Elastic Computing - Principles, Models, and Algorithms for Software Services, Things, and People on the Cloud

ISSSE, Salerno, 9 July 2013

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Distributed Systems Group

Acknowledgements

Includes some joint work with Kamal Bhattacharya, Muhammad Z.C. Candra, Georgiana Copil, Daniel Moldovan, Mirela Riveri, Ognjen Scekic

NOTE: The content includes some ongoing work

Outline

- Part 1: Elastic Computing
  - Smart evolution – people, services and things
  - Large-scale & collective problem solving
  - Humans-as-a-service
  - Multi-dimensional elasticity
  - Things–as-a-service
  - Conclusions

- Part 2: Engineering Elastic Applications in the Cloud
  - Specifying, controlling and monitoring elasticity
  - Demonstration
  - Elasticity with HBS and hybrid compute units
  - Conclusions

PART 2 – ENGINERING ELASTIC APPLICATIONS

Engineering Cloud Applications -- modeling and controlling multi-level elasticity of cloud services

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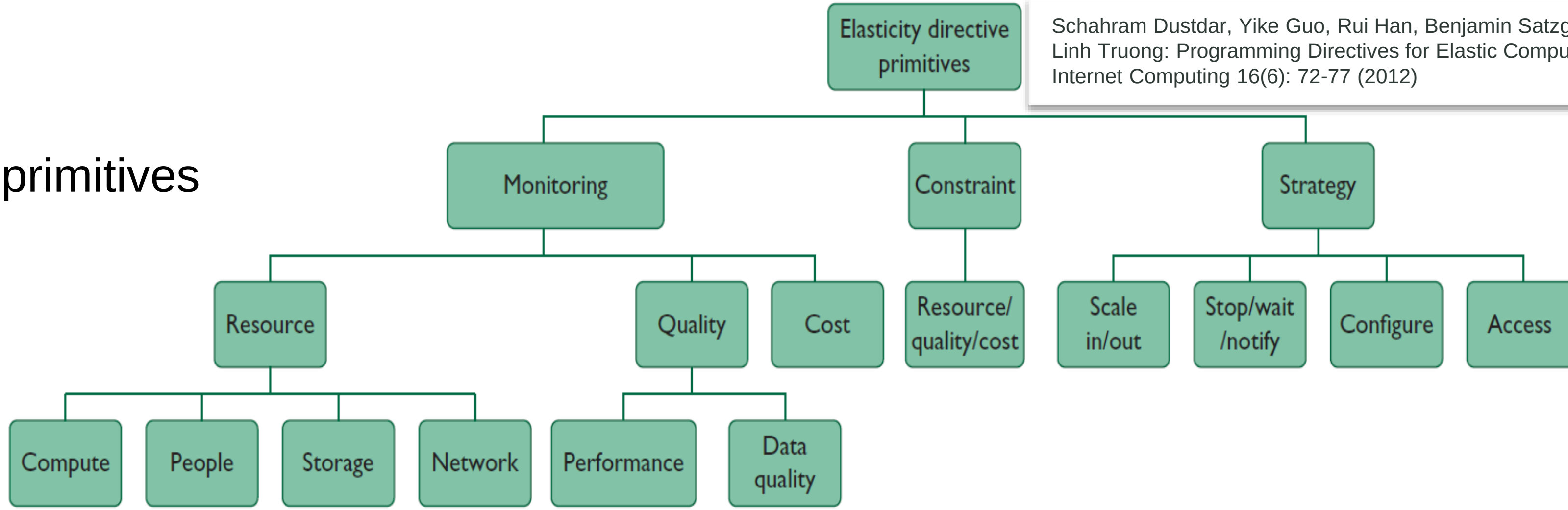
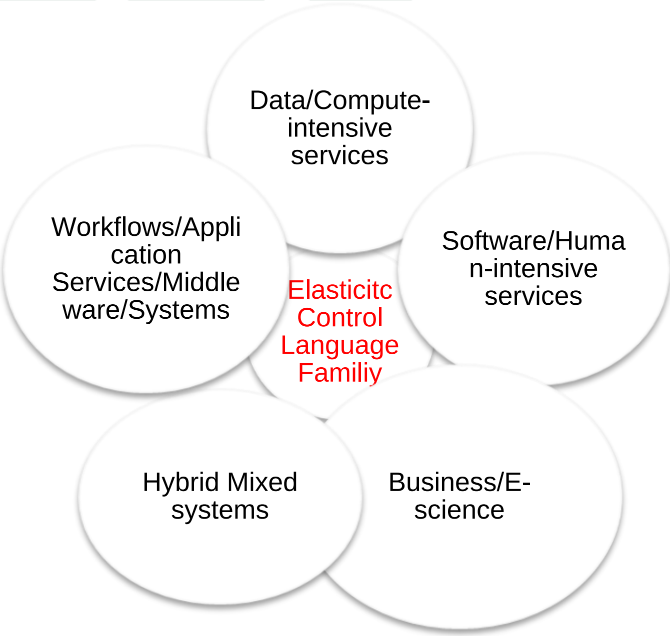
Specifying and controling elasticity

Schahram Dustdar, Yike Guo, Rui Han, Benjamin Satzger, Hong Linh Truong: Programming Directives for Elastic Computing. IEEE Internet Computing 16(6): 72-77 (2012)

Basic primitives



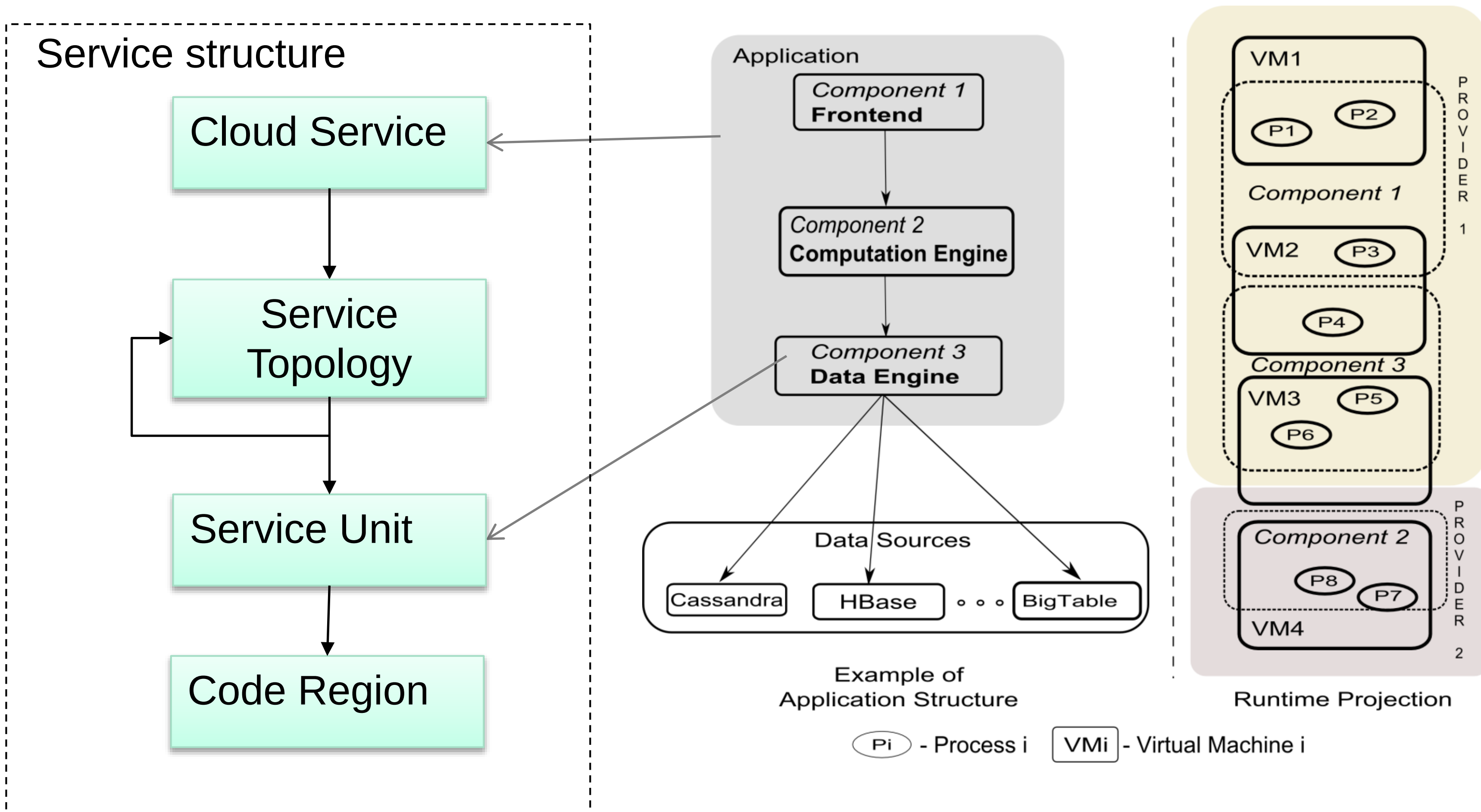
Domain-specific/
Customized features



SYBL -- Simple Yet Beautiful Language

- Stimulated by directive programming models
  - Goals: easy to use, high-level, multiple levels of control
- Language for elasticity requirements specification
- Possible users: cloud provider, application owner, application developer, software provider
- Targeted to data/compute intensive cloud services

Multi-level elasticity needed



SYBL main concepts (1)

- „Monitoring“

  Directives for describing what needs to be monitored and under what conditions

$$
\begin{aligned}
M_i := \texttt{MONITORING}\ varName = x_j \mid \\
\texttt{MONITORING}\ varName = formula(x_1 ... x_n) \\
where \\
x_j \in c, c \in \ ApplicationDescriptionInfo
\end{aligned}
$$

Georgiana Copil, Daniel Moldovan, Hong-Linh Truong, Schahram Dustdar, "SYBL: an Extensible Language for Controlling Elasticity in Cloud Applications", 13th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGrid), May 14-16, 2013, Delft, the Netherlands

SYBL main concepts (2)

- „Constraint“

  Directive for describing what needs to true and under what conditions

$$C_i := \mathtt{CONSTRAINT}\ p \in formula_i(x)\ rel\ formula_j(y)$$
$$where$$
$$x, y \in ApplicationDescriptionInfo$$
$$rel \in \{\leq, \geq, \neq, =\}$$

SYBL main concepts (3)

„Strategy“

Directive for describing how to achieve certain goals and under what conditions

$$S_i := \texttt{STRATEGY CASE } [Condition : Action] | \\ \texttt{WAIT } Condition \mid \texttt{STOP} \mid \texttt{RESUME} | \\ \texttt{EXECUTE } strategyName\ parameter_{1 \ldots n} \\ where \\ Condition : DefFunctions \to \{true, false\}$$

SYBL main concepts (4)

Other constructs: predefined functions and environment variables

Function	Description
GetEnv	Current cloud infrastructure environment
Violated	Checks whether the constraint sent as parameter is violated
Enabled	Checks whether an elasticity specification is enabled or not
Priority	Returns the priority of an elasticity specification

Environment variable	Description
optimal_cloud_provider	The cloud provider that the decision components finds to be best suited
compute_bid	The current bid for the current cloud provider
total_cost	The cost - depends on the level at which variables are being referenced

Examples of SYBL elasticity requirements

```
#SYBL.CloudServiceLevel
Mon1 MONITORING rt = Quality.responseTime
Cons1 CONSTRAINT rt < 2 ms. when nbOfUsers < 1000
Cons2 CONSTRAINT rt < 4 ms. when nbOfUsers < 10000
Cons3 CONSTRAINT totalCost < 800 Euro
Str1 STRATEGY CASE Violated(Cons1) OR Violated(
Cons2): ScaleOut
Priority(Cons1)=3, Priority(Cons2)=5

#SYBL.ServiceUnitLevel
ComponentID = Component3; ComponentName= DataEngine
Cons4 CONSTRAINT totalCost < 600 Euro

#SYBL.ServiceUnitLevel
ComponentID = Component2 ComponentName= ComputingEngine
Cons5 CONSTRAINT cpuUsage < 80%

#SYBL.CodeRegionLevel
Cons6 CONSTRAINT dataAccuracy>90% AND cost<400
```

SYBL and Implementation

- Current SYBL implementation

  in Java using Java annotations

  @SYBL_CloudServiceDirective(monitoring=„“,constraints=„“,strategies=„“)

  in XML

  Specific xml schema

  <SYBLElasticityDirective><Constraints><Constraint name=c1>...</Constraint></Constraints>...</SYBLElasticityDirective>

