Parallel Frame Rendering: Trading Responsiveness for Energy on a Mobile GPU

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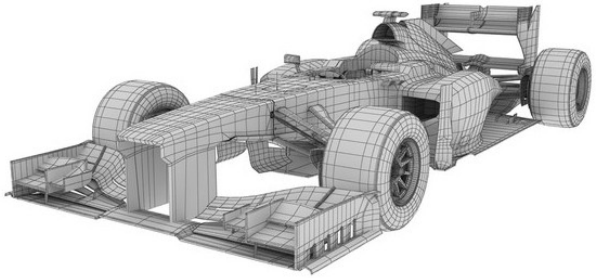
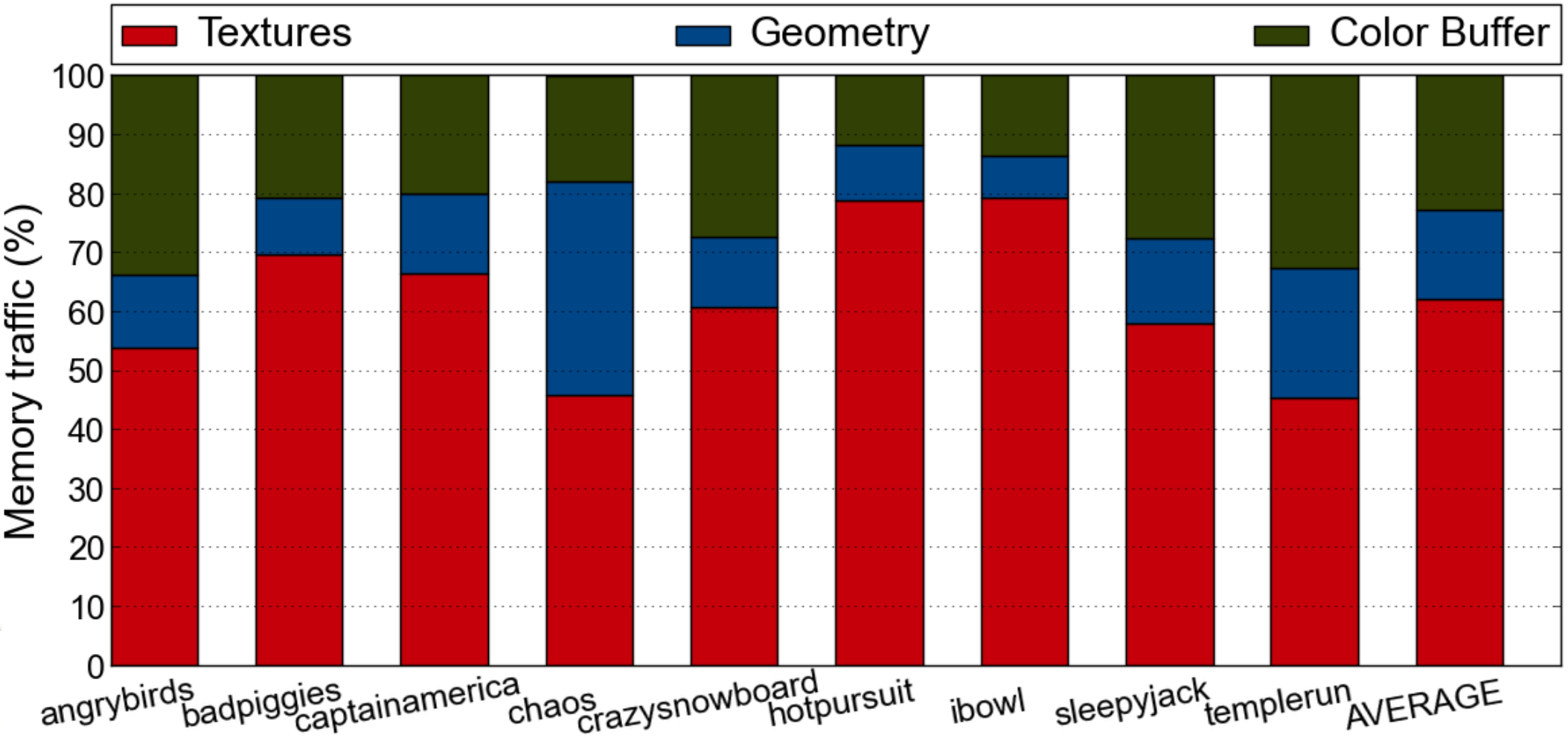
Bandwidth Usage for Graphics





Textures and 3D models from: http://www.turbosquid.com

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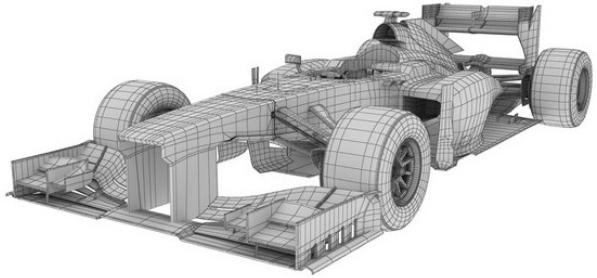

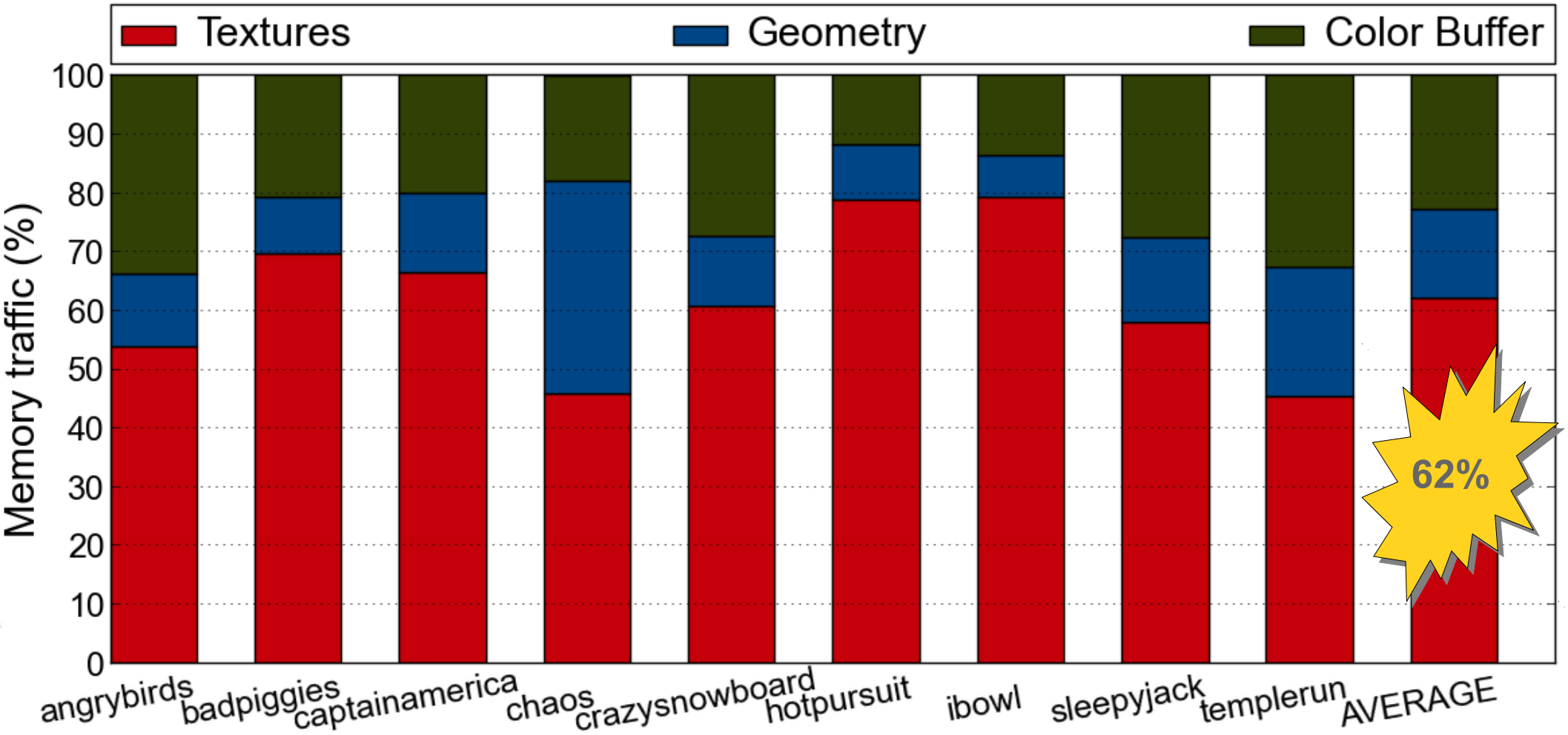

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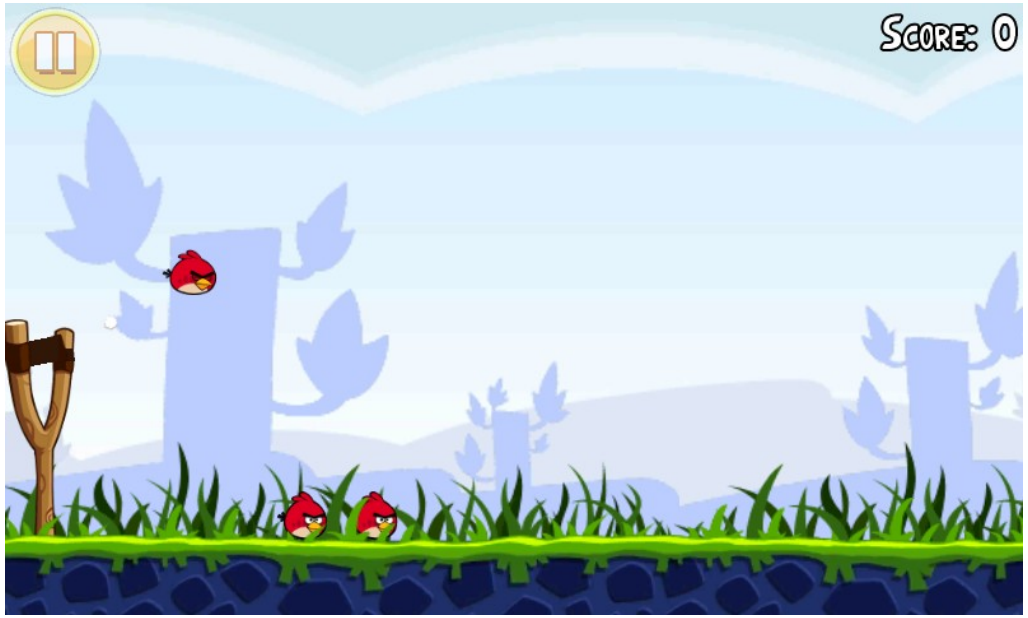
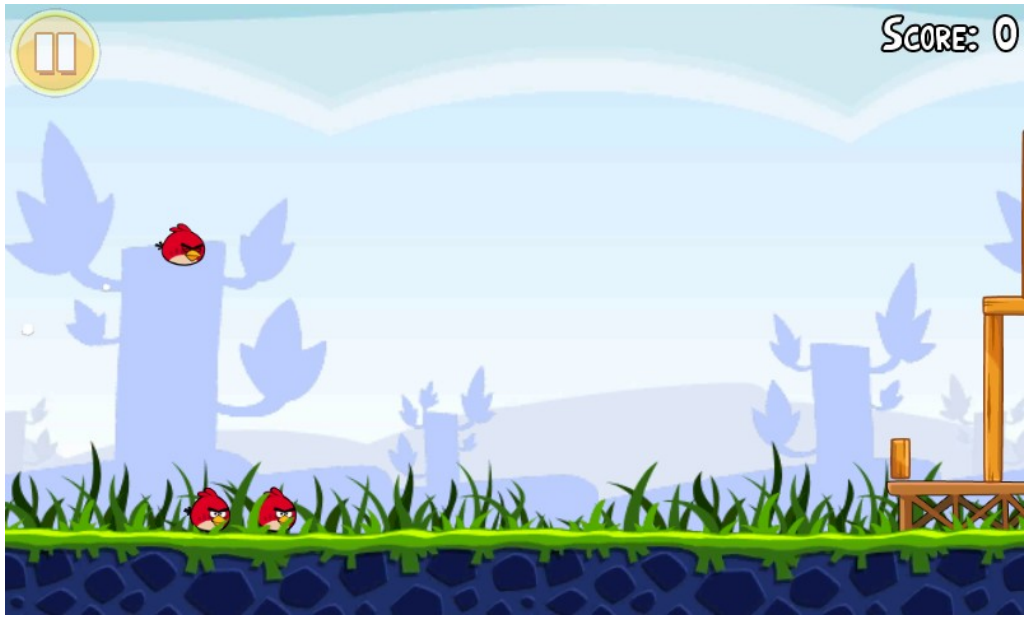
Texture Reuse

Frame i



Frame i+1



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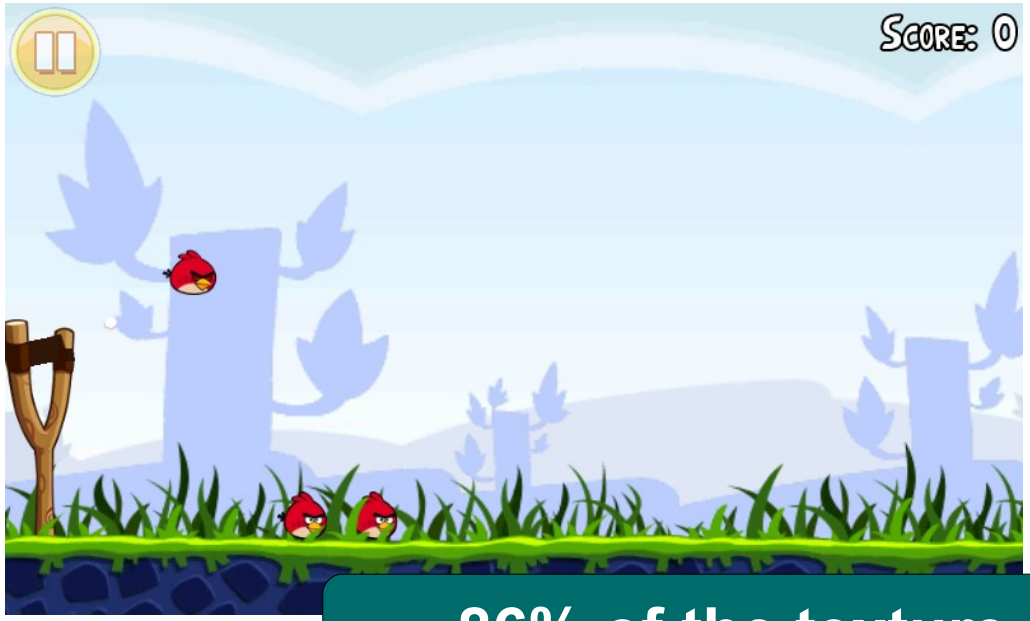
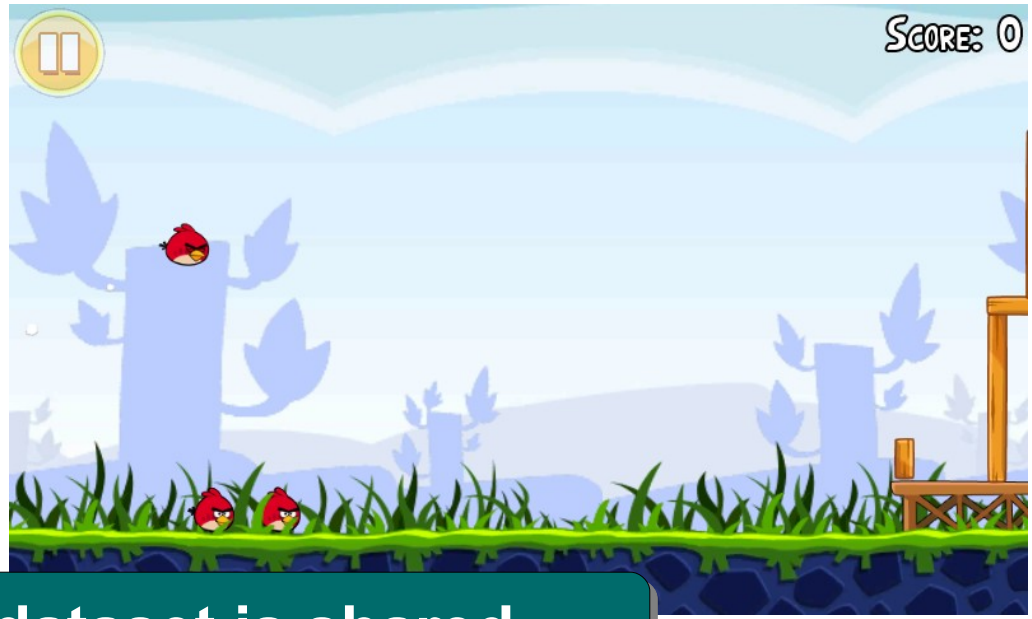


Frame i+1



86% of the texture dataset is shared

Texture Reuse

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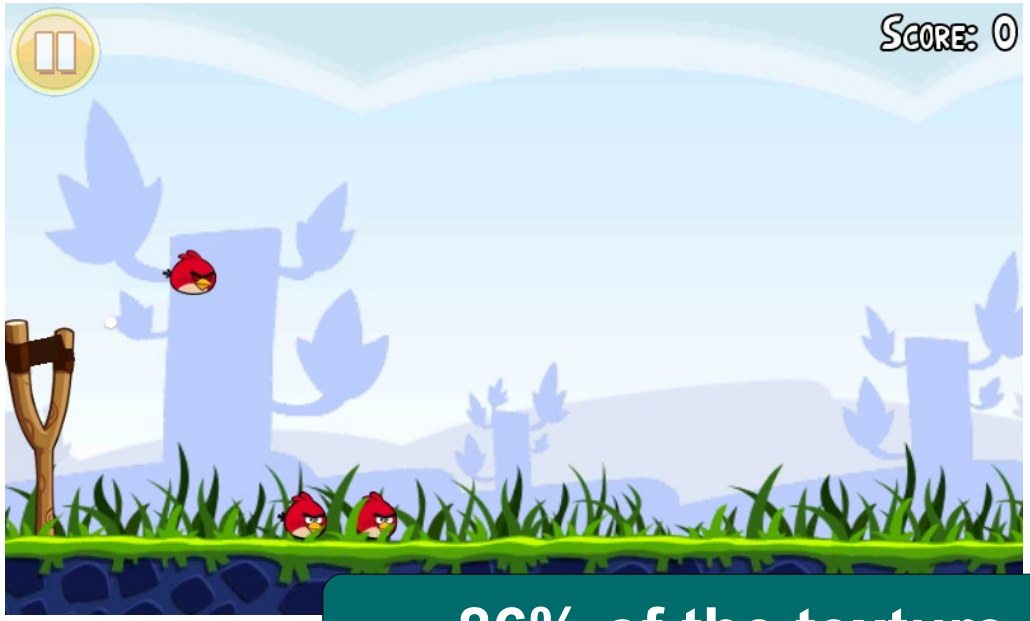

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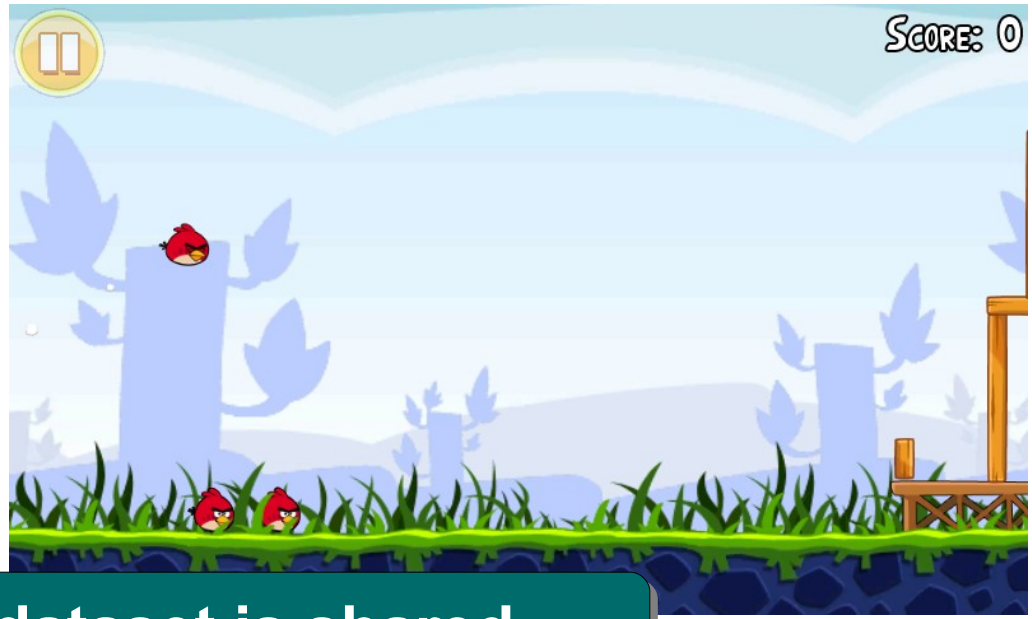

