DEVELOPMENT OF INTEL XEON PHI ACCELERATED ALGORITHMS AND APPLICATIONS AT IT4INNOVATIONS NATIONAL SUPERCOMPUTING CENTRE

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Introduction

IT4Innovations National Supercomputing Centre – www.it4i.cz
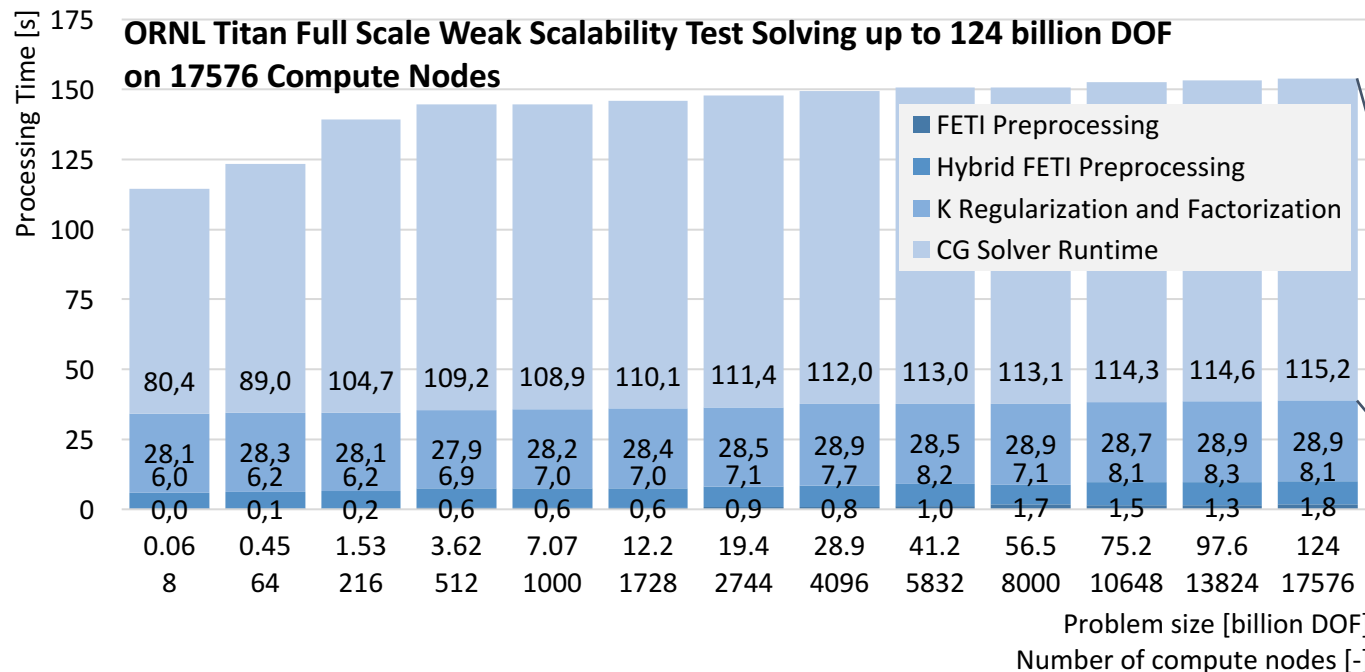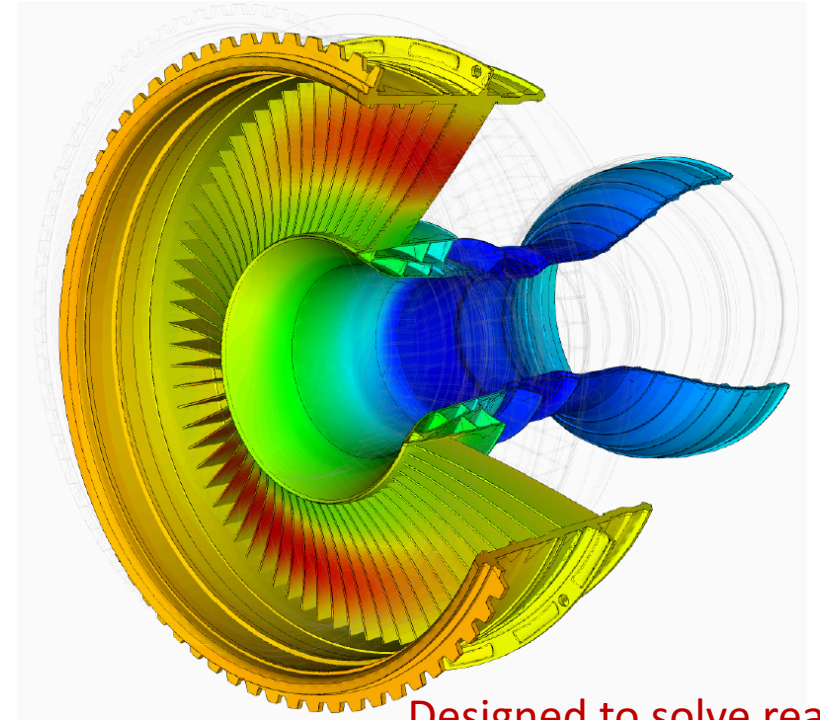
- Salomon Supercomputer - 1008 computational nodes of which 576 are regular compute nodes and 432 accelerated nodes (two Intel Xeon Phi 7120P co-processors per node)

Selected Applications from Parallel Algorithms Research Lab at IT4Innovations

- **IPC Center at IT4Innovations** – acceleration of the **ESPRESO** library and its integration into ELMER and OpenFOAM community codes (http://ipcc.it4i.cz, http://espreso.it4i.cz)

- **BEM4I** – development of efficient Boundary Element Method (BEM) assembler for multi- and many-core architectures with wide SIMD units (http://bem4i.it4i.cz)

- **Blender** – parallelization of the Blender Cycles rendering engine by MPI and OpenMP with support for Intel Xeon Phi accelerators (http://ipcc.it4i.cz/files/Download/)

ESPRESO Massively Parallel Sparse Linear Solver

- FETI domain decomposition based solver supporting massively parallel solution of structural mechanics problems

- Supports acceleration by Intel Xeon Phi processors – KNC and KNL

- Provides general API for other open source libraries (ELMER, OpenFOAM)

ORNL Titan Full Scale Weak Scalability Test Solving up to 124 billion DOF on 17576 Compute Nodes

Processing Time [s]

