Deployment of Smart Spaces in Internet of Things:

Overview of the Design Challenges

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Outline

- Motivation
- Interoperability
- Information processing
- Security and Privacy

Today's Internet

- Rapid growth: information and services
- Low communication between services
- High fragmentation of information
- Low cross-service cooperation
- Still no "Ubiquitous Computing" [Mark Weiser, 1988] with effective use of all related information, available services, and surrounding physical/digital objects

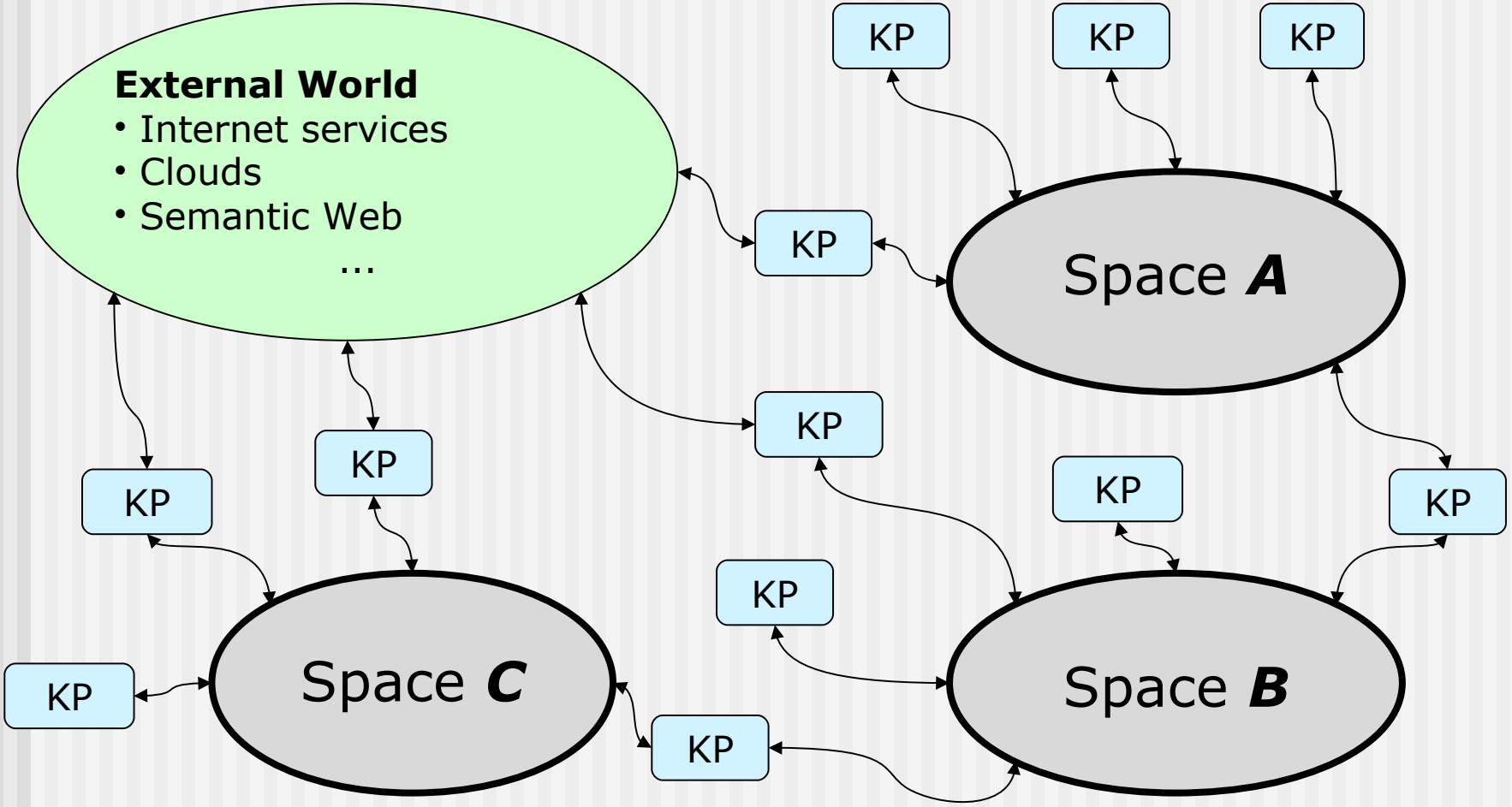
Smart Spaces

- Service infrastructure for interacting computational objects on shared knowledge base
- Objects are on variety of digital devices: surrounding and global
- Services are constructed as interactions between objects

