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Semantic Web of Things: vision, applications and challenges

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About me

Giuseppe Loseto

ACADEMIC EXPERIENCE

2021 Assistant Professor *@LUM University "Giuseppe Degennaro", Bari, Italy*

2013 Post-Doc Research Fellow *@Polytechnic University of Bari, Italy*

2012 Ph.D. in Information Engineering *@Polytechnic University of Bari, Italy*

RESEARCH INTERESTS

Semantic Web · Internet of Things · Knowledge Representation and Reasoning · Pervasive computing

SHORT BIO

- Co-author of 40+ scientific papers in international books, journals and conferences
- Member of Editorial Boards (Sensors, JLPEA) and Program Committee (ISWC'21, SEMAPRO'17-21,...)
- Design and development of 15+ research prototypes exploiting semantic technologies in mobile and embedded platforms
- Participation in 20+ national and international ICT projects
- Experience (10+ years) in teaching technical and scientific subjects

Outline

- **Vision**
  - The Semantic Web of Things (SWoT)
  - Towards a Semantic Web of Everything
- **Core framework**
  - Ubiquitous Knowledge Bases
  - Semantic matchmaking
- **Applied research**
  - Semantic-enhanced machine learning
  - Social Internet of Things with LDP-CoAP
  - Information fusion on vehicular networks
  - Semantic smart contracts for blockchain

Semantic Web of Things vision

The Semantic Web of Things

	Semantic Web[1]	SWoT[2]
Idea	Web of documents → Web of Linked Data	Semantic Web for the Internet of Things
More intelligent, interoperable and context-aware…	Web applications/agents	Pervasive computing agents
Reasoning on Vocabularies (RDFS, OWL) + Annotations (RDF) for…	Web resources	Objects, locations and events in the real world
Decision support and autonomous decision for…	Web agents	Networks of smart objects
Knowledge representation and reasoning use cases:	Large ontologies, batch processing, standard inference services	Small ontologies, quick on-the-fly queries, specialized inferences

[1] Berners-Lee et al., Scientific American, 284(5), 2001. [2] Scioscia et al., ICEC 2009.

SWoT Technological Approach

- Integrating knowledge representation in standard wireless communication protocols
  - Bluetooth
  - Radio Frequency IDentification (RFID)
  - ZigBee
  - Wi-Fi (IEEE 802.11)
  - EIB/KNX (Konnex)
  - CoAP
  - OBD-II (On-Board Diagnostics)
  - Eddystone (Physical Web)
- Optimizing inference engines for resource-constrained computing platforms
  - Mobile devices: Android, iOS
  - Single-board computers: Raspberry Pi, UDOO
  - Knowledge-based robots: drones, rovers

The Semantic Web of Everything

- The IoT is evolving to the **Internet of Everything (IoE)**
  - Interconnecting not just things, but people, processes, events, etc.
- This calls for a transition of the SWoT to a **Semantic Web of Everything (SWoE)**
- Semantic technologies must be available at all scales
  - World Wide Web & Cloud computing
  - Desktop computers, laptops, mobile devices
  - Single-board computers and wearables
  - Microcontrollers and sensors
- Multiple challenges
  - Cross-platform support is mandatory
  - Technologies must work with very limited computational resources
  - Power consumption cannot be an afterthought

