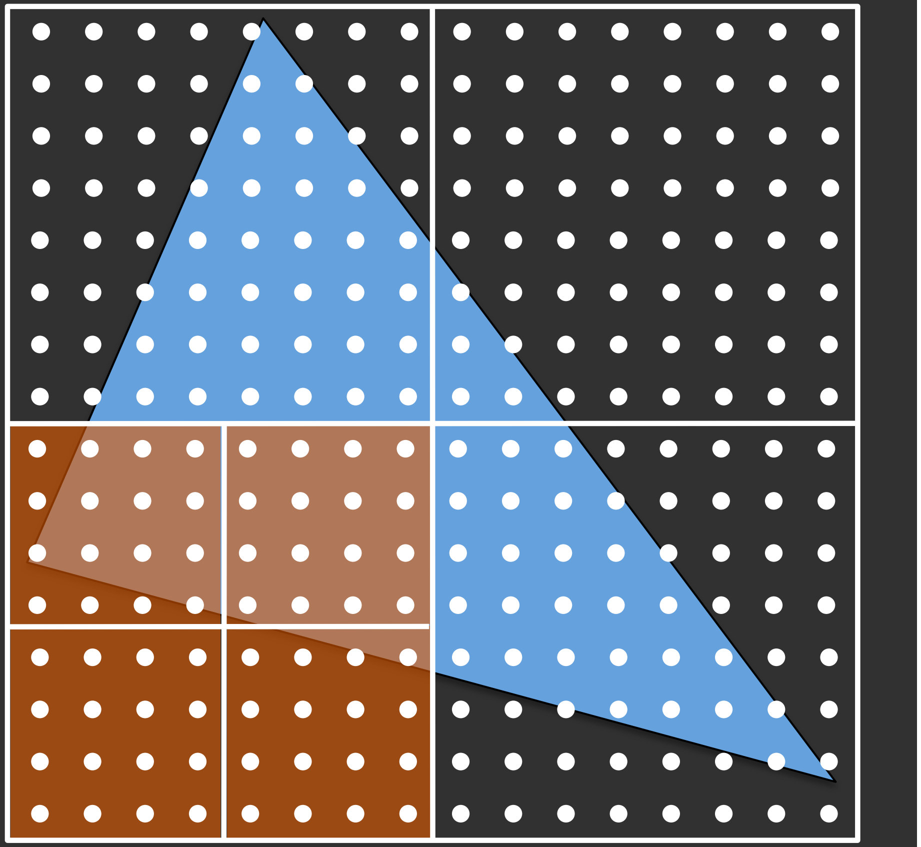
Hierarchical descent

Step 2: compute candidate sample set

- Coarse reject/accept of samples



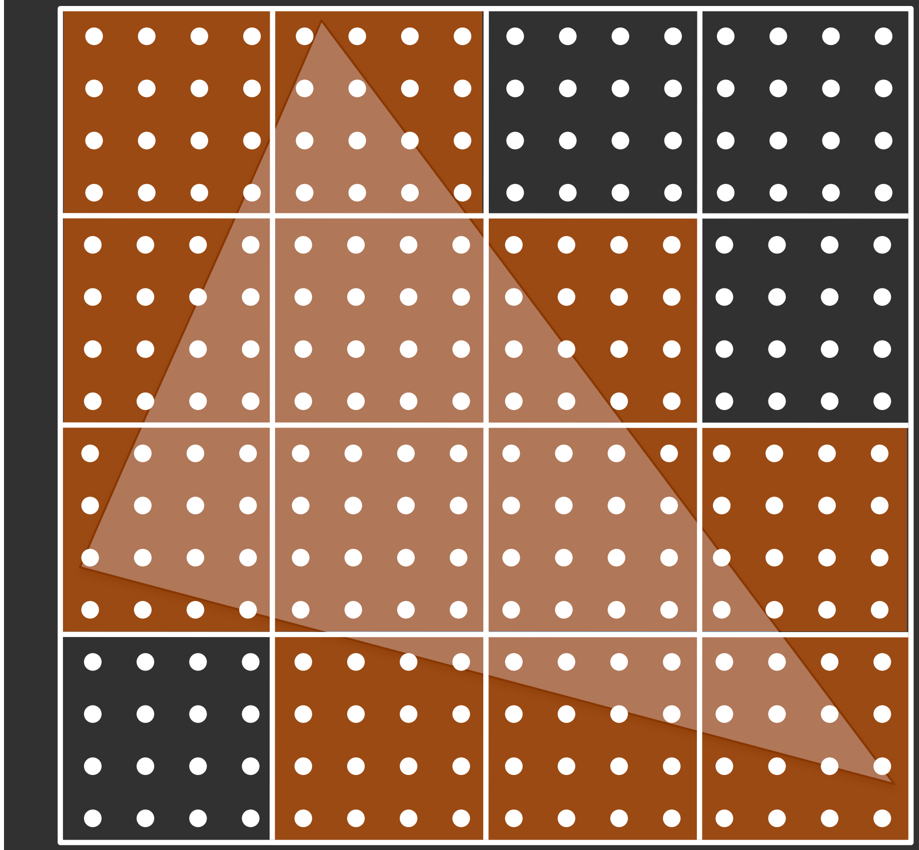
Coarse uniform grid



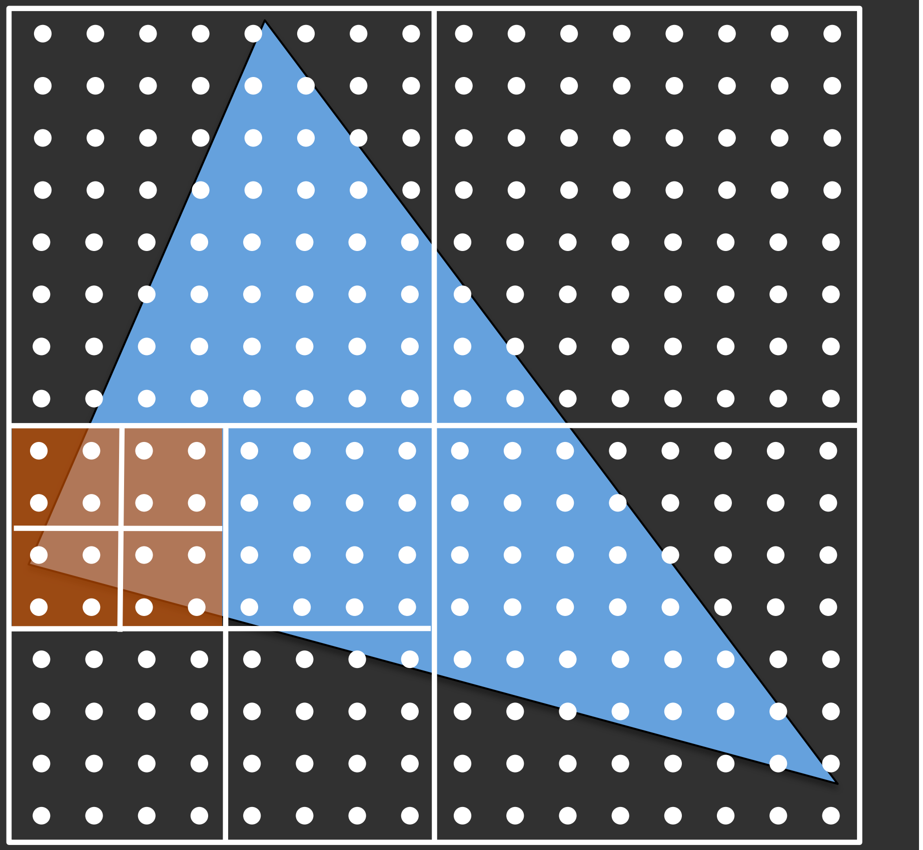
Hierarchical descent

Step 2: compute candidate sample set

- Coarse reject/accept of samples



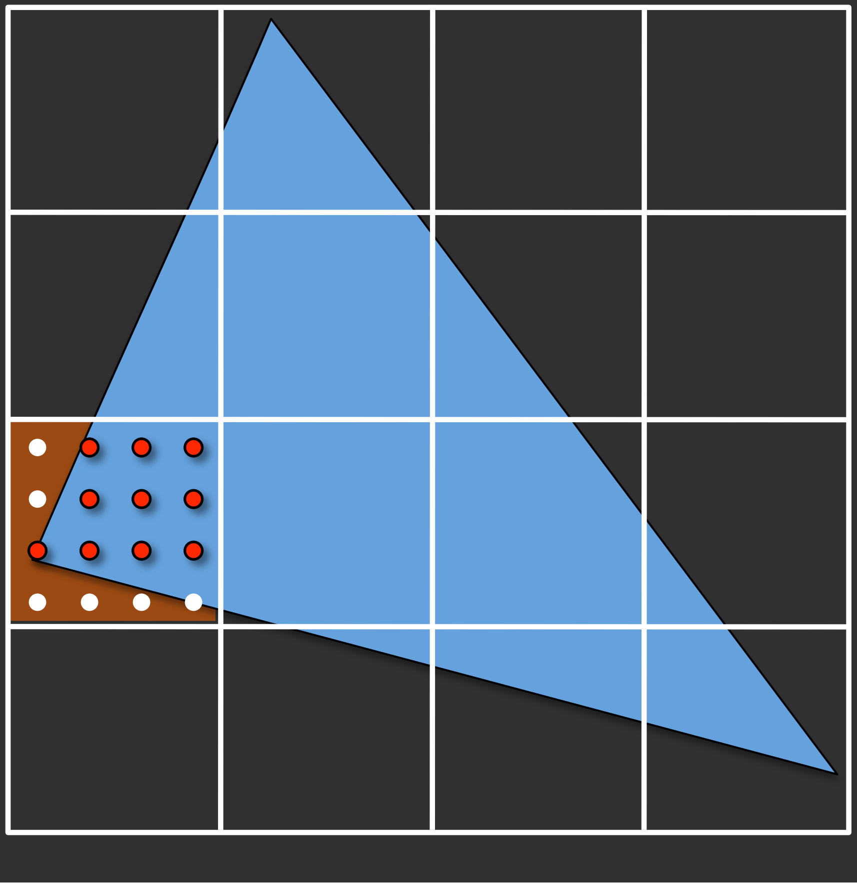
Coarse uniform grid



Hierarchical descent

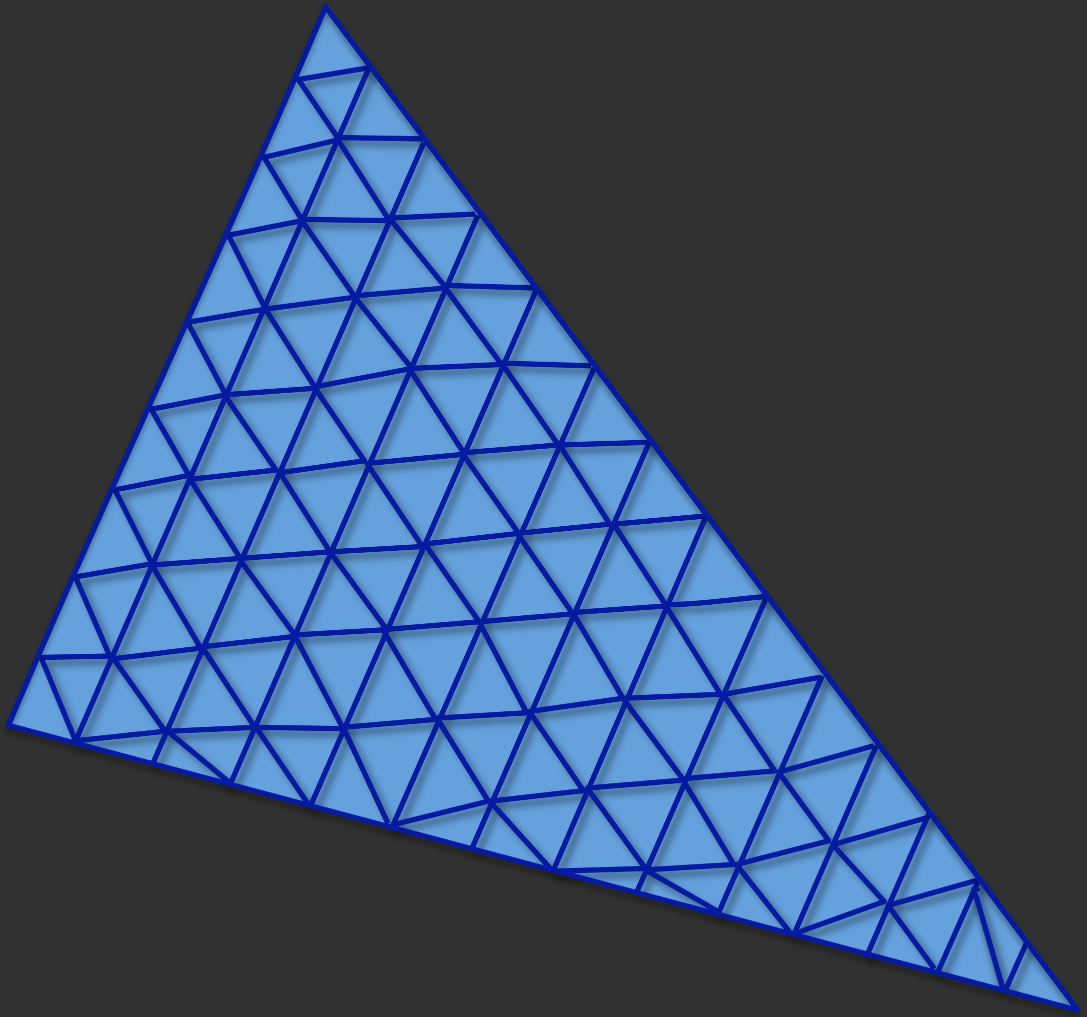
Step 3: point-in-polygon tests

- Test "stamp" of samples against polygon simultaneously (data-parallel)

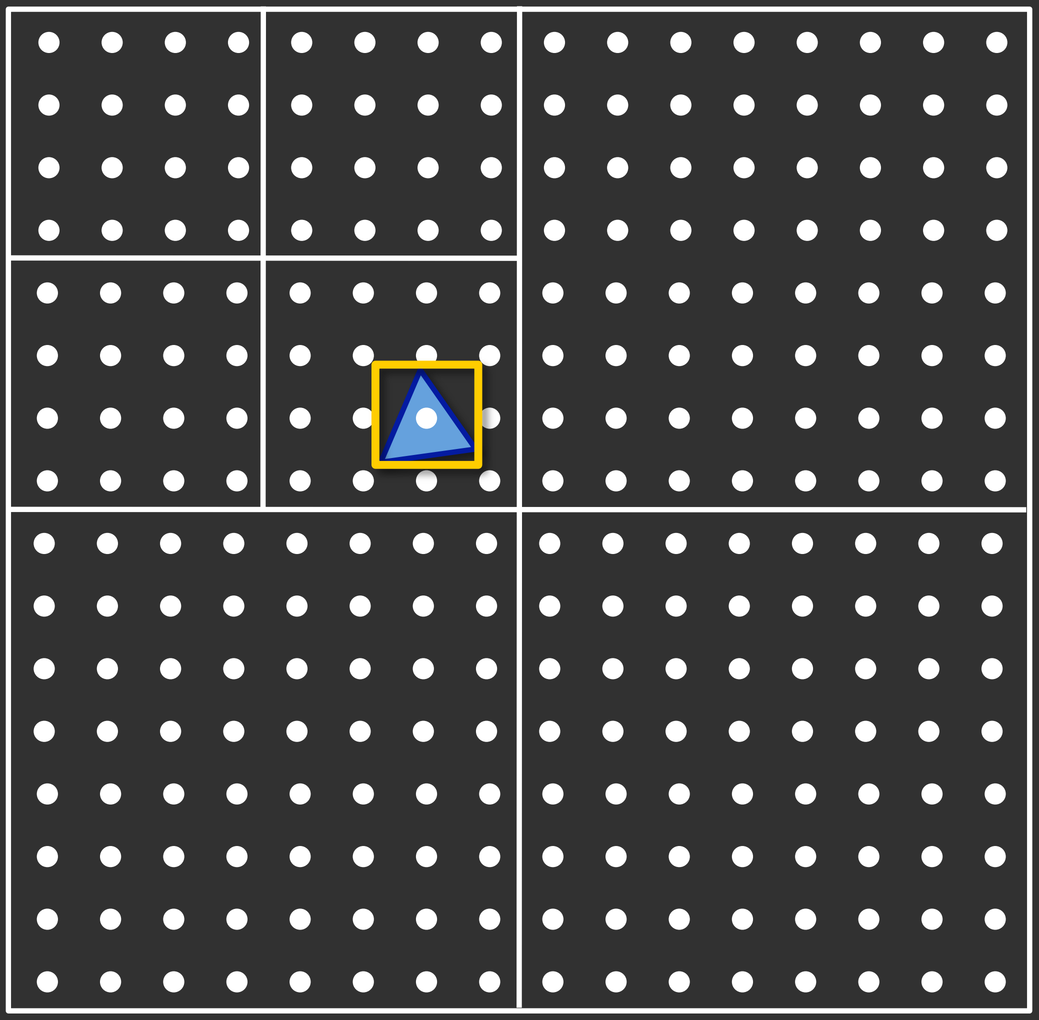


[Pineda 88]
[Fuchs 89]
[Greene 96]
[Seiler 08]

