Theory and Analysis of Higher-order Motion Blur Rasterization

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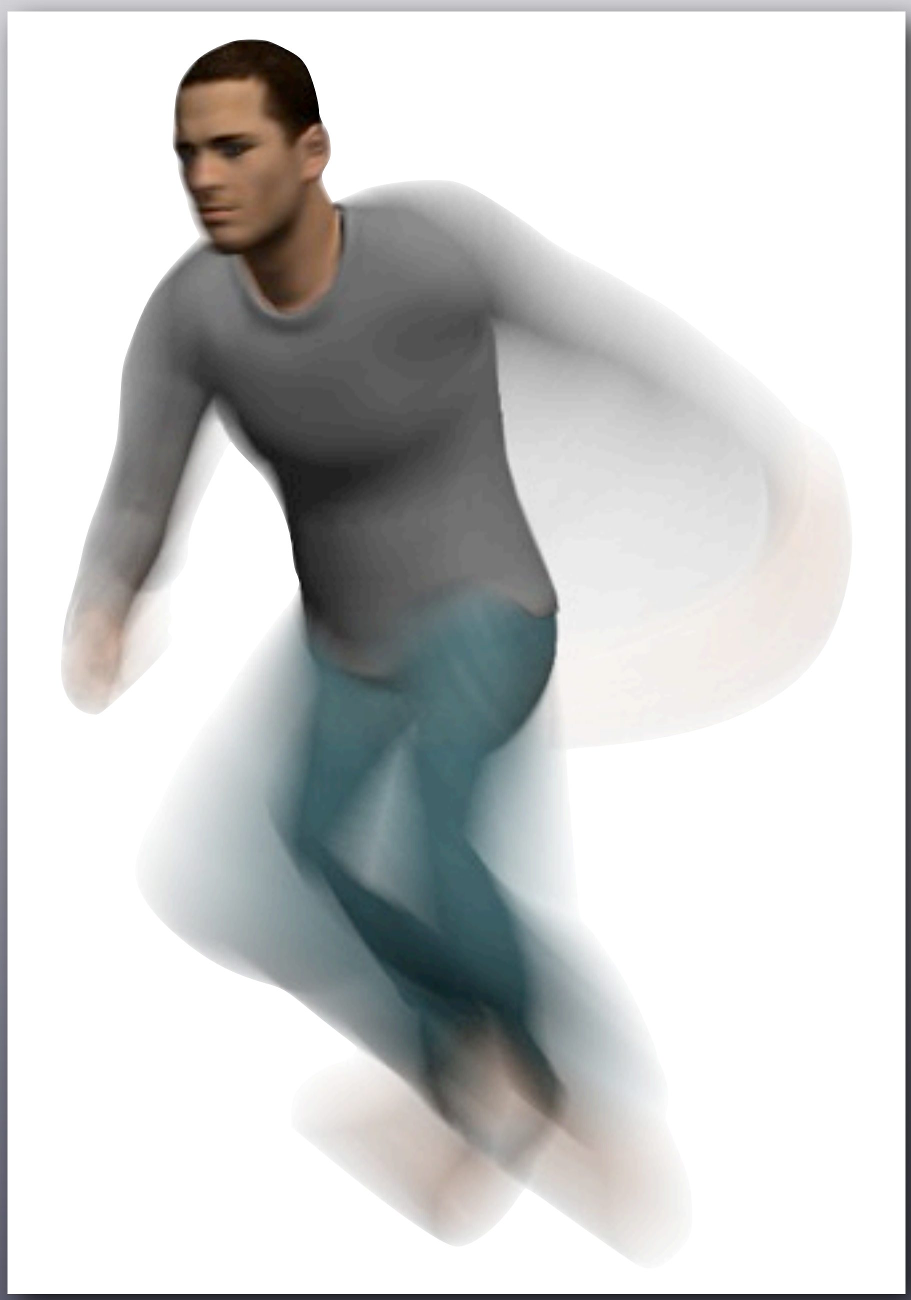
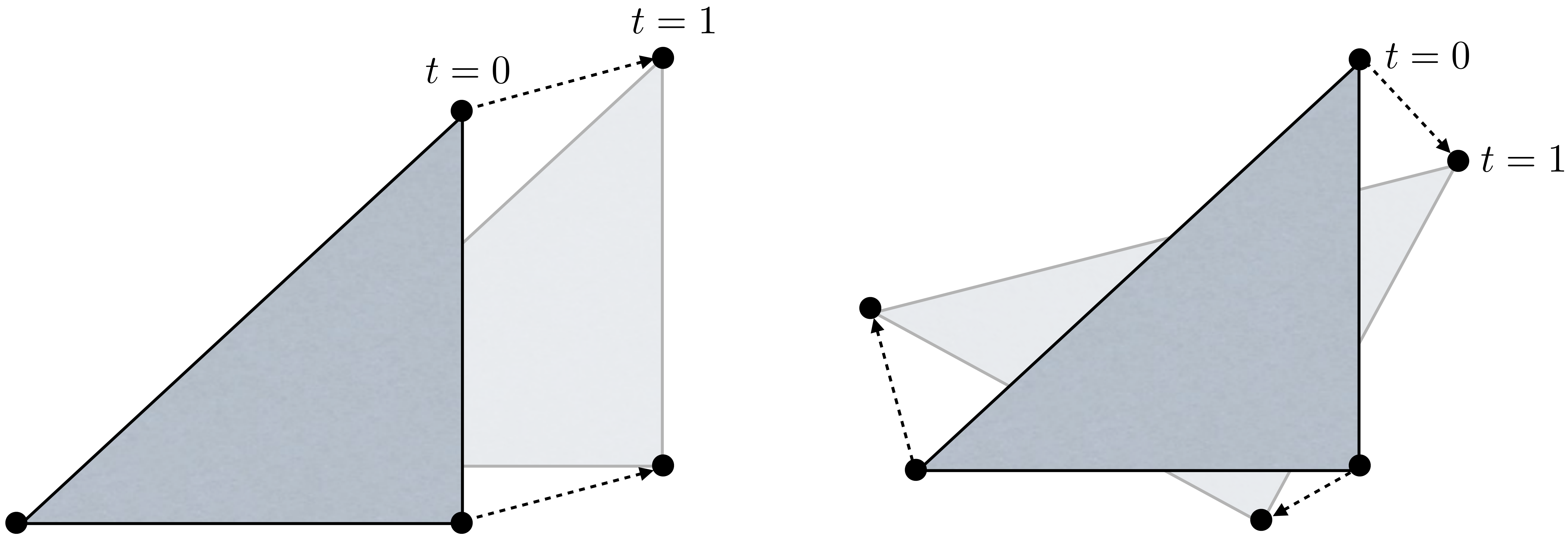
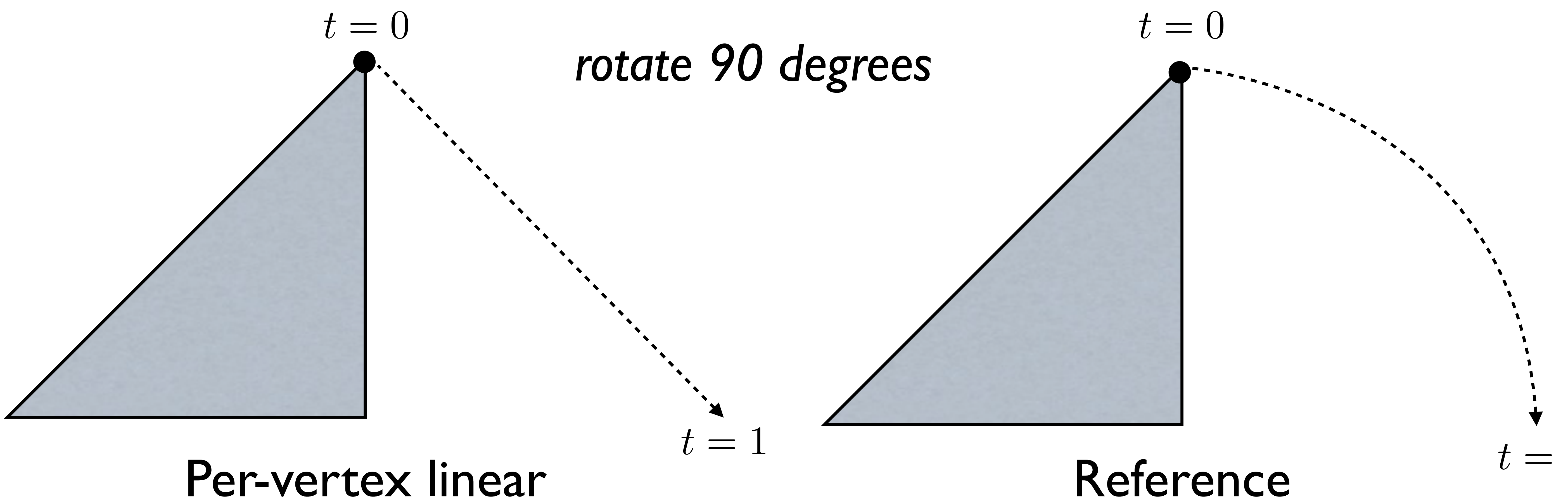
Lund Institute of Technology
Lund University



