Self-Awareness in Cyber-Physical Systems

Axel Jantsch[1] Nikil Dutt[2]

[1]TU Wien, Vienna, Austria

[2]UC Irvine, CA

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Beyond Self-Aware Embedded Computing
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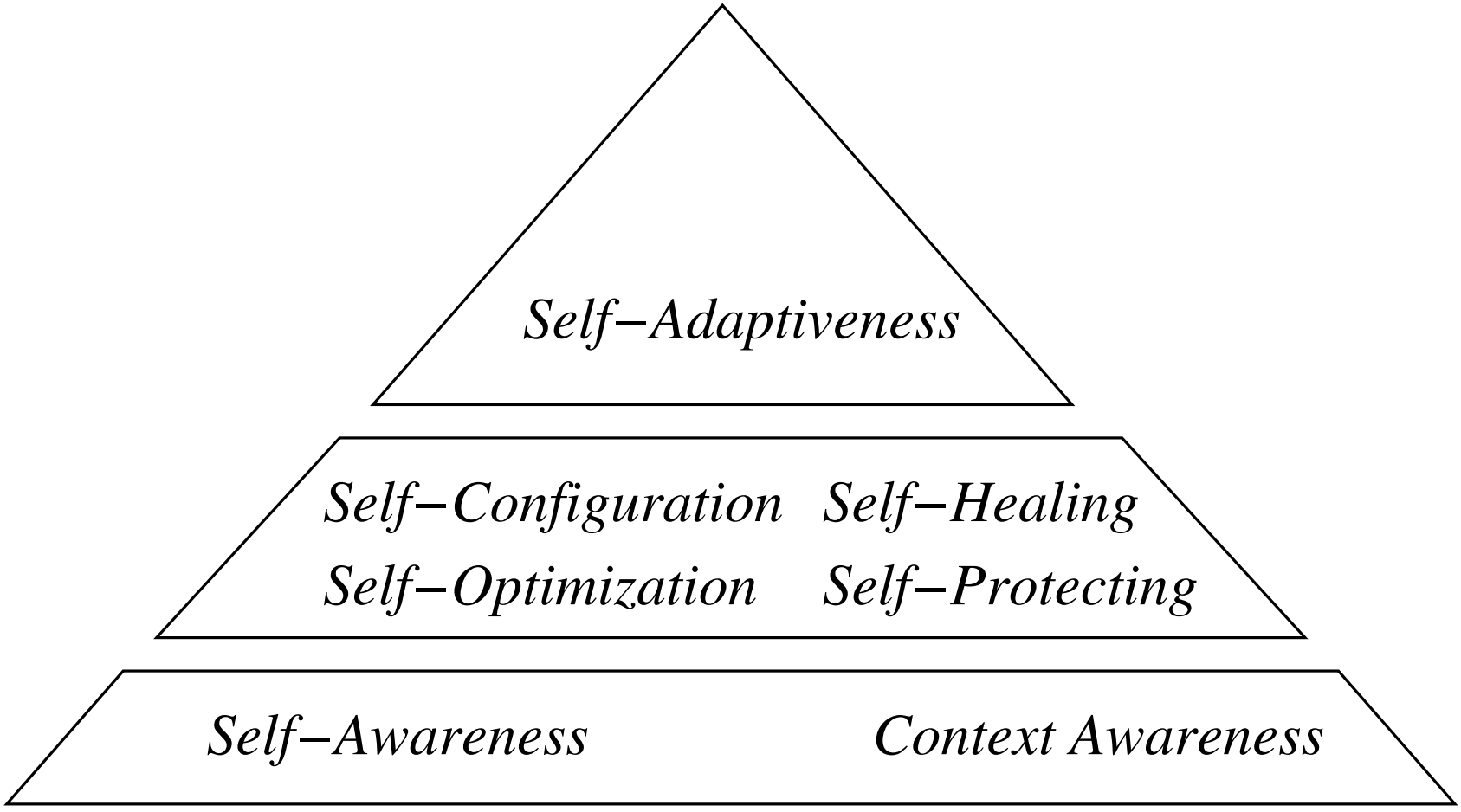
What is Self-Awareness ?

- Is it fault-tolerance? No
- Is it adaptation? No
- Is it self-monitoring? No

What is Self-Awareness ?



Self-Awareness - A Working Definition

Self-awareness of a system is the capability to correctly assess the system's own behavior and performance (self-monitoring or self-awareness in a narrow sense),

the environmental context and events (situation awareness),

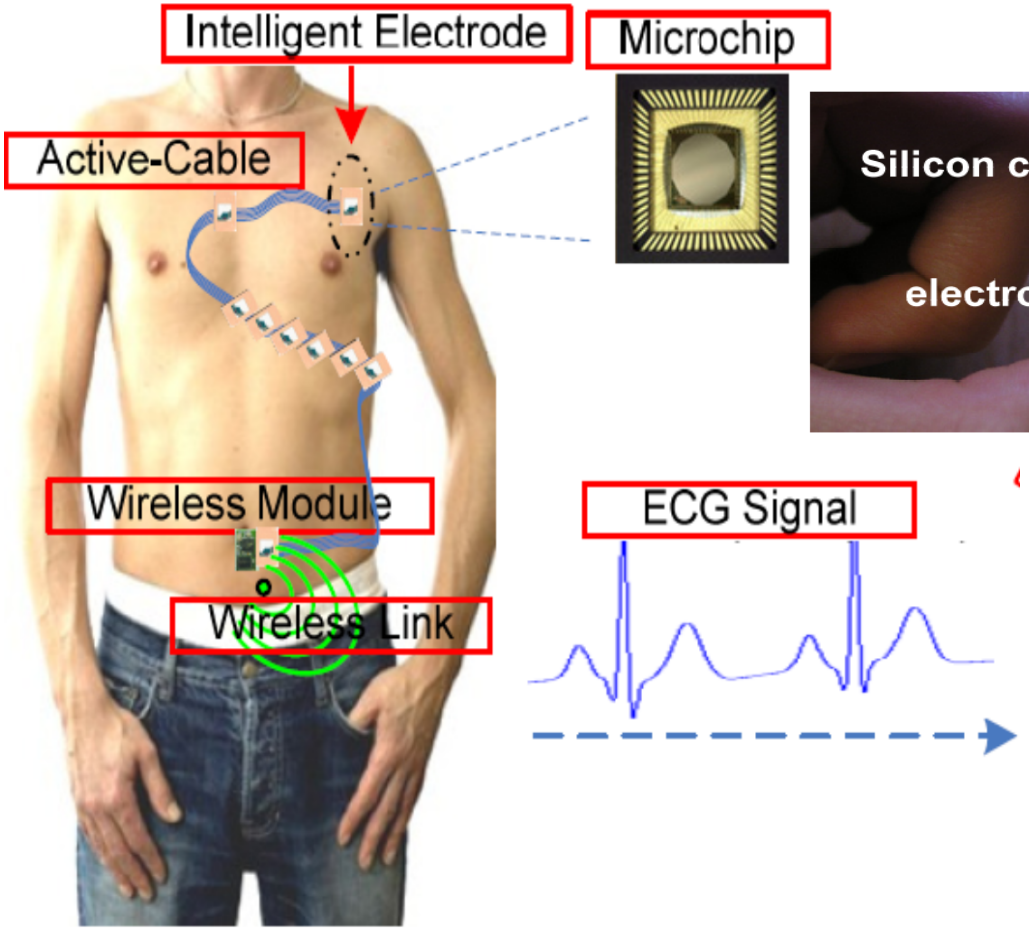
and to focus the system's activities and resources (attention);

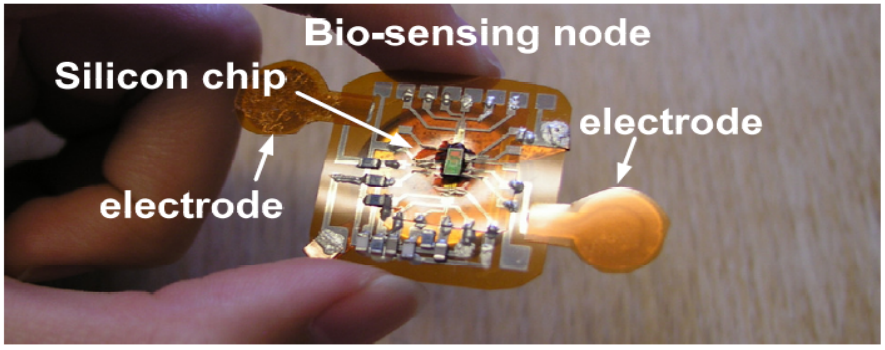
all that with proper regard to given goals and expectations.

