From the Edge to the Cloud

Research and Engineering Challenges for IoT systems

26 April 2018, CIbSE 2018, Bogotá, Colombia

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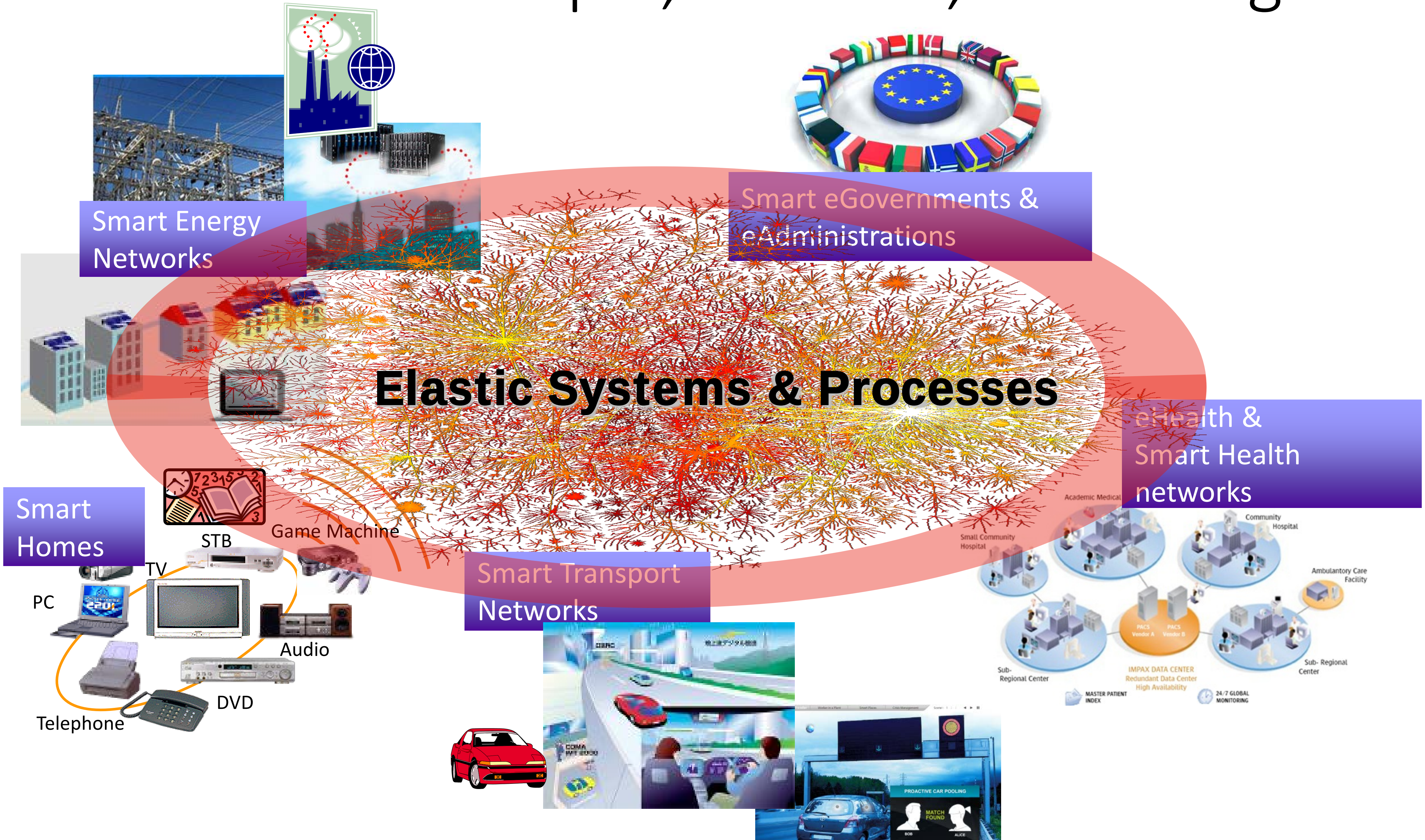
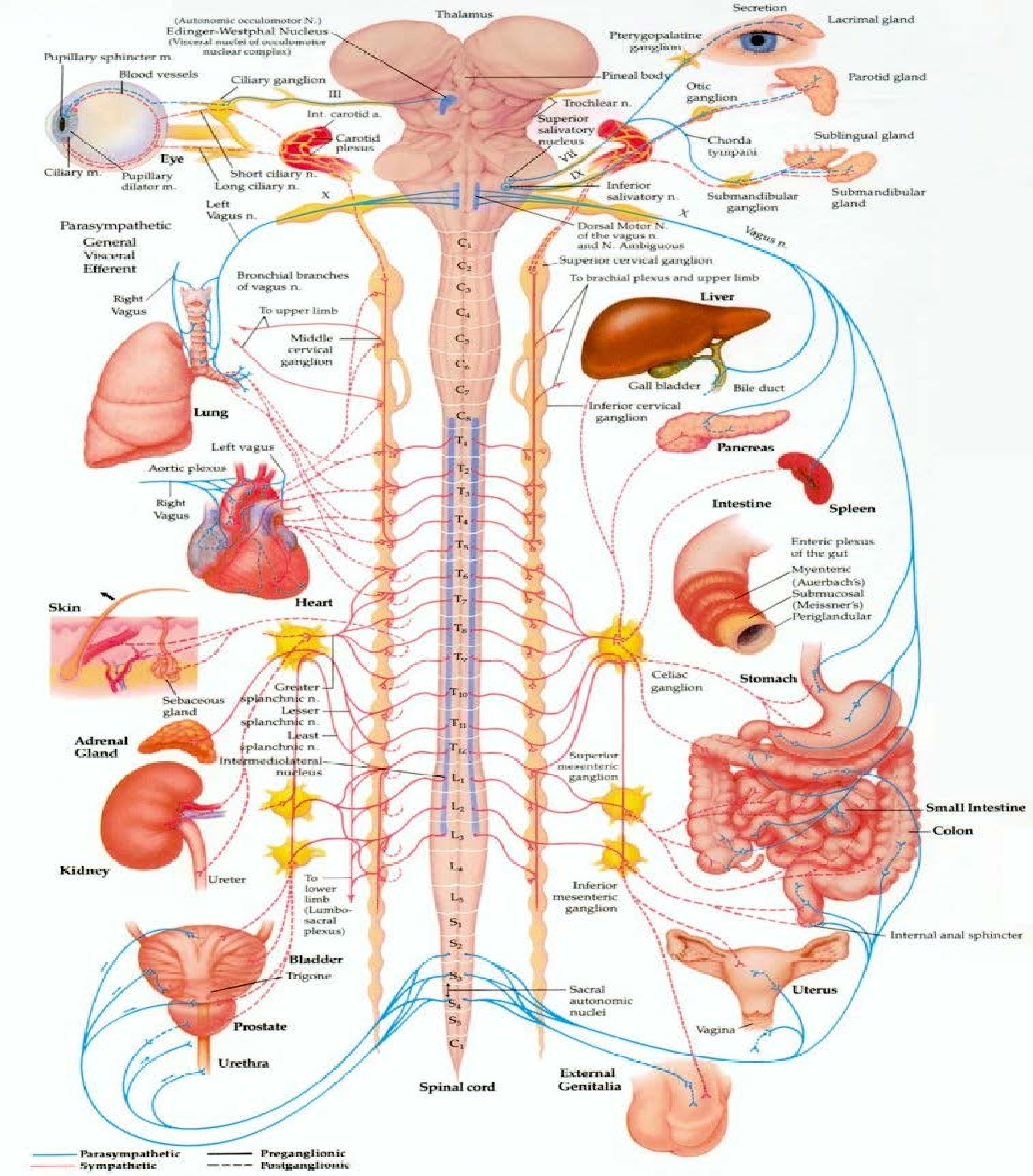
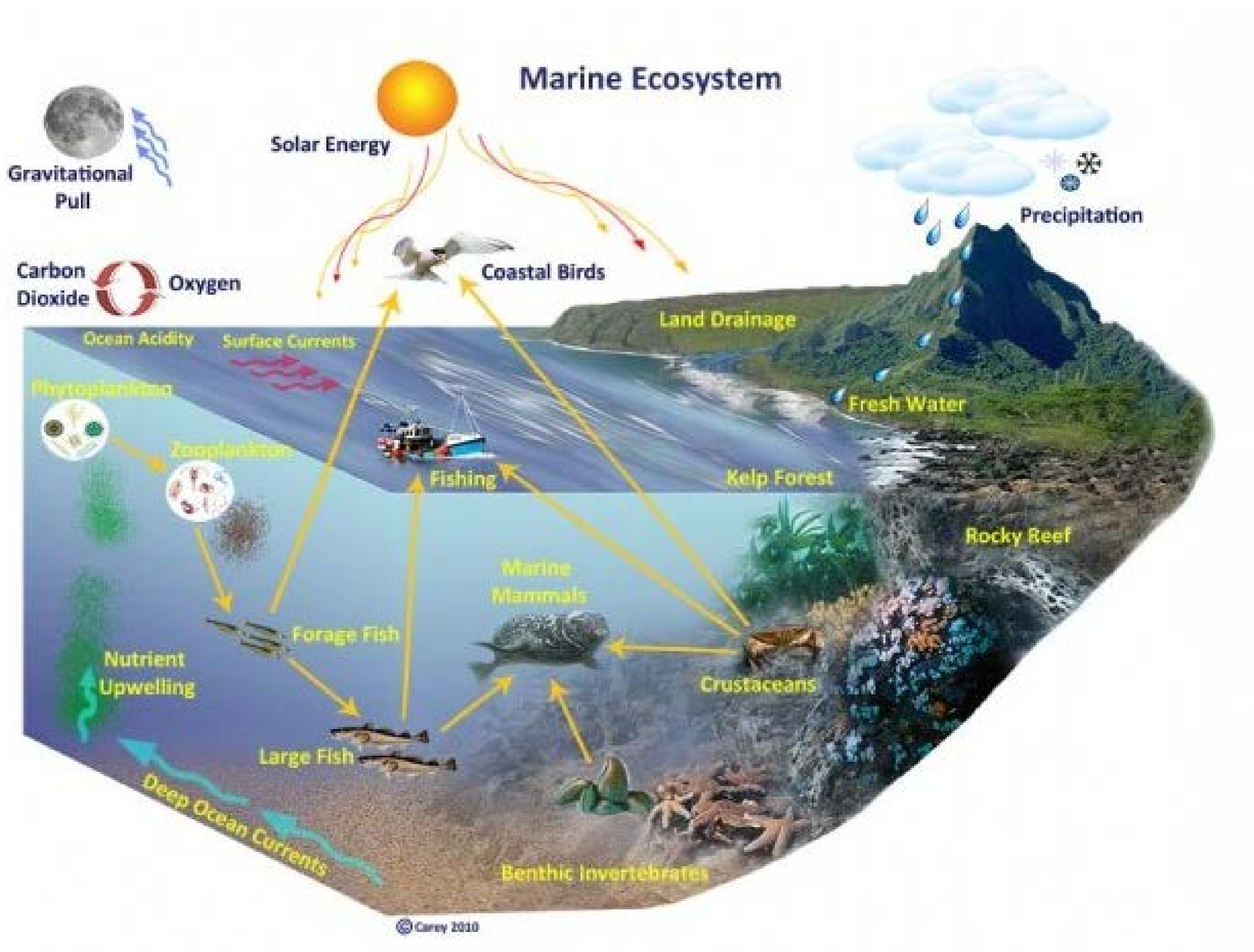
Smart Evolution – People, Services, and Things





