CS 380 - GPU and GPGPU Programming
Lecture 20: GPU Virtual Texturing, Pt. 2

Markus Hadwiger, KAUST

Reading Assignment #11 (until Nov 13)

Read (required):

- **Brook for GPUs: Stream Computing on Graphics Hardware**
  Ian Buck et al., SIGGRAPH 2004

`http://graphics.stanford.edu/papers/brookgpu/`

Read (optional):

- **The Imagine Stream Processor**
  Ujval Kapasi et al.; IEEE ICCD 2002

`http://cva.stanford.edu/publications/2002/imagine-overview-iccd/`

- **Merrimac: Supercomputing with Streams**
  Bill Dally et al.; SC 2003

`https://dl.acm.org/citation.cfm?doid=1048935.1050187`

GPU Virtual Texturing

Virtual Texturing

Example #1:

ARB Sparse Textures (originally: AMD Partially Resident Textures)

ARB_sparse_texture / ARB_sparse_texture2

`https://www.khronos.org/registry/OpenGL/extensions/ARB/ARB_sparse_texture.txt`

`https://www.khronos.org/registry/OpenGL/extensions/ARB/ARB_sparse_texture2.txt`

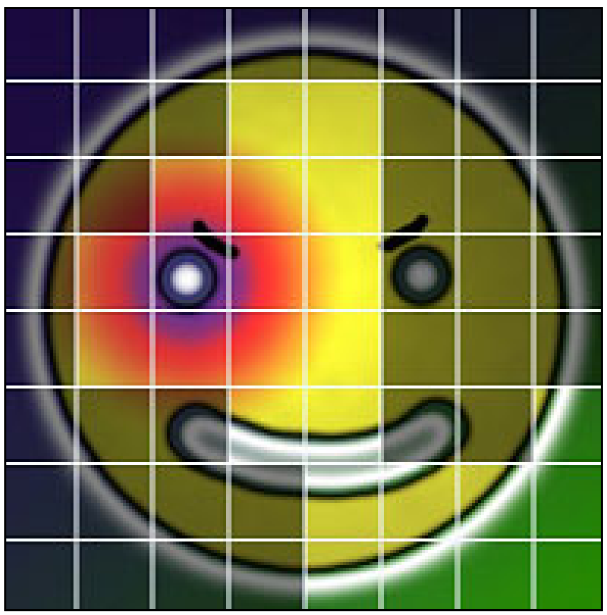
Hardware Virtual Texturing, Graham Sellers,
from SIGGRAPH 2013 course “Rendering Massive Virtual Worlds”

`https://cesiumjs.org/hosted-apps/massiveworlds/downloads/Graham/Hardware_Virtual_Textures.pptx`

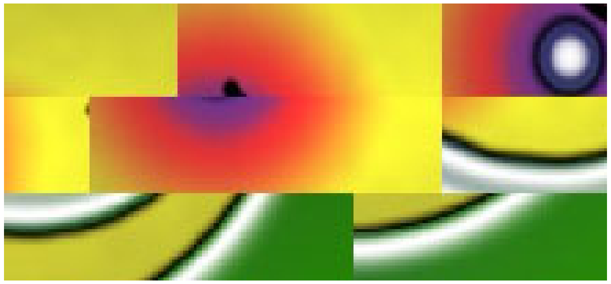
Virtual Texturing

Divide texture up into tiles

- Commit only *used* tiles to memory
- Store data in separate physical texture



Virtual Texture

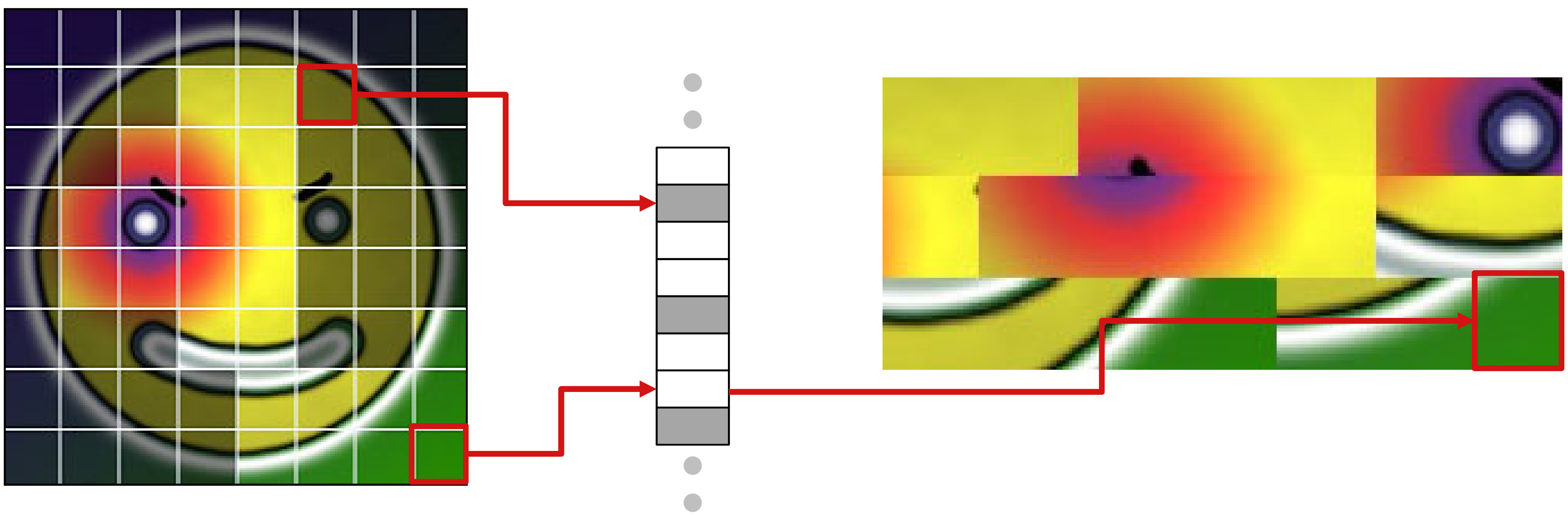


Physical Texture

Virtual Texturing

Use indirection table to map virtual to physical

- This is also known as a *page table*



Virtual Texturing

Example #2:

Adaptive Shadow Maps (ASM)

