AXIOM

Agile, eXtensible, fast I/O Module for the cyber-physical era

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Scalable Embedded Systems: Towards the Convergence of High-Performance and Embedded Computing

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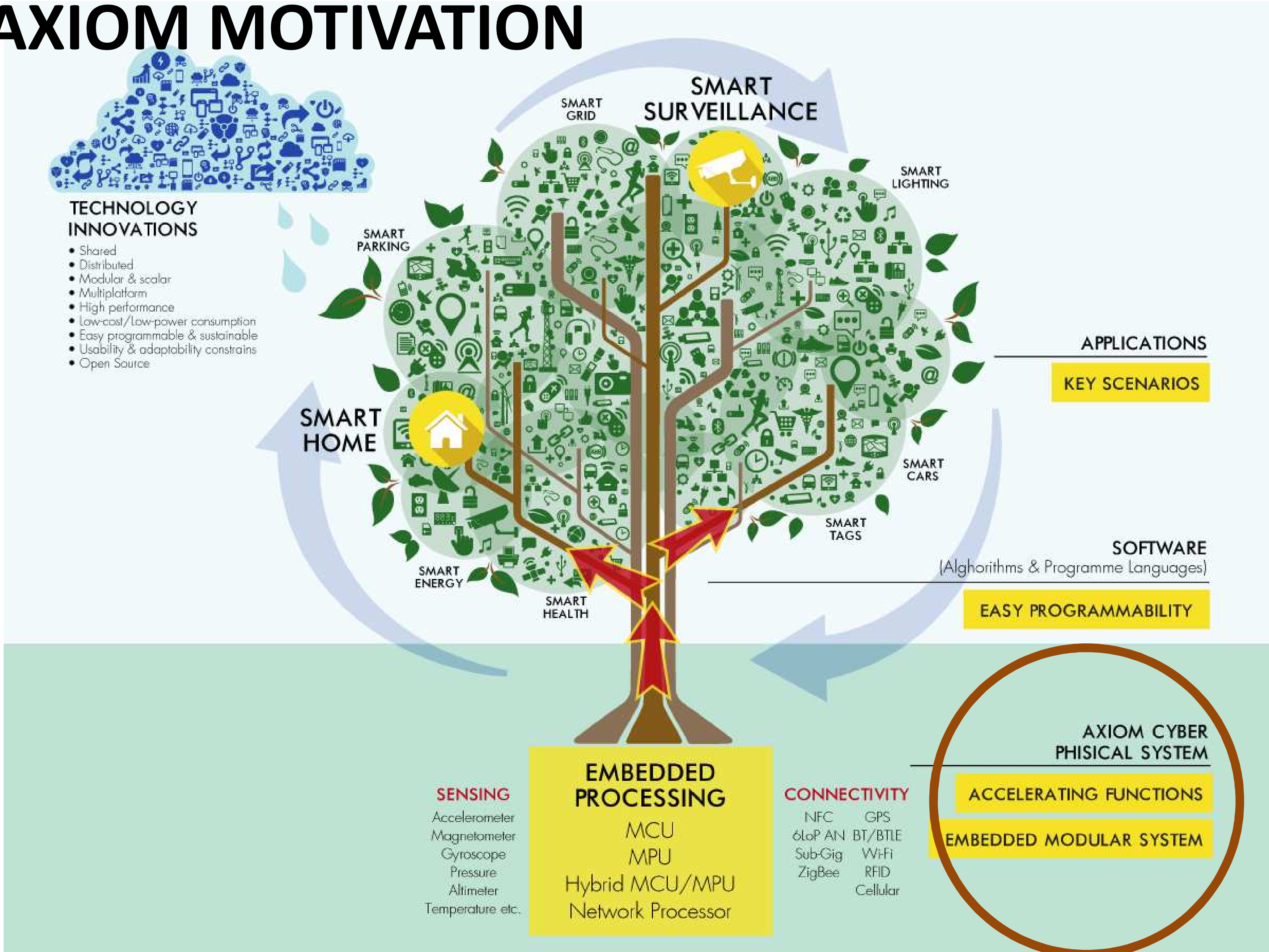
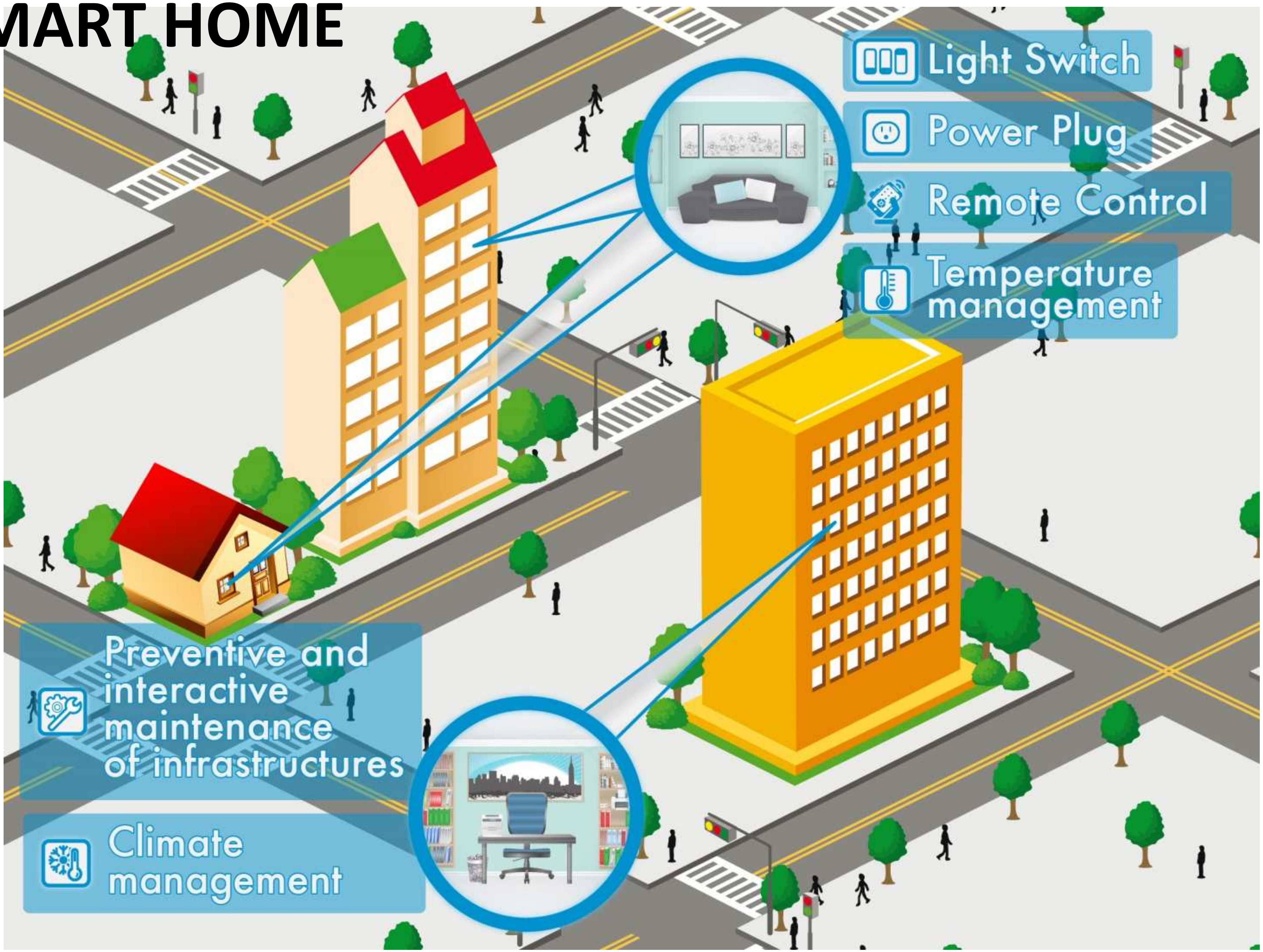
AXIOM MOTIVATION