Core framework

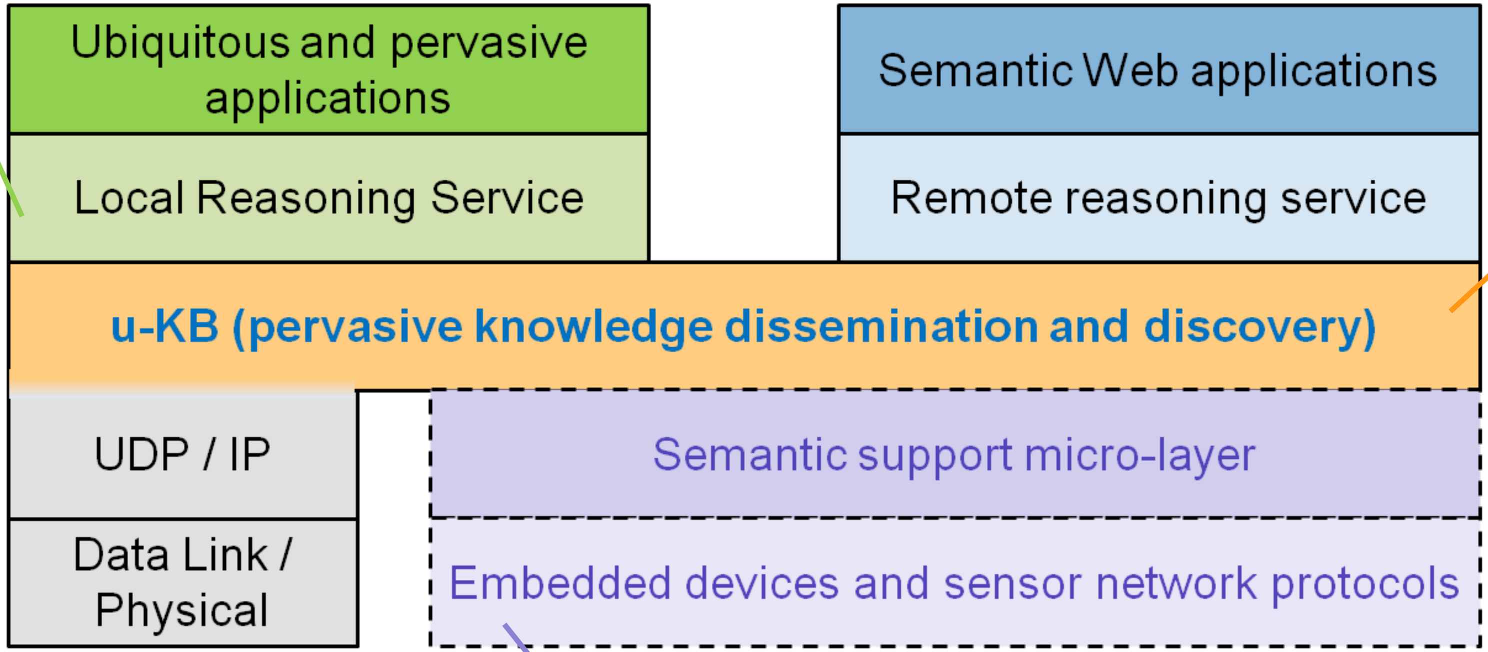
Ubiquitous Knowledge Bases[1]

[1] *Scioscia et al., ICEC 2009.*

Non-standard inference services

Matchmaking engine developed for mobile and embedded platforms (Mini-ME)

[Scioscia et al., IJSWIS, 2014]



Distributed knowledge base

Advanced service discovery

[Scioscia, Ruta, ICSC, 2009]

Semantic-based enhancement of different IoT communication protocols

Knowledge representation techniques exploited to annotate collected raw data

u-KB components

- TBox (a.k.a. ontology: conceptual knowledge)
  - Concepts, properties and constraints modeling the application domain
  - Managed by one or more MANET hosts
  - A unique identifier (OUUID) marks each ontology
- ABox (factual knowledge)
  - Scattered throughout a smart environment
  - Individuals physically tied to devices deployed in the field
- Individuals characterized by:
  - Unique ID (e.g. EPC code, MAC address)
  - Ontology Universally Unique ID
  - Semantic annotation
  - Data-oriented attributes
- Multiple u-KBs can coexist in the same smart environment

u-KB operations

Classical paradigm implemented in a novel way

Tell/Un-tell (explicit knowledge acquisition/retraction)

- Autonomic creation and update of a virtual KB
- Each host contributes with individuals detected in its proximity
- Data alignment protocol makes each host aware of network content
- Only individual ID, OUUID and data attributes (no semantic annotations) → minimize network load

