SIGGRAPH2009 NEW ORLEANS

id Tech 5 Challenges

From Texture Virtualization to Massive Parallelization

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Menu

- GPU virtual texturing, a couple of interesting issues
- How virtual texturing got us to a parallel job system
- Widespread use of the job system throughout the engine
- Getting the jobs back onto the (GP) GPU

Virtual Texturing

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

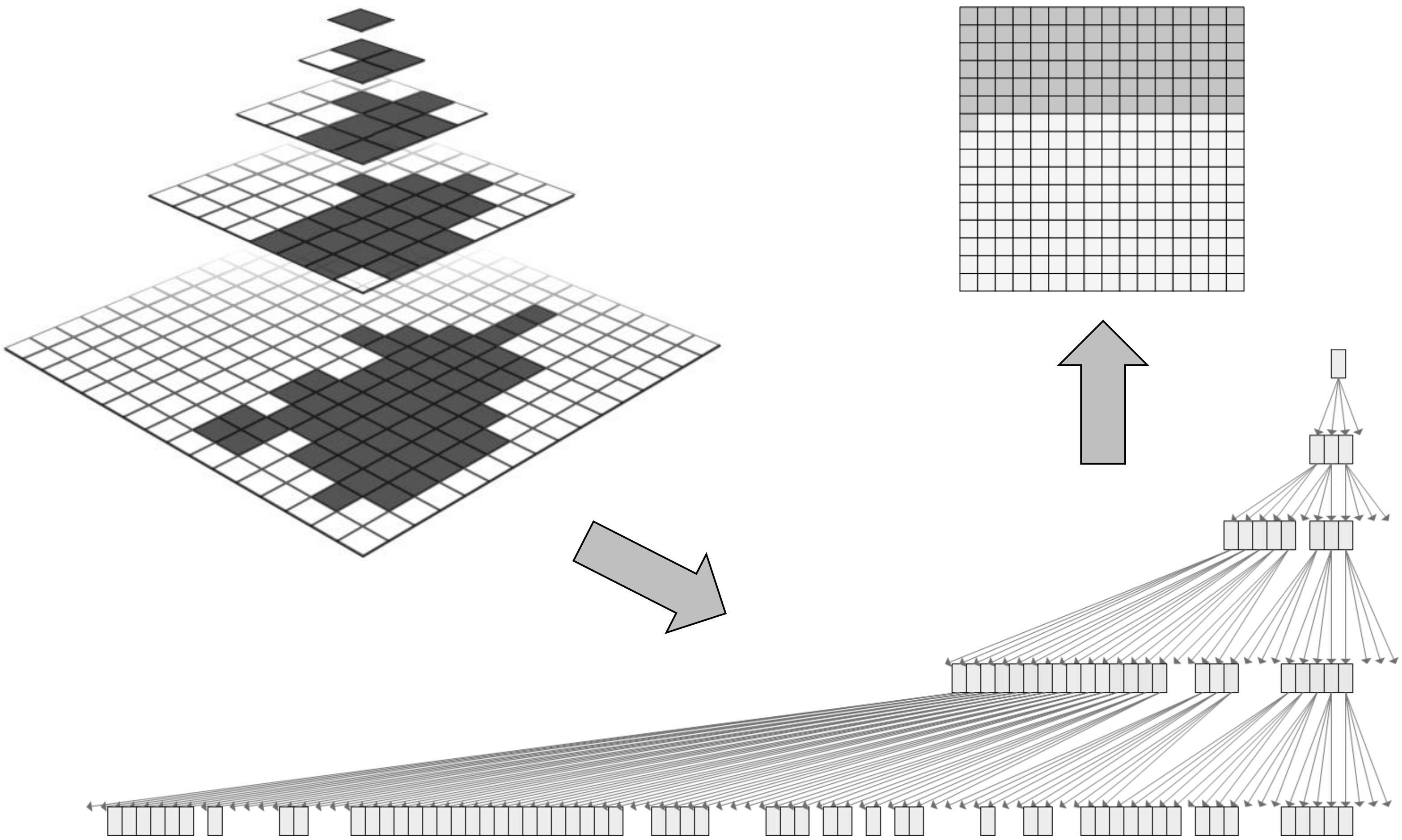
Virtual Texturing

Virtual Texturing

Virtual Texturing

Texture Pyramid with Sparse Page Residency

Physical Page Texture



Quad-tree of Sparse Texture Pyramid

Virtual Texturing

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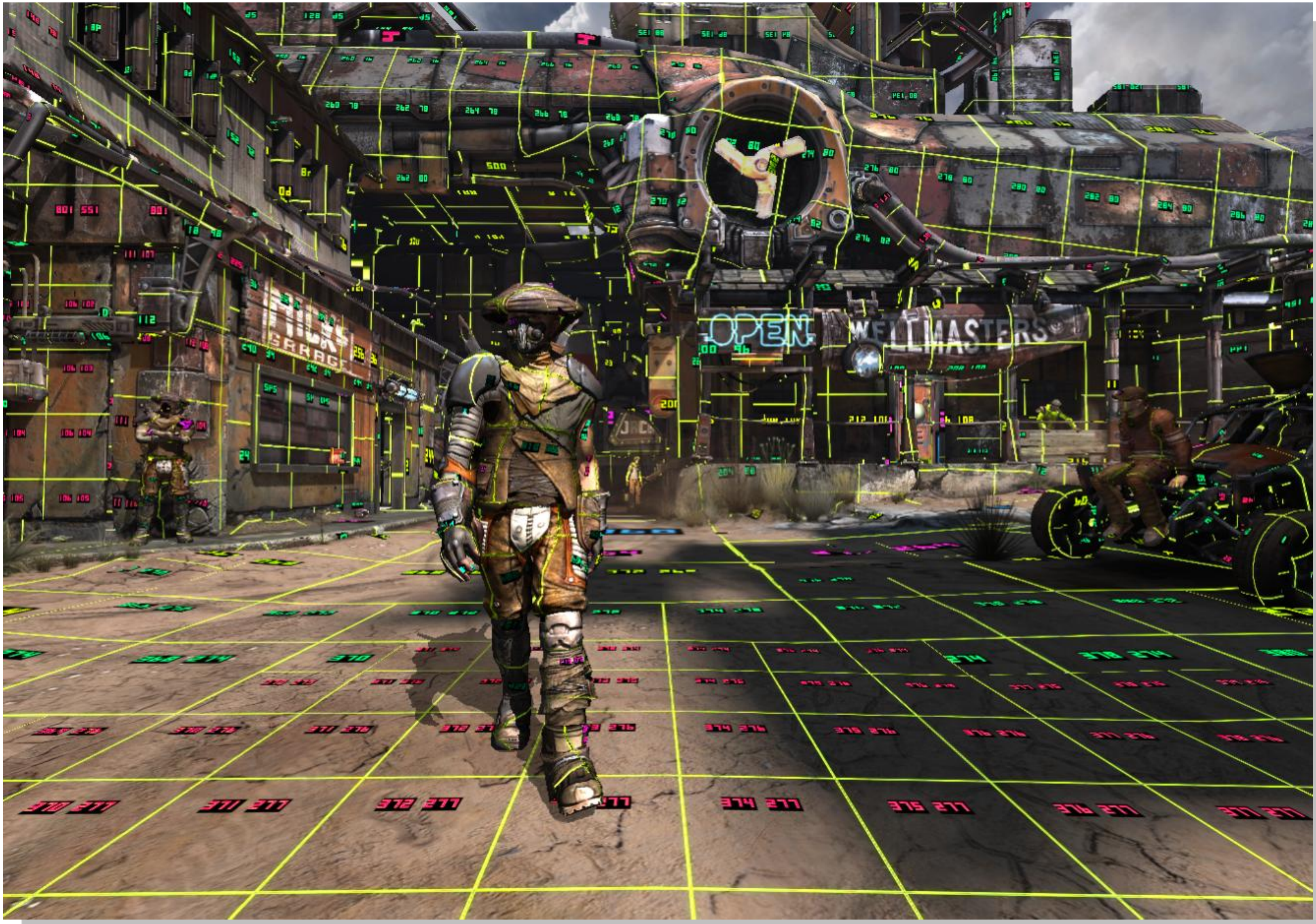
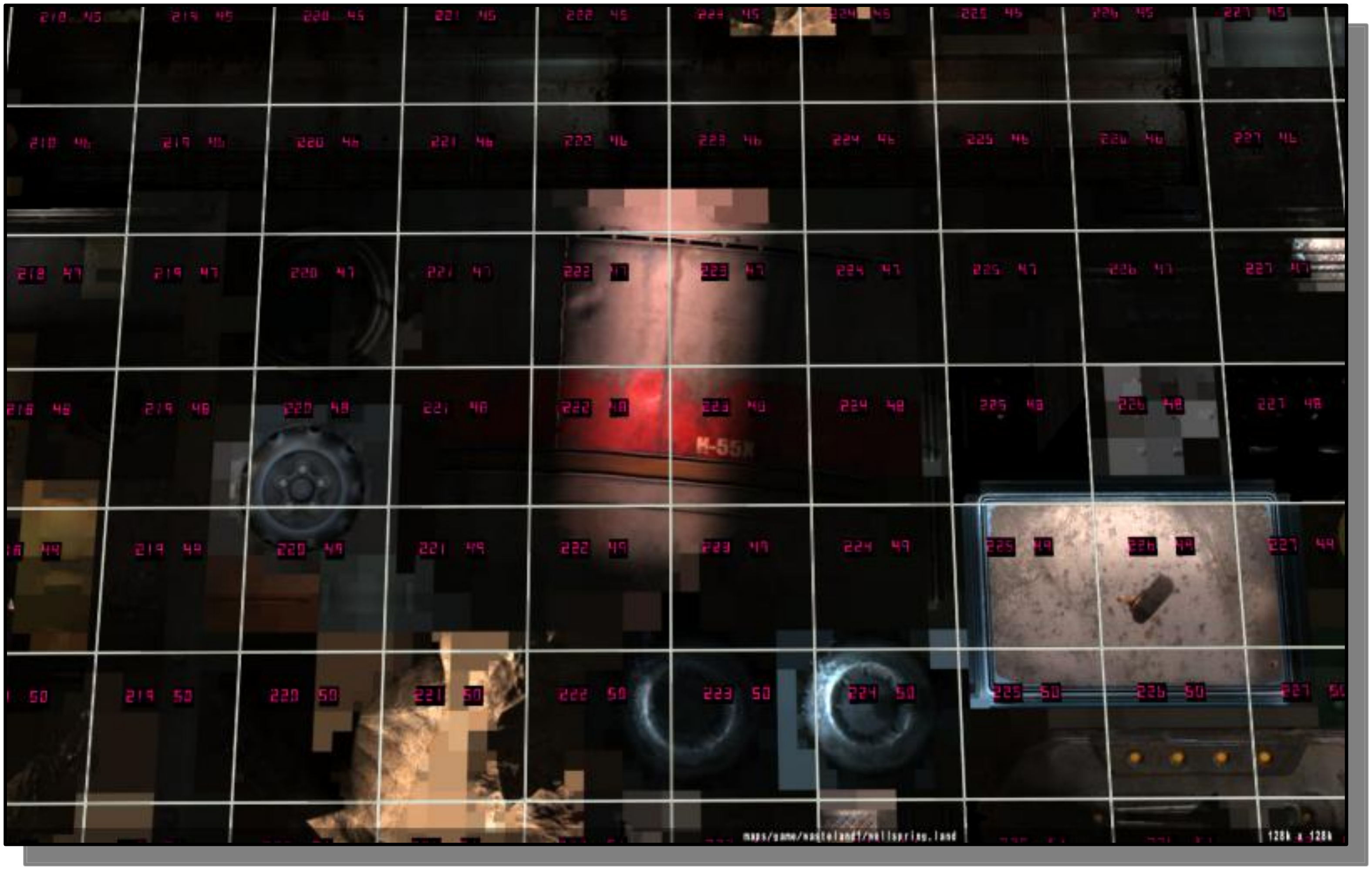


Virtual Texturing

Very Large = 128k x 128k texels (1024 pages on a side)



