Denali – Merging Graphics and Imaging on a High Performance Rendering Architecture

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Outline:

- DENALI Architecture Overview
- Key Components
- Primitive Processing
- Advanced Features
- Feature Orthogonality
- Performance Model
- Design Tradeoffs
- Video

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Architecture Design Goals:

- Host and system bus independent
- Scalable from medium to very high performance
- Embedded MIMD graphics processors
- Merging geometry, rasters and volumes on a single architecture
- Rich orthogonal 2D/3D feature set
- Performance:

  Geometry: 1M 3d tri_strip/sec
  object: xformed, lit, clip test
  device: 50 pixels, smoothly shaded

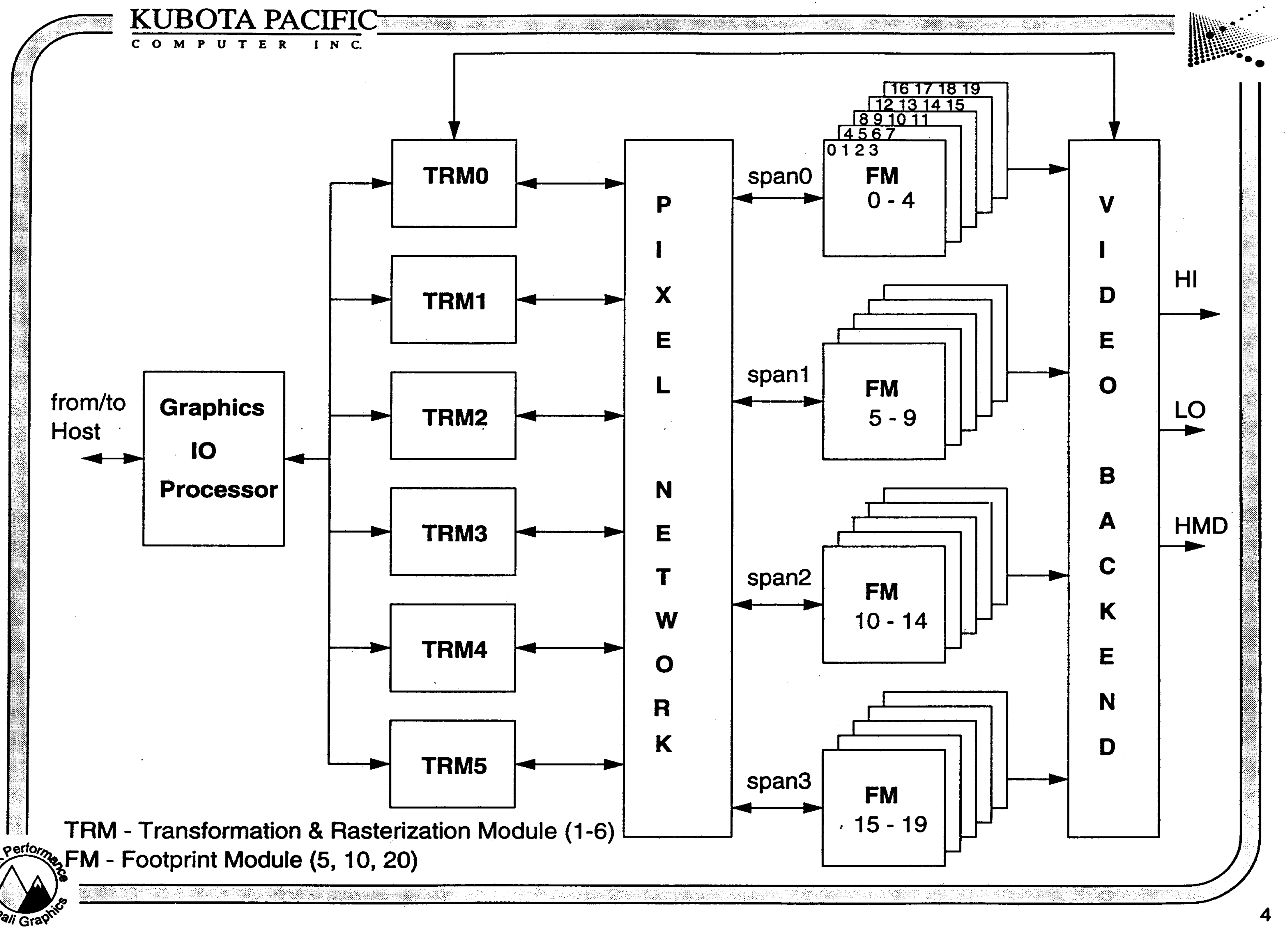
  1M 3d anti-aliased polylines/sec
  object: xformed, lit, clip test
  device: 10 pixels, smoothly shaded,
  4 pixel wide filter

  4M 2d aliased polylines/sec
  device: 10 pixels, flat shaded

  Rasters: 65 Mpixels/sec 8 bit pixels
  25 Mpixels/sec 32 bit pixels

  Volumes: 10 Mtrips/sec 16 bit scalars
  trips - tri-linear interpolations/sec

- Cost: $15K to $50K



TRM - Transformation & Rasterization Module (1-6)
FM - Footprint Module (5, 10, 20)

