OpenGL® is the only cross-platform graphics API that enables developers of software for PC, workstation, and supercomputing hardware to create high-performance, visually-compelling graphics software applications, in markets such as CAD, content creation, energy, entertainment, game development, manufacturing, medical, and virtual reality.

Specifications are available at www.opengl.org/registry

- *See FunctionName* refers to functions on this reference card.
- [n.n.n] and [Table n.n] refer to sections and tables in the OpenGL 4.5 core specification.
- [n.n.n] refers to sections in the OpenGL Shading Language 4.50 specification.

Command Execution [2.3]

OpenGL Errors [2.3.1]

enum **GetError**(void);

Graphics Reset Recovery [2.3.2]

enum **GetGraphicsResetStatus**(void);
Returns: NO_ERROR, GUILTY_CONTEXT_RESET, {INNOCENT, UNKNOWN}_CONTEXT_RESET

GetIntegerv(RESET_NOTIFICATION_STRATEGY);
Returns: NO_RESET_NOTIFICATION, LOSE_CONTEXT_ON_RESET

Flush and Finish [2.3.3]

void **Flush**(void); void **Finish**(void);

Floating-Point Numbers [2.3.4]

16-Bit	1-bit sign, 5-bit exponent, 10-bit mantissa
Unsigned 11-Bit	no sign bit, 5-bit exponent, 6-bit mantissa
Unsigned 10-Bit	no sign bit, 5-bit exponent, 5-bit mantissa

Command Letters [Tables 2.1, 2.2]

Where a letter denotes a type in a function name, T within the prototype is the same type.

b -	byte (8 bits)	**ub** -	ubyte (8 bits)
s -	short (16 bits)	**us** -	ushort (16 bits)
i -	int (32 bits)	**ui** -	uint (32 bits)
i64 -	int64 (64 bits)	**ui64** -	uint64 (64 bits)
f -	float (32 bits)	**d** -	double (64 bits)

OpenGL Command Syntax [2.2]

GL commands are formed from a return type, a name, and optionally up to 4 characters (or character pairs) from the Command Letters table (to the left), as shown by the prototype:

return-type **Name**{1234}{b s i i64 f d ub us ui ui64}{v} (*[args ,] T arg1 , . . . , T argN [, args]*);

The arguments enclosed in brackets ([args ,] and [, args]) may or may not be present.

The argument type T and the number N of arguments may be indicated by the command name suffixes. *N* is 1, 2, 3, or 4 if present. If "v" is present, an array of *N* items is passed by a pointer. For brevity, the OpenGL documentation and this reference may omit the standard prefixes.

The actual names are of the forms: glFunctionName(), GL_CONSTANT, GLtype

Synchronization

Sync Objects and Fences [4.1]

void **DeleteSync**(sync *sync*);

sync **FenceSync**(enum *condition*, bitfield *flags*);
condition: SYNC_GPU_COMMANDS_COMPLETE
flags: must be 0

Waiting for Sync Objects [4.1.1]

enum **ClientWaitSync**(sync *sync*, bitfield *flags*, uint64 *timeout_ns*);
flags: SYNC_FLUSH_COMMANDS_BIT, or zero

void **WaitSync**(sync *sync*, bitfield *flags*, uint64 *timeout*);
timeout: TIMEOUT_IGNORED

Sync Object Queries [4.1.3]

void **GetSynciv**(sync *sync*, enum *pname*, sizei *bufSize*, sizei **length*, int **values*);
pname: OBJECT_TYPE, SYNC_{STATUS, CONDITION, FLAGS}

boolean **IsSync**(sync *sync*);

Asynchronous Queries [4.2, 4.2.1]

void **GenQueries**(sizei *n*, uint **ids*);

void **CreateQueries**(enum *target*, sizei *n*, uint **ids*);
target: See BeginQuery, plus TIMESTAMP

void **DeleteQueries**(sizei *n*, const uint **ids*);

void **BeginQuery**(enum *target*, uint *id*);
target: ANY_SAMPLES_PASSED[_CONSERVATIVE], PRIMITIVES_GENERATED, SAMPLES_PASSED, TIME_ELAPSED, TRANSFORM_FEEDBACK_PRIMITIVES_WRITTEN

void **BeginQueryIndexed**(enum *target*, uint *index*, uint *id*);
target: See BeginQuery

void **EndQuery**(enum *target*);

void **EndQueryIndexed**(enum *target*, uint *index*);

boolean **IsQuery**(uint *id*);

void **GetQueryiv**(enum *target*, enum *pname*, int **params*);
target: See BeginQuery, plus TIMESTAMP
pname: CURRENT_QUERY, QUERY_COUNTER_BITS

void **GetQueryIndexediv**(enum *target*, uint *index*, enum *pname*, int **params*);
target: See BeginQuery, plus TIMESTAMP
pname: CURRENT_QUERY, QUERY_COUNTER_BITS

void **GetQueryObjectiv**(uint *id*, enum *pname*, int **params*);

void **GetQueryObjectuiv**(uint *id*, enum *pname*, uint **params*);

void **GetQueryObjecti64v**(uint *id*, enum *pname*, int64 **params*);

void **GetQueryObjectui64v**(uint *id*, enum *pname*, uint64 **params*);
pname: QUERY_TARGET, QUERY_RESULT[_NO_WAIT, _AVAILABLE]

Timer Queries [4.3]

Timer queries track the amount of time needed to fully complete a set of GL commands.

void **QueryCounter**(uint *id*, TIMESTAMP);

void **GetIntegerv**(TIMESTAMP, int **data*);

void **GetInteger64v**(TIMESTAMP, int64 **data*);

Buffer Objects [6]

void **GenBuffers**(sizei *n*, uint **buffers*);

void **CreateBuffers**(sizei *n*, uint **buffers*);

void **DeleteBuffers**(sizei *n*, const uint **buffers*);

Create and Bind Buffer Objects [6.1]

void **BindBuffer**(enum *target*, uint *buffer*);
target: [Table 6.1] {ARRAY, UNIFORM}_BUFFER, {ATOMIC_COUNTER, QUERY}_BUFFER, COPY_{READ, WRITE}_BUFFER, {DISPATCH, DRAW}_INDIRECT_BUFFER, {ELEMENT_ARRAY, TEXTURE}_BUFFER, PIXEL_[UN]PACK_BUFFER, SHADER_STORAGE_BUFFER, TRANSFORM_FEEDBACK_BUFFER

void **BindBufferRange**(enum *target*, uint *index*, uint *buffer*, intptr *offset*, sizeiptr *size*);
target: ATOMIC_COUNTER_BUFFER, {SHADER_STORAGE, UNIFORM}_BUFFER, TRANSFORM_FEEDBACK_BUFFER

void **BindBufferBase**(enum *target*, uint *index*, uint *buffer*);
target: See BindBufferRange

void **BindBuffersRange**(enum *target*, uint *first*, sizei *count*, const uint **buffers*, const intptr **offsets*, const sizeiptr **size*);
target: See BindBufferRange

void **BindBuffersBase**(enum *target*, uint *first*, sizei *count*, const uint **buffers*);
target: See BindBufferRange

Create/Modify Buffer Object Data [6.2]

void **BufferStorage**(enum *target*, sizeiptr *size*, const void **data*, bitfield *flags*);
target: See BindBuffer
flags: Bitwise OR of MAP_{READ, WRITE}_BIT, {DYNAMIC, CLIENT}_STORAGE_BIT, MAP_{COHERENT, PERSISTENT}_BIT

void **NamedBufferStorage**(uint *buffer*, sizeiptr *size*, const void **data*, bitfield *flags*);
flags: See BufferStorage

void **BufferData**(enum *target*, sizeiptr *size*, const void **data*, enum *usage*);
target: See BindBuffer
usage: DYNAMIC_{DRAW, READ, COPY}, {STATIC, STREAM}_{DRAW, READ, COPY}

void **NamedBufferData**(uint *buffer*, sizeiptr *size*, const void **data*, enum *usage*);

void **BufferSubData**(enum *target*, intptr *offset*, sizeiptr *size*, const void **data*);
target: See BindBuffer

void **NamedBufferSubData**(uint *buffer*, intptr *offset*, sizeiptr *size*, const void **data*);

void **ClearBufferSubData**(enum *target*, enum *internalFormat*, intptr *offset*, sizeiptr *size*, enum *format*, enum *type*, const void **data*);
target: See BindBuffer
internalformat: See TexBuffer on pg. 3 of this card
format: RED, GREEN, BLUE, RG, RGB, RGBA, BGR, BGRA, {RED, GREEN, BLUE, RG, RGB}_INTEGER, {RGBA, BGR, BGRA}_INTEGER, STENCIL_INDEX, DEPTH_{COMPONENT, STENCIL}

void **ClearNamedBufferSubData**(uint *buffer*, enum *internalFormat*, intptr *offset*, sizeiptr *size*, enum *format*, enum *type*, const void **data*);
internalformat, format, type: See ClearBufferSubData

void **ClearBufferData**(enum *target*, enum *internalformat*, enum *format*, enum *type*, const void **data*);
target, internalformat, format: See ClearBufferSubData

void **ClearNamedBufferData**(uint *buffer*, enum *internalformat*, enum *format*, enum *type*, const void **data*);
internalformat, format, type: See ClearBufferData

Map/Unmap Buffer Data [6.3]

void ***MapBufferRange**(enum *target*, intptr *offset*, sizeiptr *length*, bitfield *access*);
target: See BindBuffer
access: The Bitwise OR of MAP_X_BIT, where *X* may be READ, WRITE, PERSISTENT, COHERENT, INVALIDATE_{BUFFER, RANGE}, FLUSH_EXPLICIT, UNSYNCHRONIZED

void ***MapNamedBufferRange**(uint *buffer*, intptr *offset*, sizeiptr *length*, bitfield *access*);
target: See BindBuffer
access: See MapBufferRange

void ***MapBuffer**(enum *target*, enum *access*);
access: See MapBufferRange

void ***MapNamedBuffer**(uint *buffer*, enum *access*);
access: See MapBufferRange

void **FlushMappedBufferRange**(intptr *offset*, sizeiptr *length*);

void **FlushMappedNamedBufferRange**(uint *buffer*, intptr *offset*, sizeiptr *length*);

boolean **UnmapBuffer**(enum *target*);
target: See BindBuffer

boolean **UnmapNamedBuffer**(uint *buffer*);

Invalidate Buffer Data [6.5]

void **InvalidateBufferSubData**(uint *buffer*, intptr *offset*, sizeiptr *length*);

void **InvalidateBufferData**(uint *buffer*);

Buffer Object Queries [6, 6.7]

boolean **IsBuffer**(uint *buffer*);

void **GetBufferSubData**(enum *target*, intptr *offset*, sizeiptr *size*, void **data*);
target: See BindBuffer

void **GetNamedBufferSubData**(uint *buffer*, intptr *offset*, sizeiptr *size*, void **data*);

void **GetBufferParameteri[64]v**(enum *target*, enum *pname*, int[64]**data*);
target: See BindBuffer
pname: [Table 6.2] BUFFER_SIZE, BUFFER_USAGE, BUFFER_{ACCESS[_FLAGS]}, BUFFER_MAPPED, BUFFER_MAP_{OFFSET, LENGTH}, BUFFER_{IMMUTABLE_STORAGE, ACCESS_FLAGS}

void **GetNamedBufferParameteri[64]v**(uint *buffer*, enum *pname*, int[64]**data*);

void **GetBufferPointerv**(enum *target*, enum *pname*, const void ***params*);
target: See BindBuffer
pname: BUFFER_MAP_POINTER

void **GetNamedBufferPointerv**(uint *buffer*, enum *pname*, const void ***params*);
pname: BUFFER_MAP_POINTER

Copy Between Buffers [6.6]

void **CopyBufferSubData**(enum *readTarget*, enum *writeTarget*, intptr *readOffset*, intptr *writeOffset*, sizeiptr *size*);
readTarget and *writeTarget*: *See BindBuffer*

void **CopyNamedBufferSubData**(uint *readBuffer*, uint *writeBuffer*, intptr *readOffset*, intptr *writeOffset*, sizeiptr *size*);

Shaders and Programs

Shader Objects [7.1-2]

uint **CreateShader**(enum *type*);
type: {COMPUTE, FRAGMENT}_SHADER, {GEOMETRY, VERTEX}_SHADER, TESS_{EVALUATION, CONTROL}_SHADER

void **ShaderSource**(uint *shader*, sizei *count*, const char * const * *string*, const int **length*);

void **CompileShader**(uint *shader*);

void **ReleaseShaderCompiler**(void);

void **DeleteShader**(uint *shader*);

boolean **IsShader**(uint *shader*);

void **ShaderBinary**(sizei *count*, const uint **shaders*, enum *binaryformat*, const void **binary*, sizei *length*);

(Continued on next page) ▶

◀ Shaders and Programs (cont.)

Program Objects [7.3]

uint **CreateProgram**(void);

void **AttachShader**(uint *program*, uint *shader*);

void **DetachShader**(uint *program*, uint *shader*);

void **LinkProgram**(uint *program*);

void **UseProgram**(uint *program*);

uint **CreateShaderProgramv**(enum *type*, sizei *count*, const char * const * *strings*);

void **ProgramParameteri**(uint *program*, enum *pname*, int *value*);
pname: PROGRAM_SEPARABLE, PROGRAM_BINARY_RETRIEVABLE_HINT
value: TRUE, FALSE

void **DeleteProgram**(uint *program*);

boolean **IsProgram**(uint *program*);

Program Interfaces [7.3.1]

void **GetProgramInterfaceiv**(uint *program*, enum *programInterface*, enum *pname*, int **params*);
programInterface: ATOMIC_COUNTER_BUFFER, BUFFER_VARIABLE, UNIFORM[_BLOCK], PROGRAM_{INPUT, OUTPUT}, SHADER_STORAGE_BLOCK, {GEOMETRY, VERTEX}_SUBROUTINE, TESS_{CONTROL, EVALUATION}_SUBROUTINE, {FRAGMENT, COMPUTE}_SUBROUTINE, TESS_CONTROL_SUBROUTINE_UNIFORM, TESS_EVALUATION_SUBROUTINE_UNIFORM, {GEOMETRY, VERTEX}_SUBROUTINE_UNIFORM, {FRAGMENT, COMPUTE}_SUBROUTINE_UNIFORM, TRANSFORM_FEEDBACK_{BUFFER, VARYING}
pname: ACTIVE_RESOURCES, MAX_NAME_LENGTH, MAX_NUM_ACTIVE_VARIABLES, MAX_NUM_COMPATIBLE_SUBROUTINES

uint **GetProgramResourceIndex**(uint *program*, enum *programInterface*, const char **name*);

void **GetProgramResourceName**(uint *program*, enum *programInterface*, uint *index*, sizei *bufSize*, sizei **length*, char **name*);

void **GetProgramResourceiv**(uint *program*, enum *programInterface*, uint *index*, sizei *propCount*, const enum **props*, sizei *bufSize*, sizei **length*, int **params*);
**props:* [See Table 7.2]

int **GetProgramResourceLocation**(uint *program*, enum *programInterface*, const char **name*);

int **GetProgramResourceLocationIndex**(uint *program*, enum *programInterface*, const char **name*);

Program Pipeline Objects [7.4]

void **GenProgramPipelines**(sizei *n*, uint **pipelines*);

void **DeleteProgramPipelines**(sizei *n*, const uint **pipelines*);

boolean **IsProgramPipeline**(uint *pipeline*);

void **BindProgramPipeline**(uint *pipeline*);

void **CreateProgramPipelines**(sizei *n*, uint **pipelines*);

void **UseProgramStages**(uint *pipeline*, bitfield *stages*, uint *program*);
stages: ALL_SHADER_BITS or the bitwise OR of TESS_{CONTROL, EVALUATION}_SHADER_BIT, {VERTEX, GEOMETRY, FRAGMENT}_SHADER_BIT, COMPUTE_SHADER_BIT

void **ActiveShaderProgram**(uint *pipeline*, uint *program*);

Program Binaries [7.5]

void **GetProgramBinary**(uint *program*, sizei *bufSize*, sizei **length*, enum **binaryFormat*, void **binary*);

void **ProgramBinary**(uint *program*, enum *binaryFormat*, const void **binary*, sizei *length*);

Uniform Variables [7.6]

int **GetUniformLocation**(uint *program*, const char **name*);

void **GetActiveUniformName**(uint *program*, uint *uniformIndex*, sizei *bufSize*, sizei **length*, char **uniformName*);

void **GetUniformIndices**(uint *program*, sizei *uniformCount*, const char * const **uniformNames*, uint **uniformIndices*);

void **GetActiveUniform**(uint *program*, uint *index*, sizei *bufSize*, sizei **length*, int **size*, enum **type*, char **name*);
**type* returns: DOUBLE_{VEC*n*, MAT*n*, MAT*mxn*}, DOUBLE, FLOAT_{VEC*n*, MAT*n*, MAT*mxn*}, FLOAT, INT, INT_VEC*n*, UNSIGNED_INT[_VEC*n*], BOOL, BOOL_VEC*n*, or any value in [Table 7.3]

void **GetActiveUniformsiv**(uint *program*, sizei *uniformCount*, const uint **uniformIndices*, enum *pname*, int **params*);
pname: [Table 7.6] UNIFORM_{NAME_LENGTH, TYPE, OFFSET}, UNIFORM_{SIZE, BLOCK_INDEX, UNIFORM}, UNIFORM_{ARRAY, MATRIX}_STRIDE, UNIFORM_IS_ROW_MAJOR, UNIFORM_ATOMIC_COUNTER_BUFFER_INDEX

uint **GetUniformBlockIndex**(uint *program*, const char **uniformBlockName*);

void **GetActiveUniformBlockName**(uint *program*, uint *uniformBlockIndex*, sizei *bufSize*, sizei *length*, char **uniformBlockName*);

void **GetActiveUniformBlockiv**(uint *program*, uint *uniformBlockIndex*, enum *pname*, int **params*);
pname: UNIFORM_BLOCK_{BINDING, DATA_SIZE}, UNIFORM_BLOCK_NAME_LENGTH, UNIFORM_BLOCK_ACTIVE_UNIFORMS[_INDICES], UNIFORM_BLOCK_REFERENCED_BY_*X*_SHADER, where *X* may be one of VERTEX, FRAGMENT, COMPUTE, GEOMETRY, TESS_CONTROL, or TESS_EVALUATION [Table 7.7]

void **GetActiveAtomicCounterBufferiv**(uint *program*, uint *bufferIndex*, enum *pname*, int **params*);
pname: ***See GetActiveUniformBlockiv, however replace the prefix UNIFORM_BLOCK_ with ATOMIC_COUNTER_BUFFER_***

Load Uniform Vars. in Default Uniform Block

void **Uniform{1234}{i f d ui}**(int *location*, T *value*);

void **Uniform{1234}{i f d ui}v**(int *location*, sizei *count*, const T **value*);

void **UniformMatrix{234}{f d}v**(int *location*, sizei *count*, boolean *transpose*, const float **value*);

void **UniformMatrix{2x3,3x2,2x4,4x2,3x4, 4x3}{fd}v**(int *location*, sizei *count*, boolean *transpose*, const float **value*);

void **ProgramUniform{1234}{i f d}**(uint *program*, int *location*, T *value*);

void **ProgramUniform{1234}{i f d}v**(uint *program*, int *location*, sizei *count*, const T **value*);

void **ProgramUniform{1234}uiv**(uint *program*, int *location*, sizei *count*, const T **value*);

void **ProgramUniform{1234}ui**(uint *program*, int *location*, T *value*);

void **ProgramUniformMatrix{234}{f d}v**(uint *program*, int *location*, sizei *count*, boolean *transpose*, const T **value*);

void **ProgramUniformMatrixf{2x3,3x2,2x4, 4x2, 3x4, 4x3}{f d}v**(uint *program*, int *location*, sizei *count*, boolean *transpose*, const T **value*);

Uniform Buffer Object Bindings

void **UniformBlockBinding**(uint *program*, uint *uniformBlockIndex*, uint *uniformBlockBinding*);

