SPIR-V入門

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5月に大阪で開催されたKhronos DevDayで発表

LUNARG

Spencerについて

- SPIR-Vとは3年と働けました
  - 今LunarGでSPIR-Vの検証をしている仕事
- SPIR-VのVulkanの側面のみを使用したことがある。
  - OpenCLの専門家ではない
- コンパイラーエンジニアはない
  - SPIR-V からコンパイラについて学んだ
- SPIR-Vのワーキンググループは代表者した
  - は作成に関与していない

このプレゼンテーションは誰のためにあるのか

- SPIR-Vの読み方（理解）の学習
- シェーダーツールを作る必要がある場合
  - 簡単なことでも（例：OpLoadの呼び出しは何回あるのか？）
- 「SPIR-Vのマジック」の仕組みが気になった方は

SPIR-Vとは

- SPIR-V は、グラフィックスシェーダステージとコンピュートカーネルのバイナリ中間表現です

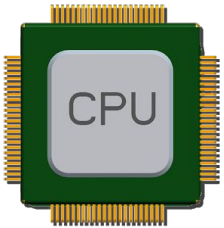
CPUのプログラミング

```
for (int i = 0; i < vertices_count; i++) {
    transform_matrix(i);
}
```

C/C++ コード

```
subs    w8, w8, w9
b.ge    .LBB0_4
ldr     w0, [sp, #8]
bl      transform_matrix(int)
```

ARM/x86/MIPS アセンブリ (ISA)



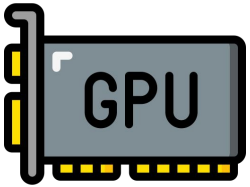
GPUのプログラミング (シェーダー/カーネル)

```
int i = get_thread_id();
transform_matrix(i);
```

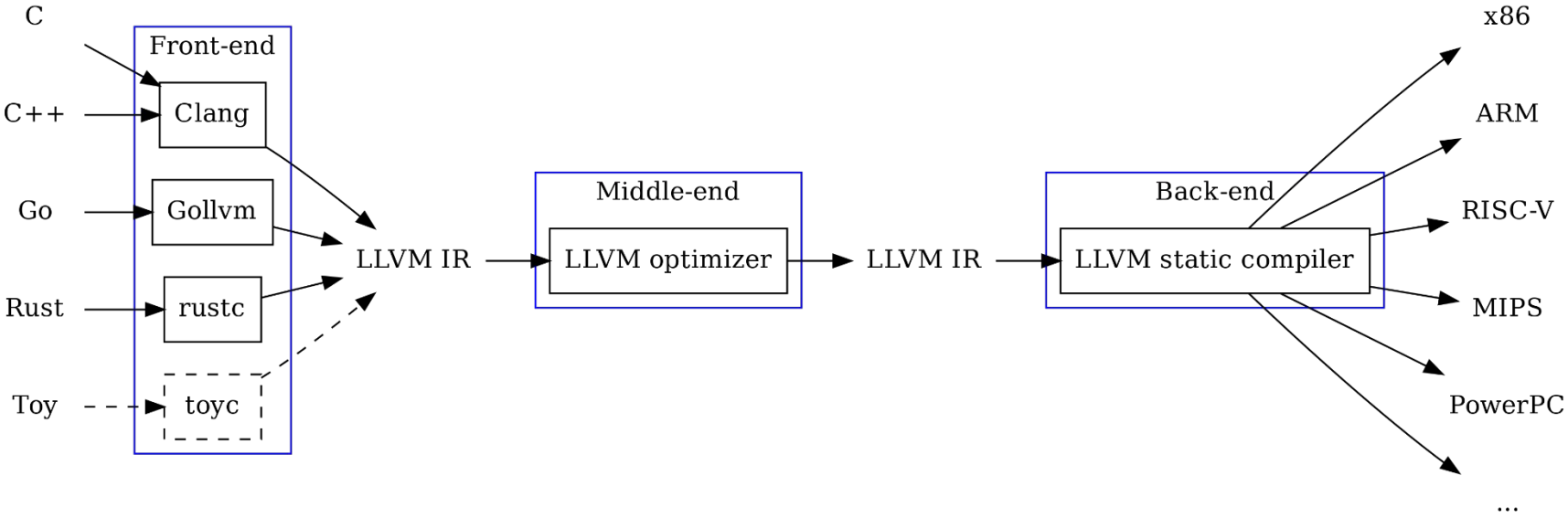
GLSL/HLSL コード

```
s_buffer_load_dwordx8  s[52:59], s[0:3], 0x00
v_mul_f32      v1, s23, v1
v_mov_b32      v5, s37
v_fma_f32      v2, s24, v5, v2
```