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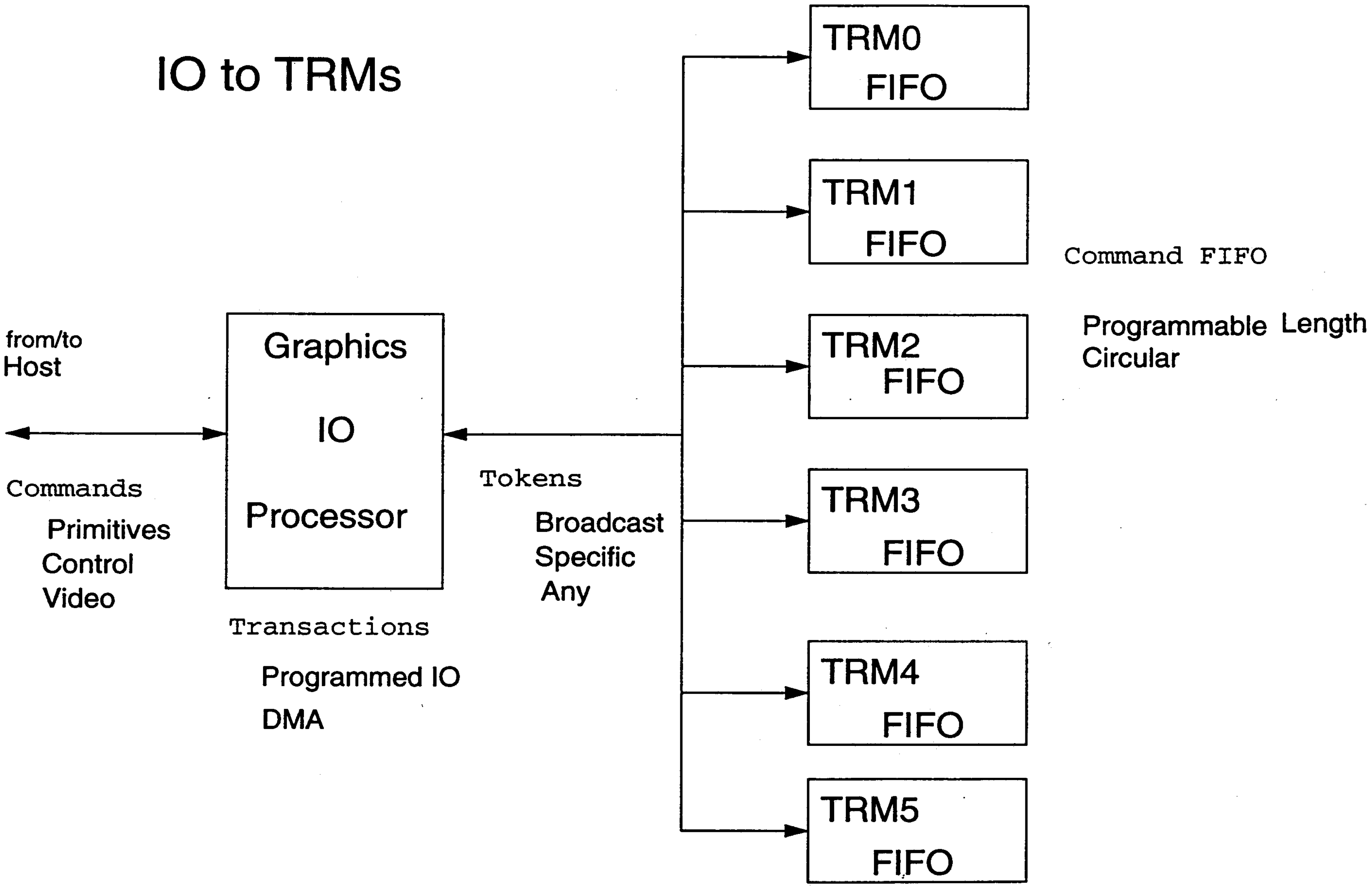
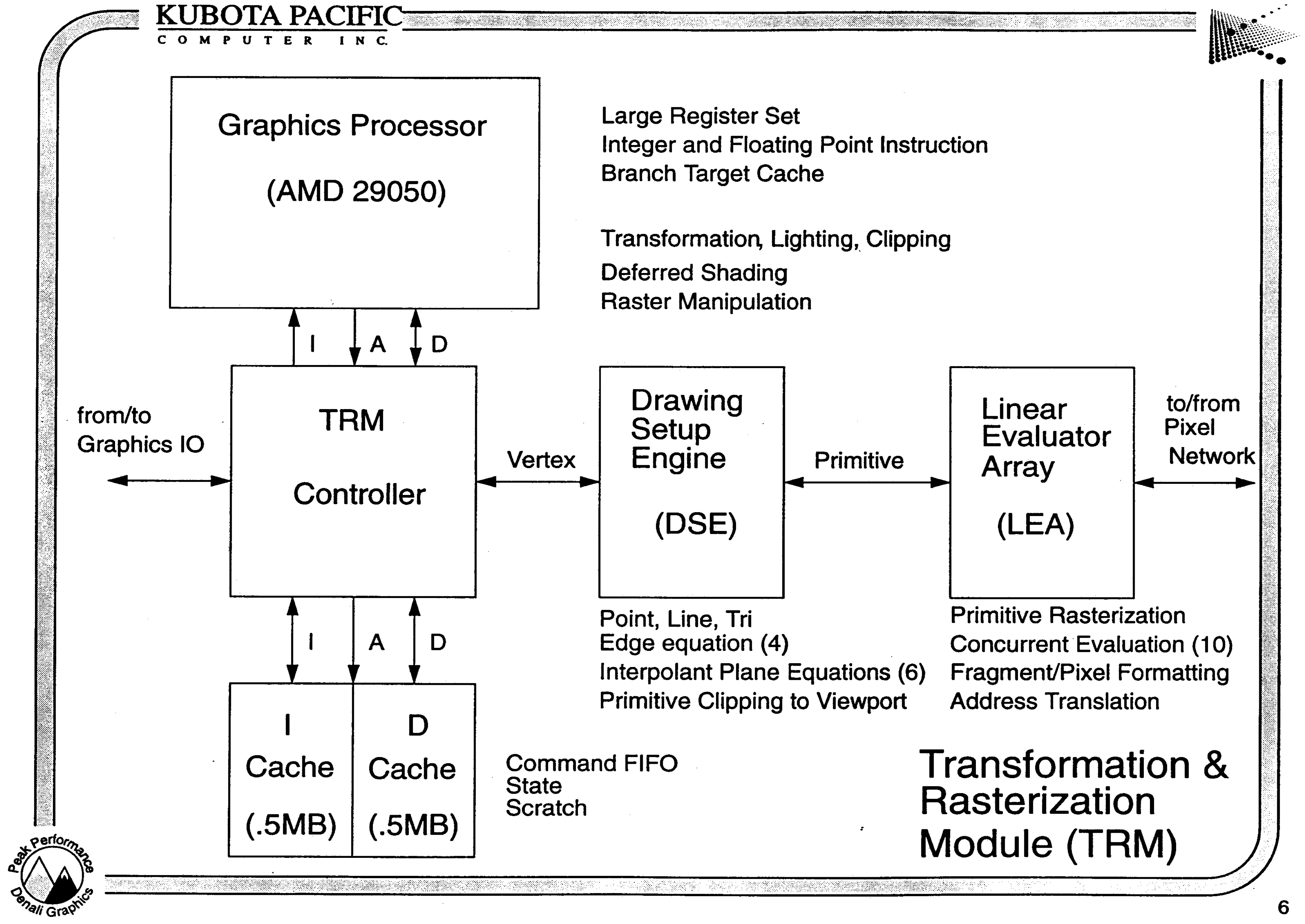
IO to TRMs



Peak Performance Denali Graphics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Graphics Processor
(AMD 29050)
Large Register Set
Integer and Floating Point Instruction
Branch Target Cache
Transformation, Lighting, Clipping
Deferred Shading
Raster Manipulation
I
A
D
from/to
Graphics IO
TRM
Controller
Vertex
Drawing
Setup
Engine
(DSE)
Primitive
Linear
Evaluator
Array
(LEA)
to/from
Pixel
Network
I
A
D
Point, Line, Tri
Edge equation (4)
Interpolant Plane Equations (6)
Primitive Clipping to Viewport
Primitive Rasterization
Concurrent Evaluation (10)
Fragment/Pixel Formatting
Address Translation
I
Cache
(.5MB)
D
Cache
(.5MB)
Command FIFO
State
Scratch
Transformation &
Rasterization
Module (TRM)
Peak Performance
Denali Graphics
6

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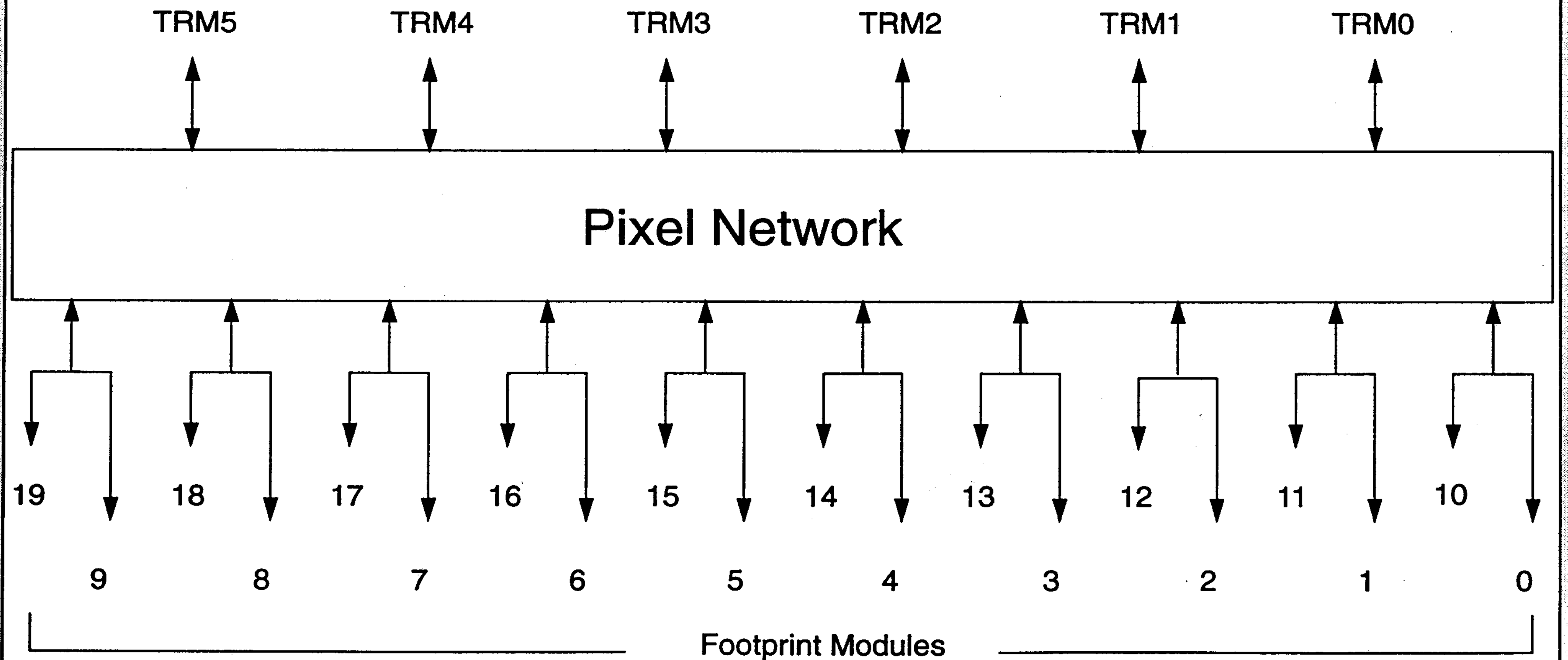
- Maximum bandwidth of 600 MBytes/sec
- Protocol for broadcast, per-span Footprint Modules, and per-Footprint Module
- Concurrent writes or reads of pixels to/from two interleaved spans
- Readback arbitration among TRM's
- Sync and flush primitives



