It's A Jungle Out There:

Toward Design Heuristics For Ambient Intelligence Ecologies

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A growing acknowledgement within a range of disciplines has arisen concerning the necessity of changing our approach to design of IT. The main reasons for this are the increasing challenges involved in designing and maintaining IT systems that are more pervasive and complex than ever, and a growing need for better and more flexible assistance from an omnipresent technology. This paper argues for a bio-mimetic design heuristic for Ambient Intelligence technology, with a specific focus on organizational and developmental issues provided by an interactivist model. The interactivist view provides a model for better functionality together with optimized infrastructure by describing intelligence as rising from adaptive self-organizing and self-maintaining capabilities. On the basis of the interactivist approach this paper sketches general design heuristics for AmbI and points to future research issues to be dealt with.

Keywords: Ambient Intelligence, bio-mimesis, interactivism, adaptive dynamics and evolutionary design.

1. DYNAMIC IT – AMBIENT INTELLIGENCE

The interweaving of IT with ever more parts of human life presents us with many design and engineering challenges. These challenges relate both to the infrastructural development and organization of an increasingly complex and pervasive technology, and to the need for a powerful but 'calm' functionality. The latter being the reason for the first. Both challenges require a different and better long-term design strategy for IT than has been practiced so far. We are already witnessing the beginning of a new tendency, as e.g. illustrated in IBM's Autonomic Computing project, which is a response to estimations of the vast amounts of working force occupied with maintaining IT within few years if the technology does not get less fragile and inflexible (cf. http://www.research.ibm.com/autonomic/). From the sociological and usability oriented end of the IT research spectrum many point to the fact that IT is becoming an even more fundamental part of a range of social, political and educational practices, by mediating widely emerging networking practices and supporting mobility [14], [18], [19], [22]. However in order to render this human-technology merging desirable and meaningful, both the quality and the nature of IT will have to change. IT has to become much more flexible, adaptive, context-sensitive, allow for non-symbolic interaction, and facilitate much more engaging interaction.

Both lines of arguments relate to the need for a new dynamic IT. Dynamic both in the sense of long term development and an IT that responds dynamically in use. In addition I will argue that not only should the design of IT change, but that we are facing a fundamentally new approach to designing and deploying IT, abandoning the traditional top-down 'creationist' approach and embracing new evolutionary methods.

The best way to achieve both the 'internally' (structurally, developmentally and organizational) and 'externally' (behavior and use) related lines of demands, is to design IT with self-organizational and adaptive capabilities – sometimes referred to as intelligent technology. Combined with a continuously growing tendency to embed IT into all relevant parts of our life I will refer to this new IT as Ambient Intelligence (AmbI). AmbI has many desirable features: Firstly, in opposition to Pervasive or Ubiquitous Computing, AmbI focuses on the functionality – intelligent assistance – and not on the means to obtain it, while still denoting the highly distributed nature of IT. Secondly 'ambient' indicates the right sort of 'non-intruding but present at hand' assistance we want from an optimally functioning technology, captured under the slogan 'If there are to be computers everywhere they'd better get out of the way'. Lastly 'intelligence' not only denotes the behavior but also the intrinsic characteristics of adaptive systems, i.e. their functional development and organization. Thus AmbI captures both of the aforementioned lines of demands for a future dynamic IT.

To develop AmbI we have presently no other option than to look to phenomena showing intelligent characteristics, i.e. natural adaptive complex systems. This paper argues for a bio-mimetic design heuristic for AmbI provided by an interactivist approach with a specific focus on organizational and developmental issues. The strength of the interactivist view is that it provides models for designing AmbI systems combining optimized infrastructure and improved functionality by explaining intelligence as rising from self-organizing adaptive capabilities. To what extent this inspiration will serve merely as a (metaphorical) heuristic for AmbI design or as a basis for straight forward replication of organizational features of natural complex systems will be for the future to tell and determined by pragmatic concerns. However throughout this paper I will take the freedom to apply a range of biological concepts to technology for the sake of coherence and to support creative thinking. I am nevertheless aware of the dangers lurking in getting blinded by metaphors and blurring distinct ontologies (thus single quotation marks indicate that the biological concept used ought to be understood metaphorically).

