Sylkan

Towards a Vulkan Compute Target Platform for SYCL

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DPS
Distributed and Parallel Systems

Background and Motivation

Background

- Accelerators are becoming increasingly common and heterogeneous

→ At the high end for **increased peak performance** levels
(e.g. HPC, dedicated professional and enthusiast GPUs)

→ At the lower end for **increased energy efficiency**
(e.g. cell phones, embedded systems)

- However, **programmability** is still far from optimal
  - Ideally needs *cross-vendor, broadly applicable* options

Cross-vendor API Choices

OpenCL™

- Most widespread **compute-specific** option
- Assumes some familiarity with **low-level HW aspects**
- Some implementation and maintenance overhead

SYCL™

- High-level **programmability-focused** C++ API
- Starting with SYCL2020, officially supports **non-OpenCL backends**
- However, often no current options for running it on some embedded devices

Vulkan®

- Primarily a graphics API, but also supports compute
- Very **widespread support on consumer HW** due to importance for graphics
- Similar low-level implementation details requirements as OpenCL

Sylkan

- Compiler and runtime system for executing **SYCL programs** on arbitrary **Vulkan devices**
- ***Goal***: extend the ease of use and programmability of SYCL to even more target platforms
- In this work:
    1. An analysis of the **semantic and engineering gap** which needs to be bridged
    2. An overview of our **prototype implementation**
    3. An initial **qualitative and quantitative evaluation** of our implementation

Semantic Mapping

Mapping from SYCL to Vulkan Compute

- Three major categories:
  1. General Terminology and Object Mapping
  2. User Code Structure and Runtime System
  3. Kernel Code

Majority of complexity in terms of required transformations

General Terminology and Object Mapping

SYCL / OpenCL	Vulkan
Platform	Instance
Device	Physical Device
Context	Device
Queue	Queue
Buffer	Buffer
Program	Shader Module
Kernel	(Compute) Pipeline
Event	Timeline Semaphore

Straightforward 1:1 mapping

Some more complexity, details later

Multiple potential options here
Timeline Semaphores most convenient since they allow **omnidirectional synchronization**

User Code Structure and Runtime System

- Code Structure
  - SYCL allows for a **single-source** application targeting heterogeneous devices
  - Vulkan follows a traditional **split host/device code** model
  - → Sylkan compiler infrastructure needs to extract device parts
- Runtime System
  - Mostly straightforward implementation work, one **key difference**:
  - SYCL tracks dependencies and performs data transfers and synchronization
  - Vulkan requires explicit manual data transfers and synchronization
  - → Sylkan RT needs to implement dependency tracking etc.

For both of these issues: DPC++ runtime used as a baseline proved extremely helpful

Kernel Code

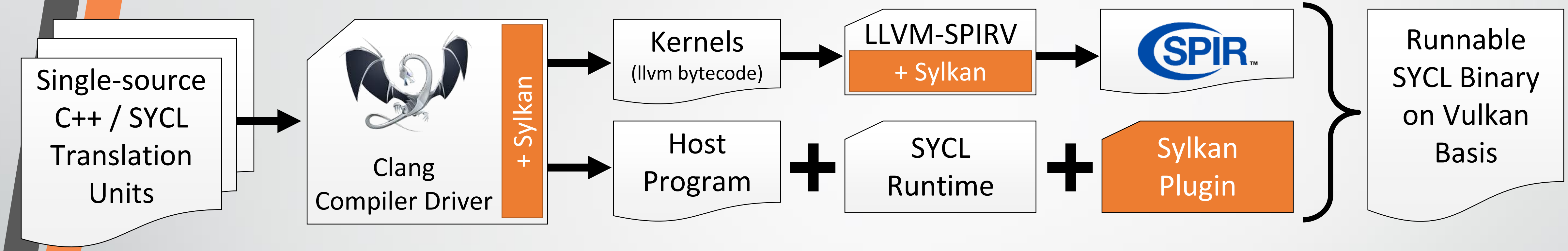
- Looks simple from high-level perspective: both OpenCL and Vulkan consume kernel code in the **SPIR-V** intermediate language
- However, SPIR-V ***capabilities*** very different – “kernel” and “addresses” for OpenCL, “shader” for Vulkan
- 4 main categories of differences:
  1. Addressing Model
  2. Address Spaces
  3. Calling Conventions
  4. Structured Control Flow

