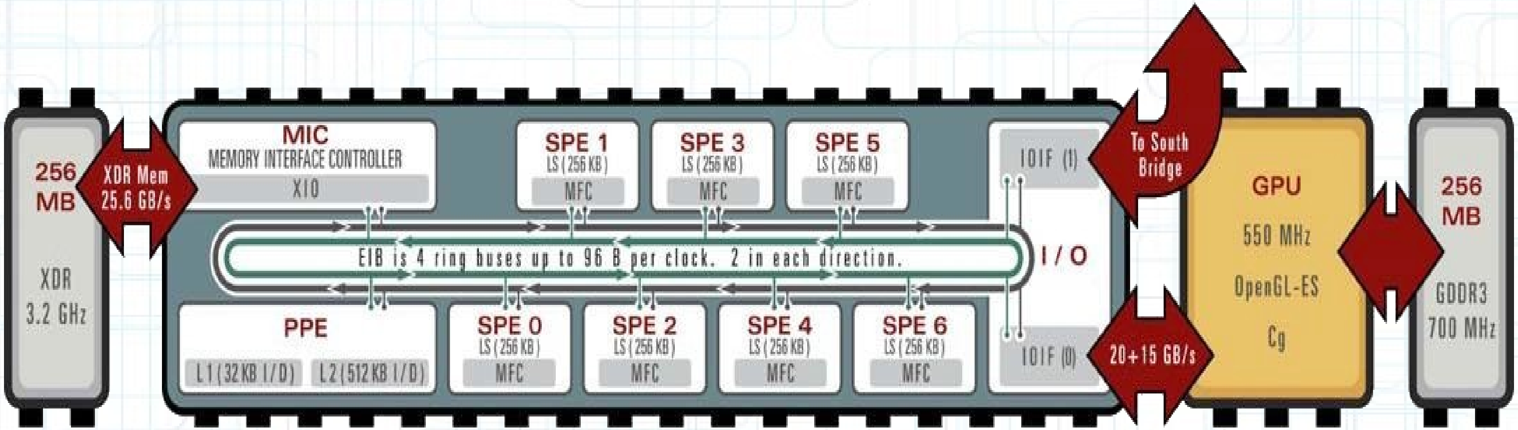
SPU Render



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Introduction

- Smash Cars 2 project
  - Static scene of moderate size
  - Many dynamic objects
  - Multiple render passes
  - Totals up to 3000 batches per frame
- PPU render up to 12 ms
  - Target – 60 fps :(

Introduction

Optimization techniques

- PPU code optimizations
  - Has been done several times
  - Would like PPU time to become ~0
- Static command buffers
  - Somewhat restricted
  - Culling is unclear
- Move code to SPU

Agenda

- Render design
- Brief description of SPU
- Porting
- Development
- Q & A

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Render – "high" level

- Rendering is done on sets of RenderItem
  - The sets are already sorted and culled
- RenderItem aggregates:
  - SceneNode
  - Material
  - Shader
  - RenderEntity

Render – SceneNode

- Transform graph node
  - Local transform
  - Global transform (derived from local)
- Local transforms are set by misc code
  - Animations
  - Physics
  - Game logic

Render – Shader

- Render pipeline setup algorithm
  - virtual void apply
    - Setups auto-parameters
      - Are computed automagically by the system
      - WorldViewProjection, ShadowMap, etc.
  - virtual void setup
    - Setups material
      - Material parameters (including textures)
      - Shaders
- 99% objects are of final type HWShader

Render – Material

- Container of instance data for Shader
  - Data layout description
    - Parameter name/type
    - Offset in data array
  - Data array
  - Accessors for name/index (get/set)
  - Render states
    - Blend, alpha test, depth, cull

Render – RenderEntity

- Drawing algorithm
  - virtual void render
- Several implementations
  - RenderStaticGeometry
  - RenderSkinnedGeometry
  - RenderMorphedGeometry
  - DynamicObject

Render – low level

- Cross-platform wrappers
  - State setup (with cache)
  - Vertex/pixel constant setup
  - Shader setup
- GCM implementation
  - PS3-specific API for CB generation
    - Is mostly present on SPU
      - This makes porting easier

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SPU – what is it?