Autonomic Nervous System

Think Ecosystems: People, Systems, and Things



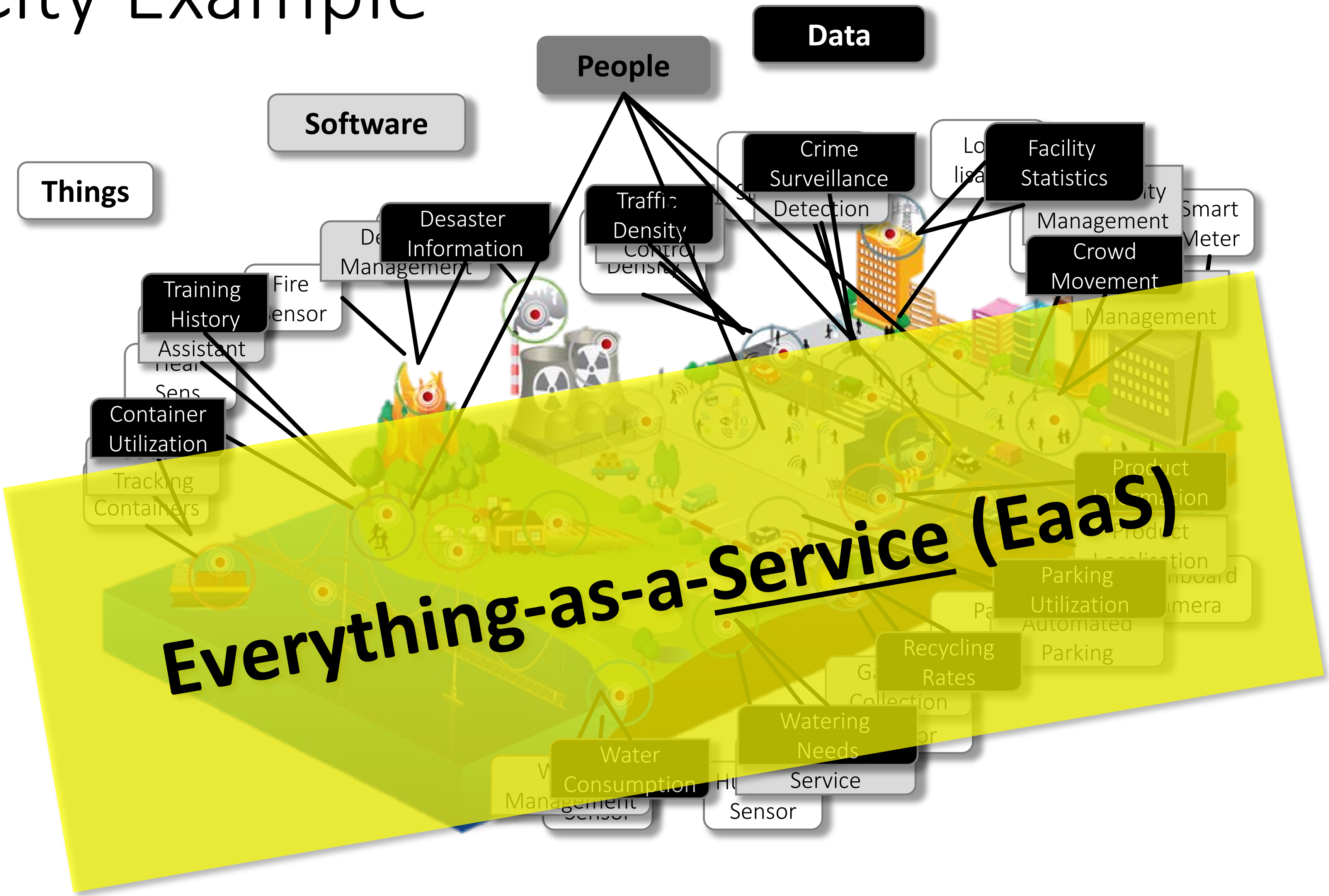
Marine Ecosystem: http://www.xbordercurrents.co.uk/wildlife/marine-ecosystem-2

Diverse users with complex networked dependencies and intrinsic adaptive behavior – has:

1. **Robustness & Resilience mechanisms**: achieving stability in the presence of disruption

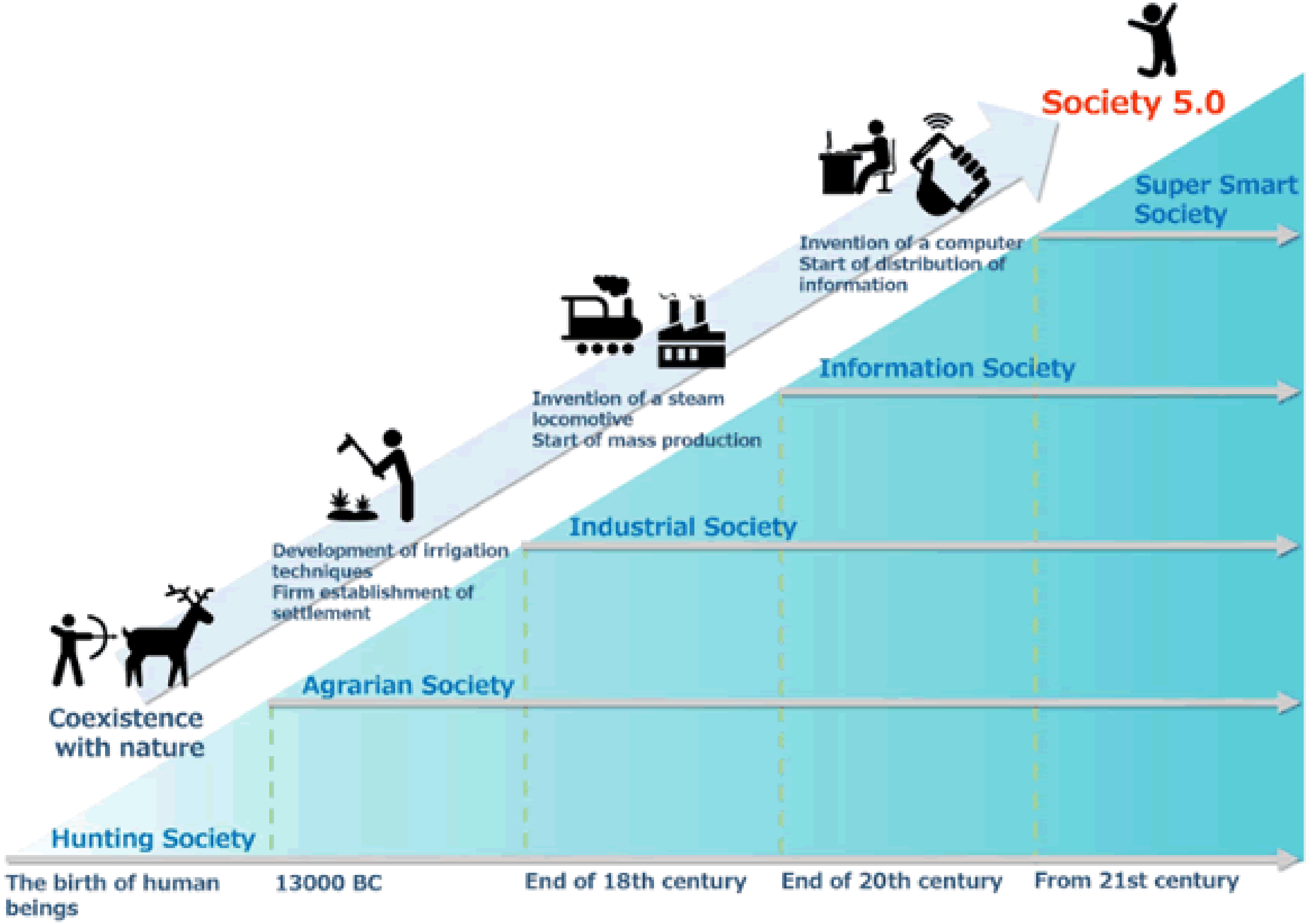
2. **Measures of health**: diversity, population trends, other key indicators

Smart City Example

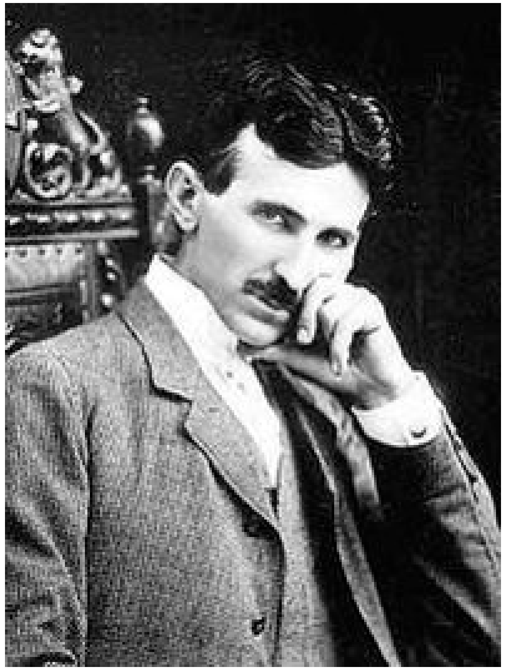



Smart City IoT Ecosystem
Airports, ports and Critical Infrastructure
Government Sector
Hospitality Sector
Healthcare Sector
Utilities and Smart Grid
Datacenters
Industrial Sector
Transport Sector
Education Sector
Finance Sector
Ubiquitous Managed Services Solution Across Business Verticals
CCTV Monitoring
Public Safety
HealthCare
Facilities Control
Industrial process parameters
Parking Control
Waste Management
KIOSK Monitoring
Numerous Forms Of Smart Services…
Managed services
Portfolio management
Event management
Analytics
Provisioning
Services
SIM profile configuration
Network configuration
Controls
Activation
Deactivation
Privacy
Security
Transaction Mgmt.
Visibility
Billing
Reporting
IoT and Cloud Computing enable smart services ecosystem and collaboration opportunities
Some 50 billion devices and sensors exist for M2M applications

Towards "Society 5.0" (Japan)



Toward realization of the new economy and society, Keidanren (Japan Business Federation), April 2016



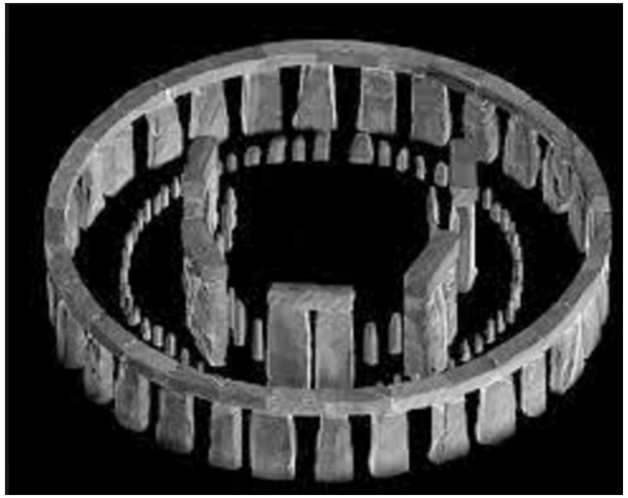
“The scientists of today think *deeply* instead of *clearly*.

One must be sane to think clearly, but one can think deeply and be quite insane.”

