Chapter 3

SCALING AMBIENT INTELLIGENCE

Compositional Devices

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Keywords: Ambient intelligence, interaction design, robotics, active tools, configurable environments.

1. Ambient Intelligence: the contribution of different disciplines

Ambient Intelligence represents a vision of the future where people are surrounded by electronic artifacts and environments, sensitive and responsive. Ambient intelligence technologies are expected to combine concepts of ubiquitous computing and intelligent systems putting humans in the centre of technological developments. This represents a long-term objective for European research bringing together researchers across multiple disciplines like computer science, electronics and mechanical engineering, design, architecture, social sciences, software engineering. Key concepts of ambient intelligence are:

- Ubiquitous Computing: that is wired, wireless and ad-hoc networking that exploit highly portable or else numerous, very-low-cost computing devices [17]; discovery mechanisms, software architectures, system integration and prototyping, portable devices;
- Context Awareness: sensors, tracking and positioning, smart devices, wearable, models of context of use, software architectures for multi platform interfaces;
- Intelligence: learning algorithms, user profiling, personalisation and adaptivity, autonomous intelligence, agent based user interfaces; and

- Natural user-system interaction: ambient interfaces, multimodal interaction, innovative interaction styles and concepts.
- Appreciation of the social interactions of objects in environments, and the cultural values the new environments contribute to determine.

At a general level, the interest for Ambient Systems is driven by both technology, design and user orientation. Such systems should allow to achieve interoperability of devices and integration of new services through available tools; and to orchestrate devices and entities to support and enhance human activities. To achieve this, systems have to be so designed as to support a range of human activities, and be intimately inter-twined with physical settings, consisting of spaces, places and everyday objects and materials.

These physical settings and devices share some important characteristics: ubiquity, transparency, intelligence, furthermore they can be personalized, they are adaptive and anticipatory. Ubiquity refers to a situation in which we are surrounded by a multitude of interconnected embedded systems. Transparency indicates that the surrounding systems are invisible and moved into the background of our surroundings. Intelligence refers to the fact that the digital surroundings exhibit some form of adaptation, e.g. by recognizing the people that live/interact in these surroundings in order to adapt themselves to them, learn from their behavior, and possibly show emotion.

Furthermore, as said above devices for ambient intelligence should be personalisable, adaptive and anticipatory, characteristics that may receive a fundamental contribution from modern artificial intelligence.

Adaptation can be defined simply as the act of changing to fit different conditions. The investigation and understanding of adaptation does not only lead to the possibility of creating adaptive devices, but may also be the corner-stone for creating devices that can be personalised. If devices are to be personalised, they should be able to change to the individual users need, i.e. they should adapt since they should change to fit different conditions (to fit different users, in this case). Also the anticipatory characteristic of ambient intelligence devices may demand adaptation, since anticipation demands the ability of a system to internally extrapolate future interactions with the surrounding environment, and hence adapt in an internal system. The extrapolation can be viewed as an adaptation process (a change in the internal system to fit the future condition). In this light, we view modern artificial intelligence as a most valuable field for supporting ambient intelligence.

But modern artificial intelligence, or more precisely embodied artificial intelligence, may also play an even more crucial role in the creation of ambient intelligence. Again, looking at the characteristics of ambient intelligence, we find that devices should be built into our natural surroundings and we should be able to interact with these devices in a natural way. This suggests that devices must have natural qualities like physicality and sensibility. Embodied artificial intelligence puts emphasis on the physical reality in the creation of intelligence, and suggests that intelligence cannot be abstracted away from the physical body and interaction with the physical, surrounding environment. Embodied artificial intelligence research, e.g. [20] [7], tells us that when creating physical entities with adaptive characteristics it is often advantageous to try to find the right balance between control, hardware, material, and energy use, and that this balance may be found through a bottom-up approach. The bottom-up approach is characterised by initially creating a minimal system with a basic behaviour, and step-by-step add components (in terms of electronic hardware, control, material, energy consumption) only as they become necessary for new, more advanced behaviours built on top of each other. We believe that embodied artificial intelligence research is one of the disciplines that may provide some answers on how to create ambient intelligence in different domains. In the development of ambient intelligence, we may also find inspiration from the development and research in tangible interfaces, since also within this field, research is focused on the development of seamless interaction with physical information processing systems. Tangible interfaces [11] may represent a valid opportunity for the development of novel interactive technologies that can overcome the limitation of the current computer-based technologies constrained to screen, mouse and keyboard interaction. Several research groups developed haptic and tangible interfaces, and today, the many approaches to tangible interfaces differ in implementation and focus, while, at the same time, sharing certain main characteristics. Using various technical means, physical objects are coupled with digital representations. Any change in the physical arrangement is recognized and interpreted as a controlling action for the digital counterpart. This is in particular the feature that characterizes most of the existing prototypes of tangible interfaces. These physical objects are mainly interfaces either to a digital counterpart (e.g. navigational systems) or to a physical target system (e.g. use of tangible devices as a control systems of other physical or digital worlds). An example of the first category are the navigational blocks [2] that provide visitors of a virtual museum with a direct manipulation experience using physical blocks to navigate a data space. This interface uses the visitor's actions in the physical world to control a computational environment, in this case a database of historical information. An example of the second category is the Tangible Computation Bricks [22], physical building blocks augmented with embedded micro-processors that implement a programming language for scientific exploration. In McNerney's implementation, building blocks can only stack in one dimension, and they allow only for sequential control. Whereas this may be suitable in some cases, in other cases a more general approach allowing two or three dimensional construction and parallel control may be suitable (see I-BLOCKS control (arithmetic, behaviours, neural networks) description and the emotional construction scenario below).