- Other possibilities

  C# Attributes

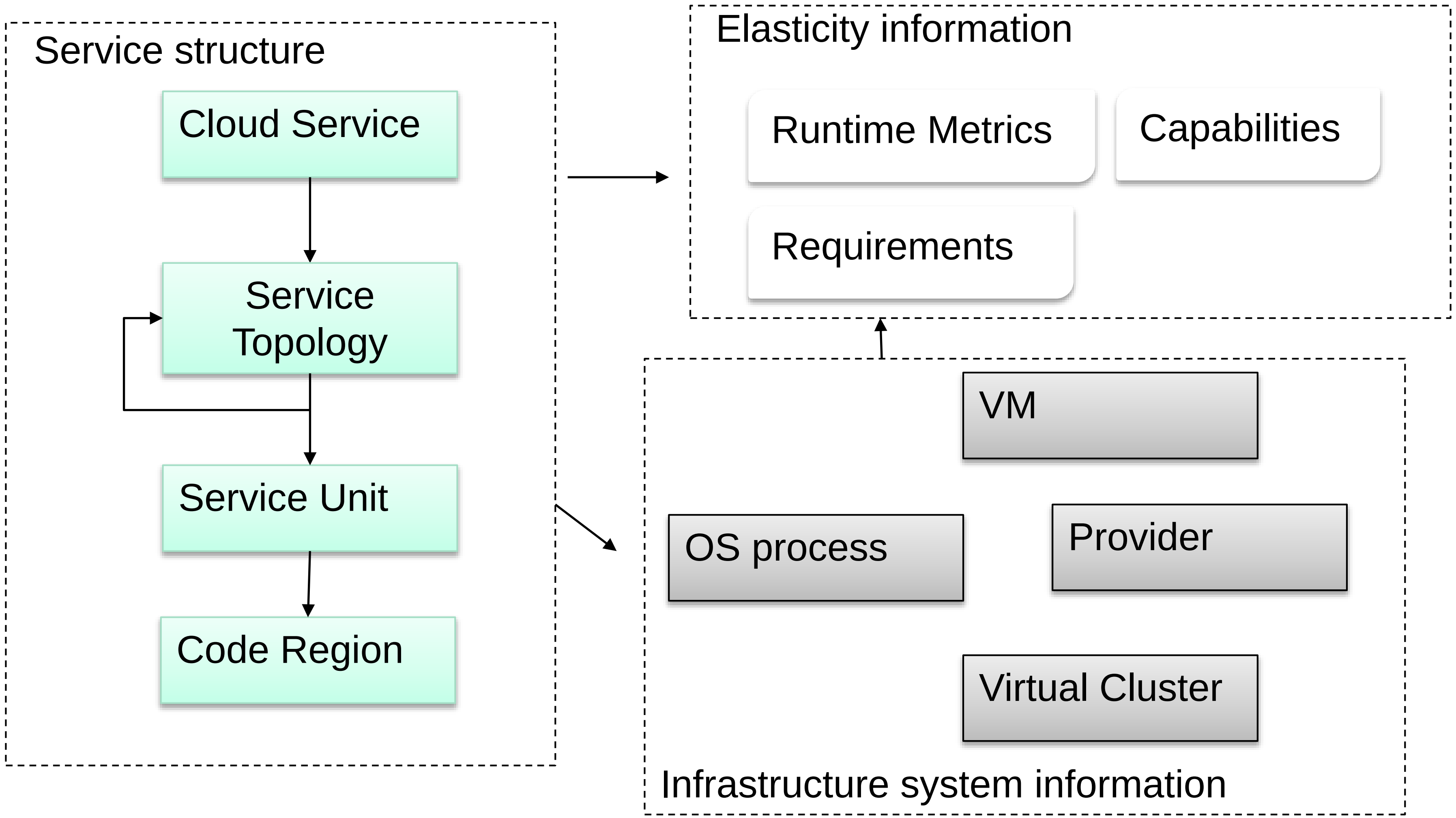
  [SYBLElasticityAttribute(monitoring=„“,constraints=„“,strategies=„“)]

  Python Decorators

  @SYBLElasticityDecorator(monitoring,constraints,strategies)

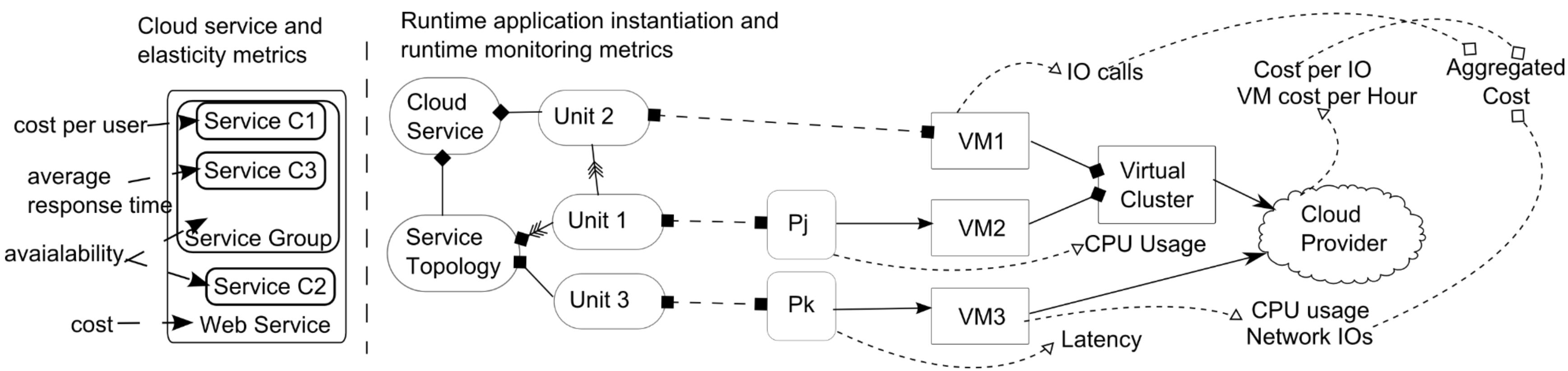
  ...

Controling the elasticity



Complex mapping and generation actions for enforcing elasticity (1)

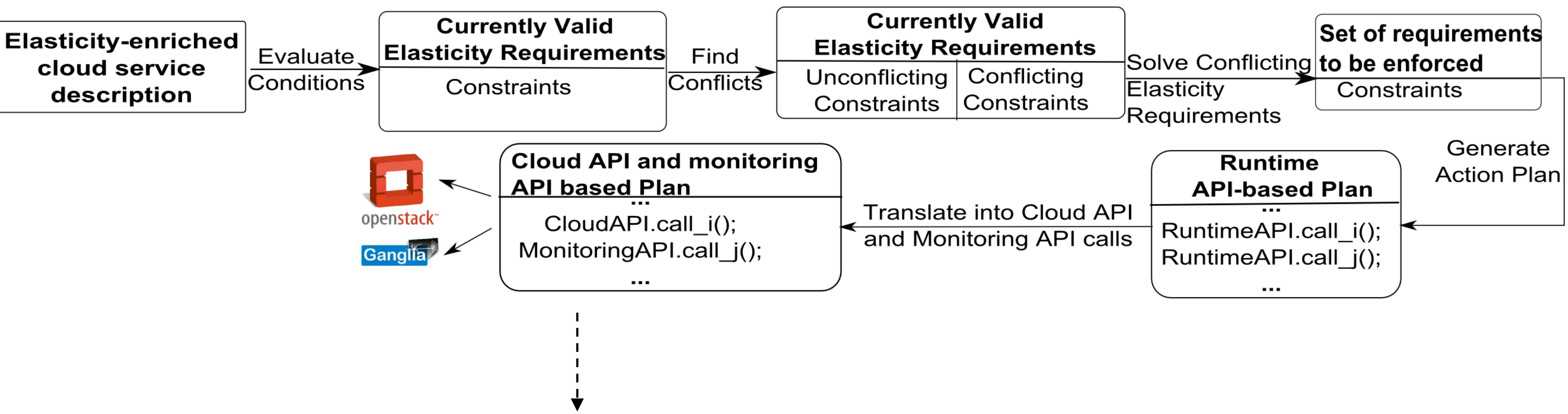
Constructing and maintaining the elastic cloud service dependengy graph



Georgiana Copil, Daniel Moldovan, Hong-Linh Truong, Schahram Dustdar, "**Multi-level Elasticity Control of Cloud Services**", June 2013, On Submission.

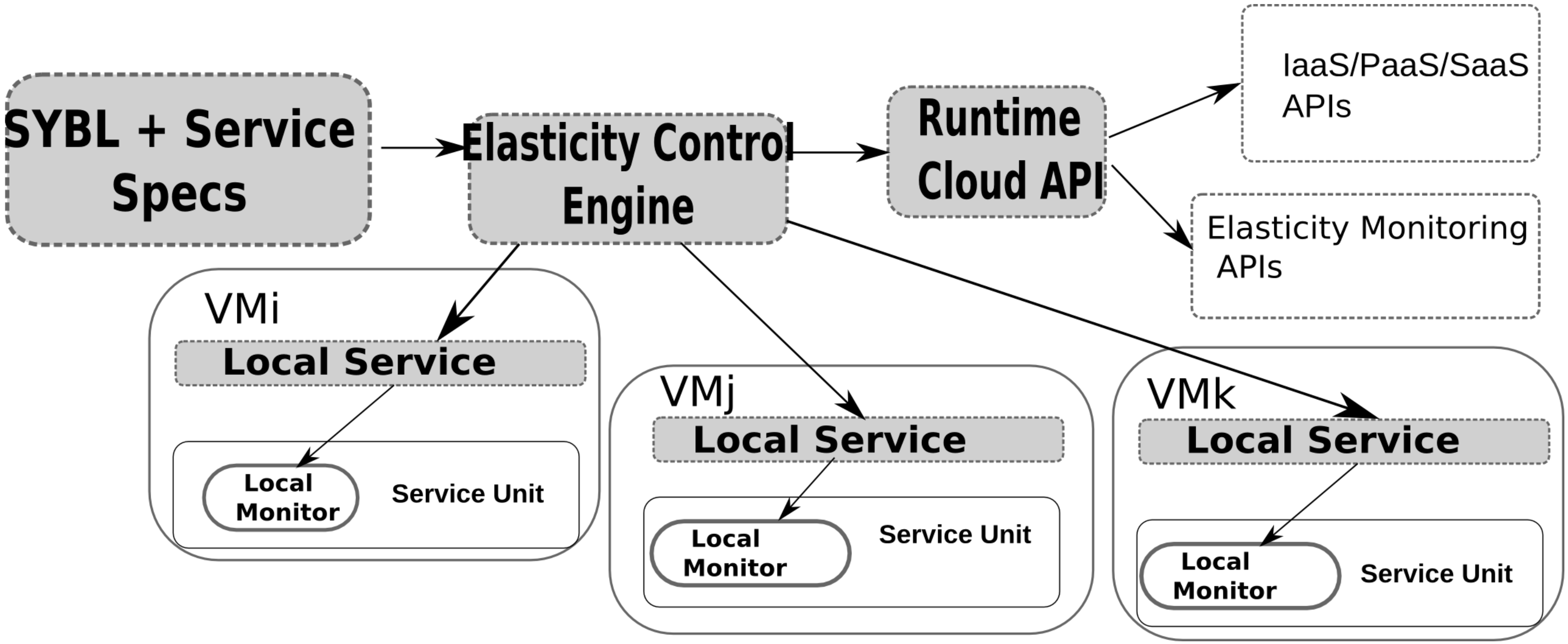
Complex mapping and generation actions for enforcing elasticity (2)

Steps in enforcing elasticity



Cloud providers/tools must support higher and richer APIs for elasticity controls

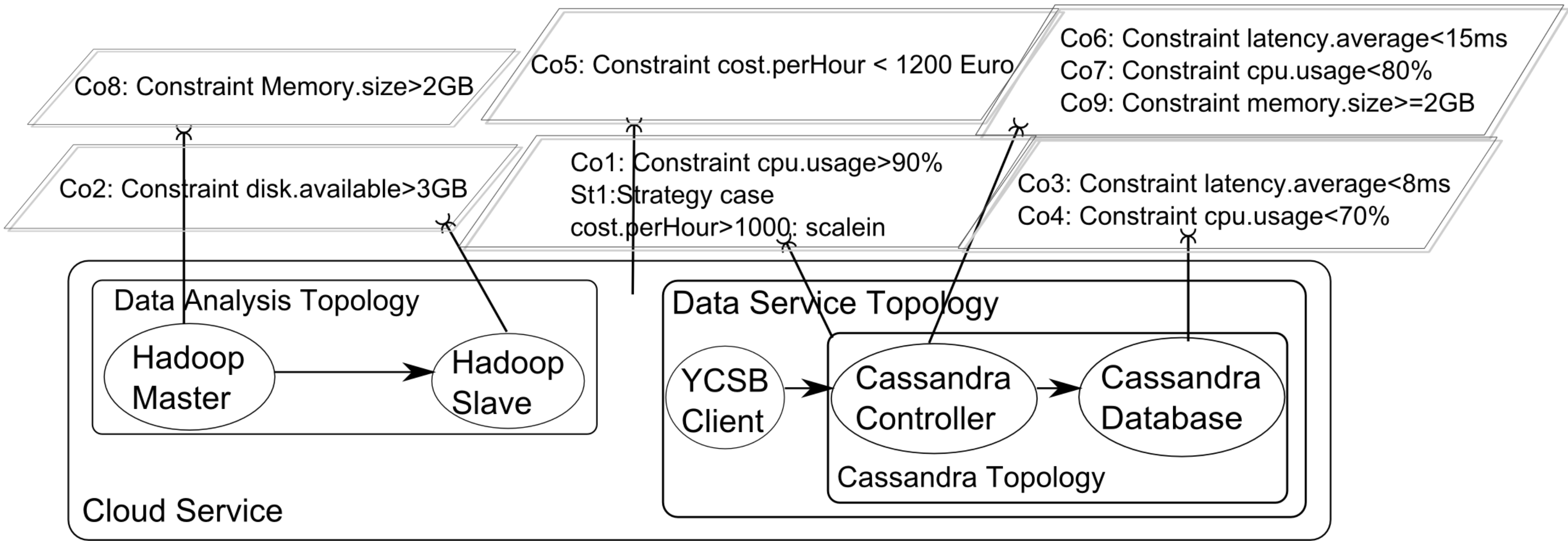
Elasticity Control as a Service



Currently, we support non-shared computational resources (VM)

