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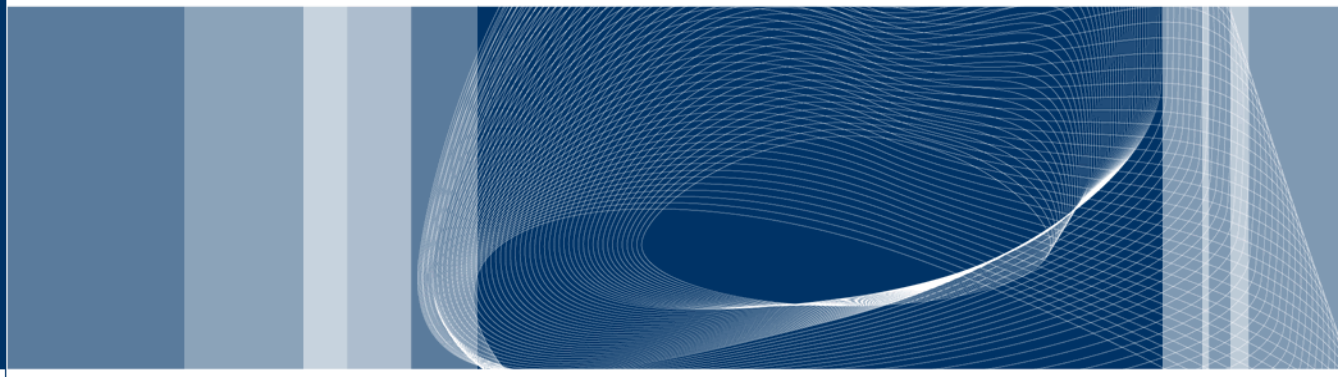

# Application Autotuning for Energy Efficient Heterogeneous HPC Systems


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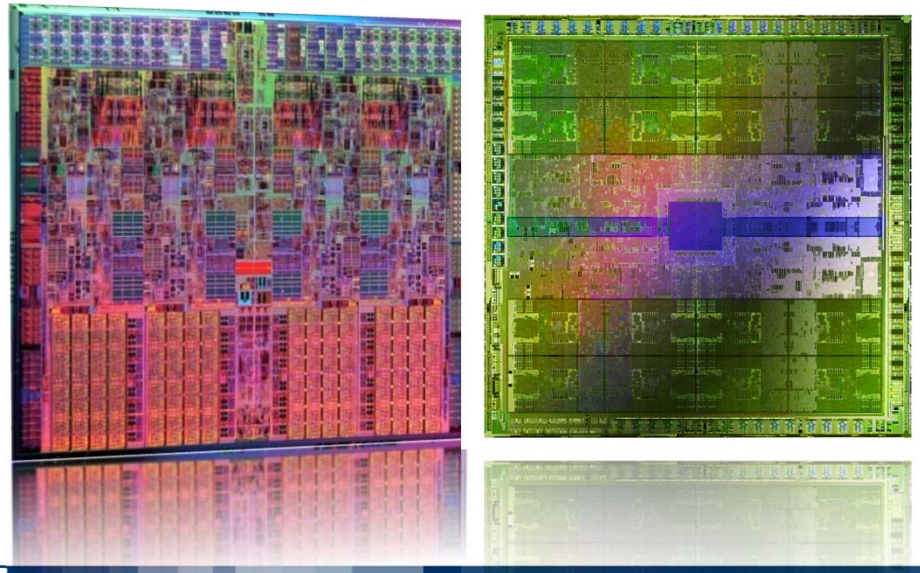
# Outline

- Research Challenges in the Exascale Era
- Application Autotuning
- ANTAREX Project
- Conclusions



# RESEARCH CHALLENGES

# Energy efficiency underlies all markets

- **Energy efficiency** is of paramount importance for all application markets (automotive, consumer, mobile, healthcare and beyond) and target systems spanning from sensors, cyber-physical systems, embedded systems up to servers and HPC systems.


iPhone 6 Plus

# World's most powerful supercomputers (June. 2017)

| Rank | Site | System | Cores | Rmax (PFlop/s) | Rpeak (PFlop/s) | Power (MW) |
|---|---|---|---|---|---|---|
| 1 | National Supercomputing Center in Wuxi, China | Sunway TaihuLight - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway , NRCPC | 10,649,600 | 93.01 | 125.44 | 15.37 |
| 2 | National Super Computer Center in Guangzhou, China | Tianhe-2 (MilkyWay-2) - TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.200GHz, TH Express-2, Intel Xeon Phi 31S1P, NUDT | 3,120,000 | 33.86 | 54.9 | 17.81 |
| 3 | Swiss National Supercomputing Centre (CSCS), Switzerland | Piz Daint - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect , NVIDIA Tesla P100, Cray Inc. | 361,760 | 19.59 | 25.33 | 2.27 |
| 4 | DOE/SC/Oak Ridge National Laboratory, US | Titan - Cray XK7, Opteron 6274 16C 2.200GHz, Cray Gemini interconnect, NVIDIA K20x, Cray Inc. | 560,640 | 17.59 | 27.11 | 8.21 |
| 5 | DOE/NNSA/LLNL, US | Sequoia - IBM BlueGene/Q, Power BQC 16C 1.60 GHz, Custom | 1,572,864 | 17.17 | 20.13 | 7.89 |

www.top500.org

# Target Scenario

- Designing and tuning applications for energy-efficient High Performance Computing systems up to the Exascale era is an extremely challenging problem.
- Exascale supercomputers (reaching billions of billions FLOP per second) cannot be built by simply expanding the number of processing nodes and leveraging technology scaling, as power demand would increase unsustainably (up to hundreds of MW).
- To reach DARPA's target of **20 MW of Exascale supercomputers** projected to the year 2020, current supercomputers (reaching up to 93 PetaFlop/s) must achieve an energy efficiency "quantum leap" to push toward **10x** energy efficiency from around **5 to 50 GFlops/W**

# Target Scenario

- **The Green500 list** looks at **GigaFlops per Watt** as energy efficiency metric to rank supercomputers by their energy efficiency.
- According to the latest Green500 list (June 2017): the “most green” supercomputer TSUBAME 3.0 installed at the Tokyo Institute of Technology achieves **14 GigaFlops/W** during its 1.9PetaFlop/s per Linpack.
- Top 4 positions in Green500 are occupied by **heterogeneous systems** equipped with Intel Xeon processors and NVIDIA’s Tesla P100 GPUs.
- Next generation green HPC heterogeneous systems will integrate the latest NVIDIA Volta GV100 GPU to further accelerating the computation.

# Target Scenario

- **Dominance of heterogeneous systems in the Green500 list** is expected to be a trend for the next coming years to reach the target of 20MW Exascale supercomputers.
- To reach the Exascale target, energy-efficient supercomputers need to be coupled with a **radically new software stack** capable of exploiting the benefits offered by heterogeneity at different levels:
  - At application level, to reduce the number of instructions per unit of computation;
  - At runtime level, to optimize the balancing and mapping of tasks and data on the heterogeneous resources;
  - At architecture level, to introduce energy-efficient and acceleration solutions exploiting heterogeneity and reconfigurability.

# My Research Challenges

- Autotuning of HPC applications with respect to changing workloads, operating conditions and computing resources
- Providing programming models and domain specific languages to express self-adaptivity strategies and extra-functional requirements
- Monitoring the evolution of HPC platforms and exploiting heterogeneous computing by runtime resource and power management

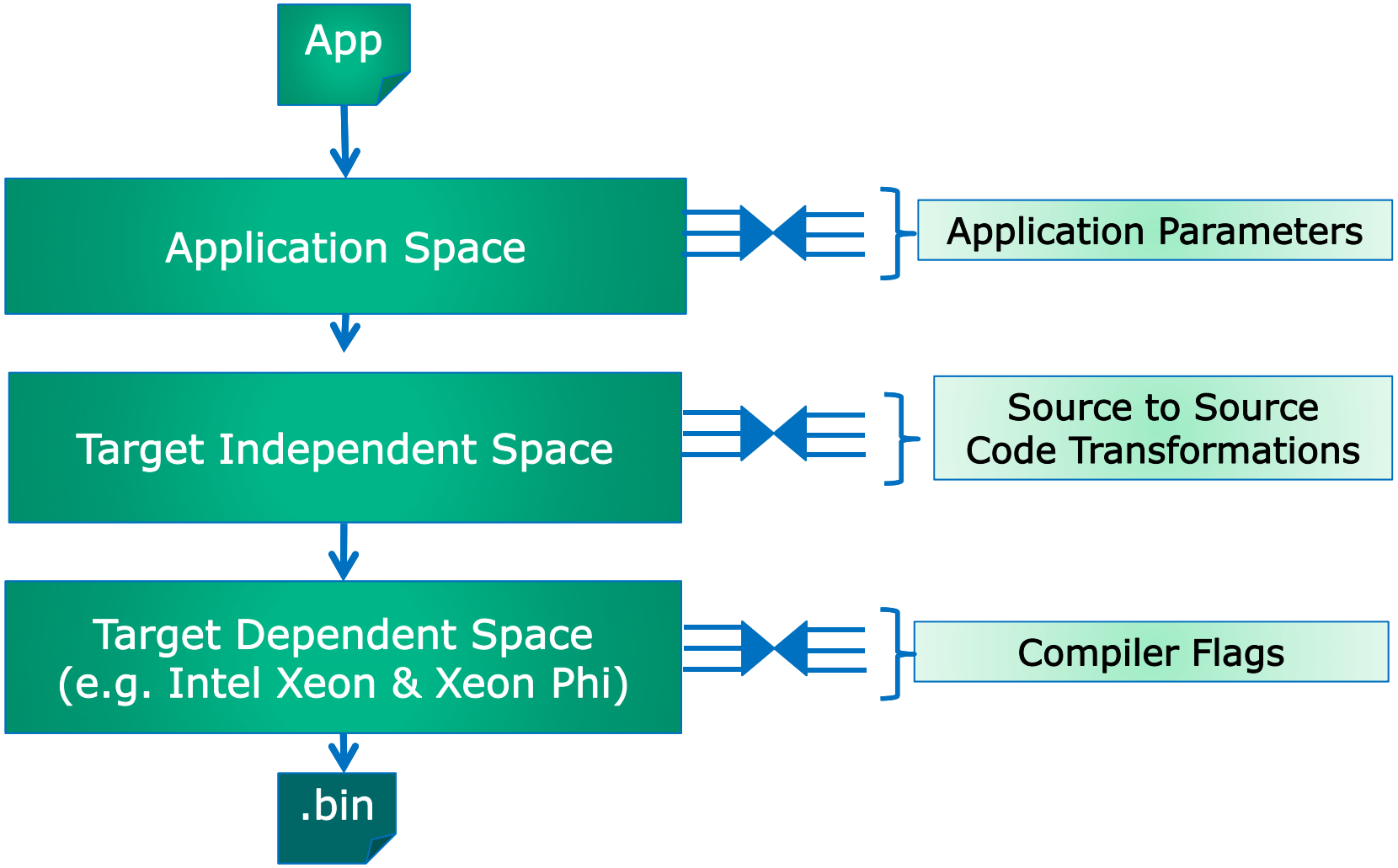
# Tunable Applications

- One or more application parameters, code transformations and code variants (***application knobs***) can be tuned at runtime
  - Adaptivity to adjust the application behavior to the changing operating conditions, usage contexts and resource availability


# Tunable Applications

- One or more application parameters, code transformations and code variants (***application knobs***) can be tuned at runtime
  - Adaptivity to adjust the application behavior to the changing operating conditions, usage contexts and resource availability
  - Approximate computing: output just needs to be *"good enough"* trading off accuracy/ throughput/energy


# Tunable Applications: Software Knobs



# AUTOMATIC DESIGN SPACE EXPLORATION

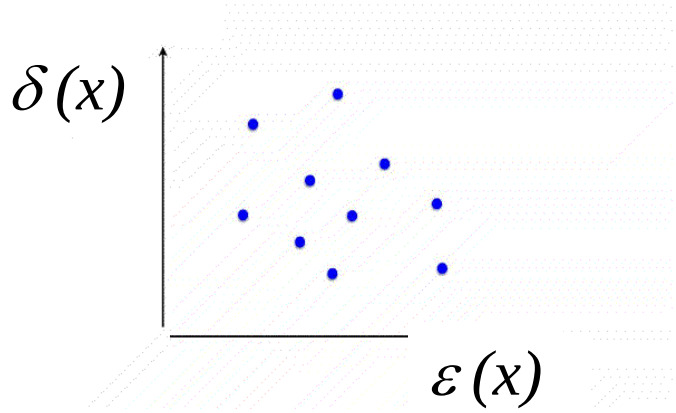
# The multi-objective optimisation problem

- **Objective function:** To minimize both energy $\varepsilon(x)$ and execution time $\delta(x)$ of the target application on system configurations *x:*

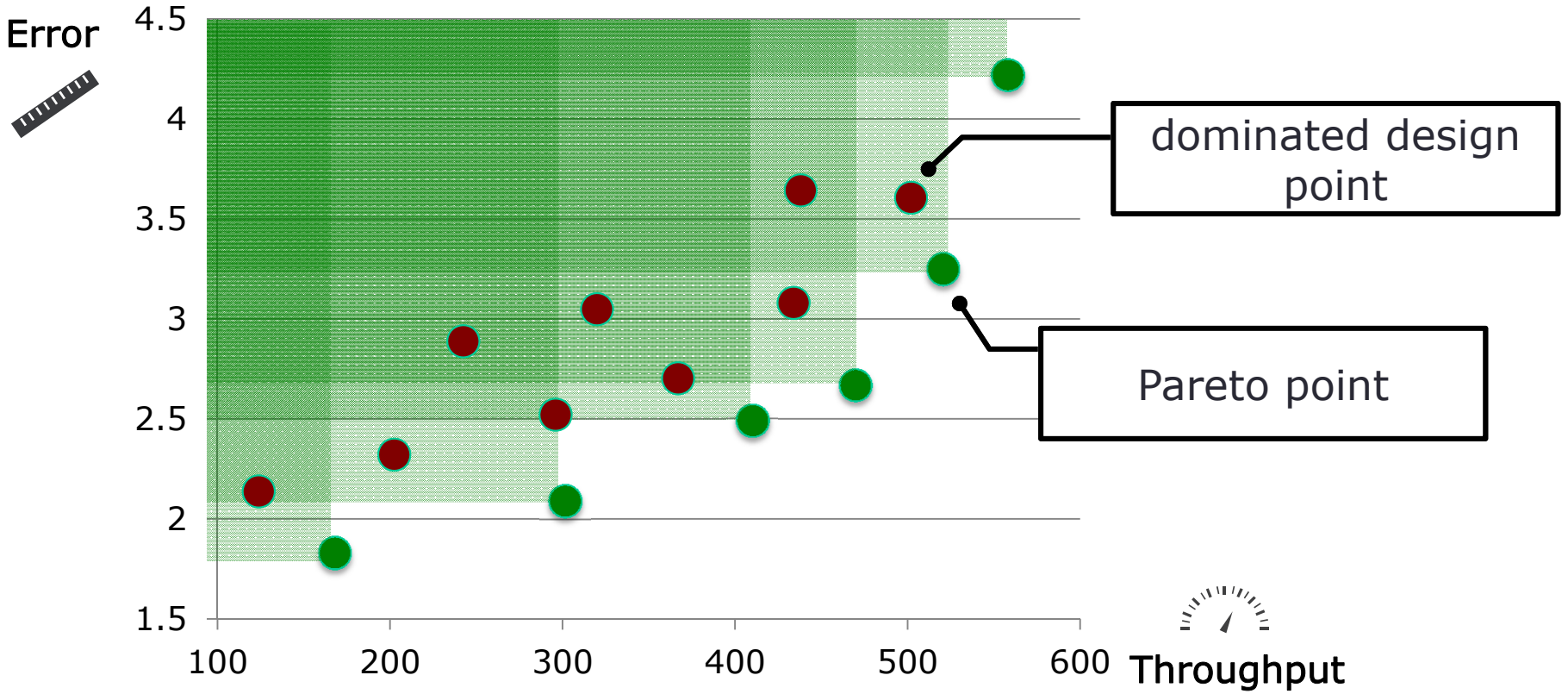
$$\min_{x \in X} \omega(x),\ \omega(x) = \begin{bmatrix} \epsilon(x) \\ \delta(x) \end{bmatrix}$$

where $X$ is the design space.

- The solution is a set of tradeoff configurations $X_p \subseteq X$ known as Pareto set



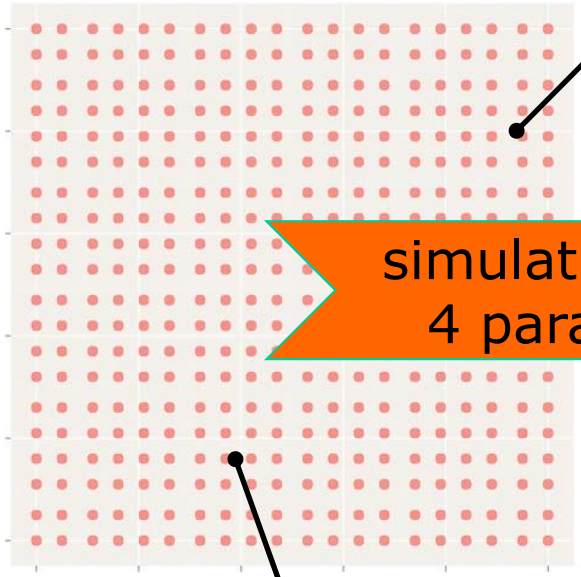
# Multi-objective exploration: Pareto Points




Multi-Objective Exploration: **best designs are not unique**.
**Pareto points** provide tradeoffs with respect to the multiple objectives

# Full search simulation time

FULL SEARCH
Can become quickly unfeasible



~10 minutes
per simulation*

simulation time on
4 parallel cores

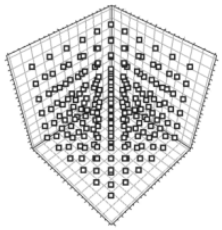
10 Years

262 144 design points
x
8 data sets
=
2 097 152 simulations

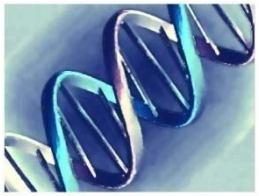
* Using a cycle-accurate simulator

# MULTICUBE Explorer

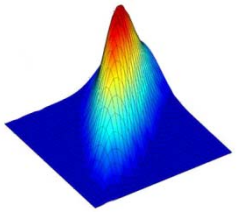
1. **Design of Experiments (DoEs):**
   To identify the experimentation plan: how to select the design points in the design space to be simulated: random, full factorial, central composite design.