Kernels vs. Shaders

- Kernels allow a ***physical** addressing model*, while shaders are restricted to ***logical** addressing* → Severely restricts use of pointers
- The *CrossWorkgroup* storage class is the default in OpenCL kernels for global memory, but is not available in Vulkan shaders
- Calling convention: kernels are functions with **parameters**, while shader parameters need to be wrapped as **global structures** and bound in descriptor sets on the host
- Shaders require **structured control flow**, which introduces a variety of constraints on the CFG structure, and requires **explicit merging** of branches and loops

Sylkan Prototype Implementation

Overview

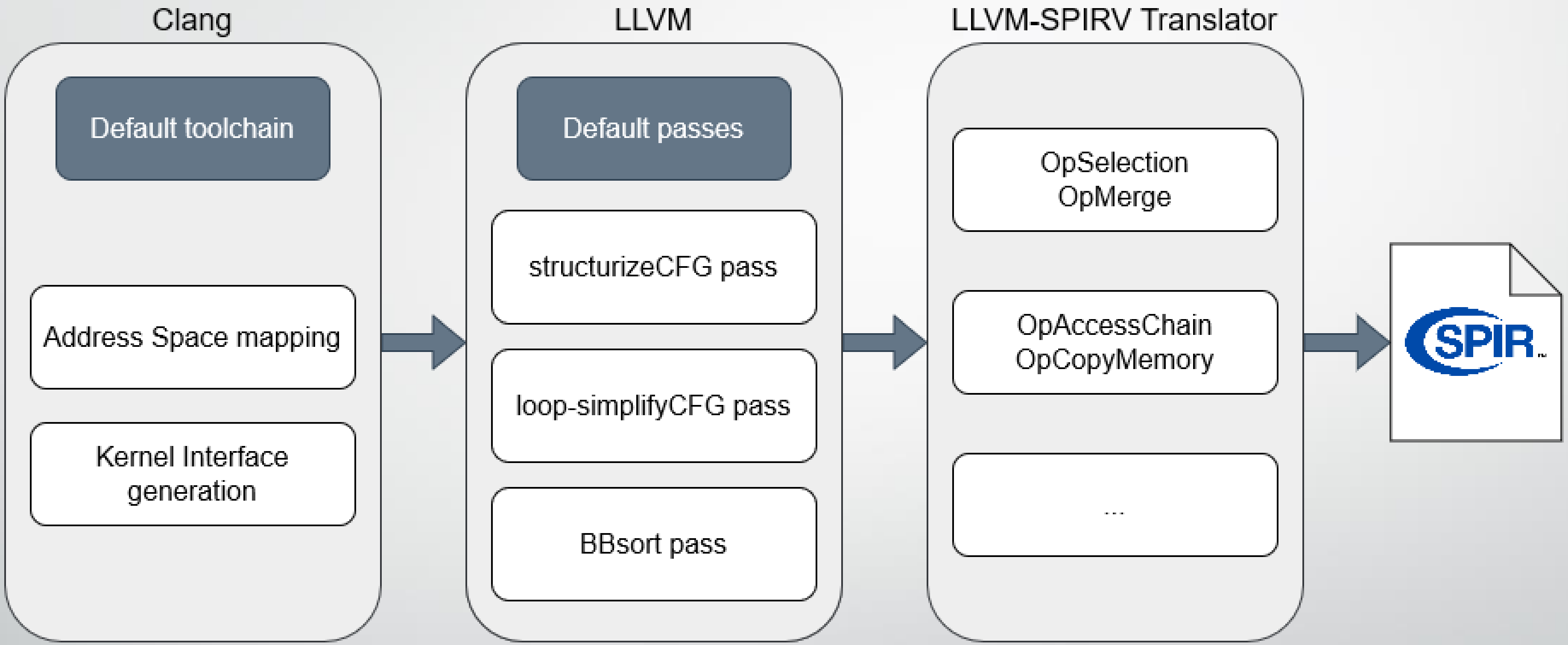


- Implementation leverages existing open source components (primarily Clang/LLVM/DPC++)
- The majority of changes were necessary in the Clang Compiler Driver and LLVM-SPIRV translator
- The Sylkan runtime plugin is entirely new