- 6 like cores
  - 3.2 GHz, in-order, dual-issue
  - 128 vector registers
  - Local Storage (LS)
    - 256 Kb – code + data
    - 6 cycle latency
    - External memory is accessed via DMA
      - Asynchronous memcpy (LS ↔ memory)
      - Alignment/size restrictions

SPU – porting tasks

- Build code for SPU
- Run code on SPU
  - Task/job manager
  - Code/data size
  - Virtual functions
- Optimization
  - Effective usage of DMA
  - Code optimization

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Porting steps

- Step 1 – working prototype
- Step 2 – data optimization
- Step 3 – code optimization

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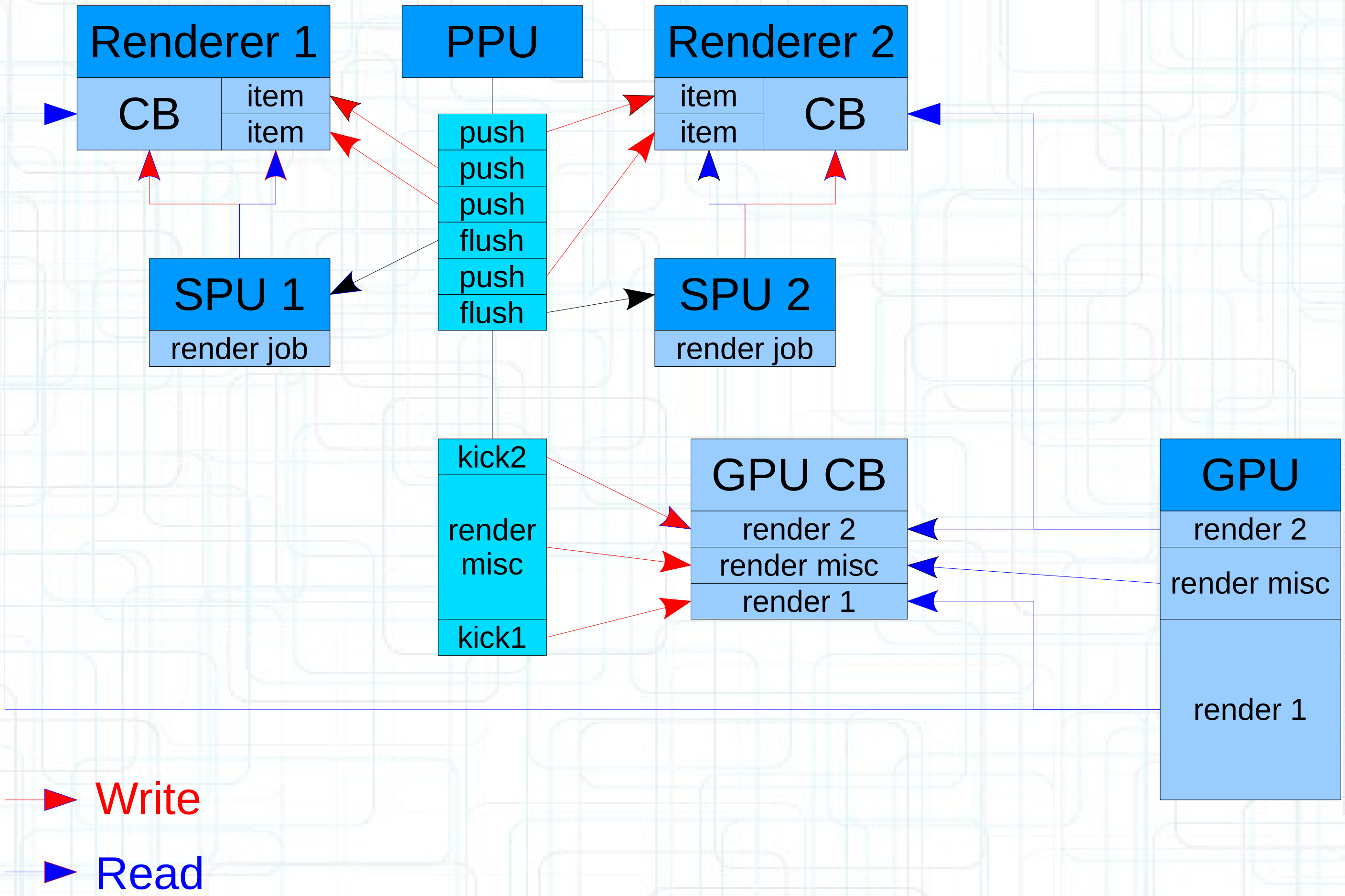
Porting steps

