byteLAKE's
CFD Kernels

Non-AI Kernels

Alveo FPGA Optimized

byteLAKE
Faster results, lower TCO.

byte LAKE

CFD Kernels

Collection of fluid dynamics algorithms,
highly optimized for Xilinx Alveo FPGA powered systems.

Faster results, lower TCO.

Why FPGAs?

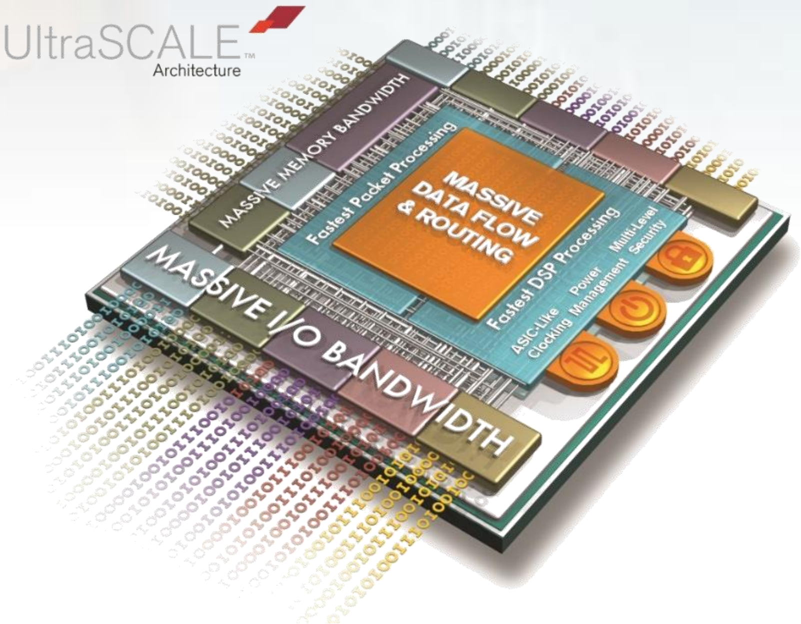
- No predefined instruction set or underlying architecture

- Developers customize the architecture to their needs
  - Custom data paths
  - Custom bit-width
  - Custom memory hierarchies

- Excels at all types of parallelism
  - Deeply pipelined (e.g. Video codecs)
  - Bit manipulations (e.g. AES, SHA)
  - Wide data path (e.g. DNN)
  - Custom memory hierarchy (e.g. Data analytics)

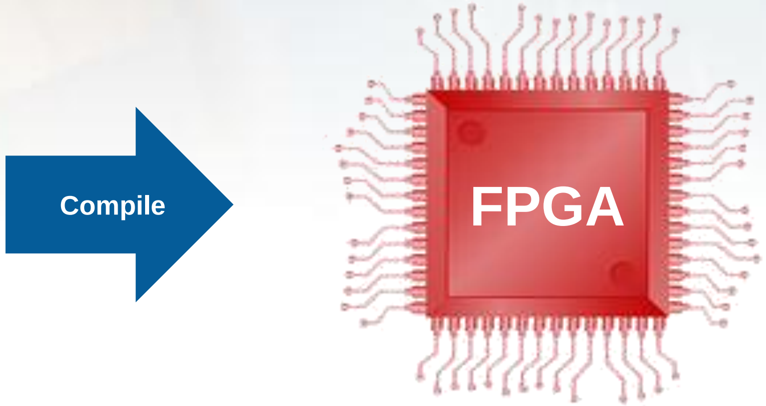
- Adapts to evolving algorithms and workload needs

