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Contributions to the Autonomy of Ubiquitous Software Systems

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Habilitation defense (HDR)

Friday 5th December 2014

A few facts about me

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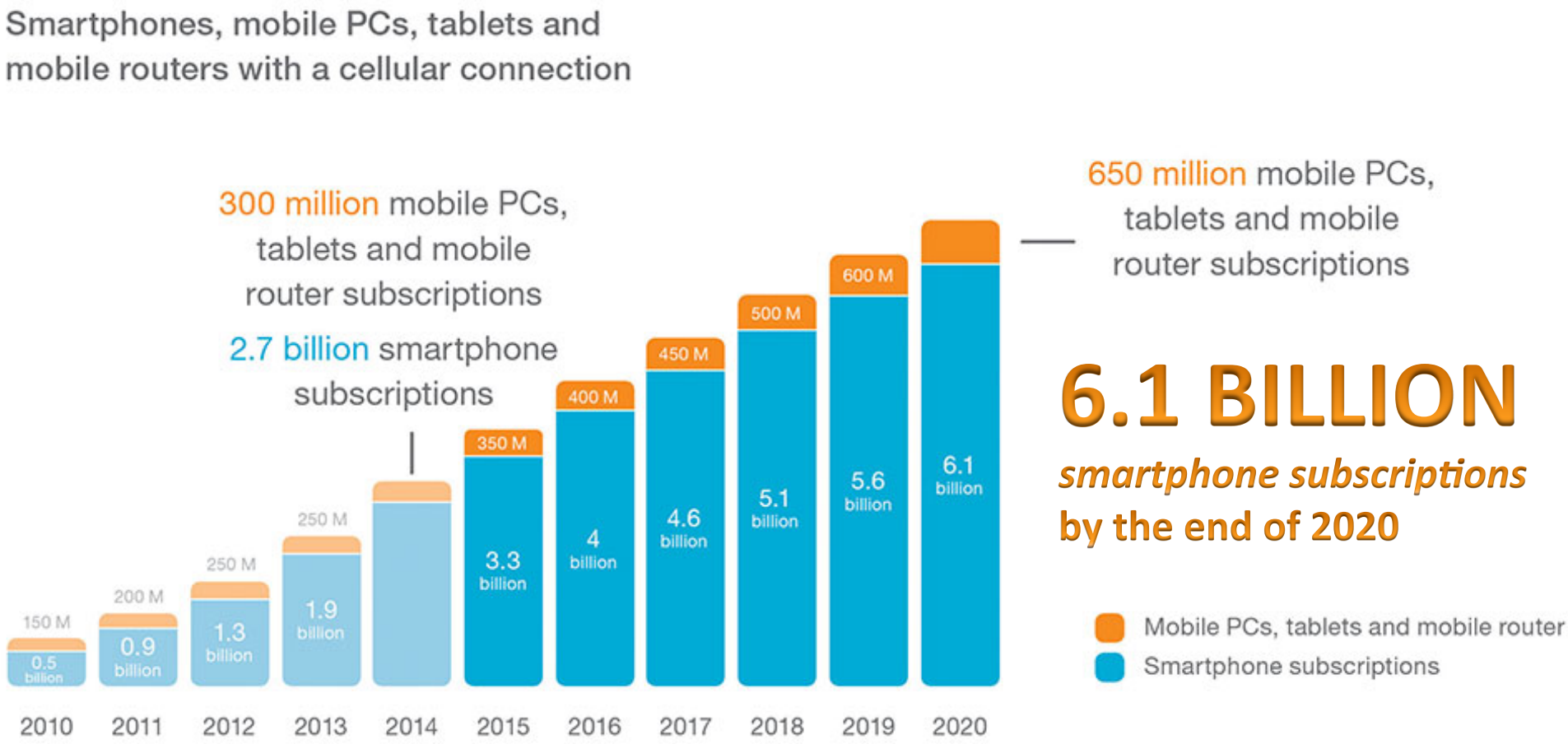
- 2003–06: **Ph.D. thesis** from USTL / INRIA
  - *Supervision: P. Merle & J.M. Geib*
  - *Topic: Middleware / components / transaction*

- 2007–08: **Postdoc researcher** @ Univ. of Oslo
  - *Member of the ND group (IFI)*
  - *Contributions to the EU FP6 MUSIC R&D project*

- 2008– : **Associate professor** @ Univ. of Lille 1
  - *Member of the Spirals team (Lille 1 & Inria)*
  - *Head of the CS Master on software engineering*
  - *Distributed systems & software engineering*
    - Middleware for ubiquitous computing

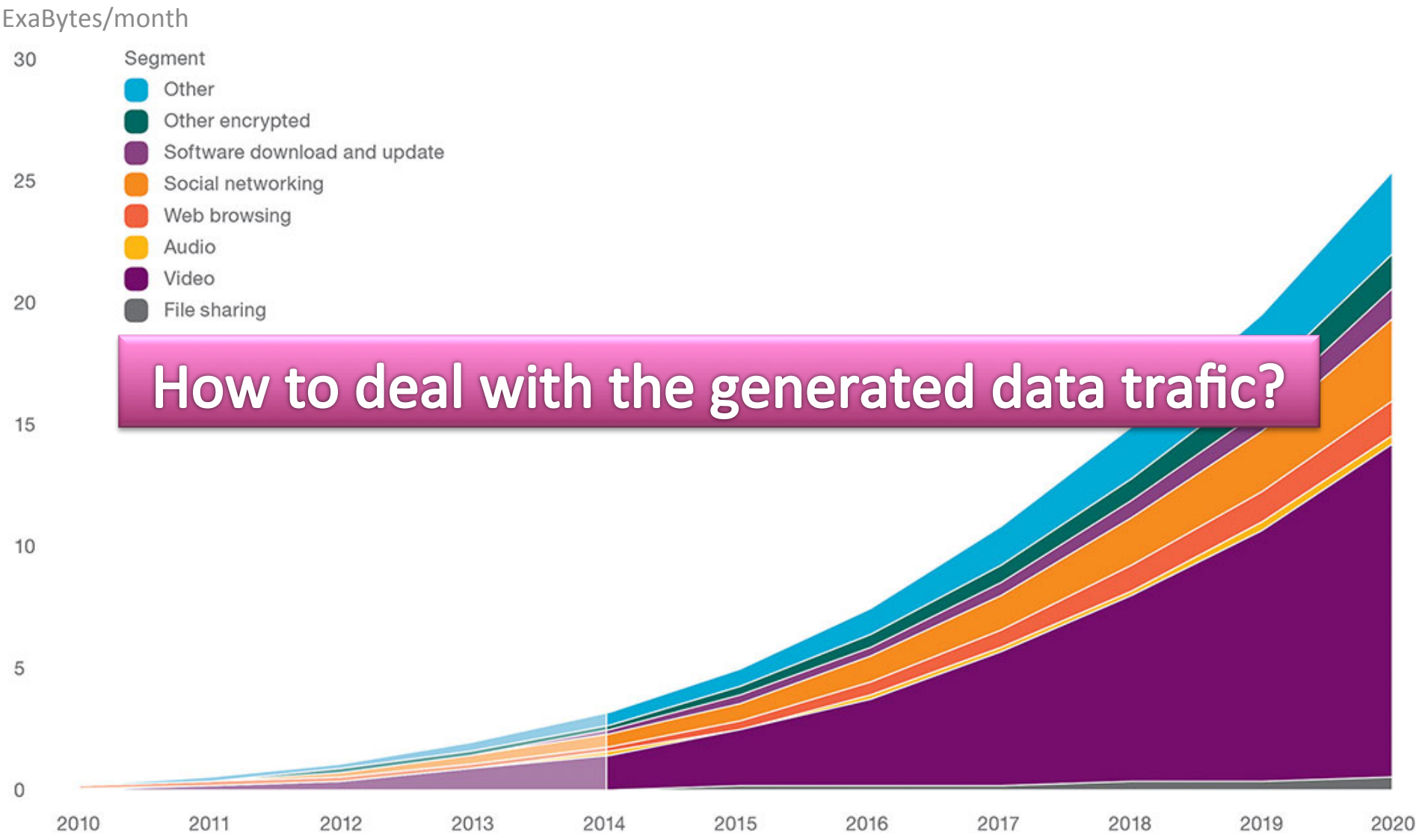
Evolution of connected devices



How to program applications for billions of connected devices?

Source: Ericsson Mobility Report. November 2014. http://www.ericsson.com/mobility-report

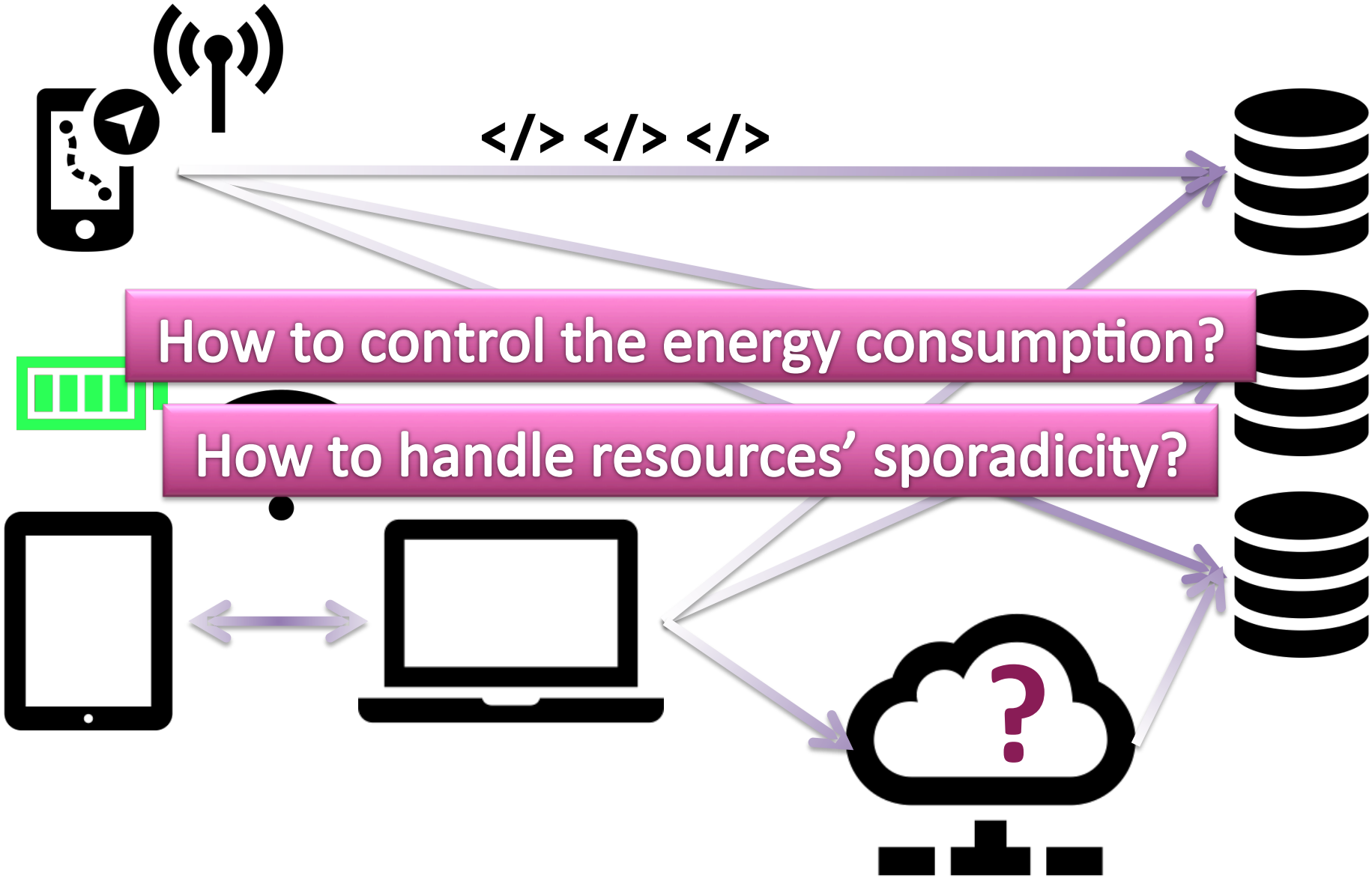
Evolution of application usages



How to deal with the generated data trafic?

