A co-designed hardware/software architecture for augmented materials

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Overview

- The Concept of Augmented Materials
- The motivation for this Concept
- Design space and issues
- The hardware and software components
- The architecture for augmented materials
- Programming materials
- Future Directions.

Creating Augmented Materials

Vision

To Create Ambient Intelligence or Pervasive Computing Systems.

Driver

User Requirements for Lower Cognitive Loading, Contextually Effective Interaction, Trust and Security, Increased Performance

Need

To Ensure Novel Technologies Evolve Effectively, Integrating to Become Universally Supportive and Unobtrusive

New Techniques for Embedding Proactive Systems into Everyday Artefacts.

Specific Challenges

Can We Create Self-aware Materials?

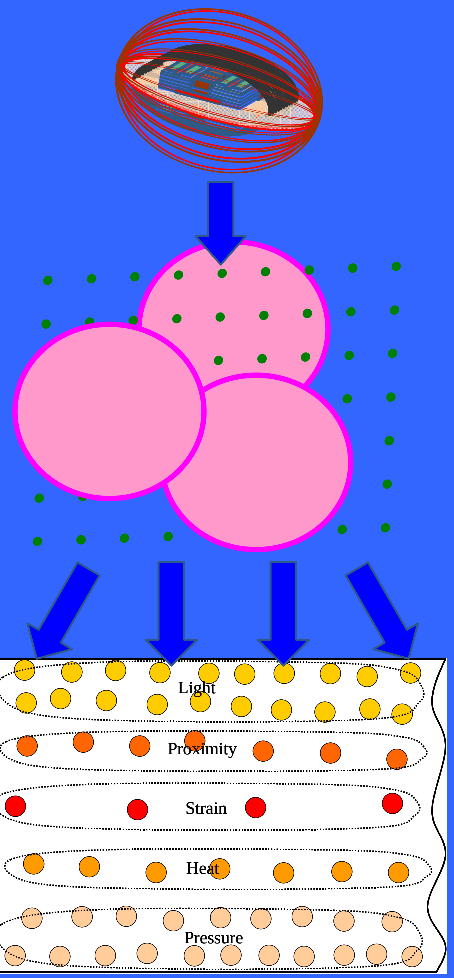
Can We Create a Programme-by-Manufacture Technique (A Materials Programming Language)?

New Vision

Deploy Autonomous Sensors (< $5mm^3$ modules)

Enable Scaled Distributed Systems Research

Embed I-Seeds Systems into Materials



Origins of Augmented Materials Research

AWS

Ambient Intelligence: A Driver for Augmented Technologies

Proactive interfaces supported by Ubiquitous computing & networking.

*"**Ubiquitous Computing** is the opposite of virtual reality. Where virtual reality puts people inside a computer-generated world, ubiquitous computing forces the computer to live out here in the world with people."* - **Mark Weiser**

…everyday objects and places become ‘infused’ and ‘augmented’…

…artefacts with new and emerging properties

…computers disappear into the background..

the disappearing COMPUTER

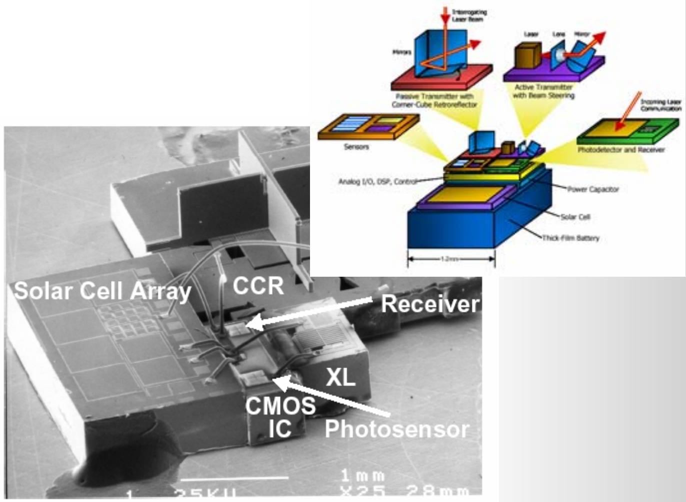
and augmented places, appear...