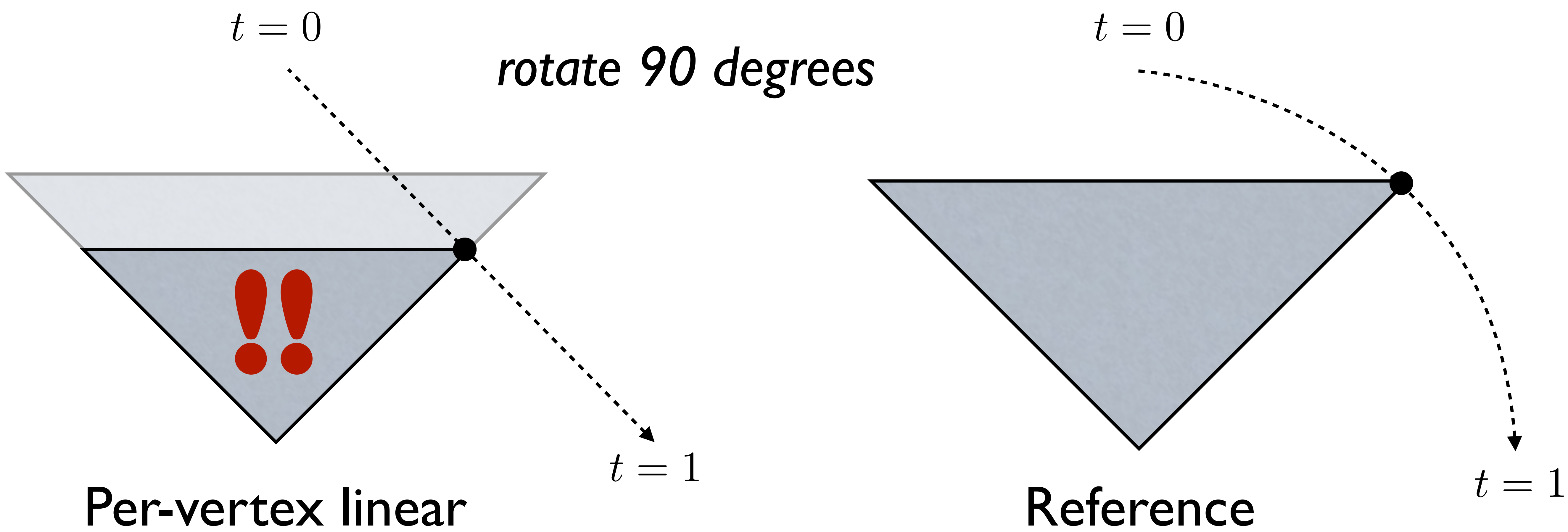
Per-vertex linear motion



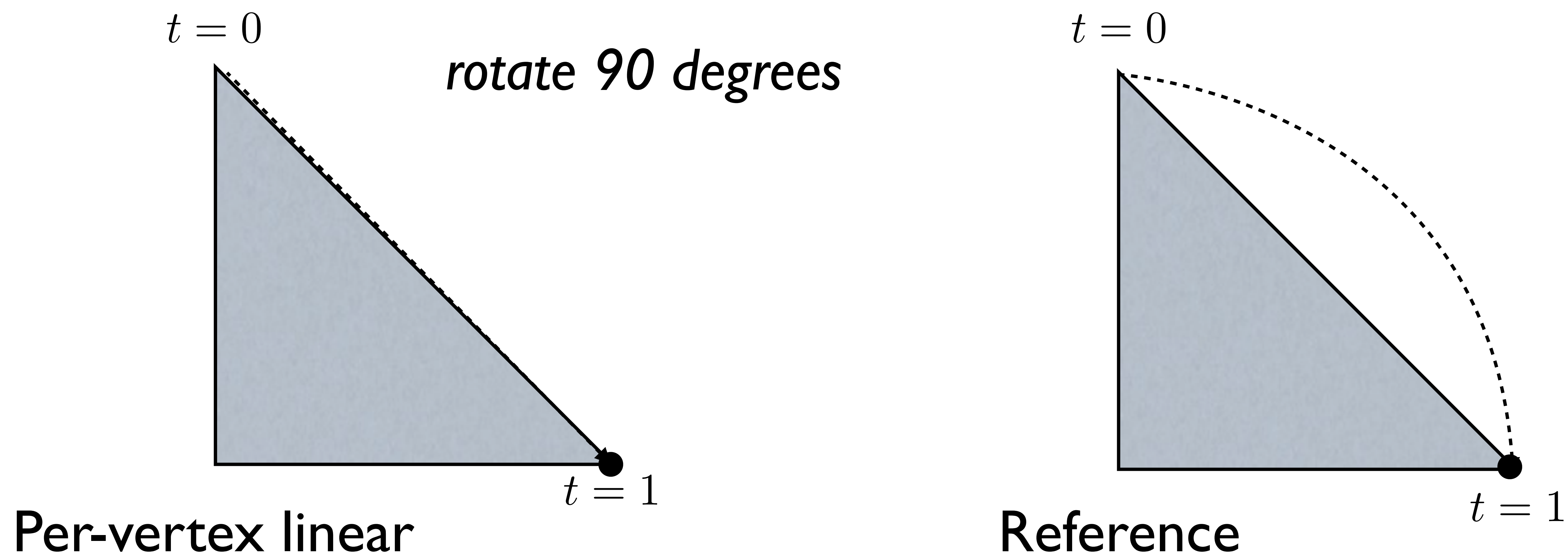
Linear vs curved motion



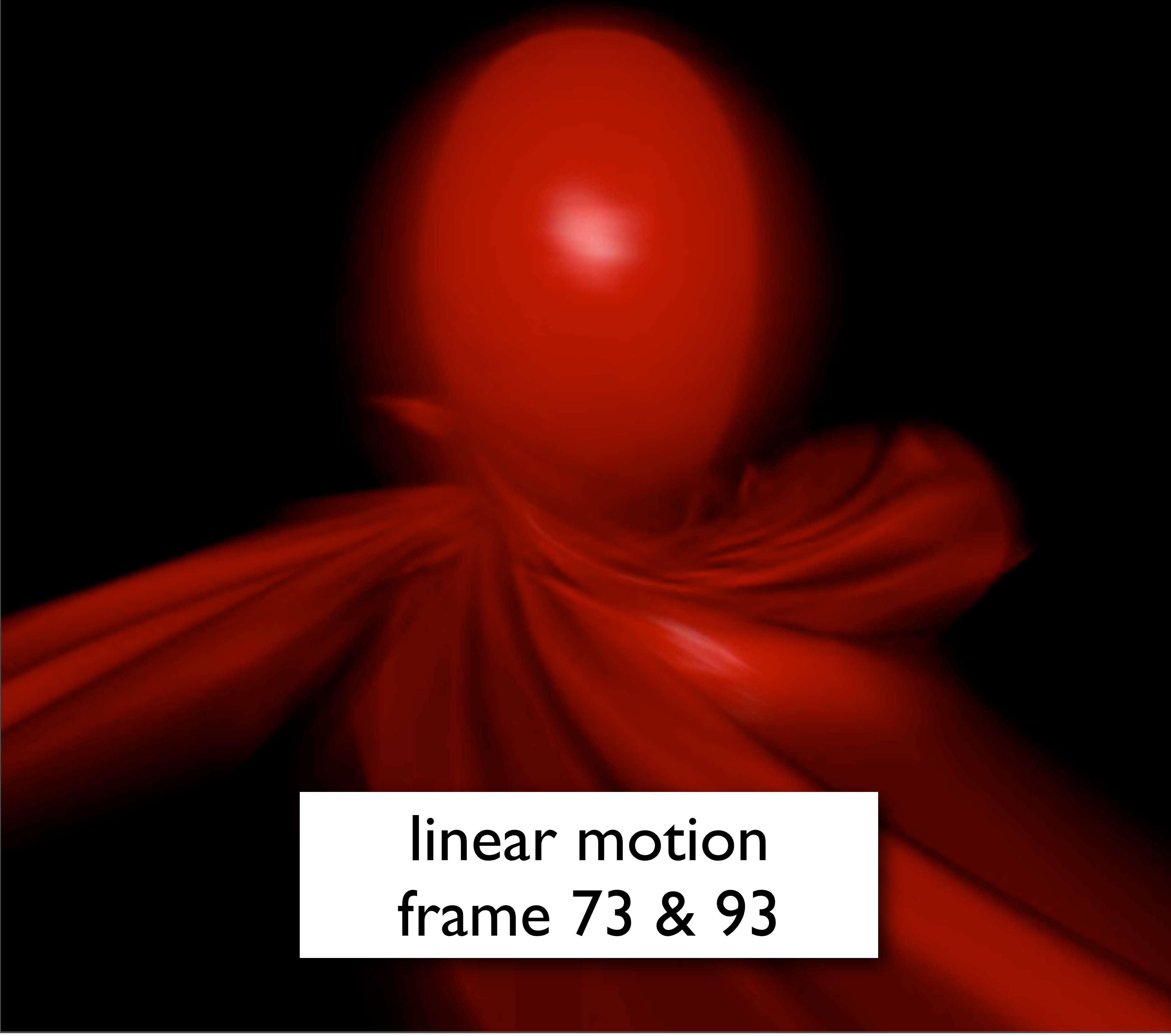
Linear vs curved motion

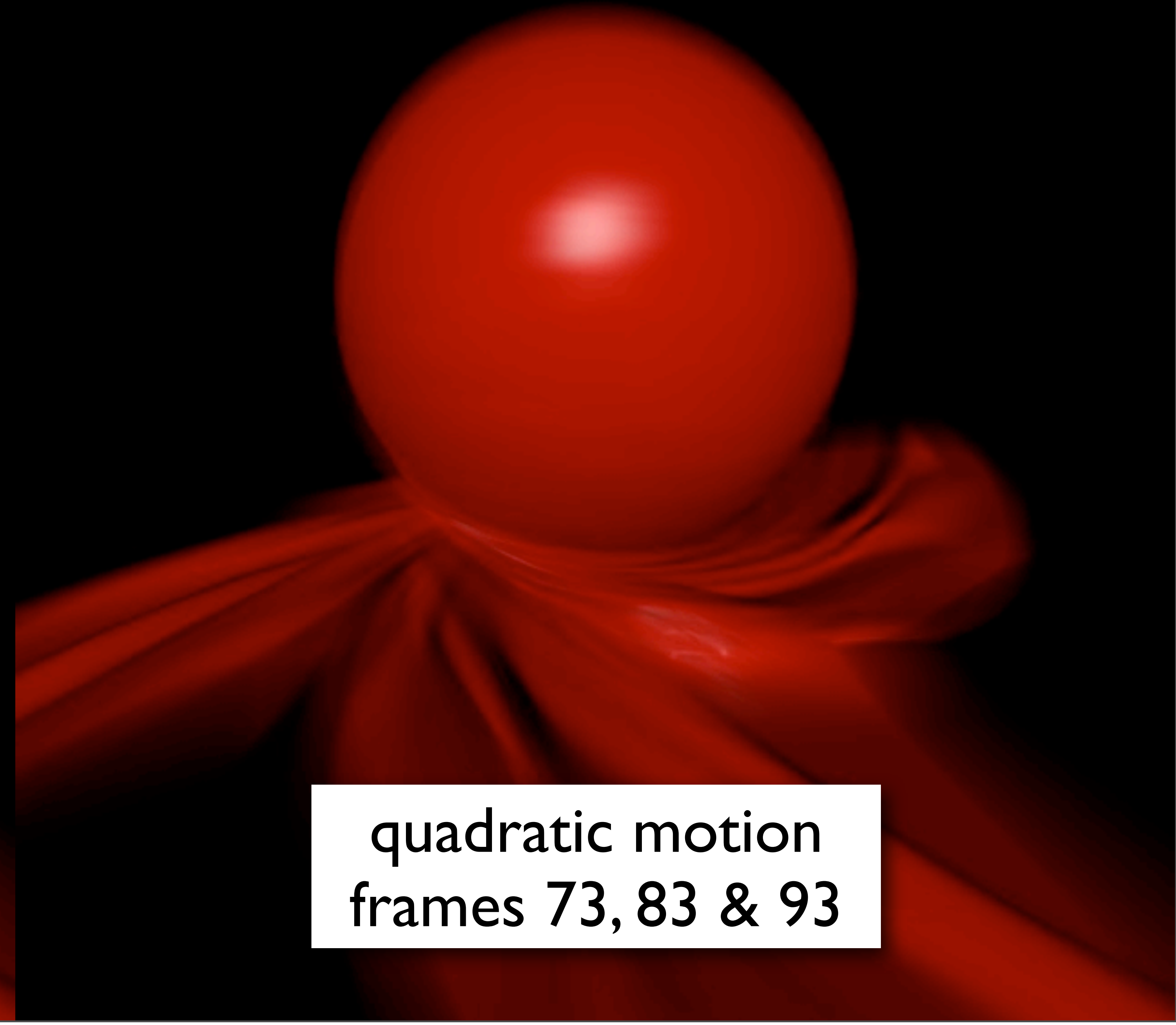


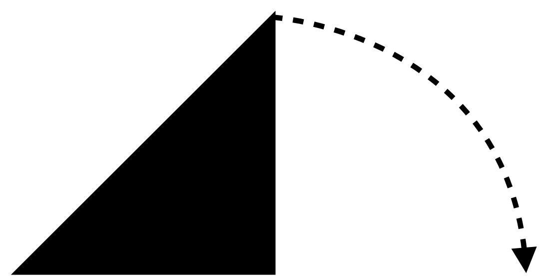
Linear vs curved motion

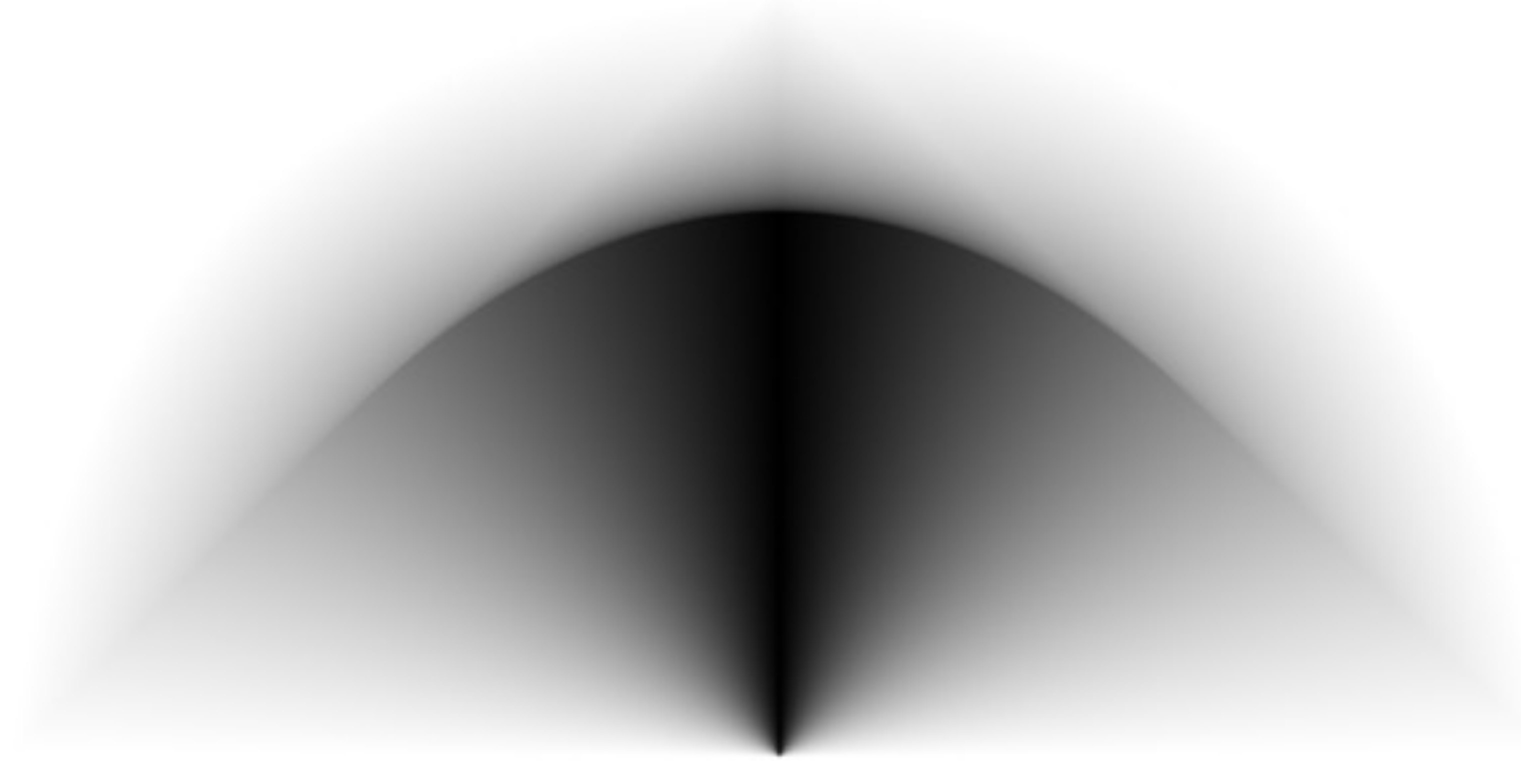


Linear vs curved motion

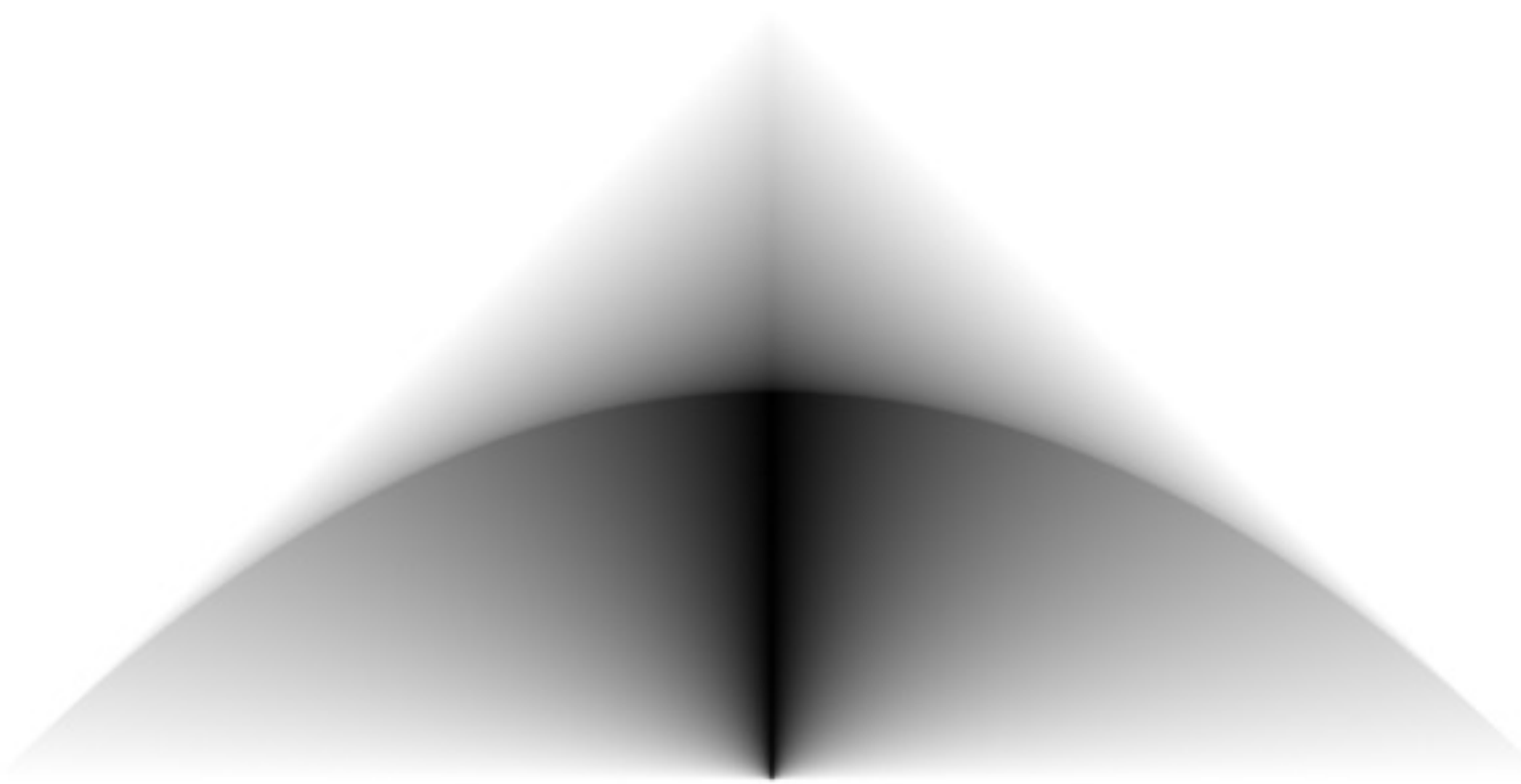




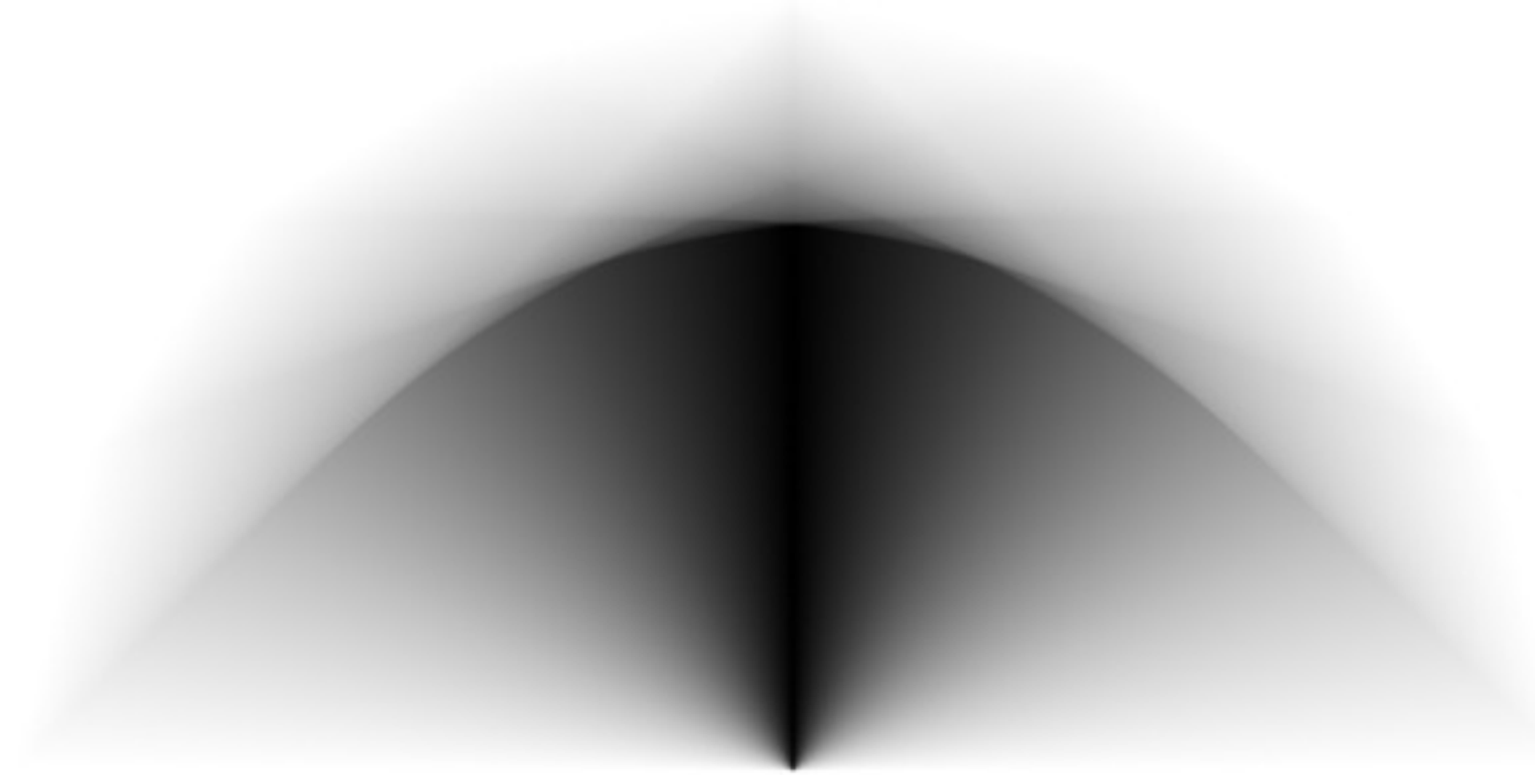




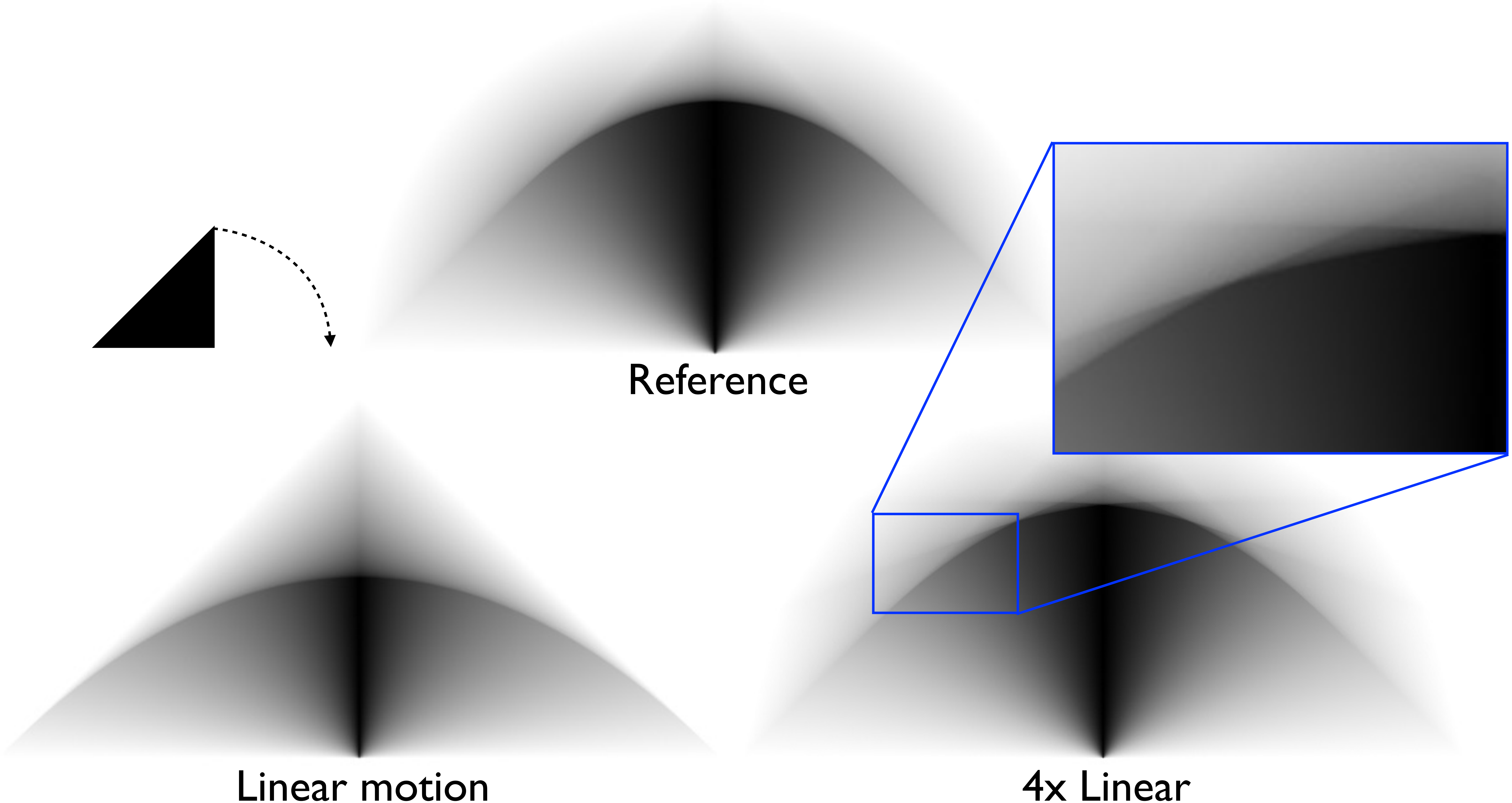
Reference



Linear motion



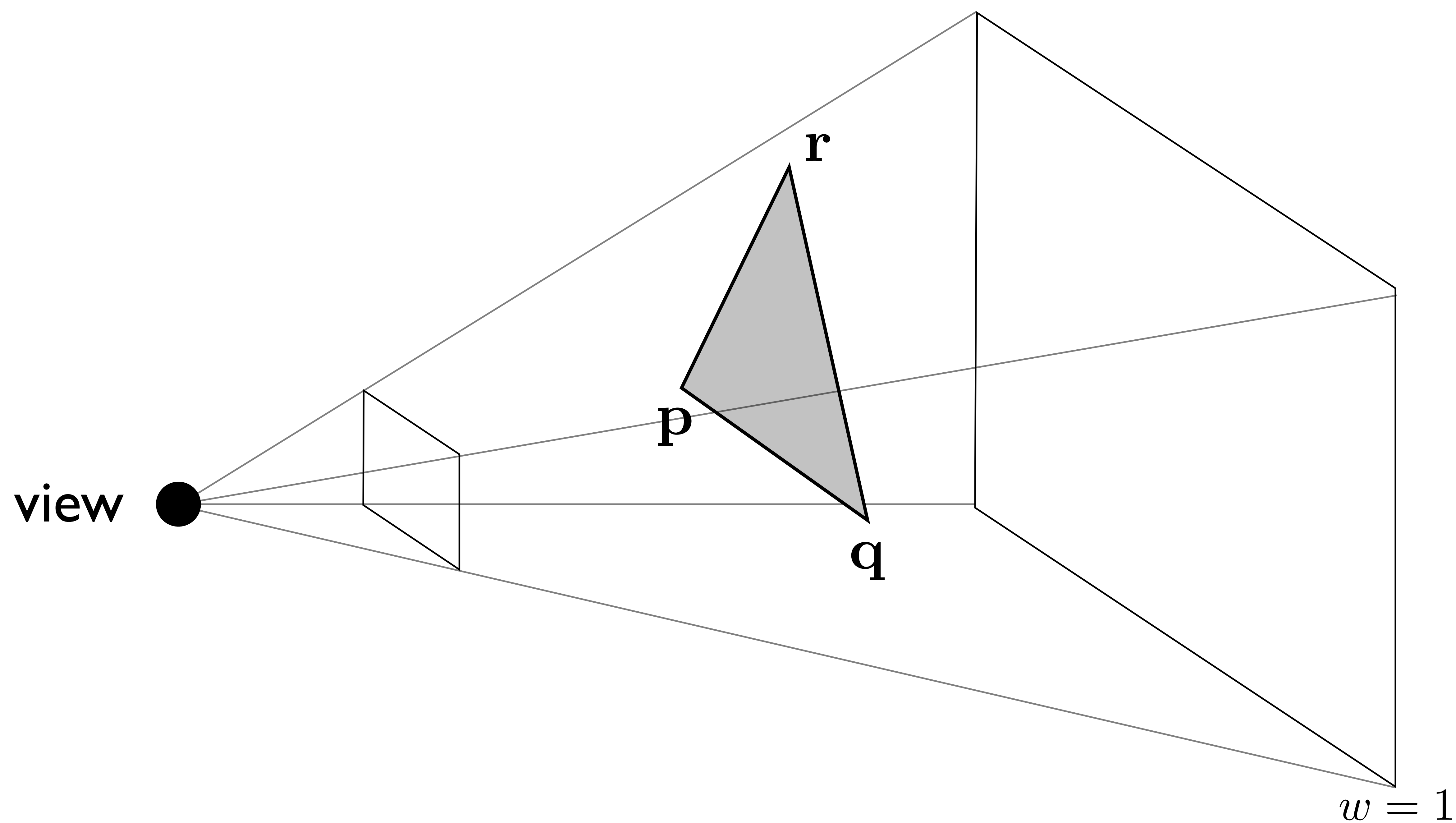