Highlights of this talk

1) Exploring the concept of ”scalable embedded system”
2) Indicating a way to achieve such scalability by supporting special threads called Data-Flow Threads (DF-Threads)
3) Illustrating how this concepts are integrated in the AXIOM project, which is focused to build a scalable Single Board Computer

SMART HOME



Light Switch
Power Plug
Remote Control
Temperature management
Preventive and interactive maintenance of infrastructures
Climate management

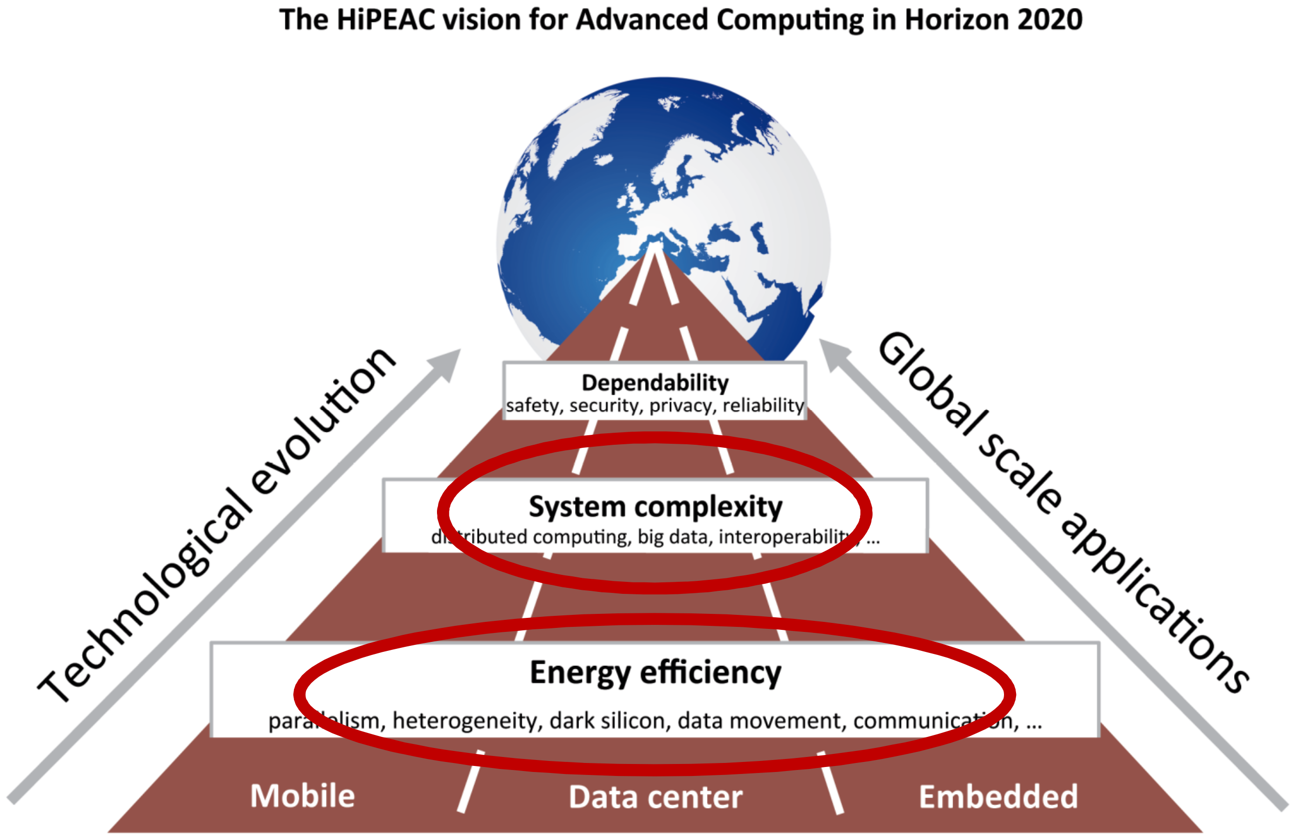
AXIOM OBJECTIVES

- **OBJ1) Producing a small board that is flexible, energy efficient and modularly scalable**
  - A as AGILITY, i.e. flexibility: FPGA, fast-and-cheap interconnects based on existing connectors like SATA
  - Energy efficiency: low-power ARM, FPGA
  - Modularity: fast-interconnects, distributed shared memory across boards
- **OBJ2) Easy programmability of multi-core, multi-board, FPGA**
  - Programming model: Improved OmpSs → X as EXTENSIBILTY
  - Runtime & OS: improved thread management
- **OBJ3) Leveraging Open-Source software to manage the board**
  - Compiler: BSC Mercurium
  - OS: Linux
  - Drivers: provided as open-source software by partners
- **OBJ4) Easy Interfacing with the Cyber-Physical Worlds**
  - Platform: integrating also Arduino support for a plenty of pluggable board (so-called "shields") → "IO" as I/O
  - Platform: building on the UDOO experience from SECO
- **OBJ5) Enabling real time movement of threads**
  - Runtime: will leverage the EVIDENCE's SCHED_DEADLINE scheduler (i.e. EDF) included Linux 3.14, UNISI low-level thread management techniques
- **OBJ6) Contribution to Standards**
  - Hardware: SECO is founding member of the Standardization Group for Embedded Systems (SGET)
  - Software: BSC is member of the OpenMP consortium