…to enrich everyday life simply and naturally...

Related work

One of the most relevant research activities on autonomous systems worldwide is the ”smart dust” project at the University of Berkeley

To develop a system of wireless sensor modules where each unit is the size of a mote of dust



- Communication within ad hoc networks has been the subject of vigorous research within the wireless sensor community
  - *Localisation using infrastructurally-positioned beacons*
  - *Also recent work in self localisation of a group of nodes with sparse knowledge of their initial positions.*
- Software for pervasive systems:
  - *Conventionally-structured desktop- and room-oriented approaches (Context Toolkit)*
  - *Amorphous computing (largely conceptual, but provides good pointers to environments for augmented materials)*

OBJECTIVE:

To explore how everyday life can be supported and enhanced through the use of collections of interacting artefacts.

These artefacts will form new people-friendly environments in which the computer-as-we-know-it has no role.

The initiative has three inter-linked objectives:

[1] Develop new methods for the embedding computation in everyday objects.

[2] Research on how new functionality can emerge from interacting artefacts.

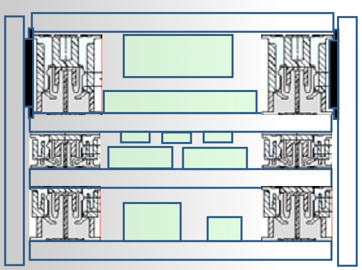
[3] Ensure people's experience is coherent and engaging in space and time.

eGadgets

- Dynamic Connectivity
- User Programming-by-Example

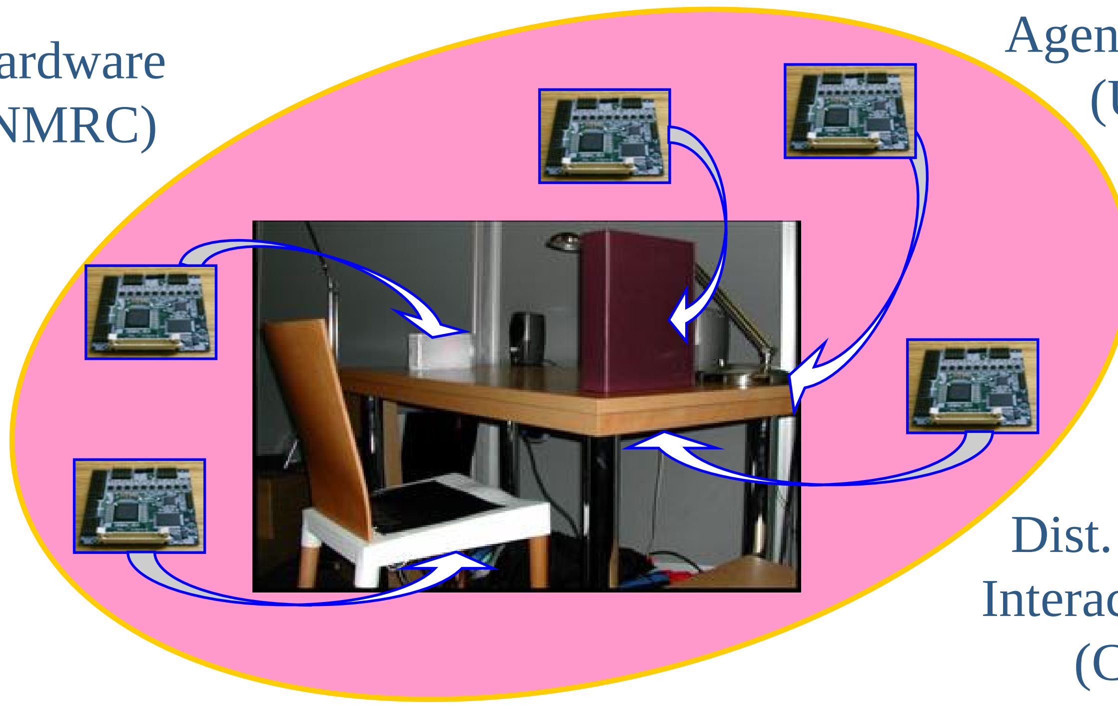
"Top-to-Bottom Slice of an Open Function Ambient System"