- Step 1 – working prototype
  - Speed does not matter
    - Non-optimal code, synchronous DMA
  - Complete functionality
- Step 2 – data optimization
- Step 3 – code optimization

Step 1 – PPU interface

- async::Renderer
  - Simple interface
    - push(RenderItem) (+ batch versions)
    - flush()
    - kick()
  - The limits are set when creating renderer
    - Maximum number of items
    - Maximum CB size
  - Double-buffering for CB

Step 1 – PPU interface



Step 1 – DMA helpers

- Convenience functions to simplify DMA
  - Allocator
    - Trivial stack allocator, ptr += size
  - fetchData(ea, size)
    - Memory allocation and synchronous DMA
    - Can handle misalignment
  - fetchObject / fetchObjectArray
    - Typed versions of fetchData
  - Later we made asynchronous variants

Step 1 – DMA helpers

- void* fetchData(alloc, ea, size)

```
uint32_t sizeAligned = (size + (ea & 15) + 15) & ~15;
void* ls = alloc.allocate(sizeAligned);
DmaGet(ls, ea & ~15, sizeAligned);
DmaWait();
return (char*)ls + (ea & 15);
```

- T* fetchObject(alloc, ea)

```
return (T*)fetchData(alloc, ea, sizeof(T));
```

Step 1 – virtual functions

- PPU vfptr does not make sense on SPU
- The solution varies across interface
  - Shader
    - Single supported shader type – HWShader
  - RenderEntity
    - Enum for all supported types
    - Enum value is stored in unused pointer bits
      - ptr = actual_ptr | type // actual_ptr % 4 == 0

Step 1 – encapsulation

- Makes porting harder
  - Methods with incorrect SPU code
    - CRT_ASSERT(next->prev == this)
  - Additional method parameters
    - render() → render(Context)
- Makes SPU code refactoring harder
- Solution (some people don't like this...)
  - #define private public [SPU-only!]

Step 1 – shader patch

- RSX lacks PS constant registers
  - Constants are embedded into microcode
  - Microcode has to be patched
    - RSX blitting
      - Huge RSX cost (up to 50% frame time)
    - PPU render
      - Ring buffer for microcode instances
      - Complex synchronization
    - SPU render
      - Instances are stored in the same buffer where CB resides

Step 1 – synchronization

- PPU/SPU
  - Data races
    - Transformation matrices
    - Material parameters
  - Objects can be deleted
  - Solution
    - SPU code has to be fast
    - PPU waits for SPU before changing data

Step 1 – synchronization

- SPU/RSX
  - PPU
    - flush() inserts WAIT at the beginning of CB
      - Waits indefinitely
    - kick() inserts CALL in main CB
  - SPU
    - Fills CB with rendering commands/shaders
    - Appends RET to the end
    - Replaces WAIT with NOP*

Step 1 – results

- Porting time – 3 days
- Render time – 25 ms
  - PPU render time is 12.5 ms
  - How to make it faster?
    - Brute-force – split queue into 5 chunks
      - 5 ms for 5 SPU
    - Write better code
- Completely separate code branch
  - Common data structures

