

EPIC: An Energy-Efficient, High-Performance GPGPU Computing Research Infrastructure

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Abstract—The pursuit of many research questions requires massive computational resources. State-of-the-art research in physical processes using simulations, the training of neural networks for deep learning, or the analysis of big data are all dependent on the availability of sufficient and performant computational resources. For such research, access to a high-performance computing infrastructure is indispensable.

Many scientific workloads from such research domains are inherently parallel and can benefit from the data-parallel architecture of general purpose graphics processing units (GPGPUs). However, GPGPU resources are scarce at Norway’s national infrastructure.

EPIC is a GPGPU enabled computing research infrastructure at NTNU. It enables NTNU’s researchers to perform experiments that otherwise would be impossible, as time-to-solution would simply take too long.

I. INTRODUCTION

The end of Dennard’s scaling left computing systems across all domains increasingly power constrained. Specialized hardware in the form of accelerators emerged as alternatives to perform computations more energy-efficient. Specifically, general-purpose, graphic-processing units (GPGPUs) became increasingly popular as a means to accelerate programs in high-performance computing (HPC) and artificial intelligence.

GPGPUs devote more compute resources to accelerate data-parallel applications by sacrificing resources that improve sequential program performance, rendering them more energy-efficient for data-parallel application domains. Nowadays, GPGPUs are significantly employed in High-Performance Computing (HPC) systems to meet performance demands while maintaining power constraints. For example, nine of the ten most powerful supercomputers in the world rely on GPGPUs for their computational power [90]. Furthermore, eight of the top ten most energy-efficient supercomputers in the world rely on GPGPUs [30].

The EPIC research infrastructure is a project between the Department of Computer Science and the IT Division at the Norwegian University of Science and Technology (NTNU) that aims at providing a GPGPU compute platform. EPIC is a part of the NTNU Idun computing cluster [38], which provides a high-availability and professionally administrated compute platform for NTNU. Idun combines compute resources of individual shareholders to create a cluster for rapid testing and prototyping of HPC software. Currently, EPIC constitutes 48% of the total number of nodes in the IDUN cluster and 100% of the GPGPU resources.

EPIC is with its 158 GPGPUs one of Norway’s largest GPGPU enabled computational infrastructures. Norwegian national infrastructure has a very limited number of GPGPU resources, e.g., Saga [79] has only 32 NVIDIA Tesla P100 [68] and Colossus [22] has 32 much older NVIDIA Tesla K20.

II. THE IDUN CLUSTER

The Idun cluster is a Tier-2 [32] research cluster at NTNU meant as a stepping stone for the national infrastructure and serves as a platform for rapid testing and prototyping of HPC software, research into energy-efficient computing, and GPU-aided simulations and design-space exploration.

Currently, Idun consists of 73 nodes connected by two networks: one ethernet network and one high-throughput and low-latency InfiniBand (IB) network. The 1 Gb/s ethernet network serves as an administration and provisioning network, while the IB network is used for inter-node communication. The IB network is a mix of FDR (4x lanes each of 14 Gb/s) and EDR (4x lanes each of 25 Gb/s), as shown in Figure 1. Each node is connected with either FDR or EDR, resulting in 56 Gb/s or 100 Gb/s per node, respectively. The individual IB switches are connected in a tree structure with 3xFDR links between each switch, resulting in 168 Gb/s inter-switch connection speed.

Idun’s storage is provided by two storage arrays and a Lustre parallel distributed file system [57]. The storage arrays, one serves as Lustre metadata target (MDT) and one as Lustre object storage target (OST), are complemented with two Lustre metadata servers (MDS) and two object storage servers (OSS). The MDT and MDSs store the namespace data of the file system, such as filenames, directories, access permissions and file layouts, while the OST and OSSs store the file data. Together, the IB network and the Lustre file system, provide the means to efficiently transfer data to the compute resources, enabling an effortless scaling of the cluster in terms of nodes and/or GPUs.