The Benefits of Awareness

- Better functionality in different contexts
- Context depending performance
- Appropriate reaction in presence of faults

Self-Awareness for Resource Constrained, Insect-like Gadgets





Properties of Awareness

- Not all information is necessary
- More information does not imply more awareness

- Raw data is interpreted/abstracted
- Data interpretation is “meaningful”
- The drawn conclusions are “robust”
- The reaction is appropriate

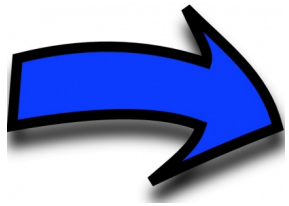
BioPatch: Temperature Sensor

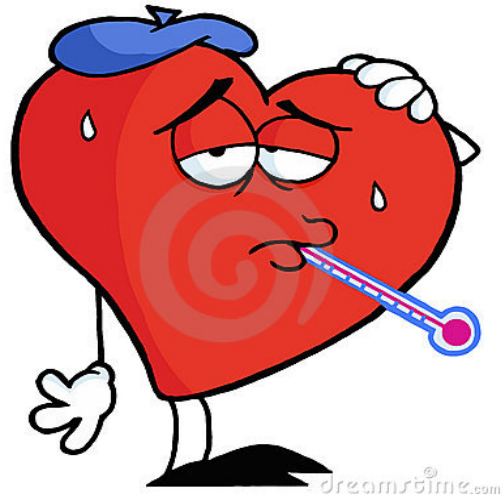
measured temperature

< 20	$\rightarrow$ person is dead
in $[20, 32]$	$\rightarrow$ alive, life threatening
in $[32, 36]$	$\rightarrow$ worrying, not life threatening
in $[36, 37]$	$\rightarrow$ normal
in $[37, 37.5]$	$\rightarrow$ elevated, not worrying
in $[37.5, 39.5]$	$\rightarrow$ fever
in $[39.5, 43]$	$\rightarrow$ high fever, life threatening
> 43	$\rightarrow$ person is dead

