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 4.3 core specification.
- [n.n.n] refers to sections in the OpenGL Shading Language 4.30 specification.

OpenGL Errors [2.3.1]

enum **GetError**(void);   Returns the numeric error code.

OpenGL Operation

Floating-Point Numbers [2.3.3]

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 [Table 2.2]

Letters are used in commands to denote types.

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)

Synchronization

Flush and Finish [2.3.2]

void **Flush**(void);

void **Finish**(void);

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*);

Timer Queries [4.3]

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

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

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

Buffer Objects [6]

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

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

Creating and Binding Buffer Objects [6.1]

void **BindBuffer**(enum *target*, uint *buffer*);
target: PIXEL_{PACK, UNPACK}_BUFFER,
  {UNIFORM, ARRAY, TEXTURE}_BUFFER,
  COPY_{READ, WRITE}_BUFFER,
  {DISPATCH, DRAW}_INDIRECT_BUFFER,
  {ATOMIC_COUNTER, ELEMENT_ARRAY}_BUFFER,
  {SHADER_STORAGE ,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

Creating/Clearing Buffer Object Data [6.2]

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

void **BufferData**(enum *target*, sizeiptr *size*,
  const void *_data_, enum *usage*);
target: see BindBuffer
usage: STREAM_{DRAW, READ, COPY},
  {DYNAMIC, STATIC}_{DRAW, READ, COPY}

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. 2 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 **ClearBufferData**(enum *target*,
  enum *internalformat*, enum *format*,
  enum *type*, const void *_data_);
target, internalformat, format: see ClearBufferSubData

Mapping/Unmapping Buffer Data [6.3]

void ***MapBufferRange**(enum *target*,
  intptr *offset*, sizeiptr *length*,
  bitfield *access*);
access: The logical OR of MAP_{READ, WRITE}_BIT,
  MAP_INVALIDATE_{BUFFER, RANGE}_BIT,
  MAP_{FLUSH_EXPLICIT, UNSYNCHRONIZED}_BIT
target: see BindBuffer

void ***MapBuffer**(enum *target*, enum *access*);
access: READ_ONLY, WRITE_ONLY, READ_WRITE

void **FlushMappedBufferRange**(
  enum *target*, intptr *offset*,
  sizeiptr *length*);
target: see BindBuffer

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

Invalidate Buffer Data [6.5]

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

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

Copying Between Buffers [6.6]

void **CopyBufferSubData**(enum *readtarget*,
  enum *writetarget*, intptr *readoffset*,
  intptr *writeoffset*, sizeiptr *size*);
readtarget and *writetarget*: *see BindBuffer*

Buffer Object Queries [6, 6.7]

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

void **GetBufferParameteriv**(enum *target*,
  enum *pname*, int *_data_);
target: see BindBuffer
pname: BUFFER_SIZE, BUFFER_USAGE,
  BUFFER_ACCESS{_FLAGS}, BUFFER_MAPPED,
  BUFFER_MAP_{OFFSET, LENGTH}

void **GetBufferParameteri64v**(enum *target*,
  enum *pname*, int64 *_data_);
target: see BindBuffer
pname: see GetBufferParameteriv,

void **GetBufferSubData**(enum *target*,
  intptr *offset*, sizeiptr *size*, void *_data_);
target: see BindBuffer

void **GetBufferPointerv**(enum *target*,
  enum *pname*, void **_params_);
target: see BindBuffer
pname: BUFFER_MAP_POINTER

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

Asynchronous Queries [4.2, 4.2.1]

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

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

void **BeginQuery**(enum *target*, uint *id*);
target: PRIMITIVES_GENERATED{*n*},
  {ANY_}SAMPLES_PASSED{CONSERVATIVE},
  TIME_ELAPSED,
  TRANSFORM_FEEDBACK_PRIMITIVES_WRITTEN{*n*}

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

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

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

void **GetQueryiv**(enum *target*, enum *pname*,
  int *_params_);

(parameters ↥)

target: see BeginQuery, plus TIMESTAMP
pname: CURRENT_QUERY, QUERY_COUNTER_BITS

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

void **GetQueryIndexediv**(enum *target*,
  uint *index*, enum *pname*, int *_params_);
target: see BeginQuery
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_RESULT{_AVAILABLE}

Shaders and Programs

Shader Objects [7.1-2]

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

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: UNIFORM{_BLOCK},
  PROGRAM_{INPUT, OUTPUT}, BUFFER_VARIABLE,
  SHADER_STORAGE_BLOCK,
  ATOMIC_COUNTER_BUFFER,
  {GEOMETRY, VERTEX}_SUBROUTINE,
  TESS_{CONTROL, EVALUATION}_SUBROUTINE,
  {FRAGMENT, COMPUTE}_SUBROUTINE,
  TESS_{CONTROL, EVALUATION}_SUBROUTINE_UNIFORM,
  {GEOMETRY, VERTEX}_SUBROUTINE_UNIFORM,
  {FRAGMENT, COMPUTE}_SUBROUTINE_UNIFORM,
  TRANSFORM_FEEDBACK_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_);

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

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 **_uniformNames_,
  uint *_uniformIndices_);

(Continued on next page >)

Shaders and Programs (cont.)

void **GetActiveUniform**(uint _program_, uint _index_, sizei _bufSize_, sizei *_length_, int *_size_, enum *_type_, char *_name_);
*type returns: DOUBLE_{VECn, MATn, MATnxn}, DOUBLE, FLOAT_{VECn, MATn, MATnxn}, FLOAT, INT, INT_VECn, UNSIGNED_INT{_VECn}, BOOL, BOOL_VECn, or any value in [Table 7.3]

void **GetActiveUniformsiv**(uint _program_, sizei _uniformCount_, const uint *_uniformIndices_, enum _pname_, int *_params_);
pname: UNIFORM_{TYPE, SIZE, NAME_LENGTH}, UNIFORM_BLOCK_INDEX, UNIFORM_OFFSET, 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

void **GetActiveAtomicCounterBufferiv**(uint _program_, uint _bufferIndex_, enum _pname_, int *_params_);
pname: see GetActiveUniformBlockiv

Load Uniform Vars. In Default Uniform Block

void **Uniform{1234}{i f d}**(int _location_, T _value_);

void **Uniform{1234}{i f d}v**(int _location_, sizei _count_, const T *_value_);

void **Uniform{1234}ui**(int _location_, T _value_);

void **Uniform{1234}uiv**(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}ui**(uint _program_, int _location_, T _value_);

void **ProgramUniform{1234}uiv**(uint _program_, int _location_, sizei _count_, const T *_value_);

void **ProgramUniformMatrix{234}{f d}v**(uint _program_, int _location_, sizei _count_, boolean _transpose_, const float *_value_);

void **ProgramUniformMatrixf{2x3,3x2,2x4,4x2, 3x4, 4x3}{f d}v**(uint _program_, int _location_, sizei _count_, boolean _transpose_, const float *_value_);