Examples of Elasticity Controls

A service provider deploys its cloud service to an IaaS infrastructure

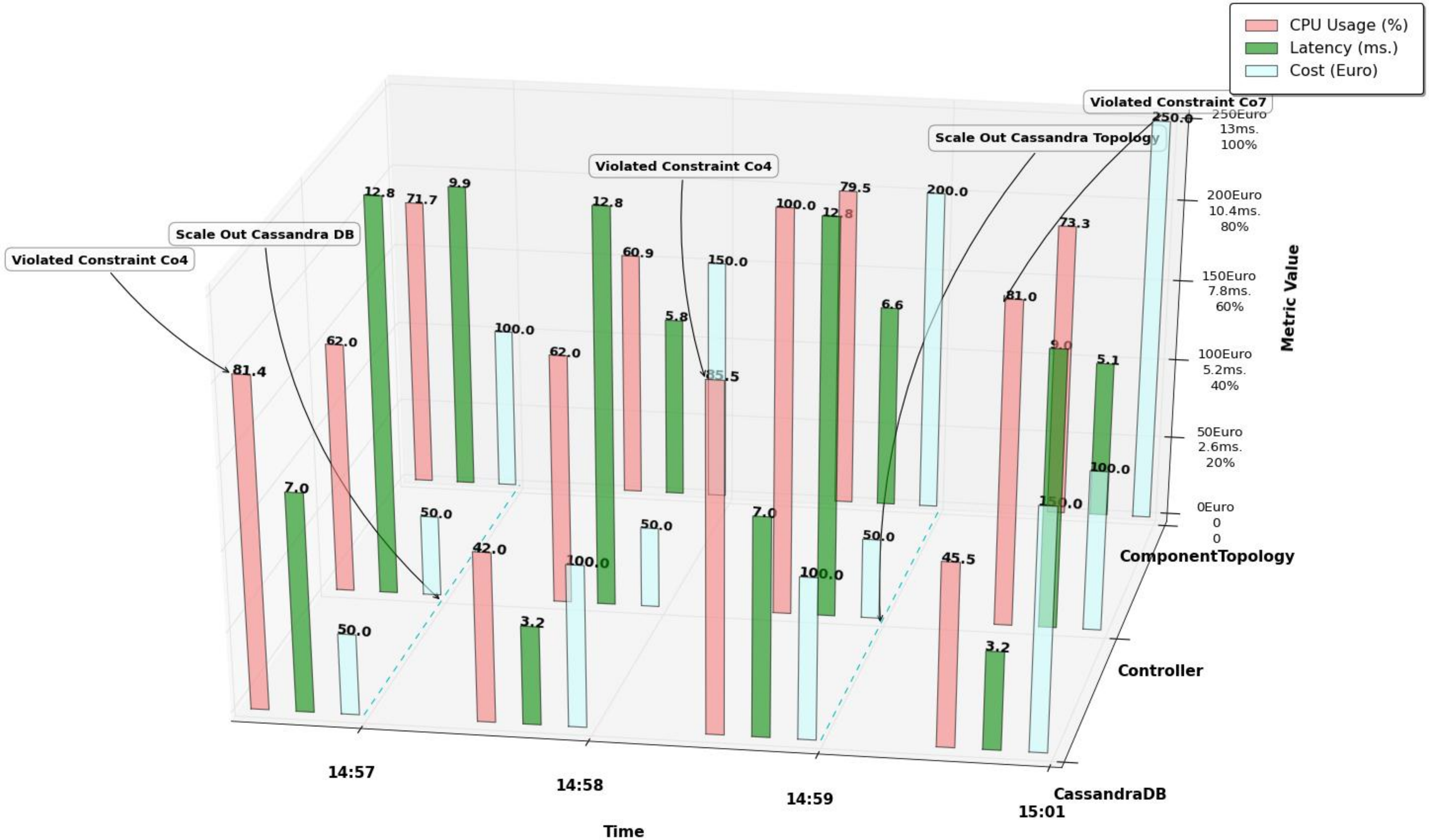


Configuration	Controllers	DB Nodes	Total execution time	Cost
Config1	1	3	578.4 s	0.48
Config2	1	6	472.1 s	0.91
Config3	2	2	382.4 s	0.42
Config4	3	7	372.2 s	0.72

Service unit level

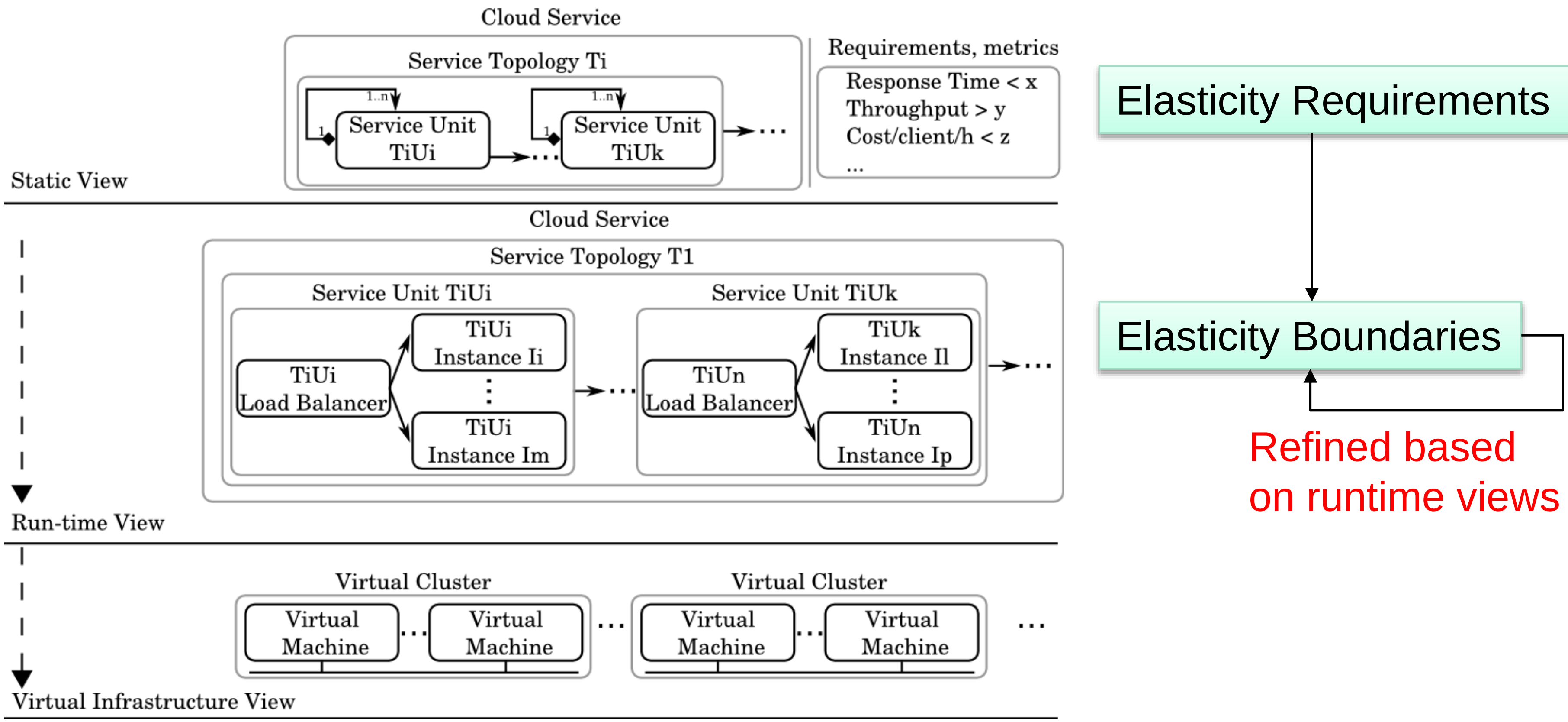
Service topology level

Elasticity actions and metrics



Engineering Cloud Applications – elasticity monitoring and analysis

The complexity of elasticity monitoring

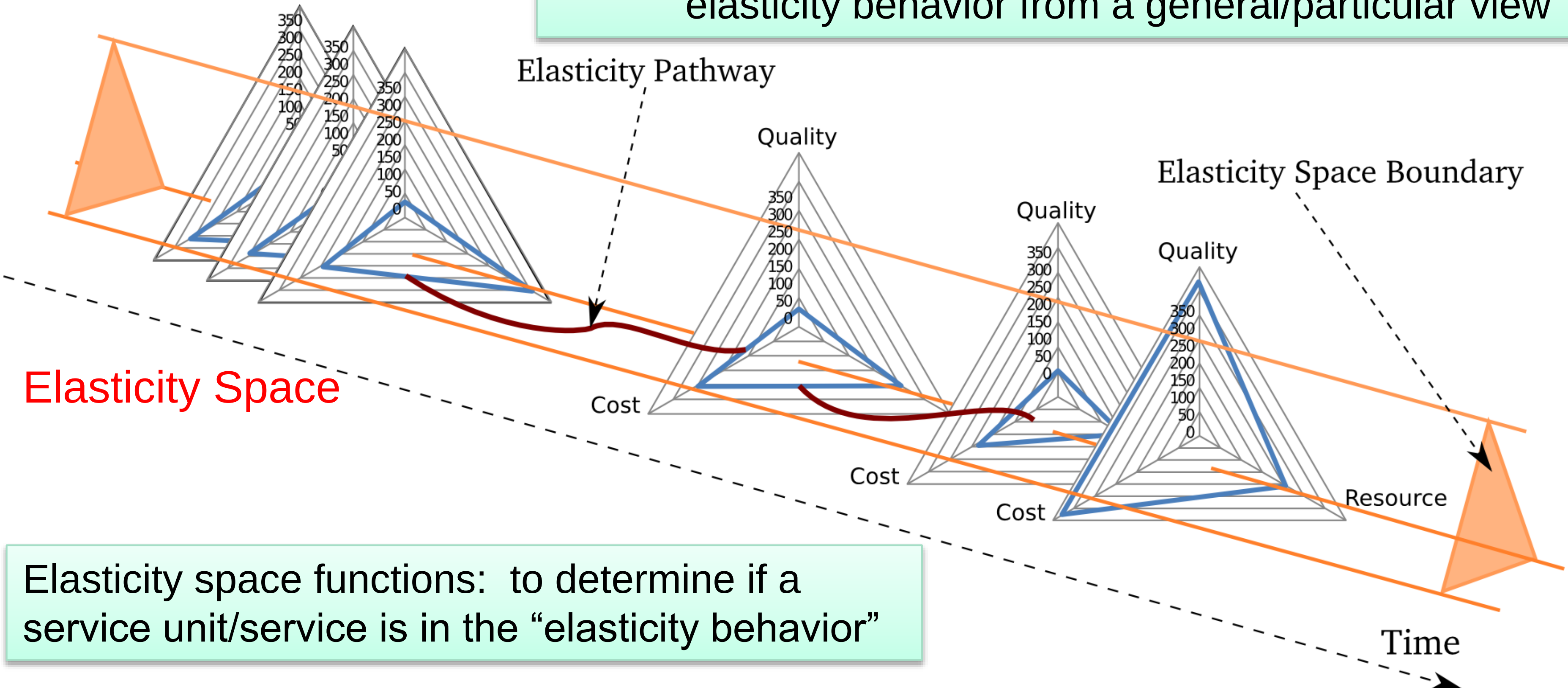


How to detect and characterize the elasticity behaviors?

Elasticity Model for Cloud Services

Moldovan D., G. Copil,Truong H.-L., Dustdar S. (2013). **MELA - Monitoring ELastic cloud Services. On Submission**

Elasticity Pathway functions: to characterize the elasticity behavior from a general/particular view



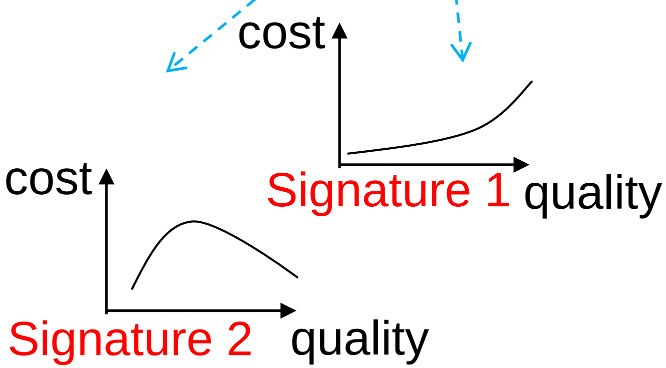
Elasticity space functions: to determine if a service unit/service is in the "elasticity behavior"

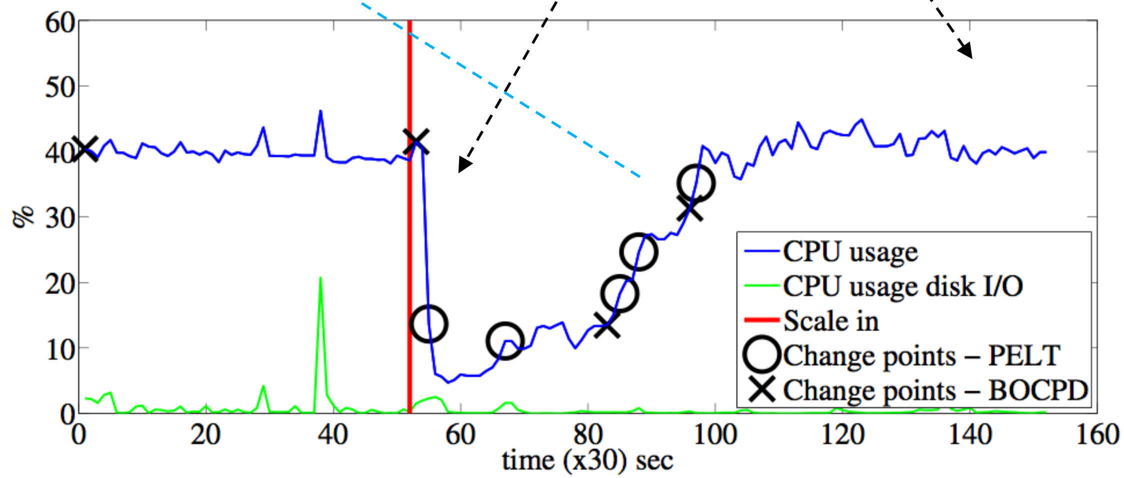
Examples of functions for Elasticity Space and Pathway