AXIOM – THE MODULE

- KEY ELEMENTS
  - K1: ZYNQ FPGA (INCLUDES DUAL ARM A9)
  - K2: ARM GP CORE(S)
  - K3: HIGH-SPEED & CHEAP INTERCONNECTS
  - K4: SW STACK – OMPSS+LINUX BASED
  - K5: OTHER I/F (ARDUINO, USB, ETH, WIFI, …)

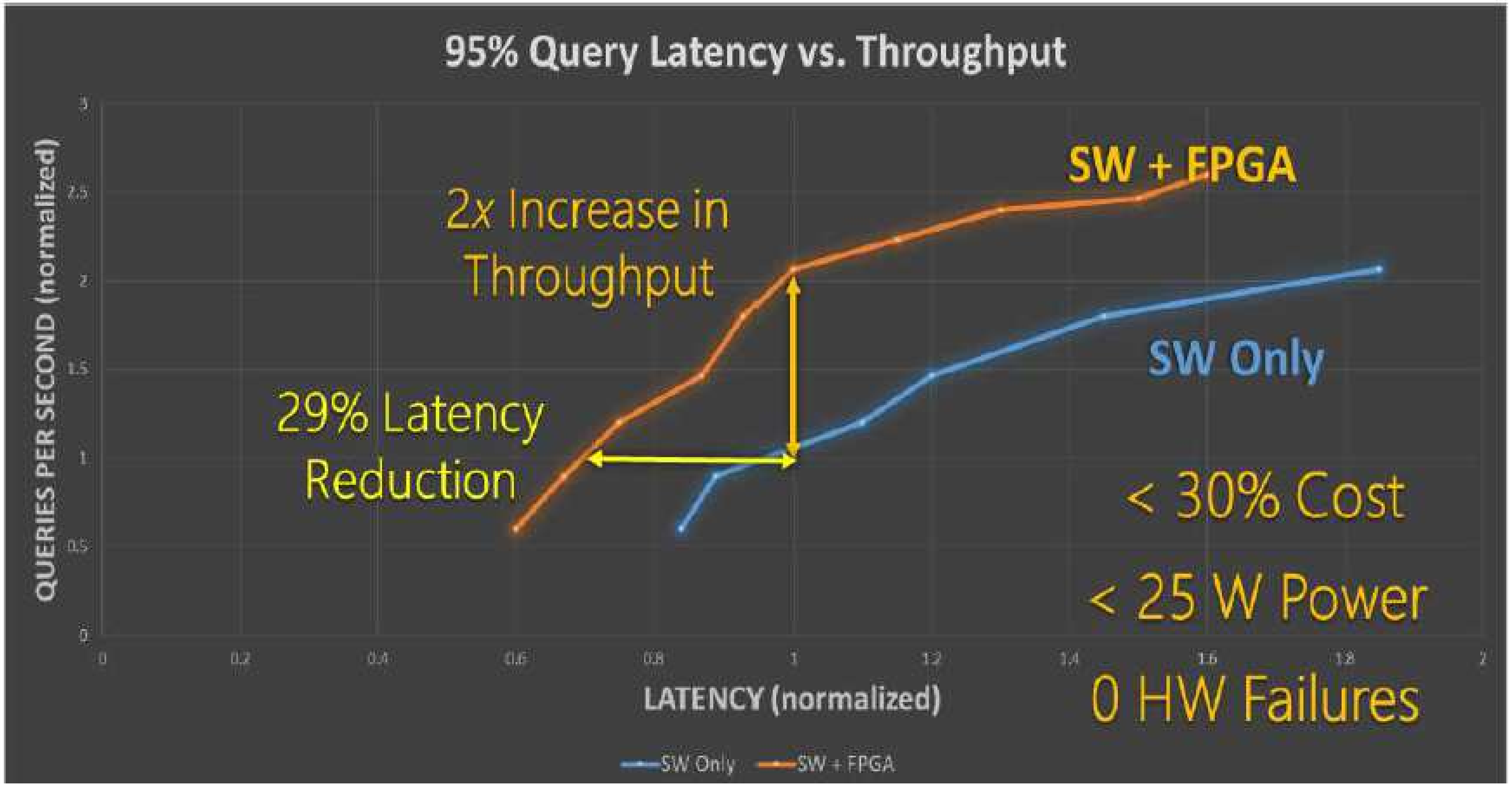
TOWARDS
HPC + EMBEDDED CONVERGENCE



SW+FPGA: is it useful?

Accelerating Large-Scale Services – Bing Search

Currently deployed in 1600+ servers in production datacenters



J. Larus, Keynote2, HiPEAC Conf. , Jan 2015

WHY OMPSS

```
#pragma omp target device(fpga, smp) copy_deps
#pragma omp task in(a[0:64*64-1], b[0:64*64-1]) \
                 out(c[0:64*64-1])
void matrix_multiply(float a[64][64],
                     float b[64][64],
                     float out[64][64]) {
    for (int ia = 0; ia < 64; ++ia)
        for (int ib = 0; ib < 64; ++ib) {
            float sum = 0;
            for (int id = 0; id < 64; ++id)
                sum += a[ia][id] * b[id][ib];
            out[ia][ib] = sum;
        }
}
...
int main( void ){
...
 matrix_multiply(A,B,C1);
 matrix_multiply(A,B,C2);
 matrix_multiply(C1,B,D);
...
 #pragma omp taskwait
}
```

Application	*Seq - DMA version*	*pthread version*	*OmpSs version*
Cholesky	71	26	3
Covariance	94	29	3
64x64	95	39	3
32x32	95	39	3