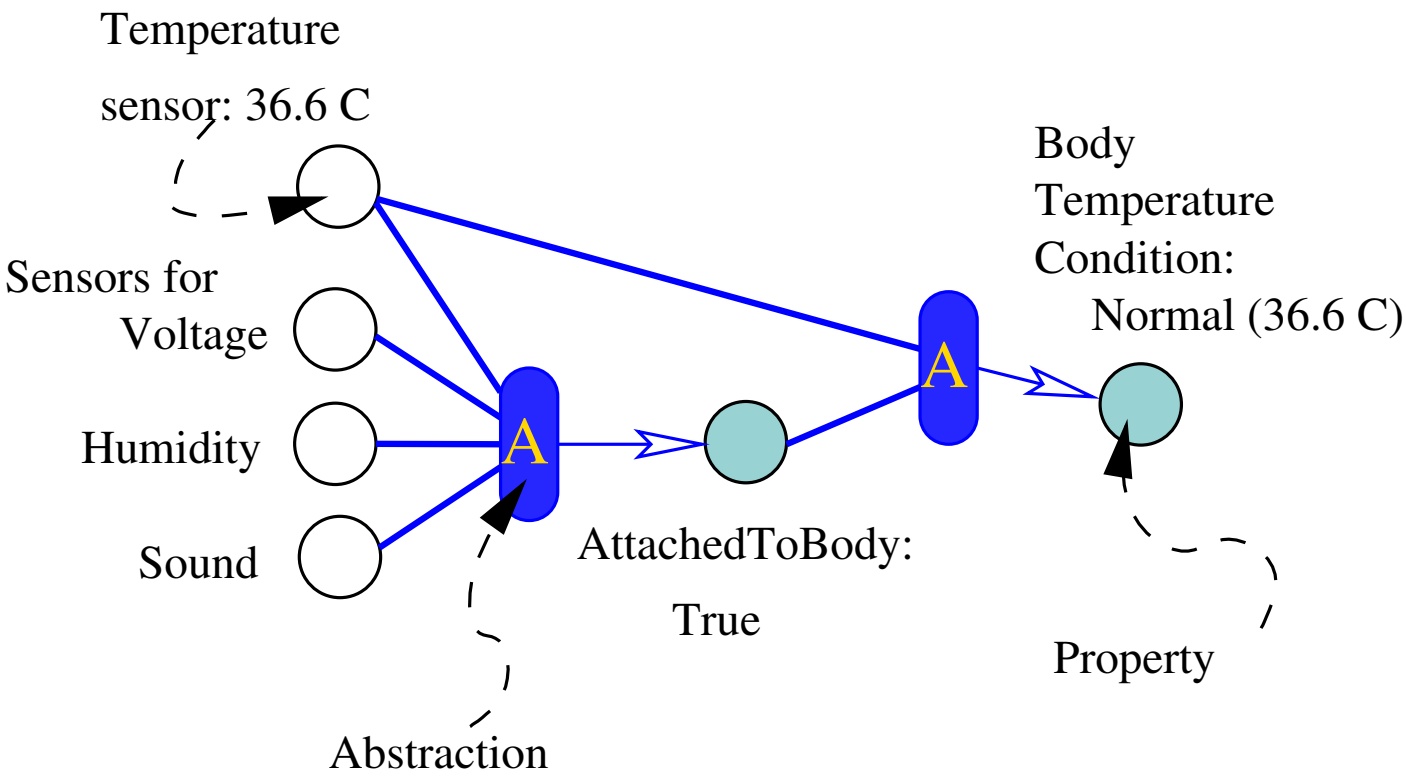
Abstractions and Models

Abstraction: Mapping of Measurements $\Rightarrow$ Properties



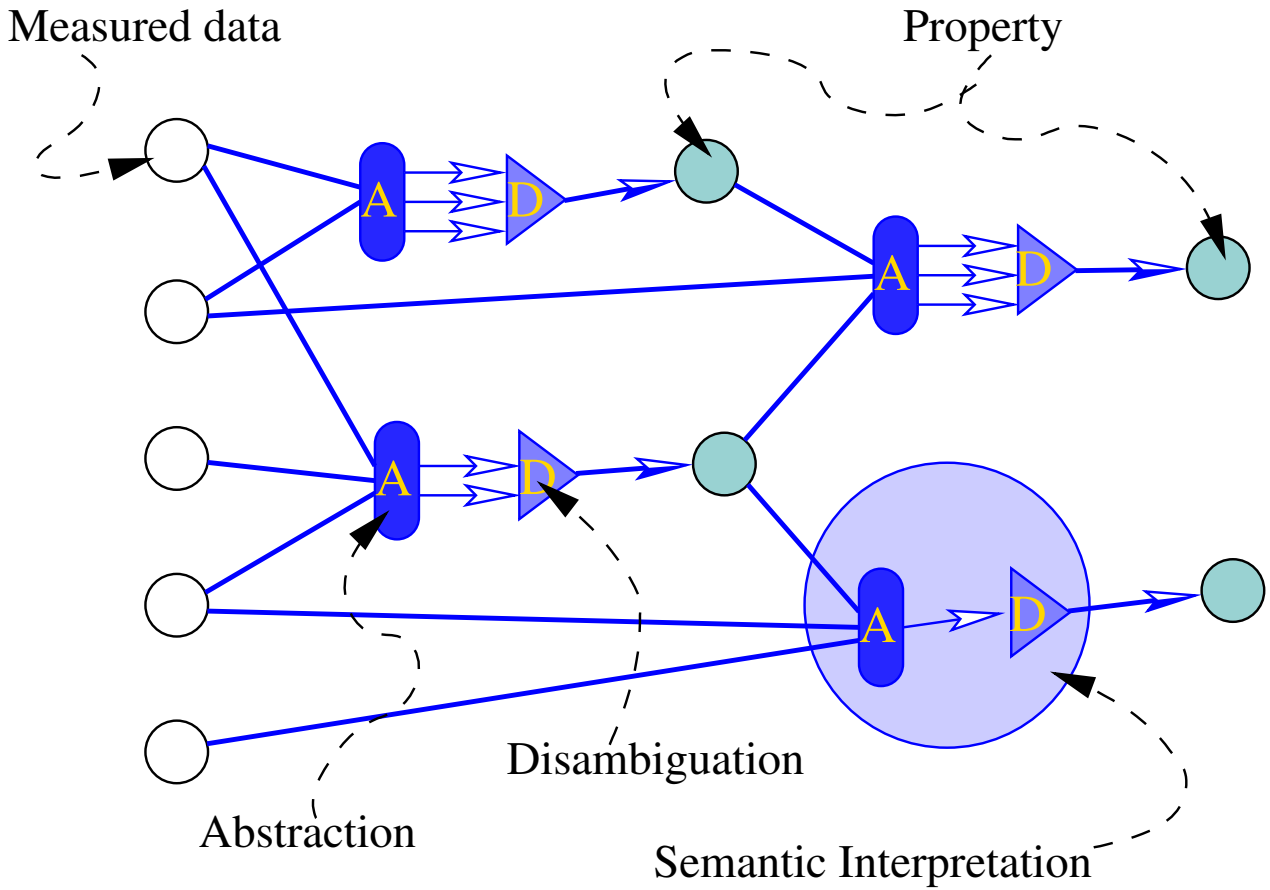


Abstractions and Models



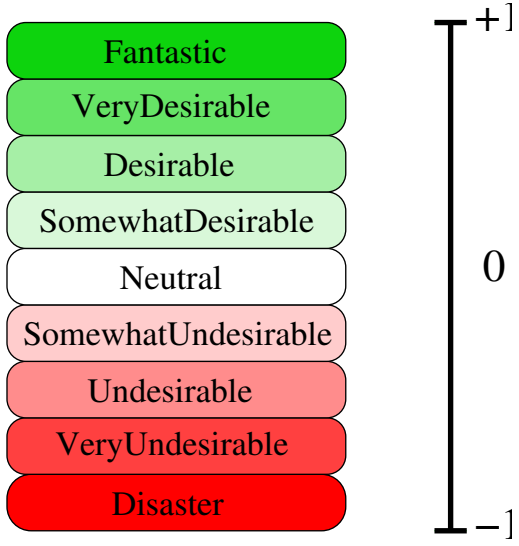
Disambiguation

Selection among several interpretations



Desirability Scale

A value range that captures the desirability of something



Semantic Attribution maps the values of a property to a point in the desirability scale.

History

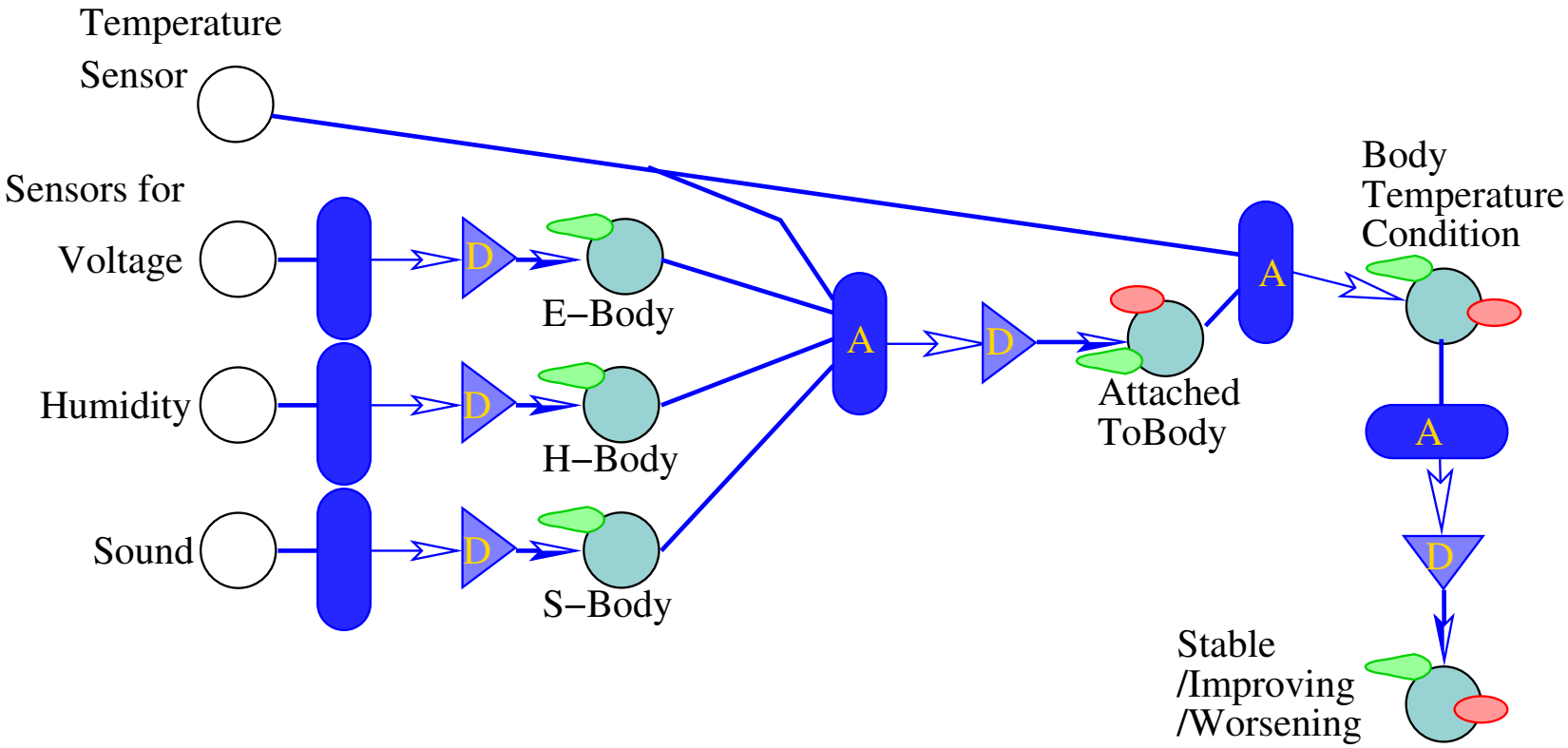
History of a Property The evolution of the values of a property.

Abstracted History The history stores abstracted values.

Attributed History The history is annotated with attributions.

Fading History If the property values are more abstracted the longer ago they have occurred.

Sensors and properties of the BioPatch



Expectations

Expectation on Environment

- all implicit and explicit assumptions about the environment;
- a value range for each of the monitored properties.

Expectation on System

- all implicit and explicit assumptions about the system;
- a value range for each of its monitored properties.

Goals

Sub-Goal A sub-goal of the system is a desired value range of a property of the system or its environment.

Goal A goal consists of one or several sub-goals.

Purpose The purpose of a system is to achieve all its defined goals.

Inspection and Simulation

Self Inspection Engine is a mapping from a set of properties onto a desirability scale;

Model Transformation Given a model and a set of actions, a transformation applies actions and derives the new values for all properties.

Simulation Given a model and a set of potential actions, a simulation is a sequence of transformations applied onto the model resulting in a new, updated model.

