The SAPERE Project

From Service-Oriented Architectures to Nature-Inspired

Self-aware Pervasive Service Ecosystems:

The SAPERE Approach

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Outline

- Motivations
- Limitations of SOA
- The Natural Inspiration
- A Reference architecture
- Comparison of Natural Metaphors
- The SAPERE Approach
- Conclusions

The Changing ICT Scenario

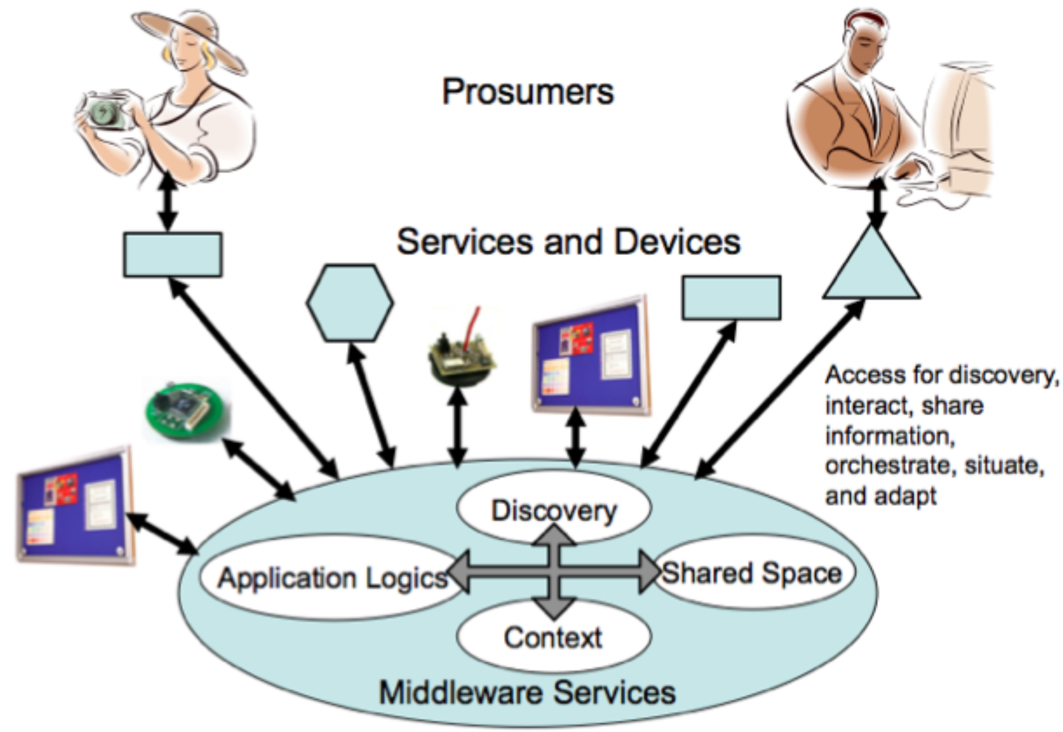
- Several emerging trends…
- Networks are changing
  - Integration of (increasingly dense) pervasive devices embedded in physical space
  - Convergence of Internet and Telecommunication networks
  - Convergence of social and technical networks
  - High dynamisms and decentralization
- And so management needs are changing
  - Decentralization requires self-management and self-configuration
  - Need to achieve 24/7 availability at limited costs
  - Opportunistic approaches to devices integration
- And service systems have to change accordingly

New Requirements for Service Systems

- Spatiality and Situatedness
  - Space-dependencies and situation-awareness
- Adaptivity
  - Capable of reacting and re-tuning in response to the dynamics of the pervasive infrastructure
  - Adapting to changing patterns and peculiar users' needs
- Service Prosumption and Diversity
  - Users also act as producers of data and services (prosumers)
  - Decentralized production models
  - Value Co-creation
- Eternal betas and eternal evolution
  - No service/software components is ever ultimate
  - New components gets on appearing

Limits of "Traditional" SOA

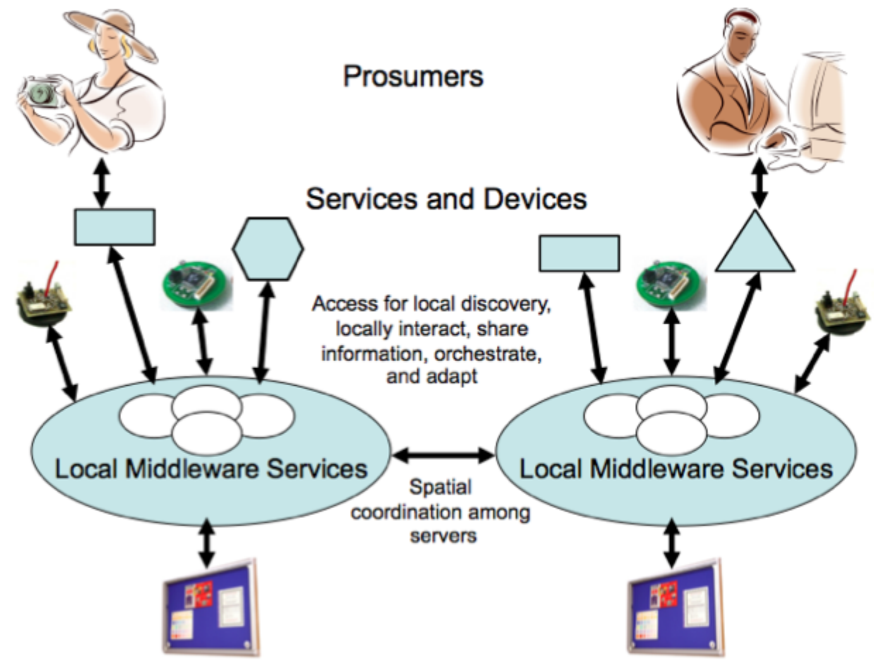
- Too centralized and heavyweight
  - Too many diverse supporting middleware services
  - Inherently centralized