2. **Optimisation Algorithms:**
   Meta-heuristics methods inspired by analogies with physics, or with biology to solve multi-objective optimization problems: simulated annealing, genetic algorithms, evolutionary strategies, etc.

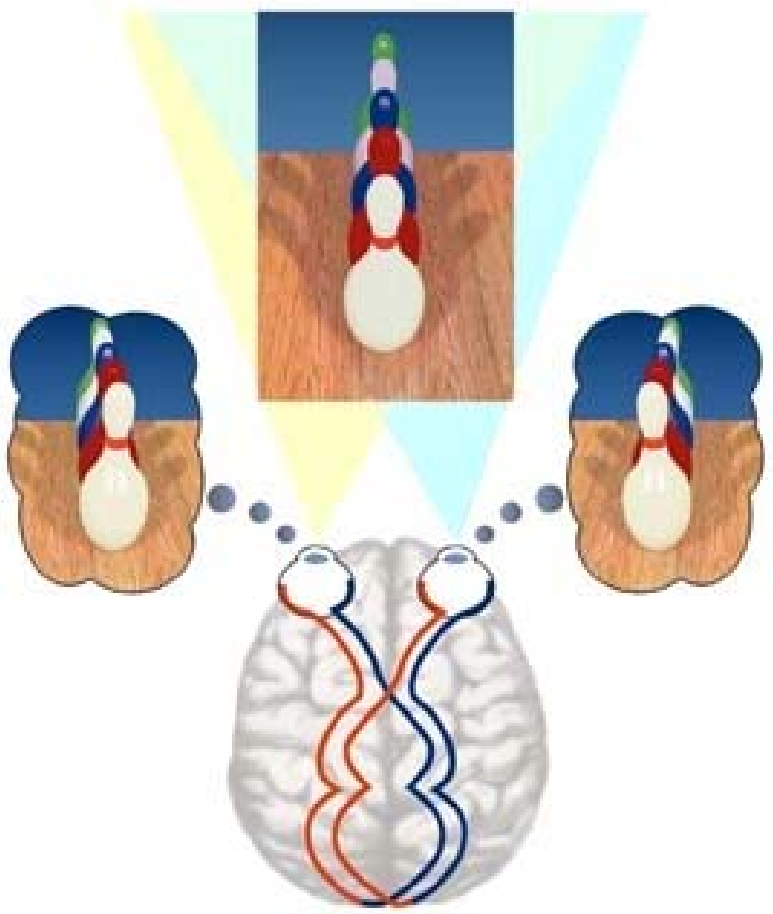


3. **Response Surface Modeling (RSM):**
   To use the set of simulated points to obtain an analytical model of the system behavior: linear regression, spline interpolation, artificial neural network, etc.



# Design-time optimization of OpenCL applications

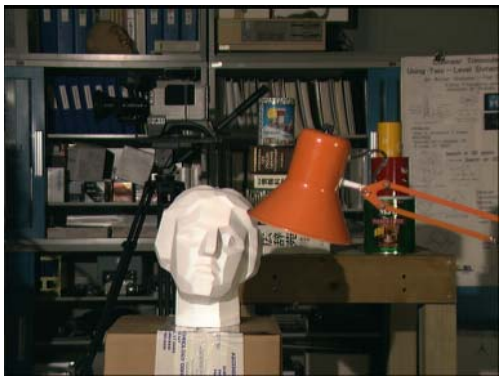
**The Multi-View Case Study:**
**The human eye stereo matching**



2 eyes → third dimension

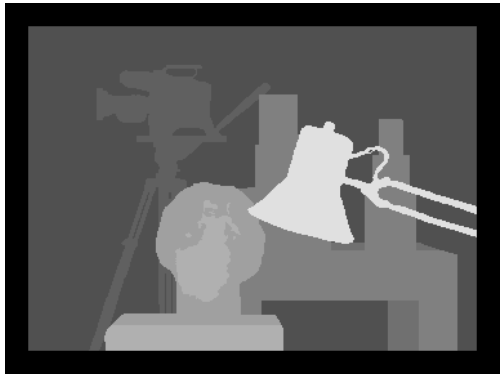
# Quality of Results: Pixel Disparity Error

Left camera



Right camera

stereo-matching



Reference disparity map

Application Knobs

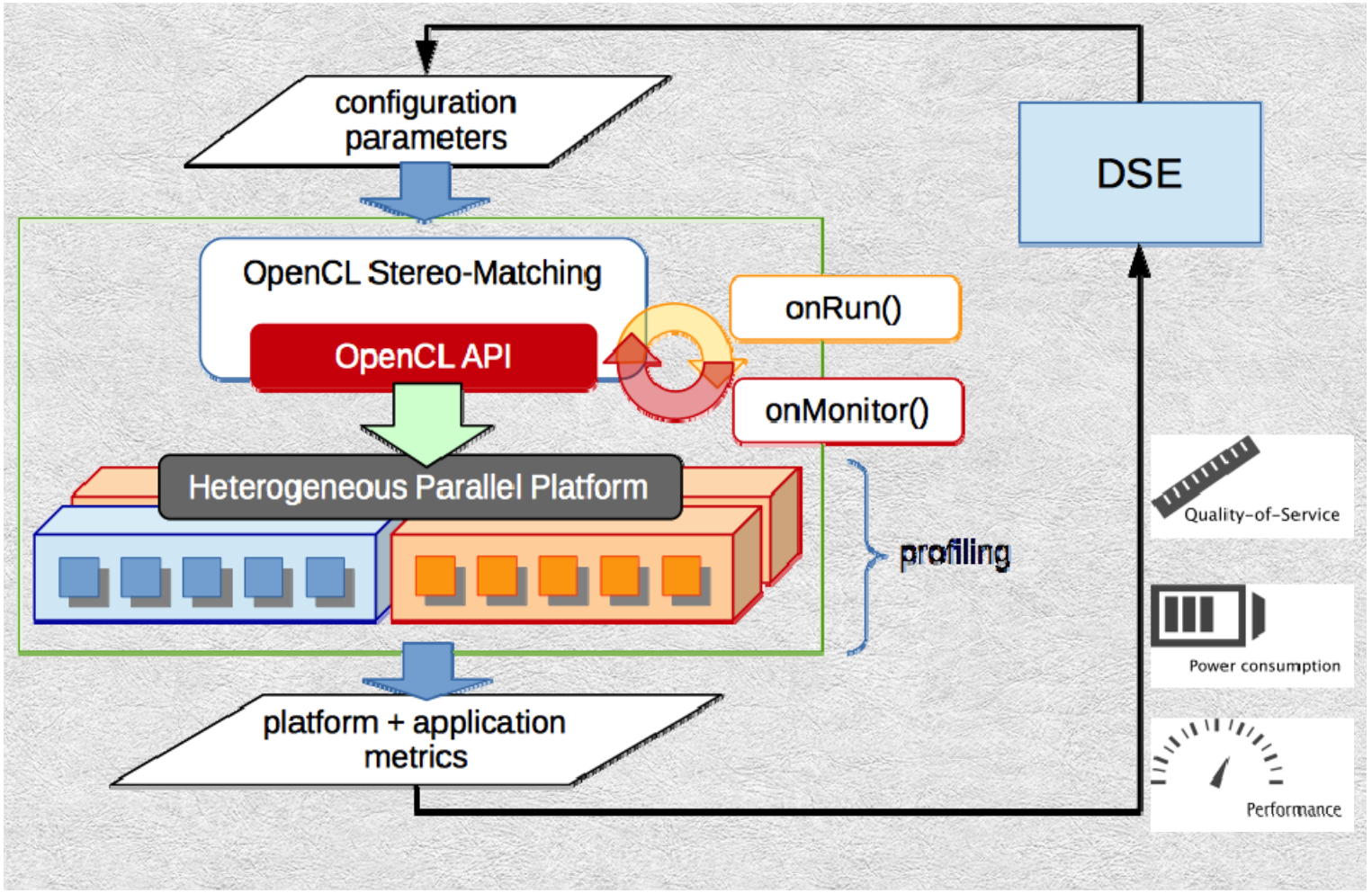
Disparity Error

1

2

3

# Design-time optimization of OpenCL applications



# Design-time optimization of OpenCL applications

- Parametric implementation:
  - Customization of application parameters and platform parameters
- Full search can become quickly unfeasible due to huge multi-dimensional design space

E. Paone, G. Palermo, V. Zaccaria, C. Silvano, D. Melpignano, G. Haugou and T. Lepley, "An Exploration Methodology for a Customizable OpenCL Stereo-Matching Application Targeted to an Industrial Multi-Cluster Architecture", in Proc. CODES+ISSS 2012.

E. Paone, F. Robino, G. Palermo, V. Zaccaria, I. Sander and C. Silvano, *"Customization of OpenCL Applications for Efficient Task Mapping under Heterogeneous Platform Constraints",* In Proceedings of DATE 2015.

# Design-time optimization of OpenCL applications

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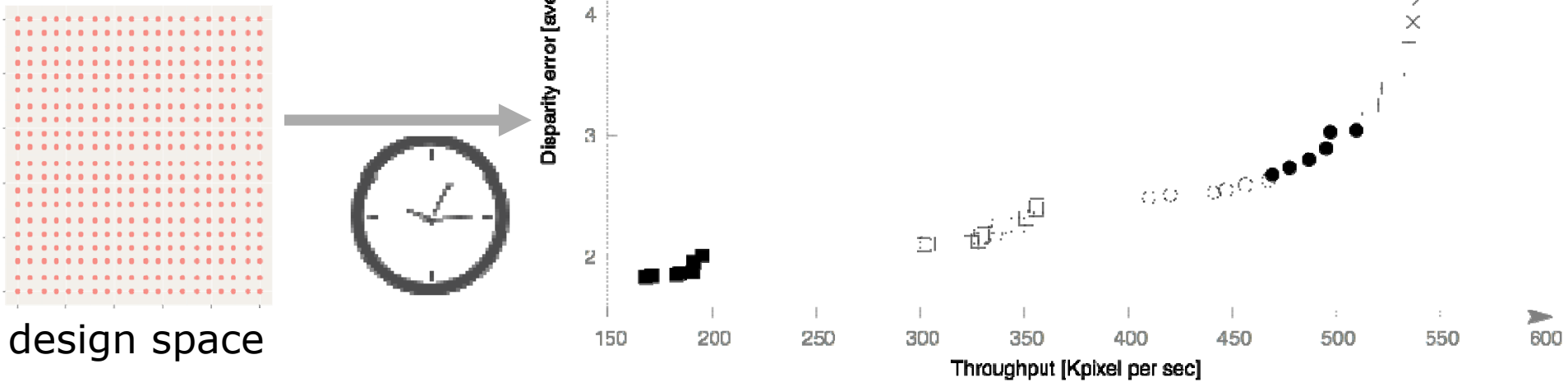

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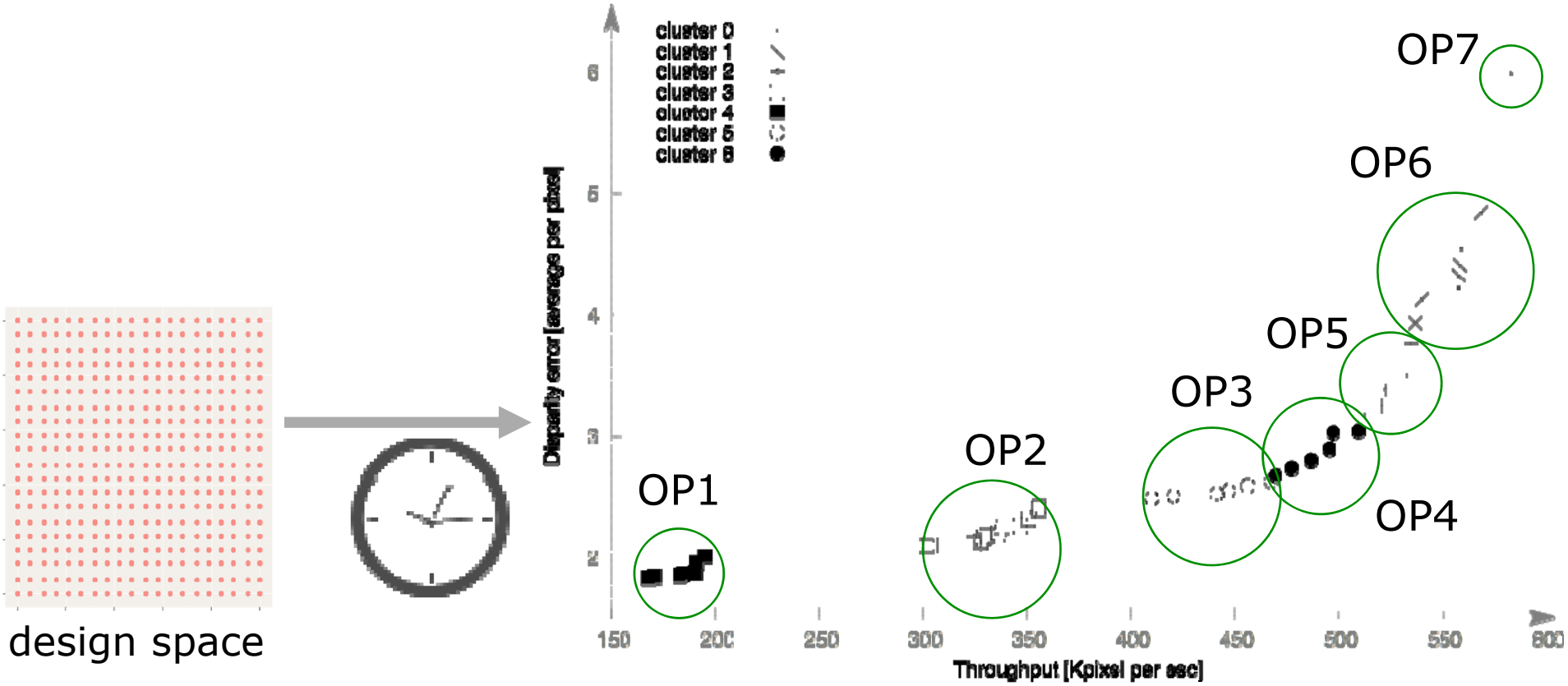
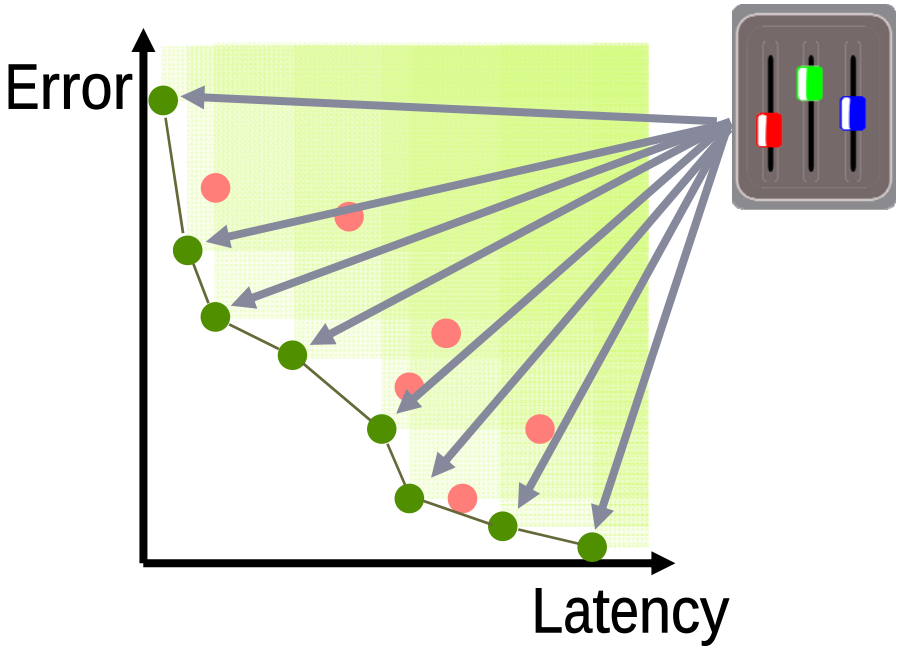


# APPLICATION AUTOTUNING

# mARGOt Application Autotuning

- **Key idea** is that most of the applications are dynamically configurable in terms of a set of tunable parameters, code transformations and code variants **(application knobs)** to trade-off accuracy and latency

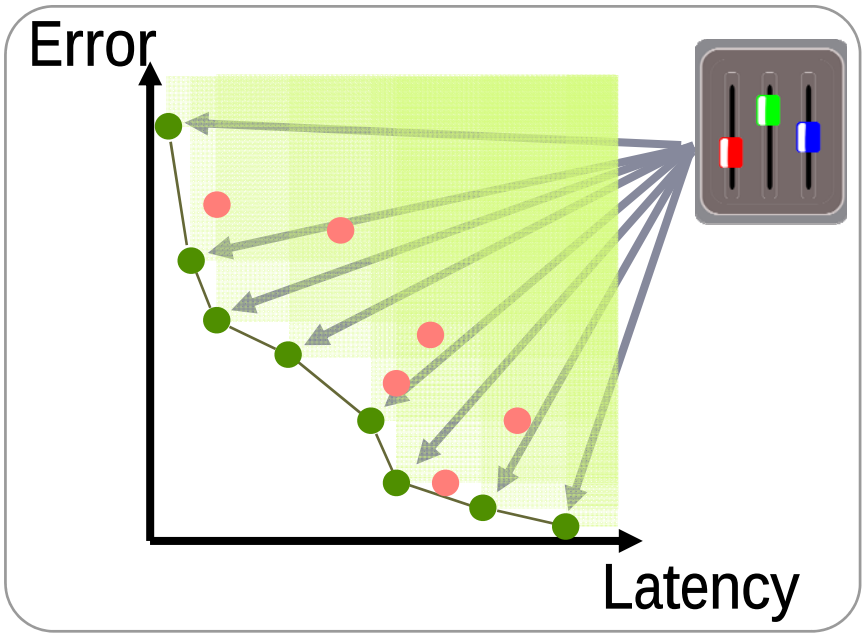


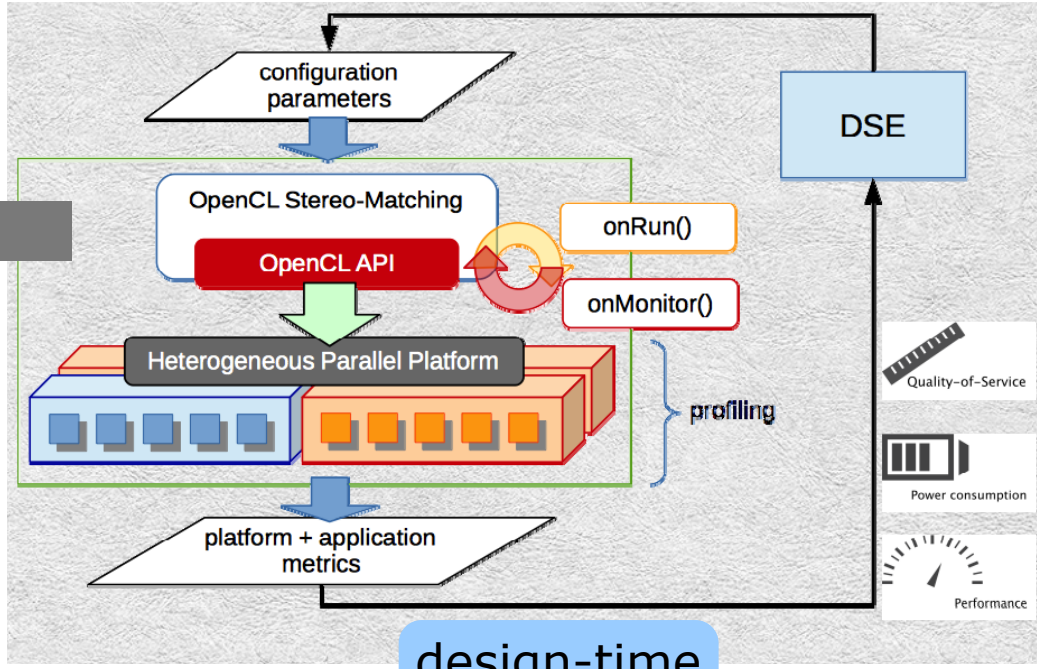
# mARGOt Application Autotuning

- **mARGOt** is a **light-weight application autotuning framework** for manycore platforms in an adaptive multi-application environment.
  - Combination of **design-time** and **run-time** techniques to create an effective way of *"self-aware"* computing with **limited runtime overhead**.
  - **Orthogonality** between application autotuning and runtime management of system resources

E. Paone, D. Gadioli, G. Palermo, V. Zaccaria, C. Silvano. "Evaluating Orthogonality between Application Auto-Tuning and Run-Time Resource Management for Adaptive OpenCL Applications", Proc. of IEEE ASAP 2014.

