Cache-Aware Sampling Strategies for Texture-Based Ray Casting on GPU

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VirginiaTech
Invent the Future

中国科学院
CHINESE ACADEMY OF SCIENCES

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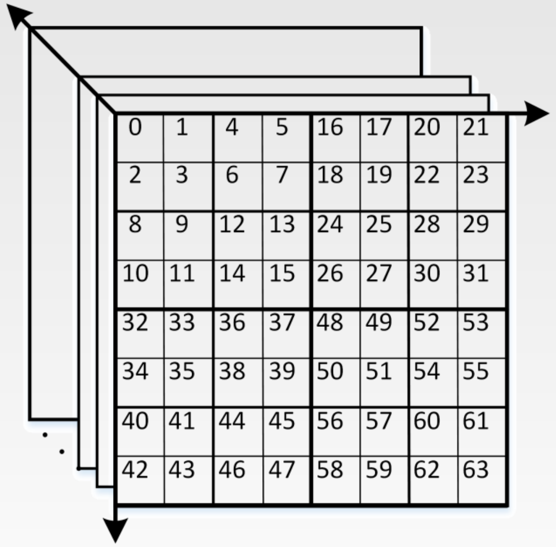
9-14 NOVEMBER 2014
PARIS, FRANCE

Overview

- Introduction/Motivation
- Related Work
- Contribution
- Result
- Application

Motivation



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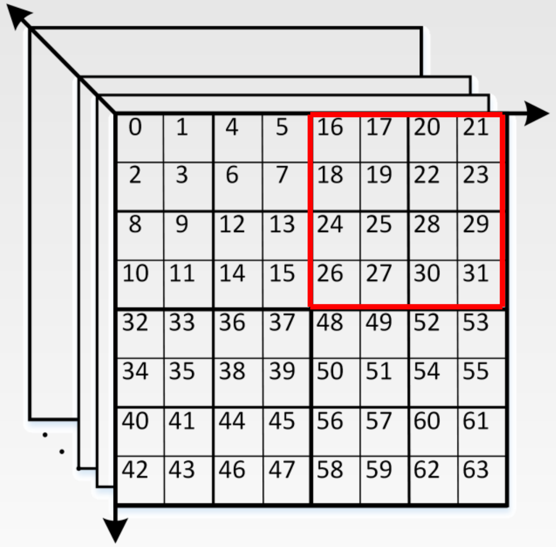

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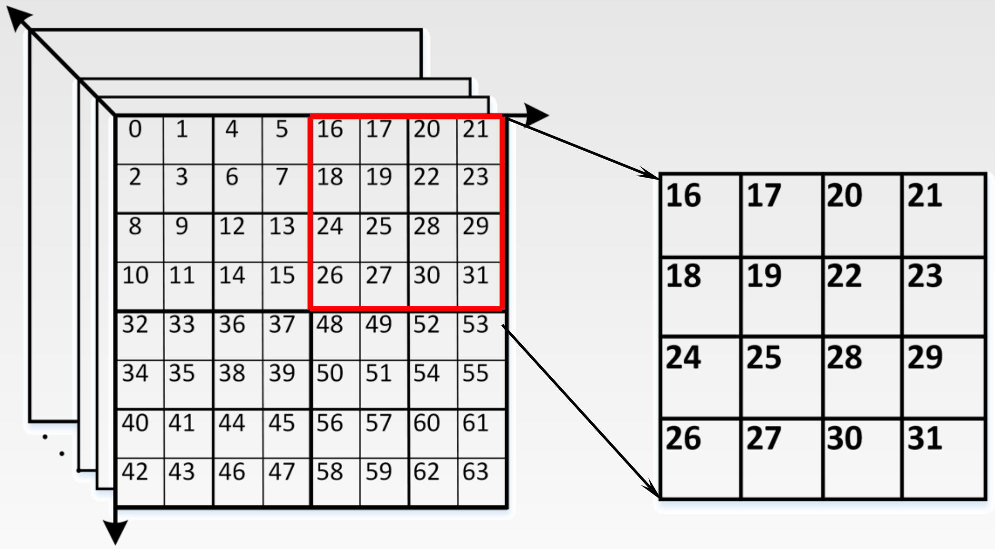

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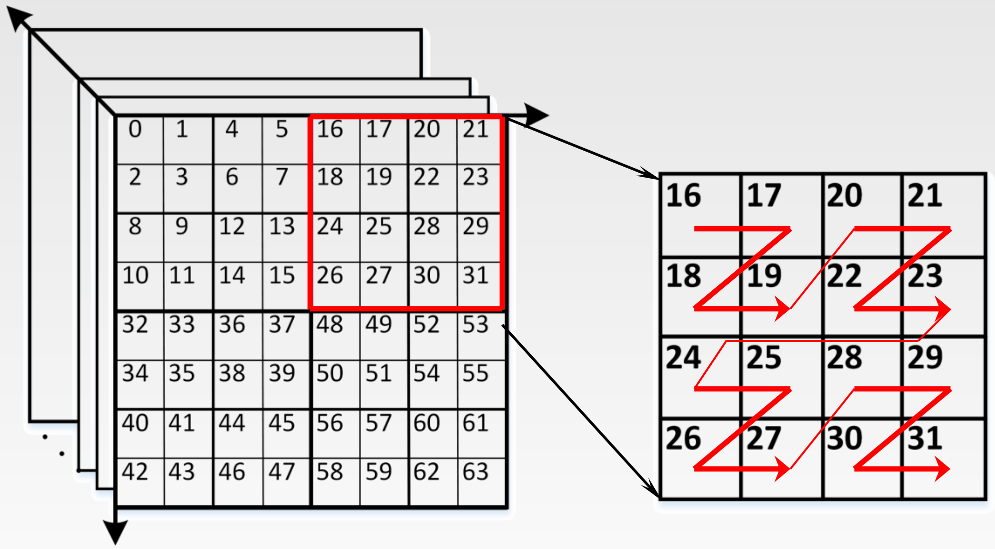

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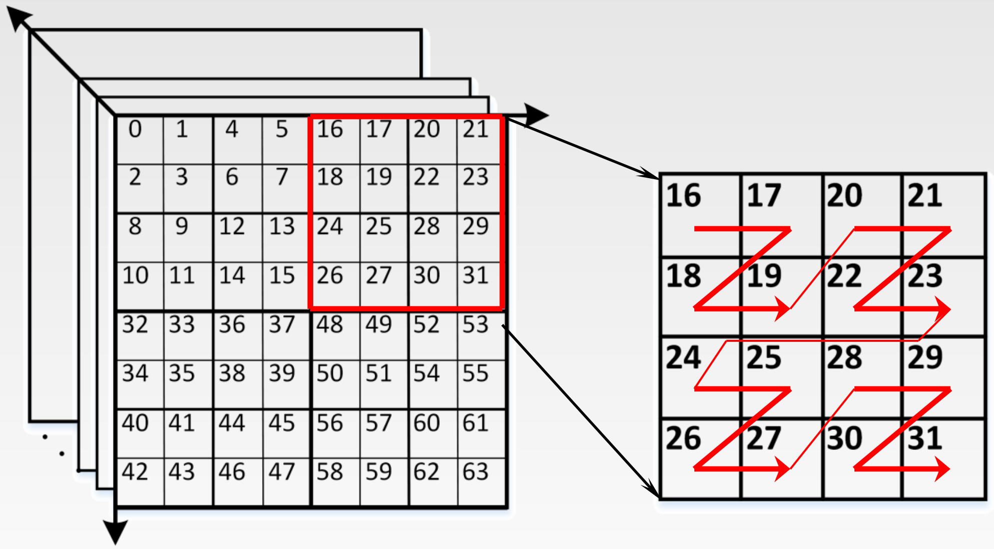

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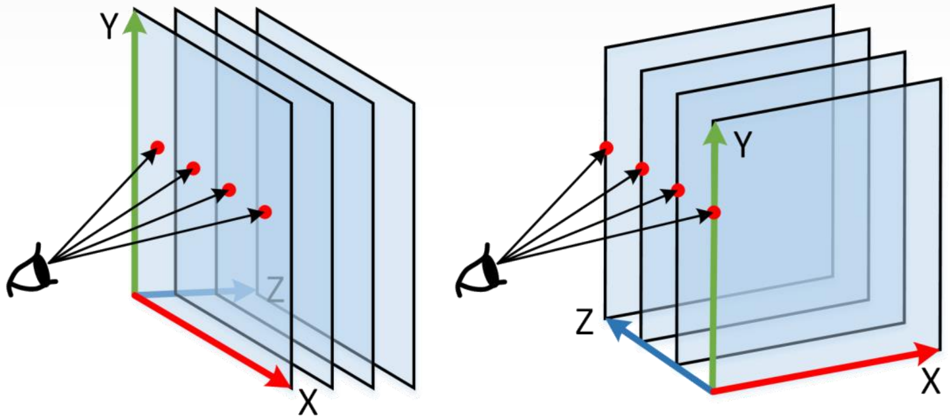


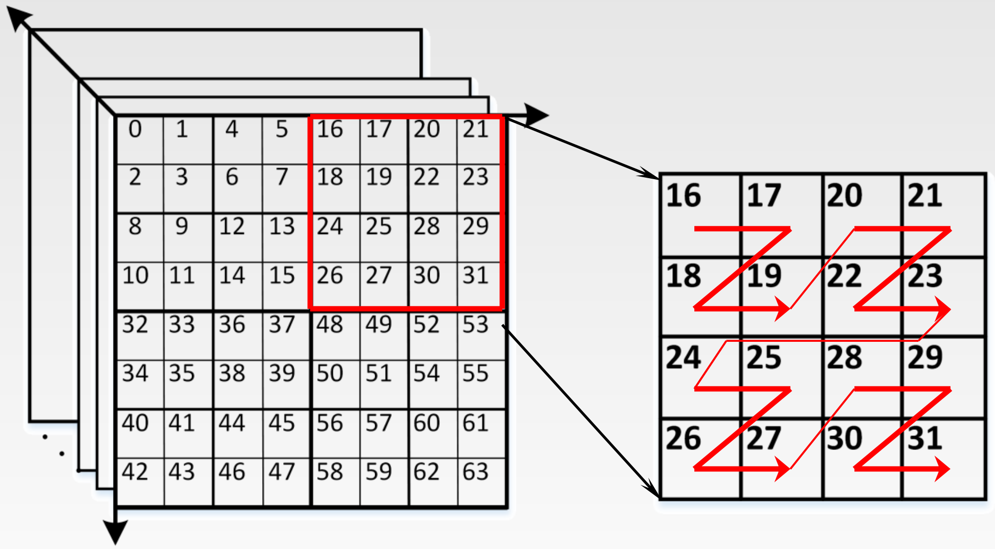
facing XY

facing ZY

Perpendicular

Parallel

Motivation



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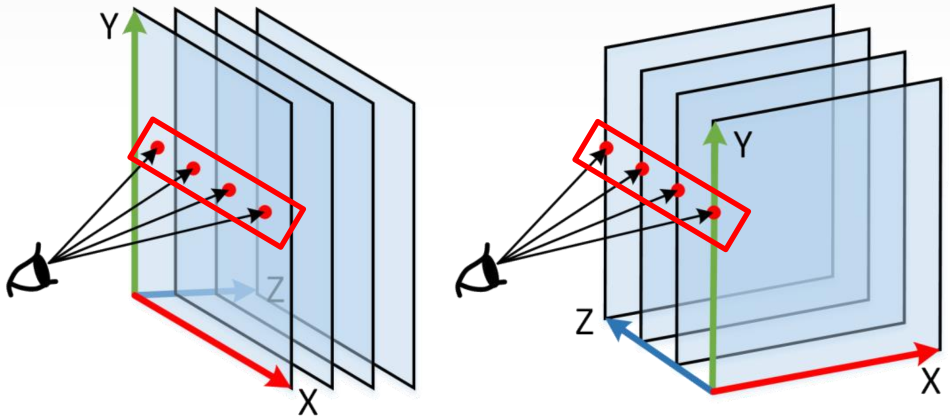

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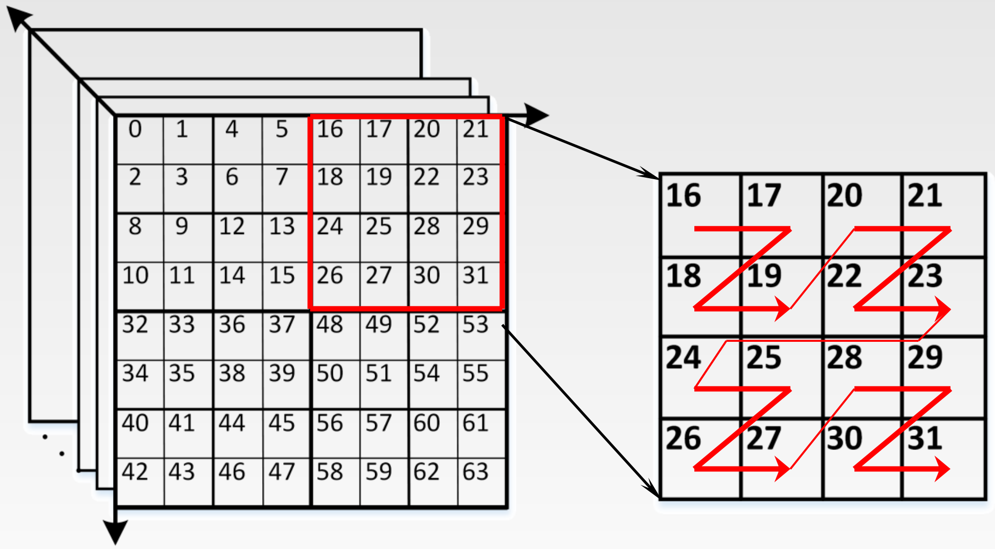

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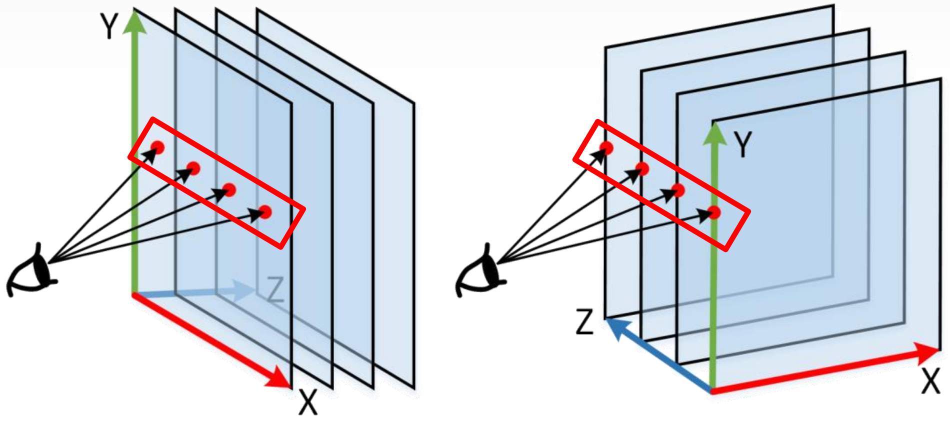
Viewing Direction



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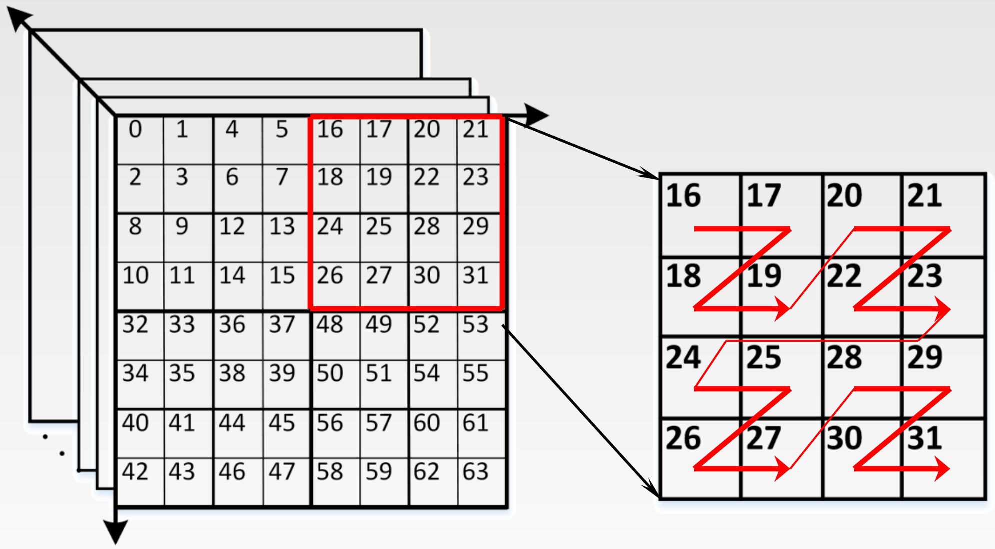

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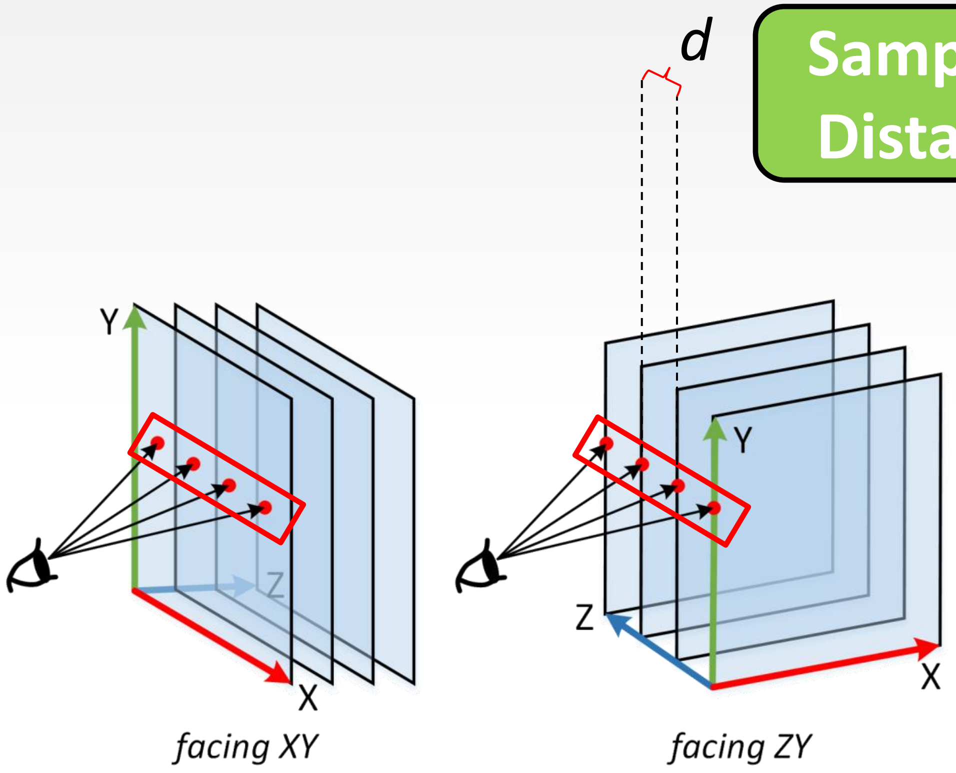
Sampling Distance

Viewing Direction



Perpendicular

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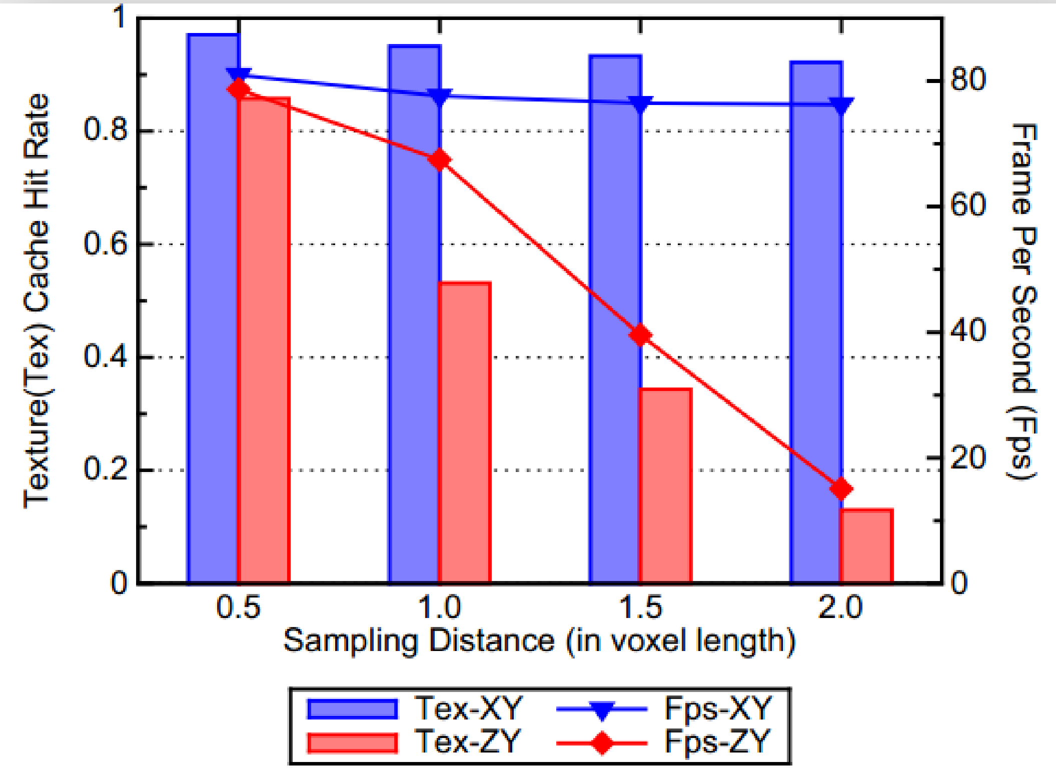
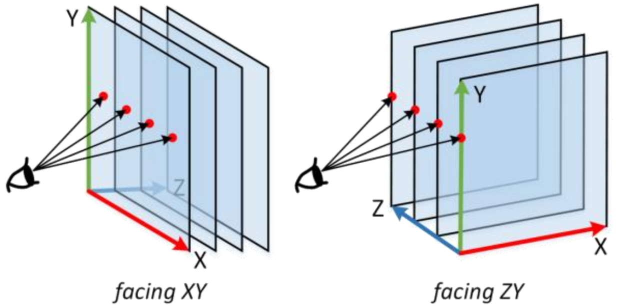


GPU: GTX GeForce Titan

Volume size: 1024x1024x1024 x 8bit

Rendered image size: 512x512



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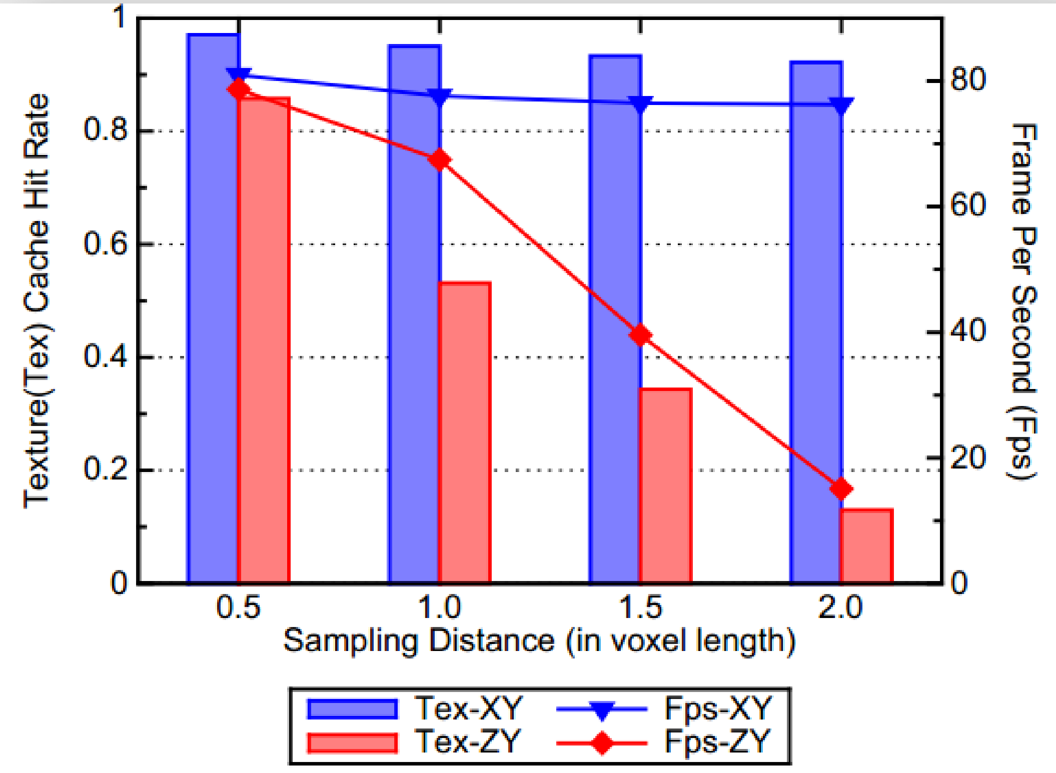
Motivation



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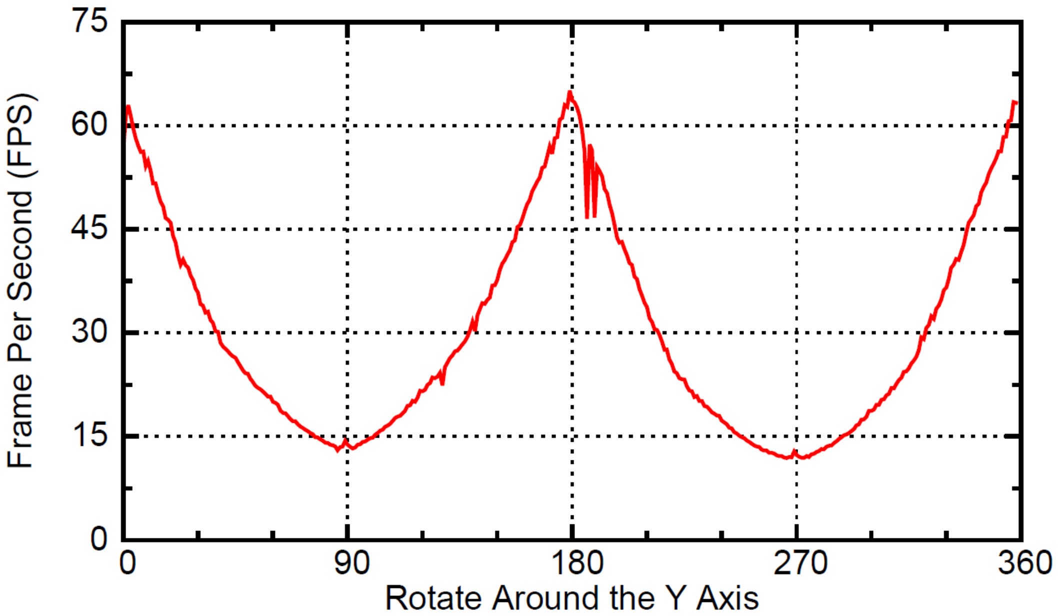