Ask (extraction of implied knowledge)

- Preliminary discovery step, based on OUUID and data attributes
- Addresses of hosts “owning” resources are retrieved
- Semantic annotations are then requested in unicast
- Subset of KB materialized just when needed for reasoning

Reasoning (1/3)

Standard inference services

- Subsumption check

  True iff concept A is at least as specific than B
- Satisfiability (a.k.a. Consistency) check

  True if a concept expression does not contain a clash

Limits

- Yes/no answers
- No explanation of outcomes
- No resource ranking capability

Reasoning (2/3)

Non-standard inferences for semantic matchmaking

Problem: given a *request* D and a set of *resources* C_i, rank resources by lowest "semantic distance" from D.

First formulated for e-commerce, then adapted to pervasive computing scenarios[1]

- **Concept Contraction**: if the conjunction of C and D is unsatisfiable, what part K of D can be kept, and what part G must be given up?
  - Provides explanation for (un)satisfiability
- **Concept Abduction**: if C does not subsume D, what hypothesis H should be made about C in order to reach a full match?
  - Provides explanation for missed subsumption

[1] Ruta et al, WIAS, 9(3), 2011

Reasoning (3/3)

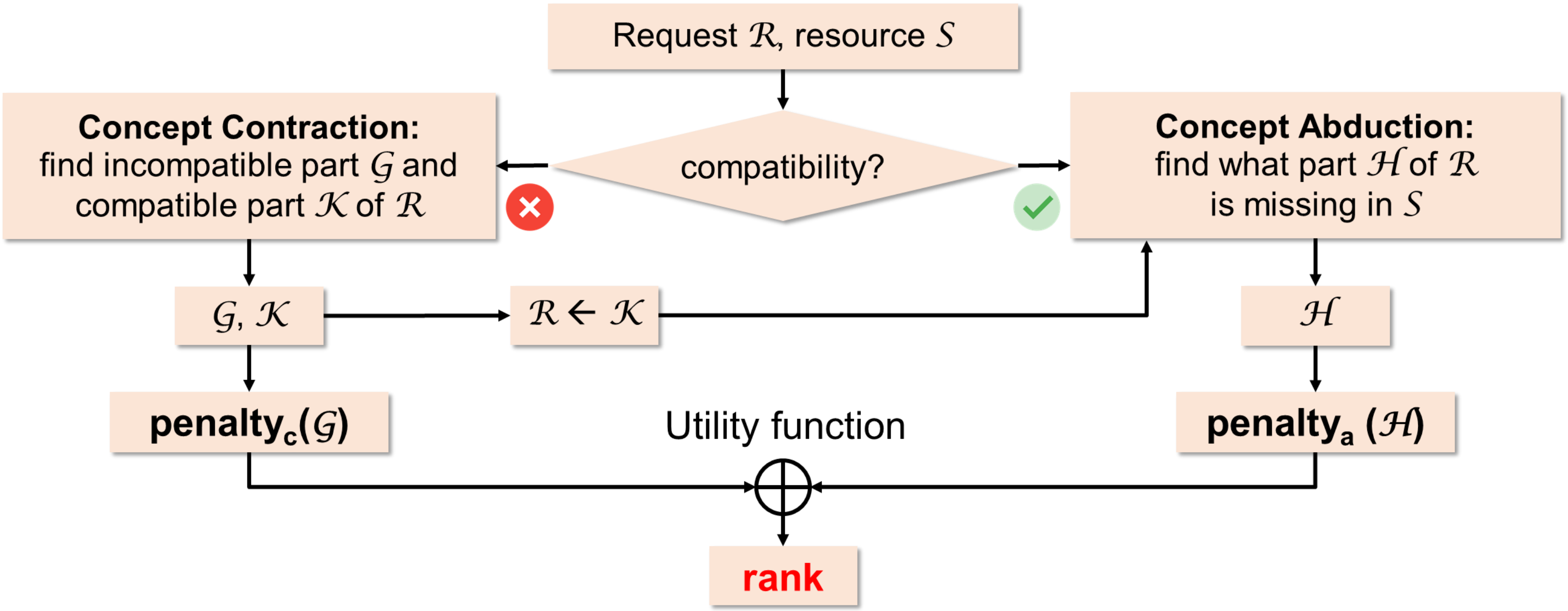
- **Concept Bonus**[1]: extract a bonus concept B from C, denoting what the resource provides even though the request did not ask for it
  - Useful for request refinement
- **Concept Covering**[2]: given a request D and a set of resources $\mathcal{C} = \{C_1, C_2, \ldots, C_k\}$, find $S_{\mathcal{C}} \subseteq \mathcal{C}$ including concepts in $\mathcal{C}$ covering D maximally and the (possible) uncovered part H
  - Based on Concept Abduction