Elasticity Space Func

Elasticity Pathway Func

Change point detection algs





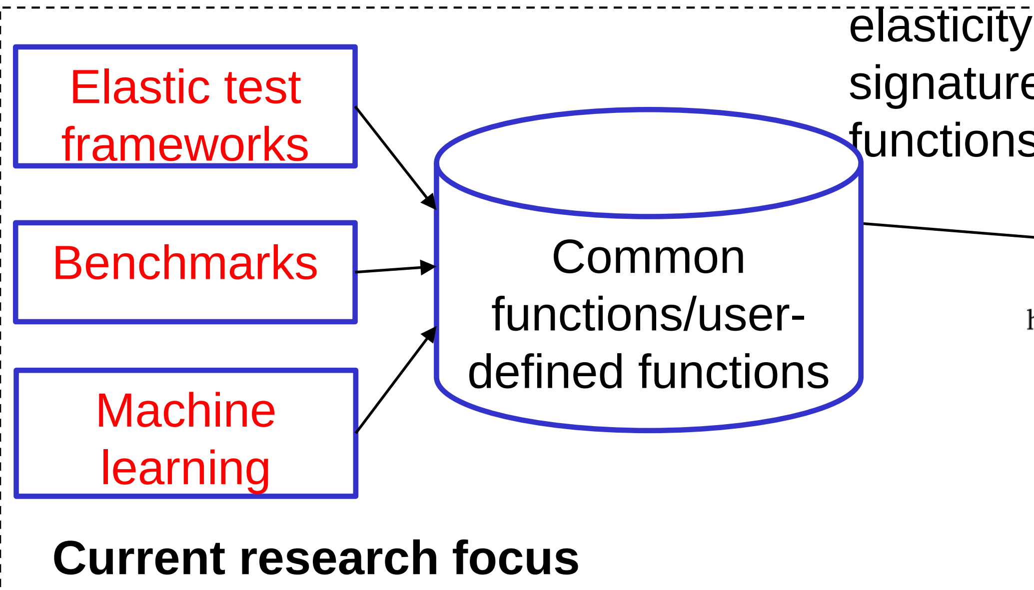
Alessio Gambi, Daniel Moldovan, Georgiana Copil, Hong Linh Truong, Schahram Dustdar: On estimating actuation delays in elastic computing systems. SEAMS 2013: 33-42

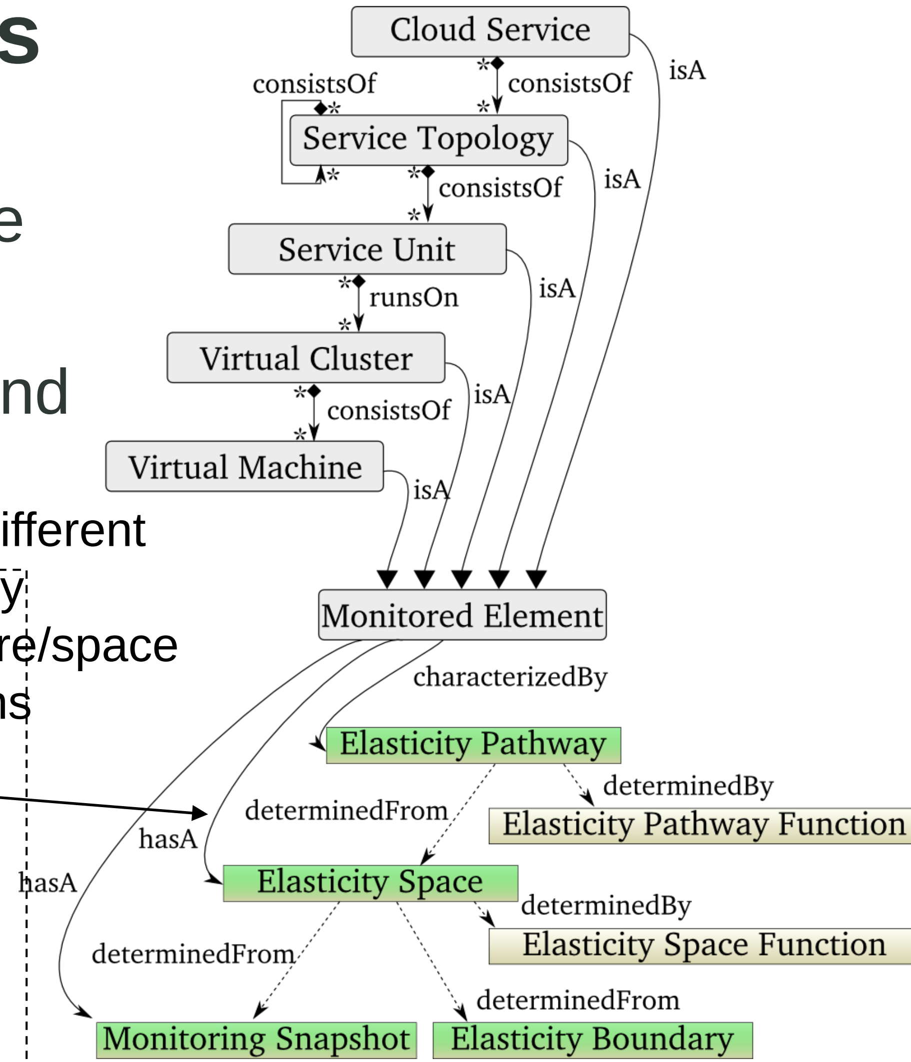
Multi-level monitoring and analysis of cloud services

Serveral possible Elasticity Space and Pathway functions

- for different types of service and elasticity behaviors

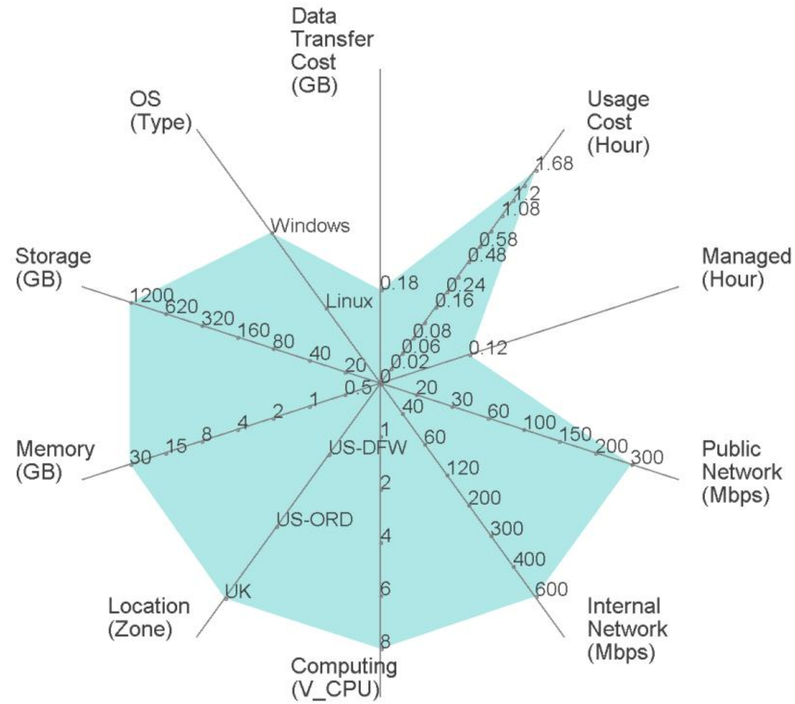
Apply different elasticity signature/space functions





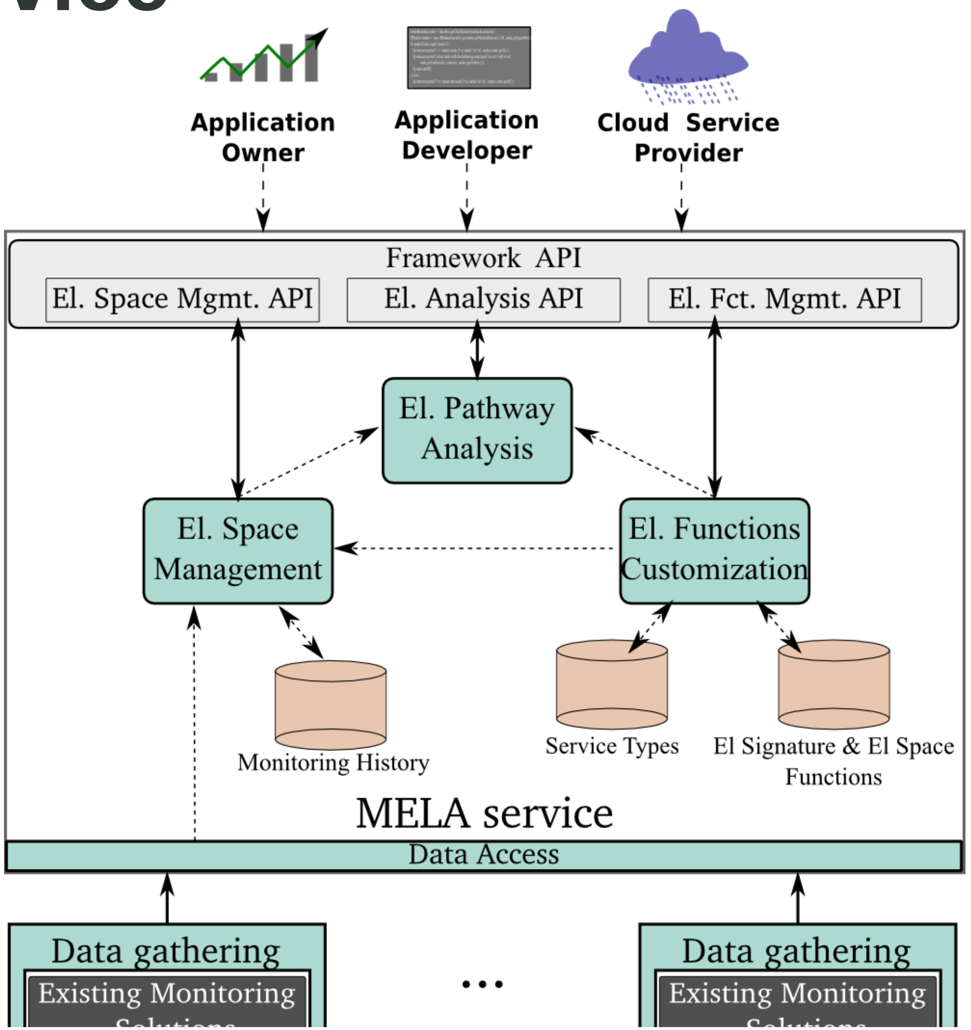
Elasticity Space for Cloud Infrastructure

Amazon Elasticity Space



Rackspace Elasticity Space

MELA -- Elasticity Monitoring as a Service

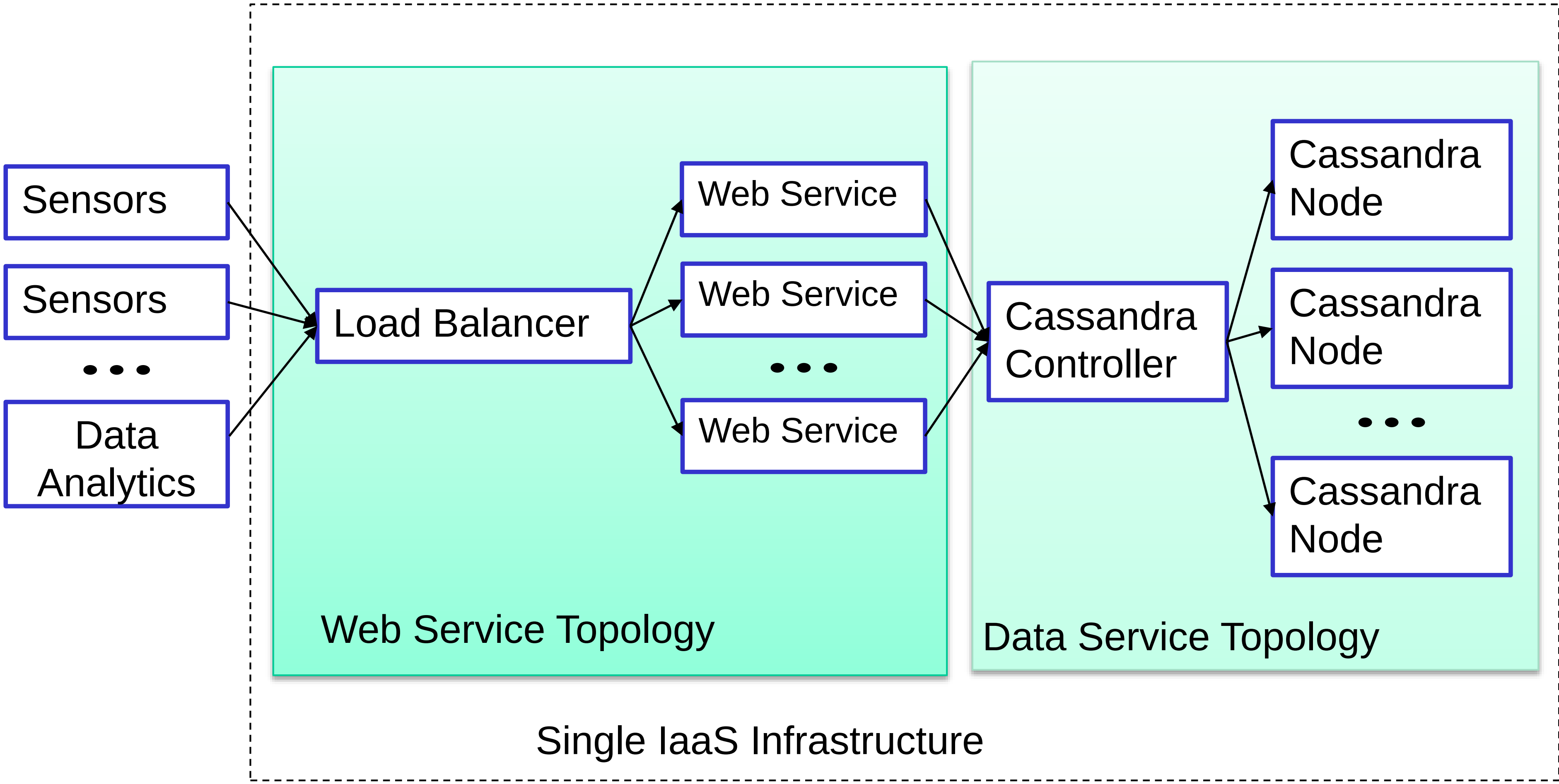


Daniel Moldovan, Georgiana Copil, Hong-Linh Truong, Schahram Dustdar, MELA - Monitoring ELastic cloud Services. June 2013, on Submission.