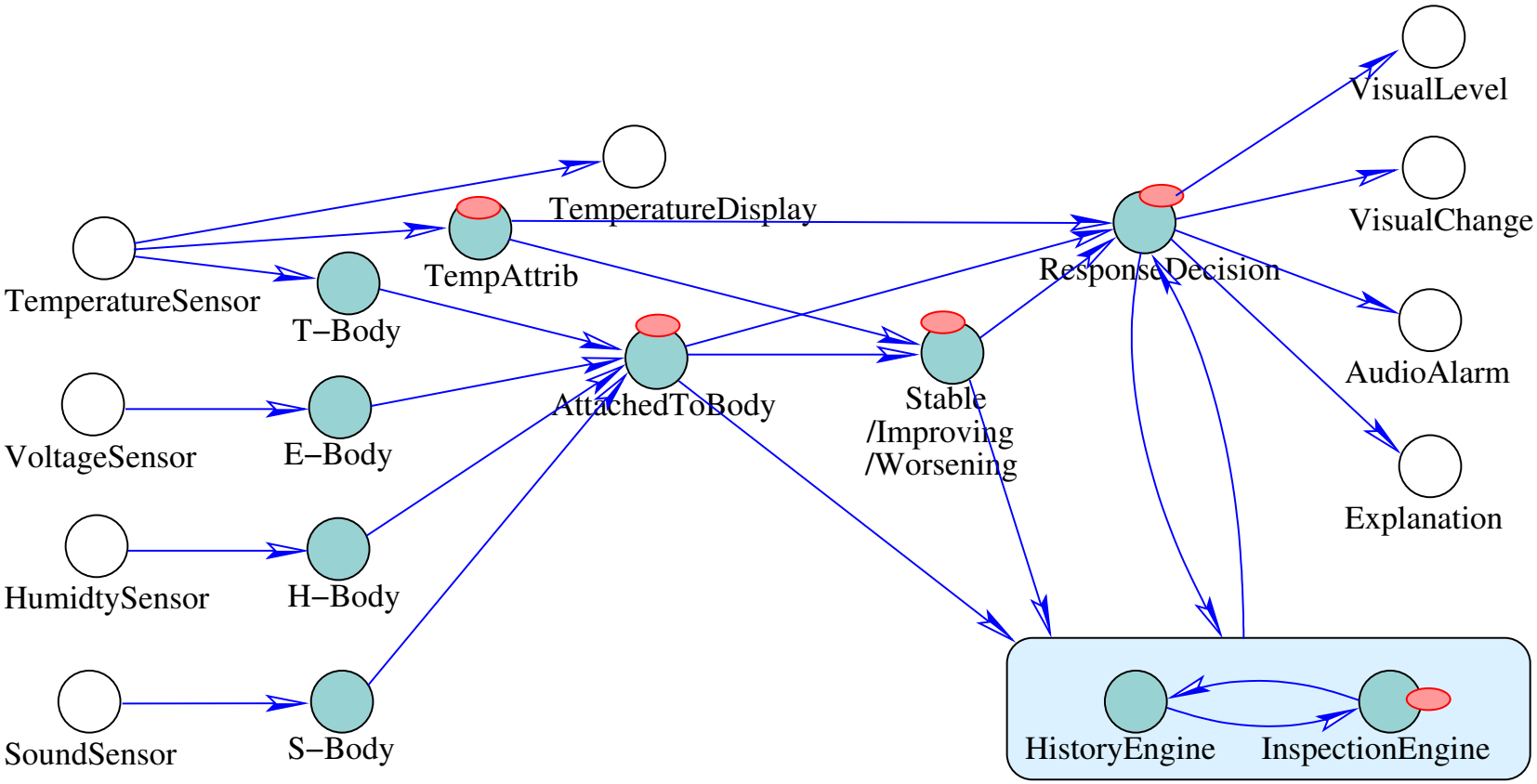
Awareness of a Property

- The system makes observations and derives the property by means of a meaningful semantic interpretation (**Meaning Condition**).
- The semantic interpretation is robust (**Robustness Condition**).
- There is a meaningful semantic attribution into a desirability scale (**Attribution Condition**).
- The system reacts appropriately to its perception of the property (**Appropriateness Condition**).
- A history of the evolution of the property over time is maintained (**History Condition**).

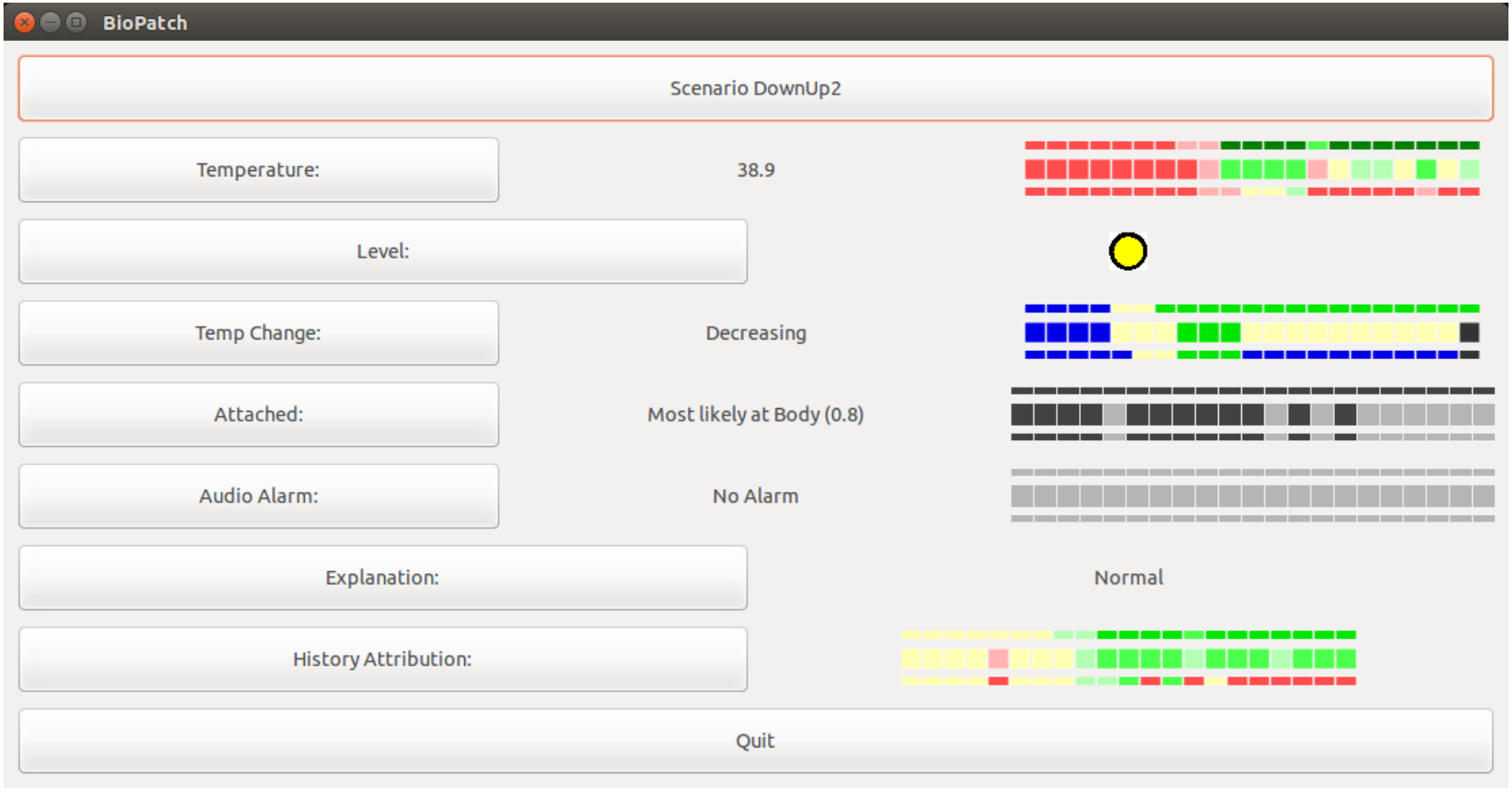
Awareness of a System

- The system can assess how well it meets all its goals (**Goal Condition**).
- The system can assess how well the goals are achieved over time and when its performance is improving or deteriorating (**Goal History Condition**).