4x Linear


Reference
Linear motion
4x Linear

Overview

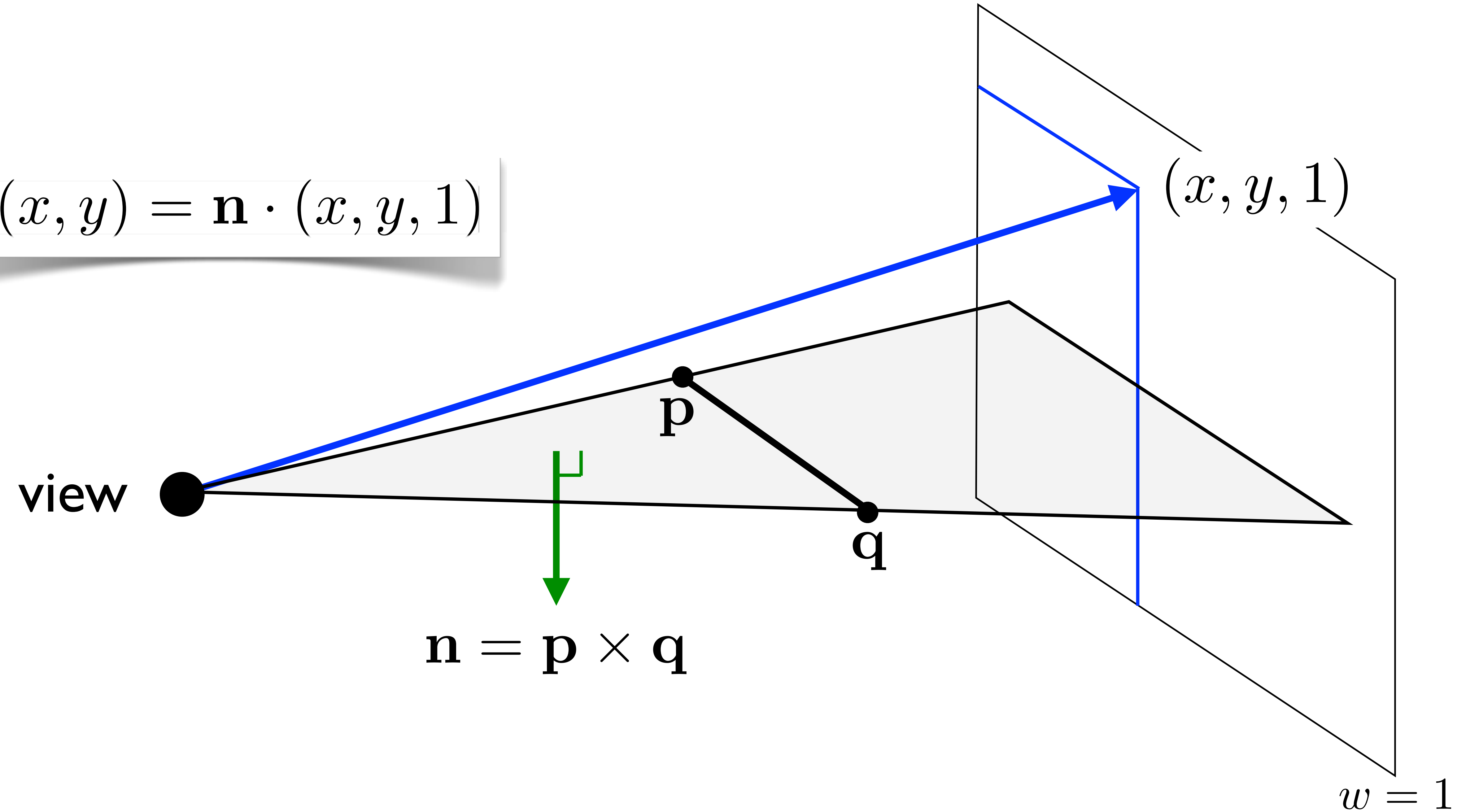
- Generalized edge equations for higher-order motion
  - Efficient traversal for higher-order motion
    - Use-case: semi-analytical rasterizer

Edge Equations: static triangle

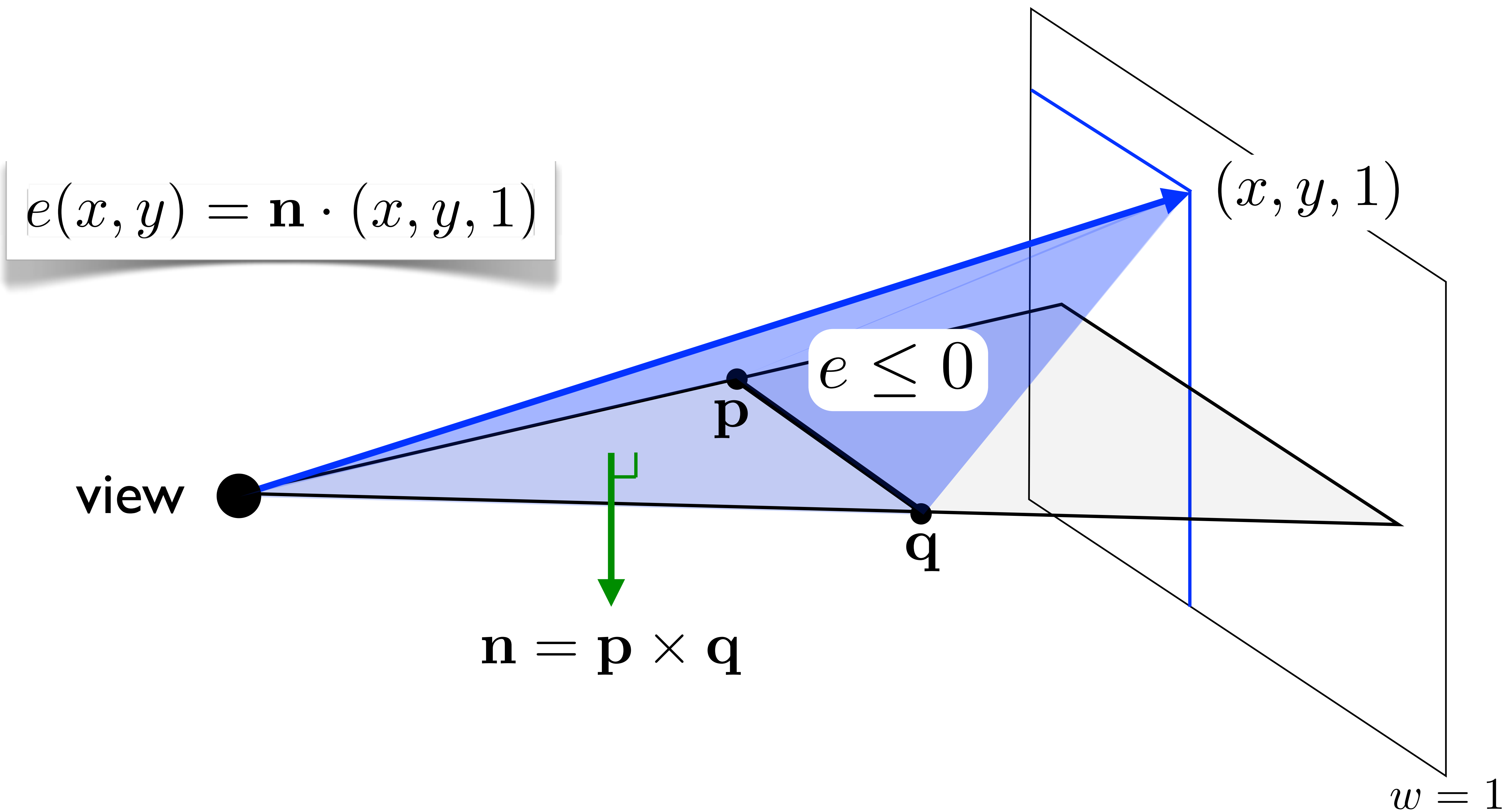


Edge Equations: static triangle

$$e(x, y) = \mathbf{n} \cdot (x, y, 1)$$

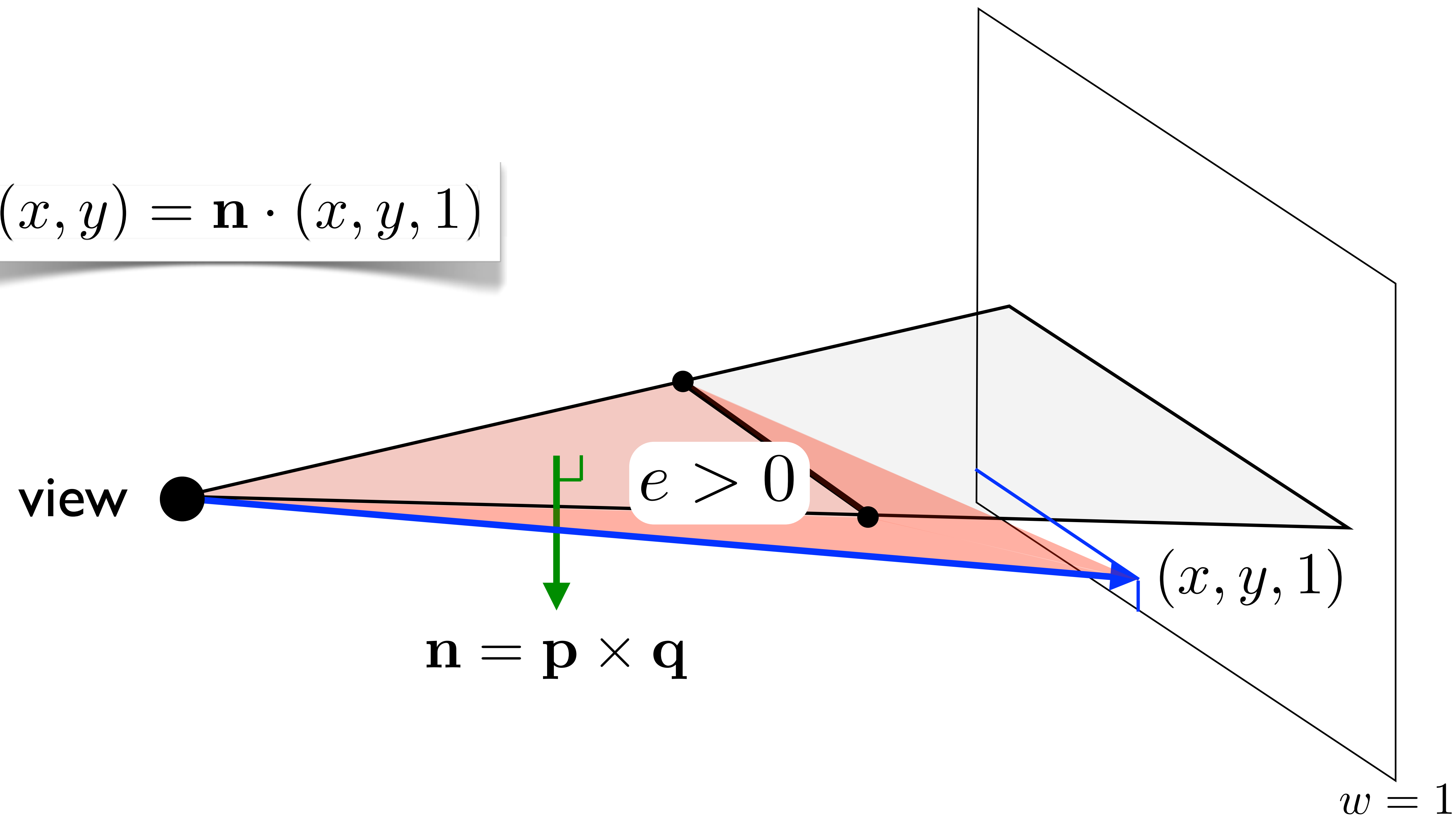


Edge Equations: static triangle



Edge Equations: static triangle

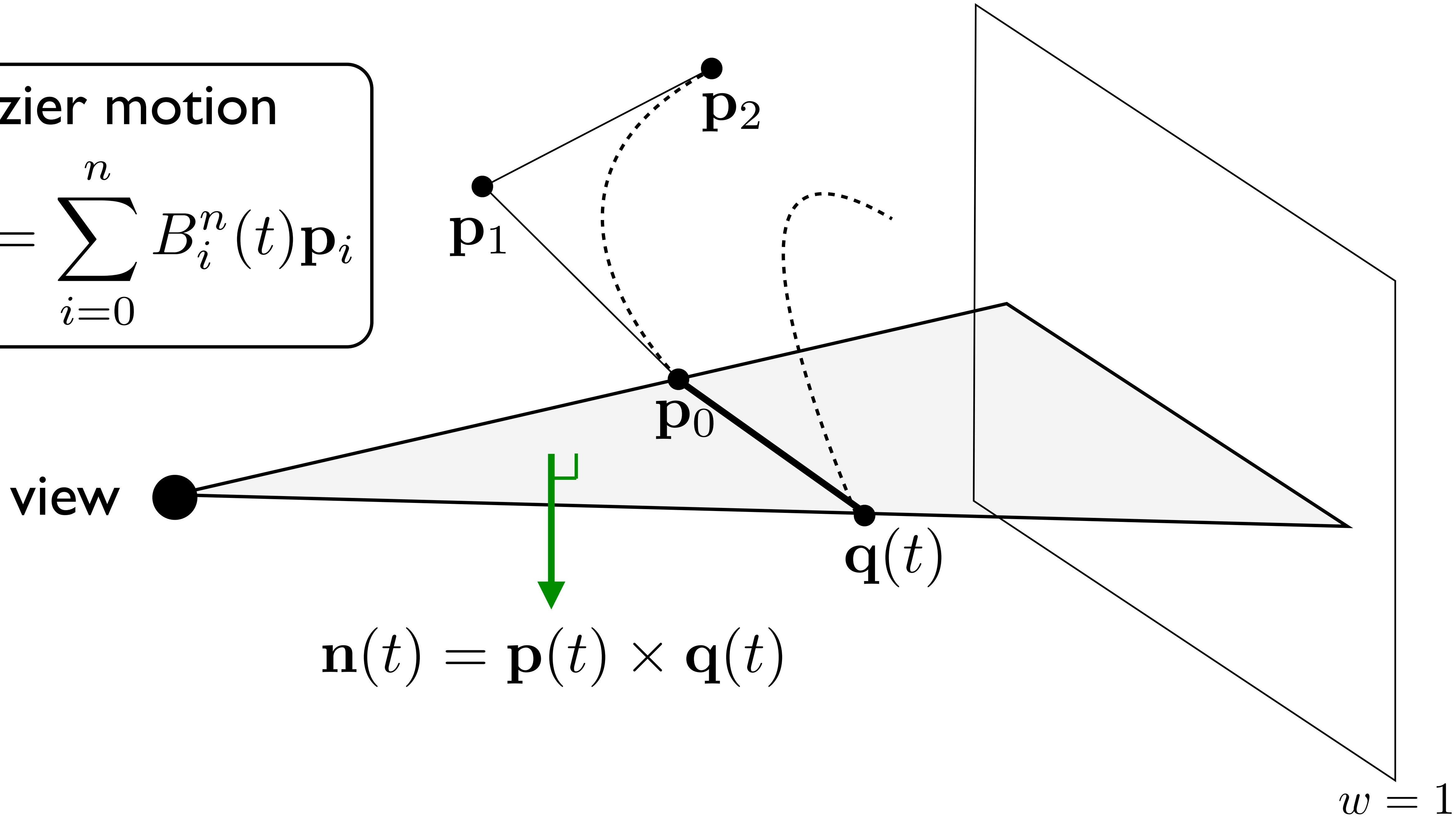
$$e(x, y) = \mathbf{n} \cdot (x, y, 1)$$