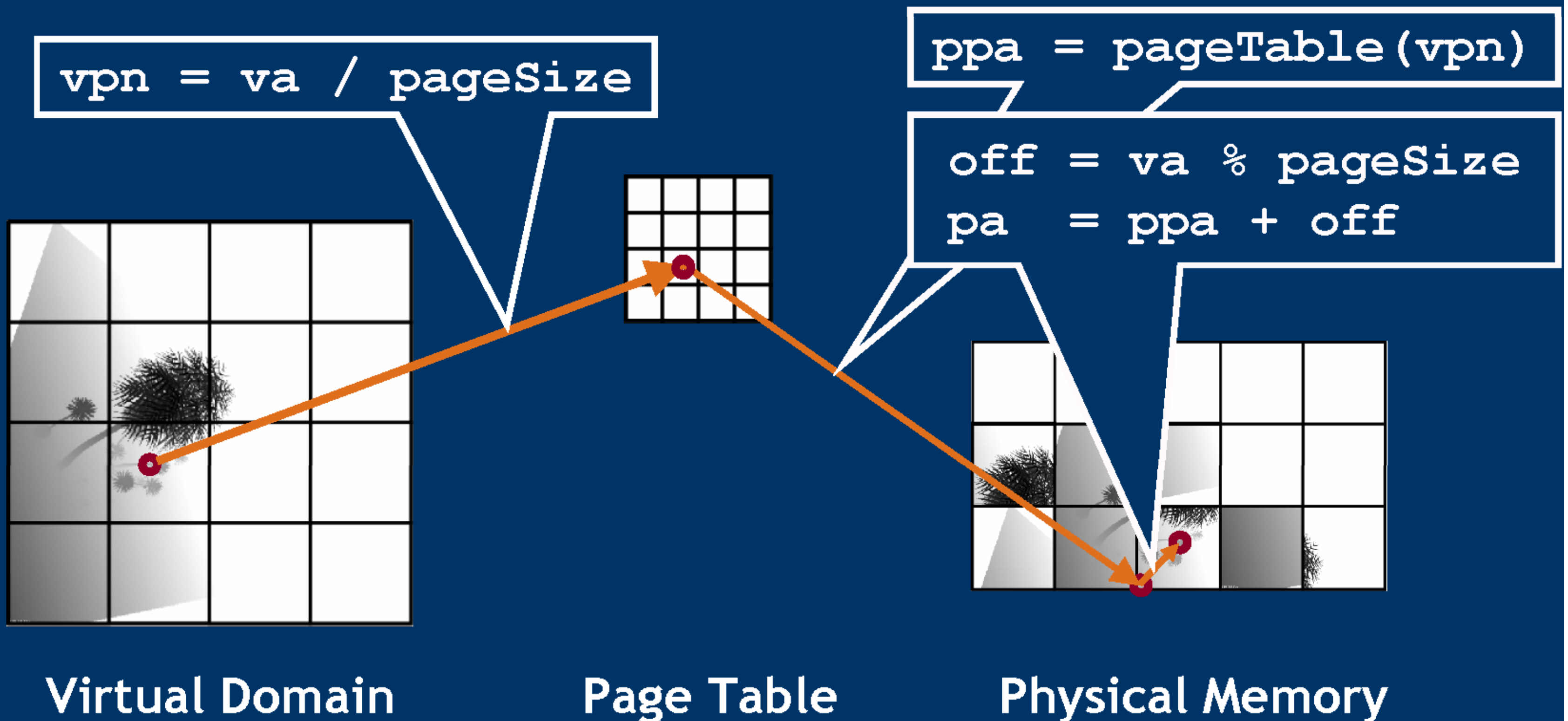
- On CPUs: Fernando et al., ACM SIGGRAPH 2001

Resolution-Matched Shadow Maps

- On GPUs: Aaron Lefohn et al., ACM Transactions on Graphics 2007

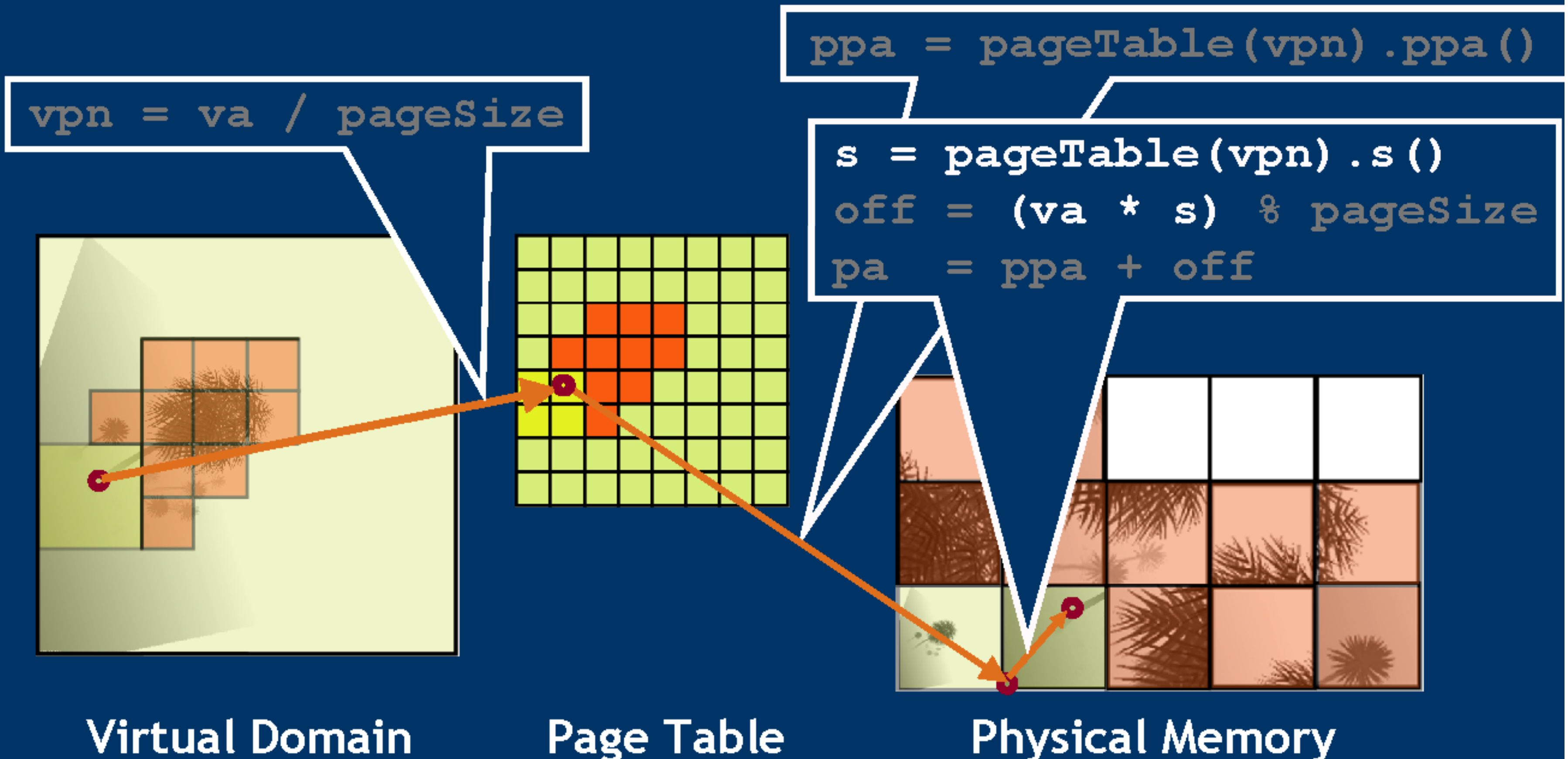
ASM Data Structure (Adaptive Shadow Maps)