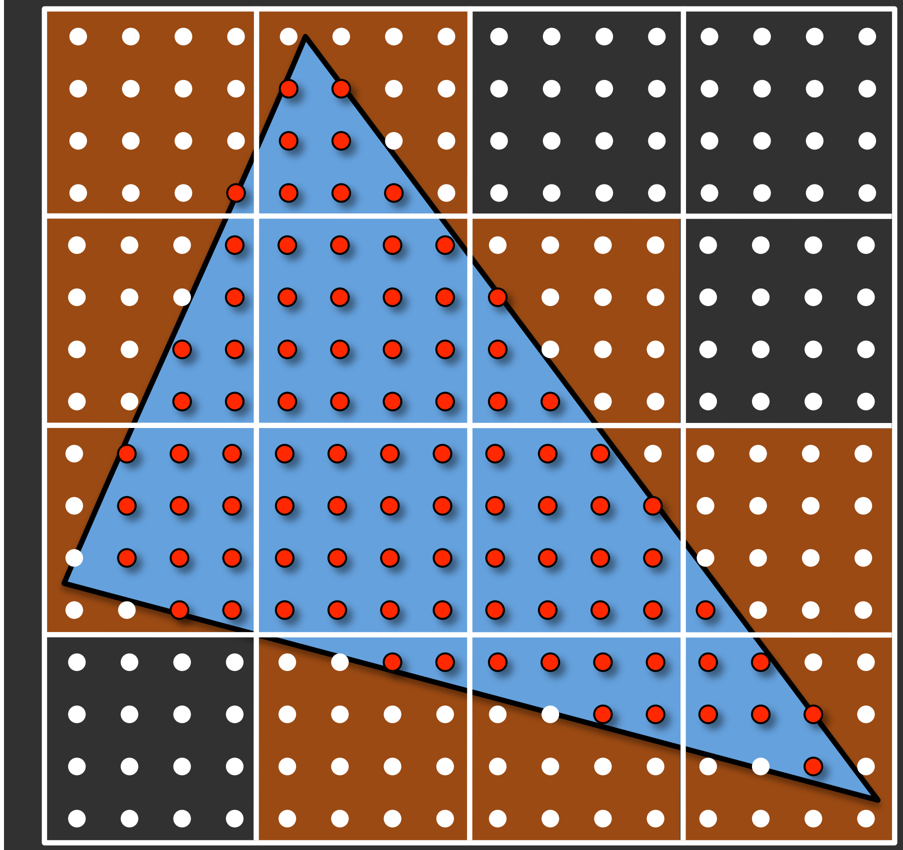
Micropolygons: more polygons = more setup



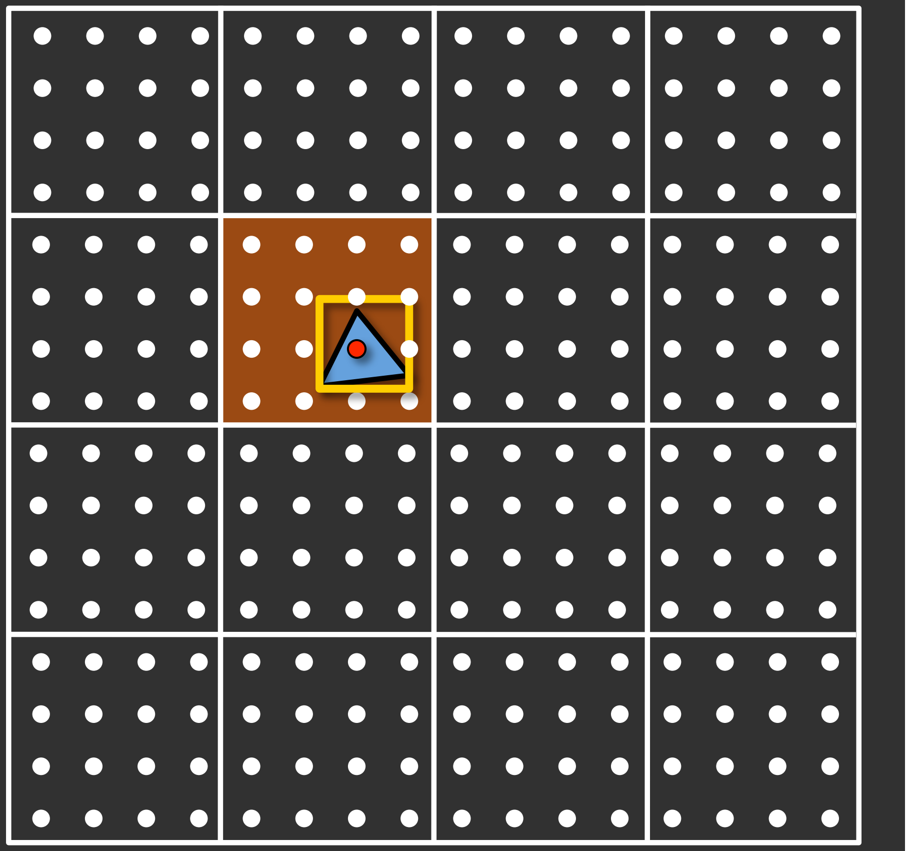
Micropolygons: coarse reject not useful



Micropolygons: large stamps yield low efficiency



47% of tested samples inside triangle



6% of tested samples inside triangle

ALGORITHM #1: NOBLUR

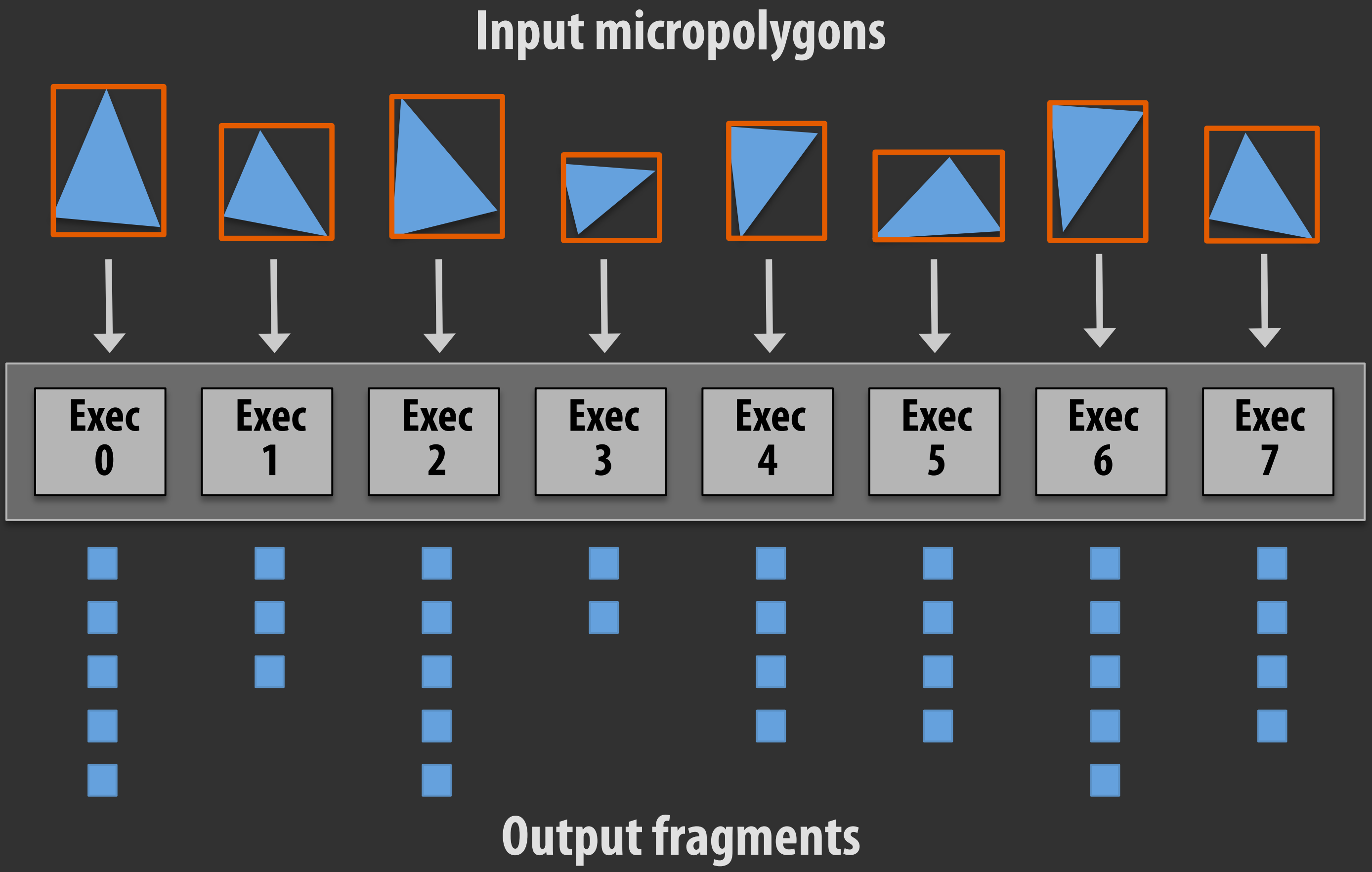
(no motion, no defocus)

NOBLUR

```
        For each MP
--------------------------------------------
Setup       Cull backfacing
--------------------------------------------
Bound       Compute subpixel bbox of MP
--------------------------------------------
            For each sample in bbox
Test           Test MP-sample coverage
```

NOBLUR parallelization

- Rasterize many micropolygons simultaneously



NOBLUR parallelization

```
        For each MP                                          PARALLEL

Setup   Cull backfacing

Bound   Compute subpixel bbox of MP

Test    For each sample in bbox
           Test MP-sample coverage                        UTILIZATION?
```

MOTION BLUR AND DEFOCUS

Motion blur and defocus

- **Many 2D-techniques for approximating blur**

  [Sung 02]

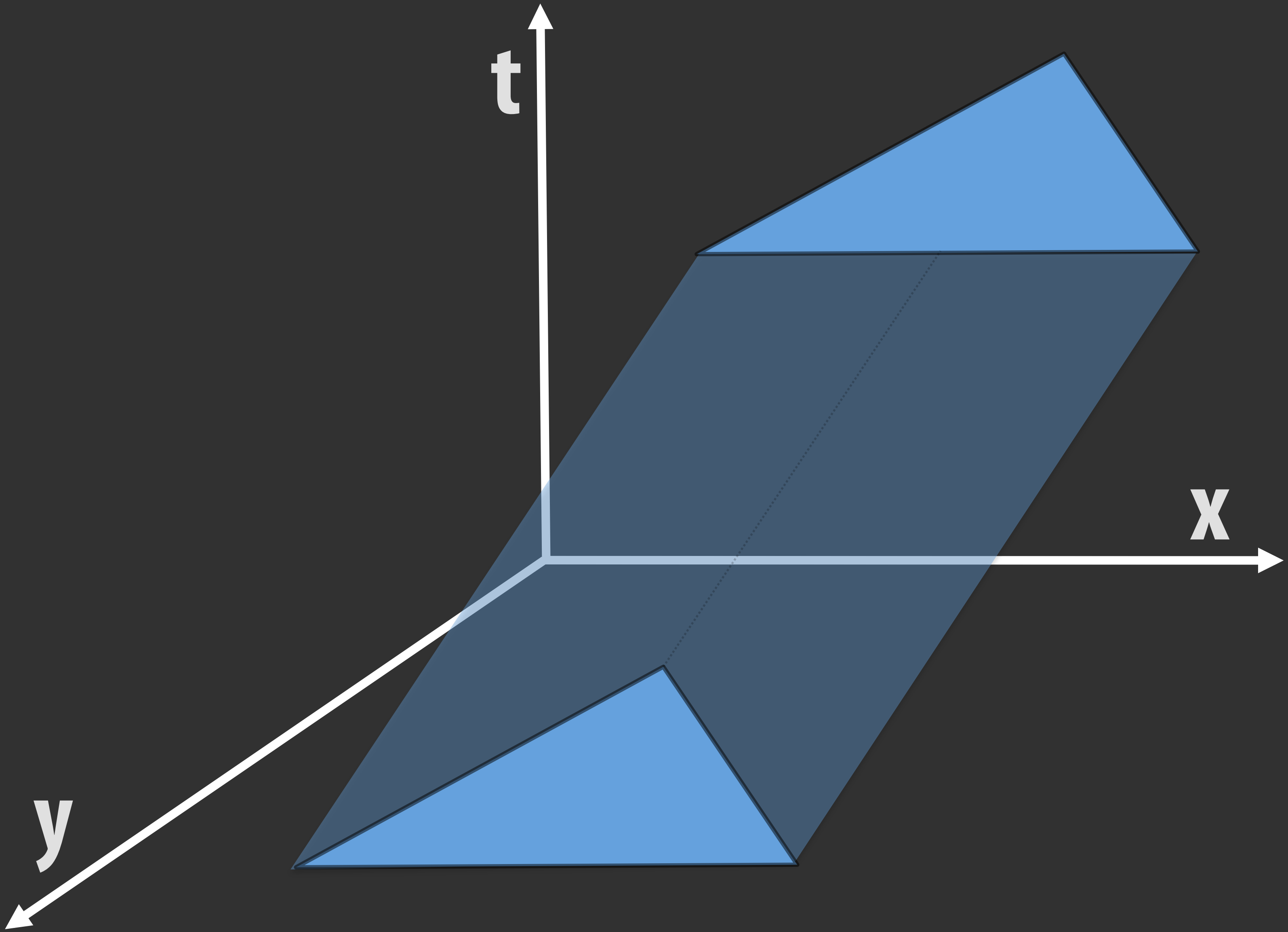
  [Demers 04]

- **Stochastic point sampling**

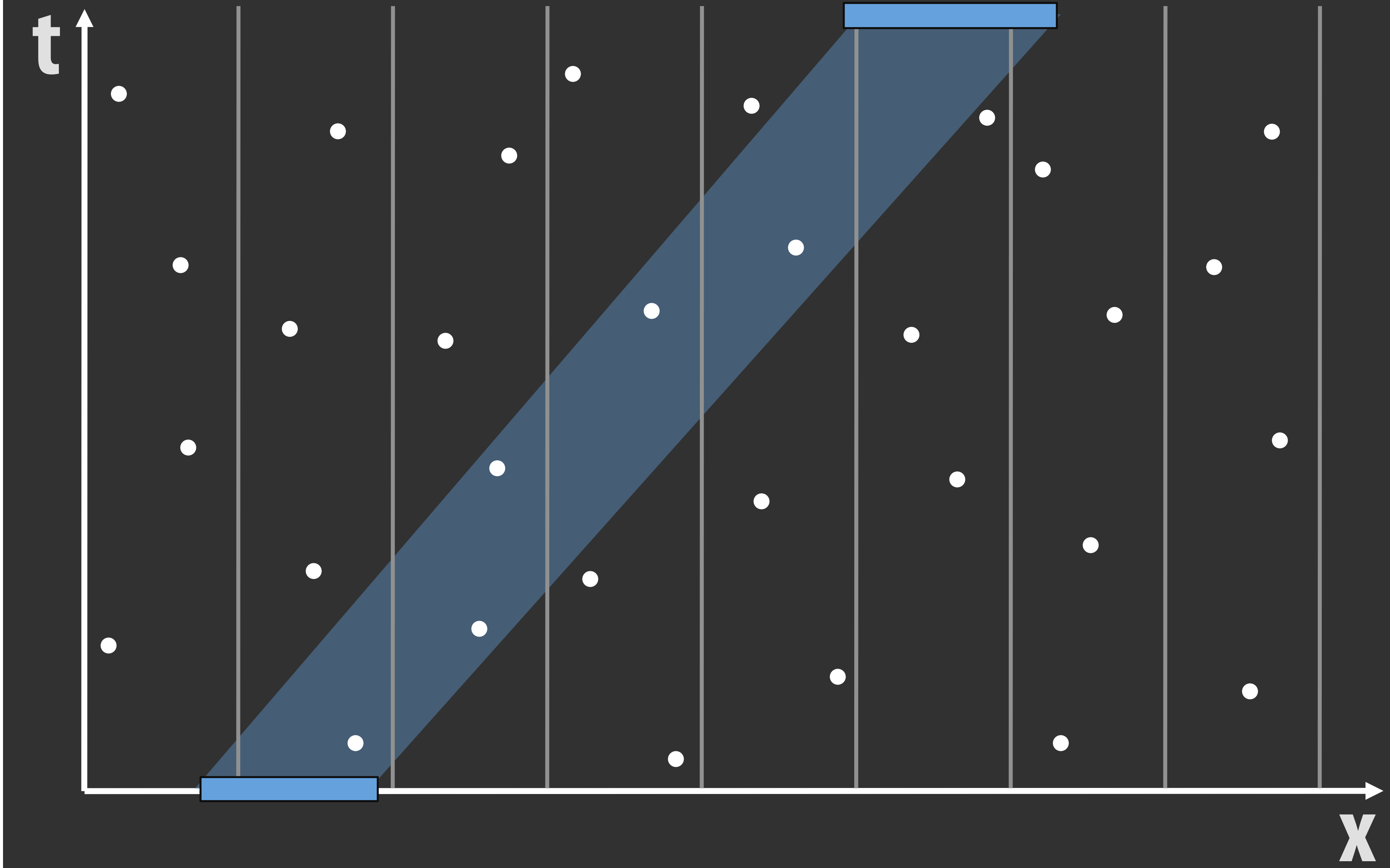
  [Cook 84, Cook 86]