D. Gadioli, G. Palermo, C. Silvano, "Application Autotuning to Support Runtime Adaptivity in Multicore Architectures", in Proc. IEEE SAMOS 2015.



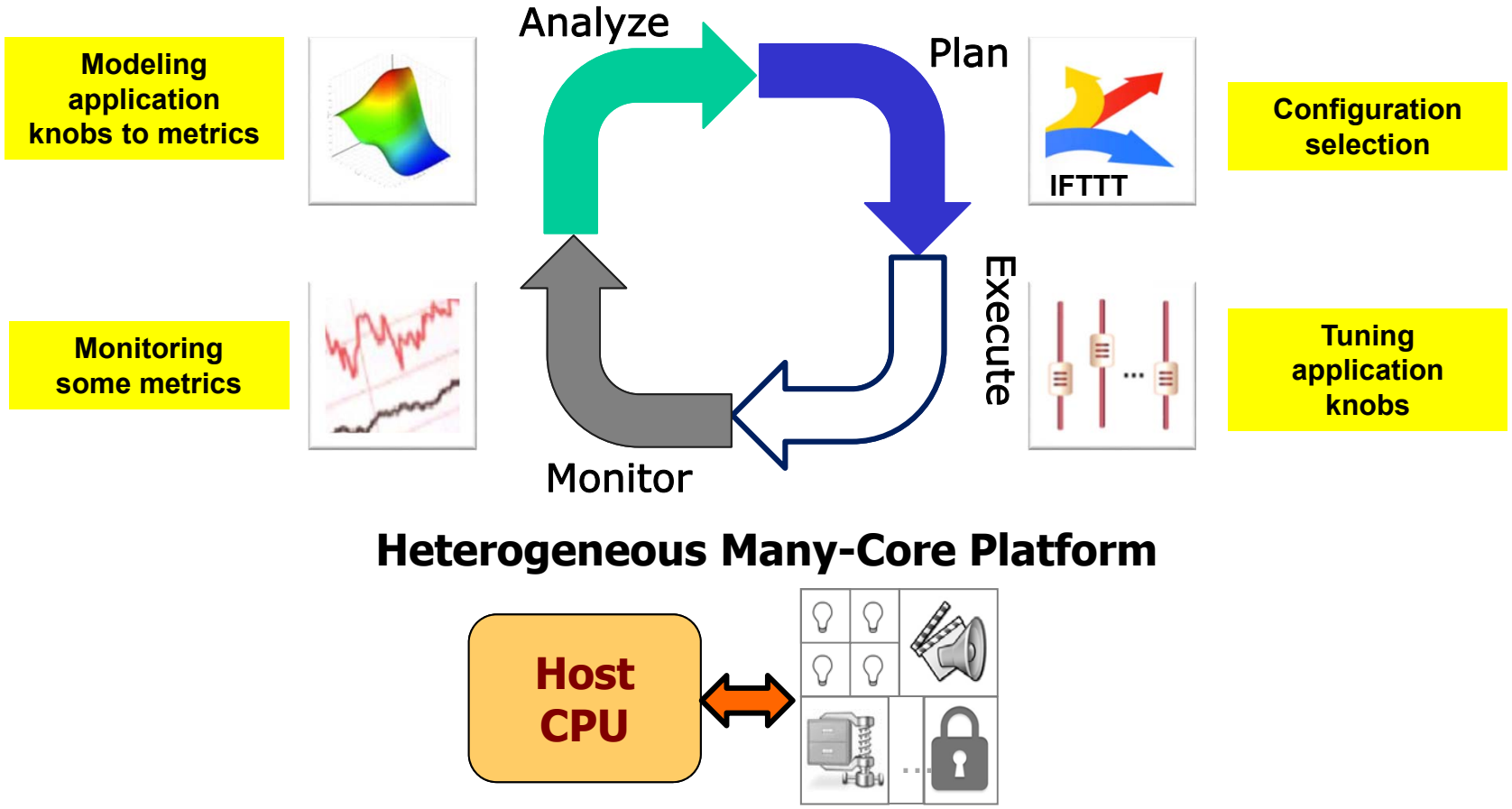




design-time

run-time

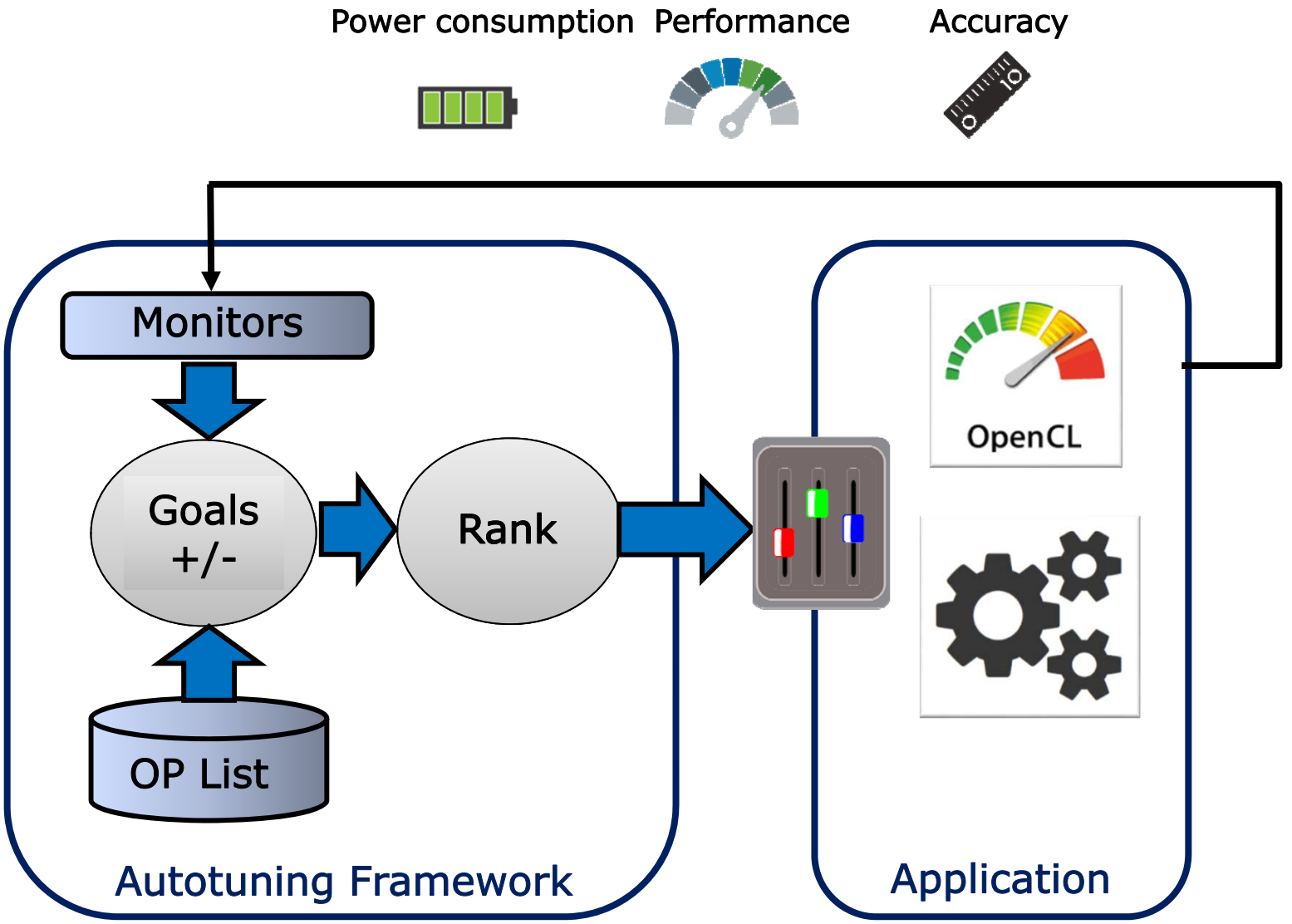
# Runtime feedback loop

- **Application autotuning** enables self-optimization capabilities based on **Monitor-Analyze-Plan-Execute (MAPE) feedback loop***

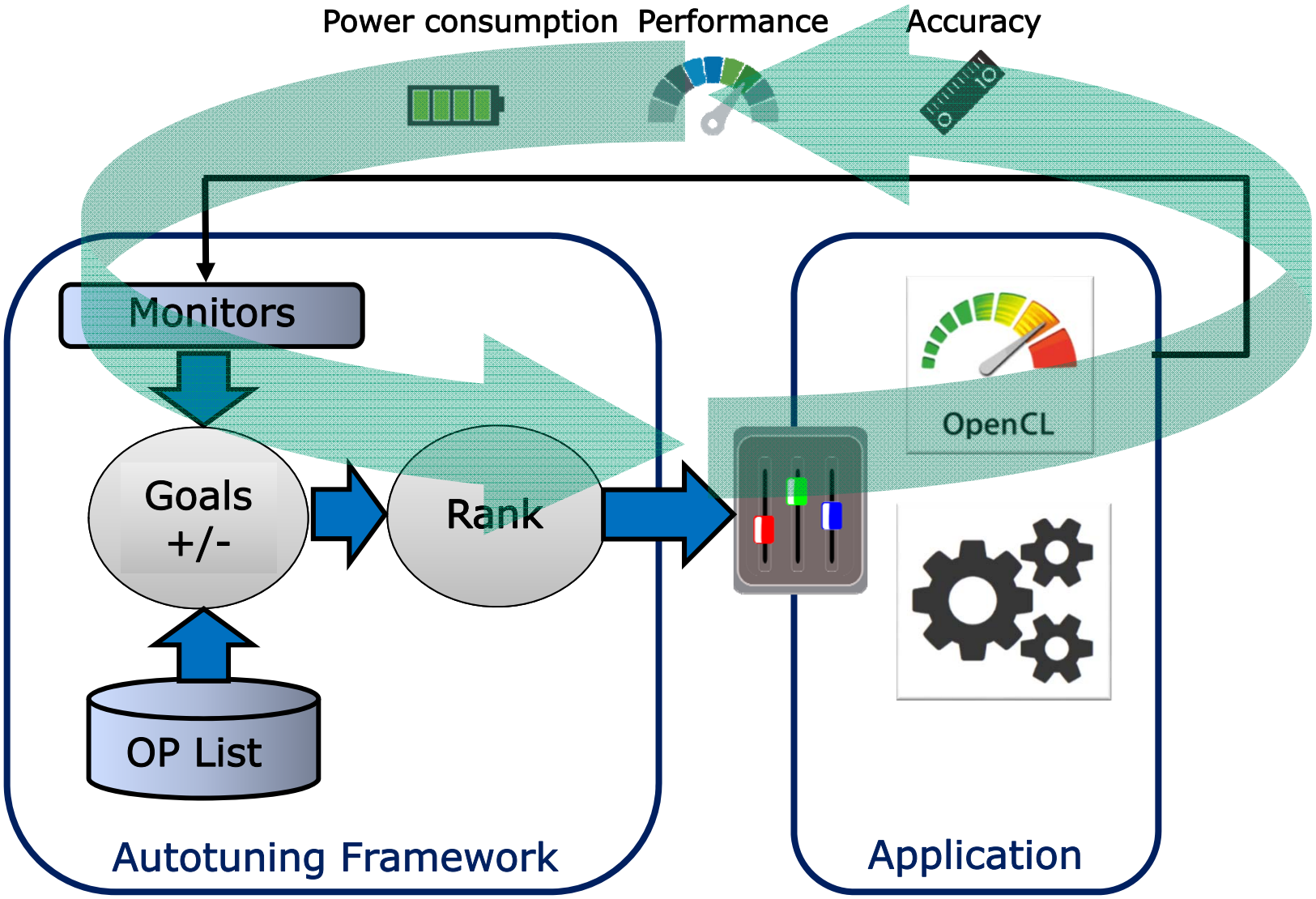



* J.O. Kephart, D.M. Chess, "The vision of autonomic computing," Computer, 2003

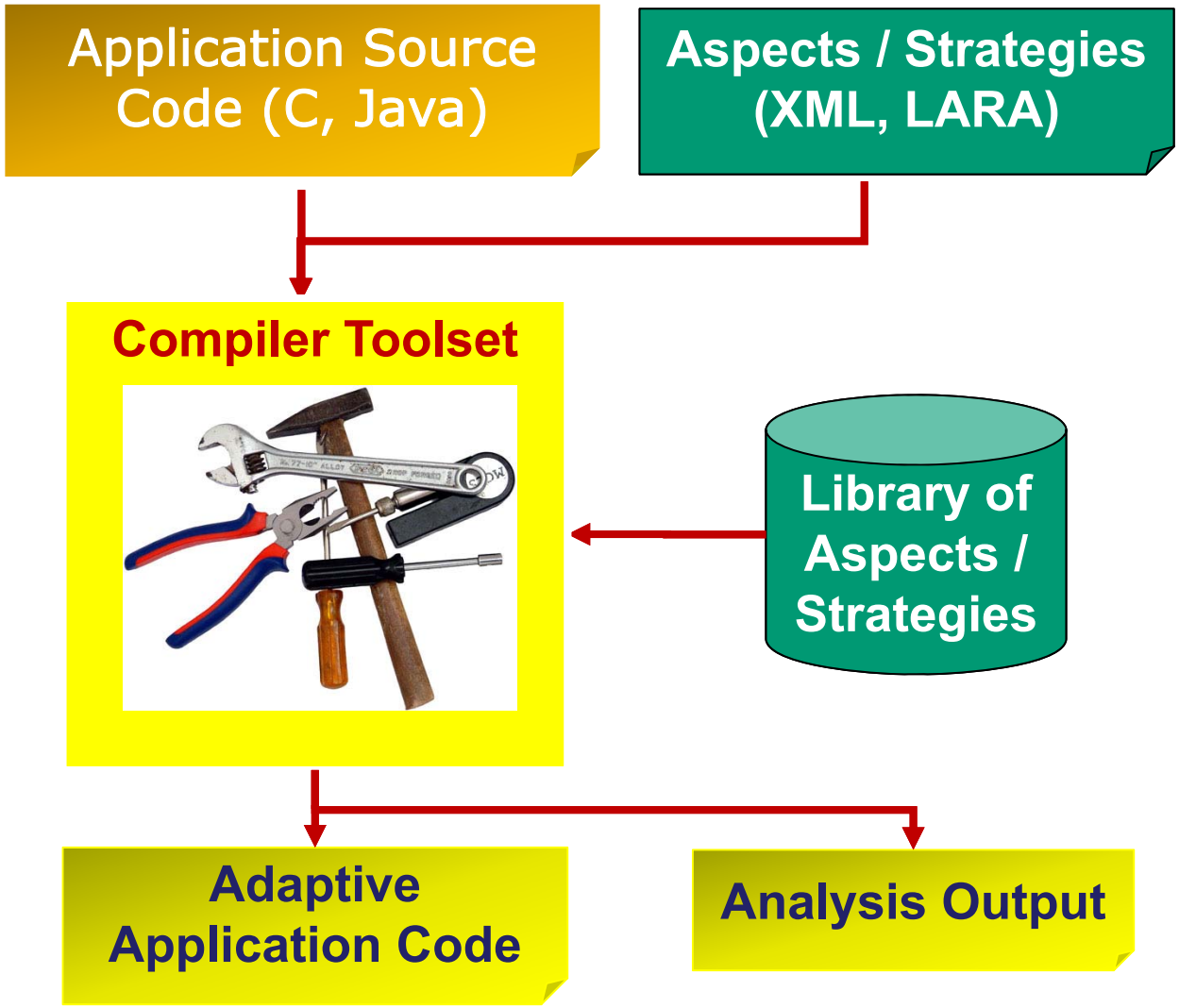
# mARGOt Application Autotuning



# mARGOt Application Autotuning



# Separation of Concerns




J. M.P. Cardoso, T. Carvalho, J. G. de F. Coutinho, W. Luk, R. Nobre, P. C. Diniz, Z. Petrov, "**LARA: An Aspect-Oriented Programming Language for Embedded Systems,**" in *Int'l Conf. on Aspect-Oriented Software Development (AOSD'12)*, Potsdam, Germany, March 25-30, 2012.

