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Evaluation of SYCL Suitability for High-Performance Critical Systems

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Outline

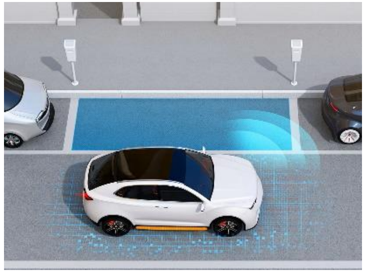
- Introduction and Motivation
- Background
- Software Porting
- Experimental Setup
- Evaluation
- Conclusions and Future Work

Introduction and Motivation



- Safety Critical systems
  - used in avionics, automotive and aerospace industries
  - **correct** and **timely** execution is important
  - any malfunction may be dangerous
  - traditionally rely on very old and simple single core processors
    - Cannot provide the performance required for new advanced functionalities

Need for higher performance in Safety Critical Systems



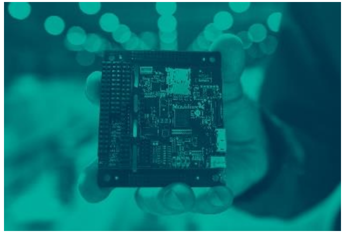
Automotive Industry Examples:

- Advanced Driving Assistance Systems (ADAS)
  - Autonomous parking, heads-up (HUP) windshield displays and smart mirrors

Avionics

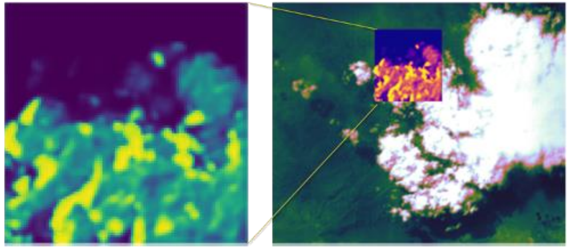
- Automatic Taxi, Take-Off and Landing (ATTOL)

Need for higher performance in Safety Critical Systems



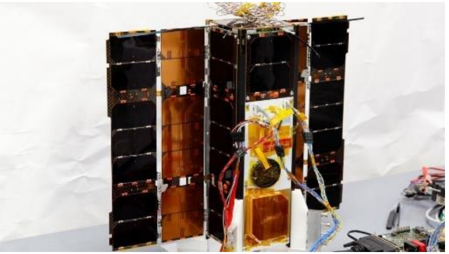
Space:

- Φ-Sat-1
  - ESA’s technology demonstration mission, launched in 2020
  - AI accelerator, Intel Movidius Myriad 2
  - First demonstration of AI for earth observation on Hyperspectral Images



OPS-SAT-1

- ESA’s technology demonstration mission launched in 2019
- Intel/Altera Cyclone V SoC, Multicore CPU and FPGA
- Several High Performance Applications, including AI



Both Φ-Sat-2 and OPS-SAT 2 are under development

Need for higher performance in Safety Critical Systems

- Legacy hardware used for safety critical systems cannot provide the required performance
- Embedded Systems on Chip (SoC) with multicore and Graphics Processing Units (GPUs) are
  - designed to comply with safety critical functional safety standards e.g. ISO 26262
  - very attractive candidate platforms for safety critical systems

RENESAS Imagination

NVIDIA

arm

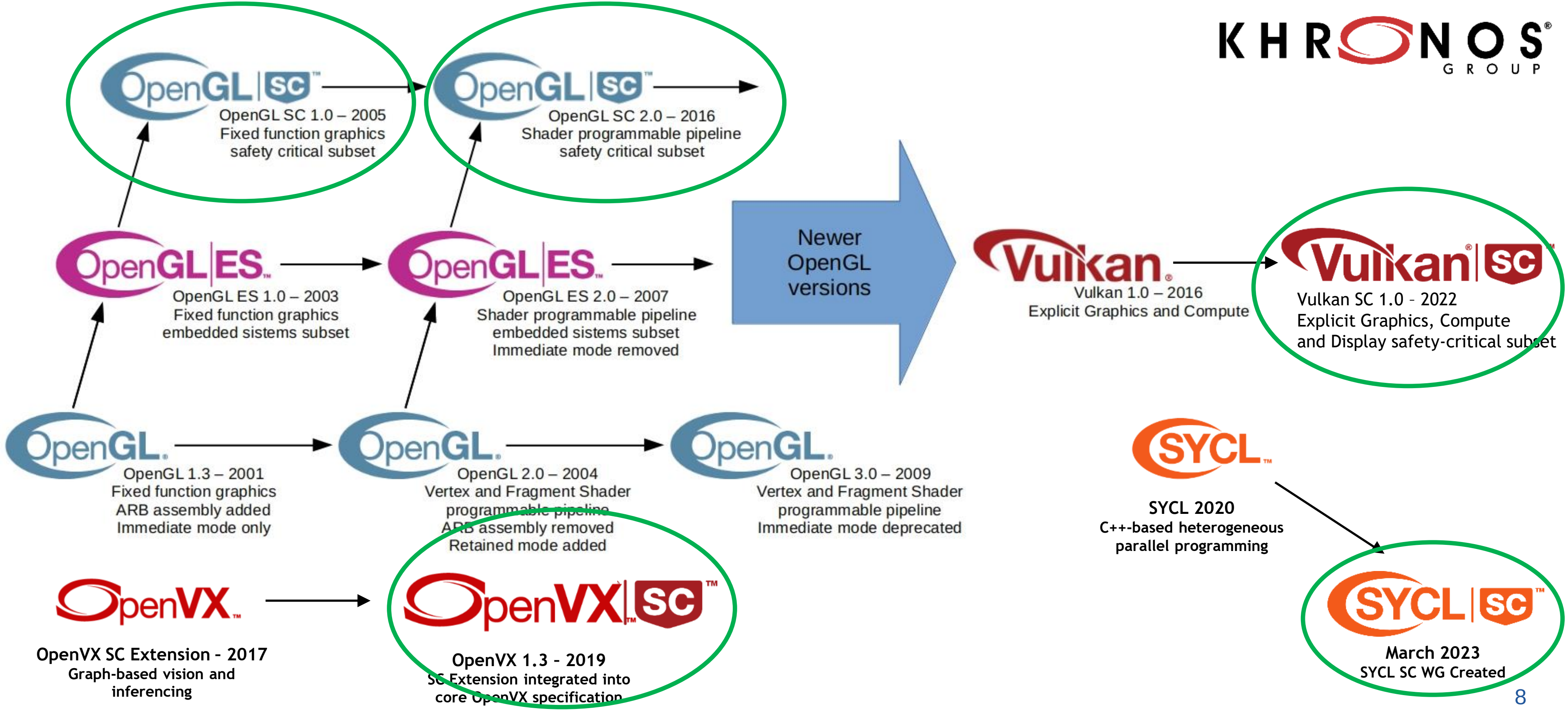
Need for high level programming models in safety critical systems

- The adoption of multicore and GPU platforms in safety critical systems require not only high performance but also ease of programmability
- Automotive functionalities are assigned a criticality level
- Automotive Safety Integrity Level (ASIL)
- Highest Criticality software (ASIL-D) needs t… with certain rules:
  - Restricted use of Pointers
  - No dynamic memory al…
  - Static verificati… …ram properties
  - Resilie… …ts
  - …pagation