2. WHY BIO-MIMESIS?

There are a range of reasons why a general bio-inspired tendency is proliferating within different fields of IT-research, besides the fact that biology just seems to be in vogue right now. In opposition to earlier forms of bio-inspired engineering (e.g. bionics) the bio-mimetic I argue for does not aim for specific solutions, but more fundamentally for the processes that lead to problem solution, i.e. adaptive dynamics. An important feature when headed for immensely difficult designing tasks.

Strictly speaking 'bio-mimetic design' is a contradiction in terms, since design denotes a deliberate teleological practice whereas evolution is an inherently contingent *post hoc* ordering process. However bio-mimesis is an effort to strengthen human designing capacities with spontaneous development dynamics found in natural complex systems. The motivation is largely because these processes are faster and often more reliable than human design and not least because they operate real time and can be automatic. Bio-mimetics is a hybrid, or 'meta-governed' approach which combines a traditional design normativity aiming for certain functionalities with the power of bottom up self-organizing capabilities.

A looming issue for future IT design is the development and maintenance of vast complex IT systems. Since nature is the only domain for self-maintaining and adaptive dynamics so far capable of dealing with such problems, it is very instructive to consult models and theories from the sciences concerned with the organization of complex adaptive systems – traditionally biology [15] but also new transdisciplinary fields such as dynamic and complex systems theory.

Homo Sapiens have evolutionarily constrained cognitive capabilities which were never selected to fully overview very complex design task like the ones we are facing with AmbI. Examples of technologies that have turned out differently than expected or which were dictated by mere feasibility instead of need are legion. Acknowledging this in our design ideology and letting go of the idea of a fully top down controlled design process can allow for a much more fruitful alliance with some of nature's benevolent organizational and developmental principles. However trite it is to refer to the 'wisdom of nature', evolution has had a lot of time perfecting adaptive techniques that we might learn from.

Finally, modern theories of complex adaptive systems use the same basic tools to describe the behavior of the individual constituents as well as the overall behavior of complex systems. This capacity is particularly important when dealing with issues of cross technology compatibility and nested complexes of subsystem. Not only does the future design of IT depend on a better understanding of interacting systems at different levels – from device-device to whole networking societies – to provide the proper functionalities, but the systems themselves have to be designed in a way that supports rapidly changing practices, mobile, long-distance and trans-media corporation and other forms of fluctuations. Hence the design of the individual devices and the general organization of technology have to be mutually supportive and constitutive to be productive.

2.1 An aside on computation, materiality and AmbI

In a longer perspective investigations of natural complex systems will have even more fundamental consequences for the design of IT. The bio-mimesis will start encompassing the logical core of computing as well [3]. Bridging the dualistic gap between hardware and software by deploying more structurally constrained forms of computing (e.g. 'lock and key' computing as it takes place chemically or the multidimensional communication in nervous systems) will allow more integrated and dynamic ways of providing technological assistance. Steps towards 'material-computing' will happen in concert with a general development of reconfigurable synthetic materials, and a lot of future IT research will focus on materials instead of just software.

On a second level the materiality of a bio-mimetic design will be important. To carry out an ecological thinking to its full pragmatic value, we will start seeing design of IT with recycling in mind, allowing the very materials of artifacts to become 'fertilization' for new artifacts [20]. Hence consumerism and abundances of devices would no longer be problematic and unethical but be the very fundament of existence for the technology if properly designed.

Until these issues has been explored sufficiently we can still apply some general organizational principles from natural systems using a traditional digital platform. Development of bio-mimetic IT will not happen overnight and the AmbI ecologies sketched in this paper can be implemented digitally which e.g. evolutionary algorithms have successfully manifested.

