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# From Service-Oriented Architectures to Nature-Inspired Pervasive Service Ecosystems:

## *The SAPERE Approach*

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# Outline

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

# The Changing ICT Scenario



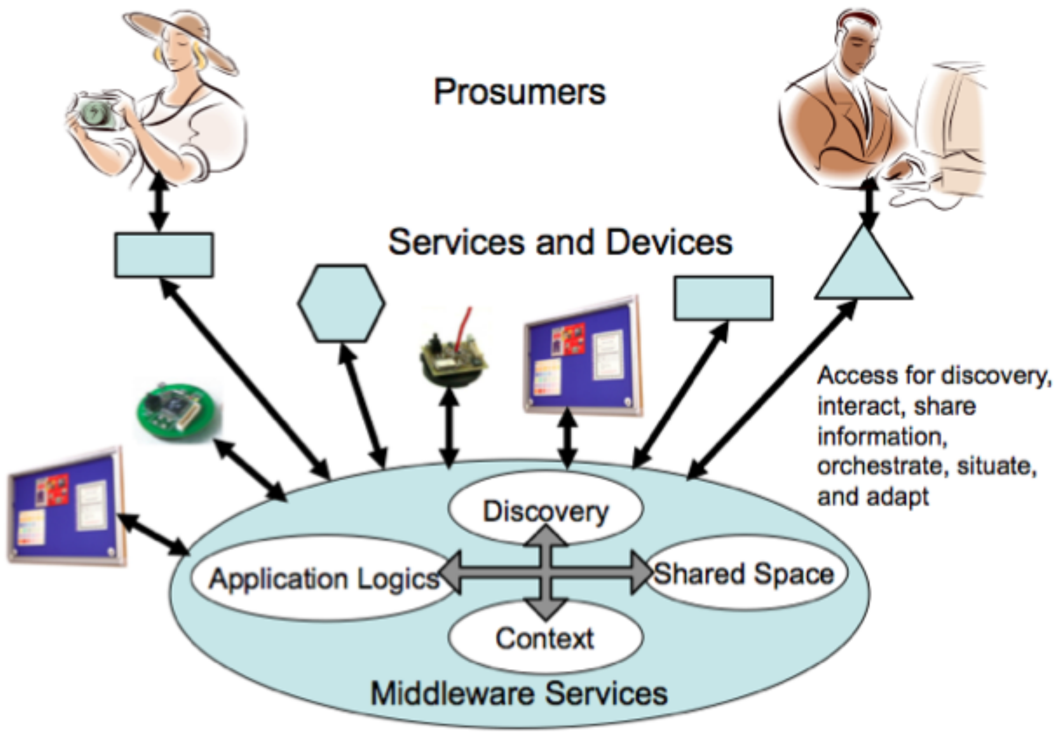
- Several emerging trends…
- Networks are changing
  - Integration of (increasingly dense) pervasive devices embedded in physical space
  - Convergence of Internet and Telecommunication networks
  - High dynamisms and decentralization
- And so management needs are changing
  - Decentralization requires 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