III. THE EPIC RESEARCH INFRASTRUCTURE

The EPIC research infrastructure consists of five distinct investments (see Table I), each with a distinct purpose:

The original **EPIC1** consists of eight nodes with two NVIDIA P100 GPUs and focused on energy-efficient computing research such as energy efficient resource management for latency-critical cloud services [67].

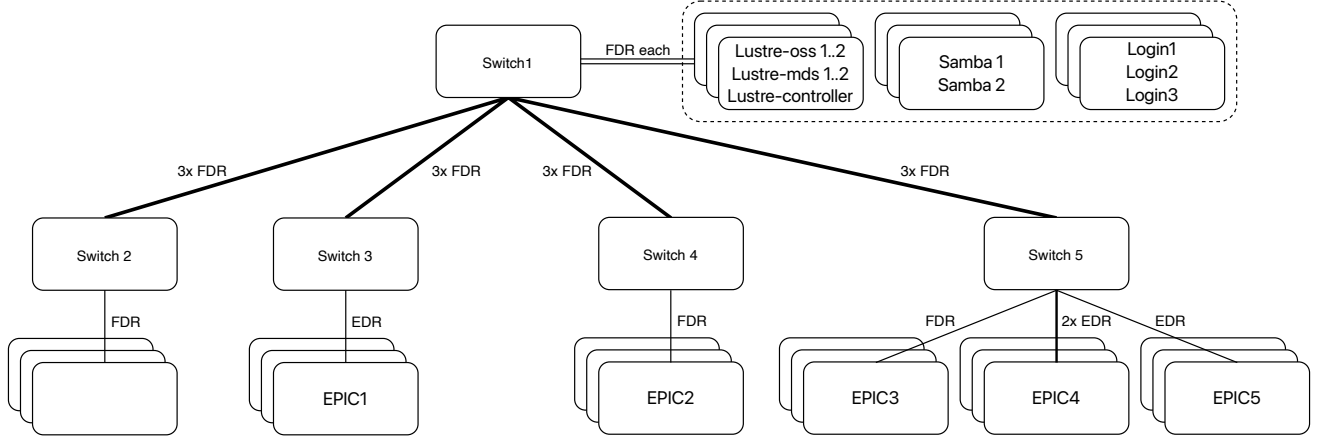


Fig. 1. The topology of the Idun with the EPIC research infrastructure.

TABLE I
EPIC CONFIGURATION

Name	#Nodes	Machine Model	#CPUs	Processor model	#Cores	Memory	#Accel.	Accelerator model
EPIC1	8	Dell PE730	2	Intel Xeon E5-2695 v4 [40]	36	128 GiB	2	NVIDIA Tesla P100 16 GiB [68]
EPIC2	19	Dell PE730	2	Intel Xeon E5-2650 v4 [39]	24	128 GiB	2	NVIDIA Tesla P100 16 GiB [68]
EPIC3	5	Dell PE740	2	Intel Xeon Gold 6132 [41]	28	768 GiB	2	NVIDIA Tesla V100 16 GiB [69]
EPIC4	2	Dell DSS8440	2	Intel Xeon Gold 6148 [42]	20	768 GiB	8	NVIDIA Tesla V100 32 GiB [69]
	1	Dell DSS8440	2	Intel Xeon Gold 6148 [42]	20	768 GiB	10	NVIDIA Tesla V100 32 GiB [69]
EPIC5	4	Dell DSS8440	2	Intel Xeon Gold 6148R [42]	24	1.5 TiB	10	NVIDIA A100-40 [70]
	7	Dell PowerEdge XE8545	2	AMD EPYC 7543 [3]	32	2 TiB	4	NVIDIA A100-80 [70]
	2	Dell R740	2	Intel Xeon Gold 6132 [41]	24	754 GiB	4	Xilinx Alveo U250 [109]

EPIC2 consists of 19 GPGPU nodes, each equipped with two NVIDIA P100 GPUs. These nodes complement EPIC1 and provide raw computational GPU power. These nodes are used for research in 3D object identification [99], physical simulations (e.g., nanomagnet ensemble dynamics modeled in MuMAX [101] and flatspin [47]), and deep learning.