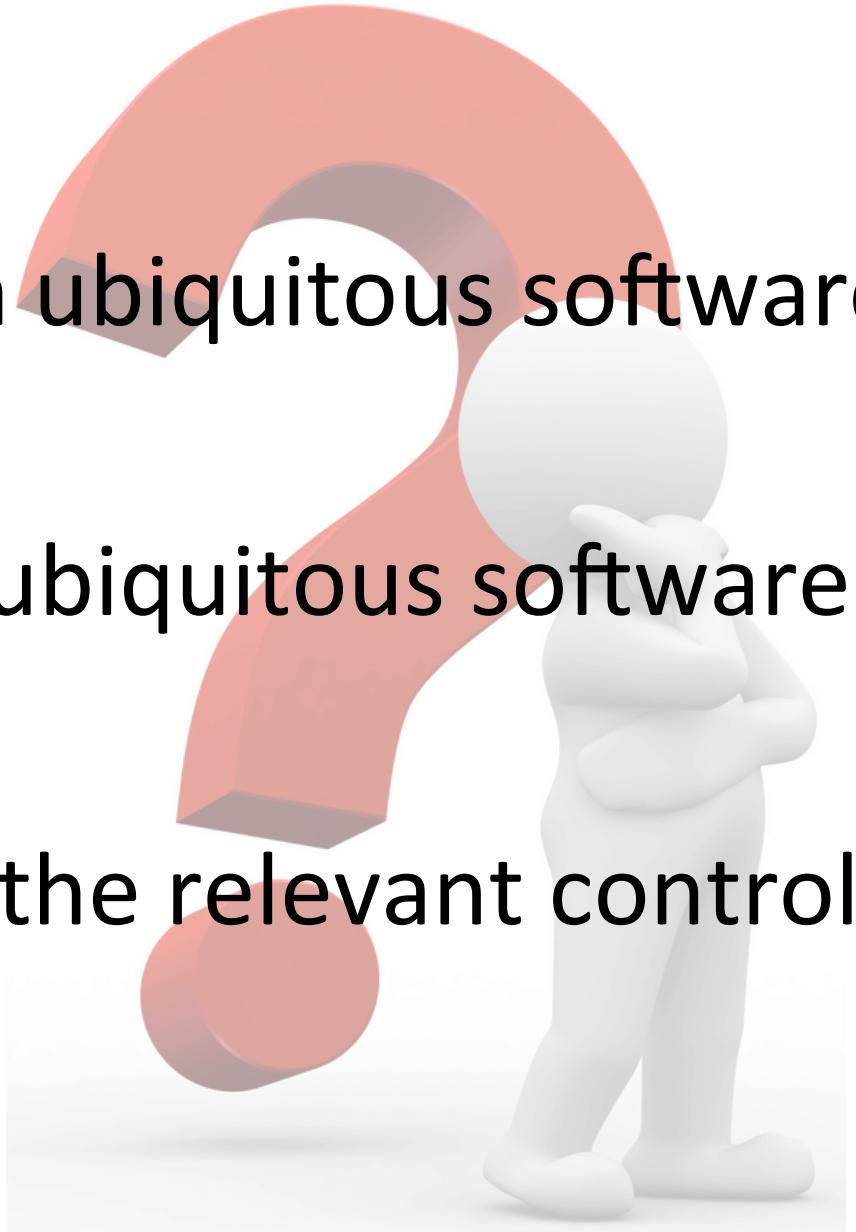
Source: Ericsson Mobility Report. November 2014. http://www.ericsson.com/mobility-report

Ubiquitous software systems



Challenges: How to…

- **Program** ubiquitous software systems?
- **Control** ubiquitous software systems?
- **Identify** the relevant control features?



Our approach: To support…

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1. Elastic Programming Models

2. Engineering of Feedback Control Loops

3. Multi-dimensional Context Monitoring

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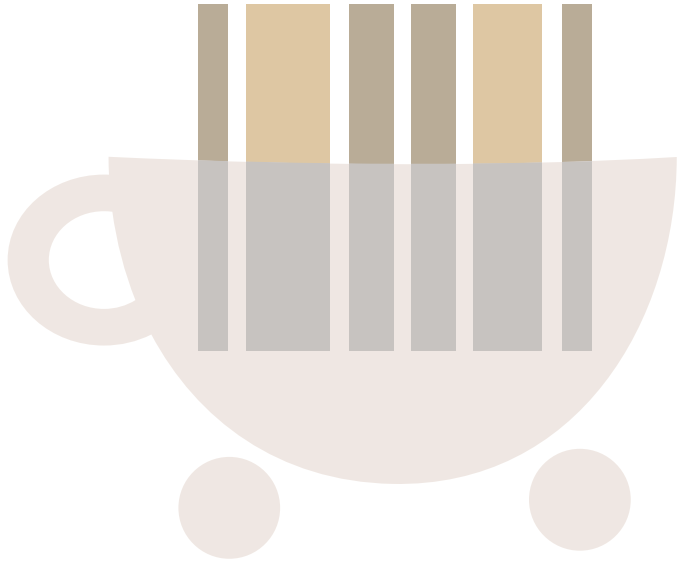

macchiato

2011–2013

Enabling opportunistic code offloading

ELASTIC PROGRAMMING MODELS

Ubiquitous software systems require

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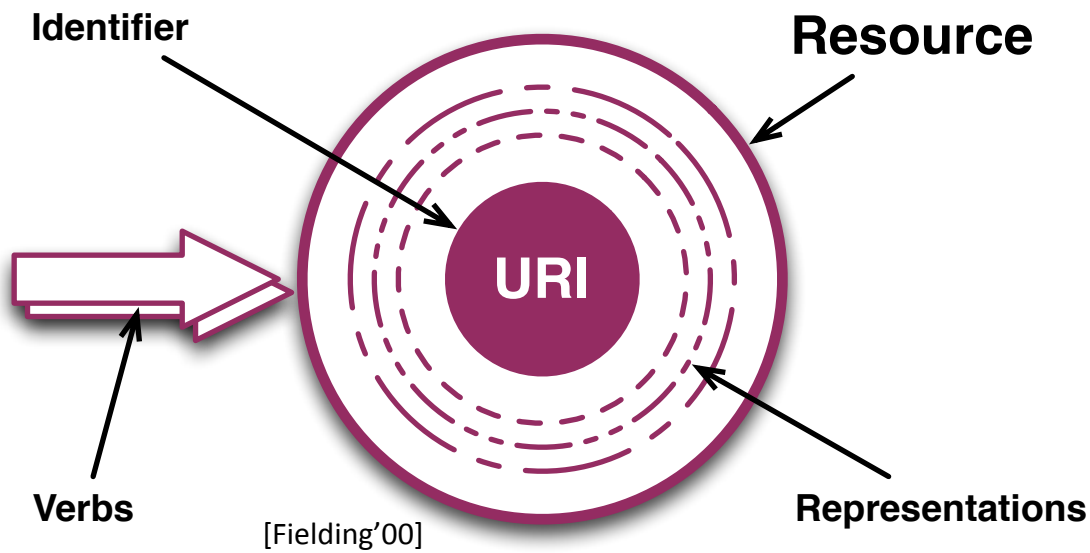
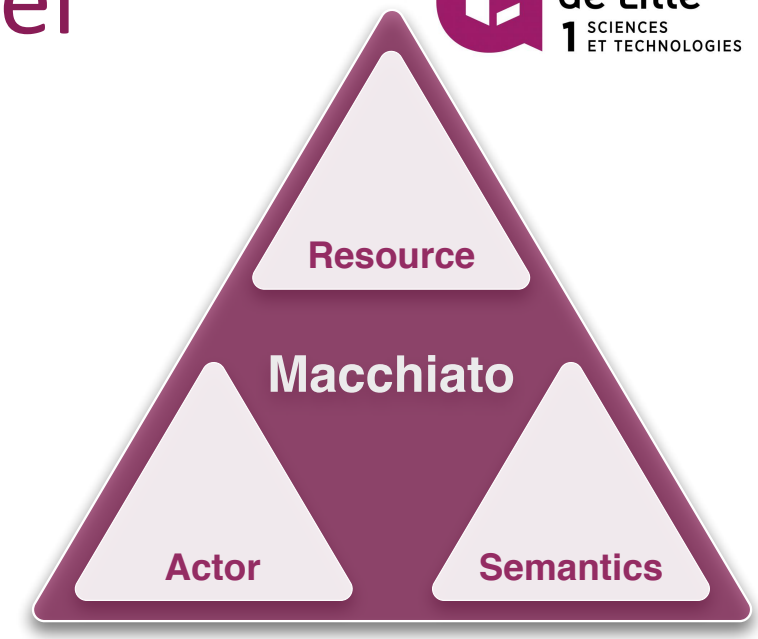
- **Discovery** of resources and capabilities
  - *Including local and remote discovery*
  - *Cyber foraging* [Satya'01, Goyal'04]
- **Optimisation** of the computing resources
  - *Including energy and network consumptions*
  - *Code offloading* [MAUI'10, Cuckoo'12]
- Leverage of interoperability and **serendipity**
  - *Exploiting unexpected opportunities*

Satya'01. M. Satyanarayanan. *Pervasive Computing: Vision and Challenges*. IEEE Personal Communications. 2001
Goyal'04. S. Goyal et al. *A lightweight secure cyber foraging infrastructure for resource-constrained devices*. WMCSA'04
MAUI'10. E. Cuervo et al. *MAUI: making smartphones last longer with code offload*. MobiSys'10
Cucloo'12. R. Kemp et al. *Cuckoo: a computation offloading framework for smartphones*. MobiCASE'12.

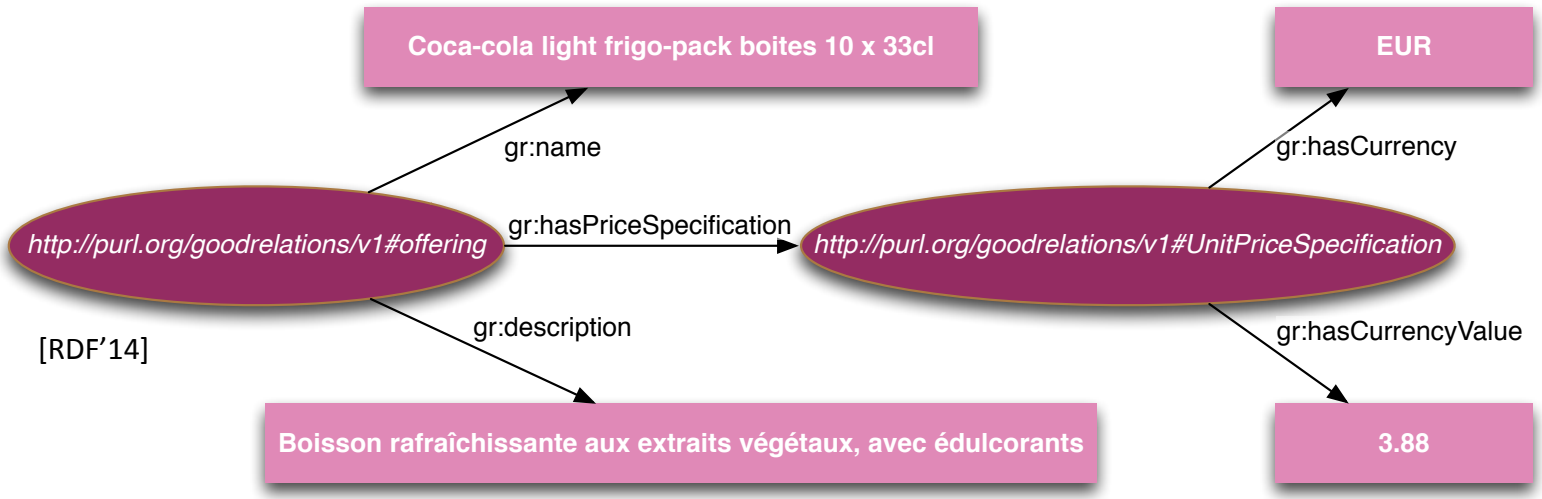
Elastic Programming Model



[Fielding'00]



[Erenkrantz'09]



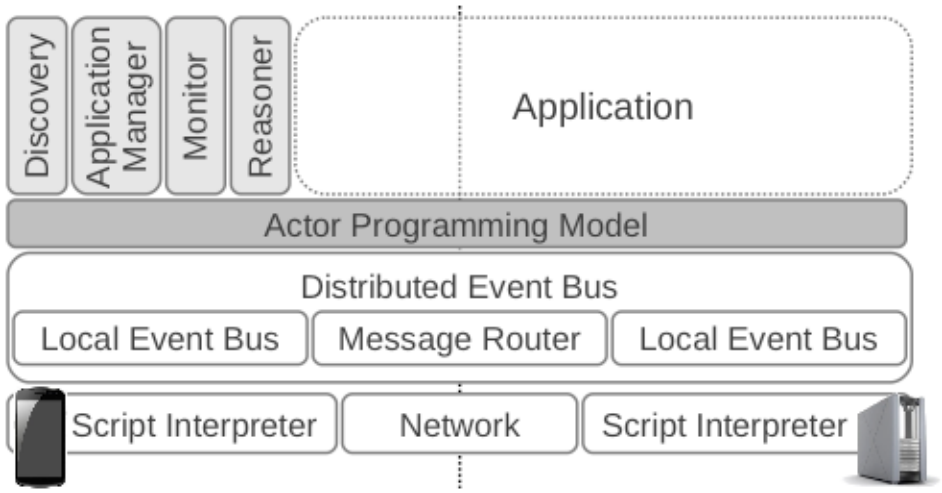
[RDF'14]