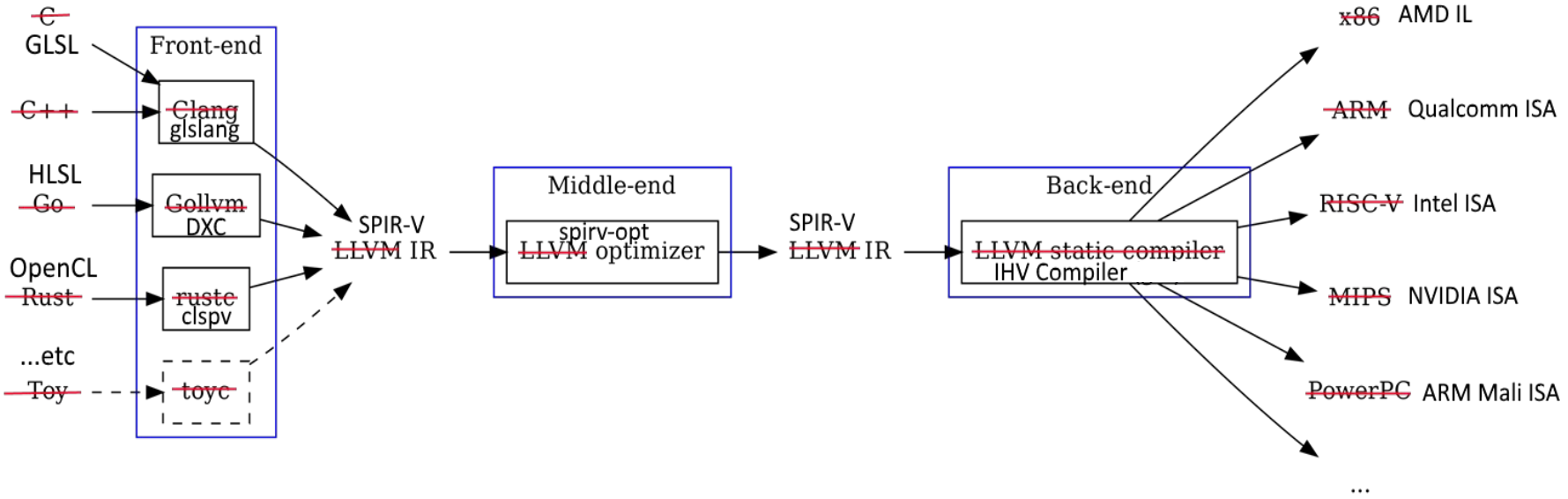
GPU アセンブリ
GPUベンダーごとに異なる



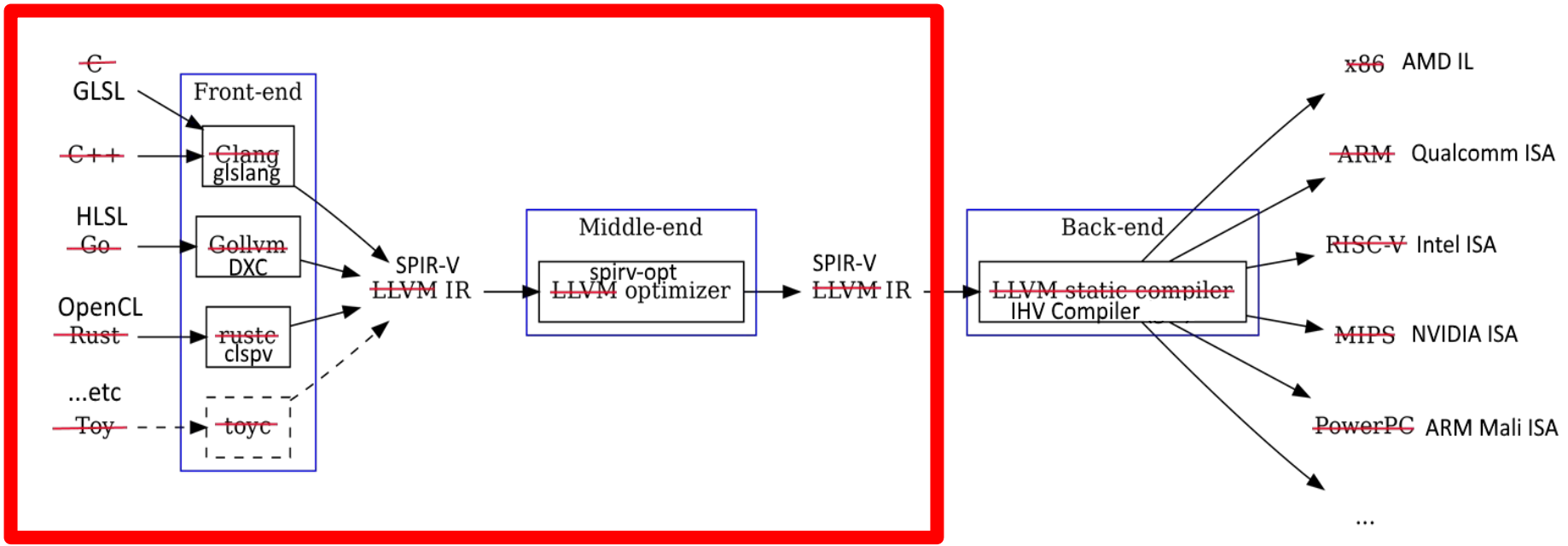
CPUにLLVMを使用する



GPUにSPIR-Vを使用する



GPUにSPIR-Vを使用する



OpenGLがやらなければならない仕事です

SPIR-V は LLVM IR に触発されています

- LLVM IR は LLVM の内部詳細です
- SPIR-Vはインターチェンジフォーマットです
- LLVMに似たSPIR-Vの構造
- 双方向翻訳ツール
  - https://github.com/KhronosGroup/SPIRV-LLVM-Translator

Shader vs Kernel

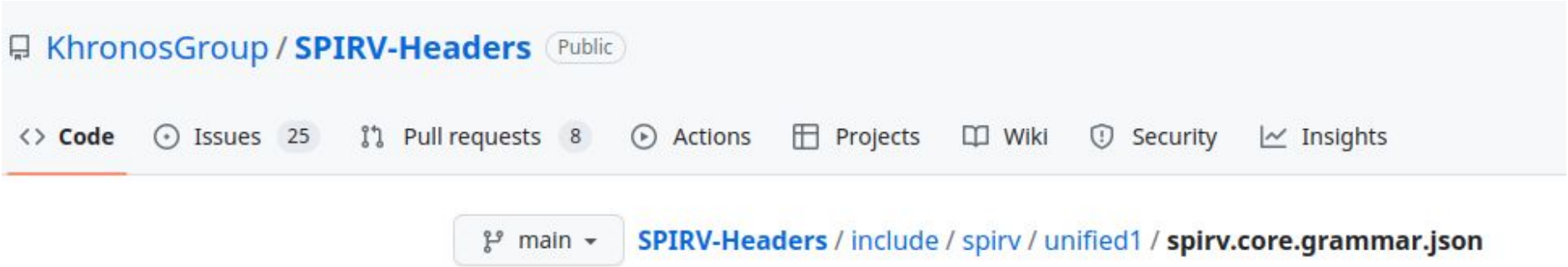
- OpenCL == Kernel
- Vulkan == Shader

Logical vs Physical

- OpenCL == Physical
- Vulkan == Logical (拡張機能を使用する場合は「Physical」)

SPIR-V Grammar JSON

- SPIR-V Headersで見つかったJSONファイル
- Vulkanのvk.xml に似たSPIR-V
- このファイルからもスペシフィケーションが生成されます



SPIR-V Grammarの使い方のユースケース

```
// Return number of optional parameter from ImageOperands
uint32_t ImageOperandsParamCount(uint32_t image_operand) {
    uint32_t count = 0;
    switch (image_operand) {
        case spv::ImageOperandsMaskNone:
        case spv::ImageOperandsNonPrivateTexelMask:
        case spv::ImageOperandsVolatileTexelMask:
        case spv::ImageOperandsSignExtendMask:
        case spv::ImageOperandsZeroExtendMask:
        case spv::ImageOperandsNontemporalMask:
            return 0;
        case spv::ImageOperandsBiasMask:
        case spv::ImageOperandsLodMask:
        case spv::ImageOperandsConstOffsetMask:
        case spv::ImageOperandsOffsetMask:
        case spv::ImageOperandsConstOffsetsMask:
        case spv::ImageOperandsSampleMask:
        case spv::ImageOperandsMinLodMask:
        case spv::ImageOperandsMakeTexelAvailableMask:
        case spv::ImageOperandsMakeTexelVisibleMask:
        case spv::ImageOperandsOffsetsMask:
            return 1;
        case spv::ImageOperandsGradMask:
            return 2;
        default:
            break;
    }
    return count;
```

```
"operand_kinds" : [
  {
    "category" : "BitEnum",
    "kind" : "ImageOperands",
    "enumerants" : [
      {
        "enumerant" : "None",
        "value" : "0x0000"
      },
      {
        "enumerant" : "Bias",
        "value" : "0x0001",
        "capabilities" : [ "Shader" ],
        "parameters" : [
          { "kind" : "IdRef" }
        ]
      },
```

Vulkan-ValidationLayers / layers / generated / **spirv_grammar_helper.cpp**

SPIR-V 拡張機能と機能系

- 機能 == Capabilities
- クライアントAPIとの通信方法（例：Vulkan）
- Capabilities == Vulkan “Features”

```
#version 450
#extension GL_EXT_shader_8bit_storage : enable

layout (set = 0) buffer StorageBuffer {
    uint8_t dataA; // 0xAA
    uint8_t dataB; // 0xBB
} ssbo;

void main() {
    uint a = uint(ssbo.dataA);
    uint b = uint(ssbo.dataB);
}
```

```
OpCapability Shader
OpCapability UniformAndStorageBuffer8BitAccess
OpExtension "SPV_KHR_8bit_storage"
```

Vulkan機能がサポートされていない場合、Validation Layers(検証レイヤ)れを検出する

```
// Provided by VK_VERSION_1_2
typedef struct VkPhysicalDevice8BitStorageFeatures {
    VkStructureType    sType;
    void*              pNext;
    VkBool32           storageBuffer8BitAccess;
    VkBool32           uniformAndStorageBuffer8BitAccess;
    VkBool32           storagePushConstant8;
} VkPhysicalDevice8BitStorageFeatures;
```

SPIR-V 命令

- SPIR-V は命令の流れ
- OpCode - 命令の名前
  - 常に「Op」で始まります
- Operands
  - OpCodeに続くWords
  - 語長 = 32 ビット

```
%16 = OpTypeInt 32 1
%48 = OpVariable %47 Function
%54 = OpLoad %16 %48
%56 = OpSLessThan %25 %54 %55
```

バイナリ vs 逆アセンブル

- SPIR-V は常にバイナリです
- プレゼンテーションのために、常に逆アセンブルを表示します

```
%16 = OpTypeInt 32 1
%48 = OpVariable %47 Function
%54 = OpLoad %16 %48
%56 = OpSLessThan %25 %54 %55
```

SPIR-V 命令

%6 = OpTypeInt 32 0

SPIR-V 命令

%6 = OpTypeInt 32 0

0x00040015 0x00000006 0x00000020 0x00000000

SPIR-V 命令

OpTypeInt

Declare a new *integer type*.