Shader Buffer Variables [7.8]

void **ShaderStorageBlockBinding**(uint *program*, uint *storageBlockIndex*, uint *storageBlockBinding*);

Subroutine Uniform Variables [7.9]

Parameter *shadertype* for the functions in this section may be {COMPUTE, VERTEX}_SHADER, TESS_{CONTROL, EVALUATION}_SHADER, or {FRAGMENT, GEOMETRY}_SHADER

int **GetSubroutineUniformLocation**(uint *program*, enum *shadertype*, const char **name*);

uint **GetSubroutineIndex**(uint *program*, enum *shadertype*, const char **name*);

void **GetActiveSubroutineName**(uint *program*, enum *shadertype*, uint *index*, sizei *bufsize*, sizei **length*, char **name*);

void **GetActiveSubroutineUniformName**(uint *program*, enum *shadertype*, uint *index*, sizei *bufsize*, sizei **length*, char **name*);

void **GetActiveSubroutineUniformiv**(uint *program*, enum *shadertype*, uint *index*, enum *pname*, int **values*);
pname: [NUM_]COMPATIBLE_SUBROUTINES

void **UniformSubroutinesuiv**(enum *shadertype*, sizei *count*, const uint **indices*);

Shader Memory Access [7.12.2]

See diagram on page 6 for more information.

void **MemoryBarrier**(bitfield *barriers*);
barriers: ALL_BARRIER_BITS or the OR of *X*_BARRIER_BIT where *X* may be: QUERY_BUFFER, VERTEX_ATTRIB_ARRAY, ELEMENT_ARRAY, UNIFORM, TEXTURE_FETCH, BUFFER_UPDATE, SHADER_IMAGE_ACCESS, COMMAND, PIXEL_BUFFER, TEXTURE_UPDATE, FRAMEBUFFER, TRANSFORM_FEEDBACK, ATOMIC_COUNTER, SHADER_STORAGE, CLIENT_MAPPED_BUFFER,

void **MemoryBarrierByRegion**(bitfield *barriers*);
barriers: ALL_BARRIER_BITS or the OR of *X*_BARRIER_BIT where *X* may be: ATOMIC_COUNTER, FRAMEBUFFER, SHADER_IMAGE_ACCESS, SHADER_STORAGE, TEXTURE_FETCH, UNIFORM

Shader and Program Queries [7.13]

void **GetShaderiv**(uint *shader*, enum *pname*, int **params*);
pname: SHADER_TYPE, INFO_LOG_LENGTH, {DELETE, COMPILE}_STATUS, COMPUTE_SHADER, SHADER_SOURCE_LENGTH

void **GetProgramiv**(uint *program*, enum *pname*, int **params*);
pname: ACTIVE_ATOMIC_COUNTER_BUFFERS, ACTIVE_ATTRIBUTES, ACTIVE_ATTRIBUTE_MAX_LENGTH, ACTIVE_UNIFORMS, ACTIVE_UNIFORM_BLOCKS, ACTIVE_UNIFORM_BLOCK_MAX_NAME_LENGTH, ACTIVE_UNIFORM_MAX_LENGTH, ATTACHED_SHADERS, VALIDATE_STATUS, COMPUTE_WORK_GROUP_SIZE, DELETE_STATUS, GEOMETRY_{INPUT, OUTPUT}_TYPE, GEOMETRY_SHADER_INVOCATIONS, GEOMETRY_VERTICES_OUT, INFO_LOG_LENGTH, LINK_STATUS, PROGRAM_SEPARABLE, PROGRAM_BINARY_RETRIEVABLE_HINT, TESS_CONTROL_OUTPUT_VERTICES, TESS_GEN_{MODE, SPACING}, TESS_GEN_{VERTEX_ORDER, POINT_MODE}, TRANSFORM_FEEDBACK_BUFFER_MODE, TRANSFORM_FEEDBACK_VARYINGS, TRANSFORM_FEEDBACK_VARYING_MAX_LENGTH

void **GetProgramPipelineiv**(uint *pipeline*, enum *pname*, int **params*);
pname: ACTIVE_PROGRAM, VALIDATE_STATUS, {VERTEX, FRAGMENT, GEOMETRY}_SHADER, TESS_{CONTROL, EVALUATION}_SHADER, INFO_LOG_LENGTH, COMPUTE_SHADER

void **GetAttachedShaders**(uint *program*, sizei *maxCount*, sizei **count*, uint **shaders*);

void **GetShaderInfoLog**(uint *shader*, sizei *bufSize*, sizei **length*, char **infoLog*);

void **GetProgramInfoLog**(uint *program*, sizei *bufSize*, sizei **length*, char **infoLog*);

void **GetProgramPipelineInfoLog**(uint *pipeline*, sizei *bufSize*, sizei **length*, char **infoLog*);

void **GetShaderSource**(uint *shader*, sizei *bufSize*, sizei **length*, char **source*);

void **GetShaderPrecisionFormat**(enum *shadertype*, enum *precisiontype*, int **range*, int **precision*);
shadertype: {VERTEX, FRAGMENT}_SHADER
precisiontype: {LOW, MEDIUM, HIGH}_{FLOAT, INT}

void **GetUniform{f d i ui}v**(uint *program*, int *location*, T **params*);

void **GetnUniform{f d i ui}v**(uint *program*, int *location*, sizei *bufSize*, T **params*);

void **GetUniformSubroutineuiv**(enum *shadertype*, int *location*, uint **params*);

void **GetProgramStageiv**(uint program, enum *shadertype*, enum *pname*, int **values*);
pname: ACTIVE_SUBROUTINES, ACTIVE_SUBROUTINE_*X* where *X* may be UNIFORMS, MAX_LENGTH, UNIFORM_LOCATIONS, UNIFORM_MAX_LENGTH

Textures and Samplers [8]

void **ActiveTexture**(enum *texture*);
texture: TEXTURE*i* (where *i* is [0, max(MAX_TEXTURE_COORDS, MAX_COMBINED_TEXTURE_IMAGE_UNITS)-1])

Texture Objects [8.1]

void **GenTextures**(sizei *n*, uint **textures*);

void **BindTexture**(enum *target*, uint *texture*);
target: TEXTURE_{1D, 2D}[_ARRAY], TEXTURE_{3D, RECTANGLE, BUFFER}, TEXTURE_CUBE_MAP[_ARRAY], TEXTURE_2D_MULTISAMPLE[_ARRAY]

void **BindTextures**(uint *first*, sizei *count*, const uint **textures*);
target: ***See BindTexture***

void **BindTextureUnit**(uint *unit*, uint *texture*);

void **CreateTextures**(enum *target*, sizei *n*, uint **textures*);
target: ***See BindTexture***

void **DeleteTextures**(sizei *n*, const uint **textures*);

boolean **IsTexture**(uint *texture*);

Sampler Objects [8.2]

void **GenSamplers**(sizei *count*, uint **samplers*);

void **CreateSamplers**(sizei *n*, uint **samplers*);

void **BindSampler**(uint *unit*, uint *sampler*);

void **BindSamplers**(uint *first*, sizei *count*, const uint **samplers*);

void **SamplerParameter{i f}**(uint *sampler*, enum *pname*, T *param*);
pname: TEXTURE_*X* where *X* may be WRAP_{S, T, R}, {MIN, MAG}_FILTER, {MIN, MAX}_LOD, BORDER_COLOR, LOD_BIAS, COMPARE_{MODE, FUNC} [Table 23.18]

void **SamplerParameter{i f}v**(uint *sampler*, enum *pname*, const T **param*);
pname: ***See SamplerParameter{if}***

void **SamplerParameterI{i ui}v**(uint *sampler*, enum *pname*, const T **params*);
pname: ***See SamplerParameter{if}***

void **DeleteSamplers**(sizei *count*, const uint **samplers*);

boolean **IsSampler**(uint *sampler*);

Sampler Queries [8.3]

void **GetSamplerParameter{i f}v**(uint *sampler*, enum *pname*, T **params*);
pname: ***See SamplerParameter{if}***

void **GetSamplerParameterI{i ui}v**(uint *sampler*, enum *pname*, T **params*);
pname: ***See SamplerParameter{if}***

Pixel Storage Modes [8.4.1]

void **PixelStore{i f}**(enum *pname*, T *param*);
pname: [Tables 8.1, 18.1] [UN]PACK_*X* where *X* may be SWAP_BYTES, LSB_FIRST, ROW_LENGTH, SKIP_{IMAGES, PIXELS, ROWS}, ALIGNMENT, IMAGE_HEIGHT, COMPRESSED_BLOCK_WIDTH, COMPRESSED_BLOCK_{HEIGHT, DEPTH, SIZE}

(Continued on next page) ▶

Textures and Samplers (cont.)

Texture Image Spec. [8.5]

void **TexImage3D**(enum *target*, int *level*, int *internalformat*, sizei *width*, sizei *height*, sizei *depth*, int *border*, enum *format*, enum *type*, const void **data*);

target: [PROXY_]TEXTURE_CUBE_MAP_ARRAY, [PROXY_]TEXTURE_2D_ARRAY, [PROXY_]TEXTURE_3D

internalformat: STENCIL_INDEX, RED, DEPTH_{COMPONENT, STENCIL}, RG, RGB, RGBA, COMPRESSED_{RED, RG, RGB, RGBA, SRGB, SRGB_ALPHA), a sized internal format from [Tables 8.12 - 8.13], or a COMPRESSED_ format from [Table 8.14]

format: DEPTH_{COMPONENT, STENCIL}, RED, GREEN, BLUE, RG, RGB, RGBA, BGR, BGRA, {BGRA, RED, GREEN, BLUE}_INTEGER, {RG, RGB, RGBA, BGR}_INTEGER, STENCIL_INDEX, [Table 8.3]

type: [UNSIGNED_]{BYTE, SHORT, INT}, [HALF_]FLOAT, or a value from [Table 8.2]

void **TexImage2D**(enum *target*, int *level*, int *internalformat*, sizei *width*, sizei *height*, int *border*, enum *format*, enum *type*, const void **data*);

target: [PROXY_]TEXTURE_{2D, RECTANGLE}, [PROXY_]TEXTURE_{1D_ARRAY, CUBE_MAP}, TEXTURE_CUBE_MAP_POSITIVE_{X, Y, Z}, TEXTURE_CUBE_MAP_NEGATIVE_{X, Y, Z}

internalformat, format, type: **See TexImage3D**

void **TexImage1D**(enum *target*, int *level*, int *internalformat*, sizei *width*, int *border*, enum *format*, enum *type*, const void **data*);

target: TEXTURE_1D, PROXY_TEXTURE_1D

type, internalformat, format: **See TexImage3D**

Alternate Texture Image Spec. [8.6]

void **CopyTexImage2D**(enum *target*, int *level*, enum *internalformat*, int *x*, int *y*, sizei *width*, sizei *height*, int *border*);

target: TEXTURE_{2D, RECTANGLE, 1D_ARRAY}, TEXTURE_CUBE_MAP_{POSITIVE, NEGATIVE}_{X, Y, Z}

internalformat: **See TexImage3D**

void **CopyTexImage1D**(enum *target*, int *level*, enum *internalformat*, int *x*, int *y*, sizei *width*, int *border*);

target: TEXTURE_1D

internalformat: **See TexImage3D**

void **TexSubImage3D**(enum *target*, int *level*, int *xoffset*, int *yoffset*, int *zoffset*, sizei *width*, sizei *height*, sizei *depth*, enum *format*, enum *type*, const void **data*);

target: TEXTURE_3D, TEXTURE_2D_ARRAY, TEXTURE_CUBE_MAP_ARRAY

format, type: **See TexImage3D**

void **TexSubImage2D**(enum *target*, int *level*, int *xoffset*, int *yoffset*, sizei *width*, sizei *height*, enum *format*, enum *type*, const void **data*);

target: **See CopyTexImage2D**

format, type: **See TexImage3D**

void **TexSubImage1D**(enum *target*, int *level*, int *xoffset*, sizei *width*, enum *format*, enum *type*, const void **data*);

target, format, type: **See CopyTexImage1D**

void **CopyTexSubImage3D**(enum *target*, int *level*, int *xoffset*, int *yoffset*, int *zoffset*, int *x*, int *y*, sizei *width*, sizei *height*);

target: **See TexSubImage3D**

void **CopyTexSubImage2D**(enum *target*, int *level*, int *xoffset*, int *yoffset*, int *x*, int *y*, sizei *width*, sizei *height*);

target: **See TexImage2D**

void **CopyTexSubImage1D**(enum *target*, int *level*, int *xoffset*, int *x*, int *y*, sizei *width*);

target: **See TexSubImage1D**

void **TextureSubImage3D**(uint *texture*, int *level*, int *xoffset*, int *yoffset*, int *zoffset*, sizei *width*, sizei *height*, sizei *depth*, enum *format*, enum *type*, const void **pixels*);

format, type: **See TexImage3D**

void **TextureSubImage2D**(uint *texture*, int *level*, int *xoffset*, int *yoffset*, sizei *width*, sizei *height*, enum *format*, enum *type*, const void **pixels*);

format, type: **See TexImage3D**

void **TextureSubImage1D**(uint *texture*, int *level*, int *xoffset*, sizei *width*, enum *format*, enum *type*, const void **pixels*);

format, type: **See TexImage3D**

void **CopyTextureSubImage3D**(uint *texture*, int *level*, int *xoffset*, int *yoffset*, int *zoffset*, int *x*, int *y*, sizei *width*, sizei *height*);

void **CopyTextureSubImage2D**(uint *texture*, int *level*, int *xoffset*, int *yoffset*, int *x*, int *y*, sizei *width*, sizei *height*);

void **CopyTextureSubImage1D**(uint *texture*, int *level*, int *xoffset*, int *x*, int *y*, sizei *width*);

Compressed Texture Images [8.7]

void **CompressedTexImage3D**(enum *target*, int *level*, enum *internalformat*, sizei *width*, sizei *height*, sizei *depth*, int *border*, sizei *imageSize*, const void **data*);

target: **See TexImage3D**

internalformat: A COMPRESSED_ format from [Table 8.14]

void **CompressedTexImage2D**(enum *target*, int *level*, enum *internalformat*, sizei *width*, sizei *height*, int *border*, sizei *imageSize*, const void **data*);

target: **See TexImage2D**

internalformat: May be one of the COMPRESSED_ formats from [Table 8.14]

void **CompressedTexImage1D**(enum *target*, int *level*, enum *internalformat*, sizei *width*, int *border*, sizei *imageSize*, const void **data*);

target: TEXTURE_1D, PROXY_TEXTURE_1D

internalformat: **See TexImage1D**, omitting compressed rectangular texture formats

void **CompressedTexSubImage3D**(enum *target*, int *level*, int *xoffset*, int *yoffset*, int *zoffset*, sizei *width*, sizei *height*, sizei *depth*, enum *format*, sizei *imageSize*, const void **data*);

target: **See TexSubImage3D**

format: **See internalformat for CompressedTexImage3D**

void **CompressedTexSubImage2D**(enum *target*, int *level*, int *xoffset*, int *yoffset*, sizei *width*, sizei *height*, enum *format*, sizei *imageSize*, cont void **data*);

target: **See TexSubImage2D**

format: **See internalformat for CompressedTexImage2D**

void **CompressedTexSubImage1D**(enum *target*, int *level*, int *xoffset*, sizei *width*, enum *format*, sizei *imageSize*, const void **data*);

target: **See TexSubImage1D**

format: **See internalformat for CompressedTexImage1D**

void **CompressedTextureSubImage3D**(uint *texture*, int *level*, int *xoffset*, int *yoffset*, int *zoffset*, sizei *width*, sizei *height*, sizei *depth*, enum *format*, sizei *imageSize*, const void **data*);

format: **See internalformat for CompressedTexImage3D**

void **CompressedTextureSubImage2D**(uint *texture*, int *level*, int *xoffset*, int *yoffset*, sizei *width*, sizei *height*, enum *format*, sizei *imageSize*, cont void **data*);

format: **See internalformat for CompressedTexImage2D**

void **CompressedTextureSubImage1D**(uint *texture*, int *level*, int *xoffset*, sizei *width*, enum *format*, sizei *imageSize*, const void **data*);

format: **See internalformat for CompressedTexImage1D**

Multisample Textures [8.8]

void **TexImage3DMultisample**(enum *target*, sizei *samples*, int *internalformat*, sizei *width*, sizei *height*, sizei *depth*, boolean *fixedsamplelocations*);

target: [PROXY_]TEXTURE_2D_MULTISAMPLE_ARRAY

internalformat: RED, RG, RGB, RGBA, RGBA{32, 32UI}, DEPTH_COMPONENT[16, 24, 32, 32F], DEPTH{24, 32F}_STENCIL8, STENCIL_INDEX{1, 4, 8, 16}

void **TexImage2DMultisample**(enum *target*, sizei *samples*, int *internalformat*, sizei *width*, sizei *height*, boolean *fixedsamplelocations*);

target: [PROXY_]TEXTURE_2D_MULTISAMPLE

internalformat: **See TexImage3DMultisample**

Buffer Textures [8.9]

void **TexBufferRange**(enum *target*, enum *internalFormat*, uint *buffer*, intptr *offset*, sizeiptr *size*);

void **TextureBufferRange**(uint *texture*, enum *internalFormat*, uint *buffer*, intptr *offset*, sizeiptr *size*);

internalformat: **See TexBuffer**

void **TexBuffer**(enum *target*, enum *internalformat*, uint *buffer*);

target: TEXTURE_BUFFER

internalformat: [Table 8.16] R8, R8{I, UI}, R16, R16{F, I, UI}, R32{F, I, UI}, RG8, RG8{I, UI}, RG16, RG16{F, I, UI}, RG32{F, I, UI}, RGB32F, RGB32{I, UI}, RGBA8, RGBA8{I, UI}, RGBA16, RGBA16{F, I, UI}, RGBA32{F, I, UI}

void **TextureBuffer**(uint *texture*, enum *internalformat*, uint *buffer*);

internalformat: **See TexBuffer**

Texture Parameters [8.10]

void **TexParameter{i f}**(enum *target*, enum *pname*, T *param*);

target: **See BindTexture**

void **TexParameter{i f}v**(enum *target*, enum *pname*, const T **params*);

target: **See BindTexture**

void **TexParameterI{i ui}v**(enum *target*, enum *pname*, const T **params*);

target: **See BindTexture**

pname: DEPTH_STENCIL_TEXTURE_MODE or TEXTURE_*X* where *X* may be one of WRAP_{S, T, R}, BORDER_COLOR, {MIN, MAG}_FILTER, LOD_BIAS,{MIN, MAX}_LOD, {BASE, MAX}_LEVEL, SWIZZLE_{R, G, B, A, RGBA}, COMPARE_{MODE, FUNC} [Table 8.17]

void **TextureParameter{i f}**(uint *texture*, enum *pname*, T *param*);

pname: **See BindTexture**

void **TextureParameter{i f}v**(uint *texture*, enum *pname*, const T **params*);

pname: **See BindTexture**

void **TextureParameterI{i ui}v**(uint *texture*, enum *pname*, const T **params*);

pname: TEXTURE_3D, TEXTURE_{1D, 2D}[_ARRAY], TEXTURE_CUBE_MAP[_ARRAY], TEXTURE_RECTANGLE, TEXTURE_2D_MULTISAMPLE[_ARRAY]