Uniform Buffer Object Bindings

void **UniformBlockBinding**(uint _program_, uint _uniformBlockIndex_, uint _uniformBlockBinding_);

Shader Buffer Variables [7.7]

void **ShaderStorageBlockBinding**(uint _program_, uint _storageBlockIndex_, uint _storageBlockBinding_);

Subroutine Uniform Variables [7.8]

Parameter _shadertype_ for the functions in this section may be one of TESS_{CONTROL, EVALUATION}_SHADER, {COMPUTE, VERTEX, 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 [7.11.2]

See diagram on page 11 for more information.

void **MemoryBarrier**(bitfield _barriers_);
barriers: ALL_BARRIER_BITS or the OR of: {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}_BARRIER_BIT

Shader|Program Queries [7.12]

void **GetShaderiv**(uint _shader_, enum _pname_, int *_params_);
pname: SHADER_TYPE, FRAGMENT_SHADER, {GEOMETRY, VERTEX}_SHADER, TESS_{CONTROL, EVALUATION}_SHADER, INFO_LOG_LENGTH, {DELETE, COMPILE}_STATUS, COMPUTE_SHADER, SHADER_SOURCE_LENGTH

void **GetProgramiv**(uint _program_, enum _pname_, int *_params_);
pname: {DELETE, LINK, VALIDATE}_STATUS, INFO_LOG_LENGTH, ATTACHED_SHADERS, ACTIVE_{UNIFORMS, ATTRIBUTES}, ACTIVE_ATTRIBUTE_MAX_LENGTH, ACTIVE_UNIFORM_{BLOCKS, MAX_LENGTH}, ACTIVE_UNIFORM_BLOCK_MAX_NAME_LENGTH, ACTIVE_ATOMIC_COUNTER_BUFFERS, TRANSFORM_FEEDBACK_{BUFFER_MODE, VARYINGS}, TRANSFORM_FEEDBACK_VARYING_MAX_LENGTH, GEOMETRY_{INPUT, OUTPUT}_TYPE, COMPUTE_WORK_GROUP_SIZE, GEOMETRY_{SHADER_INVOCATIONS, VERTICES_OUT}

Texturing [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 **DeleteTextures**(sizei _n_, const uint *_textures_);

boolean **IsTexture**(uint _texture_);

Sampler Objects [8.2]

void **GenSamplers**(sizei _count_, uint *_samplers_);

void **BindSampler**(uint _unit_, uint _sampler_);

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}

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}

Texture Image Spec. [8.5]

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

void **TexImage2D**(enum _target_, int _level_, int _internalformat_, sizei _width_, sizei _height_, int _border_, enum _format_, enum _type_, const void *_data_);
target: PROXY_TEXTURE_CUBE_MAP, POSITIVE_{X, Y, Z}, NEGATIVE_{X, Y, Z}
internalformat, format, type: see TexImage3D

void **TexImage3D**(enum _target_, int _level_, int _internalformat_, sizei _width_, sizei _height_, sizei _depth_, int _border_, enum _format_, enum _type_, const void *_data_);
target: TEXTURE_{3D, 2D_ARRAY, CUBE_MAP_ARRAY}, PROXY_TEXTURE_{3D, 2D_ARRAY, CUBE_MAP_ARRAY}
internalformat: DEPTH_{COMPONENT, STENCIL}, RED, INTENSITY, RG, RGB, RGBA; or a sized internal format from [Tables 8.12 - 8.13], COMPRESSED_{RED_RGTC1}, COMPRESSED_{RG_RGTC2}, COMPRESSED_SIGNED_{RED_RGTC1, RG_RGTC2}, or a specific compressed format in [Table 8.14]
format: DEPTH_{COMPONENT, STENCIL}, RED, GREEN, BLUE, RG, RGB, RGBA, BGR, BGRA, BGRA_INTEGER, {RED, GREEN, BLUE}_INTEGER, {RG, RGB}_INTEGER, {RGBA, BGR}_INTEGER [Table 8.3]
type: {UNSIGNED_}{BYTE, SHORT, INT}, HALF_FLOAT, FLOAT, or a value from [Table 8.2]

Alternate Texture Image Spec. [8.6]

void **CopyTexImage1D**(enum _target_, int _level_, enum _internalformat_, int _x_, int _y_, sizei _width_, int _border_);
target: TEXTURE_1D
internalformat: see TexImage3D

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 **TexSubImage1D**(enum _target_, int _level_, int _xoffset_, sizei _width_, enum _format_, enum _type_, const void *_data_);
target: TEXTURE_1D
format, type: see TexImage1D

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 **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 **CopyTexSubImage1D**(enum _target_, int _level_, int _xoffset_, int _x_, int _y_, sizei _width_);
target: see TexSubImage1D

void **CopyTexSubImage2D**(enum _target_, int _level_, int _xoffset_, int _yoffset_, int _x_, int _y_, sizei _width_, sizei _height_);
target: see TexSubImage2D

void **CopyTexSubImage3D**(enum _target_, int _level_, int _xoffset_, int _yoffset_, int _zoffset_, int _x_, int _y_, sizei _width_, sizei _height_);
target: see TexSubImage3D

Compressed Texture Images [8.7]

void **CompressedTexImage1D**(enum _target_, int _level_, enum _internalformat_, sizei _width_, int _border_, sizei _imageSize_, const void *_data_);
target: TEXTURE_1D, PROXY_TEXTURE_1D
internalformat: values are implementation-dependent

void **CompressedTexImage2D**(enum _target_, int _level_, enum _internalformat_, sizei _width_, sizei _height_, int _border_, sizei _imageSize_, const void *_data_);
target: see TexImage2D, omitting compressed rectangular texture formats
internalformat: see CompressedTexImage3D, plus COMPRESSED_x where _x_ may be {RGB8, SRGB8}_ETC2, {RGB8, SRGB8}_PUNCHTHROUGH_ALPHA1_ETC2

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: COMPRESSED_x where _x_ may be {SIGNED_}RED_RGTC1, {SIGNED_}RG_RGTC2, {RGBA, SRGB_ALPHA}_BPTC_UNORM, RGB_BPTC_{SIGNED, UNSIGNED}_FLOAT

void **CompressedTexSubImage1D**(enum _target_, int _level_, int _xoffset_, sizei _width_, enum _format_, sizei _imageSize_, const void *_data_);
target: see TexSubImage1D
format: see TexImage1D

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 TexImage2D

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

Multisample Textures [8.8]

void **TexImage2DMultisample**(enum _target_, sizei _samples_, int _internalformat_, sizei _width_, sizei _height_, boolean _fixedsamplelocations_);
target: {PROXY_}TEXTURE_2D_MULTISAMPLE
internalformat: see TexImage3DMultisample

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, STENCIL_INDEX, DEPTH_{COMPONENT, STENCIL}, or sized internal formats corresponding to these base formats

Buffer Textures [8.9]

void **TexBufferRange**(enum _target_, enum _internalFormat_, uint _buffer_, intptr _offset_, sizeiptr _size_);

void **TexBuffer**(enum _target_, enum _internalformat_, uint _buffer_);
target: TEXTURE_BUFFER
internalformat: R8{I,UI}, R16{F, I, UI}, R32{F, I, UI}, RG8{I, UI}, RG16{F, I, UI}, RG32{F, I, UI}, RGB32{F, I, UI}, RGBA8{I, UI}, RGBA16{F, I, UI}, RGBA32{F, I, UI}

(Continued on next page >)

Texturing (cont.)