These two examples, as most of the currently available prototypes of tangible interfaces, share the characteristic to specify a computation that is performed by a target system. In a sense the tangible interface is still separated by any produced output either in the physical or in the virtual world.

In this chapter, we describe a specific kind of new devices for ambient intelligence. We call these devices I-BLOCKS (Intelligent Blocks), means for exploring the design of a concept of flexible, adaptive and physical components to build intelligent artifacts and environments. With the I-BLOCKS technology, we try to take a step ahead with respect to other existing implementations of building blocks, developing building devices able to simultaneously perform computations and to act as output devices of the intended functionality. They are not control systems but both input and output devices that are constructed by the users. Therefore our objective is to develop a concept of seamless interface to manipulate physical objects (the building blocks and the constructions obtained assembling them), to build conceptual structures (the meaning associated to each block, e.g. a math block, word block), and to compose actions (combination of output blocks like motors, LEDs, loudspeakers). Manipulating I-BLOCKS do not only mean constructing physical or conceptual structures but composing actions for building complex behaviours.

2. I-BLOCKS technology

I-BLOCKS technology consists of 'intelligent' building blocks that can be manipulated to create both physical functional and conceptual structures [5], [6]. From a technological point of view, the I-BLOCKS support our more philosophical claim that both body (physical structure) and brain (functional structure) play a crucial role in intelligence. The body and the brain of natural existences are co-evolved to fit to each other and the surrounding environment. Similarly, the 'body' and 'brain' of artificial, physical entities should be co-evolved to support embodied intelligence. The focus on building both physical and functional structures with the I-BLOCKS also lead to the possibility of investigating the concept of 'programming by building' [5], in which programming of a specific behaviour simply consists of building physical structures known to express that specific behaviour.

To allow everyday users to develop functionality of artefacts, it is important to make the process of functionality creation accessible. We believe that for everyday users it is difficult and unintuitive to split the process of artifact development into two processes of physical creation (e.g. physical construction of a robot or a mobile phone interface) and functional creation (e.g. programming of the robot or the mobile phone). Especially, we aim to avoid that everyday users are required to be able to program the pre-built physical structures in a traditional programming language. The programming in a traditional programming language demands the everyday user to learn both syntax and semantics, an approach that would exclude most people from using our technology. If we want to achieve ambient intelligence with integration of technology into our environment, so that people can freely and interactively utilize it, we need to find another approach. Therefore, we suggest moving away from programming the artefacts with traditional programming languages, and instead provide methods that allow people to 'program by building' without the need for any a priori knowledge about programming languages. Indeed, we even suggest to completely removing the traditional host computer (e.g. a PC) from the creative process.

The I-BLOCKS tool that supports investigation of this innovative way of manipulating conceptual structures consists of a number of 'intelligent' building blocks (I-BLOCKS) that each contain processing and communication capabilities. Each I-BLOCK has a physical expression (e.g. a cube or a sphere). When attaching more I-BLOCKS together, a user may create a physical structure of I-BLOCKS that process and communicate with each other, depending on how the I-BLOCKS are physically connected to each other. Interaction with the surrounding environment happens through I-BLOCKS that obtain sensory input or produces actuation output. So the overall behaviour of an 'intelligent artefact' created by the user with the I-BLOCKS depends on the physical shape of the creation, the processing in the I-BLOCKS, and the interaction between the creation and the surrounding environment (e.g. the user themselves).

Our first implementation of I-BLOCKS uses an electronic circuit containing a PIC16F876 40-pin 8 bit CMOS Flash microcontroller for processing, and provides four 2-ways serial connections in each I-BLOCK for communication (see Figure 3.1). In order to better visualise the concept, we have chosen to make the housing out of rectangular LEGO DUPLO bricks [1]. So in this case, each building block contains the four serial two-way connections as two connections on the top and two connections on the bottom of each brick. In other implementations, there may be more or less connections, for instance there may be six connections (one on each side) in a cubic building block, or another number in a spherical building block.

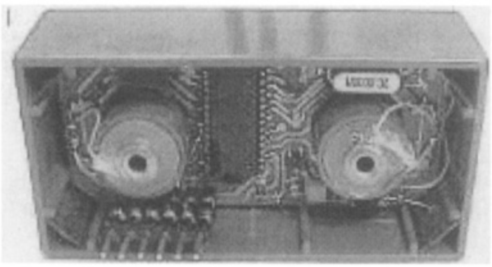

Figure 3.1. A building block with microprocessor and communication channels. ©H.H.Lund, 2002.

Energy power from a battery building block is transported through the construction of I-BLOCKS via connectors in the corners on the bottom on each block and connectors in the studs on top of each block.

There exist different types of I-BLOCKS that all share the same standard technology of providing processing and communication capabilities. We term these standard building blocks. In a number of cases, the standard building blocks are extended with the addition of sensors in order to become input building blocks, and in a number of cases extended with the addition of actuation in order to become output building blocks. Sensor building blocks include building blocks with LDR sensors, IR sensors, microphones, switches, potentiometer,

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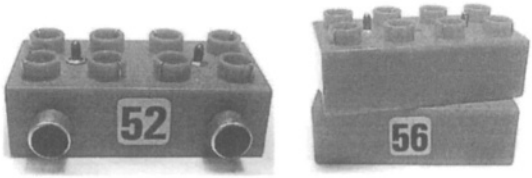


Figure 3.2. Examples of intelligent building blocks implemented in LEGO DUPLO. In this implementation, there are two connectors on the top and two on the bottom of each neural building block. On each stud, there is connection for power transfer. Left: example of sensor building block that contains two microphones. Right: example of motor building block that contains a servo motor that allows the top element to turn. ©H. H. Lund, 2002.

flex sensors, accelerometer, and output building blocks include building blocks with servo motor, DC motor, IR emitter, LEDs, sound generator, etc. (see examples in Figure 3.2). Some blocks may also combine input and output such as I-BLOCKS with ultrasound emitter and receiver, and I-BLOCKS with radio emitter and receiver.