Texture Queries [8.11]

void **GetTexParameter{if}v**(enum *target*, enum *pname*, T ** params*);

target: **See BindTexture**

pname: **See GetTexParameterI{i ui}v**

void **GetTexParameterI{i ui}v**(enum *target*, enum *pname*, T ** params*);

target: **See BindTexture**

pname: IMAGE_FORMAT_COMPATIBILITY_TYPE, TEXTURE_IMMUTABLE_{FORMAT, LEVELS}, TEXTURE_VIEW_MIN_{LEVEL, LAYER}, TEXTURE_VIEW_NUM_{LEVELS, LAYERS}, DEPTH_STENCIL_TEXTURE_MODE, or TEXTURE_*X* where *X* may be one of WRAP_{S, T, R}, BORDER_COLOR, TARGET, {MIN, MAG}_FILTER, LOD_BIAS,{MIN, MAX}_LOD, {BASE, MAX}_LEVEL, SWIZZLE_{R, G, B, A, RGBA}, COMPARE_{MODE, FUNC} [Table 8.17]

void **GetTextureParameter{if}v**(uint *texture*, enum *pname*, T **data*);

pname: **See GetTexParameterI{i ui}v**

void **GetTextureParameterI{i ui}v**(uint *texture*, enum *pname*, T **data*);

pname: **See GetTexParameterI{i ui}v**

void **GetTexLevelParameter{i f}v**(enum *target*, int *level*, enum *pname*, T **params*);

target: [PROXY_]TEXTURE_{1D, 2D, 3D}, TEXTURE_BUFFER, PROXY_TEXTURE_CUBE_MAP, [PROXY_]TEXTURE_{1D, 2D,CUBE_MAP}_ARRAY, [PROXY_]TEXTURE_RECTANGLE, TEXTURE_CUBE_MAP_NEGATIVE_{X, Y, Z}, TEXTURE_CUBE_MAP_POSITIVE_{X, Y, Z}, [PROXY_]TEXTURE_2D_MULTISAMPLE[_ARRAY]

pname: TEXTURE_*, where * may be WIDTH, HEIGHT, DEPTH, FIXED_SAMPLE_LOCATIONS, INTERNAL_FORMAT, SHARED_SIZE, COMPRESSED, COMPRESSED_IMAGE_SIZE, SAMPLES, BUFFER_{OFFSET, SIZE}, or *X*_{SIZE, TYPE} where *X* can be RED, GREEN, BLUE, ALPHA, DEPTH

void **GetTextureLevelParameter{i f}v**(uint *texture*, int *level*, enum *pname*, T **params*);

pname: **See GetTexLevelParameter{i f}v**

void **GetTexImage**(enum *target*, int *level*, enum *format*, enum *type*, void **pixels*);

target: TEXTURE_{1, 2}D[_ARRAY], TEXTURE_{3D, RECTANGLE, CUBE_MAP_ARRAY}, TEXTURE_CUBE_MAP_NEGATIVE_{X, Y, Z}, TEXTURE_CUBE_MAP_POSITIVE_{X, Y, Z}

format: **See TexImage3D**

type: [UNSIGNED_]BYTE, SHORT, INT, [HALF_]FLOAT, or a value from [Table 8.2]

void **GetTextureImage**(uint *texture*, int *level*, enum *format*, enum *type*, sizei *bufSize*, void **pixels*);

level: LOD level

format, type: **See GetTexImage**

void **GetnTexImage**(enum *tex*, int *level*, enum *format*, enum *type*, sizei *bufSize*, void **pixels*);

tex: TEXTURE_{1D, 2D, 3D}[_ARRAY], TEXTURE_3D, TEXTURE_{CUBE_MAP_ARRAY, RECTANGLE}, TEXTURE_CUBE_MAP_POSITIVE_{X, Y, Z}, TEXTURE_CUBE_MAP_NEGATIVE_{X, Y, Z}

level, format, type: **See GetTextureImage**

void **GetTextureSubImage**(uint *texture*, int *level*, int *xoffset*, int *yoffset*, int *zoffset*, sizei *width*, sizei *height*, sizei *depth*, enum *format*, enum *type*, sizei *bufSize*, void **pixels*);

level, format, type: **See GetTextureImage**

void **GetCompressedTexImage**(enum *target*, int *level*, void **pixels*);

target: **See GetTextureImage**

void **GetCompressedTextureImage**(uint *texture*, int *level*, sizei *bufSize*, void **pixels*);

level: **See GetTextureImage**

void **GetnCompressedTexImage**(enum *target*, int *level*, sizei *bufsize*, void **pixels*);

target: **See GetCompressedTexImage**

level: LOD level

void **GetCompressedTextureSubImage**(uint *texture*, int *level*, int *xoffset*, int *yoffset*, int *zoffset*, sizei *width*, sizei *height*, sizei *depth*, sizei *bufSize*, void **pixels*);

level: LOD level

Cube Map Texture Select [8.13.1]

Enable/Disable/IsEnabled(TEXTURE_CUBE_MAP_SEAMLESS);

Manual Mipmap Generation [8.14.4]

void **GenerateMipmap**(enum *target*);

target: TEXTURE_{1D, 2D, 3D}, TEXTURE_{1D, 2D}_ARRAY, TEXTURE_CUBE_MAP[_ARRAY]

void **GenerateTextureMipmap**(uint *texture*);

Texture Views [8.18]

void **TextureView**(uint *texture*, enum *target*, uint *origtexture*, enum *internalformat*, uint *minlevel*, uint *numlevels*, uint *minlayer*, uint *numlayers*);

target: TEXTURE_{1D, 2D,CUBE_MAP}[_ARRAY], TEXTURE_3D, TEXTURE_RECTANGLE, TEXTURE_2D_MULTISAMPLE[_ARRAY]

internalformat: R8, R8{UI, I}, R8_SNORM, R11F_G11F_B10F, R16{F, UI, I}, R16[_SNORM], R32{F, UI, I}, SRGB8[UI, I], RG8{F, UI, I}, RG8[_SNORM], RG16{F, UI, I}, RG16[_SNORM], RG32{F, UI, I}, RGB8[_SNORM], RGB9_E5, RGB10_A2[UI], RGBA8{UI, I}, RGBA8[_SNORM], RGB16{F, UI, I}, RGB16[_SNORM], RGB32{F, UI, I}, RGBA16{F, UI, I}, RGBA16[_SNORM], RGBA32{F, UI, I}, SRGB8_ALPHA8; COMPRESSED_*X* where *X* may be [SIGNED]_RED_RGTC1, [SIGNED]_RG_RGTC2, {RGBA, SRGB_ALPHA}_BPTC_UNORM, RGB_BPTC_[UN]SIGNED_FLOAT

Immutable-Format Tex. Images [8.19]

void **TexStorage1D**(enum *target*, sizei *levels*, enum *internalformat*, sizei *width*);

target: TEXTURE_1D

internalformat: any of the sized internal color, depth, and stencil formats in [Tables 8.18-20]

(Continued on next page) ▶

Textures and Samplers (cont.)

void **TexStorage2D**(enum *target*, sizei *levels*, enum *internalformat*, sizei *width*, sizei *height*);
target: TEXTURE_{RECTANGLE, CUBE_MAP}, TEXTURE_{1D_ARRAY, 2D}
internalformat: *See TexStorage1D*

void **TexStorage3D**(enum *target*, sizei *levels*, enum *internalformat*, sizei *width*, sizei *height*, sizei *depth*);
target: TEXTURE_3D, TEXTURE_{CUBE_MAP, 2D}[_ARRAY]
internalformat: *See TexStorage1D*

void **TextureStorage1D**(uint *texture*, sizei *levels*, enum *internalformat*, sizei *width*);
internalformat: *See TexStorage1D*

void **TextureStorage2D**(uint *texture*, sizei *levels*, enum *internalformat*, sizei *width*, sizei *height*);
internalformat: *See TexStorage1D*

void **TextureStorage3D**(uint *texture*, sizei *levels*, enum *internalformat*, sizei *width*, sizei *height*, sizei *depth*);
internalformat: *See TexStorage1D*

void **TexStorage2DMultisample**(enum *target*, sizei *samples*, enum *internalformat*, sizei *width*, sizei *height*, boolean *fixedsamplelocations*);
target: TEXTURE_2D_MULTISAMPLE

void **TexStorage3DMultisample**(enum *target*, sizei *samples*, enum *internalformat*, sizei *width*, sizei *height*, sizei *depth*, boolean *fixedsamplelocations*);
target: TEXTURE_2D_MULTISAMPLE_ARRAY

void **TextureStorage2DMultisample**(uint *texture*, sizei *samples*, enum *internalformat*, sizei *width*, sizei *height*, boolean *fixedsamplelocations*);

void **TextureStorage3DMultisample**(uint *texture*, sizei *samples*, enum *internalformat*, sizei *width*, sizei *height*, sizei *depth*, boolean *fixedsamplelocations*);

Invalidate Texture Image Data [8.20]

void **InvalidateTexSubImage**(uint *texture*, int *level*, int *xoffset*, int *yoffset*, int *zoffset*, sizei *width*, sizei *height*, sizei *depth*);

void **InvalidateTexImage**(uint *texture*, int *level*);

Clear Texture Image Data [8.21]

void **ClearTexSubImage**(uint *texture*, int *level*, int *xoffset*, int *yoffset*, int *zoffset*, sizei *width*, sizei *height*, sizei *depth*, enum *format*, enum *type*, const void **data*);
format, type: *See TexImage3D, pg 2 this card*

void **ClearTexImage**(uint *texture*, int *level*, enum *format*, enum *type*, const void **data*);
format, type: *See TexImage3D, pg 2 this card*

Texture Image Loads/Stores [8.26]

void **BindImageTexture**(uint *index*, uint *texture*, int *level*, boolean *layered*, int *layer*, enum *access*, enum *format*);
access: READ_ONLY, WRITE_ONLY, READ_WRITE
format: RGBA{32,16}F, RG{32,16}F, R11F_G11F_B10F, R{32,16}F, RGBA{32,16,8}UI, RGB10_A2UI, RG{32,16,8}UI, R{32,16,8}UI, RGBA{32,16,8}I, RG{32,16,8}I, R{32,16,8}I, RGBA{16,8}, RGB10_A2, RG{16,8}, R{16,8}, RGBA{16,8}_SNORM, RG{16,8}_SNORM, R{16,8}_SNORM [Table 8.26]

void **BindImageTextures**(uint *first*, sizei *count*, const uint **textures*);

Framebuffer Objects

Binding and Managing [9.2]

void **BindFramebuffer**(enum *target*, uint *framebuffer*);
target: [DRAW_, READ_]FRAMEBUFFER

void **CreateFramebuffers**(sizei *n*, uint **framebuffers*);

void **GenFramebuffers**(sizei *n*, uint **framebuffers*);

void **DeleteFramebuffers**(sizei *n*, const uint **framebuffers*);

boolean **IsFramebuffer**(uint *framebuffer*);

Framebuffer Object Parameters [9.2.1]

void **FramebufferParameteri**(enum *target*, enum *pname*, int *param*);
target: [DRAW_, READ_]FRAMEBUFFER
pname: FRAMEBUFFER_DEFAULT_*X* where *X* may be WIDTH, HEIGHT, FIXED_SAMPLE_LOCATIONS, SAMPLES, LAYERS

void **NamedFramebufferParameteri**(uint *framebuffer*, enum *pname*, int *param*);
pname: *See FramebufferParameteri*

Framebuffer Object Queries [9.2.3]

void **GetFramebufferParameteriv**(enum *target*, enum *pname*, int **params*);
target: *See FramebufferParameteri*
pname: *See FramebufferParameteri* plus DOUBLEBUFFER, SAMPLES, SAMPLE_BUFFERS, IMPLEMENTATION_COLOR_READ_FORMAT, IMPLEMENTATION_COLOR_READ_TYPE, STEREO

void **GetNamedFramebufferParameteriv**(uint *framebuffer*, enum *pname*, int **params*);
pname: *See GetFramebufferParameteri*

void **GetFramebufferAttachmentParameteriv**(enum *target*, enum *attachment*, enum *pname*, int **params*);
target: [DRAW_, READ_]FRAMEBUFFER
attachment: DEPTH, FRONT_{LEFT, RIGHT}, STENCIL, BACK_{LEFT, RIGHT}, COLOR_ATTACHMENT*i*, {DEPTH, STENCIL, DEPTH_STENCIL}_ATTACHMENT
pname: FRAMEBUFFER_ATTACHMENT_ *X* where *X* may be OBJECT_{TYPE, NAME}, COMPONENT_TYPE, {RED, GREEN, BLUE, ALPHA, DEPTH, STENCIL}_SIZE, COLOR_ENCODING, TEXTURE_{LAYER, LEVEL}, LAYERED, TEXTURE_CUBE_MAP_FACE

void **GetNamedFramebufferAttachment-Parameteriv**(uint *framebuffer*, enum *attachment*, enum *pname*, int **params*);
attachment, pname: *See GetFramebufferParameteriv*

Renderbuffer Objects [9.2.4]

void **BindRenderbuffer**(enum *target*, uint *renderbuffer*);
target: RENDERBUFFER

void **{Create, Gen}Renderbuffers**(sizei *n*, uint **renderbuffers*);

void **DeleteRenderbuffers**(sizei *n*, const uint **renderbuffers*);

boolean **IsRenderbuffer**(uint *renderbuffer*);

void **RenderbufferStorageMultisample**(enum *target*, sizei *samples*, enum *internalformat*, sizei *width*, sizei *height*);
target: RENDERBUFFER
internalformat: *See TexImage3DMultisample*

void **NamedRenderbufferStorageMultisample**(uint *renderbuffer*, sizei *samples*, enum *internalformat*, sizei *width*, sizei *height*);
internalformat: *See TexImage3DMultisample*

void **RenderbufferStorage**(enum *target*, enum *internalformat*, sizei *width*, sizei *height*);
target: RENDERBUFFER
internalformat: *See TexImage3DMultisample*

void **NamedRenderbufferStorage**(uint *renderbuffer*, enum *internalformat*, sizei *width*, sizei *height*);
internalformat: *See TexImage3DMultisample*

Renderbuffer Object Queries [9.2.6]

void **GetRenderbufferParameteriv**(enum *target*, enum *pname*, int **params*);
target: RENDERBUFFER
pname: [Table 23.27] RENDERBUFFER_*X* where *X* may be WIDTH, HEIGHT, INTERNAL_FORMAT, SAMPLES, {RED, GREEN, BLUE, ALPHA, DEPTH, STENCIL}_SIZE

void **GetNamedRenderbufferParameteriv**(uint *renderbuffer*, enum *pname*, int **params*);
pname: *See GetRenderbufferParameteriv*

Attaching Renderbuffer Images [9.2.7]

void **FramebufferRenderbuffer**(enum *target*, enum *attachment*, enum *renderbuffertarget*, uint *renderbuffer*);
target: [DRAW_, READ_]FRAMEBUFFER
attachment: [Table 9.1] {DEPTH, STENCIL, DEPTH_STENCIL}_ATTACHMENT, COLOR_ATTACHMENT*i* where *i* is [0, MAX_COLOR_ATTACHMENTS - 1]
renderbuffertarget: RENDERBUFFER if renderbuffer is non-zero, else undefined

void **NamedFramebufferRenderbuffer**(uint *framebuffer*, enum *attachment*, enum *renderbuffertarget*, uint *renderbuffer*);
attachment, renderbuffertarget: *See FramebufferRenderbuffer*

Attaching Texture Images [9.2.8]

void **FramebufferTexture**(enum *target*, enum *attachment*, uint *texture*, int *level*);
target: [DRAW_, READ_]FRAMEBUFFER
attachment: *See FramebufferRenderbuffer*

void **NamedFramebufferTexture**(uint *framebuffer*, enum *attachment*, uint *texture*, int *level*);
attachment: *See FramebufferRenderbuffer*

void **FramebufferTexture1D**(enum *target*, enum *attachment*, enum *textarget*, uint *texture*, int *level*);
textarget: TEXTURE_1D
target, attachment: *See FramebufferRenderbuffer*

void **FramebufferTexture2D**(enum *target*, enum *attachment*, enum *textarget*, uint *texture*, int *level*);
textarget: TEXTURE_CUBE_MAP_POSITIVE_{X, Y, Z}, TEXTURE_CUBE_MAP_NEGATIVE_{X, Y, Z}, TEXTURE_{2D, RECTANGLE, 2D_MULTISAMPLE} (unspecified if *texture* is 0)
target, attachment: *See FramebufferRenderbuffer*

void **FramebufferTexture3D**(enum *target*, enum *attachment*, enum *textarget*, uint *texture*, int *level*, int *layer*);
textarget: TEXTURE_3D (unspecified if *texture* is 0)
target, attachment: *See FramebufferRenderbuffer*

void **FramebufferTextureLayer**(enum *target*, enum *attachment*, uint *texture*, int *level*, int *layer*);
target, attachment: *See FramebufferRenderbuffer*

void **NamedFramebufferTextureLayer**(uint *framebuffer*, enum *attachment*, uint *texture*, int *level*, int *layer*);
attachment: *See FramebufferRenderbuffer*

Feedback Loops [9.3.1]

void **TextureBarrier**(void);

Framebuffer Completeness [9.4.2]

enum **CheckFramebufferStatus**(enum *target*);
target: [DRAW_, READ_]FRAMEBUFFER
returns: FRAMEBUFFER_COMPLETE or a constant indicating the violating value

enum **CheckNamedFramebufferStatus**(uint *framebuffer*, enum *target*);
target: *See CheckFramebufferStatus*

Vertices

Separate Patches [10.1.15]

void **PatchParameteri**(enum *pname*, int *value*);
pname: PATCH_VERTICES

Current Vertex Attribute Values [10.2]

Use the commands **VertexAttrib***for attributes of type float, **VertexAttribI*** for int or uint, or **VertexAttribL*** for double.

void **VertexAttrib{1234}{s f d}**(uint *index*, T *values*);

void **VertexAttrib{123}{s f d}v**(uint *index*, const T **values*);

void **VertexAttrib4{b s i f d ub us ui}v**(uint *index*, const T **values*);

void **VertexAttrib4Nub**(uint *index*, ubyte *x*, ubyte *y*, ubyte *z*, ubyte *w*);

void **VertexAttrib4N{b s i ub us ui}v**(uint *index*, const T **values*);

void **VertexAttribI{1234}{i ui}**(uint *index*, T *values*);

void **VertexAttribI{1234}{i ui}v**(uint *index*, const T **values*);

void **VertexAttribI4{b s ub us}v**(uint *index*, const T **values*);

void **VertexAttribL{1234}d**(uint *index*, const T *values*);

void **VertexAttribL{1234}dv**(uint *index*, const T **values*);

void **VertexAttribP{1234}ui**(uint *index*, enum *type*, boolean *normalized*, uint *value*);

void **VertexAttribP{1234}uiv**(uint *index*, enum *type*, boolean *normalized*, const uint **value*);
type: [UNSIGNED_]INT_2_10_10_10_REV, or UNSIGNED_INT_10F_11F_11F_REV (except for VertexAttribP4uiv)

Vertex Arrays

Vertex Array Objects [10.3.1]

All states related to definition of data used by vertex processor is in a vertex array object.

void **GenVertexArrays**(sizei *n*, uint **arrays*);

void **DeleteVertexArrays**(sizei *n*, const uint **arrays*);

void **BindVertexArray**(uint *array*);

void **CreateVertexArrays**(sizei *n*, uint **arrays*);

boolean **IsVertexArray**(uint *array*);

void **VertexArrayElementBuffer**(uint *vaobj*, uint *buffer*);

Generic Vertex Attribute Arrays [10.3.2]

void **VertexAttribFormat**(uint *attribindex*, int *size*, enum *type*, boolean *normalized*, unit *relativeoffset*);
type: [UNSIGNED_]BYTE, [UNSIGNED_]SHORT, [UNSIGNED_]INT, [HALF_]FLOAT, DOUBLE, FIXED, [UNSIGNED_]INT_2_10_10_10_REV, UNSIGNED_INT_10F_11F_11F_REV

void **VertexAttribIFormat**(uint *attribindex*, int *size*, enum *type*, unit *relativeoffset*);
type: [UNSIGNED_]BYTE, [UNSIGNED_]SHORT, [UNSIGNED_]INT

void **VertexAttribLFormat**(uint *attribindex*, int *size*, enum *type*, unit *relativeoffset*);
type: DOUBLE

void **VertexArrayAttribFormat**(uint *vaobj*, uint *attribindex*, int *size*, enum *type*, boolean *normalized*, uint *relativeoffset*);
type: *See VertexAttribFormat*

void **VertexArrayAttribIFormat**(uint *vaobj*, uint *attribindex*, int *size*, enum *type*, uint *relativeoffset*);
type: *See VertexAttribIFormat*

void **VertexArrayAttribLFormat**(uint *vaobj*, uint *attribindex*, int *size*, enum *type*, uint *relativeoffset*);
type: *See VertexAttribLFormat*

void **BindVertexBuffer**(uint *bindingindex*, uint *buffer*, intptr *offset*, sizei *stride*);

void **VertexArrayVertexBuffer**(uint *vaobj*, uint *bindingindex*, uint *buffer*, intptr *offset*, sizei *stride*);

void **BindVertexBuffers**(uint *first*, sizei *count*, const uint **buffers*, const intptr **offsets*, const sizei **strides*);

void **VertexArrayVertexBuffers**(uint *vaobj*, uint *first*, sizei *count*, const uint **buffers*, const intptr **offsets*, const sizei **strides*);

void **VertexAttribBinding**(uint *attribindex*, uint *bindingindex*);