Demo – Experimental Cloud Service

- A realistic cloud service
  - Data-as-a-Service for M2M in the cloud
  - Consumers (sensors/analytics) query/insert data into data services
  - Also most common type of distributed web applications
- An M2M software service provider(SSP) provides the cloud service
  - The SSP wants to control and monitor her cloud service for multiple consumers
  - The SSP utilizes an existing IaaS and deploys her service into the IaaS

Demo – Cloud service structure



Demo – Experiment configuration

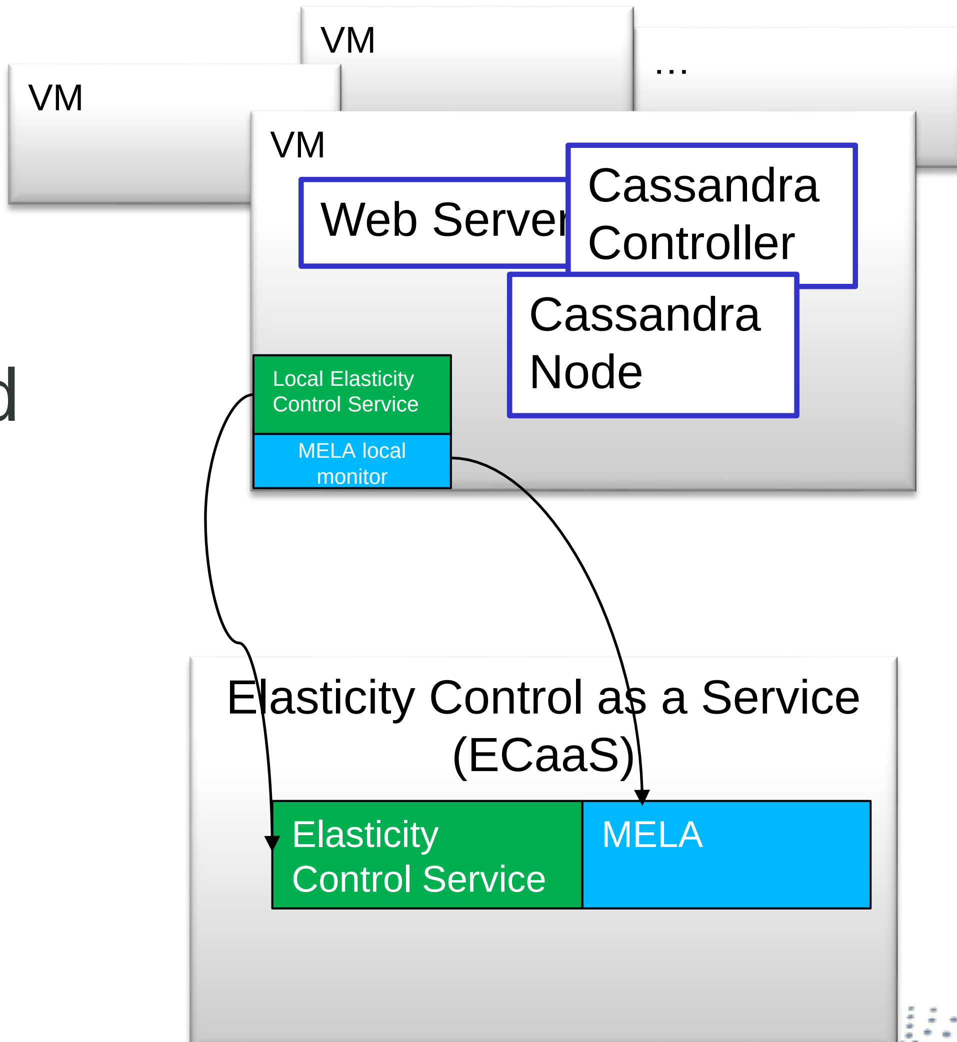
- The existing IaaS
  - Our local OpenStack (~20 VMs quota)
- The software for cloud service
  - HAProxy load balancer
    - Lightweight TCP/HTTP Load Balancer
  - Web service: provides intefaces for storing/querying data to/from Cassandra nodes
  - Cassandra:
    - distributed, scalable NoSQL data repository
- Consumer‘s workload
  - Replay events obtained from Pacific Controls
  - Simulated events from realistic scenarios

Demo – Example of what the SSP wants

- At the *whole Cloud Service* level
  - Cost no more than 1 Euro/customer/h
  - Good response time
- At *the Service Topol*ogy level
  - Web service topology
    - High throughput
  - Data service topology
    - Low latency
- At *the Service Unit* level
  - Cassandra node
    - High Request Served

Demo – Deployment

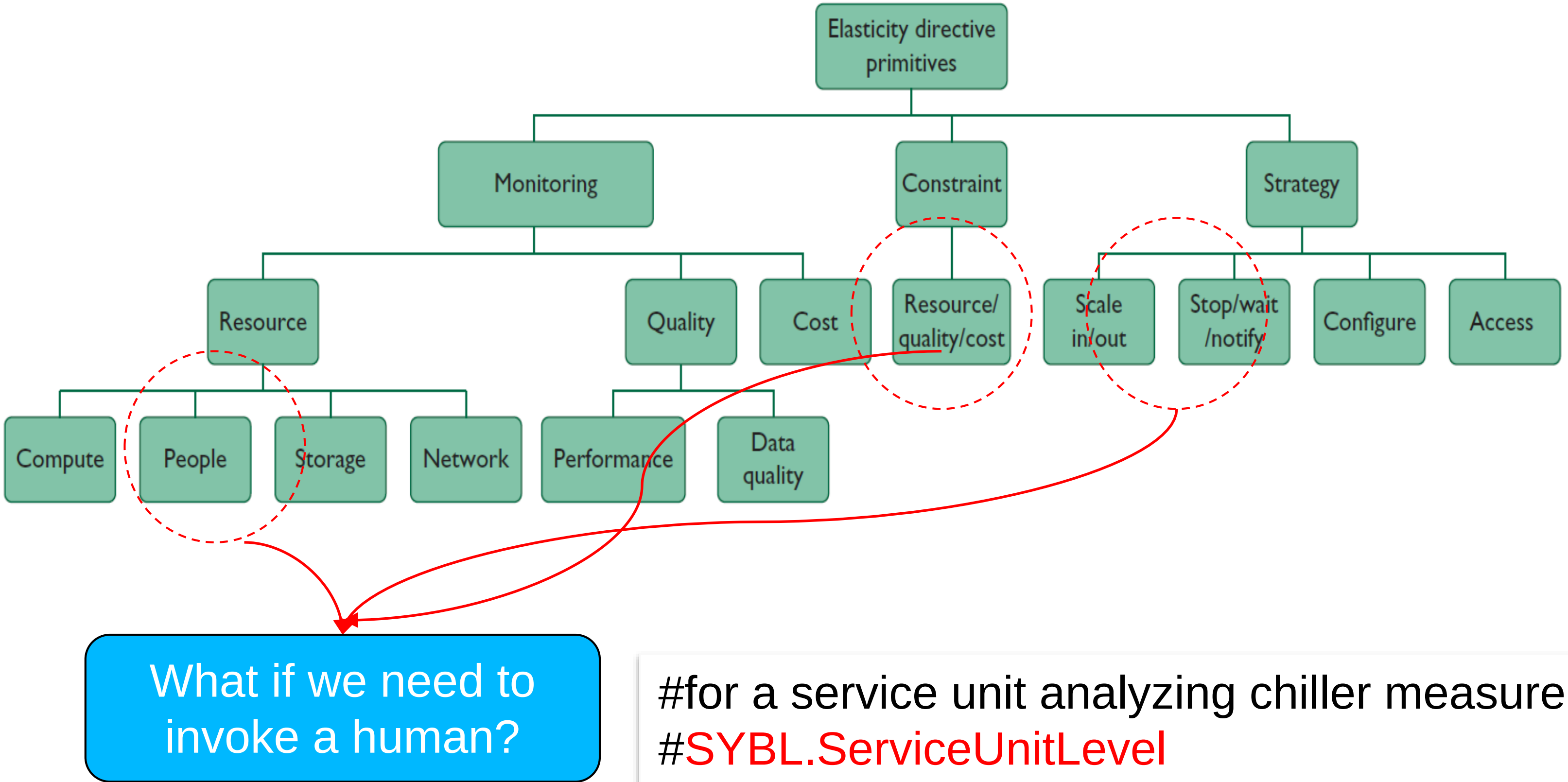
- SSP deploys VMs consisting of software for the cloud service and elasticity monitoring/control components



LIVE DEMO

Engineering Elastic Applications in the Cloud – elasticity of hybrid service units

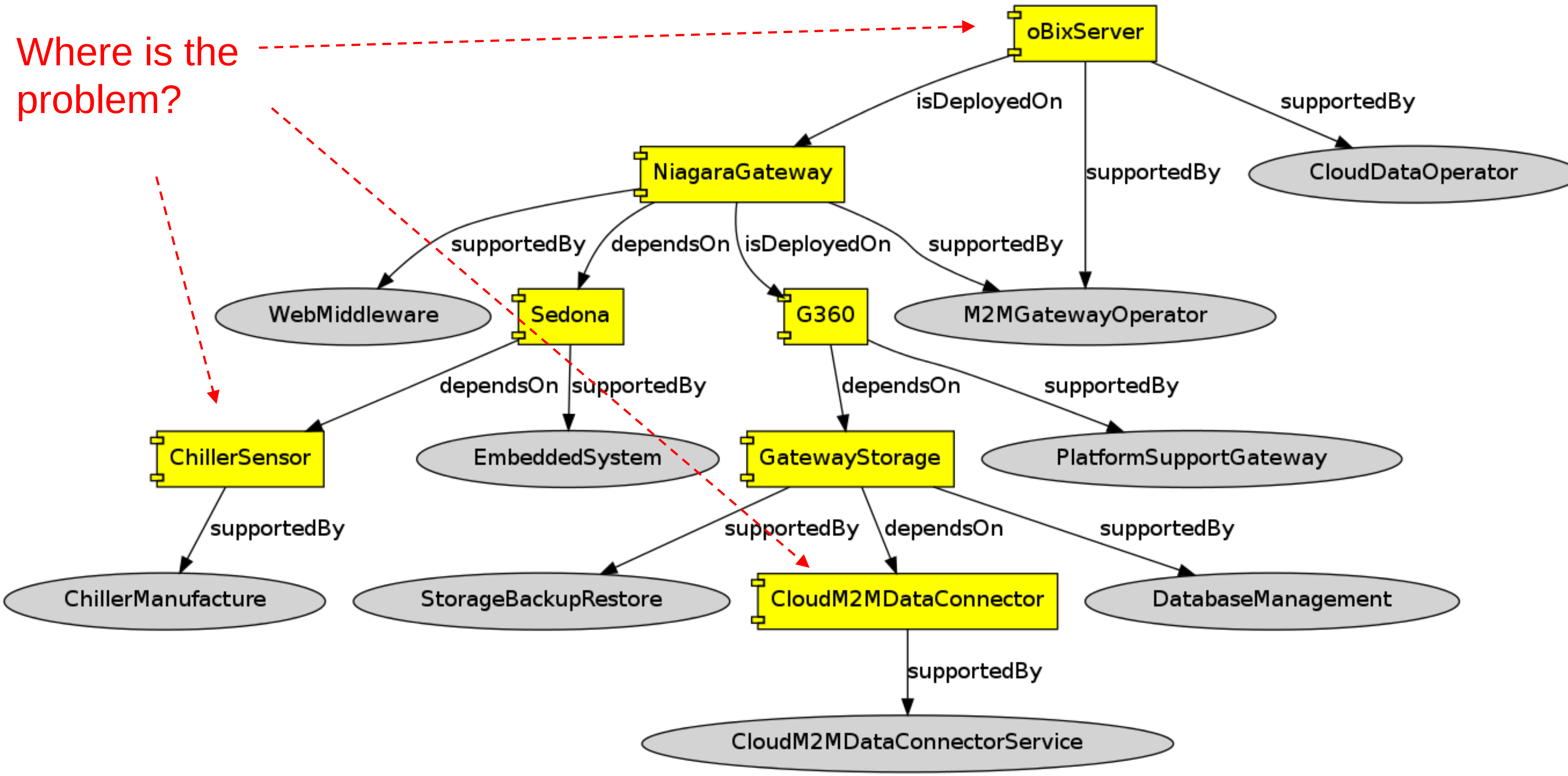
Specifying and controling elasticity of human-based services



#for a service unit analyzing chiller measurement
#SYBL.ServiceUnitLevel
Mon1 MONITORING accuracy = Quality.Accuracy
Cons1 CONSTRAINT accuracy < 0.7
Str1 STRATEGY CASE Violated(Cons1):
Notify(Incident.DEFAULT, ServiceUnitType.HBS)

Human needed for solving problems

Link management skill constraints to tasks required HBS



Issues in human-based service elasticity

- Which types of human-based service instances can we provision?
- How to provision these instances ?
- How to utilize these instances for different types of tasks?
- Can we program these human-based services together with software-based services
- How to program incentive strategies for human services?

Provisioning HBS Instances (1)

- Types of services :
  - Individual Compute Unit (ICU)
  - Social Compute Unit (SCU

Individual Compute Unit instances (iICU): iICU describe instances of HBS built atop capabilities of individuals. An individual can provide different iICU. Analogous to SBS, an iICU is similar to an instance of a virtual machine or a software.

Social Compute Unit instances (iSCU): iSCU describe instances of HBS built atop capabilities of multiple individuals and SBS. Analogous to SBS, an iSCU is similar to a virtual cluster of machines or a complex set of software services.