  [Akenine-Moller 07]

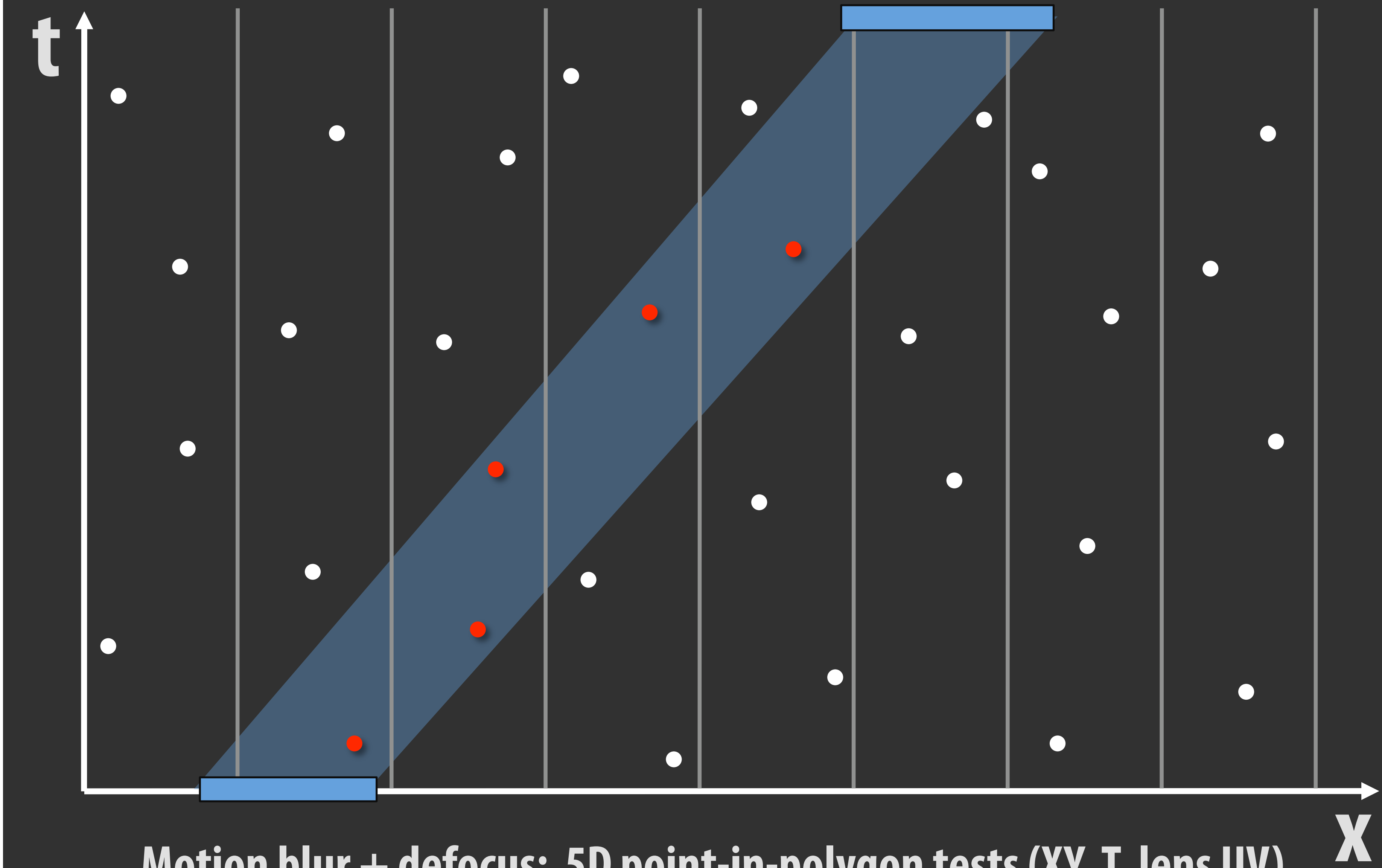
Moving micropolygon



X,T plane

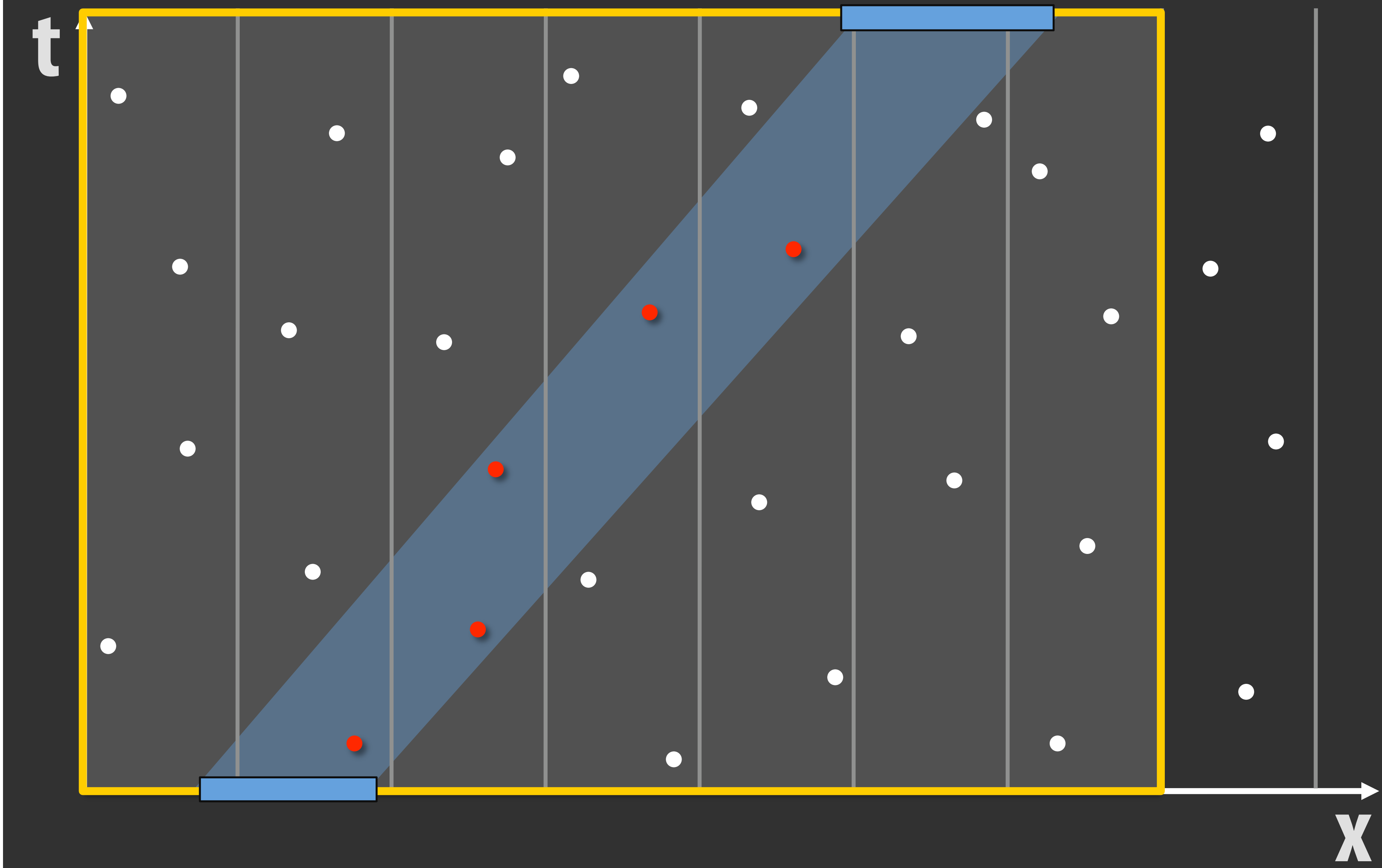


X,T plane



Motion blur + defocus: 5D point-in-polygon tests (XY, T, lens UV)

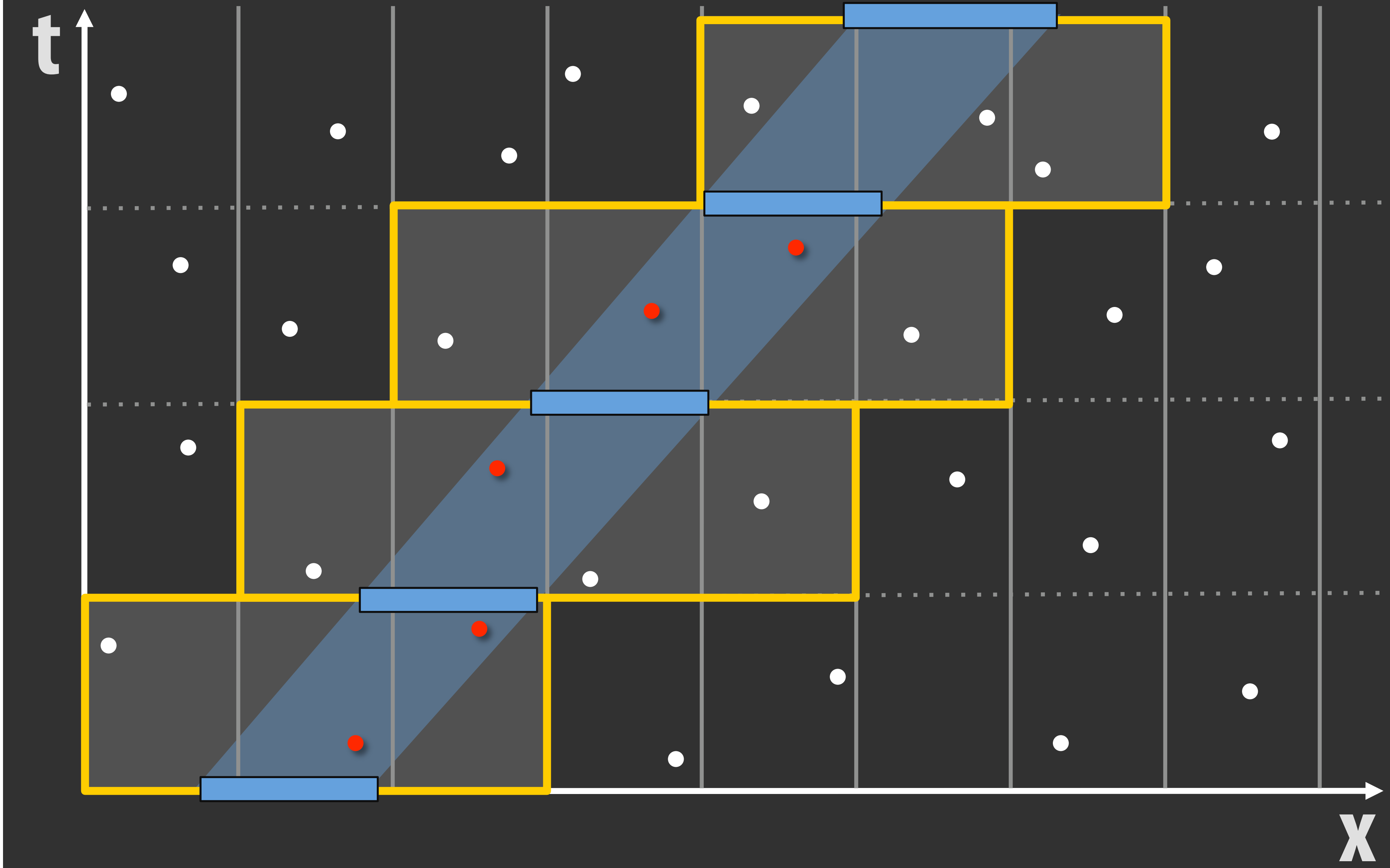
Candidate samples



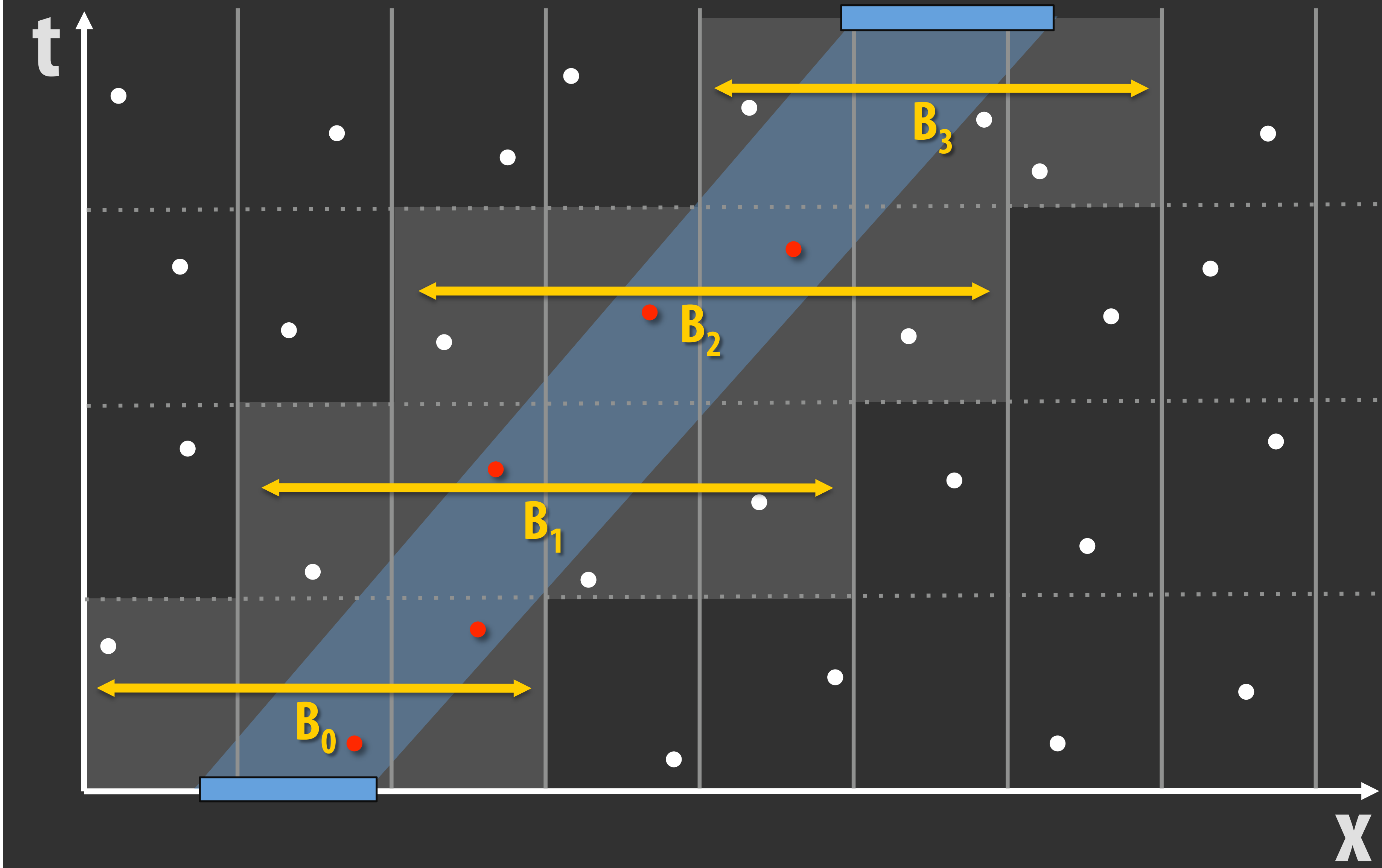
ALGORITHM #2: INTERVAL

[Cook 90]

