3. Workplan Overview

3.1 Science objectives

Project context and statement of purpose

The Science vision of the DBE originates with the original discussion paper published by the ICT for Business Unit in the summer of 2002. We reproduce and then analyse the passage where the digital business ecosystem metaphor is introduced, following a similar section where the concept of business ecosystem is recounted from various published sources:

> The digital business ecosystem is a “digital environment” populated by “digital species” that could be software components, applications, services, knowledge, business models, training modules, contractual frameworks, laws, …
> These digital species, like the life species, interact, express an independent behaviour, and evolve—or become extinct—following laws of market selection. The less adapted species, i.e. services not interesting for the market, are less and less used, becoming less and less present in the ecosystems, until they disappear. New more evolved innovative species (digital services, but also innovative business models, sectorial services) continuously appear and decree the obsolescence of the other digital species.
> Gradually more complex species appear, often originated by the composition of simpler digital species (components, basic services). As in natural ecosystems, the digital species should have enough individuals to survive and the digital ecosystems should be populated by a sufficient number of species (a critical mass of species) to be appealing for the market and continue to exist.[1]

A recurring question in the DBE project, that we wish to put to rest once and for all, has been to what extent the above passage should be taken as a metaphor, as it indeed describes itself, and to what extent it should instead be taken as a new paradigm for software and business environments, isomorphic to biological ecosystems in both structure and behaviour. Both interpretations are in fact possible.

The first paragraph defines what is meant by “digital species” and seems to restrict the DBE to a software environment. The second paragraph reinforces this interpretation (“express an independent behaviour”) but in the same sentence introduces the unavoidable selection pressure as coming from outside the digital environment, i.e. from the market. This seems reasonable and justifies the “business” in “digital business ecosystem”. The rest of the second paragraph describes the essence of the evolutionary “algorithm” that

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[1]Nachira, F, et al. (2002).
“Toward a network of digital business ecosystems fostering the local development”, Sept. http://www.europa.eu.int/information_society/topics/ebusiness/godigital/sme_research/index_en.htm

can be expected to follow from the ecosystem as defined so far. The third paragraph further describes the evolutionary algorithm and reinforces the connection to the business ecosystem. The concepts of “digital ecosystem” and “business ecosystem” are therefore given equal weight, and their coupling is described as a selection pressure that the market exerts on the digital species. This is quite reasonable, but what this passage does not address is how the digital species come about in the first place.

In other sections, the discussion paper makes it quite clear that software-producing SMEs will be among the beneficiaries of the digital business ecosystem, which will in fact empower them with new tools and with easier access to new markets. Throughout the discussion paper there is a strong emphasis on Open Source as an integral part of the ecosystem concept and as one of the features that will facilitate the adoption of advanced software technologies on the part of both developers and user SMEs. If we treat the passage quoted above as nothing more than a metaphor then it is pretty clear that the source of “digital species” are indeed simply the SME software developers. In this case the whole discussion of the digital business ecosystem paradigm can be adequately addressed by the coordination of Business, Computing (intended as both computer science and software engineering) and Social Science initiatives in research, design, implementation, policy development, dissemination, training, and adoption. There is no need for Science research.

If instead we assume that the discussion paper wishes to go beyond a biological metaphor, and speaks of digital and business ecosystems in literal terms, then the need for Science research becomes very important to the success of the DBE vision. The long-term dynamics of the digital business ecosystem becomes dependent on the integration of structural and behavioural rules from biology into the architecture and algorithms of the software infrastructure, and into the structural and behavioural rules of the businesses themselves. This is the view that we described in the project proposal and that was accepted by the Commission.

The implicit and explicit research challenges that arise from the second interpretation can be summarised in three main points:

1- the physical and biological laws of self-organisation and evolution that allow real ecosystems to construct order are still topics of intense research, only a few simple aspects have been understood and modelled satisfactorily
2- the applicability of biological processes to software is not certain
3- the relevance of biological and physical processes to social and economic interactions has been debated for centuries in the social sciences, along with several other and equally plausible points of view, as a basis for an explanatory theory of the socio-economic dynamics of development. No clear winners are yet in sight.