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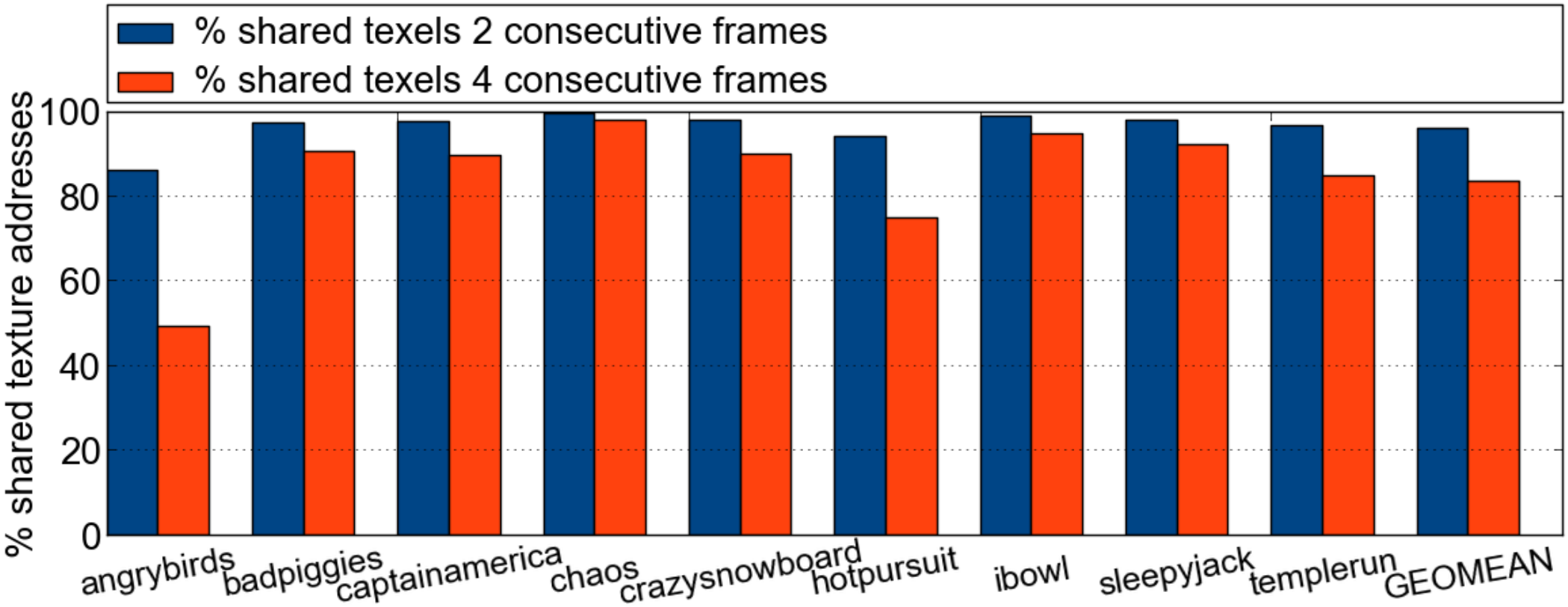
Mobile games exhibit a high degree of **texture similarity** between consecutive frames

Texture Reuse



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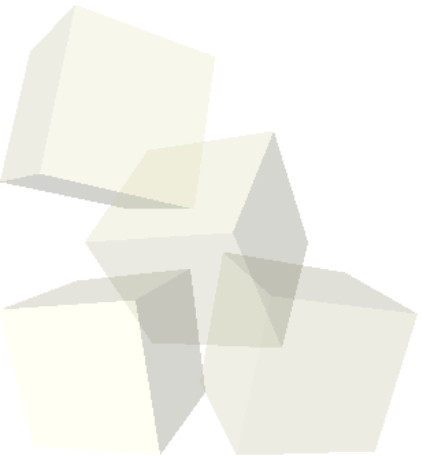
Outline

1. Motivation
2. Conventional Rendering
3. Parallel Frame Rendering
4. Experimental Results
5. Conclusions



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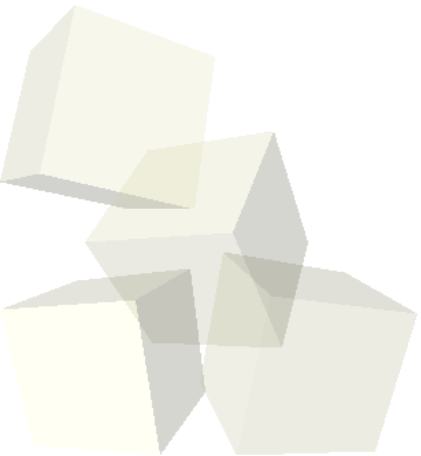

Conventional Tile-Based Rendering

CPU

Process user inputs
Physical simulation
Dispatch drawing commands

System Memory

Textures

Geometry

GPU

Command Processor

L2 Cache

Geometry Unit

Raster Unit 0

Memory Controller

Tiling Engine

Raster Unit 1

Color Buffer

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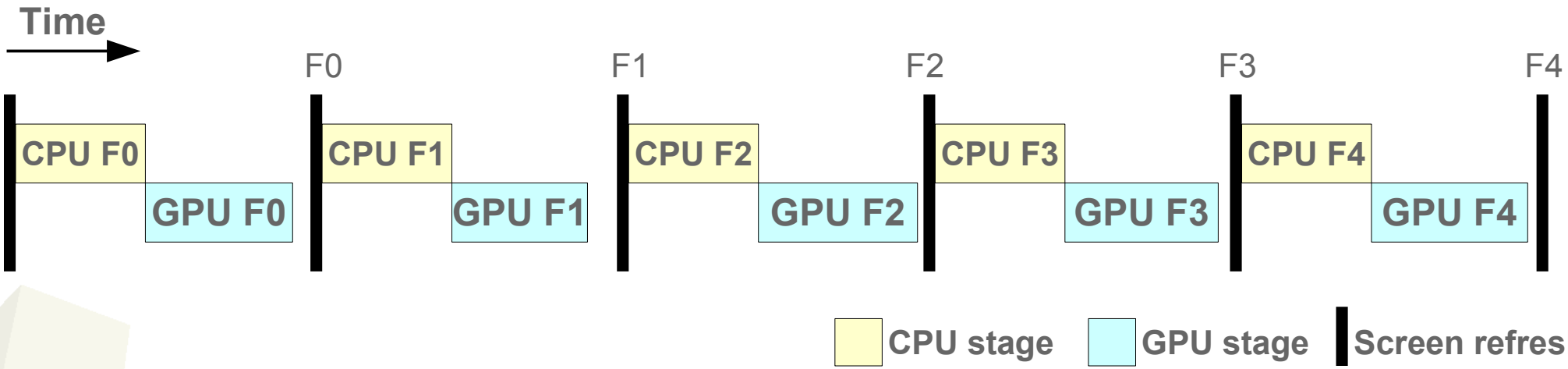

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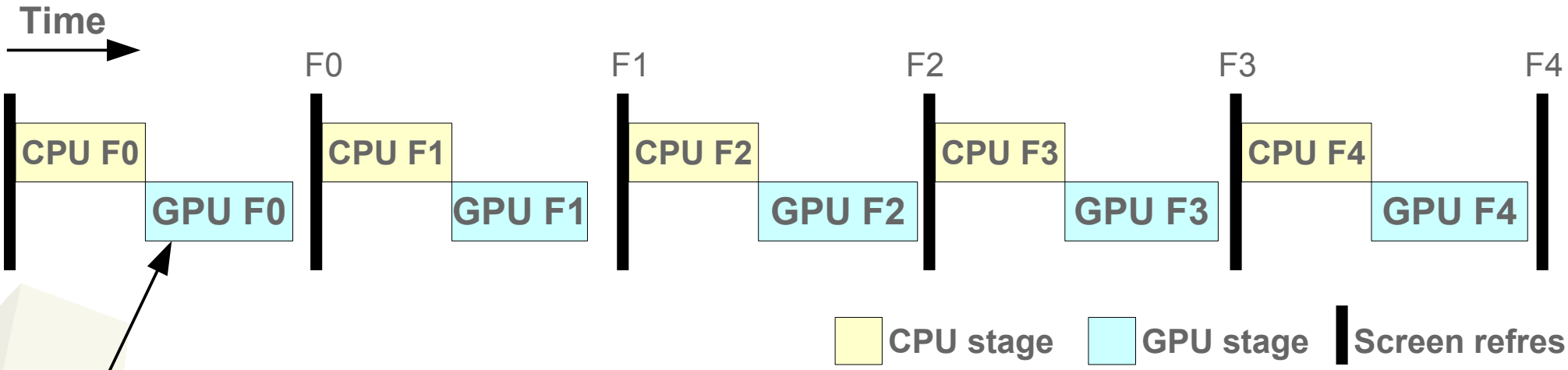

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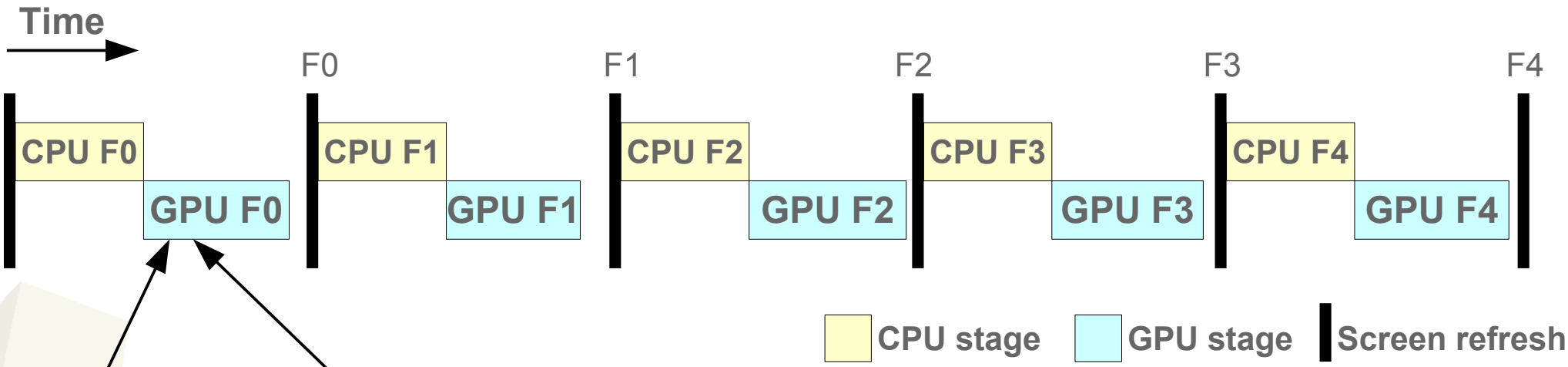

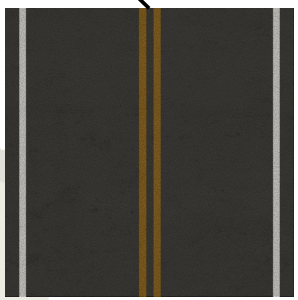

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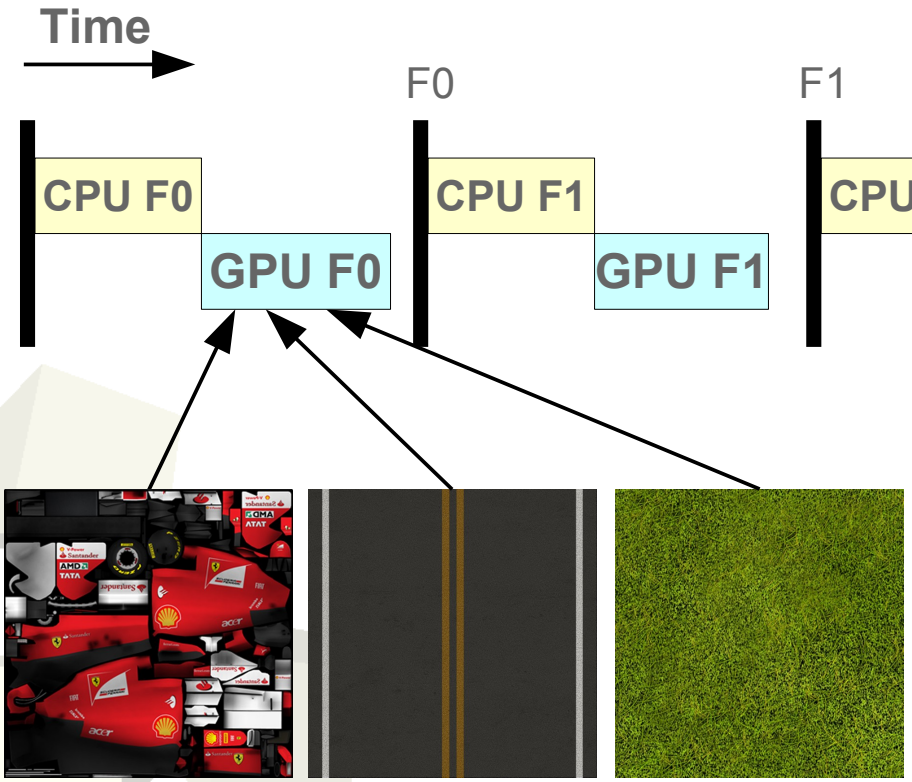

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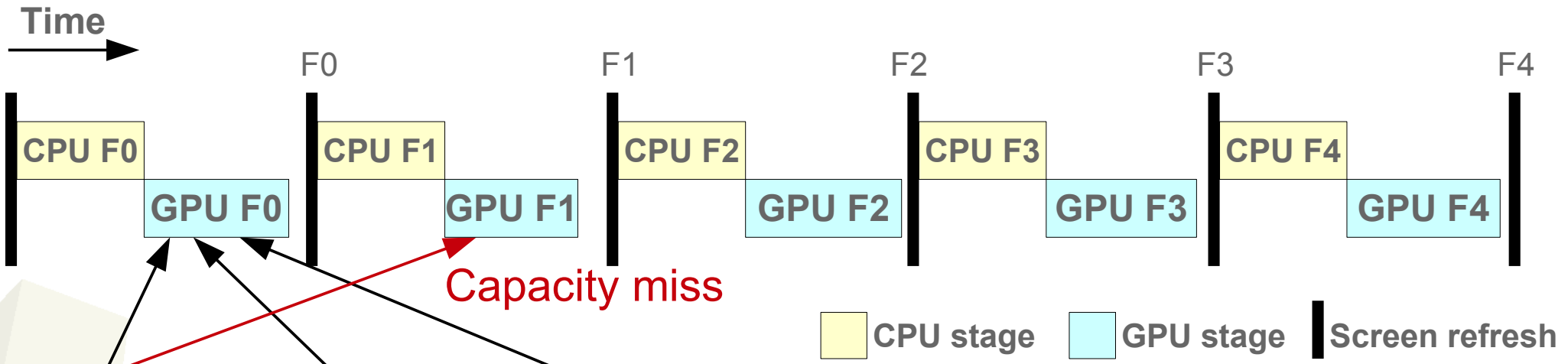
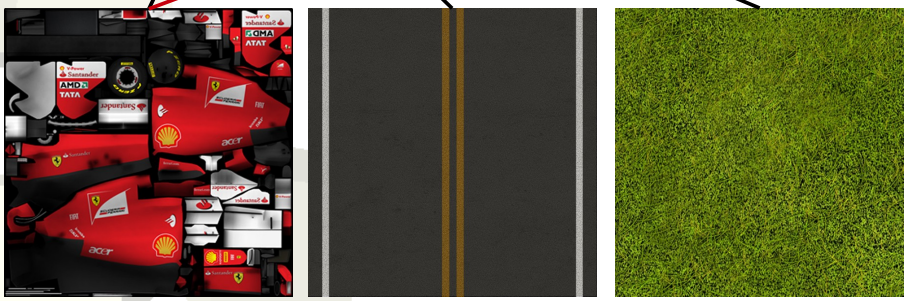
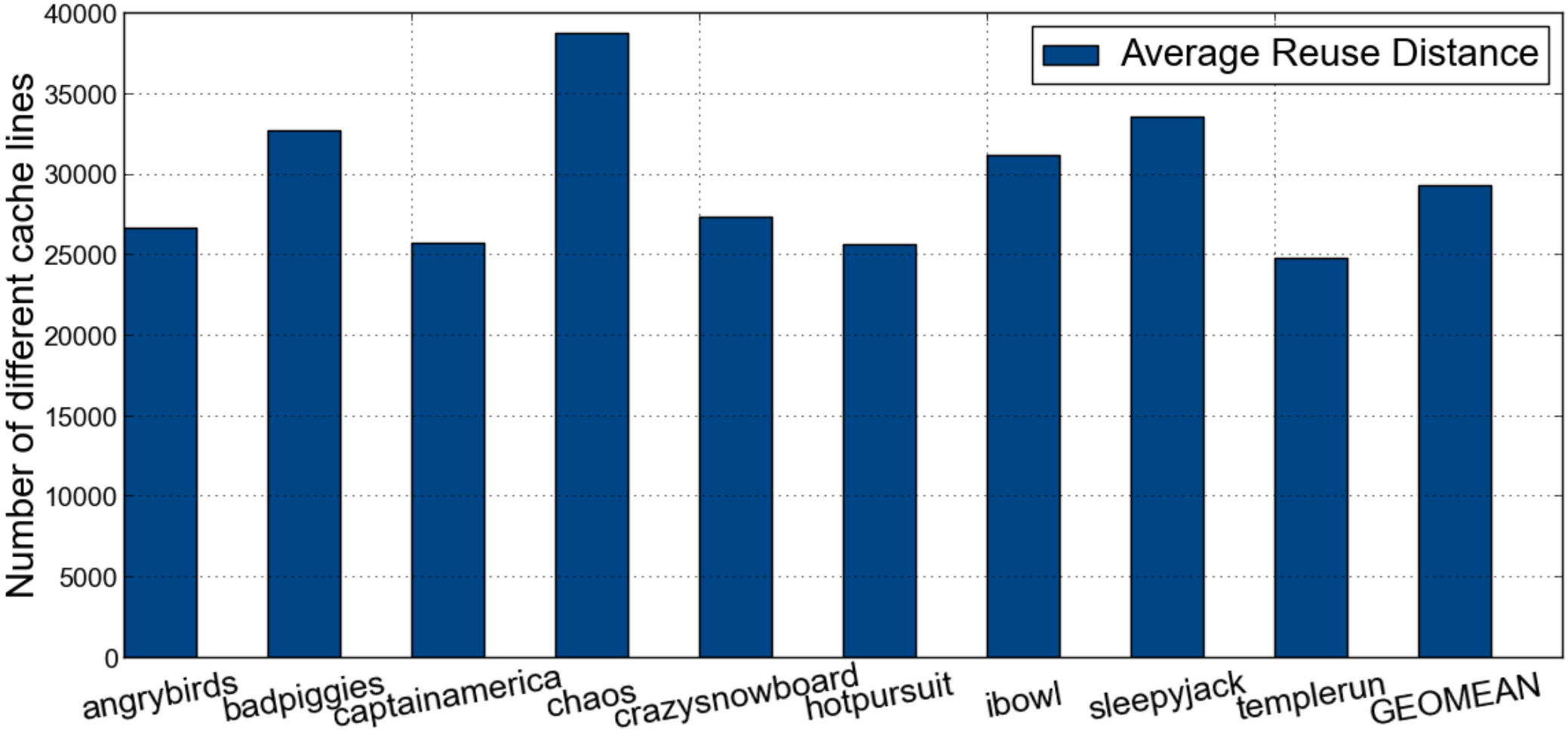




