Cooperative, Self-aware and Intelligent Systems: architectural components and future directions in Internet of Things

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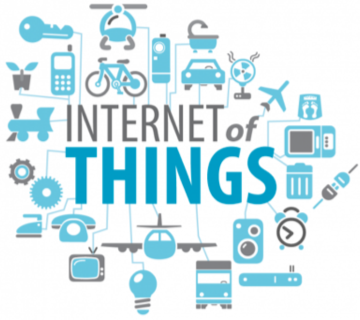
Outline

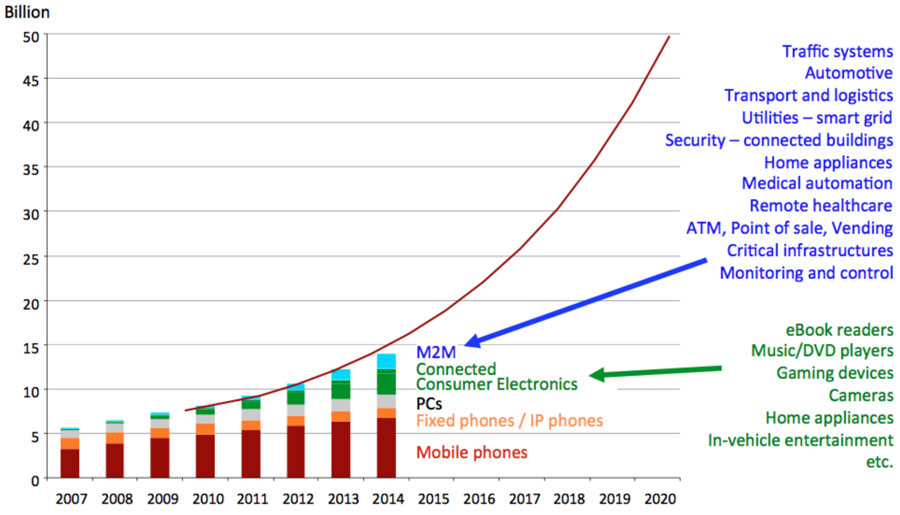
The Internet of Things (IoT)

- Everything that benefits from being connected will be connected!
  - connectivity is ubiquitous
  - technology is affordable
- 50 billion devices connected to the Internet by 2020 *(Cisco)*
- 500 billion devices by 2030 assumed when developing 5G



The Internet of Things has the potential to change the world, just as the Internet did. Maybe even more so. *(Kevin Ashton)*

Connected Devices Worldwide



Asthma inhaler (propellerhealth.com)

IoTaP application areas Societal challenges

- **Smart transport**: improving transportation systems, including logistics and public transport.
- **Smart cities**: supporting emergency services, waste management, public safety security, etc.
- **Smart energy**: improving the production, distribution, and consumption of energy.
- **Smart living**: improving the comfort and quality of domestic life.
- **Smart health**: supporting (preventive) health care anywhere and anytime.
- **Smart learning**: facilitating learning anywhere, including both professional and informal learning.

Industrial partners

CYBERCOM GROUP

TERRANET

SIGMA Connectivity

DATA DUCTUS

SIGMA Technology

maingate

verisure ALARMS WITH IQ

AXIS COMMUNICATIONS

ÅF

SONY

e·on

PART I

Cooperative, Self-aware and Intelligent Surveillance Systems (**CoSIS**)

Goal of the project:

The design of intelligent surveillance systems consisting of different types of connected devices, e.g. cameras, sensors, actuators and processors in the public and semi-public domain.

Bio-inspired Computational Intelligence Approach for Context-awareness

Fact:

Ubiquitous sensing system are generating vast amounts of data

Challenge:

1. Automatically acquiring context models from distributed data sources.
2. Deriving contextual information from multi-dimensional data sets that is relevant and actionable to its users and stakeholders.

Current state of affair:

Existing solutions are typically limiting in the sense that they attempt to map incoming sensor data to predefined high-level context descriptions.

Bio-inspired Computational Intelligence Approach for Context-awareness

The general idea:

To draw inspiration from **immunity theory** concepts in order to *acquire*, *represent* and *infer* context information.