- Hard to meet the identified requirements
  - No spatial concepts
  - Static orchestration of services and devices
  - Limited support for decentralized prosumption,
  - Long-term evolutions constrained by too many assumptions

Decentralized SOA

- Replicate and Distributed Services
  - To support space-dependent activities
  - To localize updates and event notifications



- As a result
  - The distinction between discovery, orchestration, and context services tend to disappear
  - Generally, interactions in the local space
- But
  - What degree of distribution in space?
  - Complex coordination among distributed middleware services

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Let's Take it Radically

- No more distinction between discovery, orchestration, context, etc.
  - A single (and minimal) interaction space to handle data, interactions, context, orchestration
  - Based on a limited set of general "interaction laws"
- Adaptivity by self-organization
  - Based on the set of laws and relying on spatial locations, without pre-defined orchestration patterns
- No "distributed" architecture but "continuous" one
  - Abstract a spatial continuum over the network
  - Build over the dynamic infrastructure of devices
  - Inherently open to decentralized contribution
- Isn't this resembling of natural systems?

Nature-inspired Service Ecosystems

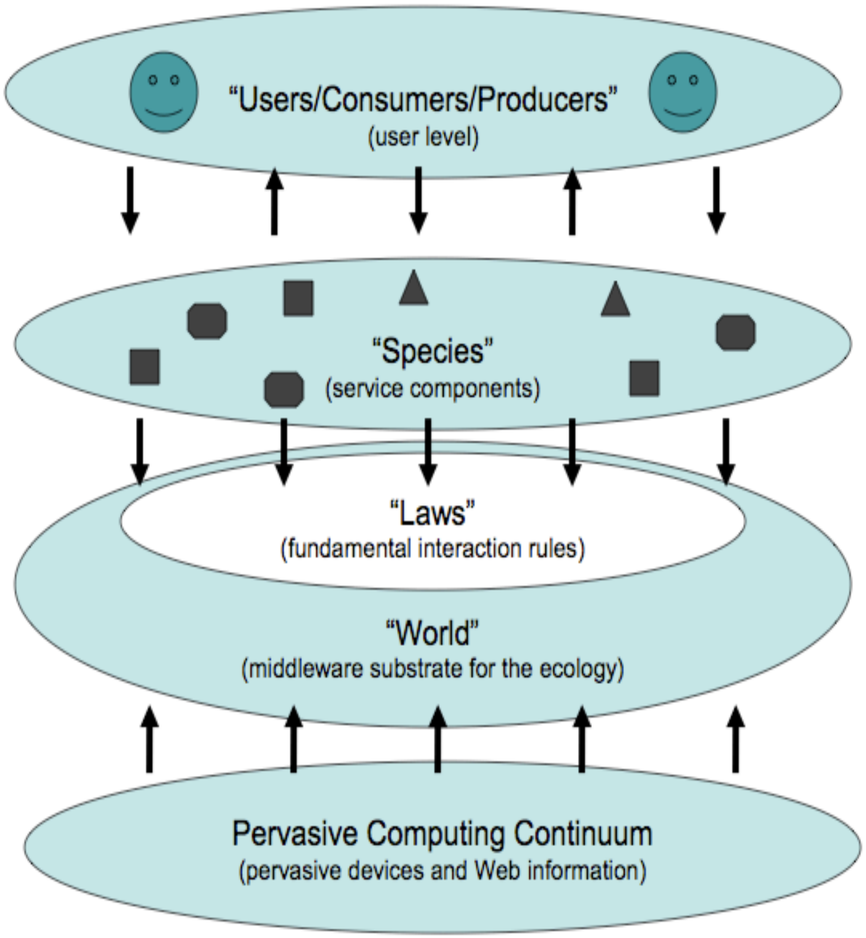
- In natural systems (and whether you think at physics, chemistry, biology, or ecology)
  - Spatiality is there by construction
  - Self-adaptation, self-configuration, self-management, are inherent part of their everyday life and self-organizing dynamics
  - Inherently open to new and increasingly diverse species
  - The infrastructure is eternal and does not change, although their components may naturally evolve
- So we can get inspiration from nature to realize "Nature-inspired Pervasive Service Ecosystems"
- But what kinds of natural systems are we talking about?

Natural Metaphors

- When modeling nature-inspired pervasive service ecosystems
  - How should its components, laws, world, be modelled?
  - What form should they take in implementation terms?
- Several possible natural metaphors can be adopted
  - Physical, chemical, biological, social
  - Corresponding at different "levels of observation"
  - Based on different mechanisms for laws and on different components behaviours
  - And in which features, of adaptability, evolvability, and the capability of controlling decentralized control are differently expressed
- But how can we comparatively reason among such apparedently diverse metaphors?

The Reference Architecture

- It abstracts from any specific nature-inspired metaphor
- Shows how general ecosystem concepts can be framed in a uniform way
- Useful to turn the architecture into an actual middleware infrastructure