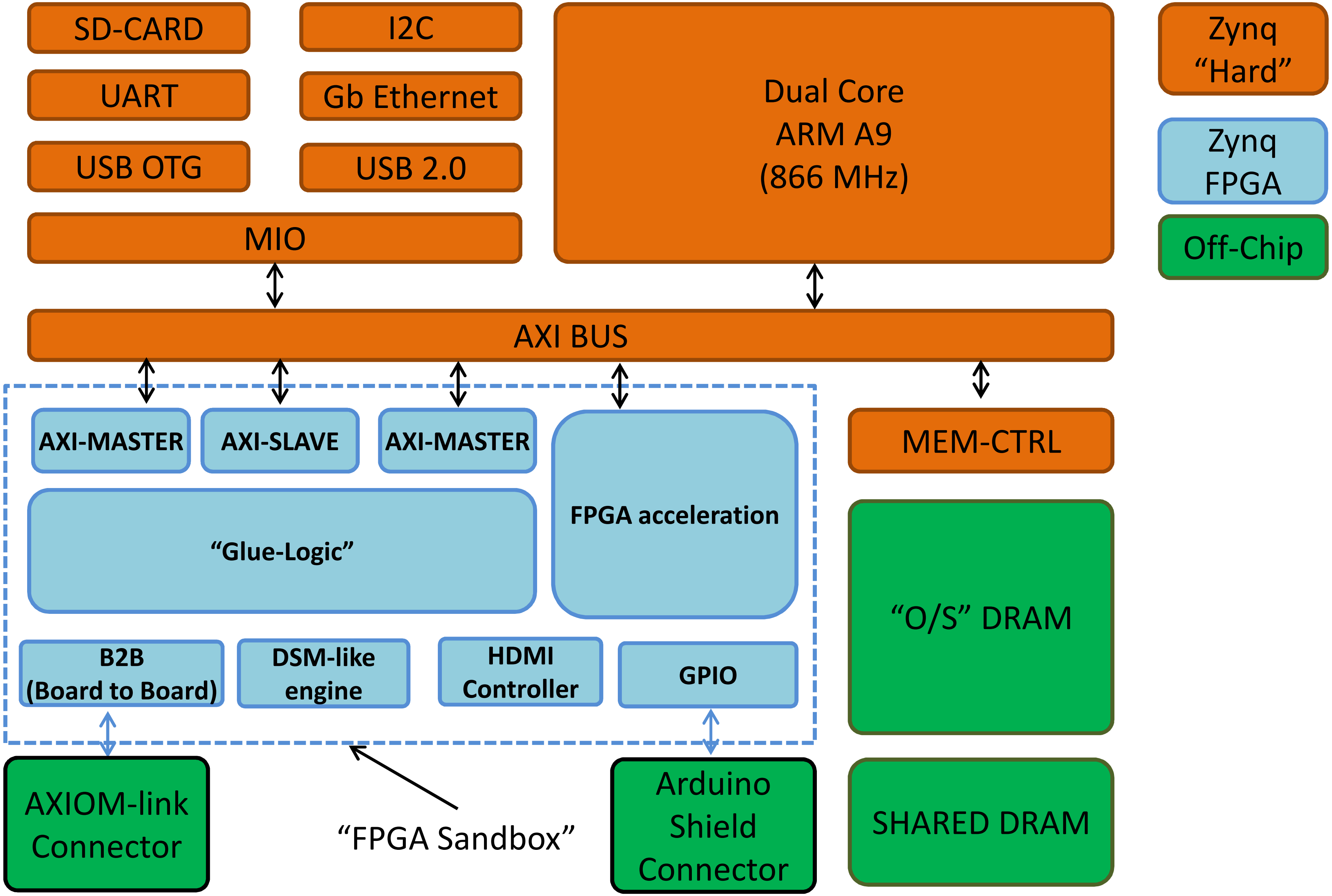
CAN WE DO THAT ?

UDOO

UDOO-NEO

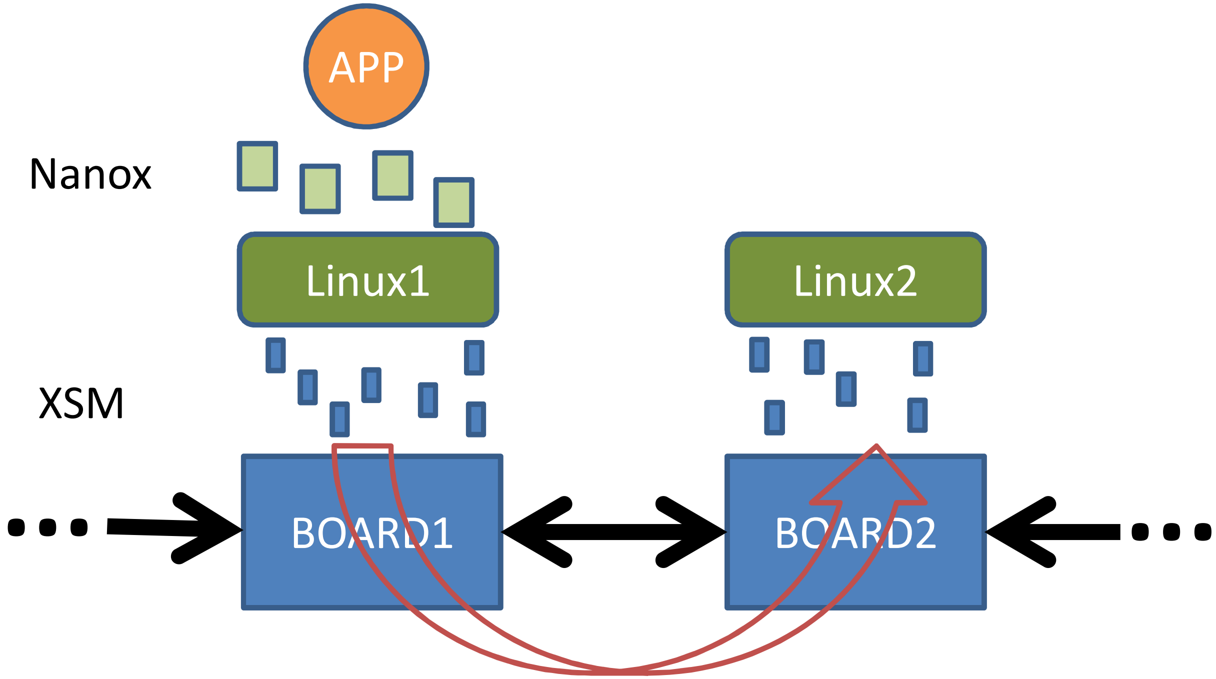
- UDOO set-up and working in less than 2 years
  - Crowd-funding raised 600,000 $ in 2 months by 4000+ backers + additional 250,000$ for the UDOO-NEO