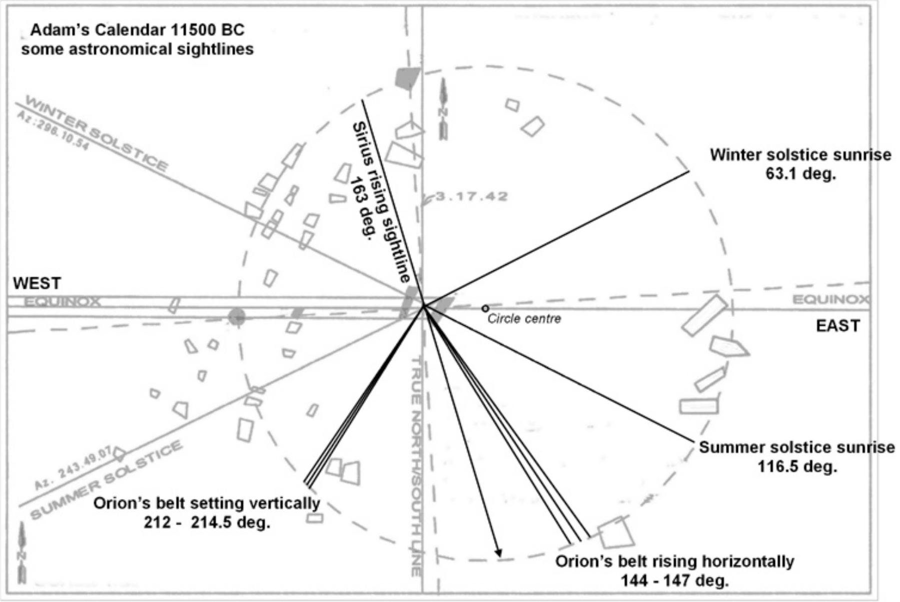
Nikola Tesla

Linear History? Ancient “Computers“

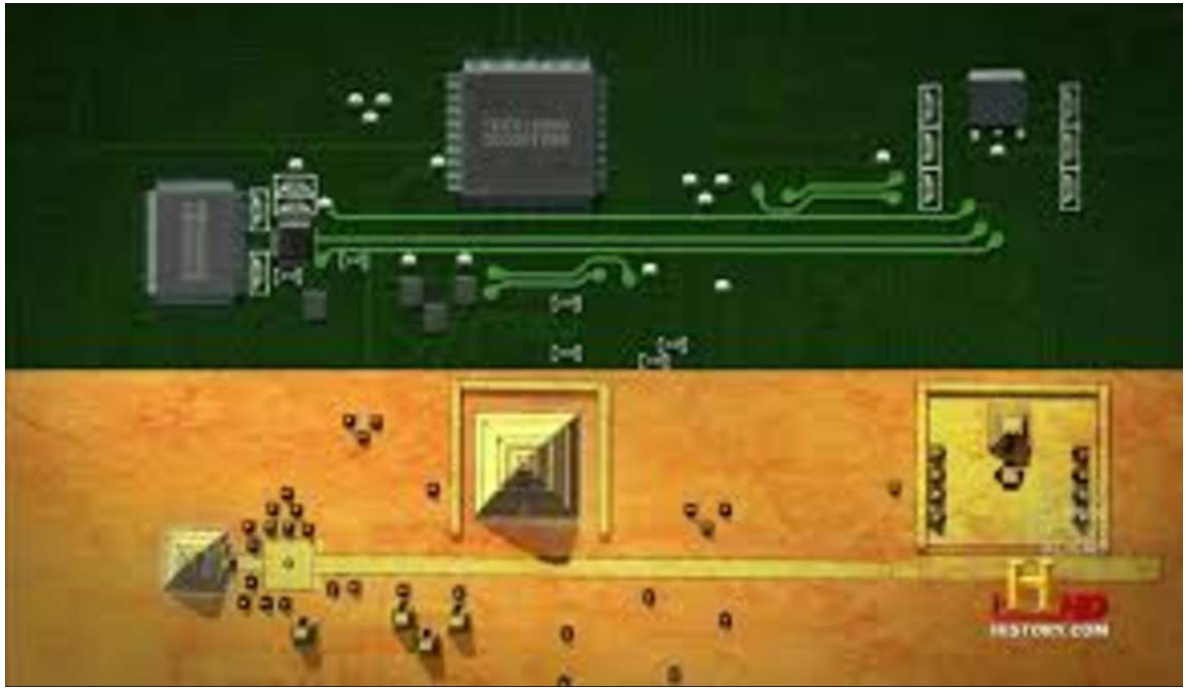
Adam‘s Calender,
Michael Tellinger

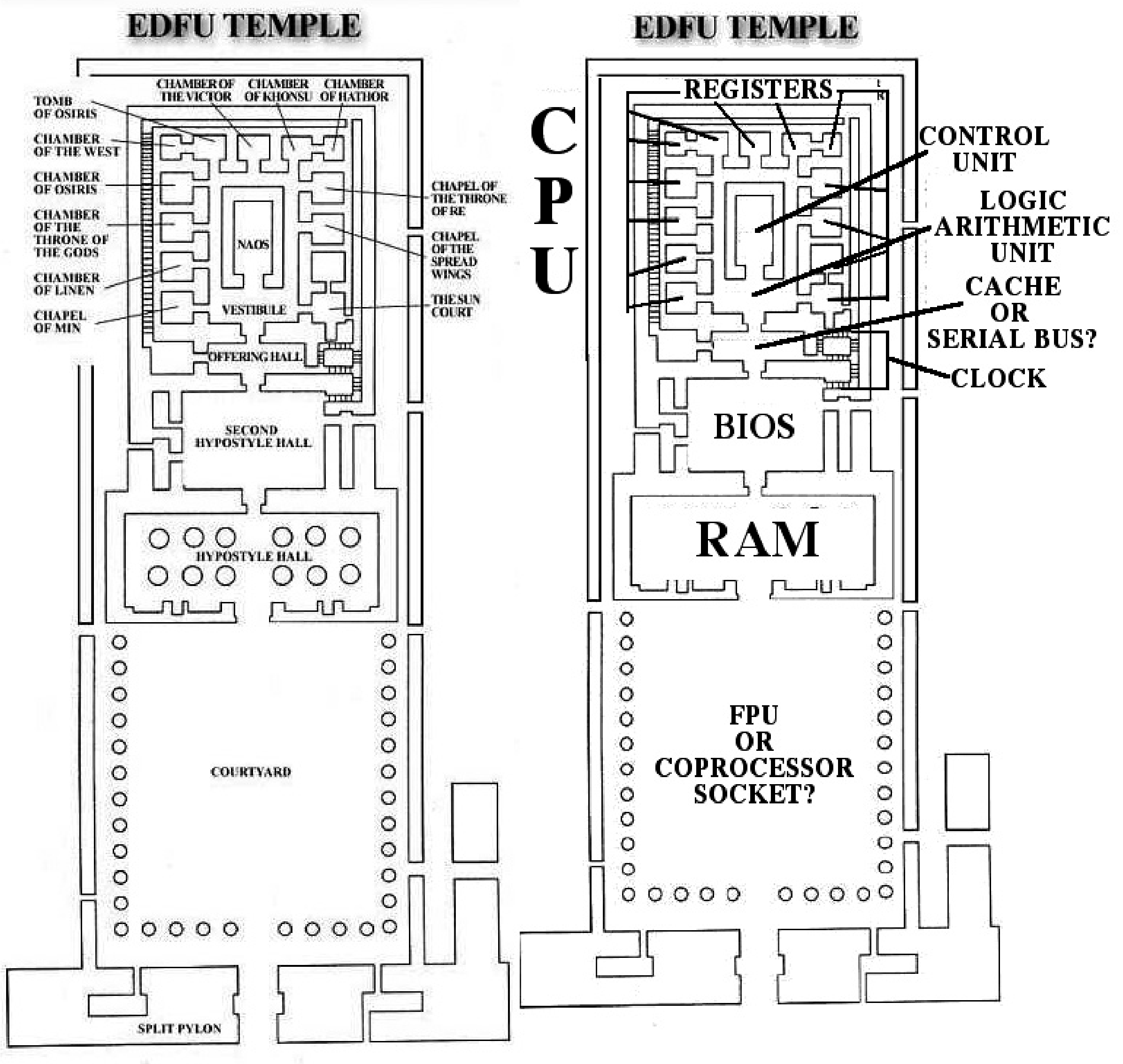


Stonehenge: A Neolithic Computer
Nature **202**, 1258 - 1261 (27 June 1964); doi:10.1038/2021258a0



Ancient Pyramids & Computer Architectures

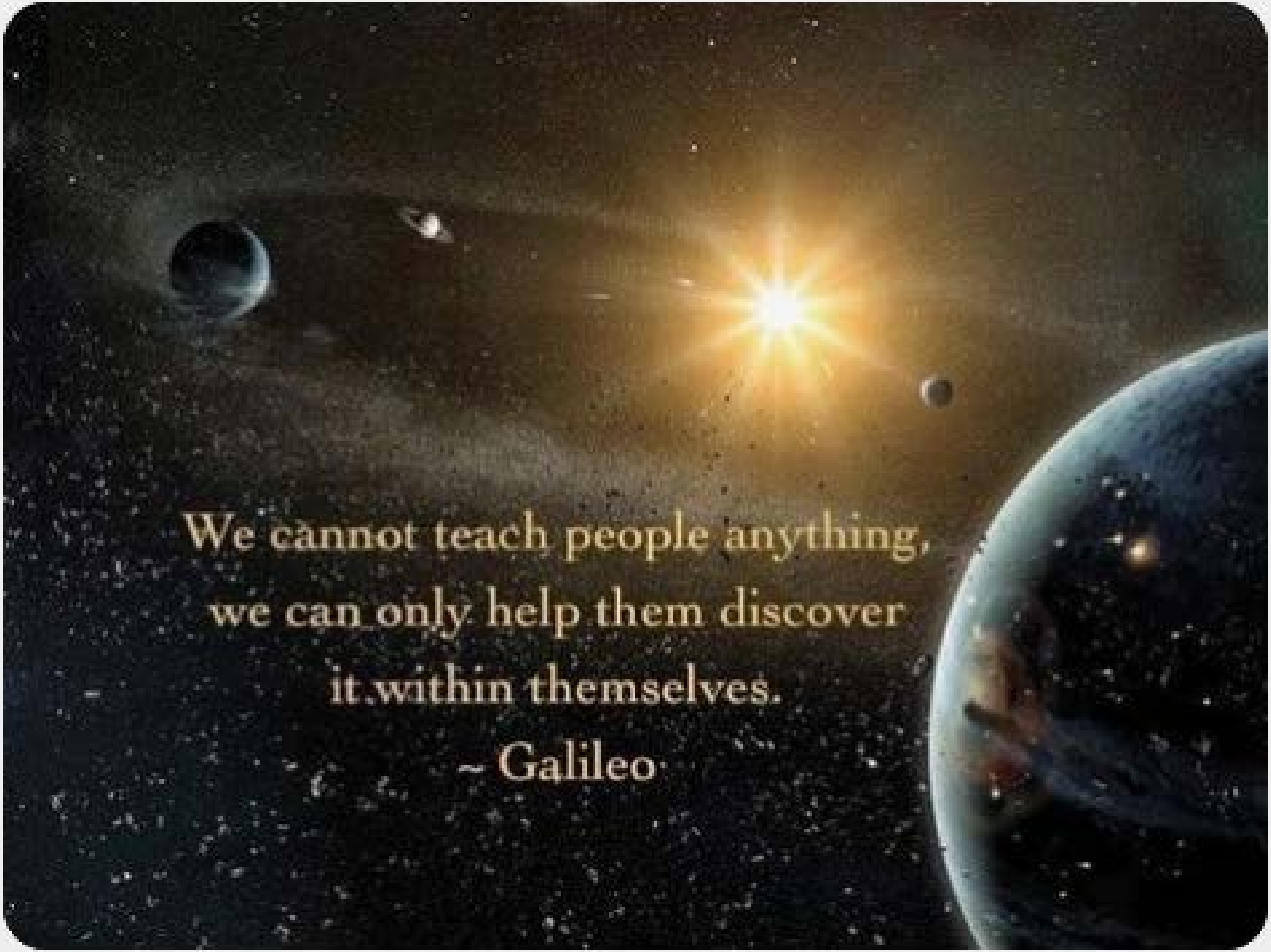




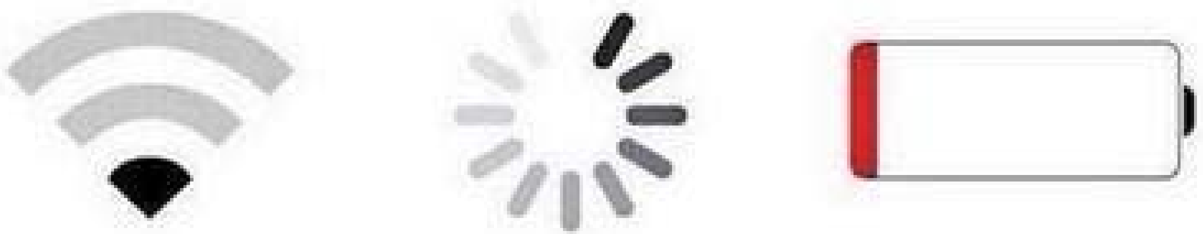
thebestbrainpossible.com

The purpose of education is to replace an empty mind with an open one.