We in the Science team of the DBE Project feel that these three points provide plenty of motivation to develop very ambitious and challenging research questions that go well beyond the use of genetic algorithms as an optimisation technique. Whereas the first interpretation of the EC paper would make the Science team, at best, equivalent to a subcontractor to the Business and Computing domains, the second interpretation justifies the presence in the project of some of the top research institutions in Europe in the natural, physical, computer, and social sciences. Our role is to contribute to the long-term sustainability of the DBE system and concept by probing deeper behind our assumptions of how ecosystems function, of how economies and social systems can interact productively with ICTs, and of what it means to compute.

Theoretical framework

The theoretical framework that allows us to rationalise the Science research agenda was not clear since the start of the project, as some of our partners might have expected. It has been put together gradually, giving precedence to more specific and pragmatic opportunities of research intervention as they presented themselves, over the formulation and imposition of a grand design from the top. Roughly half-way into the project, however, we can now begin to utilise what we have learned from our own research tasks as well as through the interactions between all project partners to propose a first attempt at a unifying theoretical framework for scientific research in the DBE. So this document implicitly and explicitly takes into account most deliverable reports and project documents that have been produced so far. As stated in the previous section, this framework does not aim to be the complete theoretical framework for the whole project, contributions from the other project domains are both welcome and necessary. The framework proposed here builds on the assumptions presented and justified above, and looks at the DBE scientific research through a biology lens. We expect this framework to evolve further during the project, as our insights improve.

Evolution and self-organisation

There is no general definition of what “self-organising” means, mainly because it is a phenomenon that can be observed in different contexts in the physical and natural sciences, and is apparently driven by correspondingly different mechanisms. Partly for this reason, stating that the objectives of the DBE will be achieved by “self-organisation” leaves engineers skeptical. More to the point, unless we advance a mechanism of self-organisation in information systems, or a framework for supporting such a mechanism, it won’t be just engineers who will feel skeptical. This document begins to propose such a framework, whose relevance will be two-fold:

1- It will provide an operational definition of self-organisation that, whilst perhaps not as sophisticated as some of us might have come to expect from “new science”, it is plausible and implementable.
2- It will strengthen the rationale for social science research in the DBE project by clarifying the role of socio-economic systems as an integral part of the self-organisation mechanism itself.

We begin by noticing that, whilst many of the sophisticated mechanisms that allow biological systems to function *evolved* through evolutionary processes over long periods of time, they do not *rely* today on evolutionary processes in order to function. We could group among these the adaptive and “intelligent” emergent behaviour of ant colonies, the self-assembly of proteins inside the cell—in fact the whole of gene expression, the workings of the brain, and so on. Another way to say this is that whereas self-organisation took billions of years to evolve, it is a mechanism that works *now*.

The above distinction provides a neat conceptual separation between evolution and self-organisation, but oversimplifies the issue since the two phenomena are in fact very much intertwined. Firstly, nobody guides evolution, it is an entirely spontaneous process, so strictly speaking it can be seen as a form of self-organisation. Secondly, although the best theoretical/philosophical framework for explaining evolution is still being debated, a strong current of opinion holds that evolution does not rely only on natural selection of the fittest individuals in a population to construct order over many generations. In this mode natural selection can in fact be viewed as mainly a negative or “subtractive” process. Cross-over is an efficient mixing of existing traits, and mutation is a weak creative process. Theoretical biologists like Kauffman have proposed that, in order to explain the rate of creation of new forms and species in the history of life on Earth, evolution needs a stronger positive or additive process of order creation than mutation, cross-over, and selection can provide.[2,3]

John Maynard Smith, one of the foremost evolutionary biologists of the last hundred years, talks about “embryonic development” in a similar way to what we call here self-organisation, juxtaposing it to natural selection and evolutionary processes on long time scales.[4] He does also talk about self-organisation, but prefers to limit its applicability of this term to processes that require no “instructions”. For example, although the formation of snow-flakes is not specifically quoted by Maynard Smith, it fits his definition of self-organisation. For our purposes this definition seems unnecessarily restrictive and it does not seem to harm anything to include processes driven by instructions, as long as the instructions themselves have assembled spontaneously. Such is the case of DNA with respect to gene expression and morphogenesis. So we are back to a simpler dichotomy of associating embryonic development and gene expression with self-organisation on one side, and natural selection with the slower process of evolution on the other. Maynard Smith summarises the situation as follows:

> There is a parallel, long appreciated, between the *developmental* changes that convert an egg into an adult, and the *evolutionary* changes that, on an enormously longer time scale, have converted simple single-celled ancestors into the existing array of multicellular animals and plants. In both cases, a single cell is converted into an organism with many cells, of many different kinds, arranged in a complex three-dimensional structure. But, despite the similarity, the

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[2] Kauffman, S (2000). *Investigations*, Oxford.