Edge Equations: moving triangle

Bézier motion

$$\mathbf{p}(t) = \sum_{i=0}^{n} B_i^n(t)\mathbf{p}_i$$



Farin 2002, Akenine-Möller et al. 2007

Generalized Edge Equation

$$e(x, y, t) = \sum_{k=0}^{2n} B_k^{2n}(t)\mathbf{c}_k$$

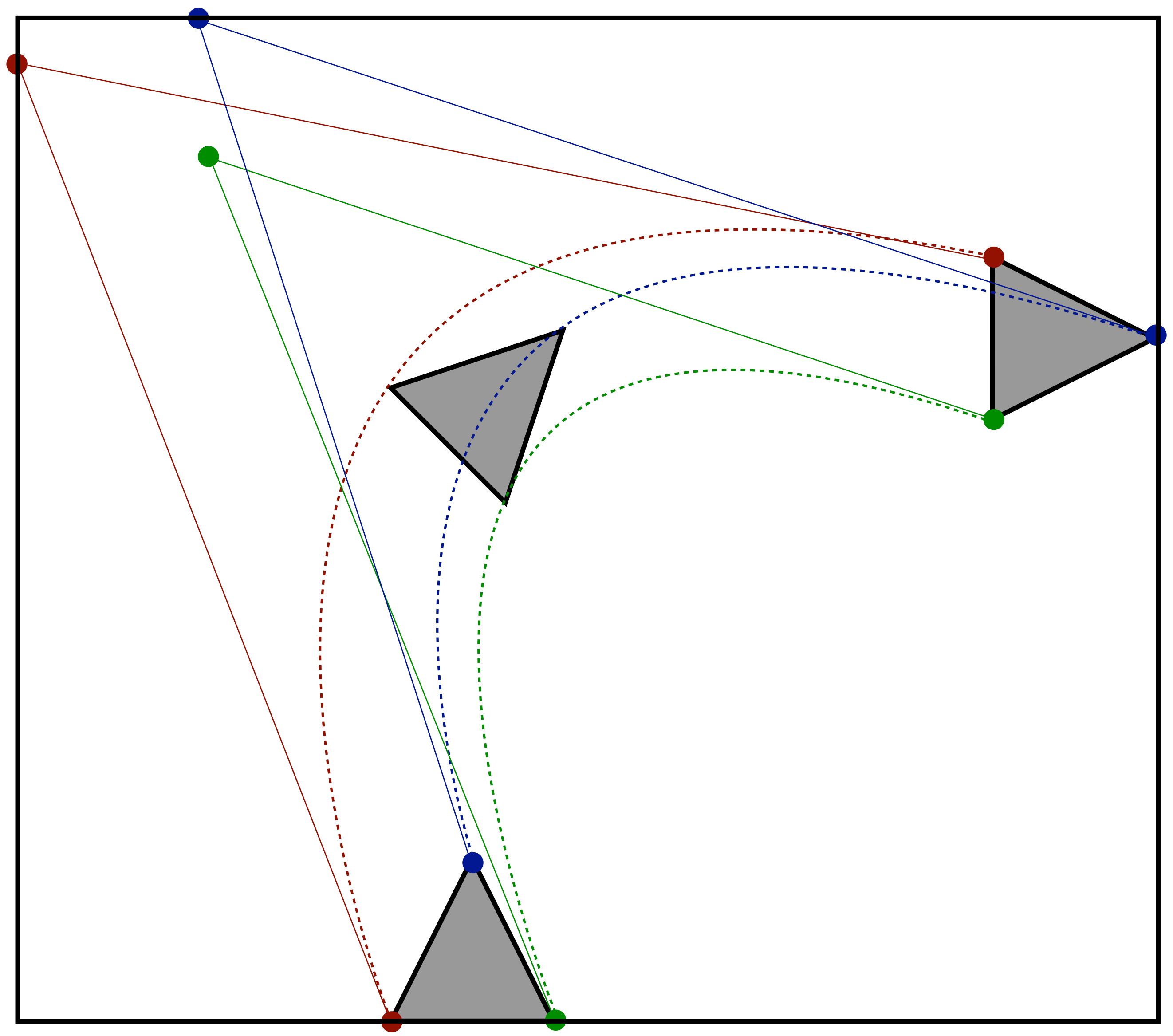
with control points:

$$\mathbf{c}_k = \Big(\sum_{i+j=k} \frac{\binom{n}{i}\binom{n}{j}}{\binom{2n}{i+j}} \mathbf{p}_i \times \mathbf{q}_j \Big) \cdot (x, y, 1)$$

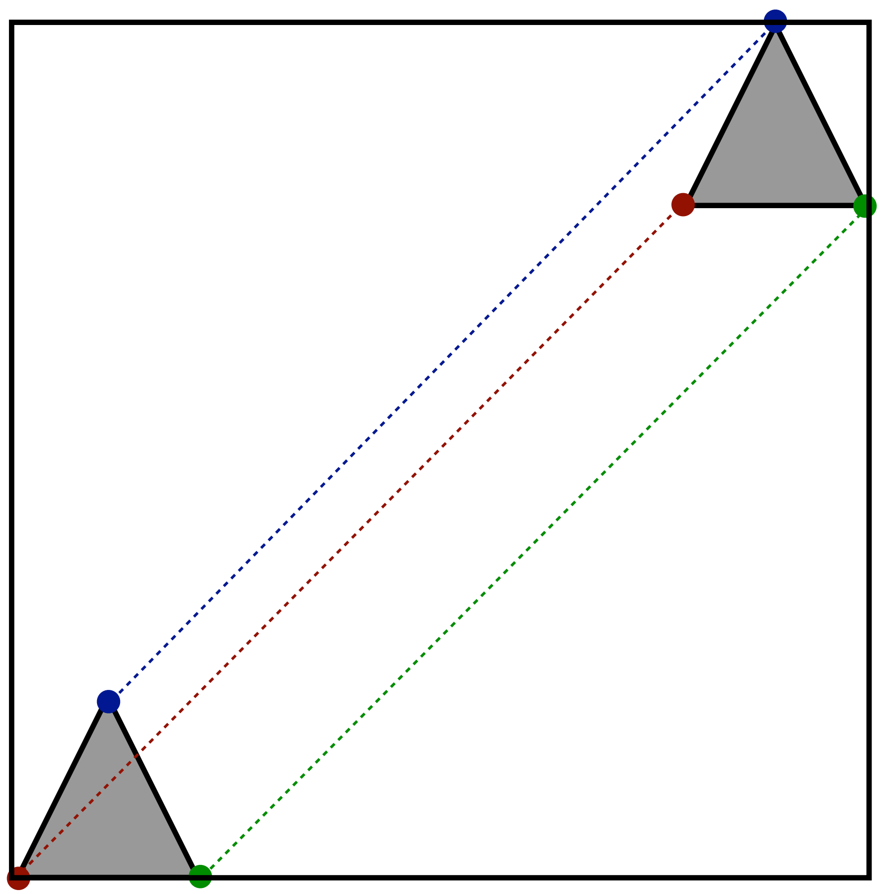
- Bernstein polynomial of order 2*n*
- 2*n*+1 scalar control points
- *n* = order of motion

Traversal

Quadratic motion



Linear motion



Laine et al. 2011
Munkberg et al. 2011
Fatahalian et al. 2009
INTERVAL: *Pixar*

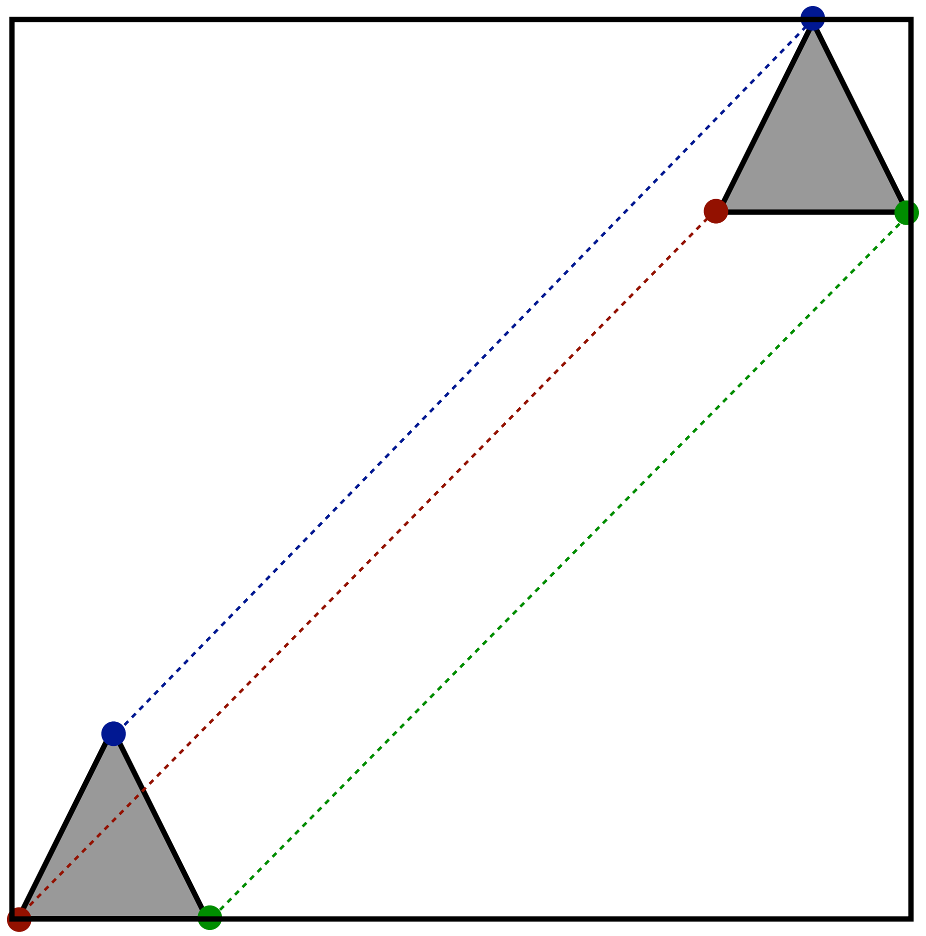
Traversal

- Generalized INTERVAL
- Tiled traversal: TILE
  - Triangle – Tile
  - Edge – Tile

Traversal: INTERVAL

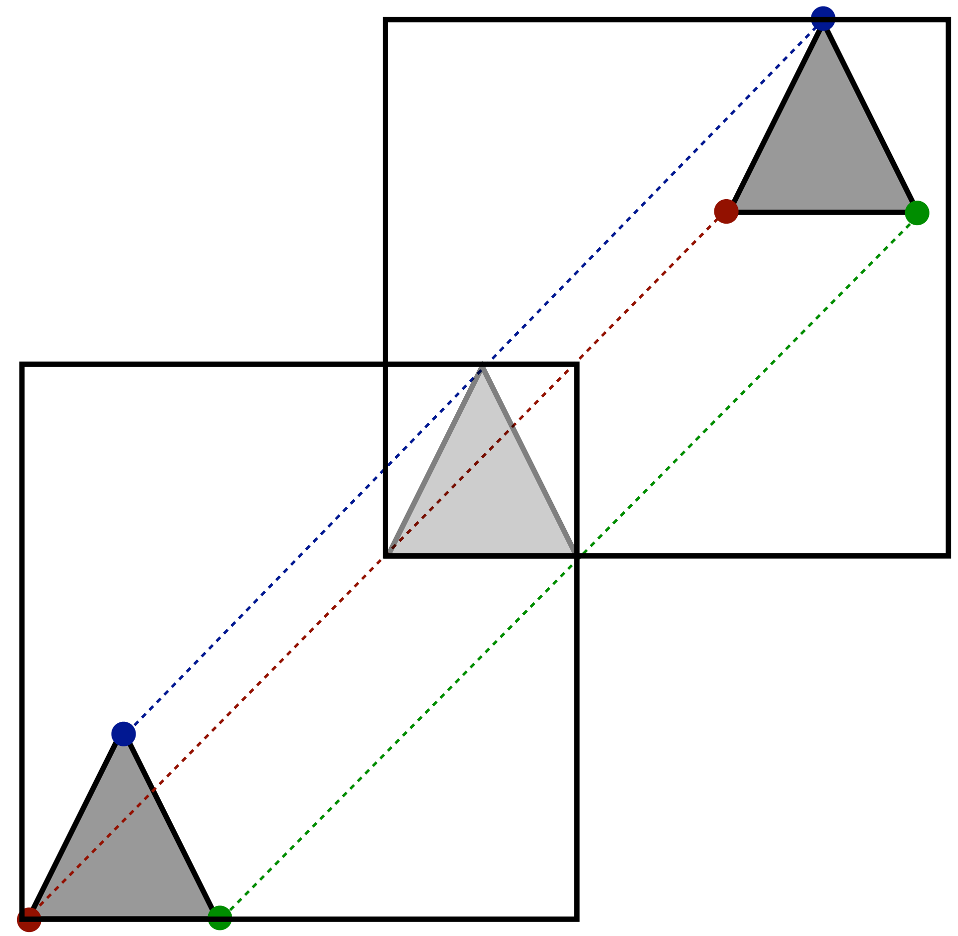
one interval

$[0, 1]$



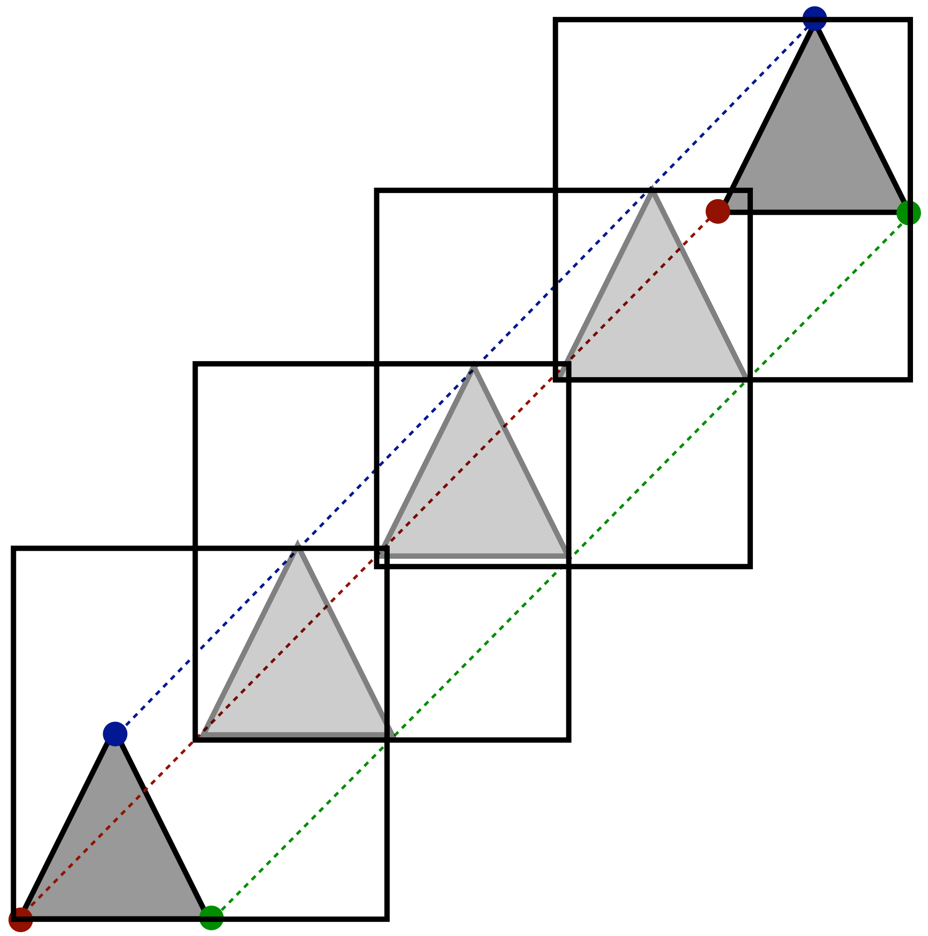
2 Intervals

$[0, 0.5],\ [0.5, 1]$



4 Intervals

$[0, 0.25],\ [0.25, 0.5],\ [0.5, 0.75],\ [0.75, 1]$



Traversal: generalized INTERVAL

one interval

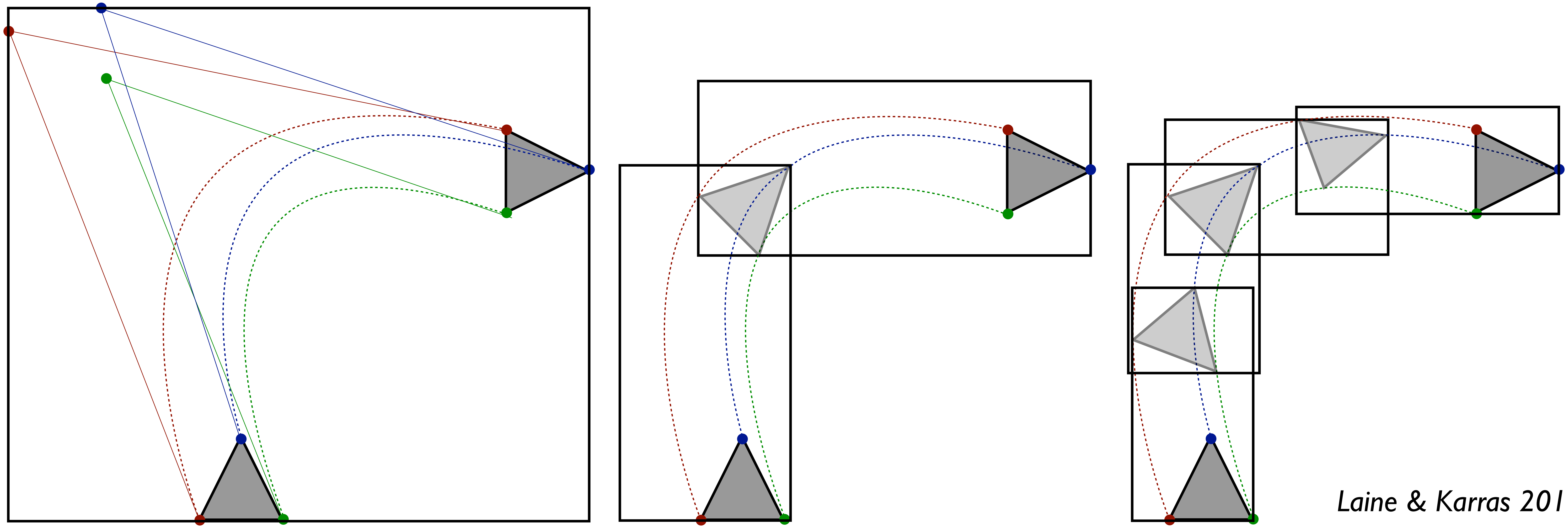
$[0, 1]$

2 intervals

$[0, 0.5],\ [0.5, 1]$

4 intervals

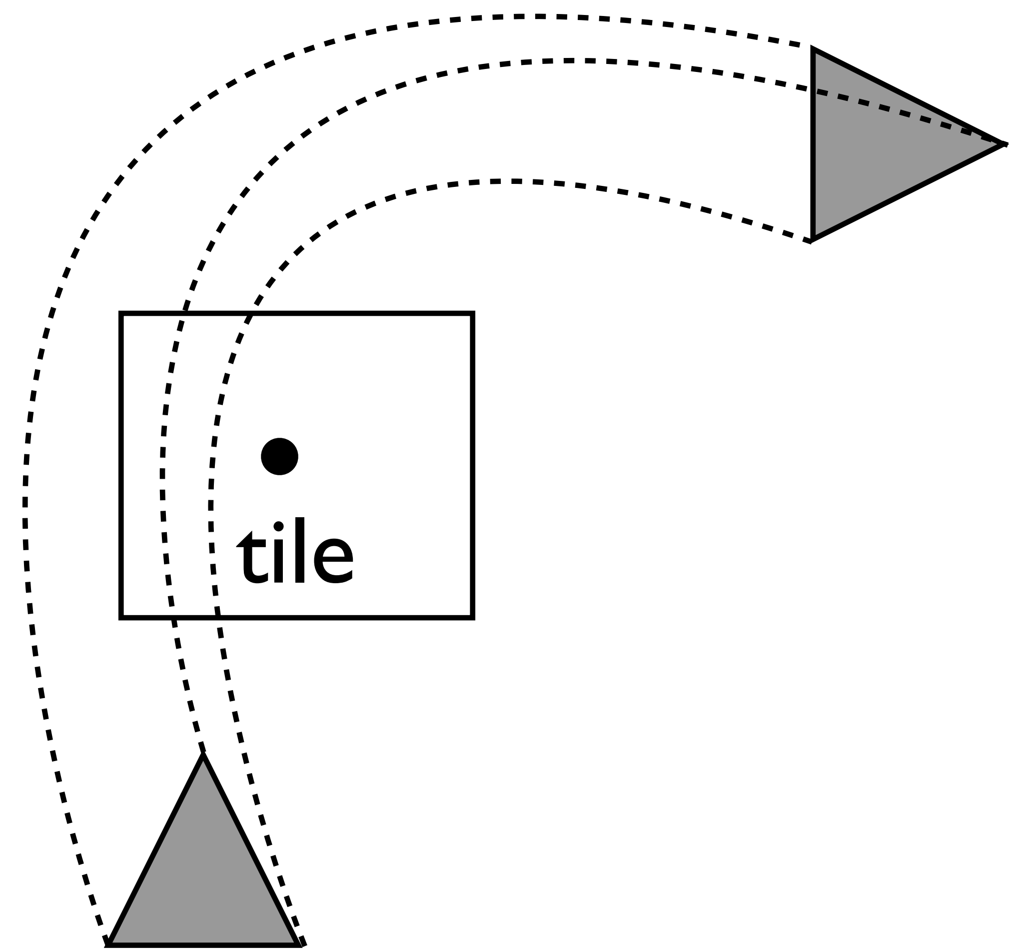
$[0, 0.25],\ [0.25, 0.5],\ [0.5, 0.75],\ [0.75, 1]$