- Page table example



ASM Data Structure (Adaptive Shadow Maps)

- Adaptive Page Table
  - Map multiple virtual pages to single physical page



Aaron Lefohn
University of California, Davis

Virtual Texturing

Example #3:

id Tech 5 Megatextures, id Software

Rage

- Virtual Texturing in Software and Hardware, van Waveren et al., SIGGRAPH 2012 course notes + slides

`http://www.jurajobert.com/data/Virtual_Texturing_in_Software_and_Hardware_course_notes.pdf`

`http://www.mrelusive.com/publications/papers/Software-Virtual-Textures.pdf`

`http://www.mrelusive.com/publications/presentations/2013_siggraph/hq_sw_hw_vts_12.pdf`

Virtual Texturing

Rage / id Tech 5 (id Software)

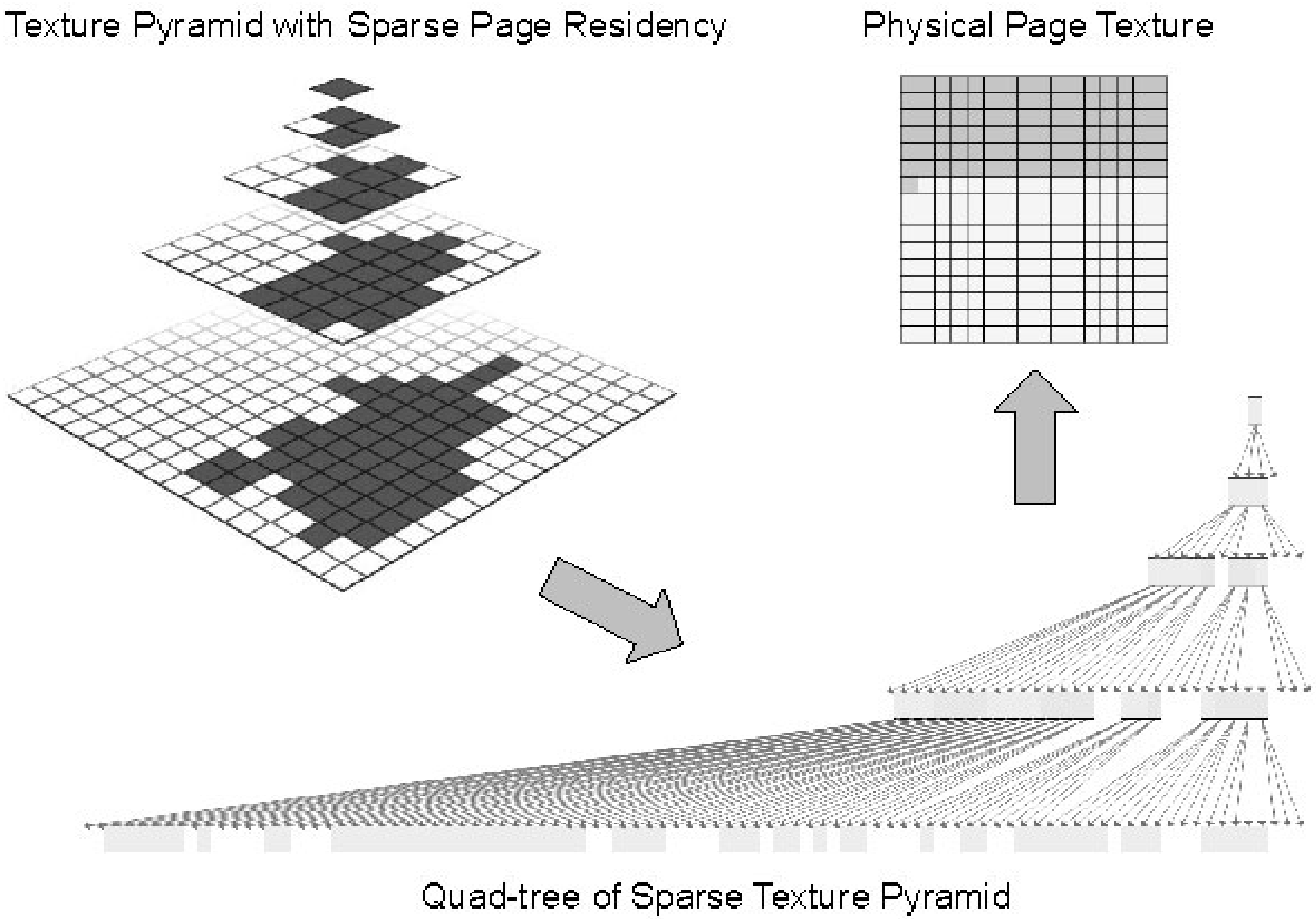
Virtual Texturing

- Unique, very large virtual textures key to id tech 5 rendering
- Full description beyond the scope of this talk