Distributed Micromodule Platform



Building Block Format

Hardware (NMRC)



Agent Intelligence (U. Essex)

Dist. Software & Interactive Design (CTI, Greece)

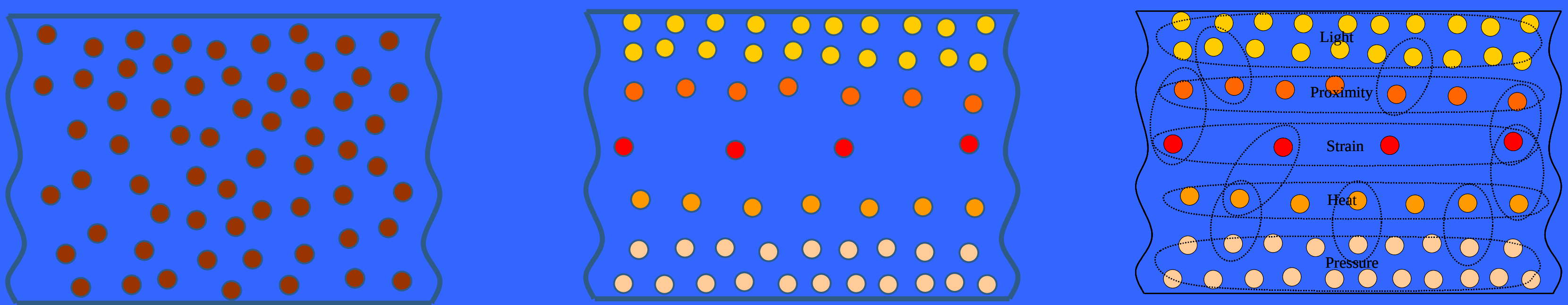
First Demonstration in October 2002

the disappearing COMPUTER

Description of Augmented Materials

Creating an Augmented Material

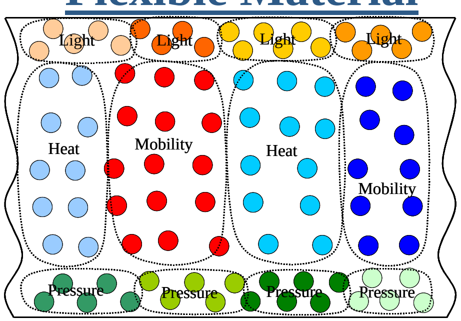
Augmenting Matter → Create "Cognisant Materials"



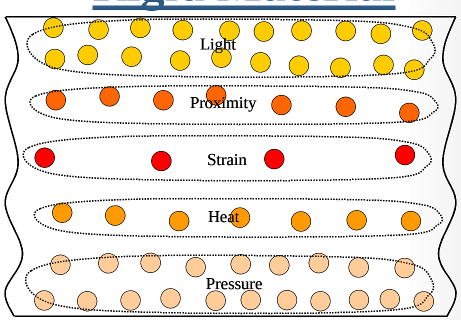
Node Deployment → Self Organisation → Distributed Control

…everyday objects and places become 'infused' and 'augmented'…

Flexible Material



Rigid Material



System Tailored to Material Behaviour

Description of Augmented Materials

- Making a material self-aware involved two stages (at least):

First stage:

- *Curing, the elements establish a “baseline” view of their configuration.*

The Second stage:

- *Lifetime, the elements update this representation over the material’s lifetime.*

Need Co-designed architecture:

- Hardware (material, sensing, processing, Communication)
- Software (knowledge, reasoning, task)