FPGAs - the Ultimate Parallel Processing Device



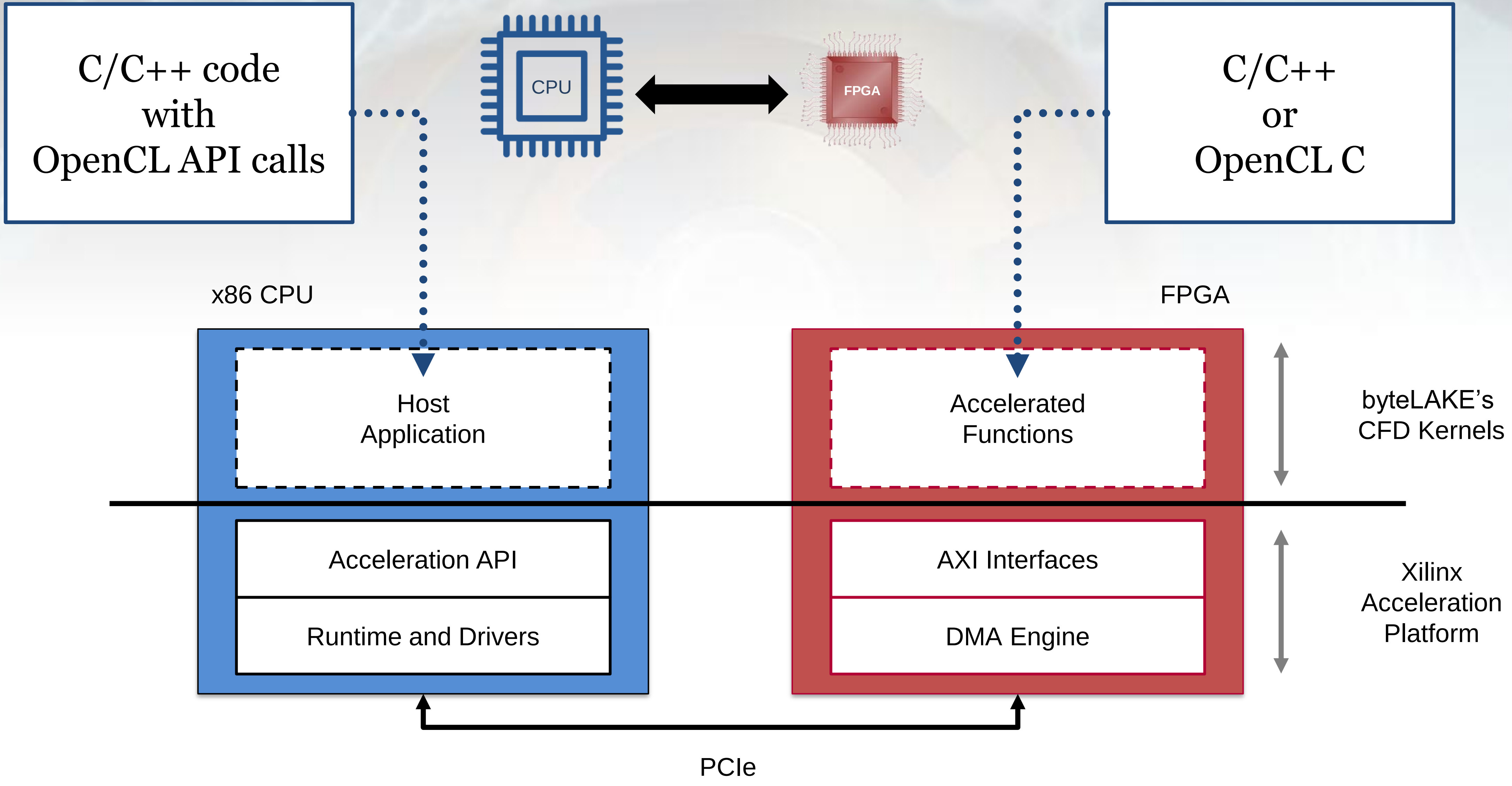
Source code in C, C++ or OpenCL

```
loop_main:for(int j=0;j<NUM_SIMGROUPS;j+=2) {
  loop_share:for(uint k=0;k<NUM_SIMS;k++) {
    loop_parallel:for(int i=0;i<NUM_RNGS;i++) {
      mt_rng[i].BOX_MULLER(&num1[i][k],&num2[i][k],ratio4,ratio3);
      float payoff1 = expf(num1[i][k])-1.0f;
      float payoff2 = expf(num2[i][k])-1.0f;
      if(num1[i][k]>0.0f)
        pCall1[i][k]+= payoff1;
      else
        pPut1[i][k]-=payoff1;
      if(num2[i][k]>0.0f)
        pCall2[i][k]+=payoff2;
      else
        pPut2[i][k]-=payoff2;
    }
  }
}
```