EPIC3 consists of five big-memory nodes, each equipped with two NVIDIA V100 GPUs. These nodes are meant for AI research that requires massive training sets, and therefore need more main memory.

EPIC4 is an extension of EPIC2 providing another 26 GPUs for raw computational power. It consists of one node with ten V100 32 GiB GPUs and two nodes with eight V100 32 GiB GPUs. In addition, the big-memory GPUs (32 GiB instead of 16 GiB) enable larger working set sizes beneficial for 3D object identification and large AI models.

EPIC5 is a further extension that adds 68 GPUs distributed across 11 nodes as well as four Xilinx Alveo U250 field programmable gate array (FPGA) accelerator cards [109] distributed across two nodes. The primary use of the FPGA accelerators are to support computer architecture research using, e.g., FireSim [51].

Even though the the purpose and configuration of EPIC1-5 differ, all 158 GPGPUs can be accessed as one distributed resource for massive GPGPU performance.

IV. RESEARCH OUTCOME

The EPIC cluster has been an indispensable resource for a wide range of research, e.g., efficient resource management, nanomagnetic modeling, 3D object identification, etc. Below is

a non-exhaustive list of published articles that relied on EPIC to produce their results:

- Energy-efficient resource management for latency-critical cloud services [67].
- Emergent computation on magnetic ensembles [46], [58], [48], [47], [73].
- Bit-serial matrix multiplication acceleration [94].
- Intermediate representation (IR) for optimizing compilers [76].
- Nano-scale structures of aluminum alloys [20], [21], [18].
- Management of Internet of things (IoT) devices [65].
- Numerical modeling of renewable energy production and storage [95], [97], [96], [98], [45], [44].
- Bankruptcy prediction using machine learning [66], [106].
- Interest rate and treasury securities modeling [107], [108].
- Isogeometric analysis of acoustic scattering [102], [104], [103].
- Framework for wind field predictions [92].
- 3D object identification [99], [100].
- Computational fluid dynamics [71], [5], [52], [7], [6].
- Shear viscosity analysis [74], [75]
- Molecular dynamics simulations [28]
- Modeling of convection flows [54].
- Genetic association studies [34], [1].
- Behavior detection in echograms [60].
- Sub-surface modifications [77], [78].
- Autoignition-stabilized flames [29].
- Speculative side-channel mitigations [80], [82].
- Modeling polymeric nanofibres [13], [12], [11]

- Emission modeling [53]
- Modeling systemic circulation [14]
- Text processing using deep learning [93]
- Digital twins [87]
- Neocortex encoding structure [63]
- Analytical models [91]
- Population activity in grid cells [27]
- Cardinality constraints [37]

A. PhD Theses

The cluster has been used to produce results for the following PhD theses:

- Emil Christiansen, “Nanoscale characterisation of deformed aluminium alloys”, 2019 [19].
- Pablo Miguel Blanco, “Coupling of binding and conformational equilibria in weak polyelectrolytes. Dynamics and charge regulation of biopolymers in crowded media.”, 2020 [15].
- Ranik Raaen Wahlstrøm, “Financial data science for exploring and explaining the ever-increasing amount of data”, 2021 [105].
- Luis Alfredo Moctezuma “Towards Universal EEG systems with minimum channel count based on Machine Learning and Computational Intelligence”, 2021 [64].
- Eivind Bering, “Stretching, breaking, and dissolution of polymeric nanofibres by computer experiments”, 2021 [10].
- Jan Inge Hammer Meling, “Hydrogen assisted crack growth in iron: a simulations approach”, 2021 [62].
- Christos Sakalis, “Rethinking Speculative Execution from a Security Perspective”, Uppsala University, 2021 [81].
- Johannes Høydahl Jensen, “Reservoir computing in-materio: Emergence and control in unstructured and structured materials”, 2021 [49].

B. MSc Thesis Projects

The cluster is also used as an educational resources where students can run their simulations and produce results for their thesis projects.