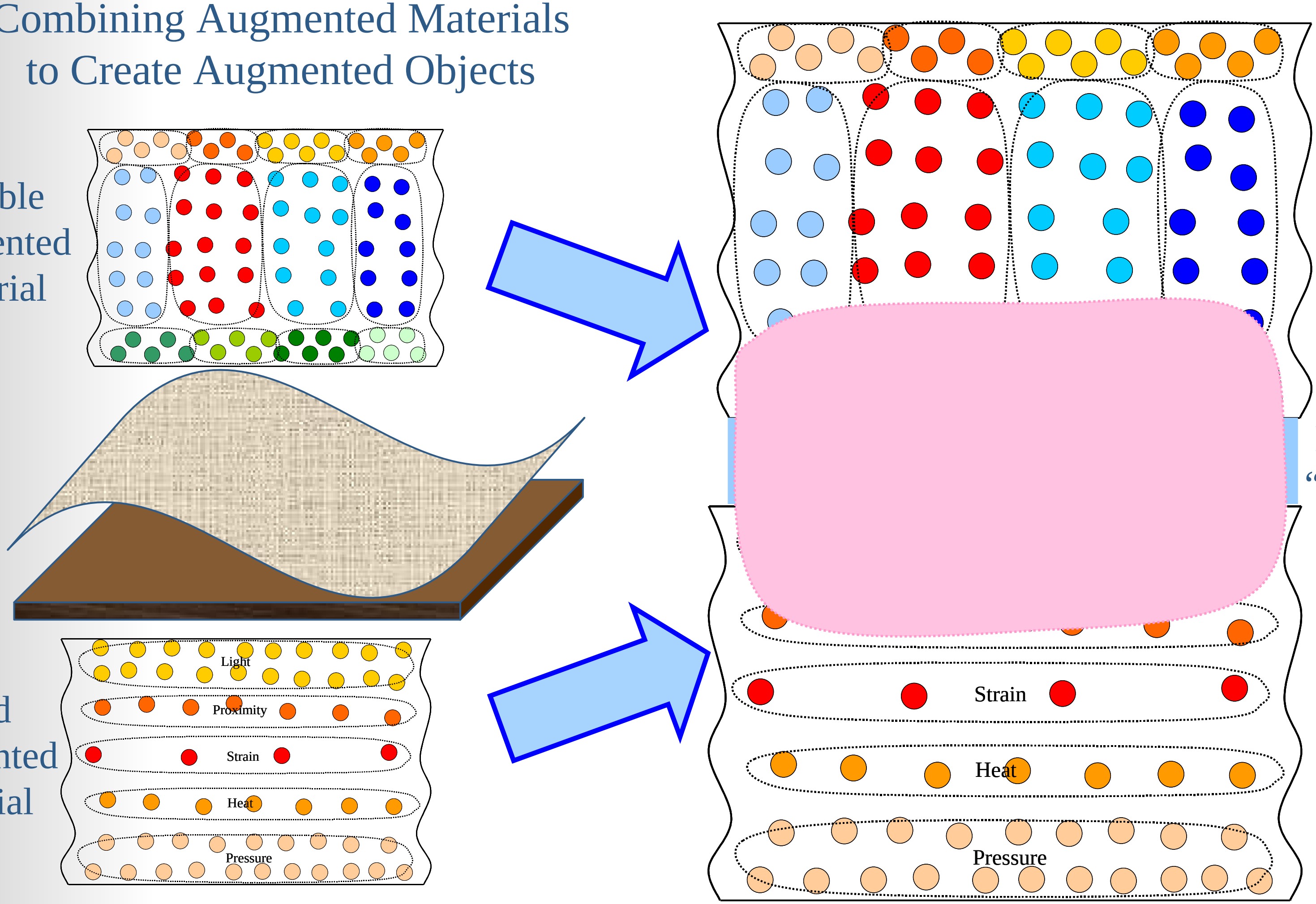
Description of Augmented Materials

From Augmented Materials to Augmented Artefacts

Combining Augmented Materials
to Create Augmented Objects

Flexible
Augmented
Material

Rigid
Augmented
Material



Material
Bonding and
“Networking”