Artificial immune systems display the following properties:

- Self-adaptability
- Self-organization
- Parallel processing
- Distributed coordination

Bio-inspired Computational Intelligence Approach for Context-awareness

Applying **Negative Selection**:

- 'Self' represents the current context denoting certain statistical properties/patterns in the data stream
- 'Non-self' detection indicates transition to another context

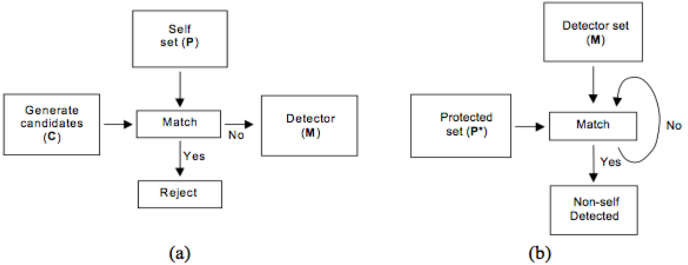
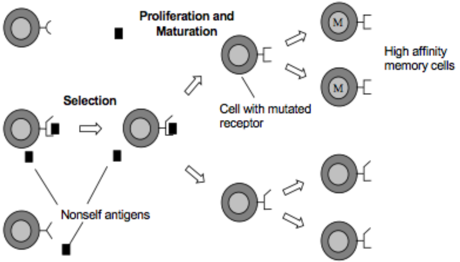


Figure: (a) Generating the set of detectors. (b) Monitoring for the presence of (undesired) nonself patterns.

Bio-inspired Computational Intelligence Approach for Context-awareness

Applying **Clonal Selection**:

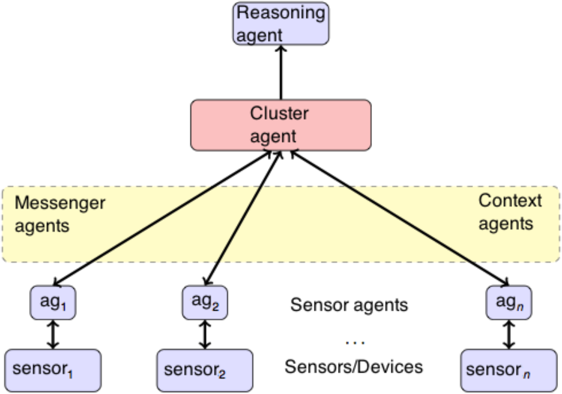
- The highest affinity cells are selected to proliferate
- Their clones suffer mutation with high rates and those whose receptors present high affinity with the antigen are evolved to memory cells



Bio-inspired Computational Intelligence Approach for Context-awareness

Approach:

Design an develop a **hierarchical architecture of intelligent agents** to implement an **artificial immune system** reasoning about **context info**.



Properties of Sparse Distributed Representations (SDR)

General approach:

- Hamming shape-spaces, where an attribute string $s = \langle s_1, \ldots s_L, \rangle$, is built upon the set of binary elements
- The degree of match is determined using the Hamming distance.

Our Approach:

- An *immune cell* is denoted by an attribute string $\|s\| = n$, which is a high-dimensional binary vector
- Only a small percentage of the bits are active $\|s\|_1 = w$, $w \ll n$
- A *match* between strings s_1 and s_2 is the *overlap* in the number of bits that are active: $overlap(s_1, s_2) = s_1 \cdot s_2$

Subsampling: spatial pooling

- Reliably compare against a subsampled version of the vector
- The probability of a false match is extremely low

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Properties of Sparse Distributed Representations (SDR)

Union property: **temporal pooling**

- Boolean OR of all vectors, resulting in a new vector X
- To determine is a new SDR y is a member of the set, we compute *match(X,y)*

$$
\begin{aligned}
x_1 &= [01000000000010000000 \ldots 010] \\
x_2 &= [00000000000000000010 \ldots 100] \\
x_3 &= [10100000000000000000 \ldots 010] \\
&\vdots \\
x_{10} &= [000000000000000110000 \ldots 010]
\end{aligned}
$$

$$X = x_1 OR x_2 OR, \ldots, x_{10}$$

$$X = [1110000000110110000 \ldots 110]$$

$$y = [10000000000001000000 \ldots 001]$$

$$\therefore match(X, y) = 1$$

Niagara building

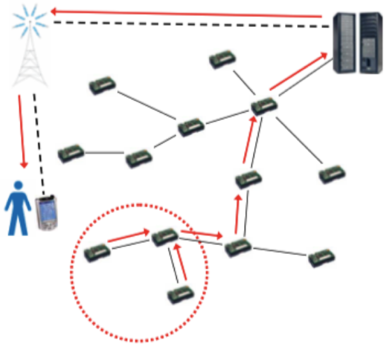
Recap

- Design of a Multiagent model based on immunity theory concepts with the scope of enhancing sensor-driven architectures with context-aware capabilities
- Provide a novel approach to represent data within an artificial immune system (AIS) based on sparse distributed representations (SDRs), which is instrumental for context modelling
- Leverage contextual information inferred from monitoring smart buildings in order to foster services that increase user satisfaction through value added services for smart environments

PART II

SENSATION Platform by Sigma

Standard operators (MIN, COUNT, AVG, etc.) over homogeneous data types (i.e. temp.)

