Intel Open Source Graphics Programmer's Reference Manual (PRM) for the 2013 Intel® Core™ Processor Family, including Intel HD Graphics, Intel Iris™ Graphics and Intel Iris Pro Graphics

Volume 3: GPU Overview (Haswell)

1/21/2014

Copyright

GPU Overview

Table of Contents

Introduction

The integrated graphics component, specifically called the Graphics Processing Unit, or GPU, resides on the same chip die as the Central Processing Unit, or CPU, and communicates with the CPU via the on-chip bus, with internal memory and with output device(s). As Intel GPUs have evolved, they now occupy a significant percentage of space on the chip, and provide customers with high performance and low-power graphics processing, eliminating the need to purchase a separate video card for most users.

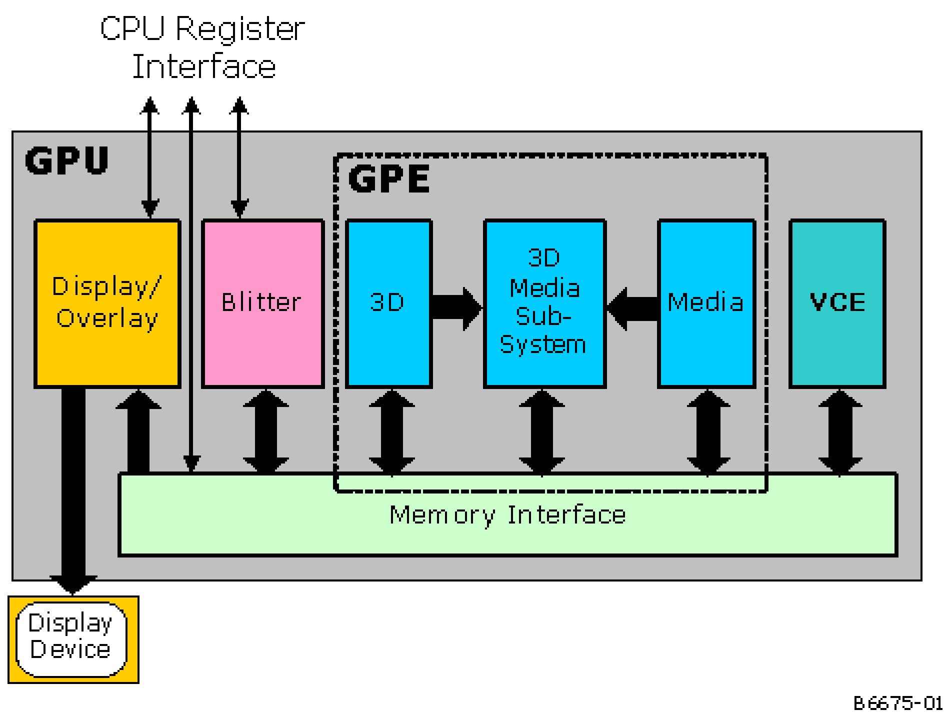
This Programmer's Reference Manual, or PRM, provides detailed narrative and referential information required by graphics device driver engineers and graphics API-level programmers to take advantage of the sophisticated architecture and programmability of the GPU.

Graphics Processing Unit (GPU)

The Graphics Processing Unit is controlled by the CPU through a direct interface of memory-mapped IO registers, and indirectly by parsing commands that the CPU has placed in memory. The Display interface and Blitter (**bl**ock **i**mage **t**ransferr**er**) are controlled primarily by direct CPU register addresses, while the 3D and Media pipelines and the parallel Video Codec Engine (VCE) are controlled primarily through instruction lists in memory.

The subsystem contains an array of cores, or execution units, with a number of "shared functions", which receive and process messages at the request of programs running on the cores. The shared functions perform critical tasks, such as sampling textures and updating the render target (usually the frame buffer). The cores themselves are described by an instruction set architecture, or ISA.

Block Diagram of the GPU



Command Stream (CS) Unit

The Command Stream (CS) unit manages the use of the 3D and Media pipelines; it performs switching between pipelines and forwarding command streams to the currently active pipeline. It manages allocation of the URB and helps support the Constant URB Entry (CURBE) function.

3D Pipeline

The 3D Pipeline provides specialized 3D primitive processing functions. These functions are provided by a pipeline of "fixed function" stages (units) and GEN threads spawned by these units. See *3D Pipeline Overview*.

Media Pipeline

The Media pipeline provides both specialized media-related processing functions and the ability to perform more general ("generic") functionality. These Media-specific functions are provided by a Video Front End (VFE) unit. A Thread Spawner (TS) unit is utilized to spawn GEN threads requested by the VFE unit, or as required when the pipeline is used for general processing. See *Media Pipeline Overview*.