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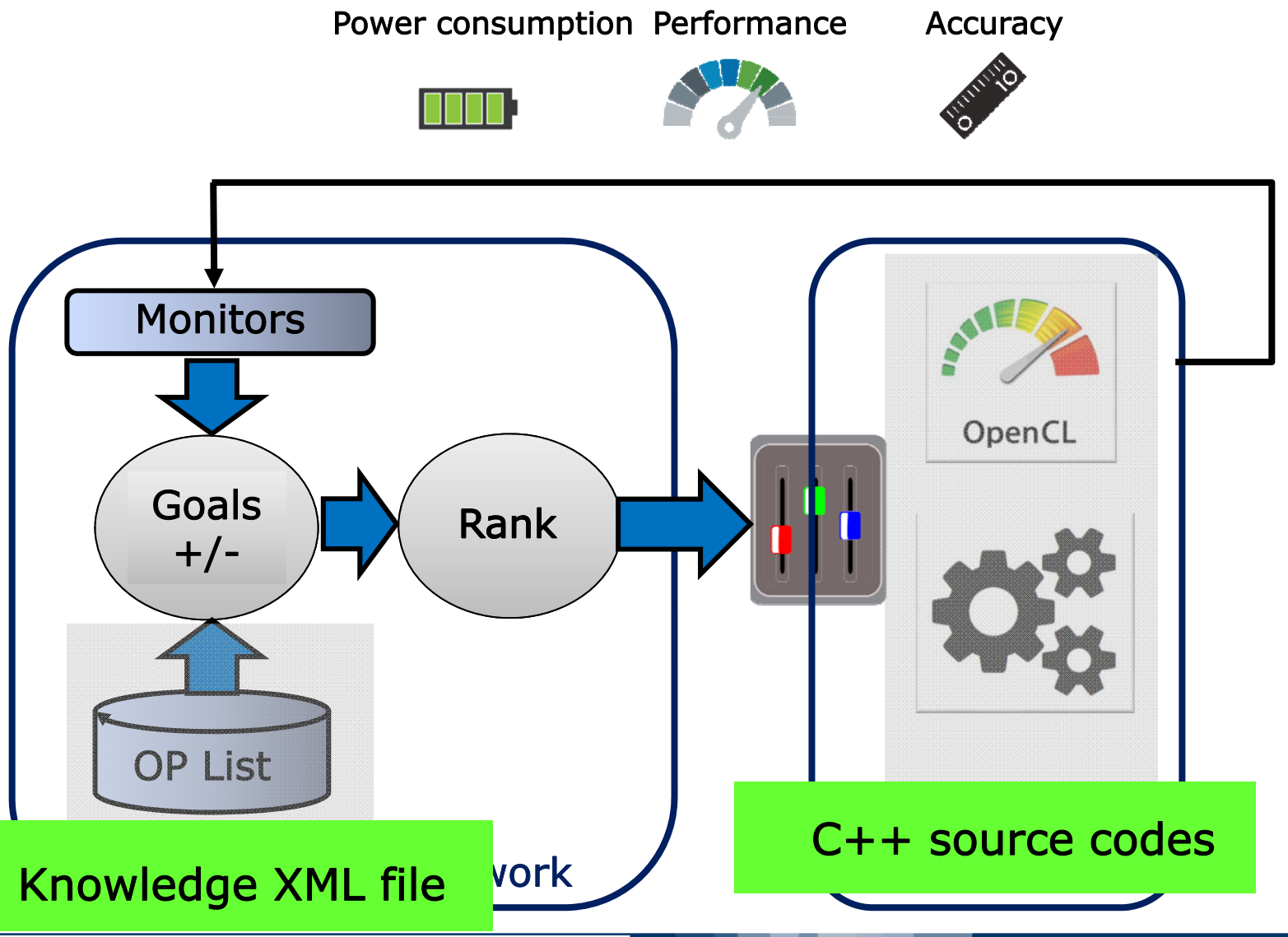

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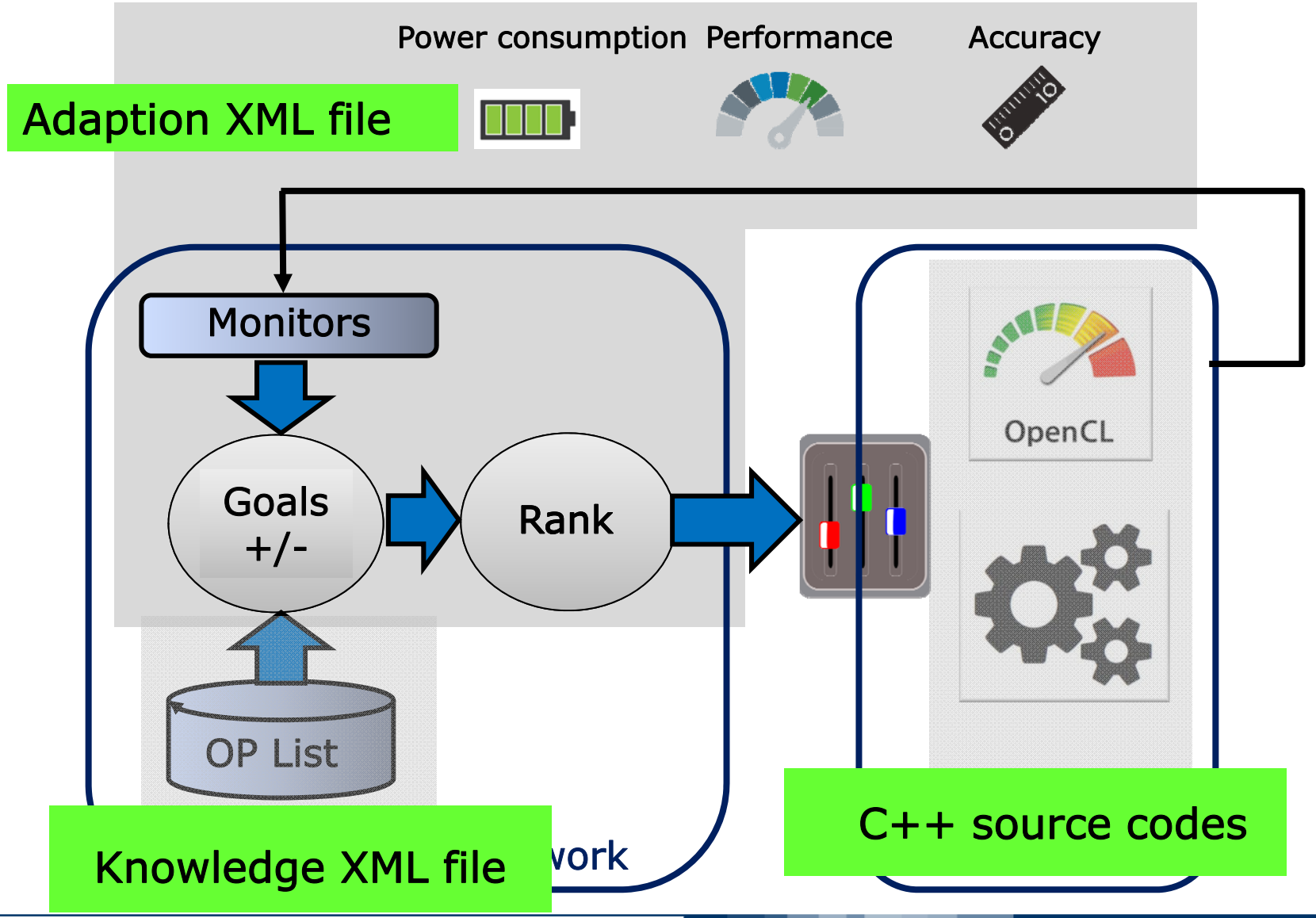

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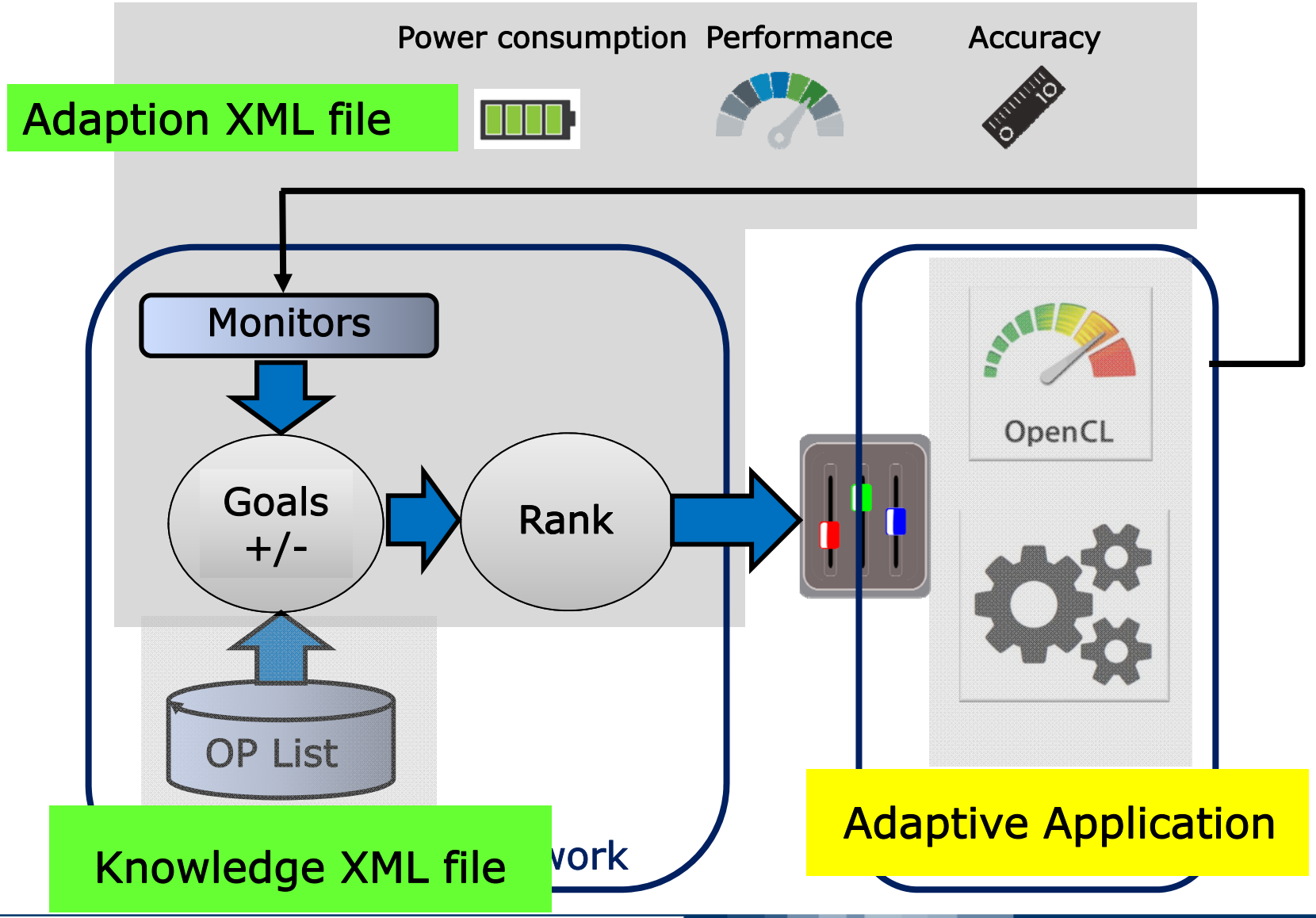
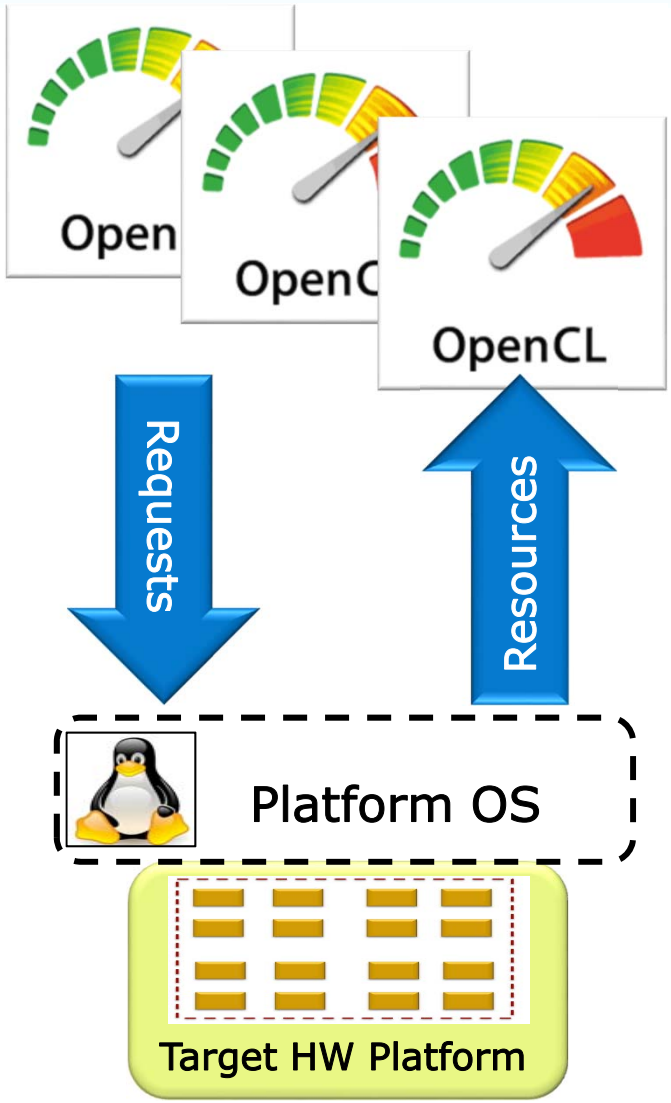


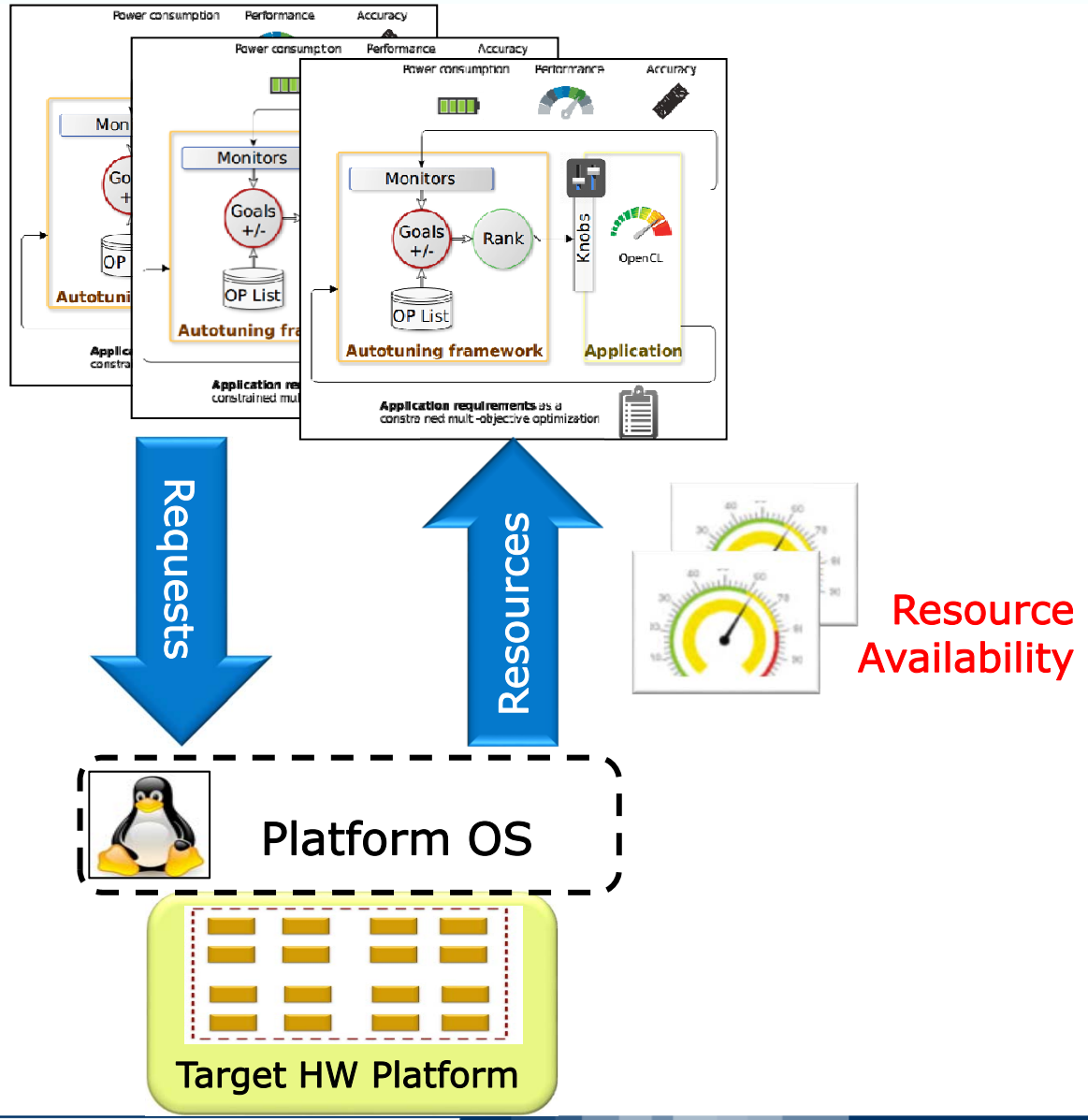
# APPLICATION AUTOTUNING AND RUNTIME RESOURCE MANAGEMENT

# Orthogonality Concept: App Autotuning & RTRM




G. Massari, E. Paone, P. Bellasi, G. Palermo, V. Zaccaria, W. Fornaciari, and C. Silvano. "Combining Application Adaptivity and System-wide Resource Management on Multi-Core Platforms", Proc. of IC-SAMOS 2014.