Sylkan Runtime & Vulkan Plugin

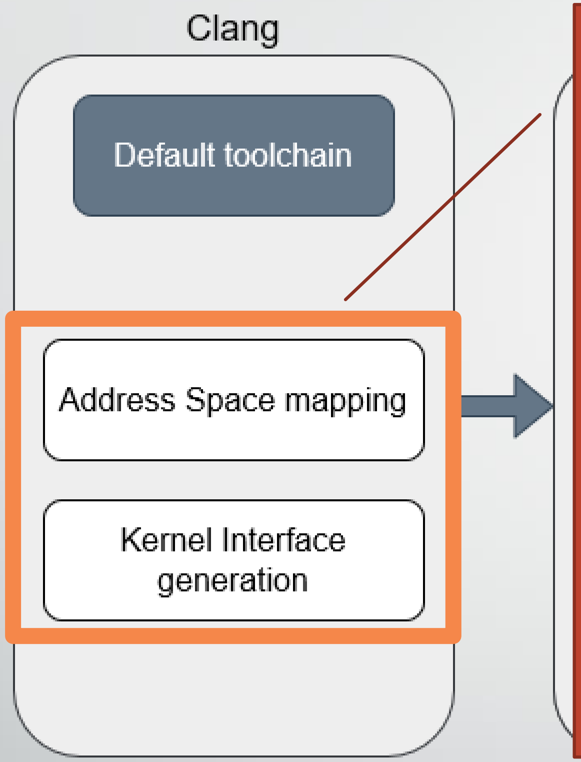
- Generally, the Sylkan runtime creates and manages objects following the previously discussed **semantic mapping**
- Automatically uses **staging buffers** for good data transfer performance
- When direct memory re-use is requested, specific alignment guarantees need to be made → can not be generally guaranteed by Sylkan for user data, falls back to staging if mis-aligned
- Omitting some details e.g. regarding extension requirements, linking and kernel lookup here, more information in the paper

Device Code Compilation



- Not an exhaustive list, but the most important steps

Device Code Compilation



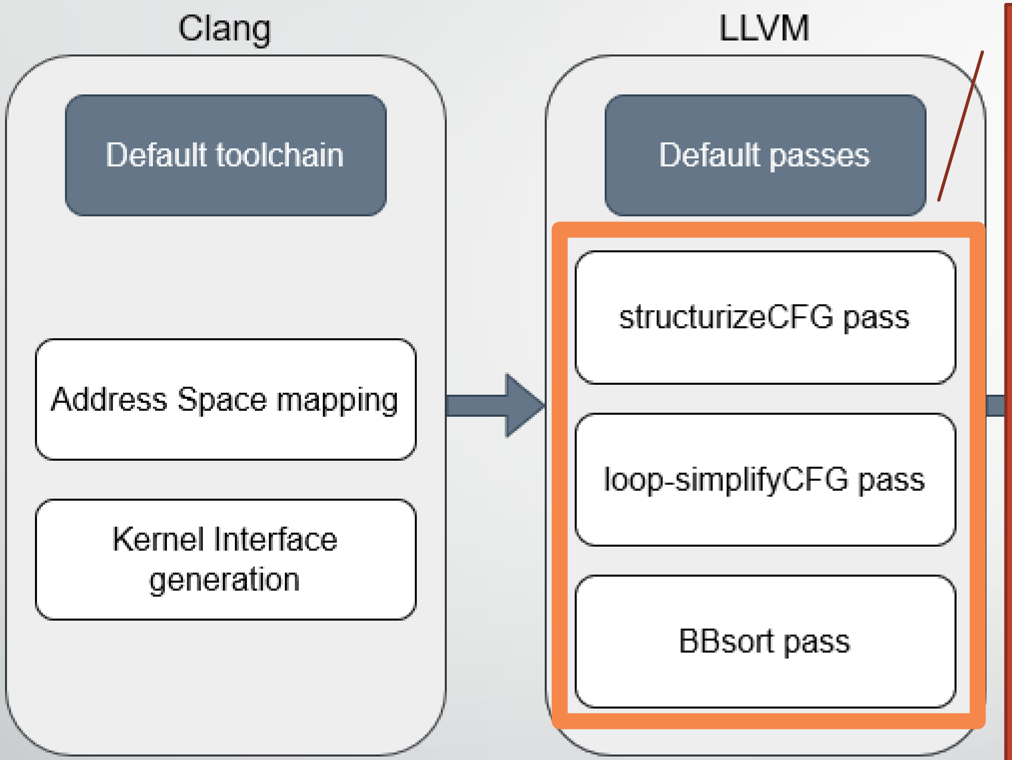
Address Space Mapping

- Replace incompatible mappings early on in the compilation process
- Modify accessor compilation to maintain type information and prevent address space casts