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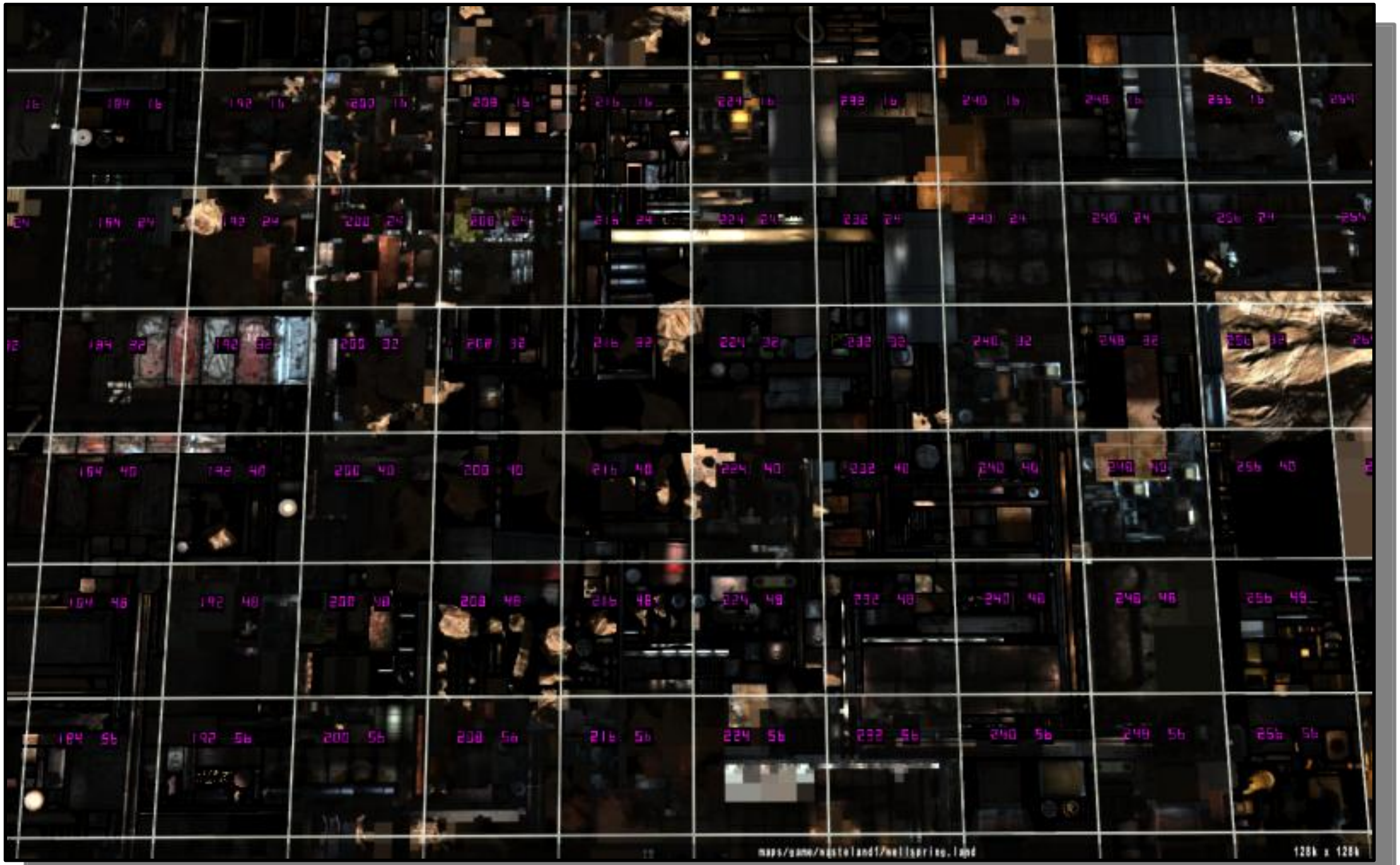
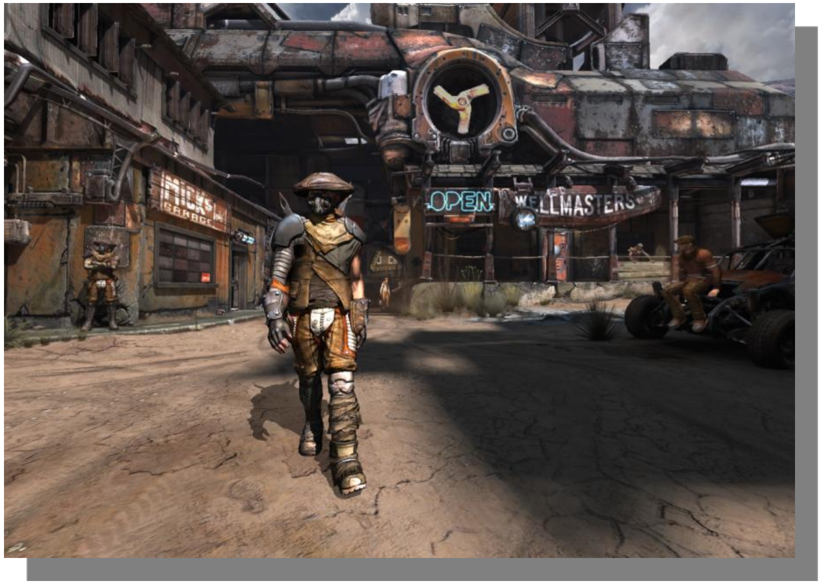
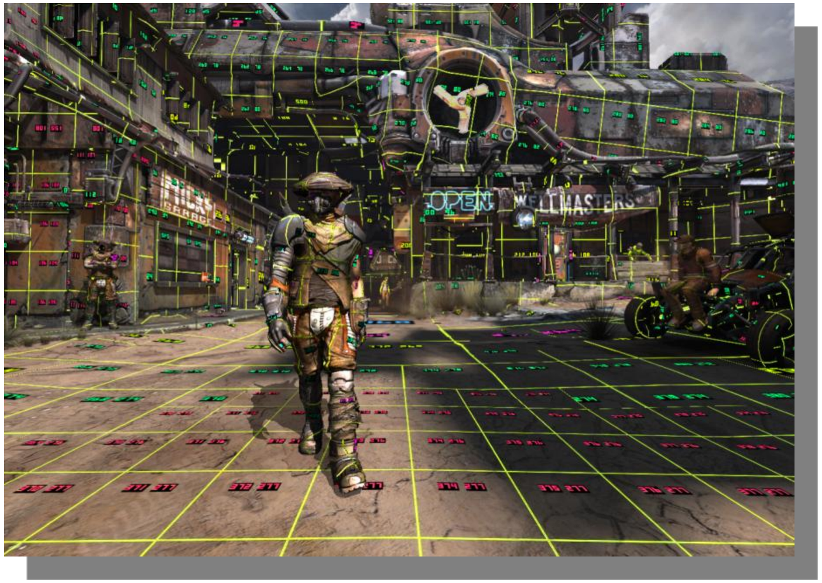