(Continued on next page)

◄Vertex Arrays (cont.)

void **VertexArrayAttribBinding**(uint *vaobj*, uint *attribindex*, uint *bindingindex*);

void **VertexAttribPointer**(uint *index*, int *size*, enum *type*, boolean *normalized*, sizei *stride*, const void **pointer*);
type: See VertexAttribFormat

void **VertexAttribIPointer**(uint *index*, int *size*, enum *type*, sizei *stride*, const void **pointer*);
type: See VertexAttribIFormat
index: [0, MAX_VERTEX_ATTRIBS - 1]

void **VertexAttribLPointer**(uint *index*, int *size*, enum *type*, sizei *stride*, const void**pointer*);
type: DOUBLE

void **EnableVertexAttribArray**(uint *index*);

void **EnableVertexArrayAttrib**(uint *vaobj*, uint *index*);

void **DisableVertexAttribArray**(uint *index*);

void **DisableVertexArrayAttrib**(uint *vaobj*, uint *index*);

Vertex Attribute Divisors [10.3.4]

void **VertexBindingDivisor**(uint *bindingindex*, uint *divisor*);

void **VertexArrayBindingDivisor**(uint *vaobj*, uint *bindingindex*, uint *divisor*);

void **VertexAttribDivisor**(uint *index*, uint *divisor*);

Primitive Restart [10.3.6]

Enable/Disable/IsEnabled(*target*);
target: PRIMITIVE_RESTART[_FIXED_INDEX]

void **PrimitiveRestartIndex**(uint *index*);

Drawing Commands [10.4]

For all the functions in this section:
mode: POINTS, PATCHES, LINE_STRIP, LINE_LOOP, TRIANGLE_STRIP, TRIANGLE_FAN, LINES, LINES_ADJACENCY, TRIANGLES, TRIANGLES_ADJACENCY, LINE_STRIP_ADJACENCY, TRIANGLE_STRIP_ADJACENCY
type: UNSIGNED_{BYTE, SHORT, INT}

void **DrawArrays**(enum *mode*, int *first*, sizei *count*);

void **DrawArraysInstancedBaseInstance**(enum *mode*, int *first*, sizei *count*, sizei *instancecount*, uint *baseinstance*);

void **DrawArraysInstanced**(enum *mode*, int *first*, sizei *count*, sizei *instancecount*);

void **DrawArraysIndirect**(enum *mode*, const void **indirect*);

void **MultiDrawArrays**(enum *mode*, const int **first*, const sizei **count*, sizei *drawcount*);

void **MultiDrawArraysIndirect**(enum *mode*, const void **indirect*, sizei *drawcount*, sizei *stride*);

void **DrawElements**(enum *mode*, sizei *count*, enum *type*, const void **indices*);

void **DrawElementsInstancedBaseInstance**(enum *mode*, sizei *count*, enum *type*, const void **indices*, sizei *instancecount*, uint *baseinstance*);

void **DrawElementsInstanced**(enum *mode*, sizei *count*, enum *type*, const void **indices*, sizei *instancecount*);

void **MultiDrawElements**(enum *mode*, const sizei **count*, enum *type*, const void * const **indices*, sizei *drawcount*);

void **DrawRangeElements**(enum *mode*, uint *start*, uint *end*, sizei *count*, enum *type*, const void **indices*);

void **DrawElementsBaseVertex**(enum *mode*, sizei *count*, enum *type*, const void **indices*, int *basevertex*);

void **DrawRangeElementsBaseVertex**(enum *mode*, uint *start*, uint *end*, sizei *count*, enum *type*, const void **indices*, int *basevertex*);

void **DrawElementsInstancedBaseVertex**(enum *mode*, sizei *count*, enum *type*, const void **indices*, sizei *instancecount*, int *basevertex*);

void **DrawElementsInstancedBase-VertexBaseInstance**(enum *mode*, sizei *count*, enum *type*, const void **indices*, sizei *instancecount*, int *basevertex*, uint *baseinstance*);

void **DrawElementsIndirect**(enum *mode*, enum *type*, const void **indirect*);

void **MultiDrawElementsIndirect**(enum *mode*, enum *type*, const void **indirect*, sizei *drawcount*, sizei *stride*);

void **MultiDrawElementsBaseVertex**(enum *mode*, const sizei **count*, enum *type*, const void *const **indices*, sizei *drawcount*, const int **basevertex*);

Vertex Array Queries [10.5]

void **GetVertexArrayiv**(uint *vaobj*, enum *pname*, int **param*);
pname: ELEMENT_ARRAY_BUFFER_BINDING

void **GetVertexArrayIndexdiv**(uint *vaobj*, uint *index*, enum *pname*, int **param*);
pname: VERTEX_ATTRIB_RELATIVE_OFFSET or VERTEX_ATTRIB_ARRAY_*X* where *X* is one of ENABLED, SIZE, STRIDE, TYPE, NORMALIZED, INTEGER, LONG, DIVISOR

void **GetVertexArrayIndexd64iv**(uint *vaobj*, uint *index*, enum *pname*, int64 **param*);
pname: VERTEX_BINDING_OFFSET

void **GetVertexAttrib{d f i}v**(uint *index*, enum *pname*, T **params*);
pname: See GetVertexArrayIndexediv plus VERTEX_ATTRIB_ARRAY_BUFFER_BINDING, VERTEX_ATTRIB_BINDING, CURRENT_VERTEX_ATTRIB

void **GetVertexAttribI{i ui}v**(uint *index*, enum *pname*, T **params*);
pname: See GetVertexAttrib{d f i}v

void **GetVertexAttribLdv**(uint *index*, enum *pname*, double **params*);
pname: See GetVertexAttrib{d f i}v

void **GetVertexAttribPointerv**(uint *index*, enum *pname*, const void ***pointer*);
pname: VERTEX_ATTRIB_ARRAY_POINTER

Conditional Rendering [10.9]

void **BeginConditionalRender**(uint *id*, enum *mode*);
mode: QUERY _[NO_]WAIT[_INVERTED], QUERY_BY_REGION_[NO_]WAIT[_INVERTED]

void **EndConditionalRender**(void);

Vertex Attributes [11.1.1]

Vertex shaders operate on array of 4-component items numbered from slot 0 to MAX_VERTEX_ATTRIBS - 1.

void **BindAttribLocation**(uint *program*, uint *index*, const char **name*);

void **GetActiveAttrib**(uint *program*, uint *index*, sizei *bufSize*, sizei **length*, int **size*, enum **type*, char **name*);

int **GetAttribLocation**(uint *program*, const char **name*);

Transform Feedback Variables [11.1.2]

void **TransformFeedbackVaryings**(uint *program*, sizei *count*, const char * const **varyings*, enum *bufferMode*);
bufferMode: INTERLEAVED_ATTRIBS, SEPARATE_ATTRIBS

void **GetTransformFeedbackVarying**(uint *program*, uint *index*, sizei *bufSize*, sizei **length*, sizei **size*, enum **type*, char **name*);
**type* returns NONE, FLOAT , FLOAT_VEC*n*, DOUBLE , DOUBLE_VEC*n*, INT, UNSIGNED_INT, INT_VEC*n*, UNSIGNED_INT_VEC*n*, MAT*nxm*, FLOAT_MAT*nxm*, DOUBLE_MAT*nxm*, FLOAT_MAT*n*, DOUBLE_MAT*n*

Shader Execution [11.1.3]

void **ValidateProgram**(uint *program*);

void **ValidateProgramPipeline**(uint *pipeline*);

Tessellation Prim. Generation [11.2.2]

void **PatchParameterfv**(enum *pname*, const float **values*);
pname: PATCH_DEFAULT_INNER_LEVEL, PATCH_DEFAULT_OUTER_LEVEL

Vertex Post-Processing [13]

Transform Feedback [13.2]

void **GenTransformFeedbacks**(sizei *n*, uint **ids*);

void **DeleteTransformFeedbacks**(sizei *n*, const uint **ids*);

boolean **IsTransformFeedback**(uint *id*);

void **BindTransformFeedback**(enum *target*, uint *id*);
target: TRANSFORM_FEEDBACK

void **CreateTransformFeedbacks**(sizei *n*, uint **ids*);

void **BeginTransformFeedback**(enum *primitiveMode*);
primitiveMode: TRIANGLES, LINES, POINTS

void **EndTransformFeedback**(void);

void **PauseTransformFeedback**(void);

void **ResumeTransformFeedback**(void);

void **TransformFeedbackBufferRange**(uint *xfb*, uint *index*, uint *buffer*, intptr *offset*, sizeiptr *size*);

void **TransformFeedbackBufferBase**(uint *xfb*, uint *index*, uint *buffer*);

Transform Feedback Drawing [13.2.3]

void **DrawTransformFeedback**(enum *mode*, uint *id*);
mode: See Drawing Commands [10.4] above

void **DrawTransformFeedbackInstanced**(enum *mode*, uint *id*, sizei *instancecount*);

void **DrawTransformFeedbackStream**(enum *mode*, uint *id*, uint *stream*);

void **DrawTransformFeedbackStreamInstanced**(enum *mode*, uint *id*, uint *stream*, sizei *instancecount*);

Flatshading [13.4]

void **ProvokingVertex**(enum *provokeMode*);
provokeMode: {FIRST, LAST}_VERTEX_CONVENTION

Primitive Clipping [13.5]

Enable/Disable/IsEnabled(*target*);
target: DEPTH_CLAMP, CLIP_DISTANCE*i* where *i* = [0..MAX_CLIP_DISTANCES - 1]

void **ClipControl**(enum *origin*, enum *depth*);
origin: LOWER_LEFT or UPPER_LEFT
depth: NEGATIVE_ONE_TO_ONE or ZERO_TO_ONE

Controlling Viewport [13.6.1]

void **DepthRangeArrayv**(uint *first*, sizei *count*, const double **v*);

void **DepthRangeIndexed**(uint *index*, double *n*, double *f*);

void **DepthRange**(double *n*, double *f*);

void **DepthRangef**(float *n*, float *f*);

void **ViewportArrayv**(uint *first*, sizei *count*, const float **v*);

void **ViewportIndexedf**(uint *index*, float *x*, float *y*, float *w*, float *h*);

void **ViewportIndexedfv**(uint *index*, const float **v*);

void **Viewport**(int *x*, int *y*, sizei *w*, sizei *h*);

Rasterization [13.4, 14]

Enable/Disable/IsEnabled(*target*);
target: RASTERIZER_DISCARD

Multisampling [14.3.1]

Use to antialias points, and lines.

Enable/Disable/IsEnabled(*target*);
target: MULTISAMPLE, SAMPLE_SHADING

void **GetMultisamplefv**(enum *pname*, uint *index*, float **val*);
pname: SAMPLE_POSITION

void **MinSampleShading**(float *value*);

Points [14.4]

void **PointSize**(float *size*);

void **PointParameter{i f}**(enum *pname*, T *param*);
pname, param: See PointParameter{if}v

void **PointParameter{i f}v**(enum *pname*, const T **params*);
pname: POINT_FADE_THRESHOLD_SIZE, POINT_SPRITE_COORD_ORIGIN
params: The fade threshold if *pname* is POINT_FADE_THRESHOLD_SIZE; {LOWER, UPPER}_LEFT if *pname* is POINT_SPRITE_COORD_ORIGIN

Enable/Disable/IsEnabled(*target*);
target: PROGRAM_POINT_SIZE

Line Segments [14.5]

Enable/Disable/IsEnabled(*target*);
target: LINE_SMOOTH

void **LineWidth**(float *width*);

Polygons [14.6, 14.6.1]

Enable/Disable/IsEnabled(*target***);**
target: POLYGON_SMOOTH, CULL_FACE

void **FrontFace**(enum *dir*);
dir: CCW, CW

void **CullFace**(enum *mode*);
mode: FRONT, BACK, FRONT_AND_BACK

Polygon Rast. & Depth Offset [14.6.4-5]

void **PolygonMode**(enum *face*, enum *mode*);
face: FRONT_AND_BACK
mode: POINT, LINE, FILL

void **PolygonOffset**(float *factor*, float *units*);

Enable/Disable/IsEnabled(*target*);
target: POLYGON_OFFSET_{POINT, LINE, FILL}

Fragment Shaders [15.2]

void **BindFragDataLocationIndexed**(uint *program*, uint *colorNumber*, uint *index*, const char **name*);

void **BindFragDataLocation**(uint *program*, uint *colorNumber*, const char **name*);

int **GetFragDataLocation**(uint *program*, const char **name*);

int **GetFragDataIndex**(uint *program*, const char **name*);

Compute Shaders [19]

void **DispatchCompute**(uint *num_groups_x*, uint *num_groups_y*, uint *num_groups_z*);

void **DispatchComputeIndirect**(intptr *indirect*);

Per-Fragment Operations

Scissor Test [17.3.2]

Enable/Disable/IsEnabled(SCISSOR_TEST);

Enablei/Disablei/IsEnabledi(SCISSOR_TEST, uint *index*);

void **ScissorArrayv**(uint *first*, sizei *count*, const int **v*);

void **ScissorIndexed**(uint *index*, int *left*, int *bottom*, sizei *width*, sizei *height*);

void **ScissorIndexedv**(uint *index*, int **v*);

void **Scissor**(int *left*, int *bottom*, sizei *width*, sizei *height*);

Multisample Fragment Ops. [17.3.3]

Enable/Disable/IsEnabled(*target*);
target: SAMPLE_ALPHA_TO_{COVERAGE, ONE}, SAMPLE_COVERAGE, SAMPLE_MASK

void **SampleCoverage**(float *value*, boolean *invert*);

void **SampleMaski**(uint *maskNumber*, bitfield *mask*);

Stencil Test [17.3.5]

Enable/Disable/IsEnabled(STENCIL_TEST);

void **StencilFunc**(enum *func*, int *ref*, uint *mask*);
func: NEVER, ALWAYS, LESS, GREATER, EQUAL, LEQUAL, GEQUAL, NOTEQUAL

void **StencilFuncSeparate**(enum *face*, enum *func*, int *ref*, uint *mask*);
func: See StencilFunc

void **StencilOp**(enum *sfail*, enum *dpfail*, enum *dppass*);

void **StencilOpSeparate**(enum *face*, enum *sfail*, enum *dpfail*, enum *dppass*);
face: FRONT, BACK, FRONT_AND_BACK
sfail, dpfail, dppass: KEEP, ZERO, REPLACE, INCR, DECR, INVERT, INCR_WRAP, DECR_WRAP

Depth Buffer Test [17.3.6]

Enable/Disable/IsEnabled(DEPTH_TEST);

void **DepthFunc**(enum *func*);
func: See StencilFunc

Occlusion Queries [17.3.7]

BeginQuery(enum *target*, uint *id*);

EndQuery(enum *target*);
target: SAMPLES_PASSED, ANY_SAMPLES_PASSED, ANY_SAMPLES_PASSED_CONSERVATIVE

Blending [17.3.8]

Enable/Disable/IsEnabled(BLEND);

Enablei/Disablei/IsEnabledi(BLEND, uint *index*);

void **BlendEquation**(enum *mode*);

void **BlendEquationSeparate**(enum *modeRGB*, enum *modeAlpha*);
modeRGB, modeAlpha: MIN, MAX, FUNC_{ADD, SUBTRACT, REVERSE_SUBTRACT}

void **BlendEquationi**(uint *buf*, enum *mode*);

void **BlendEquationSeparatei**(uint *buf*, enum *modeRGB*, enum *modeAlpha*);
modeRGB, modeAlpha: See BlendEquationSeparate

void **BlendFunc**(enum *src*, enum *dst*);
src, dst: See BlendFuncSeparate

void **BlendFuncSeparate**(enum *srcRGB*, enum *dstRGB*, enum *srcAlpha*, enum *dstAlpha*);
srcRGB, dstRGB, srcAlpha, dstAlpha: ZERO, ONE, SRC_ALPHA_SATURATE, {SRC, SRC1, DST, CONSTANT}_{COLOR, ALPHA}, ONE_MINUS_{SRC, SRC1}_{COLOR, ALPHA}, ONE_MINUS_{DST, CONSTANT}_{COLOR, ALPHA}

void **BlendFunci**(uint *buf*, enum *src*, enum *dst*);
src, dst: See BlendFuncSeparate

void **BlendFuncSeparatei**(uint *buf*, enum *srcRGB*, enum *dstRGB*, enum *srcAlpha*, enum *dstAlpha*);
dstRGB, dstAlpha, srcRGB, srcAlpha: See BlendFuncSeparate

void **BlendColor**(float *red*, float *green*, float *blue*, float *alpha*);

Dithering [17.3.10]

Enable/Disable/IsEnabled(DITHER);

Logical Operation [17.3.11]

Enable/Disable/IsEnabled(COLOR_LOGIC_OP);

void **LogicOp**(enum *op*);
op: CLEAR, AND, AND_REVERSE, COPY, AND_INVERTED, NOOP, XOR, OR, NOR, EQUIV, INVERT, OR_REVERSE, COPY_INVERTED, OR_INVERTED, NAND, SET

Hints [21.5]

void **Hint**(enum *target*, enum *hint*);
target: FRAGMENT_SHADER_DERIVATIVE_HINT, TEXTURE_COMPRESSION_HINT, {LINE, POLYGON}_SMOOTH_HINT
hint: FASTEST, NICEST, DONT_CARE

Whole Framebuffer

Selecting Buffers for Writing [17.4.1]

void **DrawBuffer**(enum *buf*);
buf: [Tables 17.4-5] NONE, {FRONT, BACK}_{LEFT, RIGHT}, FRONT, BACK, LEFT, RIGHT, FRONT_AND_BACK, COLOR_ATTACHMENT*i* (*i* = [0, MAX_COLOR_ATTACHMENTS - 1])

void **NamedFramebufferDrawBuffer**(uint *framebuffer*, enum *buf*);
buf: See DrawBuffer

void **DrawBuffers**(sizei *n*, const enum **bufs*);
**bufs:* [Tables 17.5-6] {FRONT, BACK}_{LEFT, RIGHT}, NONE, COLOR_ATTACHMENT*i* (*i* = [0, MAX_COLOR_ATTACHMENTS - 1])

void **NamedFramebufferDrawBuffers**(uint *framebuffer*, sizei *n*, const enum **bufs*);
**bufs:* See DrawBuffers

Fine Control of Buffer Updates [17.4.2]

void **ColorMask**(boolean *r*, boolean *g*, boolean *b*, boolean *a*);

void **ColorMaski**(uint *buf*, boolean *r*, boolean *g*, boolean *b*, boolean *a*);

void **DepthMask**(boolean *mask*);

void **StencilMask**(uint *mask*);

void **StencilMaskSeparate**(enum *face*, uint *mask*);
face: FRONT, BACK, FRONT_AND_BACK

Clearing the Buffers [17.4.3]

void **Clear**(bitfield *buf*);
buf: 0 or the OR of {COLOR, DEPTH, STENCIL}_BUFFER_BIT

void **ClearColor**(float *r*, float *g*, float *b*, float *a*);

void **ClearDepth**(double *d*);

void **ClearDepthf**(float *d*);

void **ClearStencil**(int *s*);

void **ClearBuffer{i f ui}v**(enum *buffer*, int *drawbuffer*, const T **value*);
buffer: COLOR, DEPTH, STENCIL

void **ClearNamedFramebuffer{i f ui}v**(uint framebuffer, enum *buffer*, int *drawbuffer*, const T **value*);
buffer: See ClearBuffer{i f ui}v

void **ClearBufferfi**(enum *buffer*, int *drawbuffer*, float *depth*, int *stencil*);
buffer: DEPTH_STENCIL

void **ClearNamedFramebufferfi**(uint framebuffer, enum *buffer*, int *drawbuffer*, float *depth*, int *stencil*);
buffer: See ClearBufferfi