L2 Cache Reuse Distances



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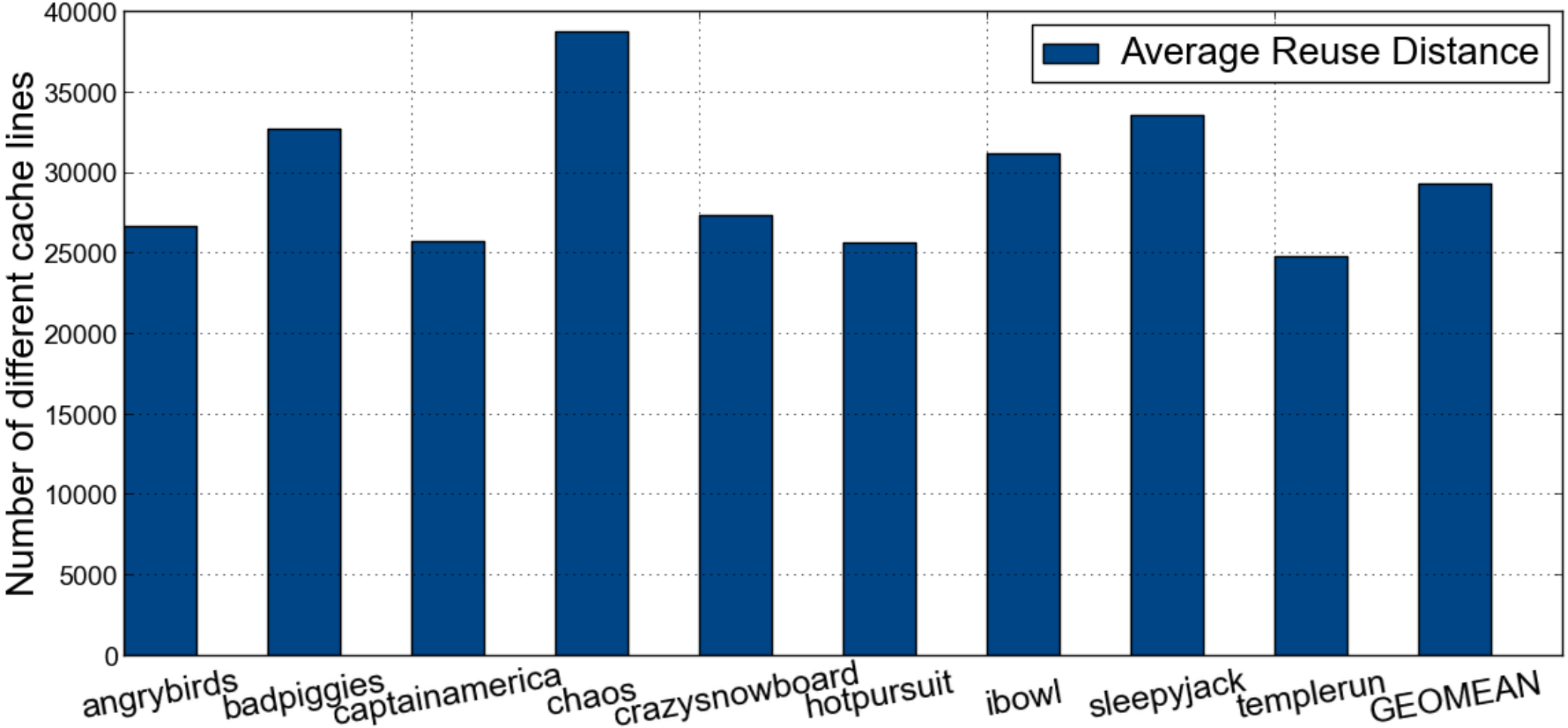

The L2 Cache cannot capture the inter-frame texture reuse due to the huge distances

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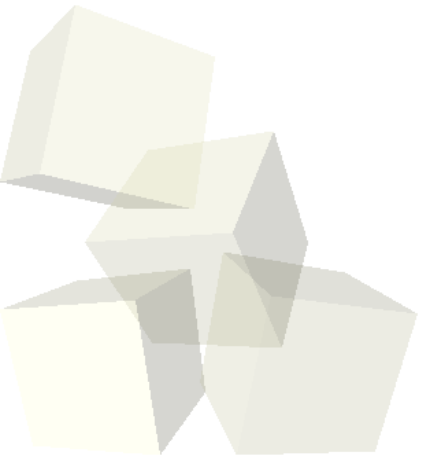
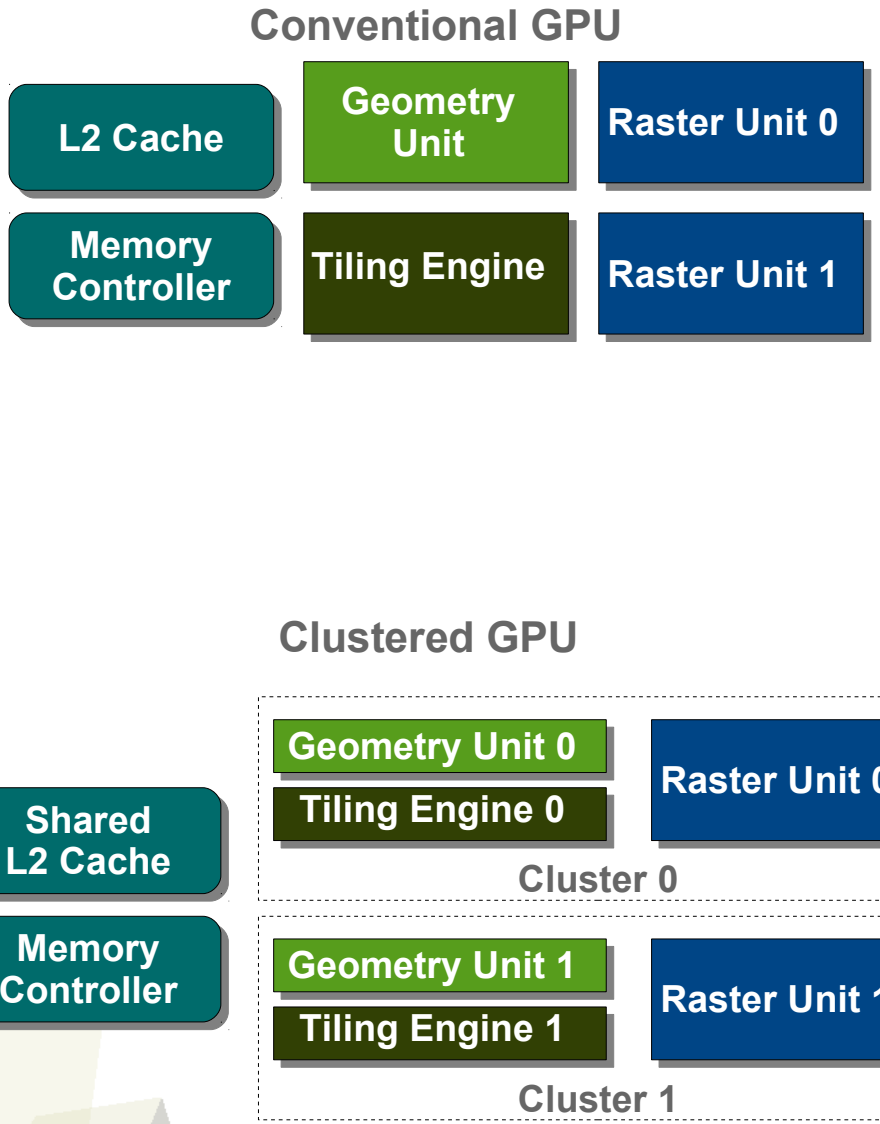


Parallel Frame Rendering



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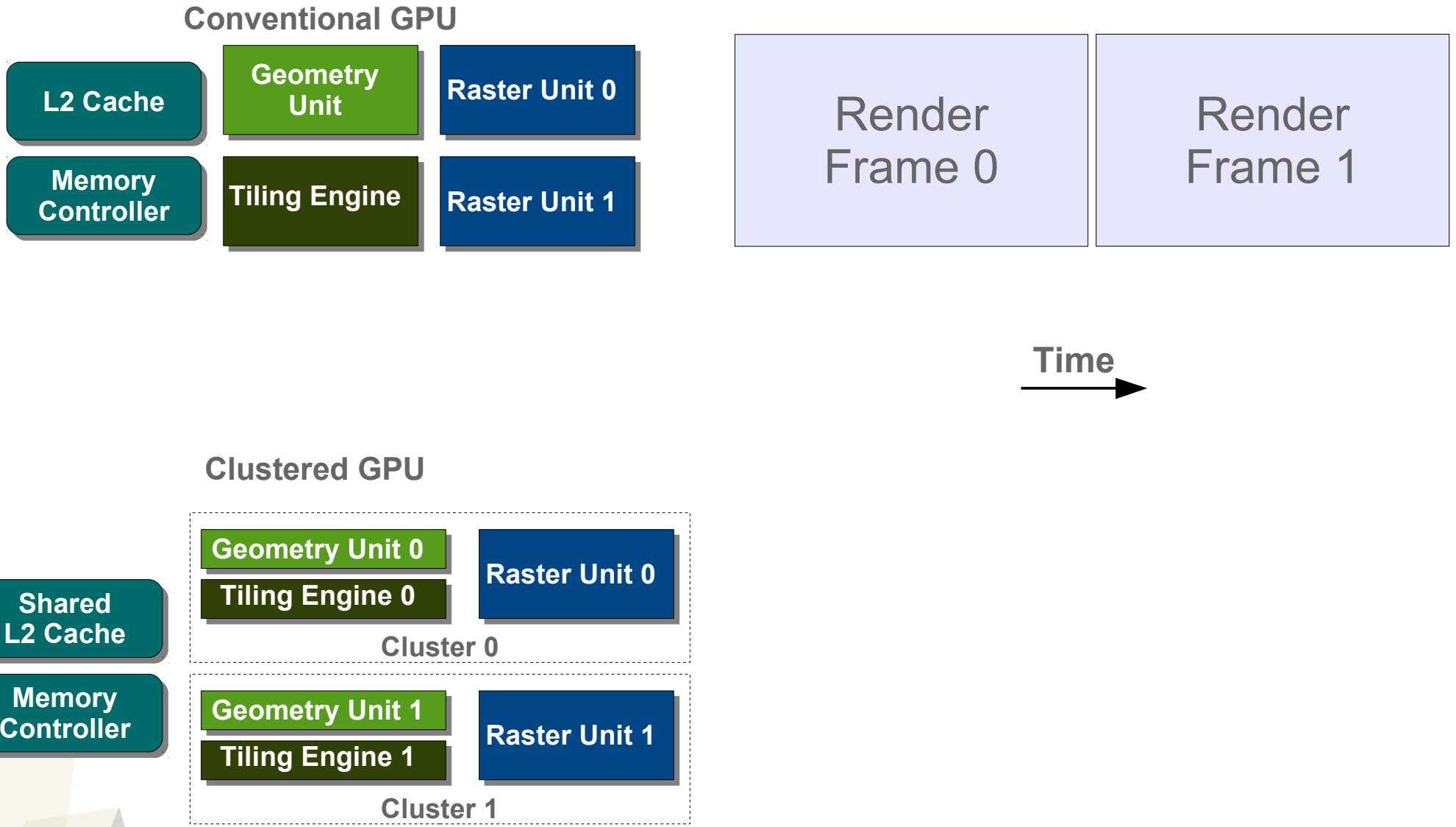

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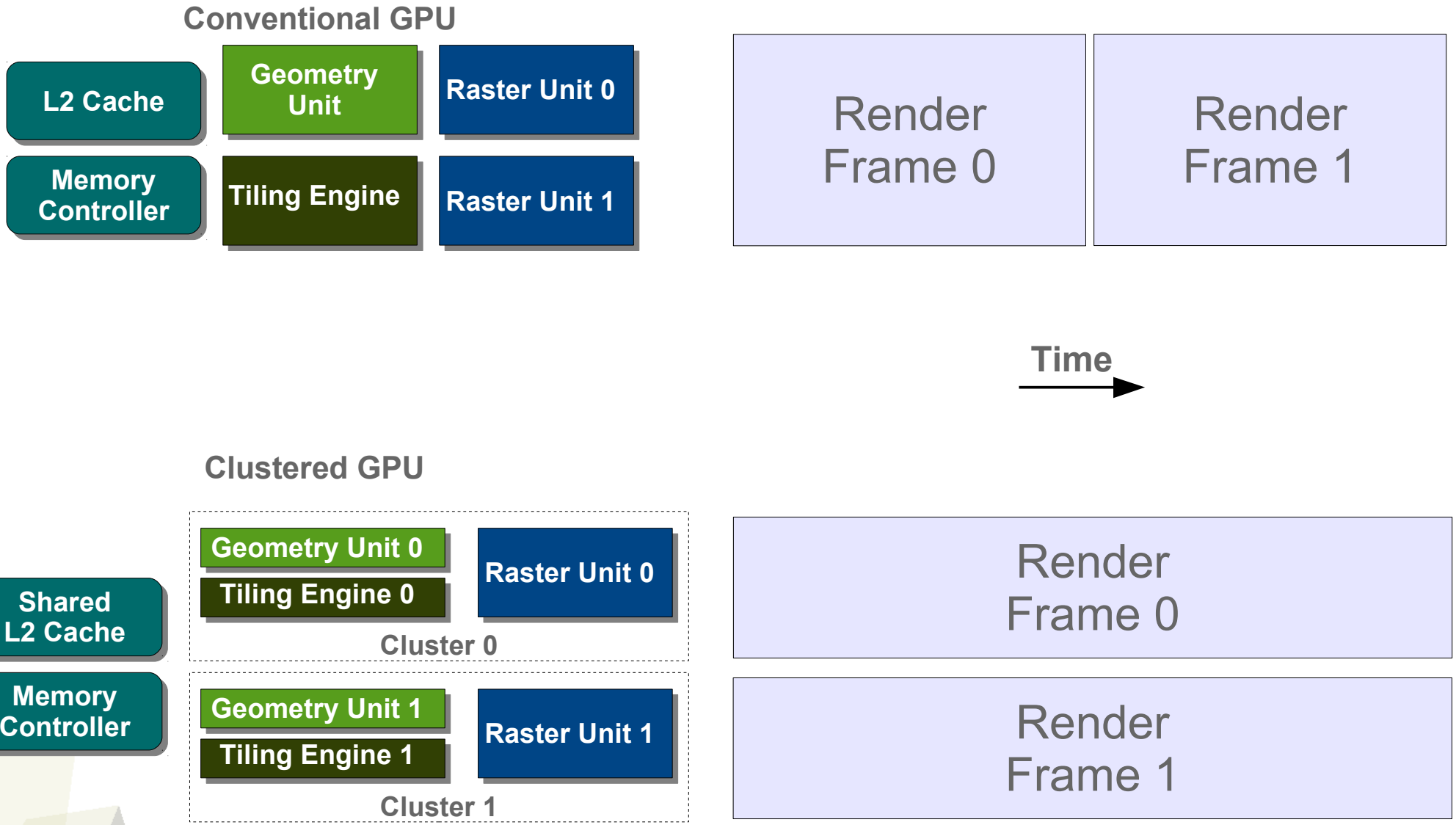
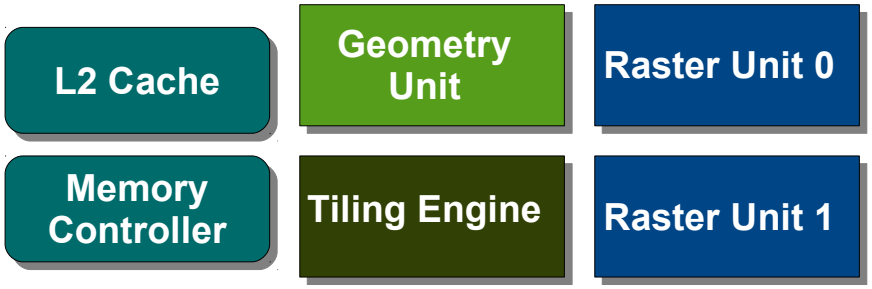
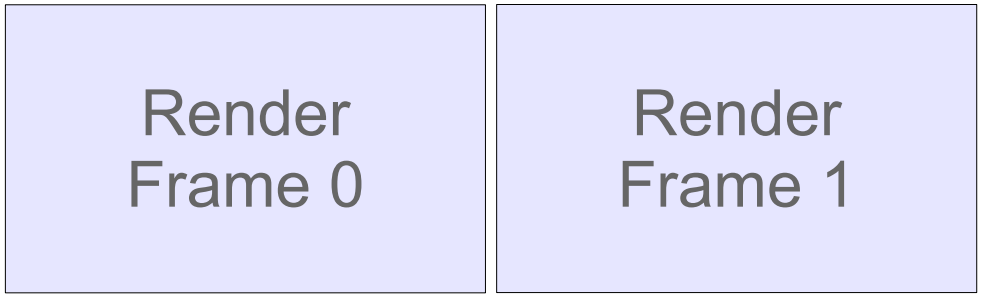


Parallel Frame Rendering

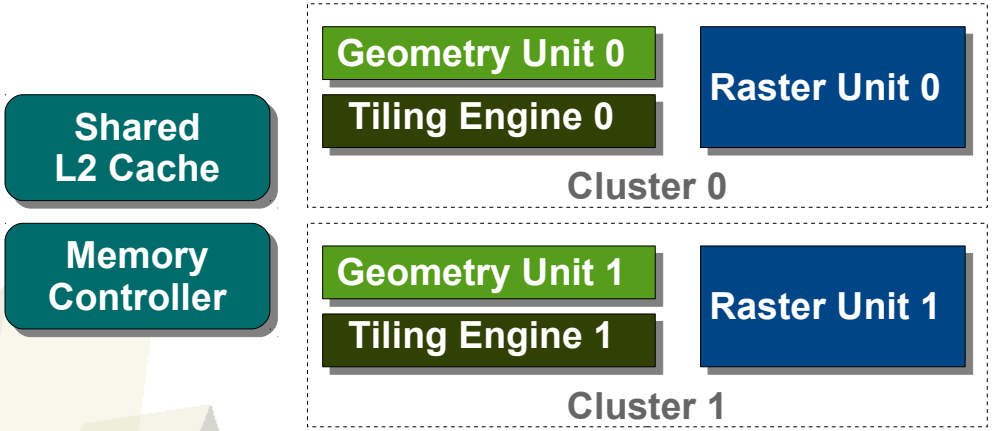
Time

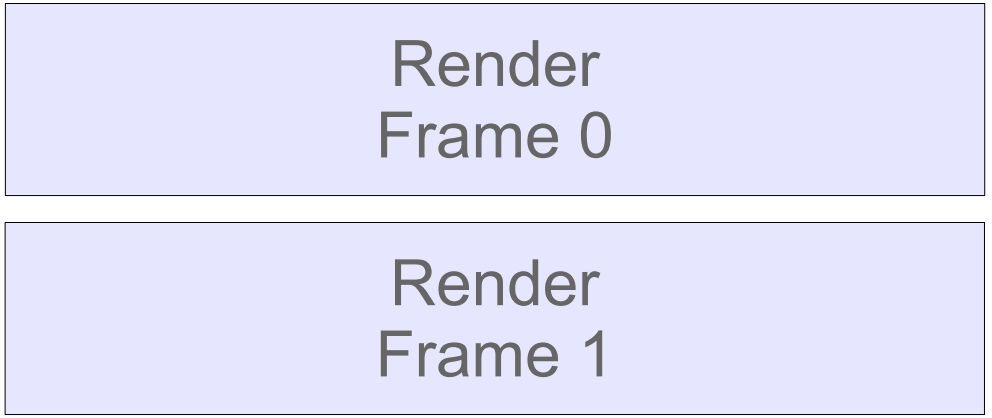
Conventional GPU





Clustered GPU





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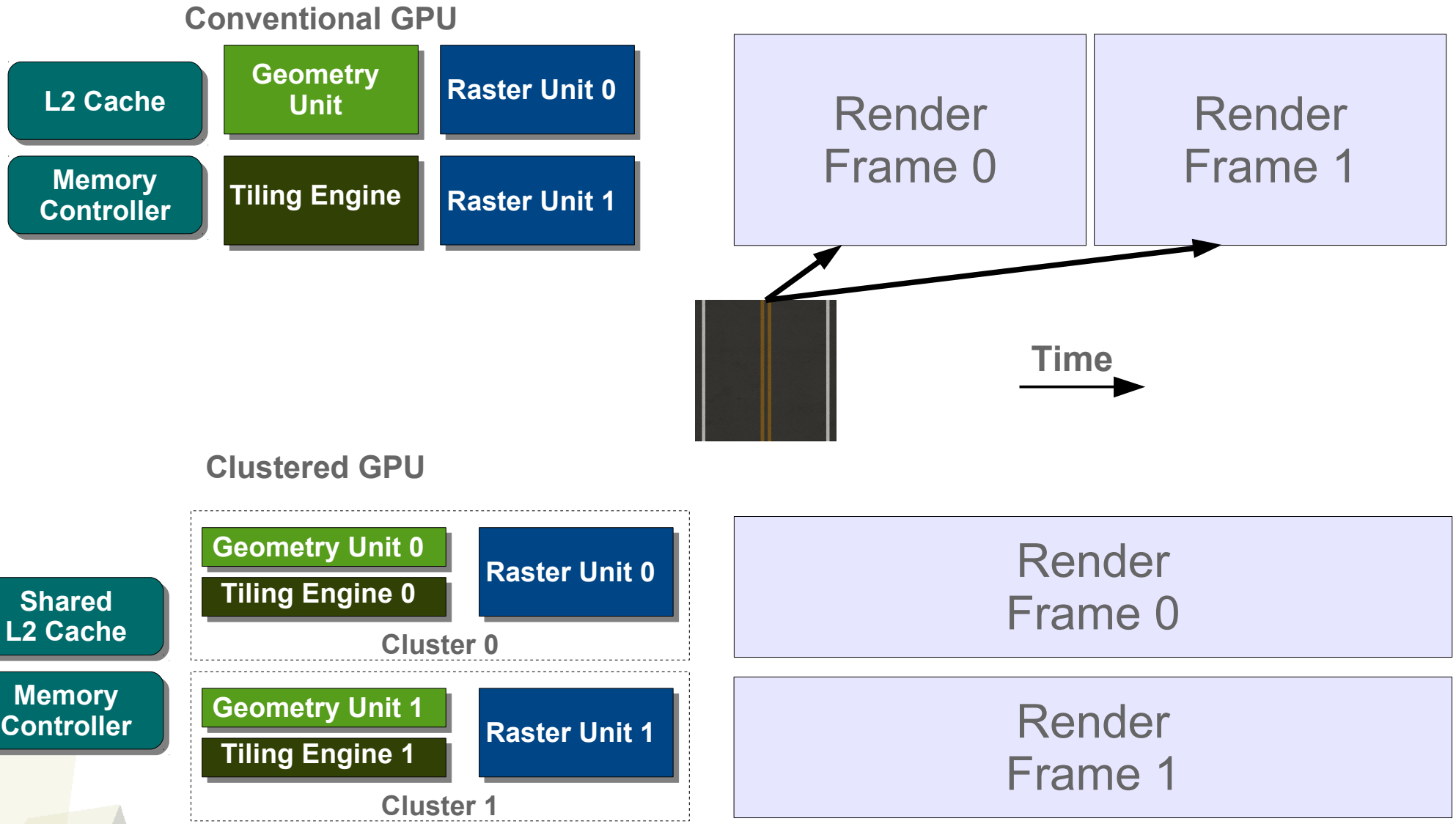