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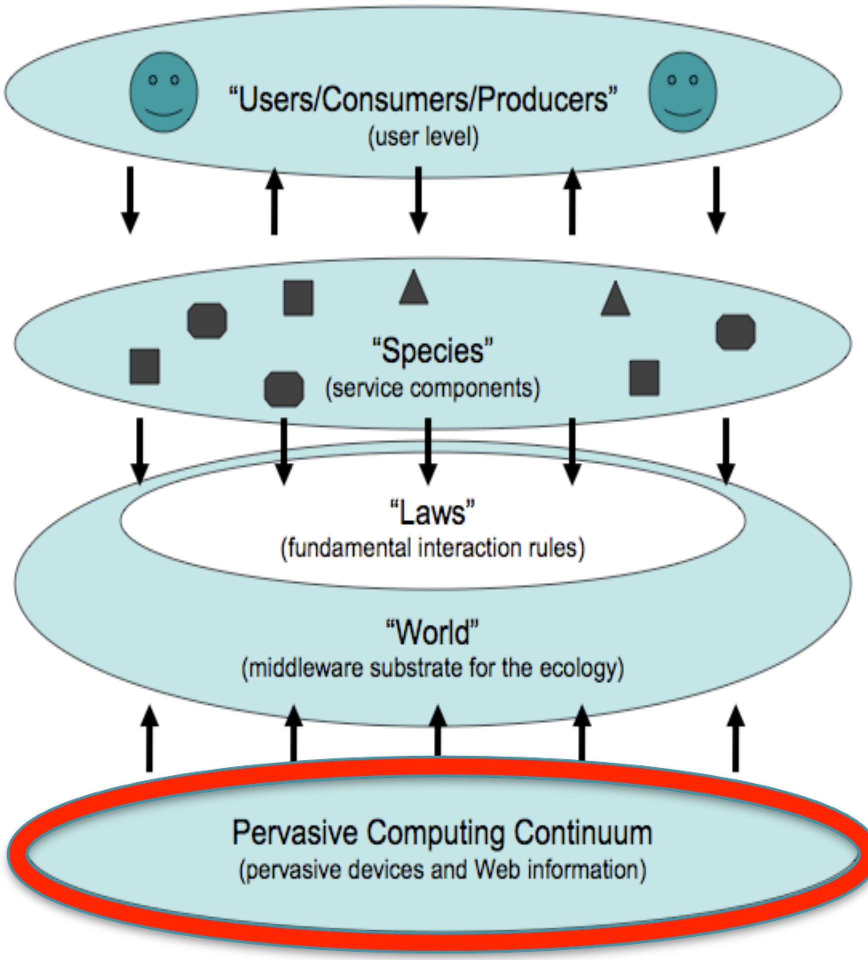
The Pervasive Computing Continuum

- Shaping the hardware ground on which the actual ecosystem will live and execute
  - Pervasive sensing and actuating devices very densely deployed in space
  - Personal computer-based systems
  - Wireless communications
- Feeding the ecosystem with data about nearly every facts of the world
  - Also via Web information



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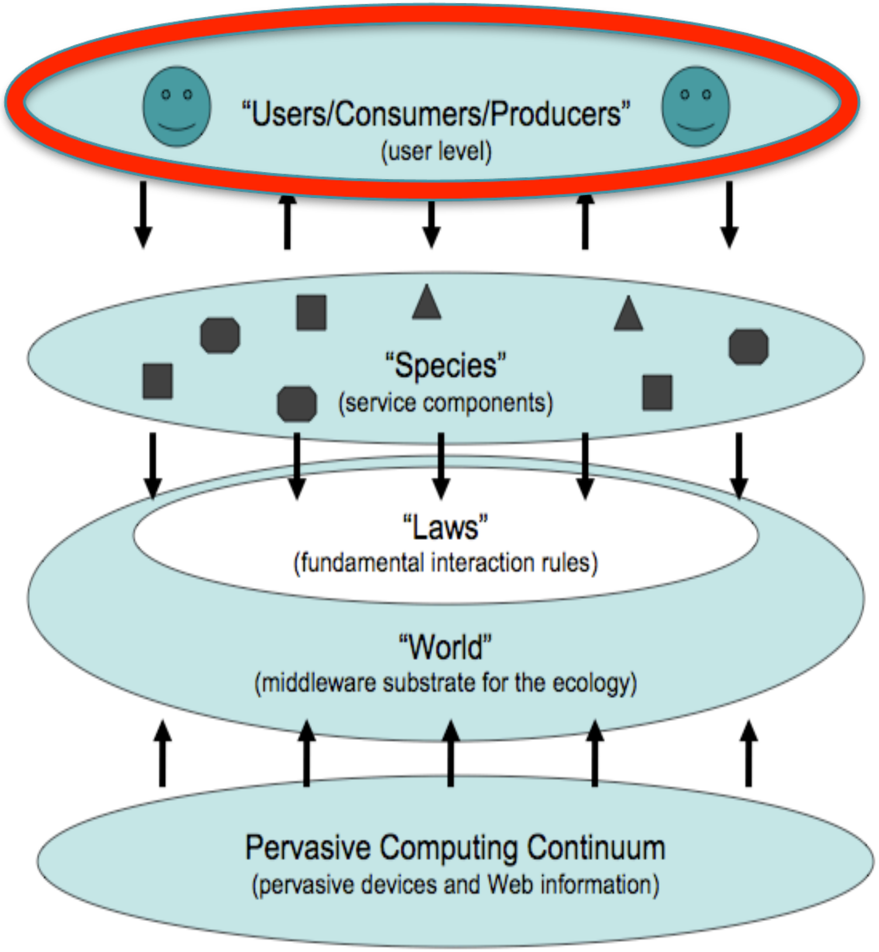
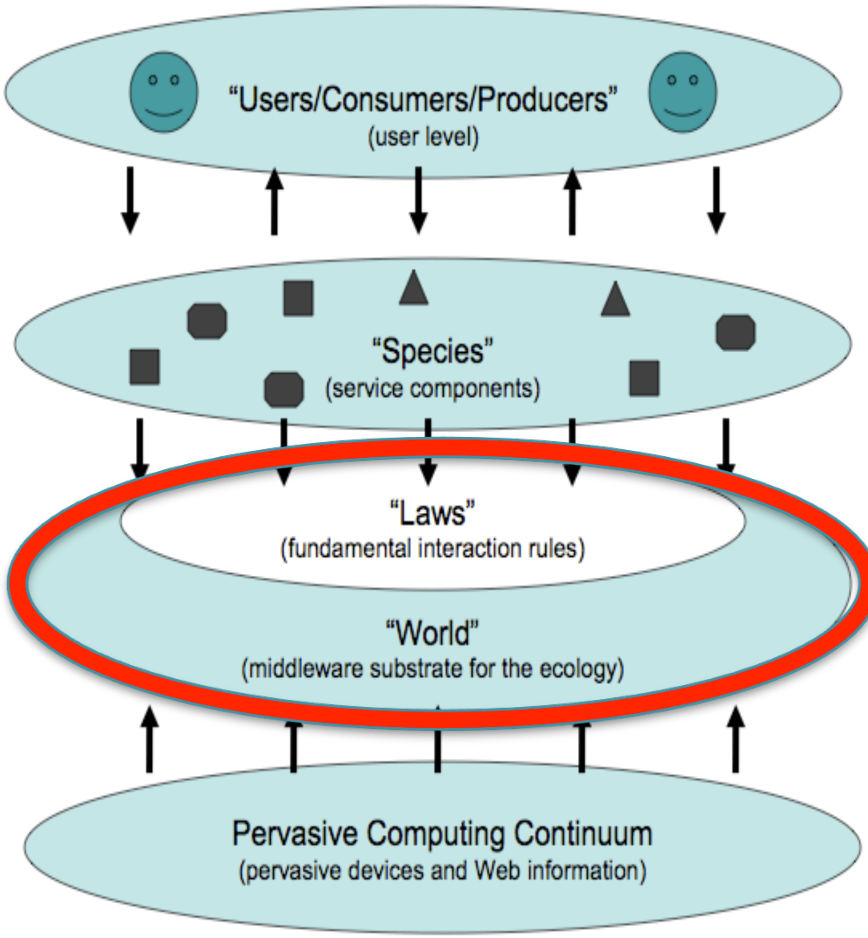
Users, Consumers, and Prosumers