Legend:
- FETI Preprocessing
- Hybrid FETI Preprocessing
- K Regularization and Factorization
- CG Solver Runtime

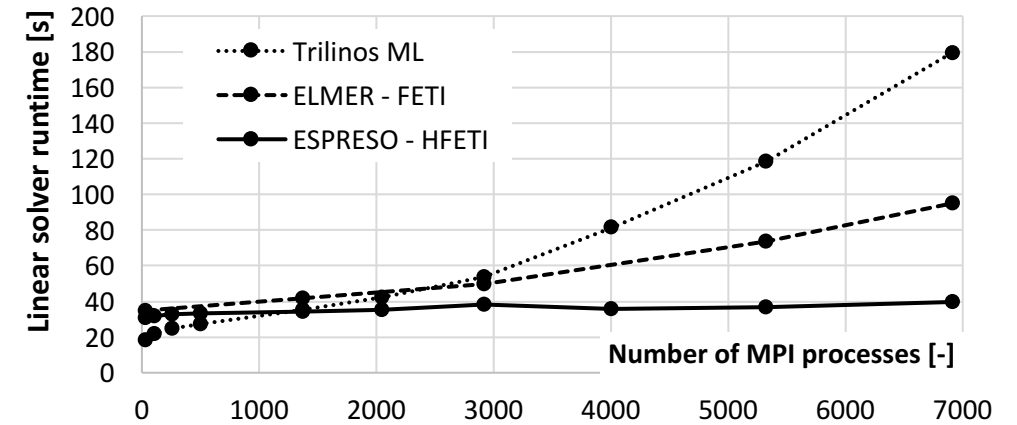| CG Solver Runtime | 80,4 | 89,0 | 104,7 | 109,2 | 108,9 | 110,1 | 111,4 | 112,0 | 113,0 | 113,1 | 114,3 | 114,6 | 115,2 |
K Reg. and Fact.	28,1	28,3	28,1	27,9	28,2	28,4	28,5	28,9	28,5	28,9	28,7	28,9	28,9
Hybrid FETI Prep.	6,0	6,2	6,2	6,9	7,0	7,0	7,1	7,7	8,2	7,1	8,1	8,3	8,1
FETI Preprocessing	0,0	0,1	0,2	0,6	0,6	0,6	0,9	0,8	1,0	1,7	1,5	1,3	1,8
Problem size [billion DOF]	0.06	0.45	1.53	3.62	7.07	12.2	19.4	28.9	41.2	56.5	75.2	97.6	124
Number of compute nodes [-]	8	64	216	512	1000	1728	2744	4096	5832	8000	10648	13824	17576

This part of the solver is accelerated by the Intel Xeon Phi co-processor

Designed to solve real world problems generated by open-source (ELMER and OpenFOAM) and commercial tools (Ansys Workbench)

KNL - Intel(R) Xeon Phi (TM) processors (previously called Knights Landing

KNC - Intel(R) Xeon Phi (TM) co-processor (previously called Knights Corner)
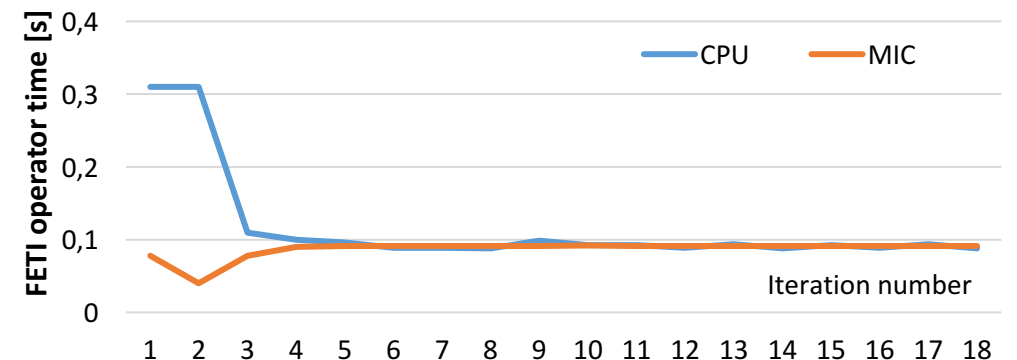
ESPRESO Advanced Features

- Within the IPCC project at IT4Innovations the library was accelerated by offloading to Intel Xeon Phi (KNC) co-processors

- Algorithmic changes have been made to replace actions with sparse FEM data structures with dense objects to fully utilize the coprocessor

- Acceleration of two key routines: (1) system matrix processing and (2) preconditioner application

- Supports offload to multiple coprocessors and dynamic CPU/co-processor load balancing

- Scalability tested on the Salomon supercomputer with up to 864 Xeon Phi 7120P co-processors

- Improved scalability of community codes (ELMER)

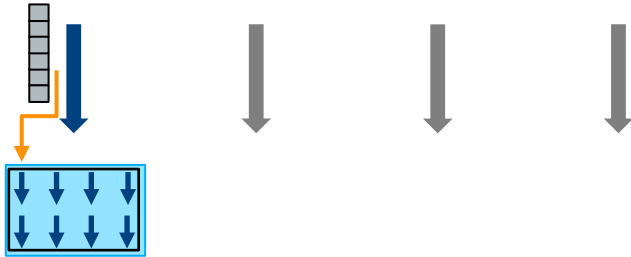**Weak Scalability Evaluation of Selected Linear Solvers in ELMER**

Linear solver runtime [s] vs Number of MPI processes [-]

- ······ Trilinos ML
- – – ELMER - FETI
- —— ESPRESO - HFETI

Compute nodes [-]; MPI ranks [-]; Problem size [million DOF]	2; 32; 3.4	5; 108; 11.6	11; 256; 27.6	21; 500; 53.9	58; 1372; 147	86; 2048; 220	122; 2916; 314	167; 4000; 431	222; 5324; 574	288; 6912; 745