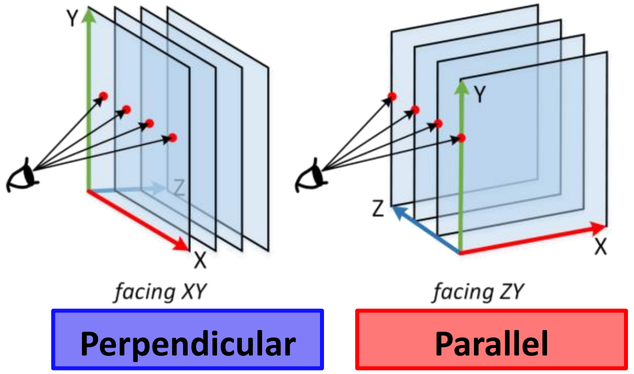

Related Work

Motivation
Related Work
Contribution
Result
Application

Motivation
Related Work
Contribution
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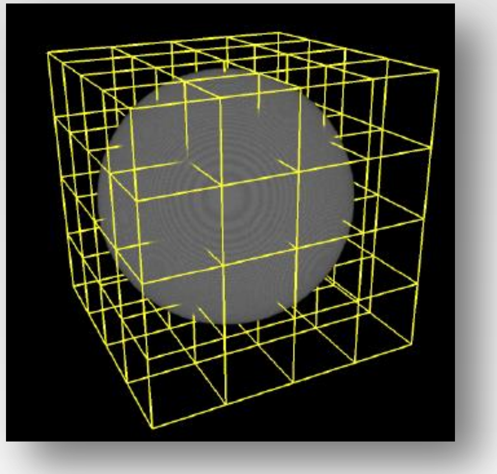
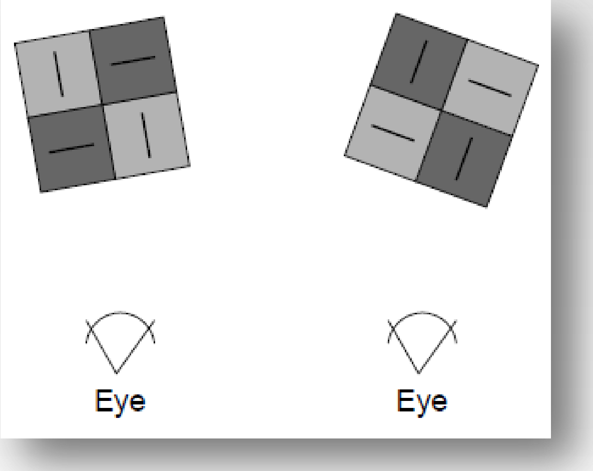
Related Work

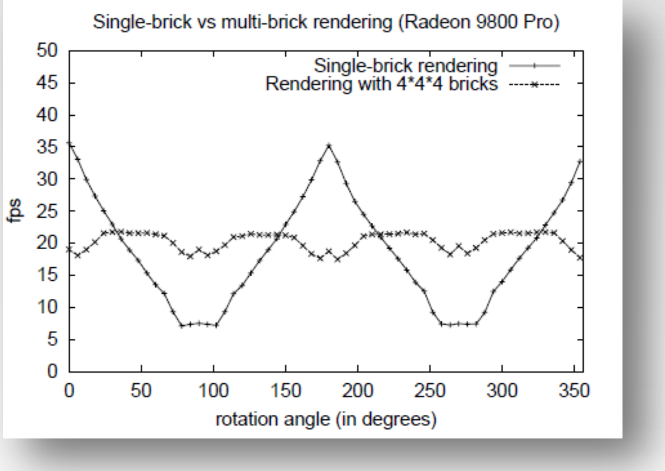
[Weiskopf04]



Partitioning a volume into small bricks



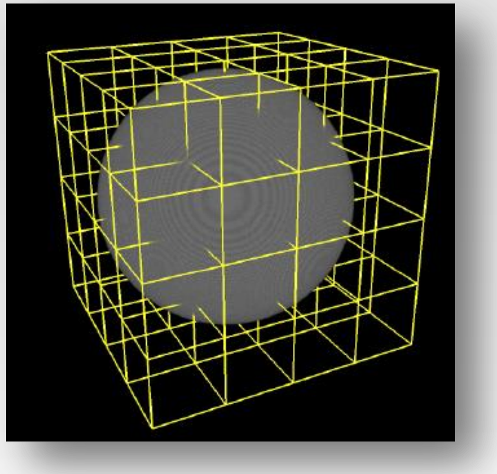
For any direction, 2 bricks are parallel and two bricks are perpendicular to the view



Achieve a roughly constant frame rate when rotating around the Y axis

Related Work

[Weiskopf04]



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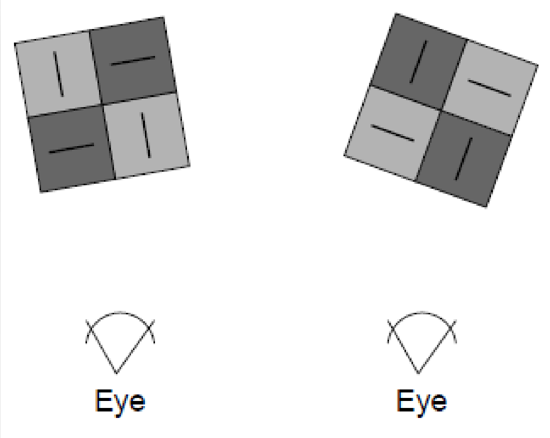

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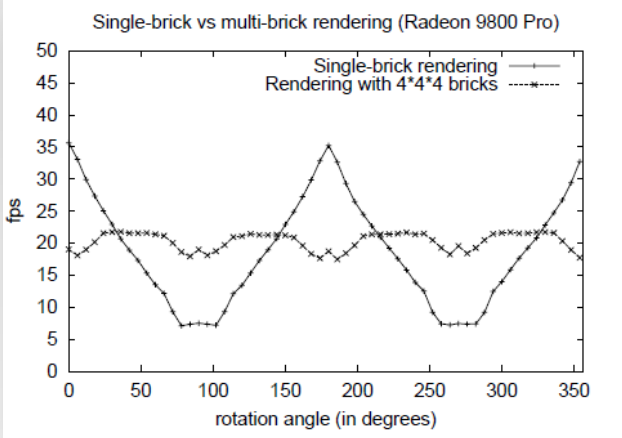
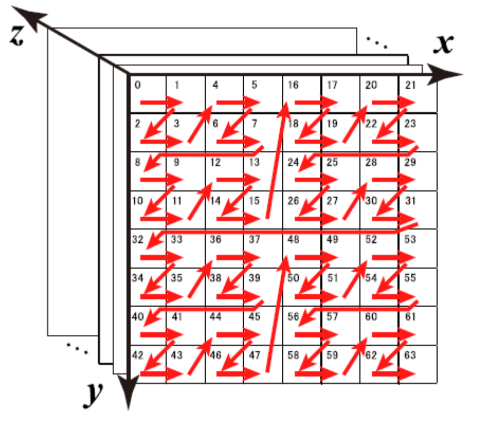


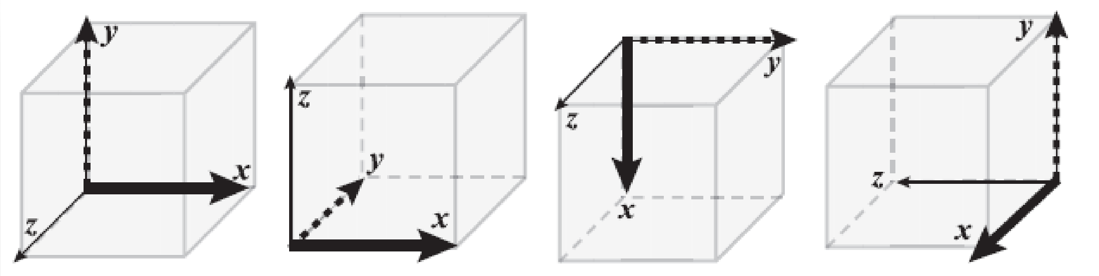
Achieve a roughly constant frame rate when rotating around the Y axis

[Sugimoto2012]
[Sugimoto2014]



Memory stride ratio of the 3D texture along X, Y and Z axis is **1:2:6**

GPU WARP



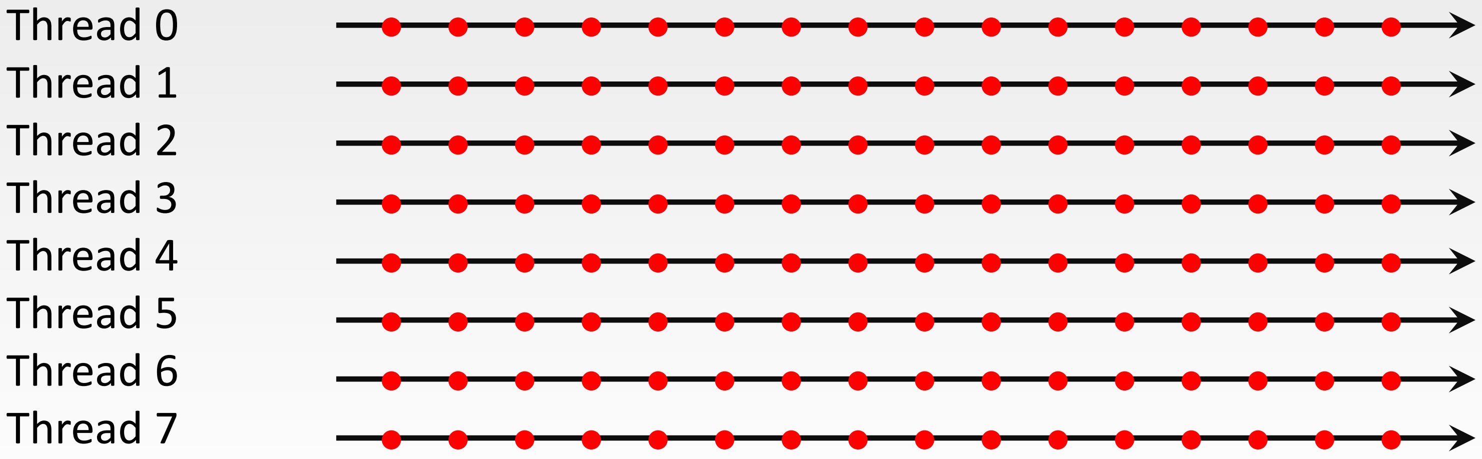
A warp of GPU threads should always take samples along the direction with smaller stride, so that higher cache locality could be achieved

Contribution

We are trying to improve the texture cache performance by minimizing the memory stride inside a WARP of GPU threads

Contribution

Map one thread to one ray (warp size = 8)



Thread 0
Thread 1
Thread 2
Thread 3
Thread 4
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Thread 6
Thread 7

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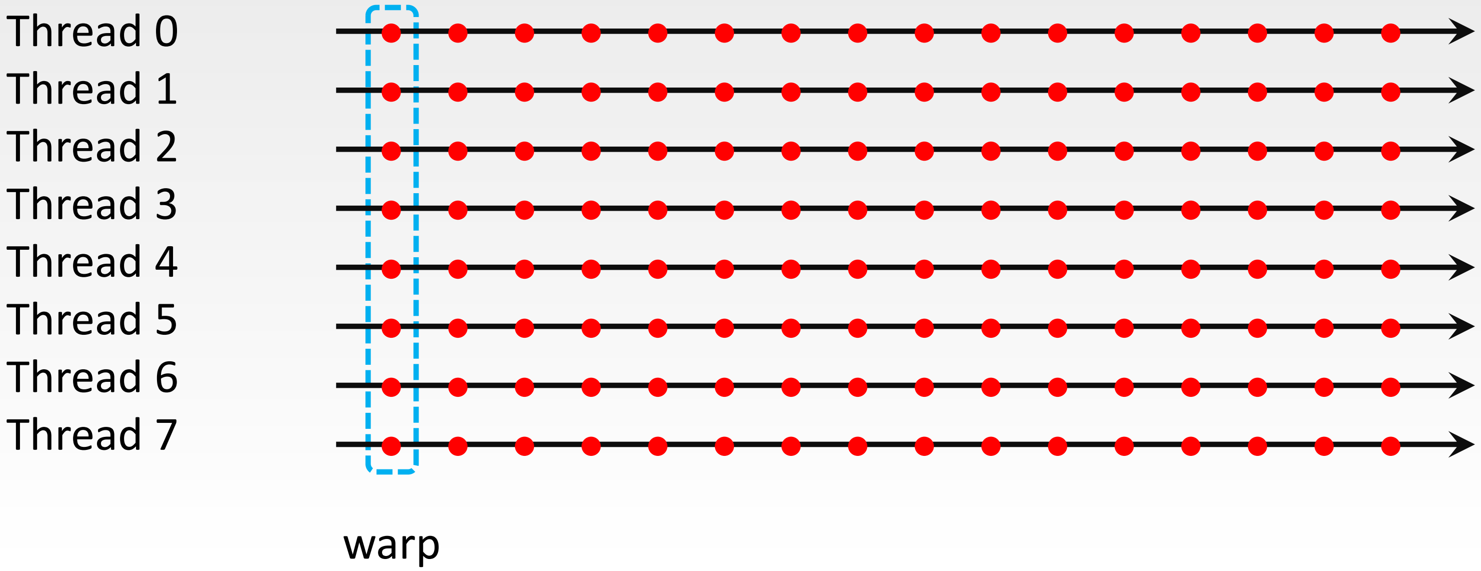

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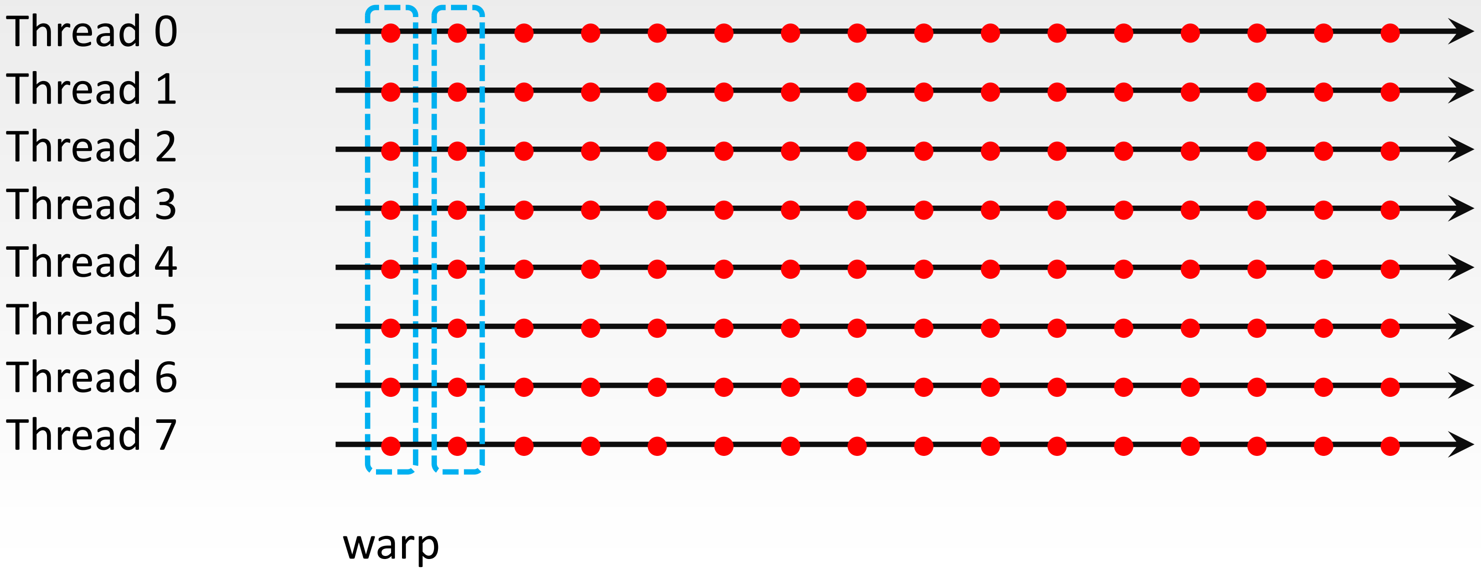

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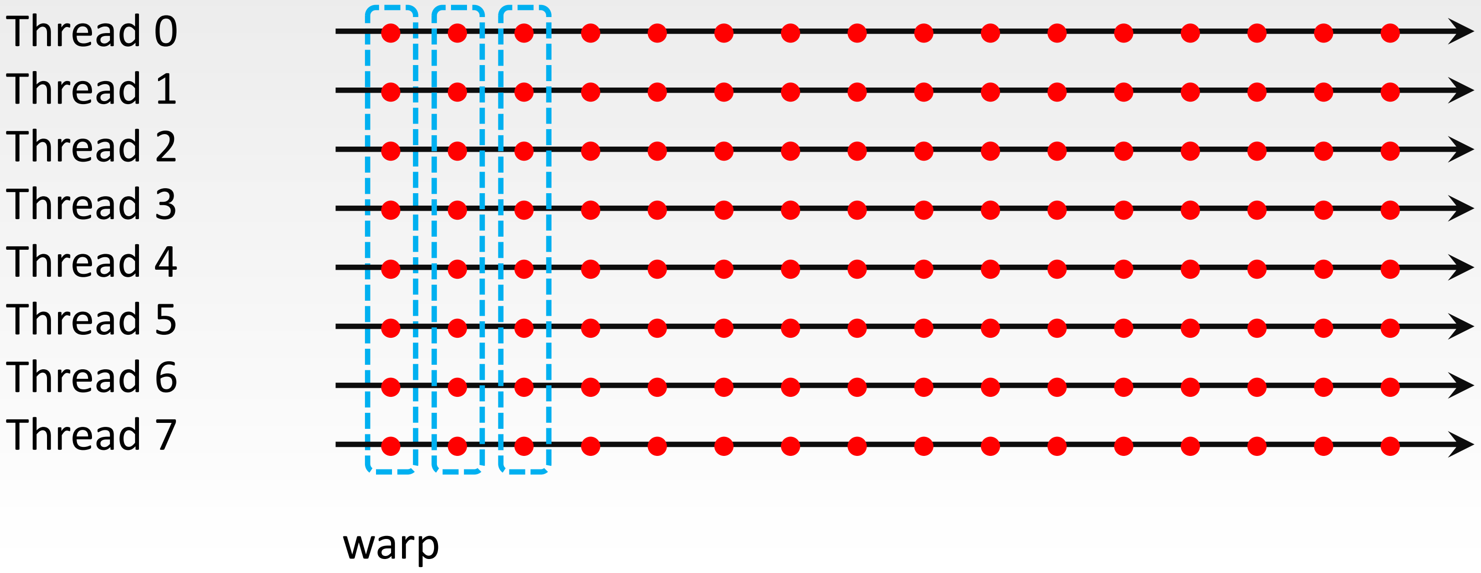

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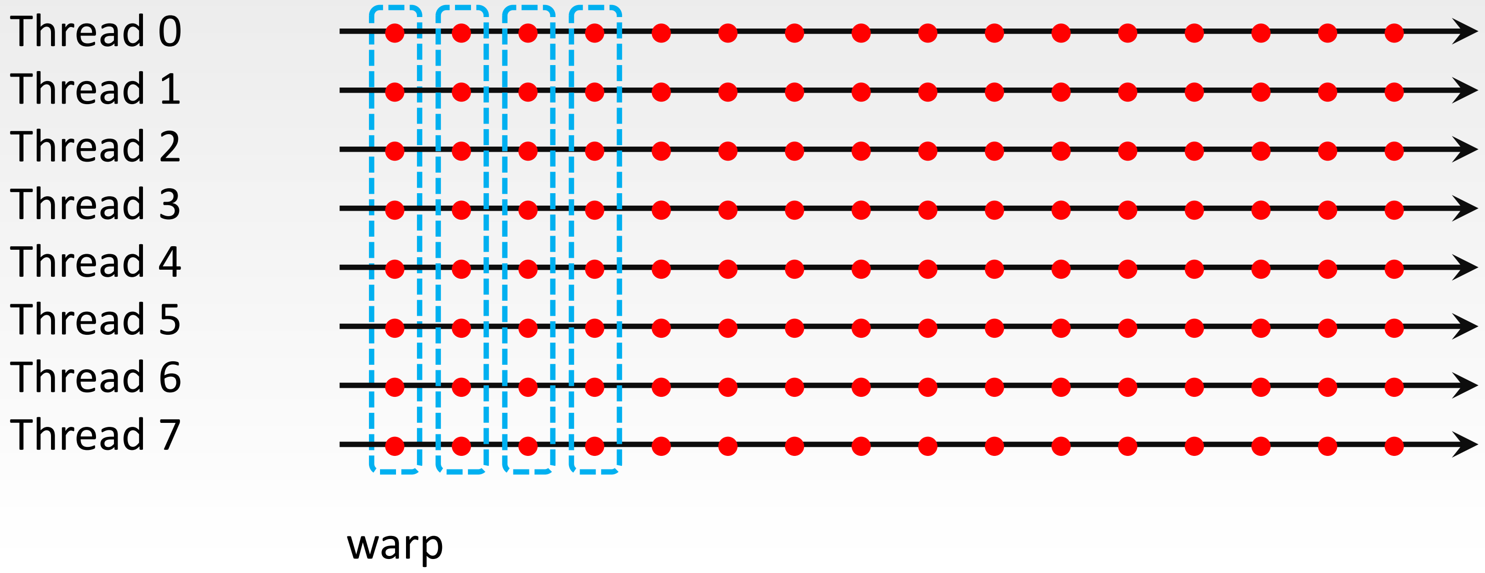

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warp

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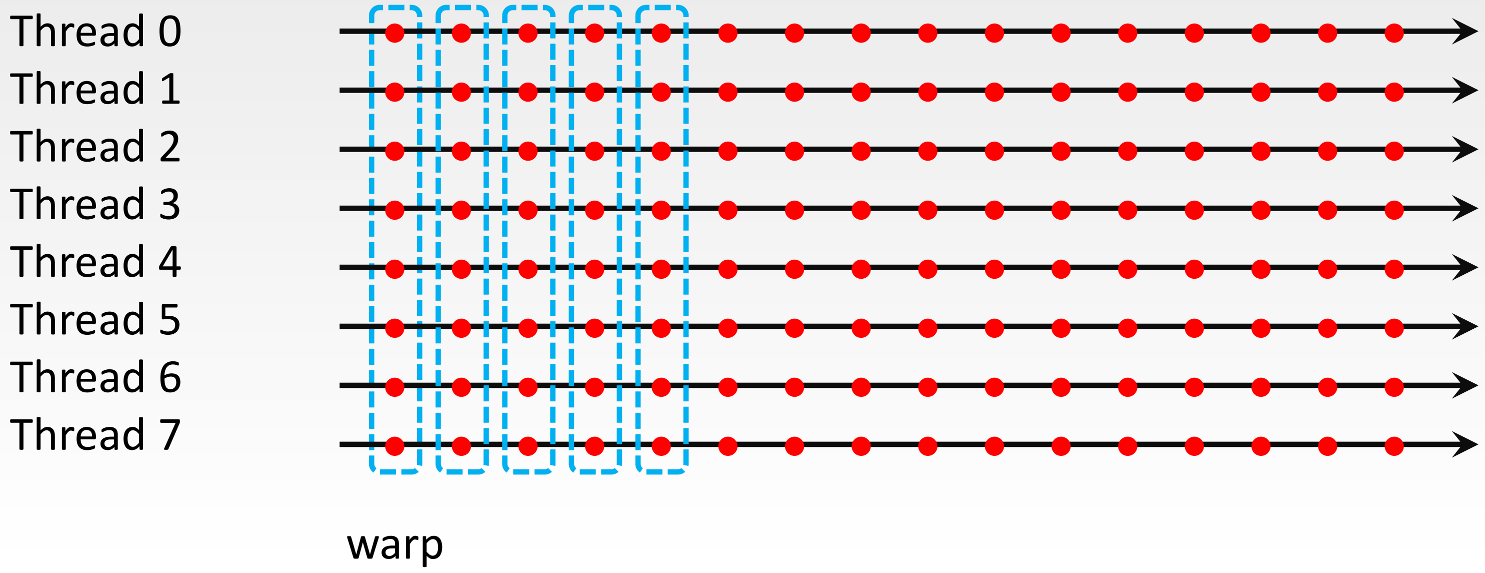

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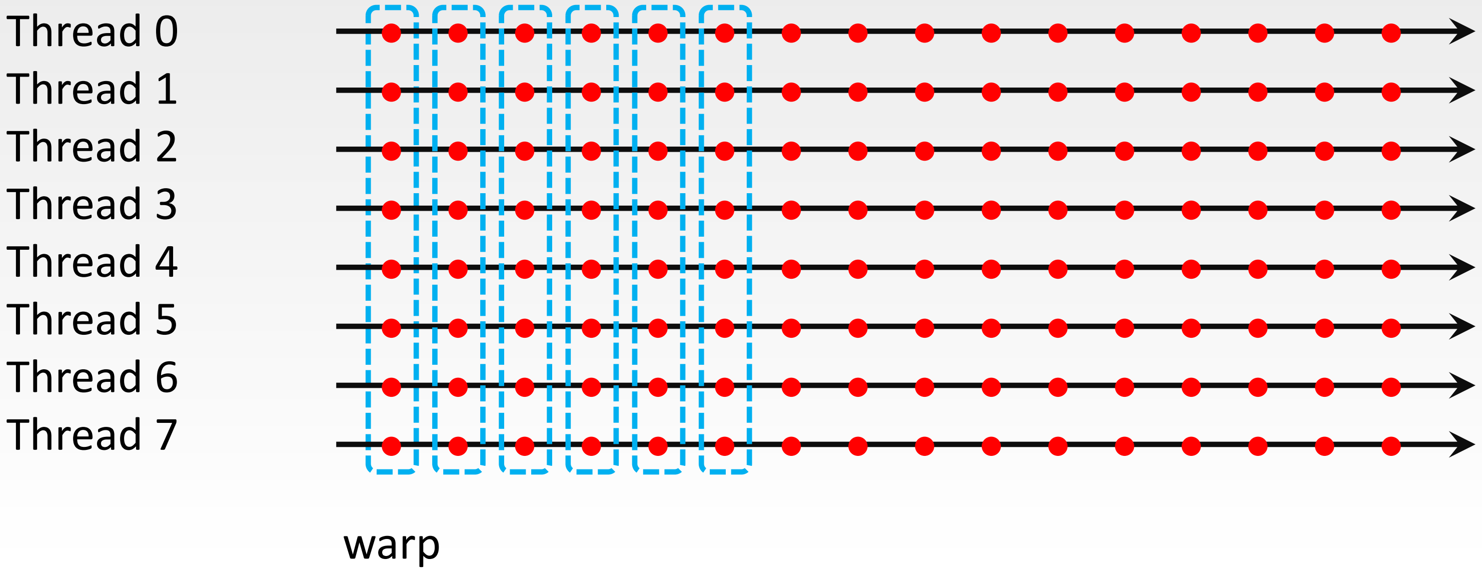