Peak Performance Denali Graphics

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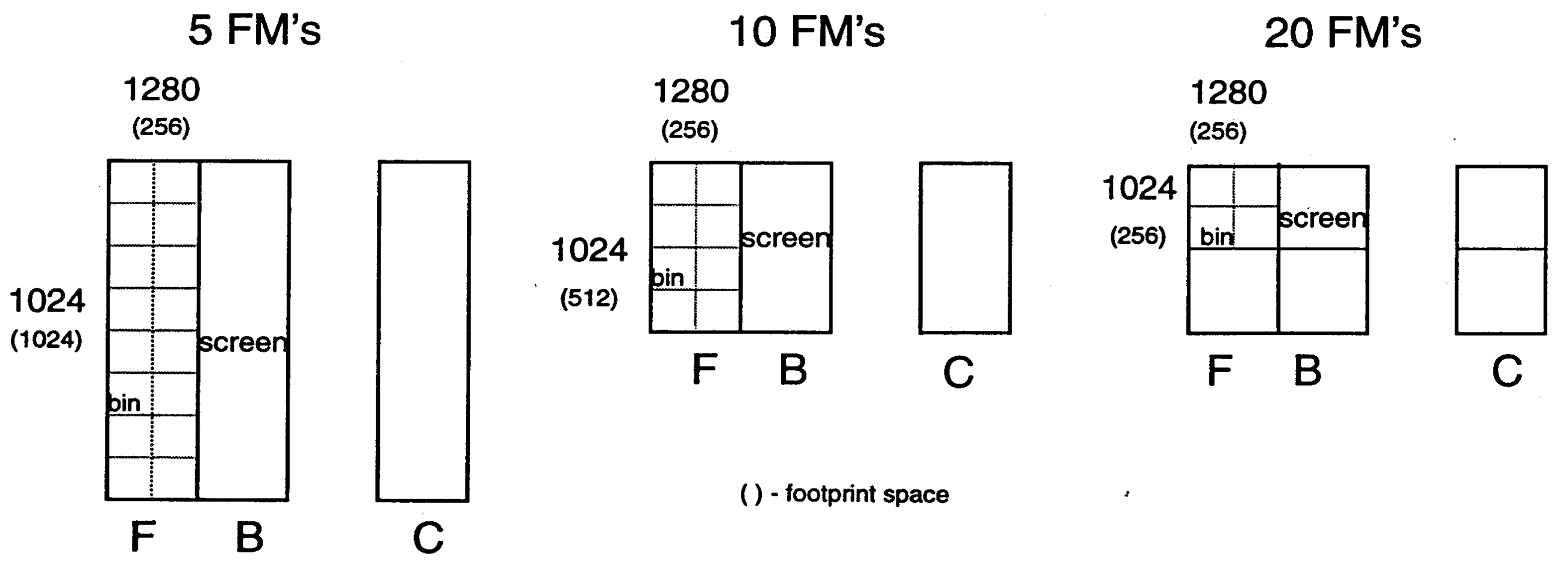
Pixel Memory - Display Memory

- Two level logical partitions: screens and bins
- Double Buffered true color (Front/Back buffer, 24 bits each)
- Control buffer: window ids (6 bits), overlay (5 bits), zero time clear (5 bits)
- Double buffered full screen stereo availability (20 FM's)
- Two screens of display memory to be used as off screen memory (20 FM's)



Peak Performance Denali Graphics

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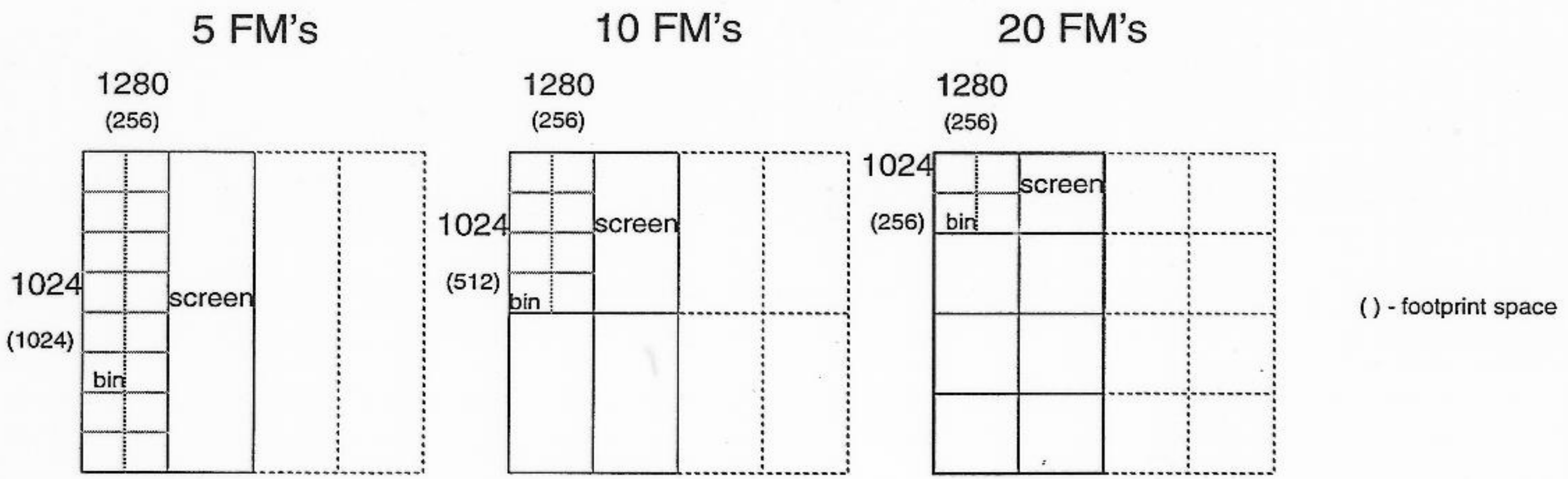
Pixel Memory - Off Screen Memory (OSM)

- Two level logical partitions: screens and bins
- Scalable - 2560 or 5120 pixels on the side
- OSM resources: depth and stencil buffers, pixmaps, accumulation buffer, tables
- Per-Footprint Module copy for tables: textures, atmospheric, translation, math
- Single (32 bits) and double (64 bits) precision pixel data formats
- Maximum OSM storage of 5K by 4K single precision words (512 bits/pixel)