[3] Kauffman, S (1993). *The Origins of Order: Self-Organisation and Selection in Evolution*, Oxford.

[4] Maynard Smith, J (1998). *Shaping Life: Genes, Embryos and Evolution*, Darwinism Today Series, Weidenfeld & Nicolson, London.

> mechanisms are entirely different: development is not driven by natural selection. All the same, the two processes are intimately connected. Development depends on genetic information that has been accumulated over millions of years of evolution, and the evolution of adult forms has depended on developmental changes in successive generations. [italics in the original]

An analogy of the developmental stages of the embryo with the evolutionary stages of life on Earth was proposed about a hundred years ago and was given the name of "recapitulation". It has since been abandoned, although as Maynard Smith says above nobody questions that ontogeny and phylogeny[5] are intimately connected. Fig. 1 provides a simplified characterisation of these concepts (the figure ignores the bifurcations in the evolutionary tree, the organisms shown actually belong to different phylogenies).

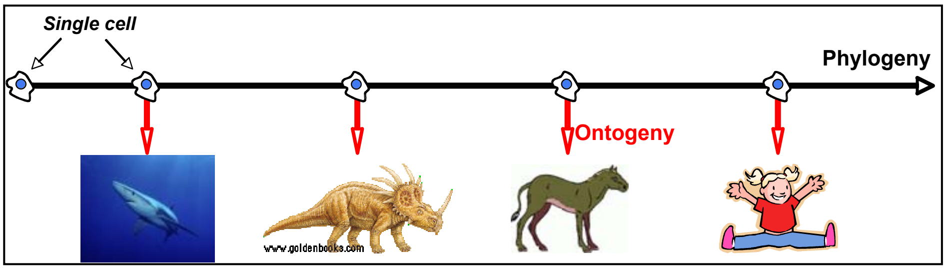

Fig. 1 Simplified comparison of phylogeny and ontogeny

The approach we are following in the DBE project as regards evolutionary computation makes sense: we should try to leverage both aspects of evolution but, if the equivalent of gene expression proves too difficult, we know that we can fall back on genetic algorithms, an optimisation method that we already understand fairly well. In summary, natural selection is slow, weak and, in a sense, asynchronous. Gene expression, morphogenesis, and the workings of the mind take place in real time and are very powerful. Although both, technically, can be regarded as different forms of self-organisation—or as different aspects of a broader definition of evolution—it is convenient to refer to the former as evolution and to the latter as self-organisation.

Paradigms of interpretation

The development of explanatory theories for both ontogeny and phylogeny has been pursued for centuries by a wide range of researchers in theoretical biology, philosophy, biochemistry, medicine, etc. Although a more in-depth and thorough discussion of the models and arguments proposed will be postponed to a later version of this document, for now we will highlight the two main opposing interpretations as they will enable us to relate all the science activities of the DBE project to a unifying fundamental dichotomy. It is important to note that our prime concern is not to understand the mechanics of how ontogeny and phylogeny depend on each other; rather, we wish to contrast two different scientific theories by means of which both can be interpreted together from different points of view.

[5] Please see the glossary on page 22.

The first point of view is neo-Darwinism and is by far the overriding interpretation in evolutionary biology. Put simply, the “neo” in neo-Darwinism became applicable during the first half of the Twentieth Century with the discovery of DNA and of all the molecular and genetic mechanisms that support the higher-level framework Darwin had developed from macroscopic observation of species. According to this interpretation, the DNA defines a code that serves as instructions to drive the metabolism of the cell, and therefore morphogenesis and ontogeny in general. Similarly, at the immensely greater spatial and temporal scales characterising phylogeny, the environment acts as a selection pressure that “sculpts” the genome of any one species in the development of its phylogeny. In both cases, neo-Darwinism describes these two different processes as mainly linear and uni-directional cause-effect mechanisms with relatively small feedback. This interpretation is summarised in Table 1.