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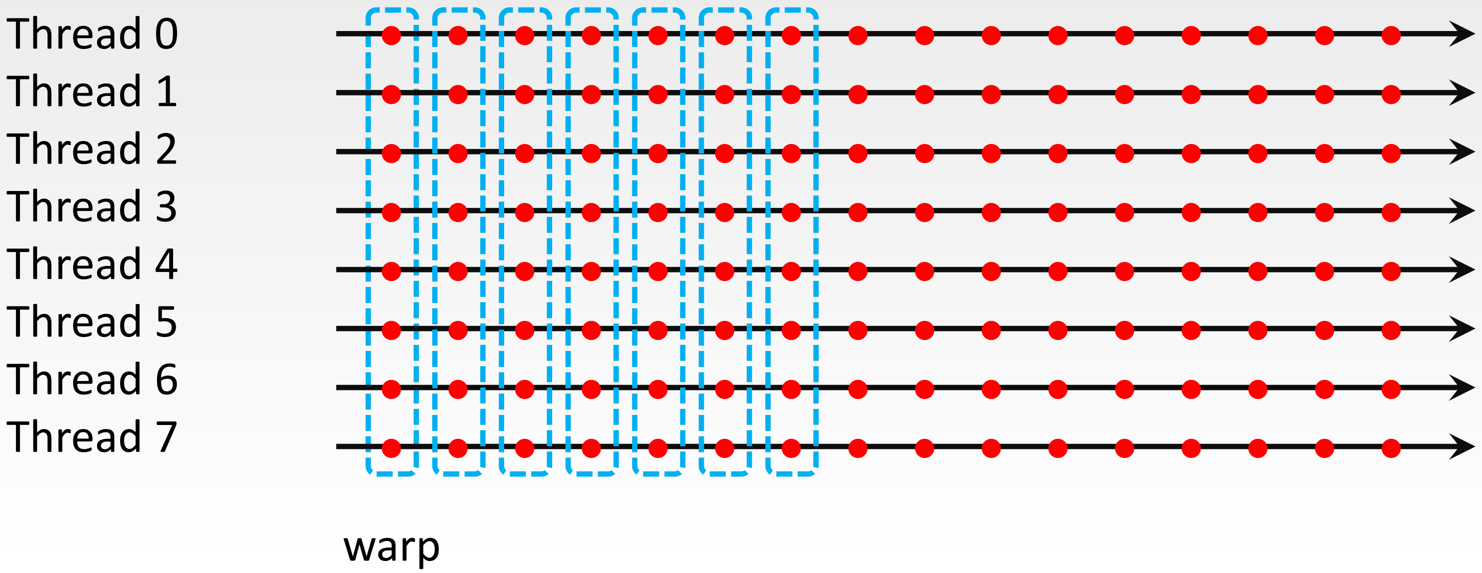

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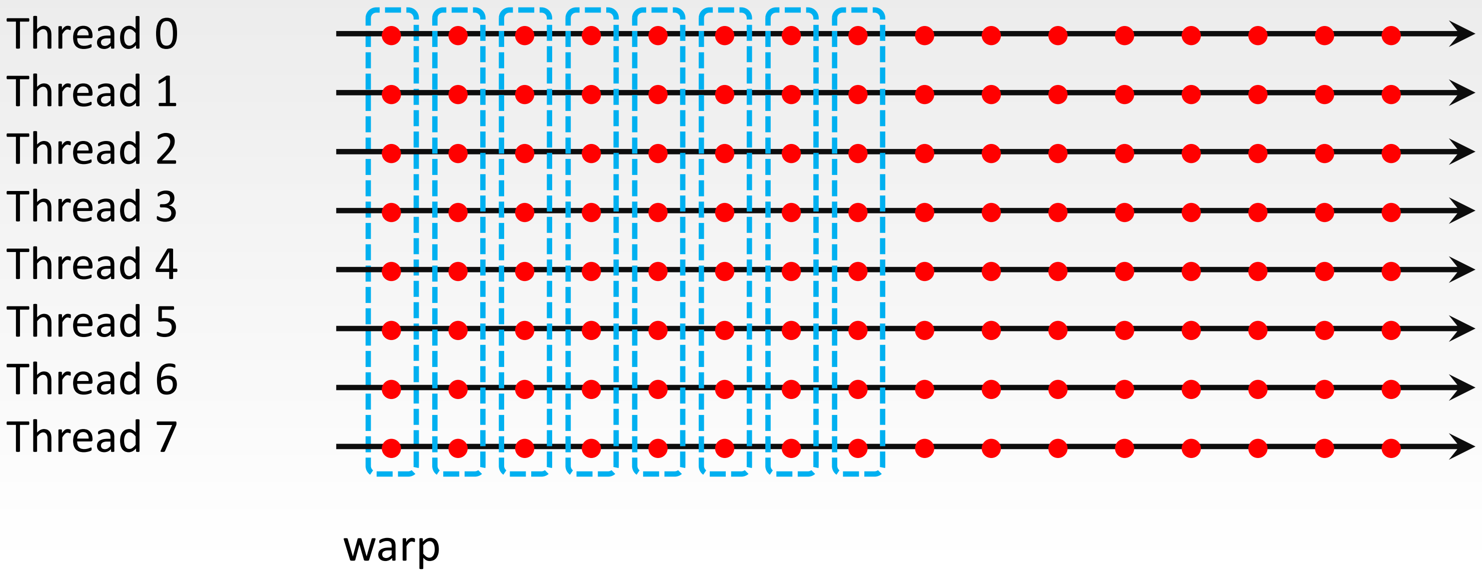

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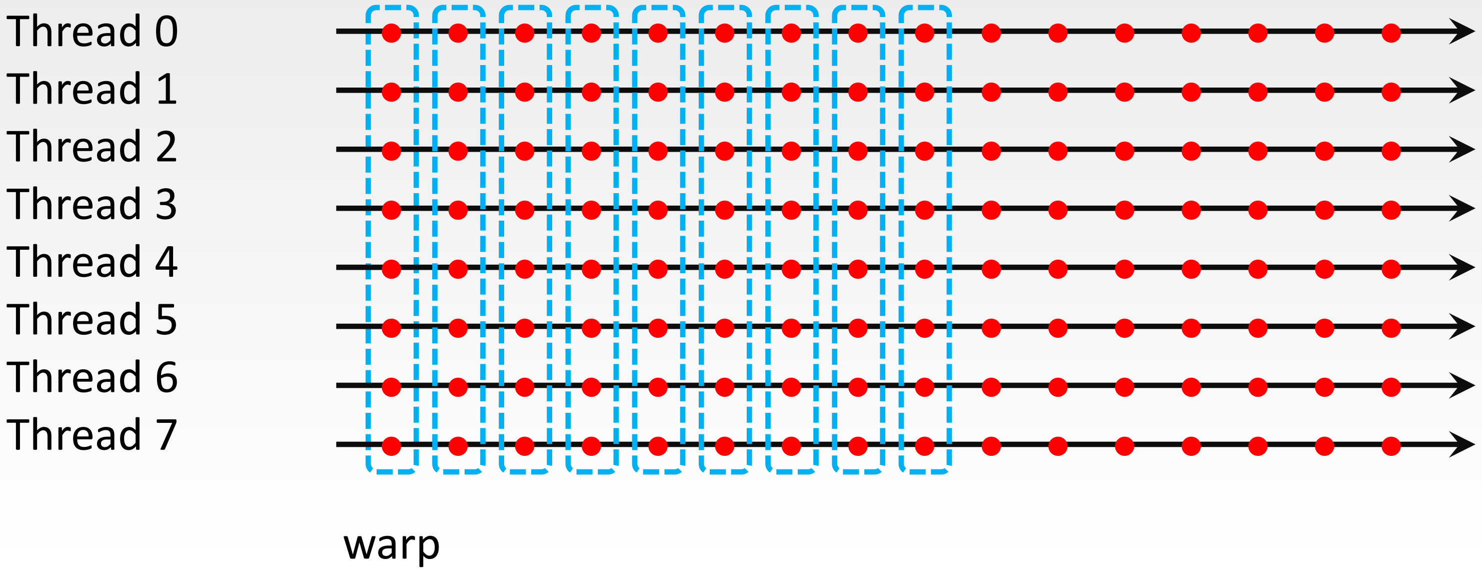

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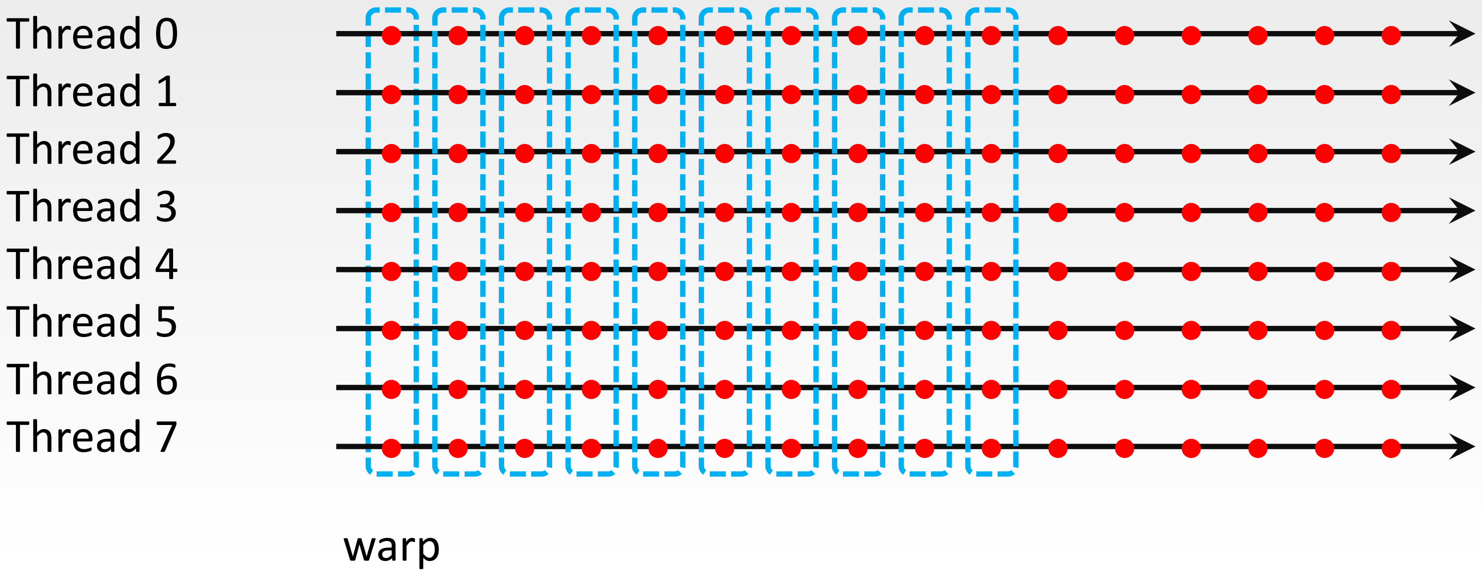

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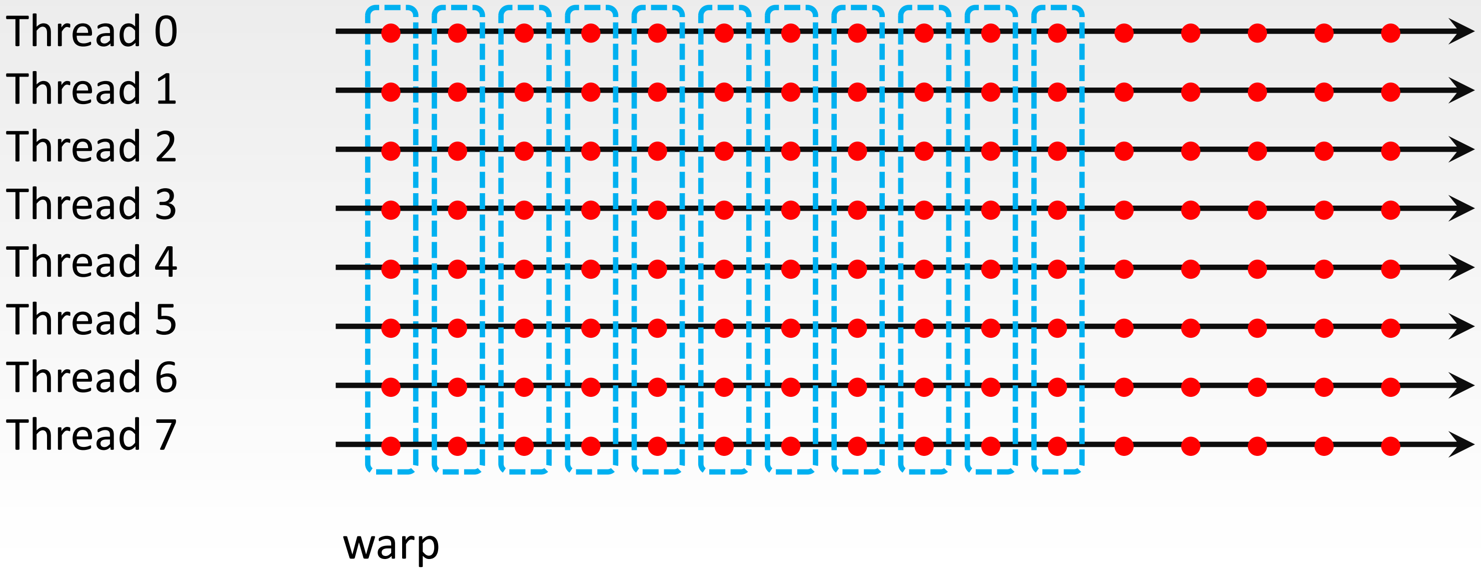

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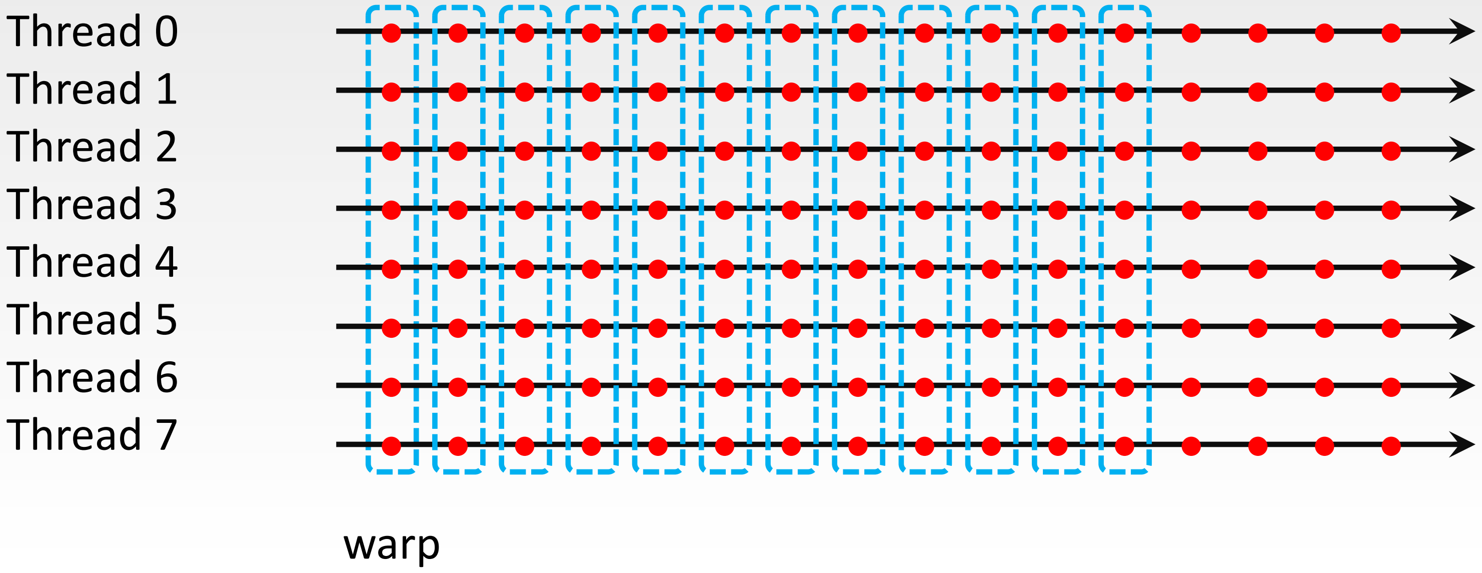

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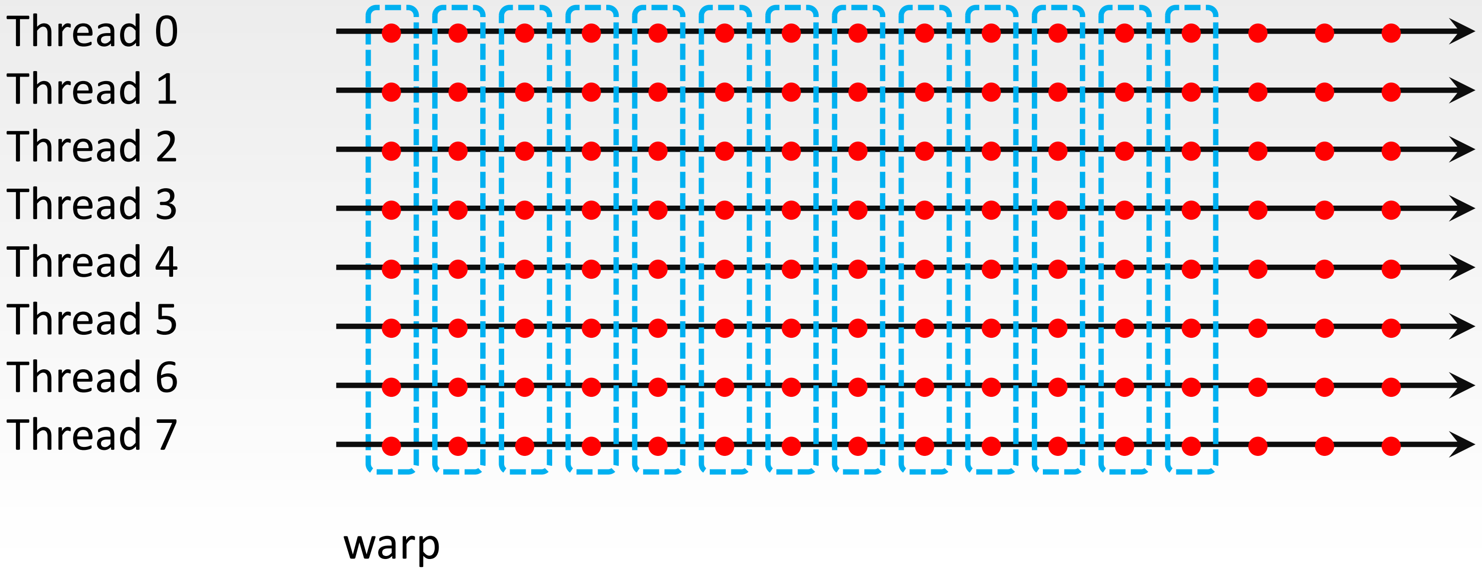

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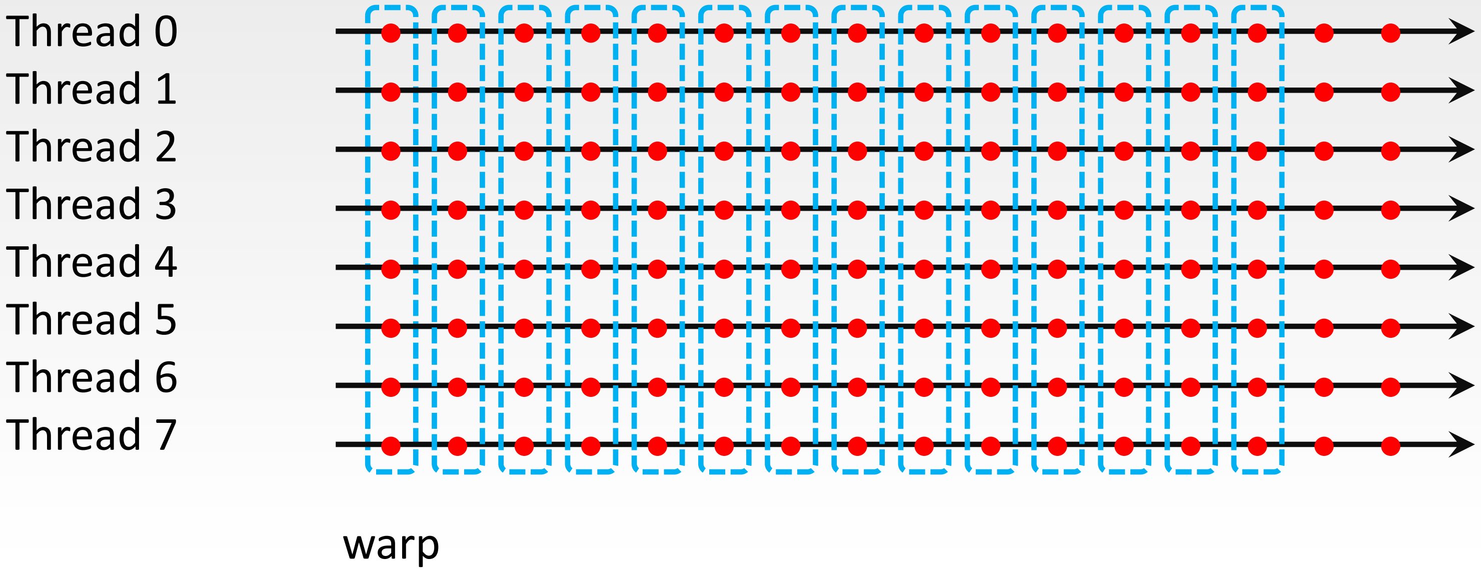

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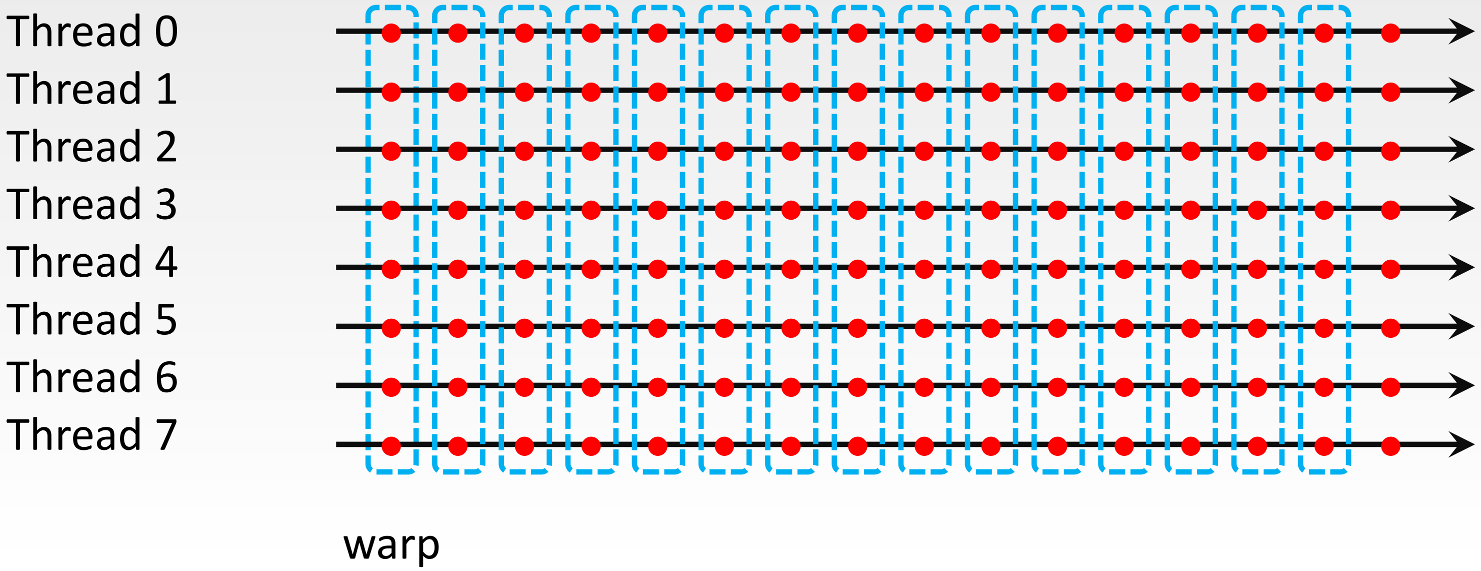

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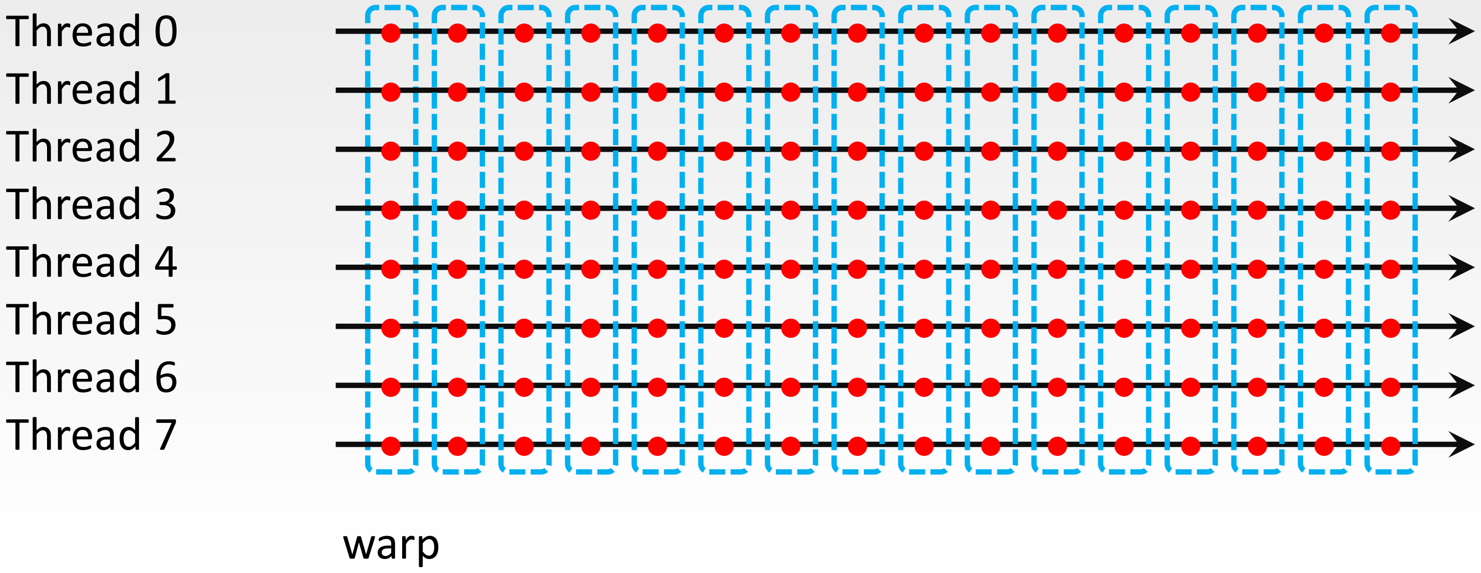