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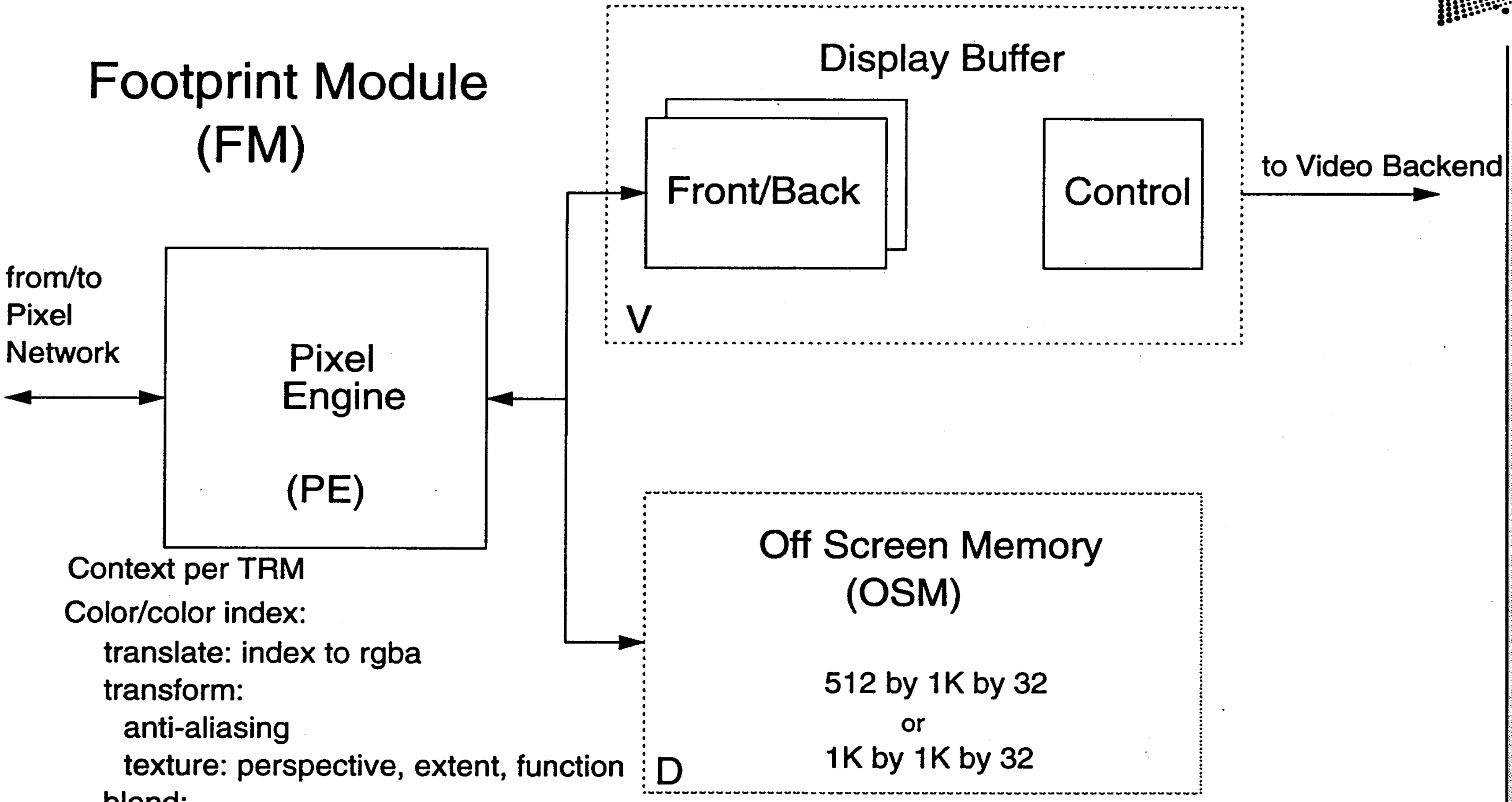
Footprint Module (FM)

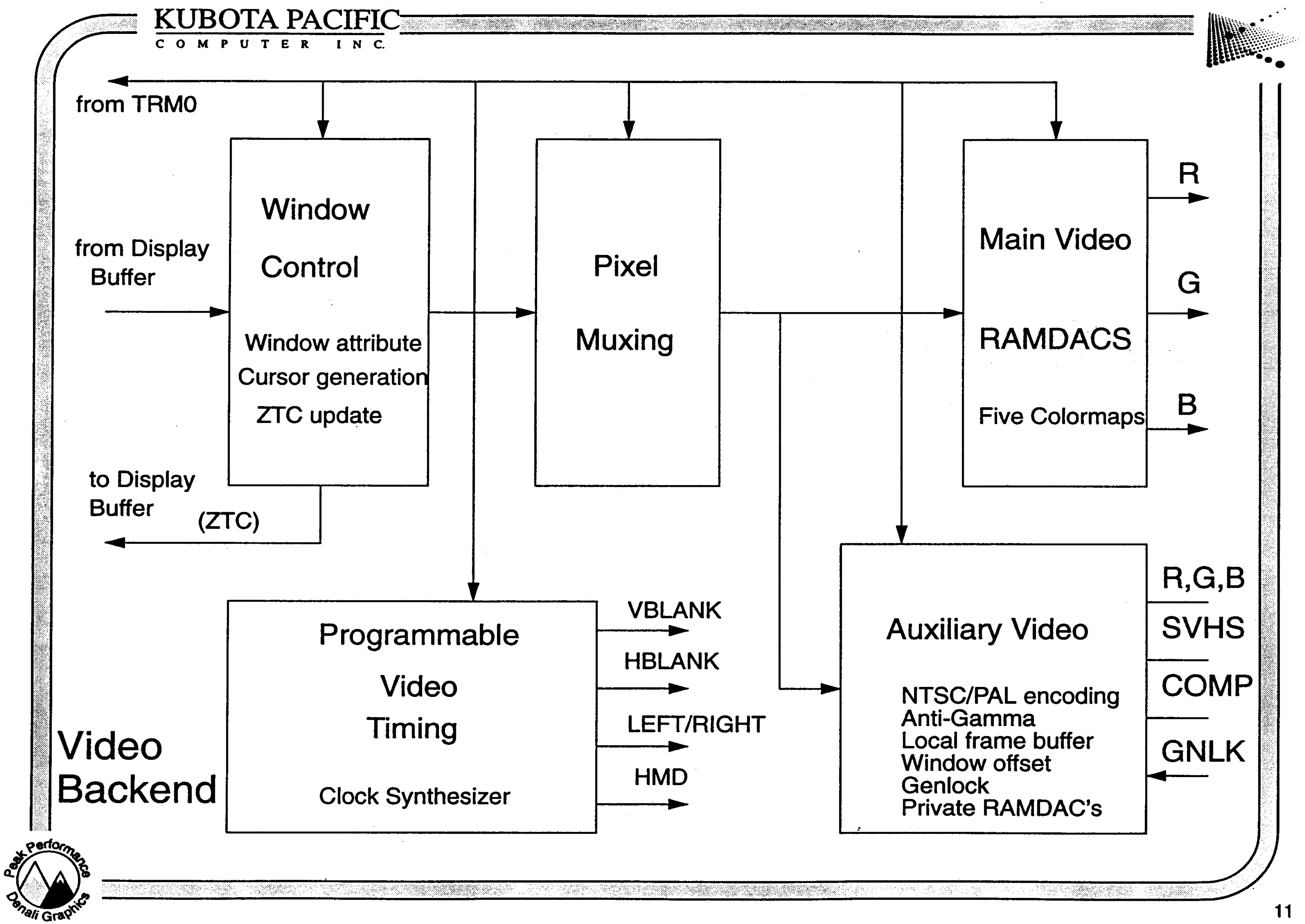


Context per TRM

Color/color index:
- translate: index to rgba
- transform:
  - anti-aliasing
  - texture: perspective, extent, function
- blend:
  - logic
  - arithmetic
  - compositing/transparency
- mask: per-bank, per-bit

Visibility: depth, stencil, threshold

Scanout: stereo control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from TRM0
from Display Buffer
Window
Control
Window attribute
Cursor generation
ZTC update
to Display Buffer
(ZTC)
Pixel
Muxing
Main Video
RAMDACS
Five Colormaps
R
G
B
Programmable
Video
Timing
Clock Synthesizer
VBLANK
HBLANK
LEFT/RIGHT
HMD
Auxiliary Video
NTSC/PAL encoding
Anti-Gamma
Local frame buffer
Window offset
Genlock
Private RAMDAC's
R,G,B
SVHS
COMP
GNLK
Video Backend
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12