# Orthogonality Concept: App Autotuning & RTRM



# Experimental Setup

## Target Platform

- Intel Xeon QuadCore CPU E5-1607 @ 3GHz & 8GB RAM
- Linux 3.5 & OpenCL 1.2 runtime provided by Intel SDK 2013

## Dynamic Workload Definition

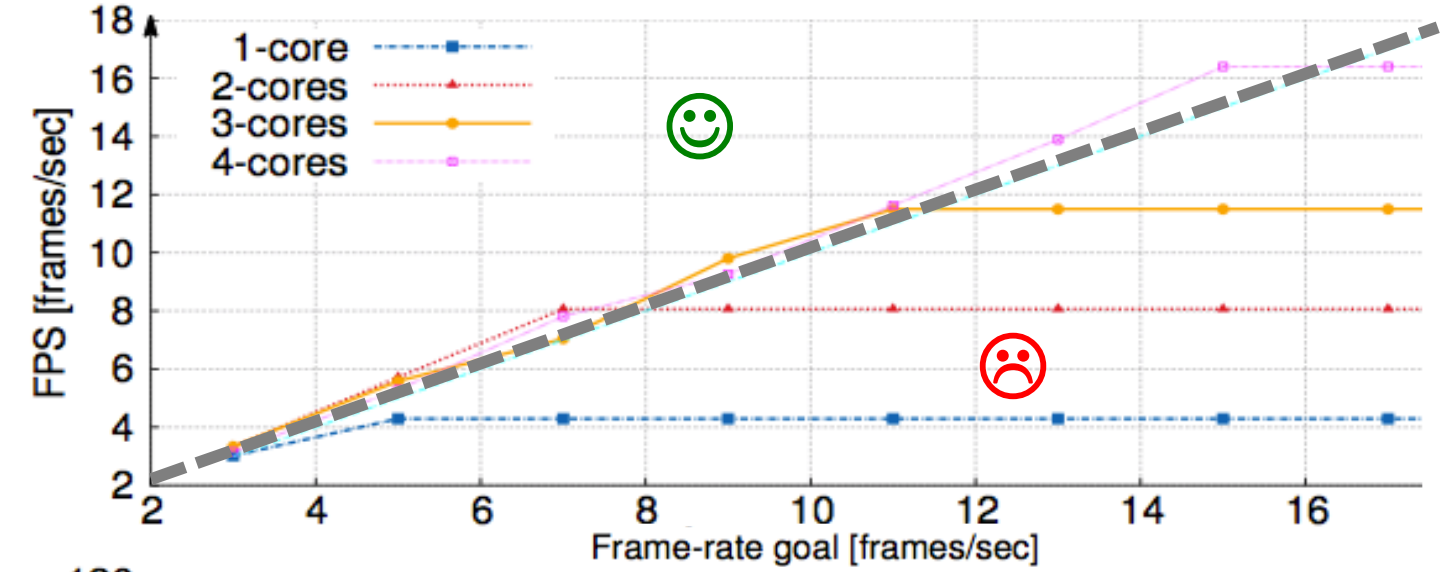
- Single application reacting to external changes
- Multiple instances of the same application

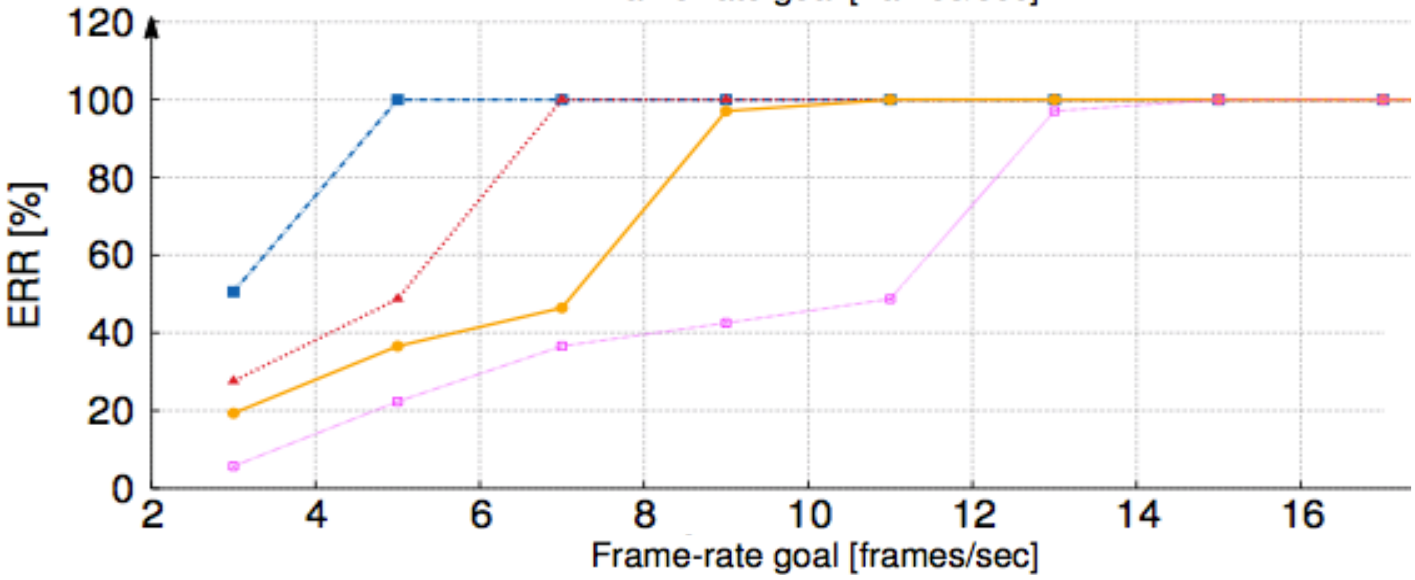
## Metrics of interest

- **Throughput:** Number of frames per second [fps]
- **Quality:** Normalized disparity error w.r.t reference
- **Resources:** Percentage of CPU used by the application

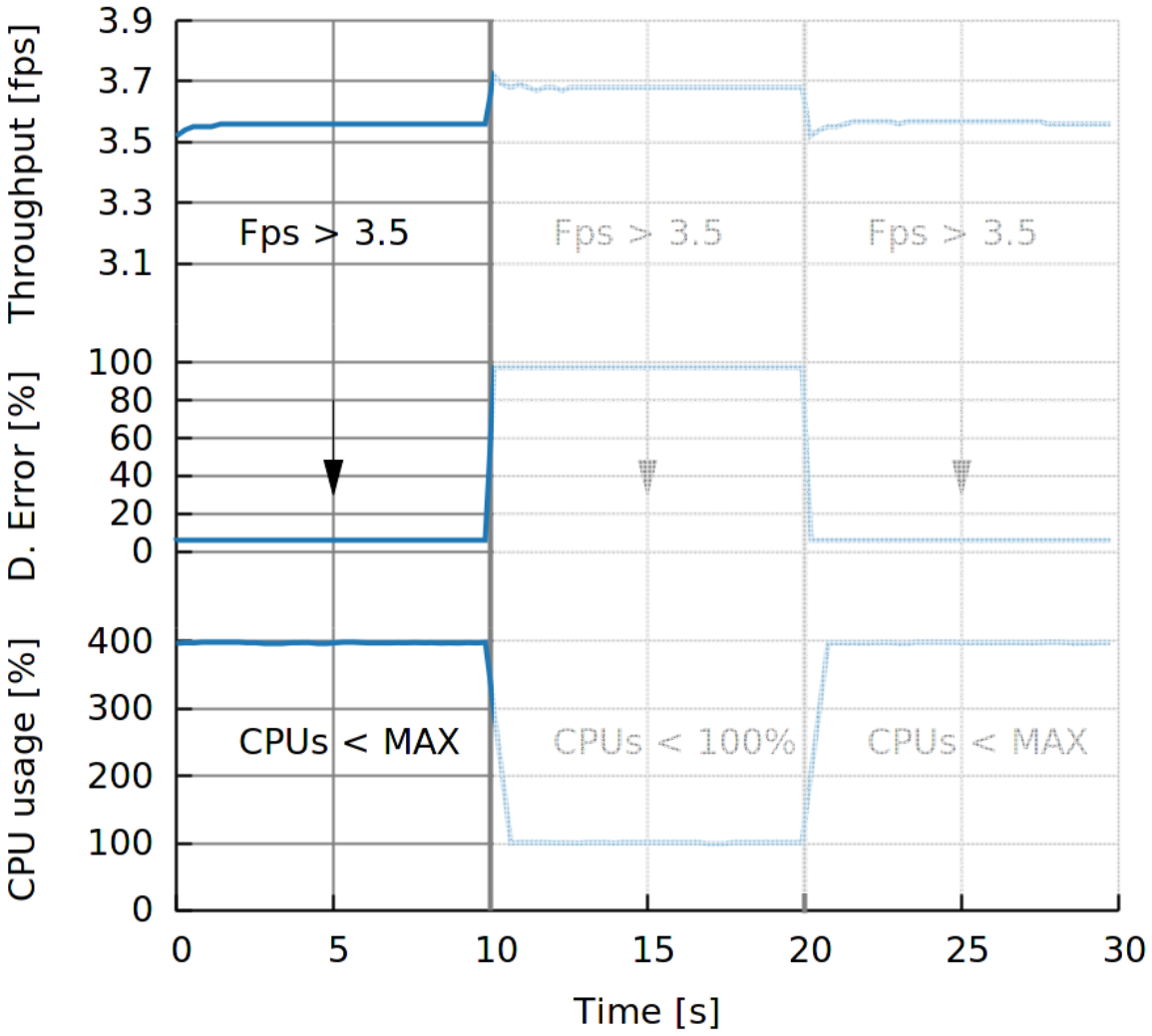
# Application Autotuning Tradeoffs

[ASAP2014]



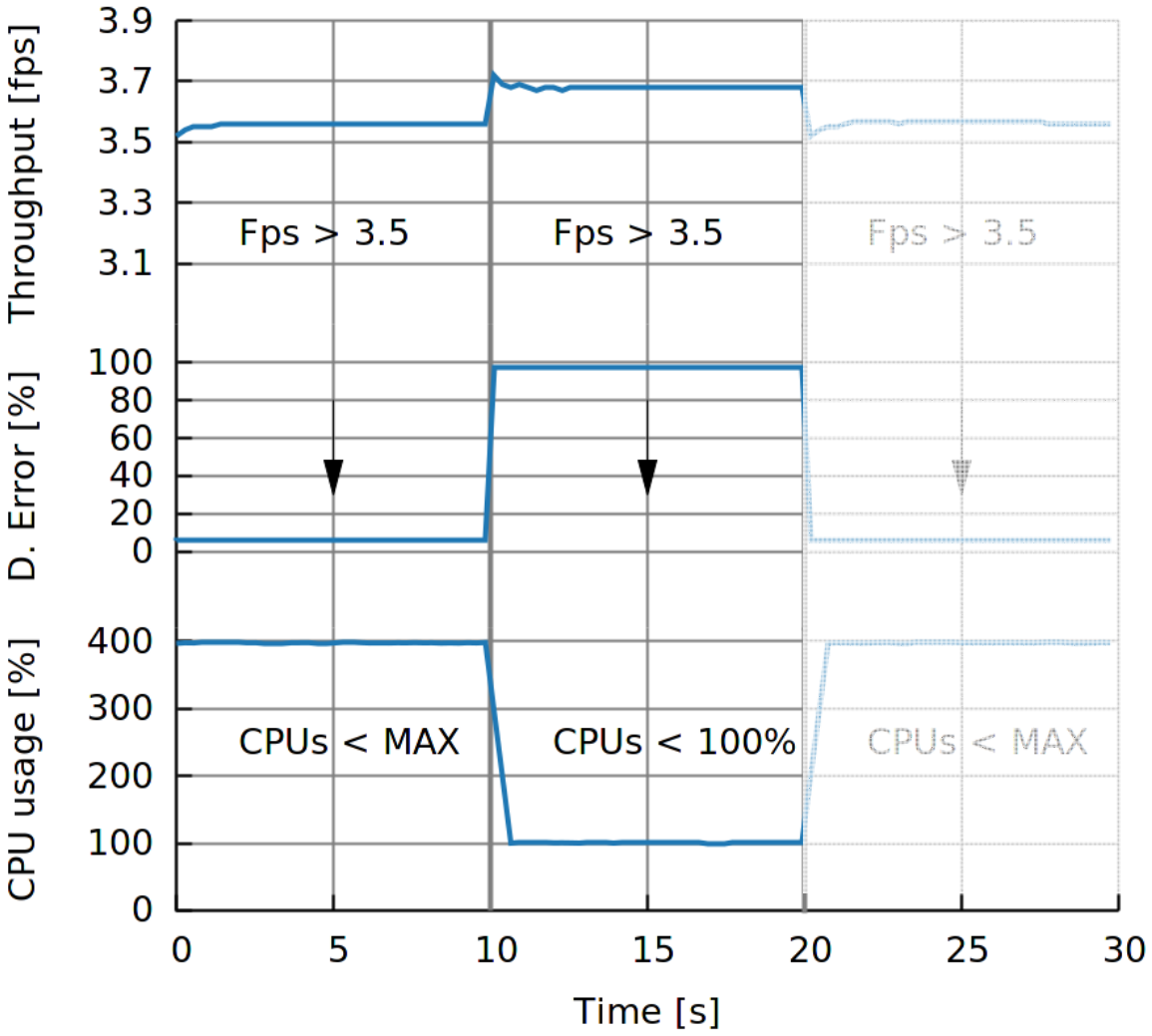
# Application Autotuning: Dynamic Adaptation (1)




- **First phase:**
  The application is processing the images by respecting the requirements

[SAMOS2015]

# Application Autotuning: Dynamic Adaptation (1)




- **First phase:**
  The application is processing the images by respecting the requirements.
- **Second phase:**
  There is a high priority task in the system requiring CPU resources

[SAMOS2015]

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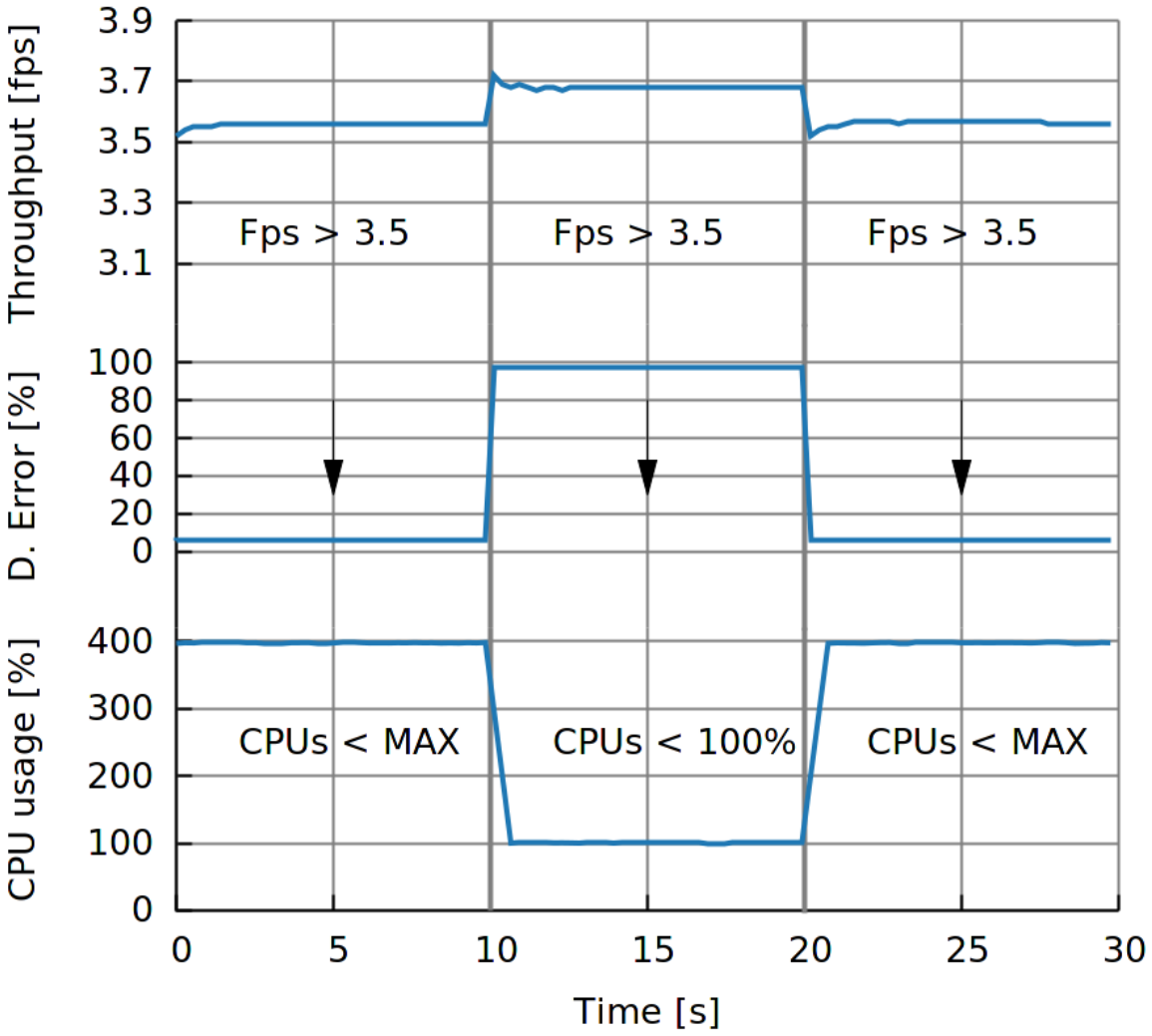
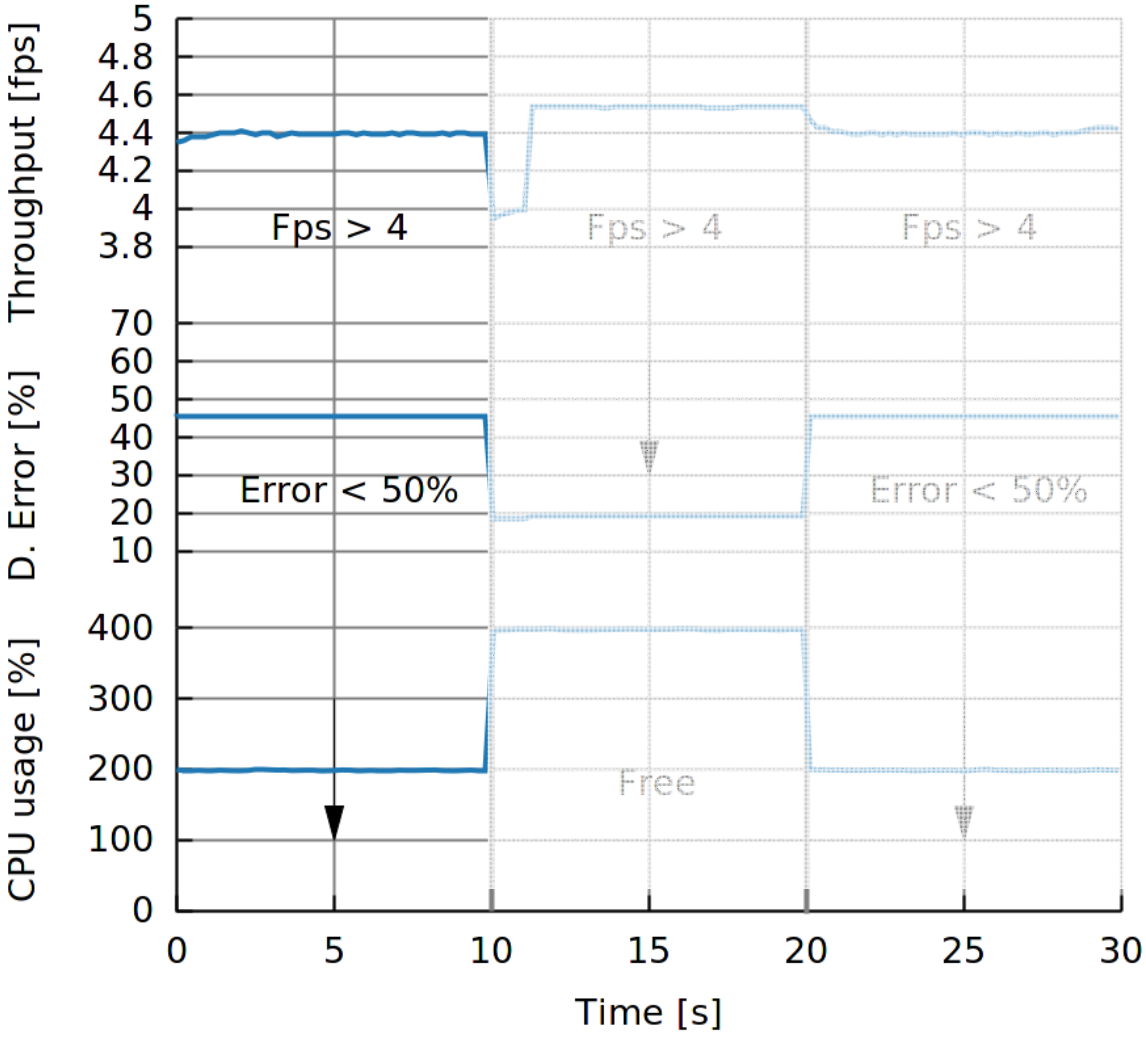