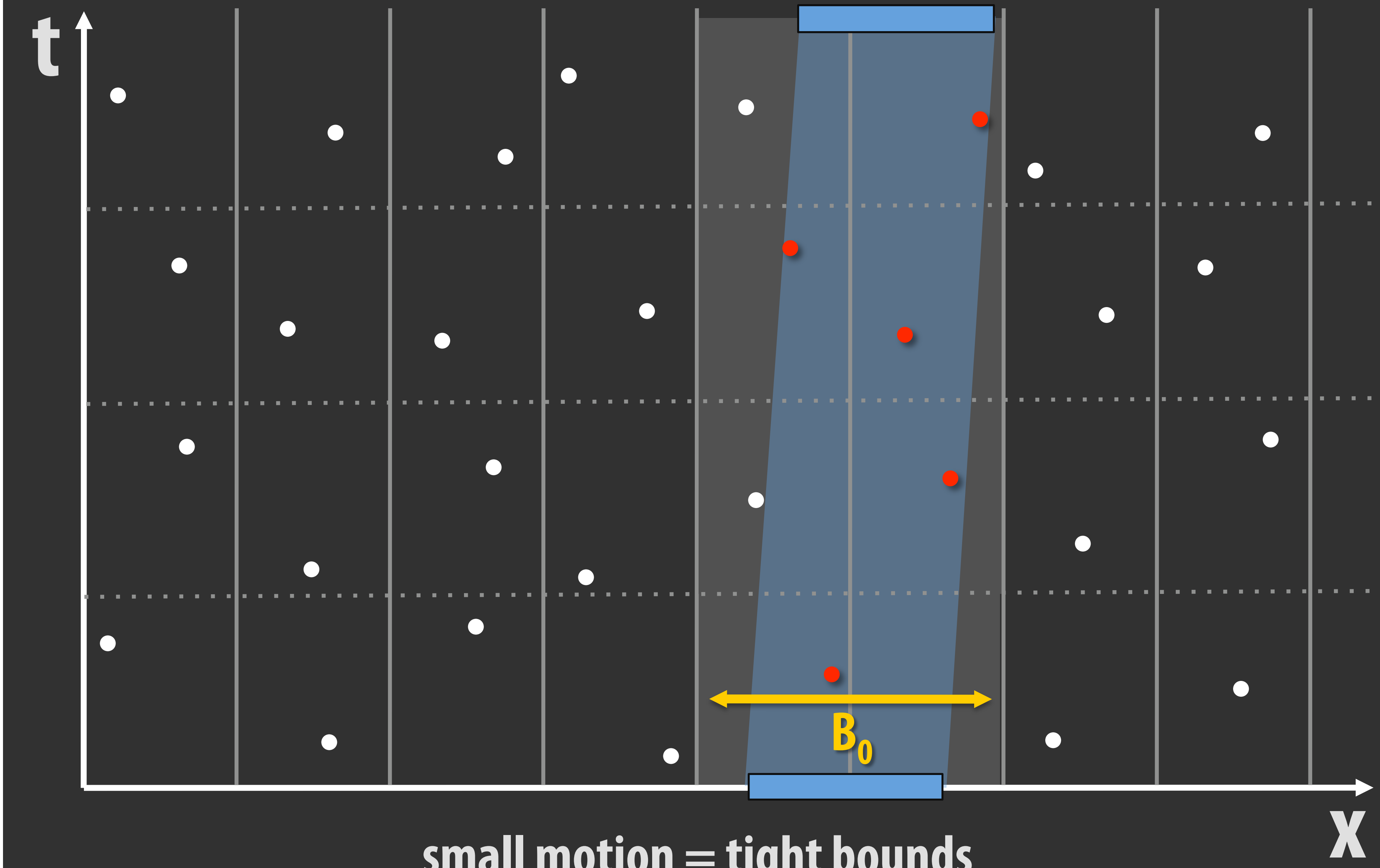
INTERVAL (4 time intervals)



INTERVAL (4 time intervals)

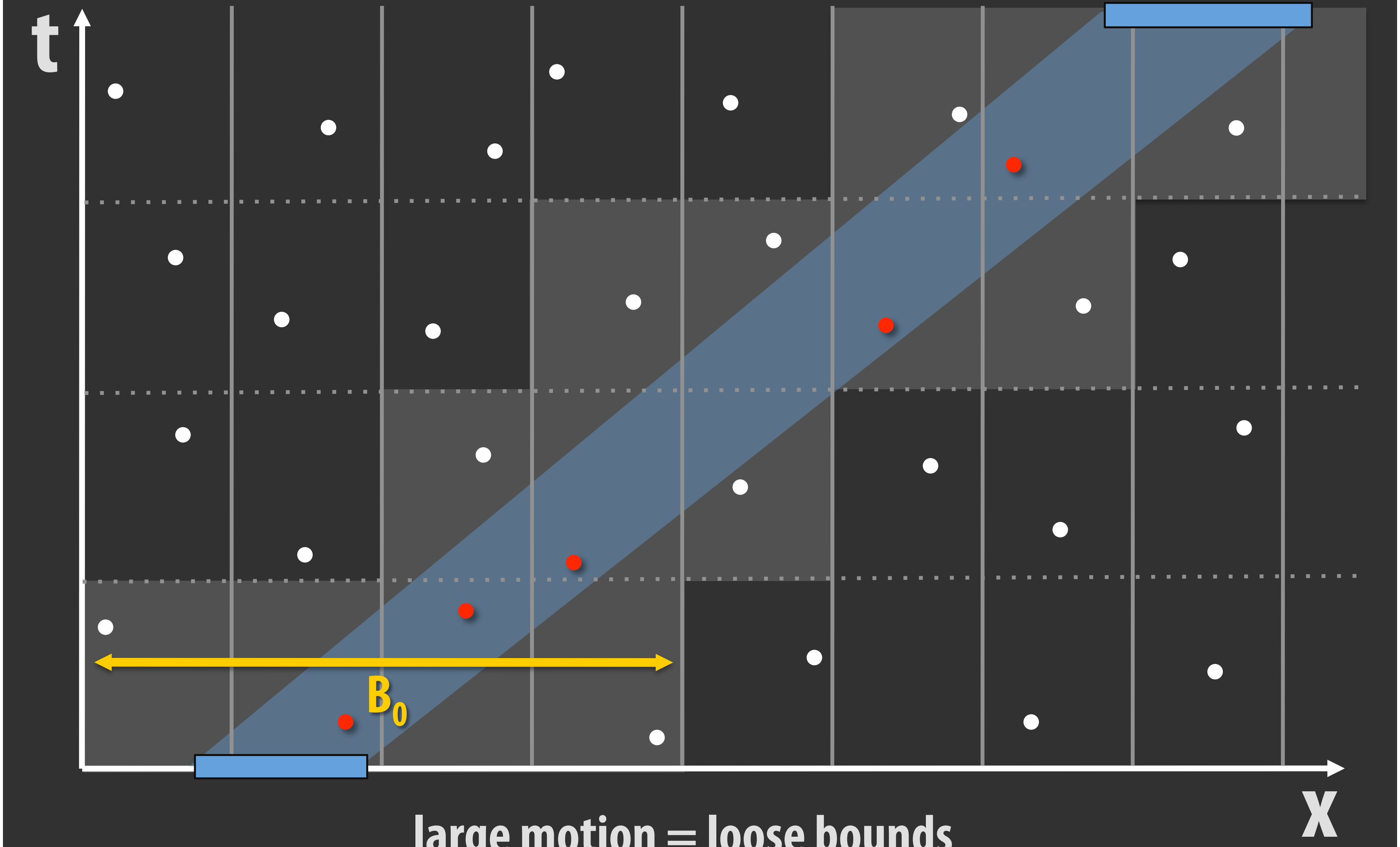


INTERVAL



small motion = tight bounds

INTERVAL



large motion = loose bounds

INTERVAL

```
         For each MP
--------------------------------------------------------
Setup       ...
--------------------------------------------------------
            For each time interval
Bound         Compute MP bbox over interval
--------------------------------------------------------
              For each sample in interval and in bbox
Test            Position MP at sample T
                Test MP-sample coverage
```

INTERVAL parallelization

```
        For each MP                                      PARALLEL

Setup       ...

Bound       For each time interval                       PARALLEL
              Compute MP bbox over interval

Test          For each sample in interval and in bbox
                Position MP at sample T
                Test MP-sample coverage              UTILIZATION?
```

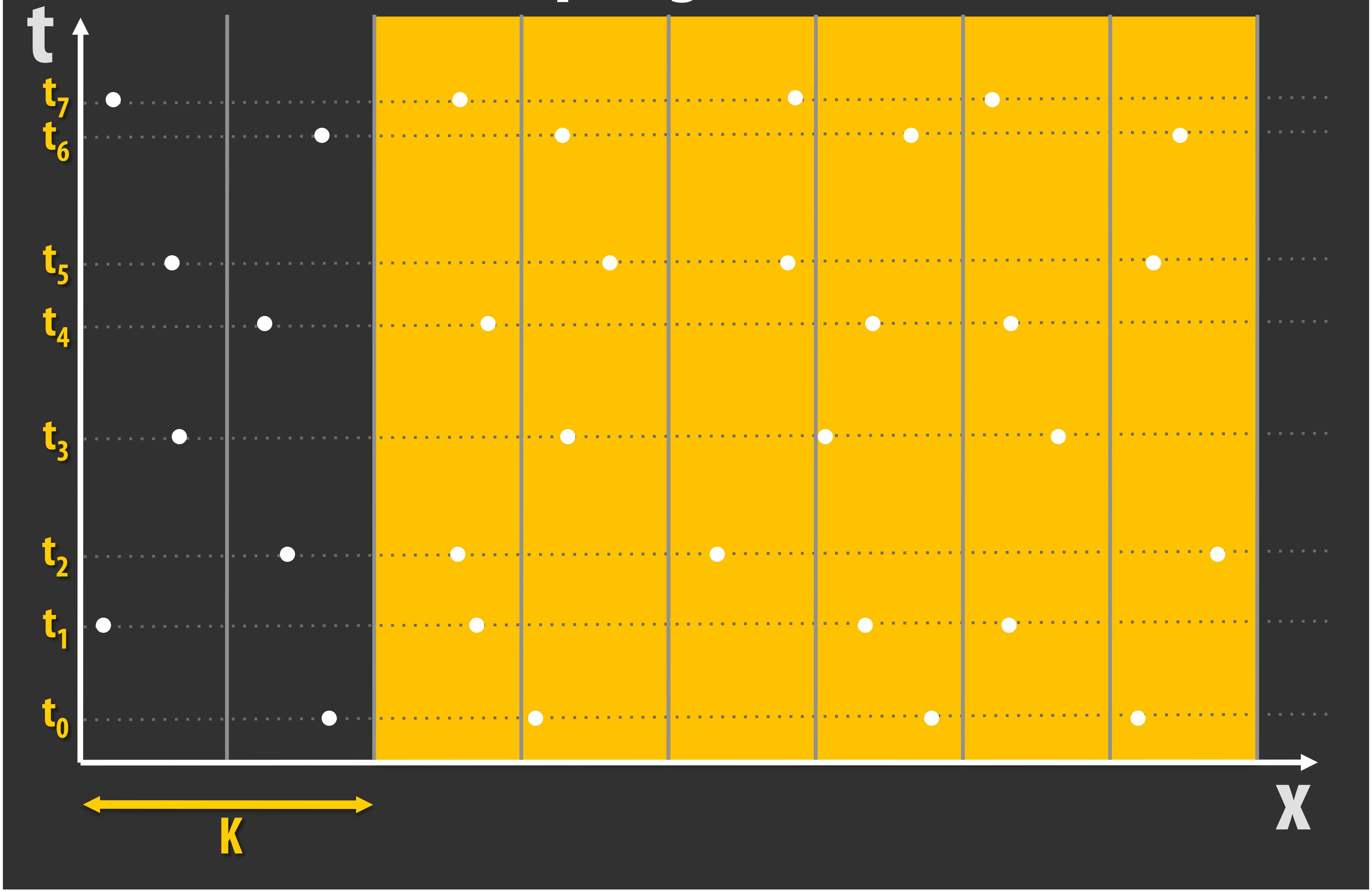
ALGORITHM #3: INTERLEAVE

INTERLEAVE: main idea

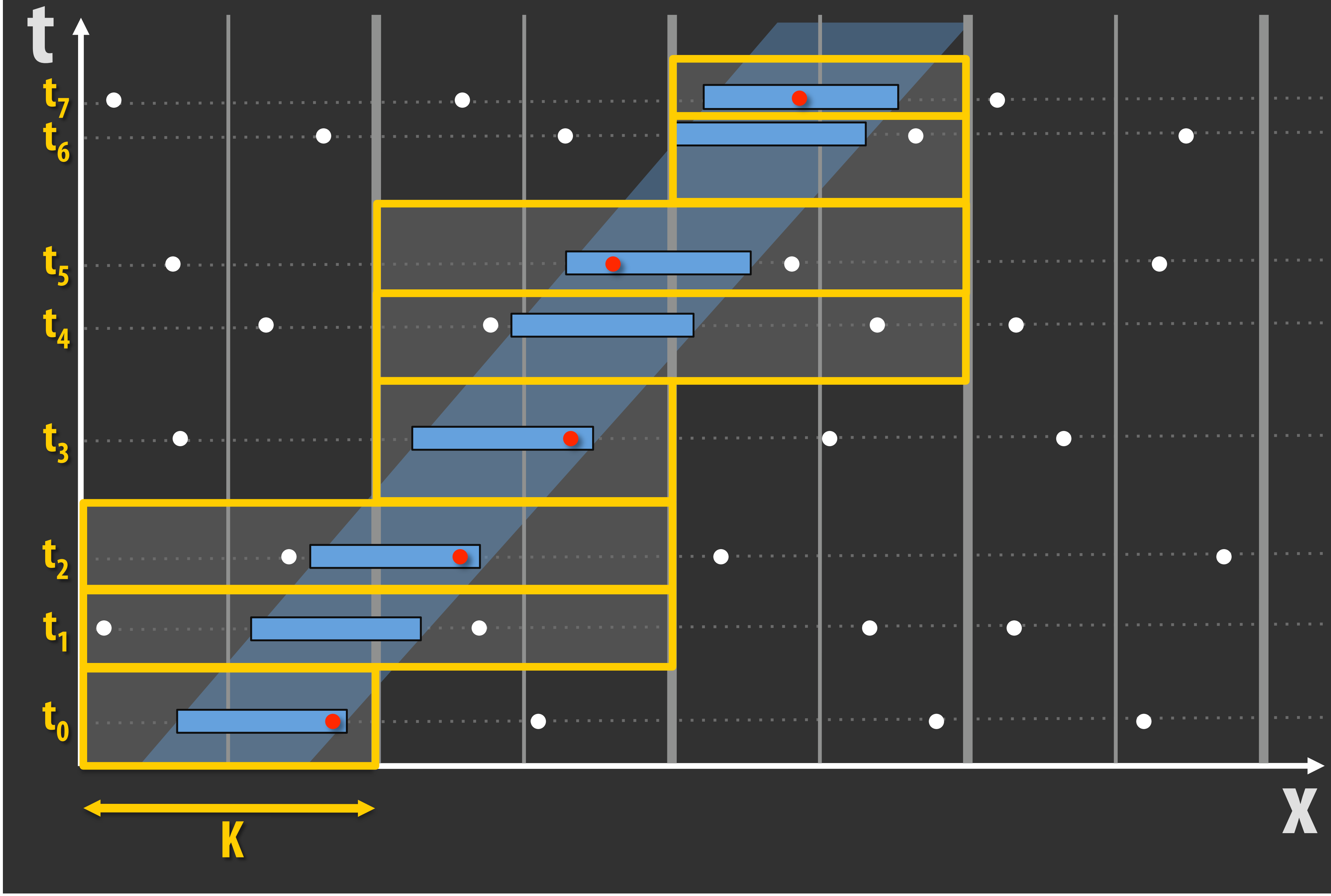
- Limit the number of unique times (or lens positions) used to sample coverage

Interleaved sampling

[Mitchell 91]
[Keller 01]



INTERLEAVE

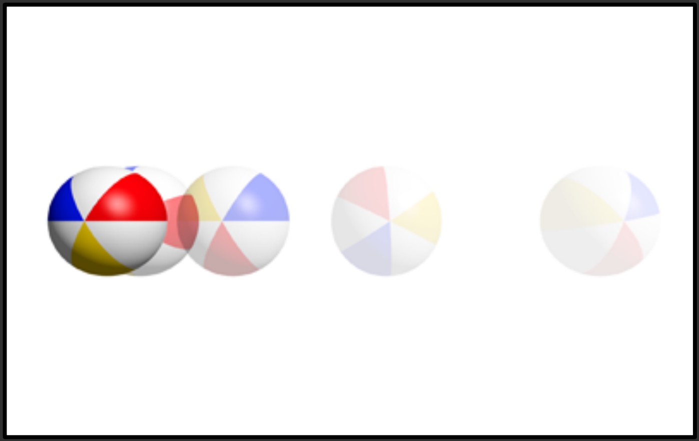


INTERLEAVE parallelism

```
        For each MP
------------------------------------------------------------
Setup      ...
------------------------------------------------------------
          For each unique time T                   PARALLEL
Bound        Position MP at T
             Compute MP bbox at T
------------------------------------------------------------
Test         For each tile in bbox                 UTILIZATION?
               Test MP-sample coverage
```