Virtual Texturing

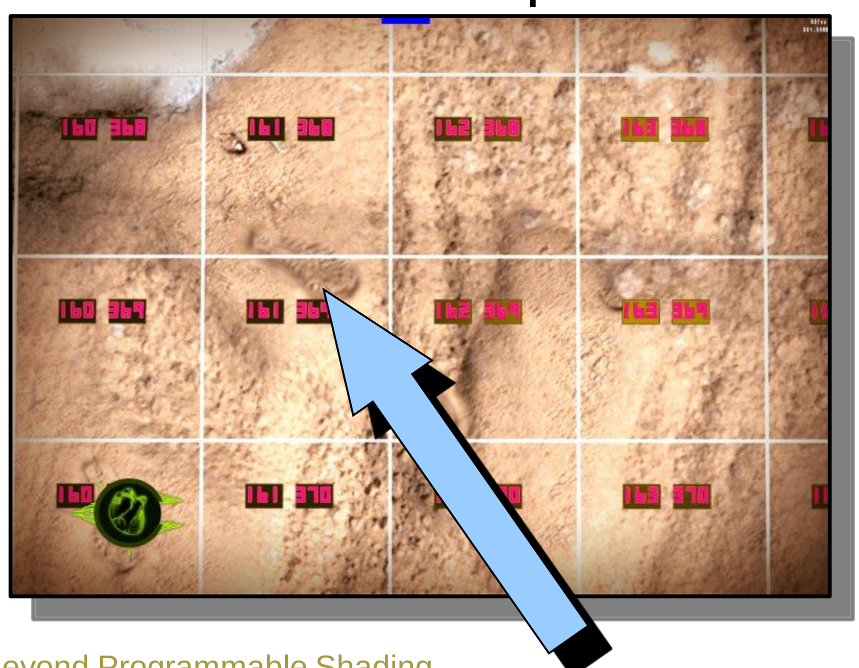
A few interesting issues...
- Texture filtering
- Thrashing due to physical memory oversubscription
- LOD transitions under high latency

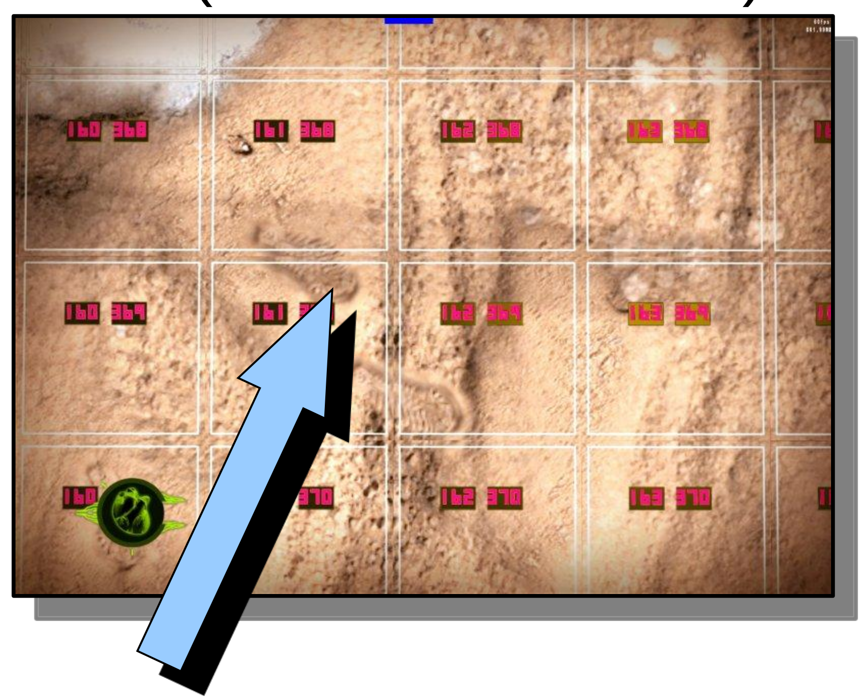




Virtual Texturing - Filtering

- 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)

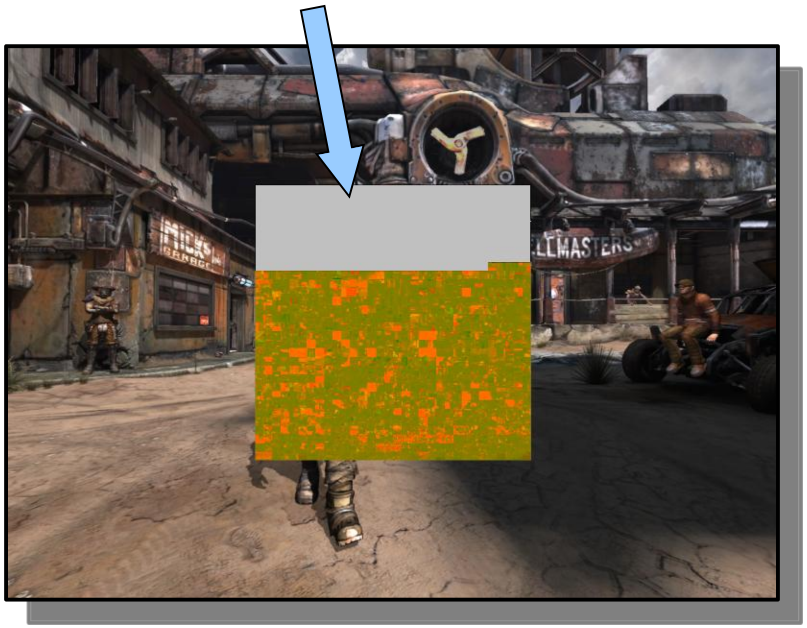




Virtual Texturing - Thrashing

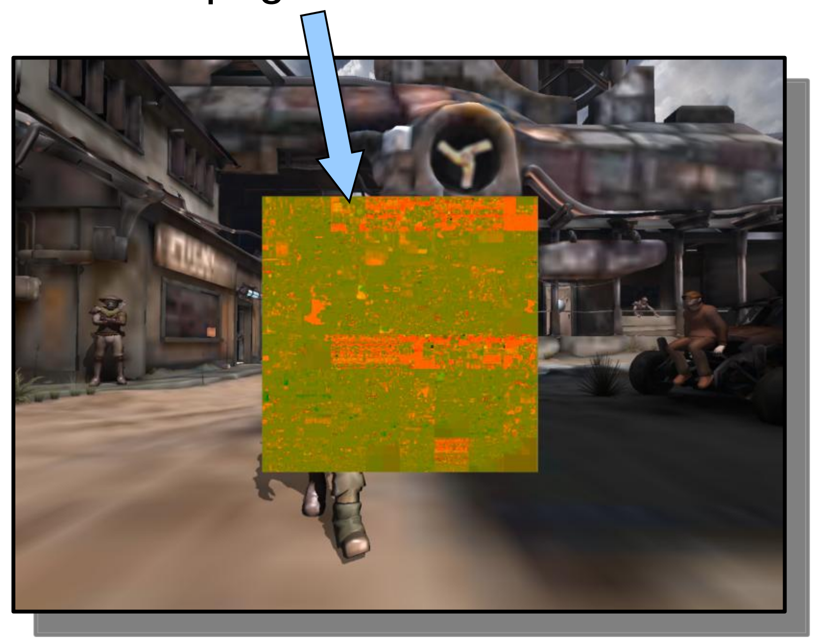
- Sometimes you need more physical pages than you have
- With conventional virtual memory, you must thrash
- With virtual texturing, you can globally adjust feedback LOD bias until working set fits