3. SELF-ORGANIZATION IN COMPLEX SYSTEMS. AN INTERACTIVIST APPROACH

The interactivist approach deployed as the main theoretical framework in this paper is currently being developed to deal with phenomena such as self-organization, autonomy, adaptivity, normativity, functions and cognition as rising from interactive processes in complex systems cf. [4], [5], [6], [7], [8], [9], [10], [11], [12], [13]. Even though interactivism has been developed for other purposes than the aim of this paper it still provides an instructive and rich framework for complex systems in ways that can ultimately lead us to some general design heuristics for AmbI. Allow me to sketch the basic ideas.

The self-maintaining robustness and developmental capabilities inherent in adaptive complex systems stems from the unique way these systems are functionally organized. Organization – or self-organization which is central for this paper – in complex systems cannot be obtained otherwise than from the interactive dynamics of the system constituents themselves, i.e. autonomously. Autonomy does not indicate that a given systems functions independently from its surroundings, only that the norms for interaction are determined from within the system. Self-organization emerges as a consequence of the dynamic interaction among system constituents following value-guided navigation. Values arise internally in adaptive systems when they are thermodynamically open, i.e. as thermodynamically non-equilibrium systems, adaptive systems depend on a controlled input of energy (and information) to maintain their existence (i.e. keeping up the functional organization of the system). This openness creates a normative asymmetry – some things contribute to self-maintenance and others do not.

Values are onboard because what the system navigates by is internal anticipatory cues of possibilities for further self-maintaining interactions which the outcome of the present action provides. Consequences of earlier interactions - success and failure - act as internally constructed normative navigators for subsequent like situations. Thus onboard norms guide the ongoing adaptivity of the individual system and provide plasticity for changes as the system seeks to get the best from the given circumstances. As we shall later see, onboard or autonomous normativity is central for the design of AmbI devices (i.e. both gadgets and applications) since it forms the fundament of self-organization. Besides the need for autonomously created norms constrains the level of imposed design but pays off with flexibility, adaptivity and robust dynamics in AmbI ecologies.

3.1 Adaptive dynamics: development and evolution

Adaptive systems have different means of adapting for the sake of self-maintenance, facilitated by both short- and long term dynamics. In the short term systems adapt via learning capabilities. No system is born with a perfect recipe for survival (in fact there is no recipe at all teleologically speaking, only some ingredients) so they have to be capable of adjusting when actions fail, and remember in which circumstances other actions bear fruit. Learning capabilities are in other words necessary in adaptive systems since the niches they inhabit are never perfectly stable nor are their innate responses flawless.

Learning in adaptive systems starts by detecting internal consequences of some spontaneous reflexes and contingencies. Henceforth the adaptive system rehearses interactive contingencies more systematically and slowly constructs anticipations of the feedback of future actions. Learning is thus a process aimed towards improving the anticipatory capabilities in the system. Anticipations are contextual and implicit in the beginning, but become increasingly generic as the system constructs better anticipative models for managing interaction.

Besides ontogenetic adaptive mechanisms, complex systems can also (as species) improve adaptability more radically by procreative means. In reproduction, combinatorial (sexual) or/and reconfigurable (mutational) possibilities for adaptation arise which allow more radical organizational changes. This is an advantage if, for example, the niche has changed drastically or in order to explore non-crowded space in the fitness-landscape.

Both short and long term adaptivity rests on the same ordering principle, namely variation and selection cycles. This principle is known as 'survival of the fittest' at the species level, but it is also the major driving force behind the trial and error interaction cycles at the ontogenetic level. Variation and selection *is* the internal ordering principle of self-organizing [8]. However since self-organizing systems are mostly components of greater self-organizing systems, selection is often conceived as a strictly external force. However, in addition to environmental sources of selection there are internal sources of selection in the form of infrastructural requirements for the mutual adjustment of parts.