Fielding'00. R. Fielding. *Architectural Styles and the Design of Network-based Software Architectures*. PhD. UC Irvine. 2000
RDF'14. W3C. *Resource Description Framework* (RDF). Feb. 2014
Erenkrantz'09. J.R. Erenkrantz. *Computational REST: A New Model for Decentralized, Internet-Scale Applications*. PhD. UC Irvine. 2009

Macchiato ubiquitous middleware

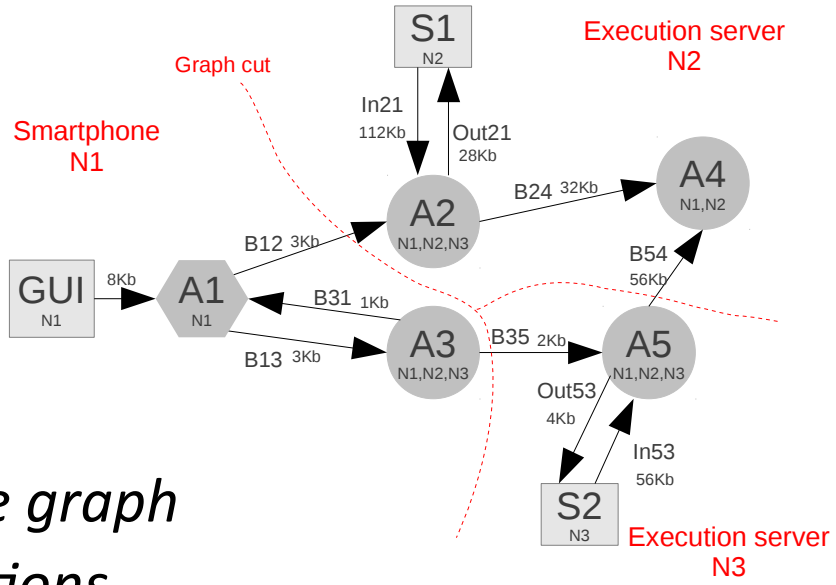
- **Distributed** middleware
  - *Based on JavaScript*
- **Actor**-based model
  - *RDF messages*
- Support for **discovery**
  - *Local discovery (UPnP)*
  - *Location-based discovery*
- Support for **offloading**
  - *Remote actor deployment*
  - *Deployment optimisation*

```
macchiato.create("search-actor").as(
  function(msg, context) {
    context.http.get(
      "http://api.developer.sears.com/v1/products"
    + "?apikey=" + context.searsapikey
    + "&store=Sears&searchType=keyword&keyword="
    + msg.search, function(result) {
        context.send(context.parseJSON(result));
      });
});
```

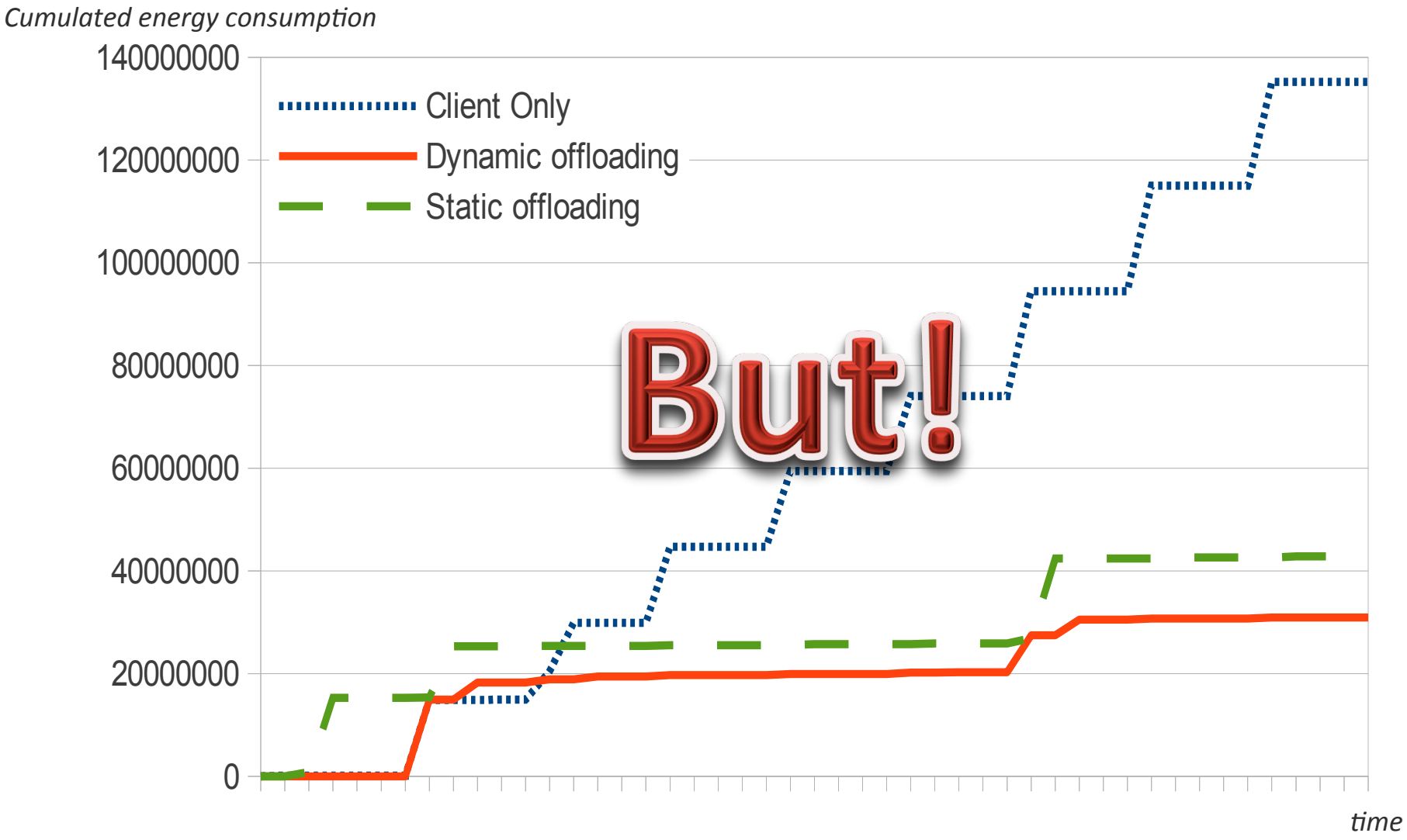


Enabling elasticity in Macchiato

- Actor graph ➔ SAT problem
- Discovery ➔ constraints
- Objective function
  ➘ network exchanges
- Reasoning engine
  - *Triggers upon change in the graph*
  - *Considers sub-optimal solutions*
  - *Queues pending messages*
  - *Keeps a local copy of actors*



Cumulated energy consumption



Kalic12. G. Kalic et al. *Energy consumption in android phones when using wireless communication technologies*. MIPRO'12

Limitations of the approach

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- User-centric process
  - *Lack of* ***coordination***
- Embedded heuristics
  - *Lack of* ***customization***
- Cost of heuristics integration
  - *Lack of* ***extensibility***
- Confidence in heuristics
  - *Lack of* ***feedback***

How to address control as a crosscutting concern?

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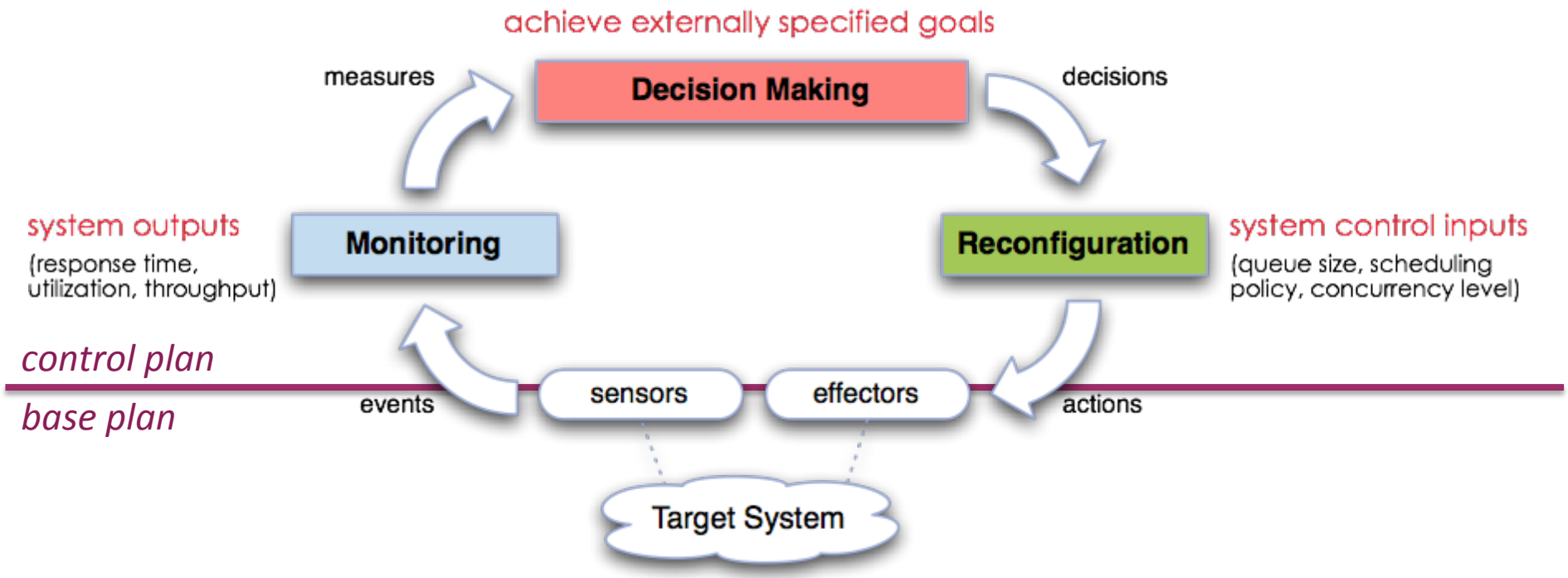
2009–2012

Self-Adaptive very Large disTributed sYstems

ENGINEERING OF FEEDBACK CONTROL LOOPS

Engineering of Feedback Control Loops



Engineering of Feedback Control Loops

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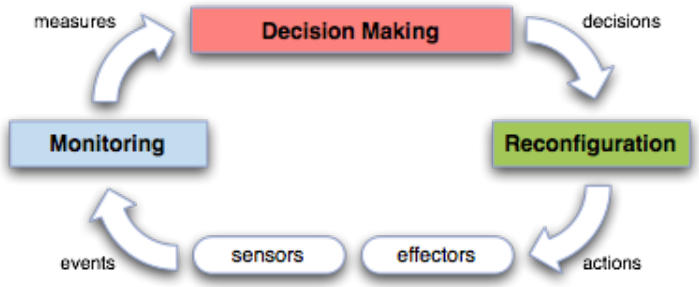
1. Raise the level of abstraction
2. Fine-grained decomposition of FCL elements
3. Explicit interactions
4. Provide reflection capabilities
5. Embed remoting

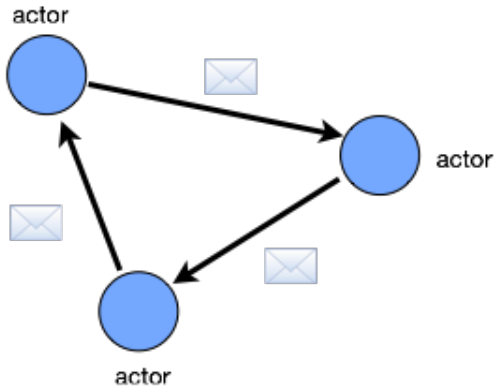


Feedback Control Loop

- Sequence of interconnected processes
- Input × State → Output
- Reactive
- Concurrent
- Dynamic

Domain-Specific Modeling

- Abstraction
- Automation
- Analysis



The Actor Model

- Message passing actor networks
- Message × State → Message(s)
- Reactive
- Concurrent
- Dynamic
- Scalable
- Remoting through location transparency