Thread Dispatching

When the 3D and Media pipelines send requests for thread initiation to the Subsystem, the thread Dispatcher receives the requests. The dispatcher performs such tasks as arbitrating between concurrent requests, assigning requested threads to hardware threads on EUs, allocating register space in each EU among multiple threads, and initializing a thread's registers with data from the fixed functions and from the URB. This operation is largely transparent to software.

Execution Units (EUs)

While the number of EU cores in the subsystem is almost entirely transparent to the programming model, there are a few areas where this parameter comes into play:

- The amount of scratch space required is a function of (#EUs * #Threads/EU)

Device	# of EUs	#Threads/EU
[DevHSW-GT3]	40	7
[DevHSW-GT2]	20	7
[DevHSW-GT1]	10	7

Shared Functions

Shared functions are hardware units which serve to provide specialized supplemental functionality for the EUs. A shared function is implemented where the demand for a given specialized function is insufficient to justify the costs on a per-EU basis. Instead a single instantiation of that specialized function is implemented as a stand-alone entity outside the EUs and shared among the EUs.

Invocation of the shared functionality is performed via a communication mechanism called a message. A message is a small self-contained packet of information created by a kernel and directed to a specific shared function. Messages are dispatched to the shared function under software control via the send instruction. This instruction identifies the contents of the message and the GRF register locations to direct any response.

The message construction and delivery mechanisms are general in their definition and capable of supporting a wide variety of shared functions.

Fixed and Shared Function IDs

The following table lists the assignments (encodings) of the Shared Function and Fixed Function IDs used within the GPE. A Shared Function is a valid target of a message initiated via a 'send' instruction. A Fixed Function is an identifiable unit of the 3D or Media pipeline. Note that the Thread Spawner is both a Shared Function and Fixed Function.

Function IDs [HSW]

ID[3:0]	SFID	Shared Function	FFID	Fixed Function
0x0	SFID_NULL	Null	FFID_NULL	Null
0x1	Reserved	---	**Reserved**	---
0x2	SFID_SAMPLER	Sampler	**Reserved**	---
0x3	SFID_GATEWAY	Message Gateway	**Reserved**	---
0x4	SFID_DP_SAMPLER	Sampler Cache Data Port	FFID_HS	Hull Shader
0x5	SFID_DP_RC	Render Cache Data Port	FFID_DS	Domain Shader
0x6	SFID_URB	URB	**Reserved**	---
0x7	SFID_SPAWNER	Thread Spawner	FFID_SPAWNER	Thread Spawner
0x8	SFID_VME	Video Motion Estimation	FFID_VFE	Video Front End
0x9	SFID_DP_CC	Constant Cache Data Port	FFID_VS	Vertex Shader
0xA	SFID_DP_DC	Data Cache Data Port	FFID_CS	Command Stream
0xB	SFID_PI	Pixel Interpolator	FFID_VF	Vertex Fetch
0xC	Reserved	---	FFID_GS	Geometry Shader
0xD	Reserved	---	FFID_CLIP	Clipper Unit
0xE	Reserved	---	FFID_SF	Strip/Fan Unit
0xF	Reserved	---	FFID_WM	Windower/Masker Unit

Function IDs [HSW]

ID[3:0]	SFID	Shared Function	FFID	Fixed Function
0x0	SFID_NULL	Null	FFID_NULL	Null
0x1	Reserved	---	**Reserved**	---
0x2	SFID_SAMPLER	Sampler	**Reserved**	---
0x3	SFID_GATEWAY	Message Gateway	**Reserved**	---
0x4	SFID_DP_SAMPLER	Sampler Cache Data Port	FFID_HS	Hull Shader
0x5	SFID_DP_RC	Render Cache Data Port	FFID_DS	Domain Shader
0x6	SFID_URB	URB	**Reserved**	---
0x7	SFID_SPAWNER	Thread Spawner	FFID_SPAWNER	Thread Spawner
0x8	SFID_VME	Video Motion Estimation	**Reserved**	---

ID[3:0]	SFID	Shared Function	FFID	Fixed Function
0x9	SFID_DP_CC	Constant Cache Data Port	FFID_VS	Vertex Shader
0xA	SFID_DP_DC0	Data Cache Data Port0	FFID_CS	Command Stream
0xB	SFID_PI	Pixel Interpolator	FFID_VF	Vertex Fetch
0xC	SFID_DP_DC1	Data Cache Data Port1	FFID_GS	Geometry Shader
0xD	SFID_CRE	Check & Refinement Engine	**Reserved**	---
0xE	Reserved	---	FFID_SF	Strip/Fan Unit
0xF	Reserved	---	FFID_WM	Windower/Masker Unit