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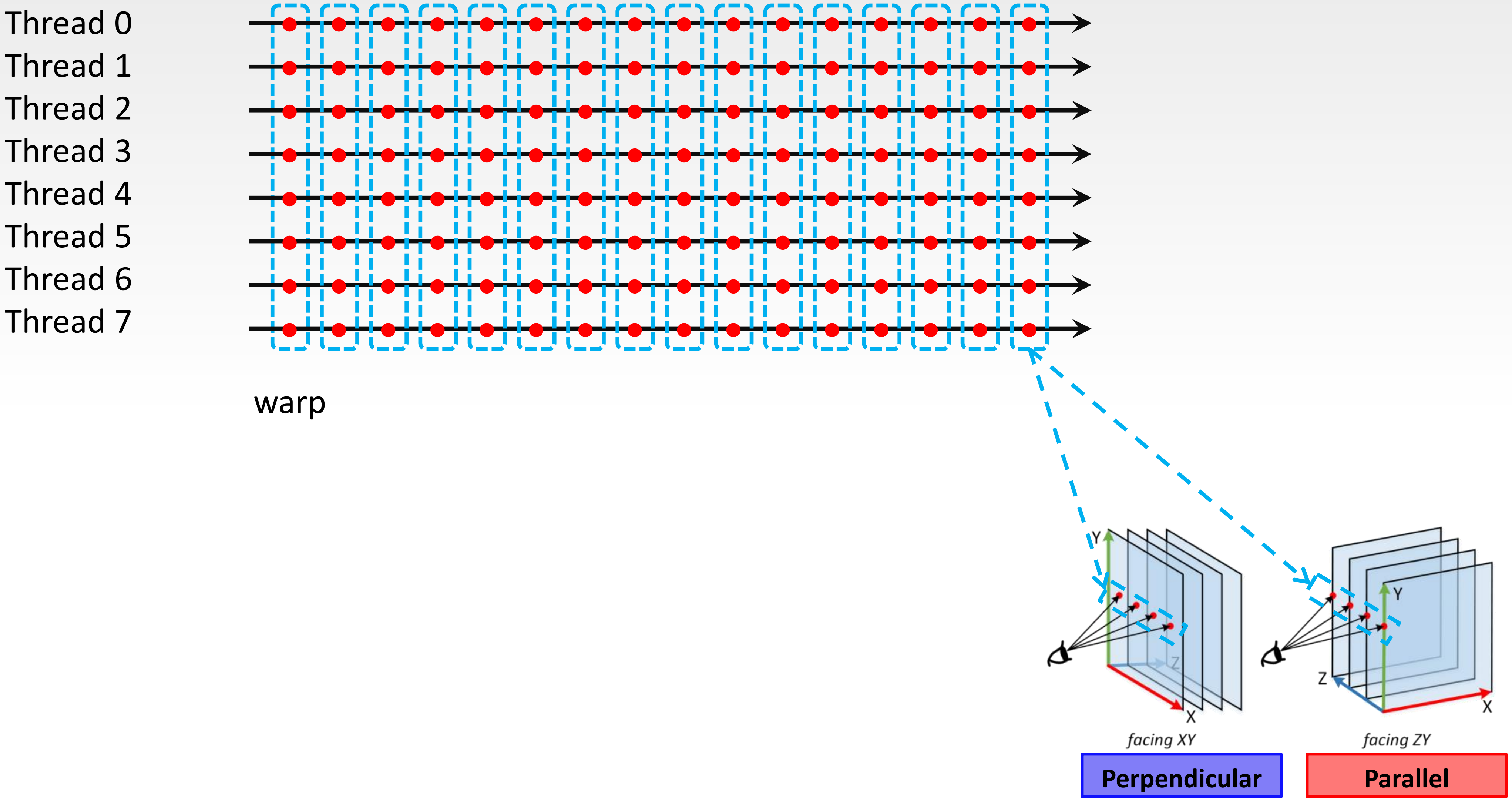

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warp

facing XY

facing ZY

Perpendicular

Parallel

Contribution

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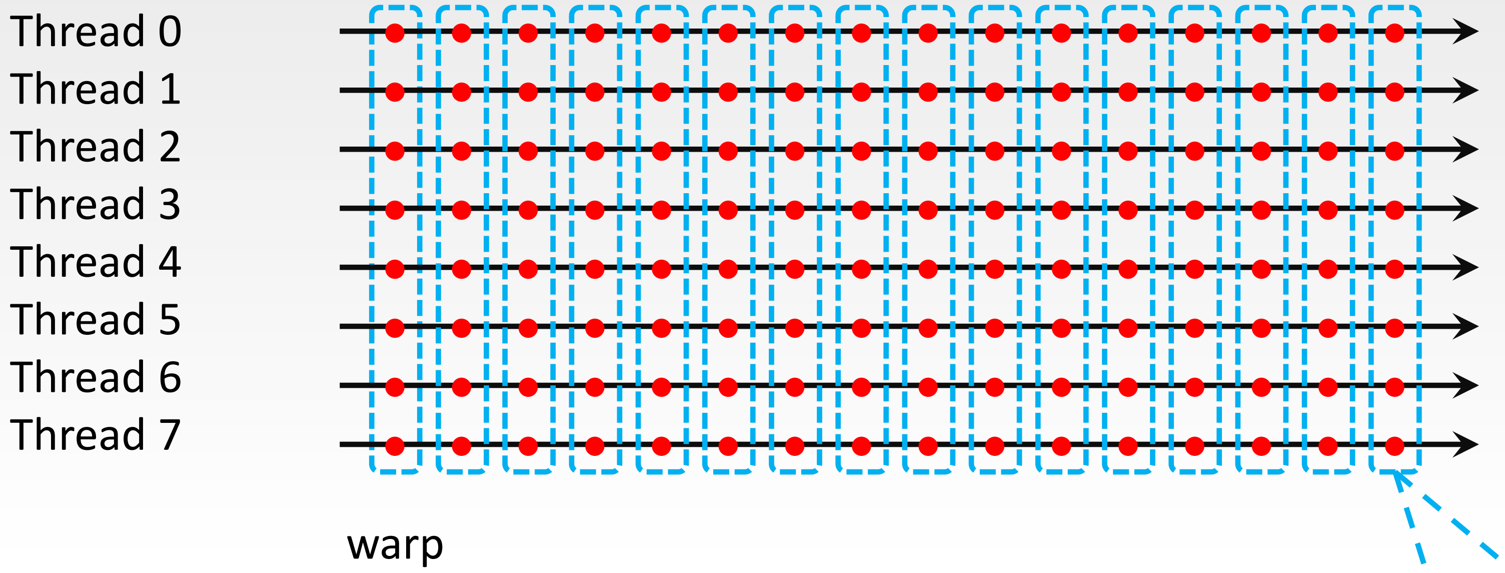
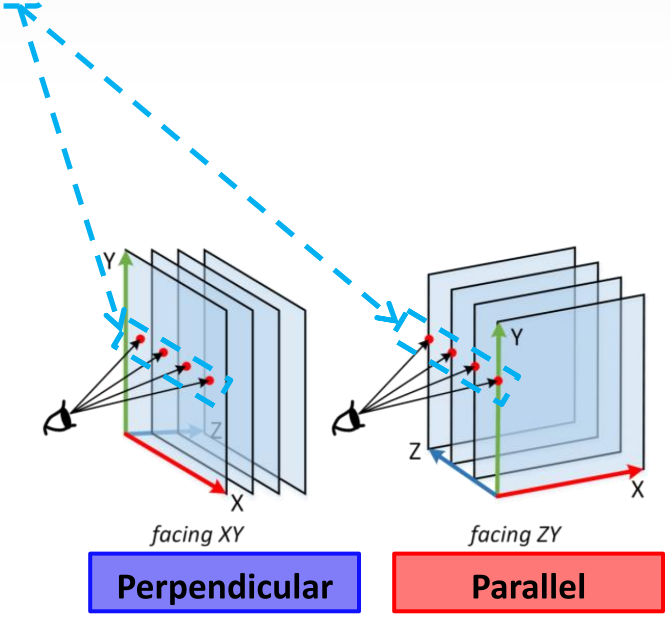
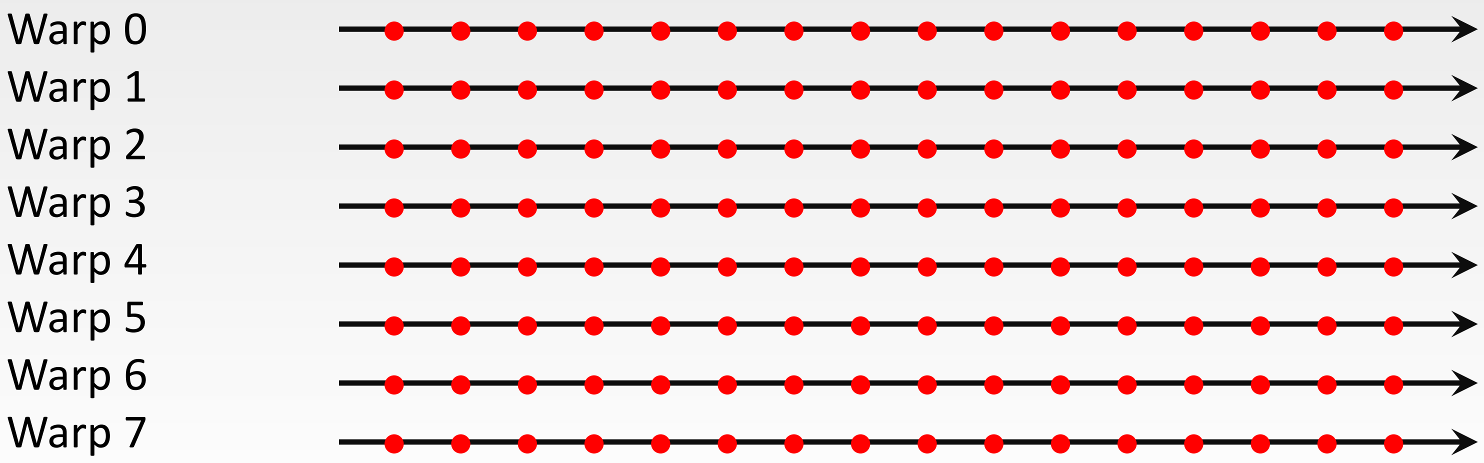


The Standard



Contribution

Map one warp of threads to one ray



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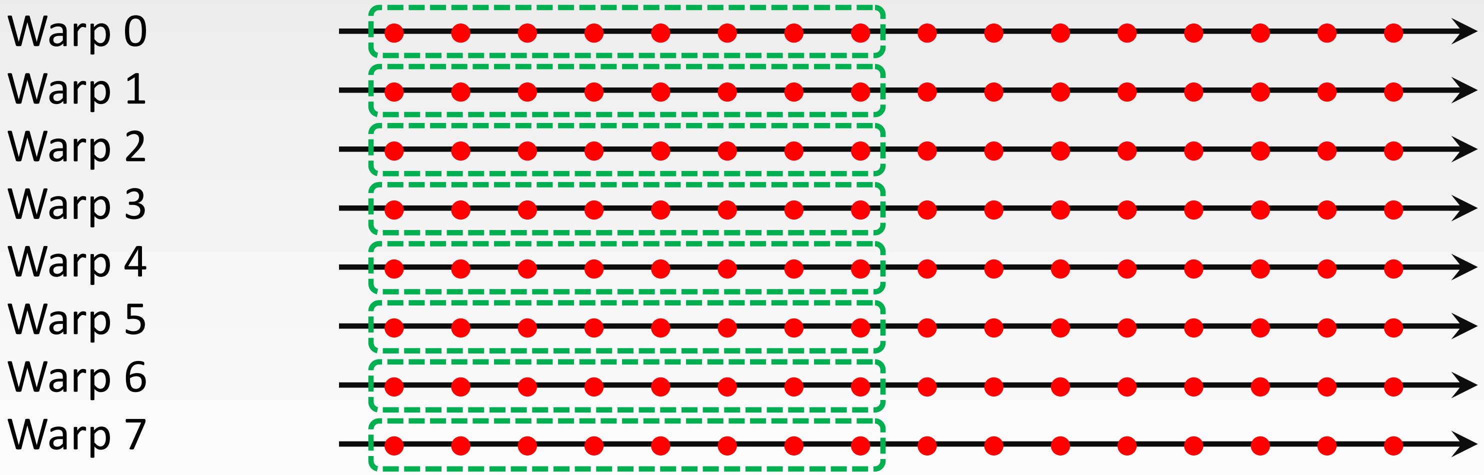

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Warp 6
Warp 7

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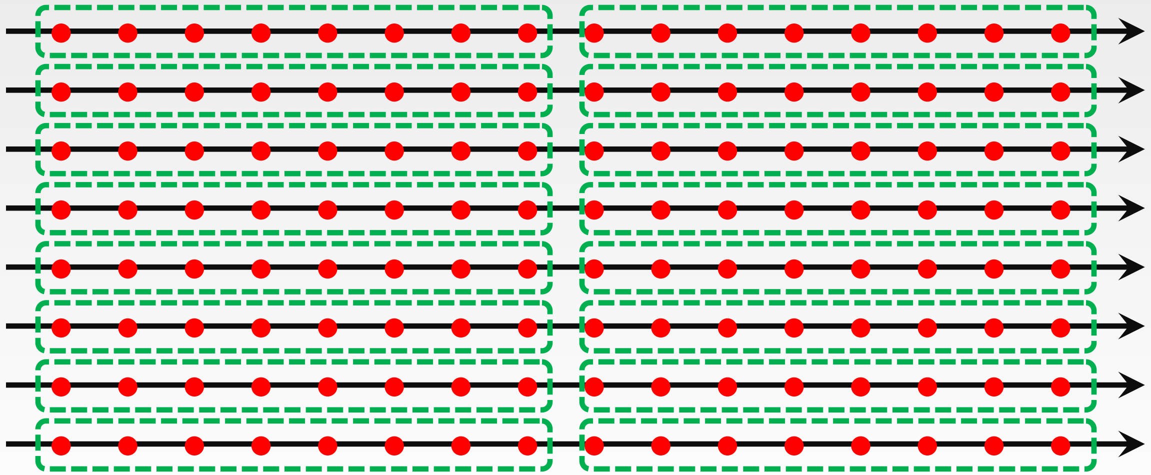

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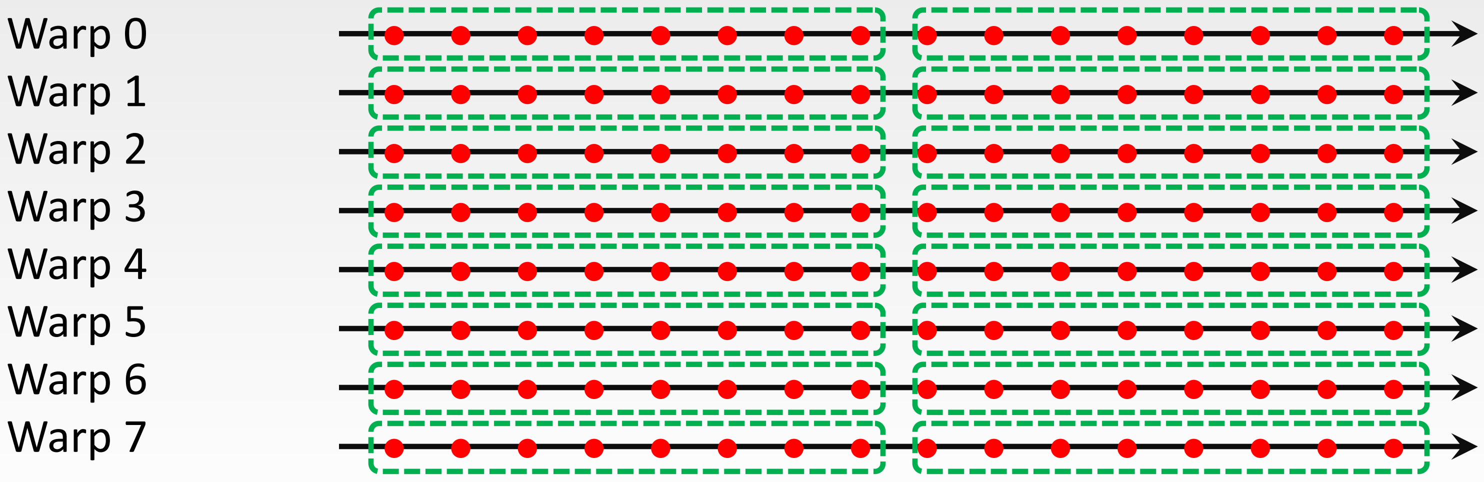

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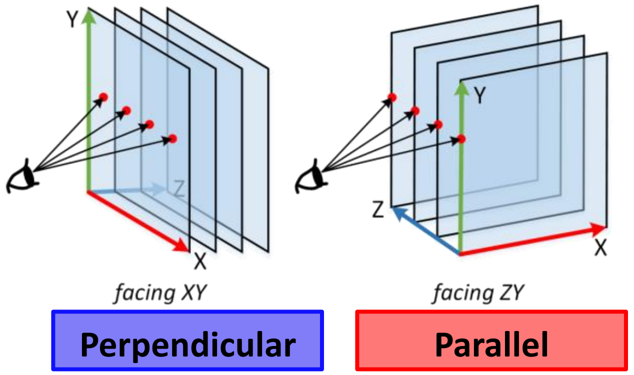

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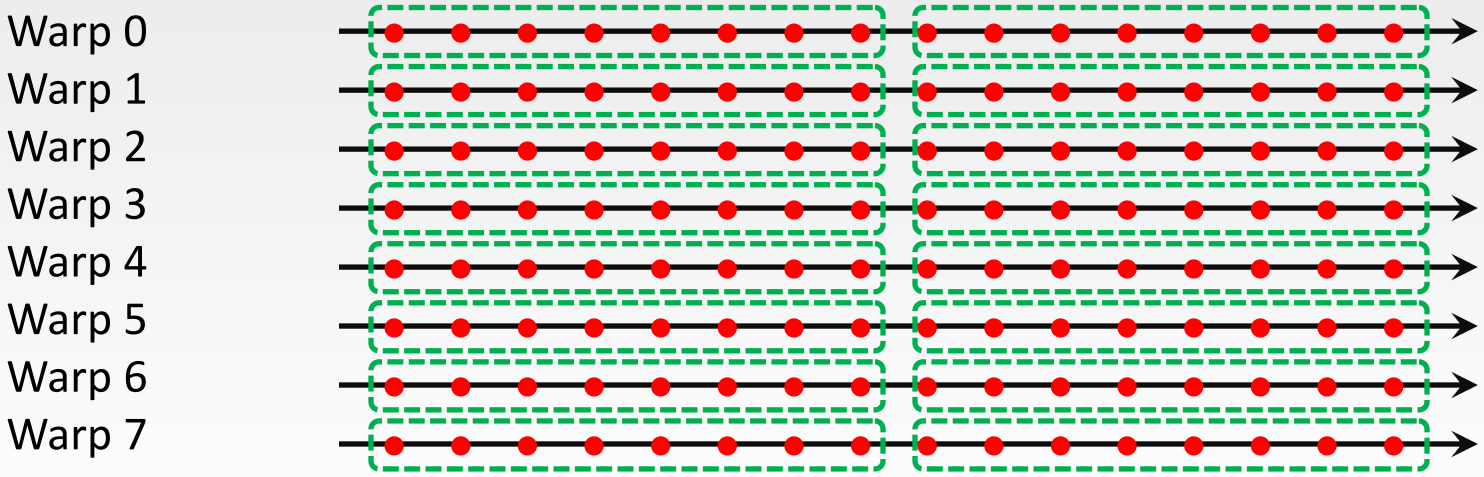
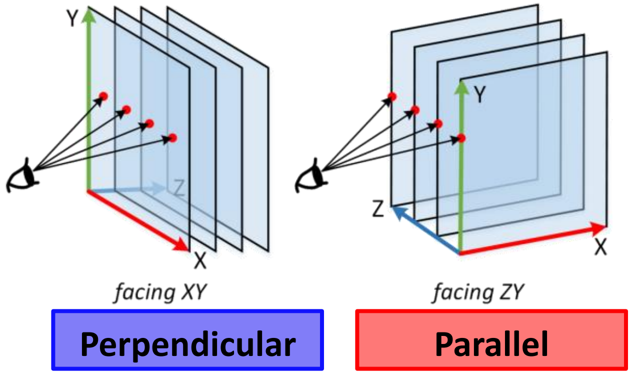


Warp Marching

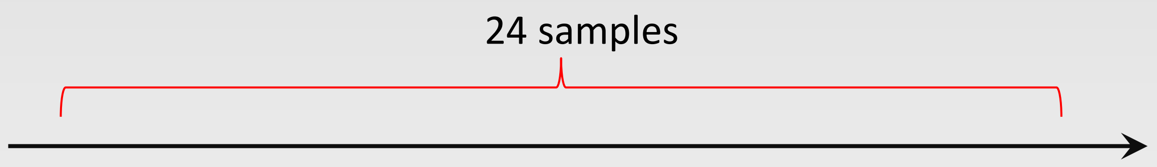


Motivation
Related Work
Contribution
Result
Application

Single Buffer Warp Marching

● *sample*
🟦 *buffer*
🟩 *intermediate result*

Single Buffer Warp Marching



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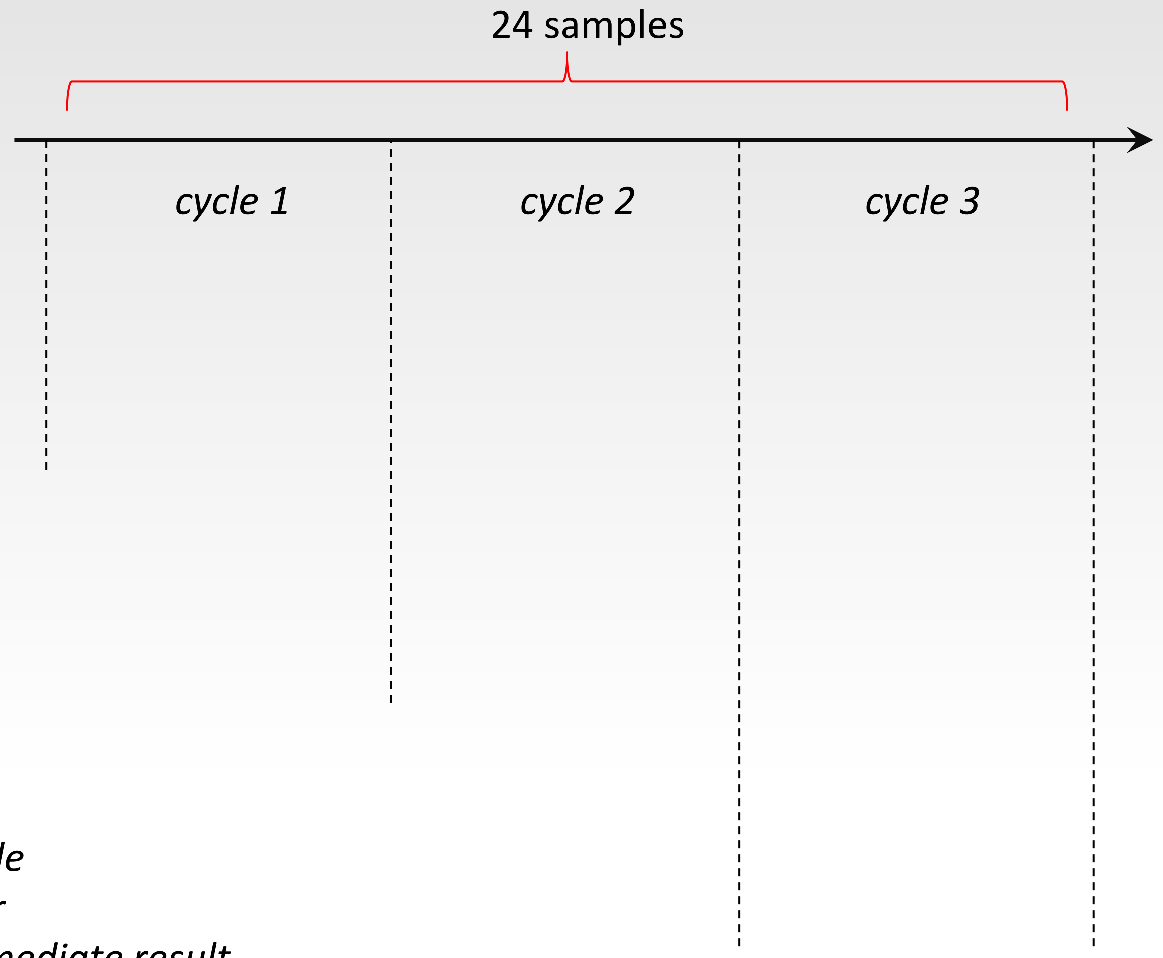

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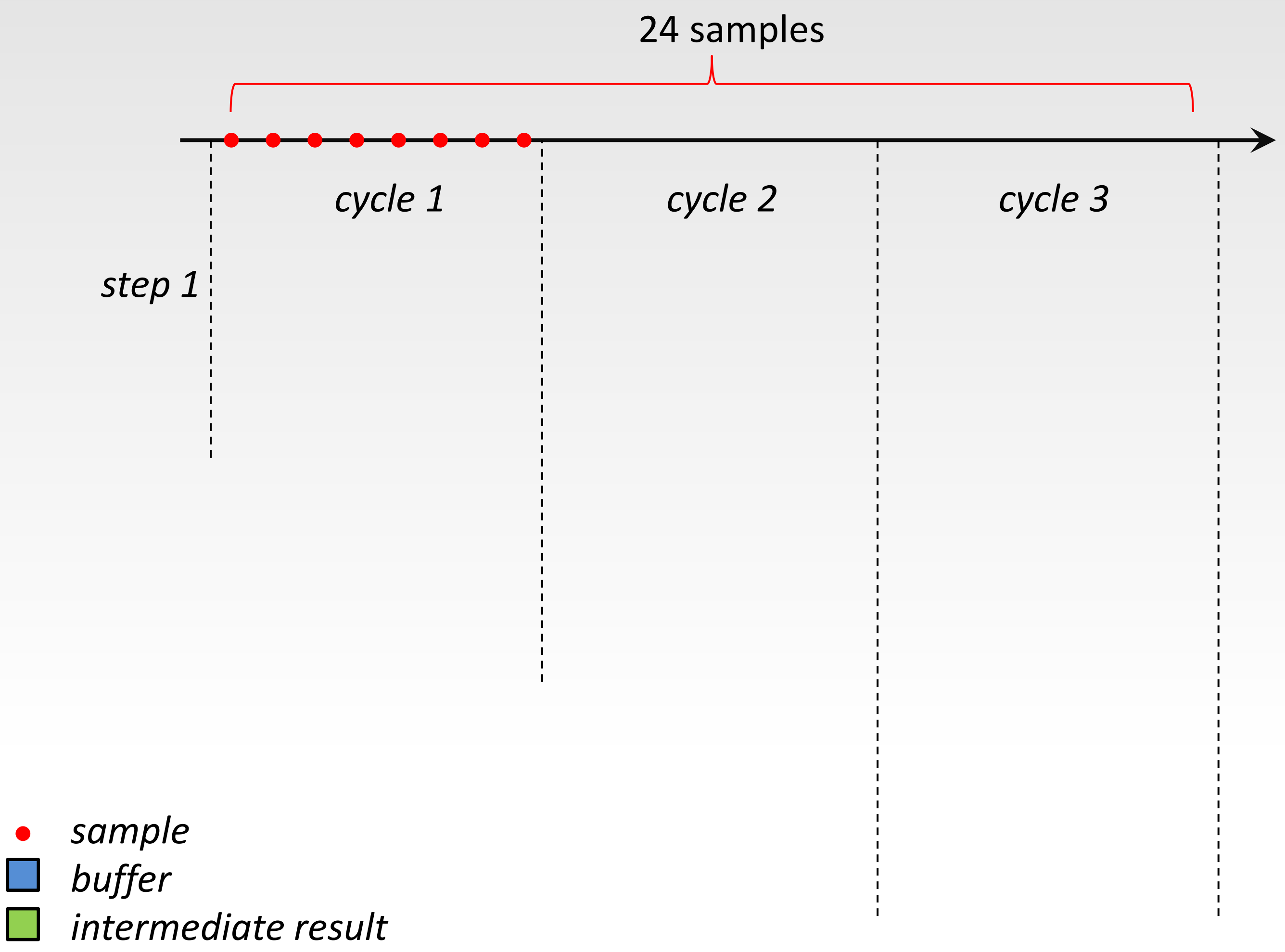
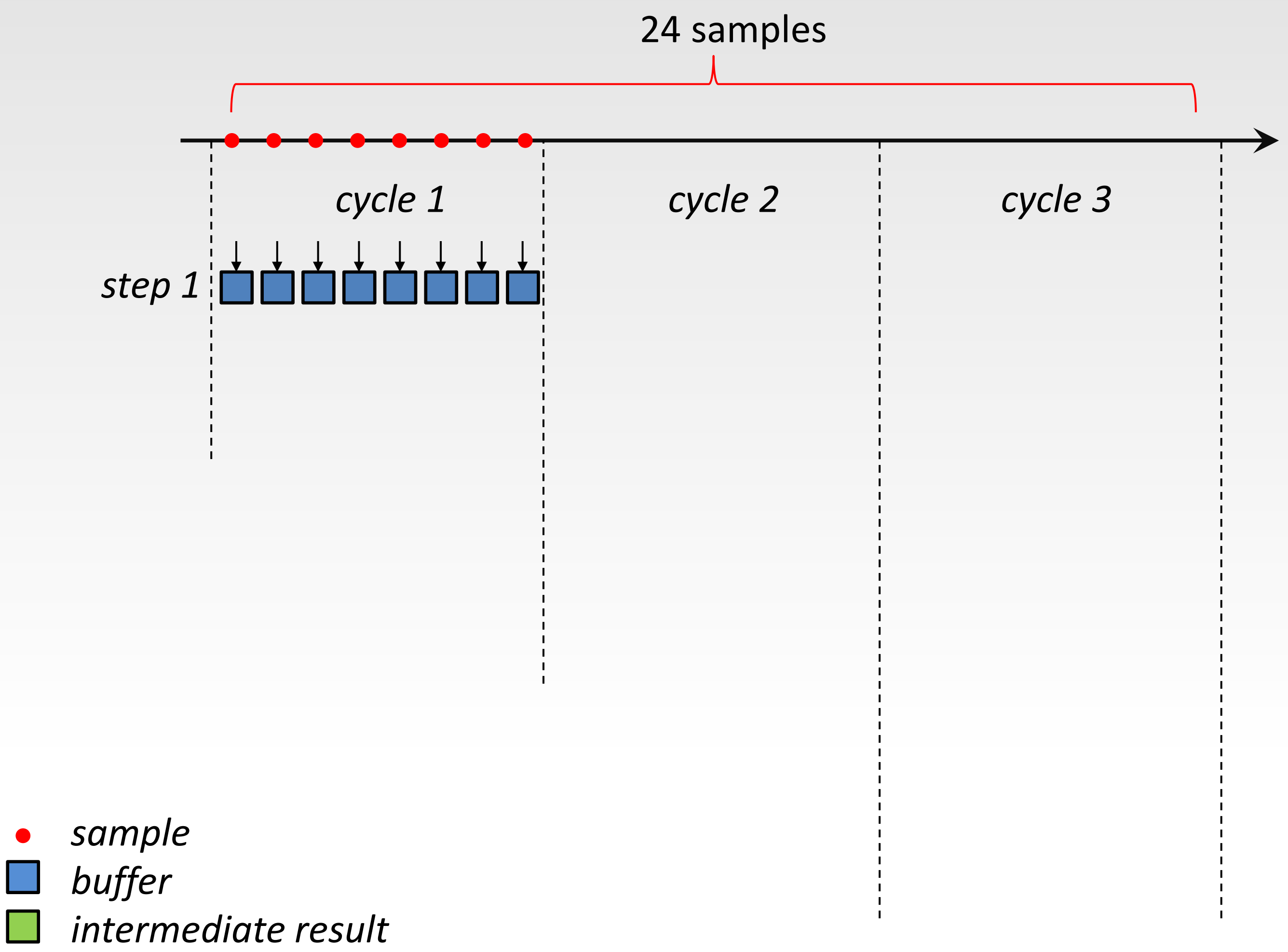
🟩 *intermediate result*