FCDL in a nutshell

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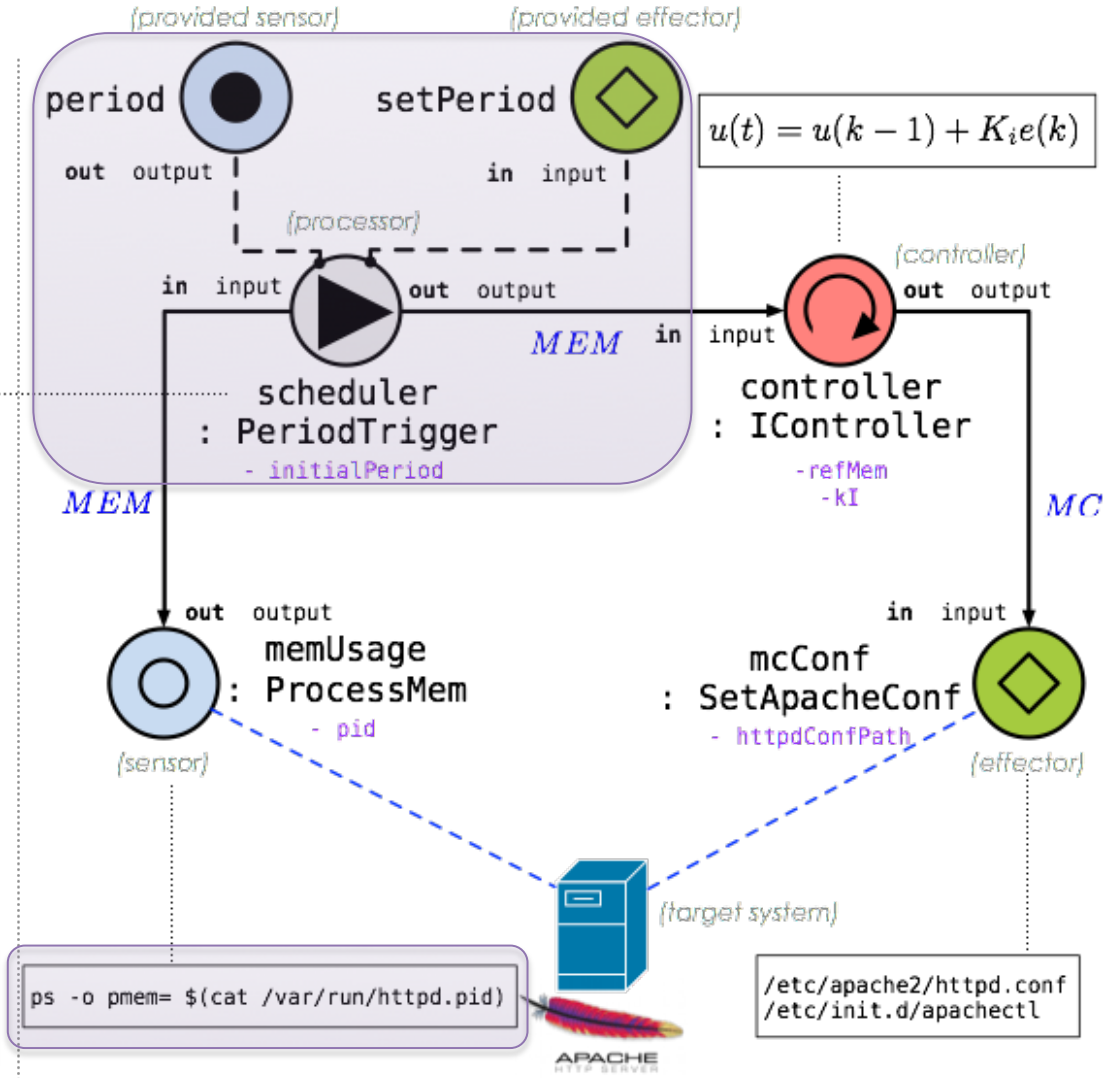
Adaptive Element

- Actor-like component
  - Sensors
  - Effectors
  - Processors
  - Controllers
- Input/output ports & properties
- Active / passive
- Implementation
  - Imperative code (e.g. Java)
  - CEP Rules (e.g. Drools)
  - STM (e.g. bzr/heptagon)
  - Matlab
  - BASH
  - ...
- Interaction contracts

$$\alpha = \langle self; \Downarrow (\mathtt{input}); \Uparrow (\mathtt{output?}) \rangle \parallel \langle \Uparrow (\mathtt{setPeriod}); \emptyset; \Uparrow (\mathtt{period}) \rangle$$



Ubiquitous computing – key results

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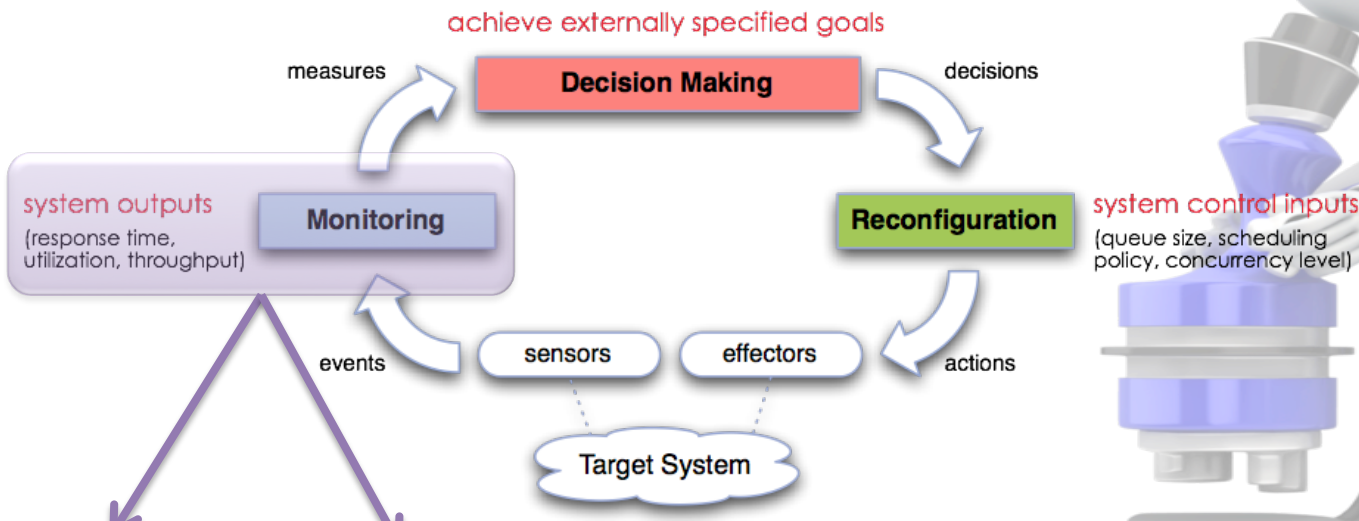
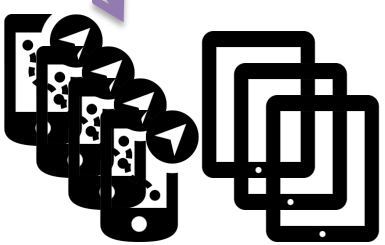
- **Publications (3 PhD thesis / 8 journals / 15 conferences)**
  - Daniel Romero. **Context as a Resource: A Service-Oriented Approach for Context-Awareness**. PhD thesis. Université Lille 1, Sciences et Technologies, July 2011.
  - Eli Gjørven. **Enabling Self-Adaptation by Applying a Technology Agnostic Middleware with Support for Integration**. PhD thesis. University of Oslo, Dec. 2011.
  - Russel Nzekwa. **Building Manageable Autonomic Control Loops for Large Scale Systems**. PhD thesis. Université Lille 1, Sciences et Technologies, July 2013.
  - R. Rouvoy et al. *Dynamic planning and weaving of dependability concerns for self-adaptive ubiquitous services*. In: **SAC'09**.
  - A. Taherkordi et al. *A Generic Component-based Approach for Programming, Composing and Tuning Sensor Software*. In: **The Computer Journal 54.2** (2011)
  - N. Petitprez et al. *Connecting your Mobile Shopping Cart to the Internet-of-Things*. In: **DAIS'12**
  - R. Rouvoy and P. Merle. *Rapid Prototyping of Domain-Specific Architecture Languages*. In: **CBSE'12**
  - A. Taherkordi et al. *Optimizing Sensor Network Reprogramming via In-situ Reconfigurable Components*. In: **ACM Transactions on Sensor Networks 9.2** (2013)
  - F. Krikava et al. *Integrating Adaptation Mechanisms Using Control Theory Centric Architecture Models: A Case Study*. In: **ICAC'14**.
- **Collaborations**
  - *University of Nice (ANR SALTY, P. Collet & F. Krikava)*
  - *University of Oslo (EGIDE PHC Aurora & SeaS associate team)*
- **Grants**
  - *ANR ARPEGE SALTY* *FUI Cappucino*
  - *FUI Macchiato* *PIA Datalyse*

A Focus on context monitoring

- A **critical task** of autonomous software systems
- Required for **system identification** & adaptation
- Produce **meaningful data** for free



In-depth monitoring



In-breadth monitoring

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PowerAPI

ADAM.lille.inria.fr

2010–2014

A focus on power consumption

IN-DEPTH CONTEXT MONITORING

Context

- Energy consumption of ICT (France) [TIC'09]
  - *13.5% in 2009*
  - *40% in 2019 (forecast)*
- Meanwhile
  - ↗ *IT devices & datacenters*
  - ↗ *Idle power consumption*
- Hardware optimizations
  - *Dynamic Voltage/Frequency Scaling (DVFS)*
  - *Hyper-threading*
  - *Turboboost*
  - *Core power states (C-States)*

How to identify energy hotspot in applications?

TIC'09. Ministère de l'écologie. *TIC et développement durable*. March 2009.

PowerAPI middleware toolkit

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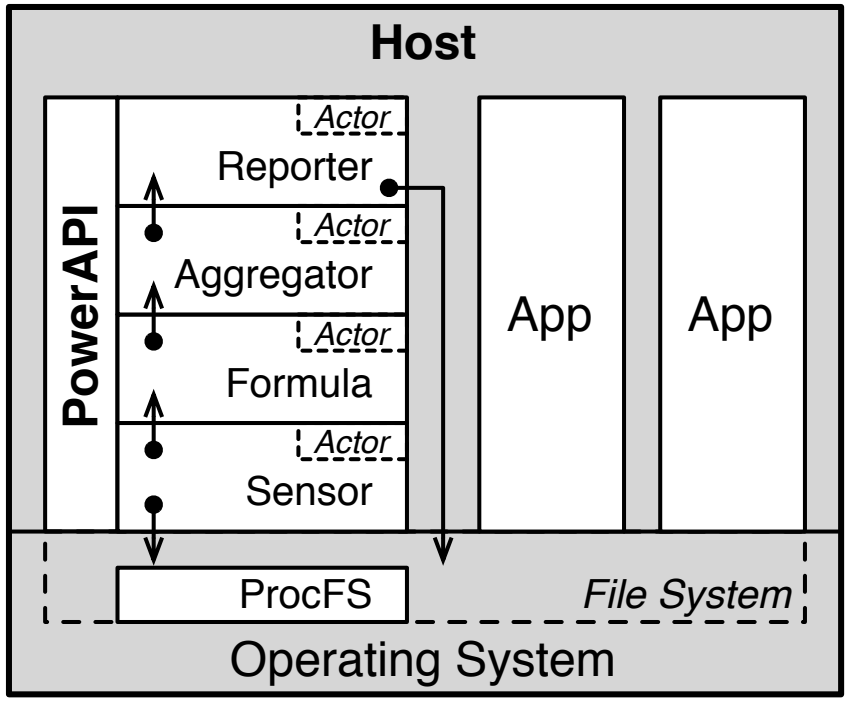
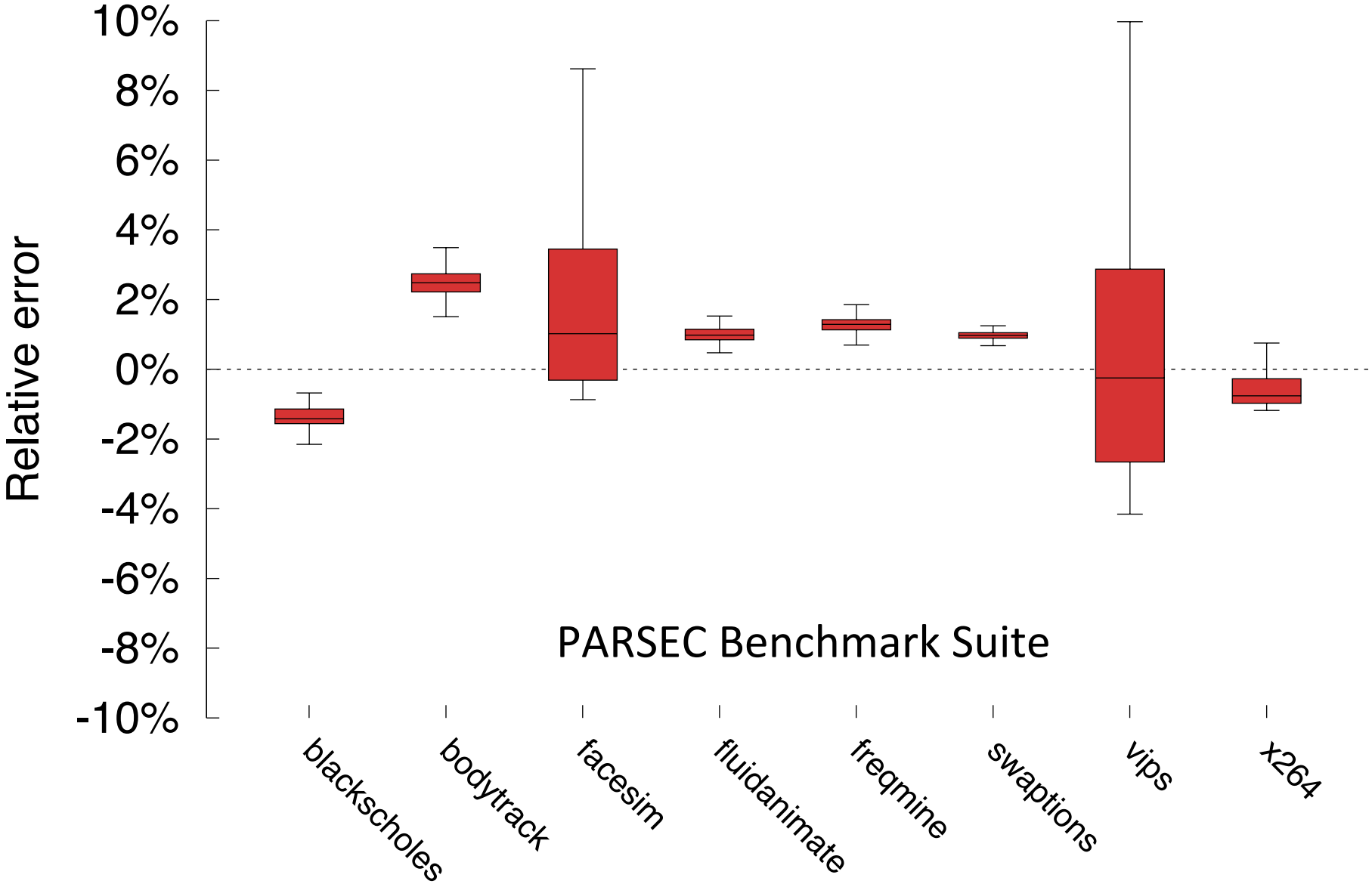
Software-defined power meters