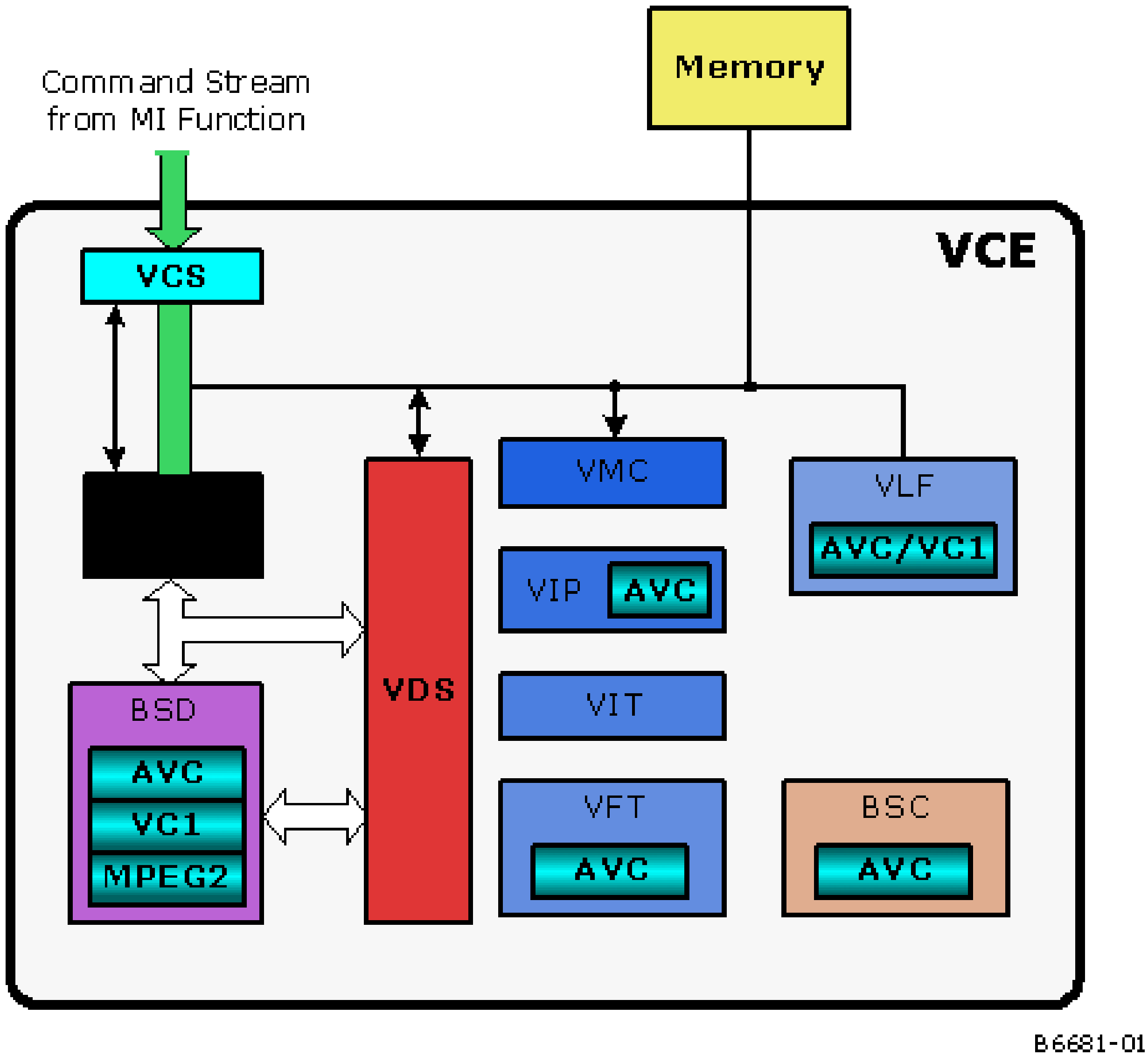
[DevHSW+] SFID_DP_DC1 is an extension of SFID_DP_DC0 to allow for more message types. They act as a single logical entity.

Video Codec Engine

The parallel Video Codec Engine (VCE) is a fixed function video decoder and encoder engine. It is also referred to as the multi-format codec (MFX) engine, as a unified fixed function pipeline is implemented to support multiple video coding standards such as MPEG and VC1:

- VCS – VCE Command Streamer unit (also referred to as BCS)
- BSD – Bitstream Decoder unit
- VDS – Video Dispatcher unit
- VMC – Video Motion Compensation unit
- VIP – Video Intra Prediction unit
- VIT – Video Inverse Transform unit
- VLF – Video Loop Filter unit
- VFT – Video Forward Transform unit (encoder only)
- BSC – Bitstream Encoder unit (encoder only)

VCE Diagram



Device	AVC BSD	VC1 BSD	AVC Dec	VC1 Dec	MPEG2 Dec	AVC Enc
	No	No	Yes	Yes	Yes	Yes

Register Address Maps

Graphics Register Address Map

This chapter provides address maps of the graphics controllers I/O and memory-mapped registers. Individual register bit field descriptions are provided in the following chapters. PCI configuration address maps and register bit descriptions are provided in the following chapter.