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, plus TEXTURE_{BORDER_COLOR, SWIZZLE_RGBA}

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

target: see BindTexture, plus TEXTURE_{BORDER_COLOR, SWIZZLE_RGBA}

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 8.16]

Enumerated Queries [8.11]

void **GetTexParameter{if}v**(enum *target*, enum *value*, T *data*);

target: see BindTexture

value: see pname for TexParameter

void **GetTexParameterI{i ui}v**(enum *target*, enum *value*, T *data*);

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

value: see pname for TexParameterI{i ui}v, plus IMAGE_FORMAT_COMPATIBILITY_TYPE, TEXTURE_IMMUTABLE_{FORMAT, LEVELS}, TEXTURE_VIEW_NUM_{LEVELS, LAYERS}, TEXTURE_VIEW_MIN_{LEVEL, LAYER}, [Table 8.16]

void **GetTexLevelParameter{i f}v**(enum *target*, int *lod*, enum *value*, T *data*);

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_{POSITIVE, NEGATIVE}_{X, Y, Z}, {PROXY_}TEXTURE_2D_MULTISAMPLE{_ARRAY}

value: TEXTURE_{WIDTH, HEIGHT, DEPTH}, TEXTURE_{SAMPLES, FIXED_SAMPLE_LOCATIONS}, TEXTURE_{INTERNAL_FORMAT, SHARED_SIZE}, TEXTURE_COMPRESSED{_IMAGE_SIZE}, TEXTURE_BUFFER_DATA_STORE_BINDING, TEXTURE_BUFFER_{OFFSET, SIZE}, TEXTURE_STENCIL_SIZE, TEXTURE_x_{SIZE, TYPE} (where x can be RED, GREEN, BLUE, ALPHA, DEPTH)

void **GetTexImage**(enum *tex*, int *lod*, enum *format*, enum *type*, void *img);

tex: TEXTURE_{1, 2}D{_ARRAY}, TEXTURE_{3D, RECTANGLE, CUBE_MAP_ARRAY}, TEXTURE_CUBE_MAP_{POSITIVE, NEGATIVE}_{X, Y, Z}

format: see ClearBufferSubData, pg 1 this card

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

void **GetCompressedTexImage**(enum *target*, int *lod*, void *img);

target: see tex for GetTexImage

Cube Map Texture Select [8.13.1]

Enable/Disable(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}

Texture View [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, BUFFER}, TEXTURE_2D_MULTISAMPLE{_ARRAY}

internalformat: RGBA{16, 32}{F, UI, I}, RGBA{8,16}{_SNORM}, RGBA8{UI, I}, RGB{16, 32}{F, UI, I}, RGB{8,16}{_SNORM}, RGB8{UI, I}, RGB9_E5, RGB10_{A2UI, A2}, RG{16, 32}{F, UI, I}, RG{8,16}{_SNORM}, RG8{UI, I}, R{16, 32}{F, UI, I}, R{8,16}{_SNORM}, R8{UI, I}, R11F_G11F_B10F, SRGB8{_ALPHA8}, COMPRESSED{_SIGNED}_RED_RGTC1, COMPRESSED{_SIGNED}_RG_RGTC2, COMPRESSED_RGBA_BPTC_UNORM, COMPRESSED_SRGB_ALPHA_BPTC_UNORM, COMPRESSED_RGB_BPTC_{UN}SIGNED_FLOAT

Immutable-Format Tex. Images [8.19]

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

target: TEXTURE_1D, PROXY_TEXTURE_1D

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

void **TexStorage2D**(enum *target*, sizei *levels*, enum *internalformat*, sizei *width*, sizei *height*);

target: {PROXY_}TEXTURE_{RECTANGLE, CUBE_MAP}, {PROXY_} TEXTURE_{1D_ARRAY, 2D}

internalformat: see TexStorage1D

void **TexStorage3D**(enum *target*, sizei *levels*, enum *internalformat*, sizei *width*, sizei *height*, sizei *depth*);

target: TEXTURE_3D, PROXY_TEXTURE_3D, {PROXY_}TEXTURE_{CUBE_MAP, 2D}{_ARRAY}

internalformat: see TexStorage1D

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

target: {PROXY_}TEXTURE_2D_MULTISAMPLE

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

target: {PROXY_}TEXTURE_2D_MULTISAMPLE_ARRAY

Invalidating 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*);

Texture Image Loads/Stores [8.25]

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 8.25]

Framebuffer Objects

Binding and Managing [9.2]

void **BindFramebuffer**(enum *target*, uint *framebuffer*);

target: {DRAW, READ_}FRAMEBUFFER

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

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

Framebuffer Object Queries [9.2.3]

void **GetFramebufferParameteriv**(enum *target*, enum *pname*, int *params);

target: {DRAW_, READ_}FRAMEBUFFER

pname: see FramebufferParameteri

void **GetFramebufferAttachmentParameteriv**(enum *target*, enum *attachment*, enum *pname*, int *params);

target: {DRAW_, READ_}FRAMEBUFFER

attachment: DEPTH, FRONT_{LEFT, RIGHT}, STENCIL, BACK_{LEFT, RIGHT}, COLOR_ATTACHMENTi, {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_LEVEL, LAYERED, TEXTURE_CUBE_MAP_FACE, TEXTURE_LAYER

Attaching Images [9.2.4]

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

target: RENDERBUFFER

void **GenRenderbuffers**(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 **RenderbufferStorage**(enum *target*, enum *internalformat*, sizei *width*, sizei *height*);

target: RENDERBUFFER

internalformat: see TexImage3DMultisample

Renderbuffer Object Queries [9.2.6]

void **GetRenderbufferParameteriv**(enum *target*, enum *pname*, int *params);

target: RENDERBUFFER

pname: RENDERBUFFER_x where x may be (WIDTH, HEIGHT, INTERNAL_FORMAT, SAMPLES, {RED, GREEN, BLUE, ALPHA, DEPTH, STENCIL}_SIZE) TESS_CONTROL_OUTPUT_VERTICES, TESS_GEN_{MODE, SPACING, VERTEX_ORDER}, TESS_GEN_POINT_MODE, PROGRAM_SEPARABLE, PROGRAM_BINARY_{LENGTH, RETRIEVABLE}_HINT