Dynamic load balancing in ESPRESO

FETI operator time [s] vs Iteration number
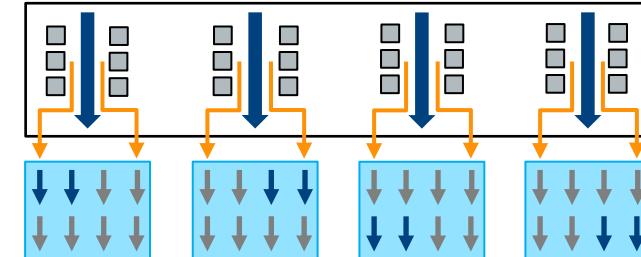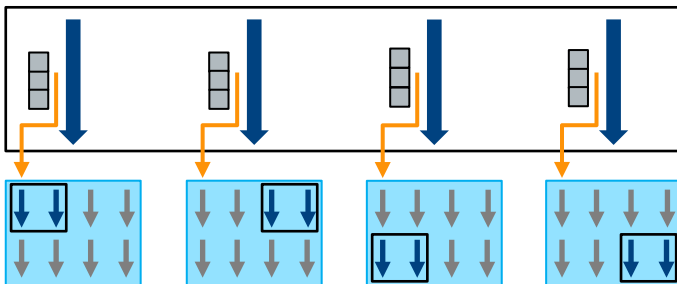
- —— CPU
- —— MIC

Offloading Approaches in ESPRESO

Matrixpack offload

- one thread on host offloads all matrices within one array (MatrixPack)
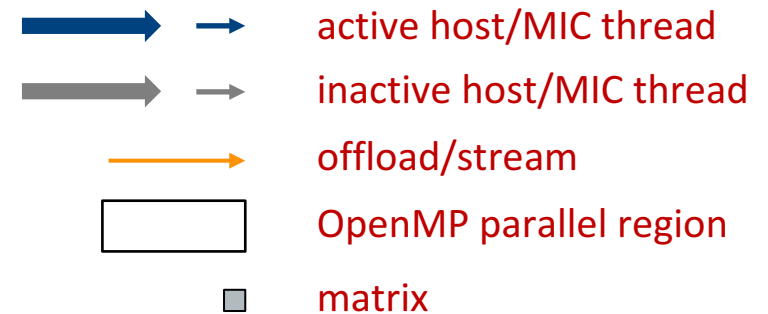- One parallel OpenMP region on device

Matrix semi-pack offload

- Each host thread processes one matrix pack
- Multiple OpenMP regions on device

Individual offload

- Each thread on host offloads its matrices individually
- No OpenMP region on device

active host/MIC thread

inactive host/MIC thread

offload/stream

OpenMP parallel region

matrix

The Future of ESPRESO – Porting to KNL

- Tests were performed on Intel Xeon Phi 7210 processors at Intel Endeavor cluster
- Slower preprocessing phase, faster solve – suitable for problems requiring large number of iterations
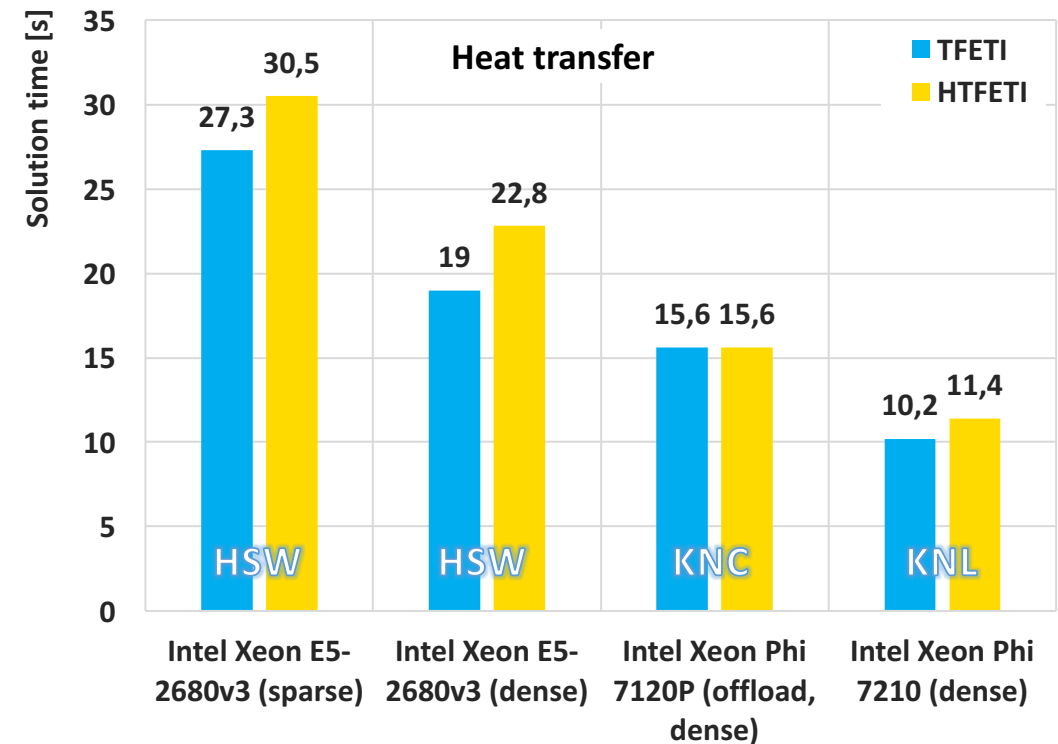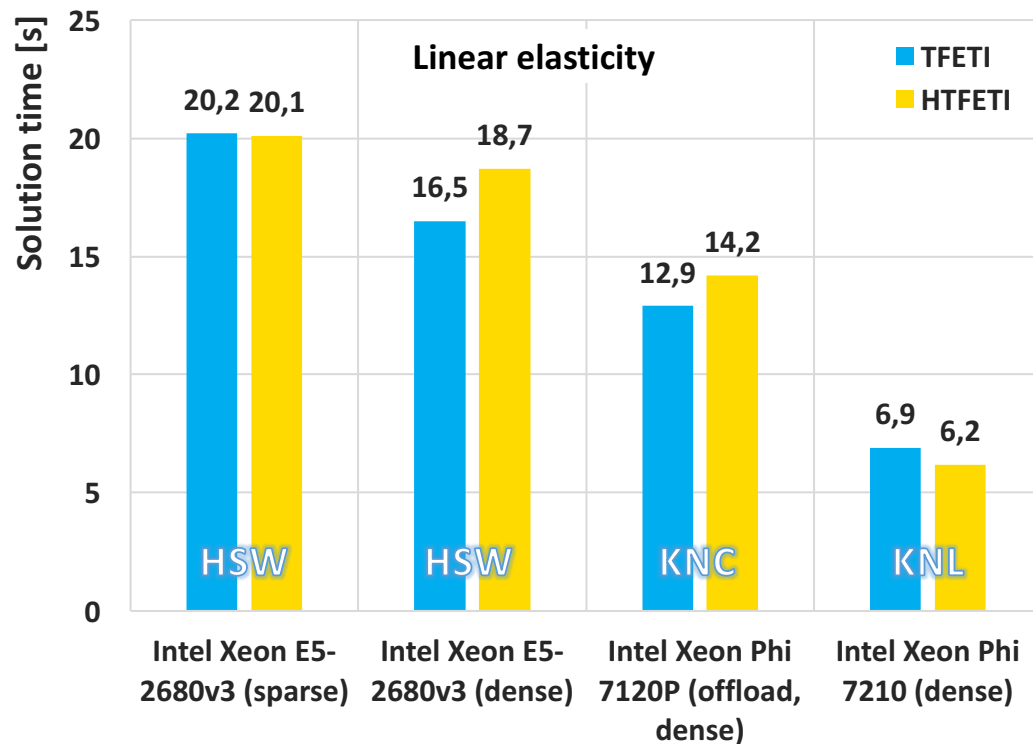
Note: Comparison of iterative solver runtime on different Xeon architectures using sparse/dense matrix structures