Memory and IO Space Registers

These are graphics MMIO ranges used for [HSW]. Note that this is only a subset of the complete definition of the MMIO address space.

Range Start (Hex)	Range End (Hex)	Unit Owning The Range
00002000	00002FFF	Render/Generic Media Engine
00004000	00004FFF	Render/Generic Media Graphics Memory Arbiter
00012000	000123FF	MFX Control Engine (Video Command Streamer)
00012400	00012FFF	Media Units (VIN Unit)
00014000	00014FFF	MFX Memory Arbiter
00022000	00022FFF	Blitter Engine
00024000	00024FFF	Blitter Memory Arbiter
00100000	00107FFF	Fence Registers
00140000	0017FFFF	MCHBAR (SA)

Note: 8800h-88FFh is a reserved range for GT. IA accesses to this region have no impact.

PCI Configuration Space

VGA and Extended VGA Register Map

For I/O locations, the value in the address column represents the register I/O address. For memory mapped locations, this address is an offset from the base address programmed in the MMADR register.

VGA and Extended VGA I/O and Memory Register Map

I/O and Memory Register Map

Address	Register Name (Read)	Register Name (Write)
2D Registers		
3B0h–3B3h	Reserved	Reserved
3B4h	VGA CRTC Index (CRX) (monochrome)	VGA CRTC Index (CRX) (monochrome)
3B5h	VGA CRTC Data (monochrome)	VGA CRTC Data (monochrome)
3B6h–3B9h	Reserved	Reserved
3Bah	VGA Status Register (ST01)	VGA Feature Control Register (FCR)
3BBh–3BFh	Reserved	Reserved
3C0h	VGA Attribute Controller Index (ARX)	VGA Attribute Controller Index (ARX)/ VGA Attribute Controller Data (alternating writes select ARX or write ARxx Data)
3C1h	VGA Attribute Controller Data (read ARxx data)	Reserved
3C2h	VGA Feature Read Register (ST00)	VGA Miscellaneous Output Register (MSR)
3C3h	Reserved	Reserved
3C4h	VGA Sequencer Index (SRX)	VGA Sequencer Index (SRX)
3C5h	VGA Sequencer Data (SRxx)	VGA Sequencer Data (SRxx)
3C6h	VGA Color Palette Mask (DACMASK)	VGA Color Palette Mask (DACMASK)
3C7h	VGA Color Palette State (DACSTATE)	VGA Color Palette Read Mode Index (DACRX)
3C8h	VGA Color Palette Write Mode Index (DACWX)	VGA Color Palette Write Mode Index (DACWX)
3C9h	VGA Color Palette Data (DACDATA)	VGA Color Palette Data (DACDATA)
3CAh	VGA Feature Control Register (FCR)	Reserved
3CBh	Reserved	Reserved
3CCh	VGA Miscellaneous Output Register (MSR)	Reserved
3CDh	Reserved	Reserved
3CEh	VGA Graphics Controller Index (GRX)	VGA Graphics Controller Index (GRX)
3CFh	VGA Graphics Controller Data (GRxx)	VGA Graphics Controller Data (GRxx)
3D0h–3D1h	Reserved	Reserved

Address	Register Name (Read)	Register Name (Write)
2D Registers		
3D4h	VGA CRTC Index (CRX)	VGA CRTC Index (CRX)
3D5h	VGA CRTC Data (CRxx)	VGA CRTC Data (CRxx)
System Configuration Registers		
3D6h	GFX/2D Configurations Extensions Index (XRX)	GFX/2D Configurations Extensions Index (XRX)
3D7h	GFX/2D Configurations Extensions Data (XRxx)	GFX/2D Configurations Extensions Data (XRxx)
2D Registers		
3D8h–3D9h	Reserved	Reserved
3DAh	VGA Status Register (ST01)	VGA Feature Control Register (FCR)
3DBh–3DFh	Reserved	Reserved

Indirect VGA and Extended VGA Register Indices

The registers listed in this section are indirectly accessed by programming an index value into the appropriate SRX, GRX, ARX, or CRX register. The index and data register address locations are listed in the previous section. Additional details concerning the indirect access mechanism are provided in the *VGA and Extended VGA Register Description* Chapter (see SRxx, GRxx, ARxx or CRxx sections).