Invalidating Framebuffers [17.4.4]

void **InvalidateSubFramebuffer**(enum *target*, sizei *numAttachments*, const enum **attachments*, int *x*, int *y*, sizei *width*, sizei *height*);
target: [DRAW_ , READ_]FRAMEBUFFER
attachments: COLOR_ATTACHMENT*i*, DEPTH, COLOR, {DEPTH, STENCIL, DEPTH_STENCIL}_ATTACHMENT, {FRONT, BACK}_{LEFT, RIGHT}, STENCIL

void **InvalidateNamedFramebufferSubData**(uint *framebuffer*, sizei *numAttachments*, const enum **attachments*, int *x*, int *y*, sizei *width*, sizei *height*);
attachments: See InvalidateSubFramebuffer

void **InvalidateFramebuffer**(enum*target*, sizei *numAttachments*, const enum **attachments*);
*target, *attachments:* See InvalidateSubFramebuffer

void **InvalidateNamedFramebufferData**(uint *framebuffer*, sizei *numAttachments*, const enum **attachments*);
**attachments:* See InvalidateSubFramebuffer

Reading and Copying Pixels

Reading Pixels [18.2]

void **ReadBuffer**(enum *src*);
src: NONE, {FRONT, BACK}_{LEFT, RIGHT}, FRONT, BACK, LEFT, RIGHT, FRONT_AND_BACK, COLOR_ATTACHMENT*i* (*i* = [0, MAX_COLOR_ATTACHMENTS - 1])

void **NamedFramebufferReadBuffer**(uint *framebuffer*, enum *src*);
src: See ReadBuffer

void **ReadPixels**(int *x*, int *y*, sizei *width*, sizei *height*, enum *format*, enum *type*, void **data*);
format: STENCIL_INDEX, RED, GREEN, BLUE, RG, RGB, RGBA, BGR, DEPTH_{COMPONENT, STENCIL}, {RED, GREEN, BLUE, RG, RGB}_INTEGER, {RGBA, BGR, BGRA}_INTEGER, BGRA [Table 8.3]
type: [HALF_]FLOAT, [UNSIGNED_]BYTE, [UNSIGNED_]SHORT, [UNSIGNED_]INT, FLOAT_32_UNSIGNED_INT_24_8_REV, UNSIGNED_{BYTE, SHORT, INT}_* values in [Table 8.2]

void **ReadnPixels**(int *x*, int *y*, sizei *width*, sizei *height*, enum *format*, enum *type*, sizei *bufSize*, void **data*);
format, type: See ReadPixels

Final Conversion [18.2.8]

void **ClampColor**(enum *target*, enum *clamp*);
target: CLAMP_READ_COLOR
clamp: TRUE, FALSE, FIXED_ONLY

Copying Pixels [18.3]

void **BlitFramebuffer**(int *srcX0*, int *srcY0*, int *srcX1*, int *srcY1*, int *dstX0*, int *dstY0*, int *dstX1*, int *dstY1*, bitfield *mask*, enum *filter*);
mask: Bitwise 0 of the bitwise OR of {COLOR, DEPTH, STENCIL}_BUFFER_BIT
filter: LINEAR, NEAREST

void **BlitNamedFramebuffer**(uint *readFramebuffer*, uint *drawFramebuffer*, int *srcX0*, int *srcY0*, int *srcX1*, int *srcY1*, int *dstX0*, int *dstY0*, int *dstX1*, int *dstY1*, bitfield *mask*, enum *filter*);
mask, filter: See BlitFramebuffer

void **CopyImageSubData**(uint *srcName*, enum *srcTarget*, int *srcLevel*, int *srcX*, int *srcY*, int *srcZ*, uint *dstName*, enum *dstTarget*, int *dstLevel*, int *dstX*, int *dstY*, int *dstZ*, sizei *srcWidth*, sizei *srcHeight*, sizei *srcDepth*);
srcTarget, dstTarget: See target for BindTexture in section [8.1] on this card, plus GL_RENDERTARGET

Debug Output [20]

Enable/Disable/IsEnabled(DEBUG_OUTPUT);

Debug Message Callback [20.2]

void **DebugMessageCallback**(DEBUGPROC *callback*, const void **userParam*);
callback: has the following prototype:

void **callback**(enum *source*, enum *type*, uint *id*, enum *severity*, sizei *length*, const char **message*, const void**userParam*);
source: DEBUG_SOURCE_*X* where *X* may be API, SHADER_COMPILER, WINDOW_SYSTEM, THIRD_PARTY, APPLICATION, OTHER
type: DEBUG_TYPE_*X* where *X* may be ERROR, MARKER, OTHER, DEPRECATED_BEHAVIOR, UNDEFINED_BEHAVIOR, PERFORMANCE, PORTABILITY, {PUSH, POP}_GROUP
severity: DEBUG_SEVERITY_{HIGH, MEDIUM}, DEBUG_SEVERITY_{LOW, NOTIFICATION}

Controlling Debug Messages [20.4]

void **DebugMessageControl**(enum *source*, enum *type*, enum *severity*, sizei *count*, const uint **ids*, boolean *enabled*);
source, type, severity: See DebuckMessageCallback (above), plus DONT_CARE

Externally Generated Messages [20.5]

void **DebugMessageInsert**(enum *source*, enum *type*, uint *id*, enum *severity*, int *length*, const char **buf*);
source: DEBUG_SOURCE_{APPLICATION, THIRD_PARTY}
type, severity: See DebugMessageCallback

Debug Groups [20.6]

void **PushDebugGroup**(enum *source*, uint *id*, sizei *length*, const char **message*);
source: See DebugMessageInsert

void **PopDebugGroup**(void);

Debug Labels [20.7]

void **ObjectLabel**(enum *identifier*, uint *name*, sizei *length*, const char **label*);
identifier: BUFFER, FRAMEBUFFER, RENDERBUFFER, PROGRAM_PIPELINE, PROGRAM, QUERY, SAMPLER, SHADER, TEXTURE, TRANSFORM_FEEDBACK, VERTEX_ARRAY

void **ObjectPtrLabel**(void* *ptr*, sizei *length*, const char **label*);

Synchronous Debug Output [20.8]

Enable/Disable/IsEnabled(DEBUG_OUTPUT_SYNCHRONOUS);

Debug Output Queries [20.9]

uint **GetDebugMessageLog**(uint *count*, sizei *bufSize*, enum **sources*, enum **types*, uint **ids*, enum **severities*, sizei **lengths*, char **messageLog*);

void **GetObjectLabel**(enum *identifier*, uint *name*, sizei *bufSize*, sizei **length*, char **label*);

void **GetObjectPtrLabel**(void* *ptr*, sizei *bufSize*, sizei **length*, char **label*);

State and State Requests

A complete list of symbolic constants for states is shown in the tables in [23].

Simple Queries [22.1]

void **GetBooleanv**(enum *pname*, boolean **data*);

void **GetIntegerv**(enum *pname*, int **data*);

void **GetInteger64v**(enum *pname*, int64 **data*);

void **GetFloatv**(enum *pname*, float **data*);

void **GetDoublev**(enum *pname*, double **data*);

void **GetDoublei_v**(enum *target*, uint *index*, double **data*);

void **GetBooleani_v**(enum *target*, uint *index*, boolean **data*);

void **GetIntegeri_v**(enum *target*, uint *index*, int **data*);

void **GetFloati_v**(enum *target*, uint *index*, float **data*);

void **GetInteger64i_v**(enum *target*, uint *index*, int64 **data*);

boolean **IsEnabled**(enum *cap*);

boolean **IsEnabledi**(enum *target*, uint *index*);

String Queries [22.2]

void **GetPointerv**(enum *pname*, void ***params*);

ubyte ***GetString**(enum *name*);
name: RENDERER, VENDOR, VERSION, SHADING_LANGUAGE_VERSION

(Continued on next page) ▶

States (cont.)

ubyte ***GetStringi**(enum *name*, uint *index*);
name: EXTENSIONS, SHADING_LANGUAGE_VERSION
index:
[0, NUM_EXTENSIONS - 1] (if *name* is EXTENSIONS);
[0, NUM_SHADING_LANGUAGE_VERSIONS-1]
(if *name* is SHADING_LANGUAGE_VERSION)

Internal Format Queries [22.3]

void **GetInternalformativ**(enum *target*, enum *internalformat*, enum *pname*, sizei *bufSize*, int **params*);
target, pname, internalformat:
See GetInternalformati64v

void **GetInternalformati64v**(enum *target*, enum *internalformat*, enum *pname*, sizei *bufSize*, int64 **params*);
target: [Table 22.2]
TEXTURE_{1D, 2D, 3D, CUBE_MAP}[_ARRAY],
TEXTURE_2D_MULTISAMPLE[_ARRAY],
TEXTURE_{BUFFER, RECTANGLE}, RENDERBUFFER
internalformat: any value
pname:
CLEAR_{BUFFER, TEXTURE},
COLOR_ENCODING,
COLOR_{COMPONENTS, RENDERABLE},
COMPUTE_TEXTURE,
DEPTH_{COMPONENTS, RENDERABLE},
FILTER, FRAMEBUFFER_BLEND,
FRAMEBUFFER_RENDERABLE[_LAYERED],
{FRAGMENT, GEOMETRY}_TEXTURE,
GET_TEXTURE_IMAGE_FORMAT,
GET_TEXTURE_IMAGE_TYPE,
IMAGE_COMPATIBILITY_CLASS,
IMAGE_PIXEL_{FORMAT, TYPE},
IMAGE_FORMAT_COMPATIBILITY_TYPE,
IMAGE_TEXEL_SIZE,
INTERNALFORMAT_{PREFERRED, SUPPORTED},
INTERNALFORMAT_{RED, GREEN, BLUE}_SIZE,
INTERNALFORMAT_{DEPTH, STENCIL}_SIZE,
INTERNALFORMAT_{ALPHA, SHARED}_SIZE,
INTERNALFORMAT_{RED, GREEN}_TYPE,
INTERNALFORMAT_{BLUE, ALPHA}_TYPE,
INTERNALFORMAT_{DEPTH, STENCIL}_TYPE,
[MANUAL_GENERATE_]MIPMAP,
MAX_COMBINED_DIMENSIONS,
MAX_{WIDTH, HEIGHT, DEPTH, LAYERS},
NUM_SAMPLE_COUNTS,
READ_PIXELS[_FORMAT, _TYPE],
SAMPLES, SHADER_IMAGE_ATOMIC,
SHADER_IMAGE_{LOAD, STORE},
SIMULTANEOUS_TEXTURE_AND_DEPTH_TEST,
SIMULTANEOUS_TEXTURE_AND_DEPTH_WRITE,
SIMULTANEOUS_TEXTURE_AND_STENCIL_TEST,
SIMULTANEOUS_TEXTURE_AND_STENCIL_WRITE,
SRGB_{READ, WRITE},
STENCIL_{COMPONENTS, RENDERABLE},
TESS_{CONTROL, EVALUATION}_TEXTURE,
TEXTURE_COMPRESSED[_BLOCK_SIZE],
TEXTURE_COMPRESSED_BLOCK_{HEIGHT, WIDTH}
TEXTURE_GATHER[_SHADOW],
TEXTURE_IMAGE_FORMAT,
TEXTURE_IMAGE_TYPE,
TEXTURE_{SHADOW, VIEW},
VERTEX_TEXTURE,
VIEW_COMPATIBILITY_CLASS

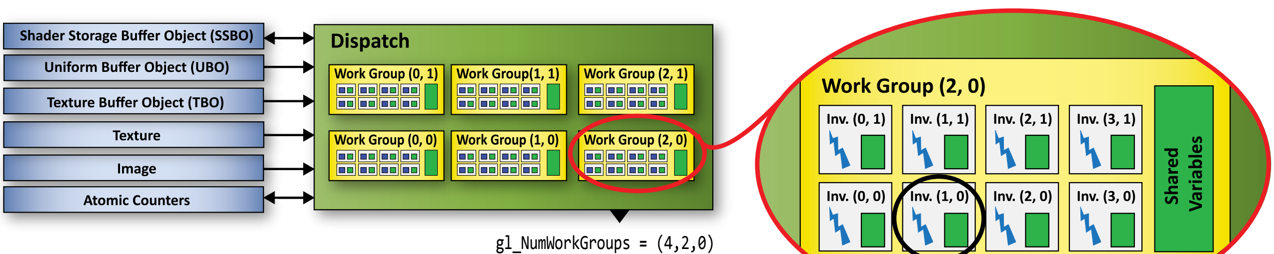
TransformFeedback Queries [22.4]

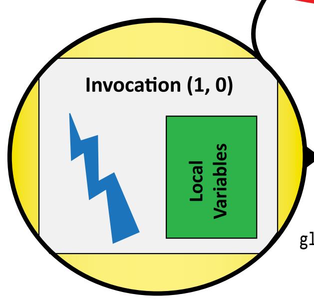
void **GetTransformFeedbackiv**(uint *xfb*, enum *pname*, int **param*);
pname: TRANSFORM_FEEDBACK_{PAUSED, ACTIVE}

void **GetTransformFeedbacki_v**(uint *xfb*, enum *pname*, uint *index*, int **param*);
pname: TRANSFORM_FEEDBACK_BUFFER_BINDING

void **GetTransformFeedbacki64_v**(uint *xfb*, enum *pname*, uint *index*, int64 **param*);
pname: TRANSFORM_FEEDBACK_BUFFER_START,
TRANSFORM_FEEDBACK_BUFFER_SIZE

OpenGL Compute Programming Model and Compute Memory Hierarchy






```
gl_WorkGroupSize = (4,2,0)
gl_WorkGroupID = (2,0,0)
gl_LocalInvocationID = (1,0,0)
gl_GlobalInvocationID = (9,3,0)
```

Use the **barrier** function to synchronize invocations in a work group:

```
void barrier();
```

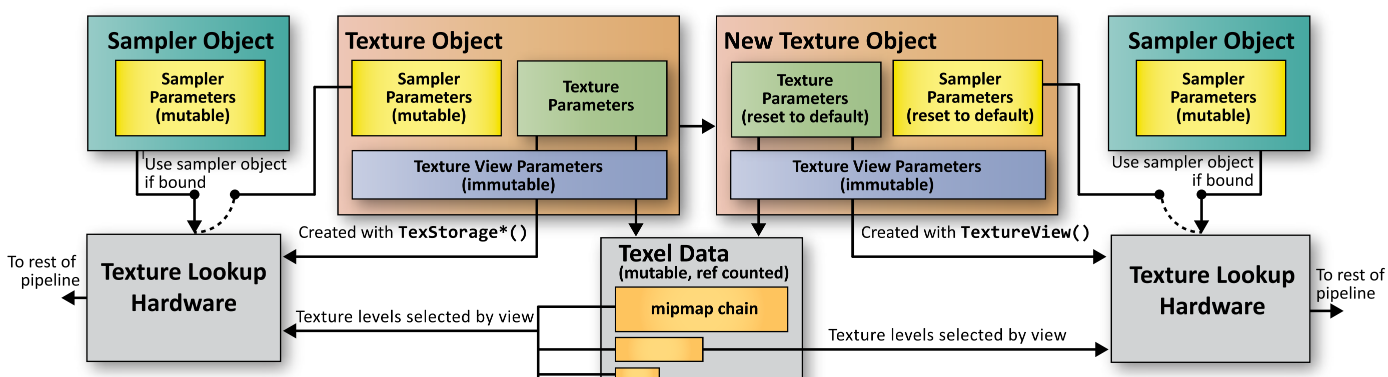
Use the **memoryBarrier*** or **groupMemoryBarrier** functions to order reads/writes accessible to other invocations:

```
void memoryBarrier();
void memoryBarrierAtomicCounter();
void memoryBarrierBuffer();
void memoryBarrierImage();
void memoryBarrierShared();     // Only for compute shaders
void groupMemoryBarrier();      // Only for compute shaders
```

Use the compute shader built-in variables to specify work groups and invocations:

```
   in vec3 gl_NumWorkGroups;       // Number of workgroups dispatched
const vec3 gl_WorkGroupSize;       // Size of each work group for current shader
   in vec3 gl_WorkGroupID;         // Index of current work group being executed
   in vec3 gl_LocalInvocationID;   // index of current invocation in a work group
   in vec3 gl_GlobalInvocationID;  // Unique ID across all work groups and threads. (gl_GlobalInvocationID = gl_WorkGroupID * gl_WorkGroupSize + gl_LocalInvocationID)
```

OpenGL Texture Views and Texture Object State



<u>Texture state set with `TextureView()`</u>

```
enum internalformat // base internal format      uint minlevel    // first level of mipmap       uint minlayer    // first layer of array texture
enum target         // texture target            uint numlevels   // number of mipmap levels     uint numlayers   // number of layers in array
```

<u>Sampler Parameters (mutable)</u>
TEXTURE_BORDER_COLOR
TEXTURE_COMPARE_{FUNC,MODE}
TEXTURE_LOD_BIAS
TEXTURE_{MAX,MIN}_LOD
TEXTURE_{MAG,MIN}_FILTER
TEXTURE_WRAP_{S,T,R}

<u>Texture Parameters (immutable)</u>
TEXTURE_WIDTH
TEXTURE_DEPTH
TEXTURE_COMPRESSED
TEXTURE_IMMUTABLE_FORMAT
TEXTURE_HEIGHT
TEXTURE_FIXED_SAMPLE_LOCATIONS
TEXTURE_COMPRESSED_IMAGE_SIZE
TEXTURE_SAMPLES

<u>Texture Parameters (mutable)</u>
TEXTURE_SWIZZLE_{R,G,B,A}
TEXTURE_BASE_LEVEL
TEXTURE_MAX_LEVEL
DEPTH_STENCIL_TEXTURE_MODE

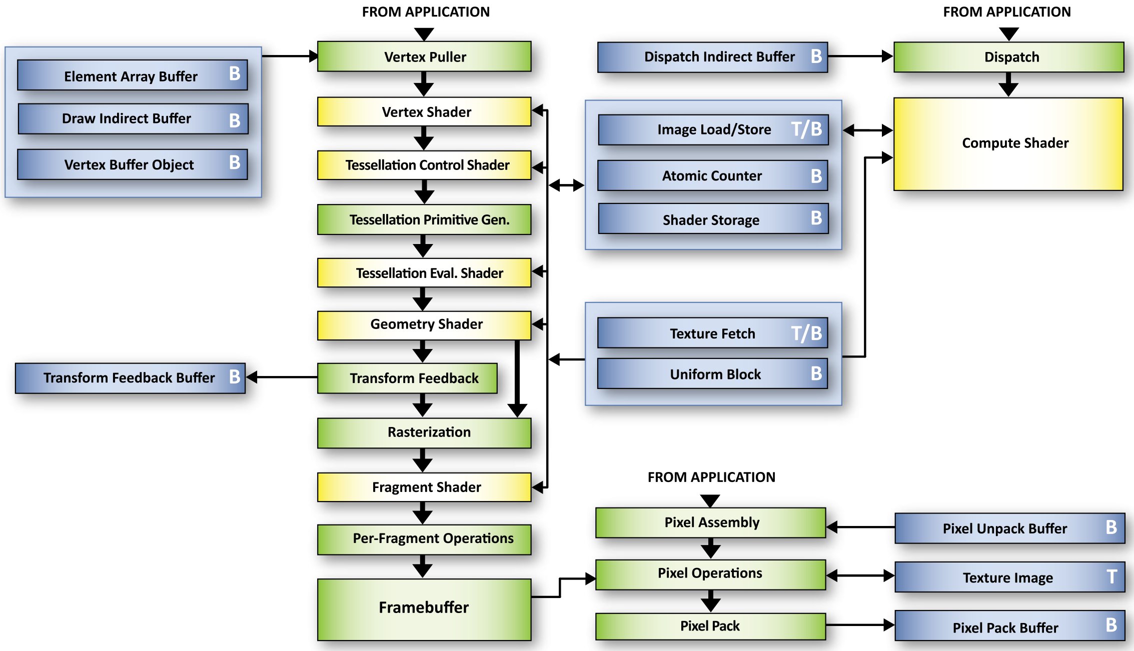
<u>Texture View Parameters (immutable)</u>
<target>
TEXTURE_INTERNAL_FORMAT
TEXTURE_VIEW_{MIN,NUM}_LEVEL
TEXTURE_IMMUTABLE_LEVELS
TEXTURE_{RED,GREEN,BLUE,ALPHA,DEPTH}_TYPE
TEXTURE_{RED,GREEN,BLUE,ALPHA,DEPTH,STENCIL}_SIZE
TEXTURE_SHARED_SIZE
TEXTURE_VIEW_{MIN,NUM}_LAYER
IMAGE_FORMAT_COMPATIBILITY_TYPE

OpenGL Pipeline

A typical program that uses OpenGL begins with calls to open a window into the framebuffer into which the program will draw. Calls are made to allocate a GL context which is then associated with the window, then OpenGL commands can be issued.