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

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, HGH}_{FLOAT, INT}

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

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

void **GetProgramStageiv**(uint program, enum *shadertype*, enum *pname*, int *values);

pname: ACTIVE_SUBROUTINES_x where x may be UNIFORMS, MAX_LENGTH, UNIFORM_LOCATIONS, UNIFORM_MAX_LENGTH

Attaching Renderbuffer Images [9.2.7]

void **FramebufferRenderbuffer**(enum *target*, enum *attachment*, enum *renderbuffertarget*, uint *renderbuffer*);

target: {DRAW, READ_}FRAMEBUFFER

attachment: {DEPTH, STENCIL}_ATTACHMENT, DEPTH_STENCIL_ATTACHMENT, COLOR_ATTACHMENTi (where i is [0, MAX_COLOR_ATTACHMENTS - 1])

renderbuffertarget: RENDERBUFFER

Attaching Texture Images [9.2.8]

void **FramebufferTexture**(enum *target*, enum *attachment*, uint *texture*, int *level*);

target: {DRAW, READ_}FRAMEBUFFER

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}

target, attachment: see FramebufferRenderbuffer

void **FramebufferTexture3D**(enum *target*, enum *attachment*, enum *textarget*, uint *texture*, int *level*, int *layer*);

textarget: TEXTURE_3D

target, attachment: see FramebufferRenderbuffer

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

target, attachment: see FramebufferRenderbuffer

Framebuffer Completeness [9.4.2]

enum **CheckFramebufferStatus**(enum *target*);

target: {DRAW_, READ_}FRAMEBUFFER

returns: FRAMEBUFFER_COMPLETE or a constant indicating the violating value

Vertex Specification [10.2.1]

Specify generic attributes with components of type float (**VertexAttrib***), int or uint (**VertexAttribI***), or double (**VertexAttribL***).

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

pname: CURRENT_VERTEX_ATTRIB or VERTEX_ATTRIB_ARRAY_x where x is one of BUFFER_BINDING, DIVISOR, ENABLED, INTEGER, LONG, NORMALIZED, SIZE, STRIDE, or TYPE

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*, void **pointer);

pname: VERTEX_ATTRIB_ARRAY_POINTER

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*, T *values*);

void **VertexAttrib4N{b si 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*, 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

Vertex Arrays

Arrays for Generic Vertex Attributes [10.3.1]

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

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

void **VertexAttribBinding**(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
index: [0, MAX_VERTEX_ATTRIBS - 1]

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

void **DisableVertexAttribArray**(uint *index*);
index: [0, MAX_VERTEX_ATTRIBS - 1]

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

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

Enable/Disable(*target*);
target: PRIMITIVE_RESTART{_FIXED_INDEX}

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

Vertex Array Objects [10.4]

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*);

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

Drawing Commands [10.5]

For all the functions in this section:
mode: POINTS, LINE_STRIP, LINE_LOOP, LINES, TRIANGLE_{STRIP, FAN}, TRIANGLES, PATCHES, LINES_ADJACENCY, TRIANGLES_ADJACENCY, {LINE, 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 **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*, int **basevertex*);

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

Conditional Rendering [10.8]

void **BeginConditionalRender**(uint *id*, enum *mode*);
mode: {QUERY_BY_REGION, QUERY}_{WAIT, NO_WAIT}

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 **GetActiveAttrib**(uint *program*, uint *index*, sizei *bufSize*, sizei **length*, int **size*, enum **type*, char **name*);
**type* returns: FLOAT_{VEC*n*, MAT*n*, MAT*n*x*m*}, FLOAT, {UNSIGNED_}INT, {UNSIGNED_}INT_VEC*n*

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

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

Varying Variables [11.1.2]

void **TransformFeedbackVaryings**(uint *program*, sizei *count*, const char * const **varyings*, enum *bufferMode*);
bufferMode: {INTERLEAVED, SEPARATE}_ATTRIBS

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

(parameters ↗)

**type* returns NONE, FLOAT{_VEC*n*}, DOUBLE{_VEC*n*}, {UNSIGNED_}INT, {UNSIGNED_}INT_VEC*n*, MAT*n*x*m*, {FLOAT, DOUBLE}_{MAT*n*, MAT*n*x*m*}

Shader Execution [11.1.3]

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

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

Tessellation Control Shaders [11.2.2]

void **PatchParameterfv**(enum *pname*, const float **values*);
pname: PATCH_DEFAULT_{INNER, OUTER}_LEVEL

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

void **EndTransformFeedback**(void);

void **PauseTransformFeedback**(void);

void **ResumeTransformFeedback**(void);

void **DrawTransformFeedback**(enum *mode*, uint *id*);
mode: see Drawing Commands [10.5] 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*);

Rasterization [13.4, 14]

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

Flatshading [13.4]

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

Multisampling [14.3.1]

Use to antialias points, and lines.

Enable/Disable(*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
param, params: The fade threshold if *pname* is POINT_FADE_THRESHOLD_SIZE; {LOWER, UPPER}_LEFT if *pname* is POINT_SPRITE_COORD_ORIGIN. LOWER_LEFT, UPPER_LEFT, pointer to point fade threshold.

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

Line Segments [14.5]

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

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

Polygons [14.6, 14.6.1]

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

Pixel Storage Modes [8.4.1]

void **PixelStore{i f}**(enum *pname*, T *param*);
pname: {UN}PACK_*x* where *x* may be SWAP_BYTES, LSB_FIRST, ROW_LENGTH, SKIP_{PIXELS, ROWS}, ALIGNMENT, IMAGE_HEIGHT, SKIP_IMAGES, COMPRESSED_BLOCK_{WIDTH, HEIGHT, DEPTH, SIZE}

Viewport and Clipping

Clipping [13.5]

Enable/Disable(CLIP_DISTANCE*i*);
i: [0, MAX_CLIP_DISTANCES - 1]

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*);

Fragment Shaders [15.0.2]

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

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

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

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

Per-Fragment Operations

Scissor Test [17.3.2]

Enable/Disable(SCISSOR_TEST);

IsEnabled(SCISSOR_TEST);

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 Operations [17.3.3]

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

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

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

(Continued on next page >)

Per-Fragment (cont.)