- They can "*observe*", i.e., query, the ecosystem and its components
  - To obtain data, or results of computations
  - In a fully decentralized way
- They can "*extract*" components
  - To consume data and service
- They can "*inject*" new components and data items
  - To personalize the network
  - To deliver own services
  - To enforce control



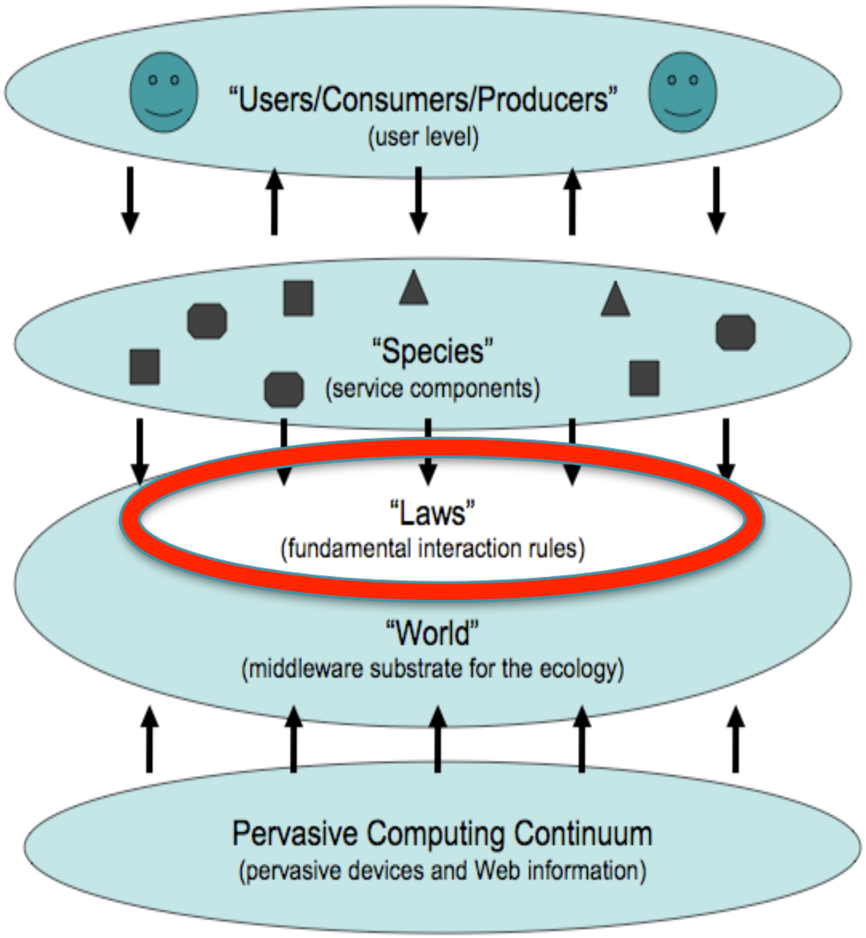
The World

- A very minimal middleware substrate
  - No "smart" middleware services
  - Networked reactive tuple spaces
- Key goals
  - Supporting the spatial lifecycle of components over a dynamic substrate
  - Enabling and enforcing interactions across components
  - According to the "laws of nature" of the ecosystem



The Eco-Laws

- Ruling interactions and the overall dynamics and self-* behaviour of the system
  - How components should interact and when
  - How components should compose/aggregate
  - When component should die/ clone/reproduce
- They are eternal
  - Species of components can change, laws can't
  - Laws apply to all components
  - Different species may react to laws in differentiated ways