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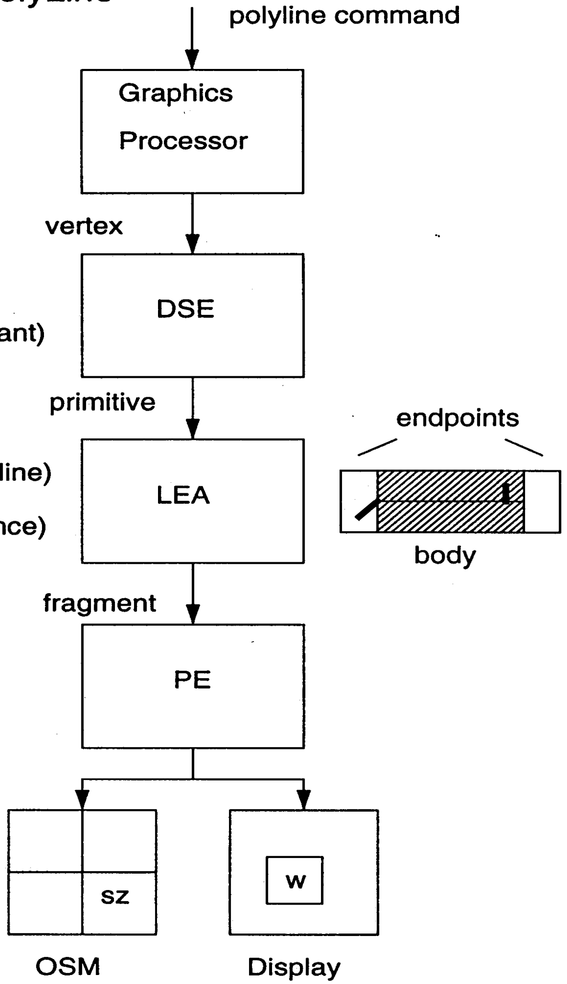
Primitive: Lighted Anti-Aliased PolyLine



transform (geometry)
light
clip
scale

vertex reordering (<1,2> <2,3> <3,4>...)
edge coefficients (x4)
interpolant coefficients (A,B,F per interpolant)
scan bounds

scans efficiently bounds
evaluates perpendicular distance (center line)
resolves endpoints
generates fragments (x, y, sz, rgba, distance)

transform: scales rgba by filter(distance)
blend:background or pixel memory

OSM: sz - stencil, depth buffer

Display: w - window

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Primitive: Textured, Lighted Triangle Strip

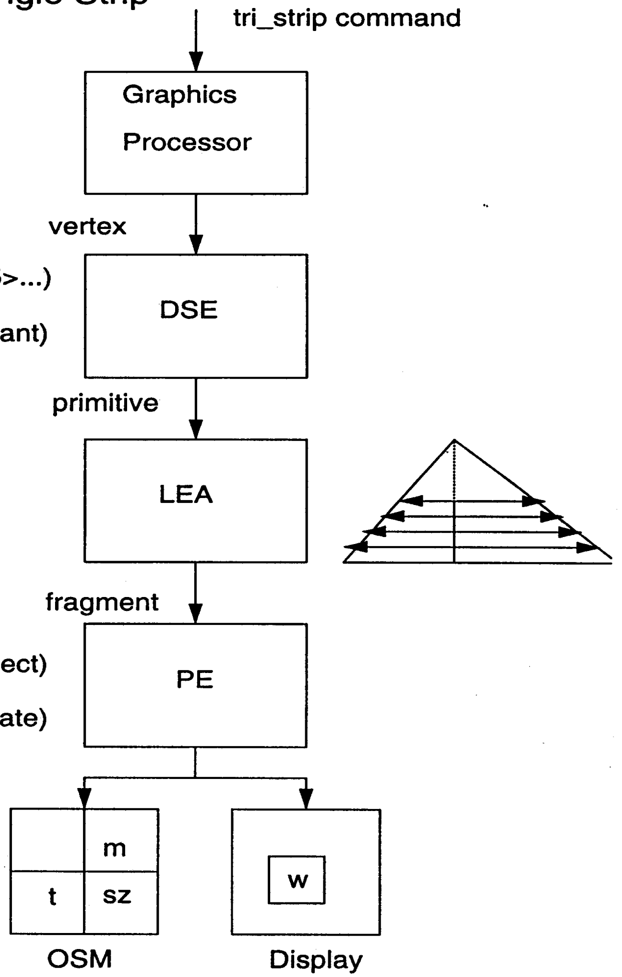
transform (geometry and texture)
light
clip
scale

vertex reordering (<1,2,3> <2,3,4> <3,4,5>...)
edge coefficients (x3)
interpolant coefficients (A,B,F per interpolant)
scan bounds

scans efficiently bounds
pre-scales texture coordinates
generates fragments (x, y, sz, rgba, uvw)

transform: perspective correction
extent test (repeat, clamp, select)
interpolation (point, linear)
texture function (blend, modulate)
blend: copy

OSM: m - math
t - texture
sz - stencil, depth buffer
Display: w - window



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Primitive: Raster, Affine Transform

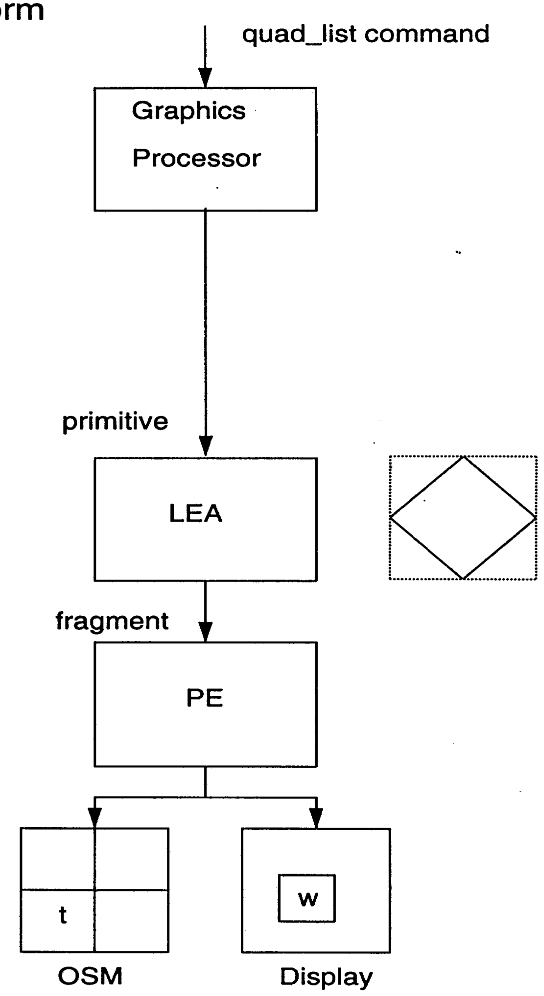
transform (geometry and texture)
clip
scale
quad setup: bounds, interpolants (uv)

scans efficiently bounds
generates fragments (x, y, sz, rgba, uv)

transform:extent test (select)
interpolation (point, linear)
blend: copy

OSM: t - texture

Display: w - window



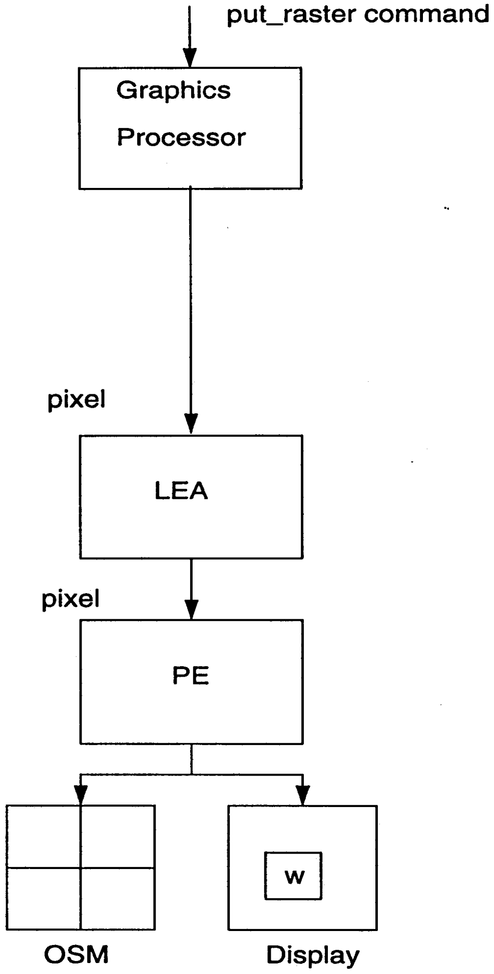
Primitive: Raster, Compositing

unpacking
index to luminance conversion *
alpha append

pixel reformatting

translate: index to rgba conversion *
transform: alpha pre-multiply
blend: compositing