Stencil Test [17.3.5]

Enable/Disable(STENCIL_TEST);

void **StencilFunc**(enum *func*, int *ref*, uint *mask*);

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

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(DEPTH_TEST);

void **DepthFunc**(enum *func*);
func: ***see StencilFuncSeparate***

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(BLEND);

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

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

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

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

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

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

void **BlendFuncSeparate**(enum *srcRGB*, enum *dstRGB*, enum *srcAlpha*, enum *dstAlpha*);
src, dst, 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**(clampf *red*, clampf *green*, clampf *blue*, clampf *alpha*);

Dithering [17.3.10]

Enable/Disable(DITHER);

Logical Operation [17.3.11]

Enable/Disable(enum 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

Whole Framebuffer

Selecting a Buffer for Writing [17.4.1]

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

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

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 **ClearBufferfi**(enum *buffer*, int *drawbuffer*, float *depth*, int *stencil*);
buffer: DEPTH_STENCIL
drawbuffer: 0

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, {DEPTH, STENCIL}_ATTACHMENT, COLOR, {FRONT, BACK}_{LEFT, RIGHT}, AUX*i*, ACCUM, STENCIL

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

Reading and Copying Pixels

Color Clamping [18.2.6]

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

Reading Pixels [18.2]

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 from [Table 8.2]

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])

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 OR of {COLOR, DEPTH, STENCIL}_BUFFER_BIT
filter: LINEAR, NEAREST

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

State and State Requests

A complete list of symbolic constants for states is shown in the tables in [6.2].

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*);

Pointer and String Queries [22.2]

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

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

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

Get Internal Format [22.3]

void **GetInternalformati64v**(enum *target*, enum *internalformat*, enum *pname*, sizei *bufSize*, int64 **params*);
target: TEXTURE_{1D,2D,3D}, TEXTURE_{1D,2D,CUBE_MAP}_ARRAY, TEXTURE_2D_MULTISAMPLE{_ARRAY}, TEXTURE_{BUFFER, RECTANGLE}, RENDERBUFFER
pname: NUM_SAMPLE_COUNTS, SAMPLES, INTERNALFORMAT_{SUPPORTED, PREFERRED}, 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, MAX_{WIDTH, HEIGHT, DEPTH, LAYERS}, MAX_COMBINED_DIMENSIONS, FRAMEBUFFER_BLEND,

(more parameters ⮥)

{COLOR, DEPTH, STENCIL}_COMPONENTS, {COLOR, DEPTH, STENCIL}_RENDERABLE, FRAMEBUFFER_RENDERABLE{_LAYERED}, READ_PIXELS{_FORMAT, _TYPE}, FILTER, {GET_}TEXTURE_IMAGE_{FORMAT, TYPE}, {AUTO_GENERATE, GENERATE_}MIPMAP, COLOR_ENCODING, TEXTURE_SHADOW, SRGB_{READ, WRITE, DECODE}, TESS_{CONTROL, EVALUATION}_TEXTURE, {GEOMETRY, FRAGMENT}_TEXTURE, {COMPUTE, VERTEX}_TEXTURE, CLEAR_BUFFER, TEXTURE_GATHER{_SHADOW}, IMAGE_TEXEL_SIZE, SHADER_IMAGE_{LOAD, STORE, ATOMIC}, {IMAGE, VIEW}_COMPATIBILITY_CLASS, IMAGE_PIXEL_{FORMAT, TYPE}, IMAGE_FORMAT_COMPATIBILITY_TYPE, SIMULTANEOUS_TEXTURE_AND_DEPTH_TEST, SIMULTANEOUS_TEXTURE_AND_DEPTH_WRITE, SIMULTANEOUS_TEXTURE_AND_STENCIL_TEST, SIMULTANEOUS_TEXTURE_AND_STENCIL_WRITE, TEXTURE_{COMPRESSED, VIEW}, TEXTURE_COMPRESSED_BLOCK_{WIDTH, HEIGHT}, TEXTURE_COMPRESSED_BLOCK_SIZE

void **GetInternalformativ**(enum *target*, enum *internalformat*, enum *pname*, sizei *bufSize*, int **params*);
internalformat: any valid internalformat
target: ***see GetInternalformati64v***, plus TEXTURE_ CUBE_MAP
*pname:****see GetInternalformati64v***, plus INTERNALFORMAT_ALPHA_TYPE

Compute Shaders [19]

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

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

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

Debug Output [20]

Enable/Disable(DEBUG_OUTPUT);

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

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

Debug Message Callback [20.2]

void **DebugMessageCallback**(DEBUGPROC *callback*, void **userParam*);

DEBUGPROC callback function type:

void **callback**(enum *source*, enum *type*, uint *id*, enum *severity*, sizei *length*, const char **message*, void **userParam*);

(parameters ⮥)

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*);

Externally Generated Messages [20.5]

void **DebugMessageInsert**(enum *source*, enum *type*, uint *id*, enum *severity*, int *length*, const char **buf*);

Debug Groups [20.6]

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

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

Synchronous Debug Output [20.8]

Enable/Disable(DEBUG_OUTPUT_SYNCHRONOUS);

Debug Output Queries [20.9]

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

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

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 4.30 specification at www.opengl.org/registry

Preprocessor [3.3]

Preprocessor Directives

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

Preprocessor Operators

#version 430 #version 430 *profile*	Required when using version 4.30. *profile* is core, compatibility, or es.
#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.: 430
GL_core_profile	Defined as 1
GL_es_profile	1 if the implementation supports the es profile
GL_compatibility_profile	Defined as 1 if the implementation supports the compatibility profile.

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(), etc.

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
int, uint	->	float
int, uint, float	->	double
ivec2	->	uvec2
ivec3	->	uvec3
ivec4	->	uvec4
ivec2	->	vec2
ivec3	->	vec3
ivec4	->	vec4
uvec2	->	vec2
uvec3	->	vec3
uvec4	->	vec4
ivec2	->	dvec2
ivec3	->	dvec3
ivec4	->	dvec4

uvec2	->	dvec2
uvec3	->	dvec3
uvec4	->	dvec4
vec2	->	dvec2
vec3	->	dvec3
vec4	->	dvec4
mat2	->	dmat2
mat3	->	dmat3
mat4	->	dmat4
mat2x3	->	dmat2x3
mat2x4	->	dmat2x4
mat3x2	->	dmat3x2
mat3x4	->	dmat3x4
mat4x2	->	dmat4x2
mat4x3	->	dmat4x4

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]

Input, **output**, **uniform**, and **buffer** variable declarations can be grouped. For example:

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

Layout Qualifiers [4.4]

layout(*layout-qualifiers*) *block-declaration*
layout(*layout-qualifiers*) **in/out/uniform**
layout(*layout-qualifiers*) **in/out/uniform**
declaration

Input Layout Qualifiers [4.4.1]

For all shader stages:
location = *integer-constant*

Tessellation Evaluation
triangles, quads, equal_spacing, isolines, fractional_{even,odd}_spacing, cw, ccw, point_mode

Geometry Shader
points, lines, {lines,triangles}_adjacency, triangles, invocations = *integer-constant*

Fragment Shader
For redeclaring built-in variable gl_FragCoord:
origin_upper_left, pixel_center_integer

For **in** only (not with variable declarations):
early_fragment_tests

Compute Shader
local_size_x = *integer-constant,*
local_size_y = *integer-constant,*
local_size_z = *integer-constant*

Output Layout Qualifiers [4.4.2]

For all shader stages:
location = *integer-constant,*
index = *integer-constant*

Tessellation Control
vertices = *integer-constant*

Geometry Shader
points, line_strip, triangle_strip,
max_vertices = *integer-constant,*
stream = *integer-constant*

Fragment Shader
depth_any, depth_greater,
depth_less, depth_unchanged

Uniform Variable Layout Qualifiers [4.4.3]

location = *integer-constant*

Subroutine Function Layout Qualifiers [4.4.4]

index = *integer-constant*

Storage Block Layout Qualifiers [4.4.5]

Layout qualifier identifiers for uniform blocks:
shared, packed, std140, std340,
{row, column}_major,
binding = *integer-constant*

Opaque Uniform Layout Qualifiers [4.4.6]

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

binding = *integer-constant*

Atomic Counter Layout Qualifiers
binding = *integer-constant,*
offset = *integer-constant*

(Continued on next page >)

Qualifiers (cont.)