2D Sequence Registers (3C4h / 3C5h)

Index	Sym	Description
00h	SR00	Sequencer Reset
01h	SR01	Clocking Mode
02h	SR02	Plane / Map Mask
03h	SR03	Character Font
04h	SR04	Memory Mode
07h	SR07	Horizontal Character Counter Reset

2D Graphics Controller Registers (3CEh / 3CFh)

Index	Sym	Register Name
00h	GR00	Set / Reset
01h	GR01	Enable Set / Reset
02h	GR02	Color Compare
03h	GR03	Data Rotate
04h	GR04	Read Plane Select
05h	GR05	Graphics Mode
06h	GR06	Miscellaneous
07h	GR07	Color Don't Care
08h	GR08	Bit Mask
10h	GR10	Address Mapping
11h	GR11	Page Selector
18h	GR18	Software Flags

2D Attribute Controller Registers (3C0h / 3C1h)

Index	Sym	Register Name
00h	AR00	Palette Register 0
01h	AR01	Palette Register 1
02h	AR02	Palette Register 2
03h	AR03	Palette Register 3
04h	AR04	Palette Register 4
05h	AR05	Palette Register 5
06h	AR06	Palette Register 6
07h	AR07	Palette Register 7
08h	AR08	Palette Register 8
09h	AR09	Palette Register 9
0Ah	AR0A	Palette Register A
0Bh	AR0B	Palette Register B
0Ch	AR0C	Palette Register C
0Dh	AR0D	Palette Register D
0Eh	AR0E	Palette Register E
0Fh	AR0F	Palette Register F
10h	AR10	Mode Control
11h	AR11	Overscan Color
12h	AR12	Memory Plane Enable
13h	AR13	Horizontal Pixel Panning
14h	AR14	Color Select

2D CRT Controller Registers (3B4h / 3D4h / 3B5h / 3D5h)

Index	Sym	Register Name
00h	CR00	Horizontal Total
01h	CR01	Horizontal Display Enable End
02h	CR02	Horizontal Blanking Start
03h	CR03	Horizontal Blanking End
04h	CR04	Horizontal Sync Start
05h	CR05	Horizontal Sync End
06h	CR06	Vertical Total
07h	CR07	Overflow
08h	CR08	Preset Row Scan
09h	CR09	Maximum Scan Line
0Ah	CR0A	Text Cursor Start
0Bh	CR0B	Text Cursor End
0Ch	CR0C	Start Address High
0Dh	CR0D	Start Address Low
0Eh	CR0E	Text Cursor Location High
0Fh	CR0F	Text Cursor Location Low
10h	CR10	Vertical Sync Start
11h	CR11	Vertical Sync End
12h	CR12	Vertical Display Enable End
13h	CR13	Offset
14h	CR14	Underline Location
15h	CR15	Vertical Blanking Start
16h	CR16	Vertical Blanking End
17h	CR17	CRT Mode
18h	CR18	Line Compare
22h	CR22	Memory Read Latch Data

Memory Object Overview

Any memory data accessed by the device is considered part of a *memory object* of some memory object type.

The following table lists the various memory objects types and an indication of their role in the system.

Memory Object Type	Role
Graphics Translation Table (GTT)	Contains PTEs used to translate "graphics addresses" into physical memory addresses.
Hardware Status Page	Cached page of sysmem used to provide fast driver synchronization.
Logical Context Buffer	Memory areas used to store (save/restore) images of hardware rendering contexts. Logical contexts are referenced via a pointer to the corresponding Logical Context Buffer.
Ring Buffers	Buffers used to transfer (DMA) instruction data to the device. Primary means of controlling rendering operations.
Batch Buffers	Buffers of instructions invoked indirectly from Ring Buffers.
State Descriptors	Contains state information in a prescribed layout format to be read by hardware. Many different state descriptor formats are supported.
Vertex Buffers	Buffers of 3D vertex data indirectly referenced through "indexed" 3D primitive instructions.
VGA Buffer (Must be mapped UC on PCI)	Graphics memory buffer used to drive the display output while in legacy VGA mode.
Display Surface	Memory buffer used to display images on display devices.
Overlay Surface	Memory buffer used to display overlaid images on display devices.
Overlay Register, Filter Coefficients Buffer	Memory area used to provide double-buffer for Overlay register and filter coefficient loading.
Cursor Surface	Hardware cursor pattern in memory.
2D Render Source	Surface used as primary input to 2D rendering operations.
2D Render R-M-W Destination	2D rendering output surface that is read in order to be combined in the rendering function. Destination surfaces that accessed via this Read-Modify-Write mode have somewhat different restrictions than Write-Only Destination surfaces.
2D Render Write-Only Destination	2D rendering output surface that is written but not read by the 2D rendering function. Destination surfaces that accessed via a Write-Only mode have somewhat different restrictions than Read-Modify-Write Destination surfaces.
2D Monochrome Source	1 bpp surfaces used as inputs to 2D rendering after being converted to foreground/background colors.