- Xilinx pioneered C to FPGA compilation technology (aka “HLS”) in 2011

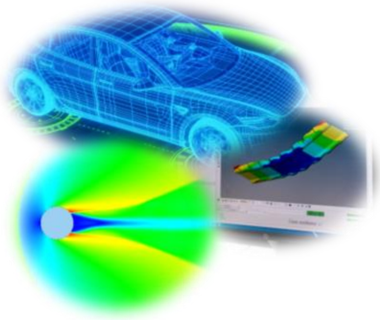
General Architecture with FPGAs



FPGAs – highway for CFD algorithms

- FPGAs are best adapted to applications where:
  - most computational effort concentrates on a small portion of the code per pipeline which is repeatedly executed for a large dataset
  - input/output communications load is small when compared to the computational load, to avoid saturating the host memory-FPGA interface.

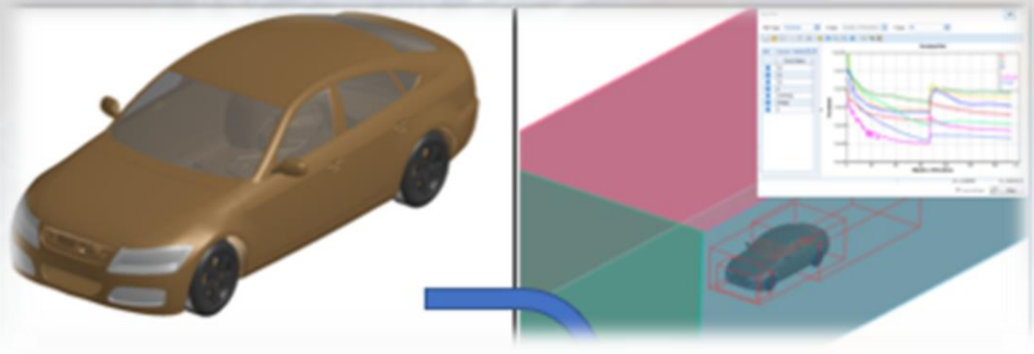
➢ **CFD codes** fulfill these requirements and, therefore, appear as **good candidates to benefit from FPGA-based accelerators**.



Where the acceleration happens?

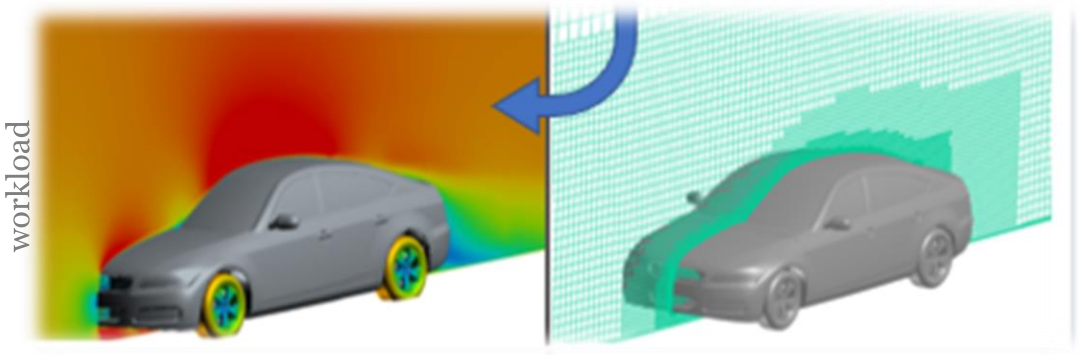
Typical CFD workflow

up to 5%
of simulation time



From CAD to MESH…
(meshing)

major
workload



…to CFD simulation and visualization.