Format Layout Qualifiers

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

For tessellation control shaders:
binding = *integer-constant*,
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]

Precision qualifiers have no effect on precision; they aid code portability with OpenGL ES:

highp, mediump, lowp

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 violation of these rules 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));
```

Array Example [5.4.4]

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

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
```

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, ..., typen argn);
```

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, ...,
    subroutineTypeNameN)
returnType functionName(type0 arg0,
    type1 arg1, ..., typen argn){ ... }
    // 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]

Shaders communicate with fixed-function OpenGL pipeline stages and other shader executables through built-in variables.

Vertex Language

Inputs

```
in int   gl_VertexID;
in int   gl_InstanceID;
```

Outputs

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

Tessellation Control Language

Inputs

```
in gl_PerVertex {
    vec4  gl_Position;
    float gl_PointSize;
    float gl_ClipDistance[];
} 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[];
} 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[];
} 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[];
};
```

Geometry Language

Inputs

```
in gl_PerVertex {
    vec4  gl_Position;
    float gl_PointSize;
    float gl_ClipDistance[];
} gl_in[];

in int gl_PrimitiveIDIn;
in int gl_InvocationID;
```

Outputs

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

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  vec2   gl_PointCoord;
in  int    gl_PrimitiveID;
in  int    gl_SampleID;
in  vec2   gl_SamplePosition;
in  int    gl_SampleMask[];
in  int    gl_Layer;
in  int    gl_ViewportIndex;
```

Outputs

```
out  float gl_FragDepth;
out  int   gl_SampleMask[];
```

Compute Language

More information in diagram on page 11.

Inputs

```
Work group dimensions
  in    uvec3 gl_NumWorkGroups;
  const uvec3 gl_WorkGroupSize;

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_MaxComputeLocalWorkSize[] =
    {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;
const  int  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 = 16384;
const  int gl_MinProgramTexelOffset = -8;
const  int gl_MaxProgramTexelOffset =  7;
```

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*)
Tf **mix**(Tf *x*, Tf *y*, float *a*)
Td **mix**(Td *x*, Td *y*, double *a*)

Returns true if components in *a* select components from *y*, else from *x*:
Tfd **mix**(Tfd *x*, Tfd *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 comp. 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*NxM* **outerProduct**(vec*M c*, vec*N r*) dmat*NxM* **outerProduct**(dvec*M c*, dvec*N r*)	outer product
mat*N* **transpose**(mat*N m*) dmat*N* **transpose**(dmat*N m*)	transpose
mat*NxM* **transpose**(mat*MxN m*) dmat*NxM* **transpose**(dmat*MxN 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***(inout uint *mem*, uint *data*)

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

Image Functions [8.12]

In these image functions, *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*)

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(IMAGE_PARAMS, uint data)
int imageAtomicAdd(IMAGE_PARAMS, int data)
```

Takes the minimum of the value of *data* and the contents of the selected texel:

```
uint imageAtomicMin(IMAGE_PARAMS, uint data)
int imageAtomicMin(IMAGE_PARAMS, int data)
```

Takes the maximum of the value *data* and the contents of the selected texel:

```
uint imageAtomicMax(IMAGE_PARAMS, uint data)
int imageAtomicMax(IMAGE_PARAMS, int data)
```

Performs a bit-wise AND of the value of *data* and the contents of the selected texel:

```
uint imageAtomicAnd(IMAGE_PARAMS, uint data)
int imageAtomicAnd(IMAGE_PARAMS, int data)
```

Performs a bit-wise OR of the value of *data* and the contents of the selected texel:

```
uint imageAtomicOr(IMAGE_PARAMS, uint data)
int imageAtomicOr(IMAGE_PARAMS, int data)
```

(Continue ↑)

Integer Functions (cont'd)

Performs a bit-wise exclusive OR of the value of *data* and the contents of the selected texel:

```
uint imageAtomicXor(IMAGE_PARAMS, uint data)
int imageAtomicXor(IMAGE_PARAMS, int data)
```

Copies the value of *data*:

```
uint imageAtomicExchange(IMAGE_PARAMS, uint data)
int  imageAtomicExchange(IMAGE_PARAMS, int 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(IMAGE_PARAMS,
        uint compare, uint data)
int imageAtomicCompSwap(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*)	derivative in *x*
Tf **dFdy**(Tf *p*)	derivative in *y*
Tf **fwidth**(Tf *p*)	sum of absolute derivative in *x* and *y*; **abs**(**dFdx**(*p*)) + **abs**(**dFdy**(*p*));

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)          vecn noisen(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)
```

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])
```