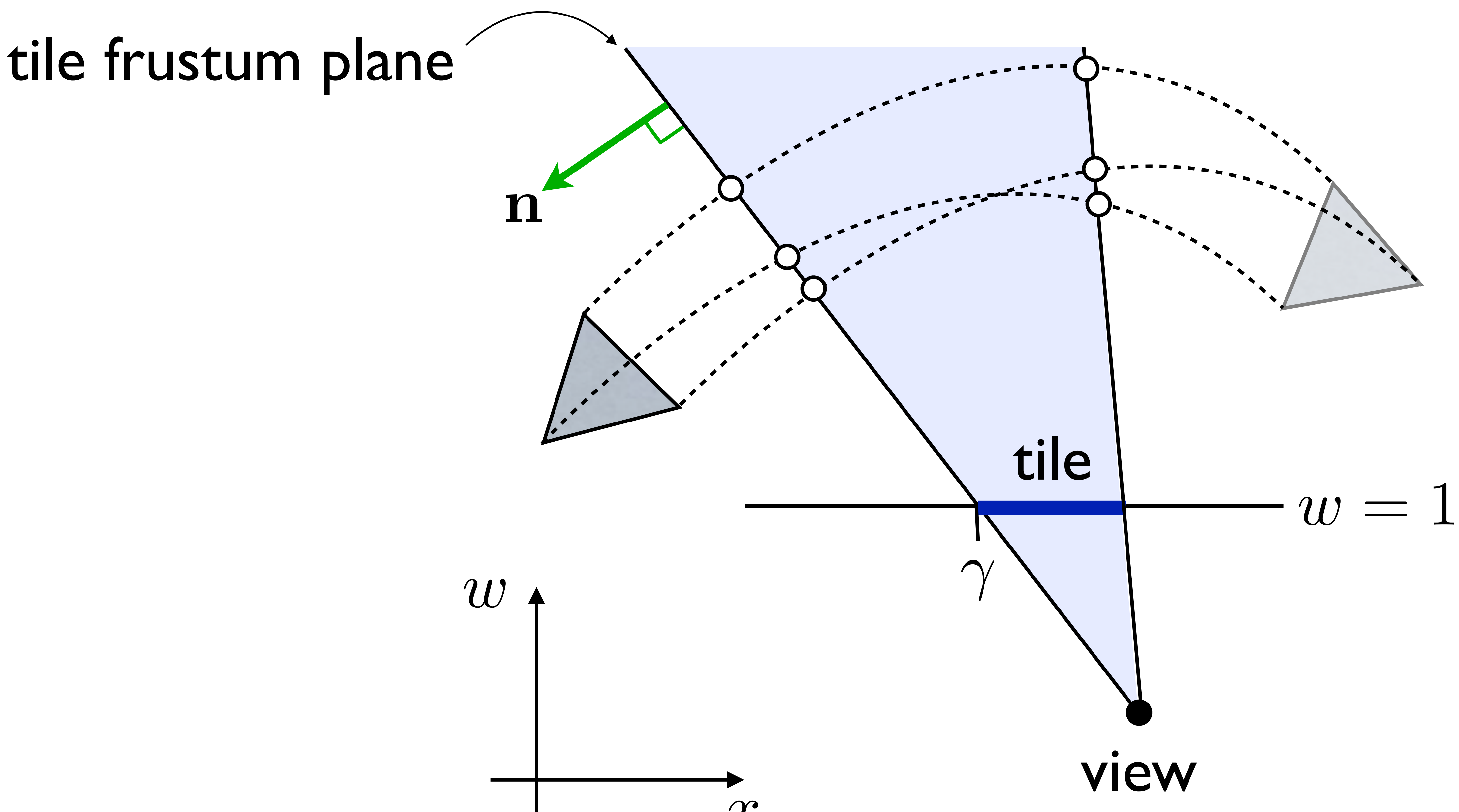
Laine & Karras 2011

TILE: tiled traversal

- Triangle – Tile
- Edge – Tile



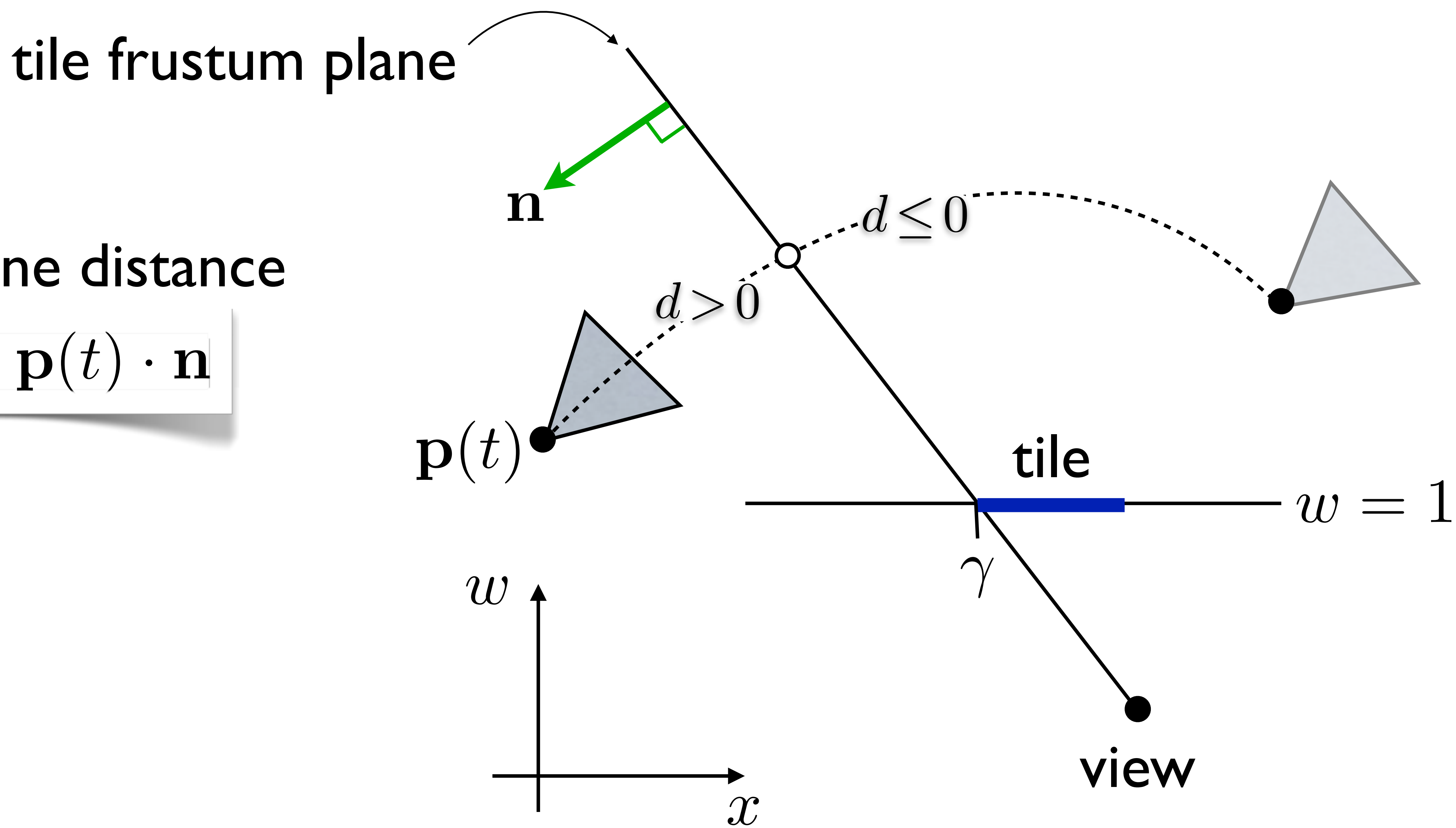
Triangle – Tile test



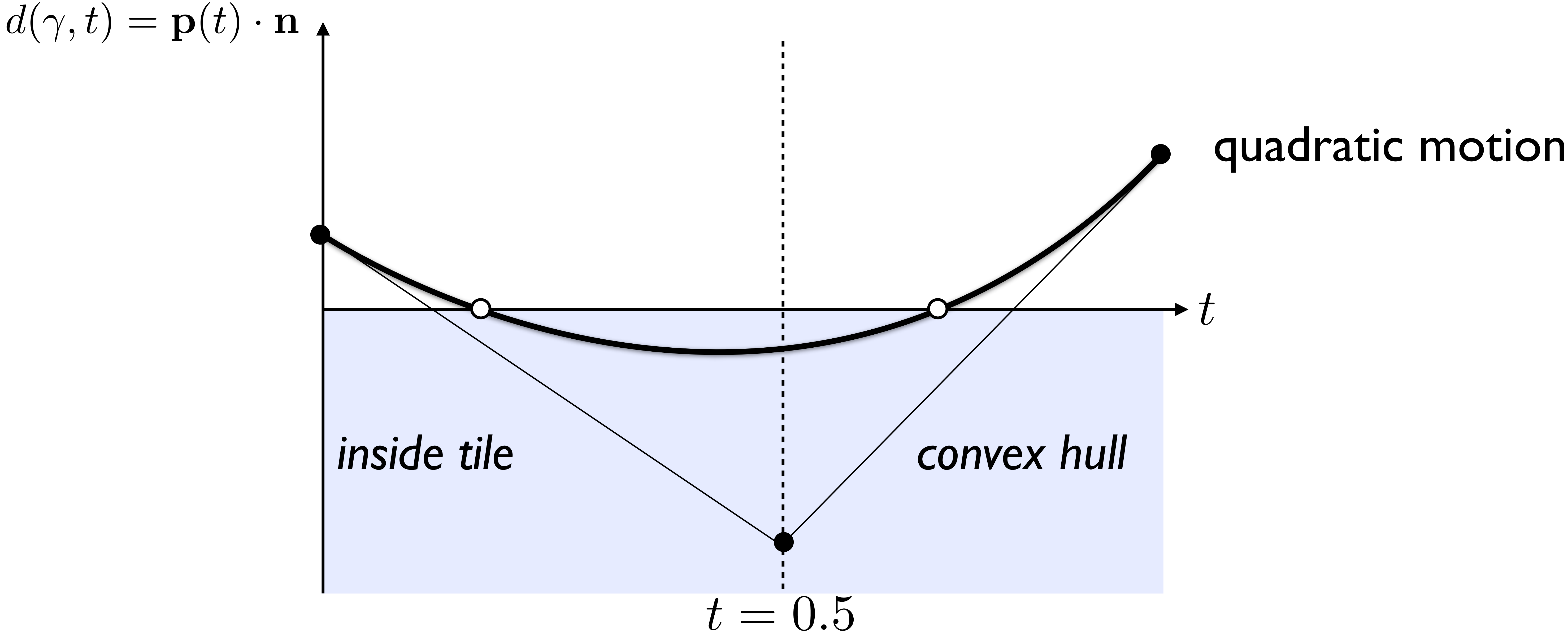
Triangle – Tile test

Vertex – plane distance

$$d(\gamma, t) = \mathbf{p}(t) \cdot \mathbf{n}$$



Vertex – Tile distance

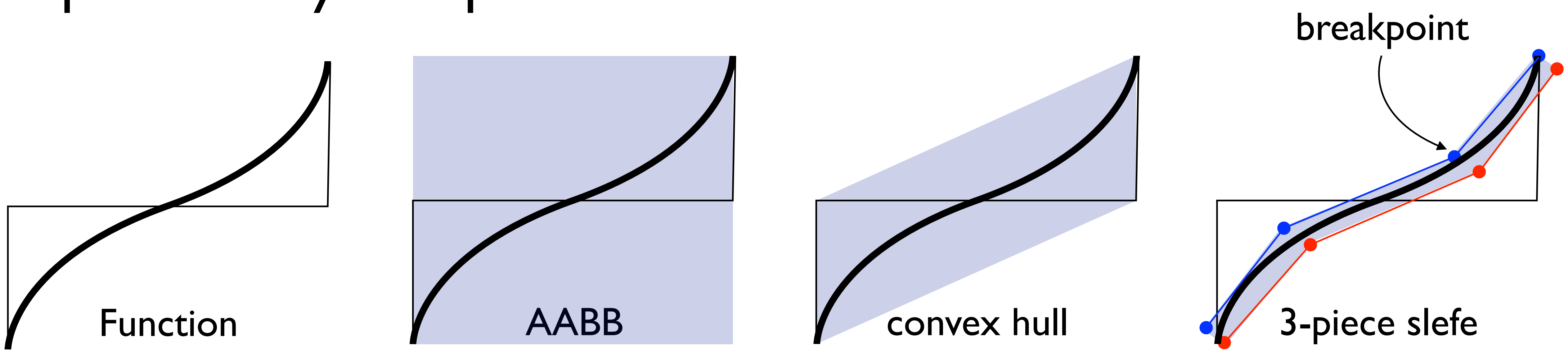


Slefes [Peters 2003]

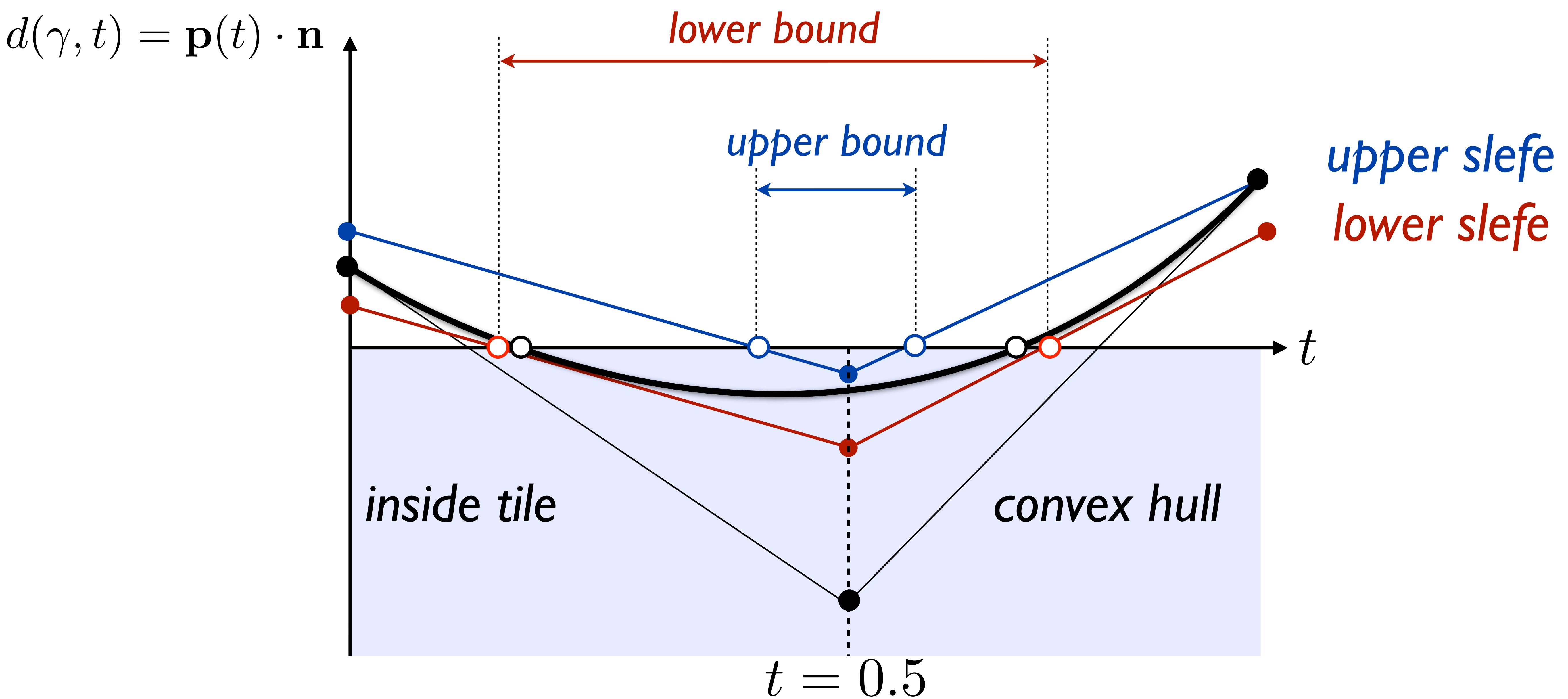
- *Subdividable Linear Efficient Function Enclosures*: Efficient bounding construct