- *MESH conversion (input)*
- **byteLAKE's CFD Kernels**
- *Data output for visualization*

Image source: https://www.openfoam.com/products/visualcfd.php

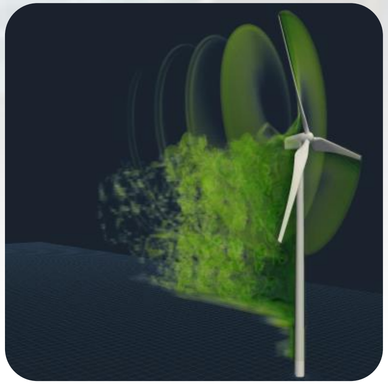
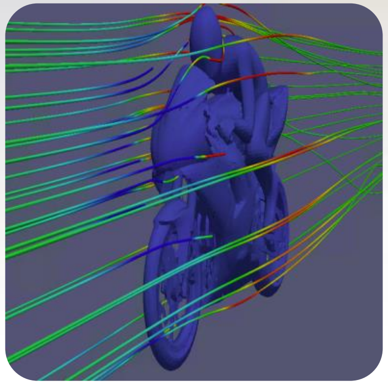
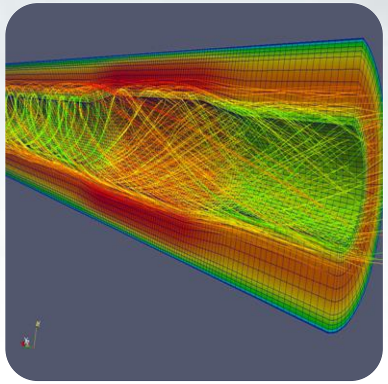
byteLAKE's CFD Kernels

byte LAKE

- **Key features**
  - collection of fluid dynamics algorithms
  - highly optimized for Xilinx Alveo FPGAs
  - on-premise and in the Cloud
  - straightforward integration
  - AI powered
- **Benefits**
  - Acceleration = faster results
  - Green Computing = reduced energy
  - Lower TCO = ultimate cost reduction
  - Excellent Performance / Watt
    = reduced operational costs

Optimized CFD across industries

byteLAKE's CFD Kernels (non-AI kernels / Alveo FPGA optimized)

Green Energy / Weather	Automotive	Construction	Chemistry / Pharma	Oil & Gas / Pipe Flow
				

Algorithms Roadmap

- Advection
- Thomas Algorithm
- Pseudo velocity / Divergence

Algorithm: Advection (MPDATA)
General Information

- **MPDATA**
  (Multidimensional Positive Definite Advection Transport Algorithm)
  - main part of the dynamic core of the Eulerian/ semi-Lagrangian (EULAG) model
  - **EULAG (MPDATA+elliptic solver) is the established computational model, developed for simulating thermo-fluid flows across a wide range of scales and physical scenarios**
  - currently, this model is being implemented as the new dynamic core of the COSMO (Consortium for Small-scale Modeling) weather prediction framework
  - advection (together with the elliptic solver) is a key part of many frameworks that allow users to implement their simulations
- **Advection**
  – movement of some material (dissolved or suspended) in the fluid.