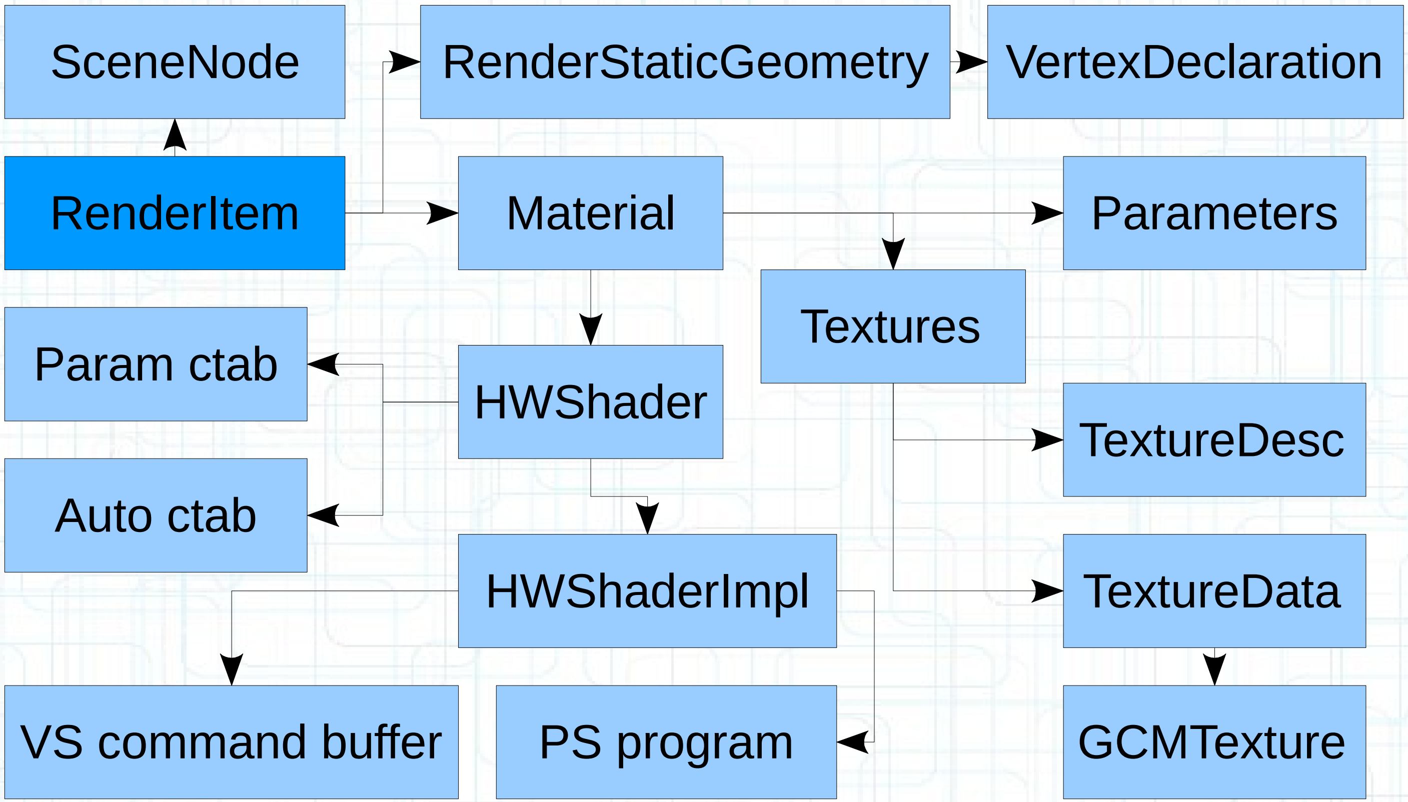
Porting steps

- Step 1 – working prototype
- Step 2 – data optimization
- Step 3 – code optimization

Porting steps

- Step 1 – working prototype
- Step 2 – data optimization
  - Change data layout
    - Lower indirection count
  - Asynchronous DMA
    - Double-buffering for input/output data
- Step 3 – code optimization