Memory Object Type	Role
2D Color Pattern	8x8 pixel array used to supply the "pattern" input to 2D rendering functions.
DIB	"Device Independent Bitmap" surface containing "logical" pixel values that are converted (via LUTs) to physical colors.
3D Color Buffer	Surface receiving color output of 3D rendering operations. May also be accessed via R-M-W (aka blending). Also referred to as a Render Target.
3D Depth Buffer	Surface used to hold per-pixel depth and stencil values used in 3D rendering operations. Accessed via RMW.
3D Texture Map	Color surface (or collection of surfaces) which provide texture data in 3D rendering operations.
"Non-3D" Texture	Surface read by Texture Samplers, though not in normal 3D rendering operations (e.g., in video color conversion functions).
Motion Comp Surfaces	These are the Motion Comp reference pictures.
Motion Comp Correction Data Buffer	This is Motion Comp intra-coded or inter-coded correction data.

Hardware Status Page

The hardware status page is a naturally-aligned 4KB page residing in snooped system memory. This page exists primarily to allow the device to report status via PCI master writes – thereby allowing the driver to read/poll WB memory instead of UC reads of device registers or UC memory.

The address of this page is programmed via the HWS_PGA MI register. The definition of that register (in *Memory Interface Registers*) includes a description of the layout of the Hardware Status Page.

Instruction Ring Buffers

Instruction ring buffers are the memory areas used to pass instructions to the device. Refer to the Programming Interface chapter for a description of how these buffers are used to transport instructions.

The RINGBUF register sets (defined in Memory Interface Registers) are used to specify the ring buffer memory areas. The ring buffer must start on a 4KB boundary and be allocated in linear memory. The length of any one ring buffer is limited to 2MB.

Note that "indirect" 3D primitive instructions (those that access vertex buffers) must reside in the same space as the vertex buffers.

Instruction Batch Buffers

Instruction batch buffers are contiguous streams of instructions referenced via an MI_BATCH_BUFFER_START and related instructions (see Memory Interface Instructions, Programming Interface). They are used to transport instructions external to ring buffers.

Note that batch buffers should not be mapped to snooped SM (PCI) addresses. The device will treat these as MainMemory (MM) address, and therefore not snoop the CPU cache.

The batch buffer must be QWord aligned and a multiple of QWords in length. The ending address is the address of the last valid QWord in the buffer. The length of any single batch buffer is "virtually unlimited" (i.e., could theoretically be 4GB in length).

Logical Contexts

This section is the lead section for the following subsections:

- BSD Logical Context Data (MFX)
- Copy Engine Logical Content Data [HSW]
- Video Enhancement Logical Context Data

MFX Logical Context Data

This section includes the following sub-sections:

- Overall Context Layout
- Context Layout
- Register State Context

Overall Context Layout

Context Layout

[HSW]: BSD effectively has no context. Switching from one task to another is accomplished by programming the UHPTR register with a new head pointer, then executing an MI_ARB_CHECK command. This will load the head pointer with the new value, "jumping" to the commands for the next task.

Register/State Context

		Valid Only When Execlists and PPGTT Enabled					
DW Range	**DW Count**	**State Field**	**Restore Inhibited**	**PPGTT and Execlists Enableds**	**PPGTT and Execlists Disabled**	**Power Context**	**Set Before Submitting Context?**
00h	1	Context Control	R	S/R	X	S/R	Yes
01h	1	Ring Head Pointer Register	R	S/R	X	S/R	Yes
02h	1	Ring Tail Pointer Register	R	R	X	S/R	Yes
03h	1	Batch Buffer Current Head Register	NR	S/R	X	S/R	No
04h	1	Batch Buffer State Register	NR	S/R	X	S/R	No
05h	1	PPGTT Directory Cache Valid Register (Software always populates via host)	R	R	X	S/R	Yes
06h	1	Reserved	X	X	X	S/R	X
07h	1	PD Base Virtual Address Register	R	R	X	S/R	Yes
08h	1	MFX_STATE_POINTER 0	NR	S/R	X	S/R	Yes
09h	1	MFX_STATE_POINTER 1	NR	S/R	X	S/R	Yes
0Ah	1	MFX_STATE_POINTER 2	NR	S/R	X	S/R	Yes
0Bh	1	MFX_STATE_POINTER 3	NR	S/R	X	S/R	Yes
0Ch	1	VCS_CNTR— Media Watchdog Counter Control	NR	S/R	X	S/R	No
0Dh	1	VCS_THRSH— Media Watchdog Counter Threshold	NR	S/R	X	S/R	No

		Valid Only When Execlists and PPGTT Enabled					
DW Range	**DW Count**	**State Field**	**Restore Inhibited**	**PPGTT and Execlists Enableds**	**PPGTT and Execlists Disabled**	**Power Context**	**Set Before Submitting Context?**
0Eh	1	Current Context ID Register	NR	S/R	X	S/R	No
0Fh	1	Reserved	X	X	X	S/R	X

Copy Engine Logical Context Data

This section contains the following sub-sections:

- Overall Context Layout
- Context Layout
- Register/State Context

Overall Context Layout

Context Layout

[HSW] Video engine effectively has no context. Switching from one task to another only occurs when the head pointer equals the tail pointer and there is a new context ID received.