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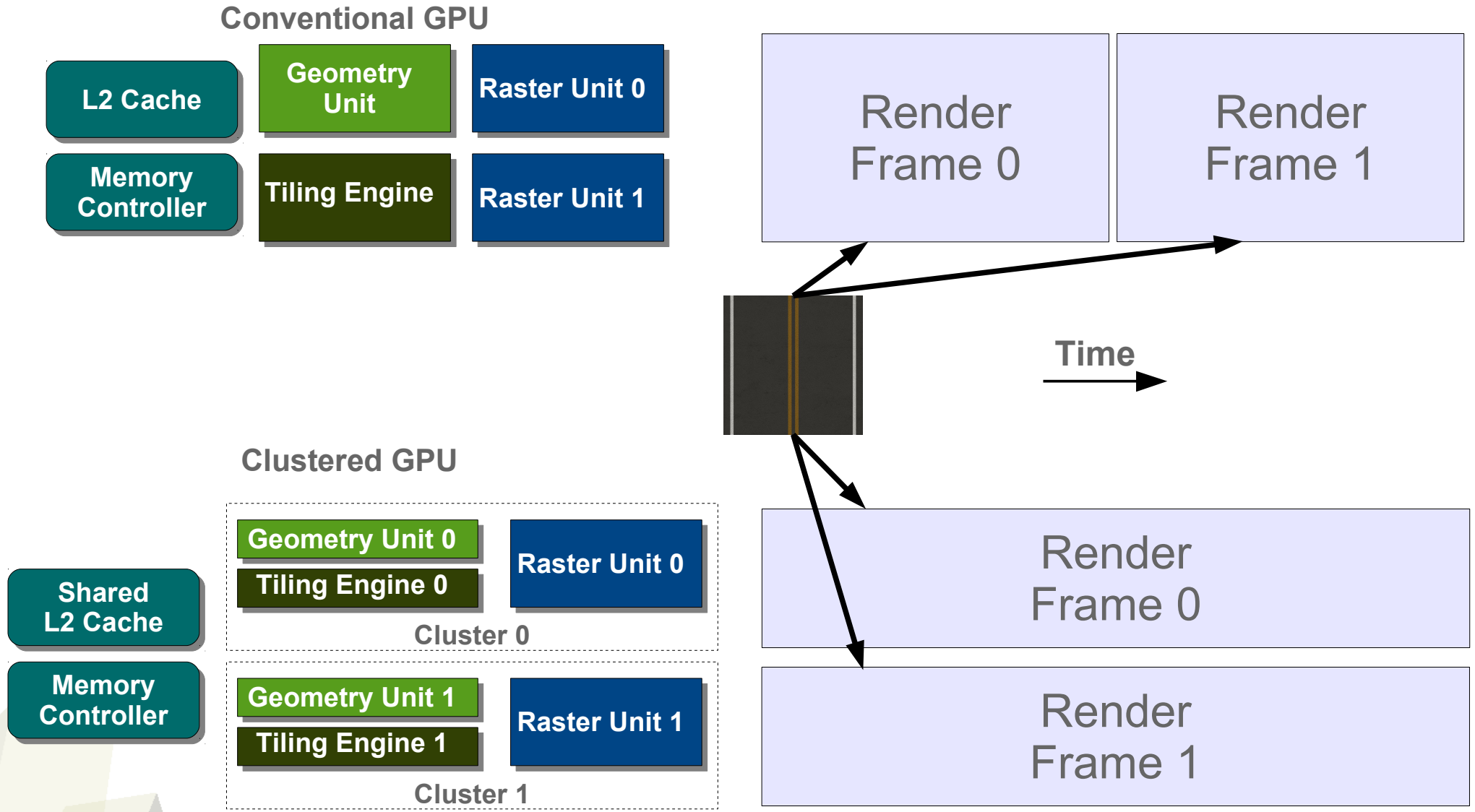

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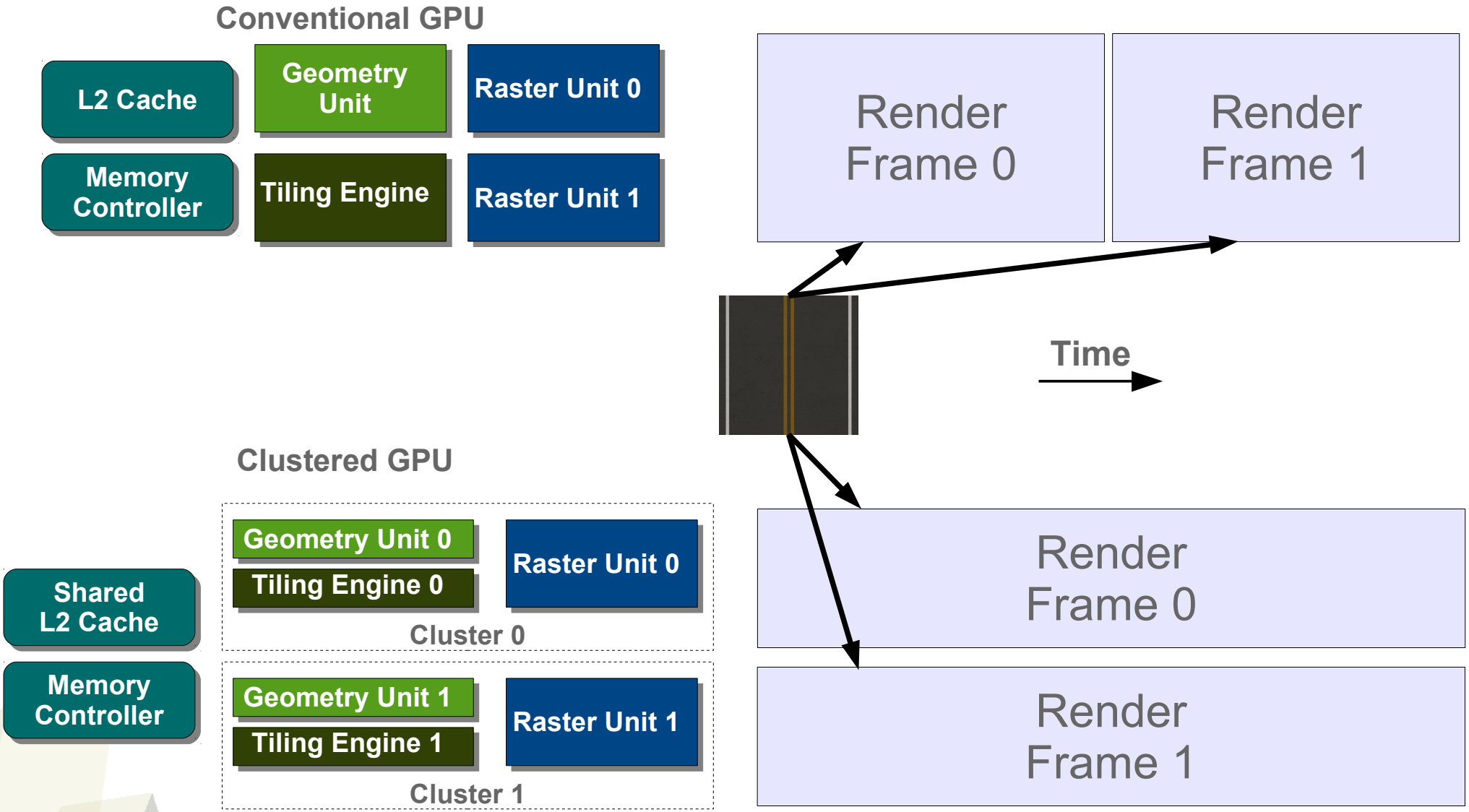
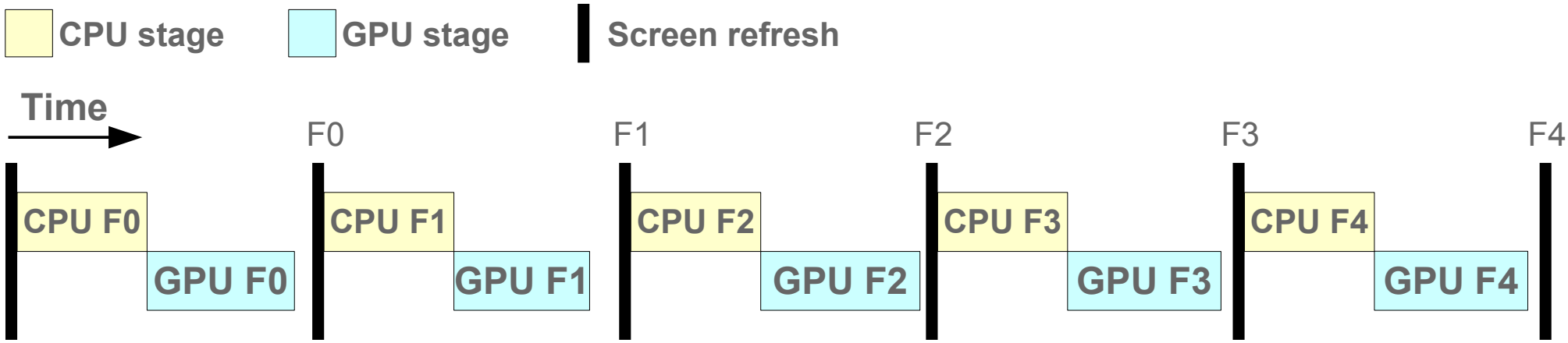


Textures are fetched once in the shared L2 cache and accessed by the 2 clusters in a short timespan

Parallel Frame Rendering



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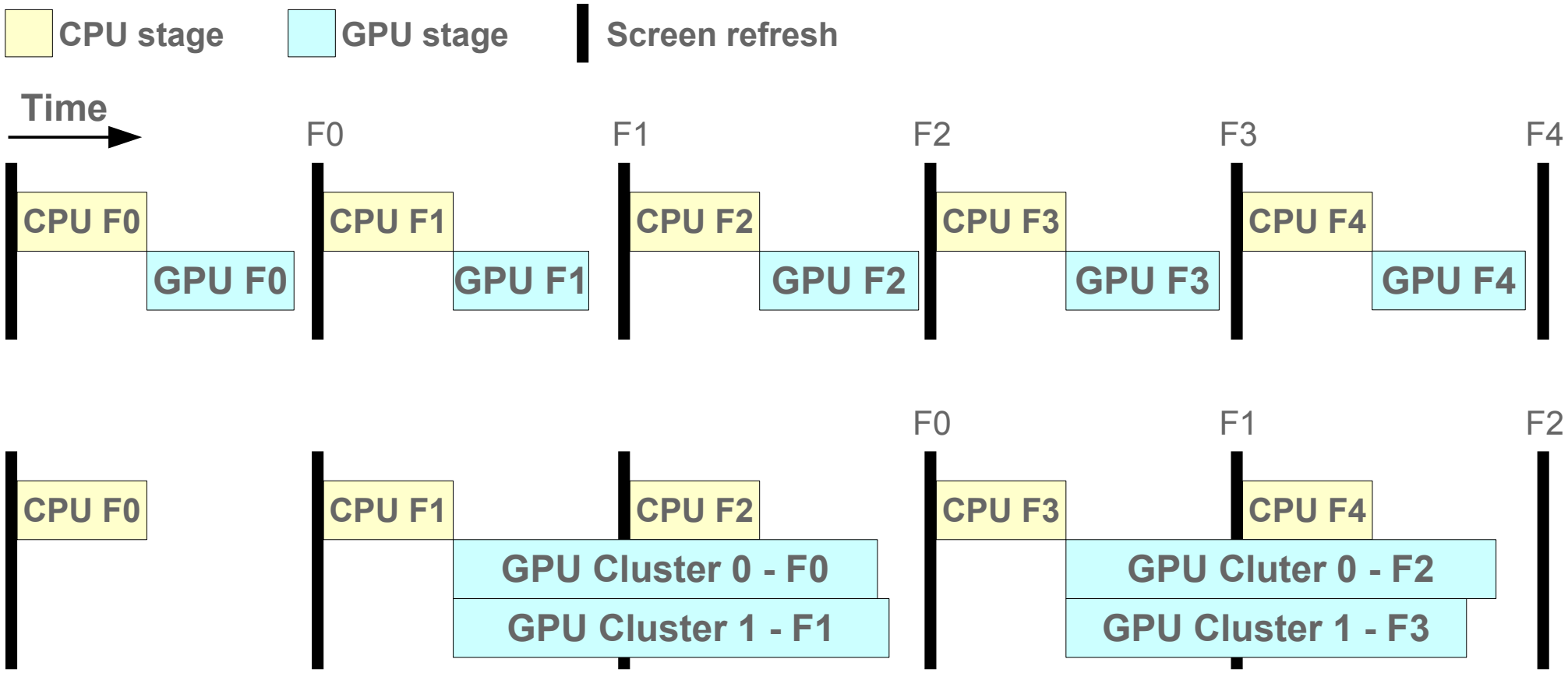

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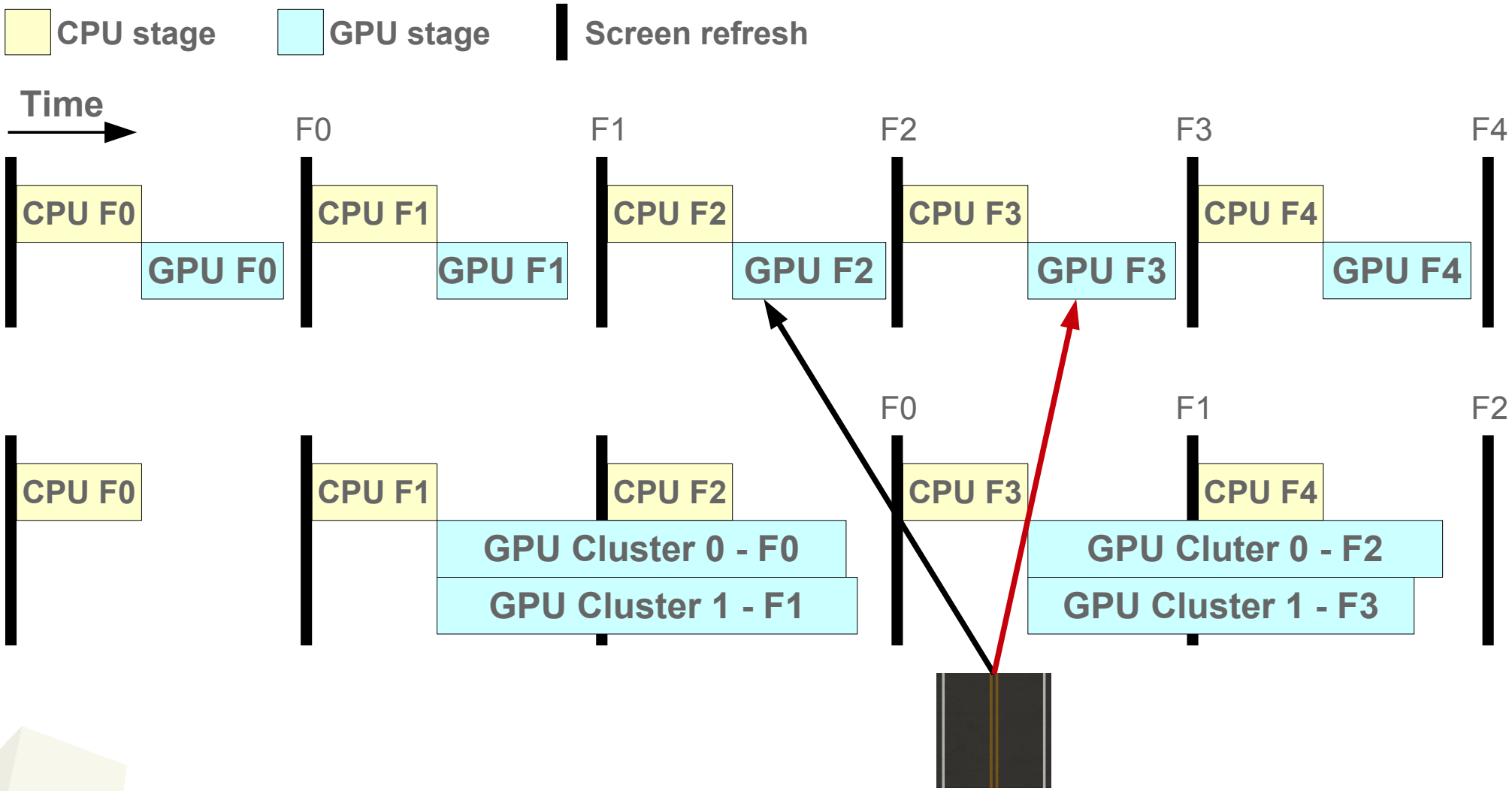