- "Sandwiches" e.g. polynomials between upper & lower piecewise-linear bounds

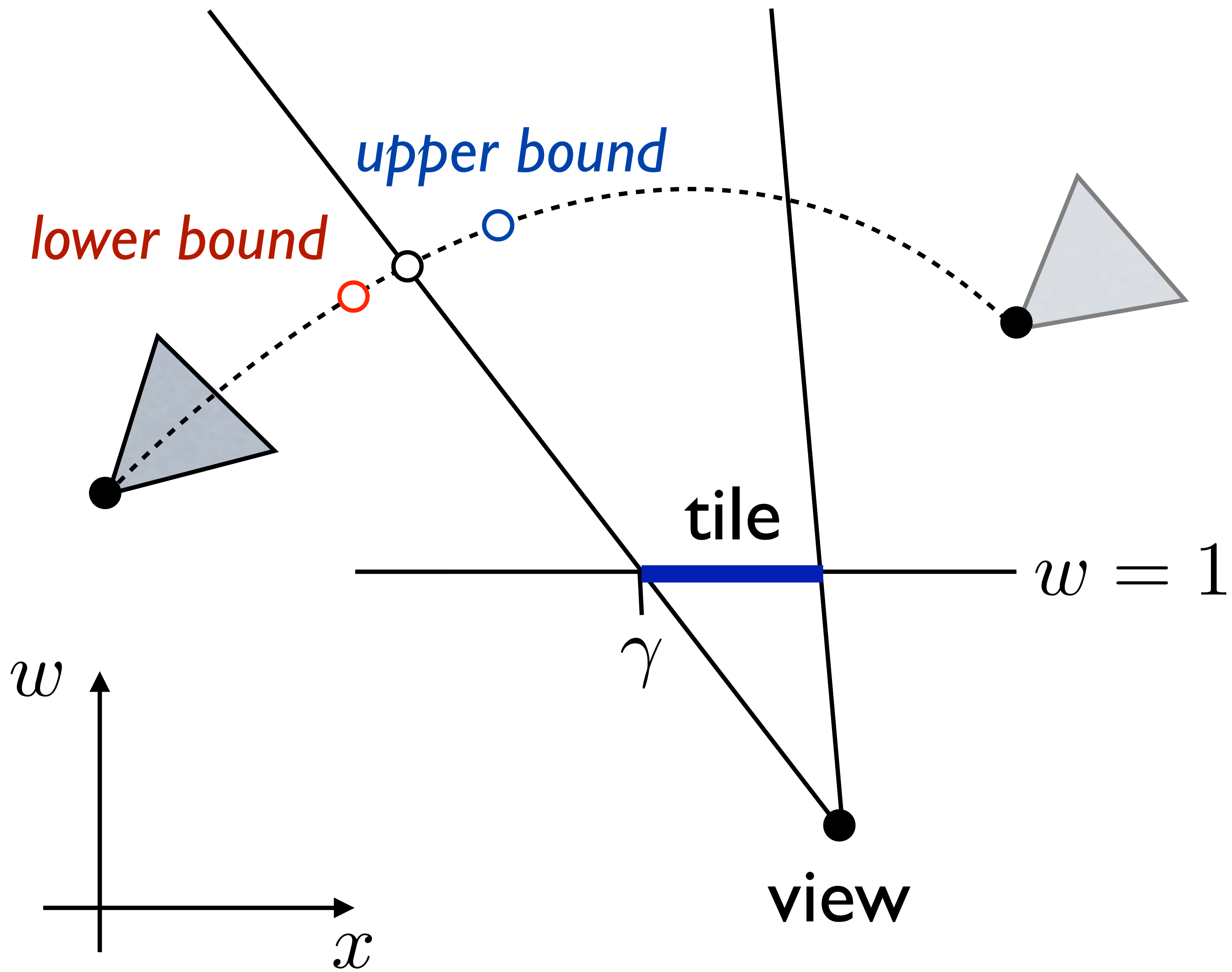
- Computationally cheap



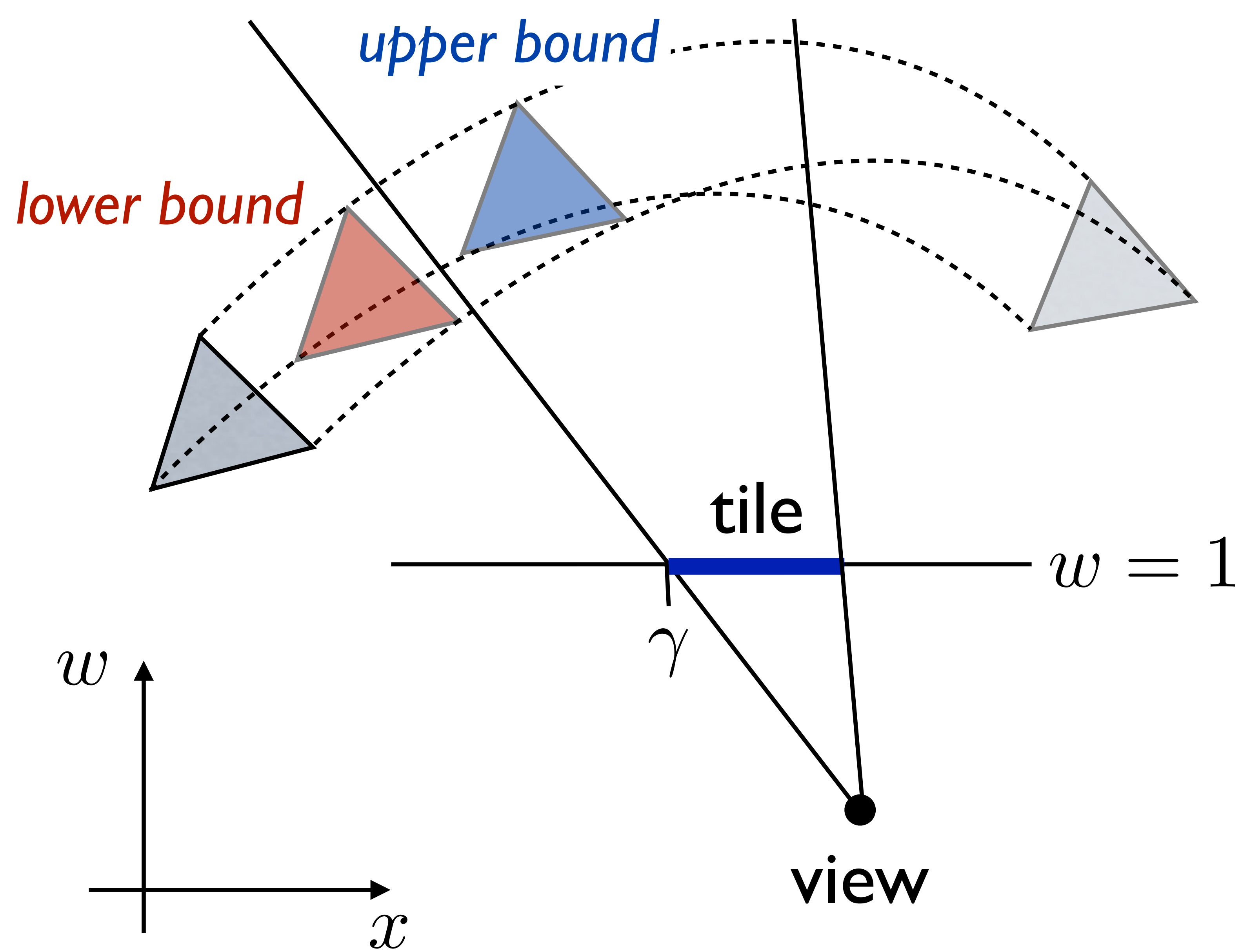
Vertex – Tile bounds



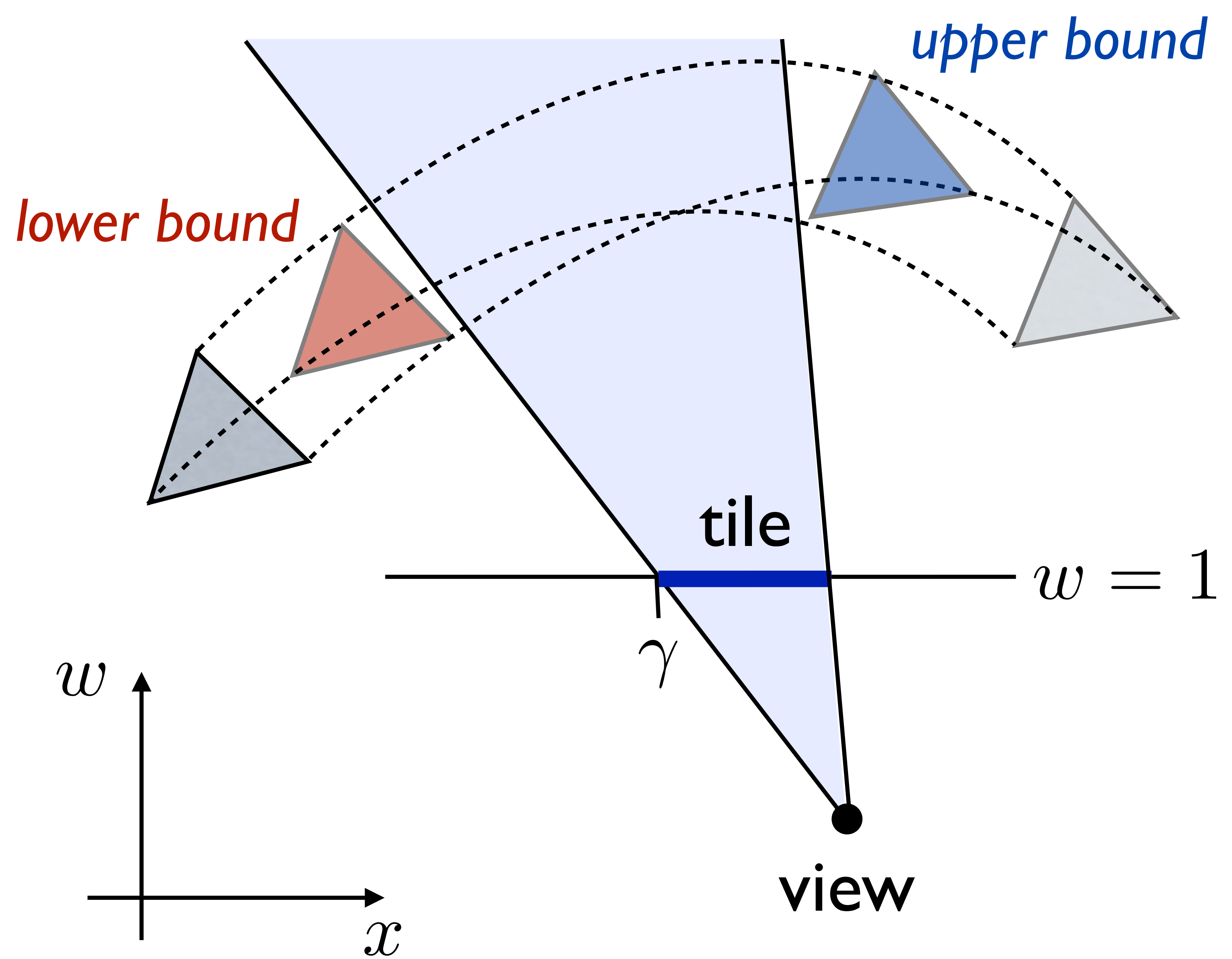
Triangle – Tile test



Triangle – Tile test



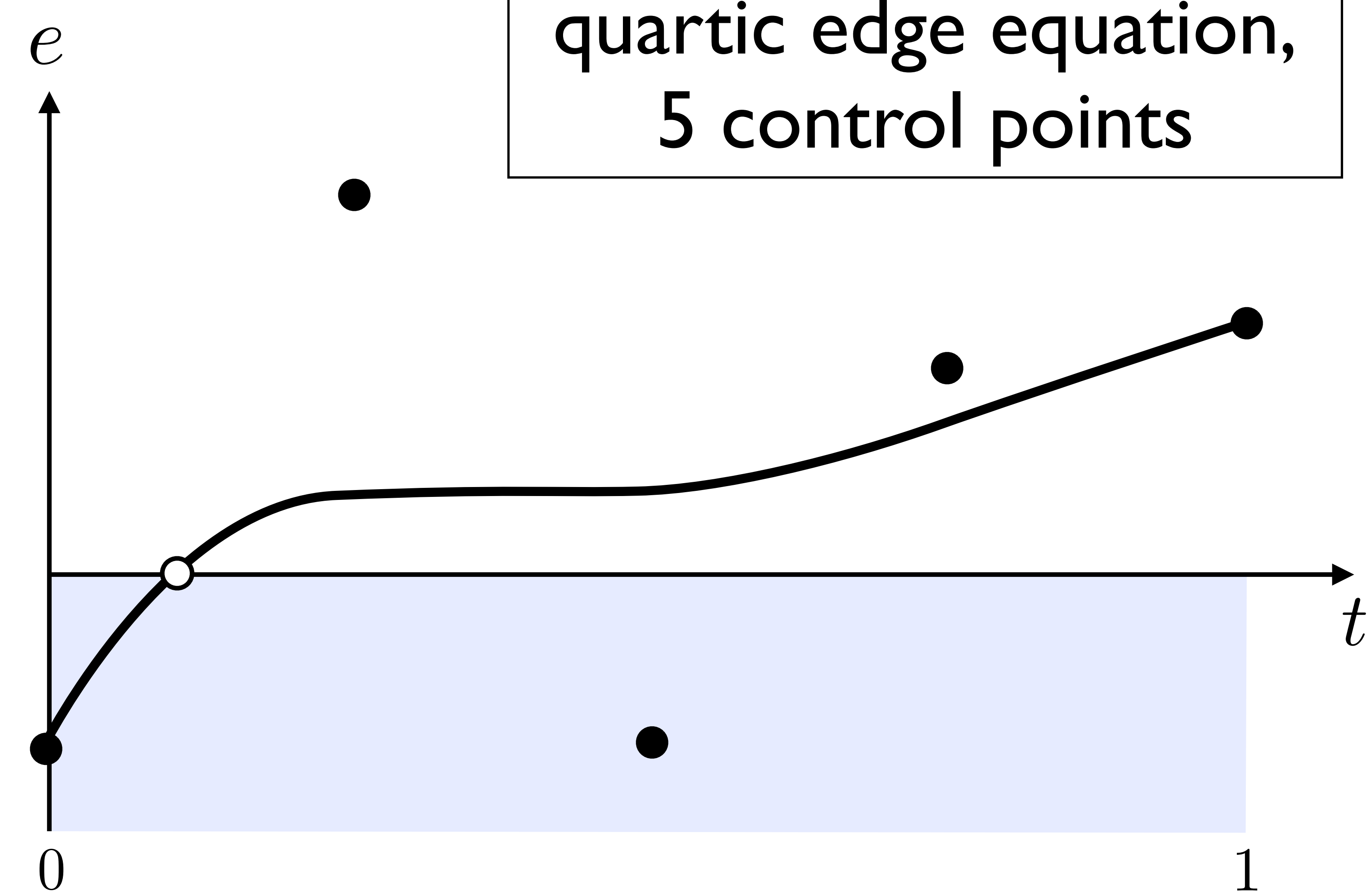
Triangle – Tile test



Edge – Tile test

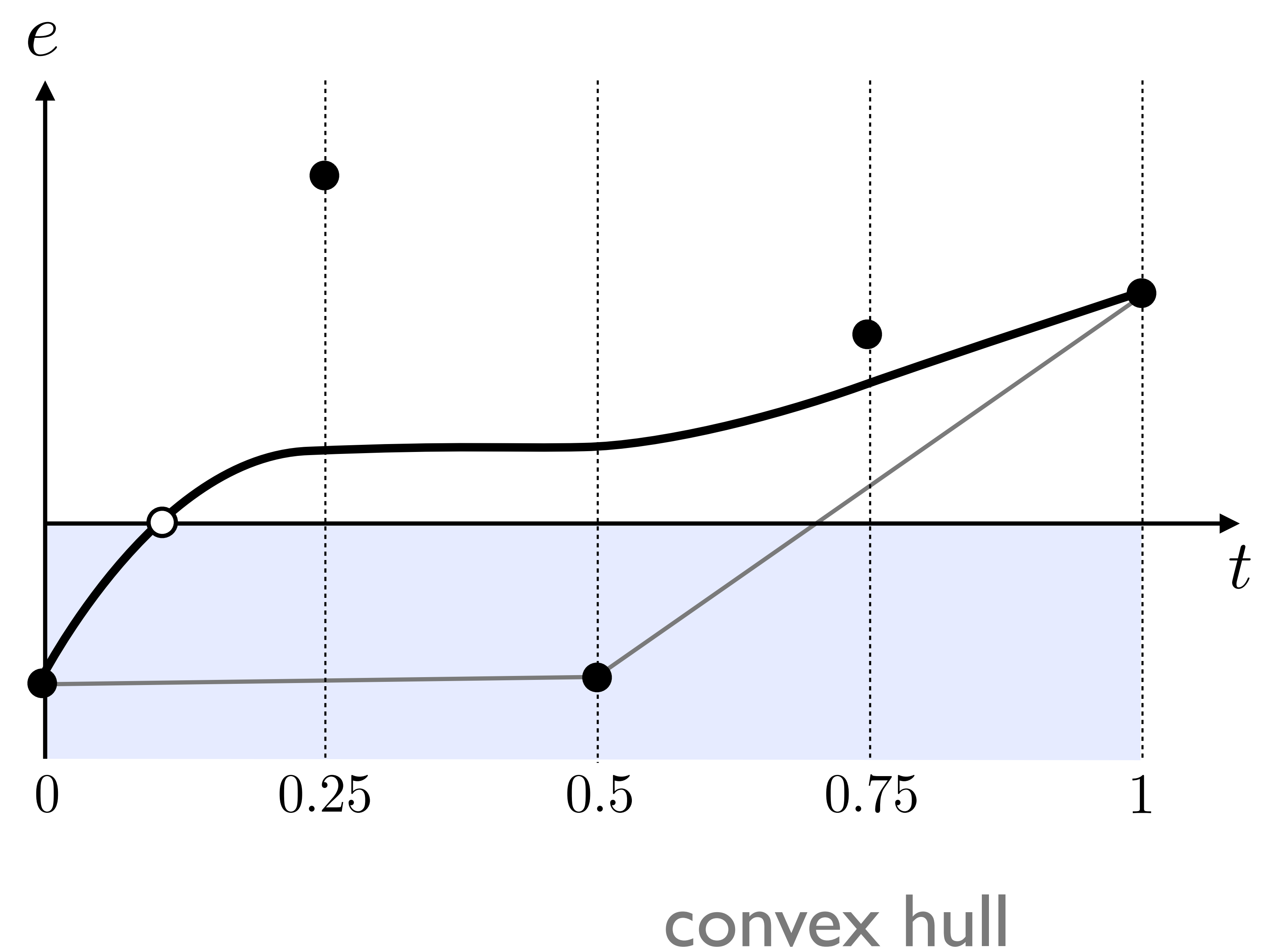
- Recall, edge equation: $e(x, y, t)$
  - Bernstein polynomial of order 2*n*
  - 2*n*+1 control points (as functions of edge vertices)
  - Pad control points with half the tile size
- Perform test once at center of tile