Width specifies how many bits wide the type is. *Width* is an unsigned 32-bit integer. The bit pattern of a signed integer value is two's complement.

Signedness specifies whether there are signed semantics to preserve or validate.
0 indicates unsigned, or no signedness semantics
1 indicates signed semantics.
In all cases, the type of operation of an instruction comes from the instruction's opcode, not the signedness of the operands.

4	21	*Result <id>*	*Literal* *Width*	*Literal* *Signedness*

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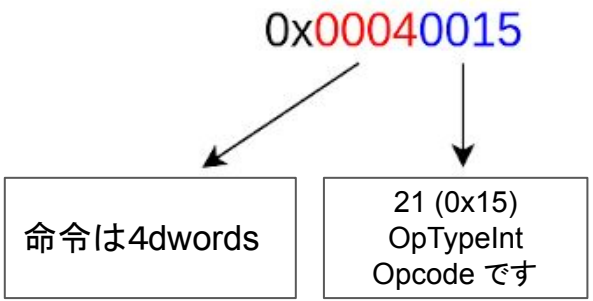
4	21	*Result <id>*	*Literal* *Width*	*Literal* *Signedness*

%6 = OpTypeInt 32 0



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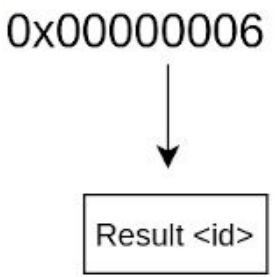
4	21	*Result <id>*	*Literal* *Width*	*Literal* *Signedness*

%6 = OpTypeInt 32 0



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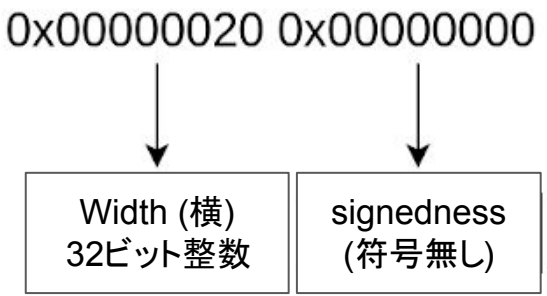
4	21	*Result <id>*	*Literal* *Width*	*Literal* *Signedness*

%6 = OpTypeInt 32 0



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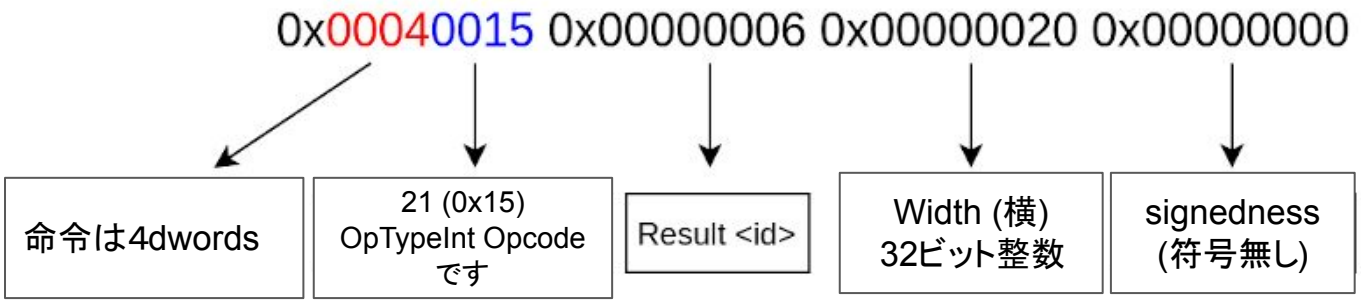
4	21	*Result <id>*	*Literal* *Width*	*Literal* *Signedness*

%6 = OpTypeInt 32 0



SPIR-V 命令

OpLoad

Load through a pointer.

Result Type is the type of the loaded object. It must be a type with fixed size; i.e., it cannot be, nor include, any **OpTypeRuntimeArray** types.

Pointer is the pointer to load through. Its type must be an **OpTypePointer** whose *Type* operand is the same as *Result Type*.

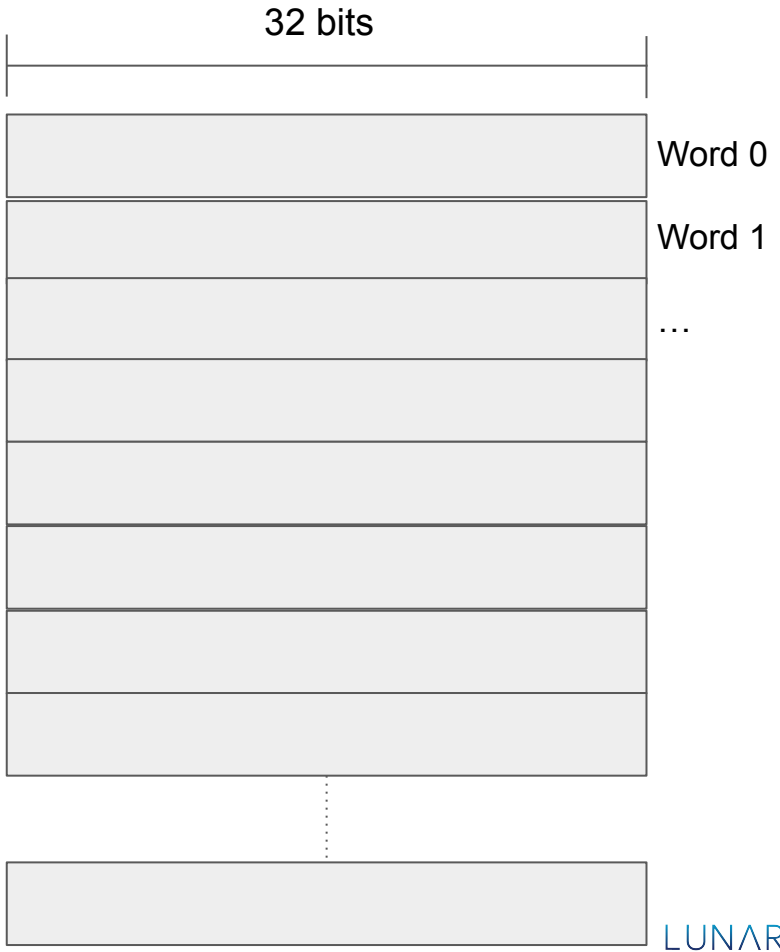
If present, any *Memory Operands* must begin with a memory operand literal. If not present, it is the same as specifying the memory operand **None**.

4 + variable	61	<id> *Result Type*	*Result <id>*	<id> *Pointer*	Optional *Memory Operands*