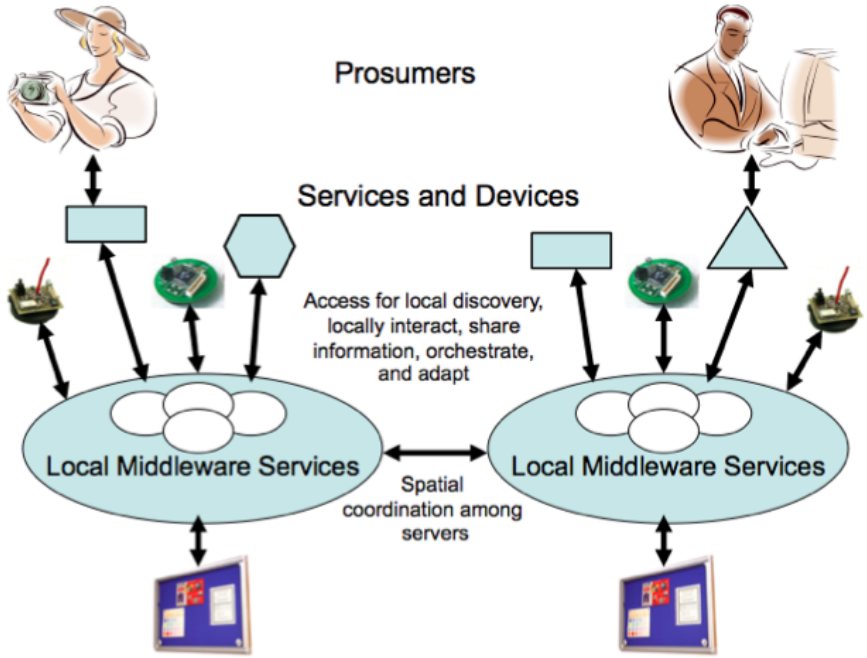
- Too centralized and heavyweight
  - Too many diverse supporting middleware services
  - Inherently centralized




- 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

# 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
- It is worth outlining that such metaphors, so far, have been mostly exploited for specific solutions, applications, and/or algorithms, but never as a comprehensive approach

# Natural Metaphors

| | Key Characteristics | | | Analysis | | |
|---|---|---|---|---|---|---|
| | Service Components | Eco-Laws | Space | Adaptive Self-organization | Diversity and Evolution | Decentralized Control |
| **Physical** | Particles (computational components) and virtual computational fields | Movements and activities driven by fields (gradient ascent/descent by components) | Network topology or physical space | + Local and global self-organizing spatial structures can be effectively accommodated | -- Few new components species can be accommodated while keeping the laws simple | + We know well how to build and control specific structures in physics |
| **Chemical** | Atoms and Molecules (semantic descriptions representing chemical properties) | Chemical Reactions (matching of semantic descriptions and bonding of components) | Localities (pervasive computing environments) | -- Mostly local self-organizing structures can be effectively accommodated | ++ Several new components species can be accommodated with the same basic laws | + Reactants and catalysts can exert control over the dynamics and structure of reactions |
| **Biological** | Simple goal-oriented organisms (e.g., ants) and pheromones | Diffusion and evaporation of chemical pheromones (affecting behaviour and activities of components) | Network topology or physical space | + Morphogenesis of local shapes, global patterns via movements and pheromones diffusion | + Reasonable number of new individuals and pheromone flavours can be accommodated without increasing complexity too much | - Mechanisms and control of morphogenesis and biological self-organization not fully understood |
| **Social** | Goal-oriented animals (agents) of various species (classes) and included passive life-forms (resources and data) | Trophic relations (eating), digest, produce, and reproduce | Niches (pervasive computing environments) | + Local self-organizing structures can be mostly accommodated, although sometimes leading to more global patterns and structures | ++ Several new species can be accommodated with the same basic laws | -- Difficult to understand how to enforce control over ecosystems of many species |

- None of them fully support the requirements
- A new synthesis is needed
- Calling for a proper framing of apparently diverse concept