BEM4I – Xeon Phi Accelerated Library

Boundary element method

- alternative to FEM
- discretization of boundary only
- singular surface integrals
- dense matrices (classic BEM)
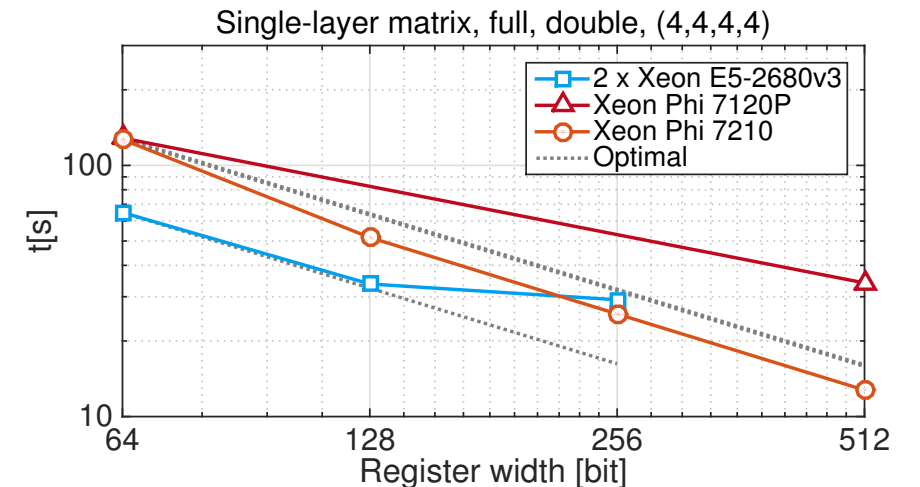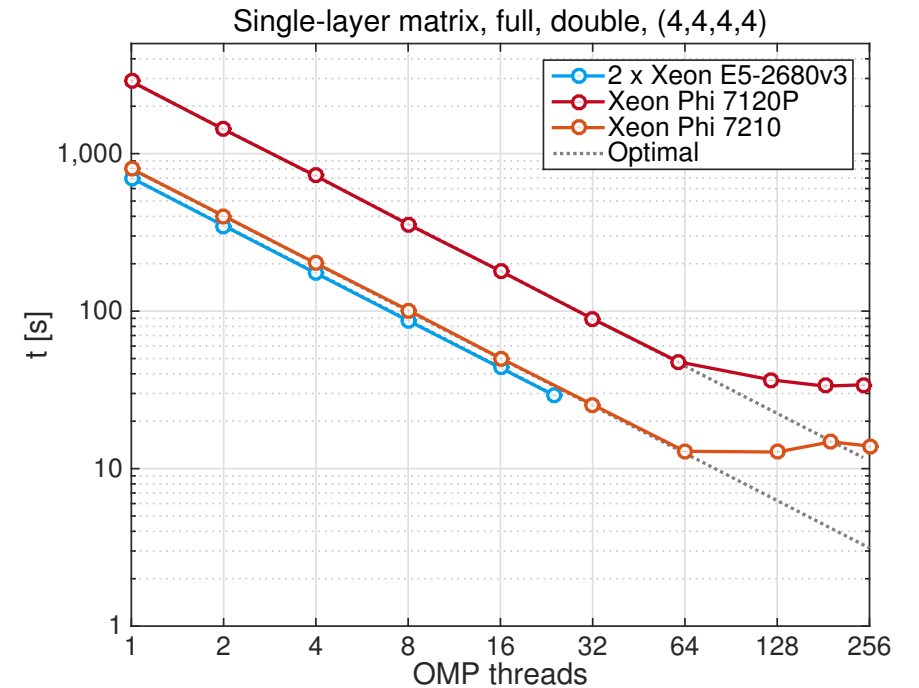
BEM4I (bem4i.it4i.cz)

- solver developed at IT4Innovations
- optimized for Intel Xeon and Xeon Phi processors
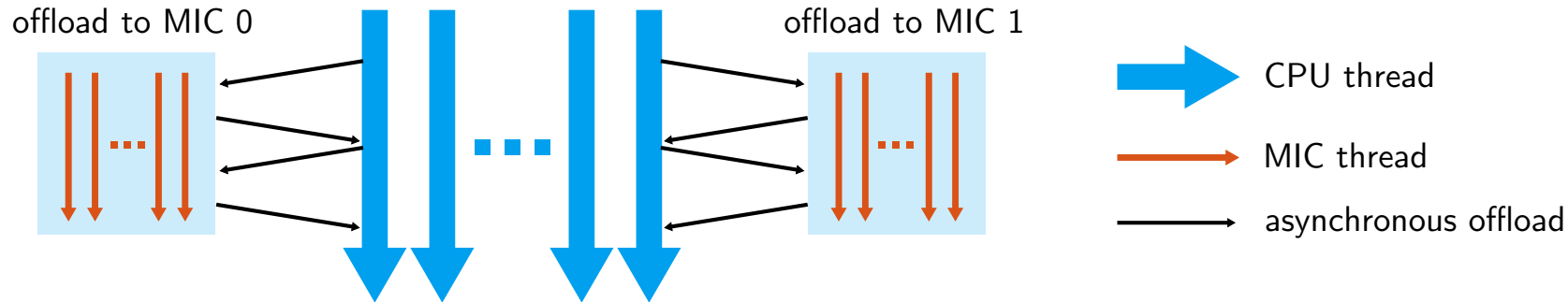
Performance (threading)

- 2 x Xeon E5-2680v3 (Haswell) processor with 24 cores
  - speedup 24 w.r.t. single threads
- Xeon Phi 7120P (Knights Corner) co-processor with 61 cores
  - speedup 61+
- Xeon Phi 7210, (Knights Landing) processor with 64 cores
  - speedup 64+

Performance (SIMD)

- speedup 8+ with AVX-512 w.r.t. scalar code

Single-layer matrix, full, double, (4,4,4,4)

Single-layer matrix, full, double, (4,4,4,4)

BEM4I – Xeon Phi Accelerated Library

offload to MIC 0　　　　　　　　　　offload to MIC 1

CPU thread

MIC thread

asynchronous offload

Possible offload to Intel Xeon Phi (KNC) co-processor

*   Intel LEO pragmas,
*   one OpenMP thread per MIC,
*   asynchronous assembly on host and MIC.