Malcolm Forbes

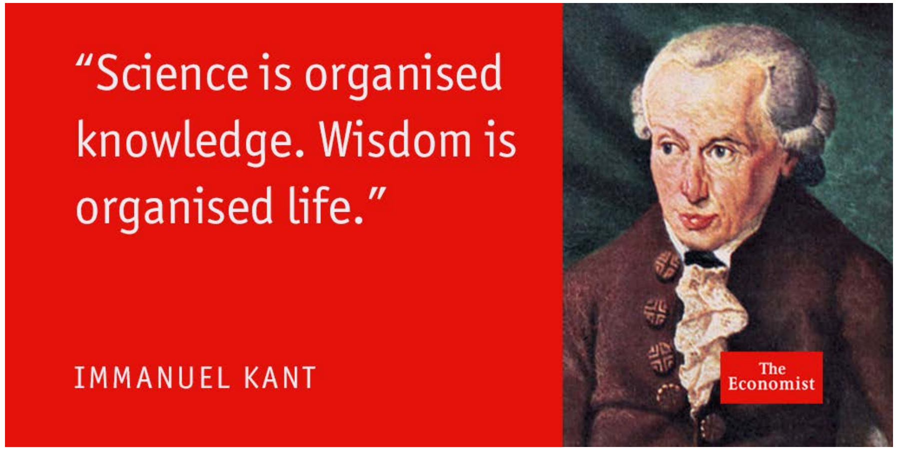

We cannot teach people anything,
we can only help them discover
it within themselves.
~ Galileo

3 biggest fears of our generation:



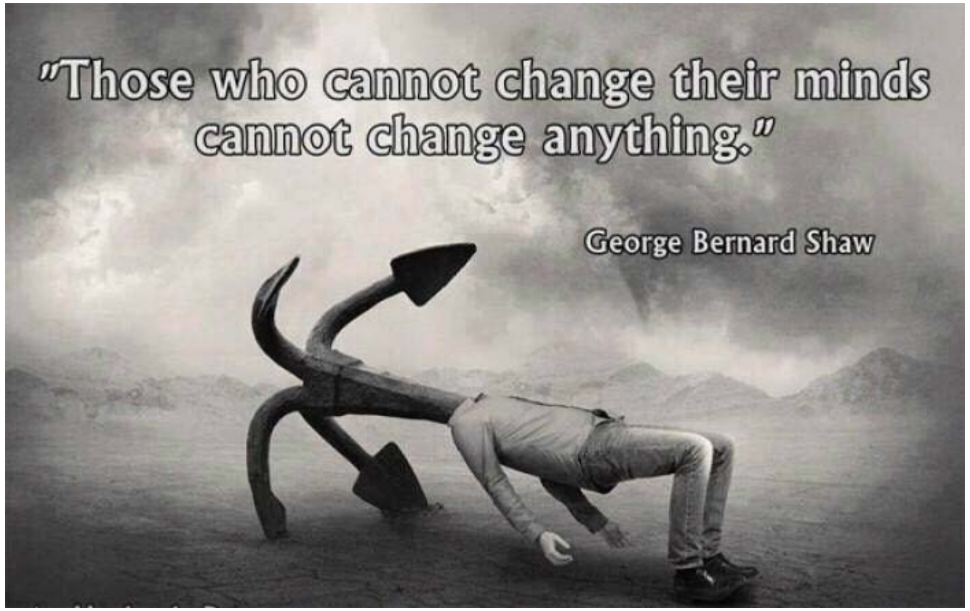
Assumptions, Models, and Abstractions

- **Co-evolution of Science & Technologies**
- Smart Cities as models of ecosystems: -> People, Things, and Systems
- Models as abstractions are useful (Platonic Forms)
- We lack a model for such an ecosystem
- From automation to creativity support
- Consciousness and creativity support -> lead to new (meta) models and understanding of technologies and science -> Architecture of Values



Layers of Paradigms

- Not reductionist
- We have to **create the abstractions and models** we want based on our understanding of human and societal needs
- Ecosystems = Architecture, Structure + Dynamics
- **New Paradigms**: (1) Elastic Computing, (2) Social Compute Units, (3) Osmotic Computing
- Emergent properties on higher levels with own properties



Paradigm 1: Elasticity (Resilience)

(Physics) The property of returning to an initial form or state following deformation

stretch when a force stresses them

e.g., ***acquire** new resources, **reduce** quality*

shrink when the stress is removed

e.g., ***release** resources, **increase** quality*

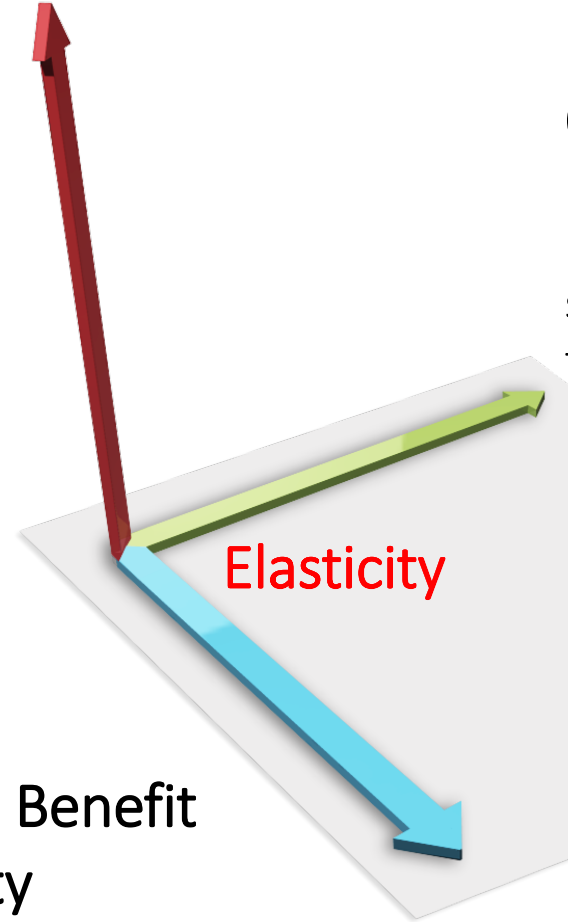
Elastic Computing > Scalability

Resource elasticity

Software / human-based computing elements, multiple clouds

Quality elasticity

Non-functional parameters e.g., performance, quality of data, service availability, human trust



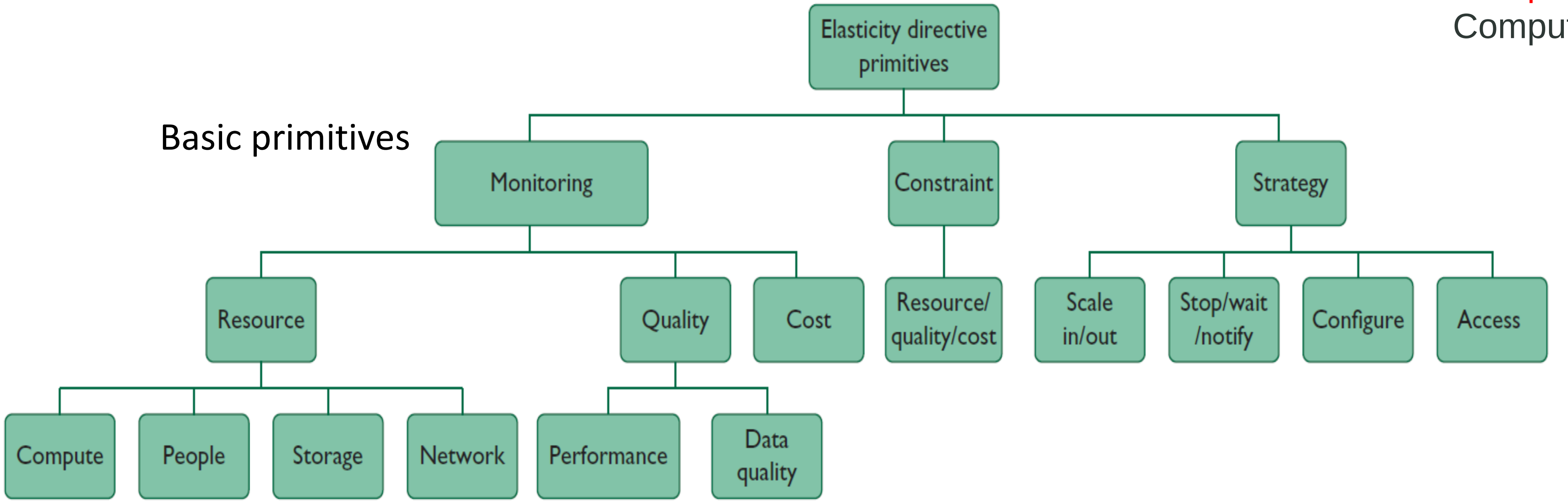
Costs & Benefit elasticity

rewards, incentives

Dustdar S., Guo Y., Satzger B., Truong H. (2011) [Principles of Elastic Processes](), *IEEE Internet Computing*, Volume 15 (2011), Issue 5; pp. 66 - 71.