Violated by existing low-level parallel programming models

[1] Trompouki and Kosmidis, Brook Auto: High-Level Certification-Friendly Programming for GPU-powered Automotive Systems, DAC 2018

Khronos Safety Critical Systems Programming Models



Objectives

- Evaluate the applicability of SYCL for programming safety critical systems
  - Performance comparison with other parallel programming models on a candidate embedded platform
  - Assessment of programmability trade-offs

High Performance Safety Critical Software Selection

- Focus on two safety critical industries, aerospace and automotive
- The selected software needed to be:
  - Computationally demanding
  - Representative of the respective domains
  - Already available in other parallel programming models
  - Open Source in order to ensure reproducibility

- Only software complying with this requirements were previously developed at BSC/UPC:
  - GPU4S Bench/OBPMark Kernels → aerospace
  - Pedestrian Detection Application → automotive

GPU4S Bench / OBPMark Kernels

- Developed during the ESA funded GPU4S (GPU for Space) project coordinated by BSC
  - Partnership with Airbus Defence and Space
  - Investigate the applicability of embedded GPU for space missions
  - Main focus
    - Study the feasibility and potential benefits of using embedded GPUs for space applications
    - Benchmark several embedded GPUs
    - Implement a demonstrator of a space case study on an embedded GPU

GPU4S Bench / OBPMark Kernels

- Lack of benchmarks for Space
  - Proprietary code, export restrictions
- Lack of GPU benchmarks for critical systems
- Definition of an open source GPU Benchmark suite: GPU4S Bench [1]
  - Building blocks from many domains identified in a space sw survey
  - ESA GPL-3 compatible license, released together with OBPMark [2]
  - Official Benchmarking suites of ESA for all types of new devices
  - Required to be used by new projects funded by ESA
  - HiPEAC Technology Transfer Award 2021

[1] GPU4S Bench: Design and Implementation of an Open GPU Benchmarking Suite for Space On-board Processing: https://www.ac.upc.edu/app/research-reports/public/html/research_center_index-CAP-2019,en.html
[2] OBPMark (On-Board Processing Benchmarks) – Open Source Computational Performance Benchmarks for Space Applications, OBDP 2021, http://OBPMark.org

GPU4S Bench Overview

- Identified building blocks and the domains they represent

Domains / Building Block	Compression	Vision Based Navigation	Image Processing	Neural Network Processing	Signal Processing
Fast Fourier Transform			GENEVIS		ADS-B, NGDSP
Finite Impulse Response Filter					ADS-B, NGDSP
Integer Wavelet Transform	CCSDS 122				
Pairwise Orthogonal Transform	CCSDS 122				
Predictor	CCSDS 123				
Matrix computation		GENEVIS (Solver)		Image classification	
Convolution Kernel		OpenCV	GO3S,GENEVIS	Image classification	
Correlation		OpenCV	GO3S,GENEVIS		ADS-B
Max detection			GO3S	Image classification	ADS-B
Synchronization mechanism		GENEVIS	EUCLID NIR, GO3S	TensorFlow	ADS-B, NGDSP
Memory Allocation		CERES Solver , OpenCV	EUCLID NIR, GO3S	TensorFLow	ADS-B, NGDSP

- Sequential reference version for functional verification
- 3 parallel versions: naïve, optimised, vendor optimised libraries:
  - Evaluate programmability: programming effort vs performance
- Implementations available in CUDA, OpenCL, HIP, OpenMP

GPU4S Bench / OBPMark Kernels contributions in this work

- Port benchmarks in SYCL
  - Both SYCL Memory Models: Unified Shared Memory (USM) and Buffers
  - Naïve and Optimised versions
  - Same organization with existing GPU4S Bench ports in other parallel programming models
    - All programming models use the same program drivers and have the same overhead
    - Programming model section takes place at compile time
  - Open source implementation [1]
  - To be merged in the next GPU4S Bench / OBPMark Kernels release

[1] Cristina Peralta Quesada. GPU4S Bench SYCL Implementation: https://github.com/crispq95/GPU4S_Bench

Pedestrian Detection

- Open Source application [1] developed at BSC/UPC
- Developed as Multi-CPU Multi-GPU benchmark for Automotive Systems [2]
- Original implementation achieved 88x times speedup over the sequential version on a server class CPU
  - Used 4 x86 CPUs and 2 GPUs
- Ported to an embedded platform (NVIDIA Xavier) and used as a research use case and demonstrator in the UP2DATE H2020 project

[1] M. M. Trompouki. 2013. Pedestrian Detection Source Code Repository. https://github.com/mtrompouki/pedestrian_detection
[2] M. M. Trompouki, L. Kosmidis, and N. Navarro. An Open Benchmark Implementation for Multi-CPU Multi-GPU Pedestrian Detection in Automotive Systems. ICCAD 2017

Pedestrian Detection

- Pedestrian detection on camera images
- Necessary functionality required for automatic emergency breaking, mandatory since 2022 in all vehicles sold in the European Union
- Implementation based on a classic vision algorithm (Viola-Jones method) instead of deep neural networks
  - Explainable, easier to be used in a certified context
- Original application [1][2] written in CUDA, hand optimized to achieve high performance

[1] M. M. Trompouki. 2013. Pedestrian Detection Source Code Repository. https://github.com/mtrompouki/pedestrian_detection
[2] M. M. Trompouki, L. Kosmidis, and N. Navarro. An Open Benchmark Implementation for Multi-CPU Multi-GPU Pedestrian Detection in Automotive Systems. ICCAD 2017

Pedestrian Detection contributions in this work

- Code ported in SYCL
- Implementations in both SYCL Memory Models: Unified Shared Memory (USM) and Buffers
- 3 implementations
  - Naïve
  - In-order queues
  - Out-of-order queues
- Code available as open source [1]
  - Will be merged in the original repository

[17] Cristina Peralta Quesada. 2022. Pedestrian Detection in SYCL.
https://github.com/crispq95/pedestrian_detector

Experimental Setup

Two platforms

- A high performance platform
  - Initial target
  - Mainly for development
  - Known to support SYCL
- An embedded GPU platform
  - NVIDIA Xavier
  - Candidate platform for safety critical systems
  - Unknown support for SYCL at the beginning of the project

Experimental Setup: High Performance Platform

Hardware

- CPU: AMD Ryzen 7 1800 Eight-Core processor
- GPU: NVIDIA GeForce GTX 1080 Ti

Software

- Ubuntu 18.04.6 LTS
- CUDA, OpenCL, OpenMP
- hipSYCL v0.9.3 compiled from source

Experimental Setup: Embedded Platform

NVIDIA Xavier

- 8-core Caramel ARM v8.2 64-bit CPU
- Volta GPU with 8 Streaming Multiprocessors
- 32 GB of memory
- ISO 26262 ASIL-D Certified for use in automotive

- One of the target platforms for GPU4S project
- Main platform in H2020 UP2DATE project

Experimental Setup: NVIDIA Xavier

- Different Power Modes available
  - Power budget limited to 15W due to thermal dissipation limitations in space
  - Selected mode: Mode 2, 15W
- Software:
  - Ubuntu 18.04.6 LTS
  - CUDA and OpenMP
  - hipSYCL v0.9.3 compiled from source
    - No differences w.r.t. high performance platform setup
    - No issues encountered