AXIOM-v1 Architectural Template

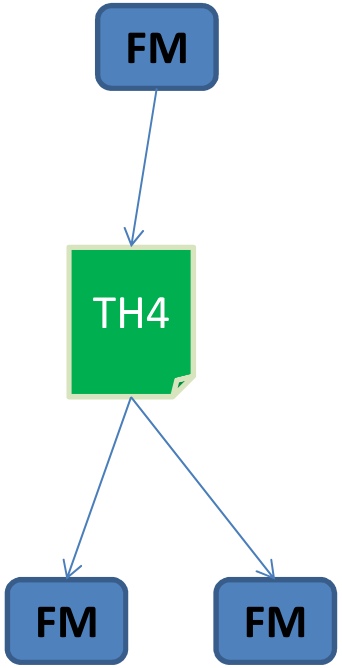


Testing Environment

- Problem to analyze



XSM Low Level

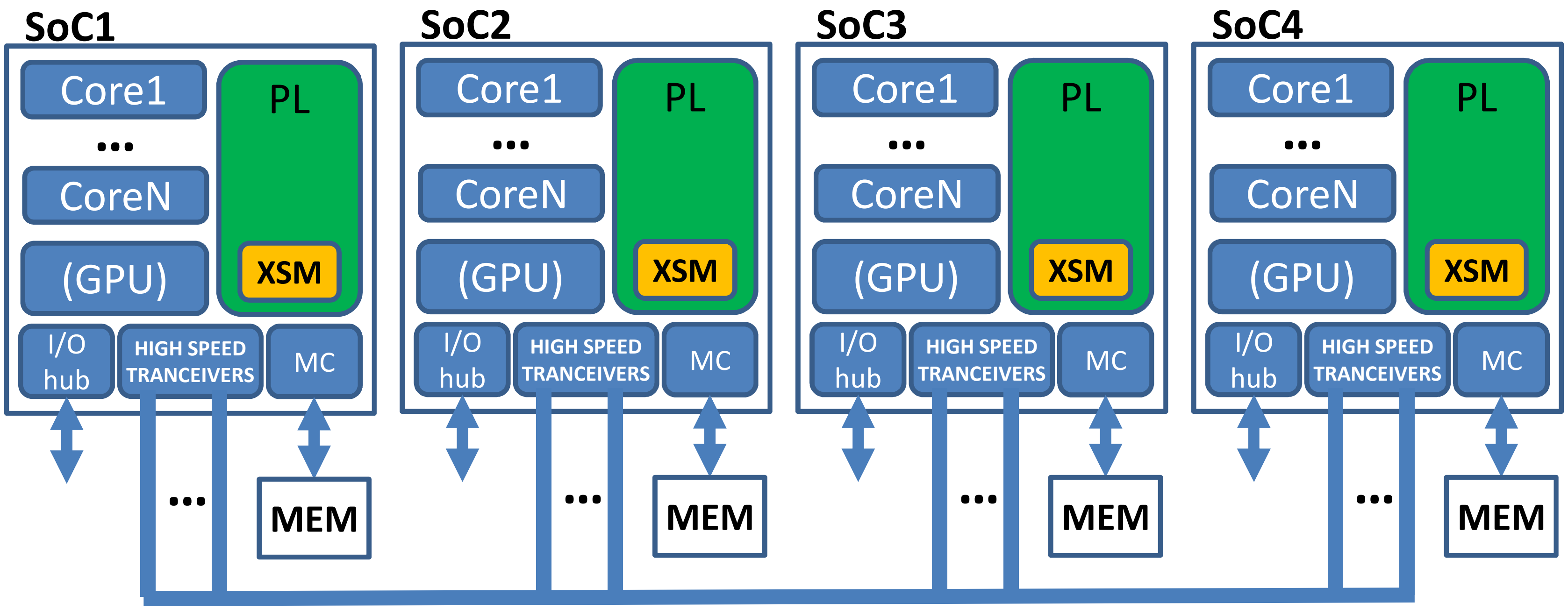


- X-thread (new incarnation of DF-thread)
  - A function that expects no parameters and returns no parameters.
    - The body of this function can refer to any memory location for which it has got the pointer through XSM function calls (e.g., xpreload, xpoststor, xsubscribe, ...). An X-thread is identified by an object of type xtid_t (X-thread identifier). In other words:

```
typedef void (*xthread_t)(void)
```

- INPUT_FRAME, OUTPUT_FRAME
  - INPUT_FRAME: A buffer which is allocated in the local memory and contains the input values for the current X-thread.
  - OUTPUT_FRAME: A buffer which is allocated in the local memory and contains values to be used by other X-threads (consumer X-threads)
- SYNCHRONIZATION_COUNT
  - A number which is initially set to the number of input values (or events) needed by an X-thread. The SYNCHRONIZATION_COUNT has to be decremented each time the expected data is written in an OUTPUT_FRAME.