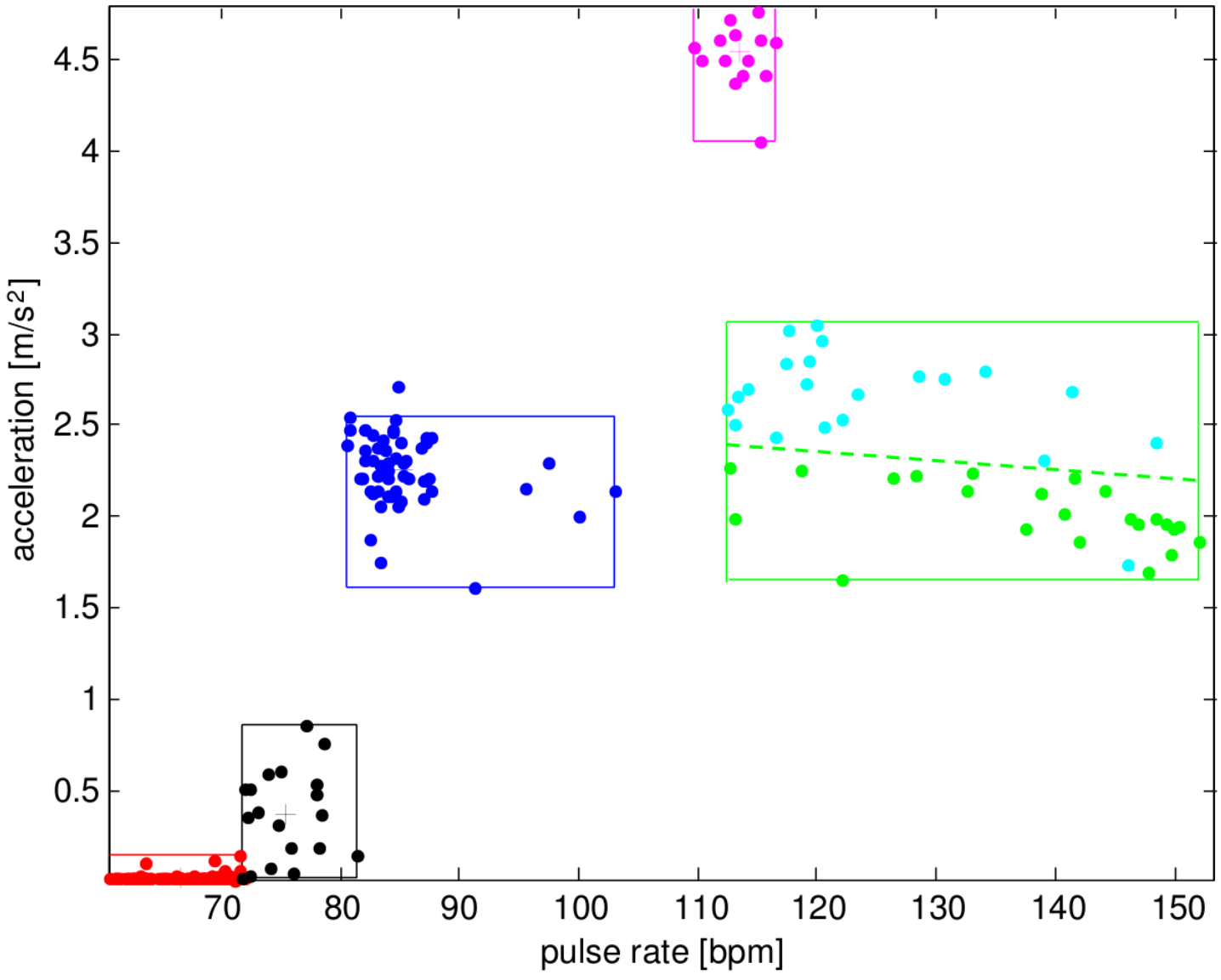
BioPatch Example



BioPatch Example



BioPatch Monitoring



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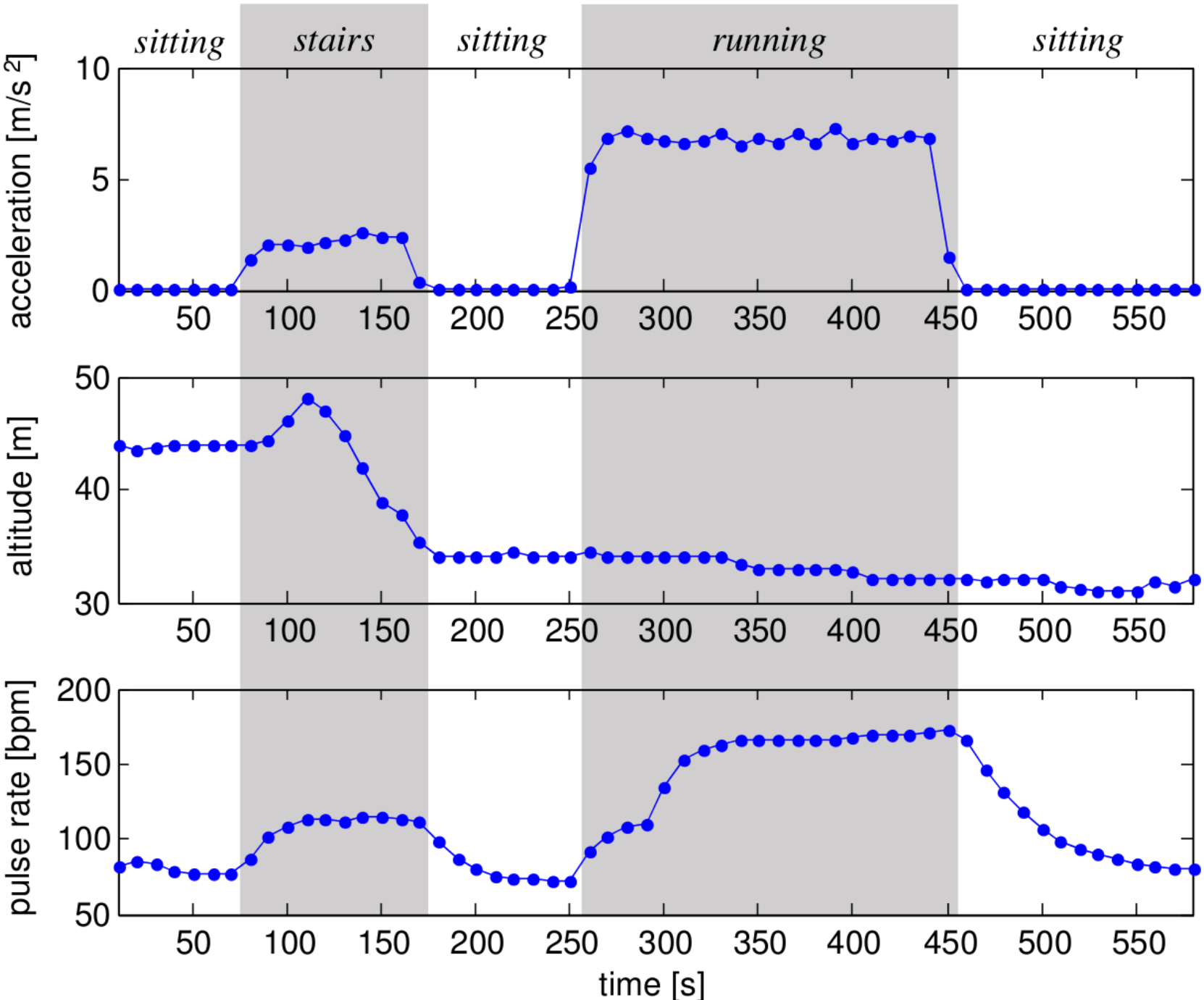

CPSoC - A Sensor Rich SoC Platform

- Sensors and actuators at five layers:
  - Device/ circuit architecture
  - Hardware architecture
  - Network/Bus communication architecture
  - Operating system
  - Application
- Observe-decide-act paradigm
- Codesign of control, communication and computing

Santanu Sarma, Nikil Dutt, N. Venkatasubramaniana, A. Nicolau, and P. Gupta. *CyberPhysical-System-On-Chip (CPSoC): Sensor-Actuator Rich Self-Aware Computational Platform*. Tech. rep. CECS Technical Report No: CECS TR–13–06. Irvine, CA 92697-2620, USA: Center for Embedded Computer Systems University of California, Irvine, May 2013