Virtual Texturing

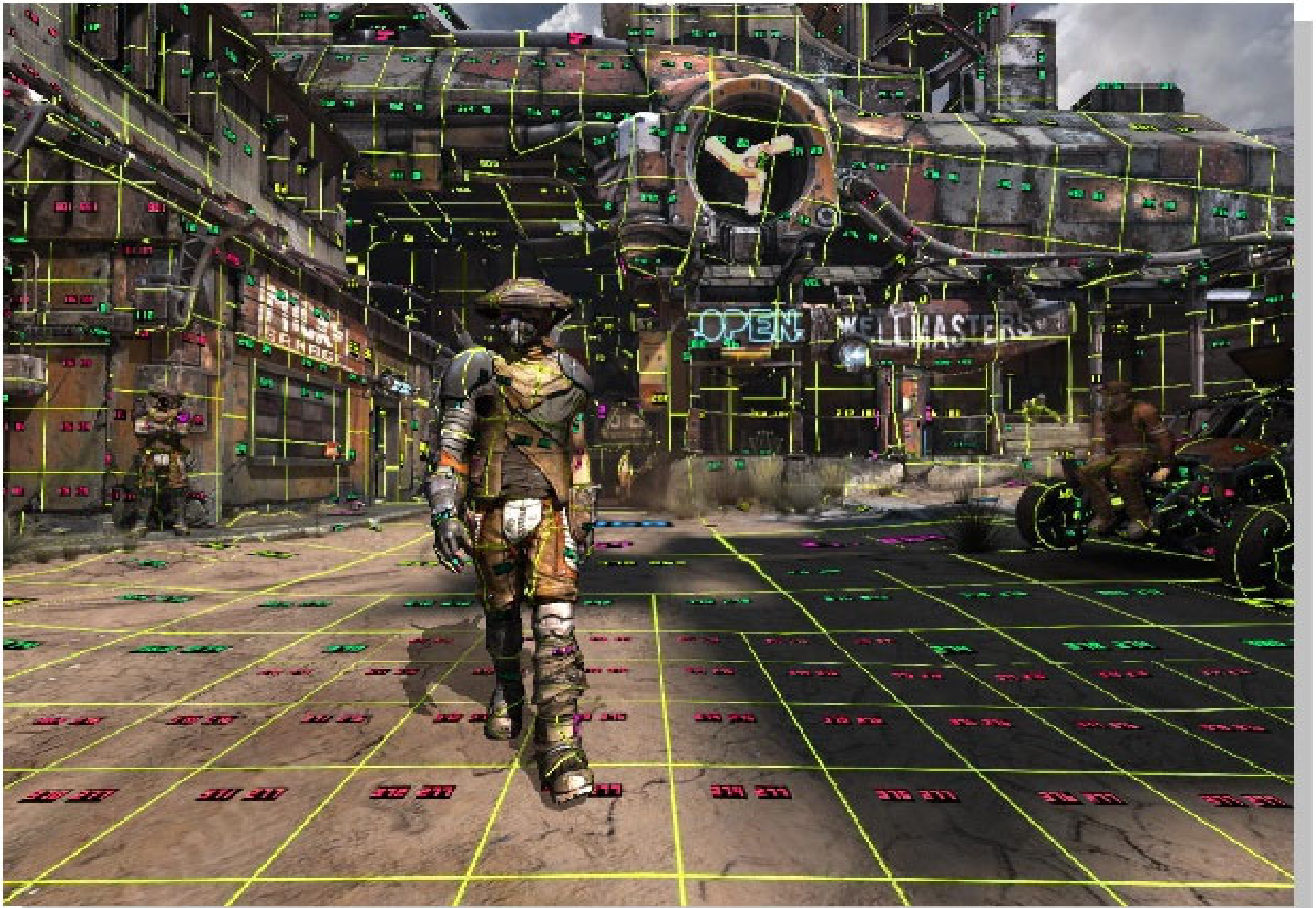
Virtual Texturing

Virtual Texturing



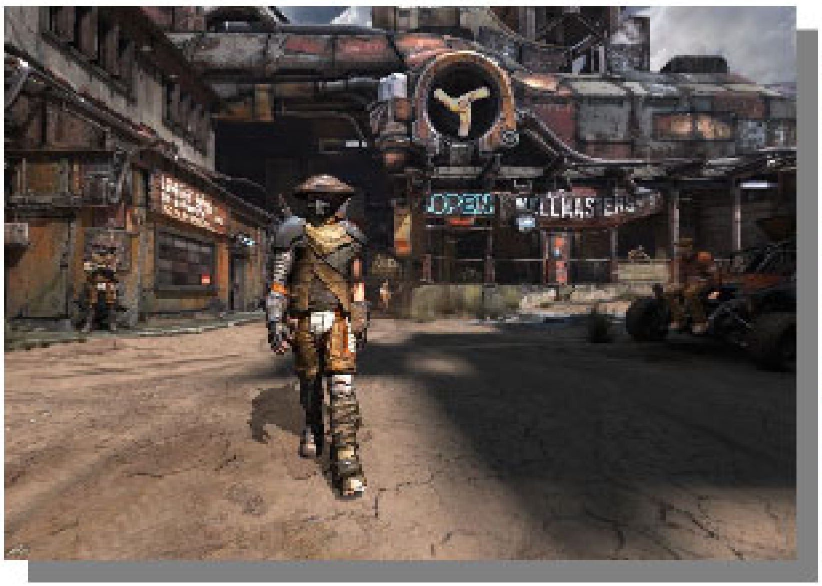
Virtual Texturing

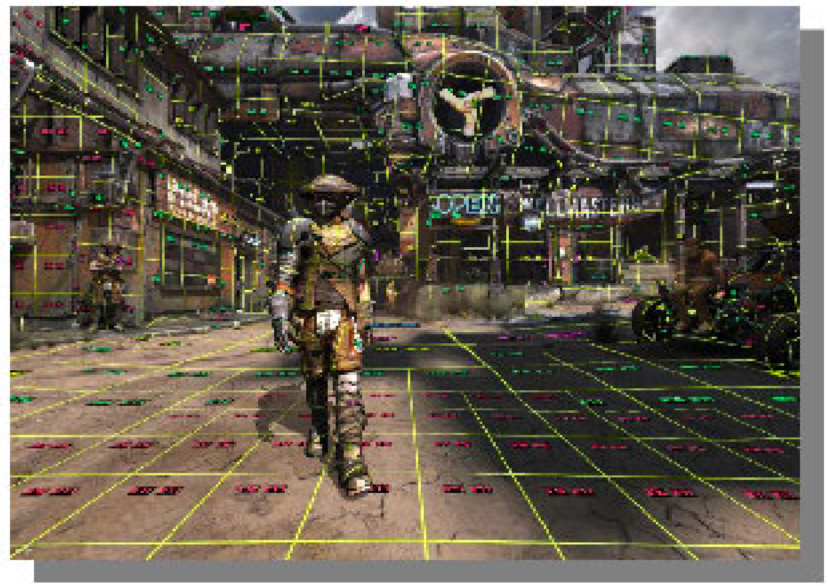
Virtual Texturing



Virtual Texturing

A few interesting issues...
- Texture filtering
- Thrashing due to physical memory oversubscription
- LOD transitions under high latency