Property	Mode
	15W
Power budget	15W
Mode ID	2
Online CPU	4
CPU maximal frequency (MHz)	1200
GPU TPC	4
GPU maximal frequency (MHz)	670
DLA cores	2
DLA maximal frequency (MHz)	750
PVA cores	1
PVA maximal frequency (MHz)	550
CVNAS maximal frequency (MHz)	716.8
Memory maximal frequency (MHz)	1333

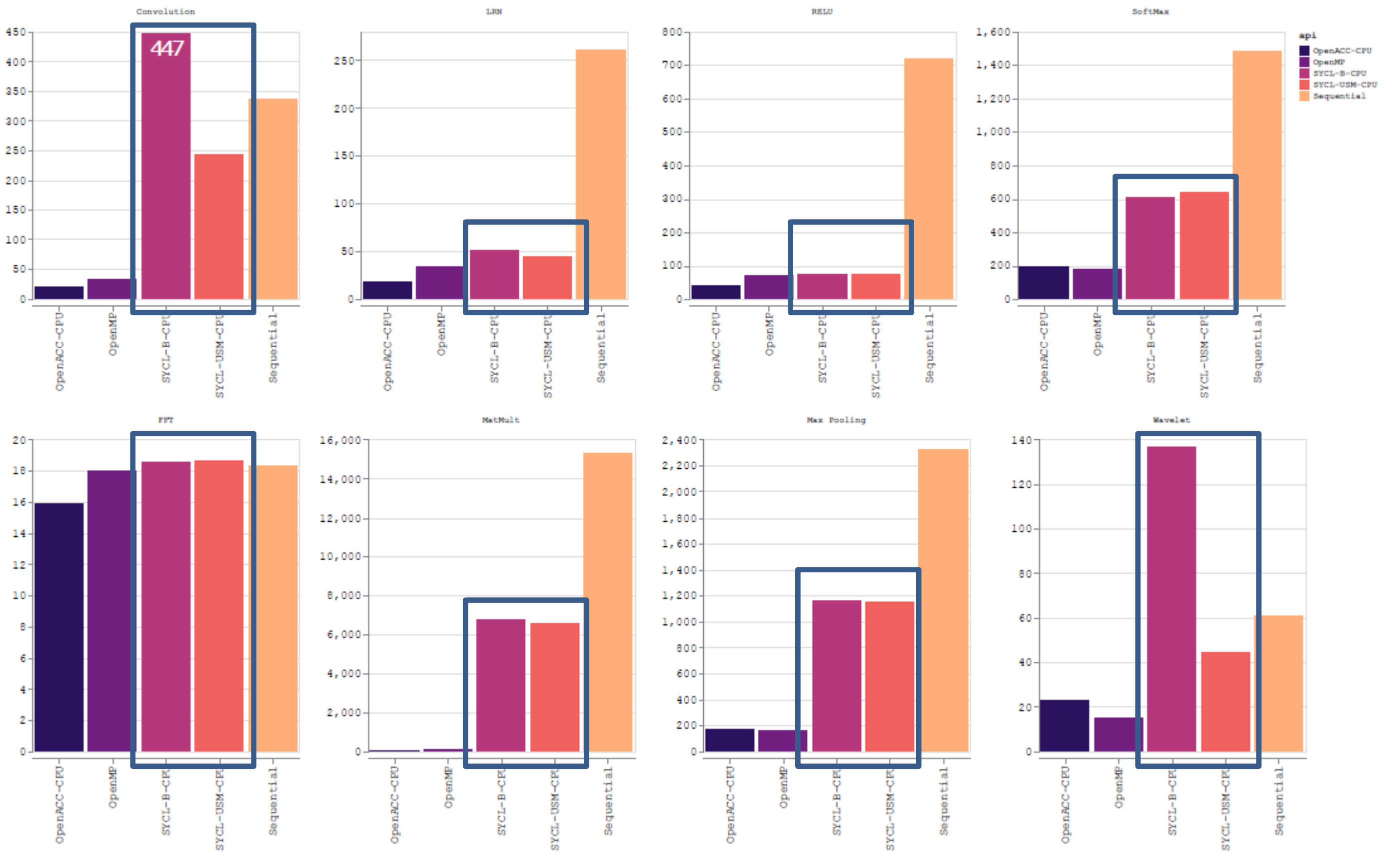
Programmability

- SYCL Buffers
  - Easier to use when development starts from scratch
  - No need for the programmer to worry about data transfers or dependencies
  - Low code complexity
    - Important for safety critical systems certification
  - Less LOC compared to USM
  - Low performance compared to USM
  - No programmability benefit for experienced programmers with low level GPU programming models