In order to verify the technological possibilities of the I-BLOCKS, e.g. versatility of control methods, we implemented different kinds of processing in the I-BLOCKS, making the I-BLOCKS becoming arithmetic blocks [5], behaviour blocks [5], neural blocks [6], spiking neural blocks [13], language blocks [8], and emotional blocks [19]. In most of these cases, the specific control implementation was driven by a wish to investigate the I-BLOCKS in a pre-defined activity for the users, e.g. as defined by teachers, therapists, engineers, etc. However, it seems apparent that one of the strengths in the I-BLOCKS system lies in the possibility for the user to be creative and expressive, so a second strand of control implementations has focused on developing I-BLOCKS control that supports free activities that are not pre-defined by the designer. Both kinds of implementations have their own pros and cons, and can be utilised in different kinds of scenarios, as will be described below.

3. Design process

In general, we believe that effective ambient intelligent solutions should offer the opportunity to the users of meaningful, engaging and intellectually interesting activities. They should definitely address specific objectives that can support users to perform potentially new activities in an effective and stimulating way. To achieve such objective, we articulated the design process on four components: User Research, Concept Development, Content Development, Enabling Technology.

User Research In envisaging scenarios of use of our I-BLOCKS, we first of all investigated how these tools mediate construction of meaning and organization of knowledge. The description of how these artefacts may interact with other physical and cultural artefacts already present in the environment is seen as equally important. This phase of work included rich ethnographic observation of users at work with the I-BLOCKS, e.g. children in learning and play contexts, and participatory design sessions with stakeholders to define requirements, discuss potentialities on the technology and evaluate solutions.

Concept Development In order to create "an experience" it is necessary to develop a system that supports the creation and management of behaviours, meaning and senses. Our I-BLOCKS are designed to support the manipulation not only of physical and functional components but also conceptual and sensorial contents. Furthermore, in order to create "one collective experience" we studied elements of cooperation, rules of composition, language, memory, interpretation and representation. Parts of these elements are still open points and research topics but a challenging aspect of studying the manipulation of I-BLOCKS is the definition of a new concept of manipulation of actions allowed by the I-BLOCKS rather than simply manipulation of objects and use of their functionality.

Content Development We developed different kits of I-BLOCKS (see the scenarios described in the following later) representing the physical and conceptual structures that the users can manipulate in their activity. The arithmetic I-BLOCKS described below are examples of contents that can be implemented in the I-BLOCKS, other examples are linguistic components like elements of a sentence to compose. An open research question is at which level the I-BLOCKS should be pre-programmed and at which granularity and how much space is left for children to create their own contents.

Enabling Technology The I-BLOCK technology is continuously adapted and evolved according to the requirements of the specific applications. As a general aim, it supports the manipulation of physical, function and conceptual structures.

4. Scaling Ambient Intelligence at level of compositional devices: predefined activities

So far, we applied this design process to the development of different scenarios. In most cases, the activity would become pre-defined for the end-user, e.g. working with specific arithmetic problems, language grammar problems, etc. Though the problem domains are pre-defined in these cases, and therefore we term these pre-defined activities, it should be noted that the construction within this problem domain is free for the exploration by the end-user. But in all cases, there will be an output from the I-BLOCKS construction that provides a feedback to the end-user on the suitability of the construction within the particular, pre-defined activity domain. Hence, in the active construction process, the end-user is provided with feedback from the I-BLOCKS construction that may provide guidance within the particular problem domain.

4.1 Arithmetic training

A simple example of such a pre-defined problem domain activity is the arithmetic training with arithmetic building blocks. The arithmetic building blocks are quite illustrative, since they clearly show the role of the morphology of the construction in defining the functionality. The arithmetic blocks include blocks for addition, subtraction, multiplication and division, sensor input blocks for setting input values, and output blocks to present output values. As an example let us look at the task of calculation of the results of arithmetic expressions, and here specifically the task to present a result for the following expression:

$$(x + y) * z \tag{3.1}$$

where x, y and z are either standard sensory inputs or user set inputs (the user can set input values with sensor building blocks by pressing a switch or turning a potentiometer). The task has been solved correctly for a solution that presents the right result with regards to every possible input. This system with arithmetic blocks solves this task quite easily as shown in Figure 3.3, because this system is built for arithmetic operation. The correct result will only be presented on the display (the block on the lower left corner) for as long as the sub-results and the final result do not exceed the a value of 255, which is the maximum value possible for the value data type, and for communication in general.

The built structure can be seen in Figure 3.3, where the binary display block on the lower left corner shows the result of adding two user set values (on the top) and then multiplying it with the user set value (on the right side on top of the multiplication block).

This example is illustrative for the role of morphology in determining the functionality of the creation. If the morphology is changed, then the functionality (output) is changed accordingly. Imagine exchanging the two standard building blocks that perform the two arithmetic operations of multiplication and addition. By doing so, the functionality would no longer be. $(x+y)*z$, but rather $(x*y)+z$. Or if the substructure of two blocks performing $*z$ is moved one level upwards in the structure, then the resulting overall structure will have the functionality of $x + (y * z)$. So it is evident that even small changes of the morphology result in changes in the overall functionality of the artefact. Imagine that the user has set the input values to $x = 3, y = 7$, and $z = 15$, then the result (output) of the original creation would be (3 + 7) $*$ 15 = 150, but (3 $*$ 7) + 15 = 36 with the second morphology, and 3 + (7 $*$ 15) = 108 with the third morphology.