32 x 32 pages



1024 Physical Pages

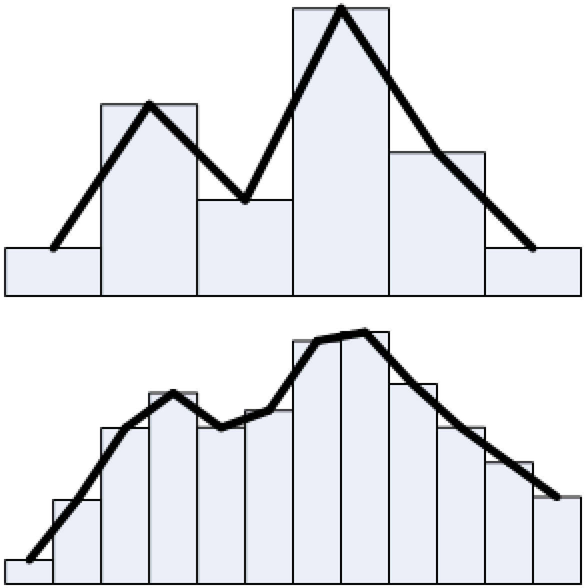
8x8 pages



64 Physical Pages

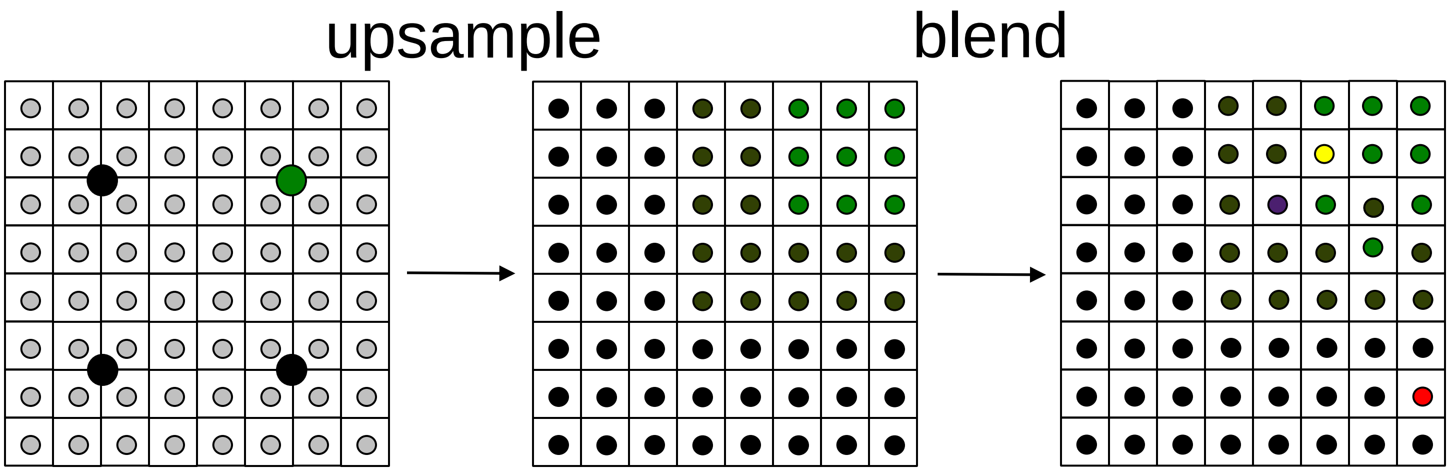
Virtual Texturing – LOD Snap

- 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



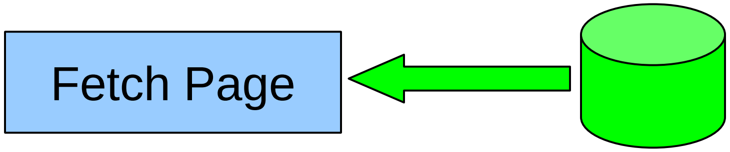
Virtual Texturing – LOD Snap

- 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



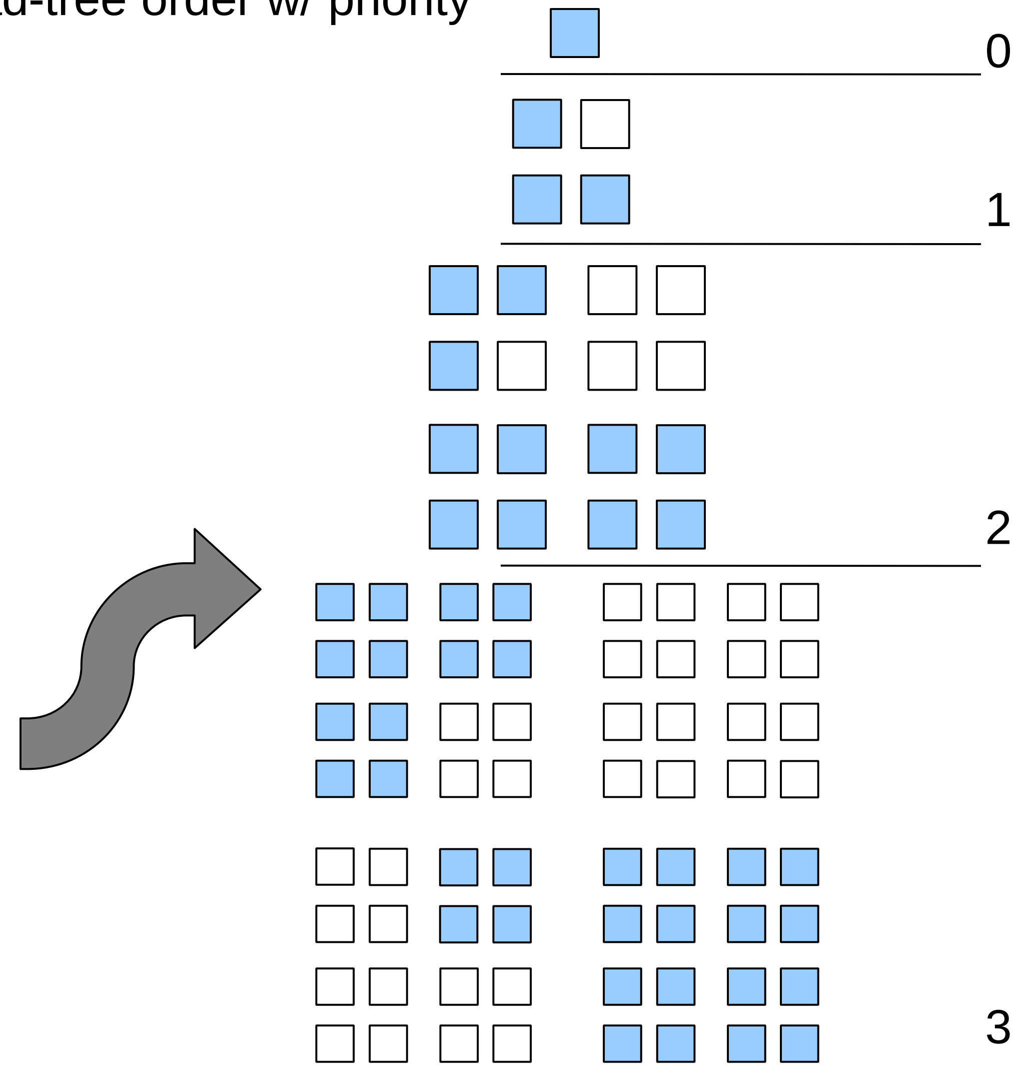
- But this is a real-time app... so no blocking allowed
- Cache handles hits, schedules misses to load in background
- Resident pages managed independent of disk cache
- Physical pages organized as quad-tree per virtual texture
- Linked lists for free, LRU, and locked pages