[1] Colucci et al., IJEC, 12(2), 2007
[2] Ragone et al., IJWSR, 4(3), 2007

The Mini Matchmaking Engine

Mini-ME reasoner: efficient implementation of the above inferences

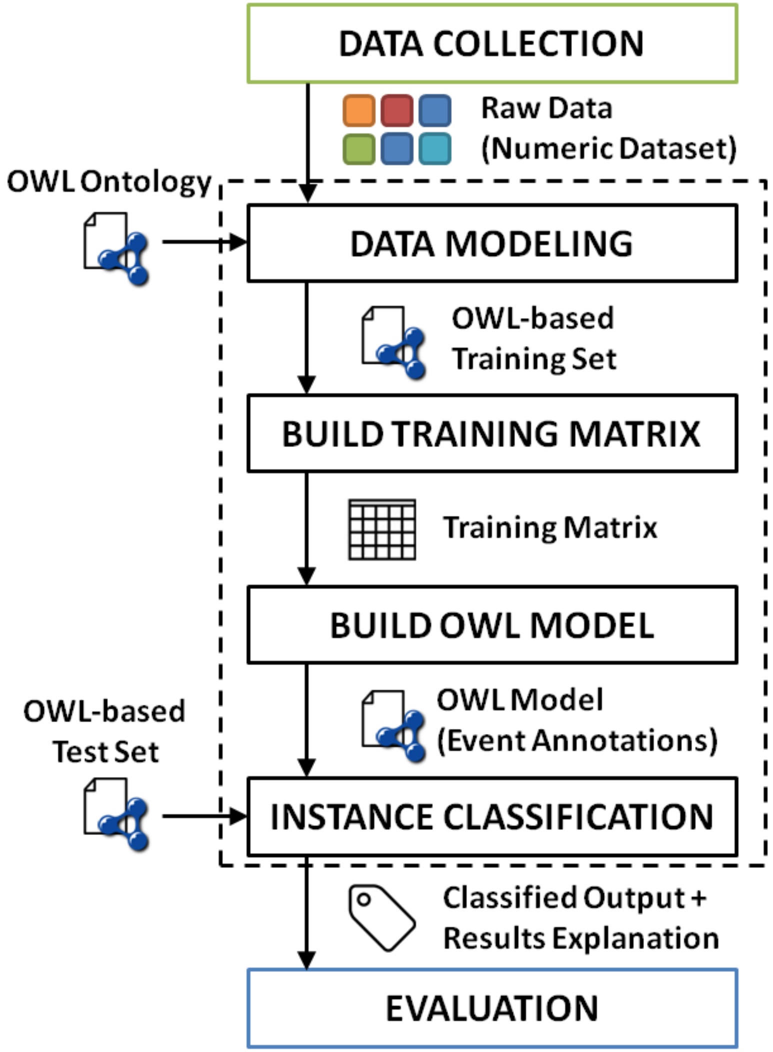
- Supported platforms: Java and Android[1], iOS[2]
- Optimized for mobile devices and single-board computers



[1] Scioscia et al., IJSWIS, 10(4), 2014
[2] Ruta et al., ESWC, 2019

Applied Research

Semantic-enhanced ML[1]