Description of Augmented Materials

Constructing an artefact using augmented materials

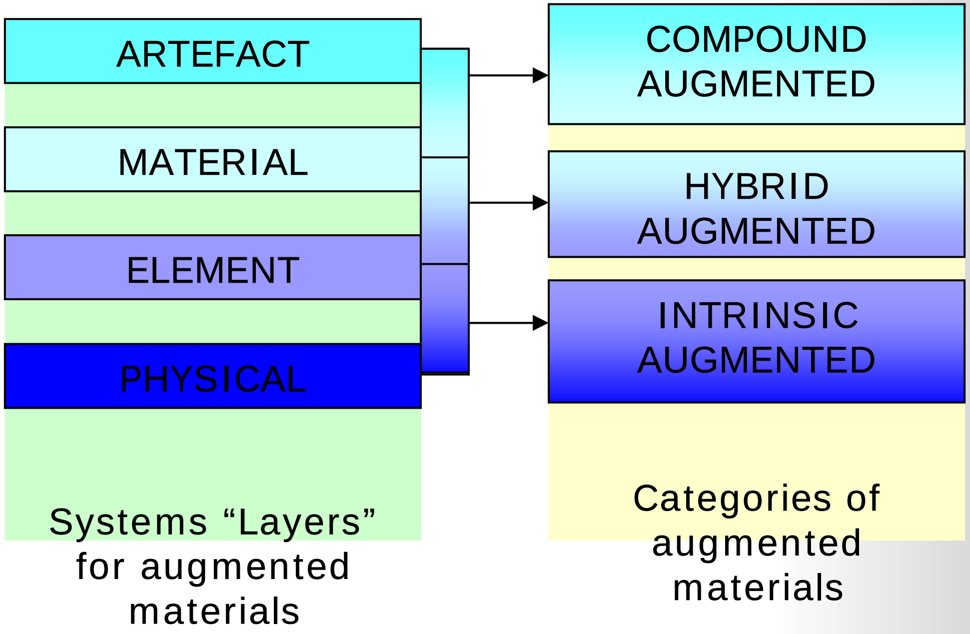
There are Four distinct levels:

Physical level, properties such as stiffness, ductility, conductivity and so forth, which condition through sensors the “physical” applications for which it can be used.

Element level, independent components capable of local sensing, local processing and communications with nearby elements.

Material level, where elements co-ordinate to present a global behaviour, typically integrating the local sensing, or physical, information into a global view of the material.

Artefact level, where the material can “understand” its function and relationships with other augmented materials in its vicinity.