4-board AXIOM System



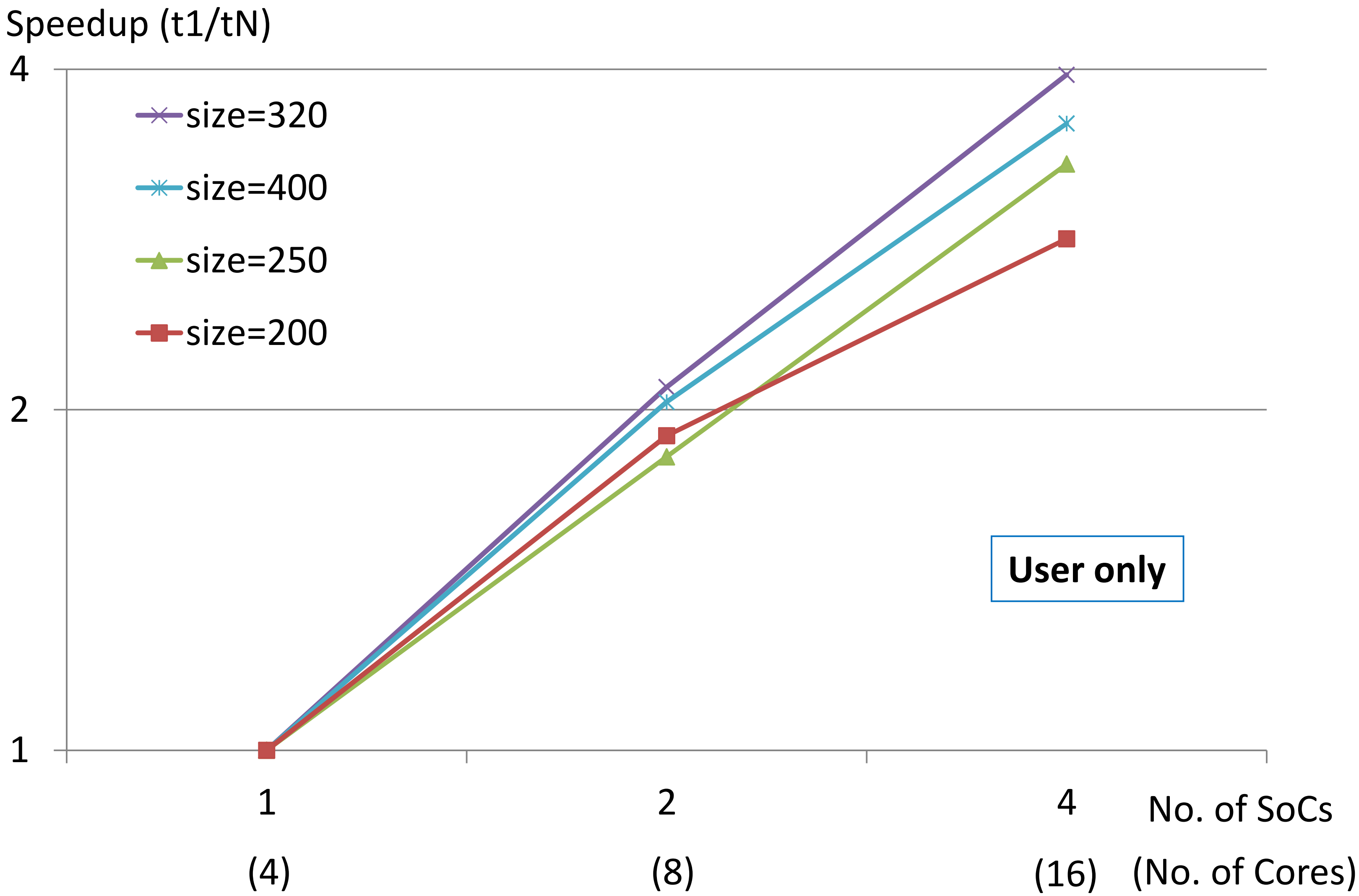
Modeled SoC

Parameter	Description
SoC	4-cores connected by a shared-bus, IO-hub, MC, high-speed transceivers
Core	1GHz, in-order superscalar
Branch Predictor	two-level (history length=14bits, pattern-history table=16kB, 8-cycle missprediction penalty)
L1 Cache	Private I-cache 32 KB, private D-cache 32 KB, 2 ways, 3-cycle latency
L2 Cache	Private 512 KB, 4 ways, 5-cycle latency
L3 Cache	Shared 4GB, 4 ways, 20-cycle latency
Coherence protocol	MOESI
Main Memory	1 GB, 100 cycles latency
I-L1-TLB, D-L1-TLB	64 entries, full-associative, 1-cycle latency
L2-TLB	512 entries, direct access, 1-cycle latency
Write/Read queues	200 Bytes each, 1-cycle latency

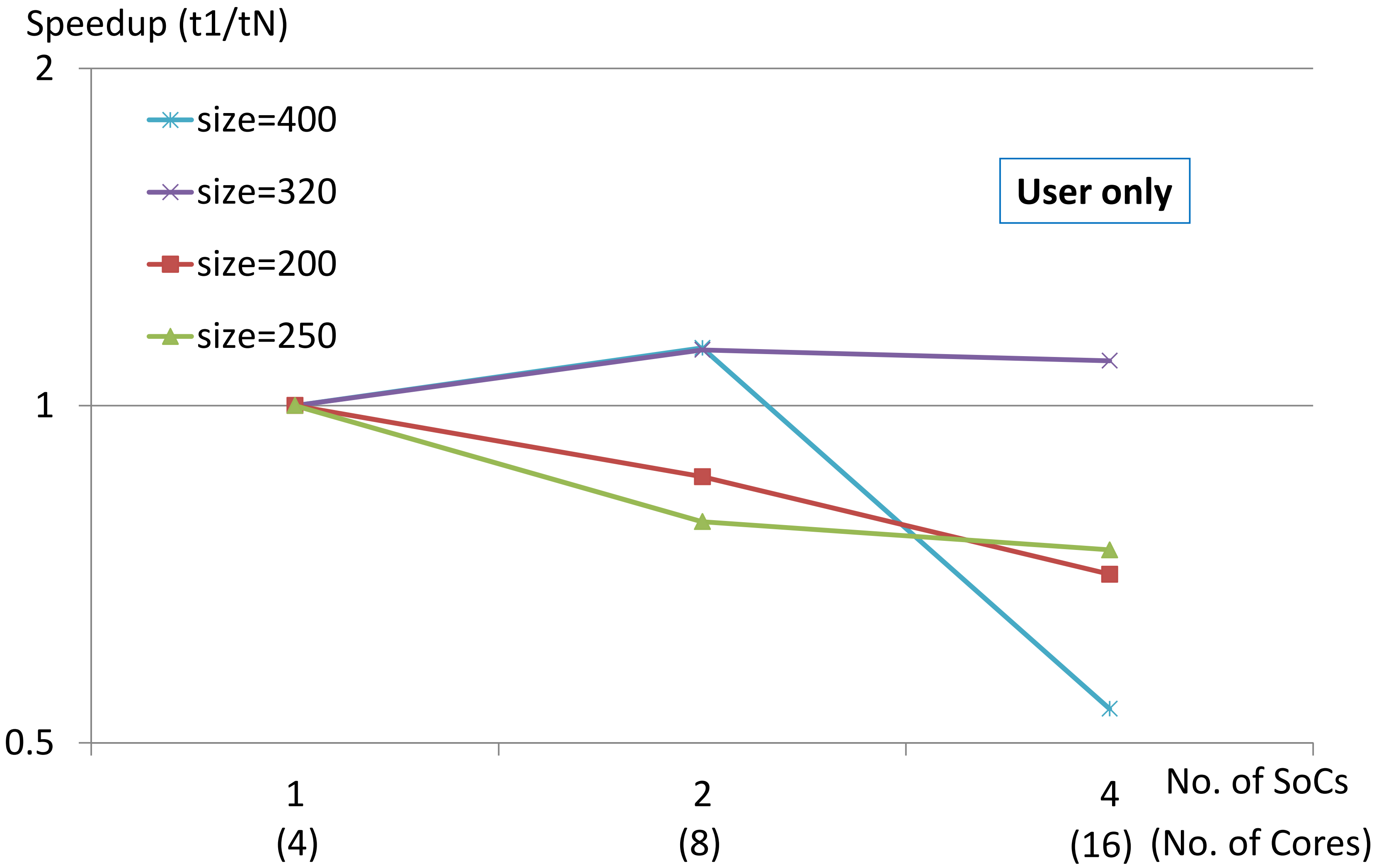
Matrix-Multiply on COTSon/XSM

- Some experiments have been performed on the COTSon/XSMLL with the following parameters
  - Square Matrix size *n*: 160,200,250,320,400,500,640,800,1000,1280,1600,2000
  - Block Size *b*: 5,10,25,50
  - XSMLL generates *n/b* X-Threads
  - Each X-thread computes a blocked matrix multiplication