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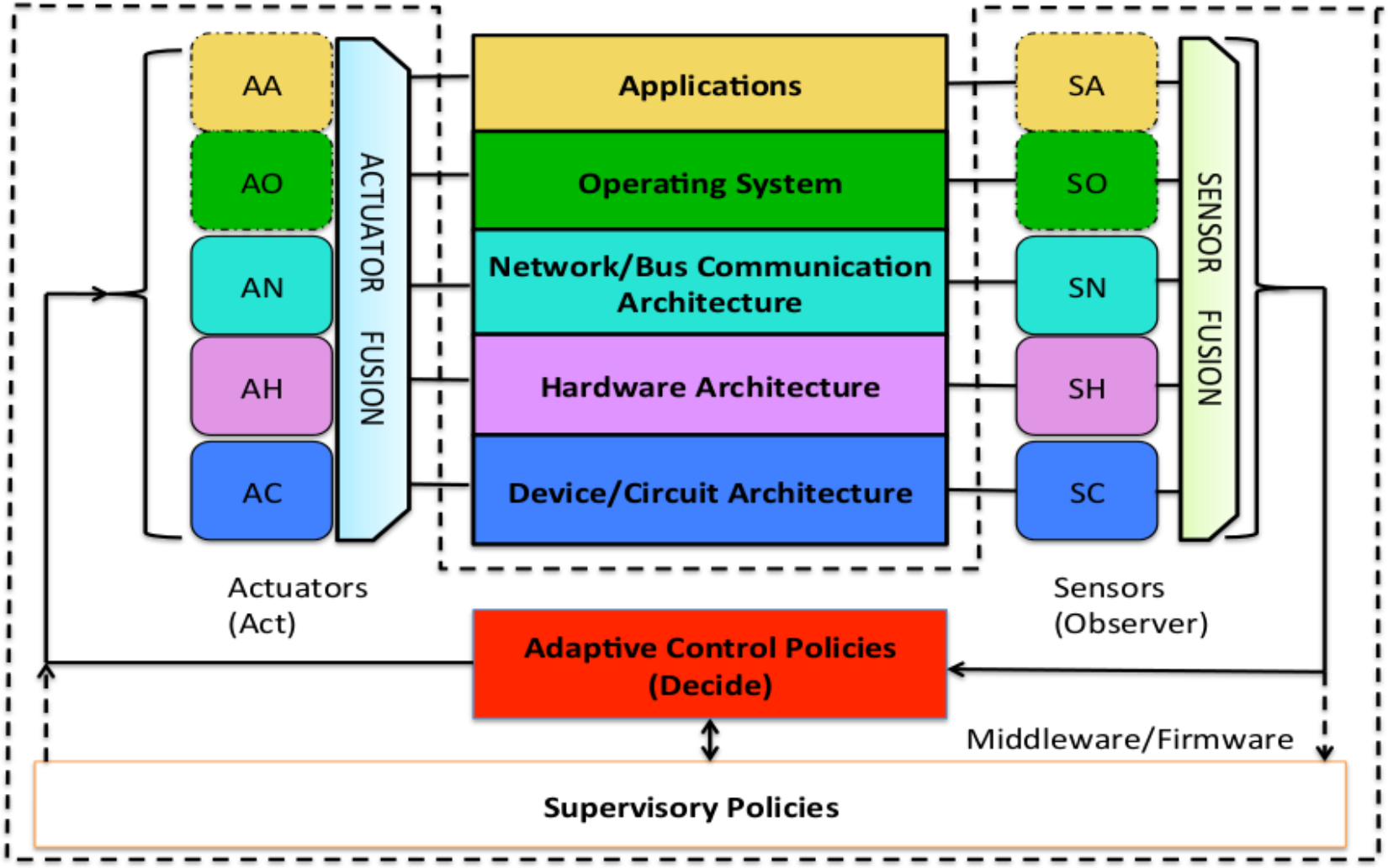

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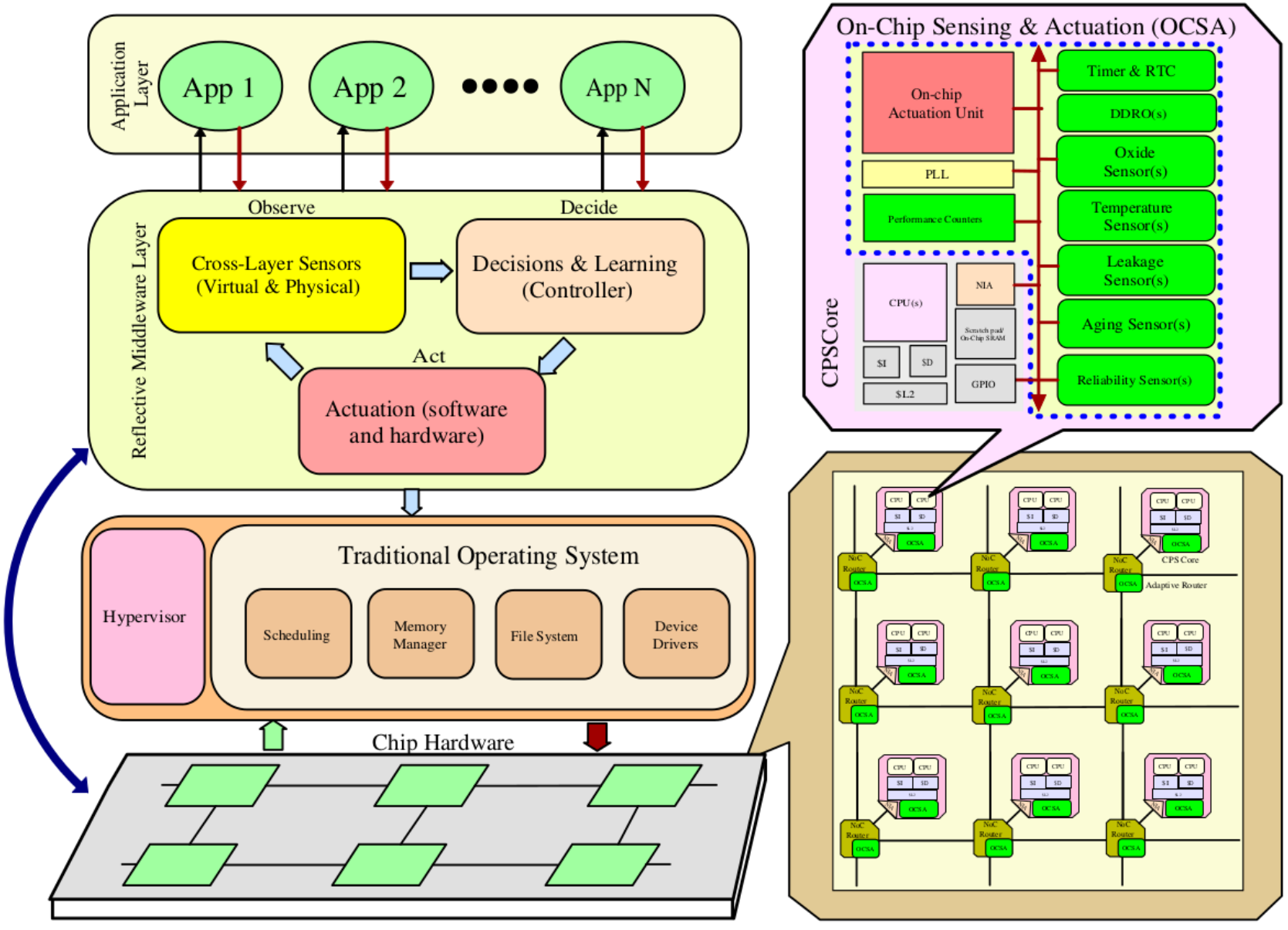