- **First phase:**
  The application is processing the images by respecting the requirements.
- **Second phase:**
  There is a high priority task in the system requiring CPU resources
- **Third phase:**
  The task has finished releasing CPU resources

[SAMOS2015]

# Application Autotuning: Dynamic Adaptation (2)




- First phase:
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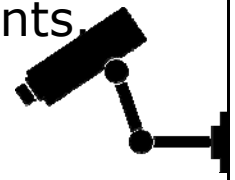
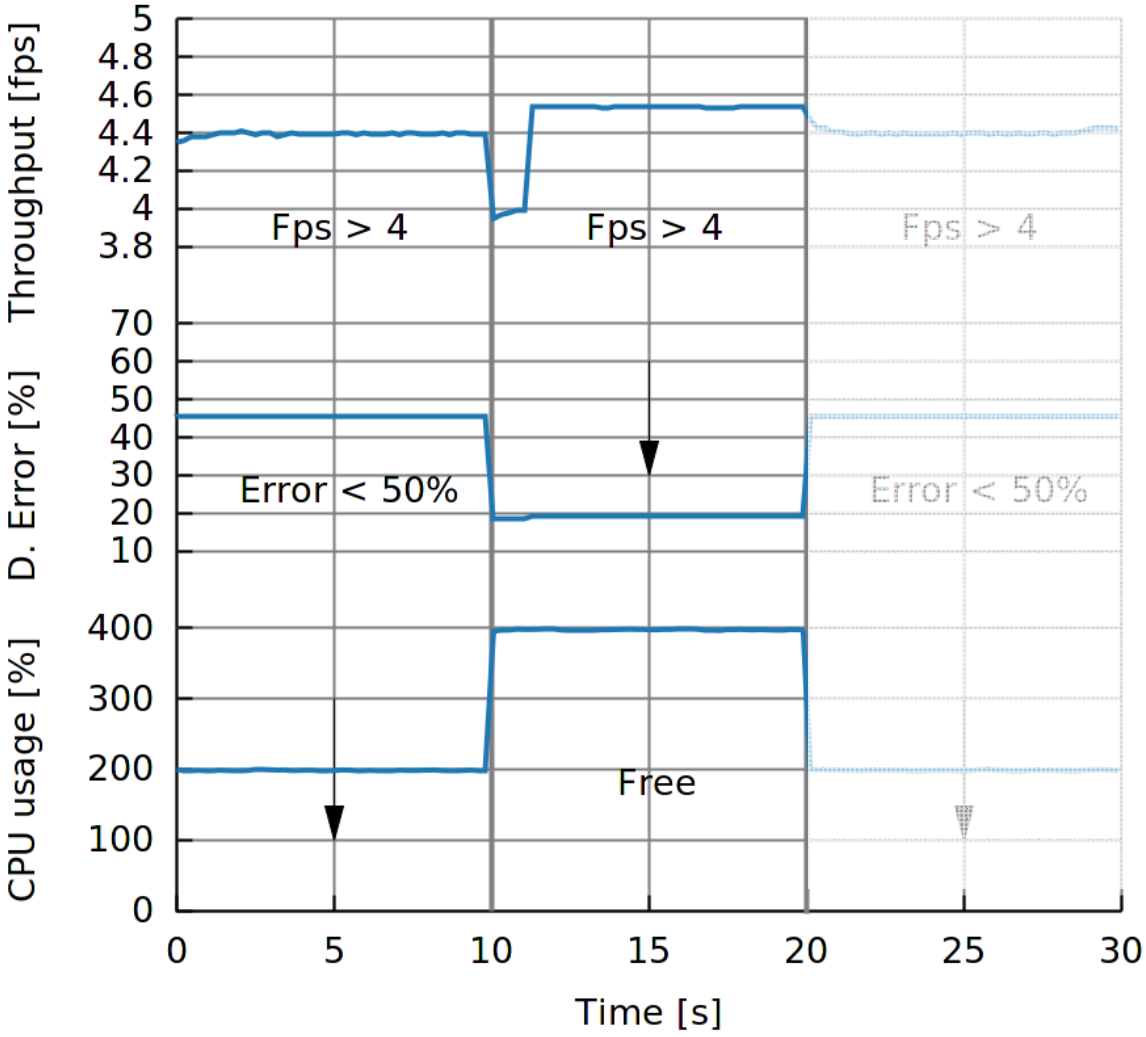
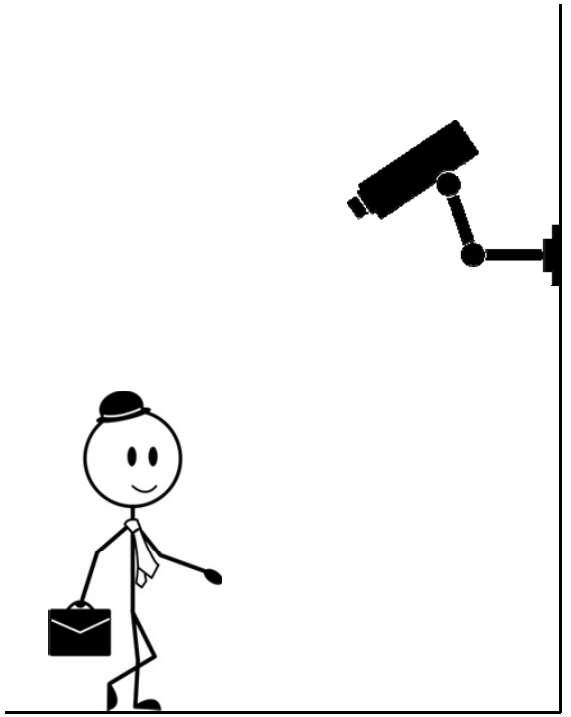


[SAMOS2015]

# Application Autotuning: Dynamic Adaptation (2)

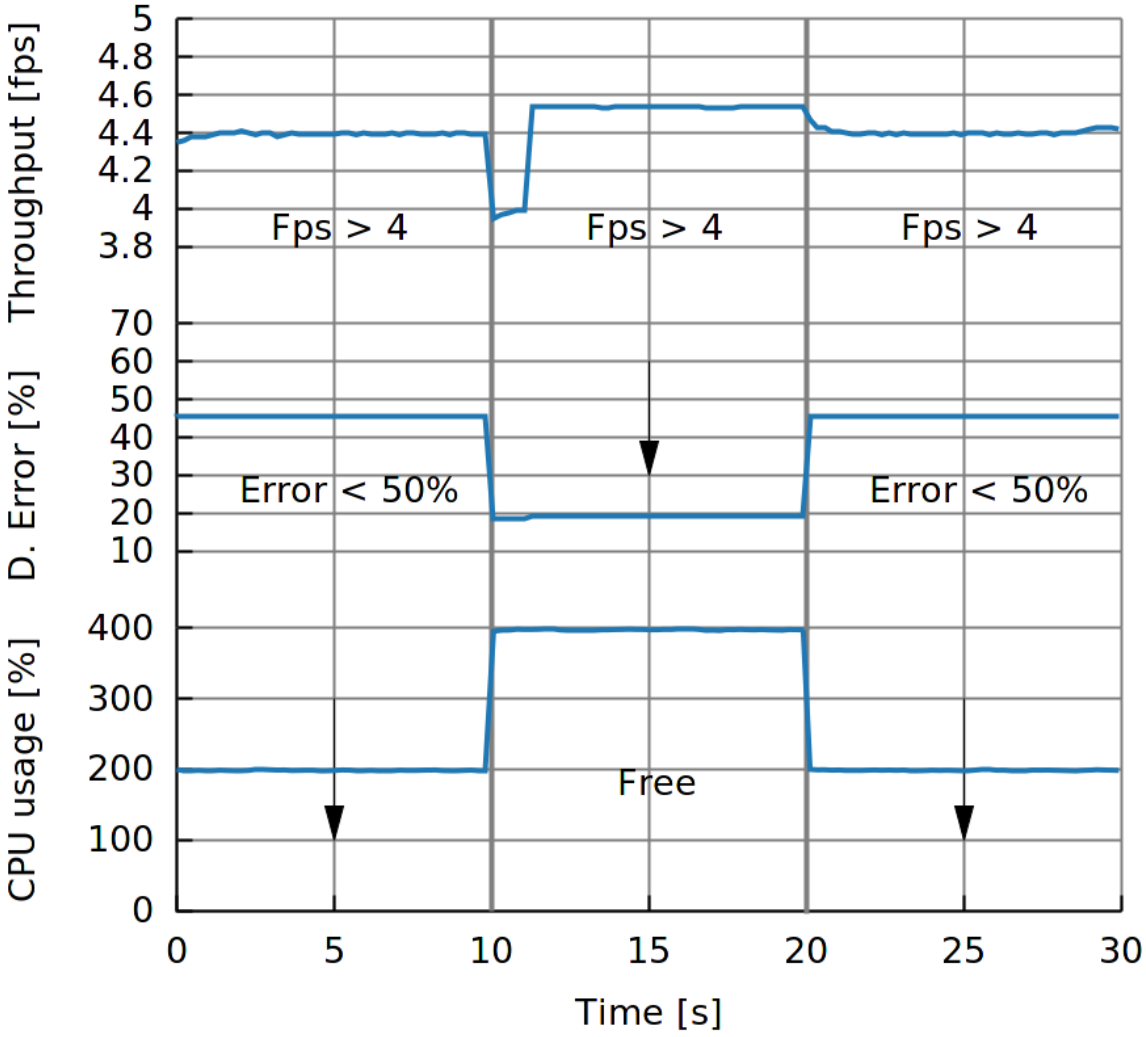



- Second phase:
  Threat detected

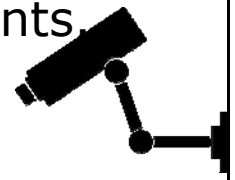


[SAMOS2015]

# Application Autotuning: Dynamic Adaptation (2)



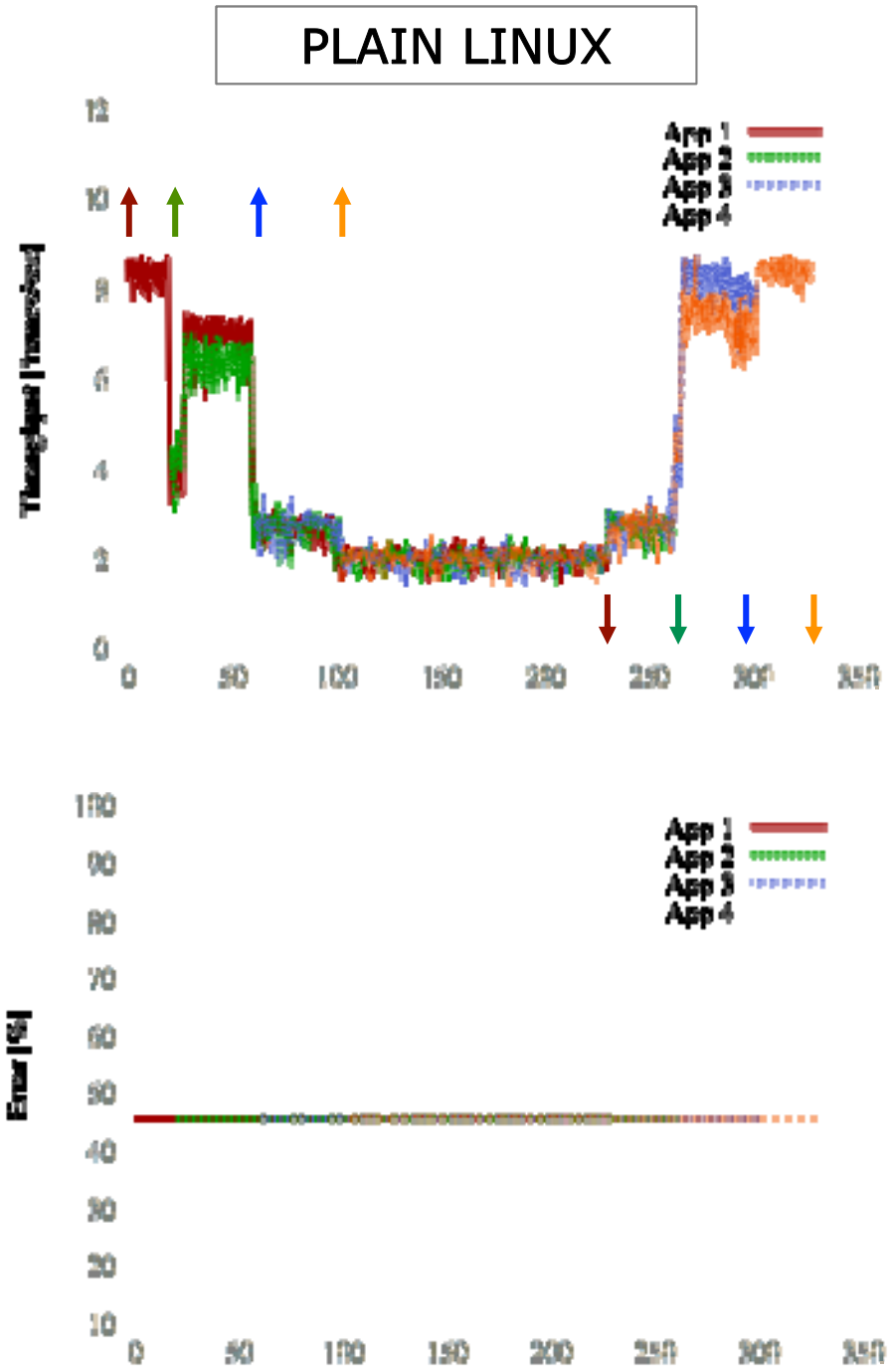

- Third phase:
  The application is processing the images by respecting the requirements



[SAMOS2015]

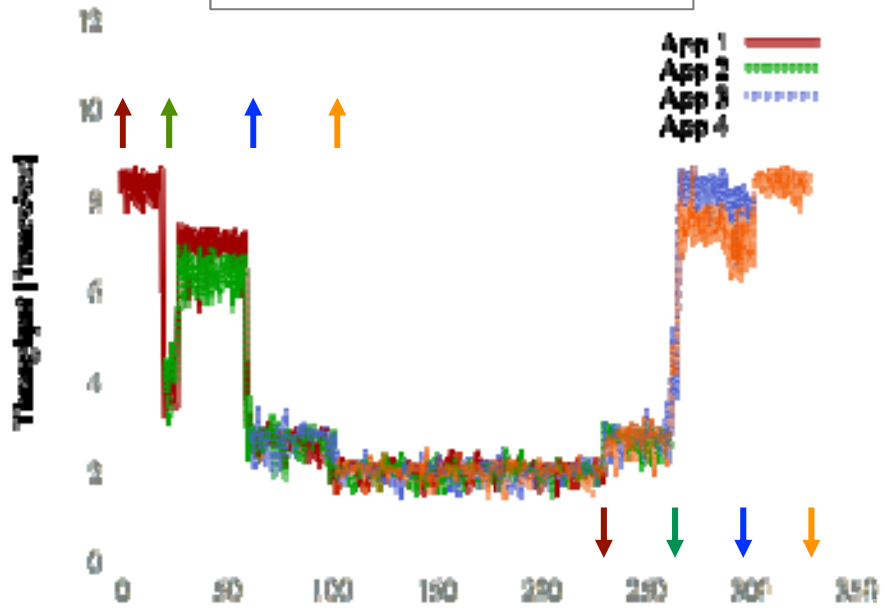
[ASAP2014]