- Internal sensors
  - *ProcFS, libpfm4*
- External sensors
  - *PowerSpy, RAPL*
- Formulas
  - *CMOS, DVFS, regression*
- Reporters
  - *GUI, Network, FUSE*



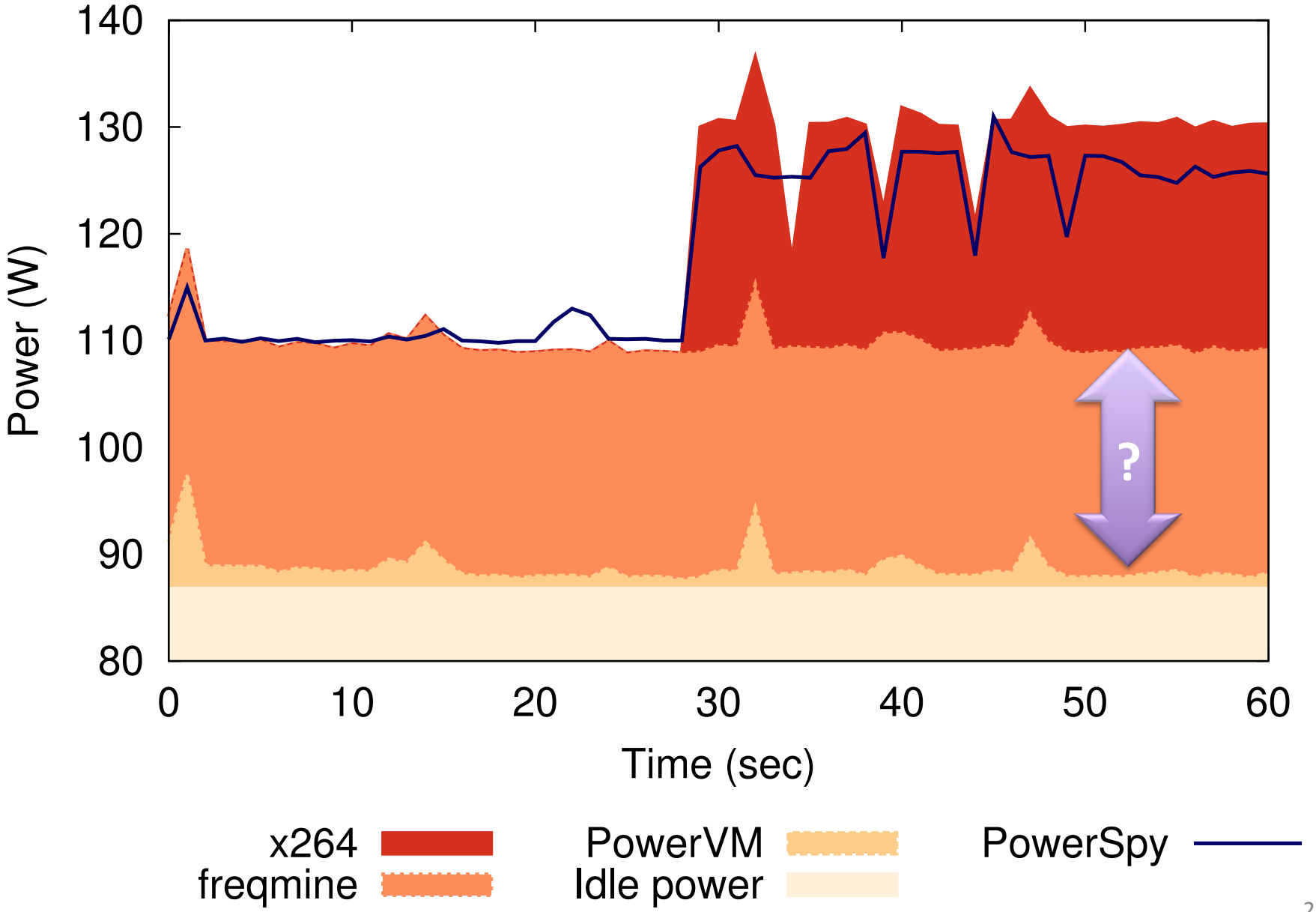
$$Power^{d}_{software} = CPU^{utilization}_{software} * Power^{d}_{CPU}$$

PowerAPI mean estimation error



PARSEC. C.Bienia. Benchmarking Modern Multiprocessors. Ph.D. Thesis. Princeton University, January 2011.

PowerAPI power estimation accuracy



Code-level power monitoring

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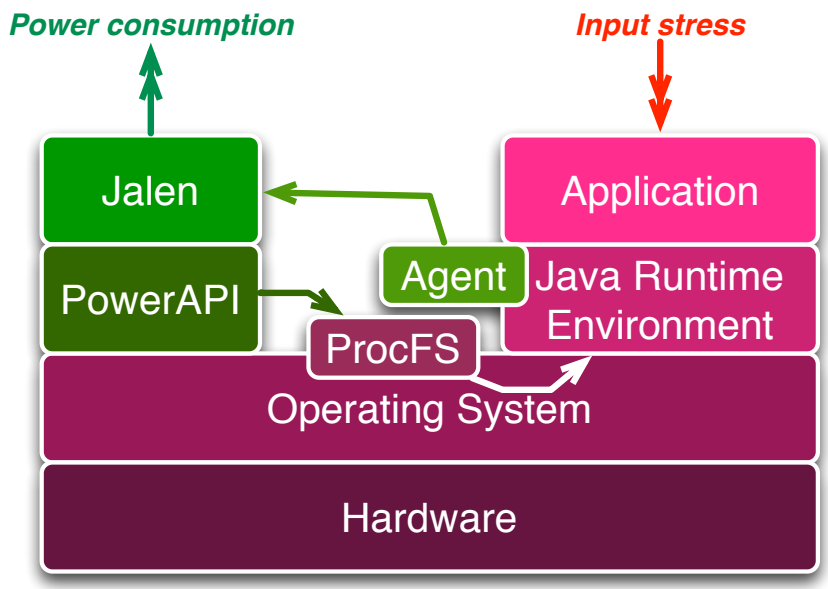
- **Jalen = PowerAPI++**
  - *Exploits process estimations*
  - *Extracts code-level metrics*
  - *Monitors utilization per thread (CPU + HDD)*
- 2 implementations
  - *Bytecode instrumentation*
  - *Statistical sampling*



$$Power_{thread}^{CPU} = \frac{Power_{software}^{CPU} * Utilization_{thread}^{CPU}}{Duration_{cycle}}$$

Jalen instrumentation overhead

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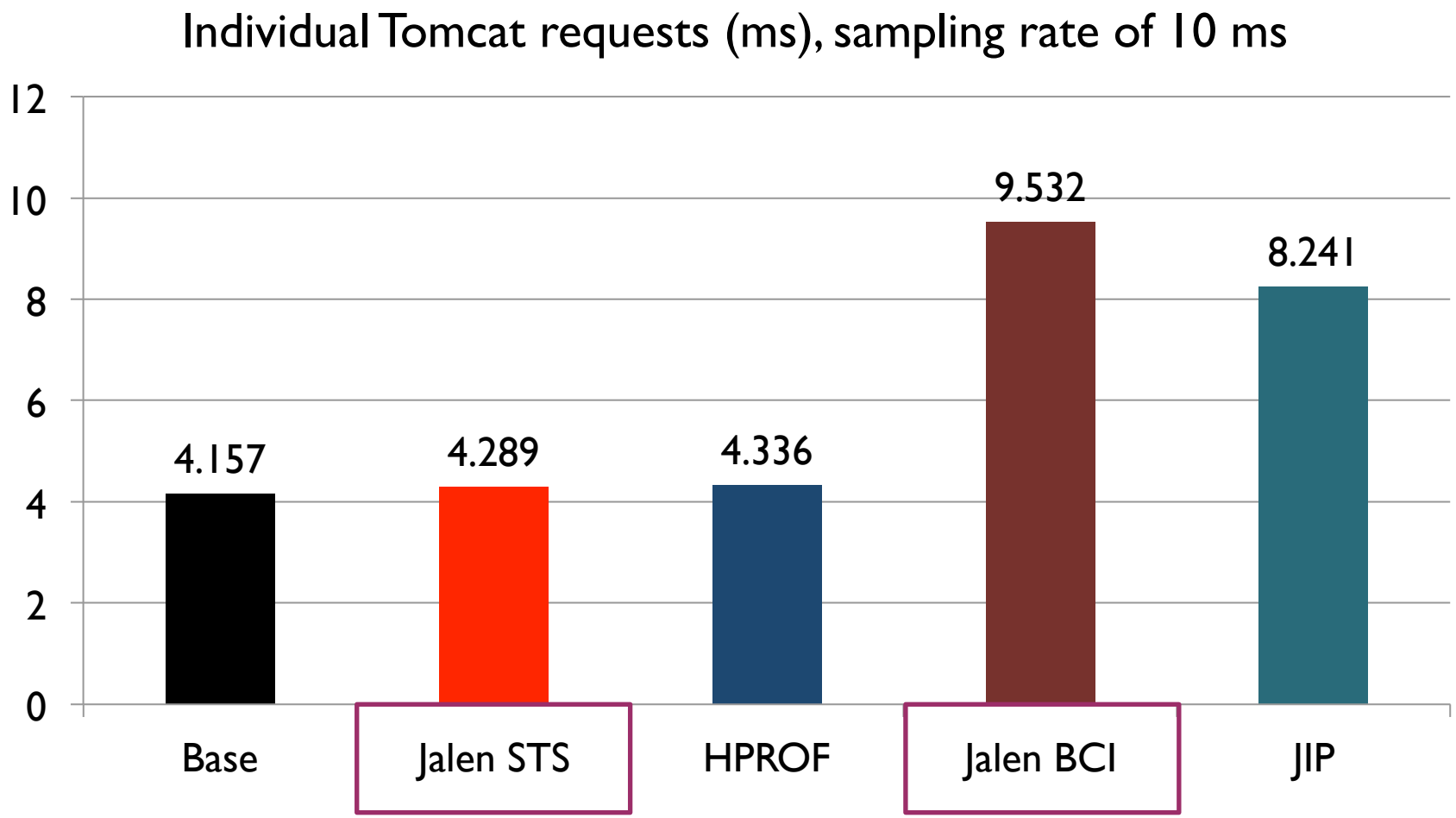
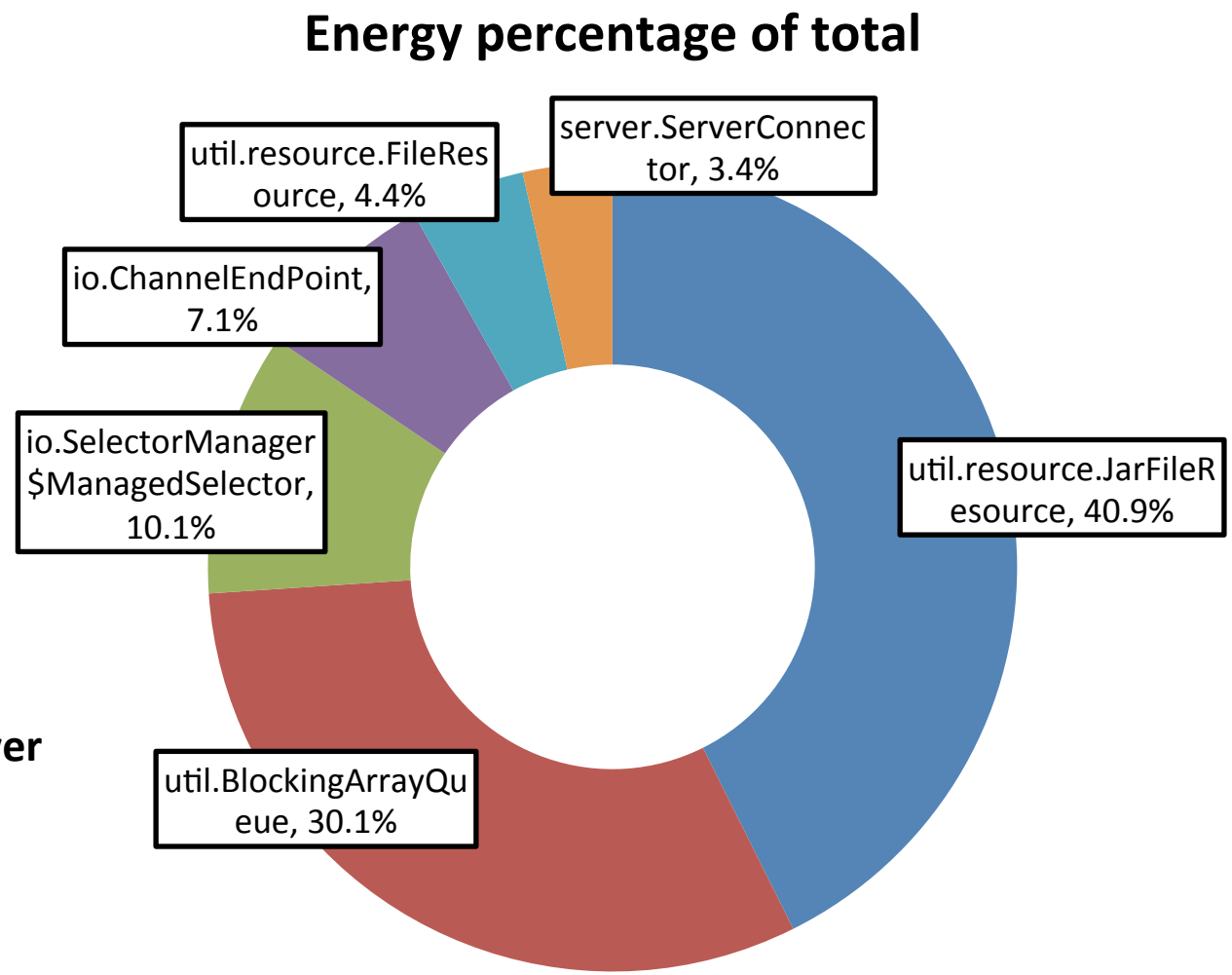