Provisioning HBS Instances (2)

Instances Descriptions

- iICU(CS, HPU, archtype, price, incentive, utilization,location, APIs)
- iSCU(CS,HPU, archtype, price, incentive, utilization,connectedness, location, APIs)
- Other (traditional) NFPs

Pricing factors

- utilization
- offering communication APIs
- connectedness

Incentive factors

- Based on utilization and types of tasks
- Declared by ICU/SCU
- Enforced by HBS cloud providers

Provisioning HBS Instances (3)

An „archetype“ characterizes the problem domain that the ICU/SCU can solve (the type of solutions)

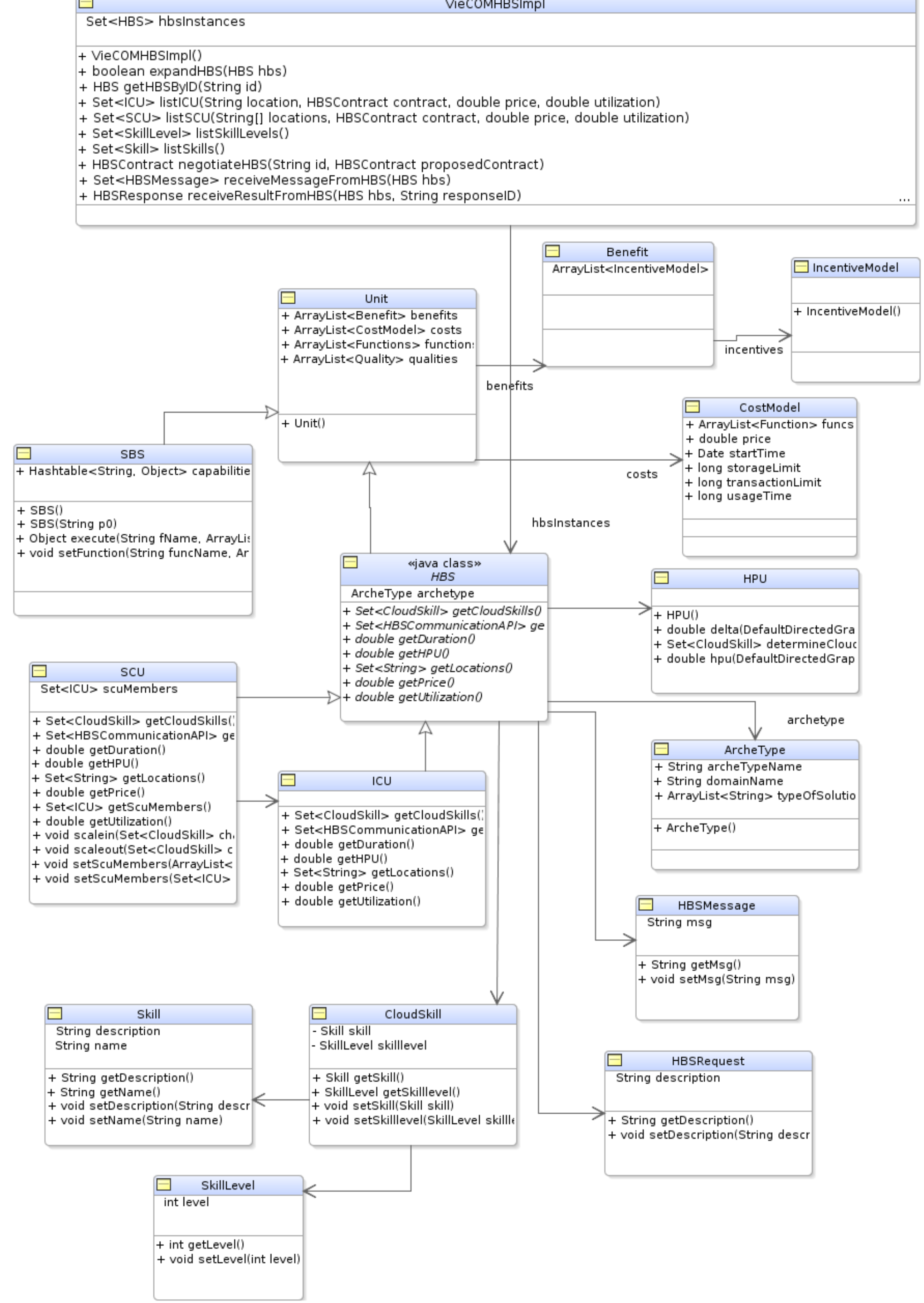
```
Archtype ={
	({WebDataAnalytics,TwitterAnalytics}, DataAnalytics),
	({DataCleansing,DataEnrichment},DataQualityImprovement)
}

Types of solutions:
		WebDataAnalytics, TwitterAnalytics, DataCleansing, DataEnrichment

Problem domains:
		DataAnalytics and DataQualityImprovement
```

Cloud APIs for utilizing HBS

APIs hide low-level platforms and utilize low level HBS communication interfaces

APIs for HBS information and management	APIs for HBS execution and communication
• listSkills();listSkillLevels(); • listICU();listSCU() • negotiateHBS() • startHBS() • suspendHBS () • resumeHBS () • stopHBS() • reduceHBS() • expandHBS()	• runRequestOnHBS () • receiveResultFromHBS() • sendMessageToHBS() • receiveMessageFromHBS()

Prototype (simulated environment)



Combined with Jcloud/boto for real SBS

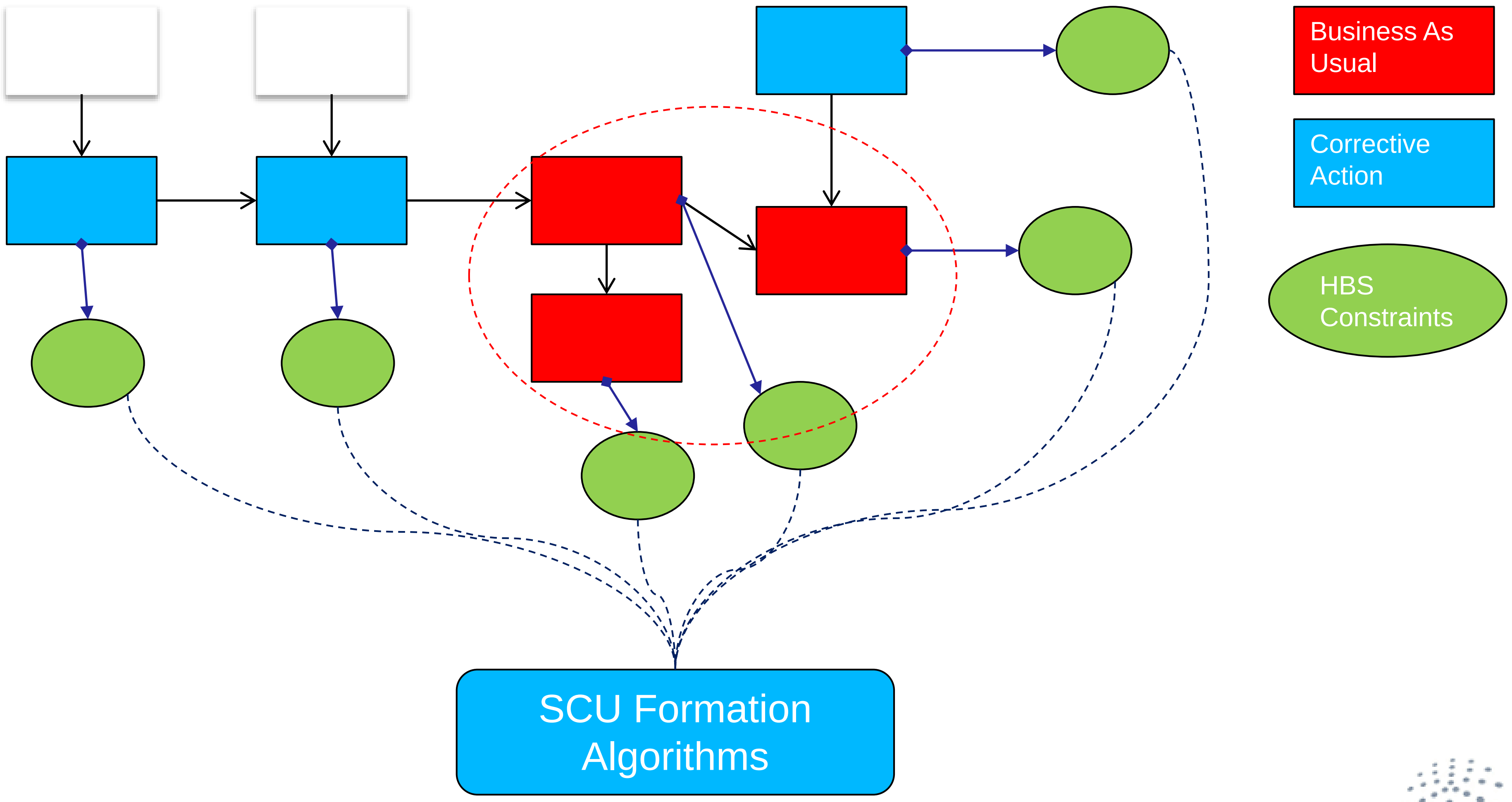
HBS for dependent/evolving tasks versus independent tasks

- Dependent tasks
  - E.g., solving problems in a M2M gateway in a building
    - Network problem?, Storage problem? Something wrong in the interface to chillers? M2M cloud connector problem?What happens if we repair the gateway?
    - Tasks are dependent and can be evolving
- Independent tasks
  - E.g., urban planning support in smart city management
  - Requests that can be serialized into a sequence of independent tasks
  - Tasks can still be ressigned/delegated among service units

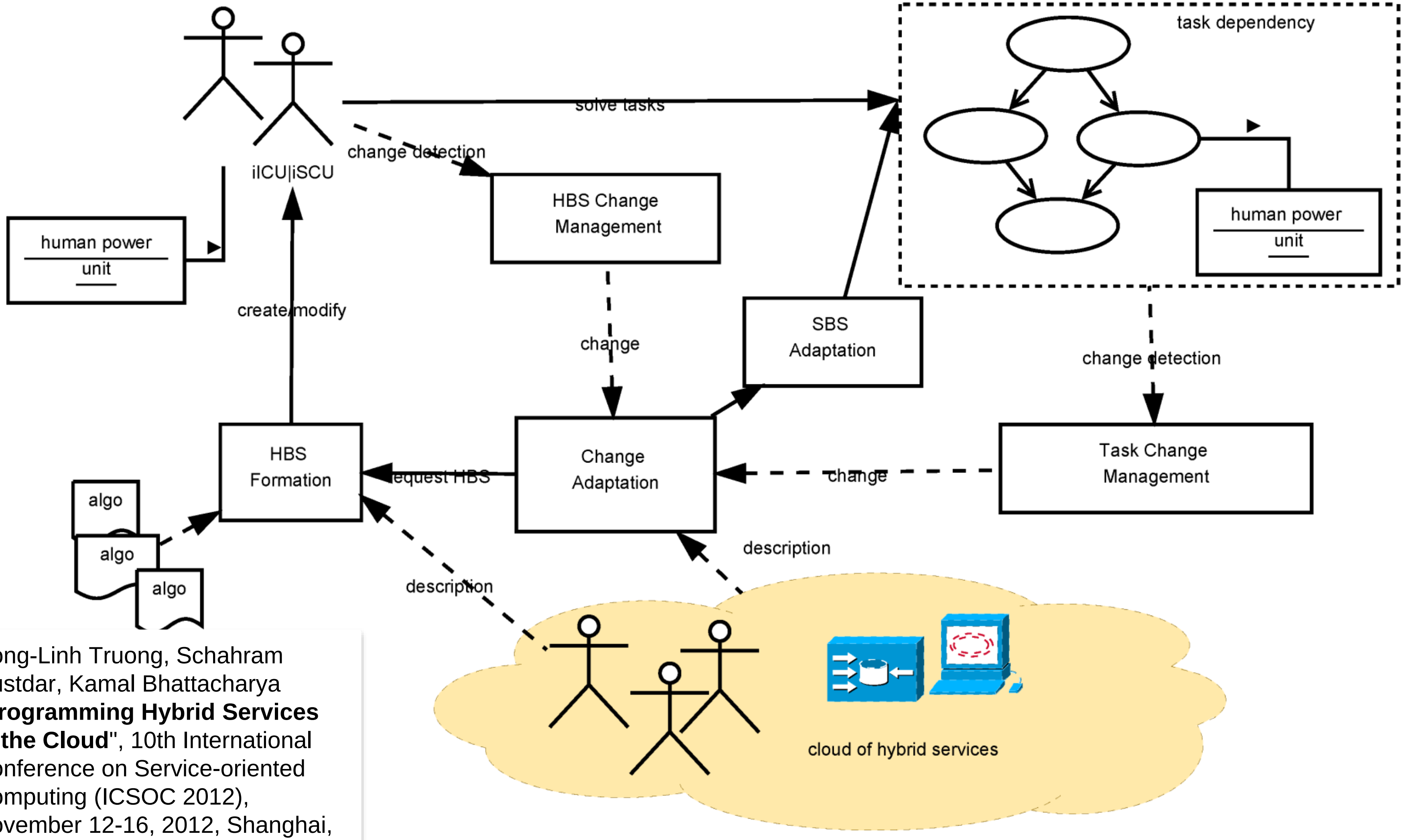
Different influences on HBS formations and operations

Forming iSCUs for dependent/evolving tasks

- Done by consumers or cloud providers

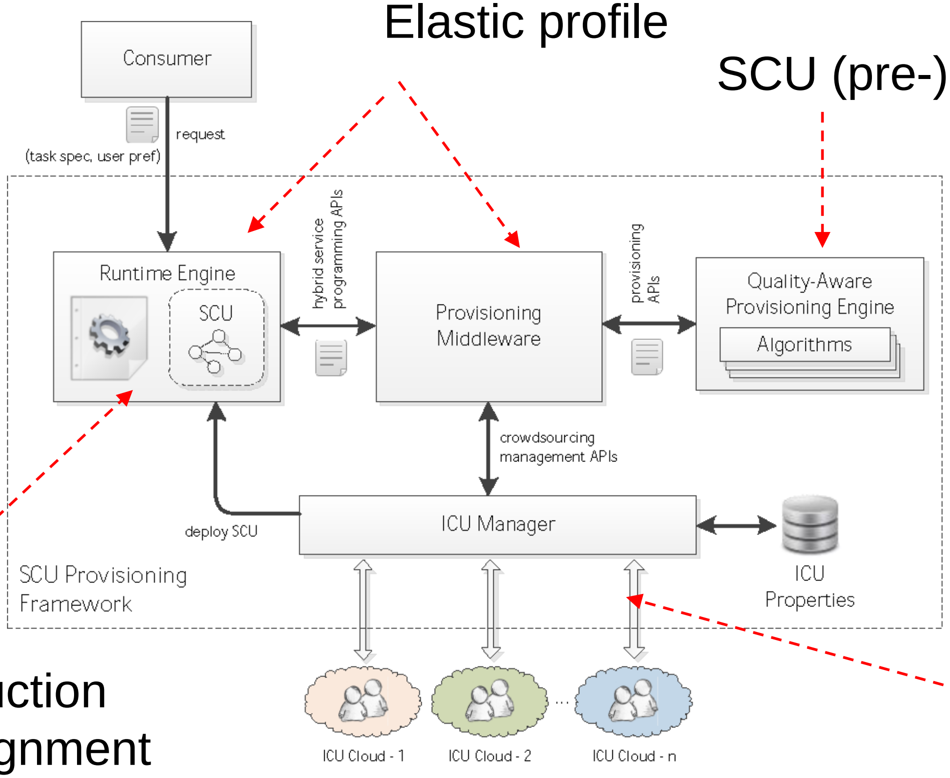


Utilizing hybrid services for evolving/dependent task graphs



Hong-Linh Truong, Schahram Dustdar, Kamal Bhattacharya "**Programming Hybrid Services in the Cloud**", 10th International Conference on Service-oriented Computing (ICSOC 2012), November 12-16, 2012, Shanghai, China. Best Paper Award.