Step 2 – memory layout



Step 2 – data layout

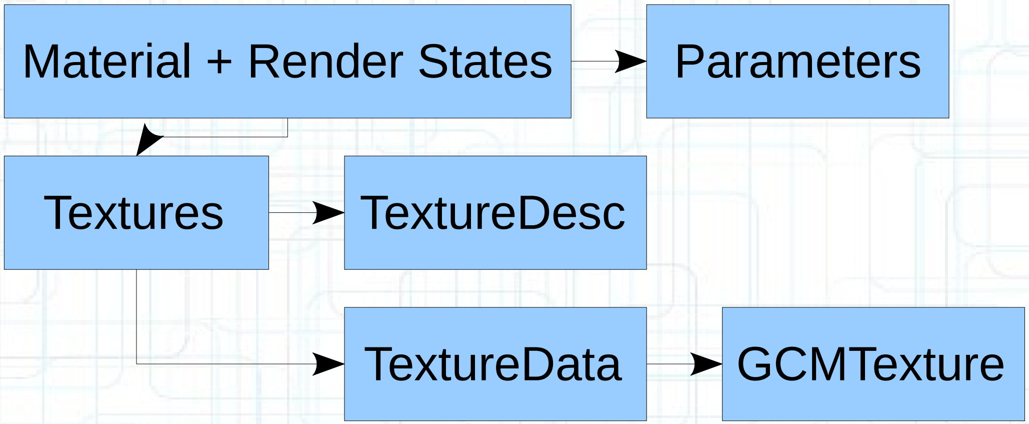
- Goal – lower indirection count
  - Actually, make graph paths shorter
- Where do they come from?
  - Shared data
  - “Variable” length arrays
    - Size is known at load time
  - “Good” architecture
    - Law of Demeter
  - Pimpl

Step 2 – materials

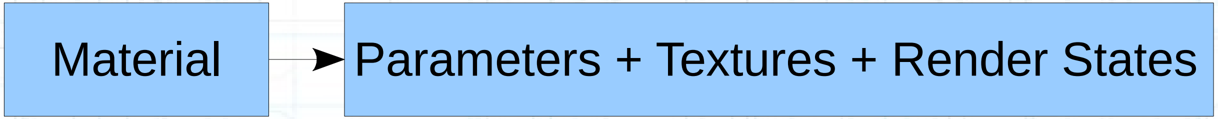
- Textures
  - struct TextureInfo
    - Stored in data array
    - Is updated in setValue
    - The contents is sufficient for texture setup
      - 4b – sampler state, 12b – texture header
- Render States
  - Stored in data array
    - 16b for all states

Step 2 – materials

- Before:



- After:

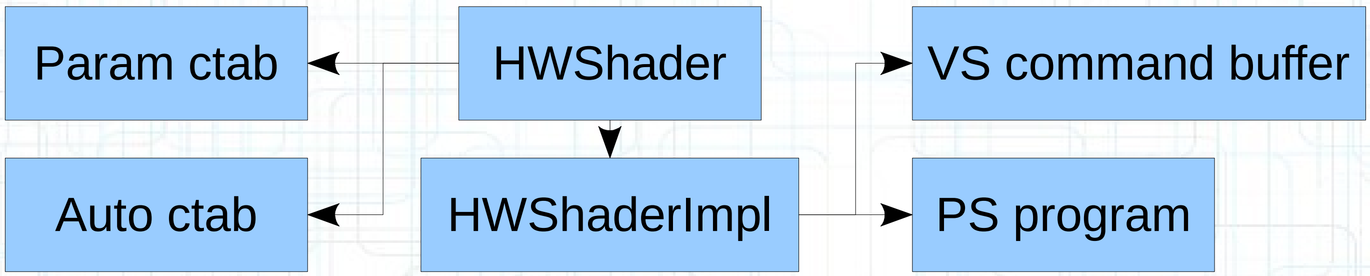


Step 2 – HWShaderImpl

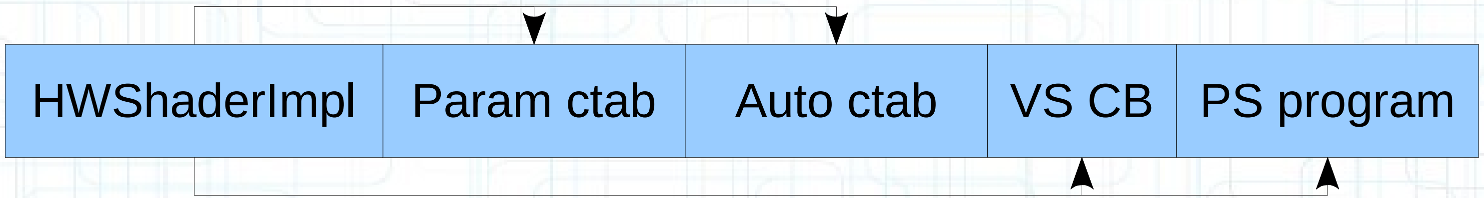
- Lots of “variable” length arrays
  - Constant tables
  - Shader data
- Solution
  - Sequential layout of everything in memory
  - Header contains offsets
  - DMA get and pointer fixup
    - vsCB = (char*)impl + impl->vsCBOffset