- Combine:
  - semantic-based inferences
  - machine learning algorithms
- Balance:
  - learning accuracy
  - computational requirements
- Benefits:
  - semantically rich models
  - explainability of results
  - suitable for mobile devices

[1] Ruta et al., Semantic Web, 10(1) 2019

Social IoT with LDP-CoAP

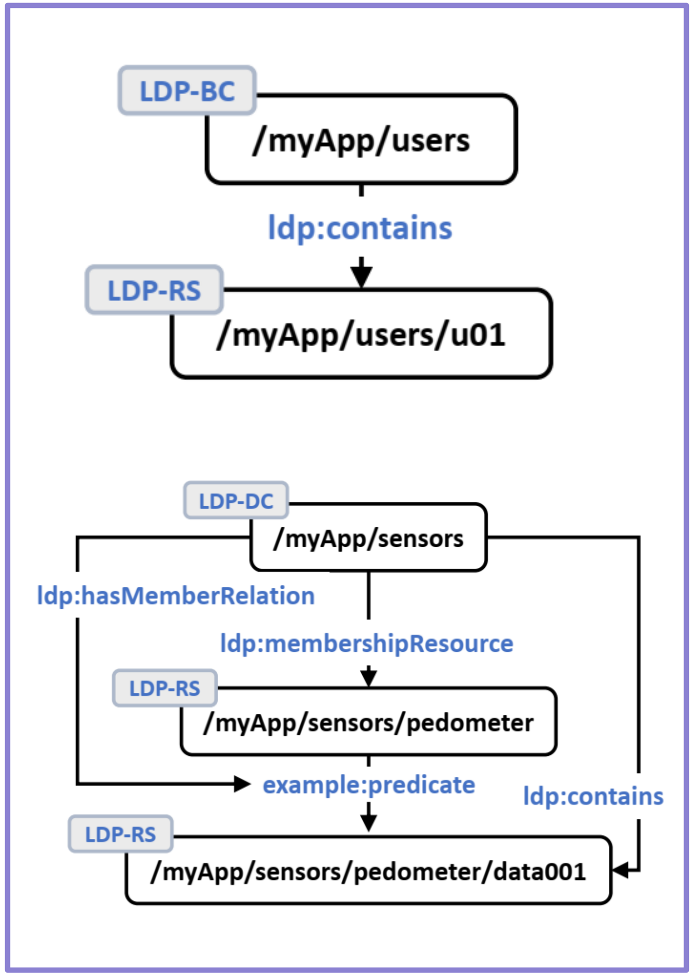
Linked Data Platform

W3C Recommendation for an interface to manage Linked Data

REST (REpresentational State Transfer) architectural style

Support for RDF and non-RDF resources

Containers to manage hierarchical collections of resources



Constrained Application Protocol (CoAP)