Specifying and controling elasticity

Dustdar, S. et al.: Programming Directives for Elastic Computing. IEEE Internet Computing 16(6): 72-77 (2012)



SYBL (Simple Yet Beautiful Language) for specifying elasticity requirements

SYBL-supported requirement levels

- Cloud Service Level
- Service Topology Level
- Service Unit Level
- Relationship Level
- Programming/Code Level

Current SYBL implementation

in Java using Java annotations

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

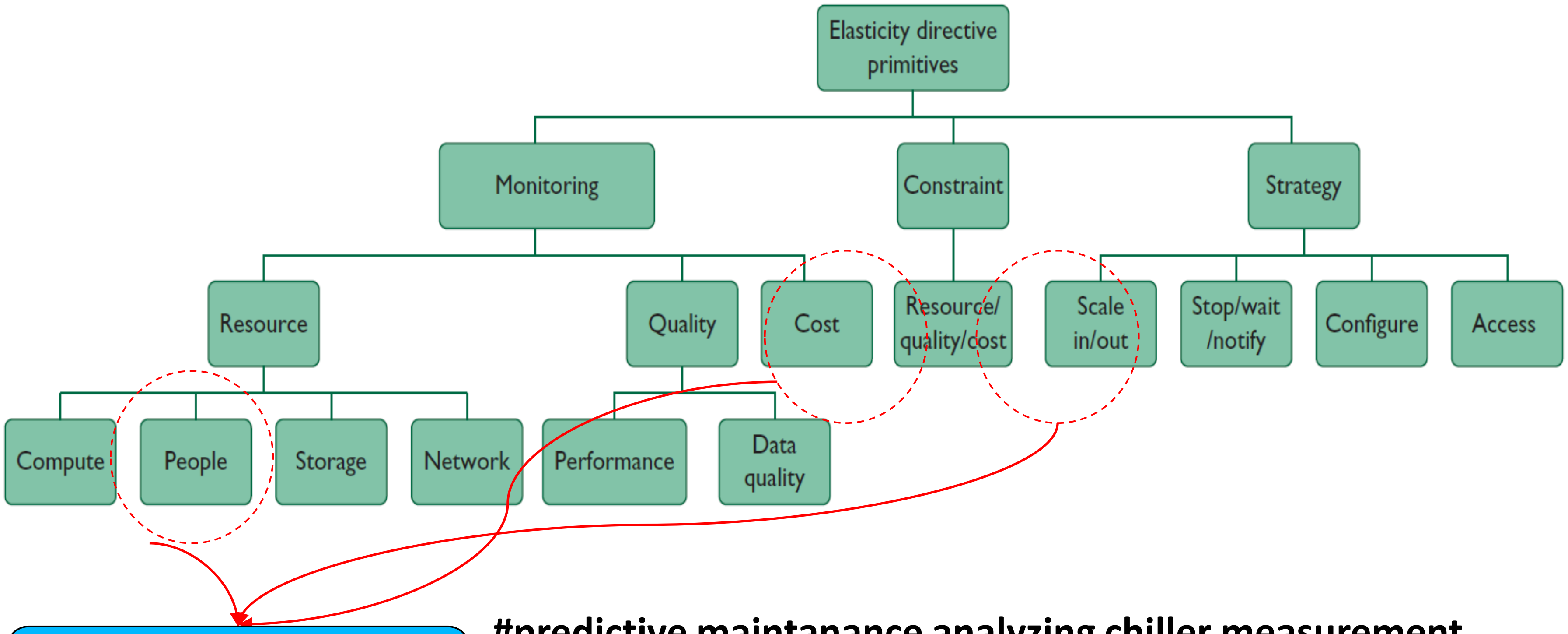
in XML

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

as TOSCA Policies

<tosca:ServiceTemplate name="PilotCloudService"> <tosca:Policy name="St1" policyType="SYBLStrategy"> St1:STRATEGY minimize(Cost) WHEN high(overallQuality) </tosca:Policy>...

Specifying and controling elasticity of human-based services



What if we need to "invoke" humans?

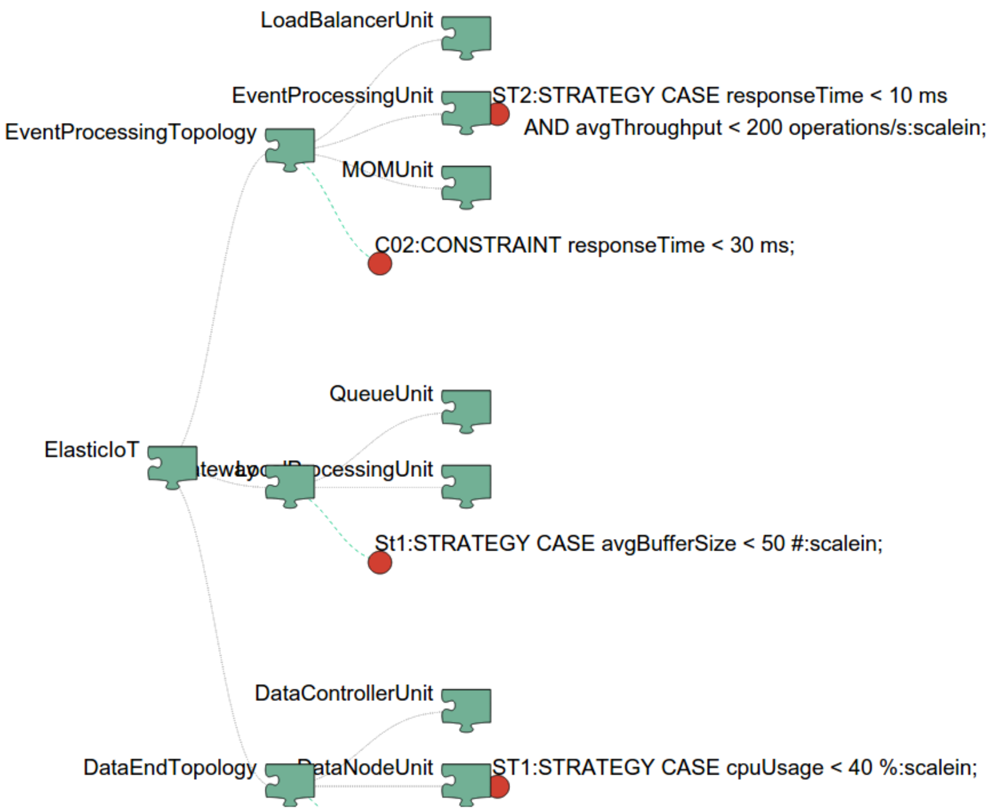
#predictive maintanance analyzing chiller measurement
#SYBL.ServiceUnitLevel
Mon1 MONITORING accuracy = Quality.Accuracy
Cons1 CONSTRAINT accuracy < 0.7
Str1 STRATEGY CASE Violated(Cons1):
Notify(Incident.DEFAULT, ServiceUnitType.HBS)

High level elasticity control

#SYBL.CloudServiceLevel
Cons1: CONSTRAINT responseTime < 5 ms
Cons2: CONSTRAINT responseTime < 10 ms
WHEN nbOfUsers > 10000
Str1: STRATEGY CASE fulfilled(Cons1) OR fulfilled(Cons2): minimize(cost)

#SYBL.ServiceUnitLevel
Str2: STRATEGY CASE ioCost < 3 Euro : maximize(dataFreshness)

#SYBL.CodeRegionLevel
Cons4: CONSTRAINT dataAccuracy>90% AND cost<4 Euro



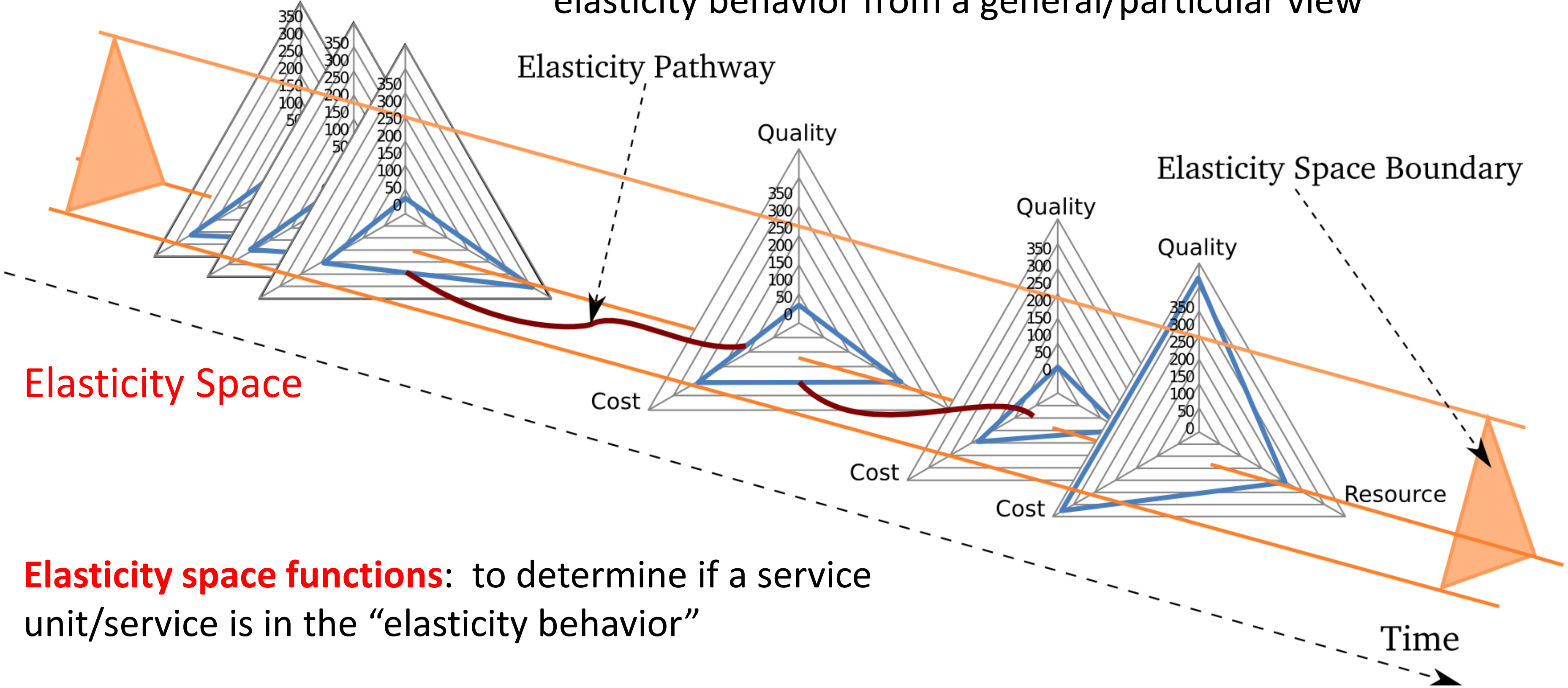
Georgiana Copil, Daniel Moldovan, Hong-Linh Truong, Schahram Dustdar, **"SYBL: an Extensible Language for Controlling Elasticity in Cloud Applications"**, 13th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing (CCGrid), May 14-16, 2013, Delft, Netherlands

Copil G., Moldovan D., Truong H.-L., Dustdar S. (2016). **rSYBL: a Framework for Specifying and Controlling Cloud Services Elasticity**. *ACM Transactions on Internet Technology*

Elasticity Model for Cloud Services

Moldovan D., G. Copil,Truong H.-L., Dustdar S. (2013). **MELA: Monitoring and Analyzing Elasticity of Cloud Service. CloudCom 2013**