Operand[1] = Result Type ID
Operand[2] = Result ID

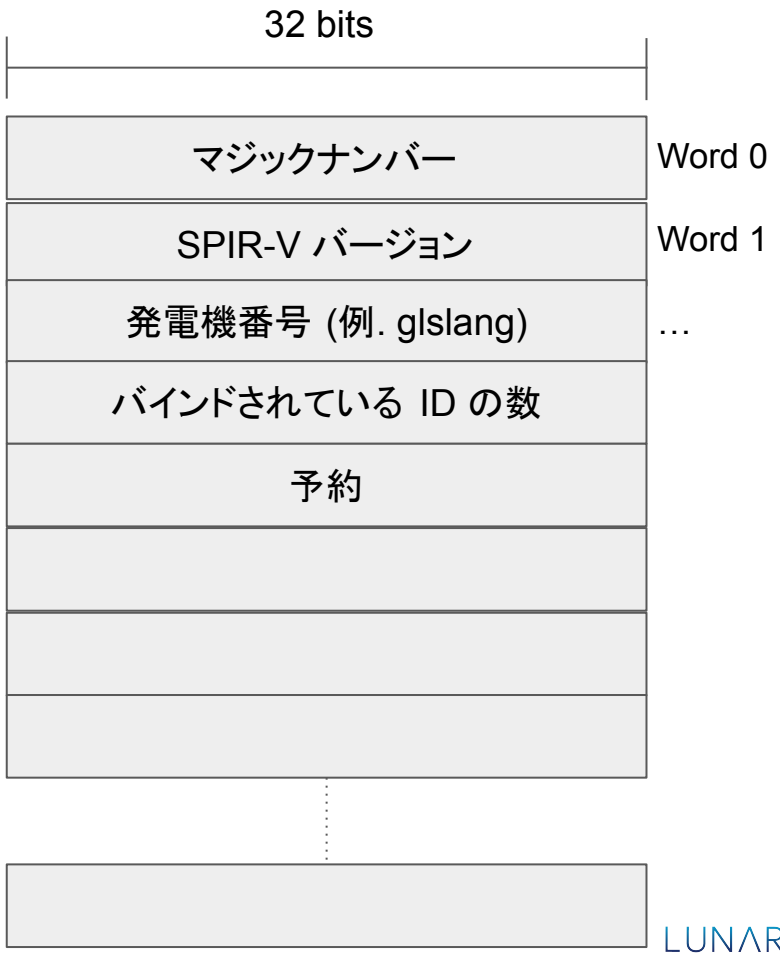
SPIR-V の構造

- 32ビットwords に続く



SPIR-V の構造

- 最初 5 words はヘッダーです



SPIR-V の構造

- 残りの words は命令です

SPIR-V の構造

- 5 欄
- それぞれ、ある特定の命令だけが許可されています。
  - spirv-val はこれが間違っている場合に警告します

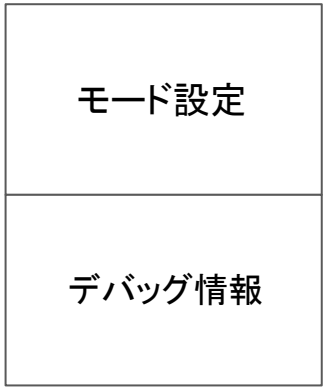
Mode Setting (モード設定)

モード設定

- Moduleのハイレベルな詳細
- Entrypoint (エントリーポイント)
- 拡張機能と機能系
- Memory model (メモリモデル)
  - Logical vs Physical
- Execution mode (実行モード)
  - Ex. OriginUpperLeft vs OriginLowerLeft

デバッグ情報

- 変数の名前
- SPIR-Vのソース
- デバッグのツールは使います

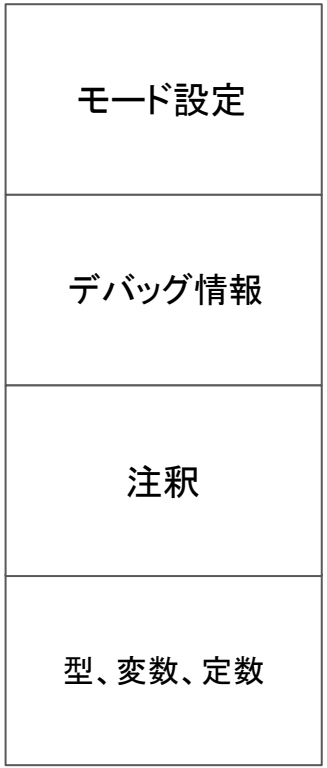


Annotations (注釈)

- Decorationsに適用します
- 今後の命令のための情報
  - RelaxedPrecision
  - ArrayStride
  - NonWritable
  - NonReadable

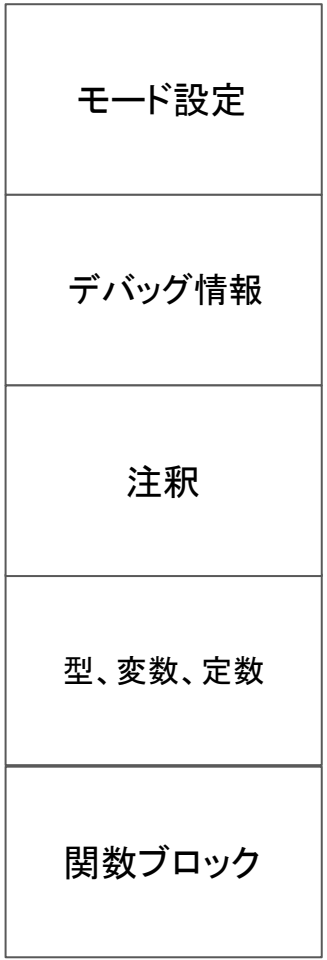
型、変数、定数

- 型を宣言する
  - OpTypeInt, OpTypeStruct, OpTypeSampler, etc
- インターフェースの変数を宣言する
  - シェーダーの間に入出力です
  - ディスクリプタ (ユニフォーム, ストレージイメージ ,など)
- 定数
  - 特殊化定数



関数ブロック

- ロジックが発生する場所
  - 読み出す, 格納する, 演算, サンプリング



ブロックを理解する

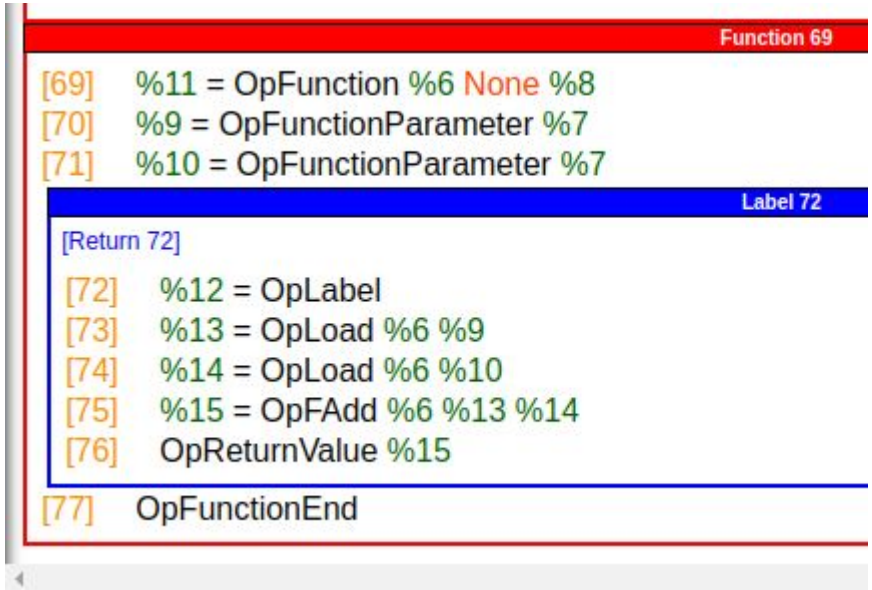
- LLVMと同じ考え方
- 複数関数ブロック
- 関数ブロックはブロックを持つことができる

```
float add(float a, float b) {
    return a + b;
}

void main() {
    float c = add(in_a, in_b);
    if (c > 0.0) {
        out_data = 1.0;
    } else {
        out_data = -1.0;
    }
}
```