Table 1. Ontogeny and phylogeny according to neo-Darwinism

	Cause, instruction	*Mechanism*	*Effect*
Ontogeny	DNA	GENE EXPRESSION	METABOLIC CYCLES, MORPHOGENESIS
Phylogeny	ENVIRONMENT	NATURAL SELECTION	GENOME

The second point of view is quite recent and can be captured under the heading of “autopoiesis”, that Maturana and Varela started to define approximately 40 years ago.[6,7] In this view the two actors present in both ontogeny and phylogeny have roles of similar weight, without a prevalent direction of causation between them. The ontogenetic interaction as proposed by autopoiesis is described in terms of “structural coupling” where, for instance, DNA only *triggers* rather than *instructs* changes in the rest of the cell, whose subsequent state is dependent not on the signal from the DNA but on the structure and composition of the cell at the time it was triggered, or on its previous history. Likewise, the cell biochemical dynamics trigger changes in the DNA that are however determined by the already existing structure of the DNA at that point in time. At intermediate spatial and temporal scales the time evolutions[8] of organisms and their environments are similarly related. At the largest spatial scales and longest time scales, phylogenetic interaction is described as a “natural drift” where the ecosystem and the species evolve together, locked in a never-ending dance. Table 2 summarises this interpretation. In physics and dynamical systems theory we recognise in structural coupling a close cousin of the non-linear coupling between the degrees of freedom of low-dimensional non-linear dynamical systems.

Table 2. Ontogeny and phylogeny according to autopoiesis

	Actor 1	*Mechanism*	*Actor 2*

6 Maturana, H, and Varela, F (1980). *Autopoiesis and Cognition: The Realization of the Living*, Reidel, Boston.

7 Maturana, H, and Varela, F (1998). *The Tree of Knowledge*: *The Biological Roots of Human Understanding*, revised edition, Shambhala, Boston.

8 In dynamical systems theory “time evolution” refers to a sequence of states visited or induced in time. Biological evolution started from this definition but quickly developed its own semantics.

Ontogeny	DNA	STRUCTURAL COUPLING	CELL
Ontogeny	ENVIRONMENT	STRUCTURAL COUPLING	ORGANISM
Phylogeny	ECOSYSTEM	NATURAL DRIFT	SPECIES

The answer may well lie somewhere in the middle between these two interpretations. In other words, whereas the mutual influence of the DNA and the rest of the cell is appealing, perhaps it is fair to say that the DNA acts *not only* as a trigger, but also contains information that determines the morphology and behaviour of the organism. It is in any case interesting for the DBE that in a more recent book Varela et al. relate these two different interpretations to two similar areas of cognitive science that have characterised that field ever since its inception: cognitivism and connectionism.[9] Table 3 shows this parallel.

Table 3. The fundamental dichotomy of the DBE		
	Evolutionary Biology	*Cognitive Science*
Symbols	NEO-DARWINISM GENETIC DETERMINISM[10]	COGNITIVISM
Behaviours	AUTOPOIESIS	CONNECTIONISM EMERGENT SYSTEMS

This parallel is especially relevant to the DBE because it allows us to build a conceptual bridge between the two most "biological" aspects of the Science research, evolution and intelligence. More importantly, however, and in a perpendicular direction, it highlights what could be regarded as a fundamental dichotomy of DBE research, namely the *presence* and the *need* for both top-down, language-based, model-driven software creation and for bottom-up, biology-inspired aggregation and optimisation of service chains.[11] We therefore wish to emphasise that both interpretations discussed above provide important reference frameworks by which to understand, justify, and plan the DBE Science research. Some activities are better understood in terms of the first interpretation, and others in terms of the second. For the purposes of this document it is sufficient to raise awareness about these different epistemological positions. We should not impose either.

In spite of the fact that in biology it is not possible to "design" organisms, it seems appropriate to associate the mechanisms of ontogeny with model-based software development (such as OMG's Model Driven Architecture framework) and the mechanisms of phylogeny with evolutionary computing and genetic algorithms. If we add the "business" to the "digital ecosystem", then the phylogeny of software can be understood to encompass the traditional software engineering development process, coupled to the market and to the success and failure of the companies that adopt it. Starting, however, with the more restrictive definition of digital ecosystem, we believe it

[9] Varela, F, Thomson, E, and Rosch, E, (1991). *The Embodied Mind: Cognitive Science and Human Experience*, MIT Press, Cambridge, Massachussetts.
[10] Discussed in Dawkins, R (1989). *The Selfish Gene*, 2nd Ed, Oxford.
[11] See DBE Deliverable Report D18.1 "DBE-Specific Use Cases", Dec 2004, for a more extensive discussion.

is important for the long-term viability of the DBE to reconcile this dichotomy at both a theoretical and a practical level. Again taking inspiration from biology, it is clear that DNA represents a solution to this problem since it provides a seamless link between long and short dynamical time scales, and between symbols and behaviours. This insight informs the DBE Science research agenda to be outlined in the rest of this document.