Sensing and processing

WIRELESS TRANSMISSION

Design of Ultra-Low Power Transceivers

System-on-Chip, Design Optimisation & Validation

SYSTEM INTEGRATION

Infinite Lifetime Wireless Nodes

Node Design, Node-building, Miniaturisation

EMBEDDED NETWORKING

Algorithms & Protocols for Autonomic Wireless Systems

APPLICATIONS

Deployment Regimes, Successful Systems, Proactive Exploitation Mechanisms

ENERGY PROCESSING

Build a “Top-to-Bottom” Philosophy for Embedded Systems

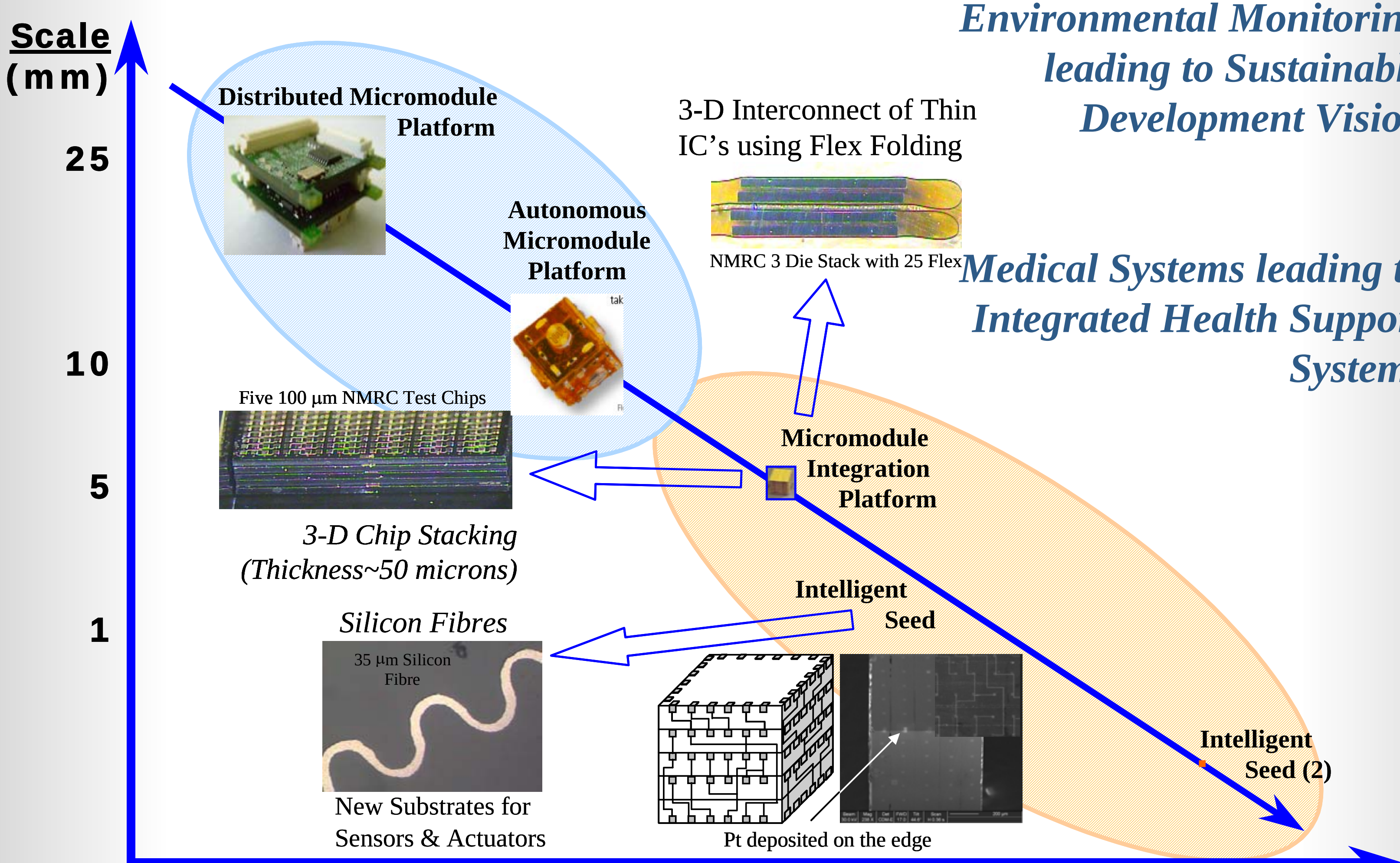
Systems Design for Infinite Lifetime
Energy Generation / Energy Storage / Energy Management