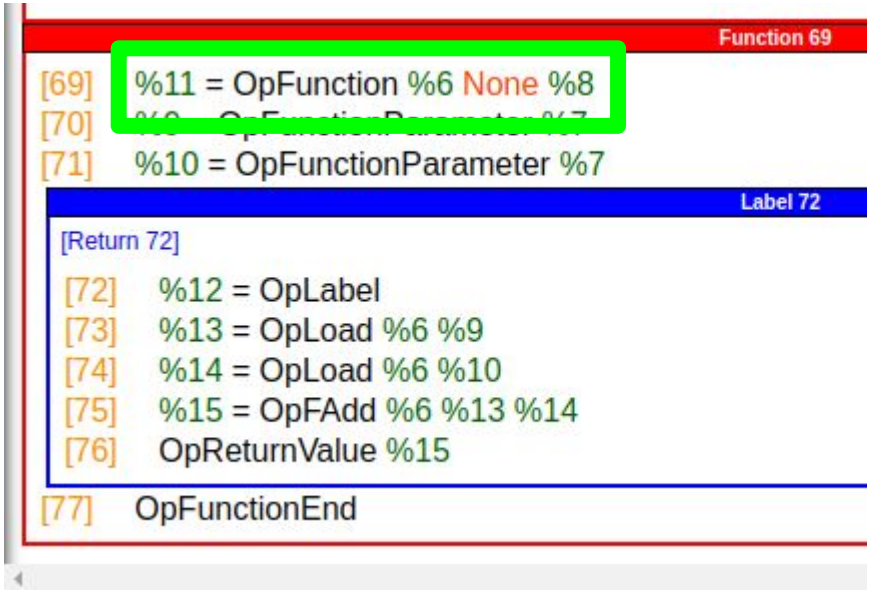
```
Function 41
[41]  %4 = OpFunction %2 None %3
  Label 42
  [Selection Header 42]
  [42]  %5 = OpLabel
  [43]  %18 = OpVariable %7 Function
  [44]  %25 = OpVariable %7 Function
  [45]  %29 = OpVariable %7 Function
  [46]  %27 = OpAccessChain %26 %21 %23
  [47]  %28 = OpLoad %6 %27
  [48]  OpStore %25 %28
  [49]  %30 = OpAccessChain %26 %21 %24
  [50]  %31 = OpLoad %6 %30
  [51]  OpStore %29 %31
  [52]  %32 = OpFunctionCall %6 %11 %25 %29
  [53]  OpStore %18 %32
  [54]  %33 = OpLoad %6 %18
  [55]  %36 = OpFOrdGreaterThan %35 %33 %34
  [56]  OpSelectionMerge %38 None
  [57]  OpBranchConditional %36 %37 %42
    Label 58
    [58]  %37 = OpLabel
    [59]  %41 = OpAccessChain %26 %21 %39
    [60]  OpStore %41 %40
    [61]  OpBranch %38
    Label 62
    [62]  %42 = OpLabel
    [63]  %44 = OpAccessChain %26 %21 %39
    [64]  OpStore %44 %43
    [65]  OpBranch %38
  Label 66
  [Return 66] [Selection Merge 42]
  [66]  %38 = OpLabel
  [67]  OpReturn
[68]  OpFunctionEnd
Function 69
[69]  %11 = OpFunction %6 None %8
[70]  %9 = OpFunctionParameter %7
[71]  %10 = OpFunctionParameter %7
  Label 72
  [Return 72]
  [72]  %12 = OpLabel
  [73]  %13 = OpLoad %6 %9
  [74]  %14 = OpLoad %6 %10
  [75]  %15 = OpFAdd %6 %13 %14
  [76]  OpReturnValue %15
[77]  OpFunctionEnd
```

```
float add(float a, float b) {
    return a + b;
}
```

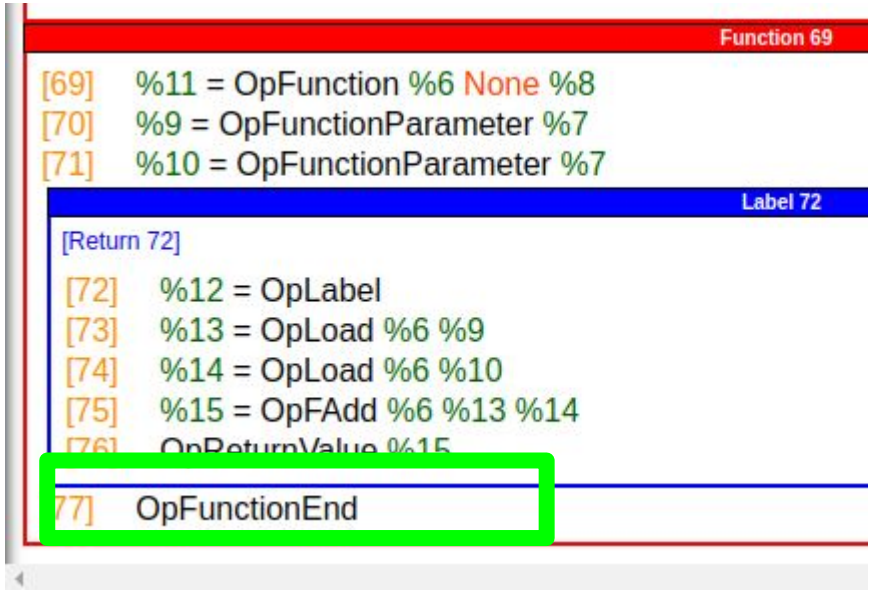


```
float add(float a, float b) {
    return a + b;
}
```

新しい「Function Block」
を定義する



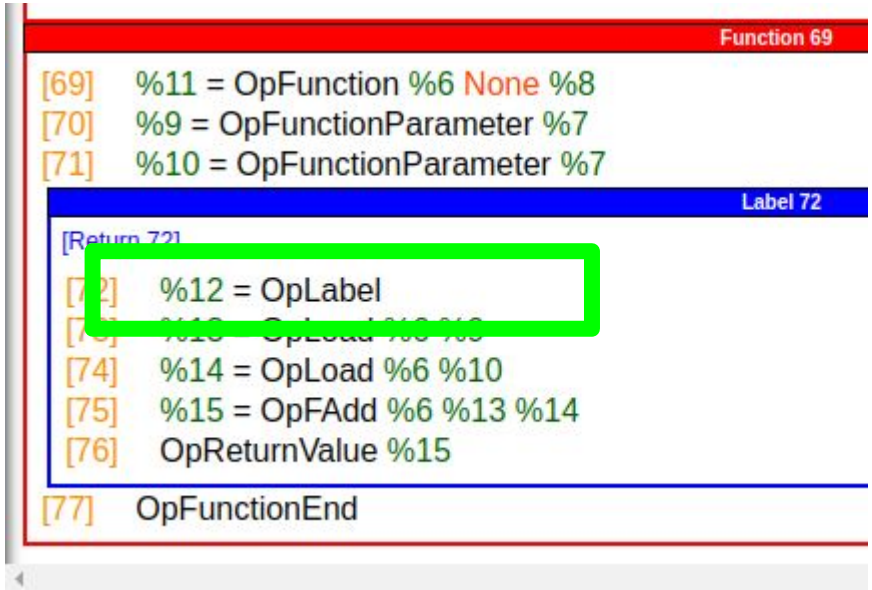
```
float add(float a, float b) {
    return a + b;
}
```



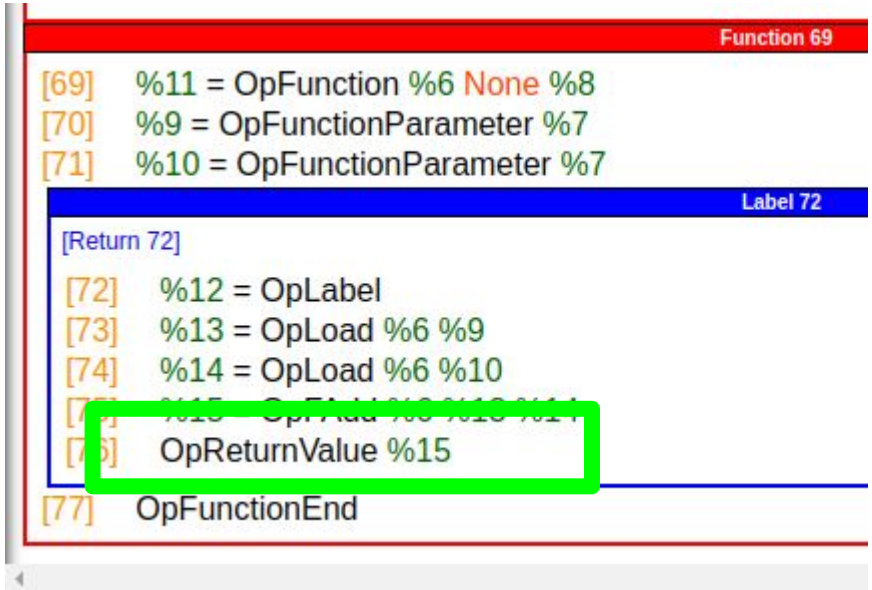
「Function Block」を終了する

```
float add(float a, float b) {
    return a + b;
}
```