Variation and selection cycles might seem a bit to slow for learning if millennia of evolution is the normal timeframe deployed. The reason why variation and selection actually works at the real time interaction level is that trials are not chaotic but happens within frames of 'creative' but relevant outcomes. Relevant variations are achieved by various 'soft' and 'hard' modulations. Soft modulation can be in the form of 'themes' (engram like traces) of interactional aspects retained from earlier interactions [4]. Themes are patterns of contingencies comprising various dimensions of an interaction. Because themes are (dynamic) aspects and not (static) components they enable innumerous but associated variations of interaction possibilities. An example of 'hard' modularization is the emergence of species, which helps governing variation from getting chaotic and producing critically many lethal mutations.

Means to guide variation while maintaining dynamics is of great importance for AmbI since we cannot tolerate to many random variations of our technology. The success of AmbI is thus intimately related to our application of the right kind of modulation and other kinds of guiding principles.

4. DESIGN OF AMBI: INTERACTIVIST ARCHITECTURAL PRINCIPLES

After the theoretical framework has been sketched let us take a look at some architectural principles for bio-mimetic AmbI.

According to an interactivist design AmbI devices will provide optimized functionality as a consequence of their efforts to adapt to their respective functional domains. Hence users will benefit from better assistance when the internal normative constraints of devices guide them to engage in self-maintaining interaction with constituents of their functional domain in order to obtain maximal positive feedback. The better they fit their functional domain the more positive feedback they will get. Just as in natural ecological niches, AmbI devices will exploit mutually supportive or even symbiotic interactions to meet their individual normative constraints. Devices will thus provide better assistance both individually and collectively by engaging in assistive interaction with users and other constituents of their functional domain (ecologically users are only one specific kind of AmbI constituent) in order to obtain positive feedback.

A tight dynamic coupling between users and other ecological AmbI constituents will emerge both developmentally and evolutionary through recursive variation and selection cycles providing best solutions for the task at hand and for similar tasks ahead. Even though adaptivity is often falsely conceived as systems adjusting to fixed circumstances, adaptation is a matter of several dynamic systems interacting to obtain a better mutual functional coupling and thereby improved self-maintenance. Actually this kind of interactional coupling is what intelligence amounts to in AmbI. As [1] clearly argues, even the highest forms of intelligence rely on ongoing interaction (e.g. semantic feedback) to carry out simple tasks. So despite common sense intelligence is simply not conceivable as an internal or isolated capacity by a system. This will also be true in the case of AmbI where user and devices will mutually form each other in functional couplings. These couplings will be most tight within 'growing' devices where various subroutine candidates compete to provide the functions needed. Couplings will also emerge at the larger evolutionary scale when different types of technologies compete to become the preferred standards and services by meeting consumer needs and wants.

Due to their anticipatory control of interaction, artifacts will be both pro-active and anticipate the likely activities and responses of the user by narrowing variations to dimensions (themes) which have earlier paid of.

Learning effects could also be non-naturally applied at higher levels to secure a faster and guidet evolution of different technologies. This brings us to:

4.1 Architectural focus I: Variation and selection

Evolution of technology does not depend on inheritance in the strict biological sense so selection will have non-biological characteristics for artifacts. However the lines of code or the organizations of neural nets underlying the behavior of most devices will be almost impossible to analyze from this behavior (due to emergent nature of behavior of the device and its functional entanglement with the functional domain) and in some sense our ability to perform deliberate variations on devices will be just as 'blind' as in nature. With the difference however, that we might apply learning mechanisms from the ontogenetic level to the phylogenetic level to achieve a more targeted and less random evolution.

Our meta-governing status allows us to manipulate evolution in another important way. We can supplement natural vertical inheritance with horizontal inheritance to speed up and guide evolution.

Besides inheritance differences the selection pressure in AmbI ecologies will probably be higher than in most natural systems. Even though both user and device will work toward successful coupling the demand for smooth assistance does not allow for front-end malfunctioning that is severe but not immediately lethal. In whatever way the assistance is maintained however is of no importance for the user and may be a merciless combat between sub-services as long as the overall service is provided.