In the example, the user is 'programming by building', i.e. the user is constructing different arithmetic expressions by building different physical structures and the structures each produce an output according to the particular physical shape. There is no traditional programming going on, but the user is simply manipulating with the physical construction in order to create an appropriate functionality. In this way, we obtain a much more natural user - system interaction than in the traditional case of first constructing a hardware artefact and then programming the artefact in a programming language such as assembler, Fortran, C, C++, Java or similar. Obtaining such a more natural interaction

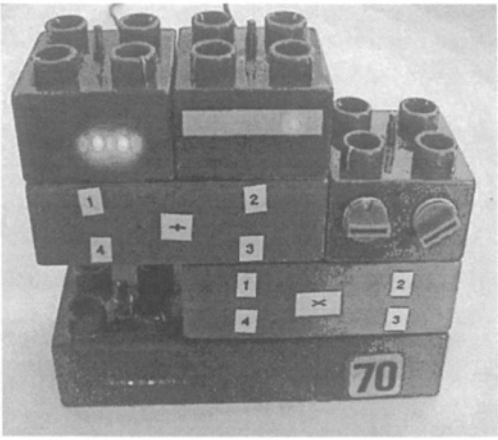


Figure 3.3. AA construction with arithmetic I-BLOCKS that performs an arithmetic calculation: $(x + y) * z$. The user can set the value of the small blocks on the top (x and y) and on the right side (z). The result is displayed as binary number with LEDs on the lower left block. ©H. H. Lund, 2002.

is crucial for ambient intelligence, since ambient intelligence demands not only an intuitive use, but also the availability to all everyday users.

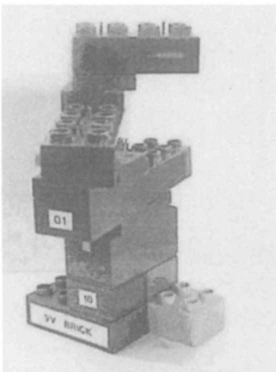
4.2 Storytelling Play Scenario

We applied the design process, described in section 3, to the development of a storytelling play scenario, based on work performed in collaboration with Scuola elementare Tozzi (Siena, Italy), Scuola elementare Marliana (Pistoia, Italy), Scuola elementare Traversagna (Pistoia, Italy). The objectives of this scenario, called also the "living tree scenarios", concern the potentiality of I-BLOCKS to support creative processes in developing narratives and in externalising emotions associated to "living entities" developed by children. The living tree is an installation placed in a park that can be configured by the users. Trees can grow up and change according to weather conditions and seasons; they can simulate the movements of sunflowers, following the sun and to be reactive to temperature and wind. The user can personalize the tree through the trees memory: the possibility to put sounds or words into the blocks. The main idea becomes to have an installation, in a public open space, where children can improve their creativity making/constructing their own "toys", using the I-BLOCKS. We want to create a sort of collaborative space where children can negotiate their abilities of constructing stories around the *living tree* attributing emotional states to the structure. The emotional state of the single tree is being represented by an expression/behaviour of the construction (e.g. flashing lights for meaning happiness).

In order to investigate this possibility, we made a first mock-up using the LEGO DUPLO implementation of I-BLOCKS. The tree is able to react to the environment, in which it is situated, and the behaviour of the tree is decided by wind, temperature and light conditions. The specific behaviour of each parameter is:

- Wind: the tree moves randomly according to wind.
- Temperature: the tree changes colour according to temperature.
- Light: the tree moves its light sensors towards the light source.

So the living tree mock-up was implemented using push-button brick (for modelling wind pressure), turn-button brick (for modelling temperature changes), LED-brick (for modelling changing of colour), LDR-brick (for allowing movement towards light), top-turned motor brick (for movement), battery brick (for power supply). The user can build different constructions (trees), and the behaviour of the tree will depend on the physical construction and the interaction with the tree. A representative example is shown on Figure 3.4. The scenarios



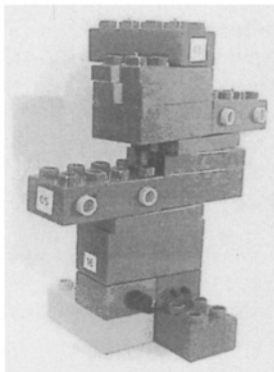


Figure 3.4. A mock-up example of the living tree made from the small I-BLOCKS, front view and back view. The construction will turn towards light, change LED activation, and make random moves, depending on the interaction with the surrounding environment.

shows a number of different qualities of I-BLOCKS, in particular their ability to sustain meaning construction, development of emotional knowledge and the opportunity to define an alternative semiotic system for expressing emotions.

Meaning construction In the vast majority of current software and educational games for young children plotlines and characters are already provided and there may be little, if any, scope for them to use their imagination for example, to decide who the characters should be or what they should look like or do. This suggests, therefore, that there is a big difference between how children play in their everyday life where they like to build stories and characters [3], and what they are able to do with the kinds of technological playing currently supported by computer-based technology.

Our aim with the use of I-BLOCKS is to bring children into a creative process both at level of the construction of physical characters of the story and at the level of the behaviour and emotional attitude these characters can exhibit in the story. Given the above, a number of research challenges arise:

- How can we harness the power of technology to sustain an imaginative, improvisational process of meaning construction?
- What kinds of interactivities and external representations to implement in the I-BLOCKS to support the child in constructing their plays? For example, how much of the behaviour, emotions and other attributes of constructed characters should the user decide and how much should be pre-determined through the implementation of basic behaviour of the I-BLOCKS?