quadratic motion:
quartic edge equation,
5 control points



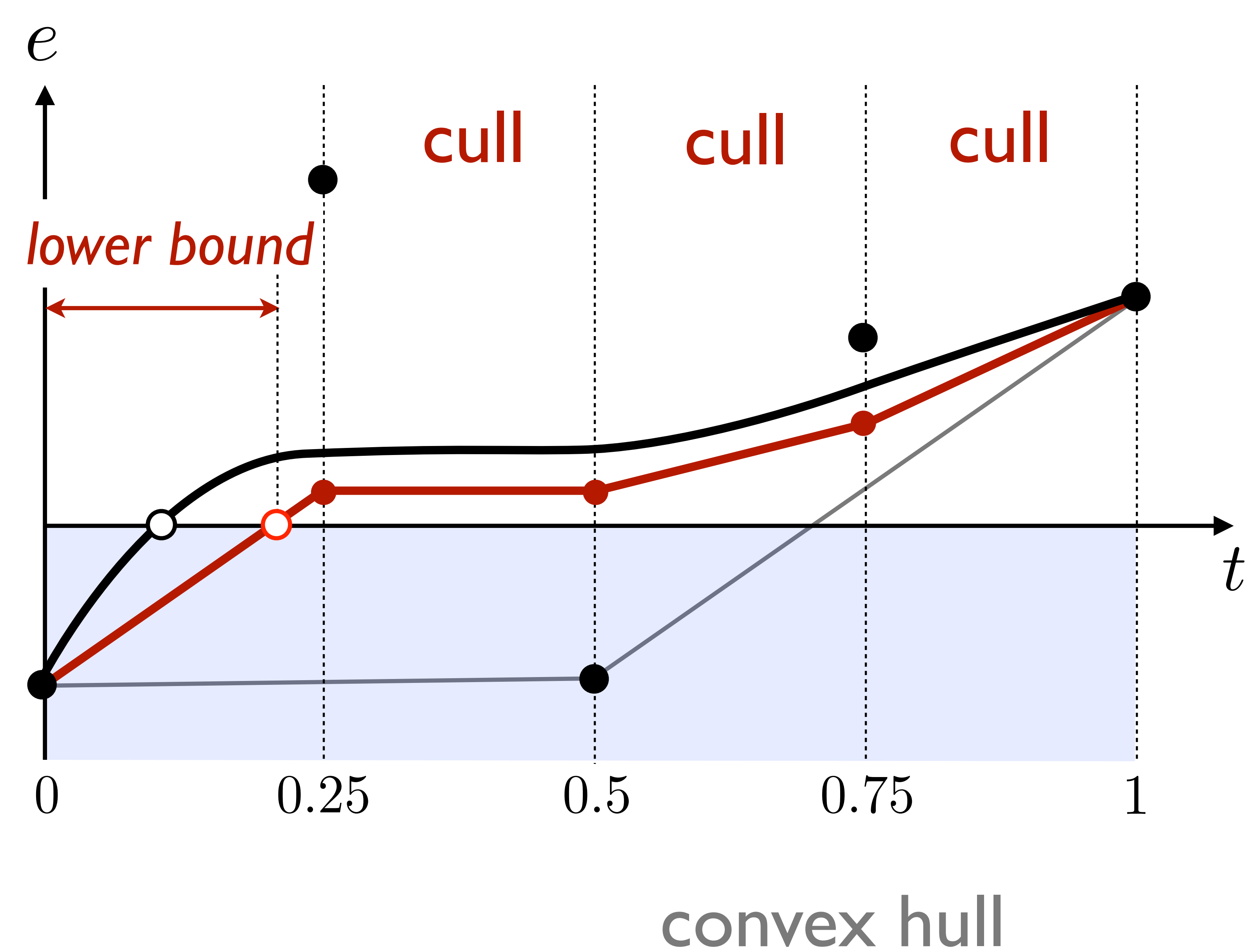
Edge – Tile test

- Cull tile if all control points are > 0



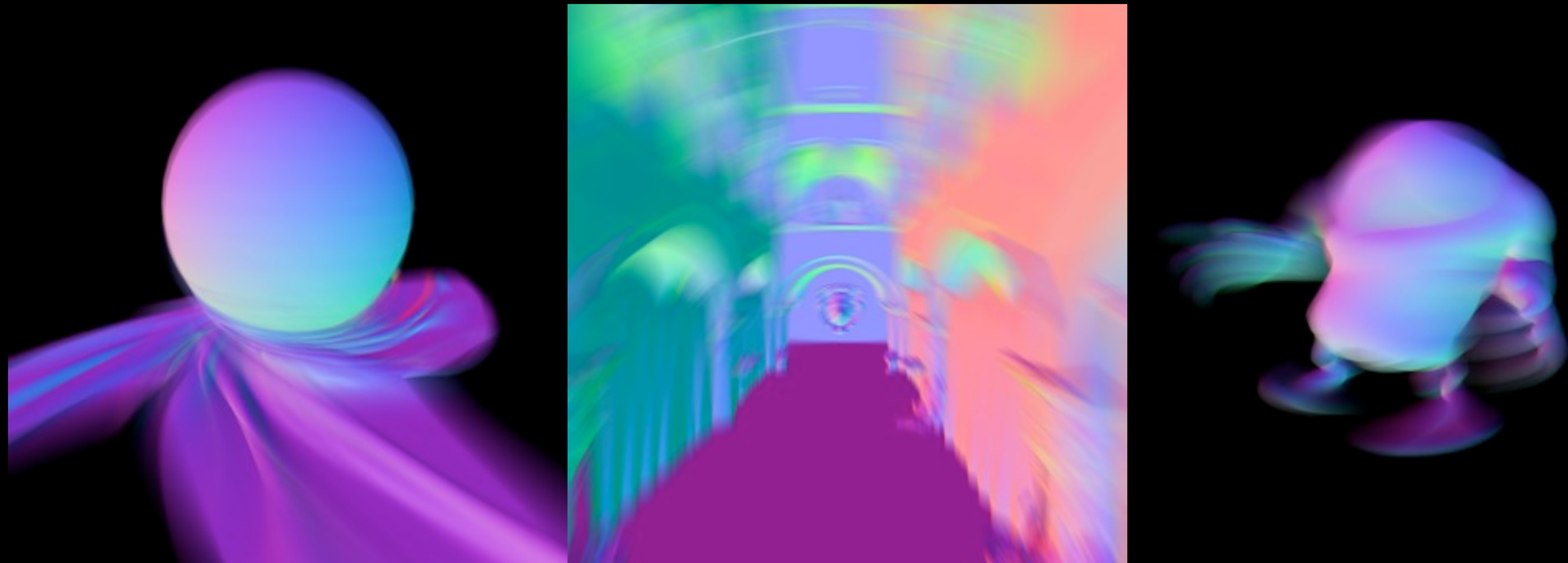
Edge – Tile test

- Cull tile if all control points are > 0
- Cull tile if all slefe breakpoints are > 0
- If two consecutive breakpoints are > 0: cull this timespan
  - Otherwise: intersect line segment with *t*-axis for conservative bound



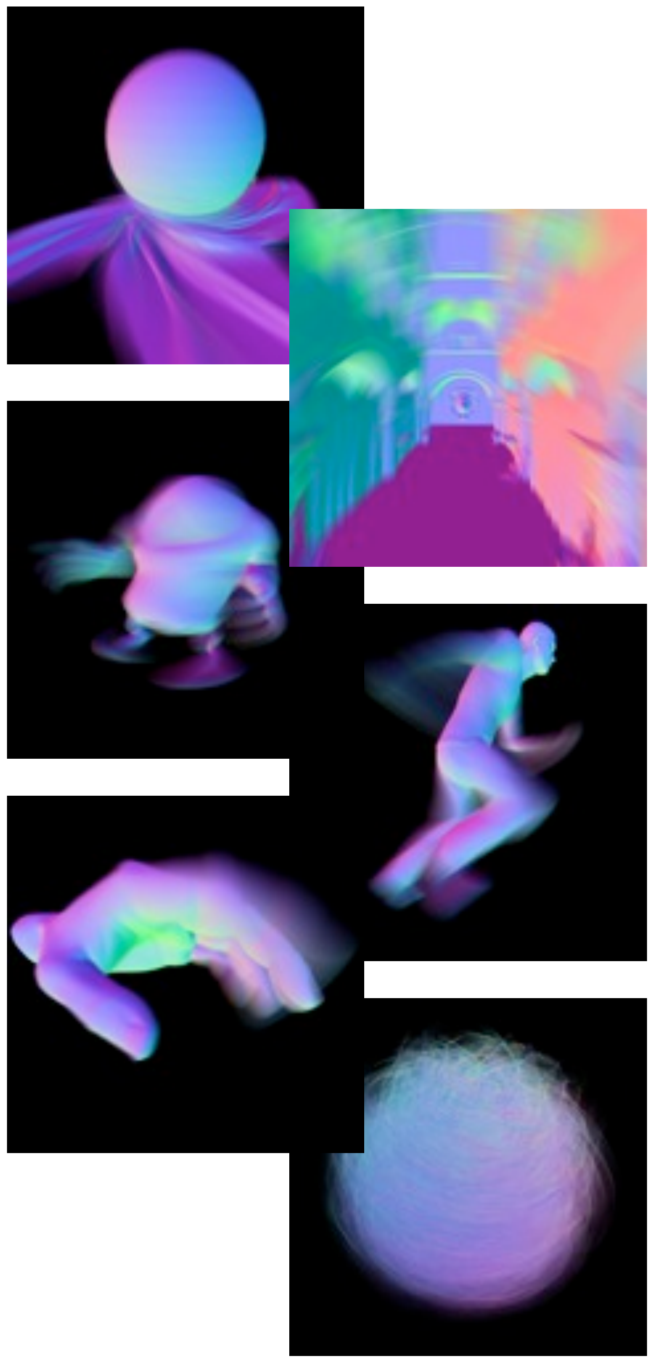
64 spp

– *STE*
– *Rendering time*



Traversal: Sample test efficiency (STE)

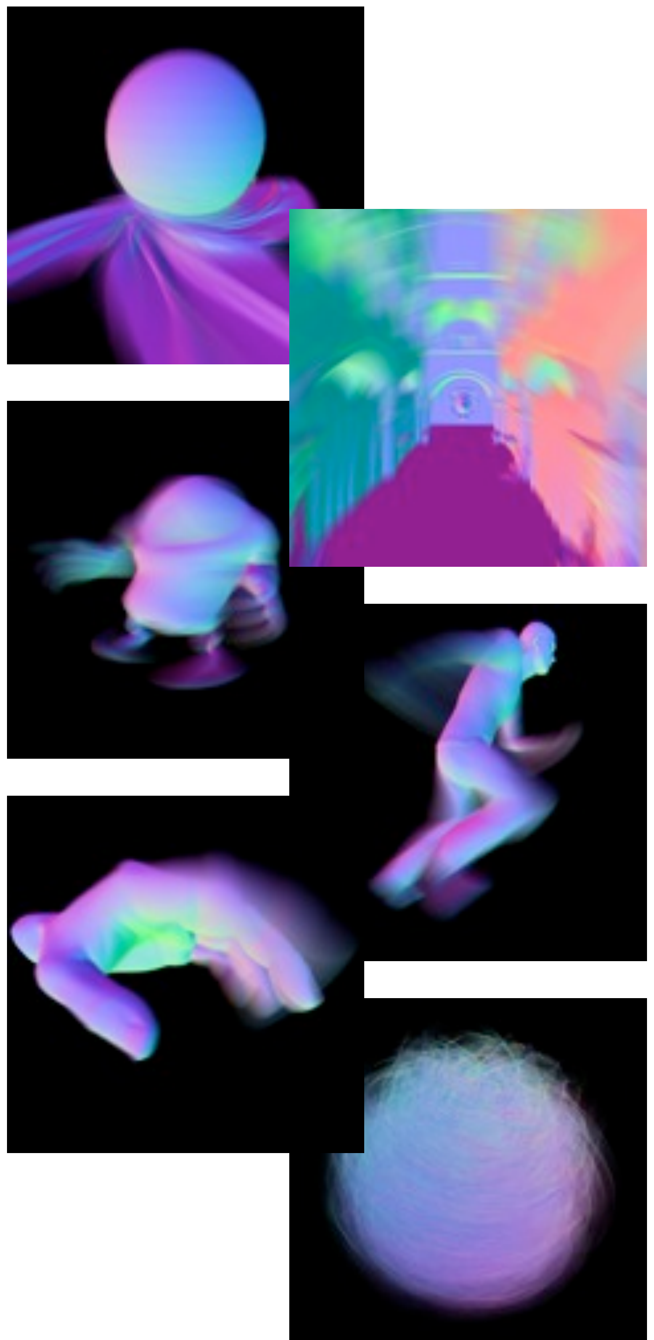
higher is better



Scene	TILE: Tile size 4 × 4	TILE: Tile size 2 × 2	TILE: Tile size 1 × 1	INTERVAL: Num intervals 4	INTERVAL: Num intervals 16	INTERVAL: Num intervals 64
CLOTHBALL	11	18	**24**	1.2	6.4	15
SPONZA	47	65	**79**	10	18	21
BIGGUY	17	27	**36**	3.1	11	18
BEN	12	21	**34**	0.68	5.2	14
HAND	30	46	**62**	7.8	19	24
HAIRBALL	3.5	7.5	**14**	0.75	2.8	4.8

Traversal: Relative performance

lower is better

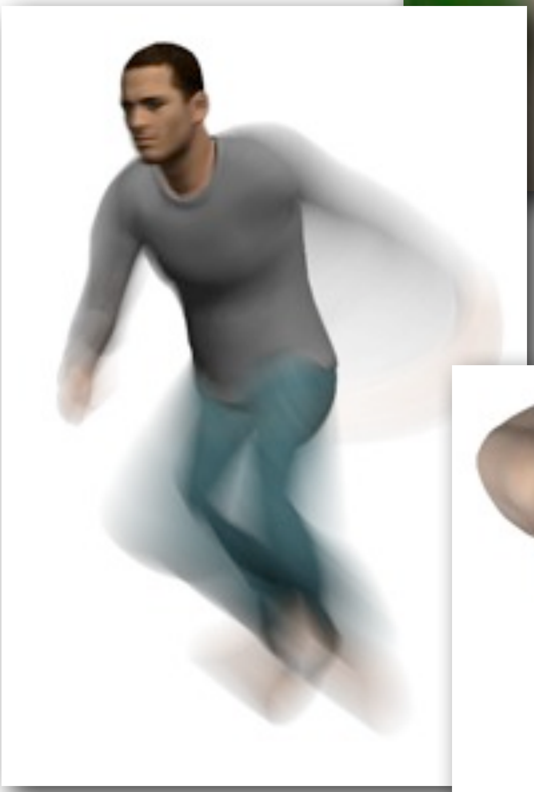


Scene	Tile			Interval		
	Tile size			Num intervals		
	4×4	2×2	1×1	4	16	64
ClothBall	1	1.38	3.5	4.3	0.93	**0.61**
Sponza	**1**	1.0	1.7	2.8	1.8	2.0
BigGuy	1	1.2	2.4	2.9	1.1	**0.77**
Ben	1	1.6	4.3	7.1	1.1	**0.52**
Hand	**1**	1.1	1.7	1.1	1.2	1.1
HairBall	1	1.0	2.0	2.8	0.87	**0.65**

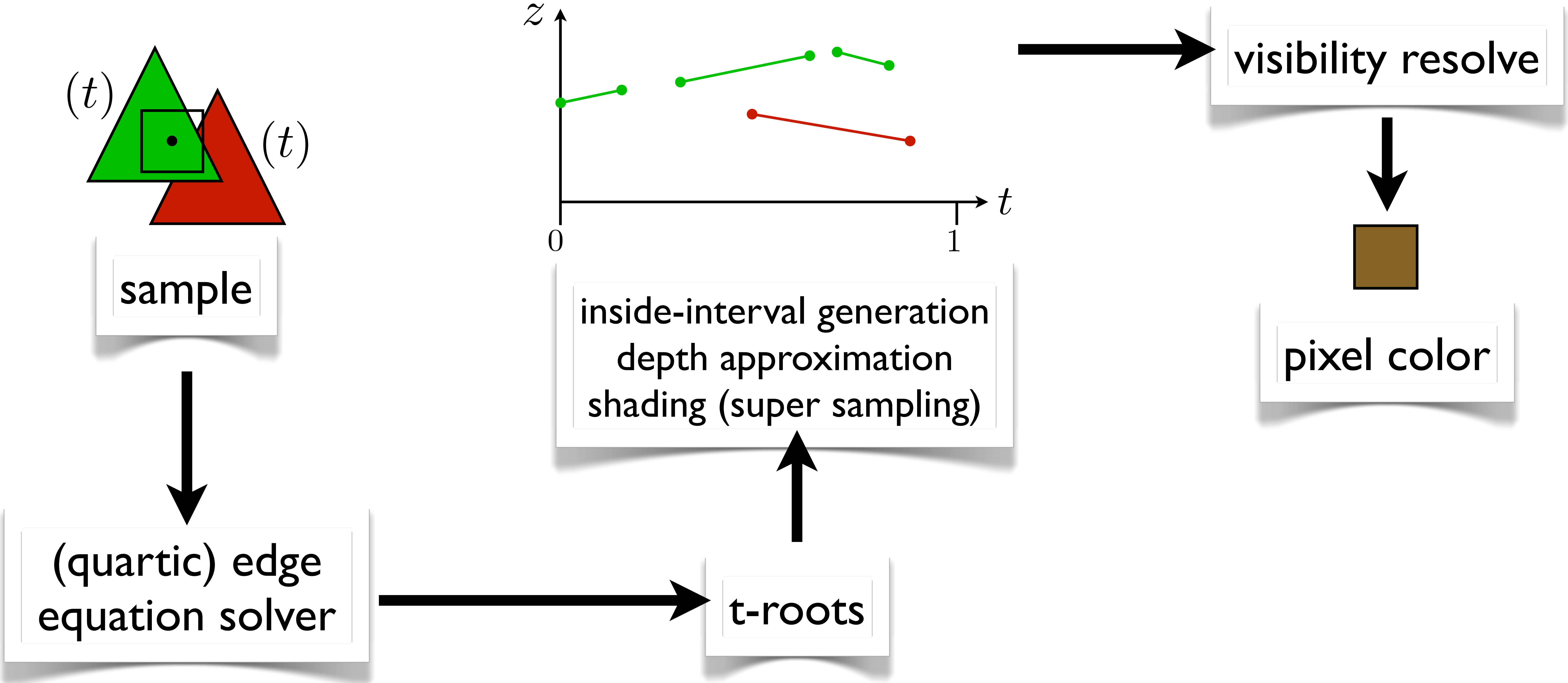
Semi-analytical rasterizer

- *Solve* edge equations w.r.t. to time (quartics)
  - Analytical solver: Neuman/Ferrari
    Numerical solver: Bézier clipping with root deflation
- Visibility: interval lists with resolve per sample
- Refined depth approximation
- Super-sampled shading

Sung et al. 2002
Glassner 1990
Paeth 1995
Sederberg and Nishita 1990
Press et al. 2007
Gribel et al. 2010 & 2011
Tzeng et al. 2012
Barringer et al. 2012