Step 2 – HWShaderImpl

- Before:



- After:



Step 2 – VertexDeclaration

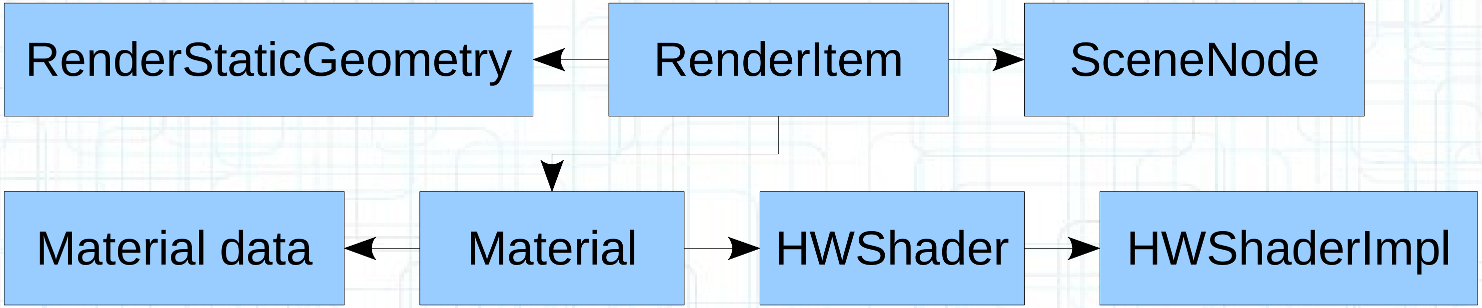
- class RenderStaticGeometry
  - VertexDeclaration* vdecl
    - Can store vdecl by value
      - Space penalty
- There are not a lot of unique instances
  - There is a declaration cache anyway
  - Can implement a software cache!
    - 4 element cache, DMA stall on cache miss
    - 30 cache misses for 3500 batches

Step 2 – FlatRenderItem

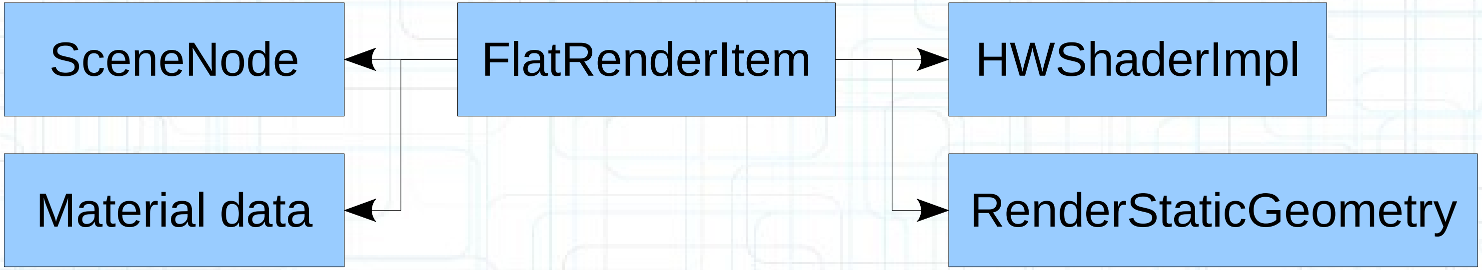
- Graph path to HWShaderImpl is long
  - item->material->shader->impl
- FlatRenderItem
  - Caches pointers/sizes
    - Material data EA/size
    - Shader impl EA/size
    - Scene node/render entity EA
  - Created at level load time

Step 2 – FlatRenderItem

- Before:



- After:



Step 2 – DMA optimizations

- Up to now all DMA are synchronous
- Can hide DMA latency!
  - Launch several requests
    - Wait for all at once
  - Double buffering
    - While current batch is being processed
      - Source data for next batch is being read
      - Result for previous batch is being written
    - Requires additional LS memory
      - Not a problem in our case

Step 2 – output DMA

- Command buffer
  - Two 8 Kb buffers
  - Swap on buffer overflow
- Shader buffer
  - Can do double buffering
  - It's easier to wait for transfer though
    - But **before** processing instead of after!
    - DmaPut has enough latency to complete