Emotional knowledge Bringing the I-BLOCKS constructions to life is not just a challenge from the point of view of technology. Since we are envisioning the possibility to build highly interactive and engaging characters, these have to be realized as individual personalities with their own desires, emotions and behaviours. This implies for children the development of cognitive abilities to make a plan to build and represent personality and emotions through the combination of I-BLOCKS. To study this, we conducted a series of pilot experiments where children were asked to draw and to build characters (living trees) using different materials (cardboard, plasticine, coloured papers etc) with emotional states (like a happy tree for example, see Figure 3.5). At the end of the task the

Figure 3.5. Pilot test where Italian children are drawing and building characters.

children were asked to describe what they realised and why they believed the character had a particular emotional state. These preliminary experiments had the objective to collect information about the different emotional states the children were able to recognise and the elements they judged *important* to represent an emotional state. These elements were later used to implement functionality of single I-BLOCKS.

Furthermore, to study how children can represent personality and emotions we reviewed the scientific literature on emotions in the childhood, in particular the 'Five Factor Model of Personality' [21] and 'The Cognitive Structure of Emotions' Model [1]. Based on evidence suggesting that some emotions are universal [18], we focused our analysis on anger, fear, happiness and sadness. These emotions can be interpreted easily by children of age 4-8 [12]. However, in our implementation these emotions do not directly map single I-BLOCKS but can be "constructed" combing I-BLOCKS behaviours obtaining changes in movement and lights that children use to mean emotional states (fear, happiness, etc). The life-likeness of a character is increased by the I-BLOCK technology that allows the construction to react to external events (e.g. temperature, touch, sound). Therefore, emotions are not pre-computed but directly manipulated by children through the physical construction of I-BLOCKS.

Semiotic system A further challenging topic of our research is the definition of a high-level language or semiotic system for defining the characters' behaviour and personality traits through the combination of I-BLOCKS. Our aim is to build up a basic kit of I-BLOCKS with a repertoire of behaviours that the children can manipulate to enable the definition of different behavioural styles and personalities.

The use of I-BLOCKS kit contributes to experiment on the above mentioned issues as described in [9].

4.3 Linguistic scenario

The linguistic scenario was defined in collaboration with the Cognitive Rehabilitation Centre, Ospedale Le Scotte (Siena, Italy). In the linguistic scenario we transfer to the I-BLOCKS a well-known task used by speech therapists in the rehabilitation of children with linguistic problems,, in order to give more feedback and more sensorial information to child. Our hypothesis is to test whether external representations, in the form of dynamic I-BLOCK constructions, would assist children in learning linguistic structures in a more effective way than with the combination of static iconic pictures like the ones currently used by speech therapists. The speech therapist indeed tries to teach to children with language problem the right structure of a sentence. During ethnographic observation sessions and interviews with therapists, we realised that the manipulation of objects is a very important feature in order to reach language skills. Every task has the form of a game, in which the speech therapist helps the child, giving scaffolding to the task.

Children with dyslexia, i.e. a difficulty in the scholastic learning, or with a SLI, i.e. Specific Language Impairment, can have problems to understand the structure of a sentence, and the speech therapist tries to help using lots of instruments. One of a task that the speech therapist purveys is to construct a sentence with special cards. These cards have different shapes: (1) Small and tall green rectangle for article, (2) Rectangle with an icon on for noun, (3) Red arrow for verb, and (4) Small square for preposition.

At the beginning all the sentences have the structure: Subject + Verb + Object, then it can be possible to add prepositions, adjectives, adverbs, and so on. In this task child manipulates directly the cards, and every card represents a well specified part of the phrase. The feedback, obviously, comes from the speech therapist. However, with the I-BLOCKS, we developed a system where the child is manipulating the structure of sentences when manipulating with the physical structure of I-BLOCKS, and at the same time receive feedback from the I-BLOCKS construction. In the first mock-up implementation, we have decided to preserve the characteristic of article (the small dimension), and to give different colours for different roles in the sentence: (1) Red small brick for article, (2) Green brick for noun, (3) Yellow display brick for verb.

So a sentence construction could take the form shown in Figure 3.6. The I-BLOCKS can now give feedback and sensorial information to the child based upon the physical structure that the child has created.

Following the Distributed Cognition approach [4], our hypothesis in designing I-BLOCKS for the linguistic scenario was that it may be possible to enhance cognition by mapping problem elements (components of a sentence) to an external, manipulative, physical and reacting construction in such a way that solutions become immediately evident and the children can receive feedback on their action of combining I-BLOCKS. [15] propose a theoretical framework in which internal representations and external representations form a "distributed representational space" that represents the abstract structures and properties of the task in "abstract task space" (p. 90). They developed this framework to support rigorous and formal analysis of distributed cognitive tasks and to assist their investigations of "representational effects [in which] different isomorphic representations of a common formal structure can cause dramatically different cognitive behaviours" (p. 88). "External representation are defined as the knowledge of the structure in the environment, as physical symbols, objects, or dimensions (e.g., written symbols, beads of abacuses, dimensions of a graph, etc.), and as external rules, constraints, or relations embedded in physical configurations (e.g., spatial relations of written digits, visual and spatial layout of diagrams, physical constraints in abacuses, etc.)" [14] p. 180).

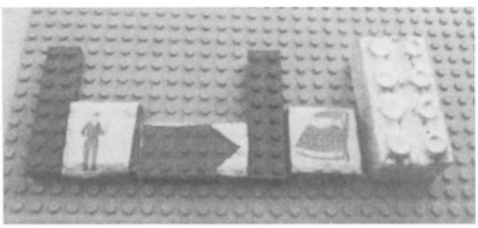


Figure 3.6. Possible construction with the I-BLOCKS mock-up for the linguistic task.