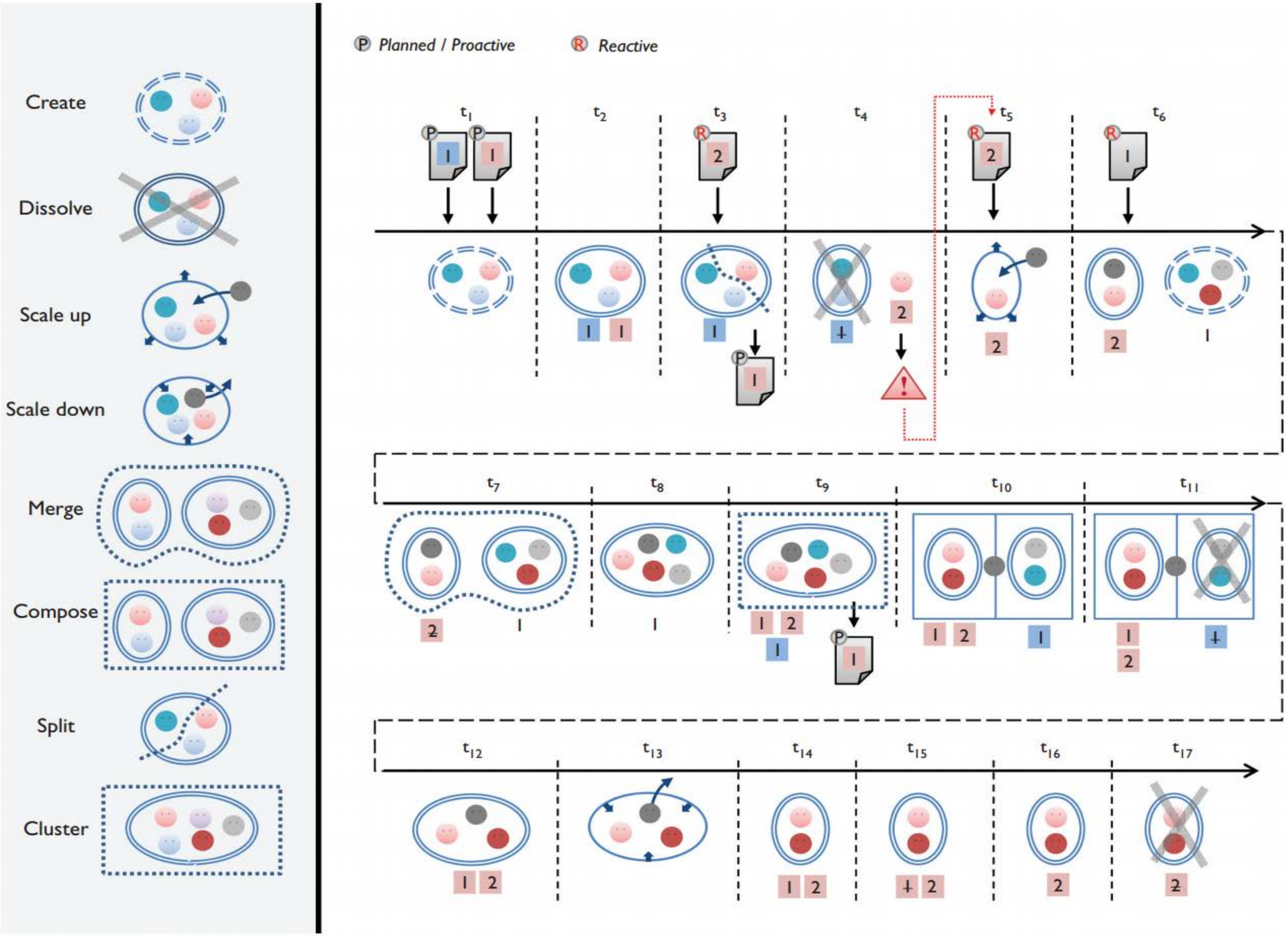
Elasticity Pathway functions: to characterize the elasticity behavior from a general/particular view



Elasticity Space

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

Paradigm 2: Social Compute Units (SCUs)



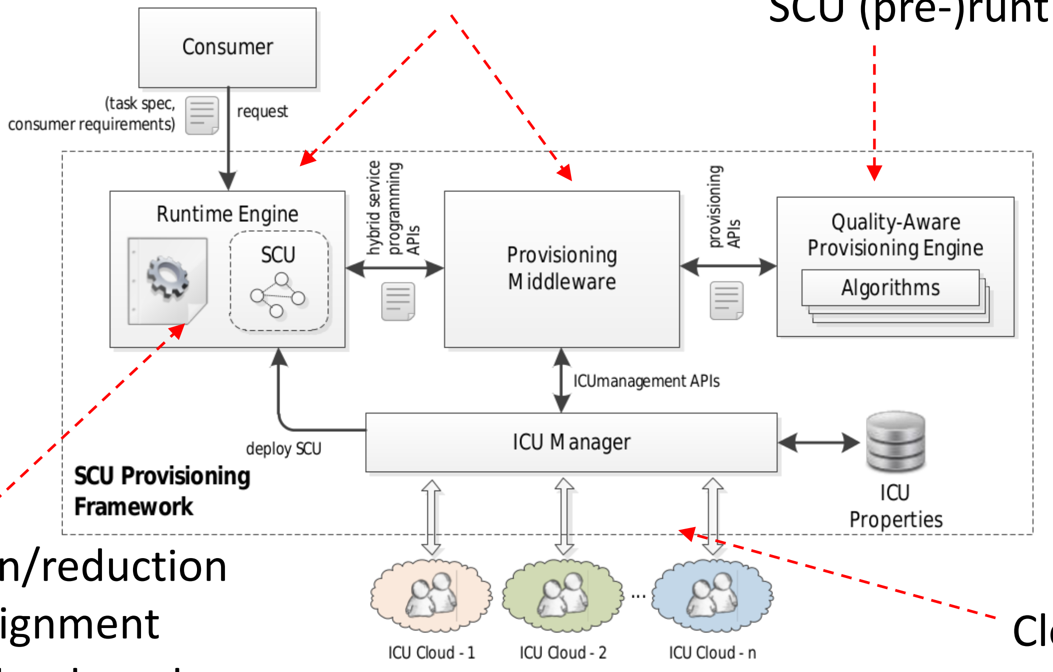
Dustdar S., Bhattacharya K. (2011). The Social Compute Unit, *IEEE Internet Computing,* Volume 15, Issue 3; pp. 64 - 69.

Fernández P., Truong H.-L., Dustdar S., Ruiz-Cortés A. (2015). Programming Elasticity and Commitment in Dynamic Processes. IEEE Internet Computing, Volume 19, Number 2, pp. 68 - 74

Elastic SCU provisioning (Paradigms 1 and 2 together)

Elastic profile

SCU (pre-)runtime/static formation



Algorithms

- Ant Colony Optimization variants
- FCFS
- Greedy

SCU extension/reduction

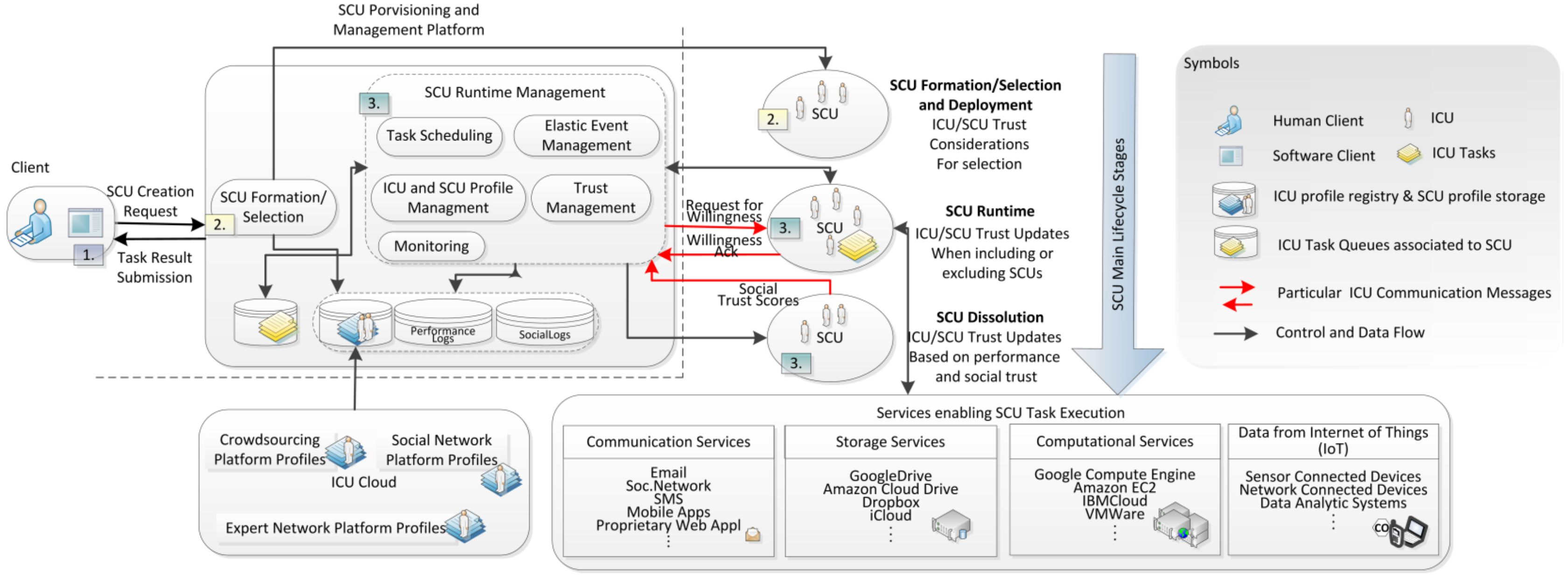
- Task reassignment based on trust, cost, availability

Cloud APIs

Mirela Riveni, Hong-Linh Truong, and Schahram Dustdar, **On the Elasticity of Social Compute Units, CAISE 2014**

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

Algorithmic Team Formation



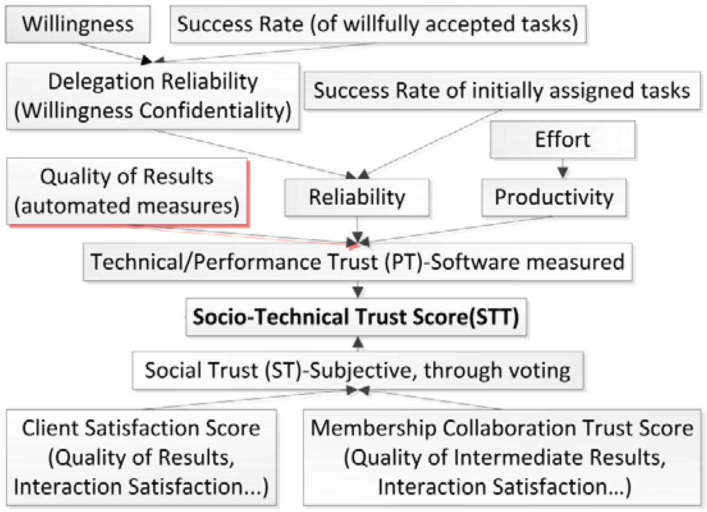
Provisioning algorithms:

- Ant Colony Optimization variants
- FCFS
- Greedy

Supported query variables:

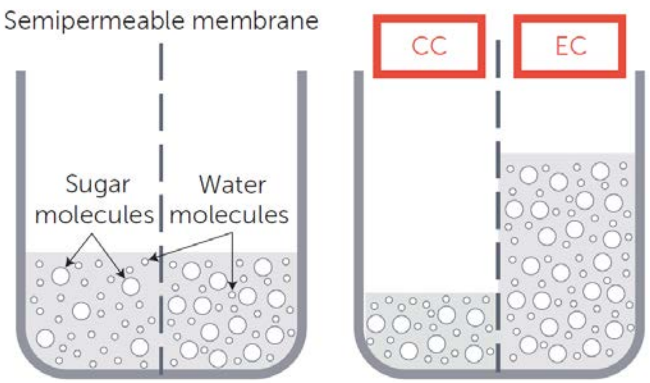
- Skills
- Skill level (fuzzy)
- Connectedness (fuzzy)
- Max Response Time
- Cost Limit
- Optimization objectives
  - cost
  - time
  - responsiveness

Trust model metrics:

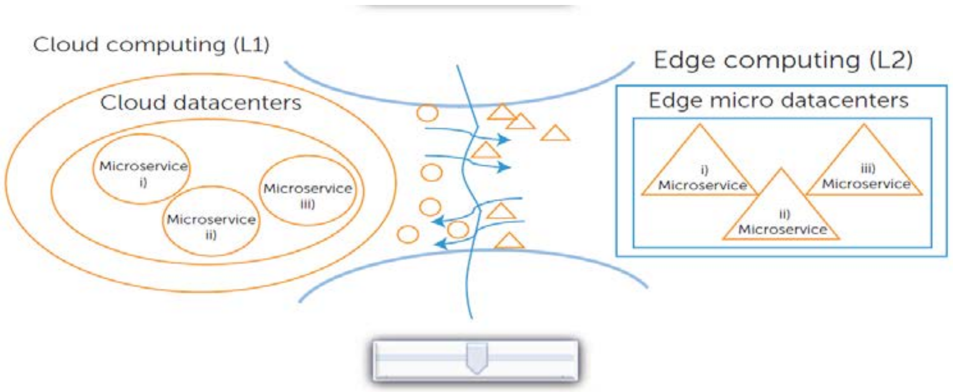


Paradigm 3: Osmotic Computing

- In chemistry, “osmosis” represents the seamless diffusion of molecules from a higher to a lower concentration solution.