Performance

*   offload to 2 x Xeon Phi 7120P (KNC) co-processor
    *   speedup up to 2.7.
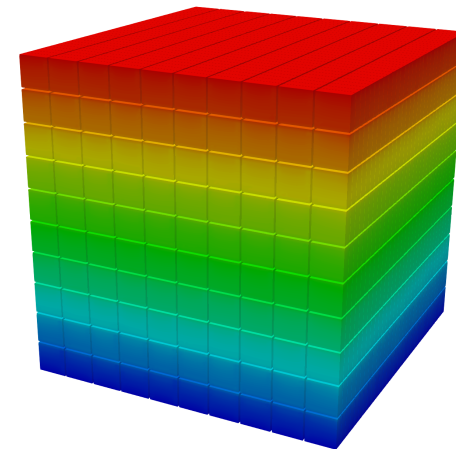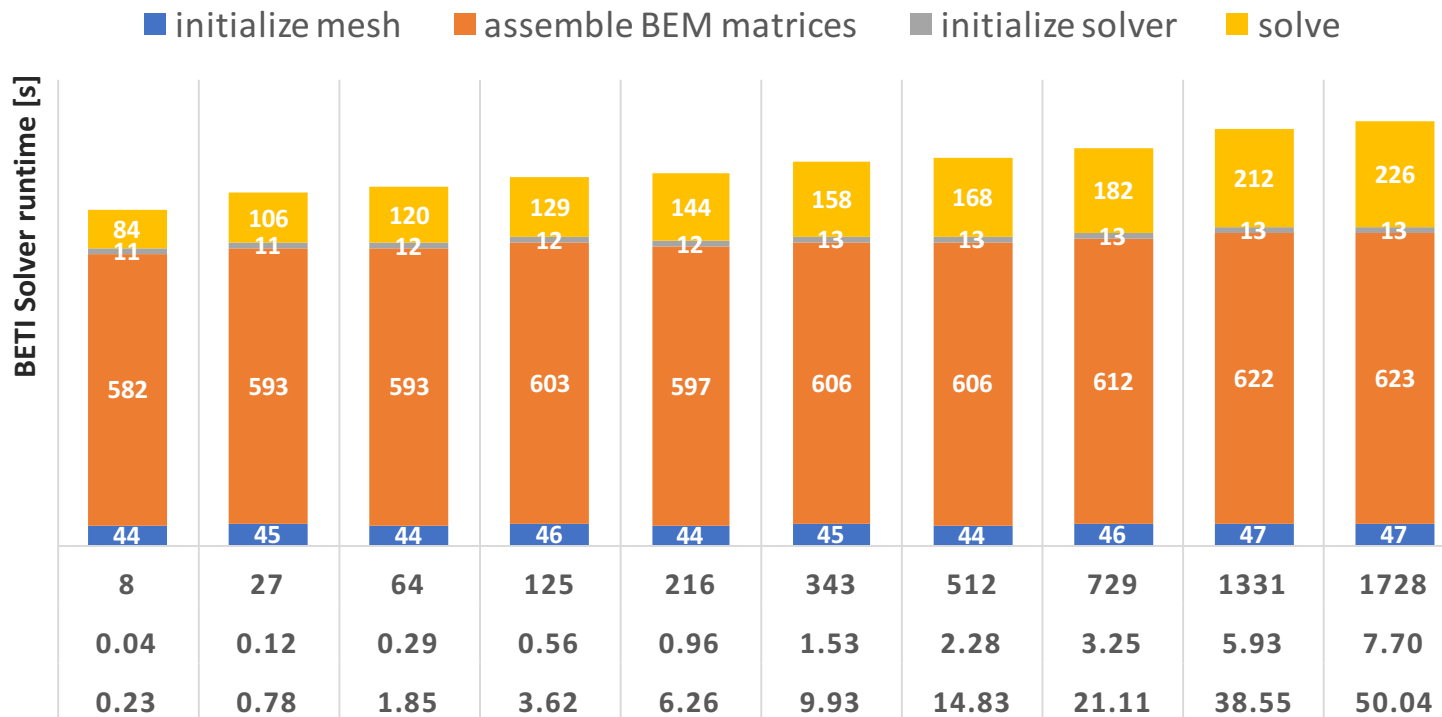
Journal publication: Merta, M.; Zapletal, J.; Jaros, J. Many Core Acceleration of the Boundary Element Method. LNCS, Springer, 2016.

Single-layer matrix (double)

KNC - Intel(R) Xeon Phi (TM) co-processor (previously called Knights Corner)
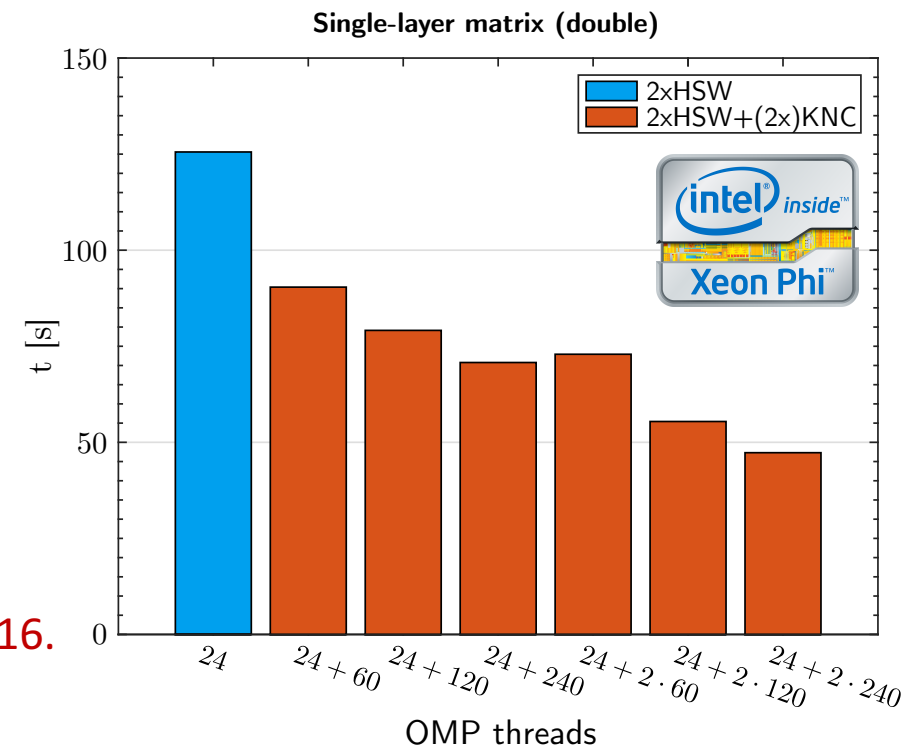
Massively parallel version: BETI = BEM4I + ESPRESO