Distributed algorithm

One of the more interesting aspects of the neo-Darwinian and autopoietic paradigm dichotomy is that it is actually reconcilable. Both paradigms are consistent with empirical observation and each incorporates aspects of the other. Each constitutes an interpretation of observed phenomena, i.e. a way of making sense of the world, which is therefore necessarily influenced by our own philosophical traditions. The neo-Darwinian view is more compatible with linear causal thinking, and indeed with the concept of an algorithm dictating behaviour without feedback.

It is not unreasonable to imagine that a different understanding of how the world works, more compatible with autopoiesis, might lead to a different definition of what constitutes "computing". Even in the case that the abstract Turing machine is sufficiently general to encompass all possible architectures, our philosophical traditions have biased us toward architectures that emphasise linear and unidirectional causation.[12] The autopoietic point of view indicates that biological algorithms are not computed by a single finite state machine; it confirms that, indeed, "It takes two to Tango". A fundamentally important link between the DBE Science and Computing research, therefore, is to investigate the feasibility of an algorithm that is distributed among several finite state machines. How can we achieve programmability and flexibility at the same time? Can we assign the role of the stack to another automaton? Clearly the connections between formal languages and dynamical systems will have to be understood better. In parallel with these more abstract investigations in theoretical computer science, the requirement and expectation that these finite state machines will interact in a useful way leads us naturally to look in more detail at how biological systems construct order.

Construction of order

Self-organising systems amaze us with their ability to construct order against the odds, i.e. defeating entropy. Statistical mechanics provides a theory for the spontaneous creation of order based on the minimisation of free energy.[13] This theory becomes less satisfactory the more complex the system in question. For instance, we know that free energy minimisation is ultimately responsible for all the activity in the muscles, nerves, and brain of a cat chasing a mouse, but we suspect that there is more to the story. In general, statistical physics works very well for equilibrium systems or for systems that approach—and reach—equilibrium, but becomes cumbersome and ineffective when non-equilibrium systems such as biological systems are considered.

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[12] Kaufmann (2000, ibid) refers to the DNA as the "instruction register of the cell"

[13] For a more extensive discussion of free energy see D18.1, ibid.

This is rather a central point in the discussion, because self-organising systems are very commonly described as "far from equilibrium" (a phrase that connotes *position*). An alternative characterisation is to say that self-organising systems are forever falling toward equilibrium, without ever reaching it (which connotes *velocity* or rate of change). It is precisely the fall toward equilibrium, that drives self-organisation. There simply is no other mechanism that enables spontaneous behaviour. These two apparently contradictory descriptions can be reconciled by recognising that biological systems are open, and in fact require a constant energy flow through them to remain alive. Thus they are indeed falling toward equilibrium while being kept away from it by this energy flow. For the purpose purely of clarifying the concept, we can invoke two very much simpler systems as examples: lasers, and gliders (which by definition must fall relative to a body of air) flying in warm air that is rising relative to the ground. The ground plays the role of "equilibrium" in this analogy, and the organism gains altitude above the ground over its lifetime, from a single cell to an adult. Its daily metabolism keeps the mean energy level (altitude) constant, since it is dependent on a "sinking" velocity that closely matches the "updraft".

The "updraft", then, is the global and uni-directional flow of energy from the sun that drives the biosphere or, similarly, the global and uni-directional flow of energy from the food we eat and the oxygen we breathe that drives our bodies. In the DBE, it corresponds to a global flow of information provided by the users. Fig. 2 shows the conceptual progression that we followed to understand where the "breath of life" in information systems comes from.

The preliminary conclusion that we reach, therefore, is that a necessary, although not sufficient, condition to achieve a self-organising information system is to couple it to its users. This may at first appear somewhat obvious, but the implication is both subtle and far-reaching. It implies that a truly self-organising information system must, in principle, be entirely subsumed to its users. Nothing, apart from its "atomic units" and their elementary rules of interaction, should be designed or engineered in the conventional sense, it should all arise spontaneously and dynamically through continued interactions with the users, who provide all patterns of behaviour.