The heavy black arrows in this illustration show the OpenGL pipeline and indicate data flow.

- Blue blocks indicate various buffers that feed or get fed by the OpenGL pipeline.
- Green blocks indicate fixed function stages.
- Yellow blocks indicate programmable stages.
- T Texture binding
- B Buffer binding

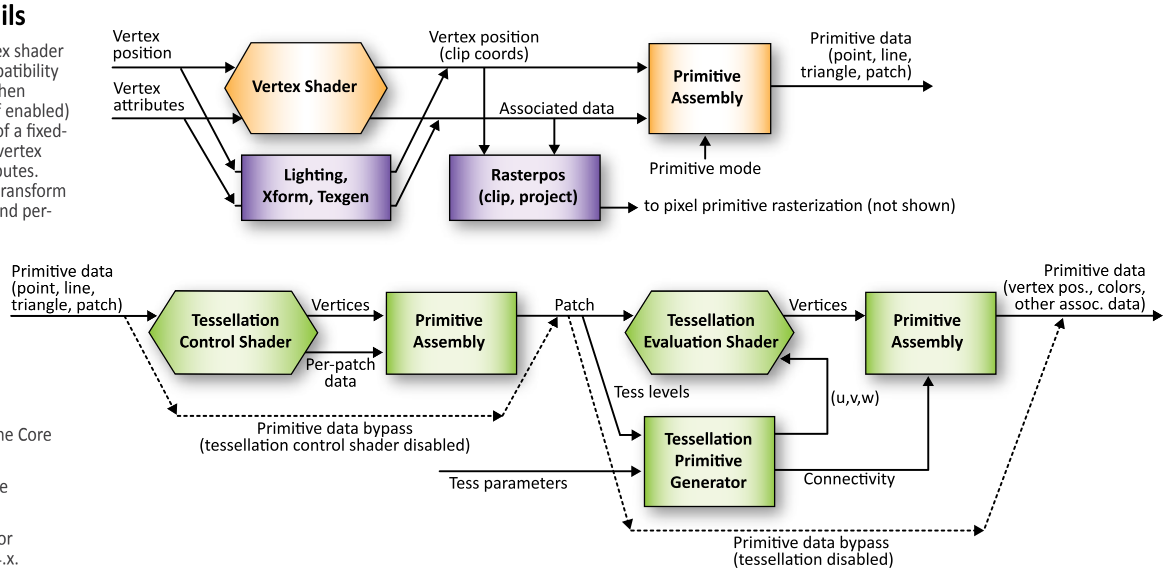


Vertex & Tessellation Details

Each vertex is processed either by a vertex shader or fixed-function vertex processing (compatibility only) to generate a transformed vertex, then assembled into primitives. Tessellation (if enabled) operates on patch primitives, consisting of a fixed-size collection of vertices, each with per-vertex attributes and associated per-patch attributes. Tessellation control shaders (if enabled) transform an input patch and compute per-vertex and per-patch attributes for a new output patch.

A fixed-function primitive generator subdivides the patch according to tessellation levels computed in the tessellation control shaders or specified as fixed values in the API (TCS disabled). The tessellation evaluation shader computes the position and attributes of each vertex produced by the tessellator.

- Orange blocks indicate features of the Core specification.
- Purple blocks indicate features of the Compatibility specification.
- Green blocks indicate features new or significantly changed with OpenGL 4.x.



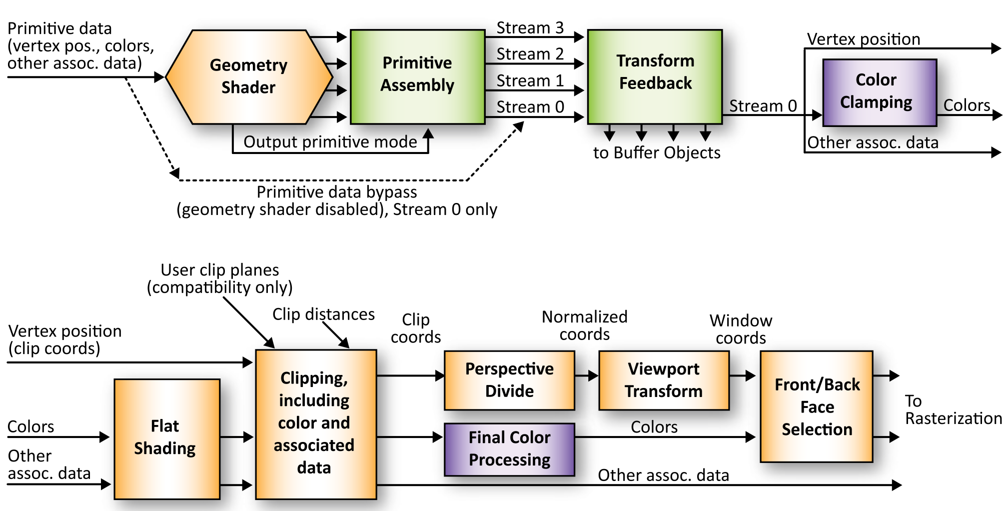
Geometry & Follow-on Details

Geometry shaders (if enabled) consume individual primitives built in previous primitive assembly stages. For each input primitive, the geometry shader can output zero or more vertices, with each vertex directed at a specific vertex stream. The vertices emitted to each stream are assembled into primitives according to the geometry shader's output primitive type.

Transform feedback (if active) writes selected vertex attributes of the primitives of all vertex streams into buffer objects attached to one or more binding points.

Primitives on vertex stream zero are then processed by fixed-function stages, where they are clipped and prepared for rasterization.

- Orange blocks indicate features of the Core specification.
- Purple blocks indicate features of the Compatibility specification.
- Green blocks indicate features new or significantly changed with OpenGL 4.x.



The OpenGL® Shading Language is used to create shaders for each of the programmable processors contained in the OpenGL processing pipeline. The OpenGL Shading Language is actually several closely related languages. Currently, these processors are the vertex, tessellation control, tessellation evaluation, geometry, fragment, and compute shaders.

[n.n.n] and [Table n.n] refer to sections and tables in the OpenGL Shading Language 4.50 specification at www.opengl.org/registry

Preprocessor [3.3]

Preprocessor Operators

#version 450 #version 450 *profile*	Required when using version 4.50. *profile* is core, compatibility, or es (for ES versions 1.00, 3.00, or 3.10).
#extension *extension_name* : *behavior* #extension all : *behavior*	• *behavior*: require, enable, warn, disable • *extension_name:* extension supported by compiler, or "all"

Predefined Macros

__LINE__ __FILE__	Decimal integer constants. __FILE__ says which source string is being processed.
__VERSION__	Decimal integer, e.g.: 450
GL_core_profile	Defined as 1
GL_es_profile	1 if the ES profile is supported
GL_compatibility_profile	Defined as 1 if the implementation supports the compatibility profile.

Preprocessor Directives

 # #define #elif #else #endif #error #extension
#if #ifdef #ifndef #line #pragma #undef #version

Operators and Expressions [5.1]

The following operators are numbered in order of precedence. Relational and equality operators evaluate to Boolean. Also See lessThan(), equal().

1.	( )	parenthetical grouping
2.	[ ] ( ) . ++ --	array subscript function call, constructor, structure field, selector, swizzle postfix increment and decrement
3.	++ -- + - ~ !	prefix increment and decrement unary
4.	* / %	multiplicative
5.	+ -	additive
6.	<< >>	bit-wise shift
7.	< > <= >=	relational
8.	== !=	equality
9.	&	bit-wise and
10.	^	bit-wise exclusive or
11.	|	bit-wise inclusive or
12.	&&	logical and
13.	^^	logical exclusive or
14.	||	logical inclusive or
15.	? :	selects an entire operand
16.	= += -= *= /= %= <<= >>= &= ^= |=	assignment arithmetic assignments
17.	,	sequence

Vector & Scalar Components [5.5]

In addition to array numeric subscript syntax, names of vector and scalar components are denoted by a single letter. Components can be swizzled and replicated. Scalars have only an *x*, *r*, or *s* component.

{x, y, z, w}	Points or normals
{r, g, b, a}	Colors
{s, t, p, q}	Texture coordinates

Types [4.1]

Transparent Types

void	no function return value
bool	Boolean
int, uint	signed/unsigned integers
float	single-precision floating-point scalar
double	double-precision floating scalar
vec2, vec3, vec4	floating point vector
dvec2, dvec3, dvec4	double precision floating-point vectors
bvec2, bvec3, bvec4	Boolean vectors
ivec2, ivec3, ivec4 **uvec2, uvec3, uvec4**	signed and unsigned integer vectors
mat2, mat3, mat4	2x2, 3x3, 4x4 float matrix
mat2x2, mat2x3, mat2x4	2-column float matrix of 2, 3, or 4 rows
mat3x2, mat3x3, mat3x4	3-column float matrix of 2, 3, or 4 rows
mat4x2, mat4x3, mat4x4	4-column float matrix of 2, 3, or 4 rows
dmat2, dmat3, dmat4	2x2, 3x3, 4x4 double-precision float matrix
dmat2x2, dmat2x3, dmat2x4	2-col. double-precision float matrix of 2, 3, 4 rows
dmat3x2, dmat3x3, dmat3x4	3-col. double-precision float matrix of 2, 3, 4 rows
dmat4x2, dmat4x3, dmat4x4	4-column double-precision float matrix of 2, 3, 4 rows

Floating-Point Opaque Types

sampler{1D,2D,3D} **image{1D,2D,3D}**	1D, 2D, or 3D texture
samplerCube **imageCube**	cube mapped texture
sampler2DRect **image2DRect**	rectangular texture
sampler{1D,2D}Array **image{1D,2D}Array**	1D or 2D array texture
samplerBuffer **imageBuffer**	buffer texture
sampler2DMS **image2DMS**	2D multi-sample texture
sampler2DMSArray **image2DMSArray**	2D multi-sample array texture
samplerCubeArray **imageCubeArray**	cube map array texture
sampler1DShadow **sampler2DShadow**	1D or 2D depth texture with comparison
sampler2DRectShadow	rectangular tex. / compare
sampler1DArrayShadow **sampler2DArrayShadow**	1D or 2D array depth texture with comparison
samplerCubeShadow	cube map depth texture with comparison
samplerCubeArrayShadow	cube map array depth texture with comparison

Signed Integer Opaque Types

isampler[1,2,3]D	integer 1D, 2D, or 3D texture
iimage[1,2,3]D	integer 1D, 2D, or 3D image
isamplerCube	integer cube mapped texture
iimageCube	integer cube mapped image
isampler2DRect	int. 2D rectangular texture

Continue ⤴

Signed Integer Opaque Types (cont'd)

iimage2DRect	int. 2D rectangular image
isampler[1,2]DArray	integer 1D, 2D array texture
iimage[1,2]DArray	integer 1D, 2D array image
isamplerBuffer	integer buffer texture
iimageBuffer	integer buffer image
isampler2DMS	int. 2D multi-sample texture
iimage2DMS	int. 2D multi-sample image
isampler2DMSArray	int. 2D multi-sample array tex.
iimage2DMSArray	int. 2D multi-sample array image
isamplerCubeArray	int. cube map array texture
iimageCubeArray	int. cube map array image

Unsigned Integer Opaque Types

atomic_uint	uint atomic counter
usampler[1,2,3]D	uint 1D, 2D, or 3D texture
uimage[1,2,3]D	uint 1D, 2D, or 3D image
usamplerCube	uint cube mapped texture
uimageCube	uint cube mapped image
usampler2DRect	uint rectangular texture
uimage2DRect	uint rectangular image
usampler[1,2]DArray	1D or 2D array texture
uimage[1,2]DArray	1D or 2D array image
usamplerBuffer	uint buffer texture
uimageBuffer	uint buffer image
usampler2DMS	uint 2D multi-sample texture
uimage2DMS	uint 2D multi-sample image
usampler2DMSArray	uint 2D multi-sample array tex.

Continue ⤴

Unsigned Integer Opaque Types (cont'd)

uimage2DMSArray	uint 2D multi-sample array image
usamplerCubeArray	uint cube map array texture
uimageCubeArray	uint cube map array image

Implicit Conversions

int	->	uint	uvec2	->	dvec2
int, uint	->	float	uvec3	->	dvec3
int, uint, float	->	double	uvec4	->	dvec4
ivec2	->	uvec2	vec2	->	dvec2
ivec3	->	uvec3	vec3	->	dvec3
ivec4	->	uvec4	vec4	->	dvec4
ivec2	->	vec2	mat2	->	dmat2
ivec3	->	vec3	mat3	->	dmat3
ivec4	->	vec4	mat4	->	dmat4
uvec2	->	vec2	mat2x3	->	dmat2x3
uvec3	->	vec3	mat2x4	->	dmat2x4
uvec4	->	vec4	mat3x2	->	dmat3x2
ivec2	->	dvec2	mat3x4	->	dmat3x4
ivec3	->	dvec3	mat4x2	->	dmat4x2
ivec4	->	dvec4	mat4x3	->	dmat4x3

Aggregation of Basic Types

Arrays	float[3] foo; float foo[3]; int a [3][2];
	// Structures, blocks, and structure members
	// can be arrays. Arrays of arrays supported.

Structures	**struct** *type-name* {
	members
	} *struct-name*[];
	// optional variable declaration

Blocks	**in/out/uniform** *block-name* {
	// interface matching by block name
	optionally-qualified members
	} *instance-name*[];
	// optional instance name, optionally an array

Qualifiers

Storage Qualifiers [4.3]

Declarations may have one storage qualifier.

none	(default) local read/write memory, or input parameter
const	read-only variable
in	linkage into shader from previous stage
out	linkage out of a shader to next stage
uniform	linkage between a shader, OpenGL, and the application
buffer	accessible by shaders and OpenGL API
shared	compute shader only, shared among work items in a local work group

Auxiliary Storage Qualifiers

Use to qualify some input and output variables:

centroid	centroid-based interpolation
sampler	per-sample interpolation
patch	per-tessellation-patch attributes

Interface Blocks [4.3.9]

in, **out**, **uniform**, and **buffer** variable declarations can be grouped. For example:

```
uniform Transform {
    // allowed restatement qualifier:
    mat4 ModelViewMatrix;
    uniform mat3 NormalMatrix;
};
```

Layout Qualifiers [4.4]

The following table summarizes the use of layout qualifiers applied to non-opaque types and the kinds of declarations they may be applied to.
Op = Opaque types only, FC = gl_FragCoord only, FD = gl_FragDepth only.

Layout Qualifier	Qualif. Only	Indiv. Var.	Block	Block Mem.	Allowed Interfaces
shared, packed, std{140, 430}	X		X		**uniform/buffer**
{row, column}_major	X		X	X	
binding =		Op	X		
offset =				X	
align =			X	X	
location =		X			**uniform/buffer** and subroutine variables
location =		X	X	X	all **in/out**, except for compute
component =		X		X	
index =		X			fragment **out** and subroutine functions
triangles, quads, isolines	X				tessellation evaluation **in**
equal_spacing, fractional_even_spacing, fractional_odd_spacing	X				
cw, ccw	X				
point_mode	X				
points	X				geometry **in/out**
[points], lines, triangles, {triangles, lines}_adjacency	X				geometry **in**
invocations =	X				geometry **in**

Layout Qualifier	Qualif. Only	Indiv. Var.	Block	Block Mem.	Allowed Interfaces
origin_upper_left pixel_center_integer		FC			fragment **in**
early_fragment_tests	X				
local_size_{x, y, z} =	X				compute **in**
xfb_{buffer, stride} =	X	X	X	X	vertex, tessellation, and geometry **out**
xfb_offset =		X	X	X	
vertices =	X				tessellation control **out**
[points], line_strip, triangle_strip	X				geometry **out**
max_vertices =	X				
stream =	X	X	X	X	
depth_{any, greater, less, unchanged}		FD			fragment **out**

Opaque Uniform Layout Qualifiers [4.4.6]

Used to bind opaque uniform variables to specific buffers or units.

binding = *integer-constant-expression*

Atomic Counter Layout Qualifiers

binding = *integer-constant-expression*
offset = *integer-constant-expression*

(Continued on next page) ▶

◀Qualifiers (continued)

Format Layout Qualifiers

One qualifier may be used with variables declared as "image" to specify the image format.

binding = *integer-constant-expression*, rgba{32,16}f, rg{32,16}f, r{32,16}f, rgba{16,8}, r11f_g11f_b10f, rgb10_a2{ui}, rg{16,8}, r{16,8}, rgba{32,16,8}i, rg{32,16,8}i, r{32,16,8}i, rgba{32,16,8}ui, rg{32,16,8}ui, r{32,16,8}ui, rgba{16,8}_snorm, rg{16,8}_snorm, r{16,8}_snorm

Interpolation Qualifiers [4.5]

Qualify outputs from vertex shader and inputs to fragment shader.

smooth	perspective correct interpolation
flat	no interpolation
noperspective	linear interpolation

Parameter Qualifiers [4.6]

Input values copied in at function call time, output values copied out at function return.

none	(default) same as **in**
in	for function parameters passed into function
const	for function parameters that cannot be written to
out	for function parameters passed back out of function, but not initialized when passed in
inout	for function parameters passed both into and out of a function

Precision Qualifiers [4.7]

Qualify individual variables:

{highp, mediump, lowp} *variable-declaration*;

Establish a default precision qualifier:

precision {highp, mediump, lowp} {int, float};

Invariant Qualifiers Examples [4.8]

These are for vertex, tessellation, geometry, and fragment languages.

#pragma STDGL **invariant**(all)	force all output variables to be invariant
invariant gl_Position;	qualify a previously declared variable
invariant centroid out vec3 Color;	qualify as part of a variable declaration

Precise Qualifier [4.9]

Ensures that operations are executed in stated order with operator consistency. For example, a fused multiply-add cannot be used in the following; it requires two identical multiplies, followed by an add.

precise out vec4 Position = a * b + c * d;

Memory Qualifiers [4.10]

Variables qualified as "image" can have one or more memory qualifiers.

coherent	reads and writes are coherent with other shader invocations
volatile	underlying values may be changed by other sources
restrict	won't be accessed by other code
readonly	read only
writeonly	write only

Order of Qualification [4.11]

When multiple qualifiers are present in a declaration they may appear in any order, but must all appear before the type.

The layout qualifier is the only qualifier that can appear more than once. Further, a declaration can have at most one storage qualifier, at most one auxiliary storage qualifier, and at most one interpolation qualifier.

Multiple memory qualifiers can be used. Any rule violation will cause a compile-time error.