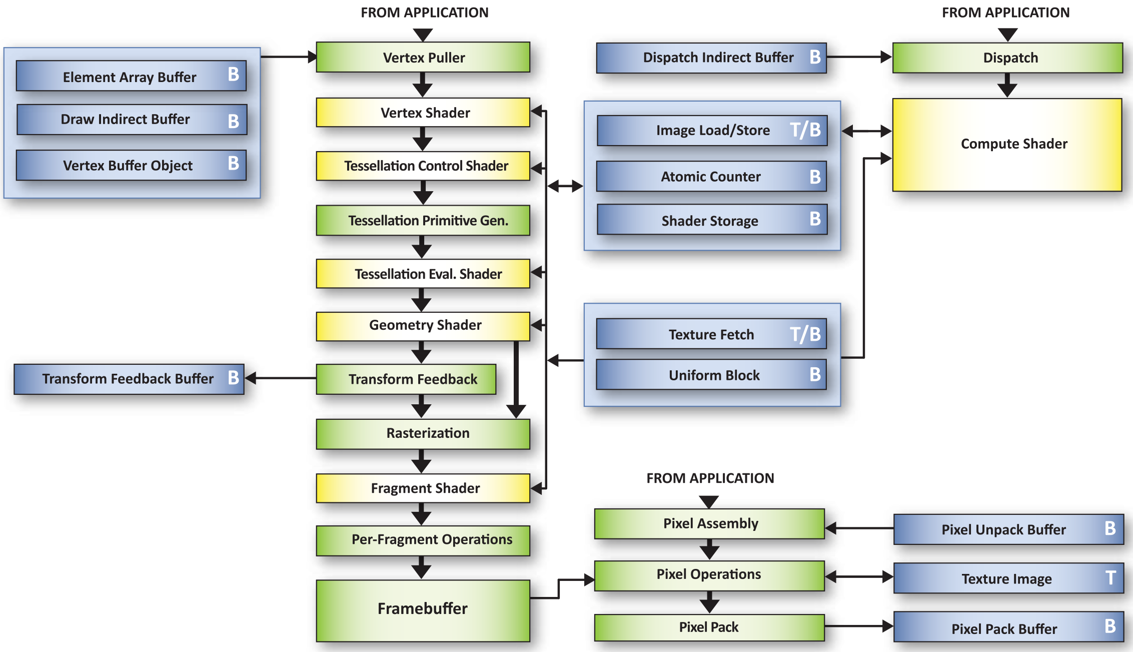
OpenGL Diagrams

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

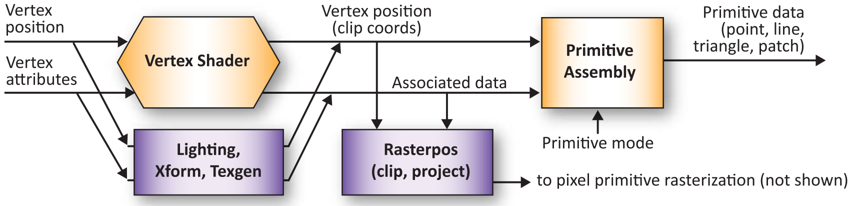


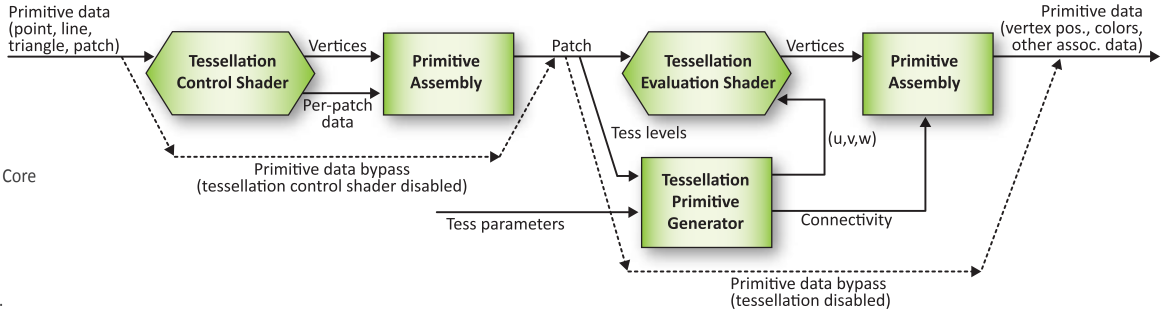
Vertex & Tessellation Details

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.


Vertex position
Vertex attributes
Vertex Shader
Lighting, Xform, Texgen
Vertex position (clip coords)
Associated data
Rasterpos (clip, project)
Primitive Assembly
Primitive data (point, line, triangle, patch)
Primitive mode
to pixel primitive rasterization (not shown)


Primitive data (point, line, triangle, patch)
Tessellation Control Shader
Vertices
Per-patch data
Primitive Assembly
Primitive data bypass (tessellation control shader disabled)
Patch
Tessellation Evaluation Shader
Vertices
Primitive Assembly
Primitive data (vertex pos., colors, other assoc. data)
Tess levels
(u,v,w)
Tessellation Primitive Generator
Tess parameters
Connectivity
Primitive data bypass (tessellation disabled)

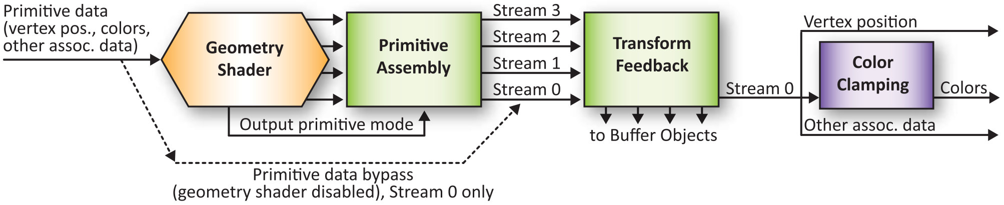
Geometry & Follow-on Details

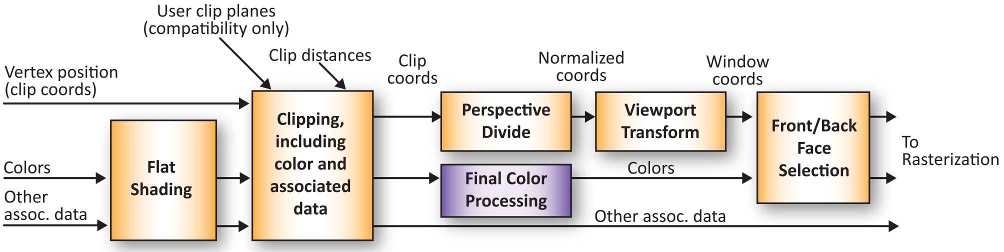
Geometry shaders (if enabled) consume individual primitives built in previous primitive assembly stages. For each input primitive, the geometry shader can output zero or more vertices, with each vertex directed at a specific vertex stream. The vertices emitted to each stream are assembled into primitives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