Elastic SCU provisioning atop ICUs



Elastic profile

SCU (pre-)runtime/static formation

Algorithms
- Ant Colony Optimization variants
- FCFS
- Greedy

SCU extension/reduction
- Task reassignment based on trust, cost, availability

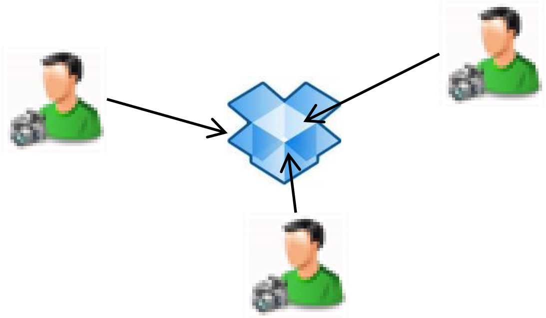
HBS cloud APIs

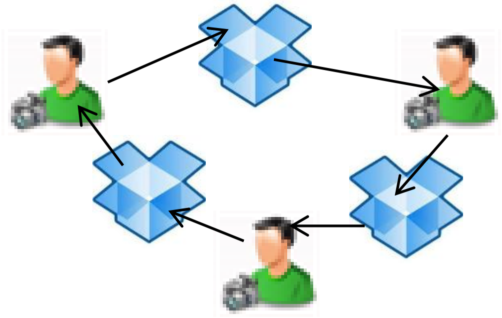
Mirela Riveni, Hong-Linh Truong, and Schahram Dustdar, **A Feedback Based Approach for Elasticity Coordination of Social Compute Units, June 2013, On submission**

Muhammad Z.C. Candra, Hong-Linh Truong, and Schahram Dustdar, **Provisioning Quality-aware Social Compute Units in the Cloud, June 2013, On submission**

Configuring iSCU

- Establish „connectedness“ based on compliance constraints and network topology
  - Addional cost might occur!
- Program SBS and HBS for the iSCU to have a complete working environment.
- Different connectedness
  - E.g., ring-based, star-based, and master-slave topologies





Selecting HBS: Some algorithms

Algorithms	Description
SkillWithNPath	Select $iICU$ for $iSCU$ based on only skills with a pre-defined network path length starting from the task to be solved.
SkillMinCostWith NPath	Select $iICU$ for $iSCU$ based on only skills with minimum cost, considering a pre-defined network path length starting from the task to be solved.
SkillMinCostMax LevelWithNPath	Select $iICU$ for $iSCU$ based on skills with minimum cost and maximum skill levels, considering a pre-defined network path length starting from the task to be solved.
SkillWithNPathUn Directed	Similar to $SkillWithNPath$ but considering undirected dependency
MinCostWithNPath UnDirected	Similar to $MinCostWithNPath$ but considering undirected dependency
MinCostWithAvail NPathUnDirected	Select Select $iICU$ for $iSCU$ based on skills with minimum cost, considering availability and a pre-defined network path length starting from the task to be solved. Undirected dependencies are considered.

- Several algorithms can be built based on existing team formation algorithms which do not consider dependency graphs
- Different weighted factors can be considered

Forming iSCU by minimizing cost and considering no direction

```
DefaultDirectedGraph<Node, Relationship> dg; //graph of problems
//...
double hpu = HPU.hpu(dg); //determine
SCUFormation app = new SCUFormation( dg);
ManagementRequest request = new ManagementRequest();
//define request specifying only main problems to be solved
//....
//call algorithms to find suitable HBS. Path length =2 and
    availability from 4am to 19pm in GMT zone
ResourcePool scu = app.
    MinCostWithAvailabilityNPathUnDirectedFormation(request, 2,
    4, 19);
if (scu == null) { return ; }
ArrayList<HumanResource> scuMembers = scu.getResources();
SCU iSCU = new SCU();
iSCU.setScuMembers(scuMembers);
//setting up SBS for scuMember ...
```

Example of star-based iSCU using Dropbox as a communication hub

```
SCU iSCU ;
//... find members for SCU
DropboxAPI<WebAuthSession> scuDropbox; //using dropbox apis
//...
AppKeyPair appKeys = new AppKeyPair(APP_KEY, APP_SECRET);
WebAuthSession session =
        new WebAuthSession(appKeys, WebAuthSession.AccessType.
            DROPBOX);
//...
session.setAccessTokenPair(accessToken);
scuDropbox = new DropboxAPI<WebAuthSession>(session);
//sharing the dropbox directory to all scu members
//first create a share
DropboxAPI.DropboxLink link = scuDropbox.share("/hbscloud");
//then send the link to all members
VieCOMHBS vieCOMHBS = new VieCOMHBSImpl();
for (HBS hbs : iSCU.getScuMembers()) {
    vieCOMHBS.startHBS(icu);
    HBSMessage msg = new HBSMessage();
    msg.setMsg("pls. use shared Dropbox for communication " +
        link.url);
    vieCOMHBS.sendMessageToHBS(hbs, msg);
}
//...
```

Programming a combination of HBS and SBS

e.g., preparing/managing inputs/outputs for HBS using SBS

```
//using JClouds APIs to store log file of web application server
BlobStoreContext context =
   new BlobStoreContextFactory().createContext("aws-s3","REMOVED
       ","REMOVED");
BlobStore blobStore = context.getBlobStore();
//.... and add file into Amazon S3
Blob blob = blobStore.blobBuilder("hbstest").build();
blob.setPayload(new File("was.log"));
blobStore.putBlob("hbstest", blob);
String uri = blob.getMetadata().getPublicUri().toString();
VieCOMHBS vieCOMHBS = new VieCOMHBSImpl();
//assume that WM6 is the HBS that can analyze the Web Middleware
     problem
vieCOMHBS.startHBS("WM6");
HBSRequest request = new HBSRequest();
request.setDescription("Find possible problems from " + uri);
vieCOMHBS.runRequestOnHBS("WM6", request);
```

Change model for task graph's Human Power Unit

```
SCU iSCU ;
// ...
iSCU.setScuMembers(scuMembers);
//setting up SBS for scuMember
// ...
double hpu = HPU.hpu(dg); //determine current hpu
//SCU solves/adds tasks in DG
//  ....
//graph change – elasticity based on human power unit
double dHPU = HPU.delta(dg,hpu);
DefaultDirectedGraph<Node, Relationship> changegraph;
//obtain changes
Set<CloudSkill> changeCS = HPU.determineCloudSkill(changegraph);
if (dHPU > SCALEOUT_LIMIT) {
   iSCU.scaleout(changeCS); //expand iSCU
}
 else if (dHPU < SCALEIN_LIMIT) {
   iSCU.scalein(changeCS); //reduce iSCU
}
//  ...
```

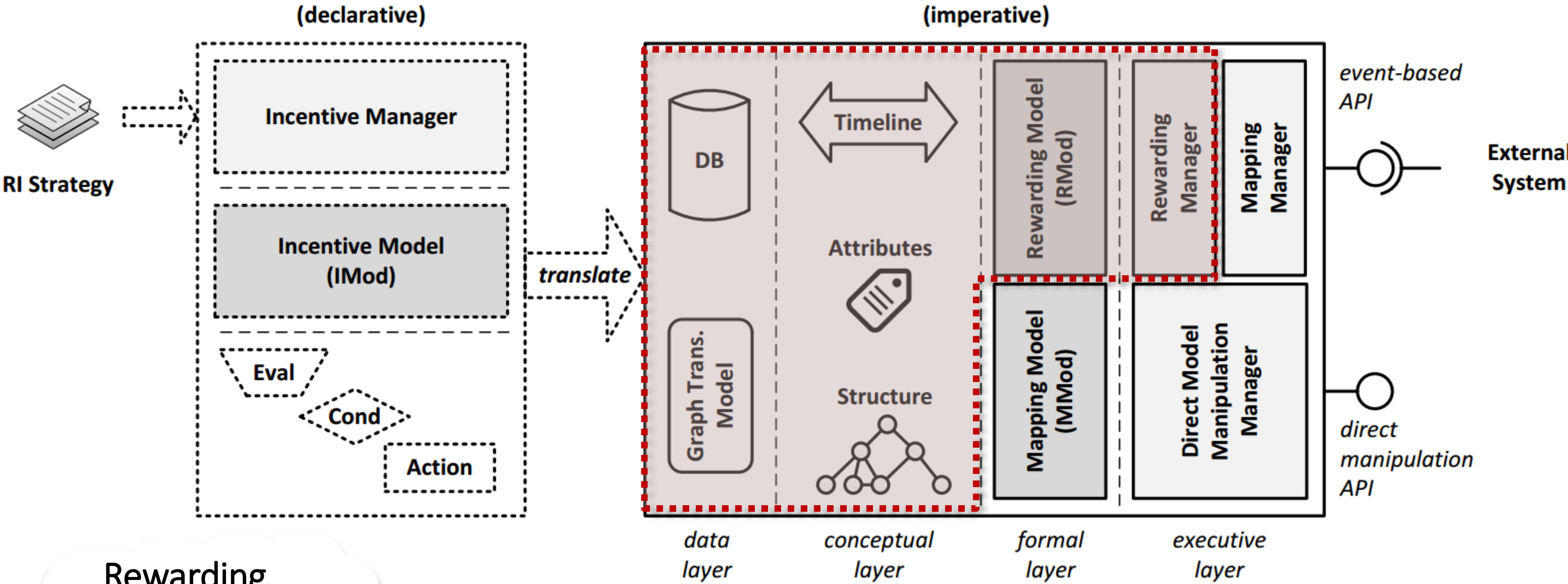
Programming and executing Incentives

domain expert

Ognjen Scekic, Hong Linh Truong, Schahram Dustdar: Modeling Rewards and Incentive Mechanisms for Social BPM. BPM 2012: 150-155

Ognjen Scekic, Hong-Linh Truong, Schahram Dustdar, "Programming Incentives in Information Systems", 25th International Conference on Advanced Information Systems Engineering(CAiSE'13), Springer-Verlag, Valencia, Spain, 17-21 June, 2013.

PRogrammable INCentives Framework (PRINC)



Rewarding Model (RMod)

Representation of external system suitable for modeling application of incentives.