Operations and Constructors

Vector & Matrix [5.4.2]

.**length**() for matrices returns number of columns

.**length**() for vectors returns number of components

```
mat2(vec2, vec2);                    // 1 col./arg.
mat2x3(vec2, float, vec2, float);    // col. 2
dmat2(dvec2, dvec2);                 // 1 col./arg.
dmat3(dvec3, dvec3, dvec3);          // 1 col./arg.
```

Structure Example [5.4.3]

.**length**() for structures returns number of members

```
struct light {members; };
light lightVar = light(3.0, vec3(1.0, 2.0, 3.0));
```

Matrix Examples [5.6]

Examples of access components of a matrix with array subscripting syntax:

```
mat4 m;              // m is a matrix
m[1] = vec4(2.0);    // sets 2nd col. to all 2.0
m[0][0] = 1.0;       // sets upper left element to 1.0
m[2][3] = 2.0;       // sets 4th element of 3rd col. to 2.0
```

Examples of operations on matrices and vectors:

```
m = f * m;       // scalar * matrix component-wise
v = f * v;       // scalar * vector component-wise
v = v * v;       // vector * vector component-wise
m = m +/- m;     // matrix +/- matrix comp.-wise
m = m * m;       // linear algebraic multiply
f = dot(v, v);   // vector dot product
v = cross(v, v); // vector cross product
```

Array Example [5.4.4]

```
const float c[3];
c.length()       // will return the integer 3
```

Structure & Array Operations [5.7]

Select structure fields or **length**() method of an array using the period (.) operator. Other operators:

.	field or method selector
== !=	equality
=	assignment
[ ]	indexing (arrays only)

Array elements are accessed using the array subscript operator ([ ]), e.g.:

diffuseColor += lightIntensity[3]*NdotL;

Statements and Structure

Subroutines [6.1.2]

Subroutine type variables are assigned to functions through the **UniformSubroutinesuiv** command in the OpenGL API.

Declare types with the **subroutine** keyword:

subroutine returnType subroutineTypeName(type0 arg0,
type1 arg1, ..., type*n* arg*n*);

Associate functions with subroutine types of matching declarations by defining the functions with the **subroutine** keyword and a list of subroutine types the function matches:

subroutine(subroutineTypeName0, ...,
subroutineTypeName*N*)
returnType functionName(type0 arg0,
type1 arg1, ..., type*n* arg*n*){ ... }
// function body

Declare subroutine type variables with a specific subroutine type in a subroutine uniform variable declaration:

subroutine uniform subroutineTypeName
subroutineVarName;

Iteration and Jumps [6.3-4]

Function	call by value-return

Iteration	for (;;) { break, continue }
	while ( ) { break, continue }
	do { break, continue } while ( );

Selection	if ( ) { }
	if ( ) { } else { }
	switch ( ) { case integer: ... break; ... default: ... }

Entry	void main()
Jump	break, continue, return (There is no 'goto')
Exit	return in main() discard // Fragment shader only

Built-In Variables [7]

Vertex Language

Inputs	in int gl_VertexID; in int gl_InstanceID;

Outputs	out gl_PerVertex {
	vec4 gl_Position;
	float gl_PointSize;
	float gl_ClipDistance[];
	float gl_CullDistance[];
	};

Tessellation Control Language

Inputs	in gl_PerVertex { vec4 gl_Position; float gl_PointSize; float gl_ClipDistance[]; float gl_CullDistance[]; } gl_in[gl_MaxPatchVertices]; in int gl_PatchVerticesIn; in int gl_PrimitiveID; in int gl_InvocationID;
Outputs	out gl_PerVertex { vec4 gl_Position; float gl_PointSize; float gl_ClipDistance[]; float gl_CullDistance[]; } gl_out[]; patch out float gl_TessLevelOuter[4]; patch out float gl_TessLevelInner[2];

Tessellation Evaluation Language

Inputs	in gl_PerVertex { vec4 gl_Position; float gl_PointSize; float gl_ClipDistance[]; float gl_CullDistance[]; } gl_in[gl_MaxPatchVertices]; in int gl_PatchVerticesIn; in int gl_PrimitiveID; in vec3 gl_TessCoord; patch in float gl_TessLevelOuter[4]; patch in float gl_TessLevelInner[2];

Outputs	out gl_PerVertex {
	vec4 gl_Position;
	float gl_PointSize;
	float gl_ClipDistance[];
	float gl_CullDistance[];
	};

Geometry Language

Inputs	in gl_PerVertex { vec4 gl_Position; float gl_PointSize; float gl_ClipDistance[]; float gl_CullDistance[]; } gl_in[]; in int gl_PrimitiveIDIn; in int gl_InvocationID;

Outputs	out gl_PerVertex {
	vec4 gl_Position;
	float gl_PointSize;
	float gl_ClipDistance[];
	float gl_CullDistance[];
	};
	
	out int gl_PrimitiveID;
	out int gl_Layer;
	out int gl_ViewportIndex;

Fragment Language

Inputs	in vec4 gl_FragCoord; in bool gl_FrontFacing; in float gl_ClipDistance[]; in float gl_CullDistance[]; in vec2 gl_PointCoord; in int gl_PrimitiveID; in int gl_SampleID; in vec2 gl_SamplePosition; in int gl_SampleMaskIn[]; in int gl_Layer; in int gl_ViewportIndex; in bool gl_HelperInvocation;
Outputs	out float gl_FragDepth; out int gl_SampleMask[];

Compute Language

More information in diagram on page 6.

Inputs	**Work group dimensions** in uvec3 gl_NumWorkGroups; const uvec3 gl_WorkGroupSize; in uvec3 gl_LocalGroupSize; **Work group and invocation IDs** in uvec3 gl_WorkGroupID; in uvec3 gl_LocalInvocationID; **Derived variables** in uvec3 gl_GlobalInvocationID; in uint gl_LocalInvocationIndex;

Built-In Constants [7.3]

The following are provided to all shaders. The actual values are implementation-dependent, but must be at least the value shown.

```
const ivec3 gl_MaxComputeWorkGroupCount =
        {65535, 65535, 65535} ;
const ivec3 gl_MaxComputeWorkGroupSize[] =
        {1024, 1024, 64};
const int gl_MaxComputeUniformComponents = 1024;
const int gl_MaxComputeTextureImageUnits = 16;
const int gl_MaxComputeImageUniforms = 8;
const int gl_MaxComputeAtomicCounters = 8;
const int gl_MaxComputeAtomicCounterBuffers = 1;
const int gl_MaxVertexAttribs = 16;
const int gl_MaxVertexUniformComponents = 1024;
const int gl_MaxVaryingComponents= 60;
const int gl_MaxVertexOutputComponents = 64;
const int gl_MaxGeometryInputComponents = 64;
const int gl_MaxGeometryOutputComponents = 128;
const int gl_MaxFragmentInputComponents = 128;
const int gl_MaxVertexTextureImageUnits = 16;
const int gl_MaxCombinedTextureImageUnits = 80;
const int gl_MaxTextureImageUnits = 16;
const int gl_MaxImageUnits = 8;
  gl_MaxCombinedImageUnitsAndFragmentOutputs = 8;
const int gl_MaxImageSamples = 0;
const int gl_MaxVertexImageUniforms= 0;
const int gl_MaxTessControlImageUniforms = 0;
const int gl_MaxTessEvaluationImageUniforms = 0;
const int gl_MaxGeometryImageUniforms = 0;
const int gl_MaxFragmentImageUniforms = 8;
const int gl_MaxCombinedImageUniforms = 8;
const int gl_MaxFragmentUniformComponents = 1024;
const int gl_MaxDrawBuffers = 8;
const int gl_MaxClipDistances = 8;
const int gl_MaxGeometryTextureImageUnits = 16;
const int gl_MaxGeometryOutputVertices = 256;
const int gl_MaxGeometryTotalOutputComponents = 1024;
const int gl_MaxGeometryUniformComponents = 1024;
const int gl_MaxGeometryVaryingComponents = 64;
const int gl_MaxTessControlInputComponents = 128;
const int gl_MaxTessControlOutputComponents = 128;
const int gl_MaxTessControlTextureImageUnits = 16;
const int gl_MaxTessControlUniformComponents = 1024;
const int gl_MaxTessControlTotalOutputComponents = 4096;
const int gl_MaxTessEvaluationInputComponents = 128;
const int gl_MaxTessEvaluationOutputComponents = 128;
const int gl_MaxTessEvaluationTextureImageUnits = 16;
const int gl_MaxTessEvaluationUniformComponents = 1024;
const int gl_MaxTessPatchComponents = 120;
const int gl_MaxPatchVertices = 32;
const int gl_MaxTessGenLevel = 64;
const int gl_MaxViewports = 16;
const int gl_MaxVertexUniformVectors = 256;
const int gl_MaxFragmentUniformVectors = 256;
const int gl_MaxVaryingVectors = 15;
const int gl_MaxVertexAtomicCounters = 0;
const int gl_MaxTessControlAtomicCounters = 0;
const int gl_MaxTessEvaluationAtomicCounters = 0;
const int gl_MaxGeometryAtomicCounters = 0;
const int gl_MaxFragmentAtomicCounters = 8;
const int gl_MaxCombinedAtomicCounters = 8;
const int gl_MaxAtomicCounterBindings = 1;
const int gl_MaxVertexAtomicCounterBuffers = 0;
const int gl_MaxTessControlAtomicCounterBuffers = 0;
const int gl_MaxTessEvaluationAtomicCounterBuffers = 0;
const int gl_MaxGeometryAtomicCounterBuffers = 0;
const int gl_MaxFragmentAtomicCounterBuffers = 1;
const int gl_MaxCombinedAtomicCounterBuffers = 1;
const int gl_MaxAtomicCounterBufferSize = 32;
const int gl_MinProgramTexelOffset = -8;
const int gl_MaxProgramTexelOffset = 7;
const int gl_MaxTransformFeedbackBuffers = 4;
  gl_MaxTransformFeedbackInterleavedComponents = 64;
const int gl_MaxCullDistances = 8;
const int gl_MaxCombinedClipAndCullDistances = 8;
const int gl_MaxSamples = 4;
const int gl_MaxVertexImageUniforms = 0;
const int gl_MaxFragmentImageUniforms = 8;
const int gl_MaxComputeImageUniforms = 8;
const int gl_MaxCombinedImageUniforms = 48;
const int gl_MaxCombinedShaderOutputResources = 16;
```

Built-In Functions

Angle & Trig. Functions [8.1]

Functions will not result in a divide-by-zero error. If the divisor of a ratio is 0, then results will be undefined. Component-wise operation. Parameters specified as *angle* are in units of radians. Tf=float, vec*n*.

Tf **radians**(Tf *degrees*)	degrees to radians
Tf **degrees**(Tf *radians*)	radians to degrees
Tf **sin**(Tf *angle*)	sine
Tf **cos**(Tf *angle*)	cosine
Tf **tan**(Tf *angle*)	tangent
Tf **asin**(Tf *x*)	arc sine
Tf **acos**(Tf *x*)	arc cosine
Tf **atan**(Tf *y*, Tf *x*) Tf **atan**(Tf *y_over_x*)	arc tangent
Tf **sinh**(Tf *x*)	hyperbolic sine
Tf **cosh**(Tf *x*)	hyperbolic cosine
Tf **tanh**(Tf *x*)	hyperbolic tangent
Tf **asinh**(Tf *x*)	hyperbolic sine
Tf **acosh**(Tf *x*)	hyperbolic cosine
Tf **atanh**(Tf *x*)	hyperbolic tangent

Exponential Functions [8.2]

Component-wise operation. Tf=float, vec*n*. Td= double, dvec*n*. Tfd= Tf, Td

Tf **pow**(Tf *x*, Tf *y*)	x^y
Tf **exp**(Tf *x*)	e^x
Tf **log**(Tf *x*)	ln
Tf **exp2**(Tf *x*)	2^x
Tf **log2**(Tf *x*)	$\log_2$
Tfd **sqrt**(Tfd *x*)	square root
Tfd **inversesqrt**(Tfd *x*)	inverse square root

Common Functions [8.3]

Component-wise operation. Tf=float, vec*n*. Tb=bool, bvec*n*. Ti=int, ivec*n*. Tu=uint, uvec*n*. Td= double, dvec*n*. Tfd= Tf, Td. Tiu= Ti, Tu.

Returns absolute value:
Tfd **abs**(Tfd *x*)   Ti **abs**(Ti *x*)

Returns -1.0, 0.0, or 1.0:
Tfd **sign**(Tfd *x*)   Ti **sign**(Ti *x*)

Returns nearest integer <= *x*:
Tfd **floor**(Tfd *x*)

Returns nearest integer with absolute value <= absolute value of *x*:
Tfd **trunc**(Tfd *x*)

Returns nearest integer, implementation-dependent rounding mode:
Tfd **round**(Tfd *x*)

Returns nearest integer, 0.5 rounds to nearest even integer:
Tfd **roundEven**(Tfd *x*)

Returns nearest integer >= *x*:
Tfd **ceil**(Tfd *x*)

Returns *x* - floor(*x*):
Tfd **fract**(Tfd *x*)

Returns modulus:
Tfd **mod**(Tfd *x*, Tfd *y*)
Tf **mod**(Tf *x*, float *y*)
Td **mod**(Td *x*, double *y*)

Returns separate integer and fractional parts:
Tfd **modf**(Tfd *x*, out Tfd *i*)

Returns minimum value:
Tfd **min**(Tfd *x*, Tfd *y*)   Tiu **min**(Tiu *x*, Tiu *y*)
Tf **min**(Tf *x*, float *y*)   Ti **min**(Ti *x*, int *y*)
Td **min**(Td *x*, double *y*)   Tu **min**(Tu *x*, uint *y*)

(Continue ⤴)

Common Functions (cont.)

Returns maximum value:
Tfd **max**(Tfd *x*, Tfd *y*)   Tiu **max**(Tiu *x*, Tiu *y*)
Tf **max**(Tf *x*, float *y*)   Ti **max**(Ti *x*, int *y*)
Td **max**(Td *x*, double *y*)   Tu **max**(Tu *x*, uint *y*)

Returns min(max(*x*, *minVal*), *maxVal*):
Tfd **clamp**(Tfd *x*, Tfd *minVal*, Tfd *maxVal*)
Tf **clamp**(Tf *x*, float *minVal*, float *maxVal*)
Td **clamp**(Td *x*, double *minVal*, double *maxVal*)
Tiu **clamp**(Tiu *x*, Tiu *minVal*, Tiu *maxVal*)
Ti **clamp**(Ti *x*, int *minVal*, int *maxVal*)
Tu **clamp**(Tu *x*, uint *minVal*, uint *maxVal*)

Returns linear blend of *x* and *y*:
Tfd **mix**(Tfd *x*, Tfd *y*, Tfd *a*)   Ti **mix**(Ti *x*, Ti *y*, Ti *a*)
Tf **mix**(Tf *x*, Tf *y*, float *a*)   Tu **mix**(Tu *x*, Tu *y*, Tu *a*)
Td **mix**(Td *x*, Td *y*, double *a*)

Components returned come from *x* when *a* components are true, from *y* when *a* components are false:
Tfd **mix**(Tfd *x*, Tfd *y*, Tb *a*)   Tb **mix**(Tb *x*, Tb *y*, Tb *a*)
Tiu **mix**(Tiu *x*, Tiu *y*, Tb *a*)

Returns 0.0 if *x* < *edge*, else 1.0:
Tfd **step**(Tfd *edge*, Tfd *x*)
Tf **step**(float *edge*, Tf *x*)
Td **step**(double *edge*, Td *x*)

Clamps and smoothes:
Tfd **smoothstep**(Tfd *edge0*, Tfd *edge1*, Tfd *x*)
Tf **smoothstep**(float *edge0*, float *edge1*, Tf *x*)
Td **smoothstep**(double *edge0*, double *edge1*, Td *x*)

Returns true if *x* is NaN:
Tb **isnan**(Tfd *x*)

Returns true if *x* is positive or negative infinity:
Tb **isinf**(Tfd *x*)

Returns signed int or uint value of the encoding of a float:
Ti **floatBitsToInt**(Tf *value*)
Tu **floatBitsToUint**(Tf *value*)

Returns float value of a signed int or uint encoding of a float:
Tf **intBitsToFloat**(Ti *value*)   Tf **uintBitsToFloat**(Tu *value*)

Computes and returns a*b + c. Treated as a single operation when using **precise**:
Tfd **fma**(Tfd *a*, Tfd *b*, Tfd *c*)

Splits *x* into a floating-point significand in the range [0.5, 1.0) and an integer exponent of 2:
Tfd **frexp**(Tfd *x*, out Ti *exp*)

Builds a floating-point number from *x* and the corresponding integral exponent of 2 in *exp*:
Tfd **ldexp**(Tfd *x*, in Ti *exp*)

Floating-Point Pack/Unpack [8.4]

These do not operate component-wise.

Converts each component of *v* into 8- or 16-bit ints, packs results into the returned 32-bit unsigned integer:
uint **packUnorm2x16**(vec2 *v*)   uint **packUnorm4x8**(vec4 *v*)
uint **packSnorm2x16**(vec2 *v*)   uint **packSnorm4x8**(vec4 *v*)

Unpacks 32-bit *p* into two 16-bit uints, four 8-bit uints, or signed ints. Then converts each component to a normalized float to generate a 2- or 4-component vector:
vec2 **unpackUnorm2x16**(uint *p*)
vec2 **unpackSnorm2x16**(uint *p*)
vec4 **unpackUnorm4x8**(uint *p*)
vec4 **unpackSnorm4x8**(uint *p*)

Packs components of *v* into a 64-bit value and returns a double-precision value:
double **packDouble2x32**(uvec2 *v*)

Returns a 2-component vector representation of *v*:
uvec2 **unpackDouble2x32**(double *v*)

Returns a uint by converting the components of a two-component floating-point vector:
uint **packHalf2x16**(vec2 *v*)

Returns a two-component floating-point vector:
vec2 **unpackHalf2x16**(uint *v*)

Type Abbreviations for Built-in Functions: In vector types, *n* is 2, 3, or 4.
Tf=float, vec*n*. Td =double, dvec*n*. Tfd= float, vec*n*, double, dvec*n*. Tb= bool, bvec*n*. Tu=uint, uvec*n*. Ti=int, ivec*n*. Tiu=int, ivec*n*, uint, uvec*n*. Tvec=vec*n*, uvec*n*, ivec*n*.
Within any one function, type sizes and dimensionality must correspond after implicit type conversions. For example, float **round**(float) is supported, but float **round**(vec4) is not.

Geometric Functions [8.5]

These functions operate on vectors as vectors, not component-wise. Tf=float, vec*n*. Td =double, dvec*n*. Tfd= float, vec*n*, double, dvec*n*.

float **length**(Tf *x*) double **length**(Td *x*)	length of vector
float **distance**(Tf *p0*, Tf *p1*) double **distance**(Td *p0*, Td *p1*)	distance between points
float **dot**(Tf *x*, Tf *y*) double **dot**(Td *x*, Td *y*)	dot product
vec3 **cross**(vec3 *x*, vec3 *y*) dvec3 **cross**(dvec3 *x*, dvec3 *y*)	cross product
Tfd **normalize**(Tfd *x*)	normalize vector to length 1
Tfd **faceforward**(Tfd *N*, Tfd *I*, Tfd *Nref*)	returns *N* if dot(*Nref*, *I*) < 0, else -*N*
Tfd **reflect**(Tfd *I*, Tfd *N*)	reflection direction *I* - 2 * dot(*N*,*I*) * *N*
Tfd **refract**(Tfd *I*, Tfd *N*, float *eta*)	refraction vector

Matrix Functions [8.6]

N and *M* are 1, 2, 3, 4.

mat **matrixCompMult**(mat *x*, mat *y*) dmat **matrixCompMult**(dmat *x*, dmat *y*)	component-wise multiply
mat*N* **outerProduct**(vec*N* *c*, vec*N* *r*) dmat*N* **outerProduct**(dvec*N* *c*, dvec*N* *r*)	outer product (where *N* != *M*)
mat*N*x*M* **outerProduct**(vec*M* *c*, vec*N* *r*) dmat*N*x*M* **outerProduct**(dvec*M* *c*, dvec*N* *r*)	outer product
mat*N* **transpose**(mat*N* *m*) dmat*N* **transpose**(dmat*N* *m*)	transpose
mat*N*x*M* **transpose**(mat*M*x*N* *m*) dmat*N*x*M* **transpose**(dmat*M*x*N* *m*)	transpose (where *N* != *M*)
float **determinant**(mat*N* *m*) double **determinant**(dmat*N* *m*)	determinant
mat*N* **inverse**(mat*N* *m*) dmat*N* **inverse**(dmat*N* *m*)	inverse

Vector Relational Functions [8.7]

Compare *x* and *y* component-wise. Sizes of the input and return vectors for any particular call must match. Tvec=vec*n*, uvec*n*, ivec*n*.

bvec*n* **lessThan**(Tvec *x*, Tvec *y*)	<
bvec*n* **lessThanEqual**(Tvec *x*, Tvec *y*)	<=
bvec*n* **greaterThan**(Tvec *x*, Tvec *y*)	>
bvec*n* **greaterThanEqual**(Tvec *x*, Tvec *y*)	>=
bvec*n* **equal**(Tvec *x*, Tvec *y*) bvec*n* **equal**(bvec*n* *x*, bvec*n* *y*)	==
bvec*n* **notEqual**(Tvec *x*, Tvec *y*) bvec*n* **notEqual**(bvec*n* *x*, bvec*n* *y*)	!=
bool **any**(bvec*n* *x*)	true if any component of *x* is true
bool **all**(bvec*n* *x*)	true if all comps. of *x* are true
bvec*n* **not**(bvec*n* *x*)	logical complement of *x*

Integer Functions [8.8]

Component-wise operation. Tu=uint, uvec*n*. Ti=int, ivec*n*. Tiu=int, ivec*n*, uint, uvec*n*.