M3: Multidevice, Multidomain, Multivendor

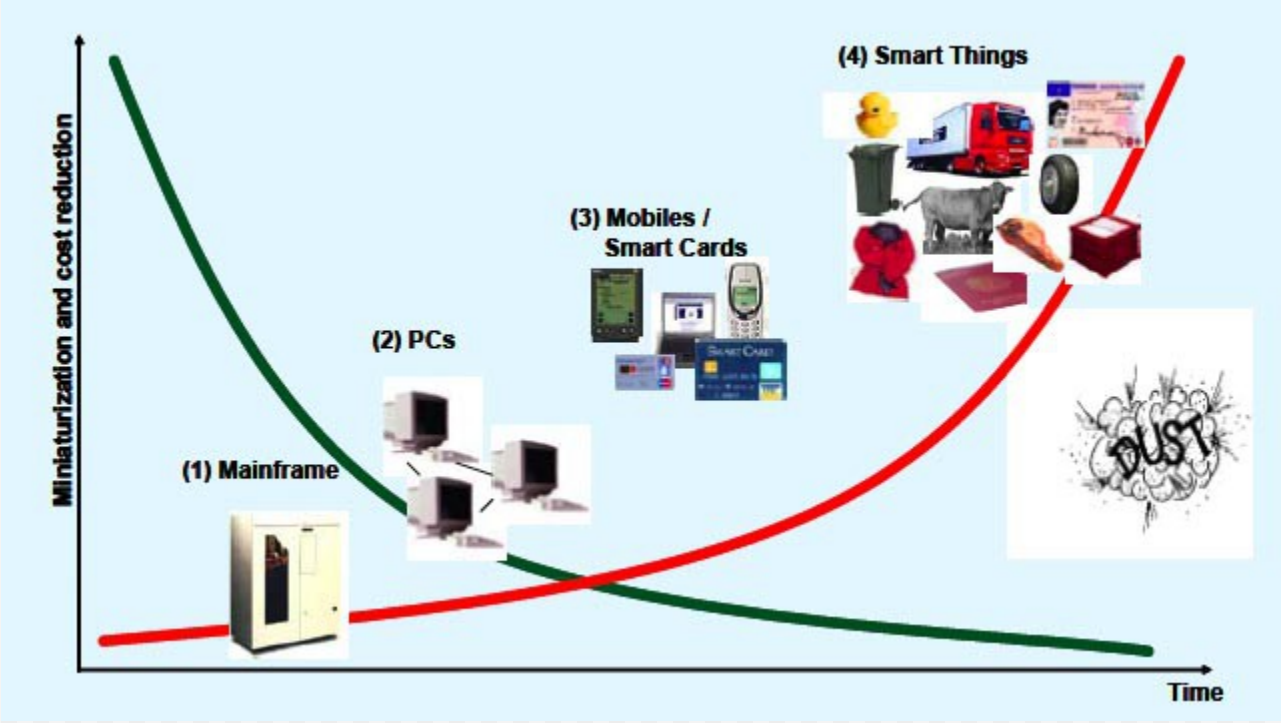
- Users connect new devices flexibly and consume information from any of the services
- **Smart-M3**: pilot open-source interoperability platform
  - SIB: Semantic Information Broker
  - KP: Knowledge Processor
  - SSAP: Smart Space Access Protocol

M3 Spaces


External World
• Internet services
• Clouds
• Semantic Web
...
KP
KP
KP
KP
Space A
KP
KP
KP
KP
KP
KP
KP
Space C
Space B
KP
KP

Internet of Things (IoT)

- **Connectivity**: anytime, anywhere, by anyone and anything
- **Smart Things**: carry chunks of application logic that let them make sense of their local situation and interact with human users



From a report of the International Telecommunication Union: "Ubiquitous Network Communities: Their Impact on the Telecommunications Industry," April 2005

Challenges

- **Interoperability**: How to manipulate with information in an open dynamic multidevice environment and to offer services to the users
- **Information Processing**: How to reason over the information and to construct the services, despite of environment heterogeneity, volatility, and ad-hoc nature
- **Security and Privacy**: How to provide integrity and confidentiality of processed data and communication as well as authentication of services and users

Interoperability

- Common language in shared space
- **Device**: technologies for devices to discover and network with each other
- **Service**: technologies to discover services and use of them
- **Information**: technologies for making information available without a need to know interfacing methods of the entity creating or consuming the information

Interoperability: Devices

- IoT ubiquitous connectivity
- SSAP support with many solutions for network connectivity: TCP/IP, NoTA, Bluetooth, 6LoWPAN
- KP Interfaces (KPI) for many platforms: programming KP logic and using SSAP primitives
- RDF triples as data exchange units
- Gateway KP to attach low-capacity devices

Interoperability: Services

- Smart space shares knowledge: data, semantics, processing
- Ontology-based representation
- Publish/Subscribe (Pub/Sub) support
- Context-awareness
  - Personalization
  - Adaptation
  - Proactive delivery

Interoperability: Information

- Semantic Web technologies
- RDF: easy exchange and linkage of data between different domains
- KPs can agree an aligned ontology for interpretation of a certain part of the space
- For application, its space $S = (I, O)$, where I is information content, O is ontology
- Ontology-driven application development (OWL)