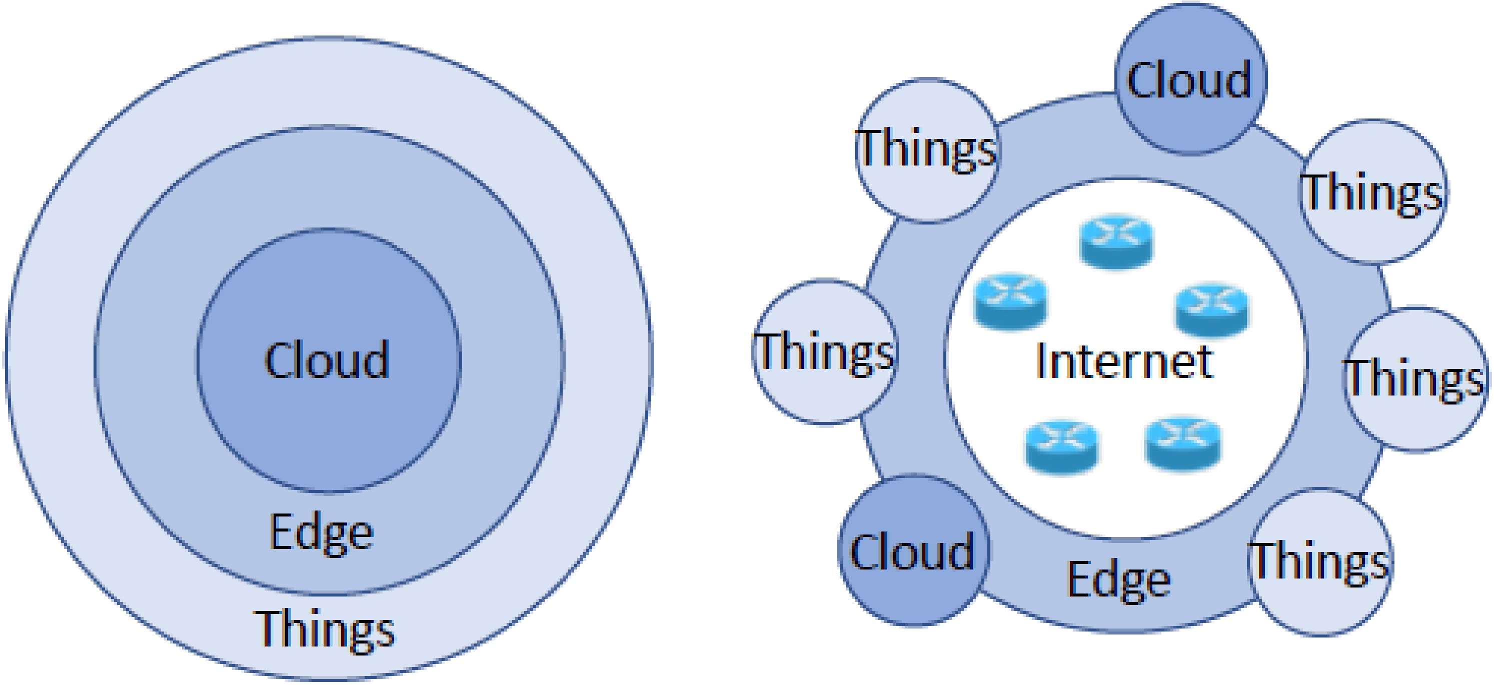


- Dynamic management of (micro)services across cloud and edge datacenters
  - deployment, networking, and security, …
  - providing reliable IoT support with specified levels of QoS.



Villari M., Fazio M., Dustdar S., Rana O., Ranjan R. (2016). [Osmotic Computing: A New Paradigm for Edge/Cloud Integration]. *IEEE Cloud Computing*, Volume 3, Issue 6, pp. 76-83

Perspectives on the IoT: Edge, Cloud, Internet



(a) A cloud-centric perspective:
Edge as “edge of the cloud”

(b) An Internet-centric perspective:
Edge as “edge of the Internet”

Cloud-centric perspective

Assumptions

- Cloud provides core services; Edge provides local proxies for the Cloud (offloading parts of the cloud's workload)

Edge Computers

- play supportive role for the IoT services and applications
- Cloud computing-based IoT solutions use cloud servers for various purposes including massive computation, data storage, communication between IoT systems, and security/privacy

Missing

- In the network architecture, the cloud is also located at the network edge, not surrounded by the edge
- Computers at the edge do not always have to depend on the cloud; they can operate autonomously and collaborate with one another directly without the help of the cloud

Internet-centric perspective

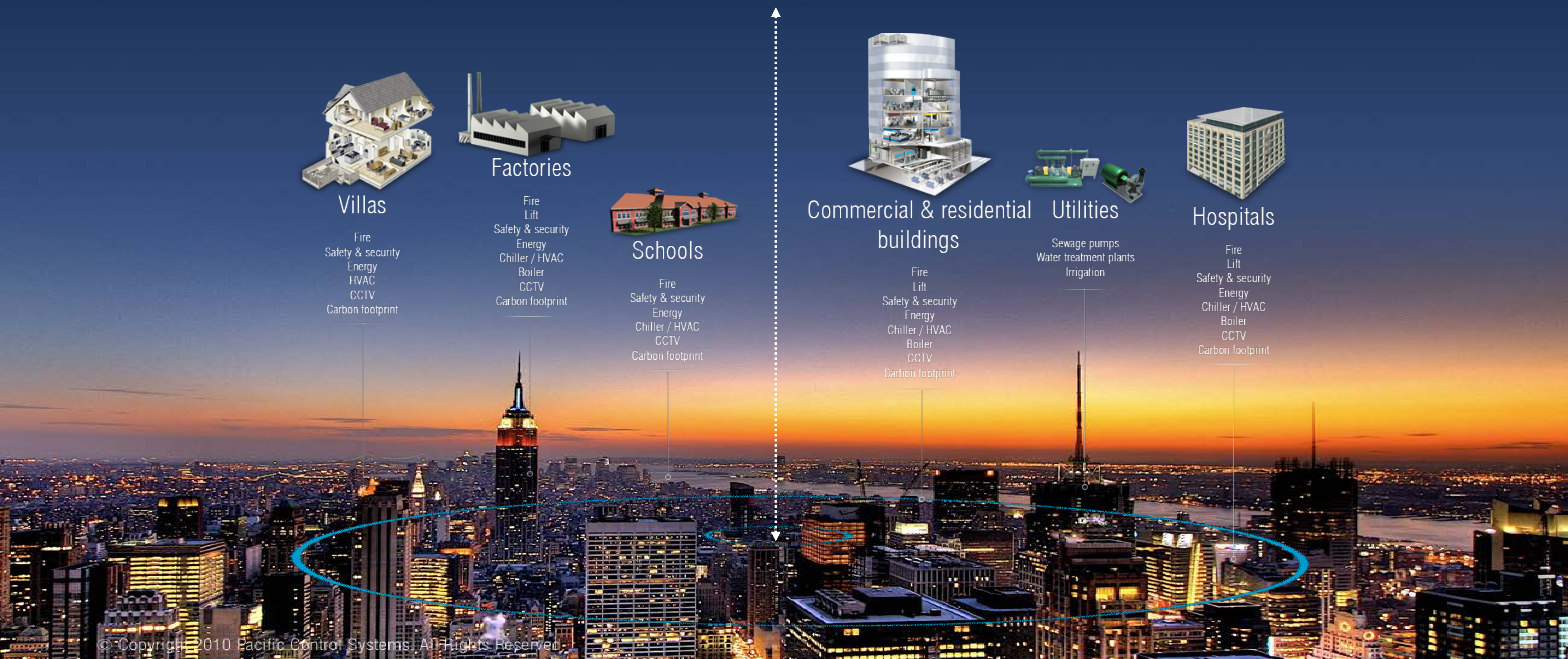
Assumptions

- Internet is center of IoT architecture; Edge devices are gateways to the Internet (not the Cloud)
- Each LAN can be organized around edge devices autonomously
- Local devices do not depend on Cloud

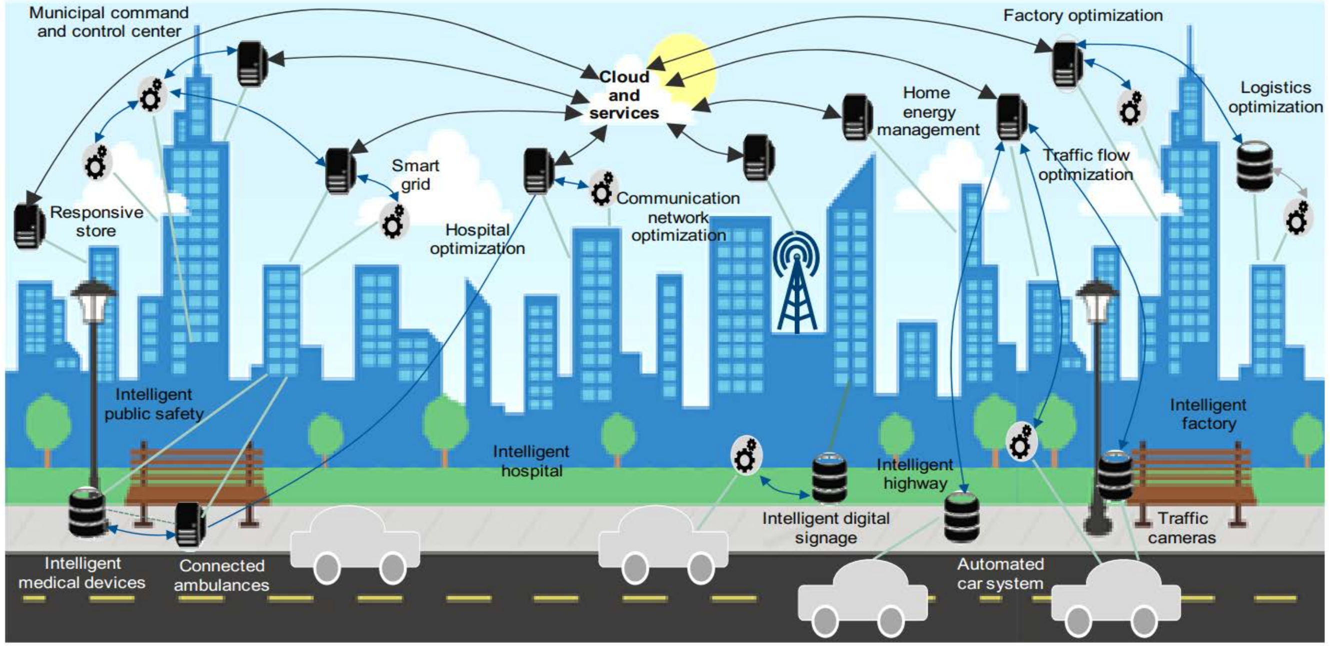
Therefore

- Things belong to partitioned subsystems and LANs rather than to a centralized system directly
- The Cloud is connected to the Internet via the edge of the network
- Remote IoT systems can be connected directly via the Internet. Communications does not have to go via the Cloud
- The Edge can connect things to the Internet and disconnect traffic outside the LAN to protect things -> IoT system must be able to act autonomously