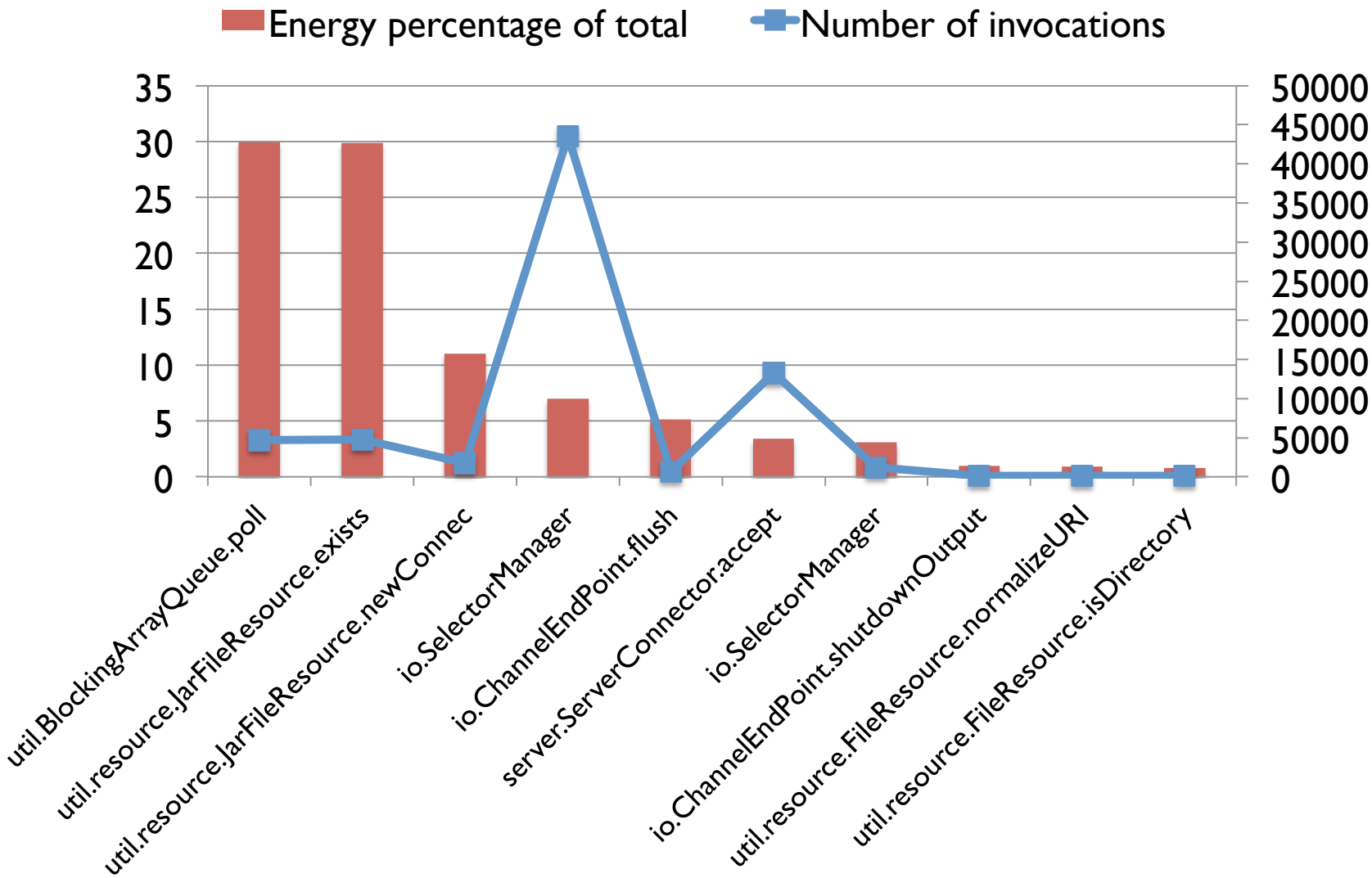
Energy dissipation into classes



Jetty web server
> 105,000 LoC

Stress
25 users
100,000 requests

Energy dissipation into methods



In-depth monitoring - key results

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- **Publications (1 PhD thesis, 3 journals, 2 conferences)**
  - *A. Noureddine.* ***Towards a Better Understanding of the Energy Consumption of Software Systems****. PhD thesis. Université Lille 1. July 2014*
  - *A. Noureddine et al. Monitoring Energy Hotspots in Software. In:* ***Journal of Automated Software Engineering*** *(2014).*
  - *A. Noureddine et al. A review of energy measurement approaches. In:* ***ACM SIGOPS Operating Systems Review 47.3*** *(Dec. 2013).*
  - *A. Noureddine et al. A Review of Middleware Approaches for Energy Management in Distributed Environments. In:* ***Software: Practice and Experience 43.9*** *(Sept. 2013).*
  - *A. Noureddine et al. Runtime Monitoring of Software Energy Hotspots. In:* ***ASE'12****.*
- **Collaborations**
  - *Power consumption estimation in virtualised environments (Univ. of Neuchâtel)*
  - *Reducing of the power consumption of a HPC cluster (L2EP, Univ. of Lille 1)*
- **Grants**
  - *FUI EconHome*
  - *Inria ADT 2013 (1 engineer)*
- **Transfer (http://powerapi.org - AGPL)**
  - *Web Energy Archive (funded by ADEME)*
  - *KaliTerre (dynamic code analysis)*

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apisense

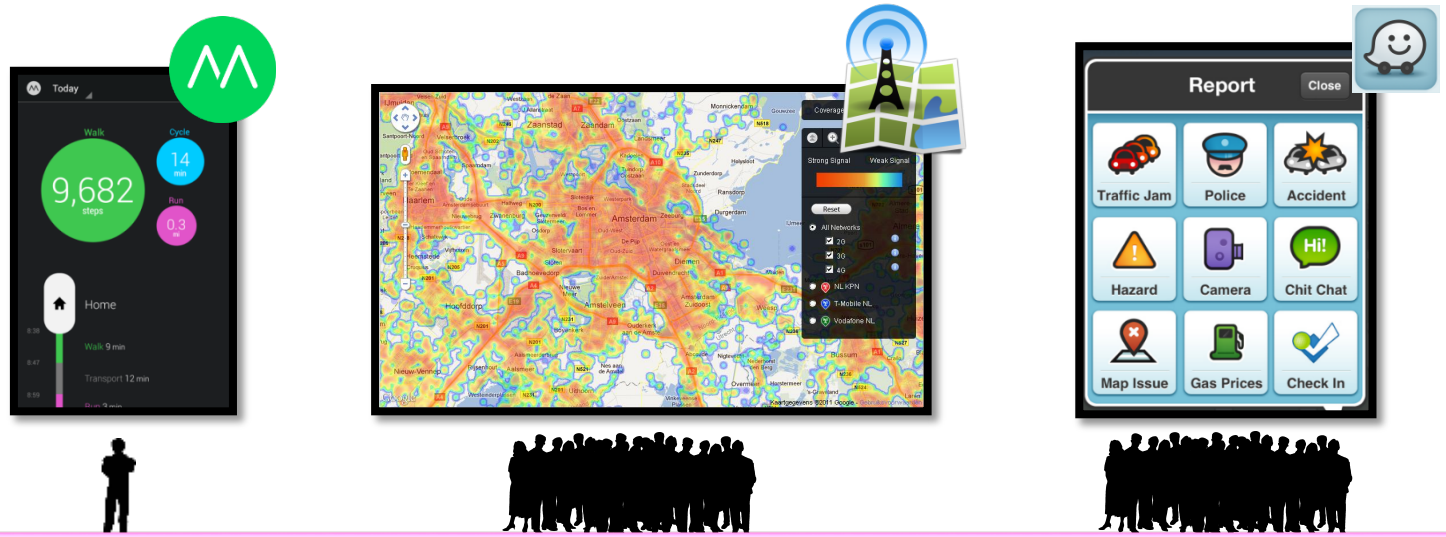
2010–2014

A focus on mobile crowd-sensing

IN-BREADTH CONTEXT MONITORING

Mobile crowd-sensing

- «*category of applications that we term mobile crowdsensing, where* ***individuals*** *with sensing and computing devices collectively* ***share data*** *and extract information* ***to measure*** *and map* ***phenomena*** *of common interest*» [Ganti'11]



How to federate crowd-sensing tasks at large?

Ganti'11. R. Ganti et al. Mobile crowdsensing: current state and future challenges. *Communications Magazine, IEEE*, *49*(11).

