Mediump support in Mesa

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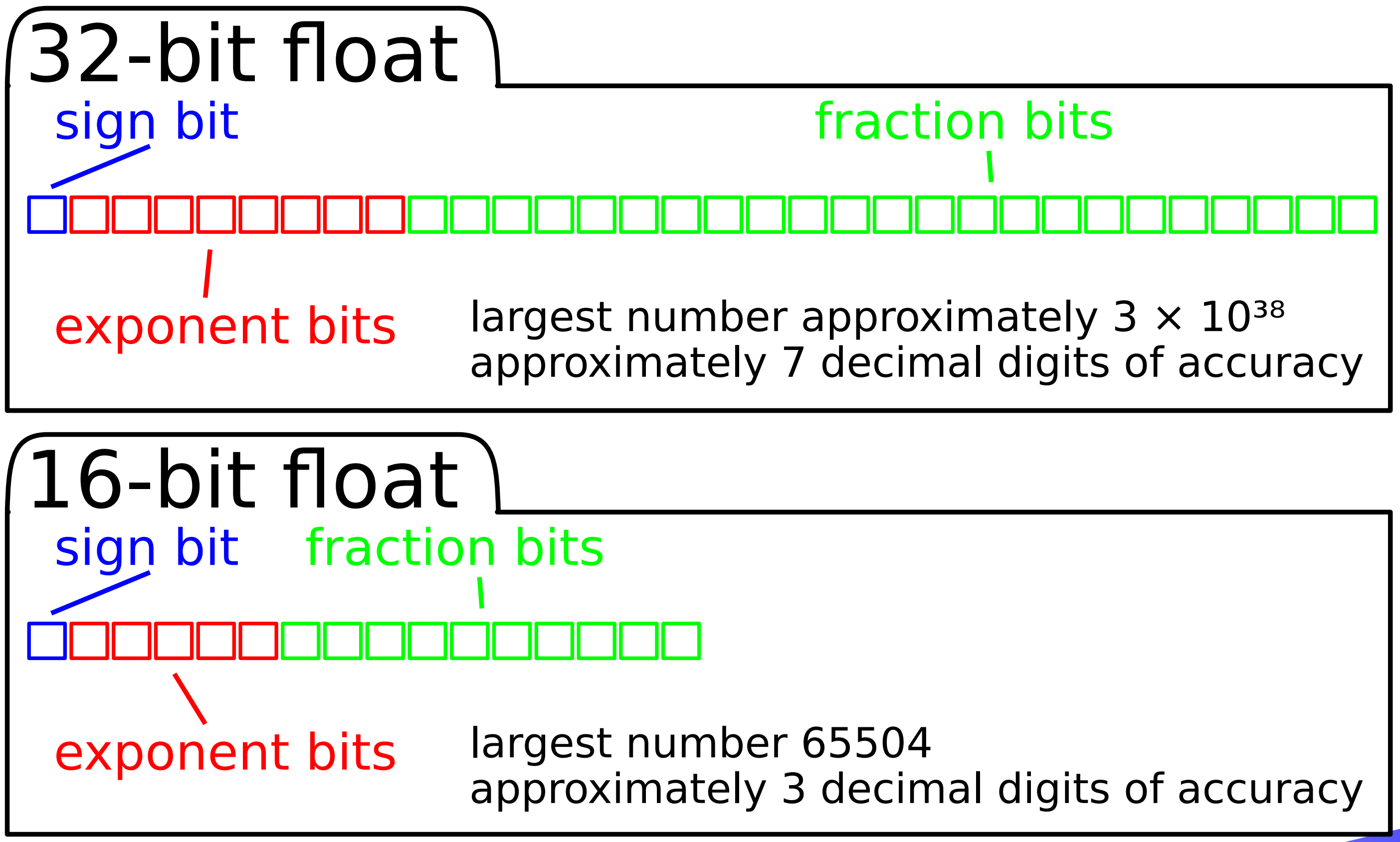
Overview

- What is mediump?
- What does Mesa currently do?
- The plan
- Reducing conversion operations
- Changing types of variables
- Folding conversions
- Testing
- Code
- Questions?

What is mediump?

- Only in GLSL ES
- Available since the first version of GLSL ES.
- Used to tell the driver an operation in a shader can be done with lower precision.
- Some hardware can take advantage of this to trade off precision for speed.

- For example, an operation can be done with a 16-bit float:



- GLSL ES has three available precisions:
  - lowp, mediump and highp
  - The spec specifies a minimum precision for each of these.
  - highp needs 16-bit fractional part.
    - It will probably end up being a single-precision float.
  - mediump needs 10-bit fractional part.
    - This can be represented as a half float.
  - lowp has enough precision to store 8-bit colour channels.