Virtual Texturing - Feedback

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

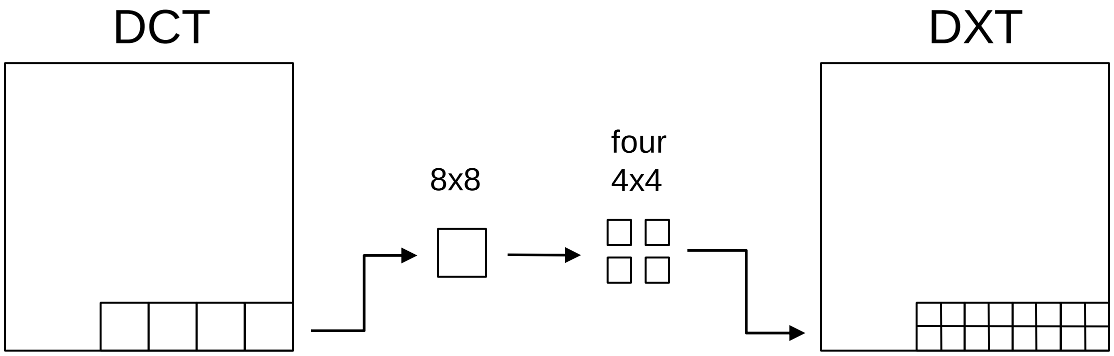
Color Buffer

Feedback Buffer



Virtual Texturing - Transcode

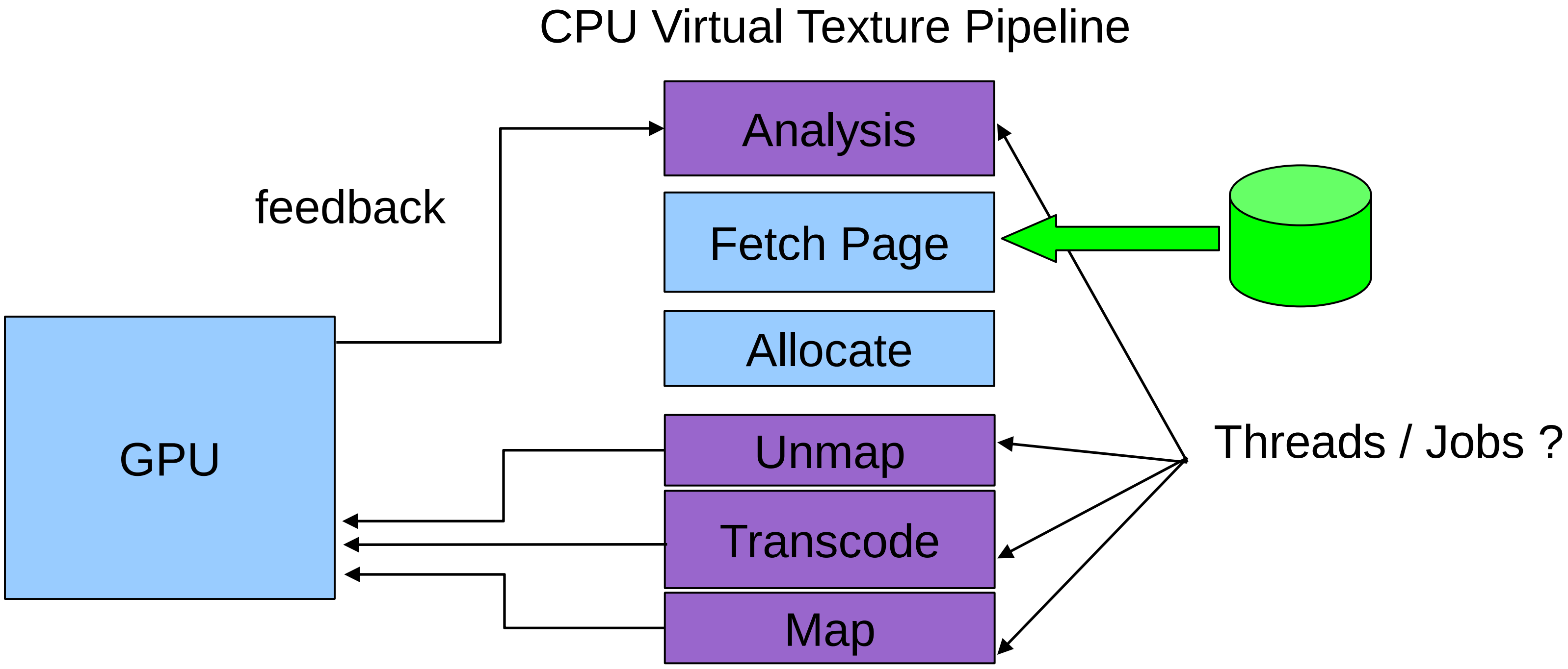
- Transcode
  - diffuse, specular, bump and cover/alpha
  - specular block scale stored in bump
- Typically 2-6kB input, 40kB output
- Unmap, Transcode, and Map all happen in parallel on platforms that can directly write texture memory



Transcode pipelined to block or row level to reduce memory profile.