The contrast between the traditional role of ICTs and the new role that the DBE Science research will enable is shown in Figs. 3 and 4, respectively. Fig. 4 captures the concept that social and economic processes create a "potential" or "voltage" that can be harnessed to drive the self-organisation processes of information systems. The potential difference between supply and demand "pushes" the information through the system. But its distributed, dynamic, and intelligent architecture allows it to learn from the flow of information it mediates, adapting over time to the needs of its users, and achieving self-organisation whilst remaining essentially a passive system with memory.

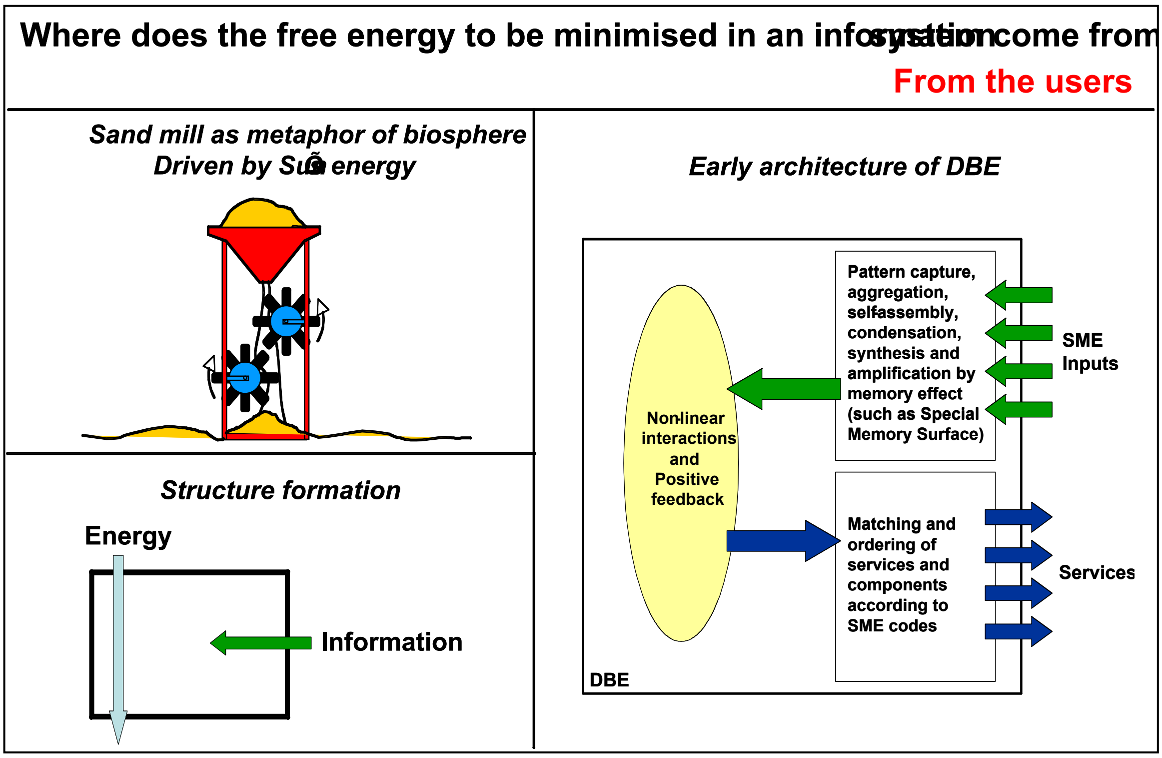


Fig. 2 Spontaneous behaviour in information systems

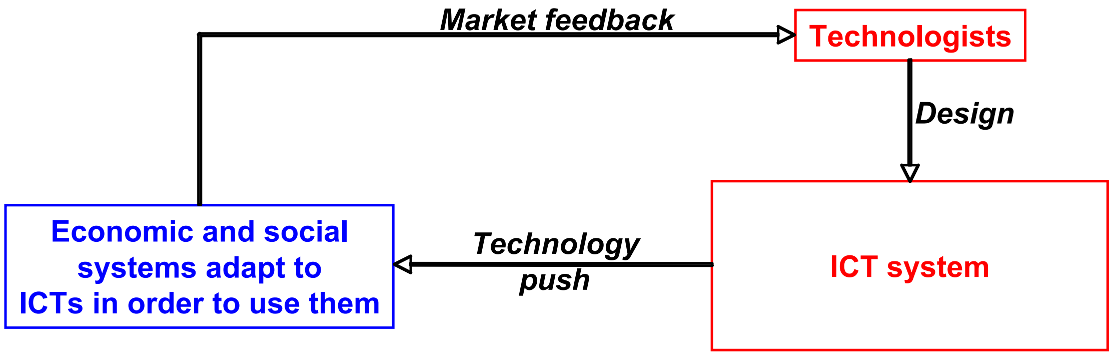
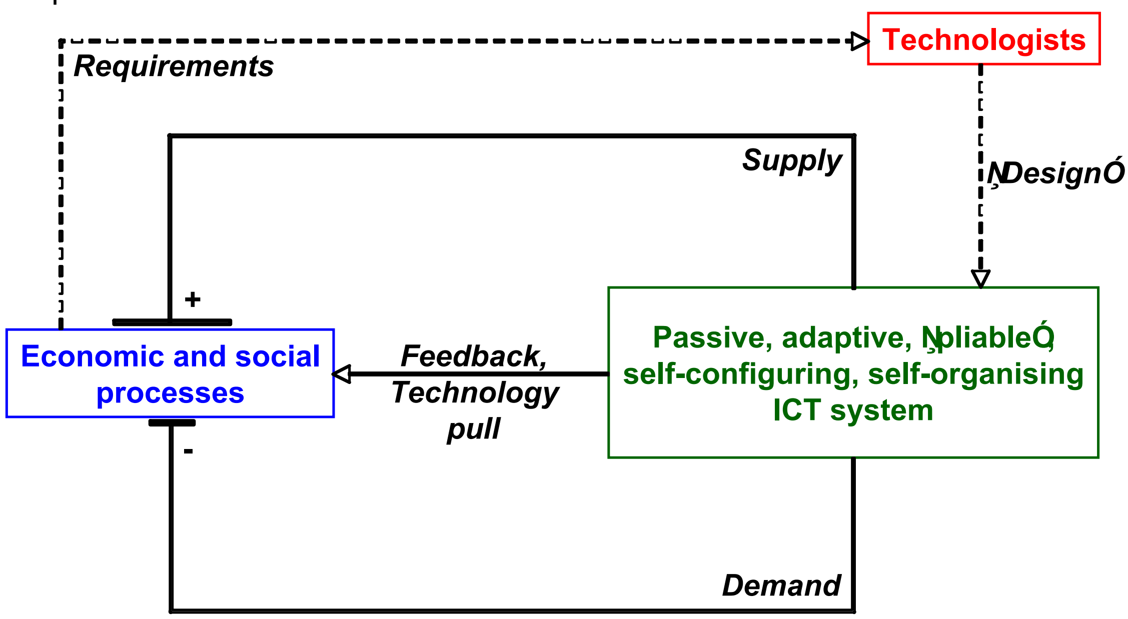


Fig. 3 Top-down, technocentric view of ICT adoption

The network is the environment

The ecosystem itself is discretised and approximated by the networks that connect the various actors and companies and allow the digital species to interact. An initial discussion of this idea is provided in Deliverable D18.1 and in the ongoing definition of the EvE architecture formalised in Deliverable D21.2, but much still needs to be done to connect the network to the ambitious dynamics of self-organising systems described above. This part of DBE Science is rich in opportunities for research in graph theory, network topology, information propagation, and simulations of topological dynamics. The relevance of these activities to the DBE P2P network infrastructure as well as to some aspects of the SME networks is clear and not difficult to translate into useful applications, architectural guidelines, and implementations.



Objective : To match the impedance between blue and green boxes

Fig. 4 Bottom-up, biology-inspired view of ICT adoption

The business ecosystem

As mentioned at the beginning of this document the Science research can also make a contribution to the analysis of the business interactions. The connections to Social Science are also interesting, although we as scientists need to be careful about not falling into the trap of social and economic Darwinism. This happened about a hundred years ago when social scientists first attempted to apply the then young theory of evolution outside biology, to social and economic systems. “The survival of the fittest” mantra became an excuse for proposing rather ruthless social and economic policies, which have been echoed as recently as the 1980s by Margaret Thatcher and Ronald Reagan.

This problem can be avoided as long as we realise that the concept of individual is not as absolute as we might be inclined to infer based on our conscious and limited human experience. If the individual becomes a fuzzy entity composed of smaller units and itself a unit in a larger entity, then when the fittest survives it is not so clear-cut anymore who is doing the surviving. Put another way, we don’t mind if our cells compete for nutrients, but we also expect them to cooperate and communicate to ensure that our bodies perform their higher-level functions properly.