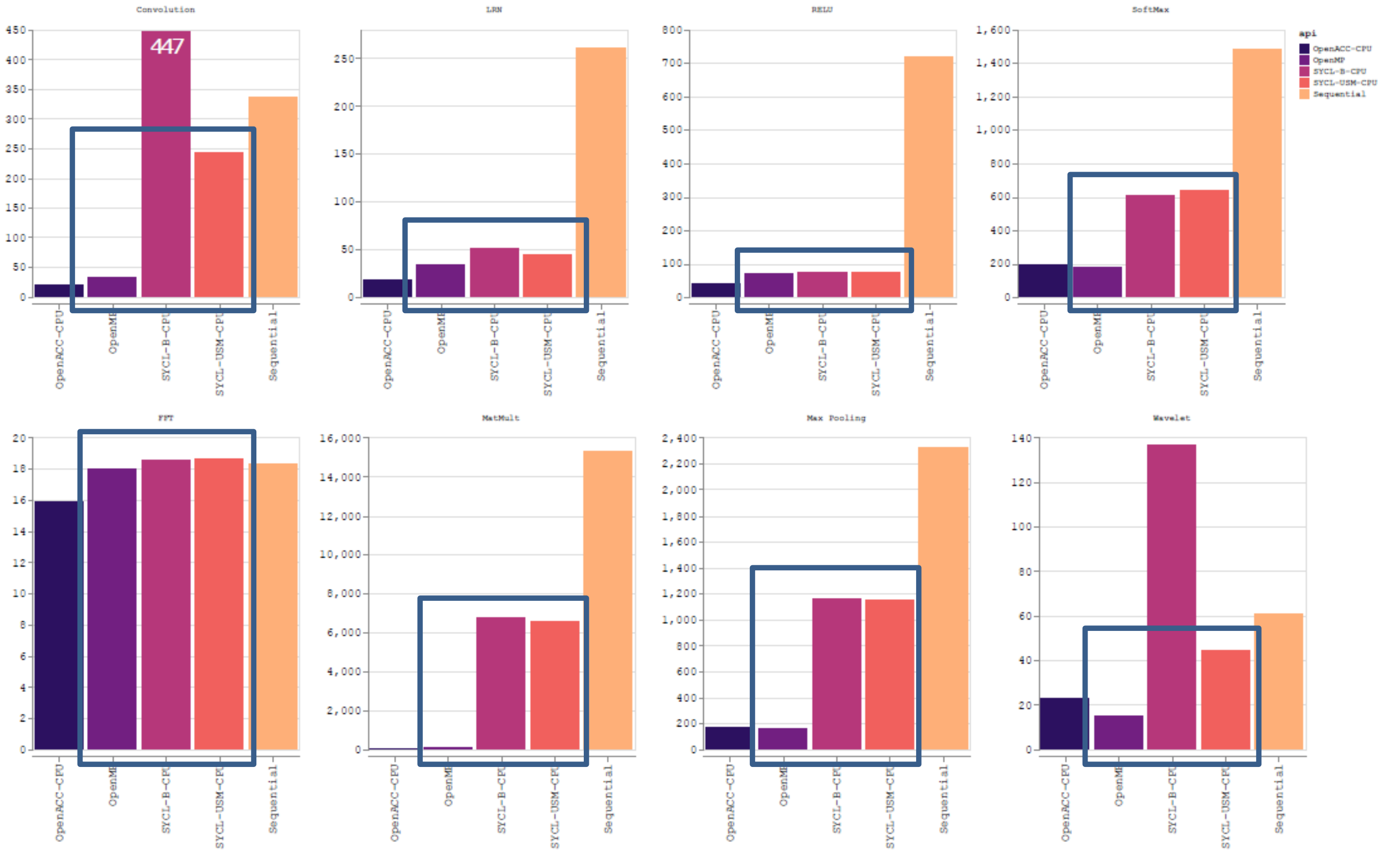
Programmability

- Unified Shared Memory (USM)
  - Uses pointers and dynamic memory allocations
    - their use is discouraged in safety critical systems
  - Major advantage of USM compared to low-level GPU programming models for safety critical systems
    - Automatically computed indices eg. in parallel_for constructs
    - Correct-by-construction
    - Reduces programming mistakes
  - USM LOC similar to the lower level GPU programming models but portable across architectures
  - USM provides a good trade-off between performance and programmability required for safety critical systems

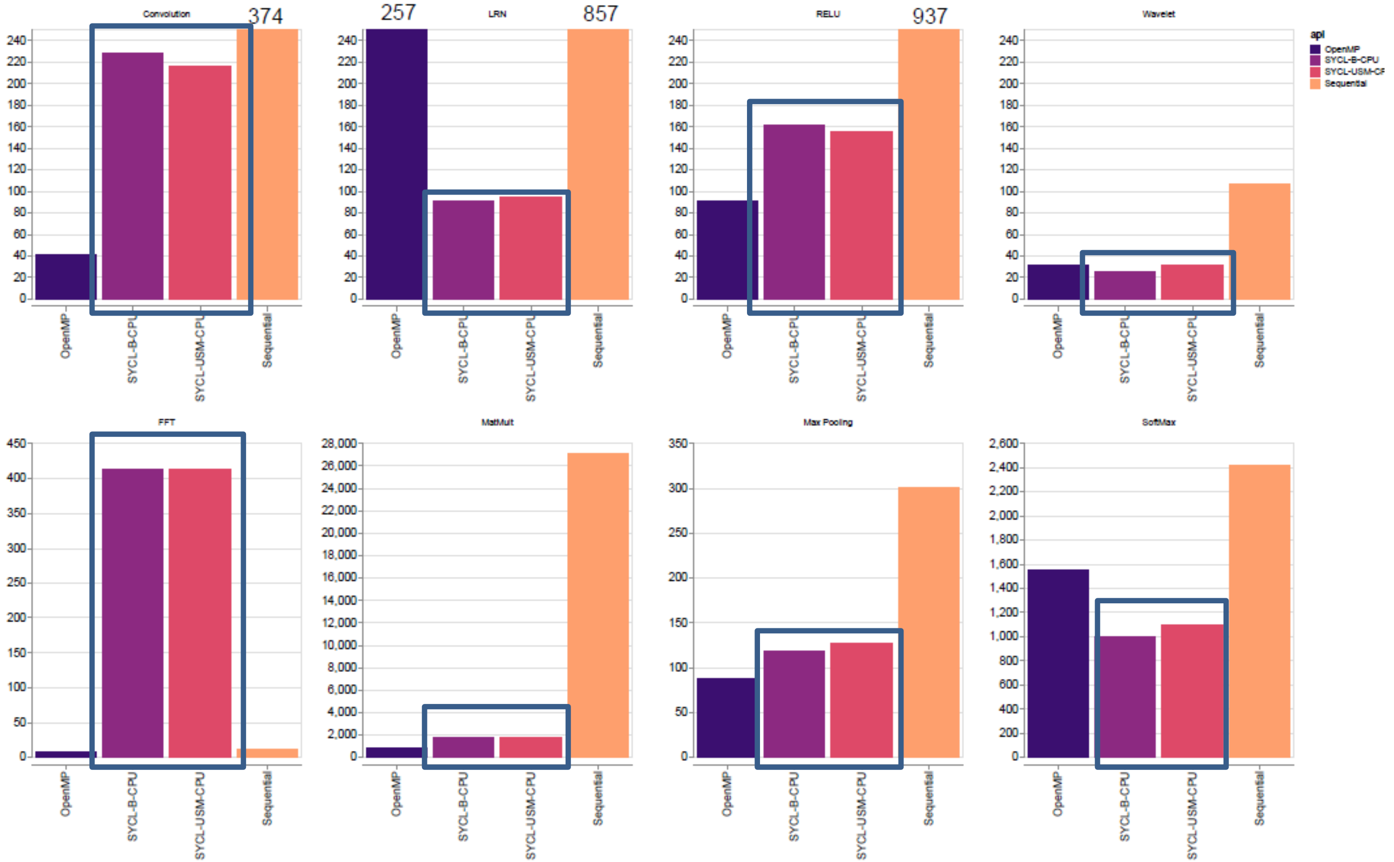
GPU4S Bench Multicore CPU: SYCL vs OpenMP / High Performance Server