In addition resource-wise recycling and decaying hardware has not yet been developed to render a lot of lethal mutations harmless (other than at non-critical sub-routine levels) or fertile. So in order to avoid a dysfunctional unevenness in assistance bio-mimetic design must facilitate developmental dynamics by variances that are within acceptable frames of deviance. But since mutation forms an indispensable part of adaptive dynamics constructive learning models are of prime importance.

In order to benefit from variation dynamics whilst avoiding catastrophic variations modularization is required. For example temporal modularization such as developmental phases ('preschool' or occasional 'courses' where devices are trained for different tasks) and structural modularization such as species and sex to put constraints on variation in order to minimize lethal or dysfunctional variations. Likewise we would want to recombine only artifacts of the same type, inhabiting similar functional domains. We might even apply 'sexual' differentiation of complementary traits in order to support order while maintaining dynamics.

Understanding and designing appropriate selection processes will be a difficult issue. This is firstly because fitness criteria are difficult to settle in advance since selection happens in relation to a functional domain and the specific ways a given technology will be used is unpredictable. And secondly because we have to find ways of executing selection. The best way to cope with fitness criteria seems to be to impose only a few initiating constraints. We will return to this shortly. As regards the execution of selection we have to design AmbI in a way that allows for both implicit and explicit selection, in contrast to natural selection for which there is no such distinction. Implicit selection happens through the (repeated) use of a given devicevby users or other devices. Just as in the immune system, devices that are deployed get to proliferate. Explicit selection is at least necessary in cases of severe dysfunctionality, low frequency of interaction and for some higher level services but we might also deploy it more generally in tandem with implicit mechanisms. Severe dysfunctionality may require the device to be shut down or disengaged if dangerous (control systems at plants or in cars), damaging (virus like) or just using disproportionate amounts of energy (this would eventually be adjusted in a properly functioning AmbI ecology but we may want to interfere before). Valuable services that are only used occasionally might need an explicit amplification of feedback, enhancement of 'fertility' or an adjustment of life span, so that the device do not go 'extinct' between infrequent interactions. Lastly some higher level services can be too subtle to differentiate using automated selection, so fine tuning may sometimes require explicit control. If explicit selection turns out to be widely necessary we have to design systems that support very easy evaluation in order to avoid tiresome feedback.

Although implicit selection is to be preferred to obtain true evolutionary dynamics and to promote calmness, we have to bare in mind that whereas nature is efficient in most respects in finding solutions evolution it is at the same time 'blind' and not controlled by any overall norms. So in order to maintain the *raison d'être* of technology, i.e. assisting us, we will have to allow for explicit control and only let the dynamics be uncontrolled when in service for our higher level need for better technology.

Variation and selection will happen at many levels and in many forms due to the heterogeneous and nested character of AmbI ecologies. Major assistive services will rely on several, perhaps even swarms of, constituent devices and sub-services competing to provide the functions necessary. Both the 'amplitude' of variations and the 'life span' of devices will be determined by the kind of the device. Major services will have larger life span and undergo relatively minor variations compared to sub-services with shorter life span and greater variation amplitudes.

4.2. Architectural focus II: Adaptation

Artifacts are not thermodynamically non-equilibrium systems. Although they will most likely depend on power to function, they will not structurally disintegrate through lack of energy supply. Moreover the process is reversible so that a 'dead' cell phone can be recharged. Thus normative constraints will not emerge spontaneously but will have to be imposed. Or rather initiated.

Studies in evolutionary robotics (e.g. [16], [21]) have shown great success in evolving neuro-controllers of robots by evolutionary techniques. Over generations robots equipped with very simple fitness functions developed light seeking behavior associated with recharging of their batteries. The robots became able to reach the recharging pit within a couple of time steps from total discharge and learned to depart immediately after recharging because feedback could only be obtained in the 'open field'. Such interesting behaviors were shown to emerge from exposing the robots to incrementally complex environments, rather than from elaborating fitness functions [16]. Experiences from research like this should be applied in AmbI artifacts. However these primarily evolutionary techniques must be complemented with developmental models to obtain dynamic ontogenetic development as well. Since the transition to more dynamic IT will happen stepwise, we will have to start by deploying stable organizational cores and only allow variation and selection to happen in some 'fringe' functionalities. Progressively we can start relying more on the epigenetic development of devices and confine 'interference to the reproductive phase.