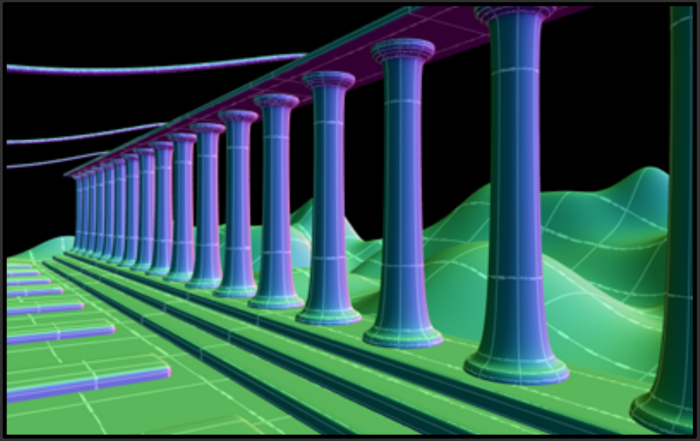
EVALUATION

Test scenes



Ball Roll

Soccer Jump



Columns

Talking

1728 x 1080 resolution, ½-pixel area triangle micropolygons

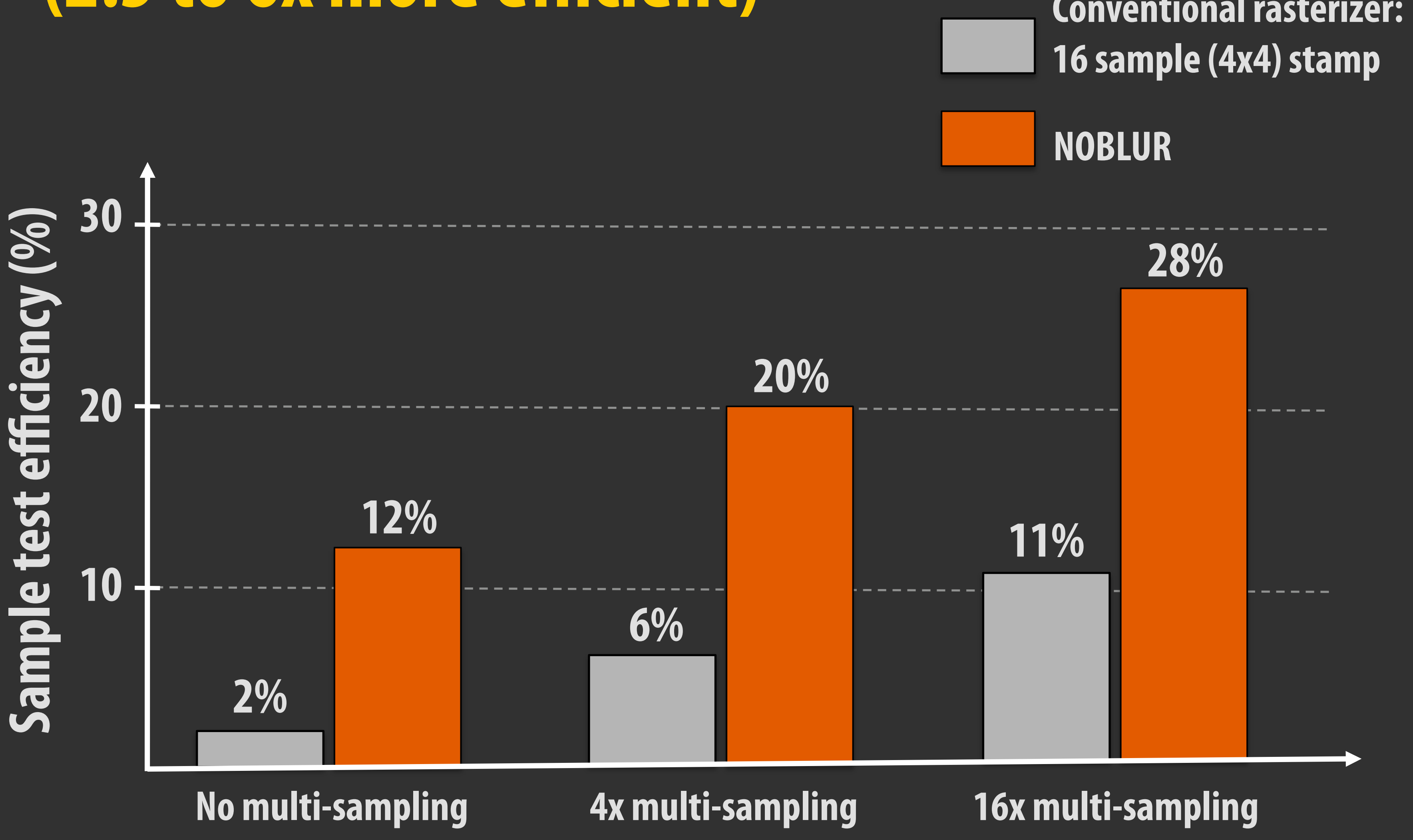
How efficient is NOBLUR?

- What fraction of sample tests generate fragments?

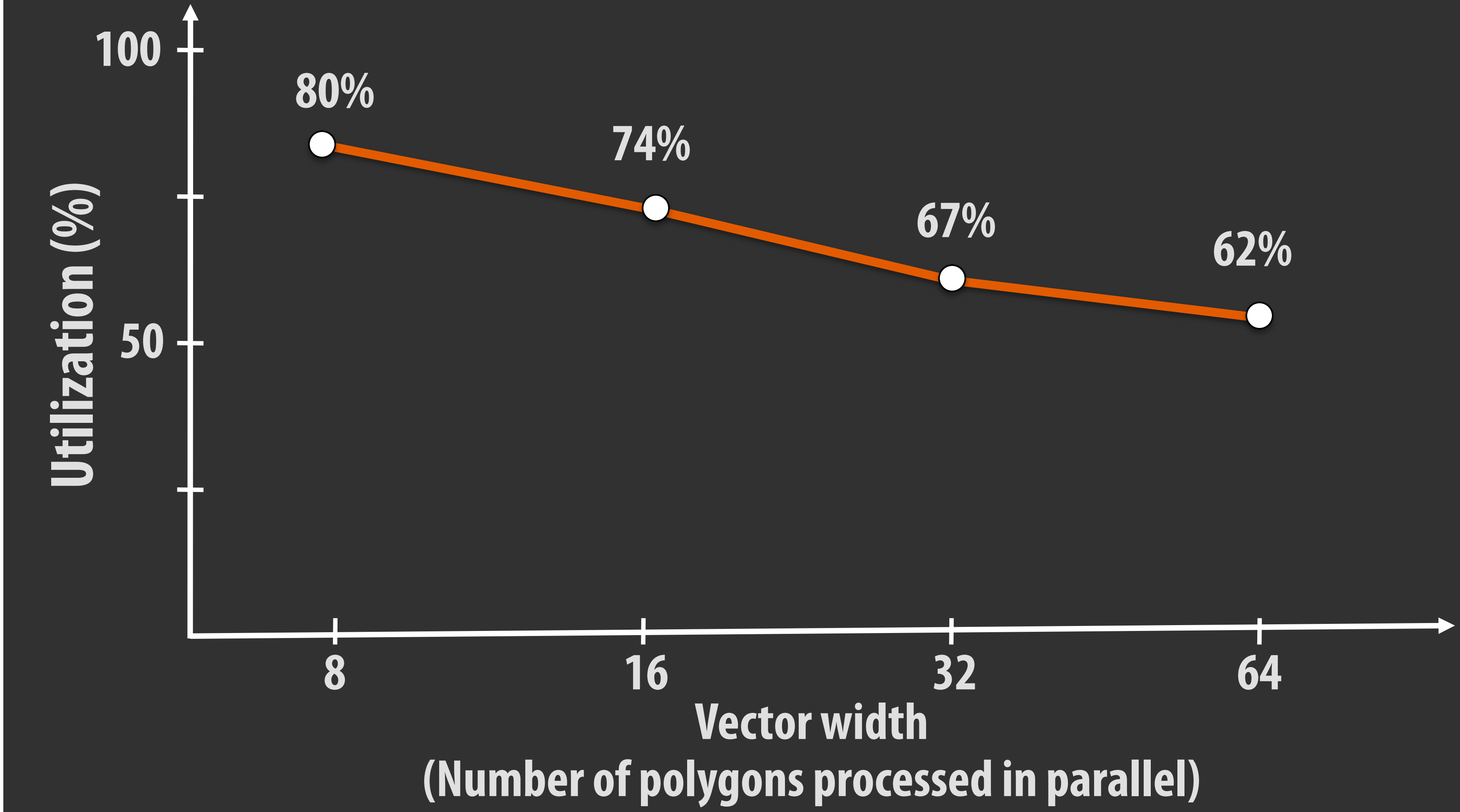
- Does parallelization across polygons efficiently utilize vector processing?

NOBLUR increases sample test efficiency

(2.5 to 6x more efficient)



NOBLUR sustains high vector utilization



Micropolygon rasterization is expensive

Primary visibility computation:

1080p resolution, 30 Hz

4x multi-sampling

Simple scene (10 M micropolygons)

Estimated cost of GPU SW implementation:

Approximately 1/3 of high-end GPU

Fixed-function micropolygon rasterization is appealing

- How much do motion blur and camera defocus cost?
- What is relative performance of INTERVAL, INTERLEAVE under varying amounts of motion or defocus?

Soccer jump

16x multi-sampling

INTERVAL:	16 time intervals
INTERLEAVE:	64 unique times

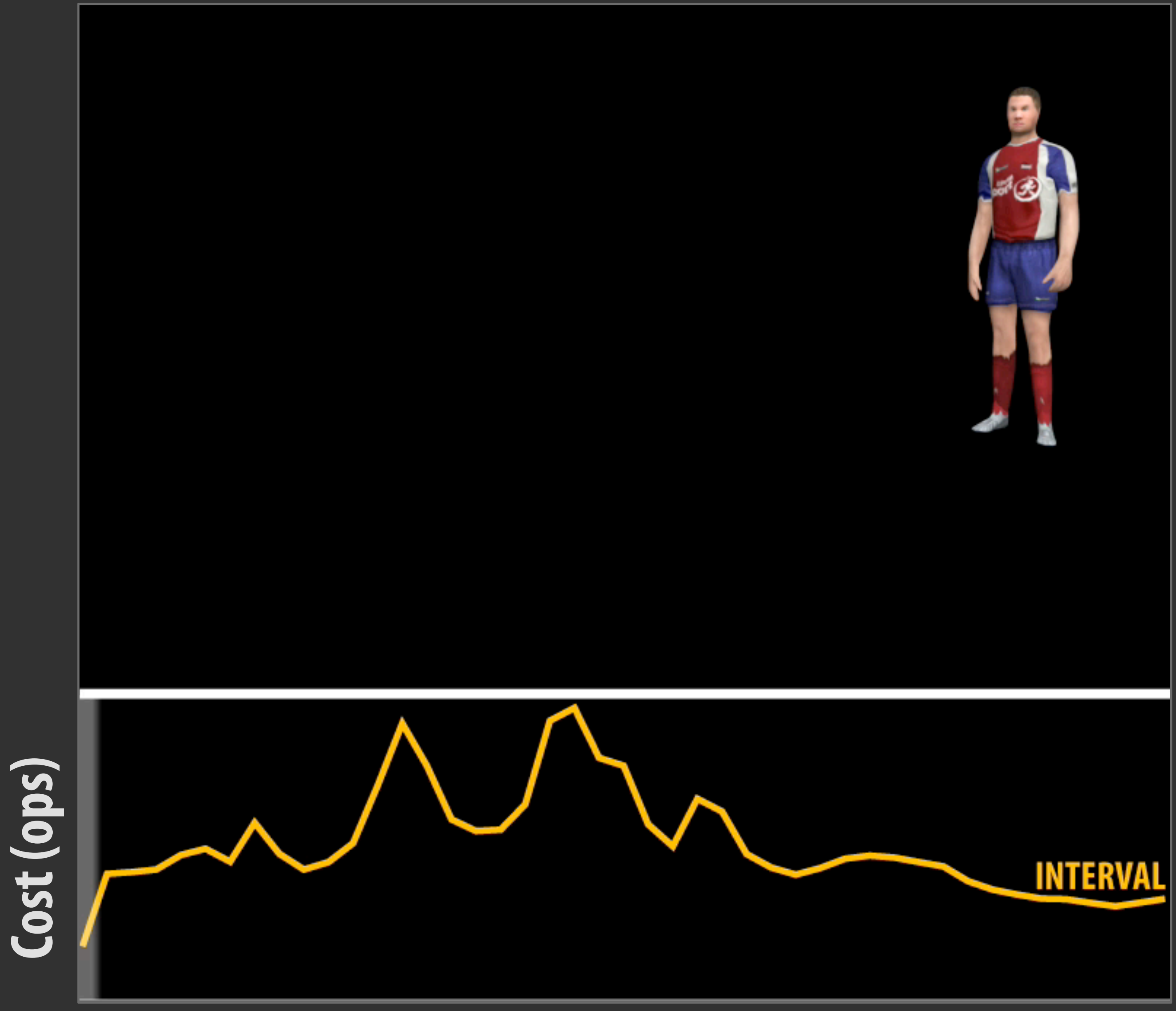
Enabling motion/defocus blur costs 3 to 7x more

- Point-in-polygon tests are more expensive
- INTERVAL, INTERLEAVE perform more tests than NOBLUR

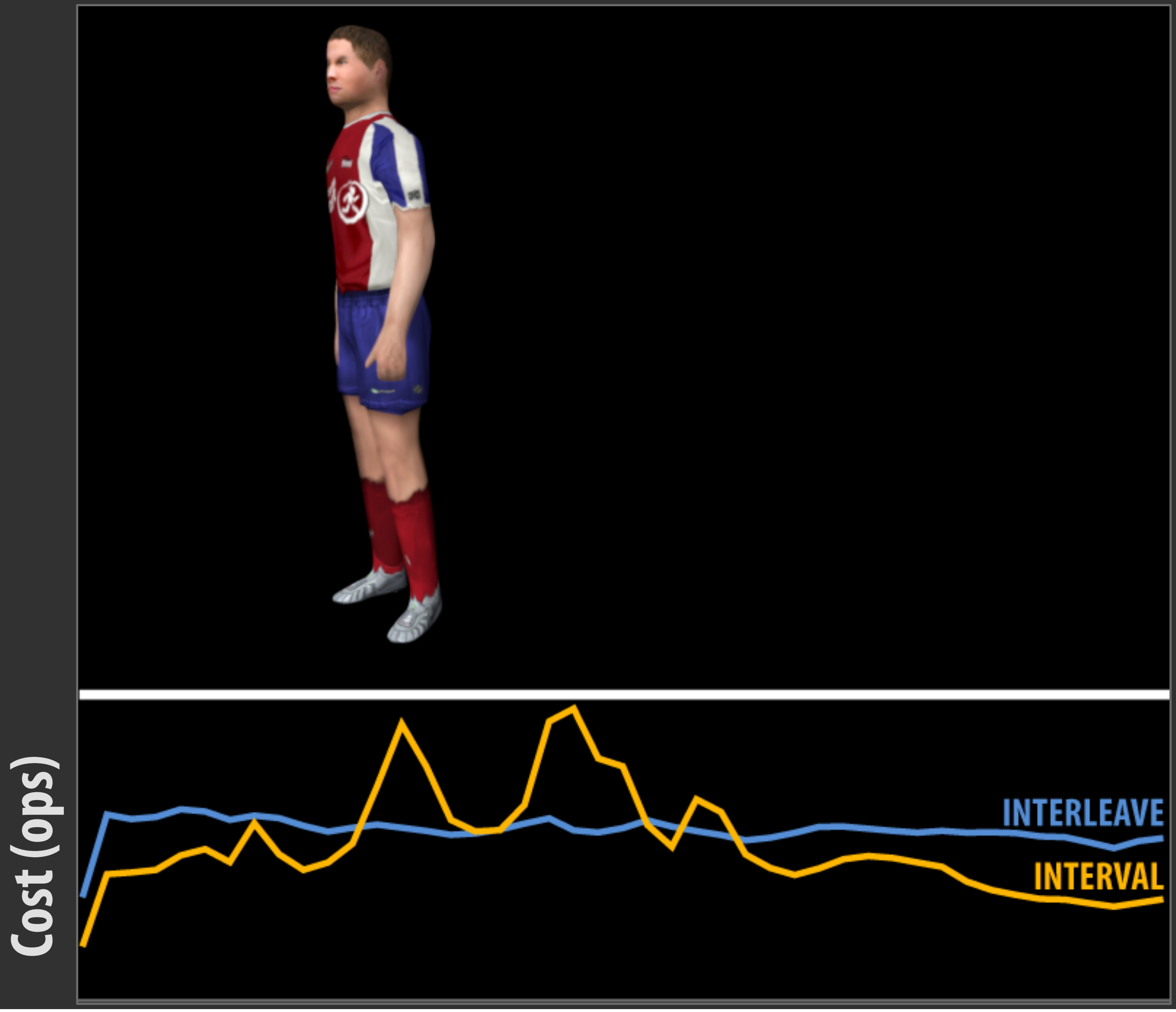
Sample test efficiency
(stationary geometry, perfect focus) →