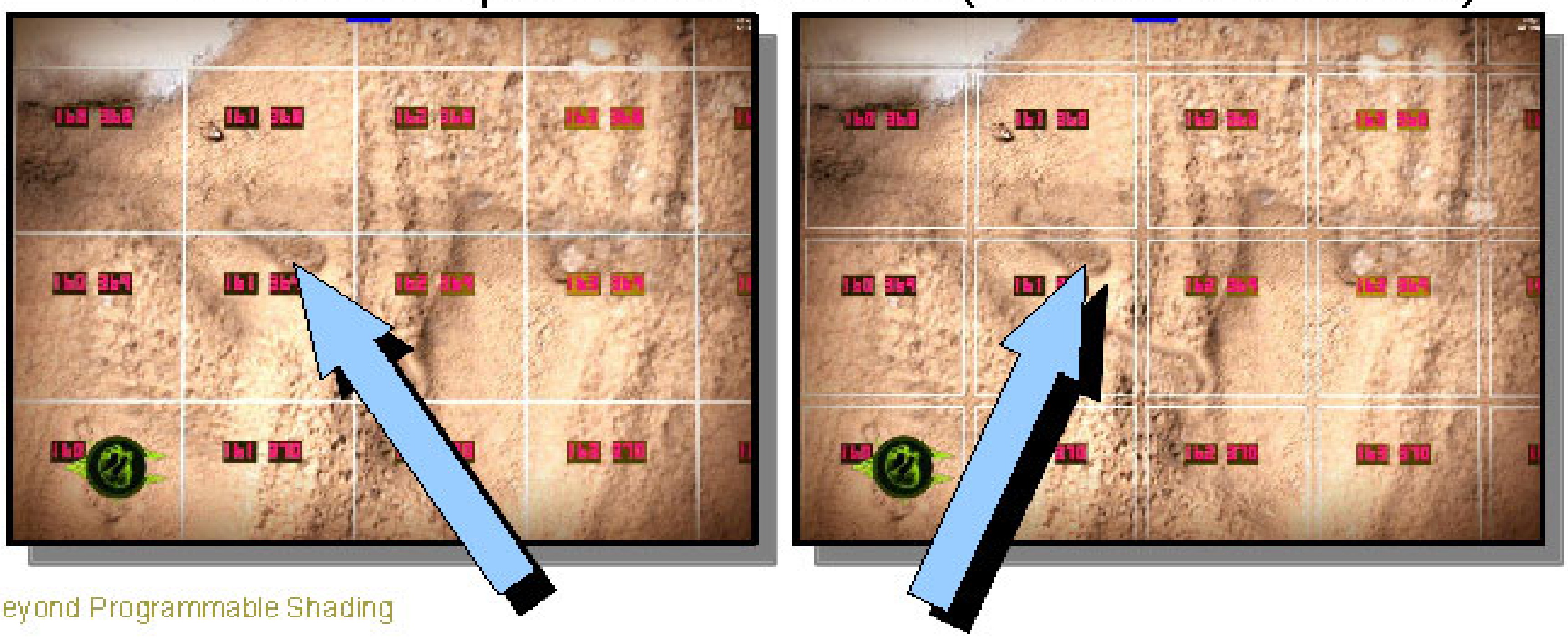




RAGE with PRTs (Image courtesy of id Software)

Virtual Texturing - Filtering

- We tried no filtering at all
- We tried bilinear filtering without borders
- Bilinear filtering with border works well
- Trilinear filtering reasonably but still expensive
- Anisotropic filtering possible via TXD (texgrad)
  - 4-texel border necessary (max aniso = 4)
  - TEX with implicit derivs ok too (on some hardware)



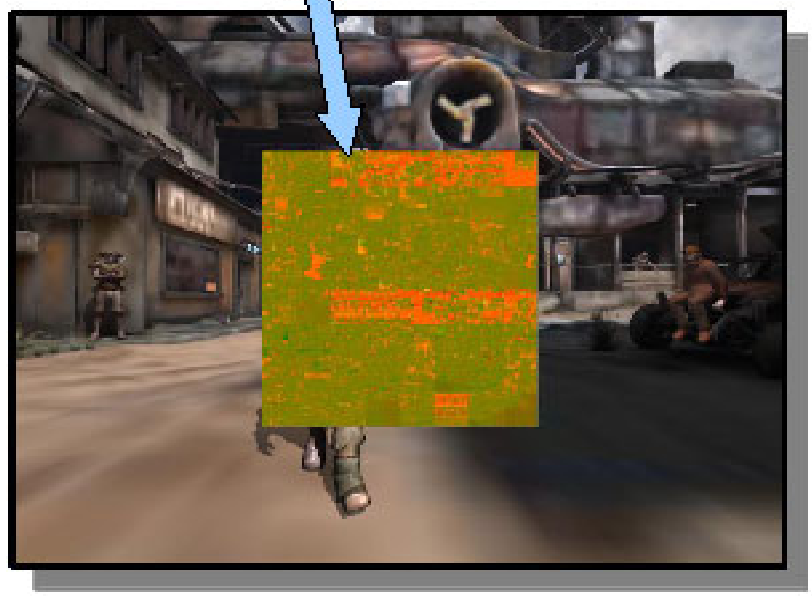
Virtual Texturing - Thrashing

- Sometimes you need more physical pages than you have
- With conventional virtual memory, you must thrash
- With virtual texturing, you can globally adjust feedback LOD bias until working set fits