- Boundary Element Tearing and Interconnecting (alternative to FETI originally implemented in ESPRESO)

- massively parallel – SIMD + OpenMP + MPI + offload to Intel Xeon Phi (KNC) co-processor

Legend: ■ initialize mesh ■ assemble BEM matrices ■ initialize solver ■ solve

BETI Solver runtime [s]

solve	84	106	120	129	144	158	168	182	212	226
initialize solver	11	11	12	12	12	13	13	13	13	13
assemble BEM matrices	582	593	593	603	597	606	606	612	622	623
initialize mesh	44	45	44	46	44	45	44	46	47	47

8	27	64	125	216	343	512	729	1331	1728	Number of MPI processes – 2 MPI processes per node with OpenMP
0.04	0.12	0.29	0.56	0.96	1.53	2.28	3.25	5.93	7.70	Problem size in surface elements [in billions]
0.23	0.78	1.85	3.62	6.26	9.93	14.83	21.11	38.55	50.04	Problem size in volume elements [in billions]

KNC - Intel(R) Xeon Phi (TM) co-processor (previously called Knights Corner)

Acceleration of Blender Cycles Rendering Engine

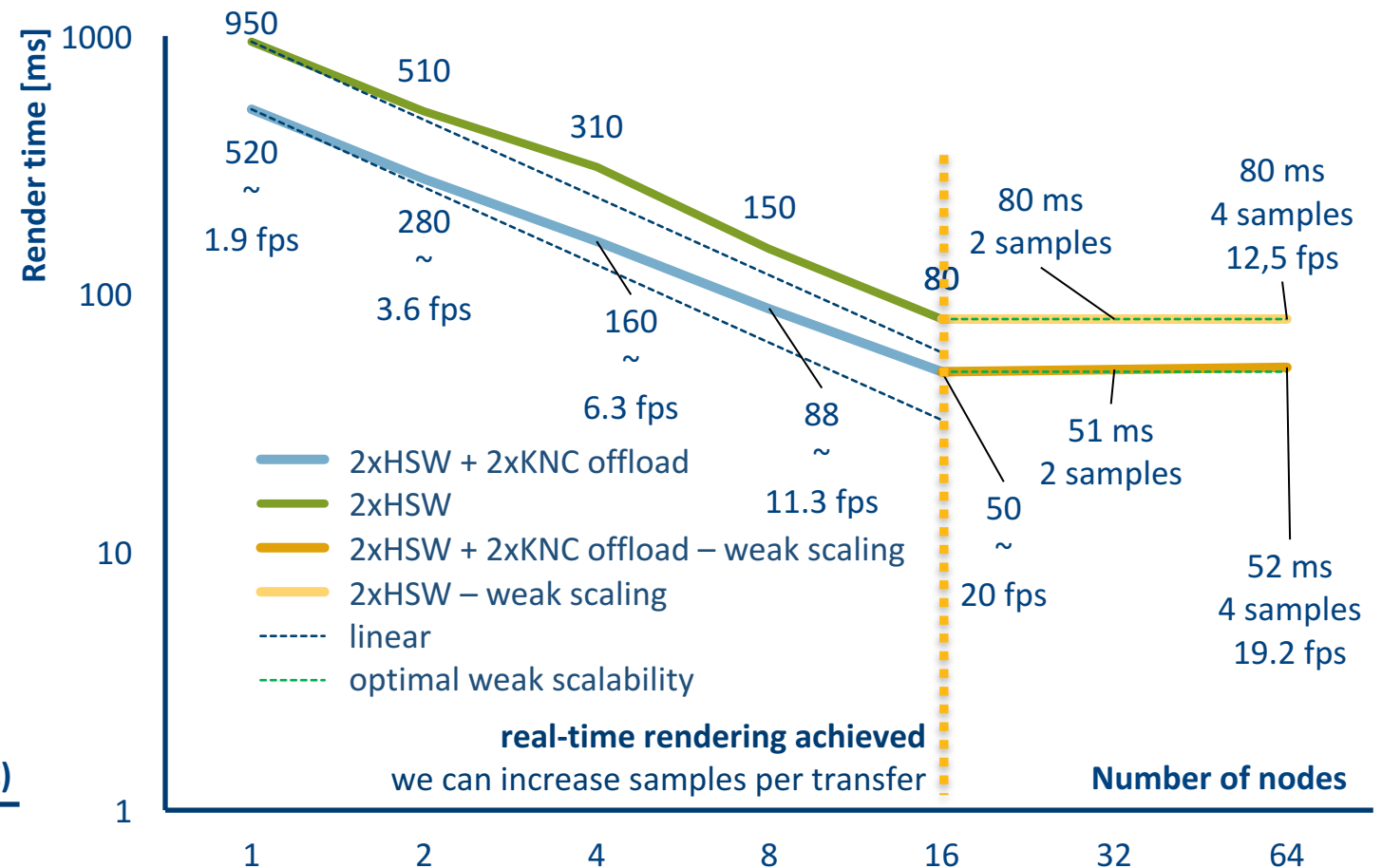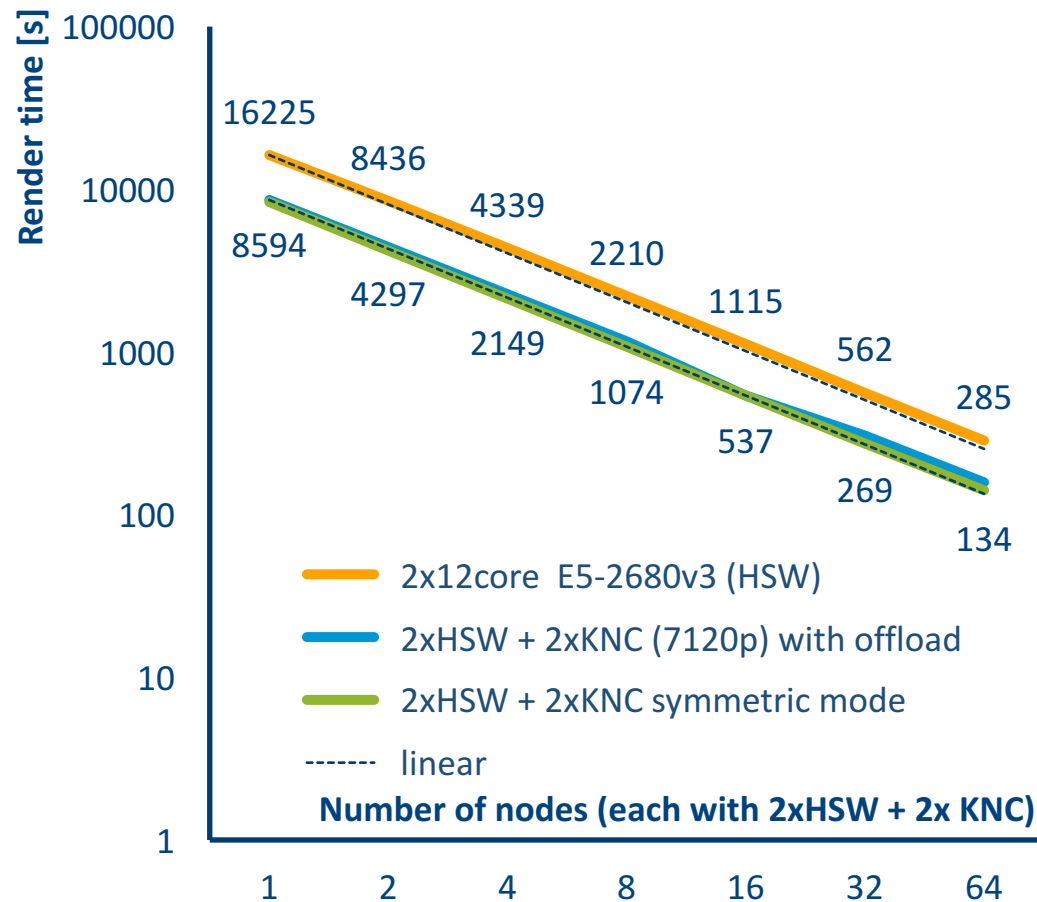# CyclesPhi – Accelerated Blender Cycles