Experiments with children with dyslexia have been performed to study if the "representational determinism" of I-BLOCKS can effectively sustain linguistic learning. Preliminary results performed at the Ospedale Le Scotte were encouraging and revealed a number of interesting properties of the bricks [10]:

- The interactive bricks sustained trial-and-error activity. The children were stimulated to seek different configurations of bricks and rapidly check the results.
- Children were in control of the experimental setting. They could check themselves the results of the activity without the support of the therapist.
- Children were much more involved in the activity. The same task performed with cards resulted boring and in some cases frustrating.
- Children were encouraged to reflect on the structure of the sentence in case of error.

5. Scaling Ambient Intelligence at level of compositional devices: free activities

As said before, a second strand of scenarios was focused on implementing I-BLOCKS tools that provide possibilities for the end-users to define their own problem domain, rather than to work with a specific, pre-defined problem domain as were the case with I-BLOCKS for arithmetic training, cognitive rehabilitation, and storytelling activities.

The rationale for developing this kind of I-BLOCKS is partly triggered by the investigation of I-BLOCKS use amongst users from different cultures (e.g. Denmark, Italy, Finland, Tanzania), where we find that under some circumstances the activities will, quite naturally, have to be individualised to the particular culture. For instance, it seemed appropriate during our explorative use of I-BLOCKS in Africa (see e.g. [8]) to allow the users to develop artefacts with a purpose closer to the everyday observations found in the daily life in their own culture than simply imposing building artefacts known from a Western culture. Similarly, differences in activities are quite obvious between children and adult, between school and hospital, etc.

The investigation of I-BLOCKS for free activities is targeted towards the development of a set of building blocks that can function as a set of atoms, which can be combined together in a large number of combinations to provide the opportunity to create the largest variety of applications. Hence, for this purpose we view the individual I-BLOCKS as atoms, and they are each developed to provide opportunities in expanding the number of possible end applications in the combination with other I-BLOCKS. In order to make the initial set of such I-BLOCKS for free activities, the authors together with J. Nielsen, L. Giusti, and K. Lundberg used the observations from the experiments with I-BLOCKS for pre-defined activities described above to develop a number of example uses that may hold a variety of application possibilities and demand a large degree of versatility from the I-BLOCKS implementation. For instance, these included a kid's room, in which we could imagine a variety of I-BLOCKS artefacts such as an alarm clock, a light controller, an intruder alert system, a thermostat, and play tools such as a versatile music instrument or a compass that could be used both inside and outside the room. The kids' room scenario was used to guide the development of the first I-BLOCKS implementation for free activities, since it provided a scenario that demanded the development of I-BLOCKS, which can be combined in a large variety of ways to construct the many different artefacts needed in the kid's room. Later, the suitability and versatility of these I-BLOCKS for free activities were verified with users in Tanzania, who used these I-BLOCKS to construct artefacts of their own invention (e.g. in their scenario of a car alarm with radio communication to a mobile phone).

The I-BLOCKS that we developed included sensor I-BLOCKS such as tilt sensor (with accelerometer), microphones, flex sensor, and actuator I-BLOCKS such as LEDs, sound generator, motor (for vibration) I-BLOCKS. Also, standard I-BLOCKS were implemented to become:

- **Inverter block**: Inverts its input, so that its output will be negative, when the input is positive and vice versa.

- **Threshold block**: Sums its inputs and compares it with its user-determined threshold. The physical block has a push button to set the threshold level, and 8 LEDs to show the threshold level.

- **Timer block**: The timer block is implemented in a LCD display block, and sends out values between 127 and 255. The timer starts at 127 and counts up to 255 one-by-one when the start button is pressed. The timer does either count up every second or minute, dependent on what the user has set it to.

- **Memory block**: Records its input for a maximum 10secs, when the record button is pressed and stores it in the block's EEPROM afterwards. The data can then be played back.

- **Warm/cold block**: small blocks that are red or blue, and which sends a high or low value on the output channels.

Also, together with T. D. Ngo, we developed radio communication I-BLOCKS that can be used together with this set of I-BLOCKS for the free activities. Each radio communication I-BLOCK contains both radio emitter and receiver. With this set of I-BLOCKS, we found in explorative studies with university students in Siena (Italy) and Iringa (Tanzania) that they were able to develop a large variety of simple artefacts such as alarms dependent on user set thresholds and light input, alarms dependent on a timer, musical instruments, etc. Also, students were able to develop more complex groups of interacting artefacts, such as an alarm dependent on proximity and touch, which with the radio communication would send alarms to another artefact that would vibrate or emit different sounds - in a scenario modelling a car alarm, which sends its alarm to a mobile phone - see Figure 3.7.

Figure 3.7. The development of two communicating artefacts with the I-BLOCKS for free activities. When the user interacts with the I-BLOCKS artefact on the top through approaching it or touching it, the artefact sends a message through radio communication to the I-BLOCKS artefact on the bottom that will respond with different motor actions or sound patterns.

6. Scaling Ambient Intelligence at the level of configurable environments: future scenarios

The use of intelligent building blocks as ambient intelligence systems is not restricted to the small scale as exemplified above with the I-BLOCKS. Indeed, the modular aspect of building blocks may also provide interesting ambient intelligence possibilities in other scenarios, e.g. on a larger scale or for self-reconfiguration. We are currently making the first investigations of such expansions of the concept to different scales and uses in an academic-industrial research project on augmenting playgrounds with intelligent processing and responses to user interaction, and in an EU FET project on the development of self-reconfigurable and self-repairing robots. We briefly describe these possible future expansions in relation to the intelligent building blocks concept.