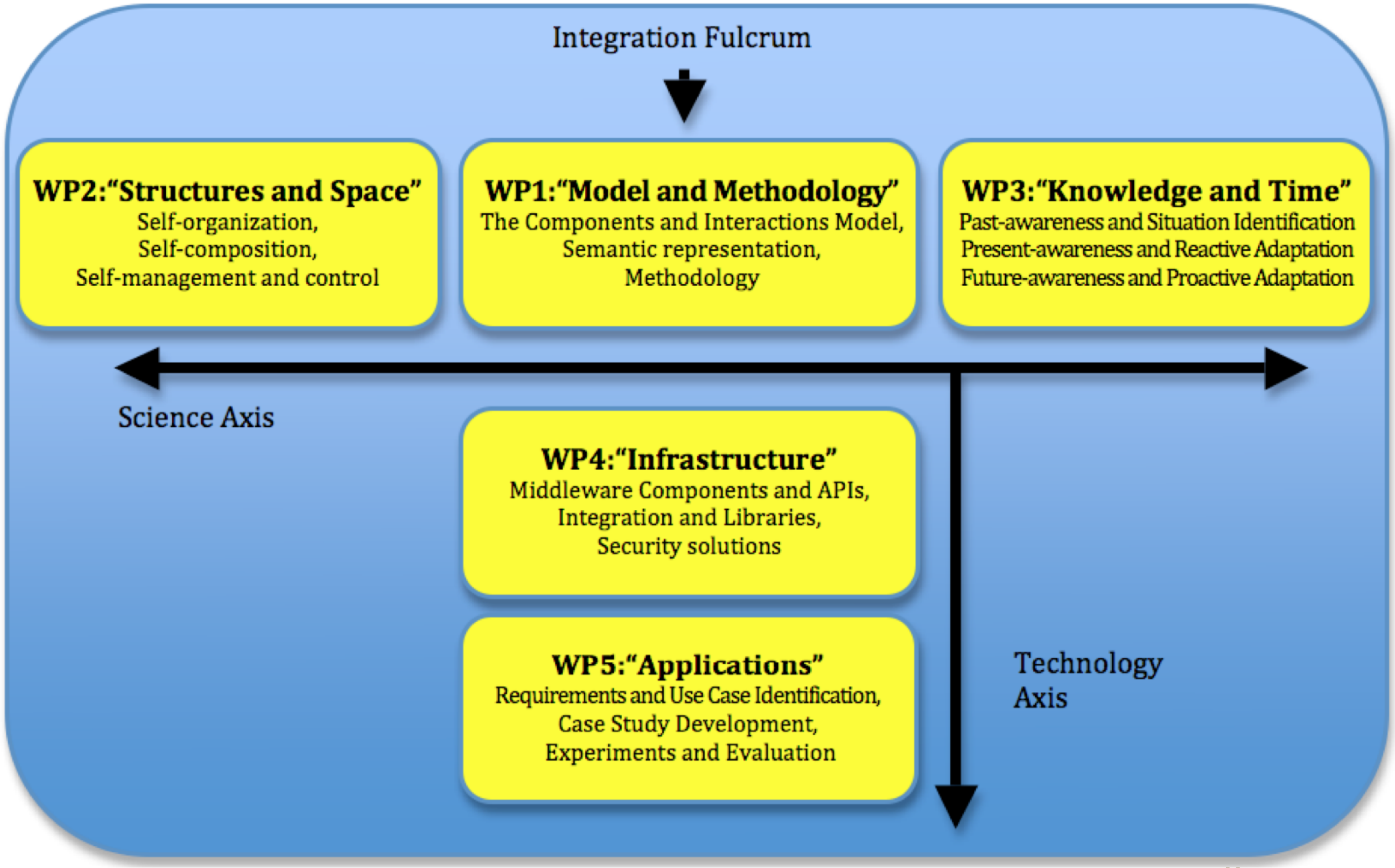
# The SAPERE Approach



- 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
- Self-awareness intended as a systemic property of the ecosystems to achieve adaptation and evolvability via self-organization
- Trying to define a new general-purpose synthesis out of existing natural metaphors
- With the help of a general reference architecture