- Blender is an open source 3D creation suite. It has two render engines: Blender Internal and Cycles.

- Cycles is a raytracing based render engine with support for interactive rendering, shading node system, and texture workflow.

- We have modified the kernel of the Blender Cycles rendering engine and then extended its capabilities to support the HPC environment. We call this version the CyclesPhi and it supports following technologies:

  - OpenMP
  - MPI
  - Intel Xeon Phi (KNC) processor with Offload
  - Intel Xeon Phi (KNC) processor with Symmetric mode
  - And their combinations

KNC - Intel(R) Xeon Phi (TM) co-processor (previously called Knights Corner)
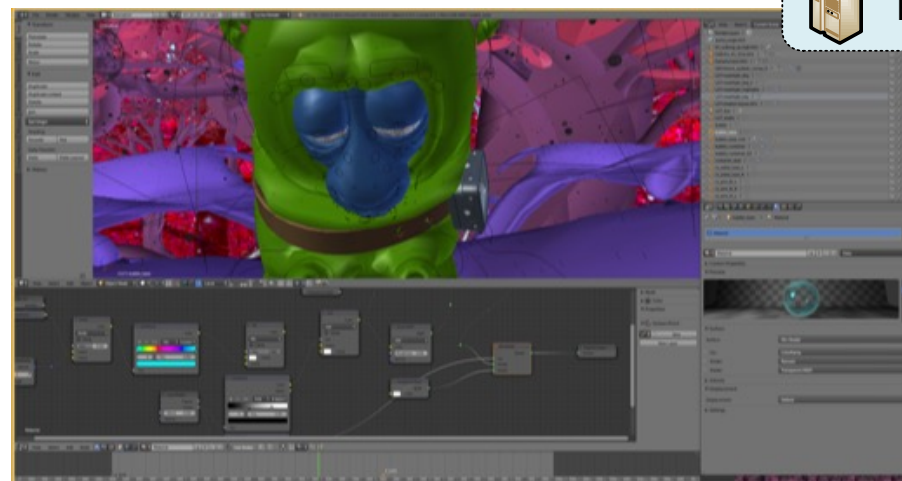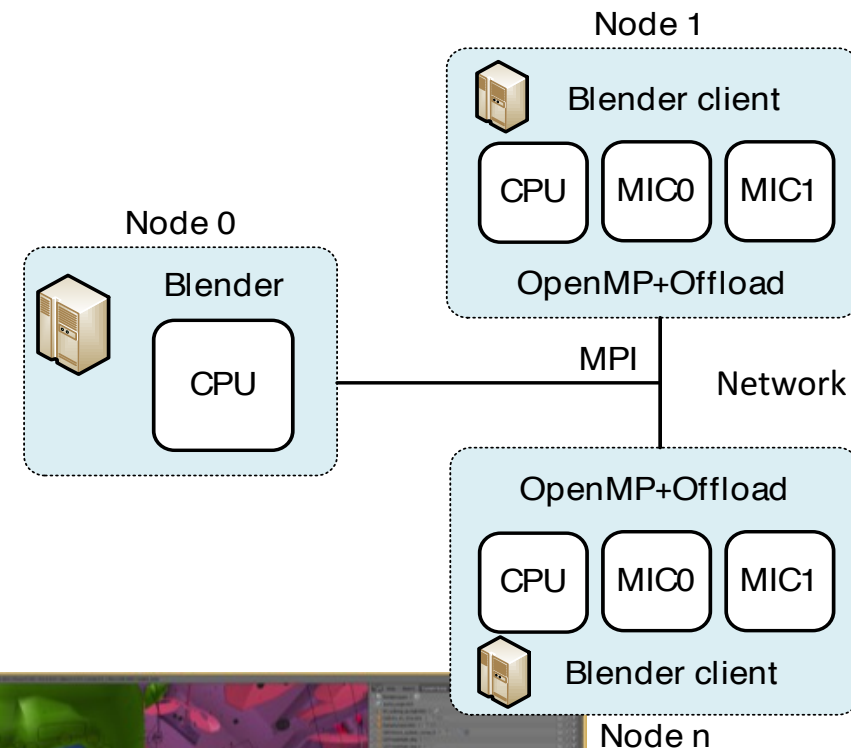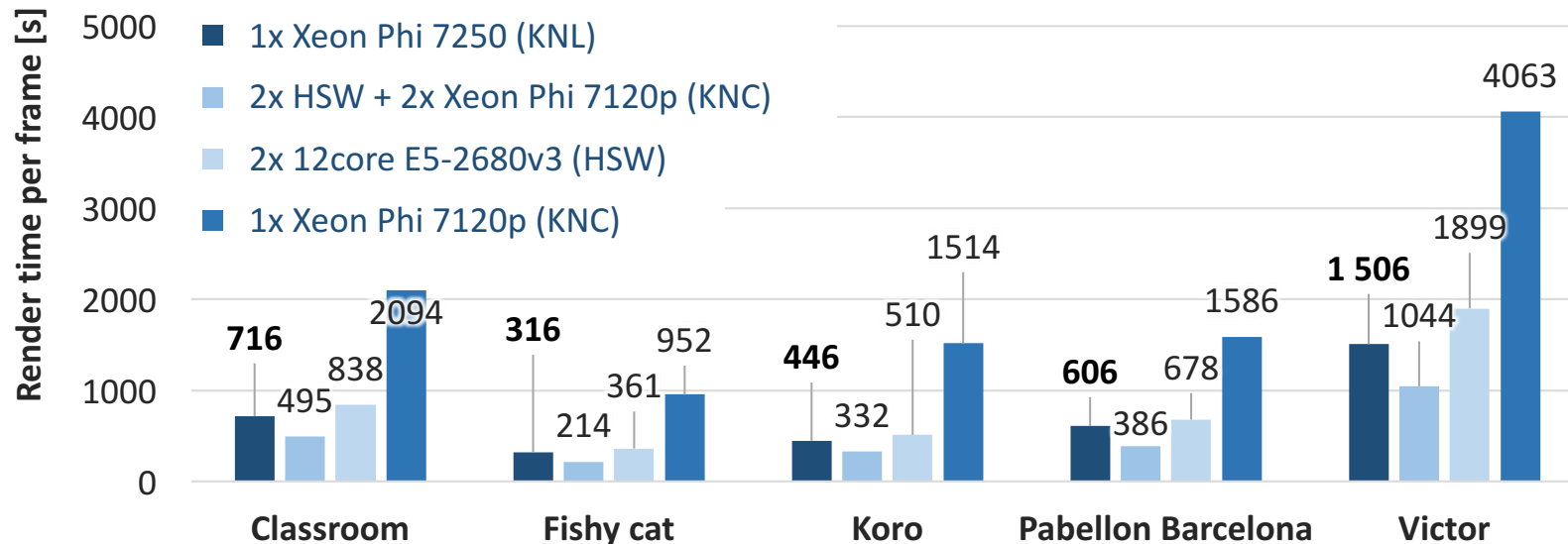
MPI Parallelization of Blender Cycles

Supports both interactive and offline rendering – with almost linear strong scalability

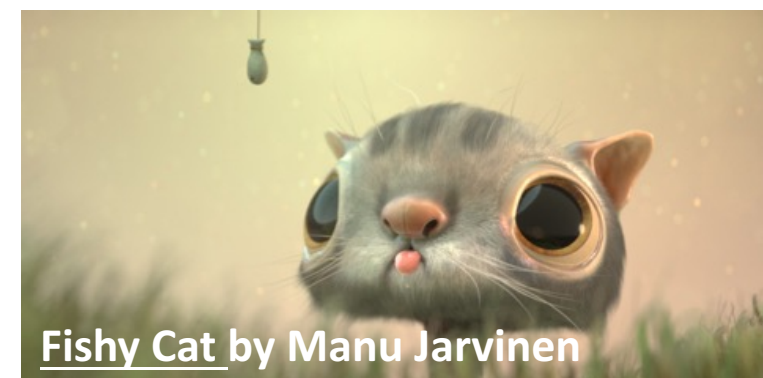Tests on Salomon supercomputer: 2x E5-2680v3 (HSW) and 2x7120p (KNC) processors per node

KNC - Intel(R) Xeon Phi (TM) co-processor (previously called Knights Corner)

Acceleration of Blender Cycles by Xeon Phi Processor