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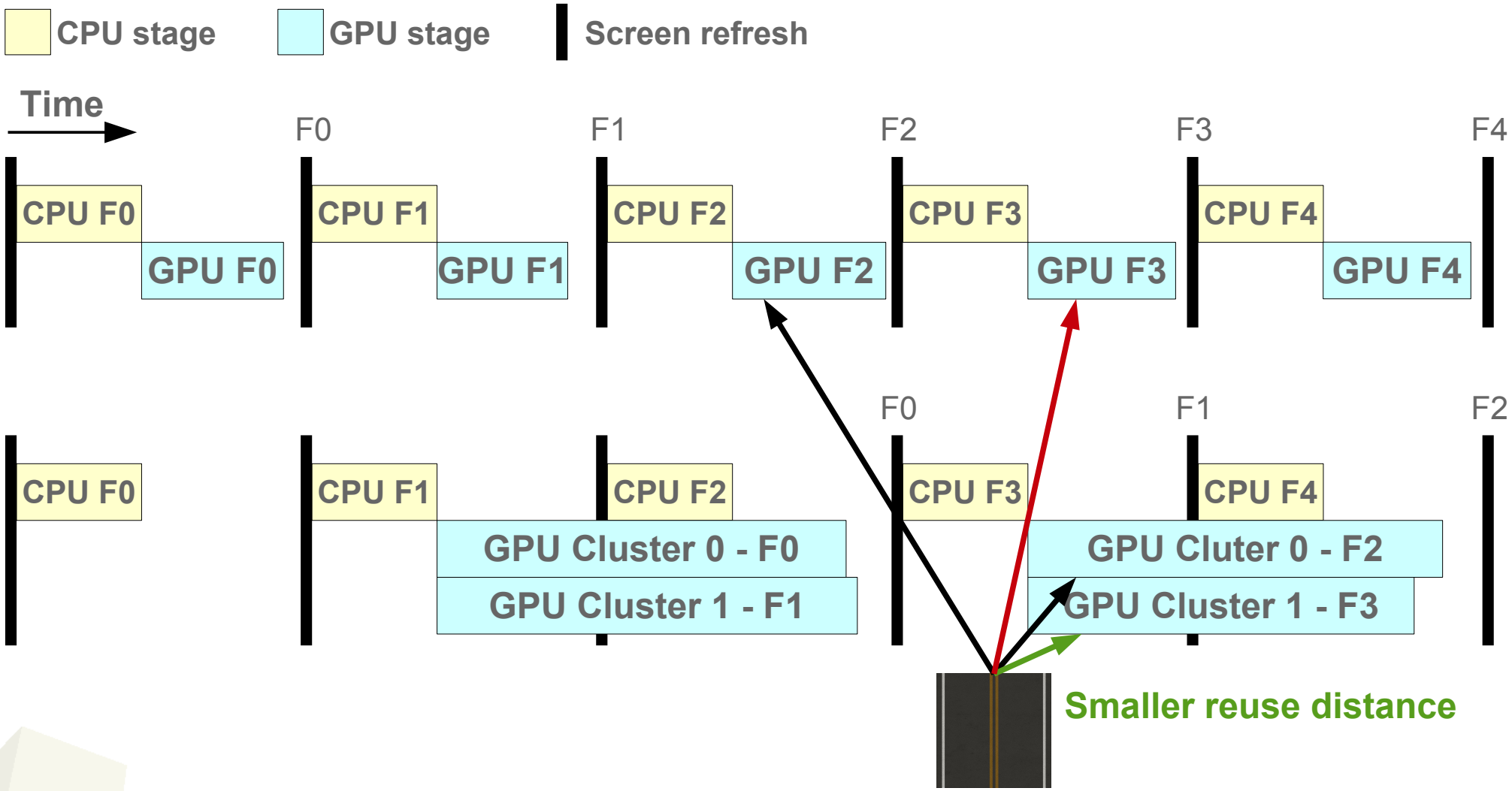

PFR saves bandwidth by overlapping the memory accesses of 2 consecutive frames

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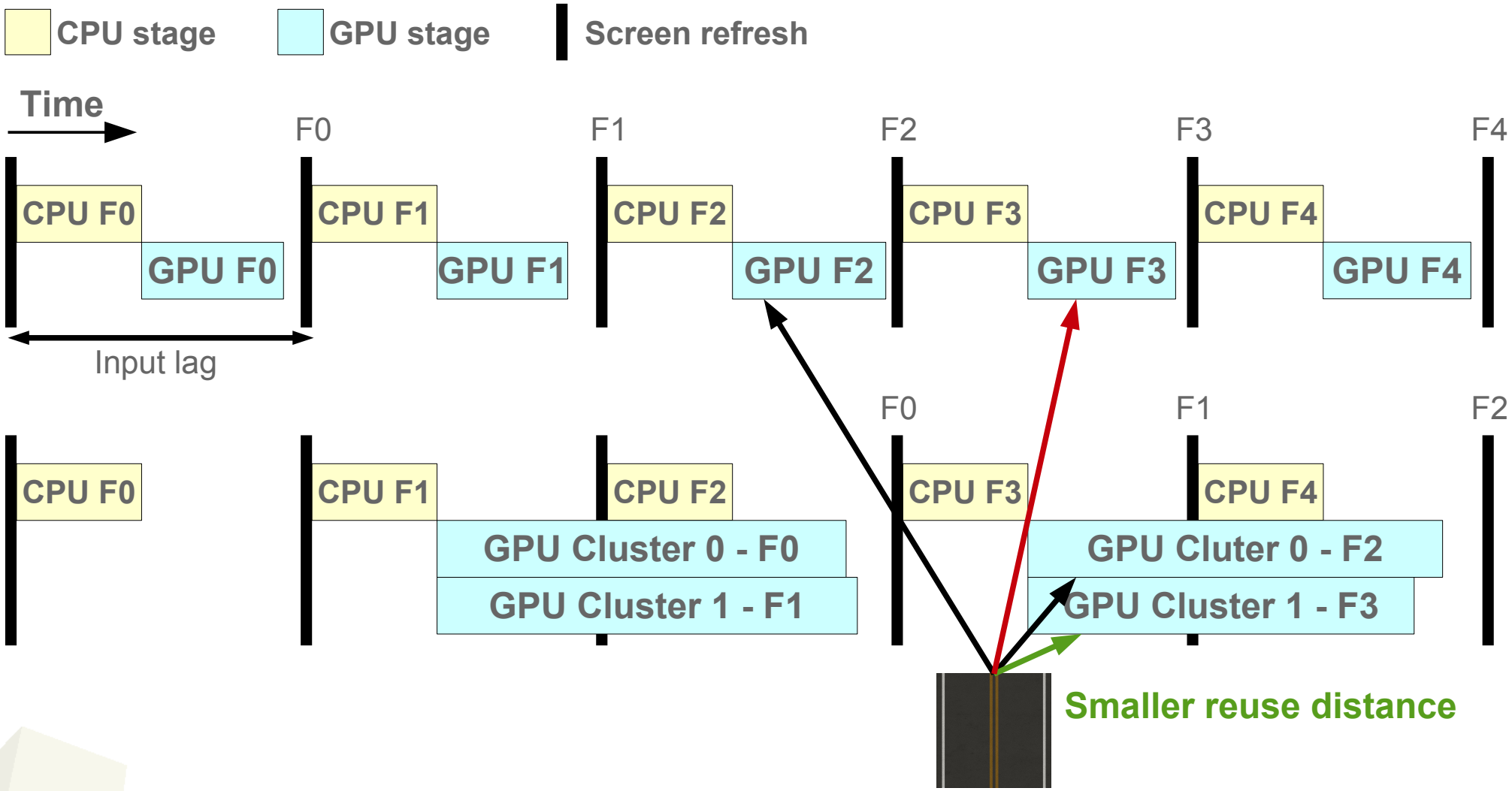

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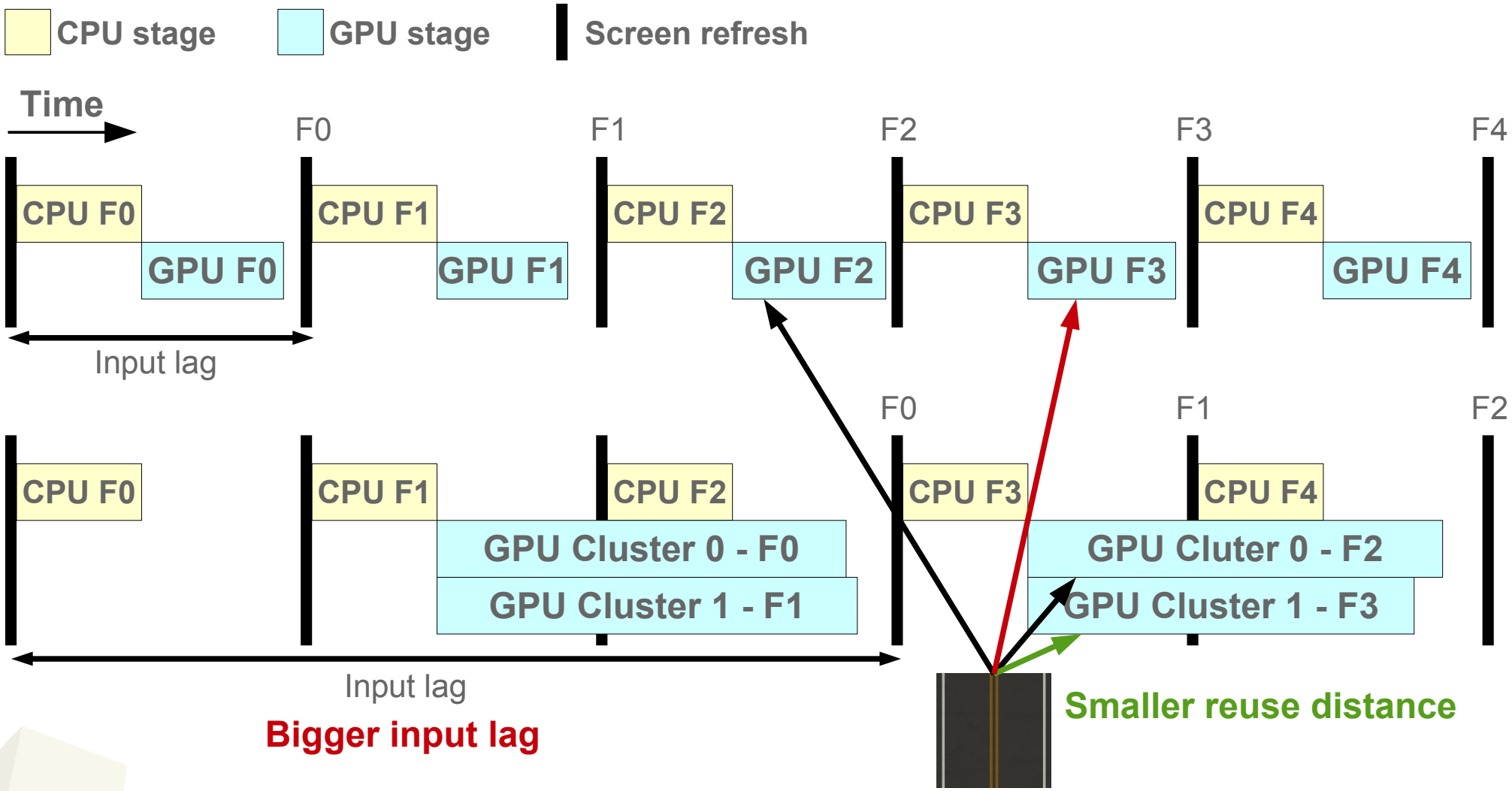

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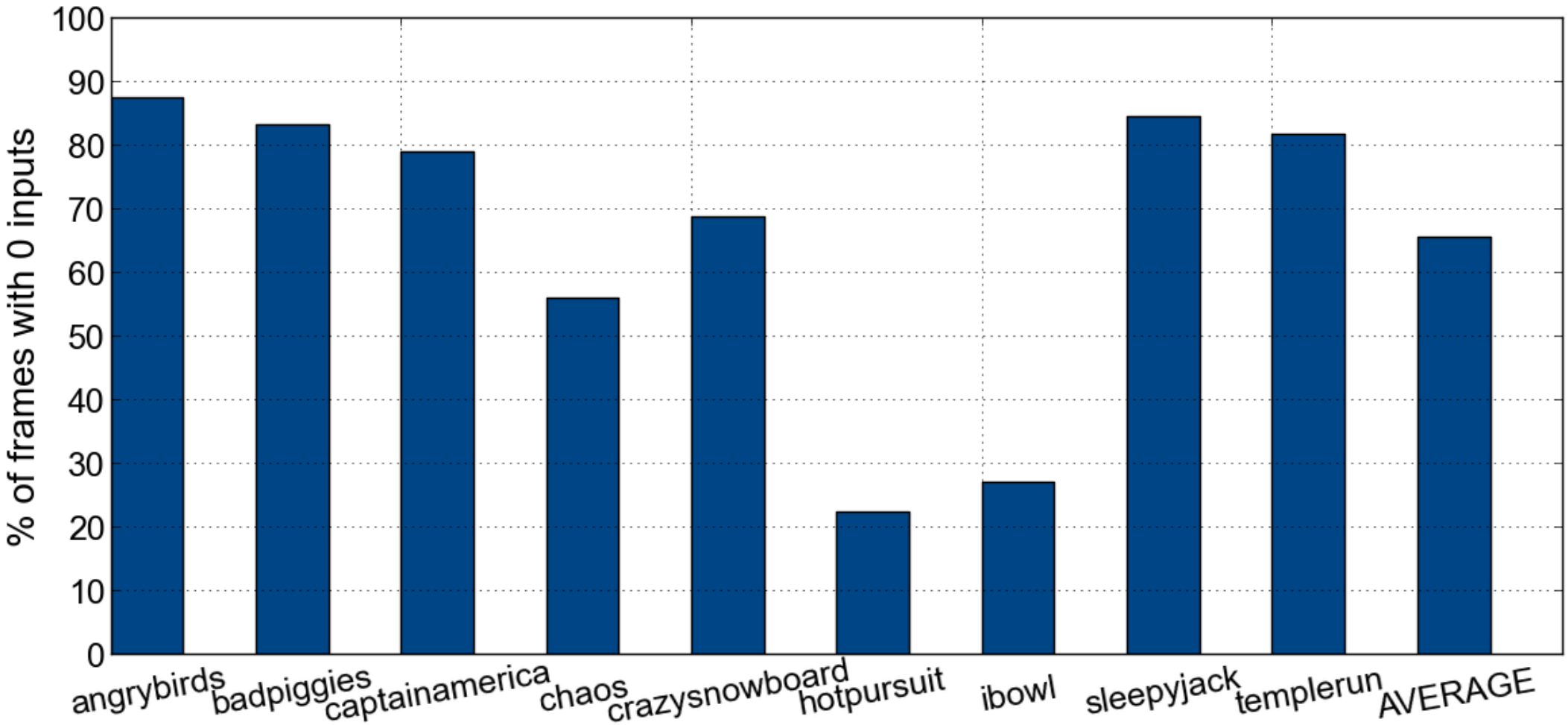
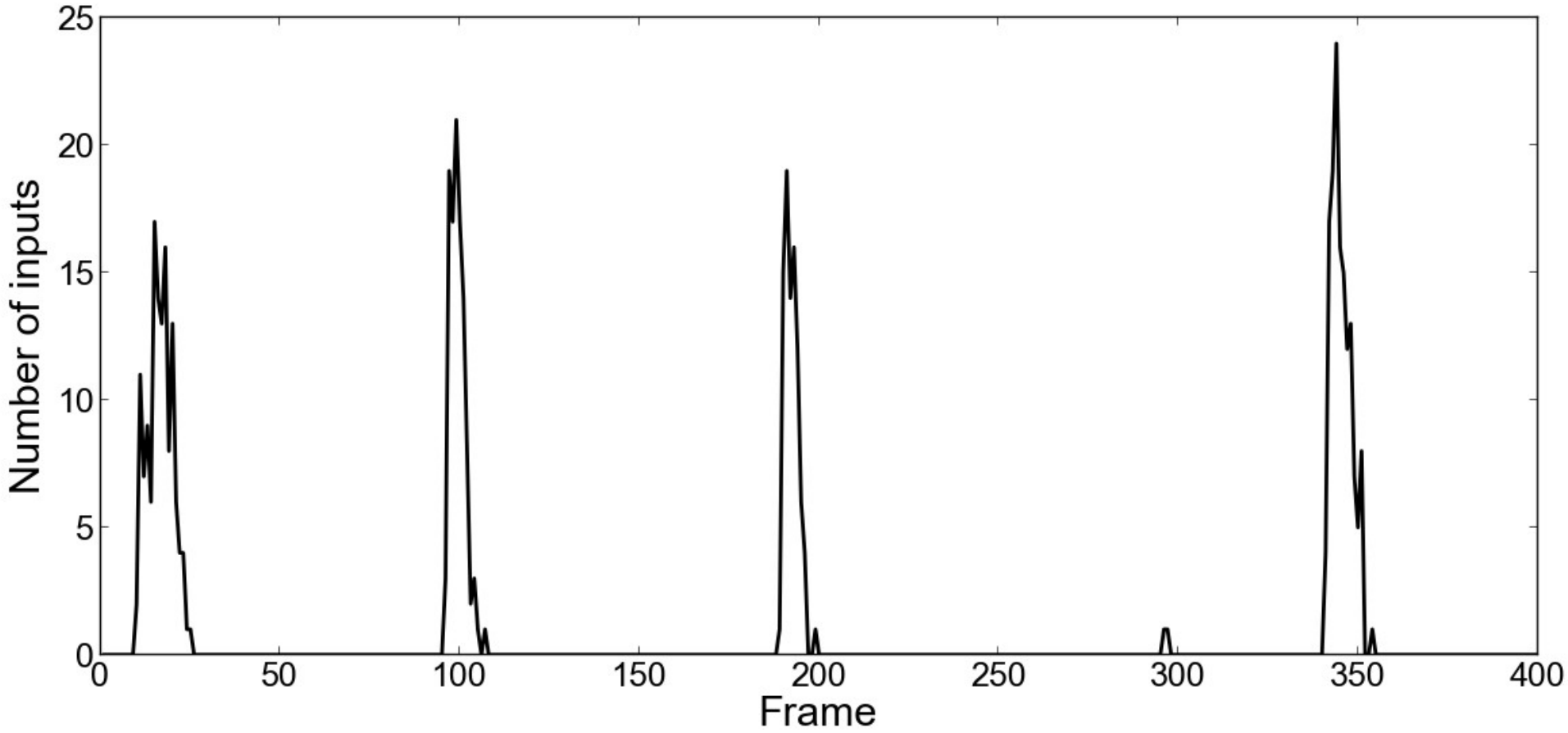
User Inputs in Mobile Games



The user does not provide any input most of the time, except in *hotpursuit* and *ibowl*

Reactive-PFR



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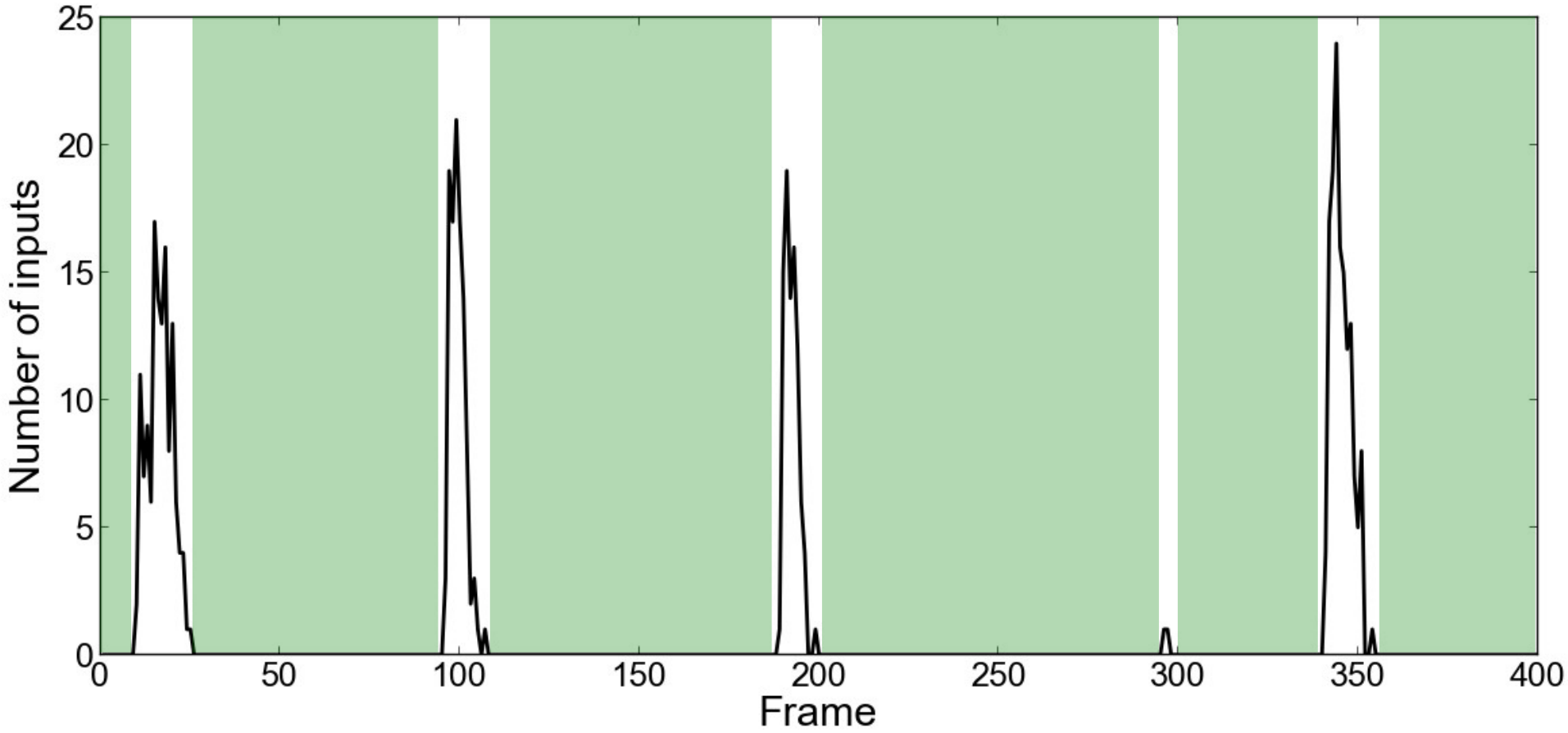