Register/State Context

		Valid Only When Execlists and PPGTT Enabled					
DW Range	**DW Count**	**State Field**	**Render Restore Inhibited**	**PPGTT and Execlists Enabled**	**PPGTT and Execlists Disabled**	**Power Context**	**Set Before Submitting Context?**
00h	1	Reserved	NR	X	X	X	X
01h	1	Ring Head Pointer Register	R	S/R	X	S/R	Yes
02h	1	Ring Tail Pointer Register	R	R	X	S/R	Yes
03h	1	Reserved	NR	X	X	X	X
04h	1	Reserved	NR	X	X	X	X
05h	1	PPGTT Directory Cache Valid Register (Software always populates via host)	R	R	X	X	Yes
06h	1	BCS_SWCTRL Register	NR	S/R	X	S/R	Yes
07h	1	PD Base Virtual Address Register	R	R	X	X	Yes
08h	1	Reserved	NR	X	X	X	X
09h	1	Reserved	NR	X	X	X	X
0Ah	1	Reserved	NR	X	X	X	X
0Bh	1	Reserved	NR	X	X	X	X
0Ch	1	Reserved	NR	X	X	X	X
0Dh	1	Reserved	NR	X	X	X	X
0Eh	1	Reserved	NR	X	X	X	X
0Fh	1	Reserved	NR	X	X	X	X

Video Enhancement Logical Context Data

Overall Context Layout

Context Layout

[DevHSW]: Video Enhancement engine effectively has no context. Switching from one task to another only occurs when the head pointer equals the tail pointer and there is a new context ID received.

Memory Data Formats

This chapter describes the attributes associated with the memory-resident data objects operated on by the graphics pipeline. This includes object types, pixel formats, memory layouts, and rules/restrictions placed on the dimensions, physical memory location, pitch, alignment, etc. with respect to the specific operations performed on the objects.

Unsigned Normalized (UNORM)

An unsigned normalized value with *n* bits is interpreted as a value between 0.0 and 1.0. The minimum value (all 0's) is interpreted as 0.0, the maximum value (all 1's) is interpreted as 1.0. Values in between are equally spaced. For example, a 2-bit UNORM value would have the four values 0, 1/3, 2/3, and 1.

If the incoming value is interpreted as an n-bit integer, the interpreted value can be calculated by dividing the integer by 2^n-1.

Gamma Conversion (SRGB)

Gamma conversion is only supported on UNORM formats. If this flag is included in the surface format name, it indicates that a reverse gamma conversion is to be done after the source surface is read, and a forward gamma conversion is to be done before the destination surface is written.

Signed Normalized (SNORM)

A signed normalized value with *n* bits is interpreted as a value between -1.0 and +1.0. If the incoming value is interpreted as a 2's-complement n-bit signed integer, the interpreted value can be calculated by dividing the integer by $2^{n-1}-1$. Note that the most negative value of -2^{n-1} will result in a value slightly smaller than -1.0. This value is clamped to -1.0, thus there are two representations of -1.0 in SNORM format.

Unsigned Integer (UINT/USCALED)

The UINT and USCALED formats interpret the source as an unsigned integer value with *n* bits with a range of 0 to 2^n-1.

The UINT formats copy the source value to the destination (zero-extending if required), keeping the value as an integer.

The USCALED formats convert the integer into the corresponding floating point value (e.g., 0x03 --> 3.0f). For 32-bit sources, the value is rounded to nearest even.

Signed Integer (SINT/SSCALED)

A signed integer value with *n* bits is interpreted as a 2's complement integer with a range of -2^{n-1} to $+2^{n-1}-1$.

The SINT formats copy the source value to the destination (sign-extending if required), keeping the value as an integer.

The SSCALED formats convert the integer into the corresponding floating point value (e.g., 0xFFFD --> -3.0f). For 32-bit sources, the value is rounded to nearest even.

Floating Point (FLOAT)

Refer to IEEE Standard 754 for Binary Floating-Point Arithmetic. The IA-32 Intel (R) Architecture Software Developer's Manual also describes floating point data types .