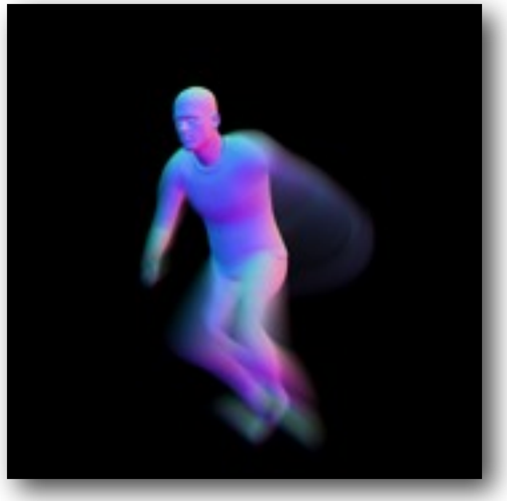


Semi-analytical rasterizer: primer



Semi-analytical rasterizer

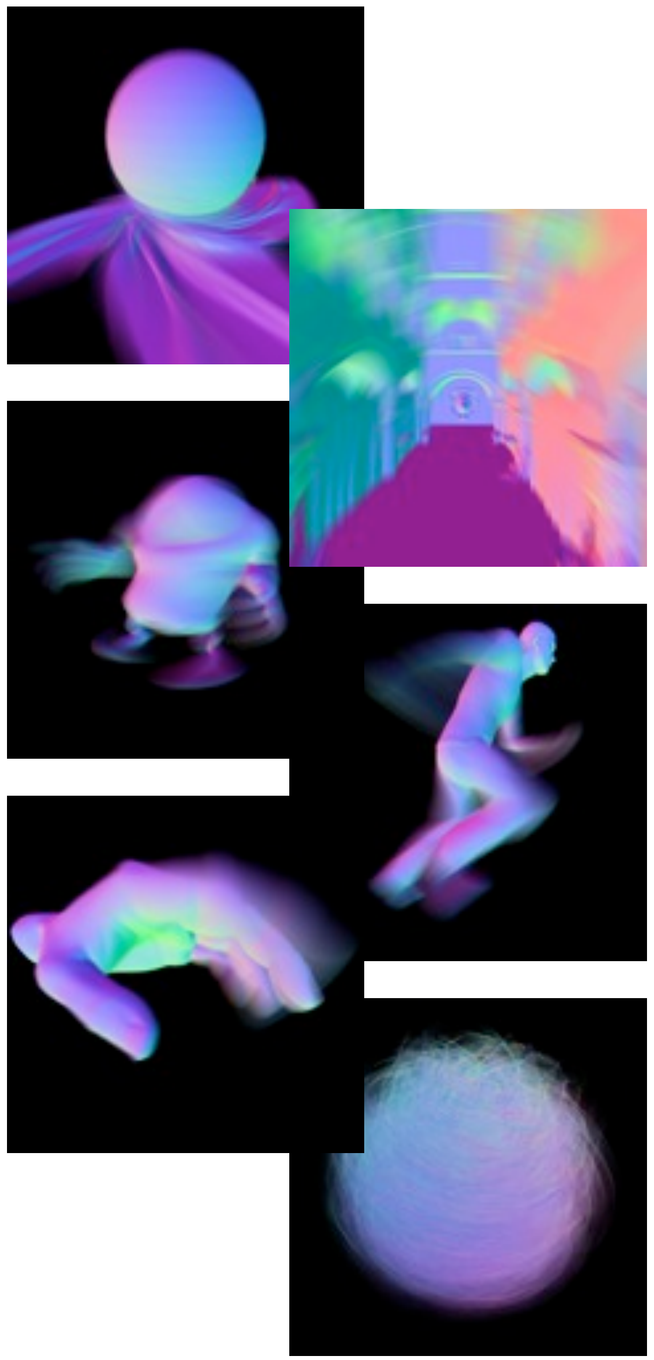





	SPONZA rot 12°	SPONZA rot 20°	BEN Frame 1-5-10	HAND Frame 1-5-10
PSNR, Power solver :	42.7dB	41.1dB	49.1dB	50.7dB
PSNR, Bézier clipping:	42.7dB	41.1dB	49.1dB	50.7dB
Vis.Acc. Power solver:	98.3%	97.4%	97.7%	99.5%
Vis.Acc. Bézier clipping:	98.3%	97.4%	97.8%	99.6%

higher is better

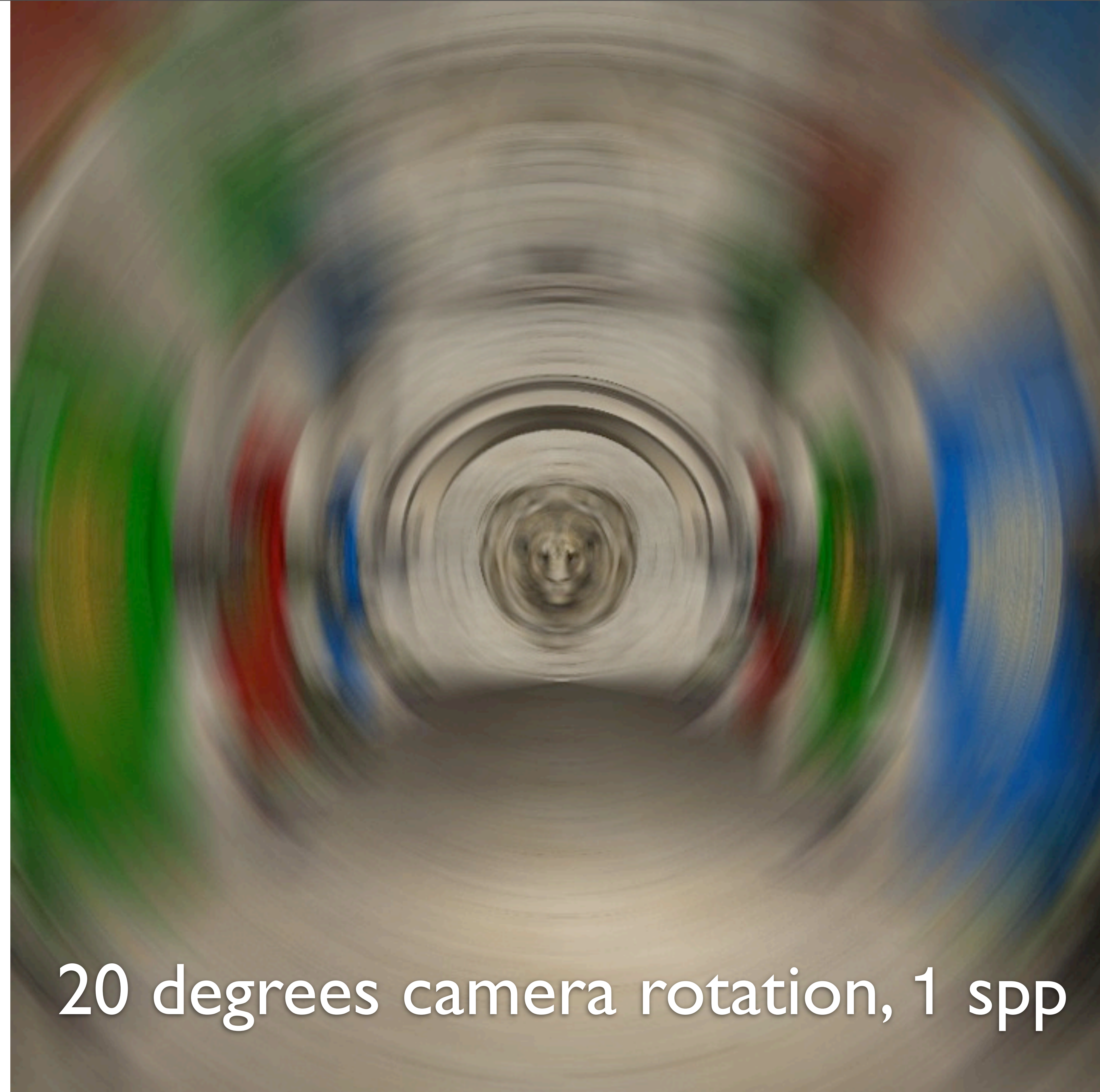
Semi-analytical rasterizer + TILE



Performance improvement
compared to Gribel et al. 2010: $\times 1.7 - \times 4.9$

Crytek Sponza

262k triangles



Summary

- Edge equations for generalized motion
- Traversal
  - Generalized INTERVAL
  - TILE: Triangle – Tile, Edge – Tile
- Semi-analytical rasterizer

Thanks to...

Lund University
Intel's Advanced Rendering Technology team
The reviewers for their valuable input

Utah 3D Animation Repository (Ben, Hand)
UNC Dynamic Scene Benchmarks (Clothball)
Samuli Laine (Hairball)
Bay Raitt (Big Guy)
Marko Dabrovic/Frank Meinl (Sponza)

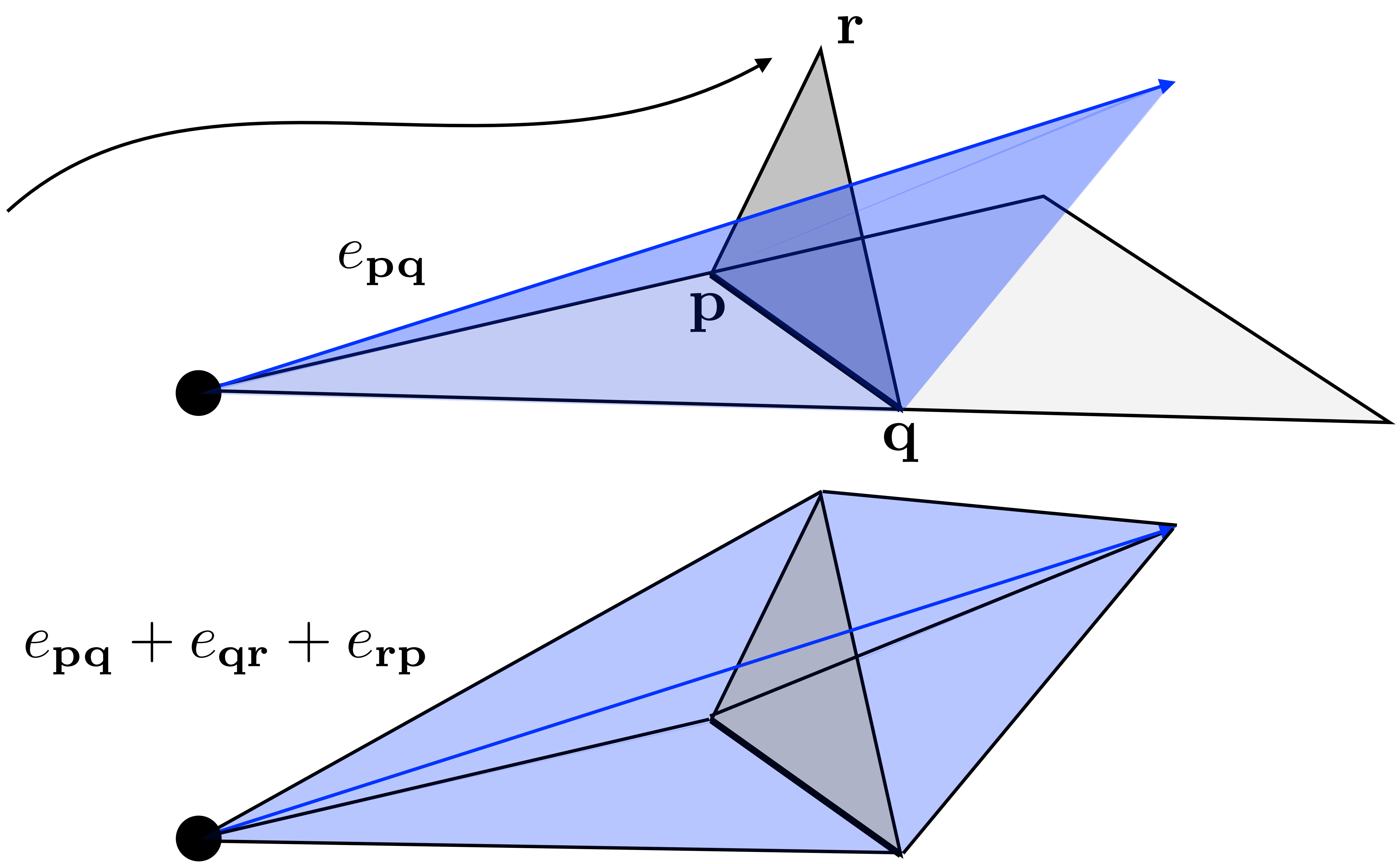
...and to *You* for listening!

Backup

Edge Equations: barycentric coordinates

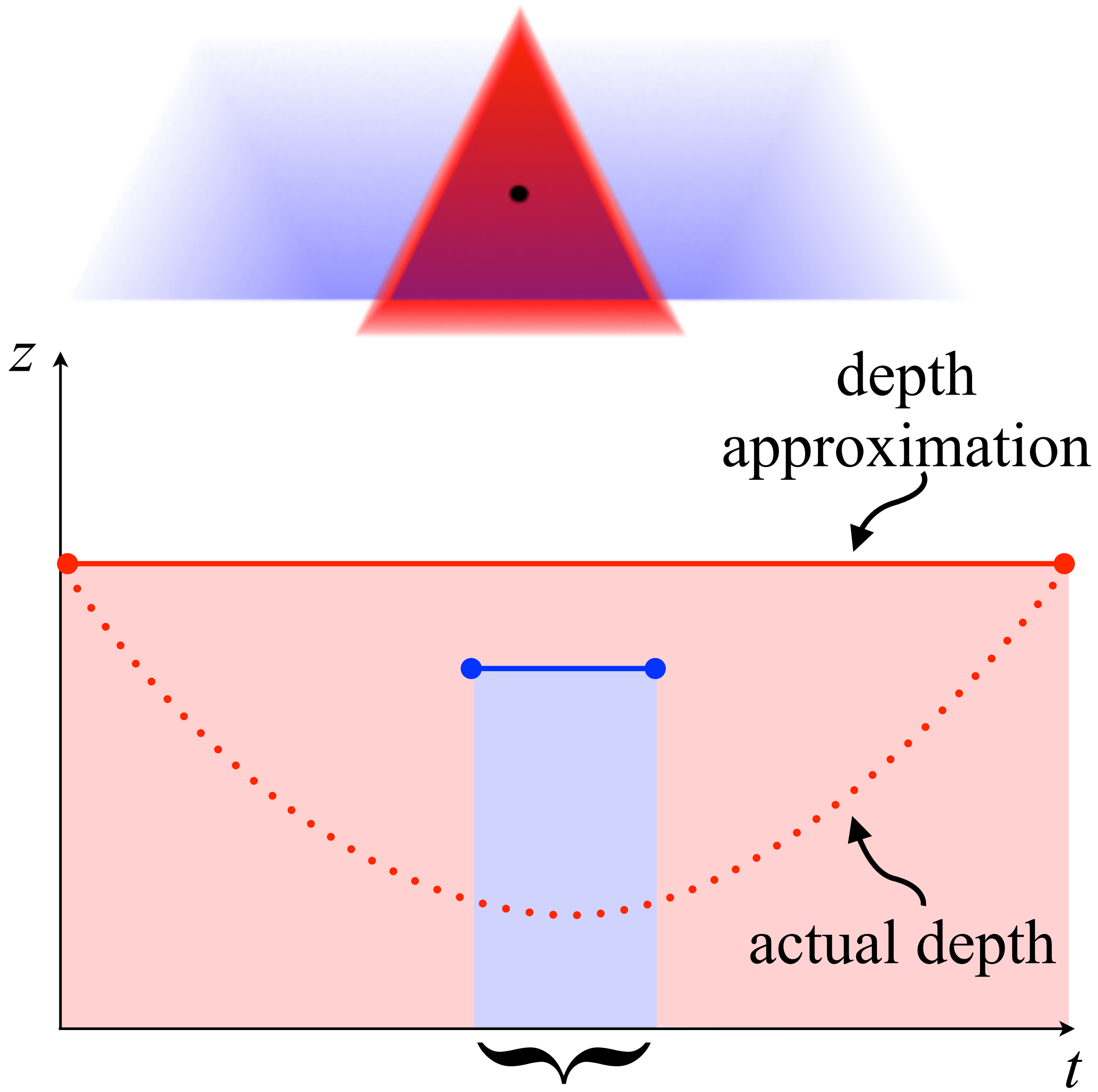
$$b_{\mathbf{r}} = \frac{e_{\mathbf{pq}}}{e_{\mathbf{pq}} + e_{\mathbf{qr}} + e_{\mathbf{rp}}}$$

barycentric weight for **r**



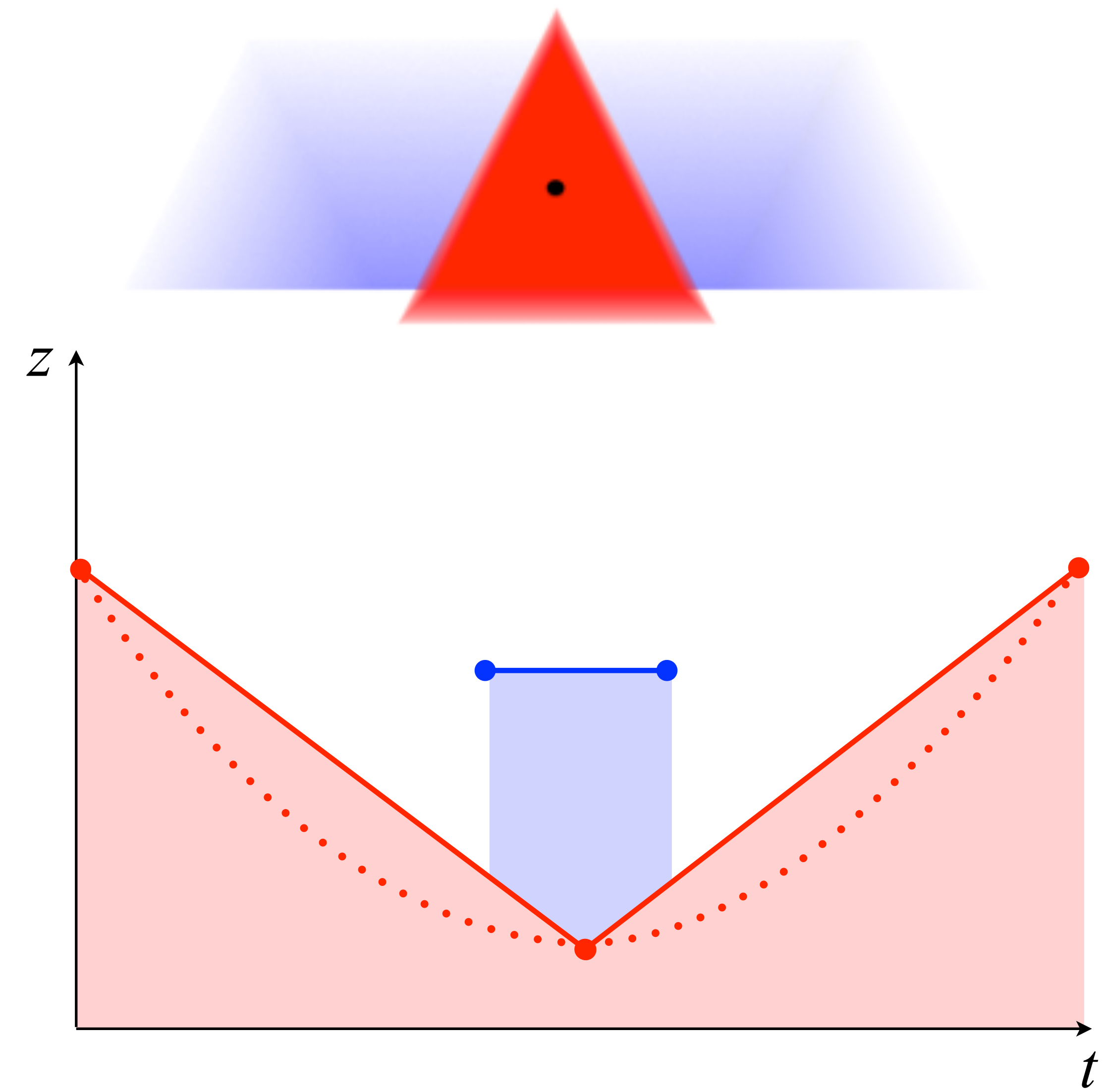
Depth approximation

no splitting



incorrect occlusion

error tolerance splitting



correct visibility

HAND

frames 1, 5, 10
16k triangles

Ben

frames 1, 5, 10
78k triangles