Kernel Interface Generation

- Requires generating structural global data and descriptor sets for all kernel parameters
- Currently implemented using individual buffers for all types of parameters

Device Code Compilation



Structured Control Flow

- In order to restructure the control flow graph to fulfil structured CFG restrictions, we leveraged 2 existing LLVM passes: **structurizeCFG** and **loop-simplifyCFG**
- One issue is that these passes may generate new blocks *after their respective successor*
- This is not allowed in SPIR-V – we remedied it by creating a new pass **BBSort** which topologically sorts the strongly connected components of the CFG

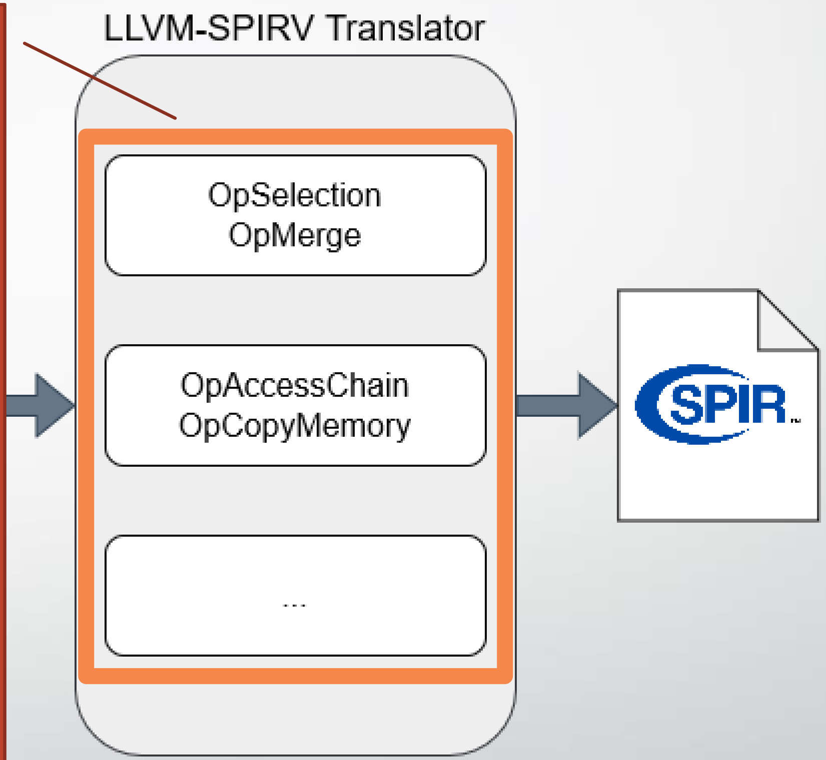
Device Code Compilation

Structured Control Flow

- Although CFG has correct structure, still need to generate explicit selection operands
  → uses dominator tree search

Addressing Model and Pointers

- Need to replace **getelementptr** with **OpAccessChain**
- Latter is more constrained, need to backtrack along possible getelementptr chains and accumulate indices



Prototype
Performance Evaluation

Benchmarks

- 3 simple benchmarks, each implemented in SYCL as well as native Vulkan:

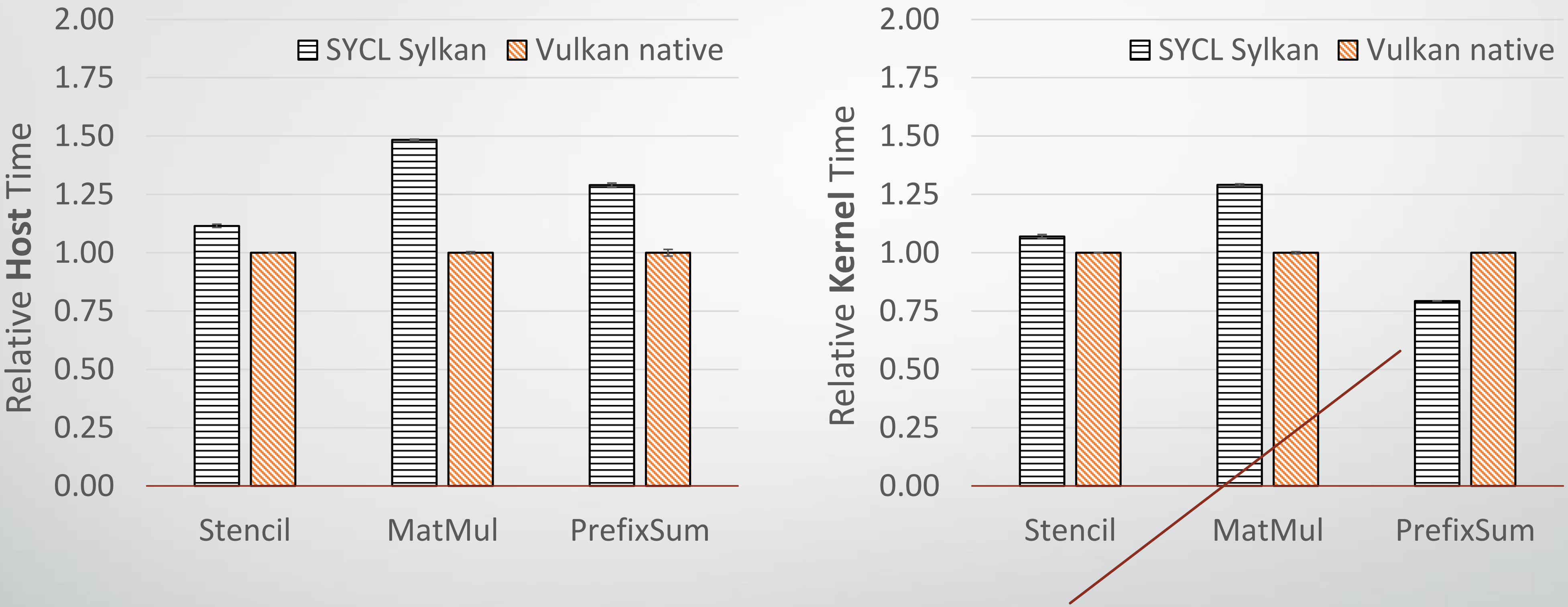
- **Stencil**
- Iterative 2D heat stencil
- Many kernel calls stress RT performance

- **MatMul**
- Basic dense matrix-matrix multiplication
- Check for fundamental codegen inefficiencies

- **PrefixSum**
- Illustrate behaviour of two distinct interacting kernels

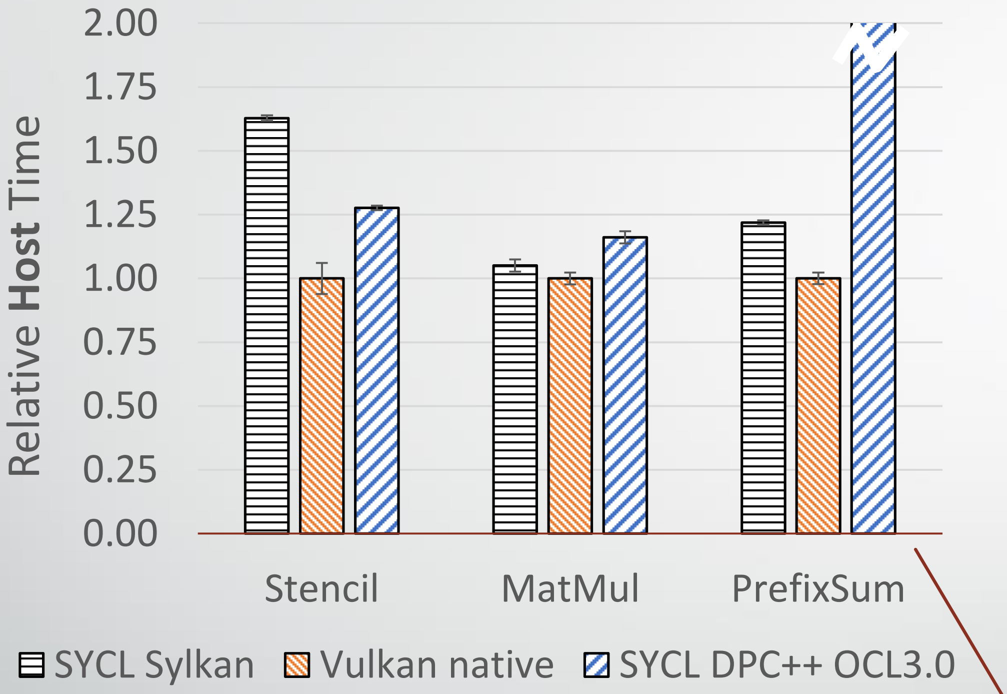
Two platforms: Nvidia GTX 1070 and Intel HD Graphics 530; Same host system
Sylkan and Vulkan versions on Nvidia; Sylkan, Vulkan and DPC++ OpenCL 3.0 on Intel
5 measurements of each point, mean reported