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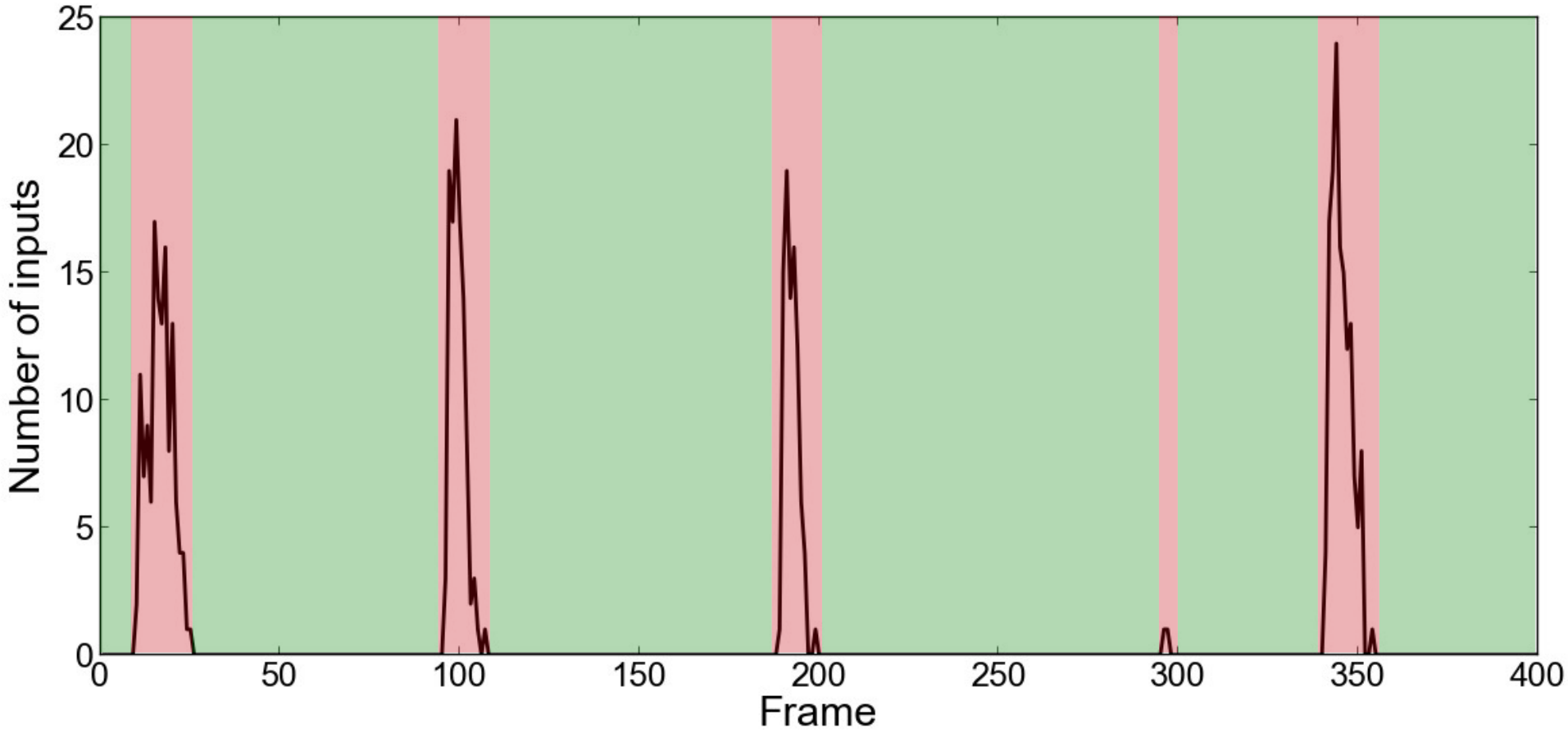

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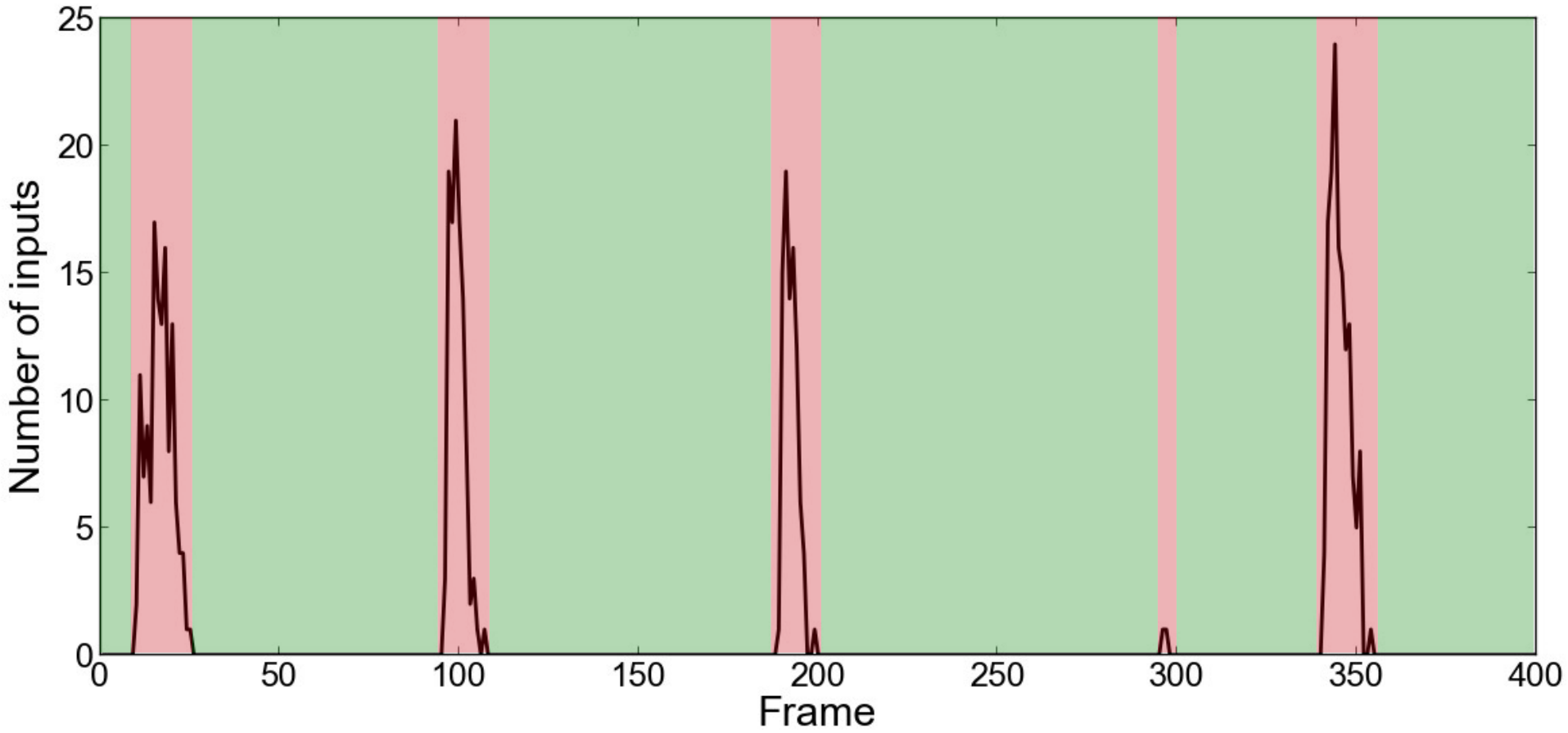
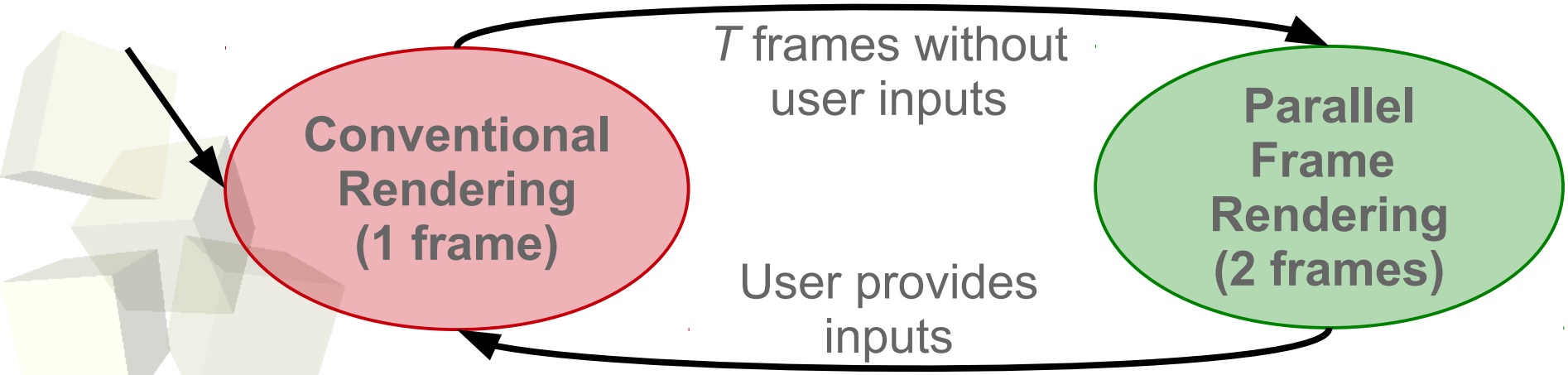
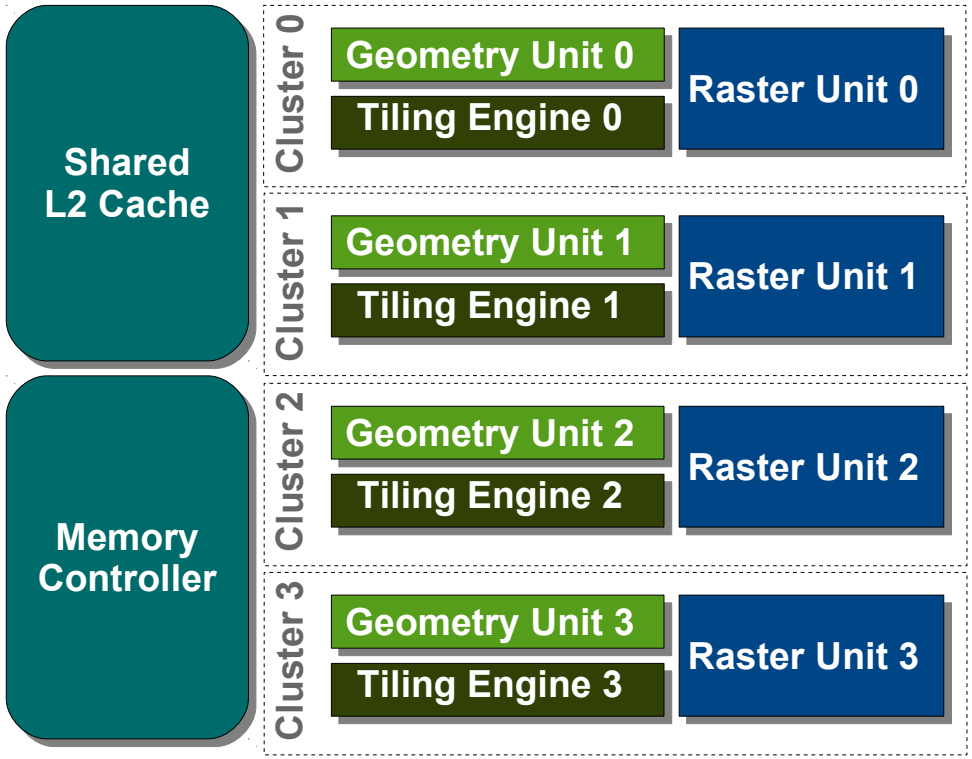




N-Frames Reactive-PFR



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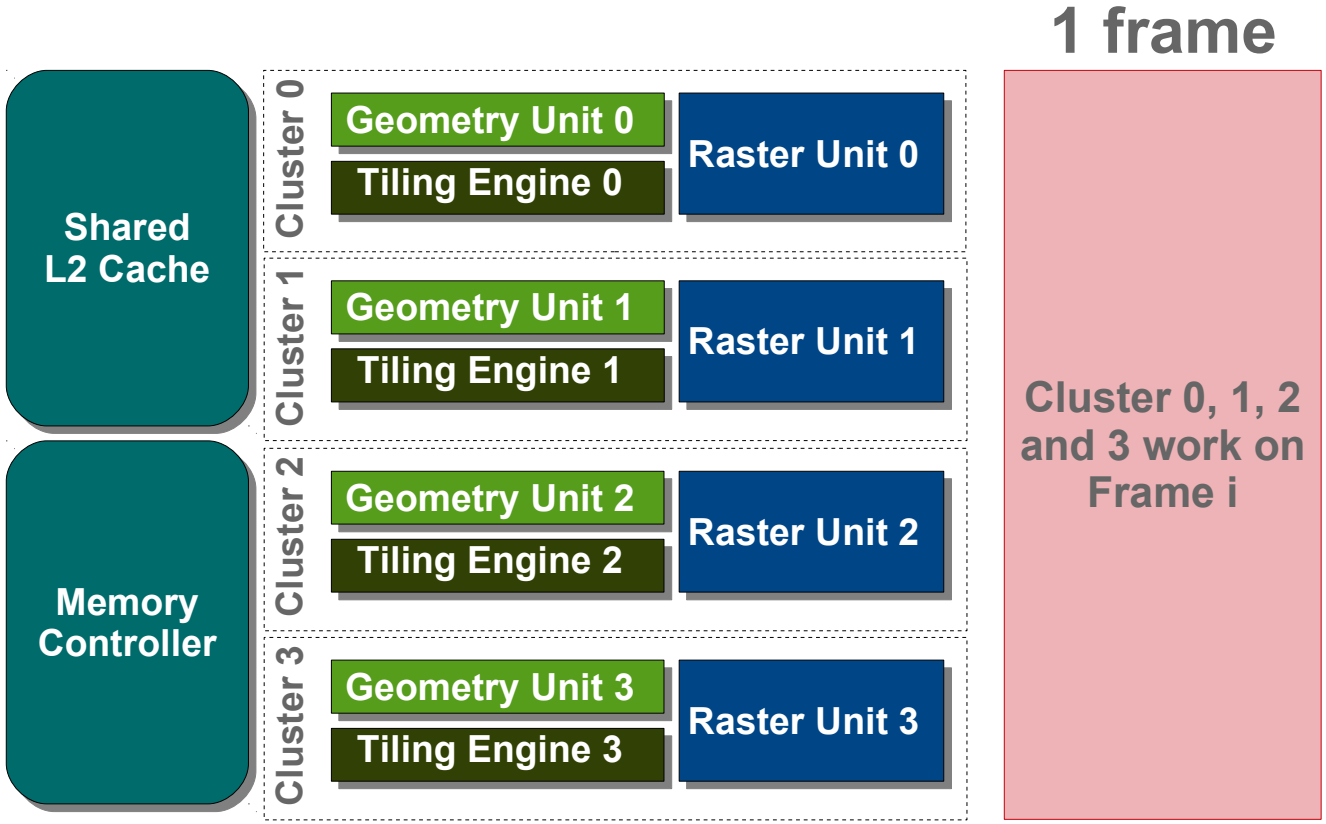

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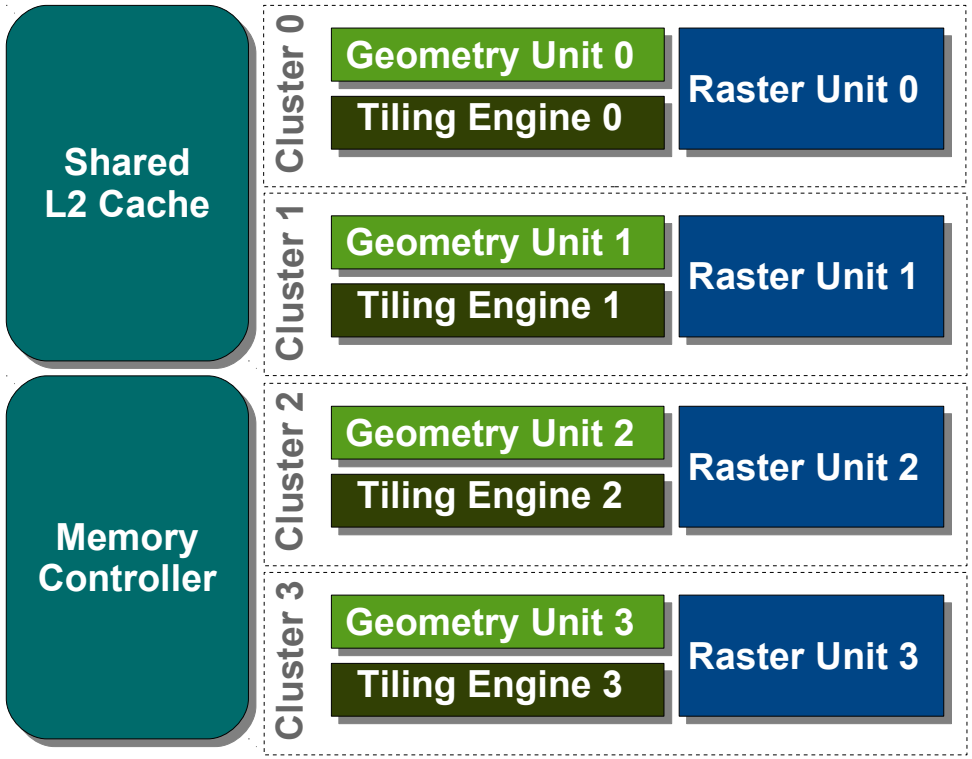

1 frame	2 frames
Cluster 0, 1, 2 and 3 work on Frame i	Cluster 0 and 1 work on Frame i
	Cluster 2 and 3 work on Frame i + 1

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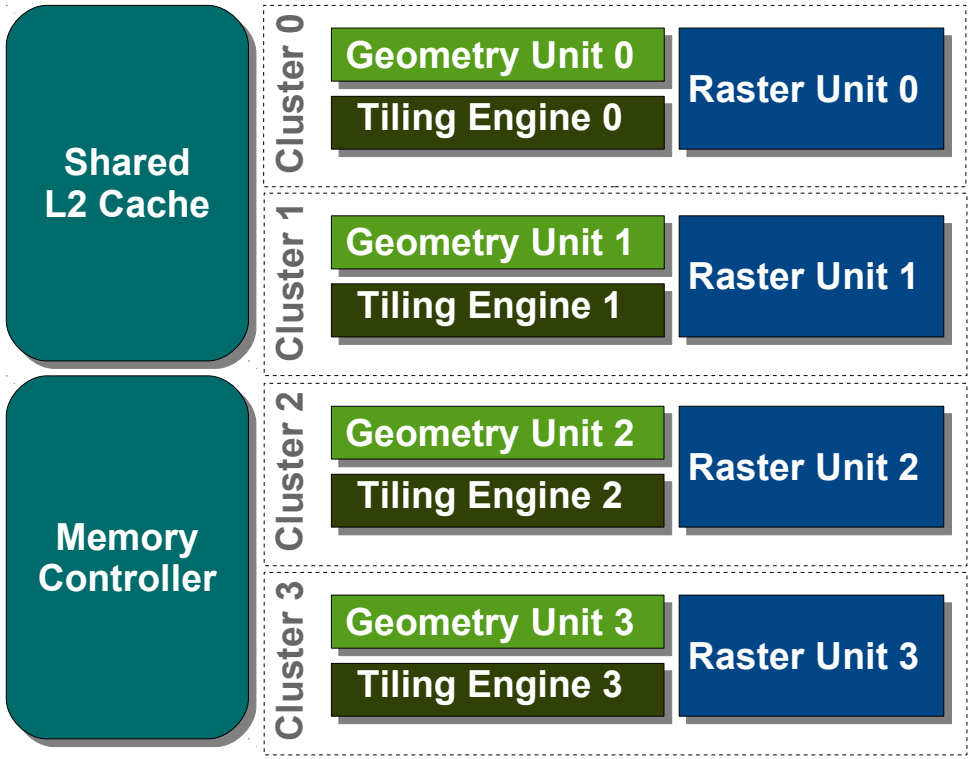