Display: w - window



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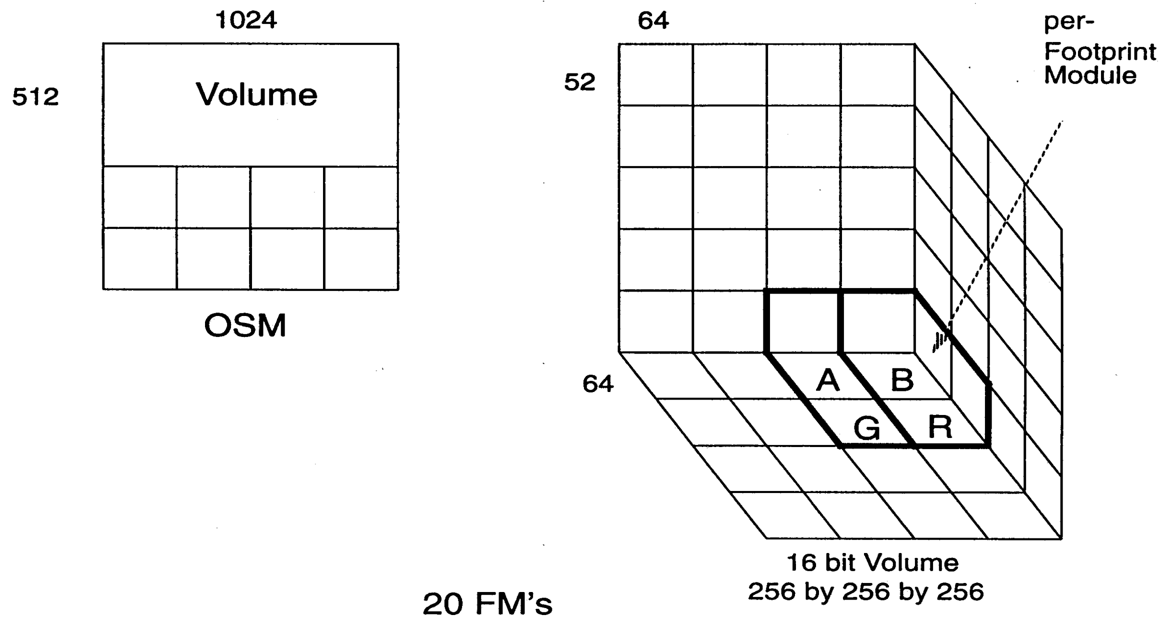
Primitive: Volume, Storage

- Subvolumes are distributed among Footprint Modules
- Each Footprint Module can store upto 64^3 voxels (8 or 16 bits)
- Four 8 bit voxels in a single precision pixel (32 bits) format
- Four 16 bit voxels in a double precision pixel (64 bits) format
- Maximum volume size stored:

  8 bit voxel - 256 by 256 by 512 (512 by 512 by 128)
  16 bit voxel - 256 by 256 by 256 (512 by 512 by 64)

- Fast addressing mode for subvolumes



20 FM's

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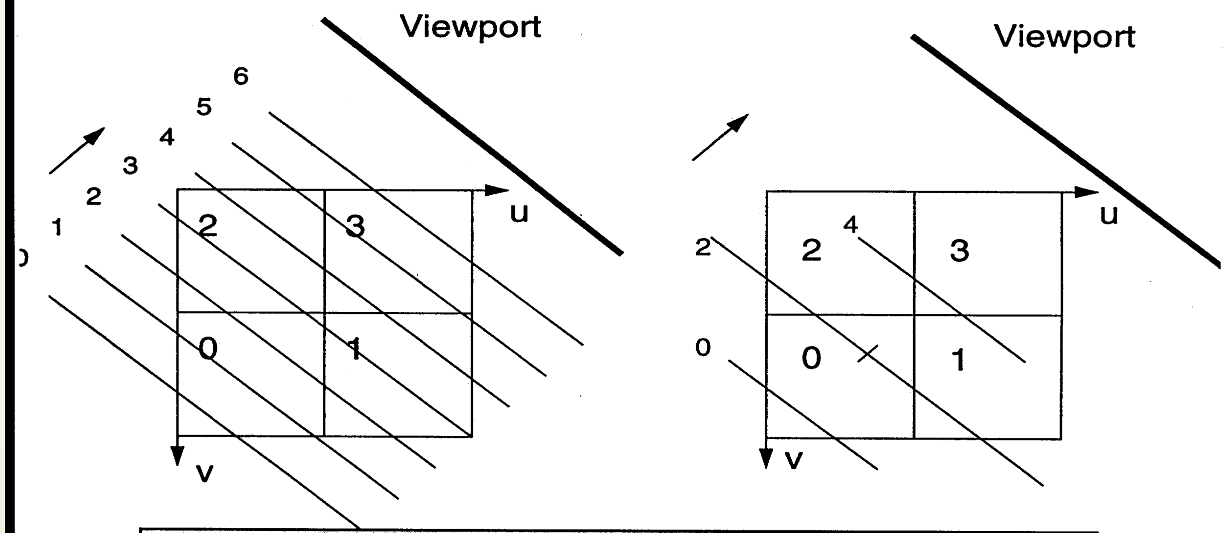
Primitive: Volume, Render

- Backward projection
- Parallel plane cutting scheme for resampling to fit footprint based architecture
- Use of Footprint Modules in a SIMD parallel processing
- The cutting plane is a planar quad that is broadcast to Footprint Modules
- Cutting plane domain is subvolume and each Footprint Module translates the plane in volume space
- Use of tri-linear interpolation for reconstruction
- Voxel thresholding support for binary classification