Information Processing: Semantic Queries

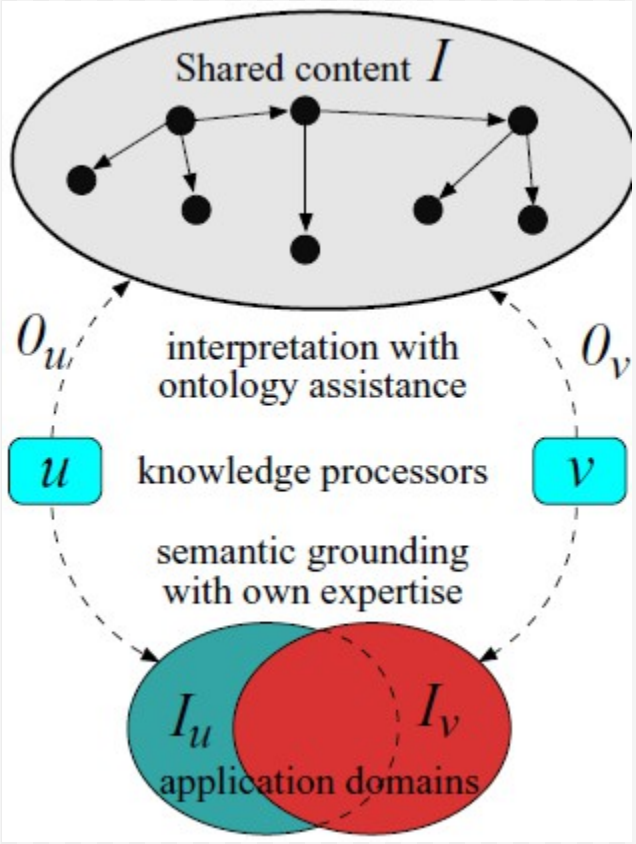
- SIB: Knowledge discovery and first-order logic reasoning at query-time
- KP: query-analysis iterations with SIB
  - constructs queries using semantic query languages as SPARQL
  - interprets the result locally
  - then can insert new knowledge or update some previous instances

Information Processing: Subscription

- Persistent query
- Coordination model
  - Synchronization of KP's local knowledge storage with the shared space
  - Receiving notifications about recent changes in the space
  - Response actions from KPs
- Broker-based infrastructure

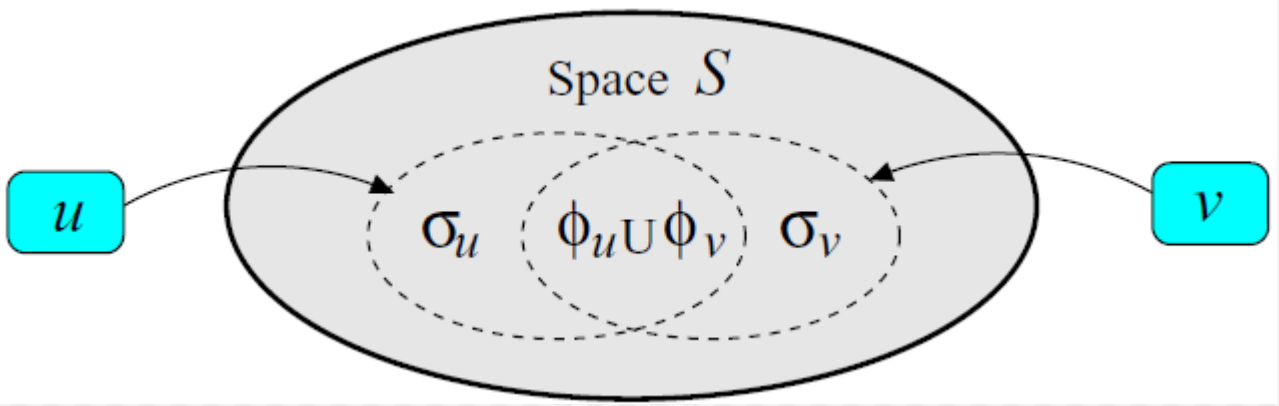
Information Processing: Ontology

- No strict ontology conformance
- KP *u* manages a non-exclusive part I_u and applies own expertise for reasoning over I_u
- Locally and dynamically agreed semantics - O_u
- KP mediators



Security and Privacy: Components

- Share level: sharing function σ_u
- Access control: access function φ_u
- Communication: data exchange protection



Security and Privacy: Share

- KP makes own decisions on its share level, keeping essentially private knowledge at the local storage only
- It does not prevent to combine private and shared knowledge in local reasoning

Security and Privacy: Access

- SIB enforces access control over brokered information
- Meta-information for access control is published in the space
  - which data are protected and which KP is their owner
- Application-specific policies

Security and Privacy: Communication

- Session-based communications, by join/leave operations
- Host Identity Protocol (HIP)
  - Transferred data are encrypted
  - KP-to-SIB communication session has robust identities (can also be used for access function)
  - Support for mobility and multi-homing
  - Light weighed HIP variants for low-capacity devices

Conclusion

Challenge	Provided solutions and feasible directions
Interoperability	Many network protocols. RDF-based operation of SSAP. Multiplatform KPIs and reusable code. Ontology libraries and code generation. Development tools for mid- and low- capacity devices.
Information processing	SPARQL queries and first-order reasoning. Subscription and proactive services. Ontology-driven development and runtime mechanisms. Multi-space operation and mediator-based synchronization.
Security and Privacy	RDF-based knowledge access control and mutual exclusion. HIP-based network communication. Ontology-based control policies and context-aware security.