NOBLUR	28%
INTERVAL	11%
INTERLEAVE	5%

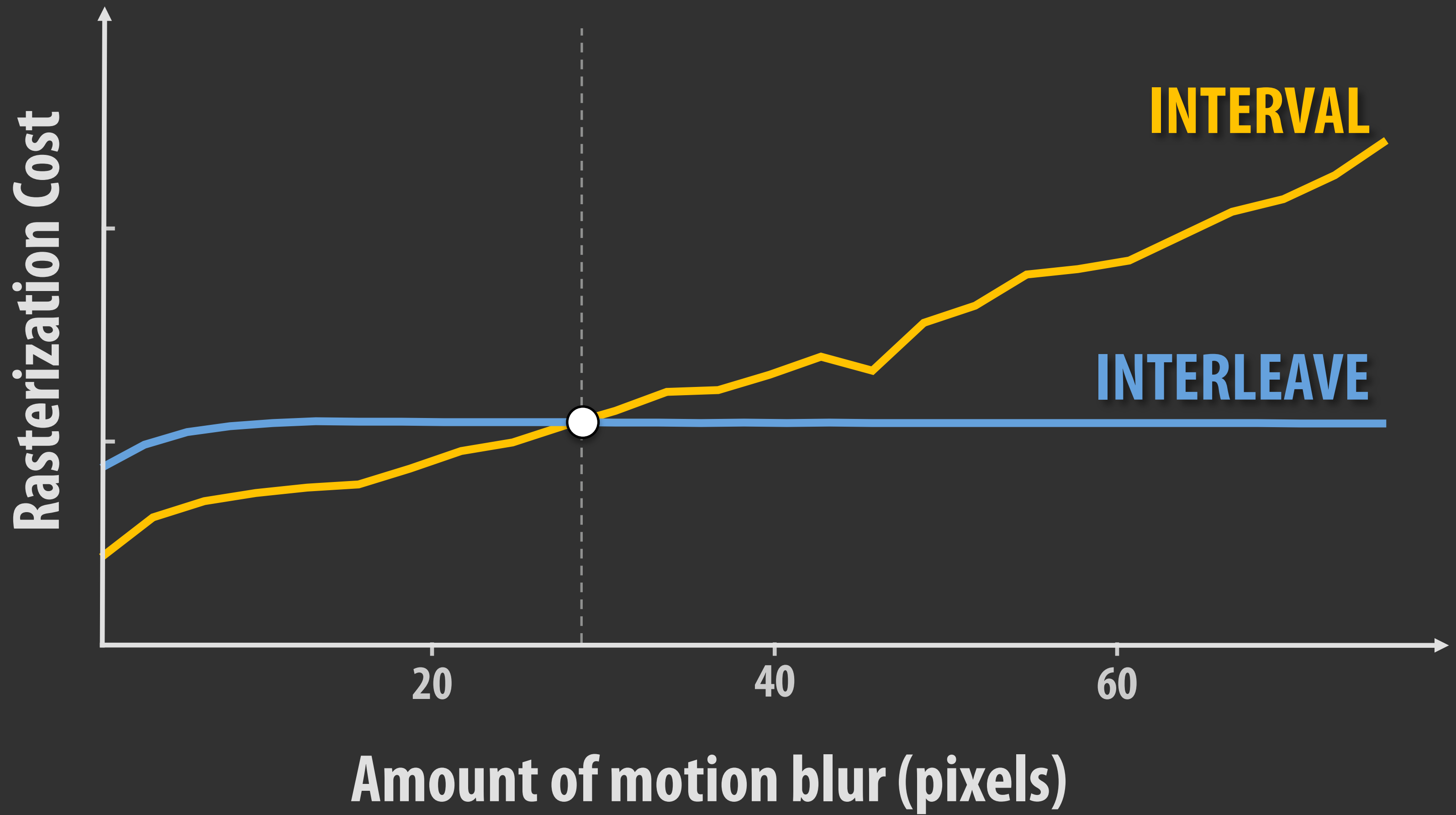
INTERVAL's performance varies with motion



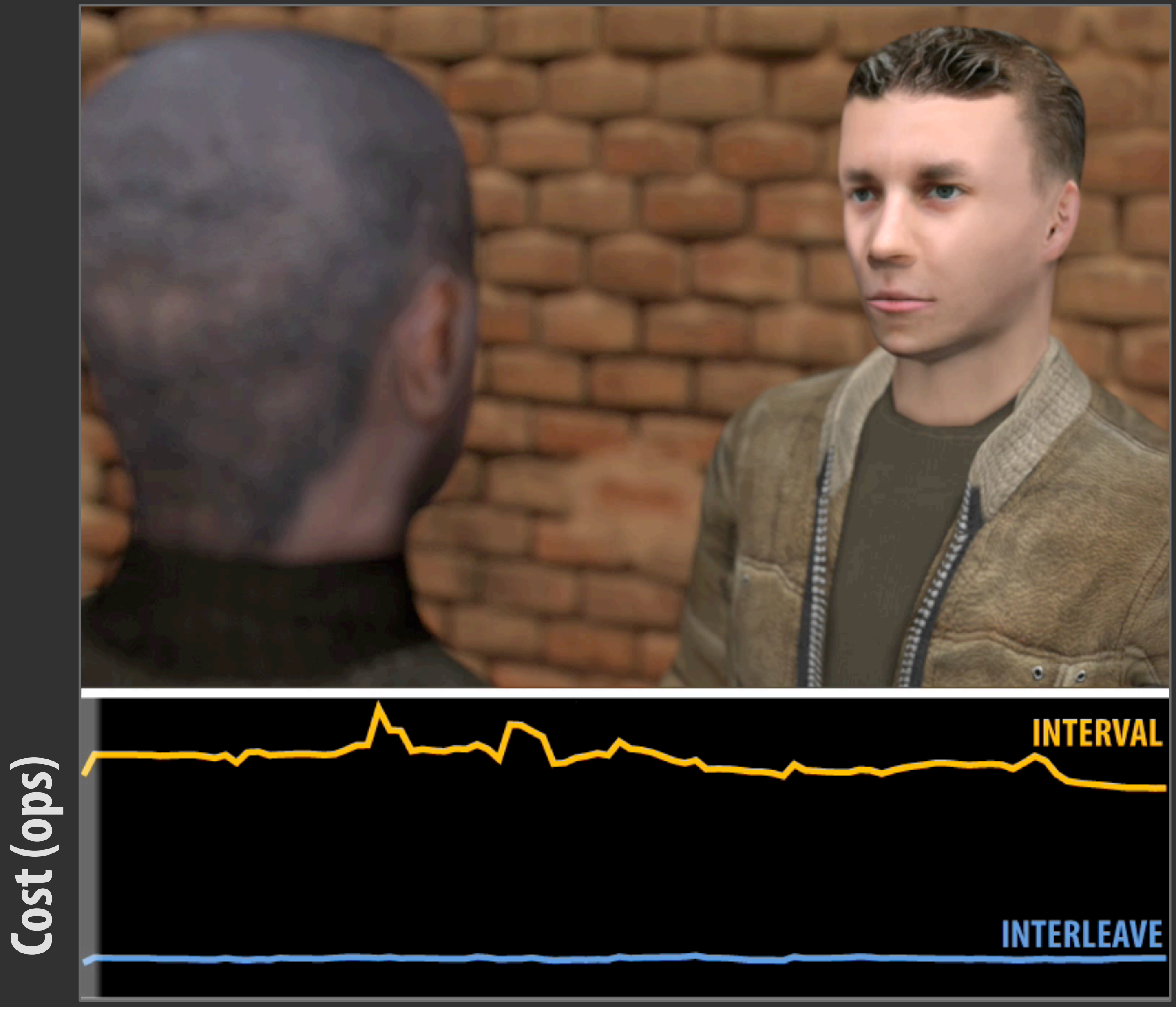
INTERLEAVE more efficient than INTERVAL at high motion



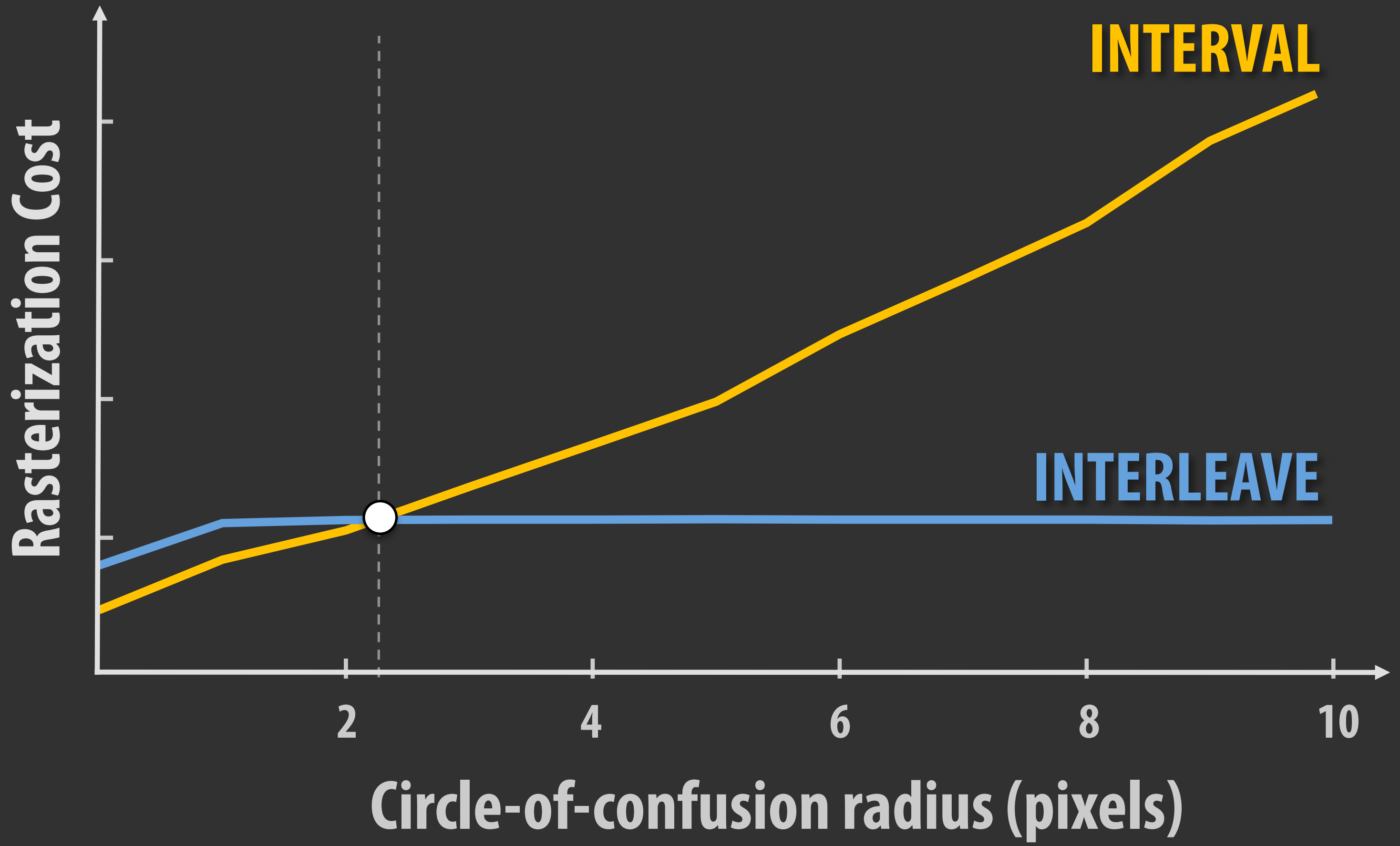
~30 pixels of motion blur equates performance



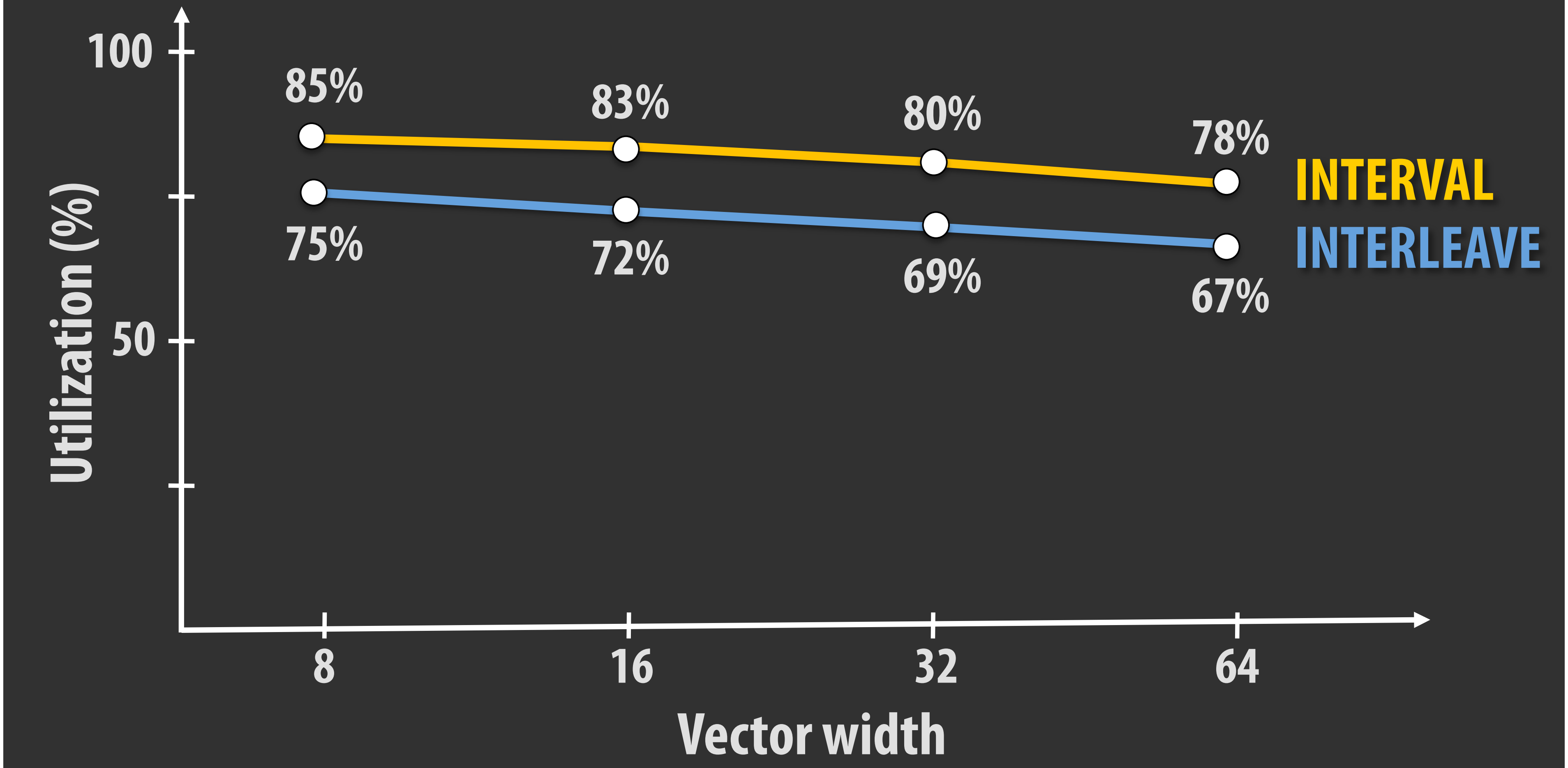
INTERVAL's costs increase sharply with defocus



~2 pixel defocus blur radius equates performance



INTERVAL/INTERLEAVE sustain high utilization



SUMMARY

Re-optimizing rasterization: NOBLUR

- Parallelize across micropolygons
- More efficient than conventional rasterization techniques
  - Especially at low sampling rates
- Utilizes wide vector processing well

- Even with these improvements, micropolygon rasterization is expensive

Extension to motion blur / defocus

- Costs 3 to 7x more in flops
- INTERVAL more efficient until motion is large
- INTERLEAVE more efficient under high motion, moderate to high defocus
- Both algorithms are inefficient
  - Only 1 in 20 polygon-sample tests generate hits

How does real-time graphics pipeline evolve to enable <u>efficient</u> micropolygon rendering?

How should surfaces be tessellated into micropolygons?

How can micropolygons be rasterized efficiently?

How is occlusion-culling best implemented?

Should the pipeline shade like GPUs or like REYES?