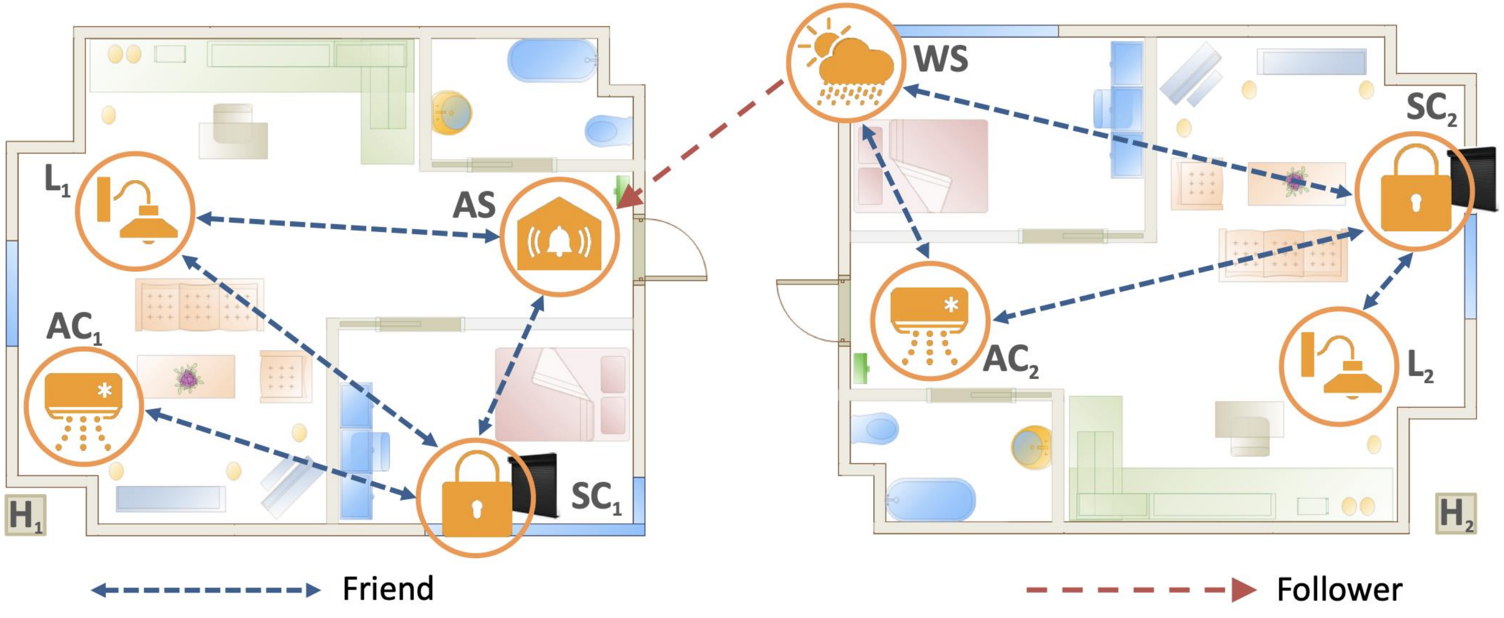
OSI level 7 standard designed for M2M communication

4 HTTP-derived methods over UDP

Resources identified by URIs

Observer pattern to get notifications upon resource changes

Social IoT with LDP-CoAP



- LDP-CoAP mapping [1] for resource management in M2M contexts
- Social relationships [2] among IoT devices in home and building automation
- Autonomous device reconfiguration via distributed collaborative service discovery[3]

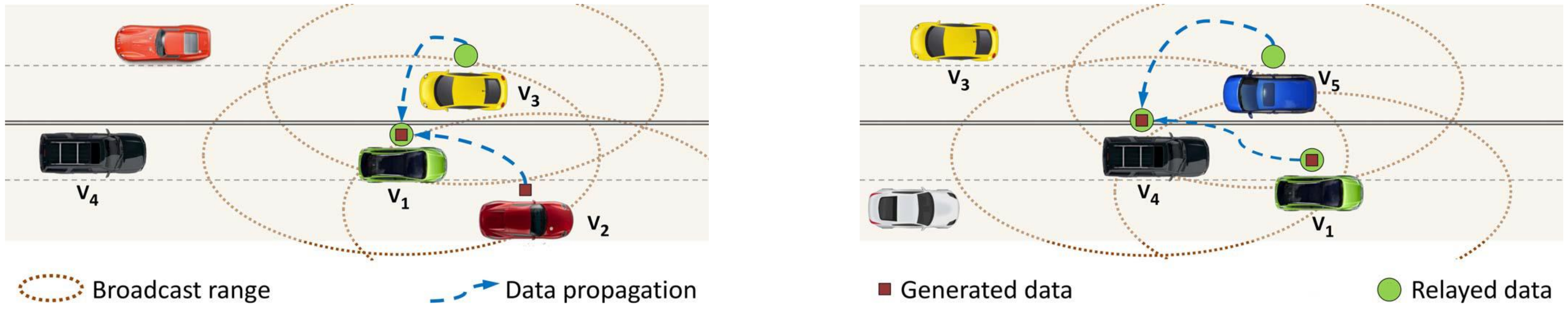
[1] Loseto et al., ISWC, part II, 2016
[2] Ruta et al., IEEE TII, 13(6), 2017
[3] Ruta et al., Semantic Web, 9(6), 2018