# Multiple Application Dynamic Workload

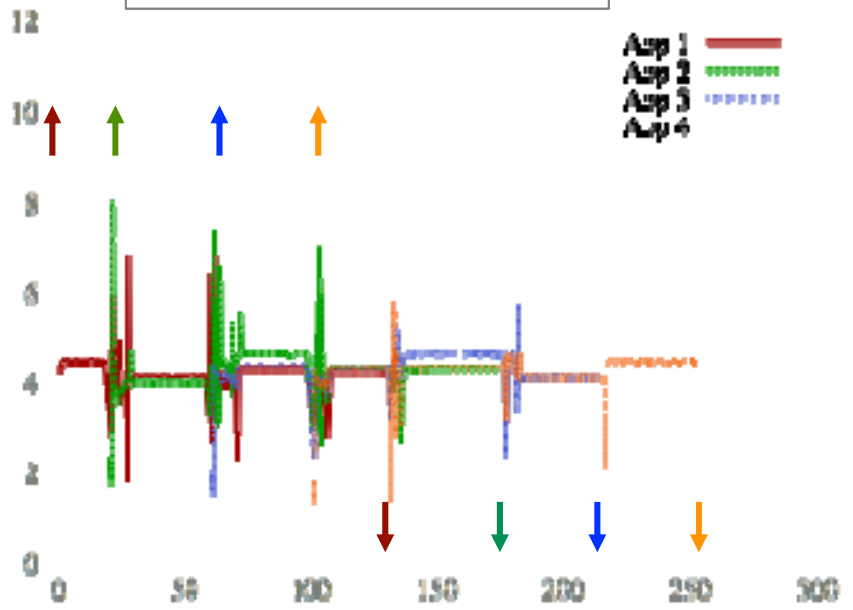


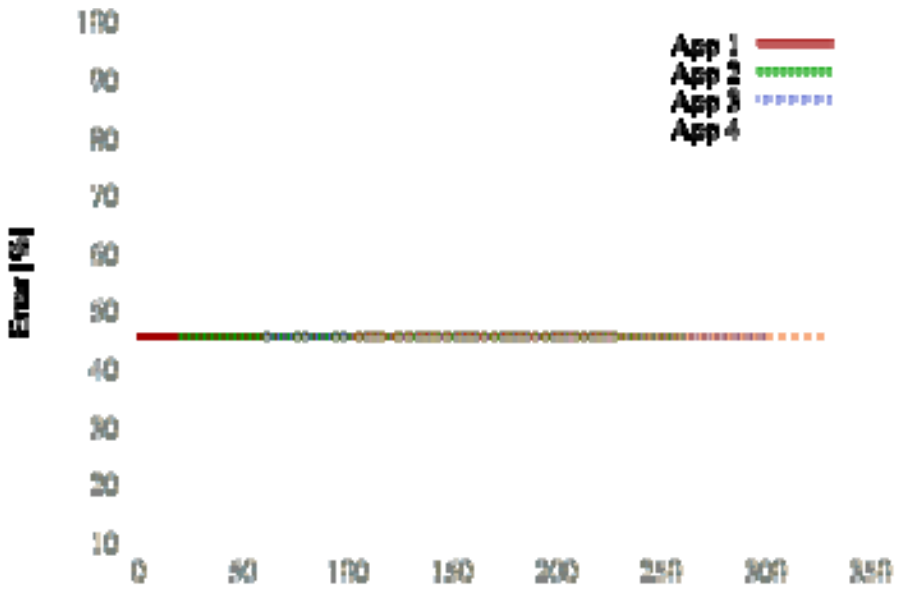
[ASAP2014]

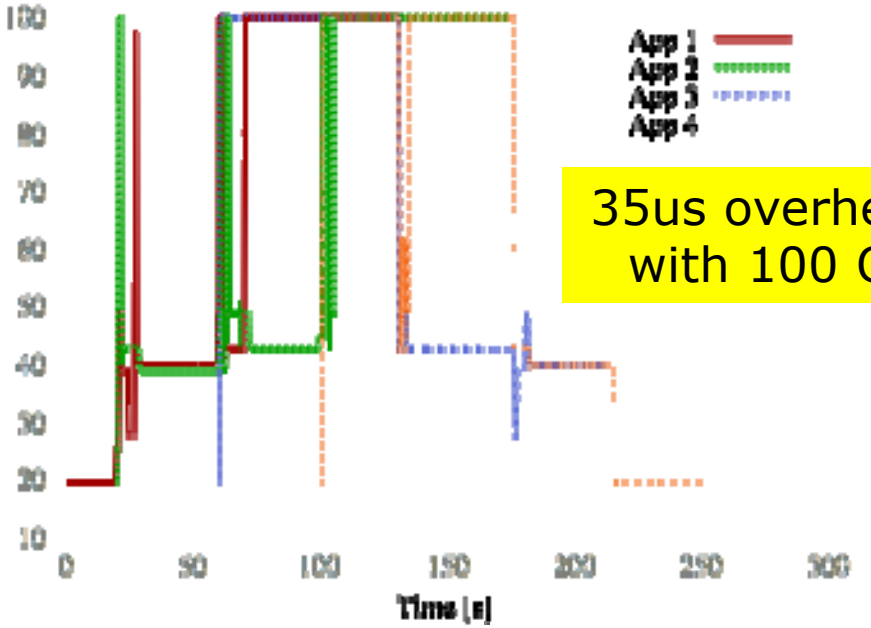
PLAIN LINUX




ARGO+LINUX



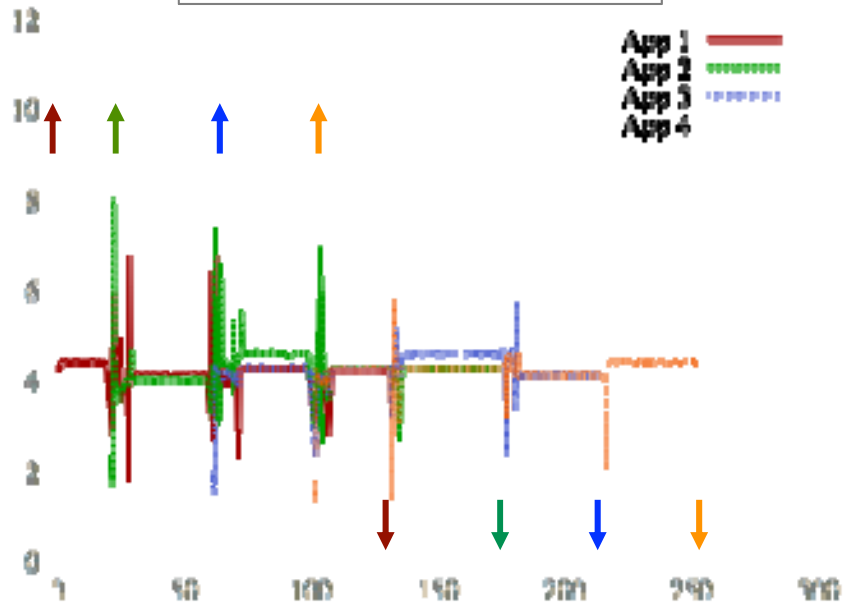



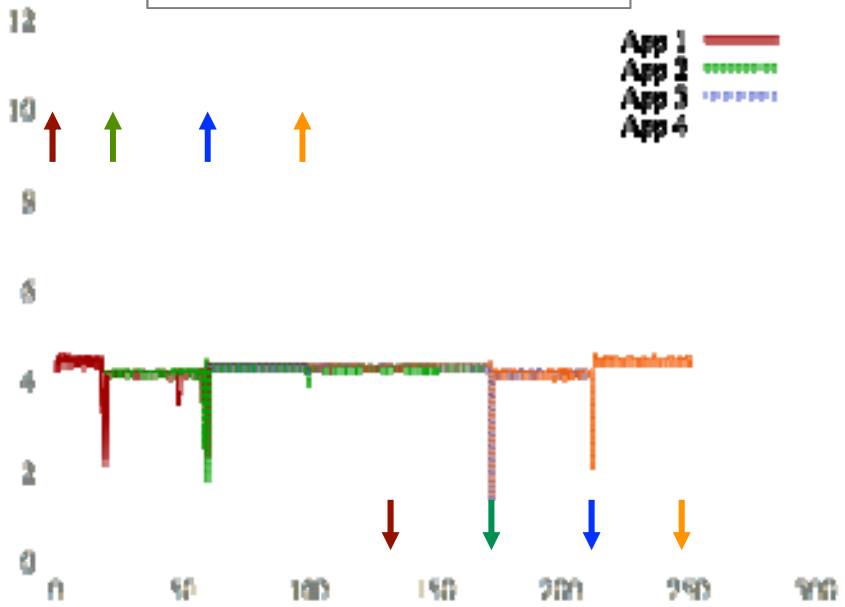

35us overhead with 100 OPs

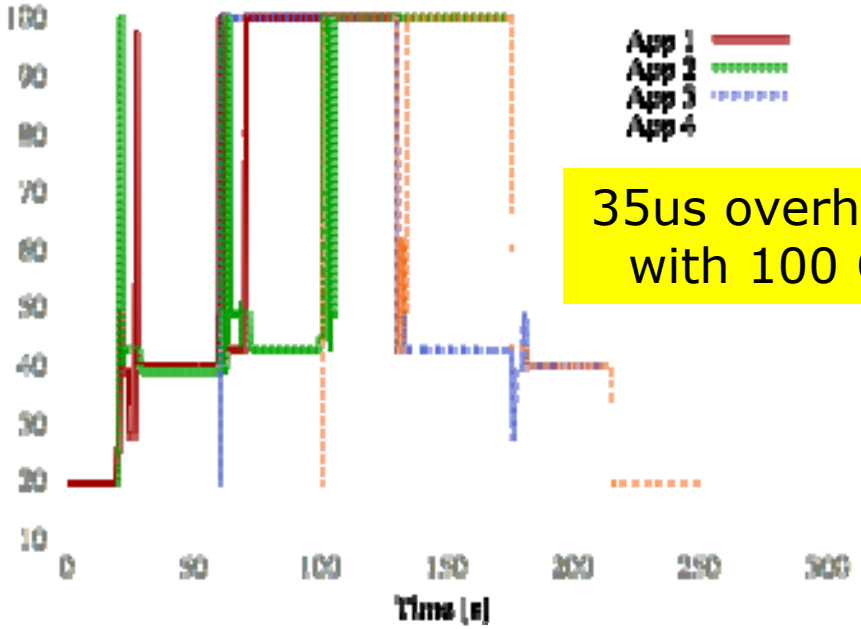
[ASAP2014]

ARGO+LINUX

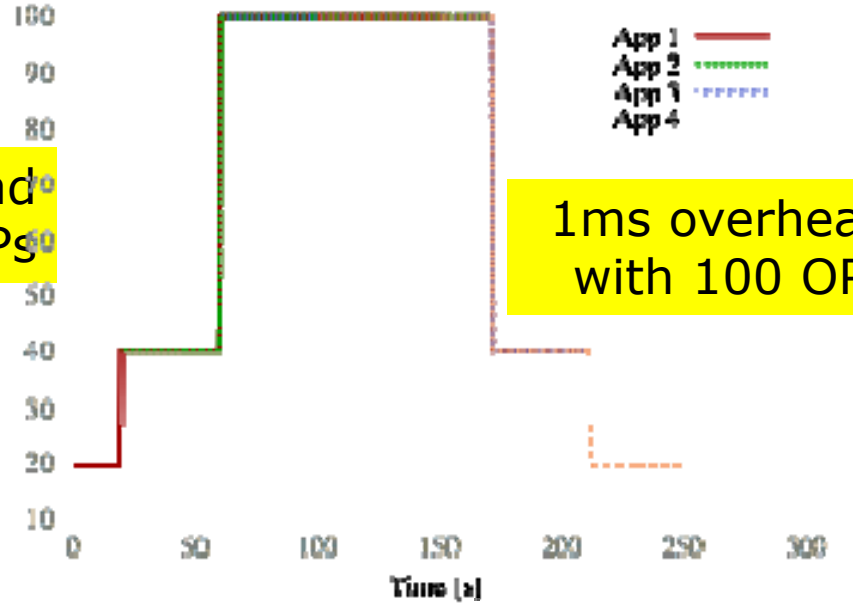



ARGO+RTRM




35us overhead with 100 OPs




1ms overhead with 100 OPs


European Commission | Horizon 2020 European Union funding for Research & Innovation

# Autotuning and Adaptivity Approach for Energy Efficient Exascale HPC Systems

http://www.antarex-project.eu/

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ETH Eidgenössische Technische Hochschule Zürich Swiss Federal Institute of Technology Zurich

Universidade do Porto Faculdade de Engenharia FEUP

CINECA

IT4Innovations national supercomputing center

VŠB Technická univerzita Ostrava

Inria informatics mathematics

Dompé

Sygic

ANTAREX
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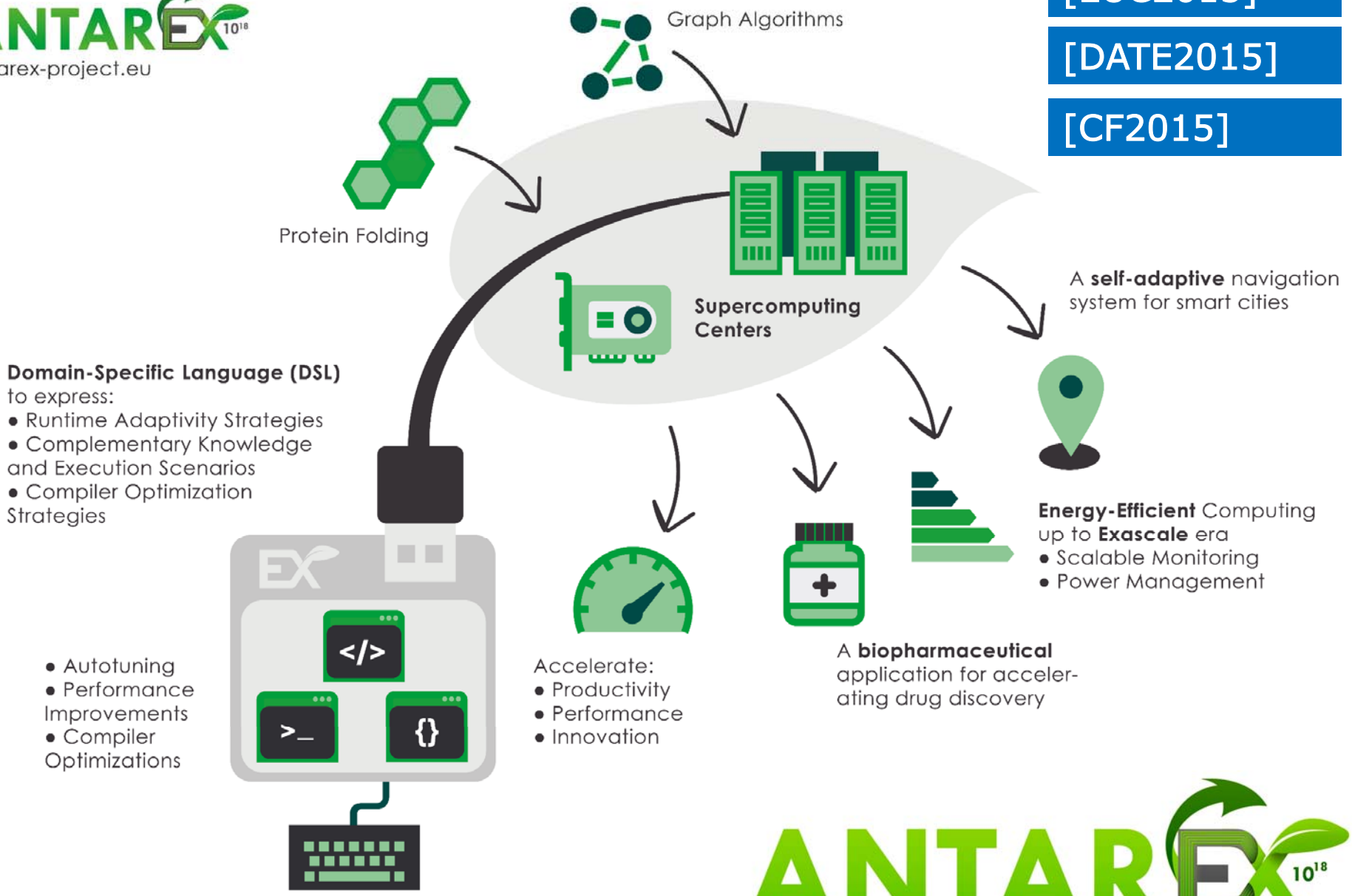
[EUC2015]

[DATE2015]

[CF2015]

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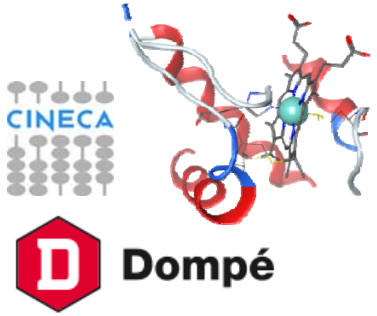
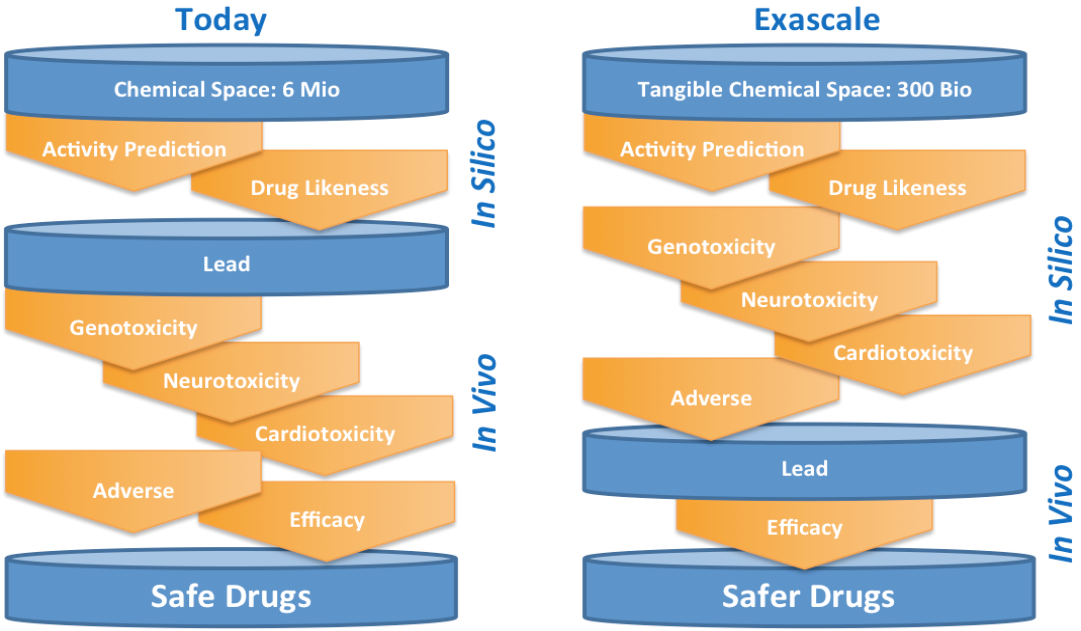
CINECA