Algorithm: Advection (MPDATA)
Compatibility

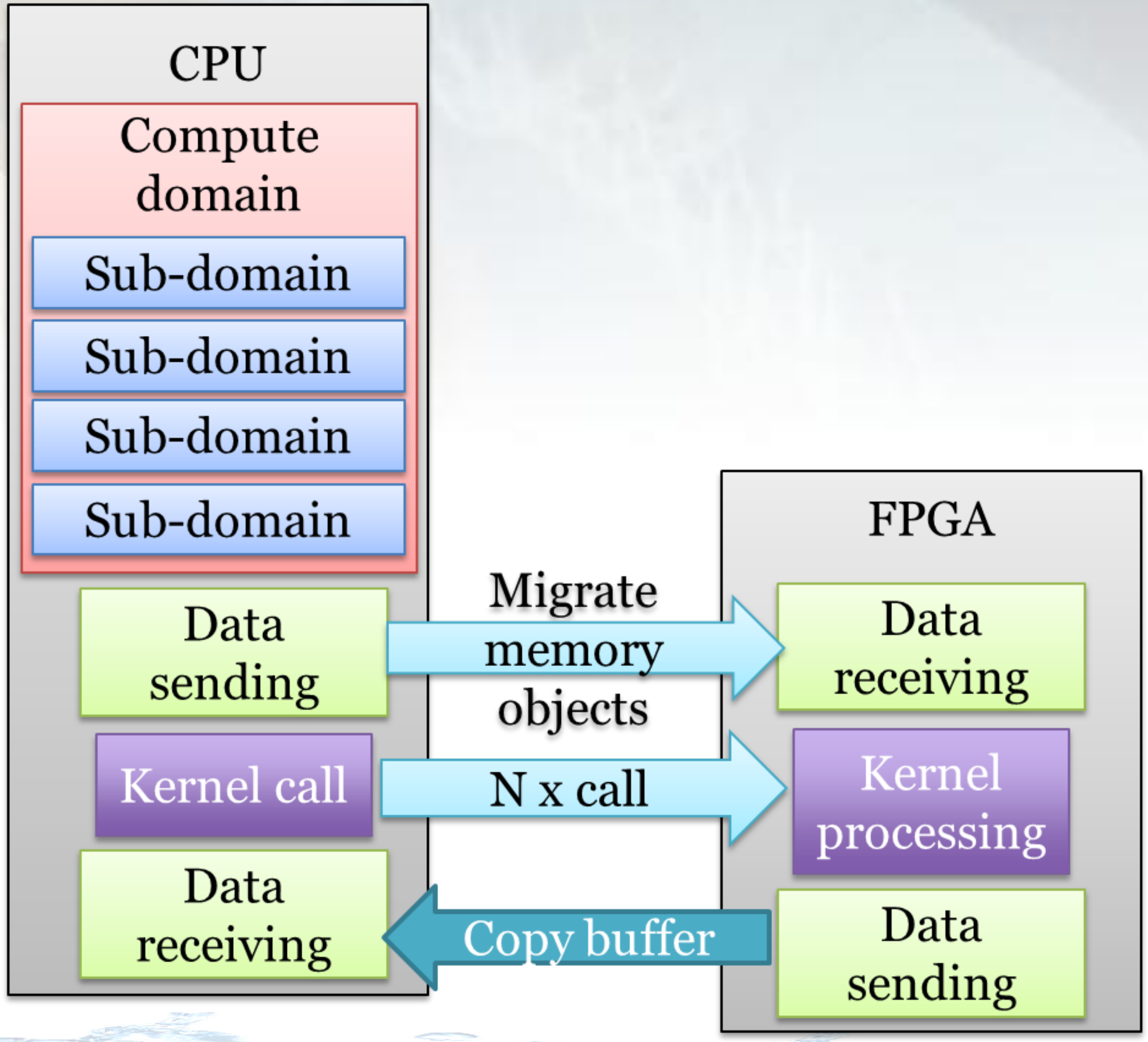
byteLAKE

- **Easy to integrate**
  - Can work as a standalone application or be called as a function via our dedicated interface (e.g. can be called as a function with input and output arrays)
  - Compatible with frameworks like TensorFlow for integrating deep learning with CFD codes
- **Easy to visualize the results**
  - Results can be stored in a raw format as a binary file of the output arrays or converted via byteLAKE tools to a ParaView format
- **See benefits already in 1-node HPC configurations**
  - Strongly adapted to Alveo U250, were single card supports the max size of arrays: 2,1 Gcells (max compute domain: 1264 x 1264 x 1264) ~ 60 GB
- **Scalable to many cards per node and many nodes**

Algorithm: Advection (MPDATA)