Information fusion on VANETS

- Semantic-based multi-agent data fusion framework[1]
  - Periodic message broadcast
  - Fusion of collected messages with locally generated information
  - Reconciliation of inconsistencies and robustness against spurious info

C (Confirmed): elements observed by both the sender and other agents	**X** (Clash): sender observations conflicting with observations of others
M (My): elements observed only by the sender, not by other agents	**E** (External): elements observed only by other agents, not by the sender

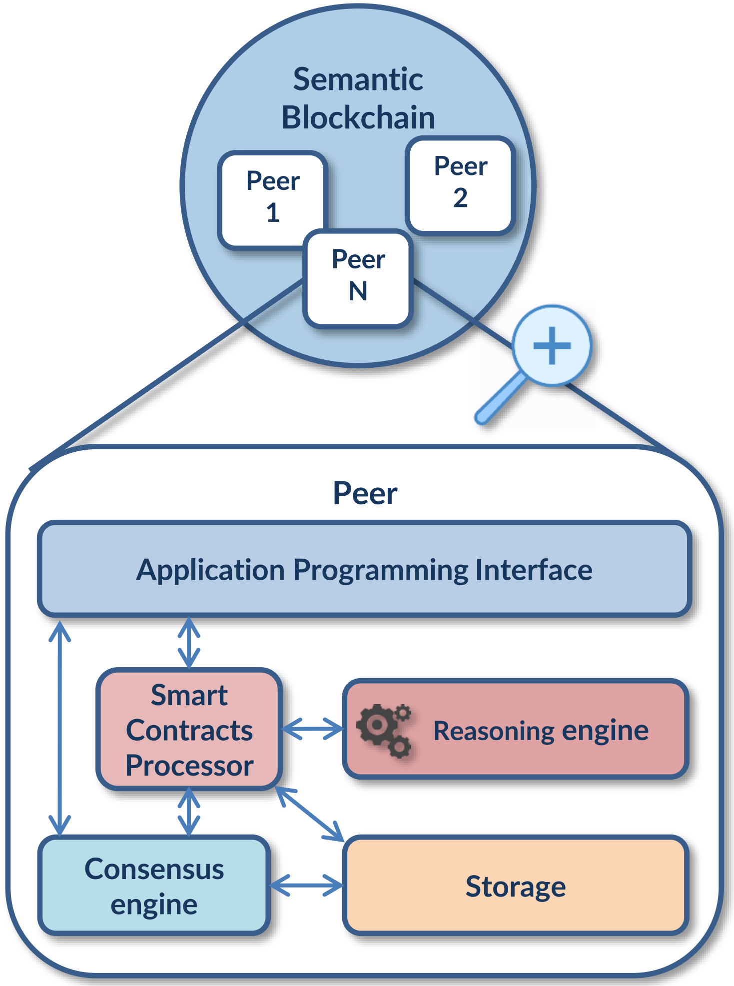
- Vehicular network case study and simulations in NCTUns



[1] Ruta et al., IEEE IoTJ, 5(4), 2018

Semantic-enhanced blockchain[1]

- SWoT blockchain → Service Oriented Architecture (SOA)
  - semantic matchmaking between request and available resources described w.r.t. ontology models
  - opportunistic and distributed execution, validated by consensus
  - transactions recorded on the ledger
- SOA primitives → semantic smart contracts
  - Registration
  - Discovery
  - Explanation
  - Selection
- Extension of the Hyperledger Iroha open source blockchain



[1] Ruta et al., OJIOT, 3(1), 2017

Contact

For more information about our projects, please get in touch with us:

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Projects Webpage: `http://swot.sisinflab.poliba.it`

Github repository: `github.com/sisinflab-swot`