A proper learning development should provide artifacts with the ability to 'afford' proper assistive interaction for the user in a Gibsonian sense of 'affordance'. In the terminology of the ecological psychologist J.J. Gibson 'affordance' refers to the interaction possibilities a given feature in the environment offers as perceived from the viewpoint of an organism. Affordances rise from closely coupled interactive cycles where a given feature or set of contingencies becomes interactional invariants for a cognitive system. Much talk within HCI and Usability about 'natural' use as a given and static feature is simply wrong or at best simplifying since use is always determined by affordance and thus highly interactively dynamic. Bio-mimetic AmbI would allow for the ongoing emergence of affordances by coupling user and device dynamically. The result will be often very personal services that has adapted to a given user's idiosyncrasies or perhaps an adaptive user (cf. the plasticity of children) that has come to like a certain device's way of providing a service.

Just as organisms primarily perceive features directly relevant for interactive self-maintenance, artifacts should perceive their environment in terms of features relevant for maintaining their assistive functionality. As a result the anticipatory capabilities of devices will provide users with the relevant functionality in a given context (universe of themes). Users will act as the main element in the functional domain of certain AmbI services which focus on specific users (e.g. PDAs) perfecting a tight adaptivity. Others will inhabit more generic domains and provide more universal services.

Since artifacts will sometime fail to anticipate the users wants, misinterpret the context or in other ways malfunction we have to make sure that the functional domains are crowded, such that many artifacts compete to provide similar functions. Such 'fine-masked' functional domains will provide better and more adequate ongoing assistance. At the same time increased competition rising from 'crowding' in a domain will put adaptive pressure on the inhabitant devices and thereby provide better long-term functionality. The reason being the almost fixed amount of feedback available determined by the number of users (the number of users can increase if some extraordinary service is offered in the domain but the number of users cannot be infinite in a certain domain). Functional domains can get to crowded functionally speaking, but only if maintained artificially. If resources are scarce, i.e. if the domain only harbors limited amounts of feedback, crowded domains will automatically be de-popularized (in number not necessarily in diversity) due to selective processes. Some kind of domain-regulatory means may have to be deployed which controls the amount of feedback available in a given domain in relation to the size and importance of the domain.

Similarly 'deserted' functional domains (i.e. needed but absent functionalities) will quickly become populated since selection pressure will be much lower, i.e. even mediocre performance will pay of better in terms of feedback than above average performance in crowded domains. This increases the likelihood of getting assistance in all contexts relevant.

5. ISSUES FOR FUTURE BIO-MIMETIC AMBI RESEARCH

Embarking on a bio-mimetic design strategy of course drags along many questions, and I do not wish to pretend that implementing bio-mimetic AmbI ecologies will be easy. In this section I will run through some general topics for future bio-mimetic AmbI research to deal with, some of which are empirical and others which are of a more philosophical nature.

A general challenge for a bio-mimetic design strategy is developing techniques to balance the autonomy of the technology with a sense of still being in normative control of the development and in the concrete functionalities. AmbI ecologies, being highly non-linear complex systems, could be perturbed beyond functionality by insensitive attempts to control the development. We may have to become used to using less explicit control. Whilst it is true that we are far from completely in control of current technological development, we still treat total design control as a goal to be achieved. The question of control and constraints is bound to be a controversial topic, both technically and ethically. A design ideology of artifacts generating functions more or less autonomously will disturb a lot of users and should be an issue of great concern. Users should in the end be the winners in all this and not become even more alienated or reluctant.