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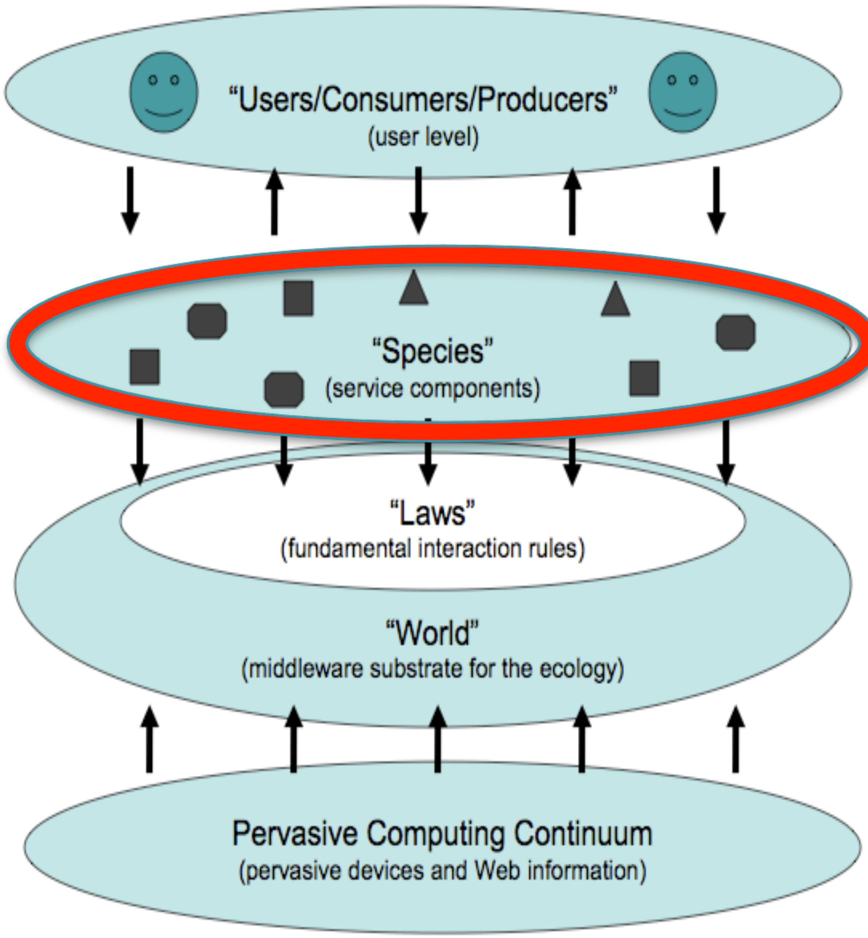
Species

- The software/digital components of the ecosystem
  - Software agents in the end
- May be of different nature
  - "Passive" data items
  - "Active" computational entities
  - Decentralized production
- Are all subject to the laws
  - But different components can react differently to laws
  - Based on internal characteritics and external interfaces



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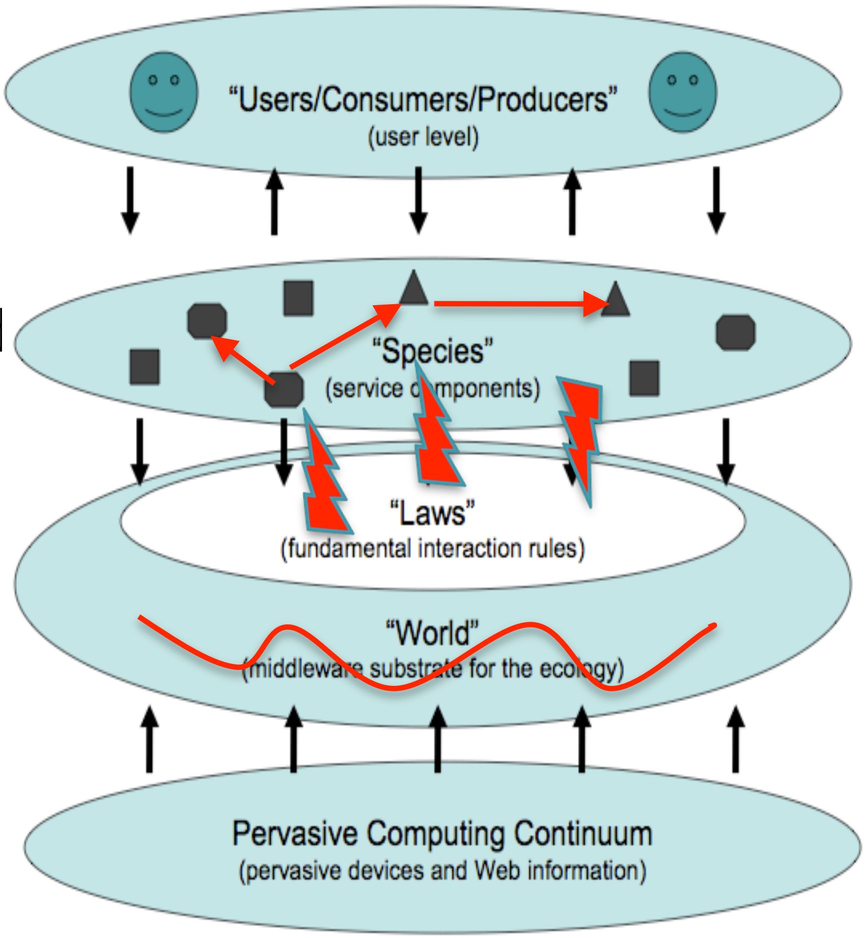
The Ecosystem Dynamics

- Species
  - Living in a region of “World”
  - Moving, acting, composing, as determined by laws
  - Not self-aware in theselves
- Laws
  - Impact on the local activities and interactions
  - Apply based on state of local components (feedback loops)
- World
  - The shape of space influence (and is influenced by) the above
- Dynamics
  - Seemingly self-aware adaptability/evolvability at the system level