Architecture

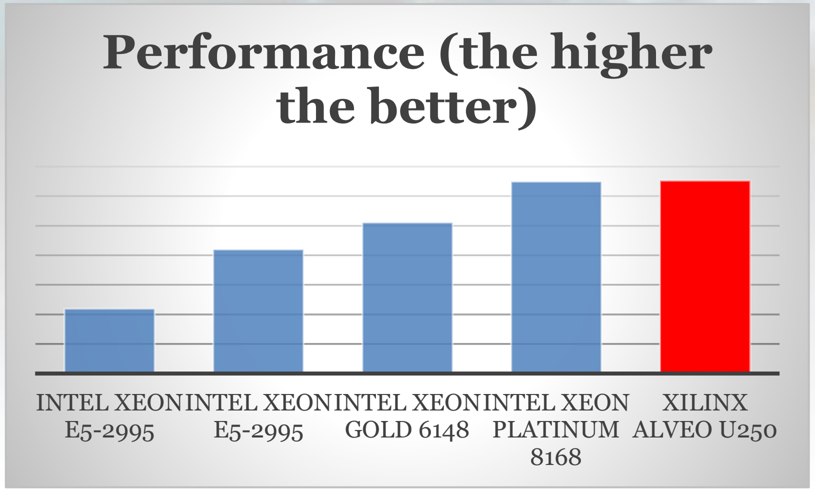
- Compute domain divided into 4 sub-domains
- Host sends data to the FPGA global memory
- Host calls Advection kernel to execute it on FPGA (kernel is called many times)
- Each kernel call represents a single time step
- FPGA sends the output array back to host

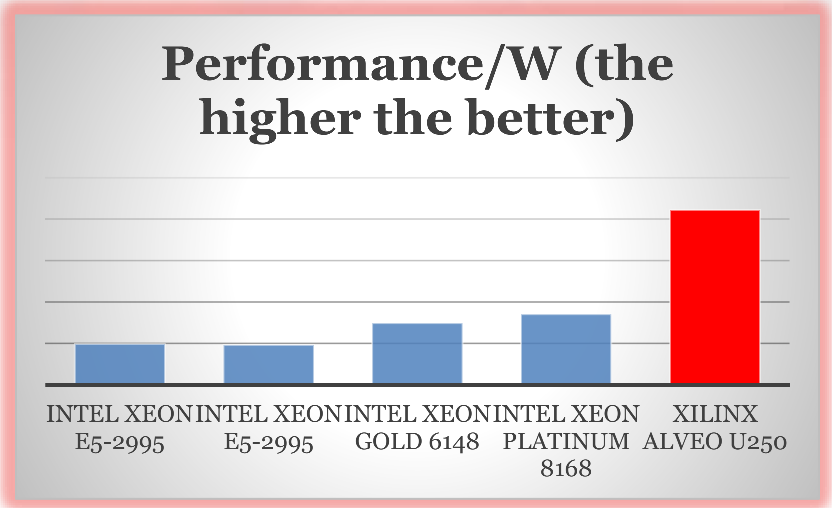


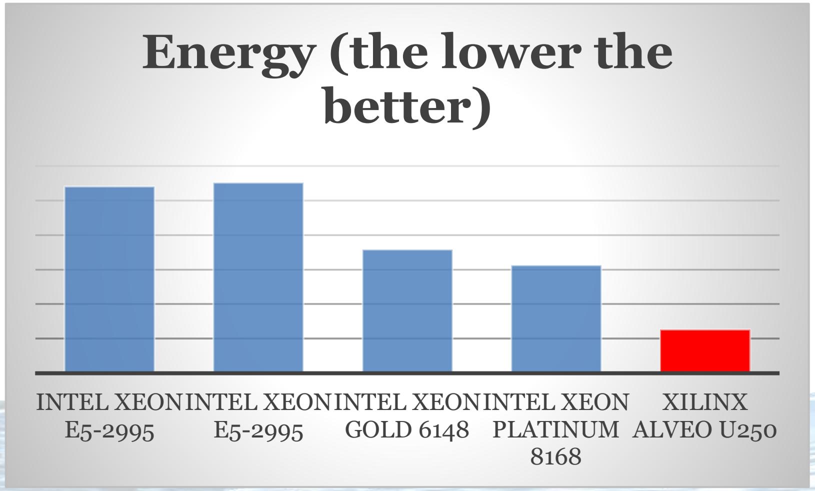
Algorithm: Advection (MPDATA)
Technical Information