Render time per frame [s]

Legend:
- 1x Xeon Phi 7250 (KNL)
- 2x HSW + 2x Xeon Phi 7120p (KNC)
- 2x 12core E5-2680v3 (HSW)
- 1x Xeon Phi 7120p (KNC)

Chart values:
- **Classroom:** 716, 495, 838, 2094
- **Fishy cat:** 316, 214, 361, 952
- **Koro:** 446, 332, 510, 1514
- **Pabellon Barcelona:** 606, 386, 678, 1586
- **Victor:** 1 506, 1044, 1899, 4063

Classroom by Christophe Seux

Fishy Cat by Manu Jarvinen

Victor by Blender Foundation

Preprocessing time [s]					
Scene (see figures)	Classroom	Fishy cat	Koro	Pabellon Barcelona	Victor
1x Xeon Phi 7250 (KNL)	18 s	110 s	120 s	11 s	1680 s
1x Xeon Phi 7120p (KNC)**	3 s	12 s	14 s	4 s	120 s
2x HSW + 2x Xeon Phi 7120p (KNC)**	6 s	14 s	19 s	4 s	150 s
2x 12core E5-2680v3 (HSW)	1 s	8 s	10 s	1 s	90 s

** preprocessing is done by the 2x 12core E5-2680v3 (HSW) and includes data transfer over PCIe bus

- Salomon supercomputer: 2x Intel Xeon E5-2680v3 CPUs + 2x Intel Xeon Phi 7120P (KNL)processors
- Intel Xeon Phi 7250 - HLRN-III Cray System

KNL - Intel(R) Xeon Phi (TM) processors (previously called Knights Landing
KNC - Intel(R) Xeon Phi (TM) co-processor (previously called Knights Corner)

THANK YOU