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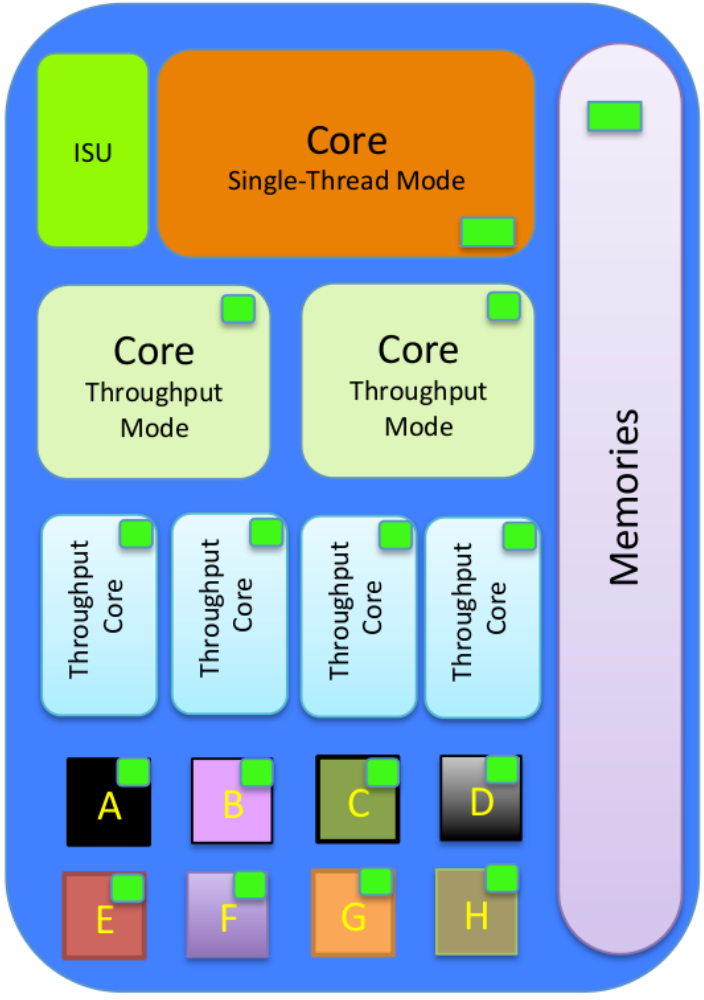

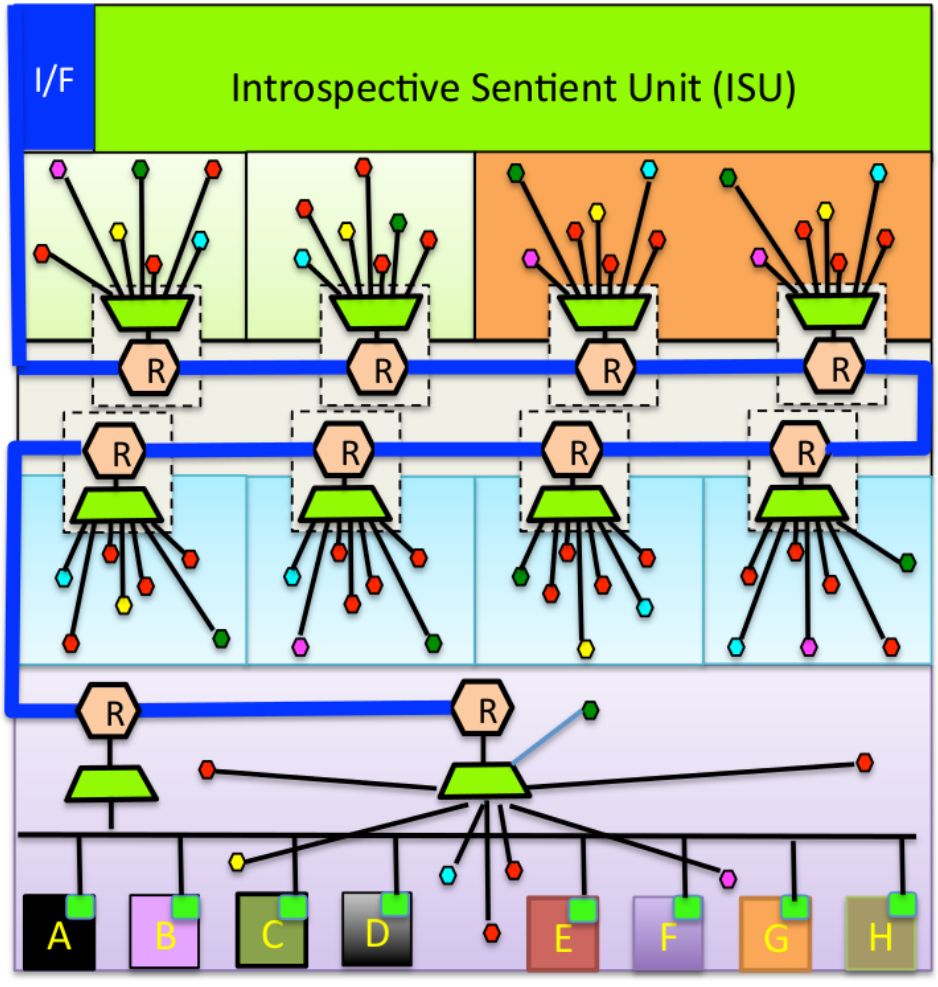

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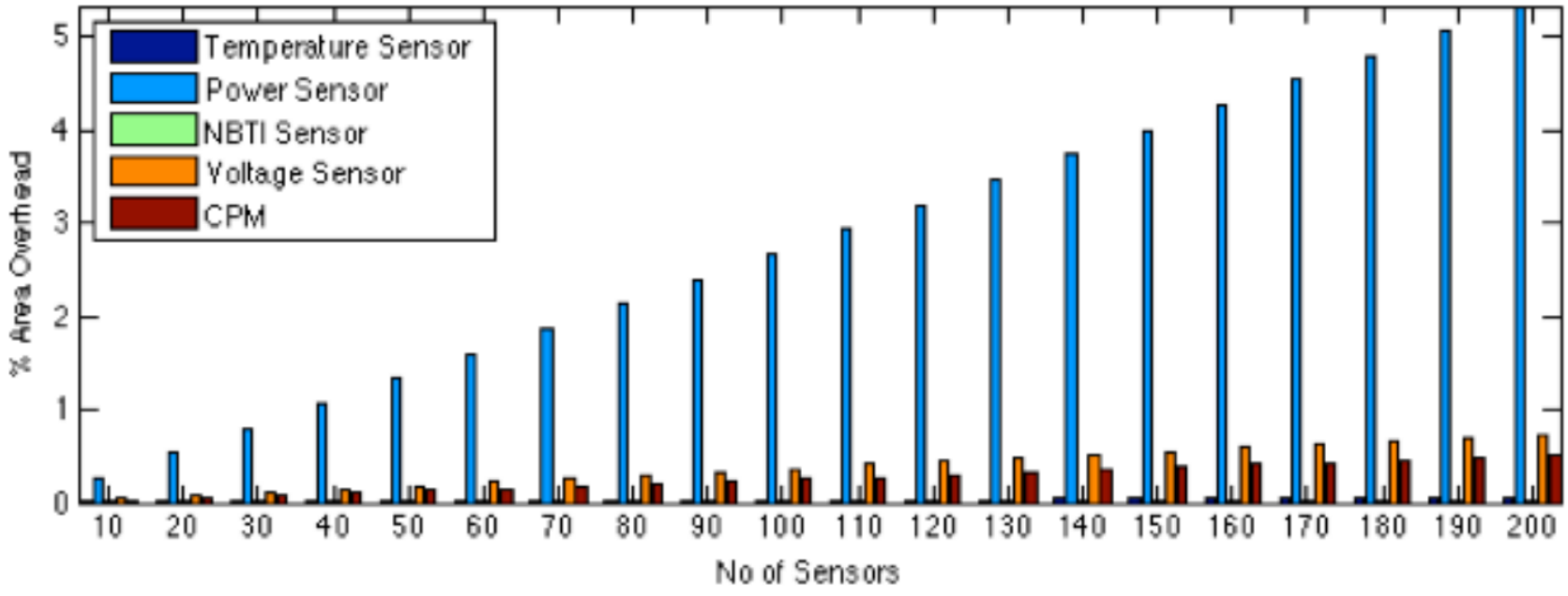
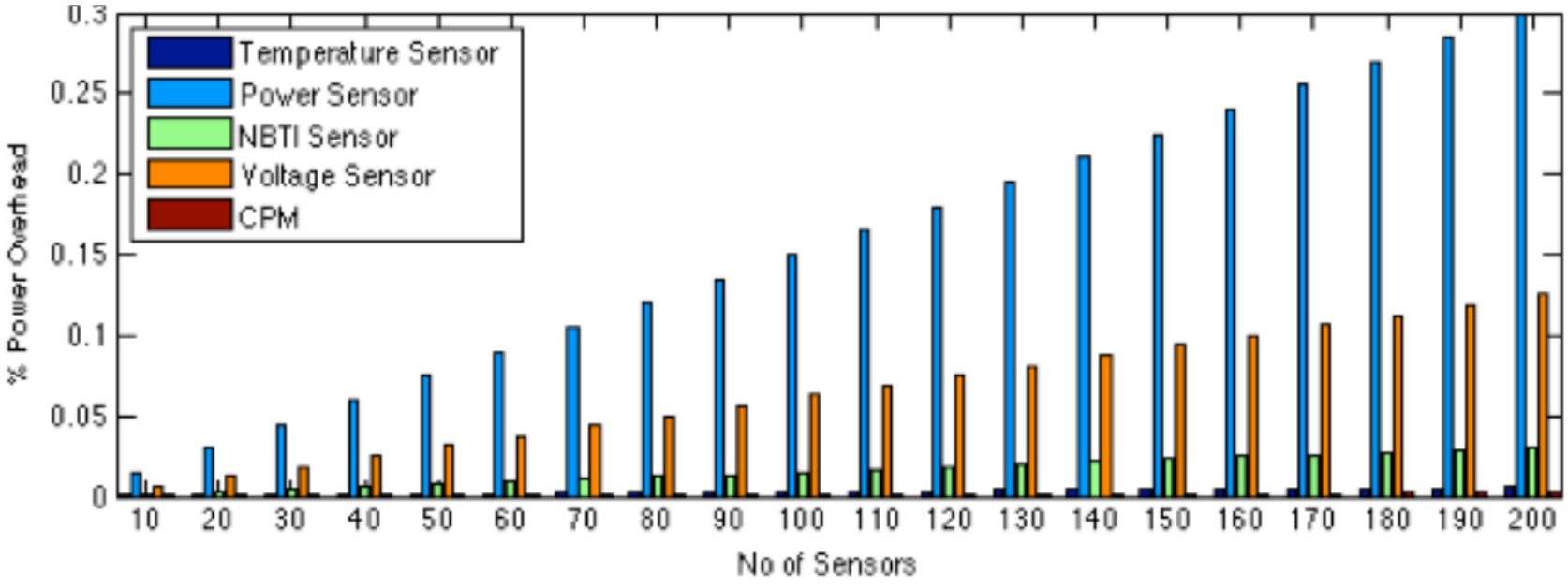