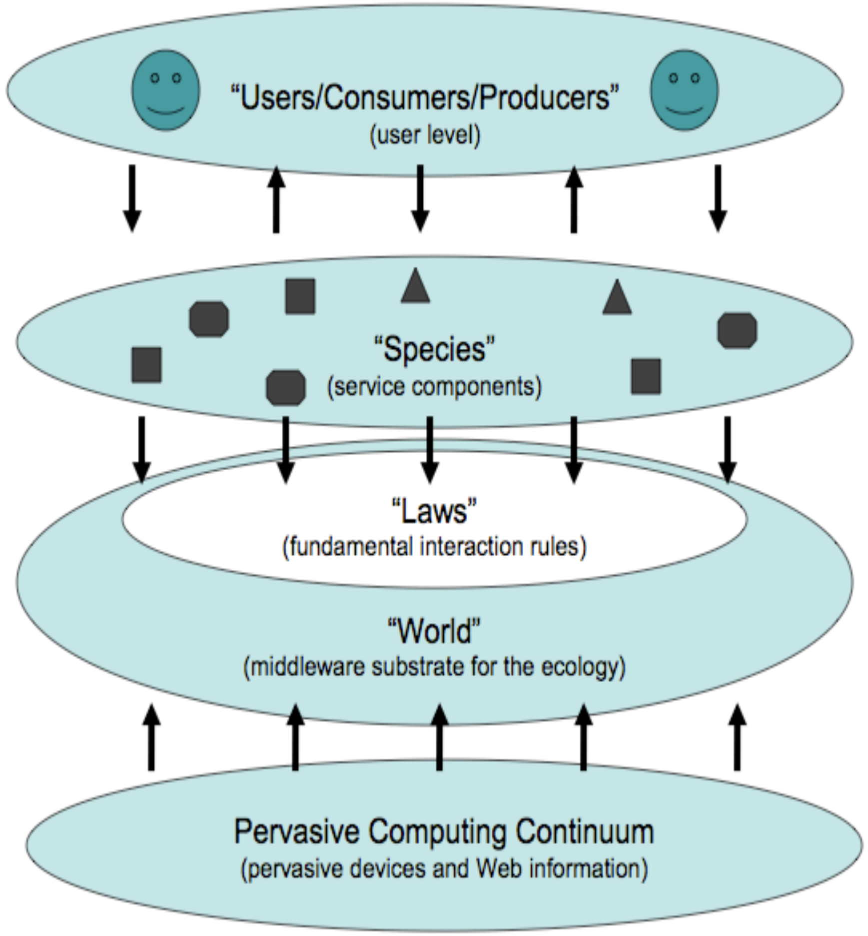
# SAPERE Specific Objectives

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



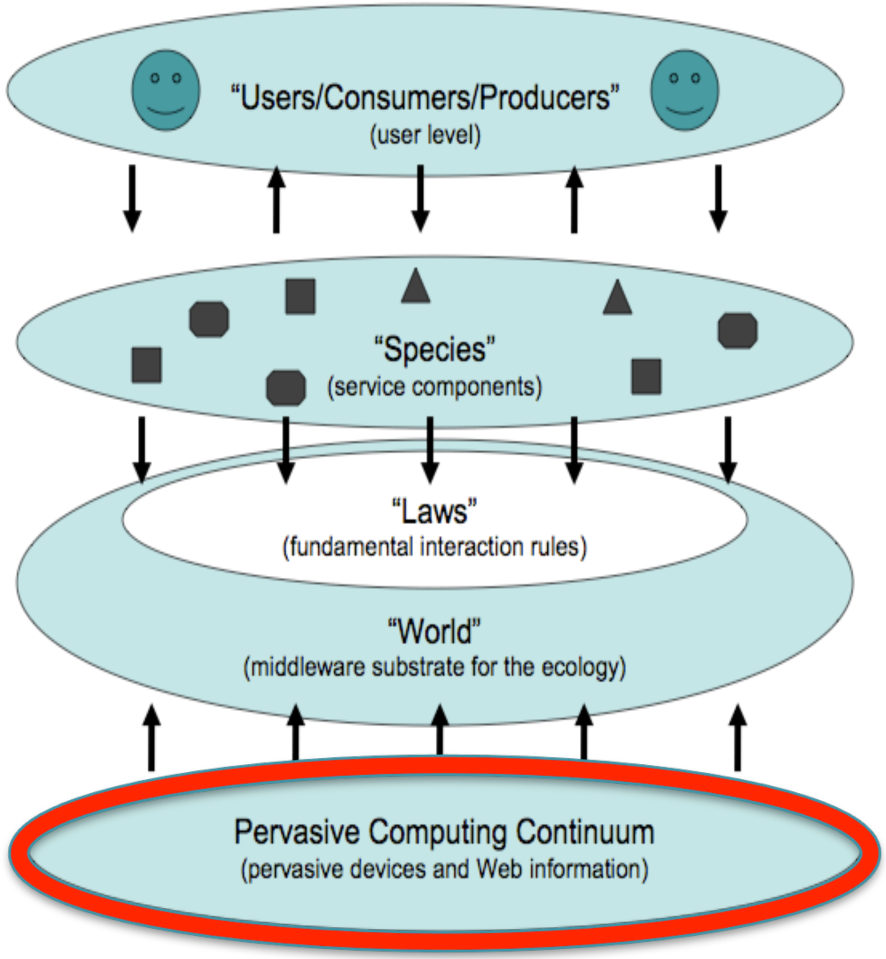
# The SAPERE Reference Architecture

- It abstracts from any specific nature-inspired metaphor
  - Although SAPERE will possibly start by investigating bio-chemical approaches
- Shows how general ecosystem concepts can be framed in a uniform way
- Useful to turn the architecture into an actual middleware
  - Which SAPERE will realize and put at work