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(SUN, AMD, NVIDIA, IBM, Intel, HP, NEC)

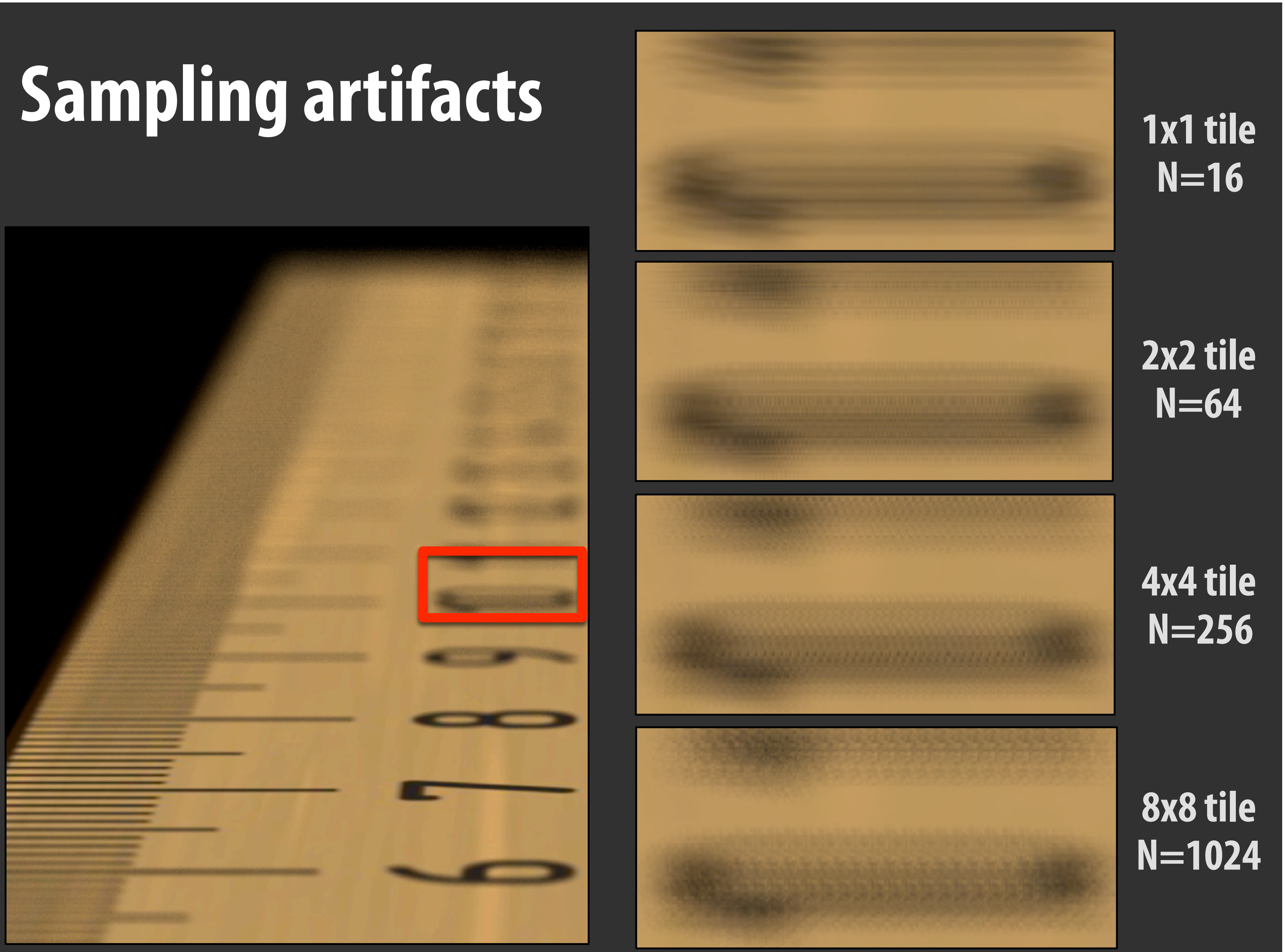
Mike Doggett, Lund University

Mike Houston, AMD

Tim Purcell, NVIDIA

ADDITIONAL SLIDES

Sampling artifacts

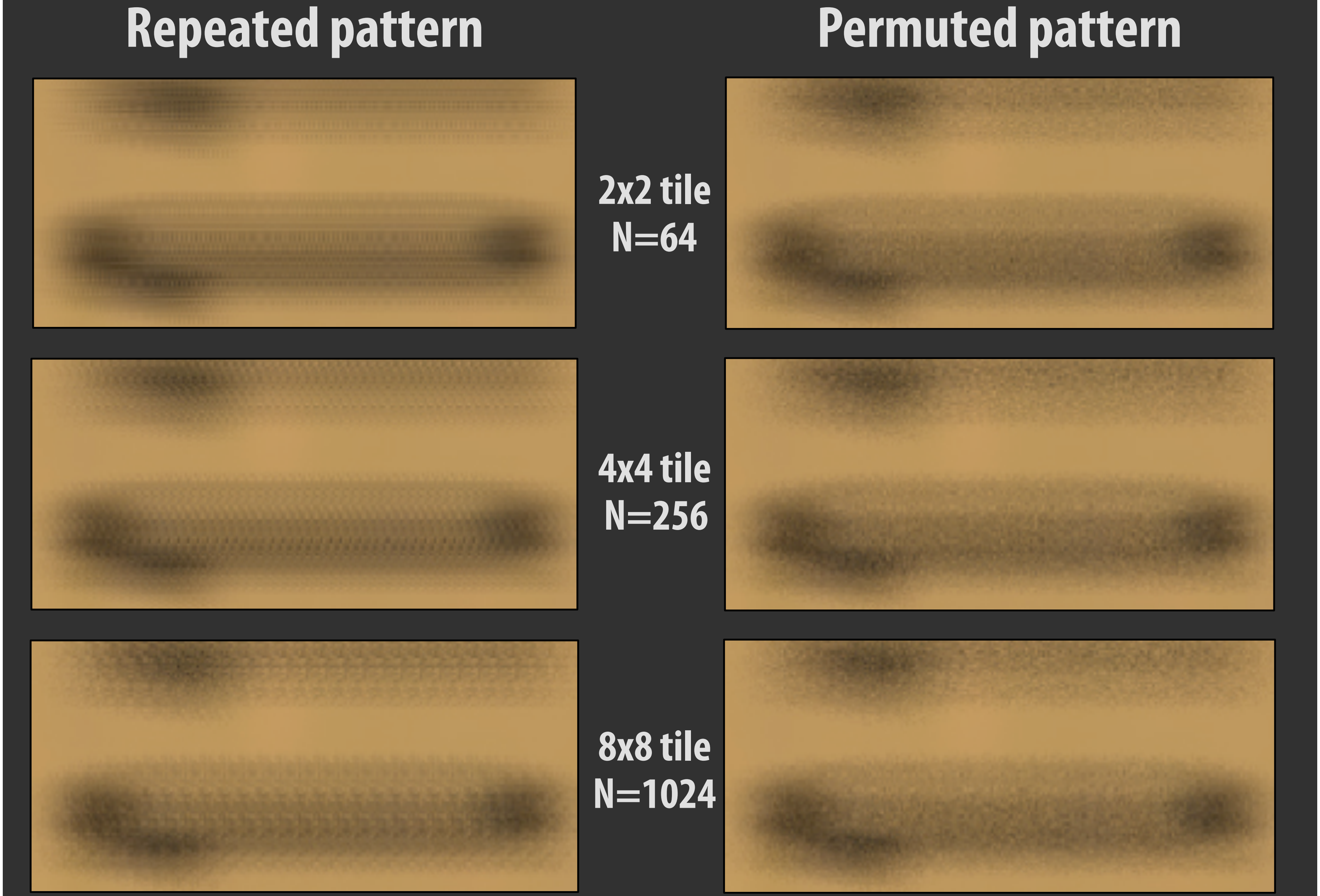


1x1 tile
N=16

2x2 tile
N=64

4x4 tile
N=256

8x8 tile
N=1024



Repeated pattern

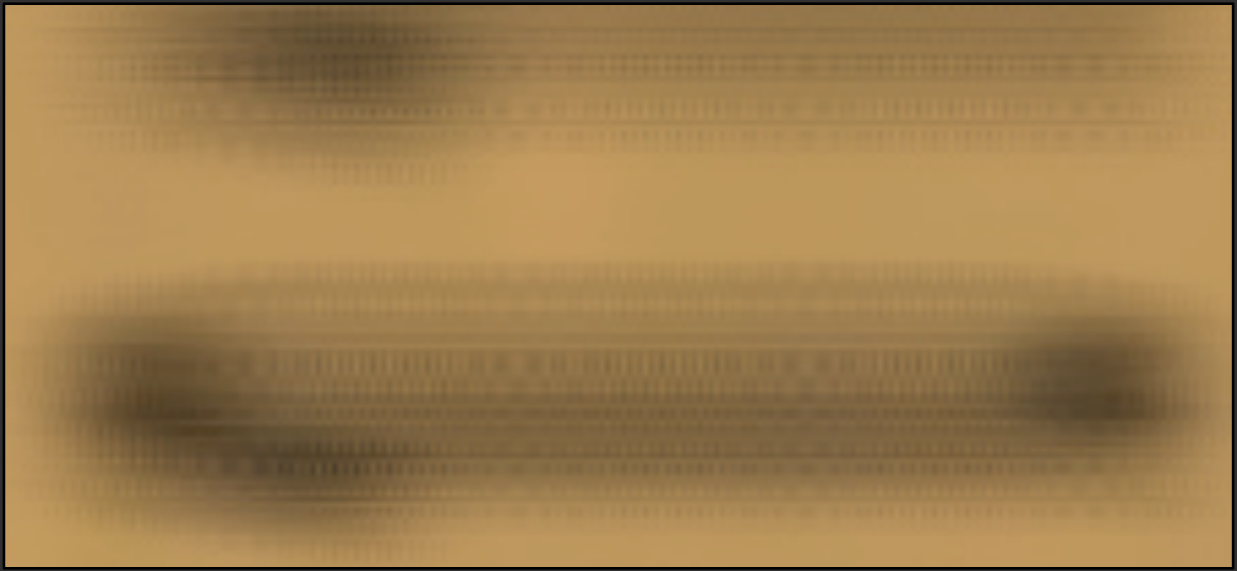
Permuted pattern

2x2 tile
N=64

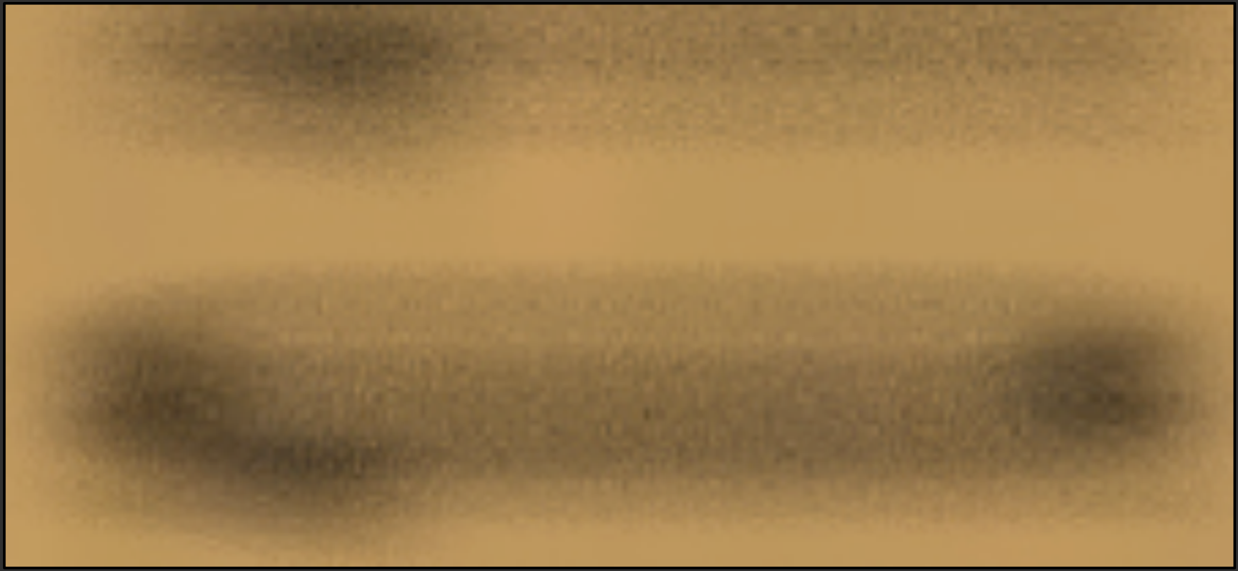
4x4 tile
N=256

8x8 tile
N=1024

INTERLEAVE 2x2 tile, N=64