Virtual sensing reduces the area overhead for 1000 sensors from 7.3% to 0.6%.

CPSoC - A Sensor Rich SoC Platform



Virtual sensing reduces the power overhead for 1000 sensors from 1.7% to 0.3%.

CPSoC - A Sensor Rich SoC Platform

VIRTUAL/PHYSICAL SENSING AND ACTUATIONS ACROSS LAYERS

Layers	Virtual/Physical Sensors	Virtual/Physical Actuators
Application	Workload, Power, Energy and Execution Time, Phases	Loop Perforation, Approximation, Algorithmic Choice, Transformations
Operating System	System Utilization and Peripheral States	Task Allocation, Partitioning, Scheduling Migration, Duty Cycling
Network/ Bus Communication	Bandwidth, Packet/Flit Status and Channel Status, Congestion	Adaptive Routing,Dynamic BW Allocation and Ch. no and Direction Control
Hardware Architecture	Cache Misses, Miss Rate, Access Rate, IPC, Throughput, MLP	Cache & Issue-Width Sizing, Reconfiguration Resource Provisioning, Static/Dynamic Redundancy
Circuit/Device	Circuit Delay, Aging, Leakage Temperature, Oxide Breakdown	DVFS, ABB, Voltage Frequncy Island Clock Gating, Power Gating

Summary of Self-Aware Properties

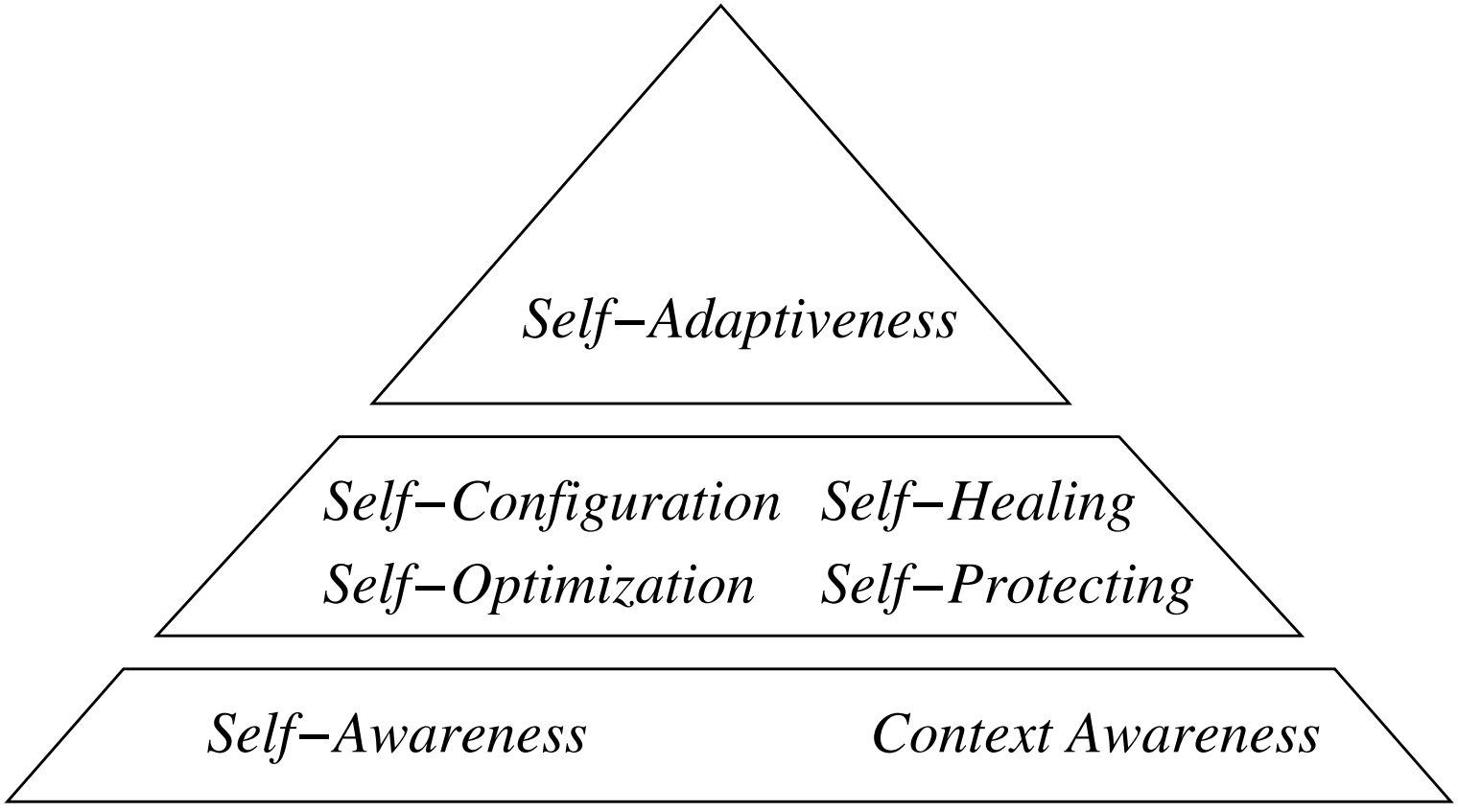
- Awareness and self-awareness are useful properties
  - Context dependent functionality
  - Context dependent performance
  - Appropriate behavior in all situations
- Necessary features:
  - Data abstraction
  - Disambiguation
  - Desirability mapping
  - History maintenance
  - Expectations and goals
  - Self-inspection
  - Prediction and simulation

Challenges:

- Application specific selection and tuning of features
- Online learning and adaptation
- Efficient implementation

Beyond Self-Awareness

We are not there yet ...



... but when we are, the rest is easy.