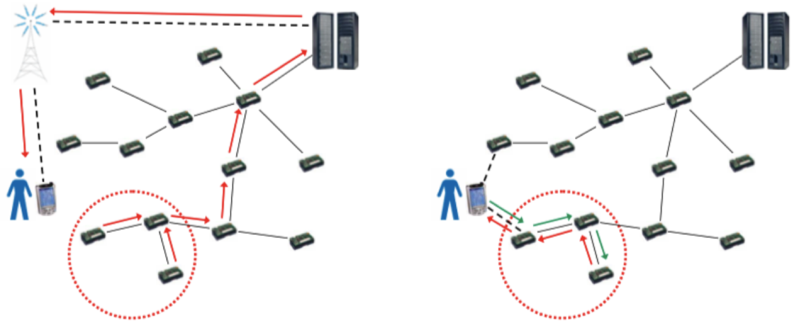


Virtual Sensors

- Combine sensed data from a group of heterogeneous physical sensors to compute an abstract measurement
- Multi-domain sensor network supporting numerous applications
- Increased performance: minimize communication overhead and latency (for mobile users)
- Increase data accuracy

DIVS: Dynamic Intelligent Virtual Sensor

- Provides generality, flexibility and a higher level of abstraction to the application developer
- Accounts for the users dynamic context (data sources supporting the virtual sensor can change over time)
- Less communication costs/ battery power needed

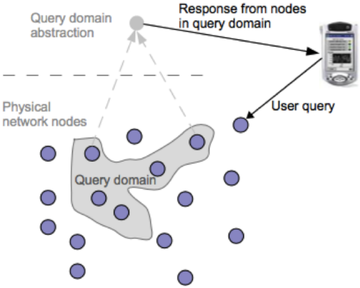


Challenges

- Difficult to specify precisely in advance the sensors from which to collect data
  - Sensors feeding data are subject to constant change (mobile user/mobile sensors)
  - User doesn't have the expertise/time to manually decide which sensors to use
  - Dynamically assigning sensors to tasks
- Enable direct/on-demand interactions with local sensors
  - Support localized cooperation of sensor nodes for more complicated tasks
  - Sensors reallocated/reprogrammed remotely to/for particular applications/tasks

Dynamic and efficient allocation of sensors to tasks/DIVS

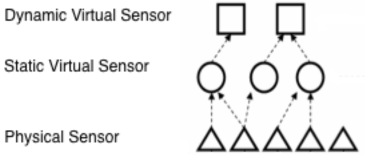
- Capture positive and negative synergies that might exist among different (groups of) nodes
- Dynamically determine the importance of sensors in an allocation (define information gain for heterogeneous tasks)
- Determine best joint sensing action (i.e. PTZ Cameras)



DIVS as a (Semantic) Service

⟨ I,O,P,E,U,TTL ⟩

- I set of sensor inputs
  - Each sensor input has an associated type (i.e. temp)
  - Data augmented with semantic annotations
  - Information gain of sensor in DIVS
- O set of outputs
- P set of preconditions
- E set of effects
- U minimum acceptable utility/ trust of DIVS
- TTL time to live



Trust-based mechanism for DIVS

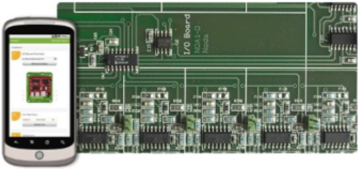
- Trust is defined as the aggregate expectation, of having an accurate measurement, derived from historical data and (correlated) information from other sources (sensors, DIVS)
- Semantically matchmaking between virtual sensors to determine possible importance of different sensor data for the aggregated value of new DIVS based on existing DIVS in a trust-based manner
- Basically, choose sensors in DIVS based on their information gain in similar DIVS (also location aware)
- Different data fusion strategies

PART III

Smart Homes in an Intelligent Energy System (**SHINE**)

Goal

To optimize the operational behaviour, the control systems are required to increasingly handle the whole supply chain as a whole where production, distribution and consumption are tied together from an information technical perspective.