32 x 32 pages

1024 Physical Pages

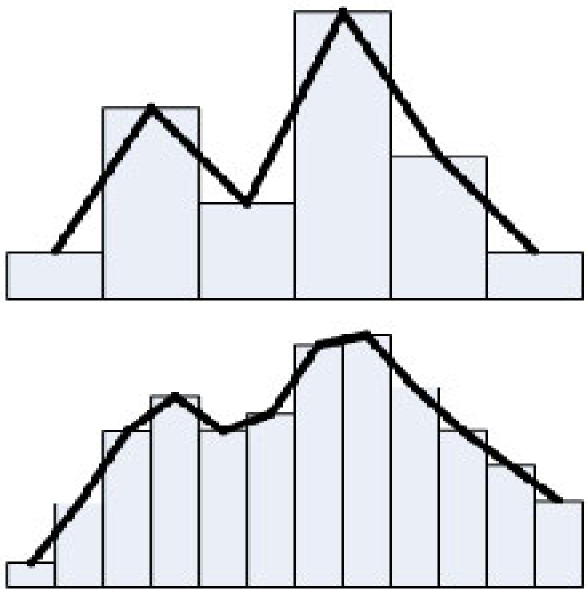
8x8 pages



64 Physical Pages

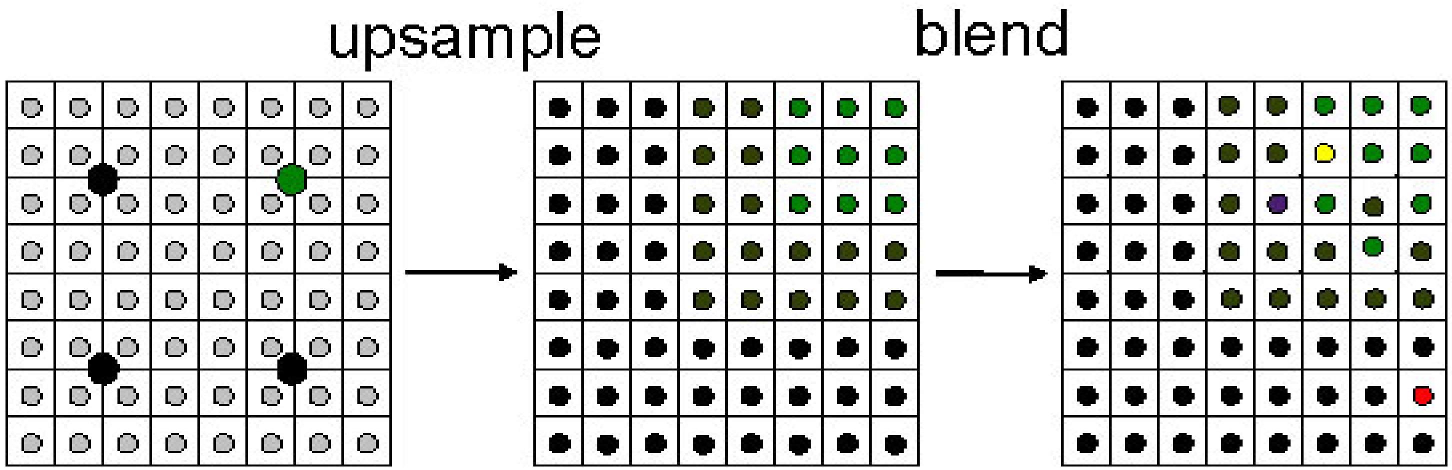
Virtual Texturing – LOD Snap

- Latency between first need and availability can be high
  - Especially if optical disk read required (>100 msec seek!)
- Visible snap happens when magnified texture changes LOD
- If we used trilinear filtering, blending in detail would be easy
- Instead continuously update physical pages with blended data



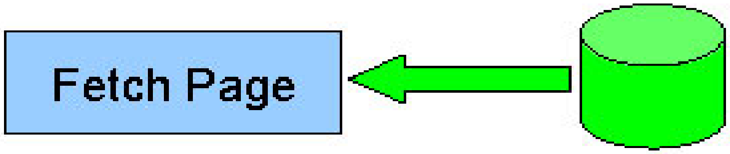
Virtual Texturing – LOD Snap

- Upsample coarse page immediately
- Then blend in finer data when available



Virtual Texturing - Management

- Analysis tells us what pages we need
- We fetch what we can



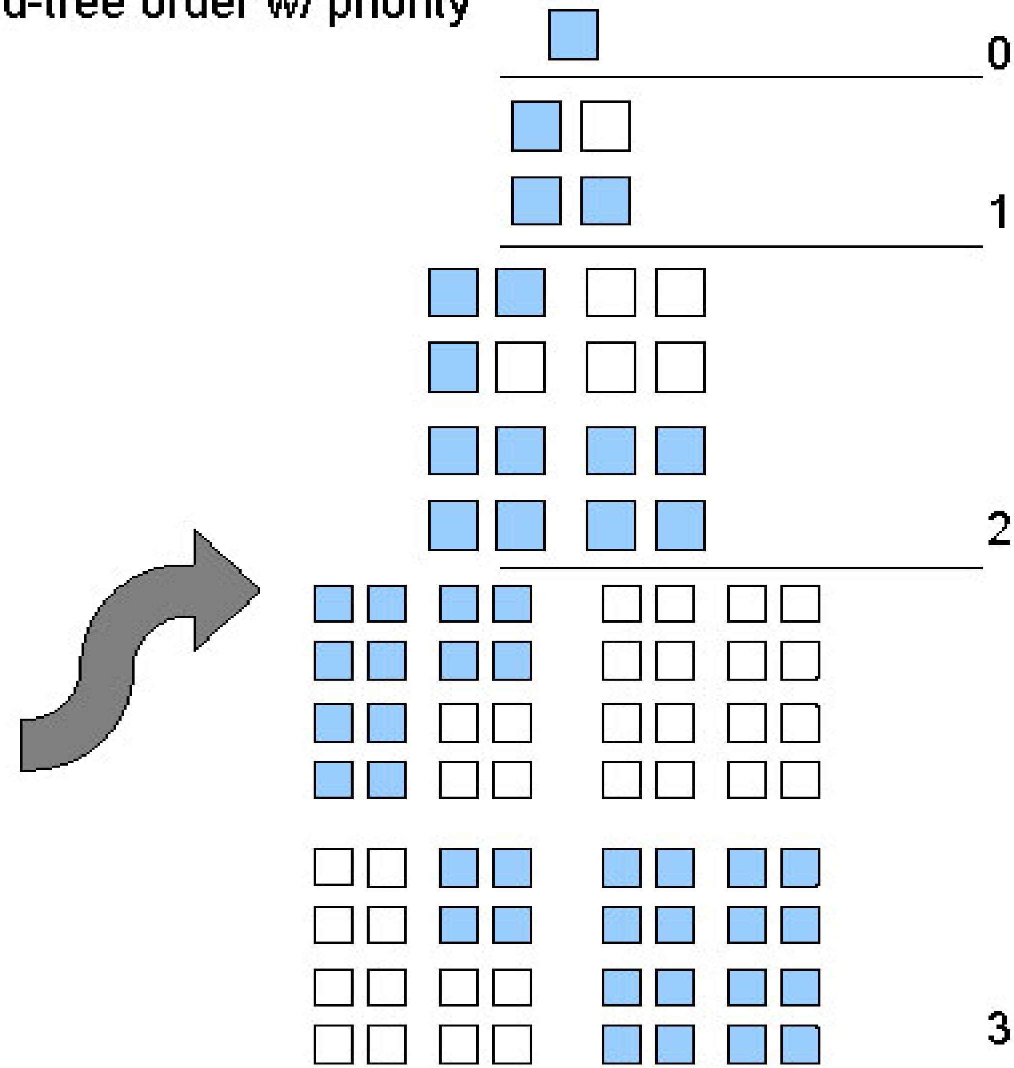
- But this is a real-time app... so no blocking allowed
- Cache handles hits, schedules misses to load in background
- Resident pages managed independent of disk cache
- Physical pages organized as quad-tree per virtual texture
- Linked lists for free, LRU, and locked pages