- The precision does not affect the visible storage of a variable.
  - For example a mediump float will still be stored as 32-bit in a UBO.
  - Only operations are affected.
- The precision requirements are only a minimum.
  - Therefore a valid implementation could be to just ignore the precision and do every operation at highp.
  - This is effectively what Mesa currently does.

- The precision for a variable can be specified directly:

```
uniform mediump vec3 rect_color;
```

- Or it can be specified as a global default for each type:

```
precision mediump float;
uniform vec3 rect_color;
```

- The compiler specifies global defaults for most types except floats in the fragment shader.
- In GLSL ES 1.00 high precision support in fragment shaders is optional.

- The precision of operands to an operation determine the precision of the operation.
- Almost works like automatic float to double promotion in C.

```
mediump float a, b;

highp float c = a * b;
```

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This operation can be done in mediump

All operands are mediump.

- The precision of operands to an operation determine the precision of the operation.
- Almost works like automatic float to double promotion in C.

```
mediump float a, b;

highp float c = a * b;
```

precision of result doesn't matter

This operation can be done in mediump

All operands are mediump.

- Another example

```
mediump float a, b;
highp float c;

mediump float r = c * (a * b);
```

- Another example

```
mediump float a, b;
highp float c;

mediump float r = c * (a * b);
```

This operation can still be done in mediump

- Another example

```
mediump float a, b;
highp float c;

mediump float r = c * (a * b);
```

This outer operation must be done at highp

This operation can still be done in mediump

- Corner case
  - Some things don’t have a precision, eg constants.

```
mediump float diameter;

float circ = diameter * 3.141592;
```

- Corner case
    - Some things don’t have a precision, eg constants.

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mediump float diameter;

float circ = diameter * 3.141592;
```

Constants have no precision

- Corner case
    - Some things don’t have a precision, eg constants.

```
mediump float diameter;

float circ = diameter * 3.141592;
```

Precision of multiplication
is mediump anyway
because one of the arguments
has a precision

Constants have no precision

- Extreme corner case
  - Sometimes none of the operands have a precision.

```
uniform bool should_pi;

mediump float result =
        float(should_pi) * 3.141592;
```

- Extreme corner case
  - Sometimes none of the operands have a precision.

```
uniform bool should_pi;

mediump float result =
        float(should_pi) * 3.141592;
```

Neither operand has a precision

- Extreme corner case
  - Sometimes none of the operands have a precision.

```
uniform bool should_pi;

mediump float result =
        float(should_pi) * 3.141592;
```

Precision of operation can come from outer expression, even the lvalue of an assignment

Neither operand has a precision

What does Mesa currently do?

- Mesa already has code to parse the precision qualiers and store them in the IR tree.
- These currently aren’t used for anything except to check for compile-time errors.
  - For example redeclaring a variable with a different precision.
- In desktop GL, the precision is always set to NONE.

- The precision usually doesn’t form part of the glsl_type.
- Instead it is stored out-of-band as part of the ir_variable.

```
enum {
   GLSL_PRECISION_NONE = 0,
   GLSL_PRECISION_HIGH,
   GLSL_PRECISION_MEDIUM,
   GLSL_PRECISION_LOW
};
```

```
class ir_variable : public ir_instruction {
   /* … */
public:
   struct ir_variable_data {
      /* … */
      /**
       * Precision qualifier.
       *
       * In desktop GLSL we do not care about precision qualifiers at
       * all, in fact, the spec says that precision qualifiers are
       * ignored.
       *
       * To make things easy, we make it so that this field is always
       * GLSL_PRECISION_NONE on desktop shaders. This way all the
       * variables have the same precision value and the checks we add
       * in the compiler for this field will never break a desktop
       * shader compile.
       */
      unsigned precision:2;
      /* … */
   };
};
```

- However this gets complicated for structs because members can have their own precision.

```
uniform block {
        mediump vec3 just_a_color;
        highp mat4 important_matrix;
} things;
```

- In that case the precision does end up being part of the glsl_type.

The plan

- The idea is to lower mediump operations to float16 types in NIR.
- We want to lower the actual operations instead of the variables.
- This needs to be done at a high level in order to implement the spec rules.

- Work being done by Hyunjun Ko and myself at Igalia.
- Working on behalf of Google.
- Based on / inspired by patches by Topi Pohjolainen.

- Aiming specifically to make this work on the Freedreno driver.
- Most of the work is reusable for any driver though.
- Currently this is done as a pass over the IR representation.