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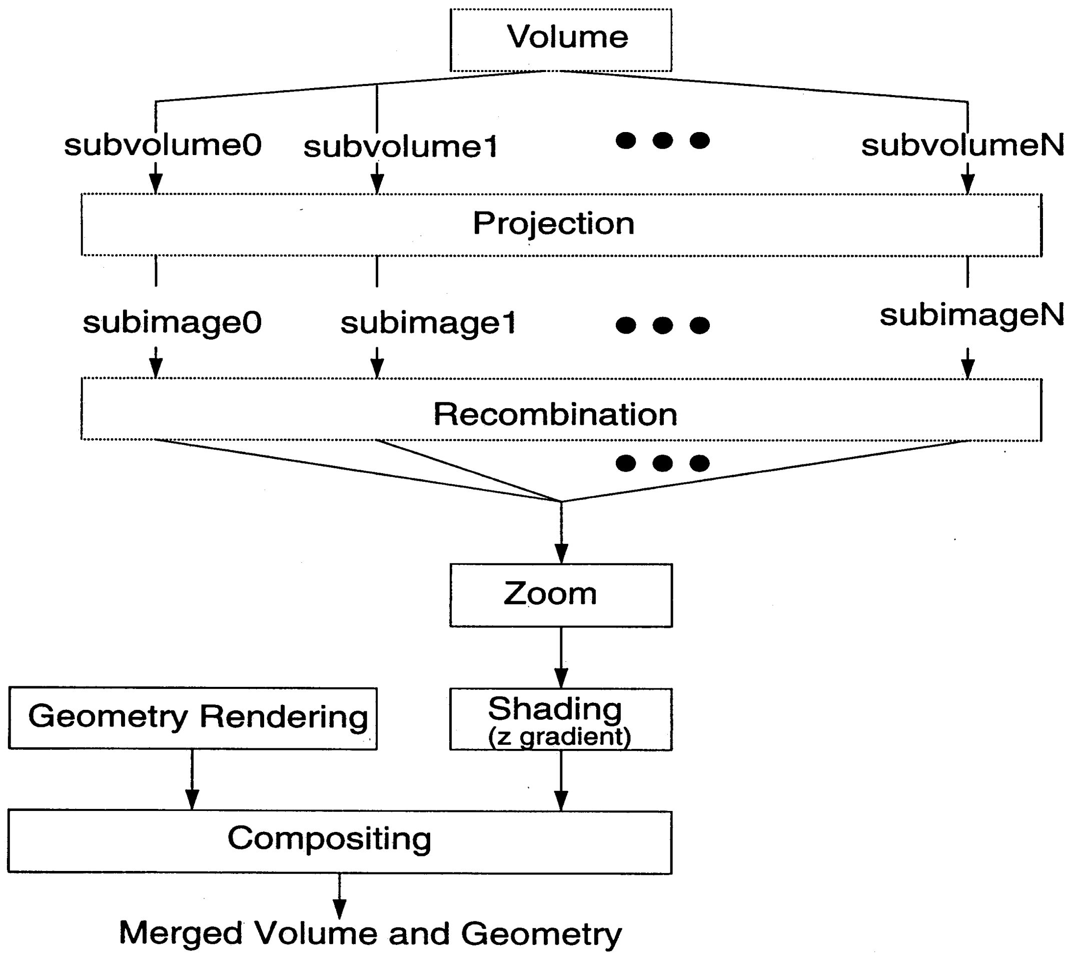
Primitive: Volume, Render



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Primitive: Volume, Render

Rendering functionality:

- Multi-Planar Reformatting (MPR): non-orthogonal cutting plane
- Volume Resampling (VR): used to generate isotropic volume for further processing
- Maximum/Minimum Intensity Projection (MIP): effective technique for detecting geometrically fine structures in a volume
- Surface Extraction (SE): scalar thresholding to extract surface from the volume
- Ray Sum (RS): technique to produce an X-ray image representation to isolate high density objects in the volume
- Transparency (XPR): 'see through' the volume capability*

Rendering Mode	Voxel Operation
MPR/VR	copy
MIP	max/min
SE	threshold
RS	add
XPR	transparency/compositing

* using forward projection, splatting

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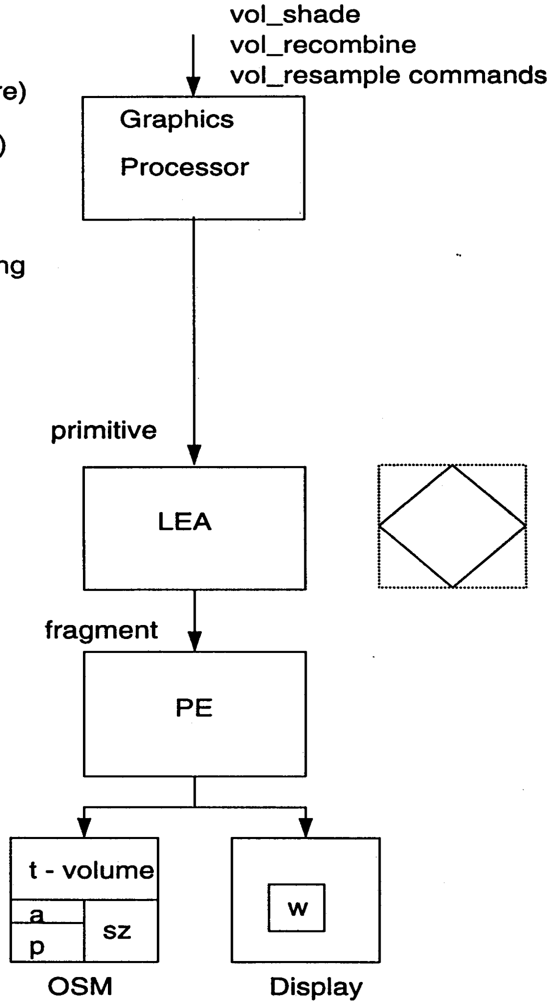
Primitive: Volume, SE

resample: transform (geometry and texture)
clip
quad setup: bounds, edges (x4)
interpolants (z, uvw)

recombine: merge sub-images

shade: z gradient type shading, lighting



scans efficiently bounds
address translation - turned off
generates fragments (x, y, sz, uvw)

resample:
transform: extent test (select)
interpolation (linear)
blend: threshold
recombine/shade:
blend: copy

OSM: t - texture
p - projection buffer
a - assembly buffer
Display: w - window

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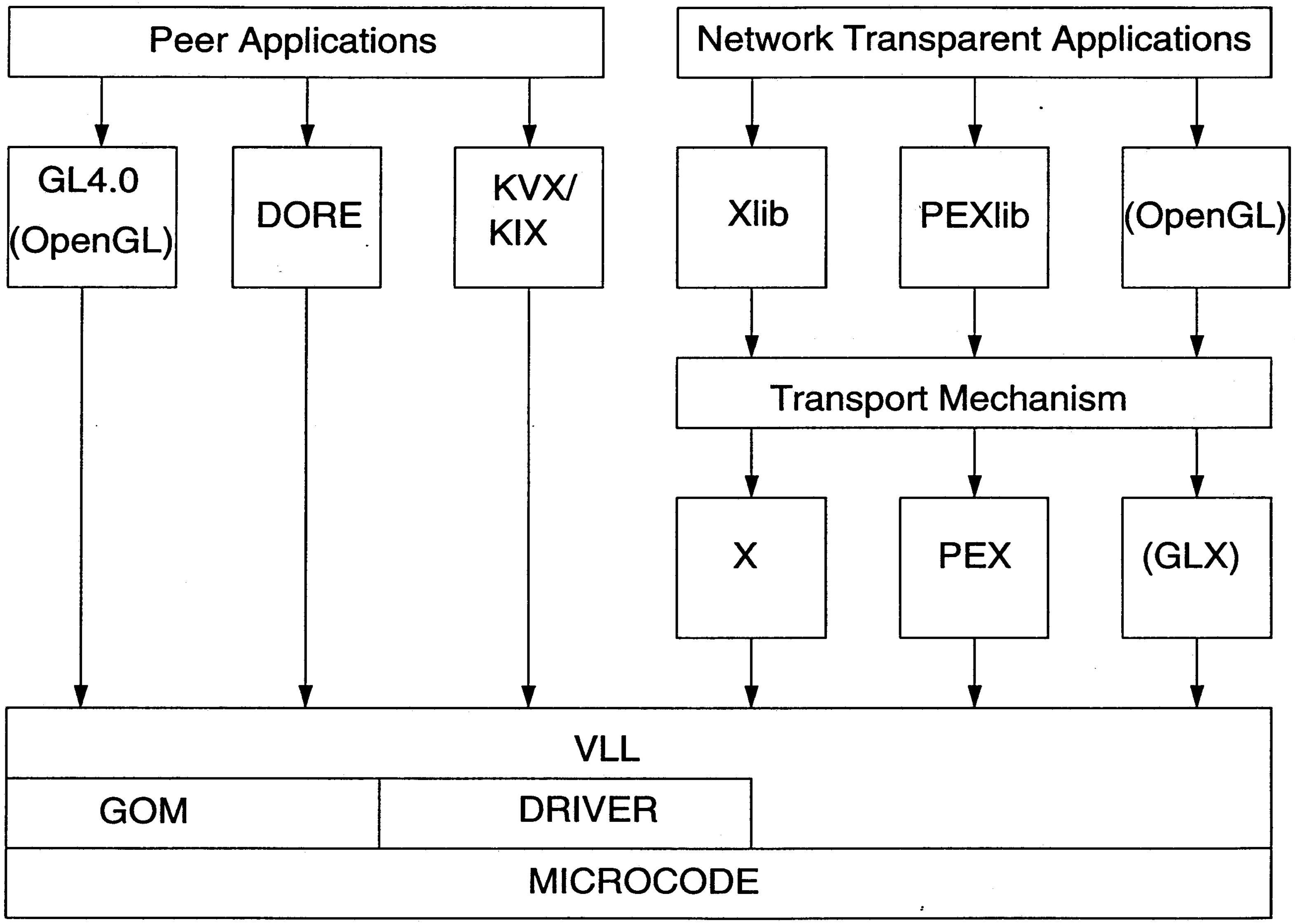