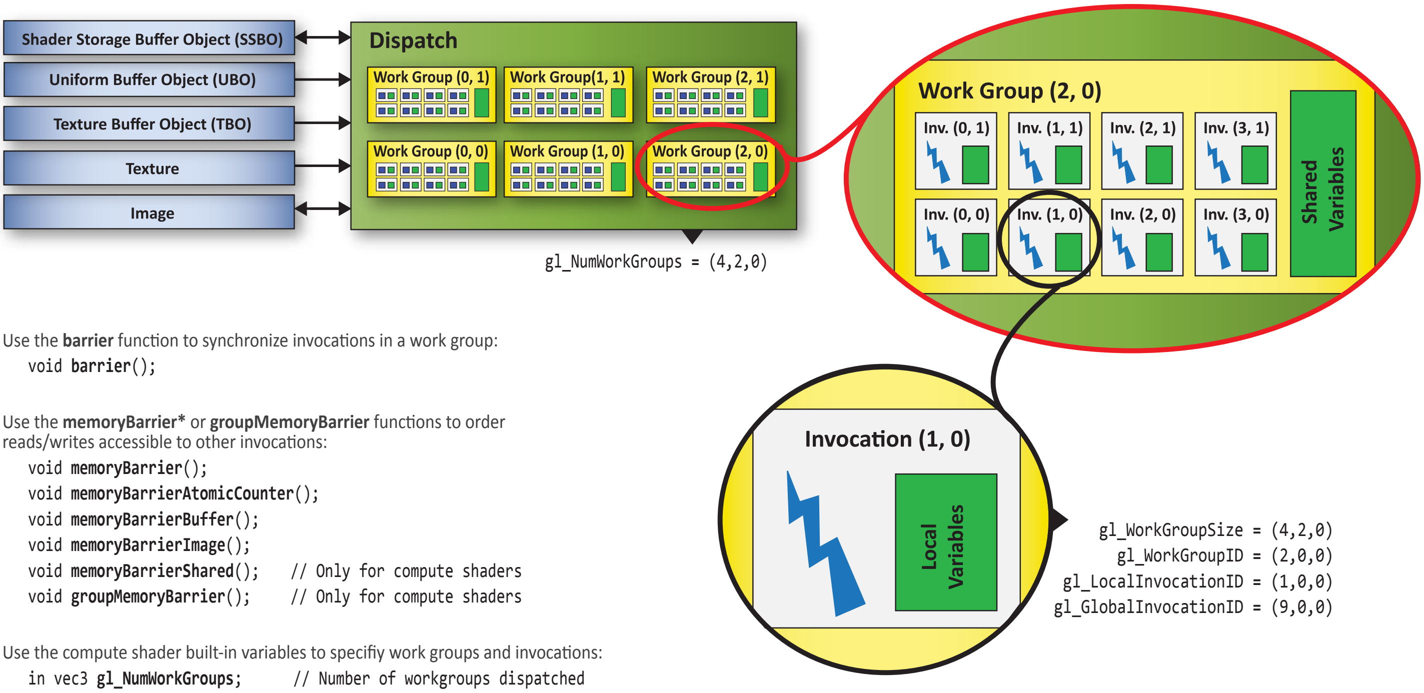
Primitives on vertex stream zero are then processed by fixed-function stages, where they are clipped and prepared for rasterization.

- 🟧 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.





OpenGL Compute Programming Model and Compute Memory Hierarchy



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

```
   void barrier();
```

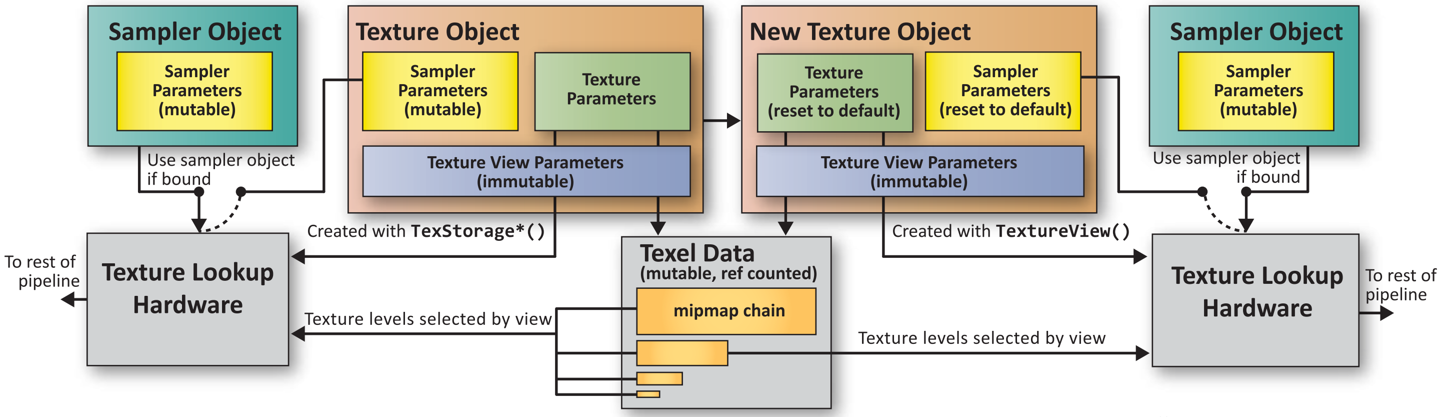
Use the **memoryBarrier*** or **groupMemoryBarrier** functions to order reads/writes accessible to other invocations:

```
   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 specifiy 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


Sampler Object
Sampler Parameters (mutable)
Use sampler object if bound
Texture Object
Sampler Parameters (mutable)
Texture Parameters
Texture View Parameters (immutable)
New Texture Object
Texture Parameters (reset to default)
Sampler Parameters (reset to default)
Texture View Parameters (immutable)
Sampler Object
Sampler Parameters (mutable)
Use sampler object if bound
To rest of pipeline
Texture Lookup Hardware
Created with TexStorage*()
Texture levels selected by view
Texel Data (mutable, ref counted)
mipmap chain
Created with TextureView()
Texture levels selected by view
Texture Lookup Hardware
To rest of pipeline

Texture state set with **TextureView()**

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

Sampler Parameters (mutable)

```
TEXTURE_BORDER_COLOR
TEXTURE_COMPARE_{FUNC,MODE}
TEXTURE_LOD_BIAS
TEXTURE_{MAX,MIN}_LOD
TEXTURE_{MAG,MIN}_FILTER
TEXTURE_SRGB_DECODE
TEXTURE_WRAP_{S,T,R}
```

Texture Parameters (immutable)

```
TEXTURE_WIDTH
TEXTURE_HEIGHT
TEXTURE_DEPTH
TEXTURE_SAMPLES
TEXTURE_FIXED_SAMPLE_LOCATIONS
TEXTURE_COMPRESSED
TEXTURE_COMPRESSED_IMAGE_SIZE
TEXTURE_IMMUTABLE_FORMAT
```

Texture Parameters (mutable)

```
TEXTURE_SWIZZLE_{R,G,B,A}
TEXTURE_MAX_LEVEL
TEXTURE_BASE_LEVEL
DEPTH_STENCIL_TEXTURE_MODE
```

Texture View Parameters (immutable)

```
<target>
TEXTURE_INTERNAL_FORMAT
TEXTURE_VIEW_{MIN,NUM}_LEVEL
TEXTURE_VIEW_{MIN,NUM}_LAYER
TEXTURE_IMMUTABLE_LEVELS
TEXTURE_SHARED_SIZE
TEXTURE_{RED,GREEN,BLUE,ALPHA,DEPTH,STENCIL}_SIZE
TEXTURE_{RED,GREEN,BLUE,ALPHA,DEPTH}_TYPE
IMAGE_FORMAT_COMPATIBILITY_TYPE
```

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.

The Khronos Group is an industry consortium creating open standards for the authoring and acceleration of parallel computing, graphics and dynamic media on a wide variety of platforms and devices.

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