Virtual Texturing - Pipeline

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



Game Engine Situation Today

- Logical GPU Architecture Stable
  - DX9 == nirvana for conventional hardware graphics
  - programmable stages, fixed topology

- CPU Architectures all over the map
  - Fast single core model definitely dead
  - Homogenous / Symmetric processors (PC, XBox)
    - big cores w/ cache, 1-2 hardware threads / core
    - some have complicated out-of-order processing
  - Heterogeneous processors (Cell)
    - 1-2 big cores
    - multiple small in-order cores w/ local memory & DMA controller
  - Streaming processors / GPGPU (NVIDIA / AMD GPUs, Intel Larrabee)
    - many cores
    - CUDA / OpenCL

- **Challenge: one engine to efficiently harness them all**

What's the big deal?

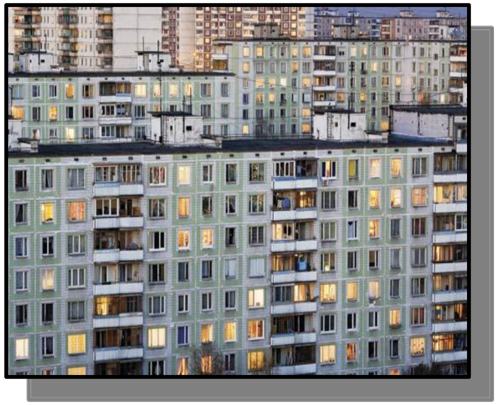
- id Tech 5 does a lot of processing
  - Animation blending – ~2 msec
  - Collision detection – ~4 msec
  - Obstacle avoidance – ~4 msec
  - Transparency sorting – ~2 msec
  - Virtual texturing – ~8 msec
  - Misc processing – ~4 msec
  - Rendering – ~10 msec
  - Audio – ~4 msec

- And at 60 Hz, not much time to do it – 16 msec
- Portable parallel software architecture is required

What Software Architecture?

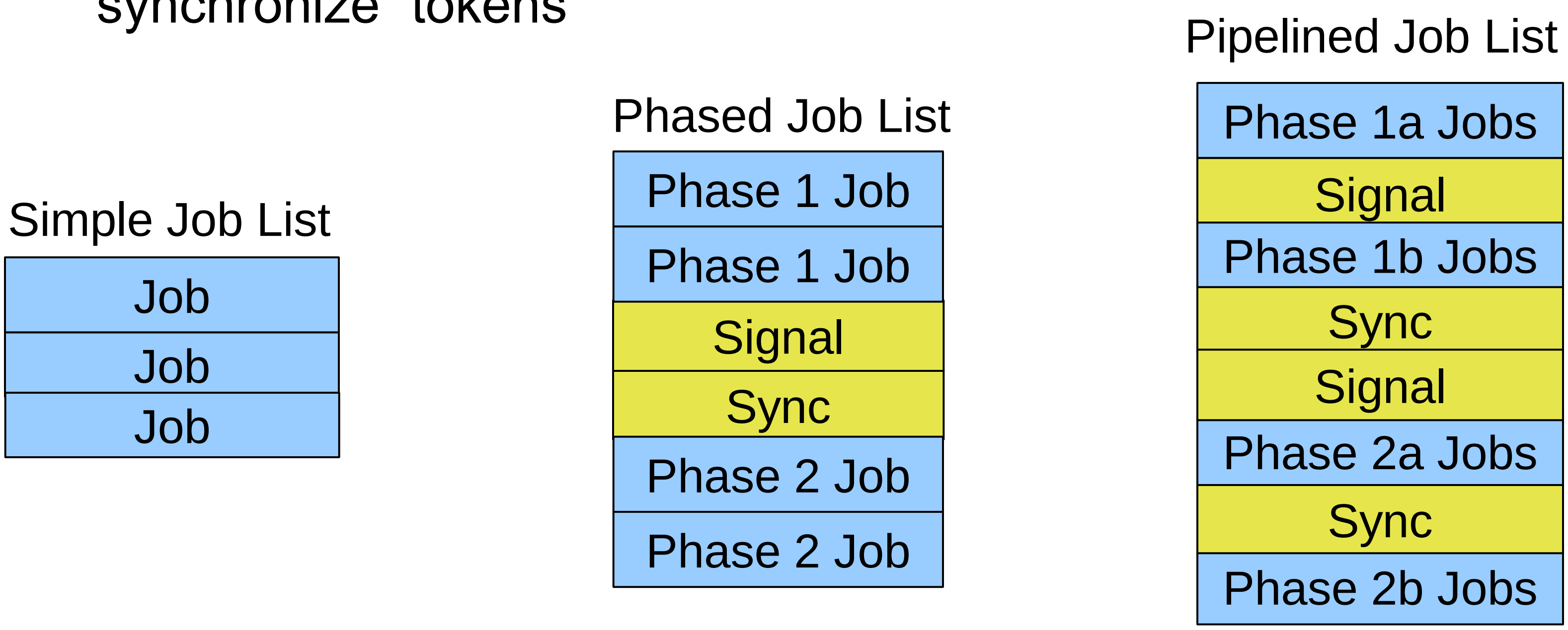
- OS thread factoring
  - Good for small # of cores
  - Not terribly invasive
  - Complexity grows nonlinearly
  - Load balancing tricky
  - Not a good match for cell SPUs

- Small stand-alone job decomposition
  - Quite invasive rewrite
  - Very scalable
  - Almost required by cell SPUs
  - Good for heterogeneous processors