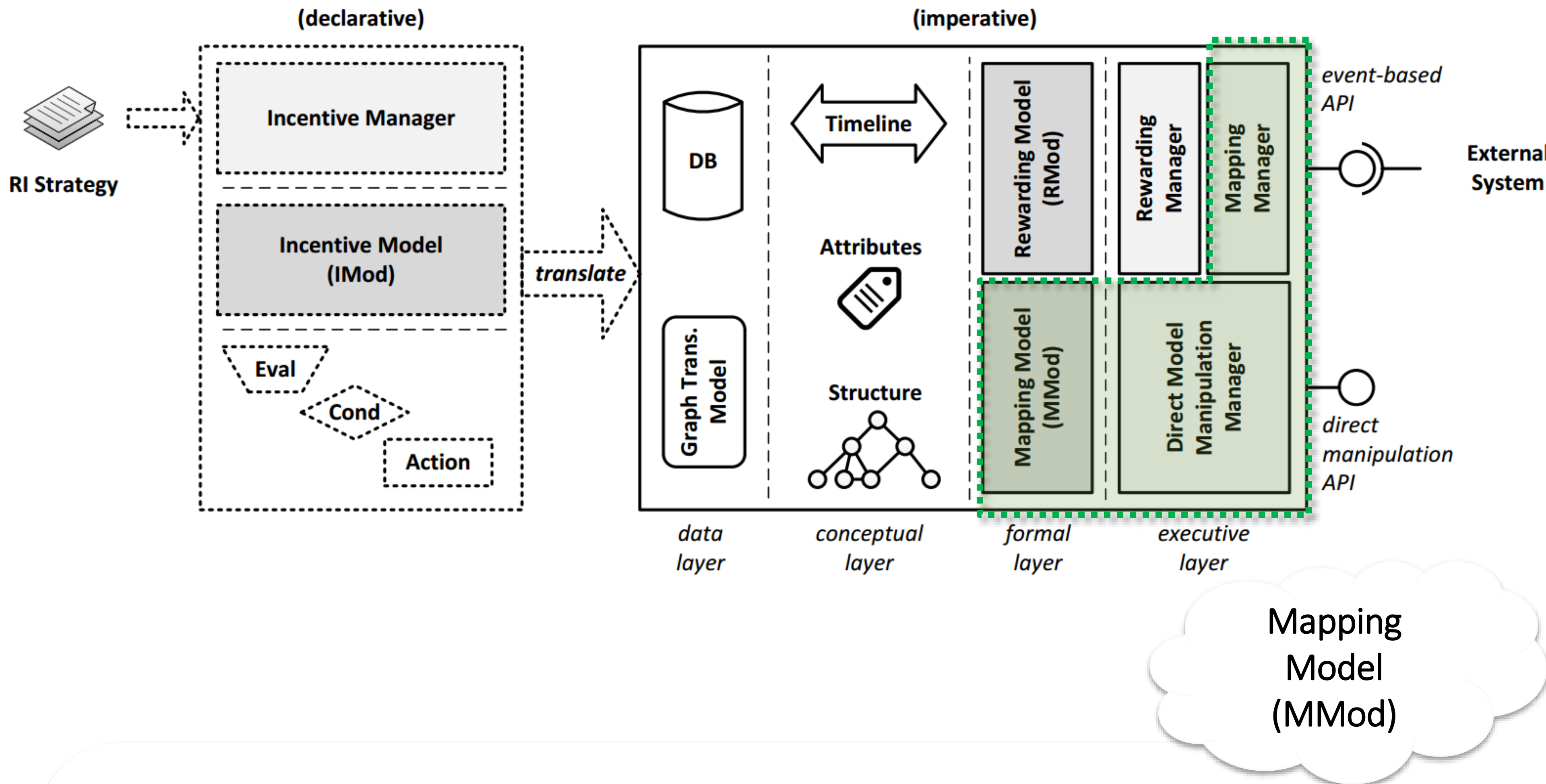
- State – Global state, individual worker attributes and performance metrics.
- Time – Records of past and future worker interactions supporting time conditions.
- Structure – Representation and manipulation of various types of relationships

The Rewarding Model (RMod)

- Examples of mechanisms that RMod can encode and execute:
  - At the end of iteration, award each ICU who scored better than the average score of his/her immediate neighbors.

- Elasticity with incentives:
  - Unless the productivity increases to a level p within n next iterations, expand/reduce current SCU by adding highly trusted ICU or removing inefficient ICU

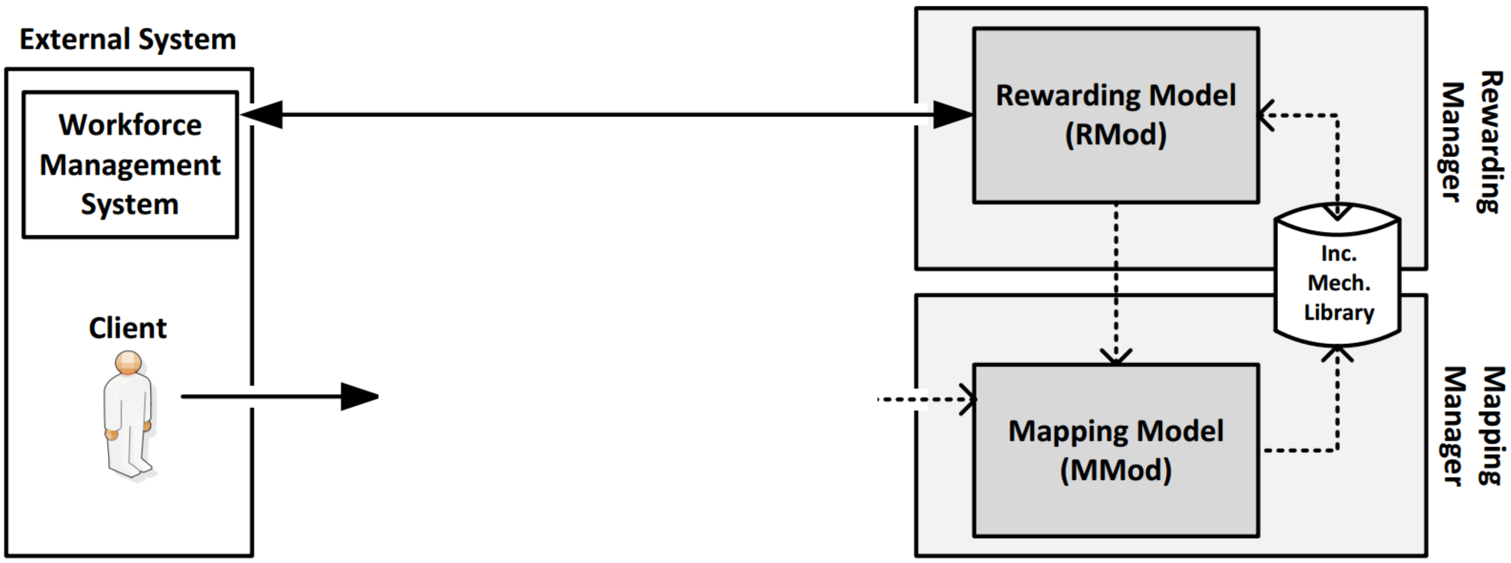
PRINC Framework

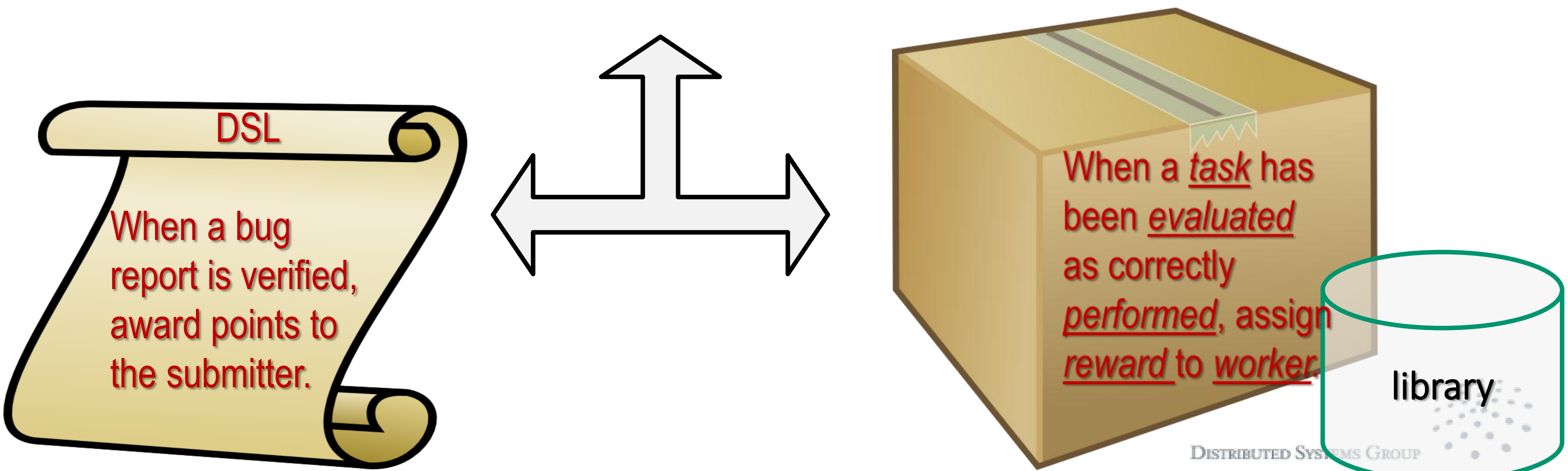


- Definition of system-specific artifacts, actions, attributes and relation types.
- Definition and parameterization of metrics, messages, structural patterns and custom incentive mechanisms.

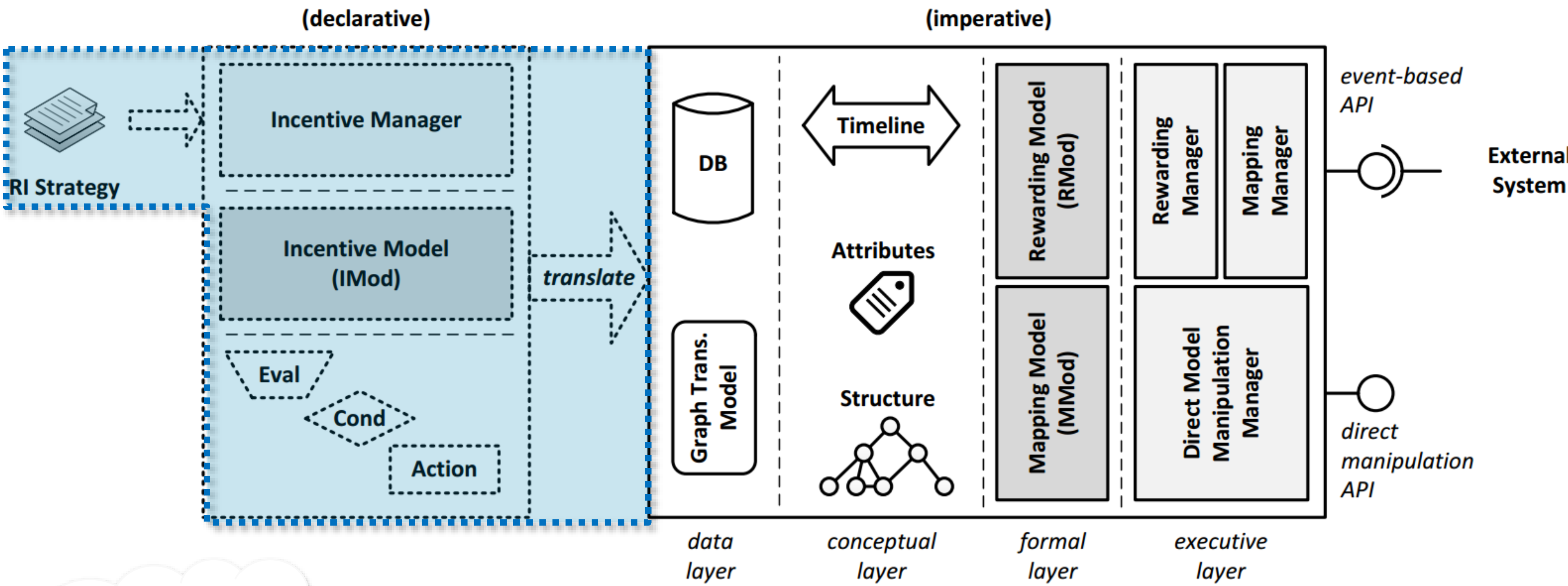
The Mapping Model (MMod)

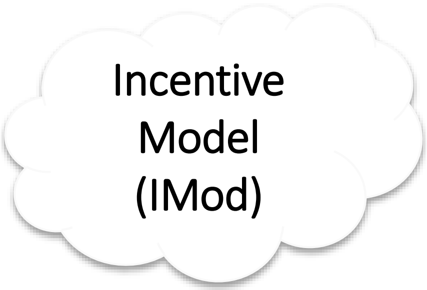
- Example: Adapting a general incentive mechanism for a software testing company.





PRINC Framework





- Declarative, domain-specific language.
- High-level, platform independent, human-friendly notation.

Illustrating Examples

- Structural incentive mechanism rotating presidency.

```
EvtID = 47; t = END(I3); {
    Worker currMgr = MANAGER(TEAM(T5));
    Worker bestWrk = BEST_OF(TEAM(T5));
    if (currMgr != bestWrk)
      SCHD_EVT(START(I4), SET_MANAGER(T5, bestWrk));
    else
      if (DB_READ('manager', I3, T5, currMgr) == 1)
        SCHD_EVT(START(I4), SET_MANAGER(T5, BEST_OF(TEAM(T5)
            - currMgr)); //replace with 2nd best
      else DB_WRITE('manager', I4, T5, currMgr);
}
```

2.

```
rule SET_MANAGER(var mark:int, var newMgrID:int)  {
     newMgr:Employee;
     if {newMgr.marked == mark && newMgr.id == newMgrID;}
     notNewMgr:Employee;
     if {notNewMgr.marked == mark && notNewMgr.id != newMgrID;}
     <-oldRelation:ManagedBy-> notNewMgr;
     negative { notNewMgr-:ManagedBy->newMgr;}
     modify
     {
          notNewMgr -:ManagedBy-> newMgr;
          delete(oldRelation);
     }
}
```

1.

3.

```
digraph {
n305601358 [label="n305601358:Employee"];
n1673058824 [label="n1673058824:Employee"];
n1578395868 [label="n1578395868:Employee"];
n261998859 [label="n261998859:Employee"];
n1673058824 -> n305601358;
n1578395868 -> n305601358;
n261998859 -> n305601358;
}
Current Manager = 305601358
digraph {
n261998859 [label="n261998859:Employee"];
n305601358 [label="n305601358:Employee"];
n1673058824 [label="n1673058824:Employee"];
n1578395868 [label="n1578395868:Employee"];
n1673058824 -> n1578395868;
n305601358 -> n1578395868;
n261998859 -> n1578395868;
}
New Manager = 1578395868
```

Conclusions (1) – Engineering Elasticity

- The evolution of underlying systems and the utilization of different types of resources under different models for elasticity requires
  - Complex, open hybrid service unit provisioning frameworks
    - Different strategies for dealing with different types of tasks
  - quality issues for software, data and people in an integrated manner for different perspectives

- We are just at an early stage of developing techniques for engineering elastic applications wrt multi-dimensional elasticity

Conclusions (2) – Engineering Elasticity

- Service engineering analytics of elastic systems
  - Programming hybrid compute units for elastic processes
  - Elasticity specifications and reasoning techniques
  - Elasticity spaces analytics
- Application domains
  - „Social computer" and smart cities (FP 7 FET Smart Cities and PC3L)
  - Computational science and engineering (FP 7 CELAR)

Thanks for your attention!

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