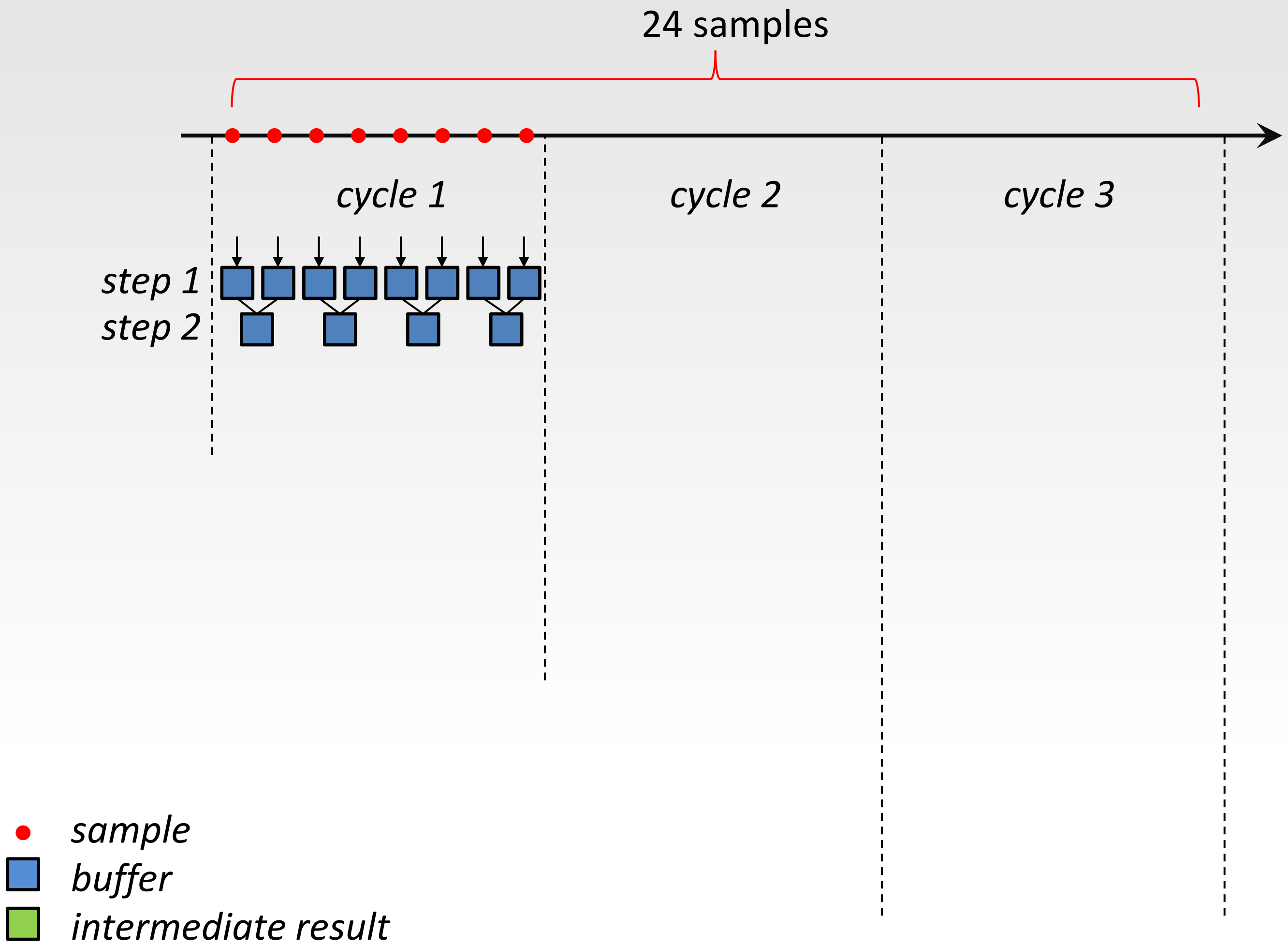
Single Buffer Warp Marching



Single Buffer Warp Marching



Single Buffer Warp Marching



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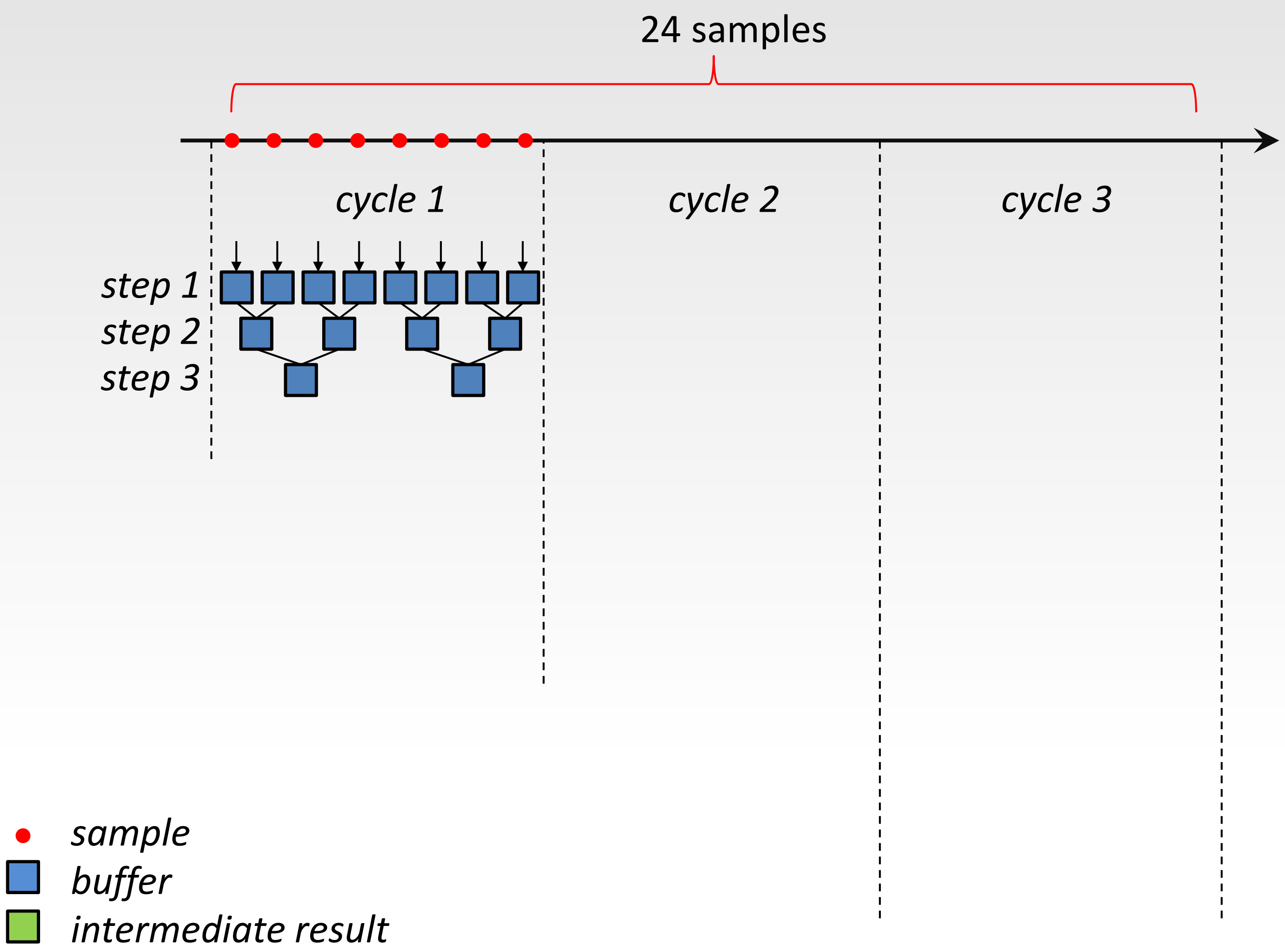
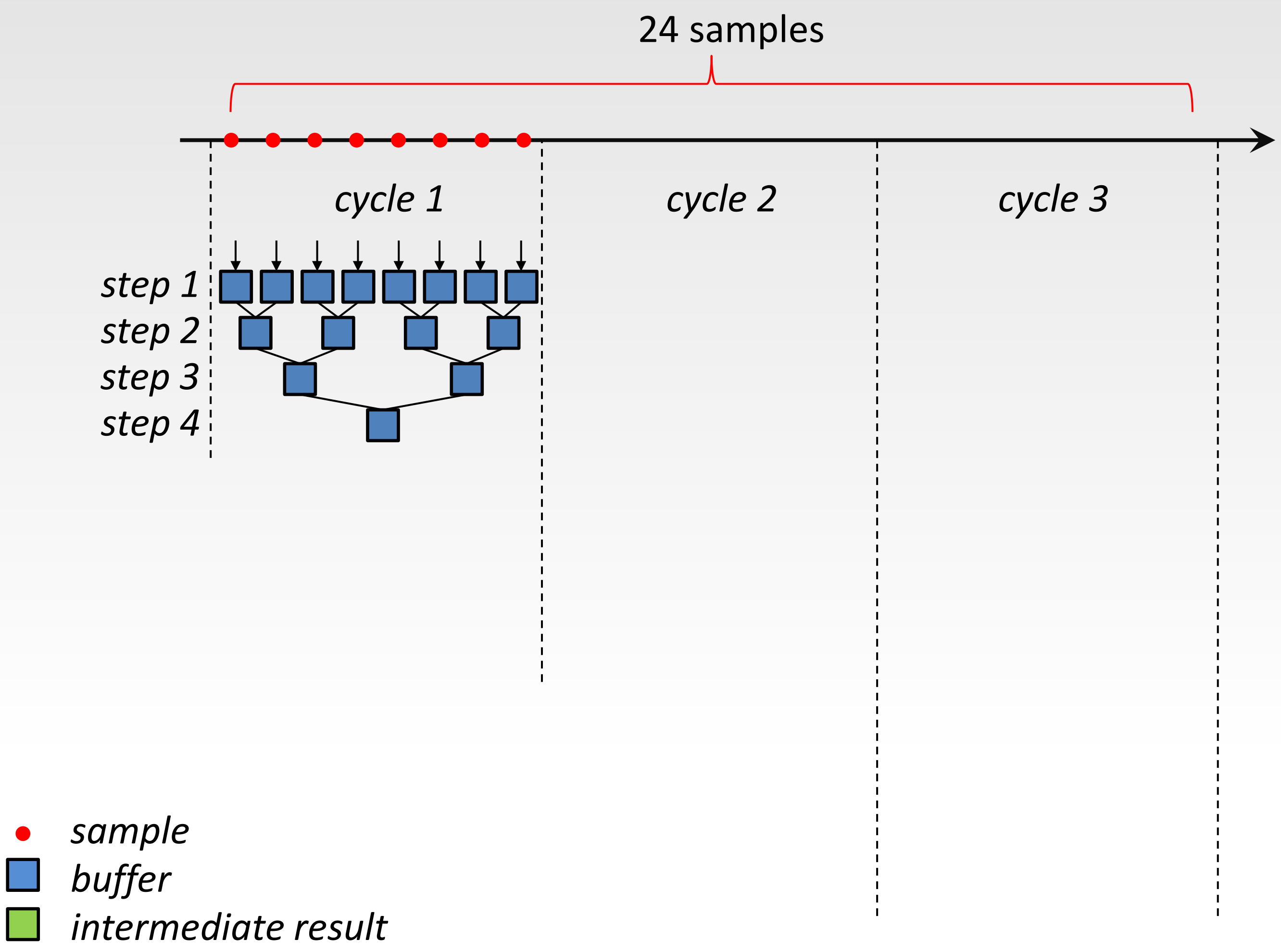
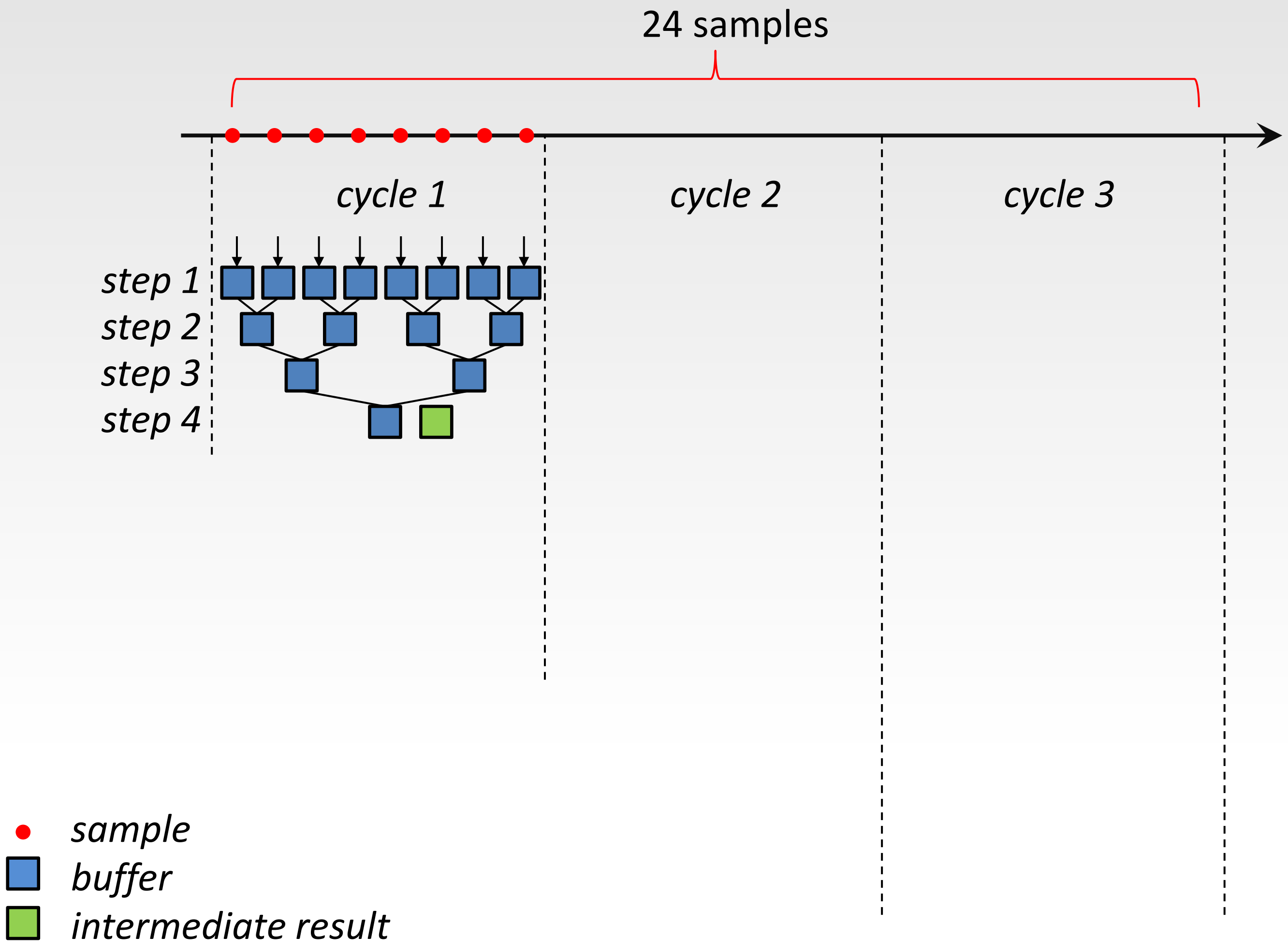
Single Buffer Warp Marching



Single Buffer Warp Marching



Single Buffer Warp Marching



- ● *sample*
- 🟦 *buffer*
- 🟩 *intermediate result*

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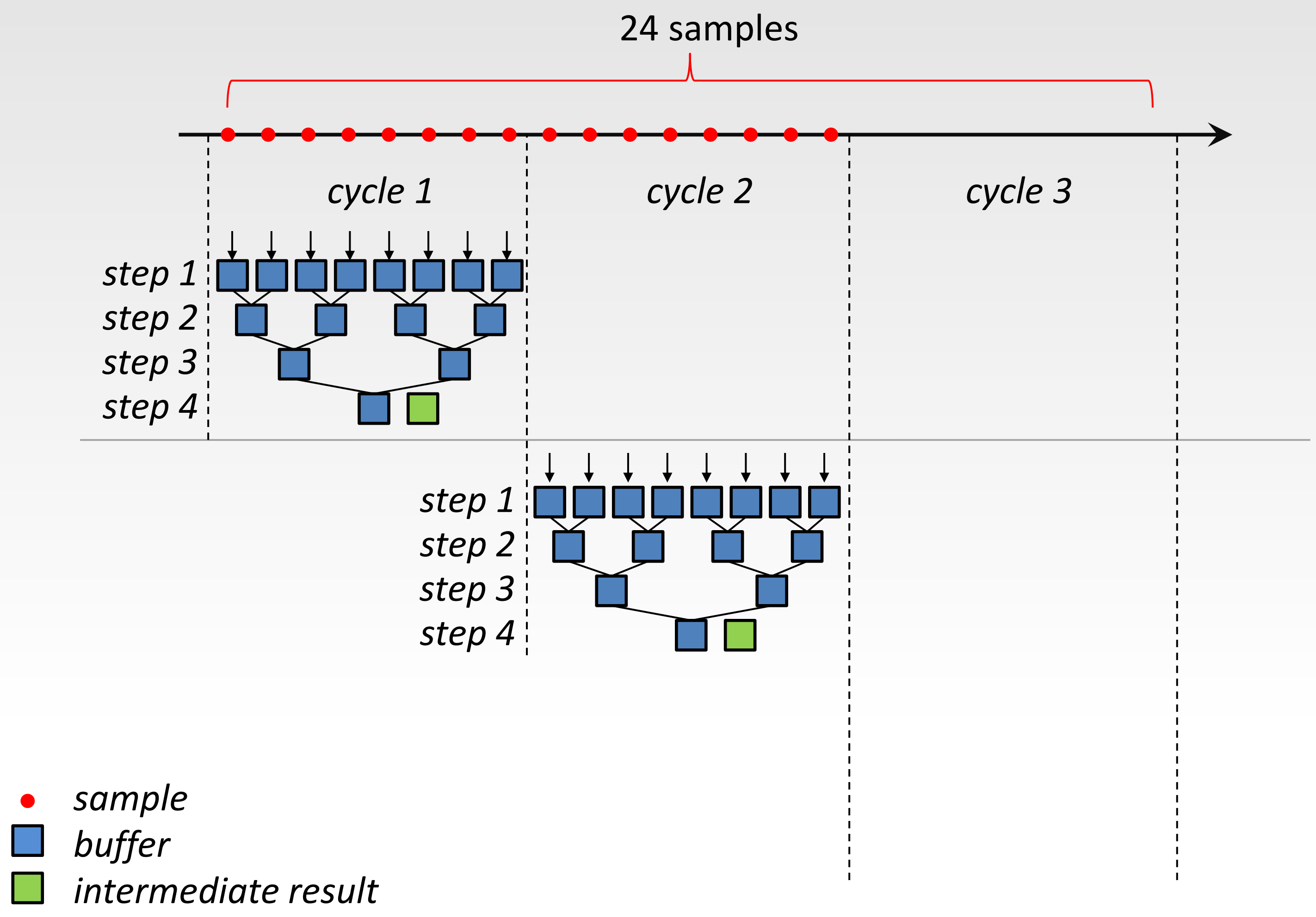
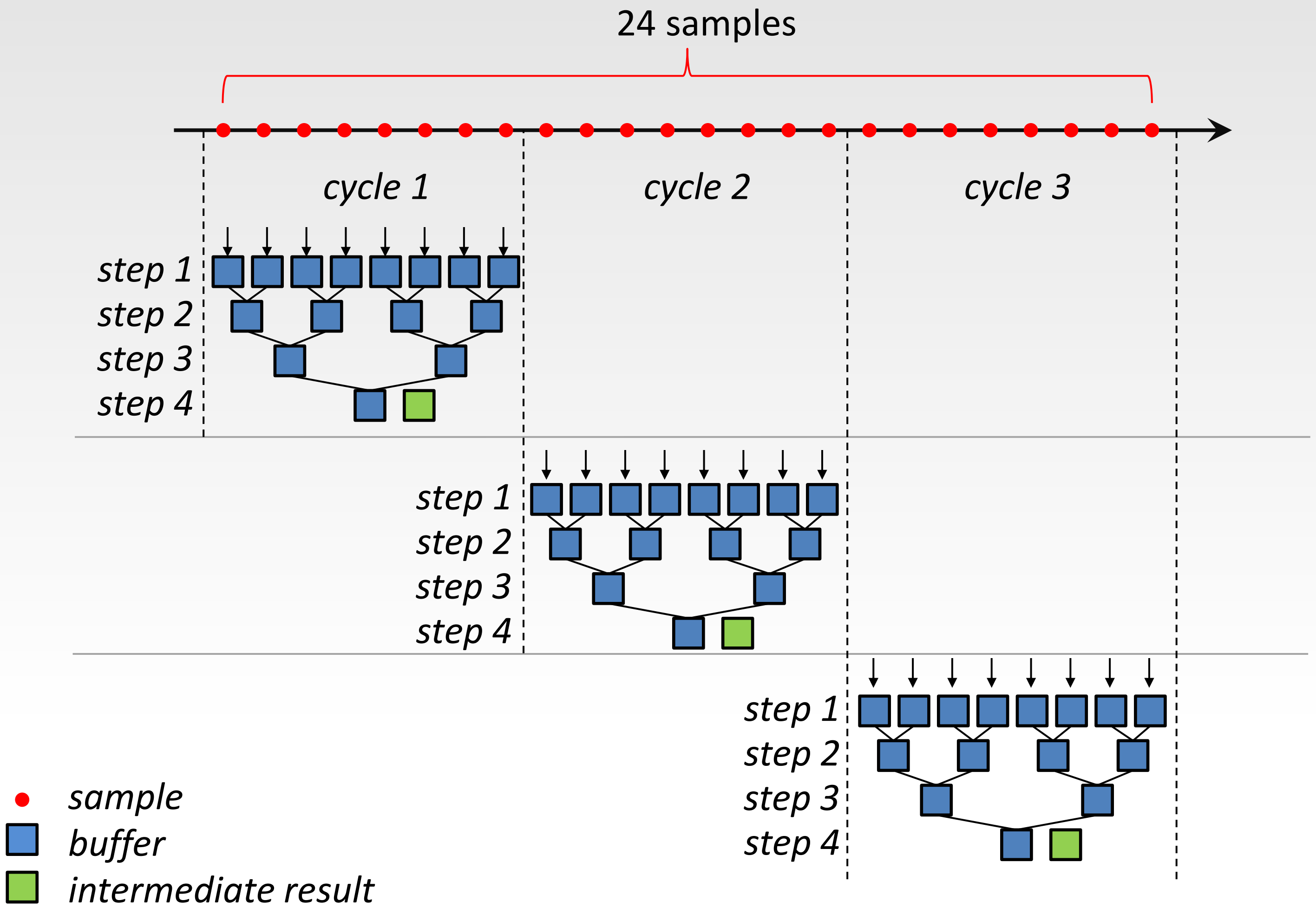
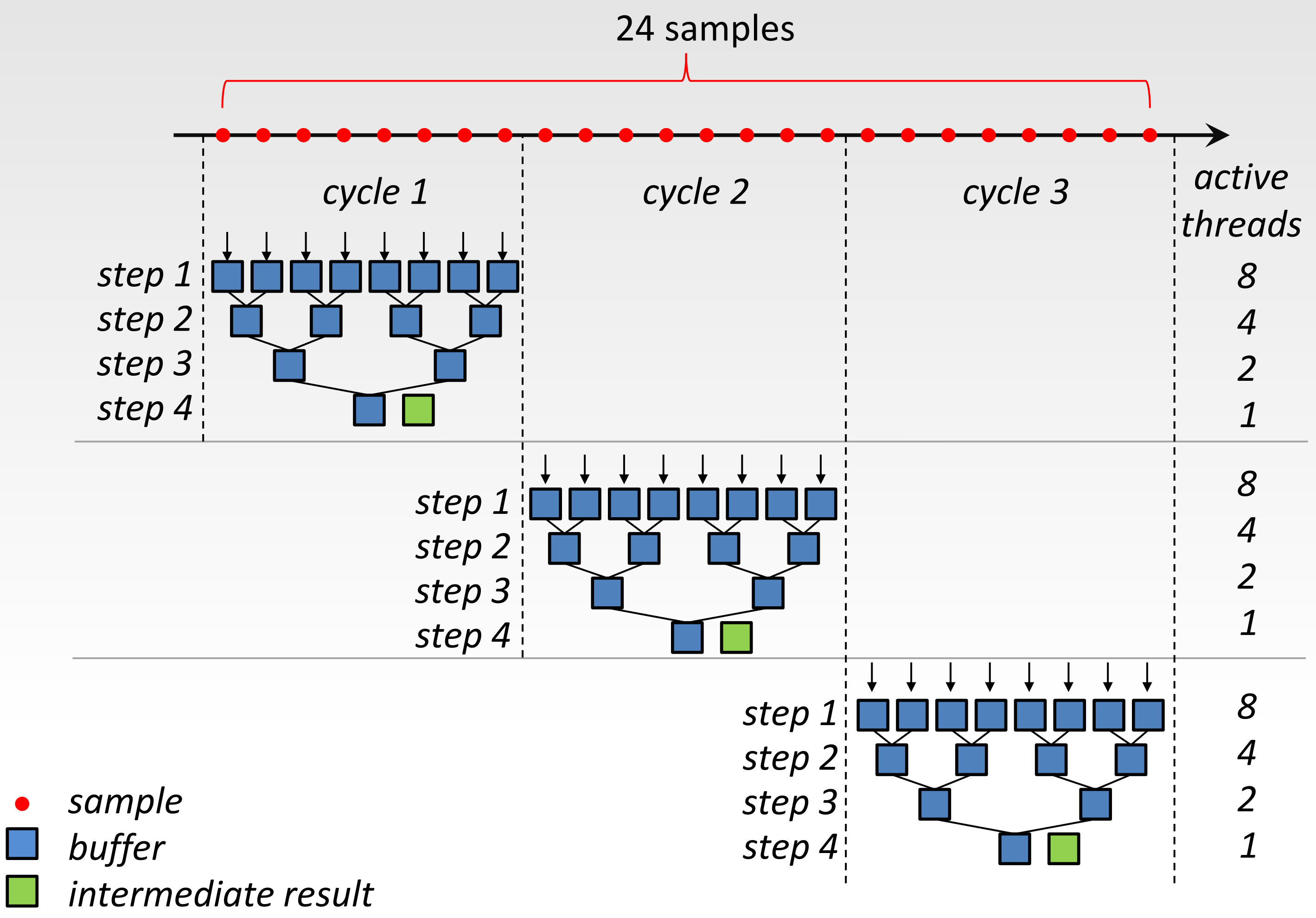