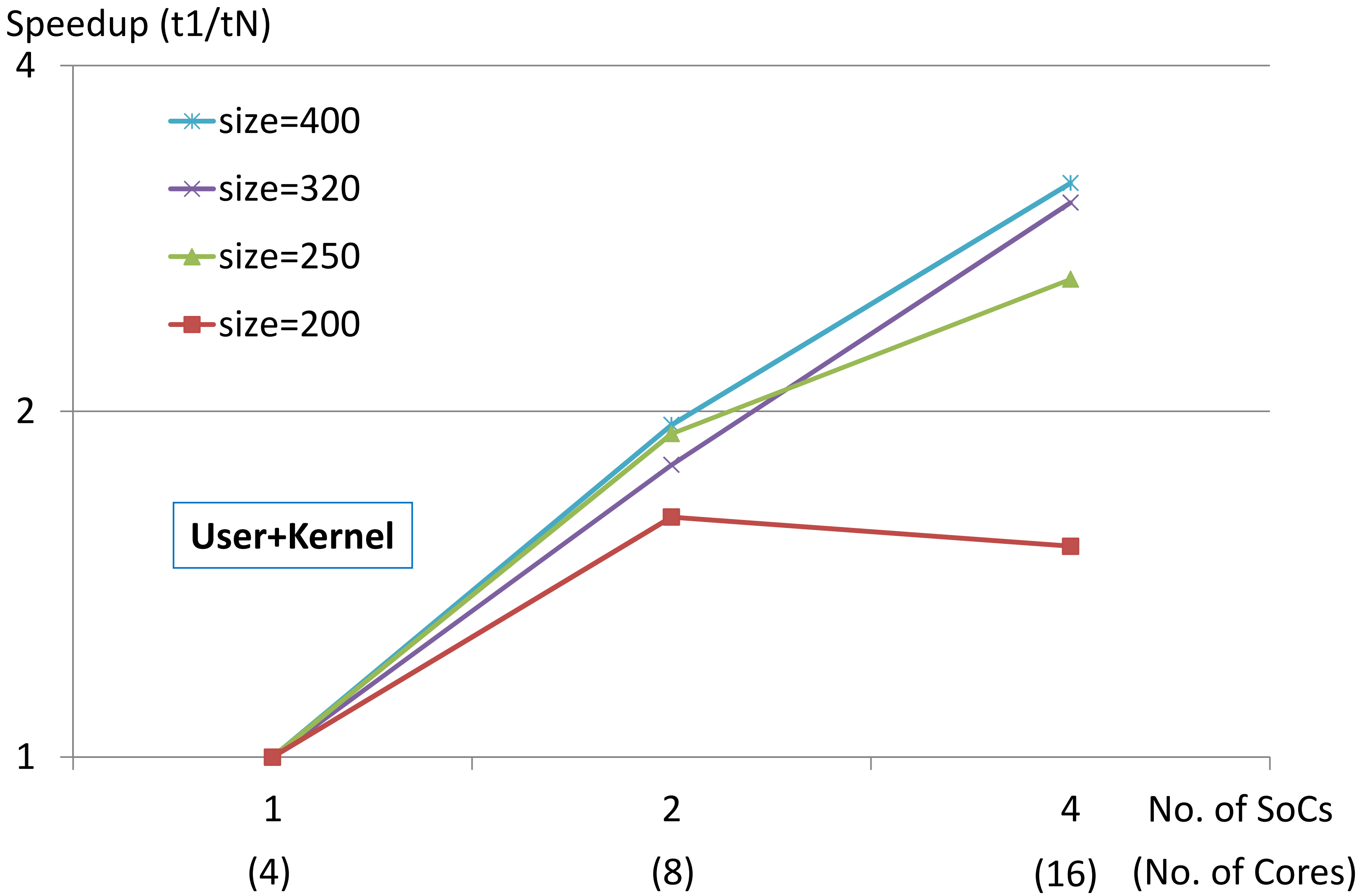
Strong Scaling for benchmark “Dense Matrix Multiplication”