Sensing and processing

Specify Applications Drivers

Environmental Monitoring leading to Sustainable Development Vision

Medical Systems leading to Integrated Health Support Systems

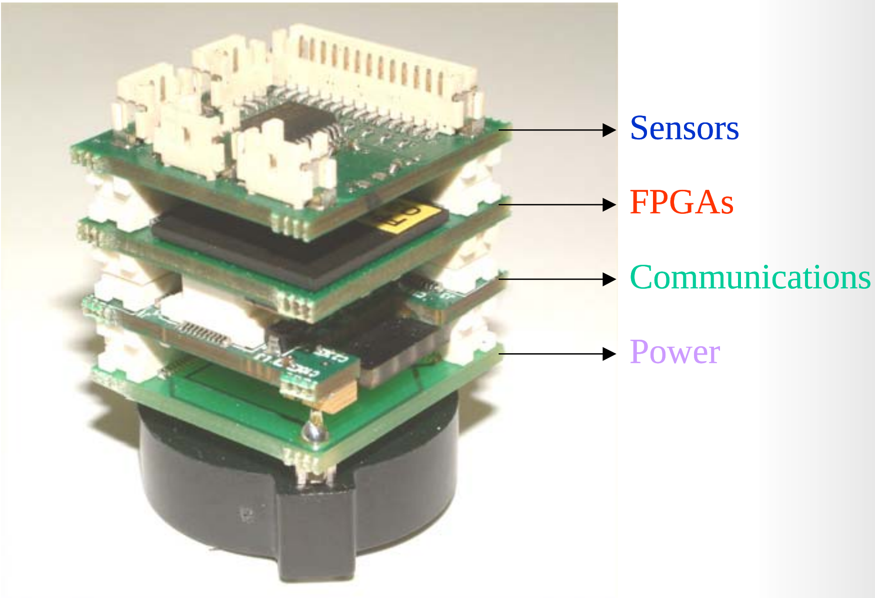


Sensing and processing

25mm Stackable Modular System – Core Module

- **FPGA layer**
  - Xilinx Spartan IIE XC2S300E FPGA
- **Sensor and RS232 Serial Port Interface Layer**
  - Interface to the FPGA Module
  - Capacity for seven resistive sensors
  - Two A to D Converters
- **Coin Cell Power Layer**
  - Interfaces to a range of Coin cells
  - Single or double cell options
- **Additional Sensor layers when required**

- **Microcontroller/Transceiver Layer**
  - ATmega128L High-performance, Low-power AVR® 8-bit Microcontroller
  - Nrf2401 Single chip 2.4GHz Transceiver
  - New Zigbee Layer in Characterisation
  - 433/868/915MHz layer in development



Programmability

Individual elements present a diverse set of possibilities.

Each element shares a common core, but the population of sensors, actuators and other devices **can vary widely**.

Open-ended behaviour: so augmented materials are not amenable to direct programming solutions of the kind normally found in embedded systems

Thus, we adopt a less familiar (but more powerful) approach based around **rich, scalable, self-organising context models and inference**.

Our overall goal is to integrate **programming into the process of manufacturing the augmented materials**, and to capture clearly the relationship between the factors affecting the material and its behavior

Programming: Elements

- The structure of the H/W module is mirrored in the software
  - *Modules must be “reflective”*
  - *Must know their sensing/capabilities from the outset*
- Elements/Modules are constrained by power & size
  - RDF used to represent context
  - Structure: (subject, predicate, object) triples
  - Sensing Strain: predicates for strain (N), vector (m)
  - Captures a binary relationship (subject & object)
  - Collections can be read as a concept graph
- Advantages:
  - *Generates a Common Framework to represent/query sensor data*
  - *The same information can be sensed by different sensors*
  - *Raises the abstraction level (away from H/W) into the knowledge plane*

Programming: Materials

- An augmented material might include several hundred sensor and processing elements
- Thus, we need to program materials as a whole.
- We assume that applications are primarily concerned with reacting to the physical environment of the material and its physical and informational properties.
- There is a close correspondence between the material and the elements within it
- The location of an element within the substrate will be a significant factor in interpreting its information.
- Given a located element, its sensor observations can be related directly to the environment and/or operation of the augmented material.

Programming: Materials

Options

- A single master element to maintain a global view of the material
- Nodes would exchange their local states with all other nodes via a gossiping protocol

- Best Option is a hybrid approach: Elements are divided into two categories – sensing elements and aggregating elements – which are then evenly distributed through the substrate.

The two classes gossip, but in different ways:

- Sensor elements gossip with nearby aggregating elements by sending changes in their local states, which may then be aggregated to provide a summary of the state of the local area

- Aggregate elements gossip with other aggregate elements, but exchange management information about which aggregate is summarizing what locale

Internal versus external semantics

Low-level sensor data can be managed largely automatically
• Closely to the physical realization of the material

Inferred information is handled using rules provided by the programmer:
• A truth-maintenance framework
• Changes in lower-level information propagate to higher-level views