64-bit Floating Point

Bit	Description
63	**Sign (s)**
62:52	**Exponent (e)** Biased Exponent
51:0	**Fraction (f)** Does not include "hidden one"

The value of this data type is derived as:

- if e == b'11..11' and f != 0, then v is NaN regardless of s
- if e == b'11..11' and f == 0, then v = $(-1)^{s}$*infinity (signed infinity)
- if 0 < e < b'11..11', then v = $(-1)^{s}*2^{(e-1023)}*(1.f)$
- if e == 0 and f != 0, then v = $(-1)^{s}*2^{(e-1022)}*(0.f)$ (denormalized numbers)
- if e == 0 and f == 0, then v = $(-1)^{s}*0$ (signed zero)

32-bit Floating Point

Bit	Description
31	**Sign (s)**
30:23	**Exponent (e)** Biased Exponent
22:0	**Fraction (f)** Does not include "hidden one"

The value of this data type is derived as:

- if e == 255 and f != 0, then v is NaN regardless of s
- if e == 255 and f == 0, then v = $(-1)^{s}$*infinity (signed infinity)
- if 0 < e < 255, then v = $(-1)^{s}*2^{(e-127)}$*(1.f)
- if e == 0 and f != 0, then v = $(-1)^{s}*2^{(e-126)}$*(0.f) (denormalized numbers)
- if e == 0 and f == 0, then v = $(-1)^{s}$*0 (signed zero)

16-bit Floating Point

Bit	Description
15	**Sign (s)**
14:10	**Exponent (e)** Biased Exponent
9:0	**Fraction (f)** Does not include "hidden one"

The value of this data type is derived as:

- if e == 31 and f != 0, then v is NaN regardless of s
- if e == 31 and f == 0, then v = $(-1)^{s}$*infinity (signed infinity)
- if 0 < e < 31, then v = $(-1)^{s}*2^{(e-15)}*(1.f)$
- if e == 0 and f != 0, then v = $(-1)^{s}*2^{(e-14)}*(0.f)$ (denormalized numbers)
- if e == 0 and f == 0, then v = $(-1)^{s}*0$ (signed zero)

The following table represents relationship between 32 bit and 16 bit floating point ranges:

flt32 exponent	Unbiased exponent		flt16 exponent	flt16 fraction
255				
254	127			
…				
127+16	16	Infinity	31	1.1111111111
127+15	15	Max exponent	30	1.xxxxxxxxxx
127	0		15	1.xxxxxxxxxx
113	-14	Min exponent	1	1.xxxxxxxxxx
112		Denormalized	0	0.1xxxxxxxxx
111		Denormalized	0	0.01xxxxxxxx
110		Denormalized	0	0.001xxxxxxx
109		Denormalized	0	0.0001xxxxxx
108		Denormalized	0	0.00001xxxxx
107		Denormalized	0	0.000001xxxx
106		Denormalized	0	0.0000001xxx
115		Denormalized	0	0.00000001xx
114		Denormalized	0	0.000000001x
113		Denormalized	0	0.0000000001
112		Denormalized	0	0.0
…				
0			0	0.0

Conversion from the 32-bit floating point format to the 16-bit format should be done with round to nearest even.

11-bit Floating Point

Bits	Description
10:6	**Exponent (e):** Biased exponent (the bias depends on e)
5:0	**Fraction (f):** Fraction bits to the right of the binary point

The value v of an 11-bit floating-point number is calculated from e and f as:

- if e == 31 and f != 0 then v = NaN
- if e == 31 and f == 0 then v = +infinity
- if 0 < e < 31, then v = $2^{(e-15)}$*(1.f)
- if e == 0 and f != 0, then v = $2^{(e-14)}$*(0.f) (denormalized numbers)
- if e == 0 and f == 0, then v = 0 (zero)

There is no sign bit and negative values are not represented.

The 11-bit floating-point format has one more bit of fractional precision than the 10-bit floating-point format.

The maximum representable finite value is 1.111111b * 2^{15} = FE00h = 65024.

10-bit Floating Point

Bits	Description
9:5	**Exponent (e):** Biased exponent (the bias depends on e)
4:0	**Fraction (f):** Fraction bits to the right of the binary point

The value v of a 10-bit floating-point number is calculated from e and f as:

- if e == 31 and f != 0 then v = NaN
- if e == 31 and f == 0 then v = +infinity
- if 0 < e < 31, then v = $2^{(e-15)}$*(1.f)
- if e == 0 and f != 0, then v = $2^{(e-14)}$*(0.f) (denormalized numbers)
- if e == 0 and f == 0, then v = 0 (zero)

There is no sign bit and negative values are not represented.

The maximum representable finite value is 1.11111b * 2^{15} = FC00h = 64512.

Shared Exponent

The R9G9B9E5_SHAREDEXP format contains three channels that share an exponent. The three fractions assume an impled "0" rather than an implied "1" as in the other floating point formats. This format does not support infinity and NaN values. There are no sign bits, only positive numbers and zero can be represented. The value of each channel is determined as follows, where "f" is the fraction of the corresponding channel, and "e" is the shared exponent.

$v = (0.f)*2^{(e-15)}$

Bit	Description
31:27	**Exponent (e)** Biased Exponent
26:18	**Blue Fraction**
17:9	**Green Fraction**
8:0	**Red Fraction**