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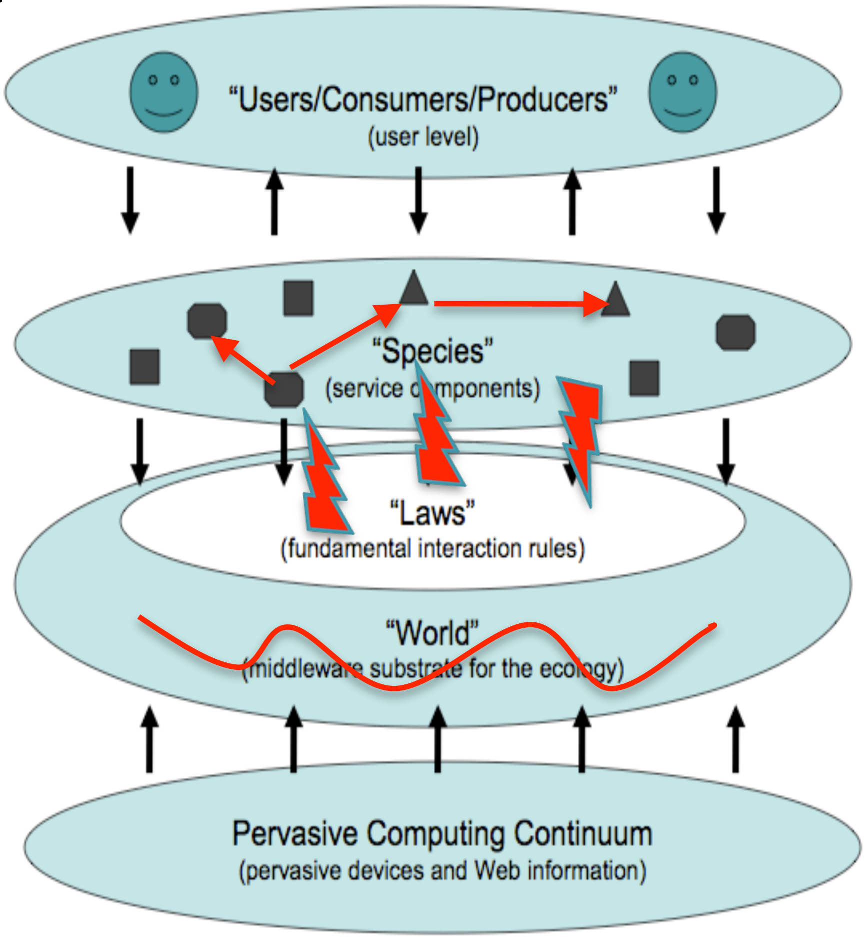
Where is Self-awareness?

- Self-awareness is not at the level of individual components
  - None of them is aware of something
  - They can only perceive and react to specific aspects of local spatial situation
- Self-awareness is a systemic, observable property of the ecosystem
  - Upon changes in a situation
  - There are spontaneous reactions in the ecosystems
  - As if it were aware of what's happening



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Which Natural Metaphor?

- Beside the abstract reference architecture of the ecosystem
  - How should its components, laws, world, be modelled?
  - What form should they actually take in implementation terms?
- Several possible natural metaphors can be adopted
  - Corresponding at different "levels of observation" of natural systems
  - Based on different mechanisms for laws and on different components behaviours
  - And in all of which self-* features, adaptability, and evolvability, are (to different extents) inherently expressed
- It is worth outlining that such metaphors, so far, have been mostly exploited for specific solutions, applications, and/or algorithms (e.g., in autonomic communications research) but never as a comprehensive approach

Metaphors

	Species	***Laws***	***World***
Physical	Particles (computational components) and messages (computational fields)	Navigation and activities driven by fields (gradient ascent by components)	The Universe (a network), as shaped by waves and particles.
Chemical	Atoms (semantically described) and Molecules (composed semantic descriptions)	Chemical Reactions (matching of semantic descriptions and bonding of components)	Space (localities/bags of components)
Biological	Cells (amorphous computing cells, modules of self-assembly components)	Diffusion of chemical gradients and morphogens, differentiation of behaviour and activity	Space (Abstract computational landscapes, or physical landscapes)
Ecological (Social)	Organisms (Agents) and Species (Classes) and Resources (Data)	Survive (goal-orientation), eat, produce, and reproduce	Niches (Pervasive computing environments

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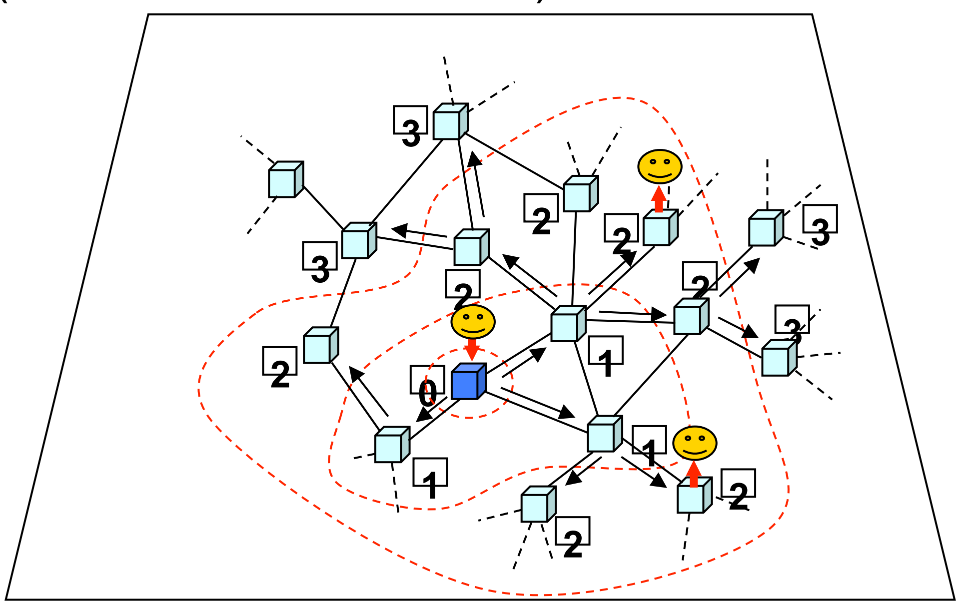
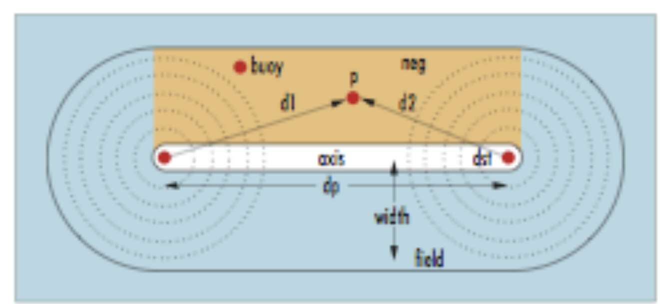
	…es)	…reproduce	

The…

The TOTA Middleware (Mamei Zambonelli, 2004)



The Proto Language (Beal, 2004)