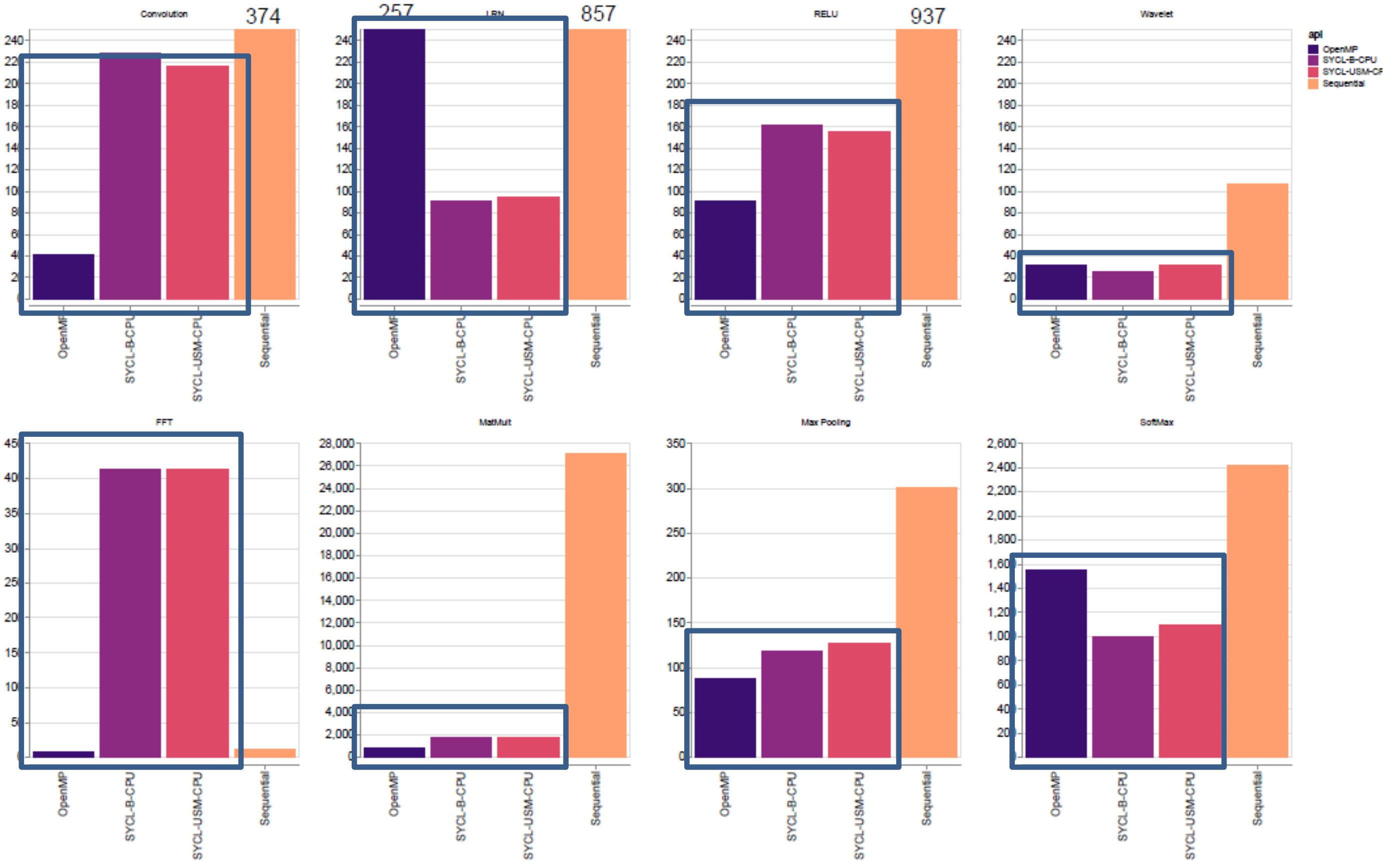
GPU4S Bench Multicore CPU: SYCL vs OpenMP / High Performance Server



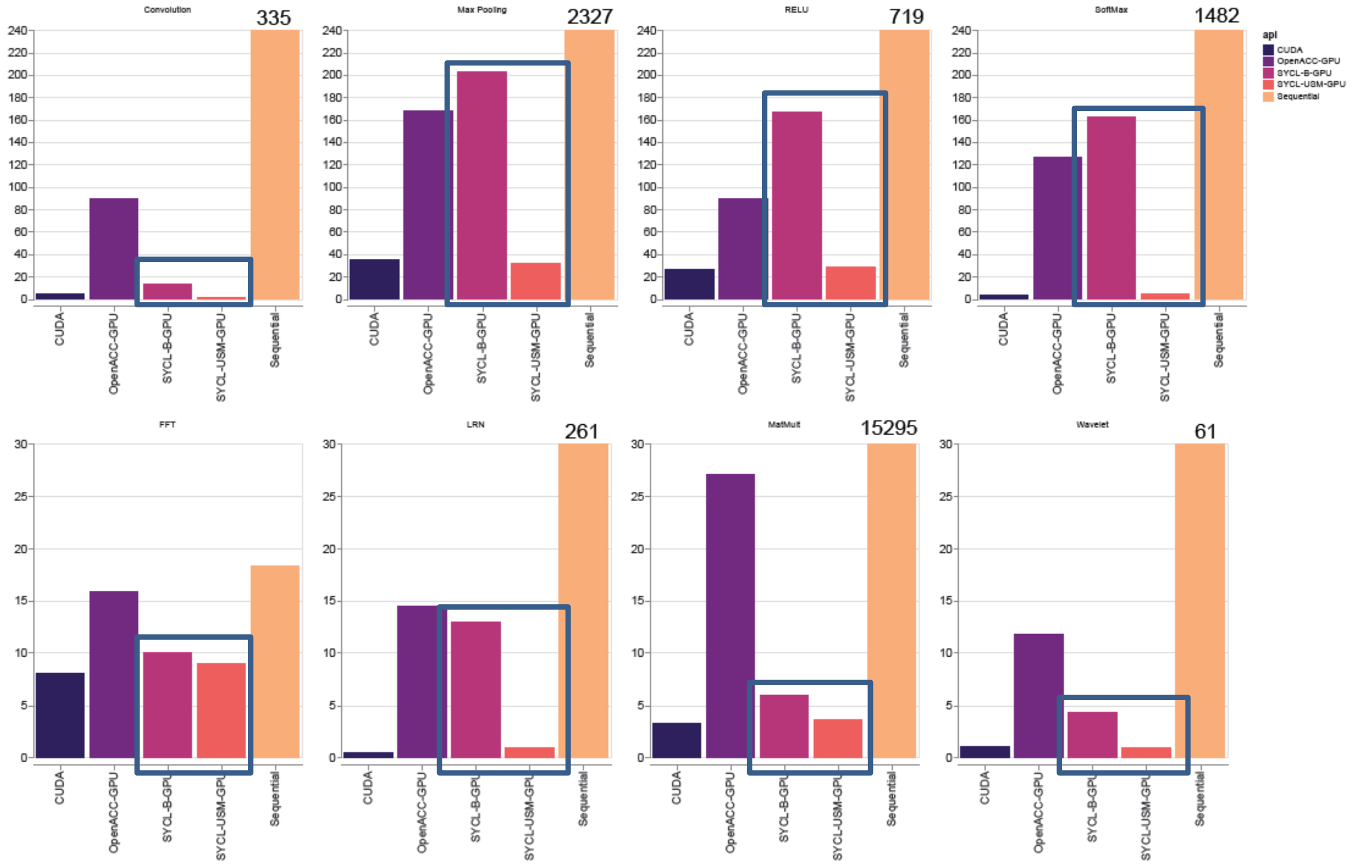
GPU4S Bench Multicore CPU: SYCL vs OpenMP / NVIDIA Xavier