```
uniform mediump float a, b;

void main()
{
    gl_FragColor.r = a / b;
}
```

These two variables
are mediump

```
uniform mediump float a, b;

void main()
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These two variables are mediump

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uniform mediump float a, b;

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    gl_FragColor.r = a / b;
}
```

So this division can be done at medium precision

- We only want to lower the division operation without changing the type of the variables.
- The lowering pass will add a conversion to float16 around the variable dereferences and then add a conversion back to float32 after the division.
- This minimises the modifications to the IR.

- IR tree before lowering pass

```
(assign  (x) (var_ref gl_FragColor)
         (swiz x (swiz xxxx (expression float /
                                         (var_ref a)
                                         (var_ref b)))))
```

- IR tree before lowering pass

division operation

```
(assign  (x) (var_ref gl_FragColor)
         (swiz x (swiz xxxx (expression float /
                                        (var_ref a)
                                        (var_ref b)))))
```

- IR tree before lowering pass

```
(assign  (x) (var_ref gl_FragColor)
         (swiz x (swiz xxxx (expression float /
                                        (var_ref a)
                                        (var_ref b)))))
```

division operation

type is
32-bit float

- Lowering pass finds sections of the tree involving only mediump/lowp operations.
- Adds f2f16 conversion after variable derefs
- Adds f2f32 conversion at root of lowered branch

- IR tree after lowering pass

```
(assign  (x) (var_ref gl_FragColor)
         (expression float f162f
            (swiz x (swiz xxxx
               (expression float16_t /
                           (expression float16_t f2f16
                                       (var_ref a))
                           (expression float16_t f2f16
                                       (var_ref b)))))))
```

- IR tree after lowering pass

```
(assign  (x) (var_ref gl_FragColor)
         (expression float f162f
            (swiz x (swiz xxxx
               (expression float16_t /
                           (expression float16_t f2f16
                                       (var_ref a))
                           (expression float16_t f2f16
                                       (var_ref b)))))))
```

each var_ref is
converted to float16

- IR tree after lowering pass

```
(assign  (x) (var_ref gl_FragColor)
         (expression float f162f
            (swiz x (swiz xxxx
               (expression float16_t /
                           (expression float16_t f2f16
                                       (var_ref a))
                           (expression float16_t f2f16
                                       (var_ref b)))))))
```

division operation
is done in float16

- IR tree after lowering pass

```
(assign  (x) (var_ref gl_FragColor)
         (expression float f162f
            (swiz x (swiz xxxx
               (expression float16_t /
                           (expression float16_t f2f16
                                       (var_ref a))
                           (expression float16_t f2f16
                                       (var_ref b)))))))
```

Result is converted
back to float32
before storing in var

Reducing conversion operations

- This will end up generating a lot of conversion operations.
- Worse:

```
precision mediump float;
uniform mediump float a;

void main()
{
    float scaled = a / 5.0;

    gl_FragColor.r = scaled + 0.5;
}
```

- This will end up generating a lot of conversion operations.
- Worse:

```
precision mediump float;
uniform mediump float a;

void main()
{
    float scaled = a / 5.0;

    gl_FragColor.r = scaled + 0.5;
}
```

operation will be done in mediump
then converted back to float32
to store in the variable

- This will end up generating a lot of conversion operations.
- Worse:

```
precision mediump float;
uniform mediump float a;

void main()
{
    float scaled = a / 5.0;

    gl_FragColor.r = scaled + 0.5;
}
```

then the result will be immediately converted back to float16 for this operation

- Resulting NIR

```
vec1 32 ssa_1 = deref_var &a (uniform float)
vec1 32 ssa_2 = intrinsic load_deref (ssa_1)
vec1 16 ssa_3 = f2f16 ssa_2
vec1 16 ssa_6 = fdiv ssa_3, ssa_20
vec1 32 ssa_7 = f2f32 ssa_6
vec1 16 ssa_8 = f2f16 ssa_7
vec1 32 ssa_9 = f2f32 ssa_8
vec1 16 ssa_10 = f2f16 ssa_9
vec1 16 ssa_13 = fadd ssa_10, ssa_22
```

- Resulting NIR