Single Buffer Warp Marching



Single Buffer Warp Marching



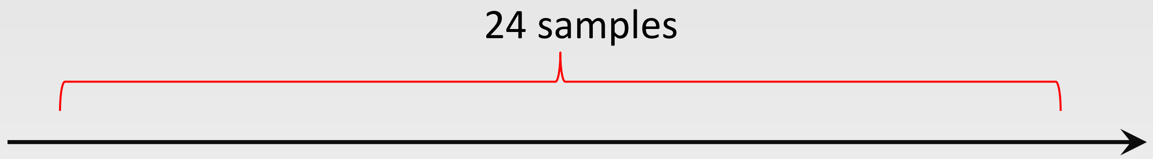
Double Buffer Warp Marching

● *sample*

🟦 *buffer 1*

🟩 *buffer 2*

Double Buffer Warp Marching



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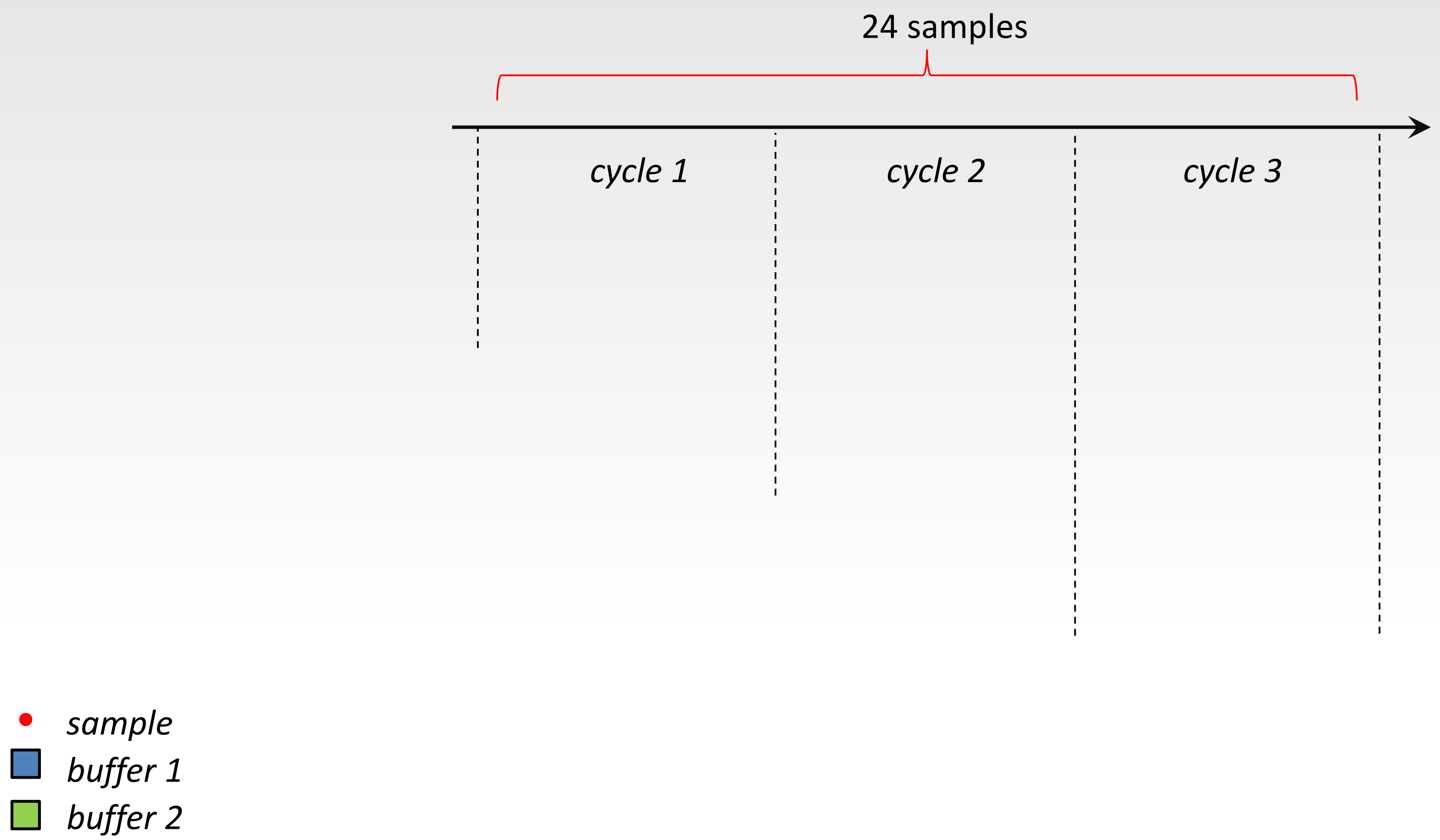
🟦 *buffer 1*

🟩 *buffer 2*

Double Buffer Warp Marching



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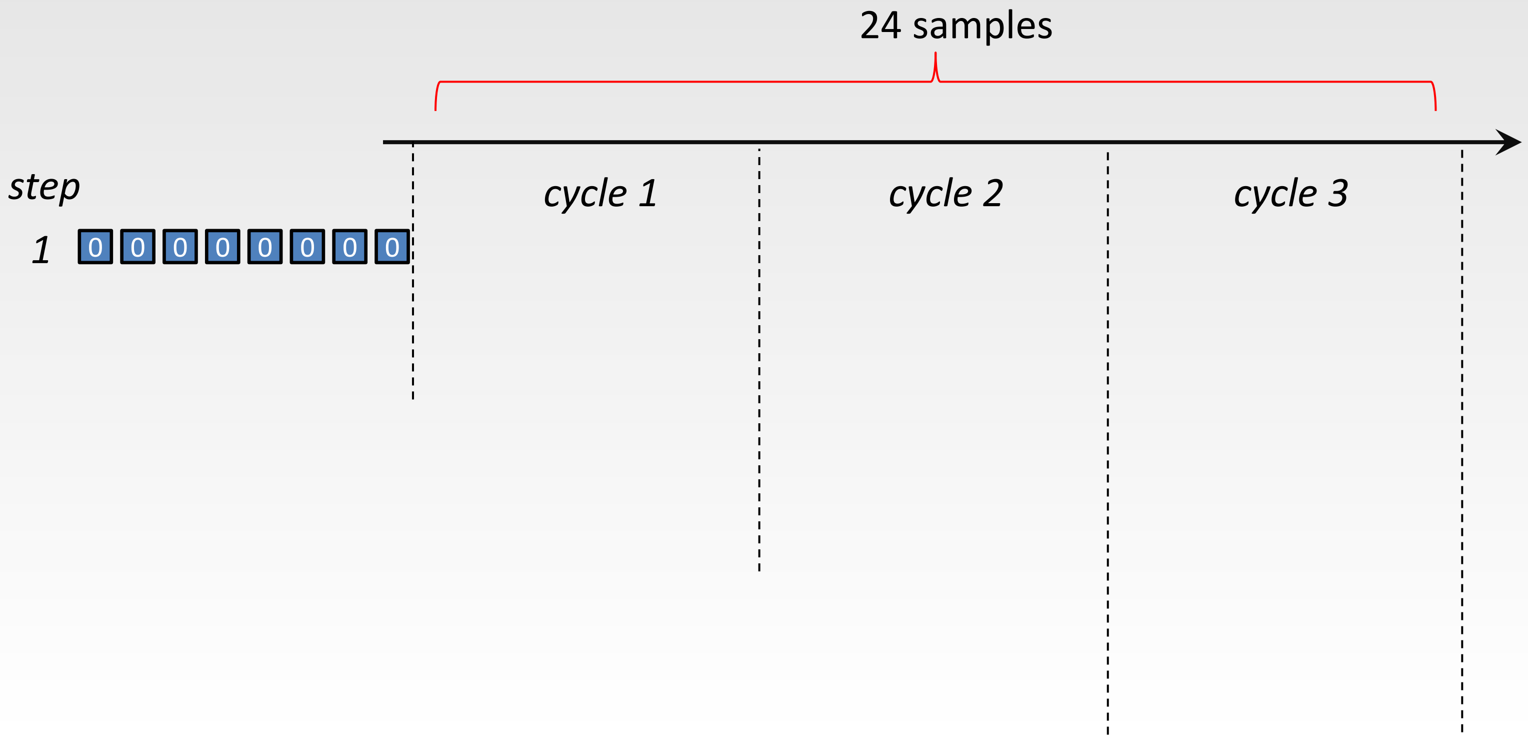
Double Buffer Warp Marching



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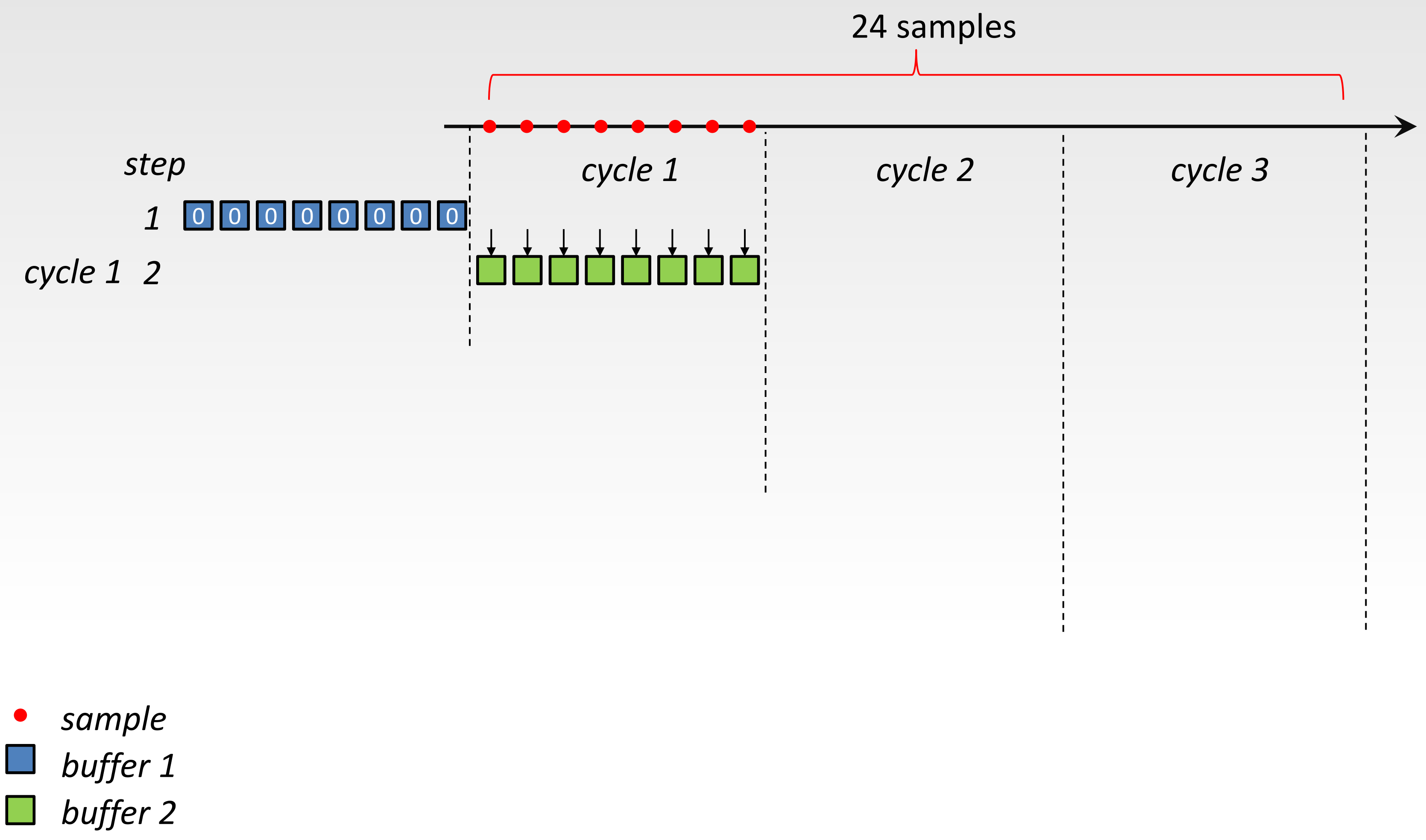
Double Buffer Warp Marching



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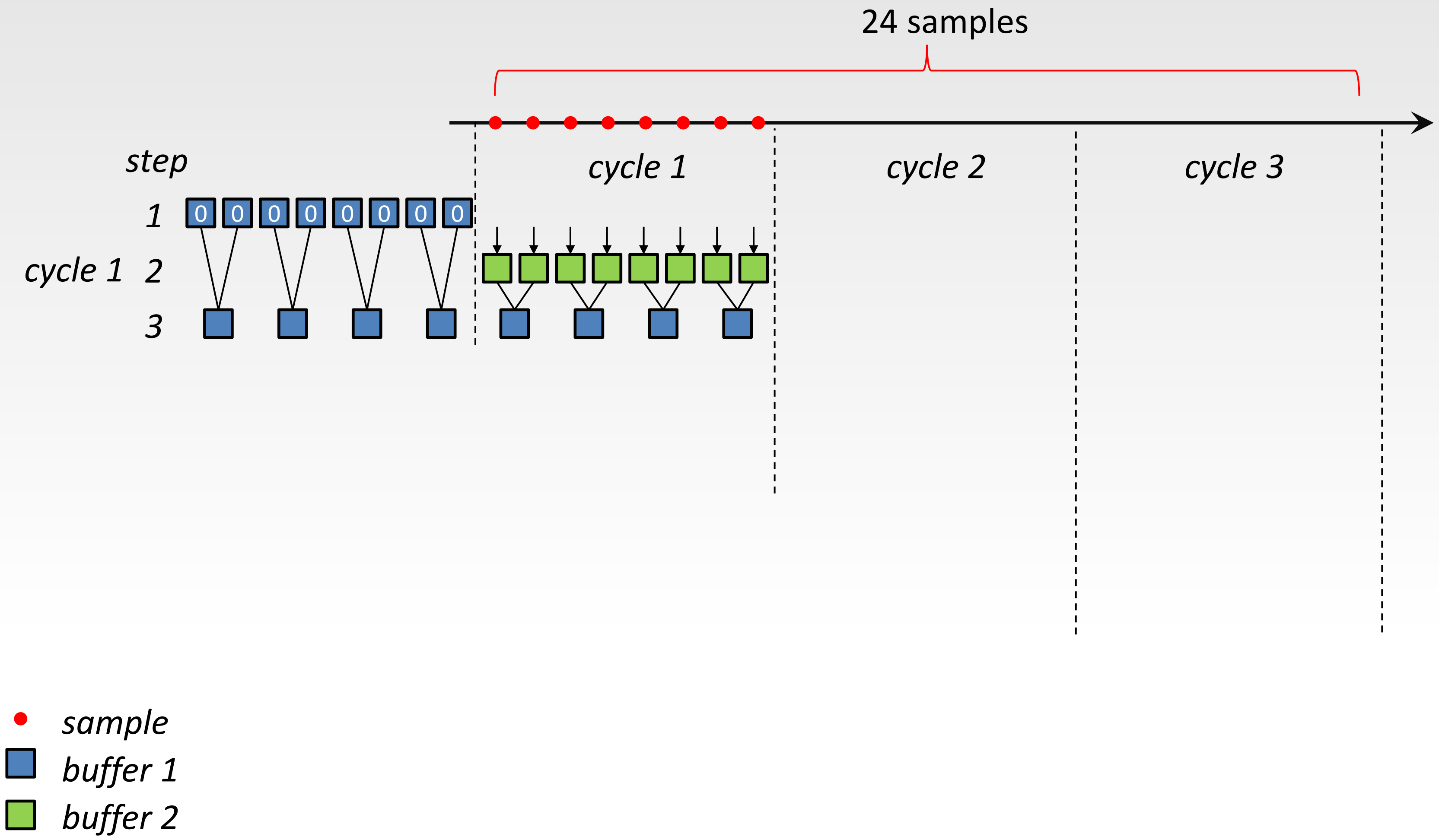
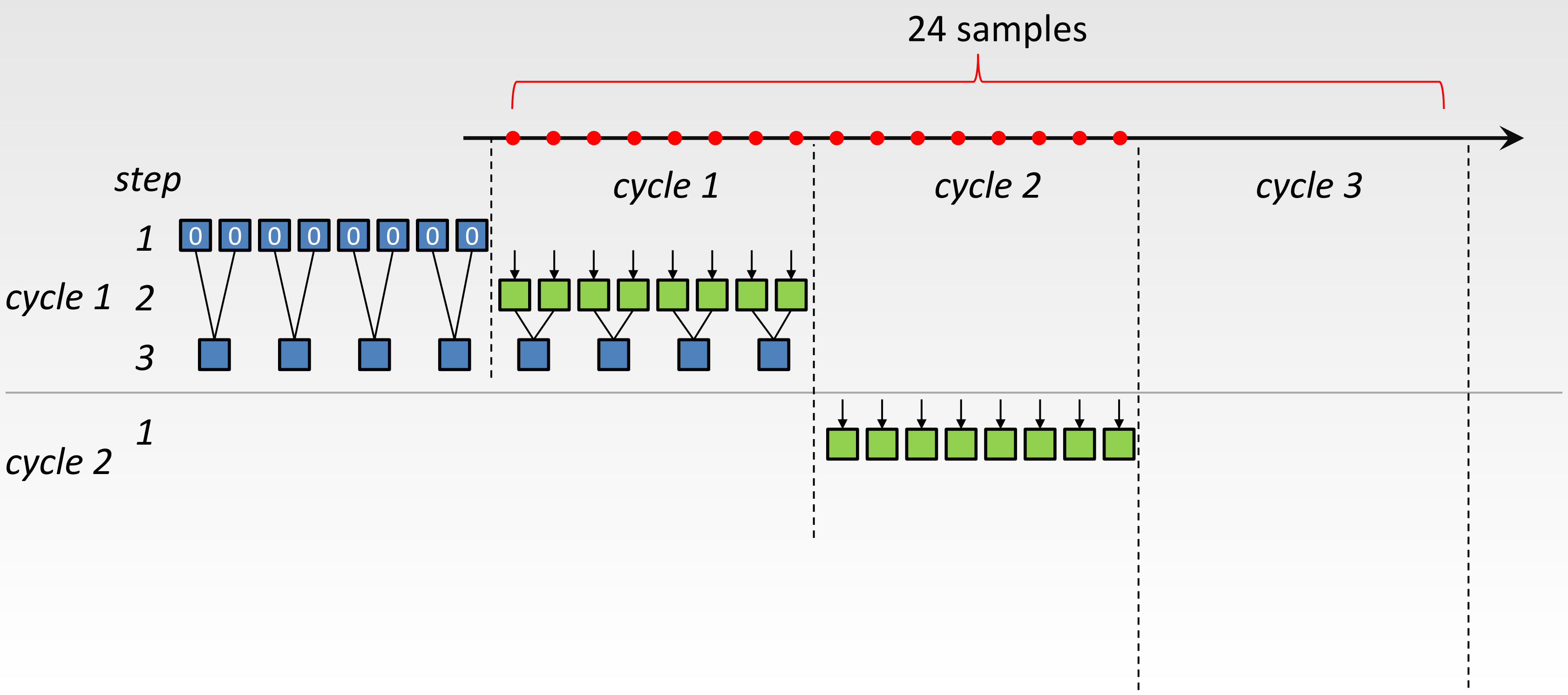
Double Buffer Warp Marching



Double Buffer Warp Marching



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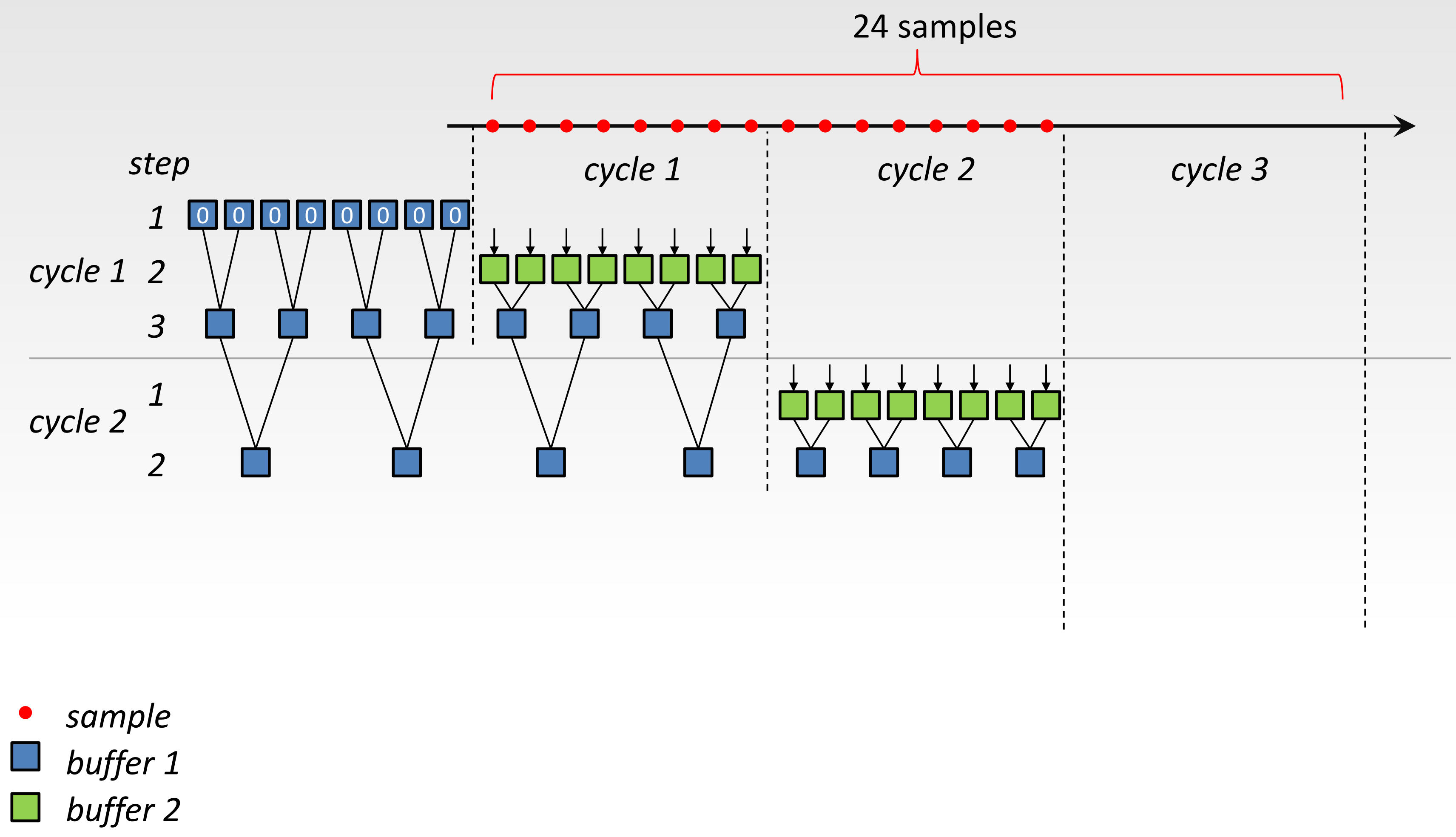
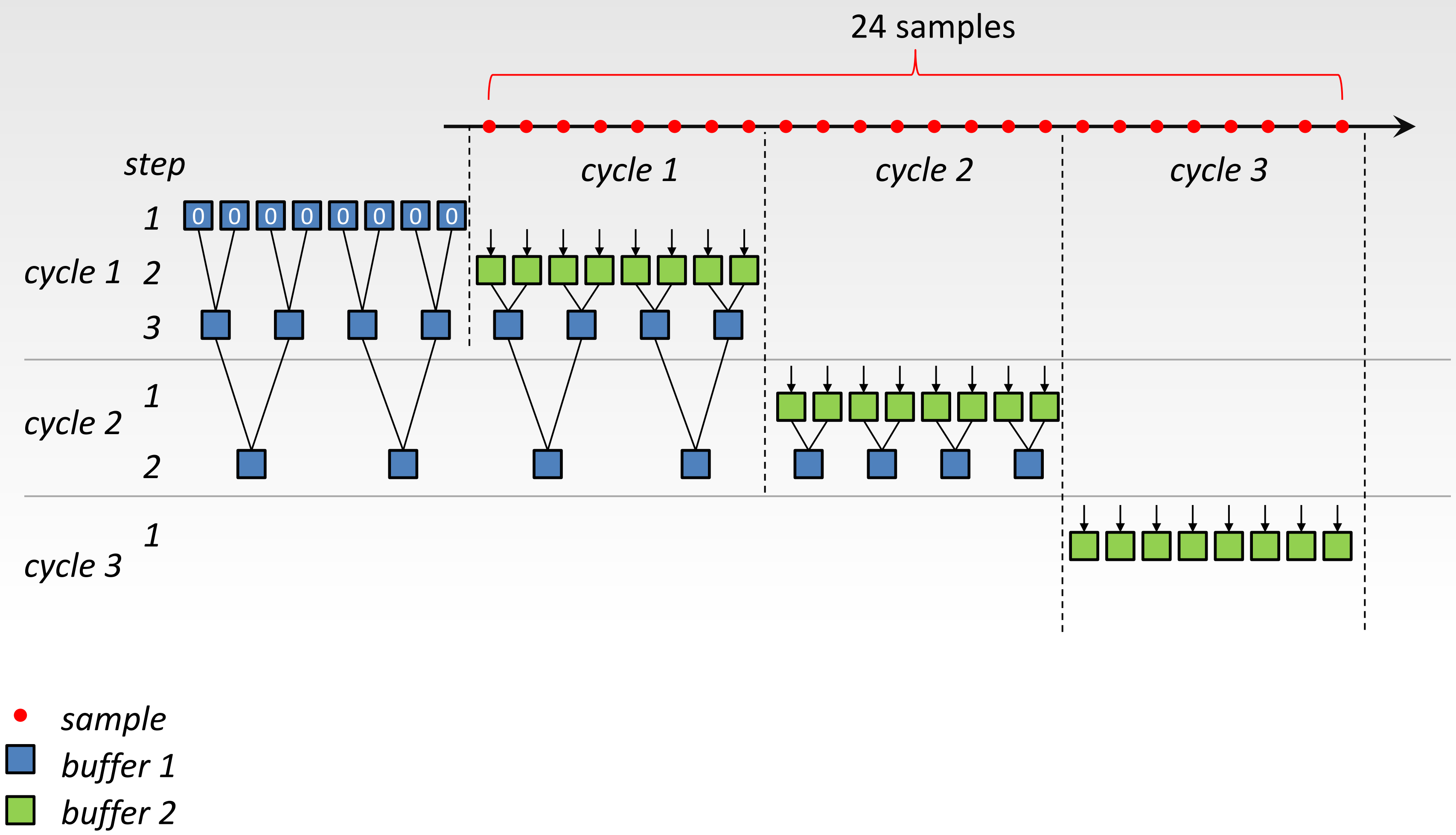
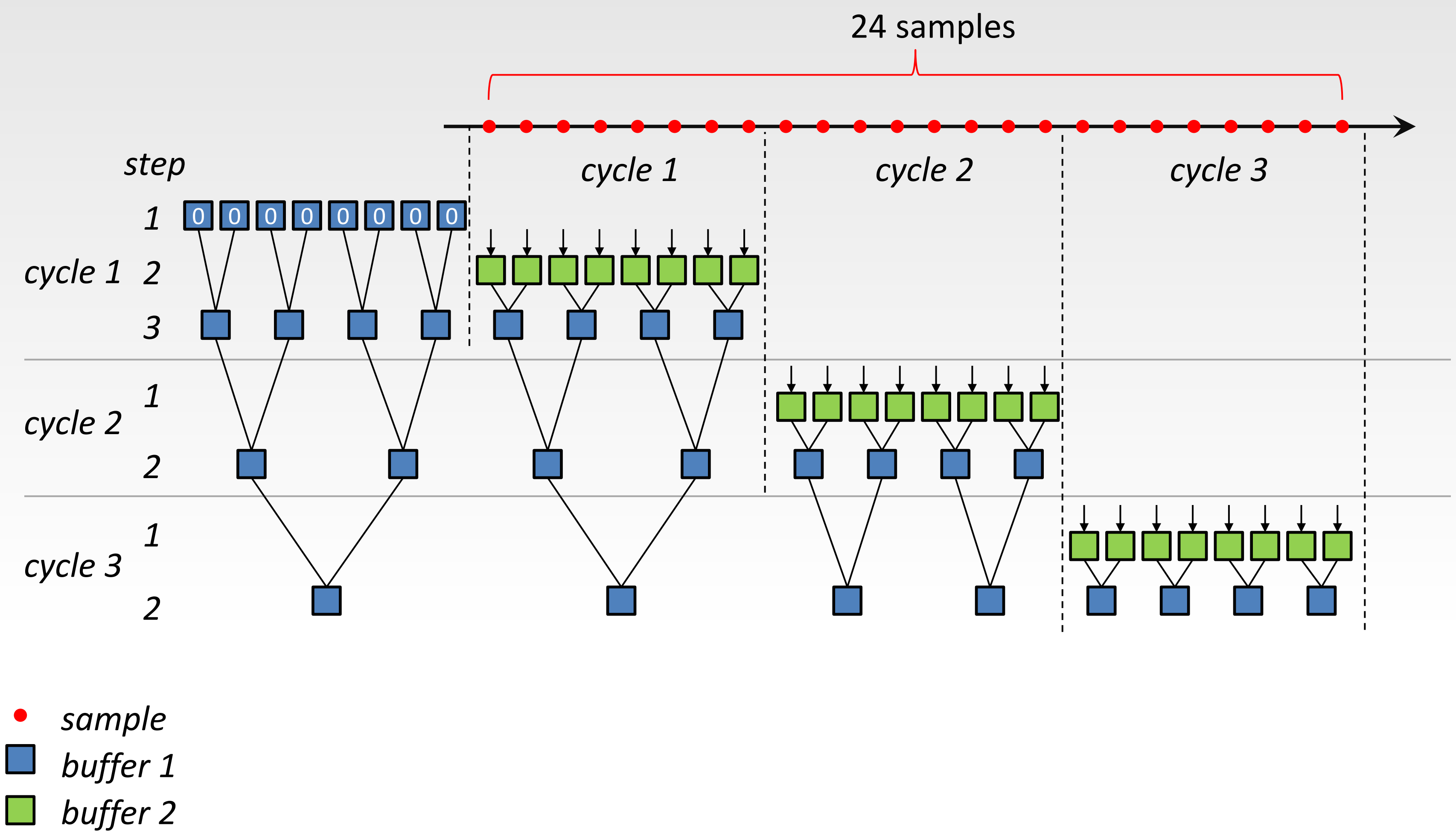