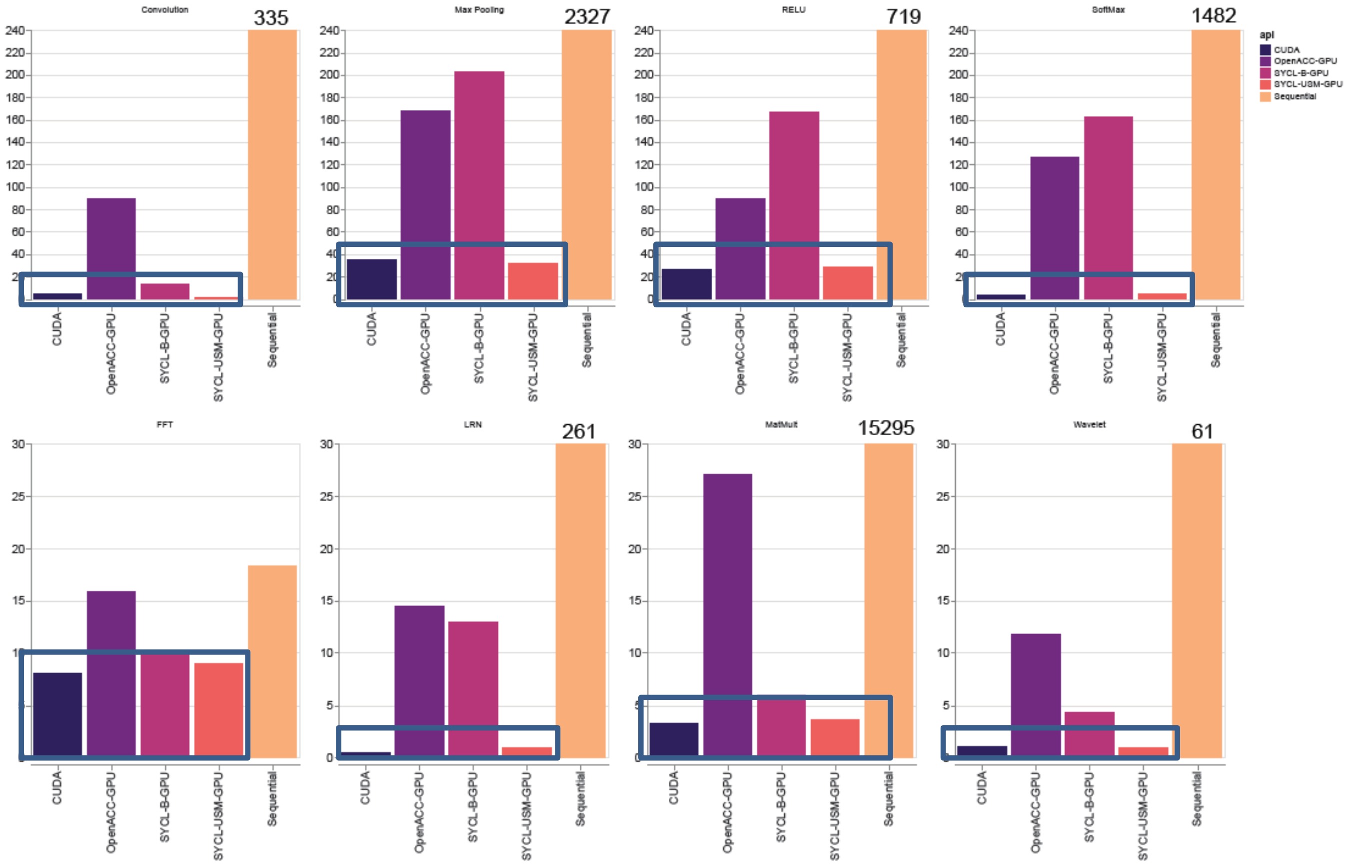
GPU4S Bench Multicore CPU: SYCL vs OpenMP / NVIDIA Xavier



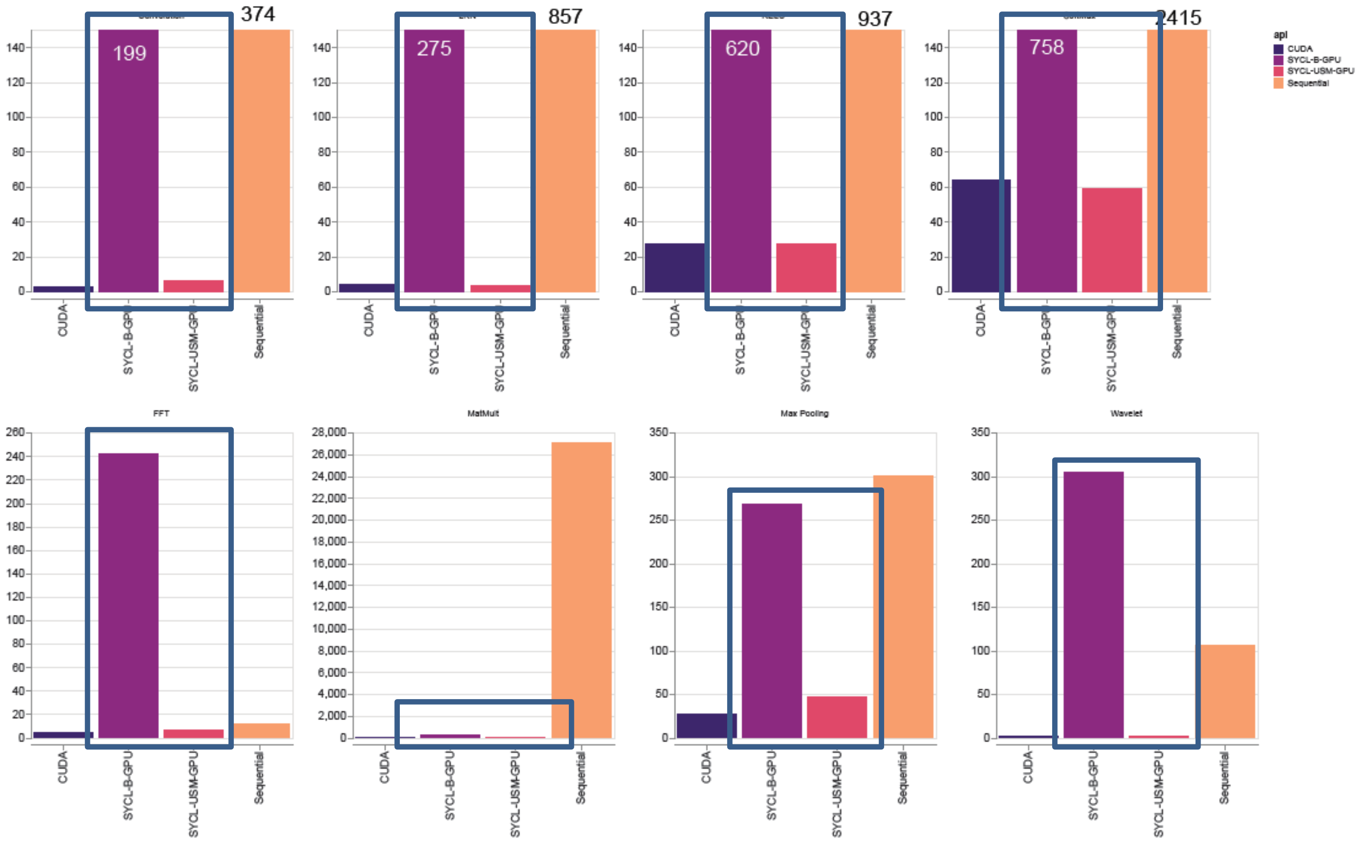
GPU4S Bench Multicore GPU: SYCL vs CUDA / High Performance Server