Another salient issue for an increasingly autonomous technology concerns ways to harmonize the pro-activity of the technology with both a smooth functionality and calmness. Smoother and better assistance is the reason to develop new IT in the first place and calmness is a major concern with proliferating IT. One way to solve this potential conflict may be to design systems that are only autonomous in a collaborative emergent manner, e.g. resembling swarm- and hive-intelligence, and not qua individual autonomous entities. Or perhaps the mere rewarding of calm devices will do the trick all by itself.

A pragmatic concern is methods to overcome possible infrastructural communication and coupling problems emerging from commercial interest from big technology companies trying to gaining markets by patenting protocols, frequencies etc., using hidden source coding or whatever puts them in a favorable or perhaps even monopolized position. Openness is a key concern for a self-organizing AmbI since this technology can only become powerful if interactive possibilities are kept at a maximum. The problem stems from the fact that evolutionary mechanisms for selecting the functionally best standards are not always consistent with contemporary economic market processes where other factors can often weigh more heavily. The history of technology is pregnant with examples of how monopoly, sociologically and psychologically efficient branding, cultural fads or other factors have prevented a seemingly better technology from becoming established. Part of the reason is that technological functionality is not an isolated quality and cannot fully be divided from contextual factors. Some of these problems (e.g. open standards) could be addressed by law, but much of it will have to be dissolved by mutual interest in participating in developing AmbI. Just as we today have more or less global internet protocols and wireless standards, commercial initiatives such as Bluetooth and an increased compatibility between different computer OSs.

6. CONCLUSION

Faced with hitherto unseen challenges in the developing IT due to increasing pervasiveness, complexity and demands for a non-intruding but flexible technology we have to change our whole conception of designing IT. Whilst aware of the differences of technology and biology and great difficulties in carrying out a major change in designing practices this paper proposes a bio-mimetic heuristics for the design of a future dynamic IT.

Claiming that the central challenge is to create genuinely dynamic IT I have argued for the rich perspectives in applying an interactivist bio-mimetic design heuristics for coping with issues concerning the development and organization of AmbI. According to an interactivist view AmbI will be organized as ecologies constituted by numbers of heterogeneous artifacts striving for self-maintenance by interacting with relevant elements in their functional domain. This coupled division of labor provides a highly dynamic technology colonizing most functional domains on the fly thus providing a both robust, flexible and adaptive technology.

We have pointed to core issues for future research to deal with. Especially variation and selection methodologies was emphasized as crucial.

Finally we have touched upon more general challenges and changes accompanying a bio-mimetic approach to IT and we went briefly through some central problems for future research. A general issue will be ways of balancing some level of control (dictated by psychological, ethical and functional concerns) with the inherent autonomy of an intelligent technology.

Since an dynamically adaptive technology will optimize its functionality both phylogenetically (over generations), and ontogenetically (in ongoing use), completely new ways of designing will emerge. We will leave the traditional top-down teleological view and embrace a new dynamic interactivist approach to the design of IT as AmbI. The teleology of traditional design will mainly be preserved only as norms for types of assistance wanted and not the specific devices. Designers will become initiators and moderators providing constraints and adaptive parameters for the developmental process, but not determine the exact nature of the use. Completely in accordance with modern user-determined technological practices as described by sociologists. What we will loose in complete design control, we will gain in functional power. By an adaptive dynamic technology we will get 'design for free' because devices will evolve and develop as a response to successful assistive interactions. AmbI technology will start providing functionalities we didn't even think of. In addition device-based AmbI ecologies will obtain greater robustness and flexibility due to the ongoing dynamic coupling of devices with users and each other. Designing AmbI from numbers of heterogeneous devices thus provides a functional win-win.

We always have to keep the somewhat metaphorical nature of a bio-mimetic approach in mind since technology and biology differs immensely in certain respects. We must therefore be aware not to get blinded by the metaphors and keep a sound pragmatic stance towards biological inspiration. On the other hand we should not deny ourselves the possibilities of new forms of better technology because of lack of vision and imagination. What seems a bit far fetched today may be standard design practice in 15 years.

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