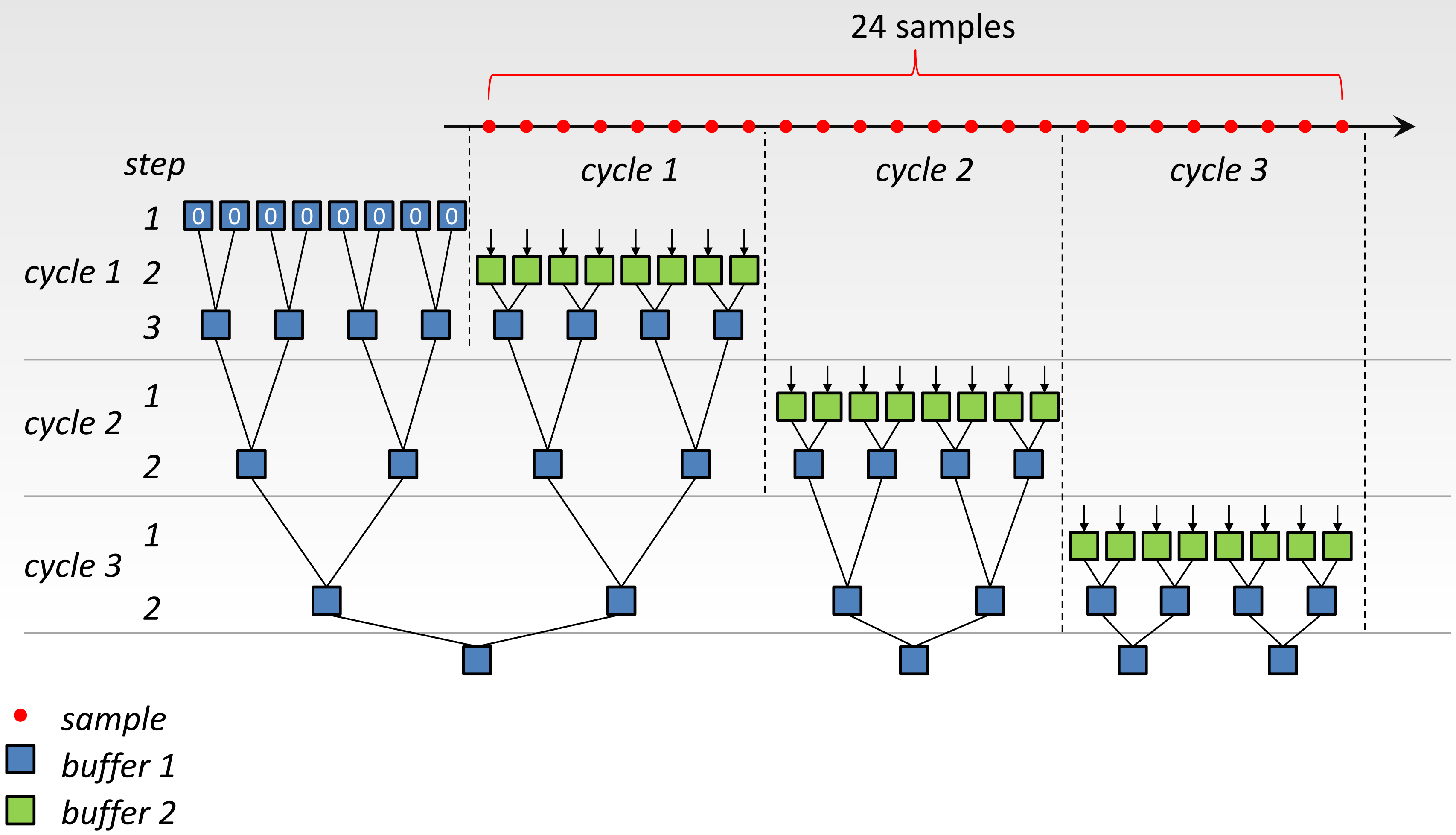
Double Buffer Warp Marching



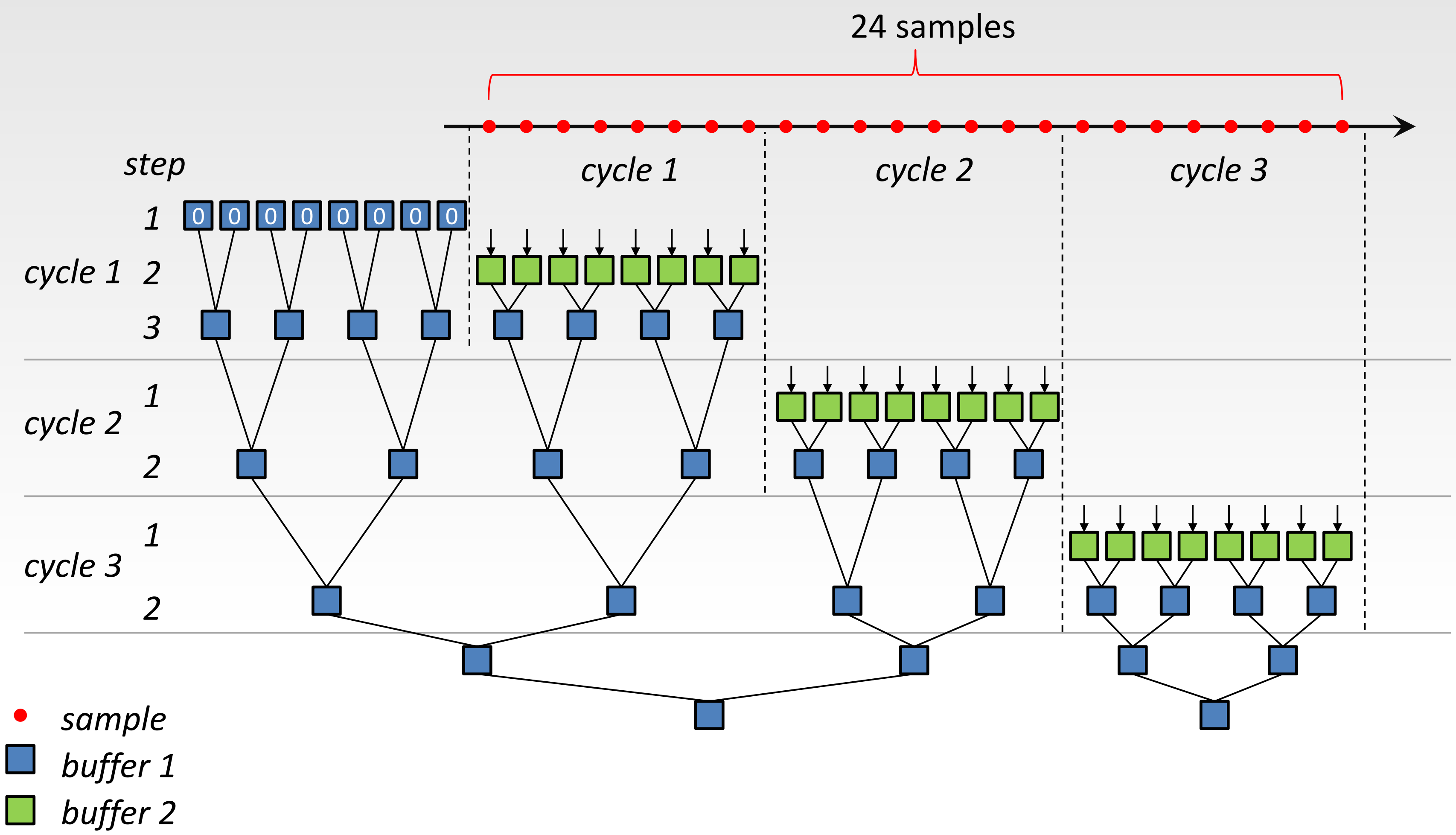
Double Buffer Warp Marching



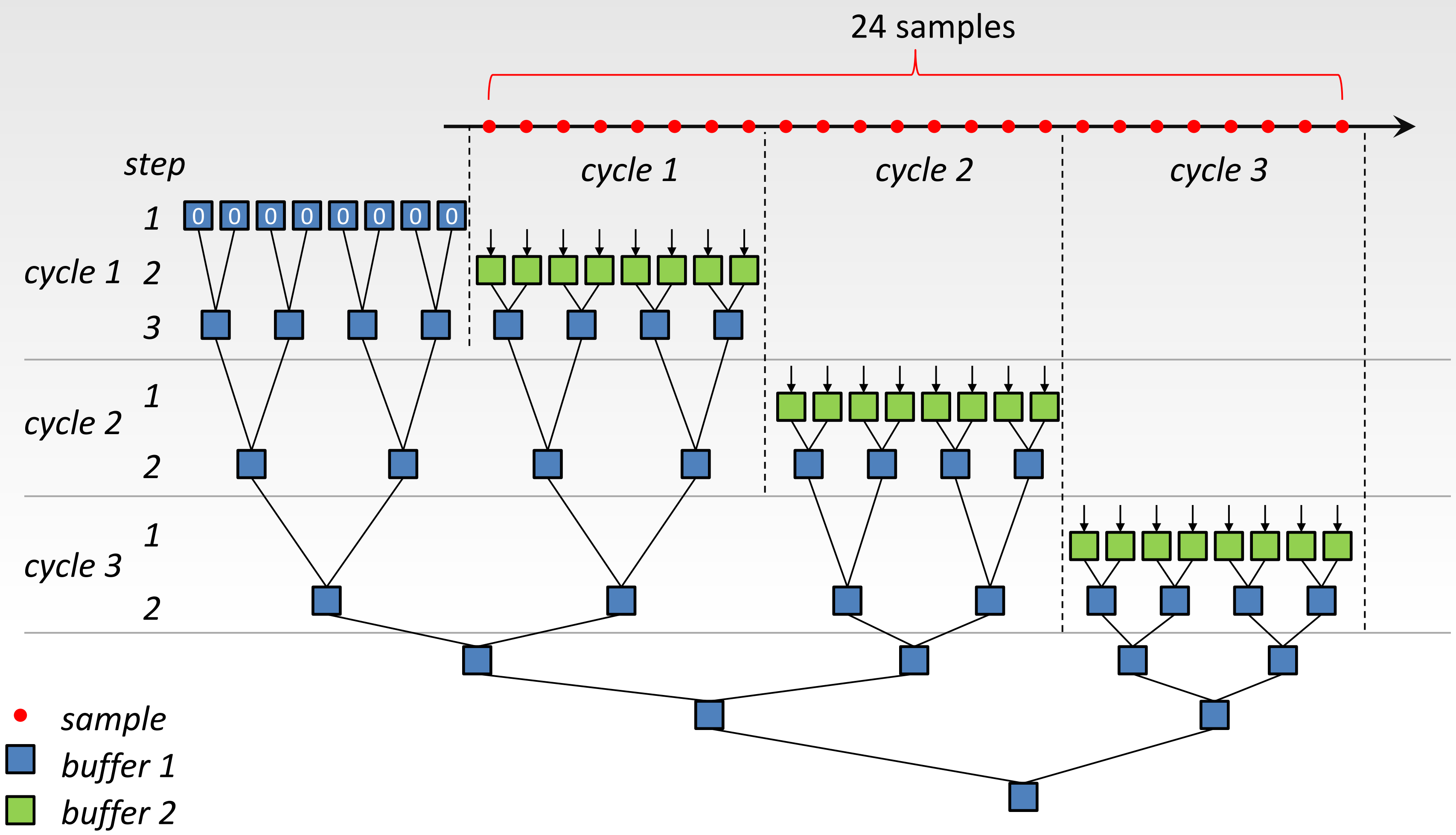
Double Buffer Warp Marching



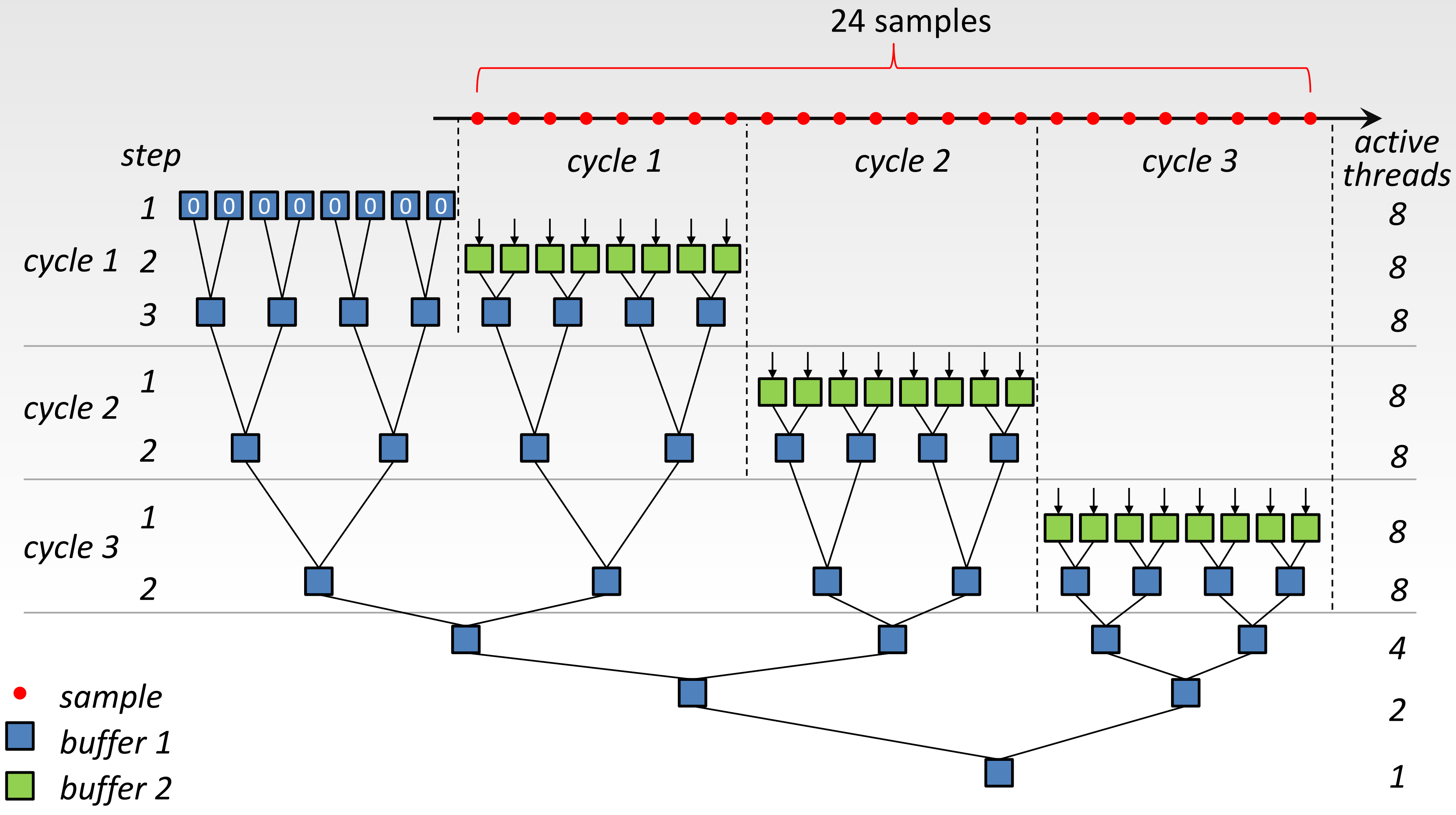
Double Buffer Warp Marching



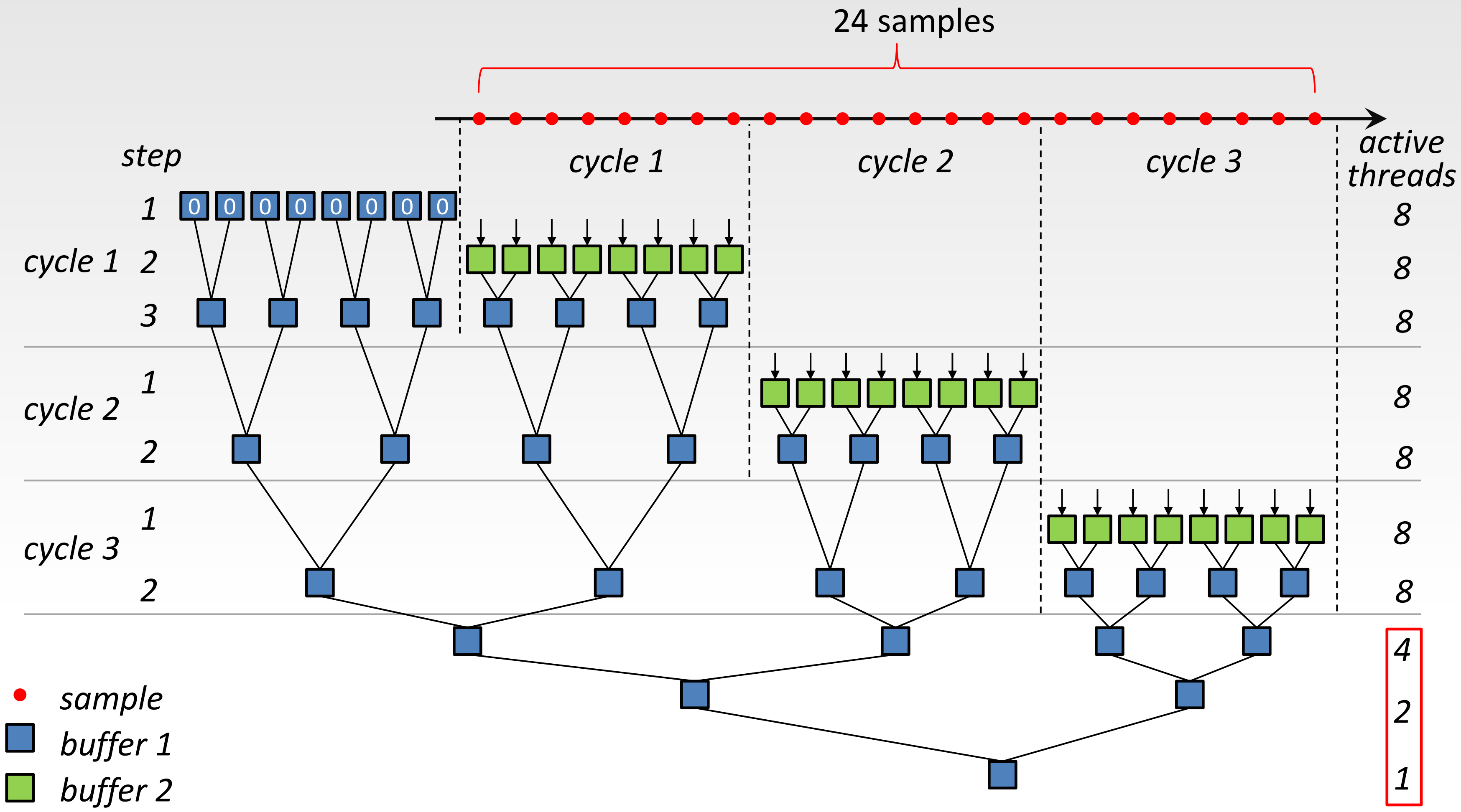
Double Buffer Warp Marching



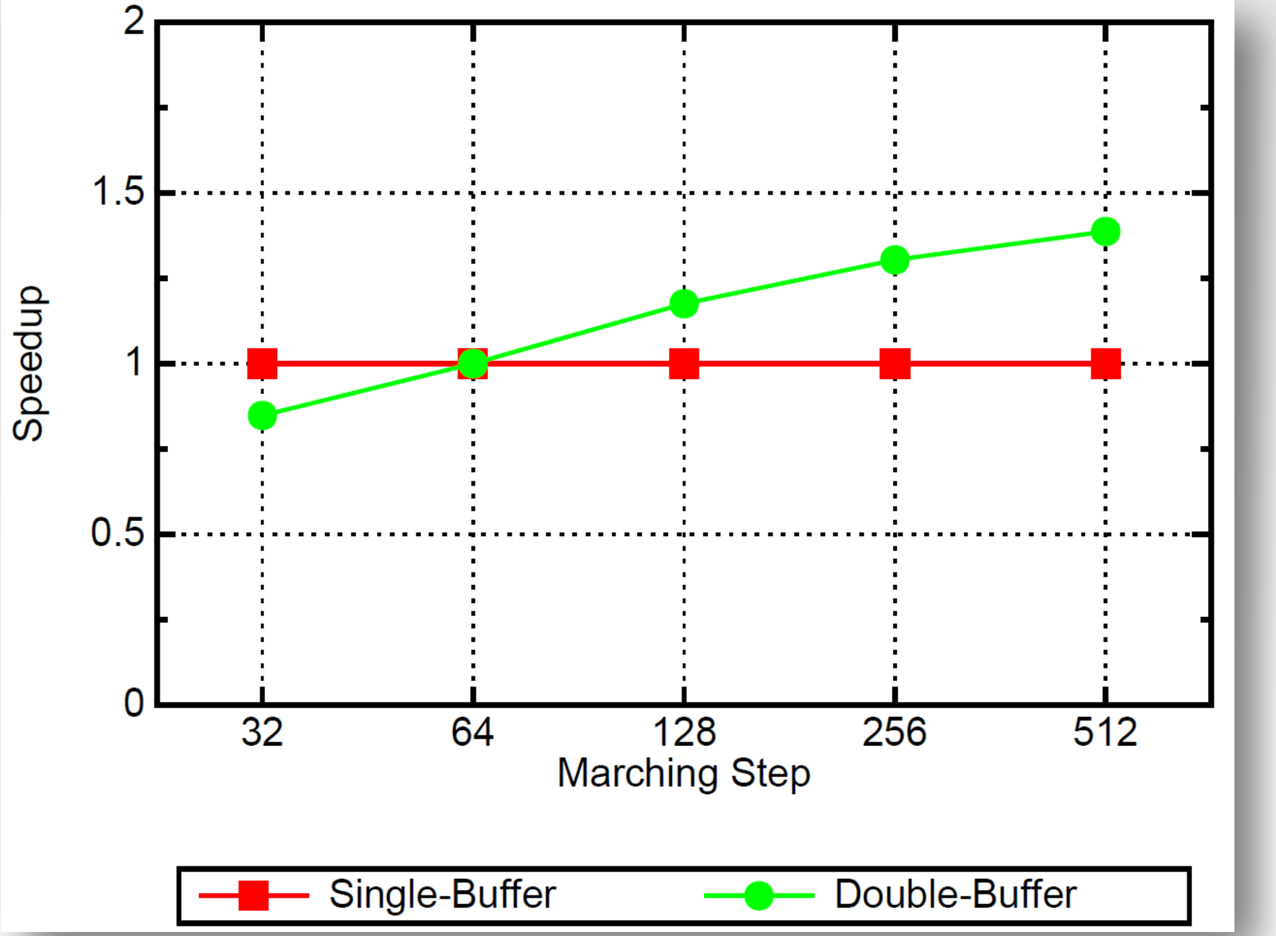
Double Buffer Warp Marching



Double Buffer Warp Marching

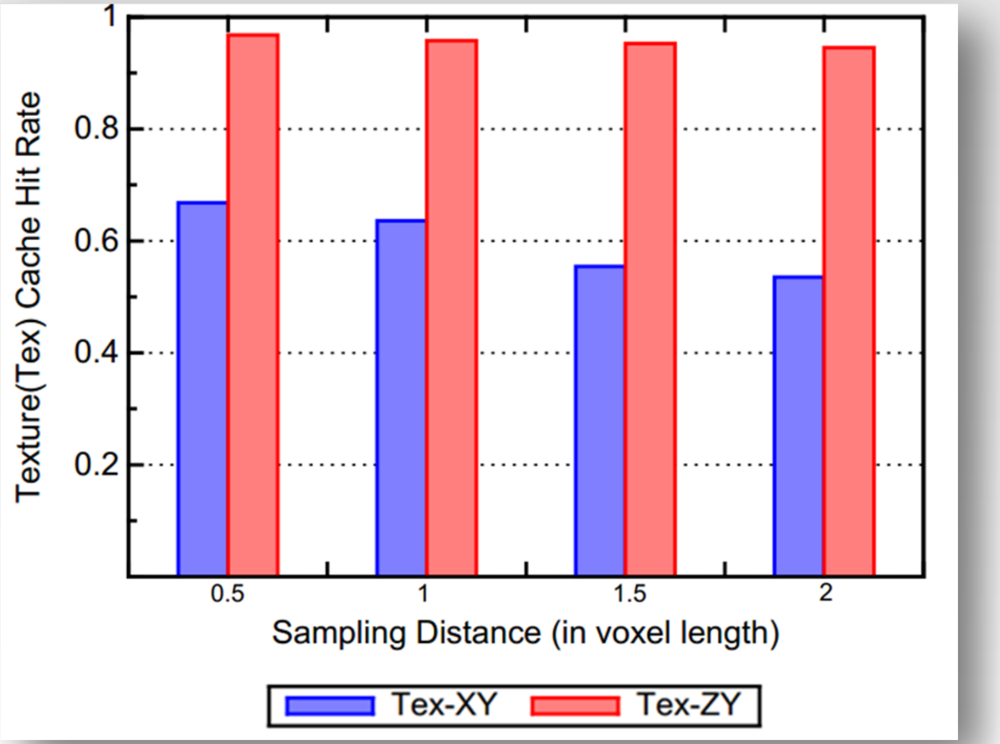


Optimization Result

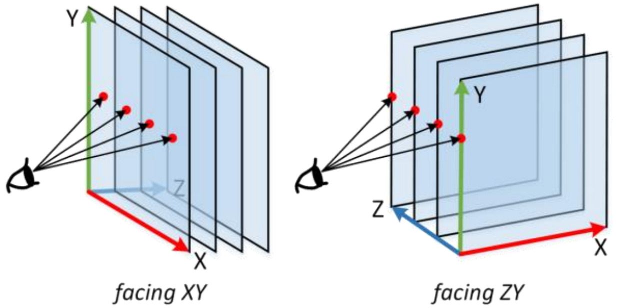


Warp size = 32

Texture Cache Performance



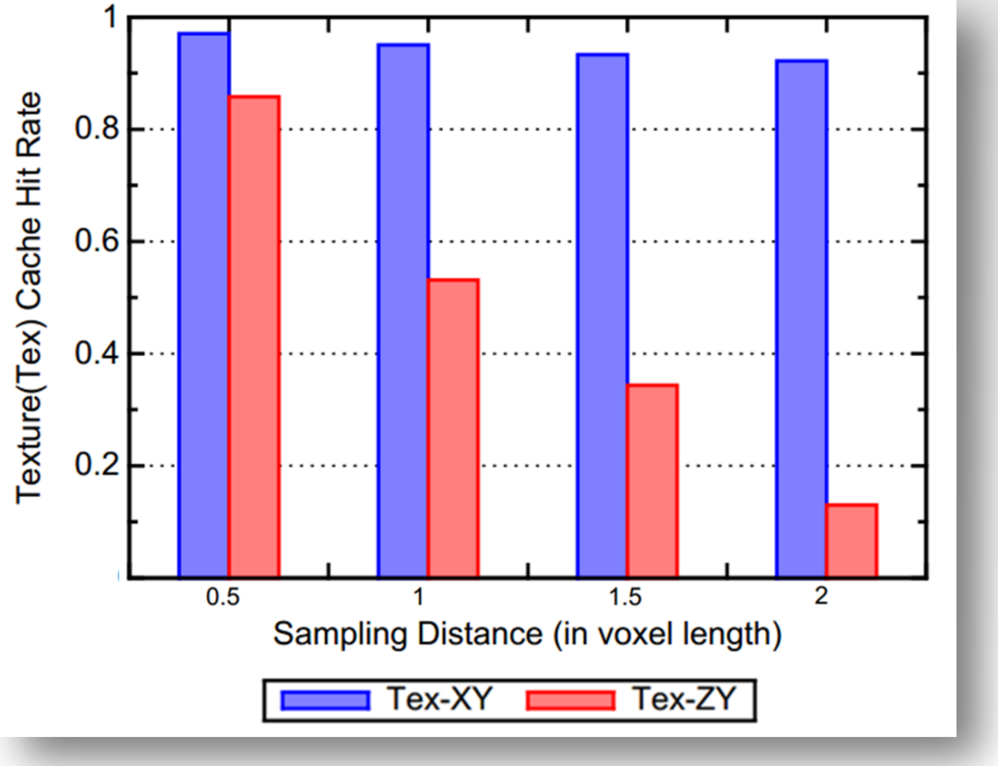
Warp Marching



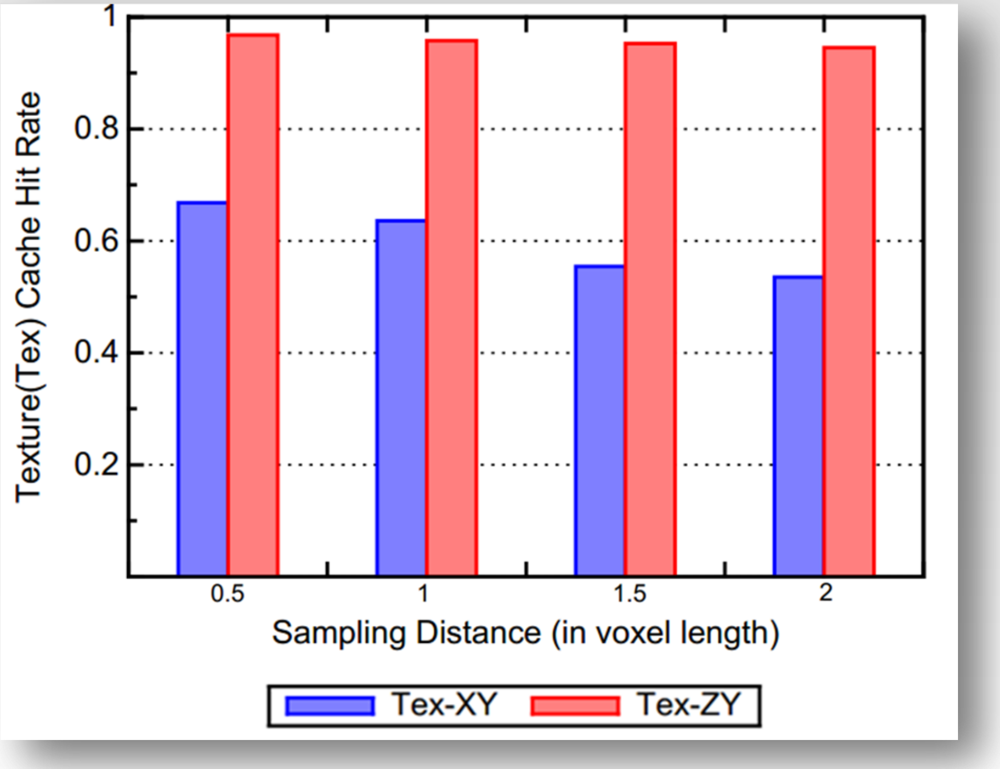
Perpendicular

Parallel

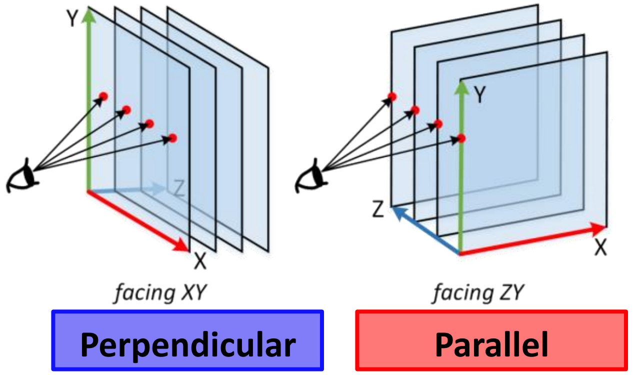
Texture Cache Performance



The Standard
(The Traditional)



Warp Marching



Perpendicular

Parallel

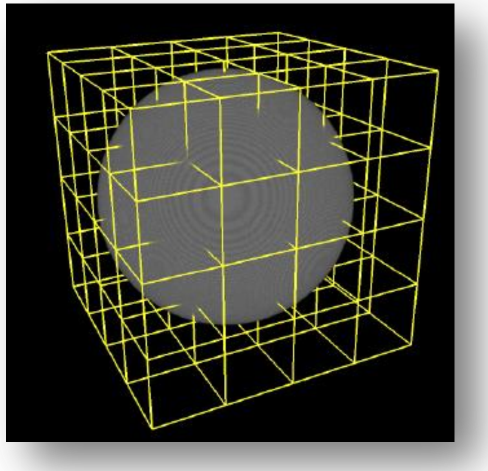
View Independent?

- Hybrid?
  - Perpendicular, the standard
  - Parallel, warp marching
- How about viewing directions in between?

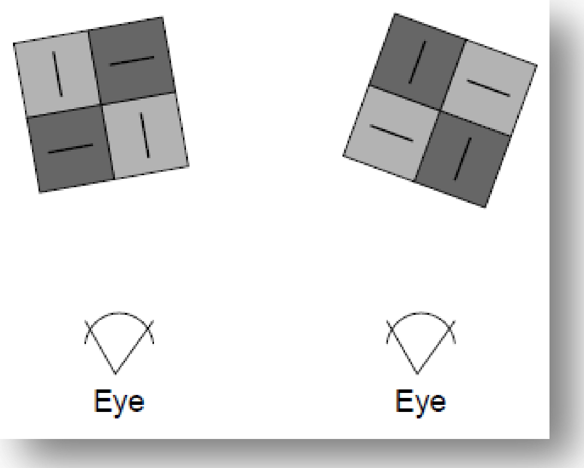
View Independent?

- Hybrid?
  - Perpendicular, the standard
  - Parallel, warp marching
- How about viewing directions in between?

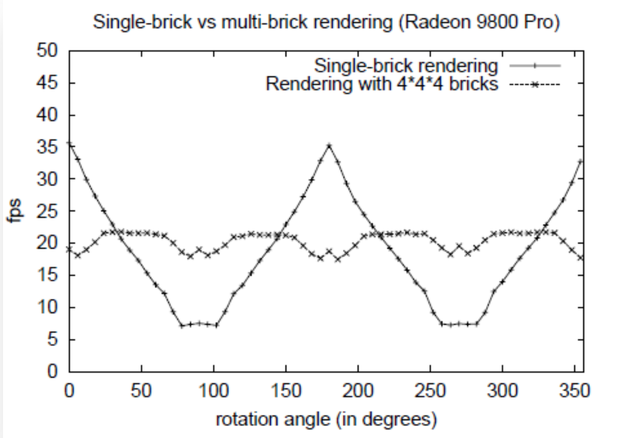
[Weiskopf04]



Partitioning a volume into small bricks



For any direction, 2 bricks are parallel and two bricks are perpendicular to the view



Achieve a roughly constant frame rate when rotating around the Y axis

Warp Shape

Thread block size 256, warp size 32

The Standard Sampling		Warp Marching	
Block Shape	Warp Shape	Block Shape	Warp Shape
32 x 8	32 x 1		
16 x 16	16 x 2		
8 x 32	8 x 4		
…	…	…	…

Warp Shape

Thread block size 256, warp size 32

The Standard Sampling		Warp Marching	
Block Shape	Warp Shape	Block Shape	Warp Shape
32 x 8 x 1	32 x 1		
16 x 16 x 1	16 x 2		
8 x 32 x 1	8 x 4		
…	…	…	…

Warp Shape

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Thread block size 256, warp size 32

The Standard Sampling		Warp Marching	
Block Shape	Warp Shape	Block Shape	Warp Shape
32 x 8 x 1	32 x 1 x 1		
16 x 16 x 1	16 x 2 x 1		
8 x 32 x 1	8 x 4 x 1		
…	…	…	…