```
vec1 32 ssa_1 = deref_var &a (uniform float)
vec1 32 ssa_2 = intrinsic load_deref (ssa_1)
vec1 16 ssa_3 = f2f16 ssa_2
vec1 16 ssa_6 = fdiv ssa_3, ssa_20
vec1 32 ssa_7 = f2f32 ssa_6
vec1 16 ssa_8 = f2f16 ssa_7
vec1 32 ssa_9 = f2f32 ssa_8
vec1 16 ssa_10 = f2f16 ssa_9
vec1 16 ssa_13 = fadd ssa_10, ssa_22
```

Lots of redundant coversions!

- There is a NIR optimisation to remove redundant conversions
- Only enabled for GLES because converting f32→f16→f32 is not lossless

Changing types of variables

- Normally we don’t want to change the type of variables
- For example, this would break uniforms because they are visible to the app
- Sometimes we can do it anyway though depending on the hardware

- On Freedreno, we can change the type of the fragment outputs if they are mediump.
- gl_FragColor is declared as mediump by default
- The variable type is not user-visible so it won’t break the app.
- This removes a conversion.
- We have a specific pass for Freedreno to do this.

```
vec1 32 ssa_1 = load_const (0x00000000 /* 0.000000 */)
vec1 16 ssa_2 = intrinsic load_uniform (ssa_1) (0, 0, 0)
vec1 32 ssa_4 = load_const (0x00000001 /* 0.000000 */)
vec1 16 ssa_5 = intrinsic load_uniform (ssa_4) (0, 0, 0)
vec1 16 ssa_7 = frcp ssa_5
vec1 16 ssa_8 = fmul ssa_2, ssa_7
vec1 32 ssa_9 = f2f32 ssa_8
vec4 32 ssa_10 = vec4 ssa_9, ssa_0.y, ssa_0.z, ssa_0.w
intrinsic store_output (ssa_10, ssa_1) (0, 15, 0, 160)
```

```
vec1 32 ssa_1 = load_const (0x00000000 /* 0.000000 */)
vec1 16 ssa_2 = intrinsic load_uniform (ssa_1) (0, 0, 0)
vec1 32 ssa_4 = load_const (0x00000001 /* 0.000000 */)
vec1 16 ssa_5 = intrinsic load_uniform (ssa_4) (0, 0, 0)
vec1 16 ssa_7 = frcp ssa_5
vec1 16 ssa_8 = fmul ssa_2, ssa_7
vec1 32 ssa_9 = f2f32 ssa_8
vec4 32 ssa_10 = vec4 ssa_9, ssa_0.y, ssa_0.z, ssa_0.w
intrinsic store_output (ssa_10, ssa_1) (0, 15, 0, 144)
```

removes this conversion

```
vec1 32 ssa_1 = load_const (0x00000000 /* 0.000000 */)
vec1 16 ssa_2 = intrinsic load_uniform (ssa_1) (0, 0, 0)
vec1 32 ssa_4 = load_const (0x00000001 /* 0.000000 */)
vec1 16 ssa_5 = intrinsic load_uniform (ssa_4) (0, 0, 0)
vec1 16 ssa_7 = frcp ssa_5
vec1 16 ssa_8 = fmul ssa_2, ssa_7
```

use 16-bit output directly

```
vec4 16 ssa_10 = vec4 ssa_8, ssa_0.y, ssa_0.z, ssa_0.w
intrinsic store_output (ssa_10, ssa_1) (0, 15, 0, 160)
```

Folding conversions

- Consider this simple fragment shader

```
uniform highp float a, b;

void main()
{
    gl_FragColor.r = a / b;
}
```

- Consider this simple fragment shader

```
uniform highp float a, b;

void main()
{
    gl_FragColor.r = a / b;
}
```

operation is using highp

- Consider this simple fragment shader

```
uniform highp float a, b;

void main()
{
    gl_FragColor r = a / b;
}
```

gl_FragColor will converted to a 16-bit output

- This can generate an IR3 disassembly like this:

```
mov.f32f32 r0.x, c0.y
(rpt5)nop
rcp r0.x, r0.x
(ss)mul.f r0.x, c0.x, r0.x
(rpt2)nop
cov.f32f16 hr0.x, r0.x
```

- This can generate an IR3 disassembly like this:

```
mov.f32f32 r0.x, c0.y
(rpt5)nop
rcp r0.x, r0.x
(ss)mul.f r0.x, c0.x, r0.x
(rpt2)nop
cov.f32f16 hr0.x, r0.x
```

32-bit float registers
for the multiplication

- This can generate an IR3 disassembly like this:

```
mov.f32f32 r0.x, c0.y
(rpt5)nop
rcp r0.x, r0.x
(ss)mul.f r0.x, c0.x, r0.x
(rpt2)nop
cov.f32f16 hr0.x  r0.x
```

result is converted
to half-float for output

- This last conversion shouldn’t be necessary.
- Adreno allows the destination register to have a different size from the source registers.
- We can fold the conversion directly into the multiplication.

- We have added a pass on the NIR that does this folding.
- It requires changes the NIR validation to allow the dest to have a different size.
- Only enabled for Freedreno.