Smart City


Villas
Fire
Safety & security
Energy
HVAC
CCTV
Carbon footprint
Factories
Fire
Lift
Safety & security
Energy
Chiller / HVAC
Boiler
CCTV
Carbon footprint
Schools
Fire
Safety & security
Energy
Chiller / HVAC
CCTV
Carbon footprint
Commercial & residential buildings
Fire
Lift
Safety & security
Energy
Chiller / HVAC
Boiler
CCTV
Carbon footprint
Utilities
Sewage pumps
Water treatment plants
Irrigation
Hospitals
Fire
Lift
Safety & security
Energy
Chiller / HVAC
Boiler
CCTV
Carbon footprint

“Traditional“ ICT view on Smart City



- Monitoring and controlling a large scale network of interconnected “things” (devices, services, sensors, actuators)
  - Enablers: IoT, Cloud, Big Data, participatory sensing

- Focus on “optimizing” physical/digital infrastructure, not society!
  - society is expected to implicitly benefit from infrastructure optimization

“Societal view“ on Smart City

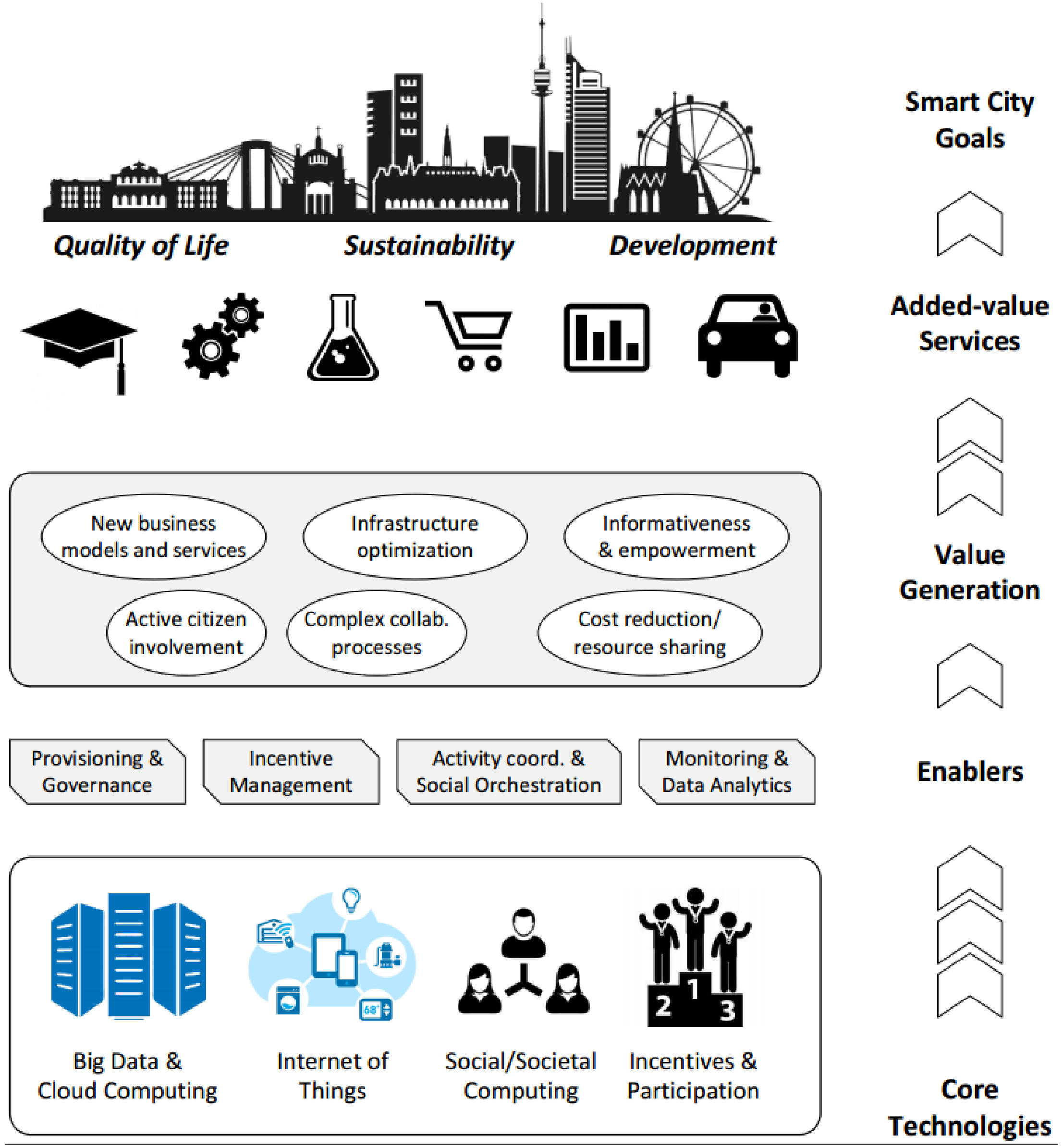
- Active involvement of individual citizens in processes and ad-hoc activities to achieve coordinated collective benefits:
  - optimize transportation, energy use, resource sharing
  - direct democracy, shaping and uptake of regulations
  - new business opportunities (novel business models) dependent on collective participation

“Holistic View“ Architecture of values

- Inclusion of all stakeholders into the active management of the Smart City

- Integrated management of physical, ICT and social infrastructure

- Generation of new values



Cyber-Human Smart City Values

Infrastructural values

- traditional management (optimizations and savings) of city-owned physical infrastructure.
- integral management of privately owned IoT-enabled devices put at disposal (computational resources and everyday objects, such as cars) for common benefit.
- dynamic, locally-scoped infrastructural optimizations and interventions through citizens and privately-owned IoT infrastructure (e.g., citizens vote for new sensors)

Cyber-Human Smart City Values

Societal values

- Direct inclusion and empowerment of citizens as key stakeholders of the city both in digital and physical environments
- Interaction, demonstration, informed-ness, learning through pervasive IoT devices and Virtual Reality
- Direct democracy, voting simulation
- Formation of ad-hoc human teams for performing complex collective activities (physical and cognitive)

Cyber-Human Smart City Values

Business values

- New labor/work models supported by:
  - Mechanisms for management of complex coordinated activities:
    - incentive mechanisms
    - team formation algorithms
    - negotiation protocols

- New business models based on:
  - Augmenting the overall city infrastructure with citizen-owned devices
  - Microtransactions
  - Dynamic and crowdsourced workforce spanning entire population

Smart City Platform

Research Challenges

- Virtualizing human and software elements
- Team formation
- Execution orchestration
- Privacy tradeoffs and ethical issues
- Runtime controllability:
    - direct – programming
    - indirect – incentives

Managing Smart City Social Infrastructure

A Brief Glimpse into the Past...

- The hope is that, in not too many years, human brains and computing machines will be coupled together very tightly, and that the resulting partnership will think as no human brain has ever thought and process data in a way not approached by the information-handling machines we know today.

– ***J. C. R. Licklider***
"Man-Computer Symbiosis"
IRE Trans. on Human Factors in Electronics,
vol. HFE-1, pp. 4-11, March 1960

A Brief Glimpse into the Past...

How did computers and humans affect each other throughout history?

- 1960s – Golden age of Artificial Intelligence
  - formal reasoners, theorem provers, playing chess
- AI considered a panacea for all future problems

A Brief Glimpse into the Past...

- Middle of ‘70s
  - Not all problems are easy to understand, model and solve
  - AI research funding drastically cut

- First half of ‘80s
  - Expert systems to support decision-making in business processes

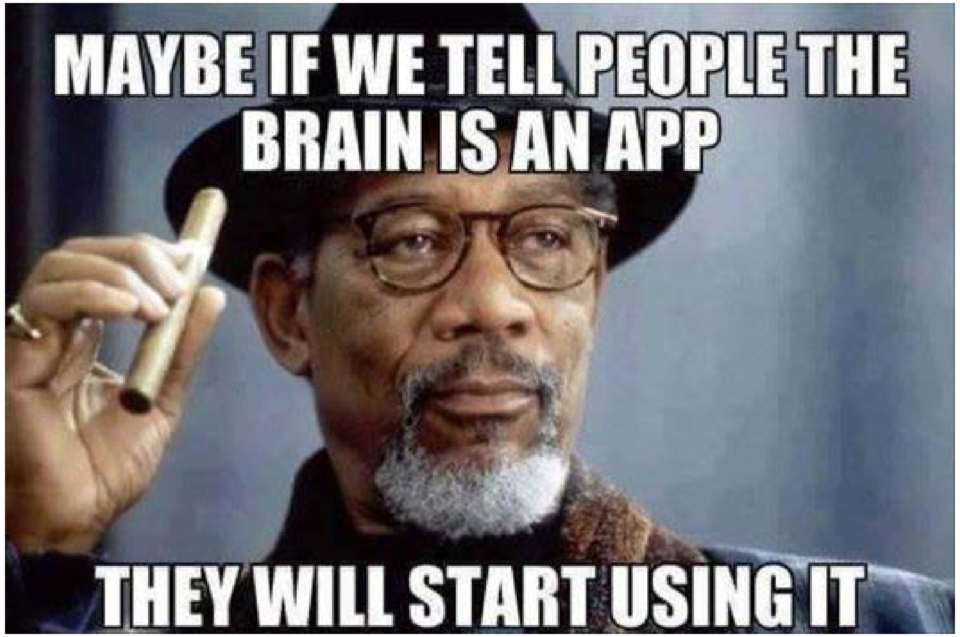
A Brief Glimpse into the Past...

- “AI winter” lasting until late 1990s

- Late 00s – revival of AI
  - Shift from high-level (rule-based) knowledge to low-level machine learning
  - Knowledge embodied in parameters of cognitive models
    - Data Mining, Machine Learning, Neural Networks

The Present

- Can a machine-only system really be considered “intelligent”?
  - Going beyond Turing Test... (or Alexa, Siri, Cortana)
  - Why not gather societal intelligence? ... and not try to match the intelligence of a single human individual?
- Intelligence utility is limited if restricted only to digital domain -> go physical
- “Embrace” AI and integrate human collectives into the process!
  - Help with tasks trivial for humans, but challenging for computers
    - not only intellectually, but also physically

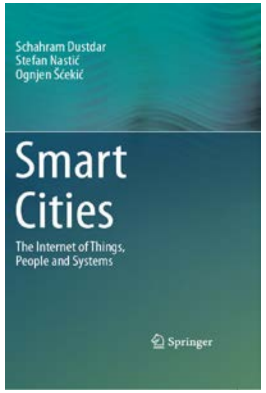


Conclusion

- Partnership Model for IoT/Edge/Cloud

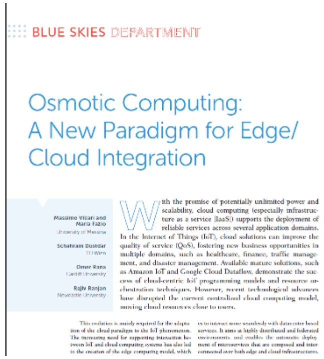
  Garcia J. M., Fernandez P., Ruiz-Cortes A., Dustdar S., Toro M. (2017). Edge and Cloud Pricing for the Sharing Economy. *IEEE Internet Computing*, Volume 21, Issue 2, pp. 78-84

- Book (IoT, People and Systems)



- 3 Major Paradigms (E, S, O)

Villari M., Fazio M., Dustdar S., Rana O., Ranjan R. (2016). Osmotic Computing: A New Paradigm for Edge/Cloud Integration. *IEEE Cloud Computing*, Volume 3, Issue 6, pp. 76-83



Thanks for your attention

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