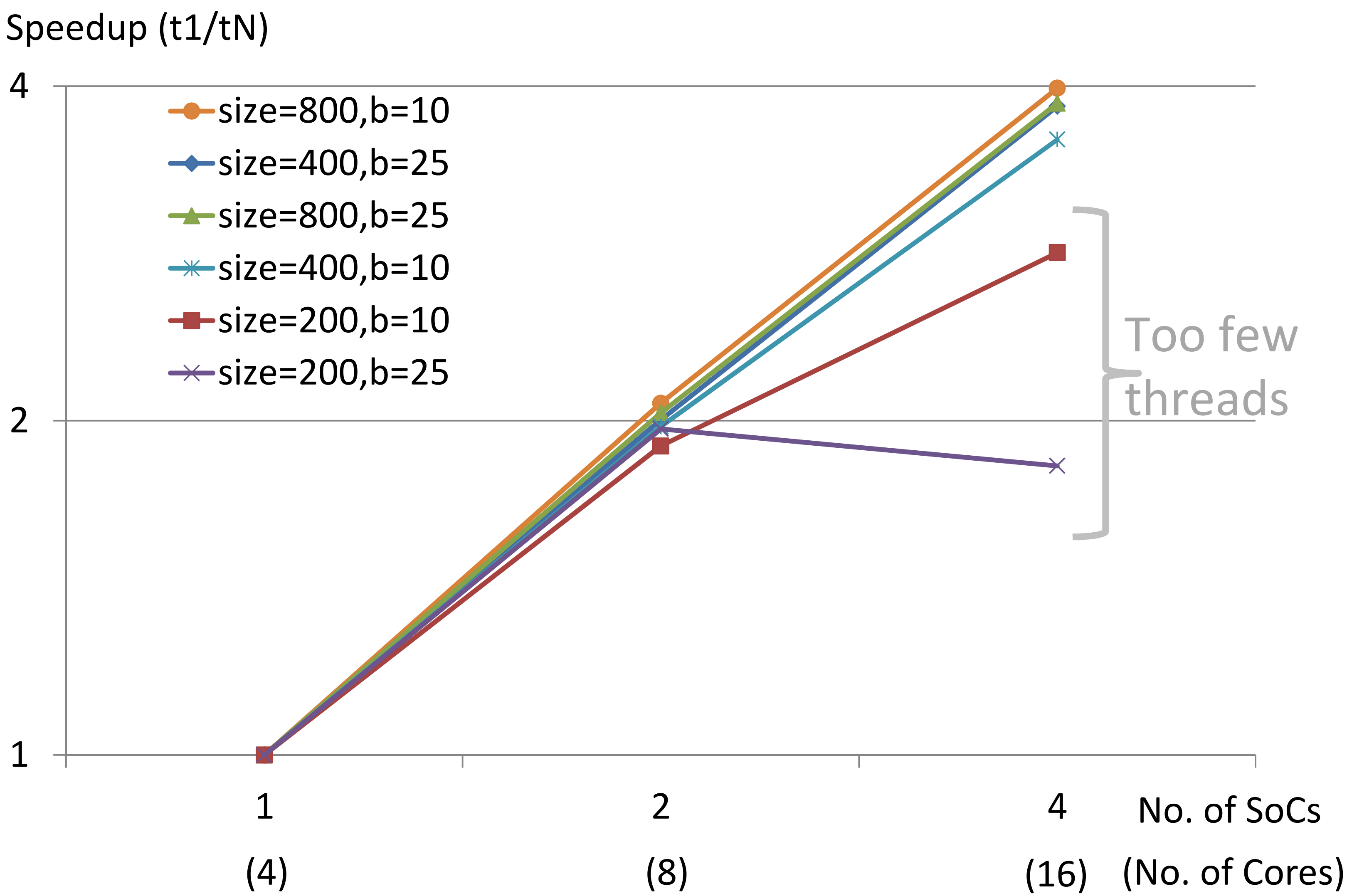
Weak Scaling for benchmark “Dense Matrix Multiplication”



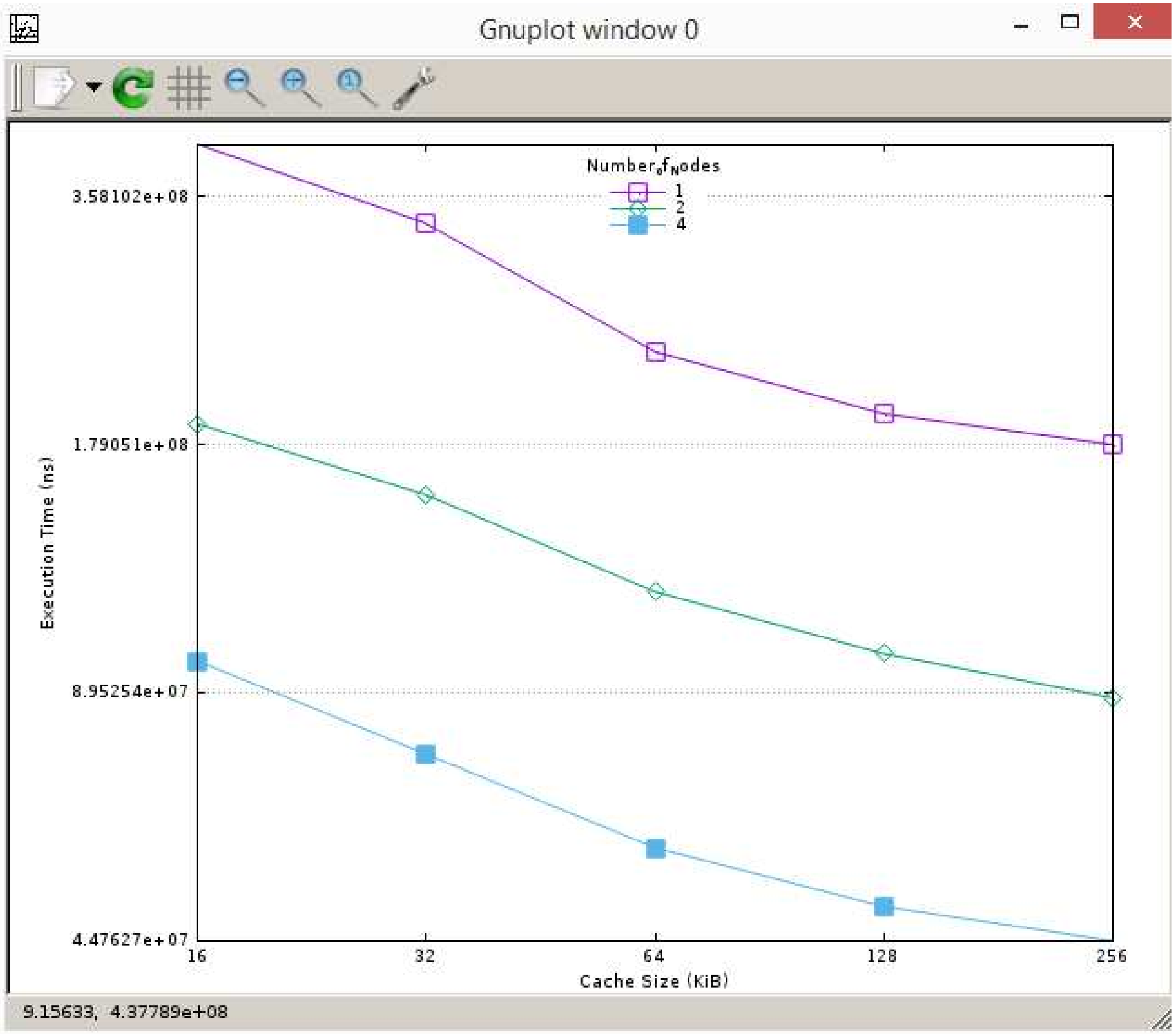
Strong Scaling for benchmark "Dense Matrix Multiplication"



Thread Granularity effects on "Dense Matrix Multiplication"



Execution time versus L2-cache size



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PROJECT ID: 645496

Roberto Giorgi –- AXIOM project --- http://www.axiom-project.eu

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