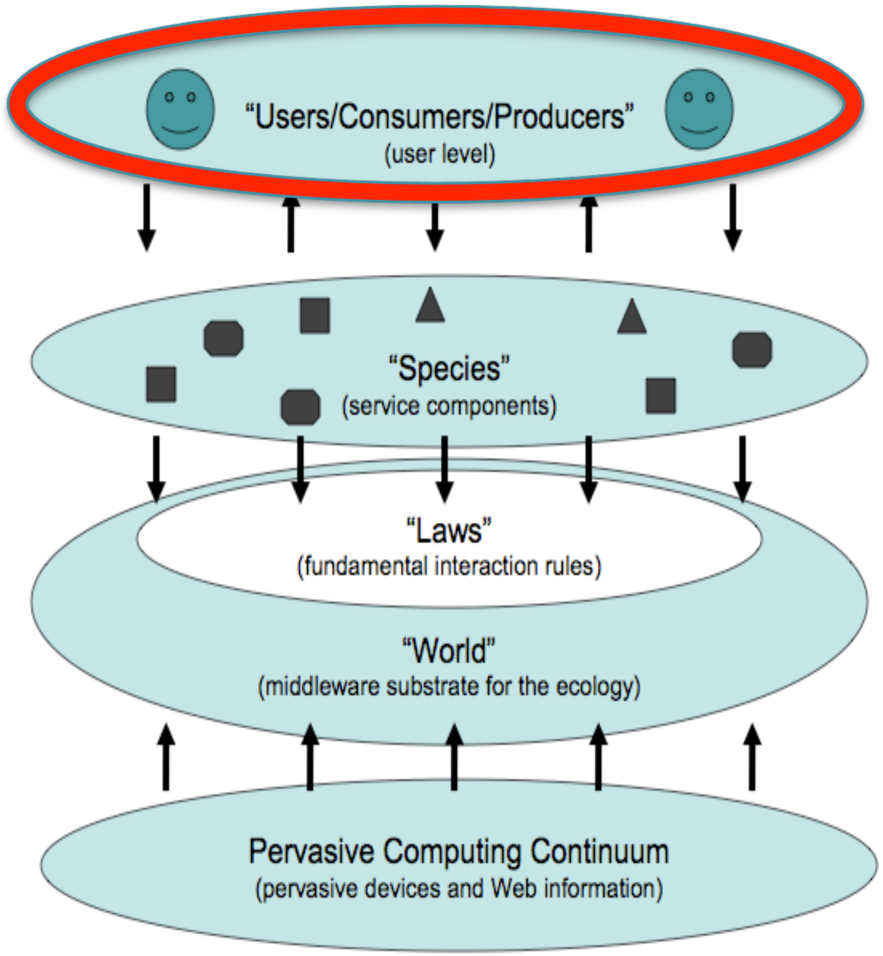
# The Pervasive Computing Continuum

- 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



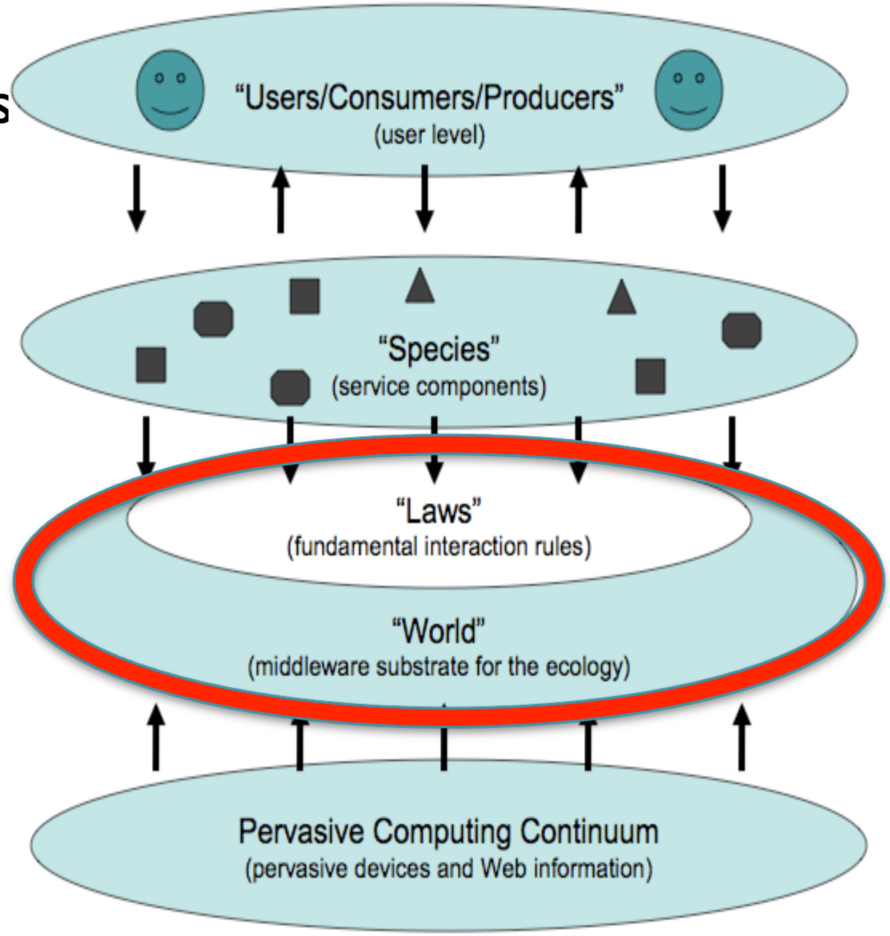
# Users, Consumers, and Prosumers

- 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