Motivation
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Warp Shape

Thread block size 256, warp size 32

The Standard Sampling		Warp Marching	
Block Shape	Warp Shape	Block Shape	Warp Shape
32 x 8 x 1	32 x 1 x 1	1x8x32	1 x 1 x 32
16 x 16 x 1	16 x 2 x 1	2x4x32	1 x 1 x 32
8 x 32 x 1	8 x 4 x 1	4x2x32	1 x 1 x 32
…	…	…	…

Warp Shape

Thread block size 256, warp size 32

The Standard Sampling		Warp Marching	
Block Shape	Warp Shape	Block Shape	Warp Shape
32 x 8 x 1	32 x 1 x 1	1x8x32	1 x 1 x 32
16 x 16 x 1	16 x 2 x 1	2x4x32	1 x 1 x 32
8 x 32 x 1	8 x 4 x 1	4x2x32	1 x 1 x 32
…	…	…	…

Warp Shape

Thread block size 256, warp size 32

The Standard Sampling		Warp Marching	
Block Shape	Warp Shape	Block Shape	Warp Shape
32 x 8 x 1	32 x 1 x 1	1x8x32	1 x 1 x 32
16 x 16 x 1	16 x 2 x 1	2x4x32	1 x 1 x 32
8 x 32 x 1	8 x 4 x 1	4x2x32	1 x 1 x 32
…	…	…	…

Combined Approach	
Block Shape	Warp Shape
2x16x8	2x2x8
4x16x4	4x2x4
…	…

Warp Shape

Thread block size 256, warp size 32

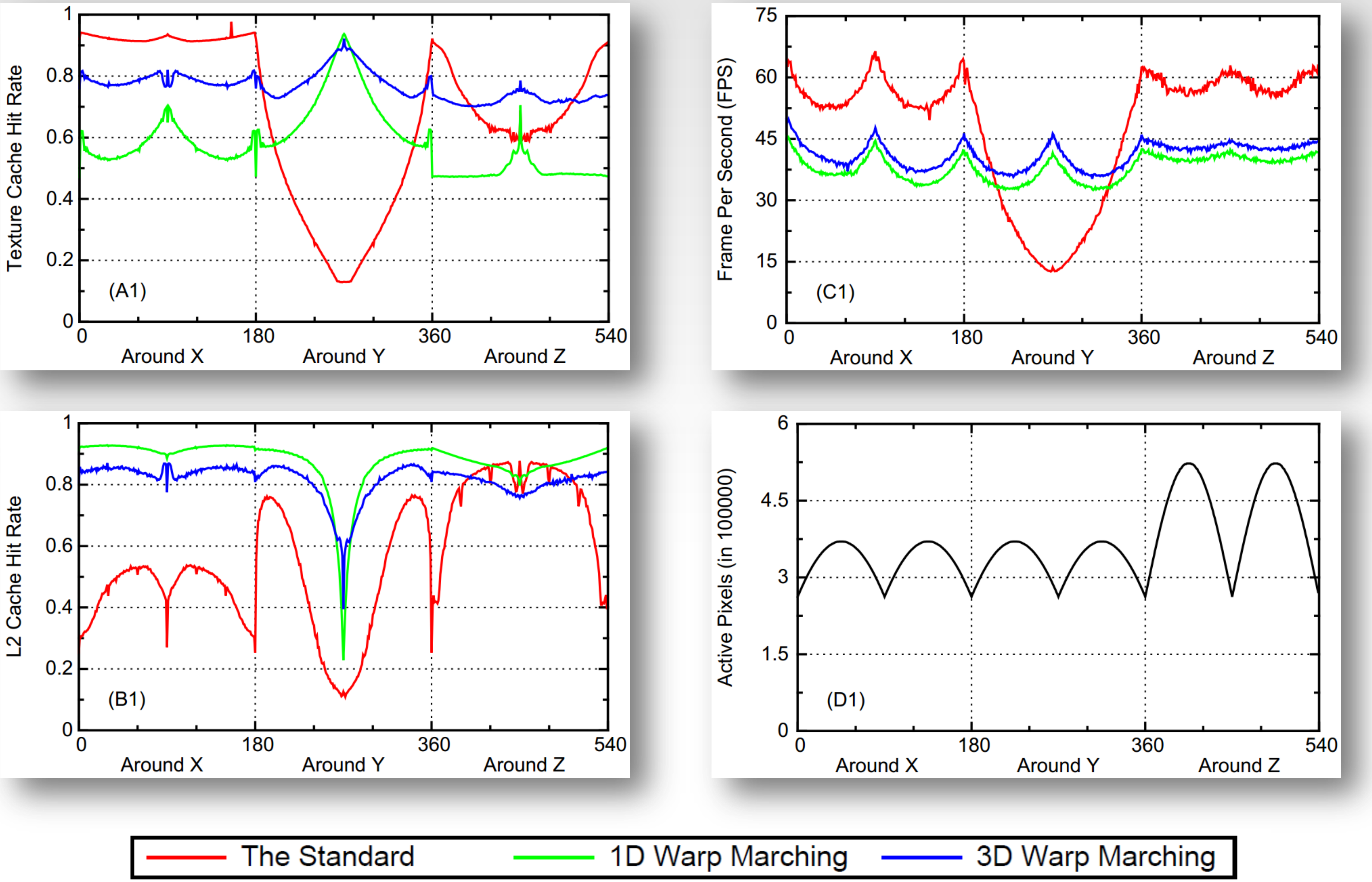
1D Warp Marching

The Standard Sampling		Warp Marching	
Block Shape	Warp Shape	Block Shape	Warp Shape
32 x 8 x 1	32 x 1 x 1	1x8x32	1 x 1 x 32
16 x 16 x 1	16 x 2 x 1	2x4x32	1 x 1 x 32
8 x 32 x 1	8 x 4 x 1	4x2x32	1 x 1 x 32
…	…	…	…

Combined Approach	
Block Shape	Warp Shape
2x16x8	2x2x8
4x16x4	4x2x4
…	…

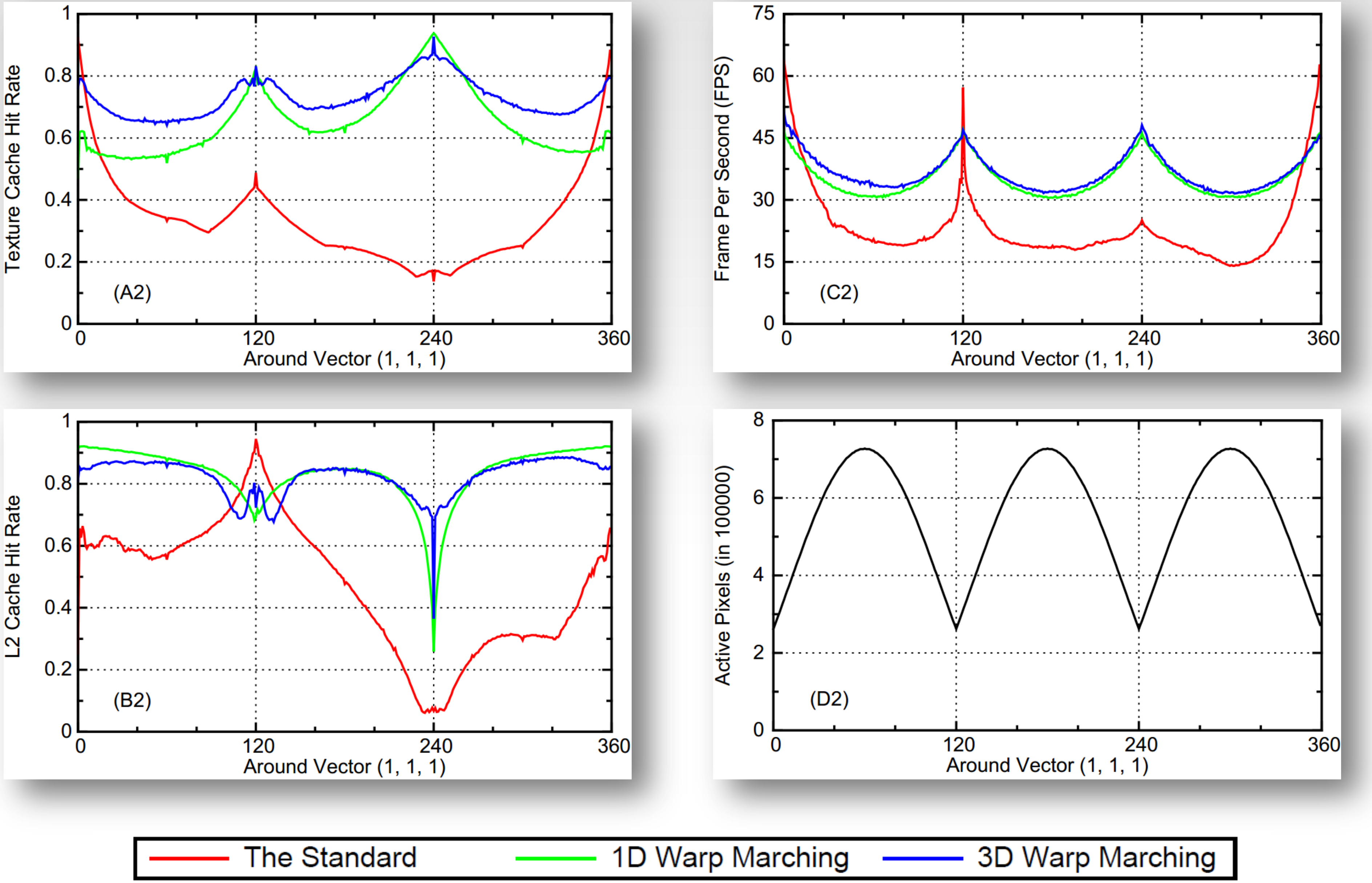
3D Warp Marching

3D Warp Marching



Rotate the volume around X, Y and Z axis 180 degree respectively

3D Warp Marching

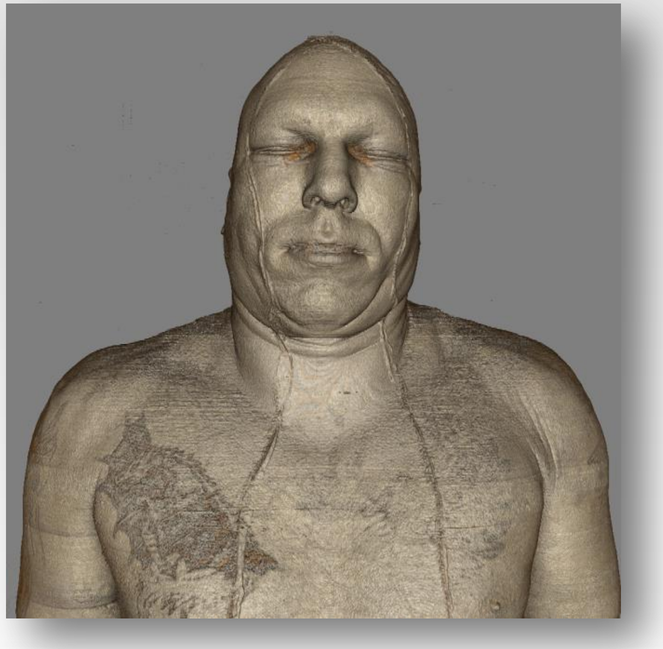


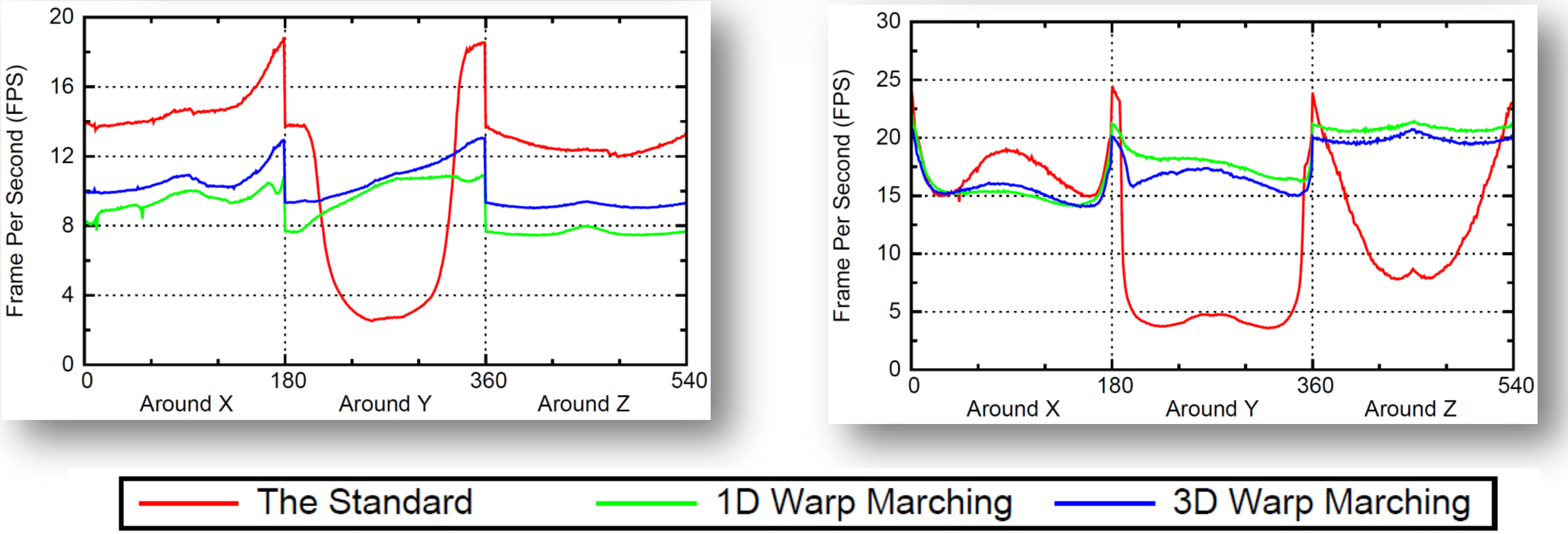
Rotate the volume around vector (1,1,1) 360 degree

Application

vhf_head (8-bit, 2.8GB)

vhm_body (8-bit, 3.8GB)





[Lum2004]: High-quality lighting and efficient pre-integration for volume rendering.

Conclusion & Future Work

- Conclusion
  - We design a cache-aware sampling strategy, i.e. warp marching, for the ray casting algorithm.
  - The 3D warp marching maintains a roughly constant texture cache hit rate regardless of volume orientation.

- Future Work
  - L2 cache performance
  - Other types of GPUs, varying warp sizes
  - New applications

Thank you

Questions?