Step 2 – input DMA

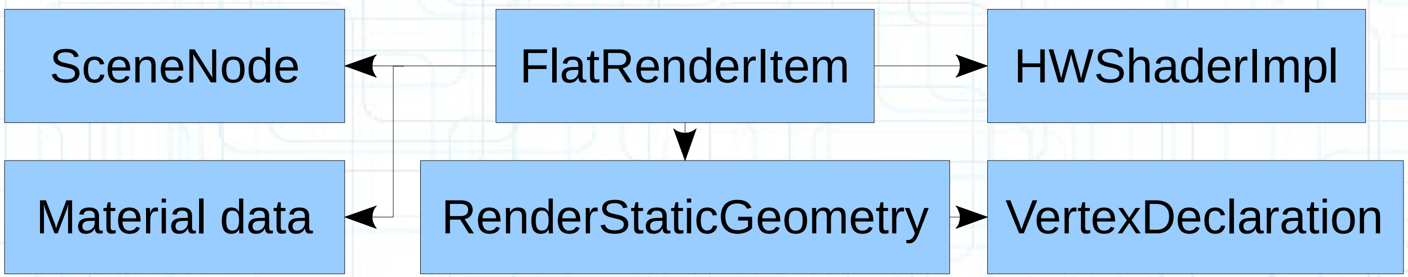
- For each batch
  - Wait for previous transfers
  - Prefetch next batch
    - 4 DmaGet at once
  - Current batch processing
- Requires loop prologue
  - Prefetch for first batch

Step 2 – input DMA

- Complex code (lack of experience atm)
  - FlatRenderItem are fetched one by one
    - It's easier to fetch in groups
- Bugs
  - The code prefetches one item past the end
    - PPU duplicates last item to avoid errors
  - Don't forget to wait for last DmaGet !
    - Otherwise stack corruption is possible

Step 2 – results

- Optimization time – 3 days
- Render time – 8 ms
  - Without double buffering – 12 ms
- PPU time did not change (don't ask)



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Porting steps

- Step 1 – working prototype
- Step 2 – data optimization
- Step 3 – code optimization
  - Profiling
    - SN Tuner
    - SPUsim
  - Optimization

Step 3 – SN Tuner

- CPU/GPU profiler for PS3
  - SPU performance counters
    - DMA stalls
    - Instruction scheduling
      - Overview of code quality
  - SPU PC sampling
    - No overhead as opposed to PPU sampling
    - Used for function cost overview
      - Had to selectively remove inlining

Step 3 – SPUsim

- SPU simulator for PC
  - Awesome for prototyping
    - Lightning fast iterations
    - Stalls statistics
    - Instruction trace
      - Shows stalls, lack of pairing
  - For small self-contained functions
    - You can setup DMA, but it's not very easy

Step 3 – branching

- Branching carries a lot of overhead
- Reduce branch counts
  - Branch flattening
  - Loop unrolling
  - Switch → function pointer table
- Zero-size DMA
- Branch hinting

Step 3 – LS load/store

- LS load/store is limited to 16b size/align
  - Compiler performs shuffle / masking
- 16b reads
  - Padding for input data
  - Loop unrolling
- 16b writes
  - Write several RSX commands at a time
  - Padding for output data (via NOP for RSX)

Step 3 – results

- Optimization time – 5 days
- Render time – 2 ms
- Further optimizations
  - Code optimization is still possible
    - But is not worth it for now
  - Parallel rendering with N SPUs
    - Different scene chunks
    - Different passes

Porting results

- PPU time – 12.5 ms
- SPU time (prototype) – 25 ms (3 days)
- SPU time (layout) – 12 ms (2.5 days)
- SPU time (async DMA) – 8 ms (1 day)
- SPU time (code) – 2 ms (5 days)
- 75 Kb SPU code, 20 Kb PPU code
  - Currently 105 / 26 Kb

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Development

- Already implemented
  - Batch sorting
  - Culling (frustum, screen size)
  - Custom game parameter setup
- Future work
  - Occlusion culling (already implemented)
  - Single buffered context
  - Uber shaders

Q & A

?

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