新しい「Block」を定義する



```
float add(float a, float b) {
    return a + b;
}
```



「 Block」を終了する

```
Function 41
[41]  %4 = OpFunction %2 None %3
  Label 42
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  [42]  %5 = OpLabel
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  [48]  OpStore %25 %28
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  [54]  %33 = OpLoad %6 %18
  [55]  %36 = OpFOrdGreaterThan %35 %33 %34
  [56]  OpSelectionMerge %38 None
  [57]  OpBranchConditional %36 %37 %42
    Label 58
    [58]  %37 = OpLabel
    [59]  %41 = OpAccessChain %26 %21 %39
    [60]  OpStore %41 %40
    [61]  OpBranch %38
    Label 62
    [62]  %42 = OpLabel
    [63]  %44 = OpAccessChain %26 %21 %39
    [64]  OpStore %44 %43
    [65]  OpBranch %38
  Label 66
  [Return 66] [Selection Merge 42]
  [66]  %38 = OpLabel
  [67]  OpReturn
[68]  OpFunctionEnd
```

```
void main() {
    float c = add(in_a, in_b);
    if (c > 0.0) {
        out_data = 1.0;
    } else {
        out_data = -1.0;
    }
}
```

関数を呼び出す

```
Function 41
[41]  %4 = OpFunction %2 None %3
  Label 42
  [Selection Header 42]
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  [43]  %18 = OpVariable %7 Function
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  [51]  OpStore %29 %31
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  [54]  %33 = OpLoad %6 %18
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  [56]  OpSelectionMerge %38 None
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    [58]  %37 = OpLabel
    [59]  %41 = OpAccessChain %26 %21 %39
    [60]  OpStore %41 %40
    [61]  OpBranch %38
    Label 62
    [62]  %42 = OpLabel
    [63]  %44 = OpAccessChain %26 %21 %39
    [64]  OpStore %44 %43
    [65]  OpBranch %38
  Label 66
  [Return 66] [Selection Merge 42]
  [66]  %38 = OpLabel
  [67]  OpReturn
[68]  OpFunctionEnd
```

```
void main() {
    float c = add(in_a, in_b);
    if (c > 0.0) {
        out_data = 1.0;
    } else {
        out_data = -1.0;
    }
}
```

コントロールフローを宣言する

```
Function 41
[41]  %4 = OpFunction %2 None %3
  Label 42
  [Selection Header 42]
  [42]  %5 = OpLabel
  [43]  %18 = OpVariable %7 Function
  [44]  %25 = OpVariable %7 Function
  [45]  %29 = OpVariable %7 Function
  [46]  %27 = OpAccessChain %26 %21 %23
  [47]  %28 = OpLoad %6 %27
  [48]  OpStore %25 %28
  [49]  %30 = OpAccessChain %26 %21 %24
  [50]  %31 = OpLoad %6 %30
  [51]  OpStore %29 %31
  [52]  %32 = OpFunctionCall %6 %11 %25 %29
  [53]  OpStore %18 %32
  [54]  %33 = OpLoad %6 %18
  [ ]   %36 = OpFOrdGreaterThan %33 %35 %34
  [ ]   OpSelectionMerge %38 None
  [ ]   OpBranchConditional %36 %37 %42
    Label 58
    [58]  %37 = OpLabel
    [59]  %41 = OpAccessChain %26 %21 %39
    [60]  OpStore %41 %40
    [61]  OpBranch %38
    Label 62
    [62]  %42 = OpLabel
    [63]  %44 = OpAccessChain %26 %21 %39
    [64]  OpStore %44 %43
    [65]  OpBranch %38
  Label 66
  [Return 66] [Selection Merge 42]
  [66]  %38 = OpLabel
  [67]  OpReturn
[68]  OpFunctionEnd
```

```
void main() {
    float c = add(in_a, in_b);
    if (c > 0.0) {
        out_data = 1.0;
    } else {
        out_data = -1.0;
    }
}
```

コントロールフローを宣言する

コントロールフローのマージを Block する

```
Function 41
[41]  %4 = OpFunction %2 None %3
  Label 42
  [Selection Header 42]
  [42]  %5 = OpLabel
  [43]  %18 = OpVariable %7 Function
  [44]  %25 = OpVariable %7 Function
  [45]  %29 = OpVariable %7 Function
  [46]  %27 = OpAccessChain %26 %21 %23
  [47]  %28 = OpLoad %6 %27
  [48]  OpStore %25 %28
  [49]  %30 = OpAccessChain %26 %21 %24
  [50]  %31 = OpLoad %6 %30
  [51]  OpStore %29 %31
  [52]  %32 = OpFunctionCall %6 %11 %25 %29
  [53]  OpStore %18 %32
  [54]  %33 = OpLoad %6 %18
  [ ]   %36 = OpFOrdGreaterThan %33 %35 %34
  [ ]   OpSelectionMerge %38 None
  [ ]   OpBranchConditional %36 %37 %42
  Label 58
  [58]  %37 = OpLabel
  [59]  %41 = OpAccessChain %26 %21 %39
  [60]  OpStore %41 %40
  [61]  OpBranch %38
  Label 62
  [62]  %42 = OpLabel
  [63]  %44 = OpAccessChain %26 %21 %39
  [64]  OpStore %44 %43
  [65]  OpBranch %38
  Label 66
  [ ]   %39 = OpLoad %6 %29
  [66]  %38 = OpLabel
  [67]  OpReturn
[68]  OpFunctionEnd
```

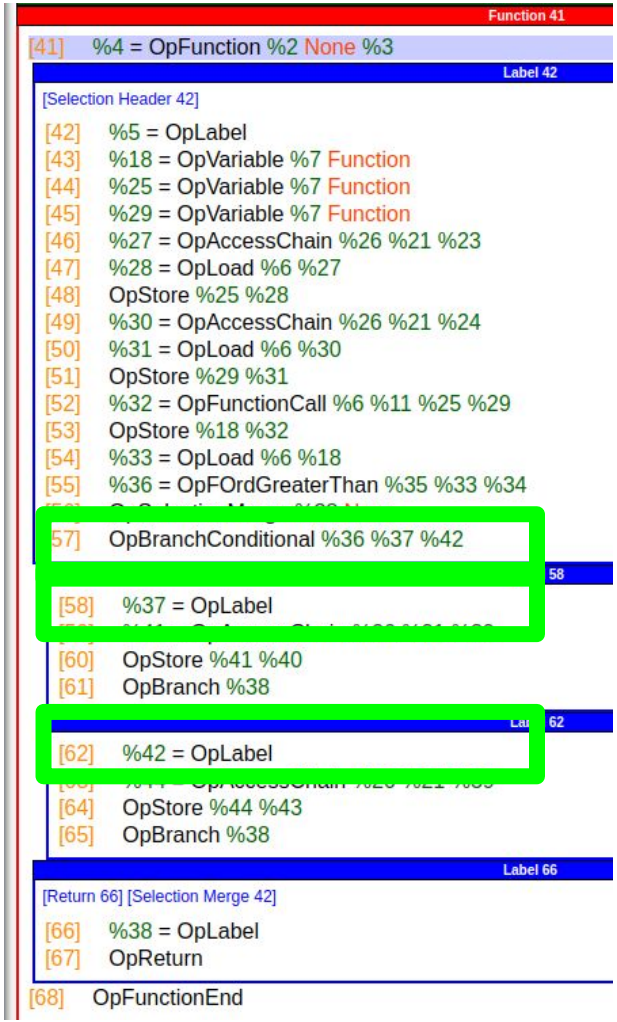
```
void main() {
    float c = add(in_a, in_b);
    if (c > 0.0) {
        out_data = 1.0;
    } else {
        out_data = -1.0;
    }
}
```