6.1 The Augmented Playground

We investigate the utilisation of building blocks on a large scale with an implementation of *tangible tiles* developed for a playground scenario with the aim to increase physical activity amongst the youth. The Western countries experience increasing problems related to obesity, and often the response from the society becomes new politics related to diet information campaigns or health care. However, a complementary route may be to increase the possibilities for physical activity - for the youth this should not only be limited to sports but to a general attractiveness to further physical activity. Unfortunately, during the latest decades, the spaces for physical play have been limited, most notably in the city space. Most city spaces may be defined as hostile rather than friendly to children's physical play.

We believe that a variety of our ambient intelligence approach presented above may provide new opportunities to increase the possibilities for physical play in the modern city space. In order to investigate this, we work together with the companies Kompan (playground producer) and Danfoss Universe (fun and science park), and the academic partners from Mads Clausen Institute, and the Danish University of Education on the development of tangible tiles as the first technological implementation of a long design plan towards small, distributed units with processing and communication capabilities that can be utilised anywhere in the modern city space for enhancing play opportunities.

The first implementation consists of tangible tiles to be configured on the ground *(2D),* whereas further development is being done in going towards other building block implementations for $2^{1/2}D$ and $3D$ (e.g. smaller objects with radio communication). The tangible tiles adhere to our definition of building blocks in having a physical expression, and being able to process and communicate (through communication, sensing and actuation). For the first implementation of tangible tiles, we moulded a 40cm*40cm rubber pad that children can jump on, see Figure 3.8 and Figure 3.9. Each tile contains an ATMEL AVR 8 micro processor and a communication board. Output is provided with 9 points each with two ultra bright LEDs, a red and a blue LED. Plexiglas rods are moulded into the surface in a 3 by 3 grid. Each rod can be enlightened by blue or red light from the LEDs at the bottom of the tile. A piezoelectric sensor between two aluminium plates is used to sense the children stepping on the title. The signal from the sensor is amplified with a fixed amplifier before being fed to the micro controller. A regulator allows the tile to run on 9V, for instance so that a standard 9V battery can be used in each tile. An additional processor on a serial line is used to control the communication on four lines (and could be expanded to wireless communication in future). Other prototype tiles with additional vibration output were also tested.

The tiles can be put together in different configurations, e.g. $4 * 4$ tiles in a square or $1 * 16$ tiles in a line.

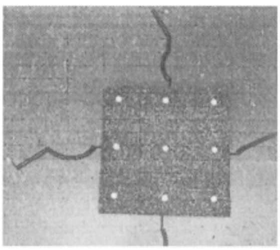


Figure 3.8. A tangible tile as a rubber pad with processing, input (pressure), output (light) and communication on the four communication lines.

With the tangible tiles it becomes easy to implement plays such as Red vs. Blue where the colour of a tile will turn from one colour to the other when jumped upon. Here the overall behaviour of the system will depend on the interaction from the users, who by the interactions with the system decides the overall light patterns. Another simple implementation may be the creation of lines and patterns - each jump on the tile creates a new line using some of the 9 LEDs in the individual tile or on neighbouring tiles by utilising the communication (e.g. a light snake chasing a child or a light tail behind the child).

Figure 3.9. The tangible tiles put in different configurations to create different plays indoor and outdoor.

The basic implementation described above is currently being adapted to sustain different kinds of play with purposes that are not restricted to the stimulation of sensory-motor coordination like in traditional playgrounds. For example, tests are currently underway to study a variety of complementary objectives like the stimulation of senses to successfully accomplish a game (e.g. blindfold children who have to communicate tactile sensations to discover, in a cooperative way, couples of titles with similar properties); spatial orientation, dialogical coordination; production of cognitive strategies to win the game; cooperation through the sharing of space, attention, discovery of rules.

Based on these tests at local schools of children playing with the tangible tiles, it became clear that there may be five areas which contain central aspects in children's approach to play tools, namely (1) performance, (2) engagement; (3) initialisation of play, (4) inspiration for new plays, and (5) play with game play. Interestingly, the possibility to physically reconfigure the tiles provided numerous new play opportunities for the children in allowing them to reconfigure the physical arrangement and thereby the overall behaviour of the system. In a similar way to the manipulation on small scale with the I-BLOCKS, on the larger scale with the tangible tiles the children can construct different functionalities of the system by the physical arrangement of the building blocks (i.e. the tangible tiles). Indeed, by changing the physical arrangement of tiles, the children may, for instance, develop new performances or change level of difficulty in plays with game play. The latter can be illustrated by our implementation of a Pong game. In this game, the light patterns move in a random pattern from one side of tiles to another side, and a child should jump on the tile where the light appear on the end row. If the children place the tiles in four rows, then the light pattern has to traverse four tiles before a child has to jump on a tile, whereas if the children make a physical configuration with only three rows, then the light pattern has to traverse only three tiles in between jumps on the tiles, making the game faster and more difficult. Hence, the physical arrangement of the tiles may define the level of difficulty of the game. Figure 3.10 shows two examples of the Pong game with $2 * 5$ tiles and $2 * 3$ tiles.

In general, as with the I-BLOCKS, the overall behaviour of an 'intelligent artefact' created by the users with the tangible tiles depends on the physical shape of the creation, the processing in the tangible tiles, and the interaction between the creation and the surrounding environment (e.g. the users themselves).

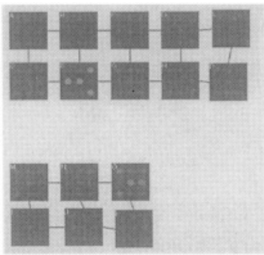


Figure 3.10. Two different physical configurations with the tangible tiles. On the top, the light pattern has to traverse 5 rows of tiles, whereas on the bottom it has to traverse only 3 tiles, making the Pong game more difficult.