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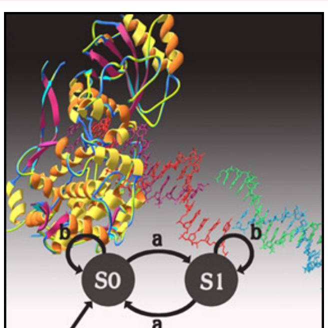

Computational Biology and DNA Computing

The **Gamma** Coordination Language (Banatre, 1990)

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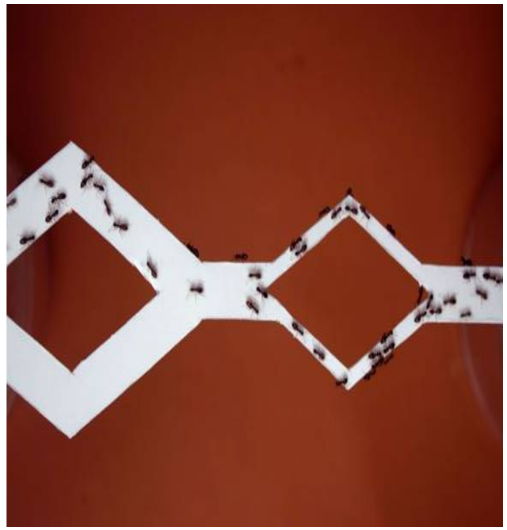
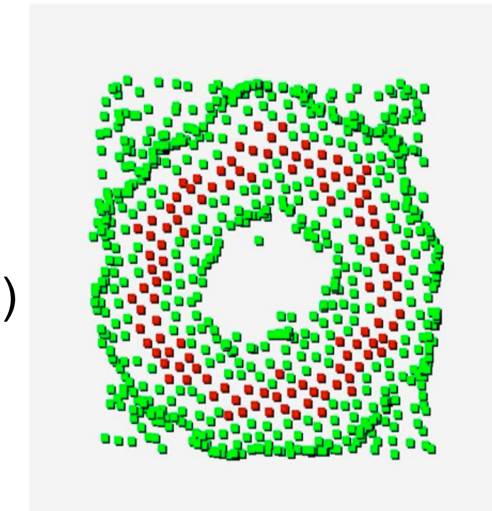
Metaphors

Ant Colonies (Parunak 2007; Babaoglu 2006)



Amorphous Computing And Swarm Robotics (Nagpal, 2002)



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Metaphors

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		s... de... and bo... co... s)	
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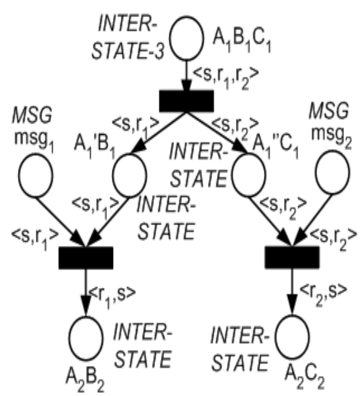
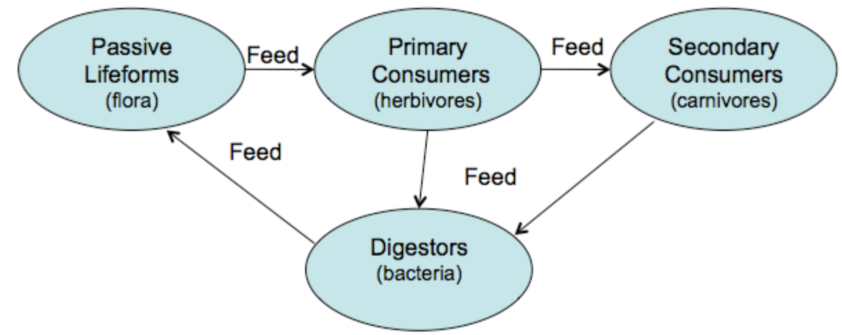
Computational Societies of agents (Jennings, 2003)



(b) CP-net representatio

Trophic Networks (Agha, 2008; Zambonelli 2008)



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Metaphors

Other metaphors

?

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Comparative Analysis

- Are these metaphor equally suitable to address the needs of future service ecosystems?
  - NO!
  - But it depends on what you want to achieve
- Let's analyse according to three dimensions:
  - **Space**: the capability of facilitating self-organization and self-adaptation of functional distributed patterns of activity
  - **Time**: the capability of tolerating evolution and increasing diversity
  - **Control**: the capability of being easy to understand, design, and control in a decentralized way

Pros and Cons

	Space (self-organization)	***Time (evolution and adaptation)***	***Control (decentralized management)***
Physical	+ (global self-organizing spatial structures)	-- (no new components, always same behaviours)	++ (we know well how to build and control specific structures in physic)
Chemical	+ (mostly local self-organizing structures, sometimes global too, as in crystals)	++ (several new components can be generated under the same basic laws)	+ (reactants and catalysts can exert control over the dynamics and structure of reactions)
Biological	+ (local, morphogenesis of local shapes)	-- (limited number of new “shapes”, and only local changes)	- (mechanisms of morphogenesis not fully understood)
Ecological (Social)	+ (local structures mostly, although sometimes leading to more global patterns)	++ (several new species and same laws)	-- (difficult to understand how to enforce control over ecologies of many species, at most only local centralized control)

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Summary

- Self-organization and self-adaptation
  - Physical and biological metaphors are well understood and extensively studied in several computational scenarios
  - Chemical and ecological metaphors could work equally well
- Diversity and evolution
  - Physical and biological metaphors are not directly suitable
  - Chemical and biological metaphors accommodate them
- Control
  - Physical and chemical systems are well understood, and tools exists to control them
  - Less control and understanding of bio/ecological dynamics
- None of the metaphors fully support the requirements
  - A new synthesis may be needed