条件付きで次に行く場所
を決める

```
Function 41
[41]  %4 = OpFunction %2 None %3
Label 42
[Selection Header 42]
[42]  %5 = OpLabel
[43]  %18 = OpVariable %7 Function
[44]  %25 = OpVariable %7 Function
[45]  %29 = OpVariable %7 Function
[46]  %27 = OpAccessChain %26 %21 %23
[47]  %28 = OpLoad %6 %27
[48]  OpStore %25 %28
[49]  %30 = OpAccessChain %26 %21 %24
[50]  %31 = OpLoad %6 %30
[51]  OpStore %29 %31
[52]  %32 = OpFunctionCall %6 %11 %25 %29
[53]  OpStore %18 %32
[54]  %33 = OpLoad %6 %18
[55]  %36 = OpFOrdGreaterThan %35 %33 %34
[57]  OpBranchConditional %36 %37 %42
58
[58]  %37 = OpLabel
[59]  %41 = OpAccessChain %26 %21 %39
[60]  OpStore %41 %40
[61]  OpBranch %38
Label 62
[62]  %42 = OpLabel
[63]  %44 = OpAccessChain %26 %21 %39
[64]  OpStore %44 %43
[65]  OpBranch %38
Label 66
[Return 66] [Selection Merge 42]
[66]  %38 = OpLabel
[67]  OpReturn
[68]  OpFunctionEnd
```

```
void main() {
    float c = add(in_a, in_b);
    if (c > 0.0) {
        out_data = 1.0;
    } else {
        out_data = -1.0;
    }
}
```

条件付きで次に行く場所
を決める




```
void main() {
    float c = add(in_a, in_b);
    if (c > 0.0) {
        out_data = 1.0;
    } else {
        out_data = -1.0;
    }
}
```

Block が "Fall Through"ことはない

```
Function 41
[41]  %4 = OpFunction %2 None %3
  Label 42
  [Selection Header 42]
  [42]  %5 = OpLabel
  [43]  %18 = OpVariable %7 Function
  [44]  %25 = OpVariable %7 Function
  [45]  %29 = OpVariable %7 Function
  [46]  %27 = OpAccessChain %26 %21 %23
  [47]  %28 = OpLoad %6 %27
  [48]  OpStore %25 %28
  [49]  %30 = OpAccessChain %26 %21 %24
  [50]  %31 = OpLoad %6 %30
  [51]  OpStore %29 %31
  [52]  %32 = OpFunctionCall %6 %11 %25 %29
  [53]  OpStore %18 %32
  [54]  %33 = OpLoad %6 %18
  [55]  %36 = OpFOrdGreaterThan %35 %33 %34
  [56]  OpSelectionMerge %38 None
  [57]  OpBranchConditional %36 %37 %42
    Label 58
    [58]  %37 = OpLabel
    [59]  %41 = OpAccessChain %26 %21 %39
    [61]  OpBranch %38
    62
    [62]  %42 = OpLabel
    [63]  %44 = OpAccessChain %26 %21 %39
    [65]  OpBranch %38
    66
    [Return 66] [Selection Merge 42]
    [66]  %38 = OpLabel
    [67]  OpReturn
[68]  OpFunctionEnd
```

```
void main() {
    float c = add(in_a, in_b);
    if (c > 0.0) {
        out_data = 1.0;
    } else {
        out_data = -1.0;
    }
}
```

SPIR-Vバイナリの解析

```
void parseModule (uint32_t* pCode, uint32_t codeSize) {
    uint32_t offset = 5; // first 5 words in module are the headers
    while(offset < codeSize) {
        uint32_t instruction = pCode[offset];

        uint32_t length = instruction >> 16;
        uint32_t opcode = instruction & 0x0ffffu;

        offset += length;
    }
}
```

SPIR-Vバイナリの解析

```
void parseModule(uint32_t* pCode, uint32_t codeSize) {
    uint32_t offset = 5; // first 5 words in module are the headers
    while(offset < codeSize) {
        uint32_t instruction = pCode[offset];

        uint32_t length = instruction >> 16;
        uint32_t opcode = instruction & 0x0ffffu;

        offset += length;
    }
}
```

SPIR-Vバイナリの解析

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    uint32_t offset = 5; // first 5 words in module are the headers
    while(offset < codeSize) {
        uint32_t instruction = pCode[offset];

        uint32_t length = instruction >> 16;
        uint32_t opcode = instruction & 0x0ffffu;

        offset += length;
    }
}
```

SPIR-Vバイナリの解析

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void parseModule (uint32_t* pCode, uint32_t codeSize) {
    uint32_t offset = 5; // first 5 words in module are the headers
    while(offset < codeSize) {
        uint32_t instruction = pCode[offset];

        uint32_t length = instruction >> 16;
        uint32_t opcode = instruction & 0x0ffffu;

        offset += length;
    }
}
```

SPIR-Vバイナリの解析

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    uint32_t offset = 5; // first 5 words in module are the headers
    while(offset < codeSize) {
        uint32_t instruction = pCode[offset];

        uint32_t length = instruction >> 16;
        uint32_t opcode = instruction & 0x0ffffu;

        offset += length;
    }
}
```

拡張命令セット

- SPIR-Vがアグノスティックであることを可能にします。
- 同じ命令に対して異なるルールを記述する言語
  - 例）**sin()** 関数の精度

```
void main() {
    float x = sin(data);
}
```

```
void main() {
    float x = sin(data);
}
```

https://registry.khronos.org/SPIR-V/specs/unified1/GLSL.std.450.pdf

Sin	
The standard trigonometric sine of *x* radians. The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point. *Result Type* and the type of *x* must be the same type. Results are computed per component.	
13	*<id>* *x*

```
void main() {
    float x = sin(data);
}
```

```
%1 = OpExtInstImport "GLSL.std.450"
%17 = OpExtInst %6 %1 Sin %16
```

Sin

The standard trigonometric sine of *x* radians.

The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point.

Result Type and the type of *x* must be the same type. Results are computed per component.

13	*<id>* *x*

```
void main() {
    float x = sin(data);
}
```

%1 = OpExtInstImport "GLSL.std.450"

%17 = OpExtInst %6 %1 Sin %16

値: 13　　<id> x

Sin	
The standard trigonometric sine of *x* radians. The operand *x* must be a scalar or vector whose component type is 16-bit or 32-bit floating-point. *Result Type* and the type of *x* must be the same type. Results are computed per component.	
13	*<id>* *x*

Entry Point, Execution Model, and Execution Mode

- Module == SPIR-Vのファイル
  - 複数Entry Pointsできます
- Model vs Mode - 綴り似ている、気を付けてください

Entry Point, Execution Model, and Execution Mode

- Moduleの中で複数Entry Pointsできます

```
float foo(float bar) {
    return bar / 2.0;
}

void vertex_main() {
    // set RoundingModeRTE
    foo(3.0);
}

void fragment_main() {
    // set RoundingModeRTZ
    foo(3.0);
}
```

Entry Point, Execution Model, and Execution Mode

- Moduleの中で複数Entry Pointsできます

```
float foo(float bar) {
    return bar / 2.0;
}

void vertex_main() {
    // set RoundingModeRTE
    foo(3.0);
}

void fragment_main() {
    // set RoundingModeRTZ
    foo(3.0);
}
```

```
        OpEntryPoint Vertex %v_main "vertex_main" %vert_out
        OpEntryPoint Fragment %f_main "fragment_main"
        OpExecutionMode %v_main RoundingModeRTE 32
        OpExecutionMode %f_main RoundingModeRTZ 32
        // ...
%foo = OpFunction %float None %1
%bar = OpFunctionParameter %ptr_float
  %2 = OpLabel
  %3 = OpLoad %float %bar
  %4 = OpFDiv %float %3 %float_2
        OpReturnValue %4
        OpFunctionEnd
```

Entry Point, Execution Model, and Execution Mode

- Execution Modelは宣言をする