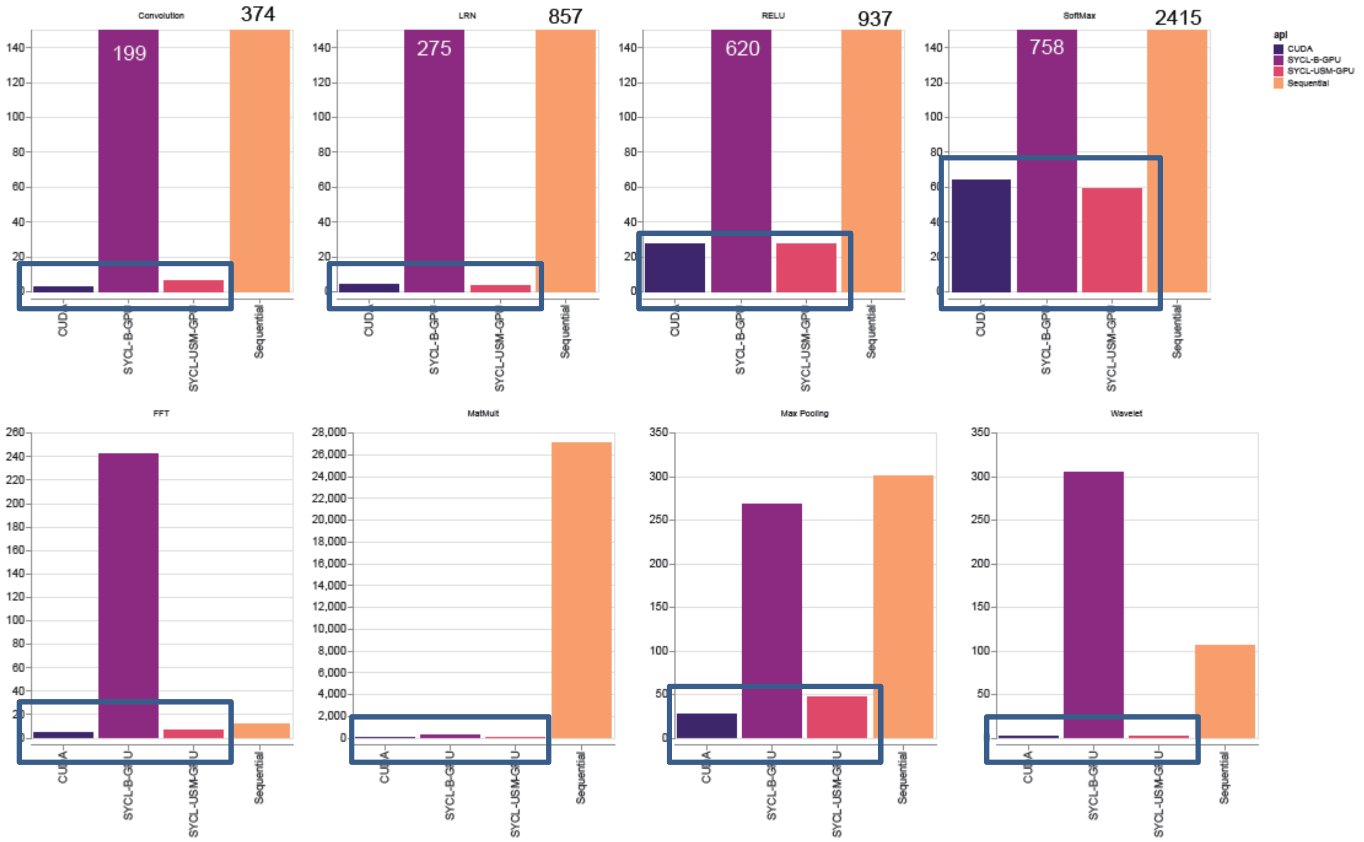
GPU4S Bench Multicore GPU: SYCL vs CUDA / High Performance Server



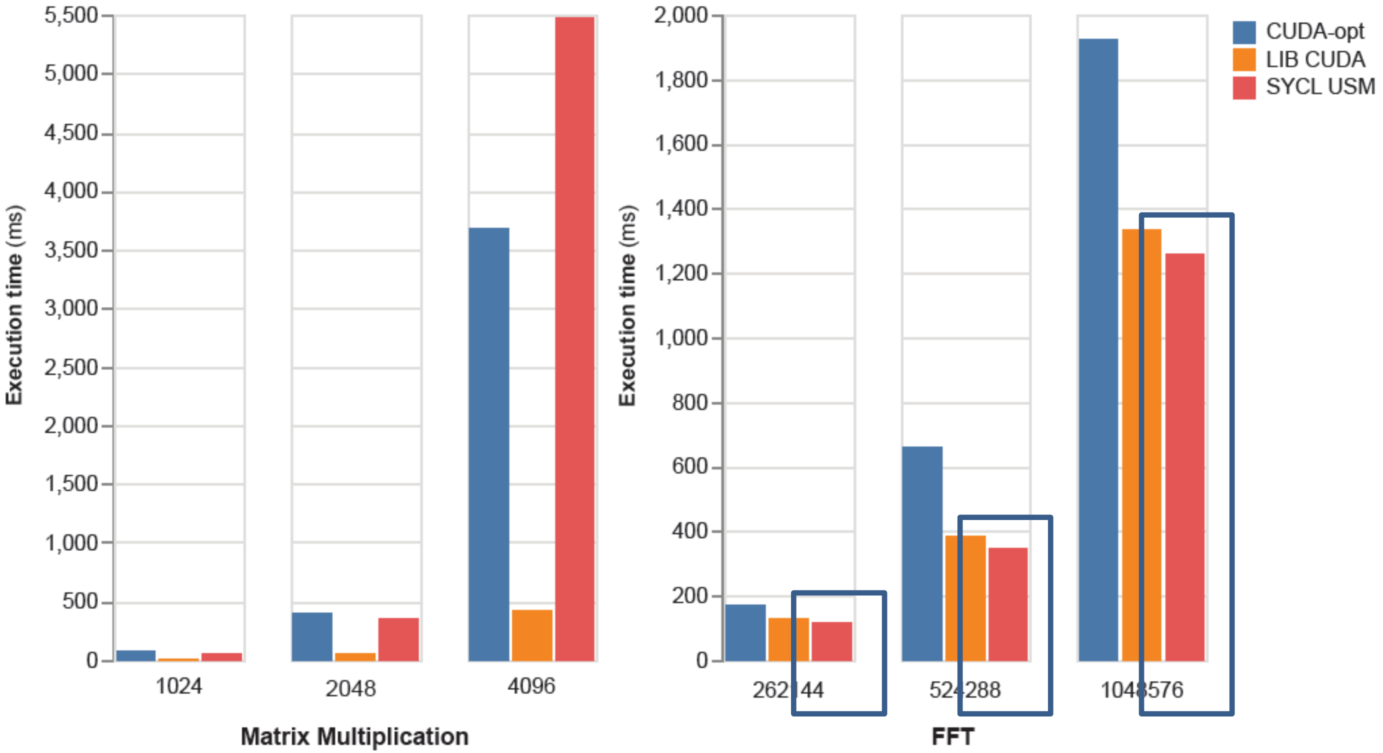
GPU4S Bench Multicore GPU: SYCL vs CUDA / NVIDIA Xavier