Economic theories of the Commons could thus be related to the balance between cooperation and competition in biological systems to provide new insights into the role of Open Source in the DBE. Quantitative models from physics could be applied to the global optimisation of such hybrid markets, and these approaches could be compared to game theory and to evolutionary game theory. An interesting starting point could be the analysis of the economy of the ant colony, along with its quasi-intelligent coordinated behaviour.

We expect additional suggestions to come from the Business and Social Science partners.

Synopsis: Science research agenda and objectives

The Science research agenda is to set very challenging long-term research questions and to define a strategy that allows us to answer them through smaller practical research problems whose solution can be used by the Computing and Business partners in the short term, i.e. during the course of the project. The Science research agenda can be broken down into the following set of high-level objectives:

Objective	Description	DBE Tasks
Languages, DNA, automatic code generation[14]		
1	To investigate the algorithmic properties of the simplest metabolic cycles of the DNA and to relate its interactions with other cell components to finite automata and formal languages	S23, S22
2	To assess to what extent the framework developed in 1 is applicable to UML and BML and to offer suggestions for increased applicability	S23, C20
3	To investigate the connections between dynamical systems and formal languages	S23
4	To begin the development a theoretical framework based on 1-3 that addresses automatic code generation from models	S23, S24
Evolution and intelligence		
5	To reconcile the model-driven (ontogenic) and the evolutionary (phylogenic) views of the DBE through appropriate architecture recommendations to the Computing group	S4, S12, S23
6	The define a high-level architecture for the Evolutionay Environment	C42
7	To investigate and develop criteria for semantic matching in order to support the formation of service chains in the Population Object	S12, S13, B18
8	To develop a distributed intelligent system to accelerate the evolutionary optimisation algorithms	S5, S6, C42
9	To develop a general and adaptive Fitness Function tailored to the DBE	S12, S3
10	To investigate the properties of genetic algorithms and adapt them to DBE needs	S3, S4, C4, C37
11	To achieve long-term learning and adaptive behaviour of the DBE	S4, S5
Networks		
12	To develop criteria to optimise information propagation in networks of heterogeneous dynamic topology, in order to support Habitat clustering and dynamic P2P links	S1, S2
13	To support the FADA network architecture development through simulations	S7, S8
Business ecosystem		
14	To investigate the applicability of global cost function optimisation of multi-agent systems, of models of swarm intelligence, and of game-theoretic approaches to the analysis of SME networks	S16, S17, S18, S20, S10
15	To work with Social Science in order to assess to what extent socio-economic systems can be reconciled with biological systems, within the context of the DBE research and regional development	S22
16	To study through simulations how sharing of and competition for services affects the efficiency of the market	S9, S10

[14] These language-related objectives are very ambitious. We plan to strengthen the research effort with other STREPS and IPs that address these problems.

Glossary

Term	Definition
Autopoiesis (biology)	A type of dynamic organisation charactersitic of living organisms that allows them to be continually self-producing
Dichotomy (philosophy)	A classification into two opposed parts or subclasses (www.dictionary.com)
Energy (physics)	Ability to do work
Natural drift (biology)	A consequence of organisms and their environment interacting and affecting each other through structural coupling. A view of evolution that gives similar weight to environment and species, in contrast to the prevailing view of the environment as the “more independent” cause of the evolution of the species through natural selection.
Non-linear coupling (physics)	Bi-directional causal relationship between two (or more) variables of a system that enables them to exchange energy and information, thereby affecting each other’s time evolution.
Ontogeny (biology)	The history of structural changes in a particular living being
Paradigm (philosophy)	Something between an abstract model, a conceptual framework, and a self-consistent system of ideas
Phylogeny (biology)	A succession of organic forms sequentially generated by reproductive relationships
Structural coupling (biology)	A form of interdependence between two actors or entities that satisfies the criterion of structural determination mutually and symmetrically. Conceptually similar to non-linear coupling in physics.
Structural determination (biology)	A process of change of an organism that, at any point in time, is determined by the organism’s previous structure but is triggered by the environment. The same holds for the environment: the organism is a source of perturbations and not of instructions.
Time evolution (mathematics)	A sequence of states of a system or variable visited or induced in time
Work (physics)	The product of a force and the distance in the direction of which it moves