Research challenges

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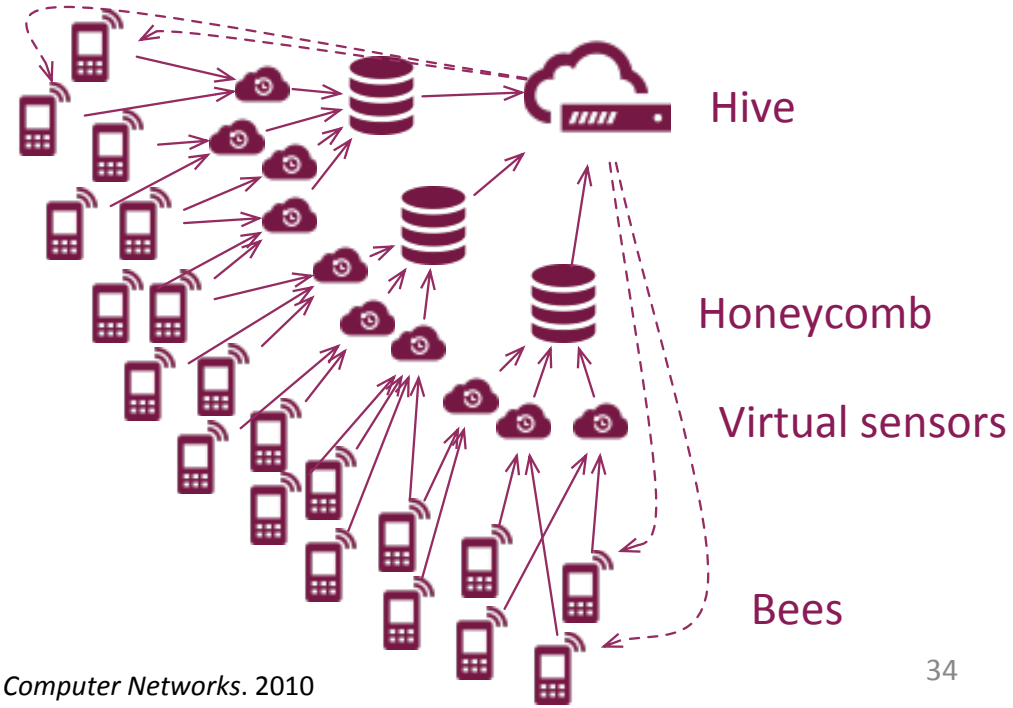
- **Flexibility** [Funf, PRISM]
  - *Supporting participative and opportunistic tasks*
- **Scalability** [MEDUSA]
  - *Supporting both individual and crowd tasks*
- **Privacy** [Anonysense]
  - *Preserving sensitive data for the participants*
- **Energy** [Pogo]
  - *Minimizing the power consumption of tasks*
- **Incentives** [Anonysense]
  - *Engaging participants to contribute along time*

Anonysense. Shin et al. Anonysense : A system for anonymous opportunistic sensing, *Pervasive and Mobile Computing*, 2011
PRISM. Das et al. PRISM : platform for remote sensing using smart-phones, *MobiSys*'10
Funf. Aharony et al. *Social fMRI: Investigating and shaping social mechanisms in the real world*, *Pervasive and Mobile Computing*, 2011
Pogo. Brouwers et al. *Pogo, a middleware for mobile phone sensing*. *Middleware*'12
Medusa. Ra et al. *Medusa: A programming framework for crowd-sensing applications*. *MobiSys*'12

APISENSE®: Mobile crowd-sensing

- Crowd-sensing language
  - *JavaScript extension*
  - *Injecting facades*
- Mobile infrastructure
  - *Bee SDK*
  - *Bee App*
- SaaS infrastructure
  - *Hive service*
  - *Honeycomb services*
  - *Virtual sensors* [Chowdhurry10]

```
$location.onLocationChange(function(event)
{
   $trace.add({
      lat : event.latitude,
      lng : event.longitude,
      signal : $telephony.signalStrength()
    });
});
```



Chowdhury10. M.K. Chowdhury et al. *A survey of network virtualization*. *Computer Networks*. 2010

Orchestrating crowd-sensing tasks

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sense

```
sense(function( ) { … } );
```

recruit

```
accept(function( ) {
   if ($network.connectionType() == 'Mobile')
      return { battery : $battery.level() };
});

ranking(function(users) {
   return users.sort('battery');
});
```

coverage

```
geoCoverage(
  [[50.614291,3.13282],[50.604159,3.15239]],
  '500 m');

timeCoverage("30 min","1 H");

duplicate(10);
```

Evaluation of APISENSE®

- Objectives
  1. *Volume of exchanged data*
  2. *Energy consumption*
  3. *Data coverage*

- Real mobility traces
  - *10 000 cabs from Bejing*

- Comparing 3 strategies
  a. ***Individual**: no coordination (witness)*
  b. ***Coll(500)**: coverage objective of 500×500 meters*
  c. ***Coll(1000)**: coverage objective of 1000×1000 meters*

Evaluation of APISENSE®

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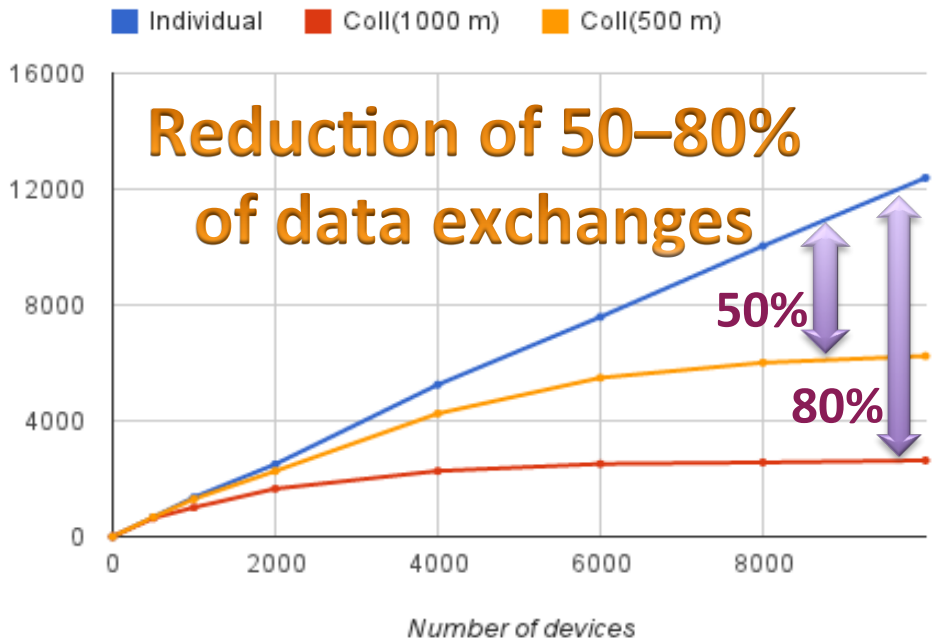

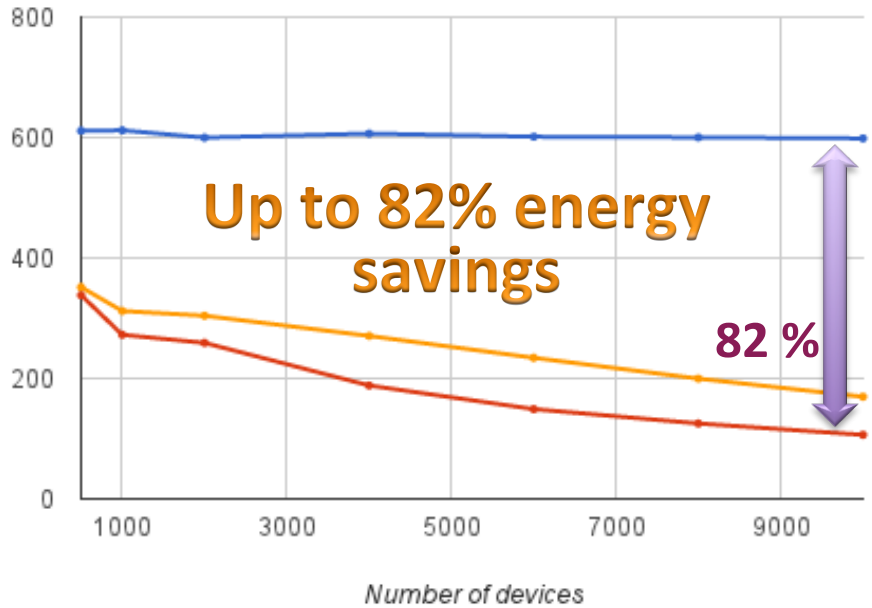

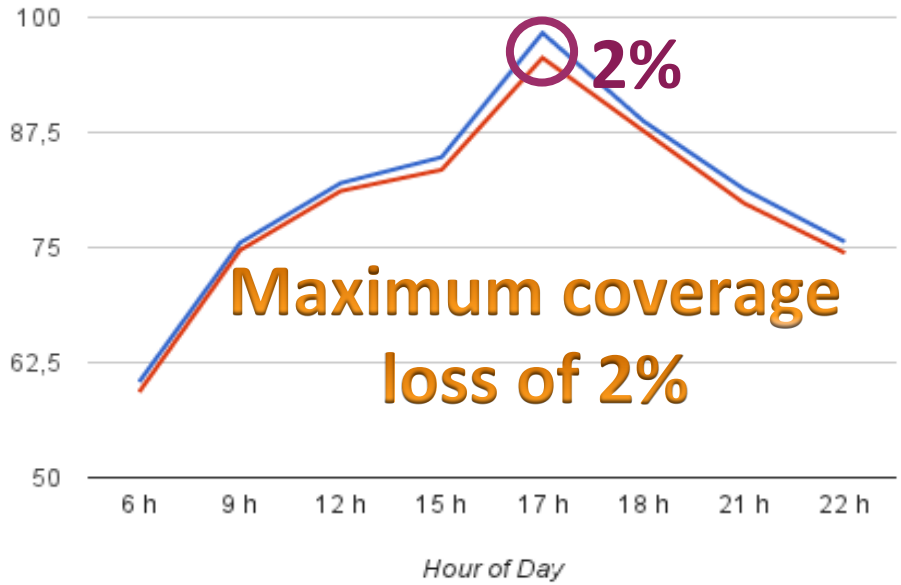

	W/B-Scanner *opportunist*	Citizen journalist *participative*
APISENSE®	**4**	**9**
Anonysense	5	N/A
Pogo	4	N/A
MyExperience	N/A	27
Medusa	N/A	45
PRISM	??	330

APISENSE®: Engaging participants

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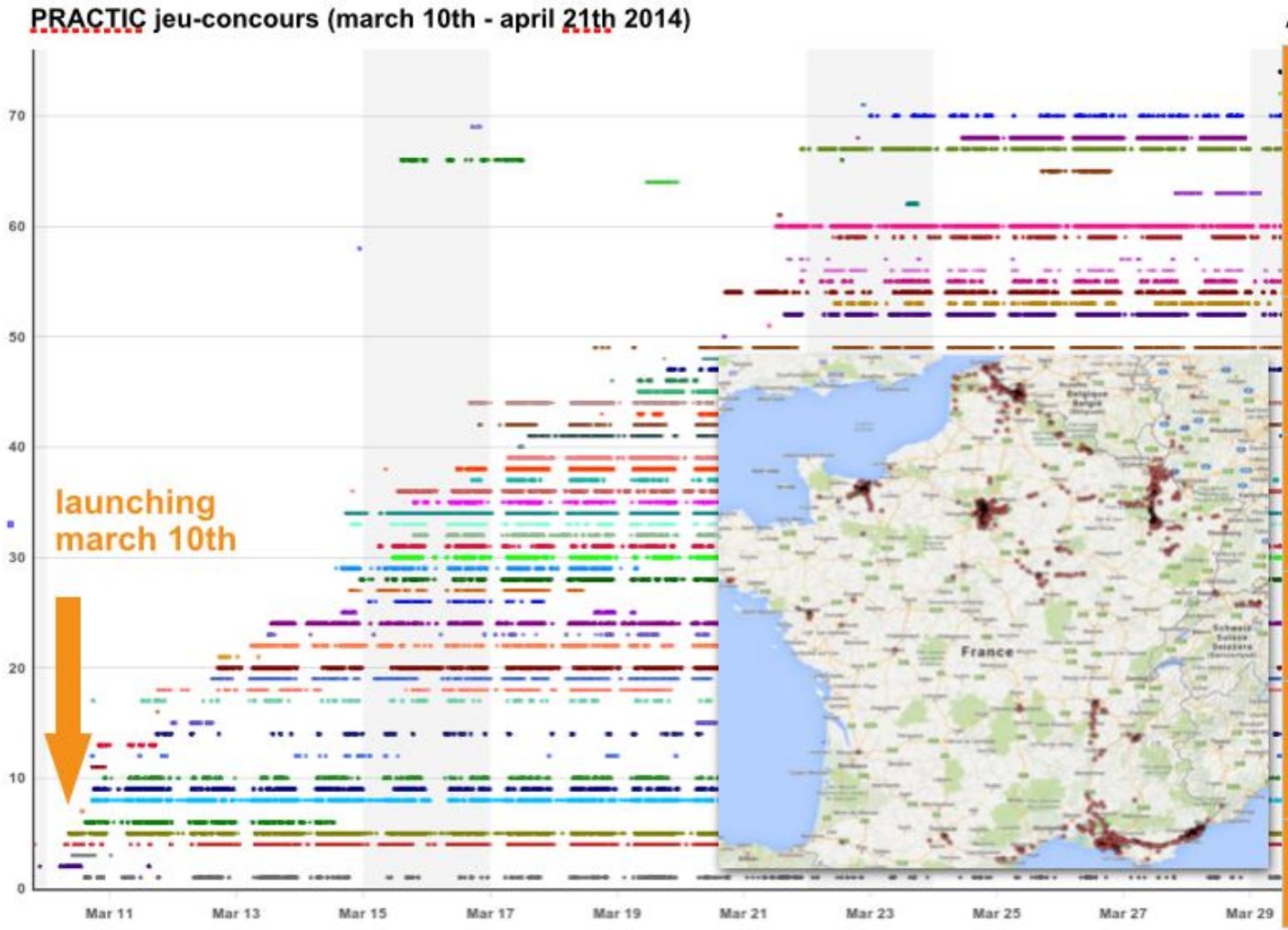

All Campaigns (except Caen)

112 371 of data	or 39 days of data per user (average)
97 volunteers	Of which : - 64 % male - 80 % age under 30 - 73 % single - 35% income < 1500€/m.
68 % of students	Of which : - 43% Computer Sc./ ingeneers - 22% Communication
14 device brands	Of which : - 41% Samsung - 24% LGE - 12%Sony
48 device models	Of which : - 12% LGE Nexus 5
13 telecom operators	Of which : - 77% Free, Orange, Bouygues and SFR; - 12% unknown
14 Androïd versions	Of which : 26% in 4.4.2