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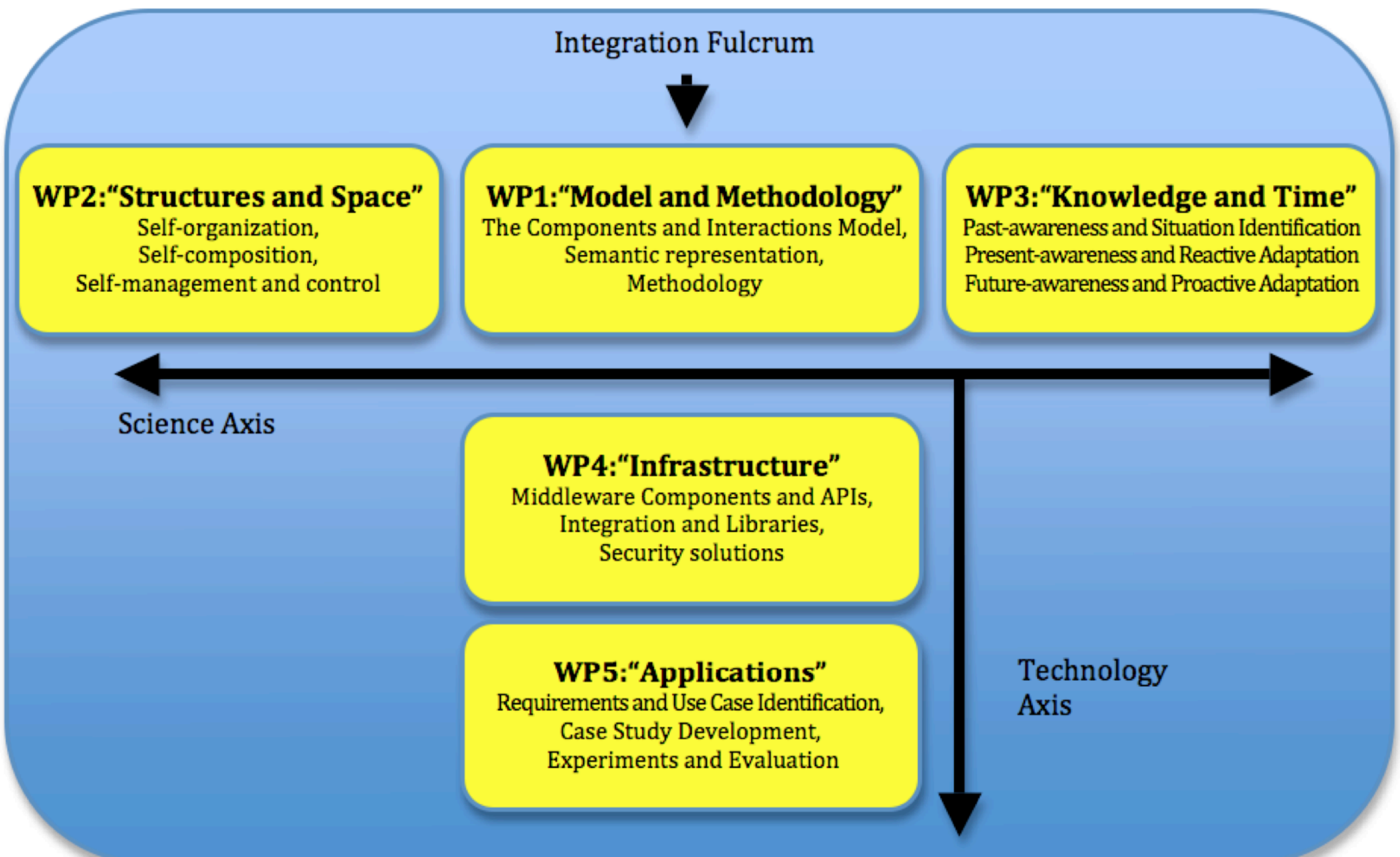
The SAPERE Approach

- SAPERE "Self-aware Pervasive Service Ecosystems"
  - EU FP7 FET Project Funded in the "Self-awareness in autonomic systems" initiatives
  - Starting October 1st 2010, lasting 3 years
  - UNIMORE (Coordinator), UNIBO, UniGeneve, UniStAndrews, UniLinz
  - Funding: 2.3M Euro
- Starts from the proposed reference architecture
  - To define and implement a fully-fledged framework for nature-inspired pervasive service ecosystems
  - Trying to define a new general-purpose synthesis out of existing natural metaphors

SAPERE Specific Objectives

- Both of a scientific and technological nature
- All of which revolving around the unifying reference architecture



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Key Expected Results of SAPERE

- A novel model and methodology to support the development of complex nature-inspired service ecosystems in open and dynamic pervasive scenarios
  - Centered around a new nature-inspired synthesis
  - Chemical + elements of bio- and physically inspired metaphors
- Release of a uniform set of:
  - Self-* algorithms for service/data composition and aggregation (in the form of libraries)
  - Algorithms and tools for distributed management of contextual-knowledge, to enforce present- and future-adaptability in the ecosystem
- A novel middleware for pervasive computing scenarios (Open Source)
  - Integrating the stated algorithms in the form of libraries
- A set of released innovative applications:
  - Showcased on the "Ecosystem of Displays" testbed

Key Envisioned Impacts

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- Scientific
  - New foundation for distributed pervasive service systems
  - New approach to autonomic → from feedback loops to inherent systemi self-awareness and holistic adaptivity
- Technological
  - Deconstructing middleware
  - New basis for open and dynamic service platforms
- Social
  - Innovative for-all and fitted-to-everybody pervasive services
  - Much easier to be deployed and used
  - New light into the idea of "collective intelligence"
- Economic
  - Easier for small actors to enter the ecosystem with highest values
  - Lower management costs for services and devices
  - Better exploitation of resources due to self-adaptivity and self-awareness
  - Towards "eternally adaptive pervasive service ecosystems"

Conclusions

- Nature-inspired service ecosystem have the potential to represent a sound approach to face, once and for all, several technical and social challenges for future and emerging network and service scenario
  - i.e., for the realization of *self-aware adaptive service ecosystems*
- However, there is still a lot of foundational and experimental research to do before even understanding if such an approach can be applicable and effective
- SAPERE will experience this at the level of models, algorithms, middleware, and applications, and relying on a sound reference architecture