Smart Homes in an Intelligent Energy System (**SHINE**)

Create different schedules for different rooms, which have a temperature sensors and heating/cooling devices assigned to them.

Smart Homes in an Intelligent Energy System (**SHINE**)

Problem Formalization:

- Set of ag: $\mathcal{A} = \{a_1, a_2, \dots, a_n\}$
- Nonempty and finite set of distinct and successive time periods: $\mathcal{T} = \{t_1, t_2, \dots, t_{|\mathcal{T}|}\}$
- Price vector: $\mathcal{P} = [\, p_1 \; p_2 \; \dots \; p_{|\mathcal{T}|} \,]$ (price for unit of energy per timeslot)
- Max available consumption vector: $\mathcal{E} = [\, e_1 \; e_2 \; \dots \; e_{|\mathcal{T}|} \,]$

Smart homes and intelligent energy systems tied together

Each agent $a_i \in \mathcal{A}$ is characterized by:

- Load vector: $\mathbf{x}^i = [\, x^i_1 \, x^i_2 \, \ldots \, x^i_{|\mathcal{T}|} \,]$, consumption over schedule $\mathcal{T}$, where $x^i_t = \{0, y_1, \ldots, y_{|x^i_t|}\}$ denotes the possible operational set-points of the radiator valves
- Valve actions: $\alpha^i = \{\alpha^i_1, \ldots, \alpha^i_{|\alpha^i|}\}$
- Mapping from loads to valve actions: $\sigma : \mathbf{x} \to \alpha$
- Preferred temp: $\gamma^i = [\gamma^i_1, \ldots, \gamma^i_{|\mathcal{T}|}]$ for each timeslot
- Acceptable temp interval: $\left[[\gamma^i_{min}, \gamma^i_{max}]\right]^{\mathcal{T}}$ for each timeslot
- Occupancy probability: $\beta^i = [\beta^i_1, \ldots, \beta^i_{|\mathcal{T}|}]$
- Thermal model: $\phi_i : \beta \times \mathcal{T} \times \mathcal{F} \to \mathbb{N}$, where $\mathcal{F}$ is the domain of ext. factors

Smart homes and intelligent energy systems tied together

Joint load optimization function minimizes the expected unifying cost, over the planning horizon:

$$\underset{x_t^i}{\operatorname{argmin}} \quad w \times \sum_{a_i \in \mathcal{A}} \sum_{t \in \mathcal{T}} x_t^i p_t + (1 - w) \times \sum_{a_i \in \mathcal{A}} \sum_{t \in \mathcal{T}} \beta_i |\phi_i(x_t^i, x_{t-1}^i) - \gamma_t^i| \quad (1)$$

where:

$$x_t^i \in \{0, 1, \ldots, n\}$$

subject to:

$$\sum_{a_i \in \mathcal{A}} x_t^i \leq e_t, \forall t \in \mathcal{T} \quad (2)$$

$$\gamma_{min}^i \leq \phi_i(x_t^i) \leq \gamma_{max}^i \quad (3)$$

Smart homes and intelligent energy systems tied together

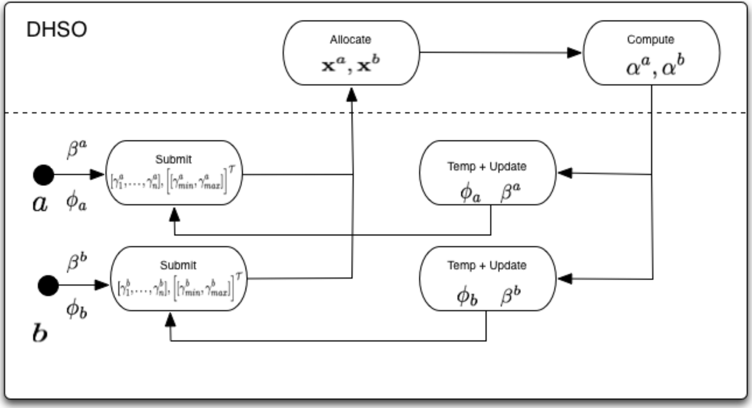


Figure: Model Predictive Control

Smart homes and intelligent energy systems tied together

Challenges:

- Learning sub-problems:
  - Learn a thermal model of the home
  - Learn an occupancy model of the home
  - Learn/elicit user preferences (i.e. temp settings, cost/comfort trade-off)
- Computational complexity
- Privacy-preservation

Thanks for your attention!