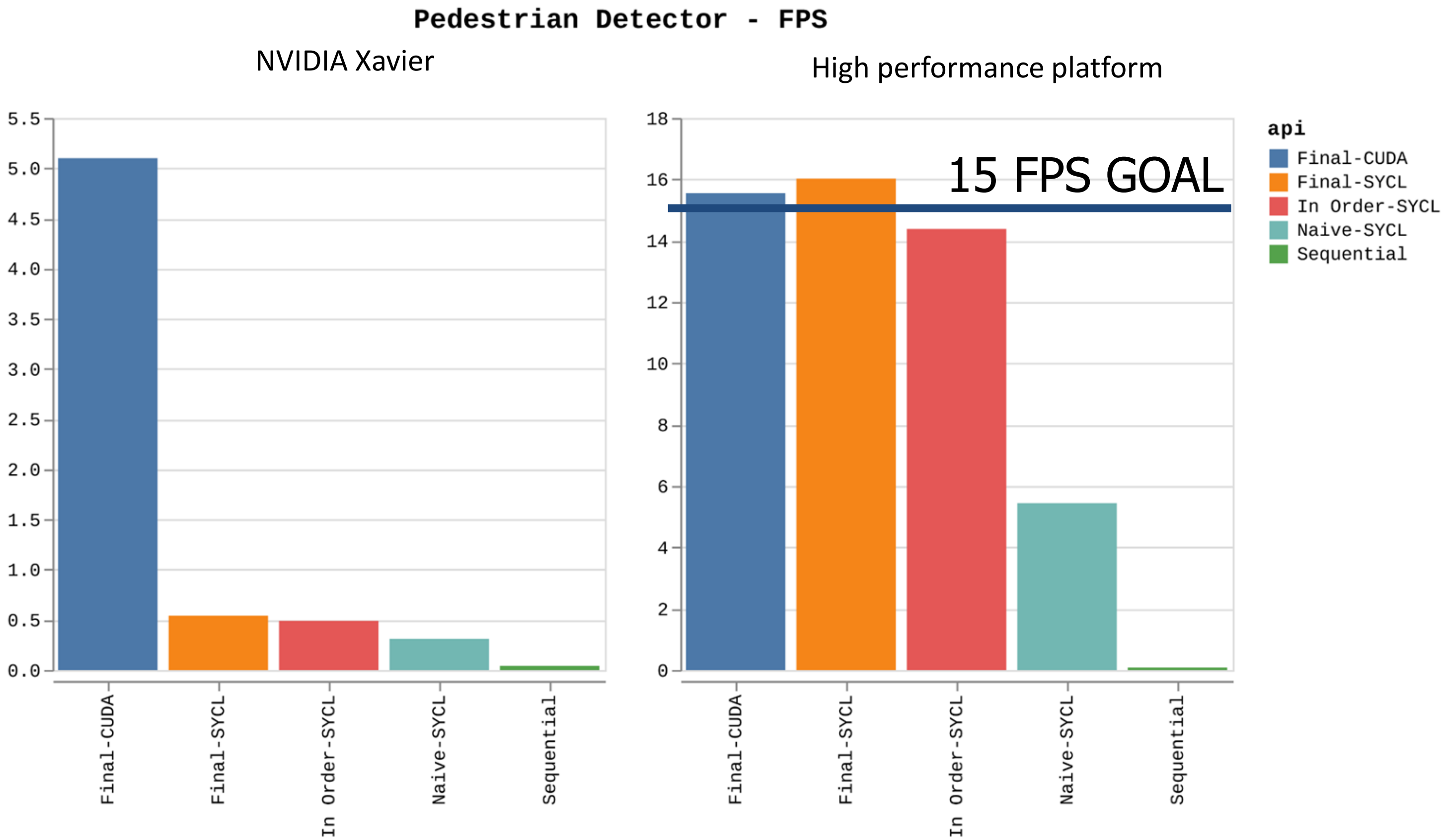
GPU4S Bench Multicore GPU: SYCL vs CUDA / NVIDIA Xavier



GPU4S Bench GPU Results on Xavier



Pedestrian Detection Results



Conclusions

- Ported open source software from two safety critical domains to SYCL
  - GPU4S Bench from the aerospace domain
  - Pedestrian detection application from the automotive domain
- Compared performance with implementations in other parallel programming models, OpenMP and CUDA
- Evaluated on a high performance and embedded multicore and GPU platform, NVIDIA Xavier

Conclusions 2/2

- Our work confirms that SYCL is a suitable programming model for safety critical systems
  - the amount of code required for the SYCL version is less than the CUDA one
  - significantly less effort is required for SYCL code development
  - SYCL provides a less error prone abstraction for safety critical software development
  - SYCL is portable among devices from different vendors
  - SYCL provides a good trade-off of programmability and obtained performance
- We can confirm that the on-going work in Khronos for the definition of the Khronos SYCL SC working group is a step towards the right direction

Future work

- Compare with Intel's DPC++ Compatibility Tool on the same software
- Compare performance with Intel's DPC++ SYCL implementation
- Investigate why hipSYCL's performance of the pedestrian detection application on NVIDIA Xavier is not as competitive with CUDA as in the case of the high performance platform
- Compare performance and programmability with other high level programming models such as OpenACC
  - Preliminary comparison results available in https://upcommons.upc.edu/handle/2117/380697
- Port ESA's Open source OBPMark Applications and ML to SYCL
- Explore the use of SYCL SC preview in the Horizon Europe METASAT project on a RISC-V based open platform GPU
  - Open source multicore CPU and GPU

Acknowledgments

- This work was funded by the Ministerio de Ciencia e Innovacion - Agencia Estatal de Investigación (PID2019-107255GB-C21 and IJC-2020-045931-I MCIN/AEI/10.13039/501100011033)
- the European Commission’s Horizon 2020 programme under the UP2DATE project (grant agreement 871465) and the HiPEAC Network of Excellence

Thank you!

Questions?

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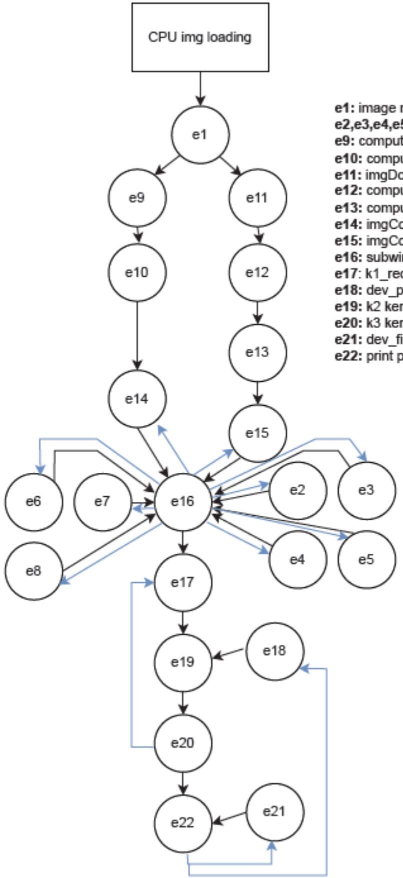
Pedestrian Detection data flow graph



e1: image memcpy HtD
e2,e3,e4,e5,e6,e7,e8: init device memory (memset)
e9: computeIntegralRowSYCL -- dev_imgInt
e10: computeIntegralColSYCL -- dev_imgInt
e11: imgDotSquareSYCL
e12: computeIntegralRowSYCL -- dev_imgSqInt
e13: computeIntegralColSYCL -- dev_imgSqInt
e14: imgCopy -- imgInt_f
e15: imgCop - imgSqInt:f
e16: subwindow_find_candidates kernel
e17: k1_reduction kernel
e18: dev_position memset
e19: k2 kernel
e20: k3 kernel
e21: dev_finalNb memset
e22: print positions kernel