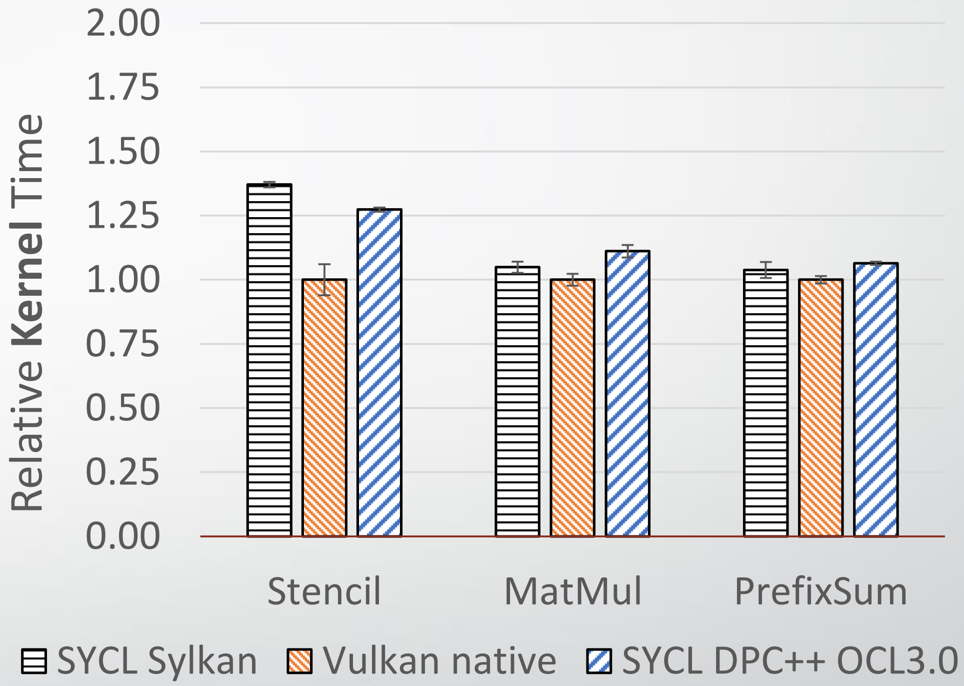
Results - Nvidia



Sylkan toolchain generates more concise SPIR-V kernel code in this case

Results – Intel





Relatively large initialization overhead (very small total time)

Conclusion & Outlook

Conclusion

- Mapping SYCL to Vulkan is not straightforward, but appears to be viable
  - Some specific/newer features may not be implementable on all platforms
  - Most significant constraints are in the supported **SPIR-V capabilities**
- Scientific prototype implementation induces a performance penalty over native Vulkan between 5% and 50% across three simple benchmarks on two platforms
  - Faster in some cases than OpenCL-based SYCL implementation

Outlook

- Current parameter passing scheme is quite inefficient
  - This is primarily an engineering resources bottleneck, needs specialized handling of various cases
- Most significant missing feature: **local memory support**
  - Most promising implementation path (with specialization constants) requires substantial redesign of toolchain

Thank you for your attention!

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https://github.com/tadeaustria/llvm/tree/syclcon2021

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