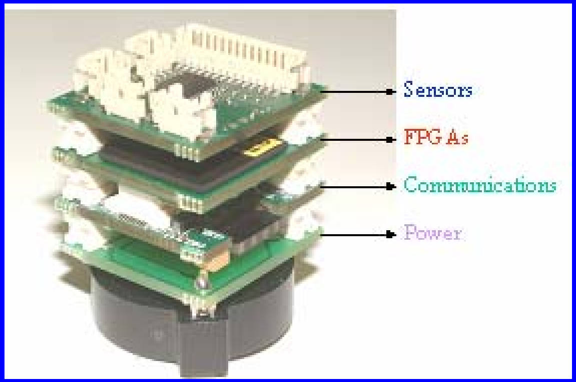
However, it is important to realise the way in which sense data – the "internal semantics" of the material – relates to the higher-level, "external" semantics of pervasive computing.

A particular type of augmented material (for example a rigid plastic) can be used to form any number of classes of objects
• A material must know what it is externally as well as knowing its internal structure.

The external semantics: provided by describing the interaction rules by which the material should interact with other materials to which it is connected.

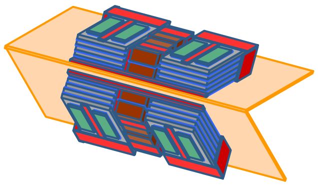
Hardware Activities: Miniaturisation

Miniaturisation of Distributed Wireless Sensor Nodes



Requirement:

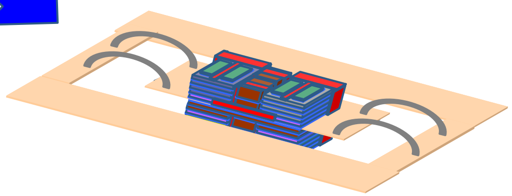
Create Solutions for Interconnect & Assembly



Chip Stacking (Thickness~50 microns)

Flex Folding thickness (3~5 microns per layer)

Three Dimensional Interconnect of Thin ICs using Flex Folding



Assembly of I-Seed Substrates and Components

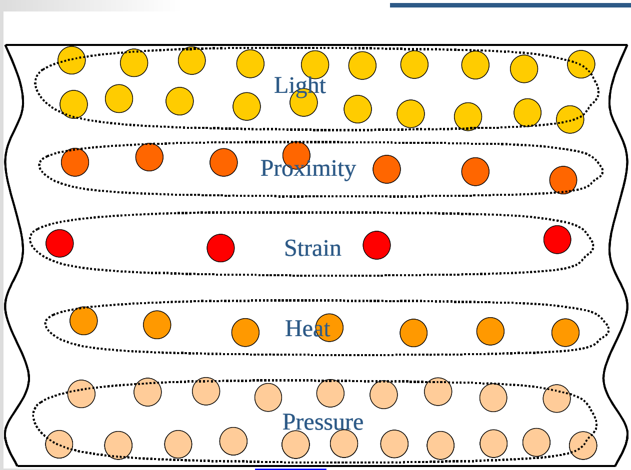
Targets

Miniaturise Functional Sensor Nodes (< 5mm cubes)

Integrate Distributed Communications Capability & Power into these Nodes

Software & Networking Activities: Embedded Network Design

Embed Sensor Networks into Materials



Challenge
Material Augmentation

Requirements
- *System Self Organisation*
- *Effective Deployment Processes*
- *Novel Form Factor for Deployment*

Challenge
Artefacts with new and emerging properties

Requirements
- *Material-to-Material "Plugging"*
- *Object Construction Tools*
- *Dynamic Connection of Objects*

Challenge
Develop Autonomous Behaviour

Requirements
- *In-line Diagnostics*
- *Accurate Reference to World*
- *Cross-layer Power Optimisation*

Conclusions

We have presented:

- The Concept of Augmented Materials
- A general approach to creating augmented materials with embedded sensing and processing elements

Future Issues:

- What are the hardware considerations in terms of location, communication, sensing and power involved in building a co-operative network of sensor elements?
- What is the appropriate programming model for applications on such a constrained platform?

A heterogeneous collection of low-power elements, coordinated by a hierarchical context model programmed in a highly declarative, whole-material style.