Virtual Texturing - Feedback

- Feedback Analysis
  - Gen ~breadth-first quad-tree order w/ priority

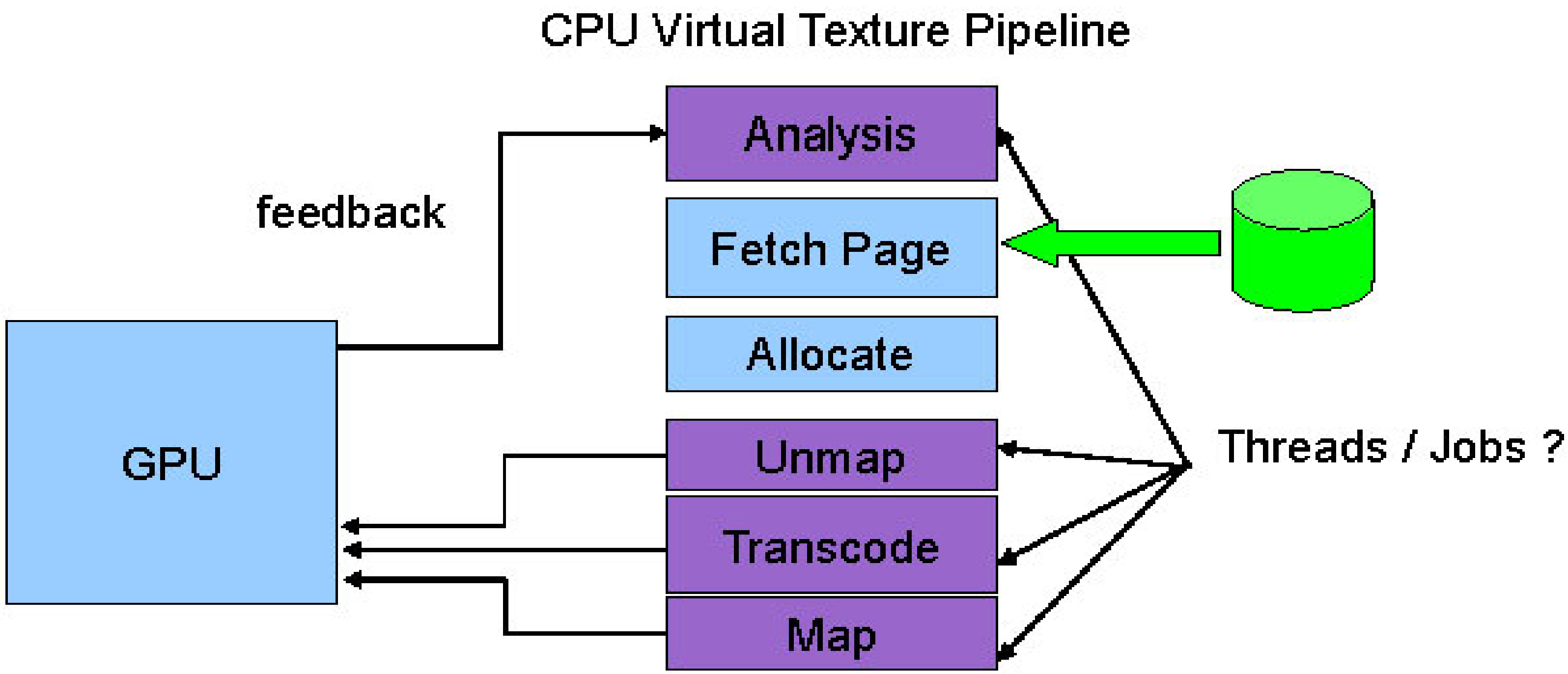
Color Buffer

Feedback Buffer



Virtual Texturing - Pipeline

- Compute intensive complex system with dependencies that we want to run in parallel on all the different platforms