Interesting insights for social sciences

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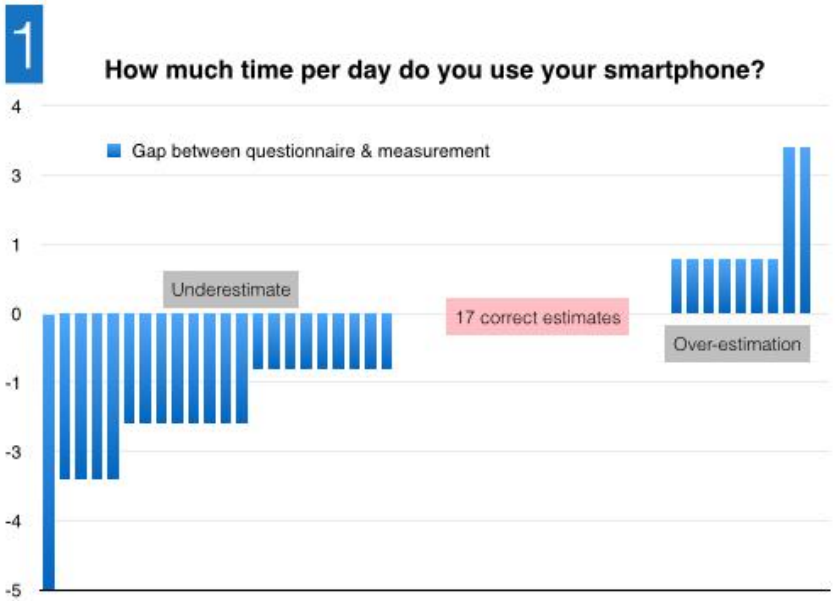

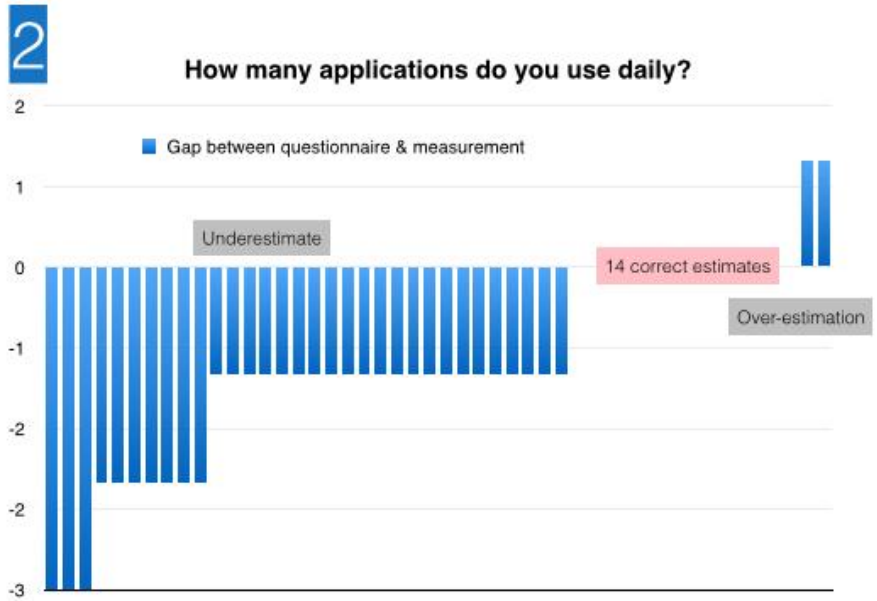

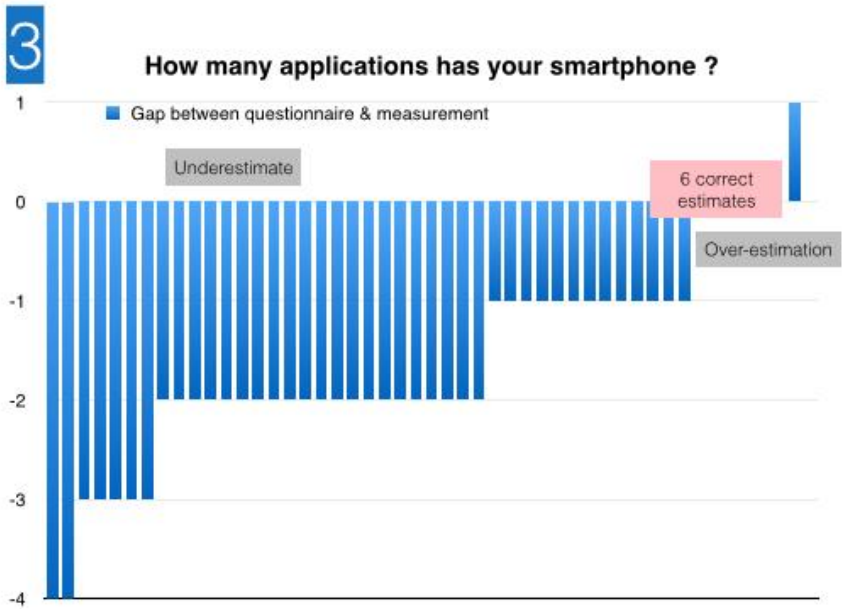

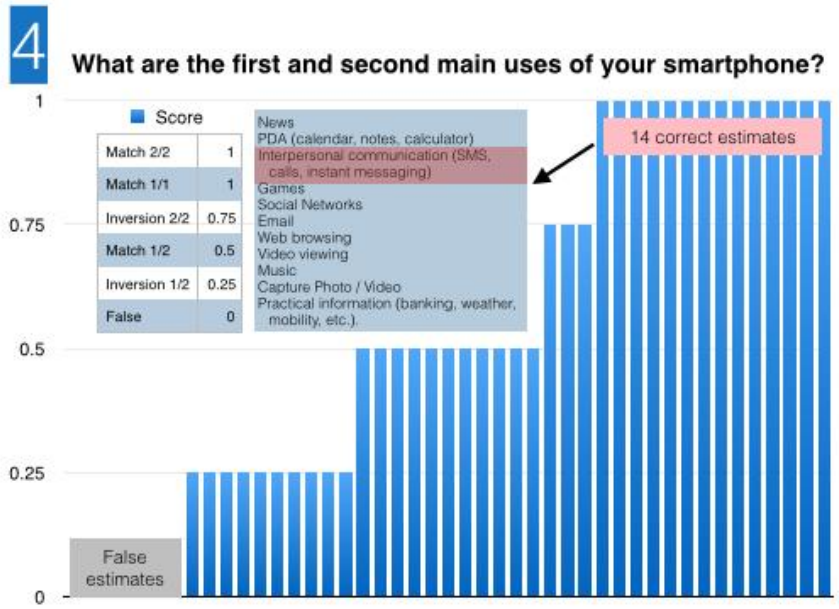

In-breadth monitoring – key results

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- **Publications (1 PhD thesis, 1 book chapter, 2 conferences)**
  - *N. Haderer.* ***APISENSE : une plate-forme répartie pour la conception, le déploiement et l'exécution de campagnes de collectes de données sur des terminaux intelligents****. PhD thesis. Université Lille 1. Nov. 2014.*
  - *N. Haderer, et al. A Cloud-based Infrastructure for Crowdsourcing Data from Mobile Devices. In:* ***Cloud-based Software Crowdsourcing****. 2014.*
  - *N. Haderer, et al. Dynamic Deployment of Sensing Experiments in the Wild Using Smartphones. In:* ***DAIS'13****.*
  - *N. Haderer et al. A preliminary investigation of user incentives to leverage crowdsensing activities. In:* ***PerHot'13****.*
- **Collaborations**
  - *PRACTIC (Inria)*
  - *Priva'Mov (LIRIS / CITI)*
  - *Carbon Footprint Estimation (EQUIPPE, Univ. Lille 1)*
  - *Indoor Air Quality (PC2A, Univ. Lille 1)*
  - *Outdoor Air Quality (LISIC, Univ. Côte d'Opale)*
- **Grants**
  - *Inria ADT 2012 (1 engineer)*
  - *Inria ADT FOCUS 2014 (3 engineers)*
  - *Microsoft Azure4Research grant*
- **Transfer (http://apisense.com)**
  - *ip-label (telecom)*
  - *Start-up (ongoing)*

Conclusion

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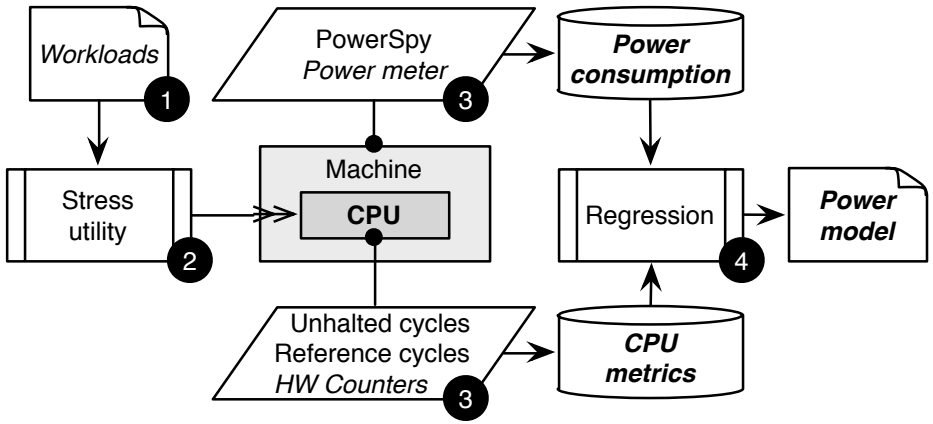
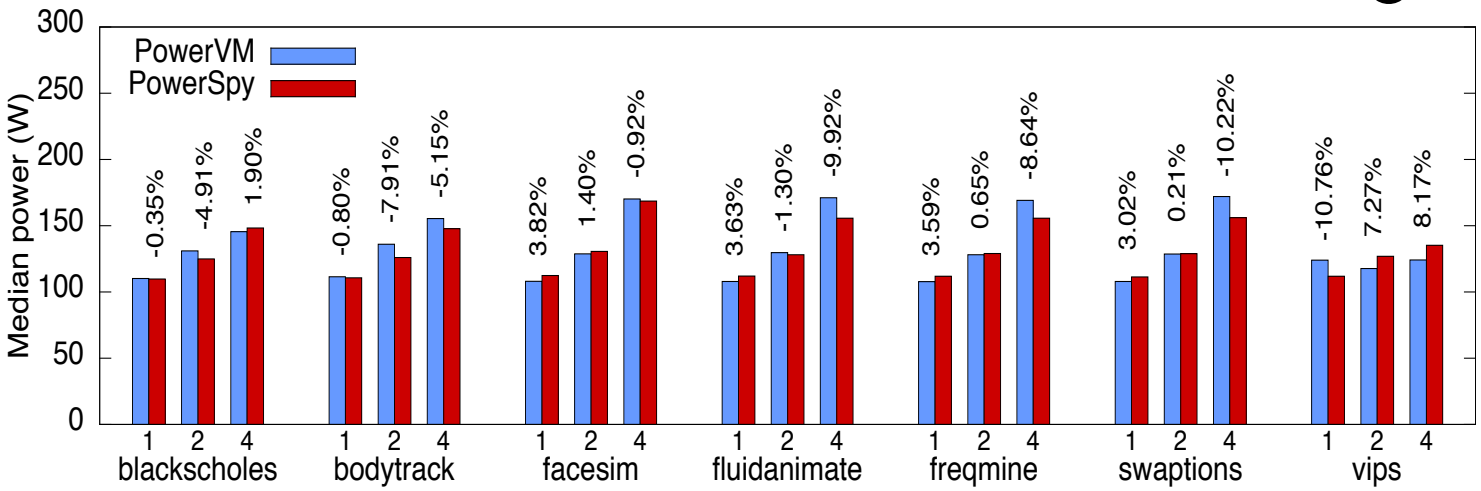
Autonomy of ubiquitous software systems

- *Elastic programming models*
  - Supporting the adaptation of software systems at runtime
- *Feedback control loops*
  - Promoting FCL as first class entities
- *Efficient context monitoring middleware*
  - Enabling in-depth monitoring with PowerAPI
  - Controlling in-breadth monitoring with APISENSE®

Perspective for PowerAPI (1/2)

- PhD thesis of Maxime Colmant (ADEME / Lille 1)
  - *Reducing the power consumption of applications running on multi-core architectures*
    - Advanced CPU features
    - Virtualisation layers
    - Asymmetric CPUs
    - GPUs





Perspective on APISENSE® (2/2)

- PhD thesis of María Gomez (Inria)
  - *Debugging mobile applications in the wild based on the quality of experience perceived by the crowd*
    - Collecting QoE (traces + feedbacks)
    - Capturing crashes (tests)
    - (Auto) Fixing bugs
    - Deploying patches