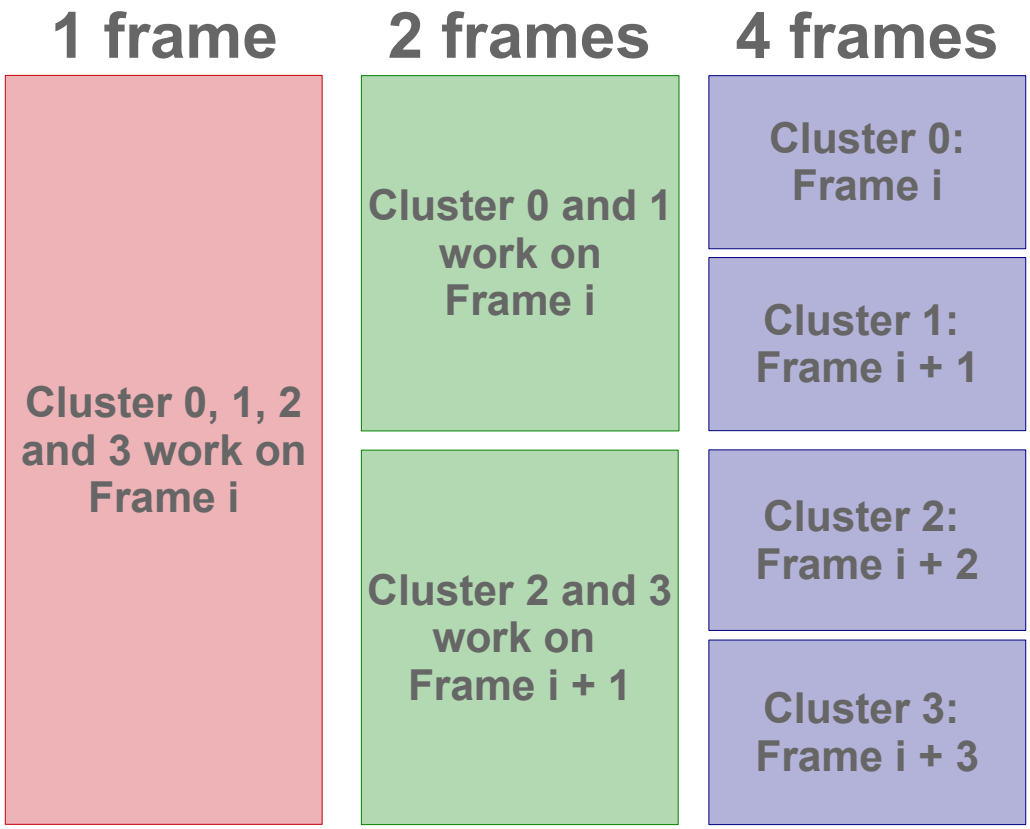

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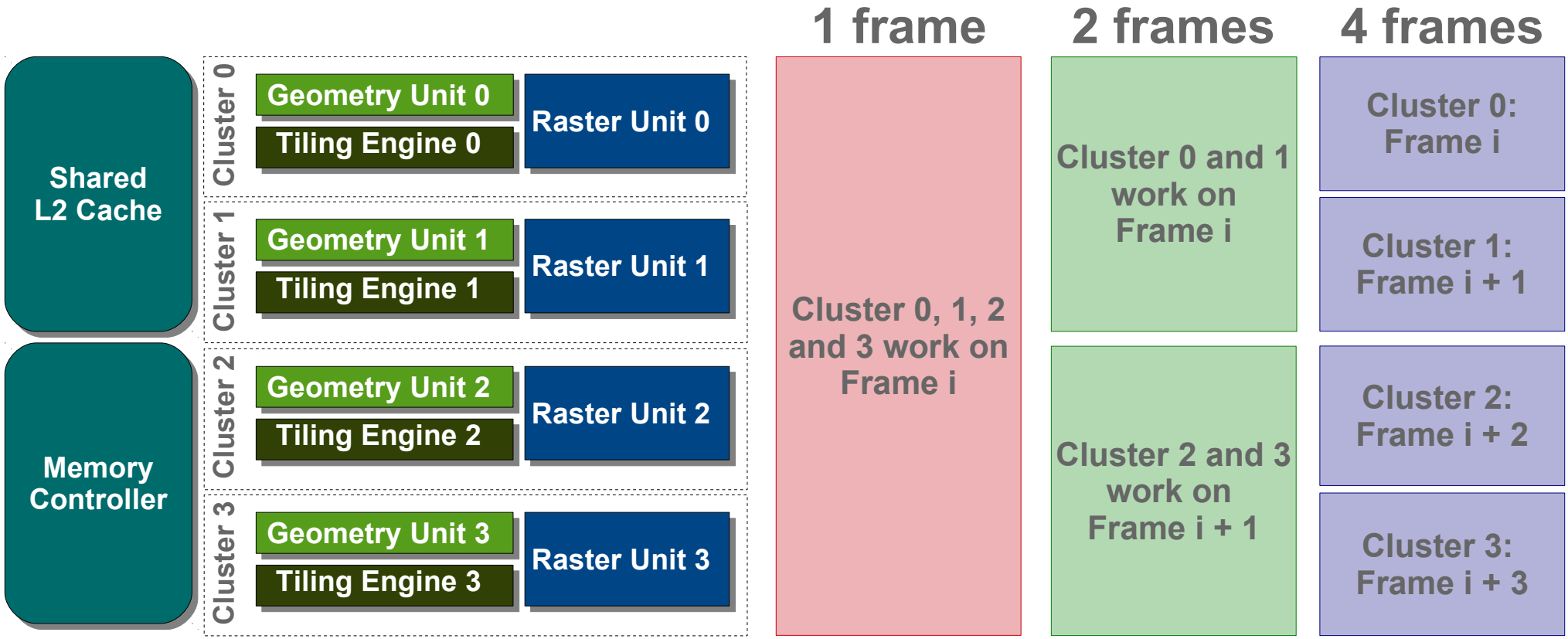
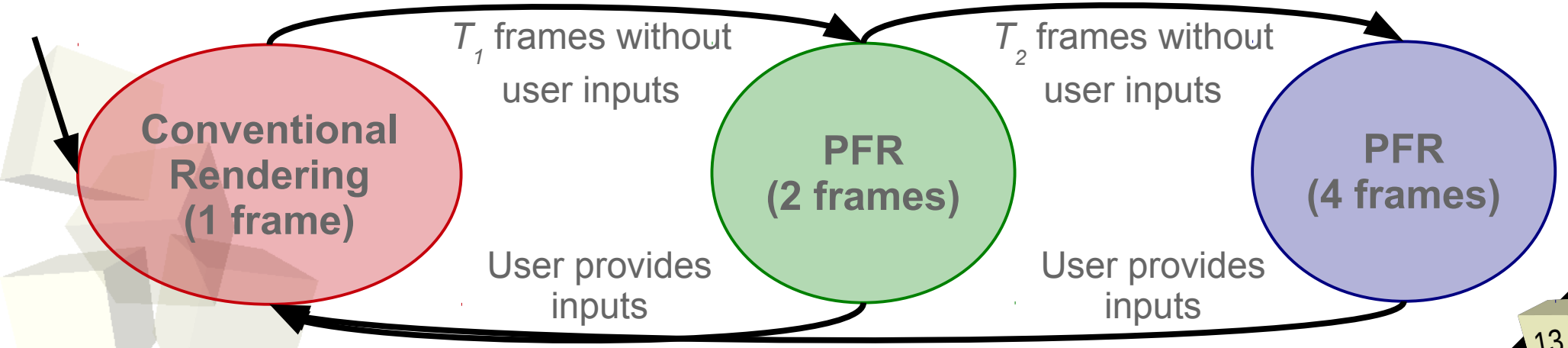
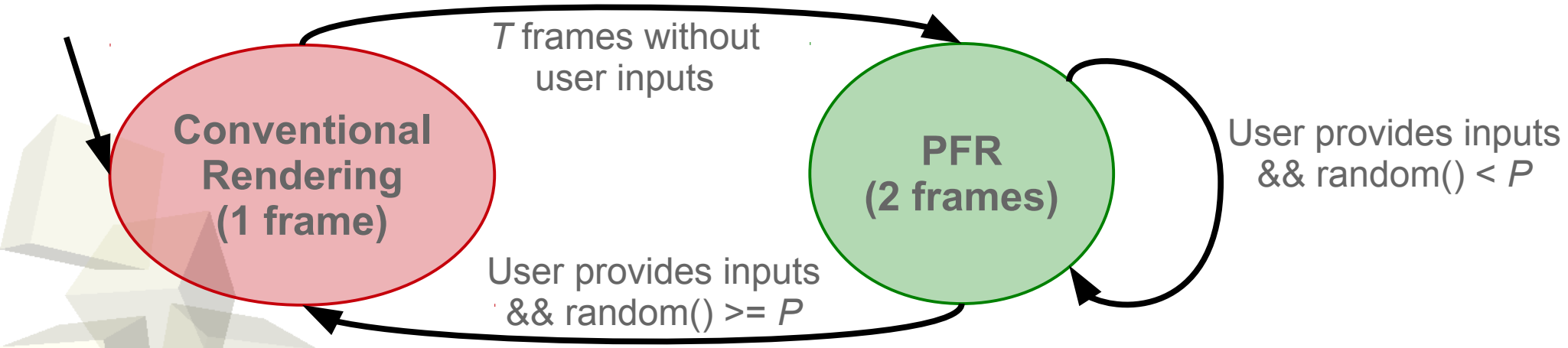




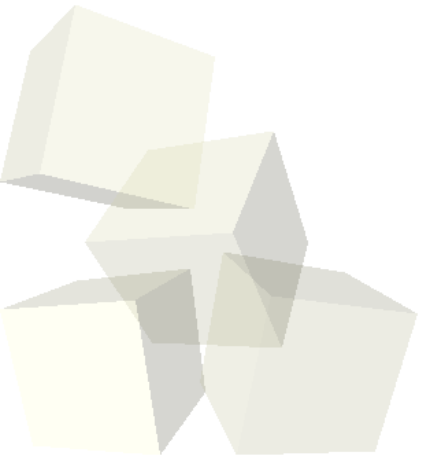
Delay Randomly PFR

- PFR delays all user inputs
  - Big bandwidth savings
  - Worse responsiveness
- R-PFR and NR-PFR do not delay any input
  - Same responsiveness than conventional GPUs
  - Smaller bandwidth savings
- Delay Randomly PFR (DR-PFR)
  - Delay a percentage, *P*, of randomly selected frames with user inputs



Outline

1. Motivation
2. Conventional Rendering
3. Parallel Frame Rendering
4. Experimental Results
5. Conclusions



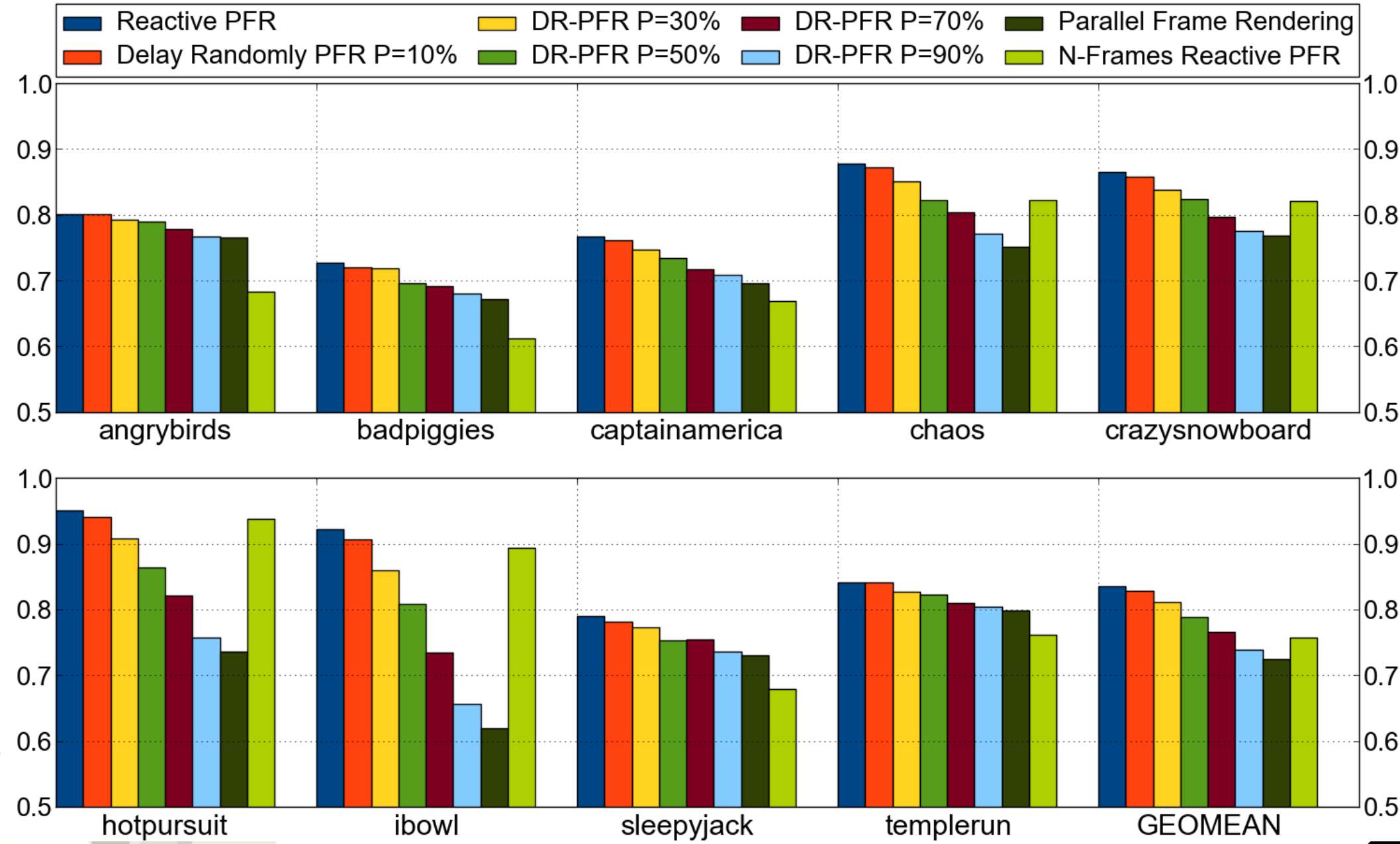
Evaluation Methodology

- TEAPOT simulator
  - Runs unmodified Android applications
  - Mobile GPU timing simulator (TBDR)
  - Power estimations (McPAT)
  - “TEAPOT: A Toolset for Evaluating Performance, Power and Image Quality on Mobile Graphics Systems”. ICS 2013.
- Workloads
  - 2D games: angrybirds, badpiggies
  - Simple 3D games: crazysnowboard, ibowl, templerun
  - Complex 3D games: captainamerica, chaos, hotpursuit, sleepyjack
- Hardware Parameters

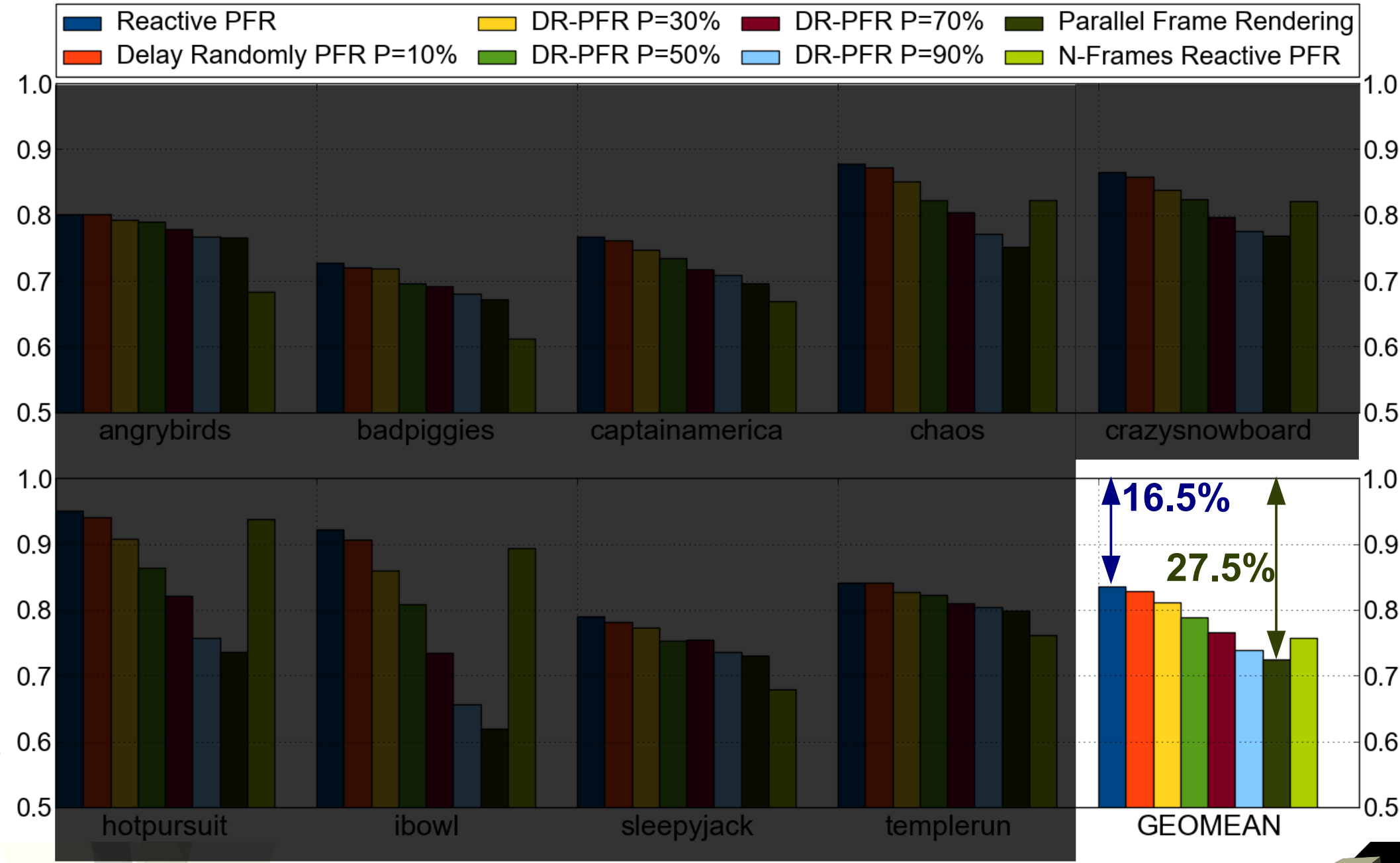
Technology	32 nm	**L2 Cache**	128 KB, 8-way, 12 cycles
Frequency	300 MHz	**Tile Cache**	32 KB, 4-way, 4 cycles
Tile size	16 x 16	**Texture Caches**	8 KB, 2-way, 1 cycle
Screen	800 x 480 (WVGA)	**Main memory**	1 GB, 8 bytes/cycle

	Conv. Rendering	**PFR, R-PFR, DR-PFR**	**NR-PFR**
Num clusters	1	2	4
Raster units/cluster	4	2	1
Vertex Proc./cluster	4	2	1