6.2 Self-reconfigurable Robots

In the case of I-BLOCKS and Tangible Tiles, the modularity is used to allow end-users (e.g. children) to configure building blocks to construct the overall behaviour of the artefact. However, it is also possible to utilise this concept to create self-assembling robotic artefacts, where it is not the user who reconfigures the system into the appropriate configuration, but it is the system itself that does so. Again, in order to utilise this concept, it is necessary to have building blocks with a physical expression, processing and communication (through neighbourhood communication, sensing, and/or actuation). Notably, for achieving self-reconfiguration, the building blocks need to provide physical displacement in some way.

We are developing building blocks for self-assembly called the ATRON modules (see Figure 3.11). The basic idea behind the ATRON modules is to make have two half cells joint together by a rotation mechanism. On each half cell, there are two female and two actuated male connectors, by which a module can connect to the neighbouring modules. A module may communicate with neighbouring modules through IR communication. The modules can be placed in a surface-centred cubic lattice structure (corresponding to the titanium atoms in the CuTi3 crystal lattice), and move in this structure to self-reconfigure into different overall arrangements or movements. (Further details regarding the ATRON hardware module can be found in [16])

If a first ATRON module is attached to a second neighbouring module and detached on other connection points, the second neighbouring module may move the first ATRON module by turning around equator with the rotation mechanism. Hence, the first ATRON module may be moved to another position in the lattice structure where it may attach itself to another module in the structure and, for instance, detach itself from the second ATRON module that transported it to the new position.

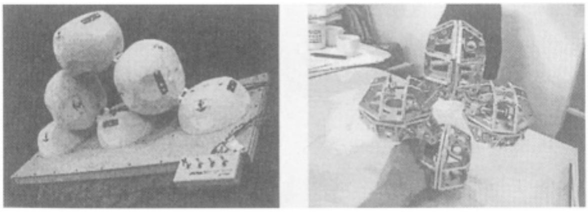


Figure 3.11. The first and the final hardware prototype of the ATRON modules.

As illustrated above, the reconfiguration of the overall system becomes a process of transitions in the lattice structure. Simulations show that, if we can perform the individual transitions in our hardware implementation in a reliable manner, numerous distributed control possibilities exists and will lead to self-reconfigurable and mobile systems. So the ATRON modules aim at providing self-assembly, where the I-BLOCKS and the Tangible Tiles relies on the user to perform the assembly of the building blocks. However, the technological approach is quite similar in that each ATRON module is a building block with physical properties, processing and communication capabilities. So the overall characteristic of the system of ATRON modules is - as with the other building block systems - decided by their physical arrangement, their processing, and their interaction with the environment.

7. Discussion and conclusions

When providing ambient intelligence solutions we believe it to be important to utilize the new ambient intelligence possibilities to provide further creativity possibilities than those that are available with traditional edutainment tools. Ambient intelligence allow people to freely and interactively utilize the new technology that is integrated into our surrounding environment in numerous, small devices. Our goal is to enhance people's creativity by introducing the new kind of I-BLOCKS devices that supports this ambient intelligence vision. Hence, the free and interactive utilization of the new technology should not only allow people to become users, but should allow people to become creators of the new solutions.

Therefore, in this chapter, we have described a new tool and some scenarios in which it can be used in a creative manner by everyday users. The possible scenarios span different scales. We emphasise the development for both predefined activities, which are suitable for meeting some specific education and rehabilitation objectives, and for free activities, which are targeted towards allowing users to define both the scenarios and the creative constructions for these scenarios.

Intentionally, we developed the I-BLOCKS to become small devices with only limited processing within each I-BLOCK, so that the overall behaviour of a construction depends on a distributed processing among the collection of I-BLOCKS in the construction. We are essentially trying to define the atoms or cells or building blocks that allow the best affordances and furthest possibilities for engaging activities. We believe that a centralised approach of providing most processing within one centralised unit (as is the traditional approach in most technological entertainment systems) will limit the creative possibilities, and therefore we are trying to distribute processing to all I-BLOCKS in order to provide an open system, where the user can create new behaviours by assembling many I-BLOCKS into a physical structure.

I-BLOCKS allow rich sensorial interaction where reality can be explored, decomposed, built and analysed. What a child builds can be combined with the products of other children in a continuous negotiation process where the evolution of transformation of the construction can be used as a way to understand the other point's of view.

Although the first implementation of I-BLOCKS provided interesting insights for designing ambient intelligence solutions, yet many improvements are still possible as was evident from the testing currently underway. For instance, our examples of future scenarios show that it may be possible to use a similar concept for work a larger scale for enhancing physical activity, and also to develop self-assembling robots. Likewise, important issues remain that to be addressed. Most of them are at the interaction level, that is at the level for example, where you need to refine the way in which intentions are mapped into action, where actions take on shapes that evoke their meaning and functionality, where the I-BLOCKS react promptly and consistently to the action and intentions, and where the modality and form of the feedback is meaningful for the user.

Acknowledgments

Part of the implementation work was performed by J. Nielsen, S. Jensen, M. Pedersen, K. Lundberg, T. D. Ngo, T. Klitbo, C. Balslev. L. Giusti, V. Palma, A. Rullo, I. Bartolucci, M. Vesisenaho, and E. Suttinen collaborated to the user research and testing with children. They all provided valuable discussions and contributed to the definition of the project vision. The work is partly sponsored by the Danish National Research Council project 'Intelligent Artefacts'. The future scenarios are collaboration work in the IT-Korridor project Body Games with Kompan, Danfoss Universe, Danish University of Education, and Mads

Clausen Institute, and in the EU FET project HYDRA with University of Zurich, University of Edinburgh, and LEGO.

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