- **First-order-accurate step of the advection scheme.**
  Second-order is an option.
- **Input data**
  - Array X – non-diffusive quantity
    (e.g. temperature of water vapor, ice, precipitation, etc.)
  - Arrays V1, V2, V3 - each of them stores the velocity vectors in one direction
  - (optional) Arrays Fi, Fe - implosion and explosion forces acting on a structure of X
  - (optional) Array D with density
  - (optional) Array rho which defines an interface for the coupling of COSMO and EULAG dynamic core
    (used to provide the transformation of the X variable)
  - DT – time step (scalar)
- **Output data**
  - single X array that was updated in the given time step

Algorithm: Advection (MPDATA)
Benchmark

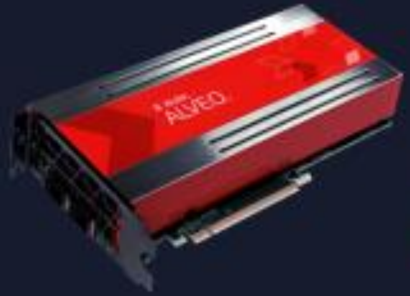






CFD Optimization

XILINX ALVEO



- Faster time to results and more efficient processing compared to CPU-only nodes
- **4x** faster
- **80%** lower energy consumption
- **6x** better performance per Watt

Algorithm: Advection (MPDATA)

TCO Simulation

Setup	CPU [USD]	Accelerator [USD]	Price [USD]	# of devices per node	Price * #
Intel Xeon Platinum 8168	8000	0	8000	2	16000
Xilinx U250 + Intel Xeon E3 1220	200	5000	5200	1-2	5200-10200

1 Alveo/node

TCO CPU/FPGA	Alveo Acceleration
1	0.325
2	**0.65**
3	0.975
4	**1.3**
...	...
10	**3.25**

2 Alveos/node

TCO CPU/FPGA	Alveo Acceleration
1	0.64
2	1.28
3	1.91
4	2.55
...	...
10	**6.38**

Applications of Advection (MPDATA)
byteLAKE's CFD Kernels

- **Applications include**
  - To characterize the sub-grid scales effect in global numerical simulations of turbulent stellar interiors
  - To compare anelastic and compressible convection-permitting weather forecasts for the Alpine region
  - Modeling the prediction of forest fire spread
  - Flood simulations
  - Biomechanical modeling of brain injuries within the Voigt model (a linear system of differential equations where the motion of the brain tissue depends merely on the balance between viscous and elastic forces)
  - Simulation gravity wave turbulence in the Earth's atmosphere
  - Simulation of geophysical turbulence in the Earth's atmosphere
  - Ocean modeling: simulation of three-dimensional solitary wave generation and propagation using EULAG coupled to the barotropic NCOM (Navy Coastal Ocean Model) tidal model

Applications of Advection (MPDATA), cont.
byteLAKE's CFD Kernels

- **Applications include, cont.**
  - Oil and Gas: provides a significant return on investment (ROI) in seismic analysis, reservoir modelling and basin modelling. Used also to monitor drilling and seismic data to optimize drilling trajectories and minimize environmental risk.
  - AgriTech: models to track and predict various environmental impacts on crop yield such as weather changes. For example, daily weather predictions can be customized based on the needs of each client and range from hyperlocal to global.

- **Example adopters**
  - Poznan Supercomputing and Networking Center, Poland: prognosis of air pollution
  - European Centre for Medium-Range Weather Forecasts, UK: weather forecast
  - Institute of Meteorology and Water Management, Poland: weather forecasts
  - German Aerospace Center: aeronautics, transport and energy areas
  - University of Cape Town, RPA: weather simulation
  - Montreal University: weather simulation
  - Warsaw University: ocean simulation

Full list

Learn more:

byteLAKE.com/en/CFDKernels

Contact us at CFDKernels@byteLAKE.com to request access to byteLAKE's CFD Kernels.

We offer a convenient and instant access in on-premise as well as Cloud configurations.

For qualified partners there is also a possibility to receive access to byteLAKE's CFD Kernels with a complete hardware infrastructure.

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(FPGA, GPU)

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Intelligent
Restaurant

Services

Edge AI

Cognitive Automation

HPC