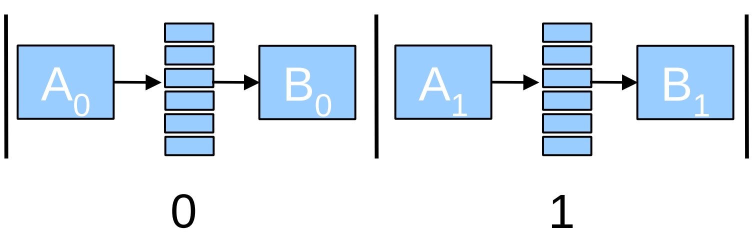
Job Processing System

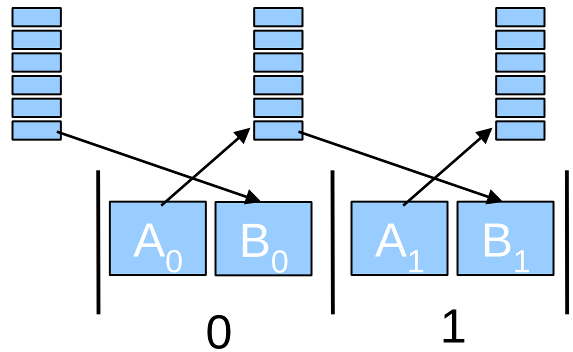
- Simplicity key to scalability
  - Job has well defined input and output
  - Independent stateless, no stalls, always completes
  - Jobs added to job lists
  - Multiple job lists
  - Job lists fully independent
  - Simple synchronization of jobs within list through “signal” and “synchronize” tokens



Death by Synchronization

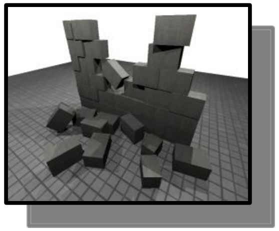
- Synchronization means waiting, waiting destroys parallelism
- Architectural decision: Job processing given 1 frame of latency to complete
  - Results of jobs show up a frame late
  - Requires some algorithm surgery
    - e.g. foliage
  - Rules out some algorithms
    - e.g. screen-space binning of transparency sort
  - But overall, not a bad compromise





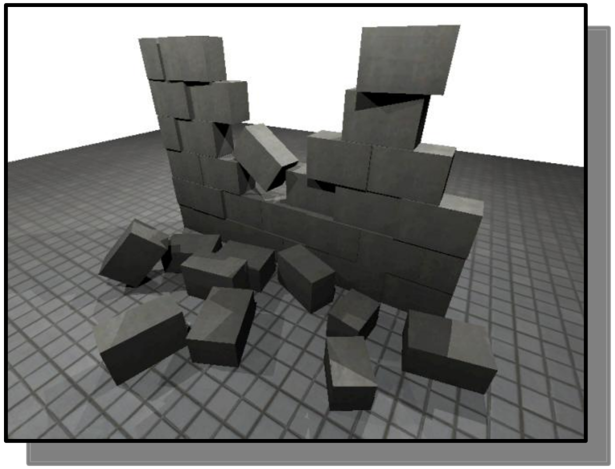
id Tech 5 Job Decomposition

- Major parts of of id Tech 5 processing factored into jobs
  - Collision detection
  - Animation blend
  - Obstacle avoidance
  - Virtual texturing
  - Transparency processing (foliage, particles)
  - Cloth simulation
  - Water surface simulation
  - Detail model generation (rocks, pebbles etc.)



Collision Detection

- Two phases
  - Query (continuous collision detection CCD)
    - Check sub-model collisions
  - Merge
    - Find the first collision or gather all contacts
- Player physics does not use delayed detection
  - 16 msec extra delay in user feedback undesirable

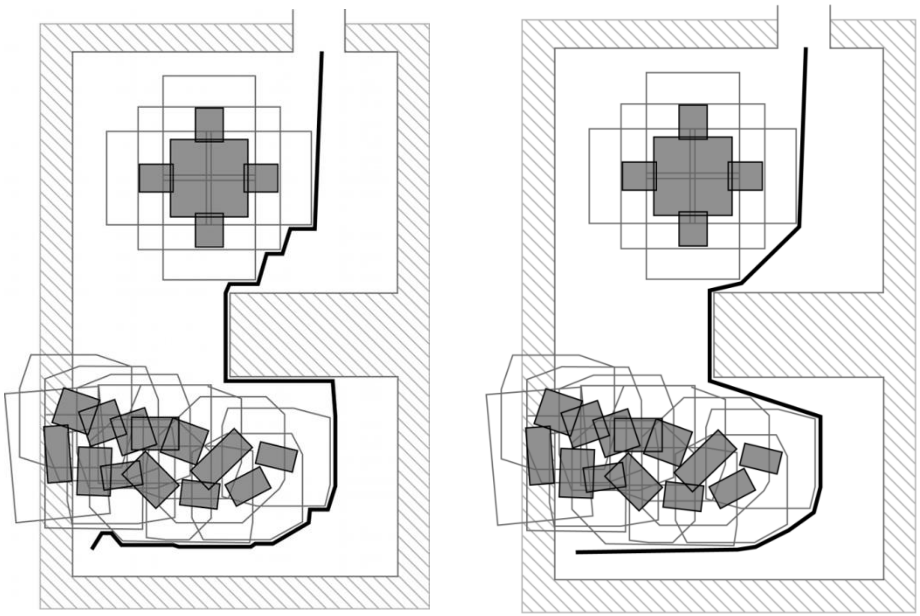


Animation Blend

- Animation graph or “web” describes valid transitions
- A stack is used to evaluate a blend tree
  - Leaves are decoded source animations
  - Parents are intermediate blend results
- Tree walking generates a command list for the stack
- Most blending happens in local space (parallel)
- Final phase moves everything to model space

Obstacle Avoidance

- One job per character that wants to avoid obstacles
- Construction of job input comes from a scan of Area Awareness System for potential obstacles and their surroundings



Transparency

- Transparency requires sorting and blending: expensive
  - Must be handled separately
- Restrict to particle systems and foliage
- Limited buffer size

- Split into a number of jobs
  - Foliage gather
  - Foliage gen
  - Particle gen
  - Transparency sort and index gen

- Tricky to keep these jobs under SPU limits

Jobs on the (GP) GPU

- We are cautiously optimistic about the job model
  - Anticipate CUDA, OpenCL, Larrabee support
    - Easy to add additional job processing resources
  - But this is new territory…

Jobs on the (GP) GPU

- Not enough jobs to fill SIMD / SIMT lanes
- Code paths of different jobs diverge too much
- Jobs are useful as unit of work (latency tolerant & small memory footprint)
- Data parallelism within jobs needs to be exploited
- Split jobs into many fine grained threads
- Data dependencies in input
- Convergence of output data
- Memory access of the fine grained threads is important

Conclusions

- Virtual texturing + great artists = awesome environments
- id Tech 5 does a lot of work and has to exploit parallelism
- Cell forced us to re-factor engine into jobs
- Latency tolerant computational services model attractive
- Jobs are now running on a variety of processors
- Hopefully soon CUDA, OpenCL, Larrabee support

Virtual Texturing

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