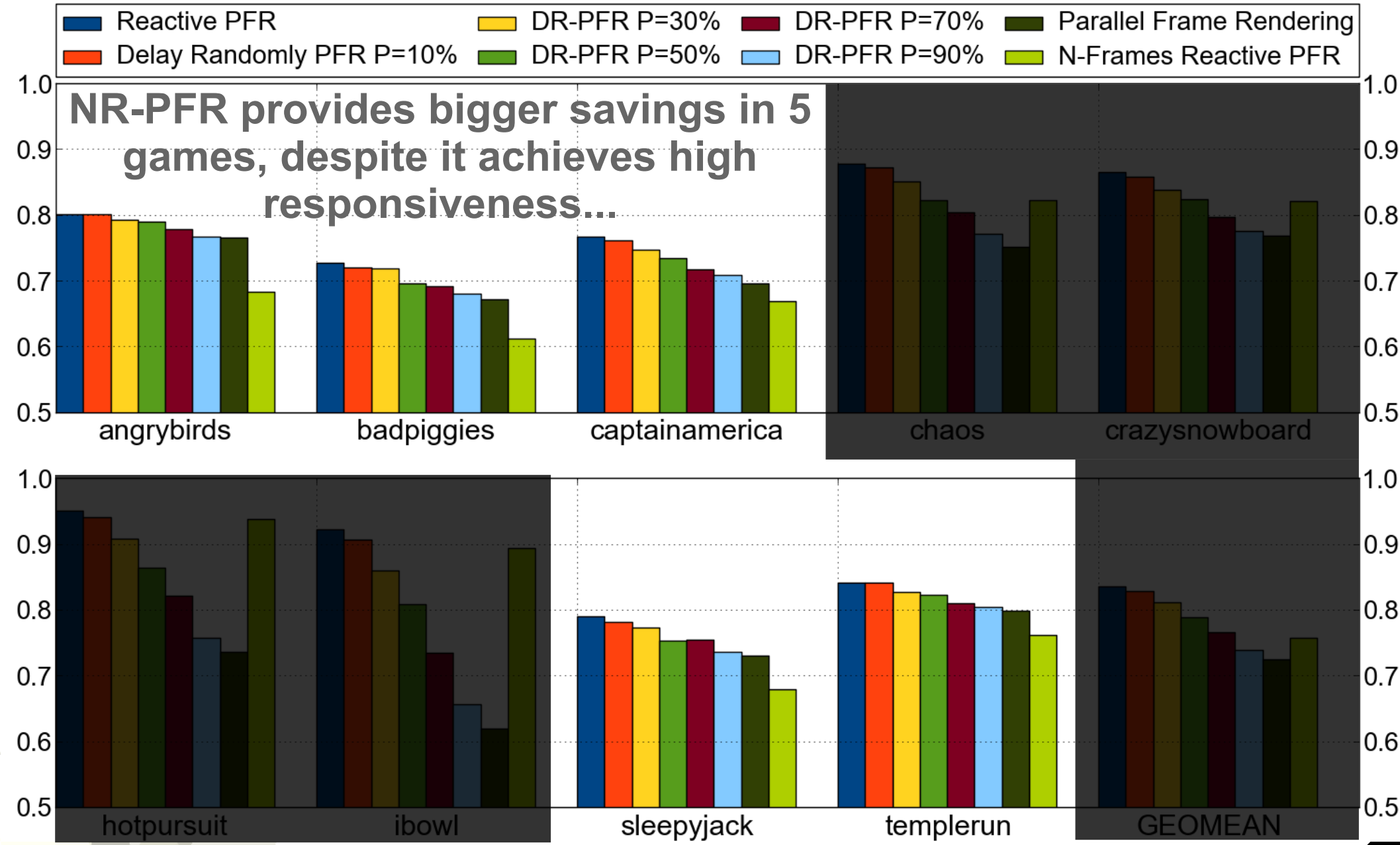
Normalized Memory Traffic



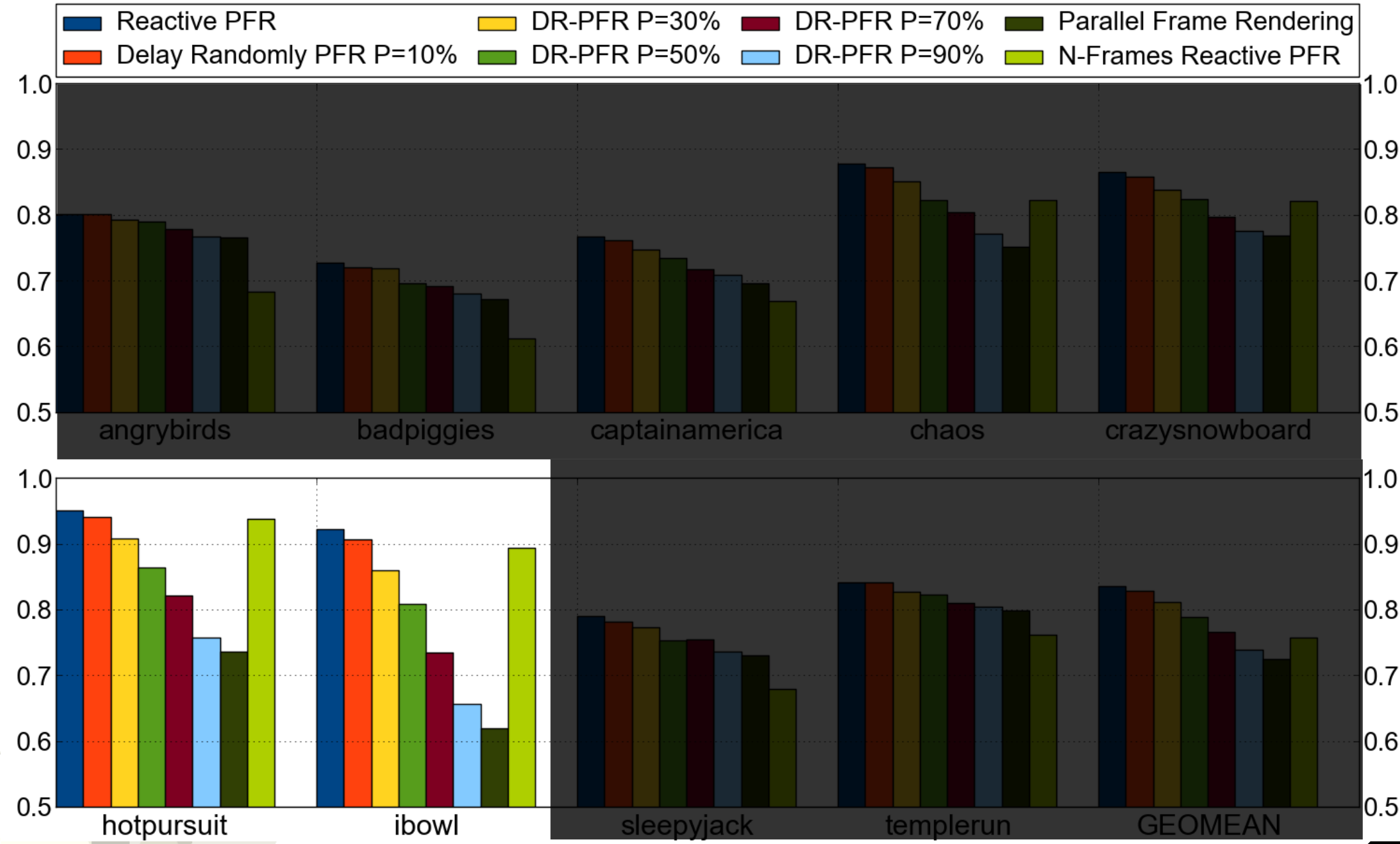
Normalized Memory Traffic



Normalized Memory Traffic

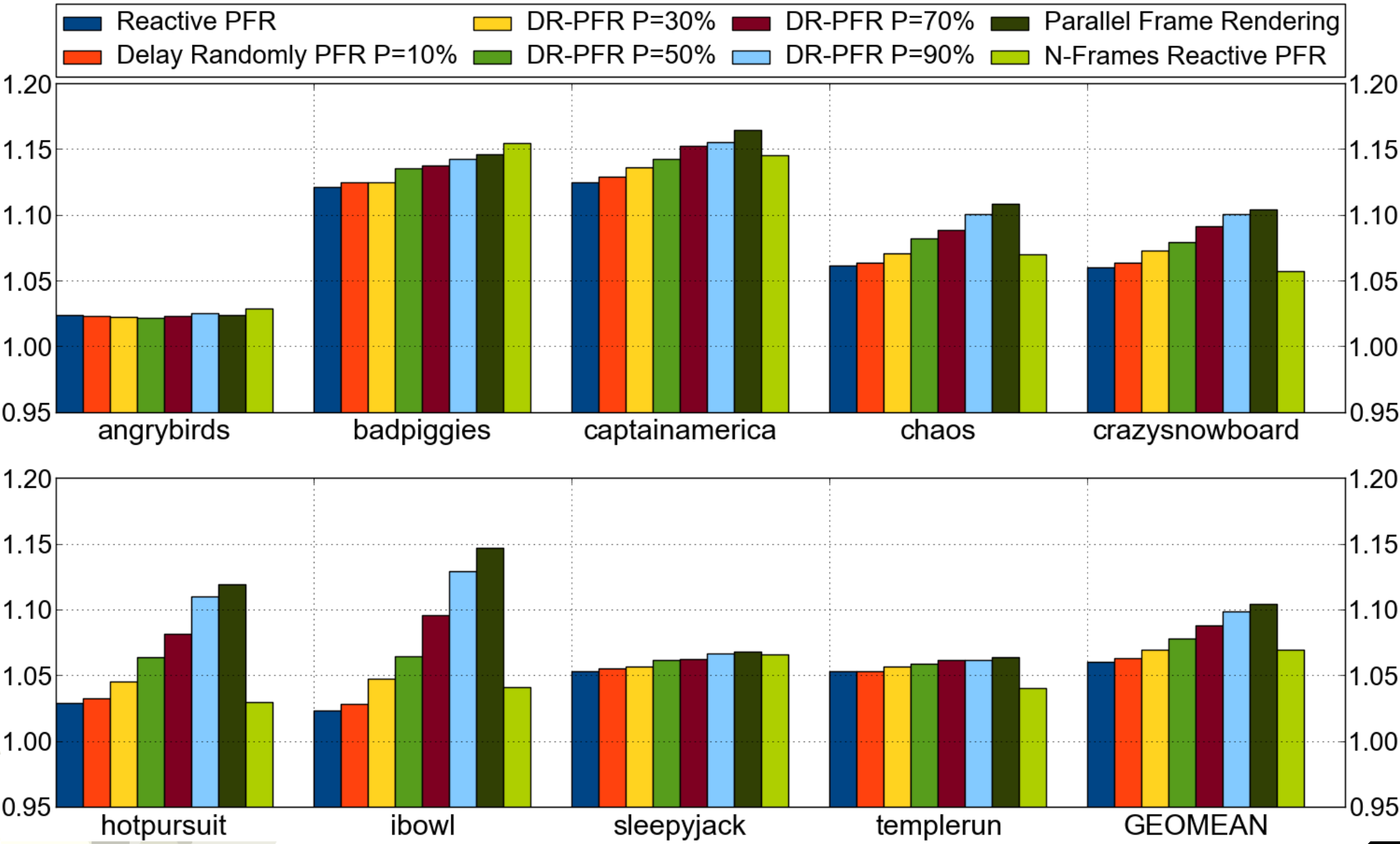


Normalized Memory Traffic



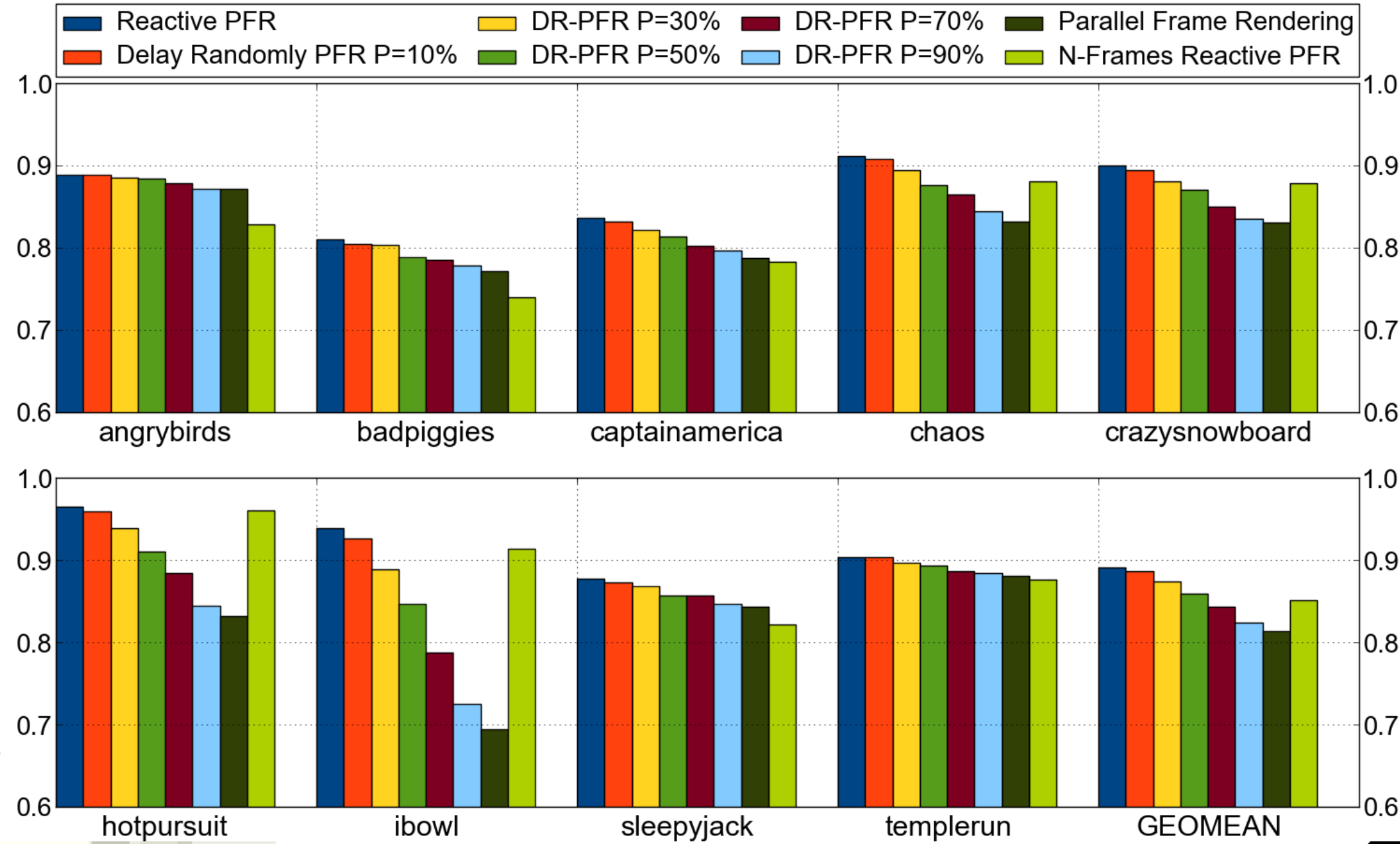
...but the Reactive versions offer modest savings for games with intensive user interaction

Speedup

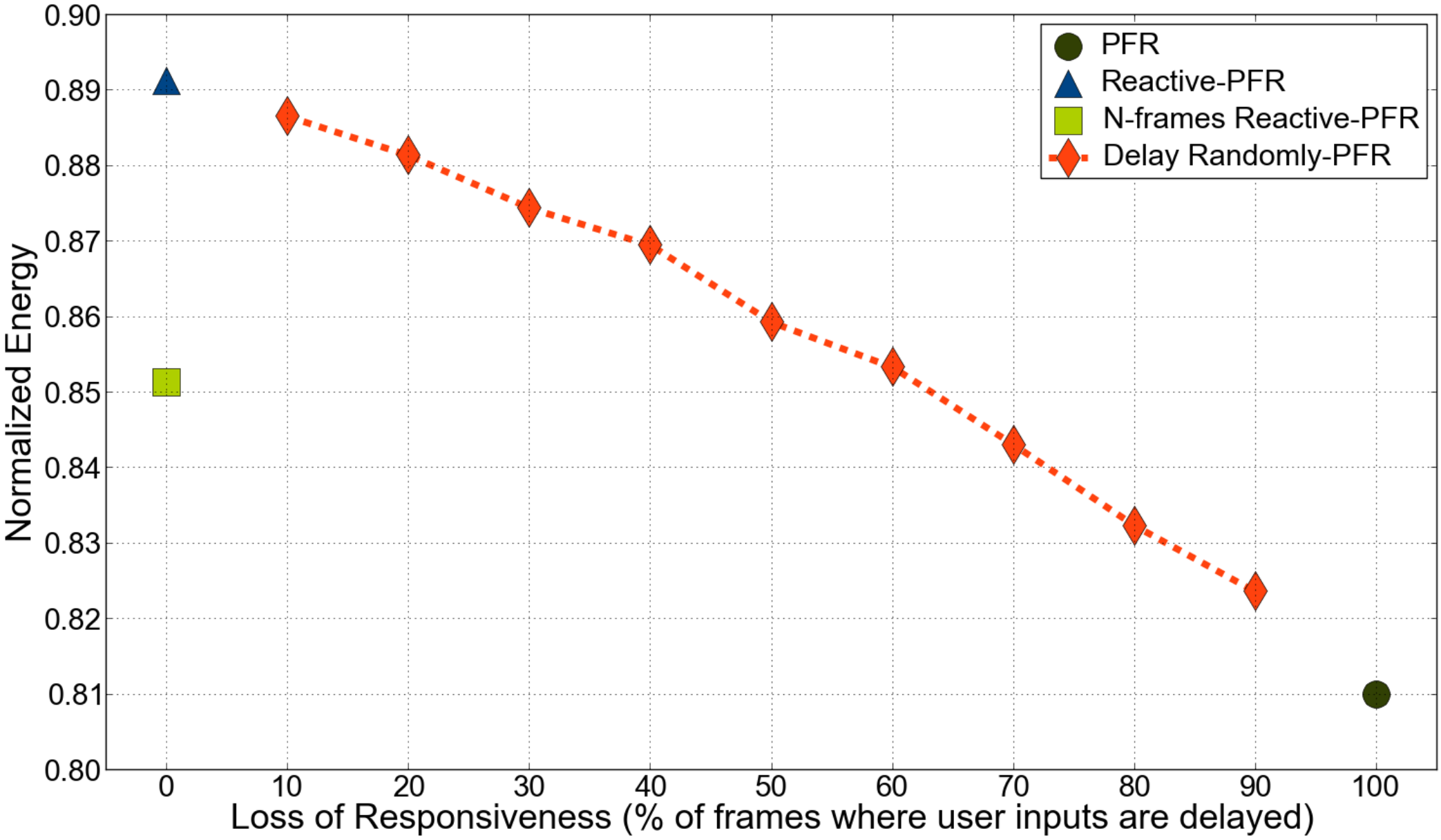


GPUs are bandwidth bound

Normalized Energy



Trading Responsiveness for Energy



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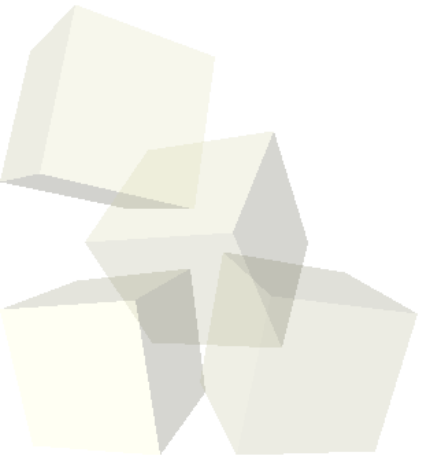

Conclusions

- Consecutive frames exhibit a high degree of **texture similarity**, since a big percentage of the texture dataset is shared
- Mobile GPU **memory bandwidth** can be significantly reduced by overlapping the memory accesses of 2 consecutive frames, we term this technique as Parallel Frame Rendering (PFR)
- PFR comes at a cost in the **responsiveness** of the system, as the input lag is increased
- **Reactive** versions of PFR are able to adapt to the amount of input provided by the user, achieving high responsiveness when necessary
- The experimental results show that PFR and its different variations provide consistent **performance** and **energy** improvements

Parallel Frame Rendering: Trading Responsiveness for Energy on a Mobile GPU

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