- André Håland and Bjørnar Birkeland, “Exploring data assignment schemes when training deep neural networks using data parallelism”, 2020 [33].
- Jørgen Boganes, “Accelerating Object Detection for Agricultural Robotics, 2020 [16].
- Daniel Ørnes Halvorsen, “Studies of turbulent diffusion through direct numerical simulation”, 2020 [36].
- Bjørn Magnus Valberg Iversen, “Combining Hyperband and Gaussian Process-based Bayesian Optimization”, 2020 [43].
- Runar Ask Johannessen, “Aggregation of Speaker Embeddings for Speaker Diarization”, 2020 [50].
- Siv-Marie McDougall, “Fluorohectorite as a CO₂ adsorbent: a DFT and DFTB study”, 2020 [61].
- M. Tarlton, Y. Roudi, and N. Bulso, “Novel Model Selection Criterion for Inference of Ising Models”, 2021 [88].

- Richard Bachmann, “Performance Modeling of Finite Difference Shallow Water Equation Solvers with Variable Domain Geometry”, 2021 [8].
- Frikk Hald Andersen and Eirik Dahlen, “Sesame Street Pays Attention to Pro-Eating Disorder”, 2021 [4].
- Martin Rebne Farstad, “Understanding the Key Performance Trends of Optimized Iterative Stencil Loop Kernels on High-End GPUs”, 2021 [23].
- Einar Aasli, “Numerical Simulation of Fluid-Structure Interaction”, 2021 [2].
- Klara Schlüter and Jon Riege, “Stochastic Multiplicative Updates for Symmetric Nonnegative Matrix Factorization”, 2021 [83].
- Karoline Bonnerud, “Write Like Me: Personalized Natural Language Generation Using Transformers”, 2021 [17].
- Richard Bachmann, “Performance Modeling of Finite Difference Shallow Water Equation Solvers with Variable Domain Geometry”, 2021 [9].
- Michael Tarlton, “Novel Model Selection Criterion for Inference of Ising Models”, 2021 [89].
- Anja Rosvold From and Ingvild Unander Netland, “Fake News Detection by Weakly Supervised Learning: A Content-Based Approach”, 2021 [25].
- Didrik Salve Galteland, “Exploring Self-supervised Learning-based Methods for Monocular Depth Estimation in an Autonomous Driving Setting”, 2021 [26].
- Veibjørn Malmin and Halvor Ødegård Teigen, “Reinforcement Learning and Predictive Safety Filtering for Floating Offshore Wind Turbine Control”, 2021 [59].
- Marthe Strand Haltbakk, “Kinetic Monte Carlo simulation of the early precipitation stages in Al-Mg-Si alloys using Cluster Expansion methods for energy barrier modelling”, 2021 [35].
- Andreas Herløvsund Søgne, “Numerical analysis of finned-tubes and finned-tube bundles”, 2021 [85].
- Aurora Grefsrud, “Efficiency of IllustrisTNG in modeling galaxy properties”, 2021 [31].
- Joakim Olsen, “Measuring Summary Quality using Weak Supervision”, 2021 [72].
- Varun Loomba and Jan Erik Olsen and Kristian Etienne Einarsrud, “Modelling of Furnace Tapping with Uniform and Non-Uniform Porosity Distribution”, 2021 [56].
- Lars Andreas Hastad Lervik, “Orientation and Projection Center Refinement for EBSD Indexing in Python”, 2021 [55].
- Vemund Fredriksen and Svein Ole Matheson Sevre, “Pulmonary Tumor Segmentation Utilizing Mixed-Supervision in a Teacher-Student Framework”, 2021 [24].
- Halvor Bakken Smedås, “ASSIST: Accuracy-driven Sampling Strategies for Improved Supervised Training”, 2021 [84].
- Robin Christian Staff, “What a Twist-Using Deep Neural Networks to Generate Plot Twists”, 2021 [86].

V. CONCLUSION

EPIC is a multi-million investment by the Department of Computer Science in collaboration with the IT Division to

provide GPGPU resources for NTNU's researchers. The large number of GPGPUs enable research studies to be performed at a scale that otherwise would be impossible to conduct. Thus, EPIC's computational resources help NTNU's researchers to stay competitive and produce state-of-the-art results.

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