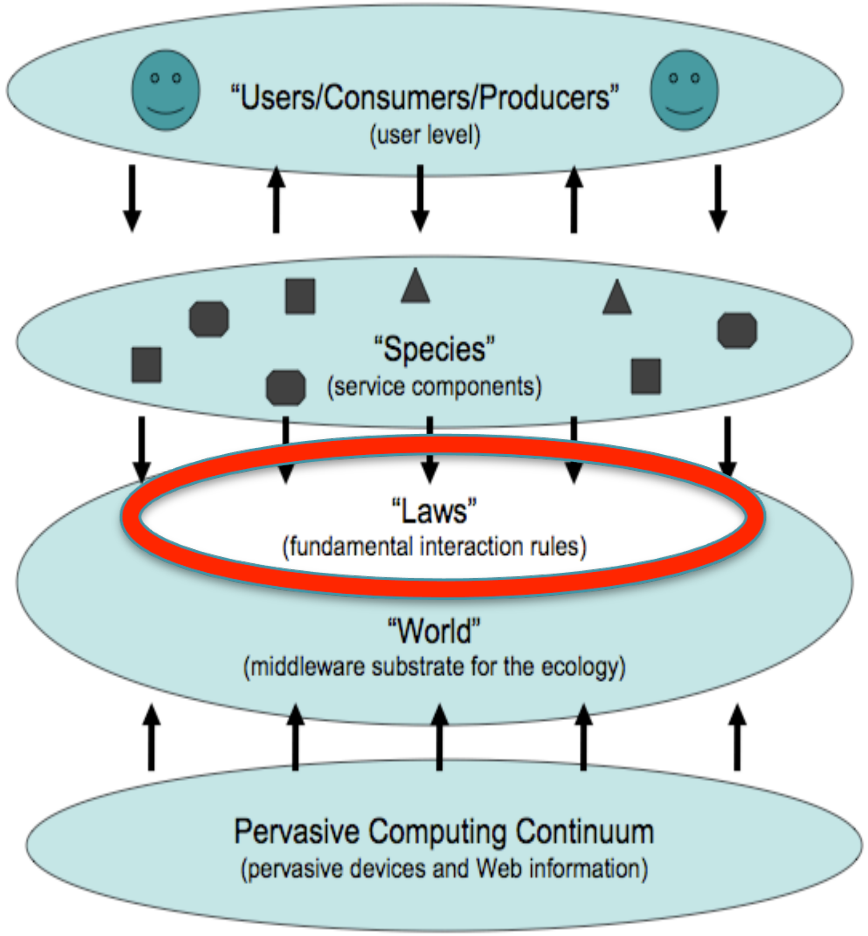
# The World

- 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



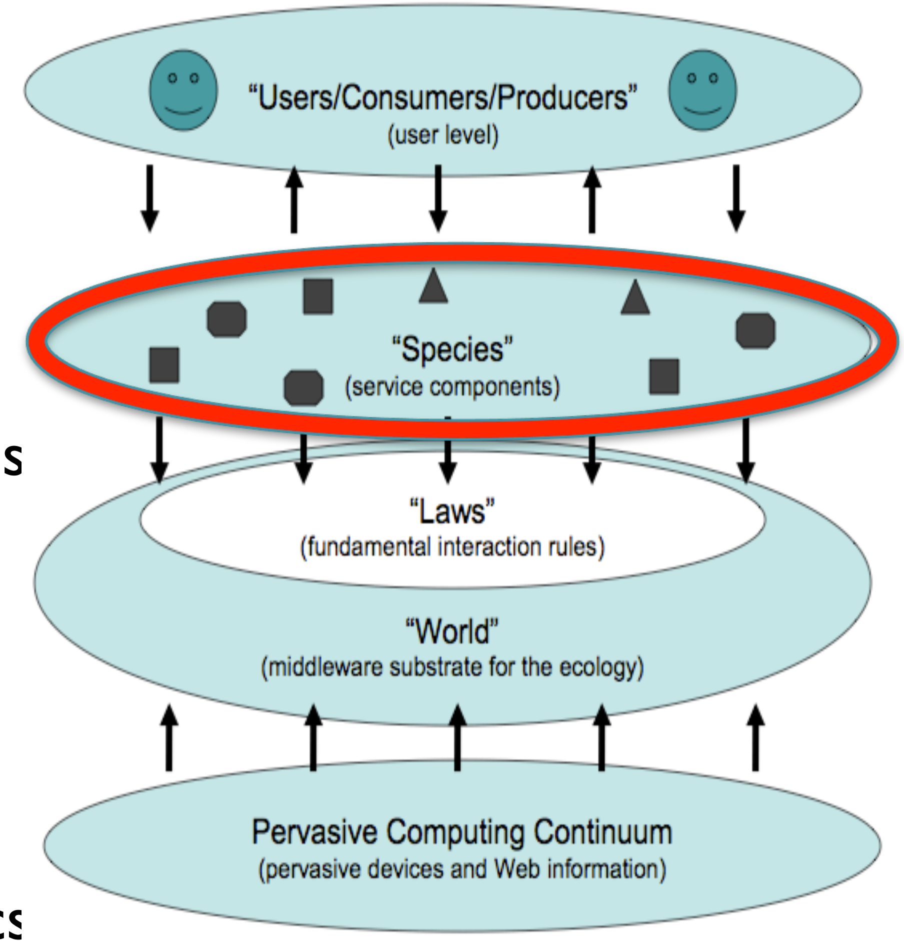
# The Eco-Laws

- 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