Graphics Software Architecture

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Advanced Features

- Firmware Spheres:
  - Spheres in perspective are ellipsoids
  - Graphics processor evaluates quadratic function per-pixel
  - Graphics processor evaluates light equation per-pixel
  - Algorithm extensible to apply anti-aliasing
  - Performance: 25 Kspheres/sec (10 pixel diameter)

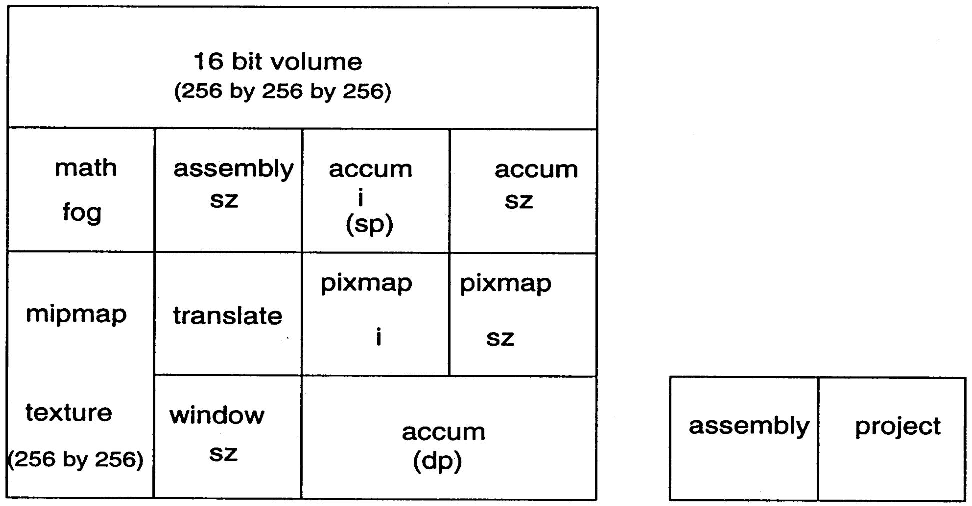
- Boolean Query:
  - Hardware returns a boolean that reflects success/failure of a visibility or alpha test
  - Application can queue up several query requests
  - Visibility:
    - Bounding volume of an object is tested for complete occlusion
    - Efficient for large depth complexity scenes and high cost pixelization (textures, transparency, anti-aliasing)
  - Opacity: complete opaqueness resolution test as means to control order dependent transparency

- Splatting:
  - Table driven splats, evaluated by the graphics processor
  - 2D image convolution (10 Msplats/sec for 3 by 3 quadratic symmetric kernels)
  - Transparent volumes*

* work in progress

Feature Orthogonality

- Multi-featured scene (global anti-aliasing, texture, order dependent transparency, atmospheric)
- Mixing firmware spheres and traditional geometry
- Successive refinement rendering passes
- Merging geometry and volumes
- Assymetry of features per-object (non-textured firmware spheres)
- Managing OSM resources



OSM (20 FM's)

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Performance Model:

- Sampling, rendering and blending are performed in separate pipe stages to increase throughput and reduce frame time
- Primitive ordering (2D/3D prioritization) is maintained via synchronization tokens that increase frame time
- Rendering latency is rendering algorithm dependent
- Refresh latency is reduced by having a separate refresh command queue that is executed at vertical retrace time
- Primitives are divided equally amongst TRM's
- Static load imbalance due to unequal processing (i.e clipping) or pixelization (i.e large vs small primitive extent) are handled efficiently via the token 'any' (from IO processor to TRM's)
- Footprint high frequency interleaving (horizontally and vertically) makes dynamic load imbalance less prominant
- Footprint page misses due to multi-TRM access is a source for dynamic load imbalance
- Footprint page coherency is preserved across TRM's for raster rendering and deferred shading (i.e. span partition)

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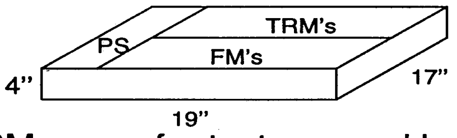
Design Tradeoffs

- Cost, space ('pizza box') and power were primary constraints



PS - power supply

- Single OSM space for textures and buffers to minimize pixel memory (DRAM) cost
- Efficient utilization of memory for large volumes coupled with constant rendering cost
- Quality of output imagery supercedes performance aspect if necessary (i.e. double precision accuracy, improved anti-aliasing)
- Cost of dedicated supersample buffer did exceed our budget
- Non-orthogonal supersample buffer with respect to features (order dependent transparency) and primitives (alpha based anti-aliasing) is undesireable
- Progressive refinement global anti-aliasing approach to allow for gaussian filtering on neighbor pixels and to maintain feature orthogonality
- Deferred shading for mipmap, environment mapping, atmospheric effects and lighted volumes (transformation/resampling limited)
- Assist pixel critical applications with efficient boolean query support

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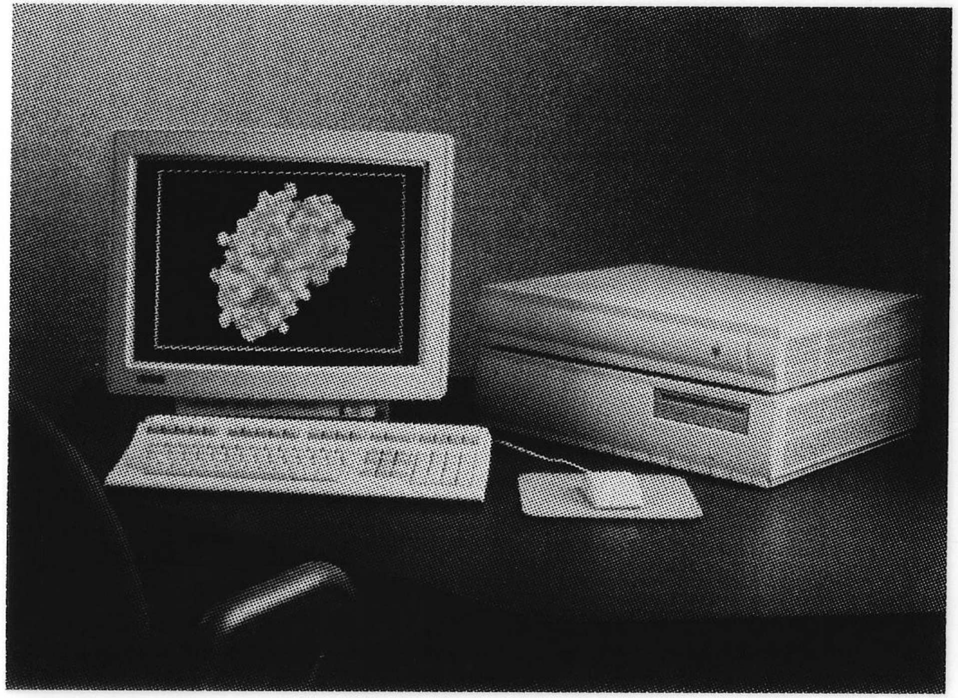
Denali - High Performance Graphics for Alpha AXP Workstations



- Balanced High Performance
- Scalable & Field Upgradable
- Widest Range of Graphic APIs
- Unique Support for Imaging
- Extraordinary Feature Set
- Full Alpha AXP Compatibility