Adds 32-bit uint *x* and *y*, returning the sum modulo 2^{32}:
Tu **uaddCarry**(Tu *x*, Tu *y*, out Tu *carry*)

Subtracts *y* from *x*, returning the difference if non-negative, otherwise 2^{32} plus the difference:
Tu **usubBorrow**(Tu *x*, Tu *y*, out Tu *borrow*)

(Continue ⤴)

Integer Functions (cont.)

Multiplies 32-bit integers *x* and *y*, producing a 64-bit result:
void **umulExtended**(Tu *x*, Tu *y*, out Tu *msb*, out Tu *lsb*)
void **imulExtended**(Ti *x*, Ti *y*, out Ti *msb*, out Ti *lsb*)

Extracts bits [*offset*, *offset* + *bits* - 1] from *value*, returns them in the least significant bits of the result:
Tiu **bitfieldExtract**(Tiu *value*, int *offset*, int *bits*)

Returns the reversal of the bits of *value*:
Tiu **bitfieldReverse**(Tiu *value*)

Inserts the *bits* least-significant bits of *insert* into *base*:
Tiu **bitfieldInsert**(Tiu *base*, Tiu *insert*, int *offset*, int *bits*)

Returns the number of bits set to 1:
Ti **bitCount**(Tiu *value*)

Returns the bit number of the least significant bit:
Ti **findLSB**(Tiu *value*)

Returns the bit number of the most significant bit:
Ti **findMSB**(Tiu *value*)

Texture Lookup Functions [8.9]

Available to vertex, geometry, and fragment shaders. See tables on next page.

Atomic-Counter Functions [8.10]

Returns the value of an atomic counter.

Atomically increments *c* then returns its prior value:
uint **atomicCounterIncrement**(atomic_uint *c*)

Atomically decrements *c* then returns its prior value:
uint **atomicCounterDecrement**(atomic_uint *c*)

Atomically returns the counter for *c*:
uint **atomicCounter**(atomic_uint *c*)

Atomic Memory Functions [8.11]

Operates on individual integers in buffer-object or shared-variable storage. *OP* is Add, Min, Max, And, Or, Xor, Exchange, or CompSwap.

uint **atomic*OP***(coherent inout uint *mem*, uint *data*)

int **atomic*OP***(coherent inout int *mem*, int *data*)

Image Functions [8.12]

In the image functions below, *IMAGE_PARAMS* may be one of the following:

gimage1D *image*, int *P*
gimage2D *image*, ivec2 *P*
gimage3D *image*, ivec3 *P*
gimage2DRect *image*, ivec2 *P*
gimageCube *image*, ivec3 *P*
gimageBuffer *image*, int *P*
gimage1DArray *image*, ivec2 *P*
gimage2DArray *image*, ivec3 *P*
gimageCubeArray *image*, ivec3 *P*
gimage2DMS *image*, ivec2 *P*, int *sample*
gimage2DMSArray *image*, ivec3 *P*, int *sample*

Returns the dimensions of the images or images:
int **imageSize**(gimage{1D,Buffer} *image*)
ivec2 **imageSize**(gimage{2D,Cube,Rect,1DArray, 2DMS} *image*)
ivec3 **imageSize**(gimage{Cube,2D,2DMS}Array *image*)
vec3 **imageSize**(gimage3D *image*)

Returns the number of samples of the image or images bound to image:
int **imageSamples**(gimage2DMS *image*)
int **imageSamples**(gimage2DMSArray *image*)

Loads texel at the coordinate *P* from the image unit *image*:
gvec4 **imageLoad**(readonly *IMAGE_PARAMS*)

Stores *data* into the texel at the coordinate *P* from the image specified by *image*:
void **imageStore**(writeonly *IMAGE_PARAMS*, gvec4 *data*)

(Continued on next page) ▶

◀ Built-In Functions (cont.)

Image Functions (cont.)

Adds the value of *data* to the contents of the selected texel:
- uint **imageAtomicAdd**(coherent *IMAGE_PARAMS*, uint *data*)
- int **imageAtomicAdd**(coherent *IMAGE_PARAMS*, int *data*)

Takes the minimum of the value of *data* and the contents of the selected texel:
- uint **imageAtomicMin**(coherent *IMAGE_PARAMS*, uint *data*)
- int **imageAtomicMin**(coherent *IMAGE_PARAMS*, int *data*)

Takes the maximum of the value *data* and the contents of the selected texel:
- uint **imageAtomicMax**(coherent *IMAGE_PARAMS*, uint *data*)
- int **imageAtomicMax**(coherent *IMAGE_PARAMS*, int *data*)

Performs a bit-wise AND of the value of *data* and the contents of the selected texel:
- uint **imageAtomicAnd**(coherent *IMAGE_PARAMS*, uint *data*)
- int **imageAtomicAnd**(coherent *IMAGE_PARAMS*, int *data*)

Performs a bit-wise OR of the value of *data* and the contents of the selected texel:
- uint **imageAtomicOr**(coherent *IMAGE_PARAMS*, uint *data*)
- int **imageAtomicOr**(coherent *IMAGE_PARAMS*, int *data*)

Performs a bit-wise exclusive OR of the value of *data* and the contents of the selected texel:
- uint **imageAtomicXor**(coherent *IMAGE_PARAMS*, uint *data*)
- int **imageAtomicXor**(coherent *IMAGE_PARAMS*, int *data*)

(Continue ⮥)

Image Functions (cont.)

Copies the value of *data*:
- uint **imageAtomicExchange**(coherent *IMAGE_PARAMS*, uint *data*)
- int **imageAtomicExchange**(coherent *IMAGE_PARAMS*, int *data*)
- int **imageAtomicExchange**(coherent *IMAGE_PARAMS*, float *data*)

Compares the value of *compare* and contents of selected texel. If equal, the new value is given by *data*; otherwise, it is taken from the original value loaded from texel:
- uint **imageAtomicCompSwap**(coherent *IMAGE_PARAMS*, uint *compare*, uint *data*)
- int **imageAtomicCompSwap**(coherent *IMAGE_PARAMS*, int *compare*, int *data*)

Fragment Processing Functions [8.13]

Available only in fragment shaders.
Tf=float, vec*n*.

Derivative fragment-processing functions

Tf **dFdx**(Tf *p*) Tf **dFdy**(Tf *p*)	derivative in *x and y*, either fine or coarse derivatives
Tf **dFdxFine**(Tf *p*) Tf **dFdyFine**(Tf *p*)	fine derivative in *x* and *y* per pixel-row/column derivative
Tf **dFdxCoarse**(Tf *p*) Tf **dFdyCoarse**(Tf *p*)	coarse derivative in *x* and *y* per 2x2-pixel derivative
Tf **fwidth**(Tf *p*) Tf **fwidthFine**(Tf *p*) Tf **fwidthCoarse**(Tf *p*)	sum of absolute values of *x* and *y* derivatives

Interpolation fragment-processing functions

Return value of *interpolant* sampled inside pixel and the primitive:
- Tf **interpolateAtCentroid**(Tf *interpolant*)

Return value of *interpolant* at location of sample # *sample*:
- Tf **interpolateAtSample**(Tf *interpolant*, int *sample*)

Return value of *interpolant* sampled at fixed offset *offset* from pixel center:
- Tf **interpolateAtOffset**(Tf *interpolant*, vec2 *offset*)

Noise Functions [8.14]

Returns noise value. Available to fragment, geometry, and vertex shaders. *n* is 2, 3, or 4:
- float **noise1**(Tf *x*)
- vec*n* **noise*n***(Tf *x*)

Geometry Shader Functions [8.15]

Only available in geometry shaders.

Emits values of output variables to current output primitive stream *stream*:
- void **EmitStreamVertex**(int *stream*)

Completes current output primitive stream *stream* and starts a new one:
- void **EndStreamPrimitive**(int *stream*)

(Continue ⮥)

Geometry Shader Functions (cont'd)

Emits values of output variables to the current output primitive:
- void **EmitVertex**()

Completes output primitive and starts a new one:
- void **EndPrimitive**()

Other Shader Functions [8.16-17]

See diagram on page 11 for more information.

Synchronizes across shader invocations:
- void **barrier**()

Controls ordering of memory transactions issued by a single shader invocation:
- void **memoryBarrier**()

Controls ordering of memory transactions as viewed by other invocations in a compute work group:
- void **groupMemoryBarrier**()

Order reads and writes accessible to other invocations:
- void **memoryBarrierAtomicCounter**()
- void **memoryBarrierShared**()
- void **memoryBarrierBuffer**()
- void **memoryBarrierImage**()

Texture Functions [8.9]

Available to vertex, geometry, and fragment shaders. gvec4=vec4, ivec4, uvec4.
gsampler* =sampler*, isampler*, usampler*.

The *P* argument needs to have enough components to specify each dimension, array layer, or comparison for the selected sampler. The *dPdx* and *dPdy* arguments need enough components to specify the derivative for each dimension of the sampler.

Texture Query Functions [8.9.1]

textureSize functions return dimensions of *lod* (if present) for the texture bound to sampler. Components in return value are filled in with the width, height, depth of the texture. For array forms, the last component of the return value is the number of layers in the texture array.

- {int,ivec2,ivec3} **textureSize**(gsampler{1D[Array],2D[Rect,Array],Cube} *sampler*[, int *lod*])
- {int,ivec2,ivec3} **textureSize**(gsampler{Buffer,2DMS[Array]}*sampler*)
- {int,ivec2,ivec3} **textureSize**(sampler{1D, 2D, 2DRect,Cube[Array]}Shadow *sampler*[, int *lod*])
- ivec3 **textureSize**(samplerCubeArray *sampler*, int *lod*)

textureQueryLod functions return the mipmap array(s) that would be accessed in the *x* component of the return value. Returns the computed level of detail relative to the base level in the *y* component of the return value.

- vec2 **textureQueryLod**(gsampler{1D[Array],2D[Array],3D,Cube[Array]} *sampler*, {float,vec2,vec3} *P*)
- vec2 **textureQueryLod**(sampler{1D[Array],2D[Array],Cube[Array]}Shadow *sampler*, {float,vec2,vec3} *P*)

textureQueryLevels functions return the number of mipmap levels accessible in the texture associated with *sampler*.

- int **textureQueryLevels**(gsampler{1D[Array],2D[Array],3D,Cube[Array]} *sampler*)
- int **textureQueryLevels**(sampler{1D[Array],2D[Array],Cube[Array]}Shadow *sampler*)

textureSamples returns the number of samples of the texture.

- int **textureSamples**(gsampler2DMS sampler)
- int **textureSamples**(gsampler2DMSArray sampler)

Texel Lookup Functions [8.9.2]

Use texture coordinate *P* to do a lookup in the texture bound to *sampler*. For shadow forms, *compare* is used as D_{ref} and the array layer comes from *P*.w. For non-shadow forms, the array layer comes from the last component of *P*.

- gvec4 **texture**(gsampler{1D[Array],2D[Array,Rect],3D,Cube[Array]} *sampler*, {float,vec2,vec3,vec4} *P* [, float *bias*])
- float **texture**(sampler{1D[Array],2D[Array,Rect],Cube}Shadow *sampler*, {vec3,vec4} *P* [, float *bias*])
- float **texture**(gsamplerCubeArrayShadow *sampler*, vec4 *P*, float *compare*)

Texture lookup with projection.
- gvec4 **textureProj**(gsampler{1D,2D[Rect],3D} *sampler*, vec{2,3,4} *P* [, float *bias*])
- float **textureProj**(sampler{1D,2D[Rect]}Shadow *sampler*, vec4 *P* [, float *bias*])

Texture lookup as in **texture** but with explicit LOD.
- gvec4 **textureLod**(gsampler{1D[Array],2D[Array],3D,Cube[Array]} *sampler*, {float,vec2,vec3} *P*, float *lod*)
- float **textureLod**(sampler{1D[Array],2D}Shadow *sampler*, vec3 *P*, float *lod*)

Offset added before texture lookup.
- gvec4 **textureOffset**(gsampler{1D[Array],2D[Array,Rect],3D} *sampler*, {float,vec2,vec3} *P*, {int,ivec2,ivec3} *offset* [, float *bias*])
- float **textureOffset**(sampler{1D[Array],2D[Rect,Array]}Shadow *sampler*, {vec3, vec4} *P*, {int,ivec2} *offset* [, float *bias*])

Use integer texture coordinate *P* to lookup a single texel from *sampler*.
- gvec4 **texelFetch**(gsampler{1D[Array],2D[Array,Rect],3D} *sampler*, {int,ivec2,ivec3} *P*[, {int,ivec2} *lod*])
- gvec4 **texelFetch**(gsampler{Buffer, 2DMS[Array]} *sampler*, {int,ivec2,ivec3} *P*[, int *sample*])

Fetch single texel with *offset* added before texture lookup.
- gvec4 **texelFetchOffset**(gsampler{1D[Array],2D[Array],3D} *sampler*, {int,ivec2,ivec3} *P*, int *lod*, {int,ivec2,ivec3} *offset*)
- gvec4 **texelFetchOffset**(gsampler2DRect *sampler*, ivec2 *P*, ivec2 *offset*)

Projective texture lookup with *offset* added before texture lookup.
- gvec4 **textureProjOffset**(gsampler{1D,2D[Rect],3D} *sampler*, vec{2,3,4} *P*, {int,ivec2,ivec3} *offset* [, float *bias*])
- float **textureProjOffset**(sampler{1D,2D[Rect]}Shadow *sampler*, vec4 *P*, {int,ivec2} *offset* [, float *bias*])

Offset texture lookup with explicit LOD.
- gvec4 **textureLodOffset**(gsampler{1D[Array],2D[Array],3D} *sampler*, {float,vec2,vec3} *P*, float *lod*, {int,ivec2,ivec3} *offset*)
- float **textureLodOffset**(sampler{1D[Array],2D}Shadow *sampler*, vec3 *P*, float *lod*, {int,ivec2} *offset*)

Projective texture lookup with explicit LOD.
- gvec4 **textureProjLod**(gsampler{1D,2D,3D} *sampler*, vec{2,3,4} *P*, float *lod*)
- float **textureProjLod**(sampler{1D,2D}Shadow *sampler*, vec4 *P*, float *lod*)

Offset projective texture lookup with explicit LOD.
- gvec4 **textureProjLodOffset**(gsampler{1D,2D,3D} *sampler*, vec{2,3,4} *P*, float *lod*, {int, ivec2, ivec3} *offset*)
- float **textureProjLodOffset**(sampler{1D,2D}Shadow *sampler*, vec4 *P*, float *lod*, {int, ivec2} *offset*)

Texture lookup as in **texture** but with explicit gradients.
- gvec4 **textureGrad**(gsampler{1D[Array],2D[Rect,Array],3D,Cube[Array]} *sampler*, {float, vec2, vec3,vec4} *P*, {float, vec2, vec3} *dPdx*, {float, vec2, vec3} *dPdy*)
- float **textureGrad**(sampler{1D[Array],2D[Rect,Array], Cube}Shadow *sampler*, {vec3,vec4} *P*, {float,vec2} *dPdx*, {float,vec2, vec3} *dPdy*)

Texture lookup with both explicit gradient and offset.
- gvec4 **textureGradOffset**(gsampler{1D[Array],2D[Rect,Array],3D} *sampler*, {float,vec2,vec3} *P*, {float,vec2,vec3} *dPdx*, {float,vec2,vec3} *dPdy*, {int,ivec2,ivec3} *offset*)
- float **textureGradOffset**(sampler{1D[Array],2D[Rect,Array]}Shadow *sampler*, {vec3,vec4} *P*, {float,vec2} *dPdx*, {float,vec2}*dPdy*, {int,ivec2} *offset*)

Texture lookup both projectively as in **textureProj**, and with explicit gradient as in **textureGrad**.
- gvec4 **textureProjGrad**(gsampler{1D,2D[Rect],3D} *sampler*, {vec2,vec3,vec4} *P*, {float,vec2,vec3} *dPdx*, {float,vec2,vec3} *dPdy*)
- float **textureProjGrad**(sampler{1D,2D[Rect]}Shadow *sampler*, vec4 *P*, {float,vec2} *dPdx*, {float,vec2} *dPdy*)

Texture lookup projectively and with explicit gradient as in **textureProjGrad**, as well as with offset as in **textureOffset.**
- gvec4 **textureProjGradOffset**(gsampler{1D,2D[Rect],3D} *sampler*, vec{2,3,4} *P*, {float,vec2,vec3} *dPdx*, {float,vec2,vec3} *dPdy*, {int,ivec2,ivec3} *offset*)
- float **textureProjGradOffset**(sampler{1D,2D[Rect]Shadow} *sampler*, vec4 *P*, {float,vec2} *dPdx*, {float,vec2} *dPdy*, {ivec2,int,vec2} *offset*)

Texture Gather Instructions [8.9.3]

These functions take components of a floating-point vector operand as a texture coordinate, determine a set of four texels to sample from the base level of detail of the specified texture image, and return one component from each texel in a four-component result vector.

- gvec4 **textureGather**(gsampler{2D[Array,Rect],Cube[Array]} *sampler*, {vec2,vec3,vec4} *P* [, int *comp*])
- vec4 **textureGather**(sampler{2D[Array,Rect],Cube[Array]}Shadow *sampler*, {vec2,vec3,vec4} *P*, float *refZ*)

Texture gather as in **textureGather** by offset as described in **textureOffset** except minimum and maximum offset values are given by {MIN, MAX}_PROGRAM_TEXTURE_GATHER_OFFSET.
- gvec4 **textureGatherOffset**(gsampler2D[Array,Rect] *sampler*, {vec2,vec3} *P*, ivec2 *offset* [, int *comp*])
- vec4 **textureGatherOffset**(sampler2D[Array,Rect]Shadow *sampler*, {vec2,vec3} *P*, float *refZ*, ivec2 *offset*)

Texture gather as in **textureGatherOffset** except *offsets* determines location of the four texels to sample.
- gvec4 **textureGatherOffsets**(gsampler2D[Array,Rect] *sampler*, {vec2,vec3} *P*, ivec2 *offsets*[4] [, int *comp*])
- vec4 **textureGatherOffsets**(sampler2D[Array,Rect]Shadow *sampler*, {vec2,vec3} *P*, float *refZ*, ivec2 *offsets*[4])

OpenGL API and OpenGL Shading Language Reference Card Index

The following index shows each item included on this card along with the page on which it is described. The color of the row in the table below is the color of the pane to which you should refer.

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