```
float foo(float bar) {
    return bar / 2.0;
}

void vertex_main() {
    // set RoundingModeRTE
    foo(3.0);
}

void fragment_main() {
    // set RoundingModeRTZ
    foo(3.0);
}
```

```
        OpEntryPoint Vertex %v_main "vertex_main" %vert_out
        OpEntryPoint Fragment %f_main "fragment_main"
        OpExecution                    ngModeRTE 32
        OpExecutionMode %f_main RoundingModeRTZ 32
        // ...
%foo = OpFunction %float None %1
%bar = OpFunctionParameter %ptr_float
  %2 = OpLabel
  %3 = OpLoad %float %bar
  %4 = OpFDiv %float %3 %float_2
        OpReturnValue %4
        OpFunctionEnd
```

Entry Point, Execution Model, and Execution Mode

- Execution ModelはEntry Pointではなく関数に適用されます

```
float foo(float bar) {
    return bar / 2.0;
}

void vertex_main() {
    // set RoundingModeRTE
    foo(3.0);
}

void fragment_main() {
    // set RoundingModeRTZ
    foo(3.0);
}
```

```
        OpEntryPoint Vertex %v_main "vertex_main" %vert_out
        OpExecutionMode %v_main RoundingModeRTE 32
        OpExecutionMode %f_main RoundingModeRTZ 32
%foo = OpFunction %float None %1
%bar = OpFunctionParameter %ptr_float
  %2 = OpLabel
  %3 = OpLoad %float %bar
  %4 = OpFDiv %float %3 %float_2
       OpReturnValue %4
       OpFunctionEnd
```

型

- OpType*
- 型を使用して、より大きな型を作成できます
- Module全体で共有される型を一度定義する

型 - mat3x2

- と同じ
  - vec2
  - vec2
  - vec2

型 - mat3x2

- %float = OpTypeFloat 32

型 - mat3x2

- %float = OpTypeFloat 32
- %v2float = OpTypeVector %float 2

型 - mat3x2

- %float = OpTypeFloat 32
- %v2float = OpTypeVector %float 2
- %mat3v2float = OpTypeMatrix %v2float 3

型 - mat3x2

- %float = OpTypeFloat 32
- %v2float = OpTypeVector %float 2
- %mat3v2float = OpTypeMatrix %v2float 3
- %ptr = OpTypePointer Input %mat3v2float

型 - 構造

```
struct myStruct {
    int a;
    float b;
    int c;
};
```

型 - 構造

- %int = OpTypeInt 32 1
- %float = OpTypeFloat 32

```
struct myStruct {
    int a;
    float b;
    int c;
};
```

型 - 構造

- %int = OpTypeInt 32 1
- %float = OpTypeFloat 32
- %myStruct = OpTypeStruct %int %float %int

```
struct myStruct {
    int a;
    float b;
    int c;
};
```

Access Chains (アクセスチェーン)

- 変数の一部にアクセスするために使用する
- 変数を介した「アクセス」の「連鎖」である。

Access Chain

```
layout(set = 0) buffer ssbo {
    float a;
    vec3 b[4];
    float c;
};

void main() {
    b[2].z = 0.0f;
}
```

Access Chain

```
layout(set = 0) buffer ssbo {
    float a;
    vec3 b[4];
    float c;
};

void main() {
    b[2].z = 0.0f;
}
```

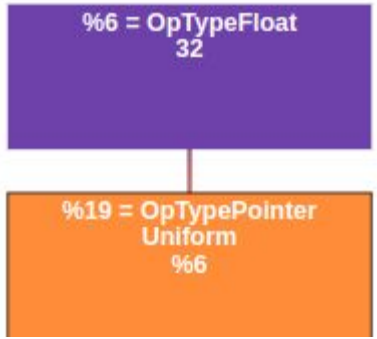
Access Chain

```
layout(set = 0) buffer ssbo {
    float a;
    vec3 b[4];
    float c;
};

void main() {
    b[2].z = 0.0f;
}
```

```
%20 = OpAccessChain %19 %13 %15 %16 %18
```

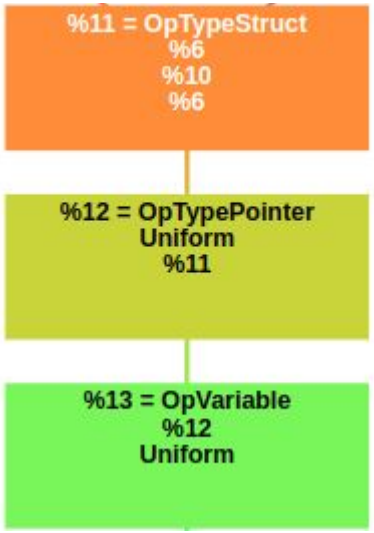
Access Chain



Result Type (結果の型)

```
%20 = OpAccessChain %19 %13 %15 %16 %18
```

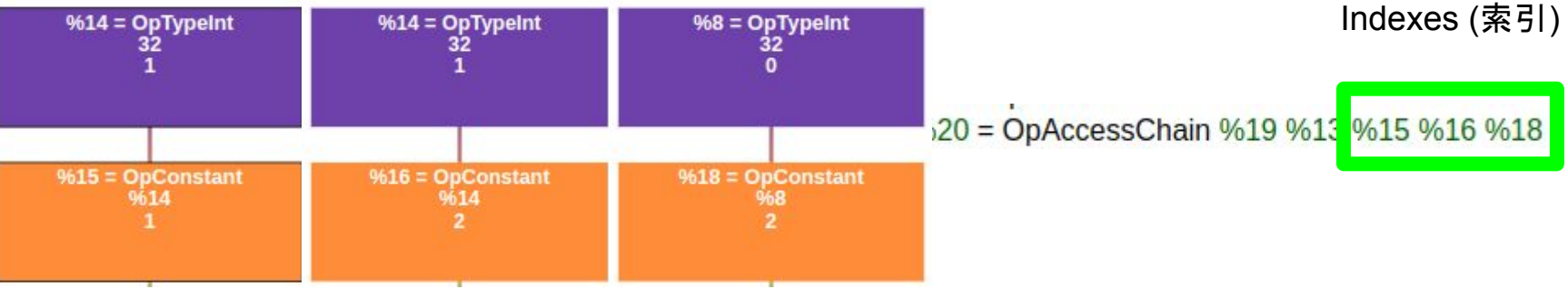
Access Chain



Base object

%20 = OpAccessChain %19 %13 %15 %16 %18

Access Chain



Access Chain

構造

```
%20 = OpAccessChain %19 %13 1 2 2
```

```
layout(set = 0) buffer ssbo {
    float a;
    vec3 b[4];
    float c;
};

void main() {
    b[2].z = 0.0f;
}
```

Access Chain

```
layout(set = 0) buffer ssbo {
    float a;
    vec3 b[4];
    float c;
};

void main() {
    b[2].z = 0.0f;
}
```

構造

```
%20 = OpAccessChain %19 %13 1 2 2
```

構造体のインデックス１

Access Chain

```
layout(set = 0) buffer ssbo {
    float a;
    vec3 [4];
    float c;
};

void main() {
    [2] z = 0.0f;
}
```

Access Chain

```
layout(set = 0) buffer ssbo {
    float a;
    vec3 b[4];
    float c;
};

void main() {
    b[2].z = 0.0f;
}
```

Access Chain

```
layout(set = 0) buffer ssbo {
    float a;
    vec3 b[4];
    float c;
};

void main() {
    b[2].z = 0.0f;
}
```

- %20 = OpAccessChain %19 %13 %15 %16 %18
- OpStore %20 %float_0


Questions?