# 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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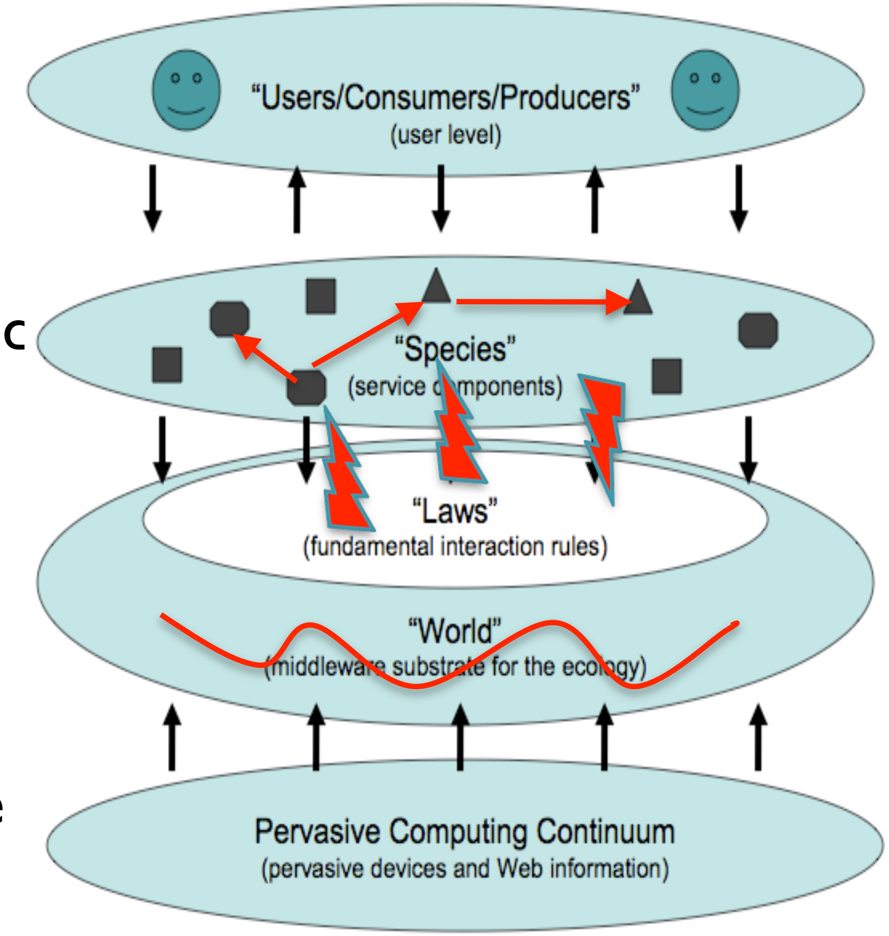
# The Ecosystem Dynamics

- 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 anc 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



# 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
- 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

# 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 *eternally 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