# Use Case 1: HPC Accelerated Drug Discovery System

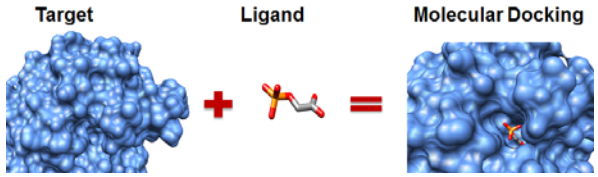
# HPC Accelerated Drug Discovery System

- Personalized Medicine will enable to *"treat the right patient with the right drug at the right dose at the right time." [FDA]*

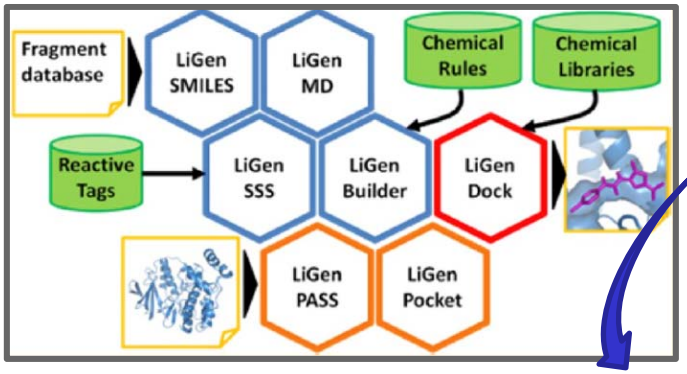



Need of HPC in Drug Discovery: HPC Molecular Simulations



# LiGen Application




ANTAREX

Developing energy and resource efficient algorithms
Using self-functionalities to adapt and scale-out the application

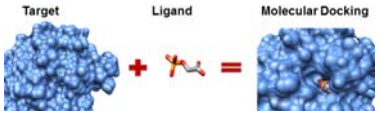
LiGen: Exascale-ready HPC Application

- Chemical Space: 300 Bio
- Peptide library: 120 Mio
- Commercial libraries: 6 Mio
- SafeInMan library: 9 K

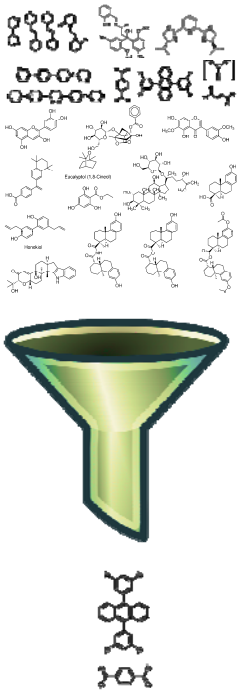
**Exascale HPC Virtual Screening**

# Geometric Molecular Docking

- **Molecular docking** is a method to calculate the preferred position and shape of one molecule w.r.t a second one when bound to each other

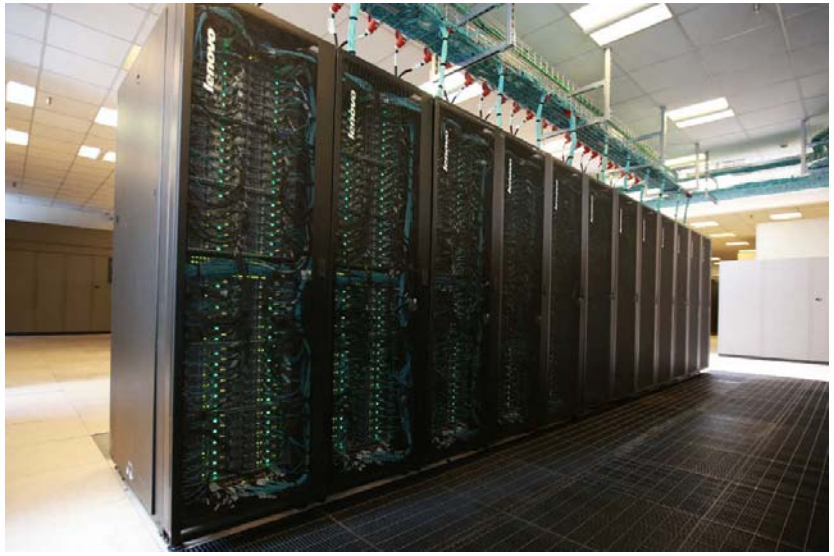



- **Geometric Docking**
  - **Shape complementarity: Geometric matching search to find out compatible pairs and most suitable poses**
- **Pharmacophoric Docking**
  - Molecular simulation: Exploration of a large energy landscape determined by chemical and physical interactions



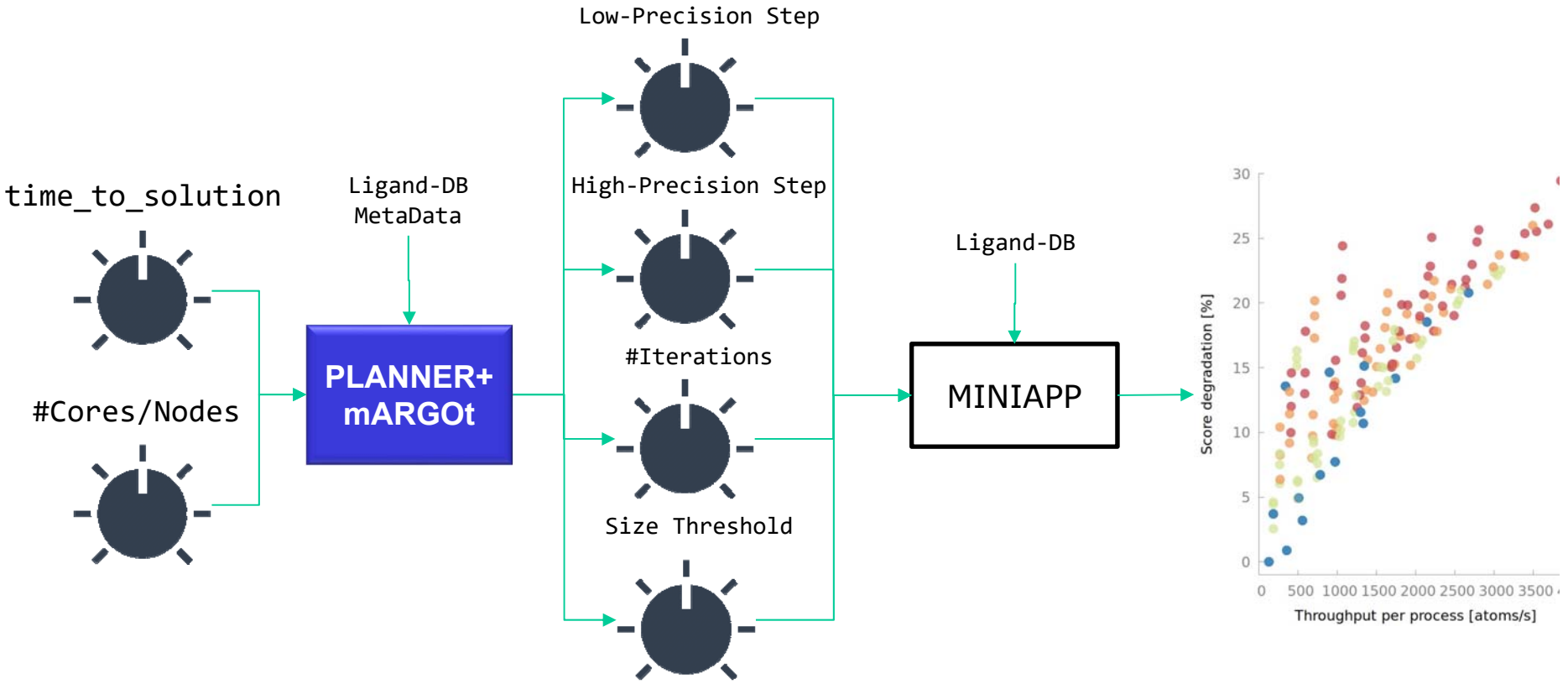
# Marconi: the most powerful supercomputer in Italy

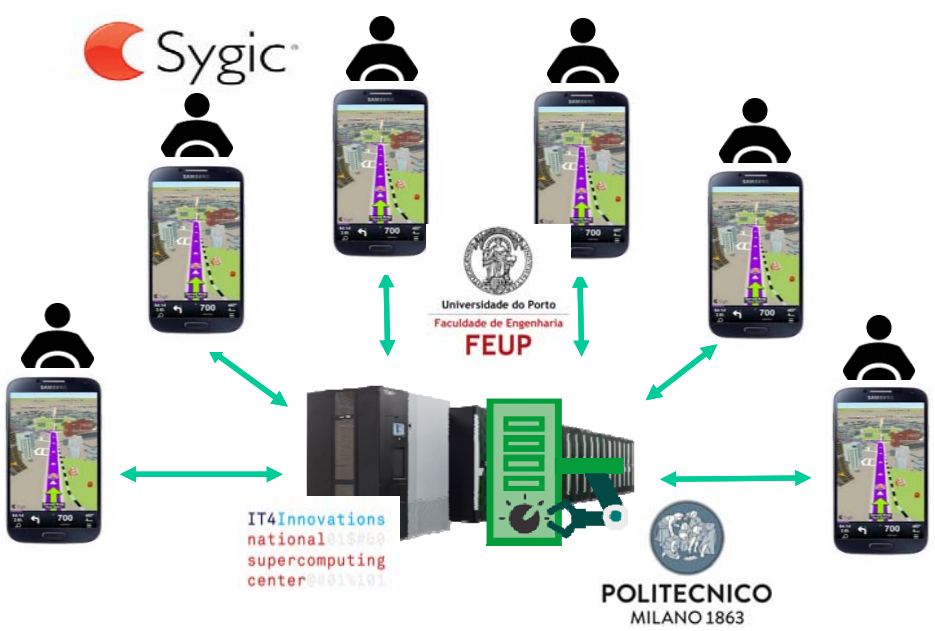
- **No. 14 in Top500 and No. 4 in Europe: Marconi Intel Xeon Phi:** 6.22 PetaFlops (Linpack performance) 10.83 PetaFlops (peak performance) with with 241,808 cores. Site: Casalecchio di Reno, BO



- **Marconi is the Cineca's Tier-0 system,** co-designed by Cineca and Lenovo based on the Lenovo NeXtScale platform and Intel® Xeon Phi™ product family alongside with Intel® Xeon® processor E5-2600 v4 product family.
- In Nov. 2017, this system is planned to reach a computational power of about 20Pflop/s with future generation Intel Xeon processors **(Sky Lakes).**

# Autotuning with mARGOt



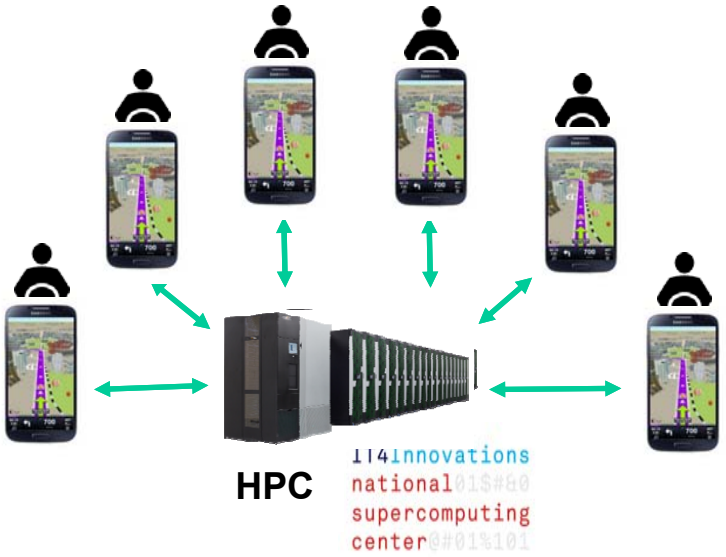



ANTAREX

# Use Case 2: Self-adaptive Navigation System

# Self-adaptive Navigation System


Sygic Company develops world`s most popular navigation application & provides professional navigation software for business solutions

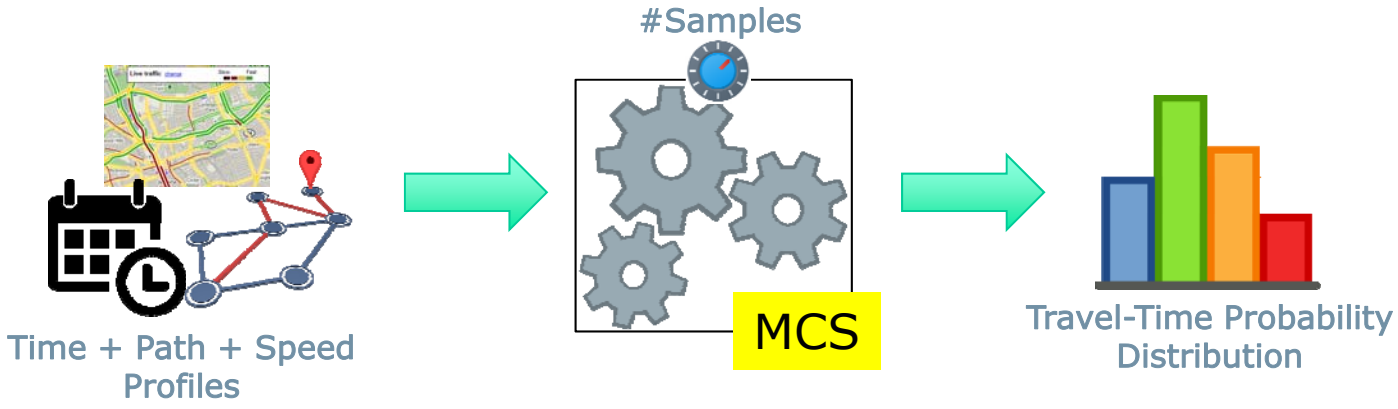



- Exploit synergies between client-side and server-side:
  - Many drivers – many routing requests to HPC system
  - Traffic status data sources
  - Continuous update of traffic flow calculation
  - ***Smart City Challenge***

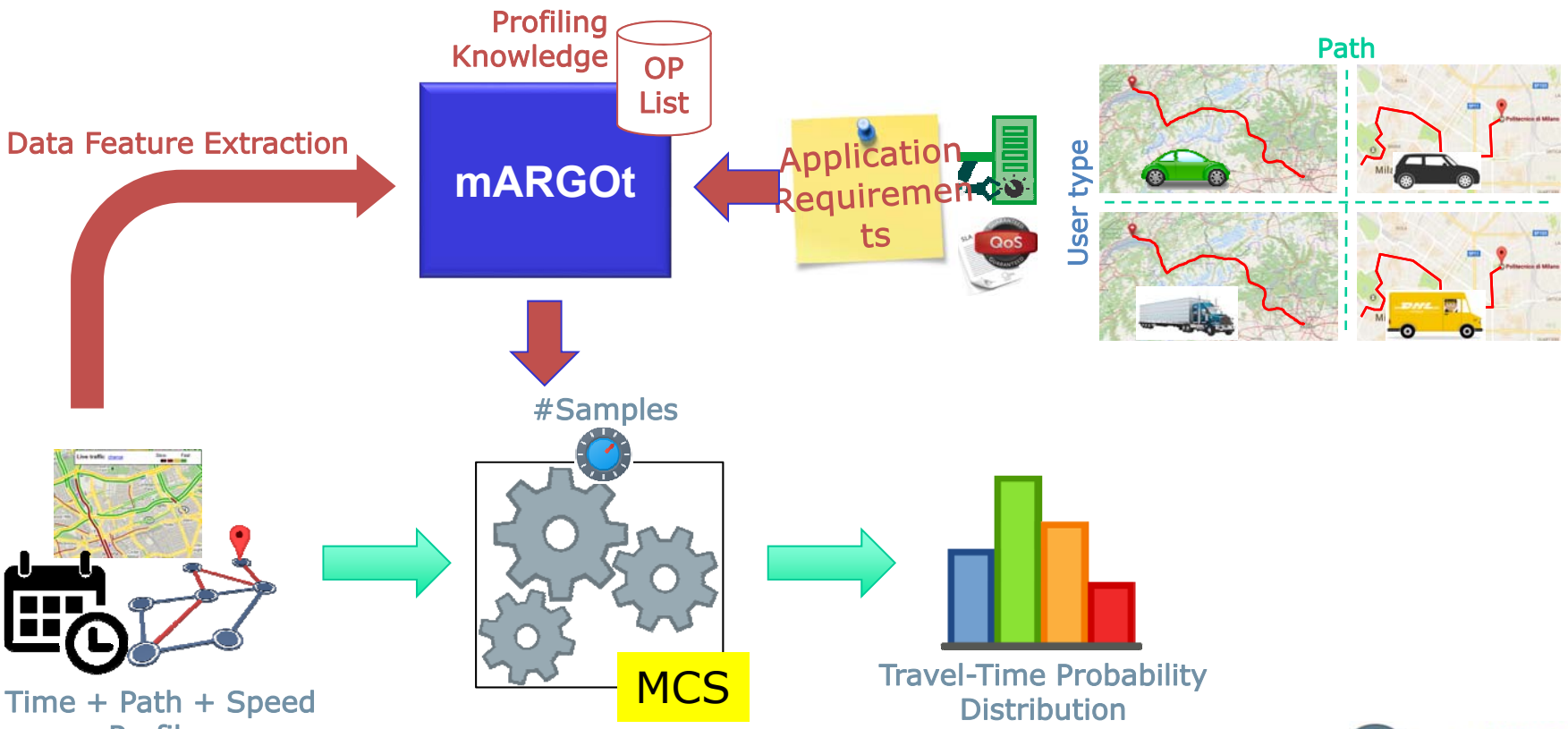
# Probabilistic Time-dependent Routing

## What is the time-dependent routing part of a navigation system?

- Module responsible for determining the ***expected travel time***
- In the client-server navigation infrastructure, the ***server side*** evaluate accurate travel time with updated traffic information
- Based on *MonteCarlo Simulation (MCS)* over the *probabilistic speed profile* on each path segment



# Autotuning with mARGOt (User & Data-aware)

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IT4Innovations national supercomputing center
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