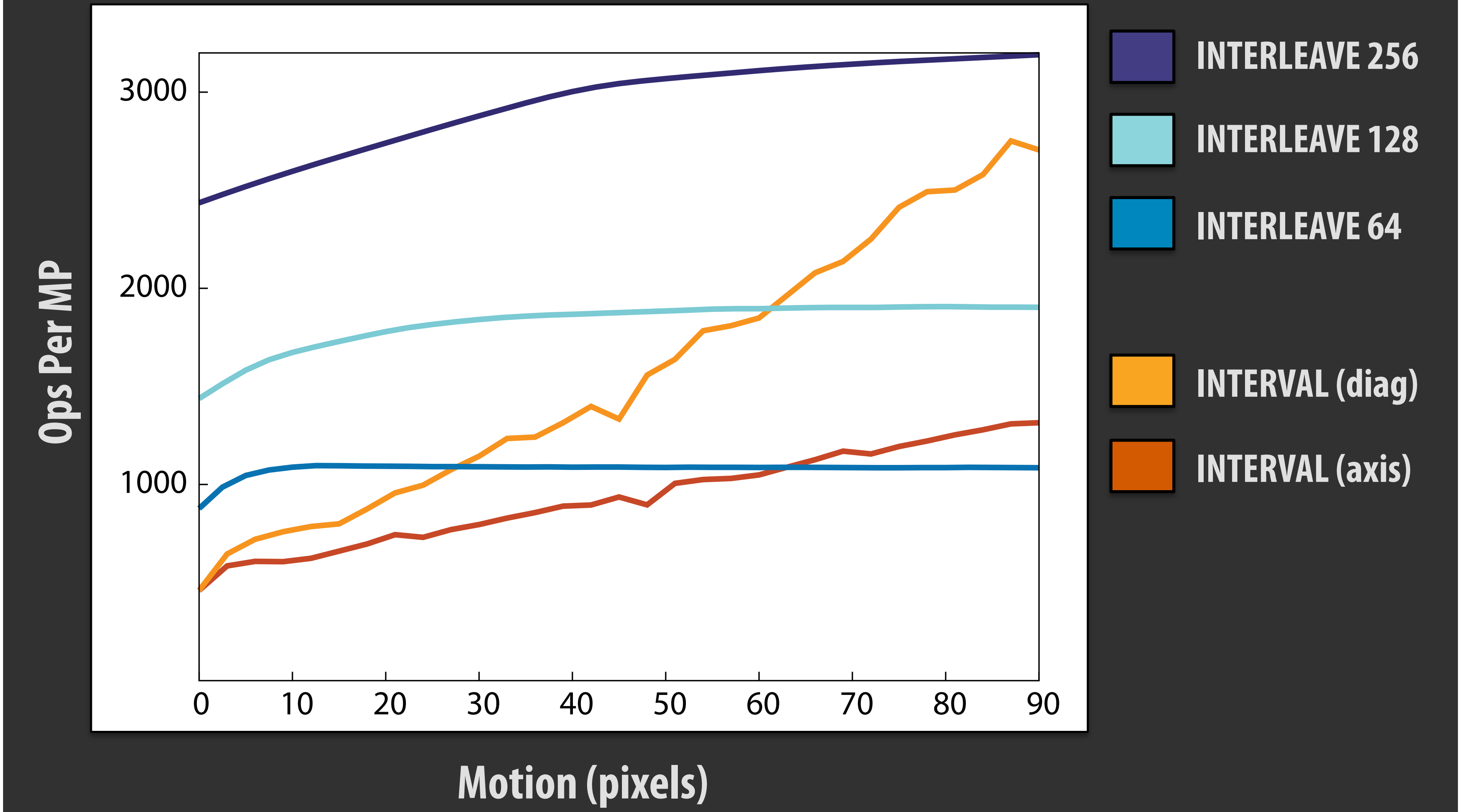
Repeated pattern



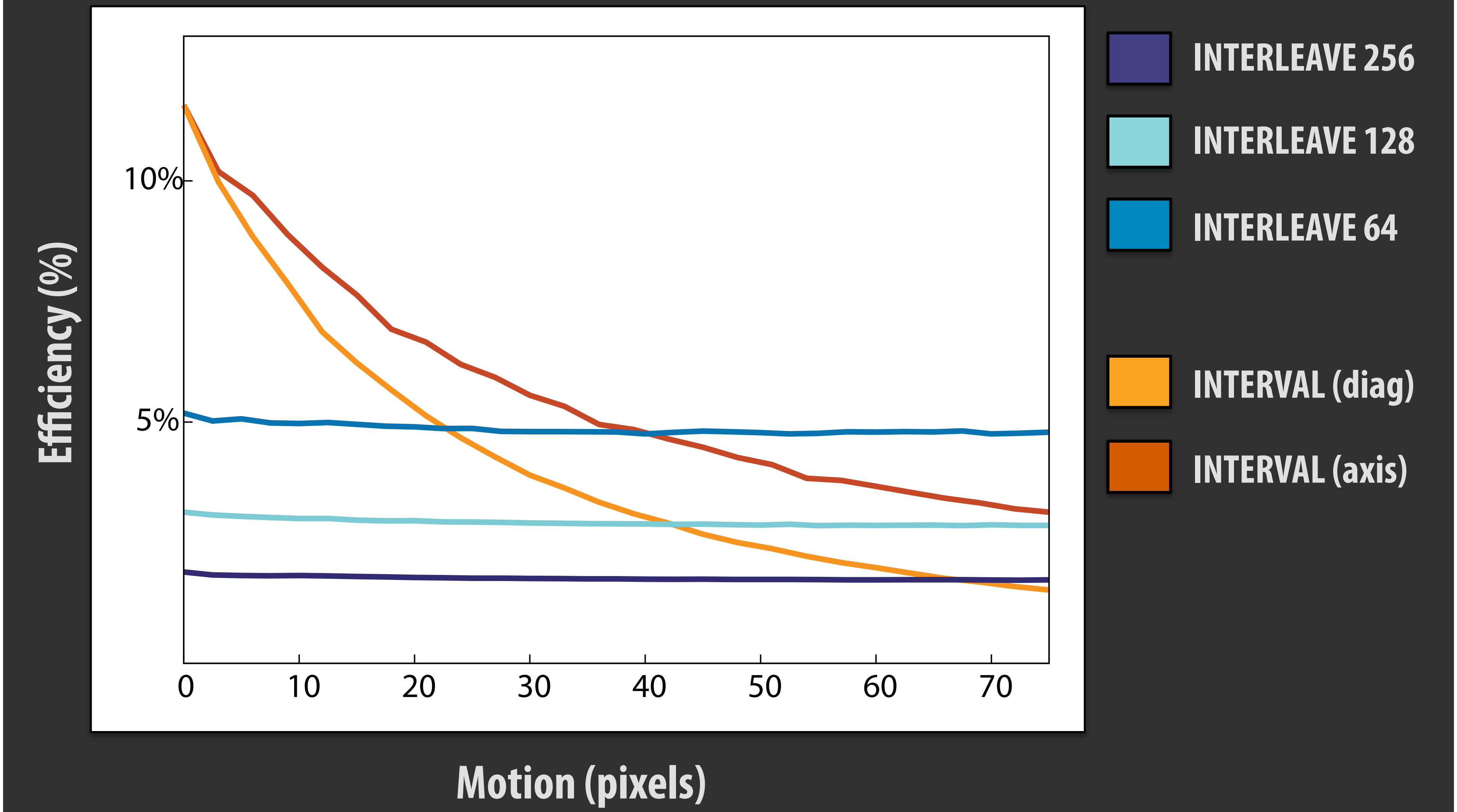
Permuted pattern

Motion blur

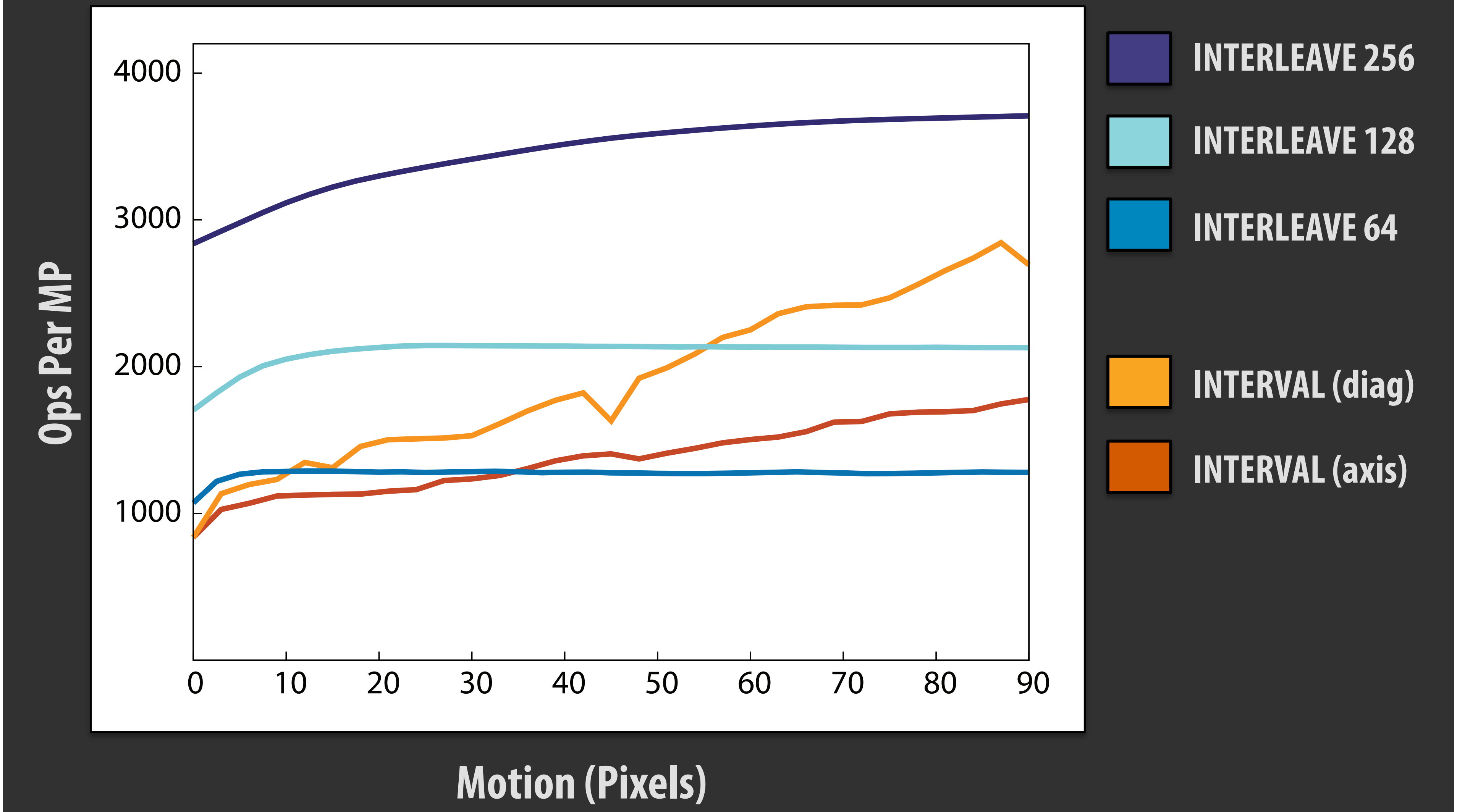
16x MSAA: motion blur



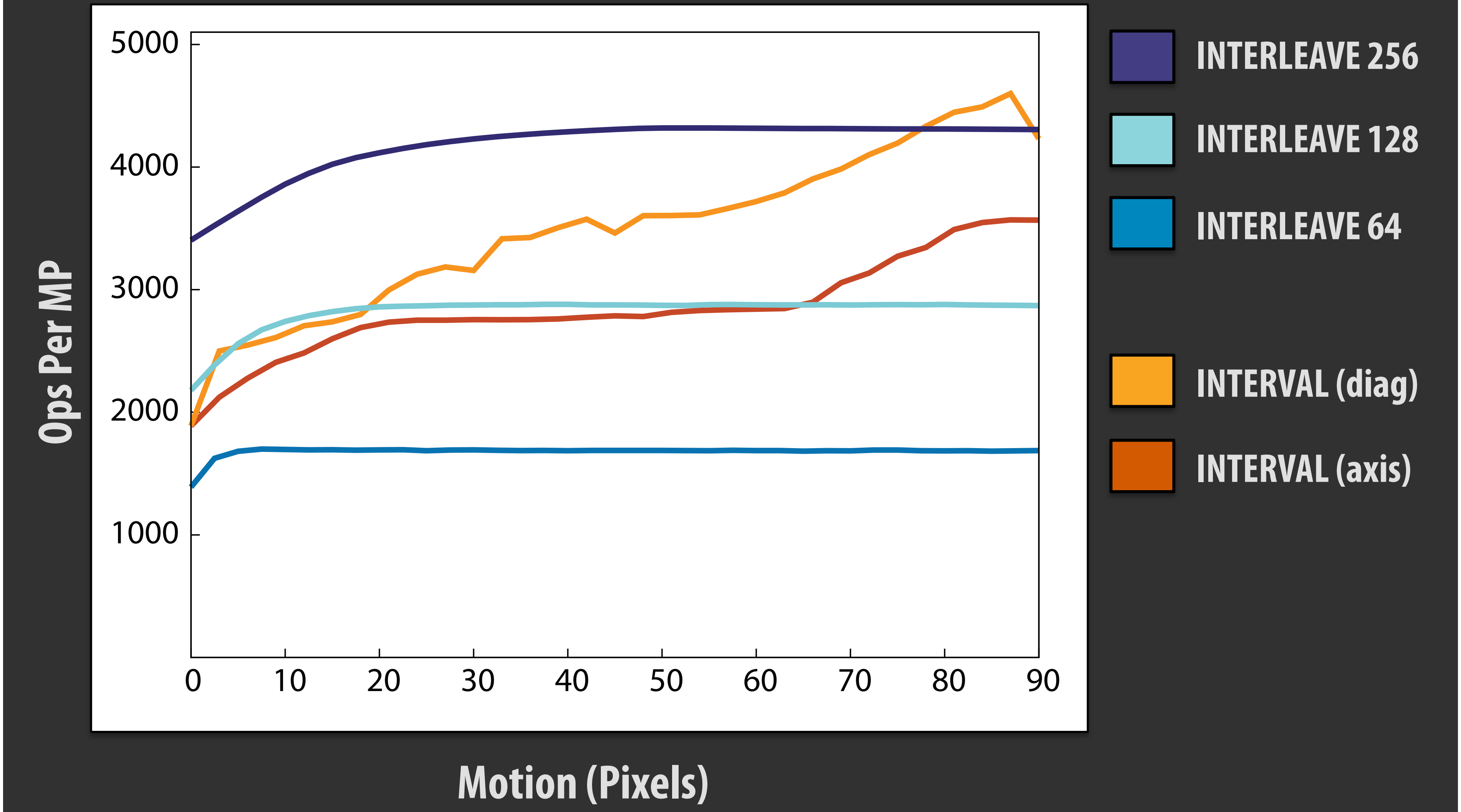
16x MSAA: motion blur (efficiency)



32x MSAA: motion blur

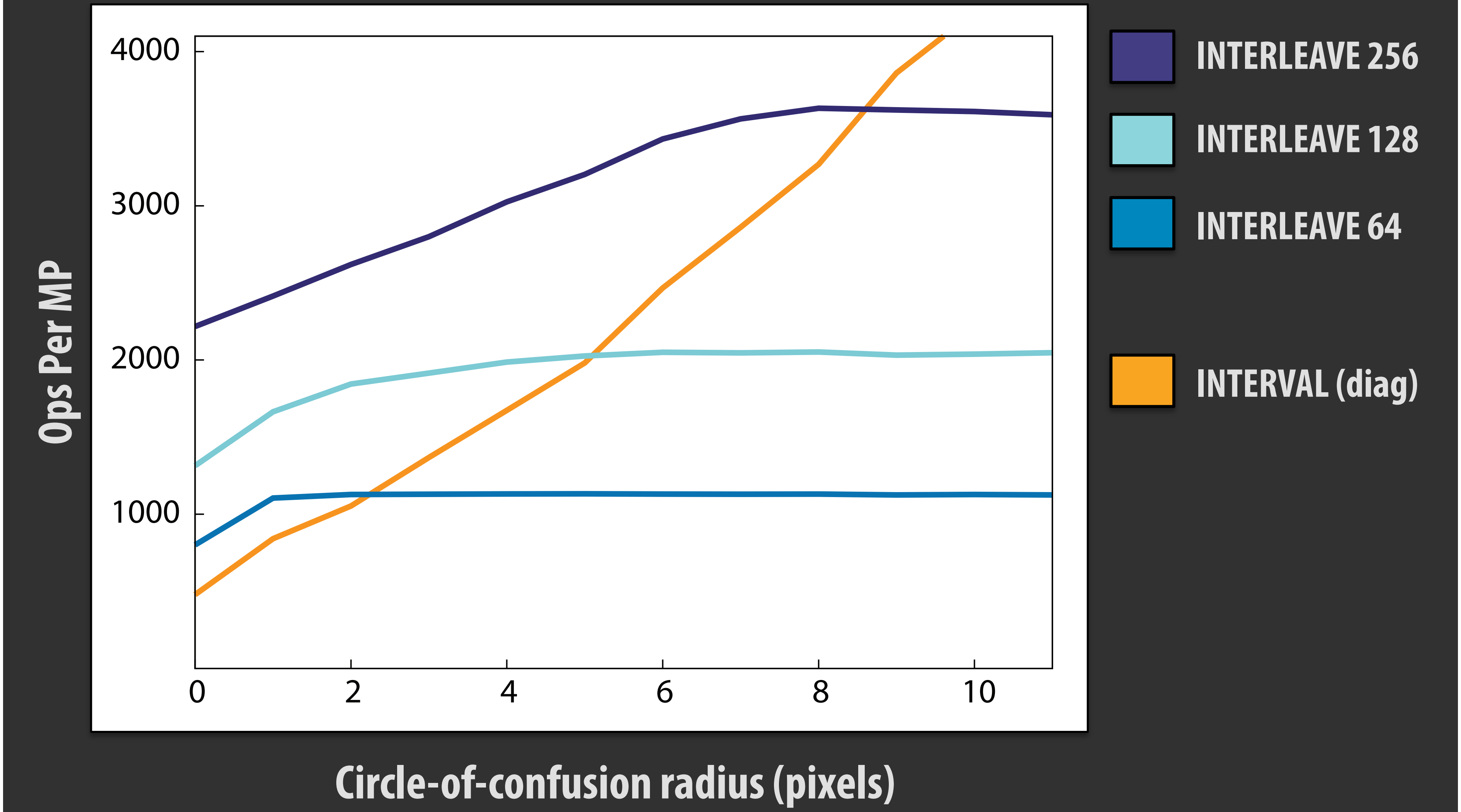


64x MSAA: motion blur

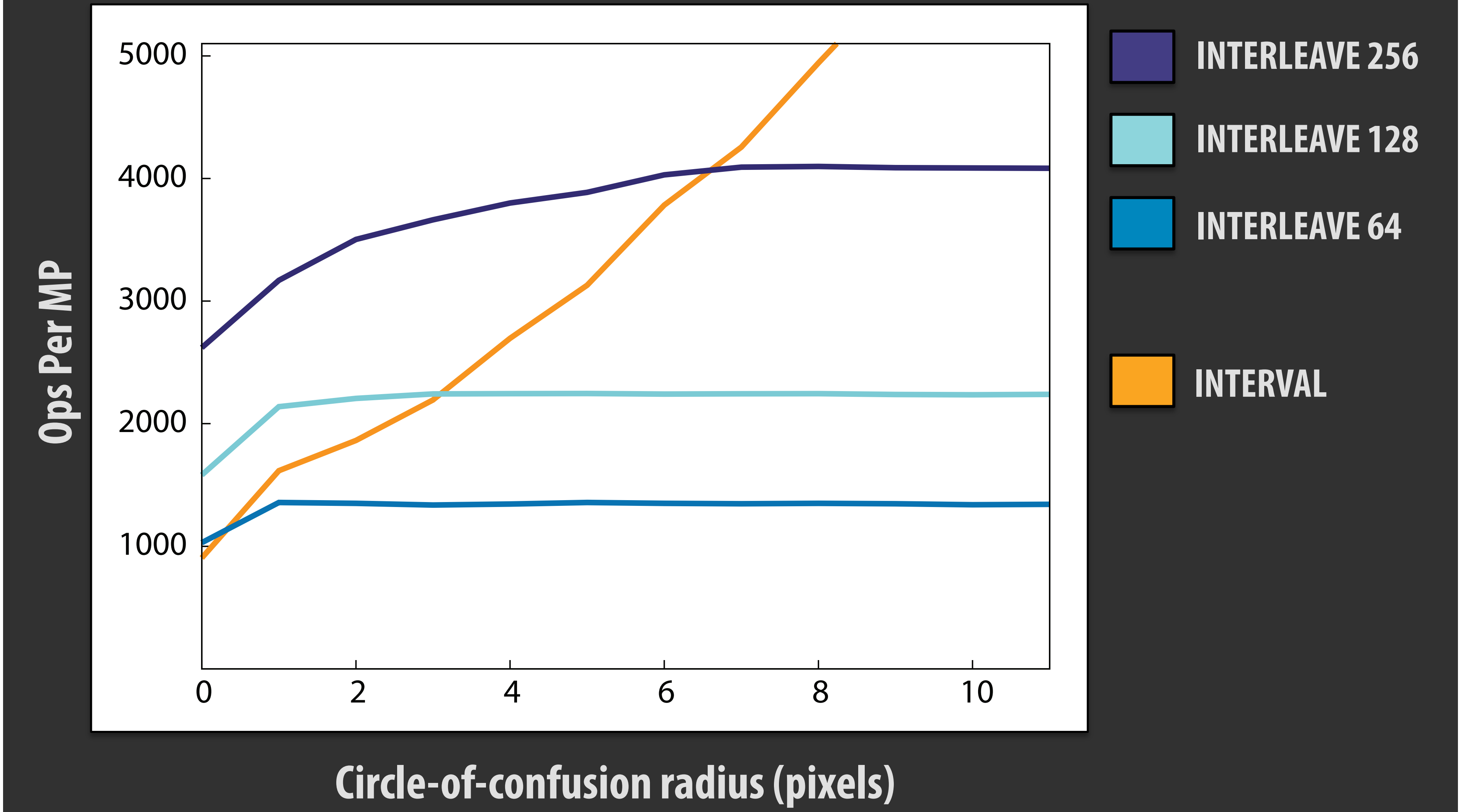


Defocus blur

16x MSAA: defocus blur



32x MSAA: defocus blur


Ops Per MP
Circle-of-confusion radius (pixels)
INTERLEAVE 256
INTERLEAVE 128
INTERLEAVE 64
INTERVAL