```
vec1 32 ssa_1 = load_const (0x00000000 /* 0.000000 */)
vec1 32 ssa_2 = intrinsic load_uniform (ssa_1) (0, 0, 0)
vec1 32 ssa_3 = load_const (0x00000001 /* 0.000000 */)
vec1 32 ssa_4 = intrinsic load_uniform (ssa_3) (0, 0, 0)
vec1 32 ssa_5 = frcp ssa_4
vec1 32 ssa_6 = fmul ssa_2, ssa_5
vec1 16 ssa_7 = f2f16 ssa_6
vec4 16 ssa_8 = vec4 ssa_7, ssa_0.y, ssa_0.z, ssa_0.w
intrinsic store_output (ssa_8, ssa_1) (0, 15, 0, 144)
```

```
vec1 32 ssa_1 = load_const (0x00000000 /* 0.000000 */)
vec1 32 ssa_2 = intrinsic load_uniform (ssa_1) (0, 0, 0)
vec1 32 ssa_3 = load_const (0x00000001 /* 0.000000 */)
vec1 32 ssa_4 = intrinsic load_uniform (ssa_3) (0, 0, 0)
vec1 32 ssa_5 = frcp ssa_4
vec1 32 ssa_6 = fmul ssa_2, ssa_5
vec1 16 ssa_7 = f2f16 ssa_6
vec4 16 ssa_8 = vec4 ssa_7, ssa_0.y, ssa_0.z, ssa_0.w
intrinsic store_output (ssa_8, ssa_1) (0, 15, 0, 144)
```

remove this conversion

```
vec1 32 ssa_1 = load_const (0x00000000 /* 0.000000 */)
vec1 32 ssa_2 = intrinsic load_uniform (ssa_1) (0, 0, 0)
vec1 32 ssa_3 = load_const (0x00000001 /* 0.000000 */)
vec1 32 ssa_4 = intrinsic load_uniform (ssa_3) (0, 0, 0)
vec1 32 ssa_5 = frcp ssa_4
vec1 16 ssa_6 = fmul ssa_2, ssa_5

vec4 16 ssa_8 = vec4 ssa_6, ssa_0.y, ssa_0.z, ssa_0.w
intrinsic store_output (ssa_8, ssa_1) (0, 15, 0, 144)
```

```
vec1 32 ssa_1 = load_const (0x00000000 /* 0.000000 */)
vec1 32 ssa_2 = intrinsic load_uniform (ssa_1) (0, 0, 0)
vec1 32 ssa_3 = load_const (0x00000001 /* 0.000000 */)
vec1 32 ssa_4 = intrinsic load_uniform (ssa_3) (0, 0, 0)
vec1 32 ssa_5 = frcp ssa_4
vec1 16 ssa_6 = fmul ssa_2, ssa_5
```

change destination type of multiplication

```
vec4 16 ssa_8 = vec4 ssa_6, ssa_0.y, ssa_0.z, ssa_0.w
intrinsic store_output (ssa_8, ssa_1) (0, 15, 0, 144)
```

```
vec1 32 ssa_1 = load_const (0x00000000 /* 0.000000 */)
vec1 32 ssa_2 = intrinsic load_uniform (ssa_1) (0, 0, 0)
vec1 32 ssa_3 = load_const (0x00000001 /* 0.000000 */)
vec1 32 ssa_4 = intrinsic load_uniform (ssa_3) (0, 0, 0)
vec1 32 ssa_5 = frcp ssa_4
vec1 16 ssa_6 = fmul ssa_2, ssa_5

vec4 16 ssa_8 = vec4 ssa_6, ssa_0.y, ssa_0.z, ssa_0.w
intrinsic store_output (ssa_8, ssa_1) (0, 15, 0, 144)
```

source types
are still 32-bit

Testing

- We are writing Piglit tests that use mediump
- Most of them check that the result is less accurate than if it was done at highp
- That way we catch regressions where we break the lowering
- These tests couldn’t be merged into Piglit proper because not lowering would be valid behaviour.

Code

- The code is at gitlab.freedesktop.org/zzoon on the mediump branch
- There are also merge requests (1043, 1044, 1045).
- Piglit tests are at: https://github.com/Igalia/piglit/
  - branch nroberts/wip/mediump-tests

Questions?