Virtual Texturing

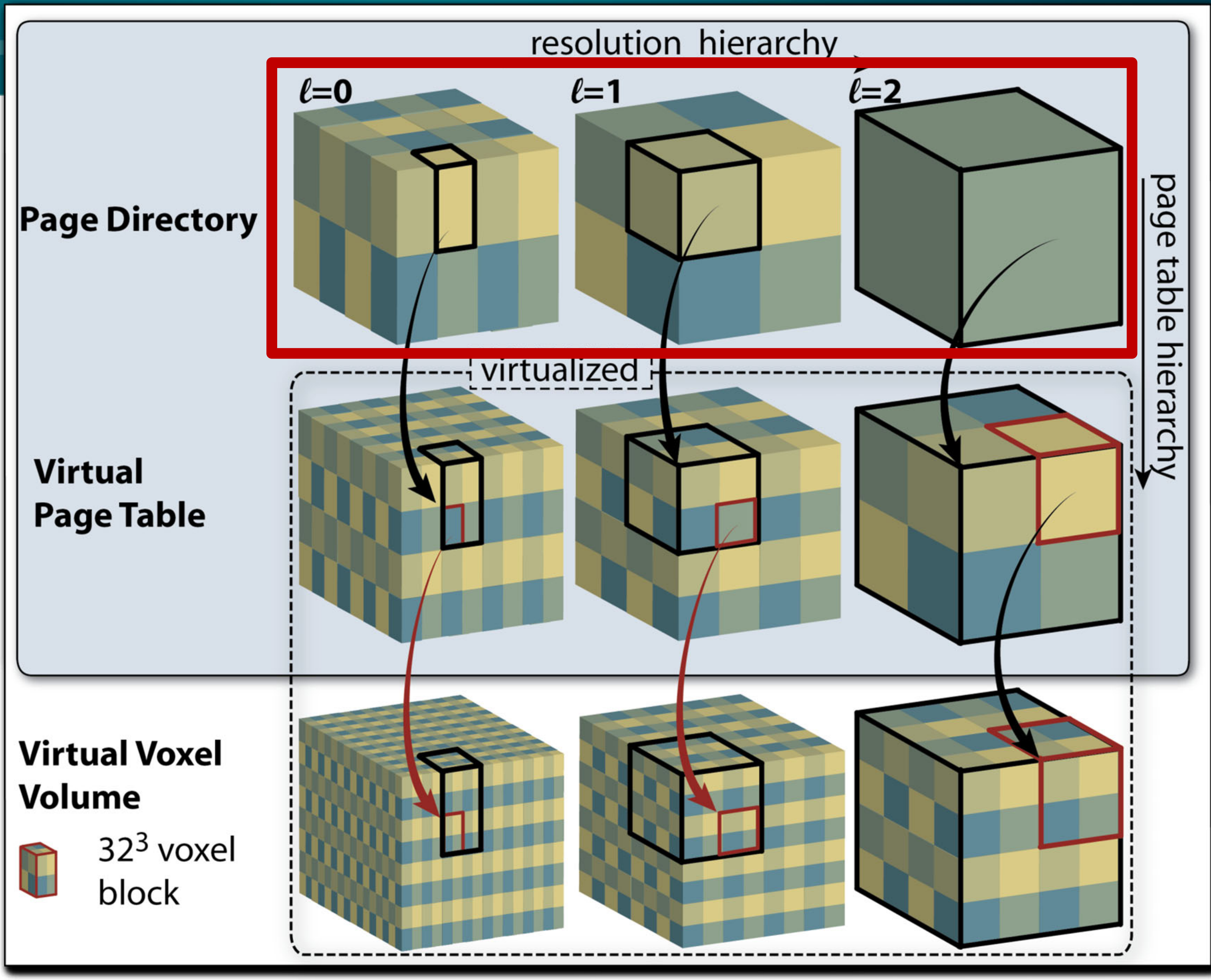
Example #4:

Petascale Volume Rendering

- Interactive Volume Exploration of Petascale Microscopy Data Streams Using a Visualization-Driven Virtual Memory Approach,
  Hadwiger et al., IEEE SciVis 2012

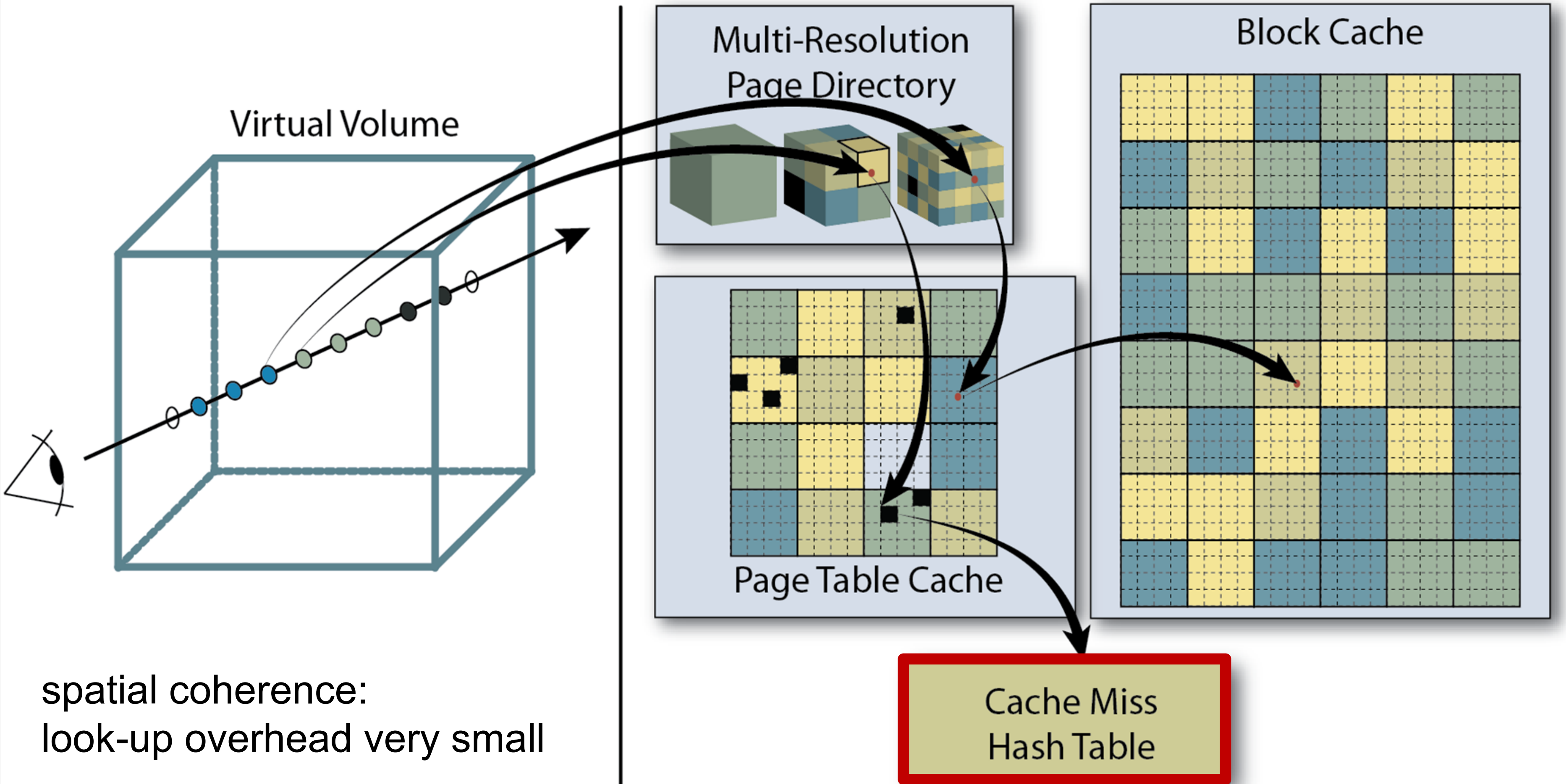
`http://dx.doi.org/10.1109/TVCG.2012.240`

Petascale Volume Rendering



multi-resolution page directory

Petascale Volume Rendering



spatial coherence:
look-up overhead very small

Thank you.